THE FREE MULTIMEDIA MAGAZINE THAT KEEPS YOU UPDATED ON WHAT IS HAPPENING IN SPACE

FREE ASTRONOMY magazine

Bi-monthly magazine of scientific and technical information ✶ March-April 2017 issue

Tabby's star, an unsolved mystery

Two probes will explore the early Solar System

The right to a dark night

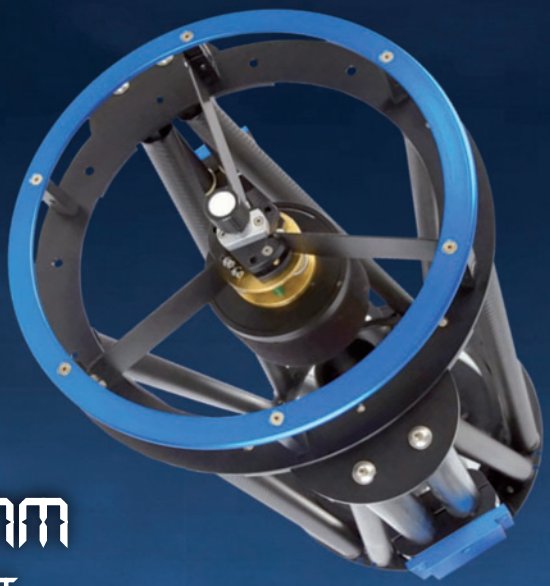
- Ultracool dwarf and the seven planets
- New independent measurement of the Hubble constant
- ALMA starts observing the Sun

"Mars is there, waiting to be reached"

www.astropublishing.com ✶ www.astropublishing.org ✶ info@astropublishing.com

NortheK

Instruments - Composites - Optics



RITCHEY-CHRÉTIEN 250 MM

F/8.5 SUPRAX OPTICS FROM SCHOTT
CARBON STRUCTURE
NORTHEK CELL STABILOBLOK 25
FOCUSER FEATHER TOUCH FTF 2000 2"
WEIGHT 15 KG.

www.northek.it - www.facebook.com/northek.it - info@northek.it - phone +39 01599521

ASTRONOMY magazine

BI-MONTHLY MAGAZINE OF SCIENTIFIC AND TECHNICAL INFORMATION FREELY AVAILABLE THROUGH THE INTERNET

March-April 2017

English edition of the magazine

ASTROFILO

Editor in chief
Michele Ferrara

Scientific advisor
Prof. Enrico Maria Corsini

Publisher
Astro Publishing di Pirlo L.
Via Bonomelli, 106
25049 Iseo - BS - ITALY
email info@astropublishing.com

Internet Service Provider
Aruba S.p.A.
Loc. Palazzetto, 4
52011 Bibbiena - AR - ITALY

Advertising - Administration
Astro Publishing di Pirlo L.
Via Bonomelli, 106
25049 Iseo - BS - ITALY
email admin@astropublishing.com

SUMMARY

4 **Tabby's star, an unsolved mystery**
This is surely one of the most intriguing subjects in recent years, and no matter how much astronomers try to find an entirely natural explanation for its complex variations in luminosity, Tabby's star will not reveal the truth. We might have to observe it continuously for a few years to learn whether its peculiarities are...

14 **A big brother of Halley's Comet ripped apart by white dwarf**
Scientists using the NASA/ESA Hubble Space Telescope have observed, for the first time, a massive, comet-like object that has been ripped apart and scattered in the atmosphere of a white dwarf. The international team of astronomers observed the white dwarf WD 1425+540, about 170 light-years from Earth in the...

16 **ALMA starts observing the Sun**
New images from the Atacama Large Millimeter/submillimeter Array (ALMA) reveal stunning details of our Sun, including the dark, contorted center of an evolving sunspot nearly twice as large as the diameter of the Earth. These images are part of the testing and verification campaign to make ALMA's...

18 **New independent measurement of the Hubble constant**
The Hubble constant — the rate at which the Universe is expanding — is one of the fundamental quantities describing our Universe. A group of astronomers from the H0LiCOW collaboration, led by Sherry Suyu (associated with the Max Planck Institute for Astrophysics in Germany, the ASIAA in Taiwan and...

20 **Two probes will explore the early Solar System**
Astronomers have long been investigating some of the most ancient bodies in our planetary system, in a quest to understand its evolution from its very beginning to the solar system as we know it now. The next step will be to go further into the history of our solar system – less than 10 million years after the birth...

28 **Comets are plunging into the star HD 172555**
Interstellar forecast for a nearby star: raining comets! NASA's Hubble Space Telescope has discovered comets plunging into the star HD 172555, which is a youthful 23 million years old and resides 95 light-years from Earth. The exocomets — comets outside our solar system — were not directly seen around...

30 **The right to a dark night**
Thanks to our mastery of electricity, our daily life is rich with breathtakingly illuminated scenes featuring historical monuments or great cities. But when was the last time the inhabitants of these cities could marvel at the beauty of the heavenly vault and its thousands of stars? A long time ago, probably too...

36 **Astronomers see a huge shadow around TW Hydrae**
Searching for planets around other stars is a tricky business. They're so small and faint that it's hard to spot them. But a possible planet in a nearby stellar system may be betraying its presence in a unique way: by a shadow that is sweeping across the face of a vast pancake-shaped gas-and-dust disk...

40 **"Mars is there, waiting to be reached"**
It drifts aimlessly in the vast cosmic ocean, patiently waiting for an intelligent species to make an appearance. At about 225 million km from the Sun, Mars is a lifeless, arid, dusty landscape, with its russet soil giving it the nickname 'the Red Planet'. Though colonising Mars is a distant idea, it is entirely possible...

46 **Ultracool dwarf and the seven planets**
Astronomers using the TRAPPIST–South telescope at ESO's La Silla Observatory, the Very Large Telescope (VLT) at Paranal and the NASA Spitzer Space Telescope, as well as other telescopes around the world, have now confirmed the existence of at least seven small planets orbiting the cool red dwarf star...

Tabby's star, unsolved my

by Michele Ferrara

This is surely one of the most intriguing subjects in recent years, and no matter how much astronomers try to find an entirely natural explanation for its complex variations in luminosity, Tabby's star will not reveal the truth. We might have to observe it continuously for a few years to learn whether its peculiarities are due to internal factors, occasional transits or something in a stable orbit around it.

an stery

This imaginative illustration shows one of the theories proposed to explain the strange photometric behaviour of Tabby's star. One of its planets is destroyed by an impact or by tidal forces. Part of the debris hurtles towards the star, changing its luminosity for a long time. Some large fragments, instead, end up in eccentric orbits, causing occasional brief but deep dimming of its light when they pass in front of the star. [NASA, JPL-Caltech]

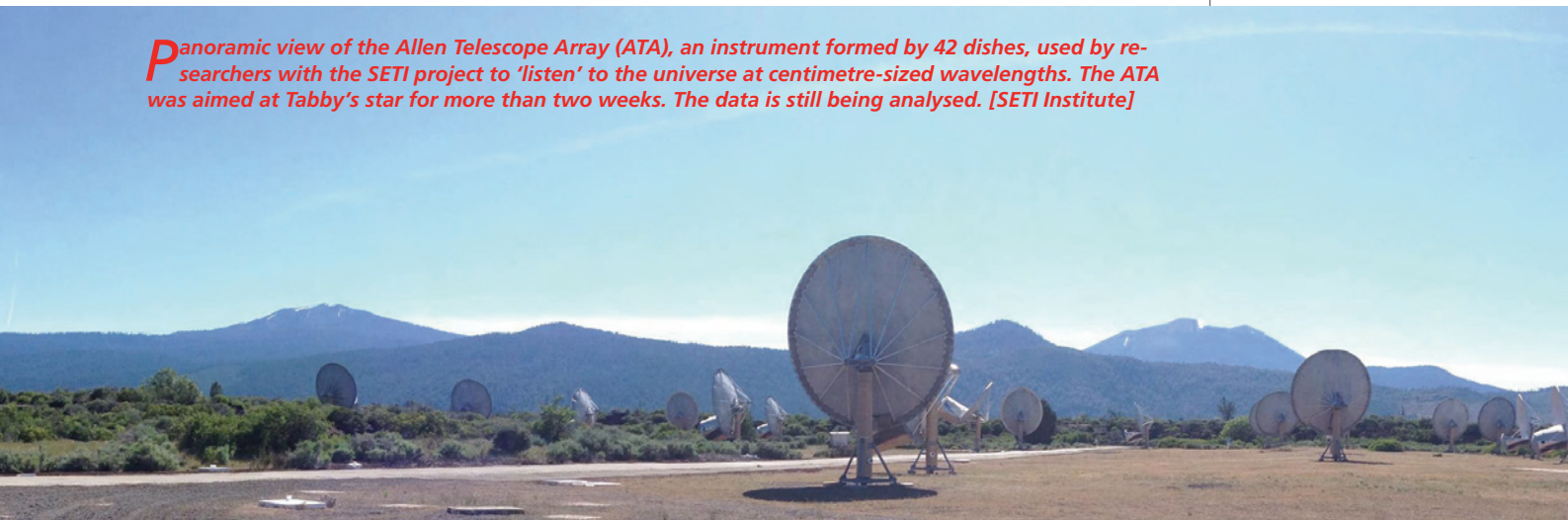
In 2015, there was a sensation over the discovery of a star with very strange variations in luminosity that were unexplainable by known natural phenomena (see the November-December 2015 issue). The leading figure in the discovery was a Yale University astronomer named Tabetha Boyajian, and so the star was later named 'Tabby's star'. The unusual celestial object was observed continually for about 4 years (from 2009 to 2013) by NASA's Kepler space telescope. In the light curve obtained during that period, two steep drops in brightness

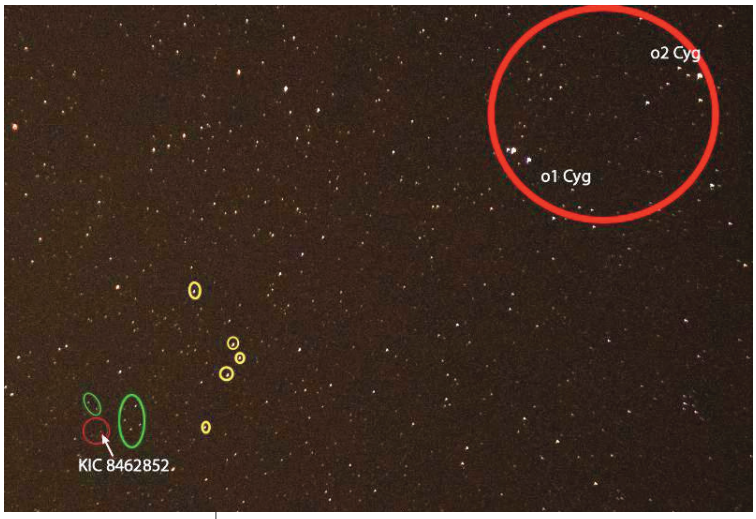
(15% and 22% of the total light emitted) were obvious, with a definitely irregular pattern.
The impossibility of definitively explaining the photometric progress of Tabby's star also left room for a bold theory advanced by a Pennsylvania State University astronomer, Jason Wright, who believes that the changes in luminosity recorded by Kepler are compatible with the presence of a gigantic artificial structure built in orbit around the star to capture some of its energy. With that, the heavens opened. As if it were heresy to assume the existence of something that Freeman Dyson had speculated about almost 60 years ago, part of the scientific community pounced on that provocative explanation, and soon a number of other scientists proposed alternative theories for natural causes. Oddly, in addition to often being obviously contradictory to each other, these alternative interpretations sometimes involve celestial phenomena or objects whose existence have not yet been proven, and therefore in some cases seem so unlikely as to indirectly strengthen Wright's theory, which is at least based on the assumption that life exists in the universe.
In approximately chronological order, let's see who proposed what in the last year or so to explain the anomalies of Tabby's star without resorting to alien presences. We can begin with Steve Howell, a scientist

At left, below and on the following page, three maps useful for finding Tabby's star (apparent magnitude 11.7) in the Cygnus constellation. The star can be seen with a small telescope. [Stellarium.org, Cloudynights.com]

with the Kepler mission, who noted that another star, called KIC 4110611, had been discovered whose light curve seemed unexplainable at first but then was clearly interpreted when it was found to be not a single star but a quintuple system featuring repeating eclipses between its compo-

Panoramic view of the Allen Telescope Array (ATA), an instrument formed by 42 dishes, used by researchers with the SETI project to 'listen' to the universe at centimetre-sized wavelengths. The ATA was aimed at Tabby's star for more than two weeks. The data is still being analysed. [SETI Institute]





nents. Good to know, but this scenario does not seem to be at all workable for Tabby's star, which, as far as we know, has only a small, rather distant companion. Also, a multiple stellar system would have difficulty generating all the irregular variations — lasting days, weeks, even months — found in the luminosity of Tabby's star. It is more reasonable to theorise that its bizarre photometric behaviour is due to the temporary transit across the stellar disc (along our line of sight) of one or more objects large and opaque enough to darken more than 1/5 of the light the star emitted. Since it obviously cannot be something well defined, like a planet, for example, some astronomers have begun speculating about the possibility that its variability might be attributable to clouds of dust and debris with an irregular shape and distribution, generated by one or more catastrophic collisions, which might have involved planets, moons and asteroids.

On the other hand, other astronomers have begun claiming that an entire family of comets (perhaps originating with the disintegration of a single enormous comet) could be the likeliest reason for the star's strange photometric behaviour in the medium term, while the most significant declines in light could be attributable to larger cometary fragments passing in front of the star.

We should consider a few issues at this point, because at first blush some things don't add up. A hypothetical extra-terrestrial in another planetary system observing Jupiter passing in front of the Sun would see our star's light dim by barely 1% (Jupiter has a diameter 10 times smaller than that of the Sun). Considering that Tabby's star has a diameter 1.5 times larger than

Video of a very popular public conference in which Tabetha Boyajian explained the star's history and the state of the art on the star that bears her name. [TED Talks]

the Sun's, to account for the greater darkening measured by Kepler, we would have to posit that the object passing in front of it would be a planet with a diameter of 700,000 km!

Planets of that size cannot exist. And this would be just the largest part of the theoretical object that would have had to be destroyed to be responsible for the photometric anomalies encountered.

Clearly, any theory of this nature seems even less likely than the reviled theory of the alien megastructure. But there's more. A cloud of debris heated by a star emits enough infrared radiation to be detectable as 'excess emission'. Tabby's star is spectral type F3, and the amount of infrared radiation emitted by this kind of star, barring external contributions, is precisely known. If an excess of emission is measured, it means that heated material is near to it, and a cloud of dust and debris is an excellent radiator.

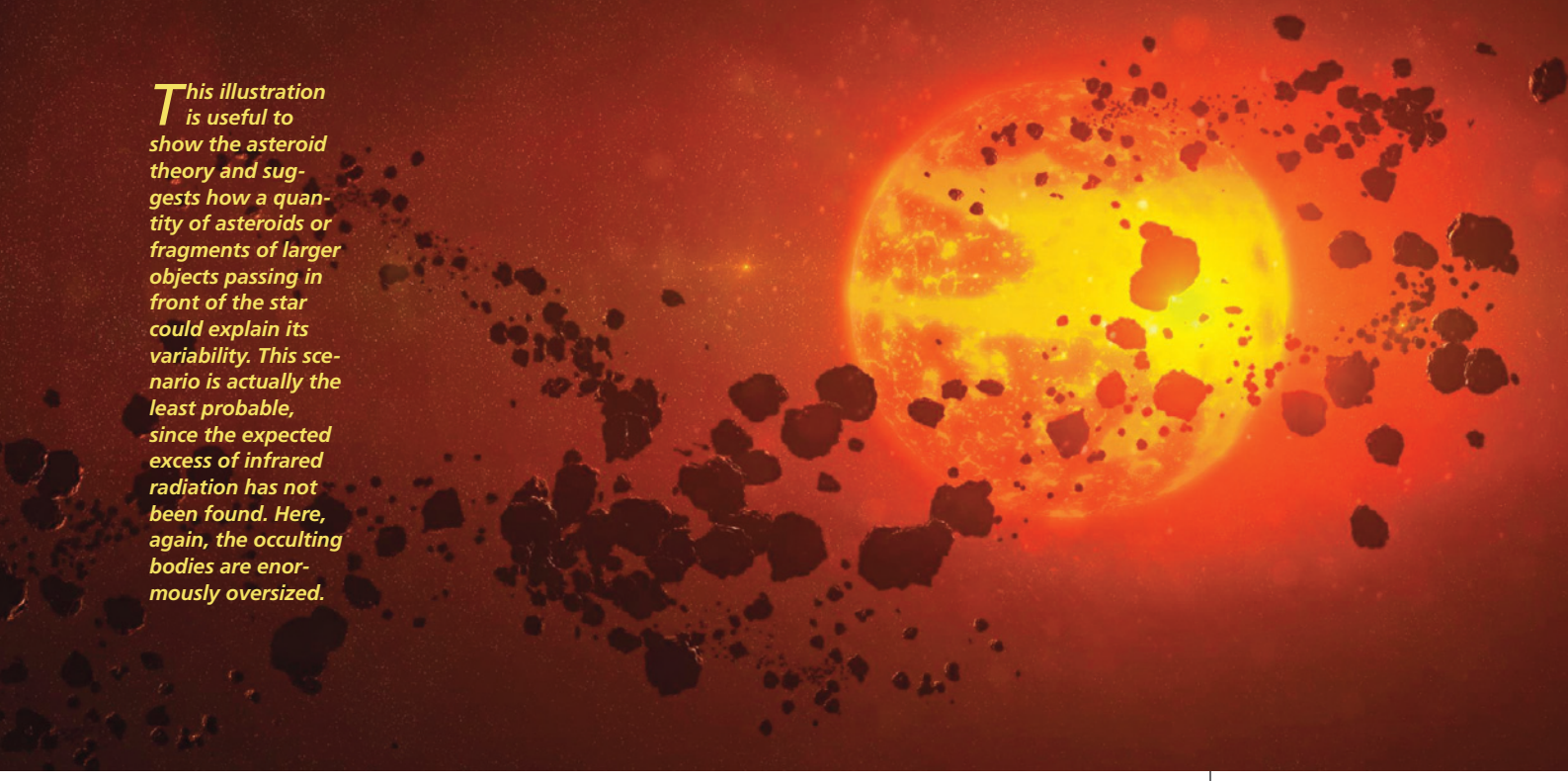
Massimo Marengo (Iowa State University), along with two other researchers, Alan Hulsebus (ISU) and Sarah Willis (Harvard-Smithsonian Center for Astrophysics), wanted to investigate the possibility of an excess of infrared emission by Tabby's star. The team examined a series of data collected in January 2015 by the Infrared Array Camera on NASA's Spitzer space telescope, a couple of years after Kepler's latest measurements. This analysis involved two different infrared wavelengths, a shorter length (3.6 microns) typical of stellar emission, where no excess was revealed, and a longer length (4.5 microns), in which the 'luminous' contribution of any dust and debris would become obvious. Once again, nothing especially interesting turned up.

The opinion of Marengo and his colleagues is that the absence of a clear excess of infrared emission by Tabby's star rules out the possibility that significant collisions could have taken place in its planetary system, which itself is also hypothetical. The only scenario that the team considered acceptable entails a group of comets arranged in an extremely eccentric orbit: after transiting in front of and around the star,

they would then quickly move away without leaving any discernible trace. The few years elapsed between the Kepler and Spitzer observations would have been enough to clear the field of any kind of occulting body, but the problem remains of the enormous overall sizes of the objects that passed in front of the star on at least two occasions. This is also a problem for the theoretical family of comets that would have had to cause an occultation equivalent to that produced by a dwarf star.

There have also been other researchers who have approached the problem with more neutrality, putting concrete data ahead of their own prejudices. This was the case with Bradley Schaefer of Louisiana State University, who tackled the job of measuring Tabby's star's luminosity on 1,338 photographic plates from the Harvard archive that were taken between 1890 and 1989, or a century of photometric data. In processing the measurements, Schaefer discovered that during that period the star's brightness gradually decreased by 19%, a change that evidently cannot be attributed to an isolated catastrophic event or to the transit of a family of comets.

This illustration summarises the cometary theory, one of the most widely shared in the search for an explanation of the variabilities of Tabby's star. Here, the size of the comets' nuclei and tails have been significantly exaggerated, so they appear closer to the observer than to the star. [NASA/JPL-Caltech]



This illustration is useful to show the asteroid theory and suggests how a quantity of asteroids or fragments of larger objects passing in front of the star could explain its variability. This scenario is actually the least probable, since the expected excess of infrared radiation has not been found. Here, again, the occulting bodies are enormously oversized.

