Postcards from the Edge of the Universe

United Nations
Educational, Scientific and
Cultural Organization

International
Astronomical
Union

Partners for the International Year of Astronomy 2009

Edited by: Lee Pullen, Mariana Barrosa & Lars Lindberg Christensen

Postcards from the Edge of the Universe

An Anthology of Frontline Astronomy
from Around the World

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André Roquette

Inside front cover: This 34 by 20-degree wide vista show the central parts of our galactic home. It was taken by Stéphane Guisard, an ESO engineer and world-renowned astrophotographer, from Cerro Paranal, home of ESO's Very Large Telescope, where one of the best skies on the planet is found.

Inside back cover: In this spectacular image, observations using infrared light and X-ray light see through the obscuring dust and reveal the intense activity near the Milky Way's core.

The typeface used in this book is Aller Sans developed for the Danish School of Media and Journalism and sponsored by Aller.

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This spectacular panoramic view shows the Carina Nebula and was taken with the Wide Field Imager on the MPG/ESO 2.2-metre telescope at ESO's La Silla Observatory in Chile.

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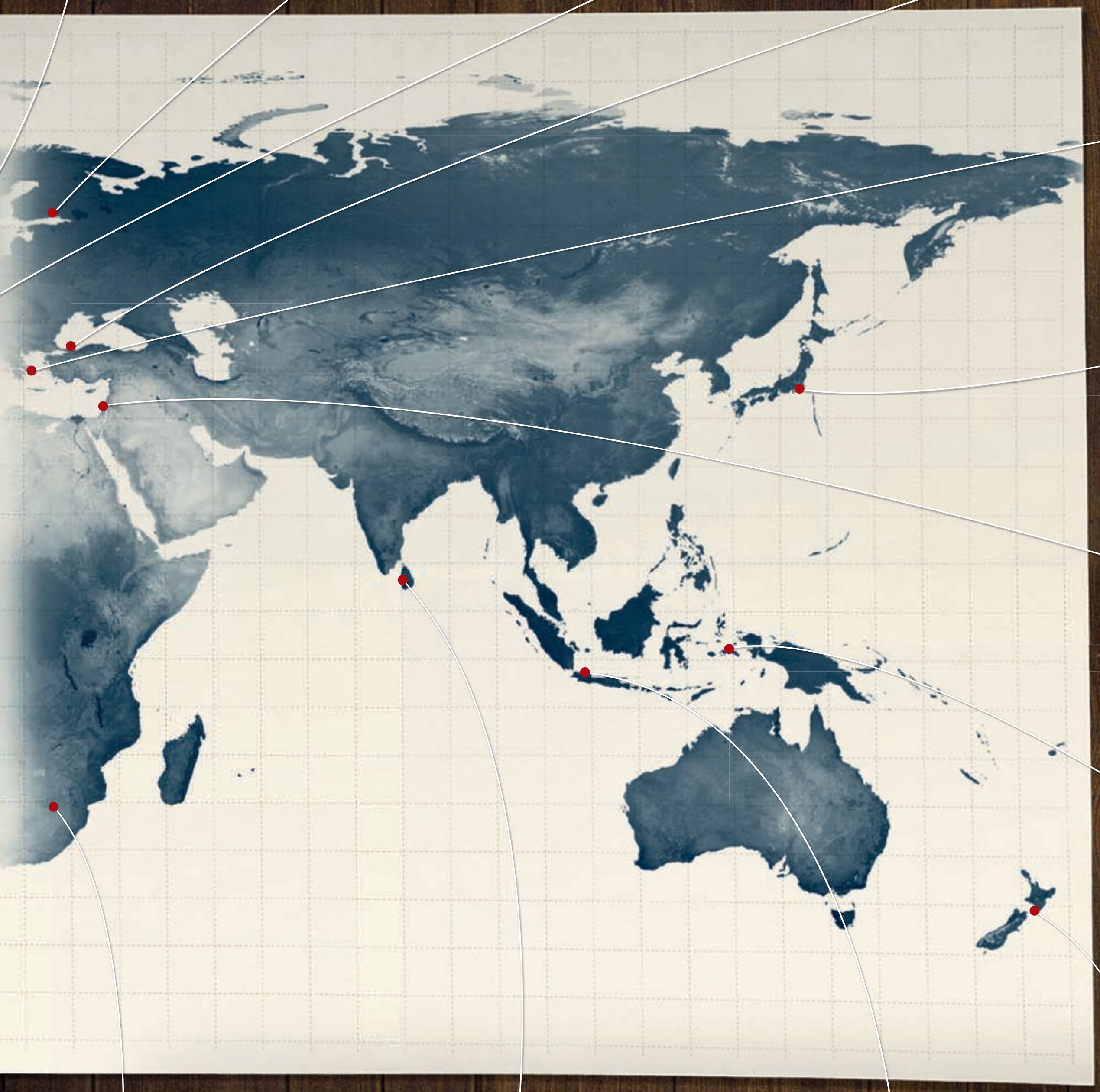

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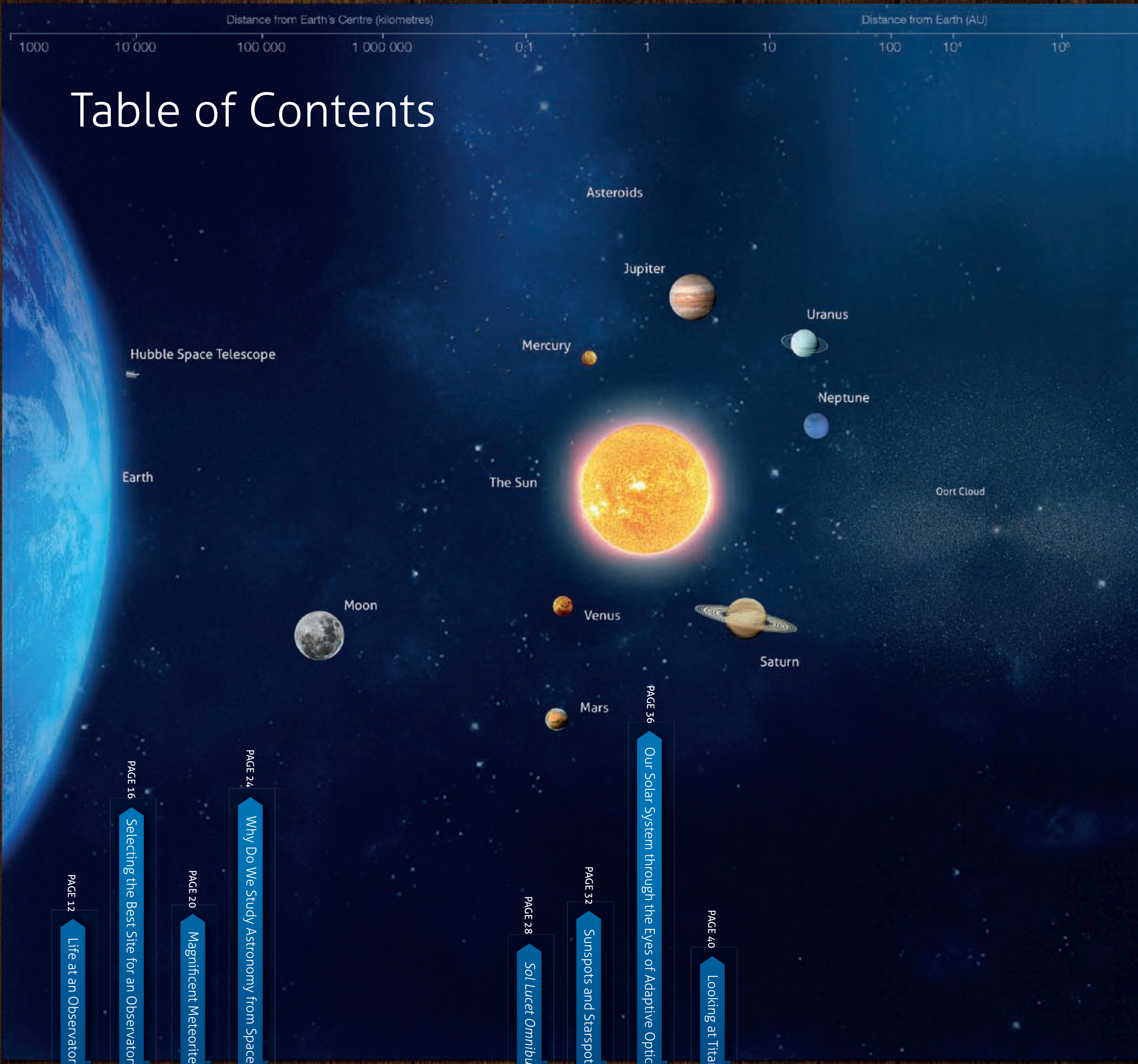

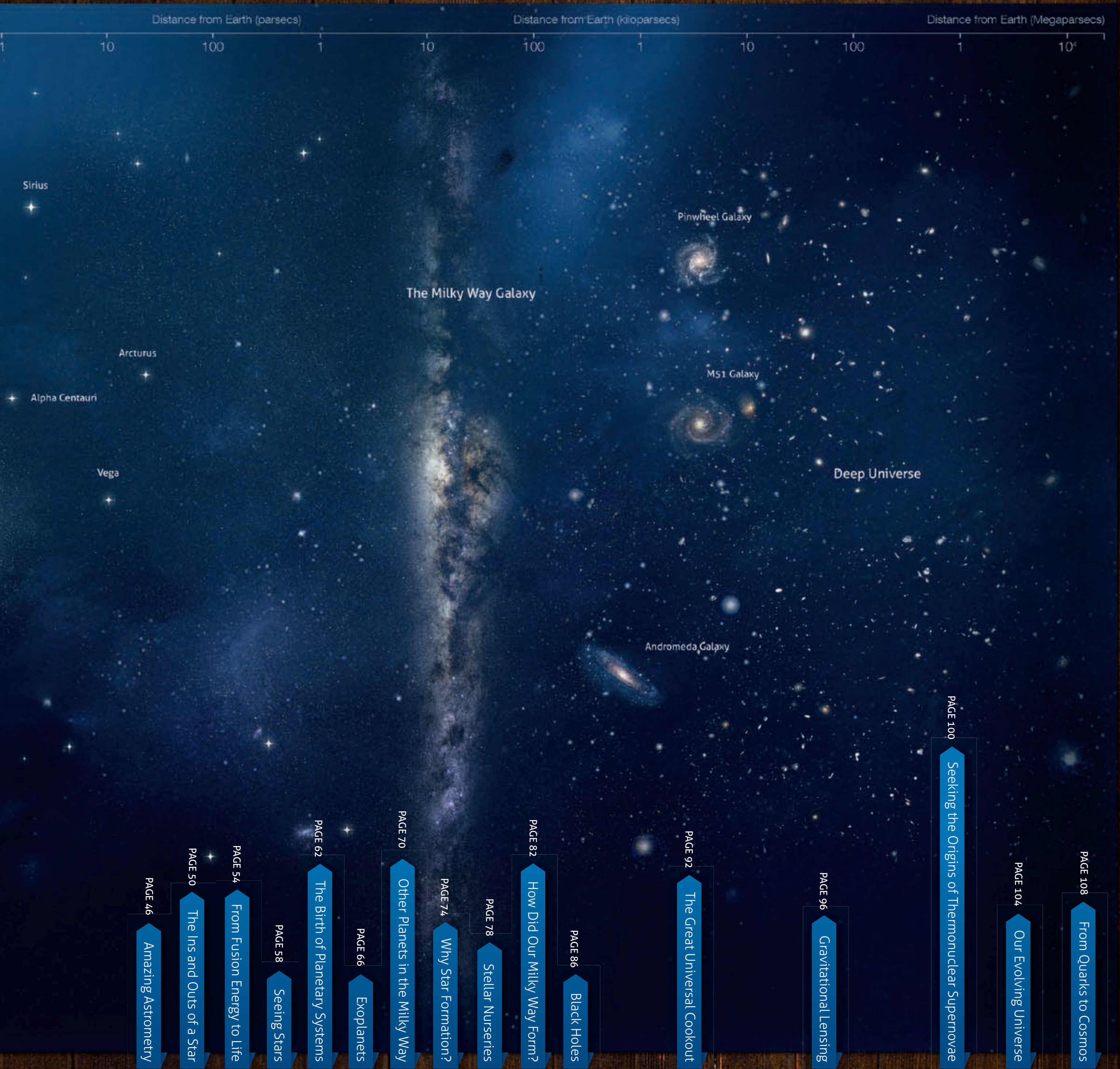
Distance from Earth (parsecs)
Distance from Earth (kiloparsecs)
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Sirius
Arcturus
Alpha Centauri
Vega
The Milky Way Galaxy
Pinwheel Galaxy
M51 Galaxy
Deep Universe
Andromeda Galaxy

Catherine Cesarsky

Former President of the International Astronomical Union,
Chair of the IYA2009 Executive Committee Working Group
& High Commissioner of Atomic Energy, France

The International Astronomical Union (IAU) launched 2009 as the International Year of Astronomy (IYA2009) under the theme The Universe, Yours to Discover. Astronomy is one of the oldest fundamental sciences. It continues to make a profound impact on our culture and is a powerful expression of the human intellect. Huge progress has been made in the last few decades. IYA2009 marked the 400th anniversary of the first astronomical observation through a telescope by Galileo Galilei. It was a global celebration of astronomy and its contributions to society and culture, with a strong emphasis on education, public engagement and the involvement of young people, with events at national, regional and global levels throughout the whole of 2009. UNESCO endorsed IYA2009 and the United Nations proclaimed the year 2009 as the International Year of Astronomy on 20 December 2007.

IYA2009 was supported by twelve Cornerstone projects. These ranged from travelling exhibitions of astronomical images to boosting astronomy education in developing countries. They were specifically designed to help achieve IYA2009's aim of making the Universe an accessible topic for all. The Cosmic Diary was one of these Cornerstones, and had the honour of being launched on 1 January, the very first day of IYA2009. As a year-long online blog, the Cosmic Diary gave a voice to professional astronomers in a way that is very rarely attempted. By allowing these experts to talk about whatever they liked, be it their research aims, pet projects, or simply what they'd been up to at the weekend, a whole new way of looking at the science of astronomy was unveiled; one where the people behind the discoveries are recognisable individuals with personalities as varied as the phenomena they are studying. The Cosmic Diary emphasised that although these astronomers are working all over the world and in different research fields, they all, through their shared interest in the Universe, contribute towards expanding our horizons.

UNESCO
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Cultural Organization

IAU
International
Astronomical
Union

Partners for the International Year of Astronomy 2009

The Cosmic Diary bloggers decided to write about their specialist fields in easy-to-understand language, essentially giving readers a direct line to scientists responsible for cutting-edge research. In this way each blog post has its own flavour, both in information content and style. It is perhaps this, more than anything, that has inspired *Postcards from the Edge of the Universe*. Great potential was seen in collecting these many aspects together into a book, and combining the science with the multi-national personalities of the astronomers. From these foundations the book you now have in your hands was formed.

Many IYA2009 projects are continuing in varying formats, helping to create a legacy that will last far into the future. *Postcards from the Edge of the Universe* is an important part of the Cosmic Diary's legacy, and I believe it will help to make astronomy a more accessible science. If so, then the aim of the project will have been realised.

C. Cesarsky

Lee Pullen

Cosmic Diary Editor

Mariana Barrosa

Cosmic Diary Manager

The book you are currently holding is an outcome of the Cosmic Diary blog, one of twelve International Year of Astronomy 2009 (IYA2009) Cornerstone projects. The Cosmic Diary first started out as a mere thought back in 2006, inspired by the very successful Quantum Diaries blog launched in 2005 to celebrate the World Year of Physics. Planning for the IYA2009 had begun in earnest, and ideas were being thrown around for Cornerstone projects to form its foundation. There was much enthusiasm for various ventures, and one in particular had the potential to really put a human face on astronomers working at the forefront of science — one of the eight fundamental goals of IYA2009. Soon named the Cosmic Diary, it was to be a blog for professional astronomers where they could write about their research as well as their personal lives.

The final decision to go ahead was taken in 2007 by the International Astronomical Union Executive Committee's IYA2009 Working Group, which oversaw IYA2009. Pedro Russo, Global Coordinator of the IYA2009, asked Mariana Barrosa to take this project on and chair an international Task Group.

After setting up a Task Group, the first step was to recruit bloggers. Mariana asked the IYA2009 Single Points of Contact already identified in various countries to recommend candidates who would be enthusiastic enough to keep blogging for at least a year, as well as possess a natural talent for communication. The Task Group was careful to choose astronomers from different countries and researching in different areas of astronomy, with the idea that the bloggers would represent as wide a cross-section of professionals as possible at the very core of the project.

Before long the project gained its own momentum and more astronomers wanted to join. The Japan Aerospace Exploration Agency, the European Space Agency, NASA and the European Southern Observatory all requested sub-blogs. We even had an historical blog run by the Royal Observatory Greenwich, reproducing diaries written in 1894! In total, the Cosmic Diary had around 60 bloggers from 35 countries. This was more than twice our original aim of having 24 bloggers. The Cosmic Diary flourished.

Lars Lindberg Christensen

IYA2009 Secretariat Manager and IYA2009 Executive Committee Working Group Secretary

Thanks to an unerring sense of dedication mixed with a hefty dose of pressure and plenty of sleepless nights, everything was up and running in time for 1 January, the very first day of the IYA2009. Over the course of the year the bloggers showed the enthusiasm that everyone had hoped for, writing over 2000 blog posts, ranging from a frontline report of a satellite launch to the confusion over how to greet people from different cultures. Many of the 250 000 visitors in 2009 left comments after posts, asking the astronomers questions and engaging in conversation

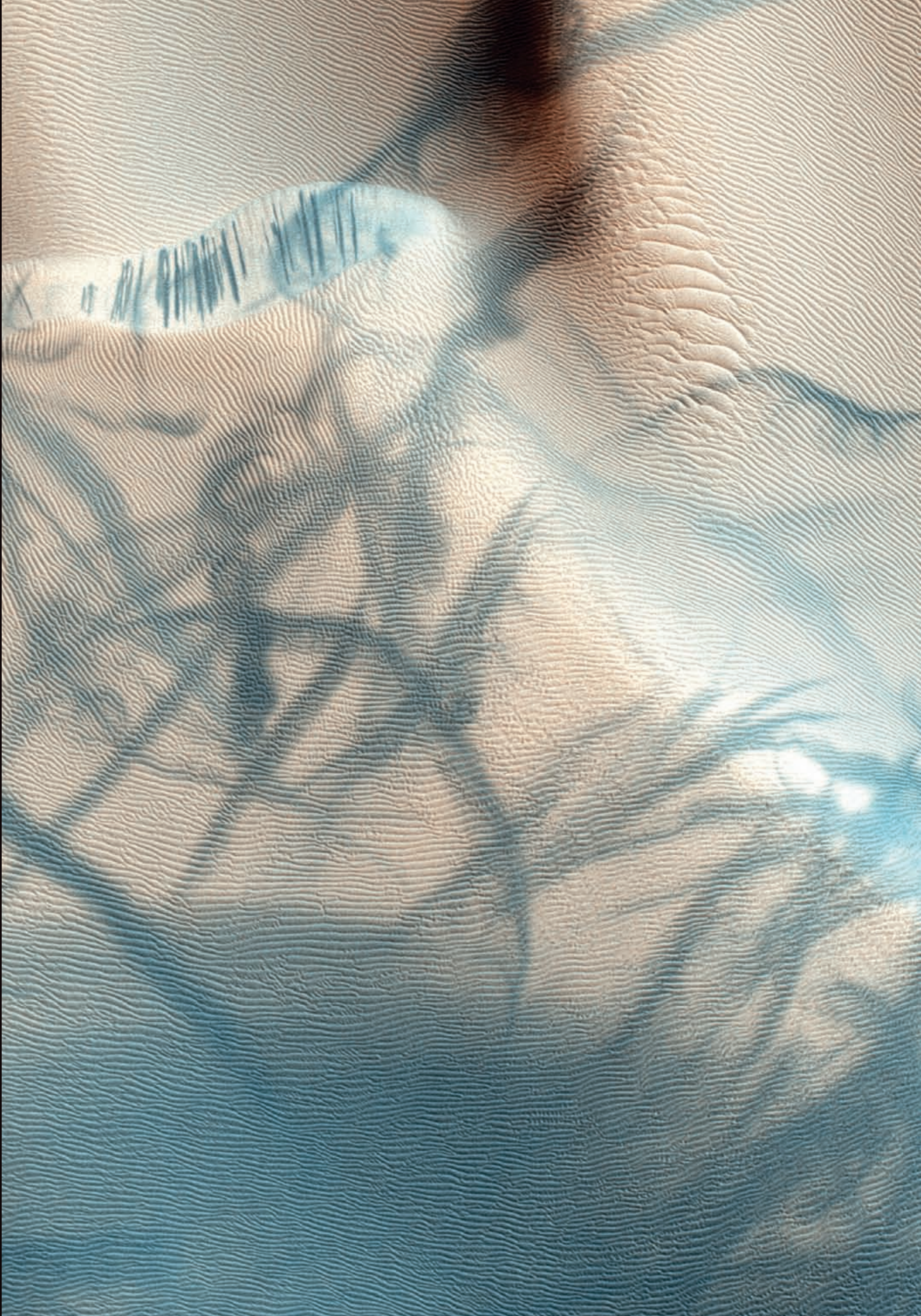
One of the highlights of the project was the fortnightly feature articles, written by the bloggers directly for the public. This was unusual in the scientific community, and the method of dissemination, via the blog, added to their appeal. It was a natural next step to compile these feature articles into a book, along with more in-depth information about the authors, where they live, and where they carry out their work. The result is *Postcards from the Edge of the Universe,* a compilation of the articles written by our bloggers, during the year when the Universe was ours to discover.

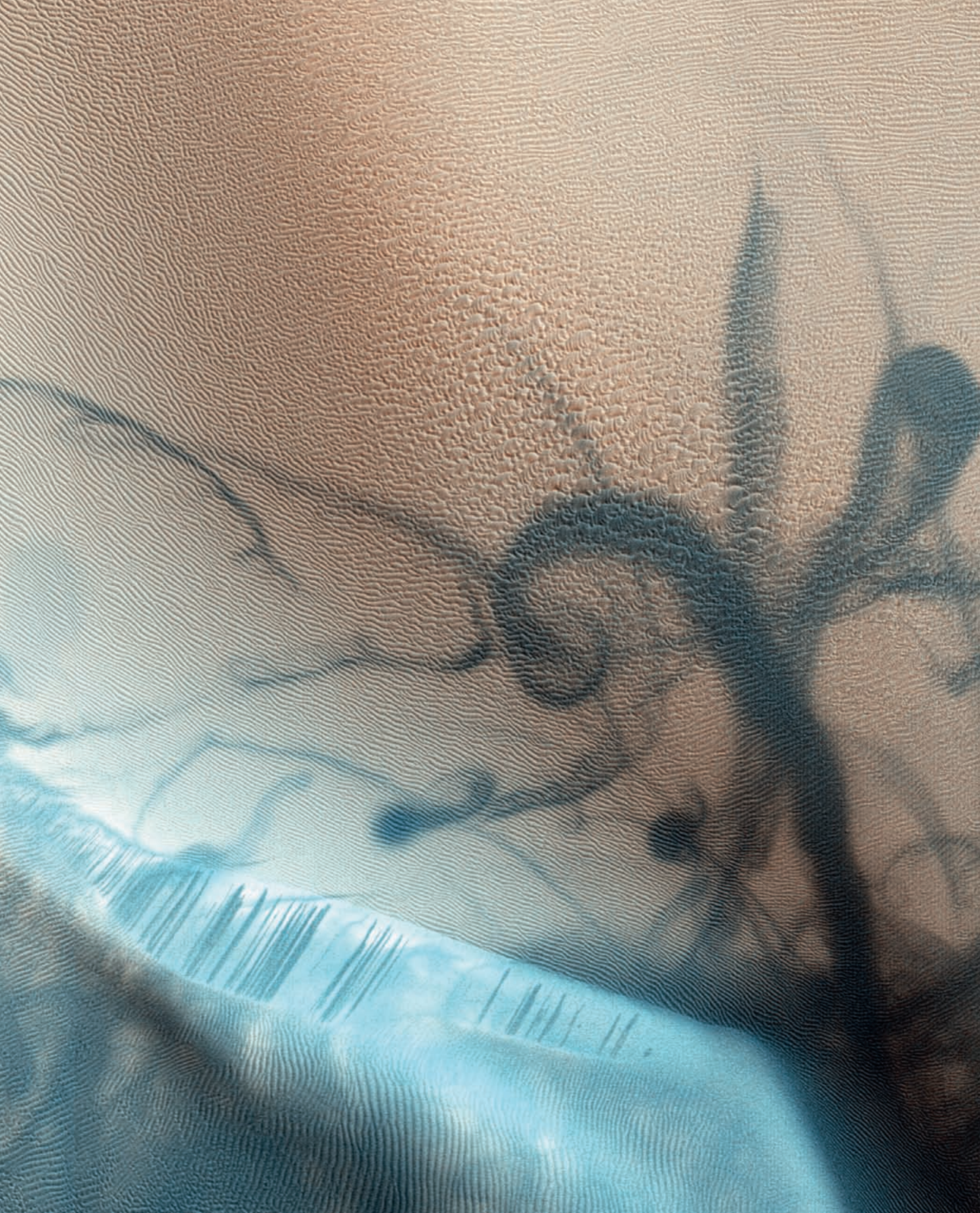
No preface would be complete without thanking the people in front of, and behind, the scenes. The Cosmic Diary Task Group, especially Henry Boffin and Douglas Pierce-Price from ESO for helping to get ideas off the ground; the International Astronomical Union’s IYA2009 Working Group for managing to balance the many multi-national aspects of the enormous IYA2009 project and for steering it clear of unproductive politics; Pedro Russo who did a masterful job in coordinating IYA2009 globally and was very supportive of the Cosmic Diary all along. Finally two people deserve particular attention: web-developer Nuno Marques and graphic designer Andre Roquette, who did a lot of the heavy lifting, and deserve a lot of the credit.

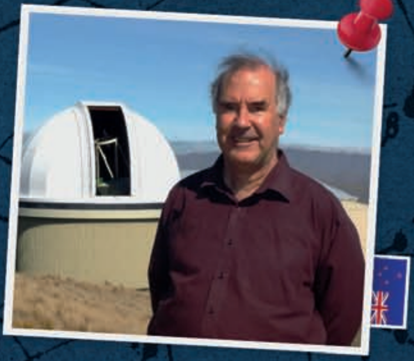
We hope that this book gives you an idea of the variety in the astronomy that is happening worldwide, and the diversity of the people driving the research forward. And if you enjoy reading it as much as we enjoyed building and managing the Cosmic Diary, then that’s what we call a result.

The Solar System

This image shows a region of Mars in the lower half of the northern hemisphere. This close-up shows the bed of a crater with rippling sand dunes. Dust devils rolling across the surface pick up the lighter red dust leaving the heavier, darker sand grains behind.







John Hearnshaw

Born in Wellington, New Zealand

Biography

John is a natural communicator. He has made a successful career out of both scientific research and education, working as an observatory director, lecturer and author. His passion for astronomy is undeniable, and his expertise is greatly valued by all who work with him. His hectic schedule means that he is often rushing around the world visiting other scientists and members of the public who are eager to learn more about science.

Apart from lecturing at all university levels in astronomy and astrophysics, John's research interests include precise stellar radial velocities, binary stars, the design of échelle spectrographs, gravitational microlensing and the history of astrophysics. He is also Chairperson of the International Astronomical Union's Commission 46 Program Group for the Worldwide Development of Astronomy. The last few years have seen John travelling to interesting places to talk to astronomers in developing countries such as Mongolia, Cuba, Trinidad and Tobago, Thailand and Laos, Vietnam, Uzbekistan, Mauritius and Paraguay.

As well as visiting many countries, John has also worked around the globe in places as varied as Germany, Japan, Sweden and South Africa.

University of Canterbury, Department of Physics and Astronomy

The University of Canterbury is one of eight publically funded universities in New Zealand, and the second oldest (founded in 1873). Today there are about 17 500 students studying science, engineering, the humanities, law, commerce and education. Traditionally the university has been especially strong in the natural sciences and engineering. The most famous graduate was Ernest Rutherford in the 1890s. He started his research career in experimental physics at Canterbury. Famous astronomers who came from Canterbury have included Beatrice Tinsley (galaxy evolution) and Roy Kerr (general relativity and rotating black holes). The University of Canterbury has a strong research programme in observational astronomy, neutrino astrophysics and theoretical cosmology, and operates Mt John Observatory, with its four optical telescopes, in New Zealand's central South Island.

www.canterbury.ac.nz
www.phys.canterbury.ac.nz

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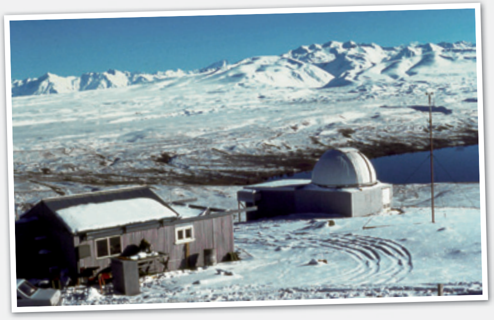
CHRISTCHURCH NEW ZEALAND

Life at an Observatory

The astounding images of the Universe that captivate so many, and the science that comes from them, are produced at observatories. These iconic institutions are instantly recognisable, with their large telescopes that scour the heavens. Join John Hearnshaw as he takes us on a tour of observatories, revealing how they are vital to modern astronomy.



Astronomers may have to brave difficult conditions, especially if working on site for a long time. This is definitely the case when snow and ice are present! This photograph shows Mt John Observatory in winter with the Southern Alps in the background.

I really am the luckiest of astronomers. I've now been an astronomer for over 40 years, and during this time I have been able to indulge in my cosmic passions more or less as I have chosen. For the last 32 years I have been working at Mt John Observatory, much of that time as the observatory director.

So why am I lucky? Because Mt John is surely one of the world's most beautiful observatories. I have seen many observatories in many countries, but none are as scenic as Mt John. It is sited in the centre of New Zealand's South Island, surrounded by high mountains and lakes. Lake Tekapo is just below the observatory, 25 kilometres in length, and is a most extraordinary turquoise-blue colour. What a sight on a fine day! Mt John, located at a latitude of 44° south, is also the world's southernmost optical observatory (except perhaps for small instruments at the South Pole). This makes Mt John invaluable for variable star campaigns that need round the clock observations, and also for monitoring far southern objects. Where else can one observe the Magellanic Clouds every month of the year?

Small is beautiful

All my astronomical life I have been working with small telescopes, mostly less than two metres in aperture. I have no regrets that I did not sign up to the big telescope league and join the rat race applying for observing time on telescopes like Gemini and Keck. First, New Zealand is a small country (just four million people) with limited resources. Investing in small telescopes, and doing this well, makes sense. Small telescopes with great instruments can often outperform large telescopes with mediocre instruments, especially if one has regular access to the equipment.
At Mt John there are four telescopes, two with 60 cm aperture, a 1-metre telescope and a 1.8-metre. The last of these was built by the Japanese, with whom we have a major collaboration on gravitational microlensing to find exoplanets.

When I came to Mt John in 1976, we just had the two small reflectors and very poor instrumentation. Immediately I borrowed a small Cassegrain spectrograph from friends and colleagues at the University of Florida, and was able to start New Zealand's first stellar spectroscopy programme that year. At the same time we started building the first Cassegrain échelle spectrograph in the southern hemisphere. It had first light in 1977. I obtained the design from the Harvard–Smithsonian Center for Astrophysics where I had been a post-doc fellow. With our échelle I was able to get superb high resolution photographic spectra of bright southern stars using a 60 cm telescope!


Observatories are usually surrounded by other buildings containing additional equipment, supplies and housing for astronomers. Here Mt John Observatory can be seen, with Lake Tekapo beyond.

Later we used an image tube which allowed us to reach fifth or sixth magnitude, and then in the 1980s we got a linear diode array, our first electronic digital detector. This was followed by our first CCD in the 1990s. An échelle spectrograph uses a special kind of diffraction grating for dispersing the light into its component colours. The light falls on the grating at a large and oblique angle, which promotes high dispersion.

Revolutionary instruments

Now I must mention one of our best projects at Mt John, the 1-metre McLellan telescope. We designed and built it ourselves in our university's workshops in the Department of Physics and Astronomy. We started in 1980 and did the optics, the mechanical design, the electronics, the control system and the dome. It was a big project and took us six years. Our 1-metre McLellan telescope (named after a former Professor of Physics) had first light in early 1986. It has now seen 22 years of continuous service and very few nights have been lost due to technical problems.

Another big project at Mt John which deserves mention is our 1.8-metre MOA telescope. MOA stands for Microlensing Observations in Astrophysics, and is a joint NZ–Japan collaboration. The telescope was installed by Nagoya University in 2004 and is dedicated to finding exoplanets, using the deflection of light rays from a distant source star by the gravitational field of a perfectly aligned lens star. This lensing action magnifies the source star's brightness for a while, perhaps a few weeks. Planets orbiting the lens star induce perturbations in this magnification process that can be detected using high time-resolution CCD photometry. We have contributed to five such discoveries so far. The MOA telescope, too, has a large CCD, with 80 million pixels, from a mosaic of ten chips at prime focus, and we measure the small changes in brightness of over 10 million stars in the bulge of the Milky Way every clear night throughout the winter months.

