OCTOBER 2024
EDITION 4

PISCIS AUSTRINUS,
THE SOUTHERN FISH

ASTRO DIGEST

ASTROBIOLOGY

HOW DO WE DETECT LIFE ON EXOPLANETS? BIO-SIGNATURES AND GEOLOGY PROVIDE US WITH VALUABLE INSIGHT

PLUNGING REGIONS

EINSTEIN WAS RIGHT, AGAIN

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BECAUSE THE UNIVERSE LOVES TO KEEP US GUESSING!

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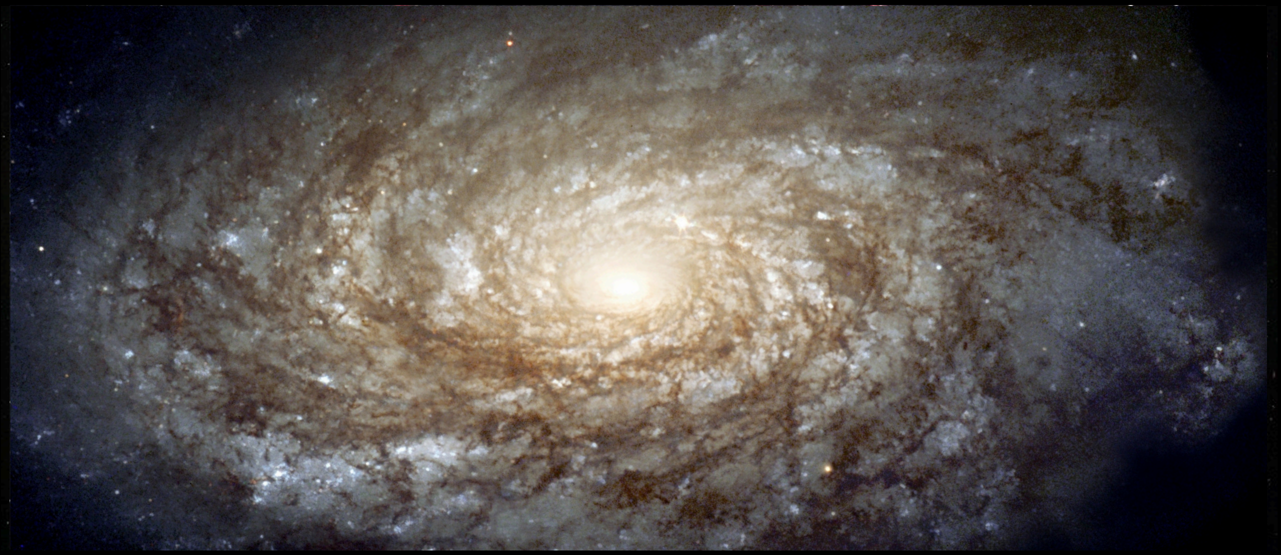

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The question of extraterrestrial life is one of the most profound existential mysteries ever faced by humanity. So much so, that we have created an entire field dedicated to study it – astrobiology. While it has historically been the underdog compared to astrophysics in terms of research grants, it has always been the centre of public attention at least since the mid 1900s, with famous UFO sightings such as the Roswell Incident playing a large part in burgeoning public curiosity. This public limelight, along with the maturing of our understanding of astrophysics, has paved the way for allowing more resources to be devoted toward astrobiology in terms of public funding in basic research.

ROSWELL INCIDENT DEPICTION, LIGHT-HEARTED. SOURCE: DALL-E
An enthusiast's illustration of how the Roswell Incident looked. Note that to this day, whether it was even remotely alien remains a distant conspiracy, though many enthusiasts would say otherwise.

With such funds, a lot of well-developed and growing fields of research have opened up within astrobiology. These will make up the bulk of our discussion here. These include the study of biological signatures, geological formations and the countless novel methods of detecting exoplanets, the last of which will be covered in the next newsletter.

Biological signatures, also known as biosignatures, are various different types of indicators that suggest the presence of current or past life on other celestial bodies (barring stars, of course!). These are often various substances or phenomena that have a consensus on being associated with life, such as specific molecules that biological processes produce (Recap: Dimethyl Sulfide, Astro Digest Edition 3). While there may be other types of life out there, current research is largely based on biosignatures produced by carbon-based life, since this is the only type of life we know about. Consequently, the search largely surrounds certain organic compounds such as methane, phosphine and dimethyl sulfide. In fact, it is the discovery of methane in the Martian atmosphere in 2004 by the Mars Express Orbiter that

