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Astronomy 2009

Challenges, vision and exploration

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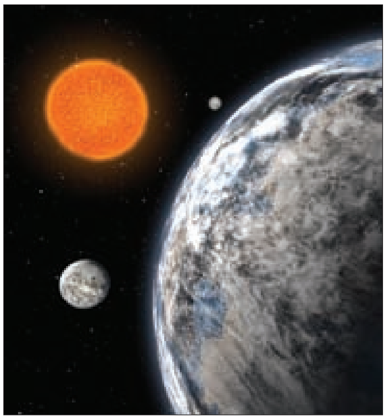

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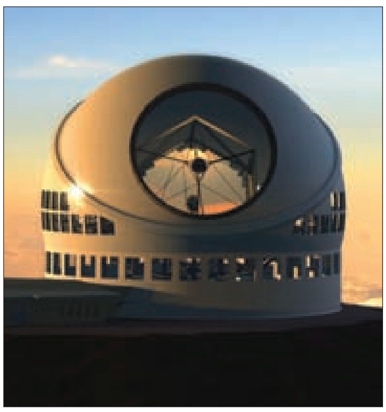

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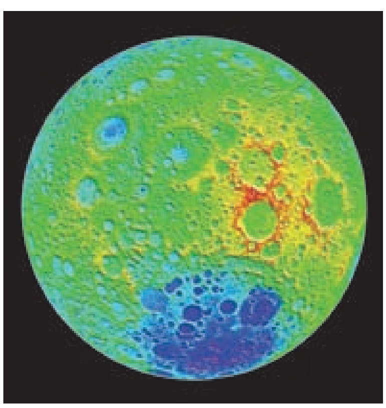

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Quanta

For the record

I am hoping that the American people will wake up

New US energy secretary **Steven Chu** *quoted in the* Los Angeles Times
In his first interview since taking office, Chu states that he sees public education as a key part of the strategy to fight global warming.

This was at exactly the wrong place to make debris

David Wright *a space-weapons expert at the Union of Concerned Scientists quoted in the* Financial Times
Wright was commenting on the collision last month between a commercial US communications satellite and a defunct Russian satellite, which hit each other while in a low Earth orbit. This is the first such collision and it is estimated to have created about 600 pieces of debris, which he thinks will take decades to burn up.

Writing really small has a long history

Physicist **Hari Manoharan** *from Stanford University quoted in the* Guardian
Researchers at Stanford University have broken the record for the smallest writing by creating two letters, "S" and "U", each less than 0.3 nm in size using a scanning tunnelling microscope to drag single carbon-monoxide molecules into the desired pattern. Writing this small could enable all 32 volumes of the *Encyclopaedia Britannica* to be fitted 2000 times over on the head of a pin.

The best hitters accelerate at the last instant. That final jolt of speed allows them to apply a bigger force to their victim

Physicist **Timothy Gay** *from the University of Nebraska-Lincoln quoted in the* New York Times
Gay was describing some of the tackles made by legendary American football player Jack Tatum – also known as "the assassin" – who was one of the hardest hitters in the game. Gay was describing how Tatum always knew the right angle and timing in order to pull off a big tackle.

Like most things Swiss, astronomy in Switzerland is not very big but it is of a very high quality

Astronomer **Simon Lilly** *from the Federal Institute of Technology in Zurich quoted in* swissinfo.ch
Lilly points out that although Switzerland does not have a big astronomy community, some of the recent work carried out by Swiss astronomers on exoplanets is a highlight of the country's science.

Seen and heard


CERN

Hanks for the memory

Hollywood came to CERN last month as Tom Hanks jetted into the Geneva lab, which was showing sneak previews of his new film *Angels and Demons* based on the novel by Dan Brown. Part of the book centres on CERN and the film features footage of the lab's 27 km tunnel, including the cathedral-sized ATLAS detector. CERN staff got to see the footage at a press conference that featured Hanks, who plays an academic trying to prevent the Vatican from being blown up with antimatter stolen from CERN, as well as co-star Ayelet Zurer and the film's director Ron Howard. We mere mortals will just have to wait for the film's release on 15 May.

Traveller's tales

A first port of call when planning a holiday might be attractive travel brochures showing sun-drenched beaches and clear-blue seas. But anyone who can't bear to take their mind off physics while on vacation can now consult *The Physical Tourist: A Science Guide for the Traveller*. The book, edited by physicists John Rigden from Washington University and Roger Stuewer from the University of Minnesota, contains a selection of historical physics-based attractions in 11 cities in Europe and the US. If you happen to be in Bern, you might want to visit the patent office where Einstein came up with his ideas on Brownian motion, the photoelectric effect and the special theory of relativity. Physics highlights in Edinburgh include Merchiston Castle – the birthplace and home of John Napier who invented logarithms – while Paris boasts the Curie museum, which contains the Nobel-prize winner's office and laboratory. Quite who would want to visit the book's pick of physicists' graves though, such as that of Roland von Eötvös in the Kerepesi cemetery in Budapest, remains a ghoulish mystery.

Calculators at the ready

Ever wondered how many "men with calculators" it takes to match a day's worth of IBM supercomputing power? Well, according to *The Times* newspaper in the UK it is 120 billion of them all number-crunching for 50 years. The paper came up with the bizarre comparison to describe the capacity of IBM's new supercomputer called Sequoia, which will be 20 times more powerful than today's best machines. When ready for action in 2012 at the Lawrence Livermore National Laboratory in the US, the supercomputer, which will be used to check the safety of the US nuclear arsenal, will run at 20 petaflops (10^{15}) floating-point operations per second. The question is, who are these men with calculators? What are they calculating? And are they allowed toilet breaks?

Spooky Einstein

Participants at the Technology, Entertainment and Design (TED) conference last month at Long Beach in California might have been surprised when they stumbled upon Einstein. Not the real one, of course, but a robotic version created by David Hanson, chief executive of Hanson Robotics in Dallas. He built a head-and-shoulders "Einstein robot" containing 32 motors mimicking 48 different facial muscles. The Einstein robot smiled or frowned at TED conference-goers and followed them with his eyes using in-built sensors – spooky action at a distance, indeed.

Cheers to Galileo

The Danish brewing company Carlsberg has a slogan about its famous tipple: Carlsberg is "probably the best beer in the world". Now a US brewer has gone one better by making a beer that is "theoretically the best beer in the universe" (although it might have difficulty proving that claim). The Sierra Nevada Brewing Company produced the Galileo's Astronomical Ale to mark the International Year of Astronomy (IYA2009). It was flowing freely at the US opening ceremony of IYA2009 last month at Long Beach in California. Sadly, physicists hoping to put the slogan to the test will be disappointed as the new ale is not yet on sale. "We've had quite a lot of interest, so perhaps we might think about brewing it again," says Laura Harter, a spokesperson for the brewer.

Frontiers

In brief

CoRoT spots tiny exoplanet
Astronomers using the CoRoT space telescope have found the smallest ever exoplanet seen to be passing between the Earth and its parent star. Less than twice the radius of the Earth, CoRoT-Exo-7b has a surface temperature of over 1000 K, as it lies so close to its parent star, and orbits in just 20.5 hours. Most of the 330 exoplanets discovered so far are huge gas giants like Jupiter, but CoRoT was able to spot the new exoplanet because it can detect changes in brightness with a sensitivity 10 times better than telescopes on the ground (*Astron. Astrophys.* at press).

Chilly way to weigh neutrinos
Physicists in the US have suggested a new method of measuring the mass of neutrinos. The Standard Model of particle physics assumes that neutrinos have zero mass, but studies of how neutrinos can change or "oscillate" from one type to another indicate that they cannot be massless. In the new approach, researchers would have to monitor tritium atoms, which beta-decay (emit electrons and neutrinos) to helium-3,when cooled to temperatures close to absolute zero. Accurate measurements of the momenta of the helium atoms and electrons before and after emission would determine the neutrino mass (arXiv:0901.3111).

'Graphane' makes its debut
A new material based on the engineering marvel "graphene" – a sheet of carbon one-atom thick – could be used for hydrogen storage. "Graphane", which consists of hydrogen atoms attached to graphene, has been produced by atomizing hydrogen gas using an electrical discharge and then allowing individual atoms to bind to the carbon. When the material is heated, it liberates the hydrogen and reverts to normal graphene. Graphane could be an economical way of storing hydrogen for use as fuel in vehicles (*Science* **323** 610).

Superconductor defies classification
Superconductors are usually classified as either type-1 or type-2, depending on how they behave in a magnetic field. Now, physicists in Belgium and Switzerland have discovered that magnesium diboride seems to straddle both categories – what they term a "type-1.5" superconductor. Under certain conditions, magnesium diboride can embrace a magnetic field by developing tiny magnetic vortices in its structure. However, over short distances these vortices repel, like type-2 superconductors, while over longer distances they attract, like type-1 materials (arXiv:0902.0997).

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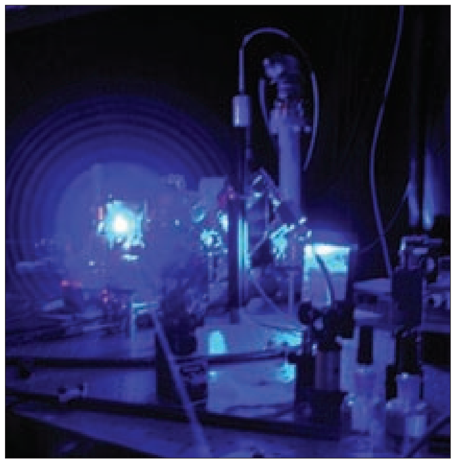
Teleportation goes the distance


University of Maryland

Far-reaching Teleportation has been achieved for entangled ions that are 1 m apart.

Physicists in the US have teleported information between distant ions for the first time. The breakthrough is a significant milestone in the quest for a workable quantum computer, say the researchers.

Quantum teleportation involves "entangling" two particles so that a measurement made on one particle instantly determines the state of the other, regardless of how far apart they are. This is difficult in practice because the particles tend to destroy their entanglement by interacting with the environment. In spite of this limitation, researchers have been able to teleport information between photons or between atoms that are situated close together.

Now, Christopher Monroe of the University of Maryland and the National Institute of Standards and Technology (NIST) and co-workers have managed to achieve atomic teleportation over much larger distances by using photons as intermediaries. The researchers placed two ytterbium ions in separate vacuum chambers 1 m apart and applied microwave pulses to drive the ions into a superposition of quantum states. Next they shone a laser onto the ions to make them emit single photons representing the superposition. These photons each travelled 2 m to a meeting point at a beamsplitter, which transferred the photons' entanglement to the ions. When the physicists performed a measurement on one of the ions and sent the outcome to the other, the latter ion embodied the former's initial state.

To check that teleportation had taken place, the researchers used a process called quantum tomography, in which they made many measurements of the ytterbium atoms and compared the results with theoretical predictions. They found that their experiment had a teleportation success rate of 90% (*Science* **323** 486).

Monroe says that this type of system is attractive for quantum memories, which can help boost quantum signals so that they can travel further. "Our method combines the unique advantages of both photons and atoms," he explains. "Photons are ideal for transferring information fast over long distances, whereas atoms offer a valuable medium for long-lived quantum memory."

Chameleons weigh in

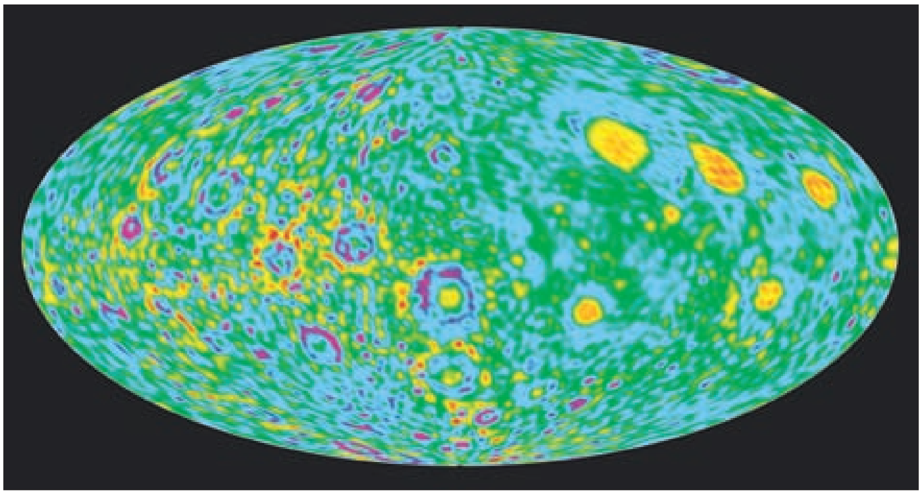
Researchers at Fermilab in the US have set a lower limit on the mass of "chameleon" particles, a hypothetical type of matter that may provide a much-sought explanation for dark energy.

First mooted in 1998, dark energy is an unknown entity that physicists believe makes up more than 70% of the universe's mass–energy content and is causing the expansion of the universe to accelerate. The most popular ideas to explain it are a cosmological constant, which would mean all of space has an innate energy, or quintessence, which would be some form of new scalar field.

Chameleon particles, postulated in 2003 by Justin Khoury and Amanda Weltman of Columbia University in New York, represent an alternative solution. Like their reptilian namesakes, chameleon particles adjust their properties to suit the local environment, in the sense that their interactions with matter are stronger and more far-reaching in a vacuum than in a dense material. In this way the particles could be pushing vast regions of the empty cosmos apart.

Now Weltman (currently at the University of Cape Town in South Africa) has joined forces with Aaron Chou and colleagues at Fermilab to make the first search for chameleon particles. They researchers used the GammeV experiment, a steel-walled vacuum chamber a few centimetres in diameter and several metres long that is placed in a strong magnetic field. By shining a laser into GammeV they hoped that photons from the laser would interact with those in the magnetic field to create chameleon particles, which would be unable to escape through the dense walls of the chamber.

Although the researchers found no traces of the particles, they were able to put a lower limit on their mass of about 1 meV (*Phys. Rev. Lett.* **102** 030402).



New light on the farside of the Moon

The farside of the Moon, for so long a symbol of the eternal unknown, has lost yet more of its mystery. Last month the first analyses of data from Japan's SELENE mission gave new insights into the nature of the Earth's only natural satellite and revealed why the near and far surfaces are so different. Since the Soviet spacecraft Luna 3 made the first trek around the Moon in 1959, scientists have known the nearside has more dark, low-lying pools of solidified lava or "maria" than the farside, which is dominated by bright, heavily cratered highlands. Measurements of the nearside obtained by later lunar probes have also implied that the solidified lava is responsible for most instances of high gravity – bar one, in the so-called Mare Orientale basin. This region has a core of high gravity surrounded by abnormally low gravity, which scientists think resulted from a meteorite impact propelling magma up through the crust. Now, Noriyuki Namiki of Kyushu University in Japan and colleagues have used data obtained by SELENE to build an improved gravitational map of the entire Moon that reveals a number of high-gravity regions like Mare Orientale that exist on the farside (*Science* **323** 900). In the map shown above, the farside of the Moon is on the left and the nearside on the right. Pink areas indicate lower gravity, while yellow and red areas indicate higher gravity. SELENE was launched in September 2007 and has returned a wide range of data, in particular about the conditions at the time of the "late heavy bombardment" 4.5 billion years ago.

Device developed to reverse the Doppler effect

It happens every time an ambulance whizzes past with its siren blaring: the Doppler effect, whereby sound waves are squeezed into a higher pitch when their source is approaching and stretched into a lower pitch when their source is receding. Now, researchers in Korea and China have developed a device that turns the Doppler effect on its head.

The device created by Chul Koo Kim of Yonsei University and colleagues consists of a type of metamaterial – a composite material with novel properties. In the past, metamaterials have been designed mostly for electromagnetic radiation, which has led to devices such as primitive invisibility cloaks or "perfect" lenses that can focus beyond the diffraction limit. The new metamaterial, however, works with sound. It consists of an elastic tube, about 3 cm in diameter, punctuated every 7 cm along its length with thin elastic membranes. The membranes give the tube the strange properties of "negative density" and "negative modulus", the latter term relating to the material's elasticity. Kim and colleagues are the first to attain both of these properties in the same device.

The researchers inserted a microphone into the tube and arranged a sound source at a frequency of 350 Hz so that it moved over the holes at 5 m s^{-1}. When they monitored the microphone's output through a loudspeaker, they found there was an jump in sound frequency of 20 Hz as the source passed the microphone; not a drop, as the conventional Doppler effect would dictate (arXiv:0901.2772).

Kim and co-workers say their device is an important step towards creating an "acoustic cloak", which could be used to hide submarines from sonar or improve the acoustics of concert halls. The next step is to translate their 1D design into 2D and 3D versions.

"This research is an important breakthrough," says Jose Sanchez Dehesa, a metamaterials researcher from the University of Valencia in Spain. "If we can now shift this structure to 2D and 3D, then it could be used to develop things like sub-wavelength resolution in ultrasonic imaging and many other interesting devices."

Innovation

Anti-reflective films look to moth eyes

Researchers in the Netherlands have developed an anti-reflective coating based on the structure of moth eyes that could make solar cells more efficient, *writes James Dacey*.

Jaime Gómez Rivas and colleagues at the AMOLF institute in Eindhoven say their moth-eye technology is superior to other current anti-reflective measures. In addition, they have developed an environmentally friendly production technique that allows the coating to be applied with high precision.

Moth eyes, which have evolved to allow the insects to see clearly at night, are covered in nanostructures that taper outwards. These structures create a medium in which the refractive index gradually increases from 1 on the outside to almost 3.4 at the insect's optical nerve, and allow very little light to reflect back out of the eye.

Gómez Rivas and colleagues have mimicked the structures by growing gallium phosphide (GaP) nanowires in lengths between 50 and 250 nm on a GaP substrate, thus producing a material with a refractive index that changes gradually with thickness. The researchers found that for a range of frequencies and angles of incidence the transmission of light was increased, with minimal reflection (*Advanced Materials* 10.1002/adma.200802767).

This is not the first "graded index" material to be produced. In the past, researchers tried to make them in a "top down" fashion by etching silicon substrates, but the resultant material, while being anti-reflective, absorbed a lot of the light. Two years ago a more effective graded-index nanostructure was produced in a bottom-up fashion combining silicon dioxide with titanium dioxide. The latest technique creates a graded index in a single material – gallium phosphide.

"The idea of slowly changing the impedance of air to that of the material is well known, but the method by which it has been achieved is rather elegant," says Pete Vukusic, who studies the optical properties of natural materials at the University of Exeter in the UK.

Francisco Garcia-Vidal, an optics researcher at the Autonomous University of Madrid, also in Spain, thinks the bottom-up technique is flexible because it will allow researchers to fabricate the nanowires and substrate from a choice of materials.

Gómez Rivas explains that his team's long-term goal is to use the anti-reflective material as a coating on solar cells, but that for the next few years the researchers will continue to seek even lower reflection. "In theory, we could get 99% transmission," he says.

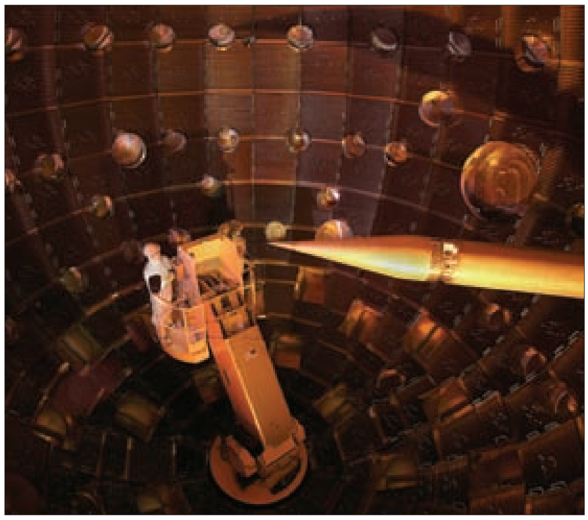
News & Analysis

World's biggest laser powers up

Physicists are on the verge of demonstrating perhaps the ultimate application of the laser: creating nuclear fusion in the lab. Later this month, staff at the Lawrence Livermore National Laboratory in California will complete the final beamline of the $4bn National Ignition Facility (NIF) – a huge laser that will produce 1.8 MJ laser pulses, more than 60 times more energetic than those from any machine currently in existence.

NIF's main goal is to focus all that energy onto a hollow sphere 2 mm in diameter made of beryllium and chilled to 1.8 K. This will make the sphere implode and squeeze the deuterium and tritium nuclei lying inside until they fuse to spark "ignition" – the point at which enough heat is generated to react surrounding fuel and achieve a sustained burn that produces excess energy. "Ignition is a grand challenge. People have been waiting for this moment for a long time," says NIF director Ed Moses.

Construction of NIF began in 1997 but did not go smoothly at first, with capacitors prone to exploding. Extensive redesigns were required, which led the US Department of Energy to re-evaluate the project and redraw its schedule and budget. NIF is now opening five years behind schedule and almost four times over budget.


National Ignition Facility

Shining star The National Ignition Facility uses 192 laser beams to trigger nuclear fusion in small pellets containing deuterium and tritium.

NIF is a huge facility – roughly the size of three football pitches. Each laser pulse starts out as a 1 μm infrared beam that is split into 48 beams and fed into preamplifiers that increase their energy 10 billion times. Each beam is then split into four and passed repeatedly through main amplifiers. After converting the wavelength into the ultraviolet, the total energy of the 192 beams is 1.8 MJ.

When the combined laser pulse hits the 2 mm sphere, it explodes, causing an implosion on the inside that forces the fuel into the centre and compresses it to a density 100 times that of lead and a temperature of 10^8 K. This is enough to spark fusion at the centre, which then burns outwards to cooler parts of the fuel. The fuel is trapped by its own inertia: the fusion burn proceeds faster than the fuel can move to escape. In theory, if all the fuel burns up, at least 20 MJ of energy will be liberated.

Moses says that NIF staff plan to ramp up the laser energy to 1 MJ this year and reach full power by the end of 2010, but predicts they will achieve ignition before then. "We're feeling pretty confident," says Moses.

Mike Dunne, head of the Central Laser Facility at the Rutherford Appleton Laboratory in the UK, agrees that NIF is "overwhelmingly likely to succeed" but warns that the laser can set up "resonant waves" in the plasma that heat it faster than it can be compressed so that ideal ignition conditions are not achieved. Another potential problem is "hydrodynamic instabilities" that mix the beryllium of the sphere with the fuel, thus spoiling the plasma's ability to retain heat.

NIF will also be used to validate computer simulations of nuclear weapons to ensure the US's nuclear stockpile is safe, while astrophysicists will use it to simulate the interiors of giant planets, stars and supernovae.

Daniel Clery

People

Top scientists join Stephen Hawking at Perimeter Institute

Nine leading researchers are to join Stephen Hawking as visiting fellows at the Perimeter Institute for Theoretical Physics in Ontario, Canada. The researchers, who include string theorists Leonard Susskind from Stanford University and Asoka Sen from the Harisch-Chandra Research Institute in India, will each spend a few months of the year at the institute as "distinguished research chairs". They will be joined by another 30 scientists to be announced at a later date.

The Perimeter Institute was founded in 1999 by Mike Lazaridis, chief executive of Research in Motion – the firm that makes the Blackberry wireless handheld devices. Home to more than 60 resident researchers, the institute focuses on areas such as cosmology, particle physics and quantum gravity. Hawking was made the institute's first distinguished research chair last November, while his Cambridge University colleague Neil Turok was appointed as executive director of the institute last May.

The new fellows include several condensed-matter physicists, such as Xiao-Gang Wen from the Massachusetts Institute of Technology, who will take the institute's research in new directions. "The methods used in condensed-matter physics and other areas such as quantum gravity are very similar," says Wen. "I get the impression that the institute is looking for people in condensed-matter physics whose work overlaps with the research already performed there."

The institute is looking for people in condensed-matter physics whose work overlaps with the research already performed there

The other new chairs, who will all keep positions at their home universities, include Yakir Aharonov from Chapman University and Tel Aviv University, who shared the Wolf Prize in 1998; Juan Ignacio Cirac, director of the Max Planck Institute for Quantum Optics in Germany; and Harvard University condensed-matter theorist Subir Sachdev.

They will be joined by string theorist Nima Arkani-Hamed of the Princeton Institute for Advanced Study; the Princeton University cosmologist Neta Bahcall; and Gia Dvali from New York University's centre for cosmology and particle physics.

Michael Banks

Detecting new Earths

As NASA's Kepler mission blasts off this month, **Michael Schirber** looks at how the spacecraft will detect Earth-like planets

"This will be a major step in our quest to understand if we are alone in the universe," says James Fanson from NASA's Jet Propulsion Laboratory (JPL) in California. He is project manager of the upcoming $590m Kepler mission, which was due to be launched on 5 March from Cape Canaveral, Florida. The mission's aims are to determine what fraction of stars have an Earth-like planet orbiting around them and to guide future missions in locating Earth-like twins that can be scrutinized for any signs of life.

The Kepler spacecraft incorporates the largest camera to be put into space. Its CCD array has more than 94 000 pixels that will monitor 105 square degrees of sky (about the size of your hand held at arm's length). Kepler will be in a "trailing orbit" that will fall behind Earth by roughly 18 million kilometres each year. From here, it will stare for three and a half years at the same part of the sky in the hope of catching any star that "blinks" as a planet passes in front.

"The mission will look at 100 000 stars and determine how many of those have Earths," says principal investigator William Borucki of NASA's Ames Research Center in California. If our type of planet is common, then Kepler might see hundreds of Earth-size transits, but it could also see none at all if terrestrial planets are rare.

NASA

Eagle-eyed NASA's Kepler spacecraft might detect as many as 500 Earth-sized planets.

Flea on a headlight

Over 330 extrasolar planets are currently known, but most are "gas giants". These planets have been the easiest to detect with the traditional "radial velocity" technique, which measures the wobble the planet's gravity induces in its star. Kepler will use a different technique, which involves looking for changes in the brightness of a star as a planet crosses in front.

In the last few years, small, dedicated ground-based telescopes have detected more than 50 transiting planets with radii between 5 and 20 times that of Earth. The big advantages of Kepler over such instruments are that it will not be limited by atmospheric blurring and will not suffer from daily temperature fluctuations in equipment. It will therefore be able to measure changes of as little as 10 parts per million in the brightness of stars.

Borucki compares this to seeing a tiny flea crossing a distant headlight. "What is exciting about Kepler is that it will detect much smaller planets than we are currently able to do from the ground," says Coel Hellier of Keele University in the UK, who is a member of the world's largest ground-based transiting survey called SuperWASP.

Measuring small changes in a star's brightness caused by a passing planet is far from easy. If someone on another planet were looking at our Sun, they would need to detect a drop of 84 parts per million in brightness to notice our planet. Even if they had this capability, they would have to wait patiently to catch the 13 hour transit that only happens once every year. Moreover, there is only a 0.5% probability that the geometry is right for seeing an Earth transit – in other words, these outside observers must be viewing the Sun along its orbital plane.

To deal with these low odds, the Kepler mission has selected a large sample: 100 000 stars that are between 150 and 2500 light-years away from Earth in the direction of the Cygnus constellation. If every one of these stars has an Earth-sized planet, Kepler would observe at most 500 of them.

Following act

The planets of greatest interest will be those in the so-called habitable zone, where temperatures are favourable for liquid water – a presumed necessity for life. To tell whether a transiting planet is orbiting in this region, astronomers will observe at least three or four transits from which they will be able to verify the planet's period. By including a separate estimate of the host star's mass, they can then calculate the orbital radius using the laws of motion derived in 1609 – four centuries ago this year – by the namesake of the mission, the astronomer Johannes Kepler.

Kepler will not be the first transit survey from space. The largest current mission is CoRoT, led by the French Space Agency (CNES) with contributions from European Space Agency (ESA) and other nations. Launched in 2007, CoRoT has so far detected seven transits, and researchers recently announced the confirmation of the smallest extrasolar planet found so far. It is presumed to be rocky, having 1.8 times the radius and 11 times the mass of the Earth.

CoRoT's recent findings bode well for Kepler, which can detect planets over orbital periods 10 times larger than CoRoT. "Kepler has a very good chance of seeing the first Earth-sized planet," says Malcolm Fridlund, ESA's CoRoT project scientist. But like all transit detections, Kepler's observations will need to be confirmed by the radial-velocity method with ground-based telescopes such as Keck in Hawaii and the William Herschel Telescope on the Canary Islands that can measure the mass of a transiting object. Lots of things can mimic a transit. Some stars, like our Sun for example, can have spots that alter the brightness as they rotate around the surface, while many others have faint companion stars than can appear like a planet when they pass in front.

"The important thing about Kepler is that it will tell us the relative number of small-, medium- and large-mass planets," says Wesley Traub, chief scientist for JPL's Exoplanet Exploration Program. Kepler will help support potential missions in the coming decade such as NASA's Terrestrial Planet Finder and ESA's Darwin mission that both have their sights set on directly imaging an Earth-like planet around a nearby star. "How deep will we have to look?" wonders Fanson. "The nearest 100 stars, the nearest 1000 stars? Kepler will help us decide by giving the frequency of Earths in our galaxy."

Fusion

New reactor to destroy nuclear waste

Physicists at the University of Texas in the US have proposed a new type of fusion reactor that could destroy the most biologically hazardous nuclear waste. It would consist of a spherical tokamak containing a deuterium–tritium plasma that would produce streams of neutrons that would be fired into the waste held in a "blanket" around the reactor. If built, the reactor could be operational in as little as 10 years' time and could even be used to generate electricity.

High-level nuclear waste contains not only uranium and plutonium but also other "transuranic" elements that are heavier than uranium and are the principal source of longer-lived radiation. Most of this type of waste is put into stainless-steel flasks and stored in vaults. Although it is possible to reprocess spent fuel and separate uranium and plutonium from the fission products, some countries, like the US and Finland, are instead planning to store unprocessed spent fuel for hundreds of years in costly underground repositories.

The new reactor, which is being proposed by Mike Kotschenreuther, Prashant Valanju, Swadesh Mahajan and Erich Schneider would destroy the transuranic waste in a two-step process involving the process of "transmutation". The idea of transmutation has been around for some time and involves converting radioactive material, which has a half-life on a geological timescale, into something with a much shorter half-life. Waste would still need to be stored, but its long-term hazards would be reduced.

However, existing transmutation methods, which are based on fission alone, can not deal with transuranic elements. What the Texas team is proposing is to first attack the waste by placing it in a standard nuclear plant such as light water reactor (LWR), which would destroy almost 75% of the transuranic waste by transmutation. The rest – non-fissile transuranic elements such as plutonium-242, americium-243 and curium-246 that cannot easily be destroyed using LWRs because the neutron flux is not great enough – would be destroyed by neutrons from the new reactor.

The proposed Compact Fusion Neutron Source (CFNS) is a version of the Mega Amp Spherical Tokamak (MAST) reactor at the UK Atomic Energy Authority in the UK and the National Spherical Torus Experiment (NSTX) at Princeton University in the US. It would generate neutrons by fusing deuterium and tritium nuclei, but the magnetic field would be about 7 T – much higher than in MAST or NSTX – to increase the fusion pressure and so create a high enough neutron flux. Transuranic waste would be destroyed by loading it around the CFNS's core. The CFNS would also contain a new kind of divertor, which would remove the heat from the sides of the reactor.

UKAEA

Burning issue
The MAST fusion reactor in Oxford is the inspiration for a new waste-burning tokamak.

The researchers say their reactor could also be used to generate power as the transuranic waste burns with about 90% being potentially sold to electricity grids and the rest used to keep the fusion process going. They say that only one such machine would be needed to destroy the transuranic waste from 15 LWRs. "Realistically, if funding is available, then the CFNS could be ready in 10–20 years," says Swadesh, who thinks it could cost a tenth of the €10bn budgeted to construct the ITER fusion experiment, which is being built in France.

> If funding is available, then the Compact Fusion Neutron Source could be ready in 10–20 years

One big problem with the technique is that the reactor would have to operate continuously. Currently, MAST and NSTX operate for only 10 s, with only the KSTAR tokamak in South Korea operating for 1000 s. "The idea is attractive," says David Ireland, a nuclear physicist from the University of Glasgow in the UK. "But there are some technical issues that would first need to be overcome, such as if it is possible to maintain the plasma for long durations."

Michael Banks

Energy

Sweden seeks U-turn on nuclear power

The Swedish government is proposing to end a nearly 30-year-old ban on the construction of new nuclear power plants. The U-turn came last month when the conservative prime minister Fredrik Reinfeldt and his centre-right coalition partners agreed to propose a bill that would let any of the country's 10 existing plants be replaced. The government described the bill, which also seeks to boost renewable energy, as a "long-term, sustainable energy and climate policy".

Sweden decided back in 1980 to phase out nuclear power following a national referendum. Under the plan, the seven existing plants and the five under construction would be allowed to continue running for the rest of their lives – but new reactors to replace them were banned. Two of the 12 plants have already closed, although nuclear energy still accounts for nearly half of Sweden's electricity production, with most of the rest coming from hydroelectric plants.

Although opposition leader Mona Sahlin from the Social Democratic Party disapproves of the plan, recent polls suggest that most of her party members support new nuclear power plants – leaving only the Greens and Left Party firmly against. But Martina Krüger, head of energy and climate at Greenpeace Sweden, says the governing coalition rules by only a slim majority "It is not a done deal," she contends. "The chance of new nuclear power plants in Sweden is very slim."

However, nuclear physicists in Sweden have welcomed the proposal, which could be voted on in parliament later this month, saying it would breathe new life into ailing university nuclear-power programmes. "This is a positive decision for us in every respect," says Ane Håkansson from Uppsala University, who believes it will win parliamentary approval. "I see this, more or less, as a paradigm shift."

Janne Wallenius, head of reactor physics at the Royal Institute of Technology in Stockholm, adds that the current law has had a "very negative impact" on his institution and meant that no PhDs in reactor physics were carried out between 1987 and 2004. Both he and Håkansson believe the bill would improve career opportunities in nuclear energy.

Ned Stafford

Energy

Italy seeks geothermal renaissance

Scientists in Italy are hoping to once again put their country at the forefront of geothermal energy research, by extracting power from one of the Earth's most explosive volcanic areas. Later this year they will drill a well 4 km deep into Campi Flegrei, a geological formation lying just to the west of Naples known as a caldera, which formed from the collapse of several volcanoes over thousands of years.