Promising projects

The McLellan telescope revolutionised stellar spectroscopy in New Zealand. In 2001 we designed and built Hercules, a large fibre-fed vacuum échelle spectrograph for precise radial velocity measurements and other studies of variable and binary stars. It is one of the best high resolution instruments on a small telescope anywhere. This was my "baby" and I am really pleased with how the instrument has performed. Hercules is the High Efficiency and Resolution Canterbury University Large Echelle Spectrograph. It now has a 16-million pixel CCD and can get

Observatories are built in locations where cloud is a rare sight. Observing time is valuable, after all! The image shows the dome of the 1.8-metre MOA telescope on Mt John at dusk.

the spectrum of a ninth magnitude star from ultraviolet to far red in an hour.

We are now in the process of improving the performance of Hercules by adding an iodine cell and a fibre double scrambler. The iodine cell superimposes a large number of fine absorption lines on a stellar spectrum, so as to give the velocity zero point, while the scrambler stabilises the image of the end of the fibre, as the light emerges into the spectrograph, and this gives a remarkably stable instrumental profile. Together these changes will allow radial velocity precisions of around 1 m/s. We expect these improvements will permit the search for Earth-like planets orbiting Solar-type stars. The Earth induces a velocity wobble in the Sun of only 9 cm/s; this means that 10 000 or so observations, each with 1 m/s velocity precision, of a Sun-like star over a few years might suffice to detect an Earth-like planet orbiting its star at the same distance as the Earth's distance from the Sun.

Pressing problems

There are big issues at Mt John still to tackle. One is ensuring a steady flow of keen young students who will do their training and research at our telescopes. Another is keeping light pollution in check. We still have some of the world's darkest and least polluted skies, but the nearby Tekapo village is expanding. Our lighting ordinance came into force in 1981, but we still have to be vigilant. And thirdly, there is the ever present problem of funding. Astronomy is expensive and running telescopes at a remote site with four resident technical staff consumes our resources. Finding ways to support Mt John financially will be a challenge for the future.

Comet McNaught from Mt John Observatory, January 2007.

Seiichi Sakamoto

Born in Tokyo, Japan

Biography

Seiichi believes it is important to take a scientific approach to many aspects of life. He also advocates that astronomers educate the public about not only the wonder of astronomy, but also the positive impact it has on our lives. To this end he is keen to communicate his work and that of other scientists to people from all walks of life. Seiichi's enthusiasm and honest work ethic has earned him the respect of many.

Seiichi's major research field is in radio astronomy and interstellar physics. He participated in the planning and construction of the Atacama Large Millimeter and submillimeter Array (ALMA). Seiichi currently works for JAXA as Director for Space Science Outreach at the Institute of Space and Astronautical Science (ISAS). He is an experienced astronomer and project coordinator, with many initiatives to his name.

Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science (JAXA/ISAS)

JAXA was established in October 2003 as an independent administrative institution, by integrating the Institute of Space and Astronautical Science (ISAS), the National Space Development Agency of Japan (NASDA) and the National Aerospace Laboratory of Japan (NAL). ISAS became one of four principal sections of JAXA. Its mission is to advance space science — scientific research conducted in outer space — in Japan, mainly by collaboration with universities. It also actively contributes to JAXA's and Japan's entire space development.

www.isas.jaxa.jp

JAXA

Selecting the Best Site for an Observatory

Professional observatories are our windows to the Universe, but finding the right place to build these colossal structures is a science in itself. Here, Seiichi Sakamoto talks us through the process of site selection, using the high-tech Atacama Large Millimeter/submillimeter Array as a case study.

The Earth's atmosphere absorbs, scatters and scintillates the signals from celestial bodies. Space is an ideal site for observations, but naturally has budgetary and technical constraints. Practically speaking, instruments much heavier than a few tons have so far been difficult to launch, and so ground-based facilities are vital. There is much literature on the importance of the scientific instruments; I will focus on the practical selection procedures of the site where the instruments are to be installed.

Astronomers love dry, high sites far away from cities

The requirements for a "good" site for astronomical observations depend on what you would like to observe. In general, a site for an astronomical project should be good in terms of atmosphere and geography.
The atmospheric factors include atmospheric transparency, seeing, meteorological conditions (e.g., surface wind, snowfall, near-surface temperature, lightning safety) and sky brightness. Geographical and geological conditions include local topography (i.e. slope, roughness), seismicity, mechanical/electric/thermal properties of rocks/soils, and available sky coverage due to latitude and skyline.

Other issues such as the existing infrastructure, accessibility, status of the host country (e.g., political status, environmental issues, satisfactory agreements, and labour level), construction cost and ease of getting funds sometimes play major roles in determination of the site. The scores and relative weighting of these conditions depend on the scientific objectives, specifications and cost of the instrument, as well as who is to promote and who is to fund. Even more complicated, they often vary over time and need to be modified within the boundaries of given budget, schedule, and manpower of the project.

Japanese site-testing equipment at the ALMA site in northern Chile. Containers, solar cells and some of the equipment are visible.

ALMA site testing

For optical telescopes, optical seeing and the fraction of photometric nights are of concern, and there are many good sites; e.g., Hawaii, northern Chile, the Canary Islands and South Africa. For submillimetre-wave and mid-infrared observations, at which wavelengths the atmospheric absorption is critical, astronomers prefer even drier and higher sites than optical observers. I will describe the selection of the site for ALMA, the Atacama Large Millimeter/submillimeter Array.

ALMA is an international project organised as the merger of three progenitors: the Japanese LMSA (Large Millimeter and Submillimeter Array), the American MMA (Millimeter Array), and the European LSA (Large Southern Array). All these required a site with high transparency and seeing in millimetre and submillimetre wavelengths, and with flat and wide areas for installation of large arrays.

In Japan, soon after the completion of the Nobeyama Millimeter Array (NMA) in the 1980s, radio astronomers started to think about an even larger array. The first concept was to fill up all 30 stations of the NMA with element antennas for short-term success, but the majority preferred going abroad for better sites. Our site survey started at this time.

An empty PET bottle of mineral water brought down from the ALMA site to Santiago (400 m above sea level), illustrating just how low the air pressure is at the ALMA site.

Initial surveys and pinpointing

After examining archived precipitation and topographic data, we picked dry and high sites in Hawaii, northern Chile, western China and northern India as candidate sites meeting the initial demands for a large millimetre and submillimetre arrays. The Antarctic plateau was discarded early on because of the poor stability of the icy surface. We organised a host of measurements with weather stations and radiometers, and surveyed several dozens of locations as a joint effort between the Nobeyama Radio Observatory (NRO), the US National Radio Astronomy Observatory (NRAO) and the European Southern Observatory (ESO).

Through this joint venture, we learned that northern Chile has superb conditions. We then concentrated our efforts to characterise the sites with the same instruments. We installed solar panels, containers as a refuge, weather stations, radiometers and radio seeing monitors for statistical characterisation of the sites. After taking measurements over a few years, we made a quantitative comparison of candidate sites and finally selected a 5000-metre altitude area near Cerro Chascon in northern Chile.

Site characterisation for design works

Once the site was fixed, we needed to learn about the atmosphere above the site in more detail and also details about the terrain to draw up practical designs for instruments and infrastructure. The items we monitored included atmospheric temperature, humidity, wind speed and direction, wind gusts, atmospheric transparency and seeing in radio waves, solar radiation in the visible and ultraviolet, cosmic ray intensity, lightning, and soil resistivity. We also launched radiosondes from the high site. Virtually all of the initial measurements were carried out by astronomers and observatory staff.

The first ALMA antenna installed near the Array Operations Site Technical Building, 5050 m above sea level. The upper part of the two-storey building is filled with air conditioners because of the low air pressure.

Site remoteness, reduced oxygen and safety

During the site testing, safety was my greatest concern. We usually drove four-wheel drive trucks to go off-road. Additional spare tyres, extra fuel tanks, and a satellite communication system were necessary during the early survey stage. For safety at a remote and high site like this, the joint site testing team established the "two-car rule" and "two-person rule", quite similar to the buddy system applied by scuba divers ("never be alone"). In addition, each car is equipped with a walkie-talkie to ensure communication.

Work at more than 4000 metres altitude is challenging. The brain consumes plenty of oxygen while there is only half the amount that we are used to. We wore pulse oxymeters to continuously monitor our arterial oxygen saturation. I applied a working-hour limit at the high site — four hours for the first day, six hours for the second and eight hours from the third day on.

Now the site is almost ready

In November 2003, a ground-breaking ceremony for site construction was held at the site. A few years later, I left ALMA to start my new career at JAXA, and I understand that the site is nearly ready and that the first antennas have been installed. ALMA will be fully operational in 2012, and the first call for proposals is expected soon. I hope I will be among those lucky enough to use it!

Brother Guy Consolmagno

Born in Detroit, Michigan, USA

Biography

Brother Guy Consolmagno SJ is a planetary scientist and Curator of Meteorites at the Vatican Observatory. He is a past chair of the Division for Planetary Sciences of the American Astronomical Society and past president of Commission 16 (Planets and Satellites) of the International Astronomical Union. He earned undergraduate and master's degrees from MIT, and a PhD in Planetary Science from the University of Arizona, was a postdoctoral fellow at the Harvard–Smithsonian Center for Astrophysics and at MIT, served in the US Peace Corps (Kenya), and taught university physics at Lafayette College before becoming a Jesuit in 1989. At the Vatican Observatory since 1993, his research explores connections between meteorites, asteroids, and the evolution of small Solar System bodies.

Brother Guy seeks to demystify the lives of scientists, and to encourage people to look at the stars, either as amateurs or professionals. To this end, along with more than 100 scientific publications, he is the author of a number of books including *Turn Left at Orion* (with Dan Davis), *Worlds Apart* (with Martha Schaefer), *Brother Astronomer* and *God's Mechanics*.

The Vatican Observatory (Specola Vaticana)

The Vatican has had astronomers since the Gregorian reform of the calendar in 1582. The Observatory in its present form was established by Pope Leo XIII in 1891 to show that the Church embraces, encourages and promotes science with the fullest possible devotion. Today a dozen astronomers from four continents, most of them Jesuit priests and brothers, work in cosmology and galaxy formation; stellar spectroscopy; and meteorites, meteors and circumstellar dust. The headquarters are in the Pope's summer gardens outside Rome, with a modern 1.82-metre telescope placed in southern Arizona.

www.vaticanobservatory.org

VATICAN OBSERVATORY

Magnificent Meteorites

Written from the control room of the Vatican Advanced Technology Telescope in Arizona, Brother Guy Consolmagno here delves deep into meteorites, addressing their creation, composition, location and importance. Tricks of the trade are put on the table as methods of analysing these pieces of cosmic debris are addressed. This all comes together with the grand aim of understanding how the Solar System and the objects within it were formed, four and a half billion years ago.

I'm writing this from the control room of the Vatican Advanced Technology Telescope on Mt. Graham, Arizona. My work here is not so very different from observers around the world on any given night... except that this really isn't my work at all. I am a meteoriticist. My real work takes place in a laboratory 8000 kilometres away from this Arizona mountaintop, in the Pope's summer home of Castel Gandolfo, Italy, where the Vatican's meteorite collection is housed. In that lab I measure the physical properties of those rocks from the asteroid belt: density, porosity, magnetic properties. So why am I at a telescope?

I started out as a theorist. I wanted to use the physics and chemistry of small Solar System bodies to make computer models that could match what we actually see in the moons around the gas giant planets, or the asteroids that orbit between Jupiter and Mars. I had assumed that meteorites were good analogues for the material that made up those small bodies, but it was hard to find data for the physical properties of the meteorites. When I was assigned to the Vatican Observatory in 1993 and got to see the wonderful collection of meteorites, I worked out a rapid, non-destructive way to get the data I needed from these samples.

Melissa Brucker (University of Oklahoma graduate student and Lowell Observatory pre-doc) and me at the controls of the Vatican Advanced Technology Telescope on Mt Graham, Arizona, measuring Centaur light curves.

Blame it on Galileo!

In one sense, you can blame it on Galileo. Not only the man who invented the telescope (and whose problems with the Church eventually led it to found an astronomical observatory, in a sort of quiet apology for those problems). But it was the Galileo spacecraft that passed by asteroid Ida on its way to Jupiter in the early 1990s and discovered a moon orbiting that asteroid. By seeing how fast the moon moves around the asteroid, we could calculate how massive the asteroid pulling on it must be. Thus it became the first asteroid for which a mass and density could be measured. Since then, other techniques from radar echoes to adaptive optics on the largest telescopes have led to the discovery of dozens more moons around asteroids.

I took part in the 1996 field season of the Antarctic Search for Meteorites programme. Every year, hundreds of meteorites are recovered from the ice sheet of Antarctica, where they are well preserved by the cold. They're easy to spot against the white ice!

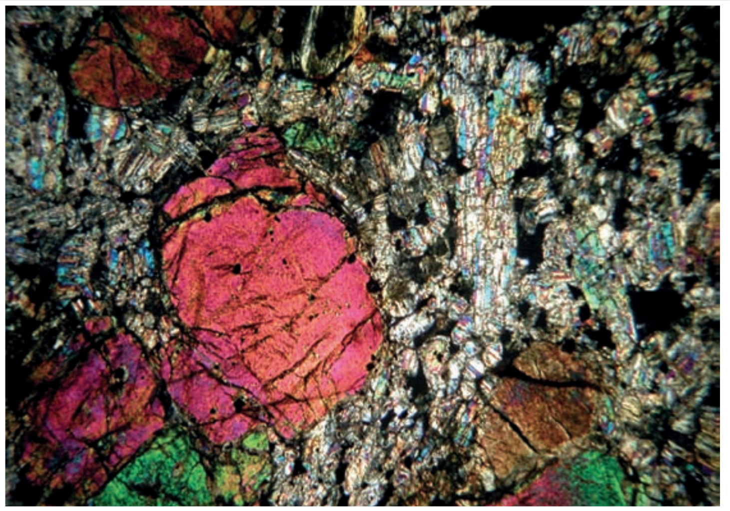
Tonight's work

Once you know the mass of an asteroid, you can divide that mass by the asteroid's volume to get its average density. And our meteorite densities have turned out to be 20% to 50% larger than the densities of the asteroids from which they come; asteroid volumes are 20% to 50% empty space! The asteroids are not solid rocks but rather highly fractured and porous piles of rubble.

Meanwhile, during this same time a whole new collection of asteroid-like objects was discovered orbiting out beyond Neptune: the Kuiper Belt. This apparently is the source for many of the comets we see. Are comets and Kuiper Belt bodies also made partly of empty space?

That's hard to tell. It's not only that they are so much further away from us than the asteroids, but, unlike the asteroids, we don't have sample comets in our lab to measure. So how can we tell what they are made of? By comparing their detailed colours with the spectra of different materials in our lab. That's one reason I observed them with the telescope in Arizona — to measure their colours and guess their composition.

In addition we have a hard time measuring the density of these distant objects. Finding their mass is hard as only a few have visible moons. Worse, they are so far from us that measuring their volumes is almost as difficult as measuring their masses.



A slice of Dar al Gani 476, a shergottite meteorite, believed to come from Mars. Measuring the physical characteristics of meteorites allows us to understand better both the current state and the evolutionary history of the planets and asteroids from which they come.

Tricks of the trade

There is a trick, however, that can let us make an intelligent guess at their average densities. If a body is not a single solid object but a very weak pile of rubble, then the faster it spins, the more its spin should pull it into an elongated shape. What holds such a body together against that spin is its gravity, which depends on its average density. So for a given spin rate, the more elongated it is, the lower its density must be.

If we can measure how fast a body spins, and how elongated it is, we should be able to estimate its density and by seeing how the brightness changes as it spins, we can compute not only how fast the body is spinning but, from the difference between the brightest and the dimmest phases, how non-spherical it is. To get a complete fit requires observing this "light curve" at many different positions in the body's orbit around the Sun.

This view of the asteroid 243 Ida is a mosaic of five image frames acquired by the Galileo spacecraft. Ida is an irregularly shaped asteroid believed to be a stony or stony iron meteorite.

And that's what we're working on tonight. We choose Centaurs, bodies perturbed out of the Kuiper Belt, because as they approach the Sun we get to see them at many different aspects in their orbits. It would take hundreds of years to get the same range of aspects for the bodies out in the Kuiper Belt itself. Even for Centaurs, however, we need light-curve data taken over many decades. Tonight's data will be one more piece of evidence that may someday allow us to understand just how these distant objects are put together.

And then, ultimately, we can compare the structure of the asteroids from which my meteorites come, with the structure of the bodies from which comets come. Then, just maybe, out of that data we'll have new insights into how all those bodies, asteroids, meteorites and comets were formed back when the Solar System itself was formed, four and a half billion years ago.

Salim Ansari

Born in Marene, Italy

Biography

Salim holds a PhD in Astrophysics from Vienna University, Austria. He has been with the European Space Agency since 1991. After his studies he held a post-doc position at Observatoire de Strasbourg, France, working on astronomical archives and data dissemination, before moving to ESA/ESRIN in Frascati, near Rome, Italy. His focus was on Information Systems.

Salim helped create the Catalogue Service ViZier at the Centre de Donnees astronomiques de Strasbourg, which was established in 1995. In January 2000 he moved to ESA/ESTEC in the Netherlands and joined the Science Directorate. He was involved in Gaia, the billion-star detector from 2001 to 2005, where he created the first Astronomical Virtual Organisation, which was known as GaiaGrid. Currently, Salim heads the IT, Communication and Education Service in the Science Directorate. Salim speaks about six languages and has lived pretty much everywhere!

European Space Agency

The European Space Agency (ESA) is Europe's gateway to space. Its mission is to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the citizens of Europe and the world. ESA's main programmes are: Earth Observation, Human Spaceflight and Exploration, Launchers, Navigation, Science and Telecommunications. Composed of 17 European member states, ESA has its main centres in France (Headquarters), the Netherlands (ESTEC), Germany (ESOC and EAC), Italy (ESRIN) and Spain (ESAC). ESA has currently about 15 operational spacecraft for the benefit of scientific research, ranging from astronomical space observatories covering a wide range of the electromagnetic spectrum to planetary and solar sciences.

www.esa.int

Why Do We Study Astronomy from Space?

Why do we actually go into space? What is it that drives us towards putting up more and more satellites to observe the Universe, when at the same time we are building bigger and bigger telescopes on the ground? For the professional astronomer this is obvious. For the public at large, it isn't. Salim Ansari has worked in space science for many years and so discussing these questions has become second nature to him. This expertise has been condensed into the following feature article, to show why we study astronomy from space.

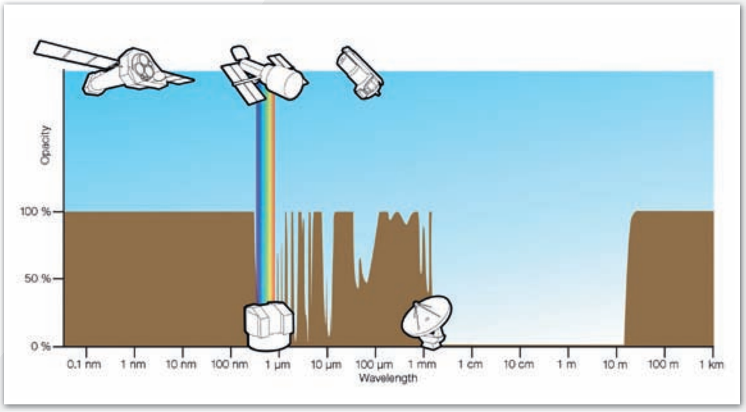
This illustration shows the NASA/ESA Hubble Space Telescope in its high orbit 600 kilometres above Earth.

In the early sixties, the first "space" balloons were launched to the edge of the Earth's atmosphere to get a glimpse of the Universe using sensitive instruments that could observe the skies in the X-ray region of the electromagnetic spectrum. It was a major breakthrough for astronomers to be able to actually go beyond the visible region of the spectrum, allowing them to take a look at the violent Universe from another perspective. X-ray astronomy was born.

At the other extreme, astronomers could place observatories high up on mountains, allowing them to see into the region beyond the visible and towards longer wavelengths. The cold Universe became apparent and with it infrared astronomy thrived. This was the beginning of human exploration of the spectral regions beyond visible light. Multi-wavelength astronomy was born.

A golden age

Today's instruments and telescopes are larger, more sensitive, better and reveal a lot more than ever before. Remember the first images from the corrected Hubble Space Telescope? They fascinated us. They showed a Universe that, even in visible light, was completely unknown. With satellites like ESA's XMM-Newton or NASA's Chandra, we are beginning to explore phenomena that we could only dream of some 40 years ago! Active galactic nuclei, violent stellar explosions, and proof of the makings of black holes fill scientific literature! On the other end, newly launched giant infrared observatories such as Herschel and Spitzer take us into the wombs of the Milky Way, where stars are being born. The sky will never be the same. It is a wonderful time to be here and to experience all these phenomena.



ESA space telescopes can detect the full range of the electromagnetic spectrum from space, from microwaves to gamma rays.

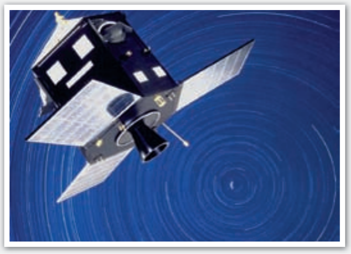
Modern technology

With the advancement of technology on Earth, today we can certainly match some of Hubble's capabilities with ground-based telescopes. Projects such as the European Southern Observatory's (ESO) Very Large Telescope are pushing optical technology to the limits to bring us ground-breaking data in visible light. The driving factor for space telescopes is certainly what is invisible from the ground. That is financially justifiable. That is why our focus in space is high-energy astrophysics (X-rays and gamma rays), because we'll never be able to build ground-based telescopes to cover those wavelength regions. The same applies to the far-infrared and beyond. We need dedicated observatories up there to study phenomena over long periods of time. However, as long as Hubble is in orbit we will make the most of it, so long as its maintenance is cheaper than building something new.

Today there are basically two types of satellites. Those that have a pointing function; meaning they need to be pre-programmed every once in a while to observe certain objects, and survey satellites that are in robot-mode. Principal Investigator satellites are regularly pre-programmed with a set of pointings in order to study specific objects in the sky over longer periods or in more detail. Objects like the Orion Nebula, where the birth of stars takes place, is a fascinating region of the sky for the infrared experts, while the galactic centre of our Milky Way is cluttered with black hole candidates and dying stars that can be studied by ESA's XMM-Newton X-ray spacecraft or Integral in the gamma ray region.

Maintaining a vigil

There are, however, several survey spacecraft that scan the sky for specific phenomena. Hipparcos, the first astrometric satellite of its kind, has contributed to astronomy in a very fundamental way by measuring the positions of more than two million stars very accurately. With its successor Gaia, to be launched in the near future, we hope to measure one billion stars, thereby giving us insight into the evolution of the Milky Way and to study relativistic effects in more detail. Planck and Nasa's Wilkinson Microwave Anisotropy Probe are studying the cosmic microwave background to answer questions about the origins of the Big Bang. Much work and research has yet to be carried out before we can even get a small glimpse of this vast Universe.



Unique to Europe, Hipparcos was the very first space mission for measuring the positions, distances, motions, brightnesses and colours of stars.

With telescopes on the ground and our satellites in space, humankind continues to push curiosity further and evolve our understanding of the heavens above!

This image was taken by the European Space Agency's Herschel Space Observatory. Star and planet formation is usually hidden from view by these great cocoons of dust. From space Herschel allows us to see through the dust to watch the process.

Emanuel Mumpuni

Born in Jakarta, Indonesia

Biography

Emanuel grew up in a deprived area of Jakarta. His family was poor, and his father worked for the Catholic Church in his neighbourhood, while his mother was an elementary school teacher. Emanuel has a younger sister, a medical doctor currently working in a medical insurance company, and a younger brother studying graphic design. Emanuel graduated from the Department of Astronomy, Bandung Institute of Technology, and soon after began working with the national space agency, the Indonesian Institute of Aeronautics and Space/LAPAN. Recently he has had the opportunity to continue his studies by working towards a Master's Degree, from the same department. There are plans to build an observatory in the eastern part of Indonesia to develop astronomy in that region. Emanuel is part of this, and also involved with the South East Asia Astronomy Network.

During Emanuel's studies he has been honing his journalistic skills. Together with some like-minded colleagues he formed langitselatan.com, a popular astronomy website in the Indonesian language. Emanuel describes himself as a simple and humble person who loves a friendly life with friends and neighbours. He likes nature adventures, music, playing the guitar, clarinet and gamelan (a traditional Javanese set of instruments), photography, as well as discussing art, culture and politics. Perhaps most of all, and due to his past, he is passionate about fighting poverty and improving lives however possible.

National Institute of Aeronautics and Space (Lembaga Penerbangan dan Antariksa Nasional), LAPAN

The emphasis of work at the Indonesian National Institute of Aeronautics and Space (LAPAN) is on research and development in space science and technology, space policy, and space applications. There are three offices assigned to support LAPAN activities: (i) The Space Technology Center; (ii) Remote Sensing; (iii) Center for Science on Space, Climate, Atmosphere, and the National Space Policy.

Emanuel Mumpuni works in the third of these, in the division of Solar and Space. This division is responsible for studies of solar and space dynamics (including observations in optical and radio and orbital analysis) and providing the information to the users.

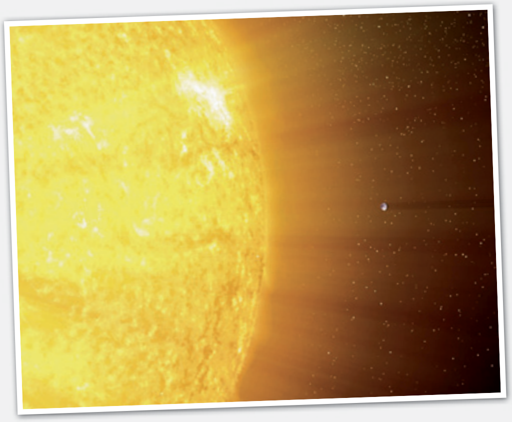
www.dirgantara-lapan.or.id

LAPAN

Sol Lucet Omnibus

The Sun Shines for Everyone

Different people over the ages have answered the seemingly simple question "What is the Sun?" in many ways. Is it a source of life? Ethereal light? A giant fireball? Emanuel Mumpuni's article takes a look at our nearest star, from a cultural as well as scientific perspective, discussing topics as varied as ancient Sun worshippers and global warming along the way.



The Sun is at the centre of our Solar System. This illustration shows the relative sizes of the Sun and the Earth by placing them impossibly close together. The Earth is tiny compared to the Sun.

The important things are always simple; the simple things are always hard. Sometimes when a trivial question pops up, the answer is neither immediate nor trivial. Like this question: "What is the Sun?"

The Sun is... A humongous fireball which is at the centre of the Solar System? Our closest star? Ethereal light? A source of life? God?
Let us start with the simplest thing: the Sun is a marker of the day. If the Sun is up, it is day, and vice versa for night. From ancient times, when the Sun started to brighten the land, people were active, hunting and harvesting. When the Sun was gone, it was time to rest. The separation of day and night sets the pattern of behaviour for life. From that variation humans gained knowledge of time, and from that understanding came the calendar and along with that came the worship of supreme beings.

The Sun can be comprehended as the primordial manifestation of faith. It is energy, the essence, the bringer of life, name any virtue that you like. The Sun has played a major role in most ancient belief systems throughout the world. But humanity evolved. Worshipping the Sun is no longer a central theme for most current faith systems, but one thing is still the same: the dynamics and variations of the Sun are vitally important for humanity.

It is an inevitable fact that the Sun is affecting the Earth, because if there were no Sun neither our atmosphere nor life could exist. There is even some debate on whether the Sun could be partly responsible for the global warming. There are at least some indications supporting this theory. During the Middle Ages, there was what is known as a "Little Ice Age". This phenomenon might relate to the Sun. During that period solar activity was at its lowest level. Solar activity is defined by the appearance of dark patches on the surface, called sunspots. For many years there were no records of sunspot numbers because none were present. This period is known as the Maunder Minimum.

We know that the Sun has dynamics, and the dynamics are felt on the Earth through climate, the seasons, day and night. If the Sun is changing, the effect will be felt on Earth.

The first photo shows a sunset as our eyes naturally perceive it, and the second as it would be if we could see the near-infrared part of the electromagnetic spectrum.

The Sun is the centre of the Solar System that contains the Earth, some other planets and minor bodies such as asteroids, meteorites and comets. The planets and minor bodies are moving around the Sun. The Sun is the largest object and contains approximately 98% of the total mass of the Solar System. If we compare the size of the Sun and the Earth, it would take 109 Earths to fit across the Sun's disc, and you would need more than one million Earths to fill the Sun. Wow!

The Sun is not a solid body. It is, in fact, a ball of dense, hot gas. Deep down in the core there is a reaction occurring called nuclear fusion. During this process atoms of hydrogen are fused to form a bigger atom, helium. During this process energy is given off as heat and light. We cannot peer directly into this core so we have to wait until the light can be observed on a "boundary" where the Sun is sufficiently transparent. This area is known as the photosphere. The photosphere is a "surface" that is constantly changing with sunspots and huge storms called prominences. These can be larger than the size of Earth!

As a machine that needs fuel to run its engine, the Sun needs hydrogen converted into helium as fuel to shine continuously. Physically the Sun consists of 75% hydrogen, 24% helium and traces of many other elements such as iron, oxygen and calcium. The Sun has enough fuel left to shine for five billion years.

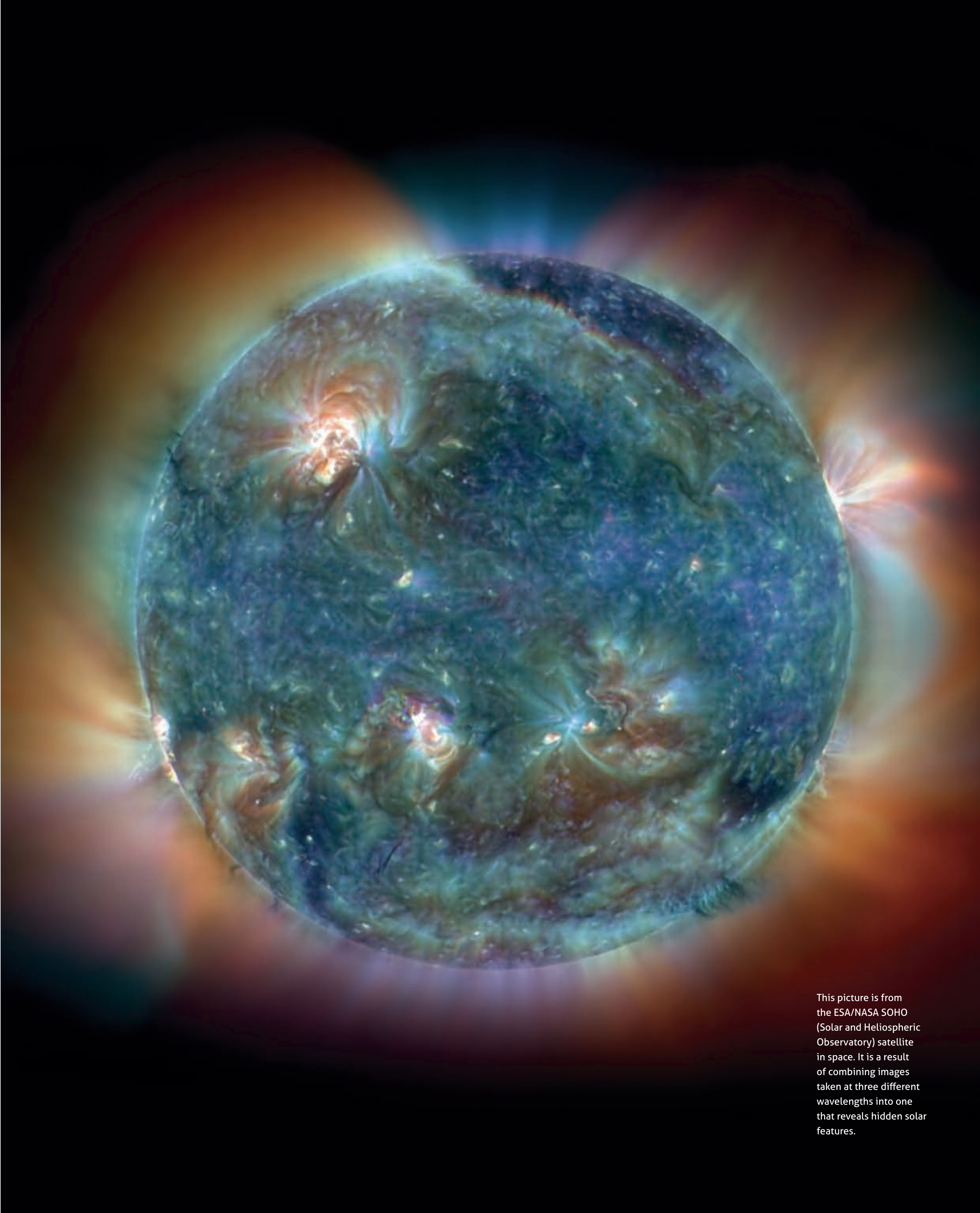
The picture on the next page was taken by a satellite telescope. We cannot see the Sun directly like this as the wavelengths are beyond those we can see. But this is the same Sun that brightens our lives on a regular basis; it just looks different.

