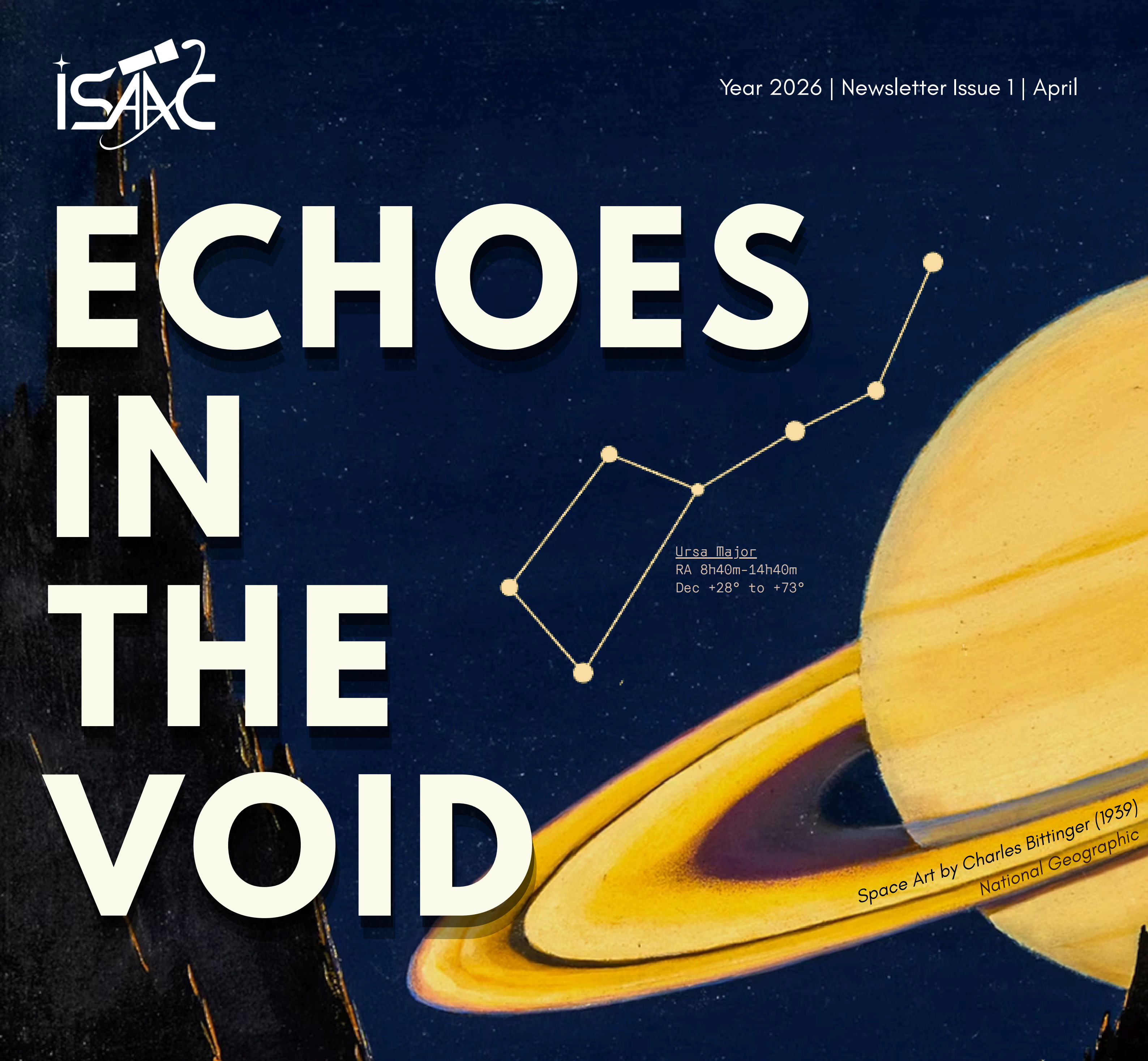
Year 2026 | Newsletter Issue 1 | April

ECHOES IN THE VOID



Space Art by Charles Bittinger (1939)
National Geographic

FUNDAMENTAL OPEN PROBLEMS IN CONTEMPORARY HELIOPHYSICS

A Review of Unresolved Mechanisms

by *Siddharth Rathod*

Cygnus
RA 19h07m-22h02m
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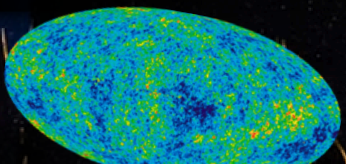
AN INTRODUCTION TO THE SEARCH FOR EXTRATERRESTRIAL LIFE

Are we alone?

by *Roshni Upadhaya*



THE ΛCDM MODEL OF THE UNIVERSE

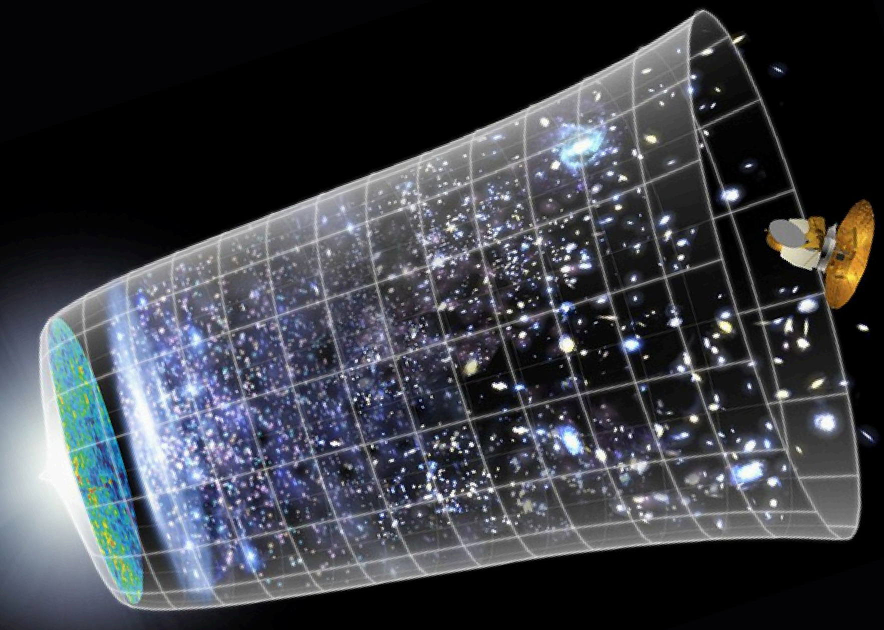
An exploration of the early cosmos

by *Swarnabha Chanda*

ISAAC

INDIAN SYNERGY OF ASTRONOMY & ASTROPHYSICS CLUBS

INTRODUCING



ISAAC

Logo by : **Divyanshu Saha**, IISER Kolkata

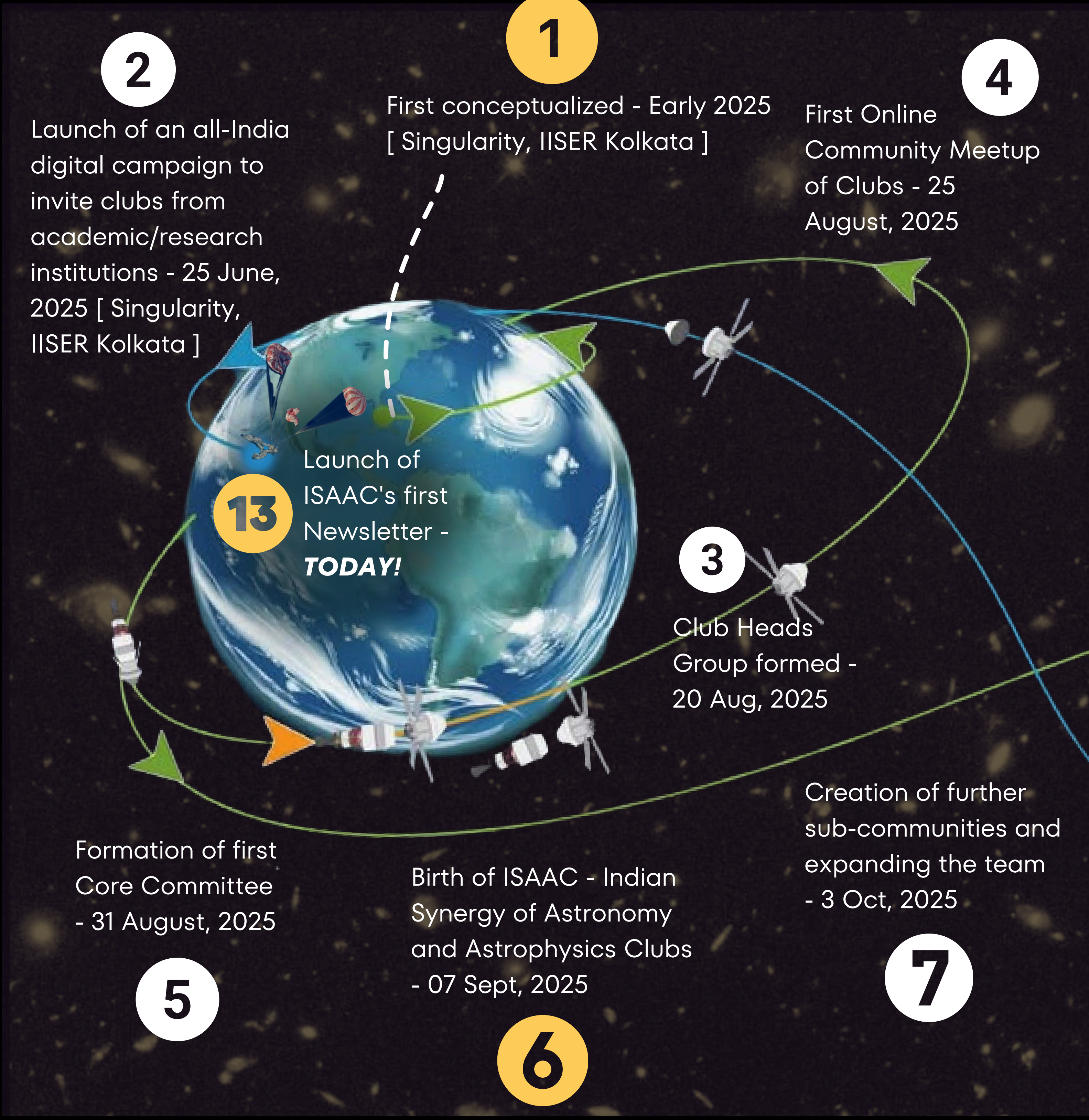
MISSION

ISAAC was established to bridge the gap between astronomy clubs functioning in isolation and to create a sustained and collaborative ecosystem. Previous attempts at nationwide coordination have often gone dormant; ISAAC seeks to be a dynamic, student-driven initiative that not only connects clubs but also enhances the quality and reach of their activities. We aim to make astronomy more accessible by encouraging knowledge exchange, shared events, and resource pooling, allowing even smaller clubs to aspire to larger goals through collaboration with more established ones.

