FY23 GPRAMA Science Performance Goals

PERFORMANCE GOALS	APD	ESD	HPD	PSD	BPSD
1.1.1 NASA shall demonstrate progress in characterizing the behavior of the Earth system, including its various components and the naturally -occurring and human -induced forcings that act upon it.		🟢			
1.1.2 NASA shall demonstrate progress in enhancing understanding of the interacting processes that control the behavior of the Earth system, and in utilizing the enhanced knowledge to improve predictive capability.		🟢			
1.2.1 NASA shall demonstrate progress in exploring and advancing understanding of the physical processes and connections of the Sun, space, and planetary environments throughout the Solar System.		🟡	🟢	🟡	
1.2.2 NASA shall demonstrate progress in exploring and probing the origin, evolution, and destiny of the galaxies, stars, and planets that make up the Universe.	🟢		🟡	🟡	
1.2.3 NASA shall demonstrate progress in exploring, observing, and understanding objects in the Solar System in order to understand how they formed, operate, interact, and evolve.			🟡	🟢	
1.2.4 NASA shall demonstrate progress in discovering and studying planets around other stars.	🟢		🟡	🟡	
1.2.5 NASA shall demonstrate progress in improving understanding of the origin and evolution of life on Earth to guide the search for life elsewhere, exploring and finding locations where life could have existed or could exist today, and exploring whether planets around other stars could harbor life.	🟡		🟡	🟢	
1.2.6 NASA shall demonstrate progress in developing the capability to detect and knowledge to predict extreme conditions in space to protect life and society and to safeguard human and robotic explorers beyond Earth.			🟢		
1.2.7 NASA shall demonstrate progress in identifying, characterizing, and predicting objects in the Solar System that pose threats to Earth or offer resources for human exploration.				🟢	
1.2.8 NASA shall demonstrate progress in understanding the properties of physical and biological systems in spaceflight environments to advance scientific knowledge, enable space exploration, and benefit life on Earth.					🟢

🟢 Leading contributor 🟡 Supporting contributor

2024 Astrophysics Division input for Government Performance and Results Modernization Act n (GPRAMA) review by Astrophysics Advisory Committee

ASTROPHYSICS

Specifically, in 2024 the APD was challenged to advance progress on two strategic science goals:

Multiyear Performance Goal 1.2.2: ***NASA shall demonstrate progress in exploring and probing the origin, evolution, and destiny of the galaxies, stars, and planets that make up the Universe.***

Multiyear Performance Goal 1.2.4: ***NASA shall demonstrate progress in discovering and studying planets around other stars.***

Furthermore, the APD contributes to the following additional performance goal, whose primary review responsibility falls under the purview of the Planetary Science Division (PSD) and Planetary Science Advisory Committee (PAC).

Multiyear Performance Goal: 1.2.5: ***NASA shall demonstrate progress in improving understanding of the origin and evolution of life on Earth to guide the search for life elsewhere, exploring and finding locations where life could have existed or could exist today, and exploring whether planets around other stars could harbor life.***

The Astrophysics Division continues to operate a number of missions and offer research opportunities that provide the broad astronomical community tools and support to make a range of discoveries across a wide variety of interdisciplinary, multiwavelength studies of our Universe. Progress towards meeting both primary performance goals in FY 2024 is judged to be **XX** by the Astrophysics Advisory Committee (**xx** affirmative votes).

Examples of progress in FY 2024, derived from NASA facilities and research opportunities are provided below.

Strategic Objective 1.2: Understand the Sun, Earth, Solar System, and Universe.

Multiyear Performance Goal 1.2.2: ***NASA shall demonstrate progress in exploring and probing the origin, evolution, and destiny of the galaxies, stars, and planets that make up the Universe.***

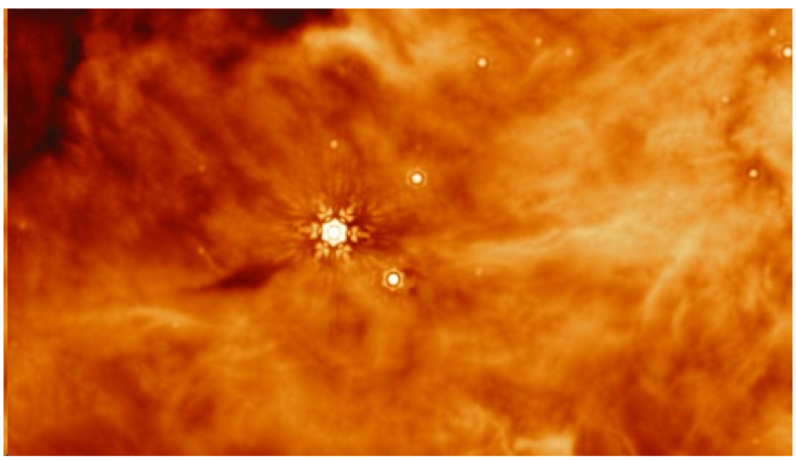
The progress towards meeting the performance goal is judged to be **XX** (xx individual votes).

Summary

The items featured in this section are:

- NASA's Webb Finds Ethanol, Other Icy Ingredients for Worlds
- NASA's Webb Opens New Window on Supernova Science

1. NASA’s Webb Finds Ethanol, Other Icy Ingredients for Worlds



This image at a wavelength of 15 microns was taken by MIRI (the Mid-Infrared Instrument) on NASA’s James Webb Space Telescope, of a region near the protostar known as IRAS 23385. IRAS 23385 and IRAS 2A (not visible in this image) were targets for a recent research effort by an international team of astronomers that used Webb to discover that the key ingredients for making potentially habitable worlds are present in early-stage protostars, where planets have not yet formed.
NASA, ESA, CSA, W. Rocha (Leiden University) Released: March 13, 2024

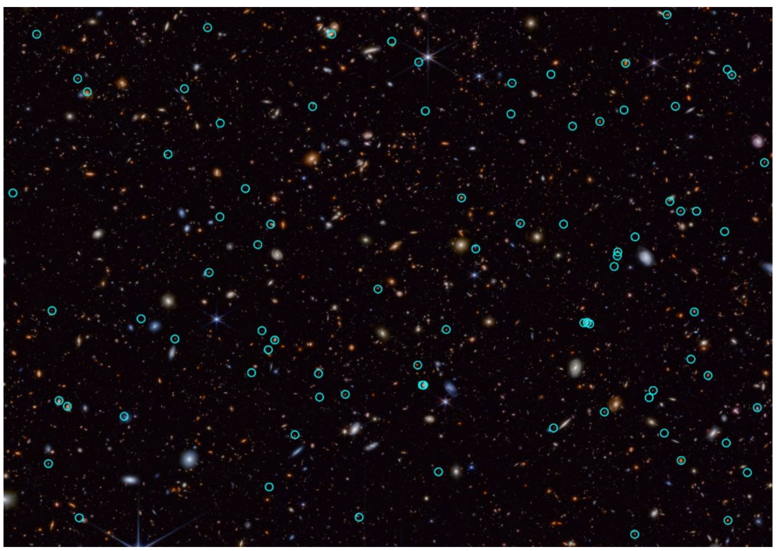
NASA’s James Webb Space Telescope has identified ethanol and a variety of other icy compounds surrounding two young protostars known as IRAS 2A and IRAS 23385. Although planets are not yet forming around those stars, these and other molecules detected there by Webb represent key ingredients for making potentially habitable worlds. An international team of astronomers used Webb’s MIRI (Mid-Infrared Instrument) to identify a variety of icy compounds made up of complex organic molecules like ethanol (alcohol) and likely acetic acid (an ingredient in vinegar). This work builds on previous Webb detections of diverse ices in a cold, dark molecular cloud.

As several complex organic molecules (COMs), including those detected in the solid phase in this research, were previously detected in the warm gas phase, it is now believed that they originate from the sublimation of ices. Sublimation is to change directly from a solid to a gas without becoming a liquid. Therefore, detecting COMs in ices makes astronomers hopeful about improved understanding of the origins of other, even larger molecules in space. Scientists are also keen to explore to what extent these COMs are transported to planets at much later stages of protostellar evolution. COMs in cold ices are thought to be easier to transport from molecular clouds to planet-forming disks than warm, gaseous molecules. These icy COMs can therefore be incorporated into comets and asteroids, which in turn may collide with forming planets, delivering the ingredients for life to possibly flourish. The science team also

detected simpler molecules, including formic acid (which causes the burning sensation of an ant sting), methane, formaldehyde, and sulfur dioxide. Research suggests that sulfur-containing compounds like sulfur dioxide played an important role in driving metabolic reactions on the primitive Earth.

Of particular interest is that one of the sources investigated, IRAS 2A, is characterized as a low-mass protostar. IRAS 2A may therefore be like the early stages of our own solar system. As such, the chemicals identified around this protostar may have been in the first stages of development of our solar system and later delivered to the primitive Earth. These observations were made for the JOYS+ (James Webb Observations of Young ProtoStars) program.

2. NASA's Webb Opens New Window on Supernova Science



The JADES Deep Field uses observations taken by NASA's James Webb Space Telescope (JWST) as part of the JADES (JWST Advanced Deep Extragalactic Survey) program. A team of astronomers studying JADES data identified about 80 objects (circled in green) that changed in brightness over time. Most of these objects, known as transients, are the result of exploding stars or supernovae.

Prior to this survey, only a handful of supernovae had been found above a redshift of 2, which corresponds to when the universe was only 3.3 billion years old — just 25% of its current age. The JADES sample contains many supernovae that exploded even farther in the past, when the universe was less than 2 billion years old. It includes the farthest one ever spectroscopically confirmed, at a redshift of 3.6. Its progenitor star exploded when the universe was only 1.8 billion years old. Credit: NASA, ESA, CSA, STScI, JADES Collaboration

NASA's James Webb Space Telescope is giving scientists their first detailed glimpse of supernovae from a time when our universe was just a small fraction of its current age. A team has identified 10 times more supernovae in the early universe than were previously known. A few of the newfound exploding stars are the most distant examples of their type, including those used to measure the universe's expansion rate.

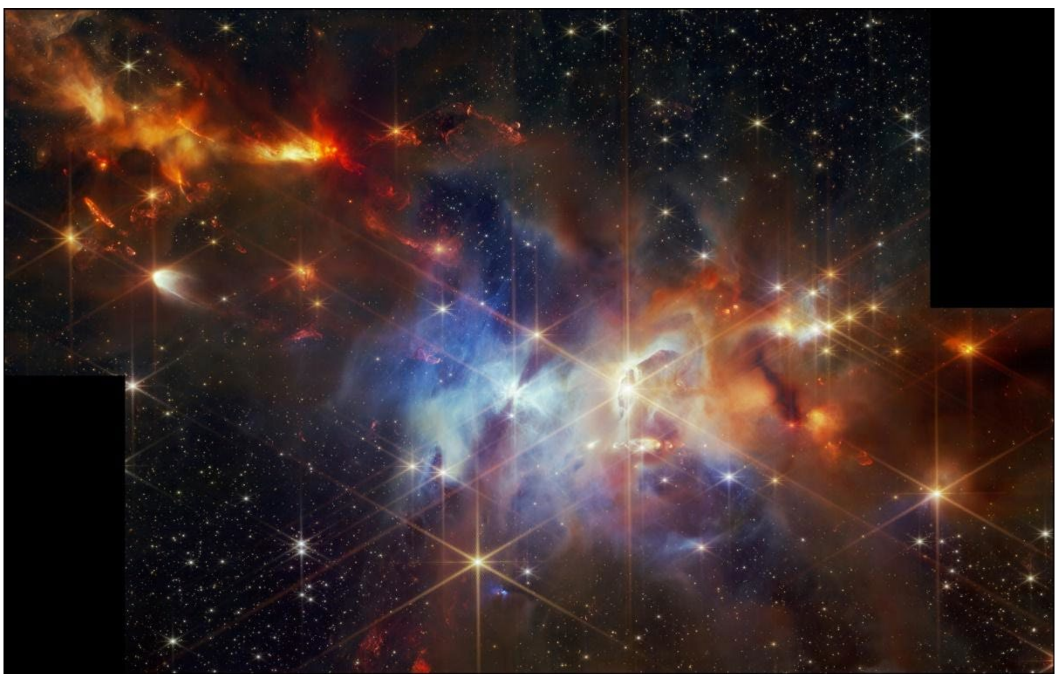
To make these discoveries, the team analyzed imaging data obtained as part of the JWST Advanced Deep Extragalactic Survey (JADES) program. Webb is ideal for finding extremely distant supernovae because their light is stretched into longer wavelengths — a phenomenon known as cosmological redshift. With JADES, scientists are seeing supernovae when the universe was in its "teens" or "pre-teens." In the future, they hope to look back to the "toddler" or "infant" phase of the universe. This is really the first sample of what the high-

redshift universe looks like for transient science in the efforts to identify whether distant supernovae are fundamentally different from or very much like what we see in the nearby universe.