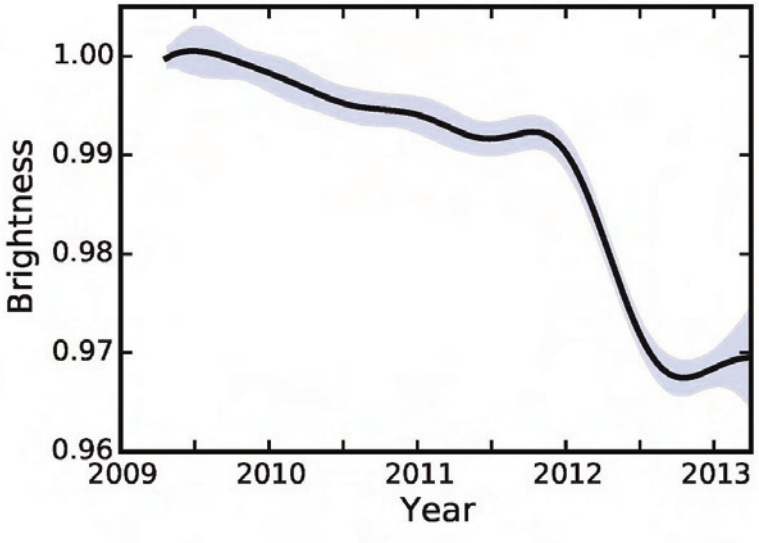
Schaefer calculated that it would take 648,000 comets, each 200 km in diameter, all passing in front of the star at conveniently timed intervals, to produce the century of darkening and the greatest drops in light, a rather surreal scenario. On the other hand, as dubious as it may seem, that progressive dimming could be compatible with the drawn-out building of a megastructure.

Speculations for sure, but on both sides. Nevertheless, all the work mentioned has been published or is being published in prestigious scientific publications like the Monthly Notices of the Royal Astronomical Society and The Astrophysical Journal.

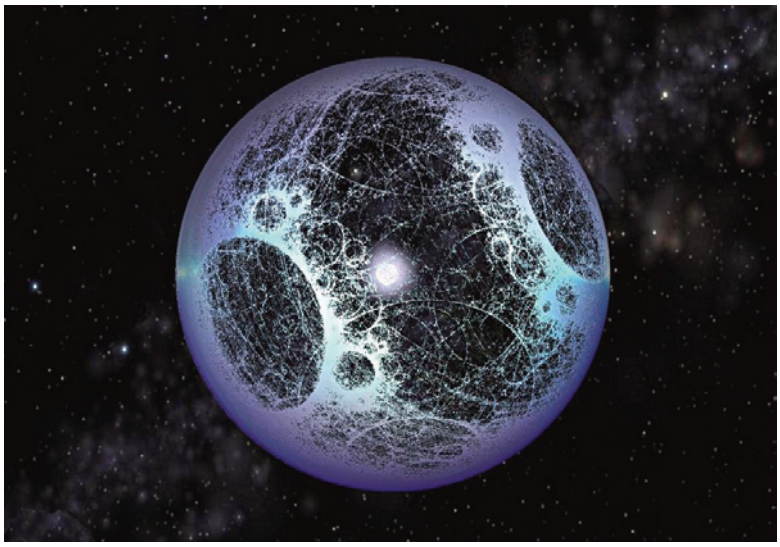
Schaefer's work, released in January 2016, inevitably attracted the attention of those who would prefer more orthodox interpretations for the oddities of Tabby's star.

These include Keivan Stassun and Michael Lund (Louisiana State University), Joshua Pepper (Lehigh University), Daniel Angerhausen (NASA) and Michael Hippke (an amateur astronomer). This team challenged Schaefer's results, claiming that the century of changes he discovered could be an artefact created by the features of various telescopes and photographic devices used to obtain the images. Going back over that material, based on a single resource (Digital Access to a Sky Century @ Harvard, or DASCH for short), Stassun and his colleagues found that during the 1960s other stars had also shown variations in luminosity similar to that of Tabby's star, surely more attributable to the equipment than to the stars themselves. This, however, is not as clear for the other 9 decades, for which Schaefer's measurements seem credible.

This bring us to August 2016, when Benjamin Montet (California Institute of Tech-



The light curve of Tabby's star based on Kepler data. The black line shows the estimates by Montet and Simon; the shading is the margin of error. The magnitude dropped by 3%. [Ben Montet]



At right, a theoretical Dyson sphere built by an alien civilisation. In this case, its structure is based on fractals. A shape like this would explain the behaviour of Tabby's star. [SentientDevelopments.com] Below, the NRAO's Green Bank Telescope in West Virginia. This is one of the largest tools used to capture any intelligent radio messages coming from the stellar system of Tabby's star. Part of the data collected during the short 'listening' period is still being processed. [Jiuguang Wang]

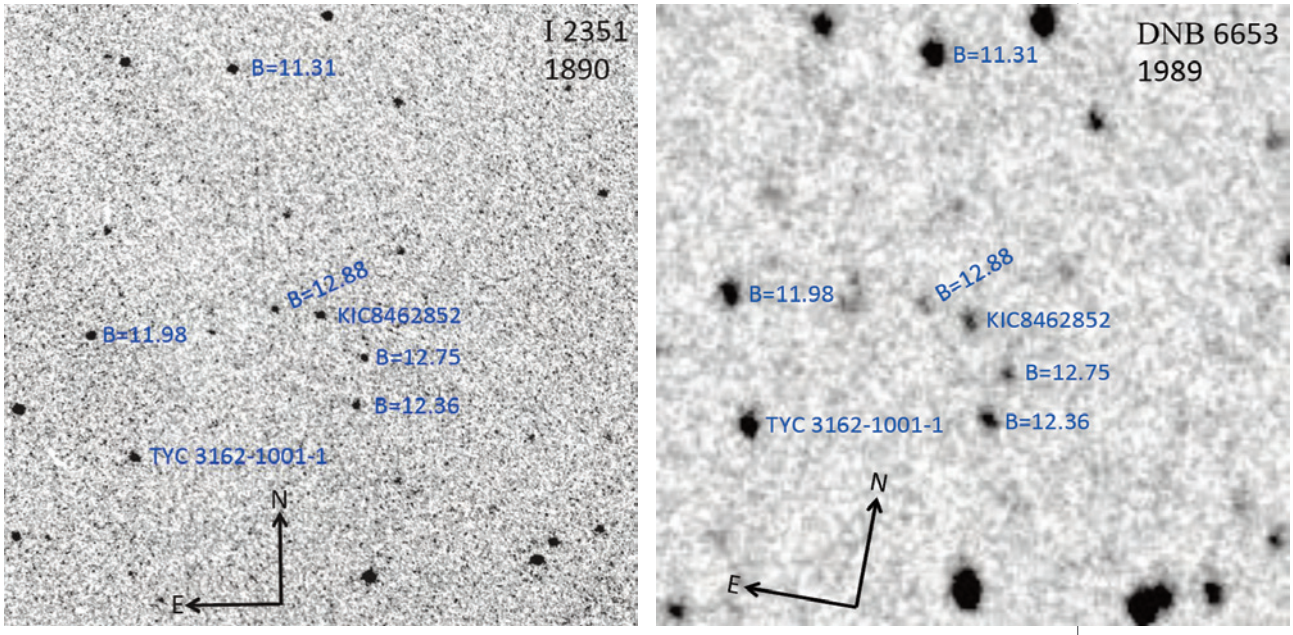
nology) and Joshua Simon (Carnegie Institution of Washington) published a detailed study of Tabby's star based on Kepler's four years of photometric data and a series of calibration images never used before for scientific measurements.

From the results, it seems that during the first thousand days of observation the star weakened in a linear fashion at a rate of about 1/3 of its magnitude per year, or about a 1% loss. Over the following six months, its luminosity dropped more quickly, losing 2%. Then, during the final roughly 200 days covered by the observations, its magnitude remained almost constant, although the overall trend was consistent with diminishing.

Montet and Simon estimated the star's luminosity very carefully, comparing it to that of 193 nearby stars and 355 stars with similar stellar parameters. None of them showed photometric behaviour comparable to that of Tabby's star. This result substantially confirms Schaefer's findings.

Months went by, and near the end of December 2016 another study was published that intended to show that Tabby's star is not being orbited by any alien megastructure. The authors were Brian Metzger and Nicholas Stone (Columbia University, New York), along with Ken Shen (University of California, Berkeley). The three researchers suggested that the century of dimming could be attributed to the star destroying and partially phagocytising a planet. Depending on the quantity of planetary mass thrown into the star, the episode would have happened over a span of time between ten and ten thousand years ago, producing a sudden increase in stellar luminosity, which since then would have gradually fallen back to typical levels.

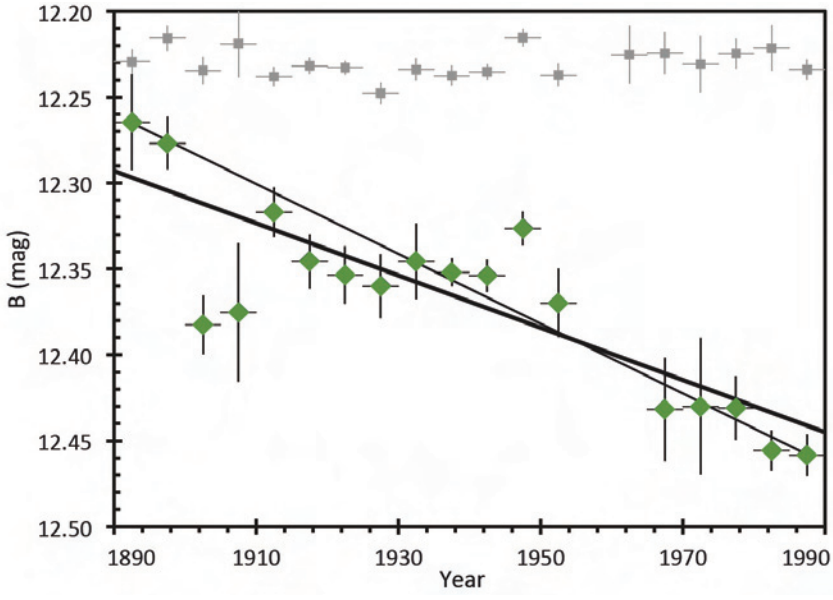
According to Metzger and his colleagues, the recent, steep minimums when the star temporarily lost 15% and 22% of its brightness could be ascribed to large planetary frag-



ments passing in front of the star and ending up in very elongated orbits. It may be useful to remember that the largest of these fragments would have to be about 700,000 km in size. It is fair, then, to ask what the initial dimensions of this 'planet' were. And we should also emphasize that all the anti-megastructure theories involve placing the remnants of whatever might have caused the drops in brightness in Tabby's star into highly eccentric orbits, a necessity that seems a bit forced. One also gets the feeling that the sceptics are following the possibilists by adapting their theories on the basis of the less abstract work of the others.

Let's conclude with a short nod to a theory by Karin Dahmen, Richard Weaver and Mohammed Sheikh (University of Illinois, Urbana-Champaign), according to which Tabby's star is nothing other than a simple irregular variable star approaching an indefinable transition phase, and so the changes in luminosity are intrinsic to the star itself. Unfortunately, the arguments made to support this theory are as complex as they are inconclusive.

Many conjectures, few certainties, and so the mystery of Tabby's star remains unsolved. ■



Scans of the first and last DASCH plates, in which Tabby's star (KIC 8462852) is visible. The images are 10 arcminutes per side. A few reference stars are indicated, with their magnitudes in blue. The drop in luminosity is obvious. [Bradley Schaefer] At left, the secular light curve of Tabby's star. The average dimming is clear (thicker line). The green diamonds are the calculated magnitudes. The small grey squares at the top are the estimates of the magnitudes of the reference stars. [Bradley E. Schaefer]

TecnoSky

ASTRONOMY INSTRUMENTS

via Fubine, 79 - Felizzano (AL) ITALY - tel. +39 0131772241
info@tecnosky.it - www.tecnosky.it

Cassegrain Ø 250 mm, 5000 mm focal lenght
Designed for hi-res imaging of the Moon and planets. Very high optical quality, certified by interferometer, with Strehl ratio >0.94.
Price € 4,303

Tecnosky Flat Field 70 Lanthanum
TecnoSky 4-element Apochromatic ED Refractor, Ø 70 mm, 474 mm focal length, f/6.78, 32 mm corrected field. Optimal chromatic correction thanks to the use of Lanthanum glasses.
Price € 450

Tecnosky 100 Apo Flat Field
FPL-53 Apochromatic Quadruplet, Ø 100 mm and fast f/5.8 focal ratio. Ideal for astrophotography with large sensors. 3" CNC focuser for up to 6 kg weight!
Price € 2,048

TecnoSky FPL-53 Apo Triplet 90/600 mm
Compact Apochromatic Refractor, Ø 90 mm, 600 mm focal length, f/6.6. Carbon fibre tube and 2.5" precision rack-and-pinion focuser. Only 3.5 kg weight!
Price € 1,000

TecnoSky 80/480 mm FPL-53 Apo Triplet
Apochromatic Triplet refractor with Ohara FPL-53 fluorite lens, f/6, ideal for astrophotography. Extremely compact with high-quality tube and 2" Crayford precision focuser with 1:10 reduction ratio.
Price € 647

Tecnosky RC10 Ø 250 mm, 2000 mm focal lenght
Entirely made in the EU. Open truss optical tube assembly in carbon fibre and aluminium, extremely rigid and yet light (13 kg). Optics certified by interferometer. Primary mirror made from Supremax 33 glass.
Price € 5,450

TecnoSky 102/714 mm FPL-53 Apo Triplet
Apochromatic Refractor Ø 102 mm, built with FPL-53 fluorite glass triplet and carbon fibre tube.
Price € 1,221

WIDE VARIETY OF: REFLECTOR AND REFRACTOR TELESCOPES - SPOTTING SCOPES - BINOCULARS - CCD CAMERAS - MECHANICAL, PHOTOGRAPHIC, VIDEO AND OPTICAL ACCESSORIES MOUNTS AND TRIPODS - POWER SUPPLIES AND BATTERIES - INSTRUMENTS BAGS AND CASES - CLOTHING FOR AMATEUR ASTRONOMERS - WEATHER STATIONS - PHOTOGRAPHIC LENSES, NIGHT VISION GEAR AND MUCH MORE. OVER 50 BRANDS TRADED. FOR FURTHER TECHNICAL INFORMATION ABOUT ALL OUR PRODUCTS AND PRICING VISIT OUR WEBSITE.

Image: Saturn by NASA

A big brother of Halley's Comet ripped apart by white dwarf

by ESA/NASA

Scientists using the NASA/ESA Hubble Space Telescope have observed, for the first time, a massive, comet-like object that has been ripped apart and scattered in the atmosphere of a white dwarf.

The international team of astronomers observed the white dwarf WD 1425+540, about 170 light-years from Earth in the constellation Boötes (the Herdsman).

The white dwarf was first found in 1974 and is part of a wide binary system, with a companion star separated by 2000 times the distance that the Earth is from the Sun.

While studying the white dwarf's atmosphere using both the NASA/ESA Hubble Space Telescope and the W. M. Keck Observatory the team found evidence that an object rather like a massive comet was falling onto the star, getting tidally disrupted while doing so.

The team determined that the object had a chemical composition similar to the famous Halley's Comet in our own Solar System, but it was 100,000 times more massive and had twice the proportion of water as its local counterpart. Spectral analysis showed that the destroyed object was rich in the elements essential for life, including carbon, oxygen, sulphur and even nitrogen.

This makes it the first detection of nitrogen in the debris falling onto a white dwarf. Lead author Siyi Xu of the European Southern Observatory, Germany, explains the importance of the discovery: "Nitrogen is a very important element for life as we know it. This particular object is quite rich in nitrogen, more so than any object observed in our Solar System." There are already more than a dozen white dwarfs known to be polluted with infalling debris from

This artist's impression shows a massive, comet-like object falling towards a white dwarf. New observations with the NASA/ESA Hubble Space Telescope show evidence for a belt of comet-like bodies orbiting the white dwarf, similar to the Kuiper Belt in our own Solar System. The findings also suggest the presence of one or more unseen surviving planets around the white dwarf which may have perturbed the belt sufficiently to hurl icy objects into the burned-out star. [NASA, ESA, and Z. Levy (STScI)]

rocky, asteroid-like objects, but this is the first time a body made of icy, comet-like material has been seen polluting a white dwarf's atmosphere. These findings are evidence for a belt of comet-like bodies, similar to our Solar System's Kuiper Belt, orbiting the white dwarf. These icy bodies apparently survived the star's evolution from a main sequence star — similar to our Sun — to a red giant and its final collapse to a small, dense white dwarf. The team that made this discovery also considered how this massive object got from its original, distant orbit onto a collision course with its parent star. The team calculated that the accreted object originally resided about 300 astronomical units — 300 times the distance Earth-Sun — away from the white dwarf. This is seven times further out than the Kuiper-Belt objects in the Solar System.

The change in the orbit could have been caused by the gravitational distribution by so far undetected, surviving planets which have perturbed the belt of comets. Another explanation could be that the companion star of the white dwarf disturbed the belt and caused objects from the belt to travel toward the white dwarf. The change in orbit could also have been caused by a combination of these two scenarios. The Kuiper Belt in the Solar System, which extends outward from Neptune's orbit, is home to many dwarf planets, comets, and other small bodies left over from the formation of the Solar System.

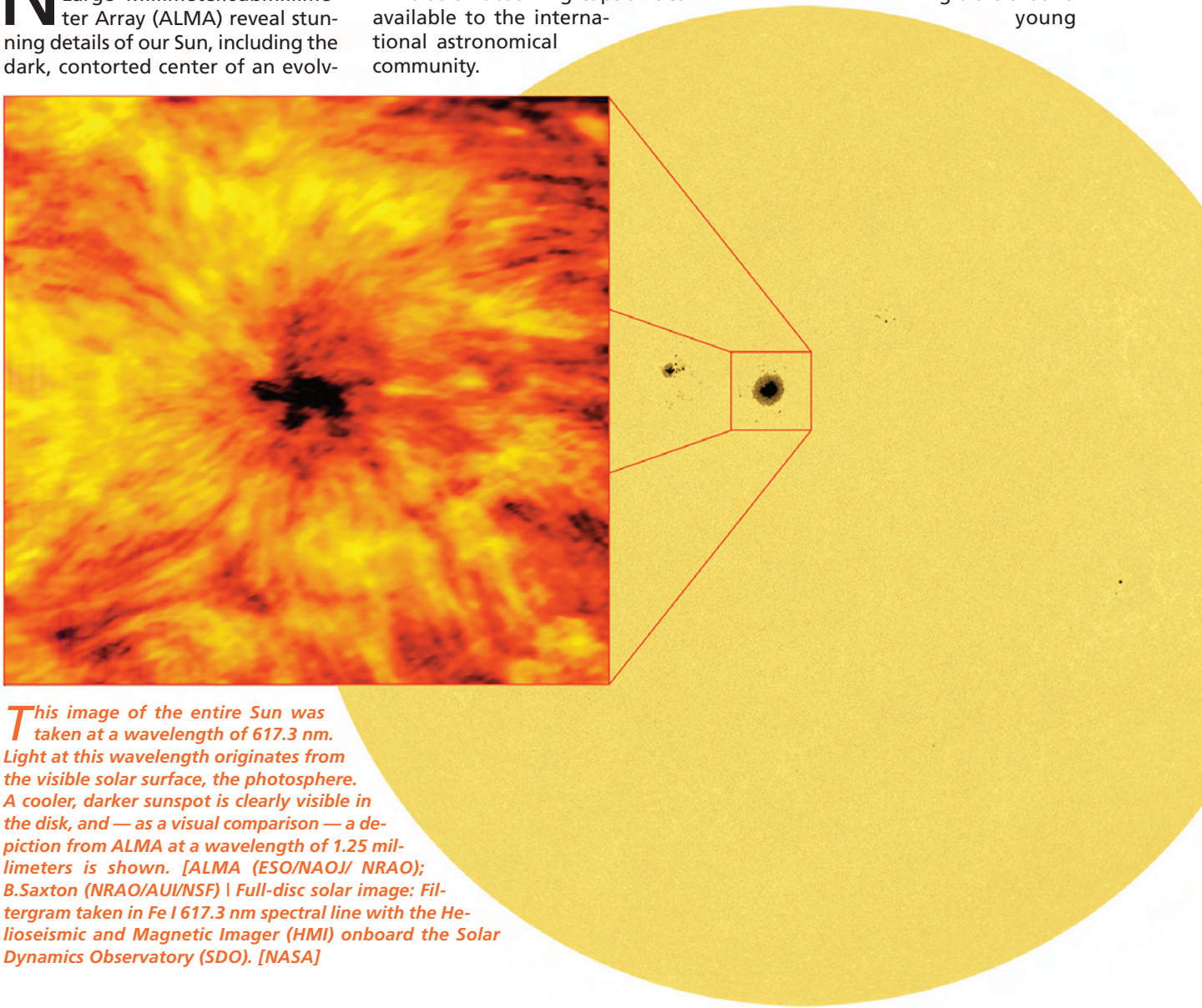
The new findings now provide observational evidence to support the idea that icy bodies are also present in other planetary systems and have survived throughout the history of the star's evolution. ■

