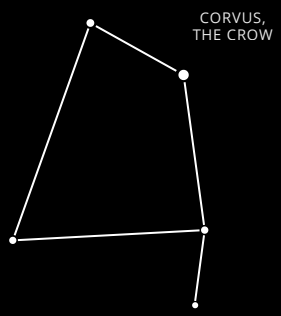
Astro SG

AUGUST 2025
EDITION 12



ASTRO DIGEST

EXTRATERRESTRIAL NUCLEOBASES

DID LIFE'S BLUEPRINT BEGIN IN OUTER SPACE?

GALILEO'S UNSCIENTIFIC SCIENTIFIC METHOD

WHAT THEY DON'T TELL YOU ABOUT ANCIENT SCIENCE...

A COSMIC CRASH LIKE NO OTHER

JUST TWO COLOSSAL BLACK HOLES ENGAGING IN A GRAVITATIONAL BALLET AND BREAKING RECORDS ALONG THE WAY

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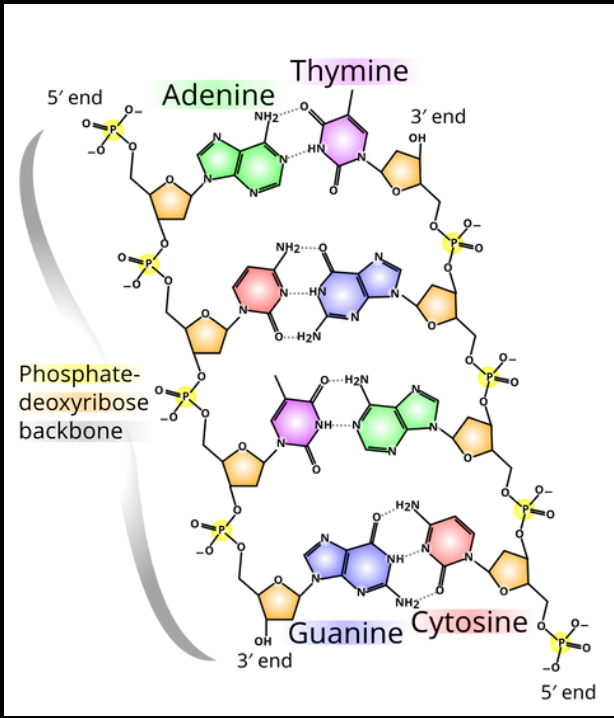
EXTRATERRESTRIAL NUCLEOBASES

In 1969, a meteorite crash-landed near Murchison, Australia. Scientists studied it vigorously for decades, unlocking openings and confirming hypotheses regarding various facets of the early solar system. But only now, half a century later, is it getting us closer to answering one of life's most profound questions. One which keeps up young science enthusiasts such as ourselves and astronomers alike – where did we come from?



SKELETAL STRUCTURES OF ORGANIC COMPOUNDS. SOURCE: WIKIMEDIA

This is a typical sketch of a segment of DNA, where the 4 nucleobases comprising it are shown. The long end of DNA is connected by the phosphate-deoxyribose sugar complex shown, while complementary nucleobases (adenine and thymine form a complementary pair, and so do guanine and cytosine) bond to each other through hydrogen bonds.

A short primer on genetic material

For the uninitiated, most life on earth runs on an organic code that exists in every living cell. This organic code is called deoxyribonucleic acid (DNA), which are molecules that hold all information regarding the organism it resides in. DNA further comprises 4 molecules – adenine, guanine, thymine and cytosine. These 4 molecules link together to form extremely long chains, giving us our DNA. The specific arrangement of these molecules gives rise to the voluminous amount of information they hold regarding its constituting organism. A good analogy for this would be how all of modern day technology runs on binary code – zeros and ones. Except in DNA's case, the code would be quaternary. These 4 molecules (and 5th molecule: uracil) are divided into 2 groups based on their chemical structure. The first group comprising adenine and guanine have a double-ring structure and are called purines. The second group comprising cytosine, thymine and uracil have a single-ring structure and are called pyrimidines.

The discovery

So what does genetic material have to do with a meteorite?

EXTRATERRESTRIAL NUCLEOBASES

A landmark paper published in *Nature Communications* by Oba et al., in 2022 detected a specific type of nucleobase, called pyrimidines, that previously eluded detection in meteorite samples. These samples come from three meteorites – Murchison, Murray and Tagish Lake. All of these are carbonaceous meteorites, which are believed to have come from the early solar system and are largely unaltered since then. Purines, on the other hand, were already discovered in the 1960s in the above-mentioned Murchison meteorite. In sum, the recent discovery of pyrimidines completes the proof that nucleobases can and do form in extraterrestrial environments. It is also important to note that purines, alongside other less prominent genetic molecules and prebiotic catalysts were also detected.