To discover the supernovae, the team compared multiple images taken up to one year apart and looked for sources that disappeared or appeared in those images. These objects that vary in observed brightness over time are called transients, and supernovae are a type of transient. In all, the JADES Transient Survey Sample team uncovered about 80 supernovae in a patch of sky only about the thickness of a grain of rice held at arm's length. A number of high-redshift supernovae were identified, including the farthest one ever spectroscopically confirmed, at a redshift of 3.6. Its progenitor star exploded when the universe was only 1.8 billion years old. It is a so-called core-collapse supernova, an explosion of a massive star.

Type Ia supernovae are exploding stars so predictably bright that they are used to measure far-off cosmic distances and help scientists to calculate the universe's expansion rate. This team identified at least one Type Ia supernova at a redshift of 2.9. The light from this explosion began traveling to us 11.5 billion years ago when the universe was just 2.3 billion years old. The previous distance record for a spectroscopically confirmed Type Ia supernova was a redshift of 1.95, when the universe was 3.4 billion years old.

3. First of Its Kind Detection Made in Striking New Webb Image

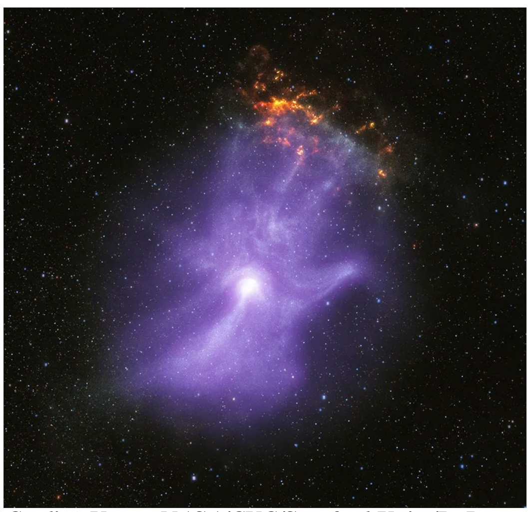


In this image of the Serpens Nebula from NASA's James Webb Space Telescope, astronomers found a grouping of aligned protostellar outflows within one small region (the top left corner). Serpens is a reflection nebula, which means it's a cloud of gas and dust that does not create its own light, but instead shines by reflecting the light from stars close to or within the nebula. NASA, ESA, CSA, K. Pontoppidan (NASA's JPL) and J. Green (STSci).

NASA's James Webb Space Telescope's Near-Infrared Camera (NIRCam) captured a long-awaited phenomenon. In this image of the Serpens Nebula, astronomers found an intriguing group of protostellar outflows, formed when jets of gas spewing from newborn stars collide with nearby gas and dust at high speeds, in the northern area (seen at the upper left) of this young, nearby star-forming region. Typically, these objects have varied orientations within one region. Here, however, they are slanted in the same direction, to the same degree, like sleet pouring down during a storm. The discovery of these aligned objects, made possible due to Webb's exquisite spatial resolution and sensitivity in near-infrared wavelengths, is providing insight into the fundamentals of how stars are born.

This region has been home to other coincidental discoveries, including the flapping "Bat Shadow," which earned its name when 2020 data from NASA's Hubble Space Telescope revealed a star's planet-forming disk to flap, or shift (this feature is visible at the center.) Next steps for the team are to use Webb's NIRSpec (Near-Infrared Spectrograph) to investigate the chemical make-up of the cloud, determining how volatile chemicals survive star and planet formation.

4. NASA X-ray Telescopes Reveal the "Bones" of a Ghostly Cosmic Hand



Credits: X-ray: NASA/CXC/Stanford Univ./R. Romani et al. (Chandra); NASA/MSFC (IXPE); Infared: NASA/JPL-Caltech/DECaPS; Image Processing: NASA/CXC/SAO/J. Schmidt)
Caption: By combining data from Chandra and IXPE, astronomers are learning more about how a pulsar is injecting particles into space and shaping its environment. The X-ray data are shown along with infrared data from the Dark Energy Camera in Chile. Young pulsars can create jets of matter and antimatter moving away from the poles of the pulsar, along with an intense wind, forming a "pulsar wind nebula." This one, known as MSH 15-52, has a shape resembling a human hand and provides insight into how these objects are formed.

NASA's Chandra X-ray Observatory and the Imaging X-ray Polarimetry Explorer (IXPE) have combined their imaging powers to reveal the behavior of a dead collapsed star that lives on through plumes of particles of energized matter and antimatter. In 2001, Chandra first observed the pulsar PSR B1509-58 and revealed that its pulsar wind nebula (referred to as MSH 15-52) resembles a human hand. Now, NASA's newest X-ray telescope, IXPE, has observed MSH 15-52 for about 17 days. In large regions the amount of polarization is remarkably high, reaching the maximum level expected from theoretical work. To achieve that strength, the magnetic field must be very straight and uniform, meaning there is little turbulence in those regions of the pulsar wind nebula. One particularly interesting feature is a bright X-ray jet directed from the pulsar to the "wrist" at the bottom of the image. The new IXPE data reveal that the polarization at the start of the jet is low, likely because this is a turbulent region with complex, tangled magnetic fields associated with the generation of high-energy particles. By the end of the jet the magnetic field lines appear to straighten and become much more uniform, causing the polarization to become much larger. These results imply that particles are given an energy boost in complex turbulent regions near the

pulsar at the base of the palm, and flow to areas where the magnetic field is uniform along the wrist, fingers and thumb. IXPE had detected similar magnetic fields for the Vela and Crab pulsar wind nebulae, which implies that they may be surprisingly common in these objects.

5. NASA's Chandra Peers into Densest, Weirdest Stars

Supernova remnant 3C 58. Credits: X-ray: NASA/CXC/ICE-CSIC/A. Marino et al.; Optical: SDSS; Image Processing: NASA/CXC/SAO/J. Major

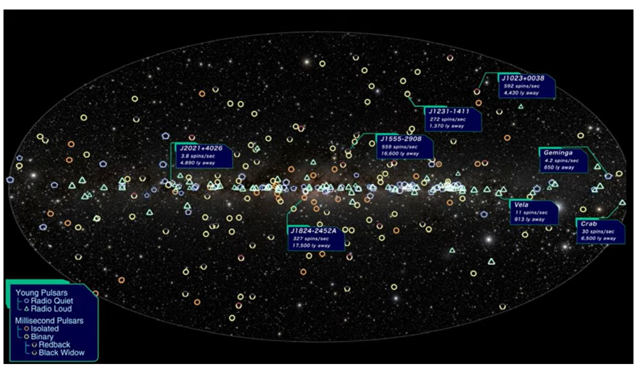
NASA's Chandra X-ray Observatory has allowed astronomers to take an important step toward understanding some of the densest and strangest objects in the universe. These results show that the interiors of neutron stars may contain a special type of ultra-dense matter that does not exist anywhere else in the universe.

For many years, scientists have wanted to investigate the nature of matter in neutron stars, including basic properties such as the pressures and temperatures in different parts of their interiors. They refer to this as understanding the neutron star's "equation of state." Data from Chandra and ESA's XMM-Newton of a sample of 70 young neutron stars is providing new clues. Specifically, the X-ray data shows how quickly the surfaces of these neutron stars are cooling over time and what information that gives about the matter within. The team thinks that part of the explanation for the rapid cooling is that these neutron stars are more massive than most of the rest.

Researchers turned to machine learning, to compare the data to different equations of state. Their results imply that a significant fraction of the equations of state can be ruled out. One possibility is a type of radioactive decay near the center of neutron stars where neutrinos carry away much of the energy and

heat, causing rapid cooling. Another idea is that there are individual quarks inside at least some neutron stars. Lastly, a type of exotic matter where particles are not mostly protons and neutrons, which are composed of three quarks, but are dominated by another type of particle called a meson, composed of a quark and an antiquark, might be to blame. These particles are usually very short-lived, lasting less than a billionth of a second, but in the special conditions in the center of a neutron star they could last much longer.

6. NASA's Fermi Mission Nets 300 Gamma-Ray Pulsars…and Counting



NASA's Fermi Gamma-ray Space Telescope has discovered 294 gamma-ray-emitting pulsars, while another 34 suspects await confirmation. This is 27 times the number known before the mission launched in 2008 and was published on Nov. 27, 2023 in a new catalog produced by a French-led international team at the Bordeaux Astrophysics Laboratory in Gironde, France.

The new catalog represents the work of 170 scientists across the globe. A dozen radio telescopes carry out regular monitoring of thousands of pulsars, and radio astronomers search for new pulsars within gamma-ray sources discovered by Fermi. Other researchers have teased out gamma-ray pulsars that have no radio counterparts through millions of hours of computer calculation, a process called a blind search. Of the 3,400 pulsars known, most of them observed via radio waves and located within our Milky Way galaxy, only about 10% also pulse in gamma rays, the highest-energy form of light.

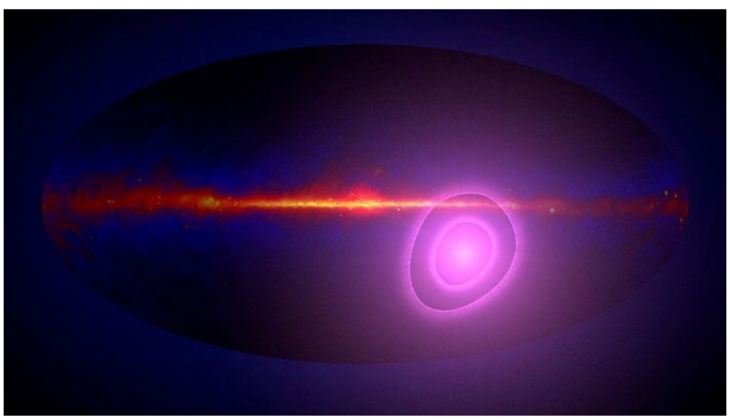
Pulsars that are thousands of times older spin much faster than young ones. One example of these so-called millisecond pulsars (MSPs) is J1824-2452A. It whirls around 328 times a second and, with an age of about 30 million years, ranks among the youngest MSPs known. "Before Fermi, we didn't know if MSPs would be visible at high energies, but it turns out they mostly radiate in gamma rays and now

make up fully half of our catalog," said co-author Lucas Guillemot, an associate astronomer at the Laboratory of Physics and Chemistry of the Environment and Space and the University of Orleans, France.

Farther afield, Fermi discovered the first gamma-ray pulsar in another galaxy, the neighboring Large Magellanic Cloud, in 2015. And in 2021, astronomers announced the discovery of a giant gamma-ray flare from a different type of neutron star (called a magnetar) located in the Sculptor galaxy, about 11.4 million light-years away.

"More than 15 years after its launch, Fermi remains an incredible discovery machine, and pulsars and their neutron star kin are leading the way," said Elizabeth Hays, the mission's project scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

7. NASA's Fermi Detects Surprise Gamma-Ray Feature Beyond Our Galaxy -



Credit: NASA's Goddard Space Flight Center. This artist's concept shows the entire sky in gamma rays with magenta circles illustrating the uncertainty in the direction from which more high-energy gamma rays than average seem to be arriving.

Astronomers with NASA's Fermi Gamma-ray Space Telescope have found an unexpected and as yet unexplained feature outside of our galaxy. With 13 years of data, scientists found a much stronger gamma-ray signal in a different part of the sky than what was expected. Intriguingly, the gamma-ray signal is found in a similar direction and with a nearly identical magnitude as another unexplained feature, one produced by some of the most energetic cosmic particles ever detected. The team was searching for a gamma-ray feature related to the CMB (cosmic microwave background), the oldest light in the universe. Scientists say the CMB originated when the hot, expanding universe had cooled enough to form the first atoms, an event that released a burst of light that, for the first time, could permeate the cosmos. In order to study the tiny temperature variations within the CMB (cosmic microwave background), this signal must be removed. Astronomers generally regard the pattern as a result of the motion of our own solar system relative to the CMB at about 230 miles (370 kilometers) per second. This motion will give rise to a dipole signal in the light coming from any astrophysical source, but so far the CMB is the only one that has been precisely measured. The scientists combined 13 years of Fermi LAT observations of gamma rays above about 3 billion electron volts (GeV). They removed all resolved and identified sources and stripped out the central plane of our Milky Way galaxy in order to analyze the extragalactic gamma-ray background. Findings revealed a gamma-ray dipole with a peak in the southern

sky away from the CMB's, and a magnitude 10 times greater than expected. It may be related to a similar feature reported for the highest-energy cosmic rays.