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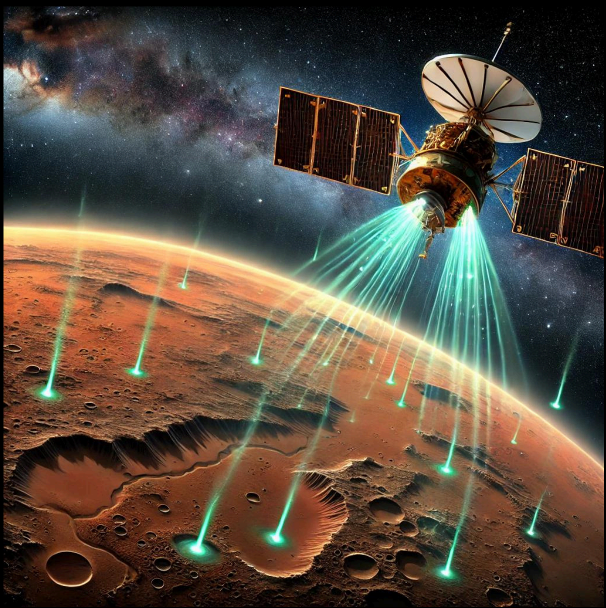
significantly sparked hope for the existence of Martian microbes. More recently, the 2020 discovery of phosphine in Venutian gas clouds caused significant excitement in the scientific community, as yet another planetary neighbour may have life forms harboured within its thick unforgiving atmosphere.



METHANE DETECTION DEPICTION. SOURCE: DALL-E
Methane was detected by a spectroscopic instrument aboard the orbiter.

Now, you may be wondering – while we can send probes to such relatively “nearby” neighbours, how is it possible that we can detect these molecules in exoplanets that are hundreds if not thousands of light years away? The answer is spectroscopy, where the host star’s light passes through the planet’s atmosphere. Absorption lines in this light are then studied to see if they match the chemical signature of various substances, which tell us whether or not said substances are present on the exoplanet.

DEPICTION OF EXOPLANET IN HOST STAR’S LIGHT. SOURCE: DALL-E
When the exoplanet’s orbit is edge-on, the host star perfectly illuminates the exoplanet’s atmosphere which may give a strong enough signal to analyse its atmospheric constituents.

Another type of biosignature is seasonal variations on the target planet’s surface. The search for this was by and large inspired by such variations on our own planet Earth. One such example is the vegetation cycle on earth. As there is more photosynthetic biomass in the northern hemisphere, spring and summer in the North correspond to lower atmospheric CO_2 levels and higher O_2 levels, and

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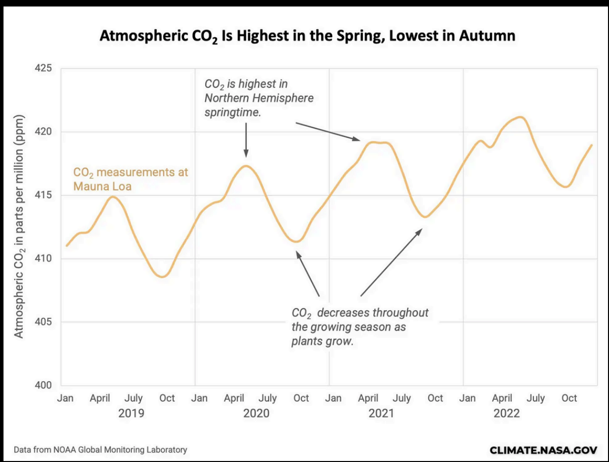
vice versa for the seasons of autumn and winter in the North. Observing such seasonal changes on other planets would significantly increase the prospect of life there.



ATMOSPHERIC CO2 OVER TIME. SOURCE: NASA
Over the course of a year, atmospheric CO2 levels vary significantly as explained and seen here, overlayed by the insidiously rising moving average brought about by anthropological climate change.

Next, we move on to understanding geological formations in the context of astrobiology. The first of these is cryovolcanoes, which are sometimes referred to as “ice volcanoes”. While these do not directly indicate signs of life, they are considered to be very significant because they suggest the presence of subsurface oceans beneath the surface of the celestial body. These oceans are believed to be optimal for harbouring life as they are shielded from harsh surface conditions and have potential heat sources to power the chemical reactions necessary for life. The most prominent of these are actually within the solar system, namely Jupiter’s moon Europa and Saturn’s moon Enceladus. The timing for this article could not be better, as NASA’s Europa Clipper is slated to launch on October 10th as of writing this article, so do look out for the launch live stream!

DEPICTION OF A CRYOVOLCANO. SOURCE: DALL-E
An artist’s imagination of an active cryovolcanic landscape.

While cryovolcanoes indicate the possibility of life within planets, volcanoes on the other hand point to the possibility of life on the surface. In astrobiology, volcanic activity is important because it can maintain or even generate atmospheres. The latter is believed to be crucial for complex life forms to exist as they protect from

