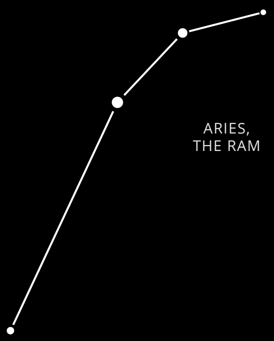
Astro·SG

MARCH 2025
EDITION 9



ASTRO DIGEST

A WELCOME TO 2025

THE GRANDEST PLANETARY ALIGNMENT THAT WE HAVE EVER SEEN, AND MORE ON THESE IMPRESSIVE EVENTS

BIRTH OF GALAXIES

THE UNIVERSE'S MOST EPIC BRAWL FOR EXISTENCE UNFOLDS HERE

ICY SPACE BALLS BAFFLE ASTRONOMERS

MYSTERIOUS ICY BALLS IN SPACE CHALLENGE OUR CURRENT UNDERSTANDING OF CELESTIAL OBJECTS

TRIVIA

BECAUSE THE UNIVERSE LOVES TO KEEP US GUESSING!

EVENTS & STARGAZING

FEATURED STARGAZING LOCATION & OBJECTS

CONTENTS

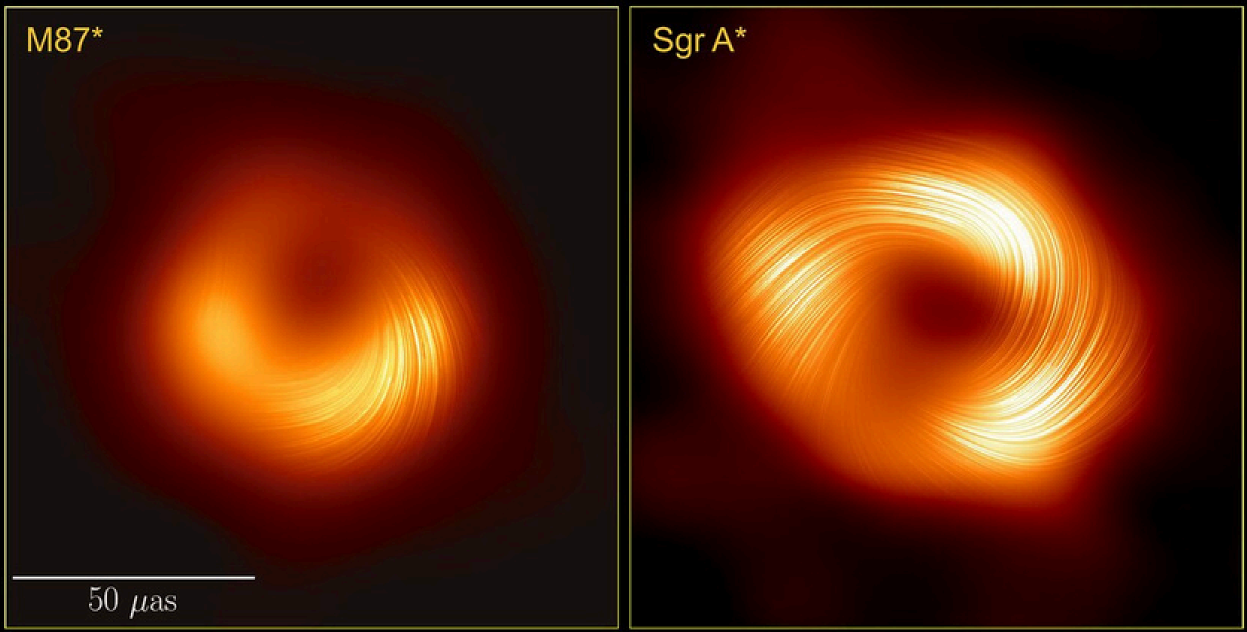
IMAGING A BLACK HOLE

A SIDE BY SIDE COMPARISON OF M87 AND SGR A* [SOURCE: ESO]

The Event Horizon Telescope is well known for its black hole images, which shocked the world when they were first released in 2017.

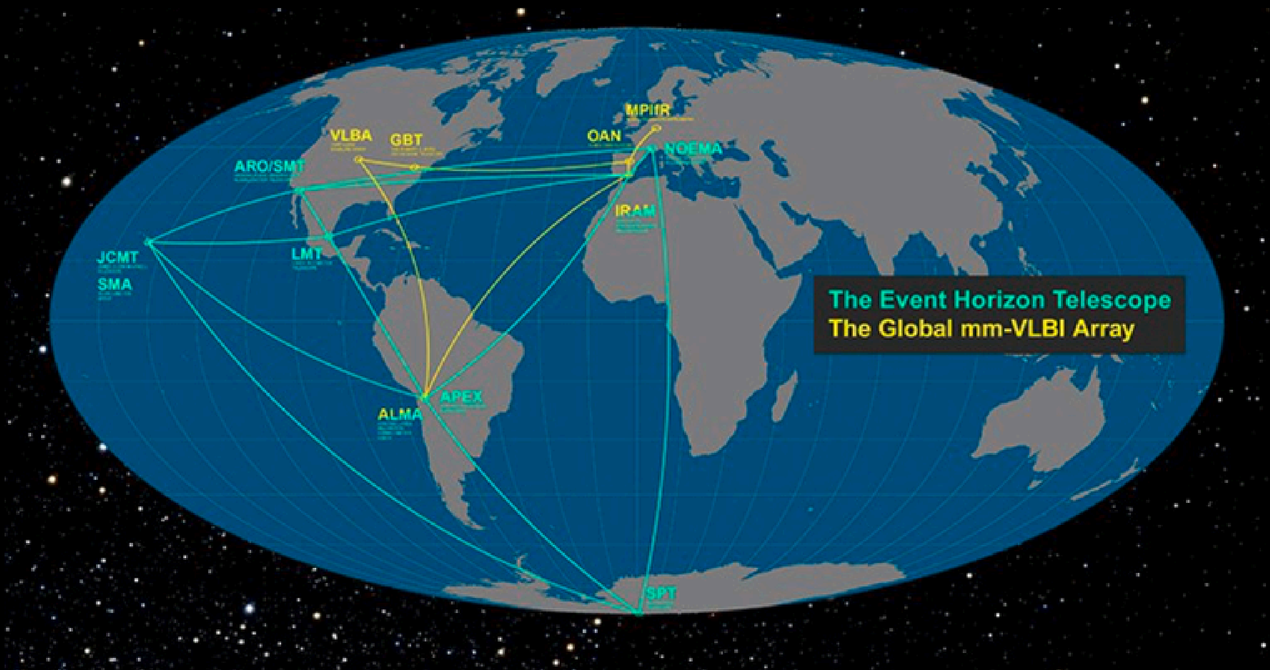
Soon after, in 2021, they released a new set of images of the same two objects (Sagittarius A* and M87), this time in polarised light.

