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- Powerful stratospheric winds measured on Jupiter for the first time
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July- August 2021

English edition of the magazine

ASTROFILO

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

Internet Service Provider
Aruba S.p.A.
Via San Clemente, 53
24036 Ponte San Pietro - BG - ITALY

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

DAVINCI+ and VERITAS to explore Venus

by Damian G. Allis
NASA Solar System Ambassador

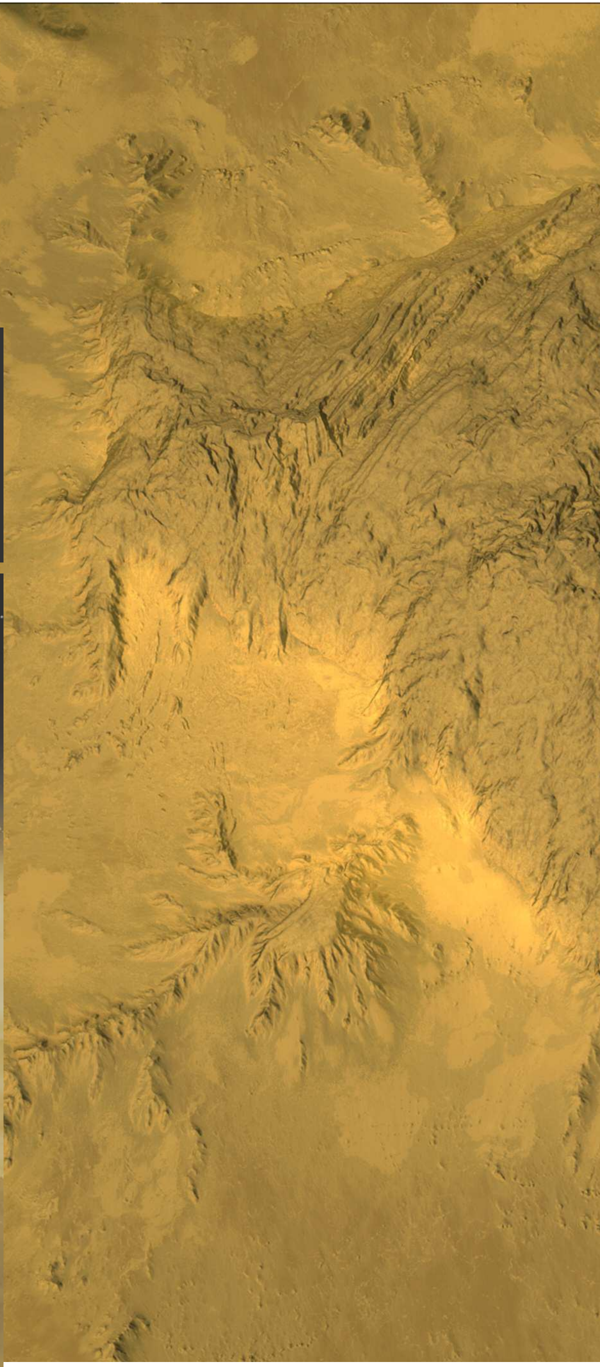
The two most recent NASA Discovery Program missions are set to greatly improve our understanding of our most luminous and mysterious sister planet. On June 2nd, NASA Administrator Bill Nelson announced that both DAVINCI+ and VERITAS had been selected – a first time for two missions to the same location in the history of the program. The MESSENGER spacecraft, the only other Discovery Program mission to study the planet Venus, only performed two flybys, of which only the second, on June 5, 2007, was used to collect spectroscopic data and images before continuing to the planet Mercury, its primary target.
In the grand architecture of NASA funding, the Discovery Program focuses on missions requiring smaller budgets than those of New

The surface of Venus, as seen without its thick atmosphere. [Withan Tor/Shutterstock.com]

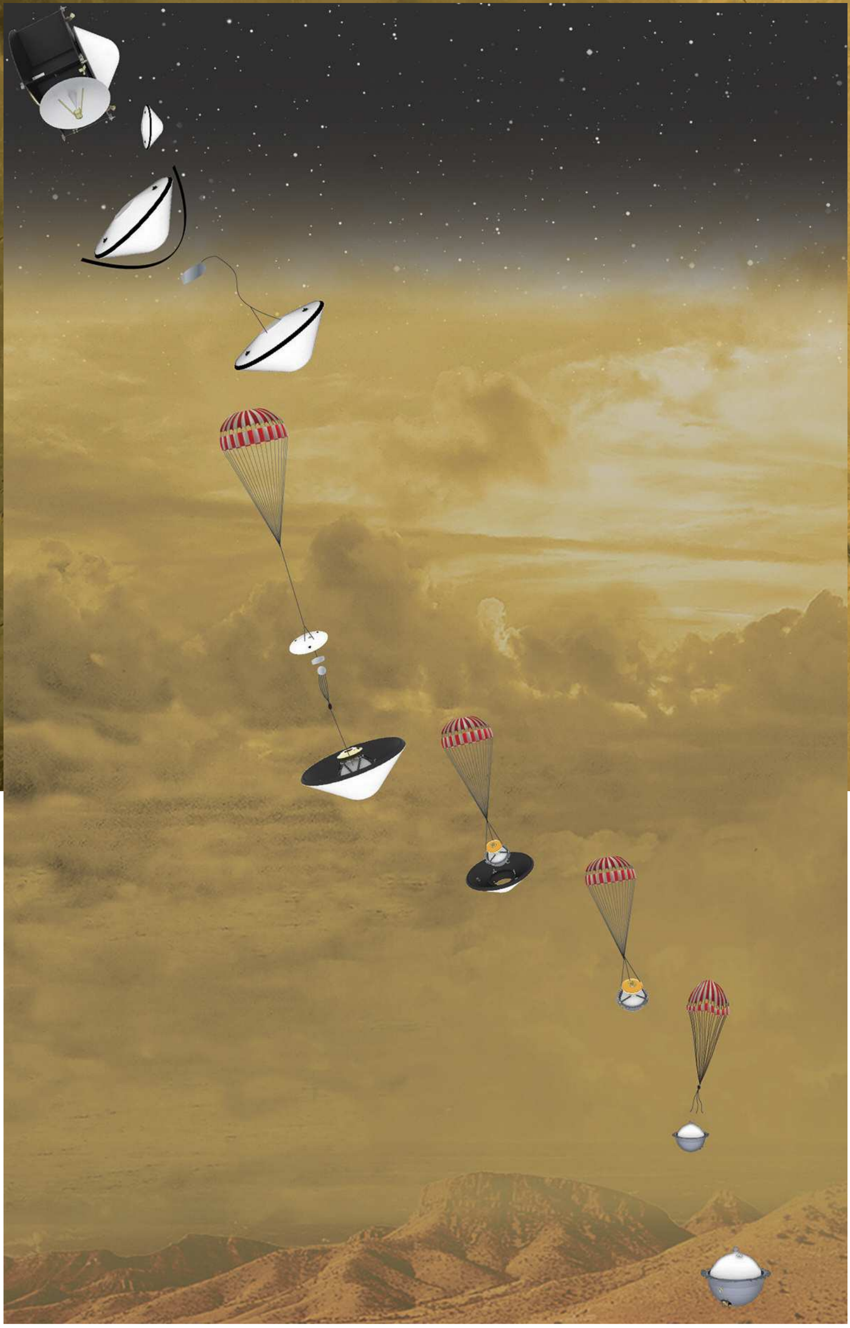
NASA will send two new missions to Venus to learn more about how the planet's hellish atmosphere turned so hostile over its history. [NASA]

Frontiers (from which New Horizons, Juno, and OSIRIS-Rex are recent examples) and Large Strategic Science Missions (formerly known as “Flagship Missions,” among which Voyager, Cassini, and Hubble are just a few). As such, these missions are more focused on specific objectives with a reduced set of specialized equipment, making them, in the often-cited words of past administrator Daniel S. Goldin, "*faster, better, cheaper*" to develop and implement. For DAVINCI+ and VERITAS, each will have a budget of about $500 million USD to complete their objectives.

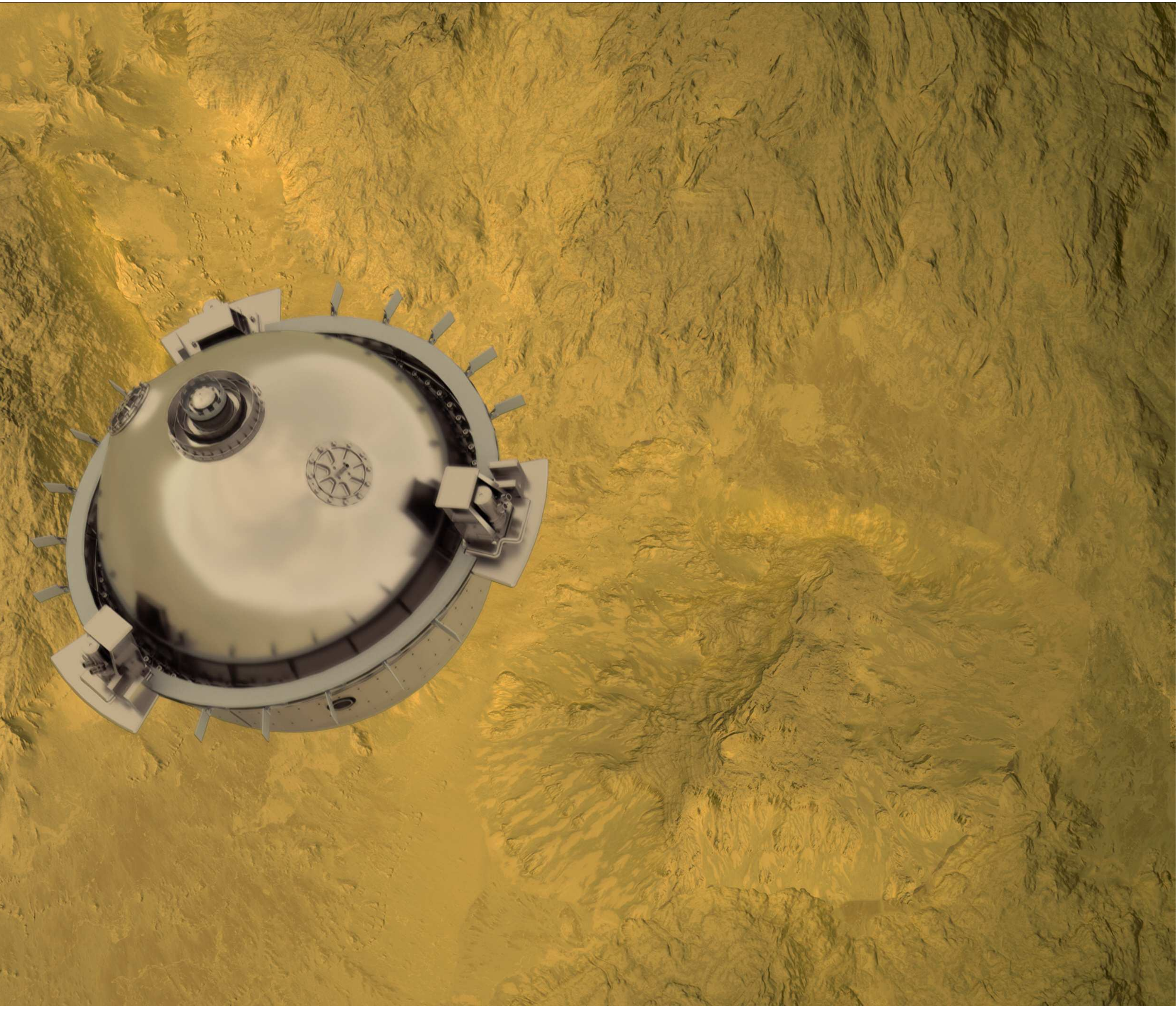
The **VERITAS** (Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy) orbiter will produce very accurate topographical maps of nearly the entire surface using its VISAR (Venus Interferometric Synthetic Aperture Radar) instru-



In the background, DAVINCI+ will send a meter-diameter probe to brave the high temperatures and pressures near Venus' surface to explore the atmosphere from above the clouds to near the surface of a terrain that may have been a past continent. During its final kilometers of free-fall descent, the probe will capture spectacular images and chemistry measurements of the deepest atmosphere on Venus for the first time. [NASA/GSFC visualization by CI Labs Michael Lentz and others] Below, an artist's concept of the descent stages for the DAVINCI+ atmospheric probe and Alpha Regio tesserae imager. [NASA/GSFC]



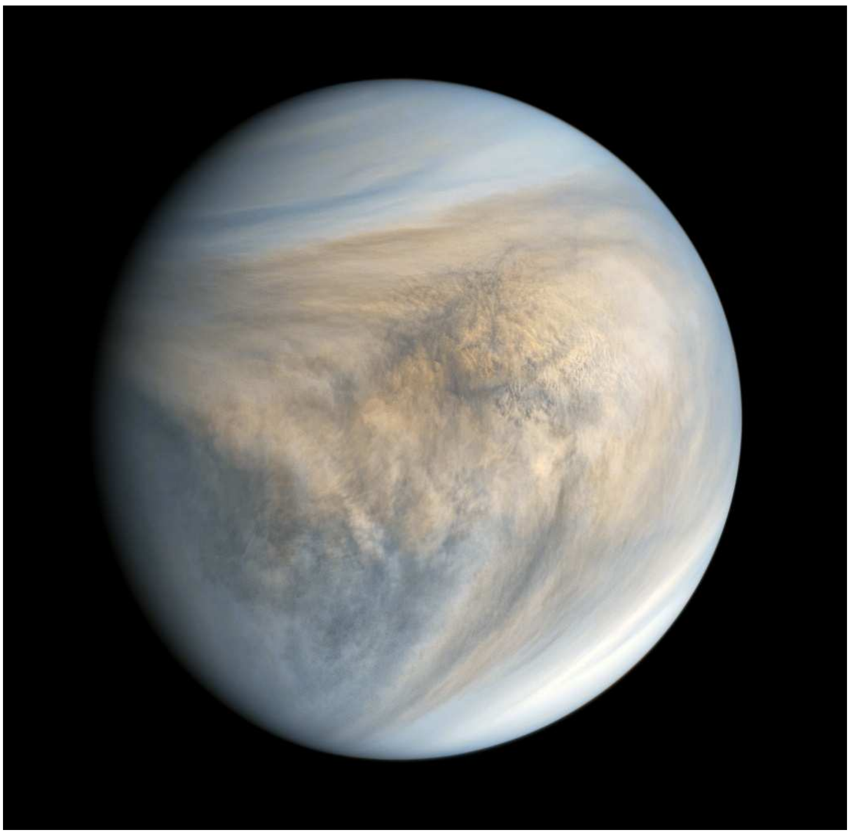
ment, while its VEM (Venus Emissivity Mapper) instrument will map mineral composition and even detect surface water vapor. Additional studies will be performed by the VERITAS communication equipment to measure gravity variations to obtain both estimates of the size of the core and initial measurements of large-scale features below the planet's surface. The surface scans will not only provide insights into ongoing geological activity, such as potential volcanism, but also provide information to estimate the ages of geological features to determine how quickly, and by what potential mechanisms, the Venusian



surface undergoes physical and chemical changes.

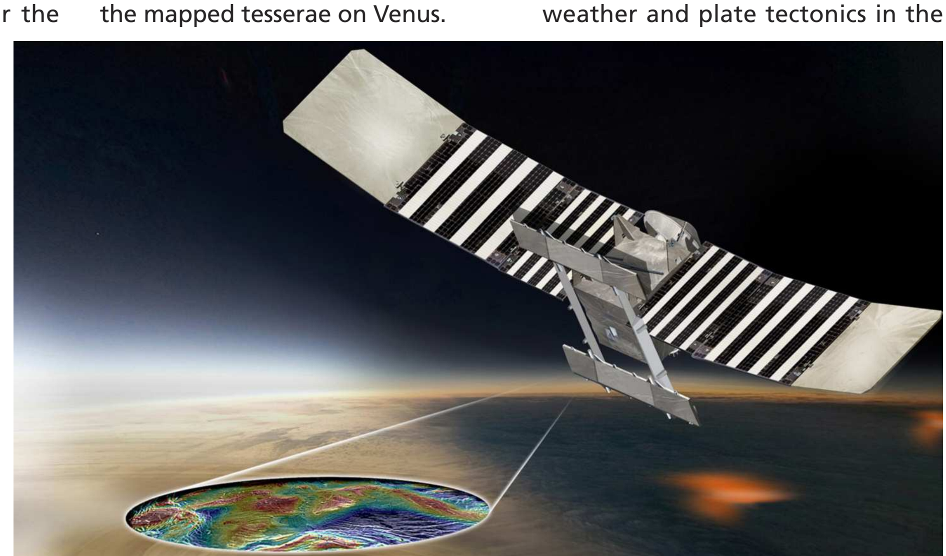
DAVINCI+ (Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging, Plus) will combine an orbiter with a descent probe to study atmospheric compo-

Named for visionary Renaissance artist and scientist, Leonardo da Vinci, the DAVINCI+ mission will bring 21st-century technologies to the world next door. DAVINCI+ may reveal whether Earth's sister planet looked more like Earth's twin planet in a distant, possibly hospitable past with oceans and continents. [NASA/GSFC]



Great detail shown in the Venusian atmosphere through imaging in the ultraviolet. The original imaging was performed by the Akatsuki orbiter, still in operation around Venus. [JAXA/ISAS/DARTS/Kevin M. Gill] Below, an artist's concept of the VERITAS orbiter mapping out a region of the Venusian surface's topology and geology by radar. [NASA/JPL-Caltech]

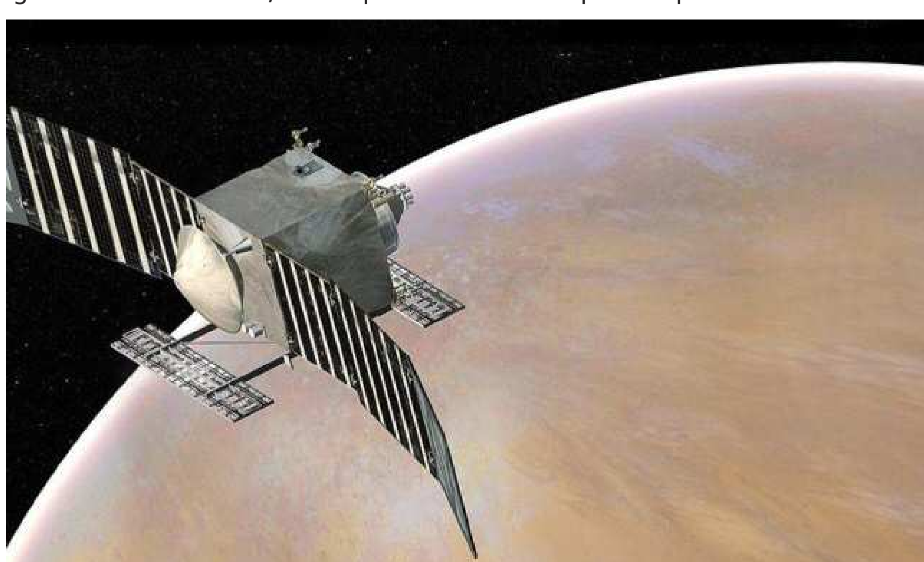
sition and dynamics, while also returning the first surface images since Venera 13, the Soviet probe that landed back in 1981. For the study of the atmosphere from orbit, DAVINCI+ will be equipped with multispectral instrumentation (ultraviolet and near-infrared) and a wide-field camera to study composition and dynamics.
Before succumbing to the extreme temperatures and pressures at the Venusian surface, the descent probe will sample at various altitudes the concentration of Noble and other gases, the distributions of various isotopes, and even begin to address the chemistry occurring within the substructures of the planet's atmosphere. Finally, the probe will perform extensive imaging of the descent and landing location. The proposed landing site is Alpha Regio, one of the mapped tesserae on Venus.



