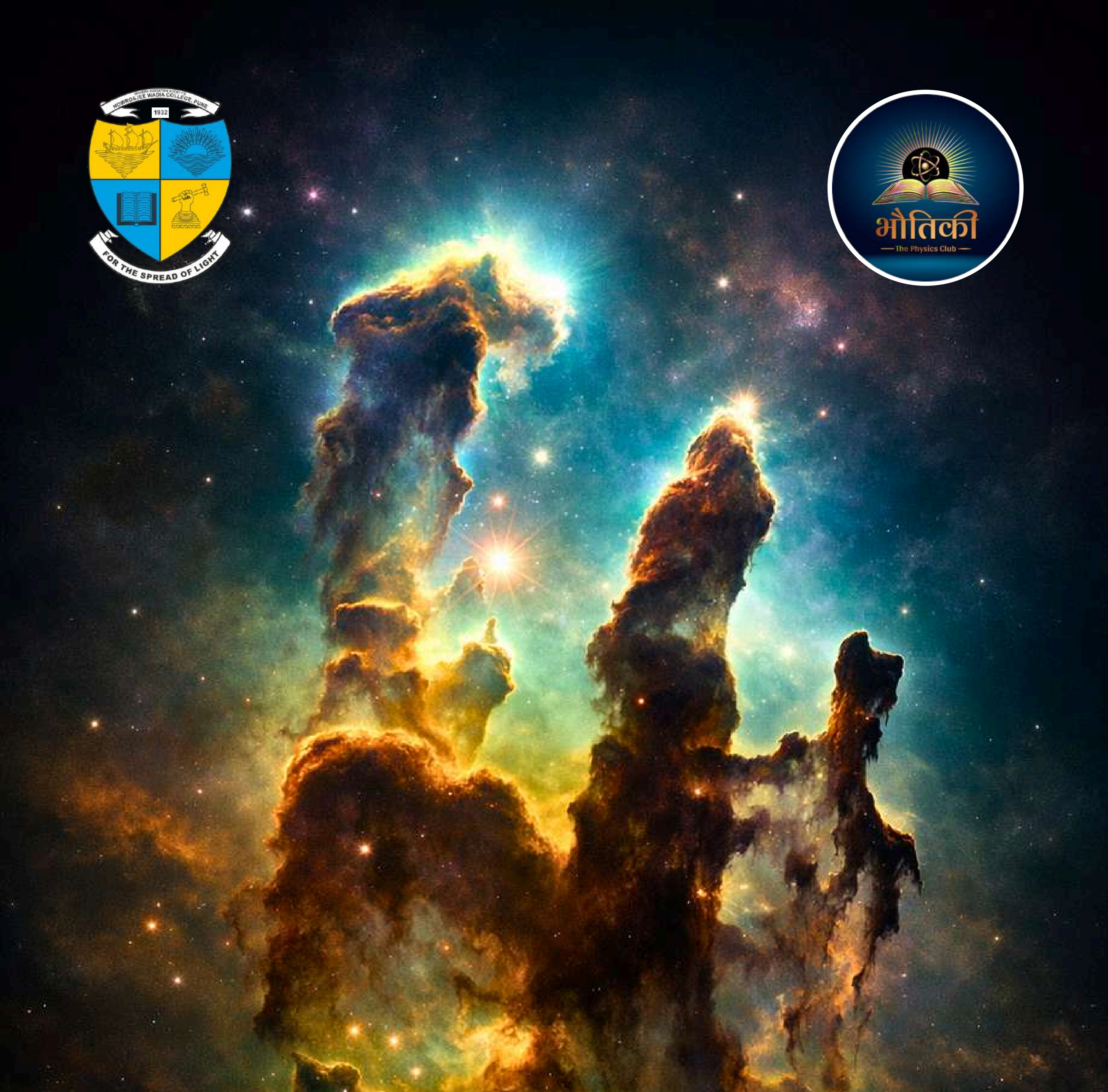

NOWROSJEE WADIA COLLEGE, PUNE
1932
FOR THE SPREAD OF LIGHT

भौतिकी
The Physics Club

BHOUTIKI PRADNYA

ASTRONOMY & ASTROPHYSICS EDITION

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PREFACE

Special Astronomy & Astrophysics Edition – BHOUTIKI

The universe is not just a backdrop to human existence, it is the grand stage upon which the drama of creation, evolution, and mystery unfolds. Every star, every particle of dust, every ripple in plasma carries within it a story that connects us to the infinite. To explore astrophysics and astronomy is to embark on a journey that stretches from the smallest molecules drifting in interstellar clouds to the most enigmatic phenomena shaping galaxies and black holes.