But does this prove that life must have come from outer space? Hardly. This only proves that it is possible. However, the discovery of nucleobases in meteorites strongly supports a large umbrella of origin-of-life hypotheses, broadly classified as abiogenesis. The latter is the belief that life on Earth arose from non-living matter.

An explanation of the current set of origin-of-life hypotheses is in order, as well as how this discovery fits in and reconciles with each of them.

THE MURCHISON METEORITE. SOURCE: WIKIMEDIA

As its fall was directly observed, it is among the most well-studied meteorites. Being of the carbonaceous variety, it is rich in organic compounds and thus especially pertinent to the search for prebiotic molecules.

Panspermia Hypothesis

Main idea: Life came to Earth from outer space via meteorites, comets, or cosmic dust.

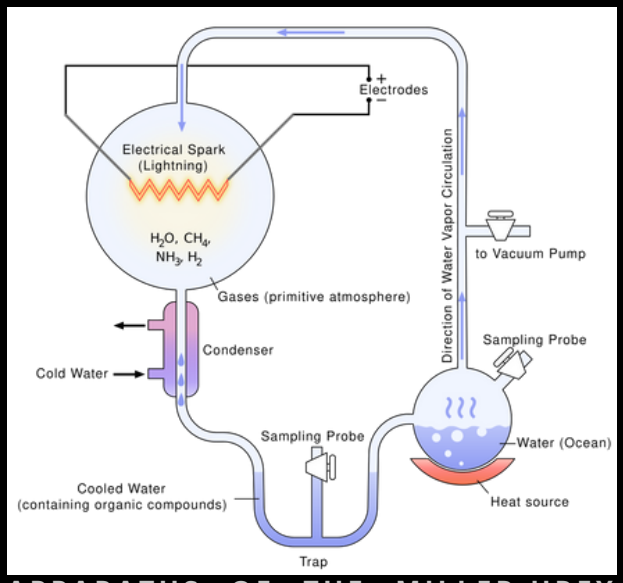
Evidence: Meteorites such as the Murchison, Murray and Tagish Lake support precisely this since they contain nucleobases, amino acids and sugars, all of which are necessary for terrestrial life forms.

EXTRATERRESTRIAL NUCLEOBASES

Primordial Soup Hypothesis

Main idea: Life arose from Earth's oceans in the Archeaen Era, in which organic compounds readily formed through chemical reactions involving lightning, UV radiation and/or volcanic activity.

Evidence: The famous Miller-Urey experiment carried out in 1952 showed amino acids could form from electricity and basic molecules like methane, ammonia, hydrogen and water. Amino acids are the building blocks of proteins, and in extension, large parts of cells.



APPARATUS OF THE MILLER-UREY EXPERIMENT. SOURCE: WIKIMEDIA

The Miller-Urey experiment was a significant milestone for astrobiology, given how early this experiment was devised and how quickly it showed success in producing viable organic compounds, most prominently amino acids.

RNA World Hypothesis

Main idea: Ribonucleic acid (RNA), which is almost chemically identical to DNA, is the original component of life to form. It precedes DNA and proteins.

Evidence: RNA can self-replicate in the form of ribozymes and also encode some genetic information.

So, what's our progress?

Ultimately, it's important to ascertain how much the discovery of the complete spectrum of nucleobases in the three meteorites helps our case. Many of the abiogenesis theories shown above require molecules like nucleobases to form spontaneously prebiotically. Finding them in meteorites, and particularly those of the type that came from the early solar system confirms that no biological processes were necessary to produce them.

It also addresses a critical gap in the origin of sufficient amounts of genetic material on Earth prior to her formation. Meteorites containing nucleobases provide a possible source of these molecules, since we already know of a time period in Earth's history during which she was relentless pounded by meteorites – the Late Heavy Bombardment.

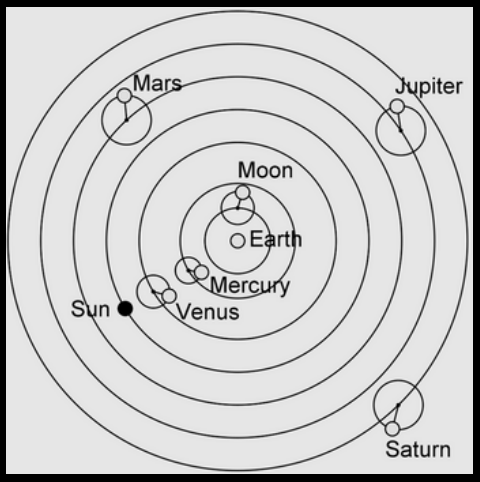
EXTRATERRESTRIAL NUCLEOBASES

Also, it retrospectively gives credence to laboratory simulations which showed that interstellar and early Earth chemistry had and could produce nucleobases.