But how?



A SIDE BY SIDE COMPARISON OF M87 AND SGR A* IN POLARISED LIGHT [SOURCE: ESO]
50μas is roughly equivalent to the angle subtended by a coin on the surface of the moon as viewed from Earth

IMAGING A BLACK HOLE



THE EHT VLBI ARRAY [SOURCE: EHT]
This image shows the different telescopes involved for the EHT (Event Horizon Telescope) and GMVA (Global mm-VLBI Array) projects, as both utilise the VLBI technique

VLBI

You might have heard about EHT's use of VLBI (Very Long Baseline Interferometry), which is a technique that basically combines the observations obtained by different telescopes all over the world so as to obtain more sets of usable data to form the final image.

Due to the differing positions of the telescopes used for observation, the same signal from the black hole will be received by the telescopes at slightly different timings. Through using very precise timing techniques, scientists can obtain the precise time delay that it takes for the signal to reach each telescope, and then gain detailed insight into the exact location of the black hole. Following that, they can compare and combine the data received by different telescopes to obtain data points for the final image. For each location, they would obtain a slightly different data point, given that the black hole's orientation to them would change slightly depending on location. This combined would offer a final image that would exceed that of each individual telescope's observing ability, despite using the same telescopes.

The key to VLBI's success lies in its ability to synchronise the timing of the data coming from multiple telescopes. But standalone, VLBI is not able to fill in the gaping gaps of data that would be present due to the simple fact that

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despite EHT's ability to mimic a telescope with an Earth-sized aperture, it is fundamentally still a telescope with more holes than mirrors. The image below shows the actual data points of a black hole that the EHT has obtained. So, the obvious question is, how did we get from this, to the gorgeous pictures that were shown to us all?

Machine Learning

This image below demonstrates that only imaging a source using a few telescopes can lead to much uncertainty given the sheer number of missing data points such that there are multiple possible images that fit the data collected.

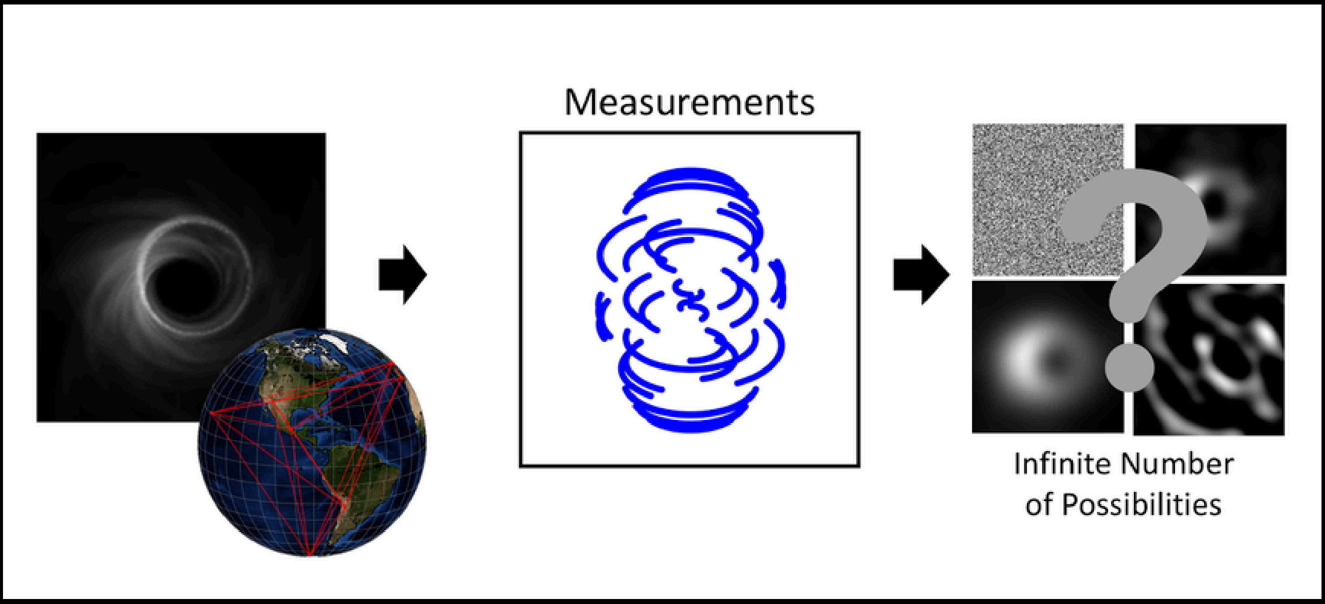


DIAGRAM DEPICTING THE PROCESS USED TO IMAGE THE BLACK HOLE [SOURCE: EHT, KATIE BOUMAN]

As the EHT fundamentally is not an Earth-sized telescope, it will only be able to collect some but not all possible data points to produce a complete image of the black hole, and this incompleteness leads to the problem where multiple final images can result from the given data points. Hence scientists would need to find a way to ensure that their final image isn't just any image, but its most accurate representation.