This issue brings together a tapestry of ideas and discoveries that illuminate the cosmos in all its wonder. Readers will encounter the mysteries of the radio sky, the origin of cosmic dust, and the presence of organic molecules in space clues that whisper of life's possibilities beyond Earth. We delve into the interstellar medium and star formation, the restless dynamics of waves in solar plasma, and the enduring puzzle of the moon's five-million-pound mystery.

The magazine also ventures into profound questions: Do black holes forget? Is time an illusion? It examines the most intense magnets in the universe, the enigma of 'Oumuamua, and the invisible maps that guide cosmic navigation. From measuring time in ancient India to understanding galaxy evolution through stellar populations, the articles bridge past wisdom with modern science, reminding us that curiosity has always been humanity's compass.

Finally, themes of darkness and light run throughout whether in the invisible mystery of dark matter, or in the transformation of starlight into science. Each contribution is a window into the cosmos, inviting readers to not only learn but to wonder, to question, and to dream.

We hope this collection inspires you to see astrophysics not as distant abstraction, but as a living dialogue between humanity and the universe. May these explorations kindle imagination, deepen understanding, and remind us that in seeking the stars, we also discover ourselves.

ABOUT COLLEGE

Welcome to Nowrosjee Wadia College – A Beacon of Excellence Since 1932

Established on July 21, 1932, just months after the founding of the Modern Education Society, Nowrosjee Wadia College has stood as a pillar of academic brilliance and cultural vibrancy in Pune. Guided by its inspiring motto "For the Spread of Light," the college has been instrumental in opening doors to higher education for generations of students, especially in the eastern region of the city.

Affiliated with Savitribai Phule Pune University and proudly holding autonomous status, Nowrosjee Wadia College has earned numerous accolades, including the prestigious First Best College Award from SPPU and an A+ grade from NAAC in 2017.

Offering a rich blend of undergraduate and postgraduate NEP 2.0 programs in both Science and Arts disciplines, the college attracts bright minds from across India and abroad. With world-class infrastructure, vibrant student life, and a legacy of excellence, Nowrosjee Wadia College remains the first choice for holistic education and personal growth.

ABOUT DEPARTMENT

Department of Physics – Advancing Research and Innovation

The Department of Physics at Nowrosjee Wadia College, Pune, is a recognized postgraduate teaching and research center under Savitribai Phule Pune University (SPPU). It currently offers comprehensive academic programs leading to B.Sc., M.Sc., and Ph.D. degrees, fostering a strong foundation in both theoretical and applied physics.

A hallmark of the department is the Electro-Acoustics Research Laboratory (EARL), an SPPU-recognized center for doctoral research. Building on its legacy of excellence, the department has expanded into Materials Science, with the Advanced Functional Materials Laboratory (AFML) offering cutting-edge research opportunities in nanomaterials and functional thin films. These studies focus on conductive and transient properties crucial to thin-film device technologies.

The department has successfully guided numerous Ph.D. and M.Phil. scholars and continues to mentor several active research candidates. Its commitment to innovation is supported by grants from prestigious bodies including the American Physical Society (APS), University Grants Commission (UGC), Indian Space Research Organization (ISRO), Department of Science and Technology (DST) and Board of College and University Development (BCUD-UoP).

ABOUT BHOUTIKI

The term 'BHOUTIKI' in the Physics Club logo likely signifies 'Physics' in Sanskrit, encapsulating the foundational principles of the natural sciences. It beautifully reflects the essence of exploring the physical universe, spanning phenomena from the microscopic to the cosmic scale.

Through 'BHOUTIKI,' we aim to honour the legacy of scientific excellence and inspire a new generation of physicists to delve into the mysteries of the universe.