ALMA starts observing the Sun

by ALMA Observatory

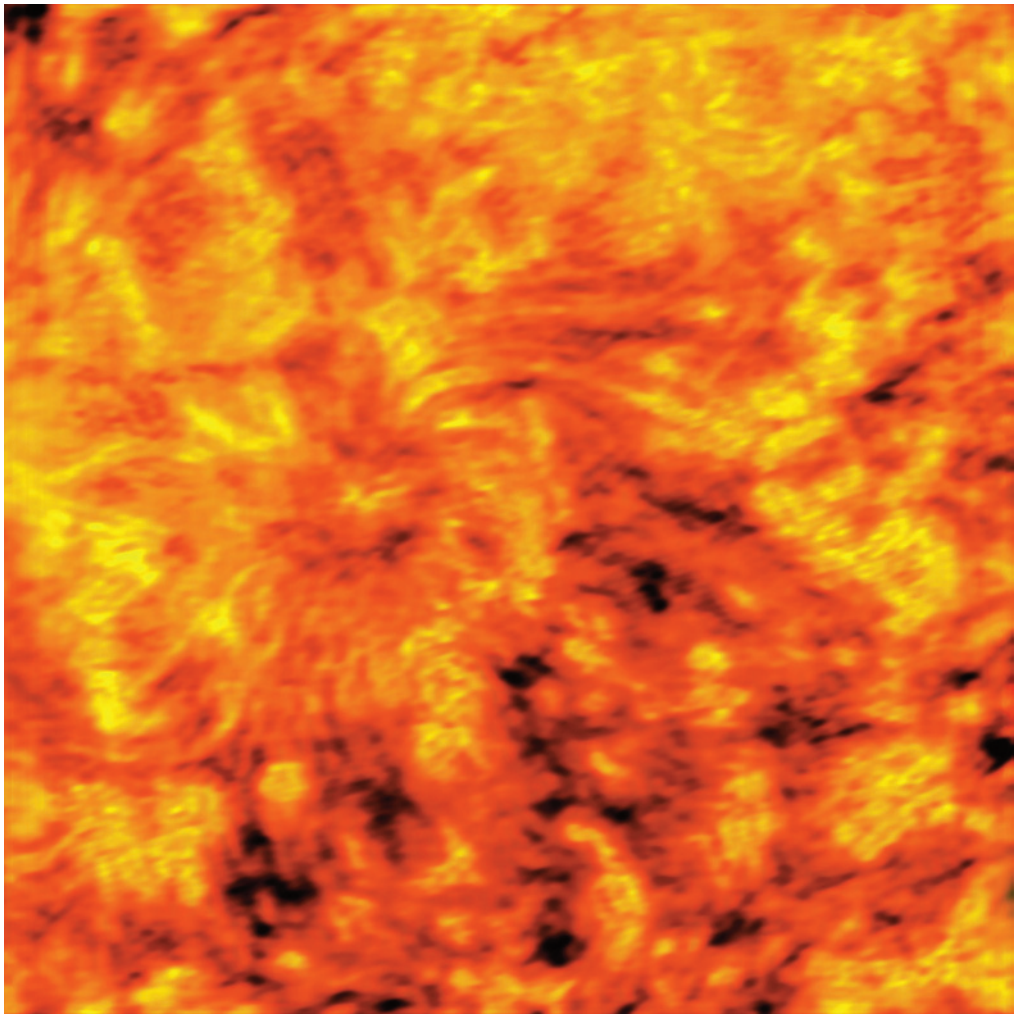
New images from the Atacama Large Millimeter/submillimeter Array (ALMA) reveal stunning details of our Sun, including the dark, contorted center of an evolving sunspot nearly twice as large as the diameter of the Earth. These images are part of the testing and verification campaign to make ALMA's solar observing capabilities available to the international astronomical community.

Though designed principally to observe remarkably faint objects throughout the Universe — such as distant galaxies and planet-forming disks around young



This image of the entire Sun was taken at a wavelength of 617.3 nm. Light at this wavelength originates from the visible solar surface, the photosphere. A cooler, darker sunspot is clearly visible in the disk, and — as a visual comparison — a depiction from ALMA at a wavelength of 1.25 millimeters is shown. [ALMA (ESO/NAOJ/ NRAO); B.Saxton (NRAO/AUI/NSF) | Full-disc solar image: Filtergram taken in Fe I 617.3 nm spectral line with the Helioseismic and Magnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO). [NASA]

stars — ALMA is also capable of studying objects in our own Solar System, including planets, comets, and now our own Sun. During a 30-month period beginning in 2014, an international team of astronomers harnessed ALMA's single-antenna and array capabilities to detect and image the millimeter-wavelength light emitted by the Sun's chromosphere – the region that lies just above the photosphere, the visible surface of the Sun. These new images demonstrate ALMA's ability to study solar activity at longer wavelengths than observed with typical solar telescopes on Earth, and are an important expansion of the range of observations that can be used to probe the physics of our nearest star. *"We're accustomed to seeing how our Sun appears in visible light, but that can only tell us so much about the dynamic surface and energetic atmosphere of our nearest star,"* said Tim Bastian, an astronomer with the National Radio Astronomy Observatory in Charlottesville, Virginia in the USA. *"To fully understand the Sun, we need to study it across the entire electromagnetic spectrum, including the millimeter and submillimeter portion that ALMA can observe."* Since our Sun is many billions of times brighter than the faint objects ALMA typically observes, the solar commissioning team had to developed special procedures to enable ALMA to safely image the Sun without damaging its sensitive electronics. The result of this work is a series of images that demonstrates ALMA's unique vision and ability to study our Sun on multiple scales. ■



ALMA image of an enormous sunspot taken with the Band 3 receiver at a wavelength of 3 millimeters. Sunspots are transient features that occur in regions where the Sun's magnetic field is extremely concentrated and powerful. They are lower in temperature than their surrounding regions, which is why they appear relatively dark in visible light. The ALMA images are essentially maps of temperature differences in a layer of the Sun's atmosphere known as the chromosphere, which lies just above the visible surface of the Sun (the photosphere). The chromosphere is considerably hotter than the photosphere. Understanding the heating and dynamics of the chromosphere are key areas of research that will be addressed by ALMA. Observations at shorter wavelengths probe deeper into the solar chromosphere than longer wavelengths. Hence, Band 6 observations map a layer of the chromosphere that is closer to the visible surface of the Sun than Band 3 observations. [ALMA (ESO/NAOJ/NRAO)]

New independent measurement of the Hubble constant

by ESA/NASA

The Hubble constant — the rate at which the Universe is expanding — is one of the fundamental quantities describing our Universe. A group of astronomers from the H0LiCOW collaboration, led by Sherry Suyu (associated with the Max Planck Institute for Astrophysics in Germany, the ASIAA in Taiwan and the Technical University of Munich), used the Hubble Space Telescope and other telescopes in space and on the ground to observe five galaxies in order to arrive at an independent measurement of the Hubble constant.

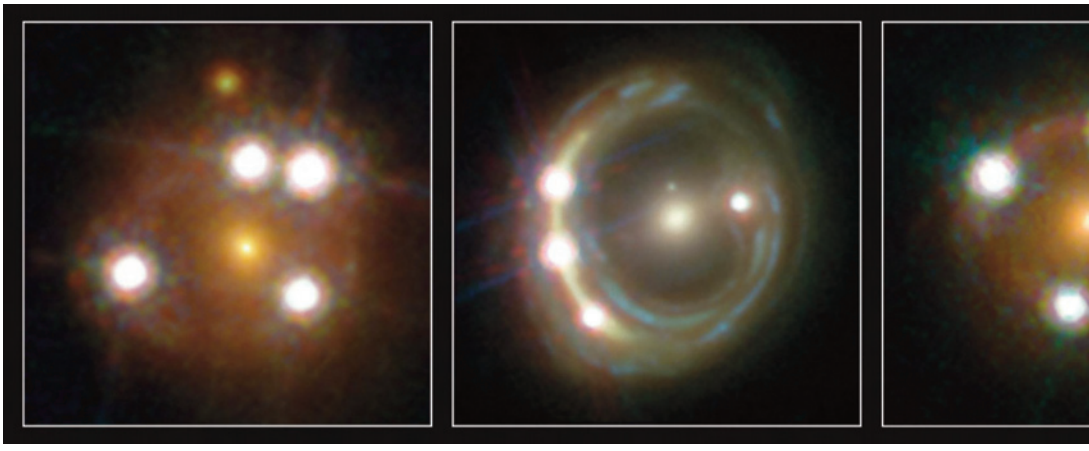
The new measurement is completely independent of — but in excellent agreement with — other measurements of the Hubble constant in the local Universe that used Cepheid variable stars and supernovae as points of reference. However, the value measured by Suyu and her team, as well as those measured using Cepheids and supernovae, are different from the measurement made by the ESA Planck satellite.

But there is an important distinction: Planck measured the Hubble constant for the early Universe by observing the cosmic microwave background.

While the value for the Hubble constant determined by Planck fits with our current understanding of the cosmos, the values obtained by the different groups of astronomers for the local Universe are in disagreement with our accepted theoretical model of the Universe. *"The expansion rate of the Universe is now starting to be measured in different ways with such high precision that actual discrepancies may possibly point towards new physics beyond our current knowledge of the Universe,"* elaborates Suyu.

The targets of the study were massive galaxies positioned between Earth and very distant quasars — incredibly luminous galaxy cores.

The light from the more distant quasars is bent around the huge masses of the galaxies as a result of strong gravitational lensing. This creates multiple images of the background quasar, some smeared into extended arcs. Because galaxies do not create perfectly spherical



This montage shows the five lensed quasars and the foreground galaxies studied by the H0LICOW collaboration. Using these objects astronomers were able to make an independent measurement of the Hubble constant. They calculated that the Universe is actually expanding faster than expected on the basis of our cosmological model. [ESA/Hubble, NASA, Suyu et al.]

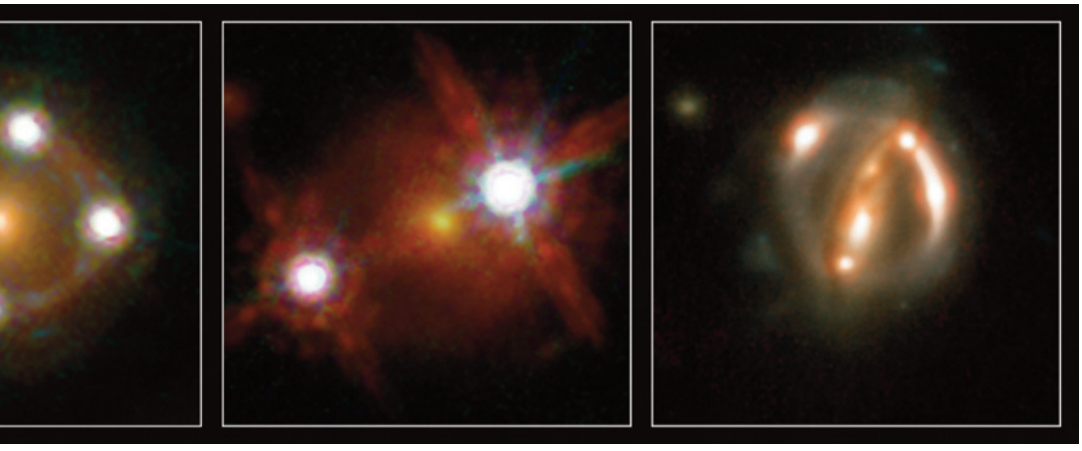
HE0435-1223, located in the centre of this wide-field image, is among the five best lensed quasars discovered to date. The foreground galaxy creates four almost evenly distributed images of the distant quasar around it. [ESA/Hubble, NASA, Suyu et al.]

distortions in the fabric of space and the lensing galaxies and quasars are not perfectly aligned, the light from the different images of the background quasar follows paths which have slightly different lengths. Since the brightness of quasars changes over time, astronomers can see the different images flicker at different times, the delays between them depending on the lengths of the paths the light has taken.

These delays are directly related to the value of the Hubble constant. Using the accurate measurements of the time delays between the multiple images, as well as computer models, has allowed the team to determine the Hubble constant to an impressively high precision: 3.8%. The H0LiCOW team determined a value for the Hubble constant of 71.9±2.7 kilometres per second per Megaparsec.

In 2016 scientists using the Hubble Space Telescope measured a value of 73.24±1.74 kilometres per second per Megaparsec.

In 2015, the ESA Planck Satellite measured the constant with the highest precision so far and obtained a value of 66.93±0.62 kilometres per second per Megaparsec.



"Our method is the most simple and direct way to measure the Hubble constant as it only uses geometry and General Relativity, no other assumptions," explains co-lead Frédéric Courbin from EPFL, Switzerland.

"An accurate measurement of the Hubble constant is one of the most sought-after prizes in cosmological research today," highlights team member Vivien Bonvin, from EPFL, Switzerland.

And Suyu adds: *"The Hubble constant is crucial for modern astronomy as it can help to confirm or refute whether our picture of the Universe — composed of dark energy, dark matter and normal matter — is actually correct, or if we are missing something fundamental."* ■

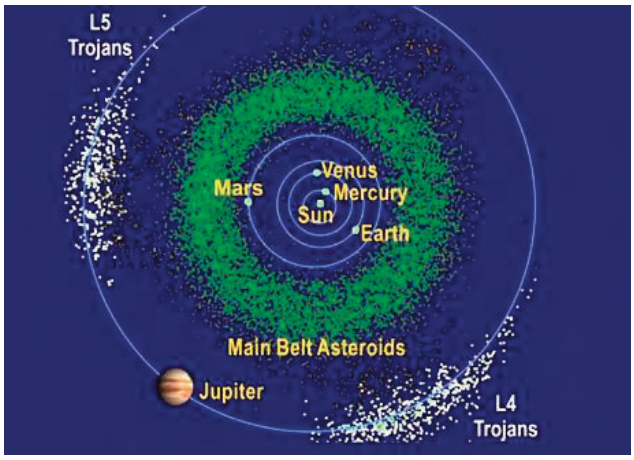
Two probes will explore the early Solar System

by Gonçalo Magalhães

NASA has selected two new missions from the Discovery Program to explore one of the earliest eras in the history of our solar system – just 10 million years after the birth of the Sun. The missions are called Lucy and Psyche, and they were chosen from five finalists, leaving behind DAVINCI, VERITAS and NEOCam (although NEOCam's funding will be extended for another year). These five projects were proposed for possible key planetary missions to perform studies of Venus (DAVINCI and VERITAS), near-Earth objects (NEOCam) and a variety of asteroids (Lucy and Psyche). The Discovery Program is managed by NASA's Planetary Missions Program Office at the Marshall Space Flight Center in Huntsville, Alabama. It includes 12 investigation projects, including the Dawn mission and the Kepler mission. Most importantly, the Discovery Program has a collection of low-cost missions for

Artist's conception of the Psyche spacecraft, which will conduct a direct exploration of an asteroid thought to be an exposed planetary core. [SSL/ASU/P. Rubin/NASA/JPL-Caltech]

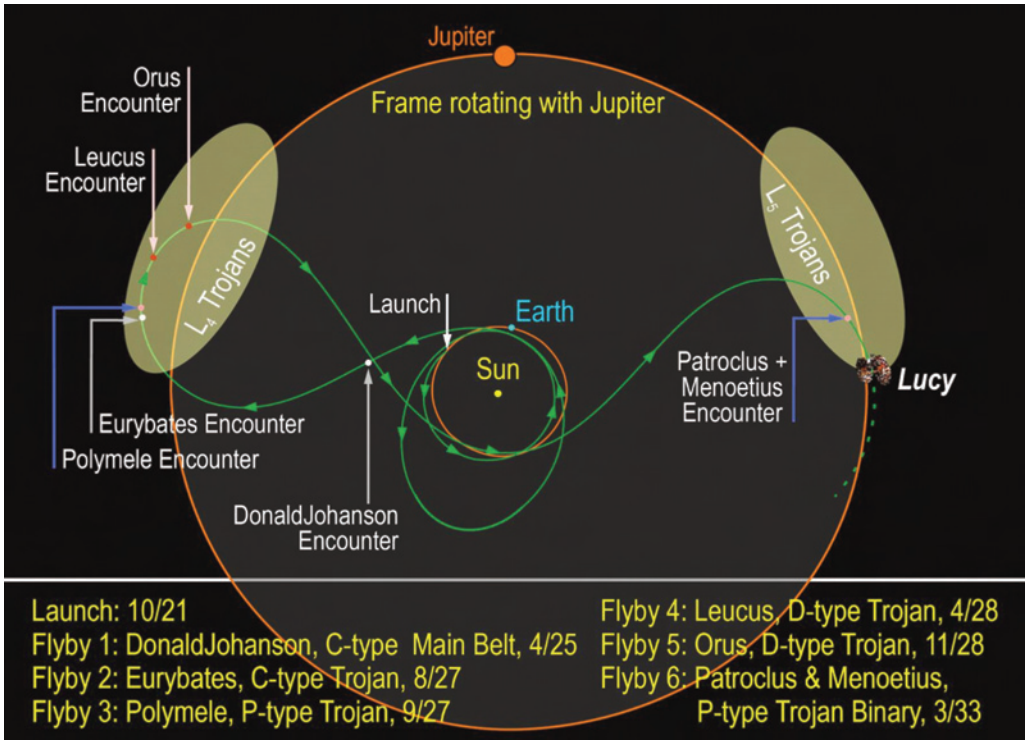
Astronomers have long been investigating some of the most ancient bodies in our planetary system, in a quest to understand its evolution from its very beginning to the solar system as we know it now. The next step will be to go further into the history of our solar system – less than 10 million years after the birth of our Sun – by exploring various Trojan asteroids and a rare metallic asteroid.



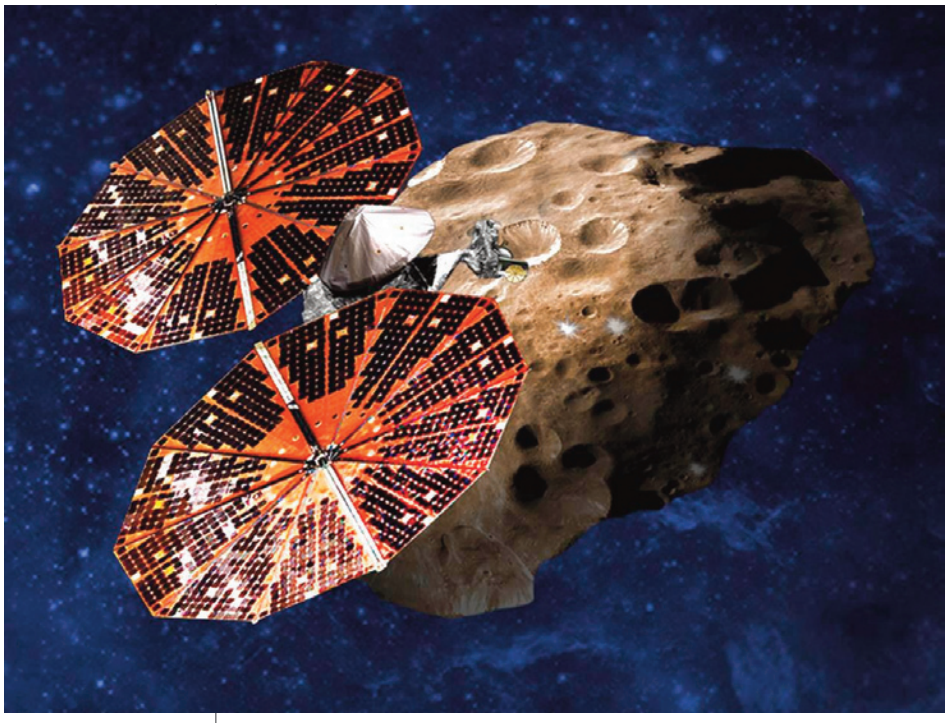
solar system targets. *"This is what Discovery Program missions are all about,"* says Thomas Zurbuchen, associate administrator for NASA's Science Mission Directorate, *"boldly going to places we've never been to enable ground-breaking science."*

Lucy is named after the well-known fossilized hominid. This probe will explore several Trojan asteroids, the first ever mission to accomplish such a thing. It will complete six flyby manoeuvres – a flyby is a hyperbolic trajectory that a probe can take using a body's gravitational pull, passing near to it without being fully captured. Lucy will first visit a Main Belt asteroid, and then it will explore four different Trojans around Jupiter's Lagrange point L4. Finally, it will make a flyby around another Trojan, this time near Jupiter's Lagrange point L5. A Lagrange point is a place with fixed coordinates on a rotating referential, in this case a referential rotating with the same angular speed as Jupiter. The points derive from the three-body problem, which considers the gravitational pull of just two bodies (in this case, the Sun and Jupiter), and then the few points where smaller bodies can remain stable are found through algebraic methods. The Trojan asteroids are celestial bodies that gathered around Jupiter's L4 and L5.