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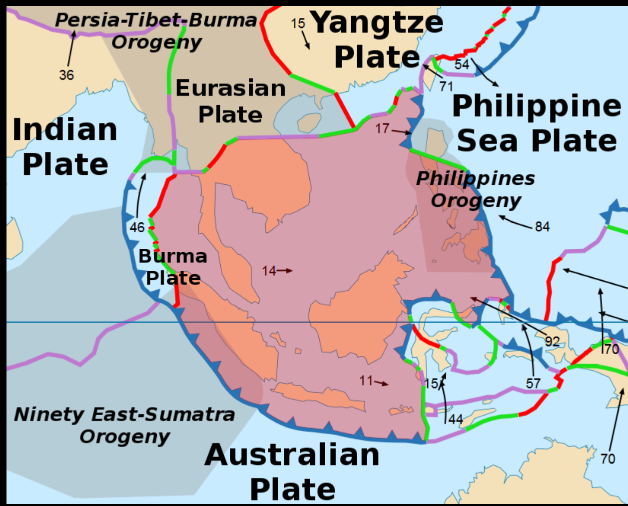
harmful cosmic rays and those of the host star and may provide the necessary chemicals to power lifeforms just like on Earth. They even regulate planetary climates and provide heat and energy necessary for sustaining life.

Tectonic activity is another prominent sign of life on a planet. For the unacquainted, it refers to the movement of large plates of rock and sediment on a planet's crust. For example, Singapore sits on the Sunda tectonic plate, along with Indonesia, Brunei and Malaysia, among others. In the context of Earth, tectonic activity plays a vital role in recycling nutrients, regulating the carbon cycle and maintaining long-term climate stability. which are all essential for sustaining life. They may also indicate a planet's ability to support a magnetic field, since they point to the possibility of moving molten iron, which can produce a strong magnetic field under the right conditions. Such a field would protect the atmosphere, and thus the surface inhabitants, from harmful cosmic radiation, just like on Earth.



THE SUNDA PLATE. SOURCE: WIKIMEDIA

Previously believed to be a portion of the Eurasian Plate, it was later found to move independently.

The third geological formation of key interest in astrobiology is surface colour, which can provide hints about the composition of the planet and its history. In astrobiology, surface colours are important for detecting potential biosignatures. A cool example is the presence of dark intercrossing lines on the surface of Europa. These are believed to be caused by tidal-force interaction with Jupiter, resulting in cracks on the icy surface. This, combined with the otherwise icy, reflective surface of Europa, which separately indicates the presence of water ice, hints at the possibility of a widespread subsurface ocean.

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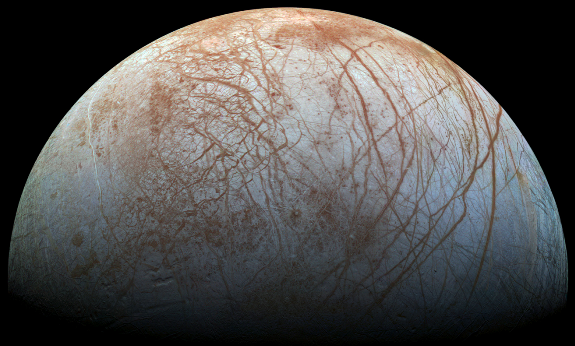


IMAGE OF EUROPA. SOURCE: NASA
Europa's icy surface is scarred with blood-red streaks, caused by tidal stress fractures.

Astrobiology has evolved from a speculative field, from the times of early believers like William Herschel, into a well-funded and dynamic area of scientific inquiry. Through the study of biosignatures, local and extraterrestrial geological formations and the continuous advancements in exoplanet-detection methods, we are progressively inching closer to answering the ultimate question of this field – Are we alone in the universe? Stay tuned to find out more about the unending allure of this field in this next newsletter!