IMAGING A BLACK HOLE

This is why astronomers turned to machine learning. The actual process is complicated, but it can be summed down in the following steps.

- Create a model and obtain the relevant test data
- Process the test data such as to induce noise to make it align closer to the observational difficulties that the EHT faces such as atmospheric effects
- Have different teams use the model to try to recreate the original test data independently of each other
- Share each team's final image and compare for similarities and differences
- Repeat 1-4 but with slightly varied model parameters to optimise it
- Try with actual black hole image data

Essentially, scientists used machine learning to fill in the missing data points with possible predictions of what they might look like. So for these pictures to be revealed to us, it's not just the improved observational techniques used, but also the ability to utilise post-observational techniques to process the image to actually create a coherent photo.

And it's impressive. Really. Imagine reaching out into the darkness, where not even light can escape, and pulling back the curtains to reveal a glimpse of something as unfathomable as a black hole. These images aren't just pictures; but instead snapshots of the universe's most intimate secrets, captured from the edge of human comprehension. The use of Machine Learning just further proves how far we have gone from the ancient times of astrology, where we took stars as signs from the gods. Now, we are a step closer to being our own gods, daring to probe into these objects so extreme that even the flow of time would back away from their path.

And this isn't just the power of technology—it's the spirit of exploration, the relentless drive to reach beyond the horizon and touch the untouchable. With every calculation, every reconstructed image, we're not just observing black holes; we're connecting to the very fabric of the universe itself, standing on the shoulders of those who dared to dream of seeing the invisible.

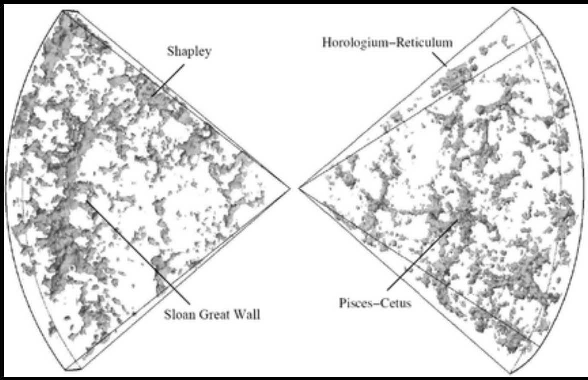
So next time, when you look up into the sky, just remember that there are many more fascinating things lying within, and one by one, we will figure them out.

BIRTH OF GALAXIES

The Milky Way, a sublimely bewitching faint fuzz in the night sky has allured generations of poets, philosophers, naturalists, mystics and lovers alike with its effuse gentle nebulae and dotted visage. Yet, the Milky Way is just one of hundreds of billions of galaxies, each with its own intricate structure and evolutionary path—diversity neatly classified in the Hubble–de Vaucouleurs Galaxy Morphology Diagram.

MILKY WAY GALAXY. SOURCE: WIKIMEDIA
Our host galaxy, the Milky Way, is home to more than a hundred billion stars. The nearest star takes about 20,000 years to get to. Consider that.

But where did all these galaxies come from? Their story traces back to the Big Bang, which many of you know is a cosmic event that set the universe into motion.



SLOAN GREAT WALL. SOURCE: WIKIMEDIA
The Sloan Great Wall is a colossal structure of galaxies, discovered through the Sloan Digital Sky Survey, that spans approximately one billion light-years, making it one of the largest known cosmic structures in the universe.

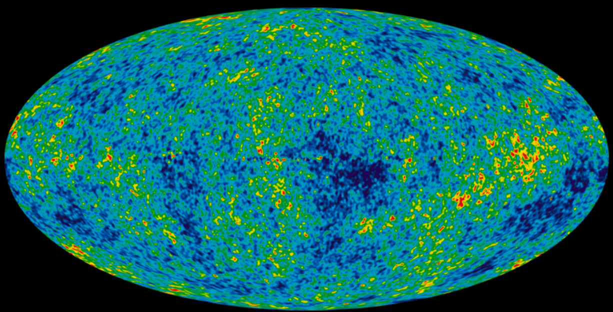
Despite its vastly intricate and sponge-like profile today, the universe began as a nearly uniform expanse of gas. How then is it possible that within just a few hundred million years of its inception, all these galaxies we see with our powerful telescopes start forming and ultimately form this breathtaking variety of galaxies? This is precisely what we will be discussing in this article.

Origin

First off, let's again rewind to the beginning of the universe - notice how we mentioned "near perfectly uniform" instead of uniform when referring to the universe's primordial matter? The reason behind the slight non-uniformity is believed to be due to quantum fluctuations in the inflaton field when the universe was much more compact.

BIRTH OF GALAXIES

That is a lot of jargon in one sentence — let's break it down. The inflaton field, which can only be well described in the language of mathematics much beyond the scope of this article, can be thought of as the "push" that caused the universe to originally expand. Before this push, the inflaton field is believed to have existed in an unstable equilibrium, such that the universe remained in its compact state. However, as the inflaton field fell out of equilibrium, so did the universe, causing the rapid expansion we know today as inflation. As the universe expanded, the quantum ripples in the inflaton field were stretched to macroscopic scales, imprinting themselves onto the distribution of matter. When the universe cooled enough for particles to form, these fluctuations froze into the cosmic matter distribution, manifesting as slight over-densities and under-densities in the primordial gas.



COSMIC MICROWAVE BACKGROUND. SOURCE: WIKIMEDIA
The Cosmic Microwave Background (CMB) is the thermal radiation left over from the Big Bang, providing a snapshot of the universe when it was just 380,000 years old.

And that was enough to begin the process of galaxy formation—regions with slightly higher densities exerted a stronger gravitational pull, attracting more matter, while underdense regions became emptier. Over time, this gravitational collapse led to the formation of the first galaxies.