The Lucy mission is crucial to understanding the history of the solar system, as the



Left, an approximate representation of the Main Belt asteroids and that of the Trojan asteroids. Below, an infographic which shows the trajectory of NASA's Lucy mission. The Lucy spacecraft will launch in 2021 and initially fly by the main belt asteroid DonaldJohanson, named for the paleoanthropologist who discovered the Lucy fossil. The spacecraft will then go on to study six diverse and scientifically important Trojans – Eurybates, Polymele, Leucus, Orus and the binary Patroclus/Menoetius – between August 2027 and March 2033. [Southwest Research Institute]



Two artist's conceptions: above, the Lucy spacecraft flying by the Trojan Eurybates – one of the six different and scientifically important Trojans to be studied. Right, the Psyche spacecraft at its destination, 16 Psyche. [SSL/JPL-Caltech/P. Rubin]

Trojans are relics of the past that have not changed much. *"This is a unique opportunity,"* says Harold F. Levison, principal investigator for the Lucy mission at the Southwest Research Institute in Boulder, Colorado. *"Because the Trojans are remnants of the primordial material that formed the outer planets, they hold vital clues to deciphering the history of the solar system."* He adds, *"Lucy, like the human fossil for which it is named, will revolutionize the understanding of our origins."*

Lucy's robotic spacecraft will build on the success of NASA's New Horizons mission to Pluto and the Kuiper Belt, using updated versions of some of the instruments it used, specifically RALPH and LORRI (Long-Range Reconnaissance Imager). It will also use the OTES instrument from the OSIRIS-REx mission.

In addition to that, various Lucy mission team members are veterans of the New Horizons mission and the OSIRIS-REx mission.

Psyche is both the name of an asteroid orbiting the Sun between Mars and Jupiter (the Main Asteroid Belt) and the name of NASA's mission to visit the asteroid.

This object is known as 16 Psyche, since it is the 16th minor planet to have been discovered. It measures about 210 kilometres (130 miles) in diameter, orbiting at an average distance from the Sun of 3 astronomical units (AU).

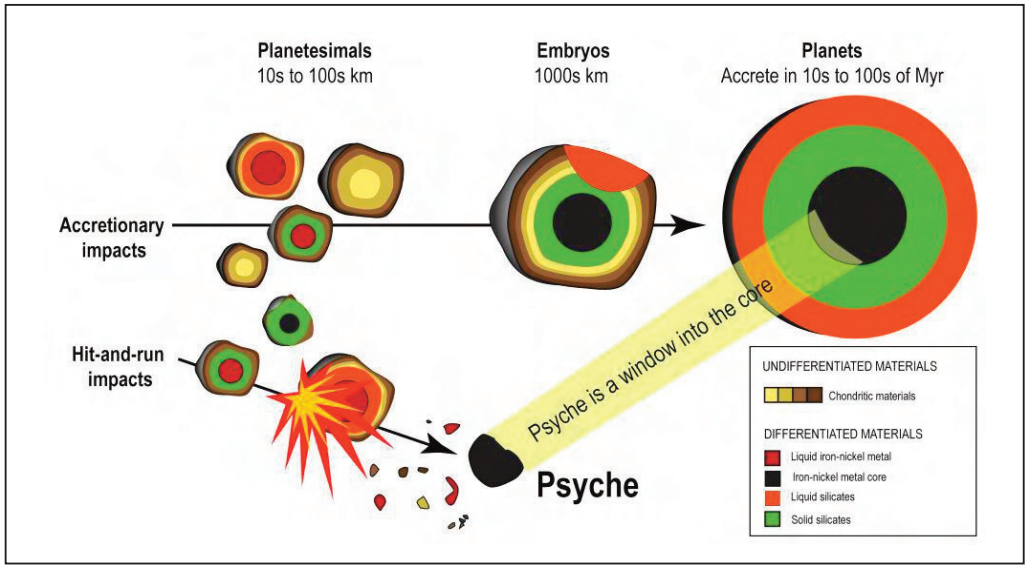
What's most interesting about 16 Psyche is its unique metallic composition, mostly metallic iron and nickel, like Earth's core. *"This is an opportunity to explore a new type of world – not one of rock or ice, but of metal,"* says Psyche Principal Investigator Lindy Elkins-Tanton of Arizona State University in Tempe. This rare feature has made researchers wonder if the asteroid was the core of an early planet that was stripped of its outer layers. If so, the Psyche mission could give us a rare look into a planet's core without having to dig through all the layers planets have, which is evidently an impossible task. *"16 Psyche is the only known object of its kind in the solar sys-*

tem, and this is the only way humans will ever visit a core. We learn about inner space by visiting outer space," says Elkins-Tanton. Another question that astronomers are struggling with concerns the asteroid's magnetic field: did it ever create its own magnetic dynamo? Does it still have one? If so, it would be the first measurement of an asteroid's magnetic field by a spacecraft. Psyche's most likely story is a scenario where a protoplanet that had separated internally into a rocky mantle and an iron core suffered powerful impacts that stripped away the mantle, leaving only the metallic core. If this is the case, the Psyche mission will enhance our understanding of our planet's composition, which would not be possible in any other way.

Since NASA selected these two missions from the five finalists, they will proceed to mission formulation. Lucy will launch in October 2021 and perform its first flyby around 1981 EQ_5, a Main Belt asteroid, by April 2025. As said above, It will be followed by three other flybys around four Trojans near Jupiter's L4 – Eurybates, 1999 WB_2, 1997 TS_{25} and 1999 VQ_{10} – between August 2027 and November 2028. Lastly, the robotic spacecraft will travel from the L4 region to the L5 region with the assistance of the Sun's gravity, and it will perform a last flyby around the Trojan binary Patroclus/Menoetius by March 2033. With this collection, the Lucy mission will cover all types of asteroids and both the L4 and L5 swarms. Trojans have been a high priority for space missions for over a decade, as they play a critical role in constraining models of the formation and evolution of the solar system. Like the human fossil for which it is named, Lucy could revolutionize our understanding of our origins.

The Psyche spacecraft will launch in October 2023 and reach 16 Psyche in 2030. It will orbit the asteroid for 12 months in four staging orbits, each with a different orbit altitude. On its last stage, it will be on a 192-km radius orbit, the closest it will ever

Animated video of how Psyche's flyby would look. Asteroid 16 Psyche is mainly composed of metallic iron and nickel. [Arizona State University/ P. Rubin/SSL/JPL] Below, the diagram shows how Psyche may be the nucleus of a differentiated body that lost its outer layers.



The Psyche mission team. Below, the Psyche Multispectral Imager, an instrument which consists of a pair of identical cameras designed to acquire geologic, compositional, and topographic data. It will discriminate between 16 Psyche's metallic and silicate constituents. [Arizona State University]

be to the asteroid's surface, performing 442 orbits over 70 days to map its elemental composition, including gravity and magnetic field mapping. The Psyche mission has the goal of understanding these building blocks of planet formation, depending on whether the asteroid is a protoplanetary core, and exploring an entire new kind of world.

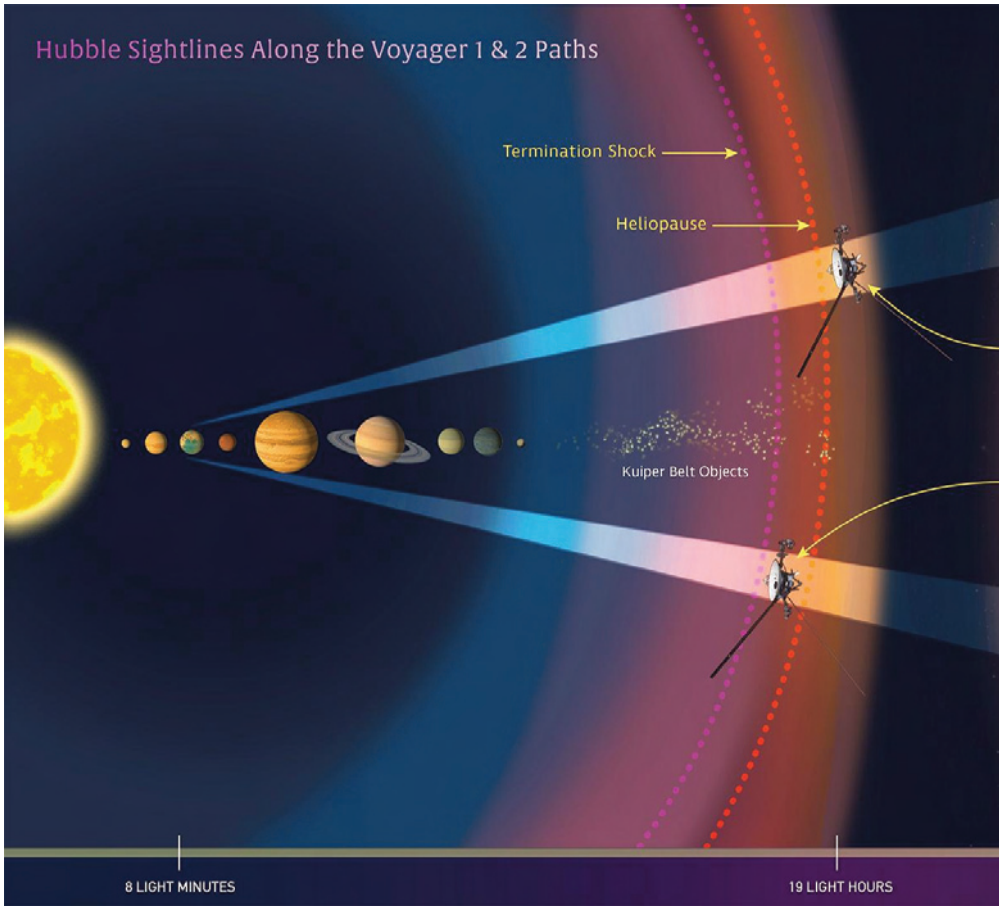
NASA's previous missions to asteroids began with the NEAR orbiter of asteroid Eros, which arrived in 2000. These missions are quite interesting, as each of them reveals another chapter in the history of our solar system. *"These are true missions of discovery that integrate into NASA's larger strategy of investigating how the solar system formed and evolved,"* says NASA's Planetary Science Director Jim Green. *"We've explored terrestrial planets, gas giants and a range of other bodies orbiting the Sun. Lucy will observe primitive remnants from farther out in the solar system, while Psyche will directly observe the interior of a planetary body. These additional pieces of the puzzle will help us to understand how the Sun and its family of planets formed, changed over time, and became places where life could develop and be sustained – and what the future may hold."* Yet another chapter in our history will be unveiled with missions Lucy and Psyche. Which mysteries of our past will be revealed in future missions? ■

Voyager 1 and 2: Hubble is providing the road map

by ESA/NASA

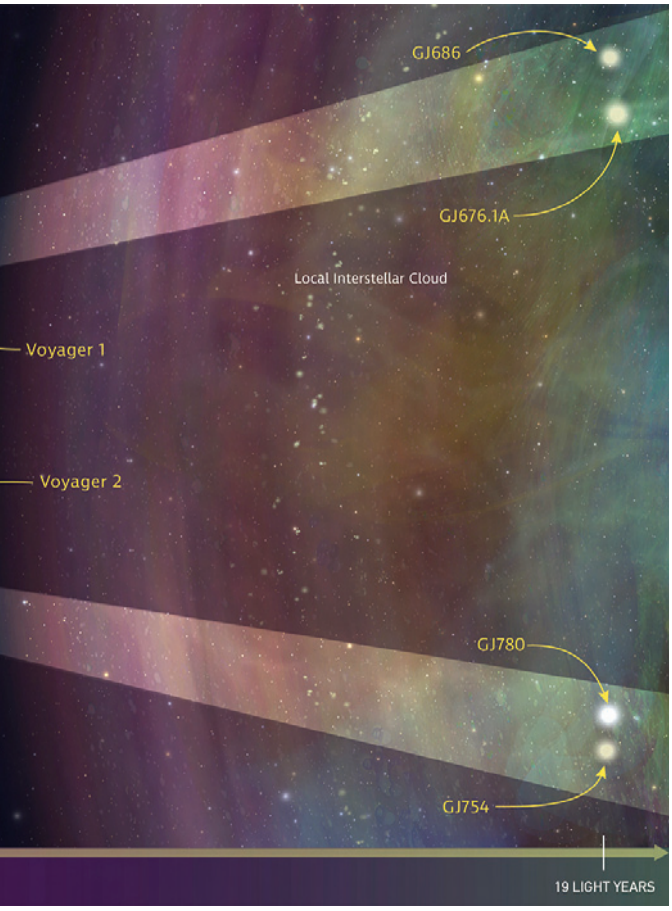
NASA's two Voyager spacecraft are hurtling through unexplored territory on their road trip beyond our solar system. Along the way, they are measuring the interstellar medium, the mysterious environment between stars. NASA's Hubble Space Telescope is providing the road map — by measuring the material along the probes' trajectories as they move through space. Even after the Voyagers run out of electrical power and are unable to send back new data, which may happen in about a decade, astronomers can use Hubble observations to characterize the environment through which these silent ambassadors will glide.

A preliminary analysis of the Hubble observations reveals a rich, complex interstellar ecology, containing multiple clouds of hydrogen laced with other elements. Hubble data, combined with the Voyagers, have also provided new insights into how our sun travels through interstellar space. *"This is a great opportunity to compare data from in situ measurements of the space environment by the Voyager spacecraft and telescopic measurements by Hubble,"* said study leader Seth Redfield of Wesleyan University in Middletown, Connecticut. *"The Voyagers are sam-*



In this illustration, NASA's Hubble Space Telescope is looking along the paths of NASA's Voyager 1 and 2 spacecraft as they journey through the solar system and into interstellar space. Hubble is gazing at two sight lines (the twin cone-shaped features) along each spacecraft's path. The telescope's goal is to help astronomers map interstellar structure along each spacecraft's star-bound route. Each sight line stretches several light-years to nearby stars. [NASA, ESA, and Z. Levy (STScI)]

pling tiny regions as they plow through space at roughly 38,000 miles per hour. But we have no idea if these small areas are typical or rare. The Hubble observations give us a broader view because the telescope is looking along a longer and wider path. So Hubble gives context to what each Voyager is passing through." The astronomers hope that the Hubble observations will help them characterize the physical properties of the local interstellar medium. *"Ideally, synthesizing these insights with in situ measurements from Voyagers would provide an unprecedented overview of the local interstellar environment,"* said Hubble team member Julia Zachary of Wesleyan University.



The team's results were presented Jan. 6 at the winter meeting of the American Astronomical Society in Grapevine, Texas.

NASA launched the twin Voyager 1 and 2 spacecraft in 1977. Both explored the outer planets Jupiter and Saturn. Voyager 2 went on to visit Uranus and Neptune.

The pioneering Voyager spacecraft are currently exploring the outermost edge of the Sun's domain.

Voyager 1 is now zooming through interstellar space, the region between the stars that is filled with gas, dust, and material recycled from dying stars. Voyager 1 is 13 billion miles from Earth, making it the farthest human-made object ever built. In about 40,000 years, after the spacecraft will no longer be operational and will not be able to gather new data, it will pass within 1.6 light-years of the star Gliese 445, in the constellation Camelopardalis. Its twin, Voyager 2, is 10.5 billion miles from Earth, and will pass 1.7 light-years from the star Ross 248 in about 40,000 years.

For the next 10 years, the Voyagers will be making measurements of interstellar material, magnetic fields, and cosmic rays along their trajectories. Hubble complements the Voyagers' observations by gazing at two sight lines along each spacecraft's path to map interstellar structure along their star-bound routes. Each sight line stretches several light-years to nearby stars.

Sampling the light from those stars, Hubble's Space Telescope Imaging Spectrograph measured how interstellar material absorbed some of the starlight, leaving telltale spectral fingerprints.

Hubble found that Voyager 2 will move out of the interstellar cloud that surrounds the solar system in a couple thousand years.

The astronomers, based on Hubble data, predict that the spacecraft will spend 90,000 years in a second cloud before passing into a third interstellar cloud.

An inventory of the clouds' composition reveals slight variations in the abundances of the chemical elements contained in the structures. *"These variations could mean the clouds formed in different ways, or from different areas, and then came together,"* Redfield said.

An initial look at the Hubble data also suggests that the Sun is passing through clumpier material in nearby space, which may affect the heliosphere, the large bubble containing our solar system that is produced by our sun's powerful wind.

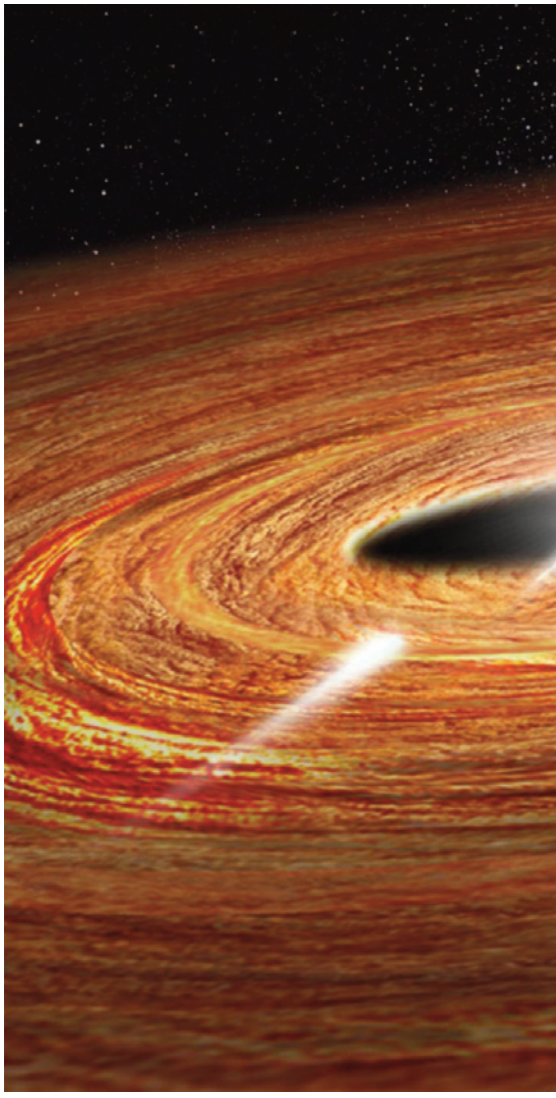
At its boundary, called the heliopause, the solar wind pushes outward against the interstellar medium. Hubble and Voyager 1 made measurements of the interstellar environment beyond this boundary, where the wind comes from stars other than our sun.

"I'm really intrigued by the interaction between stars and the interstellar environment," Redfield said. *"These kinds of interactions are happening around most stars, and it is a dynamic process."*

The heliosphere is compressed when the Sun moves through dense material, but it expands back out when the star passes through low-density matter.

This expansion and contraction is caused by the interaction between the outward pressure of the stellar wind, composed of a stream of charged particles, and the pressure of the interstellar material surrounding the star. ■

Comets are plunging into the star HD 172555



by ESA/NASA

Interstellar forecast for a nearby star: raining comets! NASA's Hubble Space Telescope has discovered comets plunging into the star HD 172555, which is a youthful 23 million years old and resides 95 light-years from Earth. The exocomets — comets outside our solar system — were not directly seen around the star, but their presence was inferred by detecting gas that is likely the vaporized remnants of their icy nuclei. HD 172555 represents the third extrasolar system where astronomers have detected doomed, wayward comets. All of these systems are young, under 40 million years old.

The presence of these doomed comets provides circumstantial evidence for "gravitational stirring" by an unseen Jupiter-size planet, where comets deflected by the massive object's gravity are catapulted into the star. These events also provide new insights into the past and present activity of comets in our solar system. It's a mechanism where infalling comets could have transported water to Earth and the other inner planets.

Astronomers have found similar plunges in our own solar system. Sun-grazing comets routinely fall into our star. *"Seeing these sun-grazing comets in our solar system and in three extrasolar systems means that this activity may be common in young star systems,"* said study leader Carol Grady of Eureka Scientific Inc., in Oakland, California, and NASA's Goddard Space Flight Center in Greenbelt, Maryland. *"This activity at its peak represents a star's active teenage years. Watching these events gives us insight into what probably went on in the early days of our solar system, when comets were pelting the inner solar system bodies, including Earth. In fact, these star-grazing comets may make life possible, because they carry water and other life-forming elements, such as carbon, to terrestrial planets."*

Grady presented her team's results Jan. 6 at the winter meeting of the American Astronomical Society in Grapevine, Texas.