Throughout the year, the club will host a wide variety of activities, each thoughtfully designed to spark curiosity and deepen participants' understanding of the intricate beauty of physics. These activities include: Guest Lectures and Seminars, Workshops and Skill Sessions, Experimental Demonstrations, Science Outreach Programs, Debates and Panel Discussions, Physics Quiz Competitions, Project Showcases, Movie Screenings and Discussions, Publication of Quarterly Digest, Experiment Design Competitions, Peer Teaching and Learning, Problem-Solving Sessions, Celebration of Physics Days, Collaborations and Competitions, Educational Visits, PHYSIQUEST: The department's flagship annual event.

With this diverse range of initiatives, the Physics Students Club aims to foster a vibrant community that celebrates the pursuit of knowledge and the joy of discovery in the realm of physics.

CONTENTS

Mysteries of the radio sky: Fast radio bursts

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The night sky appears calm and unchanging, yet the universe is filled with brief and violent flashes of energy. Among the most mysterious of these are Fast Radio Bursts (FRB), extremely short pulses of radio waves that last only a few thousandths of a second but originate from galaxies billions of light years away. Since their discovery in 2007, these radio signals have transformed from an unexpected curiosity into one of the most exciting topics in modern astrophysics. Each burst offers an opportunity to understand some of the most extreme environments in the cosmos.

The first FRB, aka Lorimer burst, was identified while astronomers were examining archival data from a Parkes radio telescope in Australia. The signal appeared as a bright millisecond pulse showing a characteristic quadratic sweep across the frequency. This delay occurs when radio waves travel through ionized gas, and the amount of delay indicates that the signal had crossed vast cosmic distances before reaching Earth. Initially, the discovery was met with skepticism because such a short and powerful signal could easily be mistaken for terrestrial Radio Frequency Interference. As more bursts were discovered with the Parkes and a repeating source with the Arecibo telescope in Puerto Rico, it became clear that these signals were genuine astrophysical events coming from far beyond our Galaxy.

In just a few milliseconds, a typical FRB can emit as much energy as the Sun produces in several days. This implies that the source must be both extremely energetic and the emission must be coherent. The combination of immense power and extremely short duration points toward exotic objects such as neutron stars, which are the dense remnants left behind when massive stars explode as supernovae.

For several years, astronomers believed that FRBs were one-time, catastrophic events. This picture changed dramatically in 2016 when a burst was observed to repeat from the same position in the sky. The discovery of repeating bursts showed that at least some sources survive the event and can produce multiple outbursts over time. This breakthrough allowed astronomers to study the same object repeatedly and determine its precise position in the sky to arcsec and sometimes to milliarcsec. The precise position helps in identifying their host galaxies.

Since then many repeating sources have been discovered, some producing only occasional bursts while others enter phases of intense activity and emit hundreds of bursts in a short period. A few sources even display periodic cycles of activity. This diversity suggests that FRBs may arise in a range of physical environments and that more than one mechanism could be responsible for producing them.

One of the leading explanations involves magnetars, which are neutron stars with magnetic fields trillions of times stronger than that of Earth. These extreme magnetic fields can store enormous amounts of energy that may be suddenly released through magnetic reconnection or crustal fractures on the star. A major clue supporting this idea came in 2020 when astronomers detected a bright millisecond radio burst from a known magnetar within our own Galaxy. Although weaker than most extragalactic bursts, the event showed that magnetars are capable of producing signals similar to Fast Radio Bursts.

Despite this progress, many questions remain. FRBs show diverse complex frequency-time structures and strong polarisation signatures indicating emission in highly magnetised environments. Some are associated with a persistent radio source. These observations suggest that the physical conditions surrounding the sources may play an important role in shaping the observed properties of the bursts.

Despite this progress, many questions remain. FRBs show diverse complex frequency-time structures and strong polarization signatures indicating emission in highly magnetized environments. Some are associated with a persistent radio source. These observations suggest that the physical conditions surrounding the sources may play an important role in shaping the observed properties of the bursts.

Apart from their mystery of origins, what makes FRBs even more interesting is that they can serve as new, unique probes to study the universe itself. As the radio waves travel across billions of light years they pass through clouds of ionized gas that fill the space between galaxies. This material slightly delays the signal across frequencies, leaving measurable traces in the burst. By studying these signatures, astronomers are looking to solve the "mission baryon problem" in cosmology by estimating the amount of matter along the line of sight of FRBs and probe the otherwise invisible plasma that permeates intergalactic space.