We can learn from pictures that there are many facets of the Sun hidden from our perception. Does that make you feel awe and wonder? The question, "What is the colour of the Sun?" can for instance be complex.

Looking at the Sun with human eyes it is fair to say that the Sun is white, with a bit of yellow. Find the answer by stepping outside and looking for yourself! But make sure you do not look directly at the Sun though, as this is very dangerous for your eyes.

Surely, the Sun has aroused awe and inspired humanity spiritually and scientifically. The thought, the idea, the emotion of the heavens have inspired paintings, poems, folklore and many other forms of human creativity and at the same time have increased the human capability to make life better.

This tantalising TRACE image shows clusters of the majestic, hot coronal loops, which span 30 or more times the diameter of planet Earth.



This picture is from the ESA/NASA SOHO (Solar and Heliospheric Observatory) satellite in space. It is a result of combining images taken at three different wavelengths into one that reveals hidden solar features.

Heidi Korhonen

Born in Hamina, Finland

Biography

Heidi was born in south-east Finland and during her childhood lived in many different places in Finland, from the southern coast to all the way north of the Arctic Circle. She was always very interested in astronomy, but was never the kind of amateur who would spend her nights staring at the stars. Still, when the time came to decide what to do after high school, she didn't hesitate to start studying astronomy. She had no idea what professional astronomers actually did, so it was a real jump into the unknown; a jump that she hasn't regretted! Heidi completed her Master's degree at the University of Oulu in Finland. Afterwards, in 1998, she moved to sunny La Palma in the Canary Islands. She worked there for 18 months at the Nordic Optical Telescope, where she met her husband, a fellow astronomer. After moving back to Oulu with him, their daughter was born in 2001 and Heidi received her PhD soon after. Next, Heidi got a position in Germany with the Astrophysical Institute Potsdam. Her second child, this time a boy, was born in Potsdam in 2003. In the summer of 2007 Heidi and her family decided it was time to move, so they relocated to southern Germany, to the Munich area. Heidi spends ten months of the year working at ESO Headquarters near Munich, and the other two at ESO's observatory in Cerro Paranal, Chile.

European Southern Observatory (ESO)

ESO is the foremost intergovernmental astronomy organisation in Europe and the world's most productive astronomical observatory. It operates three sites in Chile — La Silla, Paranal and Chajnantor — on behalf of its fourteen member states. It is building ALMA, the Atacama Large Millimeter/submillimeter Array, together with international partners, and designing the European Extremely Large Telescope.

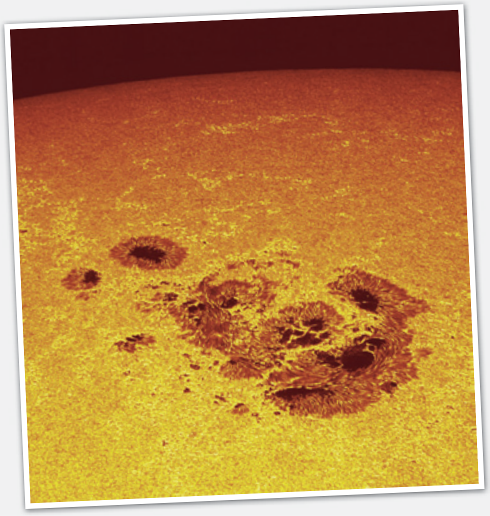
www.eso.org

ESO

Sunspots and Starspots

Magnetic Islands Larger than our Planet

The Sun may appear as a perfect sphere in the sky, but it actually has blemishes called sunspots. Their nature was a mystery until modern science was able to explain their nature and workings. Now, astronomers have a new task: to determine whether other stars exhibit the same phenomena! As Heidi Korhonen explains, this research gives interesting answers, but also raises fresh questions.



A detailed image of the largest sunspot is seen on the picture of the full solar disc overleaf. This observation was obtained with the Dutch Open Telescope on La Palma, Spain, on 2 November 2003. The complexity of this huge sunspot group is breathtaking.

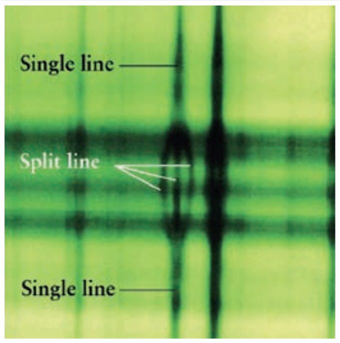
If you glance at the Sun through fog, clouds or darkened glass you will usually see a perfectly white disc (never look at the Sun directly because of the damage it will do to your eyes!). Sometimes you might see dark patches on this smooth surface. Usually these sunspots are so small that you would see them only with the aid of a telescope, but occasionally large spots occur, many times larger than the Earth and these are visible to the naked eye.

Dark or light?

Even though sunspots appear dark they still radiate light, and actually they are brighter than the full Moon. They just appear dark when compared to the rest of the Sun. What is causing this apparent darkness? When scientists first started regular observations of sunspots, after the development of the telescope in the early 17th century, their origin was already hotly debated. Some thought that they were clouds in the solar atmosphere, others that they were small bodies orbiting the Sun. Quite soon scientists agreed that they were actually something that was in the Sun itself, but it took a couple of hundred years before people really started to understand what sunspots are.

Mysterious magnetism

In 1908 the magnetic origin of sunspots was discovered by an American astronomer, George Ellery Hale. In the presence of a magnetic field, spectral lines are split into several components. Hale used this so-called Zeeman effect to show that sunspots harbour very strong magnetic fields. The Earth's magnetic field at the equator is approximately 0.3 Gauss; the field in sunspots can be as high as 3000 Gauss. In the normal solar atmosphere material is transported from the hot interior, causing an outward flow of heat and energy. In sunspots, the magnetic field acts as a valve hindering the normal heat transport. Some heat transport still occurs and thus the sunspot is still hot, approximately 4000 degrees Celsius, but even though this sounds very hot, it still is about 2000 degrees Celsius less than the rest of the solar surface.



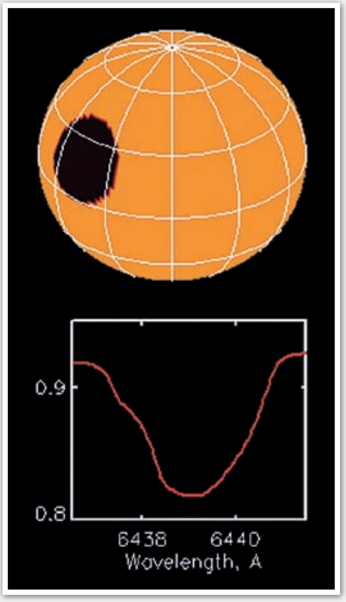
In the presence of a magnetic field, spectral lines that are normally at a single wavelength split into two or three components (Zeeman splitting). Here observations of spectral lines inside a sunspot (split lines) and in the surrounding solar surface (single line) are shown.

Modern telescopes can make extremely detailed pictures of the Sun, resolving structures that are less than 100 kilometres in size. When looking at a sunspot with such high resolution, it's possible to see an amazing amount of detail. Large sunspots consist of two main parts: the darker inner region called the umbra, and the lighter outer region called the penumbra. Even the dark umbra is not completely dark, it can host bright points or lanes, which are called umbral dots and light bridges. In the centre of the sunspot the magnetic field is at its strongest and comes straight out of the Sun (or goes directly in). When moving away from the centre of the spot the magnetic field weakens rapidly.

A common phenomenon?

Do stars other than our Sun also show spots? Or is our own star just a special case? This question is difficult to answer. Stars are very far away from us, and thus they are just points of light as seen from Earth. Even with the largest modern telescopes, it is impossible to make direct images of the surfaces of stars. The only exception to this are the nearest supergiants, very large stars that have diameters dozens of times that of the Sun. Images of the surfaces of supergiants, like Betelgeuse (the very bright red star in the constellation of Orion), are available. In these images the resolution is quite poor and only structures that are very much larger than our Sun can be seen. So, what can be done if one really wants to see spots on other stars?

The most detailed information on stellar surfaces can be obtained using Doppler imaging. This is an indirect method in which high resolution spectra are obtained at many different times during the rotation of the star. The high resolution spectra show the shape of the spectral lines in great detail, and the exact shape of the spectral line depends on many physical parameters, among them the temperature. Therefore, if spots with a different temperature from the rest of the stellar surface are on the surface when the star is observed, a change in the shape of the spectral line is seen. If the observations are repeated while the star rotates, a detailed map of the surface temperature, known as a Doppler image, can be created.



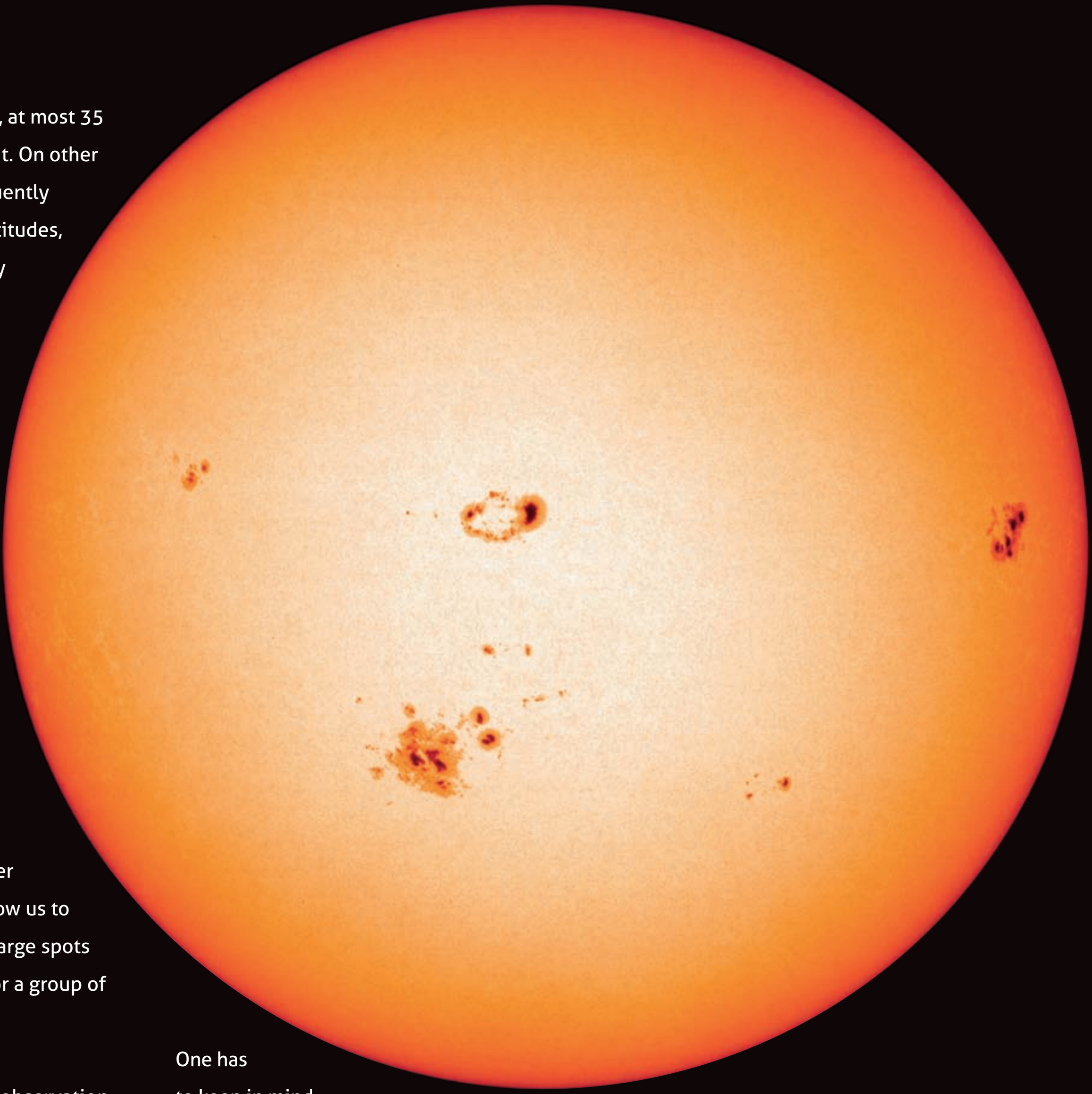
The principle of Doppler imaging. The detailed shape of the observed spectral line profile changes when a spot of different temperature is seen on the surface. A map of the surface temperature can be obtained when the star is observed at many different rotational phases, and the movement of the "bumps" in spectral lines is followed in detail.

Surprise discoveries

With Doppler images, starspots can be studied in detail. For some stars observations over several years exist, enabling us to also study starspot evolution with time. One of the most striking discoveries with Doppler imaging is the latitude range at which the spots can occur. In our Sun the spots occur very close to the equator, at most 35 degrees away from it. On other stars spots are frequently seen at very high latitudes, 50–65 degrees away from the equator, and even at the rotational poles themselves. Another surprise discovery was the sheer size of the spots. Some spots on giant stars (old stars having diameters several times that of the Sun) are larger than the Sun itself. Still, even the resolution of Doppler images does not allow us to see whether these large spots are one huge spot, or a group of smaller spots.

Another interesting observation is that while on the Sun the spots live only for a relatively short time, usually days and at most some weeks, on some other stars spots have been observed at the same location for several years. This of course does not necessarily mean that it would have to be exactly the same spot staying there the whole time; some spots could die and new ones form at the same location.

One has to keep in mind that so far all the methods for seeing spots on other stars than our Sun allow us to only see very large spots. With the current instruments and observing techniques one would not be able to detect even the largest sunspots on distant stars. Still, our observations of other stars provide very interesting, and sometimes surprising, pictures of magnetic surface structures on stars.



The solar disc observed by the MDI (Michelson Doppler Imager) instrument on-board the NASA/ESA SOHO spacecraft. The image shows the appearance of the Sun in visible light on 28 October 2003. Several large sunspot groups are seen on the solar surface. The three biggest groups are all rare naked-eye sunspots, with the biggest one occupying an area equal to about 15 Earths.

Franck Marchis

Born in Caen, France

Biography

Franck Marchis is an assistant research Astronomer at the University of California at Berkeley and a Principal Investigator at the SETI Institute. He received his PhD in 2000 from the University of Toulouse, France, in planetary science. Although he worked on his thesis while living in several places — Mexico, France and the United Kingdom — the main part of his studies took place while working at the La Silla Observatory in Chile for the European Southern Observatory.

He took part in the development of observations with the first adaptive optics system available to a large community, called ADONIS, on the 3.6-metre telescope. He moved to California shortly after receiving his PhD in November 2000 to take up a postdoctoral position at UC Berkeley. Since then he has dedicated most of his time to monitoring Io's volcanism and the study of multiple asteroid systems with the Keck 10-metre telescope and in the support of CfAO, an NSF science and technology centre. In 2003, he was hired as an assistant researcher and recently became involved in the design of a mission, co-advising students at NASA Ames who are developing a mission concept to explore a binary near-Earth asteroid. He is an associate astronomer at the Observatoire de Paris, IMCCE.

University of California at Berkeley
UC-Berkeley, a public research university located in Berkeley, California, is the oldest university of the ten campuses affiliated within the University of California. The Department of Astronomy offers undergraduate and graduate instruction in a wide variety of fields, including theoretical and observational astrophysics; infrared, optical, and radio astronomy; galactic structure and dynamics of stellar systems; high-energy astrophysics and cosmology; planetary science and spectroscopy.

http://astro.berkeley.edu/

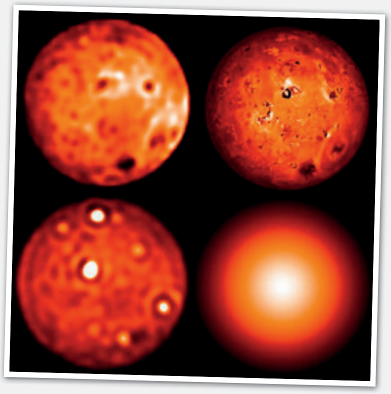
Carl Sagan Center at the SETI Institute
The SETI Institute is a not-for-profit organisation that is looking for evidence of life beyond Earth, a scientific discipline known as astrobiology. The mission of the SETI Institute is to "explore, understand and explain the origin, nature and prevalence of life in the Universe". One programme uses both radio and optical telescopes to search for deliberate signals from extraterrestrial intelligence (SETI). Other research, pursued within the Carl Sagan Center for the Study of Life in the Universe, includes the discovery of exoplanets, the potential for life on Mars and other bodies within the Solar System, and the habitability of the Milky Way.

www.seti.org

SETI Institute

Our Solar System through the Eyes of Adaptive Optics

The largest and most recently built telescopes are equipped with primary mirrors 8 to 10 metres in diameter, but in reality they do often not provide images with a quality better than can be delivered by a 20 cm telescope. The blurring effect caused by the Earth's atmosphere limits the image quality, and the only way to overcome this is to correct for it in real time using adaptive optics (AO). Franck Marchis is using AO systems to study the diversity of our Solar System, focusing his activity on monitoring volcanic activity on Io, a moon of Jupiter, searching for multiple asteroid systems and studying Jupiter's atmosphere.



Surface details of Io captured with adaptive optics (upper left) show a comparable level of detail to the upper right picture, taken from space with NASA's Galileo orbiter. The lower left image is dominated by hot spot emissions from active volcanoes, such as Loki, located near the centre of the disc. These spots can now be monitored from the ground. An image of Io without adaptive optics (lower right) doesn't reveal any hot spots.

Our Solar System, composed of the Sun, eight major planets, five dwarf planets, and millions of comets and asteroids, is characterised by great diversity not only in terms of sizes and shapes, but also with respect to interactions and phenomena. Each planet and satellite is unique due to varying factors such as volcanic activity or collisions between planets and asteroids. To understand our Solar System and its evolution, we need to monitor it in detail. That's why the contribution of ground-based telescopes equipped with adaptive optics (AO), which allows a ground-based telescope to deliver images of a comparable quality to space-borne telescopes, has been increasing over the past 15 years.

Adaptive optics on large telescopes

The charming twinkling of the stars that you may have noticed on a clear night is actually the effect of the Earth's atmosphere that bends and distorts the light coming from these stars. If you look through a telescope, you will see that this atmospheric distortion is unpredictable, blurring the view. In an attempt to limit this effect, astronomers build telescopes at high altitudes far away from cities, such as on the top of the dormant volcano Mauna Kea in Hawaii, or in the dry Atacama Desert in Chile.

For many years astronomers waited for the development of advanced computer systems and other technology before a solution could be found.

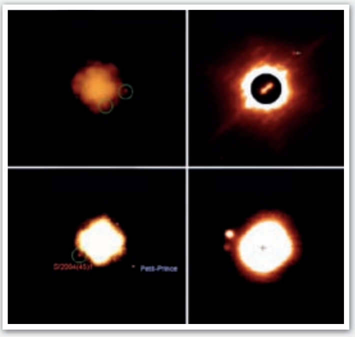
Adaptive optics is a system that corrects for the effect of atmospheric turbulence in real time. The distortions are analysed hundreds of times per second and corrections are produced by deforming the telescope's mirror using motors called actuators. Since 2001, the W. M. Keck-II telescope has been equipped with an AO system. The first AO system on the Very Large Telescope in Chile was offered to the European community in 2003. AO systems are nowadays commonly used by astronomers in all fields, from extragalactic astronomy, studies of the Milky Way to Solar

System astronomy. They often compete in image quality with those produced by the Hubble Space Telescope!

The most energetic eruption seen as it happened

On 20 February 2001, we pointed the W. M. Keck-II telescope, equipped with AO, towards Io, a moon of Jupiter known for its volcanic activity. The exquisite resolution achieved using this 10-metre telescope revealed incredible detail on the surface, such as dark calderas and craters of volcanic origin. Two days later we re-observed the same side of Io and discovered a new a bright eruption that was visible because of the high temperature of its magma, its area and the type of volcanism (fire fountains). We later realised that this eruption was the most energetic ever witnessed, either on Io or the Earth! It covered an area of 1900 square kilometres, larger than the entire city of London!

Today, ground-based telescopes equipped with AO systems are the best tools for monitoring volcanic activity on Io. Io always surprises us and it is definitely one of the most interesting targets to observe from the ground. Our ultimate goal is to understand the nature and evolution of this exotic volcanism.

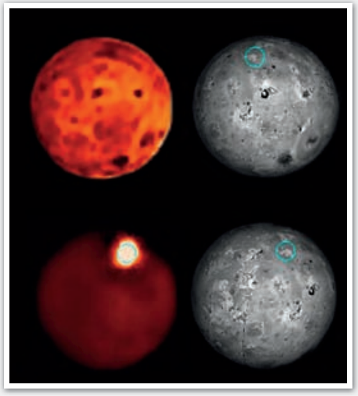


Family portrait of the four known triple asteroid systems in the main belt, imaged with adaptive optics systems.

The existence of multiple asteroid systems revealed with adaptive optics

In 2005, we announced the discovery of two tiny moons in orbit around 87 Sylvia, an asteroid with a diameter of 300 km located in the main asteroid belt. This system was the first "asteroid trio" discovered. Because 87 Sylvia was named after Rhea Sylvia, the mythical mother of the founders of Rome, we proposed naming the moons Romulus (18 km across) and Remus (7 km across). As AO systems became more reliable and efficient, it was possible to spot smaller and closer moons around large asteroids. In 2007 we discovered that 45 Eugenia also possesses two moons 7 and 6 km in diameter. Two smaller moons with diameters of 5 and 3 km were detected around 216 Kleopatra, an interesting elongated asteroid known to have a metallic composition. More recently, in 2009 our group announced that two tiny moons (less than 4 km across) were orbiting 93 Minerva, a large asteroid 145 km across.

More than just a curiosity, these moons have enabled us to determine the mass and density of their "mother asteroids", revealing that the rock turns out to be extraordinarily porous, with up to 60 percent of its interior composed of empty space. Several scenarios have been proposed to explain the existence of these asteroids. We suggested that they were formed when two large asteroids smashed into each other and broke apart. Most of the fragments from the breakup reassembled into a loose agglomeration only held together by gravity. The moons are probably the leftover debris of this catastrophic disruption.



The brightest volcanic eruption on Io! The left-hand panel shows images of Io collected on 20 and 22 February 2001 and two days later. A bright eruption from the nearby volcano named Surt appeared over two days. The right panel shows the simulated appearance of Io at the time of the observations generated from spacecraft data. Dark features of volcanic origin are visible from the ground thanks to adaptive optics.

This image of Jupiter combines a series of images taken over 20 minutes by the Multi-Conjugate Adaptive Optics Demonstrator (MAD) prototype instrument on VLT. The observations were made at infrared wavelengths where absorption due to hydrogen and methane is strong.

Monitoring the orbits of asteroid moons over long timescales could give us accurate insights about these asteroids, such as the distribution of material in the interior and their surface properties, without having to develop expensive space missions.

The future of adaptive optics

An important limit of standard adaptive optics systems is the fact that the corrections can only be done for small patches of the sky. This means that objects that appear large as seen from the Earth, like the giant planets Jupiter and Saturn, cannot be observed using the full potential of AO systems. In 2007, the European Southern Observatory (ESO) developed the first prototype of the next generation adaptive optics system called Multi-Conjugate Adaptive Optics (MCAO). The ESO MCAO system uses information provided by three reference stars, instead of just the one used in conventional AO systems, to reconstruct a 3D estimate of the atmospheric turbulence above the telescope, and thus provides a correction over a large field of view.

In 2008, we used this MCAO system to image Jupiter using two moons located on both sides of the planet as reference. This technique allowed us to observe Jupiter for almost two hours, a record duration since even the Hubble Space Telescope cannot observe Jupiter for more than 50 minutes. The image quality is about twice as good as that provided by Hubble, not only because of MCAO but also because ESO’s Very Large Telescope is much bigger. We even made a discovery: a major change in the brightness of the equatorial haze, which lies in a 16 000 km-wide belt over Jupiter’s equator.

AO systems are now more reliable than ever before. A dedicated MCAO system should be available in 2011 on the Gemini South telescope, allowing astronomers to regularly monitor the atmospheric activity of Jupiter and Saturn. The next generation of AO systems are being built and should provide improved image quality and also allow observations in visible light. They are designed to allow astronomers to study exoplanets, planets in orbit around other stars. Many more discoveries are waiting to be made with AO systems.

Athena Coustenis

Born in Athens, Greece

Biography

Athena Coustenis is an astronomer specialising in planetology and space techniques. She was born in Athens, Greece, but has lived in Paris, France for the past 27 years, and currently works at the Paris Observatory, in Meudon. Her research is devoted to the investigation of planetary atmospheres and surfaces. She focuses her attention on the outer planets. She has a particular interest in Titan, Saturn's moon, which hosts an exobiotic environment that is in some ways similar to our own planet. In recent years she has also been leading an effort to uncover the nature of the atmosphere surrounding exoplanets, mysterious worlds around distant stars.

Athena has used many of the world's largest telescopes to conduct planetary investigations. She is currently devoting most of her time to analysing data returned by the Cassini–Huygens mission to Saturn. She is also involved in the preparation of future space missions to Jupiter's and Saturn's systems. She loves explaining her findings to the public, and she has much to share.

Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique de l'Observatoire de Paris (LESIA)

The primary roles of Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique de l'Observatoire de Paris (LESIA) are the design and implementation of scientific instrumentation in space and on the ground; analysis and interpretation of scientific observations made by use of the these instruments and the development of advanced techniques applied in ground-based instruments and in space instruments. LESIA's scientific activities concern four main themes: planetology, astronomy, plasma physics and solar physics, as well as some technical areas like plasma wave analysers, coronography, sensors and electronic boards, interferometry, software, adaptive optics, photometry, solar polarimeters and magnetometers and spectrometry.

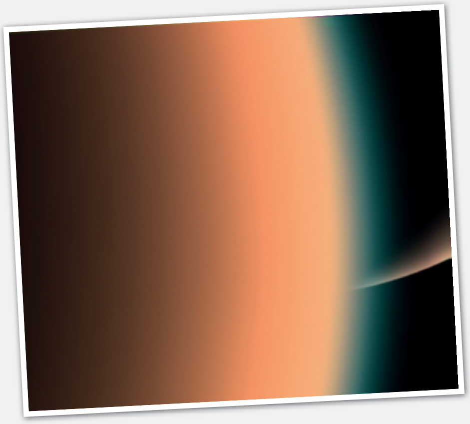
lesia.obspm.fr

l'Observatoire de Paris

Looking at Titan

An Earth-like World

In January 2005 the eyes of the world turned to Saturn's largest moon, Titan, as the Huygens probe successfully landed and sent back the first images of its previously unseen surface. Athena Coustenis is an expert on Titan and is the perfect person to give a tour of this amazing world, beginning with its discovery in 1655. The similarities between this moon and the early Earth are startling, raising an interesting question: could there be life on this world? Finally, Athena gives us insight into the future, with possible missions to explore Saturn's moons further, perhaps even featuring a high-tech balloon!



This image taken by Cassini shows Titan's stratospheric haze. The sunlit south pole of Saturn is seen in the distance.

I am an astronomer and have been working for the past 20 years at the Meudon Observatory, halfway between Paris and Versailles. My field is planetology, which means that I study planetary objects, such as Jupiter and Saturn, and their moons. One of these, Titan, has been the focus of my research since I studied for my PhD.

Titan is Saturn's largest satellite and is a unique world in the Solar System. It was discovered in 1655 by Christiaan Huygens. Since then we have found that it has an extensive atmosphere, more than four times denser at the surface than our own, and possesses a rich organic chemistry thanks to abundant nitrogen and some methane. Its surface pressure is also similar to the Earth's. So far, Titan is the only object in our Solar System — or anywhere for that matter — which has such characteristics.

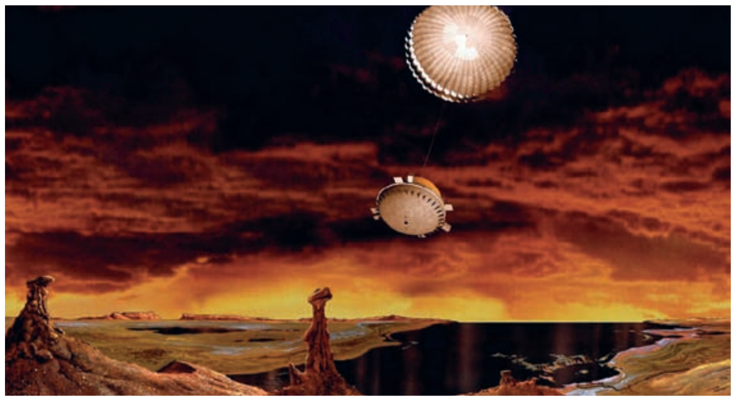
A world like early Earth

The striking resemblance with the primitive Earth, when oxygen was not yet abundant and temperatures were lower, has prompted the scientific community to study Titan with all available means.

I have been involved with many aspects of Titan's investigation during my career. I have observed Titan from the ground with large telescopes in Hawaii and Chile, used Earth-orbiting satellites like Hubble and even the data recovered during a flyby by Voyager 1 in 1980 to determine the temperature and composition of Titan.

A high-tech mission to find answers!

Cassini–Huygens is a large space mission that was put together through a highly efficient collaboration between the European Space Agency (ESA) and NASA. It comprises an orbiter with 12 instruments and carried a probe with six instruments that descended into Titan's atmosphere and landed



In this artist's impression, the European Huygens probe is about to reach the surface of Titan.

on its surface. Cassini–Huygens is the most complex interplanetary spacecraft ever built, and the scientific tools represent the most advanced technological efforts of the countries involved in the endeavour. I was involved with the Cassini–Huygens mission almost from the beginning and helped with proposing three of the instruments that were approved.

Cassini–Huygens reached Saturn and performed a flawless orbit insertion at 16:30 CEST on 30 June 2004, becoming trapped forever around the planet like one of Saturn's natural moons. On Christmas Day 2004 Huygens separated from Cassini and a little under a month later the probe became the first human artefact to descend through Titan's atmosphere. It reached the surface and returned several hours of data from an exotic landscape cut by channels and apparently soaked with the chemicals ethane and methane. I followed this event from the ESA control centre in Darmstadt, Germany and I can barely describe the thrill, the emotion and the excitement as we discovered the data little by little and then tried to reconstruct the surface of the satellite from the images sent back.

The tremendous technological and scientific achievement of the Huygens mission will bear fruit for many years to come. It once more proves the fantastic capabilities that can be achieved by international collaboration. Landing on a new world ten times further from the Sun than our own planet ranks with taking the first step on the Moon. Humanity has taken a huge leap towards broadening its horizons.

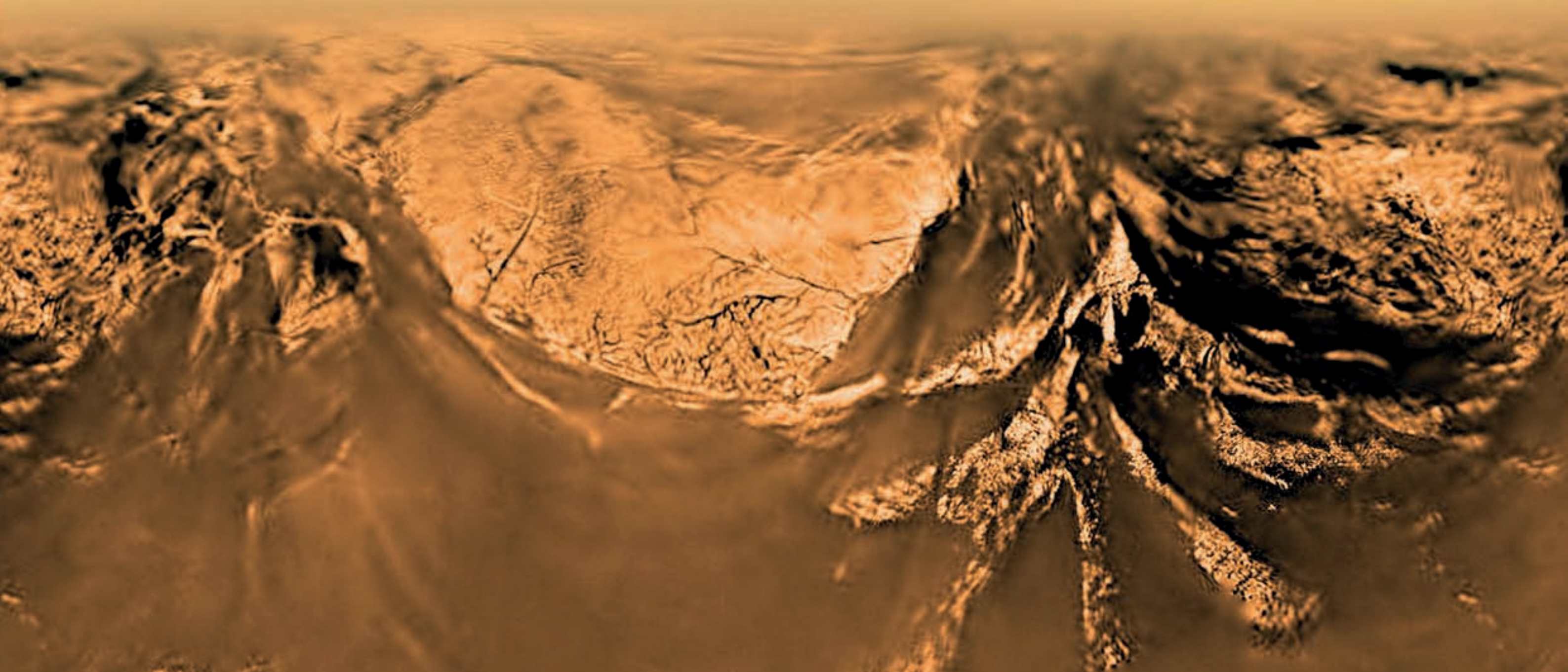
Mysterious methane

Several years of flybys by the Cassini orbiter have led to radar and near-infrared maps that show dunes made of icy material and what appear to be chemical lakes at the north pole. Titan's methane cycle is indeed exotic — at least to me! On Titan methane can exist as a gas, a liquid and a solid. Playing a role similar to that of water on the Earth, methane is cycled between the atmosphere and the surface. Cloud systems the size of terrestrial hurricanes (1000 km) appear occasionally, while smaller ones are there on a daily basis.