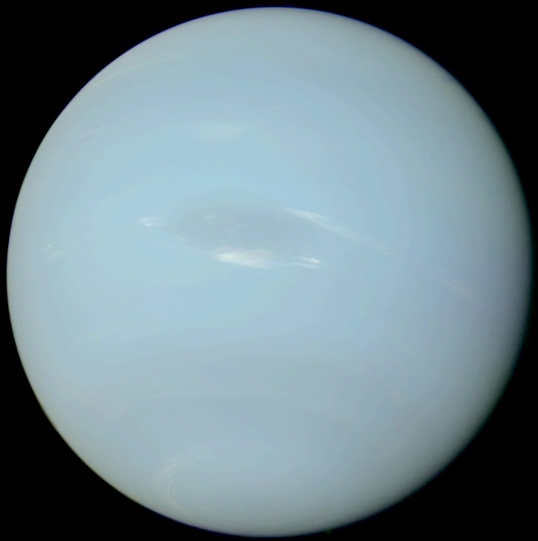
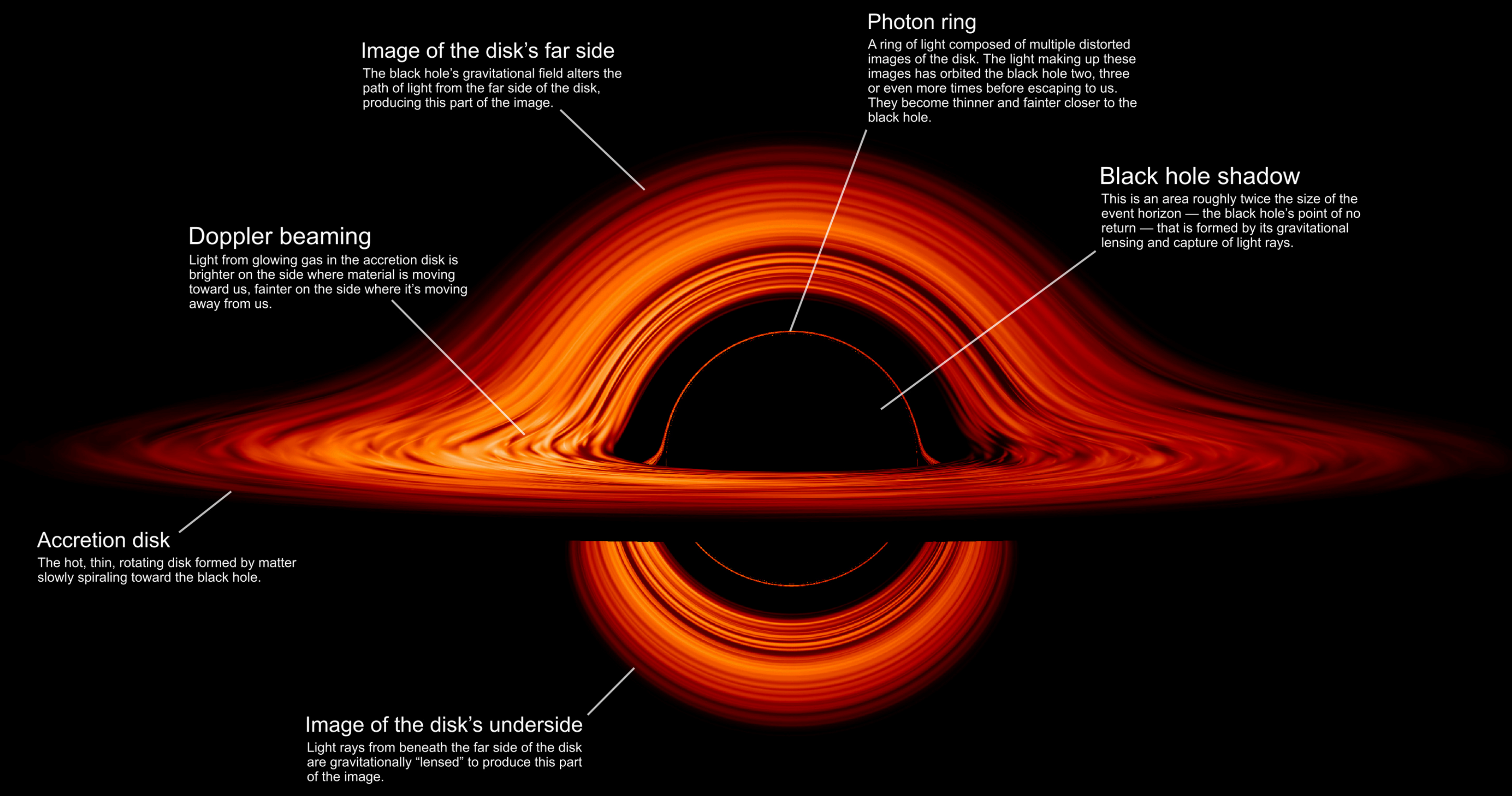


IMAGE OF NEPTUNE. SOURCE: WIKIMEDIA
Neptune's blue colour comes from the methane in its atmosphere, which absorbs the redder wavelengths and reflects the shorter wavelength portion of visible light, ie blue.

IMAGE OF PLUTO. SOURCE: NASA
Pluto's surface is among the unique ones. The reddish patches are attributed to tholins due to charged particle bombardment from the sun. The heart-shaped patch is composed of nitrogen ice, among other trace chemicals.

PLUNGING REGIONS



DEPICTION OF AN ACCRETING BLACK HOLE. SOURCE: WIKIMEDIA

The region between the photon ring and the innermost stable circular orbit visible in this photo is the plunging region of this particular black hole. Clearly, no matter is visible in that region. However, if the black hole were viewed in X-rays, the region would be brightly lit as explained in the article.

Surprise! Surprise! Another one of Einstein's predictions has mostly been confirmed to be true in May 2024 by an international team led by researchers at Oxford University. While Newton's theory of gravity predicts that matter should be able to circularly orbit a black hole, Einstein's theory of general relativity suggests that this is impossible sufficiently close to the black hole, and matter instead simply falls into it, in what has been observed to be the 'plunging region' of a black hole. Note that this is different from the event horizon of a black hole, because while nothing can escape the event horizon of a black hole, light can still escape from a plunging region, just not matter. The 2 are however closely related concepts, as the plunging region is the space between the innermost stable circular orbit (ISCO) and the event horizon.