The rapid growth of the field has been driven by new radio telescopes and improved data analysis techniques. Modern instruments can survey large areas of the sky with high sensitivity, allowing astronomers to detect bursts far more efficiently than before. At the same time automated search pipelines and machine learning methods help sift through enormous volumes of data to identify genuine signals hidden among noise and radio interference.

CHIME, a single radio telescope in British Columbia, Canada, has discovered more than 4000 FRBs, by far the largest haul of any telescope in the world, a feat made possible by its exceptionally wide field of view and high sensitivity. Several of these sources have now been localized to distant galaxies spanning a striking range of environments: some reside in actively star forming spiral galaxies, others in ancient elliptical galaxies that stopped forming stars billions of years ago, and at least one appears to originate from a dense globular cluster. This diversity tells us there is no single birthplace for FRBs. With each new detection, astronomers build a clearer picture of how these events are distributed across cosmic time and what range of physical systems may be capable of producing them.

The next generation of radio observatories is expected to detect tens of thousands of FRBs in the coming years. With such large samples astronomers will be able to study them not only as individual events but also as a population. Precise measurements of their distances and host galaxies will shed light on their origins, while the growing catalogue of bursts will strengthen their role as probes of the intergalactic medium and cosmic structure.

In less than twenty years, FRBs have evolved from an unexpected signal in archival data into a powerful tool for exploring the universe. By detecting and studying these signals, astronomers are uncovering new insights into their origins and the invisible matter that fills the space between galaxies. With thousands more bursts yet to be discovered, these cosmic flashes promise to reveal even more about the dynamic universe in the years ahead.

Ajay Kumar is a **researcher** in **radio astronomy** currently working as a **Research Scholar** at the **National Centre for Radio Astrophysics (NCRA–TIFR), Pune.** His research focuses on fascinating transient cosmic phenomena such as pulsars and **Fast Radio Bursts (FRBs),** where he combines radio observations with modern machine learning techniques to study their properties and origins. Ajay completed his **M.Sc. in Physics** from **Indian Institute of Technology Madras** and his **B.Sc. in Physics** from **Ramjas College, University of Delhi.** His work reflects the growing intersection of astronomy and data science, contributing to our understanding of some of the most mysterious signals in the universe.

The cosmic dust origins

Rishabh Singha, Kamna Sharma & Bhavana Sharma
GLA University, Mathura

One of the three primary components of the interstellar is the interstellar dust medium, and gas and cosmic rays, and plays a vital role in most astrophysical processes, e.g. the processes of star formation, radiative transfer and the chemical evolution of galaxies. The bulk of the mass is only 1% interstellar dust of the interstellar medium, but has a big impact on observational astronomy since interstellar dust absorbs, scatters and re-emits electromagnetic radiation.

In this paper, we consider physical properties, composition, size distribution and dynamical behavior of interstellar dust grains, and the interactions between radiation and gas and interstellar dust. We also present the relevant theory formulations that regulate the extinction of radiation within interstellar dust, interstellar dust grain dynamics, and interstellar dust grain thermal equilibrium space debris particles and gas.

cosmological and galactic models. The dust grains present in interstellar space are composed of three primary components silicates, carbon-based materials (amorphous carbon or graphite), etc. and Polycyclic Aromatic Hydrocarbons (PAHs). Scientifically, it was

Though they form a minor part of the total mass of the ISM, Materials. interstellar dust grains are very large in their influence on the physical and chemical processes that manage the development of the ISM. The grains of interstellar dust are used as molecular hydrogen formation catalysts, aid in the preservation of the thermal equilibrium in the ISM, and furnish surfaces in which numerous complex chemical processes may take place. Thus, it is necessary to know more about interstellar dust to interpret astronomical observations and come up with sound cosmological and galactic models. The dust grains present in interstellar space are composed of three primary components silicates, carbon-based materials (amorphous carbon or graphite), etc. and Polycyclic Aromatic Hydrocarbons (PAHs). Scientifically, it was performed with the help of infrared spectroscopy. Scientists have shown silicate properties (Si-O stretching) at around 9.7um (bending) and 18um.

