STAR LIGHT

Dr Rob Massey
Deputy Executive Secretary,
Royal Astronomical Society

There are few more fitting topics than astronomy for 2015, the International Year of Light, and the Royal Astronomical Society is proud to be a partner in the celebration of everything our science is about. Astronomers have to make the most of every photon they detect, in the process eking out information about the universe around us, to better understand the origins and ultimate fate of the planet we live on.

Anyone who has, even once in their life, been fortunate enough to see a night sky unsullied by light pollution will understand the power that view has to provoke soul-searching questions. Early civilisations were inspired too, placing their gods and heroes in the sky in constellations, and building stone circles to reflect the movement of the Sun and Moon.

Without the aid of modern instruments, early astronomers used light entering their eyes to speculate about the nature of the Sun, Moon, stars and planets, with various attempts made to establish the scale of the universe and whether the Earth was really at its centre. The Islamic world saw many of the best efforts, like Ulugh Beg's 15th century observatory in Samarkand, which used a giant sextant to measure the positions of the stars to high precision.

... using mirrors instead of lenses ...

But the real revolution began in 1608, with the application by Dutch optician Hans Lippershey for a patent for a new instrument. He assembled two lenses into a 'telescope', extending the view terrestrial observers had of their surroundings, an invention that was rapidly adopted across Europe. Telescopes do two crucial things; they collect more light than the eye can alone, making it possible to see fainter objects, and they improve resolution, letting us see those objects more clearly.

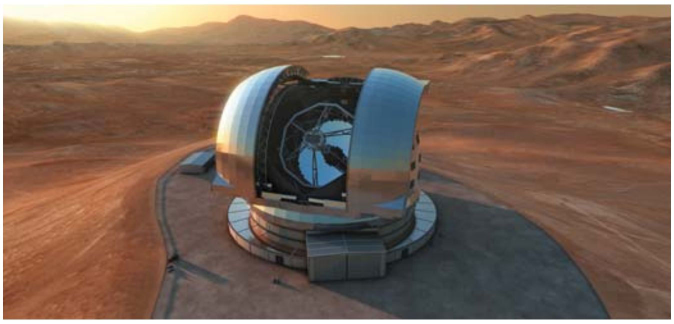
In the UK one of these 'Dutch trunkes' found its way to the traveller, mathematician and scientist Thomas Harriot, who in 1609 turned it to the night sky from his lodgings in Syon House in what is now west London. Harriot drew the first image of the Moon and soon made a surprisingly good map of its surface through a telescope, and also recorded sunspots. Unlike the deservedly more famous Galileo, little of his work was published in his lifetime, but he nonetheless deserves recognition for his efforts.

Galileo did far more across science and engineering as a whole, and in astronomy his more elegant lunar drawings reflect his artistic training. His illustrations from those first years look crude today, but are remarkable given the poor quality and restricted field of view of the earliest telescopes. With long tubes and unwieldy mountings, astronomy at the time was hindered by more than just weather.

In the same century Isaac Newton and others designed the telescopes that would improve upon those first devices, using mirrors instead of lenses to bring light to a focus. Lenses more than 1 metre across are not practical for telescopes, because they can only be held in place at their edges, whereas a mirror (supported from behind) can be built on a far larger scale. 'Reflecting' telescopes are therefore at the heart of all modern professional optical observatories. (In passing it is worth noting that William Herschel, first president of the Royal Astronomical Society, used a Newtonian reflector to discover Uranus in 1781, in the process doubling the size of the Solar System.) The issue of size is central to astronomy – seeing fainter objects more clearly is only possible by collecting more light with bigger mirrors and lenses – and this pushes astronomers and engineers to design ever larger facilities.

A Hubble Space Telescope infrared image of the Horsehead Nebula, a cloud of gas and dust in the constellation of Orion, located 1500 light years away. Credit: NASA, ESA and the Hubble Heritage Team (STScI/AURA).