Cosmic rays are accelerated charged particles – mostly protons and atomic nuclei. The rarest and most energetic particles, called UHECRs (ultrahigh-energy cosmic rays), carry more than a billion times the energy of 3 GeV gamma rays, and their origins remain one of the biggest mysteries in astrophysics. Since 2017, the Pierre Auger Observatory in Argentina has reported a dipole in the arrival direction of UHECRs. Being electrically charged, cosmic rays are diverted by the galaxy's magnetic field by different amounts depending on their energies, but the UHECR dipole peaks in a sky location similar to what Kashlinsky's team finds in gamma rays. And both have strikingly similar magnitudes – about 7% more gamma rays or particles than average coming from one direction and correspondingly smaller amounts arriving from the opposite direction.

The scientists think it's likely the two phenomena are linked – that as yet unidentified sources are producing both the gamma rays and the ultrahigh-energy particles. To solve this cosmic conundrum, astronomers must either locate these mysterious sources or propose alternative explanations for both features.

8. NASA's Roman Mission Gets Cosmic 'Sneak Peak' From Supercomputers

This image is a slice of a much larger simulation depicting the cosmos as NASA's Nancy Grace Roman Space Telescope will see it when it launches. Every blob and speck of light represents a distant galaxy, except for the urchinlike spiky dots, which represent foreground stars in our Milky Way galaxy. Credit: C. Hirata and K. Cao (OSU) and NASA's Goddard Space Flight Center.

Scientists at NASA's Jet Propulsion Laboratory contributed to a project that sets the stage for two telescopes investigating one of astrophysics' biggest mysteries.

Researchers are diving into a synthetic universe to help us better understand the real one. Using supercomputers at the U.S. Department of Energy's Argonne National Laboratory in Illinois, scientists have created nearly 4 million simulated images depicting the cosmos as NASA's Nancy Grace Roman Space Telescope and the Vera C. Rubin Observatory in Chile will see it.

Michael Troxel, an associate professor of physics at Duke University in Durham, North Carolina, led the simulation campaign as part of a broader project called OpenUniverse. The team is now releasing a 10-terabyte subset of this data, with the remaining 390 terabytes to follow this fall once they've been processed.

"Using Argonne's now-retired Theta machine, we accomplished in about nine days what would have taken around 300 years on your laptop," said Katrin Heitmann, a cosmologist and deputy director of Argonne's High Energy Physics division who managed the project's supercomputer time. "The results will shape Roman and Rubin's future attempts to illuminate dark matter and dark energy while offering other scientists a preview of the types of things they'll be able to explore using data from the telescopes."

A Cosmic Dress Rehearsal

For the first time, this simulation factored in the telescopes' instrument performance, making it the most accurate preview yet of the cosmos as Roman and Rubin will see it once they start observing. Rubin, jointly funded by the NSF (National Science Foundation) and DOE (U.S. Department of Energy), will begin operations in 2025, and NASA's Roman will launch by May 2027.

The simulation's precision is important because scientists will comb through the observatories' future data in search of tiny features that will help them unravel the biggest mysteries in cosmology.

Roman and Rubin will both explore dark energy — the mysterious force thought to be accelerating the universe's expansion. Since it plays a major role in governing the cosmos, scientists are eager to learn more about it. Simulations like OpenUniverse help them understand signatures that each instrument imprints on the images and iron out data processing methods now so they can decipher future data correctly. Then scientists will be able to make big discoveries even from weak signals.

"OpenUniverse lets us calibrate our expectations of what we can discover with these telescopes," said Jim Chiang, a staff scientist at DOE's SLAC National Accelerator Laboratory in Menlo Park, California, who helped create the simulations. "It gives us a chance to exercise our processing pipelines, better understand our analysis codes, and accurately interpret the results so we can prepare to use the real data right away once it starts coming in."

Then they'll continue using simulations to explore the physics and instrument effects that could reproduce what the observatories see in the universe.

Telescope Teamwork

It took a large and talented team from several organizations to conduct such an immense simulation.

"Few people in the world are skilled enough to run these simulations," said Alina Kiessling, a research scientist at NASA's Jet Propulsion Laboratory in Southern California and the principal investigator of OpenUniverse. "This massive undertaking was only possible thanks to the collaboration between the DOE, Argonne, SLAC, and NASA, which pulled all the right resources and experts together."

And the project will ramp up further once Roman and Rubin begin observing the universe.

"We'll use the observations to make our simulations even more accurate," Kiessling said. "This will give us greater insight into the evolution of the universe over time and help us better understand the cosmology that ultimately shaped the universe."

The Roman and Rubin simulations cover the same patch of the sky, totaling about 0.08 square degrees (roughly equivalent to a third of the area of sky covered by a full Moon). The full simulation to be released later this year will span 70 square degrees, about the sky area covered by 350 full Moons.

Overlapping them lets scientists learn how to use the best aspects of each telescope —— Rubin's broader view and Roman's sharper, deeper vision. The combination will yield better constraints than researchers could glean from either observatory alone.

"Connecting the simulations like we've done lets us make comparisons and see how Roman's space-based survey will help improve data from Rubin's ground-based one," Heitmann said. "We can explore ways to tease out multiple objects that blend together in Rubin's images and apply those corrections over its broader coverage."

Scientists can consider modifying each telescope's observing plans or data processing pipelines to benefit the combined use of both.

"We made phenomenal strides in simplifying these pipelines and making them usable," Kiessling said. A partnership with Caltech/IPAC's IRSA (Infrared Science Archive) makes simulated data

accessible now so when researchers access real data in the future, they'll already be accustomed to the tools. "Now we want people to start working with the simulations to see what improvements we can make and prepare to use the future data as effectively as possible."

More About the Mission

OpenUniverse, along with other simulation tools being developed by Roman's Science Operations and Science Support centers, will prepare scientists for the large datasets expected from Roman. The project brings together dozens of experts from NASA's JPL, DOE's Argonne, IPAC, and several U.S. universities to coordinate with the Roman Project Infrastructure Teams, SLAC, and the Rubin LSST DESC (Legacy Survey of Space and Time Dark Energy Science Collaboration). The Theta supercomputer was operated by the Argonne Leadership Computing Facility, a DOE Office of Science user facility.

The Nancy Grace Roman Space Telescope is managed at NASA's Goddard Space Flight Center in Greenbelt, Maryland, with participation by NASA's Jet Propulsion Laboratory and Caltech/IPAC in Southern California, the Space Telescope Science Institute in Baltimore, and a science team comprising scientists from various research institutions. The primary industrial partners are BAE Systems, Inc. in Boulder, Colorado; L3Harris Technologies in Rochester, New York; and Teledyne Scientific & Imaging in Thousand Oaks, California.

The Vera C. Rubin Observatory is jointly funded by the National Science Foundation and the DOE Office of Science, with early construction funding received from private donations through the LSST Discovery Alliance.

9. NASA's Hubble Traces 'String of Pearls' Star Clusters in Galaxy Collisions

Galaxy AM 1054-325 has been distorted into an S-shape from a normal pancake-like spiral shape by the gravitational pull of a neighboring galaxy, seen in this NASA Hubble Space Telescope image. A consequence of this is that newborn clusters of stars form along a stretched-out tidal tail for thousands of light-years, resembling a string of pearls.
NASA, ESA, STScI, Jayanne English (University of Manitoba)

NASA's Hubble Space Telescope has homed in on 12 interacting galaxies that have long, tadpole-like tidal tails of gas, dust, and a plethora of stars. Hubble's exquisite sharpness and sensitivity to ultraviolet light have uncovered 425 clusters of newborn stars along these tails, looking like strings of holiday lights. Each cluster contains as many as 1 million blue, newborn stars.

A team of astronomers used a combination of new observations and archival data to get ages and masses of tidal tail star clusters. They found that these clusters are very young – only 10 million years old. And they seem to be forming at the same rate along tails stretching for thousands of light-years.

This string-of-pearls star formation may have been more common in the early universe when galaxies collided with each other more frequently. These nearby galaxies observed by Hubble are a proxy for what happened long ago, and therefore are laboratories for looking into the distant past. The tails look like they are taking a galaxy's spiral arm and stretching it out into space. The exterior part of the arm gets pulled like taffy from the gravitational tug-of-war between a pair of interacting galaxies. The fate of these strung-out star clusters is uncertain. They may stay gravitationally intact and evolve into globular star clusters – or they may disperse to form a halo of stars around their host galaxy or get cast off to become wandering intergalactic stars.

10. Three-Year Study of Young Stars with NASA's Hubble Enters New Chapter

The ULLYSES program studied two types of young stars: super-hot, massive, blue stars and cooler, redder, less massive stars than our Sun. This is a Hubble Space Telescope image of a star-forming region containing massive, young, blue stars in 30 Doradus, the Tarantula Nebula. Located within the Large Magellanic Cloud, this is one of the regions observed by ULLYSES. ***NASA, ESA, STScI, Francesco Paresce (INAF-IASF Bologna), Robert O'Connell (UVA), SOC-WFC3, ES***

NASA Hubble Space Telescope's ULLYSES team studied 220 stars, then combined those observations with information from the Hubble archive on 275 additional stars. The program also included data from some of the world's largest, most powerful ground-based telescopes and X-ray space telescopes. The ULLYSES dataset is made up of stellar spectra, which carry information about each star's temperature, chemical composition, and rotation.

One type of stars studied under ULLYSES is super-hot, massive, blue stars. They are a million times brighter than the Sun and glow fiercely in ultraviolet light that can easily be detected by Hubble. Their spectra include key diagnostics of the speed of their powerful winds. The winds drive galaxy evolution

and seed galaxies with the elements needed for life. Those elements are cooked up inside the stars' nuclear fusion ovens and then injected into space as a star dies. ULLYSES targeted blue stars in nearby galaxies that are deficient in elements heavier than helium and hydrogen. This type of galaxy was common in the very early universe.

The other star category in the ULLYSES program is young stars less massive than our Sun. Though cooler and redder than our Sun, in their formative years they unleash a torrent of high-energy radiation, including blasts of ultraviolet light and X-rays. Because they are still growing, they are gathering material from their surrounding planet-forming disks of dust and gas. The Hubble spectra include key diagnostics of the process by which they acquire their mass, including how much energy this process releases into the surrounding planet-forming disk and nearby environment. The blistering ultraviolet light from young stars affects the evolution of these disks as they form planets, as well as the chances of habitability for newborn planets. The target stars are located in nearby star-forming regions in our Milky Way galaxy.

The ULLYSES concept was designed by a committee of experts with the goal of using Hubble to provide a legacy set of stellar observations. To that end, STScI hosted a ULLYSES workshop March 11–14 to celebrate the beginning of a new era of research on young stars. The goal was to allow members of the astronomical community to collaborate on the data, so that they could gain momentum in the ongoing analyses, or kickstart new ideas for analysis. The workshop was one important step in exploiting this legacy spectral library to its fullest potential, fulfilling the promise of ULLYSES.

