newsletter

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Is the Cosmos teeming with life or is life on Earth unique?

by LORD REES, OM, FRS, MASTER OF TRINITY COLLEGE, CAMBRIDGE, ASTRONOMER ROYAL and FORMER PRESIDENT OF THE ROYAL SOCIETY

The origin of planets was for long a puzzle. A popular theory a hundred years ago was that the planets condensed from gas torn from the Sun during a near-collision with a passing star. Had this theory been correct (and it turned out to have fatal flaws) it would have implied that planets were rare in the cosmos. But for several decades, astronomers have favoured a different theory, according to which planetary systems should be common. Stars are formed by a contracting cloud of dusty gas that contracts from the interstellar medium. If this cloud is spinning – even very slowly – then, as it contracts, it will spin faster and faster for the same reason that a pirhouetting skater spins faster when she draws in her arms. This leaves a disc behind around the young star. That is how we think our solar system formed, with the dust particles sticking together to make rocks and the rocks to make planets.

But only since 1995 have we had actual evidence that many stars – perhaps even most – are orbited by retinues of planets. And the study of 'extra-Solar planets' is now perhaps the most vibrant and fast-advancing in the whole field of astronomy.

Astronomers have not seen the planets themselves, but they have detected small wobbles in the motion of stars, induced by the gravitational pull of planets orbiting around them. Inevitably, the first planets to be discovered were the ones that caused the biggest wobble – they were gigantic gassy planets several times more massive than Jupiter, and moving on fast orbits, close to their parent stars.

A planet like the Earth would induce motions of only a few centimetres per second, rather than metres per second, in the parent star – too small to be detected by the 'wobble' technique. But another even simpler technique is now yielding results.

One of the classic phenomena in astronomy is the transit of Venus (Figure 1); when this planet moves across the face of the Sun, it is observed as a small black disc (barely resolvable by the unaided eye). Even if we were looking from such a vast distance that the Sun seemed a mere point of light, then the transit would still be detectable, because, by blocking out a small part of the Sun's light, it would make the Sun slightly dimmer for the duration of the transit.

The fractional dimming of a Sun-like star, caused by the transit of an Earth-like planet, amounts to only about one part in ten thousand. The Kepler spacecraft has, for nearly the last three years, been monitoring over 100,000 stars, measuring their brightness to a precision better than one part in 10,000 – and doing this every few minutes. The aim is to detect regular dips in the brightness of a star, signalling the successive transits of a planet.

Already Kepler has revealed an immense richness of data. Many hundreds of planets have been inferred – some little larger than the Earth. One star is orbited by at least six planets. One planet is orbiting a binary star: there would be two 'suns' in its sky.

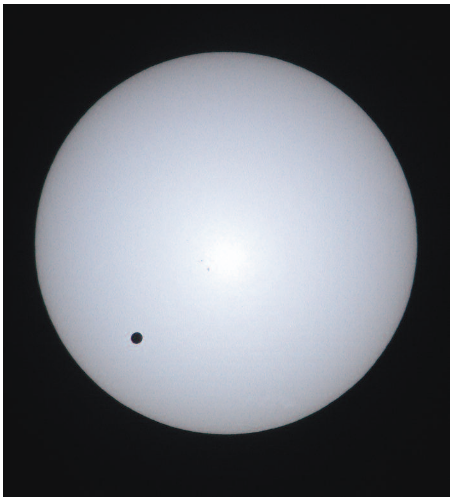

Figure 1: Transit of Venus
– courtesy of Imelda Joson and Edwin Aguirre

Soon, when we look up at the night sky, we will know, for each star, the orbits of its retinue of planets and their sizes and masses.

But we would like to image the planets, rather than just detect their indirect effects. They would be very hard to see – it is like looking at a firefly next to a searchlight – and must await the next generation of telescopes – for instance the great instrument, with a 39-metre diameter mosaic mirror, being planned by the European Southern Observatory (in which the UK participates) which, with luck, will come into operation in the early 2020s.