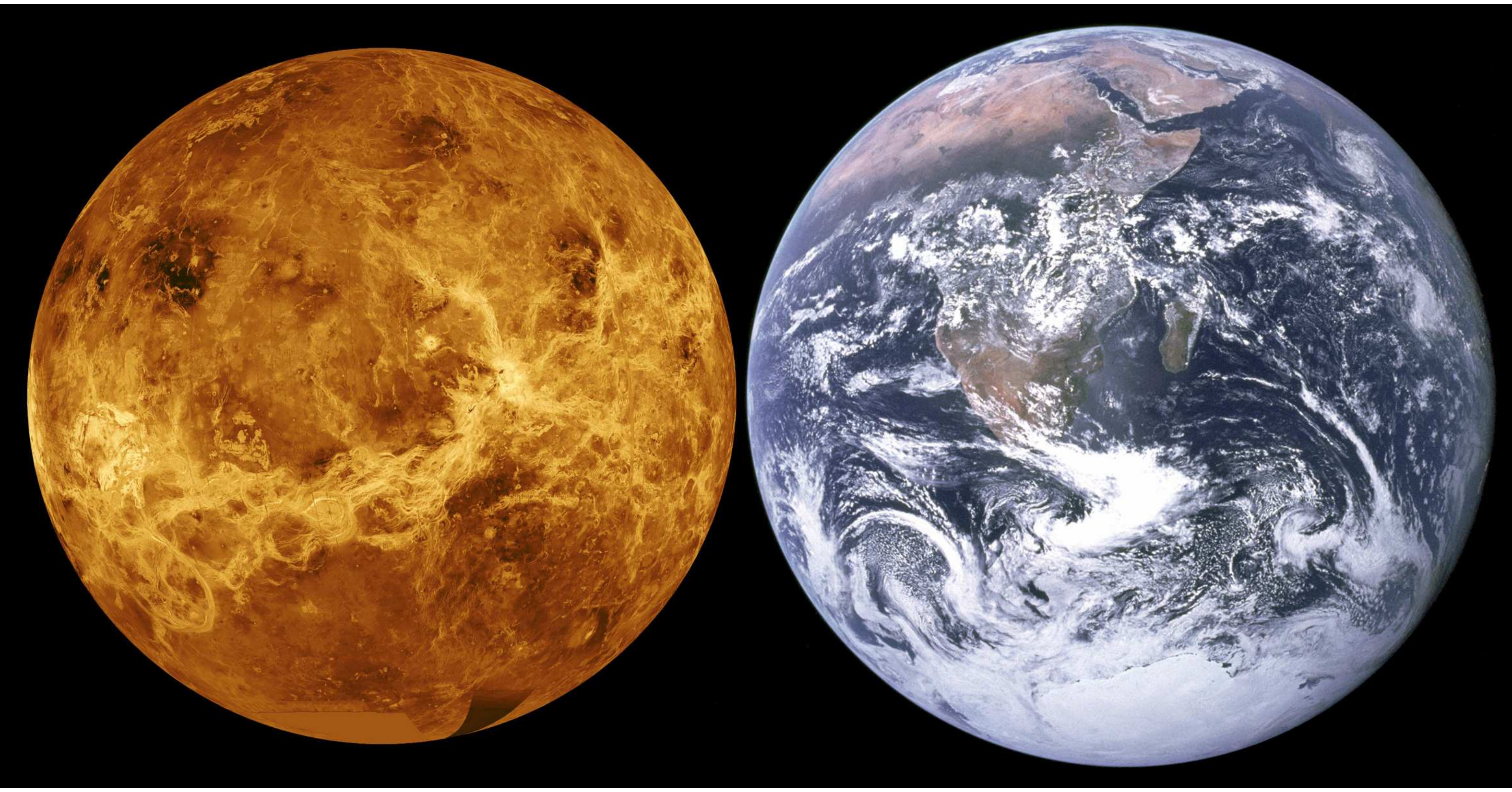
These tesserae are the most geologically ancient structures on the Venusian surface, described often as the Venusian equivalent of continents here on Earth. Their age, structures, and mineralogy might be consistent with the presence of water oceans and plate tectonics – if such an Earth-like situation could have existed on Venus. At present, a number of theories exist for the formation of Venusian tesserae. DAVINCI+ will provide an even higher-resolution study of one single location against the global imaging already being performed by VERITAS.
As for questions that these two missions hope to address, there are many.
Geology – The significance of weather and plate tectonics in the

NASA Administrator Bill Nelson announced that both DAVINCI+ and VERITAS had been selected. [NASA]

reshaping of Earth's surface is obvious when one compares the impact-scarred lunar surface, barely changed in billions of years, with what we find by looking at an Earth map, where near-pristine impact craters are sufficiently rare to count as tourist attractions, and an entire subfield of amateur astronomy is dedicated to scouring satellite imagery for signs of previously undetected ancient impacts.
Venus, to our understanding, might lie somewhere in the middle – we do not know if plate tectonics is a significant source of surface reconstruction, yet the modern surface is dated to between 300 and 600 million years old, meaning any large and ancient impacts dating to the early formation of the solar system are rare. The current source of the more youthful Venusian surface is believed to be largely volcanic activity from among the over 1600 volcanoes that have been identified, including 167 massive volcanoes that are over 100 km in diameter. At present, there is limited direct evidence of active volcanism on Venus, although indirect evidence exists from measured changes in concentration of the volcanic outgassing marker sulfur dioxide. Direct evidence of ongoing – or at least very recent – volcanism comes from a study in 2020 by University of Maryland geophysicist Laurent Montesi and co-workers, who reported that at least 37 of the several hundred named coronae (ring-like structures on the surface caused by the uplift of the crust by heated matter in the mantle) have undergone changes indicative of recent volcanic activity.
VERITAS will combine spectroscopy and radar imaging to explore this issue in detail. By analyzing rock composition, scientists will be able to determine which areas are recently cooled magma and which regions have changed due to exposure to the Venusian atmosphere, providing estimates of either the ongoing extent of, or time since, volcanic activity. Radar mapping may reveal the presence of fault lines – such discoveries would confirm that plate tectonics either is a mechanism of surface change or would at least indicate that such activity once occurred in the planet's past.



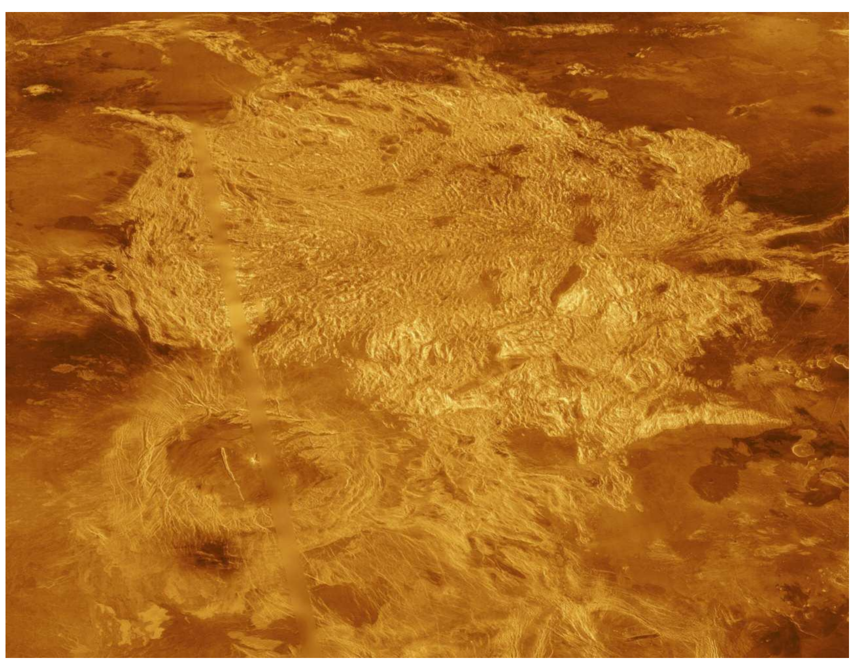
A graphic representation of the VERITAS spacecraft orbiting Venus. [NASA/JPL]



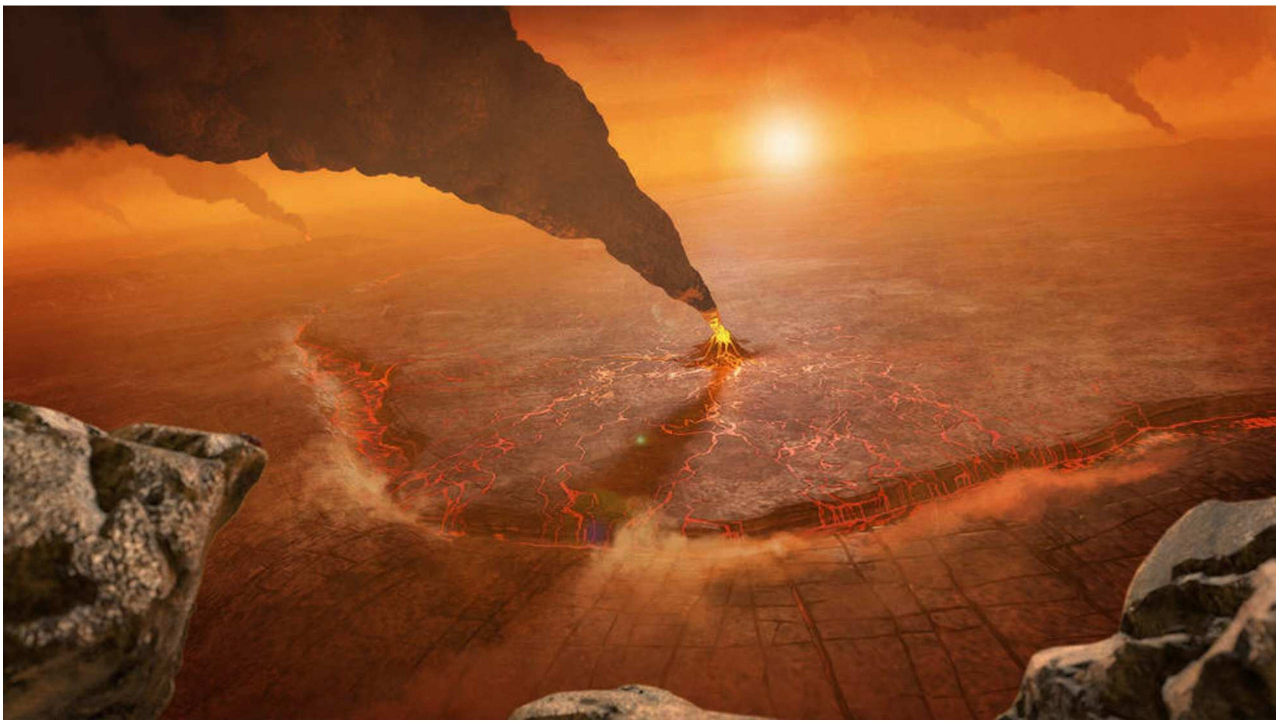
A size comparison of Earth (image taken by the Apollo 17 crew) and Venus, showing their similar size, but very different surfaces. [NASA]

Past or current habitability – With a mean surface temperature of 464 °C (867 °F) and only the scant presence of water vapor detected in the atmosphere, it is very difficult to conceive of extant life of any form on the Venusian surface. As space enthusiasts of all kinds were made well aware of during the presentation of possible phosphine detection during October 2020, the situation changes dramatically with altitude (for more information, see the November-December 2020 issue). At 50 km (30 miles) above the surface, conditions could be considered reasonable (albeit highly acidic), even if only for what we would consider extremophiles on Earth. While the many re-analyses of the original phosphine detection seem to discredit the results of the original study, the first announcement clearly motivated people to think about how life might be thriving on a planet that most thought far too extreme to even support long-term robotics missions.

Just as Mars has been revealed to have been water-rich in its past, so too have researchers hypothesized on the conditions of an ancient Venus. Computational modeling performed at NASA's Goddard Institute for Space Studies in 2016 hint at the possibility that liquid water oceans once may have existed on Venus, but that these oceans may have also been a driver for the runaway greenhouse effect we see today. Over time and due to the increased amount of solar radiation incident on Venus due to its closer proximity to the Sun, the increasing water vapor in the atmosphere would have itself been broken down by UV radiation, leaving hydrogen gas to escape into space and the reactive oxygen atoms and molecules to slowly contribute to the production of carbon dioxide that now constitutes over 95% of the atmosphere. Studies of the atmos-



A false-color image of part of Alpha Regio, the proposed landing site for the DAVINCI+ descent stage, as originally taken by the Magellan orbiter. [NASA/JPL]



An artist's concept of active volcanos on Venus, depicting a subduction zone where the foreground crust plunges into the planet's interior at the topographic trench. [NASA/JPL-Caltech/Peter Rubin]

phere and surface give us a solid foundation to begin to rewind the history of Venus to consider, just as has been done so effectively for Mars, if its ancient surface was more hospitable than today.

Extrasolar planets – This magazine has often discussed habitability and, even more recently, technosignatures – for which the focus on rocky planets within Goldilocks Zones still very much seems to be the center of discussions within the larger community. This makes the paradox of the Venus-Earth-Mars triplet so interesting – Mars is barely habitable, but at least, in terms of surface conditions, its best days are not too dissimilar from what some on Earth would consider extremely uncomfortable. That said, visitors from Earth could at least complain about the temperature (and radiation if their suits were properly equipped) with a far less cumbersome body suit than worn by astronauts performing maintenance on the ISS.

Earth is, of course, Earth, providing a wide range of environmental conditions but no surface extreme so great that some form of life cannot be found or even thriving.

Venus is the oddity in this series – we would expect higher surface temperatures and harsher environmental conditions in general, simply by its proximity to the Sun. That said, the Venusian environment is severe beyond our current ability to explain why it is so. Models of volcanism, catastrophic collisions, and even ocean evaporation are reported in the literature to explain how such a massive amount of atmospheric CO_2 could have been released over time to foster the planet's runaway greenhouse effect. The greater abundance of certain isotopes of the Noble elements are also indicators of certain atmospheric and geochemical phenomena that are potential explanations for the current conditions on Venus.

It may be discovered among solar systems similar in number and planetary placements to ours that all rocky planets near the Sun undergo the same kinds of evolution that our system has. Alternatively, we may discover that the reason for the brutal conditions of Venus are unique to its own evolution and similarly-placed planets in other solar systems are more hospitable, making them more suitable to supporting the development of living organisms.

If all development goes as planned, both missions are set to be launched between 2028 and 2030. They will be soon followed by a very recently announced European Space Agency (ESA) mission named EnVision, set for launch in the early 2030s. ■

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The NortheK Rapido 450 is designed to be disassembled into essential parts for transport in a small car. Each component is equipped with its own case, facilitating transport and assembly. The main element weighs 27 kg. Incorporated mechanical devices and the precise execution of each component allows for the collimation of the optics with extreme ease, maintaining collimation throughout an observation session while eliminating twisting and bending, regardless of the weight of the accessories used. The very thin primary optic allows for rapid acclimatization and ensures thermal stability throughout the night. Two bars equipped with sliding weights allow for the perfect balance of the telescope and accessories. On demand, it is also possible to modify the support to mount the telescope on an equatorial platform. This instrument is composed of aluminum, carbon and steel, each perfectly selected according to strict mechanical standards. It is undoubtedly the best altazimuth Newtonian on the market.

I N S T R U M E N T S - C O

The spiral of the Southern Pinwheel

by NOIRLab - Amanda Kocz

Astronomy enthusiasts might wonder why a camera called the Dark Energy Camera (DECam) would be used to image a single spiral galaxy. DECam has in fact already finished its main job, as the instrument was used to complete the Dark Energy Survey, which ran from 2013 to 2019. Like many people, rather than enjoying a quiet retirement, DECam is remaining occupied. Members of the astronomical community can apply for time to use it, and the data collected are processed and made publicly available, thanks to the Astro Data Archive at the Community Science and Data Center (CSDC) Program at NSF's NOIRLab. DECam's continued operation also makes sumptuously detailed images like this one possible. Messier 83, or the Southern Pinwheel, is located in the southern constellation of Hydra and is an obvious target for a beautiful astronomical image. It is oriented so that it is almost entirely face-on as seen

One of the deepest images ever taken of the Southern Pinwheel (combining more than 11 hours of exposure time), this view was captured with the Dark Energy Camera (DECam), which was built by the US Department of Energy (DOE) and is mounted on the Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory (CTIO), a Program of NSF's NOIRLab. Numerous background galaxies, which lie much farther away than Messier 83, appear around the edges of the image. [CTIO/NOIRLab/DOE/NSF/AURA - Ack: M. Soraisam (University of Illinois) - Image processing: Travis Rector (University of Alaska Anchorage), Mahdi Zamani & Davide de Martin]

from Earth, meaning that we can observe its spiral structure in fantastic detail.