As important though as the limitations of telescopes, are the weaknesses of the human eye. Our eyes see and interpret light in a complex way and for a short period of time, meaning that looking through even the largest instruments does not realise their potential. The use of photographic plates from the late nineteenth century improved this dramatically, as surveys of the sky with exposures of an hour or more revealed countless hitherto unsuspected faint stars, clouds of gas and dust (nebulae) and many more galaxies like our own – none of which were visible to the human eye simply looking through a telescope.



An artist's impression of the European Extremely Large Telescope (E-ELT) on its site on Cerro Amazones, 3060 metres high in the Chilean Atacama Desert. With a mirror 39 metres across, E-ELT will be the largest optical/infrared telescope in the world and will start work in the next decade. Credit: ESO/L.Calçada.

In today's observatories, so-called Charge Coupled Devices (CCDs) that record up to 90% of the light that falls on them have long superseded photography. They let observatories run at maximum efficiency, wasting as little as possible of the meagre amounts of light that strikes the telescope mirror. CCDs and similar sensors have become ubiquitous in everyday life, not least in the cameras in almost every new mobile phone.

Another indispensable part of the astronomer's toolkit is spectroscopy, in which light from an object is dispersed into its constituent colours (a spectrum) by a prism or grating. For visible light these range from long wavelength red to short wavelength blue and violet. Stars and planets have characteristic patterns of dark and bright lines in their spectrum, corresponding to specific chemical elements and molecules. With spectroscopy, astronomers can tell what an object is made of, how hot it is and also how fast it is moving towards or away from us. The power of this technique is remarkable – for example finding the signatures of oxygen and water, in the spectrum of a planet in orbit around a star, tens of light years from the Sun, could hint at the presence of life.

These days, there is a renewed push to build larger telescopes, but it is completely impractical to make single mirrors that are big enough to do the job. Engineers now make the equivalent from an array of many hexagonal segments. The last two decades have seen the construction of a number of telescopes with mirrors 8 metres and more across, with an excellent example being the Very Large Telescope (VLT) in Chile, part of the European Southern Observatory, which collects 100,000 times as much light as Harriot's first 'trunke'. The theoretical resolution of these monster instruments is extraordinary, good enough to spot a hotel-sized building on the surface of the Moon, but unfortunately (for astronomers) the Earth's atmosphere gets in the way.

Even on the highest mountaintop sites, chosen for observatories to be above most of the cloud and much of the atmosphere, still higher turbulent air turns a sharp image of a star into a blurry, shimmering smudge. To overcome this astronomers can monitor a real or artificial star (generated by a laser) in real time, deforming another mirror to restore a sharp image. These 'adaptive optics' systems let telescopes on the ground compete with those in space.

A more intuitive and ambitious solution is to put a telescope in space to begin with, something first suggested in 1947. This is also the only way to see many regions of the spectrum of 'light' or electromagnetic radiation, which extends far beyond what we can see with our eyes. The atmosphere stops infrared and microwave radiation from reaching the ground, along with ultraviolet, X-rays and gamma rays. Sounding rockets, balloons and planes carry instruments high enough for a temporary peek, but only satellite observatories can operate for any length of time.

The most famous of these is the Hubble Space Telescope, which celebrates its 25th anniversary this year and through our membership of the European Space Agency, the UK has been involved in Hubble from the start. This remarkable telescope has made major discoveries, including 'dark energy' (the mysterious force speeding up the expansion of the Universe), and sent back the first pictures of forming planetary systems.

There is no sign that this quest to push the boundaries will end any time soon. The 2020s will see even more powerful telescopes on the ground and in space. The VLT will be dwarfed by a new neighbour, the European Extremely Large Telescope, with a mirror 39 metres across, and in space the James Webb Space Telescope will take over where Hubble leaves off, observing the first stars that formed after the Big Bang using infrared light. More than a hundred thousand antennas across South Africa and Australia with make up the giant Square Kilometre Array, currently headquartered in the UK, a super-sensitive radio telescope that will have to cope with flows of data 10 times as much as that handled by the whole of the Internet put together.