The star is part of the Beta Pictoris Moving Group, a collection of stars born from the same stellar nursery. It is the second group member found to harbor such comets. Beta Pictoris, the group's namesake, also is feasting on exocomets travelling too close. A young gas-giant planet has been observed in that star's vast debris disk. The Beta Pictoris Moving Group is important to study because it is the closest collection of young stars to Earth. At least 37.5 percent of the more massive stars in the group either have a directly imaged planet, such as 51 Eridani b in the 51 Eridani system, or infalling star-grazing bodies, or, in the case of Beta Pictoris, both types of objects. The grouping is around the age where it should be building terrestrial planets, Grady said.

A team of French astronomers first discovered exocomets transiting HD 172555 in archival data gathered between 2004 and 2011 by the Euro-

pean Southern Observatory's HARPS (High Accuracy Radial velocity Planet Searcher) spectrograph. A spectrograph divides light into its component colors, allowing astronomers to detect an object's chemical makeup. The HARPS spectrograph detected the chemical fingerprints of calcium imprinted in the starlight, evidence that comet-like objects were falling into the star.

This illustration shows several comets speeding across a vast protoplanetary disk of gas and dust and heading straight for the youthful, central star. These "kamikaze" comets will eventually plunge into the star and vaporize. The comets are too small to photograph, but their gaseous spectral "fingerprints" on the star's light were detected by NASA's Hubble Space Telescope. The gravitational influence of a suspected Jupiter-sized planet in the foreground may have catapulted the comets into the star. This star, called HD 172555, represents the third extrasolar system where astronomers have detected doomed, wayward comets. The star resides 95 light-years from Earth. [NASA, ESA, and A. Feild and G. Bacon (STScI)]

As a follow-up to that discovery, Grady's team used Hubble's Space Telescope Imaging Spectrograph (STIS) and the Cosmic Origins Spectrograph (COS) in 2015 to conduct a spectrographic analysis in ultraviolet light, which allows Hubble to identify the signature of certain elements.

The telescope made two observations, separated by six days.

Hubble detected silicon and carbon gas in the starlight. The gas was moving at about 360,000 miles per hour across the face of the star.

The most likely explanation for the speedy gas is that Hubble is seeing material from comet-like objects that broke apart after streaking across the star's disk.

The gaseous debris from the disintegrating comets is vastly dispersed in front of the star. *"As transiting features go, this vaporized material is easy to see because it contains very large structures,"* Grady said. *"This is in marked contrast to trying to find a small, transiting exoplanet, where you're looking for tiny dips in the star's light."*

Hubble gleaned this information because the HD 172555 debris disk surrounding the star is viewed close to edge-on through the disk, giving the telescope a clear view of comet activity.

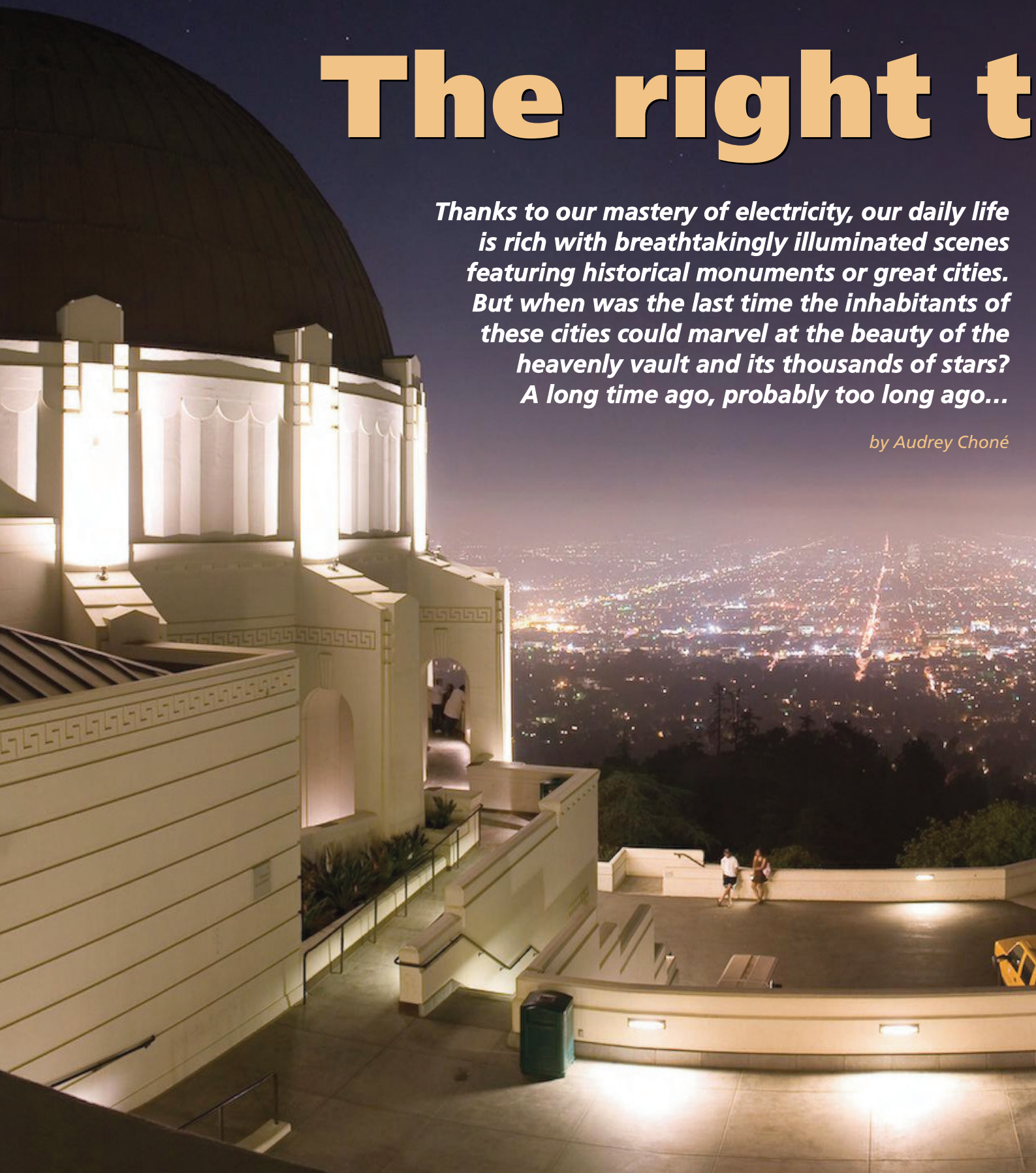
Grady's team hopes to use STIS again in follow-up observations to look for oxygen and hydrogen, which would confirm the identity of the disintegrating objects as comets.

"Hubble shows that these star-grazers look and move like comets, but until we determine their composition, we cannot confirm they are comets," Grady said. *"We need additional data to establish whether our star-grazers are icy like comets or more rocky like asteroids."* ■

The right t

Thanks to our mastery of electricity, our daily life is rich with breathtakingly illuminated scenes featuring historical monuments or great cities. But when was the last time the inhabitants of these cities could marvel at the beauty of the heavenly vault and its thousands of stars? A long time ago, probably too long ago...

by Audrey Choné

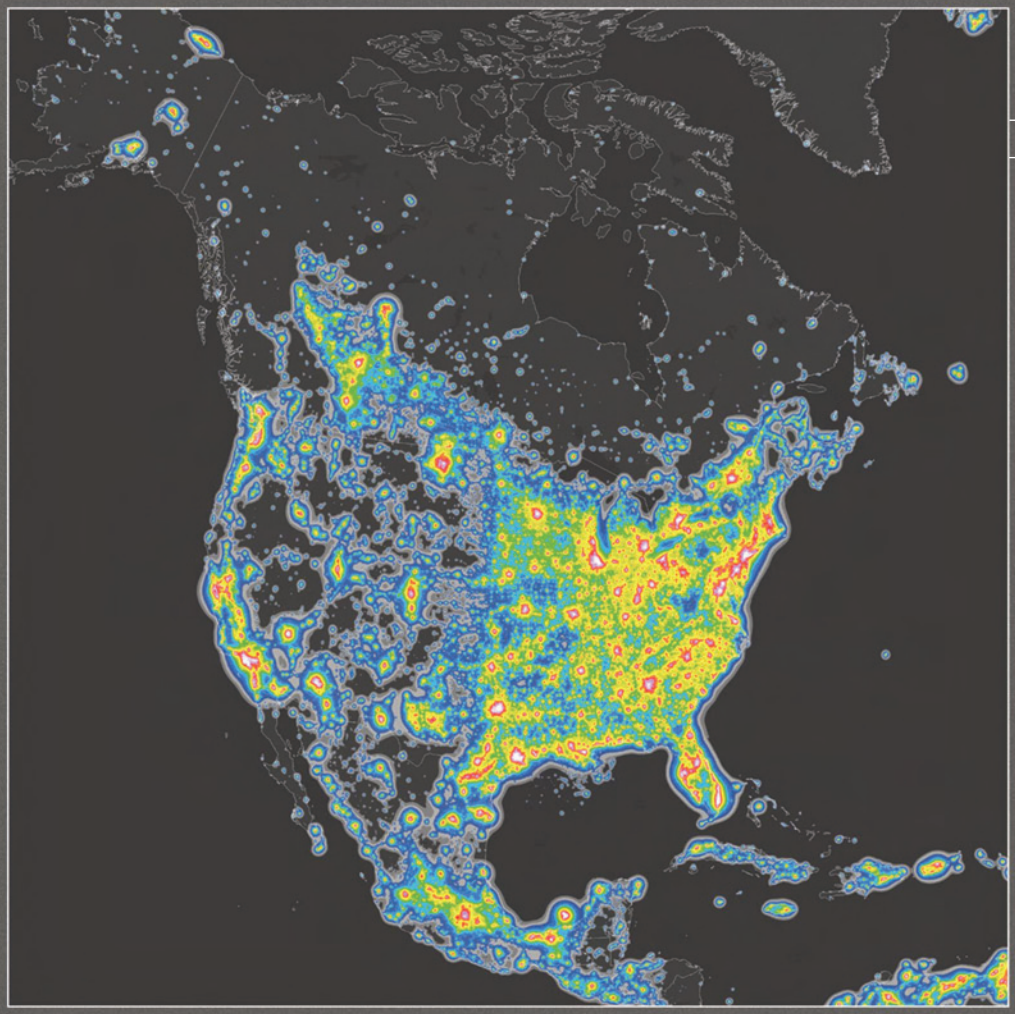


o a dark night

Light pollution in the skies of Los Angeles, as seen from the Griffith Observatory. Across the globe, light pollution is making the night sky increasingly lighter, snuffing out more and more stars.

The sky above has always inspired humanity. Many civilisations have relied on the motion of celestial objects, especially for agriculture and scientific research. Unfortunately, amateur astronomers in cities nowadays can barely see a few dozen stars with the naked eye, whereas a pitch-black night (far from developed areas, especially in the mountains) reveals around 3,000 points of light. In less than fifty years, mankind has made a starry sky an unattainable luxury for most people. How did this happen? Our mania for outdoor lighting has created a new kind of pollution: light pollution.

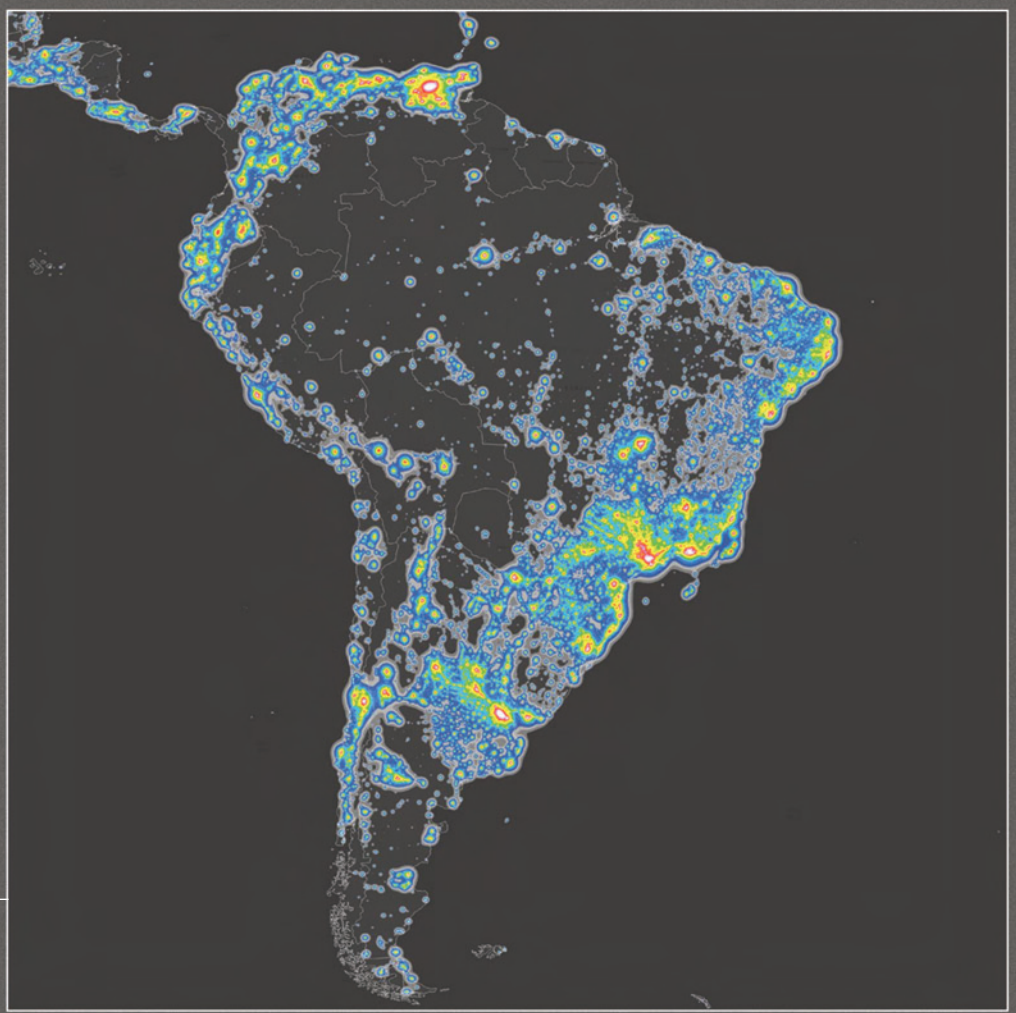
Life on Earth is based on a steady cycle of alternating day and night, respectively bringing light and warmth, then darkness and cold, to all organisms. Historically, humans were vulnerable in the dark. While some species are able to bear low temperatures thanks to fur and see perfectly in

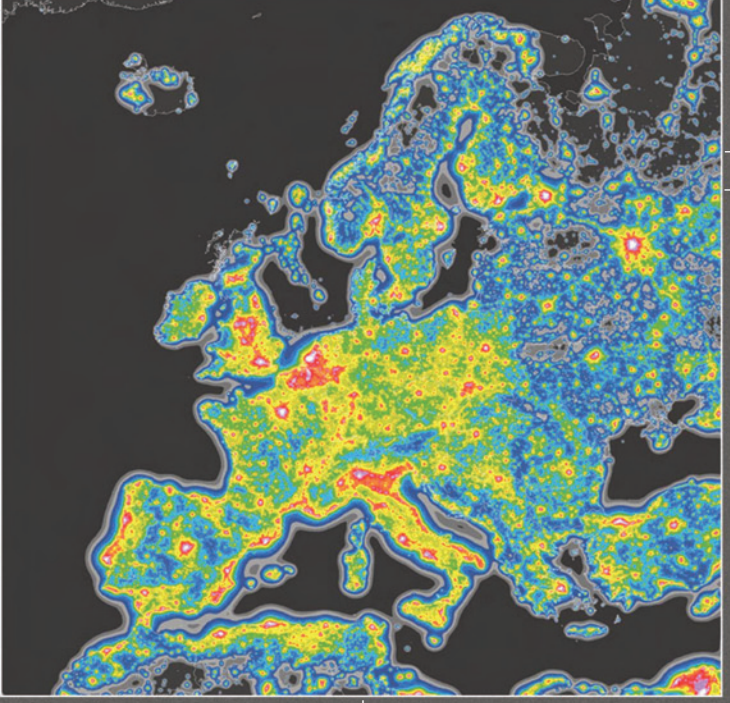


All these sources of light pollution add up, affecting not only the human ability to see starlight, but also the wildlife we share the planet with. Many species are nocturnal and take advantage of darkness to find food or move around. Insects, for example, use the position of the stars and the Moon to get their bearings. Public lighting bewilders them and attracts them hopelessly to those 'artificial moons' where they fly until exhausted — when they don't end up scorched on hot lightbulbs. These hecatombs impact all the insect species that play important roles in our ecosystem, whether for their position in the food chain, or their pollination activities. Migratory birds also suffer due to the dark thanks to an adapted eye structure that includes a reflecting membrane, cones and more photoreceptors, the human eye sees only shades of grey in the dark and is poor at detecting motion in dim light. The human eye does have cone cells that provide colour vision and the perception of movement in sunlight; our rod cells allow for some night vision and we have many of them, but they are only sensitive to differences in luminosity, and cannot detect motion and colours.

Our primitive sense of disadvantage at night led mankind to fight darkness with increasingly powerful and sophisticated lighting systems.

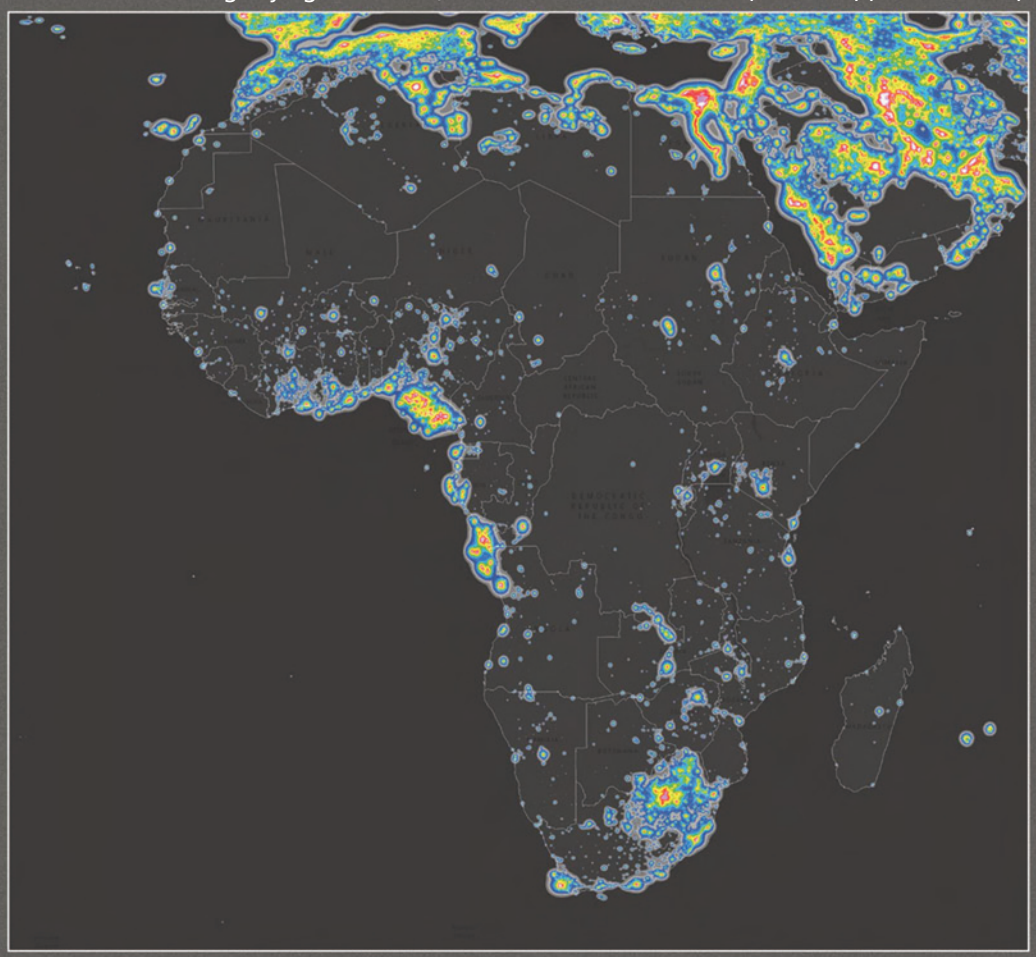
The explosion of night-time lighting isn't solely for citizen safety, however: prestige is boasted with spotlights on industrial facades, property protection is achieved with illumination of old buildings and profit is sought with advertisements and billboards.