Formation

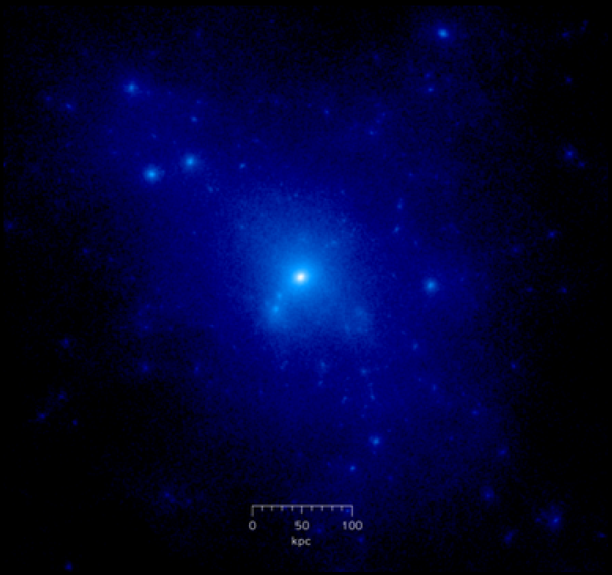
Now that we understand what triggered galaxy formation, let's dive into the complex processes that followed. Up to this point, we have loosely referred to "matter" without specifying what it consists of. Many may assume this refers to ordinary matter—the atoms and molecules that make up gas, stars, and planets. In cosmology, this type of matter is called baryonic matter, since atoms are composed primarily of baryons (protons and neutrons).

However, baryonic matter alone is not enough to explain the formation of galaxies. The early universe contained another, far more mysterious component: dark matter. Unlike baryonic matter, dark matter does not interact with light or other forces except gravity—meaning it cannot be heated, does not radiate, and does not decay radioactively.

BIRTH OF GALAXIES

And yet, dark matter played a pivotal role in shaping galaxies due to two critical reasons:

1. It is much more abundant than normal matter—approximately five times as much—so its gravitational influence is significantly stronger.
2. It does not lose energy like baryonic matter, meaning it does not collapse into dense clumps but rather forms large-scale dark matter halos that act as gravitational wells (Cimatti, Fraternali and Nipoti, 2019).



DARK MATTER HALO, SIMULATED. SOURCE: WIKIMEDIA
A cosmological simulation showing the concentration of dark matter within a dark mattr halo. A galaxy rests at the center of the halo, though it is not shown here.

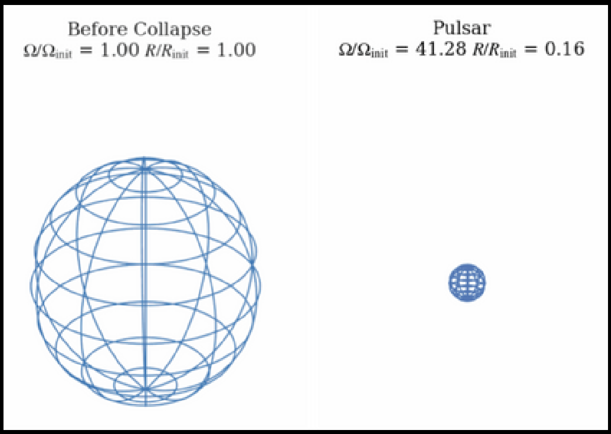
Both dark matter and baryonic matter followed the density fluctuations imprinted by the inflaton field, but because dark matter did not radiate energy away, it retained its shape, forming the cosmic scaffolding in which galaxies would emerge. Meanwhile, baryonic matter, subject to radiative cooling, gradually lost energy and collapsed into these dark matter structures, forming the first gas clouds, stars, and ultimately, the first galaxies.

This process is relatively easy to understand. As baryonic matter fell into the gravitational wells of dark matter halos, it gained kinetic energy and heated up due to collisions—a process similar to how meteors heat up when entering Earth’s atmosphere (though in this case, the heating mechanism is radiation, not air resistance). This energy loss allowed gas to settle in the centers of these overdensities, where it cooled and condensed into dense clouds. These clouds eventually collapsed under their own gravity, giving birth to the first stars and galaxies.

BIRTH OF GALAXIES

Why galaxies spin

So far, we have explained how galaxies formed, but we have yet to discuss why they spin. After all, if matter simply falls into gravitational wells, shouldn't it just form a large, stationary clump rather than a rotating disk? The answer lies in one of the fundamental laws of physics: the conservation of angular momentum. This law states that unless an external force acts on a system, its total angular momentum remains constant. In simple terms, if an object starts spinning, it will continue spinning unless something stops it. That may sound like a circular argument, but that is precisely what makes the law so fundamental to physics. This is why a spinning ice skater speeds up when pulling their arms inward—by reducing their radius, they must spin faster to conserve angular momentum.



PULSAR ROTATION. SOURCE: WIKIMEDIA

The star's rotation increases by 40 times as it turns into a pulsar during a supernova, due to the conservation of angular momentum.