We should therefore celebrate astronomy during this celebration of light. It has led to spin out companies and inventions in everything from hospital scanners to security, from analysing paintings to managing 'big data' on an enormous scale. UK astronomers are a close third in the world for the number of papers cited, have been highly regarded across the world for more than four centuries and are active in the projects that will shape the field in the next two decades.

Artist's rendition of the part of the Square Kilometre Array (SKA), showing how the 15-m wide radio dishes will look when completed. Credit: SKA Organisation.

However we should not lose sight of the passion for science and engineering that astronomy fosters. Humans are innately curious about 'star light' and what it tells us about the wider universe, and our world is a better place as a result.

THE POWER OF LIGHT

Susie Wheeldon
Solar Aid

When Edison started selling electricity in 1882, over a billion people lived off grid. Today, despite huge advances in technology – breakthroughs that allow us to land space probes on comets and fight elections by hologram – that number remains unchanged [1]. In Africa, where the charity SolarAid operates, around 600 million [2] lack even the most basic lighting and energy services, more than the populations of Mexico, Canada and the US combined.

Yet for many, things are beginning to change. All due to the power of the simple solar light.

SIMPLE, SUSTAINABLE SOLUTIONS

If you were to combine a map of Africa showing areas of highest solar irradiation with one showing areas that do not receive a power supply, you would find, remarkably, that these areas overlap.

This provides us with a huge opportunity.

About six years ago three market forces came together to enable solar lights to become affordable to those living in low-income communities. Firstly the cost of solar panels came down, secondly LED technology became more efficient and thirdly, battery storage improved.

SolarAid was already working in Africa at that time, driving a wider programme including solar energy systems on schools, solar lighting products and manufacturing. But advances in small lighting technology, the reduction in price and the speed at which they could be deployed opened the door to something huge – something that could truly begin to tackle poverty and climate change simultaneously.

THE IMPACT OF A SOLAR LIGHT

Savings

Research shows that each solar light bought by a family in rural Africa results in the elimination of the regular use of a kerosene lamp, saving them around 10% of their annual income [3]. Our customers tell us that they spend their savings on food, school costs and investment in livelihoods, such as small farming inputs or, in some instances, a larger solar light they can use to start a small business charging mobile phones.

"I use my savings for buying soap and foods."
Mphasto Gondwe, Malawi

Enterprise

Nine in ten of the people we reach live under the poverty line of $1.25 per day – so saving 10% of their income makes a staggering difference [4]. The knock on effects of reduced vulnerability, increased enterprise and better nutrition are difficult to quantify, but we are building research in this area and hear thousands of stories of customers using their savings to open small businesses and their solar lights to do productive work at night.

"Before I bought the solar I used to close my shop early but nowadays I can stay up to 9:30pm.. which has helped me to get more profits .. The customers know that I always stay for long so they always come and refer other people as well." Charles Motoki, Kenya

Indeed, in many regions, solar entrepreneurs are now beginning to kick-start a sustainable market, creating jobs and opportunity. SolarAid's model, in which it has created a social enterprise to sell lights in Africa, was adopted to enable just that. By catalysing the introduction of solar markets in rural areas, rather than giving lights away, the charity not only reinvests all income into reaching more people with clean, safe light, but is creating a fledgling solar market for other organisations to join.

Kick-starting a thriving solar industry is the only way the charity will achieve its goal of eradicating the kerosene lamp from Africa by 2020.

Kerosene lamp

Health

As well as the huge economic benefits this will bring, replacing kerosene lamps with solar light also means that homes are safer due to reduced risk of fire. Even more significantly, solar lights replacing kerosene lamps reduces indoor air pollution – the 'silent killer' – that leads to 4.3 million deaths per year [5].

"I used to find soot in the noses of my children every morning when they slept in a room with kerosene, and they would complain of chest pains."
Veledian Phiri, Zambia

Many of the parents we talk to tell us that one of the main benefits the solar light brings is an improvement in the health of their children who no longer get eye irritation or flu-like symptoms. And of course, solar lights have huge benefits for education.

