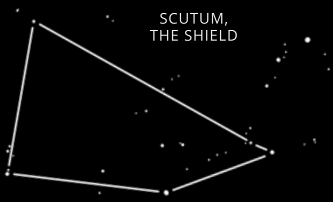
Astro·SG

SEPTEMBER 2024
EDITION 3

ASTRO DIGEST



LIFE BEYOND

HOAX OR ERA-DEFINING BREAKTHROUGH?

HUBBLE TENSION

A COSMIC PUZZLE THAT CHALLENGES THE FOUNDATIONS OF OUR UNIVERSE'S EXPANSION

PLANETS REDEFINED

AS WE RETHINK THE DEFINITION OF PLANETS, OUR UNDERSTANDING OF THE SOLAR SYSTEM—AND BEYOND—EVOLVES.

TRIVIA

BECAUSE THE UNIVERSE LOVES TO KEEP US GUESSING!

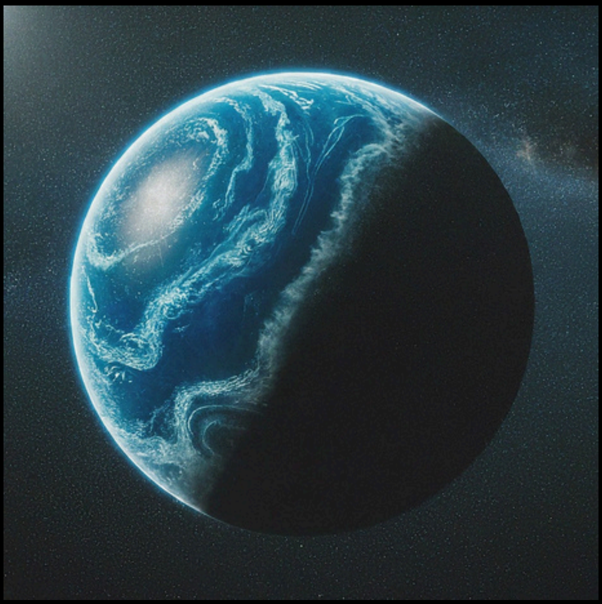
EVENTS & STARGAZING

ART & ASTRONOMY EVENT
STARGAZING

CONTENTS

LIFE BEYOND

Every now and then, a breakthrough arises in astrophysics that sends the wider community reeling with amazement. This time, scientists at Cambridge University led by astrophysicist Prof. Nikki Madhusudhan have found what appears to be the best possible candidate for a habitable – and maybe inhabited – exoplanet thus far. The exoplanet, named K2-18b and located about 124 light years away, is orbiting a red dwarf star named K2-18. Its 'life signs' were detected by none other than NASA's superstar telescope, the JWST, using its spectroscopic instruments aboard. Based on preliminary evidence, which mainly included simulating models of different types of atmospheres and comparing their spectrums to the information JWST collected to look for similar biosignatures, K2-18b is believed to be a Hycean world. A Hycean world sounds like something straight out of Star Wars. Its naming comes from 2 words: hydrogen (Hy-) and ocean (-cean). Such a planet possibly has a large ocean and a thick hydrogen atmosphere.



A HYCEAN WORLD. SOURCE: GEMINI AI
This is an AI-generated depiction of a Hycean world.

This begs the question – what features of this planet led scientists to not only suggest its habitability but also consider the possibility that it might already be inhabited? Well, there are certain compounds that serve as telltale signs for life. In the case of K2-18b, it has abundant water, methane and carbon dioxide. While water and carbon dioxide can exist without the presence of life, its presence is essential for carbon-based life to exist.

LIFE BEYOND

As for methane, it is a strong biosignature for life as it is an unstable compound and requires a large and consistent source to produce it. While various microbes are known to produce methane as a waste product, there are only a few known natural chemical reactions that can produce it. One such example is the posited water-carbon dioxide-olivine reaction on Mars, believed to be the source of its methane emission. While the compounds discussed so far are good biosignatures, we have thus far left out the one that brought K2-18b into the limelight: dimethyl sulphide.

Dimethyl sulphide, or DMS, is an organic compound that you yourself have likely been exposed to before – it is the smell of a sea breeze, as marine algae produce it in large quantities. Here on earth, it is known only to be produced naturally through biological processes, leading many to believe it to be the bellwether for detecting alien life on exoplanets.

However, like any groundbreaking discovery, this one has been met with much scepticism and appropriate caution, not just by other astrophysicists, but even by the authors of the original paper themselves. For starters, it must immediately be mentioned that the DMS signal in the spectroscopic data was quite weak, with a chi value of only 2.4σ, which gives a 1 in 66 chance of the dimethyl-sulphide detection being a statistical fluke, which is quite high. It also largely overlapped with the signal from methane, such that Webb's instruments were not sensitive enough to conclusively tell whether DMS is really present, or the spectral feature is the product of random fluctuations.

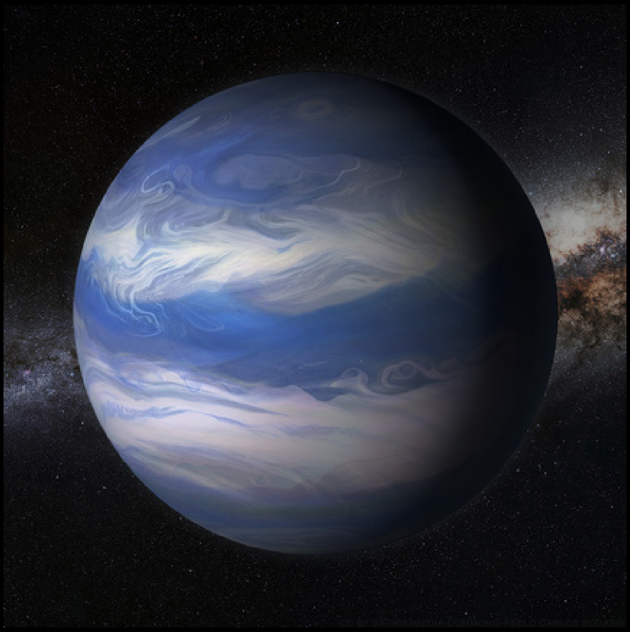
ALGAE-POPULATED WATERS OF A SHALLOW SEA. SOURCE: GEMINI AI
Can you smell the sea breeze from this picture? That's DMS!