Even with the detection of large lakes in the north, Cassini was unable to detect any viable source to resupply methane. We also found that the balance of geologic processes is somewhat similar to the Earth's, more so than for Venus or Mars. Although temperatures on Titan are very low (-180 °C on the surface), analogies can be made between the current chemistry on Titan and the chemistry that was active on the primitive Earth. Moreover, Titan is the only planetary body other than the Earth with long-standing lakes on its surface. Titan may well be the best analogue to an active terrestrial planet in the sense of our home planet, albeit with different working materials.

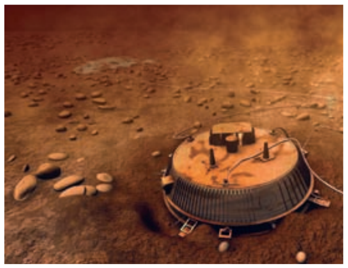
The ingredients for life

All ingredients that are supposed to be necessary for life to appear and develop — liquid water,



This phenomenal image of Titan's surface was taken by ESA's Huygens probe's view from an altitude of ten kilometres. The Huygens probe was delivered to Titan by NASA's Cassini spacecraft.

organic matter and energy — seem to be present on Titan. Indeed, interior structure models and observations suggest that Titan, as well as three of Jupiter's moons, Europa, Ganymede and Callisto, have maintained internal liquid water reservoirs, probably mixed with some ammonia and possibly sulphur. At the beginning of Titan's history, this hypothetical subsurface ocean may have been in direct contact with the atmosphere and with the internal bedrock, offering interesting analogies with the primitive Earth.



This artist's impression gives a good idea of what the Huygens probe looked like on the surface of Titan.

Consequently, we can't rule out that life may have emerged on or in Titan. In spite of the extreme conditions in this environment, organisms could have been able to adapt and persist. The conditions on Titan today — pH, temperature, pressure, salt concentrations — may be compatible with life as we know it on Earth. However, the detection of potential biological activity seems very challenging.

So what do I want to do now? I want to go back!

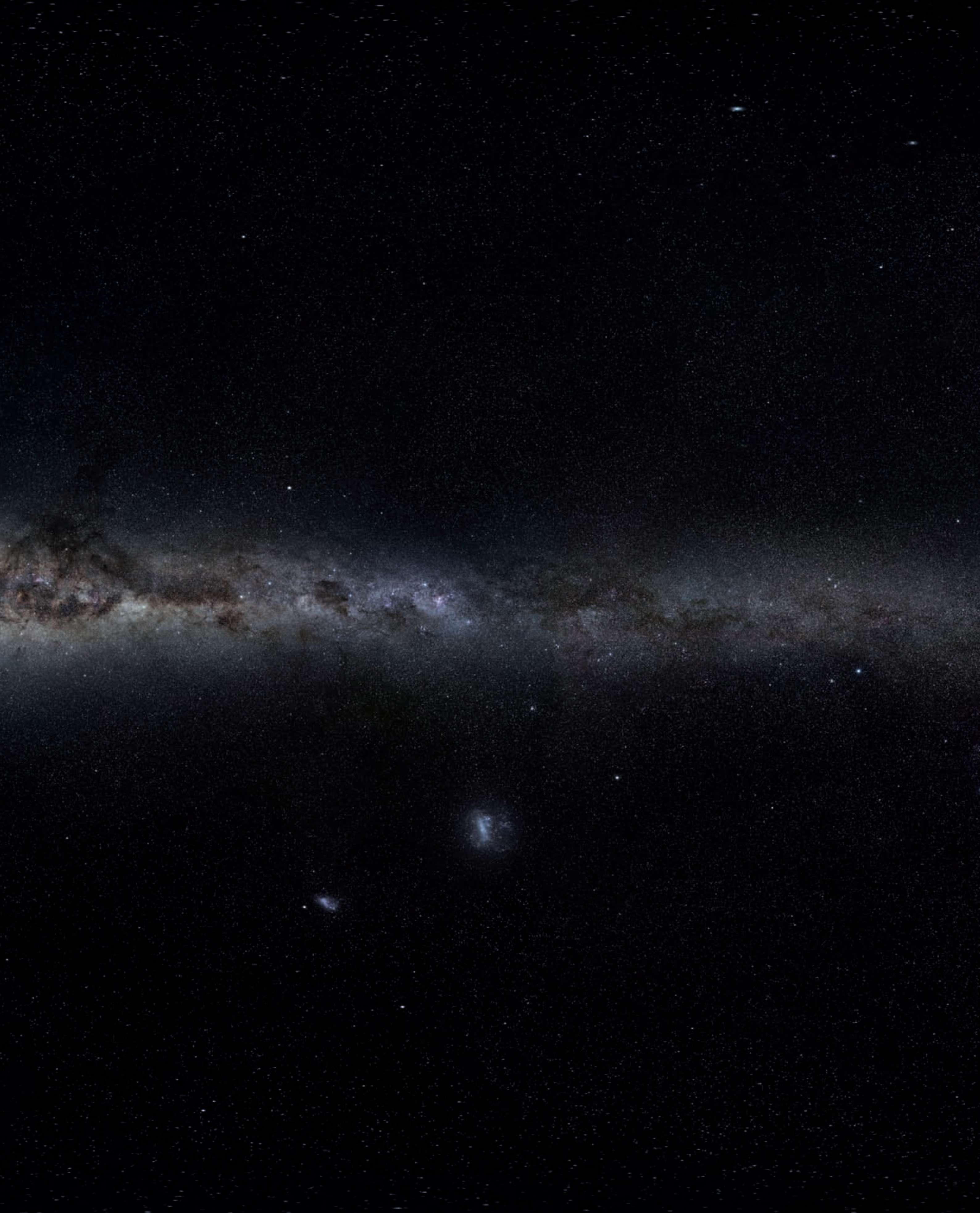
Grand plans

We need to find answers to many of the most outstanding questions that the international scientific community have raised after the Cassini–Huygens exploration. In 2007, ESA and NASA issued calls for ideas that ended in several proposals being selected for further study. I headed an effort put together by more than 155 scientists and engineers from all over the world to propose a return to the Saturn system to study Titan and another of its fascinating moons, Enceladus. ESA selected our proposal for a mission called TandEM for further studies within a plan called Cosmic Vision 2015–2025.

Since then, our European proposal and a related American study for NASA (called Titan Explorer) have merged. The new mission is called Titan/Saturn System Mission (TSSM) and includes several elements: an orbiter that will go into the Saturnian system and make several Enceladus flybys before orbiting around Titan for several months. The orbiter will also deliver a balloon and a probe onto Titan which will land in a lake! We're all very excited about this opportunity to take a closer look at a faraway, yet so familiar world. And we're all working very hard to make it happen.

The Galactic Universe

This magnificent 360-degree panoramic image, covering the entire southern and northern celestial sphere, reveals the cosmic landscape that surrounds our tiny blue planet.



Alberto Krone Martins

Born in São Paulo, Brazil

Biography

Alberto is a Brazilian, born during São Paulo's winter of 1982. The son of physicians, and with a sister who decided to pursue a medical career early in life, it would have been natural for him to follow the medical tradition. However, his parents always supported his decisions, even when that turned out not to be a career in medicine.

Alberto studied Physics at the Universidade de São Paulo, researching elementary particles, searching for something that is neither purely mathematical nor conceptual. During those studies he made some very good friends, who were also amateur astronomers and together they founded the "Clube de Astronomia de São Paulo" in 2001, which although young, is one of the largest amateur astronomy institutions in Brazil.

Alberto chose astronomy not only as a hobby, but also as a profession and started working on undergraduate astronomy projects, and later for a Master's degree at the Instituto de Astronomia, Geofísica e Ciências Atmosféricas in São Paulo. He has spent time at the Pierre Auger Observatory, the world's largest ultra-high energy cosmic-ray observatory, located at the base of the Argentinean Andes and has done simulations for ESA's Gaia satellite at the Universitat de Barcelona. He is currently a graduate student in a joint diploma PhD programme, with the Universidade de São Paulo and the Université de Bordeaux I.

Université de Bordeaux

The Université de Bordeaux was established by the Archbishop Pey Berland in 7 June 1441, under a Papal Bull issued by Pope Eugene IV. Nowadays its astronomical branch is the Laboratoire d'Astrophysique de Bordeaux (LAB), which was an independent institution (Observatoire de Bordeaux) founded by the astronomer Georges Rayet in 1878. LAB plays an important role in the research and engineering development of several modern and fundamental astronomical projects, such as ALMA, HERSCHEL, Gaia, Cassini–Huygens and Mars Express. Its teams are working in several areas, from reference frames to exobiology, covering themes as diverse as the formation of stars and planetary system, galaxy kinematics, planetary atmospheres and the search for life in the Universe.

www.univ-bordeaux.fr

Universidade de São Paulo (USP)

Despite being established only in 1934, the Universidade de São Paulo has become the most important university in Latin America, and one of the most important in the world. The IAG, or Instituto de Astronomia, Geofísica e Ciências Atmosféricas, is the home for astronomical research. The astronomy department has a strong commitment to the education of future astronomers, offering Bachelor's, Master's and PhD degrees. It has an effervescent mixture of theoretical and observational astronomers helping to advance our knowledge over a wide spectrum of themes: from the mathematical depth of celestial mechanics to the grandiosity of large-scale cosmological studies, by way of stellar kinematics, astrochemistry, star formation, interstellar medium and extragalactic astronomy. It is also deeply involved in instrumental development for modern observatories, such as SOAR and Gemini.

www.usp.br

Amazing Astrometry

Alberto Martins explains here the basics of measuring the Universe. It's a story that begins with Hipparchus of Nicaea, who lived around 140 BC, and ends with predictions of astrometrical laboratories aboard futuristic spacecraft.

What is astrometry all about? What does an astrometrist do? Simply put, astrometry measures the positions, distances and paths of bodies in the Universe.

A bit of history

Classically, astrometry is done by measuring tiny angles on the sky, and it has been like this for millennia. Hipparchus of Nicaea could perhaps be called one of the first astrometrists. He is considered to be the greatest astronomical observer from antiquity, as he created the first catalogue of the positions and brightnesses of the stars. He was also one of the fathers of trigonometry — yes, now you know who to blame!

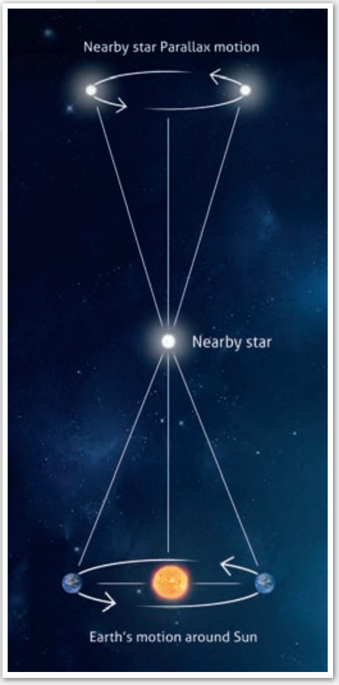
So, astrometry is about the positions and the paths of bodies in space. Why do we want to know those things? Apart from the obvious question "Where are we?", if we want to answer questions like "What is the Universe?", "How does a star work?", "Is there any dark matter there?", "How old is the Universe?", we really need to learn how things move and where things are. And the more precisely we know this, the better we will be able to answer these questions.

Knowing the distances to other astronomical objects helps us plot our place in the Universe.

Measuring distances

Let's take the most obvious example: distances. We cannot know anything about the physics of an object if we do not know how far away it is. Luckily measuring distances is one of our specialities.

The ancient Greeks believed that the stars were set in a crystal sphere around the Solar System and were all at same distance from Earth. Since then we have observed that stars appear to move periodically in the sky and it is actually possible to measure their distances using school geometry. This apparent motion is caused by the motion of the Earth around the Sun and the effect is called parallax. This is similar to the apparent shift in position of an object when you observe it by closing first one eye and then the other.



The Earth's motion around the Sun leads to the apparent movement of the stars.

The nearer the object the bigger the angle it moves through. Try it! If you measure this angle and you know the distance between your eyes, you can compute the distance between yourself and the object by simple trigonometry.

Generally we don't like to complicate anything unnecessarily, since complicated things are more likely to contain errors and/or amplify unavoidable uncertainty. But sometimes it's unavoidable. This is the case with the European Space Agency's Gaia satellite, which will measure the distances, movements and colours for more than one billion stars spread all over our Milky Way galaxy!

So, parallaxes are measured from the periodic motion of a star in the sky. But how do we observe this movement? As we observe any other motion: by comparing the position of an object with the positions of other objects, considered as fixed. Saying that there are fixed objects in the Universe is a strong statement. In fact, we don't believe that there is any such thing, but the further something is from us, the smaller its motion due to the parallax. Perhaps you've got the point: we need to use very distant objects to create a sort of "quasi-fixed reference". In astronomy we do exactly this, using very distant, but bright objects called quasars to create what we call the International Celestial Reference Frame.

Taking the measure of the Universe

Now you know how to measure distances to other bodies in the Universe: you can use parallax. But if the object you want to measure is far, far away, this motion would be very, very small and almost impossible to measure accurately. That is why parallaxes are not used to measure distances to other galaxies. Nonetheless, parallax measurements are the first rung on what we call the "cosmological distance ladder".

But what is this ladder? Let's answer with an example: if you want to be able to say that the Universe is expanding or contracting, you will need to use different astronomical methods for measuring distances further and further out until you can measure the distances to a great number of galaxies. Each method depends on the one before it, and the basis of all of them is parallax. Just as a big skyscraper needs a very good and reliable foundation, cosmologists need good parallaxes to arrive at reliable conclusions. Why? Because any errors in the parallax figures will propagate through to all the other methods.

So, imagine the size of the error at the top of the ladder if the parallaxes aren't reliable. A high ladder needs a stable base! Better to have good parallaxes!

GAIA is an ambitious project that aims to create a precise three-dimensional map of our Milky Way.

That is not all!

The measurement of distances is just a part of astrometry, although it is a very important one. But apart from all the contributions of this fundamental part of astronomy to human knowledge — such as moving the Earth away from the centre of the Universe — astrometry is of utmost importance to all kinds of navigation.

If someday the human race really wanted to voyage to the stars, just as the first navigators and explorers left Europe, astrometry will be needed (just as the ancient navigators needed it). Astrometry will indicate the path to "boldly go where no one has gone before".

Saskia Hekker

Born in Heeze, The Netherlands

Biography

Saskia was born in a small village in the Netherlands and enjoyed a wonderful childhood together with her little brother. After finishing high school she went to the Delft University of Technology to study applied physics. Besides this interesting field of work, she joined the board of the student association of applied physics for one year full-time, and organised the freshmen week for the whole university with around 2000 participants.

Saskia graduated in 2003 with a thesis entitled: "Temperature measurements in Rayleigh-Benard convection using suspended liquid crystals". In the same year she started her PhD at Leiden Observatory. She graduated in September 2007 with a thesis entitled: "Radial velocity variations in red giant stars: Pulsations, spots and planets".

Saskia enjoys reading, swimming, hiking and learning languages. She believes it is important to show the public what scientists are doing as funding often comes from taxpayers. She says that sharing knowledge is part of her job.

School of Physics and Astronomy, University of Birmingham

The HIROS (High Resolution Optical Spectroscopy) group specialises in helio- and asteroseismology. In helioseismology, the group runs the Birmingham Solar Oscillations Network (BiSON), which observes the Sun as a star. This unique network has facilities around the world to obtain continuous observations and has been running for about 30 years. In asteroseismology, the group specialises in the analysis of oscillations in solar-like stars and evolved stars showing solar-like oscillations. Currently, state-of-the-art observations from the NASA Kepler satellite are used to study the internal structures of these stars.

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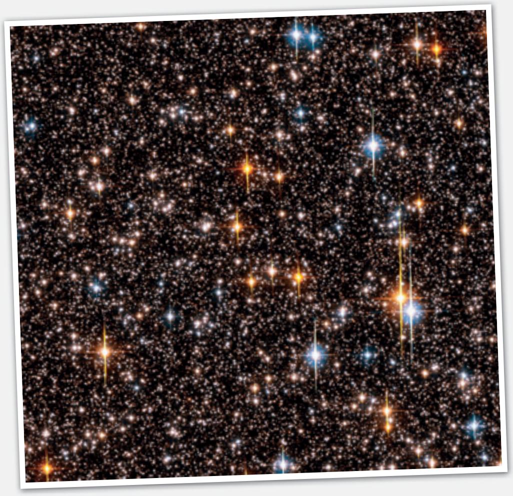
The Ins and Outs of a Star

Wouldn’t it be fascinating to know what it’s actually like inside a star? After reading this you’ll have an idea about what we know about the inner structures and lives of stars. Saskia Hekker explains why stars appear to have different colours and how astronomers measure the vibrations of stars to “look” into them. Astronomers don’t have all the answers though, and this feature finishes with some tough questions that hopefully one day we will be able to crack!



A star field in Sagittarius shows thousands of differently coloured stars.

Wouldn’t it be cool to know what it is like inside a star? We do know a thing or two. It is for instance very hot in there, a few million degrees, and matter is in an interesting state. At these temperatures it is not solid, not liquid and not a gas, but a plasma: the fourth state of matter.

The evolution of a star has something in common with humans. A star is born, it matures, ages and dies. Its embryo does not come from an egg, but from a dust cloud. This cloud becomes denser and hotter over time, as gravity pulls all the dust particles together. At a certain point when this cloud is both dense and hot enough it becomes plasma and starts fusing hydrogen to helium. This produces a lot of energy and the star starts to shine.

Around the core of the star, which is its engine and where fusion takes place, is a large “atmosphere” of gas. It consists of different layers, like our own planet’s atmosphere, and in the different layers there can be greatly varying conditions. In the convective zone it can be very turbulent and in the radiative zone very calm. These layers change over time, as the star gets older.

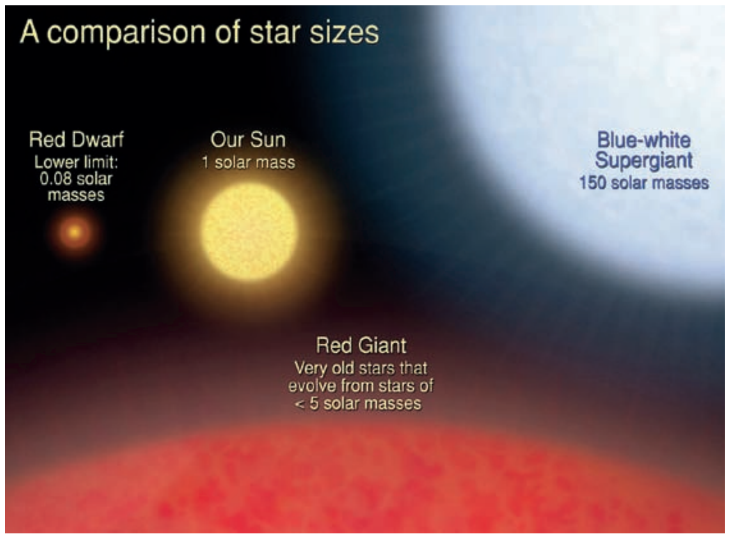
Red hot!

The colour of a star depends on the temperature of its surface. Very hot stars are blue, and cooler stars appear white, yellow, orange and red. Observe a candle burning. Close to the wick where it is hottest the flame is white and further out the colours change from blue to yellow, orange and red.

Our Sun is a mature yellow star and it will remain like this for another four billion years. Sometime after this it will run out of hydrogen, its fuel. This will not be the end of our star, but it will require a new fuel source. This will then be helium, the “ashes” of the first burning process. The core becomes even hotter and denser for the star’s “second burning life”, but the star is now old and this cannot continue for a third time. Our Sun will just die quietly when it has burned all its helium. Heavier stars die in spectacular explosions!

Good vibrations

Now we know a little bit about a star’s life, it is time to explain how we can look into a star. This is done in the same way that we look inside the Earth. For instance when there is an earthquake, the Earth shakes, but not all material inside the Earth responds in the same way, and due to this difference we can work out what type of material is present where. Similarly one can hear the differences in materials when inducing vibrations in them — for instance by knocking on a wooden, a metal or a glass door. We use this same technique on stars.



We think of our Sun as being gigantic and it is, but compared to some other types of star, it’s quite tiny!

The vibrations of the Sun, our closest star have been measured for many years now. This is done in two ways: by measuring tiny variations in its brightness and by measuring the surface moving up and down.

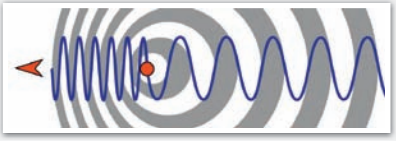
One can easily imagine that it is possible to measure something getting brighter and dimmer, but recording the surface going up and down without standing on it? We use the Doppler shift to measure this. Everyone notices the Doppler shift as an ambulance approaches. As it moves towards you, you hear a higher tone, and once it moves away, a lower tone. Astronomers observe the “higher and lower tones” of light coming from a star, and in this way can measure the stellar surface going up and down.

Key questions

These measurements are the first very important step. Once aware of the periods between the different vibrations it is possible to derive the structure inside the star. Different vibrations might probe different depths within the star and can tell us what is happening in that layer. Other vibrations go even deeper, to the star’s core and can tell us what it is like in there. So we may find answers to some of the following questions:

- How large is the core exactly?
- How large are the turbulent or quiet layers above the core?
- Do these rotate in the same directions and with the same speed as the outer layers?
- What happens at the interfaces between different layers?

We have learnt much from our Sun, and we are using this knowledge to make discoveries about other stars.



The frequency of waves from both an ambulance’s siren and a star depend on their motion. This is the Doppler effect.

Stars come in a variety of colours, which tells us about their temperature. Blue-white stars, like Sirius, shown in this artist's impression, are among the hottest.

Thomas Dall

Born in Roskilde, Denmark

Biography

Thomas grew up under dark, star-lit skies in the countryside of north-west Denmark. His love of the night sky led him to study Physics and Astronomy at Aarhus University, and during his studies to become a Student Support Astronomer at the Nordic Optical Telescope in La Palma (Canary Islands) from 2000 to 2001. Following this he obtained a PhD in Astronomy from Aarhus University. His speciality was stellar pulsations, later moving to stellar magnetic activity and stellar rotation. After the PhD he joined the European Southern Observatory in Chile, where he undertook support duties at the world-famous La Silla Observatory from 2002 to 2006. He then moved from one exotic location to another, by becoming a Gemini Fellow in beautiful Hawaii for two years, this time supporting the Gemini Observatory atop the equally famous Mauna Kea. He is currently working as an astronomer at the ESO Headquarters near Munich, where he is doing his own research and providing support to the users of ESO's telescopes. Thomas is married and has two children, aged 10 and 13. He enjoys good coffee and good wine, walking in the countryside and city with his family. While on duty travel he particularly enjoys the serene mornings on observatory mountaintops. He has been coaching his son's football team for three years and also does karate — Wado-style in Hawaii, Shotokan in Munich.

European Southern Observatory (ESO)

ESO is the foremost intergovernmental astronomy organisation in Europe and the world's most productive astronomical observatory. It operates three sites in Chile — La Silla, Paranal and Chajnantor — on behalf of its fourteen member states. It is building ALMA, the Atacama Large Millimeter/submillimeter Array, together with international partners, and designing the European Extremely Large Telescope.

ESO's User Support Department is the interface between the observatory sites in Chile and the users of the facilities. Modern observatories today are run without the user being present. Instead the user interacts with the User Support Department to define beforehand what needs to be observed and how and then observing queues are set up for the dedicated on-site staff to execute.

www.eso.org

From Fusion Energy to Life

Magnetic Fields, Exoplanets and the Earth

Magnetic fields within stars and extrasolar planets may seem like two totally separate topics, but, as is often the case in astronomy, there are many surprising links. Join astronomer Thomas Dall as he explains how these two subjects intertwine, and may even give clues as to the ultimate fate of the Earth.

Astronomy and space science have many direct applications for our lives here on Earth. Communication and weather satellites need to be launched into orbit, to give just one example.

“What can this research be used for?” A common question. Unlike, for example biochemistry, astronomy has an immediate public appeal, but it is perhaps less obvious what it can be used for in a practical sense. There are many applications of astronomy in our daily lives that are not usually recognised as such. Global Positioning Satellite (GPS) systems, the internet, smart materials, etc. These all owe part of their development to astronomy. But I want to address a few other reasons why astronomy is “profitable”.

I study magnetic fields in stars. Why stars and why not in a laboratory? Because stars are natural laboratories where Nature creates conditions and effects that are impossible to study in the lab. Why magnetic fields? There are two reasons.

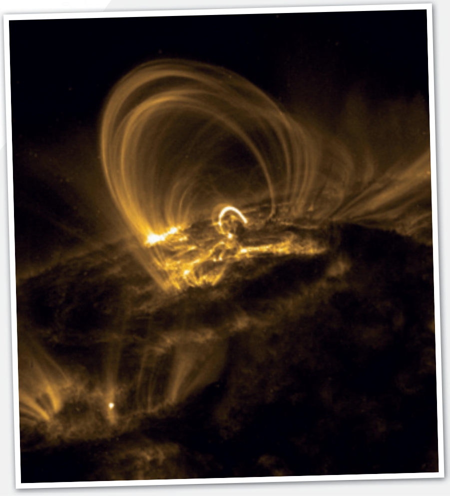
Firstly, magnetic fields influence the evolution of a star and the environment around it, which is of vital importance to the planets around the star. Planets like the Earth. Changes in the solar magnetic field can have colossal consequences for climate and life on Earth. Thus, the study of magnetic fields is important for our understanding of our own destiny, of life itself.

Secondly, magnetic fields are believed to be necessary to control the nuclear fusion by which stars create energy. The taming of fusion on Earth would mean a practically endless and cheap source of clean energy. Imagine what such an energy source would mean to the world… no more fighting over oil and gas since the fuel for fusion energy is water!

Our destiny. Life itself. Clean energy. This research is ultimately about the future of mankind. A future that we can shape and influence in an informed way. If we want to.

"How do you study magnetic fields?"

Stars are mostly like the Sun: spheres of very hot gas where nuclear reactions in the interior provide energy that is radiated as light and heat. But there's more. Like the Earth, the Sun has a magnetic field, but it is quite a different one. Whereas the magnetic field of the Earth changes only slowly with time, the much more violent movements in the solar interior make for a constantly changing solar field. The field on the Sun originates in the zone just below the surface where energy starts to be largely carried by convection (the "boiling pot" pattern visible on the solar surface) rather than carried by radiation (as it is further down in the Sun). Particularly concentrated areas of magnetic fields can penetrate the surface and cause sunspots. These spots are still very hot, but they are cool compared to the surroundings, so they appear darker.



The looped structures in this TRACE image of our Sun are caused by magnetic fields.

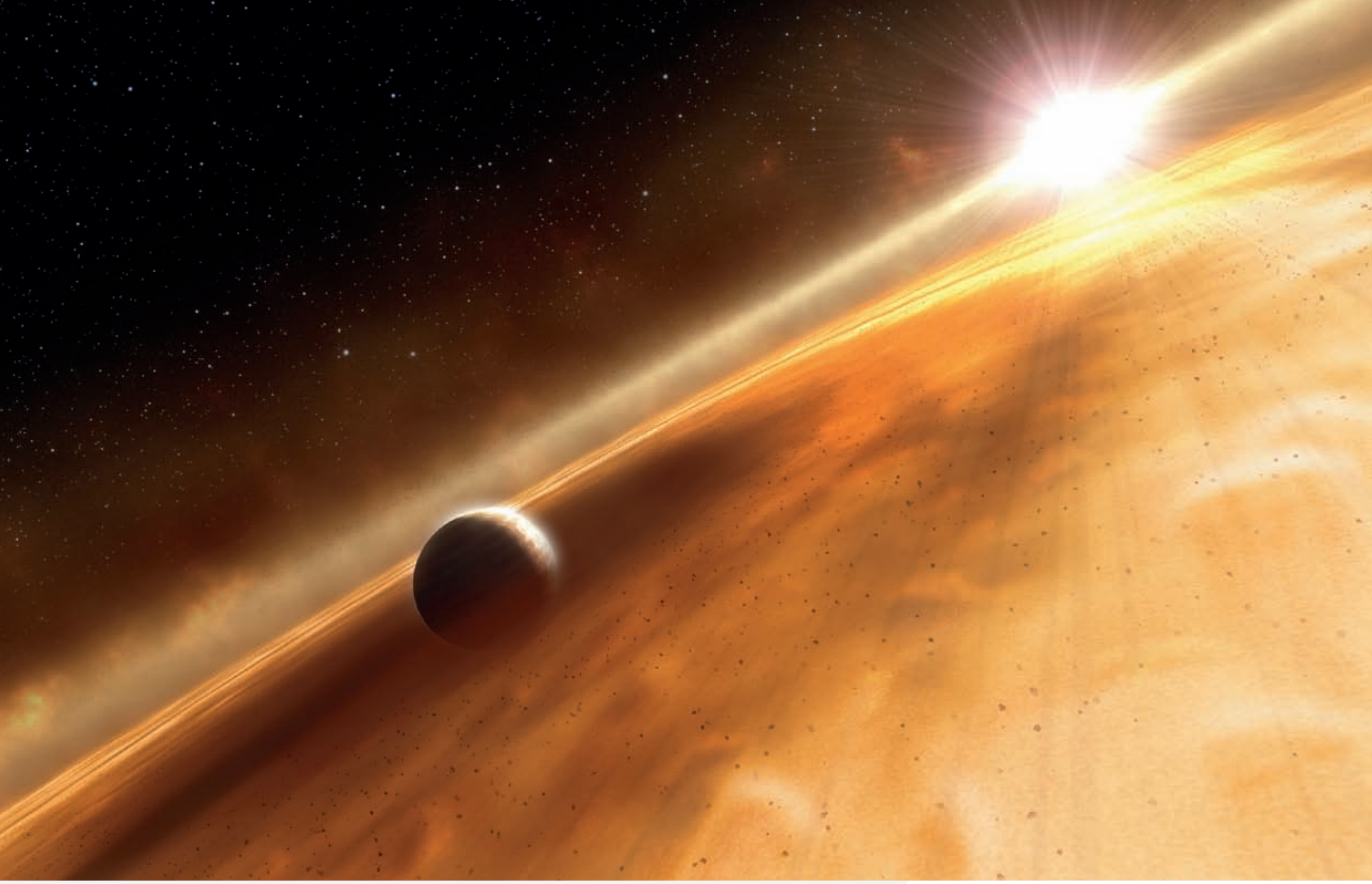
The magnetic field can, in some cases, be measured directly, but for stars other than the Sun we have mostly relied on indirect measurements of spectral lines and particular line emissions that are associated with magnetic fields. To cover our ignorance of the fields themselves, we often refer to "magnetic activity" — which means that we see the indirect evidence of magnetic fields but not the fields themselves.

"What has this to do with planets?"

One of the most exciting developments over the past ten years or so is the continuing discoveries of more and more exoplanets. The first planets found were gas giants far more massive than the largest planet in the Solar system, Jupiter. But gradually, as observing techniques improved, lighter and lighter planets have been discovered and just within the last year or so have we entered the realm of true Earth-like planet discoveries. This means that the planets being discovered now are just slightly larger than Earth, have orbits that are not too different, and for some of them this might even mean that liquid water can exist on the surface and thus that the possibility of life is present.

The prime technique to detect planets is by measuring the slight velocity shifts of the host star caused by the gravitational pull of the planet. This involves measuring the position of spectral lines to very high accuracy. Unfortunately for planet hunters, the spectral lines of most stars are not stable in their own right. They are affected by convective motions in the stellar atmosphere, but most notably they are affected by magnetic activity. Or more precisely, by stellar spots. When a spot appears on the surface of the star, it will dim the light coming from that area, which in turn will have an effect on the measured position of spectral lines. As the spot rotates across the stellar surface, the position of the line changes and it so happens to mimic quite accurately the change in line position that an orbiting planet would produce.

Fortunately, there are ways to tell a spot from a planet, but this involves long-term monitoring of the star (spots form and dissolve, planets do not) and detailed looks at the shape of the spectral line profiles



Knowing about the magnetic fields of stars can help astronomers detect and confirm new planets far from our own.

(spots change the shape of the line slightly; planets do not affect the stellar atmosphere at all). So what this means in practice is that astronomers must wait until they have watched for long enough and have made enough tests before they announce the discovery of yet another exoplanet.

“What will the future bring?”