Alongside seeing the positives of this development, it is also necessary for us to beware of the caveats and limitations of the discovery. We still do not have concrete proof that having these ingredients is sufficient for life to inevitably form from them. Abiogenesis still requires various steps that are currently insurmountable with our latest evidence and simulations. These include the formation of the necessary precursor molecules from nucleobases that lead to the formation of RNA and DNA, as well as proteins from amino acids. Basic self-replicating molecules and rudimentary metabolism remain a far cry too, let alone the compartmentalisation of these molecules into some rudimentary form of cells.

In conclusion, while the detection of nucleobases doesn't specifically show any single abiogenesis theory to stand out of others, it certainly makes most of them much more chemically plausible. It bridges the chemistry occurring in outer space, of interstellar clouds, to that of prebiotic Earth. If that's not poetic, what is?

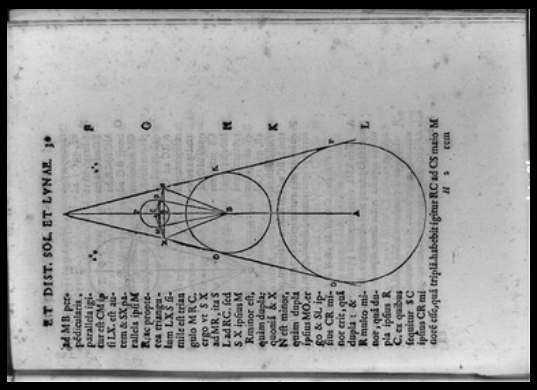
Galileo's unscientific scientific method



PTOLEMAIC MODEL
SOURCE: WIKIMEDIA

Galileo Galileo, father of observational astronomy, modern science and the scientific method. The impact of his life's work on astronomy and the overall field of science is unparalleled. In the eye of his storm of influence was his defense of the model of heliocentrism, dubbed the "Galileo affair". Popular, casual interpretations of the affair portray a then unscientific catholic church, reflexively labeling Galileo's indisputable concrete evidence for heliocentrism due to their inability to let go of their dogmatic interpretations of their religious texts. Observing the era and academic environment Galileo lived in, it is clear that the Church at that time had a great influence over western academia, it is undeniable that religious interpretation of the Bible contributed to the academic consensus to label heliocentrism as a quack fringe theory. However, this interpretation ignores certain nuances about what Galileo was arguing about and presents a damning perspective that is still very important in our modern times.

The Galileo affair was far from the first known instance of heliocentrism; the first known instance of a heliocentric model of the universe being proposed was from ancient Greek astronomer Aristarchus of Samos. Aristarchus was able to create an accurate set of formulae to derive the relative distances of the Sun, Earth and Moon; had they not been limited by the accuracy of their observational equipment, they would have gotten a very correct ratio of the Sun, Moon and Earth. Nevertheless, Aristarchus was able to conclude that the Sun was bigger than the Earth and assumed that the larger object would be at the center. Although he lacked a proper formulation of the laws of motion and gravity, his guess was correct.



ARISTARCHUS' WORKINGS
SOURCE: LIBRARY OF CONGRESS

Within his time, Aristarchus' heliocentric model was a fringe theory being largely overshadowed by the Ptolemaic geocentric model and would only start gaining traction centuries later during the period of early modern Europe, with Nicholas Copernicus' presentation of his mathematical model of heliocentrism, leading to the Copernican Revolution which would ultimately crystalise in the Galileo affair.

Galileo's unscientific scientific method

The Galileo affair was not a purely religious affair, with scientists of the time which argued that his findings did not meet scientific standards. A major argument against the motion of the Earth was the lack of observed motion of objects caused by the Earth's motion. This, of course, is a flawed argument, the lack of perceived motion from the Earth's movement is solved by considering reference frames. Galileo argued against this by proposing the experiment of dropping a rock on a smoothly moving ship, however, such an experiment was not personally conducted by Galileo and reports of physical experimentation at the time yielded differing results. Even if Galileo's experiments were proven true beyond any doubt, there was no theoretical basis for relating the moving ship to a moving Earth. It was wrong for scientists at that time to not consider relative motion in their argument, however, when considering their natural observations of their environment. It was not unscientific of them to base their observations of the natural world to form their idea of the universe. After all, natural observations are still all we have, even in our modern world of observatories, particle accelerators, our physics is still based on natural observations from these tools.