Even with this huge telescope, planets will register just faint points of light, but repeated observations could still reveal much about them. Let us imagine you were looking at our Solar System from 30 light years away. The Sun would look like a normal star while the Earth would be a faint dot. But its colour would be slightly different depending on whether the Pacific Ocean or the land mass of Asia was facing you. Just by watching it, you could infer that Earth had continents and oceans, the length of the day and something of the seasons and climate.

These are the kind of deductions we will be making, in 10 or 20 years, about planets orbiting other stars.

An actual image of such a planet – one that can be displayed on the wall-sized screens that will by then have replaced posters as room decorations – will surely have even more impact than the classic pictures of our own planet viewed from space. But this may be a challenge for the second half of the century. It would require a huge array in space spread over hundreds of kilometres to give a very blurred image revealing oceans or continents. Still further ahead, robotic fabricators may be able to manufacture, in the zero gravity of space, gossamer-thin mirrors on an even more gigantic scale. These would show more detail, and allow us to probe even further away, increasing the chance of finding a planet that might harbour life.

How likely is it that life exists on any such planets? The greatest uncertainties lie in the province of biology, not astronomy. Despite all we have learnt from Darwinism, we still do not know how life began on Earth. The prospects of life elsewhere obviously depend on whether its origin involved some 'fluke', or whether it was near-inevitable in the kind of initial 'soup' expected on a young planet. But there is a second question: Even if simple life exists, what are the odds against it evolving into something that we would recognise as intelligent? This is likely to prove far more intractable. Even if primitive life were common, the emergence of 'advanced' life may not be.

And if intelligent aliens exist, we might be wrong to anthropomorphise them. They may not be organic at all: the most durable form of intelligence may be machines whose creators may long ago have been usurped or become extinct. Some 'brains' may package reality in a fashion that we cannot conceive and have a quite different perception of reality. Others could be uncommunicative: living contemplative lives, perhaps deep under some planetary ocean, doing nothing to reveal their presence. There may be a lot more out there than we could ever detect. Absence of evidence would not be evidence of absence.

The quest for alien life is perhaps the most fascinating challenge for 21st century science – its outcome will influence our concept of our place in nature as profoundly as Darwinism has over the last 150 years.

Our Earth teems with an extraordinary range of life-forms. But there are constraints on size and shape. Big animals have fat legs, but still cannot jump like insects. The largest animals float in water. Far greater variety could exist on other planets. For instance, we know that if gravity were stronger, animals would be smaller, with much thicker legs. Life of a different kind might exist on a gas-covered planet: for instance, huge floating organisms could live in the dense atmosphere of a giant planet like Jupiter.

Far more exotic life forms could await us in the far post-human future. Humans on Earth are the outcome of four billion years of Darwinian selection. But our Solar System is barely middle aged, and if we can survive human-induced catastrophe, life could enjoy billions of years of technologically accelerated evolution – the post-human era beckons.

Perhaps, as little as a hundred years from now, small groups of people will have started to spread beyond the Earth to establish little communities elsewhere in the solar system. This could be the start of a diaspora whereby life spreads from the Earth far beyond our solar system. This would be a post-human rather than human venture because it is likely that with the possibility of genetic engineering the species could change in a few centuries.

If the cosmos is already teeming with life, the Earth's fate would be of 'merely' terrestrial significance. Thomas Wright of Durham expressed this thought 250 years ago: *"In this great Celestial Creation, the Catastrophy of a World, such as ours, or even the total Dissolution of a System of Worlds, may possibly be no more to the great Author of Nature, than the most common Accident in Life with us, and in all Probability such final and general DoomsDays may be as frequent there, as even Birth-Days or Mortality with us upon this Earth."*

But suppose Earth is the unique abode of intelligence in the Galaxy. The fate of humanity could then have an importance that is truly cosmic – reverberating through Thomas Wright's 'Celestial Creation': what happens on Earth in the next few centuries could make the difference between the emergence of ever more complex and varied life-forms, and a near-eternity bereft of any entities aware of it. ■

Maxwell, Einstein, Newton and Faraday

by D.O. FORFAR, MA, FFA, FIMA, TRUSTEE of the James Clerk Maxwell Foundation

When Einstein made his first visit to the U.K., the Press asked him if he had stood on the shoulders of Newton. Einstein replied, "That statement is not quite right, I stood on Maxwell's shoulders".