Italy has a long tradition of geothermal power, having built the world's first geothermal power plant at Larderello in Tuscany in 1911. It still operates today and provides some 800 MW of installed power, roughly equal to a nuclear plant. But with Italy relying heavily on imported oil and gas – and having no nuclear plants of its own – Giuseppe De Natale, a geophysicist at the Vesuvian Observatory in Naples, sees a new role for geothermal power.

Central to this expansion, says De Natale, will be exploiting Campi Flegrei. He points out that this is an ideal site for geothermal energy production because its subsurface temperature increases rapidly with depth and because it contains natural reservoirs, which means that the water that is used to carry away the heat does not have to be pumped in from outside. He believes that, given the political will, the fraction of the country's electricity generated by geothermal could rise five-fold to as much as 10% within the next 10 years.

Gabriele Delhey

Leading the way
Italy built the world's first geothermal power plant at Larderello, above, which now provides 800 MW of electricity.

As co-ordinator of the Campi Flegrei Deep Drilling Project, De Natale is leading an international collaboration of scientists to bore a well 4 km deep in the area by the end of the year. At this depth the water in the reservoirs should be at about 400 °C and therefore be supercritical, with liquid and vapour existing simultaneously. In this state, water reaches the surface as high-pressure steam, enabling it to transfer power to electrical turbines, with each individual supercritical well providing up to 50 MW.

However, power plants using supercritical water will take some time to develop. They are expensive because they require deep wells and are technically demanding because of the high pressures involved. They also have an impact on the environment, due to the various subterranean gases, including carbon dioxide, emitted directly into the atmosphere when the geothermal water vapour is passed through the turbines.

De Natale says that he and his colleagues will use the results of a test on supercritical geothermal energy to be carried out shortly in Iceland, a heavy user of geothermal energy. In the meantime, the team is pursuing a less powerful but more environmentally friendly technology known as "binary fluid plants". This involves pumping geothermal water at 100–180 °C from just a few hundred metres below the surface and transferring the heat from the water to a secondary fluid with a low boiling point that vaporizes and drives a turbine, before injecting the water back into the reservoir to complete a closed circuit.

"Once we have shown the people and politicians the potential of geothermal energy in this area, I believe it will be easier to persuade them to move to the more powerful supercritical technology," says De Natale.

Edwin Cartlidge
Rome

Astronomy

Sloan Digital Sky Survey tops astronomy citation list

NASA's Sloan Digital Sky Survey (SDSS) is the most significant astronomical facility, according to an analysis of the 200 most cited papers in astronomy published in 2006. The survey, carried out by Juan Madrid from McMaster University in Canada and Duccio Macchetto from the Space Telescope Science Institute in Baltimore, puts NASA's Swift satellite in second place, with the Hubble Space Telescope in third (arXiv:0901.4552).

Madrid and Macchetto carried out their analysis by looking at the top 200 papers using NASA's Astrophysics Data System (ADS), which charts how many times each paper has been cited by other research papers. If a paper contains data taken only from one observatory or satellite, then that facility is awarded all the citations given to that article. However, if a paper is judged to contain data from different facilities – say half from SDSS and half from Swift – then both facilities are given 50% of the citations that paper received.

The researchers then totted up all the citations and produced a top 10 ranking (see table). Way out in front with 1892 citations is the SDSS, which has been running since 2000 and uses the 2.5 m telescope at Apache Point in New Mexico to obtain images of more than a quarter of the sky. NASA's Swift satellite, which studies gamma-ray bursts, is second with 1523 citations, while the Hubble Space Telescope (1078 citations) is third.

Top 10 telescopes

Rank	Telescope	Citations	Ranking in 2004
1	Sloan Digital Sky Survey	1892	1
2	Swift	1523	N/A
3	Hubble Space Telescope	1078	3
4	European Southern Observatory	813	2
5	Keck	572	5
6	Canada–France–Hawaii Telescope	521	N/A
7	Spitzer	469	N/A
8	Chandra	381	7
9	Boomerang	376	N/A
10	High Energy Stereoscopic System	297	N/A

Although the 200 most cited papers make up only 0.2% of the references indexed by the ADS for papers published in 2006, those 200 papers account for 9.5% of the citations. Madrid and Macchetto also ignored theory papers on the basis that they do not directly use any telescope data. A similar study of papers published in 2004 also puts SDSS top with 1843 citations. This time, though, the European Southern Observatory, which has telescopes in Chile, comes second with 1365 citations and the Hubble Space Telescope takes third spot with 1124 citations.

Michael Banks

Geophysics

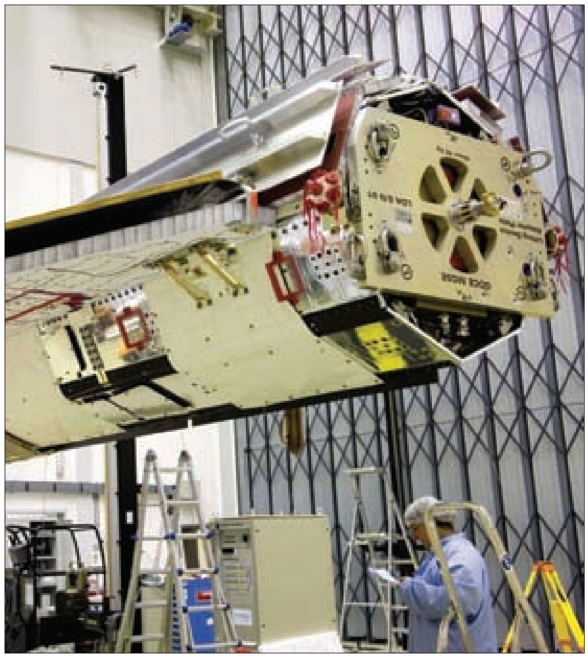
New probe plots Earth's gravity field

A mission to make a very high-resolution map of the Earth's gravitational field will be launched this month by the European Space Agency (ESA). The €350m Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) will also produce a much-improved model of the "geoid" – the gravitationally defined surface that Carl Friedrich Gauss described as the "mathematical figure of the Earth". GOCE, which will fly at an altitude of just 250 km, is expected to launch this month and operate for 20 months.

The gravitational force at the Earth's surface, g, does not have a constant value but varies across the planet. The most significant variation is due to the Earth's spin, which causes it to bulge very slightly at the equator, meaning that the surface at this point is further from the planet's centre – by about 20 km – than it is at the poles. Due to this – and also to an unequal distribution of mass inside the Earth – g is 9.83 m s^{-2} at the poles but only 9.78 m s^{-2} at the equator. Other, more minor, influences cause smaller variations in g – for example, mountains and ocean trenches lead to fluctuations at the third decimal place.

Associated with these fluctuations in g is a representation of the Earth's surface known as the geoid. This is defined as the surface of equal gravitational potential and follows the surface of the ocean without any tides and is the basic ellipsoid shape of the Earth but with very smooth, shallow bumps and depressions superimposed on top of it, according to the local variations in gravity. For example, the extra mass in a mountain 2 km in height under the sea attracts water over it to produce a bulge in the sea surface some 2 km high and 40 km across.

Plotting the variations in g itself could allow scientists to improve their understanding of geophysical processes, such as earthquakes. Mapping the geoid, on the other hand, provides a base reference – or 0 m sea level – throughout the world and lead to a better understanding of ocean circulation, and hence climate. This is because local values of the geoid can be subtracted from radar measurements of the sea level to reveal the heights of waves around the world, and this surface behaviour can then be combined with data on the topography of the sea bed to calculate currents and heat flows through the oceans.



ESA

Gravity probe GOCE has no moving parts that could mimic the tiny gravitational signals it is trying to measure.

To measure gravitational fluctuations over large distance scales, but at low resolution, GOCE will continuously record how its orbit changes – and therefore how its pull towards the Earth changes – with respect to GPS satellites. To fill in the details of fluctuations over smaller scales, GOCE will sense the minute differences in acceleration experienced by three pairs of proof masses held at the ends of arms 50 cm long inside the spacecraft. In this way, the mission should measure g to an accuracy of 10^{-5} m s^{-2} and of the geoid to an accuracy of 1–2 cm, with both sets of measurements plotted with a resolution better than 100 km.

GOCE's resolution will be far better than earlier gravity-measuring satellites, such as the US–German GRACE mission, launched in 2002, that was limited to a resolution of 600 km. GOCE mission manager Rune Floberghagen says that although GRACE can record changes in the Earth's gravitational field over time, allowing it to observe the melting of polar ice caps for example, its lower resolution means that it cannot study ocean circulation in great detail, as GOCE can. "The GRACE mission delivers low-resolution movies of gravity-field variations," says Floberghagen, "while GOCE will deliver an ultrahigh-resolution snapshot."

The Gravity Field and Steady-State Ocean Circulation Explorer will deliver an ultrahigh-resolution snapshot of gravity-field variations

Edwin Cartlidge

Sidebands

Joint mission planned for Jupiter
NASA and the European Space Agency (ESA) have agreed to develop two co-ordinated scientific missions to study Jupiter and several of its moons. NASA's Jupiter Europa Orbiter and ESA's Jupiter Ganymede Orbiter are scheduled for separate launches in 2020 and should reach the Jovian system in 2026. The combined effort is called the Europa Jupiter System Mission and will spend at least three years studying Jupiter and its moons Callisto, Ganymede, Europa and Io. The Jupiter Europa Orbiter will look at whether oceans of liquid water exist on Europa – and whether the moon could harbour life. The Jupiter Ganymede Orbiter could help scientists understand why Ganymede is the only moon in the solar system known to have an internally generated magnetic field. The two agencies also plan a joint project to Saturn consisting of a NASA orbiter plus an ESA lander and research balloon. It will be launched sometime after the Jupiter mission.

Satellites measure CO_2 levels
The Japanese space agency, JAXA, has launched the world's first satellite dedicated to monitoring greenhouse-gas emissions. Named Ibuki, which means breath in Japanese, the satellite is in orbit 667 km above the Earth's surface and is sensitive enough to detect changes in carbon-dioxide levels of about one part per million. As carbon dioxide and methane absorb energy from sunlight, this will change the intensity of sunlight reflected from the Earth's surface, which Ibuki will measure using a spectrometer at 56 000 locations on the globe. Meanwhile, NASA was expected to launch the Orbiting Carbon Observatory as *Physics World* went to press. It is also designed to measure carbon-dioxide levels and will orbit at an altitude of 705 km.

Who's Galileo?
Most people in the UK do not know what Galileo Galilei is best remembered for, according to a survey of 1002 adults carried out by the Royal Astronomical Society, the Science and Technology Facilities Council and the Institute of Physics, which publishes *Physics World*. It found that 73% of people either credit Galileo with incorrect discoveries, such as having observed Neptune or found the black hole at the centre of the Milky Way, or simply do not know that he first spotted Jupiter's four satellites. When asked whether Galileo is associated with astronomy, fashion, a type of wine or a ship, 61% chose the correct answer.

A new frontier awaits for US particle-physics lab

With construction of the world's first X-ray free-electron laser at the SLAC National Accelerator Laboratory almost complete, **Michael Banks** talks to lab boss Persis Drell about its new focus as a centre for photon science

For a lab that made its name in particle physics, shifting into new directions was never going to be easy. "Changes are hard and people do not like them," admits Persis Drell, director of the SLAC National Accelerator Laboratory in California. "But we are now opening up new frontiers in another direction and that is very exciting." That focus, which lies in photon science, reaches new fruition this month with the opening of the world's first X-ray free-electron laser (XFEL) – the Linac Coherent Light Source (LCLS).

The LCLS involves accelerating electrons in a 16 GeV linear accelerator housed in a 1 km underground tunnel and then forcing the electrons to emit intense beams of X-rays that can be used in a range of experiments from condensed-matter physics to biology (see box). It will open almost exactly a year after the lab closed its 2.2 km circumference PEP-II electron–positron collider. Those collisions produced copious amounts of B-mesons – creating a "B-factory" – that were studied by the BaBar experiment to work out why there is more matter than antimatter in the universe despite equal quantities of both having been created in the Big Bang.

Drell, who spent the bulk of her career as a particle physicist before joining SLAC in 2002 as associate director of research, was initially responsible for running BaBar. Taking over as SLAC boss in December 2007, she admits that briefings by SLAC's photon and accelerator physicists have helped her appreciate the scientific potential of this new type of light source. "I have had to do a lot of homework, but I learnt an enormous amount in the process," she says.


SLAC

New directions
The SLAC National Accelerator Laboratory.

In many ways, Drell's new interest in photon science typifies the new direction for a lab the history of which is so engulfed in particle physics. Founded in 1962 as the Stanford Linear Accelerator Laboratory – the lab changed its name last October to reflect its new direction – SLAC researchers have scooped the Nobel Prize for Physics on three different occasions. In 1976 Burton Richter – who was director of SLAC from 1984 to 1999 and who encouraged moving the lab into photon science – shared the Nobel prize with Samuel Ting for the discovery of the J/ψ particle. In 1990 Richard Taylor of SLAC shared the prize with Jerome Friedman and Henry Kendall for the first evidence that nucleons consist of quarks, while SLAC's Martin Perl won the 1995 prize with Frederick Reines for the discovery of the tau lepton.

Bye-bye BaBar

SLAC is operated by Stanford University for the US Department of Energy (DOE) and lies near Menlo Park in San Francisco Bay, a few kilometres away from Stanford's campus. Drell has a long association with SLAC: her father, the physicist Sidney Drell, was deputy director for almost three decades from 1969 to 1998. Persis Drell took up the reins as director of SLAC at a difficult time. A shortfall in the US science budget for the financial year of 2008 meant that the DOE was forced to close the PEP-II collider – and thus BaBar – in March 2008, seven months earlier than planned after almost 10 years of service. "The shutdown of the SLAC B-factory was a severe setback for particle physics in the US," says Francois Le Diberder,

Pure brilliance: the Linac Coherent Light Source

Construction of the $480m Linac Coherent Light Source (LCLS) started in 2005 at the SLAC National Accelerator Laboratory. The LCLS will generate intense, coherent X-ray beams with each pulse lasting less than 100 fs (10^{-13} s) that will allow researchers to create "movies" of chemical processes such as bonding.

The LCLS uses the last third of the 3 km linear accelerator tunnel at SLAC, where it will accelerate electrons to 14 GeV. They will then be passed through an "undulator", which causes the electrons to follow a sinusoidal path and emit synchrotron radiation as they do so. However, as the photons are initially incoherent and concentrated over a narrow range of wavelengths, the light is amplified into coherent laser light by a process known as self-amplified spontaneous emission.

As the electrons travel through the undulator, the light they emit interacts with electrons following behind and this interaction accelerates or decelerates the electrons depending on their position and the phase of the light. The net result is that the electrons bunch up as they travel and thus produce light in phase and with a higher intensity.


SLAC

This method gives an X-ray peak brilliance 10 orders of magnitude greater than existing "third-generation" light sources such as the Stanford Synchrotron Radiation Lightsource (SSRL) facility at the SLAC lab, which opened in 1977. The wavelength of the light can also be easily changed by controlling the energy of the electron beam in the linear accelerator or the magnetic field of the undulators to produce X-rays with a wavelength as short as 0.15 nm.

The LCLS will have six experimental rooms, the first of which will be built by August when users will begin using the facility. This will look into atomic and molecular physics. For example, the XFEL's ultra-short pulses will allow researchers to "see" how empty atomic shells fill with electrons.

SLAC is not the only lab to be building an XFEL – others are on their way at the DESY lab in Hamburg (see *Physics World* February p10) and the SPring-8 facility in Hyogo, Japan, which will open in 2011.

spokesperson for BaBar.

Drell is, however, pragmatic about the months of lost data collection. "All great machines get turned off one day," she says. "We could have proposed an upgraded, but this was not deemed a high priority within the national physics community in the US." However, SLAC has not seen a brain drain since it closed down PEP-II over a year ago. Drell says that the core accelerator physicists who ran BaBar now work on the LCLS. Even with PEP-II shut, SLAC has not deserted particle physics and is involved in the ATLAS detector at the Large Hadron Collider (LHC) at CERN and also has a group involved in planning the International Linear Collider (ILC), the next big particle-physics experiment after the LHC.

"I think particle physics in the US is struggling, and I feel strongly that the future of particle physics internationally will require a linear collider," says Drell. "The most important thing is that the ILC is built someday full stop – rather than where it is built."

SLAC has also moved into other directions. Under the stewardship of Jonathan Dorfan, who was director from 1999 to 2007, the lab joined the construction of the Fermi Gamma-ray Space Telescope launched by NASA in June 2008, which studies the sources producing gamma rays – the most energetic form of radiation in the universe. SLAC is also doing research and development on a 3.2 gigapixel camera planned for the Large Synoptic Survey Telescope that will track the evolution of the universe and could provide important clues to the nature of dark matter and dark energy. Then there is its work on the Joint Dark Energy Mission that will make measurements of the expansion rate of the universe to understand how this rate has changed with time.

All great machines get turned off one day. We could have proposed an upgrade to PEP-II, but this was not deemed a high priority in the US physics community

Fountain of ideas

With the PEP-II tunnel now lying dormant, other labs have expressed an interest in some of the equipment. Fermilab, for example, is planning to use some of the PEP-II magnets for the Tevatron. There is also interest from Italy, which is planning a similar experiment to BaBar known as SuperB (see *Physics World* February p11). "It is a pity for SLAC not to be the host of the next SuperB factory," says BaBar's Le Diberder. "SLAC would have been the best place in the world for this project."

As for the tunnel itself, photon scientists are eyeing it up as the home for a possible future high-powered light source. "There is a fountain of ideas for the PEP-II tunnel," says John Galayda, project leader of the LCLS.

One of these is to build a storage-ring light source in the tunnel, which would be 10 times as bright as any existing today. However, as the proposed PEP-X synchrotron would be underground, major construction is needed to build two experimental halls each containing 16 X-ray beam lines. "It is not going to be cheap and we are not going to fill the tunnel soon," says Drell. "But if we think where we want to be in the next decade, then it is a good use of the tunnel."

With an X-ray FEL and the PEP-X facility, the SLAC lab would be a world leader in photon science. "It is clear that probing materials will require a new suite of tools including XFELs and third-generation sources," says Drell. "This is going to be the long-term project at SLAC for the next 10 years."

US funding

Physical science receives stimulus boost

Science fared well in the $787bn package to stimulate the US economy that President Barack Obama signed into law last month. The "recovery and reinvestment bill" includes $21.5bn for research and development (R&D), the bulk of which – some $18bn – will go directly to researchers. The remaining $3.5bn is allocated for facilities and equipment. Politicians had been bickering over the bill since it was first unveiled on 15 January.

American legislation takes a circuitous course on its way to the president. Typically, the House of Representatives and the Senate approve different versions of a bill, and then appoint negotiators to agree on compromise legislation that both houses must approve again before sending it to the president.

On this occasion, the $838bn senate bill, signed on 10 February, included significantly less funding for physical science than the earlier house bill of $825bn. Even though the senate bill may have higher priority, most of the cuts to the physical sciences were reversed in the final $787bn bill agreed on 14 February.

Physicists have welcomed the $21.5bn for science, with more than $10bn of it going to government agencies responsible for funding the physical sciences. The National Science Foundation (NSF) will receive $3.0bn in stimulus funding on top of its $6.0bn budget for 2009. This will include $1bn for research infrastructure and construction plus $2bn for "other research and related activities".

The Office of Science of the Department of Energy (DOE), meanwhile, will get $1.6bn in funding beyond its 2009 budget of $4.0bn. Two other DOE programmes – fossil fuels, and energy efficiency and renewables – will receive $2.5bn and $1.0bn, respectively, which is almost twice as much as their 2009 budget allocations of $1.2bn and $576m.

Denver Museum of Nature & Science

Signing off US President Barack Obama is injecting $21.5bn into research.

With a budget of $737m for this year, the National Institute of Standards and Technology will receive an extra $580m, of which $360m will go on building research facilities. NASA will get an extra $1.1bn beyond its current budget of $17.2bn, with $400m going towards its science and exploration programme.

"These critical investments will not only benefit American science and innovation, but they will put thousands of Americans back to work through construction and manufacturing projects," says Cherry Murray, president of the American Physical Society. "Furthermore, these prudent investments lay the necessary foundation for long-term economic growth and prosperity for our country."

The fresh funding has implications for US science beyond the current financial year. It puts back on track the goal of doubling federal government support for physical science – an ambition of the America COMPETES Act of 2007 that had fallen behind schedule. Further evidence of the Obama administration's ambitions for science will become clear later this month, with the release of its revised budget for the 2009 financial year, which started on 1 October last year.

Peter Gwynne
Boston, MA

CERN hold-up hurts graduate students

The delay to the Large Hadron Collider is leaving some students without data for their theses, as **Matthew Chalmers** reports

When staff at CERN threaded the first protons around the Large Hadron Collider (LHC) on 10 September last year, the world watched in awe at the prospect of particles being collided at unprecedented energies. But then progress stalled dramatically on 19 September when a poor connection between two superconducting magnet cables disintegrated while carrying a test current of 8.7 kA. The incident, which produced an electrical arc that breached the collider's liquid-helium cooling system, has meant that 53 magnets have had to be repaired at a cost of about €20m.

Now CERN has announced that protons will re-enter the 27 km ring in late September – six months later than estimated immediately after the incident and two years later than advertised between 2003 and 2006. To avoid another major mishap, by September CERN will have in place a network of cables able to detect nano-ohm rises in resistance in the LHC's superconducting cables, plus extra helium-relief valves to reduce collateral damage in the unlikely event of a similar fault.

Low-energy collisions are now planned for late October, building up to 10 TeV before the end of the year. To make up for lost time, CERN will then run the LHC straight through next winter and on into autumn 2010 – incurring an extra €8m in electricity costs (40% of the LHC's annual bill) but putting the lab pretty much where it would have been had the LHC not broken down. By mid-2010 the LHC should have enough data to rival the Tevatron proton–antiproton collider at Fermilab in the US, which has an energy of about 2 TeV and threatens to steal some of the LHC's thunder.

Moustapha Thioye

Stuck? Katy Grimm of Stony Brook University.

Decision time

Among those hardest hit by the delays are final-year graduate students who were expecting to publish some of the first LHC data in their theses. "There are a couple of guys here who are really gutted," says Dave Newbold of Bristol University in the UK.

One student in his group is James Jackson, who works on the Compact Muon Solenoid (CMS) detector – one of the four main experiments at the LHC. "It was massively exciting when it was going well, but then a major disappointment," says Jackson, adding that he was fortunate to have also worked on high-performance computing and undertaken theoretical work during his PhD.

> There is not an immediate threat of running out of funding, just the threat of being a graduate student for a decade

The UK currently has about 40 experimental particle physicists in the final year of their PhD who work on the LHC and are therefore potentially affected. They include Catherine Wright from the University of Glasgow, who works on the ATLAS experiment and turned up for a six-month stint at CERN just days before the September accident. "It breaks my heart that I'll have spent four years doing a PhD with no data," she says, admitting that the lure of analysing LHC data might be enough to make her stay to do postdoc research.

Most students can beef up other aspects of their research to compensate, for instance by improving their analysis routines and running them over simulated LHC data. As CMS spokesperson Jim Virdee points out, "several hundred students have, over the past 15 years, done their theses on CMS". But other students, particularly those in the US where PhDs last six or seven years, face stricter data requirements that have forced them to take more radical decisions.

Katy Grimm of Stony Brook University in New York, who started out on ATLAS and is currently in her fifth year, has decided to do the second half of her thesis on data from the Tevatron's D0 experiment. "Luckily, there is not an immediate threat of running out of funding, just the threat of being a graduate student for a decade," she says, estimating that some 10 to15 students are switching from the LHC to the Tevatron.

That may turn out to be a shrewd move. The Tevatron is working like a dream and many physicists there think they have a good chance of sighting the Higgs boson in the next two years. "We have a lot of data at the Tevatron, many interesting thesis topics, and good opportunities to contribute to and learn from running experiments," says co-spokesperson of the D0 collaboration Darien Wood.

Waiting game

But the excitement of searching for new heavy "vector bosons" that may show up early in LHC data has led Stony Brook student Regina Caputo to hang on for a year or two. Fellow ATLAS student Andree Robichaud-Veronneau, currently in her third year at the University of Geneva, is also sticking around, although she has put on hold an analysis looking for supersymmetric particles in favour of something possible with less data, involving the already known J/ψ particle.

An upside of the delay is that physicists will be in a better position to understand the LHC collision data when they start pouring in. Numerous "splash" events obtained during the September start-up, when protons struck graphite collimators and sprayed millions of muons into the detectors, have enabled their subdetectors to be sychronized, which is vital to distinguish between particles produced in successive collisions. Hundreds of millions of cosmic rays recorded so far have allowed the giant experiments to be aligned and calibrated with great precision, which has also provided some data for students.

While the LHC is a long way from its peak design performance, running through next winter should amass almost the same volume of data had it not broken down (assuming it was operated at 10 TeV then). Full-energy collisions at 14 TeV, which will roughly double the machine's "physics reach", will not be attempted until mid-2011. Then it will take a couple of years to crank up the proton collision rate before the machine is upgraded.

Jordan Nash of Imperial College London believes that PhD students wishing to remain in physics should not be too downcast. "I don't belittle the predicament of graduate students," he says, "but the LHC will run for 10–15 years and soon those students will have the opportunity to do some excellent physics."

Feedback

Letters to the Editor can be sent to *Physics World*, Dirac House, Temple Back, Bristol BS1 6BE, UK, or to **pwld@iop.org**. Please include your address and a telephone number. Letters should be no more than 500 words and may be edited. Comments on articles from *physicsworld.com* can be posted on the website; an edited selection appears here

A year of astronomy

The opening sentence of your news story "Let the global astronomy celebrations begin" (January pp12–13) implies that the prime anchor for the International Year of Astronomy (IYA2009) is the efforts of Galileo Galilei. If this is the case, then we must be careful how much credit we give him. A more accurate opening sentence would have referred to the first *publication* of the use of an astronomical telescope by Galileo, following its first known use by the British scientist Thomas Harriot, whose diaries include sketches of the Moon made on 26 July 1609 – a few months before Galileo. Unfortunately, Harriot never published his observations; an article by Allan Chapman in *Astronomy and Geophysics* (2009 **50** 1.27) describes the events in more detail.

By recognizing Harriot's earlier success, we need not deny Galileo's substantially greater contribution to scientific astronomical investigations. Curiously, both men's observations may have been anticipated 120 years earlier by Leonardo da Vinci, who suggests in *Codus Atlanticus* (circa 1490) "making glasses to see the Moon enlarged". No record has been found that he ever did so – at least not yet.

Paul Dench
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I was pleased to learn of the programme for IYA2009 in your January issue, but there is another astronomy event taking place that might also interest readers: the International Olympiad on Astronomy and Astrophysics (IOAA), due to be held in Iran in September. The competition seeks to promote interest in astronomy and astrophysics among high-school students. Participants in the first IOAA – held in 2007 in Thailand – included 39 team leaders, six observers and 85 student contestants from 21 nations around the world. The second IOAA was held in Indonesia, with 98 contestants, 41 team leaders and 19 observers from 25 different countries.

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FAST success

I was pleasantly surprised to read your article on China's Five-hundred-meter Aperture Spherical Telescope (FAST), as few people outside the country seem to be aware of it (February p7). I am glad to hear that a construction effort of such size is now beginning to get some good coverage.

It is interesting to note that FAST will revolutionize not just pulsar detection but also galaxy detections via their neutral hydrogen emission, HI. I worked the numbers recently (2007 *Mon. Not. R. Astron. Soc.* **383** 150) and found that FAST could detect HI emission from galaxies with redshifts greater then one, which corresponds to light that has been travelling for more than half the age of the universe. In its current design, FAST will detect 10 times more galaxies than the recent HI Parkes All-Sky Survey (HIPASS) and those galaxies will have a mean redshift greater than the current record for the highest redshift observed in a single object – all in just one month of observing.

As one final impressive number, an upgraded "dream machine" version of FAST (with five times as many detectors as the basic version will contain) would detect 10^7 galaxies in just two years of surveying. This feat will have profound implications for determining the cosmological parameters of our universe, including the nature of dark energy and the amount of dark matter in the universe, as well as tracking the formation of galaxies in the last eight billion years or so.

Certainly we at the Jodrell Bank Observatory are intrigued by this machine.

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Funding open access

We were happy to see the 10-year anniversary of our open-access journal *Physical Review Special Topics: Accelerators and Beams* (PRST-AB) mentioned in your news article on open-access publishing (December 2008 pp13–14). However, your statement that PRST-AB "is funded by US national labs, whose researchers publish about 150 papers per year in the journal" is not entirely correct.

At present PRST-AB is funded by about 20 accelerator laboratories and organizations not only in the US and Canada but also in Europe, with roughly half of our sponsors coming from outside the US (see www.prst-ab.aps.org/sponsors.html). Also, roughly half of the over 200 manuscripts received by the journal each year are from authors in Europe or Asia. The European Physical Society's Accelerators Group and the American Physical Society's Division of Physics of Beams form the Affiliated Professional Groups and share the responsibility for the health and vitality of PRST-AB.

Gene D Sprouse
Editor-in-Chief, American Physical Society
Frank Zimmermann
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Light omission

I read your news story about construction of the National Synchrotron Light Source II (NSLS-II) at the Brookhaven National Laboratory being approved by the US Department of Energy (February p10). At the end, you list other synchrotron-radiation facilities that will have higher energies than NSLS-II, but you did not mention the PETRA-III facility at DESY in Hamburg. Operating at an energy of 6 GeV, PETRA-III will provide beams of X-rays of lower emittance (beam divergence multiplied by horizontal size) than any other synchrotron-radiation source in the world (1 nm rad). The first beams are due to be injected into PETRA-III this month and the first experimental stations will be completed towards the middle of this year. Researchers will be able to carry out the first experiments in the last quarter of 2009 and we look forward to welcoming more than 1000 new users every year.

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The last word on fusion

Letter writers Raoul Franklin and Nicholas Braithwaite (November 2008 p22; December 2008 p19) have commented on the suggestion – made by UK Atomic Energy Authority director Stephen Cowley in your October 2008 fusion supplement – that plasma science effectively started with the growth of fusion research. Braithwaite also raised the question of the origin of the name "plasma", suggesting two possible sources: neon discharges and blood plasma.

The latter view appears to be supported by a letter that appeared in *Nature* in 1971 from Harold Mott-Smith, who had been Irving Langmuir's chief assistant at General Electric in the 1920s (**233** 219). Mott-Smith (then aged 74) quotes from a letter he wrote to a friend in 1967. He reports that in about 1927 Langmuir's group had been studying particle densities and velocity distributions in mercury arc columns, the positive columns of Geissler tubes and gas-filled thermionic tubes, and

Comments from *physicsworld.com*

A new UK government campaign – dubbed "Science: [So What? So Everything]" – aims to boost public interest in science by countering impressions that science is "remote, elitist and irrelevant". An article on the *physicsworld.com* blog discussing the campaign ("Is science elitist?" 28 January) prompted several readers to share their opinions on what it means to be "elite", and whether elitism really is bad for science.

Science is elitist in the sense that any real understanding of the subject and command of its techniques requires concentration and application over a long period of time. Only the most able, diligent and (this is not often recognized) imaginative will succeed in science.
Harry Hamill, UK

It is important to be clear about what we mean by elitism. Under one definition, the elite rule as a self-appointed group who consider themselves superior. In another, the elite rule because they have outstanding abilities. I have met people at the highest levels of our scientific establishment whom I consider to be basically stupid. To some extent, it is possible that the scientific elite may not have outstanding personal abilities, but merely outstanding luck.
Michael de Podesta, UK

How about professional musicians or football players? We admire them for being elitist. People happily admit that someone sings better or is better at football, but admitting less intelligence is a bit more delicate for one's self-esteem. The real issue is not elitism but the difficulty of showing mastery. Everyone recognizes good music or good football play, but how do you show good science play?
Tom Weidig, Luxembourg

As much as I welcome the evangelism of science, I know it will do nothing to address the problem's roots. These include a science industry totally blind to its own mistakes (witness scientific visitor centre adverts that "prove" that all scientists wear lab coats and are severely myopic and follicly challenged) and the media's tendency to portray science as "requiring" gunk and explosions or dramatic narration and scripts for five year olds.
Nick Evanson, UK

Talented students are attracted by elite, high-status careers such as medicine. They will not be tempted by science if it is made too accessible. Scientists and engineers should be seen as an elite – not an unchallengeable elite, but a respected one based on the understanding that they achieved expertise by their intellectual prowess and sustained effort.
Glen Thomas, UK

physicsworld.com

Read these comments in full and add your own at physicsworld.com

had found similarities in the equilibrium conditions of these different devices. They felt that it was important that, having discovered this effect, they should name it, and various ideas were thrown around.

According to Mott-Smith, Langmuir suggested the name "plasma" by noting that "the 'equilibrium' part of the discharge acted as a sort of sub-stratum carrying particles of special kinds, like high-velocity electrons from thermionic filaments, molecules and ions of gas impurities". Langmuir apparently saw an analogy with the role of blood plasma, as it reminded him "of the way blood plasma carries around red and white corpuscles and germs". Mott-Smith also reports that the word "plasma" took a long time to gain acceptance, and led to requests for reprints from medical sources.

Regarding the origins of plasma science, one should also note the pioneering work of space physicists, who contributed to our understanding of the plasma state well before the beginnings of fusion research. For example, Hannes Alfvén's work on Alfvén waves, the guiding-centre approximation, adiabatic invariance of the magnetic moment, and frozen-in magnetic flux all helped lay the foundations of plasma physics.

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Imagine all the units

I am at a loss to know why Michael Albrow declares in his letter on units for vehicle fuel consumption (February p21) that while dimensions of area are "reasonable", dimensions cancelling down to 1/area are "unimaginable". Surely there are many quantities that have dimensions of 1/area. One such quantity is the occupancy of a building, which in fire engineering has units m^{-2}, meaning persons per square metre of floor area. An example from the realm of motoring – the theme of Albrow's letter – is the density of vehicles in a parking lot. Cars per unit area of the parking lot will have the units m^{-2} or (perhaps more sensibly) km^{-2}.

Clifford Jones
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Michael Albrow (e-mail albrow@fnal.gov) replies:
Clifford Jones is, of course, correct to say that we use inverse dimensions such as cm^{-2} and s^{-1} all the time in physics – but you always need a numerator. While I can "imagine" a disembodied metre, kilogram or second, I cannot "imagine" a disembodied inverse second. Persons per m^{-2} is one thing, but just "m^{-2}" is quite another. Possibly this is merely a limitation of my own conceptual abilities.