Debate about the existence of plunging regions around black holes has been going on for decades, but now for the first time, using X-ray data from NASA's Nuclear Spectroscopic Telescope Array

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(NuSTAR) and Neutron star Interior Composition Explorer (NICER) telescopes, researchers were able to gather evidence for their existence. Specifically, these telescopes observed the X-ray emission of matter close to the black hole's event horizon, which helped the scientists identify the regions. The researchers also found that there is a possibility that the plunging region of a black hole might be exerting some of the strongest gravitational forces detected in the galaxy!

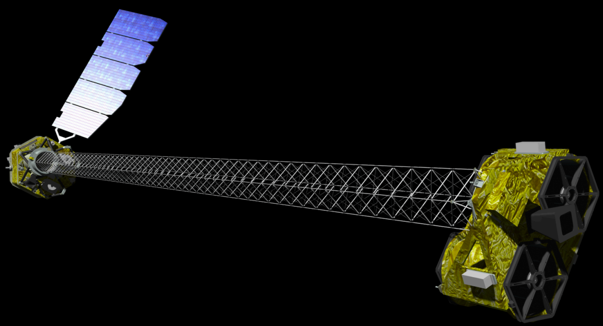


IMAGE OF NUSTAR. SOURCE: NASA
NuStar, which stands for Nuclear Spectroscopic Telescope Array, performs X-ray spectroscopy.

This is a relatively new topic for researchers to explore, with a necessity for more observations to be taken in order for researchers to understand plunging regions properly. The study that was published in May 2024 only gathered data from black holes closer to Earth, but progress is underway to build a new telescope in Africa, the Africa Millimeter Telescope, which will be used in a European initiative to try and collect data from black holes that are farther away from Earth, both in the Milky Way and beyond it! It is still early days for researchers to confidently conclude anything regarding the matter, but we can all excitedly look forward to future discoveries regarding plunging regions and how they govern and impact black holes.

DEPICTION OF THE MILIMETER TELESCOPE SOURCE: SPACEINAFRICA
The Africa Millimeter Telescope is being built atop the Gamsberg, a table-top mountain in Namibia, which is ideal due its altitude and remoteness from bright city lights.

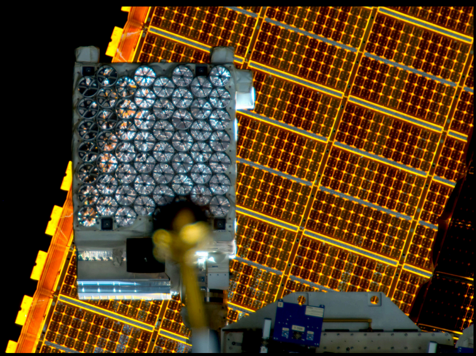
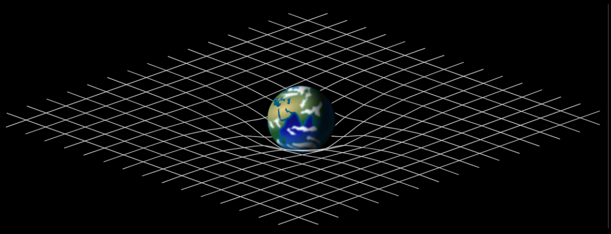


IMAGE OF NICER. SOURCE: WIKIMEDIA
Nicer, which stands for Neutron Star Interior Composition Explorer Mission, is a spectroscopic attachment mounted to the ISS.

GRAVITATIONAL LENSING

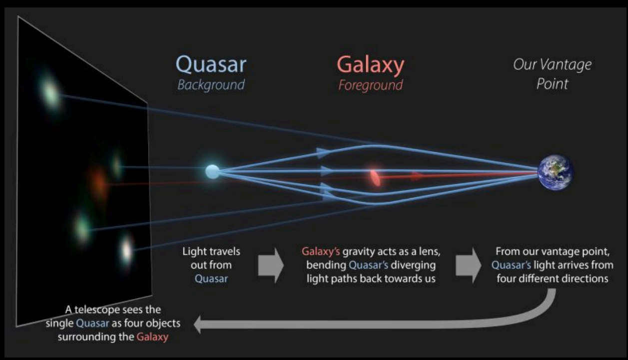


THE BENDING OF SPACETIME. SOURCE: WIKIMEDIA
Einstein's general relativity demands that gravity is not a force but rather the curving of space and time itself. This article will be focussing largely on the "bending of space" portion of that, and its benefits to astronomical observation.

According to Einstein's theory of general relativity, which is our best model for gravity, every object will bend the fabric of spacetime to a certain degree, and the degree to which it distorts spacetime in this manner depends on its mass. This is how, for example, the planets remain in orbit around the sun.

Gravitational lensing is extensively used by astronomers precisely because it enables them to observe and discover more objects. This is because it is a phenomenon that has to do with the bending of light/matter around extremely gravitationally heavy objects, such as galaxies and super-massive black holes, due to how they distort the fabric of spacetime around them.

This phenomenon actually enable us to observe light from stars and galaxies that lie directly behind the galaxy causing the gravitational lensing, which we would not have been able to otherwise see. Light from distant sources can also become gravitationally lensed due to smaller objects, such as other stars, in a phenomenon known as gravitational microlensing.