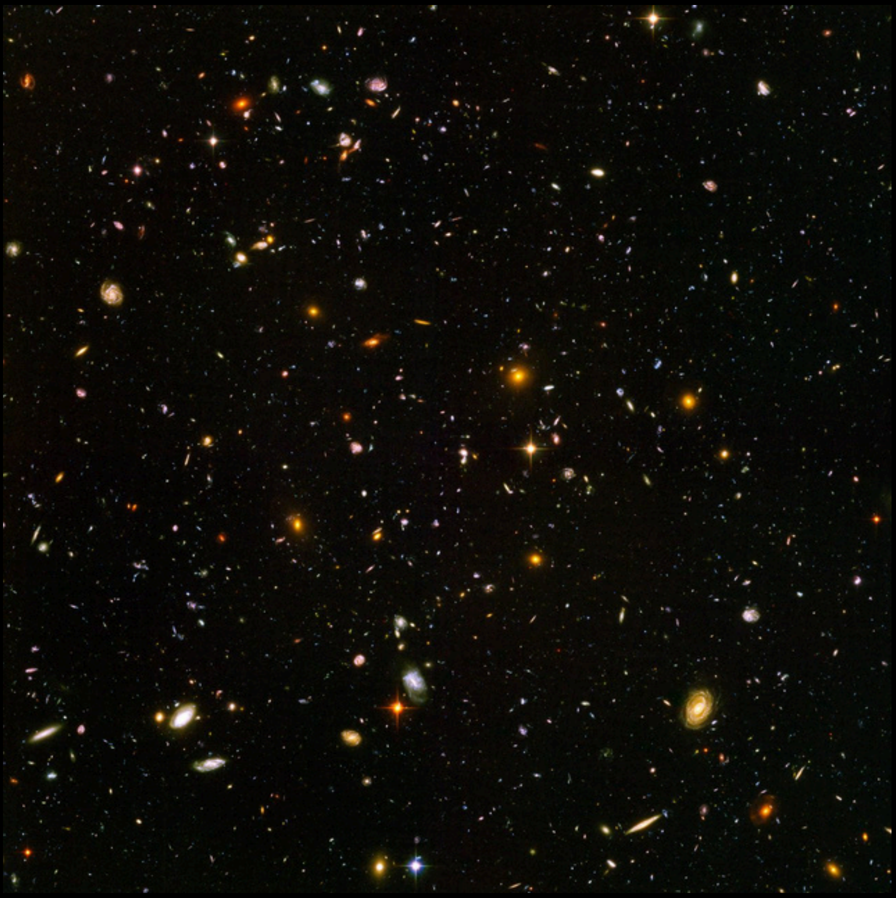
The same principle applies to infalling gas in galaxies. As matter collapses under gravity, its size decreases, which causes its rotation rate to increase. This results in the formation of rotating structures, such as spiral galaxies, lenticular galaxies, and star systems. Since gravity is self-similar on all scales, this spin manifests in everything. These aforementioned galaxies' overall structure, nebulae, stars and star systems were all made of gas that had some initial angular momentum, causing them all to spin. This explains most of the high spin galaxies we observe in the night sky which include spiral galaxies, lenticulars and the intermediate types.

However, this explanation applies mainly to disk galaxies. What about elliptical galaxies, which show little to no organized rotation? Their formation follows a different path: rather than collapsing from a spinning gas cloud, elliptical galaxies form through the random mergers of smaller galaxies. Each galaxy brings its own angular momentum, and when they collide, their spins often cancel out, leaving behind a chaotic structure with little net rotation.

BIRTH OF GALAXIES

So, there you have it! While this article covered the general process of galactic formation, there is still much more to explore regarding galaxies, such as how they evolve, their numerous properties and various interesting phenomena and correlations seen in galaxies as well as the explanations behind them.

These are just a few of the lingering mysteries that astronomers continue to explore. For now, we can gaze at the night sky and marvel at the countless galaxies twinkling across the cosmos—each a testament to the grand and intricate story of our universe.



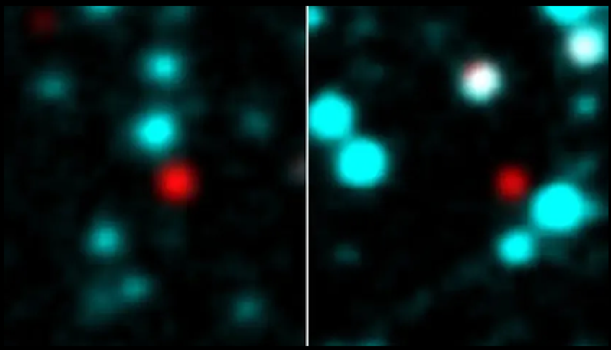
HUBBLE DEEP FIELD. SOURCE: WIKIMEDIA
The Hubble Deep Field, humanity's stare into the cosmic abyss. It has inspired a generation of astronomers to continue peering into the endless complexity of the galaxies and the universe as a whole, and will continue doing so for much time to come.

ICY SPACE BALLS BAFFLE ASTRONOMERS

In the vast and unpredictable expanse of the universe, discoveries often come in strange forms, forcing astronomers to re-evaluate everything they thought they knew about celestial phenomena. One of the latest bewildering finds has sent ripples through the scientific community: icy balls floating in space. These objects, located in a remote region of the Milky Way, defy explanation and have left experts scratching their heads. Their characteristics are so unusual that they don’t neatly fit into any of the known categories of space objects, leading to a surge of questions about their origins and nature.

A bizzare discovery

In 2021, astronomers first spotted these mysterious objects while studying data gathered between 2006 and 2011 by Japan's AKARI space telescope. The objects were situated in a region of the Milky Way that is far from any known star-forming areas. Initially, scientists believed they could be dense gas clouds, but a closer inspection using the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile provided even more perplexing data. These ice balls, as they have come to be known, appear to have characteristics similar to young stellar objects (YSOs), but they are located far from typical star-forming regions, complicating the puzzle.



Images of the icy objects as seen by the ALMA (Atacama Large Millimeter Array) telescope.
Source: LIVESCIENCE

Despite their distant location—spanning 30,000 and 43,000 light-years away—these icy balls are not stars, nor are they typical gas clouds. Instead, they appear to be objects completely surrounded by ice and dust, showing deep absorption features often associated with young stars but with no obvious stellar origins. Their unique characteristics, such as their size and icy composition, set them apart from the types of stellar formations previously studied.