11. Hubble Peers at Pair of Closely Interacting Galaxies

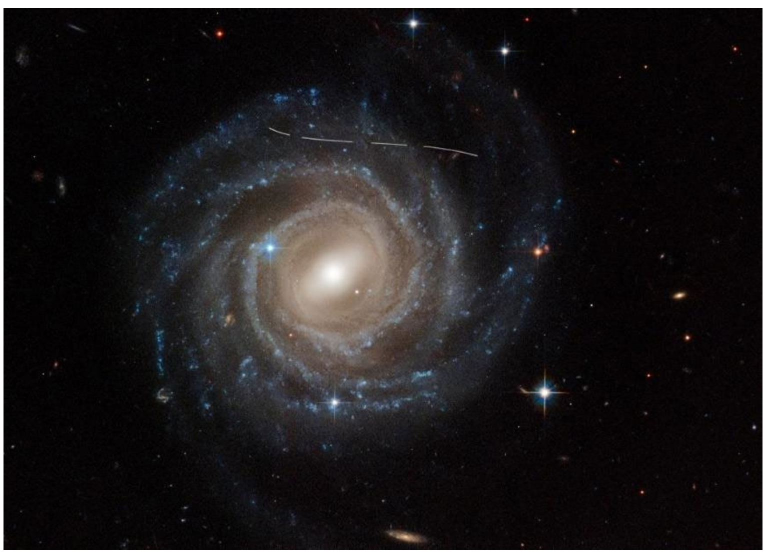
This NASA/ESA Hubble Space Telescope image features Arp 72.ESA/Hubble & NASA, L. Galbany, J. Dalcanton, Dark Energy Survey/DOE/FNAL/DECam/CTIO/NOIRLab/NSF/AURA

This image from the NASA/ESA Hubble Space Telescope features Arp 72, a very selective galaxy group that only includes two galaxies interacting due to gravity: NGC 5996 (the large spiral galaxy) and NGC 5994 (its smaller companion, in the lower left of the image). Both galaxies lie approximately 160 million light-years from Earth, and their cores are separated from each other by a distance of about 67,000 light-years. The distance between the galaxies at their closest points is even smaller, closer to 40,000 light-years. While this might sound vast, in galactic separation terms it is really quite close. For comparison, the distance between the Milky Way and its nearest independent galactic neighbor Andromeda is around

2.5 million light-years. Alternatively, the distance between the Milky Way and its largest and brightest satellite galaxy, the Large Magellanic Cloud (satellite galaxies orbit around another galaxy), is about 162,000 light-years.

Given this and the fact that NGC 5996 is roughly comparable in size to the Milky Way, it is not surprising that NGC 5996 and NGC 5994 — separated by only about 40,000 light-years — are interacting with one another. In fact, the interaction likely distorted NGC 5996's spiral shape. It also prompted the formation of the very long and faint tail of stars and gas curving away from NGC 5996, up to the top right of the image. This 'tidal tail' is a common phenomenon that appears when galaxies closely interact and is visible in other Hubble images of interacting galaxies.

12. Hubble Goes Hunting for Small Main Belt Asteroids



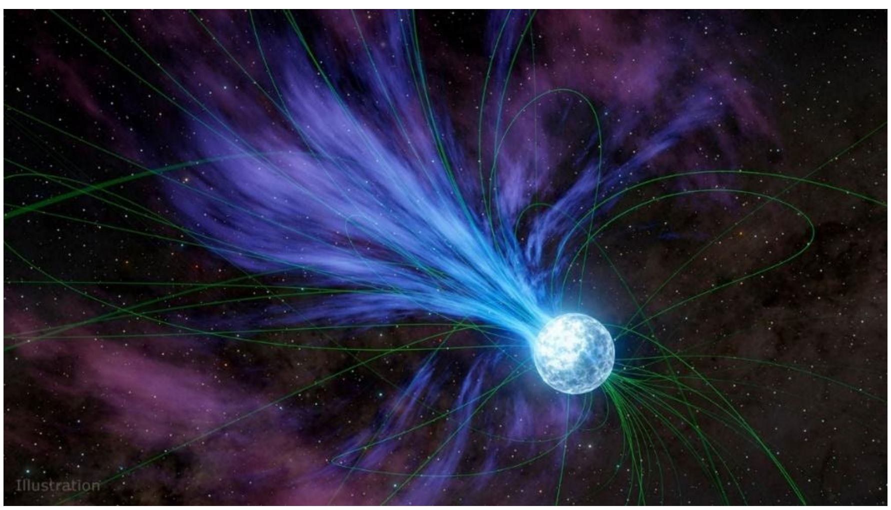
This Hubble Space Telescope image of the barred spiral galaxy UGC 12158 looks like someone took a white marking pen to it. In reality it is a combination of time exposures of a foreground asteroid moving through Hubble's field-of-view, photobombing the observation of the galaxy. The asteroid appears as a curved trail due to parallax: because Hubble is not stationary, but orbiting Earth, and this gives the illusion that the faint asteroid is swimming along a curved trajectory. The uncharted asteroid is in inside the asteroid belt in our solar system, and hence is 10 trillion times closer to Hubble than the background galaxy. Rather than a nuisance, this type of data is useful to astronomers for doing a census of the asteroid population in our solar system.
NASA, ESA, Pablo García Martín (UAM); Image Processing: Joseph DePasquale (STScI); Acknowledgment: Alex Filippenko (UC Berkeley)

NASA's Hubble Space Telescope's archives have been thumbed through by citizen scientists in order to visually search for a largely unseen population of smaller asteroids. The treasure hunt required perusing 37,000 Hubble images spanning 19 years. The payoff was finding 1,701 asteroid trails, with 1,031 of the asteroids previously uncatalogued. About 400 of these uncatalogued asteroids are below 1 kilometer in size.

Volunteers from around the world known as "citizen scientists" contributed to the identification of this asteroid bounty. Professional scientists combined the volunteers' efforts with machine learning algorithm to identify the asteroids. It represents a new approach to finding asteroids in astronomical archives spanning decades, which may be effectively applied to other datasets. The large, random sample offers new insights into the formation and evolution of the asteroid belt.

Using this data, the science community is now confirming the existence of this population of asteroids. This is important to provide insights into the evolutionary models of the solar system. Not only were citizen scientist volunteers used to visually identify the asteroids, but they also began the process of training AI to do the work in the future. A total of 11,482 citizen-science volunteers, who provided nearly 2 million identifications, were then given a training set for an automated algorithm to identify asteroids based on artificial intelligence. This pioneering approach may be effectively applied to other datasets.

13. NASA Telescopes Find New Clues About Mysterious Deep Space Signals

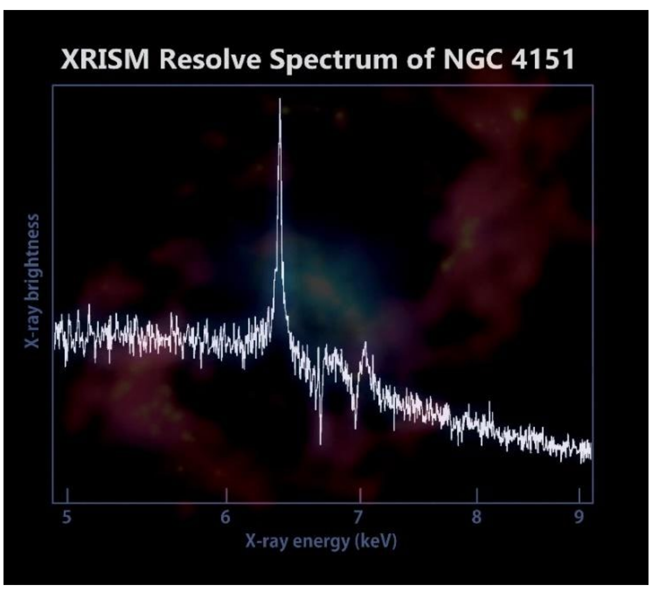


In an ejection that would have caused its rotation to slow, a magnetar is depicted losing material into space in this artist's concept. The magnetar's strong, twisted magnetic field lines (shown in green) can influence the flow of electrically charged material from the object, which is a type of neutron star. NASA/JPL-Caltech

NASA's NICER (Neutron Star Interior Composition Explorer) on the International Space Station and NuSTAR (Nuclear Spectroscopic Telescope Array) recently observed mysterious bursts of radio waves from deep space– known as a fast radio burst – mere minutes before and after it occurred. This unprecedented view sets scientists on a path to better understand these extreme radio events. While they only last for a fraction of a second, fast radio bursts can release about as much energy as the Sun does in a year. Their light also forms a laserlike beam, setting them apart from more chaotic cosmic explosions. The burst occurred between two "glitches," when the magnetar suddenly started spinning faster. SGR 1935+2154 is estimated to be about 12 miles (20 kilometers) across and spinning about 3.2 times per second, meaning its surface was moving at about 7,000 mph (11,000 kph). The study authors were surprised to see that in between glitches, the magnetar slowed down to less than its pre-glitch speed in just nine hours, or about 100 times more rapidly than has ever been observed in a magnetar.

Scientists extrapolate that the exterior of the SGR 1935+2154 magnetar is solid and when the high density crushes the interior it turns into a superfluid. Occasionally, the two can get out of sync, like water sloshing around inside a spinning fishbowl. When this happens, the fluid can deliver energy to the crust. The paper authors think this is likely what caused both glitches that bookended the fast radio burst. If the initial glitch caused a crack in the magnetar's surface, it might have released material from the star's interior into space like a volcanic eruption. Losing mass causes spinning objects to slow down, so the researchers think this could explain the magnetar's rapid deceleration.

14. NASA, JAXA XRISM Spots Iron Fingerprints in Nearby Active Galaxy



The Resolve instrument aboard XRISM (X-ray Imaging and Spectroscopy Mission) captured data from the center of galaxy NGC 4151, where a supermassive black hole is slowly consuming material from the surrounding accretion disk. The resulting spectrum reveals the presence of iron in the peak around 6.5 keV and the dips around 7 keV, light thousands of times more energetic that what our eyes can see. Background: An image of NGC 4151 constructed from a combination of X-ray, optical, and radio light.

Spectrum: JAXA/NASA/XRISM Resolve. Background: X-rays, NASA/CXC/CfA/J.Wang et al.; optical, Isaac Newton Group of Telescopes, La Palma/Jacobus Kapteyn Telescope; radio, NSF/NRAO/VLA

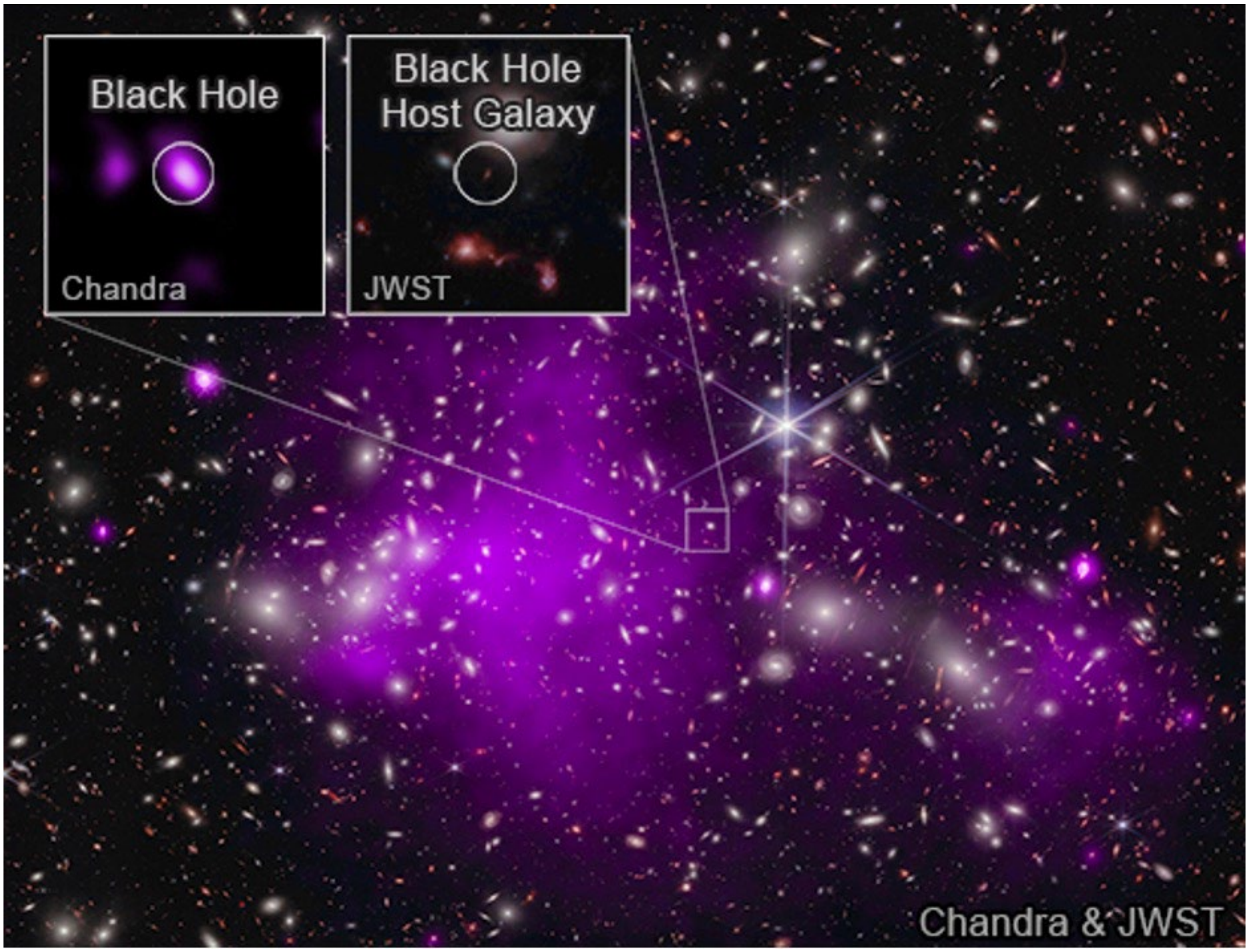
XRISM's Resolve instrument captured a detailed spectrum of the area around the black hole at the center of galaxy NGC 4151. The peaks and dips are like chemical fingerprints that can tell us what elements are present and reveal clues about the fate of matter as it nears the black hole.