GRAVITATIONAL LENSING. SOURCE: EARTHSKY
An illustration of how a massive elliptical-type galaxy can bend light and amplify the source quasar's light.

This also means that the positions of stars and galaxies that appear to be in close proximity (in the background) to the lensing galaxy are not quite accurate, as the light from them has been distorted or bent before being received on Earth.

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Therefore, astronomers have to calculate to what degree the light has been lensed in order to accurately map out the background objects that are in close proximity to giant galaxies.

Gravitational lensing/microlensing can be most elegantly visualised in the form of an Einstein ring, which is created due to the lensing effect (when light from background sources pass in the vicinity of the galaxy in the foreground that is distorting spacetime).

THE ICONIC EINSTEIN RING. SOURCE: NASA

Captured by the Hubble Space Telescope, the lensing object here is a galaxy cluster labelled SDSS J0146-0929, which has created several "gravitationally-brightened" images of a single background galaxy.

Gravitational microlensing is one of the more curious methods which is used for exoplanet detection. It follows the simple idea that the gravitational force of distant objects bend and focus light coming from a star. As a planet passes in front of the star relative to the observer (i.e. makes a transit), the light dips measurably, which can then be used to determine the presence of a planet.

Microlensing is the only known method capable of discovering planets at truly great distances from the Earth and is capable of finding the smallest of exoplanets. In addition to that, the microlensing method is the most sensitive means of detecting planets that are around 1-10 astronomical units (AU) away from Sun-like stars and is also the only proven means of detecting low-mass planets in wider orbits, where both the transit method and radial velocity are ineffective.

However, because microlensing events are unique and not subject to repeat, any planets detected using this method will not be observable again. This method is also unable to yield accurate estimates of a planet's orbital properties, since the only orbital characteristic that can be directly determined with this method is the planet's current semi-major axis.

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
Given the surface temperature, mass and radius of the sun and the orbital radius of the earth, calculate the change in the orbital radius of the Earth in meters in 100 years. Comment on whether we should be worried about this.

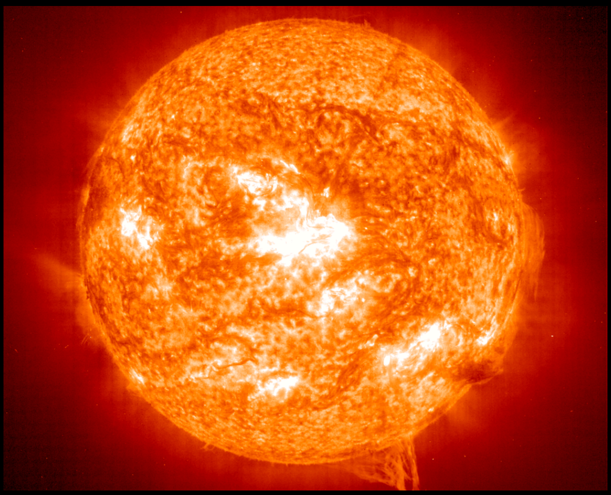
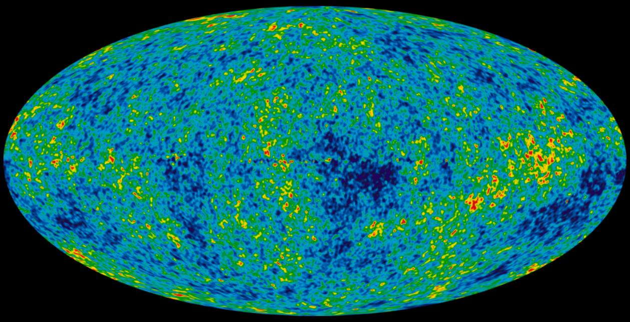


Image of the sun
Source: EIT - SOHO Consortium / ESA / NASA

Fun-Fact-of-the-Month:
Triton, Neptune's largest moon is slowly falling toward it due to strong tidal forces and will eventually be either ripped apart, forming a ring around Neptune, or crash into and get absorbed by Neptune. Worry not, as this will only take place in 3.6 billion years.

Problem II
In the previous newsletter, we discussed at length about the Hubble Tension. Much research in reducing the tension surrounds reducing the size of the sound horizon.

Why is that the case?