Off to the pub

David Saxon's review of *Kelvin: Life, Labours and Legacy* (January pp36–37) reminded me of a long-time question I have on a similar subject. In King's Lynn, Norfolk, UK, there is a pub called The Lord Kelvin. What is the story behind this? Why is there a pub so named in darkest King's Lynn but not anywhere else (if Internet searches provide a comprehensive picture) – not even in Glasgow, where the erstwhile William Thomson lived for 53 years? And do readers know of any other pubs or bars that commemorate physicists in the same way?

There are currently Sir Isaac Newton pubs in both Cambridge and Grantham, but years ago (in the late 1960s, I think) I happened to visit Woolsthorpe Manor in Lincolnshire, where Newton was born. The then resident-in-charge was an academic who had replied to an advert to live there and show the occasional visitor round. He told me that there used to be an Isaac Newton pub in Woolsthorpe village before the Second World War and that Einstein had once made a pilgrimage to Woolsthorpe itself. On reaching the village, Einstein apparently asked the way to Newton's house, but local ignorance was such that he was directed not to Newton's birthplace, but to the pub.

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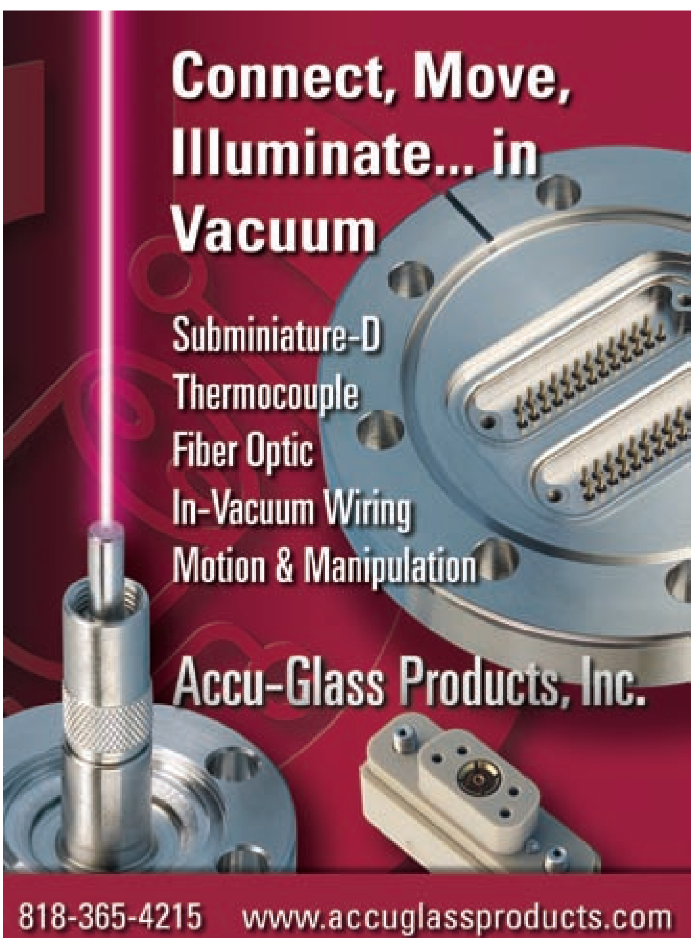
Quiz results

Congratulations to **Alexandra Gade** of the National Superconducting Cyclotron Laboratory in Michigan, US, who won the Quiz of the year 2008 (December 2008 p60).

Answers
A. LEDs **B.** Higgs boson **C.** Kobe Bryant **D.** 19 years 7 months **1.** Hybrid cars **2.** Jodrell Bank **3.** Plutoids **4.** Drill holes in it **5.** Moon vehicle **6.** 54 minutes **7.** 89 microseconds **8.** Nine days **9.** Pink elephants **10.** Rolf-Dieter Heuer **11.** E (Arthur C Clarke) **12.** B (Bill Foster) **13.** D (Douglas Osheroff) **14.** A (Freeman Dyson) **15.** C (Warren Buffett) **16.** The toilet **17.** Showering **18.** Granite countertops **19.** Stephen Hawking **20.** Dounreay



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In Galileo's footsteps

This issue marks *Physics World*'s main contribution to the International Year of Astronomy

Astronomy can lay rightful claim to being the oldest science, with its foundations dating back even further than those of mathematics. From the ancient Babylonians who observed the regular motions of Venus to medieval Islamic scholars who had the first inklings of heliocentrism, the study of the skies has fascinated humankind. But 2009 – the International Year of Astronomy – commemorates an event central to the development of Western science: Galileo Galilei's first observations with a telescope in 1609. This year also marks the 400th anniversary of Johannes Kepler's *Astronomia Nova*, in which he outlined his laws of planetary motion.

There may be more pressing scientific issues facing us today, such as the need to tackle climate change, but astronomy has several trump cards that make it worth celebrating. It has easily the best images. It is relatively simple to understand. And what can be more profound than looking at the cosmos and asking of our place in it? But, just as importantly, astronomy is the most accessible science in that it can be taken up as a hobby by anyone with relatively simple equipment – a pair of binoculars will suffice. Even those whose skies are soiled by light pollution can take part in Web-based mass-participation projects like *SETI@home* and *Galaxy Zoo*.

This special issue of *Physics World* looks at five main themes: the search for exoplanets; planetary exploration; a return to the Moon; plans for extra-large telescopes; and the legacy of Galileo himself. We ask six leading astronomers to outline the biggest challenges for the field, while we could not resist including five full-page iconic images from astronomy. More than anything, these images underline just how vast, alluring and mysterious the universe is – and that there are countless "unknown unknowns" waiting to be discovered.

Matin Durrani, Editor of *Physics World*

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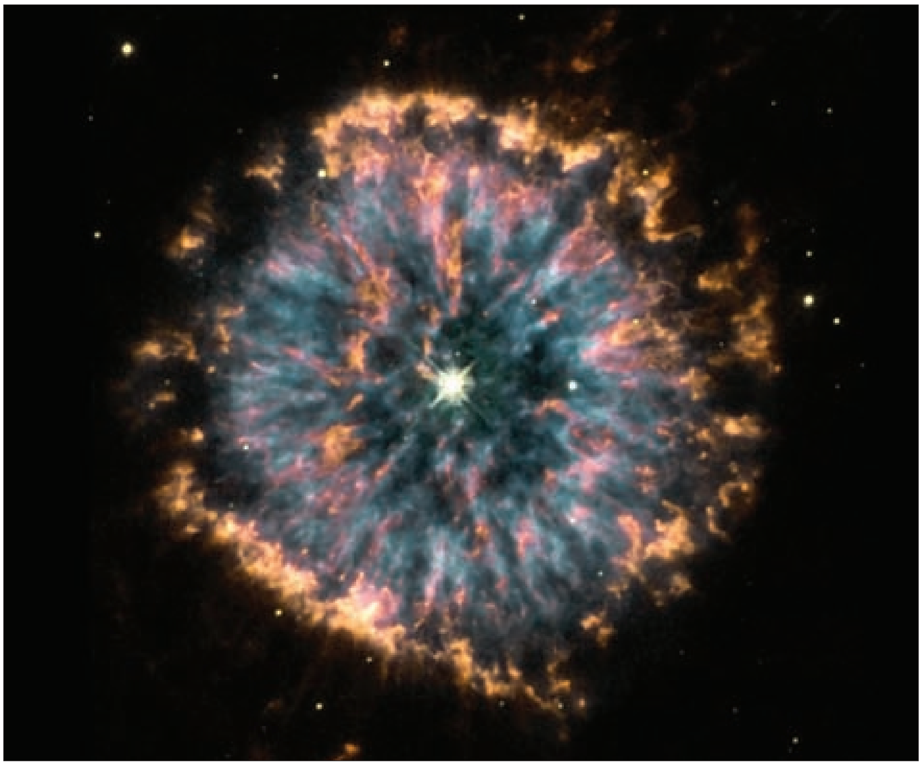
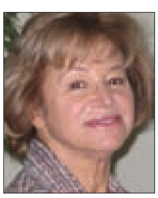
NASA



Cosmic visions

With the International Year of Astronomy now in full swing, six leading figures from the world of astronomy reveal what they think are the biggest challenges for the subject



Catherine Cesarsky is president of the International Astronomical Union

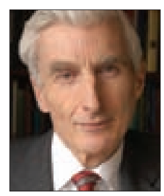
The International Year of Astronomy (IYA2009) is a global celebration of astronomy and its contribution to scientific development and cultural enrichment. Now, 400 years after Galileo Galilei first glimpsed the heavens through a telescope, astronomy is in the midst of a golden age. Taking advantage of the fantastic progress of technology, astronomers are exploring a solar system whose inner workings Galileo and Kepler started to unravel in 1609. For us, the universe is now an open book that we can read using telescopes on the ground and robotic probes in space. Using our instruments as "time machines", we can peer back across history and see galaxies as they were when the universe was less than 10% of its present age. We have also confirmed the existence of other solar systems in our galaxy.

It is this sense of discovery and awe that astronomers wish to share with our fellow citizens all over the world. We thus hope to stimulate a long-term increase in student enrolment in science and technology, and an appreciation for lifelong learning.

But despite the continued string of successes in astronomy, significant challenges remain. While we have been able to determine with unprecedented accuracy the parameters that define the geometry, dynamics, history and contents of the universe, we know almost nothing of what could make up 96% of it. We hide our ignorance behind the terms "dark matter" and "dark energy", and indeed our skill at modelling the structure of the universe and its variation with time with "cold dark matter" makes us sometimes feel that we have conquered it. It is more difficult to get to grips with dark energy, which is causing the expansion of the universe to accelerate. All we know now can be made to fit using the cosmological constant that Einstein introduced; a satisfactory mathematical solution is then obtained, but the physics is not understood.

It is likely that dark matter and dark energy will open the door to new physics, leading to the discovery of new particles and fields and/or forcing us to modify our understanding of gravitation beyond Einstein's general theory of relativity. We should gain new insights through more detailed observations of the fossil radiation from the Big Bang using the Planck satellite, developed by the European Space Agency (ESA), which is due to take off next month, and by studying the evolution of the universe's structure with the next generation of satellites such as ESA's proposed EUCLID project and NASA's planned Joint Dark Energy Mission. We may need a new Einstein to make sense of all the new results and to come up with a convincing solution.

The other fascinating challenge of 21st-century astronomy is finding life on another Earth. Over 330 planets orbiting other stars have already been found, some of them super-Earths about 3 to 10 times more massive than our planet; one of them, recently discovered by France's CoRoT satellite, orbits a star similar to our own. Prospects for progress are excellent, with the Kepler satellite to be launched this month, the European Extremely Large Telescope (E-ELT) and numerous advanced space missions being planned. But I anticipate that, when the time comes, the "proof of life" will be elusive and controversial for quite some time.



Martin Rees is at the University of Cambridge in the UK and holds the title of Astronomer Royal

A quarter of a century ago, plans for the Hubble Space Telescope and the Keck telescopes were well advanced, and both these instruments are still doing great science. If we look 25 years ahead, the projects that are now at the concept or planning stage will be the major instruments then. The timescale is very long – depressingly so. However, we can be optimistic that rapid advances in computer power will allow realistic modelling of how galaxies, stars and planets formed. Simulations in "virtual universes" will play an ever larger role in our subject.

I would highlight three main challenges for astronomy. The first concerns black holes. These are now recognized as the engines for active galactic nuclei. But we still do not know if they obey the "Kerr metric", which describes the geometry of space–time around a massive rotating body, although I would be astonished if they did not, given the vindication of general relativity. I am hopeful for better probes (and simulations) of flow patterns and magnetic effects in the innermost regions of active galaxies, plus the direct detection of gravitational waves from coalescing black holes.

At the moment, direct observations of quasars and galaxies do not get us much beyond redshifts of six, corresponding to an era around a billion years after the Big Bang. But there are strong reasons to suspect that the "dark ages" ended and the first stars formed at a much higher redshift still – perhaps only 200 million years after the Big Bang. It is still uncertain, however, what the first stars are like, and how many of them were formed. Some of the answers must wait for the James Webb Space Telescope, which is set for launch in 2013, or the next generation of giant ground-based telescopes. If we are lucky, it may turn out that some of the earliest stars end their lives as ultra-luminous gamma-ray bursts, which could be detected with current instruments at redshifts well beyond 10.

If we cannot find discrete objects at these ultra-high redshifts, then the best hope of mapping how the primordial gas got heated and ionized may be to detect the emission of light with a wavelength of 21 cm from the neutral state of hydrogen. It is a very weak signal compared with other radio backgrounds, but because hydrogen emits a line not a continuum, one can do 3D mapping or "tomography" of this substance. Major instrument arrays, including the Square Kilometer Array (SKA), which will be built in either Australia or southern Africa, will advance this area of research. We also await theoretical progress to pin down the physics of the ultra-early universe in a similar way that the physics of the nucleosynthesis era was pinned down 40 years ago.

Much closer to home – within the local spiral arm of our own galaxy – lies an equally exciting challenge: to find and study planets orbiting nearby stars. In the coming decades, huge numbers of planets will surely be found. The Kepler spacecraft should give direct evidence of how many Earth-like planets there are. Perhaps some are "twins" of our Earths that harbour life far more interesting than even the optimists hope to find on Mars or Titan. Exobiology and the study of life's origins on Earth will surge forward.

Tim de Zeeuw is director-general of the European Southern Observatory

As we celebrate the revolutionary impact of the invention of the telescope 400 years ago, we find ourselves poised to make another giant leap forward. Proposed by the European Southern Observatory (ESO), the E-ELT, with a 42 m diameter primary mirror consisting of nearly 1000 segments, would be the world's biggest eye on the sky. By jumping beyond the current generation of 8 m telescopes, the E-ELT would, if built, be a leap as large as that made by Galileo when going from the naked eye to the first telescope.

Technological developments now make it possible to observe planets orbiting other stars, peer deeper than ever into the universe, use particles and gravitational waves to study celestial sources, and to carry out *in situ* exploration of objects in our solar system. This promises tremendous progress towards answering key astronomical questions such as the nature of dark matter and dark energy, the formation and evolution of galaxies from first light to the present day, and the direct observation of Earth-like planets. These are among the most fundamental questions in science and are of enormous interest to the general public.

Astronomers are already drawing up a whole range of next-generation facilities, including extremely large telescopes working at optical and infrared wavelengths, survey telescopes that would provide deep imaging of the sky every few nights, as well as experiments to detect particles and gravitational waves, and space missions devoted to characterizing extrasolar planets. Turning these proposed new facilities from a dream to reality will require substantial investments by national and international funding agencies, as well as, in some cases, private donors. The US has a long tradition of prioritizing such plans through the series of "decadal surveys" initiated in the 1960s, and more recently the European ASTRONET consortium has developed a long-term strategic plan for European astronomy that promotes the best use of existing and future facilities such as the Atacama Large Millimetre Array (ALMA), the E-ELT and later SKA.

Building the flagship astronomical facilities of the future will present substantial technological and organizational challenges. It will provide opportunities to showcase industry's capabilities, but it also requires strong and effective management. The experience of the astronomical community in international co-operation has paved the way for global projects such as ALMA, which involves strong institutions from three continents with very different funding systems operating a single facility in a remote location in Chile. The endeavour is challenging, but success will bode well for future global facilities.

Notwithstanding the current economic climate, these new facilities will take so long to plan and build that we need to follow up our long-range plan for European astronomy and similar efforts elsewhere, including the ongoing US decadal survey. If we can make these marvellous facilities a reality, then we can take the next step in our understanding of the universe.

We know almost nothing of what could make up 96% of the universe. We hide our ignorance behind the terms "dark matter" and "dark energy"

Catherine Cesarsky

John Huchra is at the Harvard-Smithsonian Center for Astrophysics and is president of the American Astronomical Society

Astronomers have made some phenomenal discoveries over the last two decades, including detecting and imaging extrasolar planets, analysing extraterrestrial materials samples and realizing that the expansion of the universe is speeding up rather than slowing down. Yet there is still much we do not know or understand, and even, in the immortal words of former US Secretary of Defense Donald Rumsfeld, "unknown unknowns". I think that the greatest challenges for astronomy are still the cosmological ones. What is dark energy? What is dark matter? And how do these really affect the formation and evolution of the universe and its contents?

We may find the answers, or at least vital clues, within days, weeks or months. Or it may take decades to directly detect and characterize the dark stuff that makes up 96% of the contents of the universe. We may also have the wrong cosmological model and have to start all over again when new evidence yet again transforms our world view. I have now lived through two such cosmological paradigm shifts – first when we were debating the Big Bang versus the steady-state model, and then when we had become thoroughly convinced it was completely filled with mostly cold dark matter – and I would not be surprised if I saw another.

Closer to home and perhaps closer to fruition are the challenges of finding and characterizing extrasolar Earth-like planets, detecting the gravitational waves predicted by Einstein's general theory of relativity, and discovering the first stars formed after the Big Bang. These are all within the reach of astronomers in the next decade through the march of technology: large ground and space-based interferometers; the James Webb Space Telescope; and perhaps the LIGO and VIRGO gravitational-wave observatories.

We have also entered the era of time-domain astronomy, which allows us to look for ultrafast variable stars and other objects that until now have only been theorized about. X-ray and gamma-ray telescopes have been monitoring the sky for decades, but it

Finding extrasolar Earth-like planets, detecting gravitational waves and discovering the first stars formed after the Big Bang are all within the reach of astronomers in the next decade

John Huchra

is only recently that the sky has been surveyed repeatedly at optical wavelengths. Such "synoptic" surveys have been responsible for detecting gravitational microlenses, nearby supernovae, a horde of extrasolar planets, and a few of the killer rocks in space that could wipe out civilization if not detected and mitigated in time. The next decade promises to bring many additional surprises just from looking hard at the sky over and over again to watch for changes with time.

The final challenge for astronomers is not scientific but sociological. The age of the lone astronomer with his or her telescope or computer is being replaced by an era in which the remaining problems are so complex that they require teams of experts with different fortes using facilities that are so large and expensive that they require international co-operation on a grand scale. To paraphrase a colleague of mine – the astronomer Penny Sackett, who is now the chief scientist of Australia – we need to learn to succeed and not just to win. That is a hard challenge not only for astronomers but also for the whole human race.

Andrew Fabian is at the University of Cambridge in the UK and is president of the Royal Astronomical Society

The past decade has brought many exciting new discoveries that reveal much about our universe: from extrasolar planets to the dwarf planets of our own solar system; from the symbiosis of black holes and its host galaxy, to a cosmological driving force – dark energy – that inhabits the largest voids of space. But all new observations bring fresh challenges. For example, something as simple as the exact composition of the universe remains undetermined. We may have deduced the presence and relative importance of three major constituents – ordinary baryonic matter, dark matter and dark energy – but so far we only have a coherent understanding of the first of these.

What makes up dark matter and dark energy is still unknown. Dark matter can be detected only through its gravitational interaction, and dark energy is inferred from the accelerated expansion of space. There are plenty of speculative papers on the nature and origin of both, but little in the way of firm conclusions.

A major challenge for both theoretical and observational astronomy is to search for properties that can better characterize the behaviour of each dark component that will enable us to crack them open. Is all dark matter identical or does it come in different "flavours" like ordinary matter? How is the current era of accelerated expansion connected to the phase early in the life of the universe when it rapidly inflated from the microscopic to the astronomic in size? Can we find any fossil evidence for the first inflation phase, for example from the polarization of the cosmic microwave background? How much progress can we make in cosmology beyond the realm of the observational, without it becoming pure speculation?

Black holes – both the stellar-sized and the supermassive – are routinely monitored and modelled. Yet do we really know how they work? Is Kerr's solution – based on general relativity – the correct description of spinning black holes? It seems clear that matter falling into black holes – the process of accretion – is responsible for their growth and provides many of the universe's most energetic phenomena such as active galaxies, quasars and gamma-ray bursts. We probably have the basic "energetics" right but a lot of the details of how they work, such as how they make powerful relativistic outflows, remains unclear. We have discovered that a central massive black hole appears to control the final mass of its host galaxy, but how exactly does this mechanism work, given the very different scales on which the two operate? Much of the complexity seen within and between galaxies is due to gas processes and physics – the gastrophysics, if you like. Dissecting and simulating this in detail is, and will long remain, very challenging.

We now know of over 330 planets orbiting other stars in our galaxy, although nearly all of them are more than a hundred times more massive than the Earth and many are located much closer to their host sun. There is little doubt that finding objects of Earth mass, in habitable zones round other stars, is the next exciting goal. Both this and the current developments in the exploration of planets within our own solar system, such as Mars and Titan (Saturn's largest moon), can inform the natural speculation about the occurrence and propensity of planets hosting extraterrestrial life. Is it common or rare? What spectral signatures could we search for in the atmosphere of the host planet? And what of multicellular life?

Astronomy presents many challenges beyond just those mentioned so far. There is no single experimental facility that can respond to all the new objects and processes that will continue to be discovered over the next decade. Thus the final challenge for astronomers will be to co-operate and secure the funding for the range of telescopes and instruments required.

Seok Jae Park is president of the Korea Astronomy and Space Science Institute

The greatest challenge for astronomy is international collaboration, because building big and expensive telescopes can no longer be accomplished by a single country alone. Such co-operation is particularly important for a country like South Korea, which is a relatively small player in astronomy, having invested very little in the field since the end of the Second World War. Indeed, until last year, the country had only a 1.8 m optical telescope and a 14 m radio telescope.

The Korea Astronomy and Space Science Institute (KASI) was set up in 1974 to not only analyse and understand the universe through observations but also to spread knowledge of astronomy nationwide. KASI has, for example, been working on the Korean VLBI Network (KVN) project (see *Physics World* January p9), which consists of three 21 m radio telescopes that were just completed last year. While working on the project, it proved vital for Korean astronomers to co-operate with their colleagues in Japan as the KVN is similar to the four 21 m radio telescopes that make up the VLBI Exploration of Radio Astrometry (VERA) facility in Japan.

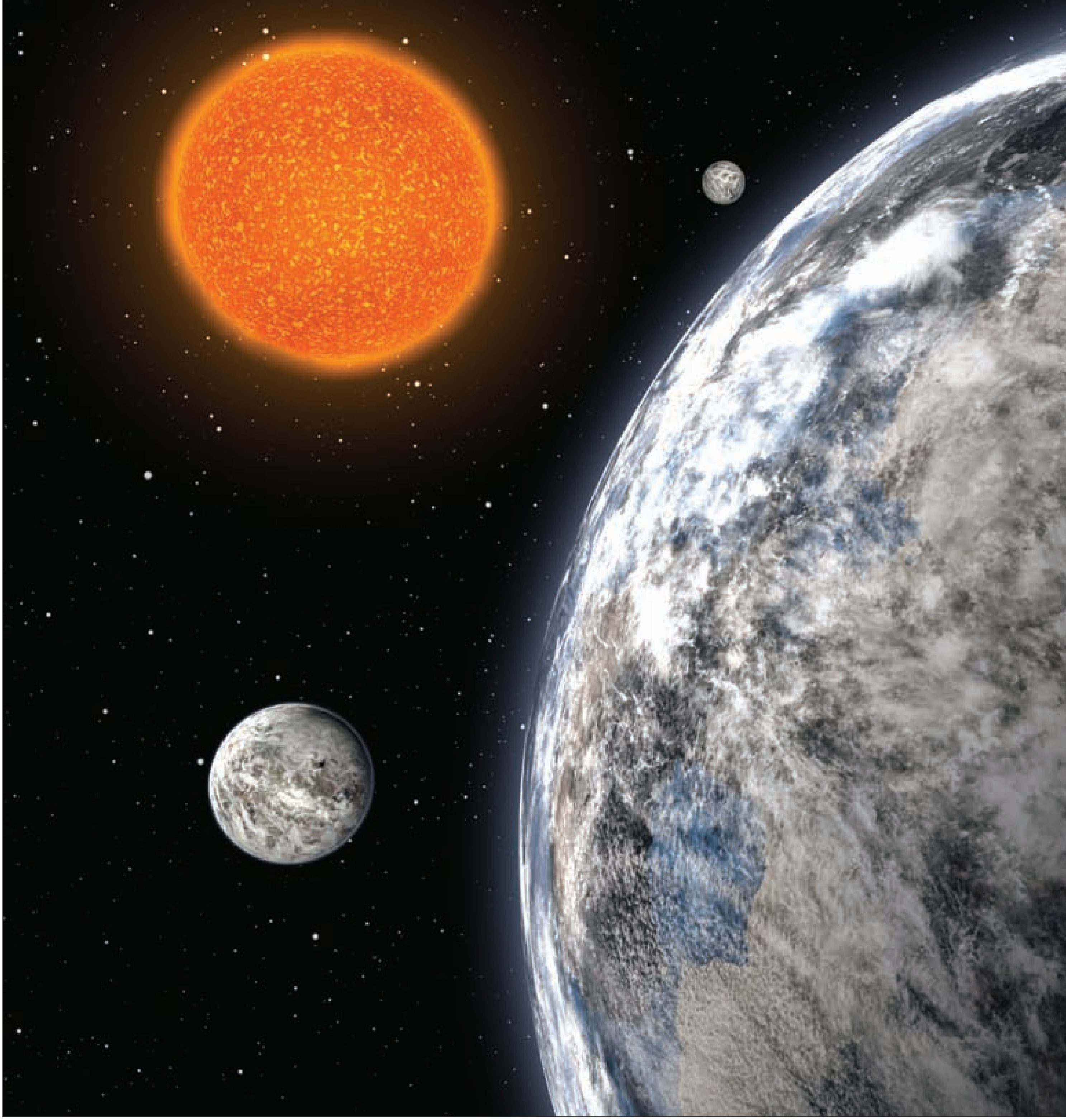
Collaboration is also crucial in optical astronomy. My institute has joined the Giant Magellan Telescope project, for which KASI has already managed to obtain the funding from the Korean government. The GMT is a next-generation 25 m extremely large telescope founded by six US and two Australian institutions. It is my hope that IYA2009 will enable astronomers from around the world to create a new tradition of co-operation in astronomy. I look forward to the many great achievements that this will bring.

Earth rising

The NASA Apollo 8 astronauts were greeted with this view of the rising Earth as they orbited the Moon on 24 December 1968. This now-famous colour photograph was taken by astronaut William Anders, and later selected as one of *Life* magazine's "hundred photos that changed the world". The Apollo 8 mission was the first-ever manned spacecraft to reach another celestial body. It took the craft three days to reach the Moon, which it then orbited 10 times in over 20 hours. The astronauts described the surface of our satellite as a "vast, lonely, forbidding expanse of nothing". It was the first time that the Earth was viewed from the outside, embraced by the vast cosmic emptiness.

Brave new worlds

The abundance of Earth-like planets will be determined in the next five years, with profound implications for the prevalence of life in the universe. **Alan Boss** describes the coming revolution in extrasolar planetology



ESO

Super-Earth trio
An artist's impression of the triple super-Earth system orbiting HD 40307.

Alan Boss is an astrophysicist at the Carnegie Institution in Washington, DC, US and the author of *The Crowded Universe: The Search for Living Planets*, e-mail boss@dtm.ciw.edu

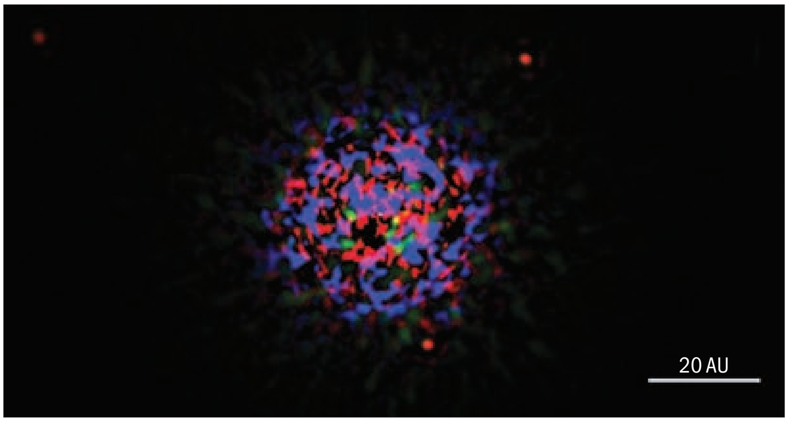
Are we alone? There is perhaps no more important single scientific question. People have pondered this issue from the very dawn of sentience, wondering if other, similar, beings inhabited a distant mountain range or the other side of an ocean. The history of humanity is largely one of exploration and expansion, and while at first this was limited to the Earth's surface, in the last few decades only the power of our interplanetary rockets has kept us from exploring our wider environment. As the science-fiction author Ray Bradbury proclaimed when the Viking landers arrived on Mars in July 1976, "There is life on Mars, and it is us."

Now we are poised to move far beyond our own planetary system – if not yet physically, then at least intellectually – as we learn how many other habitable worlds exist in our galaxy. The expectation of most astronomers is that Earth-like planets will be commonplace; in other words, Earth-size planets will be found orbiting at distances from their parent suns that would allow liquid water to exist on or near the planet's surface. This prediction is not simply a conceit concocted by wild-eyed planet hunters, but is a logical outcome of what we have learned in the last decade about extrasolar planetary systems. All of the evidence points to the inescapable conclusion that rocky, terrestrial planets similar to the Earth should be orbiting unseen around many, if not most, of the myriad of stars that we see when we look up at the night sky.

This prediction of the likelihood, or frequency, of Earth-like planets orbiting Sun-like stars is about to be tested rigorously by the Kepler Space Telescope, which is designed specifically to determine the percentage of solar-type stars that harbour Earth-like worlds. Due for launch early this month, NASA's latest telescope will search for extrasolar Earths using a method known as transit photometry. When an Earth-sized planet with a suitably inclined orbit passes between its star and the line of sight to the Earth, it blocks a tiny fraction – about one10 000th – of the star's light. Kepler is capable of measuring these tiny, periodic dimmings, and will monitor over 100 000 stars for at least three and a half years. In the process it should discover dozens of Earth-like planets. In short, we are about to determine the value of a key factor in any estimate of the prevalence of life in the universe: the frequency of habitable worlds where life could originate and evolve.

Early exoplanetology

Until 1995 the only known planets outside our solar system were two scorched rocks in orbit around a very un-Sun-like pulsar, PSR B1257+12. This shortage of extrasolar planets was not due to a lack of effort in trying to find them. Since 1980 a Canadian research team led by Gordon Walker of the University of British Columbia had been searching a sample of nearly two dozen Sun-like stars for the telltale "Doppler wobble", or periodic redshift and blueshift in the star's spectrum, caused by the orbital motion of the host star around the system's centre of mass. By 1992 the researchers had found no definitive evidence for even a single extrasolar planet comparable in size to Jupiter. They therefore stopped their search and wrote a paper describing the upper limits (of the order of one Jupiter mass) on the masses of any possible planets lurking undetected



National Research Council Canada

Seeing new worlds This image of three faint bodies orbiting the star HR 8799, which was obtained by a team at Canada's Herzberg Institute of Astrophysics (2008 *Science* **322** 1348), may be the first direct image of a triple-planet system. The speckled area in the centre is the residual light from the host star, while the red dots at 2, 5 and 10 o'clock are the orbiting planets imaged in the infrared. The planets' estimated masses range from 7 to 10 times the mass of Jupiter; with orbital distances of 24, 38 and 68 astronomical units (AU), this cluster of alien worlds resembles a larger version of the outer solar system.

around the target stars. When this paper was published in the autumn of 1995, the field of extrasolar planetology seemed to have come to a premature dead end.

Two months later, Michel Mayor, an astronomer at the Geneva Observatory in Switzerland, made a startling announcement: he and his colleague Didier Queloz had found the first reproducible evidence of a Jupiter-mass planet orbiting a solar-mass star. Mayor had only begun his planet search in 1994, but his target list contained more than 100 stars – including, crucially, 51 Pegasi, located about 50 light-years away from Earth. The newly discovered planet, named 51 Pegasi b, has a mass at least half that of Jupiter and causes a periodic Doppler shift that the Canadian team could have detected – if 51 Pegasi had been one of their target stars.

With an orbital period of just four days, 51 Pegasi b occupies an orbit 100 times closer to 51 Pegasi than Jupiter is to the Sun, making it the first example of the class of planets known as "hot Jupiters": gas giants with surface temperatures of about 1500 K, which is closer to those of low-mass stars than of Jupiter (150 K). The existence of 51 Pegasi b was confirmed a week later by the astronomers Geoff Marcy and Paul Butler, then at San Francisco State University and the University of California at Berkeley, respectively, who had been searching for gas giants with Doppler spectroscopy since 1988. After Mayor's announcement, they combed through their seven years of accumulated data on over 100 stars. They quickly found two more "Doppler planets", 70 Virginis b and 47 Ursa Majoris b. This time, the gas-giant planets had more sensible orbital periods of about 0.33 and three years, making them warm and cool Jupiters, respectively.

The field of extrasolar planets grew enormously after the Swiss and US teams announced their discoveries in early 1996. To date, these two teams have found most of the over 300 Doppler planets now known to astronomers. Such planets are surprisingly common, with over 10% of solar-type stars appearing to have gas-giant planets with orbital periods less than about five years, with even more planets orbiting at larger distances. Hot Jupiters like 51 Pegasi b occur around about 1% of solar-type stars: if the Canadian team had searched a sample of 100 stars, as the Swiss did, they might have found the first hot Jupiter.

On the theoretical side, the wave of new exoplanet data has left models of gas-giant planet formation in ferment, with two viable mechanisms that may explain the observed range in mass (roughly Saturn mass to 13 Jupiter masses) and relatively high frequency of gas-giant exoplanets. The first, "disk-instability", mechanism would allow gas giants to form in even the shortest lived protoplanetary disks. Such disks occur in regions of massive star formation. There is good evidence that the solar system formed in such a commonplace area, implying the ubiquity of similar systems. The other possible mechanism relies on "core accretion", where a roughly 10-Earth-mass core forms and then slowly accretes sufficient gas from the disk to become a gas giant. If the disk gas disappears faster than the cores form, the result is "failed cores" similar to the ice-giant planets Uranus and Neptune.