More and more planets will be discovered and eventually we will find planets that in their mass and orbit look exactly like the Earth. But these are all indirect measures. To be able to actually study these planets directly we need the next generation of super-sized telescopes. One of these is the European Extremely Large Telescope (E-ELT). This giant telescope will have a number of ultra-stable spectrographs that will allow us to study directly the properties of the planets and magnetic fields of our neighbouring stars. The lessons to be learned from this on a fundamental level cannot be overstated.

Not only could this endeavour bring us new physics, it may bring us a whole new mindset. These new discovery machines might open the door to a new understanding of our place in the cosmos and the ultimate fate of our own planet and our own civilisation. It may not be long before we know of other Earths; some still young, some mature, others doomed in orbit around dying stars. We might soon know of life outside the Earth. Truly, the story of life has just begun. The term “a world” could come to mean even more than it does today.

Gerard van Belle

Born in Tallahasse, Florida, USA

Biography

Gerard van Belle has been the instrument scientist for ESO's PRIMA instrument for the Very Large Telescope Interferometer (VLTI) for the past year. Prior to coming to ESO, Gerard worked as the Science Community Development Lead at the Michelson Science Center (MSC) at Caltech for four years, at NASA's Jet Propulsion Laboratory (JPL) for seven years on the Keck Interferometer as a senior optical engineer, and on the Palomar Testbed Interferometer as an astronomer.

His education before joining the ranks of astronomical professionals was a PhD from the University of Wyoming, a Master's from Johns Hopkins University, and an undergraduate degree from Whitman College. His work at Hopkins involved the construction and flight of ultraviolet spectrophotometers on sounding rockets, and at Wyoming he worked on the IOTA Interferometer, an early telescope array operated in partnership with Harvard University.

At ESO he is responsible for the testing and ultimate scientific success of the PRIMA instrument, whose capabilities include the detection of planets about nearby stars. Additionally, Gerard vigorously pursues his own scientific research, including high angular resolution stellar diameter and shape measurements with interferometers, and photometric planet transit detection. A personal achievement of his was the first-ever direct measurement of the shape of a main sequence star, Altair, for which he was awarded JPL's first annual award for outstanding research.

European Southern Observatory (ESO)

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www.eso.org

The PRIMA (Phase Referenced Imaging and Microarcsecond Astrometry) facility is a system designed to enable simultaneous interferometric observations of two objects. Currently interferometry is still limited in sensitivity by atmospheric turbulence: PRIMA will improve the sensitivity by using a bright guide star near a fainter object to correct some of the atmospheric turbulence, allowing longer integration times. This one-of-a-kind instrument can then be used either to measure the angular separation between the two objects with unprecedented precision or to produce images of the fainter of the two objects.

www.eso.org/sci/facilities/paranal/telescopes/vlti/instruments/prima/index.html

Seeing Stars

400 years ago, many of the remarkable discoveries of Galileo were built on the ability of the newly invented telescope to magnify planets into discs — worlds in their own right. The discovery of the rings of Saturn, the phases of Venus, and Jupiter's major moons all resulted from using new technology on the night sky. Gerard van Belle takes this opportunity to show how astronomers are advancing our knowledge of stars through the use of new technology in the study of these thermonuclear furnaces.

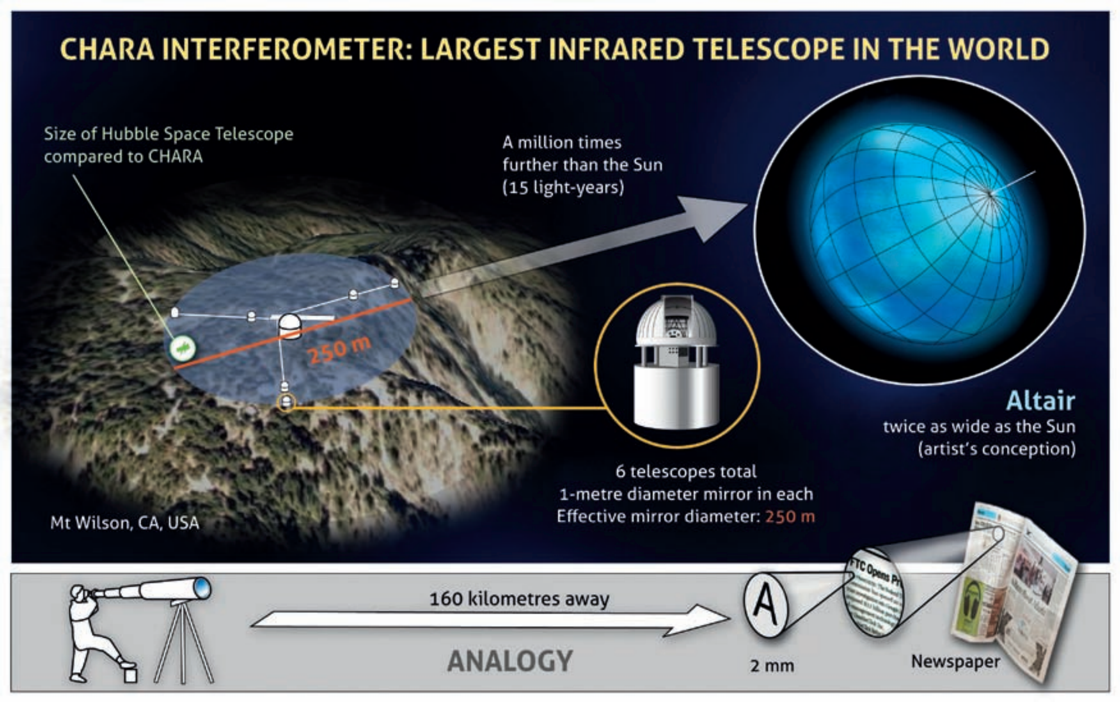
Left image: The commonly held view that most stars are round, like our Sun, is generally correct. Right image: Rapidly spinning stars look more oblate than round.

Throughout all of recorded human history, the night sky full of stars has captured the imagination and interest of people worldwide. However, aside from our own star, the Sun, the stars were nothing more than "pin-pricks in the curtain of night". This is due to their extreme distance — they are physically large bodies, but significantly further away from the Earth than the Sun. Alpha Centauri, the star system nearest to our Solar System, is more than 250 000 times further than the Sun.

Why (most) stars are round

The Sun, like all stars, is an incredible energy-releasing machine. It is, simply put, a big ball of gas: about 75% hydrogen, 25% helium. It's physically large — more than 100 times the diameter of the Earth — but more importantly, it's massive, roughly 333 000 times the mass of the Earth. The self-gravity of that much "stuff" — the propensity for each atom in the Sun to be gravitationally attracted to every other atom in the Sun — is a tremendous reservoir of potential energy. On average, the tendency is for all of these atoms to be drawn to the centre of the Sun. However, these atoms don't all immediately fall to the centre of the Sun and *poof*, form a black hole. Rather, they tend to bump into each other.

Near the core of the Sun, there's a lot of bumping going on. The crushing weight of the entire star is pushing down at that point, so the temperature is very high. So high, in fact, that some of these atoms cannot just bump into each other but get stuck to each other. Nuclear fusion is taking place, which releases a net positive amount of energy into the surroundings. This lets the Sun keep the "bumping" going on. More correctly stated, the pressure of the gas that makes up the star is large enough to counteract the tendency of gravity to contract the star towards its central point. This is true even though there is a net energy loss for the Sun since it is shining, pumping out energy into deep space in the form of electromagnetic radiation.



The CHARA array took a picture of Altair, even though it's as difficult as reading a newspaper at a distance of 160 kilometres.

This complex process can actually be summed up quite neatly: stars are machines that convert gravitational potential energy into light using nuclear fusion to power a near-balance between gas pressure and the force of gravity.

If you think of a star that is static in space — not moving, and more importantly, not spinning — the force of gravity and the pressure of gas are the same everywhere across the star's surface, so it tends to be round.

Getting in a spin

Static stars are however not very likely in a Universe as dynamic as ours. The Sun, in fact, rotates roughly once a month, which is a positively leisurely rate. However, some stars rotate with substantially more alacrity.

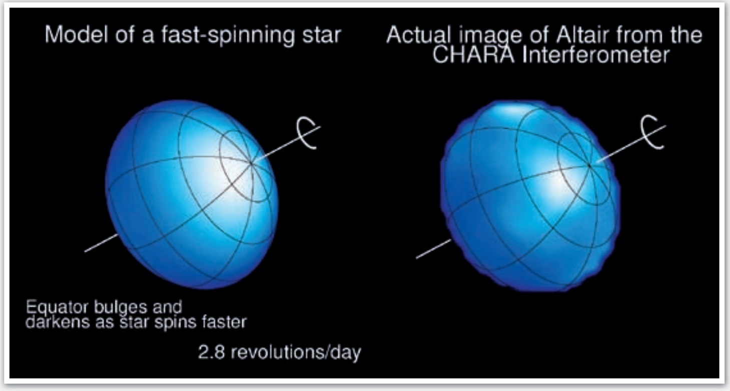
Let's consider the case of a star that is spinning very fast. The two competing, but previously balanced effects of gravity versus gas pressure are now starting to get out of whack. The reason is that the outward-pushing gas pressure is getting an assist from a similarly outward-pushing centrifugal force. Just try pulling a hand mixer out of a bowl of cake batter while the mixer is still spinning and you'll have a dramatic (and messy) demonstration of centrifugal force.

However, this centrifugal force that is competing for gravity's centripetal attention, along with the gas pressure, is greatest at the equatorial regions of the star, not present at all at the poles of the star, and scaling along the way in the in-between latitudes. As a child, you may have felt this sort of effect, and its scaling, while riding a merry-go-round or carousel — at the edge, furthest from the rotational axis, you felt the most pull to the outside, while at the centre, you may still have gotten dizzy, but felt no pull towards the outside.

The latitude dependence of the centrifugal force versus the non-latitude dependence of the other two factors, gravity and gas pressure, is what makes the star deform into an oval or "oblate" shape.

Taking pictures of rapidly rotating stars

In 2001, after many failed attempts by astronomers worldwide, my team and I were successful in measuring the effect of rotation on a rapidly rotating star. We looked at the star Altair, a nearby hot, rapidly spinning star, with the Palomar Testbed Interferometer, an ultra-high resolution technology prototype telescope designed to test techniques for finding planets about other stars. We found that a simple size measurement of the star was greater in one direction than another, and deduced that Altair's rapid rotation was finally revealing itself directly.



An image of Altair (right) in comparison to a model (left) that incorporates rapid rotation and bright poles.

More recently, a newer array of telescopes operated by Georgia State University's Centre for High Angular Resolution Astronomy (CHARA) has managed to image Altair fully. By combining the light from six small telescopes spread over the top of Mount Wilson in southern California, the CHARA array effectively creates a telescope that has the resolution of a 330-metre telescope — roughly 130 times more resolution than the Hubble Space Telescope. Investigators from the University of Michigan were able to utilise a special new instrument that combined the light from those individual telescopes and take a picture of Altair.

Pretty pictures are nice, but extracting interesting astrophysics is even more compelling. One intriguing aspect of imaging these sorts of stars is that they appear brighter at the poles than at their equators. Indeed, the star Altair shows a temperature difference of nearly 2000 degrees between its hot pole and cool equators; this effect tells astronomers a great deal about how the star is put together on the inside, in the presence of such extreme rotation. This detection is a powerful demonstration of the ability of a simple image to contain a great deal of meaningful astrophysics. It has taken many decades of telescope advances to get to this point where stellar surfaces can be directly imaged!

There is a promising future for this particular kind of work. Currently there are more than five dozen such targets that will be observed with the CHARA array and the European Southern Observatory's own Very Large Telescope Interferometer. Seeing the stars in this new way will tell us even more about how these markers in the night time sky are put together, and how they live and ultimately die.

A graphical illustration from xkcd.com of the confusion that often occurs between the fictitious centrifugal force and the centripetal force. A fictitious force is the technical name for a force that only exists from the perspective inside a rotating system such as a merry-go-round or a spinning star.

Ana Inés Gomez de Castro

Born in Vitoria, Spain

Biography

Ana appreciates the importance of the public understanding of science, and the realisation that astronomy is a worldwide endeavour. She is involved in large international projects for cutting-edge research and education. Ana is the Principal Investigator for the Spanish contribution to the international ultraviolet telescope World Space Observatory–Ultraviolet (WSO–UV) led by the Russian Space Agency and the Academy of Sciences. As coordinator of Hands-on Universe in Spain, part of a consortium creating a global education network, Ana is deeply involved in improving the understanding of science among teenagers. She also manages ultraviolet astronomy projects.

Ana's work history is varied and has seen her contribute to many projects. She was based at the Villafranca Satellite Tracking Station (European Space Agency) as a database assistant for the International Ultraviolet Explorer (IUE) for a short period, before moving to the Observatorio Astronomico Nacional to carry out her PhD on star formation. Next she moved to Canada, to McMaster University (Hamilton, Ontario) as a post-doc fellow where she worked on several different aspects of the role of magnetic fields on star formation.

Ana returned to Spain at the end of 1991 to work on the ultraviolet properties of pre-main sequence solar-type stars. In 1994, she became a professor in the Department of Physics of the Earth, Astronomy and Astrophysics of the Universidad Complutense de Madrid.

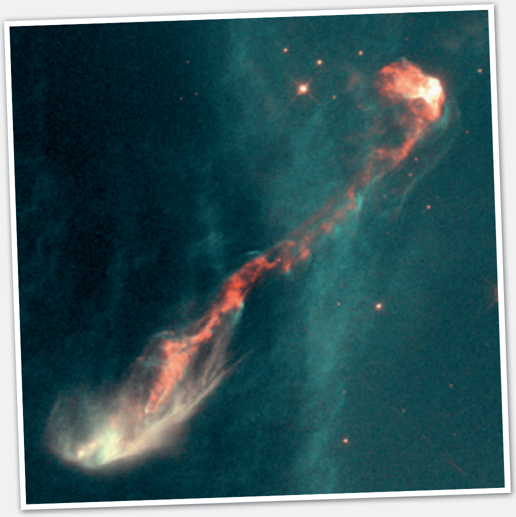
Universidad Complutense de Madrid

The Universidad Complutense de Madrid (UCM) was founded by Cardinal Cisneros in 1499, the regent after Isabella de Castille's death, and it has had a major impact on the scientific and cultural history of Spain. UCM is the largest University in Spain, it has more than 85 000 students, about 11 000 of them enrolled in graduate programmes. The UCM has about 3500 professors as permanent lecturing staff. The UCM research facilities include 35 research institutes, four university hospitals, 19 centres to support research activities (from supercomputing facilities to laboratory support) and a large library, including a history department with about 93 000 volumes, among them the famous Book of Astronomical Knowledge compiled in Toledo during the 13th century under the supervision of Alfonso X, King of Castille.

www.ucm.es

The Birth of Planetary Systems

We are all familiar with planets — we do, after all, live on one! But just how planetary systems are created has been a conundrum for scientists for some time, and many of the greatest minds have puzzled over the answer. Ana Ines describes the incredible processes that lead to the formation of planets such as our own Earth.



This Hubble image of a protostellar jet HH-47 shows dense gas being expelled from a star at incredible speed. HH-47 reveals a very complicated jet pattern that indicates that the star (hidden inside a dust cloud near the left edge of the image) might be wobbling, possibly caused by the gravitational pull of a companion star.

Planetary systems and stars are born in the same turmoil of cosmic gas and dust. Their creation is driven by the force of gravity, but gently controlled by the rotation of gas around the centre of the galaxy in which they reside. This subtle effect is responsible for forming rotating discs around the young growing suns; planets are the leftovers from these discs once the star has finally formed.

Born in turmoil

The birthplaces of planets are particularly fascinating for giant gas planets like Jupiter. They form far from the star in a calm and cool environment at temperatures below 0 °C, from dust grains surrounded by icy crusts and highly volatile gases like hydrogen and helium. However, rocky planets like the Earth endure a much harsher environment. As they are close to the "mother star", they are subjected to the violent and energetic environment produced by the star formation engine: light carrying incredible energy and irradiation by particles moving at speeds close to that of light.

As a result most of the gas and ices are removed and planets form from small silicate and carbonate particles, gradually sticking together and growing in size to reach planetary sizes.

So it seems that the very existence of planets like ours is under the control of this powerful engine. But how does it work? Scientists have agreed to think of it like a gigantic hydraulic power plant. This may sound a bit strange, but the similarities will surprise you!

A cosmic power plant

How does a hydraulic power plant work? Gravitational energy is stored by confining water within a reservoir above the level of the turbines. This energy is released when the gate opens and water surges over the blades of a large turbine wheel, turning the wheel. The next step is to turn this energy into the electricity that powers our homes. To do this we'll add a couple of ingredients: a shaft with magnets and some copper coils.

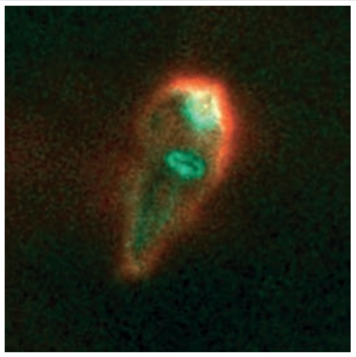
The turbine turns the shaft, rotates the magnets and produces an electric current in the copper coils. This effect was first discovered in 1831 by Michael Faraday when he measured how electric current changed in a loop of wire as it swept through a magnetic field. It's quite simple and really easy to reproduce at home. This is how we transform gravitational energy into electric power on Earth. The amount of power generated depends on the amount of water flowing on the turbine; more water means more electricity.

So what has a hydroelectric power plant got to do with the creation of a star? First you have to imagine the disc where planets are built as a gigantic reservoir and the growing young sun as a gigantic magnetised turbine. Let's put some numbers on this analogy: this stellar turbine has a radius of some 100 000 km and it is accommodating a matter flow of about 2000 tons per second coming in with a velocity of about 1 million kilometres per hour! In one year, the growing star consumes about a billionth of the mass of our Sun. The growing sun's magnetic field is about a thousand times stronger than the field that moves a needle in a compass. So these young suns behave as gigantic magnets onto which matter falls. So far so good, but where is the copper coil? And where does the electrical energy go? The answer is that there are no wires, instead the currents are controlled by gravity and the electromagnetic fields they themselves generate. No wonder this problem needed so many clever people to understand it.

Young stars burn bright

The astronomical observations of young stars are helping a lot to understand the process. Today we know that about 10% of the gravitational energy is transformed into the ejection of beams of gas aligned with the rotation axis of the stellar turbine. These beams move at velocities comparable to those of the matter falling onto the star. They carry a significant fraction of the mass of the disc reservoir away from the young forming star. We call them protostellar jets and they make some of the most beautiful astronomical images.

Close to the star, the environment is very harsh. Gigantic eruptions suddenly release a hundredth of the solar luminosity as X-ray and ultraviolet radiation are produced. This action takes place within a region that may extend as far out as the orbit of Mercury. Modern space experiments (such as the SOHO satellite) show splendid pictures of the Sun's corona. The corona has a temperature of ten million degrees and radiates strongly in hard X-rays. In the newborn Sun, a similar but much larger structure irradiated the disc; the corona could reach Mercury's orbit, thus acting as enormous heating panels irradiating the disc, all the way out to the Earth's orbit. This is the reason why neither ices nor gases like hydrogen and helium can survive within the inner region of the discs and why terrestrial planets are solid and built of very robust molecules such as silicates or carbonates.



A protoplanetary disc is seen as a green oval. Radiation from the hot star is heating up the disc, causing matter to dissipate, like steam evaporating from the surface of boiling water. A strong stellar wind is propelling the material away from the disc. The material is glowing because it is gaining energy from the radiation from the hot star.

There is however, another intriguing point to this story. We all know that excess ultraviolet radiation harms our bodies. The reason is that our molecules, the molecules of life, are

extremely sensitive to ultraviolet radiation. They react to it, and in the presence of ultraviolet radiation the organic chemistry is accelerated. Ultraviolet radiation is bad for us, but it is of great importance to understand how life grew on our planet, or perhaps even in other forming solar systems in the Milky Way.

Exciting times

We are just beginning to grasp our origins, but it is clear that understanding this powerful engine that controls the birth of planets like ours and the appearance of large organic molecules, and maybe life, is of extraordinary importance. Major clues are hidden in this knowledge. Exciting times are waiting ahead with the new ultraviolet telescopes that will allow us to peer into these fascinating engines.

Huge clouds of interstellar gas and dust, like the famous Orion Nebula, are the birthplaces of stars and planets.

Avivah Yamani Riyadi

Born in Ambon, Indonesia

Biography

Born and raised in Ambon, a small city in Indonesia, Avivah's interest in astronomy began when her father introduced her to the stars and planets. The beauty of the night sky impressed her and made her think about things beyond our own Earth. In her teenage years she also developed interests in computers and design, along with an interest in social and education problems in her country.

After finishing high school in 1997, Avivah moved to Bandung and started university life in the astronomy department of Bandung Institute of Technology. Here she took a major in the Solar System and exoplanets. She also developed her interest in building websites and sharing information through online media. After finishing her undergraduate level studies in 2003, she decided to continue her studies in astrophysics at the same institute, working on building a planetary simulator. She also joined a friend in creating an astronomy magazine to share information with the public. Unfortunately this publication failed, but undeterred she began her own blog to share the enjoyment of life and astronomy with others. Spotting that the general public in Indonesia had a need for the right information and a basic astronomy education, she started to build an astronomy education network with her colleague. Currently Avivah works as a writer and communicator, with a keen interest in social science, philosophy, art, archaeology and history. She is involved extensively with astronomy communication with the public, enjoying the challenge of conveying complex ideas in an easy-to-understand manner. Other than astronomy, Avivah loves to travel and doing outdoor activities like camping and hanging out with friends in roadside cafes. She lives in Bandung, which is a high altitude location, making the weather pleasantly cool.

Langitselatan

Langitselatan is an astronomy communication and educator media centre in Indonesia. Langitselatan is an Indonesian phrase for southern sky (Langit means sky and selatan means southern). The purposes of Langitselatan are to build science and astronomy awareness among the Indonesian public by introducing fun astronomy and by acting as a base for astronomy information and education. The Langitselatan staff communicates astronomy with the public through online media, star parties, telescope training and hands-on activities. Langitselatan also functions as a community builder and it has already created a community of its own named the Langitselatan community. Apart from public outreach, Langitselatan also conducts research in exoplanet astronomy, ethnoastronomy and archeoastronomy.

www.langitselatan.com

langitselatan

Exoplanets

The Quest to Find Other Worlds

We have long wondered whether there could be planets orbiting any of the countless stars we see in the night sky. The efforts of astronomers searching for these alien worlds began to bear fruit when the first exoplanets were found in the early 1990s. Avivah Yamani talks enthusiastically about the history of planet hunting and the methods of finding them.

An artist's impression of the star 51 Pegasi and the exoplanet orbiting it.

In this gigantic Universe, it seemed entirely possible that there might be other solar systems. So the question emerged: could we find planets around other stars?

The search begins!

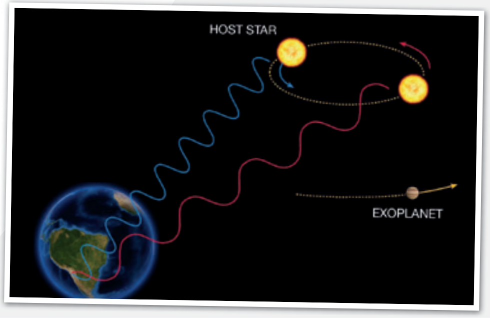
In the early 1990s, after years of looking, the first planet outside our Solar System was discovered. This exoplanet was discovered by Aleksander Wolszczan and Dale Frail around a pulsar in the constellation of Virgo. This discovery surprised astronomers. Why? Well, astronomers used to think that planets would only be found around stars similar to our Sun.

Then in 1995, a planet was found by Michel Mayor and Didier Queloz orbiting a star like our Sun, named 51 Pegasi in the constellation of Pegasus. This was the first planet discovered close to a star just like our own.

Since then exoplanets have been found with increasing frequency as technological advances have made it easier to find them indirectly. To date, about 500 exoplanets have been discovered with dozens of multiple-planet systems among them. However, none of them is a new Earth. And most of these planets have never been seen by the observer; they have been discovered using indirect methods. In astronomy we can't touch the objects we study, but we can observe many objects directly with telescopes. A few exoplanets have been observed directly, such as the exoplanets discovered by the Very Large Telescope, the Hubble Space Telescope, and a planetary system around HR 8799 using telescopes from the Keck and Gemini Observatories. Exoplanets are very dim in comparison to the bright stars and finding them presents a challenge. They don't produce light of their own and are lost in the glare of the parent sun. And, just like their parent stars, these exoplanets reside at enormous distances from us. Indirect methods allow astronomers to search for exoplanets by looking for changes in the stars.

Radial velocity: wobbles in space

The most productive technique for finding exoplanets is the radial velocity method. With this, we can measure variations in the radial velocity of the stars as star and planet revolve around their common centre of mass. The planet's gravitational tug will induce the star to move, or wobble, a bit. It looks like a dancing star, moving towards and away from the observer. This phenomenon can be detected by analysing the star's spectrum. It's a bit like the sound of an ambulance's siren changing in pitch as it moves towards and then away from you. The larger the planet and the closer it is to the star, the more and faster the star will move and the greater the shift in the spectrum.



Detection of exoplanets using the radial velocity method. When the star moves towards the Earth its light will be bluer and when it moves away the light will be redder.

Astrometry: measuring the position of the stars

Another indirect method is astrometry. This measures the difference in the star's position that is caused by an orbiting planet. However, the changes are really tiny and it is even more difficult to find a planet with this method. No exoplanets have so far been detected in this way.

Transit: looking for mosquitoes crossing a distant lamp

Another way to find exoplanets is with the transit method. This detects changes in a star's brightness when a companion planet passes in front of it and blocks a small portion of its surface causing a reduction in its brightness. With a sensitive instrument we can detect this reduction in brightness periodically as a planet passes in front of the star. However, this method can currently only detect planets fairly close to their parent star.

Gravitational microlensing: lenses in space

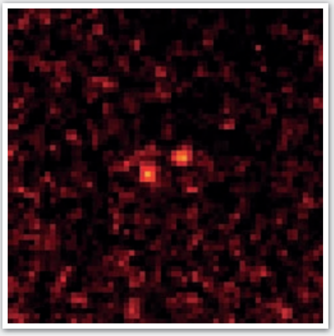
When a planet passes in front of a host star along our line of sight, the planet's gravity behaves like a lens. This focuses the light rays and causes a temporary sharp increase in the star's brightness. It also causes a change in the apparent position of the star.

Pulsar timing: searching for anomalies in a pulse

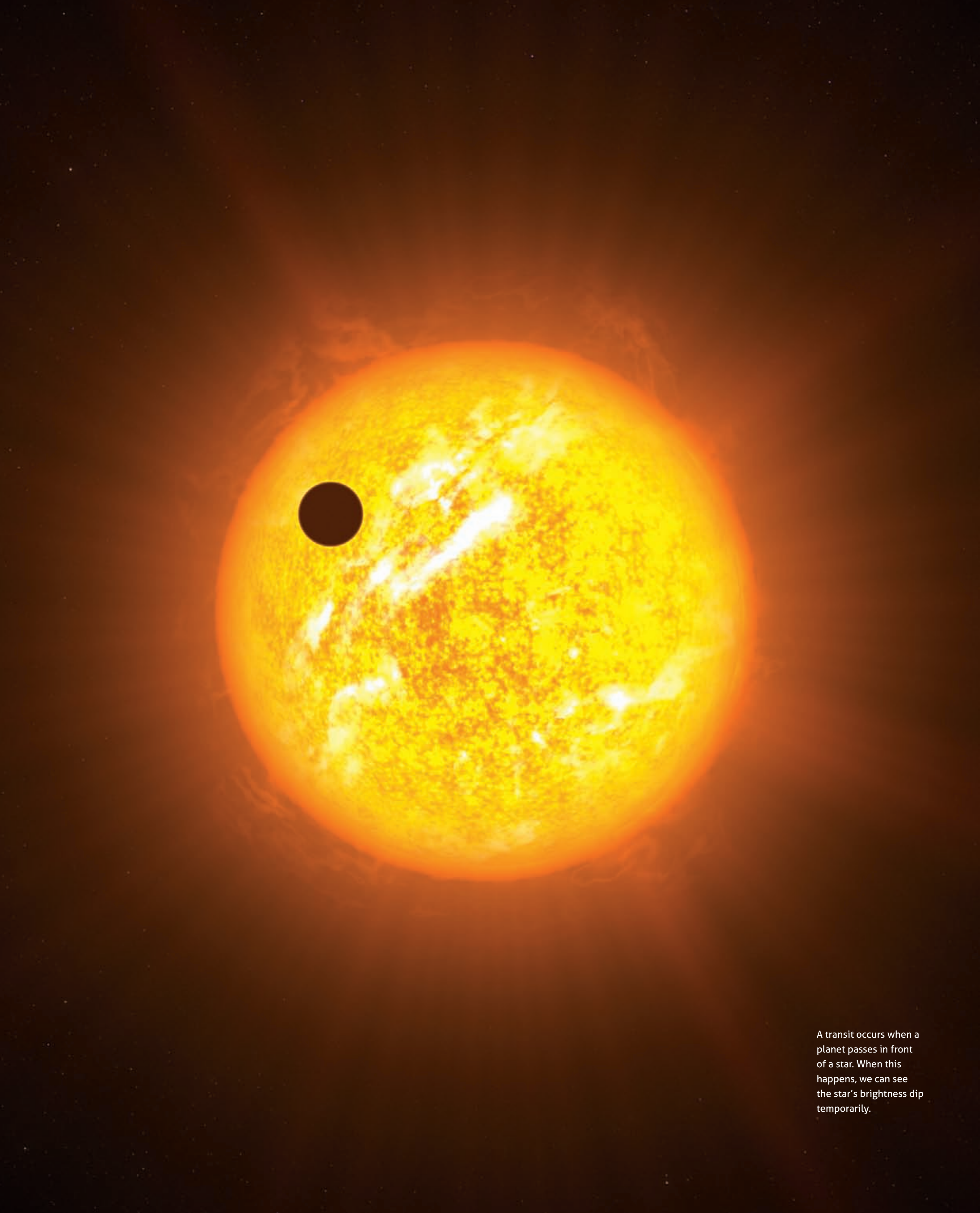
Pulsars are magnetised rotating neutron stars that emit radio waves and appear like radio pulses for observers on Earth. Slight changes in pulsar timings will be recognised by the observer. If this happens, we can track pulsar motions to work out if there is a planet orbiting the pulsar, or if there is something else making the changes.

Next stop: exoplanets like the Earth

Most of the planets detected so far by astronomers are Jupiter-sized or super-Earth-sized. One day soon, maybe we will find planets like our own orbiting another star. The Kepler mission was launched in March 2009. It will detect exoplanets using the transit method and show us if Earth-like planets are common in the Universe.



Direct imaging of exoplanets is possible with existing technology, but not much detail can yet be seen! Here Fomalhaut b is seen in two positions in its orbit around Fomalhaut in an image from the NASA/ESA Hubble Space Telescope.



A transit occurs when a planet passes in front of a star. When this happens, we can see the star's brightness dip temporarily.

Aude Alapini

Born in Cotonou, Benin

Biography

Half Beninese, half Belgian, Aude was born in Cotonou, Benin in 1983. She grew up in Benin, and attended the French Ecole EFE Montaigne. In 2001 she went to the Universite Paris XI in Orsay, France, to study for a DEUG de Physique, followed by a Magistere de Physique. For her Master's degree Aude studied at the University of Manchester in the United Kingdom and at the Observatoire de Paris–Meudon in France, specialising in astrophysics. She is currently completing a PhD at the University of Exeter in the United Kingdom. Her preferred topic is the detection and characterisation of exoplanets. In her spare time, Aude enjoys travelling, scuba-diving, hiking, movies, and spending time with family and friends. She is very interested in the practical applications of physics, such as medicine, energy production, and nanotechnology.

School of Physics, University of Exeter

The School of Physics of the University of Exeter performs world-leading research in astrophysics, biomedical physics, electromagnetic materials, quantum systems and nanomaterials. The astrophysics group at Exeter specialises in star formation and both the observational and theoretical aspects of exoplanets. Astrophysicists in Exeter design advanced star and planet formation simulations, perform millimetre, submillimetre, optical and infrared observations of star- and planet-forming regions and exoplanets using first class telescopes on the ground and in space, and are involved in the development of intelligent telescopes that observe with the minimum of human intervention.

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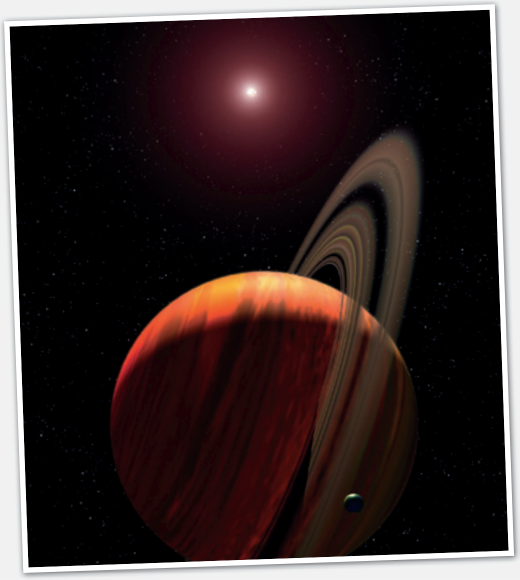
UNIVERSITY OF EXETER

Other Planets in the Milky Way

It is one of humanity's ultimate quests: to find other planets around other stars, beyond our own Solar System. Thanks to new technology and ingenious astronomers, we now know that there are countless worlds in our Milky Way and beyond. But as they are so far away, how can we know for sure that they are really there? And can we see what it's like on these far-flung worlds? Read on for the answers Aude Alapini gives us!