The dust grains internal structures are either compact or porous. When dust grains are created where there is a high density, they can be covered by an icy outer layer (mantle) consisting of water, carbon monoxide and carbon dioxide together with ammonia. The existence of such kind of icy layers in dust grains plays a significant role.in astrochemistry since they offer surfaces to numerous varieties of chemical responses and molecular assemblage.

The size of dust particles in interstellar space range in a variety of sizes primarily with a size of just a few nanometers to 0. 25um.The interstellar dust size is commonly defined in classical Mathis Rumpl-Nordsieck (MRN) size distribution which is calculated according to the evolution of the dust and the density of the surrounding interstellar gas and ionized gas.

$$\mathbf{n(a)\ da = C\ a^{-3.5}\ da \qquad ..(1)}$$

The number density of grains is defined as N (a) and C and a+da is the normalization constant and the dust to gas ratio volume.

This power law of distribution is equivalent to derived extinction curves of Milky way data at short wavelengths. Even when there may be a few differences between MRN, galactic environments distributions and derived data.

The dust of interstellar triggers the extinction of stellar emissions due to starlight absorption and scattered.

Extinction at the wavelength of lambda is defined

$$A_\lambda = 1.086\ \tau_\lambda \quad ..(2)$$

where τ_λ represents optical depth where the optical depth in the line of vision is given by

$$\tau_\lambda = \int n_d\ \sigma_\lambda\ dl \quad ..(3)$$

where n_d is the number density of dust grains,σ_λ is the wavelength-dependent extinction cross-section, and dl represents an infinitesimal element along the line of sight.

Extinction is sensitive to wavelength, which produces interstellar reddening effects. This is normally typified by:

$$E(B - V) = A_B - A_V \quad ..(4)$$

The quantities of blue **(B)** and visual **(V)** extinctions are the quantities **AB** and **AV** respectively.

UV and visual photons are absorbed by dust. After that, the consumed energy is re-radiated in the form of infrared radiation.

The temperature of the dust grains is brought to a balance through the balancing of the energy taken by the grains relative to the amount of energy which they give out, which can be represented as follows:

$$\int Q_{abs}(\lambda)\ J_\lambda\ d\lambda = \int Q_{em}(\lambda)\ B_\lambda(T_d)\ d\lambda, \quad ..(5)$$

Absorption efficiency **Qabs(l)** and emission efficiency **Qem(l)** are defined in terms of how effective a dust grain is in receiving and giving off, respectively, radiation incident on it; **Jλ** is the radiation field where a dust grain is situated; **Bλ(Td)** is the function of Planck; and Td is the temperature of the dust grain.

The interstellar dust is usually at temperatures ranging between 10-30K (within molecular clouds), in place near a hot star they might be hundreds K temperatures because of the existence of a powerful radiation field.

The interactions of the dust grains with the gas, radiations fields, etc. And the magnetic fields that occur in the interstellar medium (ISM). The motion of a dust grain of mass md moving with a velocity of the vector. The following equation of motion can be used to express v:

$$m_{d_{dt}}^{\ dv} = F_{drag} + F_{rad} + F_{Lorentz} \quad ..(6)$$

where $F_d$rag is the force of gas drag and $F_r$ad is the force due to radiation pressure and $F_{Lorentz}$ is the force due to the interaction between charged dust grains and magnetic fields in the interstellar medium.

The radiations pressure can be significant in the regions that are forming stars or where they are burning enclosing stars that are brightly lit, and it is what causes an outward push when a is the radius of a spherical dust grain, it is provided b**y**

$$F_{rad} = \frac{L \star Qpr}{4\pi r^2 c}\pi a^2 r \quad ..(7)$$

L^* is stellar luminosity, Q_{pr} is the efficiency of radiation pressure, r is distance from the radiation source, c is the velocity of light, and ˆr is a unit vector in the radial direction.