The galaxy lies around 15 million light-years away, which makes it a neighbor in astronomical terms. It has a diameter of around 50,000 light-years, so it is a little diminutive in comparison to our own Milky Way, which has a diameter of 100,000–200,000 light-years. In other ways, however, the Southern Pinwheel probably gives a good approximation of how our Milky Way would look to a distant alien civilization.

Six different filters were used on DECam in order to create this spectacular new view of a classical beauty. Filters allow astronomers to select which wavelengths of light they wish to view the sky in. This is crucial for science observations, when astronomers require very specific information about an object, but it also allows colorful images like this one to be created. Observing celestial objects — such as the Southern Pinwheel — with several different filters means that different details can be picked out.

CosmoView Episode 22: The spiral of the Southern Pinwheel. [Images and Videos: CTIO/NOIRLab/DOE/NSF/AURA, M. Soraisam (University of Illinois), /LBNL/DECam/R. Hahn, R. Sparks. Image processing: Travis Rector (University of Alaska Anchorage), Mahdi Zamani & Davide de Martin. Music: Stellardrone - Airglow]

For example, the dark tendrils curling through the galaxy are actually lanes of dust, blocking out light. In contrast, the clustered, bright red spots are caused by glowing, hot hydrogen gas (which identifies these as hubs of star formation). Dusty trails and dynamic ionized gas have different temperatures, and are therefore visible in different wavelengths.

Filters allow both to be observed separately, and then combined into one intricate image. In all, 163 DECam exposures, with a total combined exposure time of over 11.3 hours, went into creating this portrait of Messier 83.

Yet these observations were not just about creating a pretty picture. They are helping to prepare for upcoming observations by Vera C. Rubin Observatory, a future program of NOIRLab. In ten years of operation, starting in 2023, Rubin Observatory will carry out an unprecedented optical survey of the visible sky named the Legacy Survey of Space and Time (LSST). *"The Messier 83 observations are part of an ongoing program to produce an atlas of time-varying phenomena in nearby southern galaxies in preparation for Rubin Observatory's Legacy Survey of Space and Time,"* said Monika Soraisam of the University of Illinois, who is the principal investigator for DECam's observations of Messier 83. *"We are generating multi-color light curves of stars in this galaxy, which will be used to tame the onslaught of alerts expected from LSST using state-of-the-art software infrastructure such as NOIRLab's own ANTARES alert-broker."*

Built by the US Department of Energy (DOE), DECam is mounted on the Víctor M. Blanco 4-meter Telescope at CTIO in Chile. DECam is a powerful instrument that uses 74 highly sensitive charge-coupled devices (CCDs) to take images. CCDs are the same devices that are used to take photos in everyday cell phones. Of course, the CCDs in DECam are much larger, and they were specifically designed to collect very faint red light from distant galaxies. This capability was crucial for DECam's original purpose, the Dark Energy Survey. This ambitious survey probed one of the most fundamental questions of the Universe — why is our Universe not only expanding, but expanding at an accelerating rate? For six years DECam surveyed the skies, imaging the most distant galaxies to collect more data to enable astronomers to further investigate our accelerating Universe. Taking beautiful images such as this one must seem a lot simpler for DECam.

"While DECam has fulfilled its original goal to complete the Dark Energy Survey, it continues to be a valuable resource for the astronomical community, capturing sweeping views of objects like Messier 83 that both delight the senses and advance our understanding of the Universe," said Chris Davis, Program Director for NOIRLab at the National Science Foundation. ■

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50 years ago, we walked on the Moon
PART ONE OF TWO

Powerful stratospheric winds measured on Jupiter for the first time

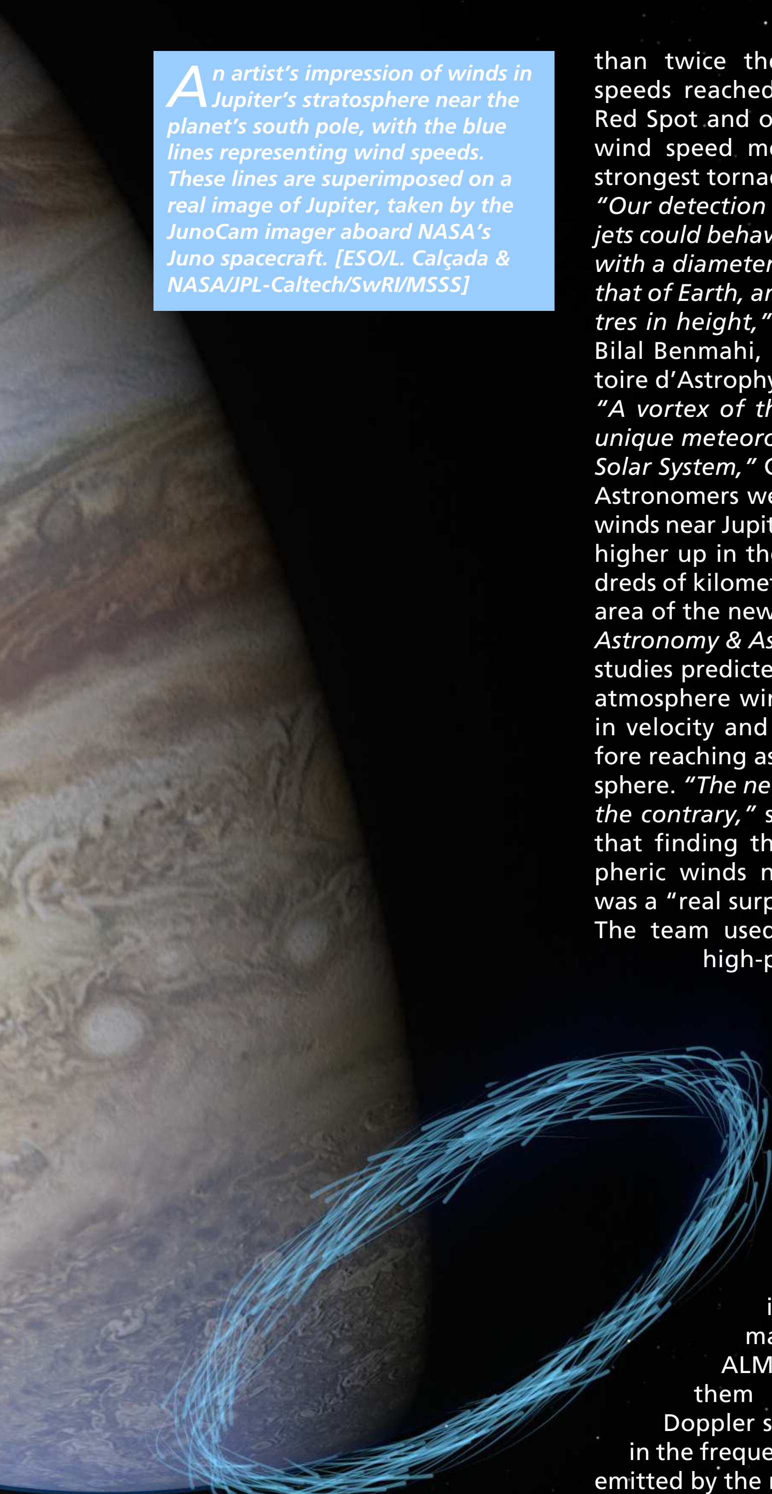
by ESO - Bárbara Ferreira

Jupiter is famous for its distinctive red and white bands: swirling clouds of moving gas that astronomers traditionally use to track winds in Jupiter's lower atmosphere. Astronomers have also seen, near Jupiter's poles, the vivid glows known as aurorae, which appear to be associated with strong winds in the planet's upper atmosphere. But until now, researchers had never been able to directly measure wind patterns in between these two atmospheric layers, in the stratosphere.

Measuring wind speeds in Jupiter's stratosphere using cloud-tracking techniques is impossible because of the absence of clouds in this part of the atmosphere. However, astronomers were provided with an alternative measuring aid in the form of comet Shoemaker–Levy 9, which collided with the gas giant in spectacular fashion in 1994. This impact produced new molecules in Jupiter's stratosphere, where they have been moving with the winds ever since.

A team of astronomers, led by Thibault Cavalié of the Laboratoire d'Astrophysique de Bordeaux in France, have now tracked one of these molecules — hydrogen cyanide — to directly measure stratospheric "jets" on Jupiter. Scientists use the word "jets" to refer to narrow bands of wind in the atmosphere, like Earth's jet streams.

"The most spectacular result is the presence of strong jets, with speeds of up to 400 metres per second, which are located under the aurorae near the poles," says Cavalié. These wind speeds, equivalent to about 1450 kilometres an hour, are more



An artist's impression of winds in Jupiter's stratosphere near the planet's south pole, with the blue lines representing wind speeds. These lines are superimposed on a real image of Jupiter, taken by the JunoCam imager aboard NASA's Juno spacecraft. [ESO/L. Calçada & NASA/JPL-Caltech/SwRI/MSSS]

than twice the maximum storm speeds reached in Jupiter's Great Red Spot and over three times the wind speed measured on Earth's strongest tornadoes.

"Our detection indicates that these jets could behave like a giant vortex with a diameter of up to four times that of Earth, and some 900 kilometres in height," explains co-author Bilal Benmahi, also of the Laboratoire d'Astrophysique de Bordeaux. *"A vortex of this size would be a unique meteorological beast in our Solar System,"* Cavalié adds.

Astronomers were aware of strong winds near Jupiter's poles, but much higher up in the atmosphere, hundreds of kilometres above the focus area of the new study, published in *Astronomy & Astrophysics*. Previous studies predicted that these upper-atmosphere winds would decrease in velocity and disappear well before reaching as deep as the stratosphere. *"The new ALMA data tell us the contrary,"* says Cavalié, adding that finding these strong stratospheric winds near Jupiter's poles was a "real surprise".

The team used 42 of ALMA's 66 high-precision antennas, located in the Atacama Desert in northern Chile, to analyse the hydrogen cyanide molecules that have been moving around in Jupiter's stratosphere since the impact of Shoemaker–Levy 9. The ALMA data allowed them to measure the Doppler shift — tiny changes in the frequency of the radiation emitted by the molecules — caused by the winds in this region of the planet. *"By measuring this shift, we were able to deduce the speed of the winds much like one could deduce the speed of a passing train by the change in the frequency of the train whistle,"* explains study co-author Vincent Hue, a planetary scientist at the Southwest Research Institute in the US.

In addition to the surprising polar winds, the team also used ALMA to confirm the existence of strong stratospheric winds around the planet's equator, by directly measuring their speed, also for the first time. The jets spotted in this part of the planet have average speeds of about 600 kilometres an hour.

The ALMA observations required to track stratospheric winds in both the poles and equator of Jupiter took less than 30 minutes of telescope time. *"The high levels of detail we achieved in this short time really demonstrate the power of the ALMA observations,"* says Thomas Greathouse, a scientist at the Southwest Research Institute in the US and co-author of the study. *"It is astounding to me to see the first direct measurement of these winds."*

"These ALMA results open a new window for the study of Jupiter's auroral regions, which was really unexpected just a few months back," says Cavalié. *"They also set the stage for similar yet more extensive measurements to be made by the JUICE mission and its Submillimetre Wave Instrument,"* Greathouse adds, referring to the European Space Agency's JUpiter ICy moons Explorer, which is expected to launch into space next year.

ESO's ground-based Extremely Large Telescope (ELT), set to see first light later this decade, will also explore Jupiter. The telescope will be capable of making highly detailed observations of the planet's aurorae, giving us further insight into Jupiter's atmosphere.

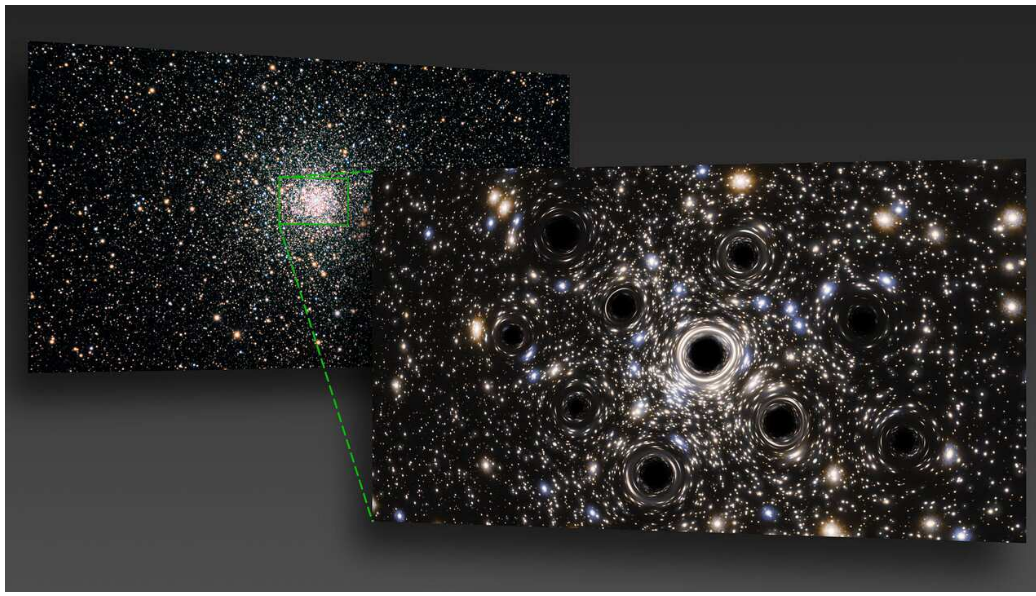
Hubble uncovers concentration of small black holes

by NASA/ESA - Bethany Downer

Scientists were expecting to find an intermediate-mass black hole at the heart of the globular cluster NGC 6397, but instead they found evidence of a concentration of smaller black holes lurking there. New data from the NASA/ESA Hubble Space Telescope have led to the first measurement of the extent of a collection of black holes in a core-collapsed globular cluster.

Globular clusters are extremely dense stellar systems, in which stars are packed closely together. They are also typically very old — the globular cluster that is the focus of

This ancient stellar jewelry box, a globular cluster called NGC 6397, glitters with the light from hundreds of thousands of stars. [NASA, ESA, and T. Brown and S. Casertano (STScI). Ack: NASA, ESA, and J. Anderson (STScI)]



An artist's impression created to visualize the concentration of black holes at the center of NGC 6397. In reality, the small black holes here are far too small for the direct observing capacities of any existing or planned future telescope, including Hubble. It is predicted that this core-collapsed globular cluster could be host to more than 20 black holes. [ESA/Hubble, N. Bartmann]

this study, NGC 6397, is almost as old as the Universe itself. It resides 7800 light-years away, making it one of the closest globular clusters to Earth. Because of its very dense nucleus, it is known as a core-collapsed cluster. When Eduardo Vitral and Gary A. Mamon of the Institut d'Astrophysique de Paris set out to study the core of NGC 6397, they expected to find evidence for an "intermediate-mass" black hole (IMBH).
These are smaller than the supermassive black holes that lie at the cores of large galaxies, but larger than stellar-mass black holes formed by the collapse of massive stars. IMBH are the long-sought "missing link" in black hole evolution and their mere existence is hotly debated, although a few candidates have been found. To look for the IMBH, Vitral and Mamon analysed the positions and velocities of the cluster's stars. They did this using previous estimates of the stars' proper motions from Hubble images of the cluster spanning several years, in addition to proper motions provided by ESA's Gaia space observatory, which precisely measures the positions, distances and motions of stars. Knowing the distance to the cluster allowed the astronomers to translate the proper motions of these stars into velocities.
"Our analysis indicated that the orbits of the stars are close to random throughout the globular cluster, rather than systematically circular or very elongated," explained Mamon. *"We found very strong evidence for invisible mass in the dense central regions of the cluster, but we were surprised to find that this extra mass is not point-like but extended to a few percent of the size of the cluster,"* added Vitral.
This invisible component could only be made up of the remnants (white dwarfs, neutron stars, and black holes) of massive stars whose inner regions collapsed under their own gravity once their nuclear fuel was exhausted. The stars progressively sank to the cluster's centre after gravitational interactions with nearby less massive stars, leading to the small extent of the invisible mass concentration. Using the theory of stellar evolution, the scientists concluded that the bulk of the unseen concentration is made of stellar-mass black holes, rather than white dwarfs or neutron stars that are too faint to observe.
Two recent studies had also proposed that stellar remnants and in particular, stellar-mass black holes, could populate the inner regions of globular clusters.
"Our study is the first finding to provide both the mass and the extent of what appears to be a collection of mostly black holes in a core-collapsed globular cluster," said Vitral. *"Our analysis would not have been possible without having both the Hubble data to constrain the inner regions of the cluster and the Gaia data to constrain the orbital shapes of the outer stars, which in turn indirectly constrain the velocities of foreground and background stars in the inner regions,"* added Mamon, attesting to an exemplary international collaboration.
The astronomers also note that this discovery raises the question of whether mergers of these tightly packed black holes in core-collapsed globular clusters may be an important source of gravitational waves recently detected by the Laser Interferometer Gravitational-Wave Observatory (LIGO) experiment.

Unrivaled view of galaxy Messier 106

by NOIRLab - Amanda Kocz

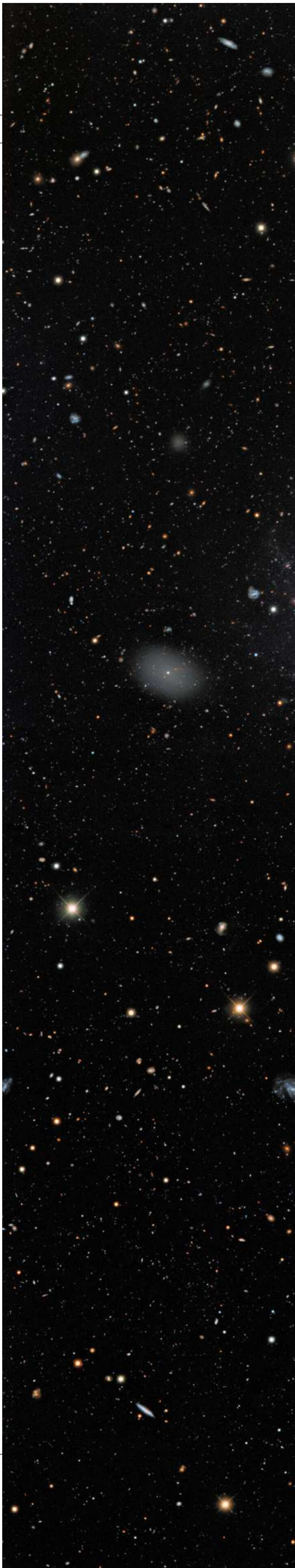
This celestial snapshot captures the majesty of the spiral galaxy Messier 106, also known as NGC 4258. The image is arguably the best yet captured of the entire galaxy. Obtained using the Nicholas U. Mayall 4-meter Telescope at Kitt Peak National Observatory, a Program of NSF's NOIRLab, this image shows not only the glowing spiral arms, wisps of gas, and dust lanes at the core of the galaxy but also the leisurely twisting bands of stars at its outer edges.