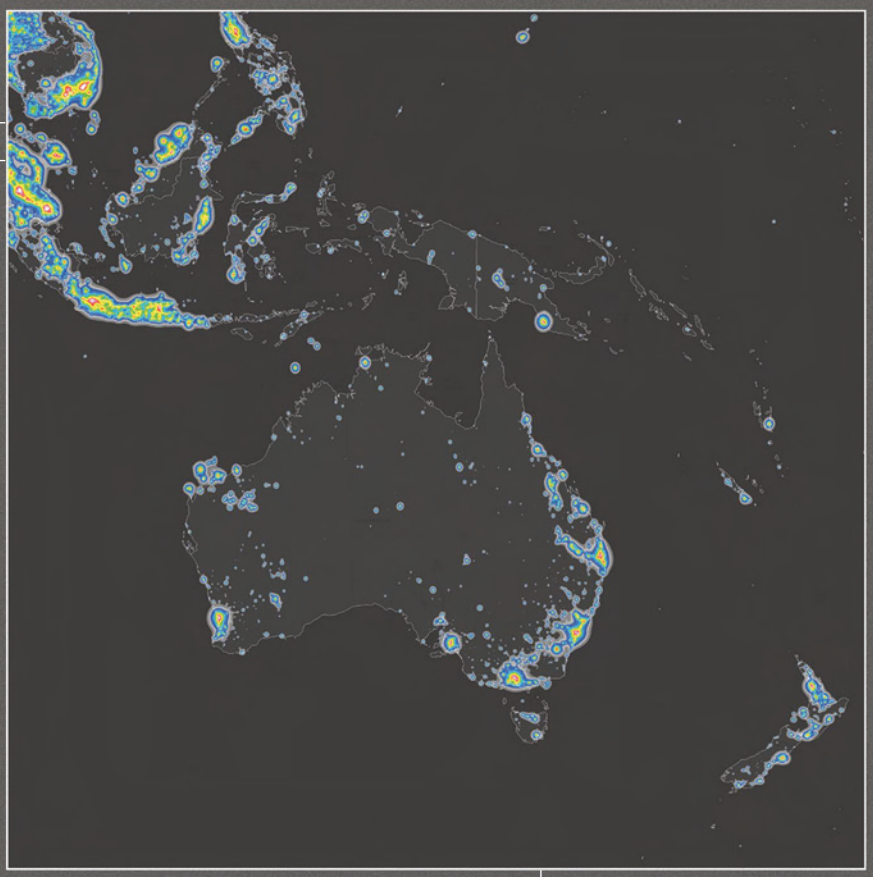




The maps on this page and the previous one show, in twofold increasing steps, the artificial brightness of the sky over the Americas, Europe and Africa as a ratio to the natural brightness of the sky, assumed to be 174 µcd/m² (1µ = 10^{-6} candelas). It's very easy to identify the most light-polluted regions as well as the darkest ones. [F. Falchi et al., Science Advances]

the ubiquity of outside lighting. Night is when they do most of their flying, and the light halos surrounding cities disorient them and can even lead them to crash into lighted buildings. Many mammals, too, are active at night and are particularly sensitive to light. An overexposure to artificial light dazzles their retinas and makes them vulnerable to various dangers (predation, collision with vehicles and so forth). As a consequence, these species are forced to avoid brightly lighted areas, further fragmenting their remaining habitat. Although humans are responsible for this plague of public lighting, we also have to bear its disadvantages, such as its impact on the quality of our slumber. Indeed, since aesthetic criteria frequently win over practicality in the design of lighting systems, the façades of inhabited buildings are often over-illuminated. The residents then must close their shutters to achieve darkness, obviously degrading their quality of sleep on hot summer nights. In addition to this discomfort, many studies have shown that an excess of nocturnal light has a negative influence on our moods and even our physical health. The argument used most often to justify adding new outside lighting is security, both on the road and at home. Street lamps are supposed to help





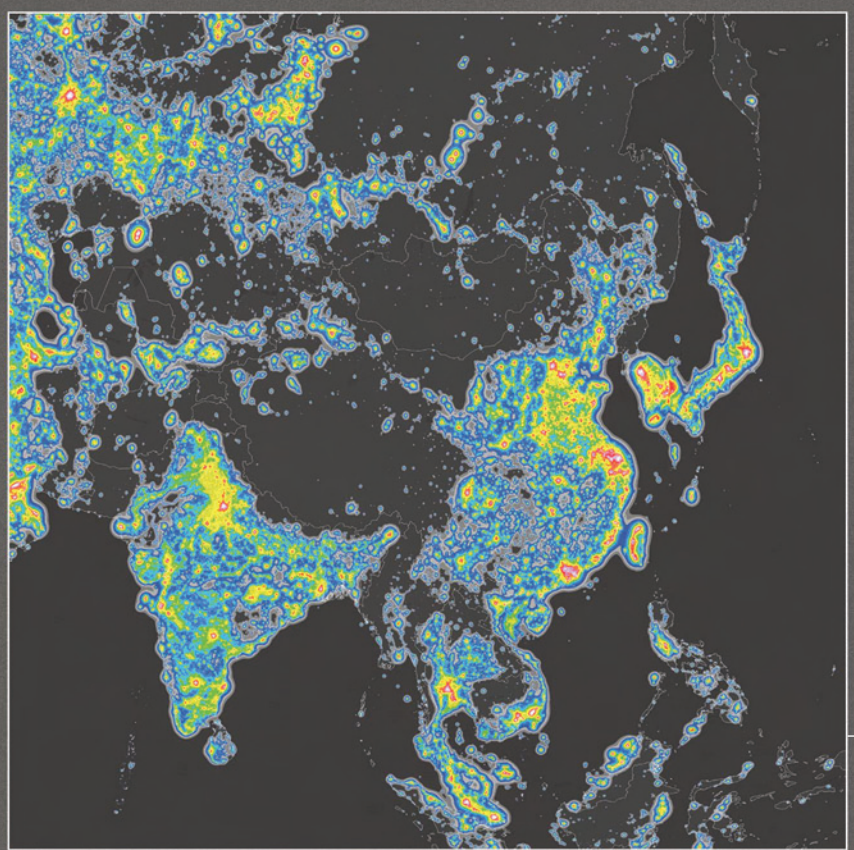
drivers see farther and better. Unfortunately, drivers tend to drive faster along a well-lighted street despite the risk, whereas more shadowy portions of road inspire slower, more conservative driving behaviour. As far as home security goes, statistics show that 80% of burglaries take place in full daylight, between 2 and 4 pm, and no correlation has been proven between crime and an absence of public lighting.

Several solutions could allow us to see the Milky Way again, without requiring us to switch off all outside light sources.

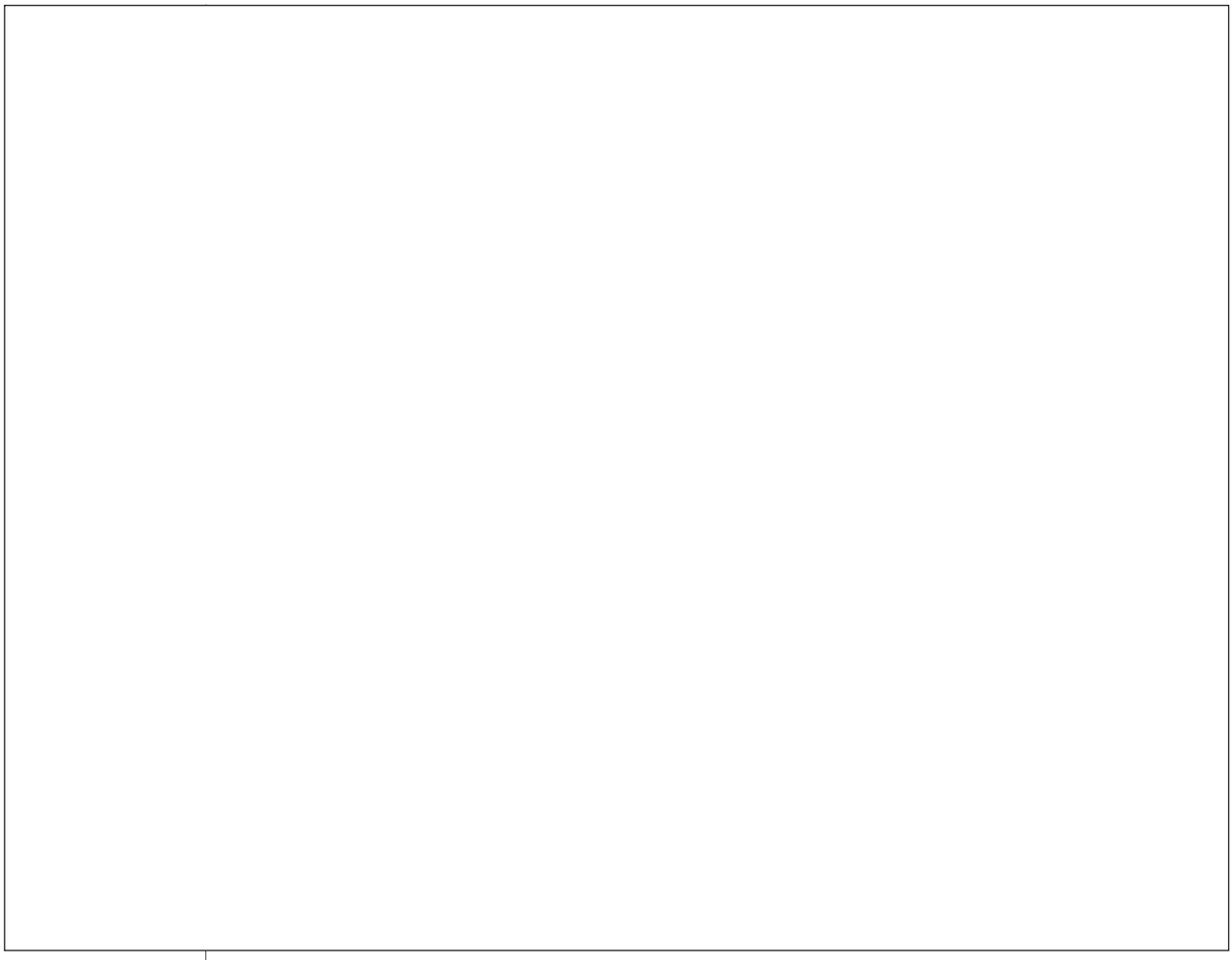
One first step would be to cut down on superfluous lighting like spotlights on public buildings or billboards. These specific sources are the main cause of light pollution, since they are aimed upward and reinforce the light halo effect over cities. In addition, the colour of light emitted outside is important. White or blue tints (often given off by LED technology), produce a blinding glare, muddling both human and animal vision. These colours should be avoided entirely in favour of more yellow lights, which are less dazzling (and are also available in energy-efficient LED form).

Eventually, all outside lighting systems should be designed to shine downward, to illuminate the ground and not the skies. All these solutions would allow a reduction of the light halo over cities and towns as well as a limit on squandering energy and consequently money for the communities adopting them.

In France, the Association Nationale pour la Protection du Ciel et de l'Environnement Nocturnes [National Association to Protect the Sky and Environment] (ANPCEN) holds a national competition to recognise towns trying to limit or eradicate light pollution for the sake of the well-being of the population and the preservation of the nocturnal environment and the night sky. The small city of Latrape, south of Toulouse, was labelled Starry Village of France after participating in the competition, promoted by its astronomy club, Les Pleïades. "*We triggered this initiative, which goes along* [with] *our environmental efforts, and is indispensable for the future of our hobby, and the well-being of all*", explains Jacques Sanchez, the group's



Light pollution in Asia and Oceania. Technical data are as shown on the previous maps. [F. Falchi et al., Science Advances]



This amazing video clearly demonstrates how light pollution changes the way we see the night sky. [Sriram Murali]

president. Moreover, a town that receives this award sets an example and can incite other municipalities to follow suit. *"Since then, nearby villages switch off their night lightings. Non-essential streetlamps are not repaired if they stop working. We distributed articles on lighting to inhabitants, and always put forward this label"*, explains Mr Sanchez.

A town winning the prize should not rest on its laurels: the label is awarded for 5 years, after which renewal is only granted if recommended measures have been implemented: improving the lighting networks, setting up automatic shut-offs at night or installing motion detectors to enable smart lighting. Even if the visibility gained is merely local, these actions raise awareness of light pollution. During its 229th meeting (3-7 January 2017), the American Astronomical Society stated that accessing a starry sky is a universal right, and encouraged municipalities to make outside lights more respectful of the environment. Removing unnecessary lights, replacing white and blue tinted streetlights and adapting light intensity to need are some of the actions that communities should take. On a more global scale, anyone can contact the International Dark-Sky Association, which will put every person concerned about the nocturnal environment in contact with their closest association…for the night is dark and full of wonders. ■

Astronomers see a huge shadow around TW Hydrae

by ESA/NASA

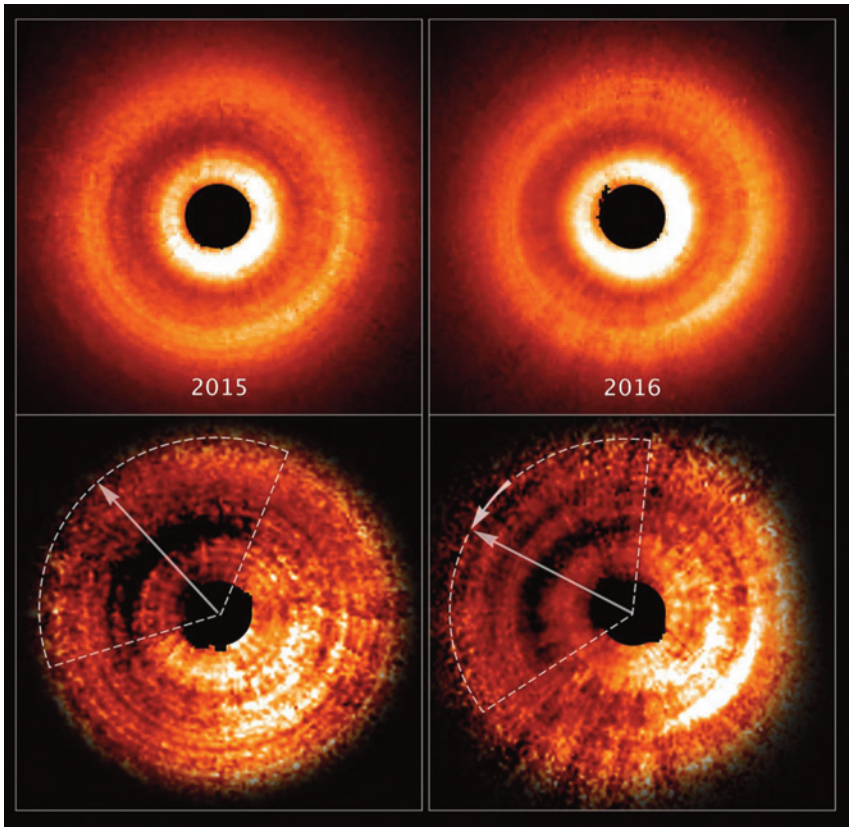
Searching for planets around other stars is a tricky business. They're so small and faint that it's hard to spot them. But a possible planet in a nearby stellar system may be betraying its presence in a unique way: by a shadow that is sweeping across the face of a vast pancake-shaped gas-and-dust disk surrounding a young star.

The planet itself is not casting the shadow. But it is doing some heavy lifting by gravitationally pulling on material near the star and warping the inner part of the disk.

The twisted, misaligned inner disk is casting its shadow across the surface of the outer disk.

A team of astronomers led by John Debes of the Space Telescope Science Institute in Baltimore, Maryland, say this scenario is the most plausible explanation for the shadow they spotted in the stellar system TW Hydrae, located 192 light-years away in the constellation Hydra, also known as the Female Water Snake.

The star is roughly 8 million years old and slightly less massive than our sun. The researchers uncovered the phenomenon while analyzing 18 years' worth of archival observations taken by NASA's Hubble Space Telescope. *"This is the very first disk where we have so many images over such a long period of time, there-*



These images, taken a year apart by NASA's Hubble Space Telescope, reveal a shadow moving counterclockwise around a gas-and-dust disk encircling the young star TW Hydrae. The two images at the top, taken by the Space Telescope Imaging Spectrograph, show an uneven brightness across the disk. Through enhanced image processing (images at bottom), the darkening becomes even more apparent. These enhanced images allowed astronomers to determine the reason for the changes in brightness. The dimmer areas of the disk, at top left, are caused by a shadow spreading across the outer disk. The dotted lines approximate the shadow's coverage. The long arrows show how far the shadow has moved in a year (from 2015-2016), which is roughly 20 degrees. [NASA, ESA, and J. Debes (STScI)]

fore allowing us to see this interesting effect," Debes said. *"That gives us hope that this shadow phenomenon may be fairly common in young stellar systems."*

Debes presented his team's results Jan. 7 at the winter meeting of the American Astronomical Society in Grapevine, Texas.

Debes' first clue to the phenomenon was a brightness in the disk that changed with position. Astronomers using Hubble's Space Telescope Imaging Spectrograph (STIS) first noted this brightness asymmetry in 2005.

But they had only one set of observations, and could not make a definitive determination about the nature of the mystery feature. Searching the archive, Debes' team put together six images from several different epochs.

The observations were made by STIS and by Hubble's Near Infrared Camera and Multi-Object Spectrometer (NICMOS).

STIS is equipped with a coronagraph that blocks starlight to within about 1 billion miles from the star, allowing Hubble to look as close to the star as Saturn is to our sun. Over time, the structure appeared to move in counterclockwise fashion around the disk, until, in 2016, it was in the same position as it was in images taken in 2000.

This 16-year period puzzled the researchers. They originally thought the feature was part of the disk, but the short period meant that the feature was moving way too fast to be physically in the disk.

Under the laws of gravity, disks rotate at glacial speeds. The outermost parts of the TW Hydrae disk would take centuries to complete one rotation.

This simulation shows a shadow sweeping around a gas-and-dust disk encircling the young star TW Hydrae. The simulated view is based on an analysis of data taken between 1998 and 2016 by NASA's Hubble Space Telescope. This video also shows what the moving shadow might look like in the future as it continues its journey around the disk. The shadow completes a revolution every 16 years. Astronomers think that an unseen planet in the disk is gravitationally pulling on material near the star and warping the inner part of the disk. The twisted, misaligned inner disk is casting its shadow across the surface of the outer disk. [NASA, ESA, and J. Debes (STScI)]

"The fact that I saw the same motion over 10 billion miles from the star was pretty significant, and told me that I was seeing something that was imprinted on the outer disk rather than something that was happening directly in the disk itself," Debes said. *"The best explanation is that the feature is a shadow moving across the surface of the disk."*

The research team concluded that whatever was making the shadow must be deep inside the 41-billion-mile-wide disk, so close to the star it cannot be imaged by Hubble or any other present-day telescope. The most likely way to create a shadow is to have an inner disk that is tilted relative to the outer disk. In fact, submillimeter observations of TW Hydrae by the Atacama Large Millimeter Array (ALMA) in Chile suggested a possible warp in the inner disk. But what causes disks to warp? *"The most plausible scenario is the gravitational influence of an unseen planet, which is pulling material out of the plane of the disk and twisting the inner disk,"* Debes explained. *"The misaligned disk is inside the planet's orbit."*

Given the relatively short 16-year period of the clocklike moving shadow, the planet is estimated to be about 100 million miles from the star — about as close as Earth is from the Sun. The planet would be roughly the size of Jupiter to have enough gravity to pull the material up out of the plane of the main disk. The planet's gravitational pull causes the disk to wobble, or precess, around the star, giving the shadow its 16-year rotational period.

Recent observations of TW Hydrae by ALMA add credence to the presence of a planet. ALMA revealed a gap in the disk roughly 9 million miles from TW Hydrae. A gap is significant, because it could be the signature of an unseen planet clearing away a path in the disk. This new Hubble study offers a unique way to look for planets hiding in the inner part of the disk and probe what is happening very close to the star, which is not reachable in direct imaging by current telescopes.

"What is surprising is that we can learn something about an unseen part of the disk by studying the disk's outer region and by measuring the motion, location, and behavior of a shadow," Debes said. *"This study shows us that even these large disks, whose inner regions are unobservable, are still dynamic, or changing in detectable ways which we didn't imagine."* ■

Keck Observatory will peer deep into the cosmic web

by Keck Observatory

Above, the Keck Cosmic Web Imager (KCWI) is traveling to the Keck Observatory. Left, W.M. Keck team in front of KCWI.

