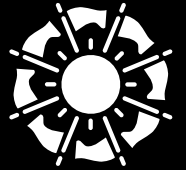




United Nations
Educational, Scientific and
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INTERNATIONAL
YEAR OF LIGHT
2015

INSPIRED BY LIGHT

Reflections from the
International Year of Light 2015

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Educational, Scientific and
Cultural Organization



INTERNATIONAL
YEAR OF LIGHT
2015



Antelope Canyon, Page, Arizona.
CREDIT: Shutterstock/Sourav and Joyeeta.



INSPIRED BY LIGHT

Reflections from the
International Year of Light 2015

Produced in January 2016 by SPIE, the European Physical Society (EPS), and The Abdus Salam International Centre for Theoretical Physics (ICTP) to commemorate the International Year of Light and Light-based Technologies 2015.
Website: <http://light2015.org>

SPIE.

P.O. Box 10
Bellingham, Washington 98227-0010 USA
Website: <http://spie.org>

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This volume was compiled and edited by the Editorial Team:
Jorge Rivero González, European Physical Society
Joseph Niemela, The Abdus Salam International Centre for Theoretical Physics
Krisinda Plenkovich, SPIE

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**INTERNATIONAL
YEAR OF LIGHT
2015**

FOUNDING PARTNERS OF THE INTERNATIONAL YEAR OF LIGHT AND LIGHT-BASED TECHNOLOGIES 2015

- American Institute of Physics (AIP)
- American Physical Society (APS)
- Deutsche Physikalische Gesellschaft (DPG)
- European Physical Society (EPS)
- The Abdus Salam International Centre for Theoretical Physics (ICTP)
- IEEE Photonics Society
- Institute of Physics (IOP)
- Light Science & Applications (LSA)
- Lightsources.org
- 1001 Inventions
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- SPIE

Preface

The International Year of Light and Light-based Technologies 2015 (IYL 2015) has been a tremendously successful global initiative with thousands of events reaching millions of people in over one hundred countries. United by the interdisciplinary theme of light, IYL 2015 has brought a diverse range of participants in concert with UNESCO, all committed to raising awareness of how light science and technology provide solutions to the many challenges facing the world today.

The many IYL activities during 2015 have involved professionals, students, young people, and interested citizens as well as groups from many different communities: optical scientists and engineers, astronomers, educators, designers, architects, artists, lighting professionals, healthcare workers, and many others. A very important activity of the year has been providing various forums for members of these different communities to be able to share their different perspectives, both with each other but also with the wider public. To this end, a cornerstone action of IYL 2015 has been a near-daily blog, where volunteers generously took the time to provide a written record of their own involvement with light science and technology, or their particular involvement with the International Year of Light.

The volume that you are holding is a selection of 56 contributions written by authors from 24 countries covering all of the major themes of the year. The contributors range from research students to a Nobel laureate, and from industry professionals to representatives from NGOs; the breadth of topics and themes is remarkable and reflects the vital role that light plays in our lives.

I believe that these writings and the topics that they cover give both a snapshot of the state of the art of light-based technology and its many applications, and at the same time provide a valuable and lasting testament to the commitment and passion shown by the international community to celebrate the International Year of Light.

I would like to thank all of those who contributed to the IYL 2015 blog during the year as well as those whose pieces were selected for this collection. I also thank all of the individuals and organizations involved in IYL 2015 for making the year a resounding success.



John Dudley

Chair of the IYL 2015 Steering Committee
January 2016





Solar. CREDIT: Steven Erra.



1

Culture and Education

Active Learning in Optics and Photonics (ALOP)

Joseph J. Niemela, Abdus Salam International Centre for Theoretical Physics, Italy

Creativity is well understood to be one of the essential characteristics for artists, but it is equally important for scientists. So that raises the following question: How do you keep the brightest and most creative students interested in pursuing a career in physics as they enter the university and at the same time impart real conceptual understanding so that they have a proper “canvas” on which to start their work throughout those careers?

That was a question discussed more than 10 years ago by representatives of UNESCO, the UNESCO Category I Centre ICTP (International Centre for Theoretical Physics in Trieste) and SPIE at a meeting in Trieste hosted by the late Gallieno Denardo. Noting that light science is an ideal subject to stimulate interest in STEM subjects in a classroom setting, the answer from that meeting was to develop a “training the trainer” manual called Active Learning in Optics and Photonics (ALOP) to help teachers in developing countries engage their students more effectively. It wasn’t a fix for the often low salaries of teaching professionals compared to those offered elsewhere, but it was important not to give students added incentives to leave physics.

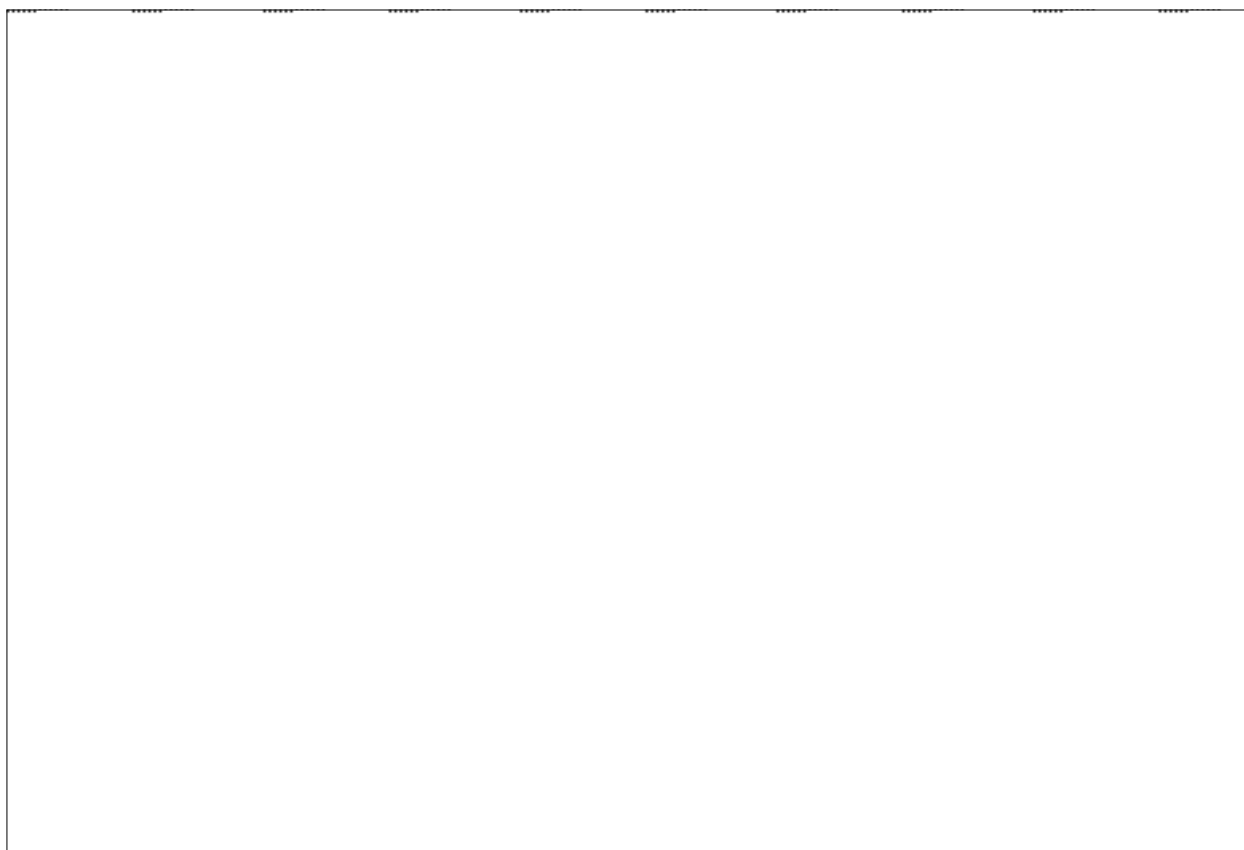
Since Gallieno had no intention of leaving Trieste to go globe-trotting around the world, he quickly passed this idea on to me, suggesting that I take his place in a meeting in Manila with Minella (that trips me up even today) Alarcon, the UNESCO Science and Math Programme Specialist, and original ALOP Director, as well as some of the team members who would be assembling there to try things out. I’m very grateful to him for that suggestion, as working with the ALOP team resulted in new and wonderful friendships and connections I don’t think I would have had otherwise. It was also my first introduction to the optics community, a community that I have enjoyed working with immensely ever since. You never know in life....



SPIE CEO Dr. Eugene Arthurs attending the ALOP workshop in New Delhi, India. CREDIT: ALOP.

In Manila with Minella one thing became obvious: The cost-to-effect ratio using optics and photonics was relatively small, and most of the necessary equipment could be obtained or built in even the poorest countries. No optical rails? Meter sticks and putty work in most cases for the classroom. Low-cost equipment actually has an advantage of sorts: it avoids “black-box” solutions and demonstrates to students how easy it can be in certain cases to coax quantitative information from Nature. This is not an extra “fact” for them to absorb but a belief that can stick with them. ALOP is very adaptable to local conditions and so remains “relevant” across different cultures. To date, the ALOP Training Manual has been translated into French, Spanish, and Arabic.

Part of the strategy that leads to ALOP’s success is its encouragement of students to construct the knowledge from their own observations, guided by a “facilitator” (rather than a “teacher”) whose role it is to lead them from observation to discovery. This process—known as active- or inquiry-based learning—keeps students engaged, which means that they are using their brains in the classroom, not waiting to switch them on the day before an exam. We often refer to ALOP and similar programmes as being both “hands on” and “minds on.” The biggest problem we have with training teachers in this method is to get them to stop



Observation time at an ALOP workshop in Kathmandu, Nepal. CREDIT: ALOP.

lecturing! That is an attribute for which they have a special propensity, even at home (if I hadn't grown up with teacher parents I wouldn't have known that). Another reason that ALOP is so successful is that some reasonable fraction of teachers—especially in secondary schools—are teaching outside the area of their competence for any of a variety of reasons, and ALOP workshops can give them an understanding of light sciences that they perhaps never properly obtained. That in itself can be a great help to their students.

How do you measure if the students' minds are really engaged? Simple—you just need to buy a decibel meter (the kind the city government used to employ when our band played in public...back when it still made sense to have a comb in my back pocket) and look for a high signal. That means they are actively learning and engaged and not day dreaming about something or someone more interesting while the teacher is lecturing. Plenty of time to do that in history class. Of course, there is also a test based on results from physics education research to gauge how well they (and hence we) do.

Ten years later, ALOP workshops have reached close to a 1000 teachers from roughly 50 developing countries in Africa, Asia, and Latin America. They are typically lecturers in universities as well as some secondary school teachers of

physics. Follow-up activities, in which trained trainers train others locally are an important part of the overall strategy and have been very successful in a number of regions around the world. The program has been sustained by long-term support from SPIE. Additional support has been provided by the Optical Society, the U.S. National Academies of Science, Essilor Corp., the International Commission for Optics, and the European Physical Society, amongst others.

ALOP is one of the IYL 2015 global outreach activities, with workshops taking place in Indonesia, Mauritius, Mexico, South Africa, Bolivia, Panama, and Pakistan, the latter being home to one of the most courageous advocates ever for the right of girls to an education, Malala.

It is a treat to work with enthusiastic teachers and optics researchers from around the world and to see their dedication. We always leave with a renewed enthusiasm and dedication ourselves!

Joseph J. Niemela is a Senior Scientist and Programme Specialist at the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy where he heads its Office of External Activities (OEA) as well as the Applied Physics group. He is also coordinating the IYL 2015 Global Secretariat, which is hosted at the ICTP, and directs the ALOP programme together with Jean-Paul Ngome Abiaga at UNESCO.

Astronomy for Development

Ramasamy Venugopal, International Astronomical Union,
Office of Astronomy for Development, South Africa

The International Year of Light and Light-based Technologies 2015 (IYL 2015) is a celebration of the role that light and light-based technologies have played in global development. Astronomy and the scientific study of light, represented by the International Astronomical Union (IAU)-supported Cosmic Light component, have of course made major contributions. It was the feeble light from thousands of far-away stars and galaxies that probably sparked some of our earliest curiosity in the natural world. Over the centuries, our pursuit of light literally served as a beacon, as curiosity drove scientific understanding and ushered in technological, social, and economic progress. For a long time, astronomy propelled technological innovations that improved our scientific capabilities and went hand in hand with development.

Today, astronomy continues to engage and inspire every new generation. By virtue of its nature, astronomy holds a privileged position. It can stoke curiosity, spur innovation, and inspire the next generation of scientists and engineers. But can it still drive broader societal development? Can astronomy still make the world a better place?

That was the question the IAU sought to answer when it created a decadal strategic plan to utilize astronomy as a tool to stimulate sustainable development. To execute

this plan, the Office of Astronomy for Development (OAD) was set up in partnership between the South African National Research Foundation and the IAU. The OAD's primary role is to implement the Astronomy for Development charter globally. It performs this function via three task forces, targeted at different groups: Task Force 1: Universities and Research, Task Force 2: Children and Schools, and Task Force 3: Public Outreach.

Every year, under the three task forces, the OAD facilitates and funds projects that use astronomy to address a challenge related to sustainable development. These projects could be workshops that use astronomy concepts to impart skills in programming or mathematics, training sessions for human capacity development, collaboration programs, outreach campaigns, or any number of other projects that target sustainable development.

Since 2012, 68 projects have been funded globally by the OAD, in addition to many more projects run by its Cape Town office. One funded project that is relevant to IYL 2015 is the Dark Skies Outreach to Sub-Saharan Africa led by Dr. Connie Walker. A National Optical Astronomy Observatory (NOAO)-developed project, it implemented the successful GLOBE at Night and Dark Sky Rangers programs, an international citizen-science cam-

paign to raise public awareness of the impact of light pollution, in 12 African countries. The goals were to "help students identify wasteful and inefficient lighting and provide ways to reduce consumption and to keep energy costs in check." The NOAO designed and produced kits that contained activities related to energy conservation and responsible lighting. These were sent to coordinators in the 12 countries who were then trained via several Google hangout sessions. These coordinators in turn trained teachers in local schools, thus disseminating the ideas across the community.

The Dark Skies Outreach project brought awareness of light pollution, inspired the community to fix the problem by supplying essential tools and methods, and ended up creating an international network working together. It is, in principle, also sustainable as the coordinators could train more individuals without requiring much external assistance. Responsible lighting goes beyond safeguarding dark skies as light pollution affects our health, wildlife, and energy demands. Astronomy merely served as a useful tool to bring the problem into focus.

A cornerstone of the OAD's modus operandi is the emphasis on impact and evaluation. We would ideally want projects to run evaluations and scientifically measure the impact of their work. This would help



Pheneas Nkundabakura country coordinator in Rwanda for Dark Skies Africa. CREDIT: Pheneas Nkundabakura, Dark Skies Africa.

identify and create a suite of best practices that would serve as the foundation for future projects. Such a positive feedback loop would create a wealth of knowledge and make the most of our efforts.

IYL 2015 is a testament to the key role that light continues to play in our lives. From being a subject of enquiry to contributing to scientific enlightenment and driving development, it has now come full circle. Cli-

ché though it may be, astronomy still has the power to light up our lives.

Ramasamy Venugopal has an M.S. degree in space studies from International Space University, Strasbourg and is passionate about science communication, science outreach, science advocacy, and science for development. From February to May 2015 he was a visiting fellow at the Office of Astronomy for Development in Cape Town, South Africa, where he also works on university-level projects.

Changing the Way We Recruit Photonics Technicians and Engineers

Carolyn Hulla-Meyer, Cincinnati State Technical and Community College, USA

I am new to the field of Photonics. Currently, I provide outreach services at Cincinnati State Technical and Community College. We are a two-year college located in Cincinnati, Ohio, USA. I work specifically for the Electro-Mechanical Engineering Technology (EMET) program, under a grant from the National Science Foundation. My specific role is to increase enrollment in the EMET program's Laser Major. I attend recruiting events to engage high school teachers and spark the interest of students and parents.

In the Western world, we've fully embraced the technology that provides us cheaper electricity, less-invasive surgery, mobile phones, and high-speed Internet. We've embraced it so much that we don't even know there's an umbrella term for it! As I'm discussing the Laser Major, my job is to make something so ordinary, sound New! Exciting! Fresh! In other words, evoke a sense of awe. It's fun because it's not as hard as I thought it would be. We are fascinated by light, as humans. Isn't that interesting? We are fascinated by light. We watch fires glow for hours. We are mesmerized by displays of fireworks. Our attention is drawn to anything that flashes, sparks, or sparkles. Diffraction glasses have proven themselves to be great at getting a student's attention. If you are ever trying to get any kind of reaction from an apathetic teenager, have them put a pair on.

Then, shine a bright LED flashlight in their direction and watch that bored-looking face light up! Once they are curious, I begin to explain how valuable a degree in photonics is and why they need to take advantage of the opportunity.

According to a 2012 survey conducted by University of North Texas Survey Research Center, the U.S. optics and photonics industry will need 4,115 photonics technicians over the next 5 years, with only 280–300 graduates being produced every year.¹ Here in Cincinnati, there is a high concentration of companies in the manufacturing industry. We design and build everything from consumer products to playing cards to jet engines. Lasers are becoming a necessary part of manufacturing processes. This means that people with the skills needed to adjust, maintain, and repair them are in high demand. On October 2014, Cincinnati State received more placement requests for students with laser training than we have students to fill them! On top of that, we are one of only two colleges in the Midwestern states to offer a laser program.

Contributing to this problem is the attachment to the image of what an engineer, or a technician, or a machine operator "looks like." Women and minority populations continue to be socialized to believe they are "not smart enough" to be engineers, or that they are "too soft" to work with tools. The aforementioned

study suggests that just 4% of photonics technicians are African American, 14% are Hispanic, and 18% are Asian, with just 19% being female.¹ We can't expect the field to be overflowing with applicants when only a fraction of the population is being actively recruited!

I recently attended an event aimed at encouraging eighth grade students to start thinking about their future career. I was at a career-technical high school. In the U.S., students at this type of high school learn the state-required curriculum through the lens of work skills that are required in a particular industry. They will then pursue a career, or continue on to college. I spoke to hundreds of students at the two-day event. I will not soon forget this interaction with about 6 young women who were around 13 years old. I got their attention by pushing six pairs of diffraction glasses in their general direction, and directing them to "Look through these glasses!" After the exclamations of "Whoa!" and "Cool!" quieted, I asked them what they thought being an engineer was all about. They said things like "Sitting at a desk all day," "working with wrenches and machinery," and "being super-smart or really good at math." "Basically," said one young woman, "it's not for us."

I asked them what they like to do in their spare time. I heard lots of things but waited for the activities that I could relate to engineering.



"To me, the field of optics and photonics is all about opportunity."

Carolyn Hulla-Meyer

CREDIT: James Webb Space Telescope.

Things like drawing, taking things apart, and putting them back together, or solving puzzles. I stated that those are all things that a person with a "technical mind" might like to do. It takes perseverance, a good work ethic, and a desire to make your community or business better. I asked them, "Have you ever considered being in engineering technology as a career?" They all shook their heads, "no." Three of them, though, finished the thought by proudly stating "... but I will now."

While those glasses may have attracted the young women to my table, what created the feeling of awe was someone telling them "this field has the potential to change the world, and despite what you are told, you can be a part of it." We need to do a better job of countering these stereotypes with role models who represent the diverse nation we are. This means that we need to respect the contribution made by women and minorities

equally. Benjamin Banneker, for example, was the first African-American Presidential Appointee when he became a key member of the surveying team that designed Washington, D.C.² Emily Roebling was the chief engineer over the design and construction of the Brooklyn Bridge, which is modeled after the Roebling Bridge in Cincinnati. She became head of the project after her husband became bedridden due to illness.³

"Optics and photonics is all about the science and engineering related to light," says the SPIE poster hanging in my office. To me, the field of optics and photonics is all about opportunity. Employers are ready and waiting for trained individuals, and they don't care what that student looks like or where they came from.

MORE INFORMATION

1. http://www.op-tec.org/pdf/2012_Needs_Assessment_Summary_Report_Revised_02222013.pdf.

2. <http://www.usasciencefestival.org/schoolprograms/2014-role-models-in-science-engineering/377-benjamin-banneker.html>.
3. A. M. Lewis, "Emily Warren Roebling: She Built the Bridge" in *Women of Steel and Stone: 22 Inspirational Architects, Engineers, and Landscape Designers*, Chicago Review Inc., pp. 103–110 (2014).

CREDIT AND DISCLAIMER

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Carolyn Hulla-Meyer is an Outreach Specialist at Cincinnati State Technical and Community College in Cincinnati, Ohio, USA. Her prior experience in recruiting and career coaching drove her desire to promote job growth in the U.S.' post-recession economy, and as a women's rights activist, she uses her passion to encourage and assist young women in pursuing high-paying, in-demand careers.



CREDIT: SolarAid.

Helping Others Find Light

Dalma Novak, IEEE Photonics Society, USA

Those of us who are fortunate to work directly in the photonics or optical technology fields, or are members of the wider technical community, already have an innate appreciation of the transformative nature of light-based technologies and the crucial role they place in our daily lives. Light is not something we take for granted; we recognize implicitly how optical technologies have revolutionized medicine, manufacturing, communications, and energy. However, while developed countries have benefited tremendously from these advancements, there are many people in developing countries who lack basic access to the very technologies that we consider both commonplace and fundamental for existence. For example, more than one-fifth of the world's 7.3 billion population has no access to electricity, almost 600 million people living in Africa alone. Without electricity families have no clean source of light, having to rely instead on expensive (and dangerous) alternatives like homemade kerosene lamps; families can spend up to 40% of their income just on kerosene. With respect to access to communications, less than 20% of the global Internet usage comes from Africa. This disparity in technology richness and its detrimental consequences were recently highlighted by the UN Secretary General, Ban Ki Moon, who noted, "Widespread energy poverty still condemns billions to darkness, ill health, and missed opportunities for education and prosperity."

As citizens of the world, it is our social responsibility to address the challenge of universal and affordable access to light-based technologies. Supplying low-cost solar lights to the world's poorest people promises to have a tremendous impact in this regard. Replacing inefficient kerosene lamps, which generate toxic fumes and soot, with clean solar lights brings immediate health benefits. The World Bank has estimated that breathing

particulate-laden kerosene fumes is the equivalent of a two-pack-a-day cigarette smoking habit, so it's not surprising to learn that two-thirds of adult women with lung cancer in developing nations are in fact, nonsmokers. Kerosene accidents also kill thousands every year. A number of nonprofit organizations are responding to the huge global need for inexpensive solar lights. Solar Aid is one such international charities working towards providing access to safe, clean solar lamps in some of the most remote regions of the world. To date they have supplied 10 million people in Africa with access to solar light, saving families hundreds of millions of dollars and providing children with two billion additional nighttime study hours.

In late September more than 150 world leaders met at the UN headquarters in New York for the UN Sustainable Development Summit to formally adopt a new sustainable development agenda for promoting shared prosperity and well-being for all over the next 15 years. The provision of solar lights to those in need directly underpins a number of the goals of this sustainable development program as well as the mission of the International Year of Light and Light-based Technologies 2015 (IYL 2015). By supporting humanitarian organizations like Solar Aid through the donation of solar lights, our international light community has the opportunity to quickly improve the lives of the world's poorest people, turning a world of darkness into one of promise and freedom. Let's all take action today.

Dalma Novak is currently the 2014–2015 IEEE Photonics Society (IPS) President and is Vice President of Engineering at Pharad, LLC in Hanover, Maryland, USA, where she develops technologies for realizing high-performance RF-over-fiber systems. She received a Ph.D. from the University of Queensland, Australia and was formerly a professor before moving to industry R&D.

IYL 2015: An Opportunity for Africa

Yanne K. Chembo, FEMTO-ST Institute, CNRS, France

There are currently more “international days” than days in the year (approximately 400). Each of these days is intended to raise awareness on important problems (diseases, human rights, environment, etc.), or on even more important issues (“Go barefoot day,” “Raspberry cake day,” etc.). Only at the highest level can a topic be considered sufficiently important to deserve a full year of celebration. This is why United Nations supports between one and five “international years” every year. Different from the selection of international days, the UN selection process for international years is so rigorous that we can trust every chosen topic to be essentially pertinent for Mankind. Through this selection process, the year 2015 has been proclaimed International Year of Light and Light-based Technologies (IYL 2015), but it is noteworthy that it is also the International Year of Soils (IYS).

I am fortunate to be an active participant of IYL 2015, and in particular, to represent the African Physical Society (AfPS) in many IYL 2015-related events. Some of the questions I am asked very often is, “Why would such a year be important for Africa? Why do you think we should pay attention to IYL 2015 while we are still struggling with very fundamental problems like education, healthcare, and basic infrastructures, etc?” My answer is always simple: the economy.

It should first be pointed out that Africa is, to a large extent, an un-



UNESCO's Active Learning in Optics and Photonics (ALOP) Workshop in Rwanda in 2011. CREDIT: UNESCO.

known continent. This is why whenever I present the African perspective of IYL 2015 to an international audience, I invariably start with a slide entitled “Africa in numbers,” which aims to provide some key socio-economic indicators about the continent. The mainstream cliché of Africa (sometimes popularized by Africans themselves) portrays a continent plagued with wars, chronic instability, and structural underdevelopment. This cliché—as most clichés—bears some partial truths. However, there is another reality that is much less trivial to grasp, but is no-less factual: The African continent currently enjoys unprecedented economic growth so vigorous that its wealth doubles every decade. Many books and articles have already identified and analyzed this

trend. I encourage the reader to consult the online article cited below this post, entitled “The world’s fastest-growing middle class,” which proposes a compelling synthesis of the current boom in African economy.¹

Therefore, even though it might appear surprising for many, light-based technologies are intimately linked to the ongoing economic growth in Africa. For example, telecommunications (optical fiber and mobile) are directly linked to 5 to 10% of the GDP of most African countries and can indirectly impact up to 20% of the economic activity. Currently, one of the most important projects in my home country (Cameroon) is the deployment of an optical fiber backbone that is expected to pro-

vide broadband access to the majority of the population. Another important challenge in Africa is access to electricity, which is undoubtedly a key prerequisite for economic growth. The sector of solar energy is becoming the focus of major investments in the African continent, and the number of solar panels grows at a truly exponential pace, with a 60% growth every year.

Therefore, a priority for African policy makers should be to ensure that enough technicians, engineers, and researchers are trained in photonics technology in order to work in these economically relevant sectors. It is here that I take the opportunity to highlight the valuable efforts of the major optical photonics societies (IEEE, OSA, and SPIE) that are actively supporting the creation and funding of Student Chapters in Africa. Such structures are ideal platforms to enhance the networking skills of

the students, to help them keep informed about current research, and to give them the opportunity to lead many outreach activities in relation to optics and photonics. Indeed, beyond the economic standpoint, IYL 2015 can be an excellent tool to raise awareness about many other issues. For example, I highlight the challenge of affordable eyeglasses, which is an important problem for tens of millions of Africans. Or the development of sustainable photonics technologies for the amelioration of African healthcare. And why not realize African-based production of photonics components and systems; after all, Africa is a “geological scandal” that can provide almost all of the natural resources needed to manufacture almost anything you may want.

Many think that the XXI century will be a new “Siècle des Lumières,” and this time, all of the indicators are

green for Africa to both contribute and benefit in a significant way.

If you have never been to Africa, hopefully, you now see that it has many opportunities to choose from. Therefore, you have no more excuses: join us—you will be very welcome to celebrate the IYL 2015 on our continent.

MORE INFORMATION

1. N. Heeralall and R. Ben Abdelkrim, “The world’s fastest-growing middle class,” UHY, UK News: <http://www.uhy.com/the-worlds-fastest-growing-middle-class/>.

Yanne K. Chembo obtained two Ph.D. degrees (in physics and in laser physics) and is currently a CNRS researcher at the FEMTO-ST Institute, France, where he leads the microwave photonics group. He represented the African Physical Society as a member of the delegation that presented the International Year of Light proposal during an informational meeting at the UN Headquarters in New York in 2013.

Light and Luminosity at CERN

Lucio Rossi, CERN High Luminosity Large Hadron Collider, Switzerland

“Light as luminosity” is the theme of the CERN celebrations on the occasion of the International Year of Light and Light-based Technologies (IYL 2015).

At CERN, light is linked to luminosity, and the High-Luminosity Large Hadron Collider (LHC)¹ project plays an important part in it.

Light is the means with which we can see and can reach reality. Over 100 years ago, Einstein discovered that light waves behave like particles. Just 90 years ago, Louis de Broglie put forward the unimaginable idea that a particle can behave like a wave, with a wavelength inversely proportional to its momentum. This completed the particle-wave duality initiated by Albert Einstein in his annus mirabilis when he realized that waves behave like particles, and he thus introduced the concept of light quanta, the photons.^{2,3}

In particle accelerators we provide such a huge amount of energy that the wave associated with each particle becomes a wave with which we can see in finer detail. In this way, particle accelerators can generate the finest “light.”

But light is only a means, a bridge between reality and our minds, where the image is formed and vision occurs. Indeed the light generated by the Large Hadron Collider at CERN would be useless without “eyes”—the LHC detectors that collect the collision events to record the detail illuminated by the light. As with actual eyes, the collected information is then transmitted to the mind for image formation. At the LHC, the computers, the physics theory, the brains of

the experimentalists and theoretical physicists—all of these form the “mind” where wonderful images, for example, the image of the Higgs boson, are formed and, finally, known. Exactly as with sight, some signals (most of them, in fact) are first treated “unconsciously” (by the trigger), and only a selected part is treated consciously on a longer time scale.

Now the LHC is restarting, and we will be able to generate light that is almost as twice as fine, thanks to the 13TeV collision energy. Moreover, the HL-LHC project is already on the starting blocks to be ready 10 years from now. Why high luminosity? Just as in a room where we might ask for more light to investigate finer details and measure the properties of objects more precisely, with the LHC we are planning to increase luminosity by a factor of 5 (instantaneous) or 10 (integrated) to make more-precise measurements and so extend our sight, i.e., the physics reach of the collider and the detectors.

MORE INFORMATION

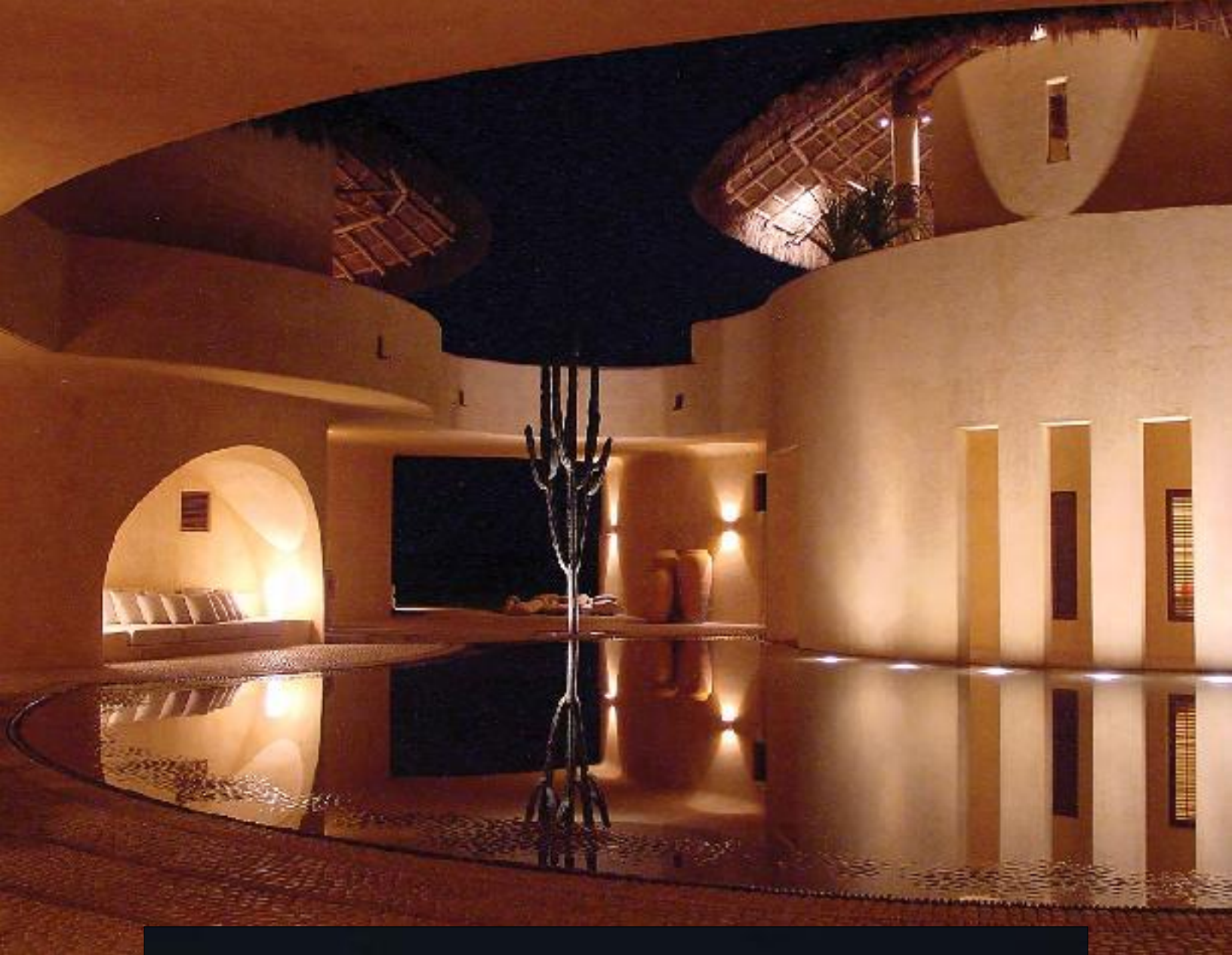
1. On HL-LHC: High Luminosity Large Hadron Collider: <http://cern.ch/hilumilhc>.
2. L. Rossi, “Viewpoint: Seeing is believing,” *CERN Courier*, 23 Feb. 2015: <http://cerncourier.com/cws/article/cern/60169>.
3. “Einstein’s most famous equation,” *Symmetry Magazine*: <https://www.youtube.com/watch?v=6569GBcQKTs>.

Lucio Rossi heads the High Luminosity Large Hadron Collider, a project with a budget of about 1B Swiss francs, and he has served as a researcher and professor at the University of Milan. He is active in public outreach and regularly lectures to the general public on science and the relation between science/technology and certainty/truth.





Projection of the IYL 2015 logo on the Globe of Science and Innovation, one of CERN's symbols. CREDIT: CERN.



Top: Beach Residence, Pacific Coast Mexico. CREDIT: Victor Palacio.
Bottom: Plaza Concordia, Puebla, Mexico. CREDIT: Victor Palacio.

Light in Architecture

Victor Palacio, International Association of Lighting Designers (IALD) Mexico

Light is the most important factor in the appreciation and understanding of architecture. The relationship between light and architecture is grounded in the principles of physics; it is about energy and matter, but in this particular case, it also implies an emotional effect on people.

The quality of lighting in a space defines its character and creates impressions. The human eye perceives its form through the incidence and reflection of light and in that way acquires information about the ambiance in a given place. Visual impressions are interpreted in our brains and put in context to create emotions that move us to take particular actions.

Lighting in a living room will be warm and dimmed, and there will be no brilliant points; instead, the distribution of light reveals textures and color, and balances the dark and clear areas. This atmosphere, when read by our visual system, creates a comfortable impression that helps us to relax and enjoy the moment.

In opposition, lighting in a workplace, for example a laboratory, will be cool in appearance, and brilliant and focused on the specific places of work. All of the room will be evenly lit, and it will be perceived as wide and clean; this impression creates a dynamic mood in which different tasks are developed with more energy—mental and physical.

In public spaces, light provides a safe environment where people can meet and have a great diversity of activities. Historic districts, squares, parks, and pedestrian streets are

all appreciated and become useful thanks to good lighting.

How can we add value to our homes, institutions, public spaces, commercial areas, cultural facilities, working spaces, and practically all spaces by the use of light?

It is important to first understand the visual needs of the users of a space. Lighting is ultimately the energy that lets us develop visual tasks like reading, identifying colors, perceiving volumes, measuring distances, and more!

Secondly, it is really relevant to analyze the space: its form and function. As was mentioned before, lighting will be different depending on the use given to a place. Surface finishes, materials, shape, color, form, and physical dimensions are key elements in the way that light will react and then provide information and impressions.

Next, there is no good lighting solution without the use of the correct light source. It is not a matter of using always the most technologically advanced fixture—not at all! It is about selecting the right lamp for the place and moment that you need to illuminate. A candle is a great solution for the lighting of a table in a terrace of a quiet restaurant, while an ultrahigh-efficiency optics luminaire is needed to illuminate a soccer stadium. There is no good or bad solution in itself, it always depends upon the visual needs and the characteristics of the space.

Finally, light as a form of energy used in architecture requires electricity. This means that the use of

light has an impact on the environment; therefore, it is also essential to plan and design the lighting in the most energy efficient way in order to preserve our planet.

One of the pioneers of the use of light as part of the architectural concept was Richard Kelly. He established three basic visual effects in order to design the lighting of any space:

- focal glow: the light that attracts attention to an object, a surface, or a detail,
- ambient luminescence: continuous light like that of a foggy sky that is completely even and uniform without shadows, and
- play of brilliance: the shining effect of light reflected on a brilliant surface, like the sun on a water spot or the glass drops of a chandelier.

The balance of these three elements will create a visually appropriate light scene accordingly to the character and use of a space.

Light defines the architectural space; it contributes to its perception and understanding while adding value to its function and bringing an emotional component for its users.

Light is magic!

Victor Palacio is the founder of ideas y Proyectos en luz, S.C., an independent lighting design practice in Mexico City for a broad range of projects including museums, residences, and corporate, urban, and retail projects. Victor is a frequent lecturer at lighting courses and international architectural lighting events, has volunteered for the Illuminating Engineering Society, and currently is the President Elect of the International Association of Lighting Designers.

Message in a Bottle

Vaqaas Ataullah Butt, ACE Welfare Foundation, Pakistan



CREDIT: Liter of Light Pakistan.

“As you sow, so shall you reap,” they say, but is it really true? I say yes, if what you sow is light, then what you reap is a more enlightened world. How, one may ask? For instance, a bright Pakistani child growing up in a village may seek to study and pursue a career in modern science and become a beacon of hope and inspiration for many others; but the absence of light in the same child’s life may hinder his or her growth and capacity to pursue even basic education. There seems to be a correlation between education and becoming enlightened, and clearly, light seems to be a key ingredient in the mix.

As a British Pakistani citizen currently residing in Pakistan and leading the Liter of Light movement in Pakistan, I had my own “light bulb” moment after realising that this simple yet innovative idea could help millions of underprivileged families in Pakistan. The savings generated can be spent on more important things like books, health care, nutrition, and livelihood. Around one-half of Pakistan’s population, especially in rural areas, lives without reliable and affordable power supplies. With electricity prices in Pakistan amongst the highest in Asia, added to economic instability, paying monthly electricity bills can

be a struggle for even those who have electricity.

In rural areas however, the residents have gotten used to living in darkness. In most Pakistani villages, there is actually no concept of living a normal life after sunset. Women can be seen preparing meals out in the open, generally in the courtyard on their mud houses, while kids go running around, using streets as a playground. The overwhelming majority of people have adapted to a lifestyle that starts with the sunrise and ends at sunset. Without the presence of light, they are at a disadvantage in virtually every aspect

of their lives. In some areas, this actually forces the residents to chop trees and disturb our fragile ecosystem, while others are left with no choice but to burn kerosene oil as an expensive alternative, exposing themselves to toxic fumes that are associated with health-related diseases like bronchitis and cancer.

The ongoing war in Afghanistan has forced 1.6 million Afghans to migrate to Pakistan, while a recent joint military offensive conducted by Pakistan's Armed Forces against the armed terrorist groups has regrettably displaced more than 1.2 million Pashtoons from the tribal belt of the North Waziristan Agency into different areas of Pakistan. According to the UNHCR findings, which compare the number of refugees to the size of a country's population or economy, the contribution made by Pakistan relative to the size of its economy and the burden carried by the country makes it the biggest host country of refugees in absolute terms.

Since Pakistan is blessed with an ample amount of sunlight, Liter of Light Pakistan made a logical conclusion to improve the living standards of these unfortunate families by bringing a ray of light into their homes at night. The team, in partnership with PEPSICO and Sika Pakistan, visited the UNHCR Jalozai refugee camp in September 2014. The camp remains one of the largest and most populous refugee or transit camps in Pakistan and is located 35 km southeast of Peshawar in the Khyber Pakhtunkhwa province.

At Jalozai refugee camp, Liter of Light Pakistan was up against the rugged and rocky terrain of the area. Digging a hole no deeper than a foot and half in the ground to install street lights had never been more challenging. There were times when halfway through the digging, the team encountered rocks and had to start all



CREDIT: Faisal Khattak, Provincial Disaster Management Authority, Pakistan.



CREDIT: John Nadem.

over again, leaving many volunteers with blisters on their palms. The team was also shocked to witness the absence of light in the restrooms used by the refugee community. The cubicles designed and donated by UNICEF were not fitted with light bulbs. Women, children, the elderly, and disabled seemed to be the worst affected by the darkness. A simple visit to the restroom at night was extremely challenging and in some cases virtually impossible. Some of these cubicles were fitted inside the Mother and Children Maternity (MCH) hospital where women were brought in emergency cases during labour.

The last power cut left the camp 14 days without electricity. Although the hospital was equipped with emergency generators, running them continuously for the whole night was just not possible. One of the proudest moments for Liter of Light Pakistan was to become the first chapter out of 55 participating countries to install a bottle bulb inside the labour ward of a refugee camp.

Liter of Light is a global movement that involves upcycling trashed and thrown away PET (polyethylene terephthalate) bottles into zero-carbon-emitting and eco-friendly solar bottle bulbs. Inspired by Alfredo Moser's bottle bulb, Illac Diaz founded the Liter of Light project in the Philippines in 2011.

The invention is relatively simple. It involves filling a 1.5 L soda bottle with purified water and chlorine and installing it onto the roof of a house. The water inside the bottle refracts the sunlight during the day time and creates the same intensity as a 55-watt light bulb. With the correct installation and materials, a solar bottle can last up to three years. With a little upgrade to the day bottle, coupled with a simple circuit and a small solar panel, the bottle bulb can also produce 3 watts of ecofriendly light at night.

Moreover, by adding a PVC pipe or a bamboo, the light can also be installed outdoors as a street light. The solar panel charges the battery attached to the circuit from the direct sunlight. The circuit is designed to automatically switch on in the evening and off upon sunrise.

Doe Zantamata once said: "It starts with a dream. Add faith, and it becomes a belief. Add action, and it becomes a part of life. Add perseverance, and it becomes a goal in life. Add patience and time, and it ends with a dream come true." And just how perfectly Elizabeth Green puts it: "Sometimes, the most ordinary things could be made extraordinary, simply by doing them with the right people."

Vaqas Ataullah Butt is the Executive Director of ACE Welfare Foundation, Pakistan and the founder of Liter of Light Pakistan. He received his M.S. degree in business administration in 1999 from The Institute of Management Sciences, Lahore, Pakistan and served as a Special Constable—a volunteer police officer—in South Yorkshire, UK.



Manna. CREDIT: Sonia Soberats.

Night Is Canvas

Steven Erra, Light Painting World Alliance, USA

At the Light Painting World Alliance website, you'll find the phrase "Night is Canvas." Night is no ordinary word for me, as I suffer from night blindness. It's a powerful, often frightening word, separating me from the able bodied, putting me in the folder labelled "Unabled"—legally blind, asking for help to cross the street. Night and its draining, light-less hardships needn't be only that. After all, the other part, the "canvas," is what matters more in the end.

I belong to a group of photographers based in New York City called the Seeing With Photography Collective. Many in our art group are blind or sight impaired, like myself. We create and exhibit light paintings. The very nature of our visual limitations can provoke any viewer or perceiver of these images ... "Is less more? What is he/she seeing?"

Night is often our permanent reality, too, as sightless people. I myself am nearly blind, but I see a little too, now and then, so I stand in two realms. Every cast shadow, each building entrance, robs me of sight. I'm desperate for light really, any light, any scrap of stray, ineffectual photon—I feel the desperation—my dying retinas ravenous to see, like an emaciated, skeletal dog that will gnaw and scour the air off the alley.

From the context of blindness, the word "light" glows with particular symbolism beyond its physical nature. It glows with reflected and dimming echoes morphing with sighs and regrets at its intolerable loss, its hopes, its whispered paradises ... of incandescent agility and certainty. Light's abandonment lingers like afterglow,



Entangled. CREDIT: Steven Erra.

we swallow hard, losing spectacle, comparison, choice, and pleasure. To speak of light, we speak of its opposite nature too, embedded and not apparent. A dual part barely recognized, yet always there lurking, frowning, and nodding within the dark.

Our group originated from a photography class for blind and sight-impaired students. Mark Andres, our teacher, taught us the technique of light painting in 1997. Mark was interested to learn what we would make of the technique as it involves using the mind in a place where we all were equally in the dark. It wasn't about capturing a decisive moment as much as constructing something.

There was resonance with

the technique, and we as a group haven't put down our flashlights yet.

There are a variety of people who shoot light paintings but can't see. Some have little background in photography or any visual art media, and some enjoyed photography for the usual reasons before losing their eyesight. Others were actively involved in serious image making for a very long time and found there an artistic outlet to explore. Some in our group see nothing, though many have some remaining, but minimal, vision. A few see well, even what's termed "normally."

When I was told there was an actual photography class for blind and sight-impaired students back in 1993, I remember I was surprised, a little skeptical, but beaming with happiness because others had understood that making visual art and not seeing were not mutually exclusive. I felt like a connection was made between two



Kingdom Chrome. CREDIT: Mark Andres, Donald Martinez, Benjamin Paige, and Phil Malek.

threads that had been re-attached. Two electric wires that needed to join, finally did in that bland basement classroom at the VISIONS Blind Services Organization where we work.

At first it sounds improbable, but just at first. Like some new rhythm, some unfamiliar but absorbing thing.

Memories play a part in our group's imagery, but they aren't the sole theme by any means. Sunshine and faces, that funny red chair, costumes, picnics and monsters, movies and night clubs, cartoons and sports events, ancient frescoes and scary subway rides, and countless other memories of the world of light all reform before our flashlights. Despite sight loss, we all have memory and ideas to explore in our mind's eye long after our biological eyes give up on the act and art of looking.

We re-create them again, different maybe, not duplicates, not snapshots, but works that bring out that memory or theme with the perspectives all shifted, energized, sparkling. The light painter's dark frame invites all photographers to come and illuminate. I think it must be hard for any photographer to resist the urge to try one given the chance. Its darkness is very familiar territory, our default color, our resigned dark

velvet blindfold that we can't tear away. We run our hands around the framed out scene, through the central spaces, feeling fringes and walls, touching what's on the other side of the camera's view. And we shine our little flashlights on that night canvas, painting with light...quivering fabrics shaken and moved around fire beings amid Interstellar jewels.

The light paintings aren't made quickly; they take a few minutes, and our models shift a little, droop a little over time. The laughs ensue at the results, three eyes, squashed noses, pinheads, people morphed into squat statuettes and ghostly elves.

Mostly it's a collaborative effort when we work, but more-experienced artists can work independently, too. And focusing? That's done by a sighted assistant, but do film directors focus their own motion picture cameras? The minor things like focusing are a different story from the major things like ideas, composition, and lighting that are done by the sightless, sighted, or sight-impaired photographer. None of this is surprising, of course—as a visual artist I understand it.

The blind photographers will also direct where each person, object, or background area is, and how all should be positioned, so again, the

creative control is left to the photographer, the sighted assistant just letting them know things like what's in, or not in, the camera's frame.

There's struggle, there's the battle against the dark. I sense this in our work, but, maybe it's my own internal projection. We light-less, enact on some level, a very core, very primal encounter that's a universal archetype—the struggle of light over dark. It's mainly subconscious and maybe not fully realized, even by we who make the work. Archetypes can work well as form, as far as art goes, I think.

And there's defiance in that frame too; the flashlight as weapon in this effort, this determination to hold on, and not go quietly into the darkness.

Some have said our imagery can be nightmarish or sad, and that's sometimes so. Yet there's an enormous variety of themes and styles found among our member's work, fashionable runway stylizations, Biblical tableaux, happy partying, and old Master re-enactments are all here, cheerfully hued, non-angst-ridden enough to be hung comfortably above a living room sofa.

Comparing our group's work with other light paintings, I see a difference, but I'm not sure what it is.

I don't see us as being fixated on pretty lights or special effects just for the sake of prettiness or coolness that you forget a minute later. They seem simpler but still visually nuanced and raw simultaneously.

We sometimes teach workshops, and I recall some photographers who had a difficult time letting go of their light meter mindset and stared at me in skeptical disapproval when I said the timing was a matter of experience. It was sort of fun being a guy with a white blind cane walking into things and giving lessons on how to make photographs. You get used to these sorts of things, really.

In a way, taking images without seeing is a significant reorganization of expectations. A blindfold can work great as a teaching tool. We use them with the sighted students. Many really are thrilled to be blindfolded, and smile and grope around, saying "Wow," and get goosebumps feeling things, and just delve into their other senses that are mainly ignored in the photography studio. But other photographers have quite a hard time letting go.

By deliberately shutting out light itself and briefly inviting in the harrowing, dreadful fear of any visual artist, blindfolding touches on certain elements of psychology and creativity that are good to be aware of. Donald Martinez, a sighted member of our collective, sometimes closes his eyes when he makes a light painting to distance himself

further from the tightness, the crispness, and control—the domination of light upon the mind.

Human nature doesn't want to relinquish feedback from our efforts, our ears from our music, our taste from our cooking, yet some can never have the full visual assessment of their work that eyes provide. How

world of light? Maybe we can act as a sort of mirror. One that reflects your views, maybe shifting and nudging cozy presumptions.

I've no confident theory to present on the nature of blind photography. For me and many in the Seeing With Photography Collective, it's an experience to be lived, dim and flickering at times, loud and warm at others.

Without light ... voices take on an expansive, rich meaning. Ideas loom more directly. There's less distraction by visual clutter. Working in the dark with my group causes me no gut-churning dread, no dizzying loss. Something memorable happens creating imagery in the dark, with the dark, the dark as our supportive friend, all of us sighted or blind together, thinking, trying, laughing, describing, listening ... weaving something.

Light is essentially indifferent; angled into the lens of an eye or cold camera, we give it meaning and arrange its context. In the intertwining of sighted and not sight-

ed, one thread describing another, eventually we all must close our eyes in sleep, lightless, sighted and blind alike, and all our dreaming eyes understand and gaze, and see.



Radiant Abyss. CREDIT: Victorine Floyd Fludd.

do blind photographers know what they have made? Those who can see describe and become the eyes ... providing the scope, the tone, and narrative that will form the structure of the new creation, glowing unseen on the camera's digital screen and glowing, too, in a different way, in the internal mind of the unseeing artist.

Lately, the work of blind and sight-impaired visual artists is becoming more widely known. It's a new facet in the cultural legacy of art. What do we have to offer the

Steven Erra is a visual artist, a photographer, and painter who has shown his work in numerous exhibitions and publications and has been legally blind for many years due to retinitis pigmentosa. He has a B.F.A. from Parsons School of Design and is involved with the Seeing With Photography Collective and the Light Painting World Alliance.

Our Cosmic Light

Lina Canas, IAU Office for Astronomy Outreach, Japan



The planetarium show “The Sky in Your Hands” has a tactile component: a half-sphere with constellations in high relief that helps the audience follow the show’s narrative through touch. CREDIT: Astronomical Observatory of the University of Valencia (OAUV), Spain; Navegar Foundation and Ciência Viva, Portugal.

Astronomy is a very visual science. Who amongst us, while working in science outreach hasn’t experienced first-hand the enthusiasm reflected in a child’s face when they see the amazing images that reach us from outer space? And it is easy, with a single image, to produce a sense of awe and enthusiasm for the mysteries of our cosmos. Whether it is the simple glimpse of a sky full of stars or a more complex image captured by large telescopes, we must admit, at least a little bit, that astronomy has it easy when it comes to engaging audiences with powerful visual images. Now imagine that your audience is blind or visually impaired. You have to start thinking and designing all of your approaches to science outreach anew, and your universe just expanded a bit wider.

To hold “the sky in your hands”

During the International Year of Astronomy 2009 in Spain,

there was a very special project called “El Cielo en Tus Manos” (The Sky in Your Hands). This project, lead by Amelia Ortiz-Gil, from Astronomical Observatory of the University of Valencia (OAUV), aimed to take the predominantly visual experience of the planetarium and share it with visually impaired audiences.