Resolve's spectrum of NGC 4151 reveals a sharp peak at energies just under 6.5 keV (kiloelectron volts) — an emission line of iron. Astronomers think that much of the power of active galaxies comes from X-rays originating in hot, flaring regions close to the black hole. X-rays bouncing off cooler gas in the disk causes iron there to fluoresce, producing a specific X-ray peak. This allows astronomers to paint a better picture of both the disk and erupting regions much closer to the black hole.
The spectrum also shows several dips around 7 keV. Iron located in the torus caused these dips as well, although through absorption of X-rays, rather than emission, because the material there is much cooler than in the disk. All this radiation is some 2,500 times more energetic than the light we can see with our eyes. Iron is just one element XRISM can detect. The telescope can also spot sulfur, calcium, argon, and others, depending on the source. Each tells astrophysicists something different about the cosmic phenomena scattered across the X-ray sky.

NGC 4151 is a spiral galaxy around 43 million light-years away in the northern constellation Canes Venatici. The supermassive black hole at its center holds more than 20 million times the Sun's mass. The galaxy is also active, which means its center is unusually bright and variable. NGC 4151 is one of the closest-known active galaxies. Other missions, including NASA's Chandra X-ray Observatory and Hubble Space Telescope, have studied it to learn more about the interaction between black holes and their surroundings, which can tell scientists how supermassive black holes in galactic centers grow over cosmic time.

15. NASA Chandra and JWST Telescopes Discover Record-Breaking Black Hole

https://chandra.si.edu/photo/2023/uhz1/

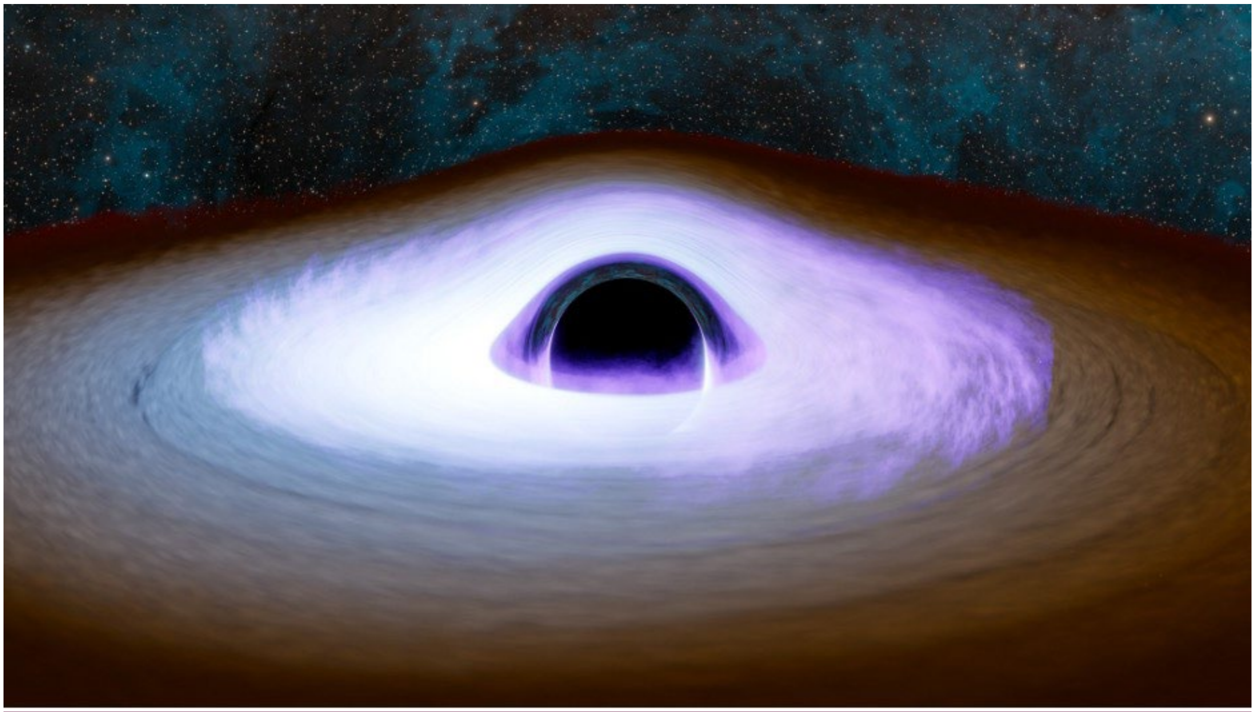


Credits: X-ray: NASA/CXC/SAO/Ákos Bogdán; Infrared: NASA/ESA/CSA/STScI; Image Processing: NASA/CXC/SAO/L. Frattare & K. Arcand)
Caption: The galaxy, UHZ1, discovered by JWST is 13.2 billion light-years away, seen when the universe was only ~500 Myrs old (or roughly 3% of its current age). The Chandra X-ray Observatory detected a growing supermassive black hole within this galaxy, which is the most distant black hole ever detected in X-rays.

NASA's Chandra X-ray Observatory detected the most distant black hole ever detected in X-rays, located in the center of a distant host galaxy observed by JWST. This observation may explain how some of the first supermassive black holes in the universe formed; a mystery that has plagued astronomers for decades. The purple parts of the image show X-rays from large amounts of hot gas in Abell 2744. The infrared image from Webb shows hundreds of galaxies in the cluster, along with a few foreground stars. The insets zoom into a small area centered on the host galaxy UHZ1. The large size of the X-ray source compared to the that of the galaxy is because it represents the smallest size that Chandra can resolve. The X-rays actually come from a region that is much smaller than the galaxy. This discovery is important for understanding how some supermassive black holes — those that contain up to billions of solar masses and reside in the centers of galaxies — can reach colossal masses soon after the big bang. Do they form directly from the collapse of massive clouds of gas, creating black holes weighing between about ten thousand and a hundred thousand suns? Or do they come from explosions of the first stars that create black holes weighing only between about ten and a hundred suns? The team of astronomers found strong evidence that the newly discovered black hole in UHZ1 was born massive and they estimate that its mass falls between 10 and 100 million suns.

16. NASA's IXPE Helps Researchers Determine Shape of Black Hole Corona

https://www.nasa.gov/missions/ixpe/nasas-ixpe-helps-researchers-determine-shape-of-black-hole-corona/



Credits: NASA/Caltech-IPAC/Robert Hurt
Caption: This illustration of material swirling around a black hole highlights a particular feature, called the "corona," that shines brightly in X-ray light. The corona can be seen as a purple haze floating above the underlying accretion disk and extending slightly inside of its inner edge. The warp in the disk is a realistic representation of how the black hole's immense gravity acts like an optical lens, distorting our view of the flat disk that encircles it.

NASA's Imaging X-ray Polarimetry Experiment (IXPE) mission is rewriting the textbooks on the shape and structure of the corona around black holes. The corona is a region of very hot electrons, with temperatures of around a billion degrees. This corona is much hotter than the Sun's corona, that burns at less than two million degrees Fahrenheit. To date, the geometry of the corona, which is associated with smaller stellar-mass black holes – those formed by a star's collapse – as well as with much larger supermassive black holes such as the one at the heart of the Milky Way galaxy, has been a mystery to astronomers. IXPE, which is NASA's first X-ray imaging polarimeter, demonstrated that the corona was found to be extended in the same direction as the accretion disk – providing, for the first time, clues to the corona's shape and clear evidence of its relationship to the accretion disk. Understanding the accretion disk, which is a whirlpool of hot gas that forms as matter falls into a black hole, is critical to understanding the behavior and evolution of these still somewhat mysterious objects. IXPE data suggests both types of black holes create accretion disks of similar geometry, which is a very surprising result given the differences in how these different mass black holes came into being.

17. A hidden treasure in the Milky Way – Astronomers uncover ultrabright x-ray source

https://www.utu.fi/en/news/press-release/a-hidden-treasure-in-the-milky-way-astronomers-uncover-ultrabright-x-ray-source

https://www.space.com/cygnus-x-3-binary-system-brightness-mystery-solved

Credit: Alexander Mushtukov
Caption: An artist's impression of the accretion disk around the compact object in the X-ray binary system Cygnus X-3, showing the X-rays scattering off the interior of the funnel-shaped cavity before being detected by IXPE.

18. **JWST's 'Little Red Dots' Offer Astronomers the Universe's Weirdest Puzzle**
https://www.scientificamerican.com/article/jwsts-little-red-dots-offer-astronomers-the-universes-weirdest-puzzle/

NASA's *James Webb Space Telescope* is pushing the cosmic frontiers of space exploration, revealing a large abundance of ``little red dots'' in the early Universe when it was merely a few million years old. These ``little red dots'' are compact and relatively high mass and appear red in multicolor images. While they were originally mistaken for massive, compact galaxies, more recent Webb observations reveal that their spectral properties are suggestive of an underlying intermediate mass black hole that may be 100 to 1000 times more massive than the black hole at the center of our Galaxy. If confirmed, this means that very massive black holes were formed when the Universe was only 0.4-1 Billion years old. This is currently believed to be a too short of a timescale for forming such massive black holes, challenging current models for black hole and galaxy formation.

[PSD has provided the following 3 examples.]4

Summary

The items featured in this section are:

- **Investigating the Origin of Organic Hydrocarbons in the Ryugu Sample**
- Examining the Effects of Gravity in Kuiper Belt Formation
- Characterizing Planet-Formation Conditions in Large Million-Year-Old Disks

1. Investigating the Origin of Organic Hydrocarbons in the Ryugu Sample

Zeichner et al., Polycyclic aromatic hydrocarbons in samples of Ryugu formed in the interstellar medium
https://doi.org/10.1126/science.adg6304

Polycyclic aromatic hydrocarbons (PAHs) contain up to about 20% of the carbon in the interstellar medium, but the origin of these compounds extracted from meteorites has long been debated. They may have formed in hot (>1000K) circumstellar environments or cold (about 10K) interstellar environments. In this study, the authors used a new analytical tool—Orbitrap-based mass spectrometry—to measure the relative abundances and isotopic compositions of several PAHs that were extracted from Ryugu samples (returned by the Hayabusa-2 mission) and to determine their formation location. The results of the work indicate that although some of the PAHs likely formed at very low temperatures in the interstellar medium, other PAHs were more likely to have formed or have been reprocessed at moderate-to-high temperatures (e.g., in a circumstellar environment or on the parent body, respectively). Although the findings of the work do not provide an unambiguous determination of PAH formation locations, the study demonstrates that at least some PAHs predate the formation of the solar system.

2. Examining the Effects of Gravity in Kuiper Belt Formation

Kalb et al., More realistic planetesimal masses after Kuiper belt formation models and add stochasticity
https://doi.org/10.1016/j.icarus.2024.116057

Much of the modern Kuiper belt is thought to be the result of Neptune's migration through a primordial belt of planetesimals (possibly interrupted by an instability amongst the giant planets). Most prior studies that examined this Kuiper belt formation process used massless test particles in their models and indirectly inferred the primordial population of Pluto-mass bodies to be between 1,000 and 4,000. In this work, however, the aim was to examine how the gravity of Pluto-mass (i.e., realistic mass) bodies alters models of Kuiper belt formation. The authors used graphics processor unit (GPU)-accelerated N-body simulations to model the process of Kuiper belt formation, with differing numbers of Pluto-mass bodies in the initial population of small bodies. The results show that the removal of bodies from Neptunian resonance is more efficient than previously suspected, which enables small numbers of primordial Pluto-mass bodies. The team finds that between about 200 and 1,000 Pluto-mass bodies originally existed in the outer solar system. If more than 1,000 bodies existed, the simulations indicate that many more than two Pluto-mass bodies should now be present in the Kuiper belt, whereas only two—Pluto and Eris—are known. A population of about 200 Pluto-mass bodies can account for the existence of Pluto and Eris.