LIFE BEYOND

Secondly, barring DMS, there are other planetary models that can explain the current data collected about the exoplanet. A prominent explanation is that K2-18b has a thick hydrogen atmosphere just like the Hycean planet scenario, but instead of being over an ocean of liquid water, this explanation points to the possibility of a magma ocean. This was put forward by Shorttle and collaborators, who point out that the magma ocean scenario explains the abundance of carbon dioxide and methane, as well as the lack of ammonia because nitrogen dissolves into magma instead of reacting with the hydrogen in the atmosphere to form ammonia.

They have also stated that while it would be extremely difficult to distinguish between these two scenarios, the magma-ocean scenario is far more likely as it would have been extremely difficult for K2-18b to develop with a water ocean over time. This is especially when you consider that the star K2-18 would have been very hot while young, it would have been extremely difficult for the planet to have even evolved with a water ocean.

The third and final scenario that has been put forward for discussion highlights the fact that K2-18b might not even have a surface at all, rather it may be a mini-Neptune type gas planet. This is what Wogan and collaborators have proposed, and in addition to this, they compared models of the data that simulated a Hycean world without life, a Hycean world with life, and a mini-Neptune type planet. It is important to note that there is a distinguishable difference between Hycean worlds with and without life, as microbial life can impact the atmosphere of a planet by altering the ratio of the chemicals, thus giving us alternate biosignatures.

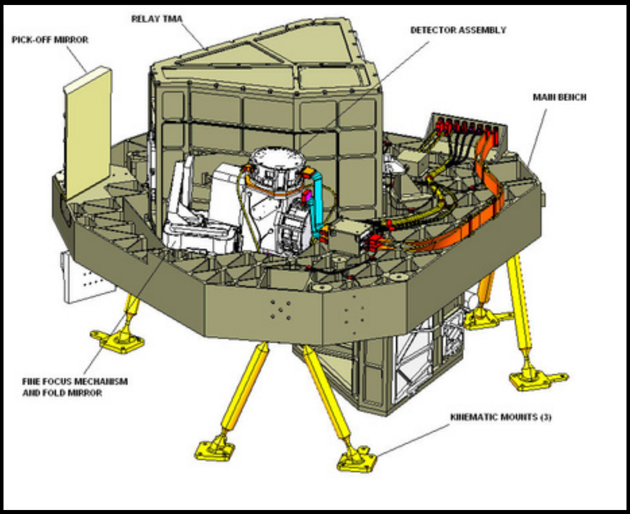


ARTIST'S DEPICTION OF A MINI NEPTUNE. SOURCE: WIKIMEDIA
This class of planets is believed to have a thick hydrogen-helium atmosphere with a rocky core.

LIFE BEYOND

This comparison found that, the data fit of the Hycean world with life is equally as probable as the mini-Neptune model, with both fits having a chi-squared value of 1.51, which is much lower than the chi-squared value of the Hycean world without life model, which is 3.22. The paper argues that the mini-Neptune model poses less problems as the ocean model requires the existence of life to explain its atmospheric conditions, and it’s also hard to reconcile the necessary cooler temperature of the planet with a high likelihood of the planet experiencing a runaway greenhouse effect.

This is definitely not the last word on K2-18b that we will be hearing. Every model proposed so far faces its own challenges, and we must wait for future readings from JWST or any other detector in the future to ultimately determine whether we have really found extraterrestrial life. A new ammonia detection from JWST would favour the gaseous-planet model, while a stronger reading of dimethyl sulphide would certainly increase the odds of a Hycean world with life being probable. Who knows? The search continues.



NIRISS. SOURCE: NASA
Depiction of the Fine Guidance Sensor/Near InfraRed Imager and Slitless Spectrograph, used for obtaining spectroscopic data from K2-18b.

HUBBLE TENSION

Following part 1 of the Hubble tension conundrum in the August newsletter, this following section highlights the three phases of the universe that some scientists and astronomers think need modification to solve the mystery of Hubble tension finally, as well as two other paradigms that are less popular but may prove equally important in solving this mystery.