Using a half-sphere with stars and constellations engraved in high relief, the user can access through touch

what is being projected on the dome. During the show, the audience is guided by two narrators: one that tells the tales of the night sky and the other that guides them through the tactile half-sphere. More than a mere tactile experience in the planetarium, this is an inclusive experience, where groups of friends and family, visually impaired or not, can be together in the same place learning about astronomy and enjoying the beauty of the night sky.



One of the many impressive resources featured in the kit is the tactile Moon model. Highlighted in relief are craters, maria, and mountains. The 3D model of the tactile Moon was produced by Amelia Ortiz Gil from OAUV in Spain and is featured in the “A Touch of the Universe” kit. This project produced 30 of these kits for developing countries. CREDIT: OAUV, Spain and NUCLIO/ACAPO, Portugal.

Teaming up, OAUV and Astronomers Without Borders (AWB) together produced a sustainable international program that is still running today. Anyone who wants to implement the project can acquire all related materials for free. These include the complete soundtrack; digital file for the 3D-printed half-spheres, or a DIY half-sphere using low-cost materials. Customized support for anyone who wants to implement the show is also available.

To have “a touch of the Universe”

Another example of the great tactile resources for visually impaired children is “A Touch of the Universe,” a nonprofit project supported by the IAU Office of Astronomy for Development. This project carefully developed and gathered a selection of tactile astronomy resources into a kit. Thirty sets of these selected materials were distributed among educators and teachers in socially and economically deprived regions around the world, areas that significantly lack inclusive educational materials.



“Meet our Neighbours” activities are divided into three main components: (1) the children explore the different tactile images and choose their favourite celestial object, (2) build the images using low-cost material, and (3) explain the main astronomical features to their peers. The groups are composed of both visually impaired and sighted children, promoting inclusion- and interaction-based astronomy activities. CREDIT: NUCLIO/ACAPO, Portugal.

This kit comprises a very balanced set of resources that allows educators to address many different topics in astronomy, such as the shape of constellations and relative distance and perspective. With a 3D-printed model of the Moon, the participants can explore its dominant surface features such as maria, craters, or mountains, the different

moon phases, and much more. Although designed focusing on a visually impaired public, these materials can be successfully used by all. The booklet of suggested activities that accompanies the resources targets both blind children and their sighted peers and can be used by both in joint activities.

Meeting our celestial neighbours

Launched in 2013 by Núcleo Interativo de Astronomia (NUCLIO) and Europlanet, “Meet our Neighbours!” is a project dedicated to taking astronomy to visually impaired children in socially deprived areas through the use of tactile astronomy hands-on, low-cost activities. This project presents ways to avoid the expensive tactile printing costs by producing a set of 13 tactile images of the main objects of the Solar System using daily-basis materials. It promotes inclusion in interactive activities for groups of visually impaired children and their sighted peers by exploring, building, and presenting the tactile images.

And Meet our Neighbours! is only one example of these activities; whether you want to address distances in the Solar System or between different stars in constellations, build a tactile DIY cardboard

planetarium, explore through touch different types of galaxies or even explain different components in space probes, the network of tested, low-cost resources is growing around the world, which is full of many creative enthusiasts.

Telescope observing sessions

Telescope observations remain a challenge when it comes to sharing the visual content of the celestial object being observed. Several activities have been designed by exploring the telescope through touch: the educators first explain the path of light and its trajectory through the telescope. Then, they can complement the activity by using a tactile model of what is being observed.

Wanting to make “live” observing sessions is the next natural step for any educator. The process is relatively easy. By connecting the telescope to a webcam, we can record the image of the objects being observed live onsite during a telescope observation. After using an image editing software, the images are ready to be printed on swelling paper (a special type of paper that allows the inked areas to swell when heated) and then run through a thermal printer. This allows visually



In this special observation session dedicated to the Moon, a 3D tactile Moon model was used. After pointing the telescope to a specific region of the Moon, the audience could explore the same feature in the tactile model. CREDIT: NUCLIO/+Ciência/GalileoMobile.

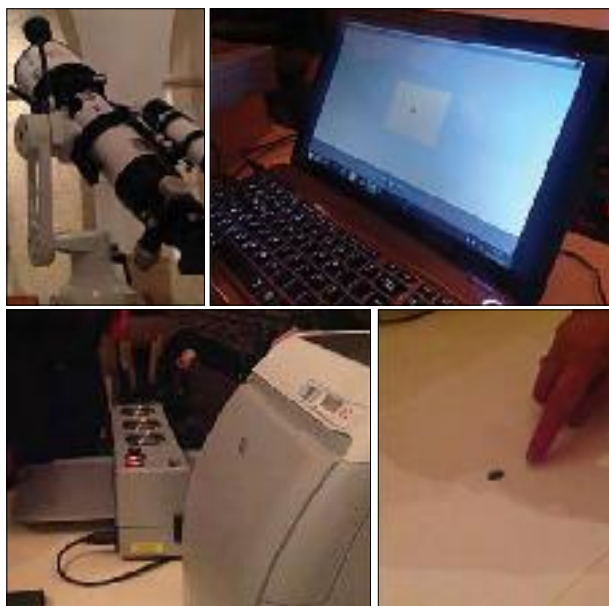


Using low-cost materials, educators designed and built tactile models so that students could learn about distances in the solar system or discover more about constellations in a cardboard tactile planetarium. CREDIT: NUCLIO and José Fanica, Portugal.

impaired audiences who attended the event to perceive the objects being observed in real time alongside the other participants.

Live online remote telescope observations

These projects aim to make it possible for both sighted and visually impaired audiences to take part in live, online observing events together. An example of these projects for outreach events is “Stars for All,” a live, online, remote observing event promoted by The Virtual Telescope Project in Italy and hosted by Dr. Gianluca Masi during Global Astronomy Month.



Real-time telescope observations for visually impaired audiences imply many different aspects to be taken into account when onsite. Besides the webcam connected to a telescope, it is required that you have also swelling paper and thermal printers. This event involved the efforts of several Portuguese education and astronomy outreach institutions, using the collaborative efforts of different institutions to produce an activity that was free and accessible to all. CREDIT: NUCLIO, Moimenta da Beira Astronomy School Club, Espinho Planetarium and Crtic Cinfães, Portugal.

If you are a teacher in a classroom and want remote access to a large telescope, Faulkes Telescope has a program that offers the opportunity for students to remotely operate it and take their own pictures of the cosmos. Often, visually impaired students are cast aside from these opportunities in classroom activities. So, by allowing real-time images to be printed off and converted into a tactile surface, students with visual impairments around the world can experience the wonders of observing with large remote telescopes, live, together, and alongside their classmates.

Global collaborative nonprofit efforts—become part of a movement

These are the projects that are supported and carried out by the individual efforts of many. For every project, every idea encountered the support of enthusiastic educators, outreach communicators, and amateur and professional astronomers willing to aid and partake in this adventure. And these are only a glimpse of a vast universe into which every one of us can contribute actively and creatively. All of the projects are collaborative and nonprofit. All materials and resources mentioned here are freely available to anyone who wishes to implement them. The information that light carries and that reaches us from every corner of our Universe is amazing, and it's everyone's right to be able to access it and explore it in their own special way. It is our duty to turn this into a reality in order to make cosmic light truly ours.

Lina Canas is currently based at the National Astronomical Observatory of Japan (NAOJ) in Tokyo, working for the International Astronomical Union Office for Astronomy Outreach as Assistant Outreach Coordinator. She has worked with various nonprofit organizations such as Astronomers Without Borders, Europlant, Galileo Teacher Training Program, and GalileoMobile to further astronomy education and outreach.

Safe and Efficient Light for Everyone—Tell Your Children

Jean-Claude Fouere, Light Up The World (LUTW), Canada

As you are turning on the bedside light and are about to read a story to your children, tell them that in many parts of the world, millions and millions of children their age live with no electricity and with no electric light. Tell your children that most of these children spend the evening with the dim light of an open fire, a candle, a kerosene lamp, or a flashlight. Tell your children that because of the very poor lighting, these children are really not able to do any school work or read a book at night.

It is estimated that 1.3 billion people worldwide have no direct access to electricity and no electric light. Instead, they resort to candles, kerosene lamps, or flashlights. Kerosene generates noxious fumes that are harmful to health. Indoor pollution from the fumes can cause many respiratory issues such as asthma and bronchitis, and the accidental ingestion of kerosene can lead to poisoning and even death. Candles and kerosene lamps are also prone to causing dangerous body burns and triggering house fires that, in crowded areas, can devastate entire communities. In addition, candles and kerosene lamps give light that is very dim, only one hundredth to one tenth of the standards recommended to accommodate many tasks and to allow for reading.

Tell your children that there is now realistic hope that this situation can be addressed effectively as, fortu-



A locally trained technician works on a home installation in the Andes of Peru. CREDIT: Light Up The World.

nately, a number of good technical solutions have been developed in the last few years. Tell them that light-emitting diodes, or LEDs, are becoming available in most regions of the world.

Many organizations, private foundations, and not-for-profit and for profit companies are working in earnest to install solar photovoltaic (PV) + LED lighting systems and provide technical training in communities that do not have access to power from the grid.

Tell your children that for the price of a pair of sneakers, a solar lantern can be purchased and provided to a family in many parts of the world, giving the children enough light to read, helping them with their schooling. Tell your children that for the price of a laptop computer, a low-power PV + LED lighting

system can be installed to provide light, greater opportunities for communication, and comfort to a whole household.

Tell your children that your family can help a family far away by supporting organizations that will bring them light—and a better life.

Jean-Claude Fouere sits on the Board of Directors of Light Up The World (LUTW), a Canadian nonprofit organization focused on providing sustainable energy and lighting to communities as a catalyst for sustainable development. Working in some of the most remote and undeserved areas in the world, LUTW provides technical training and builds the capacity of local service providers to transition away from unhealthy fuels and disposable batteries for energy and light.

Solar Lights Drive Clean Tech Enterprise in Rural Kenya

Linda Wamune, SunnyMoney, SolarAid, UK

The war on climate change is not one that can be won in a boardroom or conference hall. It is a war that has to be taken to the frontlines and intertwined into the lives of the men, women, and children who currently rely on burning dangerous and polluting fossil fuels for their most basic needs. For many of those living in regions most affected by the impacts of climate change, it is a war that starts with light.

As Pope Francis recently highlighted, tackling climate change cannot be done without simultaneously tackling poverty. In the 21st century, over half a billion people live without electricity in Africa, many of whom have no alternative but to light toxic kerosene in their home at night in order to study, work, or spend time with their family. SunnyMoney has joined the fight against energy poverty by finding ways to ensure that high-quality and affordable solar lights are available in rural Africa, setting these regions on a pathway to low-carbon development. To date, there are over 10 million people across the continent benefiting from SunnyMoney solar lights—people who no longer have to inhale toxic fumes, purchase expensive kerosene, or risk potentially fatal burns.

How we reach rural communities with life-changing light

In Kenya we achieve last-mile distribution of solar lights into remote rural areas having little transportation and communications infrastructure by first engaging education authorities at a national level and then by working with head teachers. The head teachers educate students, their parents, and the community at large on the dangers of kerosene use for lighting and the benefits of switching to clean, bright, and safe solar lights. SunnyMoney's school

shop owners, or community-based nongovernmental organizations.

Once SunnyMoney has completed a school campaign in a particular region, some of the participating head teachers choose to become agents. As highly respected and trusted members of the community, the transition to agent is often a smooth one for the head teachers, who benefit from the additional income from selling solar lights. "I identify people who can buy the solar lights by talking to [other] teachers, talking

to my friends from rural areas where I know there is no electricity. I also talk about it whenever I am invited for a fundraising in churches," says Fred Cheserek, a SunnyMoney teacher agent from Eldoret. Having localised sales agents safeguards SunnyMoney's continued presence in the region and ensures easy access to clean, bright, affordable solar lights for those living in rural communities.



Headmaster of Kaparuso primary school shows solar lights to parents, Longisa, Bomet district, Kenya. CREDIT: Corrie Wingate.

campaigns generate awareness and interest in solar lights, which in turn create entrepreneurial opportunities that kick-start a solar light market in the region. In order to develop and sustain a solar market in rural Kenya, SunnyMoney recruits and trains locally based sales agents. Agents come from all walks of life and are categorized as either individuals,

Why local entrepreneurs are choosing solar lights

Research conducted by SunnyMoney lists helping people without access to light as a key motivating factor for individuals to become agents. This is followed by the financial savings from owning a solar light and the perception in the market that Sunny-



Joe Nyeru, SunnyMoney talks to parents at Masimba school. CREDIT: SolarAid.

Money lights are durable and of good quality. “I come from a rural area and I see some of the people who work for me struggling so much financially and more so buying requirements like kerosene. This motivated me to be an agent,” said Mr. Cheserek.

The sense of social responsibility is one shared by many SunnyMoney agents, and sentiments like the one from Mr. Cheserek are commonplace. For business owners, ensuring that there is demand for solar lights is key, and SunnyMoney is constantly ensuring that their activities drive demand by increasing awareness of the benefits of solar lights. “People who are my customers used to ask for solar lights. By then I did not have them and that’s the reason I started storing them,” said Mr. Yego, a shop owner from Bomet in Kenya. As an added incentive, SunnyMoney delivers solar lights for free to agents across the country (*minimum order of KES 15,000 required for free delivery*).

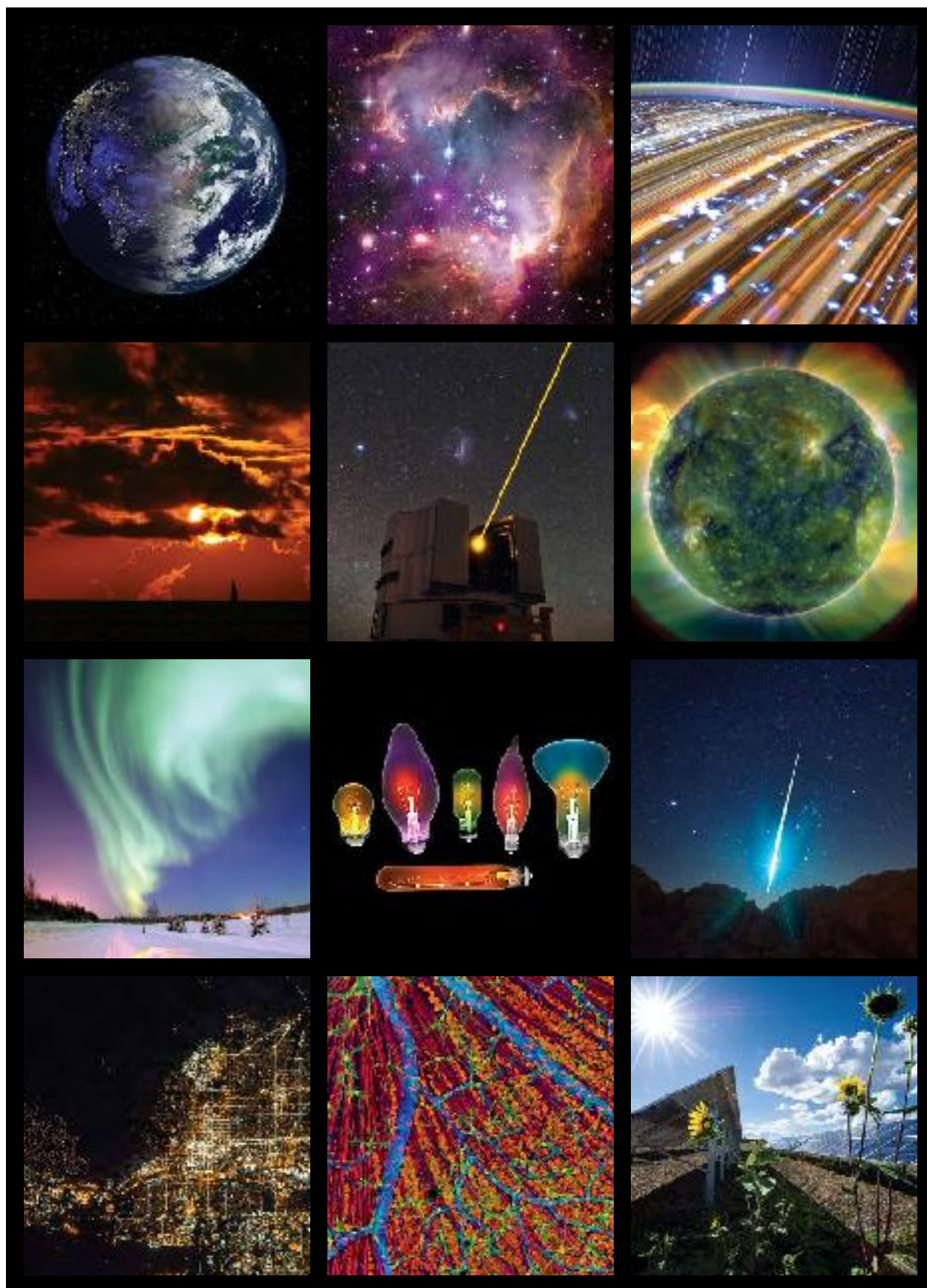
We also support our agents with training and marketing support, and by directing sales enquiries to them.

Agents are taken through a course on the various models of solar lights in SunnyMoney’s range to ensure a good understanding of each product’s specifications, warranty, maintenance, and care. They are also taught basic troubleshooting techniques in order to differentiate between manufacturer and user faults. In addition to product training, SunnyMoney invests in marketing support for its agents in the form of advertising campaigns, fliers, and brochures. Solomon Serem, an independent SunnyMoney agent, says, “Once in a week I will employ two men to take the solar lanterns to the markets. They do outdoor advertising. They do a lot of demos. I also put the lights on Olx [online-based selling platform] that is a local online shop that sells everything.”

Solar lights: tackling poverty and climate change

Solomon and other SunnyMoney agents are on the front line of the carbon war, fighting daily to bring clean, bright light to those living in their communities. Lights improve lives literally and financially. And they enable millions living in areas most vulnerable to the impacts of climate change to lead the way towards a brighter future.

Linda Wamune is a key team player for SunnyMoney sales and growth and has forged operations in Kenya for the past five years, contributing significantly to the social enterprise becoming the largest seller and distributor of solar lights in Africa, and opening up the market in Kenya. As an authority on solar rural distribution, Linda has been invited to global forums such as the 2014 Climate Summit at the UN Headquarters in New York and the launch of the IYL 2015 Opening Ceremonies in Paris, France.



The glow of a candle, the rise of the Sun, and the illumination of a lamp are things that can bring comfort and warmth to our lives. But there is much more to light than meets the eye. Light takes on many forms that are largely invisible and undetectable without modern technology. Light allows us to communicate, entertain, explore, and understand the world we inhabit and the Universe we live in. CREDIT: IYL 2015/Light Beyond the Bulb. Individual images shown are featured at <http://lightexhibit.org/photoindex.html>.

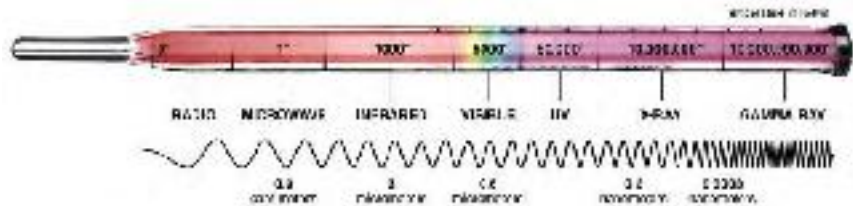
Taking Light Beyond the Bulb

Kimberly Arcand and Megan Watzke,
NASA's Chandra X-ray Observatory, USA

Now that we've flipped the calendar page to January, we have a chance to celebrate that 2015 has been declared the International Year of Light and Light-based Technologies (IYL 2015) by the United Nations. We don't take this opportunity—pardon the pun—lightly. This is for several reasons. First, our jobs revolve around light. We work for NASA's Chandra X-ray Observatory, which is a telescope in space that observes x rays from the Universe. X rays are a kind of light. In fact, there are many different kinds of light, but there's only one that the human eye can detect naturally (called optical, or visible, light).

This brings us to a second driving force for IYL 2015: there are countless ways that light in its many forms impacts us every day. We can imagine sunlight streaming through a window in the morning, but beyond that, light is also responsible for our news delivered on the radio and the phone call that just arrived on our cell. From the mundane to the majestic, light is all around us. It can do amazing things.

We didn't want to let IYL 2015 pass us by, so we have developed a project with key partners that can help anyone and everyone learn about light. We call the project Light: Beyond the Bulb, and the goal of this online collection of beautiful images is to showcase the enormous spectrum of things that light does. Keep in mind, this program provides just a sample.



Many kinds of light: This illustration shows the range of the electromagnetic spectrum in order of increasing frequency or energy, from radio waves, to microwave, to infrared, to visible or optical, to ultraviolet, to x rays, to gamma rays. CREDIT: NASA/CXC/M. Weiss.

It would be impossible to represent everything that light can do, but the collection provides some of the most stunning examples we could find: from brain imaging to bioluminescence, from lasers to light pollution, and from auroras to astronomy.

The goal of Light: Beyond the Bulb is to share these images and stories about light both online and also as physical displays. We want to have displays not just in science centers or schools, but also in more everyday situations such as at bus stops, public parks, cafes, malls, libraries, and beyond. So if you, as an individual, or your school, business, or organization would like to sponsor and help host an exhibit showcasing light, please let us know. We've come up with some ideas and tips on how to get started.

The more science we can share, the better. It certainly helps to have the United Nations, UNESCO, and all of the partners of IYL 2015 as allies in this quest. Please join us in celebrating the International Year of Light. At the end of the day, when the dark has come, we are all still creatures of light.

As of October 2015, there have been over 600 exhibit sites around the world, with over 35 participating countries, and more than a dozen language translations. Exhibit sites have ranged from an airport in New Zealand to a public square in Serbia to schools in China to the U.S. Senate Rotunda in Washington, D.C. An updated list of exhibit locations may be found at <http://lightexhibit.org/iylxhibits.html> with select exhibit photos at http://lightexhibit.org/exhibit_photos.html.

Together with SPIE (the international society for optics and photonics), the Chandra X-ray Center/Smithsonian Astrophysical Observatory is leading *Light: Beyond the Bulb* for the International Year of Light 2015 (IYL 2015). *Light: Beyond the Bulb* is a cornerstone project for the International Astronomical Union.

Kimberly Arcand directs visualizations for NASA's Chandra X-ray Observatory.

Megan Watzke is the science writer for Chandra. Together, they were the project creators and co-leads for the award-winning *From Earth to the Universe* open exhibition project of the International Year of Astronomy 2009.

The Dream of Illuminating

Kari Kola, Lighting Designer and Light Artist, Finland



Living Mine installation in Finland. CREDIT: Kari Kola.

I have worked in many fields of lighting for almost 15 years. The more I learn the more I realise how little I know. This makes me humble and enthusiastic about all aspects of light.

Last fall I was wondering what would take place at the opening ceremony of the International Year of Light and asked my friend Pasi Vahimaa (professor of photonics / IYL 2015 National contact for Finland) about it. We had a conversation, and I proposed that it would be really nice to do something in large scale. Then Pasi introduced my idea to John Dudley (Chair of the IYL 2015 Steering Committee). I proposed to John that I really would like to do something, and he said yes. I got very excited and happy even, though I needed to get most of the

funding for my project and the timetable was really tight for a project of such scale.

To prepare the project, I started to wonder from where I have I learned the most. What is the strongest and the most important thing about light to me? Since I live in the North, the answer was clear. I decided to use the theme of Northern Lights (aurora borealis) and sunrise (aurora) in the piece. And of course, just to make it bit more harder, I wanted to do this in 360 degrees, covering all sides of the UNESCO Headquarters in Paris.

Scheduling the whole process was very intense. There were only two months to make all the planning including concept, music composing, technical details, crew, equipment,

transport, etc. So I started to call friends in the field of lighting to find out if they would join the journey to making something really special. I wrote the concept of the installation, and we started working. The planning was aimed to make really fast build of technics and a really strong atmosphere and concept for the Opening Ceremony.

I was privileged to get precious help from UNESCO and from the IYL 2015 team. It was also an honour to work with students from all around the world, who really helped me with the build on site. I collected a team from Finland, Portugal, and the Netherlands, with backups from France and Denmark. I had the privilege to work with specialists in different fields.

We built everything in one day,



Light is Here installation at UNESCO Headquarters during the IYL 2015 Opening Ceremony. CREDIT: UNESCO/Nora Houguenade.

and during the second day we just cleaned, programmed, and synced everything. I used more than 200 different hi-power LEDs, 12 video projectors (video content from Nuno Maya), special effects, and soundscape. It was, as planned, a 360-degree installation, and for me this was a dream come true. It was a long journey from the eastern part of Finland to Paris for an occasion like this. It wouldn't have been possible without the people around me inspiring me all the time.

At the moment I'm working in multiple light-art pieces. Some of them are more than two-hectare-sized outdoor pieces. Tampere Light-weeks (the oldest light event in Finland) is celebrating its 50th anniversary, and I will make a large-scale dynamic installation. In the SIGNAL Festival (Prague), I will make an installation for one of the islands located in the river at the centre of town as well as one special video piece on my hometown Joensuu. That will be my '10 years as a light artist' piece.

I'm always trying to learn more, and I'm open to any possibilities that light will bring in life. Even though I have worked with light for a long time, it's still like a big playground for me. Creating big illusions and atmospheres with light is my passion, and I think I'm just getting started. I'm also finally opening a website (www.karikola.com) about my works because many people have asked about this.

There is lots of symbolic value and positive aspects in light that we should remember: it affects in really many ways how we are, how we feel, how we see things, and lots more. The world needs light now more than ever because of all the positivity that there is in light.

I think that nothing is impossible; it is just a matter of deciding how much

you want to use your energy towards achieving it.

Kari Kola is a lighting designer and a light artist from Finland who has designed and executed lighting for many operas, musicals, plays, concerts, landscapes, festivals, and dance pieces, and has also carried out many sizable (over one hectare in size) outdoor light installations, designed multichannel soundscapes, and taught in different fields of lighting. His specialty is mixing different art forms when creating a show or an installation, and outdoor installations are his greatest passion and main expertise.



Nordic Elements installation in Portugal. CREDIT: Kari Kola.

Why Bother with Outreach?

Nathalie Vermeulen, Vrije Universiteit Brussel, Belgium

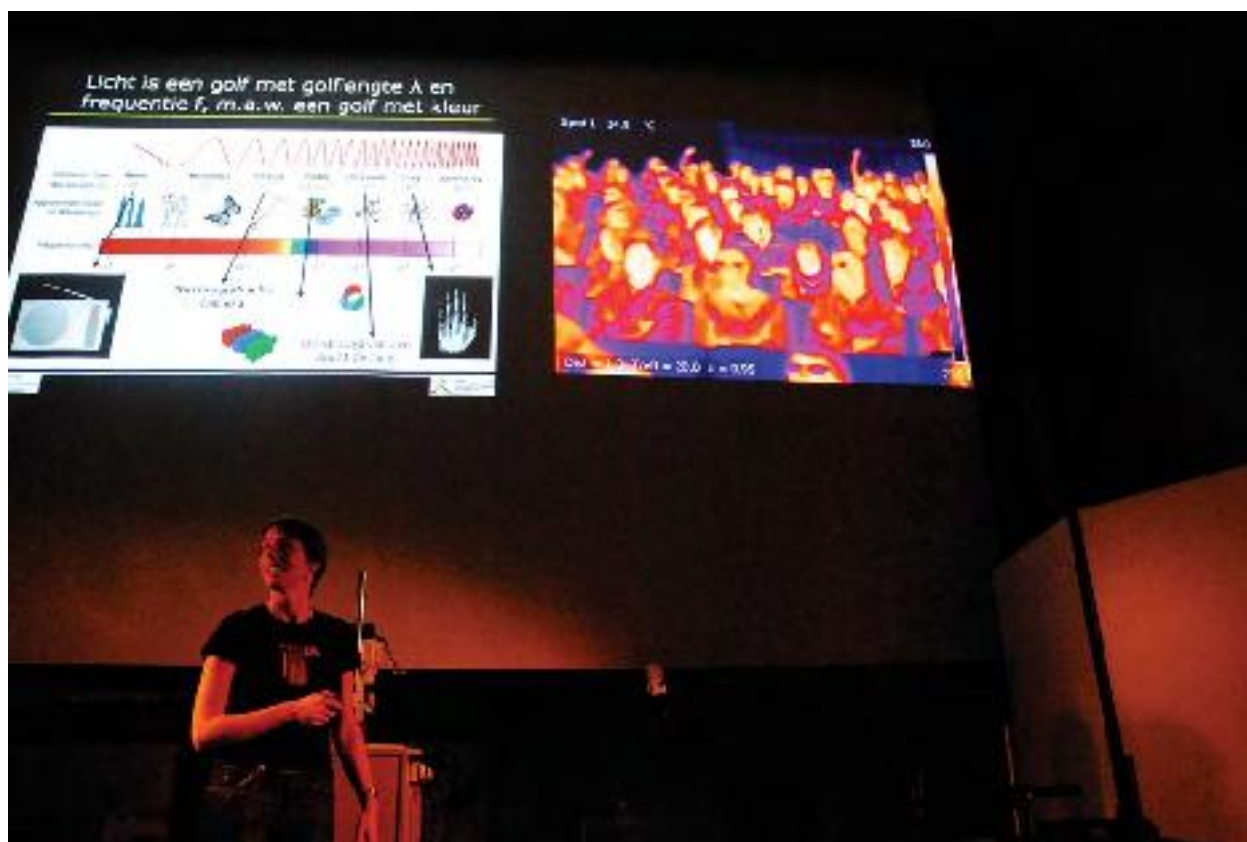
One of the main goals of the International Year of Light 2015 is to reach out to citizens to show them the importance of light and optical technologies in their lives, for their futures, and for the development of society. Outreach is a concept that we researchers are all acquainted with, but probably only a few of us have already actively contributed to an outreach activity for the public at large. I must confess that initially I was also slightly reluctant to get involved in exhibitions, workshops, science shows, and light talks aimed at inspiring young minds for a career in optics

and photonics. For me—and I believe for many researchers—the reason for holding back was that such activities can consume a significant amount of our “precious” time. And in the academic world one generally does not obtain as much credit for contributing to outreach events as for writing top-level papers and project proposals. However, over the years I experienced that reaching out to the public at large can be as rewarding for the event organizers as for the public itself.

One particular showcase I would like to highlight in this respect is the

Photonics Science Show that the Brussels Photonics research group at the Vrije Universiteit Brussel organizes every year for more than 800 secondary school pupils. During this event, our aim is to entertain our young audience with spectacular live-on-stage photonics experiments while also explaining the basic physical concepts that support these experiments.

Both Ph.D. students and postdocs are involved in the organization of this large-scale event, and some researchers need more convincing than others to prepare their part of



Explaining the basics of infrared imaging. CREDIT: B-PHOT.



Getting the audience involved through a Mexican wave to illustrate the concept of a wave. CREDIT: B-PHOT.

the show and get on stage in front of such a lively audience. But often those people who were a bit reluctant at first afterwards regret that they hadn't participated any earlier since they really enjoyed the thrill of reaching out and feeling the vibes of an enthusiastic public.

I think experiences like these can be quite refreshing in a world focused on publication and research projects. If in addition outreach would

obtain a little more weight in the academic evaluation criteria for a researcher's career, also the most skeptically minded researchers could be persuaded to give it a try. In my opinion, intensifying our efforts to reach out to youngsters really could make a significant difference in how pupils perceive STEM classes and as such could have an important impact on who will staff our research groups in the future.

Nathalie Vermeulen is a professor with the Brussels Photonics Team at the Vrije Universiteit Brussel, Belgium, whose research focuses on generating light with multiple wavelengths in optical chips. She received a prestigious European ERC Starting Grant as well as the LIGHT2015 Young Women in Photonics Award.



CREDIT: Shutterstock/panyajampatong.





At USA-based JILA, a strontium optical atomic clock currently has the best accuracy, reproducibility, and stability of any clock in the world. Inside a small chamber, a blue cloud of strontium is suspended in a lattice of crisscrossing laser beams. The strontium vibrates at an incredibly fast frequency; a natural atomic metronome ticking out miniscule fractions of a second. The clock only loses or gains one second every five billion years.

CREDIT: The Ye group and Brad Baxley, JILA. CREDIT: Marti/JILA.



2

People and
History

55th Anniversary of the Laser's Invention

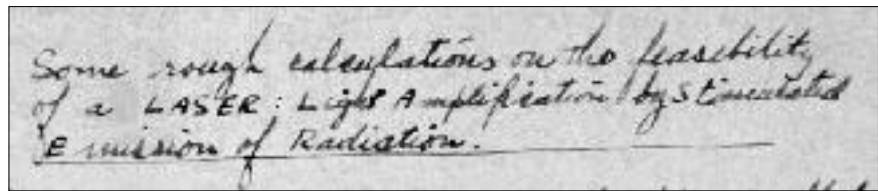
Augusto Beléndez, University of Alicante, Spain

Fifty five years ago the laser, one of the most important and versatile scientific instruments of all time, was invented. It was on 16 May 1960 that the North American physicist and engineer, Theodore Maiman, obtained the first laser emission.

This date is therefore of great importance not only for those of us who carry out research in the field of optics and other scientific fields, but also for the general public who use laser devices in their daily lives. CD, DVD and Blu-ray players, laser printers, barcode readers, and fibre optic communication systems that connect to the worldwide web and Internet are just a few of the many examples of laser applications in our daily life. Lasers also have a range of important biomedical applications; for example, they are used to correct myopia, treat certain tumours, and even whiten teeth, not to mention the beauty clinics that continually bombard us with advertisements for laser depilation, which has become so popular nowadays. However, the laser is of great importance not only due to its numerous scientific and commercial applications or the fact that it is the essential tool in various state-of-the-art technologies but also because it was a key factor in the boom experienced by optics in the second half of the last century. Around 1950 optics was considered by many to be a scientific discipline with a great past but not much of a future. At that time, the most prestigious journals were full of scientific papers from other branches of physics. However, this situation changed dramatically thanks to the laser, which led to a vigorous development of optics. It is indisputable that the laser triggered a spectacular reactivation in numerous areas of optics and gave rise to others such as optoelectronics, nonlinear optics, and optical communications.

What is a laser?

A laser is a device capable of generating a light beam of a much greater intensity than that emitted by any other type of light source. Moreover, it has the property of coherence, which ordinary light beams usually lack. The angular dispersion of a laser beam is also much smaller, so when a laser ray is emitted and dispersed by the surrounding dust particles, it is seen as a narrow, straight light beam. But let us leave to one side the specialized technical points, more suitable to other types of publications, and concentrate on aspects of the invention of the laser that are no less important and no doubt of greater interest to the general public. The word laser is actually an acronym for Light Amplification by Stimulated Emission of Radiation and was coined in 1957 by the American physicist Gordon Gould (1920–2005), working for the private company Technical Research Group (TGR), who changed the “M” of Maser to the “L” of Laser.



First page of Gordon Gould's 1957 lab notebook where he defines the term 'LASER.'
CREDIT: AIP Emilio Segrè Visual Archives.

In the image above, the phrase “some rough calculations on the feasibility of a LASER: Light Amplification by Stimulated Emission of Radiation” may be seen from Gordon Gould's manuscript, 1957.

The origins of the development of the laser may be found in a 1916 paper by Albert Einstein on stimulated emission of radiation: “Strahlungs-emission und -absorption nach der Quantentheorie” (Emission and ab-

sorption of radiation in quantum theory). But it was an article published on 15 December 1958 by two physicists, Charles Townes (who died on 27 January 2015 at the age of 99) and Arthur Schawlow titled “Infrared and optical Masers,” which laid the theoretical bases enabling Maiman to build the first laser at the Hughes Research Laboratories (HRL) in Malibu, California in 1960. Maiman used as the gain medium a synthetic ruby crystal rod 1 cm long with mirrors on both ends and so created the first-ever active optical resonator. It is probably not general knowledge that Hughes Research Laboratories was a private research company founded in 1948 by Howard Hughes, eccentric multimillionaire, aviator, self-taught engineer, Hollywood producer, and entrepreneur played by Leonardo DiCaprio in the 2004 film *Aviator*, directed by Martin Scorsese. The executives of the Hughes Research Laboratories gave Maiman a deadline of nine months, \$50,000 dollars, and an assistant to obtain the first laser emission. Maiman was going to use a movie projector lamp to optically excite the gain medium, but it was his assistant, Irnee D’Haenes, who had the idea of illuminating the ruby crystal with a photographic flash.

When he obtained the first laser emission, Maiman submitted a short article to the prestigious physics journal *Physical Review*. However, the article was rejected by the editors who said that the journal had a backlog of articles on masers—antecedent of the laser in the microwave region—and so had decided not to accept any more articles on this topic since they did not merit prompt publication. Maiman then sent his article to the prestigious British journal *Nature*, which is even more particular than *Physical Review*. However, it was accepted for publication and saw the light (excuse the pun) on 6 August 1960 in the section Letters to *Nature* under

the title “Stimulated optical radiation in ruby,” with Maiman as its sole author. This article, which had barely 300 words and took up the space of just over a column, may well be the shortest specialized article on such an important scientific development ever published. In a book published to celebrate the centenary of the journal *Nature*, Townes described Maiman’s article as “the most important per word of any of the wonderful papers” that this prestigious journal had published in its hundred years of existence. After Maiman’s article was officially accepted by *Nature*, Hughes Laboratories announced that the first working laser had been built in their company and called a press conference in Manhattan, New York on 7 July 1960.

In a very short time the laser stopped being a simple curiosity and became an almost unending source of new scientific advances and technological developments of great significance. In fact, the first commercial laser came on the market barely a year later in 1961. In the same year the first He-Ne lasers, probably the most well-known and widely used lasers ever since, were commercialized. In these early years between 1960 and 1970 none of the researchers working on developing the laser—the majority in laboratories of private companies such as those of Hughes, IBM, General Electric or Bell—could have imagined to what extent lasers would transform not only science and technology but also our daily life over the subsequent 55 years.

Augusto Beléndez is a full professor of applied physics, leader of the Group of Holography and Optical Processing, and Director of the University Institute of Physics Applied to Sciences and Technologies at the University of Alicante, Spain. His main interests are in holography, holographic recording materials, holographic optical elements, optical storage, and teaching physics and engineering; he is also actively involved in public outreach.



Charles H. Townes. CREDIT: Roy Kaltschmidt.



Arthur Leonard Schawlow. CREDIT: Wikipedia.



Theodore Maiman (1927–2007), winner of the Wolf Foundation Prize in Physics, 1983. CREDIT: AIP Emilio Segrè Visual Archives.

A Reflection on Women in Optics This International Women's Day

Michelle L. Stock, Laser Consultant, USA



Annual Women in Optics Presentation and Reception held during SPIE Photonics West. CREDIT: SPIE.

How can you see inside the depth of living tissue? One way is with a technique called two-photon excitation microscopy, which allows imaging through about one millimeter depth. This technique is now widely used in biology and biomedicine, and its development can be directly linked to Maria Goeppert-Mayer, a Nobel Laureate (1963, Physics) and pioneering woman scientist and mathematician.

Dr. Goeppert-Mayer is most famous for proposing the nuclear shell model of the atomic nucleus, the work cited for her Nobel, but she wrote her doctorate in 1930 on the theory of possible two-photon absorption by atoms. It took the invention of the laser thirty years later for her

theory to be proven experimentally. By the late 1980s, besides applying two-photon absorption to imaging living cells, researchers began to look at how to store very large amounts of data (3D optical data storage), how to make micro-sized three-dimensional objects (3D microfabrication), and how to treat cancer (photodynamic therapy). Dr. Goeppert-Mayer's doctorate idea continues to impact several key technology fields.

On March 8th, the International Women's Day (IWD) was celebrated. The theme for 2015 is "Make it Happen." This International Year of Light and Light-based Technologies 2015 (IYL 2015) makes it a great time to reflect on how women have, are, and will impact the science and

technology of light by making innovations happen.

The IWD was launched in 1911 as a means to encourage effective action for advancing and recognizing women. Incidentally, during that same year, an icon of women in science, Marie Curie, won her second Nobel Prize. For many of us, Dr. Curie and Dr. Goeppert-Mayer are important role models, showing that even at times when women were actively discouraged from aspiring to become scientists and engineers, determination could overcome the challenges presented by society. Dr. Goeppert-Mayer, in particular, had to overcome significant hurdles to obtain a paying job in her chosen field.

These days, while more women

are graduating with Bachelor's degrees than men in some parts of the world, there is still a large disparity in the numbers that are becoming scientists and engineers.¹ That disparity is easy to see for those of us who are in the midst of our careers in optics and photonics—just go to any conference in our field and witness how few women attend, let alone present their work or lead conferences.

For that reason, there is a need beyond the IWD to support and encourage women to participate in the broad and impactful field of optics. Societies such as SPIE (the international society for optics and photonics) work hard to provide mechanisms for connecting women in our field and encouraging them to join it. Each year, SPIE highlights women in optics in its yearly planner that features profiles of successful women in STEM. SPIE also organizes events such as the annual Women in Optics (WiO) Presentation and Re-

ception, held during SPIE Photonics West Conference. The most recent WiO event in February 2015 had a panel discussion titled: "The Road Less Traveled: Women in Science & Technology Leadership." This year's panelists included Susan Toussi, VP of Engineering at Illumina, a leader in high-throughput DNA sequencing, and Nicoletta Casanova, CEO of FEMTOprint, making 3D printing stations for glass microdevices (incidentally, based on a technique related to Dr. Goeppert-Mayer's dissertation topic). The stories that they shared about their paths to succeed at a high level in optics were inspiring, and many students were able to benefit from hearing about their journeys and talking with the panelists during the reception.

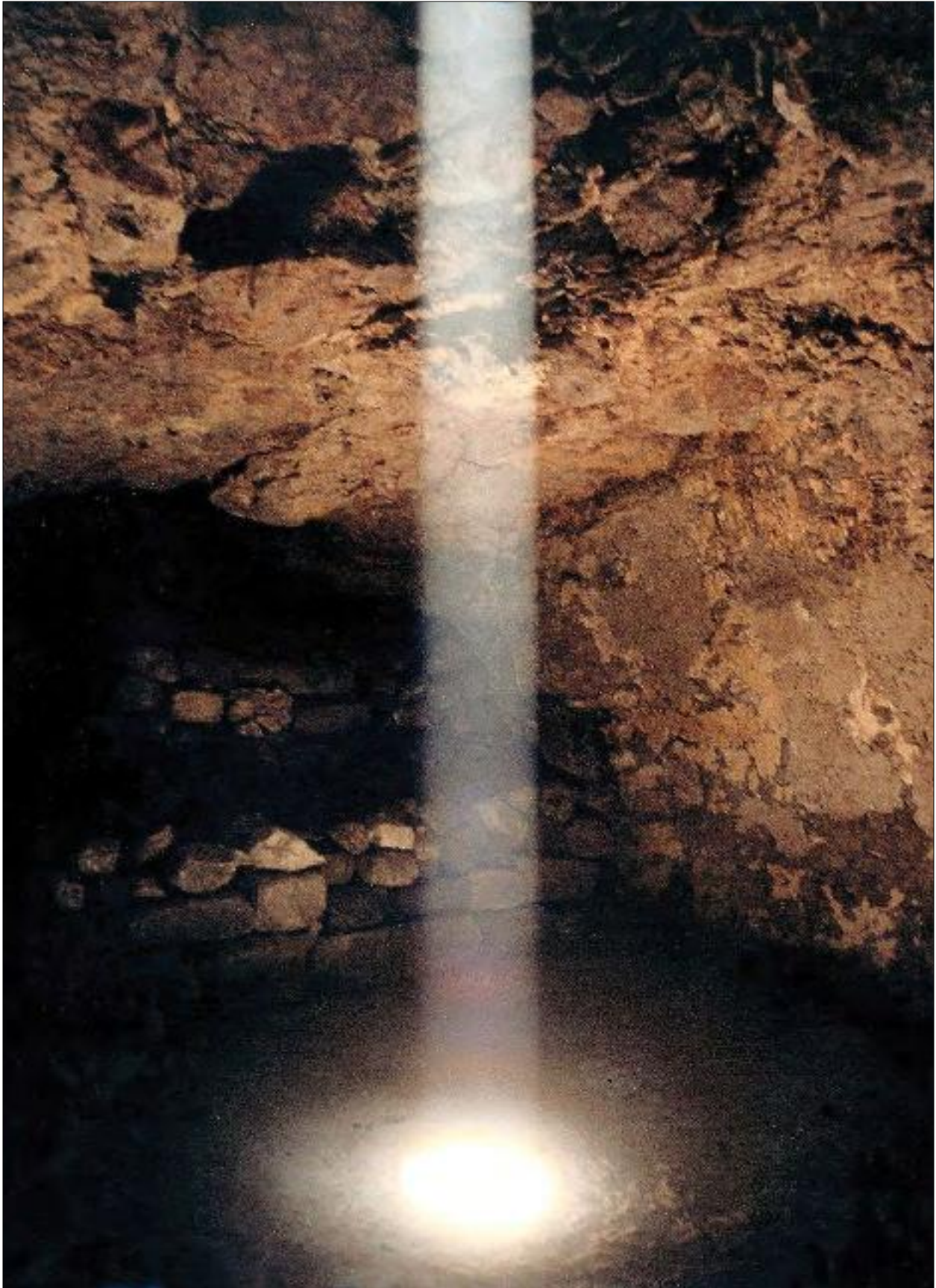
This IWD during IYL 2015, let's celebrate the women who have lit the way, support the women who are 'making it (optics innovations) happen,' and encourage the young women who will be contributing

to our world through their future work. Who knows? You may be fostering a woman who makes the next great idea in optics happen.

MORE INFORMATION

1. See <http://www.light2015.org/Home/ScienceStories/Women-in-Science.html>.

Michelle L. Stock obtained her Ph.D. in ultrafast fiber lasers in 1994 from the University of Michigan and has spent her career in the field of lasers as an engineer and business developer, currently working as a consultant to companies developing leading-edge lasers. Dr. Stock is chairperson of Mi-Light (the Michigan Photonics Industry Cluster) and has been active in the U.S.-based National Photonics Initiative (NPI), SPIE, OSA, and LIA.



Sunlight column during Zenith Passage of the Sun in Cave of the Sun in Xochicalco, México. CREDIT: <http://www.montero.org.mx>.

Ancient Lights

Javier Mejuto, Ricardo Pastrana, and David Espinoza,
National Autonomous University of Honduras, Honduras

For centuries, human beings have not only been simple spectators of the movement of celestial objects over the sky, but all over the world, different cultures, regardless of their moment in history, have tried to understand and use the sky for their benefit.

For Central American cultures such as the ancient Mayan civilization, the Sun was very important. Ancient Mayans realized that each year, in the intertropical region they lived, there was a useful correlation between astronomical events and the weather: the Zenith Passage of the Sun.

This happens when the Sun is at the zenith, vertical over the observer's head. It occurs twice a year: first, after the spring equinox, when the apparent movement of the Sun from south to north ends and second, after the summer solstice, when the apparent movement of the Sun from north to south ends. This happens typically at the end of April and September, respectively, with substantial variations depending on the latitude. For example, in México, D.F., the first passage is around May 16th, the second is around July 17th, with an approximate one day of variation. For Tegucigalpa, Honduras, these occur on April 27th and August 14th, and for San José, Costa Rica, the Zenith Passage occurs on April 15th and August 26th.

The dates of the Zenith Passage of the Sun vary strongly with the latitude. This event has two consequences: the first is an increase of heat because of the perpendicular incidence of solar rays and the second is that vertical objects cast no shadow, as can be seen in the figure above.

This astronomical event was really important in Mesoamerica, as the first Zenith Passage of the Sun coincides with the beginning of the rainy season. Mayan people used the disappearance of the altar Stela's shadow as a marker of the beginning of the rainy season.

It is known that Maya rulers had two main functions: main priest and king maintaining the order both in cosmos and in society. In order to maintain the livelihood of the population through harvests, especially of maize, instructions were given to the population living in the suburbs of large city-states to start preparing farmland for the imminent arrival of the rains. Likewise, people gathered for harvest after observing the loss of shadow from vertical elements during the second passage of the Sun across the zenith. In Copan, Honduras, we have a beautiful example of a rainy season marker, the Stela D. As a sundial, the shadow moves along several monuments until the First Zenith Passage of the Sun, when its shadow disappears. These are the so-called horizontal observatories.

As priests, the rulers had also to ensure the cycle of life with several rituals that represented how the dry lands become fertile with the rains. The P structure of Monte Albán and Cave of the Sun in Xochicalco, both in Mexico, are magnificent examples of the Zenith Passage of the Sun for ritual purposes. In these types of structures, called zenithal observatories, an aperture on the top was designed in order to project a light column inside the monument when the position of the Sun is perpendicular to the building, corresponding



Shadow disappearance during Zenith Passage of the Sun at the altar of Stela D, Copán, Honduras.

to the exact moment when the Sun is at the zenith.

Therefore, the sunlight was used by Mayan elites both as a survival tool and as way of showing their knowledge, which was only available for a few of them. This is also an example of how they used nature and deities, many of them with astronomical origin, as tools to justify their power and privilege.

Javier Mejuto heads the Department of Archaeoastronomy and Cultural Astronomy at the Universidad Nacional Autónoma de Honduras (UNAH). In addition to several cultural astronomy research projects, he is currently involved in projects related to history, archaeology, and astronomy, all of which are mainly related to American indigenous people.

Ricardo Pastrana is an astronomy teacher at the UNAH developing teaching activities and university–society collaborations, and performing research on light pollution. He is also an ambassador to the Network for Astronomy School Education, a program of the International Astronomy Union aimed at training teachers in astronomy education.

David Espinoza is the coordinator of the Central American regional academic Master's degree in astronomy and astrophysics from the UNAH. He earned a B.S. degree in physics at the UNAH and a M.S. degree in physics and mathematics at the University of Granada, Spain.

Ibn al-Haytham Optics

Azzedine Boudrioua, University of Paris 13, France

Introduction

In ancient times, light was considered as “fire,” and what interested the Greeks was not the light itself, but the vision. Two theories emerged: the theory of “visual fire,” or extramission, and the theory of “external light,” or intromission. The first works on vision are attributed to Euclid (325–265 BC), who developed the theory of extramission as a model for the study of optics. He introduced the concept of visual ray and rectilinear propagation. The concept of visual ray is not to be confused with the light ray as we understand it today. As G. Simon wrote in his book *Archaeology of Optics*, “... The visual ray is in no way equivalent to an inverted light ray.”

Three centuries later, Ptolemy (100–170 AD) reported that reflection and refraction have the effect of breaking the sight, and they are cause of an error ... The eye produces light, and a visual ray is a kind of quasi-hardware extension of the soul to feel the visible world as the touch.

The contribution of Islamic civilization is mainly due to scholars of the Abbasid period (750–1250 AD). In a frenetic translation movement, Islamic scholars initially translated and studied all of the works of the Greeks. In a climate of tolerance and respect of all religions, Muslims, Christians, and Jews endeavored together to build a new civilization that lasted for more than five centuries. Hunayn Ibn Ishaq (Isaac) (808–873 AD), a Nestorian Christian, is the perfect example of this new era. He

was an authority on the translation of Greek works. He led teams of Jews, Christians, and Muslims in the House of Wisdom of Baghdad.

Arab Optics

Four names played a key role in the development of Arab Optics: Al-Kindi (801–873 AD), Ibn Sahl (940–1000 AD), Ibn al-Haytham (965–1040 AD), and Al-Farisi (1267–1320 AD). Presumably, the interest of Arab scholars in burning instruments was crucial in the development of optics. They were aware of the legend that Archimedes fired the Roman fleet of General Marcellus Syracuse to defend his city in 212 BC by reflecting several beams at one focal point. Reproducing this sophisticated weapon was one of the objectives of this new research on catoptrics and anaclastic glass. Al-Kindi (801–873 AD), known as the Philosopher of the Arabs of the medieval period, supported Euclid’s theory of visual rays (extramission) and even made some corrections to it.

Ibn Sahl (940–1000 AD) was the author of a treatise on burning instruments written around 984 AD and a mathematician associated with the Baghdad court. He explained how lenses and conical instruments deflect and focus light. Ibn Sahl studied burning instruments not only by reflection but also by refraction—something that nobody had done before him. Although his work was within the Greco-Arab continuity of research on burning instruments, his studies of refractive lenses was the first break with the tradition



Ibn al-Haytham (965–1040 AD). CREDIT: Wikimedia Commons.

of that time. His genius idea was to characterize every medium by a constant ratio, allowing him to discover the law of refraction five centuries before Snellius (i.e., Snell’s law). In the East, subject to internal divisions and heated theological debates, the deterioration of the Abbasid power already announced the Mongol invasion and planned the destruction of Baghdad and its pearls in 1258.