3. Characterizing Planet-Formation Conditions in Large Million-Year-Old Disks

Pascucci et al., Large Myr-old disks are not severely depleted of gas-phase CO or carbon
https://doi.org/10.3847/1538-4357/ace4bf

Recent high-resolution images of circumstellar disks around young stars have revealed a variety of complex structures, some of which point to advanced planet formation. These disks therefore provide an opportunity to study planet formation in action. Some of the fundamental properties of these disks, like their mass and gas-to-dust mass ratio, however, remain poorly constrained. In this work, the team thus investigated if million-year-old protoplanetary disks are severely depleted in gas-phase carbon monoxide (CO) and carbon. To do this, they measured the line fluxes from several CO isotopologues and atomic carbon, from a sample of 16 relatively large protoplanetary disks (with radii of more than 200 au). They then compared these fluxes with predictions from self-consistent disk thermo-chemical models that include interstellar-medium carbon and oxygen elemental abundances as input parameters. Except for one disk, the models reproduce the measured line fluxes—with gas masses comparable to, or higher, than the minimum-mass solar nebula and with gas-to-dust mass ratios of more than about 10. This means that most large million-year-old disks are not significantly depleted in gas, CO, or carbon and that these disks still have enough mass to form giant planets.

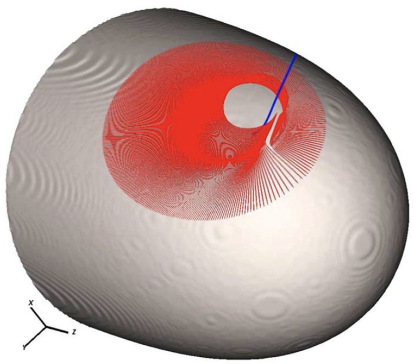
[HPD has provided the following 1 example.]
Summary

The items featured in this section are:

- **Magnetic Trapping of Galactic Cosmic Rays in the Outer Heliosheath and Their Preferential Entry into the Heliosphere**

1. **Magnetic Trapping of Galactic Cosmic Rays in the Outer Heliosheath and Their Preferential Entry into the Heliosphere**

Science Overview:
This paper examines the geometry of interstellar magnetic field lines close to the boundary of the heliosphere in the direction of the unperturbed local interstellar magnetic field, where the field lines are spread apart by the heliopause (HP). The moving heliosphere pushes the magnetic field lines apart thus creating a diamagnetic cavity surrounded by a region of compressed magnetic field known as *draped* field in the very local interstellar medium (VLISM). This region is affected by the heliosphere through the disturbances emitted by the HP and ENAs of heliospheric origin on outward trajectories. Such field parting establishes a region of weaker magnetic field of about 300 au in size in the northern hemisphere that acts as a giant magnetic trap affecting the propagation of galactic cosmic rays (GCRs). The choice of an analytic model of the magnetic field in the very local interstellar medium allows us to qualitatively study the resulting magnetic field draping pattern while avoiding unphysical dissipation across the HP-impeding numerical magnetohydrodynamic (MHD) models. We investigate GCR transport in the region exterior to the heliosphere, including the magnetic trap, subject to guiding center drifts, pitch angle scattering, and perpendicular diffusion. The transport coefficients were derived from Voyager 1 observations of magnetic turbulence in the VLISM. Our results predict a ring current of energetic ions drifting around the interior of the magnetic trap. It is also demonstrated that GCRs cross the HP for the first time preferentially through a crescent-shaped region between the magnetic trap and the upwind direction. In addition to the heliosphere, we examine several extreme field draping configurations that could describe the astrospheres of other stars.



Caption: One complete orbit of a 1 GeV cosmic-ray proton placed in a magnetic trap with an initial pitch angle of 80° (red line). The trajectory integration time was 3950 days. A single magnetic field line ending at the null point is shown in blue. The HP surface is colored in light gray. The direction of the drift is counterclockwise.

Significance:
Modeling predicts a ring current around the heliosphere and "examine[s] several extreme field draping configurations that could describe the astrospheres of other stars."

Reference(s):
Vladimir Florinski, Juan Alonso Guzman, Jens Kleimann, Igor Baliukin, Keyvan Ghanbari, Drew Turner, Bertalan Zieger, Jozsef Kóta, Merav Opher, Vladislav Izmodenov, Dmitry Alexashov, Joe Giacalone, and John Richardson (2024), Magnetic Trapping of Galactic Cosmic Rays in the Outer Heliosheath and Their Preferential Entry into the Heliosphere, The Astrophysical Journal, Volume 961, Number 2. DOI 10.3847/1538-4357/ad0b15
Published 2024 January 31

Multiyear Performance Goal 1.2.4: ***NASA shall demonstrate progress in discovering and studying planets around other stars.***

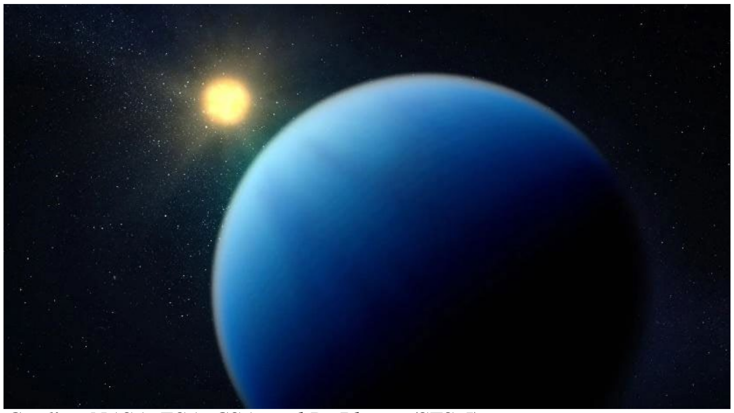
The progress towards meeting the performance goal is judged to be XX (xx individual votes).

Summary

The items featured in this section are:

- NASA Data Reveal Possible Reason Some Exoplanets Are Shrinking
- A Six-Planet Solar System in Perfect Synchrony Has Been Found in The Milky Way
- Discovery Alert: Watch the Synchronized Dance of a 6-Planet System
- NASA's Hubble Observes Exoplanet Atmosphere Changing Over 3 Years
- Webb Cracks Case of Inflated Exoplanet
- NASA's Webb Investigates Eternal Sunrises, Sunsets on Distant World
- NASA's Webb Images Cold Exoplanet 12 Light-Years Away

1. NASA Data Reveal Possible Reason Some Exoplanets Are Shrinking

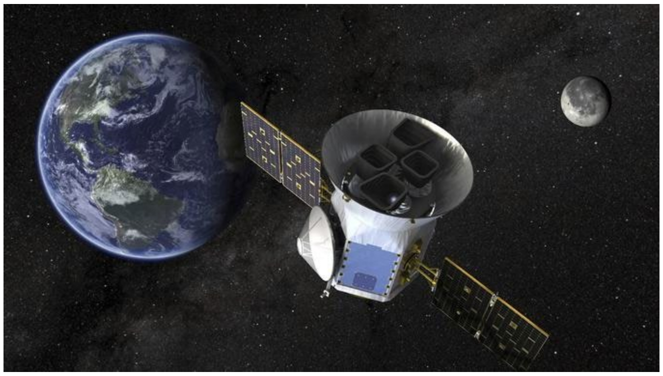


Credits: *NASA, ESA, CSA, and D. Player (STScI)*
Caption: *This artist's concept shows what the sub-Neptune exoplanet TOI-421 b might look like. In a new study, scientists have found new evidence suggesting how these types of planets can lose their atmospheres.*

In a new study using NASA's retired Kepler Space Telescope, astronomers found evidence of a possible cause for why some exoplanets seem to be losing their atmospheres and shrinking. The cores of these planets are pushing away their atmospheres from the inside out.

Exoplanets come in a variety of sizes, from small, rocky planets to colossal gas giants. In the middle lie rocky super-Earths and larger sub-Neptunes with puffy atmospheres. But there's a conspicuous absence – a "size gap" – of planets that fall between 1.5 to 2 times the size of Earth (or in between super-Earths and sub-Neptunes) that scientists have been working to better understand. Exoplanet scientists have enough data now to say that this gap is not a fluke. There's something going on that impedes planets from reaching and/or staying at this size. Researchers think that this gap could be explained by certain sub-Neptunes losing their atmospheres over time. This loss would happen if the planet doesn't have enough mass, and therefore gravitational force, to hold onto its atmosphere. So sub-Neptunes that aren't massive enough would shrink to about the size of super-Earths, leaving the gap between the two sizes of planets. But exactly how these planets are losing their atmospheres has remained a mystery. Scientists have settled on two likely mechanisms: One is called core-powered mass loss; and the other, photoevaporation. The study has uncovered new evidence supporting the first. This study was conducted using the NASA Exoplanet Archive where the team spent more than five years building the necessary planet candidate catalog. But the research is far from complete, and it is possible that the current understanding of photoevaporation and/or core-powered mass loss could evolve. The findings will likely be put to the test by future studies before anyone can declare the mystery of this planetary gap solved once and for all.

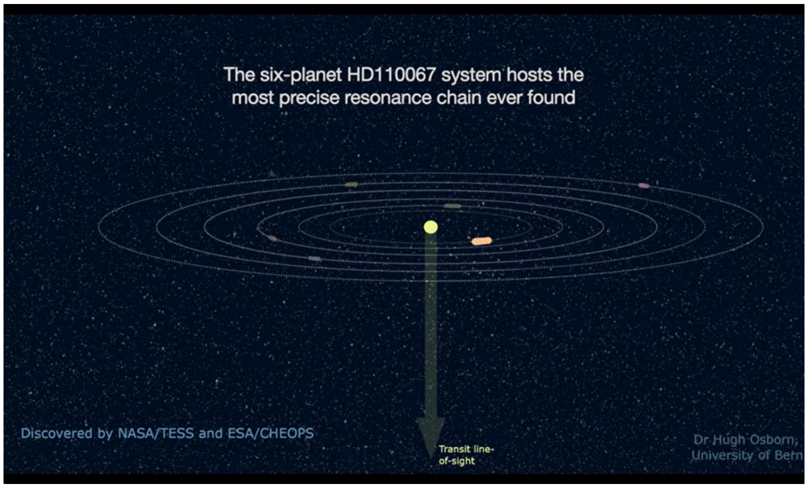
2. A Six-Planet Solar System in Perfect Synchrony Has Been Found in The Milky Way



This image provided by NASA shows an artist's illustration of the TESS telescope. Astronomers have discovered six planets orbiting a bright nearby star in perfect rhythmic harmony. They say it's a rare, frozen-in-time cosmic wonder that can help explain how solar systems across the galaxy came to be. The compact in-sync system is 100 light-years away. (NASA via AP)

Astronomers have discovered a rare in-sync solar system with six planets moving like a grand cosmic orchestra, untouched by outside forces since their birth billions of years ago. The find, announced Wednesday, can help explain how solar systems across the Milky Way galaxy came to be. This one is 100 light-years away in the constellation Coma Berenices. A light-year is 5.8 trillion miles. A pair of planet-hunting satellites — NASA's TESS and the European Space Agency's CHEOPS — teamed up for the observations. None of the planets in perfect synchrony are within the star's so-called habitable zone, which means little if any likelihood of life, at least as we know it. "Here we have a golden target" for comparison, said Adrien Leleu of the University of Geneva, who was part of an international team that published the results in the journal Nature. This star, known as HD 110067, may have even more planets. The six found so far are roughly two to three times the size of Earth, but with densities closer to the gas giants in our own solar system. Their orbits range from nine to 54 days, putting them closer to their star than Venus is to the sun and making them exceedingly hot. As gas planets, they're believed to have solid cores made of rock, metal or ice, enveloped by thick layers of hydrogen, according to the scientists. More observations are needed to determine what's in their atmospheres. This solar system is unique because all six planets move similarly to a perfectly synchronized symphony, scientists said. In technical terms, it's known as resonance that's "precise, very orderly," said co-author Enric Palle of the Institute of Astrophysics of the Canary Islands. The innermost planet completes three orbits for every two by its closest neighbor. It's the same for the second- and third-closest planets, and the third- and fourth-closest planets. The two outermost planets complete an orbit in 41 and 54.7 days, resulting in four orbits for every three. The innermost planet, meanwhile, completes six orbits in exactly the time the outermost completes one. All solar systems, including our own, are thought to have started out like this one, according to the scientists. But it's estimated only 1-in-100 systems have retained that synchrony, and ours isn't one of them. Giant planets can throw things off-kilter. So can meteor bombardments, close encounters with neighboring stars and other disturbances. While astronomers know of 40 to 50 in-sync solar systems, none have as many planets in such perfect step or as bright a star as this one, Palle said. The University of Bern's Hugh Osborn, who was part of the team, was "shocked and delighted" when the orbital periods of this star system's planets came close to what scientists predicted. "My jaw was on the floor," he said. "That was a really nice moment."