So far, astronomers have mostly found large planets around other stars, such as the one in this artist's impression.

Needle in a haystack

Trying to detect exoplanets is a challenging task. Unlike the nearby planets in our Solar System, exoplanets are very difficult to observe directly. Planets are millions of times fainter than their star, and seen from hundreds of light-years away — a light-year is a year travelling at the speed of light, which is more than a million times faster than an aeroplane! — they appear so close to their star that they are hidden from us in the glare. So far only ten or so exoplanets have been directly imaged using careful techniques that cancel out the light from the star to see the fainter object in orbit. These planets are bigger than Jupiter and in large orbits.

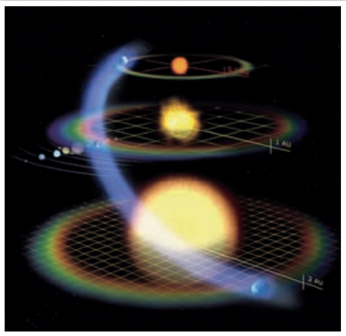
Scientists have developed several other methods to detect exoplanets. Instead of trying to see the planet directly, these methods aim at detecting the planet indirectly, such as through its influence on its star or on stars far behind it.

The snappily named 51 Pegasi b, found in 1995, was the first discovery of a planet around a star similar to the Sun. This exoplanet was discovered by Swiss astronomers using the radial velocity method, which needs a bit of explaining. 51Pegasi b is a planet more than 150 times as massive as the Earth — about half the mass of Jupiter — and 20 times closer to its star than the Earth is to the Sun. It would take us 50 years travelling at the speed of light to reach it. When a planet orbits a star, it causes the star to also move in a small orbit of its own. The radial velocity method consists of measuring the speed at which the star moves towards and away from us due to a planet orbiting around it. This speed is called the radial velocity and is only a few kilometres per hour for small planets like the Earth, less than walking speed. It is measured by studying features in the light coming from the star. With this method, scientists can measure the minimum mass of an exoplanet. So far, almost 500 exoplanets have been discovered with this method, making it the most popular technique. Other successful systems include transits (when the exoplanet moves in front of its host star), and microlensing (when the gravity of the exoplanet briefly enhances and focuses the light from the star).

Which types of exoplanets have we found so far?

Since 51 Pegasi b, astronomers have found almost 500 exoplanets in our galaxy, with new ones being discovered every week. Small planets like the Earth are extremely challenging to detect, as the smaller the exoplanet the weaker its signal. None found so far resemble the Earth in terms of composition or habitability. Most of them are more massive than Jupiter, meaning that they are very different from the Earth. They are also closer to their star than Mercury is to the Sun, meaning that it is extremely hot on their surfaces, often more than ten times hotter than boiling water! These exoplanets are nicknamed "hot Jupiters".

Among all the exoplanets discovered so far, the one that resembles the Earth most is perhaps Gliese 581 d. Gliese 581 is a star three times smaller than the Sun, 20 light-years away from us. Gliese 581 d is the fourth planet around this star, orbiting slightly closer to its star than the Earth does around the Sun. Its mass is expected to be more than eight times that of the Earth, but its exact mass and radius are still unknown. This means that, for now, it is impossible to know what Gliese581d is made of.

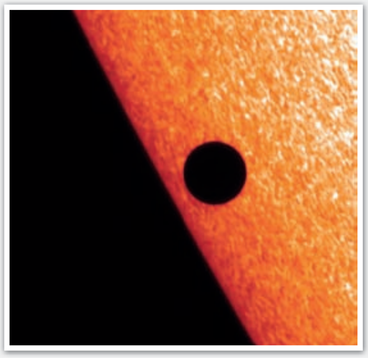


The "habitable zone" around a star is the region where water can exist as a liquid on a planet's surface. This exact distance depends on the star.

How much can we know about these exoplanets?

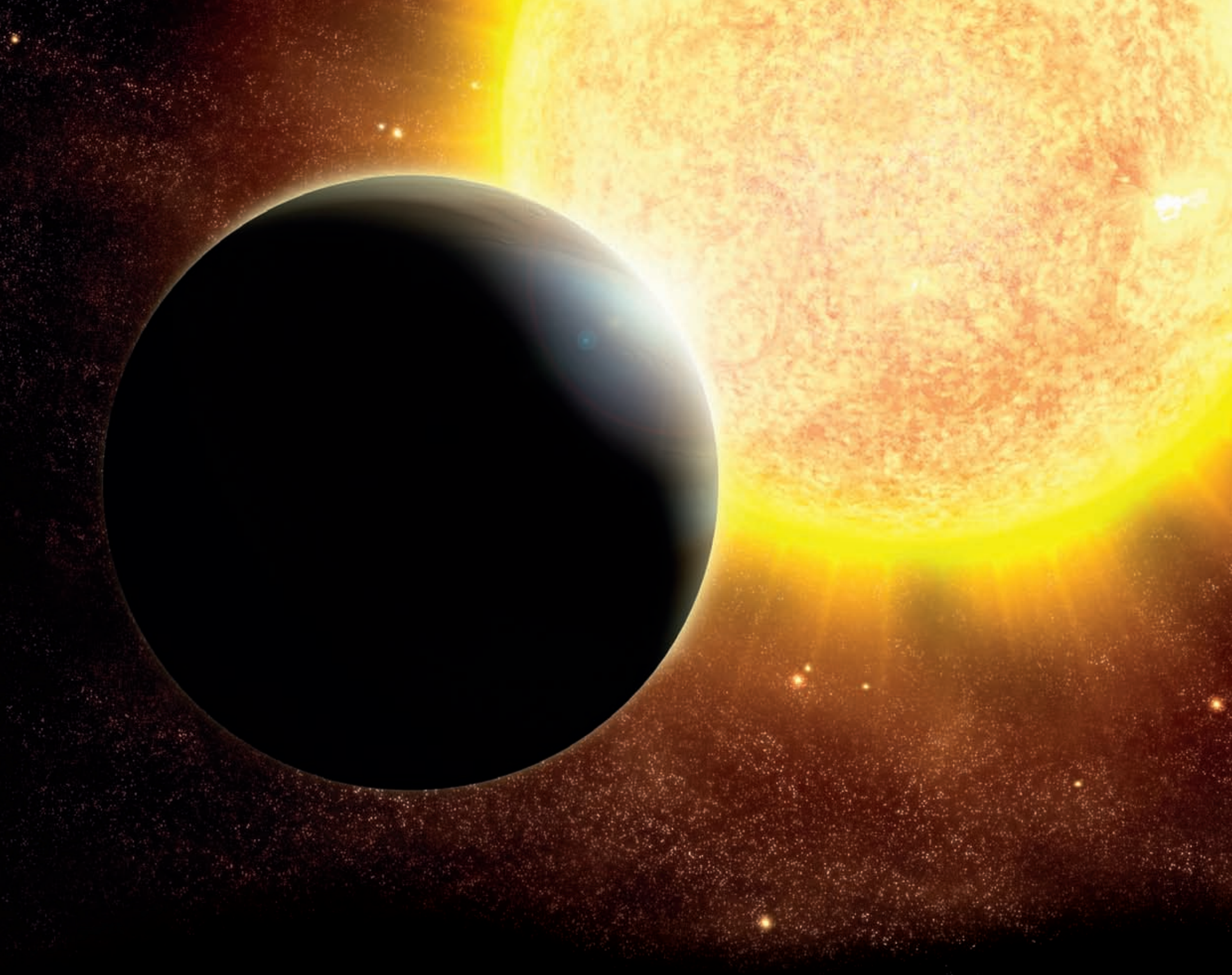
With our current technology, astrophysicists can already do a lot of great science, using ingenious scientific techniques to stretch the performance of available instruments. With the right observations, astrophysics can measure the mass and radius of an exoplanet, the shape of its orbit, and have a rough idea of its composition and atmosphere. The mass and radius of an exoplanet are used to calculate the planet's density, which gives some information on the composition. The shape of the orbit of an exoplanet gives some information on the temperature and how it might have formed.

Detecting the atmosphere of an exoplanet was meant to be achievable only with the next generation of space telescopes, but clever astrophysicists have developed ingenious methods with the current orbiting observatories Hubble and Spitzer. Detecting the atmosphere of an exoplanet can currently be achieved for transiting planets in two ways. The first is by studying the light from the star that passes through the planet's atmosphere. The other way is by studying the light from the exoplanet itself by measuring the difference between the light received from both the star and the planet and the light received from only the star when the planet disappears behind it.



During a transit, a planet passes in front of its star as seen from the Earth, meaning that we see the star's brightness decrease a little. The dark spot in this picture is actually the planet Mercury, during a transit of our own Sun.

In some cases astrophysicists can even detect brightness variations as the planet moves around in its orbit. These give some information



Artist's impression of a transiting Jupiter-mass exoplanet around a star slightly more massive than the Sun.

on the presence of clouds in the atmosphere and atmospheric circulation of the exoplanet. We are actually starting to study some kind of "weather" on these worlds!

What's next?

The next generation of space telescopes, Darwin (launch after 2015) and Terrestrial Planet Finder (launch after 2020), are designed to find and study habitable exoplanets with direct imaging. With these telescopes, scientists hope to discover worlds resembling the Earth, and look for chemical signatures of life in the atmosphere of these planets.

Finding and studying exoplanets is really exciting science. It helps us understand how our Solar System was formed and what our place is in the Universe. It is a scientific way of looking for answers to questions such as: "Are there other planets like the Earth in the Universe?" and "Is there life on these planets?"


Image credit: DCO

David Barrado y Navascués

Born in Madrid, Spain

Biography

As a staff researcher at the Centro de Astrobiología, a joint institute between the Spanish Space Agency (Instituto Nacional de Técnica Aeroespacial or INTA) and the High Research Council (Consejo Superior de Investigaciones Científicas or CSIC), David is involved with MIRI, the Mid-infrared Instrument for the James Webb Space Telescope. Previously, he was awarded a Ramon y Cajal fellowship, a prestigious tenure-track programme of the Spanish ministry of research, and a Fulbright postdoctoral fellowship to work at the Harvard–Smithsonian Center for Astrophysics, where he also finished his PhD dissertation.

David has worked as a post-doc at the Universidad Autonoma de Madrid and at the Max-Plank-Institut für Astronomie at Heidelberg, Germany. He has more than 100 published refereed scientific papers to his name and has extensive observing experience at the most important observatories. These include 8- and 4-metre-class telescopes such as Subaru, the VLT, Keck, Magellan, La Palma, Kitt Peak, Calar Alto and many others. He has worked with space telescopes including ESA's Infrared Space Observatory and XMM-Newton, the American Spitzer Space Telescpe and the Japanese Akari.

At present he is Director of the German–Spanish Astronomical Centre at Calar Alto in southern Spain. During the last few years David has devoted part of his time to outreach activities, explaining the work of astronomers to the public. He is particularly passionate about his writing.

Centro de Astrobiología — CAB (INTA-CSIC)

The Center for Astrobiology, a Spanish institute associated with the NASA Astrobiology Institute, has several lines of research, covering topics from prebiotic chemistry to planetary geology and biology, and includes astrophysics as one of its main areas of activity. Star formation, molecular chemistry in different astrophysical environments and the search for exoplanets and their characterisation are all the focus of very active research. The institute has access to a world-class observatory and is involved in the development of instrumentation, including the Mid-infrared Instrument for the James Webb Telescope or the Mercury Imaging X-ray Spectrometer on BepiColombo.

www.cab.inta-csic.es

CENTRO DE ASTROBIOLOGÍA
ASOCIADO AL NASA ASTROBIOLOGY INSTITUTE
GOBIERNO DE ESPAÑA CSIC Instituto Nacional de Técnica Aeroespacial

Why Star Formation?

Stars have a life cycle, but how are they "born"? Why do they form in the way that they do, and how does this influence their lives? How important is gravity, or what they are made of, or where they are created? David Barrado y Navascués reveals that until relatively recently these were questions it seemed we had little hope of answering, but thanks to modern scientific technology and techniques, the secrets of the stars can be revealed to all.

Barnard 30, a dust cloud located at 400 parsecs in the head of Orion, as seen with the Spitzer Space Telescope.

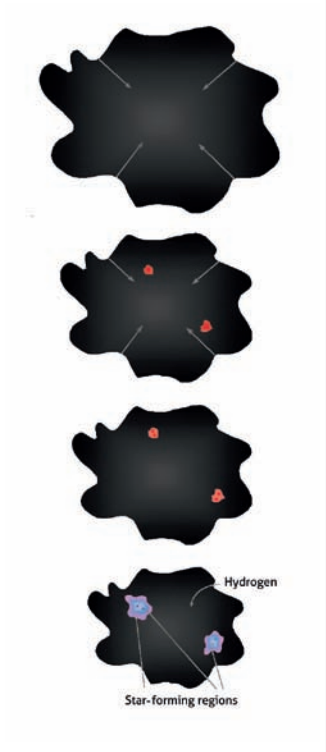
Before I was 12 years old I watched a documentary that really made an impact on me. Its name was *Michelangelo: The Last Giant*, by the well-known director Tom Priestley. Even though I barely remember anything at all about it, it left a feeling that still, almost thirty years later, remains with me. It made me wonder about the world, but also sparked a desire: I wanted to be like Michelangelo Buonarroti and do as many things as he achieved.

Later I realised that I should keep my education as broad as possible, becoming a good professional in the area of my choosing, but also learning about other fields. I never had any doubt about my future profession: it would be astrophysics. Looking back, I believe I already knew that my work would be in stellar astronomy.

Galaxies caught my eye; cosmology my imagination. But... I felt some kind of closeness with the stars, perhaps induced by too much science fiction. I wanted to navigate the stellar oceans, even if I could only do it with my mind. And this is just what I do: I am trying to learn how stars are born, what their properties are and how they evolve.

Life cycles

Like humans, stars have a life cycle. They are born in large groups, cohorts that can include dozens, hundreds or even thousands of stars. Despite their shared circumstances of birth these stars can be very different from each other since one basic stellar property, their mass, can vary. Some stars are similar to our own Sun, or even much bigger, as much as one hundred times so, as in the case of Eta Carinae, a stellar behemoth. But most stars are much less massive than the Sun, on average about half its mass. And a star's mass is basically what determines a star's fate, its internal structure, its external properties, how long its life is going to be, and its end: grandiose in the case of a very massive star, more humble for Sun-type stars. But even for Sun-type stars the end can be spectacular, since



A cartoon showing the initial steps of the collapse and fragmentation of a molecular cloud.

they produce beautiful planetary nebulae. As for the least massive stars, they are so spartan in the amount of energy they produce they are essentially eternal, since they will last for billions or trillions of years.

Stars release energy that is primarily produced by nuclear reactions in their interiors. During most of their life they fuse the simplest atomic element, hydrogen, into the second most basic, helium. But the rate of production depends essentially on the stellar mass: the bigger the star the greater the rate of production, since the star needs to counter the gravitational forces pulling all the mass towards the centre. This is achieved by producing energy and heating the interior.

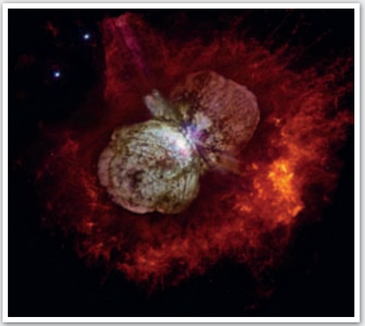
Burning questions

But then the questions remain: how are stars formed? Why do they have different masses? The answers are very easy to outline, but so complex that we do not completely understand all the details. However, we have a nice (albeit incomplete) picture of the process, although but much research remains to be done.

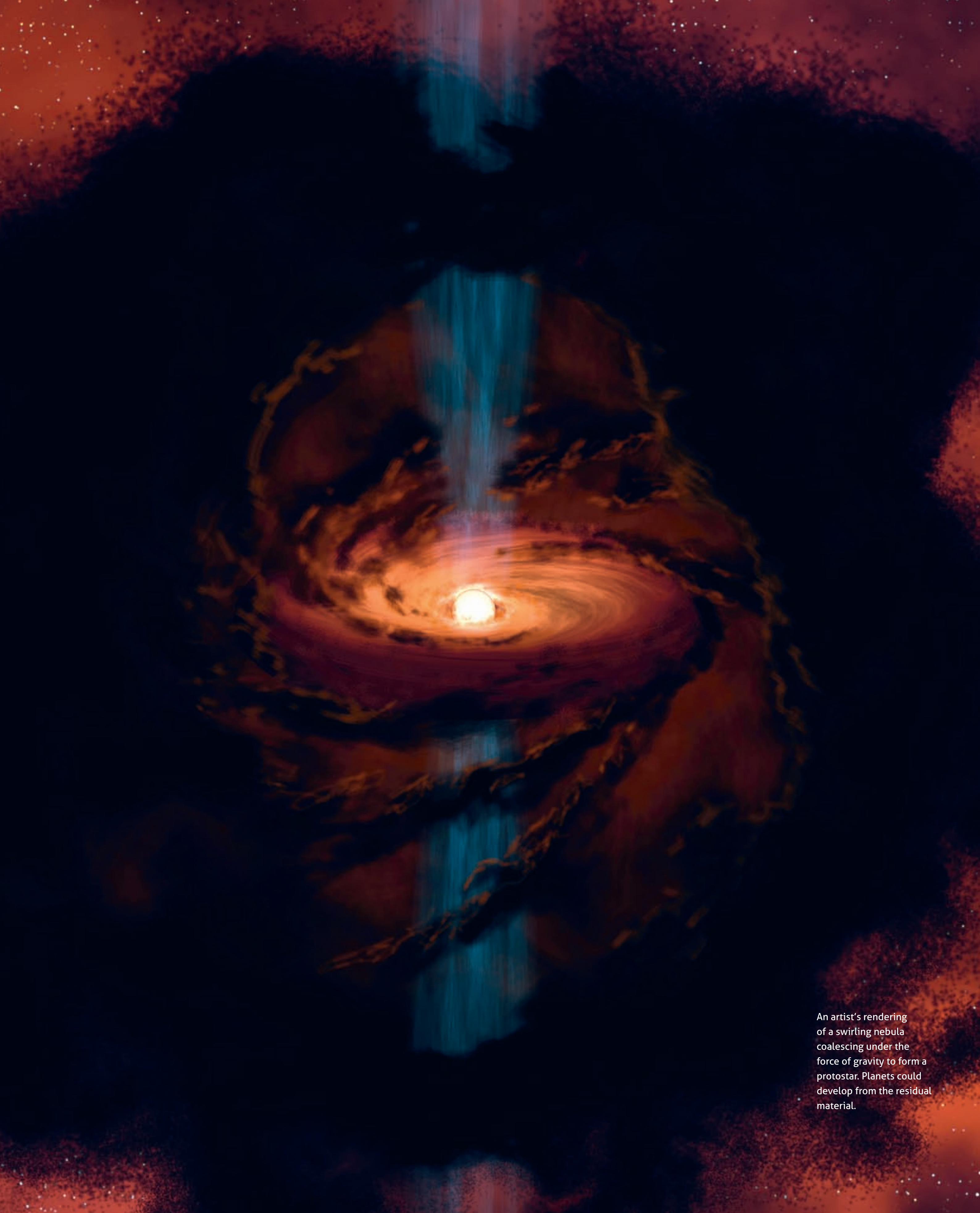
We know that new generations of stars are born in the huge molecular clouds that are randomly distributed across the Milky Way, our own galaxy. These clouds are normally located close to the Milky Way's equator, the Galactic Plane. They are made of very cold gas and dust. The density (amount of matter in a given volume) can be so low that we might be tempted to think of it as empty. But it is not.

Sometimes these clouds are affected by nearby events. It might be the gravitational interaction with another massive cloud just passing by. Or the disruption created by the spiral arms of the galaxy. Or perhaps the shock generated by a nearby supernova. Whatever the reason, the cold cloud starts to collapse. The material becomes denser and hotter and breaks up its gigantic substructures, much larger than the Solar System. The inner part of this substructure is much hotter and denser than the rest, but we cannot see it because the outer layers have become so opaque that visible light cannot cross it. This is a protostellar core, which eventually will evolve into a real star.

These cores will go on collapsing, converting part of gravitational energy into heat, just as, on a smaller scale, we convert the potential energy of water behind a dam into movement and electricity. Eventually they will become so hot and dense that the first nuclear reactions will take place in the interior. Some matter falls onto the star, but a fraction of it settles on a circumstellar disc. This also interacts with the central star, and beautiful and interesting phenomena can be produced out of these processes: powerful outflows of material; changes in the brightness of the star; an evolution in the properties of the disc, which might eventually produce a planetary system...



The vast star Eta Carinae is expected to explode in a spectacular supernova.



An artist's rendering of a swirling nebula coalescing under the force of gravity to form a protostar. Planets could develop from the residual material.

Joana Ascenso

Born in Coimbra, Portugal

Biography

Joana was born in Coimbra, Portugal, on 8 September 1979. She was the first of two daughters of Jaime and Judite Ascenso, a wine producer and a laboratory analyst, respectively, and sister to Alexandra Ascenso. After living in Coimbra until the age of 18, Joana left to study Physics and Applied Mathematics — Astronomy at the University of Porto. She finished the Licenciatura in 2002 and started her Master's studies on the spectral properties of TTauri stars, also at the University of Porto. As a student she was a guide in a Starlab portable planetarium, presenting astronomy in schools, and also a guide for the Porto planetarium until the end of her Master's degree in 2004. She then started a PhD thesis on embedded clusters and star formation with Dr João Alves and Prof. Teresa Lago. The first two years of the thesis were divided between CAUP (Porto, Portugal) and ESO (Garching, Germany). When Dr João Alves moved to the Calar Alto Observatory (Spain), the thesis continued between Porto and Granada (Spain). As an observational astronomer, she has visited ESO's observatories in Chile, La Silla and Paranal, at least once a year since the beginning of her thesis. After her PhD Joana spent a year at the Harvard–Smithsonian Center for Astrophysics (Cambridge, USA) working on the infrared properties of molecular clouds. Apart from astronomy, Joana is involved in a social project for the distribution of free software in schools.

Centro de Astrofísica da Universidade do Porto (CAUP)

CAUP has a tradition in three major areas of research: low-mass star formation, astroseismology and extragalactic astronomy. As technology has evolved and research worldwide has developed, the area of star formation at CAUP has broadened to include high-mass star formation and the study of young stellar clusters. Recently, the area of exoplanets has gained strength and now represents a significant fraction of the science done in the institute. CAUP is furthermore responsible for the University of Porto master's and doctoral programmes in astronomy, and it is also the leading national institution in science outreach, responsible for the scientific contents of the Porto planetarium, and astronomy for schools.

www.astro.up.pt

Centro de Astrofísica
da Universidade do Porto

Stellar Nurseries

Stars are formed in large clouds of gas and dust that are scattered throughout the cosmos. But how much of this process do we really understand? Is it the same for all stars? Are they produced one at a time? Using state-of-the-art observatories and venturing away from visible-light wavelengths, Joana Ascenso explains how all these questions and many more can now be answered.

Stars are born in clouds of gas and dust, like the famous Eagle Nebula.

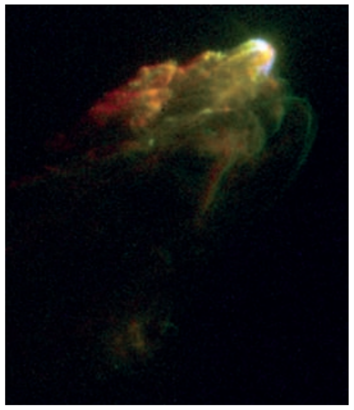
Stars are formed in large clouds made up of vast amounts of gas and dust called giant molecular clouds. These are found all over our Milky Way, and also throughout most of the galaxies in the Universe. The formation process appears to be the same for all stars, with small, albeit significant differences between light and heavy stars. Under the action of gravity, turbulence and magnetic fields, the dust and gas begin to gather to form protostars that will grow in size as the material is continuously pulled together from the cloud to the star-to-be. The temperature and pressure in the centre of the protostar progressively increases until a point when it is hot enough to ignite the fusion of hydrogen, the most abundant element in the Universe, and in giant molecular clouds in particular. These nuclear reactions then become the main source of energy of the now adult star.

Stars like our Sun

The exact steps in the formation of individual stars depend on their mass. Low-mass stars, like our Sun, take a considerable amount of time to reach adulthood, allowing them to be studied in detail. Over the years, astronomers have drawn what seems to be a consistent picture applying to all low-mass stars, in which a small portion of the cloud gathers in the form of a cocoon around the protostar from which it grows. This cocoon, or envelope, then evolves into a flat disc, from which the star continues to grow, although at a slower rate. During this process the young protostar develops outflows from its poles in a direction perpendicular to the disc, which helps the rotating material from the disc to slow down and "fall" into the central star. As the outflows impact the surrounding cloud, they produce bright and colourful shocks forming beautiful so-called Herbig–Haro objects.

Deeper understanding

Massive stars form more rapidly and evolve into adulthood while still completely embedded in their thick cocoons, so they emerge from the cloudy veil already fully formed. For this reason, understanding of their formation has remained elusive for many years. Several theories involving, for example, the merging of smaller stars into one massive star have been proposed. But nowadays, based on better and deeper observations and crucial theoretical development, it is generally accepted that massive stars form in roughly the same manner as their low-mass counterparts, with infall of gas from an envelope and later from a disc as the primary growth mechanism of the central protostar. The winds of massive stars are naturally stronger and more energetic, often affecting neighbouring lower-mass stars and the leftover cloud violently.



Young stars can emit high speed jets of material. These jets were only discovered 20 years ago.

Peering through the dust

Star formation does not occur in isolation. Rather than producing one star at the time, giant molecular clouds produce clusters of stars numbering from a few tens to over ten thousand, spanning the entire spectrum of stellar masses from light to heavy. Interestingly, regardless of the number of stars formed or of the external conditions of the cloud, the percentage of stars of any given mass seems to be constant in all known star-forming regions, as if nature always follows the same recipe for star formation. This is still a puzzle to astronomers today as it is not easy to envision a process potentially responsible for such a high degree of homogeneity over such a wide range of cluster masses, but the answer is slowly emerging, helped by the constant technological improvement of the observing facilities.

During their first million years, star clusters are invisible to traditional visible-light telescopes because the newly-born stars are still shrouded in the cloud, heavily obscured by the circumstellar and ambient dust. In the late 1980s, with the advent of telescopes sensitive to infrared light, the first young clusters were observed. Infrared radiation can pierce the obscuring dust more effectively and unveil the formation process. Since then, and mainly in the last ten years, telescopes bearing increasingly more advanced detectors have made it possible to study the early stages of star formation. As the massive stars begin to form and ignite their powerful winds, the gas and dust still left in the cloud are blown away and the cluster reveals itself in visible light. This happens around an age of 5 to 10 million years, the blink of an eye by astronomical standards.

Star clusters provide more than just pretty pictures; the information gained from studying them is very important for astronomers.

Finding pieces of the puzzle

My job as an astronomer is to contribute to the understanding of these star-forming regions using state-of-the-art observations in the near- and mid-infrared. Being a remote science, the understanding of the light that we receive, be it in the form of images or spectra, is crucial. A simple picture can tell a rich and enlightening tale of the star formation process, and its thorough analysis can be of invaluable importance for finding the missing pieces of the puzzle and putting them in the appropriate context. I am especially interested in the study of the global properties of star clusters — why different clusters share so many similarities, where in a cluster planets form and how they survive the presence of the destructive massive stars, or whether and why massive stars appear to concentrate at the cluster cores. More recently I have studied dark clouds, the precursors of stars and clusters.

As technology evolves, we will be able to probe the most difficult and unknown episodes of star formation — those that occur in the earliest of ages, deep inside the cloud and that were up to now hidden from our view. A myriad of telescopes providing unprecedented quality and coverage of the electromagnetic spectrum are soon to be completed, making this a very interesting time for the study of star formation. Soon, it will be possible to study the obscured processes occurring inside the clouds in great detail. This promises to revolutionise our theories of the mysterious formation of stars and planets from giant clouds of gas and dust and I have no doubt that Galileo would be thrilled and inspired had he lived today.

Infrared radiation penetrates the gas and dust, so infrared telescopes can obtain outstanding views of young stars.

Gayandhi de Silva

Born in Colombo, Sri Lanka

Biography

Gayandhi was born in 1981 in Sri Lanka and spent her childhood travelling around the Middle East and South East Asia with her family. Her family emigrated to Australia in 1994, where she grew up. In 2002 she received her Bachelor of Science degree, majoring in Maths and Physics from Monash University. That same year, at 21 years of age, Gayandhi got married before starting her PhD in Astronomy and Astrophysics at Mount Stromlo Observatory, part of the Australian National University. Her thesis was on the chemical homogeneity of open star clusters. In 2004 she had her first child, in the middle of her thesis. After resuming her research, Gayandhi completed her PhD in 2006 and was awarded an ESO fellowship to Chile. There her main duties were supporting the Very Large Telescope science operations at Paranal Observatory. In 2008 she had her second child and transferred to ESO Garching, to work within the User Support Department.

European Southern Observatory (ESO)

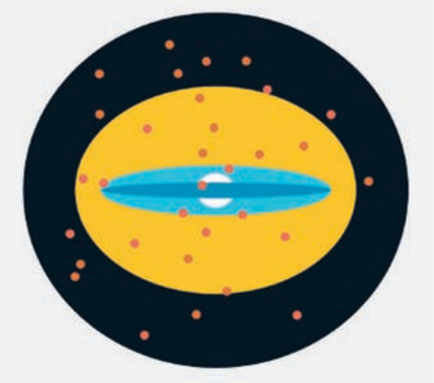
European Southern Observatory (ESO) — User Support Department (USD)
ESO is the foremost intergovernmental astronomy organisation in Europe and the world's most productive astronomical observatory. It operates three sites in Chile — La Silla, Paranal and Chajnantor — on behalf of its fourteen member states. It is building ALMA, the Atacama Large Millimeter/submillimeter Array, together with international partners, and designing the European Extremely Large Telescope.

ESO's User Support Department is the interface between the observatory sites in Chile and the users of the facilities — the international astronomers who have been awarded observing time. Modern observatories today are run without the user being present. Instead the user interacts with the User Support Department to help users prepare the materials required for observations, to ensure no problems occur once the observations are carried out at the telescopes and that the user is content with the obtained data.

www.eso.org

How Did Our Milky Way Form?

Despite decades studying galaxy formation, we still have only a crude picture of how galaxies like our own Milky Way came to exist. Much detail on the physical scenario is still missing and understanding it requires the joint effort of observations, theories and complex numerical simulations. The newly developed technique of chemical tagging is an observational tool that may eventually allow us to identify the members of the clusters that formed the original building blocks of our Milky Way. It is a complex, yet fascinating field of study, and one that Gayandhi de Silva is happy to walk us through.



A schematic diagram of the Milky Way, showing its main components. The black region represents the dark matter halo. The yellow, old stellar halo contains the oldest stars in our galaxy. The disc is represented in blue, with the thick disc in dark blue and thin disc in light blue. In the centre, in light yellow, is the bulge and the small red dots represent the distribution of dense globular clusters in the Milky Way.

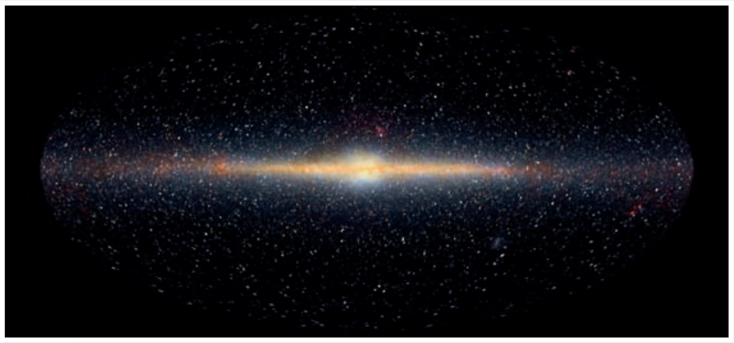
The Milky Way is a spiral disc galaxy, with several components, each the result of different formation and evolutionary processes. These parts are seen in other spiral galaxies, and are not unique to the Milky Way. The major components include the dark matter halo, which is thought to have assembled first, initiating and driving the galaxy formation process; the stellar halo, which is the oldest stellar component of our galaxy and hosts most of the very massive and dense globular clusters; the central bar, which is also referred to as the bulge when the Milky Way is viewed edge-on from the side; and the stellar disc, which can be split into two sub-discs — thin and thick discs. The stellar disc is the defining component of all spiral galaxies including the Milky Way. Therefore understanding how the galactic disc formed is fundamental to understanding galaxy formation. That said, the disc is also the most difficult component to study as it is constantly evolving, undergoing numerous evolutionary processes, with new stars being formed and mixed into the background field.

A currently popular model for galaxy formation is one of "hierarchical aggregation", where smaller independent structures join forces to form the larger structures. However within this hierarchical structure formation model, the details of the formation and evolution of our Milky Way's disc is poorly understood, due to the complexity of the factors involved.