Cosmic Microwave Background.
Source: Wikimedia

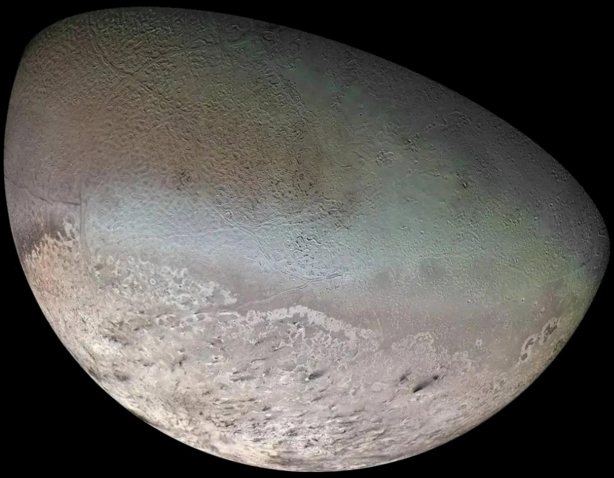


IMAGE OF TRITON
SOURCE: NASA

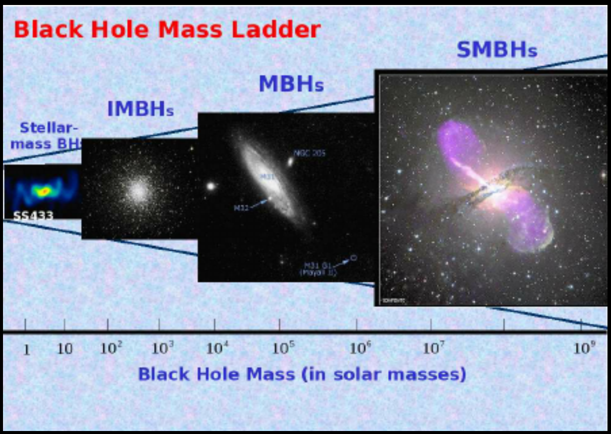
ANSWERS FOR THE PREVIOUS NEWSLETTER

Problem I

'You found a star Z with a parallax of 2". Given that its peak wavelength is half that of the sun and its radius is 3 times that of the sun, find Pz:Ps where Pz is the power emitted by star Z and Ps is the power emitted by the sun.'

The parallax given is a red herring since the magnitude of the star is not provided; the only two formulae needed are the Wien's Displacement law and the Stefan-Boltzmann law.

Using Wien's displacement law, we can find that the temperature of star Z is twice that of the sun
Subbing that into the Stefan-Boltzmann law, we can conclude that the power emitted by star Z is 144 times that of the sun.



Filling up the gaps. *(Problem II)*
Source: Safonova, Margarita. (2010). Searching for IMBHs in globular clusters. 217-232.

Problem II

'Not long ago, scientists discovered strong evidence for the presence of an intermediate mass black hole in the globular cluster, Omega Centauri. This marks a new addition of the highly sought after family of intermediate mass black holes. Why are they so sought after?'

The reason why these black holes are so important to scientists can be seen in their name -- intermediate mass. This means that the mass of these black holes lies right between stellar black holes (up to a few tens of solar masses) and supermassive black holes (millions to billions of solar masses).

It is currently observed that there is a huge gap in terms of black hole mass between stellar black holes and supermassive black holes, and this gap suggests that there may be very few black holes with masses between these two categories, typically referred to as intermediate mass black holes (IMBHs).

As such, the discovery of such IMBHs will enable a deeper understanding about the pathways for black hole formation that are not currently accounted for in existing models, and reshape our theories regarding galaxy formation, cosmic evolution, and the fundamental nature of dark matter.

EVENTS AND STARGAZING

Inaugural SAND Bingo Challenge

Join us for another round of our astrophysics-themed Bingo, where you can take on challenges and help your school collect points. With SAND 2025 still more than half a year away, there's still time to complete as many challenges as possible and aim for stellar prizes! The Bingo Challenge is still live on our Discord channel—come join the fun! Not sure how to enter? Just drop us an email/message and we'll get back to you!

Please note: This event is only eligible for secondary and tertiary schools that are open to participate in SAND 2025.

Featured Stargazing Location: Marina Barrage Green Roof

With its stunning waterfront views and open skies, Marina Barrage Green Roof is a popular spot for stargazing right in the heart of Singapore. Although city lights are still present, the expansive green rooftop and the open skyline offer a breathtaking ambience to catch a glimpse of the stars. It might not match the secluded vibe of Pulau Ubin, but Marina Barrage's convenient location, coupled with a Bortle Scale rating of around 8, makes it an ideal spot for urban stargazers. Gather your friends, bring a picnic mat, and enjoy a relaxed evening of stargazing!

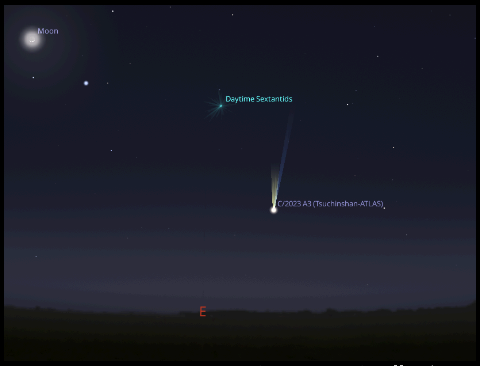
MARINA BARRAGE GREEN ROOF.
Left: The iconic skyline seen along the expansive Green Roof. Regardless of the evening crowd, there is bound to be enough space for you and your friends. Right: a Starlink satellite seen traversing the sky nearby the constellation Bootes from this specific spot at the Green Roof.