A popular target for amateur astronomers, Messier 106 can be spotted with a small telescope in the constellation Canes Venatici. Messier 106 is similar in size and luminosity to our galactic neighbor the Andromeda Galaxy, but it lies 10 times farther away — more than 20 million light-years from Earth. Though the galaxy measures more than 130,000 light-years from edge to edge, the vast distance between it and the Milky Way renders Messier 106 minuscule when seen from here. Its size in the night sky — if it were visible to the naked eye — is less than that of a penny held at arm's length! Despite its tranquil appearance, Messier 106 has an unusually energetic inhabitant. The supermassive black hole at the heart of the galaxy — which is about 40 million times as massive as our Sun — is particularly active. As well as consuming vast amounts of gas and dust, the spinning black hole has warped the surrounding disk of gas, churning up vast amounts of material. This process has created the bright, red streamers of gas emanating from the heart of Messier 106, visible in the center of this image.

Accompanying Messier 106 is a pair of dwarf galaxies belonging to the same galaxy group. The loose collection of stars and dust visible in the bottom-right of this image is the small irregular galaxy NGC 4248. Another small galaxy — UGC 7356 — lies to the lower-left of Messier 106 and is dwarfed by its larger neighbor. Messier 106 and its companions are framed by a variety of objects, from foreground stars to background galaxies. Stars from our own galaxy stud the image, easily identified by the criss-cross diffraction patterns surrounding them. In the background, distant galaxies litter the image, some of them visible through the tenuous disk of Messier 106.

As well as being a striking subject for astronomical images, Messier 106 has been instrumental in measuring the scale of the Universe. Astronomers measure distances in the Universe using an interconnected chain of measurements called the cosmic distance ladder, with each rung of the ladder allowing measurements of more and more distant objects. Calibrating these measurements requires objects with a known brightness — such as pulsating stars known as Cepheid variables.

Measurements of the Cepheids in Messier 106 have allowed astronomers to calibrate Cepheids elsewhere in the Universe — helping them to measure the distances to other galaxies. This image was one of the last to be taken with the Mosaic camera before the installation of the Dark Energy Spectroscopic Instrument (DESI), a project of the Department of Energy's Office of Science and Lawrence Berkeley National Laboratory. ■

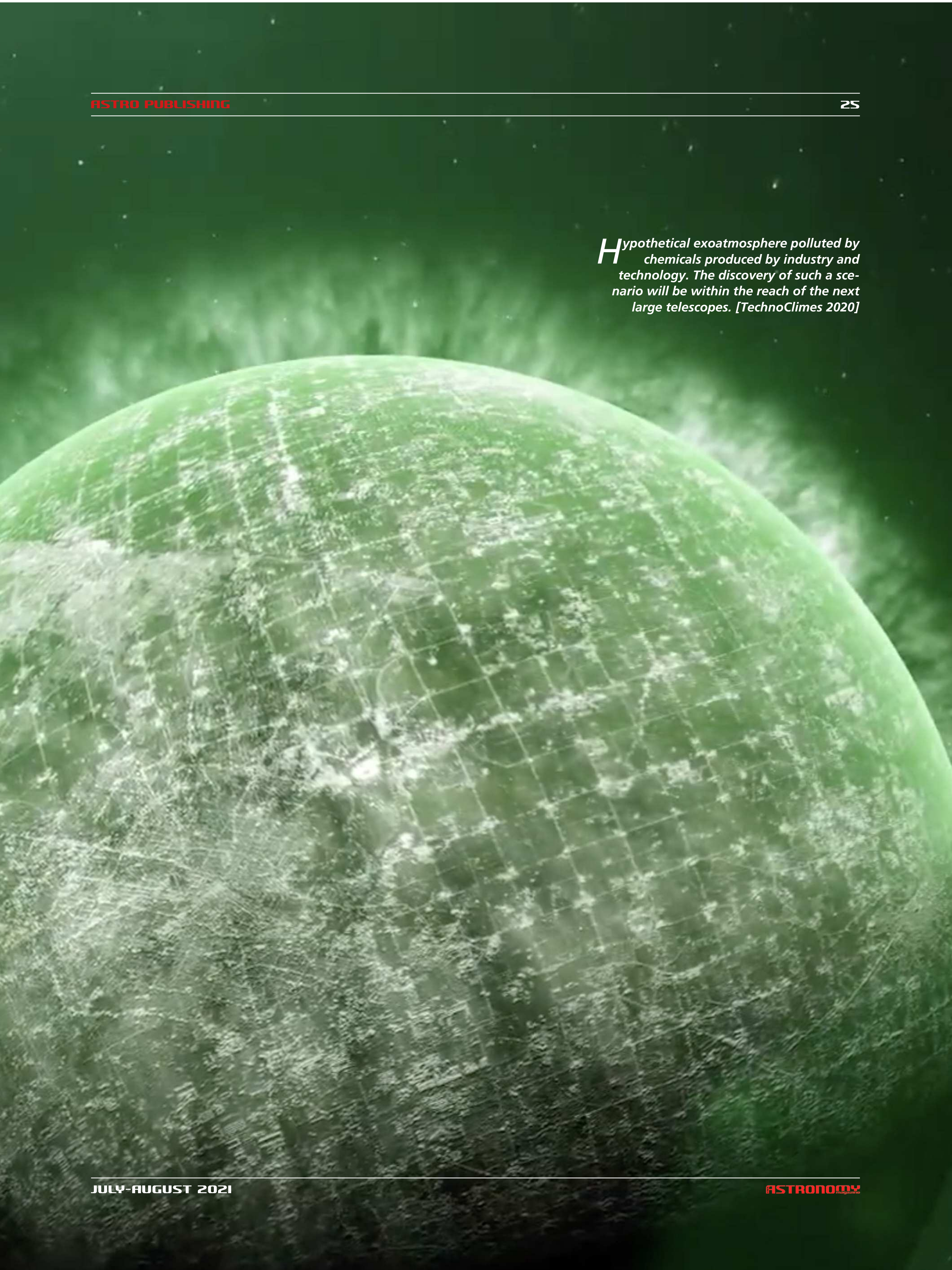


Ichnoscale – the parameter for technological civilizations

by Michele Ferrara
revised by Damian G. Allis
NASA Solar System Ambassador

For some years now, astrobiologists engaged in the search for possible alien civilizations have been outlining more and more concretely the scientific programs to be undertaken to discover technosignatures of non-terrestrial origin. Very strictly, we can define technosignatures as observational evidence of the existence of technological applications in the universe. Discovering possible biosignatures produced by the "simple" existence of life on another planet (ET) would already be a lot, but it would be quite another thing to realize that that life has developed sufficient intelligence to create technologies (ETI). The fact that life exists on Earth has been evident, for an external observer, for at least half a billion years (since the Cambrian explosion), therefore up to distances in space that exceed the boundaries of the local supercluster of galaxies (Laniakea). That the Earth also hosts a technological civilization is instead clearly visible only within the Orion arm of the Milky Way, up to a few hundred light-years away.

Because we don't know if other technological civilizations exist, and much less do we know how their technologies can manifest themselves, when we go in search of them we can only hope that they

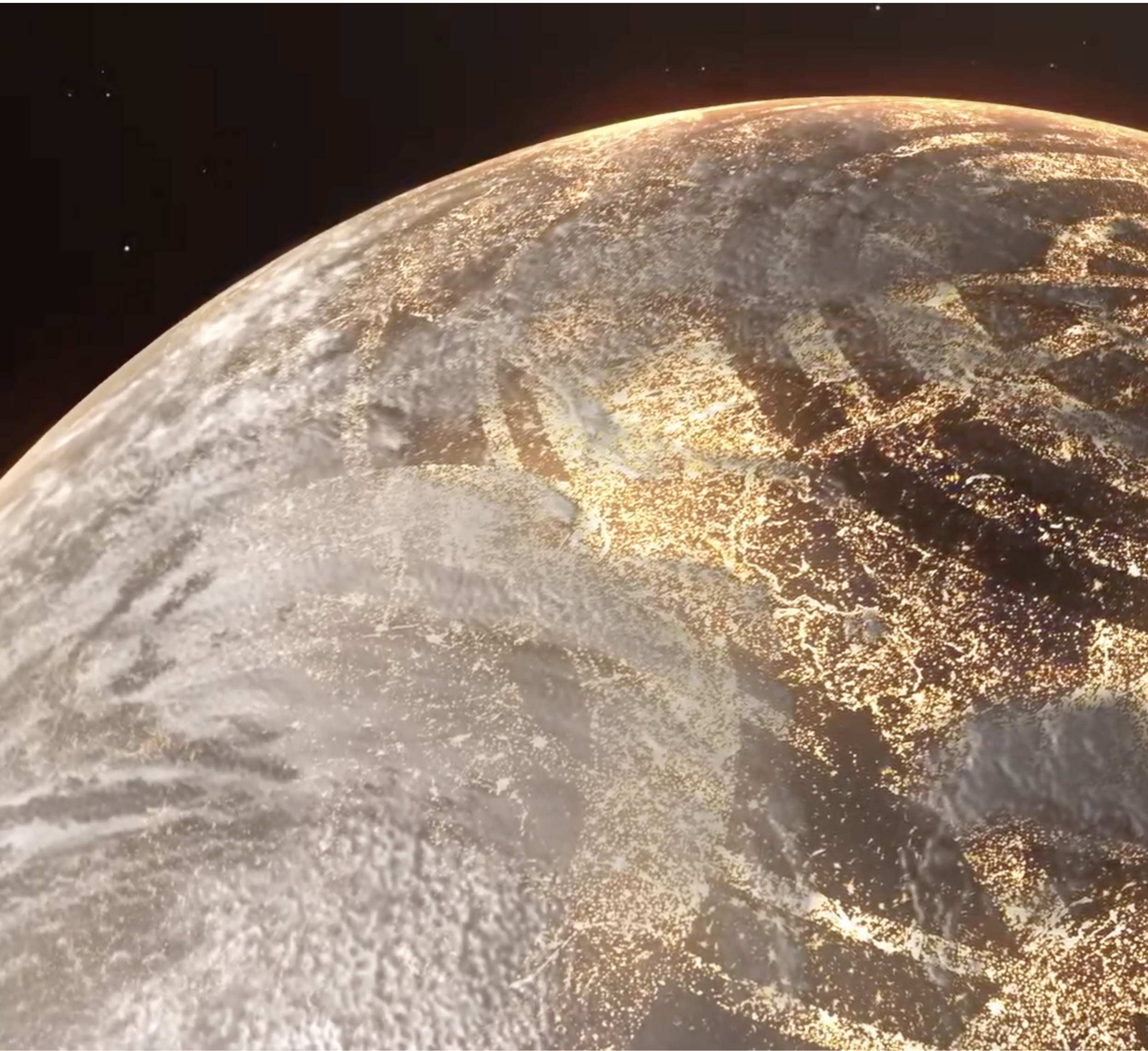


Hypothetical exoatmosphere polluted by chemicals produced by industry and technology. The discovery of such a scenario will be within the reach of the next large telescopes. [TechnoClimes 2020] have followed an evolutionary path similar to ours and are hence recognizable with the instruments at our disposal.

Since there are various forms through which an ETI can reveal itself, astrobiologists looking for technosignatures can make use of the databases from many research programs already started with other purposes. For example, the study of exoplanets atmospheres in transit in front of their stars can highlight molecules that are hardly present in nature in certain abundances.

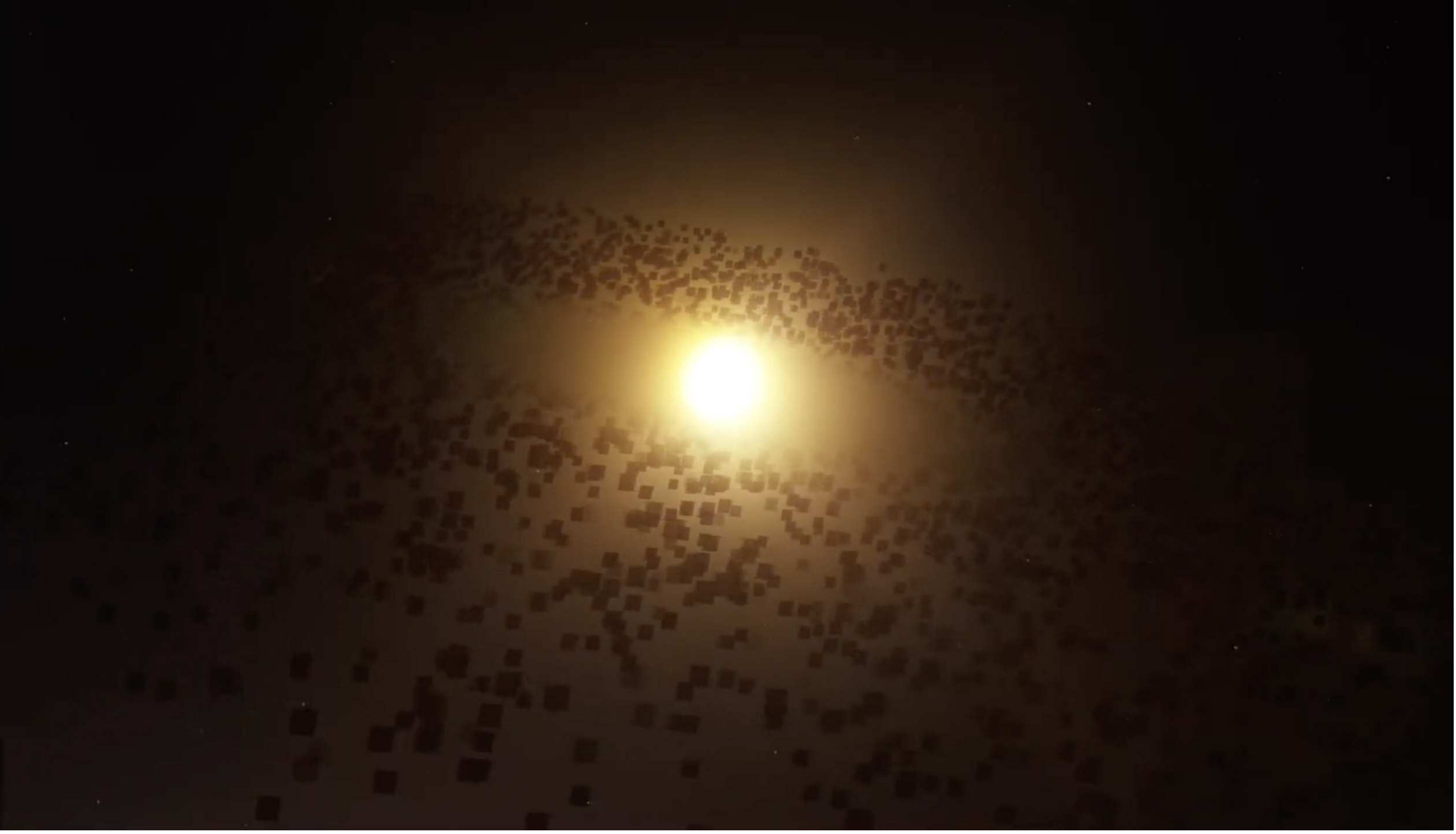
After sixty years of fruitless searches for alien signals in the radio domain, many ETI hunters are increasingly

The night lights of an exoplanet akin to the one shown here could be observed from Earth. Similarly, an alien civilization might notice our artificial lights, which on some continents have intensity peaks similar to these. [TechnoClimes 2020]



turning to other methods of investigation, made possible by the remarkable advances made by our technology in recent years, by the copious discoveries of planetary systems and by the imminent arrival of new ground- and space-based powerful telescopes. In the wake of this renewed enthusiasm, in 2018 NASA had begun to consider the search for technosignatures as an activity to be evaluated and supported. Not surprisingly, the agency had organized the "NASA Technosignatures Workshop" meeting in September of that year, with the specific intent of defining the state-of-the-art in the field of technosignatures, the current limits of their research and the projects to be developed in the immediate future. One of the points of discussion at the meeting was the role that NASA might have played in advancing knowledge on technosignatures, in partnership with other organizations. The interest shown by the agency on that occasion represented a turning point in the general approach to non-radio technosignatures, which thus became something more than a bizarre field of research on the edge of sci-fi.