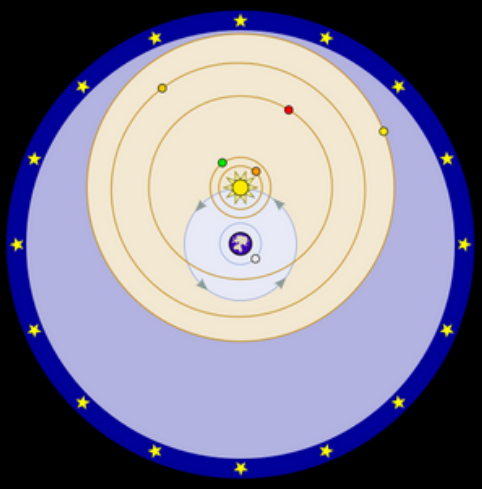
Furthermore, even if Galileo was able to justify his comparison, this would only disprove an argument against heliocentrism, without providing any argument for heliocentrism, against geocentrism. It is important to note that the model of heliocentrism at that time did not predict the general motion of celestial bodies any better than already prevalent preexisting theories.

GALILEO'S TELESCOPE
SCOURCE: WIKIMEDIA

On the offensive, Galileo presented his observations from his telescope, of the changing sizes of the planets, the phases of Venus and Jupiter's moons as evidence against heliocentrism. These observations showed that different celestial bodies could orbit different objects and provided evidence that the planets orbited the Sun and not the Earth.

Galileo's unscientific scientific method

However, during those times, telescopes were a novel piece of equipment, Galileo himself did not even study the physics of telescopes until long after he had already started arguing for heliocentrism. Furthermore, although the function of telescopes could be inferred from objects on Earth, there were clear artifacts when observing Earth objects which had cast doubt on Galileo's observations. There was a consensus during that age that objects on Earth behaved the same way as objects in space. They lacked the data to scientifically prove that the laws of physics were the same everywhere and thus it was reasonable for scientists to have doubts about these observations. Repeats of Galileo's observations were also inconclusive with some repeaters being unable to obtain the same results that Galileo had. There also existed models of that time, such as the Tychonic model, which centered the planet's orbits around the sun, but still had the sun orbit the Earth.



TYCHONIC MODEL
SOURCE: WIKIMEDIA

Something that would have proven the motion of the Earth was stellar parallax, as the Earth moved around the Sun, the stars would shift. However, this was never observed by Galileo and would only have been observed centuries later with better telescopes. Galileo would argue against the perceived lack of stellar parallax by arguing that the stars were farther than initially believed. When presented with data against his hypothesis, instead of dismissing the hypothesis, he tweaked it in response.

This was the extent of his arguments for heliocentrism. It was only with the advent of better equipment and understanding of the mechanics of telescopes and their artefacts that heliocentrism was properly proven. Galileo's evidence was not grounded in scientific standards; he would often utilise persuasive writing in his texts to have readers support his new theory, calling geocentrists simpletons and avoided talking about the Tychonic model of geocentrism even as it became the prevalent model in the scientific community. It was, however, thanks to this kind of support and marketing that heliocentrism could live on and ultimately be proven. It is through diversity in ideas, even those that initially seem incorrect that science prospers.