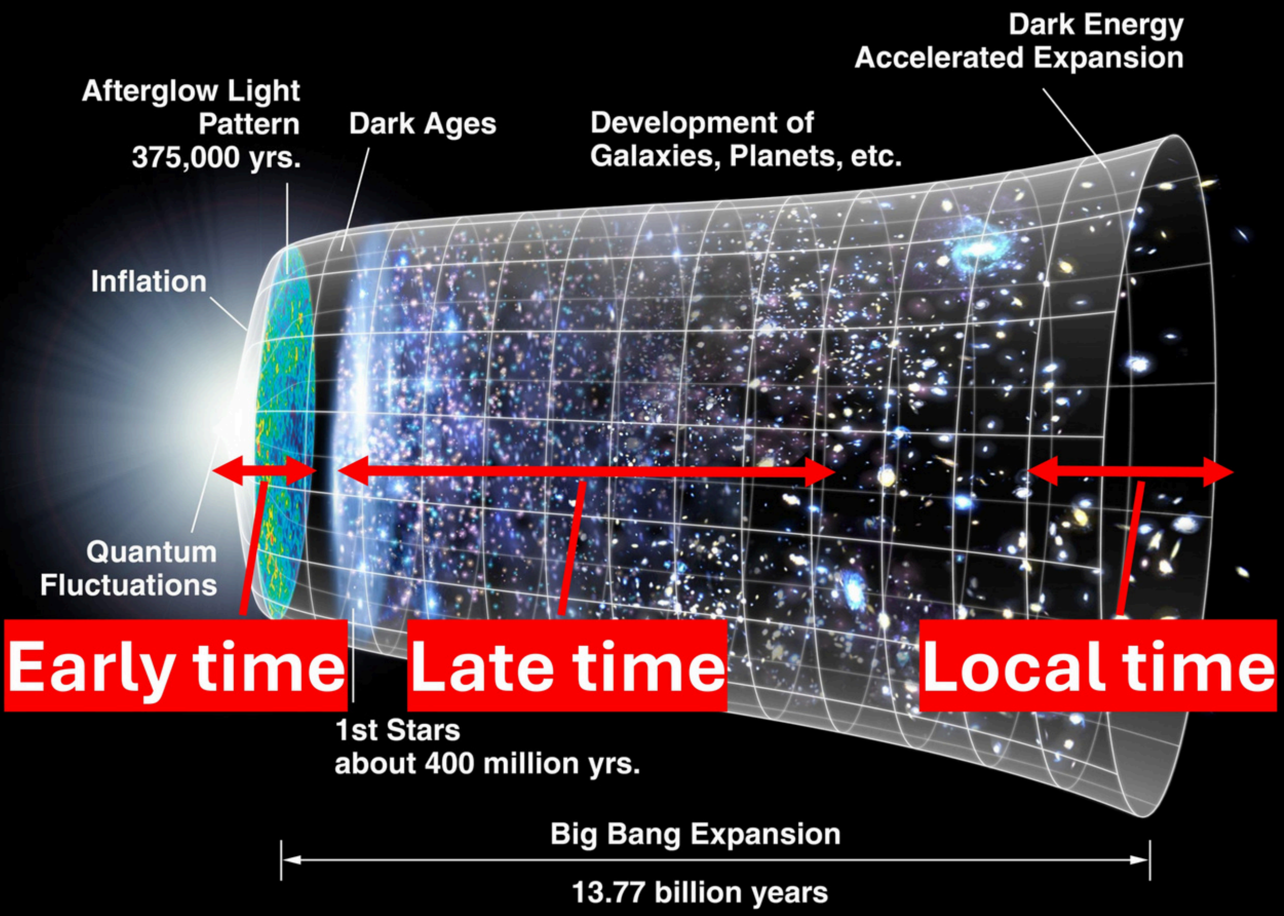
So when are these 3 phases of the Universe? Well, these are introducing new physics in early time, late time, and local time. First, let us understand what new physics means.

Presently, all of cosmology is governed by the theory of General Relativity (GR). That is, regardless of what the universe is made up of, be it ordinary matter, radiation, dark matter/energy or other elusive forms of energy, it is in totality, constrained and governed by GR. New physics would entail modifications to this underlying theory of GR which would thereby change the rate of expansion and hence, the Hubble constant. The changes to GR are, as stated above, split into 3 time/redshift domains.

Early time refers to the period just after the Big Bang and till around recombination, i.e. the point where the Cosmic Microwave Background formed ($z>1100$, where z is the redshift value). Late time refers to the period much after this, but still at high redshift. This would be anywhere from the Epoch of Reionization to the Matter-Dominated era (through $6<z<1100$). Finally, local-time new physics entails changes in GR in the low redshift period, i.e. the Dark Energy Dominated Era ($\sim 0<z<6$). An important note here would be that the redshift ranges provided above are only approximations and would differ depending on the theory of interest.

The immediate question after this would be, why is there a need for so many modifications? Why not merely try tweaking the theory in one domain (e.g., early-time new physics) and thereby fix the tension? While this is indeed a poignant question, it unfortunately does not hold good in practice. Significant research today has sought modifications in early-time new physics. However, as Vagnozzi (2023) points out, none of the present papers have produced a higher H_0, while keeping prevailing data well-fitted to the modified theory.