3. **Discovery Alert: Watch the Synchronized Dance of a 6-Planet System**



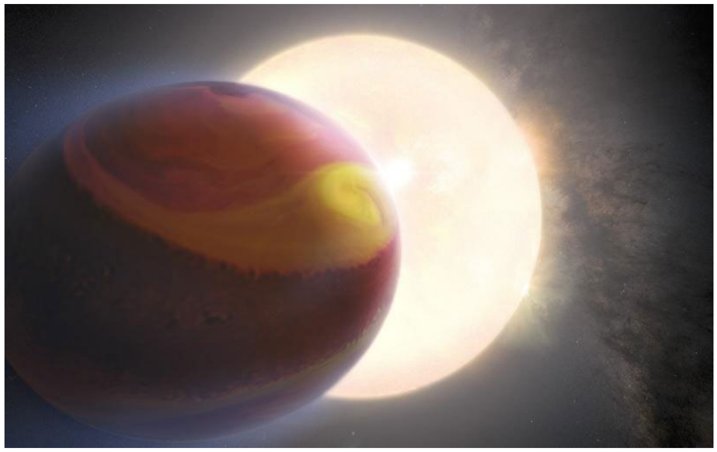
Credits: NASA/Dr. Hugh Osborn, University of Bern
Caption: This animation shows six "sub-Neptune" exoplanets in rhythmic orbits around their star – with a musical tone as each planet passes a line drawn through the system.

Six planets, observed by NASA's TESS, orbit their central star in a rhythmic beat, a rare case of an "in sync" gravitational lockstep that could offer deep insight into planet formation and evolution. The internal four planets keep a "3/2 resonance" (wherein the planet closest to the star makes three orbits for every two of the next planet out) and the outermost two planets follow a "4/3 resonance" which is repeated twice (wherein a pattern of four orbits for every three of the next planet out.) The planets likely have been performing this same rhythmic dance since the system formed billions of years ago. Such reliable stability means this system has not suffered the shocks and shakeups scientists might typically expect in the early days of planet formation – smash-ups and collisions, mergers and breakups as planets jockey for position. And that, in turn, could say something important about how this system formed. Its rigid stability was locked in early; the planets' 3/2 and 4/3 resonances are almost exactly as they were at the time of formation.

The first hints of this discovery came from TESS (the Transiting Exoplanet Survey Satellite), whichh tracks the "transits" that planets make as they cross the faces of their stars. Combining the TESS measurements, made in separate observations two years apart, revealed an assortment of transits for the host star, called HD 110067. But it was difficult to distinguish how many planets they represented, or to pin down their orbits.

This data stymied multiple scientists across the globe, as excessive light scattered through the observation field by Earth and the Moon seemed to make the TESS data unusable. But where there's a will, there's a way, and scientists Joseph Twicken and David Rapetti happened to be working on a new computer code to recover transit data thought to be lost because of scattered light. At Twicken's suggestion, Rapetti applied his new code to the TESS data. He found two transits for the outer planets – exactly where the scientists had predicted.

4. NASA's Hubble Observes Exoplanet Atmosphere Changing Over 3 Years

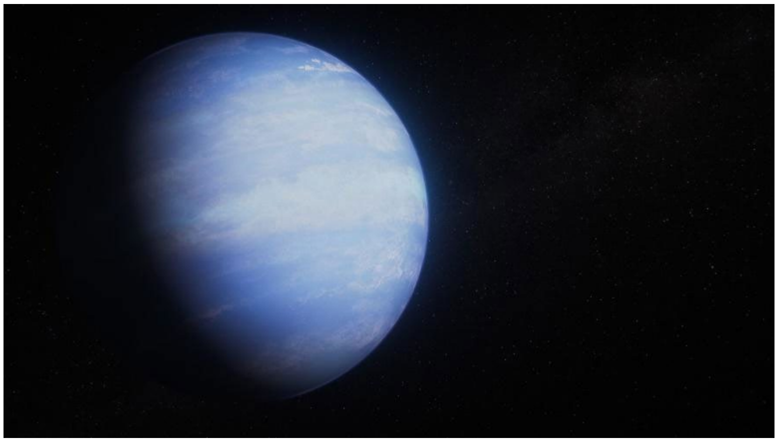


This is an artist's concept of the exoplanet WASP-121 b, also known as Tylos.
CREDIT: NASA, ESA, Quentin Changeat (ESA/STScI), Mahdi Zamani (ESA/Hubble)

NASA Hubble Space Telescope's international team of astronomers assembled and reprocessed Hubble observations of WASP-121 b taken in 2016, 2018, and 2019. They found that the planet has a dynamic atmosphere, changing over time. The team used sophisticated modelling techniques to demonstrate that these dramatic temporal variations could be explained by weather patterns in the exoplanet's atmosphere. The team found that WASP-121 b's atmosphere shows notable differences between observations. Most dramatically, there could be massive weather fronts, storms, and massive cyclones that are repeatedly created and destroyed due to the large temperature difference between the star-facing side and dark side of the exoplanet. They also detected an apparent offset between the exoplanet's hottest region and the point on the planet closest to the star, as well as variability in the chemical composition of the exoplanet's atmosphere (as measured via spectroscopy). The team reached these conclusions by using computational models to help explain observed changes in the exoplanet's atmosphere. "The remarkable details of our exoplanet atmosphere simulations allow us to accurately model the weather on ultra-hot planets like WASP-121 b," explained Jack Skinner, a postdoctoral fellow at the California Institute of Technology in Pasadena, California, and co-leader of this study. "Here we make a significant step forward by combining observational constraints with atmosphere simulations to understand the time-varying weather on these planets."

The team used four sets of Hubble archival observations of WASP-121 b. The complete data-set included observations of WASP-121 b transiting in front of its star (taken in June 2016); WASP-121 b passing behind its star, also known as a secondary eclipse (taken in November 2016); and the brightness of WASP-121 b as a function of its phase angle to the star (the varying amount of light received at Earth from an exoplanet as it orbits its parent star, similar to our Moon's phase-cycle). These data were taken in March 2018 and February 2019, respectively. "The assembled data-set represents a significant amount of observing time for a single planet and is currently the only consistent set of such repeated observations," said Changeat. The information that we extracted from those observations was used to infer the chemistry, temperature, and clouds of the atmosphere of WASP-121 b at different times. This provided us with an exquisite picture of the planet changing over time."

5. Webb Cracks Case of Inflated Exoplanet



This artist's concept shows what the warm Neptune exoplanet WASP-107 b could look like based on recent data gathered by NASA's James Webb Space Telescope along with previous observations from NASA's Hubble Space Telescope and other observatories. Observations captured by Hubble's WFC3 (Wide Field Camera 3), Webb's NIRCam (Near-Infrared Camera), Webb's NIRSpec (Near-Infrared Spectrograph), and Webb's MIRI (Mid-Infrared Instrument) suggest that the planet has a relatively large core surrounded by a relatively small mass of hydrogen and helium gas, which has been inflated due to tidal heating of the interior.
NASA, ESA, CSA, Ralf Crawford (STScI)

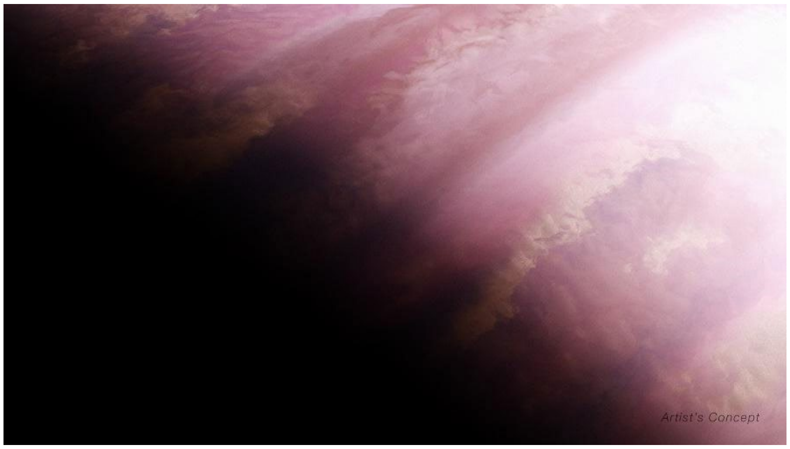
NASA's James Webb Space Telescope recent observations and Hubble Telescope's previously collected data shows surprisingly little methane (CH4) in WASP-107 b's atmosphere, indicating that the interior of the planet must be significantly hotter and the core much more massive than previously estimated. The unexpectedly high temperature is thought to be a result of tidal heating caused by the planet's slightly non-circular orbit and can explain how WASP-107 b can be so inflated without resorting to extreme theories of how it formed. The results may explain the puffiness of dozens of low-density exoplanets, helping solve a long-standing mystery in exoplanet science.

At more than three-quarters the volume of Jupiter but less than one-tenth the mass, the "warm Neptune" exoplanet WASP-107 b is one of the least dense planets known. While puffy planets are not uncommon, most are hotter and more massive, and therefore easier to explain. Based on its radius, mass, age, and assumed internal temperature, it was thought WASP-107 b had a very small, rocky core surrounded by a huge mass of hydrogen and helium, but it was hard to understand how such a small core could sweep up so much gas, and then stop short of growing fully into a Jupiter-mass planet. If WASP-107 b instead has more of its mass in the core, the atmosphere should have contracted as the planet cooled over time since it formed. Without a source of heat to re-expand the gas, the planet should be much smaller. Although WASP-107 b has an orbital distance of just 5 million miles (one-seventh the distance between Mercury and the Sun), it doesn't receive enough energy from its star to be so inflated.

Combining observations from Webb's NIRCam, Webb's MIRI, and Hubble's WFC3, the team was able to build a broad spectrum of 0.8- to 12.2-micron light absorbed by WASP-107 b's atmosphere. Using Webb's NIRSpec, a separate team built an independent spectrum covering 2.7 to 5.2 microns. The precision of the data makes it possible to not just detect, but actually measure the abundances of a wealth of molecules, including water vapor (H2O), methane (CH4), carbon dioxide (CO2), carbon monoxide (CO), sulfur dioxide (SO2), and ammonia (NH3).

Both spectra show a surprising lack of methane in WASP-107 b's atmosphere: one-thousandth the amount expected based on its assumed temperature. WASP-107 b's giant radius, extended atmosphere, and edge-on orbit make it ideal for transmission spectroscopy. If it is known how much energy is in the planet, and what proportion of the planet is heavier elements like carbon, nitrogen, oxygen, and sulfur, versus how much is hydrogen and helium, it can be calculated how much mass must be in the core.