A COSMIC CRASH LIKE NO OTHER

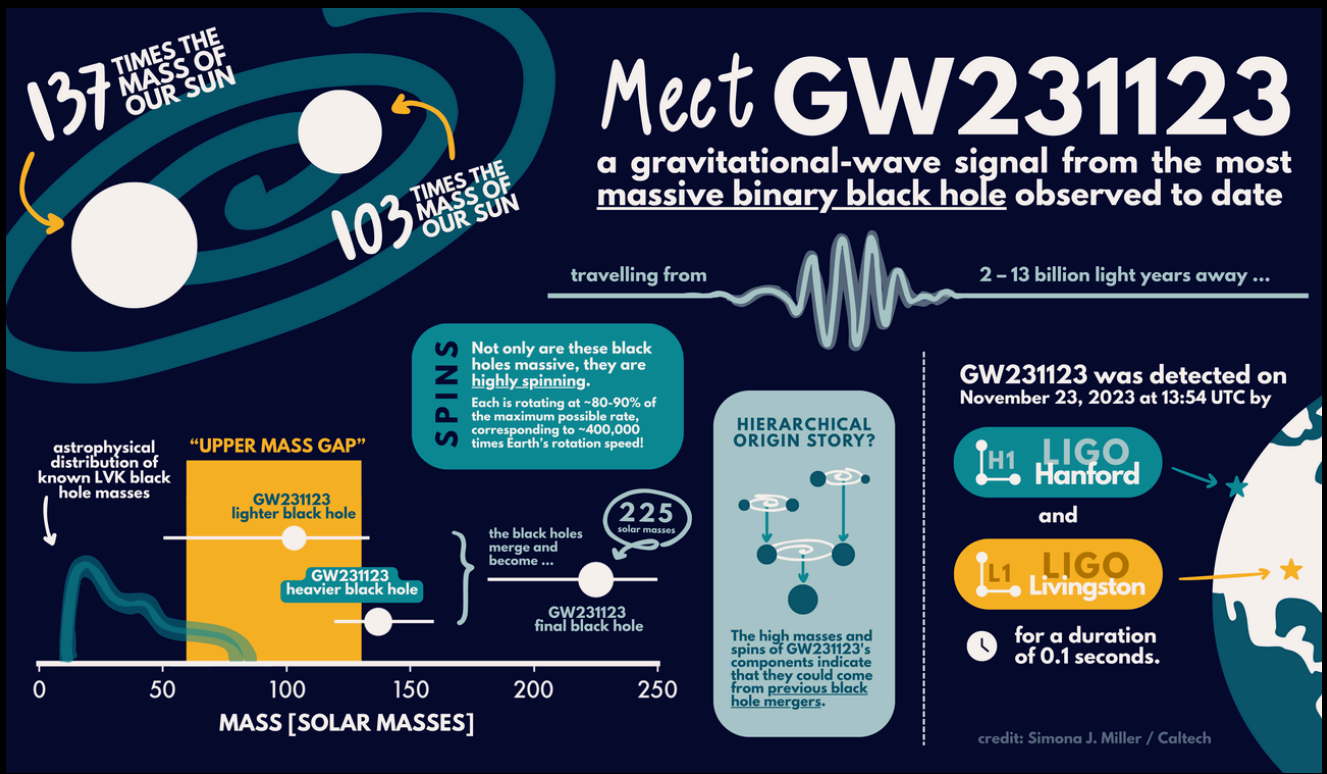
What happens when giants collide?

In late 2023, scientists witnessed something so powerful it literally shook the fabric of space-time: two colossal black holes—each heavier than 100 Suns—spiraled into one another and merged, sending ripples across the cosmos. These ripples, known as gravitational waves, traveled over 10 billion light-years to reach Earth and left behind one of the most intriguing mysteries in astrophysics.

This event, dubbed GW231123, is now officially the most massive black hole merger ever detected. It wasn't just a record—it was a revelation.

Breaking the rules of black hole physics

According to the rules of stellar evolution, there exists a range of solar masses (roughly 60–130 times the mass of the Sun) where stars aren't supposed to collapse into black holes., known as the 'pair instability mass gap'. They should explode into nothing. Yet here we are, with two black holes in this forbidden zone—one about 100 solar masses and the other around 140.



A SCHEMATIC DETAILING THE GW231123 BLACK HOLE MERGER.
SOURCE: SIMONA J. MILLER / CALTECH

A COSMIC CRASH LIKE NO OTHER

Together, they formed a super-sized 225 solar mass black hole, catapulting it into the realm of what astrophysicists call an intermediate-mass black hole (IMBH)—a hypothesised but rarely observed class.

So what gives? The answer may be hierarchical mergers—where black holes are formed by previous generations of black holes colliding. It's a cosmic nesting doll of chaos, and GW231123 is the best candidate we've ever seen for it.

The briefest, loudest signal

When LIGO, Virgo, and KAGRA picked up the signal in November 2023, it lasted only a tenth of a second. That's all it took for two spinning behemoths to smash together at nearly the speed of light. In that sliver of time, they released more energy than all the stars in the observable universe—*combined*.

The data, analyzed and shared in this preprint, revealed that the merger's ringdown phase (the "echo" of the final black hole) was especially strong, helping scientists pin down its mass and spin with remarkable accuracy.

The resulting black hole is not just massive—it's spinning near the maximum speed allowed by Einstein's equations.