Keck Observatory is pushing the cutting edge of scientific discovery with the addition of the world's most sensitive instrument for measuring the tendrils of faint gas in the intergalactic medium known as the cosmic web. The 5-ton instrument, the size of an ice cream truck, is named the Keck Cosmic Web Imager (KCWI). KCWI will uncover vital clues about the life-cycle of galaxies, helping to unravel mysteries about our universe.

Physics professor, Christopher Martin, and his team at Caltech, in collaboration with Keck Observatory, University of California Santa Cruz and industrial partners, designed and built the spectrograph to study the cosmic web in unprecedented detail. KCWI will enable astronomers to study many other exceedingly faint objects in the universe as well.

"For decades, astronomers have demonstrated that galaxies evolve. Now, we're trying to figure out how and why," says Martin, describing the potential of this instrument. *"We know the gas around galaxies is ultimately fueling them, but it is*

Below and right, KCWI on Maunakea summit. [W. M. Keck Obs.]

so faint, we still haven't been able to get a close look at it and understand how this process works."

The design of KCWI is based on its predecessor, the Palomar Cosmic Web Imager. KCWI will be installed on one of the twin 10-meter Keck Observatory telescopes, the largest optical/infrared telescopes in the world. The telescopes' location on Maunakea provides the most pristine viewing conditions in the world for this science. This unbeatable combination of technology and location will enable KCWI to provide some of the most-detailed glimpses of the universe ever, including the study of gas jets around young stars, the winds of dead stars and even supermassive black holes.

"The best location in the world for astronomy calls for the best tools for astronomy," said Hilton Lewis, director of the Keck Observatory. *"With KCWI on the world's largest telescope, we are well positioned to develop our understanding of the evolution of galaxies by capturing high-resolution spectra of some of the faintest, most difficult to study objects in the universe in ways never before possible."* KCWI arrived by ship from Los Angeles on January 20 and was carefully transported up to the observatory atop Maunakea. The instrument will be installed and tested, followed by the first observations in the coming months. ■

"Mars is there, to be reached"

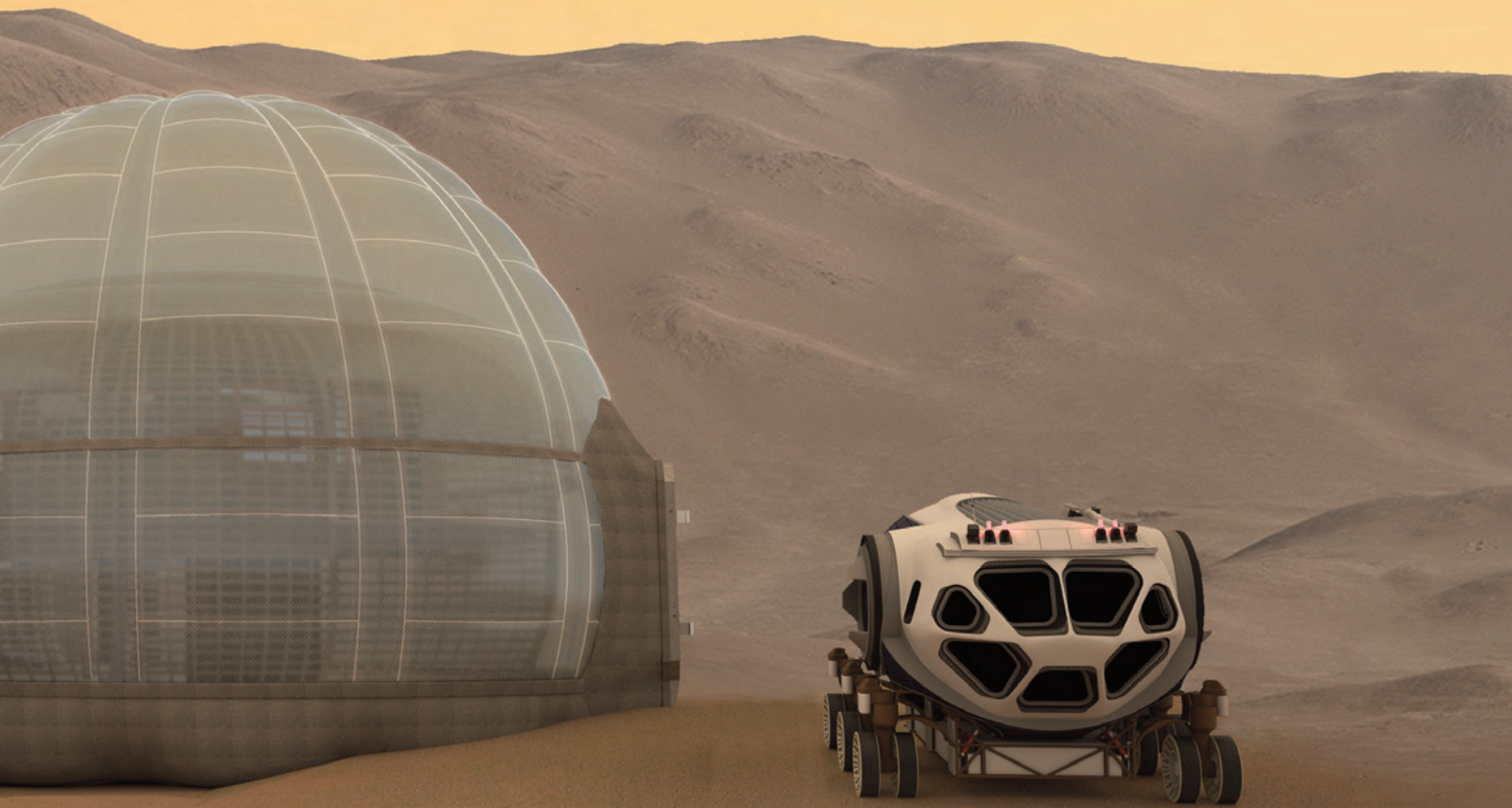
by Krishna Bharadwaj

It drifts aimlessly in the vast cosmic ocean, patiently waiting for an intelligent species to make an appearance. At about 225 million km from the Sun, Mars is a lifeless, arid, dusty landscape, with its russet soil giving it the nickname 'the Red Planet'. Though colonising Mars is a distant idea, it is entirely possible. The concept of ice homes brings this dream of colonisation a step closer to reality.

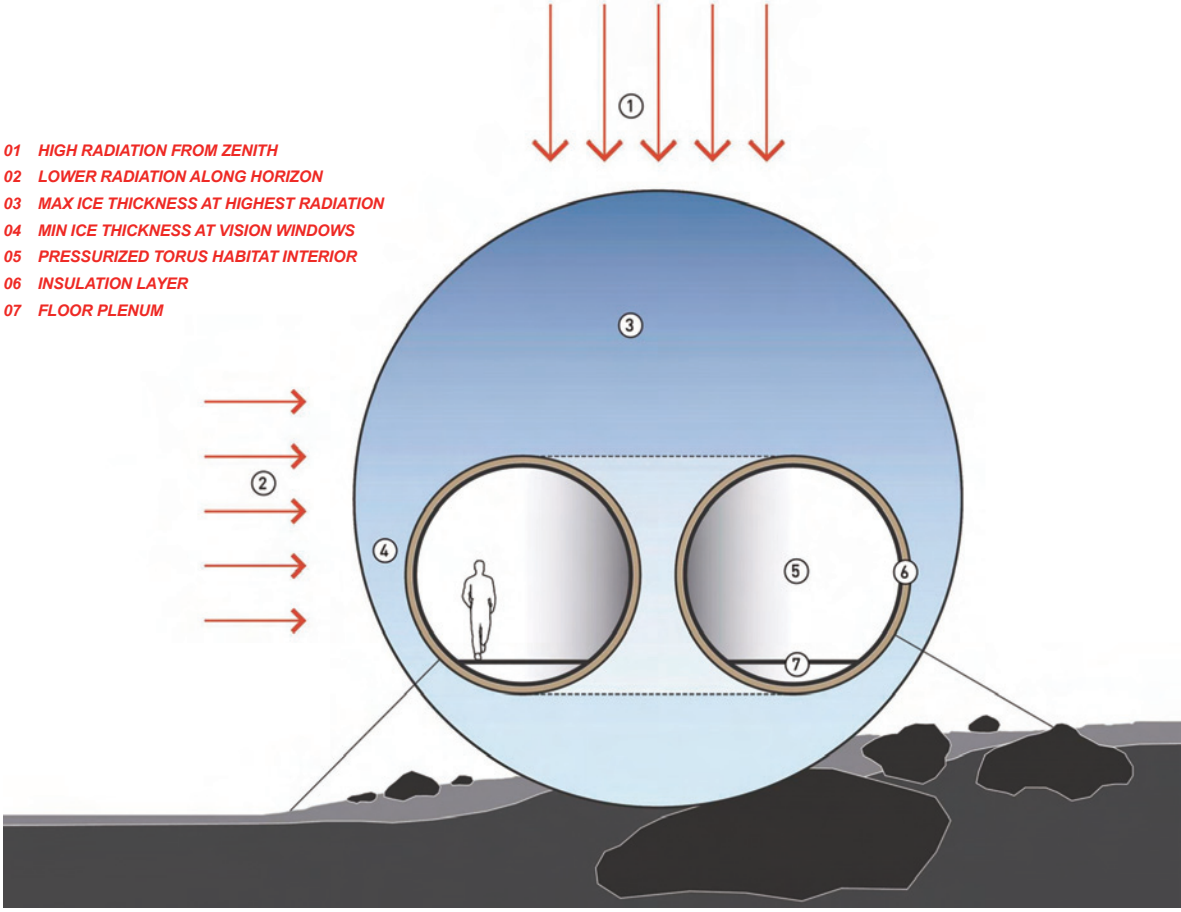
An artist's rendering of the Mars Ice Home concept developed by Clouds AO along with NASA's Langley Research Center and a team of experts. The Mars Ice Home will be a component of a human Mars outpost. [NASA, Clouds AO, SEArch]

waiting

Buzz Aldrin

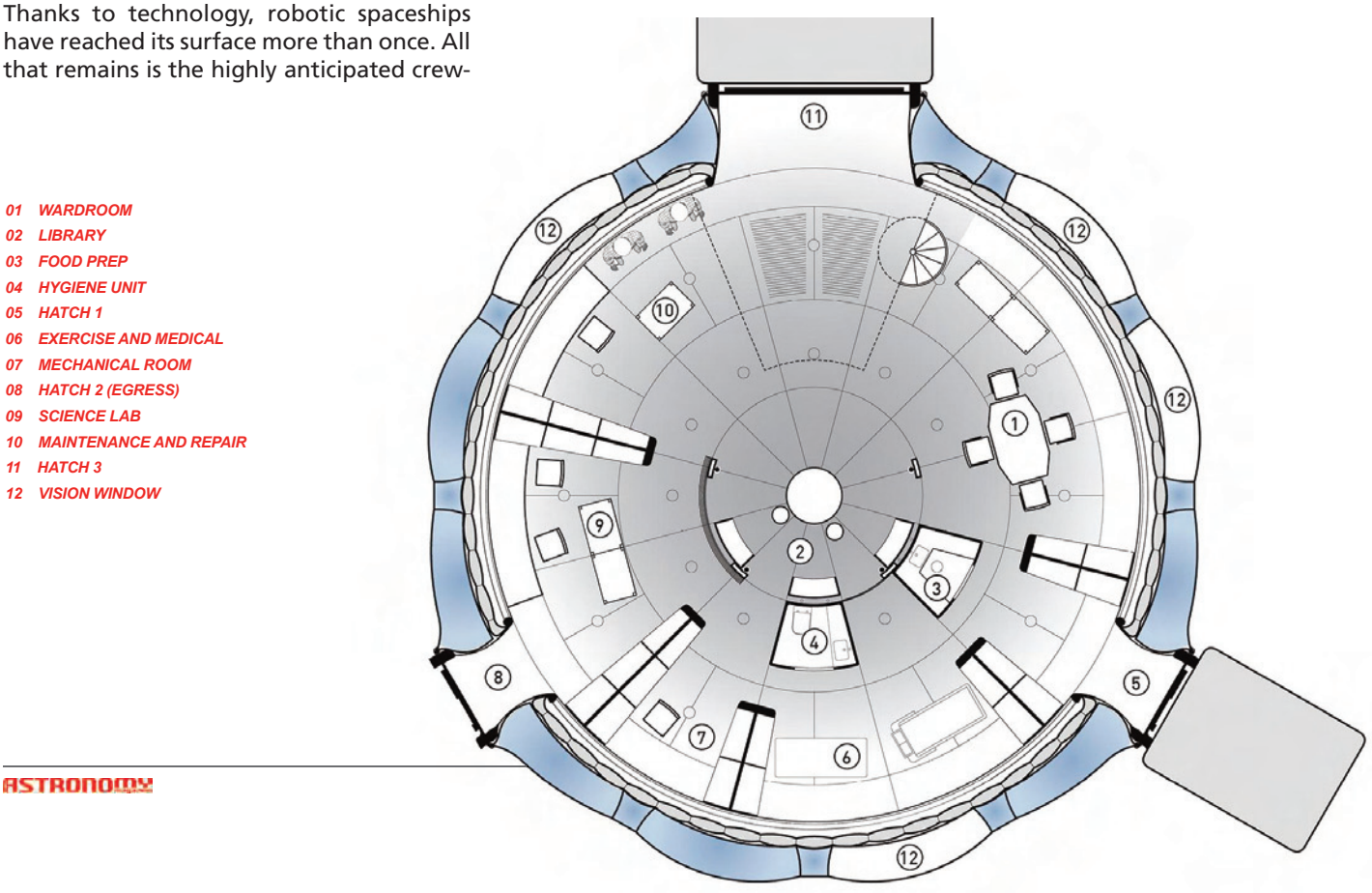


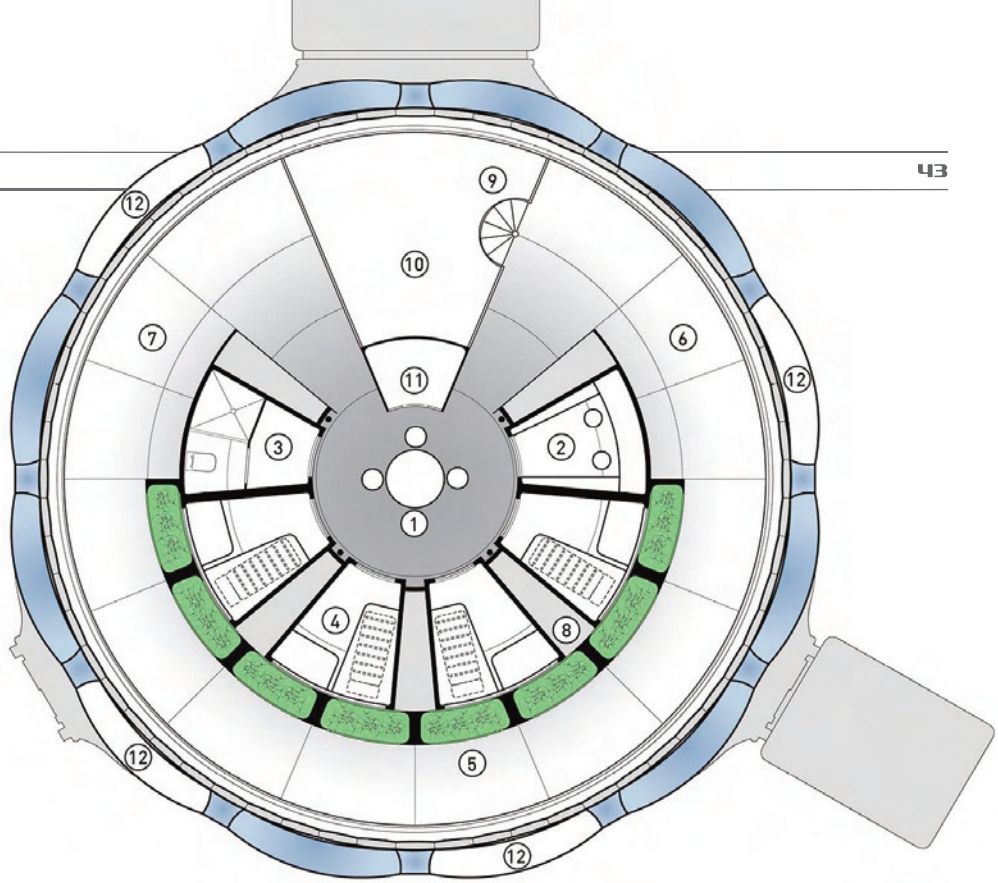
"All civilizations either become spacefaring or extinct." As Carl Sagan noted, it is something of a necessity for our species to venture into space in search of new worlds if it is to survive, thrive and leave its mark on the cosmos. As a species stuck on a ball hovering around a medium-sized star, we are very lucky to have had the opportunity to be alive at a time when we have a basic understanding of the Universe's complexities. Our existence is negligible when compared to the grand existence of the Universe. Nevertheless,



thanks to our stubborn will, we have come a long way from being hunter-gatherer nomads.
We have made more progress in engineering and technology in the past 200 years than we had in the previous 2000 years. We have set foot on the Moon, sent unmanned spaceships to neighbouring planets and done much more. Of all the planets in our Solar System, the one that captures our interest the most is definitely Mars. As the fourth planet from the Sun, Mars has favourable conditions for potentially supporting life. It's not surprising that it continues to captivate our imagination and spur unending curiosity. Since the dawn of space science, humanity has wanted to set foot on the Red Planet.
Thanks to technology, robotic spaceships have reached its surface more than once. All that remains is the highly anticipated crewed mission. To make such a mission possible, astronauts would need a habitat much like that of Earth.
Mars, with its thin atmosphere, lacks adequate oxygen and other elements critical for human survival. Mars is also constantly bombarded with harmful radiation, which enters

The drawings on this page and the following one illustrate the internal structure of the Mars Ice Home. [NASA, Clouds AO, SEArch]



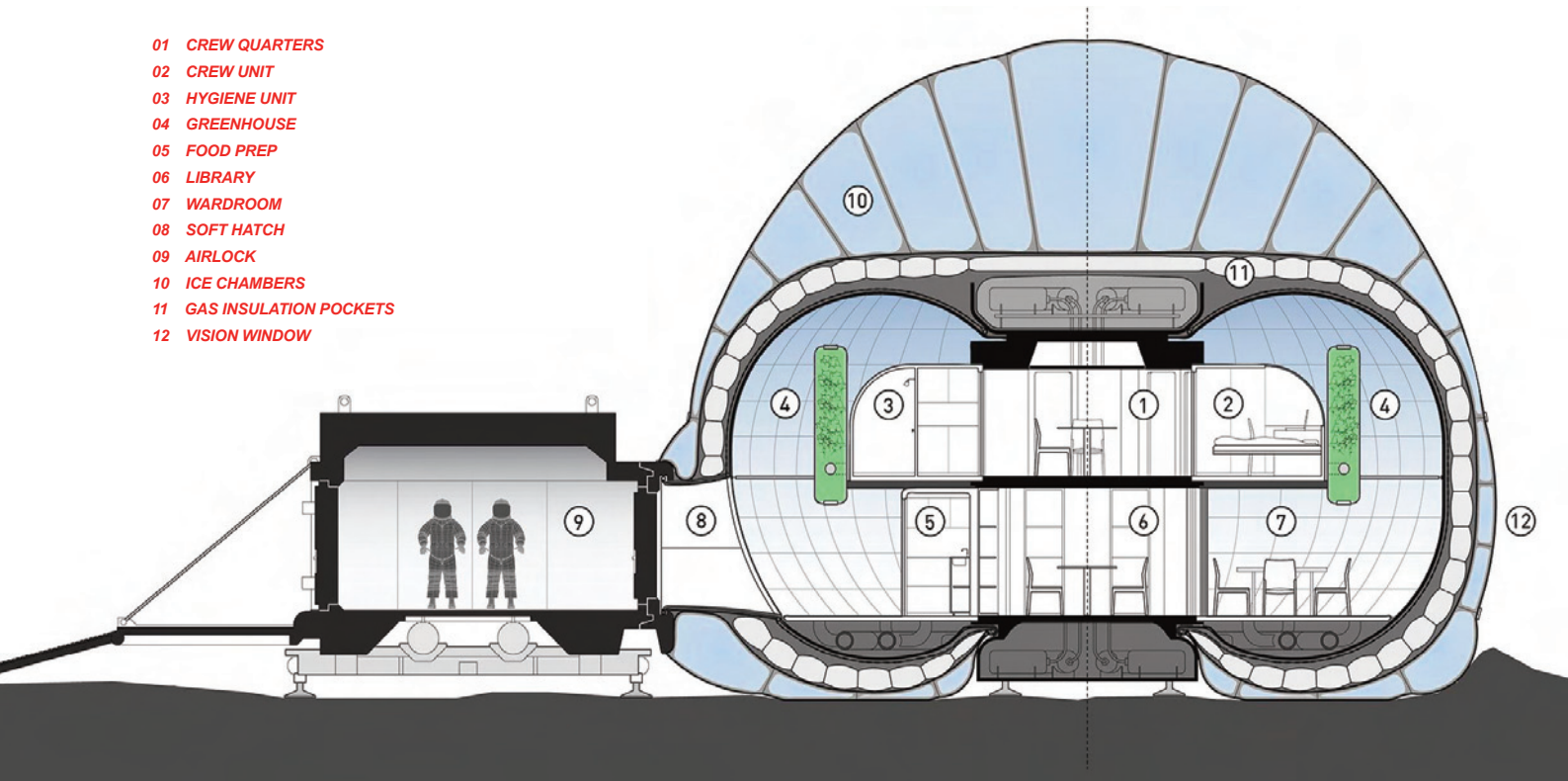


01 CREW QUARTERS
02 STUDY
03 HYGIENE UNIT
04 CREW UNIT
05 GREENHOUSE
06 STORAGE
07 STORAGE
08 MECHANICAL
09 STAIR
10 OPEN TO BELOW
11 STORAGE
12 VISION WINDOW

its atmosphere almost unfiltered. If astronauts are to set foot on the Red Planet, they will need protection from this radiation and other dangers.