EVENTS AND STARGAZING

The month of October offers clear skies and a host of celestial sights. As the season deepens, new constellations and elusive objects become visible, offering fresh opportunities for stargazers. Whether you're equipped with advanced tools or simply using the naked eye, October's skies have plenty to offer for everyone.

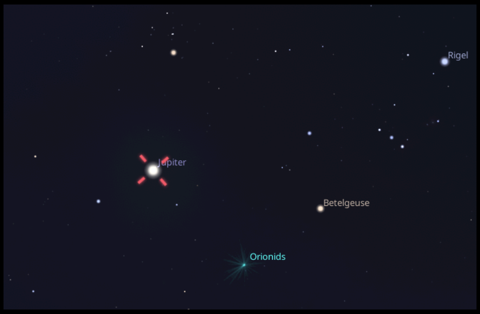
Free-hand stargazing

- **Comet C/2023 A3 (Tsuchinshan-ATLAS).** This comet is set to light up our skies in mid-October, potentially shining as brightly as Venus. This comet is already visible at around 6am daily as of writing this, but do keep an eye on the western horizon just after sunset from October 12 to 17, as this cosmic spectacle makes its way through the evening sky. Don't miss out on what could be the comet of the year! (Sources: livescience.com, Space.com, EarthSky)



Source: Stellarium

- **Jupiter.** This constant will continue shining brightly in our night sky this month. With a good phone, you may be able to catch all 4 of its moons on the following days: 1,12,14 and 19 October.

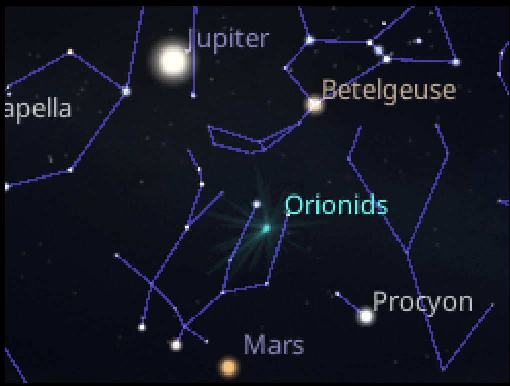


Source: Stellarium

EVENTS AND STARGAZING

Free-hand stargazing (Cont'd)

- **Orionids.** This iconic celestial square is quite imposing and impressive due to its near perfect visual geometry. Given the arrival of autumn, this asterism is well placed to be observed and is near the zenith around midnight (Sources: Time and Date, Space.com, In-The-Sky.org, EarthSky)



Source: Stellarium

Binoculars

- **Pleiades (M45).** This star cluster, also known as the "Seven Sisters," is starkly visible in Singapore's night sky in October. It can be spotted in the east just after sunset and climbs higher as the night progresses. Known for its striking blue stars, the cluster is easily visible to the naked eye and makes for a great viewing target, even without equipment. Look for it near the constellation Taurus.

Source: Stellarium

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Binoculars (Cont'd)

- **The Alpha Persei Moving Cluster.** The Alpha Persei Moving Cluster, also known as Melotte 20, is a striking collection of bright stars easily visible with binoculars or a wide-field telescope. Located near the star Alpha Persei in the constellation Perseus, the cluster forms a loose group of young, hot stars that appear to drift together through space. With a pair of binocs, you can trace its brightest members, forming a sprawling, sparkling pattern that stands out beautifully against the backdrop of the night sky.

Source: Stellarium

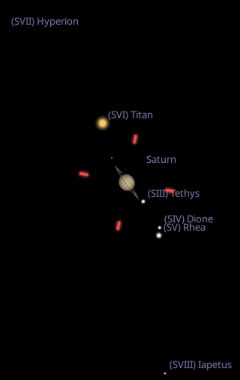
- **Algol.** Also known as the Demon Star, this is one of the most famous variable stars, easily found in the constellation Perseus. It represents the "eye" of Medusa in mythology and regularly dims and brightens over a period of just under three days, making it an intriguing target for stargazers.

Source: Stellarium

EVENTS AND STARGAZING

Telescope

- **Saturn.** While it is easily a naked eye object, Saturn truly comes to life through a telescope. In October, this gas giant is positioned high in the night sky, allowing a clear view of its magnificent rings. Using a moderate telescope, you can also spot several of Saturn's moons, including Titan, which appears as a small, bright dot nearby. Look closely at the planet's golden hue and try to discern the subtle banding on its surface, a captivating feature that makes Saturn a must-see object for any stargazer!



Source: Stellarium

- **California Nebula.** This nebula is best viewed with a wide-field telescope, as it's too faint for binoculars. Located in Perseus, its subtle, elongated glow of ionized hydrogen gas requires dark skies and patience to reveal. The nebula's flowing, reddish structure, illuminated by the nearby star Xi Persei, resembles the shape of California and makes for a rewarding observation under ideal conditions.


Source: Stellarium

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Comet A3 is brightening. Will it be the comet of the year?
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