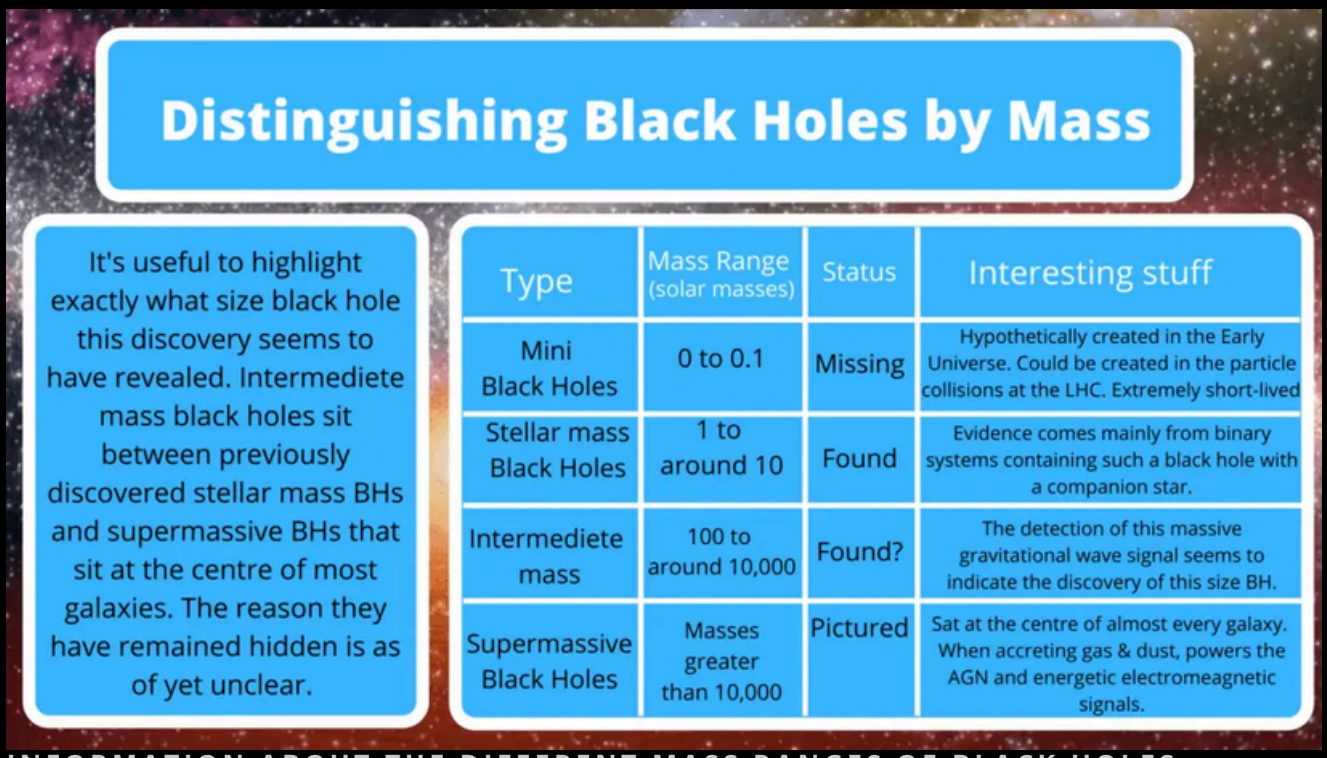
What makes this different

Most of the black holes we've detected in mergers so far fall within the 10–50 solar mass range. These are believed to come from supernovae — the explosive deaths of massive stars. But GW231123 is in a class of its own:

- Mass gap violator: One black hole falls within the forbidden range that classifies as an intermediate black hole.
- Spin to win: Their extreme spins suggest a more exotic origin—like prior black hole collisions.
- Distance and age: This event happened over 10 billion years ago, making it one of the most distant black hole mergers ever seen.

Scientists theorise this merger likely occurred in a dense star cluster, where black holes are packed closely together, interacting and eventually colliding in a cosmic free-for-all. Other theorists speculate it could even hint at primordial black holes, dating back to the early universe.

A COSMIC CRASH LIKE NO OTHER



INFORMATION ABOUT THE DIFFERENT MASS RANGES OF BLACK HOLES THEORISED. SOURCE: ZME SCIENCE

The gravitational wave network

This discovery was made during the O4 observational run of the global gravitational wave network, consisting of LIGO (Livingston & Hanford, USA), Virgo (Italy) and KAGRA (Japan). Each detector contributed crucial data to triangulate the source, filter out noise, and confirm the astronomical nature of the signal. With each new run, detector sensitivity improves, making the invisible universe just a little more visible.

Why this matters

GW231123 is more than just an event,
it's a challenge to astrophysical theory and a window into cosmic history. Here's what it means:

- Intermediate-mass black holes do exist and might be more common than previously theorised.
- Black hole growth is complex, involving multiple generations and exotic formation environments.
- We're seeing farther into the universe's past—this merger occurred when the universe was less than 4 billion years old.
- New models needed: Scientists now have to rethink supernova limits, stellar evolution, and even general relativity in high-spin, high-mass regimes.

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

Suppose the Earth was instantaneously replaced by a black hole of mass identical to that of the Earth. What would happen to the Moon? I.e., how would the Moon's trajectory change?