Researchers at NASA's Langley Research Center in Hampton, Virginia, have come up with an idea for building homes with ice, which they believe will filter out harmful radiation and protect astronauts from extreme temperatures. *"After a day dedicated to identifying needs, goals, and constraints, we rapidly assessed many crazy, outside-the-box ideas and finally converged on the current Ice Home design, which provides a sound engineering solution"*, says Langley's senior system engineer, Kevin Vipavetz. The idea is to build a torus-shaped inflatable tube that can be filled with water.

01 CREW QUARTERS
02 CREW UNIT
03 HYGIENE UNIT
04 GREENHOUSE
05 FOOD PREP
06 LIBRARY
07 WARDROOM
08 SOFT HATCH
09 AIRLOCK
10 ICE CHAMBERS
11 GAS INSULATION POCKETS
12 VISION WINDOW

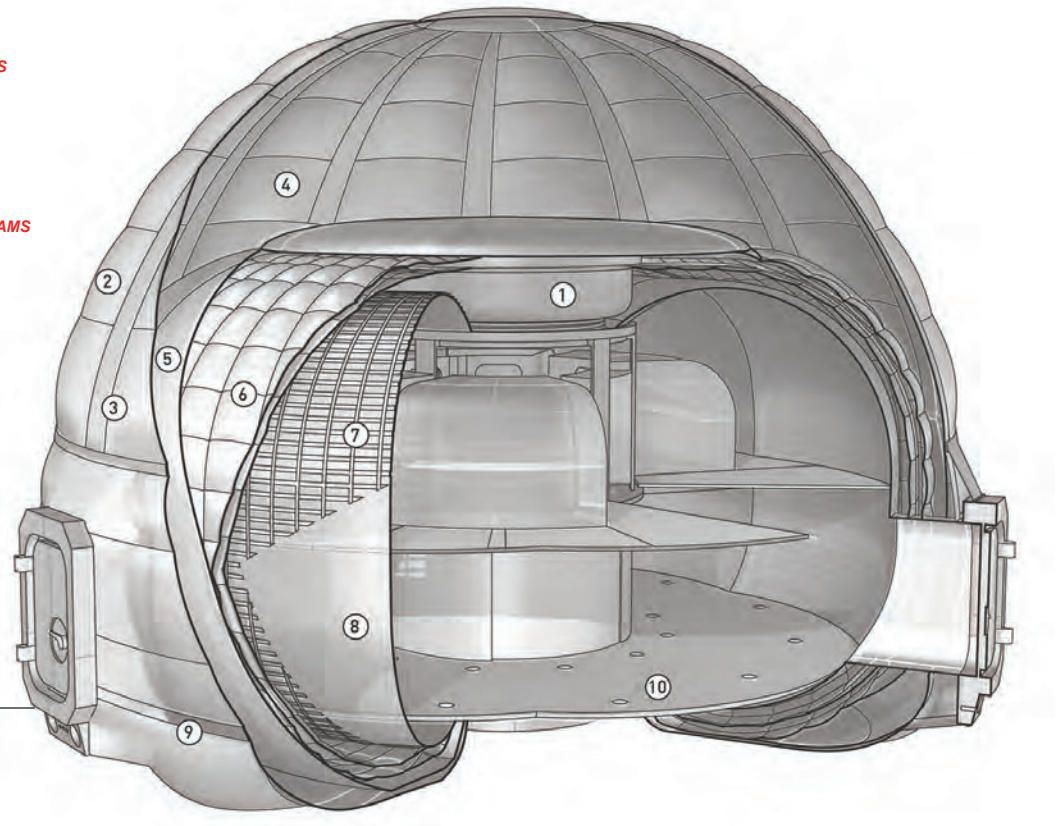


The main advantage of this kind of construction is that it is lightweight and doesn't require complex operations.
Its lightness also facilitates conveyance by robots, avoiding most of the difficulty that transportation presents.
The empty, inflatable part can be filled completely with water before the crew arrives. Water, being hydrogen rich, provides effective shielding from harmful cosmic rays.
We have long known that the Red Planet hosts abundant ice deep beneath its surface, which provides the materials required for construction.
Another advantage of such a building is that the stored water can be converted and used as rocket fuel. The thick layer of ice above the dwelling, besides filtering harmful radiation, allows visible light to pass through relatively unaffected.

Team members with the Ice Home Feasibility Study discuss past and current technology development efforts for inflatable structures at NASA's Langley Research Center. [Courtesy of Kevin Kempton] Below, the outermost layers of the Mars Ice Home. [NASA, Clouds AO, SEArch]

"The materials that make up the Ice Home will have to withstand many years of use in the harsh Martian environment, including ultraviolet radiation, charged-particle radiation, perchlorates, as well as dust storms — although not as fierce as in the movie 'The Martian'," says Langley researcher Sheila Ann Thibeault. Implementing the design concept for the Ice Home re-

01 WATER BLADDER
02 OUTER LAYER: BETA CLOTH
03 STRUCTURAL VERTICAL SEAMS
04 ICE CHAMBER LAYER
05 MYLAR INTERLAYER
06 CO2 INSULATION POCKETS
07 RESTRAINT LAYER
08 BLADDER AND SCUFF LAYERS
09 STRUCTURAL HORIZONTAL SEAMS
10 HVAC CONCEALED IN FLOOR



Translucent ice is the key design element of the Mars Ice Home. It allows natural light to permeate the habitat interior, keeping occupants connected to the diurnal cycles that affect human biorhythms; transparent windows allow views of the surrounding landscape. [NASA, Clouds AO, SEArch]

quires a critical assessment of the materials available on Mars, which is quite difficult considering the limitations of our current technology. Studying the availability of water resources on Mars is crucial, as a significant quantity of water is required to perform the construction. Experts who develop resource extraction systems believe that the habitats could be filled in about 400 Earth days if the water flow rate is about 35.3 cubic feet (or 1 cubic meter) per day. The construction is flexible enough to incorporate additional design considerations such as a work space where crews can service parts for robots and machinery without needing pressure suits. The design uses a layer of CO_2 as insulation between the living space and the thick layer of ice, which will also moderate the temperature. Moreover, as Mars boasts an abundance of CO_2, the demand is easily met.

This kind of building, in addition to providing protection, can act as a storage unit for fuel, which makes it very efficient.

Another approach, however, considered underground construction of habitats.

This method would require the dwellings to be set up before the crew arrives, which would necessitate heavy-duty robots and machinery for transportation. This concept, though it provides effective radiation shielding, would be very complex in practice. The 'ice home' concept clearly is the preferred choice, as it doesn't require underground construction, eliminating the need for heavy robots and machinery and thus reducing the cost tremendously. Reaching Mars is definitely not an impossible feat, though very challenging. The day is not very far off when astronauts will first set foot on the Red Planet, but before they do, there must be adequate preparation of a living space. ■

Ultracool dwarf and the seven planets

by ESO

Astronomers using the TRAPPIST–South telescope at ESO's La Silla Observatory, the Very Large Telescope (VLT) at Paranal and the NASA Spitzer Space Telescope, as well as other telescopes around the world, have now confirmed the existence of at least seven small planets orbiting the cool red dwarf star TRAPPIST-1. All the planets, labelled TRAPPIST-1b, c, d, e, f, g and h in order of increasing distance from their parent star, have sizes similar to Earth.

Dips in the star's light output caused by each of the seven planets passing in front of it — events known as transits — allowed the astronomers to infer information about their sizes, compositions and orbits. They found that at least the inner six planets are comparable in both size and temperature to the Earth.

Lead author Michaël Gillon of the STAR Institute at the University of Liège in Belgium is delighted by the findings: *"This is an amazing planetary system — not only because we have found so many planets, but because they are all surprisingly*

This artist's impression shows the view from the surface of one of the planets in the TRAPPIST-1 system. At least seven planets orbit this ultra cool dwarf star 40 light-years from Earth and they are all roughly the same size as the Earth. They are at the right distances from their star for liquid water to exist on the surfaces of several of them. This artist's impression is based on the known physical parameters for the planets and stars seen, and uses a vast database of objects in the Universe. [ESO/N. Bartmann/spaceengine.org]

similar in size to the Earth!" With just 8% the mass of the Sun, TRAPPIST-1 is very small in stellar terms — only marginally bigger than the planet Jupiter — and though nearby in the constellation Aquarius (The Water Carrier), it appears very dim. Astronomers expected that such dwarf stars might host many Earth-sized planets in tight orbits, making them promising targets in the hunt for extraterrestrial life, but TRAPPIST-1 is the first such system to be found. Co-author Amaury Triaud expands: *"The energy output from dwarf stars like TRAPPIST-1 is much weaker than that of our Sun. Planets would need to be in far closer orbits than we see in the Solar System if there is to be surface water. Fortunately, it seems that this kind of compact configuration is just what we see around TRAPPIST-1!"*

The team determined that all the planets in the system are similar in size to Earth and Venus in the Solar System, or slightly smaller. The density measurements suggest that at least the innermost six are probably rocky in composition. The planetary orbits are not much larger than that of Jupiter's Galilean moon system, and much smaller than the orbit of Mercury in the Solar System. However, TRAPPIST-1's small size and low temperature mean that the energy input to its planets is similar to that received by the inner planets in our Solar System; TRAPPIST-1c, d and f receive similar amounts of energy to Venus, Earth and Mars, respectively.

All seven planets discovered in the system could potentially have liquid water on their surfaces, though their orbital distances make some of them more likely candidates than others. Climate models suggest the innermost planets, TRAPPIST-1b, c and d, are probably too hot to support liquid water, except maybe on a small fraction of their surfaces.

The orbital distance of the system's outermost planet, TRAPPIST-1h, is unconfirmed, though it is likely to be too distant and cold to harbour liquid water — assuming no alternative heating processes are occurring. TRAPPIST-1e, f, and g, however, represent the holy grail for planet-hunting astronomers, as they orbit in the star's habitable zone and could host oceans of surface water.

These new discoveries make the TRAPPIST-1 system a very important target for future study. The NASA/ESA Hubble Space Telescope is already being used to search for atmospheres around the planets and team member Emmanuël Jehin is excited about the future possibilities: *"With the upcoming generation of telescopes, such as ESO's European Extremely Large Telescope and the NASA/ESA/CSA James Webb Space Telescope, we will soon be able to search for water and perhaps even evidence of life on these worlds."* ■

Celestial cat meets cosmic lobster

by ESO

Astronomers have for a long time studied the glowing, cosmic clouds of gas and dust catalogued as NGC 6334 and NGC 6357, this gigantic new image from ESO's Very Large Telescope Survey Telescope being only the most recent one. With around two billion pixels this is one of the largest images ever released by ESO. The evocative shapes of the clouds have led to their memorable names: the Cat's Paw Nebula and the Lobster Nebula, respectively.

NGC 6334 is located about 5500 light-years away from Earth, while NGC 6357 is more remote, at a distance of 8000 light-years. Both are in the constellation of Scorpius (The Scorpion), near the tip of its stinging tail. The British scientist John Herschel first saw traces of the two objects, on consecutive nights in June 1837, during his three-year expedition to the Cape of Good Hope in South Africa. At the time, the limited telescopic power available to Herschel, who was observing visually, only allowed him to document the brightest "toepad" of the Cat's Paw Nebula. It was to be many decades before the true shapes of the nebulae became apparent in photographs — and their popular names coined.

The three toepads visible to modern telescopes, as well as the claw-like regions in the nearby Lobster Nebula, are actually regions of gas — predominantly hydrogen — energised by the light of brilliant newborn stars. With masses around

This spectacular image from the VLT Survey Telescope shows the Cat's Paw Nebula (NGC 6334, upper right) and the Lobster Nebula (NGC 6357, lower left). These dramatic objects are regions of active star formation where the hot young stars are causing the surrounding hydrogen gas to glow red. The very rich field of view also includes dark clouds of dust. With around two billion pixels this is one of the largest images ever released by ESO. Note that the circular features in the image around bright stars are not real, they are due to reflections within the optics of the telescope and camera. [ESO]

This montage shows a few of the highlights from a spectacular image from the VLT Survey Telescope showing the Cat's Paw Nebula (NGC 6334) and the Lobster Nebula (NGC 6357). This part of the sky contains active regions of star formation where hot young stars make their surrounding clouds of hydrogen glow with a characteristic red colour. There are also clouds of dark dust in this rich celestial landscape. [ESO]

10 times that of the Sun, these hot stars radiate intense ultraviolet light. When this light encounters hydrogen atoms still lingering in the stellar nursery that produced the stars, the atoms become ionised. Accordingly, the vast, cloud-like objects that glow with this light from hydrogen (and other) atoms are known as emission nebulae. Thanks to the power of the 256-megapixel OmegaCAM camera, this new Very Large Telescope Survey Telescope (VST) image reveals tendrils of light-obscuring dust rippling throughout the two nebulae. At 49511 x 39136 pixels this is one of the largest images ever released by ESO.

OmegaCAM is a successor to ESO's celebrated Wide Field Imager (WFI), currently installed at the MPG/ESO 2.2-metre telescope on La Silla. The WFI was used to photograph the Cat's Paw Nebula in 2010, also in visible light but with a filter that allowed the glow of hydrogen to shine through more clearly. Meanwhile, ESO's Very Large Telescope has taken a deep look into the Lobster Nebula, capturing the many hot, bright stars that influence the object's colour and shape. Despite the cutting-edge instruments used to observe these phenomena, the dust in these nebulae is so thick that much of their content remains hidden to us. The Cat's Paw Nebula is one of the most active stellar nurseries in the night sky, nurturing thousands of young, hot stars whose visible light is unable to reach us. However, by observing at infrared wavelengths, telescopes such as ESO's VISTA can peer through the dust and reveal the star formation activity within.

Viewing nebulae in different wavelengths (colours) of light gives rise to different visual comparisons on the part of human observers. When seen in longer wavelength infrared light, for example, one portion of NGC 6357 resembles a dove, and the other a skull; it has therefore acquired the additional name of the War and Peace Nebula. ■

An ESO Workshop on

THE IMPACT OF BINARIES ON STELLAR EVOLUTION

03 – 07 July 2017 | ESO HQ, Garching, Germany

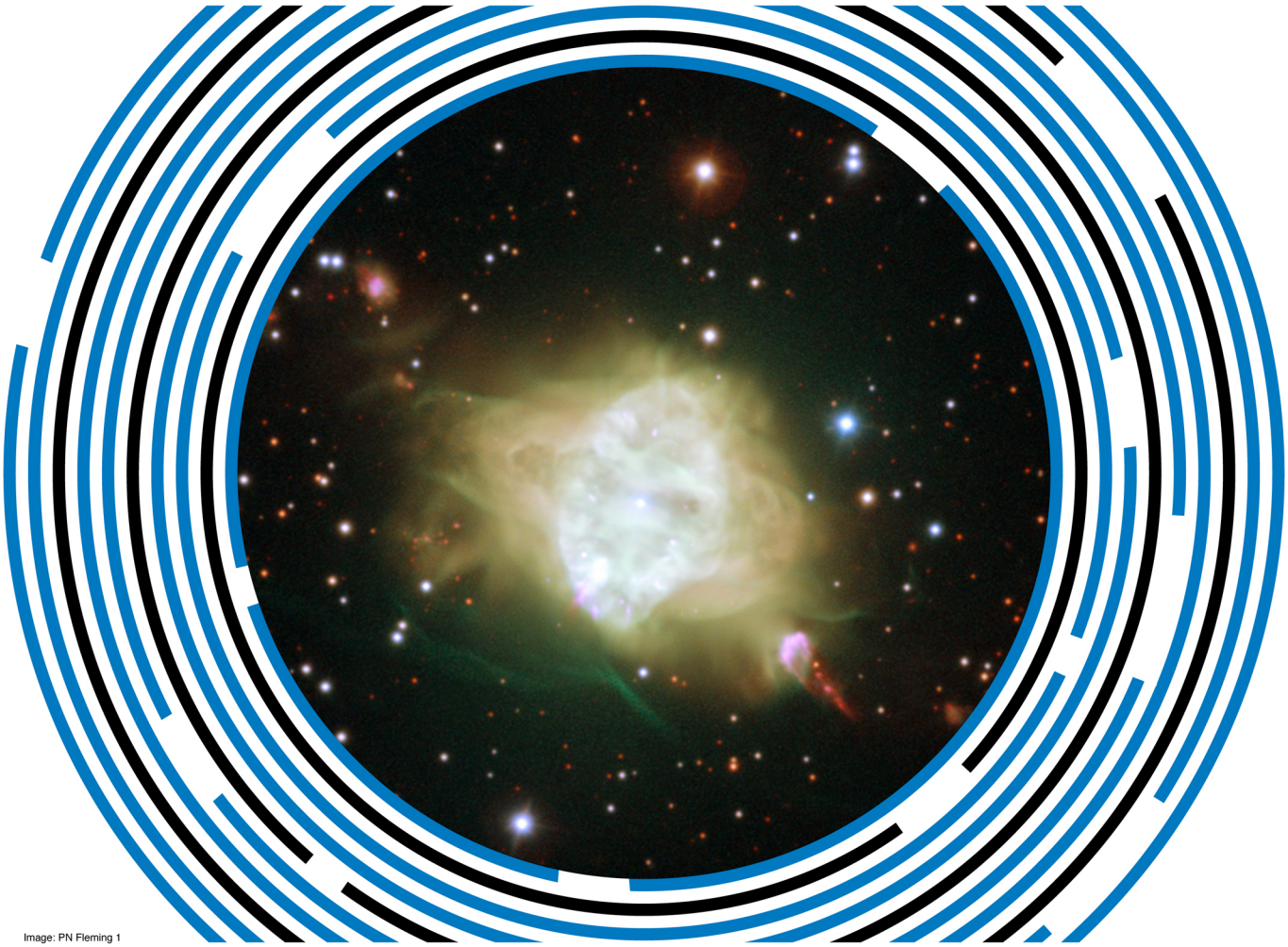


Image: PN Fleming 1

Main topics:

Binary statistics / problems in stellar evolution / stellar mergers / N-body systems / resolved and unresolved populations / chemical evolution / nucleosynthesis / GAIA / gravitational waves

Contact: imbase17@eso.org
http://www.eso.org/sci/meetings/2017/Imbase2017.html

Abstract submission deadline: 31 March 2017
Registration deadline: 02 June 2017

SOC:

- Giacomo Beccari (co-Chair, ESO, Germany)
- Henri Boffin (Chair, ESO, Germany)
- Romano Corradi (GTC, Spain)
- Selma de Mink (Amsterdam, the Netherlands)
- Monika Petr-Gotzens (ESO, Germany)
- Antonio Sollima (Bologna, Italy)
- Christopher Tout (Cambridge, UK)
- Sophie Van Eck (Brussels, Belgium)

NortheK

Instruments - Composites - Optics

DALL KIRKHAM 350 MM

F/20 23% OBSTRUCTION

SUPREMAX 33 PRECISION OPTICS FROM SCHOTT
CARBON STRUCTURE - 18-POINT FLOATING CELL
MOTORIZED FOCUSER 2.5" FEATHER TOUCH
VENTILATION AND SUCTION SYSTEM
OF THE BOUNDARY LAYER
WEIGHT 34 KG.

ALSO AVAILABLE IN THE VERSIONS
NEWTON F/4.1 WITH 3" CORRECTOR
RITCHEY CHRÉTIEN WITH F/9
CORRECTOR/REDUCER
CASSEGRAIN CLASSIC F/15

www.northek.it - www.facebook.com/northek.it - info@northek.it - phone +39 01599521