Two years later, in August 2020, NASA sponsored a second workshop on the topic, named "TechnoClimes 2020" and organized by the Blue Marble Space Institute of Science. The purpose of this second meeting among the leading experts in the sector was to produce a research agenda for technosignatures, evaluating projects and missions that could offer new opportunities, regardless of the current limits of available resources. For the first time, the efforts of different initiatives were combined, offering an overview of current and near-future capabilities in undertaking a systematic search for technosignatures. The instruments that astrobiologists will have at their disposal in a few years will allow them to detect in space technosignatures with intensities comparable to those of terrestrial ones, up to distances of tens or hundreds of light-years. Currently, with the astronomical infrastructures at our disposal, we can only detect technosignatures much more intense than ours, probably produced by superior technologies.
According to one of the conclusions emerged from TechnoClimes 2020, it is unlikely that civilizations with a relatively low level of technological development (more or less like ours) could come into contact with each other, because this would require transmission or reception capacity

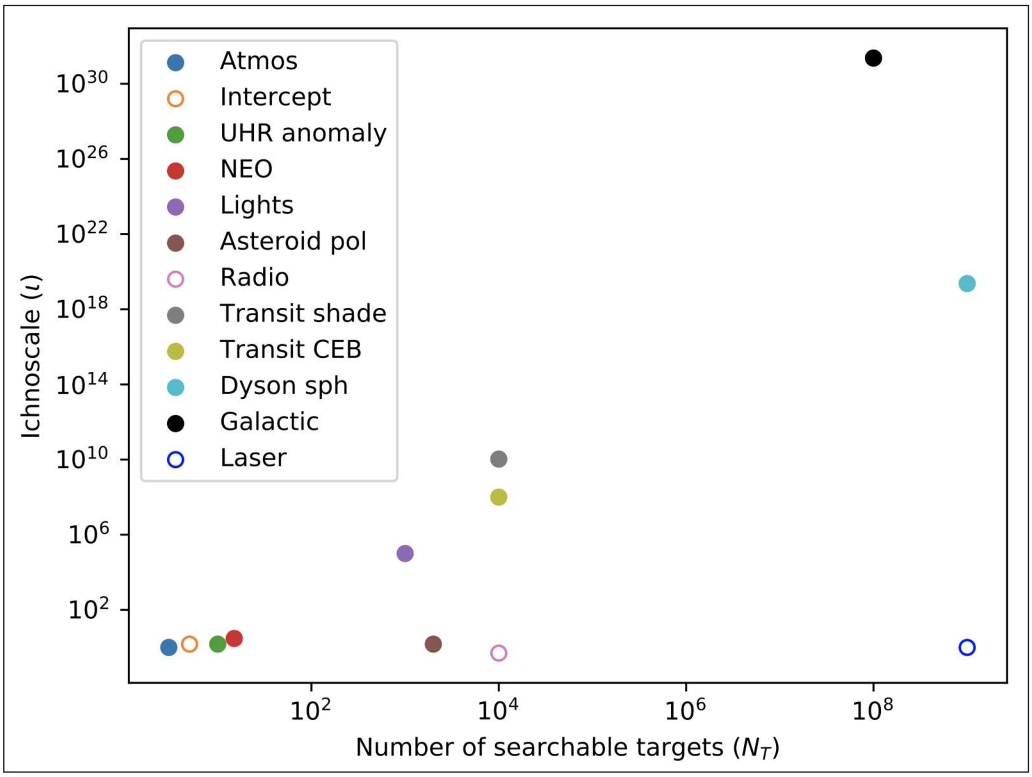


Megastructures such as Clarke's belts (populous swarms of satellites, an example above) or Dyson spheres (cages to imprison stellar heat) would reduce the brightness of planets and stars, producing an excess infrared, phenomena recognizable from Earth. [TechnoClimes 2020]

not yet available, or the construction of very large or very bright structures, works that would hardly be a top priority. It is also for this reason that many insiders believe that our first contact is more likely to take place with a more advanced civilization than ours.

"More or less advanced" is an expression often used when talking about a possible alien civilization. In reality, it has a very relative meaning, because we have only one experience and no idea how technologically more or less advanced others may be. TechnoClimes 2020 has provided a tool that allows for a less subjective assessment. It is an arbitrary but reasonable scale that uses the relative weight of each terrestrial technosignature as a unit of measurement. Technosignatures are quantified through a parameter called "ichnoscale" (footprint scale), which defines the relative value of a hypothetical alien technosignature with respect to its terrestrial expression. To better understand this concept, let's assume that an alien civilization has built a giant space station around its planet. In this specific case, the value of the ichnoscale would be equal to the average size of that megastructure divided by the average size of the International Space Station, the largest artifact currently present in Earth's orbit. Considering the small size of the ISS, it is understandable that the ichnoscale would be of some order of magnitude. As a second example, let's imagine we sight an alien probe passing through our solar system. In this case the ichnoscale would not be much bigger than one, since we too are theoretically able to send a probe to a nearby planetary system, as evidenced by

Technosignatures are observational manifestations of technology, particularly those that could be detected with the tools of astronomy. City lights, air pollution, and satellites are all examples of technosignatures on Earth. Could the next generation of telescopes find evidence of alien technology on another planet? [TechnoClimes 2020]



Ichnoscale (relative footprint of a given technosignature in units of current Earth technology) vs number of targets for several possible technosignatures. Filled (empty) circles represent continuous (discontinuous) observables. [Hector Socas-Navarro et al. – TechnoClimes 2020]

the development of the Breakthrough Starshot project.

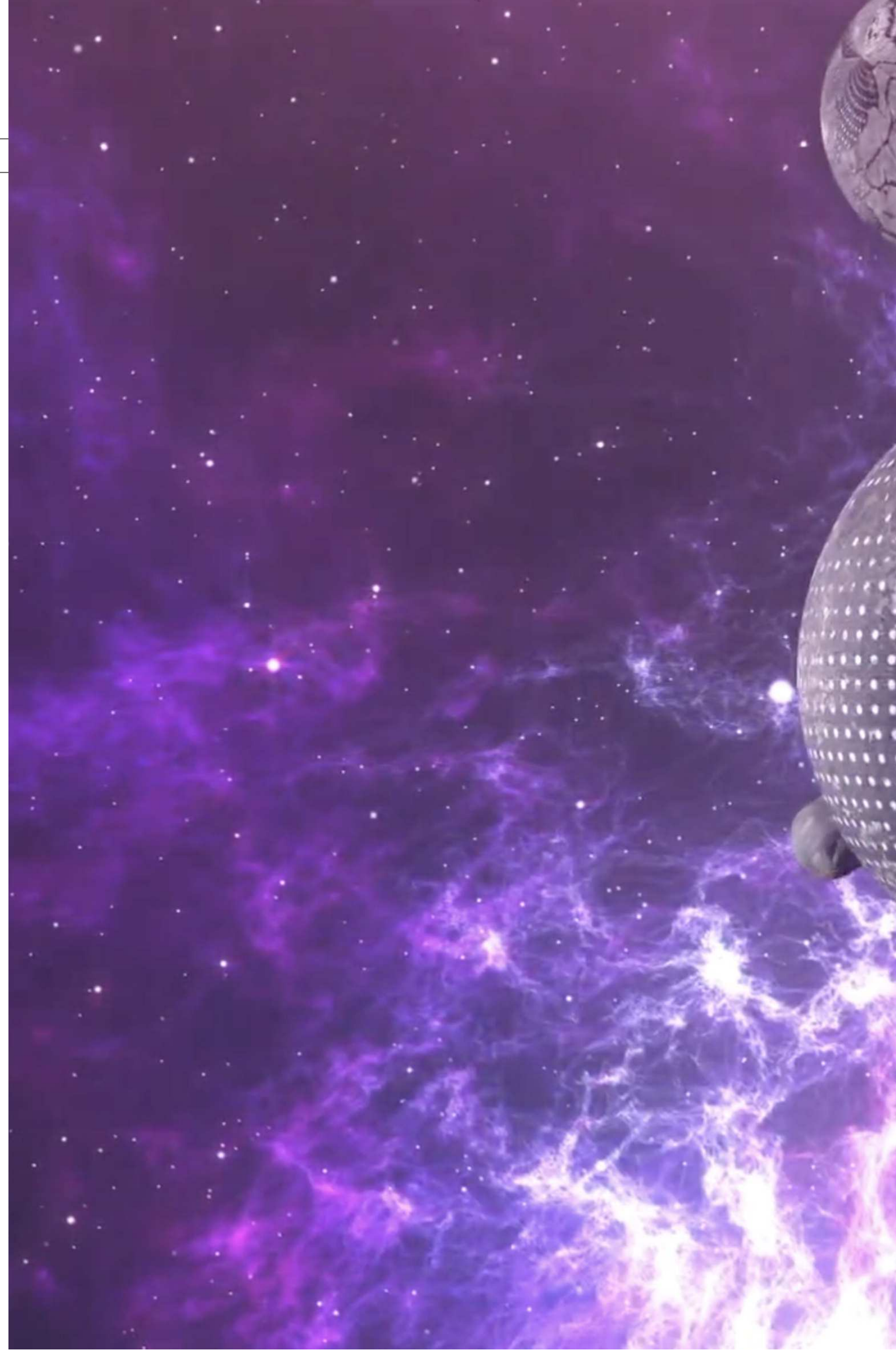
Some participants in TechnoClimes 2020 have put on a Cartesian plan the number of possible targets where to look for twelve different types of technosignatures and the related ichnoscale. From the resulting graph we can see that most of the technosignatures are expected in a limited number of targets and within relatively contained ichnoscale values. Since we can reasonably expect civilizations with low ichnoscale to be more abundant, it is no coincidence that the technosignatures most accessible to us appear in the lower part of the graph (where we could place ourselves).

Technosignatures of the most abundant targets, those represented on the right side of the graph, may seem the most obvious to look for. In reality, our current instrumentation is unsuitable for providing a precise localization (spatial resolution) of artificial infrared sources (Galactic and Dyson spheres). Better it could go with laser signal recording (Laser), which however could be discontinuous or occasional. For now, technosignatures requiring a direct characterization of exoplanets (Lights, Transit shade, Transit CEB) are also beyond our reach.

Six technosignatures with the lowest ichnoscale value remain, two of which (Intercept and Radio) are however very unpredictable. Among the remaining four technosignatures, three (UHR anomaly, NEO, Asteroid pol) concern the possibility of discovering artifacts of extraterrestrial origin on asteroids and the Moon, while the last one (Atmos) is the technosignature that we can most realistically hope to discover in the near future, that means traces of artificial pollutants in the atmosphere of a terrestrial planet, evidence of industrial or engineering activities.

But let's go back to the three previous technosignatures, those that at first glance seem the most fanciful and that contemplate the possibility

Hector Socas-Navarro, physicist at the Instituto de Astrofísica de Canarias, is the main creator of the scale that parameterizes the technosignatures. [IAC]



Hypothetical megastructures of planetary size could be detected due to the anomalous heat dispersion revealed compared to a natural rocky body. Alongside, some "hybridized" moons. [TechnoClimes 2020]

of finding, in heliocentric orbit or on the surfaces of rocky bodies, artifacts sent into our solar system by one or more alien civilizations. It seems very unlikely that such finds could be made, but the basic idea is not so crazy. We know well that the stars are not fixed with respect to each other and that in their motion around the center of the galaxy they can occasionally "graze" each other. It has been calculated that, on average, every 100,000 years a star transits less than a light-year from the Sun, penetrating the Oort Cloud. This implies that since life was born on Earth, some tens of thousands of stars have passed at a close enough distance to allow any technological civilizations they host to notice the chemical "contamination" of our atmosphere, caused precisely by the presence of life forms. Just as we are planning to send a probe into the probably sterile Proxima Centauri planetary system, over four light-years away, it is conceivable that others have planned a similar mission when, passing even closer to our solar system, they realized that on the third planet there was something far more vital.

Some TechnoClimes 2020 attendees believe that if we have received visits from alien probes, they may still be somewhere in our planetary system, albeit likely inactive and deteriorated. The same researchers suggest that if the aliens' goal was to study the Earth and its inhabitants (in a broad sense) for a relatively long period, those wrecks could be either on the Moon or on asteroids with orbits closer to that of our planet, such as the NEOs and the Earth's Trojans. It seems unrealistic that these populations of small asteroids could have been characterized so precisely by possible alien astronomers, to the point of planning and making a landing on one of them, in a position that allows the study of our planet. Inserting a probe into Earth's orbit would undoubtedly be less complicated and more informative. A subsequent deorbiting with entry into the atmosphere would have prudently erased all traces of the visit. Less discreet aliens could have placed observation instruments on the Moon, certainly well known to those who are able to observe the Earth from a few light-years away.

A civilization with ichnoscale slightly higher than ours would already be able to do all this, and we cannot entirely exclude the presence of alien technosignatures on the lunar surface. In fact, despite the intense and continuous mapping of our nat-

ural satellite, the maximum resolution with which we can regularly investigate its surface is that of 100 m/pixel offered by NASA's Lunar Reconnaissance Orbiter (LRO). An interstellar probe can be expected to be much smaller than that size, to ensure the shortest possible travel time. Indeed, since it is necessary to reach fractions of the speed of light, the mass must be reduced to the essential (according to our current knowledge).

LRO is, however, also capable of a much better resolution, 0.5 m/pixel, but this is only used on small areas of particular interest, such as the Apollo landing sites and those of other past and future missions. Mapping the entire lunar surface at that very high resolution would require telemetry capabilities not yet available, or the development of machine learning techniques that are just in their infancy, but which are indispensable for having most of the processing carried out directly by artificial intelligence aboard a lunar mapper. Only the images of anomalous structures would be sent to Earth for in-depth analysis.

The search for technosignatures is a relatively young branch of astrobiology, and some of its aspects may raise perplexity. However, it is also the only one among all the scientific disciplines that will be able to tell us if there is someone else out there who is aware of the universe. ■

ESA's Test-Bed Telescope 2 installed at La Silla

by ESO - Bárbara Ferreira

Part of the world-wide effort to scan and identify near-Earth objects, the European Space Agency's Test-Bed Telescope 2 (TBT2), a technology demonstrator hosted at ESO's La Silla Observatory in Chile, has now started operating. Working alongside its northern-hemisphere partner telescope, TBT2 will keep a close eye on the sky for asteroids that could pose a risk to Earth, testing hardware and software for a future telescope network. *"To be able to calculate the risk posed by potentially hazardous objects in the Solar System, we first need a census of these objects. The TBT project is a step in that direction,"* says Ivo Saviane, the site manager for ESO's La Silla Observatory in Chile.
The project, which is a collaboration between the European Southern Observatory (ESO) and the European Space Agency (ESA), *"is a test-bed to demonstrate the capabilities needed to detect and follow-up near-Earth objects with the same telescope system,"* says ESA's Head of the Optical Technologies Section Clemens Heese, who is leading this project.
The 56-cm telescope at ESO's La Silla and TBT1, its identical counterpart

The open dome of the European Space Agency's Test-Bed Telescope 2 stands out against its fellow telescopes at ESO's La Silla Observatory in Chile. The Test-Bed Telescope 2 joins its partner Test-Bed Telescope 1, located at ESA's deep-space ground station at Cebreros in Spain, scanning the sky for near-Earth objects. The project acts as a technology demonstrator for ESA's planned 'Flyeye' telescope network. The domes of ESO's 0.5 m and the Danish 0.5 m telescopes are visible in the background of this image. [F. Ocaña/J. Isabel/Quasar SR]

In this picture, an engineer reaches out of the white telescope dome towards the black structure of the Test-Bed Telescope 2, a European Space Agency telescope hosted at ESO's La Silla observatory, as it is lowered into place by crane. The dome is designed to protect the telescope from the harsh conditions of the Atacama Desert in Chile. [P. Sinclaire/ESO]

located at the ESA's deep-space ground station at Cebreros in Spain, will act as precursors to the planned 'Flyeye' telescope network, a separate project that ESA is developing to survey and track fast-moving objects in the sky. This future network will be entirely robotic; software will perform real-time scheduling of observations and, at the end of the day, it will report the positions and other information about the objects detected. The TBT project is designed to show that the software and hardware work as expected.

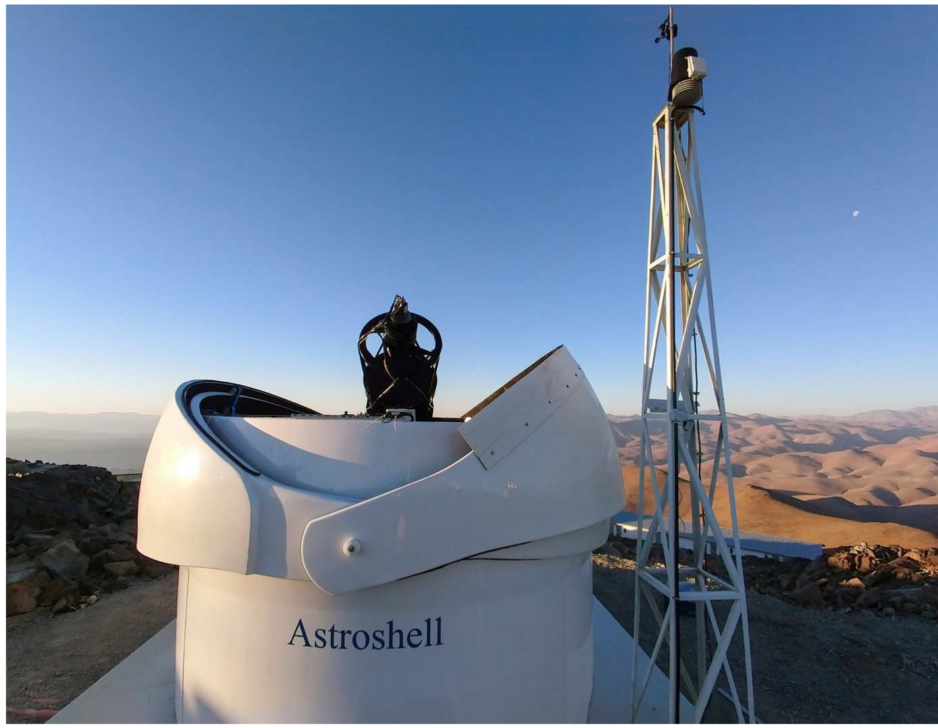
"The start of observations of TBT2 at La Silla will enable the observing system to work in its intended two-telescope configuration, finally fulfilling the project's objectives," says Heese.

While seriously harmful asteroid impacts on Earth are extremely rare, they are not inconceivable. The Earth has been periodically bombarded with both large and small asteroids for billions of years, and the 2013 Chelyabinsk meteor event, which caused some 1600 injuries, most due to flying splinters and broken glass, further raised the public's awareness of the threat posed by near-Earth objects. Larger objects do more damage, but are thankfully easier to spot and the orbits of known large asteroids are already thoroughly studied. However, it is estimated that there are large numbers of smaller, yet-undiscovered objects we are unaware of that could do serious damage if they were to hit a populated area.