Interstellar dust has significance in the evolution of molecules chemically clouds and the making of stars. It is the atomic process that is supported by dust grains. The most abundant molecule in space is the hydrogen to form the molecular hydrogen in the universe.

$$H + H \rightarrow H_2, \quad ..(8)$$

Besides the catalysis of the creation of the molecular hydrogen, the dust grains also protect the dense molecular clouds against UV radiation so that the cooling process can become more effective to make the gravitational collapse and occur effectively. The reactions, which take place on the surface of dust, will result in the formation of complex organic molecules. They may be deposited into the gas phase through thermal desorption or shocks or other energetic processes, and they add to the chemical enrichment of the interstellar medium.

Interstellar dust is a fundamental part of the universe and has a significant role in the physical environment of the ISM and in the manner of the interpretation of different astronomical observations. The interstellar dust, and its influence on the extinction, thermal balance, dynamics and chemistry of the surrounding space makes it a vital area of research on both the understanding of the evolution of the galaxy and the formation of the stars. It is expected that the infrared astronomy, laboratory astronomy, and mathematical modeling that are still in development would help us learn even more about the properties and the roles of dust grains in forming our universe.

Organic molecules in space: From interstellar clouds to the origins of life

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Abstract
The fact that organic molecules were found in space has revolutionized our knowledge of Earth based chemistry. Organic compounds are no longer believed to be limited to life and are now found in the interstellar clouds, comets, and even in the planetary environment. This paper deals with the formation of organic molecules in space, the reactions by which they are formed and their contribution to the origin of life on the Earth. We showcase the cosmic environments as natural laboratories of complex carbon-based chemistry by connecting astronomy and organic chemistry.

1. Introduction
Organic chemistry is the branch that is traditionally connected with the life and the biological systems on the Earth. But there is one surprising fact about organic molecules that modern astronomic observations have provided: organic molecules are ubiquitous in the universe. Since carbon forms the basis of simple compounds such as methane and methanol and complex molecules such as amino acids, even carbon-based chemistry can take place in the low temperature and dilute areas of interstellar space.

This realization has resulted in the development of astro-organic chemistry, which is an interdisciplinary study involving aspects of organic chemistry, spectroscopy and astrophysics. The study of the formation and survival of organic molecules in space has important implications to chemical evolution and the potential origin of life.

2. Interstellar Molecular Clouds: Star Chemical Reactors.
The stars and planets are formed in large regions referred to as interstellar molecular clouds. These are clouds composed of gas and dust and temperatures as low as 10K. Even in the coldest regions such as these, they contain abundant chemical activity.

The grains of dust in these clouds serve as microscopic reaction surfaces just like organic chemistry catalysts. Atoms and simple molecules are adsorbed on such surfaces where they are reacted via ultraviolet radiation and cosmic rays. These processes help simple molecules to be combined to give more complex organic compounds.

3. The Creation of Organic Molecules in Space
Organic chemists are well known with many of the organic molecules found in space. These are alcohols (methanol) and aldehydes (formaldehyde), acids (formic acid) and even amino acids like glycine. Their shape is formed according to reaction pathways, which are similar to classical organic ones, but in highly different physical conditions.

The important chemical reactions are:

- Radical-radical reactions, which are effective at low temperatures.
- The reactions of dust grains with hydrogenation.
- Ultraviolet radiation photochemical reactions.

In contrast to organic synthesis in the laboratory, these reactions are slow (long-lived), which allows complex molecules to be produced when the density is low.

4. Evidence of Organic Molecules Detection: Spectroscopically

Vibrational analysis and molecular orbital theory are foundations of spectroscopy that are used to confirm the presence of organic molecules in space. Every organic molecule has wavelengths which it absorbs or emits to give characteristic spectral fingerprints.

Radar and infrared telescopes capture the rotational and vibrational transitions of organic molecules thus enabling the astronomers to detect them even at very large distances in the universe. These observations show that the same chemical principles on which the study of organic chemistry is conducted in the laboratory are also applicable everywhere.

5. Comets and Meteorites: Organic matter Carriers

Comets have been referred to as frozen vestiges of the early solar system. Comet studies by spectroscopes and space vehicles have shown that comets are very diverse in the range of organic compounds present in them, including hydrocarbons, alcohols and nitrogen-based compounds.

The presence of organic material on the early earth was probably deposited by comets and meteorites that struck the earth. This could have filled the primitive Earth with prebiotic molecules to initiate chemical evolution and, ultimately, life.