VISION

We envision becoming the primary platform for astronomy and astrophysics enthusiasts in India, a space where students from all academic/ research institutions in India can exchange knowledge, build projects, and find opportunities in the field. In time, we aim to strengthen our academic and outreach impact by connecting various national institutions and outreach groups, while continuing to remain fully student-driven in spirit.

TIMELINE



1

First conceptualized - Early 2025 [Singularity, IISER Kolkata]

2

Launch of an all-India digital campaign to invite clubs from academic/research institutions - 25 June, 2025 [Singularity, IISER Kolkata]

3

Club Heads Group formed - 20 Aug, 2025

4

First Online Community Meetup of Clubs - 25 August, 2025

5

Formation of first Core Committee - 31 August, 2025

6

Birth of ISAAC - Indian Synergy of Astronomy and Astrophysics Clubs - 07 Sept, 2025

7

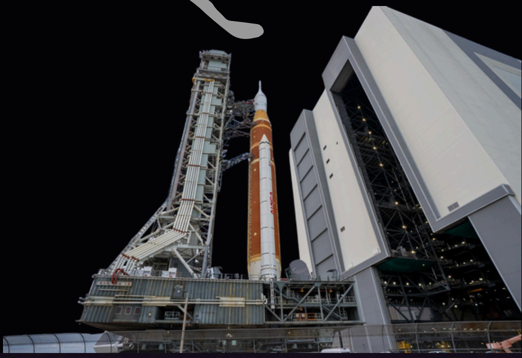
Creation of further sub-communities and expanding the team - 3 Oct, 2025

13

Launch of ISAAC's first Newsletter - ***TODAY!***

Artemis II Mission Map, NASA

Artemis II *(April 1–10, 2026) was a nine-day lunar flyby mission. With a crew of four astronauts, it was the first crewed flight of the NASA-led Artemis program and the first crewed flight beyond low Earth orbit since Apollo 17 in 1972. Artemis II was the second flight of the Space Launch System (SLS) and the first crewed flight of the Orion spacecraft, named Integrity by the crew. -Wikipedia*



NASA's SLS (Space Launch System) and Orion spacecraft rolling out of the Vehicle Assembly Building at NASA's Kennedy Space Center on Saturday, Jan. 17, 2026. NASA/Brandon Hancock

8

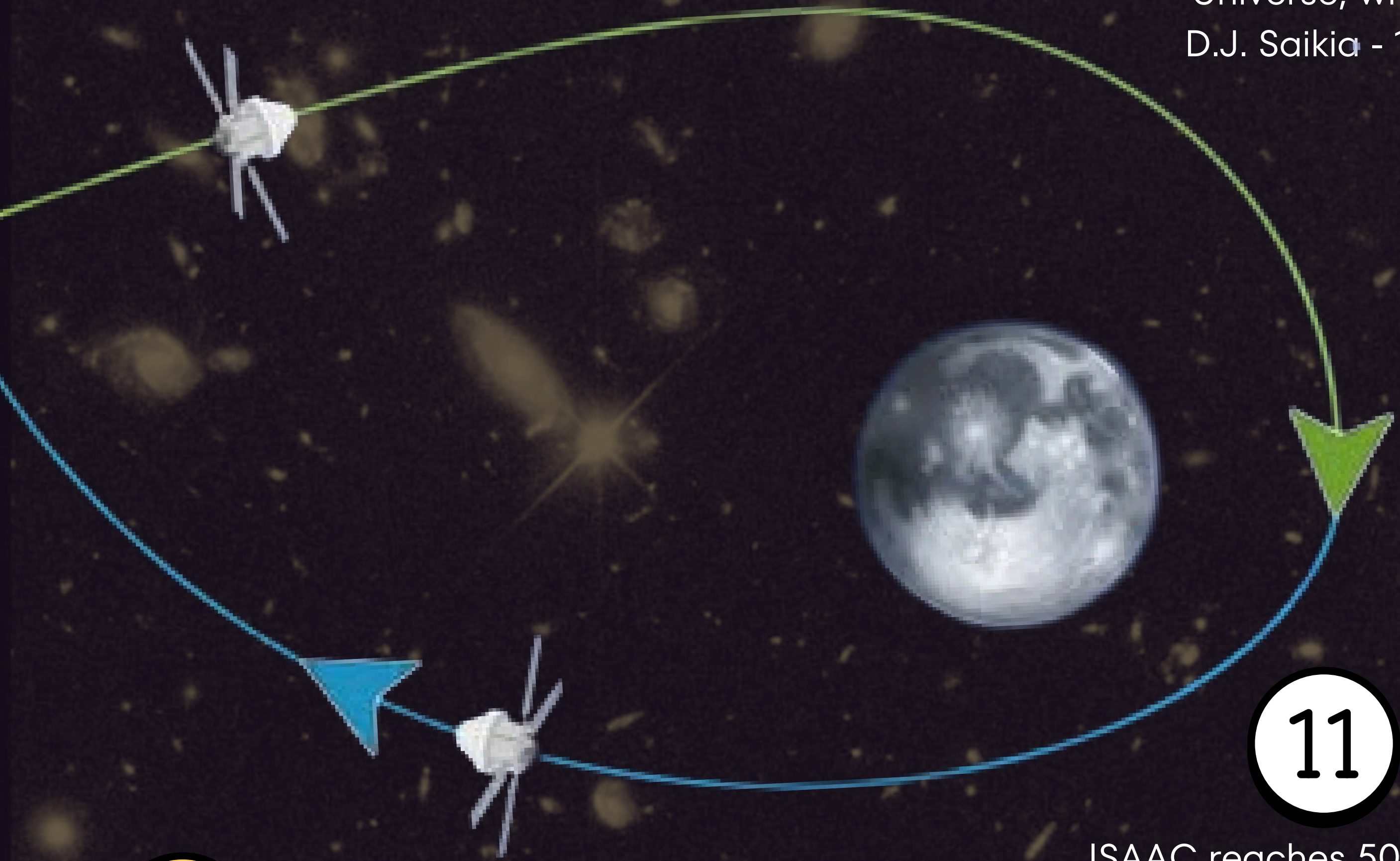
Launch of ISAAC's official logo! - 24 October, 2025

9

Creation of first social media accounts - ISAAC's insta handle and YouTube Channel - 01 Nov, 2025

10

ISAAC's first event! - An online talk on Black Holes in Our Universe, with Prof. D.J. Saikia - 16 Nov, 2025



11

ISAAC reaches 50 official member clubs - 25 Nov, 2025

12

First Offline Meeting of ISAAC - Mar 05, 2026 at IUCAA Pune

MISSION LOG

FROM THE CO-FOUNDERS' DESK

ISAAC began with a simple observation. Astronomy clubs across the country, despite being active and enthusiastic, often operate in isolation. Talks, workshops, and observing sessions are regularly organised, but they tend to remain confined within individual institutes. While there is no shortage of initiative, there has been very little connection between these efforts.

At the same time, the availability of resources varies significantly from one institute to another. Some clubs benefit from access to telescopes, faculty guidance, or strong senior mentorship, while others are still in the process of building themselves from the ground up. This disparity is not due to a lack of interest, but rather the absence of a shared platform that brings these communities together.

ISAAC was formed in response to this gap.

What started as a set of conversations last year, initiated by Singularity, the Astronomy Club of IISER Kolkata, gradually expanded into a broader network of clubs across the country. By August, with support from multiple institutes, ISAAC took shape as a student-led initiative aimed at connecting astronomy and astrophysics clubs across India.

Co founders -

- **Jameer Manur**, *Antariksh, IUCAA, Pune*
- **Pranjal Sengupta**, *Niharika, IACS Kolkata*
- **Ruturaj Kulkarni**, *Singularity Club, IISER Kolkata*
- **Susnata Chattopadhyay**, *Singularity Club, IISER Kolkata*

At its core, ISAAC is intended to facilitate collaboration, resource sharing, and collective growth. Theidea is not to replace individual clubs, but to strengthen them by making it easier to work together. A talk hosted by one club can reach students across institutes. A student looking for guidance need not be limited by their immediate environment. Projects can extend beyond institutional boundaries and find collaborators elsewhere.

Even in its early stages, ISAAC has shown the value of this approach. Shared discussions, coordinated efforts, and the exchange of ideas have demonstrated how collaboration can meaningfully expand what student communities are able to achieve.

At the same time, ISAAC remains very much a work in progress. There are several directions it can grow in, including collaborative events, workshops, research discussions, and shared resource platforms. What will ultimately matter is that it continues to remain active, relevant, and driven by the participation of its member clubs. This newsletter is one such step in that direction. It brings together contributions from students across institutes and reflects the kind of community ISAAC is working towards building. A space where ideas can be shared, work can be showcased, and students can learn from one another.

I hope you enjoy this first edition of our newsletter, and stay tuned for everything ISAAC has in store.