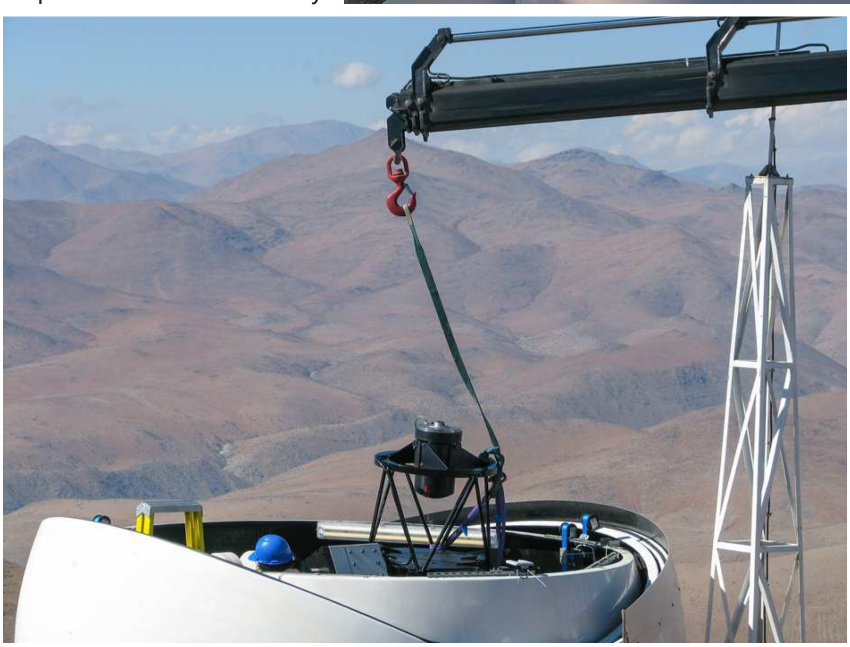
That's where TBT and the future planned network of Flyeye telescopes come in. Once fully operational the network's design would allow it to survey the night sky to track fast-moving objects, a significant advancement in Europe's capacity to spot potentially hazardous near-Earth objects.

TBT is part of an ongoing inter-organisational effort to build a more complete picture of these objects and the potential risks they pose. This project builds on ESO's previous involvement in protecting the Earth from potentially dangerous near-Earth objects. Both ESO and ESA are active in the United Nations-en-

dorsed International Asteroid Warning Network and many observations of these objects have been performed with ESO's telescopes. ESO's New Technology Telescope at La Silla, for example, has been used for observations of small near-Earth asteroids in support of the European NEOShield-2 project.
The ongoing inter-organisational collaboration between ESO and ESA is particularly significant in the study of near-Earth objects. While TBT is the first telescope project to be realised under a cooperation agreement between the two organisations, ESO has been helping ESA track potentially dangerous objects since 2014, by using its Very Large Telescope at Paranal Observatory



The black telescope structure of the European Space Agency's Test-Bed Telescope 2 peers out of its open dome in front of the rolling desert landscape. The telescope is located at ESO's La Silla Observatory, which sits at a 2400 metre altitude in the Chilean Atacama desert. [F. Ocaña/J. Isabel/Quasar SR]



This picture shows the Test-Bed Telescope 2 inside its dome, right after it was positioned in place with the help of a crane, against the dramatic backdrop of the Atacama Desert. It is the clear, dark Atacama skies that make this location ideal for ground-based telescopes. [P. Sinclaire/ESO]

to observe very faint objects. These efforts combined are a significant leap forward for the worldwide search and management of asteroids, and have already proved useful in ruling out collisions of asteroids with the Earth.
The installation and first light of TBT2 at ESO's La Silla Observatory was achieved under strict health and safety conditions. ESO's observatories temporarily stopped operations last year due to the COVID-19 pandemic, but have since resumed science observations under restrictions that ensure the safety and protection of everyone at the sites. ■

Stellar flare from Proxima Centauri recorded in multiple wavelengths

by ALMA Observatory

Astronomers using the Atacama Large Millimeter/submillimeter Array (ALMA) have spotted a flare from Earth's nearest neighboring star, Proxima Centauri, that is 100 times more powerful than any similar flare seen from the Sun. The flare, which is the largest ever recorded from the star, has revealed the inner workings of such events to astronomers, and could help to shape the hunt for life beyond the Solar System.

Stellar flares occur when the release of magnetic energy in stellar spots explodes in an intense burst of electromagnetic radiation that can be observed across the entire electromagnetic spectrum, from radio waves to gamma rays. This is the first time that a single stellar flare, other than those that occur on the Sun, has been observed with such complete wavelength coverage.

The study was precipitated by the serendipitous discovery of a flare from Proxima Centauri in 2018 ALMA archival data. *"We had never seen an M dwarf flare at millimeter wavelengths before 2018, so it was not known whether there was corresponding emission at other wavelengths,"* said Meredith MacGregor, an assistant professor at the Center for Astrophysics and Space Astronomy (CASA) and Department of Astrophysical and Planetary Sciences (APS) at CU Boulder, and the lead author on the study. To better understand the flares on Proxima Centauri — a red dwarf star located roughly four light-years or 20 trillion miles from Earth — a team of astronomers observed the star for 40 hours over the course of several months in 2019 using nine telescopes on the ground and in space.

In May 2019, Proxima Centauri ejected a violent flare that lasted just seven seconds, but generated a surge in both ultraviolet and millimeter wavelengths. The flare was characterized by a strong, impulsive spike never before seen at these

Artist's conception of the violent stellar flare from Proxima Centauri discovered by scientists in 2019 using nine telescopes across the electromagnetic spectrum, including the Atacama Large Millimeter/submillimeter Array (ALMA). Powerful flares eject from Proxima Centauri with regularity, impacting the star's planets almost daily. [NRAO/S. Dagnello]

wavelengths. The event was recorded by five of the nine telescopes involved in the study, including the Hubble Space Telescope (HST) in ultraviolet, and ALMA in millimeter wavelengths.

"The star went from normal to 14,000 times brighter when seen in ultraviolet wavelengths over the span of a few seconds," said MacGregor, adding that similar behavior was captured in millimeter wavelengths by ALMA at the same time.

"In the past, we didn't know that stars could flare in the millimeter range, so this is the first time we have gone looking for millimeter flares," said MacGregor, adding that the new observations could help researchers gather more information about how stars generate flares, which can have an impact on nearby life.

Powerful flares from our Sun are uncommon, occurring only a few times in a solar cycle. According to MacGregor, that's not the case on Proxima Centauri. *"Proxima Centauri's planets are getting hit by something like this not once in a century, but at least once a day, if not several times a day,"* said MacGregor. The star is prominent in discussions surrounding the prospect for life around red dwarf stars because of its proximity to Earth, and because it is host to Proxima Centauri b, a planet that resides in the star's habitable zone.

"If there was life on the planet nearest to Proxima Centauri, it would have to look very different than anything on Earth," MacGregor said. *"A human being on this planet would have a bad time."*

Future observations will focus on unveiling the many secrets behind Proxima Centauri's flares in the hopes of uncovering the internal mechanisms that cause such powerful outbursts.

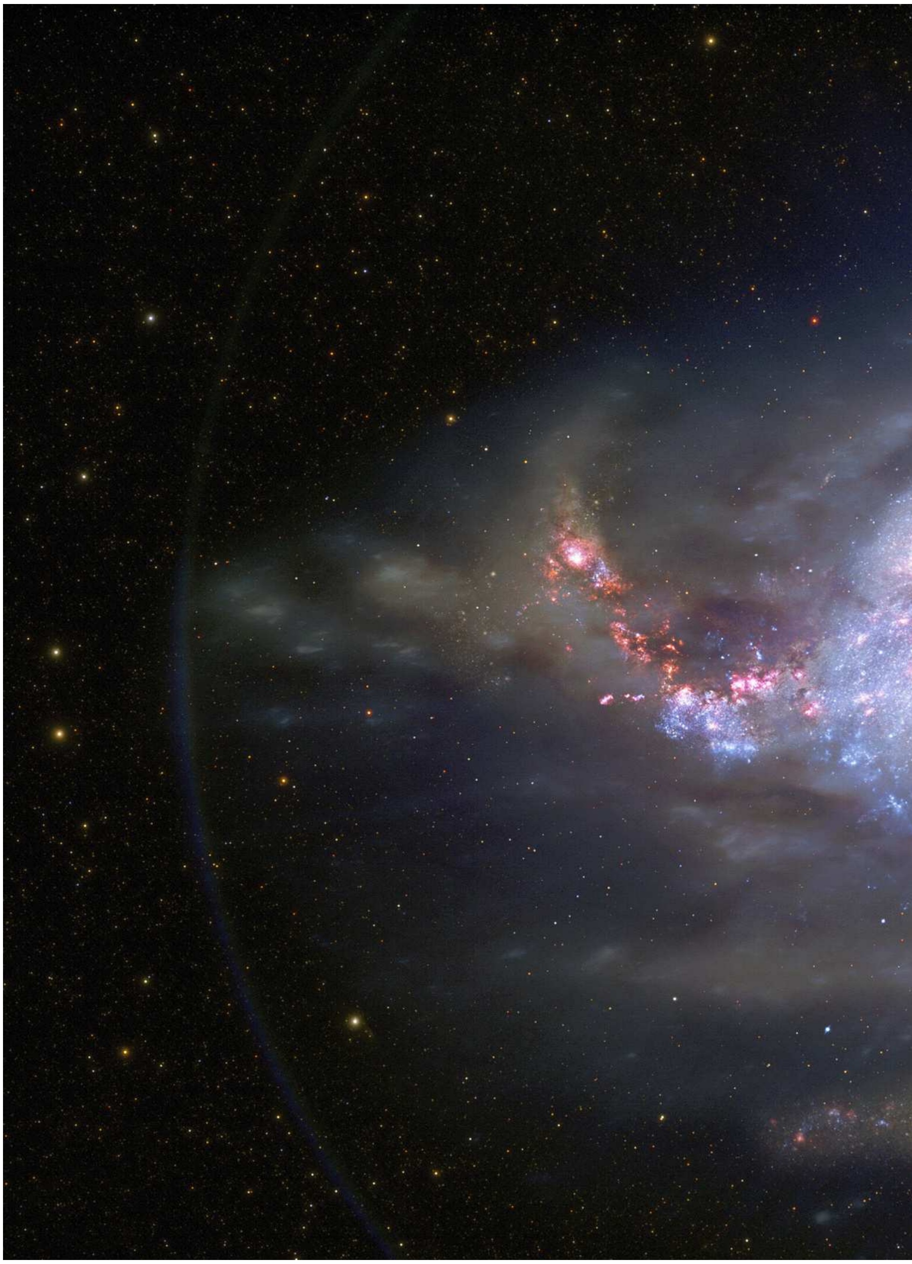
"We want to see what surprises this star has in store for us to help us understand the physics of stellar flaring," said MacGregor. ■

Black hole pairs found in distant merging galaxies

by NOIRLab - Amanda Kocz

Astronomers have found two close pairs of quasars in the distant Universe. Follow-up observations with Gemini North spectroscopically resolved one of the distant quasar pairs, after their discovery with the Hubble Space Telescope and Gaia spacecraft. These quasars are closer together than any pair of quasars found so far away, providing strong evidence for the existence of supermassive black hole pairs as well as crucial insight into galaxy mergers in the early Universe. The quasars in each of the two pairs are separated by just over 10,000 light-years, suggesting that they belong to two merging galaxies.

Double quasars are scientifically interesting but rare objects — particularly in the most distant reaches of the Universe — and these are the most distant quasars found that are so close together. We see these quasar pairs as they existed roughly 10 billion years ago. *"We estimate that in the distant Universe, for*



Astronomers have discovered two pairs of quasars in the distant Universe, about 10 billion light-years from Earth. In each pair, the two quasars are separated by only about 10,000 light-years, making them closer together than any other double quasars found so far away. The proximity of the quasars in each pair suggests that they are located within two merging galaxies. [International Gemini Observatory/ NOIRLab/NSF/AURA/J. da Silva]

every one thousand quasars, there is one double quasar. So finding these double quasars is like finding a needle in a haystack," commented Yue Shen, an astronomer at the University of Illinois and lead author of the paper announcing this discovery. Quasars are the intensely bright cores of distant galaxies, powered by the feeding frenzies of supermassive black holes. These energetic objects profoundly affect galaxy formation and evolution, making observations of quasar pairs in the early Universe a unique way for astronomers to investigate the evolution of merging galaxies. Quasar pairs also provide a natural laboratory in which to study the processes leading to the formation of binary supermassive black holes.
"This truly is the first sample of dual quasars at the peak epoch of galaxy formation that we can use to probe

CosmoView Episode 26: Black hole pairs found in distant merging galaxies. [International Gemini Obs./NOIRLab/NSF/AURA/J. da Silva/J. Pollard. Music: Stellardrone-Airglow]

ideas about how supermassive black holes come together to eventually form a binary," elaborated team member Nadia Zakamska of Johns Hopkins University.

Finding the two quasar pairs was a daunting challenge, requiring a new method that combined data from several space and ground-based telescopes, including the international Gemini Observatory, a Program of NSF's NOIRLab. Quasar pairs at such large distances can only be resolved by sharp-eyed telescopes such as Hubble or Gemini, but observing time on these telescopes is too valuable to use it to sweep through large areas of the night sky in search of rare astronomical objects.

To focus their search, the researchers first identified 15 quasars for further investigation using the Sloan Digital Sky Survey, a three-dimensional map of objects in the night sky. From this list of 15 quasars, they then used observations from the Gaia spacecraft to identify four potential quasar pairs. Finally, these candidates were imaged with the Hubble Space Telescope, which visually resolved two quasar pairs, giving this novel method a success rate of 50%.

The team then used the Gemini Multi-Object Spectrograph (GMOS) on Gemini North (located on Maunakea in Hawai'i) to verify the discovery and further investigate one of the quasar pairs. The combination of the sensitivity of GMOS and superb observing conditions allowed the team to resolve individual spectra from both quasars in the pair. These spectra provided the team with independent measurements of the distance to the quasars and their composition, as well as confirming that the two quasars are indeed a pair rather than a chance alignment of a single quasar with a foreground star.

"The Gemini observations were critically important to our success because they provided spatially resolved spectra to yield redshifts and spectroscopic confirmations simultaneously for both quasars in a double," explained Yu-Ching Chen, a graduate student at the University of Illinois who is on the discovery team. *"This method unambiguously rejected interlopers due to chance superpositions such as from unassociated star-quasar systems."*

While the team members are confident in their discovery, there is a small possibility that they have actually observed double images of single quasars. These astronomical doppelgängers can be formed by gravitational lensing, which occurs when an intervening massive galaxy distorts and splits the light from a distant object, often resulting in multiple images of that object. The researchers are convinced that this is highly unlikely, however, as they could not detect any foreground galaxies in their observations. With their method successfully demonstrated, the researchers now plan to search for more quasar pairs, building up a census of double quasars in the early Universe.

"This proof of concept really demonstrates that our targeted search for dual quasars is very efficient," concluded Hsiang-Chih Hwang, a graduate student at John Hopkins University and the principal investigator of the Hubble observations. *"It opens a new direction where we can accumulate a lot more interesting systems to follow up, which astronomers weren't able to do with previous techniques or datasets."*

"This exciting investigation illustrates yet again the discovery potential of combining archived survey data with new, focused observations from state-of-the-art facilities," said Martin Still, Gemini Program Officer at NSF. *"The international Gemini Observatory proved to be the ideal instrument to confirm the identity of these black holes and characterize their environment."* ■

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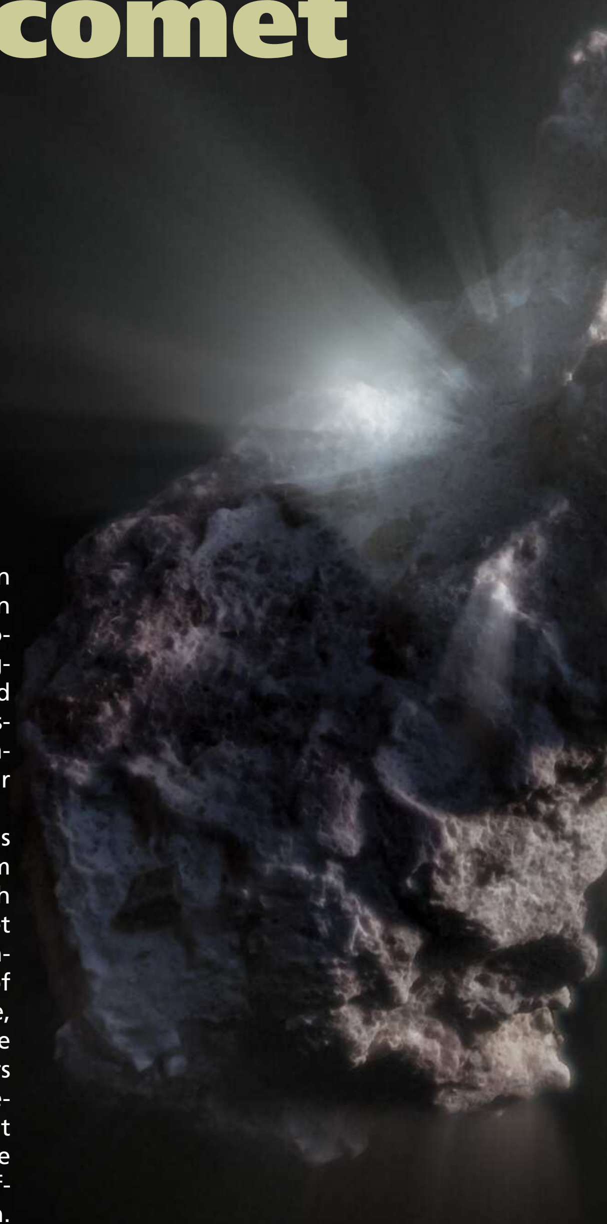
2I/Borisov may be the most pristine comet ever found

by ESO - Bárbara Ferreira

New observations with the European Southern Observatory's Very Large Telescope (ESO's VLT) indicate that the rogue comet 2I/Borisov, which is only the second and most recently detected interstellar visitor to our Solar System, is one of the most pristine ever observed. Astronomers suspect that the comet most likely never passed close to a star, making it an undisturbed relic of the cloud of gas and dust it formed from. 2I/Borisov was discovered by amateur astronomer Gennady Borisov in August 2019 and was confirmed to have come from beyond the Solar System a few weeks later. *"2I/Borisov could represent the first truly pristine comet ever observed,"* says Stefano Bagnulo of the Armagh Observatory and Planetarium, Northern Ireland, UK, who led the new study published in *Nature Communications*. The team believes that the comet had never passed close to any star before it flew by the Sun in 2019. Bagnulo and his colleagues used the FORS2 instrument on ESO's VLT, located in northern Chile, to study 2I/Borisov in detail using a technique called polarimetry. Since this technique is regularly used to study comets and other small bodies of our Solar System, this allowed the team to compare the interstellar visitor with our local comets.