6. **NASA's Webb Investigates Eternal Sunrises, Sunsets on Distant World**



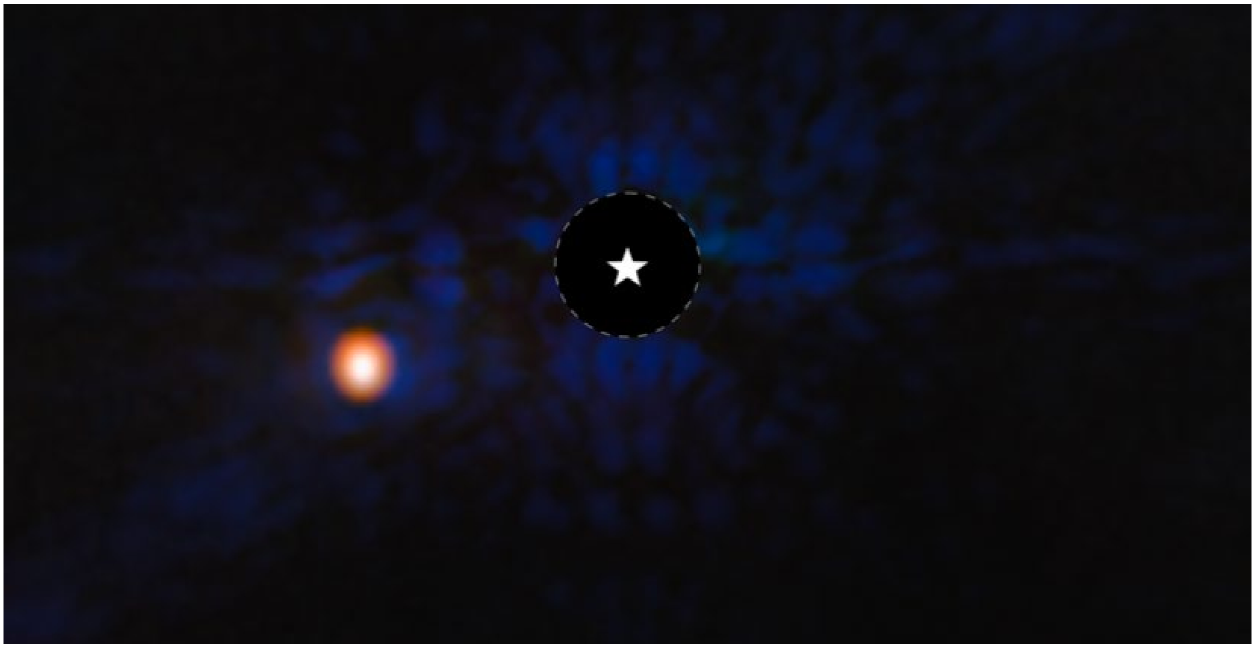
This artist's concept shows what the exoplanet WASP-39 b could look like based on indirect transit observations from NASA's James Webb Space Telescope as well as other space- and ground-based telescopes. Data collected by Webb's NIRSpec (Near-Infrared Spectrograph) show variations between the eternal morning and evening atmosphere of the planet. NASA, ESA, CSA, R. Crawford (STScI)

NASA's James Webb Space Telescope has finally confirmed what models have previously predicted: An exoplanet has differences between its eternal morning and eternal evening atmosphere. Using Webb's NIRSpec (Near-Infrared Spectrograph), astronomers confirmed a temperature difference between the eternal morning and eternal evening on WASP-39 b, with the evening appearing hotter by roughly 200 Celsius degrees.

Astronomers analyzed the 2- to 5-micron transmission spectrum of WASP-39 b. Previously published Webb spectra of WASP-39b's atmosphere, which revealed the presence of carbon dioxide, sulfur dioxide, water vapor, and sodium, represent the entire day/night boundary. The new analysis builds two different spectra from the terminator region, essentially splitting the day/night boundary into two semicircles, one from the evening, and the other from the morning. Data reveals the evening as significantly hotter, a searing 800 degrees Celsius, and the morning a relatively cooler 600 degrees Celsius. Extensive modeling of the data obtained also allows researchers to investigate the structure of WASP-39 b's atmosphere, the cloud cover, and why the evening is hotter. Astronomers confirmed gas circulation around the planet as the main culprit of the temperature difference on WASP-39 b. On a highly irradiated exoplanet like WASP-39 b that orbits relatively close to its star, researchers generally expect the gas to be moving as the planet rotates around its star: Hotter gas from the dayside should move through the evening to the nightside via a powerful equatorial jet stream.

Using General Circulation Models, 3-dimensional models similar to the ones used to predict weather patterns on Earth, researchers found that on WASP-39 b the prevailing winds are likely moving from the night side across the morning terminator, around the dayside, across the evening terminator and then around the nightside. As a result, the morning side of the terminator is cooler than the evening side. In other words, the morning side gets slammed with winds of air that have been cooled on the nightside, while the evening is hit by winds of air heated on the dayside. Research suggests the wind speeds on WASP-39 b can reach thousands of miles an hour!

7. **NASA's Webb Images Cold Exoplanet 12 Light-Years Away**



This image of the gas-giant exoplanet Epsilon Indi Ab was taken with the coronagraph on NASA's James Webb Space Telescope's MIRI (Mid-Infrared Instrument). A star symbol marks the location of the host star Epsilon Indi A, whose light has been blocked by the coronagraph, resulting in the dark circle marked with a dashed white line. Epsilon Indi Ab is one of the coldest exoplanets ever directly imaged. Light at 10.6 microns was assigned the color blue, while light at 15.5 microns was assigned the color orange. MIRI did not resolve the planet, which is a point source. NASA, ESA, CSA, STScI, Elisabeth Matthews (MPIA)

NASA's James Webb Space Telescope has directly imaged an exoplanet roughly 12 light-years from Earth. The planet, Epsilon Indi Ab, is one of the coldest exoplanets observed to date. The planet is several times the mass of Jupiter and orbits the K-type star Epsilon Indi A (Eps Ind A) and was observed using the coronagraph on Webb's MIRI (Mid-Infrared Instrument). Only a few tens of exoplanets have been directly imaged previously by space- and ground-based observatories.

As planets cool and contract over their lifetime, they become significantly fainter and therefore harder to image. Cold planets are very faint, and most of their emission is in the mid-infrared to which Webb is ideally suited to conduct mid-infrared imaging. Epsilon Indi Ab is one of the coldest exoplanets to be directly detected, with an estimated temperature of 35 degrees Fahrenheit (2 degrees Celsius) — colder than any other imaged planet beyond our solar system, and colder than all but one free-floating brown dwarf. The planet is only around 180 degrees Fahrenheit (100 degrees Celsius) warmer than gas giants in our solar system. This provides a rare opportunity for astronomers to study the atmospheric composition of true solar system analogs.

Using a few photometric measurements of the atmosphere, the team believes this may mean there is significant methane, carbon monoxide, and carbon dioxide in the planet's atmosphere that are absorbing the shorter wavelengths of light. It might also suggest a very cloudy atmosphere.

[PSD has provided the following 2 examples.]

Summary

The items featured in this section are:

- Possibility of detecting volcanism on Earth-like exoplanets
- New constraints on optical properties of hazy exoplanet atmospheres

1. Possibility of detecting volcanism on Earth-like exoplanets

Ostberg et al., The prospect of detecting volcanic signatures on an ExoEarth using direct imaging
https://doi.org/10.3847/1538-3881/acfe12

Although the James Webb Space Telescope (JWST) provides the first opportunity to study the atmospheres of terrestrial exoplanets and to estimate their surface conditions, Earth-size planets around Sun-like stars are currently inaccessible with JWST, but future direct imaging missions will be sensitive enough to characterize the atmospheres of these exoplanets. Being able to detect active volcanism on an Earth-like planet would be particularly valuable because it would provide insight into the planet's interior and provide important comparisons with Earth (and Venus). In this work, the team therefore investigated the observational requirements that would be necessary for detection of volcanic activity on an Earth-like exoplanet from a future telescope. They used a 3D climate model to simulate several volcanic eruptions on Earth and then treated Earth as an exoplanet being observed from a hypothetic telescope with a coronograph. Data from the model was used to simulate the planet's reflectance spectra and how it would change over time. The results showed that the most detectable and least ambiguous evidence of volcanism would be changes in ozone absorption and the slope of the reflectance spectrum—the size of ozone and water features would decrease while volcanic eruptions were ongoing and would slowly return to their original size after the eruptions cease. It would therefore be difficult to identify ongoing volcanism for a single observation. Changes in such absorption features over the course of several observations, however, may provide the evidence required to identify volcanism on an Earth-like exoplanet.

2. New constraints on optical properties of hazy exoplanet atmospheres

He et al., Optical properties of organic haze analogues in water-rich exoplanet atmospheres observable with JWST
https://doi.org/10.1038/s41550-023-02140-4

James Webb Space Telescope (JWST) observations include atmospheric characterization of transiting exoplanets and some of the first exoplanets to be observed by JWST have equilibrium temperatures below 1,000K—a regime where photochemical hazes are expected to form. The optical properties of these hazes (which control how they interact with light) are critical for interpreting exoplanet observations, but relevant experimental data have not previously been available. In this work, therefore the team measured the density and optical properties of organic haze analogues that were generated in water-rich exoplanet atmosphere experiments. They report optical constants for the organic haze analogues that are relevant to current and future observational and modeling efforts across the entire JWST instrumentation wavelength range (and a large part of Hubble's). In addition, the authors used the new optical constants to generate hazy model atmospheric spectra. These synthetic spectra show that differences in haze optical constants have a detectable effect on the spectra and can thus impact how exoplanet observations are interpreted.

[HPD has provided the following 1 example.]
Summary

The items featured in this section are:

- **A possible direct exposure of the Earth to the cold dense interstellar medium 2-3 Myr ago**

1. **A possible direct exposure of the Earth to the cold dense interstellar medium 2–3 Myr ago**

Astrosphere – interstellar medium interactions may impact the habitability of exoplanets

Science Overview:

Evidence suggests that the heliosphere is important or even essential to the existence of life on Earth and at exoplanets. Often likened to an enormous bubble or cocoon, it is the protected space in which our solar system and other planetary systems exist. Cold, dense clouds in the interstellar medium of our Galaxy are 4-5 orders of magnitude denser than their diffuse counterparts. Moving through the interstellar medium during its lifetime, our Solar System has most likely encountered denser clouds than surround it at present. However, evidence for such an encounter has not been studied in detail yet. Here we derive the velocity field of the Local Ribbon of Cold Clouds (LRCC) by modelling the 21 cm data from the HI4PI survey (which mapped the detailed structure of neutral hydrogen across the Northern and Southern hemispheres), finding that the Solar System may have passed through the LRCC in the constellation Lynx 2-3 million years ago. Using a state-of-the-art simulation of the heliosphere, we show that during the passage, the heliosphere shrinks to a scale of 0.22 au, smaller than the Earth's orbit around the Sun. This would have put the Earth and all the planets in direct contact with the dense interstellar medium for a period of time and exposed it to a neutral hydrogen density above 3,000 cm^{-3}. Such a scenario agrees with geological evidence from ^{60}Fe and ^{244}Pu isotopes. The encounter and related increased radiation from Galactic cosmic rays might have had a substantial impact on the Earth's system and climate.

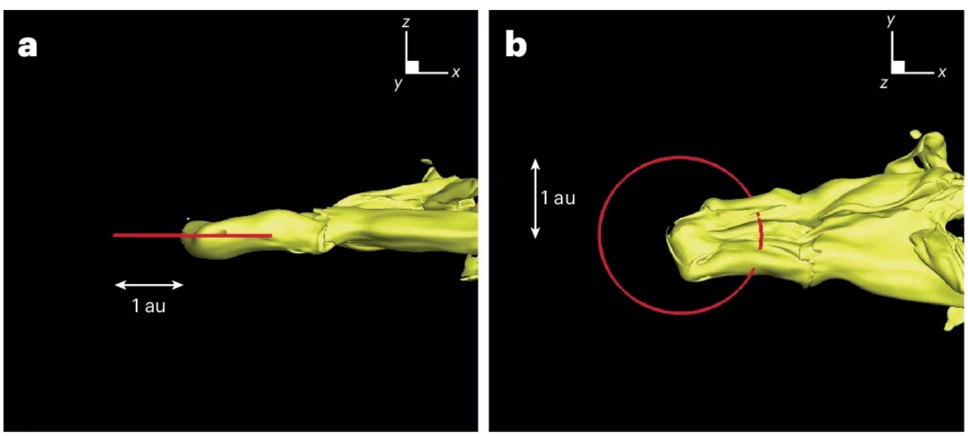


Figure: a,b, Side view in (x,z) coordinates (a) and top view in (x,y) coordinates. The orbit of Earth around the Sun is plotted in red. The isosurface of the heliosphere is plotted with speed of 100 km s^{-1}. We plotted the tail out to 4 au. (Figure 4 in Opher et al., [2024])

Significance:

A new science area that joins research in heliophysics with astrophysics, terrestrial climate, biodiversity, and fossil records in deep sea sediments, crust, and lunar samples. The direct exposure of the Earth to the cold dense interstellar medium most certainly had a substantial impact on our planet and its climate, producing colder temperatures, increases in hydrogen in the atmosphere, and enhanced radiation. These conditions may help to explain a range of phenomena, including ice ages, and the extinction and diversification of species. This has implications for the habitability of exoplanets.

Reference(s):

Opher, M., Loeb, A. & Peek, J.E.G. A possible direct exposure of the Earth to the cold dense interstellar medium 2–3 Myr ago. *Nat Astron* 8, 983–990 (2024). https://doi.org/10.1038/s41550-024-02279-8.