HUBBLE TENSION

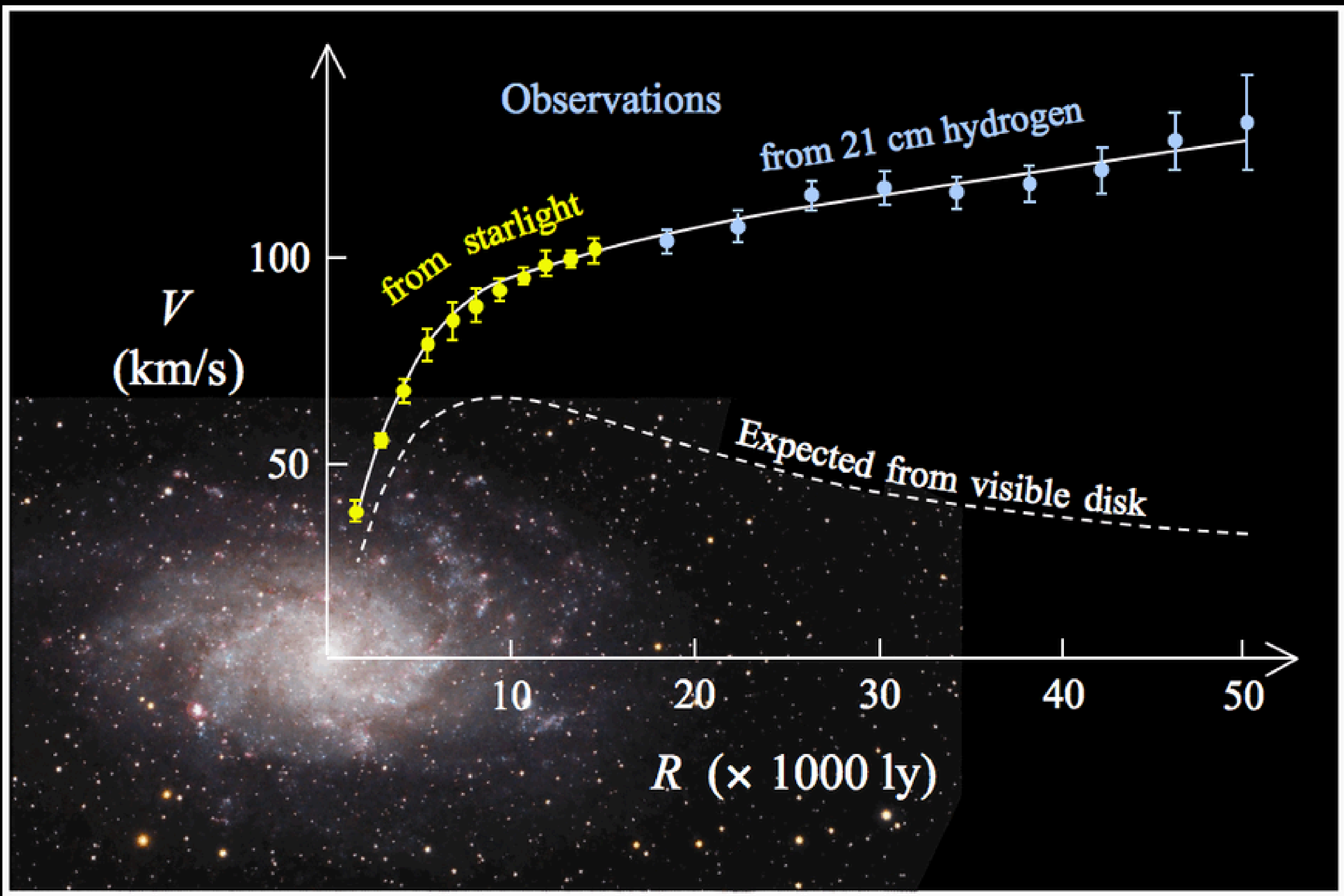


THE THREE PERIODS. SOURCE: WIKIMEDIA
The 3 phases, Early time, late time and local time are shown superimposed on the universe spanning from the Big Bang to present day.

The same can be said for modifications in late-time and local-time physics. Now, we can precisely see why multiple changes are necessary to reduce the tension if we focus on modifying the theory of General Relativity to resolve the tension. As of today, such a modified theory of General Relativity has not yet been found. However, much speculation points to Modified Newtonian Dynamics (MOND) theories as solving much of the tension. Perhaps, some of you may partake in its very discovery!

We shall now move on to another explanation behind the Hubble Tension. To explain a cosmological phenomenon, there are 2 key aspects to it - the underlying theory, and a model overlaying it which behaves based upon the theory. The former was what was covered up till now, and now we shall delve into the latter. The prevailing model agreed upon by most cosmologists is the ΛCDM model. In its full form, this stands for the Lambda - Cold Dark Matter model.

HUBBLE TENSION



GALACTIC ROTATION CURVE. SOURCE: WIKIMEDIA
MOND, originally an alternative theory from dark matter used to explain the anomalous rotation curves of galaxies, may have far-reaching consequences in cosmology if it can also provide a watertight explanation for the Hubble tension.

The 'Λ' here refers to the cosmological constant, popularly known as dark energy. 'CDM' is the predominant component of matter in the universe. The ΛCDM model states that the universe constitutes 68% dark energy, 27% dark matter, 5% ordinary matter and a negligible portion of radiation. The reason why this model prevailed is purely because it fitted present data more accurately than any other model and not because either dark energy or dark matter has been directly observed.

Consequently, this leaves room for speculation regarding the actual percentages of these components and possibly newer components of unknown matter/energy. Herein precisely lies the second possible explanation behind the Hubble Tension. Two ideas are now briefly discussed to give you a taste of model-based modifications—Early Dark Energy (EaDE) (Poulin, et. al., 2019) and Evolving Dark Energy (EvDE) (Shahnawaz et. al., 2024).

HUBBLE TENSION

These will be explained in contrast to the prevailing form of known dark energy which is believed to be a uniform and time-invariant amount of vacuum energy that fills all of space.

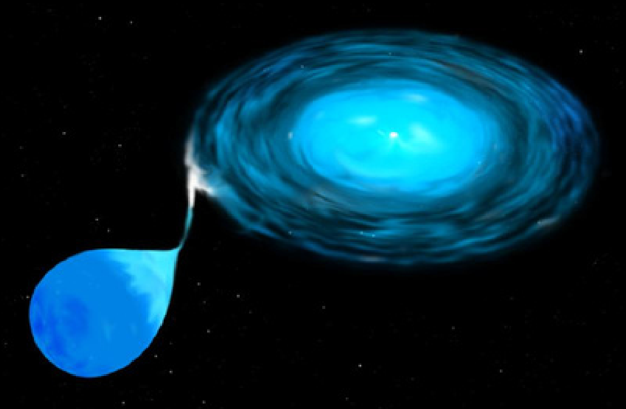
EaDE delves into the possibility of dark energy that is temporarily significant in the early universe and then diminishes as the universe evolves. This will affect measurements in the calculated length scale of the fluctuations in the CMB, which as described in the August Newsletter, would affect the inferred value of the Hubble constant, and thereby work to either reduce or negate the tension.

EvDE is a generalisation of this, with many theorised forms of dark energy such as quintessence, phantom energy, k-essence, coupled dark energy, chameleon & dilaton fields etc. The effects of some of these may even be observable. With more powerful telescopes such as the JWST being commissioned, their observations may not be too far away.

Finally, we arrive at the last and perhaps least involved possible cause of the tension - errors in data analysis. Here, we will specifically delve into the work by Oxford astrophysicist Professor Subir Sarkar.