6. The Cosmic Chemistry to Origins of life

The implication of astro-organic chemistry towards the origin of life is one of the most interesting. The presence of amino acids and other biologically interesting molecules in space has indicated that life building blocks can be naturally assembled in space. With this view, the origin of life becomes less an issue on earth, and more a cosmic chemical issue. Thus, the origin of organic chemistry is not in biology but it is the gradual development of simple molecules in space to complex systems able to self-organize.

7. Organic Chemistry Under Extreme Conditions

Reactions in space conditions Organic reactions the conditions in space are drastically different to those encountered on Earth:

- Extremely low temperatures
- Near-vacuum densities
- High radiation fields

These problems notwithstanding, the versatile bonding character of carbon allows the creation of stable organic structures. Polycyclic aromatic hydrocarbons (PAHs) are the most common aromatic compounds because of their stability, with which organic chemists are familiar with the concepts of resonance and conjugation.

8. Conclusion

Organic chemistry has been redefined due to the discovery of organic molecules in space. Organic chemistry is no longer restricted to the Earth or to the living systems, and it has come to refer to the cosmic phenomenon, that is subject to universal laws of physics.

The analysis of organic molecules in the interstellar clouds, comets, and planetary systems helps us to understand the chemical evolution at the largest scales. This interdisciplinary knowledge is in-between astronomy and organic chemistry, and it implies that the emergence of life can be deep-seated in the chemical processes of the universe itself.

From atoms to stars: How chemical elements shape stellar evolution

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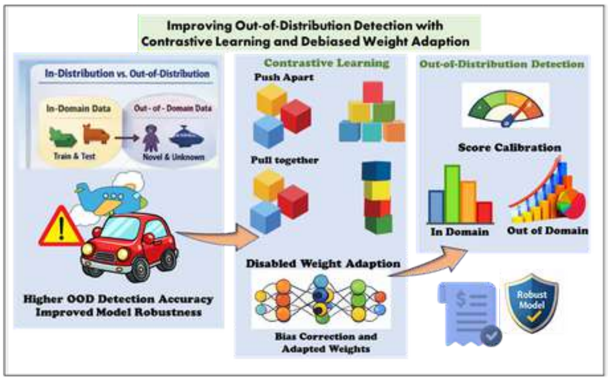
Abstract
Stars are not merely luminous objects in the night sky; they are active chemical and physical systems that govern the evolution of matter in the universe. From the fusion of hydrogen in stellar cores to the creation of heavy elements during supernova explosions, stars play a central role in shaping the periodic table. This article explores the deep connection between chemical elements and stellar evolution, highlighting how nuclear processes, stellar structure, and chemical composition together determine the life cycle of stars and the chemical enrichment of the cosmos.



1. Introduction

Modern astrophysics has revealed a profound truth: the elements that form planets, oceans, and living beings were created inside stars. This realization bridges chemistry and astrophysics, showing that the microscopic world of atoms and the macroscopic universe of stars are fundamentally linked.

While chemistry traditionally focuses on reactions between atoms and molecules under terrestrial conditions, stars represent environments of extreme temperature and pressure where nuclear reactions dominate. Understanding stellar evolution therefore requires an appreciation of both physical laws and chemical composition. In this article, we examine how chemical elements influence stellar behavior and how stars act as cosmic factories that generate and recycle matter.

2. Stars as Chemical Systems

A star is essentially a massive sphere of ionized gas, or plasma, held together by gravity. Hydrogen and helium constitute the majority of stellar matter, while heavier elements—collectively called “metals” in astrophysics—exist in much smaller quantities. Despite their low abundance, these heavier elements play a crucial role in determining stellar properties such as opacity, temperature, and luminosity.

The balance between gravitational collapse and energy generated by nuclear fusion defines a star’s stability. From a chemical perspective, stellar interiors can be viewed as extreme reaction vessels where nuclei interact under conditions far beyond laboratory limits.

3. Nuclear Fusion and Element Formation

The primary source of stellar energy is nuclear fusion, a process in which lighter atomic nuclei combine to form heavier ones, releasing energy according to Einstein’s mass–energy equivalence principle. In stars like the Sun, hydrogen fusion occurs mainly through the proton–proton chain reaction. In more massive stars, the carbon–nitrogen–oxygen (CNO) cycle dominates.