Problem II

You are given the following equipment and materials. A vat of mercury, support beams, a large, cylindrical container, a small secondary mirror and a motorized turntable. Is it possible to make a telescope out of these?

TRIVIA

Fun Fact of the Month

Whenever you accelerate at a uniform rate, there is a point far behind you whose distance from you does not change.

You read that right! Despite accelerating away from that point, it does not get farther from you, as long as you keep accelerating uniformly. This is due to the constancy of the speed of light. This is known famously as the Rindler Horizon, whose formula is given by c^2/a.

For example, if you were accelerate at a constant rate of 1 m/s^2, an object at the point exactly 89875517873681764m or roughly 3 parsecs behind you will maintain precisely that distance away from you, if you were to measure so with a meter rule!

In simple terms, as you accelerate, two effects come into play. First, the special relativistic effect of length contraction causes all points behind you to reduce in distance from you as your speed increases. But concurrently, all points behind you also happen to be moving away due to your acceleration away from there. There must thus be a point that is neither moving away (due to your acceleration) nor toward you (length contraction). That point is precisely your very own Rindler Horizon!

ANSWERS FOR THE PREVIOUS NEWSLETTER

Problem I

This problem fortunately or unfortunately requires calculus.

The most intuitive way to go about this is to consider the fraction df of the distance the ant would walk in an amount of time dt, and see if the fraction reaches 1 (ie, the ant completes its journey) in a finite amount of time.

At a given time t, the Earth Moon distance would be $D_0+v_{moon}t$. In a time dt, the ant would have marched $df=v_{ant}dt/(D_0+v_{moon}t)$

Integrating both sides, from 0 to 1 for the LHS and 0 to T_{total} for the RHS, we get:

$$\int_0^1 df = \int_0^{T_{total}} \frac{v_{ant}\,dt}{D_0+v_{moon}t}$$

$$1 = \frac{v_{ant}}{v_{moon}} ln\left(\frac{v_{moon}T_{total}+D_0}{D_0}\right)$$

Rearranging,

$$T_{total} = \frac{D_0}{v_{moon}}\left(e^{\frac{v_{moon}}{v_{ant}}} - 1\right)$$

Using the current average Earth-Moon distance of 384,400km, we get a staggering $T_{total}=384{,}400{,}000e^{100}$s, or about 23.7 billion trillion trillion times the age of the universe 💀.

ANSWERS FOR THE PREVIOUS NEWSLETTER

Problem II

There are a few options for you to determine your location, using a few clever tricks. Given that it is the 1400s, not even the most rudimentary modern day tools are available at hand.

Estimating latitude

1. Use the night sky.
    a. Use the North star, Polaris, if you are in the Northern Hemisphere. The angle between the North star and the horizon can be measured using a cross-staff, astrolabe or quadrant. This angle is precisely the latitude of your current position.
    b. If you're in the southern hemisphere and therefore can't see Polaris, find the southern celestial pole by finding the intersection of the line passing through the long edge of Crux and the perpendicular bisector of Rigil Kent and Hadar. Use the previously mentioned equipment to find the angle this point makes with the horizon. This angle is precisely your latitude, but of course in the southern direction.
2. Solar observations. At local noon, when the Sun is at its highest point (aka its culmination), you would measure its altitude above the horizon using an astrolabe, quadrant or a backstaff. Then this angle would need to be corrected according to the seasonal solar declination using almanacs, such as those by Regiomontanus.

Estimating longitude

Given it is the 1400s, there unfortunately is no direct means of finding one's longitudinal bearings at a given place, unless of course there are specific known landmarks.

Nonetheless, if a record is kept by the ship's navigator regarding the ship's direction and speed over the course of its journey, then one could theoretically maintain a crude estimate of their longitude based on displacement, the Earth's radius and celestial sightings. This method is also known as dead reckoning. That being said, as marine chronometers were not invented until the 18th century, any accurate measure of time at sea was still a

EVENTS AND STARGAZING

Featured Stargazing Location: Yishun Dam

SOURCE: GOOGLE MAPS

Tucked away in Singapore's northeast, Yishun Dam provides for a surprisingly scenic and quiet ambience to local stargazers, and that too along both its northern and southern facing side. Given its distance from the bustling city center in the south, this area has the main advantage of less light pollution than other stargazing locations in Singapore. It also has the added benefit of having relatively little foot traffic, aside from otherwisely moderately used Yishun Avenue 1.

Although it is certainly not as dark as our offshore favorite Pulau Ubin, Yishun Dam comes in a fantastic second given its accessibility for residents in the northeast/north.

As seen in the image, one can also wager a guess that this place probably has some breathtaking sunrises and sunsets – and they are definitely right! Arriving early to catch a scenic sunset over the reservoir would probably result in a lasting memory with friends. And as always, keep looking up!