Al-Farisi (1260–1320 AD) reconsidered the study of a burning sphere and investigated the rainbow, which fascinated opticians and scholars of the time. He performed several experiments with a sphere filled with water as a model of a drop of water. This allowed him to give the first correct explanation of the appearance of the rainbow colors in the sky as a combination of reflection and refraction.

Ibn al-Haytham

Ibn al-Haytham (also known as Alhazen or Alhacen) was born in Basra, Iraq. He studied and commented on the works of Aristotle, Euclid, Archimedes, and Ptolemy and devoted his life to the study of physics. He lived in Cairo during the time of the Fatimid Caliph Al Hakim (1010), where he died, devoting his life to his work, which includes (according to bibliographer Al-Qifti) more than 100 titles covering different fields. Ibn al-Haytham undertook the reform of optics as a builder who makes a masterpiece for posterity. He rejected the Greek theories, suggested a new paradigm, and explained reflection and refraction as follows: light is material, and it propagates with a high velocity. Refraction is due to the change of light velocity when it changes the medium of propagation. The shock of light with matter creates reflection. He took into account two factors in the movement of light, one perpendicular to the surface between the two media with a constant velocity, and the other parallel to the surface provided with a variable velocity. His theory is very modern in design, and his approach is scientific.

This illustrious scientist really laid the foundations of modern optics with its experimental approach to light propagation. For him, optics consisted of two parts: the theory of vision and physiology of the eye, and the associated psychological perception; and the theory of light with geometrical optics and physical optics. For Ibn al-Haytham, the eye was an optical instrument, and light was an independent physical entity of visual sensation. Ibn al-Haytham can be regarded as the first to introduce the scientific method, which was very similar to the modern scientific method and experimentation in physics.

Kitab al Manazir

The legacy of Ibn al-Haytham was



Cover page for Ibn al-Haytham's *Kitab al-Manazir* (Book of Optics).
CREDIT: Wikimedia Commons.

transmitted to us primarily through his major work *Kitab al-Manazir* (Book of Optics), which was written around 1028 and translated into Latin and published in the West in the early 13th century. The first Latin translation under the title of *Perspectiva* (*De aspectibus*) was performed by Gerard of Cremona (1114–1187), an Italian translator of Cremona, Italy. This work greatly influenced the work on optics of most Renaissance scholars. The first to study and disseminate the works of Ibn al-Haytham was his fervent disciple Roger Bacon (1214–1292). The Polish Witelion (1230–1275) was another scholar of the medieval age to be interested in the work of Ibn al-Haytham and its dissemination in Europe. Fourteen copies have been identified in Europe, and half of these are available in England. This is not surprising given that the English John Pecham (1277–1273) developed an optical manual for teaching based on *Kitab al Manazir* that remained in use until the late 16th century.

Anne-Valérie Dulac wrote, “The Pecham text explicitly claims its

belonging to Alhacen’s optics and the name of Alhazen is cited several times and even many copies of Alhazen’s writings are included in many places.” *Kitab al Manazir* was printed for the first time in Basel in 1572 by Frédéric Risner in a book entitled *Opticae Thesaurus*, which also included a perspective of 10 books written by the Polish Vitellion (Witelo) in 1270. According to D. Lindberg, this book referenced Tycho Brahe, Kepler, and Descartes, and was a very important text book on optics until the late 17th century.

Impact of Ibn al-Haytham’s Optics

Ibn al-Haytham was an icon of the medieval period, as illustrated by the work of Johannes Hevelius (1611–1687) published in 1647, *Selenographia Lunae Sive Descriptio* (The Selenography or the Study of the Surface and the Relief of the Moon), which was considered as the first lunar atlas. Ibn al-Haytham and Galileo appear on the frontispiece of *Selenographia* as two scientists representing explorers of nature through rational thought and observation, respectively.

In literature and art, the existence in the Shakespearean text of two competing visions of visual perception emphasizes the influence of Alhazen’s optics. Ibn al-Haytham is cited several times in the epic poem *Roman de la Rose* of Guillaume de Lorris and Jean de Meun published in 1275, one of the most widely read literary works in French for 300 years. In England, Geoffrey Chaucer refers to Ibn al-Haytham in his work *The Canterbury Tales*, written during 1387–1400 and considered as one of the major works of English literature. More recently, Charles Falco argued that the writings of Ibn al-Haytham on optics influenced the use of perspective by Renaissance artists. One of the great painters of the Renaissance, Alberti (1435) uses the model of direct sight of Ibn al-Haytham.

In the field of philosophy, Ibn al-Haytham is regarded as a pioneer of phenomenology. He articulated a relationship between the physics of the observable world and intuition, psychology, and mental functions. In psychology, Ibn al-Haytham is regarded as the founder of experimental psychology, for his pioneering work on visual perception and optical illusions. In his Book of Optics, Ibn al-Haytham was the first scientist to argue that vision occurs in the brain rather than in the eyes, as already mentioned.

Conclusion

With Ibn al-Haytham's work, optics no longer had the meaning it had previously: geometry of vision. Light exists independently of vision and moves with high but a finite velocity. It propagates like corpuscles. Also, with Ibn al-Haytham's work, the scientific method was born with a priority given to experimental evidence. Until the 17th century, Alhazen was the reference and the lighthouse that illuminated culture and throughout the European continent.

MORE INFORMATION

Ahmed Khan, S., "Arab origins of the discovery of the refraction of light," *Optics and Photonics News* **18**(10), pp. 22–23 October (2007).

Dulac, A.-V., "Shakespeare et l'Optique Arabe," in *Actes des Congrès de la Société Française Shakespeare* **27**, pp. 17–36 (2009).

Falco, C. M., "Ibn al-Haytham and the origins of computerized image analysis," *International Conference on Computer Engineering & Systems* (ICCES 2007), xx–xxiii (2007).

Falco, C. M., and Aimée L. Weintz Allen, "Ibn al-Haytham's contributions to optics, art, and visual literacy," in *Painted Optics Symposium: Re-examining the Hockney–Falco thesis 7 years on*, D. Hockney, Ed., pp. 115 (2008).

Gonzalez, V., *Universality and Modernity of Ibn al-Haytham's Thought and Science*, The Institute of Ismaili Studies, London (2002).

Gorini, R., "Al-Haytham the man of experience. First steps in the science of vision," *Journal of the International Society for the History of Islamic Medicine* **2**(4), 53–55, (2003).

Kwan, A., J. Dudley, and E. Lantz, "Who really discovered Snell's law?" *Physics World* **15**(4), 64 (2002).

Krystek, L., Archimedes and the Burning Mirror, http://www.unmuseum.org/burning_mirror.htm.

Lindberg, D. C., "Medieval Islamic achievement in optics," *Optics and Photonics News*, pp. 31–35, July (2003).

Maite, B., *La Lumière*, Editions du Seuil, Paris (1981).

Hogendijk, J. P., and A. I. Sabra, Eds., *The Enterprise of Science in Islam: New Perspectives*, The MIT Press, Cambridge, Massachusetts (2003).

O'Connor, J. J., and E. F. Robertson, "Abu Ali al-Hasan ibn al-Haytham," MacTutor History of Mathematics (1999) (www-history.mcs.st-and.ac.uk/Biographies/Al-Haytham.html).

Rashed, R., "A pioneer in anaclastics—Ibn Sahl on burning mirrors and lenses," *Isis* **81**, 464–491 (1990).

Rashed, R., "Analysis and synthesis according to Ibn al Haytham," in *Artifacts, Representations and Social Practice*, C. C. Gould and R. S. Cohen, Eds., Kluwer Academic Publishers, Dordrecht, the Netherlands, pp. 121–140 (1994).

Rashed, R., *Histoire des Sciences Arabes*, Tomes 1, 2, et 3, Editions du Seuil, Paris (1997).

Rashed, R., *L'Optique et la Catoptrique, Oeuvres Philosophiques et Scientifiques d'Al-Kindi*, Vol. 1, E. J. Brill, Ed., Brill Academic Publishers, Leiden, the Netherlands (1997).

Rashed, R., *Optique et Mathématiques: Recherches sur l'Histoire de la Pensée Scientifique en Arabe*, Variorum Reprints, Aldershot, UK (1992).

Rashed, R., "Problems of the transmission of Greek scientific thought into Arabic: Examples from mathematics and optics," in *History of Science* **27**, Science History Publications Ltd., pp. 199–209 (1989).

Raynaud, D., "Ibn al-Haytham sur la vision binoculaire: un précurseur de l'optique physiologique," *Arabic Science and Philosophy* **13**, 79–99 (2003).

Ronchi, V., *Histoire de la Lumière*, Editions Jacques Gabay, Paris (1996).

Simon, G., *Archéologie de la Vision: l'Optique, le Corps, la Peinture*, Editions du Seuil, Paris (2003).

Steffens, B., *Ibn al Haytham, First Scientist*, Morgan Reynolds Publishing, Greensboro, North Carolina (2007).

Turner, H. R., *Science in Medieval Islam: An Illustrated Introduction*, University of Texas Press, Austin, Texas (1995).

von Fuat Sezgin, H., *Wissenschaft und Technik im Islam*, Institut für Geschichte der Arabisch-Islamischen Wissenschaften an der Johann Wolfgang Goethe-Universität, Frankfurt am Main (2003).

Azzedine Boudrioua is a full professor at the University Paris 13, where he leads the Organic Photonics and Nanostructures group of the Laboratoire de Physique des Lasers, performing research in the fields of nanophotonics and nonlinear optics. He is also interested in the history of medieval optics and coordinates the Ibn al-Haytham International Working Group.

In a Blaze of Brilliance: How Light's Speed Was Finally Clocked

Bruce Watson, Author, USA

Late in his career, when he had won the Nobel Prize for Physics and had clocked light's speed with an accuracy no one had thought possible, the American physicist Albert Michelson was asked why he studied light. Michelson did not hesitate. "Because it's so much fun," he said.

Ever since Euclid published his *Optics* in 300 BC, many had had fun with light. Bouncing rays off mirrors, bending them through lenses, light's early students marveled at ordinary beams. But it took 20 centuries of study for anyone to measure light's blazing speed. Light's earliest students wondered whether light even had a speed.

The Greek philosopher Empedocles thought so, but Aristotle argued that light was "not a movement." Islamic scientists such as Alhacen and al-Biruni disagreed with Aristotle—light's speed was finite—but Kepler and Descartes considered



In 1879, the American physicist Albert Michelson clocked light's speed to within 99.9998 percent of accuracy. CREDIT: Wikimedia Commons.

light to be instantaneous. During the Scientific Revolution, Galileo proposed the first light speed test. Set two men on hillsides kilometers apart, Galileo suggested. Have one flash a lantern, and the other reply with his own flash as soon as he saw

the first. Galileo never conducted his speed test, but in 1667, Florence's Academia del Cimento did. Alas, even from the hillsides kilometers apart, the time lapse between flashes was far too quick to measure. If light had a speed, how could anyone hope to clock it? Then in 1676, a Dutch astronomer working in Paris used the clockwork of the planets to finally time a beam of light.

In the half-century since Galileo had first seen Jupiter's moons, their pinpoints of light had been charted on timetables. Comparing these tables to his own observations, the astronomer Ole Roemer spotted a discrepancy. When the earth and Jupiter were on opposite sides of the solar system, the Jovian moon Io emerged from behind the giant planet several minutes late. In August 1676,

Roemer made a bold prediction. On November 9, with Jupiter at its farthest from Earth, Io's reappearance would be 11 minutes behind schedule. When Roemer's prediction proved precise, the Dutch astronomer Christiaan Huygens triangulated

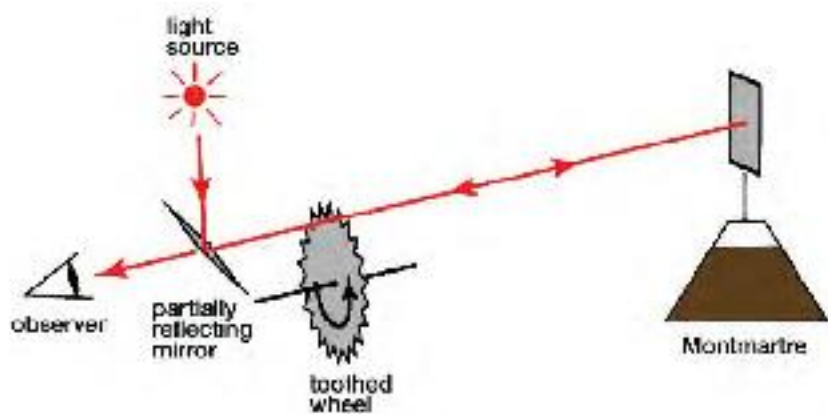


Across the U.S. Naval Academy campus at Annapolis, Maryland, discs embedded in pavement trace the path of Michelson's light speed test. CREDIT: Wikimedia Commons.

ed the distance to Jupiter, divided distance by time, and announced a speed of light that astounded even Isaac Newton—231,745,536 meters per second. Though nearly 25 percent slow, it was a start.

A half century later, British astronomer James Bradley used “stellar aberration,” the apparent shift of the stars due to the earth’s orbital velocity around the sun, to come closer. Sunlight, Bradley announced, reaches the earth in eight minutes and twelve seconds. He was just eight seconds off. Then in the mid-1800s, two French physicists gave light a more precise speed.

In 1849, Hippolyte Fizeau sent a beam of limelight through a spinning cogwheel. Chopped into pulses, the beam sped across Paris to the hills of Montmartre and back. The whole effect was like spinning a spoked wheel in front of a TV screen, where the TV’s stroboscopic light sometimes syncs its pulses through the spokes and sometimes goes slower, making the wheel appear to spin backwards. Timing the pulses, the shaggy-bearded Fizeau measured light at 316,197,472 meters per second. Closer, closer....



In 1849, using mirrors and a cogwheel, the French physicist Hippolyte Fizeau obtained the first near estimate of light’s speed. CREDIT: Bruce Watson.

Thirteen years after Fizeau’s test, Leon Foucault, already famous for his pendulum proving the earth’s rotation, came up with the most ingenious idea yet. Foucault equipped his lab with mirrors, one fixed and one whirling at 800 rpm. He then bounced light off the spinning mirror, reflecting it to the stationary mirror 20 meters away. By the time the beam returned, even at the speed of light, the spinning mirror had moved the tiniest fraction of a degree. Measuring the angle defined by the beam coming and going, computing the mirror’s angular

motion into time, Foucault clocked light at 298,050,509 meters per second. Foucault’s measure lasted until the late 1870s when a young American ensign turned his attention to light.

Albert Michelson, son of Prussian immigrants, grew up in Sierra Nevada mining camps during the Gold Rush. Like many landlocked boys, Michelson dreamed of the sea. Too young to serve in the Civil War, he earned an appointment to the U.S. Naval Academy. As an ensign, Michelson measured his ship’s speed

by taking readings of wind and water. Something in the process of calculating against the wind, across the water, stayed with him. A few years later, while teaching physics at the Naval Academy, Michelson read of Foucault's light speed and thought he could come closer.

Michelson's equipment—a lens, a steam boiler, a tuning fork, and two mirrors—cost him ten dollars. For such a price, he would measure light with the precision of the stars. Each of Michelson's many tests began an hour before sunrise or sunset, when he found light “sufficiently quiet to get a distinct image.” In a storage shed perched on the seawall of Annapolis' Severn River, Michelson fired up the boiler. Within minutes, its steam spun one mirror, slowly at first, then so fast it sometimes flew off its mooring. When the mirror was whirling at 257 revolutions per second—yes, per second in 1879—Michelson was ready. Aiming his lens, he caught sunlight and bounced it off the whirling mirror. The beam split the leafy campus. (A line of inlaid discs on the Annapolis campus now charts light's path in this historic test.) Striking

the fixed mirror precisely 605.05 meters away, Michelson's beam scorched back to the glass that had since spun a fraction of a fraction of a revolution. Michelson filled his log with data: Date of Test, Distinctness of Image, Speed of Mirror, Displacement of Image... but only one number really mattered. It varied with each test, but on average, Albert Michelson's measurement of light—299,851,365 meters per second—was 99.9998 percent of its actual speed. The news made headlines. “It would seem that the scientific world of America is destined to be adorned with a new and brilliant name,” the New York Times wrote. “Ensign A. A. Michelson, a graduate of the Annapolis Naval Academy, and not yet 27 years of age, has distinguished himself by studies in the science of optics which promise a method for the discovery of the velocity of light with almost as much accuracy as the measurement of the velocity of a projectile.”

Though Michelson studied light “because it's so much fun,” he lived in awe of it. In lectures, he urged budding physicists to notice “the exquisite gradations of light and shade,

and the intricate wonders of symmetrical forms and combinations of forms which are encountered at every turn.” Yet aesthetics never interfered with his determination to pinpoint light's speed. During the 1920s, when he was in his seventies, Michelson beamed light across mountaintops in Southern California, bouncing it off a whirling eight-sided prism and fixing a speed—299,796,647 meters per second—that stood until the age of lasers.

Today, using lasers and oscilloscopes, we know that light travels at exactly 299,792,458 meters per second (in a vacuum). Small wonder that the universal mathematical symbol for light's speed is *c*, short for the Latin *celeritas*, or swiftness.

Bruce Watson is the author of *Light: A Radiant History from Creation to the Quantum Age* (Bloomsbury, 2016), which traces humanity's evolving understanding and control of light, starting with creation myths, then moving into scripture, philosophy, architecture, Islamic science, art history, poetry, physics, and quantum physics. Watson's work has appeared in numerous newspapers and publications.

James Clerk Maxwell: Man of Light

Basil Mahon, Science Writer, UK

Next time you turn on your TV, think of James Clerk Maxwell. In one of the greatest feats of human thought, he predicted the electromagnetic waves that bring the signal from the transmitter to your set. He also provided the means of producing the coloured image on your screen by showing that any colour can be made by combining red, green, and blue light in the appropriate proportions.

Maxwell was born in 1831 into a distinguished Scottish family and went to a top school in Edinburgh before studying at both Edinburgh and Cambridge Universities. In an astonishing and short career (he died aged 48), Maxwell made groundbreaking discoveries in every branch of physics that he turned his hand to. But in the International Year of Light 2015, it is fitting that we celebrate in particular his discoveries about light: not only his electromagnetic theory, first published 150 years ago, but also his demonstration of the way we see colours.

Both topics pressed on his mind once he had completed his degree at Cambridge, but it was the colour problem that he tackled first. At the time, nobody knew how we see colours. In the early 1800s the English physiologist and physicist Thomas Young had put forward the interesting idea that the human eye has three types of receptor, each sensitive to a particular colour, and that the brain manufactures a single perceived colour according to



CREDIT: Wikimedia Commons.

the relative strengths of the signals along each of the three channels. But Young couldn't supply supporting evidence, and his theory had been largely neglected for the best part of half a century. Then Maxwell's mentor James Forbes thought of taking a disc with differently coloured sectors, like a pie chart, and spinning it fast so that one sees not the individual colours but a blurred-out mix. Painters traditionally mixed red, yellow, and blue to get other colours, so Forbes did the same, but the results were puzzling. For example, when mixing yellow and

blue, he didn't get green, as painters did, but a dull sort of pink. And he couldn't get white, no matter how he mixed the colours.

Maxwell soon discovered the source of his mentor's confusion. Forbes had failed to distinguish between mixing colours in the light that reaches the eye, as when spinning a disc, and mixing pigments, as a painter does. Pigments extract colour from light—what you see is whatever light is left over after the pigments have done their extraction. So perhaps Forbes' choice

of the painter's primary colours, red, yellow, and blue, was wrong. Maxwell tried, instead, mixing red, green and blue, and the results were spectacular. Not only did he get white by using equal proportions of the three colours, it seemed that he could get any colour he wanted simply by varying the proportions of red, green, and blue.

To put things on a proper footing he ordered sheets of coloured paper in many colours from an Edinburgh printer and had a special disc made, with percentage markings round the rim, a handle, and a shank for winding a pull-string: he called it his colour top. He cut out paper discs of red, green, and blue and slit them so they could be overlapped on the colour top with any desired amount of each colour showing. This way, he was able to measure what percentages of red, green, and blue on the spinning disc matched the colour of whatever paper was held alongside. Using this homely device, he devised Maxwell's colour triangle, a diagram that showed the proportions of red, green, and blue needed to make any colour. It differs only in detail from the standard chromaticity diagram used today. For more precise experiments, he invented an ingenious "colour box," which used prisms and narrow slits to extract pure spectrum colours from sunlight and combine them in any desired proportions.

A few years later, in 1861, Maxwell accepted an invitation from Michael Faraday to speak at the Royal Institution in London and chose to talk about colour vision. It was the perfect opportunity to demonstrate the three-colour principle, but his spinning disc was too small for people at the back to see clearly, and his colour box could only be used by one person at a time. He decided instead to attempt something that had never been done before—to produce a colour pho-

tograph. He took three ordinary black and white photographs of the same object, one through a red filter, one through a green filter, and one through a blue, then projected them through the same filters onto a screen, superimposing the three beams of light to form a single image. The audience sat spellbound as the image of a tartan ribbon appeared on the screen in glorious colour. Maxwell had taken the world's first colour photograph.

Nobody managed to repeat Maxwell's feat, and it was many years before the next colour photograph appeared. The mystery was solved 100 years later by a team from Kodak Research Laboratories. The experiment should never have worked because the plates Maxwell used were completely insensitive to red light. By a bizarre chain of favourable coincidences, ultraviolet light had acted as a surrogate for red. Lucky Maxwell! But perhaps he made his own luck: it was a rule with him never to discourage a man from trying an experiment, no matter how dim the prospects of success. After all, he said, "if he doesn't find what he is looking for, he may find something else."

Maxwell may have been lucky with the photograph, but his way of producing a full-colour picture by mixing red, green, and blue has stood the test of time. To see it demonstrated, just turn on a TV.

The task of producing a complete theory of electromagnetism was much harder, but in three awe-inspiring stages, spread over nine years, he succeeded. Maxwell began by reading all he could about the work already done by others and found that he had to make a choice. On the one hand, there was the highly mathematical approach of men like André Marie Ampère, by which forces were assumed to result from electric charges or mag-

netic poles acting on one another at a distance, with the space between them playing only a passive role. On the other hand, there was the experimental work of Michael Faraday, who proposed that space itself was infused with electric and magnetic "lines of force." Current opinion strongly favoured action-at-a-distance because it gave precise formulae, whereas, Faraday, who knew no mathematics, gave none. But, to Maxwell, Faraday's ideas rang true, and he set out to try to represent them in mathematical language.

Maxwell was a master at spotting analogies in different branches of the natural world, and he began by using the steady flow of an imaginary incompressible fluid as an analogy for both electric and magnetic lines of force. This way, he showed that all the known formulae for electric and magnetic forces in static conditions could be derived equally well from the conventional action-at-a-distance theories or from Faraday's lines of force. A stupendous achievement but, for the present, Maxwell couldn't think how to deal with changing lines of force. As was his way, he got on with other work while ideas brewed at the back of his mind.

Six years later he came up with a new model. He filled all space with imaginary tiny spherical cells that could rotate and were interspaced with even smaller particles that acted like ball bearings. By giving the cells a small but finite mass and a degree of elasticity, Maxwell constructed a mechanical analogy for magnetic and electric lines of force and showed that any change in one induced a change in the other. This extraordinary model not only yielded all the known formulae of electricity and magnetism, it predicted electromagnetic waves that travelled at a speed determined solely by the basic properties of electricity

and magnetism. This speed turned out to be within 1.5 percent of that at which light had been measured by experiment—compelling evidence that light itself was electromagnetic. An astounding result, but the response of fellow scientists was muted. The goal in any branch of physics, they believed, was to identify nature's true mechanism, and they regarded Maxwell's model as an ingenious but flawed attempt to do this for electromagnetism and light. Everyone expected that Maxwell's next step would be to refine the model but, instead, he put the model on one side and set out to build the whole theory from scratch, using only the laws of dynamics.

The result, two years later, was the magnificent paper whose 150th anniversary we are now celebrating: "A dynamical theory of the electromagnetic field." Here, the spinning cells were replaced by an all-pervading medium that had inertia and elasticity but no specified mechanism. In what seemed like a conjuring trick, he used a method devised by the French mathematician Joseph Louis Lagrange that treated a dynamic system like a "black box;" by specifying the system's general characteristics, one could derive the outputs from the inputs without knowing the detailed mechanism. This way, he produced what he called the equations of the electromagnetic field; there were twenty of them. When he presented the paper to the Royal Society the audience simply didn't know what to make of it. A theory based on a bizarre model was bad enough, but one based on no model at all was incomprehensible.

Up to the time Maxwell died, in 1879, and for several years afterwards, no one else really understood his theory. It sat like an exhibit in a glass case, admired by some but out of reach. Maxwell could

easily have condensed the theory but remarked that "to eliminate a quantity which expresses a useful idea would be a loss rather than a gain at this stage of our enquiry." Not everyone thought this way; in 1885 a self-taught former telegraph operator called Oliver Heaviside succeeded in making the theory accessible by summarising it in the four now famous "Maxwell's equations." It is right that they are called Maxwell's equations but they are, in part, Heaviside's creation too.

The first two of these four equations described how static electric and magnetic fields behave. The third and fourth equations defined the relationship between electricity and magnetism. They showed that any spatial variation in the electric field caused the magnetic field to vary in time, and vice versa, and predicted that every time an electric current changed, or a magnet jiggled, waves of electromagnetic energy would spread out into space at a fixed speed determined solely by the elementary properties of electricity and magnetism. This speed was that of light, but, according to the theory, light waves were only a small part of a vast spectrum of possible waves, with wavelengths varying from nanometres to kilometres. Even with Heaviside's simplification, all of this remained a theory with more sceptics than adherents until, in 1888, Heinrich Hertz emphatically verified it by producing and detecting Maxwell's waves in his laboratory. Inventors like Guglielmo Marconi latched on to Hertz's discovery, and their radio telegraphy was followed by sound radio, television, radar, satellite navigation, and mobile phones.

There is more. Though Maxwell never pursued the point, his equations imply that the measured speed of light is always the same regardless of whether the observer is travelling towards the light source or away from it. This

fact necessarily leads to Einstein's special theory of relativity which, among other things, tells us that mass is a form of energy and that nothing can go faster than light: nature has a speed limit, and it depends entirely on the elementary properties of electricity and magnetism.

By bringing the power of mathematics to Faraday's hitherto derided idea of lines of force in space, Maxwell has transformed both the world and the way scientists think about it. As Oliver Heaviside used to say, "Good old Maxwell!"

Basil Mahon has had careers as an officer in the Royal Electrical and Mechanical Engineers and as a statistician in the British Civil Service. He has since followed up a lifetime interest in science and its history by writing and has co-authored, with Nancy Forbes, *Faraday, Maxwell, and the Electromagnetic Field* and authored *The Man Who Changed Everything: the Life of James Clerk Maxwell and Oliver Heaviside: Maverick Mastermind of Electricity*.

Optics in Ancient China

Ling-An Wu, Institute of Physics, Chinese Academy of Sciences, China

Gui-Lu Long, Tsinghua University, China

Qihuang Gong, Peking University, China

Guangcan Guo, University of Science and Technology of China, China

The Warring States period of China, between 475 and 221 BC, was a time of academic and scholarly prosperity when many schools of learning were established. Some are well known in the world today, such as Confucianism and Taoism, but some are not so well known. One school that is little known in the West but is particularly important with regard to science and technology is Mohism, founded by Mo Zi, who paid great attention to the natural sciences and engineering. Among his many contributions, it is noteworthy to recall his achievements in optics since we are celebrating the International Year of Light in 2015. His major contributions include: an outline of the basic concepts of linear optics, the straight-line propagation of light, images and shadows, the reflection of light by plane, concave and convex mirrors, the pinhole camera, and the refraction of light. These are recorded in the Book of Mo Zi.^{1–5}

In another development, Liu An (179–122 BC), the King of Huai-Nan in the Western Han Dynasty (202 BC to 9 AD) and a Taoist master and thinker, also made important contributions to optics. Taoism attaches great importance to the natural sciences. The world famous Chinese bean curd food, tofu, was invented by Liu An as a byproduct while making elixirs, or alchemical medicines. These are recorded in the Book of



Focusing sunlight with a lens to start a fire. CREDIT: Ling-An Wu, Gui-Lu Long, Qihuang Gong, and Guangcan Guo.

Huai-Nan and the Wan-Bi-Shu.^{6,7} These writings describe the reflection of light by multiple mirrors being used to set up the world's earliest surveillance periscope.⁷ Also recounted are the focusing of sunlight to light a fire using a concave mirror or a lens made of ice.

Although these early contributions from ancient China have been noted and studied by certain renowned scholars such as Joseph Needham⁴ and some famous popular science writers,⁵ they are not widely known. For instance, they are not even touched upon in various recent re-

views of the history of optics.

Mo Zi's Contributions

Mo Zi (also known as Mo Tzu, Mo Di, Mo Ti, or Micius) lived between 468 and 376 BC in the Warring States period of China. He was a philosopher, thinker, scientist, engineer, and military strategist. He advocated the "universal love" of mankind as compared to the "extensive love" of Confucius and also promoted a simple lifestyle. His many contributions to the natural sciences in mechanics, acoustics, optics, and other fields are collected in the Book of Mo Zi.

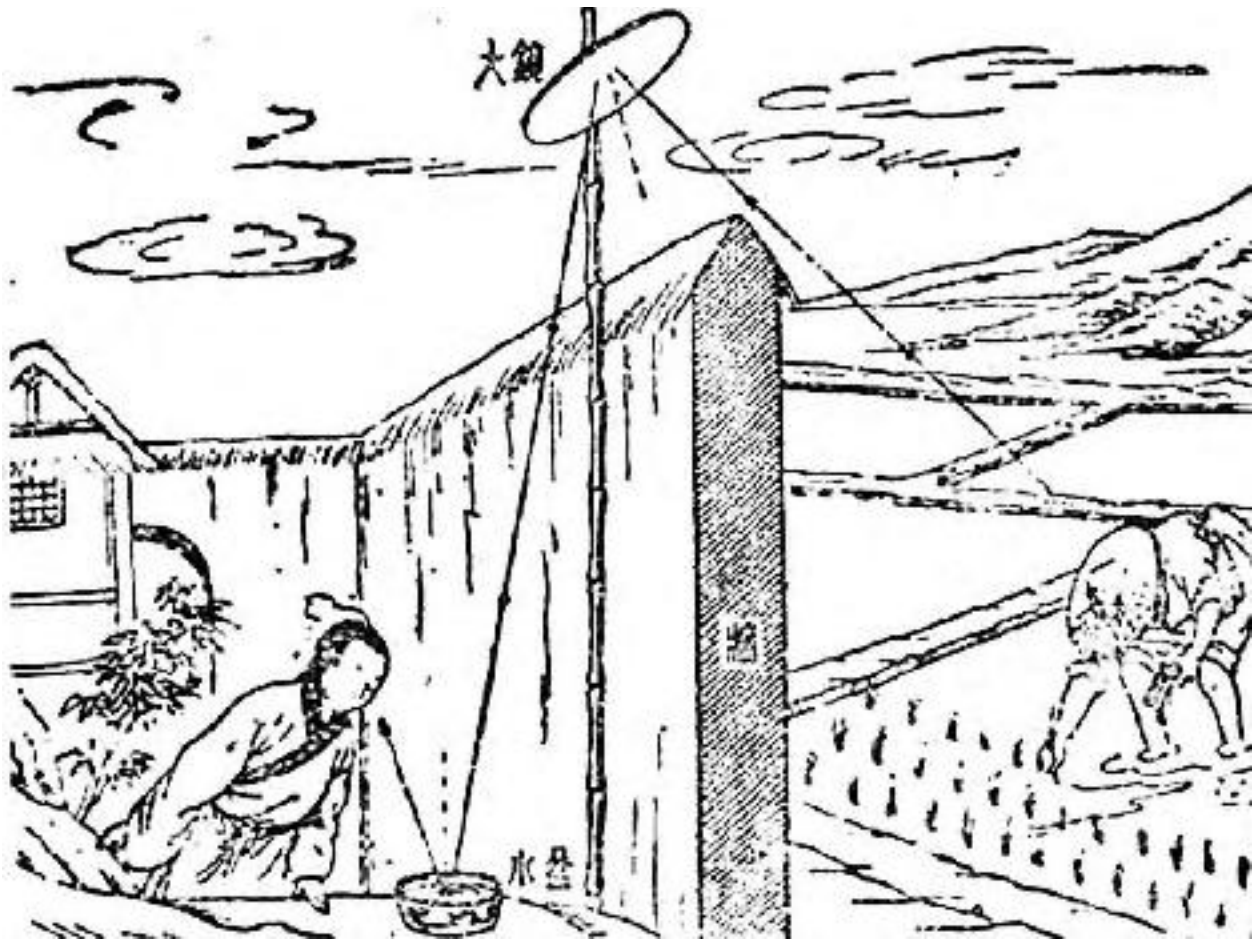


Illustration of the reflection of light by multiple mirrors (the world's first surveillance periscope!). CREDIT: Ling-An Wu, Gui-Lu Long, Quihuang Gong, and Guangcan Guo.

Unfortunately, over the course of history, much of the original book was lost, and the surviving transcripts are very fragmented. An informative account of optics (in English) from the Book of Mo Zi can be found in Vol. 4 of Needham's monumental work *Science and Civilisation in China*,⁴ as well as in Cooper's *Our Sun: Biography of a Star*.⁵ It seems evident that Mo Zi actually conducted experiments in optics, as his writings include the basic concepts and applications of linear optics. Below is a summary of his contributions, where the quotations are taken from Needham's translated excerpts from the Book of Mo Zi.^{1,4}

- Straight-line propagation of light. "An illuminated person shines as

if he was shooting forth (rays)." This is in contrast to the ancient Greek conception of the eye shooting out rays onto the object of vision.

- Shadow formation, umbra, and penumbra. "When there are two shadows (it is because there are two sources of light)." The reason is given as "doubling:" "Two (rays of) light grip (i.e., converge) to one light-point. And so you get one shadow from each light-point. If the source of light is smaller than the post, the shadow will be larger than the post. But if the source of light is larger than the post, the shadow will still be larger than the post. The further (from the source of light) the post, the shorter and

darker will be its shadow; the nearer (to the source of light) the post, the longer and lighter will be its shadow."

- Pinhole camera, focal point, and inversion. "The bottom part of the man becomes the top part (of the image) and the top part of the man becomes the bottom part (of the image). The foot of the man (sends out, as it were) light (rays, some of which are) hidden below (i.e., strike below the pinhole) (but others of which) form its image at the top. The head of the man (sends out, as it were) light (rays, some of which are) hidden above (i.e., strike above the pinhole) (but others of which) form its image at the bottom. At

a position farther or nearer (from the source of light, reflecting body, or image) there is a point (the pinhole) which collects the (rays of) light, so that the image is formed (only from what is permitted to come through the collecting-place)."

- Reflection by plane mirrors. "A shadow can be formed by the reflected (rays of) the sun. "If the light(-rays) from the sun are reflected (from a plane mirror perpendicular to the ground) onto a person, the shadow (of that person) is formed (on the ground) between that person and the sun. Standing on a plane mirror and looking downwards, one finds that one's image is inverted. (If two mirrors are used) the larger (the angle formed by the mirrors within the limit of 180 degrees) the fewer (the images). A plane mirror has only one image. If now two plane mirrors are placed at an angle, there will be two images. If the two mirrors are closed or opened (as if on a hinge), the two images will reflect each other. The image-targets are numerous (i.e., there are many images) but (the angle between the two mirrors) must be less than when they were originally in the same line (i.e., 180 degrees). The reflected images are formed from the two mirrors separately."
- Reflection and focusing of light by concave mirrors. "With a concave mirror, the image may be smaller and inverted, or larger and upright. (Take first) (an object in) the region between the mirror and the focal point. The nearer the object is to the focal point (and therefore the farther away from the mirror), the larger the image will be. The farther away the object is from the focal point (and therefore the nearer to the mirror), the smaller the image will be. In both cases the

image will be upright. From the very edge of the centre region (i.e., almost at the focal point), and going towards the mirror, all the images will be larger than the object, and upright. (Take next) (an object in) the region outside the centre of curvature and away from the mirror. The nearer the object is to the centre of curvature, the larger the image will be. The farther away the object is from the centre of curvature, the smaller the image will be. In both cases the image will be inverted. (Take lastly) (an object in) the region at the centre (i.e., the region between the focal point and the centre of curvature). Here the image is larger than the object (and inverted)."

- Reflection of light by convex mirrors. "With a convex mirror there is only one kind of image. The nearer the object is to the mirror, the larger the image will be. The farther away the object is, the smaller the image will be. But in both cases the image will be upright. An image given by an object too far away becomes indistinct."

Later, in the 11th century, Shen Kuo wrote: "The ancients made mirrors according to the following methods. If the mirror was large, the surface was made flat (or concave); if the mirror was small, the surface was made convex. If the mirror is concave it reflects a person's face larger; if the mirror is convex it reflects the face smaller. The whole of a person's face could not be seen in a small mirror, so that was why they made the surface convex. They increased or reduced the degree of convexity or concavity according to the size of the mirror, and could thus always make the mirror correspond to the face. The ingenious workmanship of the ancients has not been equaled by subsequent generations. Nowadays, when people get hold of

ancient mirrors, they actually have the surfaces ground flat. So perishes not only ancient skill, but even the appreciation of ancient skill."⁴

- Refraction of light and the refractive index of water. "The (apparent) size of a thorn (in water) is such that the sunken part seems shallow... If you compare it (the difference between the real and apparent depth is) one part in five. This gives a refractive index of 1.25 for water, which is not bad compared with the actual value 1.33."

The Contributions of Liu An, King of Huai-Nan

Huai-Nan is a place in today's Anhui province of China. Liu An (179–122 BC), King of Huai-Nan during the Western Han dynasty, was the grandson of Liu Bang, the first emperor of the Han dynasty and the leader of a peasant uprising. Liu An was a Taoist master and a thinker. Taoist scholars and practitioners were pragmatic and attached great importance to the natural sciences and engineering. One goal of Taoism was to achieve longevity through exercise and taking elixirs, and so in their quest for longevity, they made many important contributions to the sciences. Liu An's great contribution was in the compiling of two books, the *Book of the Master of Huai-Nan* or *The Huainan Philosophers* and *Huai-Nan Wan-Bi-Shu*.^{6,7}

The reflection of light by multiple mirrors, as well as from the surface of water, was well known in those days, and it is recorded that "A large mirror being hung up (above a large trough filled with water), one can see, even though seated, four 'neighbours.'"⁷ Using this setup, a soldier behind a wall could see outside the wall, and a landlord could oversee his laboring serfs "(see the drawing on the previous page for illustration). This was probably the world's first surveillance periscope!

The use of concave bronze mirrors to light fires was also very common and is clearly described in the Book of the Master of Huai-Nan (although the phenomenon was already mentioned in even earlier writings): “It is like collecting fire with a burning-mirror. If (the tinder is placed) too far away, (the fire) cannot be obtained. If (the tinder is placed) too near, the centre point will not (be hit either). It should be just exactly between ‘too far away’ and ‘too near.’”^{4,6}

Making fire from ice was also mentioned in Huai-Nan Wan-Bi-Shu: “A piece of ice is cut into the shape of a round ball and held facing the sun. Mugwort tinder is held to receive the bright beam from the ice, and thus fire is produced”^{4,7} (see the photos on page 53). This is well known in northeast China, where to this day children playing outdoors in the winter like to make ice lenses; even a very crudely fashioned round lump of ice can start a fire. On the other hand, the ancient burning-mirrors were bright and highly polished, and indeed are evidence of the high level of metalworking in those days.

The earliest bronze mirrors that have been found were excavated from the tomb of Queen Liang of the Guo state (central China), dating back to 760 BC, more than 200 years earlier than Mo Zi. It is a pity that so much knowledge has been lost over the course of China’s history, as the ancients certainly knew much more about optics than what is found only in currently existing written records.

As we are celebrating the International Year of Light in 2015, it is meaningful to look back on the role of light in the very early days of human society. This special year aims

to let everyone, young and old, in every part of the globe, understand and appreciate the basics of light and to promote optical technology for the benefit of all countries. Optics and light are indispensable to our everyday life. The earliest discoveries and inventions in optics of ancient China and the world stemmed from the need and desire to emerge from the darkness of backwardness to the light of progress. The mirrors described above were luxury commodities in ancient times that were affordable only to a minority of the privileged. Today, light-based technology is a major economic driver with the potential to revolutionize the 21st century and to bring prosperity to all mankind. Let us strive towards that goal.

MORE INFORMATION

1. Mo Zi, *Book of Mo Zi* (originally written around 385 BC); see *Book of Mo Zi* (in Chinese), proofed and noted version, by Yu-Jiang Wu and Qizhi Sun, Zhonghua Book Press (2008).
2. Lin-Zhao Qian and Qingshi Zhu, *The Collected Works of Lin-Zhao Qian* (in Chinese), pp. 458–467, Anhui Education Press (2001).
3. Nian-zu Dai, *Ancient Chinese Physics* (in Chinese), Shandong Education Press (1991).
4. J. Needham, *Science and Civilization in China*, vol. 4, Part 1: Physics, Cambridge Univ. Press (1962).
5. C. Cooper, *Our Sun: Biography of a Star*, Race Point Publishing, London (2013).
6. Liu An, *Book of Huai-Nan* (written between 179 and 122 BC); see *Book of Huai-Nan* (in Chinese), Guang-Zhong Chen, Zhonghua Book Press (2012).
7. *Liu An and Wan-Bi-Shu* (written between 179 and 122 BC); see *Huai-Nan Wan-Bi-Shu and Four Other Ancient Books* (in Chinese), The Commercial Book Press, Hong Kong (1939).
8. M. Herzberger, “Optics from Euclid to Huygens,” *Applied Optics* **5**(9), 1383–1393 (1966).
9. J. N. Mait, “A history of imaging: Revisiting the past to chart the future,” *Optics and Photonics News* **17**(2), 22–27 (2006).

Ling-An Wu is a professor in the Institute of Physics, CAS, studying experimental and theoretical quantum optics and nonlinear optics. She obtained a Ph.D. from the Univ. of Texas at Austin and is active in many social missions, especially in promoting the role of women in physics and in outreach programs for young students.

Gui-Lu Long is a professor at Tsinghua University and director of the Institute of High Energy and Nuclear Physics. He received his Ph.D. from Tsinghua University, and his research interests are in quantum communication, quantum computing, and optical microcavities.

Qihuang Gong is the Cheung Kong Professor of Physics at Peking University, where he is also the Founding Director of the Institute of Modern Optics and Deputy Dean of the Physics School. His current research interests are in ultrafast optics, nonlinear optics, and mesoscopic optical devices for applications, and he serves in key positions in the Chinese Optical and Chinese Physical Societies.

Guangcan Guo is a professor at the University of Science and Technology of China and has long been engaged in theoretical and experimental research of quantum optics, quantum information, and quantum computing. He is currently the director of the Key Laboratory of Quantum Information and a director of the Chinese Physical and Chinese Optical Societies.

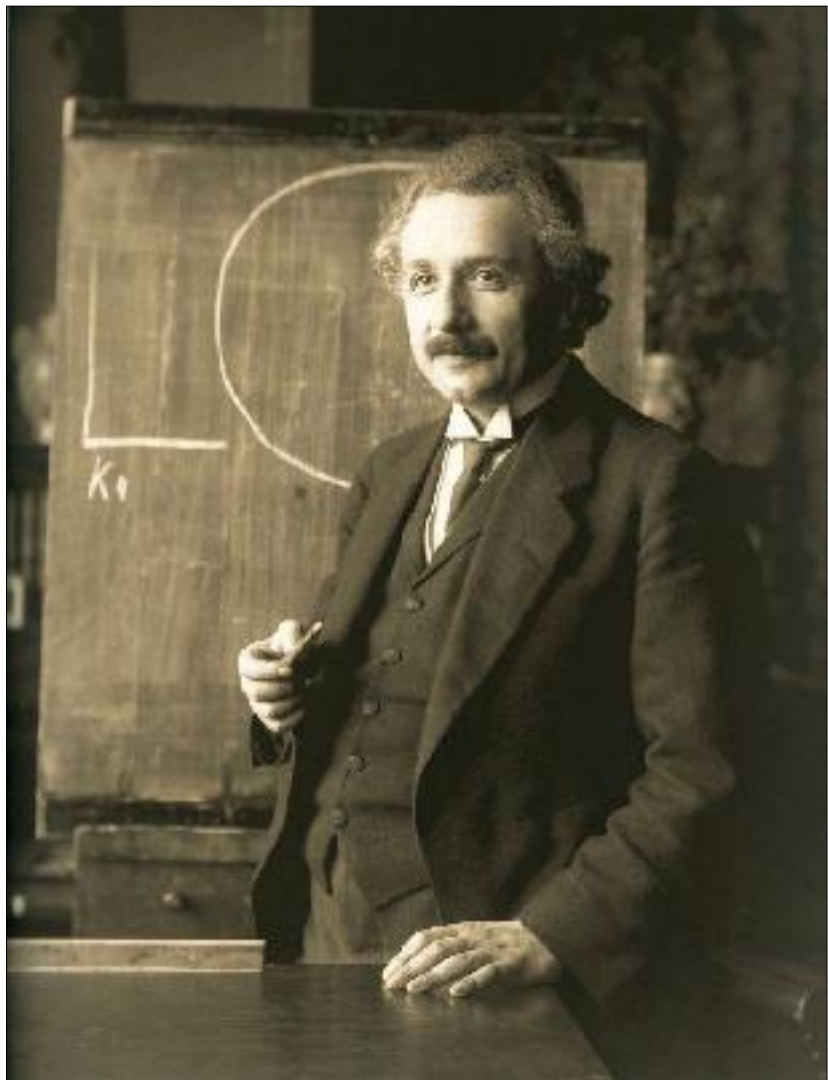
Solar Eclipse Observations Proved That Einstein Was Right

Stefania Pandolfi, University of Copenhagen, Denmark

Roughly speaking, a scientific theory is a self-contained explanation of some natural facts, and the simpler and more predictive it is, the more powerful. This means that if the theory is correct, it can forecast the occurrence of some distinguishing events, whose empirical confirmation would strike a blow for the theory itself. The smoking gun of Einstein's general theory of relativity was a phenomenon observed during the solar eclipse of May 1919.

It's a very interesting story also from a historical and sociological point of view, other than being one of the greatest turning points in modern science. Einstein finished working on his general theory of relativity right at the beginning of World War I and presented his results at the Prussian Academy of Sciences in 1915. His theory broke away from the Newtonian concept of absolute space and time in which natural phenomena just "happen" in favour of a more comprehensive scenario in which space and time are tied to each other, and the resulting spacetime is shaped by the matter (and therefore the energy) it contains.

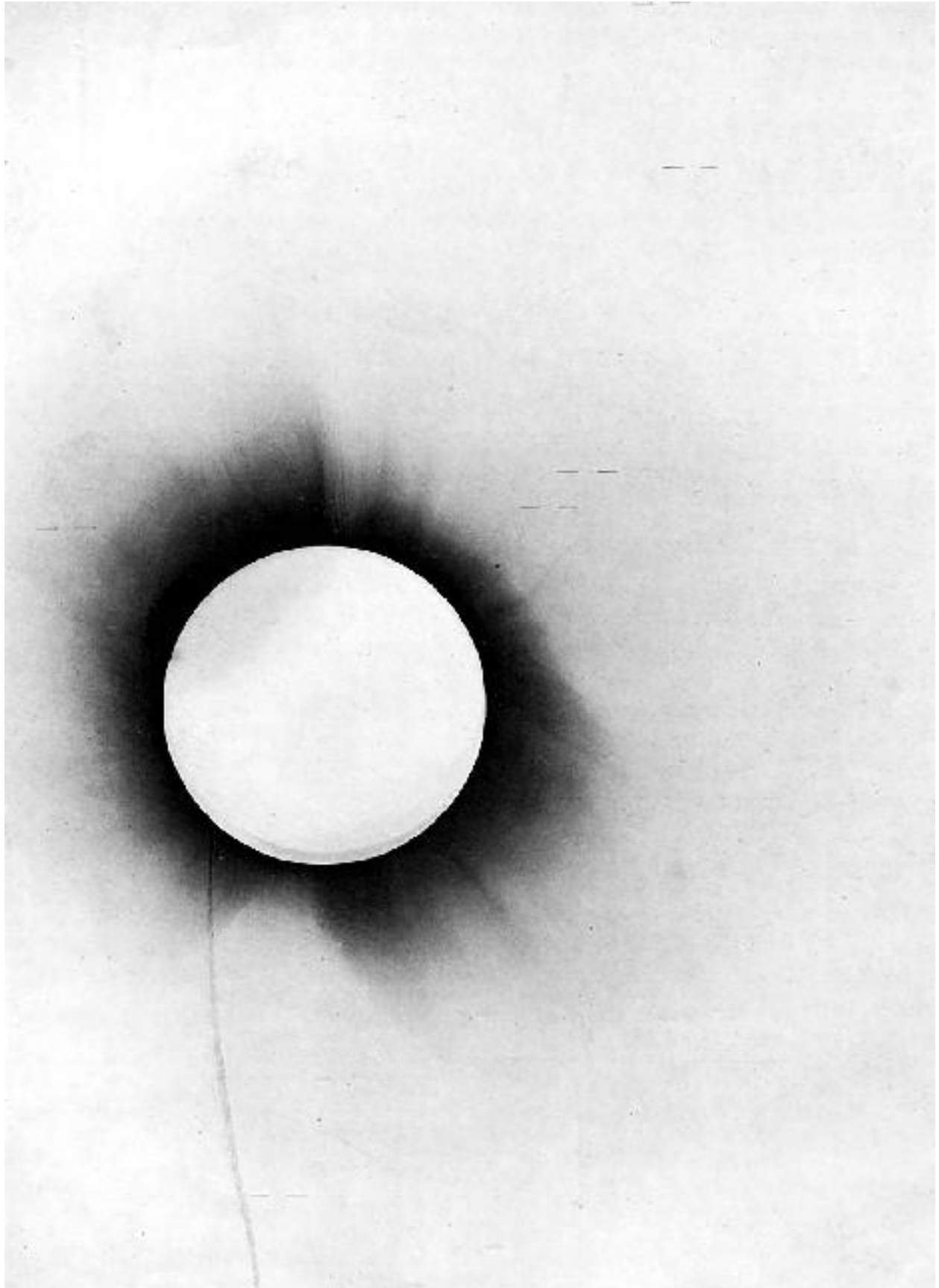
Although the math behind the general relativity theory is awesomely daunting, the underlying concept is simple and elegant: the spacetime of the universe with no matter around (as in an empty universe)



CREDIT: Wikimedia Commons.

is just flat, and the light rays propagate in straight lines. Instead, in the presence of a massive body (for example, a star), the spacetime

right around it will be distorted. In a two-dimensional analogy, the spacetime can be represented by a billiard table; in the empty universe



Negative of the 1919 solar eclipse taken from the report of Sir Arthur Eddington with the title: "A Determination of the Deflection of Light by the Sun's Gravitational Field, from Observations Made at the Total Eclipse of May 29, 1919." CREDIT: Wikimedia Commons.

case, a ball that is thrown will roll smoothly over it, following a straight line. In the same analogy, the massive object, the star, might be depicted as a dip in the middle of the table. The closer you get to it, the more curved the surface will be; the ball will now deviate from a straight line trajectory, and the closer to the dip, the more it will deviate.

Leaving metaphors aside, if a light ray happens to pass close to a massive object such as a star, it will be forced to bend in order to follow the curved spacetime around it, as it cannot travel anywhere else; it has to comply with the warps of the spacetime and cannot just “detach” from it, as there’s nothing else “outside” it.

The curvature of the spacetime given by the presence of the Sun bends the light of a background star so that it appears to come from a slightly different position in the sky, away from it. The consequence is that a star, or a group of stars, normally seen at a certain position when the Sun is in another part of the sky, would appear to be slightly shifted when the Sun passes in front of them.

Ironically enough, this idea of light bending had been already formulated by Sir Isaac Newton himself in his book *Opticks* in 1704. He also computed the predicted value for the light ray bending of background stars when grazing the surface of the Sun; the background stars would appear to be shifted by an angle of 0.87 seconds of arc (when the Sun itself occupies an angle in the sky of about one-half of a degree, i.e., 1800 arcseconds). At that time, a measurement of such a tiny value was certainly outside of technological possibilities, but at the beginning of the 20th century, it was within reach.

The value predicted by the theory of general relativity instead is twice as

large as the Newtonian value (1.74 arcseconds) and therefore even easier to detect, in principle. As was the case with many German scientists during World War I, before the solar eclipse of 1919, Einstein and his theory were known only in the German speaking wing of the science community. With Britain and Germany at war, there was no direct contact of any type between the two countries.