Education

Our research shows that with a solar light children can study an average of an extra hour each day [6]. Kerosene is often a luxury which can only be used sparingly. But with free solar light, children can do their homework, do better in exams and can write their own futures.

"Kerosene was expensive. I did not allow [my daughter] to study at night – now she is free to study anytime." Honoratha Elipidi, Tanzania

Well-being and opportunity

Some of the other ways in which a solar light can benefit a family may be more difficult to

quantify, but nonetheless are valuable. Parents tell us that having light in their home at night they feel safer and no longer have to worry about leaving their children in danger of an open flame. When light is free, families can come together, and enjoy sharing time with friends and neighbours. There is less fear of standing on a snake whilst going out to the latrine (something we don't worry about in the UK!), and more hope for students with the same dreams of those around the world, to become teachers, doctors, lawyers or business leaders.

"I understand the power of energy first-hand. It transformed my life, my own life, when I was a young boy in post-war Korea. A simple light bulb illuminated a whole new world of opportunity for me, enabling me to study day and night. This memory has stayed with me such a long time, throughout my life. I want the same opportunity for all young boys and girls around the world. Widespread energy poverty still condemns billions to darkness, to ill-health, to missed opportunities for education and prosperity." UN Secretary General, Ban Ki Moon

Solar lights and the environment

The switch from kerosene to solar lights will have a double benefit. One relates to development. The other will enable sustainable development to mitigate climate change.

On a micro scale, each solar light replacing a kerosene lamp removes up to 200kg of CO_2 per year [7], as well as toxic black carbon – or soot – that has a large, and immediate, impact on climate warming. On a macro scale, not only do those figures add up to create a significant whole, but the switch to solar lighting can drive low-carbon growth. We are beginning to see evidence of a clean energy ladder, where a family that has bought a small solar light, may look to buy a larger light – or even a home system.

"I have not used the money [that I'm saving] I have kept it somewhere, [because I] am planning to buy another solar which is big." Gladys Ombati, Kisii-Kenya

Off-grid lighting, solar home systems and mini grids can

provide a way for unelectrified rural communities to leapfrog the need for carbon intensive systems. We have seen how emerging economies moved to mobile phone technology without putting in land lines. They now lead the world in mobile enabled financial services. A similar shift could give emerging economies a clear advantage as we move towards a low carbon future.

Getting solar lights to those who need them most

Having solar light technology is one thing, getting it where it needs to go is another. This is where SunnyMoney comes in. Unelectrified areas are often those which lack transport infrastructure, strong commerce and good communications networks. SunnyMoney works through education authorities and a network of 700 solar entrepreneurs, to reach local communities with solar lights and to build the awareness and trust needed to encourage adoption of the new technology.

The organisation has now become the biggest distributor of solar lights in Africa, having sold over 1.7 million lights, reaching 10 million people. This has enabled people living in some of the world's poorest countries to save over $300 million dollars, and children to study for more than 2 billion extra hours.

Yet this is just the tip of the iceberg. SunnyMoney works in Kenya, Malawi, Tanzania, Uganda and Zambia. SolarAid's goal, however, is to develop solar markets across Africa by 2020, eradicating the toxic kerosene lamp. The educational uplift and financial savings this could bring will be astounding. Families will save billions of dollars. At government level, it will relieve pressure on already stretched resources and reduce the need for kerosene subsidies – themselves costing billions of pounds.

It is an ambitious goal. It is one we will not achieve alone. But in this UNESCO International Year of Light, we will be doing all we can to make it a reality.

For more information - or to donate or get involved, please see www.solar-aid.org

References

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ILLUMINATING LIGHT IN MEDICAL DIAGNOSTICS AND TREATMENT

Liz Benson
Clinical Scientist, King's College Hospital, London

John Allen
Clinical Scientist, Freeman Hospital, Newcastle Upon Tyne

The use of light in medicine is widespread.