Professor Stephen Hawking, perhaps the best known of to-day's physicists, stated in a recent television programme that there was a story that Einstein had a picture of Maxwell (in addition to that of Faraday and Newton) on the wall of his Princeton study. The photograph of Einstein in his Princeton study (Figure 2) provides the proof. We can assume that it was also true of Newton's and Faraday's picture. Einstein's picture of Maxwell can be identified; it is the photograph of the portrait of Maxwell (Figure 3) by Lowes Dickinson that hangs in the hall of Trinity College, Cambridge.

In 1931, in an essay about Maxwell, Einstein wrote *"before Maxwell, physical reality… was thought of as consisting of material particles… Since Maxwell's time, physical reality has been thought of as represented by continuous fields… This change in the conception of reality is the most profound and most fruitful that physics has experienced since the time of Newton"*. Faraday and Maxwell saw electromagnetic fields, and their attendant taut 'lines of force', as a means by which energy could be transmitted with a finite speed. The energy carried by fields, warming any object in their paths, is an example of the power of fields to transmit a physical effect (e.g. heat) across space.

Maxwell stated that it was Faraday (1791–1867) who, in 1846, first proposed that light was an electromagnetic wave. Faraday had recognised the ability of magnetism to alter light (its plane of polarisation).

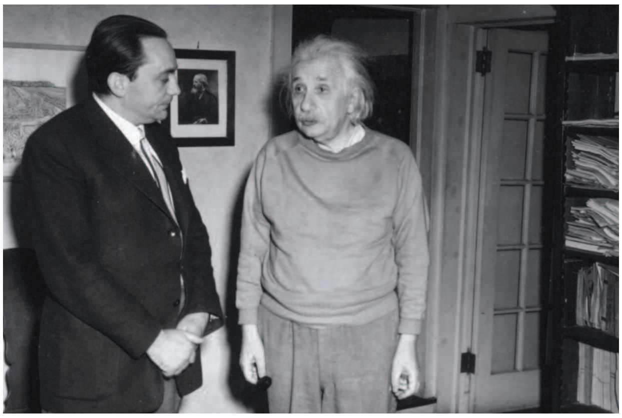

Figure 2: Photograph of Einstein with Maxwell picture on the wall – courtesy of Shelby White and Leon Levy Archives Center, Institute for Advanced Study, Princeton, USA and its Director, Professor Peter Goddard, FRS.

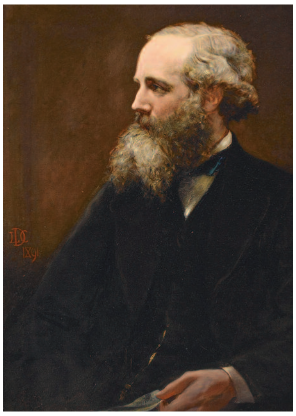

Figure 3: Courtesy of the Master and Fellows, Trinity College, Cambridge.

It was known that waves would travel through an elastic material at a speed equal to the square root of the ratio of its elastic modulus to its density. In his 1861 paper *'On Physical Lines of Force'*, Maxwell assumed that electromagnetic waves travelled through such a 'material' called, 'the aether'. Maxwell estimated the aether's elastic modulus and density using known experimental results for the value of certain electrical constants based on experiments that were nothing to do with light itself. The value of these electrical constants had only been known since 1856, so Faraday himself was not able to estimate, in 1846, the speed of electromagnetic waves. However, in 1861, Maxwell was able to do so. This speed proved to be equal (within experimental error) to the known speed of light as derived by the French physicist, Fizeau (1819–96) from experiments on light itself. This so confirmed Faraday's prediction of 1846 that Maxwell was able to conclude in 1861 *"we can scarcely avoid the inference that light consists in the transverse undulations of the same medium which is the cause of electric and magnetic phenomena"*.