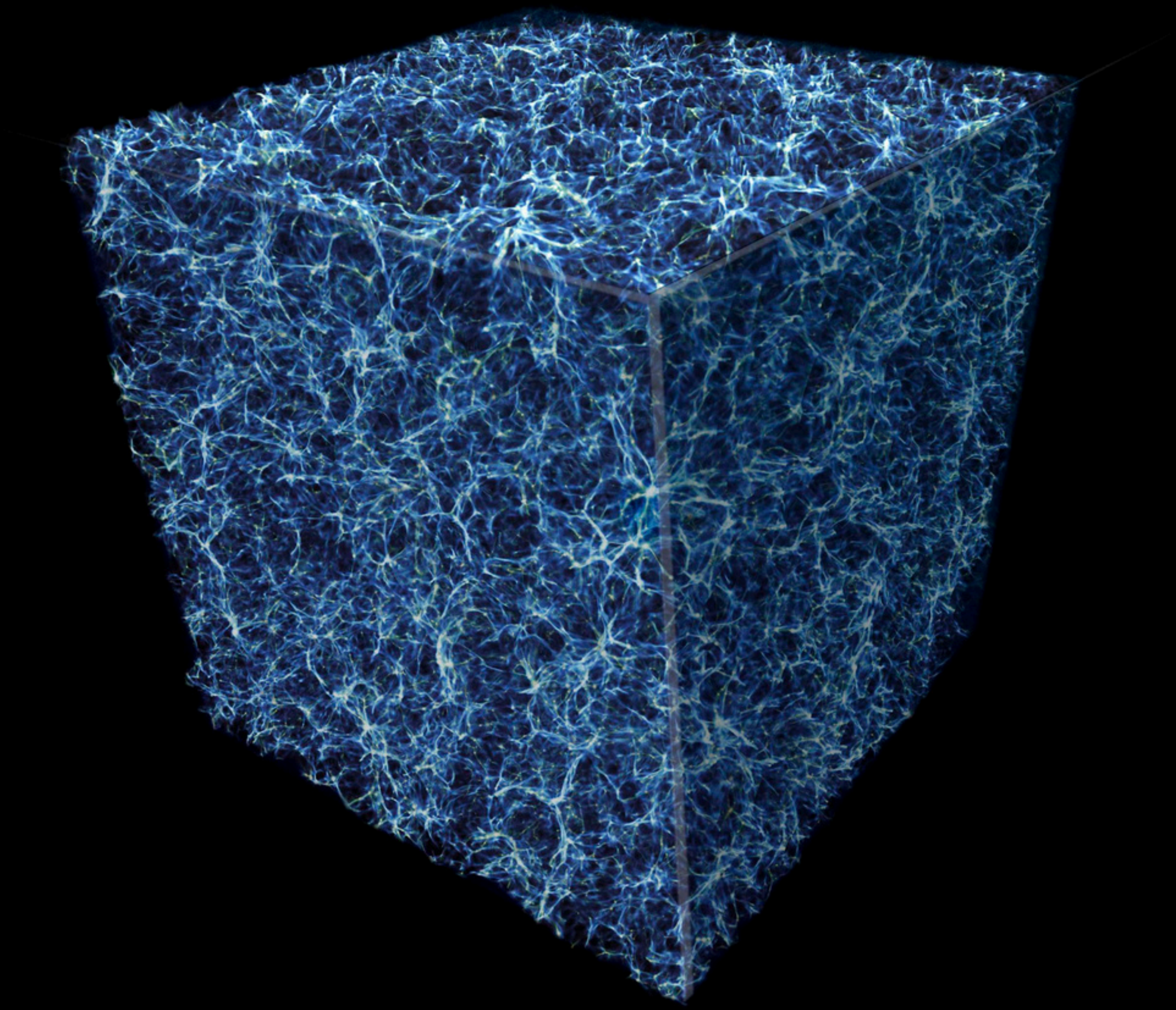
His work argues for significant systematic uncertainties in the calibration and analysis of Type Ia supernova data, such as that in Rameez and Sarkar, 2021. This is also supported by physicist and philosopher Sabine Hossenfelder who had a podcast with Prof. Sarkar regarding this.

Prof. Sarkar also believes that the assumption of homogeneity and isotropy, applicable at the large scales in the universe, may not be valid for the length scales where the Type Ia supernovae data were taken (Mohayee, Rameez and Sarkar, 2021). If the universe is more inhomogeneous than assumed by the original papers that give the Type Ia supernova-based Hubble constant, this could lead to an underestimation or overestimation of the



PRECURSOR TO TYPE IA SUPERNOVA. SOURCE: WIKIMEDIA
A white dwarf star accretes mass from its binary companion. When its mass reaches about 1.4 solar masses (Chandrasekhar Limit), it explodes as a Type Ia supernova.

HUBBLE TENSION



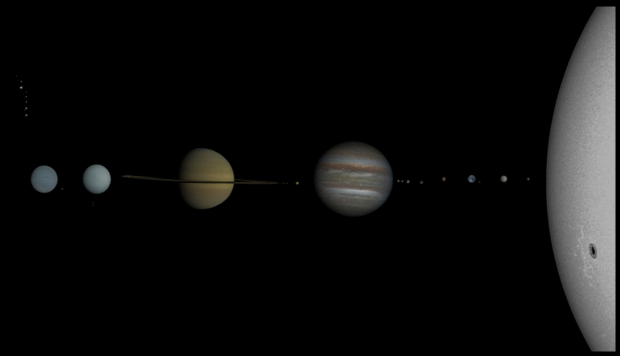
LARGE SCALE STRUCTURE OF THE UNIVERSE. SOURCE: WIKIMEDIA
On the scale of the Type Ia Supernova data set, the prevailing belief was that the universe is already more or less homogeneous. Sarkar's work challenges that.

Hubble constant depending on the observed region.

All these, along with other discrepancies in supernova data analysis, he concludes are the cause behind the tension and not underlying problems in the ΛCDM model and theory of General Relativity.

Ultimately, cosmologists have yet to find an explanation upon which a consensus can be formed. Looking at the bigger picture, cosmology still has many unanswered questions and undiscovered gems for you cosmology enthusiasts to delve into. Till that happens, keep exploring!

PLANETS REDEFINED



THE SOLAR SYSTEM. SOURCE: WIKIMEDIA
An illustration of the solar system (not to scale)

Recently, a research paper on Arxiv has suggested a new definition of planets, which would help refine the current definition established by the IAU in 2006. Before we get into that, it'd be nice to first go through the current definition by the IAU.

Before the IAU redefined the planet in 2006, there was no real definition of a planet. That was alright for a while, and still remained the same after Pluto's discovery in 1930, with Pluto becoming the ninth planet known to humanity. However, with the discovery of Pluto's moon Charon, the mass of Pluto was found to be significantly less than that of all the other planets, though it was still much more massive than that of the largest asteroids.