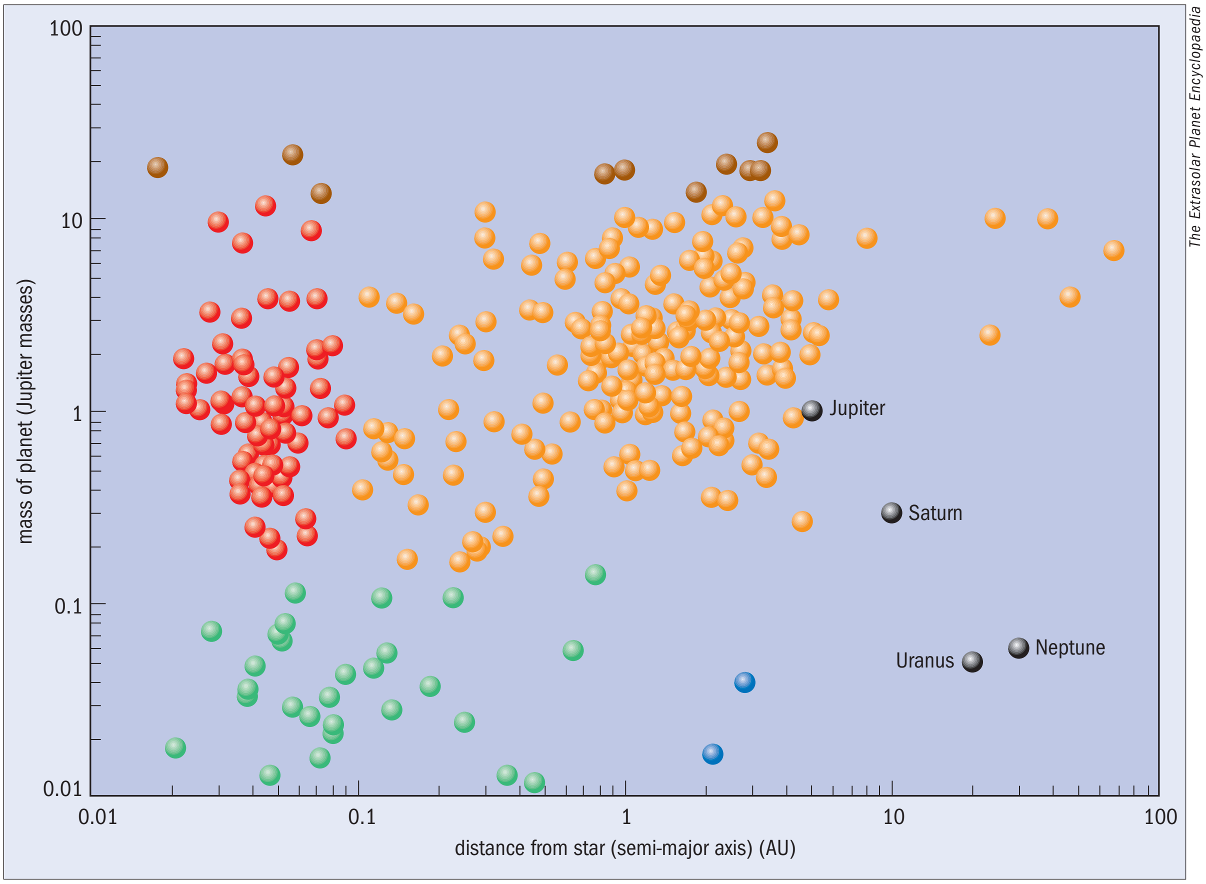
From hot Jupiters to super-Earths

Short-period planets like the hot Jupiters have a 10% chance of having their orbits inclined such that the planet passes in front of its host star as seen from Earth. By measuring the fractional change in the star's brightness during these transits, we can calculate a planet's size relative to the size of the star, which can in turn be estimated based on its stellar classification. Hence, transit measurements offer final proof that the Doppler-planet candidates actually are gas-giant planets similar to Jupiter and Saturn. The 10th hot Jupiter found using Doppler spectroscopy by Butler (by then at the Carnegie Institution) and his colleagues turned out to be the first transiting planet, HD 209458 b.

Transits also provide the opportunity to study a planet's atmosphere as starlight passes through it during a primary eclipse (which occurs when the planet passes in front of its star), or as the planet's thermal emission is blocked during a secondary eclipse (planet behind the star). Clever observations with the Hubble and Spitzer space telescopes have allowed astronomers to detect the presence of water, carbon dioxide, methane, sodium and hydrogen in the atmospheres of several known hot Jupiters. Transit surveys are also being used to discover new hot Jupiters, with over 50 such planets having been found so far using this method followed up with Doppler confirmations.

Continued improvements to Doppler spectrometers have allowed the Mayor, Marcy and Butler groups to discover not only Jupiter-type planets but also short-period planets with masses as little as four times that of the Earth. Most of these hot and warm "super-Earths" are known to be accompanied by gas-giant siblings at greater orbital distances. This configuration – reassuringly similar to that of the terrestrial and gas-giant planets in our solar system – suggests that these super-Earths formed closer to their parent stars than the gas giants did. Theoretical models of planet formation firmly predict that these planets must be at the high-mass end of the range of rocky extrasolar planets; hence, rocky planets with even smaller masses must exist as well.

Estimates of the frequency of hot and warm super-



An exoplanet encyclopedia A "discovery space" plot of known extrasolar planets according to their mass and distance shows all three classes of planets familiar from our solar system – gas giants (orange), cold super-Earths or ice giants (blue), hot and warm super-Earths or terrestrial planets (green) – as well as hot Jupiters (red) and brown dwarfs (brown). One astronomical unit (AU) is the mean distance of the Earth from the Sun.

Earths based on Doppler surveys imply that perhaps a third of all solar- and lower-mass stars have such planets. Mayor's team has even found one star, HD 40307, that has three orbiting super-Earths with masses of about four, seven and nine times that of the Earth (see image on page 26). Several other multiplanet systems have also been found using Doppler spectroscopy. The 55 Cancri system, for example, contains at least five known planets, with the innermost planet being a hot super-Earth with an orbital period of 2.8 days.

Total eclipse of a star

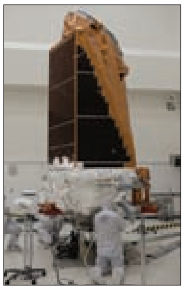
In addition to the Doppler-wobble and transit methods, a third technique, known as microlensing, has also recently been used to discover planets. When a foreground star happens to pass directly in front of a distant background star, the background star's light can be bent toward the Earth by the gravity of the foreground star. The result is a gradual brightening and dimming of the background star as the unseen foreground star passes in front of it. If the foreground star has a planet in orbit at a distance similar to the asteroid belt in our solar system, then observations will reveal an additional, sharper brightening and dimming of the background star that can only be caused by a third body. The critical distance is known as the Einstein radius, since Einstein predicted this effect in 1936. However, he assumed that it could never be observed in practice because the chance of having the two stars line up in exactly the right configuration when viewed from the Earth would be small, and the chance of observing it at the right time even smaller.

Acting independently, two teams of astronomers (led by Ian Bond from the Institute of Astronomy in Edinburgh, UK, and Andrzej Udalski of the Warsaw University Observatory in Poland) discovered the first microlensing planet in 2004. The new planet had a mass 2.6 times that of Jupiter, and was designated OGLE 2003-BLG-235/MOA 2003-BLG-53 b as its discovery involved observations by both Bond's Microlensing Observations in Astrophysics (MOA) team and Udalski's Optical Gravitational Lensing Experiment (OGLE) team.

This discovery was made possible by Udalski's participation in the OGLE search for microlensing events, which involves monitoring hundreds of thousands of stars in our galactic bulge with a modest 1.3-m telescope at the Carnegie Institution's Las Campanas Observatory in Chile. Einstein could not have foreseen such a dedicated effort to test his 1936 prediction.

Microlensing has detected eight planets to date: five gas giants and three cold super-Earths with masses in the range from about 3 to 13 Earth-masses, including one multiple system containing planets analogous to Jupiter and Saturn. The cold super-Earths discovered using microlensing appear to be similar to the solar system's ice-giant planets, Uranus and Neptune, because of their similar masses and orbits at large distances where ices will be common. Combined with the Doppler discoveries of abundant gas giants, and hot and

Astronomers have identified extrasolar analogues for each type of solar-system planet



NASA/Kim Shiflett

Set for launch
NASA's Kepler mission, due to take off this month, will scan 100 000 stars for orbiting planets.

warm super-Earths, astronomers have identified extrasolar analogues for each of the three basic classes of solar-system planets.

Seeking (higher) resolution

One of the major goals of planet hunters is to take a spatially resolved image of a planet, so that the planet's atmosphere can be more easily distinguished from that of the host star. Six claims for the first image of an extrasolar planet were advanced in 2008 alone.

Perhaps the most convincing of the six is the image of three possible planets in orbit around the star HR 8799 by Christian Marois and his colleagues at Canada's Herzberg Institute of Astrophysics (see image on page 28 and *Physics World* January p5). The masses of the planets are estimated to be in the range of 7 to 10 Jupiter masses, and they orbit HR 8799 at distances of about 24, 38, and 68 astronomical units (the mean distance of the Earth from the Sun), distances comparable to those of the ice giants and Kuiper belt in our solar system.

One of the main uncertainties in estimating their masses is in estimating their ages: given a theoretical model of how a newly formed planet cools with time, the age of the star is used as the age of the planet, allowing the planet's mass to be guessed. Marois has estimated that HR 8799 is about 60 million years old, but if the star were considerably older than that, then the masses of the three orbiting bodies would be greater than about 13 Jupiter masses. This limit is important: once over it, such "planets" can burn deuterium and so are classed as brown dwarf stars rather than planets (see figure on page 29).

Only further observational and theoretical work will decide which, if any, of these six candidate images is indeed that of a planetary system. These ambitious efforts presage the ultimate goal of obtaining direct images of nearby Earth-like planets and studying their atmospheres for evidence of molecules associated with habitable (carbon dioxide, water) and inhabited (oxygen, methane) worlds.

Given the discoveries of the last decade, we cannot argue that the solar system is a fluke of the universe. While the chaotic nature of the planet-formation process rules out finding an exact analogue, it is clear that planetary systems similar to our own must be a common feature of our galactic neighbourhood. Indeed, only last month astronomers using the CoRoT space telescope discovered the smallest sized transiting exoplanet to date: a fiery new world less than twice the radius of the the Earth that orbits its star every 20 hours.

The Kepler mission will determine how frequently Earths occur in our galaxy: do 1% of Sun-like stars have Earth-like companions? 10%? 100%? Given that there are billions of Sun-like stars in our galaxy alone, the number of Earth-like worlds must be similarly immense. Whatever the answer, by the time Kepler finishes its primary mission in 2013, we will know just how crowded the universe really is.

Next month in Physics World

Physicists on Wall Street
One of the many culprits of the current global recession is a theory of economics that does not account for market crashes and the irrational behaviour of economic agents. But can physicists do anything to help change this paradigm?

Under pressure
New lab experiments are replicating the high-pressure conditions that exist at the cores of planets – and it could soon be possible to test matter at the gigabar scale

The marketplace of ideas
Great advances in science are often the product of serendipity and maverick research. So why are most funding systems biased towards research proposals with predictable outcomes and mainstream appeal?

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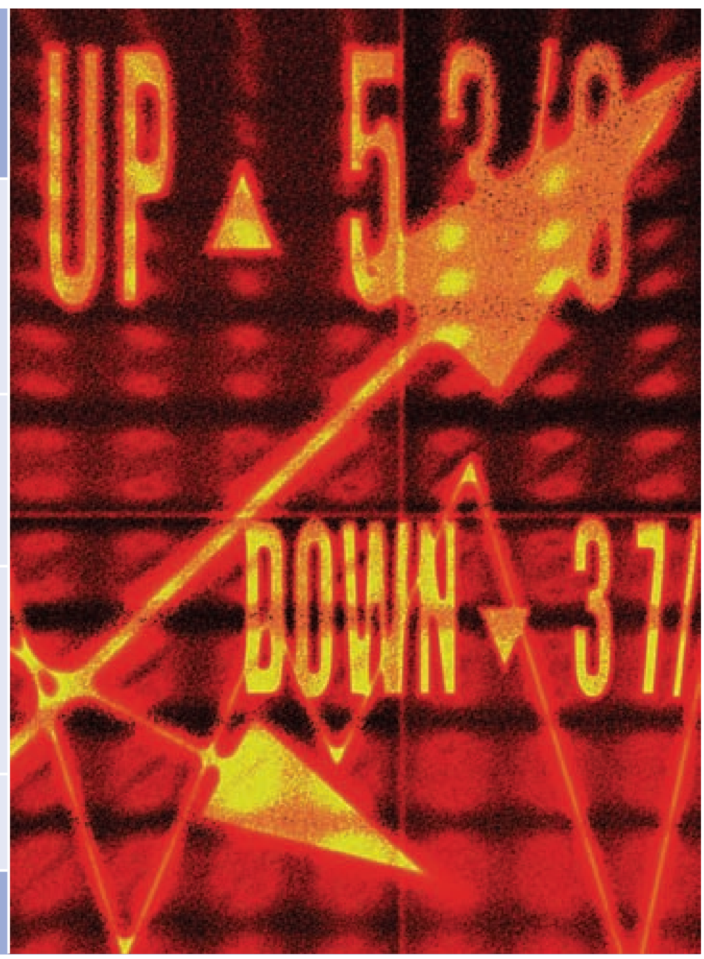
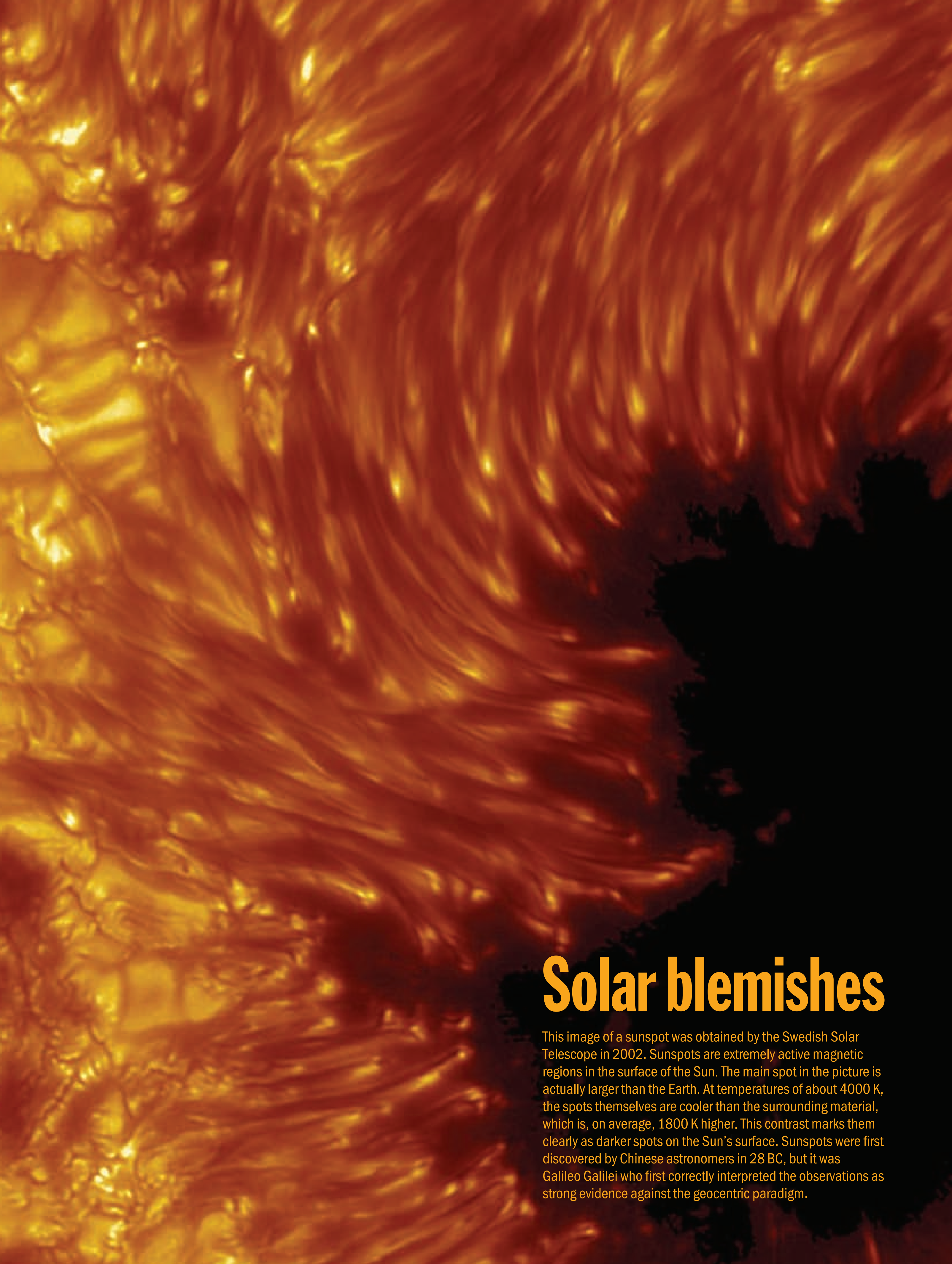
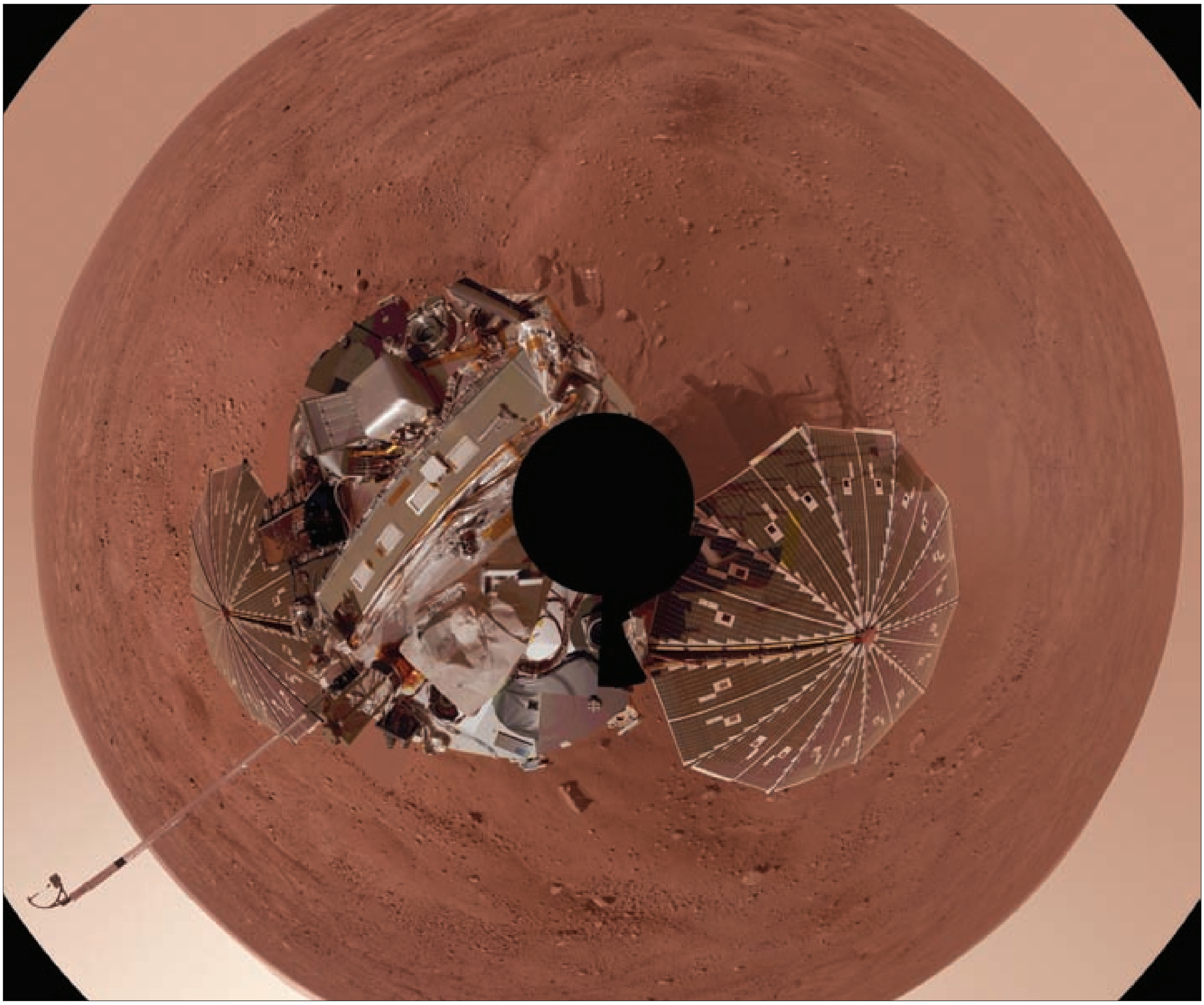




Solar blemishes

This image of a sunspot was obtained by the Swedish Solar Telescope in 2002. Sunspots are extremely active magnetic regions in the surface of the Sun. The main spot in the picture is actually larger than the Earth. At temperatures of about 4000 K, the spots themselves are cooler than the surrounding material, which is, on average, 1800 K higher. This contrast marks them clearly as darker spots on the Sun's surface. Sunspots were first discovered by Chinese astronomers in 28 BC, but it was Galileo Galilei who first correctly interpreted the observations as strong evidence against the geocentric paradigm.


NASA

Up close and personal

Mark Williamson describes how space technology has allowed planetary astronomy to develop from a science of entirely remote observation to one of immersive experimentation

In 1609, when he peered expectantly through his hand-made telescope at the mountains of the Moon and the four large satellites of Jupiter, Galileo Galilei could have had no idea that nearly four centuries later these astronomical bodies would be orbited by "artificial satellites" hand-built by like-minded inquisitors of the solar system. That one of these spacecraft would be named after him would probably have been dismissed as idle fantasy. However, the spacecraft known as Galileo, launched in 1989 and de-orbited into Jupiter's turbulent atmosphere in 2003, is just one of many interplanetary spacecraft dispatched to explore the solar system since the beginning of the space age in 1957.

Although he was spared the levels of particulate and light pollution we suffer today, Galileo must have noticed that the performance of his telescopes was limited by the atmosphere. Heat rising from buildings or the ground itself would have caused a familiar shimmering of the Moon's image, while the longer atmospheric pathlength of light from stars observed near the horizon would have made them twinkle, just as it does today.

From the late 1940s, when sounding rockets began to be used for research on the upper atmosphere, it

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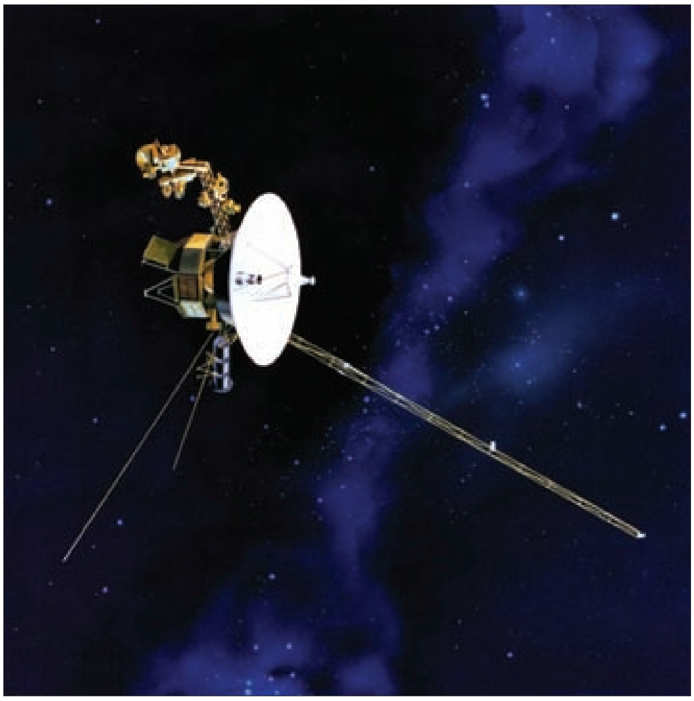
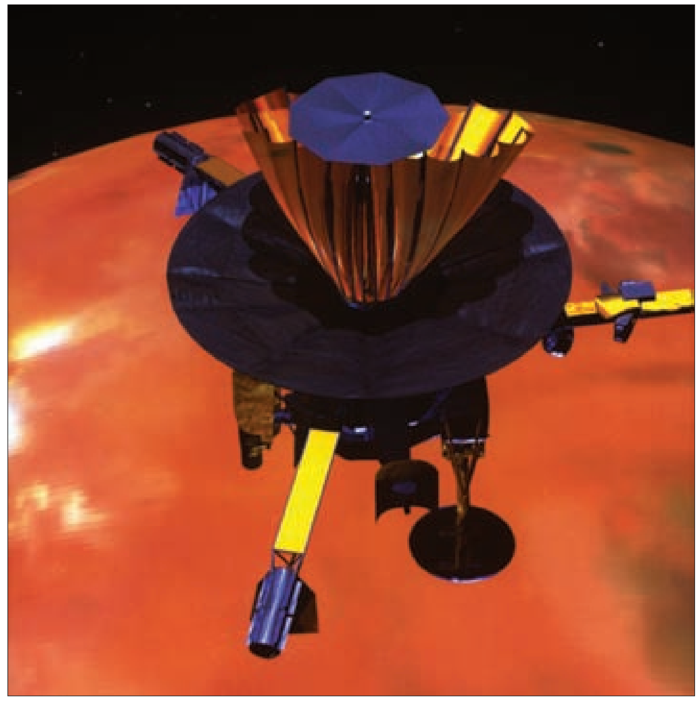
NASA





Probing the giants
Jupiter has been explored by Voyager (above left) and Galileo (above right), while Cassini (opposite-page left) and Huygens (opposite-page right) have probed Saturn.

was clear to scientists that the Earth's atmosphere absorbs extraterrestrial radiation at some wavelengths, and that the only way to conduct a complete investigation of the universe is to place instruments beyond it. The concept of the space telescope had already been discussed as early as 1929 by German rocket pioneer Hermann Oberth in his book *Wege zur Raumschiffahrt* ("Paths to Space Travel"), but it is a paper written in 1946 by the US astronomer Lyman Spitzer that is credited with introducing the advantages of a space-based telescope to the research community. The paper, entitled "Report to Project RAND: Astronomical Advantages of an Extra-Terrestrial Observatory", pointed out that not only could a space-based telescope detect the infrared and ultraviolet wavelengths absorbed by the atmosphere, but also that its angular resolution would be limited only by diffraction (instead of atmosphere turbulence).

Once the technology had been developed to build and launch satellites, the notion of what is now known as "space astronomy" became a reality. Spitzer's vision was rewarded by seeing NASA's Orbiting Solar Observatory (OSO-1), the first astronomical observatory in space, launched in March 1962. The OSO series led to the Orbiting Astronomical Observatory (OAO) in the late 1960s – a telescope with which Spitzer was particularly associated – and eventually to the Hubble Space Telescope in 1990.

Being there

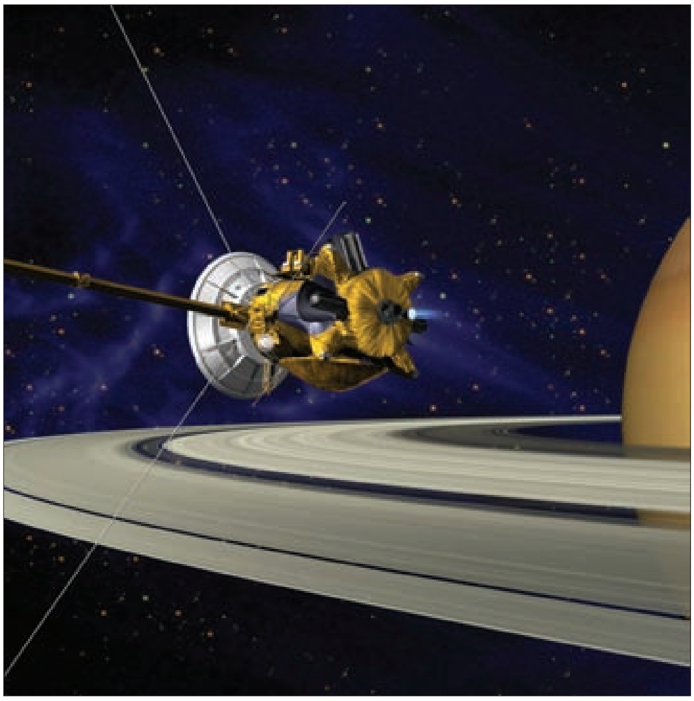
Orbiting observatories have proved crucial to the development of astronomy, astrophysics and cosmology because they provide data on distant stars and galaxies that ground-based observers cannot obtain. But the remote-sensing techniques of space astronomy have important limitations when it comes to the planets and the minor astronomical bodies. Even the Hubble Space Telescope can produce only low-resolution images of the surface of Mars or the cloud tops of Jupiter.

It was clear from the early days of the space age that the best way to conduct planetary astronomy was to transport the observing instruments to the vicinity of planets and satellites. In the 1950s, during the Cold War, politics rather than science was the driving force. After the first heat of the space race had been won by the Soviet Union with its Sputniks, a second heat began: the race to land a spacecraft on the surface of our nearest planetary body, the Moon (see "Sputnik's legacy" *Physics World* October 2007 pp23–27).

Thus the US launched its first Moon probe, Pioneer 1, on 11 October 1958 and the USSR launched Luna 1 on 2 January 1959. The former got little more than quarter of the way to the Moon before succumbing to the Earth's gravitational pull, while the latter missed its target by some 6000 km. But the fact that both nations were planning "Moon shots" less than a year after Sputnik 1 indicates the depth of their respective desires to be first in the various heats of the space race.

It is interesting to note that spacecraft were sent to both the Moon *and* Venus even before OSO 1 reached Earth orbit in 1962. The pragmatism of remote sensing was apparently outweighed by the desire to "get there" physically, but mainly, as with most aspects of space exploration at the time, by the political need to score points against the opposition.

From an engineering point of view, however, there are other more fundamental challenges, such as the need to provide accurate guidance and control, tracking and telemetry, thermal and radiation protection, and to launch the object in the first place. Indeed, the early history of space exploration is littered with examples of failed launches, fried electronics and "heat stroke". For example, NASA's unmanned lunar programme Ranger began badly when the first two spacecraft fell victim to upper-stage rocket failures. Then, Rangers 3 and 4, having been sterilized by heating to 125 °C for 24 hours (ostensibly to avoid possible contamination of the lunar surface), failed to complete their missions after their central computers and sequencers broke down. Ranger 3 missed its target by



ESA

37 000 km and Ranger 4 acquired the dubious honour of being the first spacecraft to crash on the farside of the Moon.

Now that planetary exploration is somewhat more routine, it tends to be pursued in phases – using fly-by, orbital and landing missions – that, by and large, represent increasing accuracy in guidance and control. For the exploration of Jupiter, for example, we saw the Pioneer and Voyager fly-bys of the 1970s followed by the Galileo orbiter of the 1990s; for Saturn, the Voyager fly-bys of the early 1980s and the Cassini orbiter of the present decade. There have so far been no "landing missions" in the Jupiter system, unless one counts the atmospheric entry probe from the Galileo mission that, in 1995, became the first spacecraft to enter Jupiter's atmosphere, and then Galileo's later dive into the Jovian cloudscape at the end of its mission. Furthermore, the Huygens probe, developed by the European Space Agency (ESA), made a spectacular landing on Saturn's largest moon Titan in January 2005 and transmitted a wealth of data that could never have been gathered remotely (including details of atmospheric structure and composition, wind speed, surface chemistry and images of icy boulders) (see "Tuning it to Titan" *Physics World* February 2006 pp20–23).

Close-up observation has a number of technical advantages. "Spatial resolution is improved enormously and proximity to the planet also improves the signal-to-noise ratio for spectral measurements, enabling higher spectral resolution," says Wendell Mendell, head of NASA's Office for Lunar and Planetary Exploration. A spacecraft in orbit around a planet can observe temporal changes, such as atmospheric storms on the gas giants and volcanic eruptions on their satellites (such as those observed on Io by Voyager in 1979 and Galileo in 1996), mainly because it can conduct long-term global surveys, as opposed to taking snapshots. Also, adds Mendell, "phenomena such as X-ray or gamma-ray emission can often be detected only when close to the object".

Marcello Coradini, ESA's co-ordinator of solar system missions, goes as far as to quantify the benefits of space probes. "Between 90% to 95% of what we understand of the planets and their satellites", he says, "is due to *in situ* space missions that have allowed us to reveal, both from orbit and on the surface, details, features and geological, geophysical and geochemical processes otherwise impossible to detect and study."

The lure of Mars

Among the many discoveries made possible by spacecraft, Ian Crawford, a senior lecturer in planetary science at Birkbeck College in London, cites the volcanoes of Io, the methane lakes of Titan and "the probable subsurface ocean of Europa". But it is one of our nearer planetary neighbours, Mars, that has perhaps excited space scientists the most in recent years. The history of its telescopic exploration is well known – most famously because of Percival Lowell's mistaken identification of canals on its surface. The first successful attempt at a Mars fly-by mission was NASA's Mariner 4, which made a close approach of some 9000 km in July 1965. It took just 22 photographs, covering only 1% of the planet's surface, and their content was immediately disappointing to earthbound canal-spotters and anyone hoping for complex life forms, such as vegetation. Mars was apparently a dead planet.

Mariner 6 and Mariner 7 flew past Mars in July and August 1969, respectively, somewhat closer, at about

Planetary exploration tends to be pursued in phases – using fly-by, orbital and landing missions – that represent increasing accuracy in guidance and control

NASA

The red planet
Mars was explored by Viking 1 in the 1970s (above left is Carl Sagan with an engineering model from the mission) and more recently by the Mars Global Surveyor (above right), the Sojourner rover (opposite-page left) and the Mars Exploration Rover Opportunity (opposite-page right).

3500 km, and taking 200 images each, but the results were much the same. The Martian surface – apart from the polar caps that were visible from the Earth anyway – looked very much like the barren, cratered plains of the Moon. Considering that two men from Earth had landed on one of those plains in the same month that Mariner 6 made its fly-by, it is hardly surprising that its achievements failed to take the world by storm.

Mars did not become truly interesting to space scientists until Mariner 9 entered its orbit in November 1971. It mapped the whole surface of the planet in over 7000 photographs and gathered data on atmospheric composition, density and temperature, which effectively prepared the way for the first landing mission – Viking 1 – in July 1976. As Crawford points out, Mariner 9 revealed the volcanoes, canyons and river valleys of Mars, providing tantalizing "evidence of past habitable conditions on that planet". Unfortunately, the two Viking missions failed to provide evidence of life on Mars – a failure that contributed to a 20-year hiatus in NASA's Mars exploration programme that lasted until the mid-1990s. But as Carl Sagan once said, "absence of evidence is not evidence of absence".