Chemical tagging of the disc

Ubiquitous throughout the disc and woven into the field of background stars we find star clusters that represent the birth sites of stars. These disc star clusters are referred to as galactic or open star clusters. However, open clusters lead a life of uncertainty between survival and disruption. Most open cluster stars will dissolve and disperse into the Milky Way's background, like children in a family growing up and eventually leaving home. Therefore most of the bound star clusters that we see today are young clusters, such as the Pleiades.

Infrared image of the Milky Way taken by the DIRBE instrument on board the Cosmic Background Explorer (COBE) satellite.



However, a few old open clusters also exist in the disc. These rare old open clusters can be regarded as fossil structures and are witnesses to the formation history of the disc. Studying the chemical properties of these old fossils shows that all stars within the cluster share the same chemistry. This chemical signature acquired at birth is preserved within the stars throughout their lives, except in particular cases such as binary stars, variable stars or very massive stars. Most other stars should retain their original chemical signature despite their travels around the Milky Way. Therefore we can use this chemical signature as a tag to identify the origin of a given star in the Milky Way. This technique is now referred to as chemical tagging.

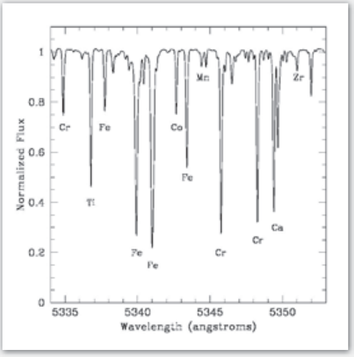
Untangling the Milky Way galaxy

While members of most star clusters have now dispersed into the field background, we can use the chemical tagging technique to trace them back to their original birth site, thereby reconstructing the lost fossil clusters of the Milky Way disc. To study the chemical signatures we require high quality spectra. Instruments such as the Ultraviolet and Visual Echelle Spectrograph (UVES) available at ESO's 8-metre Very Large Telescope (VLT) and the High Resolution Echelle Spectrograph (HiRes) available on the 10-metre Keck telescope, provide the high resolution data that is required to measure very accurate chemical compositions of these stars. The abundances of numerous elements can be measured from the absorption line features in the spectra.

Tracing the solar family

Just as DNA can be used to trace a family tree, the chemical tagging technique can be used to recover the original family members of our Sun. Although our Sun is now a single star, it was born in a star cluster. Its siblings, who are now located elsewhere in the Milky Way, can be traced by looking for their unique chemical signature. Finding other stars that share the same chemical make-up as the Sun is one of the goals of chemical tagging. The long-term goal of chemical tagging is to reconstruct the ancient building blocks of the Milky Way disc. By reconstructing these original clusters we will get insights into the formation and evolutionary processes, such as the rate of star formation, or possible accretion of smaller external galaxies. This will enable us to develop a sequence of events of how the Milky Way came to be as we see it today. The currently available instruments on ground-based telescopes are able to provide data on the nearby regions of the disc, but are not sufficient to perform large-scale chemical tagging of the entire disc.

This field of research will be greatly boosted by European Space Agency's upcoming Gaia mission. Gaia is set to be launched by 2012 and will provide data for about one billion stars in our Milky Way. There is much to look forward to in the future!



A region of the solar spectrum with several elemental line features. By measuring the depths of the absorption lines astronomers can derive the abundance of the different elements.

The well-known Pleiades star cluster is a young open cluster with an age of about 100 million years. As the cluster travels around the Milky Way, its member stars will eventually disperse into the Milky Way background.

Nadine Neumayer

Born in Spaichingen, Germany

Biography

The small city in south-western Germany where Nadine grew up has a lot to offer: beautiful landscapes and clear, dark nights. She often enjoyed the view of the Milky Way crossing the sky and was fascinated by the idea that there are millions of other galaxies out there. This was the beginning of her interest in astronomy. After finishing high school Nadine travelled to Chile to visit the La Silla Observatory and get an idea of what the life and work of an astronomer would be like. With the deep wish to become a professional astronomer, she started to study Physics and Astronomy at the University in Heidelberg. Having completed her undergraduate studies, she moved to Cambridge for one year and obtained a Certificate of Advanced Study in Mathematics in 2000. Back in Heidelberg she continued her study of physics and astronomy and completed her diploma thesis at the end of 2002. In 2003 Nadine started a PhD at the Max-Planck Institute for Astronomy (MPIA) in Heidelberg. Right at the beginning of her thesis she travelled to Chile again — this time as an astronomer — and took the first data for her own research. Half way through Nadine's PhD thesis in September 2007 she had her first daughter, Johanna, and two years later, during her first postdoc position at the MPIA, Johanna's sister, Lena, was born. Since December 2007 Nadine has been a fellow at the European Southern Observatory in Garching, Germany. Nadine says that it is a challenge and a great gift to have a family and also to work as a scientist.

European Southern Observatory (ESO)

ESO is the foremost intergovernmental astronomy organisation in Europe and the world's most productive astronomical observatory. It operates three sites in Chile — La Silla, Paranal and Chajnantor — on behalf of its fourteen member states. It is building ALMA, the Atacama Large Millimeter/submillimeter Array, together with international partners, and designing the European Extremely Large Telescope.

www.eso.org

Black Holes

Few scientific topics capture people's imaginations as much as black holes. Even just mentioning them is often enough to interest and captivate an audience. But how much do scientists actually know about these astronomical anomalies? How are they related to quasars, X-rays and galaxies? And of course, if they swallow light, how can we see them? Nadine Neumayer's article will help put many pieces of the puzzle together, explaining something of the nature of black holes.

A Hubble image of the nearby quasar 3C 273.

Black holes are among the brightest objects in the Universe. This sounds strange, doesn't it? Well, let's rephrase it a little: black holes give rise to the brightest objects in the Universe. Better? Indeed, it was the brightest objects in the Universe, quasars, that led astronomers to the concept of black holes. Quasars are very distant objects and are as bright as a million to a billion stars. But unlike stars, quasars emit radiation over a huge range of wavelengths, from radio to X-rays. Their extreme luminosities come from within a very small region, and if one looks close enough, one always finds that the quasar is sitting in the middle of a galaxy: the host galaxy. The vast energy output of quasars cannot be explained by the same mechanisms that make stars shine. It can best be explained by material spiralling onto a supermassive black hole.

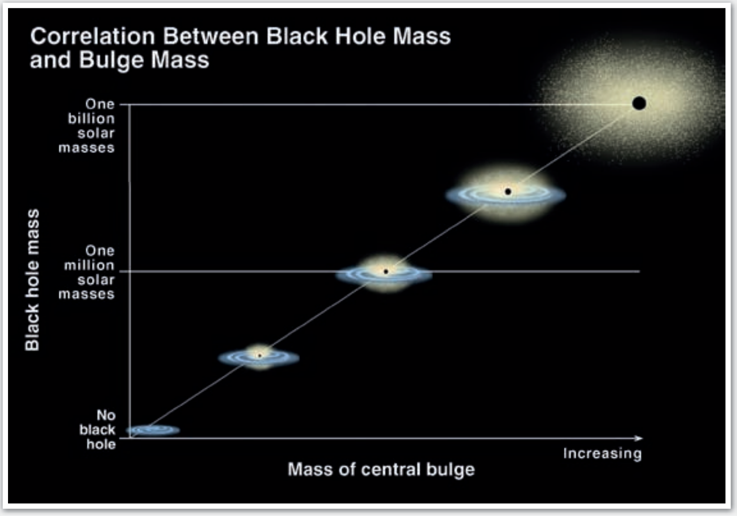
Hungry holes

Quasars are very far away. They are the furthest objects observed in the Universe, with their distances in the region of a few to a hundred billion light-years. These enormous distances make it difficult to study them — and especially their faint host galaxies — in detail. Fortunately we find scaled-down versions of quasars in our cosmic neighbourhood (a few to almost fifty million light-years). They share the common feature of an extremely luminous point source sitting at the centre of a galaxy and are thus combined under the name "active galactic nuclei". They are fainter than their more distant counterparts. This is due to the fact that their central black holes are not as big, and that there is less material to feed them.

Finding galaxies with lower and lower central activities led astronomers to speculate that there must be black holes that have completely run out of fuel and that are now sitting quietly and unseen at the centres of galaxies. These black holes are not directly observable, but they can still be detected. The gravitational influence of black holes on stars and gas moving around them betrays the presence of quiescent black holes.

A monster at the heart of our Milky Way

The best example is the black hole at the centre of our own galaxy, the Milky Way. Although not visible, there must be an object present with a mass of about three to four million times the mass of our Sun to explain the fast movement of stars at the Galactic Centre. The region within this enormous mass is so small that no other explanation holds than the presence of a black hole.



Astronomers believe that every galaxy with a bulge of stars at its centre also harbours a supermassive black hole. Observations suggest a direct relationship between the mass of the black hole and the total mass of the bulge, so the formation of the black hole and the bulge may be related.

Current observations suggest that Nature cannot make a big galaxy without a black hole at the centre. Indeed, the central black hole seems to be linked to the rest of the galaxy, in the sense that bigger galaxies tend to have bigger black holes. This suggests that galaxies and their central black holes evolve and maybe even form together. Part of the story is fairly well understood. It seems likely that galaxies grow and evolve by merging. If two galaxies merge, the resulting galaxy is roughly the sum of the individual galaxies. During the merger process the two black holes sink to the centre of the newly formed system and will eventually merge to a single black hole, with a mass being the sum of the individual black holes. Computer simulations show that these processes work and are able to explain the observations.

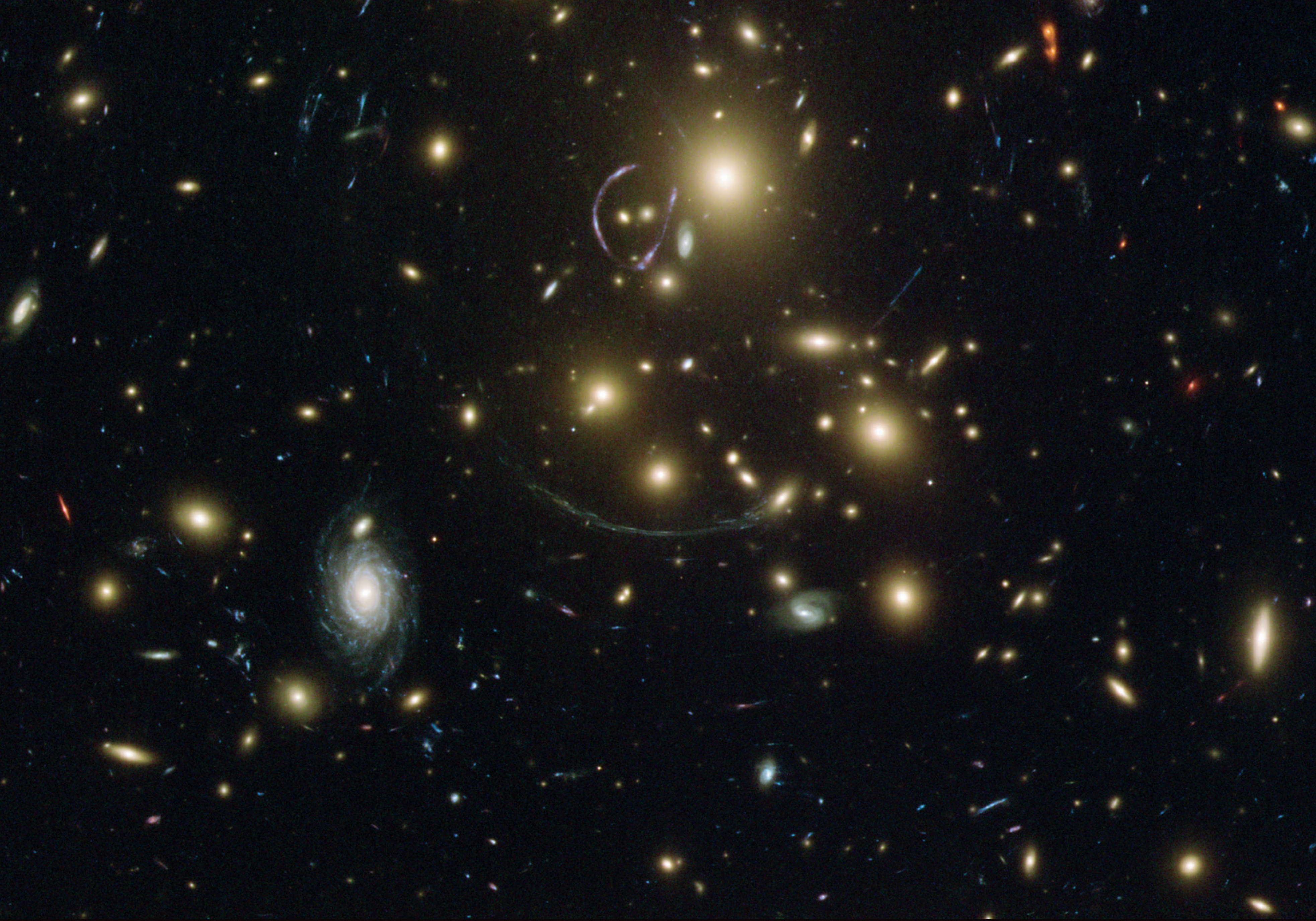
Enduring mysteries

However, it remains unclear how black holes get to the centres of galaxies in the first place. This is one of the questions that particularly interests me. There are galaxies that seem not to have grown black holes at their centres yet, or at least they are so small that current telescopes are unable to detect them. But for a large number of these small galaxies astronomers have observed a very dense cluster of stars at the centre. These star clusters could be the birthplaces of black holes and might provide the key to understanding the formation of these unusual gravitational phenomena.

Very recently, a black hole was discovered in the biggest star cluster in the Milky Way, Omega Centauri. Astronomers have long been speculating that this cluster is the remnant of a small galaxy that merged with the Milky Way a long time ago. The mass of Omega Centauri’s black hole is about 40 000 times the mass of our Sun.

Using the best telescopes currently available and the next generation of improved telescopes, black holes of intermediate masses will probably be detected at the centres of small nearby galaxies. These could be the seeds for the larger supermassive black holes found in bigger galaxies. So, pieces of the puzzle for black hole formation are beginning to fit together. There is a lot still to discover!

A new discovery has resolved some of the mystery surrounding Omega Centauri, the largest and brightest globular cluster in the sky: it appears to harbour an elusive intermediate-mass black hole in its centre.



The Distant Universe

Abell 1703 is composed of over one hundred different galaxies that act as a powerful cosmic telescope, or gravitational lens. The gravitational lens produced by the massive galaxy cluster in the foreground (the yellow, mostly elliptical galaxies scattered across the image) bends the light rays in a way that can stretch the images and so amplify the brightness of the light rays from more distant galaxies. In the process it distorts their shapes and produces multiple banana-shaped images of the original galaxies. The result is the stunning image seen here — a view deeper into the Universe than possible with current technology alone.

Tijana Prodanovic

Born in Novi Sad, Serbia

Biography

Tijana was born in Novi Sad on 14 December 1978. She first became interested in astronomy at the tender age of ten, and wanting to know about the Universe has stayed with her ever since. In 2001 Tijana graduated with a bachelor's degree in astrophysics from the University of Belgrade, Serbia, and in the same year enrolled at the University of Illinois at Urbana–Champaign, USA where she was awarded a PhD in astrophysics in 2006. Tijana then returned to Serbia and her hometown of Novi Sad, where she is now the assistant professor of astronomy and astrophysics at the University of Novi Sad. Her scientific research is focused primarily on the nucleosynthesis of light elements, which are crucial in cosmology, and cosmic-ray and gamma ray astronomy.

Besides scientific work, Tijana is also dedicated to teaching and bringing modern methods to classrooms at the University of Novi Sad and Serbia in general. During her graduate studies in the USA she was twice awarded the Excellent Teachers Award. Moreover, in 2008, Tijana won the national, and came second in the international, FameLab competition for the best science communicator, organised by the British Council. Tijana is also very active in public outreach. She regularly gives popular public lectures in astronomy and is a Chair of the Scientific Committee of Novi Sad Astronomical Society.

Physics Department, Faculty of Science, University of Novi Sad

The Physics Department of the Faculty of Science, University of Novi Sad, consists of five major research groups: nuclear physics, experimental condensed matter physics, electronics, theoretical physics and a general physics group. Scientific research areas covered by these five groups are nuclear physics, plasma physics, X-ray crystal structure analysis, and theoretical and experimental condensed matter physics. Moreover, some important research is also done in the fields of astrophysics and medical physics. Undergraduate degrees offered within this department are physics, astronomy–astrophysics, meteorology, medical physics and optometry. Available postgraduate studies are in the fields of plasma physics, nuclear physics, condensed matter and the physics of materials.

www.uns.ac.rs

The Great Universal Cookout

The Origin of the Elements

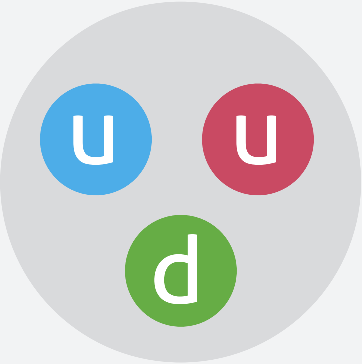
Making chemicals in the Universe is almost like following a recipe, and this is the theme of this feature written by Tijana Prodanovic. Condensing quarks, getting the right temperature for protons and then cooking up elements are all covered. Everything has to be just right to get high quality results and the timings have to be spot on, otherwise you may end up with some very unexpected results...

Say you want to make pancakes, but are missing all the key ingredients. What do you do? You go grocery shopping of course! But have you ever wondered about those groceries? How did they get there? How were they made? Well, that's one question I think about a lot — how did we get the ingredients for the ingredients? How did we get all the nice chemical elements like the H in the H_2O essential for every living thing, like the O in the O_2 we breathe, like lithium in our long-lived lithium batteries? And not just that, but also the questions like why hydrogen is so cheap when it's so essential for our survival, and gold so expensive when it's just bling? And I'm not talking about chemistry here. I'm talking about pure and very cool astrophysics at work — the great Universal cookout!

Recipes for astronomers

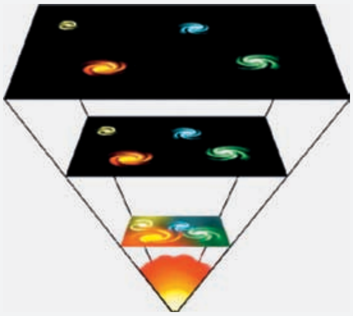
There are two main recipes for making chemical elements in the Universe. One can be found at the very beginning, what we call the Big Bang — the birth of our Universe. Some 13 billion years ago, just a tiny fraction of a second after the Big Bang, the Universe was an unpleasant newborn. It was an extremely dense and hot place, worse than the centre of the Sun. But it was growing, fast, and because of that it was cooling, becoming less and less dense. There's much we still don't know about the very first moments, but we believe that it was all just highly concentrated energy mixed with the most fundamental, indivisible particles — quarks and leptons.

In a millionth fraction of a second after the Big Bang, quarks started sticking together to make protons — the essence of the most abundant element in the Universe — hydrogen. A proton is a positively charged particle that is a "naked" version of hydrogen, that is, the nucleus of the hydrogen atom, and when you add an electron, an indivisible, negatively charged particle, and let it bond with this proton, you get a hydrogen atom.



Protons are made up from different types of quarks.

Because hydrogen, with a single proton at its nucleus, is the lightest element of all, it was the simplest and thus the first thing the Universe made in its first second! At that moment the temperature of the Universe was about ten thousand billion degrees Celsius, about a million times hotter than the centre of the Sun! Besides protons, another type of particle was formed from quarks — neutrons. These are very similar to protons but have no charge. The way to then create heavier chemical elements is to fuse them, to build them up, from lighter ones.



The origin of the Universe can be traced back to the Big Bang, when the first elements were formed.

The perfect temperature for a cookout

During the first seconds after the Big Bang, the Universe was still too hot for protons to merge to form the next element in line — helium. As the Universe expanded it cooled, until it reached the temperature of about a billion degrees, which was at about one minute after the Big Bang. Still much hotter than the centre of the Sun, this temperature was perfect for protons and neutrons to start combining together to make heavier stuff. First came deuterium — a heavier version of hydrogen, and then deuterium started sticking together to make the good old helium that makes us sound funny when we inhale it. If you check a table of elements you'll see that the next element in line is lithium, which had just started forming from helium, but it was too late.

By about three and a half minutes after the Big Bang, the temperature dropped to a "freezing" hundred million degrees which was now too "cold" for elements to continue to combine. And there you have it — four minutes after the Big Bang, the Universe was made of hydrogen, deuterium, helium and trace amounts of lithium. Because this efficient cooking-up of elements only lasted for about 150 seconds, little of the initial hydrogen was spent. This is why hydrogen makes up 90% of the ordinary matter atoms in the Universe, helium about 10%, and deuterium and lithium can only be found in traces.

Cosmic cookers

The Universe remained this way for some 200 million years until the first ovens for cooking up elements appeared — stars. The temperature in the centre, the core of a star, is high enough for helium to start forming out of hydrogen. That same cooking process allows stars to shine and keeps them stable against gravity, which tries to shrink them. But a star has a limited amount of hydrogen inside its core, and when it is all converted to helium a star has no option but to start shrinking. You may wonder "why doesn't the star make heavier stuff out of helium and just continue shining?" The problem is that to cook up heavier elements you need higher temperatures, and so even though the temperature in the centre of the star was high enough to fuse hydrogen into helium, it was not enough to fuse helium to make the next element in the chain — carbon.

The star then begins to lose its battle against gravity and its core starts shrinking. However, as things compress they get denser and hotter, just like a hand pump. By pumping you compress the air inside the pump into a smaller volume. This forces the air to become denser and hotter, which you notice if you pump vigorously — the pump itself heats up. Thus as the star's core shrinks, it grows hotter until the point it can start fusing helium into carbon, which helps it fight gravity and the shrinking stops.

Supernova explosions spread elements throughout the Universe. This is the supernova remnant Cassiopeia A as seen with Hubble.

This process repeats — a star cooks up everything it has in its core making the next heavier element, then shrinks to reach a higher temperature, and then starts fusing the product of the last cook-up to create an even heavier element, and so on! So elements heavier than lithium are made inside stars!

However, this can only continue until the star's core ends up as iron which cannot be further combined to make anything heavier. But we know there are other elements, such as gold, for instance, which are heavier than iron! So where do these elements come from?

Creating gold

When a star has used up all it has, and is left with an iron core which cannot be used for fusing heavier elements anymore, the battle against gravity is finally lost. This drives the star to its death in the form of one of the most violent explosions possible — the star explodes as a supernova!
A supernova explosion is so violent that it can cook up all the remaining elements in the periodic table of elements, even gold! But exploding stars don't just create elements; they spill them out all over the Universe!

Remember, at first the Universe was made only out of hydrogen, helium and lithium, but as stars started exploding they began expelling all the other heavy elements they had fused during their lifetimes and in their final moments as supernovae. Consider, all the carbon that makes up our bodies, the oxygen we breathe, the iron in our blood cells, was all made in stars! And thus, just like the great astronomer Carl Sagan once beautifully put it, "We are made of star stuff!"

Assaf Horesh

Born in Tel Aviv, Israel

Biography

Born on Israel’s 28th Independence Day, Assaf was his parents’ first child, but he now has a brother and sister. He has been interested in science and especially space since he was a little boy, but his first love was aviation. Another passion is music and he began learning to play the electric organ at the age of seven. At the age of 18, like all Israelis, he joined the army. He was first an infantry soldier and later became an officer, finishing his service at age 23. He then went on a wonderful two-month tour of the USA, after which he began his undergraduate studies at Tel Aviv University. That year is also important to Assaf for another reason: he fulfilled his childhood dream and got a private pilot’s license! On finishing his undergraduate studies Assaf immediately enrolled as a graduate student and began working with Professor Dan Maoz. His master’s project was in the field of gravitational lensing. After this he decided to continue his studies as a PhD student. Assaf is a member of the Tel Aviv University Astronomy Club (TAU Astroclub), an outreach programme aimed at making astronomy accessible to the general public. Assaf believes that a broad education is the foundation of a better society.

Tel Aviv University

Located in Israel’s cultural, financial and industrial heartland, Tel Aviv University is the largest university in Israel and the biggest Jewish university in the world. It is a major centre of teaching and research, comprising nine faculties, 106 departments, and 90 research institutes. Its origins go back to 1956, when three small education units — the Tel Aviv School of Law and Economics, an Institute of Natural Sciences, and an Institute of Jewish Studies — joined together to form the University of Tel Aviv. Tel Aviv University offers an extensive range of study programmes in the arts and sciences, within its Faculties of Engineering, Exact Sciences, Life Sciences, Medicine, Humanities, Law, Social Sciences, Arts and Management. The original 170-acre campus has been expanded to include an additional 50 acres, which are now being developed. Recent achievements include the development of carbon dioxide lasers to seal wounds inside the body and out, a technique known as laser welding. The university operates the Wise Observatory, which is involved in exoplanet research, supernova surveys and observations of active galactic nuclei.

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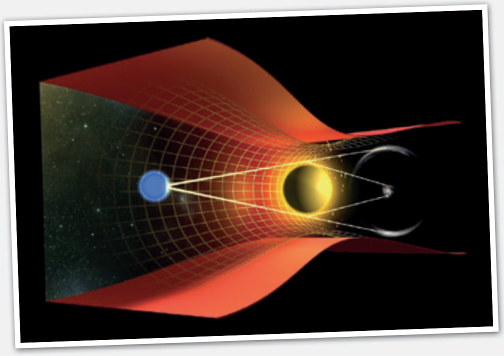
Gravitational Lensing

Magnifying the Cosmos

Imagine if you could bend light to create a cosmic magnifying glass that lets you peer out into space to see some of the most distant objects known to man. That's exactly what astronomers do, exploiting a phenomenon first predicted by Albert Einstein: gravitational lensing. Assaf Horesh talks us through this strange effect, explaining both how it produces stunning images and is used by scientists.



This image illustrates gravitational lensing. Imagine an alignment of the Earth (represented as a blue sphere on the left), a massive body (represented as a yellow sphere near the centre) and a spiral galaxy. The massive body distorts spacetime (represented as the yellow grid) and observers on Earth, instead of seeing the spiral galaxy as it is, see the galaxy distorted, as arcs of light. It is like having a "lens" in front of the galaxy.

Looking through a telescope at the starry skies can be an amazing experience. The telescope reveals a detailed view of the Moon's craters, gives a first glance at Saturn's rings and uncovers stars unseen by the naked eye. A telescope gives you the opportunity to explore deeper and further out into the Universe. Imagine that instead of peering through a telescope you are looking through a cluster of thousands of galaxies, and instead of seeing deeper into our own Milky Way galaxy you can go further, and watch the Universe when it was still young, observing some of the first galaxies ever formed. This is the strength and beauty of the phenomenon that we call gravitational lensing, namely the bending of light rays by immense quantities of matter.

A rich history

Discussions about the effect of gravity on light can be traced back hundreds of years into the past. By 1704, Sir Isaac Newton already raised the question in his book, *Opticks*, of whether the gravitational force of a body acts on light rays, bending the rays. This question intrigued many other scientists, including Mitchell and Laplace. The first explicit calculation of the bending of light rays by gravity was made by the German astronomer Johann von Soldner, in 1801. Soldner calculated the angle by which a light ray is deflected when passing at some distance from a gravitational mass. However, Soldner based his calculation on classical Newtonian mechanics, leading to an incorrect expression of this deflection angle.

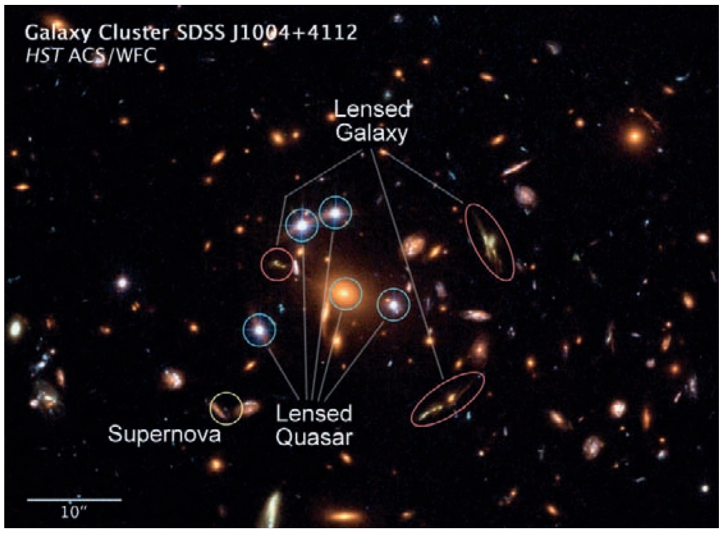
The full theoretical description of gravitational lensing, which is still used today, was derived by Albert Einstein in 1915 using his theory of general relativity. Einstein's prediction of the deflection induced by the Sun's mass on light rays was first confirmed by Eddington in 1919, who measured the positions of stars that appeared projected close to the Sun's limb during the 1919 solar eclipse. The light rays from these stars were bent by the Sun's gravitational field. Due to this deflection the stars appeared to be at

Einstein rings arise from a precise alignment of the background galaxy and the lensing galaxy.

different positions when compared with a different time of the year when they were observed at night, and when their light rays were not deflected since they did not pass close to the Sun.

Einstein rings

The gravitational lensing of light manifests itself in different forms. The most simple and striking form is that of an Einstein ring. Imagine a distant point source of light, like a quasar, situated far behind a massive galaxy. The galaxy acts as a gravitational lens, bending and focusing the light from the point source into a ring-shaped image. This form of gravitational lensing is called strong lensing, since the light from the point source is greatly magnified. This magnification can be explained by realising that instead of seeing a point source of light we see a larger image of it in the shape of a ring, and thus we see more light. But strong lensing exists in nature in more complicated forms as well. For example, if the mass of the gravitational lens is not distributed symmetrically, then the symmetry of the ring-like lensed image is also broken. Instead of a ring, we will see several images of the point source. Due to the strong lensing effect, these images are sometimes also distorted and appear in the form of beautiful colourful arcs.



When individual objects are lensed into several "images", the result can look surreal!

Microlensing

Another form of gravitational lensing is called microlensing, a special case of strong lensing. Microlensing applies when the Einstein ring or the multiply-lensed images are on scales too small to be resolved. Then we only observe a net increase in the amount of light reaching us from the lensed source compared to the amount of light that would have reached us if it were not lensed.

Microlensing can be used as a tool for discovering new exoplanets. This is achieved by tracking the brightness of millions of stars in our Milky Way. When one of them passes behind an exoplanet, an increase in its brightness is observed. The planet, in this case, is too faint to be observed directly, but its effect as a gravitational lens on the brightness of the star passing behind it serves as indirect evidence of its existence. Recently, an international team of scientists, including Israeli astronomers, were able to find a solar look-alike planetary system in which two planets, closely matching Jupiter and Saturn, orbit a star half the size of our Sun.

Weak lensing

Gravitational lensing also appears in a less prominent form called weak lensing. In this case, the light from galaxies that lie behind a gravitational lens, but not in its strong "focusing" area, is only slightly deflected. Therefore, neither an Einstein ring, nor multiple images nor arcs of these galaxies will appear. Instead, the gravitational lens induces small distortions on the galaxy shapes, compared to their unlensed shapes. Although not as visually striking as strong lensing, weak lensing has turned out to be an important tool in studying the distribution of dark matter in the Universe.

Unveiling the Universe's secrets

On a more personal note, I find gravitational lensing to be a phenomenon that encompasses all the things that make astronomy such an exciting field of research. It provides both amazing visual images and is an important tool to unveil the secrets of the Universe.

Strong lensing makes these galaxies appear like arcs, stretching over the vastness of space. Here the galaxy cluster Abell 2218 is seen with Hubble.

Nando Patat

Born in Udine, Italy

Biography

Nando's passion for astronomy started in 1975, when he looked at the Moon with his father's 6 x 30 binoculars. That vision has stayed with him for the rest of his life, and led him through the early years of his education. After studying at Liceo Scientifico L. Magrini in Gemona (Italy), Nando moved to Padua in the autumn of 1985, where he started his career in astronomy just in time to be blessed by Halley's Comet passing close to the Sun. After spending one year at the Asiago Astrophysical Observatory and a two-year studentship in Munich, he obtained his PhD in astronomy in 1996. In 1997 he taught maths in Italy and at the end of that year moved to Chile, where he was offered an ESO postdoctoral fellowship. In 1999 Nando was offered a staff position in the Quality Control Group and so moved back to ESO Headquarters, where he was in charge of Very Large Telescope instruments. In 2001 he joined the User Support Department where he is currently a member of the ESO Faculty as a full astronomer. Nando mainly works on optical photometry, spectroscopy and spectropolarimetry of nearby supernovae of all types. His other interests include statistical data analysis and atmospheric physics related to ground-based astronomy. In his spare time, (which is not much, with four kids!) he plays the piano and flute, carries out archaeoastronomical research and explores cross-fertilisation between science and the arts.

European Southern Observatory (ESO)

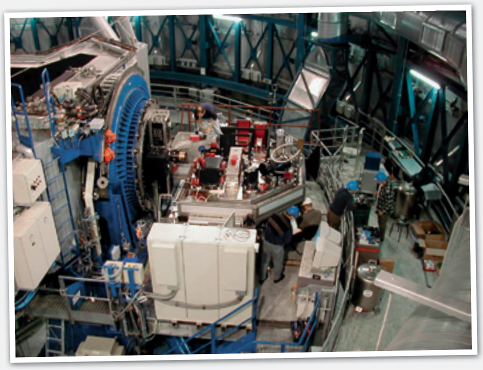
ESO is the foremost intergovernmental astronomy organisation in Europe and the world's most productive astronomical observatory. It operates three sites in Chile — La Silla, Paranal and Chajnantor — on behalf of its fourteen member states. It builds ALMA together with international partners, and designs the European Extremely Large Telescope.