A British astronomer, Sir Arthur Stanley Eddington, holder of the most prestigious chair in Britain and director of the Cambridge Observatory, learned about Einstein’s theory of general relativity through a Dutch scientist, Willem De Sitter, who was in (neutral) Holland at the time.

Eddington was fascinated by Einstein’s theory and became its first promoter among the scientists of the Royal Astronomical Society, highlighting the importance of testing it against Newton’s theory using light bending measurements. These measurements could only be performed during a total solar eclipse because, otherwise, the stars close to the Sun wouldn’t have been visible at all.

Right after the end of the war, two expeditions were organised to observe the eclipse of the 29 May 1919. One was directed to Sobral, in the north of Brasil, and a second, led by Eddington, headed to the Principe Island, part of the present Sao Tome and Principe, off the coast of Equatorial Guinea, in West Africa.

Their mission was very well defined, in theory: taking photographs of the stars around the Sun during the total eclipse, and then comparing them with photographs of the same stars, in the same patch of the sky, taken when the Sun was not there. The amount of displacement of the position of the stars, if measured with enough precision, would have pointed to one of the concurrent

theories of gravity, with a substantial degree of credibility.

In November 1919, the long-awaited results were presented at a special joint meeting of the Royal Astronomical Society and the Royal Society of London. The measurements from both Sobral and Principe were highly compatible with the Einstein’s value and extensively veered away from the Newtonian value.

Even though part of the scientific community was doubtful about the reliability of the measurements, which indeed were taken in non-optimal conditions and with several challenges, the results triumphantly conquered the headlines of the major newspapers at the time. It was a tremendous press success, and Einstein himself was deemed an undisputed genius. The entire story was also greeted as a seed for faster reconciliation between Britain and Germany.

So far, Einstein’s general relativity theory is the most complete description of gravitation and spacetime that we have. However, the theory might eventually be found to break down in extreme physical cases—cases that we would not be able to explain within its framework—and we would need to replace it with another, more general theory of gravity. Stay tuned!

Stefania Pandolfi earned a Ph.D. in cosmology and is currently a postdoctoral researcher at the University of Copenhagen as well as a member of the ESA’s Planck and Euclid collaborations. Despite her happy and fruitful astrophysics career, the burning flame for science communication grew too large to be held back, so she got a Masters in Journalism and Institutional Science Communication and is turning her innate passion into a new exciting career.



Working alone in his room in Paris, Etienne-Louis Malus (1775-1812) used small crystals and complex calculations to prove that light is polarized. CREDIT: Wikimedia Commons.

The French Captain's Discovery: Polarized Light

Bruce Watson, Author, USA

It may not be sunny where you are reading this, but you'll need sunglasses to continue. Dark shades in hand, study the screen in front of you, whether laptop, desktop, or mobile. Now put on your sunglasses. Whoa, where did the light go? Try it again. Without the glasses, you can read these words. With the glasses, the screen dims or, depending on how much you paid for those glasses, goes dark. What is happening? The puzzle of "polarized light" owes its solution to a dapper French captain in Napoleon's army, a contest of cutting-edge physics, and little crystal found on the coast of Iceland.

At the dawn of the 19th century, Isaac Newton was the oracle of all things pertaining to light. In the 100 years since Newton published *Opticks*, light had been the talk of Europe. Bursting from prisms, light's lovely colors delighted children and adults. Poems eulogized light's beauty. And its avatar, the great Newton, was hailed as "our philosophical sun." But although light was widely celebrated, it was rarely studied. The science of optics, trapped behind Newton's shadow, made little progress in the 1700s. If there was anything more to be learned about light, surely the great Newton would have found it.

Throughout the so-called Enlightenment, only a handful of scientists dared to challenge Newton. Light had to be made of particles because Newton said it was. The few who

considered light a wave had a lot of explaining to do. Yet, some were troubled by an anomaly that had also troubled Newton. The puzzle centered on what happened to light when it passed through the crystal known as Iceland spar.

Legend had long held that the Vikings used a "sunstone" to steer their ships on cloudy days. A sailor held this crystal to the sky, turned it ninety degrees and, using some directional property of sunlight, found his way home. Perhaps. But the rest of Europe did not discover Iceland spar until the 1660s when a traveler brought several chunks back to Denmark. Many marveled at the crystal. When placed on a printed page, it doubled each letter, making ghostly words hover. Then, someone noticed that the spar split candlelight, sending two beams in different directions. Newton soon got word and made his own examination. In *Opticks*, he noted how "that strange substance, Island (sic) Crystal" divided beams. His prisms split white light into colors, yet this spar divided light without making a spectrum. Shining light through two crystals, Newton noticed yet another oddity. If their broad faces were parallel, the second spar also split the first's beams. But turn one spar 90 degrees and it split one beam but not the other, rather like the sunlight the Vikings had spotted through their sunstones. Light, Newton concluded, must not be symmetrical. "Every Ray of Light has therefore two opposite Sides."



The little crystal, Iceland spar, baffled Isaac Newton and others by splitting light into two beams. The spar and its anomalies ultimately led to the downfall of Newton's particle theory of light. CREDIT: Bruce Watson.

Iceland spar challenged Newton in ways that no scientist had dared. Wave theorist Christiaan Huygens was equally intrigued. A mathematician on par with Archimedes, Huygens devoted an entire chapter in his 1690 *Treatise on Light* to Iceland spar. "Amongst transparent bodies," the Dutch astronomer wrote, "this one alone does not follow the ordinary rules with respect to rays of light." The bulk of Huygens' treatise is coldly clinical, yet he found the spar's tricks "marvelous." He calculated the angles of waves passing through the spar, showing how a crystal could have two refraction indexes, cleaving one beam into two. Yet when pondering why a second spar split the "ordinary" but not the "extraordinary" ray, Huygens was stumped. Others made their own investigations of Iceland spar but came away as baffled as Newton and Huygens. The mystery was finally solved by that dapper French captain.

Etienne-Louis Malus is hardly a household name, yet hardly a household is without a device he made

possible, including the screen you're reading. Born in Paris in 1775, Malus became fascinated with light while studying at the Ecole Polytechnique. When Napoleon, in 1798, yanked dozens of young engineers from classrooms to join his Egyptian campaign, Malus was one of the reluctant recruits. With his dark, curly hair, mutton chops, and stiff epaulets, he cut a dashing figure, yet he was appalled by war. Contracting bubonic plague, he was shipped to the pesthouse in Jaffa, then back to Cairo. There he wrote in his journal of "the tumult of carnage...the smell of blood, the groans of the wounded, the cries of the conquerors...." Somehow surviving, he was sent back into battle. Seeking hope amid misery and slaughter, he turned to light.

Late into the night, in a palm-thatched tent on the sands of the Nile Delta, this brilliant but embattled captain studied light. His tent glowed as he shifted candles and mirrors, calculated angles, and kept his spirit alive even as his body struggled with dysentery and other diseases. When finally sent back to Europe, Malus supervised engineering projects while continuing his experiments. By 1807, suffering what would now be called post-traumatic stress disorder, he was holed up in his room near the Luxembourg Gardens. There he became enthralled by Iceland crystals. Beaming light through them, he noticed yet another startling trait. When he sent a beam through the spar, it split in two, as Newton and others had noticed. Yet if the beam struck the spar at a precise angle—52 degrees, 54 minutes—the light shot straight through, without splitting!

Malus soon learned of a contest at Paris' Academie des Sciences. Members of that prestigious body loved nothing more than to quarrel, bicker, and compete to prove scientific principles. The latest contest required entrants to explain and calculate the split rays of Iceland spar. Determined to win the contest, Ma-

lus spent a year obsessed with light. "I live here like a hermit," he wrote. "I pass whole days without speaking a word." In a room littered with candles and crystals, he etched a copper sheet with a scale in millimeters, then set a spar on the copper to measure each angle of each double image. Blending the law of refraction with some advanced algebra, he piled equation on equation. "No one before had carried the use of intricate algebraic formulas in conjunction with experiment to such a high art," observed Jeb Z. Buchwald, historian of science at CalTech.

In December 1808, Malus submitted his contest entry. Academie elders, though loyal to Newton, could not refute Malus' math, which relied heavily on Christiaan Huygens' controversial wave theory. Malus won the contest. It was Huygens' waves, not Newton's particles, that explained Icelandic spar, but the embattled soldier was not done with his crystals.

One bright afternoon, Malus sat in his room near the Luxembourg Gardens. Spotting sunlight glinting off the windows of the Luxembourg Palace, he lifted a spar to his eyes. He expected the sun's reflection to be doubly refracted, yet through the crystal he saw just a single image. That evening, still peering through spars, Malus studied a candle's reflection in water. Stooping to adjust his angle of incidence, he looked, checked, looked again. At the spot where candlelight struck water at 36 degrees, the double refraction turned to single. Reflected off glass or water, Malus concluded, light changes.

Consulting his trig tables, this time not the sine function but the cosine, Malus concluded that, as Newton had suspected, light has "sides." Malus then coined a term we still use: polarized light. Light was indeed asymmetrical. To test his theory, Malus built an elaborate device with rotating mirrors above parallel axes. Now he could bounce light at any angle. A lit-

tle more math ("the cosine squared of the planar angle"), a bit more insight (if you rotate a spar ninety degrees the "ordinary" ray behaves like the "extraordinary," and vice-versa), and Malus proved the principle of polarization. Light did not resemble tennis balls, as his fellow Frenchman René Descartes had written, but was more like a football (American) that wobbled end over end or, when refracted at certain angles, flew in a perfect spiral. Light beams passing through Iceland spar or reflected off water or glass became polarized with their "sides" aligned.

Malus published his discovery in 1809. The following year, he published his calculations of double refraction through Iceland spar. One can only imagine what other discoveries awaited this genius, but the horrors of war soon caught up with him. Etienne-Louis Malus died in 1812, at age 37, of complications from diseases contracted in Egypt. Though his name is known only to physicists, every decent pair of sunglasses filters polarized glare, and every flat screen in a TV, laptop, or mobile device uses polarized light to brighten and darken its pixels. Others would soon extend Malus' discovery. In 1815, the British physicist David Brewster devised a formula to compute the angle at which light polarizes when reflected off of different surfaces. Brewster's angle is calculated by using the refractive index of the material and the light's wavelength. Brewster's work enabled later discoveries of chromatic, circular, and elliptical polarization, all paving the way for the light of the 21st century, including your screen. You may put your sunglasses away now.

Bruce Watson is the author of *Light: A Radiant History from Creation to the Quantum Age* (Bloomsbury, 2016), which traces humanity's evolving understanding and control of light, starting with creation myths, then moving into scripture, philosophy, architecture, Islamic science, art history, poetry, physics, and quantum physics. Watson's work has appeared in numerous newspapers and publications.

The Future of Science in the Hands of Young Girls

Sandra Benitez-Herrera, Museum of Astronomy and Related Sciences, Brazil

If you ask any random person on the street what the mental image they have about a scientist is, what do you think they would answer? What is your own personal idea of a scientist? Is it a young, promising, female researcher in, say, applied mathematics? Or is it a gray-haired male professor in theoretical physics? Maybe a 15-year-experienced laboratory (lady) chief? A respectable, bearded, old man head of a psychology department? Is your image in white or is it colorful?

Science, unfortunately, as many other things in life, is not a prejudice-free area. Though it encourages some of the better qualities of the human race, such as a selfless search for knowledge, or the understanding among different people for a greater cause rather than for personal benefit, or the innovation of technologies to make people's lives easier, it also sometimes reflects some of our worst mistakes.

Common belief relies upon the idea that until very recently, there didn't exist any female scientists who actually made world-changing contributions to science and technology. Though women in science were not the majority in past times, there are a great deal of names that we should rescue from the trunk of memories.

Why, you may ask. Well, first, because many of them never got the credit for their work or the proper reward they deserved. But second,



The mathematician Emmy Noether was one of the greatest minds of the 20th century. Her work was fundamental in the development of abstract algebra and theoretical physics. CREDIT: Wikimedia Commons.

and more importantly, because our young girls need female role models to identify with to overcome the idea that science is only a male-dominated business in which they have no voice or future.

A canonical example of a long-time ignored female scientist is the German mathematician Emmy Noether, whose contributions to abstract algebra and theoretical physics were fundamental for the development of those areas at the beginning of the 20th century. Noether's theorem, which allows one to derive conserved quantities from symmetries, is widely today used in many areas of physics, such as quantum physics or astrophysics. Einstein himself considered her to be one of the most important mathematicians of our history, yet she was never allowed to take up a full faculty position at Göttingen University, where she conducted most of her research, and she had to give classes under the name of the department's director.

One may think that with the passing of time things have improved, but, sadly, the list of women who have been (or currently are) unfairly under-recognized in the history of science is long. A modern example is the exclusion of Dr. Jocelyn Bell for winning the Nobel Prize in Physics, despite having been the first person to observe and precisely analyse radio pulsars. Her advisor and another male academic won the prize in 1974. These are just two examples, but there are plenty.¹ Rescuing the names of all these women from oblivion by including them in our textbooks and in our societal consciousness is essential if we aim for a truly equal society.

A disheartening study published only a few weeks ago and conducted by Opinionway for the L'Oréal Foundation has shown that approximately 67% of Europeans (including females) think that women do not possess the necessary abilities to

make a career in science. The study reflects that one of the main reasons argued for the alleged lack of abilities is a primary absence of interest in science. Indeed, it is quite disturbing to learn that the majority of the European population actually believes that women have no interest in science at all, since intrinsic injustices preventing women from reaching high positions in basically any field of academia are concealed by this line of reasoning.

In countries like Germany or France, for instance, less than 30% of researchers are female, as has been reported by the UNESCO's Institute for Statistics. Curiously enough, in countries such as Bolivia or Venezuela, female researches make up 63% and 56% of all researchers, respectively. Comparing the numbers from country to country, it seems only fair to point out that the supposed lack of interest might highly depend on factors other than biology.

Following this argument, we find several studies using international data on school mathematics performance, opposing the common assumption about gender and math achievement, in particular, the idea that girls and women have less ability due to an innate difference. In a major study carried out at the University of Wisconsin-Madison, the researchers involved came to the conclusion that "None of our findings suggest that an innate biological difference between the sexes is the primary reason for a gender gap in math performance at any level. Rather, these major international studies strongly suggest that the math-gender gap, where it occurs, is due to sociocultural factors that differ among countries, and that these factors can be changed."²

Our societies need to leave the old preconceptions behind and start thinking about strategies to motivate girls into liking science. They need to support young female scien-

tists who encounter many obstacles and sometimes really hostile work environments in their paths towards high-level scientific positions.

An important initiative to create awareness among Europeans is the promising campaign called Change the Numbers launched by L'Oréal that is putting a strong emphasis on the encouragement of young girls to pursue a degree in science or technology. In the past years, similar attempts have been materializing to inspire young girls to dream of a bright future in science, or at least, to help them give up the misconception that technical jobs are not made for them. An interesting program working in this direction since 2001 is Girls' Day. German authorities, aware of the sparse numbers of females in their scientific institutions, have come up with the idea of establishing a dedicated day during which thousands of teenage girls across the country visit technical universities, research labs, and institutes to become familiar with the scientific and technical world, get in contact with researchers of different areas, and imagine the (very cool) jobs they could have when they grow up.

Another stimulating exercise is the recently founded company Goldie Blox, which designs construction toys for girls with the aim of getting them passionate about engineering and eliminating the pink stereotype surrounding girls' toys. "Our girls deserve more" is the motto used by this firm that has been successful in re-igniting the debate on non-gender toys and raising social awareness towards the undeniable influence that current toys have on the aspirations of young girls (that is, becoming moms or beauty queens instead of doctors, scientists, or engineers).

As a follow-up to this debate, the well-known toy company LEGO decided to create three mini-figures depicting female researchers: an astronomer, a paleontologist, and



CREDIT: iStock/Christopher Futcher.

a chemist, to give visibility to women working in science. The brand is contemplating other appealing designs such as a robotics engineer, a mechanic, and a geologist.

These efforts and many others around the globe will surely contribute to breaking the current stereotypes against women in science. However, the task seems a challenging one when even male researchers have this kind of prejudices still hidden deep down in minds. Earlier this year, Caltech astrophysicist Shrinivas Kulkarni referred to scientists as “boys with toys.” The immediate response to his sexist comment was a viral twitter campaign showing many female scientists at their work stations, controlling sophisticated scientific instruments. Twitter’s #girlswithtoys is a good example of how humor can be used as another way to fight discrimination.

People must realize that women and girls care about science. There are social conventions and long-established stereotypes that convince

them that they are good enough for it. We need to surpass the irrational belief that women are not sufficiently smart to do science, and understand that we are as capable as anyone to conduct a major research project, to make prodigious discoveries, to design heavy machinery for industry, to be responsible for the R&D department of a private company, or, essentially, to accomplish anything we dream of.

And to win the battle of equality in science, it is mandatory that more women are empowered in high academic positions so our societies watch them make meaningful contributions to science and, more importantly, hear them speak about it. Giving interviews in public media, attending high-level conferences, giving public outreach talks, being the ones who talk about and discuss scientific progress are all fundamental to changing the present situation. It is time for women to begin talking about science and explaining it to the community. It is time for girls to feel that science is

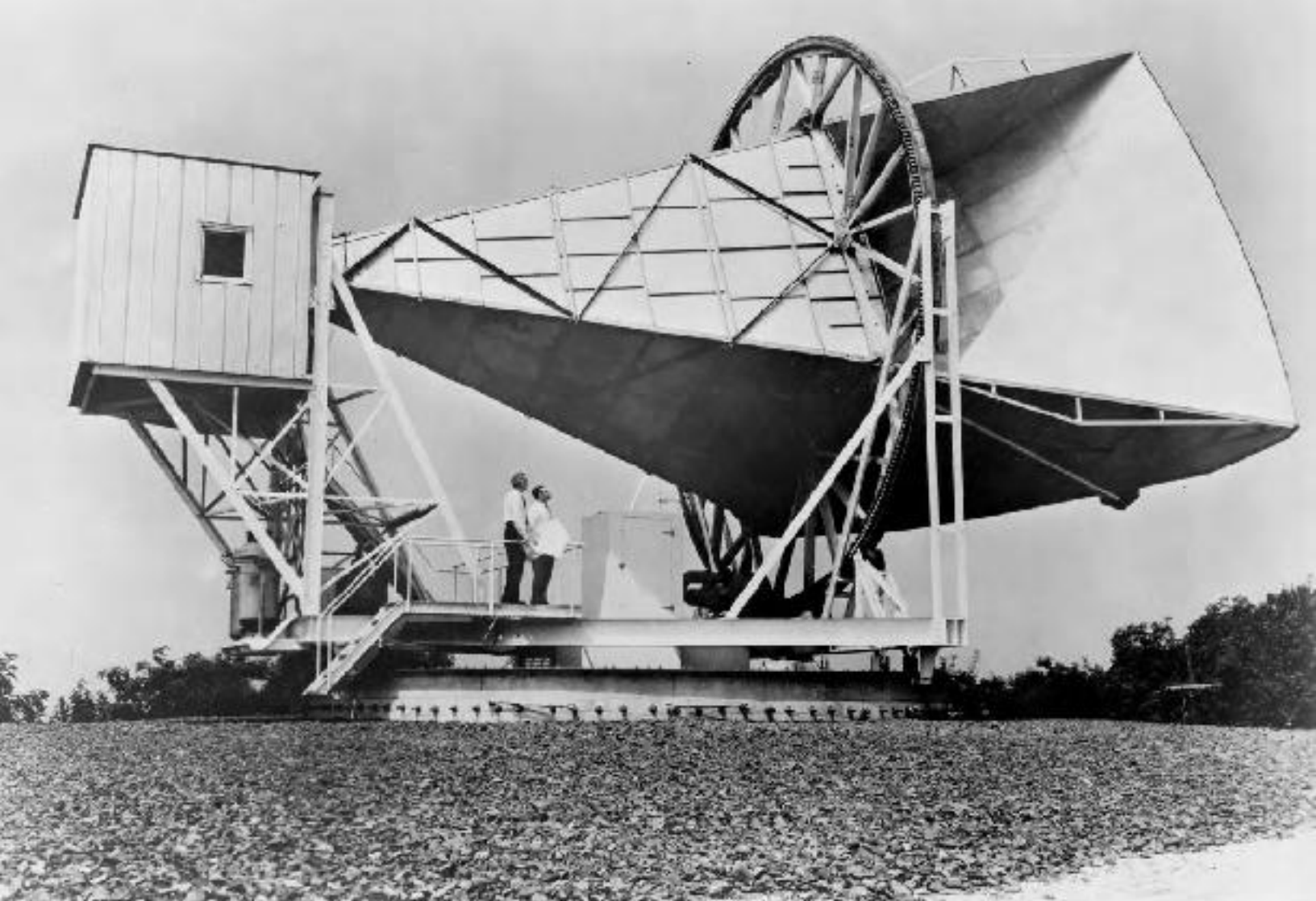
a new world that they can explore and excel in, that science can be a very important and rewarding part of their identities.

As beautifully said by the 1986 Physiology and Medicine Nobel Prize winner, Rita Levi-Montalcini: “After centuries of dormancy, young women ... can now look toward a future moulded by their own hands.”

MORE INFORMATION

1. Encyclopedia Britannica Blog: <http://blogs.britannica.com/2011/03/10-women-scientists-famous-famous/>.
2. J. M. Kane and J. E. Mertz, “Debunking myths about gender and mathematics performance,” *Notices of the American Mathematical Society* **59**(1), 10–21 (2012).

Sandra Benitez-Herrera is a Spanish astrophysicist based in Rio de Janeiro, Brazil, who earned her Ph.D. in astrophysics from the Technical University of Munich. She holds a science communication position at the Museum of Astronomy and Related Sciences and has been an active member of the GalileoMobile outreach project since 2011.



The 15-meter Holmdel horn antenna at the Bell Telephone Laboratories, used by Penzias and Wilson to detect the CMB on 20 May 1964. CREDIT: Wikipedia public domain.

The Most Ancient Cosmic Light: 50 Years of Cosmic Microwave Background

Claudia Mignone, ESTEC, European Space Agency, The Netherlands

The Universe has not always been the sparkling mix of stars and galaxies we live in and observe today. In its first few minutes, it was a hot and dense jumble of light and particles, expanding and cooling down ever since. Likewise, our understanding of the Universe and its evolution has changed dramatically over time, with the current picture of cosmic history emerging from an exciting progression of theoretical and experimental investigations throughout the past century.

The cosmic microwave background (CMB) radiation is a relic of the light that filled the early cosmos almost 14 billion years ago. It can still be observed today across the sky at much longer wavelengths than visible light, in the domain of microwaves. Its discovery in 1965 was crucial to settling the cosmological debate between supporters of an expanding Universe, starting hot and dense and later cooling down, and those who believed in a stationary cosmos, with similar properties on large spatial as well as temporal scales. Interestingly, the

name “big bang” now used to refer to the former theory was coined by Fred Hoyle, one of the scientists who devised the latter. The decisive event in the dispute, the discovery of the CMB, happened by pure chance.

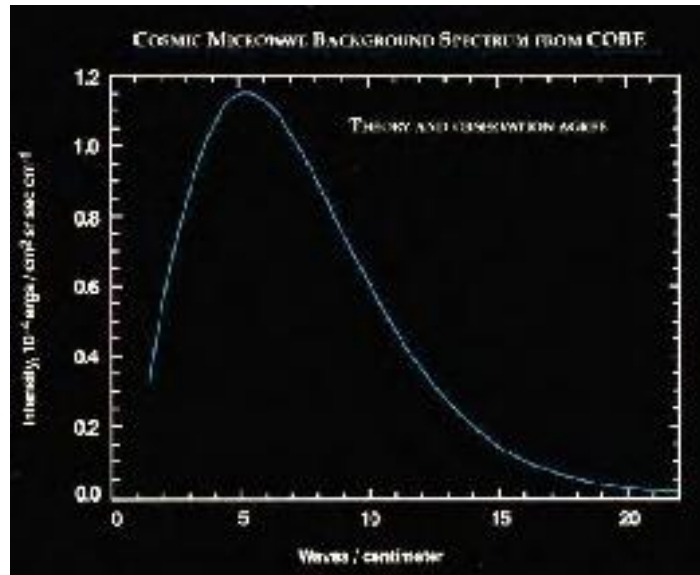
It was 1964 when Arno Penzias and Robert Wilson, two radio astronomers at the Bell Telephone Laboratories, first detected this curious signal. They were scanning the sky with a satellite communications antenna to study microwave light emitted by celestial sources. Anywhere they pointed in the sky, they found a slightly higher signal than expected: a uniform background “noise” corresponding to a temperature of about 3 K. Penzias and Wilson considered all possible sources of this nuisance to their data, but without success.

Interestingly, about 15 years before, and for completely different reasons, three physicists had contemplated the existence of just such a background: George Gamow, Ralph Alpher, and Robert Herman, who were studying the origin of chemical elements in the Universe.¹ The nuclear reactions that turn hydrogen into helium and release energy in stars had been discovered a decade earlier, and the three physicists were trying to explain the abundance of different chemical elements. Between 1948 and 1949, they suggested that the nuclei of elements heavier than hydrogen might have formed in the early Universe, as long as it had been sufficiently hot and dense in its first few minutes.

Additionally, Alpher and Herman noted that in that case, a relic of the primordial heat—about one billion degrees—must have survived until now, becoming much colder, though, falling to only a few degrees above absolute zero due to cosmic expansion.

Following similar lines of thought, cosmologists at Princeton University were investigating this “big bang” origin of the Universe in the 1960s. Robert Dicke, who had developed a sensitive microwave receiver during the World War II, later tried to use it to seek cosmic microwaves, together with Peter Roll and David Wilkinson, who built a new detector to look for the CMB, and James Peebles, a theoretical physicist studying the cosmological consequences. By 1965, they had not seen anything, but news about their research spread; eventually, Penzias and Wilson understood the significance of the mysterious signal they had found a few months before.

The search was over. The discovery of the CMB was announced in May 1965 by Dicke, Peebles, Roll, and



The CMB spectrum as measured with the FIRAS instrument on board NASA's COBE satellite. The measurements closely match the expected intensity from a constant-temperature blackbody spectrum with error uncertainties smaller than the width of the theoretical curve. CREDIT: NASA.

Wilkinson, outlining the implications of a microwave background for the history of the Universe, and by Penzias and Wilson, describing their experimental method of detection.

Finding the CMB represented a triumph for the “big bang” description of the Universe; the fossil light, with roughly the same temperature across the sky, could not be easily explained in the alternative, steady-state cosmos. But that was not the end; the detection of the CMB triggered a series of increasingly accurate experiments and fine theoretical calculations over the past fifty years, as scientists sought more details about this early cosmic signal.

Soon, some issues emerged as scientists tried to explain the physical meaning of the CMB. For starters, the discovery had been obtained at one single frequency, but to confirm that this was thermal radiation from the early Universe, observations at several wavelengths were needed to prove that it had a blackbody spectrum.² This search, which also required space-based observations, lasted around 25 years, until 1990, when a team of astronomers led by John C. Mather detected the most precise blackbody radiation ever observed, with NASA's Cosmic Background Explorer (COBE) satellite, pinning down the CMB temperature to just above 2.7 K.

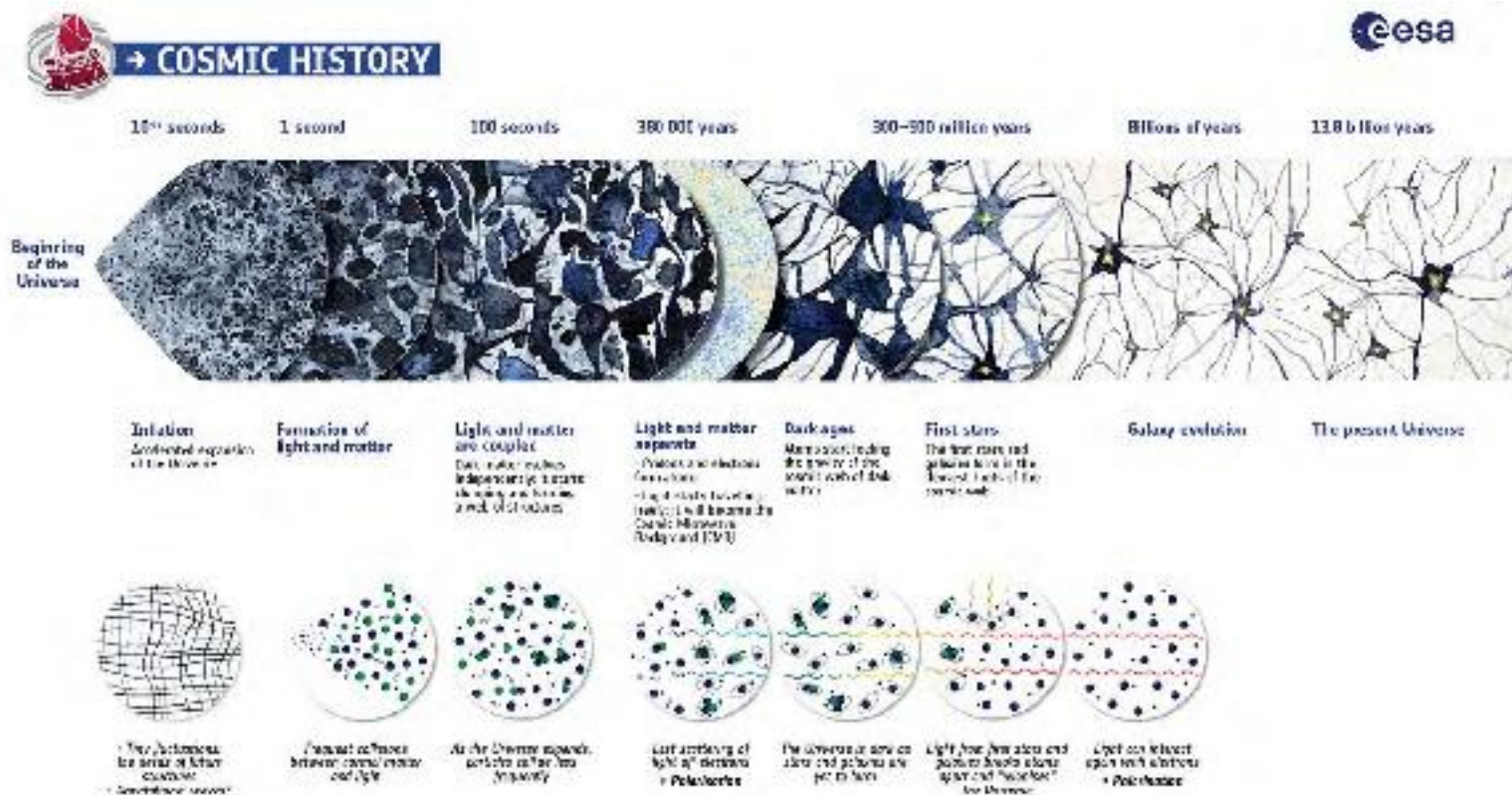
While its origin is rooted in the very early Universe, the CMB did not start its journey until about 380,000 years after the “big bang.” Before then, the cosmos was pervaded by a fluid of particles and light tightly bound to one another by frequent collisions, and just too dense

for photons—the particles of light—to propagate freely. At first, there were only elementary particles, including quarks, electrons, and neutrinos, but soon quarks assembled into protons and neutrons. By the time the Universe was a few minutes old, all neutrons were locked in the nuclei of light elements (as thought by Gamow, Alpher, and Herman, leading to predicting the CMB), and the “cosmic soup” consisted mainly of protons, electrons, neutrinos, and photons bumping into one another.

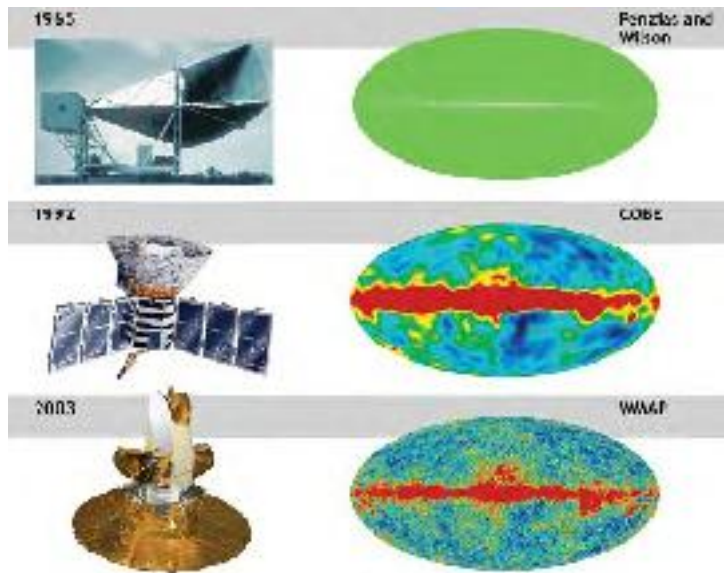
In matter as we know it, we find protons and electrons in atoms, but in the young Universe, these particles were separated; if they ever combined, attracted to one other due to their opposite electric charge, they could form an atom, but this would not last long, as a photon would soon break it apart. The high density of the early cosmos prevented photons from travelling freely and neutral atoms from forming. As the Universe was expanding, becoming cooler and less dense, particles had more “room” to move around, and their collisions became less frequent. When the temperature dropped from billions of degrees in the first few minutes to 3000 K about 380,000 years later, photons were finally set free and started their cosmic journey. Almost 14 billion years later, we can now detect them as the CMB.

Scientists also realised that the CMB, discovered as a uniform signal across the sky, must not be so uniform. As a snapshot of the early Universe, it must contain a record of matter distribution back then, when stars and galaxies had not yet formed but their seeds were present as slightly denser clumps of matter. In 1970, theoretical calculations by Rashid Sunyaev and Yakov Zel’dovich, as well as by James Peebles and Jer Yu, predicted that small inhomogeneities in the early distribution of matter would translate into tiny anisotropies in the CMB, expected to be around 1/1000 K. However, observations did not find any; where were the seeds of today’s stars and galaxies?

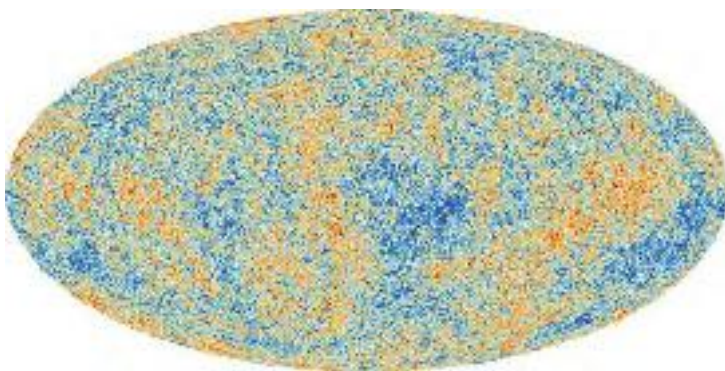
A possible solution, proposed by Peebles in 1982, invoked the invisible dark matter,³ which manifests itself only via gravity, unlike ordinary matter that makes stars, planets, and ourselves. Adding dark matter to the young Universe cocktail means that today’s structures could have their origin in tiny fluctuations of this dark component, which does not interact with photons, leaving no imprint on the CMB. Ordinary matter—basically protons and electrons—would still be inhomogeneous in the early cosmos, but to an even lower degree: about 1 part in 100,000. After the release of the CMB, particles of ordinary matter would feel the gravitational pull of denser



An artist's view of the evolution of the Universe, highlighting the phenomena that gave rise to the cosmic microwave background. CREDIT: ESA.



A comparison between the signal that Penzias and Wilson would have seen on the entire sky with their antenna (top) and the CMB maps by NASA's COBE (middle) and WMAP (bottom) satellites. CREDIT: NASA/WMAP Science Team.



Map of the temperature fluctuations in the CMB detected by ESA's satellite Planck. CREDIT: ESA and the Planck Collaboration.

clumps of dark matter, starting to form structure and leading to the birth of stars and galaxies.

Several experiments kept looking for such anisotropies, until the first detection came in 1992 by George F. Smoot and collaborators, using data from the COBE satellite.

While COBE demonstrated that the CMB contains tiny anisotropies, it was up to its successors —NASA's Wilkinson Microwave Anisotropy Probe (WMAP) and European Space Agency's (ESA's) Planck satellites—to measure them in greater detail. These extremely precise maps of the CMB enabled astrophysicists to delve into the history of the Universe, constraining its geometry and the properties of its constituents.

Together with other observations, these data led to the “standard model” for cosmology: a spatially flat Universe dominated not only by dark matter, but also by the mysterious dark energy responsible for accelerating the present expansion of the cosmos. The data also allowed investigations of the very beginning of the cosmos, an extremely brief phase of accelerated expansion known as inflation, when the Universe was only a tiny fraction of a second old.

And there is more since the CMB conceals additional information about inflation and the origin of the Universe “hidden” in the polarisation of the ancient cosmic light. While scientists have been seeking it during the past few years with Planck and ground-based observatories, including the BICEP2 experiment at the South Pole, this primordial signal has so far remained elusive. The search is still on, and we are all looking forward to the next surprise in the future of CMB research.

MORE INFORMATION

1. In fact, the first published paper on this series is by R. A. Alpher, H. Bethe, and G. Gamow; the addition of Hans Bethe to the author list was a famous pun by Gamow, who wanted the sequence of author names to resemble the first three letters of the Greek alphabet: alpha, beta, gamma. Bethe is one of the physicists who discovered the nuclear reactions that power the stars, but he was apparently unaware that Gamow had added his name to this paper.
2. A blackbody spectrum is that emitted by an object in thermal equilibrium, spanning many wavelengths and peaking at a specific one, with a shape that is determined exclusively by the body's temperature.
3. Astronomers had postulated the existence of dark matter ever since the 1930s to explain the peculiar properties of certain galaxies and galaxy clusters.

Claudia Mignone is an astrophysicist and science writer based at ESTEC, ESA, where she has been writing about space science for the past five years. Originally from Salerno, Italy, after scrutinising the Universe's expansion during her Ph.D. studies at Ruprecht-Karls University in Heidelberg, Germany, she became a full-time communicator of the wonders of astronomy.



Boston Light at sunset. CREDIT: Jeremy D'Entremont.

What Is It About Lighthouses?

Jeremy D'Entremont, Author and Historian, USA

In early human history, darkness was very frightening. Wild animals and our enemies could kill us more easily in the darkness. We hid in our caves and waited for the light. The idea of light, or fire, cutting through the darkness is a common one in various cultures and religions. We eventually learned to light fires to illuminate our caves or campgrounds at night, but as we started venturing out on the seas in boats, the idea of being out in the darkness was scary.

The first navigators traveled mainly during the day. As mariners ventured out more at night, some learned to plot their course by the movement of the stars and constellations. But there was always the danger of running into hidden rocks, shoals, and other obstacles.

The origins of the lighthouse go back to simple bonfires built on beaches and hillsides in many cultures around the world. The Greeks built braziers filled with fire and put them on hillsides at the entrances to harbors and along navigation routes to guide mariners. The Greeks also built some of the earliest true lighthouses—basically columns surmounted by fires—at least as early as the fifth century BC.

The world's first great lighthouse, the Pharos of Alexandria, was built in the third century BC in the harbor at Alexandria, Egypt, a city that had been founded by Alexander the Great. This lighthouse was built of

giant blocks of limestone and had a furnace at the top, with the fire possibly magnified by a mirror. It stood more than 300 feet tall and is regarded as one of the seven wonders of the ancient world.

England and France were leaders in lighthouse construction for many years. Some of the world's great wave-swept lighthouses are in the British Isles, including the famous towers at Eddystone and Bell Rock. When the first lighthouse in North America was built in Boston Harbor in 1716, there were still only a handful of lighthouses in the world. Today, most of the 10,000 or so lighthouses in the world are automated; only a small percentage of them still have resident keepers.

One of the most important advancements in the history of lighthouses was the invention of the Fresnel lens in France in the early 1820s. These glass lenses were constructed of many individual prisms that bent the light coming from a light source inside the lens into a powerful horizontal beam. Fresnel lenses, often called the “jewels of the lighthouses,” were eventually used around the world. Most have been replaced by modern equipment, but many Fresnel lenses are now displayed in museums as beautiful examples of functional art.

The struggle of nature versus humans and their creations is at the heart of many of the most popular stories of lighthouses. There's of-

ten great heroism in the struggle against nature. Abbie Burgess was the daughter of the keeper at the Matinicus Rock Light Station, far offshore in Maine's Penobscot Bay, USA. In 1857, when she was 16 years old, Abbie was left in charge of the station when her father went away for supplies. Not only was she expected to keep the two lighthouses lit at night, she also had to take care of her invalid mother and two younger siblings.

A storm hit just after Abbie's father left. The island was flooded, and Abbie had to move her mother and siblings into one of the lighthouse towers to keep them safe. A series of storms and high seas prevented her father from returning for a month. Never once did the lights go out at night during that time, and Abbie kept everyone safe. She was celebrated as a national heroine. This is just one shining example of the dedication of lighthouse keepers and their families all over the world.

Even in these days of GPS and other modern technology, lighthouses still serve a vital purpose for navigation. Electronics can fail, and when that happens there's nothing better than the sight of a lighthouse to show us the way to safe harbor.

Lighthouses represent many things to many people, but they have universal qualities that make them a very special class of structure and help to explain why they're so iconic in our culture. Lighthouses were



A look inside the magnificent Fresnel lens in the Umpqua River Lighthouse, Oregon, USA.
CREDIT: Jeremy D'Entremont.

built for completely positive, altruistic reasons—to safeguard life and property. It's no accident that churches, schools, and all kinds of businesses employ their symbolism. For most people, a picture of a lighthouse conjures all kinds of good feelings. They represent all that is good in humanity.

MORE INFORMATION

Clifford, M. L., and J. C. Clifford, *Women Who Kept the Lights: An Illustrated History of Female Lighthouse Keepers*, 2nd Ed., Cypress Communications, Alexandria, Virginia (2001).

D'Entremont, J., *Lovers' Light: The History of Minot's Ledge Lighthouse*, Coastlore Media, Portsmouth, New Hampshire (2015).

D'Entremont, J., *The Lighthouse Handbook: New England*, 2nd Ed., Cider Mill Press Book Publishers, Kennebunkport, Maine (2012).

D'Entremont, J., *The Lighthouse Handbook: West Coast* (coming in 2016).

Ross Holland, Jr., F., *America's Lighthouses: An Illustrated History*, Dover Publications, Mineola, New York (1988).

Willard Compton, S. and M. J. Rhein, *The Ultimate Book of Lighthouses: History, Legend, Lore, Design, Technology, Romance*, Thunder Bay Press, San Diego, California (2000).

Jeremy D'Entremont is the author of more than a dozen books and hundreds of articles on lighthouses and other maritime subjects. He is the historian of the American Lighthouse Foundation, founder of Friends of Portsmouth Harbor Lighthouses, and webmaster of www.newenglandlighthouses.net.

What Would Charlie Do?

Sona Hosseini, Jet Propulsion Laboratory,
California Institute of Technology, USA

For many, Dr. Charlie Townes is a renowned scholar and for me, well, it is different.

A day after returning from the IYL 2015 Opening Ceremony trip, I open my laptop to send an email to Charlie, but I see another email that he has passed away! I am shocked, confused, and upset. Thoughts are running through my head: “but we were supposed to meet soon; but I had gifts for him from UNESCO; I can’t imagine what Frances is going through now.” He was looking forward to turning 100, and for some reason everyone, including me, believed he would. I cannot stop my tears. The last four years flashed in my memory; there are too many

emotions and thoughts going on in my head for me to decipher at the moment.

I remember one cold October day at Lick Observatory. Kostas Chloros, the telescope operations manager at the time, and I were going through the potential locations for my instrument. Kostas pointed to a storage space called the Laser Pool in the basement of the 3-Meter Shane telescope coude focus. It was used to develop instruments in old days. History has always been interesting for me, and so we went to check it out. It was dark and dirty, filled with lots of boxes and old tools. We crawled in a midst of spider webs and turned on the

dusty lights, only one working. All at once we were in a passage into an unknown history and future. It was accessible with pool ladders, and its walls were covered in dirty greasy pool tiles, something to do with the laser lunar experiment that once took place there. There were some black felts covering one side of the area, indicating that someone had tried to make a darkroom there, and there was a mysterious milling table without the top sitting in middle of the space on a concrete floor. We decided to repurpose the storage area for my instrument, and little did I know at the time, but my instrument in the Laser Pool would become my entire world for the next four years, and that my



Charlie and Frances Townes meet me for the first time in his office at 557 Birge Hall on Tuesday, May 13th, 2014 at 11:00 am. CREDIT: Sona Hosseini.

life path would cross the work of giants in astronomical instrumentation.

The first time I heard Dr. Townes' name, it was a couple of weeks since I had started working at the Laser Pool. I was adjusting the alignment of my optical elements, when Steve Vogt stopped by, looked inside the basement, and said with curiosity, "so someone is using this place?" Then he said, "the last time I saw someone using this place, it was about 30 years ago by Charlie Townes' group. I used to come here and see him working." Based

on the Lick Observatory's logbooks,¹ Dr. Townes was the last observer to use the Laser Pool with his instrument from May to October, 1981. Since then the Laser Pool was used as storage until I cleaned it up and started using it in December 2010 for building Khayyam. My conversation with Steve about Charlie and his work at the Laser Pool completely changed my feeling about the Laser Pool as well as my level of responsibility in using the Laser Pool for my project. It made a huge difference to know that it was Charlie's group that had used the old black felts that I replaced; I was working and designing my instrument in the very same location as Charlie but three decades later!

Working at Lick Observatory gave me an incredible opportunity to learn about world famous scientists who have built instruments there. Among all, Charlie Townes became a prominent figure in the development of my dissertation project long before we met in person. In every successful or frustrating event, hopeful moments and hopeless tears, I would remember him and ask myself, "What would Charlie



Charlie and Frances Townes and me at their apartment in Oakland, California on November 20, 2014. I showed him the final draft of my Ph.D. dissertation. We were supposed to meet again after my return from the IYL 2015 Opening Ceremony at UNESCO HQ in Paris, but unfortunately this visit was the last time I saw them before Charlie passed away on January 27, 2015. CREDIT: Sona Hosseini.

have done if he was here instead of me?" ... I must have asked that question more than a million times. I would sit inside the Laser Pool, walk around and pretend to think like him, finding the right questions to ask, figuring out how to know what I do not know, and learning how to learn. I remember one of those nights I got the courage to send him a short email, basically saying "Hello! I am Sona, and I'm working in your old lab!" He replied to me within two days, and we met for the first time in person a week later in his UC Berkeley office lab with along with his wife, Frances, and Walt Fitelson.

It was an amazing experience. He asked about my project and what I was doing at Lick, and I told him everything! All of the stories about how I always dreamed of designing and building my own astronomical instrument and doing science with it. I very much enjoyed our conversation and the questions he asked about my instrument. It was amazing to see that he instantly noticed the difference between the spatial heterodyne spectroscopy (SHS) technique and the other interferometers, and then cut straight to the chase of its setup

criteria and practical applications. I absolutely loved it! He started telling me some of his stories and about the people he worked with at the Laser Pool. It was exciting to exchange similar stories from Lick and the Laser Pool from different decades! He told me about how Ali Javan became his student and some of the projects on which they worked together. He told me his opinion about instrumentation projects nowadays and expressed his concerns about the lack of young people getting their hands dirty in the field. "They lack vision," he said about those who only build instruments on computers. I was ecstatic to see how happy he was to see me being engaged in all aspects of instrumentation, from mechanical and optical design to data reduction and scientific observation. When I told him "this is the first time we meet, but not the first time I speak to you," he chuckled and said, "You'll be just fine young lady."

I was fortunate to see Charlie and Frances again and have more discussions later. We maintained the friendship, and I kept them updated about the progress of my work. Last time I visited them, they invited

me to their apartment, and I handed him the draft of my dissertation. Charlie recalled the Laser Pool; there were a few minutes of pause and silence when he was skimming through my draft. I was looking at him and thinking of all the memories that may be passing through his mind from Lick, the Laser Pool, his projects, and his friends and colleagues. He kindly made few comments on my pictures and signed my cover page as a gift; the best graduation gift! I told them about the International Year of Light 2015, all the activities and the opening ceremony at the UNESCO HQ in Paris in January, and we talked about catching up afterwards.

Unfortunately, the news of Charlie passing away came exactly the day that I intended to write back to him to set a time to meet. I was back from the IYL 2015 Opening Ceremony and was so excited to tell them about the event and give them my gifts. It is hard to describe, but simultaneously as I was reading the news of him passing away, my Pandora radio station played the music that reminded me of Charlie when I was working at Lick ("Dietro Casa" by Ludovico Einaudi), as if the world also wanted to present an elegant ceremonial way to honor him and his part in my career.

Dr. Townes had an unforgettable and great role in my Ph.D. process. From the very beginning, I felt his presence in the Laser Pool and in my project. His scientific work on the laser lunar experiment, microwave spectroscopy, and the optical and infrared maser and laser devices had changed the pathway of science and technology, but just like other great achievers in the world, his true contribution was in the lives of all



Best graduation gift ever: Dr. Townes' memorable autograph on my dissertation cover page November 20, 2014. CREDIT: Sona Hosseini.

the people he touched who came after him.

My story about Charlie illustrates many things: the inspiration he gave to students and scientists who have never met him; the tradition of people designing, building, and operating their own instruments; his accessibility and support to students like me, even when he was not able to give any scientific assistance; and, moreover, the role that facilities like Lick played in his and others' work. Although I never worked with Charlie in the lab, for what he achieved at the Laser Pool, the same underground basement I spent nearly four years of my life, he became one of my greatest mentors. Every time I was ready to give up, I asked myself again, "What would Charlie do?" I reminded myself of the times he must have felt the same way in the Laser Pool, thinking he knew what to give up and what not to give up;

retelling myself that activity is not the same as achievement. My short time at Lick was truly challenging on professional and personal levels, and I cannot imagine what Charlie must have gone through during those years, living and working on site and in the end being so successful. I learned from him that whenever I want to achieve something, I have to concentrate and make sure I know exactly what it is I want, and then work on the simplest setup version that gives me what I want. What I learned from Charlie did not come in great books; it came in the form of turning a dream into a vision and perseverance.

Charlie has always been present and will always remain present for me for the rest of my career.

MORE INFORMATION

1. Private conversations with Kostas Chloros, Keith Baker, Tony Misch, Walt Fitelson, Ed Wishnow, and Remington P.S. Stone.

Sona Hosseini fell in love with astronomy during her first-grade elementary school trip to NASA Space Center Houston, when astronomy became the center of her personal and professional activities. Ever since, she has worked with some of the world's best scientific leaders and has led many instrumentation projects for astrophysics and planetary studies, culminating in joining Jet Propulsion Lab in July 2015.



CREDIT: IYL 2015/Light Beyond the Bulb.
<http://lightexhibit.org/photoindex.html>.