In 1865, in his paper *'A Dynamical Theory of the Electromagnetic Field'*, Maxwell gave the equations governing all electric and magnetic phenomena. Certain of the equations were mathematical expressions of previous laws of electricity and magnetism which had already been discovered by Coulomb, Ampère, Oersted and Faraday. In addition to these laws, Maxwell considered that a changing electric field would give rise to a special form of current. He used the analogy of positive and negative charges inside molecules (although these were then hardly known) being "displaced" (pulled slightly apart) in one direction and then in the opposite direction (without the charges leaving the molecule) thereby creating a special current which needed to be included in Ampère's law for the magnetic field. This was new and innovative and Maxwell called this special current the 'displacement current', which we now know exists even in a vacuum. The equations governing the electromagnetic field are now known as Maxwell's Equations and are among the most fundamental equations in the whole of physics as they unify the electric and magnetic forces.

Maxwell was then able to confirm, even more elegantly than he was able to do in his 1861 paper, that these equations lead to undulating, but mutually supportive, electric and magnetic fields. Maxwell showed again that the speed of these waves was, to within experimental error, equal to the known speed of light. Maxwell reiterated *"that it seems we have strong reason to conclude that light itself (including radiant heat and other radiations if any) is an electromagnetic disturbance in the form of waves propagated …according the electromagnetic laws"*. This conclusion was the most remarkable conclusion of 19th century theoretical physics as many eminent physicists of the time did not yet believe in such electromagnetic waves travelling with finite speed; thinking instead that electric and magnetic effects were transmitted instantly ('action at a distance').

Some twenty two years later, in 1887, Hertz demonstrated, in the laboratory, such electromagnetic waves being transmitted, received and having all the properties – reflection, refraction, interference – of waves travelling at a finite speed. This was the most remarkable demonstration of 19th century experimental physics.

Maxwell's words *"…including radiant heat and other radiations if any"* have proved prescient and have been amply vindicated by the progressive discovery of the vast spectrum of electromagnetic radiation of different wavelengths – radio waves, microwaves, infrared light, visible light, ultraviolet light, x-rays and gamma rays. Electromagnetic waves now provide the means for modern devices to communicate without wires, for example to-day's mobile 'phones.

Galileo and Newton had said that, in order to change (transform) between the viewpoints of two different observers (viewing the same event but the second observer travelling with a constant speed and direction relative to a stationary observer) the speed of the moving observer would need to be added to the speed of a body as measured by the moving observer. Thus, according to Galileo and Newton, 'faster than light' speeds were perfectly possible. Maxwell's equations, on the other hand, gave an identical value for the speed of electromagnetic waves, no matter what the relative speeds of the observers. These opposing theories could not both be right!

In his 1905 paper *'On the Electrodynamics of Moving bodies'*, Einstein derived the mathematical transformation (to change from one observer to another) that would result from the supposition that each observer, in his own frame of reference, measured an identical value for the speed of light. It turned out to be the same transformation which the physicist Lorentz (1853-1938) had formulated earlier.

In the same paper, Einstein showed his debt to Maxwell by demonstrating that Maxwell's equations transformed correctly between two observers, provided the Lorentz transformation was used to change the viewpoint between the observers. It was such considerations that enabled Einstein to state confidently that Nature behaved according to the Lorentz's transformation and not according to the simpler Galileo/Newton transformation. Maxwell's equations, without any alteration, are compatible with Einstein's *'Theory of Special Relativity'* whereas Newton's equations had to be changed. For example, the mass of a body now became dependent on its speed (as seen from Einstein's formula $m(v) = m \big/ \sqrt{1 - v^2 / c^2}$) whereas the mass of a body, under Newton, had been a constant, *m*, independent of the body's speed.

Furthermore, there could be no aether because, if there was such a thing, there would be a privileged observer for whom the aether was at rest. Einstein told us that there are no privileged observers in inertial frames of reference.