ESO's User Support Department is the interface between the observatory sites in Chile and the users of the facilities. Modern observatories today are run without the user being present. Instead the user interacts with the User Support Department to define beforehand what needs to be observed and how. Then we set up and organise observing queues for the dedicated on-site staff to execute.

www.eso.org

Seeking the Origins of Thermonuclear Supernovae

This article is about one of the most energetic events in the known Universe: Type Ia supernovae. They are thought to occur when an extremely dense, small and hot star called a white dwarf gathers material from a companion in a binary system. Its greediness for matter comes at a price, although, as Nando Patat tell us: when the white dwarf reaches a critical stage it undergoes a violent thermonuclear explosion that converts the star into one of the brightest sources in the sky, outshining a whole galaxy. Yet, the exact nature of the binary system is still unclear...



The Ultraviolet and Visual Echelle Spectrograph (UVES) mounted on ESO's VLT Kueyen 8.2-metre telescope.

Many of the stars we see in the Universe are actually part of binary systems; two stars orbiting each other. Explanations of why thermonuclear explosions take place within a binary system composed by a white dwarf and a donor star were first suggested in the 1970s. Although we have several ideas, the true answer remains an unsolved problem.

Thermonuclear explosions — kaboom!

Most stars spend normal lives creating energy through nuclear fusion. Once they run out of fuel they cool down, and quietly fade away. Some others go through extraordinary epiphanies, giving rise to one of the most powerful phenomena we know: a supernova explosion.

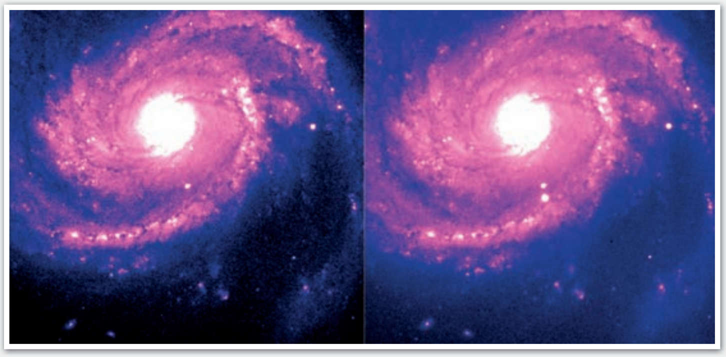
There are two main mechanisms that can blow up a star: the collapse of a stellar core and a thermonuclear explosion. The first is supposed to take place in young, massive stars. The second is thought to be responsible for one particular variety of supernova explosion, called Type Ia supernovae, which have become a hot topic in science over the last ten years. Type Ia supernovae are actually all very similar, making them useful to astronomers trying to measure cosmic distances. This fiendishly difficult task has always been the torment of astronomers. One solution is the use of so-called standard candles: if you can find a type of object that all have the same brightness, then you can deduce their distance from how bright they appear to be from Earth; the dimmer they are, the further away. As it turns out, Type Ia supernovae are one of these standard candles, billions of times brighter than the Sun. This means they are visible even at extremely large distances.

In the last ten years the study of these supernovae has gone one step further. Astronomers have used these extraordinarily bright candles to map the geometry of the Universe, coming to the conclusion that its expansion underwent a significant acceleration due to the existence of a mysterious dark energy. This has opened a whole new chapter in physics and probably is one of the most exciting discoveries ever made.

The quest for the progenitors

However, not everything is known about Type Ia supernova explosions. Early on we realised that they must come from relatively old, low-mass stars. But how can an otherwise quiet star turn into such a catastrophic event? A possible solution was proposed in the 1970s: an old white dwarf belonging to a binary system gathers material from its companion until it reaches a limit, when a thermonuclear explosion is ignited. A white dwarf is made up of matter which is in a very special condition, called degenerate. Normally, if you heat a gas, its pressure increases. This causes the expansion of the gas which, in turn, produces a decrease in the temperature and acts as a thermostat that self-regulates the system. However, when matter is degenerate, this thermostat is switched off and temperature can rise out of control.

So once a white dwarf reaches the required critical conditions to ignite the thermonuclear burning of carbon, the lack of a self-regulating mechanism causes the star to be completely incinerated. The gas is ejected into space at velocities that exceed one tenth of the speed of light — very fast indeed! In principle, different stars can act as donors in the binary system, even another white dwarf.



The host galaxy Messier 100 before (left) and after (right) the explosion of SN2006X. The supernova is the bright stellar object in the centre of the right-hand image.

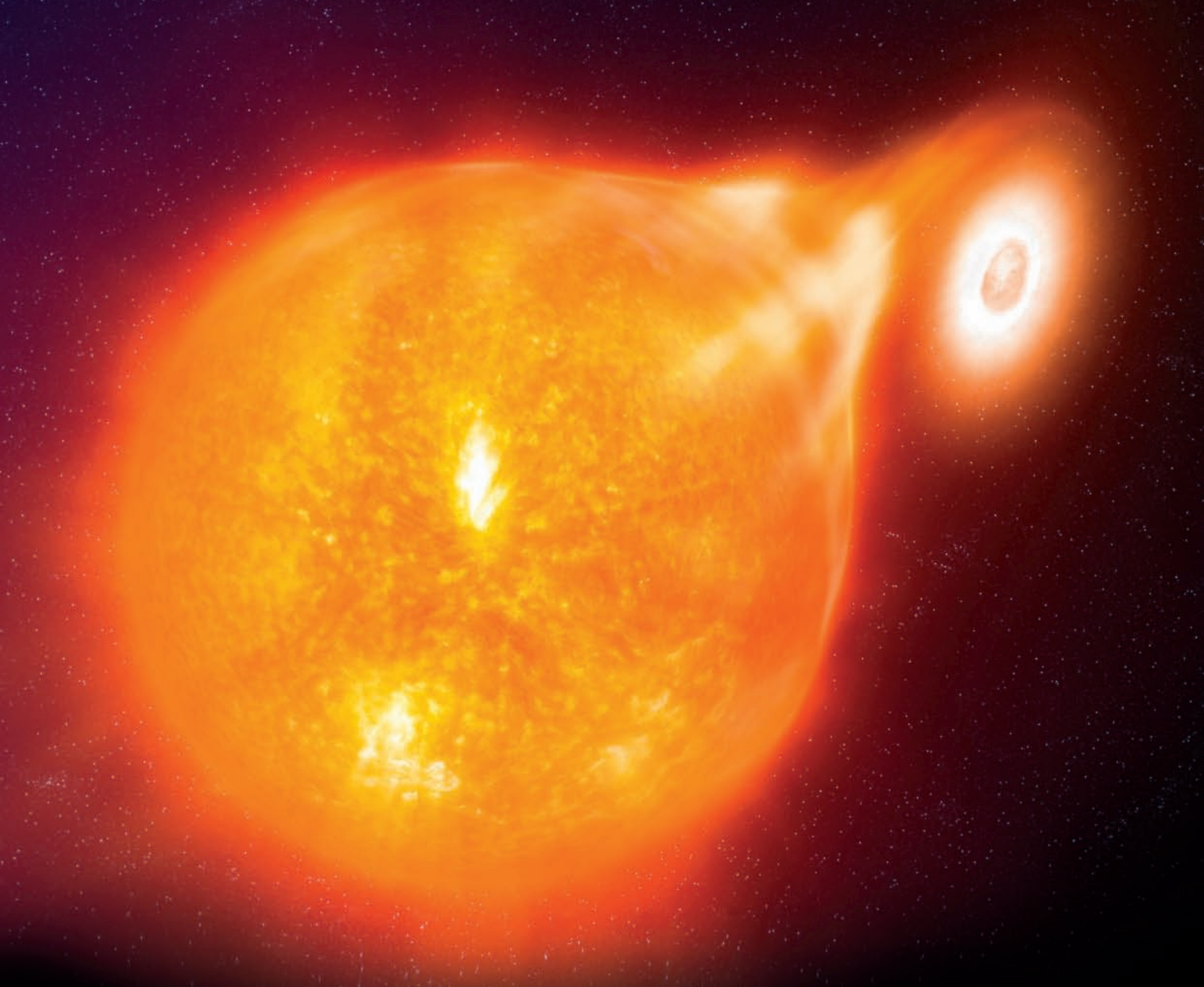
Chasing the companion star

So far all attempts to detect any matter around Type Ia supernovae have been frustratingly difficult. In the autumn of 2005 my collaborators and I realised that there may be a way to detect tiny amounts of material in the intermediate surroundings of the exploding star, which would help in understanding the nature of the companion.

Hydrogen is the most abundant element in the Universe, but we can only see it at the right temperature: neither too hot nor too cold. Luckily hydrogen is not the only element in space. In particular there are two others, calcium and sodium that are rather rare (a million times less abundant than hydrogen), but which leave very strong spectral signatures that we can detect. This means we can track down even tiny amounts of those elements. If a supernova shines through these elements we should be able to see them — for the technically minded, we actually look for the absorption lines. But how could we tell if the gas is related to the exploding system? For a distant cloud the absorption would remain constant with time, while if the gas is close to the explosion site, then the strong supernova radiation field can modify its physical condition and produce changes in the amount of absorption. The plan was set: study the next supernova explosion carefully, study the light, and see where it came from.

SN2006X and its heritage

The first chance to test our idea came in February 2006, when a new



Type Ia supernova, imaginatively named SN2006X, was discovered in the spiral galaxy Messier 100 in the Virgo Cluster. We repeatedly observed it with the European Southern Observatory's Very Large Telescope. Much to our delight, a number of features were indeed seen to change. We believe this was the long-sought sign that SN2006X had been generated within a binary system with a red giant star as a donor.

Our results were soon followed by theoretical and observational work, some favouring, but some disputing our idea. However, as often happens when a new discovery is made, we were left with more questions than answers and, as of today, the debate is still open. Many other objects will have to be studied before the matter can be settled. Rather than the final word of a book, our finding can be regarded as the first word of a new chapter. This is what makes science so exciting!

An artist's impression of a binary system hosting a white dwarf accreting material from a companion star. The white dwarf (on the right) is gathering material from a red giant, which is losing gas in the form of a stellar wind, the diffuse material surrounding the giant. Only part of the gas is accreted by the white dwarf, through an accretion disc that surrounds the compact star. The remaining gas escapes from the system and eventually dissipates into the interstellar medium.

Yavuz Eksi

Born in Istanbul, Turkey

Biography

Yavuz was born in 1972 in Istanbul. For his undergraduate degree he studied electrical engineering at the Technical University of Istanbul, graduating in 1995. This was followed by a master's thesis, for which he worked on accretion discs. His PhD studies at Bogazici University were on young neutron stars. He completed this in 2003, and then spent the next few years as a postdoc at Sabanci University and the Harvard–Smithsonian Center for Astrophysics. Since 2006 Yavuz has been working in the physics department at the Technical University of Istanbul.

Yavuz sees popularising astronomy as the ideal opportunity to interact with the general public who finance space science projects with their taxes. He sees the lives of astronomers as being privileged, and believes that a duty exists to communicate astronomy with the public. Yavuz is fascinated by the fact that our Universe is evolving. We are all part of a changing complex system, and explaining this is a challenge he relishes.

Istanbul Technical University

Established in 1773 as the Royal School of Naval Engineering, Istanbul Technical University (ITU) has always been the leading institute for engineering in Turkey. The ITU is strongly identified with architectural and engineering education in Turkey. Since its inception and foundation under Ottoman rule, it has constantly led the way in reform movements, and in the Republic of Turkey, it has assumed pivotal roles in the reconstruction, modernisation and administration of the country. The efforts and expertise of ITU graduates have been major contributors in the planning and construction of Turkey's roads, bridges, dams, factories, buildings, energy plants, communication networks, villages and cities. ITU is a state university that defines and continues to update methods of engineering and architecture in Turkey. The aim of the ITU is to rank among leading universities globally.

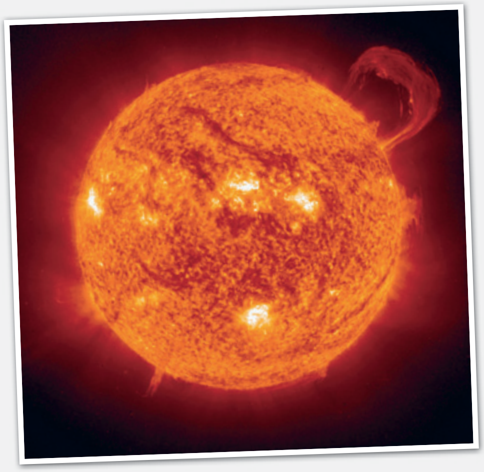
www.itu.edu.tr/en/

Our Evolving Universe

The galaxies, stars, planets and life on our world are stories within stories that are still unfolding. This article highlights the fact that our Universe is far from static. Stars form and expire, galaxies merge and planets are transformed. Our world had a past before us and it is expected to have a future. Thanks to science, we know that the evolution of the Universe is an ongoing process and we are not witnessing its ultimate form.

At the time I was starting my career in astronomy I learned that the magnetic field of the Earth reverses its direction over geological timescales. The needle of a compass that points to the North Pole today would have pointed to the South Pole a few million years ago. I was upset that I had not learnt this before. This was a recurring theme throughout my education — I would learn repeatedly that stasis was an exception and that most often phenomena were evolving on very long timescales.

The galaxies, stars, planets, and life on our world, are long stories-within-stories that are still unfolding. It is remarkable that our Universe has produced such entities as us, humans, who systematically attempt to reconstruct these stories based on the evidence scattered around. This evidence-gathering process we call science has revealed many episodes of some of the stories, but scientific advances link into other stories that we are yet to discover, continually broadening our horizons and expanding our understanding of the Universe of which we are part.



We think of the Sun, our closest star, as being perfect and with a timeless existence. But it is a dynamic body, and one day in the far future it will run out of fuel.

Changing times

The stories are always about evolution and change. The luminosity of our nearest star, the Sun, has been remarkably stable for a few billion years. Yet we know that every star, including the Sun, has to evolve because they use themselves as fuel. The timescale for an appreciable change is very long compared to our personal lives and even the history of our civilisation. Nevertheless, we, the inhabitants of a rock orbiting the Sun, were able to discover that the heavens do change. This replaced the older view current in the Middle Ages, according to which celestial objects were eternal and did not change.

There are regions in our Milky Way where new stars are forming out of gas clouds. And we occasionally witness the sudden explosion of a star that has used up its fuel. Although the lifetime of a single star is too long for us to follow from birth to death, by observing many of them at different stages and filling the gaps with reasoning we have achieved an understanding of the lives of stars and the processes that take place in them.

This stunning image of a nebula is a snapshot of one small segment of its life. New stars are forming deep inside, which will one day shine brightly.

Stars with a golden glow

The evolution of an individual star is only a small sub-plot in the grand story of our Milky Way. The Sun was not among the first stars that populated the Milky Way. Earlier generations of stars formed from gas clouds, lived their lives synthesising — by nuclear fusion — many of the elements of the periodic table up to iron, and finally exploded into the interstellar medium returning matter back to the gas clouds.

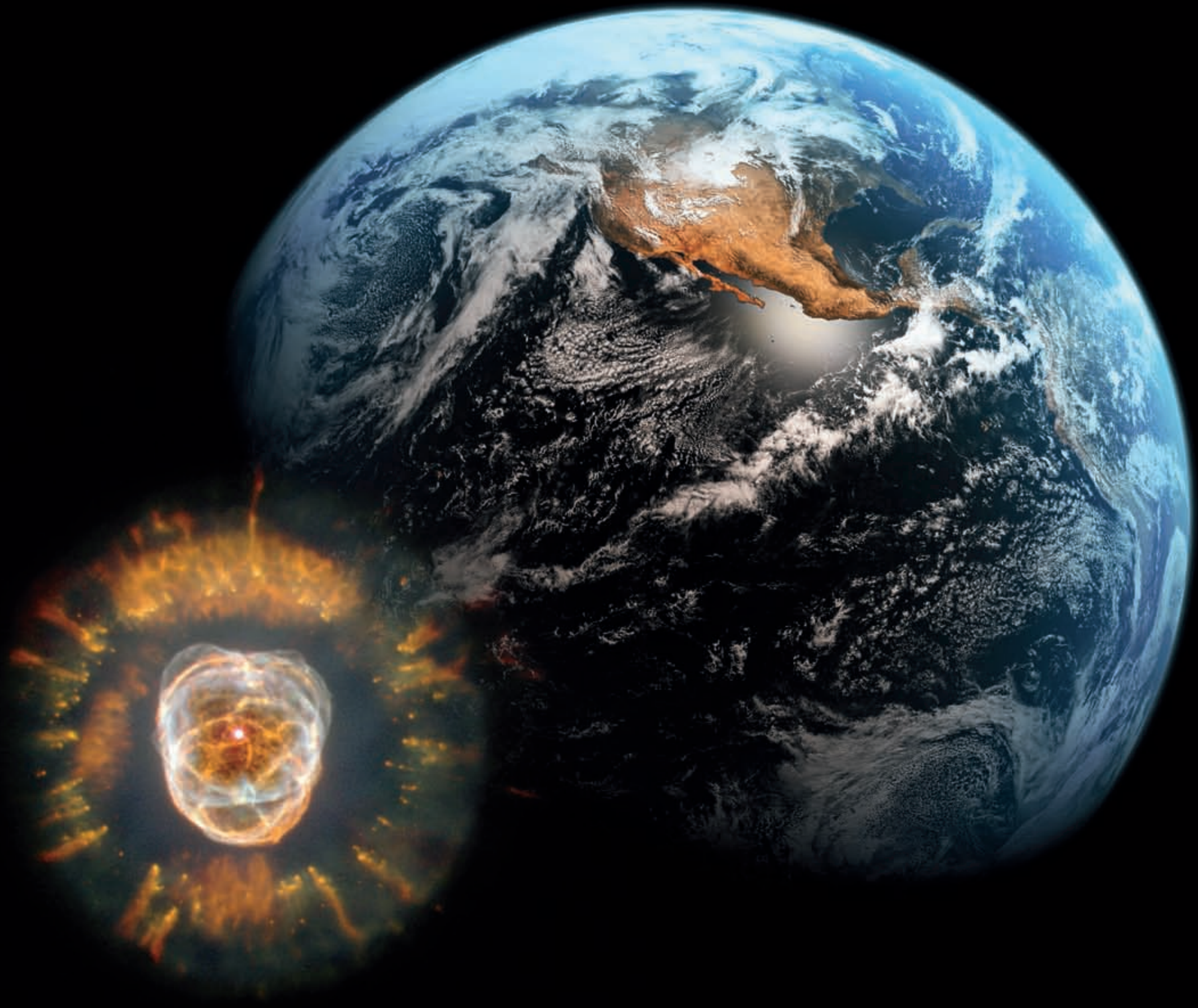
During such an explosion some elements even heavier than iron were synthesised. This is, for instance, the only way that the element gold can be produced in the Universe. The existence of elements like silver, gold and uranium as well as carbon, oxygen and nitrogen on our Earth suggests that the Solar System formed from a gas cloud enriched by the gases expelled into the interstellar medium by previous generations of stars. Our Sun was not always there and will not always be there either.

We could not exist without the Sun, but it took many generations of stars to produce the elements we need for our bodies and in our everyday lives. We are not isolated from the rest of the Universe, interacting only with our star: we rely on a galaxy, a web of stars linked by continuous creation and death. The formation of the Sun and the planets around it is not the last word of our galaxy, or of the Universe. New stars have continued to form since the birth of our Solar System!

Earth-shattering science

Earthquakes are not only incredibly powerful and destructive, they challenge our common notion that the ground beneath our feet is stable. The continents of Africa and South America were once attached, as a glance at the world map shows. There is sufficient evidence that landmasses are moving across the globe! As the continents drift, they sometimes push against each other, and it is the release of this accumulated stress that causes earthquakes, a scientific explanation that also stretches the imagination as we see the slow, but inexorable progress of two juggernauts lumbering towards a final cataclysm.

The Earth, our home, is not a finished project, even if it appears sufficiently steady for our practical purposes. There is no reason for the Earth’s surface to stop moving just because we have started building houses or drawing national borders on a map. I am fascinated by the fact that we are living on a celestial object that evolves just like the rest of the Universe.



Left image: The Sun will produce a planetary nebula when its nucleus runs out of fuel. Right image: The Earth exists within an evolving Universe, so is it any wonder that it experiences changes, such as earthquakes?

The indifference of the planet's crust to our presence is a sobering thought, stressing our insignificance even on the planetary scale. Some people see the objectivity of science as a just cold bundle of information. They may contrast it with the ancient explanation for earthquakes as a punishment of a supernatural power — placing us in a privileged position that might deserve such an attention. It is a remarkable human achievement to understand earthquakes as a consequence of the journey of landmasses across the globe. I find this explanation far more imaginative than the ancient view, which is strongly challenged by the fact that earthquakes also occur on other planets where nobody lives.

Past, present and future

We are floating in an ocean of culture that implicitly assumes that creation is a completed process. Our great illusion is to regard the Earth as a single finished product; the land, plants and animals created for our use. In this solipsistic picture the rest of the Universe is there only to make our show on the Earth possible. This is a huge obstacle to understanding nature and loving our planet as it is. It also does not help us when we try to save the Earth. Our world had a past before us and it is expected to have a future. Evolution is an ongoing process and no phase of it is privileged to be the ultimate form.

Claire Lee

Born in Johannesburg, South Africa

Biography

Claire has had a love for astronomy and physics since she was young, and is particularly interested in the relation between the two fields of particle physics and cosmology. She is currently working towards a PhD on the search for the Higgs boson with the ATLAS experiment at the Large Hadron Collider, wanting to bring together what she has learnt in experimental nuclear physics with her passion for understanding the Universe. Chris, Claire's husband, shares her love for astronomy. He bought her an 8-inch Newtonian telescope and arrived home from work one day to find her on the roof searching for Comet McNaught!

Claire has been a committee member of the Johannesburg centre of the Astronomical Society of South Africa and editor of their monthly newsletter, *Canopus*. Now she focuses her attention more on the various physics-related committees she serves on, such as the South Africa–CERN committee, the editorial board for the South African Institute of Physics (SAIP) newsletter *Physics Comment*, and taking over as webmaster for the Nuclear, Particle and Radiation Physics subgroup of the SAIP.

Claire says that we live in a world of prejudice, where science is seen as "elitist" and scientists are smart but crazy people who walk around in a lab coat all day. Living in South Africa the reaction is even more distinctive as a lot of young people, especially those from disadvantaged communities, do not believe that they can do science. These youngsters are the future of science, and Claire feels that it is important for them to realise that they can do whatever they dream of doing — that astronomers, physicists, and other scientists are just normal people like themselves.

University of Johannesburg

The University of Johannesburg Department of Physics is involved in cutting-edge research in a variety of fields. The astrophysics group works on active galaxies, pulsating stars, stellar instabilities and the Square Kilometre Array, coupled with observational programmes at the Sutherland Observatory. In the field of condensed matter physics, the behaviour and properties of chromium alloys are a major focus, with their applications to the field of data storage, as well as metallic and intermetallic compounds at extremely low temperatures and powerful magnetic fields, and materials research at extreme high pressures. There is also a group working on photovoltaics, including the production of low cost thin film solar panels. The high energy physics group is involved in particle physics research with ATLAS at the LHC, with a focus on the Higgs search, top quark physics and the discovery of hidden sectors, as well as nuclear physics at Jefferson Lab. A highlight in applied nuclear physics is the development of a diamond-bearing rock sorter based on PET imaging technologies. And finally, research on the properties and applications of diamond as optical elements, radiation detectors, and potential for quantum computing is done in collaboration with a number of local and European facilities.

www.uj.ac.za/physics

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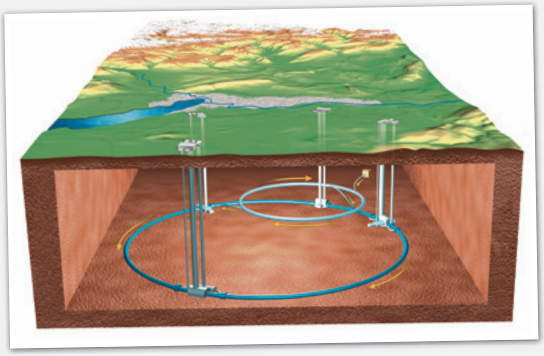
From Quarks to Cosmos

Exploring the Universe through Particle Physics

Astronomers and particle physicists used to work independently from each other, but now, more than ever, there is significant overlap between the fields. The Large Hadron Collider, the world's largest and highest-energy particle accelerator, aims to use the science of the very small to answer questions of the grandest scales imaginable. Particle physicist Claire Lee explains how this is possible.



This computer-generated image shows the location of the 27-km Large Hadron Collider tunnel (in blue) on the Swiss–French border.

Since the dawn of time, people have wondered about the Universe: how it began, why it looks the way it does, when and how it will end. Astronomers have contemplated the formation of stars and galaxies, why they group together into clusters and superclusters, why these clusters are all moving away from each other at an increasing rate, despite gravity trying to pull them back together... the list goes on.

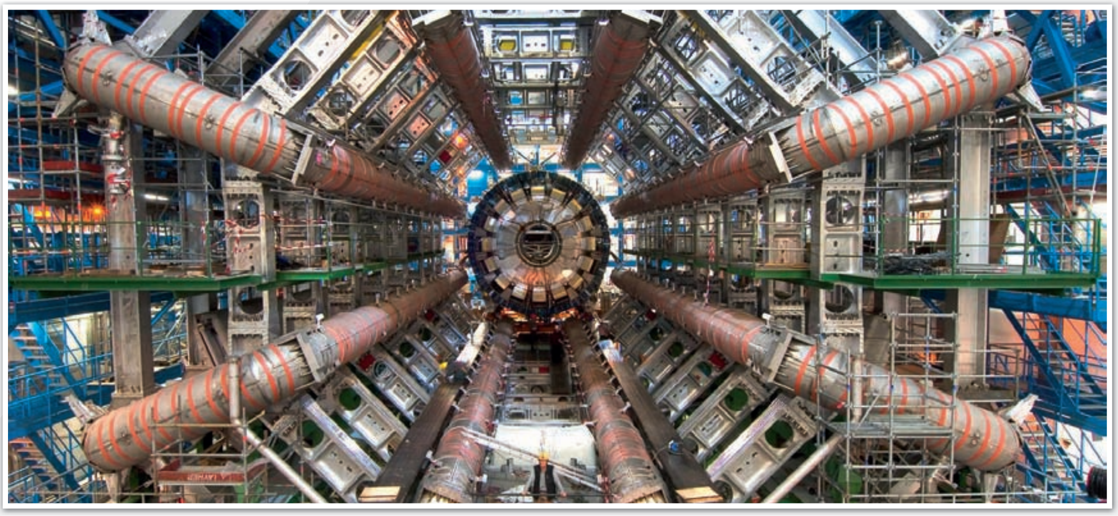
A murky Universe

To find the answers to these questions, astronomers turn their telescopes to the sky, scanning through wavelengths from high energy gamma rays to the lowest energy radio sources, searching through space for the next clue in our quest to solve the myriad of puzzles about space.

To astronomers, the Universe is murky for the first 380 000 years after the Big Bang; we can't see what happened using telescopes. But we can using particle physics. Back then the Universe was so hot it was just a primordial soup of the basic particles that make up everything we see in the Universe today. Using particle accelerators to probe inside protons, we can see way back in time, all the way back to a tiny fraction of a second after the Big Bang.

The Large Hadron Collider (LHC) at CERN, the European Organization for Nuclear Research, is the world's largest particle accelerator — a 27 km ring of over 9000 magnets that crosses the border between France and Switzerland. The superconducting magnets are cooled with liquid helium to -271 °C, making the LHC one of the coldest places in the Universe.

Inside the accelerator, two counter-rotating beams of protons travel very close to the speed of light and collide head-on in the centres of four large detectors, 600 million times per second. The detectors: ALICE, ATLAS, CMS and LHCb, are each designed differently in order to learn something new and different about the Universe.



The ATLAS detector is 44 metres long, 25 metres in diameter, and weighs around 7000 tonnes. ATLAS is a general-purpose detector, measuring a broad range of signals.

A massive problem

In particle physics we have the Standard Model, which describes all the elementary particles that make up the Universe we see. The Standard Model has a major problem: the simplest version of the theory requires the masses of all the particles to be zero. Now this is obviously not the case as the Universe has given us a whole zoo of particles with a wide range of masses. We can't say we really understand how the Universe works until we know how everything in it got its mass.

Fortunately in 1964 some physicists came up with a theory for giving the particles the masses they have (most notable among them was Peter Higgs after whom the mechanism was named). According to this theory, as the Universe cooled during the first fraction of a second after the Big Bang a field suddenly materialised. We call this a phase change, much the same way liquid water changes to ice as it cools. Before this phase change all the different elementary particles had zero mass and moved around at the speed of light. But once the Higgs field had "frozen out", the particles started to get dragged to slower velocities, some to a greater degree than others. The more a particular particle was slowed, the more of its total energy was concentrated into mass.

In particle physics a field is made up of a whole lot of particles — bosons — that carry the field's effects. The Higgs field is thus made up of many Higgs bosons, popping in and out of existence all the time. It's the way that each particle interacts with these Higgs bosons that determines how much it is slowed down, and hence, how much mass it has. If the Higgs boson really does exist, then there is a good chance that it will be created at the LHC and detected in the ATLAS or CMS detectors.

This NASA/ESA Hubble Space Telescope view of a galaxy cluster shows warping and distortions from gravitational lensing, strong evidence for the existence of dark matter.

What's the (dark) matter?

The Standard Model of particle physics describes all the particles in the Universe that we can see. But there's something else out there that we can't see: the aptly named dark matter.

Dark matter is pretty easy to find if you know where to look, because it's almost everywhere. Or perhaps I should say it's easy to see its effects: gravitational lensing, for example, can detect huge halos of dark matter by measuring how much light is bent as it passes a cluster of galaxies. From general relativity, we can calculate the mass of the cluster by how much it bends the path of the light. But this ends up being far more than the mass we would get if we just added up all the stuff we can see.

The problem with dark matter is that we can't see it — the only way we interact with it is through the gravitational force — and we really have no idea what it is. But there's about five times more of it than all the normal matter, and it's responsible for the large-scale structure of the Universe: the way the galaxies group themselves into clusters, the clusters into superclusters, and so on.

Thankfully, particle physics has a possible solution: supersymmetry. Supersymmetry extends the Standard Model of particle physics by matching each particle of one kind with a new partner particle of another kind. These new particles are much heavier than their partners, which is why we don't see them with our detectors, even if they do exist. The lightest one of these particles — called the neutralino — is the best candidate we have for all that elusive dark matter out there, and it's possible that the LHC will have enough energy to create neutralinos in its collisions.

Where did all the antimatter go?

Another thing that puzzles physicists is why we have anything in the Universe at all. At the Big Bang, equal amounts of matter and antimatter were created. But when one particle of matter meets one particle of antimatter, they annihilate in a burst of energy, leaving no particles behind. Somehow, though, there must have been a slight excess of matter, so that when all the antimatter had annihilated, the Universe was left with all the matter we see today. The aim of the LHCb experiment is to find out just why there was this matter–antimatter asymmetry that ultimately gave us the Universe.

Probing the Big Bang

Finally, proton–proton collisions aren't the only ones that will happen at the LHC. The ALICE detector is specifically designed to look at collisions between lead ions. These collisions will recreate the conditions of extremely high densities and temperatures that existed a fraction of a second after the Big Bang. With the LHC, physicists will be able to take a look at what the Universe was like as it began, learning more about the most fundamental constituents of matter and the first hundred microseconds of the evolution of our Universe.

Regular checks are performed to ensure that magnets in the Large Hadron Collider tunnel are perfectly aligned, as they are needed to control the paths of the particle beams.

Breaking boundaries

Even with the amazing discoveries we have had over the centuries, we are still far from a complete understanding of how the Universe works. Traditionally, astronomers would use their telescopes to study the sky and physicists would create particle collisions inside their detectors, with very little overlap between the two fields. But now we are entering a new era where the boundaries between astronomy and particle physics are no longer clearly defined, where we can draw conclusions about the very large by investigating the very small. We still have a number of questions about our Universe, and now particle physics may be able to give us some answers.

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From sunspots to black holes, planets around other stars, supernovae and dark matter, *Postcards from the Edge of the Universe* unveils the mysteries of today's research, looking at cutting-edge astronomy from around the world. Twenty-four frontline astronomers from all corners of the globe explain their science.

This book is based on the science carried out by a hand-picked selection of the best bloggers from the Cosmic Diary (www.cosmicdiary.org), one of the twelve Cornerstone projects of the International Year of Astronomy 2009 (IYA2009). The contributions have been compiled into this edited anthology, giving a unique snapshot of contemporary astronomy. The four-page popular-science articles all have a personal flavour, as each contributor has selected their own favourite astronomical topic, giving the reader a unique and personal insight into work on the frontline of astronomy.

Cosmic Diary is a collective blog that puts a human face on astronomy. Sixty professional scientists from 32 countries blog in text and images about their lives, families, friends, hobbies and interests, as well as their work, latest research findings, and the challenges that face them.