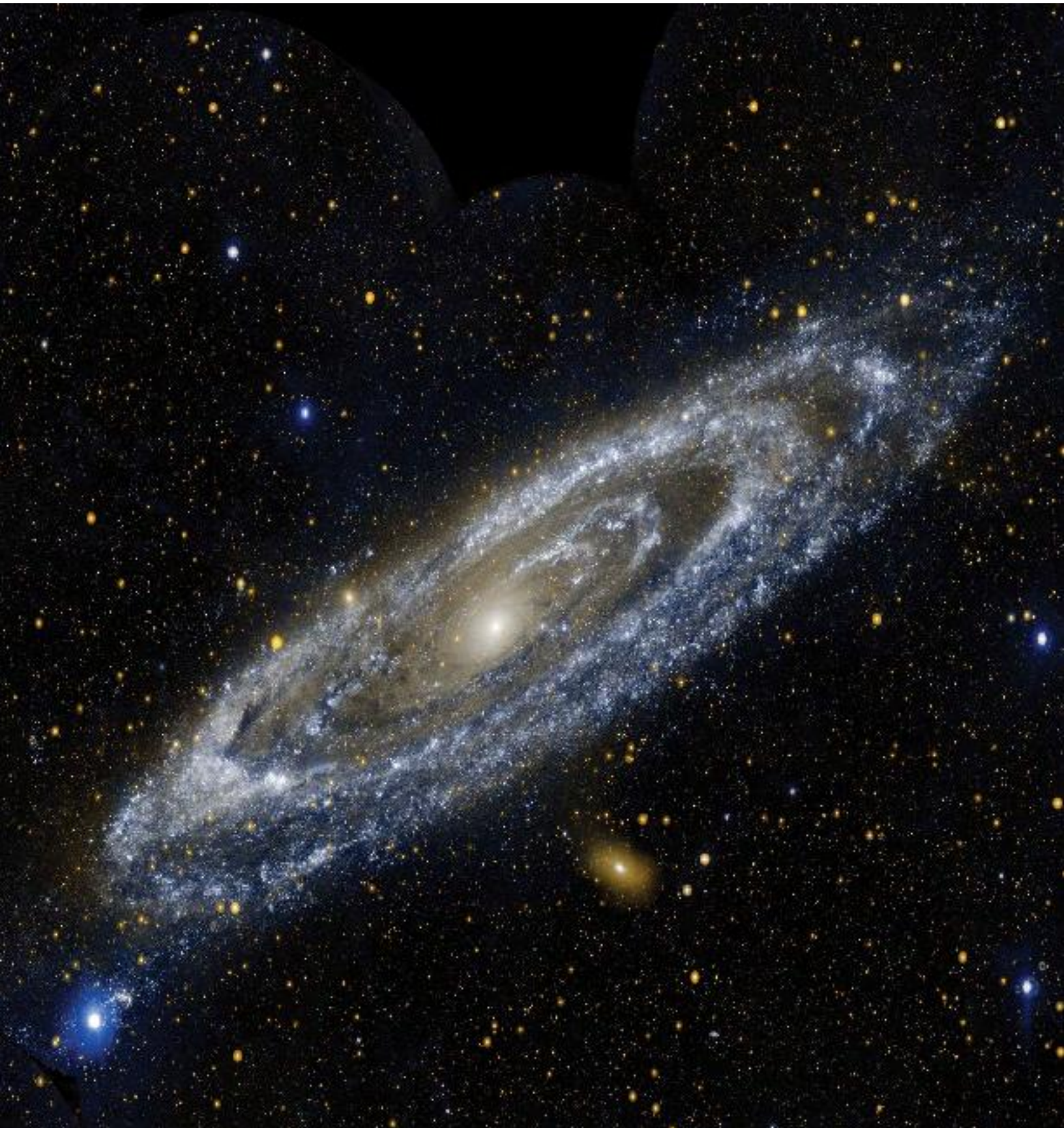


A photographer captures the Milky Way over the town of Aulon, Pic du Midi International Dark Sky Reserve, France.
CREDIT: Nicolas Bourgeois/Pic du Midi/Université de Pau et des Pays de l'Adour.



3

Science and Technology



The Andromeda Galaxy. CREDIT: NASA/JPL-Caltech.

Astronomers Travel in Time and Space with Light

John C. Mather, NASA Goddard Space Flight Center, USA

As an astronomer, I use light to travel through the universe and to look back in time to when the universe was young. So do you! All of us see things as they were when the light was emitted, not as they are now. The farthest thing you can easily see without a telescope is the Andromeda Nebula, which is a galaxy like the Milky Way, about 2.5 million light years away. You see it as it was 2.5 million years ago, and we really don't know what it looks like today; the disk will have rotated a bit, new stars will have been born, there could have been all kinds of exploding stars, and the black hole in the middle could be lighting up.

People may be skeptical of the Big Bang theory, even though we have a TV show named for it, but we (I should say Penzias and Wilson) measured its heat radiation 51 years ago at Bell Telephone Labs in New Jersey. Their discovery marks the beginning of the era of cosmology as a measurement science rather than speculation. Penzias and Wilson received the Nobel Prize in 1978 for their finding, which had been predicted in 1948 by Alpher and Herman. By the way, heat radiation is just another form of light—we call it radiation because we can't see it, but it's exactly the same phenomenon as electromagnetic waves, and the only difference is the wavelength. In the old days of analog



The Arecibo Radio Telescope at Arecibo, Puerto Rico. CREDIT: H. Schweiker/WIYN and NOAO/AURA/NSF.

television, if you tuned your TV in between channels, about 1% of the "snow" that you could see came from the Big Bang.

So when we look at the heat radiation of the early universe, we really are gazing right at what seems to us a cosmic fireball, which surrounds us completely. It's a bit of an illusion; if you can imagine what astronomers in other galaxies would see, they would also feel surrounded by the fireball, and they would also think they were in the middle. So from a mathematical version of imagination, we conclude that there is no observable center and no edge of our universe, and that the heat of the fireball fills the entire universe uniformly.

Astronomers are also using light to find out whether we are alone in the universe. The Kepler observatory showed that thousands of stars blink a little when their orbit-

ing planets pass between us and them, and other observatories use light to measure the wobble of stars as their planets pull on them. Eventually, we will find out whether planets like Earth have atmospheres like Earth's too—with water, carbon dioxide, oxygen, methane, and other gases that would be evidence of photosynthetic life. I think in a few decades we will have evidence that some planets do have life, and we will find this evidence using light for remote chemical analysis.

Also, astronomers at the SETI project are using light (long-wavelength light we can pick up with radio telescopes) to look for signals from intelligent civilizations. That's a harder project because we don't know what to look for. But if we wanted to send signals all the way across the Milky Way, we could do it with laser beams, and if somebody over there knew what to look for, he or she could decode the message. On with the search!

John C. Mather is a Senior Astrophysicist and is the Senior Project Scientist for the James Webb Space Telescope at NASA's Goddard Space Flight Center in Greenbelt, Maryland, USA. His research centers on infrared astronomy and cosmology. Dr. Mather is the recipient of numerous awards, including the Nobel Prize in Physics (2006) with George Smoot, for the COBE work, and the NASA Distinguished Service Medal (2007).

Astronomy and the Origin of Cinema

Jorge Rivero González, European Physical Society, France

As far back as I remember, I was always fascinated by both astronomy and cinema. As a kid, I was mesmerized by the stars shining both on the sky and on the screen of my neighborhood's cinema. Memories from movies like the Star Wars trilogy or from observing the Perseid meteor shower left a huge impact on me.

Now that I am older, I don't go outside to admire the stars so often, and my neighborhood's cinema no longer exists, but my love for astronomy and cinema didn't fade away. I still feel quite excited when I see the latest outstanding snapshot of the oldest light in the Universe by ESA's Planck satellite or when I see how Wes Anderson uses symmetry on his movies, to name a few examples. It's no wonder then that at some point in my life I wanted to become either a cinema director or an astrophysicist. I went for the latter.

I understand the astrophysicist profession as a craft aimed to decipher cosmic light, showing the true nature of the observable Universe, and that its final aim should be taking this knowledge to everyone. Cinema can also show us the true nature of life, but it is just an illusion. An illusion, at 24 frames per second, which fools our eyes into sensing motion when light is projected onto a big screen.

13th February 2015 marks an important date for the history of cinema:



Transit of Venus in 2004. The photograph was taken from Israel. CREDIT: Wikimedia Commons.

it's the 120th anniversary of the patent of the cinematograph by the Lumière brothers, who are considered the founding fathers of cinema for creating this primitive motion projector. But, did you know that many historians consider the invention of a French astronomer, Jules Janssen, crucial for the development of motion pictures?

Pierre Jules César Janssen (1824–1907) is considered a pioneer among the solar physicists. He is best known for the first detection of helium on the solar atmosphere. He was also an avid inventor, and one of his inventions, the so-called 'photographic revolver' is considered by historians a turning point in pre-cinema history and the history of photography. The creation of this device was aimed to address one of the scientific challenges of the 19th Century: to precisely determine the mean distance between the Earth and the Sun, the so-called astronomical

unit,¹ taking advantage of the transit of the planet Venus in front of the Sun on 9 December 1874.

The famous astronomer Edmond Halley proposed this method back in 1716. Depending on where you are located on Earth, Venus' apparent position against the background solar disk changes. You just need two simultaneous measures from two places with different latitudes and to measure the duration of the transit. This is

known as solar parallax. It seems easy, but actually there are two major problems. First, Venus transits are rare events; there have been only seven in the last five centuries! And second, it is also quite complicated to determine the exact moment the planet begins and ends its transit across the solar disk. In addition, it's not a trivial matter for different observers to agree when this happens, or to agree on the appearance of the so-called "black-drop effect," which is an optical effect that distorts the planet's black silhouette during the moments it comes into contact with the solar disk.

To overcome the latter problem, the astronomers planning the observation of the Venus transit in 1874 defined different strategies such as using observers especially trained for the event together with a standard set of telescopes in different expeditions around the world. Janssen's approach was different; he



The cinématographe Lumière at Institut Lumière, Lyon, France. CREDIT: Wikimedia Commons.

developed a technique to register the transit on a series of images at short, regular, and adjustable intervals during the periods surrounding the contacts.

For that purpose he designed a device that could be attached to a telescope and would record one image per second on a rotating disk, which could register 48 images in 72 seconds. The disk would turn by means of a system driven by a clockwork mechanism. A rotating disk shutter with adjustable slit width would allow the exposure time to be adjusted. His invention was called the 'photographic revolver' because its design resembled the one for the Colt revolver. By 6 July 1874, the instrument was completed and tested on a practice model made for training the observers from the transit.

On 9 December 1874, Janssen's expedition to Japan to observe the Venus

transit took 47 images using his invention. Other expeditions, made by British astronomers, around the world took similar devices to record the transit as well. Unfortunately, even though the results were an improvement over the measurements made on the last Venus transit in 1769, the observations made using this technique were not as precise as expected and were quite similar to other measures using the naked eye and the projection of the Sun on screen.

During the following year, Janssen kept developing his invention and then presented the photographic revolver to the Société Française de Photographie (French Photograph Society) in 1875. His work later inspired other famous figures in the history of cinema such as Étienne Jules Marey or the Lumière brothers, who, eventually, with the invention of their cinematograph, achieved the illusion of motion, the illusion of cinema. This illusion is ad-

mired by many people around the world and shows that among the many other important developments in our society produced by science, one of these is a new type of art.

1. The Astronomical Unit (au) is defined as the mean distance between the Earth and the Sun. The au equals 149,597,870,700 m according to its definition adopted by the XXVIIIth General Assembly of the International Astronomical Union (IAU 2012 Resolution B2).

MORE INFORMATION

F. Launay and P. Hingley, "Jules Janssen's 'Revolver Photographique' and its British derivative, 'The Janssen Slide,'" *Journal for the History of Astronomy* **36**, 57–79 (2005).

Jorge Rivero González is a science communicator working at the European Physical Society (EPS) as the EPS IYL 2015 Outreach Officer and the editor of the IYL 2015 blog. Since 2009 he has been a member of the GalileoMobile project, a science education programme that brings astronomy closer to young people around the world.



CREDIT: George Morgan.

Changing Lives with Light

Thanh-Nga Trinh Tran, Vietnam Vascular Anomalies Center, Vietnam

It's hard to imagine, but pulses of light can have a huge impact on the quality of life. Since the development of laser technologies, where light is used to heat a specific tissue and selectively destroy it, light has been used to treat millions of children affected by disfiguring birthmarks such as congenital nevi (abnormal collection of pigmented cells) and port-wine stains (abnormal collection of blood vessels). The reason that light is so effective is that it can destroy only the cells or tissues that are targeted, while leaving the other healthy cells and tissues alone. These treatments are safe, effective, and, in the correct hands, have no permanent side effects. Before selective laser treatment, surgery, or radiation therapy started being used in Vietnam and other parts of Southeast Asia, children were subjected to an outdated and dangerous treatment—radioactive phosphorus. In this treatment, a radioactive paste is applied to hemangiomas, which are a common skin

growth in baby girls. This paste causes permanent scars, loss of skin pigment, destruction of hair and other normal skin structures, and a lifelong increase in the risk of skin cancers. Motivated by the desire to stop this dangerous practice and improve the lives of children, a group of Vietnamese and U.S. physicians (namely, Dr. Hoang Minh of the University of Medicine and Pharmacy of Ho Chi Minh City, Dr. Rox Anderson, Dr. Martin Mihm, and Dr. Thanh-Nga Tran of Harvard Medical School, Dr. J. Stuart Nelson of the University of California, Irvine, and Dr. Thuy Phung of Texas Children's Hospital) came together in 2009 to create the Vietnam Vascular Anomalies Center (Vietnam VAC), a non-profit organization dedicated to the use of light technologies to treat children with disfiguring birthmarks. Our goal was to create a permanent local clinic with modern laser and medical therapies, and to train physicians in Vietnam in the principles of safe and effective laser practices.

The center had its humble beginnings in a small room at Nguyen Tri Phuong Hospital with no air conditioning and only one piece of equipment—the Candela Vbeam Perfecta, a pulsed dye laser made specifically for vascular lesions, generously donated by the Syneron-Candela Corporation. On the first day of its operation, the clinic was flooded with over 500 patients from all over southern Vietnam who filled the hallway and courtyard of the hospital, awaiting treatment. We quickly realized that Vietnamese children needed better treatment not only for vascular birthmarks, but also for other kinds of life-altering skin lesions such as malformations of veins or lymph vessels, and pigmentation problems such as nevus of Ota and congenital nevi. Syneron-Candela Corporation donated two more lasers (alexandrite lasers, which target melanin, the primary pigment in hair and skin) capable of helping these children. Often, multiple lasers are required to treat complicated lesions such as congenital nevi, which contain deep, abnormal pigment cells and hair follicles. We were fortunate enough to enlist the support of other companies including Lumenis, Lutronic, and Cutera Corporations for additional lasers with different capabilities. For example, the Lumenis UltraPulse fractional CO₂ laser is capable of normalizing scars, which are common in Vietnam after burns or trauma. The scar treatment is specifically needed because there are many open fires in Vietnam with families living in close quarters, leaving children susceptible to scalding and burns. In addition, there is still a pervasive and horrifying practice of throwing acid onto the faces of jilted lovers or enemies. There are many patients with frozen joints and contracted scars, severely limiting movements. We embraced the opportunity to help children by using lasers and modern medicine, regardless of the specific cause of their life-altering skin problem. In this way, the Vietnam Vascular Anomalies Center began to grow.

To prevent further damage to children by the continued use of radioactive phosphorus, we initiated a public health education campaign consisting of television documentaries and articles in scientific publications and influential local newspapers explaining the danger of this practice as well as alternative treatment options. In 2013, we were successful in convincing the Cancer Hospital in Ho Chi Minh City to abolish this dangerous practice and adopt modern treatment options. It was a proud moment for Vietnam VAC, which moved from its humble beginnings to having a seat at the University of Medicine and Pharmacy of Ho Chi Minh City as an official center headed by Dr. Hoang Van Minh. A new office and operating room at Branch No. 3 of the Hospital of the University of Medicine and Pharmacy now houses the Vietnam VAC.

The problem of how to help children with severe scarring and depigmentation from radioactive phosphorus treatment remains. Dr. Rox Anderson, whose research introduced many modern laser technologies into medicine, together with Momelan Corporation (now KCI) created a new technology called fractional epidermal blister grafting, which is able to transfer normal epidermis to replace the mutated epidermis from radioactive phosphorus treatments. Small suction blisters are harvested from normal skin and then grafted onto the diseased skin after removal of its abnormal epidermis. We have successfully used this technology combined with laser treatment to mitigate the effects of scarring and depigmentation on these unfortunate children. The results suggest that epidermal blister grafting may be applicable to other people with radiation damage, such as after treatment for breast cancer. This is an unexpected benefit from our work in Vietnam—by solving a problem unique to children in Southeast Asia, we have a new strategy to help others with radiation injury to the skin.

In March 2015, Vietnam VAC celebrated six years of operation with a continuing medical education (CME) course and training session in Vietnam, culminating in a conference of over 500 physicians from all over Vietnam as well as the United States. This is a remarkable achievement for the Vietnamese team, led by Dr. Minh, who works tirelessly to make the center the largest and only VAC in Vietnam whose mission is compassionate clinical care, education, and research. With the leadership of Dr. Thuy Phung, a skin pathologist from Texas Children's Hospital, Vietnam VAC has been improving the state of dermatopathology in Ho Chi Minh City, which started with only one doctor and an old microscope, and was using candle wax for embedding. We provided training for physicians in the United States, obtained donated equipment, and held courses in dermatology, laser medicine, and pathology. For hemangiomas, safe laser and/or beta blocker drug treatment has replaced radioactive phosphorus treatment. Dr. Phung, who studies the mechanisms of hemangioma growth and treatments, teaches in both Vietnam and the United States. Vietnam VAC also invited pediatric dermatologists and introduced alternative treatments for hemangiomas to the pediatricians at large in Ho Chi Minh City. Over the past six years, through partnership with laser companies and the generous support of many friends, donors, and colleagues, the center has treated over 2,000 children on a free, safe, and effective basis.

So how does light change lives? In our case, it's by alleviating the not-knowing and not-having through education, compassionate care, and humanitarian medical collaboration. We need no more validation than to hear a mother thanking us for having this clinic in Ho



CREDIT: George Morgan.

Chi Minh City because her daughter was about to have her arm amputated, and now has a normal arm after laser treatment. Instead of being ostracized or isolated from society due to major disfigurement, children and their families have a much more normal life. We hope to continue to expand our outreach to other parts of Vietnam, including Can Tho and Da Nang, so we can reach even more disadvantaged children. The Vietnam VAC could be, and should be, a model for starting similar centers in other countries.

Light provides the energy for life on earth and for powerful treatments. Just as one photon has a negligible impact, while many photons can improve a child's life, it takes many people working together to create and maintain the Vietnam VAC. Please read more about us at www.vietnamvac.org and keep abreast of what we do. We are grateful to be part of the International Year of Light and Light-based Technologies 2015 and its mission to improve lives around the world.

Thanh-Nga Trinh Tran is cofounder of the Vietnam Vascular Anomalies Center, a nonprofit humanitarian organization dedicated to the care of underserved children with vascular anomalies, pigmented birthmarks, scars, and wounds. Through her work, Dr. Trinh Tran has helped improve both education and patient outcomes for many children in developing countries.

Chasing Cosmic Light

John Barentine, International Dark-Sky Association, USA

Much of our world is now awash in artificial light at night, the result of more than a century of electrification. This light has enabled all manner of nighttime human activity from transportation to commerce, but it now presents a significant challenge to industrialized nations and emerging economies. Artificial light at night has been known to cause negative effects on humans and animals, and light wasted from overabundant and inefficient sources is a problem in terms of both energy security and climate change.

During the International Year of Light 2015 we are reminded by the Cosmic Light theme that a natural form of light has fundamentally shaped the human experience throughout the history of our species: the light of distant stars and galaxies. Starry nights have inspired great works of art, literature, and music, as well as centuries of scientific discovery. Every fascinating fact we know about astronomy was ultimately found as a result of humans looking skyward at night, asking “How?” and “Why?”

Technology and industry provide societies with the means to roll back the influence of night and extend human activities well into the overnight hours, but this ability has come at great cost. In many cities, light pollution now effectively masks cosmic light, putting it outside the experience of billions of people who know little or nothing of the stars in their own skies. It threatens to sever our most immediate connection to the vast cosmos beyond our planet.

The mission of my organization, the International Dark Sky Association (IDA), is to preserve and protect the nighttime environment and our heritage of dark skies through environmentally responsible outdoor lighting. IDA has worked since 1988 to achieve our mission by raising awareness of the negative effects of light pollution among voters, consumers, property owners, and elected officials around the world. We also work with the global lighting industry to advocate for better design of outdoor light fixtures. IDA is committed to the notion that outdoor lighting, economic development, and dark night skies can successfully co-exist.

I manage an IDA program called International Dark Sky Places that recognizes the efforts of communities, parks, and reserves around the world in preserving and protecting dark locations for the benefit of future generations. The underlying philosophy of the program is that, while humanity has certainly benefitted from the application of artificial light, it also needs places of respite where people can experience the qualities of the natural night. Many certified Dark Sky Places feature new outdoor lighting technologies that visitors can experience in the hope that they will take these ideas back to the cities and towns in which they live.

The Dark Sky Places have developed a reputation among discerning travelers as destinations for high-quality tourism. A growing number of “astrotourists” trek across the globe in



The Milky Way over Ancestral Puebloan ruins at Hovenweep International Dark Sky Park, Utah, USA. CREDIT: Jacob Frank/National Park Service.

search of authentic dark-skies experiences, producing a measurable economic impact in nearby communities. For example, a 2011 study of Galloway Forest International Dark Sky Park in Scotland found that every £1 spent on the development of the Dark Sky Park yielded £1.93 of activity in the local economy. Anecdotal reports from other Dark Sky Parks also note significant increases in visitation attributed to their IDA designations.

In the 1994 La Laguna Declaration, UNESCO asserted, “Future generations have the right to an uncontaminated and undamaged Earth, including pure skies.” Furthermore, the Declaration insists that they are entitled to such skies “as the ground of human history, of culture, and of social bonds that make each generation and individual a member of one human family.” We believe similarly that the natural night should be accessible to all, for every one of us shares just one night sky. We invite everyone to visit a Dark Sky Place, marvel at the unspoiled night skies that still exist, and contemplate ways to bring the experience of cosmic light back into our own lives.

John Barentine holds a Ph.D. in astronomy, is the Program Manager at IDA, and has contributed to science in fields ranging from solar physics to galaxy evolution; in fact, the asteroid (14505) Barentine is named in his honor. Throughout his career, he has been involved in education and outreach efforts to help increase the public understanding of science.

Citizens Measure Air Pollution with Their Smartphones

Elise Hendriks, iSPEX-EU project, Leiden Observatory, Leiden University, The Netherlands

Many people carry it every day—a smartphone. Have you ever thought it could be used as a scientific tool to help scientists know more about air pollution?

iSPEX is an innovative way to measure tiny particles in the atmosphere, or atmospheric aerosols. These particles can be of natural origin, such as sea salt or tiny ash particles from forest fires or volcanic eruptions, or human made, such as soot particles produced by traffic and industry. All of these particles contribute to air pollution, and their

impact on our environment and health is as-yet poorly understood. Atmospheric aerosols form one of the largest uncertainties in our current estimates of climate change. They can cause heart and respiratory disease, and in the shape of volcanic ash are a danger to air traffic.

To assess their role and consequential effects, aerosols need to be measured with high spatio-temporal resolution. Present ground-based aerosol monitoring networks are limited in spatial coverage. Satellite-based aerosol monitoring is, despite its global coverage, limited



iSPEX app. CREDIT: iSPEX.

in spatial and temporal resolution—with global coverage up to once a day with a ground resolution of only a few kilometers—and lacks sufficient information on aerosol particle characteristics. Therefore, a different strategy is needed to overcome these current limitations.

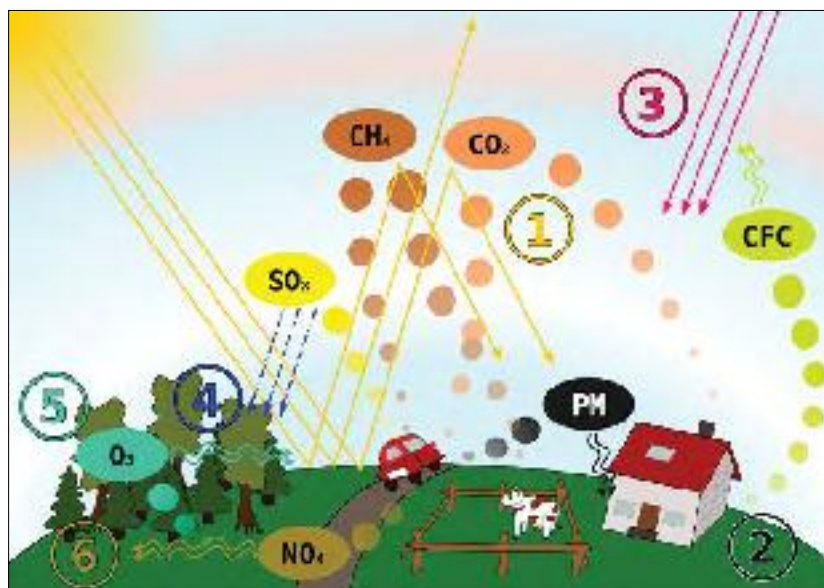
Astronomy brought down to Earth

The idea is simple. Click an add-on onto your phone in front of its main camera, and it turns your phone into an optical sensor. The iSPEX add-on is a “spectropolarimeter” that, in combination with the phone’s camera, sensors, and computing and communications capabilities, can be used to measure atmospheric aerosols.

iSPEX is developed building upon the measurement principles of its big brother, the Spectropolarimeter for Planetary Exploration, or simply, SPEX, a highly sophisticated instrument built for observation of other planets and their atmospheres. In comparison to SPEX, of which only a few exist in the world, iSPEX is simple and designed to be available



Dutch iSPEX team performing measurements. CREDIT: iSPEX.



Schematic drawings of the causes and effects of air pollution: (1) greenhouse effect, (2) particulate contamination, (3) increased UV radiation, (4) acid rain, (5) increased ground-level ozone concentration, and (6) increased levels of nitrogen oxides. CREDIT: Wikimedia Commons.

and used by thousands of people, and it is primarily meant for measurement of aerosols in our Earth's atmosphere.

How it works

In order to measure atmospheric aerosols with your phone, you will need the iSPEX add-on and the iSPEX app. The app instructs participants to scan the cloud-free sky while the phone's built-in camera takes pictures through the add-on. Each picture taken through the iSPEX add-on contains information on both the spectrum and the linear polarization of the sunlight that is scattered by the combination of molecules and aerosols in the atmosphere. The greater the quantity of aerosols present the less blue and polarized the sky is.

The data collected with iSPEX—spectrum and polarization as a function of scattering angle from the sun—provide unique information about the aerosol properties, including the amount of aerosol, the particle size distribution, and the chemical composition. This type of information is crucial in assessing the impacts of atmospheric

aerosols on the environment and health. After each measurement, the app displays the preliminary result, a qualitative color code of the sky condition on a live map, both in the app and on the project website. The data is then processed and further analysed by the iSPEX team to obtain maps of iSPEX-based aerosol information.

Citizen science with iSPEX

In principle, iSPEX allows anyone who is suited with the appropriate smartphone to be able to measure atmospheric aerosols at any location around the world at any daytime hour. Although a single iSPEX measurement may not be as accurate, a collection of many iSPEX measurements can provide information of scientific value—with the appropriate accuracy. As such, iSPEX can yield more information on atmospheric aerosols than is currently available. It is these features that make iSPEX not only a fun way for anyone to learn the science of atmospheric aerosols and their impacts on our daily lives, but also a way to make a valuable contribution to ongoing research on aerosols at the same time. This we call citizen science!

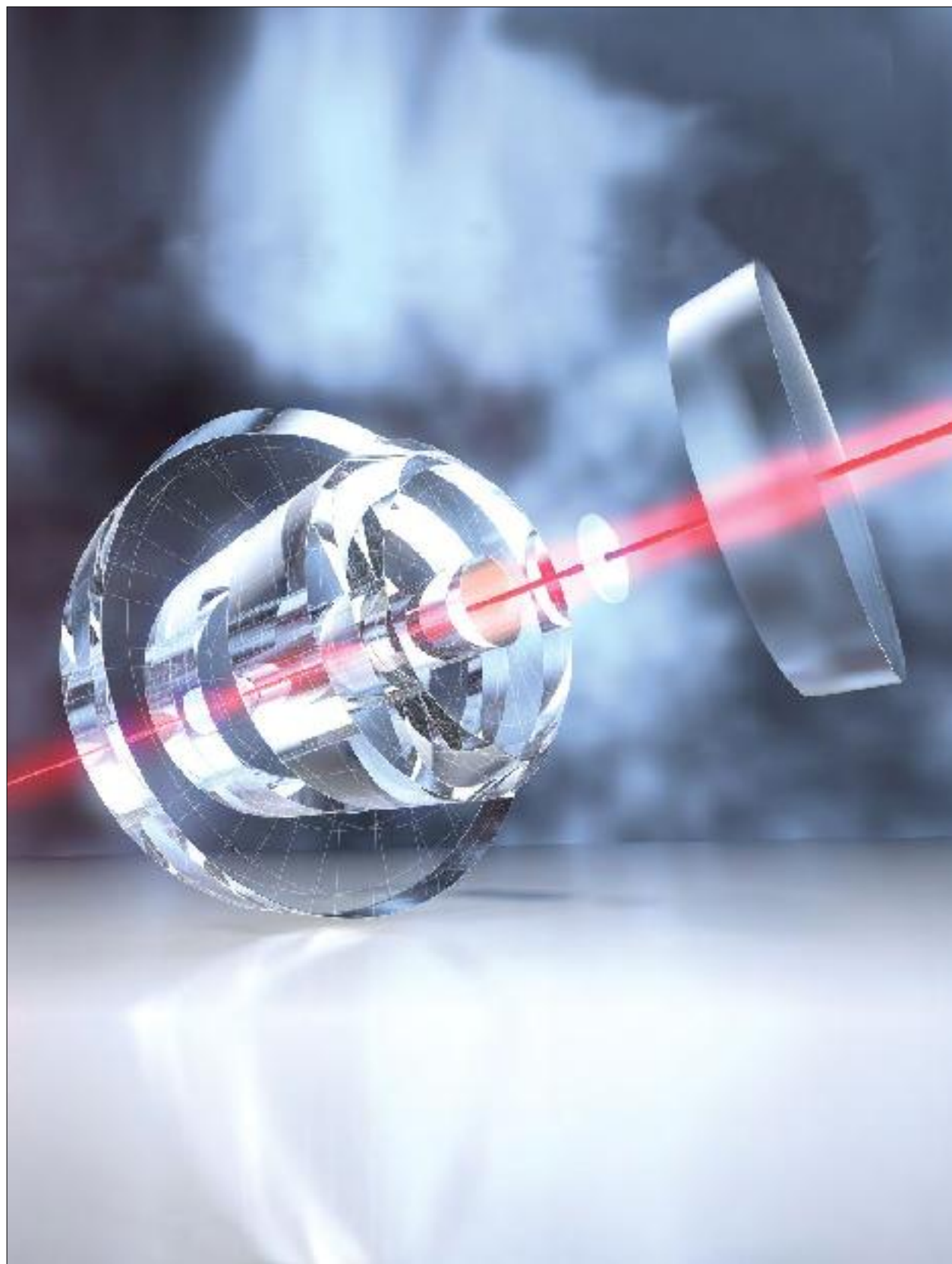
After an initial citizen campaign in the Netherlands in 2013, with thousands of participants and promising scientific results,^{1,2} we organised the first Europe-wide campaign: iSPEX-EU. From 1 September to 15 October 2015, thousands of citizens in ten European cities took to their streets, squares, and parks to measure air pollution with their smartphones. Participating cities included Athens, Barcelona, Belgrade, Berlin, Copenhagen, London, Manchester, Milan, Rome, and Toulouse.

iSPEX-EU was organised as part of the EU-funded project LIGHT2015 and is one of the many activities running during the International Year of Light and Light-based Technologies 2015.

MORE INFORMATION

1. F. Snik, J. H. H. Rietjens, A. Apituley, H. Volten, B. Mijling, A. Di Noia, S. Heikamp, R. C. Heinsbroek, O. P. Hasekamp, J. M. Smit, J. Vonk, D. M. Stam, G. van Harten, J. de Boer, and C. U. Keller, "Mapping atmospheric aerosols with a citizen science network of smartphone spectropolarimeters," *Geophysical Research Letters* **41**(20), 7351–7358 (2014).
2. A. M. Land-Zandstra, J. L. A. Devilee, F. Snik, F. Buureijer, and J. M. van den Broek, "Citizen science on a smartphone: Participants' motivations and learning," *Public Understanding of Science* [published online before print September 7, 2015, doi: 10.1177/0963662515602406 (2015)].

Elise Hendriks leads the present iSPEX-EU project and is based at Leiden Observatory, part of Leiden University in the Netherlands. She holds a Master's degree in physics, obtained at Utrecht University in 2001, and has a background in remote sensing of cold environments and applied research on air quality.



Artist's rendition of an optical cavity employing crystalline supermirrors. CREDIT: Brad Baxley, Part to Whole, Boulder, Colorado, USA.

Crystalline Supermirrors— From Concept to Reality

Garrett Cole, Crystalline Mirror Solutions GmbH, Austria

Here I provide a brief overview of how two scientists from the University of Vienna stumbled upon an enabling technology born from “blue sky” research in the burgeoning field of quantum optomechanics and made a successful transition from academia to industry. The fruit of this endeavor is Crystalline Mirror Solutions, or CMS, a high-tech startup commercializing high-performance optics for laser-based precision measurement and manufacturing systems. Although it was not apparent at the outset, there were ultimately two key elements that led to the success of this endeavor. The first was of course the conception of the basic technology itself, while the second relied on effective “local” infrastructure and funding organizations to ultimately bring this idea out of the laboratory and to the commercial market.

In the first instance, a novel idea was generated from the fusion of two seemingly disparate fields, namely, expertise in fundamental quantum optics, as contributed by Prof. Markus Aspelmeyer, and expertise in materials science and semiconductor microfabrication brought by myself, Dr. Garrett Cole. This unique example of technical cross-fertilization was facilitated by a Marie Curie International Incoming Fellowship (IIF) that brought me to Austria from California in the fall of 2008. The aim of this grant was to apply my engineering background

to ongoing cavity optomechanics experiments in Vienna in order to develop quantum-enabled devices. The combination of these divergent disciplines—specifically, that of basic research aiming to push the limits of scientific knowledge with the more practical engineering side exploiting advanced microfabrication techniques to turn these basic concepts into reality—helped to sow the initial seeds for success. Realizing a technical breakthrough is one thing, but executing on it is admittedly the more difficult aspect, and this is where the second key element comes in to play. Fortunately, Markus and I were able to draw from the fertile grounds of Europe’s quantum optics hub in Vienna for both Austrian and EU funding in order to transform our idea from an initial concept into physical reality in the form of engineering prototypes. As detailed in this write-up, working with these agencies, we received additional assistance in setting up the legal and financial framework of our company, as well as in securing protection for the intellectual property produced along the way.

In order to provide the requisite technical background for our innovation, we have to go back a few years, actually more than one hundred.... Linear optical cavities, most notably the namesake interferometer demonstrated by Charles Fabry and Alfred Pérot, have been key optical elements for both applied and

fundamental scientific applications since their initial demonstration in 1897. The design of such a system is deceptively simple: light is passed through a pair of parallel high-reflectivity mirrors, and interference between the multitude of reflections between the mirrors generates well-defined fringes or optical resonances emerging from the device, from which spectral properties of light can be deduced and accurate measurement of space—and in combination with other elements, time—can be realized.

Building upon more than a century of progress, state-of-the-art Fabry–Pérot cavities have reached a point where their ultimate performance is limited by fundamental thermo-mechanical fluctuations, or Brownian motion, of the components of the cavities themselves. Recently, these unavoidable fluctuations have materialized as a barrier to ever more precise measurements of time and space, such as those obtained using advanced optical atomic clocks and interferometric gravitational wave detectors. As a consequence of this limitation, researchers in the optical precision measurement community have been searching for more than a decade now for a means to minimize the adverse effects of this so-called “thermal noise.” A breakthrough in this area requires the development of mirrors, or, more specifically, mirror materials, that also exhibit high mechanical quali-

ty. The latter point may not be obvious at first glance, but based on statistical mechanics, most notably the fluctuation dissipation theorem, one finds that enhanced stability, realized through a reduction in the Brownian noise, is obtained by minimizing the intrinsic mechanical damping of the mirrors. Working in the field of cavity optomechanics at the Vienna Center for Quantum Science and Technology, we happened upon such a solution.

In this case, Markus and I were investigating the potential for observing macroscopic quantum phenomena in high-performance microfabricated resonators. By a fortuitous coincidence, our optomechanical systems had technical requirements similar to those of ultra-stable optical cavities, namely, the simultaneous need for high optical and mechanical quality factors. Unbeknownst to us (at least initially), in pursuing the development of ever better micro-resonators, we had stumbled upon a mirror technology that promised to solve the long-standing thermal noise issue in Fabry–Pérot cavities. Stemming from this finding, initial discussions with researchers from the precision measurement community motivated us to pursue the potential for applying our low-loss mirrors to “macroscopic” (centimeter-scale) systems, rather than the micromechanical devices we were focused on in Vienna.

Ultimately, the proprietary manufacturing process that is now the heart of CMS built upon all of my prior experience, combining aspects of semiconductor mirrors borrowed from surface-emitting lasers, an epitaxial layer transfer technique gleaned from advanced nanofabrication processes, along with my more recent work in Vienna, which had yielded an extensive knowl-

edge of mechanical dissipation processes. After more than two years of development, these areas were combined to create our novel “crystalline coating” technology. Ultimately, this coating process involves separating and then directly bonding (using no adhesives or intermediate films) high-quality single-crystal semiconductor heterostructures onto curved optical substrates. With this process we circumvent two previous impediments to applying high-quality monocrystalline structures in general optics applications, including the difficulty of direct crystal growth on a curved optical surface, and the fact that the typical glass optical substrates, with their amorphous structure, lack the order required for seeded crystal growth. Compared with existing optical coating technology, our crystalline coatings yield an immediate tenfold reduction in mechanical loss, with a further order of magnitude improvement possible at cryogenic temperatures. Thus, coating Brownian noise levels can be reduced by up to a factor of ten with our mirrors, leading to significant performance enhancements in precision optical interferometers requiring the ultimate levels of stability.

With the technical foundation in place, the more difficult aspect was in bringing this unique mirror technology “out of the laboratory and into the light,” as we have previously described it. As luck would have it, our external collaborators encouraged us by demanding the product before it even existed. This greatly simplified our decision as to whether or not we should pursue commercialization of this technology, as we already had an immediate customer base knocking on our door. During this transition, the University of Vienna was instrumental in establishing the relevant support contacts outside of our scientific network.

After an initial consultation with INITS (a Viennese business incubator of the Vienna Business Agency, the University of Vienna, and the Vienna University of Technology), Markus and I received financing from both the AWS-operated JITU pre-seed program of the BMWFJ and the newly established Proof of Concept initiative of the European Research Council. One critical aspect at this early stage was the fact that the financial support offered by AWS and the ERC made prototype development possible. These initial prototypes resulted in our first technical demonstrator, entitled, “Tenfold reduction of Brownian noise in high-reflectivity optical coatings,” which was published in the August 2013 issue of *Nature Photonics*, covering research pursued in collaboration with the University of Vienna and our collaborators from JILA in Boulder, Colorado. Once the technology was proven, we were overwhelmed by the interest in our coatings from the precision measurement community. At this point it was clear that the only way to effectively fulfill the demand was by formally spinning off the technology and forming a start-up company, leading to the founding of CMS GmbH.

CMS is fortunate in that we had an immediate customer base and, coupled with the excellent funding opportunities for high-tech startups in Europe, we could pursue prototype development and even initial sales without the need for outside private investment. The process of growing a company is not without its headaches; there are of course growing pains and dead ends from a business and technical perspective, and there were times (and continue to be instances) where we have to risk our own personal finances, as meager as they may be, to bridge small gaps in funding. One key piece of

advice for those considering taking on such a risky endeavor is to build up and rely upon a trusted network of contacts to assist with issues that will inevitably be out of reach to the typical knowledge base of a scientist or engineer. Seeking out expert opinions from friends, family, and colleagues for legal and financial matters, including such heady topics as corporate and patent law, accounting, etc., can be extremely helpful. In this area we have been fortunate to be able to draw from our individual networks and have even brought some friends into the fold, particularly our new CEO, Dr. Christian Pawlu.

Though we seemingly operate in a niche field, improving the sensitivity of optical precision measurement systems has a far-reaching impact, from fundamental scientific research efforts to advanced technologies including trace chemical analysis, inertial navigation, and broadband communications. As a newcomer and small player in this arena, CMS has grown to encompass nearly ten staff members covering two continents (with operations in Vienna, Austria, and Santa Barbara, California) and continues to generate not only significant business interest from both the

scientific community and industrial partners, but also high-impact publications and awards for our young enterprise. On the scientific front, CMS has teamed up with partners at the leading national metrology laboratories to build the world's most stable clocks, as well as to pursue the development of prototype gravitational wave detector optics along with members of the LIGO Scientific Collaboration. If Charles and Alfred were around to witness the technical revolutions stemming from the invention of their elegant interferometer, itself developed in the pursuit of fundamental optical and atomic physics, I think that they would be quite pleased with the progress over the last century.

In conclusion, as has been demonstrated time and time again, under the proper conditions, fundamental research will yield entirely unexpected technological innovations. In that vein, CMS now stands as another example of how the exploration of foundational questions can generate an unexpected high-tech product, standing in stark contrast to the pervasive myth that one can "force" innovation to occur through some form of regimented milestone-driven processes. Ambitious researchers, when given the

freedom to operate within their respective areas of expertise and, even more importantly, coupled with a supportive and well-financed spin-off infrastructure, can realize a successful transition to budding entrepreneurs. It has been a very rewarding, yet at times tumultuous, experience, but if given a second chance I would nonetheless pursue it again. The text above provides one admittedly unproven example and is somewhat biased as it is of course my own personal experience, but I hope that this post inspires others to consider this path. Even more importantly, I hope that this story provides policy makers with some background on the environment necessary to ensure that these ideas are spawned in the first place and, once developed, can ultimately be nurtured and guided towards success.

Garrett Cole, cofounder of Crystalline Mirror Solutions, obtained his Ph.D. in materials from University of California Santa Barbara in 2005. Leveraging his expertise in microfabrication, tunable surface-emitting lasers, and cavity optomechanics, Dr. Cole developed the proprietary substrate-transfer process at the heart of CMS and, along with Markus Aspelmeier, cofounded the venture in 2012.

Easy Path for Photonics in Agriculture

Sarun Sumriddetchkajorn, National Electronics and Computer Technology Center, Thailand

We all know that photonics is simply defined as the “science and applications of light”¹ and therefore is one of key technology enablers in many applications. In particular, photonics in agriculture is not an emerging new application, and most of the time we are not even aware of its use in this field.² For example, we have observed through our naked eyes the brightness of sunlight radiating our plants and have tried to manipulate it via low-cost nets to fit the plants’ needs. We have also estimated the greenness of rice or palm fields in order to apply the appropriate amount of fertilizer. In addition, we have used infrared radiation from incandescent light bulbs for egg incubating and hatching.

Now, with the miniaturization of electronic components and optical devices through mass production processes, several photonic modules can be implemented and can easily gain more acceptability. One simple example is in horticulture, where synthetic blue and red light from low-cost light emitting diodes (LEDs) is programmed for efficiently controlling the growth rate and color of vegetables, flowers, ornamental plants, and fruits.

Even if we look around us, the use of hand-held devices, especially smartphones and tablets, has been growing very rapidly. Not only do their processing speed and storage parts improve every six months, but

they are also equipped with at least one color image sensor. With their programmability, their functionalities can be extended for agriculture application. As mentioned earlier, rather than randomly observing the greenness of rice leaves by the naked eye and then estimating the amount of nitrogen fertilizer needed for rice fields, we can snap an image of the leaf then analyze its color by using an application program called “BaiKhaoNK.”³ Note that BaiKhao is from the Thai language and means “rice leaf.” Once the color of the rice leaf is analyzed, the amount of nitrogen fertilizer is suggested on the display.

With the same principle, we can analyze the color level of the solution as well. One application example is ClApp, which is specifically implemented for the analysis of chlorine concentration in water for baby shrimp farms.^{4,5} ClApp is designed to work in conjunction with an AppsBox and a widely used chemical indicator called o-tolidine.

Combining visible imaging and fluorescent imaging can also lead to an innovative approach to estimating fruit ripeness. Green fruits such as bananas and mangoes can be spatially analyzed and classified into immature, ripe, and overripe levels.⁶

Acknowledgements

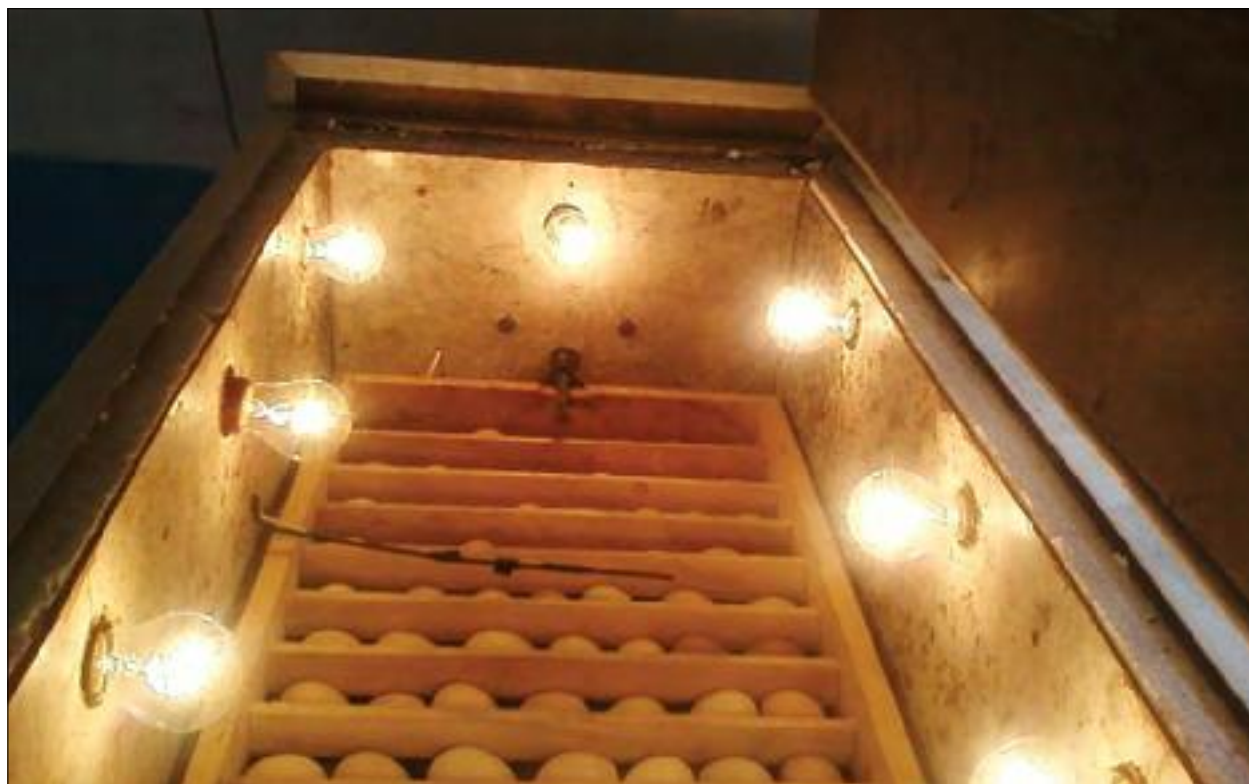
The author would like to thank all past and current members of the Photonics Technology Laboratory at

NECTEC for their work and support. All resources and support provided by NECTEC are also acknowledged.

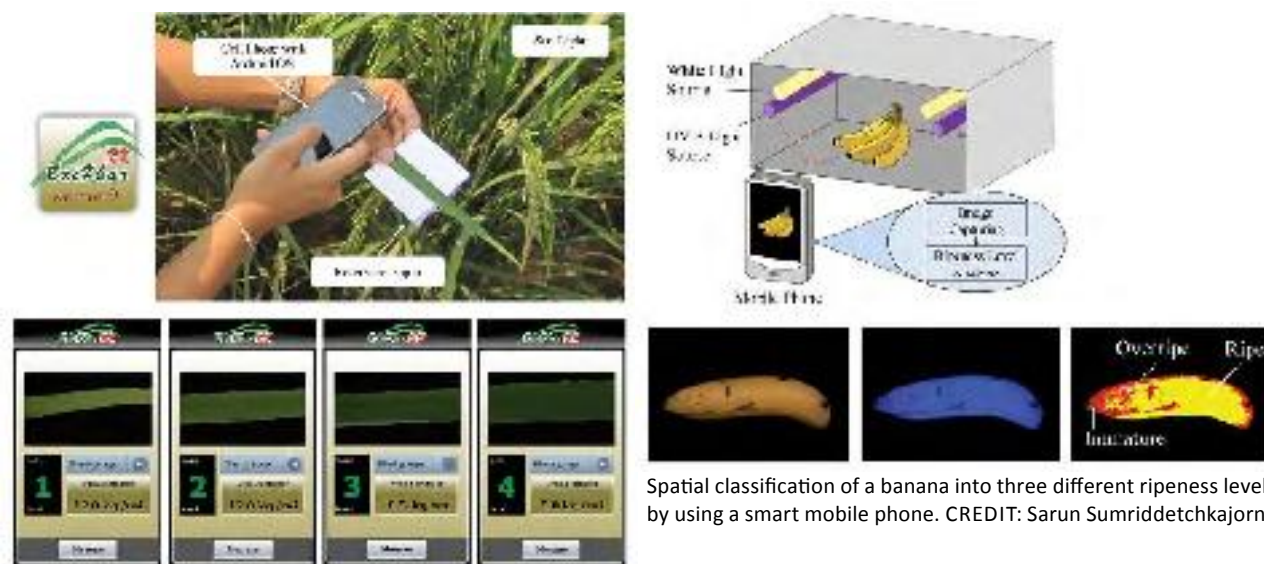
MORE INFORMATION

1. Optics and Photonics: Essential Technologies for Our Nation, National Academy Press, Washington, D.C., USA (2012).
2. S. Sumriddetchkajorn, “How optics and photonics is simply applied in agriculture,” *Proc. SPIE* **8883**, 888311 (2013).
3. Y. Intaravanne and S. Sumriddetchkajorn, “BaiKhao (rice leaf) app: A mobile device-based application in analyzing the color level of the rice leaf for nitrogen estimation,” *Proc. SPIE* **8558**, 85580F (2012).
4. S. Sumriddetchkajorn, K. Chaitavon, and Y. Intaravanne “Mobile platform-based colorimeter for monitoring chlorine concentration in water,” *Sensors and Actuators B: Chemical* **191**, 561–566 (2014).
5. S. Sumriddetchkajorn, K. Chaitavon, and Y. Intaravanne “Mobile device-based self-referencing colorimeter for monitoring chlorine concentration in water,” *Sensors and Actuators B: Chemical* **182**, 592–597 (2013).
6. Y. Intaravanne, S. Sumriddetchkajorn, and J. Nukeaw, “Cell phone-based two-dimensional spectral analysis for banana ripeness estimation,” *Sensors and Actuators B: Chemical* **168**, 390–394 (2012).

Sarun Sumriddetchkajorn received his Ph.D. in optical science and engineering in 2000 and since then has been applying his research in photonics to solve problems for the industrial, medical, environmental, and education sectors. In 2001 he joined NECTEC, where he is Director of the Intelligent Devices and Systems Research Unit.



Eggs incubated under infrared radiation from incandescent light bulbs. CREDIT: GreenChip website: <http://articles.greenchip.com.ua/3-0-23-2.html>.



Spatial classification of a banana into three different ripeness levels by using a smart mobile phone. CREDIT: Sarun Sumriddetchkajorn.

A smart mobile phone embedded with the “BaikhaonK” application program is used to analyze a rice leaf. CREDIT: Sarun Sumriddetchkajorn.

“CIApp” kit used for analyzing the chlorine concentration in water. CREDIT: Sarun Sumriddetchkajorn.





The Hubble Space Telescope in orbit around the Earth. CREDIT: NASA.

Hubble Space Telescope's 25th Anniversary

Jennifer Wiseman, NASA Goddard Space Flight Center, USA

On 24 April 2015 we celebrate the 25th anniversary of the launch of the Hubble Space Telescope. Hubble is hardly the first telescope; ever since Galileo, astronomers have used telescopes to study the sources of light from the universe, near and far. Stars, galaxies, nebulae, and planets too far away for humans to visit become accessible by studying the information contained in their radiation that travels to our telescopes. And yet after a journey of sometimes thousands or even billions of light-years, the light from these distant sources can be blurred or obscured by Earth's atmosphere before it reaches our telescopes on the ground. The Hubble Space Telescope, launched in 1990, solves this dilemma by orbiting the Earth above the atmosphere, providing crystal-clear images that have opened our eyes to a universe barely imagined before.

So what news has the light from the Cosmos brought us via the Hubble telescope? We first notice magnificent beauty. The exquisite angular resolution that Hubble can achieve allows us to see individual stars in dense clusters, revealing rich varieties of stars like gemstones: red and blue, bright and faint. Astronomers study populations of stars to determine their age, composition, and how they were formed. Stars and interstellar gas make up galaxies,

which themselves can be beautiful spiral pinwheels, rotating and sometimes even merging with one another.

Then there is the sheer magnitude of the universe. There are at least 200 billion stars in our own Milky Way galaxy alone, and hundreds of billions of other galaxies within the observable universe. Hubble's sensitive camera is allowing us to see some of the faintest, most distant galaxies ever detected. The light from these ancient objects has traveled over 13 billion years to get to us, traversing space that is itself stretching and expanding, reddening the light that we see. Light from some distant galaxies is actually magnified, and its path altered, by the gravitational effects of massive clusters of galaxies it passes along its journey to us. This "gravitational lensing" effect can distort the appearance of distant galaxies into long arcs and multiple apparitions. Astronomers measure that distortion to study the distribution of mysterious invisible "dark matter" in the foreground clusters.