Ruturaj Kulkarni,
on behalf of the Co-founders,
ISAAC

CONT

ENTS

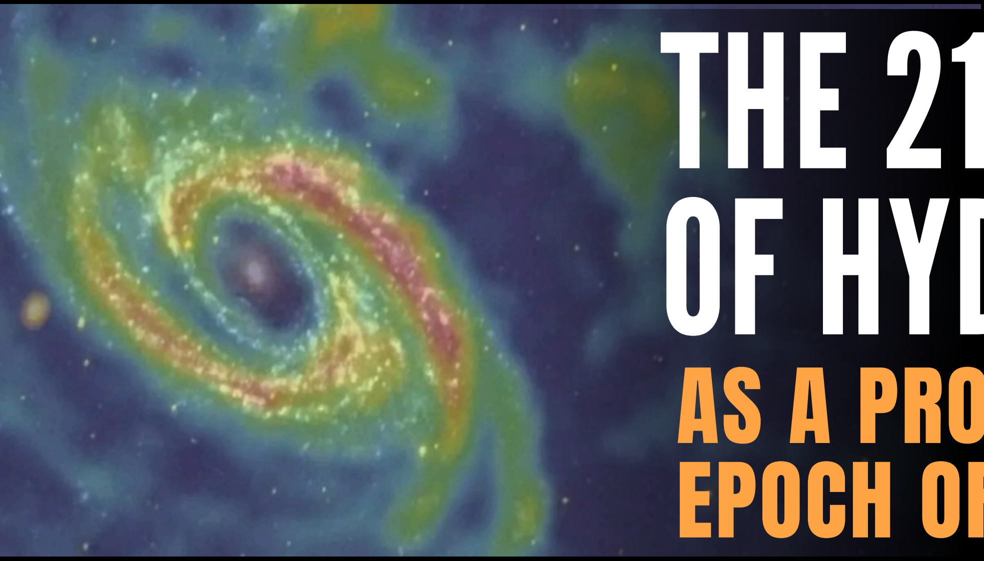
Solar eclipse as seen by the Artemis II mission. It is important to photograph it to study the behavior of the Sun's upper layer - NASA

Christina Koch looks out of the Orion spacecraft's windows back at Earth - NASA

The new photo of the far hemisphere of the moon, with Earth in the background - NASA

THE 21 CM LINE OF HYDROGEN

AS A PROBE OF THE EPOCH OF REIONIZATION



This map of the galaxy Messier 81, constructed from data taken with the Very Large Array, maps out this spiral-armed, star-forming galaxy in 21 centimeter emissions. The spin-flip transition of hydrogen, which emits light at precisely 21 centimeters in wavelength, is in many ways the most important length for radiation in the entire Universe. *(Credit: NRAO/AUI/NSF)*

*by **Sandipan**,*
Astronomy Club, Kirori Mal College, University of Delhi

Neutral hydrogen (HI) is the most abundant baryonic component of the Universe prior to and during the formation of the first luminous sources. One of its most important observational signatures is the 21 cm hyperfine transition corresponding to radiation at a rest frequency of 1420.405 MHz. Unlike optical or infrared tracers, the 21 cm line allows direct observation of diffuse hydrogen gas without requiring the presence of stars or galaxies; it also enables three-dimensional tomographic mapping of the intergalactic medium (IGM) from the cosmic dark ages through the Epoch of Reionization (EoR) and beyond. As a result, it has become a cornerstone of modern cosmology, particularly in studies of the cosmic dark ages, the cosmic dawn, and the Epoch of Reionization.

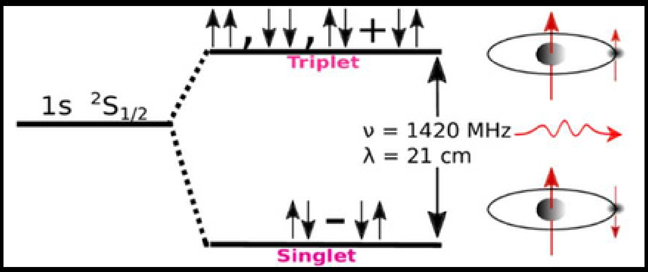


Fig 1: A schematic diagram for hyperfine transition in ground state of neutral hydrogen atom.

This hyperfine transition line of atomic hydrogen (in the ground state) arises due to the interaction between the electron and proton spins. The excited triplet state is a state in which the spins are parallel, whereas the spins at the lower (singlet) state are antiparallel.

The 21 cm line is a forbidden line for which the probability for a spontaneous 1→0 transition is given by the Einstein A coefficient that has the value of $A_{10} = 2.85 \times 10^{-15}\ \text{sec}^{-1}$. Such an extremely small value for Einstein-A corresponds to a lifetime of the triplet state of 1.1×10^7 years for spontaneous emission. Despite its low decay rate, the 21 cm transition line is one of the most important astrophysical probes, simply due to the vast amounts of hydrogen in the Universe as well as the efficiency of collisions and Lyman-α radiation in pumping the

the line and establishing the population of the triplet state.

The relative population of the hyperfine states is described by the spin temperature T_s, defined through the Boltzmann relation:

$$\frac{n_1}{n_0} = 3\exp\left(-\frac{T^*}{T_{\text{spin}}}\right)$$

where n_1 and n_0 are the number densities of the triplet and singlet states, respectively, and $T^* \approx 0.068$ K corresponds to the energy difference of the transition.

The spin temperature does not evolve independently; instead, it is governed by three competing processes: interaction with CMB photons, which couples T_s to the CMB temperature; collisions between hydrogen atoms and other particles, which couple T_s to the kinetic temperature of the gas; and the Wouthuysen–Field effect, whereby resonant scattering of Lyman-α photons mixes the hyperfine states and couples T_s to the gas temperature. The balance between these mechanisms determines whether the 21 cm line appears in emission or absorption relative to the cosmic microwave background.

The observable quantity in 21 cm cosmology is the differential brightness temperature relative to the CMB:

$$\delta T_b \approx \frac{T_s - T_{\text{CMB}}}{1+z}\left(1 - e^{-\tau_{21}}\right)$$

where τ_{21} is the optical depth of the hyperfine transition and z is the redshift.

For most cosmological applications, the optical depth is small, allowing a linear approximation. The resulting signal depends on the neutral hydrogen fraction, the baryon density, the spin temperature, and density and velocity fluctuations in the IGM. Thus, the 21 cm brightness temperature encodes both thermal and structural information about the Universe.

During the dark ages, before the formation of the first stars, the 21 cm signal traces density fluctuations in neutral hydrogen. In this era, collisions dominate the coupling of spin temperature to the gas temperature, making the signal a direct probe of primordial structure formation.

As the first stars and galaxies form, ultraviolet radiation, particularly Lyman-α photons, strongly affects the spin temperature through the Wouthuysen–Field effect. This period is expected to produce a strong absorption feature in the global 21 cm signal, reflecting the cooling of the IGM relative to the CMB.

During reionization, ionized bubbles form around early galaxies and quasars. The 21 cm signal becomes

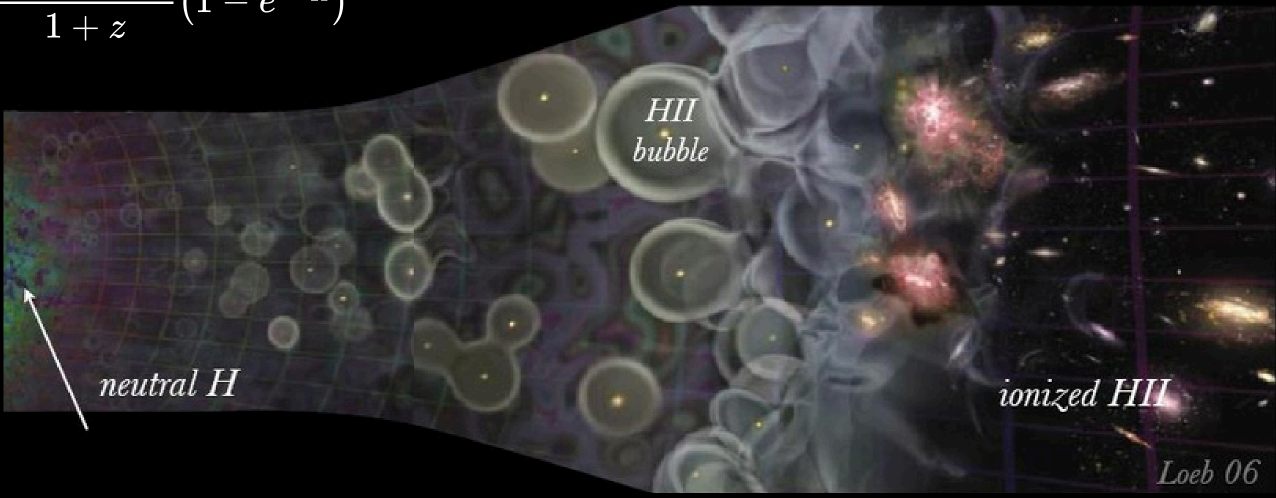


Fig 2: The basic process of reionization: radiation eats away at the neutral medium, creating H II (ionized hydrogen) bubbles, until the universe is completely ionized. *Image Credits: Aaron Parsons.*

highly non-uniform, allowing spatial mapping of ionized and neutral regions. Measurements of this signal provide constraints on the timing, duration, and sources of reionization.

After reionization, neutral hydrogen remains confined to dense regions within galaxies. In this regime, 21 cm intensity mapping is used to trace large-scale structure and study cosmological parameters without resolving individual galaxies.

Detecting the 21 cm signal is extremely challenging due to strong foreground emission from Galactic synchrotron radiation, radio frequency interference, and instrumental systematics. Despite these challenges, several experiments like LOFAR, MWA, GMRT, HERA, and the upcoming Square Kilometre Array (SKA) aim to measure the 21 cm signal across a wide range of redshifts.

In conclusion, the 21 cm line of neutral hydrogen is one of the most powerful probes of the early Universe. Its sensitivity to the thermal, ionization, and density structure of the IGM makes it uniquely suited for studying the cosmic dark ages, the emergence of the first luminous sources, and the Epoch of Reionization. As observational capabilities improve, 21 cm cosmology is expected to play a central role in precision cosmology and our understanding of cosmic evolution.