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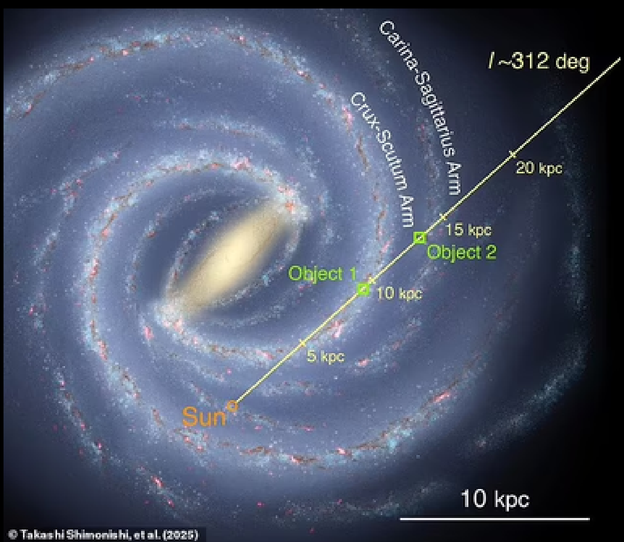
Understanding the mystery

The nature of these icy orbs has left astronomers speculating about their origins. The research, published in January 2025 on the arXiv preprint server, suggests that they could represent a previously unknown type of isolated icy object in space. This hypothesis challenges conventional knowledge, as objects like these don't fit within the established models of star and planetary formation.



Rough locations of the 2 icy objects in the milky way.
Source: DAILYMAIL

One theory proposes that these objects could be "young stars" in a very early and unusual phase of their development. Stars are born from dense, turbulent clouds of gas and dust, gradually gathering material until they begin nuclear fusion. However, these objects appear to be too isolated and small for such a formation process. The size of these icy balls, measuring up to 10 times the size of our solar system, is relatively small compared to other gas clouds. For comparison, some gas clouds stretch across regions many times the size of the Milky Way.

Interestingly, infrared readings of these objects reveal that they contain large amounts of silicon dioxide and carbon monoxide—elements typically found in the gas surrounding young stars. However, the context in which these objects exist does not correspond with our understanding of stellar birth, leading some researchers to believe that they may be a completely new class of astronomical objects.

The ice connection

One of the most intriguing aspects of these objects is their icy nature. Ice is a common feature in many parts of the universe, especially in cold regions where the temperature is low enough for gases to freeze into solid forms. In the case of these ice balls, the ice

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surrounding them could be a clue to their formation process. The types of ice and dust present in these objects could shed light on the chemical processes occurring in their vicinity, offering a glimpse into a phenomenon never before observed.

But why is ice such a significant feature? Ice is essential in many astrophysical processes, particularly in the formation of planets and stars. In star-forming regions, icy grains of dust play a crucial role in gathering mass and helping matter to coalesce. These mysterious objects seem to share some of the chemical signatures of such regions, but their isolation and the strange composition of their surroundings suggest they have followed a very different path to formation.

A new type of object?

What makes these ice balls truly remarkable is their placement in the universe. Astronomers typically observe star-forming regions, where massive clouds of gas and dust collapse under gravity to give birth to stars. But these icy objects are not found in such regions. Instead, they exist far from the bustling star formation zones, in what seems like a cosmic void.

This has led some to speculate that these objects could be an entirely new class of astronomical bodies—something that does not fit into the typical categories of stars, planets, or gas clouds. Some scientists have even suggested that these icy balls could be the first detected remnants of an entirely unknown class of objects, perhaps something akin to ancient stellar embryos or objects that formed under conditions not previously considered by astronomers.

The role of ALMA and the James Webb Telescope

To get to the bottom of this mystery, astronomers have employed some of the most powerful telescopes available today. The Atacama Large Millimeter/submillimeter Array (ALMA) has provided crucial data on the chemical composition and structure of these objects, offering insights into their potential origins. However, to gain an even deeper understanding, astronomers are turning to the James Webb Space Telescope (JWST), which is capable of capturing highly detailed infrared images of distant objects.

ICY SPACE BALLS BAFFLE ASTRONOMERS

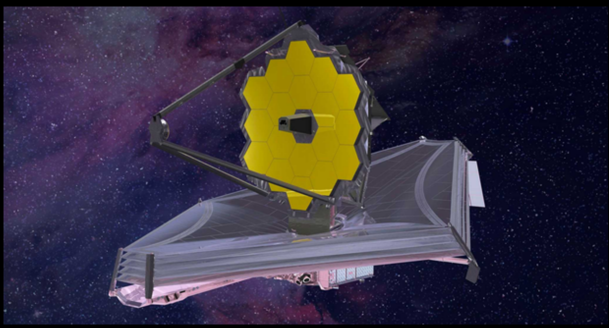


Image of the James Webb Space Telescope
Source: WEBB SPACE TELESCOPE

The JWST's unparalleled resolution could provide a clearer picture of these objects' structure, allowing astronomers to study their surface features and internal compositions in much greater detail. The hope is that this data will reveal whether these ice balls are truly a new class of celestial object or if they can be explained within the framework of known stellar or planetary phenomena.

What's next for the ice balls?

As more data comes in from the ALMA telescope and the upcoming JWST observations, astronomers will continue to refine their understanding of these strange objects. Their unique characteristics—an icy exterior, unusual location, and composition—make them an exciting subject of study. They may hold secrets that could unlock new insights into the processes that shape the universe, from the birth of stars to the formation of planets and even the nature of matter itself.

Conclusion:

In the grand scale of the universe, the discovery of two strange, icy balls far from typical star-forming regions may seem like a minor event. But for astronomers, it is a fascinating puzzle that challenges existing theories and opens up new avenues for exploration. These objects may turn out to be a previously unknown form of celestial body, providing insights into the early stages of stellar formation or even pointing to entirely new cosmic processes.

As we continue to explore the mysteries of space, we are reminded of the infinite surprises the universe holds. Whether these icy objects turn out to be ancient stellar remnants or the product of a completely new process, they represent the exciting frontier of astronomical discovery—a reminder that there is always more to learn about the universe we call home.

TRIVIA

Welcome to the Trivia! Here, we will include interesting facts and problems that we have curated for you, the reader.