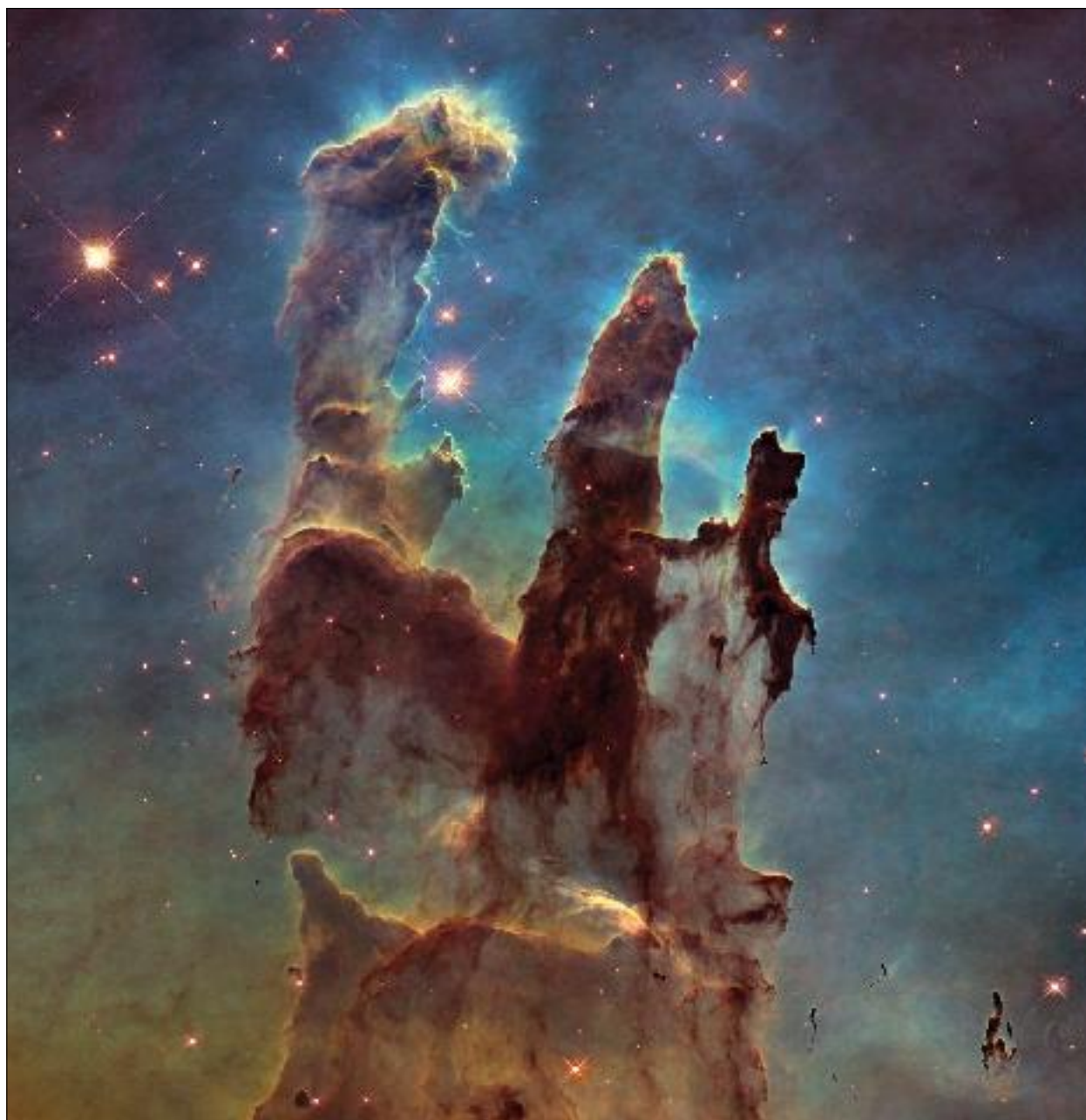
The light Hubble receives is also telling us of incredible activity in the universe. We see our own solar system buzzing with activity, such as aurorae on Uranus and Saturn, and asteroids colliding. We also see magnificent clouds of interstellar dust and gas where infant stars are

vigorously forming deep inside. Hubble's ability to detect infrared light from these warm, young stars enables us to see into these hidden nurseries. Light from more distant galaxies, as they stretch away from us with the expansion of space, is even showing us that this expansion is accelerating; some kind of "dark energy" is pushing the universe apart.

So the International Year of Light and Light-based Technologies 2015 is a perfect time to celebrate how the Hubble Space Telescope and the technology and ingenuity that brought it about are revealing a universe of remarkable magnitude, activity, and beauty. Hubble

observations continue to transform our understanding of the amazing universe in which we abide. Happy 25th Birthday, Hubble!

Jennifer Wiseman is the NASA Senior Project Scientist for the Hubble Space Telescope and a senior astrophysicist at Goddard Space Flight Center, where she studies the formation of stars using visible-light, radio, and infrared telescopes. Dr. Wiseman is interested in science public engagement and science policy, as evidenced by her previous positions as Councilor of the American Astronomical Society, program director for the American Association for the Advancement of Science, and Congressional Science Fellow for the American Physical Society.



The Eagle Nebula. CREDIT: NASA and ESA.



CREDIT: Shutterstock/Svetlana Danilova.

Lasers and Leaves

Eugene Arthurs, SPIE, USA

Looking back, my career path was not determined by some grand plan but rather by the beauty of the light from an argon ion laser in the Applied Physics Department of my university. It wasn't the science that the laser was bought for, Raman spectroscopy, or an understanding of how the laser would change the world, that drew me.

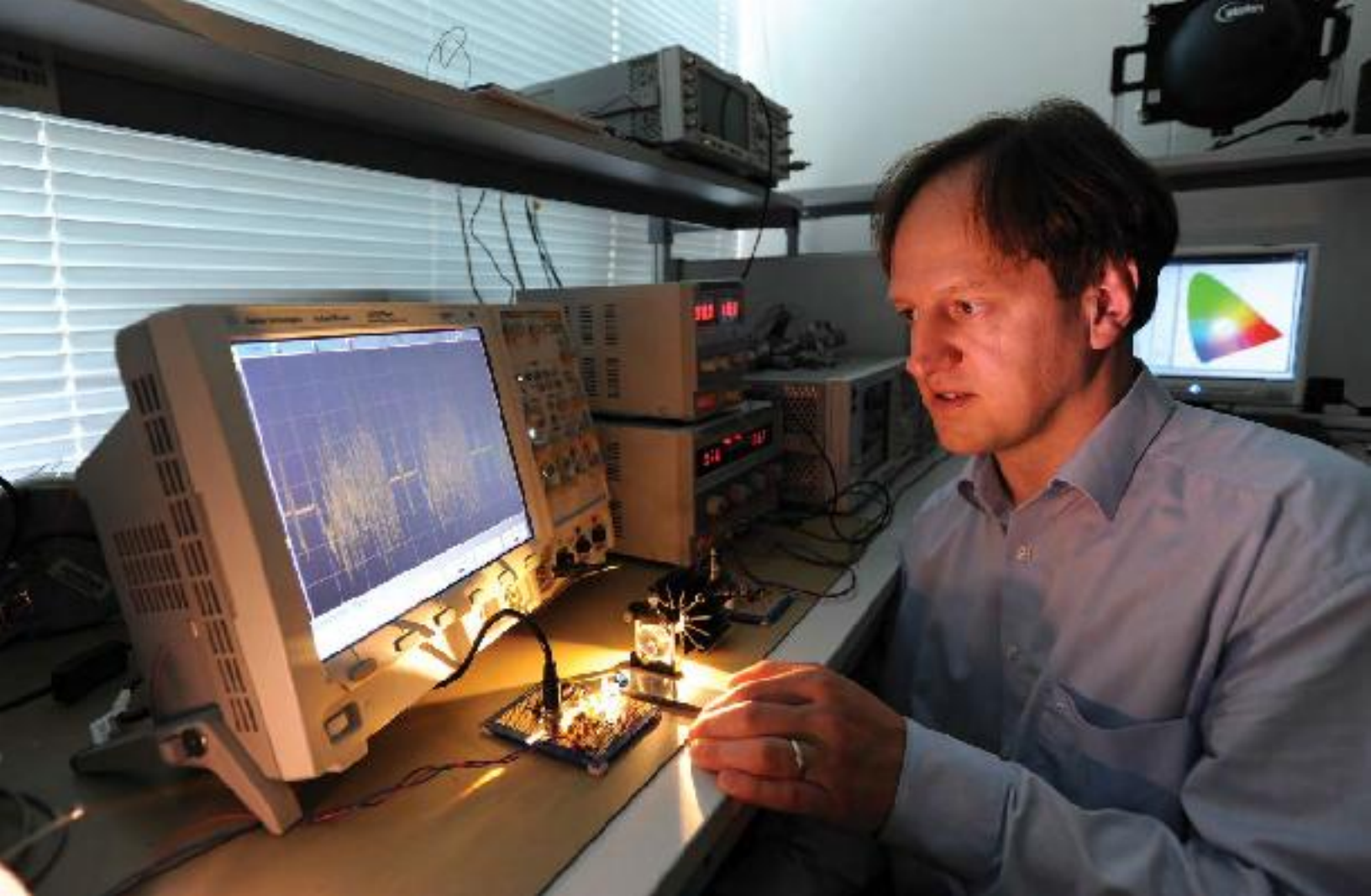
At the time I was soon to graduate with a physics degree—the first in my family history to get a science degree—and was interviewing with a local branch of IBM where my love of mathematics might give me an edge and where I might find stimulating work in Northern Ireland. But fate intervened, and I was seduced by the light, by the pure intense green beam, and lasers became my thing. Mentioning lasers also gave some sort of defense against the many enquiries from caring relatives about when was I going to get a real job.

Another indelible memory comes to mind: An important insight came to me in 1980 when I was at the home of my boss at the time, Dick Daly, founder of an early laser company. It was the fall (autumn to some) on Long Island, New York, which meant leaves everywhere. Dick pointed to one of his huge piles of leaves and said with his characteristic grin, "One of my photon stores." The concept of storing photons was of great interest to laser jocks like Dick and me. Short-pulse high-power lasers benefit greatly from materi-

als that can hold a lot of energy. But Dick's observation was way beyond the world of lasers and has caused me to think since then about the profound relationship between light and life. The chloroplasts in leaves use the photons from the sun to convert carbon dioxide into oxygen and carbon. All of our forests, our plants, have been busy "sequestering" carbon dioxide for hundreds of millennia, while tuning our atmosphere to be human friendly.

It takes the energy from many photons to grow a leaf, but at the end of the day, what a leaf is, is mostly a carbon-based organic structure built by light. This lesson from one of my many mentors led me to realize that as all fossil fuels started as vegetation, we are burning our way through earth's store of photon energy from the sun, accumulated over 300 million years or more. With many processes and great lengths of time, nature has stored this photon energy from leaves, wood, and other biomass in high-density forms such as oil and coal. The high density is key to modern transportation and collection of fuel for large centralized power plants. Now we have a formidable challenge to capture and store solar energy arriving today in ways that will challenge nature's gifts. Nature had all that time to store photons; our version of solar energy is more "real time." But the sooner that solar becomes a significant part of the global energy mix the better for our planet, for all of us.

Eugene Arthurs is the SPIE (the international society for optics and photonics) CEO. He is a member of the Photonics21 Board of Stakeholders. Prior to joining SPIE staff, Eugene held positions with scientific technology companies in both the U.S. and Europe. He serves on several boards in the realm of optics, photonics, and scientific development.



Harald Haas on the laboratory. CREDIT: Harald Haas.

Li-Fi: An Enabling Technology That Can Transform Our Lives

Harald Haas, University of Edinburgh, UK and pureLiFi Ltd., UK

Li-Fi was first introduced to the general public in a TED Talk in 2011, when I showed video streaming using off-the-shelf LED lights. This TED Talk has now been watched more than 1.6 million times, and Li-Fi has been featured by the BBC, New York Times, TIME Magazine, CNN International, ZDF and CNBC, indicating the high level of interest and potential high economic and social impact of the new, emerging Li-Fi technologies.

Li-Fi technology uses light waves instead of the current radio-frequency spectrum to communicate data. Li-Fi is a bi-directional, networked, mobile, high-speed data communication technology. It complements the existing Wi-Fi and has the additional benefits of greater capacity, security, and energy efficiency.

The visible light spectrum is huge (about 390 THz of bandwidth are available), licence-free, secure, and

safe. Devices such as LED lights and photodetectors are inexpensive and in common use, and Li-Fi technology can use existing lighting systems already in place in rooms and buildings.

How Li-Fi works

With a Li-Fi chip integrated, a LED light in a room ceiling becomes a Li-Fi access point, and in the latest developments, all Li-Fi access points together can be coordinated to form an optical attocell network.

This gives a high data density and enables an interconnected networking of the access points, giving multiuser access and handover when users move in a room or, indeed, a building.

At the Li-Fi Centre in Edinburgh, data transmission speeds of 3.5 Gbit/s at 2 m distance and real-time video streaming at 1.1 Gbit/s at 10 m distance have been demonstrated. The team has also demonstrated that it is possible to reach 100 Gbit/s when using different colour laser LEDs as illumination devices. While laser LEDs are not yet considered for the mass market lighting, they have niche applications such as in the most advanced car headlights where these devices are currently being used. Moreover, in 2014, researchers at the Li-Fi R&D Centre demonstrated the highest data rate received by an off-the-shelf solar cell of 15 Mbit/s. In the latest research in 2015, the use of single photon avalanche diodes (SPAD) in Li-Fi was first demonstrated and achieved the highest receiver sensitivities; this sensitivity will enable new applications to be developed for low-light situations, such as oil downhole monitoring.

These are new, small, low-power Li-Fi devices and offer great potential in the future.

Li-Fi is an emerging industry

Li-Fi could have a huge impact on our everyday lives, and independent market research forecasts that Li-Fi will be a \$9 billion global industry by 2018. There is a desire for new lighting services and a demand for more data, and in the future, lighting systems will provide functions and services in addition to simple room or building illumination.

Li-Fi Research and Development Centre

The Li-Fi Centre was established in 2013 at the University of Edinburgh,

and its team of researchers and development engineers will catalyse the new Li-Fi industry by making strong links with industry and businesses. The Li-Fi Centre produces Li-Fi platform technologies of up to a technology readiness level (TRL) 7. The Li-Fi Centre offers a unique systems platform to translate leading UK photonics device and communications technologies into new emerging markets. There is great potential for completely new applications including data centres, the Internet-of-Things, security and data access, health monitoring systems, smart cities and traffic management, smart homes, indoor navigation systems in large buildings, data communication in hazardous environments such as oil rigs and petrochemical plants, underwater communications, and new hybrid 5G and 6G mobile communication networks.

pureLiFi Limited

The first Li-Fi spin-out company, pureLiFi, is taking these networking and multiuser technologies to market through their Li-Flame product, which was launched in March 2015. Their earlier product, Li-1st, is a point-to-point communication system that was launched in 2013.

Applications

Li-Fi is particularly suitable for environments where Wi-Fi is unsuitable or where Wi-Fi does not provide enough capacity to meet increasing demands. New, innovative hybrid (Li-Fi/Wi-Fi) networks are now being developed, such as, for:

- settings where secure data exchange is paramount such as hospitals, company headquarters, and homeland security agencies.
- modern manufacturing plants where hundreds of tools and machines require constant and reliable connection to central servers. This 'Internet-of-Things' also has

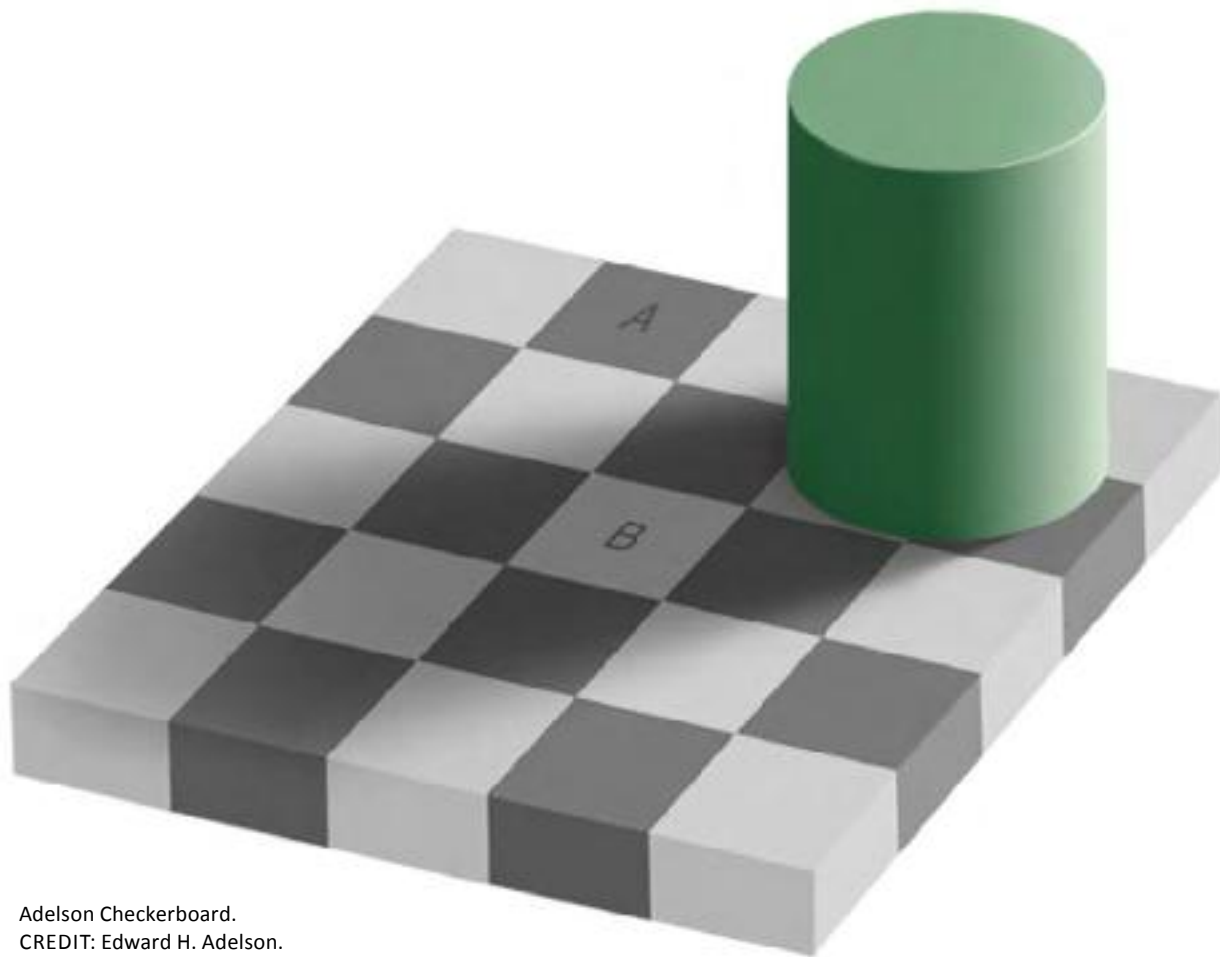
many new applications for homes and offices that will, for example, improve energy efficiency.

- intrinsically safe environments such as refineries, oil platforms, or petrol stations where electro-magnetic radiation of the antennas of radio-frequency communication systems could spark explosions.

Harald Haas is Professor and the Chair of Mobile Communications at the University of Edinburgh and is cofounder and Chief Scientific Officer of the spin-out company, pureLiFi Ltd. He pioneered the transmission technique 'spatial modulation,' which is one of the principals of Li-Fi technology, and he holds 26 patents and 20 pending patent applications.

Light and Vision: Between Object and Subject

Alessandro Farini, CNR-National Institute of Optics, Italy



Adelson Checkerboard.
CREDIT: Edward H. Adelson.

It is impossible to separate our vision from light, but the relationship between light, vision, and perception is not completely clear nowadays. We can see an object because the light hits the object, the object reflects some wavelengths, and part of the electromagnetic radiation can reach our retina, but the result is very complex, and a huge part of the process of vision happens inside our brain. Our retina is something completely different from the CCD of a photographic camera because in a certain sense the retina is a part of a brain that can pre-process the light signal.

Look for example at the famous Adelson checkboard. From a physical point of view, squares A and B have the same luminance (quantity of light that can reach the sensor of an instrument), but the brightness (perceived quantity of light) is completely different. So, light measured from an instrument and light perceived from the brain are two different things. This fact should be taken into account in many different fields: lighting design, colour rendering of smartphone monitors, colour reproduction, and so on.

Such an observation could be the introduction to a never-ending philosophical discussion: Is our reality subjective or objective? But the main theme is that it is impossible to separate reality from our perception; I'm Italian, so probably the best way to describe this link is using the words of Dante Alighieri in *Divina Commedia*: "l'uomo da sensato apprende ciò che fa poscia d'intelletto

degno," translated as "since only in perceiving through the senses can they grasp that which they then make fit for intellect." (Par. IV 41–42). This quotation recalls the scholastic philosophy "Nihil est in intellectu quod non prius fuerit in sensu" (Latin for "nothing in the intellect without first being in the senses").

Light is an important part of our perception. Changing light that hits an object can change the perceived color of the object. So if a story is about the color of an object, the subject of this story is simply something that does not exist. Our car, our t-shirt, our trousers should change color between morning and noon, from noon to afternoon, and between afternoon and indoor lighting. Luckily, we have a skill called color constancy that ensures that the perceived color of objects remains relatively constant under varying illumination conditions. So we can re-adapt our vision under different lighting scenarios.

The continuous reinterpretation of light made by our visual system is a proof that vision (or knowledge, in general) is something that involves a subject and an object. To see something, you need to look at it, but you need also to take into account your mind and your experience. You can observe the same painting after twenty years have passed, and the same light reaches your retina, but you perceive something different because everything is in context, not isolated. Due to this link, studying light and its relationship with human vision is a never-end-

ing process. The more our research advances the more the supposed arrival point becomes a new starting point for us as we study light in this International Year of Light 2015 and for posterity.

Alessandro Farini received a Ph.D. in optics from the University of Florence and is now lead researcher of the Visual Ergonomy Lab. at the CNR-National Institute of Optics in Florence, Italy, where he studies lighting and ophthalmic optics. He also has a degree in optics and optometry and teaches photophysics of vision and psychophysics at the University of Florence.

Light Enables Tomorrow's Technologies

Elizabeth Rogan, The Optical Society (OSA), USA

Living in a high-tech world, we don't always stop to think about what enables us to video chat across the globe, detect cancer, or even play an interactive video game. In all of these cases, a key enabler is photonics—applying light (photons) to advance technologies.

The Optical Society (OSA) has been a leader in the science of light for almost 100 years. As a founding partner of IYL 2015, OSA supports the IYL 2015 goal of “highlighting to the citizens of the world the importance of light and optical technologies in their lives, for their futures and for the development of society.”

OSA does its part to raise public understanding of optics and photonics through educational outreach programs, professional development opportunities, consumer education campaigns, advocacy activities, and more. From OSA's perspective, the importance of light is evident in the groundbreaking research that is published in our peer-reviewed journals and presented at our technical conferences—much of which serves as perfect examples of light as an enabling technology.

For instance:

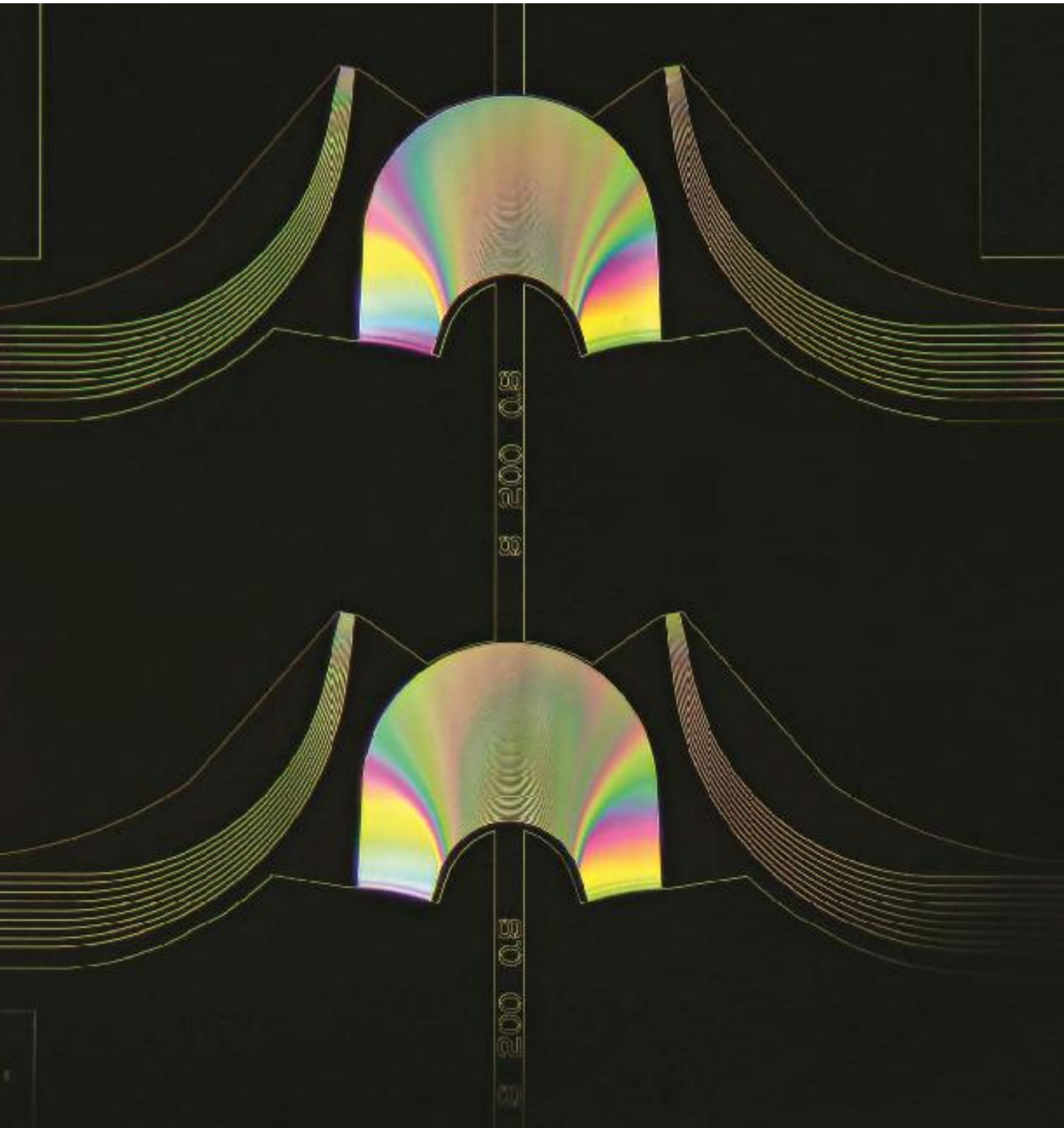
- **Smartphone apps:** Researchers used a laser to etch a waveguide directly onto a smartphone display—doing this opens the door to embedding apps such as temperature sensors and biomedical monitors into new real estate: the display glass itself.
- **Space communications:** MIT and NASA recently presented their results from the Lunar Laser Communication Demonstration, showing how they were able to transmit data, via a laser, over the 385,000 km between the moon and Earth at a record-shattering download rate of 622 megabits per second.
- **Self-driving cars:** A new LIDAR (“light radar”) system has been developed that can remotely sense objects across distances as long as 30 feet—which could one day enable your self-driving car to spot a child in the street half a block away, or let you answer your smartphone from across the room with a wave of your hand or play “virtual tennis” on your driveway.
- **Wearable tech:** Google Glass made its mass-market debut earlier this year, and researchers are working on ways to improve similar augmented reality technology by superimposing 3-D images on the display to reduce strain on the eyes. Meanwhile, a new biometric-sensing wristwatch that uses light to monitor glucose and dehydration levels is the first wearable device that can measure glucose concentration directly and noninvasively.
- **Urban lighting:** In response to ever-crowded urban conditions in developing countries, researchers in Egypt have developed an inexpensive way of re-directing natural sunlight into dimly lit streets and alleys, where lack of sun is linked to health problems.

Cases like these of how light and light-based technologies can improve our everyday lives are plentiful. OSA is excited to lend its voice and resources to showcase the role of optics and photonics in society on a global scale.

Elizabeth Rogan is the CEO of OSA, the Optical Society, a founding partner of the International Year of Light and Light-based Technologies 2015. She is responsible for the oversight, strategic direction, and fiscal soundness of OSA's programs and activities, and serves as the Society's spokesperson and advocate to a wide range of its constituencies throughout the global optics community.



An invisible waveguide (pathway for light) being written via laser into a smartphone's display glass. CREDIT: *Optics Express*.



Silicon photonic components such as this demultiplexer are enabling components for emerging data center photonics. CREDIT: National Research Council of Canada.

Light in the Cloud: Photonics Innovation for Data Centers

Claire Doggart and Dan-Xia Xu, National Research Council Canada, Canada

The widespread adoption of new cloud computing services, streamed entertainment, online gaming, and social networking means that there is more data being transferred around the world now than ever before, and the amount is always increasing. On the global information highway, data centers act as traffic controllers that receive and direct thousands of requests for information and services every second. Data centers are large banks of information storage and servers that organize and control this data. A combination of software and hardware is used to connect and direct traffic between massive populations of servers and computers around the world.

Initially, these connections were all switched electronically, through large amounts of copper wiring. However, as cloud traffic continues to grow and with it the burden on data centers, this electronic switching presents issues of speed, space constraints, and an immense use of electric power. When Internet users perform actions like search queries and streaming videos, these requests need to be properly directed, and an increase in the amount of data flow means that more controls are required to manage the information traveling through centers across the globe. To handle increasing congestion, the data centers are

under pressure to increase their data capacity while operating within the constraints of sustainable cost and available power.

To solve these problems, the industry has increasingly switched to using light rather than electronics to channel information through its data centers. With photonics, a combination of lasers, integrated photonic chips, and fiber optic cables can be used by data centers for faster communications, lower power consumption, and smaller devices that are easy to mass produce. Silicon photonics involves the use of tiny chips (the size of a speck of confetti) built onto a 'wafer' of silicon, which is a natural semiconductor. This greatly reduces the cost of manufacturing, as it erases the need to assemble many small parts by hand—including filters, optical modulators, and detectors—into the transceiver. Instead, using a process called complementary metal-oxide semiconductor (commonly referred to as CMOS) that is used to make microelectronic chips, manufacturers can print or etch thousands of photonic devices on a single chip and mass produce them on silicon wafers.

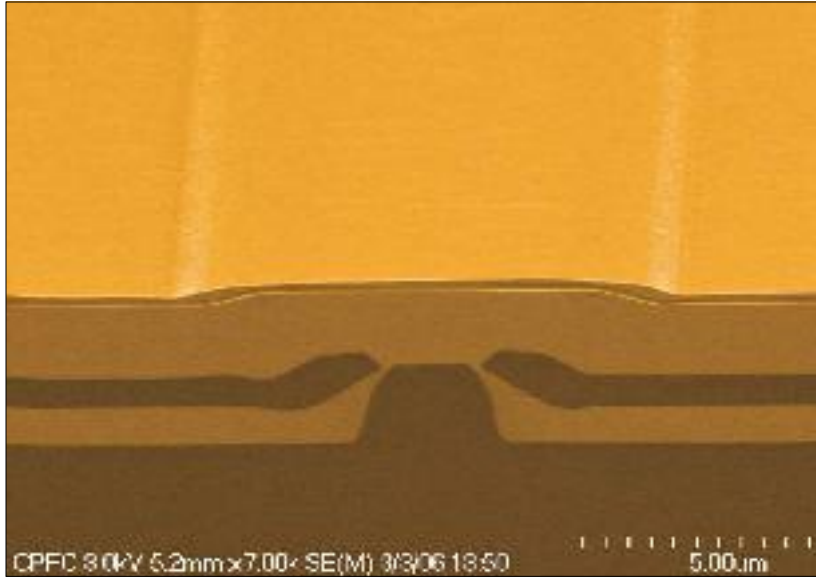
To see further improvement in speed and space usage, data centers are adopting a technology borrowed from long-distance telecommuni-

cations called wavelength division multiplexing (WDM) to carry multiple signals at various wavelengths. Because WDM transceivers allow for a combination of different data streams within the same fiber, you can carry much more information at the same time with fewer optical cables required. Although helping to alleviate pressure on data centers, these new photonic components still have a lot of room for improvement in size, performance, and even temperature control.

At the National Research Council of Canada (NRC), we and our industry partners are collaborating to create new photonic component technologies to make the data center systems run more effectively and more efficiently.

Photonics integration with advanced light sources

In employing the WDM technology, a component called a multiplexer that combines several light streams into one path is at its core. Current commercial systems often still use multiplexers in stand-alone modules. At NRC we have developed silicon photonic multiplexers that are the size of a grain of sand and provide high spectral performance and low transmission loss. Of course, these multiplexers are meant to be integrated with other components on chip. NRC has a long history of



The Canadian Photonic Fabrication Centre offers advanced semiconductor laser design and fabrication services. CREDIT: National Research Council of Canada.

expertise in the WDM technology based on several material platforms, and we have set up design capabilities that can be quickly adapted to meet client requirements. We continue to refine device designs and invent new configurations to meet the industry's emerging needs.

OAs silicon does not produce light, lasers made of III-V semiconductors are often used as light sources to integrate into the silicon photonics platform. Light on the chip eventually needs to be channeled to an optical fiber for transport across the data center. Highly efficient coupling of light between the laser or the fiber and the silicon chip is of paramount importance in reducing energy loss. To do this, we are working on making a laser that is integration ready, in that it is specifically designed and tailored for easy integration. We have also developed light couplers on silicon chips based on our own subwavelength grating (SWG) technology. These couplers enable more than 90 percent of the light to go through the coupling process, which is record-setting performance. Apart from using

single-wavelength lasers, NRC has developed quantum dot lasers that can emit several different wavelengths from a single chip. In this configuration, only a single interface is required to pass through several data streams, greatly reducing the packaging effort and cost.

For a data center and its users, this added data capacity means that there would be less lag time when accessing or uploading information. Data center operations would cost less, and there would be more room for capacity growth due to the compactness of the components.

Reducing power consumption

One of the greatest challenges for data centers to overcome is the massive power usage required to run operations. One data center can use enough electricity to power 180,000 homes.¹ Often these centers are built beside rivers to access more direct power. The construction and operation of hydropower dams significantly affects natural river systems as well as wildlife populations. Reducing the demand on power consumption represents sig-

nificant financial and environmental benefits, allowing data center operators to be better corporate citizens while cutting costs.

The servers and switches consume a lot of power to run. By making the components smaller, making each part more efficient, and using on-chip integration of multiple functions, great energy saving can be achieved. When using multiple chips is necessary, reducing the light loss at the junction and reducing the number of connections are key. These are areas NRC is already addressing.

Even with these advancements, there will still be a lot of heat generated by the processors and electronics. A significant amount of power is used to keep equipment and components at the correct temperatures to work according to their design. Although the use of photonics cuts down the amount of power used for cooling, temperature control is still needed. Almost all photonic device properties change with temperature, and these potential changes can greatly affect device performance. NRC is working on ways to reduce this dependency on thermal controls so that devices can operate over a wider temperature range and, eventually, without temperature control at all. This work involves innovation in the design of the photonic components, as well as the introduction of new materials.

To feed the growing hunger for information, data centers have been required to rapidly innovate and adopt new technologies. Although carrying data using light rather than electricity is a significant game changer, ongoing work is needed to make photonic solutions more compact, efficient, and easy to manufacture to ensure their continued penetration within the data center market. The benefits of harnessing the power of light not only further

the bottom line of the data center operators but also provide benefits both environmentally and to end users.

MORE INFORMATION

1. B. Walsh, "The surprisingly large energy footprint of the digital economy," *TIME*, 14 Aug. 2013.

Claire Daggart is an award-winning Communications Coordinator with the NRC Canada supporting research groups in construction, information and communications technologies, and measurement science and standards. She is an honours graduate of the University of Ottawa specializing in media communications.

Dan-Xia Xu is a Senior Research Officer with the NRC Canada and an adjunct professor with Carleton University in Ottawa, Ontario. She holds a Ph.D. from Sweden's Linköping University for her work on silicon-germanium heterojunction bipolar transistors and multiquantum-well tunneling diodes, and is currently focusing her research on silicon photonics for optical communications and biological sensing.



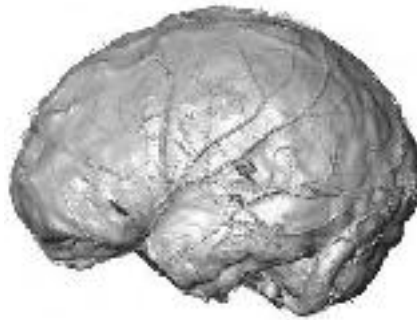
Juvenile Neanderthal mandible from Molare, Italy, with the lower-left second deciduous molar virtually extracted and dissected using x-ray microtomography. The transparency of enamel shows the dentine and the pulp chamber. CREDIT: The Abdus Salam International Centre for Theoretical Physics (ICTP) from C. Tuniz, P. Bayle, F. Bernardini, L. Bondioli, A. Coppa, D. Dreossi, R. Macchiarelli, L. Mancini, and C. Zanolli, "A new assessment of the Neanderthal child mandible from Molare, SW Italy, using x-ray microtomography," *American Journal of Physical Anthropology* **147**, Issue suppl. 54, 92 (2012).

Light on Our Origins

Claudio Tuniz, Abdus Salam International Centre for Theoretical Physics (ICTP), Italy

At the end of *On the Origin of Species*, Charles Darwin wrote: “Light will be thrown on the origin of man and his history.” This is the only reference to our origins in the 502 pages of the 1859 edition of his book. The father of biological evolution was convinced that the world was not ready to receive the news of our kinship with apes and other animals. More than 30 years later, the German physicist Wilhelm Röntgen produced a new electromagnetic radiation in a wavelength range known as x rays, an achievement that earned him the first Nobel Prize in Physics in 1901. Immediately, some scientists realized that this new “light” could be used to fulfill Darwin’s prophecy.

One of these scientists was the Croatian paleoanthropologist Dragutin Gorjanović-Kramberger, who used x rays to radiograph the remains of the Neanderthals discovered in 1899 in the Krapina cave. Today, new x-ray sources, such as synchrotron accelerators, are illuminating the remains of Neanderthals and other extinct hominids. Novel microscopes provide 3D images for the inner structure of their teeth, skull, and many other bones, revealing all of their biological secrets. The microarchitecture of their teeth preserves a detailed record on the



Reconstruction of a *Homo sapiens* brain based on x-ray microtomography of a skull from the Museum of Natural History, Trieste, Italy. CREDIT: ICTP.

hominid life history, including the length of his childhood, which is critical for the evolution of cognitive capabilities. One can also virtually reconstruct the brains of different hominids from the x-ray images of the skull’s inner surface, tracing the evolutionary process that led to the development of the modern human mind.

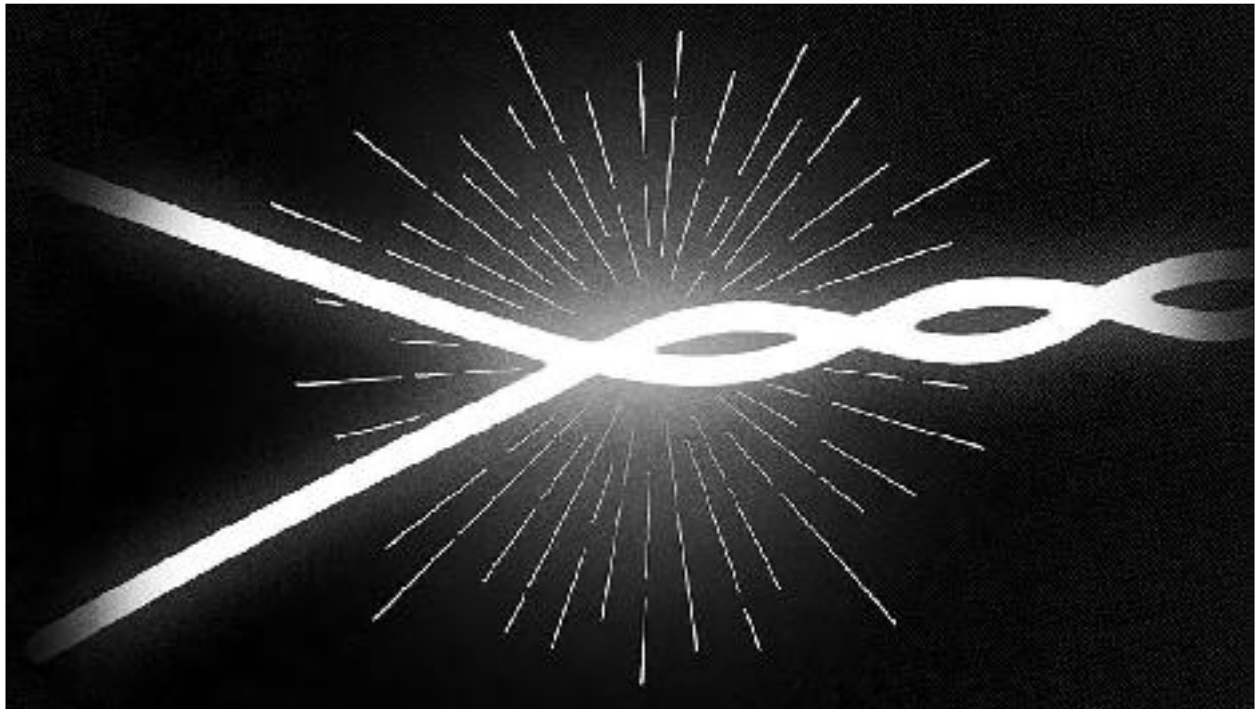
We hope to understand why we became the ‘Masters of the Planet’ while other human species, like the Neanderthals and the Denisovans, who had lived for millennia side by side with our direct ancestor, *H. sapiens*—sometimes with intimate encounters—became extinct. Probably, the secret lies in our capacity to become a social organism, thanks to the size and the peculiar structure of our brain cortex.

To shed light on our origins we need all kinds of “lights:” x rays to read bones, skulls, and teeth; laser-based dating techniques to synchronize archaeology, climate change, and genetic clocks; and radar and other electromagnetic waves to find more fossil and archaeological evidence from the past.

Claudio Tuniz is a scientist with the Abdus Salam International Centre for Theoretical Physics in Trieste, Italy and associate scientist with the Enrico Fermi Centre in Rome, Italy.

Light-Speed Computing

Ben Skuse, Research Media, Ltd., UK



Representation of laser-light soliton interactions for potential optical computer applications of the future.
CREDIT: Research Media Ltd.

Computer science's self-fulfilling prophesy, Moore's law, has provided a focus and motivation for researchers to innovate for the past 45 years¹ of uninterrupted exponential inflation in performance. Moore's law predicts that the number of transistors on a chip will double roughly every two years. Intel's chips are a great example of this law in action: from the company's first effort in 1971, the 4004, containing 2,300 transistors to their ubiquitous 10 million transistor Pentium models of the 1990s to their latest innovative processors like the 2012 Core™, packing in a staggering 1.4 billion transistors.

However, with manufacturing processes closing in on the atomic level, experts are beginning to raise concerns that computers are reaching their fundamental limit of miniaturisation. For instance, electronic barriers in chips that were once thick enough to block current are already now so thin that electrons can penetrate them—a phenomenon known as quantum tunnelling. As a result, many researchers are going back to basics, looking at the primary factors that fundamentally affect performance.

Two clear frontrunners have emerged as the next step in computer evolution: quantum computing and optical

computing. The former's unprecedented parallelism offers millions of times more power than today's most advanced supercomputers. In a quantum computer, qubits replace bits as the computer's alphabet, and atoms, ions, photons, or electrons and their respective control devices work together to perform memory and processing tasks. However, despite significant progress towards true quantum computing, numerous hurdles remain, and reaching the full potential of quantum machines is still a distant prospect.

Bending light

Optical computers, on the other hand, are a far less bizarre proposi-

tion. In their most simple form, electronic hardware is simply replaced by photonic equivalents: wires carrying current are traded for optical waveguides, and electrons are substituted by photons in transistors. This 'simple' change has the potential to make optical computers roughly 10 times faster than their electronic equivalents.

Decades of work has been conducted in this area. For my part, during my Ph.D. studies at the University of Edinburgh under the tutelage of Prof. Noel Smyth, I worked on the mathematical modelling of special optical waves in liquid crystals. These waves, named nematicons, could one day form the basis of future devices in optical computers; we concentrated on beam steering for all-optical logic operations. Our models aimed to approximate experiments conducted by a team led by Prof. Gaetano Assanto at the University of Rome 'Roma Tre' in Italy—a group still making fascinating discoveries in this area.

But despite fantastic progress, huge challenges remain in creating optical components that can compete with electronic devices. Often, optical

materials such as liquid crystals fail in one or more of the key properties, like cost, speed, size, energy, etc., needed to outdo silicon electronics.

New directions

Although dauntingly high, these barriers to optical computing are far from insurmountable, and there are plenty of reasons to be optimistic that optics may offer an alternative to the evermore difficult challenge of keeping pace with Moore's law. For instance, the field of materials science has been blooming in recent years. With the design and manipulation of materials at the nanoscale opening doors to unique and unsurpassed properties, the perfect material for optical logic may be just round the corner. And looking to revolutionise not only components but computer design itself, the UK company Optalsys recently launched a proof-of-concept massively parallel optical processor capable of performing mathematical functions and operations. The team behind the technology predicts it will provide a step change in computing for the big data and computational fluid dynamics applications of the future.

MORE INFORMATION

1. Gordon E. Moore, Intel cofounder, described this trend for the first time in 1965 in his publication "Cramming more components onto integrated circuits," *Electronics*, 114–117, 19 April 1965. The term "Moore's law" was coined around 1970 by the Caltech professor Carver Mead in reference to the statement by Moore.

Ben Skuse is a Senior Editor for Research Media Ltd., where he produces the Technology series of the flagship publication *International Innovation* and manages a tight-knit editorial team. Despite his Ph.D. in allied mathematics, early on, he began freelance writing about science instead of doing research, and he undertook an M.Sc. in science communication, after which he continued freelance writing for Research Media until 2012, when he rose to his current position.

LightAide: Inspired Design Opens Minds

Catherine Rose, Philips Lighting, USA

Seeing two children working together at school might not seem extraordinary. But in a U.S. school recently, something truly remarkable was happening. Two children with different special needs were engaging in social play together. A student with learning disabilities used the LightAide device to read the sight words, while a student with a vision impairment helped by pressing a switch to change the words. Misty Brown, their teacher, found that both students were attentive and engaged like never before. After finishing, the students requested to work together again in the future, showing that LightAide can bring students of different abilities together.

Through a WonderBaby.org contest, five other schools were able to educate and engage children with light using LightAide. Ralph Pfluger Elementary School (Buda, Texas) Life Skills teacher, Jessica Ovalle, utilized LightAide to help younger children practice cause and effect. With other children, she incorporated textured posters and scented markers to supplement LightAide's preprogrammed activities. University of Alabama in Huntsville (UAH) Rise School used LightAide in their integrated preschool program consisting of children both with and without special needs. Using LightAide during the circle time routine, children worked on social interaction and weather identification; they responded to the activities more



Timmy engaging with the LightAide eye-tracking activity. CREDIT: Jennifer Esty.

independently and worked well with their peers. Loge Elementary School in Boonville, Indiana created a seven-day lesson plan using the LightAide rainbow activity, highlighting a color each day.

The winning classroom at Ox Ridge Elementary in Connecticut worked with students to interact on a level playing field, giving children with vision impairments or cerebral palsy the opportunity to learn together. Betsy Caridi, teacher of the visually impaired, commented about the impact of LightAide in the classroom, "Another important objective is to help the typically developing peers understand and accept a student's unique skills and contributions as a second grade learner!" As part of the contest, the staff integrated LightAide into their lessons and

shared a LightAide lesson plan at the end of the contest. Ox Ridge Elementary gathered the most "likes" on their lesson plan, winning the LightAide.

LightAide engages children with 66 different preprogrammed activities, incorporating adapted switches. Children can explore turn taking, letter recognition, counting, colors, and more. The brightly colored LEDs are exciting and motivating to children who might not have usual vision or brain development. Each of the preprogrammed activities is described in the detailed Activity Workbook, helping teachers and parents engage with their children. The activities vary from simple to more complex, allowing children to progress through the activities. LightAide was designed to be portable and



Jessica using LightAide to match uppercase letters. CREDIT: Jennifer Esty.

light weight. Since it's based on LED technology, the product stays cool, so it encourages children to explore tactilely without danger. LightAide is currently used around the globe for kids with cortical visual impairment (CVI), CHARGE syndrome, cerebral palsy, autism, and ADHD.

Development of LightAide was possible through combining the teacher insights from Perkins School for the Blind with technical expertise within Philips Color Kinetics. Over the 2 years of development, 3 different prototypes of LightAide were tested by more than 20 teachers and parents. As teachers and parents used LightAide, they requested new activities to be created. Every activity was reviewed for link to early childhood curriculum, assuring applicability and importance of the learning objectives. It is no surprise that LightAide has great impact on the

learning of children; it was designed with the child at the center.

It was actually the special needs of a child—my own daughter, Alexis—that inspired LightAide. As a small child with vision and hearing impairments, she was attracted to lights and enjoyed her toys with colored lights. At Perkins, Alexis used a light board with Christmas tree lights attached to a switch, teaching her cause and effect. I brought Alexis to work, and she was impressed by the dazzle of the lights. I went to work creating LightAide to help Alexis and kids like her. Thankfully, a dedicated team of creative and out-of-the-box thinkers supported the launch of LightAide as a commercial product. Now, LightAide is improving lives of children in 9 countries and in 35 U.S. states. Proof positive that inspired design can truly open minds worldwide.

Catherine Rose is Senior Segment Manager for Healthcare at Philips Lighting and leads multidisciplinary teams to transform space with light, recently, leading global activities for LightAide, an LED system for children with low vision and other special needs. She is adept at integrating technical solutions with entrepreneurial insights to improve the world around her.

Lighting the Future Takes More Than Just Bright Ideas

Yan Zheng, Technology Consultant, USA

You just got a new cellphone, but before you know it, you're seeing ads for the next-gen model, and you haven't even figured out how to change the background of your current phone. It might seem like the progression of technology is a relentless juggernaut. However, the truth is that it takes a lot to keep innovation moving, and many of today's best tools happen to take advantage of the new advancements in photonics, an ever-growing field.

For example, take the task of handling the growing mass of data on the Internet. Let's say you spent a minute reading this post. Well, according to Intel, in that minute the world could have listened to 31,773 hours of music, shared 3.3 million pieces of content on Facebook, or watched 138,889 hours of videos on YouTube! This explosion of data wouldn't be possible without photonics. That is, lasers to create super-highways of information, high-speed modulators to pack the data onto these highways, fiber optical cables to send photons crisscrossing the globe, and detectors to convert photons back to electrons for our computers to read.

What's amazing is that for nearly four decades scientists and engineers have been able to discover better and faster ways to send data with light, which has been one of the key reasons the Internet has

been able to grow the way that it has. For example, if we were to get our hands on the recently announced high-speed single laser transmitters from the Technical University of Denmark, we would be able to achieve a record-breaking data transmission of 43 Terabits per second (that's 43 trillion ones and zeros) over a single fiber, or equivalent to sending the Avatar Blu-ray DVD in just 8.8 seconds!