Down among the rocks

Put simply, if any form of life, however simple, can be found on another planet, then the chances that more intelligent life exists elsewhere in the universe are significantly improved. It is thought extremely unlikely that life would have developed independently on two planets in a given solar system and nowhere else.

It is this postulate that has driven most planetary-exploration programmes in recent times, not least the "follow the water" theme initiated by NASA in the late 1990s, following data from the Clementine spacecraft that indicated the presence of ice in a crater near the Moon's south pole. As for Mars, it was clear from some of the Mariner 9 images that water, or at least some form of liquid, had shaped many of its geomorphological features. It was also clear, however, that these features were a relic of the planet's past, because liquid water could not exist at the low atmospheric pressures detected on the planet.

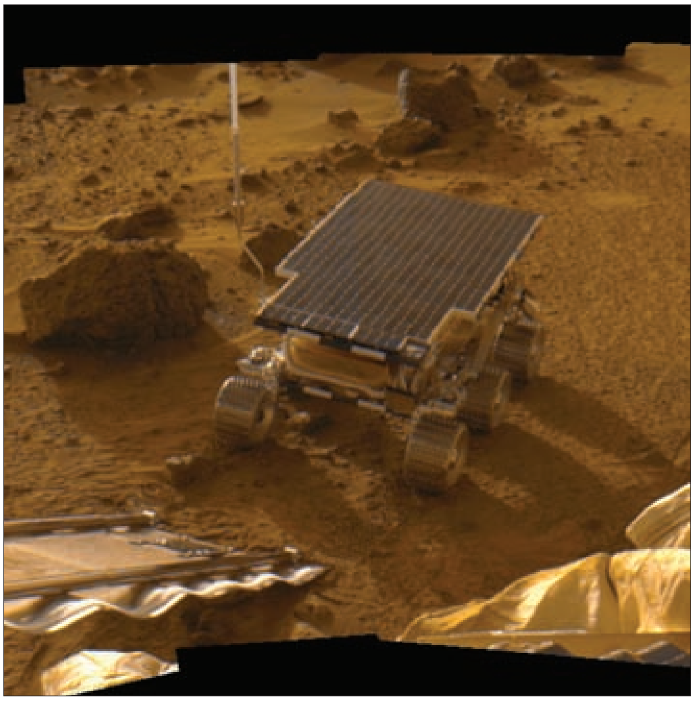
Mars' polar caps were formerly thought to consist mainly of frozen carbon dioxide, but observations from orbiting spacecraft, such as NASA's Mars Global Surveyor and ESA's Mars Express, in recent years have shown that the north cap is predominantly water ice and that the south cap also contains water. Since then, however, the emphasis has shifted to finding evidence of water beyond the polar caps. And the only way to do this conclusively is to get down among the rocks, preferably using a rover that can move easily on rocky terrain.

NASA's first Mars rover was the tiny, 10 kg Sojourner, which was a passenger on the Mars Pathfinder lander (later named Carl Sagan Memorial Station) that was launched in December 1996. It touched down in the Chryse Planitia region of Mars on 4 July 1997. The mission was historic in being the first to deposit a rover on the surface of another planet, but also because it marked the first Mars landing since 1976.

Sojourner operated for a little less than three months, returning some 550 images and analysing rocks and soil in the vicinity of the lander. Among the many scientific highlights of the mission was what NASA called "the possible identification of…conglomerates that formed in running water, during a warmer past in which liquid water was stable". Indisputable proof of water was, however, elusive.

It was the Mars Exploration Rovers (MERs), Spirit and Opportunity, that really proved the efficacy of the "up close and personal" approach to planetary exploration. Launched in 2003, the rovers survived their airbag-assisted landings in January 2004 and easily completed their primary three-month missions the following April. The fact that they were both still operational as of early 2009 is a testament to the engineering design of the two craft.

John Callas, MER project manager at NASA's Jet Propulsion Laboratory (JPL), describes the rovers as



"our robotic proxies on the surface of Mars". "As field geologists," he says, "the two rovers have found clues about the ancient environment, [discovering] extensive evidence of sustained, liquid surface water during the planet's early history."

Spirit's discovery of silica-rich soil in the Gusev crater was described by Albert Yen, a geochemist at JPL, as "some of the best evidence Spirit has found for water". The reasoning was that acid vapours produced by volcanic activity in the presence of water, or water in a hot-spring environment, could have produced the silica.

However, what NASA scientists felt sufficiently confident to describe as "proof" of the existence of water came only with the Phoenix Mars Lander, which dug a trench in June 2008 to uncover "crumbs" of a bright material thought to be water ice. Had they been composed of carbon dioxide or salt, they would not have vaporized, but four days later the crumbs had disappeared, proving that they contained water. Phoenix principal investigator Peter Smith, of the University of Arizona's Lunar and Planetary Laboratory, said at the time that "with great pride and a lot of joy" they had "found proof that this hard material really is water ice and not some other substance".

ESA's Marcello Coradini sums up the importance of planetary spacecraft. "Without them," he says, "we would not have discovered ice beneath the surface of Mars, we would not be able to discriminate between carbon dioxide and water layering in the polar caps, and we would never have detected methane in the lower layers of the Martian atmosphere." These and a wealth of other discoveries can only reinvigorate the search for life on Mars.

But planetary science is still in its infancy and, in common with other disciplines, most missions produce more questions than answers. John Callas repeats a familiar litany: "Did Mars support life? Is there life there today? Can we find evidence of extant or extinct life? And, if Mars was once Earth-like, why did it change?" Future missions will have to answer these questions.

New paradigm

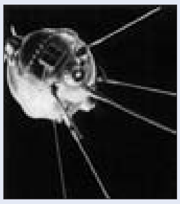
Analysing the history of solar-system exploration in terms of the three phases – fly-by, orbit and landing – shows that all of the planets have been subject to fly-by missions (except "former planet" Pluto, which should receive a visit from NASA's New Horizons probe in 2015). Venus, Mars, Jupiter and Saturn have been targeted by orbiters, while Mercury is due to join the list in 2011 when NASA's Messenger spacecraft arrives. So far, only the surface of Venus and Mars (and of course Saturn's moon Titan) have been explored using landers, a fact that indicates the relative difficulty and expense of this method of research.

That said, the challenge of placing a spacecraft from Earth on the surface of a celestial body – including moons, asteroids and comets – has far-reaching payoffs in terms of understanding our solar neighbourhood and the Earth itself. As Coradini puts it, "On-surface science will allow us to reveal fine geochemical and mineralogical differences that are at the basis of our understanding of the formation and evolution of the solar system."

The difference between the planetary astronomy of the past and today's *in situ* missions is akin to the difference between aerial archaeology and actually "digging the dirt". In effect, the development of space technology has allowed astronomy to develop from a

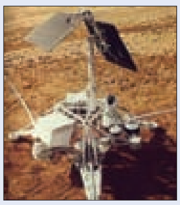
Proof of the existence of water came only with the Phoenix Mars Lander, which dug a trench in June 2008 to uncover "crumbs" of a bright material thought to be water ice

Space milestones



2 January 1959
The Soviet Union launches its first lunar spacecraft, Luna 1 (also called Lunik 1 or Mechta, Russian for "dream"). It passes within 6000 km of the Moon two days after launch and becomes the first artificial object to escape Earth's gravitational field.

11 March 1960
Pioneer 5 becomes the first true "deep space" probe by returning data when 36.2 million kilometres from Earth. It confirms the existence of the interplanetary magnetic field and provides warning of solar storms that could cause electromagnetic interference on Earth.

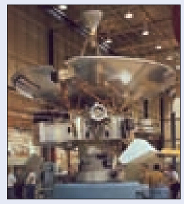


2 June 1966
Surveyor 1 is the first spacecraft to execute a controlled landing on a celestial body, the Moon. It transmits more than 11 000 photographs of the lunar surface.

20 July 1969
Apollo 11's lunar module Eagle is the first manned spacecraft to land on the Moon (touchdown: 8.17 p.m. GMT). The first lunar extra-vehicular activity is conducted by Neil Armstrong ("boot down": 2.56 a.m. GMT on 21 July 1969).

17 November 1970
Luna 17 delivers the first tele-operated rover to the Moon, Lunokhod 1. It and Lunokhod 2, launched three years later, are the only planetary rovers until Sojourner lands on Mars in 1997.

15 December 1970
Venera 7 makes the first radio transmission from the surface of another planet, Venus.



3 December 1973
The first spacecraft to have traversed the asteroid belt, Pioneer 10 flies past Jupiter. It becomes the first spacecraft to escape the solar system (by its former definition) when it passes the orbit of Pluto on 13 June 1983.

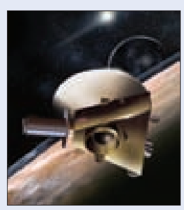
20 July 1976
Viking 1 is the first spacecraft to soft-land on Mars and is the first to conduct *in situ* analyses of the Martian environment.

13 March 1986
The European Space Agency's Giotto Comet Halley interceptor makes the first close encounter of a comet, approaching to within 600 km.

7 December 1995
A probe from the first Jupiter orbiter Galileo enters the Jovian atmosphere. The craft itself is de-orbited in 2003 as a protective measure.

4 July 1997
Mars Pathfinder delivers the first tele-operated rover, Sojourner, to Mars. It remains operational until late September 1997.

4 January 2005
Launched in October 1997, the Cassini Saturn orbiter drops its Huygens Titan entry probe, which lands on Saturn's largest moon. Cassini continues its tour of the Saturn system.



19 January 2006
NASA's New Horizons probe is the first spacecraft launched towards the Pluto/Charon system, which it is expected to reach in July 2015 before continuing on to the Kuiper belt.

NASA, ESA

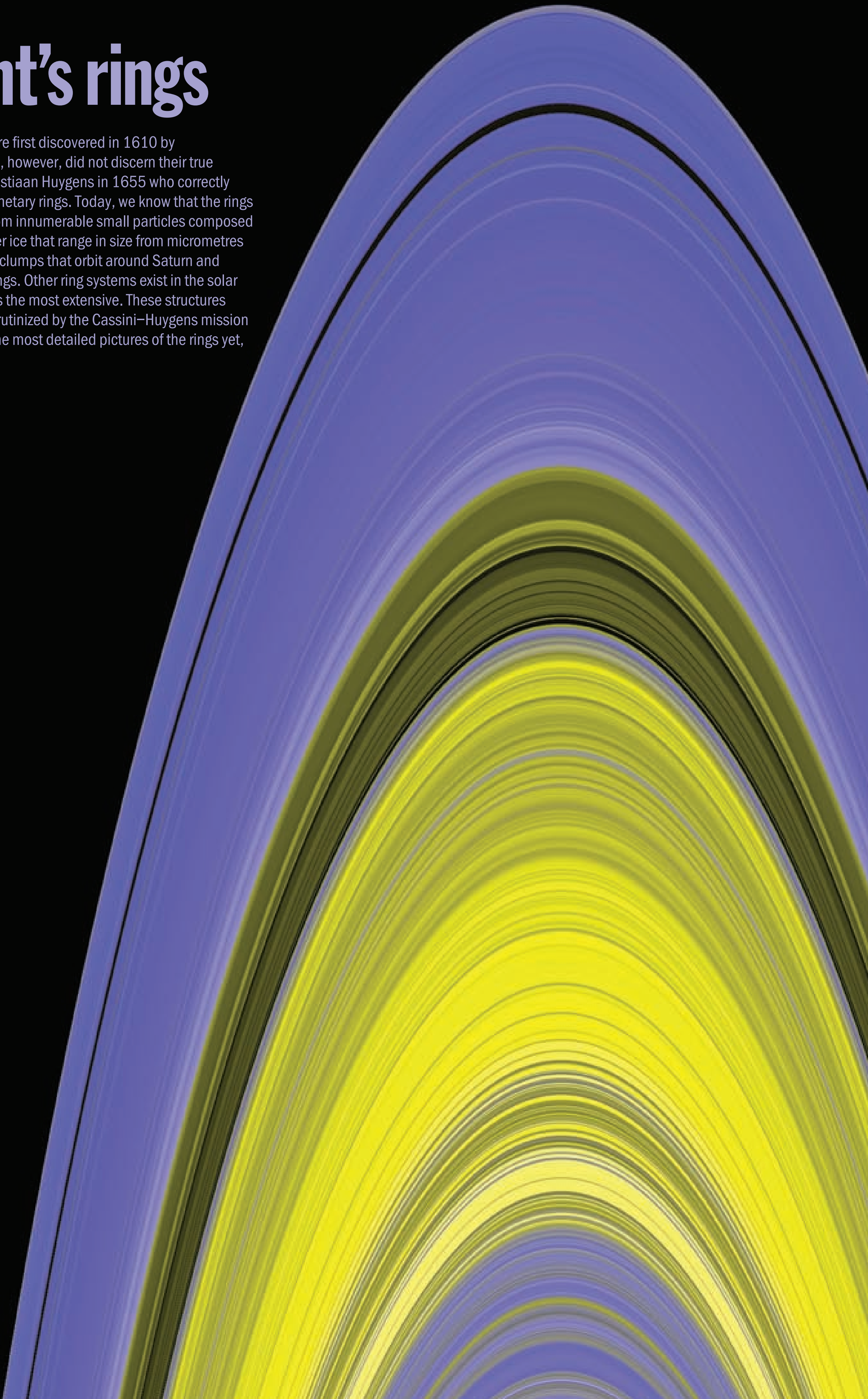
science of entirely remote observation to one of immersive experimentation, from sampling Titan's atmosphere to digging for ice on Mars. The next level of understanding will come from samples returned to the Earth, where sophisticated analyses can be performed in laboratory settings that are impossible to implement on a spacecraft. Returned samples also remain available for the future, when technological advances in scientific instrumentation may allow observations that are not possible at the time of the mission.

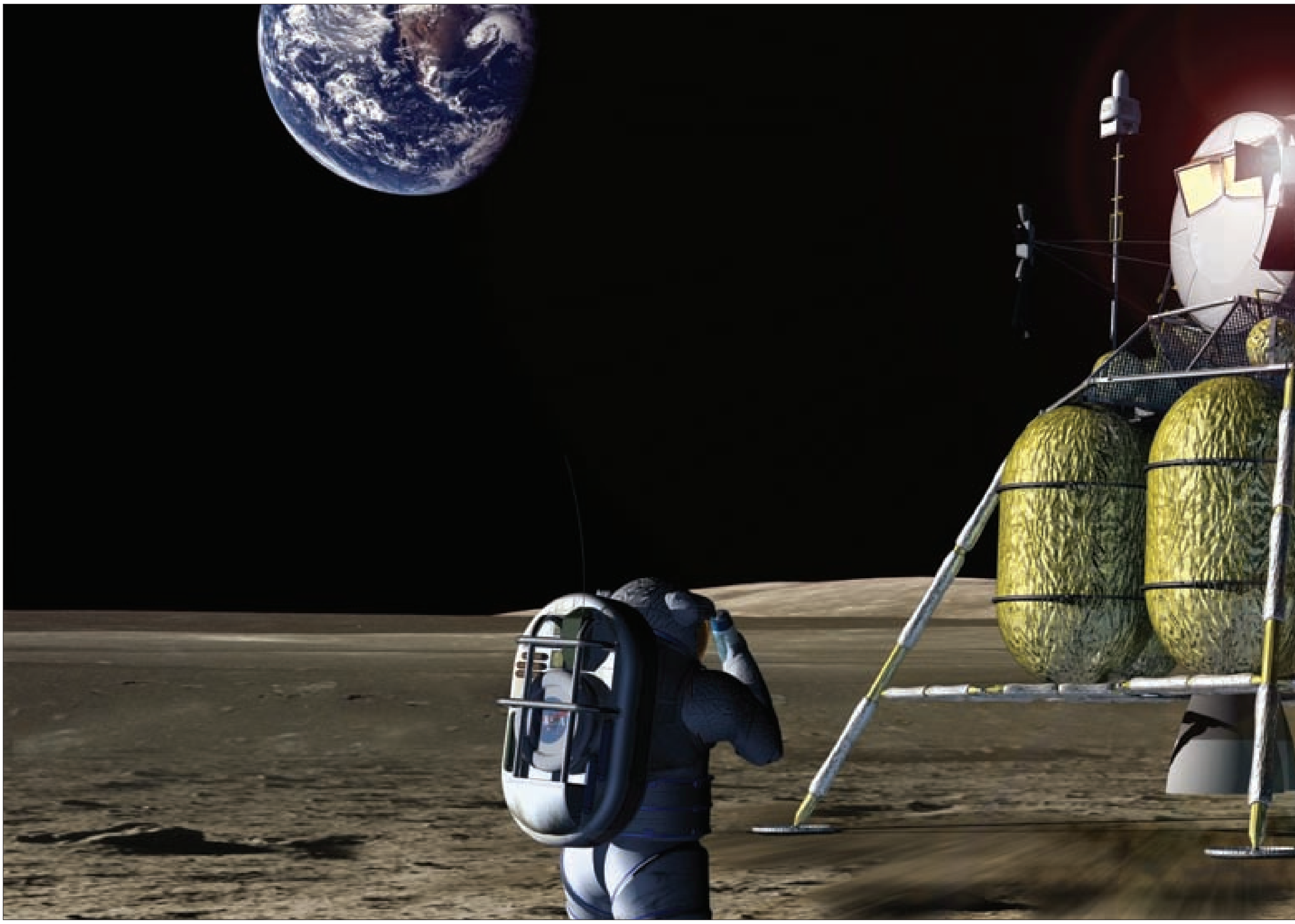
Crawford goes even further with his view that the whole paradigm of planetary science changed once space technology made it possible to conduct *in situ* investigations of other planets. "In a real sense," he says, "space exploration has removed the planets from 'astronomy' by making it possible to apply the expertise and techniques of geology and geophysics (and perhaps even biology) to other planets which formerly could only be applied to the Earth." This "explosion of new knowledge", adds Crawford, is epitomized by comparing a modern planetary-science textbook with one written prior to the space age, when the other planets were "little more than indistinct dancing images in telescopes".

Astronomy has come a long way in the 400 years since Galileo Galilei, and most of the progress has been made in the 50-odd years of the space age. But the indisputable advantages of proximity observation with spacecraft provide a challenge for scientific and budgetary prioritization alike. No nation can afford even a fraction of the missions being proposed by the space-science community, which leaves many disappointed. While the thrill of planetary-science missions will never subside, the discovery of more than 330 extrasolar planets (so far!) may, unintentionally, add to this budgetary dilemma. "Ultimately," predicts Crawford, "we are going to need space probes to explore these extrasolar planetary systems as well, which will be a real challenge for spacecraft designers." One wonders what Galileo would have made of that.

A giant's rings

The rings of Saturn were first discovered in 1610 by Galileo Galilei. Galileo, however, did not discern their true nature, and it was Christiaan Huygens in 1655 who correctly identified them as planetary rings. Today, we know that the rings of Saturn are made from innumerable small particles composed almost entirely of water ice that range in size from micrometres to metres. These form clumps that orbit around Saturn and create the full set of rings. Other ring systems exist in the solar system, but Saturn's is the most extensive. These structures were more recently scrutinized by the Cassini–Huygens mission in 2006, which took the most detailed pictures of the rings yet, as shown here.





Another giant leap for mankind

The Moon has been neglected by space scientists and astronomers alike since the Apollo days, but now we want to go back. **Paul D Spudis** explains what motivates the new vision of lunar exploration

Paul D Spudis is at the Lunar and Planetary Institute, Houston, US, e-mail spudis@lpi.usra.edu

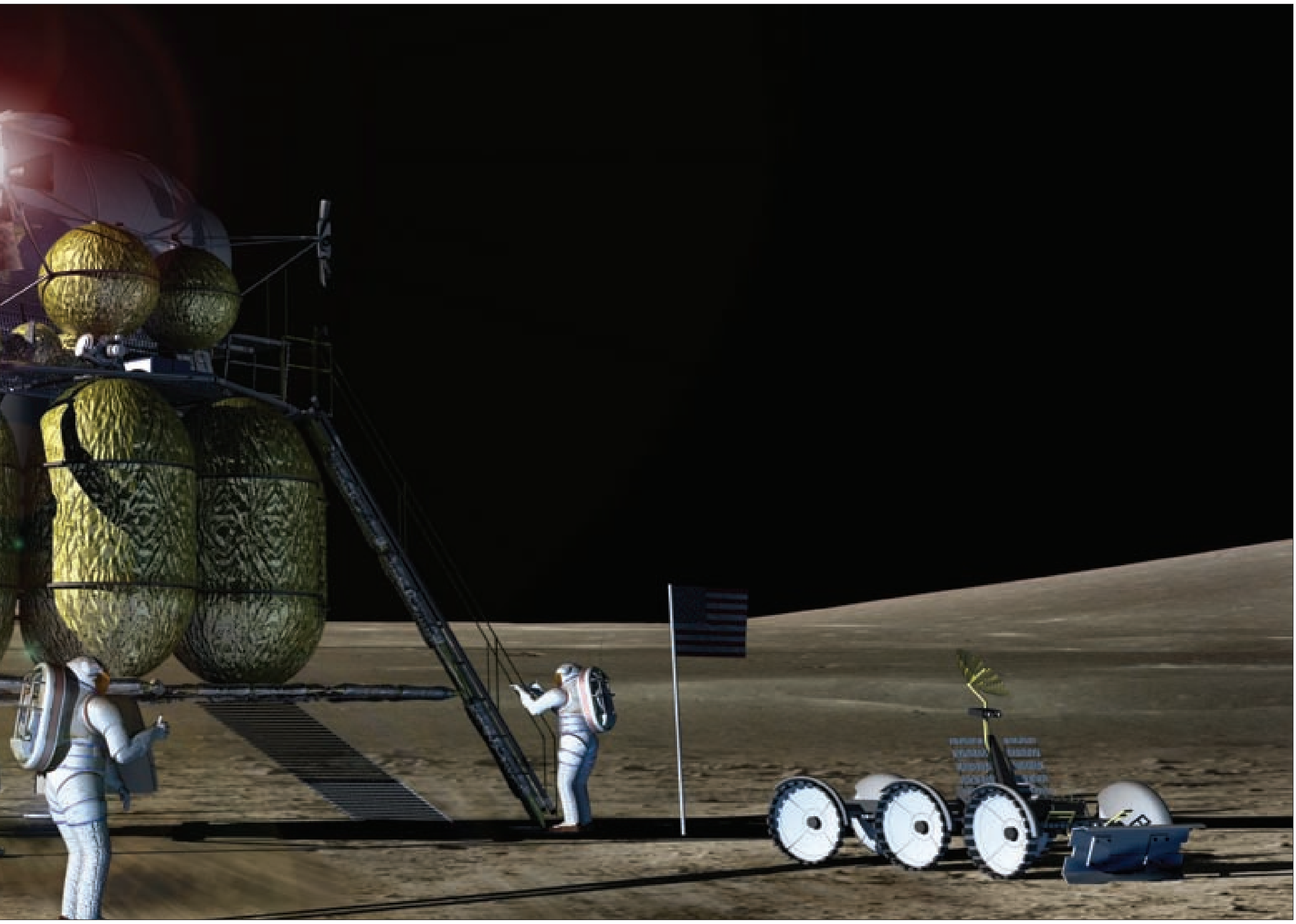
Three spacecraft are currently orbiting the Moon, Chang'e-1 from China, Kaguya from Japan and Chandrayaan-1 from India. The American Lunar Reconnaissance Orbiter will join them later this year. Russia is developing lunar rover hardware, for itself and for other countries. In Europe, both Germany and the UK are contemplating their own lunar missions, both outside the boundaries of the European Space Agency, to which they both belong. China and India are discussing the idea of sending manned missions to the Moon within the next decade or so. The Moon has once again risen to the top of the space agenda worldwide.

What is going on? Why has the Moon suddenly become *the* destination for spacefaring nations? After the Apollo programme ended in 1975, relatively little attention was paid to the Moon. Yet a small group of lunar scientists, enthusiasts and space visionaries have continued to think seriously about both the scientific questions the Moon poses as well as the opportunities it offers. We know a lot more about the Moon that we did only a couple of decades ago. And we now understand that the Moon has a key role to play in humanity's exploration of the solar system.

Return to the Moon

Our spacecraft have reached the breadth of the solar system, probed the nature of the Sun, and examined our galaxy. For almost 50 years, we have tentatively explored the edges of the cosmos, examining the physics and history of our universe.

We have accomplished much with this model of space exploration but are limited in what we can send into space. Launch vehicles are costly and not always reliable. The high cost of spaceflight makes the fate of such programmes inevitably tied to political winds that may change at a moment's notice. Failures occur, and



Vision of the future
An artist's impression of NASA's Constellation programme, which aims to return humans to the Moon.

when they do, it can take years to recover and obtain the information originally sought.

The current paradigm of space exploration has developed largely because we must lift everything we need for our study out of Earth's deep gravity well. Because launch costs are so high, satellites must be built to last for long periods of time, thus making individual missions costly and rare. The logistical train to the various levels of Earth orbit where our space assets reside is long, tenuous and difficult to maintain.

The US's new Vision for Space Exploration (VSE), proposed by President George Bush in 2004 and endorsed by Congress in 2005, outlines a different approach to the fundamentally limiting problem of spaceflight: what if we were no longer limited only to what we can lift from the Earth's surface? Suppose that we were able to "live off the land" in space? What would the advent of this scenario mean for the future exploration of space?

The human part of the space programme has been trapped in low Earth orbit with no plans to go further, even though robotic space exploration passed that horizon years ago. The International Space Station (ISS) could have served as a test bed for farther destinations, but did not, largely as a result of conscious policy decision. The tragic loss of the Space Shuttle *Columbia* in 2003 only drew attention to the hollowness and lack of direction in space policy.

The VSE proposes that a new vehicle be designed and built for human spaceflight beyond the confines of low Earth orbit, one that can adapt to different kinds of missions going to varying destinations. We would conduct robotic exploration of the Moon in preparation for the resumption of human exploration of our satellite by the next decade. On the Moon, we would learn how to live and work productively on another world and use the knowledge and capabilities created from these activities to venture beyond it to the planets.

Water from outer space

One of the most interesting and unusual aspects of the VSE is the idea of using the abundant resources found at the Moon and elsewhere in space to create new capabilities. Although widely discussed in space-advocacy circles, the use of space resources has been dismissed by many in the spaceflight community, with development considered only likely in the far distant future. Yet, we have been using one cosmic resource since the very first flights into space – the conversion of abundant solar energy into electricity to power the spacecraft sent to various destinations.

Space resources consist not only of energy, but of materials as well. We know that the bodies closest to us in space offer usable resources that can be harvested –

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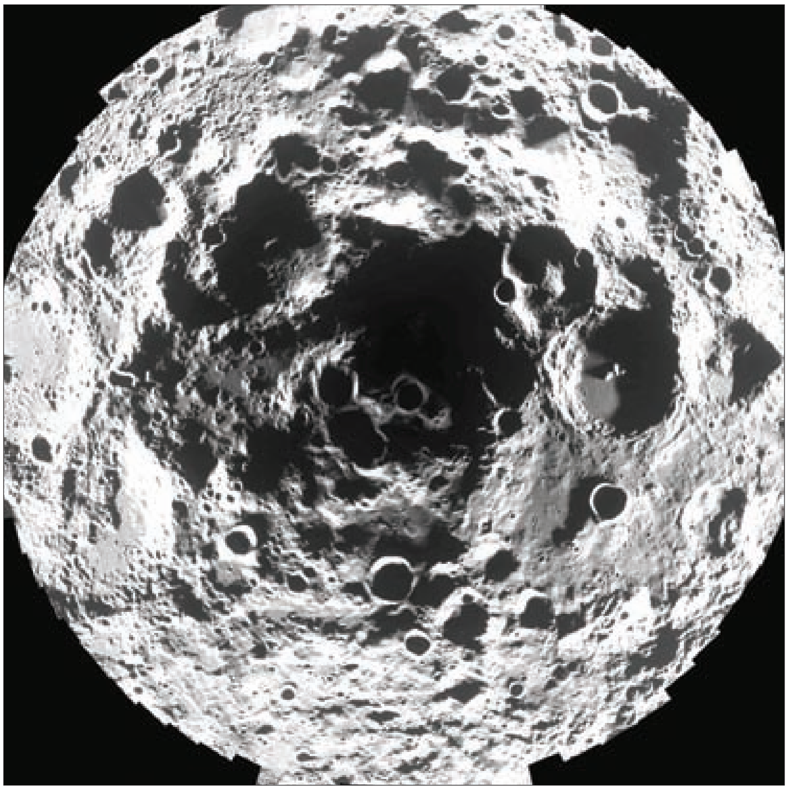


Polar probe
In 1994 the Clementine mission mapped the poles of the Moon using a high-resolution camera. Above is a mosaic of images of the lunar south pole.

water (bound in minerals or as condensates in specialized environments) and the bound oxygen found in common rock-forming minerals. The Moon and near-Earth asteroids also contain metals and ceramics that can be used in the construction of new rockets and spacecraft.

A supply of water on the Moon would make the establishment of a self-sustaining lunar presence come about sooner and easier. The samples returned by the Apollo missions revealed that the lunar interior is essentially devoid of water. However, the surface is regularly bombarded with water-rich objects such as comets, and scientists suspect that some of that water might have accumulated to usable quantities. Where would this water end up? Most of it would be split by sunlight into its constituent atoms of hydrogen and oxygen, and lost into space, but some would migrate by literally hopping along to places where it is very cold. As the Moon's axis of rotation is nearly perpendicular to the plane of its orbit around the Sun, the Sun always appears close to the horizon at the poles of the Moon. If you are on a topographic high, you may be in permanent sunlight. If you are in a hole, you may be in both permanent darkness and in extreme cold, with temperatures as low as 40–50 K. Moreover, these "cold traps" have existed on the Moon for at least the last two to three billion years – plenty of time for water to accumulate from impacting comets.

The discovery of ice has enormous implications for a permanent human return to the Moon

Two NASA missions sent to the Moon in the 1990s looked for evidence of water at the poles. In 1994 Clementine thoroughly mapped the poles of the Moon, revealing areas of near-permanent sunlight and permanent darkness. Although the spacecraft did not carry instruments designed to look for lunar ice, during the mission an improvised experiment obtained information on some properties of the polar surface. Radio waves are reflected from planetary surfaces differently depending on the compositional make up of the surfaces. Specifically, radio waves are scattered in all directions when they are reflected from surfaces consisting of ground-up rock (as exists on most of the Moon, Mercury, Venus, Mars and the asteroids). However, radio waves are reflected more coherently from ice surfaces (the polar caps of Mercury and Mars, and the icy surfaces of Jupiter's satellites Europa, Ganymede and Callisto). When radio waves encounter ice, they are partly absorbed and reflected multiple times by internal flaws in the ice then reflected back out into space. A consequence of multiple reflections is that some of the radio reflections come back in the same sense as they were transmitted (think of the reflection of light from two mirrors – reflection from a single mirror makes text unreadable, but double reflection makes the text "normal" again). Thus, ice reflects the radio waves back partly in the same sense as incident waves.

Analysis of the data returned from the radio-wave experiment on Clementine reveal that ice deposits might exist in permanently dark regions near the south pole of the Moon. Initial estimates suggest that a small ice lake (more than 10^9 m^3 in volume) exists at the south pole. This amount of water would be equivalent to the fuel (hydrogen and oxygen) used for more than a 100 000 Space Shuttle launches.

The Lunar Prospector (LP), launched in 1998, orbited the Moon in a 100 km orbit for over 18 months. It carried a variety of instruments that, in many ways, complemented the instruments of the earlier Clementine mission. The LP's neutron spectrometer detected high concentrations of hydrogen at both poles. In the form of water ice, results from the LP show an amount of hydrogen equivalent to about 10 m^3 of ice, with the south pole having slightly more than the north pole. Moreover, the low-altitude (high-resolution) neutron data show that these high concentrations of hydrogen are correlated with the large areas of darkness seen in the Clementine images. This result almost certainly means that water ice exists in the dark areas, thus confirming Clementine's earlier result.

The discovery of ice has enormous implications for a permanent human return to the Moon. Water ice is made up of hydrogen and oxygen, two elements vital to human life and space operations. Lunar ice could be mined and disassociated into hydrogen and oxygen by electric power provided by solar panels or a nuclear generator. Hydrogen and oxygen are prime rocket fuels, giving us the ability to refuel rockets at a lunar "filling station" and making transport to and from the Moon more economical by at least a factor of 10. Additionally, both the water from lunar polar ice and the oxygen generated from the ice could support a permanent outpost on the Moon. The extraction and use of this material, rare on the Moon but so vital to human life and operations in space, will make our expansion into the solar system easier and reaffirms the immense value of the Moon as a stepping stone to the wider universe.

New missions to the Moon

The initial steps in a return to the Moon involve robotic orbiters. Chang'e-1, Kaguya (SELENE) and Chandrayaan-1 are all currently in lunar orbit. These missions are making maps of the Moon at unprecedented levels of detail and quality. Soon we will know the global topography, composition and structure of the Moon to a degree never before attempted for any planet, including the Earth. The basic data acquired by these missions will let us select future landing sites for both scientific and resource purposes.

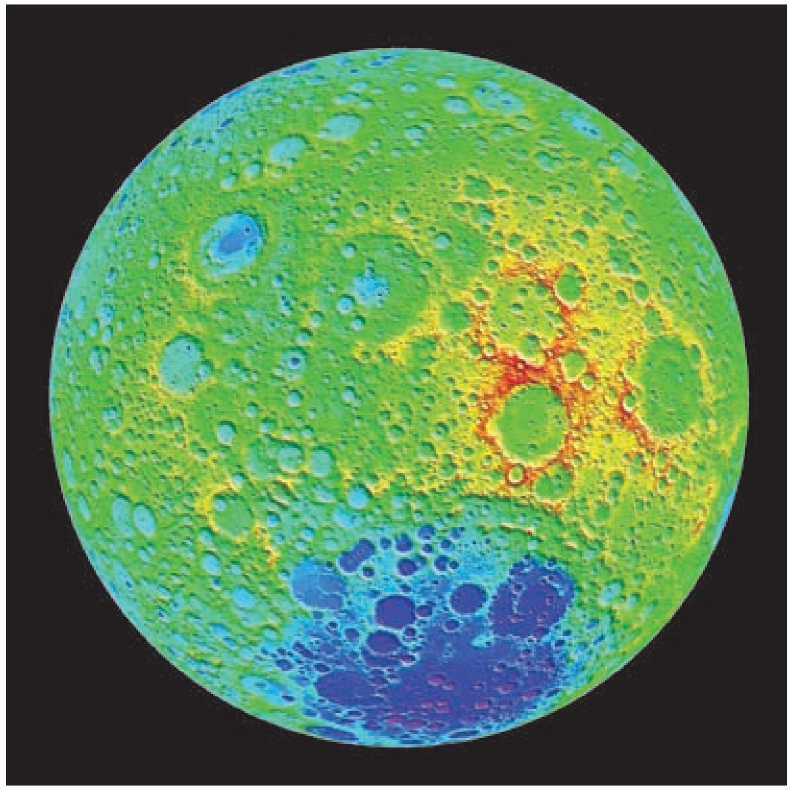
These missions should be followed by others, including both orbiters and landers. A series of small spacecraft in lunar orbit could create a communications and navigation infrastructure for the Moon, providing continuous communication with areas out of sight from the Earth (such as the far side and deep craters near the poles) and positional information for both orbital and surface navigation around the Moon (a lunar GPS). With landers, we can explore the surface using rovers, as shown by the recent experience with the Mars Exploration Rovers, and deliver robotic payloads to begin developing the surface infrastructure near a future outpost site. Rovers can access the dark floors of polar craters, gathering detailed chemical and physical information on the ice deposits – necessary precursor information for the extraction of water.