Einstein showed that, as a consequence of his 1905 paper, *"If a body gives off energy L in the form of radiation, its mass diminishes by* L/c^2 *"*. Einstein derived this by considering a body emitting an electromagnetic wave. The formula Einstein used for the energy of the electromagnetic wave was the same one that Maxwell had derived. Einstein viewed the same event from the standpoint of both the stationary and the moving observer, using the Lorentz transformation to change the viewpoint from one observer to the other. By comparing the same event, as viewed from the two different viewpoints, he found the basis for his famous equation, $E=mc^2$. ■

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The Tartan Ribbon and Colour Photography

By Dr. R.C. DOUGAL, CPhys, FInstP and D. O. FORFAR, MA, FFA, FIMA,
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For his research on the composition of colours, James Clerk Maxwell was awarded, in 1860, the Rumford medal of the Royal Society of London. On 17 May 1861, Maxwell gave a remarkable demonstration at the Royal Institution, London; a demonstration which pioneered both coloured photography and the projection of full-colour images on television and computer screens. Maxwell, with the help of the photographer Thomas Sutton, projected on to a screen an image of a rosette fashioned from a length of brightly patterned ribbon- the image was in colour!

Maxwell worked from Thomas Young's proposal, in 1801, that we deduce colours from the combined responses of three sets of colour receptors ('cones') formed as interlocking layers on the retina of the eye. One set of receptors responds only to light from objects coloured blue or violet; another to a range of colours, peaking at green; and the third to a range of colours peaking closer to yellow and including red.

Maxwell's purpose was to show that all colours could be imaged using just three primary components – namely red, green and blue. Further, if all three components were present in the right proportions, all three sets of receptors would respond such that we would deem the source colour to be white.

Sutton photographed the ribbon in bright daylight. He made three negatives, each using, in front of the camera lens, a glass trough filled with a differently coloured liquid. These formed the red, green and blue filters. From these negatives were made positives in the form of three black-and-white glass slides.

For his demonstration, Maxwell used three magic lanterns with one black-and-white slide in each and with the light from each lantern filtered through the same colour filter as had been used to make the negative. Thus, using the 'blue' slide, the image (on the screen) formed by the blue-filtered light stimulated the blue receptors in the eye in much the same way as viewing the tartan ribbon directly would have done. Similarly for the 'green' slide and the 'red' slide. He then superimposed the three images. The strategy, which Maxwell had first proposed in 1855, worked! The colour at any point on the screen was nearly the colour of the corresponding point on the ribbon.

In conducting this demonstration, Maxwell had luck on his side. The emulsion on the film coped well with Sutton's blue-filtered light, as it contained wavelengths of about 400 – 460 nm. The green-filtered light (wavelengths approximately 420 – 550 nm) only activated the emulsion weakly and Sutton needed a long exposure time to obtain a 'green' negative.

However, the wavelengths of the red-filtered light lay in the range of about 550 – 750 nm. In Maxwell's day, photographic emulsions were not sensitive to wavelengths above about 430 nm. So the light which was transmitted through the red filter should have had no effect on the emulsion and no negative on the emulsion should have been formed. However research by R. M. Evans and Kodak Laboratories, commemorating the centenary of the event, showed that the red filter also transmitted light from the ribbon in the near ultraviolet (wavelengths in the range 320 – 400 nm). In daylight, the tartan ribbon reflected, from the red dye used in the ribbon's manufacture, such light.


Colour Ribbon – courtesy of the National Picture Library, Bradford.

Thus, it was ultraviolet light that had produced the 'red' negative. The projection, using the 'red' slide and red filter, included, in the image on the screen, those parts of the ribbon which had used the red dye, so all (rather unexpectedly!) was well.

The image produced by ultraviolet light (that would have been invisible to the human eye) was made visible. This was an example of 'false colour imaging'. Maxwell was well ahead of his time as commercial colour photography did not begin until the early years of the 20th century. Nevertheless, on that day, in 1861, three-colour separation and false colour imaging were born. ■