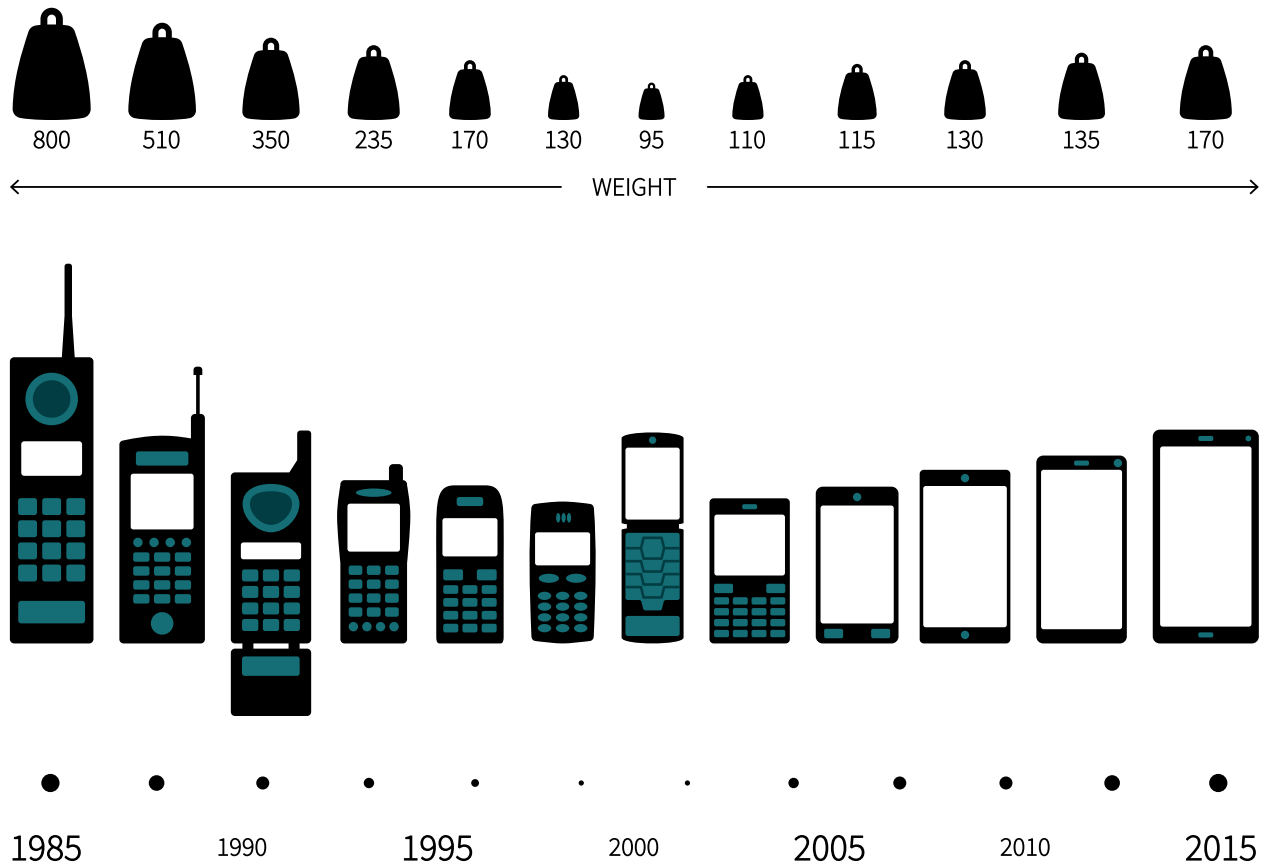
Photonics is also making its mark in new fields like autonomous vehicles. Take a look at Google's self-driving car and you will notice a large cone on the roof spinning around at hundreds of revolutions per minute. That cone is actually a Velodyne® laser system designed to create an image of the environment by measuring the distance between the car and nearby objects using a technique called LIDAR (Light Detection And Ranging). LIDAR is much like microwaves and RADAR, but the wavelength of the light used in LIDAR is hundreds of times smaller than that of microwaves used in commercial RADAR systems. The images LIDAR creates have far better resolution, too. But there's a catch: LIDAR systems can be very expensive. The Velodyne system Google uses on their self-driving car costs three times as much as the car itself (\$80K)! Luckily, researchers at the University of California, Berkeley might have a solution. By integrating all of the photonic components of a typical

LIDAR system into a semiconductor chip the size of a quarter, they think they can significantly cut down on the cost and size of these systems.

Many other amazing innovations in photonics are poised to change the way we live and work. However, getting scientific discoveries from the lab to the field has always been a difficult task due to the lack of infrastructure, funding, or a qualified workforce to bridge this gap, also known as the 'valley of death.' That is why the recent announcement by the White House for the creation of a photonics-focused Institute for Manufacturing Innovation is not only exciting, but crucial. The Integrated Photonics Institute for Manufacturing Innovation (IP-IMI), supported by the National Photonics Initiative (NPI), will be a \$220M program headed by the U.S. Department of Defense with matching funds from industry. The goal is to develop an industrial commons that will serve as a central hub for research and innovation in photonics.

The United States isn't the only country thinking about how to strategically invest in photonics. The European Union invested nearly €460M on photonics research under the EU Framework 7 Programme and will likely continue under their new research and development plan, Horizon 2020. China also sees photonics as an important field for not only advancing its manufactur-

MOBILE PHONES EVOLUTION



CREDIT: Shutterstock/Alex Oakenman.

ing capabilities, but also to discover new disruptive technologies. In a recent interview, the chief scientist of China's National Basic Research program stated that Chinese investment in optics and laser-related programs has increased 20% and is now at a staggering \$3.2B.

From powering the Internet to being a key technology in the automation

revolution, there is a lot that photonics can do, and I haven't even mentioned energy-efficient lighting, noninvasive health monitoring, or even mapping the universe! Let's be ready for it by thinking about how to apply these ideas to today's challenges and by making future policies that will help us leverage tomorrow's innovations.

Yan Zheng is a microelectronics and photonics technology consultant for universities, small businesses, and government laboratories working on projects aimed at addressing the needs of the commercial sector and national defense. He also supports U.S. Government agencies in developing innovative technologies.

Optical Communications: Lighting Our Way to Development

Kumar N. Sivarajan, TSDSI—Telecommunications Standards Development Society, India

In the last decade, we have witnessed one of the most significant technology revolutions in human history. Telecommunications, particularly mobile telephony, has transformed several nations that have long been languishing at the bottom of the development pyramid. According to GSMA (Groupe Speciale Mobile Association), there are over 5 billion mobile connections in the developing world today, and these are increasing at the rate of 17 per second! Mobiles have literally reached communities “where no man has gone before,” either due to the absence of roads or on account of other socio-cultural distances that were hard to bridge. In developing countries like India, there are more people with mobile phones today than with a bank account. Thanks to mobile communications, services such as healthcare, financial services, and education will eventually become available to these billions of people.

However, while the role of wireless technologies is widely recognized, and terms like “2G, 3G, 4G, GSM, CDMA, and LTE” have now entered common parlance, the importance of light-based technologies in sparking the mobile economy has surprisingly gone unnoticed.

Optical fiber: the invisible link

“Mobile is evidently wireless, so what does light have to do with it?” you might ask. While it’s true that there is no wired link from your mobile phone to the neighboring cell tower, optical fiber technology forms the backbone of today’s telecom networks. 95% of all kinds of telecommunications traffic, whether emanating from land phones, mobile phones, or modems, eventually lands on an optical fiber network at a cell tower, a telephone exchange, or at a local service provider office. Optical networks utilize fiber cables comprising hundreds of thin strands of special transparent glass that are laid underground and hence remain hidden from public view. Telecom operators use laser-based optical networking equipment to aggregate voice and Internet

traffic from the neighborhood and transmit them digitally as modulated light waves on these glass fibers. While laying these fiber cables is a long and laborious process, optical fiber has a shelf life of a few decades, since the same fiber can be used to offer higher and higher speeds by upgrading the associated optical networking equipment without needing to re-invest in the fiber plant. For example, a single fiber strand is capable of carrying tens of terabits of traffic today through modern techniques called dense wavelength division multiplexing (DWDM) and coherent optical processing. Without such light-based technologies, today’s telecommunication networks could not be scaled to deliver thousands of services to billions of subscribers using mobile or home broadband networks. Apart from offering virtually unlimited bandwidth, transmission over optic fiber is also more reliable, since it’s not affected by impairments such as electromagnetic interference and weather. Because signal losses in a fiber are very low, data can be economically transmitted over thousands of kilometers without having expensive electronics equipment deployed along the way for signal regeneration. Due to these advantages, optical fiber is already the medium of choice for national, long distance, and international connectivity, and over the last decade it has found its way into city-wide networks as well.

Light: Coming soon to a block near you

The global telecom sector is on the cusp of a broadband revolution. While the first phase of telecom growth was driven by voice services, the current phase is data dominated. The advent of smartphones, high-definition video, and “always on” social media applications have made things even more exciting for optical communications. The deluge of broadband data and the stringent quality requirements of the more popular “visual” applications have made it essential for telecommunication carriers to take optical fiber links closer to their subscribers’ homes on what is called FTTH (fiber to the



Optical fiber is reaching Indian villages. CREDIT: Digital Empowerment Foundation (DEF).

home). Unlike wireless access, with optical connectivity there's no spectrum congestion due to a large number of users sharing the same limited set of frequencies. The quality of service experience and access speeds on FTTH will therefore be significantly better compared to wireless infrastructure. Although many governments are working towards identifying and auctioning new spectra for mobile communications, this will continue to be a scarce resource for years to come. Wireless broadband can ensure connectivity but, eventually, it will be optical fiber that delivers capacity.

This primary role of optical fiber in delivering broadband is the reason governments in both developed and developing countries are taking increasing interest in building country-wide optical fiber networks for broadband connectivity. For example, the Indian government is investing billions of dollars to create a National Optical Fiber Network (NOFN) that will extend optical fiber connections to every village household or at least up to its 250,000 local village offices. Australia is making rapid progress with its National Broadband Network (NBN), which intends to deliver the country's first national wholesale-only, open access, broadband network to all Australians. Similarly, Bangladesh is implementing the "1000 Union Parishad" project for extending nationwide

optical fiber connectivity to villages. Similar efforts are also underway in the Philippines, Indonesia, Sri Lanka, Thailand, Malaysia, and many other countries. Optical fiber infrastructure is becoming as crucial as consumer utilities like electricity, water, and gas because of its potential to deliver a host of applications like telemedicine, e-governance, e-learning, and online banking to remote villages. Hence, besides laying new optical fiber cables, large utility providers such as railway, oil, gas, and power transmission companies are also unbundling their abundant fiber resources and making them available for broadband delivery to citizens.

Optical communications appears to be finally getting its due credit as a critical enabler for delivering affordable broadband connectivity to underserved populations, thus facilitating economic development, essential service delivery, and poverty alleviation around the globe.

Kumar N. Sivarajan is the Chairman of TSDSI, India's telecommunication standards development organization and the CTO of Tejas Networks, India's leading optical equipment company, which he cofounded in 2000. Kumar holds a Ph.D. in electrical engineering from California Institute of Technology, USA and is a distinguished alumnus of the Indian Institute of Technology (IIT), Madras.

Photonics Is a Player at the 2014 World Cup

Dan Curticapean, University of Applied Sciences Offenburg, Germany

At the FIFA World Cup 2014, 800 players and their coaches are responsible for showcasing the “Beautiful Game” to the world—the clever tactics, the graceful moves, the spectacular strikes. Behind the scenes, however, the field of photonics has been a most valuable player in the development and ever-increasing popularity of the sport, contributing to lighting technology, image transmission, photography, and even art.

With the shifting of kickoff times into the evening hours, the world of sports—and of football in particular—entered a new dimension, both in an aesthetic and an economic sense. The latest in floodlighting technology has been installed in sports arenas, with photonics playing a crucial role.

Lighting Technology

It is remarkable to note that the first soccer game involving floodlighting was kicked off in Sheffield, England on 14 October 1878, at 7:30 p.m.^{1–3} The light intensity then was compared to the power of 8,000 candles.^{2,3} Floodlighting systems have improved continuously ever since. The images of players from the 1970s and 80s, with four shadows cast around them, are gone today, thanks to the uniform illumination of the playing field. According to FIFA regulations, today’s modern stadiums must reach an illuminance of around 2,500 lx.¹ São Paulo’s floodlighting system consists of 350 headlights,^{4–6} each powered by

more than 2,000 W and together reaching a wattage of about 725 kW.

Taking into account the Brazil World Cup playing schedule,⁷ the geographical location of the playing venues, and their respective sunset times, about 40 World Cup games will have been kicked off under floodlights, amounting to approximately 3,780 minutes or 726,800 seconds of floodlighting (these figures also include estimated extra-time periods and penalty shootouts from the round of 16 onwards). With the same amount of energy it will take to light the 2014 World Cup, an Olympic-size swimming pool full of water could be lifted about 6.7 km into the air (1000 m higher than Mount Kilimanjaro) or a mass equal to half of the Apollo 11 command spacecraft (which returned from the Apollo mission) could be transported from the Earth to the Moon.

Goal-line technology⁸ is another area where uniform and high-quality illumination is essential. To provide a clear indication as to whether the ball has fully crossed the goal line, goals are equipped with seven high-speed cameras each, transmitting data at 500 high-resolution frames per second.

Photography

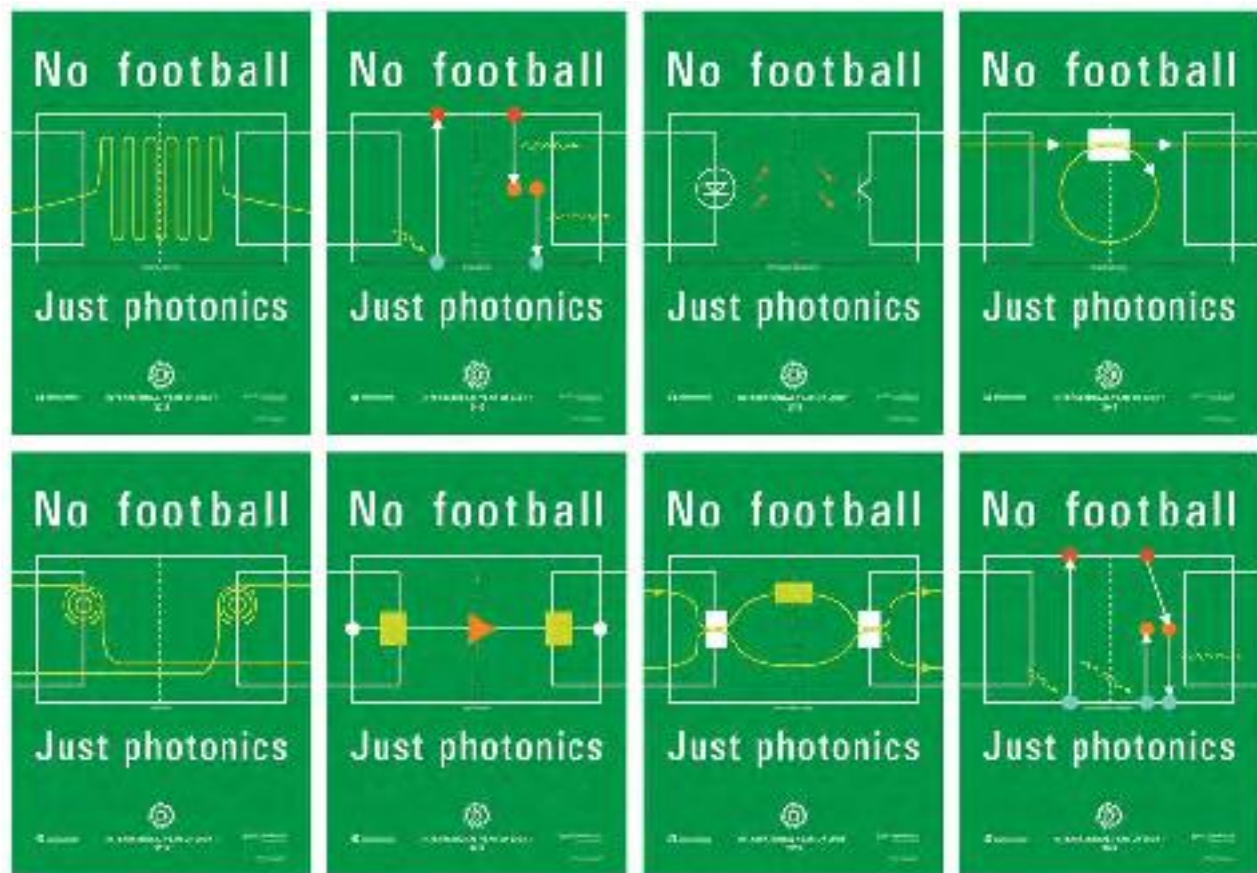
Photographers’ work has been positively impacted in much the same way. Digital cameras allow for noiseless exposures⁹ with ISO speeds of up to 25,600 today, which would be unimaginable even at the World Cup in France just 16 years ago.

Yet another challenge for photographers is ‘blink-free’ pictures of entire sports teams. The chance of achieving such a photograph has also risen in proportion to advances in shutter-speed technology, however.^{10–12}

Thanks to photonics and digital technology, the number of photographs taken during the World Cup games is at a record high as well. Estimates are that around a half million photos are taken per game, 32 million for the entire tournament. What’s more, today’s photographers can save and edit their pictures directly in the cloud instead of on memory cards, making the photos instantly accessible to editors around the globe. Assuming that there are 200 accredited photographers (including also remote-controlled cameras) at a game, with an average of 2,500 takes per camera,¹³ photographers will produce a total of 24 TB (terabytes) of photographic material (125 GB per photographer). Extending this calculation to the entire tournament, each photographer will yield approximately 8 TB of material, amounting to about 1600 TB for all photographers together. Thanks to photonics, not only do we get to view ever finer and sharper images and broadcasts, but these reach us in real time around the globe through optical fiber technology.

Image Transmission

With smartphones, tablets, and the like, modern-day transmission technology provides viewers with



Artwork Poster: No football—Just photonics. CREDIT: Offenburg University/Phillip Hastigspth.

a multitude of options and enables them to be their own director^{14,15} through applications that were unimaginable even at the last FIFA World Cup in South Africa.

Art

Finally, football and photonics sometimes play so well together that they create art! For example, the poster collection “No football—Just photonics,” which was designed to advertise the International Year of Light and Light-based Technologies 2015. In a series of schematic representations, it shows an optical comb generator, Raman scattering, a photo coupler, an optical ring resonator, an optical amplifier, a Mach-Zehnder coupler, as well as erbium-doped fiber amplifiers, all working their magic on a soccer field.¹⁶

MORE INFORMATION

1. de.wikipedia.org/wiki/Flutlicht.
2. www.chrishobbs.com/firstfloodlitfootball1878.htm.
3. www.stuffbypaulbrown.com/the-first-floodlit-football-match/.
4. www.osram.de/osram_de/news-und-wissen/stadionbeleuchtung-aus-einer-hand-fussball-arena-in-sao-paulo/index.jsp#logo.
5. www.siteco.com/de/de_de/produkte/katalog-aussenleuchten/chapter/1551/category/6860/family/9055.html.
6. www.osram.de/osram_de/produkte/lampen/hochdruck-entladungslampen/halogen-metallidampflampen-mit-quarztechnologie/powerstar-hqi-ts17539/index.jsp.
7. www.fifa.com.
8. Karen Thomas, “Keeping an eye on the ball,” SPIE Newsroom. DOI: 10.1117/2.2201406.01; 2014.
9. DIN 19010.
10. www.theage.com.au/news/national/aussies-win-open-and-shutter-case/2006/10/07/1159641577422.html.
11. www.daserste.de/information/wissen-kultur/wissen-vor-acht-werkstatt/sendung-werkstatt/wie-blinzelt-man-beim-fotografieren-moeglichst-wenig-100.html.
12. www.tagesspiegel.de/wissen/aha-warum-blinzelt-auf-gruppenfotos-fast-immer-jemand/3896998.html.
13. Note: Some data used in this article for calculations are estimates only.
14. www.zdfsport.de/fussball-wm-2014-in-der-zdf-mediathek-33433842.html.
15. www.sportschau.de/fifawm2014/fussball-wm-sportschau-app100.html.
16. www.offenburg-university.de/iyl2015/.

NOTES

This blog post is an abbreviated version of Prof. Curticepean’s full publication which can be found on SPIE.org.

Dan Curticepean is Professor and Head of the Media Technology Lab. at the University of Applied Sciences Offenburg, Germany, where he leads the Magic of Light project team, which encourages education and enthusiasm around optics, photonics, and physics. He has authored several publications, especially on topics pertaining to the fields of optics and photonics.



Ph.D. student Ceri Brenner, University of Strathclyde, installing the target wheel into the interaction chamber in the Petawatt Target area of the Vulcan laser facility in the Central Laser Facility at the STFC's Rutherford Appleton Laboratory, 30th September 2010.
CREDIT: Ceri Brenner.

Pressing Fire on the Most Powerful Laser in the World: Bringing Research to Reality

Ceri Brenner, Rutherford Appleton Laboratory, UK

In the past, when people would ask me what I do for a living, I would answer, “I’m a laser plasma research physicist.” This reply would often result in a blank stare, and the conversation would then lead in the direction of “but what does that mean?” and “oh it must be too complicated for me to understand.” I found that describing myself as a physicist was too daunting for most people. This is one of the reasons that I am so active in science communication, for I’d really like there to be a day when introducing myself as a research physicist is as normal or accepted as saying I am a lawyer, a nurse, or a teacher. Until then, I’m dedicated to taking a different approach, one that is inviting and not intimidating.

I now say that I work with the most powerful lasers in the world to design new technology that helps to solve really important challenges that we face, such as where we’ll get our energy sources from in the future and how we can use technology to beat the trickiest and most widespread of diseases, such as cancer. My job is to bring research to reality and figure out the physics needed for tomorrow’s technology.

My tool of choice for this endeavour is super-intense, high-power lasers. I work for the Central Laser Facility (CLF), which is at the centre of the Rutherford Appleton Labo-

ratory in Oxfordshire, UK. The CLF is paid for by UK taxpayers via the Government’s Science & Technology Facilities Council (STFC), whose mantra is “Impact, Inspiration and Innovation,” to which I am perfectly aligned. For I now know that I am an application-driven, solution-focussed physicist, but it took me a while to figure that out. By the end of my undergraduate physics degree, I was pretty jaded about the idea of studying the subject any further and was instead going to use it to get me a big shot job in the city. But then I discovered high-power lasers by doing a summer placement at the CLF. I learned that these lasers were generating some of the most extreme conditions one could imagine, millions of degrees in temperature, compressing metals into flowing lavas of charged particles that are as dense as lead, using only light from a laser pulse that lasts for a trillionth of a second. How extraordinary! I was hooked.

And then when I learned that physicists were using these extreme laser–solid interactions to deliver fusion reactions on earth so that we can do away with burning coal and nuclear fission in power stations, or for building miniature accelerators that sit neatly in hospitals to deliver beams of ions for zapping away cancers tumours. Well, I turned my back on the city and signed up for a Ph.D. in this field pretty much

straight away and thought: this is how I was going to use my physics training to contribute to our future and leave a legacy behind in the form of new knowledge that will last longer than I ever will.

Here comes the science bit.....

Plasma, the fourth state of matter, is generated when the building blocks of matter, atoms, are shaken or heated so violently that they rip apart, leaving their charged insides—electrons and ions—exposed and interacting with one another in a flurry of “fluid dynamics meets Maxwell’s equations.” Plasmas don’t exist without an extreme condition generating them and so will quickly relax back down to a gas, getting rid of their excess energy in a flash of light, which is the bit that we observe. 99% of the known or visible (hat tip to you dark matter and energy folk) universe is in this plasma state (the sun is a big burning ball of plasma, for example) driven by the extreme conditions of outer space. Here on earth we’ve figured out a few ways to generate our own beautiful plasmas; by driving electrical current through a gas (like in plasma TV’s, neon lights, or plasma balls) or by whacking an intense pulse of light (and therefore an extreme source of electric field in the electromagnetic wave) onto matter.

I’m intrigued the most by the latter.

For a laser plasma can have properties that liken it to the plasma conditions at the centre of stars and planets or in the blast waves of supernova explosions. And this means that if one wishes to study these great and faraway astrophysical objects and events, all one needs to do is call up a few high-energy, high-power laser beams and shoot them all into the centre of a target chamber that can be set up with a suite of diagnostics to help you interpret the physics of what's really going. And talking of solar cores, if we want to copycat the energy release process that's going on at the centre of every star to keep our power stations burning and generating electricity for us all using a clean and abundant fuel, then lasers are most definitely one approach to seeing that dream come true.

My Ph.D. was on the subject of laser-driven proton beams, by which an intense laser pulse is used to drive matter into the fourth state, plasma, and from there set up a micron-sized particle accelerator by separating the negative electrons from the positive ions (the laser electric field pushes the electrons out the way). This charge-separation state in turn sets up an incredibly large electric field (TV/m for people who know their E fields) inside the plasma bubble. Any charged particles in the vicinity of that hyped-up field will be whipped up from 0 to 60 (MeV, for example) over a distance less than the width of a human hair. My Ph.D. mission was to see if, by changing the properties of the laser pulse (it's energy content, the width and shape of the pulse rise-time, the size of the focal spot), we can control and enhance the particle beam that comes from our micro-plasma accelerator (to be exact, my Ph.D. thesis title is "Laser-driven proton beams: Mechanisms for spectral control and efficiency enhancement.") We need to

be able to demonstrate control over the process if we ever want to use this accelerator technology for applications and especially for use in a clinical environment, for proton beam cancer therapy, for example.

Radiotherapy (beams of x rays that shine through the patient from many angles) is a very common and successful treatment for cancer tumours, while proton therapy is a highly sought-after treatment for tumours below the skin, particularly for those that are growing in or alongside vital organs that need to be protected from radiation dose. Compared to x rays, protons interact differently with the atoms that make up the building blocks of all matter. They deposit their energy a lot more locally than x rays, and the depth at which they do this depends on the energy of the beam and the tissue that it interacts with (all of which we can predict very well with well-developed theory and codes). This means that we can send a proton beam into a patient, and it will only do harmful damage to the exact location where the tumour is and not the healthy tissue around it, which is really useful for treating cancers positioned next to the spinal cord and brain or for treatment for children who often have secondary cancer growth from their x-ray treatment later in life. There are currently about 50 proton and ion treatment centres around the world. "Why the hell isn't there one in every hospital?" was my first reaction to hearing this—I was outraged! At which point my Ph.D. supervisor started to explain how big conventional particle accelerator technology is and how much it costs to build and maintain a centre, and about cost-benefit analysis blah blah blah This was the flame that lit my passion for laser-driven accelerators for applications. I set out to make my mark on the world by joining the world-wide effort that

is trying to figure out how we can bring the theoretical idea of using laser light to push particles and turn it into a real prospect for inspiring applications.

I finished my Ph.D. three years ago and since then have moulded myself a role at the CLF that is enabling me to do just that. I'm the CLF's applications development scientist, specialising in high-power laser plasma accelerators for use in medicine through to advanced manufacturing. I bring together collaborations between laser-plasma physicists, high-energy radiation detector engineers, industrial R&D departments, and conventional radiation technology specialists to work on the task of developing the physics needed to realise the potential (pun intended) of these light-based particle pushers. In fact, this month (March 2015) I'm leading the first CLF experiment dedicated to demonstrating the application of plasma accelerators in high-energy x-ray, gamma-ray, and neutron generation for imaging of high-value, UK-manufactured industrial components that need to be nondestructively inspected. And because I am the lead and principle investigator for this experiment on the CLF's Vulcan high-power laser, I truly do get to press FIRE on the most powerful laser in the world.

Ceri Brenner is an application development scientist at the Central Laser Facility, Rutherford Appleton Laboratory, developing laser plasmas for applications in medicine through manufacturing. Ceri has a Ph.D. in physics from University of Strathclyde and describes herself as a "solution focused physicist, driven by a passion for contributing to society through applied physics and new technology."

Seeing Is Believing: Using the Power of 10 Billion Suns to Light Up Our World

Sarah Bucknall, Diamond Light Source, UK

What is the fastest thing on Earth? Usain Bolt? A cheetah? Lewis Hamilton in a Formula 1 racing car? Unless we delve into the realms of quantum physics, we all know that nothing can travel faster than the speed of light. But there are a few things that can get close. Electrons, for example, inside a particle accelerator race around at a fraction below the speed of light—so fast that they could complete 7.5 revolutions of the Earth's equator in one second.

Arguably, the world's most famous particle accelerator is the Large Hadron Collider at CERN, Switzerland, where protons are accelerat-

ed and collided to give scientists a glimpse inside atoms and help us better understand the origins of our universe. But not all particle accelerators are atom smashers. In the 1940s scientists discovered something called synchrotron radiation, a special kind of extremely bright light that they realised could be exploited to study the world around us in ultrafine detail. Forty years later, a dedicated, purpose-built synchrotron radiation source was built at Daresbury, Cheshire in the UK. This type of accelerator sends particles in one direction only, passing the electrons through special magnetic fields to create powerful energy known as synchrotron light.

A bright light for science

At ten billion times brighter than the sun, synchrotron light is one of the brightest lights in our universe. It spans the electromagnetic spectrum from infrared to ultraviolet light to x rays. Scientists use it to study the atomic and molecular details of all kinds of matter and material. From proteins to meteorites to metal alloys, a synchrotron allows scientists to look deep inside their specimens. Often, being able to see inside something helps us to understand how it works. Think of a mechanical clock. If you open it up and look at the structure of the cogs that make up the clockwork inside, you start to get an idea of how it works. The same prin-



Lightsources.org is a founding partner of the International Year of Light and Light-based Technologies 2015. CREDIT: Lightsources.org.



An aerial view of Diamond Light Source, the UK's national synchrotron facility, on the Harwell Science and Innovation Campus, Oxfordshire. CREDIT: Diamond Light Source.

ciple applies with synchrotron research; being able to determine the structure of things helps scientists to understand their function.

This kind of knowledge can be incredibly powerful. Synchrotron science impacts a broad range of research: from finding sustainable energy solutions and inventing

smart, new materials through to creating novel vaccines to tackle deadly viruses and diseases.

Light for life

Recently, scientists have used the UK's national synchrotron Diamond Light Source to increase their understanding of the foot-and-mouth disease virus (FMDV). This has led

to a new methodology to produce a vaccine that is entirely synthetic, making it much easier to store and reducing the need for a cold chain. This is important research because it represents a big step forward in the global campaign to control FMDV in countries where the disease is endemic, and the vaccine could significantly reduce the threat to countries

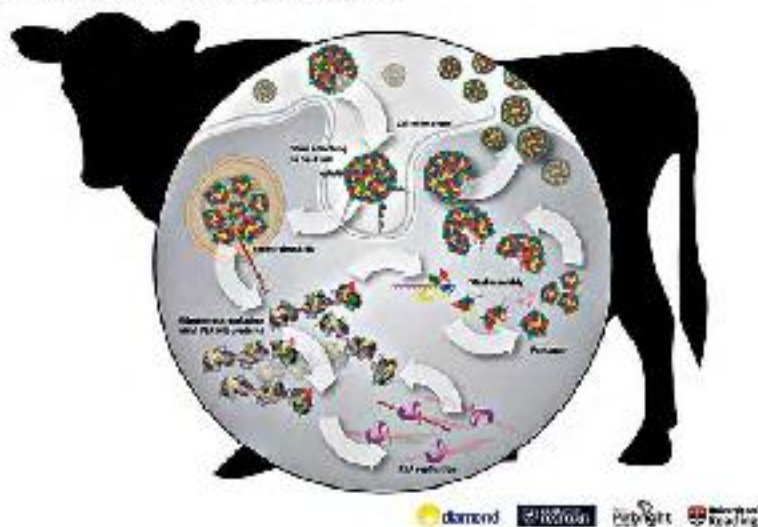


currently free of the disease. Crucially, this new approach to making and stabilising vaccines could also impact how viruses from the same family (including polio) are fought.

Revealing our history

From modern-day medicines to ancient artefacts, synchrotrons cast their light far and wide. They can be a handy tool for conservationists wanting to know more about their artefacts without damaging them. In

Foot and Mouth disease virus lifecycle



The foot-and-mouth disease virus life cycle. CREDIT: Diamond Light Source, University of Oxford, Pirbright Institute, and University of Reading.

the past 20 years, synchrotrons have shone their spotlight on the works of Turner, Rembrandt, and van Gogh, to name but a few, giving an insight into the materials and methods used by these world-famous painters. From art to archaeology, in January 2015 the BBC reported on pioneering archaeological work carried out at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France. Scientists used the ESRF's x rays to read a burnt, rolled-up scroll buried by Mount Vesuvius in AD79 without having to unroll it.

A global endeavour

There are over 40 synchrotrons around the world, and it doesn't stop there. Cutting-edge, complementary facilities are in operation and under development, using incredibly bright light to further our knowledge and capabilities. Free-electron lasers (FELs) are the next generation of light source. These pioneering particle accelerators produce super-brilliant, ultra-short flashes of x-ray light to piece together snapshots of atoms in motion, furthering our understanding of the processes taking place. The applications of such insights are complementary to and as

vast as synchrotron research, from biology to chemistry to physics and Earth sciences.

Whether you knew it or not, these incredible research facilities frequently impact our daily lives. On average, each operational light source facility publishes more than one paper a day in a peer-reviewed scientific journal. Each paper reports on new findings that advance our knowledge across the board.

So next time you download a new track to your smartphone, or take an antihistamine to alleviate your allergies, think about how a light 10 billion times more powerful than the sun has been used to reveal the secrets within. It is a light for science. A light that is fuelled by our thirst for knowledge. A light that will keep on burning until we have no more questions to answer.

Sarah Bucknall is a Science Communicator at Diamond Light Source, UK's national synchrotron facility. She represents Diamond Light Source on the Management Board for lightsources.org, a collaboration and website providing a vital resource for information on the latest news and research from the synchrotrons and FELs around the world, and a founding partner of IYL 2015.

Teleporting Light

Félix Bussi eres, University of Geneva, Switzerland

When I was still a boy, maybe 7 or 8 years old, I looked in the mirror and pondered on what seems obvious at first: The reflection I saw changed as I moved around. I asked myself, “How can the mirror deal with all these different reflections? Does it reflect one, then the other, or is it reflecting all of them simultaneously?”

As far as I can remember, those are probably the very first physics questions I asked myself. Not knowing what light and mirrors really are, I could not find the answers, and nobody in my entourage could either ... but I did not forget about it.

I think that understanding what light is and what we can do with it has always been part of my motivation to follow one research direction or another. Light pervades us, it puts everything in touch, close or remote. It allows me to see my kids grow into little persons. It allows us to observe the universe as it was more than four billion years ago. I find this fascinating—light is a universal messenger.

A messenger of speakable messages

Light delivers messages. In particular, it runs through the fibre optic mesh installed around the globe, relentlessly carrying the least and the most important messages that we want to share with each other. In a modern version of the smoke signals our ancestors used to communicate over long distances, billions and billions of light particles code binary signals.

At this level, light seems like a com-

mon object, one that we can see with bare eyes and manipulate. Light can speak for us when sounds cannot be transmitting directly, and nowadays this can feel almost natural to a lot of people.

Pervading all these communications is the fundamental concept of the information unit, the bit. In practice, bits can be a sequence of zeros and ones coded into optical pulses. For reasons that will be more obvious below, I will dub this kind of information as “speakable,”¹ meaning that a person (or a machine) can literally speak it out loud, and it will make sense to any person (or processor) receiving it.

At the level of this speakable information, light is like a ripple at the surface of a pond. It is a wave that spreads around a point of origin and can be registered in a continuous fashion. Waves also superimpose on each other and go unperturbed as they cross, as if they actually never did.

Seeing light in this way, mirrors are merely changing the course of a wavefront, and indeed all reflections happen simultaneously.

A messenger of unspeakable messages and correlations

Light differs in a strange and unexpected way when one considers its intimate details. In 1905, Albert Einstein proposed that light actually comes in discrete energy packets that we now call photons.² This observation was instrumental in the development of quantum mechanics, the theory describing the microscopic behaviour of light and matter.

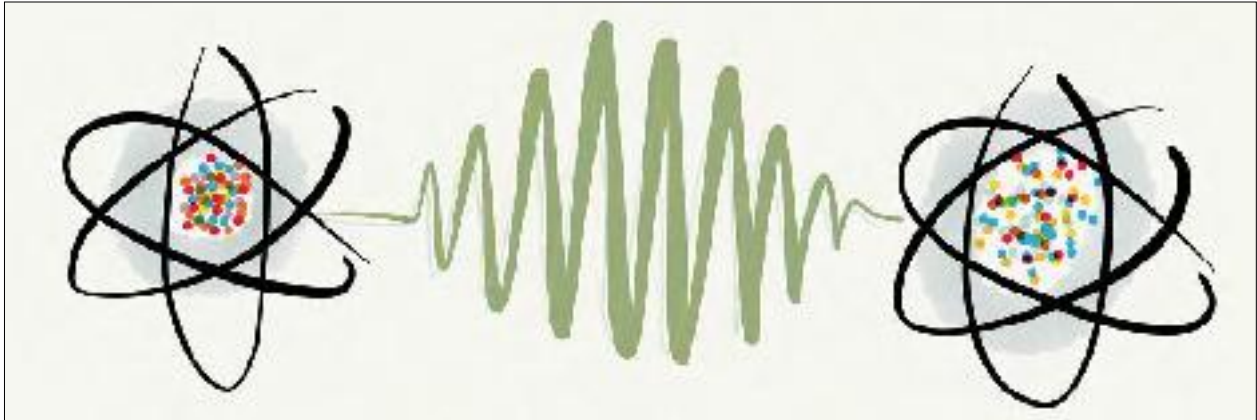
Quantum mechanics has profound consequences.

If light comes as discrete photons, how can it look like it is a wave when billions of photons strike the mirror? The answer is confounding: Photons travel as waves, but only until they are detected. Said differently, a photon can travel two paths at the same time... until one tries to look at which path it took! A mirror reflecting a photon travelling two paths at once is indeed reflecting two “images” at the same time... but only until something comes in its way (e.g., the eye of an observer) that forces it to randomly show up in one path or the other (but not both). This effectively means that the mirror reflected only one “image” at the time!

It was only very late in my academic training that I realized that my question about the mirror was ultimately linked to the very nature of light. This is in fact very satisfying. But at the same time, the wave-like or particle-like nature of photons leads to an even more puzzling scenario. Light can carry “unspeakable” messages.

Let me be more precise. A speakable message is something like this: The photon took this path or that one. This is essentially a bit of information. Now, the quantum nature of light means that a photon can simultaneously travel the two paths, and the information remains “unspeakable” (that is undetermined) until it is detected in one path or the other. This is what we now call a “quantum bit.”

Taking the concept further, it turns



Artist's view of two entangled atomic ensembles. CREDIT: Félix Bussi res.

out that two photons can be created in a way that they carry very unique correlations that we call entanglement. The effect of entanglement is this: The result of a measurement performed on one photon of an entangled pair will yield a purely random result, but then a properly executed measurement performed on the other photon will yield a result that is strongly correlated with the other photon's result. And the word "strongly" might be too weak to explain really what happens, as first realized by John Stewart Bell in his seminal work in 1964 (the initiated reader will have already noticed that I am borrowing Bell's terminology of unspeakable correlations).¹

The correlations that emerge from entangled photons cannot be interpreted as correlated speakable messages,¹ as was initially suggested by A. Einstein, B. Podolsky, and N. Rosen in 1935.³ These unspeakable correlations seem to somewhat protrude from space and time. We do not have a simple and fully satisfying explanation for their existence. They do not reconcile with our seemingly speakable, macroscopic existence.

As fascinating as this can be, it also leads to a feat. Unspeakable correlations are a resource we can use, and this leads to the emergence of a new chapter in photon-based com-

munication: quantum teleportation, or the art of teleporting unspeakable messages using unspeakable correlations!

Teleporting unspeakable messages using unspeakable correlations

Entanglement yields correlations; photons from an entangled pair are intimately linked to each other, a fact that can be exploited. Let us imagine two persons, Alice and Bob, where Alice wants to send a quantum bit of information to Bob. If her quantum bit is encoded in a photon, Alice could directly send the photon to Bob... but she could also be more playful and use entanglement instead.

So let us imagine that Alice and Bob each have one-half of an entangled pair of photons. Thanks to quantum mechanics and entanglement, Alice can perform a special kind of measurement (that we can call a joint measurement) on both the photon carrying the quantum bit she wants to send and her half of the entangled photon pair.

As I said earlier, measuring a photon encoding an unspeakable message will perturb its state, and therefore the joint measurement destroys the state of the quantum bit but reveals no information about it. The unspeakable message might seem lost, but this is not so. Indeed, be-

cause the joint measurement included one-half of the entangled pair, the correlations are such that the quantum bit now exists in the state of Bob's photon. There is a condition though: Alice must first inform Bob of her measurement result (she must transmit a speakable message). Even though this result contains no information whatsoever about her quantum bit, Bob can nevertheless use it to recover Alice's unspeakable message (her quantum bit) in his photon.

One crucial fact should be noted: this happens even if Bob's photon never encountered Alice's photon! Entanglement can carry an unspeakable message from one photon to another, without the need of speaking it out loud! This is fundamentally different from the common experience we have when light is used as a carrier of speakable messages...

... and this is one of the marvellous things that we can do with quantum mechanics.

Teleporting light and using it for cryptography

After the discovery of the theoretical possibility of quantum teleportation in 1993,⁴ it became crucial to show that quantum teleportation was feasible to realize in practice. This happened for the first time in 1997 using photons,⁵ and it was lat-

er extended to several other kinds of systems such as nuclear spins, atoms, and solid state devices.⁶

The possibility of quantum teleportation is now an established fact, and the community is focussing on ways to exploit teleportation for applications. Two fundamental applications are in computing and cryptography.⁶ My expertise is in the latter, and I will now try to give you a glimpse of why this is fundamental.

Cryptography is the art of writing or solving codes and is best known as a method to implement confidential communication (of speakable messages). The history of cryptography is an eventful one and dates back to at least 1900 BC. One crucial observation must be made: The principles behind all forms of encryption based on scrambling speakable messages using an algorithmic procedure have been either defeated or otherwise not proven secure against an all-powerful eavesdropper. Even to this day, the most widely used encryption methods over the Internet are not known to be secure.

Should we panic? This is a good question. We should certainly think about the future of cryptography, especially since we actually know that a full-fledged quantum computer could in fact break one of the most heavily used cryptographic methods based on the hardness of factoring large number into its prime factors.^{7,8}

A solution to the quantum computer threat is quantum cryptography,^{9–11} which involves sending single photons encoding unspeakable messages one by one from Alice to Bob. A careful choice of randomly chosen unspeakable messages (quantum bits) then allows Alice and Bob to generate a provably secure cryptographic key. The key can then be used to perform unbreakable encryption.

This elegant idea has now spun into commercial products.^{12–14} The most important limitation of this method is however the maximum distance over which it can be implemented, which is at most a few hundred kilometres when using optical fibre for the transmission of the single photons. Interestingly, one solution to extending the range beyond is to use quantum teleportation of light between Alice and Bob in a cascaded fashion.¹⁵

Recently, my research team and I realized an important step in that direction.¹⁶ We were able to perform a quantum teleportation over 25 km of optical fibre. Importantly, one end of the link had a quantum memory, which was, in our case, a crystal capable of storing the quantum state of an entangled photon for some time and then release it for the purpose of synchronizing quantum messages.¹⁷ The teleportation happens from one photon to another one that is stored in the memory; hence, we realize a light-to-matter teleportation. Our contribution raises the hope that quantum cryptography over longer distances might be feasible in the near future.

This seems futuristic enough, and one may wonder if it can be used to teleport humans. This would necessitate two identical copies of the same human body, and we would teleport the quantum state of the atoms of the first body to the second one. Needless to say, this is an inconceivable task, and I do not know if anyone would be willing to try that in the first place! But it is certainly entertaining to consider the possibility.

From light to quantum feats

Quantum teleportation is one of many fascinating and useful feats that quantum mechanics allows us realize or envision for the future of cryptography and computing.¹⁸ Understanding this started with

the photon, the simplest, yet perhaps the most fundamental “particle” that led to the development of quantum mechanics.

Light is indeed a universal messenger of speakable and unspeakable messages and correlations, and it will most likely continue to play the role of a work horse leading us towards fundamental discoveries, applications, and scientific and social enlightenment in a broad sense.

MORE INFORMATION

1. John S. Bell, *Speakable and Unspeakable in Quantum Mechanics*, Cambridge University Press, Cambridge (1987).
2. https://en.wikipedia.org/wiki/Photoelectric_effect.
3. A. Einstein, B. Podolsky, and N. Rosen, “Can quantum-mechanical description of physical reality be considered complete?” *Physical Review* **47**, 777 (1935).
4. C. H. Bennett, G. Brassard, C. Crépeau, R. Jozsa, A. Peres, and W. K. Wootters, “Teleporting an unknown quantum state via dual classical and Einstein–Podolsky–Rosen channels,” *Physical Review Letters* **70**, 1895 (1993).
5. D. Bouwmeester, J.-W. Pan, K. Mattle, M. Eibl, H. Weinfurter, and A. Zeilinger, “Experimental quantum teleportation,” *Nature* **390**, 575 (1997).
6. S. Pirandola, J. Eisert, C. Weedbrook, A. Furusawa, and S. L. Braunstein, “Advances in quantum teleportation,” *arxiv:1505.07831* (2015).
7. P. W. Shor, “Polynomial-time algorithms for prime factorization and discrete logarithms on a quantum computer,” *SIAM Journal on Computing* **26**, 1484 (1997).
8. <http://www.nature.com/news/online-security-braces-for-quantum-revolution-1.18332>.
9. C. H. Bennett and G. Brassard, “Quantum cryptography: Public key distribution and coin tossing,” *Proc. of the Int. Conf. on Computers, Systems & Signal Processing*, Bangalore, India, p. 175 (1984).
10. A. K. Ekert, “Quantum cryptography based on Bell’s theorem,” *Physical Review Letters* **67**, 661 (1991).
11. N. Gisin, G. Ribordy, W. Tittel, and H. Zbinden, “Quantum cryptography,” *Reviews of Modern Physics* **74**, 145 (2002).

12. <http://www.idquantique.com>.
13. <http://www.sequarenet.com>.
14. <http://www.quintessencelabs.com>.
15. H.-J. Briegel, W. Dür, J. I. Cirac, and P. Zoller, "Quantum repeaters: the role of imperfect local operations in quantum communication," *Physical Review Letters* **81**, 5932 (1998).
16. F. Bussières, C. Clausen, A. Tiranov, B. Korzh, V. B. Verma, S. W. Nam, F. Marsili, A. Ferrier, P. Goldner, H. Herrmann, C. Silberhorn, W. Sohler, M. Afzelius, and N. Gisin, "Quantum teleportation from a telecom-wavelength photon to a solid-state quantum memory," *Nature Photonics* **8**, 775 (2014).
17. F. Bussières, N. Sangouard, M. Afzelius, H. de Riedmatten, C. Simon, and W. Tittel, "Prospective applications of optical quantum memories," *Journal of Modern Optics* **60**, 1519 (2013).
18. N. Gisin, *Quantum Chance: Nonlocality, Teleportation and Other Quantum Marvels*, Springer International Publishing Switzerland (2014).

Félix Bussières is a senior researcher in the Group of Applied Physics at the University of Geneva, where he leads the research activities on macroscopic entanglement and superconducting single-photon detectors. With a Ph.D. from the École Polytechnique de Montréal (2010), his research demonstrates several fundamental building blocks of quantum networks using optical fibres, thereby contributing to closing the gap between academic research and real-world applications.

The Economic Impact of Light-based Technologies

Mat Wasley, Scottish Universities Physics Alliance, UK

2015 is the International Year of Light and Light-based Technologies. For the sake of brevity, we often omit the “light-based technologies” part when talking about the year, but those three words describe a €300 billion market and a range of components and products that underpin our modern existence. But what are these technologies, and how did they come to be such a significant market?

The impact of light runs right through history. The story of Archimedes holding back the Roman fleet by focussing sunlight with mirrors is a tempting place to start, but unfortunately it seems unlikely to have happened. A more tangible example might be found in the history of glassmaking, dating back thousands of years as early technologists learned to melt sand with potash and other ingredients to create a new material that changed the appearance of the light passing through it. This process added value to raw materials. Artisans and early scientists alike produced objects of pure beauty and functionality, sometimes together, from bright jewellery to dazzling stained glass windows through to new instruments, microscopes, and telescopes for seeing the small and the far away. In the process, new markets and industries were created, and demand for these grew, and the objects went from the rare to the everyday.

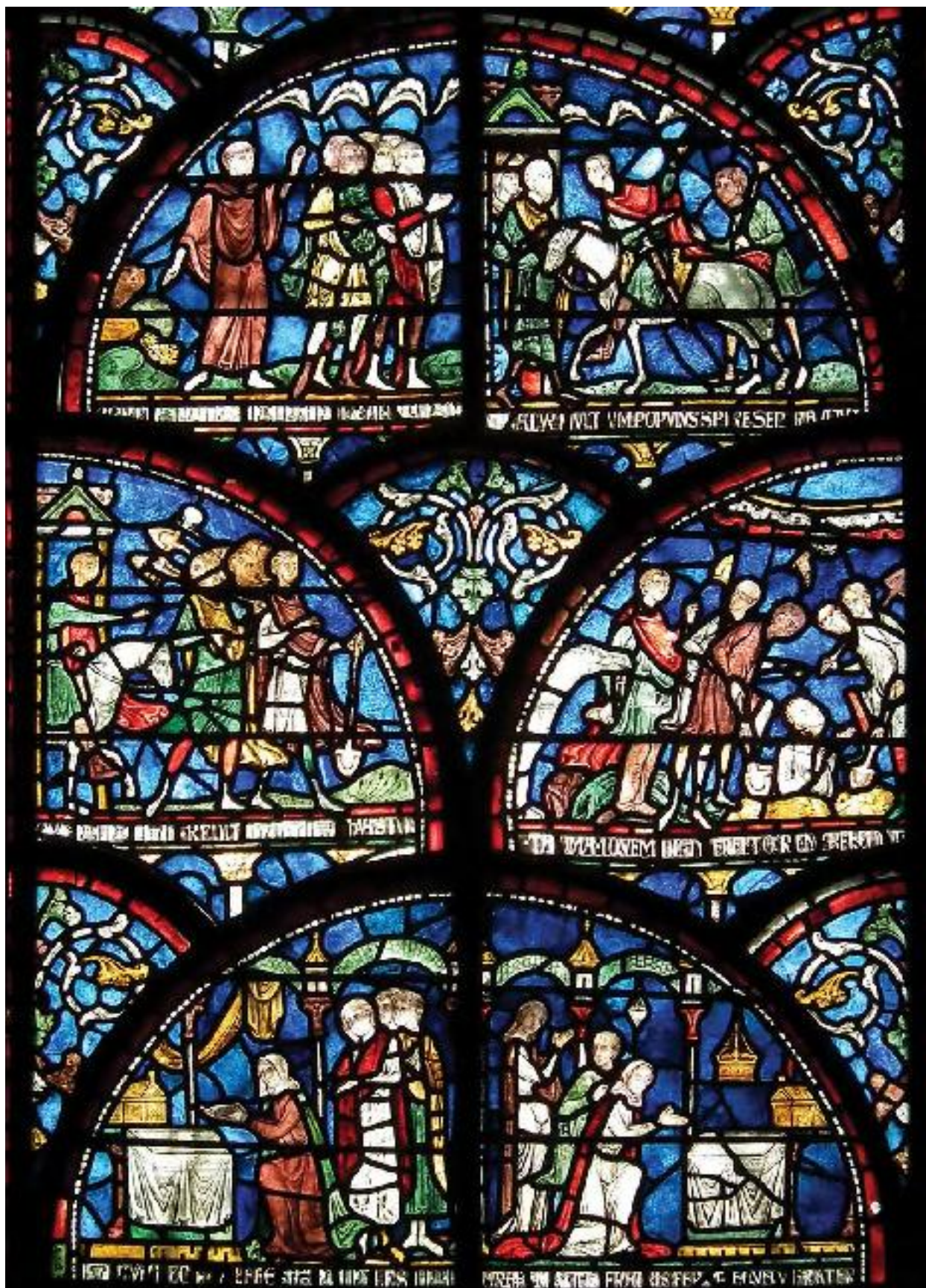
These industries are still very much alive today, and sales of optical components are worth around \$4B, but they form only a small part of the total market for light-based technologies. Some market segments are perhaps easier to grasp than others. For example, most people in the



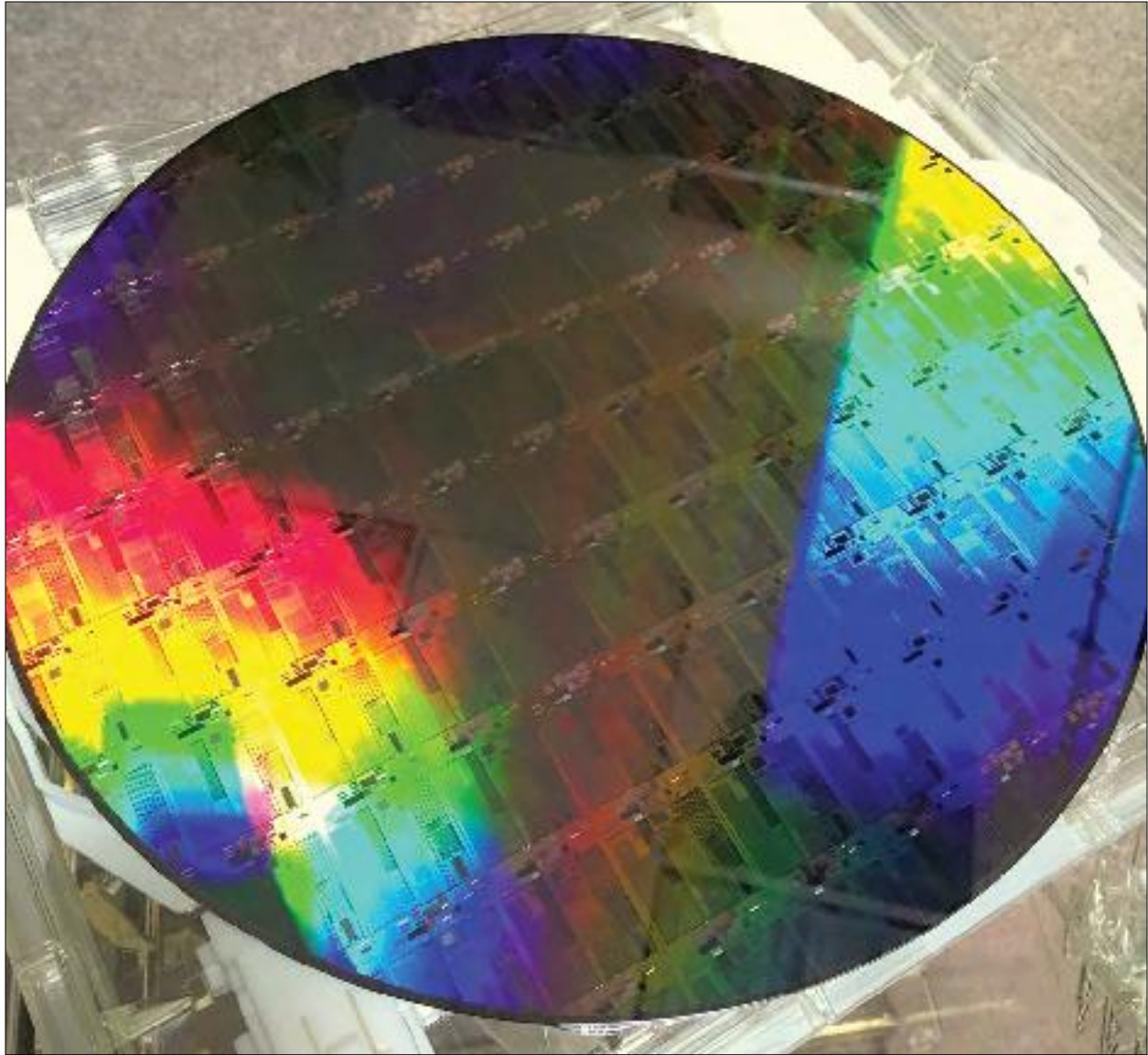
Early example of impact from light-based technology? CREDIT: Wikimedia Commons.

developed world would have some understanding of the \$120B lighting market, which has seen incandescent bulbs replaced by compact fluorescent bulbs and now increasingly by LEDs and, not too far from now, by OLEDs. Other segments though are perhaps less obvious but are highly significant. Part of the reason for this is the underpinning nature of much of the technology. Photonics, the science and technology of generating, controlling, and detecting photons, is recognised by the European Commission as a Key Enabling Technology. In the U.S., its status as an enabling technology has also been recognised, leading to a National Photonics Initiative.