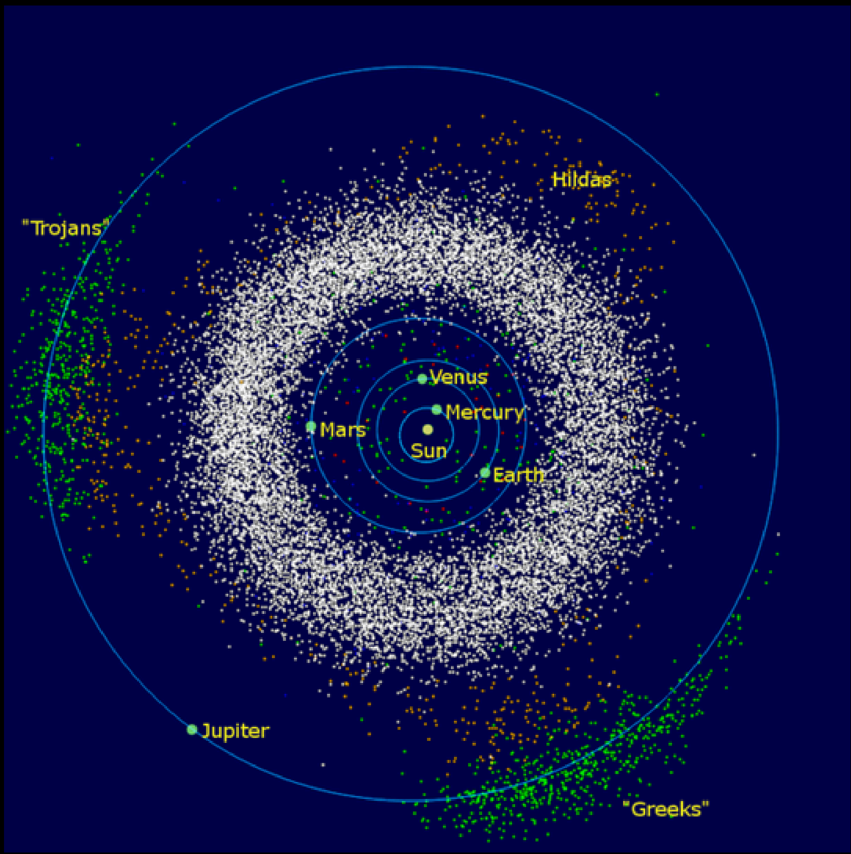
This cast initial doubts on the legitimacy of Pluto as a planet, though the killing blow came with the discovery of Eris in 2005.

Around the same time, other similar celestial bodies were revealed to scientists such as Makemake and Haumea, proving that Eris and Pluto were likely quite common instead of being much more rare such as the eight planets whose titles were uncontested. But the significance of Eris lies in its size and mass, as it was only slightly smaller than Pluto yet more massive.

So the question became an argument of logic, as if Pluto was a planet so should Eris, but if Eris were to be a planet then so should Makemake and Haumea, so on and so forth. Hence, during the 2006 IAU General Assembly, it was decided that a planet is defined with the below three characteristics:

1. It must orbit the sun.
2. It must have enough mass to achieve hydrostatic equilibrium (be roughly spherical in shape).
3. It must have "cleared its neighbourhood" in its orbit

PLANETS REDEFINED



JUPITER AND ITS TROJANS. SOURCE: WIKIMEDIA
Note the position of Jupiter vis-à-vis the Trojans in its orbit around the Sun.

On the surface, this new definition seems quite clear-cut, but upon further examination, one can't help but question just what it means to have "cleared its neighbourhood," how closely the object must be to a sphere, and why there is the requirement to orbit the sun, considering all the thousands of exoplanets discovered nowadays that orbit many different things.

And that new research paper that was mentioned at the start of this article aims to tackle just that. The extended definition can be summarised by the below:

a) the object of orbit is to include one or more brown dwarfs, stars, and stellar remnants

b) use mass as the qualitative guideline for a body to be approximately in hydrostatic equilibrium

c) coining the term "dynamical dominance" instead of "cleared its neighbourhood"

Along with two other criteria, these are the recommendations that the authors proposed for defining a planet.

PLANETS REDEFINED

Resolution A (Quantitative)

The IAU resolves that a planet is a celestial body that
(a) orbits one or more stars, brown dwarfs, or stellar remnants, and
(b) has sufficient mass for its self-gravity to overcome rigid body forces so that it is approximately in hydrostatic equilibrium and assumes a nearly triaxial shape, and
(c) has sufficient mass to dynamically dominate the neighborhood around its orbit, i.e.,
$M_p > 0.0012\, M_\star^{5/8}\, a_p^{9/8}$,
where M_p is the mass of the planetary body expressed in Earth masses, $M_\star$ is the mass of the central body expressed is solar masses, and a_p is the semi-major axis expressed in astronomical units, and
(d) has a true mass below the limiting mass for thermonuclear fusion of deuterium (currently calculated to be 13 Jupiter masses for objects of solar metallicity), and
(e) has a mass ratio with the central object below the L4/L5 instability, i.e.,
$M_p/M_\star < 2/(25 + (621)^{1/2}) \simeq 1/25$.

Resolution B (Non-quantitative)

The IAU resolves that a planet is a celestial body that
(a) orbits one or more stars, brown dwarfs, or stellar remnants, and
(b) has sufficient mass for its self-gravity to overcome rigid body forces so that it is approximately in hydrostatic equilibrium and assumes a nearly triaxial shape, and
(c) has sufficient mass to dynamically dominate the neighborhood around its orbit, and
(d) has a true mass below the limiting mass for thermonuclear fusion of deuterium (currently calculated to be 13 Jupiter masses for objects of solar metallicity), and
(e) has a mass ratio with the central object below the L4/L5 instability (approximately 1/25).

THE PROPOSED RESOLUTIONS. SOURCE: ARXIV, QUANTITATIVE CRITERIA FOR DEFINING PLANETS HTTPS://ARXIV.ORG/ABS/2407.07590
The proposed resolutions submitted by the authors of the paper to the IAU

This formulation proposed by the paper provides a much more precise interpretation that is also more analytical in nature. The full derivation and substantiation behind this proposal can also be found in the paper which is linked here and in the bibliography.

It was also mentioned that the authors hope that this issue can be resolved during the 2024 IAU General Assembly which was held in August, though it was not one of the three resolutions approved by the IAU for voting in the 2024 IAU General Assembly.

But regardless of the result, it's still something rather exciting to hear about. Especially considering how planets are actually a rather old topic. This paper is proof that it certainly still holds the interest of some passionate individuals willing to spend the effort to research on planets and hopefully, make a difference.

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

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.