In parallel with this programme of robotic exploration, a new human spacecraft (the Crew Exploration Vehicle, a replacement for the Space Shuttle) will need to be developed and tested. Humans will return to the Moon using both the knowledge gained and equipment emplaced by the robotic precursors. Using the Moon's resources will enable us to build a space-transportation infrastructure in "cislunar space" (between the Earth's atmosphere and the Moon). Such a system – allowing routine access to the Moon and all points in between – is a fundamental step towards creating true spacefaring capability. A system that can routinely land on the Moon, refuel and return to Earth orbit, bringing with it fuel and consumables produced on the lunar surface, also gives us the ability to journey to the planets.

The ability to routinely access cislunar space would also bring about a new capability, one of surprising significance. All current satellite assets, commercial and strategic, reside in the volume of space between the Earth and the Moon. Currently, we have no way of accessing these satellites – if one breaks down or becomes obsolete, it is written off and must be replaced. If we had the ability to travel between the various energy levels of cislunar space, carrying out servicing and upgrading missions, we could maintain a more robust, more capable and more extensible set of satellite assets. Thus, cislunar space would become as accessible as low Earth orbit is today and we could use this lunar-based transport system for a variety of commercial missions as well as exploration.

The meaning behind the vision

Rather than being simply a "new human space programme" or a "manned Mars mission", the entire solar system is the goal of this new vision. Existing launch vehicles, spacecraft, instrumentation and supporting infrastructure are too limited – in mass, power, bandwidth and computational ability. The goals of the VSE are nothing less than revolutionary: to exploit our existing capabilities by developing and using new technology, but also to *create* new capabilities by using space resources and building spacefaring infrastructure.



NAOJ/JAXA

Moon map
The Japanese mission SELENE is currently mapping the topography of the Moon. This image shows the farside of the lunar surface.

Thus, the vision is not a zero-sum game, with some winners and some losers – the goal is for *all* to win through the creation of new capabilities.

It is important to emphasize that the VSE does not call for the use of space resources to lower the costs of the US space programme, although that is a long-term goal of such use. The real goals are to understand how difficult it is to use lunar and space resources, to develop the technologies needed to do so, and to experiment with different processes in a real space environment. It may turn out that using space resources is more trouble than it is worth; if so, we can then devote our efforts to a space programme that does not feature an extensive human presence. In other words, can we make what we need from what we find in space?

However, it is my view that a new scientific opportunities will become available through the presence of people on lunar and planetary surfaces. A key goal of the VSE is to break down the false dichotomy between human and robotic exploration. To maximize the return, both techniques are needed. We can use a return to the Moon to learn how to best explore planetary surfaces and to decide the optimum mix of human and robotic capability.

We face a clear choice in our future direction in space. We can continue on our existing path, limited in space by what we can launch from the Earth, or we can embrace a model that creates new capabilities by using the unlimited resources of space to build a transportation infrastructure that can routinely access cislunar space and beyond. We can generate new wealth by extracting these resources for the use in space and back on Earth. Using the combined power of people and machines, we can robustly explore planetary surfaces and build scientific instruments of extraordinary power and capability. The first step in this direction will represent another giant leap for mankind.

Galactic spiral

The Whirlpool galaxy, also known as Messier 51a, is a spiral galaxy located about 23 million light-years from Earth in the constellation Canes Venatici. Discovered in 1845, it was the first galaxy to be recognized as a spiral, and the distinctive structure is believed to be the result of it interacting closely with its companion galaxy. Messier 51a is one of the most famous spiral galaxies in the sky and has been widely studied by astronomers seeking to understand the structure of galaxies and how they interact. This image was obtained by the Hubble Space Telescope in 2001.

Sites for new eyes

Astronomers are planning a new generation of extra-large telescopes that will provide fascinating insights into the universe. But as **Robert P Crease** finds out, choosing where to locate these and other big facilities can require close interaction with the local communities involved

Robert P Crease is chairman of the Department of Philosophy, Stony Brook University, and historian at the Brookhaven National Laboratory, e-mail rcrease@notes.cc.sunysb.edu

Cerro Toloncharr, an isolated mountain peak rising 4475 m in the Atacama region of north-eastern Chile, is the most remote of five sites considered as locations for a huge new astronomical facility known as the Thirty Meter Telescope (TMT). Reaching the closest settlement involves a five-hour drive on an unpaved road across a dried-up and desolate lake. That gets you to the village of Socaire (population about 500) high up in the Andes across the border from Argentina. But you are still hours away from the peak itself.

It was at the summit of Cerro Tolonchar in January 2006 that about a dozen Atacamans from nearby villages, including community elders and religious leaders, performed a *ceremonia del pago* accompanied by several members of the TMT project. In the Atacaman religion, the *ceremonia del pago* (or "repayment ceremony") is performed whenever a mountain is to be "disturbed", and it involves giving thanks and offerings to the goddess Pachamama ("Earth Mother"). Had the disturbance involved extracting something from the mountain – through mining, say – the ceremony might have included an animal sacrifice. But as the TMT collaboration was only seeking to install temporary test telescopes, the ceremony called for participants to throw cocoa leaves on a fire, scatter wine and drink toasts to the goddess and those present.

TMT project manager Gary Sanders had gone to great lengths to make sure that the ceremony was properly and respectfully carried out. A physicist by training, much of his career has been spent working on large science projects, including the (cancelled) Superconducting Super Collider (SSC) in Texas and the LIGO gravitational-wave detectors in Washington and Louisiana. In choosing a site for the SSC and LIGO, the US government solicited proposals from the relevant states, thereby assuring a certain amount of community enthusiasm and support for the projects. But as Sanders discovered, siting a telescope is very different. "The fact that you need a mountain severely restricts your sites and means that you may have to come to a community having picked out its mountain as your perfect site," he says.

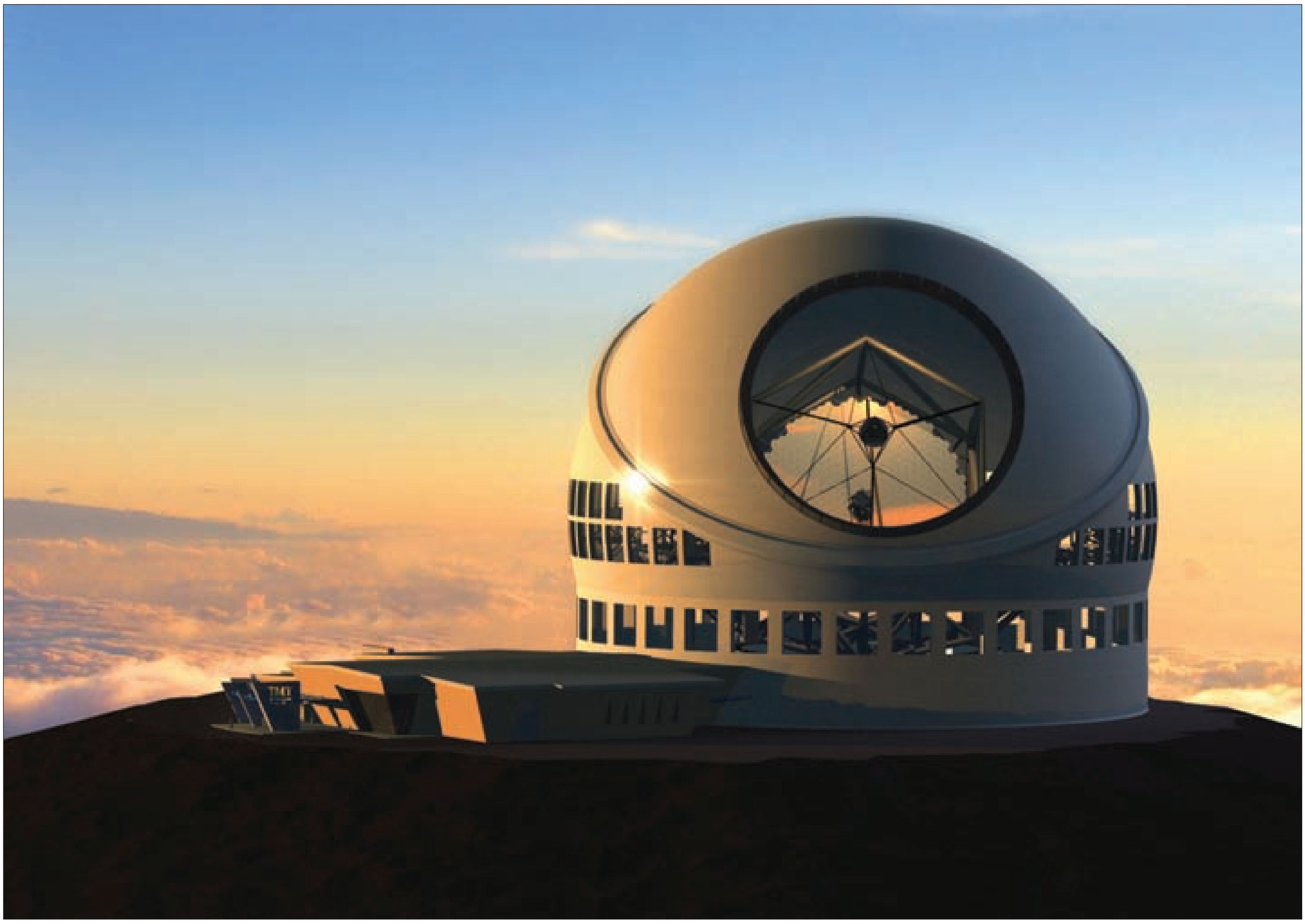
For several years, Sanders and collaborators have been scouting locations for the TMT. Other contenders included two other sites in Chile, one in Mexico and Mauna Kea in Hawaii. The final choice is now between either Cerro Armazones (a site not far from Cerro Tolonchar) or Mauna Kea, with the a final decision expected in July. While Sanders' experiences with previous facilities have involved structuring diverse clusters of scientists and engineers to work together, the TMT project has included a new challenge that is bound to be important for large scientific projects of the future: learning how to shape the interface between that project and its cultural surroundings.

Message from the mountains

The TMT is one of three large optical telescopes at the advanced-planning stage – the others being the Giant Magellan Telescope (GMT) and the European Extremely Large Telescope (E-ELT). While these instruments are vastly different from the optical telescopes that were first used 400 years ago by the likes of Galileo Galilei, even in the early 17th century telescopes were relatively expensive instruments to build and were mainly privately funded. Galileo's telescopes, for example, were underwritten by his patron Cosimo II de' Medici, the Grand Duke of Tuscany. Modern telescopes are still largely what Sanders calls "a rich man's sport". In the US, they are funded mainly by wealthy private patrons such as the Rockefeller Foundation, which built the 200-inch Mount Palomar telescope, and the oil-rich Keck family, who paid for the Keck Observatory on Mauna Kea. Indeed, some \$200m of the TMT's estimated \$1bn price tag comes from Intel co-founder Gordon Moore, with the rest from the US National Science Foundation and funding agencies in Canada, Japan and elsewhere.

But as the *ceremonia del pago* reveals, astronomers can no longer simply find a suitable mountain top far from cities with desirable atmospheric properties and then strike an agreement with the local government. Today, those siting telescopes can have to deal with cultural issues that in the past were ignored. To be sure, telescopes are not threatening, polluting or dangerous – in the way that, say, nuclear reactors or accelerators may be perceived to be. Who could possibly object to a telescope – a largely passive scientific instrument that could shed light on the cosmos and the human place in it?

Scientists are used to addressing technical issues, where a goal is clearly defined, while trust-seeking is a social issue that is less clearly definable



Thirty Meter Telescope

Top class
How the planned Thirty Meter Telescope might look.

The problem is that a high mountain may be important to the life and practices of a local community, which may consider the peaks sacred regions to be left free of human artefacts. As Sanders wrote in one TMT newsletter, "Mountain tops have been a special place as we humans have travelled with our wondering through animism to polytheism and then to monotheism and to science and then back again. It is in our heart and our mind. We strive to understand. We journey to mountain tops for a message. Remember that in the Judeo–Christian bible, the Ten Commandments are delivered from a mountain top."

Local communities now tend to want, and receive, a much larger role in deciding what happens to mountains in their regions. For example, during the recent construction of the Atacama Large Millimetre Array (ALMA) in the Chilean desert, project managers helped to rebuild several historical shrines and sites, and thoroughly investigated the environmental impact of the project. The growing sensitivity to community concerns means that those planning large telescopes – or other large scientific facilities – should pay attention to the TMT's experience, and be prepared to learn from it.

Sacred places

The TMT's designers began their site-selection process in 2001 by scouring the planet with satellite images. They then used lasers and test telescopes to study atmospheric conditions to compile their shortlist of five possible sites. Each had its own scientific and technical advantages, but while the proposed Mexican site did not have any ceremonial significance to local communities, other sites in Chile and Hawaii did. Chile, for instance, wisely treats its spectacular mountain skies – which are beloved by astronomers for being dark, clear and dust-free – as a natural resource, like its copper. The country has had decades of experience with international observatories since the first large one – the Cerro Tololo Inter-American Observatory – was built some 40 years ago, and it has established a well-organized process for handling requests for new facilities. Large observatories have the status of international organizations, and their representatives are treated as diplomats and work through the foreign ministry. Seeking to site an observatory in that country involves a clear and transparent process.

For the past few years, this process has included a policy according to which every indigenous community in the region has to support the observatory in writing. After the diplomatic and petitioning process is initiated, a new level of engagement with local communities is required, with the outcome not a foregone conclusion. Some of these mountain communities, having been pushed around by the mining industry, are said to have endured bad experiences with outsiders who make promises and then disappear.

"It's not enough to provide a few street lights and schools, and show up every six months or so," Sanders says. "They expect a real and substantive interaction.

The Thirty Meter Telescope

Thirty Meter Telescope

The Thirty Meter Telescope (TMT) is named after its 30 m diameter primary mirror, which is made from 492 individual segments. The telescope will operate in wavelengths from ultraviolet to mid-infrared, enabling astronomers to study the origin and evolution of planets, stars and galaxies, writes Lee Pullen.

Site

Either Cerro Armazones in Chile's Atacama Desert or Mauna Kea in Hawaii. The final choice will be made in summer 2009.

Costs

The current design and development programme has a price tag of $1bn, of which $300m has so far been raised. Intel co-founder Gordon Moore has pledged $200m.

Lead organizations

The Association of Canadian Universities for Research in Astronomy, the California Institute of Technology and the University of California.

Scientific goals

The TMT will seek to shed light on the early universe, when the first heavy elements formed. Other key aims include studying small objects in the Kuiper belt (a region of the solar system beyond Neptune), the atmospheres of planets in our solar system, and the connection between supermassive black holes and galaxies.

Technology

The observatory will launch with wide-field optical, infrared imaging and infrared multi-object spectrometers. It will also have an integrated adaptive-optics system to correct for the blurring because of Earth's atmosphere. The science instruments will gradually be upgraded in the TMT's first 10 years to include other tools such as a high-resolution optical spectrometer and a wide-field infrared camera. All installed instruments will be mounted simultaneously and it will be possible to switch from one to another within 10 minutes. The current plan is for the observatory to eventually be fully equipped with nine instruments.

Top three facts

- If completed on schedule, the TMT will be the first operational "next-generation" telescope with a diameter bigger than 8 m.
- The TMT is designed to complement the future James Webb Space Telescope and the Atacama Large Millimeter Array (ALMA) by observing objects at different wavelengths and collaborating on long-term projects like galaxy-assembly studies.
- It will be more than 10 times as sensitive as current ground-based telescopes; perhaps even 100 times when using adaptive optics.

Timeline

2004: project office established
2007: site-testing review
2009: preliminary design review
2010: final design/construction readiness review
2018: first light with full primary mirror and first science output

Website

www.tmt.org

You have to maintain a genuine presence." The *ceremonia del pago* atop Cerro Toloncharwas but one in a series of events that Sanders said the TMT collaborators had with the Atacamans over the past few years. Some TMT scientists stayed in the region during site testing, and they expect to hold another such ceremony following the removal of the test telescope.

Meanwhile, the TMT collaboration found that Hawaii – a kingdom conquered by the US and annexed in 1898 where the self-determination of the indigenous population is on the rise – required even more interaction. Mauna Kea – the TMT's target Hawaiian location – is the prime real estate for telescopes there. Rising to 4200 m, Mauna Kea is the highest mountain in Hawaii and is surrounded by temperate ocean water, assuring clear and dust-free skies. There are already 13 instruments on the mountain, including the 8 m diameter Gemini North telescope, which might suggest that adding a 14th would not be a problem.

But Mauna Kea is the most sacred place in Hawaiian culture, deemed the meeting place of the Earth Mother and the Sky Father, and it is held "in trust" by the State of Hawaii for the Hawaiian people. Some Hawaiians regard it with such awe that they have no desire to climb it, regarding the view from below as the most sacred kind of encounter, which makes any alteration of its landscape all the more damaging. Furthermore, some Hawaiians think that permitting observatories to be built atop the mountain has not been positive. In return for its use in astronomy, the Hawaiians receive a paltry $1 a year, plus 10–15% of the observing time for astronomers at Hawaiian universities. Many Hawaiians find this little enough compensation, but that is not all.

The mountain has numerous shrines, and some families, following the birth of a child, still bury the afterbirth on its slopes. Defiled shrines and other insults have created some bad feeling towards the telescopes. One recent official environmental-impact statement referred to the impact of astronomy on Mauna Kea as "substantial, adverse, and significant". And the management process for the mountain, by the State of Hawaii, has been criticized as piecemeal, although a comprehensive 299-page management plan, which will affect the TMT process, was finally unveiled last month. As a result, several recent telescope projects planned for Mauna Kea have stalled or even cancelled. These include the $70m "Outrigger" interferometry project, which was to have consisted of an additional four to six telescopes at the Keck Observatory but that has been cancelled after delays due to community opposition driving up the cost. As the TMT team is discovering, opposition to further projects is rising regardless of the prospective benefits. The very concept of compensation is not recognized by some Hawaiians in the same way it is in most of the developed world. The TMT proposal has some local opponents who reject the value of any compensation, whether for universities or the local population. As one opponent of the telescope wrote, "Education benefits don't compensate for desecration."

The TMT planners therefore have had to do much more than fulfil the legal requirements that have sufficed in the past. They have had to assess the local views very carefully, engage in dialogue with many different community groups – for the community is not monolithic – and incorporate these views as much as possible into their plans. The TMT designers, for instance, installed test telescopes on concrete blocks rather than in the ground so that no soil was removed. And they relocated the instrument in a plateau below the summit ridge to make it less visible.

Good neighbours

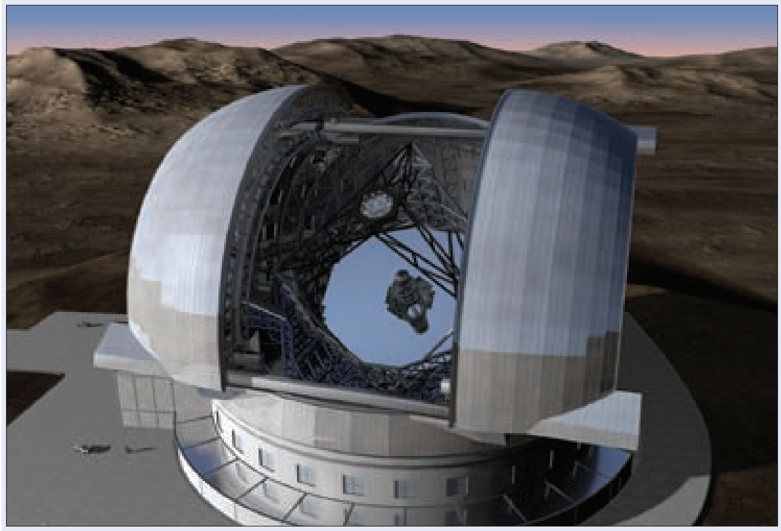
The degree of interaction between the TMT project team and its prospective neighbours is new for telescope builders. But these interactions have not come easily, for they run against the habits of hundreds of years. Astronomers tend to assume that everyone shares the same awe and love of the subject that they do, which can prevent them from recognizing the need to interact at all. "Everybody loves astronomy, right?" Sanders asks rhetorically. "Astronomy is good – an expression of our wonder and yearning for meaning, right? So you must be delighted if I want to put my telescope on your mountain, right?" He recalls one meeting in Hawaii at which an astronomer had described the telescope as cathedral-like, and was stunned when a community member said it looked instead like a white pimple. The first challenge is to get scientists to see that others do not view the telescope through the same eyepiece that they themselves do.

Another challenge crops up after a dialogue is initiated, when the power and privilege that scientists often bring to the table, thanks to their wealthy and well-positioned benefactors, can interfere with the discussions by creating resentment and resistance. Community groups that do not feel empowered may react negatively when they feel that the encounter is not between peers. "It's what happens when you come into the room to talk to the community and ignore the fact that the community may have had to worry about the fuel to get to the meeting tonight, or get a babysitter tonight – and you've got the power or privilege of the [US government] or Gordon Moore behind you, or Caltech or Harvard. It's not spoken perhaps, but it's in the room."

A third challenge is that the astronomers come to the table with their site already selected by a global process, feeling that they *have* to have *this* site – a potentially intimidating imperative. Finally, scientists are used to addressing technical issues, where a goal is clearly defined, while trust-seeking is a social issue that is less clearly definable. Sanders remembers another meeting in Hawaii at which an outraged citizen described the telescope as "the size of a football field". He recalls his heart sinking as he realized that the first thought forming in the head of many of his colleagues was a technical one: "No, no it's not – it's only as big as the Statue of Liberty!" The right reaction, he says, is not to focus on technical claims such as how big the telescope is – even when these claims are false – but to listen and respond to the social concerns of the people making them. That involves shifting from a technical mode of thinking that seeks to find what works to get what we want, to another that seeks to discover and address community concerns.

Yet this process also exposes projects to delays and even possible cancellation. "There's a tension here I just don't know how to resolve," says Sanders. "The

The European Extremely Large Telescope


ESO

The European Southern Observatory (ESO), which runs telescopes in Chile, has been working with astronomers from around Europe since 2005 on plans for their next large facility. The European Extremely Large Telescope (E-ELT) is the result of that collaboration. LP

Costs
About €100m for the design. Construction and instruments will cost about €1bn, with annual running costs of about €35m.

Site
Several options are being examined, including Argentina, Chile, Morocco and Spain.

Lead organization
European Southern Observatory

Scientific goals
The core aims of the E-ELT include studying the earliest stars and galaxies, and tracking down Earth-like planets in habitable zones around other stars. Astronomers also hope to directly measure the acceleration of the universe's expansion.

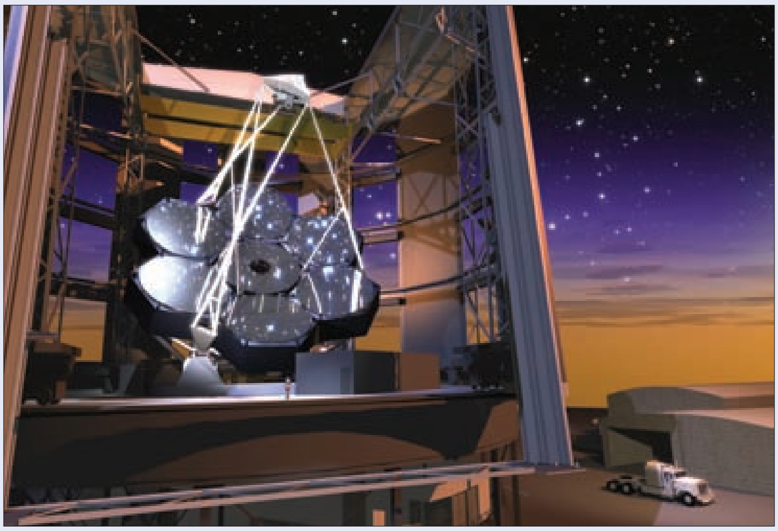
Technology
The primary mirror will be 42 m in diameter, made from 984 smaller segments that are each 1.45 m wide. The secondary mirror will be up to 6 m in diameter. A tertiary mirror will pass the light onto a comprehensive adaptive-optics suite, consisting of another two mirrors, one of which will be continuously shape-controlled by over 5000 actuators, thereby correcting for any blurring caused by the Earth's atmosphere. The E-ELT is sensitive enough to detect reflected light from Jupiter-like and potentially Earth-like planets, and will try to probe their atmospheres using low-resolution spectroscopy. It will even be able to detect water and organic molecules in gas clouds around stars, thus providing clues as to which planets may become habitable in the future. Two to three instruments such as diffraction-limited cameras and spectrographs will be ready for the observatory's opening, with a full range of instruments being installed over the subsequent decade.

Top three facts
- With its 42 m diameter mirror and light-collecting area of over 1200 m^2, the E-ELT will be the largest optical/near-infrared telescope in the world and will gather 15 times more light than any other telescope operational today.
- The E-ELT dome will be about as a big as a football stadium, being about 80 m high and having a diameter at its base of about 100 m.
- More than 30 European scientific institutes and hi-tech companies are taking part in the E-ELT design study.

Timeline
Late 2009: site to be chosen
Late 2010: decision to build
2011: foreseen start of construction
2018: start of operations

Website
www.eso.org/public/astronomy/projects/e-elt.html

The Giant Magellan Telescope



Giant Magellan Telescope, Carnegie Observatories

The Giant Magellan Telescope (GMT) will have a primary mirror consisting of six 8.4 m diameter individual segments surrounding a seventh central mirror, which will give it the same resolving power as a single mirror with a diameter of 24.5 m. The primary mirror is segmented in this way as there is no known method of manufacturing a single mirror of this large size. The GMT will be able to gather more than four times as much light as the biggest existing instruments can manage. LP

Site
Cerro Las Campanas in Chile. Famed for its clear, dark and crisp skies, the site is already home to the Magellan, Du Pont, Swope and Warsaw telescopes, so roads, water, power supplies and other infrastructure are already in place.

Costs
The current estimate is $700m. About $130m has been raised to date. Additional pledges requiring matching funds are also on the table.

Lead organizations
Astronomy Australia Limited, the Australian National University, the Carnegie Institution of Washington, Harvard University, the Korean Astronomical Space Sciences Institution, Smithsonian Astrophysical Observatory, Texas A&M University, the University of Arizona and the University of Texas at Austin.

Scientific goals
The GMT seeks to shed light on planets beyond our solar system, determine the nature of dark matter and dark energy, study the origin of chemical elements and investigate the growth of black holes. It will operate at visible, near- and mid-infrared wavelengths.

Technology
The GMT's mirror will be made from borosilicate glass – a material that can be easily moulded into the correct shape, keeps its form even when hot or cold, and is relatively inexpensive. Each mirror is designed to have a honeycomb structure consisting of 1681 cores with a mass one-fifth that of a solid mirror of the same size. The GMT will use adaptive optics to correct for the blurring effects of the Earth's atmosphere.

Top three facts
- The GMT will produce images up to 10 times sharper than those obtained by the Hubble Space Telescope.
- The hi-tech dome features two large shutters that can also be used to block the wind and provide shade from the Moon.
- An extra mirror will be built so that the telescope can still be operational even when one mirror is being recoated.

Timeline
2003–2006: conceptual design
2007–2011: design development
2011–2018: construction and commissioning
2018: science operations

Website
www.gmto.org

tension is between the need to build an expensive project that is schedule- and resource-driven, and the need to establish long-term trust with a community of humans. But establishing trust is not something that you can schedule. Nobody knows how to write down the steps for it. And the trust has to be durable because the project will create a thing that will be a continuing presence in the community." Indeed, the TMT project is discovering that the technical suitability of its candidate sites may ultimately not be the deciding factor, and that social challenges will play a significant role in the process. The scientists may well not get their first pick of a site, so they need carefully planned alternatives.

A question of trust

For over six decades, large scientific-technological projects have been prone to the dream that the optimal way to carry them out is to insulate the project from the public, just as with the Manhattan Project during the Second World War. This dream in effect separates the technical and social sides of a project, giving the former to the scientists and the latter to the politicians. While that approach was fine for both groups as long as the politicians could adequately support such projects, such backing is no longer guaranteed.

Nuclear scientists and engineers have long been aware of the need to address community and environmental issues, and the Achilles heel of such projects is nuclear-waste disposal. More recently, accelerator builders have discovered the importance of social issues – one vulnerable aspect of these projects being the fear, however misguided, that they might produce black holes. Now, as the TMT experience reveals, even seemingly benign instruments such as telescopes may encounter social issues – and when they do, it will not suffice simply to try to rekindle a sense of wonder and awe for astronomical research. Astronomers will also have to appeal to something still deeper: common cultural cause between telescope builders and members of the affected communities.

This is sufficiently beyond the scope of traditional scientific management that the US National Science Foundation has sponsored Sanders to teach an annual three- or four-day workshop, called Project Science, on managing big-science projects. In it, Sanders discusses relevant social-science literature and case studies of past, current and emerging projects. One might call this new dimension "project architecture", in analogy to the way that engineers focus on a building's construction while architects add the additional element of catering to the interface between it and the surroundings. Project architecture requires paying attention to how the development fits in with the surroundings, which will require learning more about such things as achieving sensitivity, earning trust and developing responsiveness to the concerns of community groups.

For hundreds of years, the principal difficulty in building telescopes was compensating for atmospheric distortion, a technical problem now largely solved by adaptive optics. As Sanders is discovering, the potential show-stoppers of the 21st century also include social challenges on the ground, involving factors that scientists are less familiar with, notably community dialogue and trust.

Into the deep

Showing the universe as it was between 400 and 800 million years after the Big Bang, the Hubble Ultra Deep Field penetrates further back into the history of the universe than any other image in the visible-frequency range. It reveals the first galaxies to emerge from the “dark ages” when the first stars reheated the cold, dark universe. The image was obtained by the Hubble Space Telescope in an exposure from 24 September 2003 through to 16 January 2004 of the constellation Fornax. This is a part of the sky with a very low density of bright stars in the near-field, which allows much better detection of the dimmer, long-distance, objects. The patch of sky used by Hubble is the equivalent of about one-tenth of the full diameter of the Moon as viewed from the Earth. The image contains an estimated 10 000 galaxies.

The Galileo affair

Maurice A Finocchiaro discusses the lessons and the cultural repercussions of Galileo's telescopic discoveries

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In June 1609 Galileo Galilei heard about an optical instrument invented in Holland the year before, consisting of an arrangement of lenses that magnified images three to four times. Despite not having a prototype in his possession, he was soon able to duplicate the instrument, mostly by trial and error. He was also able to increase its magnifying power first to nine, then to 20, and, by the end of the year, to 30. Moreover, rather than merely exploiting the instrument for practical applications on Earth, he started using it to make systematic observations of the heavens to learn new truths about the universe.

Within three years Galileo had made several startling discoveries. He discovered that the Moon had a rough surface full of mountains and valleys. He saw that innumerable other stars existed in addition to those visible with the naked eye. He found that the Milky Way and the nebulae were dense collections of large numbers of individual stars. The planet Jupiter had four moons revolving around it at different distances and with different periods. The appearance of the planet Venus, in the course of its orbital revolution, changed regularly from a full disc, to half a disc, to crescent, and back to a half and a full disc, in a manner analogous to the phases of the Moon. And the surface of the Sun was dotted with dark spots that were generated and dissipated in a very irregular fashion and had highly irregular sizes and shapes, like the clouds above the Earth; while they lasted, these spots moved in such a way as to imply that the Sun rotated on its axis with a period of about one month.

Many of these discoveries were also made independently by others; for example, lunar mountains were also seen by Thomas Harriot in England, and sunspots by Christoph Scheiner in Germany. However, no-one understood their significance as well as Galileo. Methodologically, the telescope implied a revolution in astronomy, in so far as it was a new instrument for the gathering of new kinds of data, vastly transcending the previous reliance on naked-eye observation. Substantively, these discoveries provided a crucial, although not conclusive, confirmation of the Copernican hypothesis of the Earth's motion. To understand the latter, some background is needed.

The Copernican revolution

In 1543 Copernicus had published a book elaborating a world system the key point of which was that the Earth rotates on its own axis daily and revolves around the Sun yearly. Copernicus's accomplishment was to give a new argument supporting an old idea that had been almost universally rejected since the ancient Greeks. He demonstrated that the known facts about heavenly motions could be explained in quantitative detail if the universe is a heliocentric system where the Earth revolves around the Sun (the geokinetic hypothesis); and that this explanation was more coherent (and simpler and more elegant) than the geostatic account.

However, the Copernican revolution required much more than this argument. The geokinetic hypothesis had to be supported not only with new theoretical arguments, but also with new observational evidence. The telescope provided such novel evidence. For example, lunar mountains and sunspots showed that there were significant similarities between the Earth and the heavenly bodies. This refuted the traditional doctrine of the Earth–heaven dichotomy; and so it became possible for the Earth to be a planet, i.e. located in "heaven". The satellites of Jupiter showed that it was physically possible for one body to revolve around another, while the latter revolved around a third; and hence it became possible for the Earth to revolve around the Sun while the Moon revolved around the Earth. And the phases of Venus proved the heliocentricity of its orbit, thus confirming this particular element of the Copernican system.