CRXSSWORD

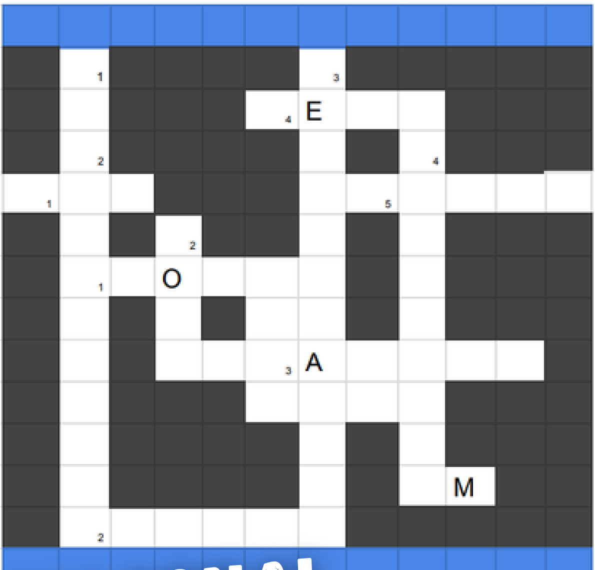
HINTS ...

DOWN

1. Branch of space science devoted to the Sun's interior, atmosphere, and its interaction with the heliosphere and planetary environments. (12)
2. A solar system object marked by basins such as Mare Tranquillitatis and Mare Imbrium, relics of early Solar System impacts (4)
3. Epoch when the first luminous sources ionised neutral hydrogen, ending the cosmic dark ages of the early Universe. (12)
4. A recently discovered ------(Across 3) named after an Indian river, reflecting India-inspired nomenclature in extragalactic astronomy. (9)

ACROSS

1. ESA's autonomous technology-demonstration programme, spanning solar missions from its second flight to the third in late 2024, the latter employing precision formation flying to create artificial eclipses for probing the Sun's ------ (Diagonal 1) (5)
2. A gas giant hosting moons like Iapetus, whose subsurface oceans and surface dichotomies reveal complex planetary processes. (6)
3. A self-gravitating stellar system whose flat rotation curves provided early evidence for the existence of dark matter. (6)
4. Scientific effort focused on detecting technosignatures and signals from extraterrestrial intelligent civilizations. (4)
5. A trans-Neptunian object in 3:2 mean-motion resonance with Neptune, belonging to the dynamically excited Kuiper Belt. (5)



DIAGONAL

1. The Sun's outer atmosphere studied by the Visible Emission Line Coronagraph onboard Aditya-L1, exhibiting temperatures hotter than the photosphere. (6)
2. The concordance cosmological model describing a Universe dominated by dark energy and cold dark matter. (9)

P.S. - The number in the parenthesis (n) denotes the number of letters in that particular word

SOLUTION - page 17

THANU PADMANABHAN (1957–2021)

A LIFE DEDICATED TO UNDERSTANDING THE UNIVERSE

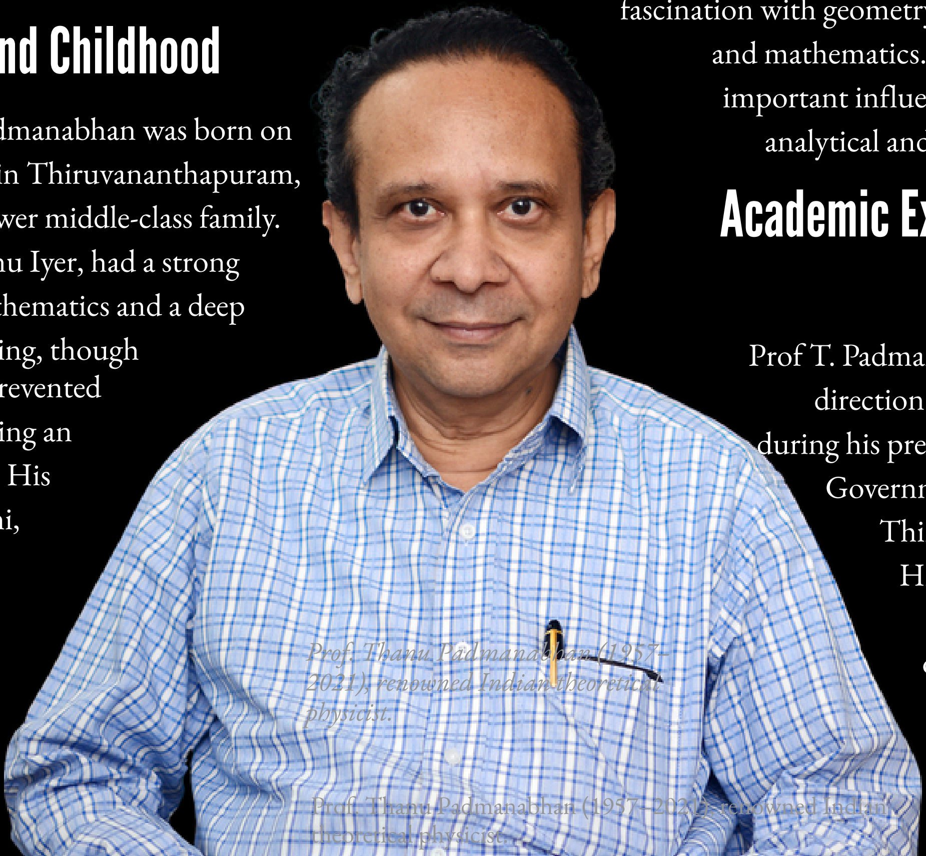
*by **Priyanshu Rathore**, Astronomy Club, Kirori Mal College, University of Delhi*

Prof. **Thanu Padmanabhan**, fondly known as Paddy, was among the most influential theoretical physicists of modern India. Renowned for his deep insights into gravitation, cosmology, and quantum gravity, his work reshaped how physicists think about spacetime, gravity, and the large-scale structure of the Universe.

Early Life and Childhood

Prof. Thanu Padmanabhan was born on 10 March 1957 in Thiruvananthapuram, Kerala, into a lower middle-class family. His father, Thanu Iyer, had a strong aptitude for mathematics and a deep respect for learning, though circumstances prevented him from pursuing an academic career. His mother, Lakshmi, provided a disciplined and supportive home environment. From an early age, Padmanabhan grew up in surroundings where intellectual honesty and excellence were deeply valued.

Educated in Malayalam medium at a government school, he did not emerge as a conventional child prodigy. Nevertheless, he showed an early fascination with geometry, logical reasoning, and mathematics. Chess was another important influence, sharpening his analytical and strategic thinking.



Prof. Thanu Padmanabhan (1957–2021), renowned Indian theoretical physicist.

Prof. Thanu Padmanabhan (1957–2021), renowned Indian theoretical physicist.

Academic Excellence and Influences

Prof T. Padmanabhan's academic direction changed decisively during his pre-degree years at the Government Arts College, Thiruvananthapuram. His exposure to The Feynman Lectures on Physics revealed to him the elegance of theoretical physics as a discipline combining mathematical structure with physical reality.

An equally important influence was the Trivandrum Science Society, a student-driven collective devoted to self-learning beyond rigid curricula. Through intense self-study and peer discussions, he mastered advanced texts such as the Berkeley Physics Course and the Landau–Lifshitz Course of Theoretical Physics.

He completed his B.Sc. (1977) and M.Sc. (1979) in Physics from the University of Kerala, securing gold medals in both degrees. Remarkably, he published his first research paper in general relativity while still an undergraduate.

Research and Scientific Contributions

Prof T. Padmanabhan pursued his doctoral research at the Tata Institute of Fundamental Research (TIFR), Mumbai, under Prof.Jayant Narlikar, earning his Ph.D. in 1983. His thesis in quantum cosmology addressed foundational questions related to cosmological singularities and the wave function of the Universe.

Over a career spanning more than four decades, he made profound contributions to general relativity, cosmology, quantum field theory, and quantum gravity. His most influential idea was that gravity may not be a fundamental interaction, but an emergent phenomenon arising from the thermodynamic properties of spacetime.

In 1992, he joined the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, where he served as a Distinguished Professor and played a central role in shaping India’s research culture in gravitation and cosmology

Achievements and Teaching

Prof. T. Padmanabhan authored over 300 research papers and more than a dozen influential textbooks, including Structure Formation in the Universe, Gravitation, and Quantum Field Theory. These works remain standard references worldwide.

His achievements were recognized through numerous honors, including the Shanti Swarup Bhatnagar Award, Padma Shri, and the Infosys Prize in Physical Sciences. Above all, he was an exceptional teacher and mentor, guiding generations of students who continue to contribute actively to physics research and education.

Prof T. Padmanabhan remained intellectually active until his sudden passing on 17 September 2021. His life stands as a powerful reminder that scientific excellence arises from curiosity, discipline, and integrity. For students and young researchers, his legacy demonstrates that physics is not merely a career, but a lifelong pursuit of understanding nature at its deepest level.

Prof. T. Padmanabhan received
Padma Sri Award from Dr
APJ.Abdul Kalam.

Several hundred never before seen galaxies are visible in this "deepest-ever" view of the universe, called the Hubble Deep Field (HDF), made with NASA's Hubble Space Telescope.

THE FIRST LOOK UP

EARLY HUMANS AND THE COSMOS

by Riyah Mohan,
Singularity,
IISER Kolkata

> *"You investigate for curiosity, because it is unknown, not because you know the answer."*
> *- Richard Feynman*

It has become a tradition for every science-related article to start with a quote from the great Richard Feynman, which makes me wonder- if I could go back in time and ask him what the greatest asset of a scientific mind is, what would his answer be? The same question when asked to my fellow batchmates extracted a similar answer! Curiosity has been the driving force behind every scientific innovation throughout history but it didn't suddenly appear in modern laboratories or classrooms. Long before formulas, telescopes, or even writing existed, people were already paying attention to what was happening above them by just simply staring at the vast sky. If there is one thing that humans have always been good at- it's got to be observing. From a little kid watching the light inside the refrigerator go off as they slowly close its door to a geneticist combing through endless sequences of DNA looking for a single meaningful mutation, this quality is something humans seem wired to do.

The first ever record of any humane interest in star-gazing was observed in Homo erectus. They used to track the Sun's path to tell day from night or noticing seasonal changes in plants and animals would have been essential for hunting and migration. While they didn't engrave patterns in stone or mark calendars, their daily lives depended on an awareness of celestial rhythms, showing that the human instinct to watch the sky has deep evolutionary roots.