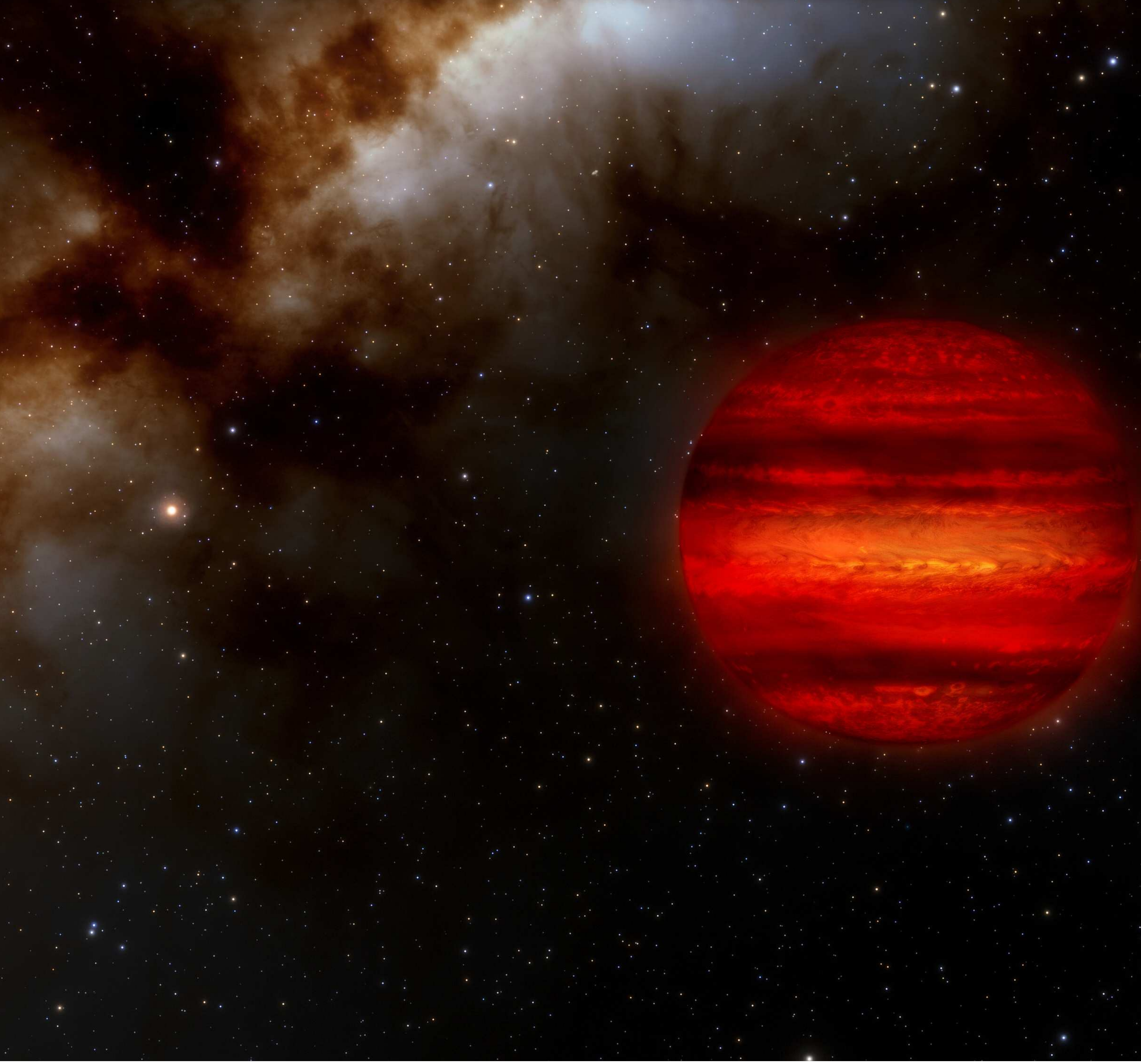
The team found that 2I/Borisov has polarimetric properties distinct from those of Solar System comets, with the exception of Hale–Bopp. Comet Hale–Bopp received much public interest in the late 1990s as a result of being easily visible to the naked eye, and also because it was one of the most pristine comets astronomers had ever seen. Prior to its most recent passage, Hale–Bopp is thought to have passed by our Sun only once and had therefore barely been affected by solar wind and radiation. This means it was pristine, having a composition very similar to that of the cloud of gas and dust it — and the rest of the Solar System — formed from some 4.5 billion years



This image shows an artist's impression of what the surface of the 2I/Borisov comet might look like. [ESO/M. Kormesser]

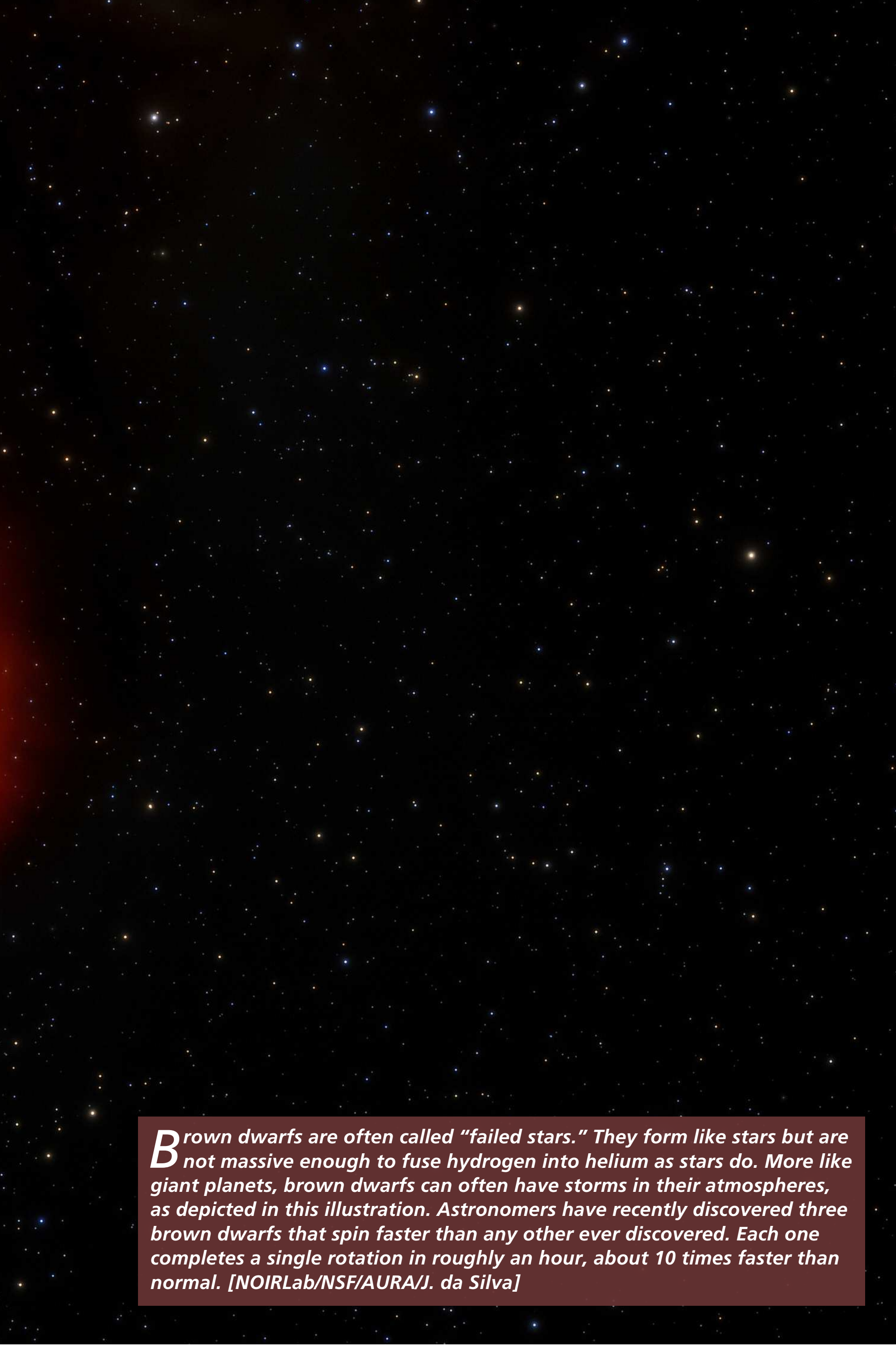
ago. By analysing the polarisation together with the colour of the comet to gather clues on its composition, the team concluded that 2I/Borisov is in fact even more pristine than Hale–Bopp. This means it carries untarnished signatures of the cloud of gas and dust it formed from. *"The fact that the two comets are remarkably similar suggests that the environment in which 2I/Borisov originated is not so different in composition from the environment in the early Solar System,"* says Alberto Cellino, a co-author of the study, from the Astrophysical Observatory of Torino, National Institute for Astrophysics (INAF), Italy. Olivier Hainaut, an astronomer at ESO in Germany who studies comets and other near-Earth objects but was not involved in this new study, agrees. *"The main result — that 2I/Borisov is not like any other comet except Hale–Bopp — is very strong,"* he says, adding that *"it is very plausible they formed in very similar conditions."*

"The arrival of 2I/Borisov from interstellar space represented the first opportunity to study the composition of a comet from another planetary system and check if the material that comes from this comet is somehow different from our native variety," explains Ludmilla Kolokolova, of the University of Maryland in the US, who was involved in the *Nature Communications* research. Bagnulo hopes astronomers will have another, even better, opportunity to study a rogue comet in detail before the end of the decade. *"ESA is planning to launch Comet Interceptor in 2029, which will have the capability of reaching another visiting interstellar object, if one on a suitable trajectory is discovered,"* he says, referring to an upcoming mission by the European Space Agency. ■



Gemini North helps set rotational speed limit for brown dwarfs

by NOIRLab - Amanda Kocz



Brown dwarfs are often called "failed stars." They form like stars but are not massive enough to fuse hydrogen into helium as stars do. More like giant planets, brown dwarfs can often have storms in their atmospheres, as depicted in this illustration. Astronomers have recently discovered three brown dwarfs that spin faster than any other ever discovered. Each one completes a single rotation in roughly an hour, about 10 times faster than normal. [NOIRLab/NSF/AURA/J. da Silva]

Three brown dwarfs have been discovered spinning faster than any other found before. Astronomers at Western University in Canada first measured the rotation speeds of these brown dwarfs using data from NASA's Spitzer Space Telescope and confirmed them with follow-up observations with the Gemini North telescope on Maunakea in Hawai'i and the Carnegie Institution for Science's Magellan Baade telescope in Chile. Gemini North is one of the pair of telescopes that make up the international Gemini Observatory, a Program of NSF's NOIRLab. *"We seem to have come across a speed limit on the rotation of brown dwarfs,"* said Megan Tannock, the Western University physics and astronomy graduate student who led the discovery. *"Despite extensive searches, by our own team and others, no brown dwarfs have been found to rotate any faster. In fact, faster spins may lead to a brown dwarf tearing itself apart."*

Brown dwarfs are, simply put, failed stars. They form like stars but are less massive and more like giant planets.

Tannock and Western University astronomer Stanimir Metchev worked with international collaborators to find three rapidly rotating brown dwarfs spinning around their axes once every hour. This is approximately 10 times faster than normal, and about 30 percent faster than the most rapid rotations previously measured in such objects.

The astronomers used large ground-based telescopes, Gemini North in Hawai'i and Magellan Baade in Chile, to confirm the rapid rotations. They did this by measuring alterations in the brown dwarfs' light caused by the Doppler effect and using a computer model to match those alterations to spin rates. The researchers found that these brown dwarfs spin with speeds of about 350,000 kilometers per hour (around 220,000 miles per hour) at their equator, which is 10 times faster than Jupiter.

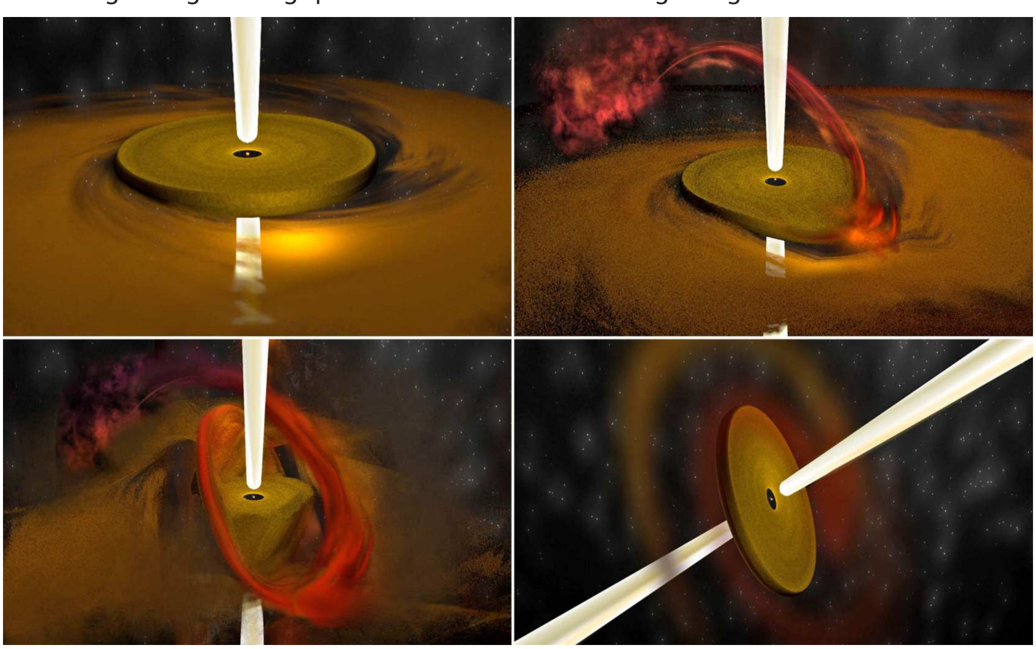
"These unusual brown dwarfs are spinning at dizzying speeds," said Sandy Leggett, an astronomer at Gemini North who studies brown dwarfs. *"At about 350,000 kilometers per hour, the relatively weak gravity of the brown dwarfs is barely holding them together. This exciting discovery by the Tannock team has identified rotational limits beyond which these objects may not exist."*

The team first identified the rapid rotation rates by using NASA's Spitzer Space Telescope to measure how quickly the brightness of the objects varied. *"Brown dwarfs, like planets with atmospheres, can have large weather storms that affect their visible brightness,"* explained Metchev. *"The observed brightness variations show how frequently the same storms are seen as the object spins, which reveals the brown dwarf's spin period."* ■

ALMA shows massive young stars forming in "chaotic mess"

by ALMA Observatory - Nicolás Lira

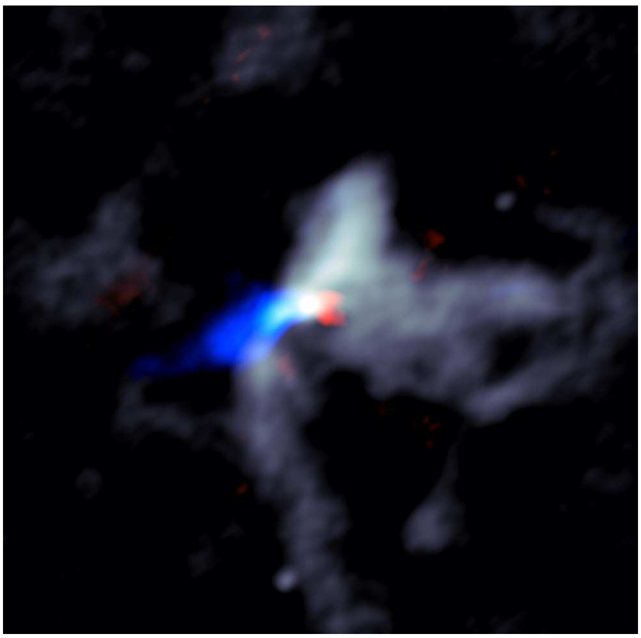
A team of astronomers using the Atacama Large Millimeter/submillimeter Array (ALMA) has taken a big step toward answering a longstanding question — do stars much more massive than the Sun form in the same way as their smaller siblings? Young, still-forming stars similar in mass to the Sun are observed gaining material from their surrounding clouds of gas and dust in a relatively orderly manner. The incoming material forms a disk orbiting the young star and that disk feeds the star at a pace it can digest. Condensations of material within the disk form planets that will remain after the star's growth process is complete.



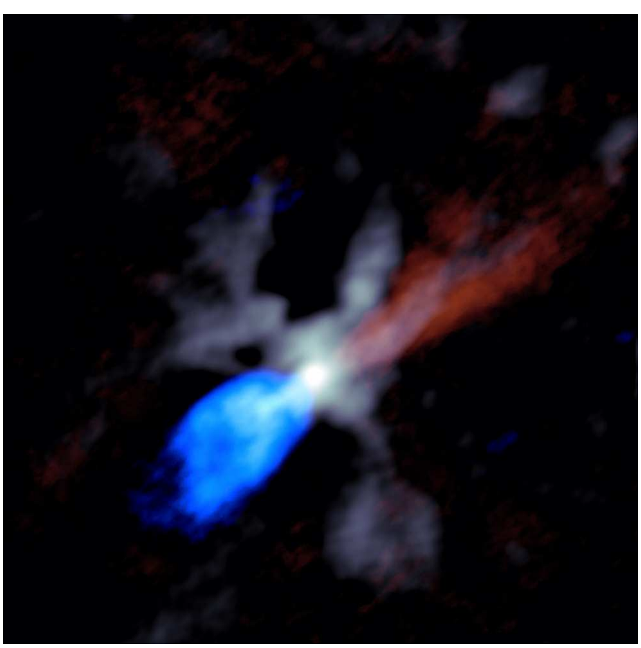
Artist's conception illustrates process seen in forming stars much more massive than the Sun. At top left, material is being drawn into the young star through an orbiting disk which generates a fast-moving jet of material outward. At top right, material begins coming in from another direction, and at bottom left, begins deforming the original disk until, at bottom right, the disk orientation – and the jet orientation – have changed. [Bill Saxton, NRAO/AUI/NSF]

The disks are commonly seen around young low-mass stars, but have not been found around much more massive stars in their forming stages. Astronomers questioned whether the process for the larger stars is simply a scaled-up version of that for the smaller ones.