The answers to the problems can be found in the next newsletter, but for now, we hope you'll enjoy this new segment!

Problem I
Identify the Big Dipper, Little Dipper and Polaris.

Problem II

What are standard candles, their examples and their use in astronomy?

TRIVIA

Fun fact of the Month

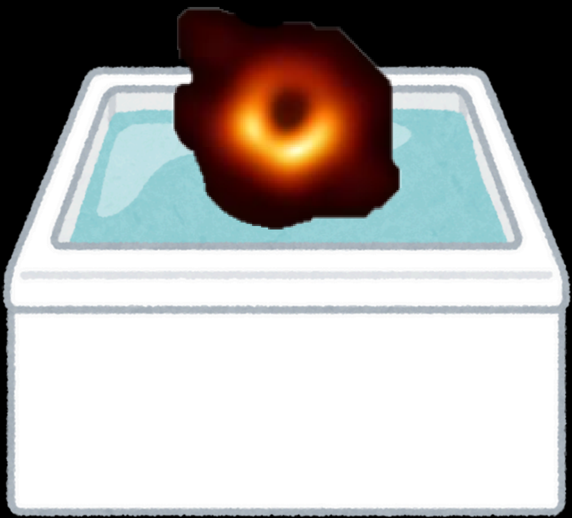
The average density of supermassive black holes is lower than that of water.

The radius of a black hole is often defined by the radius at which even objects going at the speed of light do not possess sufficient kinetic energy to escape its gravity. This sphere of influence is directly proportional to its mass. This results in the volume of a black hole being directly proportional to the cube of its mass.

In contrast to the density of an object which is calculated by dividing mass with volume, the density of a black hole is therefore inversely proportional to the square of its mass.

As a black hole grows in mass, its density rapidly decreases.

This highlights the emptiness of space, where even the most massive objects known are so sparsely distributed in mass.



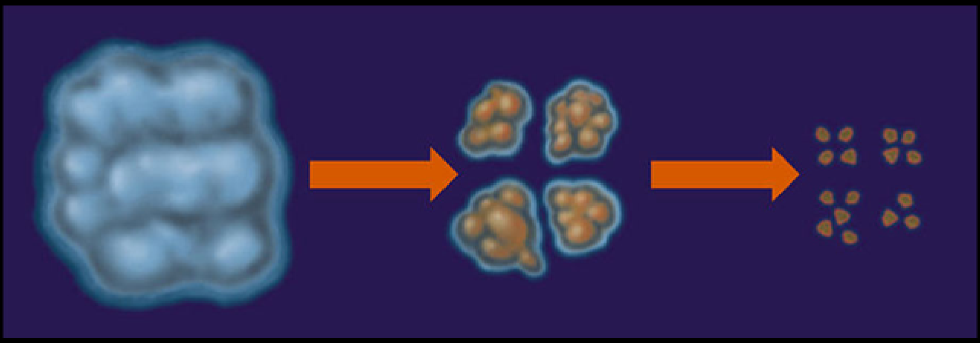
If the mass of Sagittarius A* was evenly distributed, it would float on water, provided we find a large enough sea!

ANSWERS FOR THE PREVIOUS NEWSLETTER

Problem I

Problem II

The start of a star's red giant is marked by a lack of sufficient hydrogen fusion within the core providing the pressure to support the star's outer layers. As the outer layers fall, their gravitational potential energy is converted into kinetic energy (Heat!). Our sun originates from a fragmentation off the edge of a Wolf-Rayet bubble at the edge of the Milky Way. The collapse of this fragment caused the gas within to heat up sufficiently such that nuclear fusion could occur, nuclear fusion that would slow this collapse, from 30 minutes to ten billion years, long enough for Earth, Life, Astronomy.sg to form.



Fragmentation of Gas Clouds
Pearson Prentice Hall, inc

EVENTS AND STARGAZING

GAC Astrophotagraphy workshop

Sign up link: https://www.onepa.gov.sg/events/astronomy-workshop-astrophotography-part-ii-8-march-2025-70507547

Featured Stargazing Location:

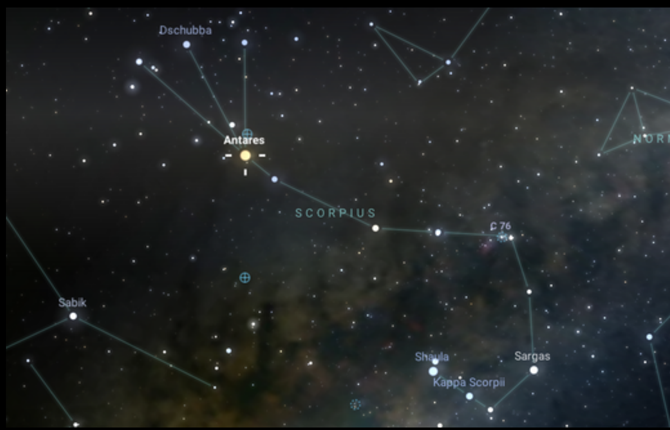
East Coast Park

East Coast pointed away from the mainland

We recommend setting up towards the eastern end of east coast park to avoid the light pollution from the central region of Singapore near the other end. Being at the end of the mainland, this region features unblocked views towards the east and south areas, the perfect spot to catch rising celestial objects!

EVENTS AND STARGAZING

March’s skies offer a new chapter of the celestial sphere. As the cloud cover gradually recedes, February offers crisp skies perfect for stargazing. As we step into the new year, spend a few minutes staring outside your window at the wonders the universe has to offer.