The ancestor up next is Homo heidelbergensis, who are also related to Neanderthals (spoiler alert?). They may have likely paid attention to seasonal patterns. Coordinating hunts and moving with herds would have required an understanding of when certain resources were available, which indirectly tied to cycles of the Sun, Moon, and possibly stars! Although there are no solid evidences, their sophisticated hunting strategies hint at a mind capable of noticing as well as remembering environmental cycles — the earliest building blocks of astronomical thinking.

Neanderthals (Homo neanderthalensis) have always been the most looked-into species, other than us, of course. They were also the ones that provided the first hints of deliberate attention to celestial patterns, and this time, we have evidence. The arrangement of bones and painted shells hint at the fact that they may have kept record of the cycles in nature. Scratch marks in Gorham's Cave in Gibraltar closely resembles the lunar phases and this suggests that the Neanderthals may have had a possible calendar system, which begs the question — did they hate Mondays too?

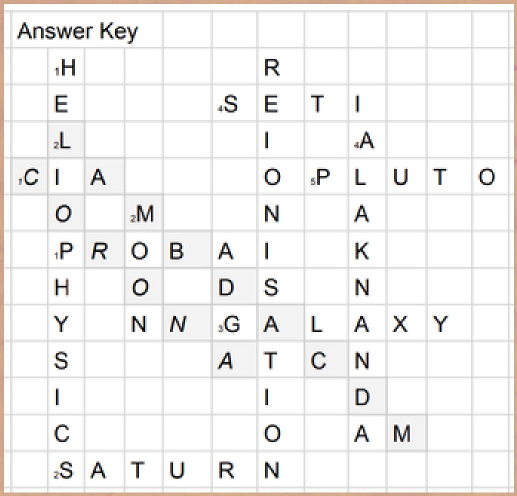
We now have a lesser-known relative of us as well as the Neanderthals. Denisovans remain mysterious, known mostly through bones and DNA and sadly, there are no direct evidence of astronomical curiosity in them. Despite this, it is reasonable to think they, too observed the sky for survival purposes — noting day length, seasonal changes and lunar cycles to track time or resources.


... did they hate Mondays too?

Lastly, we arrive at us, Homo sapiens. They took observation to a whole new level, combining both survival and abstract thought (curiosity!). Engraved ochre pieces from Blombos Cave reveal the art of pattern-making that suggests that early humans were good at record-keeping. Notched bones such as the Lebombo specimen point toward lunar timekeeping and a general awareness of repeating celestial cycles. Cave paintings at Lascaux, the arrangement of dots associated with animal figures in particular, have been interpreted as representations of star clusters like the Pleiades. This means that our ancestors knew that the night sky carried meaning beyond navigation or guidance. This growing understanding of celestial patterns is clearer at later sites such as Nabta Playa, where stone circles were placed in line with the Sun at certain times of the year. This was likely done to mark seasonal changes. Over time, this shift from simple observation to careful recording laid the groundwork for astronomy as a more organized field of knowledge.

Science has always been a tool for us. While we use it to cure diseases, predict weather patterns and send rockets into space, for early humans, the sky was not just something to look at, but something to understand. By watching the Sun, Moon, and stars, they learned when to move, hunt, and gather—and perhaps when to wonder. That quiet curiosity still lives on today, every time we look up and ask what lies beyond.

Stay Curious!



Answer Key											
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	$_{1}$P	R	O	B	A	I		K			
	H		O		D	S		N			
	Y		N	N	$_{3}$G	A	L	A	X	Y	
	S				A	T	C	N			
	I					I		D			
	C					O		A	M		
	$_{2}$S	A	T	U	R	N					

SOLUTION of the
Crossword on page 13

image: “Petrova Lines”, a massive trail of "Astrophage" (alien microbes) stretching from the Sun to Venus, *from Project Hail Mary (film) by Phil Lord and Christopher Miller*

AN INTRODUCTION TO THE SEARCH FOR EXTRATERRESTRIAL LIFE

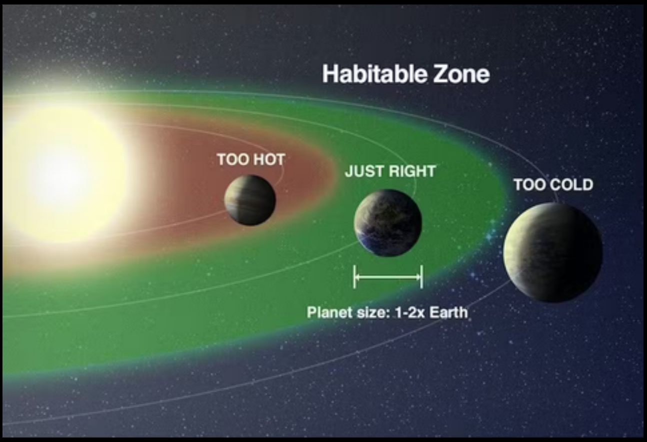
By Roshni Upadhaya, Astronomy Club, Kirori Mal College, University of Delhi

Are We Alone?

The question of whether humanity stands alone in the vast cosmic expanse has captivated thinkers for a thousand years. What was once the sole domain of philosophy and science fiction has now blossomed into a rigorous scientific discipline: astrobiology. This interdisciplinary field, drawing on biology, chemistry, and physics, is actively engaged in the quest to uncover life beyond Earth, fundamentally reshaping our understanding of the universe and our place within it.

The Scientific Pursuit: Where to Look and What to Seek

As Cesare Barbieri illuminates in A Brief Introduction to the Search for Extraterrestrial Life, the scientific approach primarily focuses on identifying "life as we know it." This realistic strategy streamlines the search by targeting environments conducive to the kind of life familiar to us. The most crucial ingredient in this search is liquid water. Consequently, much attention is given to the "Goldilocks Zone", the orbital region around a star where temperatures are neither too hot nor too cold for liquid water to persist on a planet's surface.



Goldilocks zone also known as Habitable zone, *NASA*

Beyond surface water, the search extends to "ocean worlds" within our own solar system, such as Jupiter's moon Europa and Saturn's moon Enceladus, both believed to harbor vast subsurface oceans beneath their icy shells. Even Mars, with its ancient riverbeds and geological evidence of past water, remains a prime candidate for hosting microbial life, either past or present. Scientists are also very careful when they look for biosignatures.

You can think of these as chemical "fingerprints" found in the air (atmosphere) around a planet that might reveal something is living there. For example, if they find a lot of oxygen or methane that shouldn't be there naturally, it is a big clue. Since rocks and volcanoes usually don't make those gases in large amounts on their own, finding them could mean that something is breathing, growing, or living on that world.

The James Webb Space Telescope (JWST) serves as a revolutionary tool in the search for extraterrestrial life, moving beyond simply finding planets to analyzing their potential for habitability. Its mission focuses on two primary areas:

1) *Atmospheric Analysis and Biosignatures :*

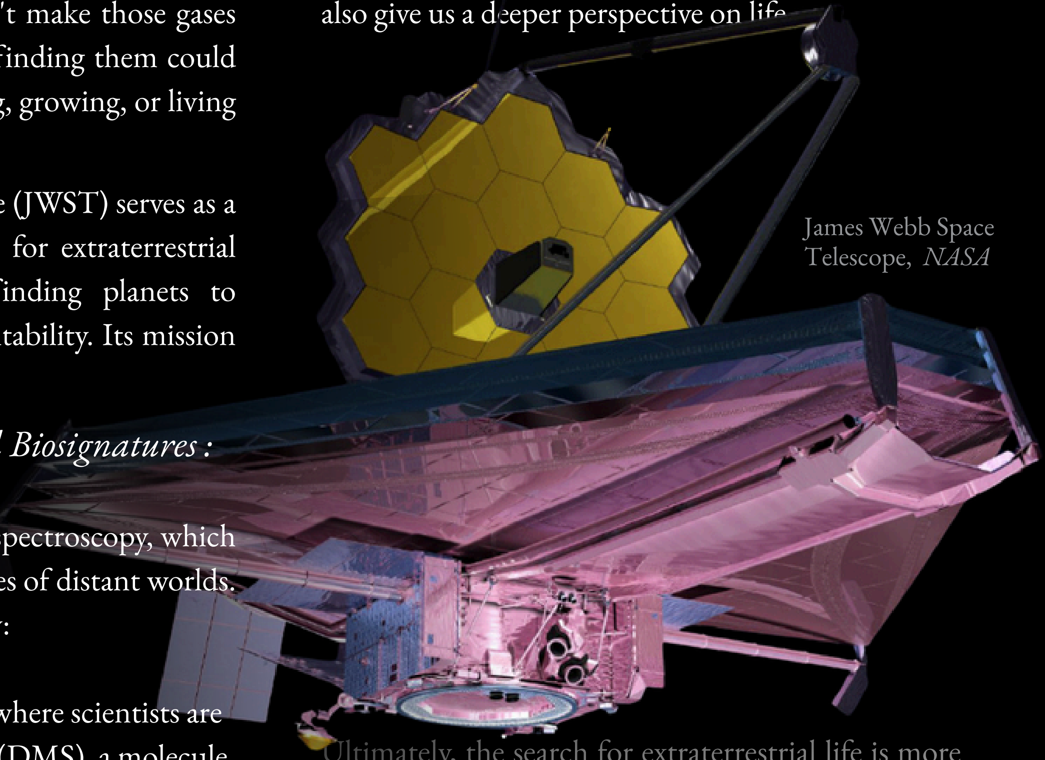
JWST's primary strength lies in spectroscopy, which allows it to "sniff" the atmospheres of distant worlds. It is currently being used to study:

- *K2-18b* : A "Hycean" world where scientists are looking for dimethyl sulfide (DMS), a molecule that, on Earth, is only produced by life.
- *TRAPPIST-1 System* : Scientists are using the telescope to study the rocky, Earth-sized planets in this system to determine if they possess atmospheres capable of supporting life.
- *LHS 1140 b* : Observations of this potential "water world" suggest it may have a nitrogen-rich atmosphere.