The International Year of Light 2015 gives us an opportunity to appreciate well-established practices and to increase awareness of novel techniques for diagnosis and treatment. The Clinical Scientist has a crucial role in both the development and safe use of optical techniques across wavelengths from ultraviolet (UV) to the infrared (IR). From research and development to the testing of existing and innovations in medical equipment, ensuring the safe implementation of such devices, and carrying out procedures on patients; our professional roles are varied, challenging and interesting.

... used to indicate blood vessel abnormalities ...

LIGHT FOR DIAGNOSTICS

Many diagnostic applications of light look close to the skin surface: measuring blood flow, identifying skin and blood vessel anatomy and investigating the composition of tissues. Some key examples are summarised below.

In photoplethysmography (PPG) an LED and a photodiode are used at sites such as the ear lobe, finger and toe pads. The LED light, often near infrared, is modulated by changes in blood volume in the skin and a corresponding optical pulse signal detected by the photodiode. These measurements may be used to indicate blood vessel abnormalities such as narrowing, abnormal physiology and to provide a non-invasive measure of tissue oxygen saturation. In imaging PPG (iPPG) the pulse signals at each pixel of the camera can be used to form maps of the blood perfusion in layers of the skin.

Laser Doppler Perfusion Imaging (LDPI) can also be used for tissue perfusion mapping. A laser light is incident on the skin and penetrates to a depth governed by wavelength and power. The light is scattered by blood flowing in the tissue, the Doppler shift in the received signal indicates the degree of blood flow present. LDPI is particularly useful in imaging burn wounds to give the clinician information about burn depth. When a perfusion image, taken in the window of 2-5 days after a burn, shows a high degree of perfusion this is consistent with good healing potential of the affected tissue. A further application of LDPI is in diagnosis of endothelial dysfunction, an exciting area which has great future potential in medicine. Using a technique similar to laser Doppler, Laser Speckle Contrast Imaging (LSCI) uses the changes in 'speckle' pattern from a laser light illuminating skin to give information on the speed of blood flow but with the advantages of higher scan speeds and higher spatial resolution.

All objects produce infra-red or thermal radiation. This radiation may be detected using a thermal camera. In humans, higher temperatures are associated with increased blood flow. Therefore thermal imaging can be used indirectly to detect conditions indicated by abnormal levels of blood flow such as Raynaud's phenomenon, tissue inflammation, erythromelalgia, complex regional pain syndrome, and predicting the onset of foot tissue problems in patients with diabetes.

One can tell a lot by looking at a patient's hands. In capillaroscopy a microscope is used at the nail fold of the finger to look for evidence of changes to blood vessel structure ('morphology') and which might point to a connective tissue disease. Capillaroscopy is simple in concept but very powerful clinically. As well as the blood vessels, light also enables the structure of tissue to be seen and abnormalities identified. In optical coherence tomography (OCT) infra-red light is used in a similar way to ultrasound with reflections detected to produce a map of the region of interest. In this way, tissue discontinuities, micro-structures and blood vessel composition can be imaged at very high spatial resolution.

The phrase 'looking a bit off colour' is often used to describe someone who is ill. This concept is applied scientifically using spectrophotometry to measure the colour of tissue. The skin is illuminated using white light and the reflectance at different colours in the spectrum measured. One key colour range in clinical measurements is green. This method can be used to assess tissue oxygen saturation and in particular for the assessment of tissue viability in leg amputation level assessments.

... higher temperatures are associated with increased blood flow ...

We can all glow ("fluoresce") in the dark! By shining light of specific colours on our tissue, typically in the UV, it can be re-emitted at slightly longer ("red-shifted") wavelengths. Knowing the fluorescence signatures of different tissues, such as collagen or haemoglobin, allows an "optical biopsy" to be made. This fluorescence spectroscopy approach is largely a research technique with great potential looking for a clinical application.

... porphyrins then act to kill the bacteria ...