Moreover, the Earth's motion had to be not only constructively supported with new arguments and evidence, but it also had to be critically defended from a host of powerful old and new objections. These objections were based on astronomical observation, Aristotelian physics, scriptural passages and traditional epistemology. For example, according to Aristotelian physics, the natural state of bodies was rest and a constant force was needed to keep a body in motion; thus, supposedly, bodies on a rotating Earth could not fall vertically, as they are seen to do. And according to the scriptural passage in Joshua 10:12–13, God miraculously stopped the diurnal motion of the Sun to prolong daylight, so that Joshua could lead the Israelites to victory before nightfall. Galileo answered the astronomical objections by showing that the observational consequences implied by Copernicanism were indeed visible with the telescope, although still invisible with the naked eye. He answered the physical objections by articulating a new physics centred on the principles of conservation and composition of motion. And he answered the biblical objections by arguing that Scripture is not a scientific authority, and so scriptural passages should not be used to invalidate astronomical

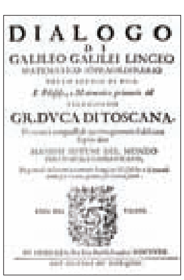
> Galileo's key contribution to the Copernican revolution was a successful defence of Copernicanism guided by the ideals of critical-mindedness, open-mindedness and fair-mindedness

National Maritime Museum, Greenwich, London

Telescopic vision
Galileo did not invent the telescope, but he did pioneer its use for astronomy.

Heavenly visions
The telescope Galileo used from 1609 onwards to make systematic observations of the skies.

Gianni Tortoli/Science Photo Library



Science Photo Library

Controversial consequences
Galileo's 1632 *Dialogue on the Two Chief World Systems* led him to be condemned by the Church as a heretic.

claims that are proved or provable.

Finally, the defence of heliocentrism required not only the destructive refutation of these objections, but also the appreciative understanding of their strength. Galileo was keen on this, and so in his writings we find the anti-Copernican arguments stated more clearly and incisively than in the works of advocates of geocentrism.

However, Galileo also realized that his case in favour of Copernicanism was not absolutely conclusive or decisive. Some counter-evidence remained, since, for example, his telescope failed to reveal an annual parallax of the fixed stars.

In short, Galileo's key contribution to the Copernican revolution was to elaborate a successful (although not definitive) defence of Copernicanism that stressed argumentation and observation judiciously guided by the ideals of critical-mindedness, open-mindedness and fair-mindedness.

Galileo's trial

As is well known, however, Galileo's efforts were hindered by the Catholic Church. In fact, the trial of Galileo can be interpreted as a series of ecclesiastic attempts to stop him from defending Copernicus. In 1616 the Church's department of book censorship decreed that the geokinetic doctrine was contrary to Scripture, and this decree amounted to a general prohibition on defending Copernicanism from scriptural objections. Furthermore, Cardinal Robert Bellarmine warned Galileo to cease defending the Earth's motion – a warning that amounted to a personal prohibition on defending Copernicus from an astronomical, scientific and philosophical point of view. In 1633, after a formal trial, the Inquisition condemned Galileo as a suspected heretic for defending the geokinetic hypothesis and denying the astronomical authority of Scripture. He had done these things implicitly, indirectly and probably in his *Dialogue on the Two Chief World Systems, Ptolemaic and Copernican* (1632), which was a critical discussion, examining the arguments on both sides, showing that the geokinetic arguments were stronger than the geostatic ones, implying that Copernicanism was probably true, and thus defending it in that sense.

The condemnation of Galileo in turn generated a more protracted, complex and polarized controversy that is still ongoing. However, I believe these complexities can be simplified, without oversimplification.

At first, various questions were raised about the physical reality of the Earth's motion; but gradually, historians of science established incontrovertibly that Galileo was right on this issue. As this realization emerged, questions began to be raised about whether his supporting reasons, arguments and evidence had been correct; that is, whether he had been right for the wrong reasons. This is an instructive issue, but Galileo's reasoning can be defended from this criticism. For some time, he was also criticized for his hermeneutical principle that Scripture was not a scientific authority; but history vindicated Galileo in this regard too, at least from the viewpoint of the official position of the modern Catholic Church, which was promulgated in 1893 by Pope Leo XIII in the encyclical *Providentissimus Deus*. However, before this theological vindication, the myth spread that Galileo had been condemned for being a bad theologian, namely for preaching and practising the use of Scripture to support astronomical claims (i.e. the opposite of what he actually did); it took the whole 19th century before this myth was dispelled. In any case, on the hermeneutical issue too, it is important to check the correctness of his argument to justify that Scripture is not a scientific authority; although this Galilean reasoning has been the target of many objections, I believe it can be defended from them.

As it became increasingly clear that Galileo could not be validly convicted of being a bad scientist, a bad theologian or a bad logician, he started being blamed for other reasons. Some authors began to stress the legal situation, charging that he was guilty of disobeying the Church's 1616 admonition regarding Copernicanism. However, if this admonition is interpreted as a prohibition on mere discussion, the existence of such a special injunction is undermined by the record of the trial proceedings, first published in 1867–1878. These records include only one document stating that Galileo was forbidden to even discuss the topic, but this document is highly irregular in several respects, whereas there are several more reliable relevant documents that say nothing about such a strict prohibition, although they should have mentioned it if it had occurred. On the other hand, if the admonition is taken as a prohibition on defending Copernicanism, nobody denies its existence, but the issue reduces to whether such a prohibition was legitimate, and if it was, whether Galileo's defence was scientifically and logically fair and valid.

Finally, there is the issue of whether Galileo should be credited or blamed for helping us understand that science and religion are in conflict or that they are in harmony, as the case may be. The resolution of this issue requires that we admit three crucial things. First, the original affair featured an historical conflict between those who affirmed and those who denied that Copernicanism contradicted Scripture; and the irony is that it was Galileo who denied the conflict and the Church officials who advocated it. Second, the original affair epitomized more the conflict between cultural conservation and innovation than the conflict between science and religion; this is the case because there were many clergymen who sided with Galileo and many scientists who sided with the Church, which means that there was an internal split within both the Church and science. Third, in the subsequent four centuries the original affair was usually perceived (rightly or wrongly) as epitomizing the conflict between science and religion; thus, the most essential feature of the subsequent controversy is indeed the science versus religion conflict.

The two cultures

The controversy shows no signs of abating to this date. This is obvious not only from the recent rehabilitation efforts by the Catholic Church, but also from the recent anti-Galilean critiques by left-leaning social critics.

For example, in 1942, the tricentennial of Galileo's death, there was the first partial and informal rehabilitation. In the years that followed, this was done by several clergymen who held *the* top positions at the Pontifical Academy of Sciences, the Catholic University of Milan, the Pontifical Lateran University in Rome, and the Vatican Radio. They published accounts of Galileo as a Catholic hero who upheld the harmony between science and religion, who had the courage to advocate the truth in astronomy even against the Catholic authorities of his time, and who had the religious piety to retract his views outwardly when the 1633 trial proceedings made his obedience necessary.

In 1979 Pope John Paul II began a further informal rehabilitation of Galileo that was not concluded until 1992. In two speeches to the Pontifical Academy of Sciences, and in other statements and actions, the pope admitted that Galileo's trial was not merely an error but also an injustice. The pope also declared that Galileo was theologically right about scriptural interpretation, as against his ecclesiastical opponents; that even pastorally speaking, his desire to disseminate novelties was as reasonable as his opponents' inclination to resist them; and that he provides an instructive example of the harmony between science and religion.

At about the same time that Galileo was being rehabilitated by various Catholic officials and institutions, he became the target of unprecedented criticism on the part of various representatives of secular culture. It was an unexpected reversal of roles, with his erstwhile enemies turning into friends and his former friends becoming enemies. These critics elaborated what might be called social and cultural criticism of Galileo; that is, they tried to blame Galileo by holding him personally or emblematically responsible for such things as the abuses of the industrial revolution, the social irresponsibility of scientists, the atomic bomb, and the rift between the two cultures. They were mostly left-wing writers. Chief among them were the German playwright Bertolt Brecht, whose play *Galileo*, written in 1938, became a classic of 20th-century theatre; Arthur Koestler, who wrote the 1958 bestselling book *The Sleepwalkers: A History of Man's Changing Vision of the Universe*; and Paul Feyerabend, the Austrian-born philosopher, who advanced his version of social criticism in a book entitled *Against Method*, first published in 1975.

Science Photo Library

Science on trial
Galileo was put on trial by the Catholic Church over his views supporting Copernican astronomy.

These developments have not been properly assimilated yet. For example, the Catholic "rehabilitations" tend to be either unfairly criticized (even by Catholics) or uncritically accepted (even by non-Catholics). And the left-leaning social critiques tend to be summarily dismissed by practising scientists, whose professional identity is thereby threatened, or dogmatically advocated by self-styled progressives, who seem not to have learned much from Galileo and to want to turn the clock back to pre-Galilean days. I believe this controversy is likely to continue for the foreseeable future.

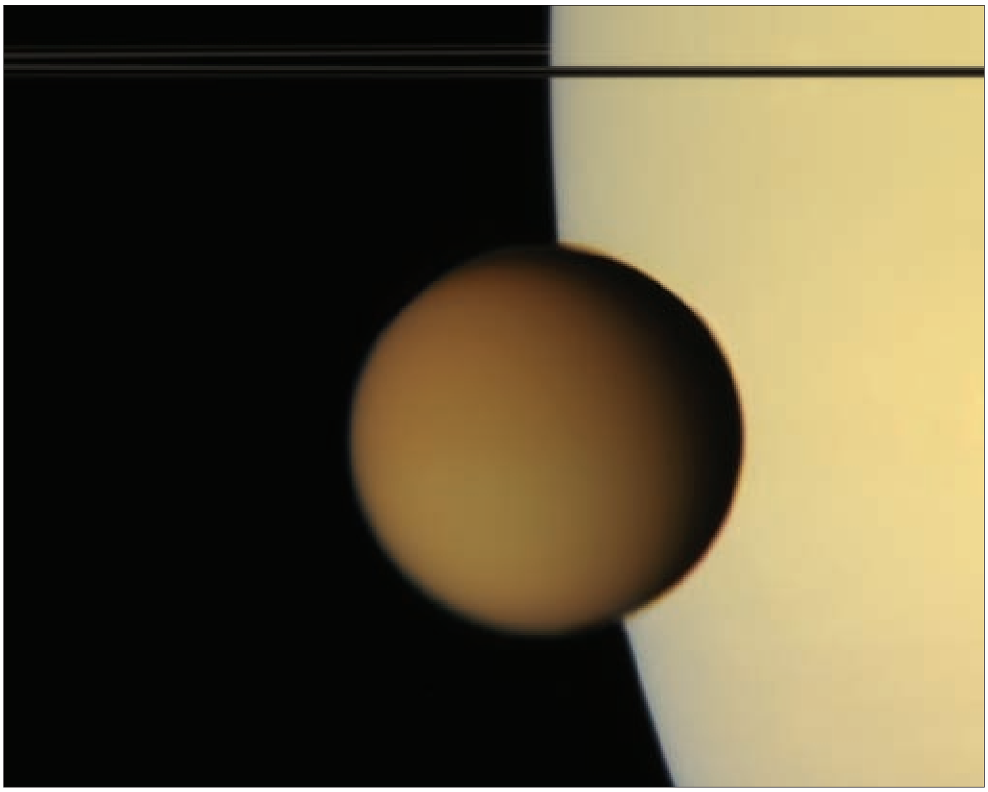
Nevertheless, I believe I have devised a framework that paves the way for coming to terms with the controversy and eventually resolving it. In my approach, one interprets the controversy in terms of arguments for and against the rightness of Galileo's condemnation; one displays towards these arguments the same attitude that Galileo displayed towards the arguments for and against the Earth's motion; and the key elements of this Galilean attitude (labelled critical-mindedness, open-mindedness and fair-mindedness) are to know and understand the arguments against one's own view and appreciate their strength before refuting them. In short, my overarching thesis is that today, in the context of the Galileo affair and the controversies over science versus religion and over institutional authority versus individual freedom, the proper defence of Galileo should have the reasoned, critical, open-minded and fair-minded character that was also displayed by his own defence of Copernicus.

These are some of the cultural repercussions and lessons of the telescopic discoveries that Galileo began making in 1609. And such are, in part, the challenges and opportunities of the quatercentenary of their occurrence.

Reviews

Agustin Chicarro

A pale orange dot



NASA

A world unveiled
Titan as viewed by the Cassini orbiter, with Saturn in the background.

Titan Unveiled
Ralph Lorenz and Jacqueline Mitton
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£17.95/$29.95hb
296pp

The first planetary satellites (other than our own Moon) were discovered by Galileo Galilei in 1610. These were the four largest moons of Jupiter: Io, Europa, Ganymede and Callisto. Christiaan Huygens followed suit in 1655 by discovering Titan, Saturn's largest satellite; a few years later, Giovanni Cassini was the first to observe several of Saturn's smaller moons, as well as the main gap in its rings. It is Titan that stands out, however. Called at first "Luna saturni" and only given its modern name by John Herschel in 1848, Titan is the most massive satellite in the solar system. With a diameter of 5151 km, it dwarfs the other 60-odd moons of Saturn, and is even larger than the planet Mercury.

Modern studies of Titan began in 1944 with Gerard Kuiper's discovery that it has a nitrogen and methane atmosphere. More recently, NASA's Voyager 1 spacecraft flew within a few thousand kilometres of Titan in 1980 on its way out of the solar system. This fantastic journey captured scientists' imagination and paved the way for the Cassini–Huygens mission. This joint venture between NASA and the European Space Agency was launched in 1997 to study the Saturnian system and Titan in particular. The results of this mission are the main subject of *Titan Unveiled*, by Ralph Lorenz and Jacqueline Mitton.

The orbiter component of the mission, Cassini, went into orbit around Saturn on 1 July 2004, and is equipped with a radar system capable of penetrating Titan's thick atmosphere to map its surface in detail. The Huygens landing probe was designed to investigate Titan's atmosphere during its two-hour descent to the moon's surface. After landing on 25 December 2004, it analysed Titan's surface for about two hours before succumbing to the harsh conditions there.

> Titan is an active body with a young surface that mimics an array of terrestrial features

The orbiter mission is still ongoing, keeping hundreds of scientists and engineers from all over the world busy. Breathtaking data have been gathered by both the orbiter and the lander, showing that Titan is an active body with a young surface that mimics an array of terrestrial features. We can observe dunes, rivers and large lakes of liquid methane and ethane from orbit, while images of the landing site show large pebbles made of methane ice. In addition to an overall flat surface, methane clouds have been identified in the southern hemisphere beneath a thick global atmospheric haze. Carl Sagan famously referred to the Earth as a "pale blue dot"; by analogy, we can think of Titan as a "pale orange dot" in space.

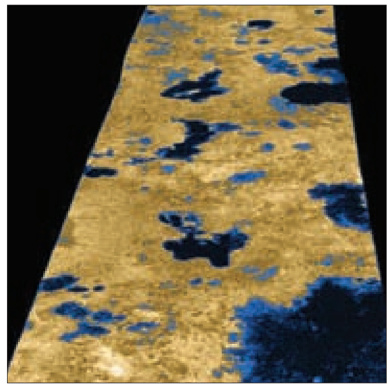
Beyond the glamour of exploration, the importance of these scientific results lies in this hydrocarbon world being a laboratory for organic processes, similar to those that are known to have taken place in the early Earth as a prelude to the evolution of life itself. Titan thus opens up a window on our own past.

Titan Unveiled can be seen as a follow-up to another book by the same authors, *Lifting Titan's Veil*, which was published in 2002 and focused on the Cassini–Huygens mission before its arrival at Saturn. Lorenz is one of the mission scientists, and his experiences in developing one of the lander experiments, working on both sides of the Atlantic, make him uniquely qualified to take us behind the scenes. Mitton is a full-time writer and media consultant specializing in astronomy.

Titan Unveiled starts with an account of the astronomical discoveries of Titan in the past (particularly in the decade preceding Cassini–Huygens), continues with the development of the mission and closes with a summary of its most relevant results. The mission is described in great detail, including its arrival at the Saturnian system, the descent through Titan's atmosphere, the probe's landing and the various orbiter fly-bys.

The atmosphere and surface processes are featured prominently in this exciting account. For example, we learn that Titan's atmosphere, like that of Venus, contains a "super-rotation" mechanism: the bulk of the atmosphere rotates much faster than the solid moon spins on its axis, with a "quiet" (i.e. slower-rotating) layer about 70 km above the surface. The book also discusses some early theories about Titan that were subsequently proved incorrect, such as the expectation that its atmosphere would contain some noble gases like krypton and xenon, and looks at how we can explore Titan further in the future.

As an active participant in the mission, Lorenz provides an intimate account of this unique adventure. The text combines a lively narrative with a non-technical description of the mission and a summary of the main results, peppered with personal accounts throughout. The drawings and photographs are particularly outstanding.



NASA

Lab for life? Lakes of methane on Titan's surface could host organic processes like those that preceded life on Earth.

Titan Unveiled is highly recommended to the intellectually curious general public, as well as to the most seasoned planetary scientists and engineers. In fact, anyone with an interest in science, astronomy, planetary science and exploration, engineering or the evolution of our own planet will find this book captivating and uplifting. Landing on Titan has been one of the greatest adventures of the current decade; in the words of the authors, "planetary exploration gives us a sense of perspective, a notion of who we are, where we came from and what our destiny might be".

This new field of comparative planetology is at the forefront of human endeavour, and will help us unravel the mysteries of the solar system's origin and evolution. Thanks to the mission described in this book, Titan can be viewed together with other large, rocky objects in our solar system – the Moon, Mars, Mercury, Venus and of course the Earth – as another completed piece of the planetary puzzle. It has finally revealed its well-kept secrets.

Agustin Chicarro is project scientist on the European Space Agency's Mars Express mission, e-mail achicarr@rssd.esa.int

Web life: *Cosmic Diary*

URL: www.cosmicdiary.org

What is it?
Cosmic Diary brings together a smorgasbord of blogging astronomers from around the world, with more than 50 contributors commenting on new discoveries and long-standing questions in astronomy – as well as offering insights into their ordinary working lives and outside interests. The site is sponsored by the International Astronomical Union and UNESCO, and it is one of 11 "cornerstone projects" of the International Year of Astronomy 2009 (IYA2009).

Who writes the blogs?
Contributing authors range from Aude Alapini, a Belgian/Beninese astrophysics PhD student at the University of Exeter in the UK, to Brother Guy Consolmagno, curator of meteorites at the Vatican City Observatory. They are a truly international bunch, with over 30 countries and five continents represented, and most are in the early or middle stages of their careers, with a median age of just under 40. Almost half are women, a statistic that reflects a key goal of IYA2009, which is to support and promote women in astronomy. There are a few familiar names, including Alan Hale, co-discoverer of the comet Hale–Bopp (and now head of the Earthrise Institute, which promotes the use of space and astronomy as a bridge between cultures). But most are relative unknowns outside their field.

What topics do the blogs cover?
Some bloggers have chosen to focus on their own research and outreach work, while others offer an inside look at the "glamorous" life of an itinerant observer as they travel between their home institutions, conferences and telescope sites. Several writers have used *Cosmic Diary* to post their favourite photos of stars and galaxies, and many contain posts on news stories, astronomy-related or otherwise, including the inauguration of US President Barack Obama. A few bloggers from the developing world – such as Rogel Sese of the Philippines – have written about the challenges of doing astronomy in their home countries.

Who is it aimed at?
The project's guidelines call for writers to use "easy-to-understand language to translate the nuts and bolts of their scientific research into a popular-science article". Hence, the biggest beneficiaries of this mega-blog are likely to be non-astronomers working both within science and outside it. However, if you are looking for more technical details, do not give up – over the course of the year, each blogger will also write a "feature" article explaining their research in greater depth. Given the blog's international flavour, it is worth noting that all entries are written in English, although several authors have elected to translate entries into their native languages as well.

How often is the blog updated?
A fair number of those involved in *Cosmic Diary* are new to blogging, and several have taken to it with the zeal of converts, posting a dozen or more entries in January alone. At the other end of the scale, a few blogs still contained no entries over a month into IYA2009 – although one of the latecomers, Serbian astrophysicist Tijana Prodanovic, made up for lost time with a humorous post about how holidays in her country follow the older Julian calendar, and hence IYA2009 did not *really* begin until 14 January.

Any advice on navigating through all these blogs?
Excerpts from the five most recent posts occupy the top half of the site's main page, so it is easy to see at a glance who has updated their blog on any given day. Meanwhile, a sidebar contains links to blogs by authors who work for big organizations like the European Southern Observatory and the Japanese Aerospace Exploration Agency. This might be useful for readers who want to keep track of particular projects via the blog. The division between these blogs and the remaining "unaffiliated" ones can make flipping between entries confusing, however.

● You can also read the latest posts from *Cosmic Diary* at *physicsworld.com*

John Steele

Ancient astronomy revealed

Tony Freeth/Antikythera Mechanism Research Project

In a spin
A computer model of the dials from the Antikythera Mechanism.

Decoding the Heavens: Solving the Mystery of the World's First Computer
Jo Marchant
2008 William Heinemann
£12.99/$25.00hb
336pp

In the autumn of 1900 a team of sponge divers from the small Greek island of Symi, just north of Rhodes, made one of the most spectacular underwater discoveries of modern times. After being blown off course on their journey back to Symi from the southern Mediterranean sponge-fishing grounds, they sheltered near the island of Antikythera, located between the southern tip of the Greek mainland and the north-west corner of Crete. When the winds died down, the team's captain, Dimitrios Kontos, decided to send the divers down in the hope of adding some final sponges to their catch. Instead, Elias Stadiatis, the first diver into the water, spotted a shipwreck on the sea bed.

The wreck turned out to be a Roman ship from the first century BC. While its discovery was interesting enough in itself, its cargo was more important still: a collection of some of the finest statues of marble and bronze from ancient Greece that have yet been found. Interest surrounding their discovery was intense, and the statues were brought to the surface and taken to the National Archaeological Museum in Athens.

But although it went more or less unregarded at the time, the most important discovery of all was a small lump of bronze and wood that was also taken to the museum. On closer inspection, this was revealed to be a geared device for calculating astronomical phenomena such as eclipses and the passage of the Moon through the zodiac. Today, the device is known as the "Antikythera Mechanism".

In *Decoding the Heavens*, Jo Marchant tells the fascinating story of the Antikythera Mechanism and the people who have gradually figured out what it is and how it worked. Marchant was a science journalist at *Nature* in 2006 when the Antikythera Mechanism Research Project (AMRP) – an international collaboration between researchers from Greece, the UK and the US – published a paper in that journal on the reconstruction of the mechanism (**444** 587). Marchant wrote a news story to accompany the paper, and her book – an accessible and highly engaging account of studies of the mechanism since its discovery – grew out of this early involvement.

The Antikythera Mechanism was used to calculate astronomical phenomena such as eclipses

The Antikythera Mechanism was built sometime in the late second or early first century BC. Who built it is not known, but it seems likely that it was constructed for use in the western part of the Greek world, possibly in Syracuse. Perhaps half of the device is preserved today, split into seven largish fragments and more than 70 smaller pieces. A complex arrangement of gearwork turned by a handle on the side drove pointers on three dials. One dial on the front tracked the motion of the Moon through the zodiac, while two on the back indicated the current month in a calendrical cycle of 235 months (known as the Metonic cycle) and an eclipse cycle of 223 months (the Saros cycle). It is possible that other pointers on the front dial gave the positions of the five planets known to ancient astronomy: Mercury, Venus, Mars, Jupiter and Saturn.

Marchant's book explains clearly the current understanding of how the mechanism worked. She does an admirable job of describing the complexities of epicyclic gearing and what it represents. But the real highlights are her accounts of the individuals who have studied the mechanism since its discovery. These include Derek de Solla Price, a British physicist and subsequently a historian of science at Yale University who published the first detailed attempt at reconstructing the mechanism in 1974. We also learn about Michael Wright, a curator at the Science Museum in London, and his Australian computer-scientist colleague Allan Bromley, who together identified several flaws in Price's reconstruction and made crucial breakthroughs in understanding the mechanism from the 1980s to today. Finally, we get the story of Tony Freeth and his collaborators in the AMRP, who have provided a full reconstruction of this unique artefact of ancient science.

The various trials and tribulations of these scientists provide compelling material for telling how the original design and purpose of the mechanism were gradually uncovered. Everything is here, from personal problems (betrayal by collaborators, job loss, marital break-up) to practical difficulties like faulty equipment and intransigent officials. There is even an amusing (although not at the time!) anecdote about whether a giant computed-tomography machine built by the UK-based firm X-Tek could actually be manoeuvred through the streets of Athens and into the National Archaeological Museum to examine the mechanism, after it had been transported all the way from Hertfordshire to Greece. (It could. Just.)

Marchant convincingly portrays the excitement and tension felt by everyone (including me) at a conference in Athens in 2006 where the AMRP announced its results. The size and composition of the conference audience – which included historians of ancient science from many countries, more than 20 representatives of the world's media and almost 500 members of the general public – reflected the intense interest generated by the project.

Decoding the Heavens was published in October 2008, so Marchant was able to include a few final remarks on the results published in the ARMP's second *Nature* paper, which appeared in July 2008 (**454** 614). These include the remarkable discovery that a subsidiary dial within the upper back dial pointed to each year in a four-year cycle tied to the important athletic competitions in the Greek world – top among which were the ancient Olympic Games.


Antikythera Mechanism Research Project

Greeks bearing gears Computed-tomography imaging of this fragment of the mechanism revealed 27 separate cogs.

The strengths of Marchant's book are those she brings as a professional science writer. It is a lively and engaging account, almost addictive reading. But the book is not without its flaws, and there are several inaccuracies in the attribution of discoveries to modern scholars. To give an example, I am credited with the discovery of why the lower back dial, which predicted eclipse possibilities, is made up of four spirals, but this finding was made by Freeth. Perhaps such errors are unavoidable, but it is particularly unfortunate as work on the Antikythera Mechanism has become highly competitive. As Marchant portrays in her book, incorrect attributions can easily become sore points between competing researchers.

Overall, however, the author has done a fine job in writing an accessible and enjoyable book that, despite its faults, will open up the world of the Antikythera Mechanism to a wider audience. Readers should, however, head the warning from Freeth, who started out just planning to make a film about the mechanism in the late 1990s but has ended up as the primary researcher in the AMRP: interest in the Antikythera Mechanism can become an addictive occupation!

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Between the lines: astronomy special

Probing the skies
The Yerkes Observatory houses the world's largest refracting telescope.

Telescopes on parade

We all know that telescopes – from backyard Newtonian reflectors to sophisticated space-borne instruments – are the *sine qua non* of modern astronomy. The evolution of their design in the 400 years since Galileo Galilei first put his eye to the lens will be familiar to many, but anyone wanting a refresher course on telescope history will find *Eyes on the Skies* an illuminating guide. Written by science communicators Govert Schilling and Lars Lindberg Christensen in honour of the International Year of Astronomy (IYA2009), the book begins with a brief overview of 17th- and 18th-century astronomy, including some fascinating titbits on two Englishmen, surveyor Leonard Digges and astronomer Thomas Harriot, who may have pipped Galileo to the post in building telescopes and using them for astronomy. A section on the first "golden age" of big telescopes describes some of the technical challenges that began to limit their sizes – first of refracting instruments like the University of Chicago's giant 40-inch Yerkes Telescope, built in 1893 and still the largest of its type, and later of reflectors like the one at Mount Palomar in California. The book concludes with a look at future projects like the European Extremely Large Telescope (see pp46–50) that could reshape our image of what a "telescope" looks like. This beautifully illustrated book is a companion to another IYA2009 publication that focuses on what all these telescopes allow us to see. *Hidden Universe* (also written by Christensen, with astronomer Bob Fosbury and visualization scientist Robert Hurt) describes a journey through different "slices" of the electromagnetic spectrum. Their story of how different telescopes have peeled away layers of the "cosmic onion" offers a useful counterpoint to the history of the telescopes themselves.

● 2009 Wiley £16.99/$29.95hb 146pp; £16.99/$29.95hb 132pp

Scientific sleuthing

Fluctuations in the cosmic microwave background are stretch marks from the birth of the universe. Gravity explains why stars are not ejected from spinning galaxies "like contestants on *Indian Idol*". And scientists are cosmic detectives, always trying to figure out the who's, what's, when's and perhaps even the why's of the universe. Such is the picture presented in *The Cosmic Detective: Exploring the Mysteries of Our Universe*, by physicist Mani Bhaumik. The author's own story – born in rural Bengal during the struggle for Indian independence, he became a laser physicist in the US and is now a prominent science popularizer – makes a few cameo appearances, and longtime devotees of popular-science books may find it more compelling than the book's narrative on how the universe was formed. The book's main audience, however, will be readers who are old enough to find science picture-books unsatisfying but are not yet ready to tackle more complex works (like Steven Weinberg's *The First Three Minutes*) that cover similar material. For them, Bhaumik's lively prose and engaging analogies make an excellent introduction to modern cosmology.

● 2009 Puffin Rs 199 92pp

For all eyes only

If all this talk about astronomy has inspired you to do some observing of your own, there a lot of books out there to help – so many, in fact, that a comprehensive review is out of the question. However, two well-timed new entries into this crowded field are worth considering. *Stargazing Basics: Getting Started in Recreational Astronomy* presents a brief primer on the equipment used by amateur astronomers, its limitations, and how to decide what (if any) new kit you should buy. Author Paul Kinzer is an amateur astronomer himself, and clearly familiar with the challenge of selecting from the dizzying range of possibilities. He wisely avoids recommending particular models, as specific suggestions will quickly become outdated. Instead, the book offers tips on telling flashy but poor-quality features from those that will enhance an evening's stargazing. Perhaps surprisingly, Kinzer argues that bigger and more expensive telescopes are not always better. Indeed, a good pair of binoculars will let you see more than 100 000 stars (compared with a few thousand with the naked eye), and they are better than telescopes for viewing objects like the Moon and the Andromeda galaxy.

● 2008 Cambridge University Press $19.99/£11.99pb 160pp

Sky guide

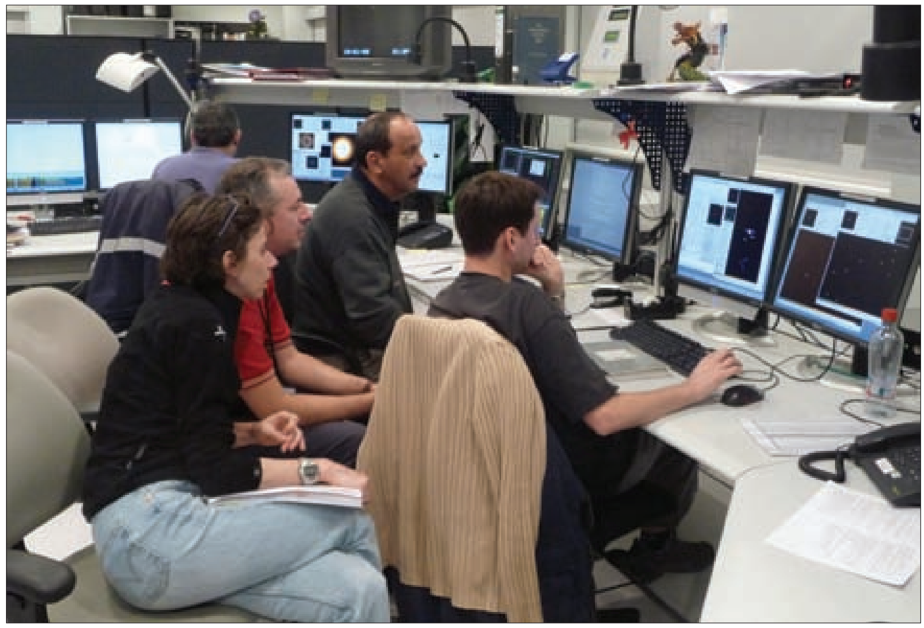
Observing the Night Sky with Binoculars builds on this theme, offering a month-by-month guide to stars and other objects visible in the northern hemisphere. Stephen James O'Meara's text describes what you can see in particular constellations – and in some cases, like the black-hole candidate Cygnus X-1, what you cannot. He also includes some of the mythical lore that has grown up around these patterns during a long history of observing. This aspect of the book will be most useful when planning a night's viewing in advance, as the text is too long to read comfortably with a red-filtered torch (the filter helping to preserve night vision). However, simple star charts and pictures of nebulae allow the book to double as a valuable supplement to the many free star charts or "planispheres" available online.

● 2008 Cambridge University Press $34.99/£19.99pb 168pp

Careers

Living life on 'Mars'

The quest for clear, dark skies has led astronomers to build telescopes far away from the lights and smog of modern civilization, but what is it like to live and work in such places? **Elena Mason** describes her career at one of the world's most remote observatories



All in a night's work Elena Mason (left) commissioning the "X-shooter" instrument at the Paranal Observatory.

It is 6 a.m. The sky is still dark outside. My doorbell rings. It is the taxi that will drive me to Santiago airport to catch the early plane to Antofagasta in northern Chile. After a flight up the spine of Chile lasting an hour and 40 minutes, the journey is not yet over. My destination is the Paranal Observatory in the Atacama Desert, which is still a two-hour bus ride away and literally in the middle of nowhere. The last hour of the drive crosses an endless, Mars-like landscape of brown-red hills scattered with massive rocks, detaching me from my usual world and dropping me into a somehow different dimension.

Operated by the European Southern Observatory (ESO), Paranal is among the biggest observatories in the world, with four 8 m telescopes. While I am working there, time seems to flow differently, and I soon forget which day of the week it is. As an astronomer, I work during the night, from sunset to sunrise. It is easy to work too hard, and I am away from my family and my usual life one or two weeks every month, amassing over 100 nights per year at the observatory.

It is simple to explain why astronomers build observatories in such remote places: the total absence of light pollution, lots of clear-sky nights, good "seeing" (image quality) and extremely low humidity, which is critical for observing in the near-infrared part of the spectrum. But why people end up working in such places is a little more complicated. Although astronomers are sometimes pictured as nerds with few social skills, keen to isolate themselves in the company of books and complicated formulas, in fact, places like Paranal exist because they are where astronomy can best be done. Most of the astronomers I meet are quite normal and most work in universities with a regular nine-to-five routine, only travelling to remote places a handful of times each year to do their observations.

Although Paranal is an isolated place, it is also a little village where about 100 people live at any given time. Most of these "villagers" are not even astronomers, but engineers, technicians, administrators and people working on catering and services. They work (a lot!) during the day and relax during the evening in the gym, in the cinema room, at the pool table or in the sauna. It is a bizarre place that works hard to appear normal.