2) *Detecting Technosignatures :*

Beyond searching for biological life, JWST has the potential to find technosignatures. These are signs of advanced civilizations, such as artificial industrial pollution. For example, the telescope could detect fluorinated gases like CFCs, which do not occur naturally and would indicate industrial activity.

Finding life beyond Earth wouldn't just change science; it would also change how we think about our place in the universe. In his book Astrobiology and Christian Doctrine, Andrew Davison explains that this discovery would challenge our old ideas but also give us a deeper perspective on life.



James Webb Space Telescope, *NASA*

Ultimately, the search for extraterrestrial life is more than just a hunt for biological markers; it is a journey of self-discovery. Whether we find a universe teeming with life or a profound cosmic silence, the answer will forever change how we cherish our own small, blue home.

A view of Earth taken by *NASA* astronaut and Artemis II Commander Reid Wiseman from one of the Orion spacecraft's four windows after completing the translunar injection burn on April 2, 2026.

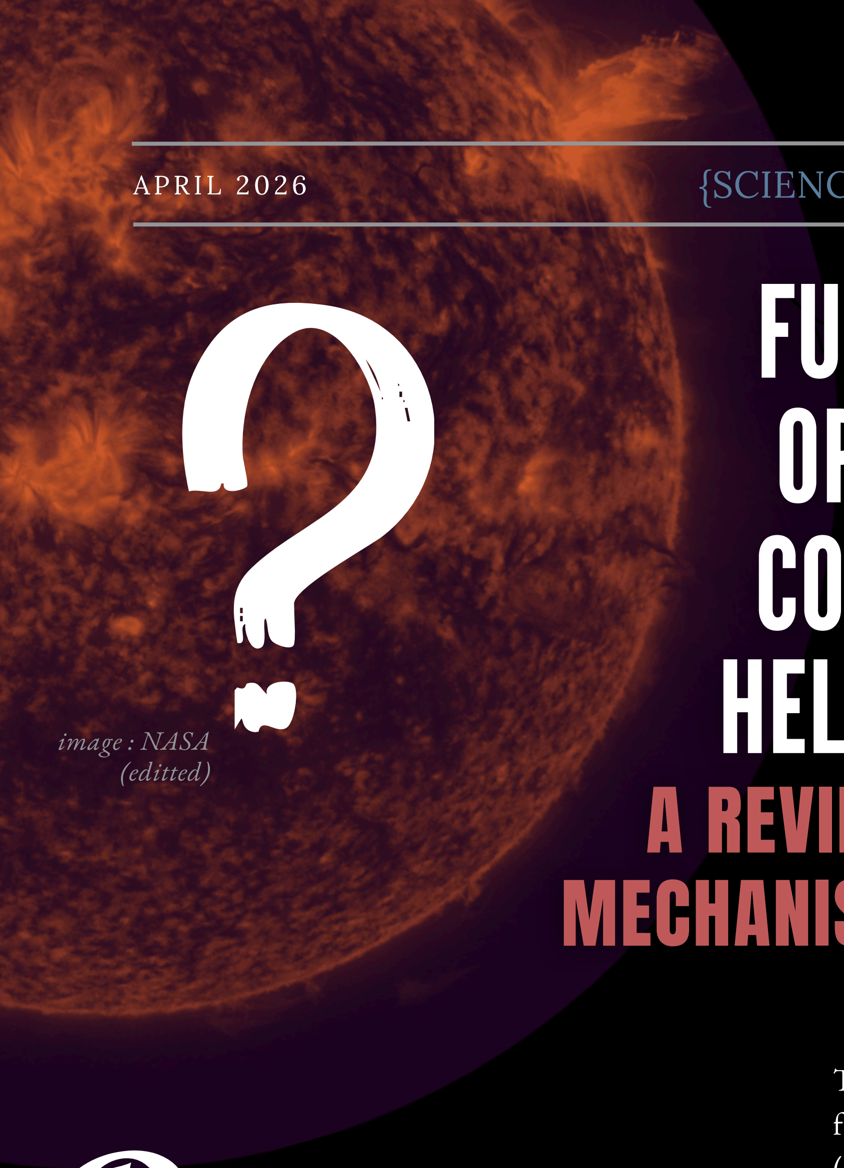


image : NASA (editted)

FUNDAMENTAL OPEN PROBLEMS IN CONTEMPORARY HELIOPHYSICS:

A REVIEW OF UNRESOLVED MECHANISMS

by Siddharth Rathod, Astronomy Club, Kirori Mal College, University of Delhi

Despite the proximity of the Sun and the wealth of data provided by recent missions such as the Parker Solar Probe (PSP) and Solar Orbiter, fundamental questions regarding solar atmospheric thermodynamics and electrodynamics remain unresolved. This article outlines the primary theoretical discrepancies in heliophysics, specifically addressing the coronal heating problem, the solar dynamo mechanism, and the acceleration of the solar wind, discussing the governing physical constraints and mathematical challenges inherent in each.

The Coronal Heating Problem

The thermodynamic structure of the solar atmosphere presents a paradox that violates simple thermal equilibrium. While the photosphere maintains an effective temperature of $T_{eff} \approx 5778$ K, the overlying corona exhibits temperatures exceeding 10^6 K. According to the Second Law of Thermodynamics, heat cannot spontaneously flow from a cooler body (photosphere) to a hotter body (corona) without external work. The problem is generally formulated as identifying the mechanism responsible for the non-thermal energy deposition required to maintain coronal temperatures against radiative losses and thermal conduction.

Two primary mechanisms are currently debated, both rooted in Magnetohydrodynamics (MHD).

Wave Heating (AC Mechanism): This theory posits that magnetohydrodynamic waves, specifically Alfv´en waves, propagate upward from the photosphere. The Alfv´en Number (MA), or Alfv´en Mach number, is a dimensionless quantity in plasma physics comparing a fluid's flow velocity to the local Alfv´en speed. The Alfv´en speed (vA) is defined as:

$$v_A = \frac{B}{\sqrt{\mu_0 \rho}}$$

Where B is the magnetic field strength, µ0 is the vacuum permeability, and ρ is the plasma density. The challenge lies in the dissipation mechanism. In the collisionless regime of the corona, standard viscous or resistive damping is inefficient. Current research focuses on phase mixing and turbulent cascades where energy transfers from large scales to small scales until it reaches the ion-cyclotron scale.

Nanoflares (DC Mechanism): Proposed by Eugene Parker, this model suggests the corona is heated by ubiquitous, impulsive energy releases caused by the braiding of magnetic field lines. As footpoints move stochastically in the photosphere, magnetic flux tubes become entangled. When the angle between field lines exceeds a critical threshold, current sheets form, leading to magnetic reconnection.

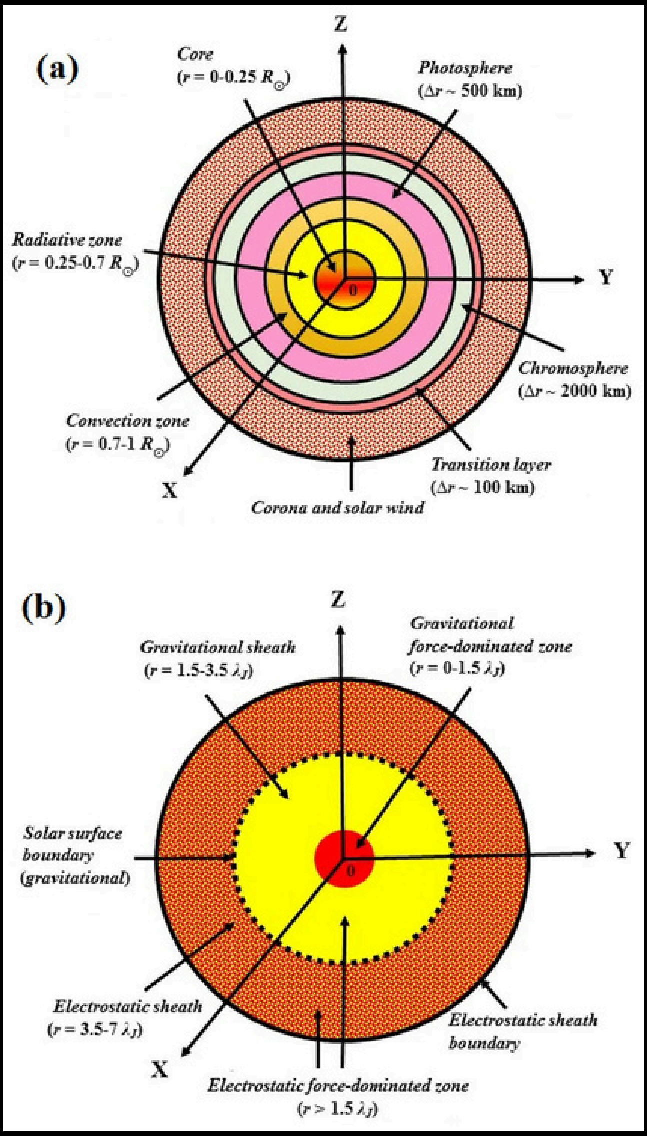


Figure 1: Schmeatic Diagram of the Sun and its ambient atmosphere

Finding life beyond Earth wouldn't just change science; it would also change how we think about our place in the universe. In his book Astrobiology and Christian Doctrine, Andrew Davison explains that this discovery would challenge our old ideas but also give us a deeper perspective on life.

The Coronal Heating Problem

The Sun's magnetic field is generated by a self-exciting dynamo mechanism within the convection zone. While the phenomenological 11-year sunspot cycle (Schwabe cycle) is well-observed, a predictive mean-field dynamo theory remains elusive.

The evolution of the solar magnetic field is governed by the *Induction Equation,* derived from Maxwell's equations and Ohm's law in the MHD approximation:

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{u} \times \mathbf{B}) + \eta \nabla^2 \mathbf{B}$$

Here, the first term $\nabla\times(\mathbf{u}\times\mathbf{B})$ represents the advection and amplification of the magnetic field by plasma flow **u**. The second term $\eta\nabla^2\mathbf{B}$ represents diffusion due to magnetic diffusivity η.