EVENTS AND STARGAZING

The July skies open the chapter for summer constellations and some very interesting deep-sky objects. Keep reading to find out!

Free-hand stargazing

- **Perseids Meteor Shower -** Being one of the most widely anticipated meteor showers annually, the Perseids are best viewed between the pre-dawn hours of 3 am and 6:30 am on the 12th and 13th of August. With observers potentially being able to observe up to 100 meteors per hours, we feel this is all the motivation you need to shake yourself awake in the early morning and get out there to witness this spectacle!
  What to look for: Fast, bright meteors streaking across the north-eastern region of the sky, radiating from the constellation of Perseus.

WHERE TO VIEW THE PERSEIDS SHOWER
SOURCE: STELLARIUM

- **Full Sturgeon Moon -** Getting its catchy name from Native American fishing tribes (Sturgeon fish was the most commonly caught), the full Sturgeon Moon on the 9th of August marks one of summer's most luminous lunar events. While it can be seen throughout the night, it is best viewed during moonrise - the hour after sunset, thus offering a stunning view as it rises into the sky.
  What to look for: A bright, round moon in the Southeast skies just after sunset, and as an added bonus, Saturn will also be visible just to the East of the Sturgeon Moon!

FULL STURGEON MOON
SOURCE: WIKIMEDIA

EVENTS AND STARGAZING

Binoculars

- **The Double Double (Epsilon Lyrae) -** A fascinating star system located near (1.7 degrees northeast of) Vega in the constellation of Lyra, it is seen as a single star to the naked eye. But with the aid of binoculars, it can be viewed as a pair of identical white stars. With even more magnification (using a telescope), the true nature of the system is revealed, 4 individual stars, two pairs of binary systems bound by gravity, hence the name, 'The Double Double'.

THE DOUBLE DOUBLE (EPSILON LYRAE)
SOURCE: VIEWFROM.EARTH

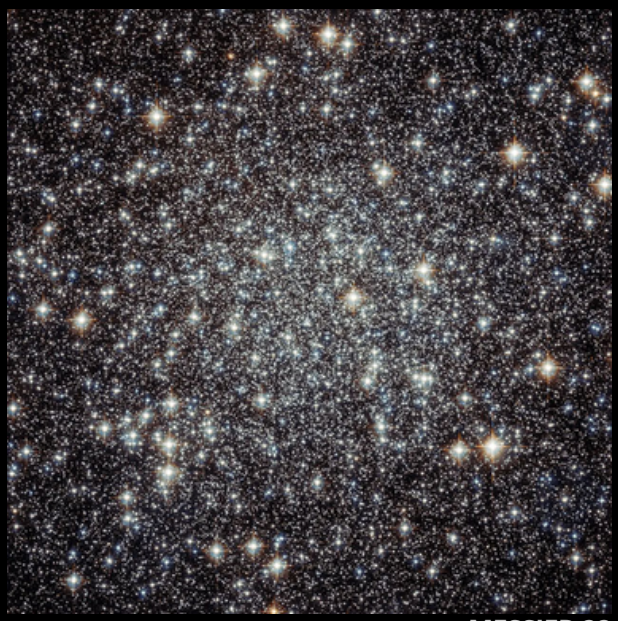
- **The Ring Nebula (Messier 57) -** A well known planetary nebula that is also in the constellation of Lyra. Located roughly between Beta and Gamma Lyrae, the nebula's bright, donut-shaped ring is composed of ionised gas illuminated by the hot core of the former star - now a white dwarf - at its centre.

THE RING NEBULA
SOURCE: NASA, ESA

EVENTS AND STARGAZING

Telescope

- **Messier 22 -** While generally best viewed from the Southern hemisphere, this globular cluster located in the constellation of Sagittarius is still visible from parts of the Northern hemisphere closer to the equator (hence potentially all of you in Singapore!). It was one of the first globular clusters found with a planetary nebula, and the cluster sparkles in the night sky about 10,600 light years away from Earth.



MESSIER 22
SOURCE: ESA/HUBBLE, NASA

- **Albirio (Beta Cygni) -** A low magnification on your telescope can easily separate the exquisite Alberio binary system, consisting of a primary star which appears gold and a secondary one which appears a stunning sapphire blue. It is the second brightest object in the constellation of Cygnus the Swan.

ALBIRIO (BETA CYGNI)
SOURCE: EARTHSKY

SOURCES

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File:Messier51 sRGB.jpg - Wikipedia

Extraterrestrial Nucleobases
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File:Tagish Lake meteorite.jpg - Wikimedia Commons
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