"Our ALMA observations now provide compelling evidence that the answer is no," said Ciriaco Goddi, of Radboud University Nijmegen in the Netherlands.



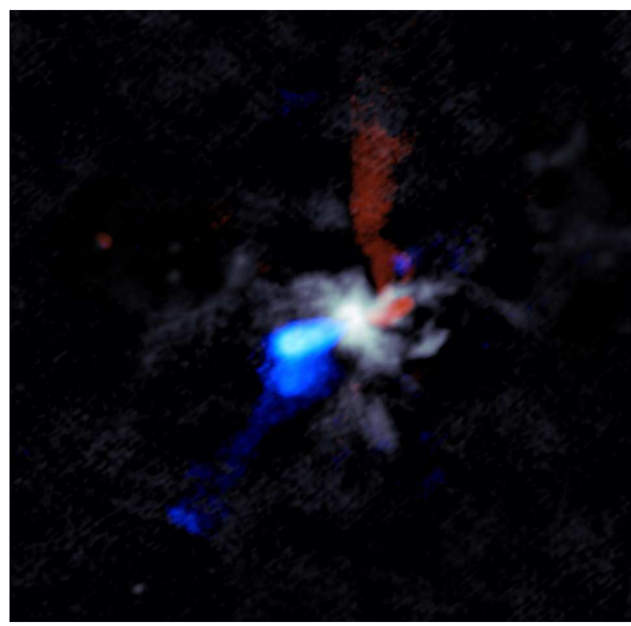
ALMA image of the chaotic scene around some massive young protostars: W51e8 (above), W51e2 (right), W51n (below). Grey shows dust close to the star, while the red and blue indicate material in the jets moving rapidly outward from the star. Red shows material moving away from Earth and blue material moving toward Earth. [Goddi, Ginsburg, et al., Sophia Dagnello, NRAO/AUI/NSF]



Goddi led a team that used ALMA to study three high-mass, very young stars in a star-forming region called W51, about 17,000 light-years from Earth. They used ALMA when its antennas were spread apart to their farthest extent, providing resolving power capable of making images 10 times sharper than previous studies of such objects.

They were looking for evidence of the large, stable disks seen orbiting smaller young stars. Such disks propel fast-moving jets of material outward perpendicular to the plane of the disk.

"With ALMA's great resolving power, we expected to finally see a disk. Instead, we found that the feeding zone of these objects looks like a chaotic mess," said Adam Ginsburg of the University of Florida.

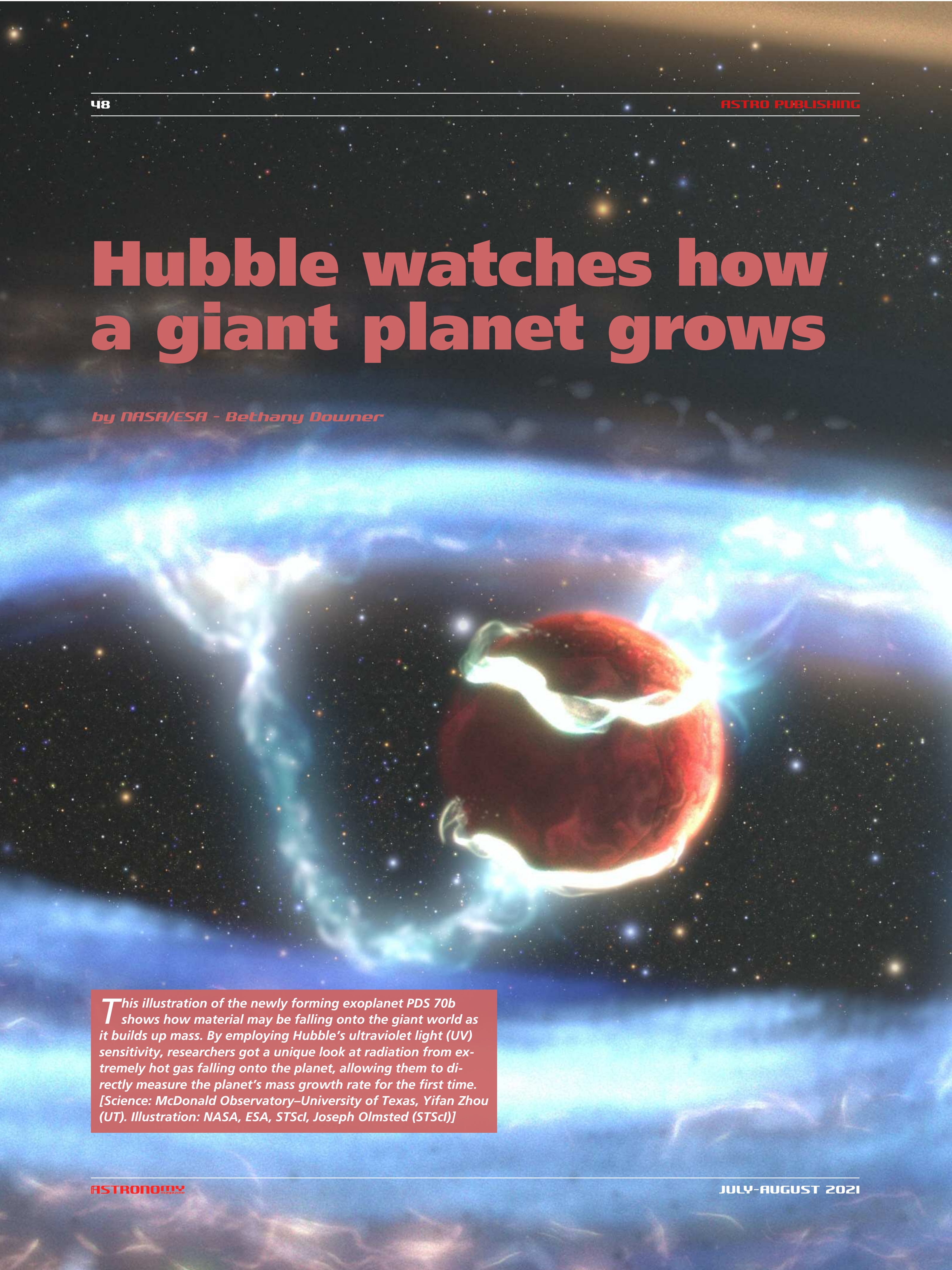


The observations showed streamers of gas falling toward the young stars from many different directions. Jets indicated that there must be small disks that are yet unseen. In one case, it appears that some event actually flipped a disk about 100 years ago.

The researchers concluded that these massive young stars form, at least in their very early stages, by drawing in material from multiple directions and at unsteady rates, in sharp contrast to the stable inflows seen in smaller stars. The multiple channels of incoming material, the astronomers said, probably prevent the formation of the large, steady disks seen around smaller stars. *"Such a 'disordered infall' model was first proposed based on computer simulations, and we now have the first observational evidence supporting that model,"* Goddi said.

Hubble watches how a giant planet grows

by NASA/ESA - Bethany Downer



This illustration of the newly forming exoplanet PDS 70b shows how material may be falling onto the giant world as it builds up mass. By employing Hubble's ultraviolet light (UV) sensitivity, researchers got a unique look at radiation from extremely hot gas falling onto the planet, allowing them to directly measure the planet's mass growth rate for the first time. [Science: McDonald Observatory–University of Texas, Yifan Zhou (UT). Illustration: NASA, ESA, STScI, Joseph Olmsted (STScI)]

NASA's Hubble Space Telescope is giving astronomers a rare look at a Jupiter-sized, still-forming planet that is feeding off material surrounding a young star.

"We just don't know very much about how giant planets grow," said Brendan Bowler of the University of Texas at Austin. *"This planetary system gives us the first opportunity to witness material falling onto a planet. Our results open up a new area for this research."*

Though over 4,000 exoplanets have been cataloged so far, only about 15 have been directly imaged to date by telescopes. And the planets are so far away and small, they are simply dots in the best photos. The team's fresh technique for using Hubble to directly image this planet paves a new route for further exoplanet research, especially during a planet's formative years.

This huge exoplanet, designated PDS 70b, orbits the orange dwarf star PDS 70, which is already known to have two actively forming planets inside a huge disk of dust and gas encircling the star. The system is located 370 light-years from Earth in the constellation Centaurus.

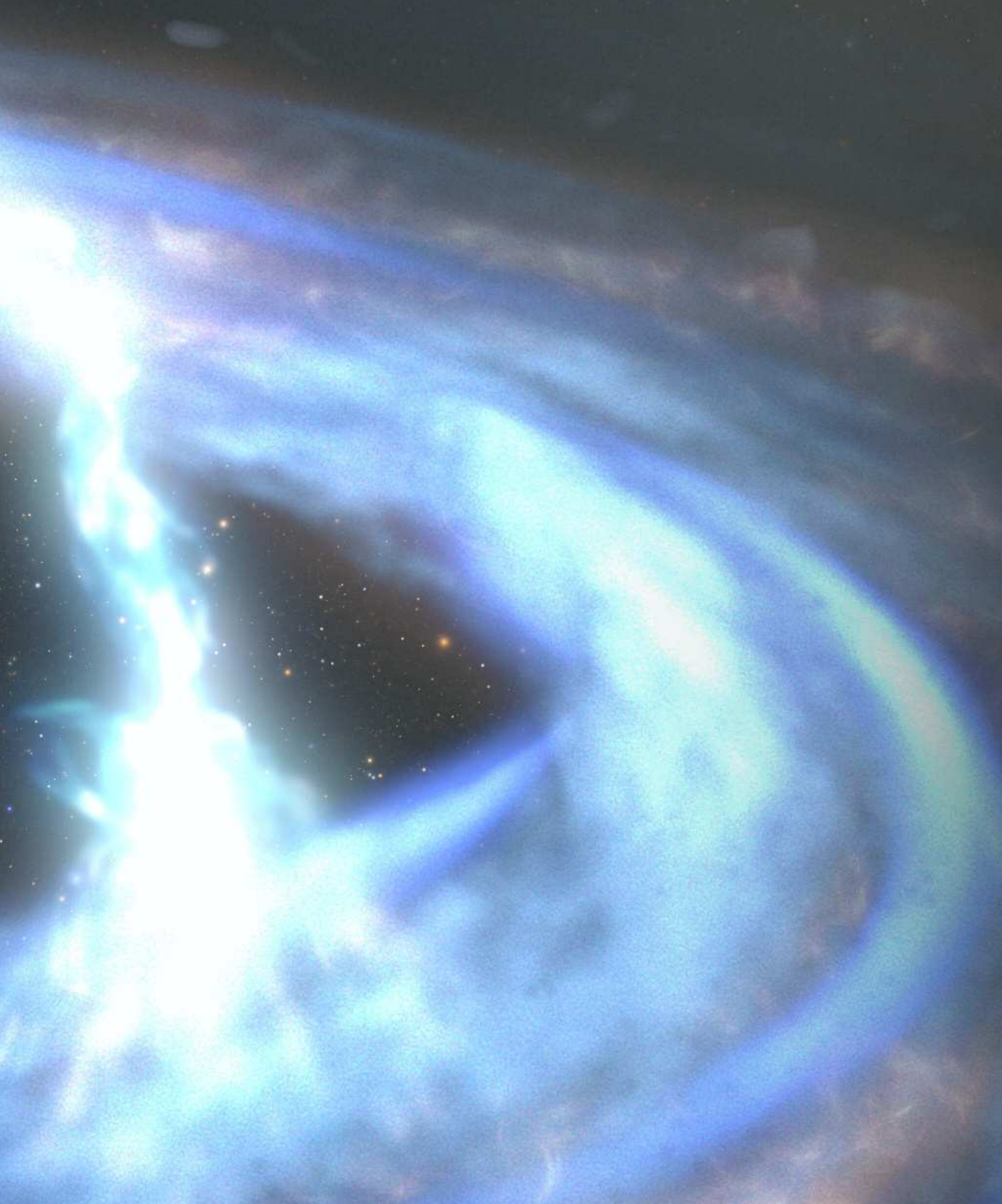
"This system is so exciting because we can witness the formation of a planet," said Yifan Zhou, also of the University of Texas at Austin. *"This is the youngest bona fide planet Hubble has ever directly imaged."* At a youthful 5 million years, the planet is still gathering material and building up mass.

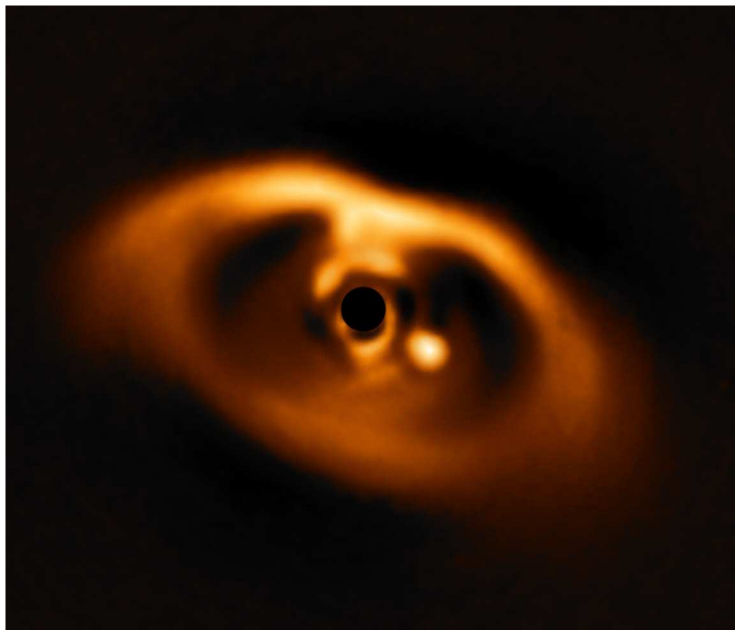
Hubble's ultraviolet light (UV) sensitivity offers a unique look at radiation from extremely hot gas falling onto the planet. *"Hubble's observations allowed us to estimate how fast the planet is gaining mass,"* added Zhou.

The UV observations, which add to the body of research about this planet, allowed the team to directly measure the planet's mass growth rate for the first time. The remote world has already bulked up to five times the mass of Jupiter over a period of about 5 million years. The present measured accretion rate has dwindled to the point where, if the rate remained steady for another million years, the planet would only increase by approximately and additional 1/100th of a Jupiter mass.

Zhou and Bowler emphasize that these observations are a single snapshot in time – more data are required to determine if the rate at which the planet is adding mass is increasing or decreasing. *"Our measurements suggest that the planet is in the tail end of its formation process."*

The youthful PDS 70 system is filled with a primordial gas-and-dust disk that provides fuel to feed the growth





The European Southern Observatory's Very Large Telescope caught the first clear image of a forming planet, PDS 70b, around a dwarf star in 2018. The planet stands out as a bright point to the right of the center of the image, which is blacked out by the coronagraph mask used to block the light of the central star. [ESO, VLT, André B. Müller (ESO)]

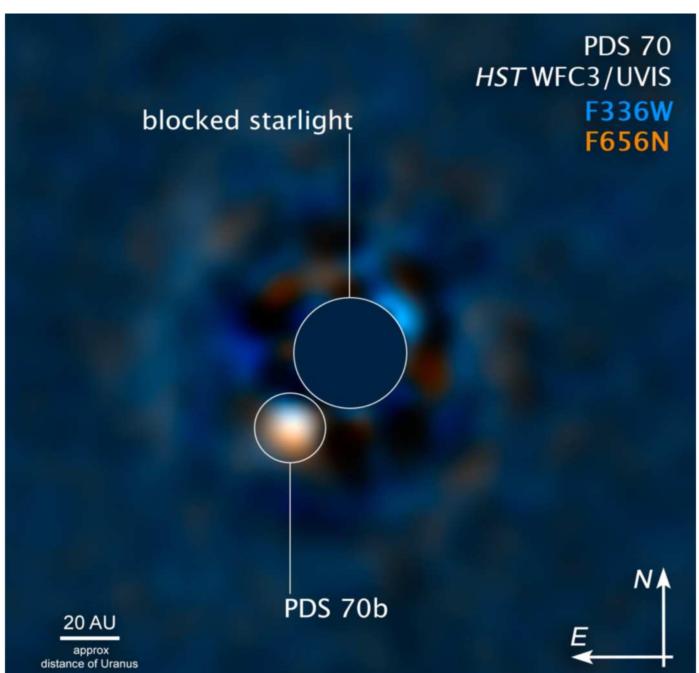
of planets throughout the entire system. The planet PDS 70b is encircled by its own gas-and-dust disk that's siphoning material from the vastly larger circumstellar disk. The researchers hypothesize that magnetic field lines extend from its circumplanetary disk down to the exoplanet's atmosphere and are funneling material onto the planet's surface.

"If this material follows columns from the disk onto the planet, it would cause local hot spots," Zhou explained. *"These hot spots could be at least 10 times hotter than the temperature of the planet."* These hot patches were found to glow fiercely in UV light. These observations offer insights into how gas giant planets formed around our Sun 4.6 billion years ago. Jupiter may have bulked up on a surrounding disk of infalling material. Its major moons would have also formed from leftovers in that disk.

A challenge to the team was overcoming the glare of the parent star. PDS 70b orbits at approximately the same distance as Uranus does from the Sun, but its star is more than 3,000 times brighter than the planet at UV wavelengths.

As Zhou processed the images, he very carefully removed the star's glare to leave behind only light emitted by the planet. In doing so, he improved the limit of how close a planet can be to its star in Hubble observations by a factor of five.

"Thirty-one years after launch, we're still finding new ways to use Hubble," Bowler added. *"Yifan's observing strategy and post-processing technique will open new windows into studying similar systems, or even the same system, repeatedly with Hubble. With future observations, we could potentially discover when the majority of the gas and dust falls onto their planets and if it does so at a constant rate."* ■



Hubble observations pinpoint planet PDS 70b. A coronagraph on Hubble's camera blocks out the glare of the central star for the planet to be directly observed. Though over 4,000 exoplanets have been cataloged so far, only about 15 have been directly imaged to date by telescopes. The team's fresh technique for using Hubble to directly image this planet paves a new route for further exoplanet research, especially during a planet's formative years. [NASA, ESA, McDonald Observatory–University of Texas, Yifan Zhou (UT). Image processing: Joseph DePasquale (STScI)]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