A major theoretical hurdle is the α-Ω **Dynamo Discrepancy**. Standard models rely on two effects: the Ω-effect, where differential rotation shears the poloidal field creating a strong toroidal field; and the α-effect, where helical turbulence (caused by the Coriolis force) twists the toroidal field back into a poloidal field. However, simulations of the solar convection zone often fail to reproduce the correct cycle period or the equator-ward migration of sunspots (the Butterfly Diagram) without using arbitrary parameters. The role of the Meridional Circulation remains a critical but poorly constrained variable.

Acceleration of the Solar Wind

The solar wind is a continuous outflow of plasma. The fundamental question is how the wind is accelerated from subsonic velocities near the surface to supersonic velocities ($v \approx 400 - 800$ km/s) in the interplanetary medium.

Eugene Parker's 1958 hydrodynamic solution treats the corona as an isothermal fluid expanding against gravity. The conservation of mass and momentum for steady, radial, spherical flow yields:

$$\frac{1}{v}\frac{dv}{dr}(v^2 - c_s^2) = \frac{2c_s^2}{r} - \frac{GM_\odot}{r^2}$$

Where v is the radial velocity, $c_s = \sqrt{k_B T/m}$ is the isothermal sound speed, and G and M⊙ are the gravitational constant and solar mass. For the wind to transition from subsonic $(v < c_s)$ to supersonic , , $(v > c_s)$ the right-hand side of the equation must vanish exactly where v = cs (the critical point). Observations indicate that the fast solar wind accelerates much faster than this model predicts, implying an additional momentum deposition term likely driven by Alfv´en wave pressure.

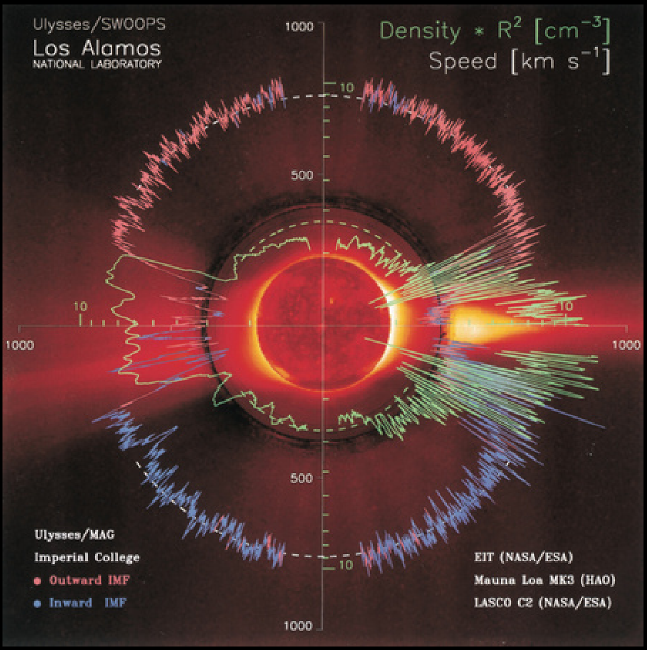
The Physics of Solar Eruptions

Solar flares and Coronal Mass Ejections (CMEs) are the primary drivers of space weather. The central engine for these events is Magnetic Reconnection, a process where magnetic topology changes, converting magnetic potential energy into kinetic energy and heat.

The classic Sweet-Parker model predicts a reconnection rate proportional to $s^{-1/2}$, where S is the Lundquist number (a dimensionless ratio comparing the timescale of an Alfv´en wave crossing to the timescale of resistive diffusion). In the solar corona, S is extremely high $(10^{12} - 10^{12})$, which theoretically results in a reconnection rate far too slow to explain the explosive timescale of solar flares.

Modern research is shifting toward the Petschek model or collisionless Hall-MHD reconnection. The **Petschek Model** fixes the "slow bottleneck" of older theories. Instead of forcing plasma through a long, thin tunnel (Sweet-Parker), it uses shockwaves to create a wide funnel. This allows magnetic energy to release instantly, like a whip cracking. Hall-MHD zooms in to the atomic level, realizing that heavy ions and light electrons separate during the snap. This separation creates a "fast lane" for the magnetic field to slip through, preventing the particle traffic jam that usually slows down the process.

Heliophysics is currently transitioning from a descriptive era to a precise physical understanding. Solving these problems requires bridging the gap between fluid dynamics (MHD) and kinetic theory. With the current solar maximum providing a wealth of high-energy data, the next decade promises to constrain the mathematical models that describe our host star.



SWOOPS observations of the solar wind during Ulysses' first full polar orbit around the Sun. *Credit: McComas, D. J., et al. (2000), J. Geophys. Res., 105, 10,419-10,433.*

QUANTUM COMPUTING AND THE SEARCH FOR ROGUE PLANETS

By Sonalika Shaw,
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The Mystery of Rogue Planets

According to astronomers, rogue planets may be abundant in our galaxy; they could number in the billions. Rogue planets are planetary bodies that float through the cosmos independent of any stars around them. They are believed to exist in planetary systems before being cast out by the intense gravitational forces of surrounding bodies or stars.

After they are ejected into space, rogue planets will be alone in the void, drifting through the dark, making them extremely difficult to observe. Although thousands of exoplanets have recently been discovered, only a few rogue planets have been confirmed.

“Rogue planets are among our galaxy’s most enigmatic objects due to their lack of a host star to 'illuminate' their existence,” said David Bennett, an astronomer at Notre Dame University. Bennett's research focuses on the study of the employment of American scientists via devices from outside sources.

By studying rogue planets (free-floating worlds), scientists may learn about the formation and

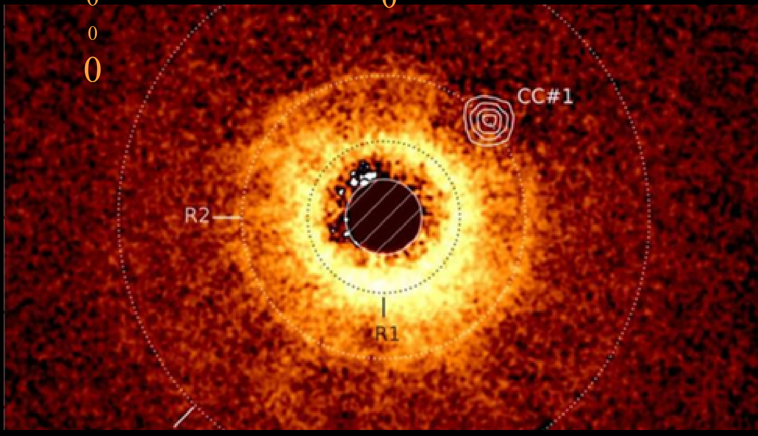


Image of the disk around the star TWA 7 recorded using ESO's Very Large Telescope's SPHERE instrument. The image captured with JWST’s MIRI instrument is overlayed. We can clearly see the empty area around TWA 7 B in the R2 ring (CC #1).
(Image credit: A.-M. Lagrange and al. - Evidence for a sub-Jovian planet in the young TWA7 disk, 2025)

eventual demise of planetary systems within the Milky Way galaxy.

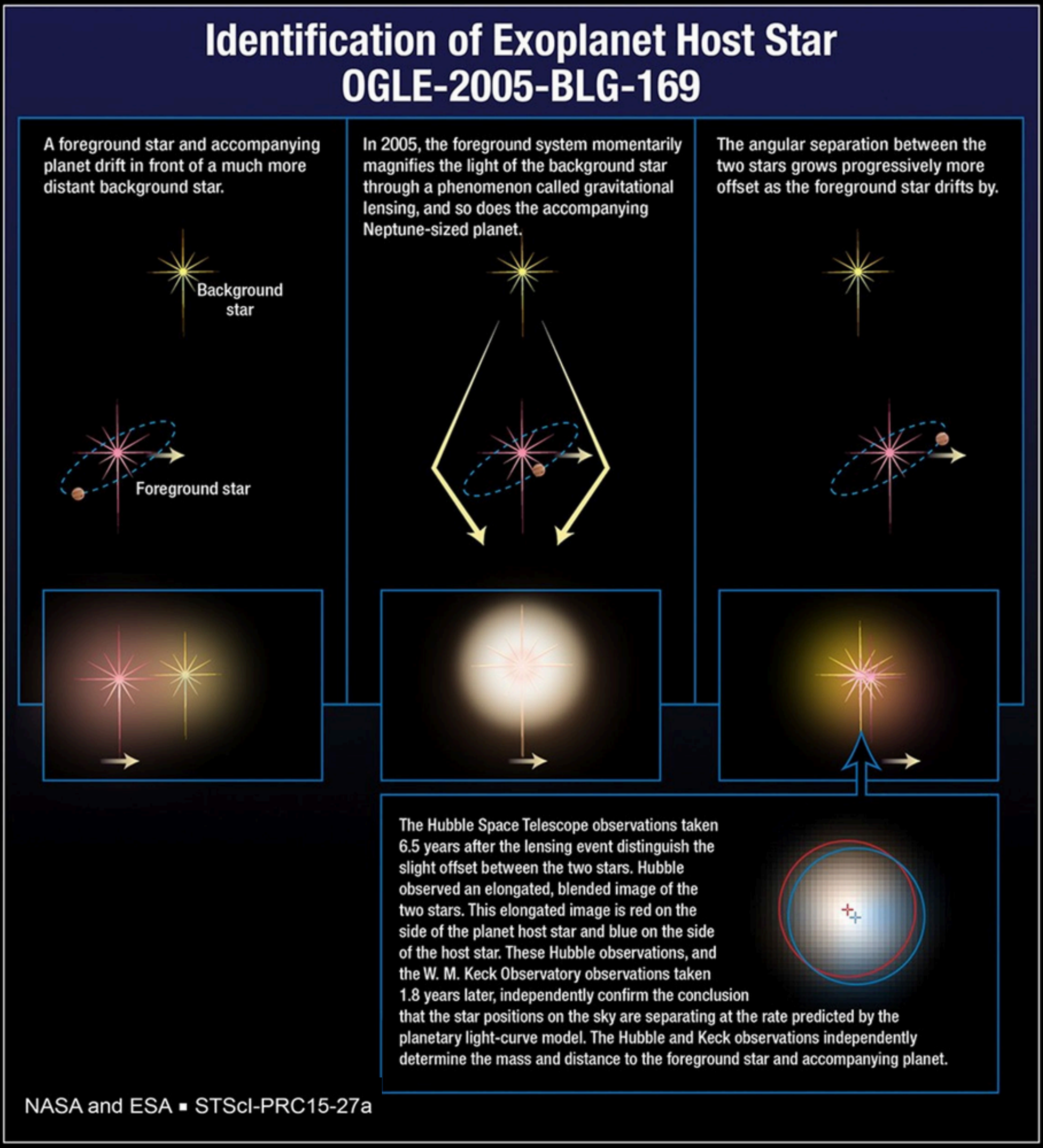
The Detection of Rogue Planets Is Challenging

Most of the known techniques for detecting new planets are based largely on observing a planet’s interaction with its host star. Examples of these techniques include the Transit Method, which detects a planet when it passes in front of its star and blocks some of the light, and the Radial Velocity Method, which measures the mass of the star as it is being moved through space by the planet's gravitational attraction.