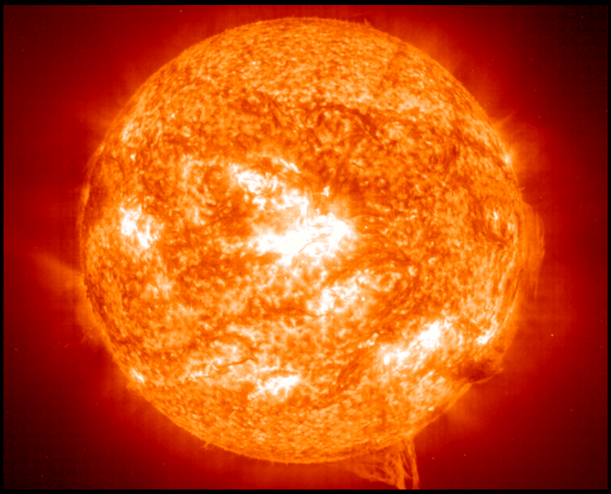


Image of the sun

Source: EIT - SOHO Consortium / ESA / NASA

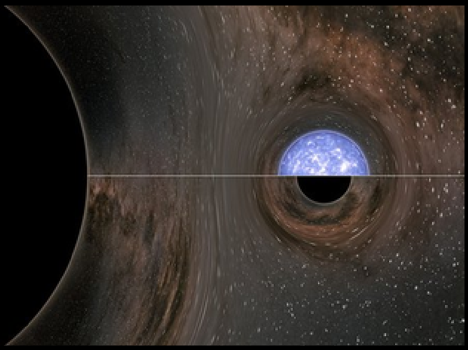
Fun-Fact-of-the-Month:

One of Jupiter's moons, Europa, experiences tidal heating. This is why Europa is known to have a liquid ocean underneath its icy surface.

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?

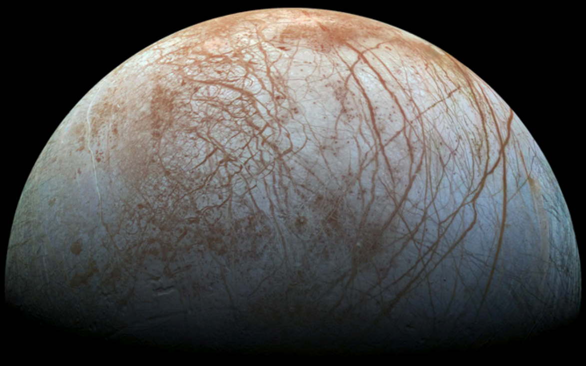


Left shows the illustration of a black hole, right shows the illustration of an object in the mass gap-- could be either a neutron star or a black hole

Source: Caltech

Image of Europa

Source- NASA Science



EVENTS AND STARGAZING

🌌 **Starry SAM Late Nights with Science Centre Singapore** 🌌

Date: 6th Sep 2024, Friday
Time: 6:30pm
Location: Science Café @ Singapore Art Museum
Fees: $20.00

Looking for a night where art and astronomy collide? Head over to the Singapore Art Museum for an evening that's out of this world! Join CQT Senior Research Fellow Dr. Tan Peng Kian and SAM curatorial assistant Angelica Ong as they dive into the fascinating connections between art and science.

Explore the wonders of the solar system with Science Centre Observatory's mobile planetarium, or take to the skies with telescopes for some stargazing. Feel free to join in for stargazing even if you are not purchasing a ticket, as it is free for members of the public to enjoy!

As a bonus, attendees get a 20% discount on tickets to "Olafur Eliasson: Your curious journey." And yes, dinner is included!

✨ Don't miss out—mark your calendars for this stellar event! ✨

Please note:
This event is for ages 18 and above. Café tickets cover dinner, the talk, planetarium shows, and stargazing only. A separate ticket is required for the Olafur Eliasson exhibit.

This event is organized by the Singapore Art Museum and Science Centre Singapore.

Link: Click here

ORGANISERS:

sam singaporeartmuseum CONTEMPORARY ART IN SOUTHEAST ASIA

SCIENCE CENTRE singapore

EVENTS AND STARGAZING

Inaugural SAND Bingo Challenge

Introducing the SAND Bingo Challenge, with our very own astrophysics twist to this classic game. Attempt to complete as many challenges as possible before SAND 2025 to help your school win stellar prizes that are light years beyond cool! The Bingo Challenge is live on our discord channel, so do make sure to check it out and sign up!

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

Featured Stargazing Location: Pulau Ubin

Nestled in nature with its vibrant wildlife, expansive mangroves, and chill vibes, Pulau Ubin is one of Singapore's top stargazing spots. Thanks to its escape from the city's bright lights, the island boasts a Bortle Scale rating of around 7—way better than the mainland's 9. So, why not round up your crew and head to this floral paradise for a night of celestial exploration? The stars are calling!

CHEK JAWA WETLANDS. SOURCE: WIKIMEDIA
Here's a panoramic view from the boardwalk portion of the Chek Jawa Trail. Being far removed and facing away from the mainland, the skies here will not disappoint, lest weather prohibits.

EVENTS AND STARGAZING

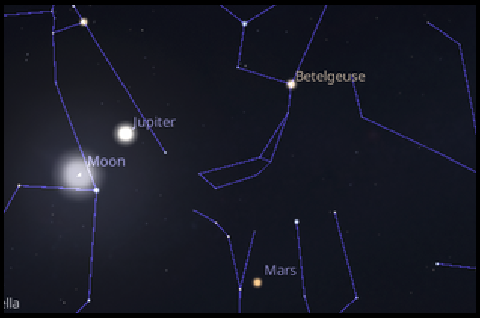
The month of September will herald the coming of the Autumn sky. Depending on your available tools, you will be able to see ever more elusive objects. Regardless of this, there are ample objects to observe for anyone patient and avid enough.

Free-hand stargazing

- **September 18th** While the partial lunar eclipse on September 18th will unfortunately not be visible from Singapore, this date also marks when there will be a full moon while the moon is at its closest approach (perigee) to Earth (called a supermoon), thus providing us with dark skies and some great night-sky watching. The moon will appear about 16% larger than normal as well as up to 30% brighter than the average full moon!