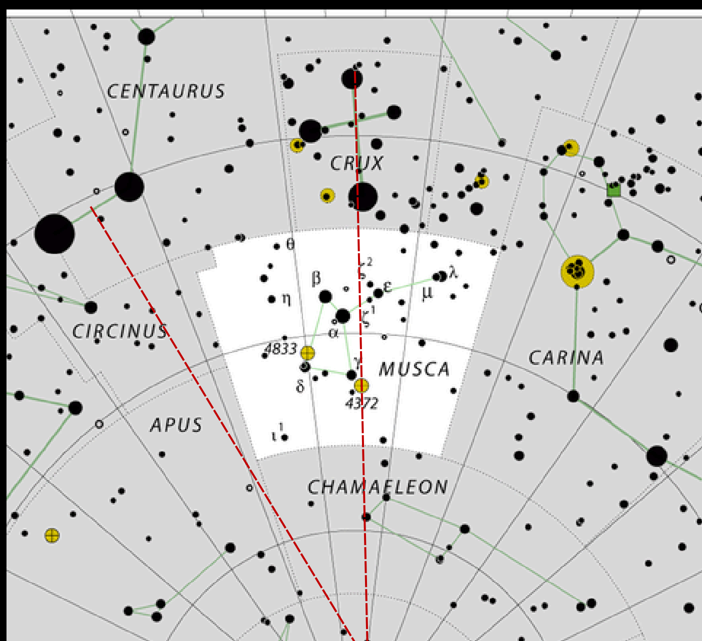


Antares within Scorpius
Source: Stellarium

Free-hand stargazing

- **Antares -** Antares is the brightest star within Scorpius, it can be easily located from its 3 branching stars. Its nomenclature is derived from the Greek word Antares, means “rival to Ares” due to its very distinct reddish bearing a similarity to Ares (Mars).

- **South Navigating stars -** Being considerably farther from the southern celestial pole, the south navigating stars are less likely to be shrouded by objects on the ground. Navigation involves the 4 brightest stars of Crux (forming the Southern Cross) and the 2 bright stars located at the left of the cross, Alpha Centauri and Hadar (forming the Southern Pointers). The southern celestial pole is located near the intersection created by extending the perpendicular bisector of the Southern Pointers and projecting the longer end of the Southern Cross.

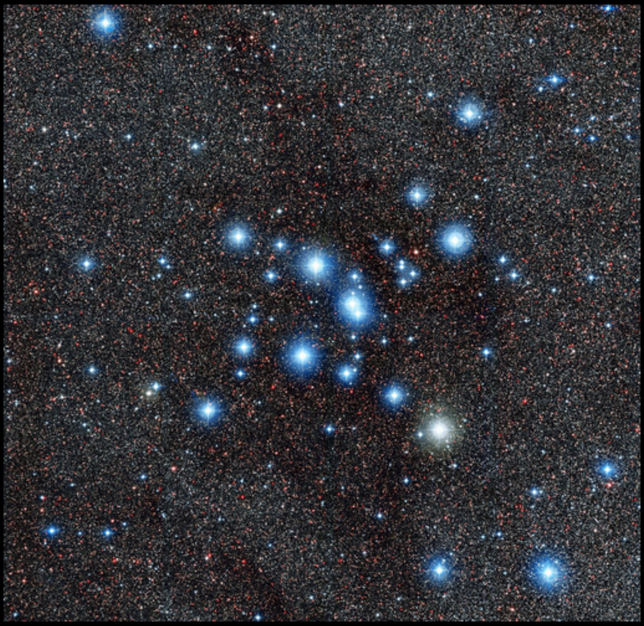


Southern Pointer stars with red annotations pointing South
Source: IAU

EVENTS AND STARGAZING

Binoculars

- **Ptolemy's cluster -** This open cluster was first recorded in the 2nd century by the Greek astronomer Ptolemy, who had incorrectly labelled it as a nebula. It can be easily located by taking the 2 nearby stars, Shaula and Lesath, at the end of Scorpius' hook. The cluster can be found by extending a the line between the 2 stars away from Scorpius.



Closeup of Ptolemy's Cluster
Source: European Southern Observatory

- **Butterfly Cluster -** This cluster is just 3 degrees northwest of Ptolemy's cluster. It is named after its vague resemblance to a butterfly by astronomers that have very vivid imaginations. Try and catch this celestial butterfly that continues to elude the writer, no net required!

Closeup of Butterfly Cluster
Source: NOIRLab

EVENTS AND STARGAZING

Binoculars (Cont'd)

- **Messier 3 -** Many amateur astronomers consider M3 to be one of the finest northern globular clusters, containing nearly half a million stars! M3 forms a straight line with Arcturus of Boötes (the 4th brightest star in our sky) and the α and β stars of Canes Venatici. It will be immediately apparent during star hopping as a thick dense cloud of stars.


Messier 3, one of the largest clusters visible
Source: ESA/Hubble

Telescope

- **Antares Nebula -** Located between Antares and us, is a large complex of interstellar clouds known as the Rho Ophiuchi Cloud Complex. The portion of the complex directly in-between Antares and Earth, which gets illuminated by this bright star, is sometimes referred to as the Antares Nebula.


Ophiuchi Cloud Complex with Antares
Source: Irida Observatory (Velimir Popov and Emil Ivanov 2013)

EVENTS AND STARGAZING

Telescope (Cont'd)

- **Running Chicken Nebula -** Forming a rough parallelogram with the bottom 3 stars of Crux, the running chicken nebula is illuminated by a bright open cluster of stars forming a distinct 'J' shape. The open cluster is easy to see even with a small telescope, however the faint gas clouds are much more challenging.

Closeup of Running Chicken Nebula
Source: ESA/VPHAS+

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https://commons.wikimedia.org/wiki/File:Via_l%C3%A1ctea_sobre_el_Sajama.jpg
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Icy space balls baffle astronomers
Unlike anything ever seen before
Research paper on the icy balls
James Webb Space Telescope
ALMA Observatory
Position of icy balls in the milky way
JWST picture

SOURCES

Events and Stargazing
Running Chicken Nebula
Antares Nebula
Messier 3
Butterfly Cluster
Ptolemy's Cluster
South pointing stars

Trivia
Test