The Role of Quantum Computing

The emerging technology of Quantum Computing could be the solution to this problem. Quantum Computers are different from normal computers in that they have something called Qubits that can exist in multiple states at once.

This allows them to process vast amounts of data and identify subtle patterns that could be present but are not easily visible.



Identification of Exoplanet Host Star OGLE-2005-BLG-169

A foreground star and accompanying planet drift in front of a much more distant background star.

In 2005, the foreground system momentarily magnifies the light of the background star through a phenomenon called gravitational lensing, and so does the accompanying Neptune-sized planet.

The angular separation between the two stars grows progressively more offset as the foreground star drifts by.

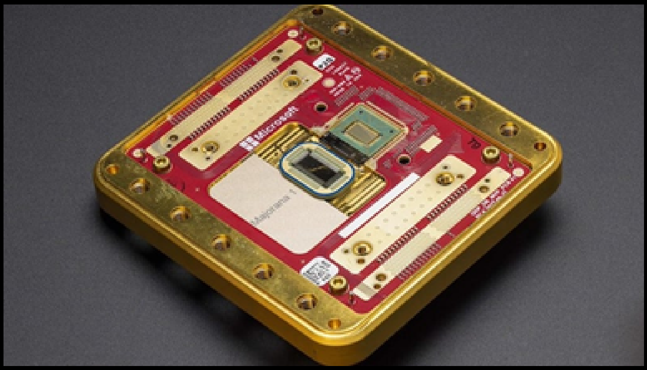
The Hubble Space Telescope observations taken 6.5 years after the lensing event distinguish the slight offset between the two stars. Hubble observed an elongated, blended image of the two stars. This elongated image is red on the side of the planet host star and blue on the side of the host star. These Hubble observations, and the W. M. Keck Observatory observations taken 1.8 years later, independently confirm the conclusion that the star positions on the sky are separating at the rate predicted by the planetary light-curve model. The Hubble and Keck observations independently determine the mass and distance to the foreground star and accompanying planet.

NASA and ESA ▪ STScI-PRC15-27a

Diagram illustrating the discovery of the exoplanetOGLE-2005-BLG-169Lb through gravitational microlensing. As a foreground star passes in front of a distant background star, its gravity bends and magnifies the light, allowing astronomers to detect planets that would otherwise remain invisible. *Image - NASA*

> *Quantum computing has the potential to transform how scientists process massive astronomical datasets."*

By using quantum algorithms and other sophisticated methods of detection, scientists could be able to identify faint signals that could be coming from rogue planets.



Quantum processors use qubits to perform complex computations that may help analyze massive astronomical datasets produced by microlensing surveys.
Image source - internet

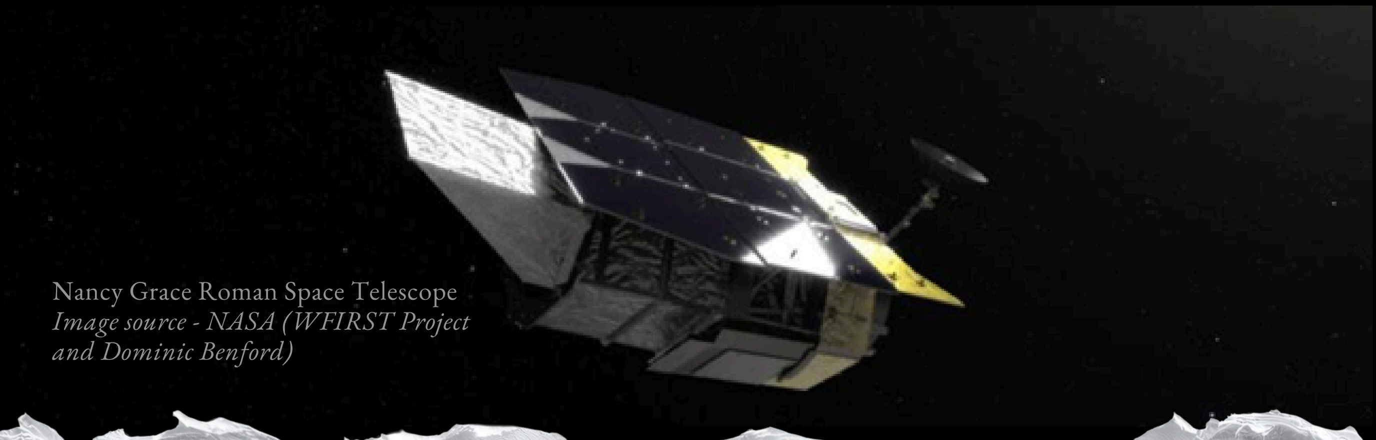
A New Frontier in Planet Discovery

The union of astronomy and quantum technology is a new frontier in science that promises a lot of exciting things for future generations of scientists. Future missions into space are likely to reveal unprecedented levels of data that could be used to reveal a lot of information about rogue planets.

The James Webb Space Telescope and the Nancy Grace Roman Space Telescope are just some of the technologies that could be used to reveal more information about these hidden objects in our universe.

Future planetary discoveries will likely depend not only on more advanced telescopes, but also on powerful new methods for analyzing the enormous volumes of data they produce.

The future of quantum technology could reveal countless numbers of unseen worlds drifting silently through the vast expanse of our universe.

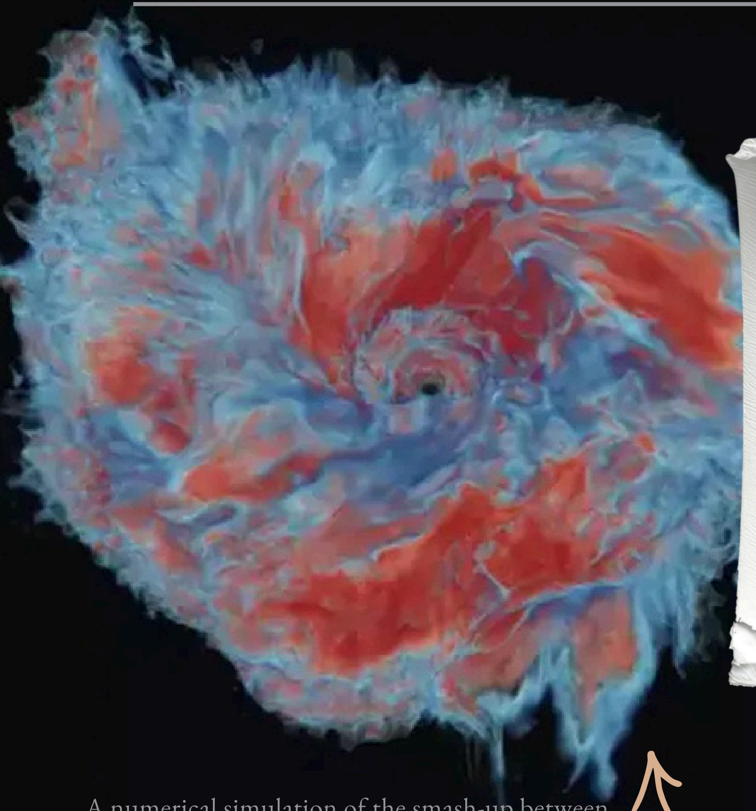


Nancy Grace Roman Space Telescope
Image source - NASA (WFIRST Project and Dominic Benford)

SPACE FACTS

(by Sonalika Shaw, Celestia)

1The Andromeda Galaxy is about 2.5 million light-years from Earth and can be seen with the naked eye. **This means the light you see left Andromeda 2.5 million years ago**. That light then traveled across space for millions of years until it finally reached your eyes. So when you look at Andromeda, you are actually seeing the galaxy as it was **2.5 million years in the past.**



A numerical simulation of the smash-up between neutron stars that launches a kilonova blast.
Image credit: I. Markin (University of Potsdam)

SPACE FACTS

2

1.The International Space Station travels around Earth at a very high speed and completes one full orbit in about 90 minutes. This means astronauts on board see about 16 sunrises and sunsets every day.

3 SPACE FACTS

There are meteorite MINES in Antarctica. The snow has been falling for millions of years and built up to a layer that is miles thick. Any rock you find is a meteorite. The snow also flows and in some places is pushed against mountains. Katabatic (dry) winds come down off the mountains and evaporate the ice, leaving the meteorites near the bases. Before 1970, humans had discovered only about 10,000 meteorites in total. But after scientists began searching Antarctica, they found another 10,000 in just 15 years , helping raise the total to over 70,000 known meteorites today.

4

There's enough space between the earth and the moon to line up all the other planets in the solar system.

5

Gold did not form in our solar system. In fact, it couldn't have. Elements that heavy require an environment with an enormous number of free neutrons and extreme energy .It is created through the Rapid Neutron Capture Process, which requires extremely high energy and a large number of free neutrons. These conditions are produced during collisions of two Neutron Star objects, events known as Kilonova. During these collisions, heavy elements such as gold, platinum, and uranium are formed in seconds and then scattered across space. Some of this material later became part of the cloud that formed the Solar System, which is why the gold found on Earth is much older than our planet.

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a portion of the Hubble Legacy Field

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