Source: Gemini AI

- **September 24th** The Moon and Jupiter will make close passby, sharing the same Right Ascension and being separated by only 6 degrees. Be sure to catch these two iconic celestial bodies as they gracefully glide across the night sky, starting just after midnight!



Source: Stellarium

EVENTS AND STARGAZING

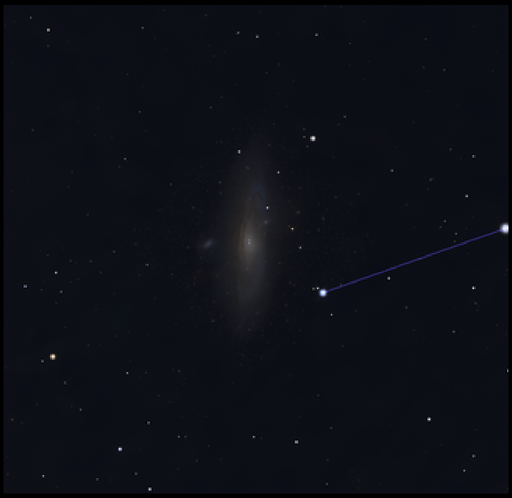
Free-hand stargazing (Cont'd)

- **Great Square of Pegasus** 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

Source: Stellarium

Binoculars

- **The Andromeda Galaxy (M31)** Say hello to the closest major galactic neighbour to the Milky Way! At a distance of just over 2.5 million light years and boasting an apparent magnitude of +3.1, it is one of the brightest and most easily observable features in the night sky.



Source: Stellarium

EVENTS AND STARGAZING

Binoculars (Cont'd)

- **Caldwell 14 (The Double Cluster)** Most easily visible in the Autumn months of September and October, the open star clusters NGC 869 and NGC 884 are located about halfway in between the constellations of Cassiopeia and Perseus. Labelled as h Persei and chi Persei, respectively, these 2 clusters can be neatly distinguished by binoculars, so why don't you give it a go!

Source: Wikimedia

- **Nu Draconis (Kuma)** While best seen in July, this iconic double star system can still be easily observed using binoculars for a large portion of the year! Famously referred to as the eyes of the constellation Draco the dragon, this close pair of equally bright stars should be on everyone's observation list!

Source: Wikimedia

EVENTS AND STARGAZING

Telescope

- **The Owl Cluster (NGC 458)** While being bright enough to be detected by binoculars, a telescope would truly do justice to this beautiful star cluster. Located near the centre of the constellation Cassiopeia, with the double star system phi Cassiopeiae appearing as a bright pair of pale gold stars representing the eyes of the owl, see if you can trace the hundreds of stars that represent the owls wings and body!

Source: Wikimedia

- **Almach** One of the most visually appealing colour-contrast doubles in the sky, this star system can be resolved into 2 separate stars, a yellow/orange primary star and a smaller, blue secondary star, with a telescope. However, what cannot be resolved using an amateur telescope, even with good visibility, is the fact that each of the 2 visible stars are actually binaries themselves, making Almach in effect a quadruple star system!

Source: Wikimedia

SOURCES

Front Page
Alien Image (Generated By Gemini AI)
Galaxies Image (Generated By Gemini AI)
Solar System Depiction

Content Page
Content Page Header - Triangulum Galaxy

Life Beyond
Hycean World Depiction (Generated By Gemini AI)
Beach Depiction (Generated By Gemini AI)
Mini-Neptune Depiction
JWST Fine Guidance Sensor
K2-18b: did JWST really find evidence of life on this exoplanet?
Sky & Telescope Article on K2-18b
Madhusudhan, N., Sarkar, S., Constantinou, S., Holmberg, M., Piette, A. A., & Moses, J. I. (2023). Carbon-bearing molecules in a possible Hycean atmosphere. The Astrophysical Journal Letters, 956(1), L13.
Shorttle, O., Jordan, S., Nicholls, H., Lichtenberg, T., & Bower, D. J. (2024). Distinguishing oceans of water from magma on mini-Neptune K2-18b. The Astrophysical Journal Letters, 962(1), L8.
Wogan, N. F., Batalha, N. E., Zahnle, K. J., Krissansen-Totton, J., Tsai, S. M., & Hu, R. (2024). JWST observations of K2-18b can be explained by a gas-rich mini-Neptune with no habitable surface. The Astrophysical Journal Letters, 963(1), L7.

Hubble Tension
Timeline of the Universe
M33 Rotation Curve
Structure of the Universe
Accretion Disk Binary System
Adil, S. A., Akarsu, Ö., Di Valentino, E., Nunes, R. C., Özülker, E., Sen, A. A., & Specogna, E. (2024). Omnipotent dark energy: A phenomenological answer to the Hubble tension. Physical Review D, 109(2), 023527.
Mohayaee, R., Rameez, M., & Sarkar, S. (2021). Do supernovae indicate an accelerating universe?. The European Physical Journal Special Topics, 230(9), 2067-2076.

SOURCES

Hubble Tension (cont.)
Poulin, V., Smith, T. L., Karwal, T., & Kamionkowski, M. (2019). Early dark energy can resolve the Hubble tension. Physical review letters, 122(22), 221301.
Rameez, M., & Sarkar, S. (2021). Is there really a Hubble tension?. Classical and Quantum Gravity, 38(15), 154005.
Vagnozzi, S. (2023). Seven hints that early-time new physics alone is not sufficient to solve the Hubble tension. Universe, 9(9), 393.

Planets Redefined
Jupiter and its Trojans
Sci.News article about New Definition of Planets
Margot, J. L., Gladman, B., & Yang, T. (2024). Quantitative Criteria for Defining Planets. The Planetary Science Journal, 5(7), 159.
Anton Petrov's take on this

Trivia
SOHO Image of the Sun
Intermediate Mass Black Hole in Omega Centauri
Image of Black Hole Mass Gap
Image of Europa

Events
Science Centre Singapore
Singapore Art Museum

Stargazing
Bright Supermoon Depiction (Generated by Gemini AI)
Double Cluster
Nu Draconis
Owl Cluster
Almach double star
Triangulum Galaxy
Solar System