The smartphone provides a good example of the underpinning nature of photonics. Doing something as commonplace and apparently straightforward as checking email on a phone requires a multitude of photonics technologies. Starting with the phone itself, lasers



Early industry based on transmission of light at selected wavelength: stained glass windows at Canterbury Cathedral.
CREDIT: Wikimedia Commons.



Replacing copper with light: a silicon photonics wafer. CREDIT: Wikimedia Commons.

are used to pattern and drill the circuit boards inside, to cut the display glass, to fabricate the display, to pattern the touchscreen, and a whole lot more.¹ Electrons inside the phone are converted to photons, which are sent to a nearby cell tower and the core network thanks to James Clerk Maxwell's discovery of the laws of electrodynamics. The photons are converted back to electrons and then to photons again and travel via fibre optic cable to a data centre. Here, silicon photonic technology is being used to replace cop-

per with fibre and increase bandwidth.

We could measure the economic impact in the above example by looking at the market size for the lasers used in smartphone manufacture and the fibre optic cables and connectors used in the network and data centre. However, without photonics the smartphone wouldn't even be possible, so perhaps we should include the \$270B smartphone market; and since the vast majority of communications

use fibre optics, perhaps we should even include the value of the entire Internet!

The impact of light-based technologies goes further. Worldwide revenue from the flat-panel displays in our televisions, monitors, and, increasingly, phones, is estimated at \$180B. Other significant markets include production technology, medical/life science, and optical components. The \$300B market size quoted at the start of this article applies only to the photonics industry;

the wider economic impact enabled today by light-based technologies is vastly greater.²

It seems certain that the economic impact of light-based technologies will increase in the years to come. The markets mentioned above are forecast to grow, and new photonics markets will emerge. The drive for higher bandwidths and greater efficiencies will see optical technology take an even greater share in the Internet, with light no longer stopping at the data centre but continuing into the server rack, and perhaps ever further into integrated circuits themselves. Light-based technologies will also play their part in the next quantum revolution, bringing unprecedented control over light and matter, opening up

new, undreamt of applications and markets. Light-based technologies are already significant today but have the potential to be revolutionary tomorrow.

MORE INFORMATION

1. Coherent article on lasers in smartphone manufacture: <https://www.coherent.com/downloads/Lasers-Enable-Smartphone.pdf>.
2. Market sizes given are estimated based on multiple sources and are provided for the purposes of illustration only.

ACKNOWLEDGMENTS

Thanks to the many people who gave inspiration and help for this article, particularly Dr. Richard Mosses of the Scottish Optoelectronics Association for additional material on early technologies and inspiration throughout. Any errors are mine alone.

Mat Wasley is Business Development Manager for the Scottish Universities Physics Alliance, where his role is to maximise the impact of physics research in Scotland. He graduated in Physics from the University of Bath and started a career in applied research, then transitioned to project management, business development, and technology communication.

The Healing Power of Light: Blue Light Cures Neonatal Jaundice

Christine M. O'Brien and Isaac Pence, Vanderbilt University, USA

From newborns to the elderly, people around the world are treated every day using technology rooted in optics and photonics.

By harnessing the power of light to understand and heal disease, we are able to continue to develop new ways to improve people's lives. Here, we focus on neonatal jaundice as a simple case of how light can help us to see and treat disease in the most vulnerable infants.

Three out of five infants have neonatal jaundice within the first month of life, a condition caused by high levels of bilirubin in the blood.¹ Bilirubin is a chemical naturally produced in the body as red blood cells break down; this product is toxic to brain cells and can cause permanent damage if levels are too high. Normally, the liver breaks down bilirubin; however, the infant liver may be underdeveloped, in which case that infant needs help to break it down.

Diagnosing neonatal jaundice

Bilirubin has yellow pigmentation, which can cause the infant's skin and eyes to have a yellow hue. Because of this coloring, light can be used to test if too much bilirubin is present by simply measuring how light reflects off of the infant's skin.



CREDIT: Philips Healthcare.

Four major features impact how light will reflect from infant skin: melanin, hemoglobin, bilirubin, and the age of the skin. The first three contributors absorb light of different colors, so each can be measured using different colors of light. Finally, the infant's age is known, so combining this information with the reflected light gives clinicians a way to measure the concentration of bilirubin for any infant by simply shining light on the baby's skin.

Accidental discovery of light therapy

Exposing infants to sunlight has been practiced for hundreds of years; however, the exact reason that sunlight helped the babies was unknown. One warm summer day in

the 1950s at the premature unit at Rochford General Hospital, Essex, Sister J. Ward brought a premature infant outside. Upon returning to the unit, the baby was a pale yellow except for a small bright yellow section which had been covered up by the baby's sheet. The nurse suggested it had been caused by the sun, but this suggestion was not taken very seriously.²

Not long after this incident, a tube of blood from an infant with severe jaundice was placed on a windowsill before being taken to the lab for analysis. After sitting by the window, the sample measurements were well below the expected level: 13–14 mg/100 mL. Since these measurements were obviously in-

correct, a fresh blood sample was drawn and analyzed, which read 24 mg/100 mL. The blood sitting on the windowsill was measured again and read even lower, at 9 mg/100 mL. Finally, these two sets of findings caused researchers to investigate the effect of light on bilirubin.²

Treating neonatal jaundice

Research teams determined that irradiating bilirubin with blue light causes the bilirubin molecules to interact with oxygen. This causes the bilirubin molecules to change structure, creating a form of bilirubin that can be excreted naturally in the urine or bile, decreasing the infant's toxic bilirubin levels.¹

The ideal wavelength to deliver treatment spans 460–490 nm, i.e., blue light, since this is the region in which bilirubin most highly absorbs light. Note that this does not include ultraviolet (UV) light; therefore, no harmful ionizing radiation is delivered to the neonate.¹ Infants who are in need of treatment are commonly placed in special beds that

have a blue light bulb that shines on them from above. Recently, blankets that are capable of delivering blue light therapy have been developed, allowing the infant to be with his/her mother during this important bonding time.

Even the simple act of shining light on the body has tremendous healing potential, and the detection and treatment of neonatal jaundice are two great examples of the use of light to improve patient care and our daily lives. The International Year of Light 2015 offered a fantastic opportunity to recognize the countless applications of light-based technologies in the medical field, and the roles they will play in the future of healthcare.

MORE INFORMATION

1. M. J. Maisels and A. F. McDonagh, "Phototherapy for neonatal jaundice," *New England Journal of Medicine* 358(9), 920–928 (2008).
2. R. H. Dobbs and R. J. Cremer, "Phototherapy," *Archives of Disease in Childhood* 50(11), 833–836 (1975).

Christine M. O'Brien is a graduate student at Vanderbilt University studying the use of Raman spectroscopy, a light-based method that looks at the molecular makeup of a sample or tissue, for women's health applications. Christine is the current President of the Vanderbilt SPIE Student Chapter and enjoys participating in outreach aimed at teaching and exposing young students to light-based technologies and careers.

Isaac Pence is a graduate research assistant at Vanderbilt University investigating the use of light-based technologies, such as Raman spectroscopy, to improve disease diagnosis in clinical medicine. Isaac is an active member and former leader of the Vanderbilt SPIE Student Chapter, through which he and his fellow students try to promote photonics and science outreach, sharing of ideas, and optics research and technologies for health care.

The Height of Light: From a Curiosity to a Global Phenomenon

Sarah Bates, National Science Foundation, USA

Lasers have long energized our imaginations, bringing us light sabers and holodecks. And, more recently, even laser cats.

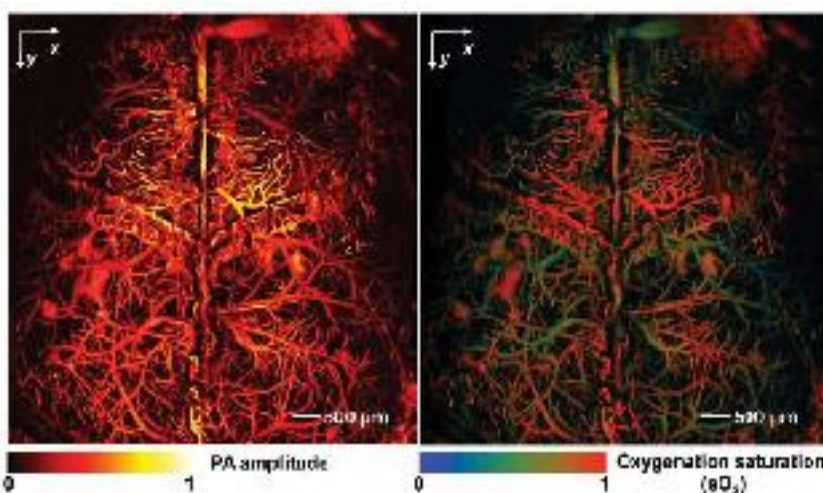
In reality, light-based technologies enable our modern lifestyles, from high-speed communications to observatories that glimpse at the universe's origins. Underlying these innovations are fundamental properties, materials, and designs.

Lasers, in particular, were famously described as a “solution looking for a problem” in 1960. That’s a phrase that could refer to many areas of discovery-driven research. Importantly, in retrospect, that phrase drives home an antithetical point: We don’t know where solutions will come from.

Knowledge and inventions created by modern explorers of the unknown (i.e., scientists and engineers) often start out as curiosities and end up bringing our world closer together.

To celebrate lasers and other light sources, the U.S. National Science Foundation, which invests in the best and the brightest of those science and technology pioneers, recently put out an article series on light. Here are some excerpts.

Besides laser cats, where would you like to see light take us next?



A mouse brain imaged without imaging agents by using photoacoustic microscopy. CREDIT: Junjie Yao and Lihong Wang, WUSTL.

Seeing more deeply with laser light

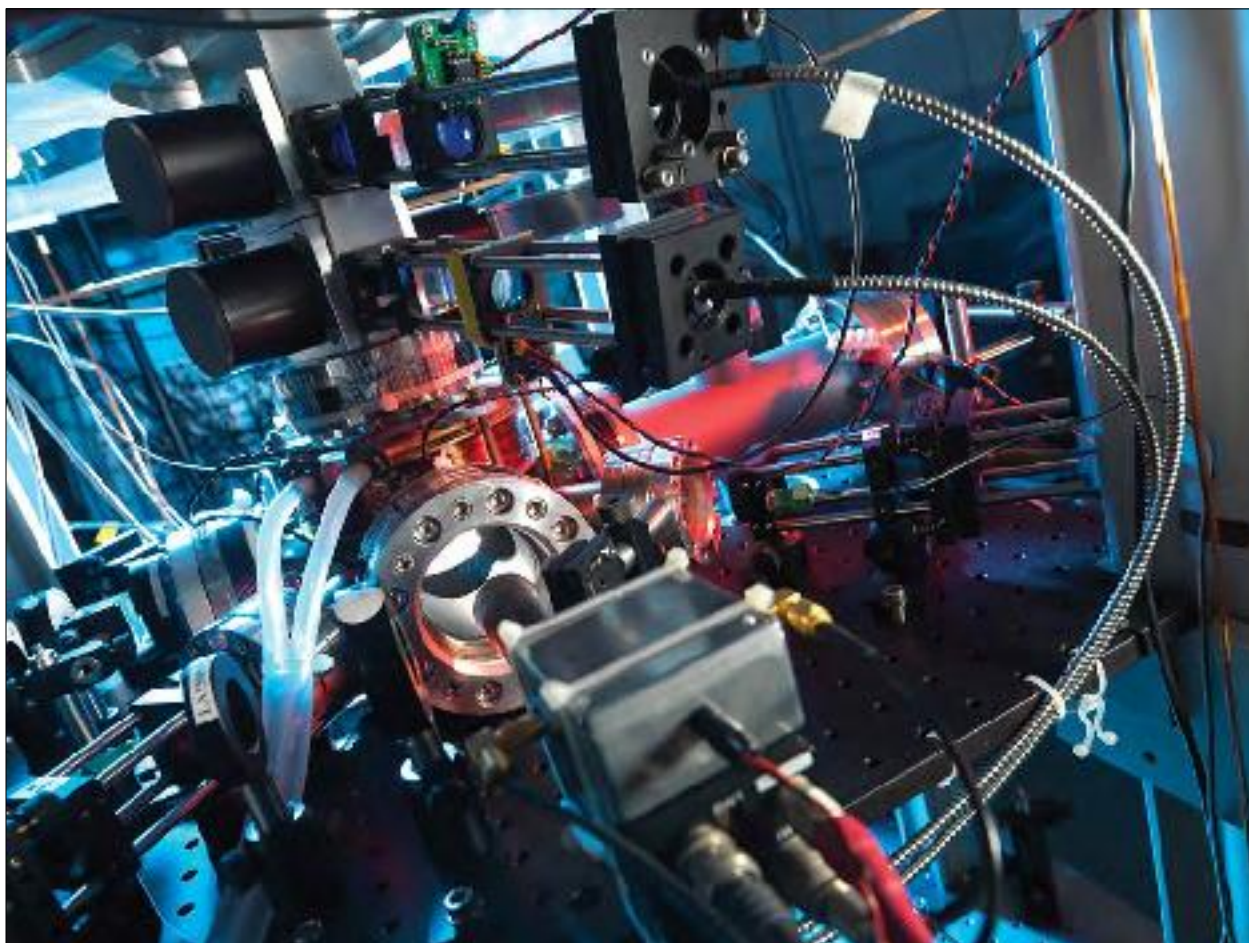
A human skull, on average, is about as thick as the latest smartphone. Human skin is only about three grains of salt deep. Yet skulls and skin still present hurdles for any kind of imaging with laser light. Why?

Laser light contains photons, or miniscule particles of light. When photons encounter biological tissue, they scatter. Corraling the tiny beacons to obtain meaningful details about the tissue has proven one of the most challenging problems laser researchers have faced. Researchers at Washington University in St. Louis (WUSTL) decided to eliminate the photon roundup completely and use scattering to their advantage.

The result: An imaging technique that penetrates tissue up to about 2.8 inches. This approach, which combines laser light and ultrasound, is based on the photoacoustic effect, a concept first discovered by Alexander Graham Bell in the 1880s.

Whispering galleries that speak loudly on disease detection

Commonly used health tests, such as pregnancy and blood sugar tests, involve putting a drop of fluid on a test strip infused with a substance designed to detect a specific molecule. The strip acts as a simple biosensor, a device that detects chemicals with the help of biological molecules such as proteins or enzymes. These devices work, but are limited in scope and can be im-



UK National Physical Laboratory cesium fountain clock. CREDIT: National Physical Laboratory, UK.

precise. Other health tests require time-consuming chemical reactions or bacterial culture.

Researchers at University of California-Riverside are creating a new biosensor that uses laser light, engineered viruses, and advanced manufacturing techniques to more accurately detect the smallest amounts possible of biological molecules in our food, in our water, and even in our own blood.

Thanks to these technologies, biosensors of the future may be in fibers woven into clothes.

Building a better atomic clock

Prior to the mid-18th century, it was tough to be a sailor. At the time, sailors had no reliable method for measuring longitude, the coordinates

that determine a point's east-west position on the globe. To find longitude, you need to know the time in two places—the ship you're on and the port you departed from. By calculating the difference between those times, sailors got a rough estimate of their position. The problem was that the clocks back then couldn't keep time well.

Today, time is as important to navigation, only instead of calculating positioning with margins of errors measured in miles and leagues, we have GPS systems that are accurate within meters. And instead of springs and gears, our best timepieces rely on cesium atoms and lasers.

An NSF-funded scientist at University of Alabama at Birmingham who



A fiber-making process that is a lot like making cotton candy, except that electric fields are involved. CREDIT: Joe Cheeney, University of California-Riverside.

works on atomic clocks was inspired by the story of John Harrison, an English watchmaker who toiled in the 1700s to come up with the first compact marine chronometer. This device marked the beginning of the end for the “longitude problem” that had plagued sailors for centuries. The scientist and other researchers now look for new ways to make clocks more accurate, diminishing any variables that might distort precise timekeeping.

Figuring out how to hide things

The idea of cloaking and rendering something invisible hit the small screen in 1966 when a Romulan Bird of Prey made a surprise attack on the Starship Enterprise on Star Trek. Not only did this make for good TV, it inspired budding scientists, offering a window of technology’s potential. Today, pop culture has largely embraced the idea of hiding behind force fields and other materials. And

so have mathematicians, scientists, and engineers.

Researchers have developed new ways in which light can move around and even through a physical object, making the light invisible to parts of the electromagnetic spectrum and undetectable by sensors. Additionally, mathematicians, theoretical physicists, and engineers are exploring how and whether it’s feasible to cloak against other waves besides light waves. In fact, they are investigating sound waves, sea waves, seismic waves, and electromagnetic waves including microwaves, infrared light, and radio and television signals.

Letting go with lasers

Plenty of parents dread hosting a party that involves confetti. Just like glitter, it often finds its way to everything else you touch. Why do small objects stick to things when larger objects don’t?

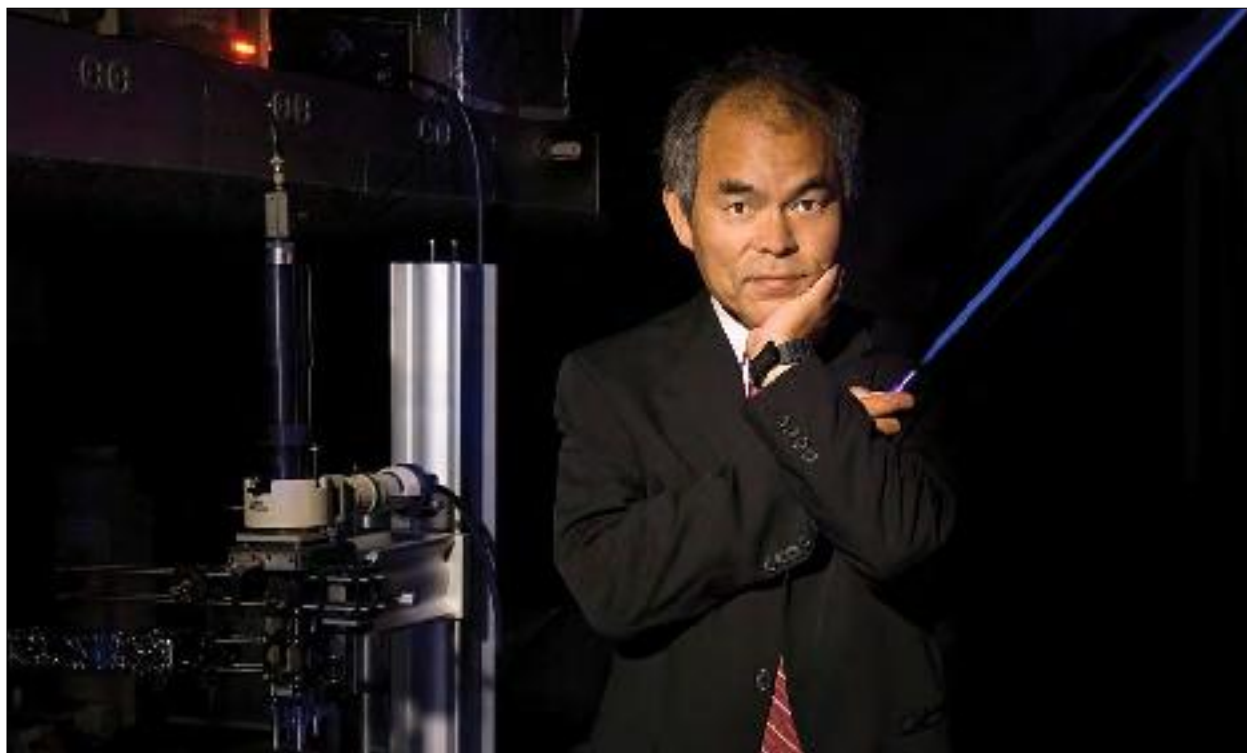
It’s all about the physics of letting go. When you place your hand around a smooth soda can, you exert a force through your grip in order to pick it up; if no force is applied, gravity keeps the can in place as your hand raises without the can.

The two basic principles of volume and weight that make picking up a soda can easier than handling a speck of glitter continues to apply as objects become smaller. With these principles in mind, University of Illinois at Urbana-Champaign researchers are using lasers to “break” adhesive forces to manufacture objects too small for the human eye to see.

Sarah Bates is a public affairs specialist with the National Science Foundation, where she oversees communications for the Directorate for Engineering. She works with a team of talented science communicators to tell stories about fundamental science and engineering research.

The Lighting Revolution

Michael Banks, *Physics World*, UK



CREDIT: Randall Lamb, University of California Santa Barbara.

Light-emitting diodes are ubiquitous in our daily lives, helping to provide light in our homes as well as give a crisp display in TV and smartphones screens. But if it wasn't for the pioneering work of three researchers in Japan—Isamu Akasaki and Hiroshi Amano from Nagoya University and Shuji Nakamura, then based at the Nichia Corporation—it might have been different.

In the 1980s, the trio managed to create highly efficient blue light-emitting diodes (LEDs), a discovery that opened the way for a new form of lighting through the production of white light from LEDs.

LEDs work by applying a current to a layer of semiconductor materials that then emit a particular wavelength of light depending on the chemical make-up of those materials. The first red LED was created in the early 1960s using gallium arsenide, and researchers then managed to create devices that emitted light at shorter wavelengths, reaching green by the end of that decade.

However, scientists struggled to create devices that could deliver enough blue light, which is essential for a source of white light, needing, as it would, red, green, and blue LEDs. There were some early examples of blue LEDs, led

by researchers at the Daresbury Laboratory in the UK, but the development of blue LEDs that could be commercially viable sources of light only really took off in the 1980s.

Akasaki, Amano, and Nakamura focused on the compound semiconductor gallium nitride (GaN) to make blue LEDs and overcame problems in getting blue light by creating high-quality crystals of GaN. By tweaking various layers of gallium nitride, as well as indium gallium nitride layer—a key material as it emits blue and green light—they managed to generate blue light efficiently. Their breakthrough was honoured

last year when they shared the 2014 Nobel Prize for Physics for “the invention of efficient blue light-emitting diodes (LEDs) which has enabled bright and energy-saving white light sources.”

To tie in with the International Year of Light and Light-based Technologies 2015, I interviewed Nakamura during the American Physical Society March meeting in San Antonio, Texas earlier this year. During our chat, Nakamura highlighted the challenges he faced to build a blue LED and even admitted that people today don’t really understand how it works. “Nobody knows the physics behind why it works and is so efficient—it’s still a mystery,” he says.

But now that LEDs are well established, what might come next in the

lighting revolution? One prospect that excites Nakamura is laser lighting—a semiconductor device that produces coherent radiation in the visible or infrared spectrum when current passes through it.

By using laser diodes, it could be possible to obtain a luminescence 1000 times higher than an LED to make a very bright light source. Nakamura says it could take 5 to 10 years, but there are a number of challenges to overcome. “Currently, laser diodes are very expensive—around \$10 for a laser diode, but just \$0.10 for an LED,” says Nakamura. “Also, the ‘wall plug’ efficiency of laser diodes is around 30%; this is not high enough compared to the blue LED, which is about 50–60%.”

Nakamura told me that his life

hasn’t changed much since winning the Nobel prize—the most distinguished award in physics—only that the Japanese media follow him more and that students recognize him now. Although, at least Nakamura has a “free car-park space” at the University of California, Santa Barbara, where he now works.

But while his life may not have changed much, no doubt the discoveries he has made have helped changed how we live our lives.

Michael Banks is news editor at *Physics World* magazine, in Bristol, UK. He joined the Physics World team in October 2007, after completing his Ph.D. in experimental condensed-matter physics at the Max Planck Institute for Solid State Research in Stuttgart, Germany.

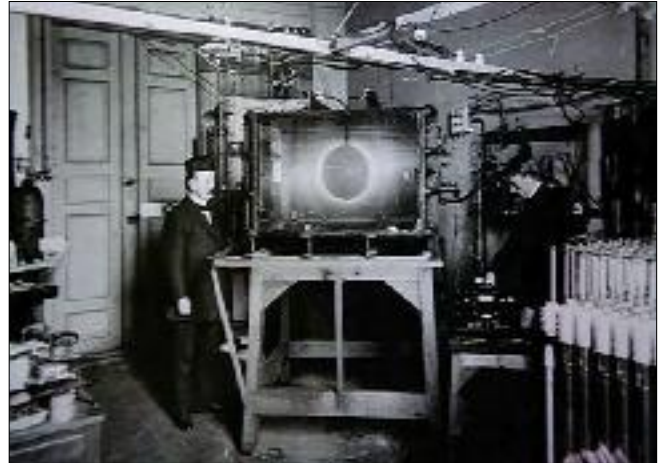
The Northern Lights: A Magic Light Display

Pål Brekke, Norwegian Space Centre, Norway

For thousands of years people in the northern part of the world have marveled at the spectacular and fearful displays that occasionally light up the night sky. The Norwegian scientist Kristian Birkeland (1867–1917) was the first to explain the real cause: particles from the Sun were sparking the Northern Lights. To prove his theory—which is still valid today—he built his own small world in a glass box, electrified his model of Earth with its own magnetic field, and showed how particles from the Sun could ignite auroras. The particles were captured by the Earth’s magnetic field and channeled down toward the Polar Regions.

The Northern Lights mechanism

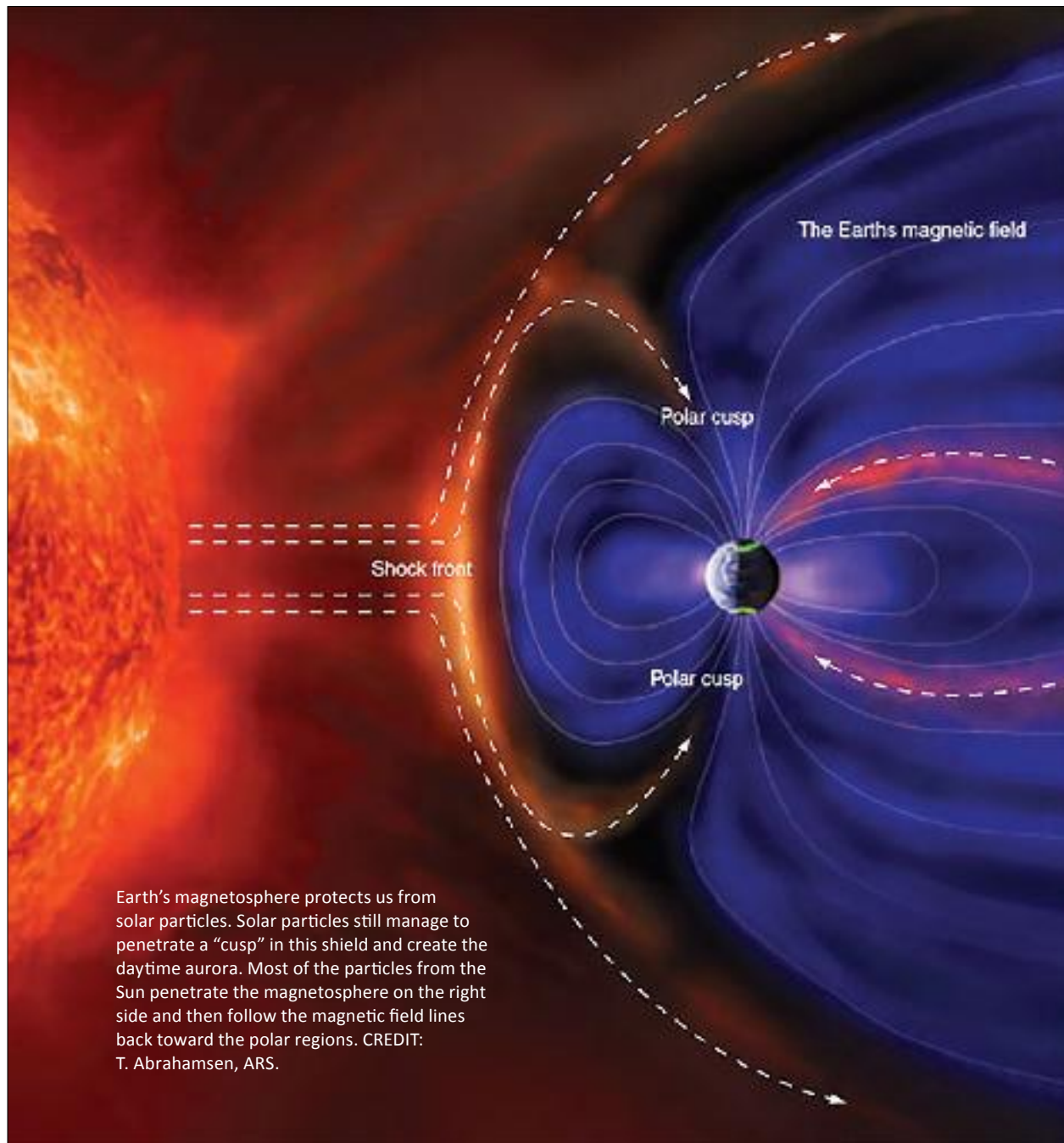
When particles and magnetic fields from the Sun reach Earth, something strange happens. It’s as if they are deflected by an invisible shield—the Earth’s magnetic



Kristian Birkeland with his Terella experiment. The metal sphere was his model Earth, while the vacuum glass container was space. When Birkeland sent particles toward the sphere, the Polar Regions glowed. CREDIT: University of Oslo.



The aurora oval (green) is the belt around the geomagnetic North Pole where aurora activity is highest. CREDIT: From the documentary *The Northern Lights: A Magic Experience* by P. Brekke and F. Broma, SOLARMAX (2015).



field—called the magnetosphere. The two magnetic fields couple together and disturb the magnetosphere. Some particles manage to enter the magnetosphere and will be guided along the magnetic field lines toward the Polar Regions of the Earth. Eventually they collide with atoms in the Earth's atmosphere.

These collisions usually take place 80–300 km above ground. Here they cause oxygen and nitrogen to become excited and to emit light in much the same way as fluorescent lights or in advertising neon signs. The result is a

dazzling dance of green, blue, white, and red light in the sky forming in a ring-shaped area called the aurora oval.

Modern science

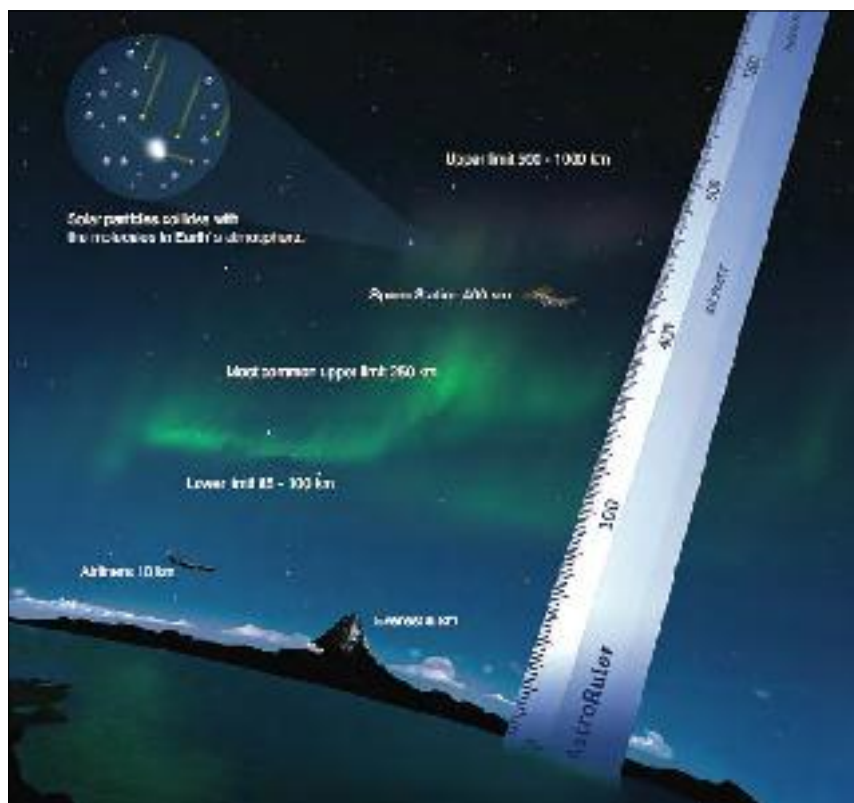
The science of heliophysics improves our understanding of the Sun and its interactions with the Earth and solar system. Today we study the Northern Lights from ground-based instrumentation, sounding rockets, and satellites. A large number of other all-sky cameras and instruments are situated in many northern countries to study the Northern Lights. This includes incoherent scat-

ter radars such as the large EISCAT antennas at Svalbard. Co-located is the new Kjell Henriksen Observatory, which was opened in 2008 and is the largest of its kind, with 30 instrument rooms with domes. Here, scientists around the world can remotely operate their instruments from their home institution. What makes Svalbard special is that it is located right under the magnetic cusp where particles from the solar wind can enter directly into Earth's atmosphere and create the daytime aurora.

Using rockets launched from Fairbanks, Alaska in the US, and Andøya or Svalbard in Norway, one can spear through the aurora and actually measure its physical properties. Satellites provide a global view and have given us a lot of new knowledge about the Northern Lights and the interaction between the solar wind, the magnetosphere, and the atmosphere. NASA maintains a fleet of solar, geospace, and heliospheric spacecraft as a distributed observatory to study these interactions and the complex system that makes up our space environment. Missions such as the Solar Terrestrial Relations Observatory (STEREO), the joint ESA/NASA Solar and Heliospheric Observatory (SOHO), the joint ESA/NASA Cluster, and NASA's Time History of Events and Macroscale Interactions during Substorms (THEMIS) all have provided insight into the dynamic processes that cause the Northern Lights.

How to predict the Northern Lights

NASA's Solar Dynamics Observatory (SDO), SOHO, and several other satellites are observing the Sun 24 hours per day, and scientists can detect eruptions on the Sun that will produce strong Northern Lights. By monitoring the activity on the Sun every day and by measuring the speed of the solar wind outside Earth's magnetosphere



The height of the aurora compared with the typical height of clouds, the highest mountain peak on Earth, Mount Everest, the typical cruising altitude of an airliner, and the space station. CREDIT: "The Explosive Sun," P. Brekke and T. Abrahamsen, Andøya Space Centre.

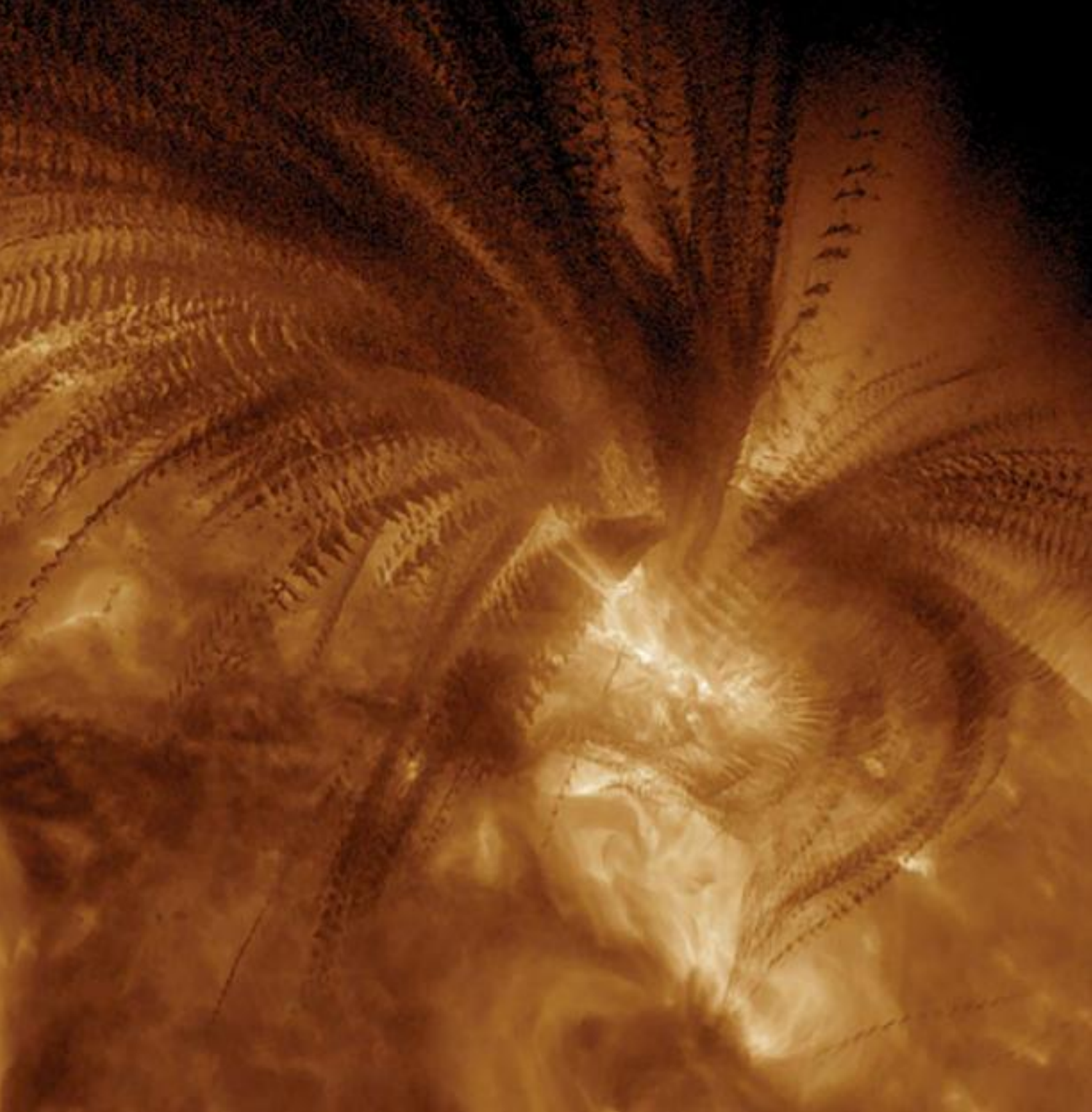
using NASA's Advanced Composition Explorer (ACE) spacecraft, scientists can predict the strength and the location of the aurora.

MORE INFORMATION

P. Brekke and F. Boms, *The Northern Lights: A Guide*, Forlaget Press, Oslo (2014).

The Northern Lights: a Magic Experience, a documentary by P. Brekke and F. Boms, SOLARMAX (2015).

Pål Brekke is currently a Senior Advisor at the Norwegian Space Centre, as well as a delegate to the ESA Science Programme Board, ESA Space Situational Awareness (SSA), a delegate to the International Living with a Star program, a Prof. II at the University Center at Svalbard (UNIS), Norway, an author, and a filmmaker. He received a Ph.D. in 1993 from the Institute of Theoretical Astrophysics, University of Oslo, where his research focused on the ultraviolet emissions from the Sun observed with instruments on sounding rockets and the space shuttle Challenger.



On 6 July 2011 the Sun exhibited a very large eruption, in which a large, massive filament was thrown up from the surface. The cool, dark material absorbed EUV light coming from behind it, causing a dark appearance of the ejection material. While, commonly, most of such ejected material becomes part of a coronal mass ejection moving into the planetary system, in this case most fell down again subject to solar gravity. This image is a stroboscopic composite from a sequence of originals taken one minute apart. Putting all of this together makes a shape reminiscent of a sword fern. Solar scientists use these trajectories to measure where material moves largely in free fall (ballistically) and where the magnetic forces become comparable to gravity to bend matter away. One example of such bending can be seen to the right of center, low in the image, and others in the upper left. CREDIT: NASA.

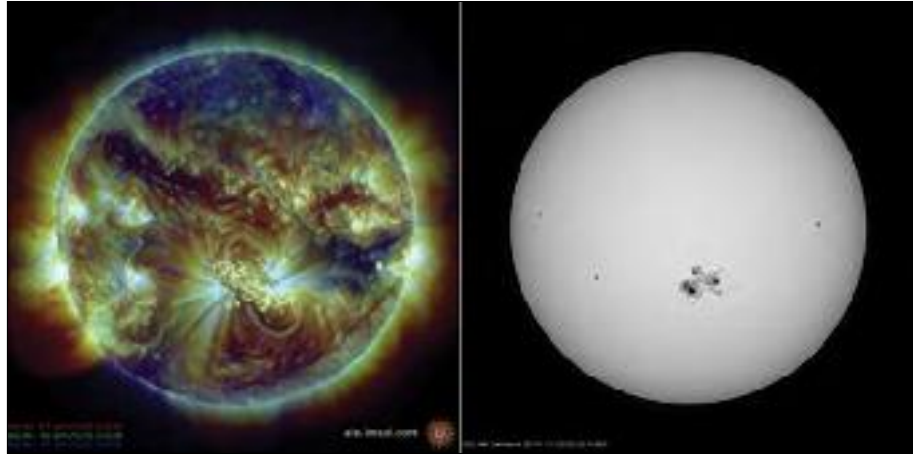
The Sunlight We Cannot See

Karel Schrijver, Lockheed Martin Advanced Technology Center, USA

Imagine the Sun's surface as an utterly black sphere. Imagine a cloudscape above this that comprises colorful fans of glowing wisps of translucent fog, all vastly larger than the Earth, which are continually swaying and pulsing, occasionally being torn apart by lightning storms of literally astronomical proportions.

Difficult? Not with some of the remarkable telescopes onboard NASA's Solar Dynamics Observatory (SDO). These telescopes see that dynamic cloudscape, the Sun's outer atmosphere, all the time, every day of the year, taking a picture almost every second over the past five years. These telescopes look at the Sun's extreme ultraviolet (EUV) glow. That glow comes only from parts of the Sun's atmosphere where the temperature exceeds a million degrees, not from the solar surface that is "merely" a few thousand degrees and that consequently is simply black in SDO's EUV images.

High above the solar surface, at heights between about 4,800 km to over 160,000 km, temperatures soar to several million degrees, with large differences existing side by side, kept apart by magnetic forces. Three of the four telescopes that make up SDO's Atmospheric Imaging Assembly (AIA) take EUV pictures at a handful of EUV colors. When combined in triplets, transformed



Images taken by NASA's Solar Dynamics Observatory on October 24, 2014. The image on the left shows the Sun's hot atmosphere in EUV light, with colors measuring temperature: blue is about 1.1 million degrees Celsius, green about 1.6 million, and red 2.2 million. The image on the right is taken in visible light at the same time, showing how we would see the Sun if viewed with a safe telescope. The sunspots seen on that day were the largest in over 25 years; the Earth would easily fit into the dark core of the largest spot. CREDIT: NASA.

into red, green, and blue hues that our eyes can see, the beauty of the Sun's outer atmosphere is revealed.

The EUV light from the Sun's atmosphere cannot be seen by unaided human eyes. In fact, no eyes on Earth can see that light because it does not penetrate our atmosphere, which is good, because EUV light is a dangerous form of light that can quickly and deeply damage human tissues. In order to record EUV light, telescopes have to be launched into space. And that is what NASA did with SDO early in 2010; it is orbiting the Earth, looping in the sky somewhere over Arizona. There, a large antenna captures SDO's radio signals. Within minutes, the transmitted images are stored in the digital archive from where they are distributed to anyone anywhere in the

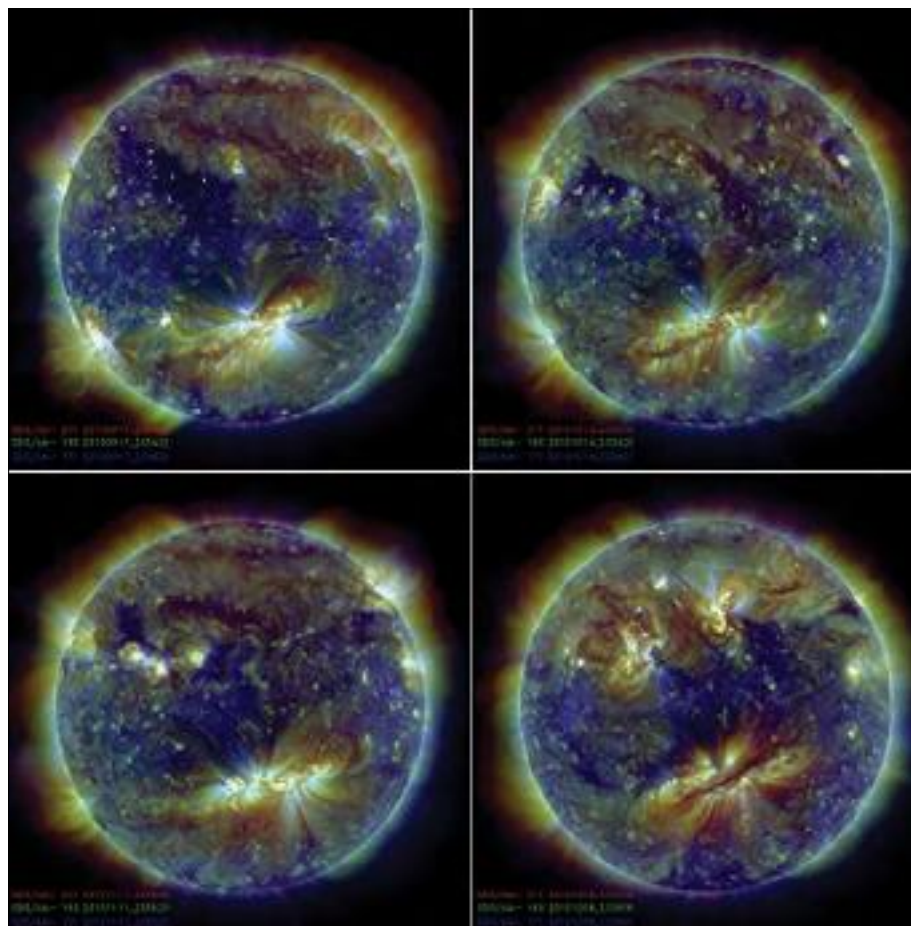
world who wants to view the Sun in light that human eyes can never see.

Why do we do this? One reason is that the Sun is the only star in the universe that is close enough to Earth to be observed in detail. These observations help us uncover how a star can maintain a strong magnetic field, how that magnetic field can form sunspots (and similarly star-spots on other stars) when it rises to the surface from deep inside the star, and how the motions in that field cause the Sun's atmosphere to be hundreds of times hotter than its surface. The EUV is brightest wherever the field is strongest (as is the comparable x-ray glow from the hottest parts of the Sun's atmosphere); large sunspots formed by bundles of strong magnetism have a very bright hot atmosphere above

them. Observing the Sun's atmosphere is also teaching us how strong and dynamic magnetism can lead to explosions on the Sun that are so violent that we would measure them in units of billions of nuclear bombs. Studying how and why this all happens helps us understand the other stars in our Galaxy and beyond. And it helps us understand how stars may affect the planets that orbit them.

That brings us to another important reason to observe the Sun: Stars, including the Sun, not only shine steadily in the visible light that warms the planets, but send out explosions of x-ray and EUV light, sprays of particles at near light speed, and racing magnetic clouds. At the surface of the Earth, shielded by a thick atmosphere and geomagnetic field, living beings are not significantly affected even by the largest explosions on the Sun. But satellites and astronauts in space can be. And the large, high-voltage electric power grids on Earth can also be perturbed. The causes of the Sun's variability, and the consequences of that variability around Earth and in society's technologies are now described by the term "space weather." SDO was built both to help us understand the astrophysics of our local cosmos and to learn how we can protect ourselves from inclement space weather.

Scientists from around the world discover new things about our Sun and thus about distant stars like it by using SDO's EUV images, made in light that cannot be seen by human eyes. These images are recorded by dig-




These EUV images of the Sun's outer atmosphere were recorded with SDO's AIA telescopes one solar rotation (approximately 27 days) apart so that the same side of the Sun is seen in each image. The large, bright, magnetic region in the southern hemisphere changes shape gradually, with a long, dark filament forming in its center, but is recognizable from image to image. Elsewhere on the Sun, new magnetic regions emerge, and existing ones are distorted, while their temperatures (shown by the colors) change all the time. There are no fixed features in the magnetic landscape of the Sun. SDO observes the Sun continuously so that we can follow all of the changes ... until the Sun's rotation makes a region vanish from view altogether. CREDIT: NASA.

ital cameras floating in space, then transformed into radio signals (another form of light that human eyes cannot see) and sent down to Earth. And then, having been transmitted through the Internet by electrons, we can finally see the Sun's beautiful, mesmerizing atmospheric glow when all is put together again on monitors in false color for us to behold. Light of all sorts, visible and invisible, is the astronomer's lifeblood without which we would not know the universe around us. SDO's AIA is one wonderful example of that.

Karel Schrijver is a solar physicist at the Lockheed Martin Advanced Technology Center in Palo Alto, California, USA and the principal investigator for the Atmospheric Imaging Assembly of the Solar Dynamics Observatory. He was trained as an astrophysicist specializing in magnetic activity of stars like the Sun and received his doctorate in 1986, since which time he has devoted his research to solar activity and the heliosphere, and the impact of solar magnetism on society.

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Fresnel Lens of the Heceta Head lighthouse on the Oregon Coast.
Built in 1894, the tower is 56 feet tall and is the most powerful light along
the Oregon coast. The light can be seen 21 nautical miles out to sea.

CREDIT: Shutterstock/David Gaylor.





INTERNATIONAL
YEAR OF LIGHT
2015

The International Year of Light and Light-based Technologies 2015 (IYL 2015) has been a tremendously successful global initiative with thousands of events reaching millions of people in over a hundred countries. United by the interdisciplinary theme of light, IYL 2015 has brought together a diverse range of participants along with UNESCO, all committed to raising awareness of how light science and technology provide solutions to the many challenges facing the world today.

This book contains a selection of writings that were inspired by IYL 2015 and published on the IYL 2015 blog throughout the year. It has been produced as a retrospective to help celebrate the IYL culminating activities in early 2016. The selections reflect the many ways in which light enriches our world, our cultural experiences, and our quality of life.



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