LIGHT FOR TREATMENT

One of the most well-established applications of light for treatment is UV therapy. UV is used to treat skin conditions such as psoriasis, eczema and vitiligo. Psoriasis is caused by the fast growth of skin cells, the UV wavelength penetrates beneath the skin and slows the growth of these skin cells. UV radiation may also be used to kill the bacteria that infect the plaques associated with psoriasis. Vitiligo is an autoimmune response in which the body destroys the pigment in patches of tissue. UVB wavelength light is used to re-pigment the skin and reduce the appearance of patches.

The use of visible light in blue-light therapy is also well-established. In the treatment of jaundice, exposure to blue-light oxidises bilirubin to biliverdin, which is then excreted in bile. In the treatment of acne blue-light activates the porphyrins within the acne bacteria. These porphyrins then act to kill the bacteria and relieve the acne. Not to be forgotten, infra-red wavelengths are applied in physiotherapy treatment. Infra-red light is applied directly to the injured part of the body, the radiation acts to heat the area and improve the circulation to that area. This increased circulation leads to a more rapid healing process.

Medical lasers of various wavelengths are used extensively throughout healthcare for many applications including ophthalmology, laser eye surgery, urology, gynaecology and the treatment of skin lesions.

LIGHT FOR CANCER

One of the biggest challenges facing healthcare today is the diagnosis and treatment of cancer. The use of light has been applied to this problem in several areas, a selection of these are discussed here.

Raman Spectroscopy is a rapidly developing technique, used to indicate the nature of cells. A laser light is directed at the tissue of interest. As the light interacts with the tissue cells an energy exchange takes place – Raman scattering. The scattered photons are detected and the energy exchange that has taken place indicates the state of the cell: normal, infected or cancerous. This application is used in areas that can be reached with a laser and via an endoscope, for example the skin and the urinary bladder. A map of cells in a region of interest is produced and the nature of cells and boundaries of tumours may be defined.

Cerenkov Luminescence Imaging (CLI) is also a developing technique with its first use on humans demonstrated in 2013. In CLI the ß-emitting radionuclides used in Positron Emission Tomography (PET) are utilised. When the radionuclide collects in its target organ these ß particles travel through tissue and cause the emission of Cerenkov Luminescence. This can be detected and is proportional to the concentration of radionuclide within an organ. The use of CLI has been demonstrated intra-operatively in the analysis of the removal of cancerous cells. This has implications for cancer surgery, in particular the reduction of re-section and cancer recurrence rates in breast cancer.

... reduction of re-section and cancer recurrence rates ...

Photo Dynamic Therapy (PDT) is one of the most established light based cancer treatments. In PDT the patient is given a photosensitizing drug which is excreted from normal cells but remains in cancerous cells. The patient is then exposed to the specific wavelength of light which activates the drug. The drug emits active oxygen which destroys cancerous cells. This treatment is suitable for cancers in areas which can be reached with a light source either superficially or using an endoscope, for example skin cancer or oral cavity cancers.

Laser surgery is often carried out to remove cancerous tissue and growths. The laser is a more effective cutting implement than is a traditional scalpel. Laser beams are high precision and blood is coagulated immediately so that bleeding is reduced and there is less tissue damage, therefore healing times are lower. Lasers may also be used for excision of less accessible tumours.

A FINAL WORD ON LIGHT

This article describes the numerous applications of light in medicine. When implementing all of these an important consideration is the safety of patients and members of staff. The health implications associated with excess exposure to UV are well documented, as are the hazards associated with the use of laser beams. One of the most important roles of the Clinical Scientist is to ensure that all assessment techniques are rigorously tested prior to introduction, that clinical protocols are in place for the use of such techniques and of course that the light emitting devices within the healthcare environment are safe and fit for purpose, to ensure optimal patient treatment

There were two other speakers at the seminar: **Professor Sir David Payne**, University of Southampton spoke on **Photonics and Communication**; and **Professor Sir Colin Humphreys**, University of Cambridge, gave a presentation on **Light Emitting Diodes**. Summaries of their talks will be published in the next issue.