Beyond the ends of the Earth

When I applied for a fellowship at Paranal seven years ago, I was unaware of all these things. I just knew that Paranal existed, and I wanted to work there. Before that, I had earned a Master's degree in astronomy at the University of Padova in Italy, where Galileo Galilei himself taught about 400 years ago. I then did a PhD in astrophysics at the University of Wyoming in the US, but even after that I had still not gained much experience actually doing observations. So, I decided to fill in this gap by applying for an ESO postdoc position at Paranal.

By the time I applied for a longer-term staff position in 2004, I was familiar with the place. I had become used to its dryness (my skin had not, though), and I had started liking and enjoying that Martian landscape so much that a hike across the desert is now a magical break from the working routine. I had even decided that I much preferred to observe at night and take care of an instrument than to teach (I actually said this at my job interview). So, here I am.

Within the constraint of needing to work 105 nights per year at Paranal in 7–14 night stretches, an individual's schedule at ESO can be quite flexible, allowing us to participate in conferences, work at other observatories and get involved in collaborations. When I am not doing observations, I work on my scientific research at ESO's offices in Vitacura, Santiago. I am interested in cataclysmic variable stars, which are interacting binary systems where a white dwarf (a dead star) accretes matter from a "cold sun". Such systems display all kinds of variability phenomena, ranging from the small, rapid, random variations in brightness ("flickering") that characterize the ongoing mass transfer to a sudden increase in luminosity ("outburst"). My time in Vitacura allows me to analyse my variability data and also go to seminars, journal clubs and coffee breaks where I can discuss results, progress or problems with other astronomers.

When I am at Paranal, however, I mostly forget about my research and focus on performing observations with one of the telescopes. Each telescope is equipped with three instruments. For example, one telescope hosts the near-infrared (NIR) instruments NaCo (a imager and spectrograph), SINFONI (an integral field unit spectrograph) and HAWK-I (a wide-field imager). NaCo and SINFONI are adaptive-optics-assisted instruments that can either use a real star or a laser-generated one to correct the wavefront. During a night of observing, we astronomers decide which of several programmes or projects we want to carry out and set up the relevant instrument to "stare" at the target object, recording almost every photon that hits the telescope. We then classify the results according to their quality with respect to certain requirements.

The technical side

Paranal is quite special in that most of the observations are done by staff astronomers, like me, working in "service mode", which means that we perform observations for users (such as astronomers based at universities) without requiring them to do the work in person. This guarantees the best sky conditions to the work that needs them most; in a given night, we can execute several different programmes for different users, although we will not necessarily complete them in a single night. At smaller observatories, in contrast, the person who makes a proposal for telescope time must perform their own observations.

Occasionally during an observing night I feel like I am part of an assembly line. Sometimes the observations being carried out are interesting and/or challenging enough to get me excited. Other times, I just hope for long and boring observations that require little attention so that I can catch up on tasks like creating documentation for the instrument's users or evaluating the technical feasibility of the proposed observations. Occasionally, a night shift is used to train newcomers, and this is both fun and a good test of expertise.

However, the most interesting nights are the technical ones, when my colleagues and I have to perform tests with the instrument that we are responsible for – either because it has experienced a major failure and needs to be fixed or recalibrated, or because it is a brand new instrument just arrived at the observatory and so needs to be properly characterized before offering it as an option to the user community. For example, we are currently commissioning a new instrument called X-shooter, which is a composite spectrograph that can deliver, within a single observation, a spectrum from the very blue to the near infrared (wavelengths from 300 to 2500 nm). An instrument with such a wide spectral coverage is bliss for all astronomers interested in the spectral-energy distribution and/or the redshift of targets like gamma-ray bursts, supernovae, close binary systems, white and brown dwarf stars, and many other sky objects.

Commissioning an instrument requires a dedicated team of 5–10 people at the observatory itself, not counting the many others who work on the instrument's design or construction. This team takes care of aligning the instrument optics, defining the reference position of its various functions, digging into and debugging the software, testing it on the sky, and finally reducing and analysing the data to verify that the instrument is performing as expected. This can take every night of a full whole two-week shift, and typically two or three such shifts are needed to complete the commissioning.

Once my shift is over, I return to Santiago, usually arriving home at night after another half a day of travel. My sleep patterns are mixed up for the next few days, and I sometimes fall asleep at random times. I usually feel okay, but if I try to do some sport, for example, I discover that my body is not yet back to normal. At work, I might forget why I have given a file a particular name. It is at these times that I feel like my research is progressing two steps forward and one back, but this is probably part of the game. By taking it easy, I slowly get back to a regular life, and I am once again able to think about the science. Now, where was I with my paper about Nova Scorpii 2008?

Elena Mason is a staff astronomer at the Paranal Observatory in Chile, e-mail emason@eso.org

Once a physicist: David Florence

David Florence won a silver medal for Great Britain in the single canoe slalom event at the 2008 Olympics Games in Beijing

Why did you study physics?

I did mathematical physics because it was just what I was best at. I enjoyed it at school, so I applied to do it at Nottingham University. I fell into it, to be quite honest. Once at university, I struggled at first, partly because I found it quite difficult to combine studying with competing and training in sport, which is pretty much full time as well. But by the end of my university career, I had learned to be organized, and to manage my time pretty effectively, so I enjoyed it a lot more.

What was your training schedule like?

I did not have a huge number of lectures while I was at university, maybe 10 or 15 hours' worth a week, so the main problem was fitting in my training with the studying and some of the exams. I would be training about 12 times a week, for an hour each time – but it is not just an hour of training, because you also have to go down to the slalom courses beforehand to vet them, look at the white water and prepare for it, and then do video analysis afterwards. My schedule is fairly similar now that I am a full-time athlete, but it is obviously easier for me to go abroad to training camps.

How did you become interested in canoeing?

My uncle and father had done it when they were younger, and on one occasion my uncle brought some canoes to the beach on a family day out. I would have been about 14 then, which is pretty late to get into a sport – there cannot have been many other people at the Olympics who got started so late. I was really keen on it, though, and began training hard reasonably quickly.

Do you see any applications of physics in what you are doing now?

Not directly, but having an analytical mind can be a big help when you are training or racing. Being able to analyse a course carefully is essential, for example – you need to know exactly what you are going to do. So it is very helpful to have that kind of mindset that allows you to figure out for yourself how to get better, how to do things faster and how to learn better techniques.

What do you do when you are not training?

I tried to learn Chinese in the run-up to the Beijing games, at least to some standard, and I'm learning the guitar – I already play the bagpipes. I have not really kept up with physics, but I do still read the science section on the BBC website.

What do you plan to do next?

After the 2008 Olympics, I realized that if I retired, I did not have any idea what I wanted to do instead, so I thought I would use the next four years to figure that out. I applied to be an astronaut with the European Space Agency, figuring that with a degree in mathematical physics I might have some chance. I was not successful, but there was no harm in trying. Now, I am hoping to compete in the London 2012 Olympics, although you have to be selected, and that is a long way off. I am going to give the next four years my best shot, and now that I have an Olympic medal, I hope to get enough support from sponsors so that I can give it a really good effort in the London games.

● www.davidflorence.co.uk

Careers and people

‘Lifetime award’ for stellar research

George Preston of the Carnegie Observatories in Pasadena, California, has been awarded the 2009 Henry Norris Russell Lectureship, the highest distinction given by the American Astronomical Society (AAS). Preston has spent his career studying how old, metal-poor stars in the Milky Way evolve, and his findings have led to a new understanding of stellar magnetic fields and a group of pulsating stars known as R R Lyrae variables. He will receive the “lifetime achievement” prize when he delivers a lecture at the annual meeting of the AAS in January 2010. Other awards are listed on the society’s website.

● aas.org/grants/awards.php

US astronomers honoured

Three researchers have won prizes of up to \$25 000 each from the US National Academy of Sciences (NAS) for their “extraordinary scientific achievements” in astronomy-related fields. Charles Bennett of Johns Hopkins University has won the Comstock Prize in Physics for mapping the cosmic microwave background. The J Lawrence Smith medal went to Robert Clayton of the University of Chicago, whose studies of oxygen isotopes in meteors shed light on how they and other bodies were formed in the early solar system. The head of NASA’s Astroparticle Physics Laboratory, Neil Gehrels, will receive the Henry Draper Medal for his contributions to gamma-ray astronomy, including his leadership of the Compton Gamma Ray Observatory. The trio will receive their awards at a ceremony next month.

Pair share quantum prize

Peter Zoller of the University of Innsbruck, Austria, and Ignacio Cirac of the Max Planck Institute for Quantum Optics in Garching, Germany, have won the inaugural Basic Sciences award from the BBVA Foundation. The pair will share a €400 000 prize for their pioneering ideas on the theory of quantum-information science, some of which have already been used to build prototype quantum computers with cold, trapped ions or atoms. The prize is one of eight new “Frontiers of Knowledge” awards given by the Spanish financial group Banco Bilbao Vizcaya Argentaria, in collaboration with Spain’s National Research Council.

Women who are worth it

Applications for the 2009 L’Oreal-UNESCO UK and Ireland Fellowships for Women in Science are now being accepted. Four of the fellowships, worth £15 000 each, are awarded annually to women pursuing postdoctoral research in science at UK or Irish universities. The closing date for applications is 8 April.

● womeninscience.co.uk

Another gong for graphene

Interdisciplinary research on graphene has received a boost from the UK’s Engineering and Physical Sciences Research Council (EPSRC), with two of its £5m Science and Innovation Awards going to fund new centres for studying this innovative form of carbon. One team from Manchester and Lancaster universities, including graphene pioneer Andre Geim, will focus on expanding the possible applications of graphene beyond physics to materials science, chemistry and engineering. The other centre, hosted by Exeter and Bath universities, will use the prize money to fund research into the use of graphene in nanoelectronics, photonics and bioscience.

Movers and shakers

Pierre Darriulat, a former director of research at CERN who is now at the Hanoi-based Vietnam Auger Training Laboratory, has won the 2008 André Lagarrigue Prize from the French Physical Society for his work on constructing detectors at CERN.

The director of the Carnegie Institution’s Geophysical Laboratory, **Russell Hemley**, will receive the 2009 Bridgman Award from the International Association for the Advancement of High Pressure Science and Technology.

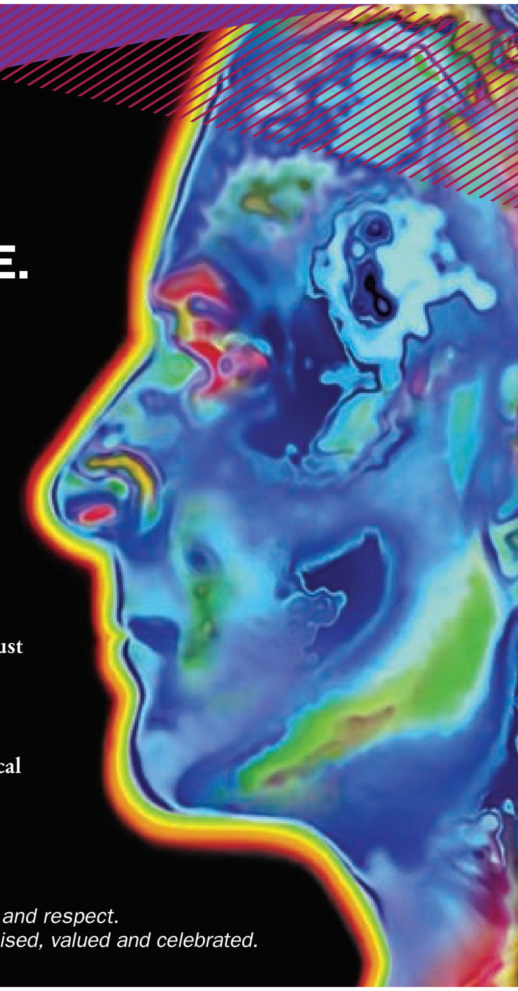
Atomic physicist **Deborah Jin** of the National Institute of Standards and Technology in Boulder, Colorado, will receive the 2009 William Procter Prize for Scientific Achievement from the Sigma Xi research society. The honour comes with a \$5000 prize and recognizes scientists for their ability to communicate complex ideas.

Chi-Chang Kao has been named as director of the new Joint Photon Sciences Institute at the Brookhaven National Laboratory in New York. He will also remain chair of Brookhaven’s National Synchrotron Light Source, a position he has held since 2006.

Fuqing Zhang, an atmospheric scientist at Pennsylvania State University, has won the American Meteorological Society’s 2009 Clarence Leroy Meisinger Award for his work on the meso-scale dynamics of phenomena such as tropical cyclones.

Postgraduate Opportunities

Home Office



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Closing date: 20th March 2009.

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School of Physics and Astronomy

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HERIOT WATT UNIVERSITY

Applications are invited from EU candidates interested in studying towards a PhD in multi-scale modelling. This project aims to reduce uncertainties in the prediction of fluid-rock interactions during CO_2 subsurface storage. CO_2 injection at the pore-scale will be studied and insights gained will be combined with larger-scale simulation.

The position is available for three years from 1st April 2009, although a later start date will be considered. The award includes tuition fees and £12,940 annual stipend. Applicants should have obtained, or expect to obtain, a first or upper second class honours degree in mathematics, physics or other numerate discipline. A strong programming background is essential.

For details contact Dr Steven McDougall (steve.mcdougall@pet.hw.ac.uk).

An application form can be obtained from www.postgraduate.hw.ac.uk/admissions.

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Imperial College London

Department of Physics

Doctoral Training Centre for Theory and Simulation in Materials

Starting from October 2009

Applications from physical scientists and engineers are invited for ten four-year studentships leading to both MSc and PhD degrees in the newly-established Doctoral Training Centre (DTC) in Theory and Simulation of Materials (TSM) at Imperial College London. Funding is available for UK and EU candidates meeting the Research Council criterion of having been 'ordinarily resident' in the UK for the past three years.

This DTC has been set up to provide advanced training in TSM to mathematically strong physical scientists and engineers by providing a cutting-edge educational and research environment, spanning the disciplines of physics, materials, chemistry and mechanical engineering. The DTC brings together 20 academic staff in these four departments at Imperial College London and is directed by Professor Adrian Sutton FRS.

PhD study within the DTC will differ significantly from the traditional approach in the UK. The first year will consist of a new 12-month, 90-ECTS, Bologna-compliant MSc in TSM to provide a rigorous foundation in theoretical materials physics and simulation techniques across the length and time scales. The PhD research project will occupy years 2-4 and will involve bridging length and/or time scales. Each student will have two supervisors (one of whom may be in industry or at another university).
A key emphasis will be the development of new theory, new models and new computational algorithms. The research of the DTC will be carried out in the Thomas Young Centre (www.thomasyoungcentre.org), the London Centre for TSM involving University College London and King's College London as well as Imperial College London.

One of the special features of this DTC is that each intake of students will enjoy a strong sense of cohort identity. This will be fostered by the cohort itself being responsible for organising activities such as a monthly journal club, seminars and conferences both for themselves and other year groups. They will also attend award-winning residential transferable skills courses and networking activities together. Each cohort will have a dedicated cohort mentor, who will hold weekly meetings throughout the duration of the programme to take feedback and to discuss all aspects of the DTC with students.

Prospective applicants are encouraged to make informal enquiries by contacting the Admissions Tutor Dr Peter Haynes: p.haynes@imperial.ac.uk Applicants should normally have, or expect to achieve, a first class (or equivalent) Bachelor's or Master's degree in the physical sciences or engineering. Applications will be processed when received, with the expectation that all studentships for the 2009 cohort will be filled by **31 March 2009**.

Further information is available at:
www.cmth.ph.ic.ac.uk/dtc/

Valuing diversity and committed to equality of opportunity

St Andrews University and **DIAMOND** announce a fully-funded PhD into X-ray Excited Optical Luminescence (XEOL) of minerals supervised by Dr Adrian Finch (St Andrews) and Professor Fred Mosselmans (Diamond). It will involve beamline development to study trace elements in feldspar, the commonest mineral in the crust. The candidate will be a graduate of Earth, physical, chemical or engineering sciences with a good BSc or Masters degree. The project is multi-disciplinary and the candidate will learn engineering, computing, physical science and mineralogical skills.

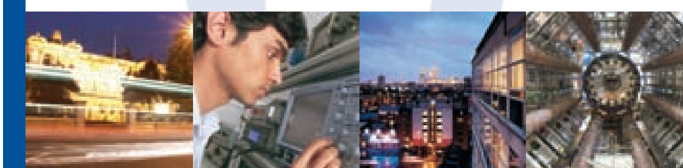
Enquiries and applications by CV to **Adrian.finch@st-and.ac.uk**

Queen Mary
University of London

Postgraduate Studentships at World Leading Physics Department

Queen Mary, University of London is a research intensive university highly ranked in the UK in the 2008 Research Assessment Exercise. Many of the research activities within the Department of Physics were classified as world leading and internationally excellent.

The department is offering up to eight 3-4 year PhD studentships, including fees and a maintenance grant of £14,940 for 2009 Entry. The positions are available to high calibre applicants in the areas of experimental particle physics, string theory and molecular and materials physics.



The research projects will include:

- Analysis of data from the Atlas experiment at the LHC accelerator at CERN, and the T2K neutrino oscillation experiment in Japan.
- Development of new approaches to string theory and M theory with applications to gauge theories and gravity.
- Experimental characterisation of organic electronic and carbon nanotube/graphine based systems.

Further details are available at **www.ph.qmul.ac.uk/postgrad**

German Research School for Simulation Sciences

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The **German Research School for Simulation Sciences** is a joint venture of Forschungszentrum Jülich and RWTH Aachen University. Combining the resources of a research center and a university in an unprecedented, synergistic manner, we aim to advance cutting-edge interdisciplinary research and training in the fast-evolving field of computational science and engineering.

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Students of the German Research School for Simulation Sciences have access to the **world-class high-performance computing facilities** and **extraordinary visualization resources** at Jülich Supercomputing Centre and the Centre for Computing and Communication of RWTH Aachen University. The language of the school is English.

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Mathematical, Physical and Life Sciences Division

Department of Physics

J.A.I.

Director of John Adams Institute for Accelerator Science University of Oxford & Royal Holloway, University of London in association with Wolfson College Oxford and a University Lectureship in Accelerator Science University of Oxford & STFC Rutherford Appleton Laboratory in association with Wolfson College Oxford

The John Adams Institute for Accelerator Science, based in the Sub-department of Particle Physics at the University of Oxford and in the Department of Physics at Royal Holloway University of London (RHUL), was established in October 2004 as a joint venture between the two universities as part of a major initiative in accelerator science, and is supported by the Science and Technology Facilities Council and Diamond Light Source Limited. There are currently 15 academic staff, 9 research staff, more than 20 research students and a large number of technical staff associated with the Institute. The current portfolio of projects includes the R&D for a future high-energy linear electron-positron collider and a neutrino factory, the Muon Ionisation Cooling Experiment (MICE), the development of non-scaling Fixed-Field Alternating Gradient accelerators for a variety of applications including Charged Particle Cancer Therapy using protons and light ions, novel light sources and ultra-short x-ray pulses, plasma wave accelerator diagnostics, and upgrades to ISIS and the LHC. The Institute also has a vigorous outreach programme. More details about the John Adams Institute can be found at **http://www.adams-institute.ac.uk**.

The Director of the John Adams Institute for Accelerator Science

Grade RSIV: Salary to be negotiated.

The Institute is seeking to appoint a Director at professorial level, replacing Professor Ken Peach, who will retire next year. The successful candidate will have an outstanding international reputation in accelerator science. The Director will be responsible for the academic leadership and strategic goals of the Institute, for maintaining the high-quality academic training programme and the extensive links with the UK and international accelerator and particle physics communities, other academics and industry. He or she will be responsible for the current programme in accelerator science and the future development of the field. The Director, who will be employed by the University of Oxford on a stipend in the RSIV range (Professorial equivalent) at a level to be negotiated, will be predominantly based in Oxford, and will hold a supernumerary Fellowship at Wolfson College Oxford. Informal enquires about this post may be made to Professor Brian Foster, email:b.foster@physics.ox.ac.uk or +44 1865 273323, and further particulars are available at **http://www.physics.ox.ac.uk/pp/jobs/JAI-Director-fp.htm**. The deadline for applications is Friday 15 May 2009. Interviews will be held on 1 June 2009; candidates should keep this date free in case they are called for interview.

University Lectureship in Accelerator Science, jointly with the STFC Rutherford Appleton Laboratory

£42,351 - £56,917 pa

The Institute is also looking for a University Lecturer in Accelerator Science to work on R&D topics of common interest to the Institute and the STFC Accelerator Science and Technology Centre (ASTeC), mainly based on programmes presently under way at the STFC's Rutherford Appleton Laboratory in Oxfordshire. This is a joint appointment with the ASTeC; the salary will be on the Oxford UL scale from £42,351 to £56,917 pa. The successful candidate will be offered a supernumerary Fellowship at Wolfson College Oxford. The appointee will undertake lecturing, research and administration within the John Adams Institute and the Sub-department of Particle Physics in Oxford, and will undertake research at the Rutherford Appleton Laboratory. Applications are welcome in any area of accelerator science. This work involves close international collaboration. Informal enquiries about this post may be made to Professor Ken Peach, email: k.peach1@physics.ox..ac.uk, and further particulars are available at **http://www.physics.ox.ac.uk/pp/jobs/JAI-UL-fp.htm**. The deadline for application is Friday 15 May 2009. Interviews will be held on 29 June 2009; candidates should keep this date free in case they are called for interview.

Applicants should submit before the deadline of 15 May 2009 a letter of application setting out how they meet the selection criteria set out in the further particulars, supported by a curriculum vitae, a publications list, a statement of research interests, and the names and addresses of three referees, to Mrs. Sue Geddes, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH, UK, email: s.geddes@physics.ox.ac.uk, Fax: 0044 1865 273417. Applicants should state whether they wish to be considered for the Directorship or the Lectureship.

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Lecturer Experimental or Theoretical Physics

School of Physics/Faculty of Science

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The School of Physics seeks to appoint a Lecturer in Experimental or Theoretical Physics, who will lead our engagement with the new John Monash Science School (to commence operation on the Clayton Campus in 2010). Applicants will hold a PhD in physics and have a record of publications and citations in high impact physics journals. Successful applicants will be expected to attract national competitive grants, establish an independent research program, supervise research students and contribute to Enhancement Programs and undergraduate teaching. The capacity for scientific outreach and experience in engaging with high school students and staff is desirable.

The university reserves the right to appoint by invitation. For more information about the School of Physics, go to http://www.physics.monash.edu.au/

All applications should address the selection criteria. Please refer to "How to Apply for Monash jobs' below.

The Benefits
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Enquiries Only
Associate Professor Michael Morgan on +61 3 9905 3645 or email michael.morgan@sci.monash.edu.au

Applications To Mrs Jean Pettigrew jean.pettigrew@sci.monash.edu.au

Ref No A099708

Applications Close Thursday, 1 May 2009

Go to http://cerebus.sss.monash.edu.au/employ/job.asp?refnumber=A099708&work=&staff=academic&faculty=&keyword=&whichpage=1&pagesize=7 for position details and application information.

MONASH University

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Open position: POSTDOCTORAL researcher

The CHRISTIAN DOPPLER LABORATORY on LASER – ASSISTED DIAGNOSTICS at Johannes Kepler University Linz (Austria) is a research project in cooperation with major industrial companies. It concentrates on (1) Fundamental studies on the interaction of intense laser radiation with complex materials, (2) Quantitative element analysis by plasma spectroscopy and related techniques, and (3) Development of In-line analysis systems.

We are looking for a highly motivated and skilled Postdoctoral researcher with relevant scientific background. The annual gross salary is between €42.000 and €48.000 approximately. Please, send your application in electronic form to Johannes.Pedarnig@jku.at and Johannes.Heitz@jku.at (www.cdlabor-lad.jku.at/, www.applphys.jku.at/).

The University of Edinburgh
SUPA Advanced Fellowship in Experimental Particle Physics
ATLAS experiment

Applications are invited for an Advanced Fellowship, tenable for up to four years. The particle physics group is in the process of joining the ATLAS experiment. We are seeking a scientist with a strong research record in particle physics to play a prominent role in shaping the portfolio of our activities within ATLAS. This will be in collaboration with the University of Glasgow as part of the Scottish Universities Physics Alliance.

Application details: http://www.jobs.ed.ac.uk/
Deadline: 25th March 2009
Contact: Dr. Phil Clark P.J.Clark@ed.ac.uk

SUPA

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Fax: 01277 243 299

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www.brentwoodschool.co.uk

Brentwood School is committed to safeguarding and promoting the welfare of children, and applicants must be willing to undergo child protection screening appropriate to the post, including checks with past employers and the Criminal Records Bureau.

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We are looking to recruit a physicist to join our small team producing world class optical thin film coatings, based in Plymouth, Devon. Candidates should have experience of design of optical thin films including rugate filters. Experience in a commercial environment would be an advantage, but is not essential. The successful candidate may be required to undertake security clearance. Some overseas travel will be necessary.

Please email CV to **hr@afe-uk.com**, including details of current salary.

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Announcement

The International Center for Condensed Matter Physics of the University of Brasilia has openings for postdoctoral positions in the theoretical areas of Non-Equilibrium Nanostructures and *Ab Initio* Calculations for Nanostructures and Correlated Systems and for the experimental Material Sciences group.

All positions will be available from May 2009. Applications should be made by e-mail before next April 13th. Later applications may also be considered depending on developments. For more detailed information please visit our website http://www.iccmp.br, contact by e-mail the leader of the research group you wish to join or by e-mail visitors@iccmp.web.br.com.

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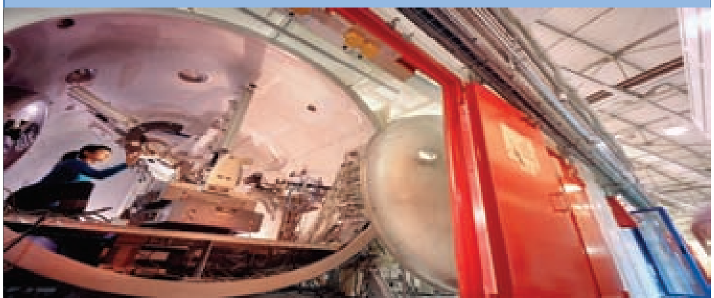

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Lecturers in Materials Science

Department of Materials Science & Metallurgy

The Department of Materials Science & Metallurgy (DMSM) at Cambridge seeks to appoint two Lecturers to start in the academic year 2009-10. Rated in the Research Assessment Exercise 2008 as the top materials department and one of the top UK departments in any science/engineering discipline, DMSM provides an outstanding environment in which to pursue forefront materials research. Candidates are sought who can further enhance DMSM's international research profile, and who will play an active part in curriculum development and teaching at Bachelor's, Master's and doctoral levels.

Appointments are to the retiring age, subject to satisfactory completion of a probationary period. The pensionable scale of stipends for a University Lecturer is £36,532 to £46,278 a year.

An application, electronic or single-sided hard copy, should include a curriculum vitae, a publications list, contact details for three professional referees, and a statement (up to six pages) covering the applicant's research experience to date and research plans for the future. This should be accompanied by a completed form PD18 (parts I and III, available from http://www.admin.cam.ac.uk/offices/hr/forms/pd18/), and should be sent to Dr REM Ward, Academic Secretary, Department of Materials Science & Metallurgy, Pembroke Street, Cambridge, CB2 3QZ, UK (lectureships2009@msm.cam.ac.uk). The closing date for receipt of applications is 30 April 2009.

General information on DMSM's research and teaching is available at http://www.msm.cam.ac.uk/. For informal enquiries, and to obtain further particulars, prospective candidates may contact the Head of DMSM, Professor AL Greer (alg13@cam.ac.uk).

The University of Cambridge has a responsibility to ensure that all employees are eligible to live and work in the U.K.

The University is committed to Equality of Opportunity.

Centre for Graphene Science

Seven permanent academic positions in graphene research at the Universities of Exeter and Bath, United Kingdom

The Universities of Exeter and Bath are establishing a 'Centre for Graphene Science', following strategic investments of the Universities into materials research and a £5 million award from the EPSRC/HEFCE. The aim of this Centre is to bring together and create internationally leading research teams. Its research will focus on three main areas: methods of producing graphene and graphene nanostructures; experimental and theoretical studies of graphene-based systems; and development of new electronic, photonic, chemical, biological and medical devices and sensors.

The **University of Exeter** (www.ex.ac.uk) invites applications for the posts of **Lecturer/Academic Fellow in Physics** (refs 1946/2000), **Academic Fellow in Engineering** (refs 1947/2002), and **Professor/Associate Professor of Physics** (refs 1945/1969). The University of Bath (www.bath.ac.uk) invites applications for the post of **Lecturer in Physics** (ref. 09025PP, details available at the link below). The position of **Academic Fellow** will be with limited teaching responsibilities for the first three (ref. 1947) or five (refs 2000, 2002) years and will become **Lecturer** after that.

At Exeter the salary range is £31,513-£35,469 for Lecturer/Academic Fellow and £50,816-£53,650 for Associate Professor (the salary of Professor will be by negotiation). The starting salary of the Lecturer at Bath will be £36,532.

Applicants should have a PhD in physics, engineering, materials science or a related discipline. Experience in graphene or carbon-based systems are particularly welcome. The successful applicants will establish an independent research programme that will strengthen and complement the existing research infrastructure and expertise at the two Universities. They should have a strong record in attracting research funding (or potential to do so), and commitment to interdisciplinary research that will forge links both within the Centre and with other educational bodies and industry worldwide.

Further information and application packs are available from
http://www.ex.ac.uk/jobs and applications submitted to
hradmin@exeter.ac.uk (Exeter), and
http://www.bath.ac.uk/jobs/job_desc.cgi?09025PP (Bath).

The closing dates for completed applications: 12 noon on 27th March 2009 (Refs 1945, 1946, 1947, 1969) and **12 noon on 1st May 2009** (Refs 2000, 2002, 09025PP).

Informal enquiries:

Exeter: Prof. Alex Savchenko (a.k.savchenko@ex.ac.uk)
tel: +44 1392 264197

Bath: Prof. Simon Bending (S.Bending@bath.ac.uk)
tel: +44 1225 385173.

The Universities of Exeter and Bath are equal opportunities employers.

UNIVERSITY OF EXETER

UNIVERSITY OF BATH

Clutching at dark straws

Astronomy has the honour of being the oldest science, the most humbling science and the science that produces the prettiest pictures. A less-celebrated asset is the sheer chutzpah of the members of the international astronomical community. Although ad hoc assumptions are a frequent factor in the progression of any science, in other fields these tend to be somewhat more discreet and generally easier to swallow.

First, a historical example. Newton's theory of gravitation was jolly popular in its day, ruling unchallenged until 1781, when some bright sparks noticed that Uranus's orbit had the temerity to differ from Newton's predictions. The theory of gravitation was otherwise so successful that it followed that the solar system itself must be at fault, having failed to declare the existence of all its planets on its customs forms. Sure enough, Neptune was discovered, sneakily distorting Uranus's orbit and throwing out all the calculations.

The solution worked so well that when other bright sparks discovered that Mercury's orbit was also wrong, they tried inserting a planet called Vulcan between Mercury and the Sun. Amateur astronomers "saw" Vulcan a few times, but its orbit was never determined, probably because the planet never existed. Mercury's orbit remained an anomaly until 1916, when Einstein announced that it was not just Mercury that was non-intuitive – it was the entirety of space and time. The "anomaly" was in fact the first sign of the previous theory failing under extreme conditions.

In a completely unrelated incident, Fritz Zwicky's 1933 observations of the Coma cluster of galaxies suggested that there was not enough mass in the group to bind them all together. Later, Vera Rubin discovered that the stars making up the galaxies seemed to be travelling too fast. In both cases, the astronomical community responded initially by pointing and laughing, although in Zwicky's case this was pretty much par for the course.

As more results came in confirming the reluctance of astronomical bodies to obey the law of gravity, doubts began surfacing. If the numbers were wrong, either all the detectors were broken (unlikely) or the calculations were full of errors (heartbreaking). But if they were right, then the assumptions about the universe – including the fiercely held modesty that the Earth occupies a fairly generic region of space – were going to have to go. Damn.

In the face of these problems, most scientists would be turning to a major revision of theory – or, alternatively, to drink. But our brave astronomers took a different course. They insisted that their equations were right, but that the mass of the universe was wrong. Their solution requires positing not just a planet or two – and what's a planet or two between friends? – but six times more universe than we can see, in a form that we cannot detect except by inference: the ubiquitous "dark matter". Throw in a magical, all-pervading "dark energy" that inflates the universe like an overstrained metaphorical balloon, add an assortment of particles with silly names, sprinkle liberally with funding, and bingo, you can now solve any other tricky problems that had been keeping you awake all day.

If your theory does not work, you are of course at liberty to suspect that the fault lies with the data, rather than the theory itself. But when you end up performing Calabi–Yau-level mental contortions to keep your theory alive, it seems a lot simpler to try a new theory than to patch up the old one *ad infinitum* with dark sticking plasters.

Dark credit mysteriously fails to interact with the economy, so it has no effect on spending or employment

When a theory acquires too much fudging, it is usually time for a newcomer to take over the pack. Such changes usually involve junking an assumption once thought to be unquestionable – such as "spheres are the only acceptable shape for heavenly bodies" and "time is absolute", to name but two astro-related ones. And to their credit, astronomers have made these gestalt switches in the past.

However, there are other fields where clinging to old theories while sticking your fingers in your ears and singing is a valuable skill. To this end, I suggest that a team of astrophysicists be seconded immediately to work on the problems facing the global economy. I confidently expect them to declare the existence of dark credit, which is not connected to any actual observables like property or gold but is nevertheless detectable due to the financial gravitas it imparts to banks. The current global round of lay-offs is due to the fact that dark credit mysteriously fails to interact with the rest of the economy, so it has no effect on spending or employment. It is there, however, because if it were not, our economic models would be in trouble – and they are so successful, there cannot be a problem. So, dark credit must exist.

If you are unconvinced by this circular argument, then you have only to observe how money becomes bent when it interacts with investment bankers – a well-known way of proving the existence, and mapping the location, of dark credit. Hopefully the imaginative thinking, together with the soothing, confident proclamations of this astronomy–economy task force, will bring some stability back to the world markets, and some funding back into physics. They can use it to build another billion-Euro Polo mint in Switzerland.

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● Readers are invited to submit their own Lateral Thoughts. Articles should be between 900 and 950 words long, and can be e-mailed to pwld@iop.org