As stars evolve, they begin to fuse helium into carbon and oxygen. Very massive stars continue this process, forming elements such as neon, magnesium, silicon, and iron. This sequence mirrors the structure of the periodic table, where lighter elements serve as the building blocks for heavier ones.

Fusion reactions cease at iron because further fusion does not release energy. Elements heavier than iron are produced during energetic events such as supernova explosions, where rapid neutron capture processes occur.

4. Stellar Nucleosynthesis and the Periodic Table

Stellar nucleosynthesis explains the cosmic origin of chemical elements. The periodic table, often studied in chemistry classrooms, can also be interpreted as a record of stellar processes operating over billions of years.

Each generation of stars enriches the surrounding interstellar medium with newly formed elements. Subsequent stars inherit this enriched material, leading to an increase in chemical complexity across cosmic time. Thus, the periodic table is not static but reflects an evolving universe shaped by stellar life cycles.

5. The Hertzsprung–Russell Diagram and Chemical Evolution

The Hertzsprung–Russell (HR) diagram is a fundamental tool for understanding stellar evolution. By plotting stellar luminosity against surface temperature, astronomers can classify stars and trace their evolutionary paths.

Chemical composition significantly affects a star's position on the HR diagram. Stars with higher metallicity tend to be cooler and more luminous, while metal-poor stars are generally hotter and bluer. These differences allow astronomers to study stellar populations and reconstruct the chemical history of galaxies.

6. Spectroscopy: Decoding Stellar Chemistry

The primary method for determining stellar composition is spectroscopy, which relies on atomic physics. Each element produces characteristic absorption or emission lines at specific wavelengths. By analyzing stellar spectra, astronomers can identify elements present in a star and estimate their abundances.

This technique demonstrates the universality of physical laws: the same atomic transitions observed in laboratory experiments govern the light emitted by distant stars. Spectroscopic studies have revealed how the universe has gradually become enriched with heavier elements over time.

7. Cosmic Recycling of Matter

Stars not only create elements but also distribute them throughout the universe. Stellar winds, planetary nebulae, and supernova explosions eject processed material into interstellar space. This enriched matter becomes the raw material for new stars, planets, and potentially life.This continuous cycle of matter illustrates the interconnectedness of cosmic evolution. The atoms in our bodies were once part of ancient stars, emphasizing humanity's deep connection to the cosmos.

8. Conclusion

The relationship between atoms and stars reveals a fundamental unity in nature. Stellar evolution is governed by chemical composition, while the periodic table itself is shaped by stellar processes. By studying stars, we gain insight into the origin of matter and the chemical evolution of the universe.

This interdisciplinary perspective not only enriches our understanding of astrophysics but also highlights the cosmic significance of chemistry. In exploring how elements shape stars and how stars shape elements, we uncover the story of matter itself.

Astrophysics is witnessing a period of rapid discovery in early 2026, driven by powerful space observatories such as the **James Webb Space Telescope** and the **Hubble Space Telescope,** along with advanced AI-based simulations that help analyze vast astronomical datasets. These technologies are enabling scientists to explore the universe with unprecedented precision and uncover new phenomena. Recent research has revealed evidence of a **4.4-billion-year-old** planetary collision, offering important clues about how planetary systems form and evolve. Such discoveries highlight how modern observations and data analysis are transforming our understanding of the cosmos.

Astronomy - Active galactic nuclei

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रात्री आकाशाकडे उघड्या डोळ्यांनी पाहिल्यावर आपल्याला असंख्य तारे दिसतात. यातले शुक्र, मंगळ, शनी, गुरु हे ग्रह ताऱ्यांसारखेच लखलखीत चमकतांना दिसतात. पण आपल्याला माहिती आहे की त्यांचा प्रकाश हा सूर्याचा परावर्तित प्रकाश आहे, ज्यामुळे आपण त्यांना पाहू शकतो. ताऱ्यांचा प्रकाश मात्र त्यांच्या केंद्रातील अणुसंलयन प्रक्रियांद्वारे (thermonuclear reactions) निर्माण होतो. रात्रीच्या आकाशात दुर्बिणीच्या मदतीने ताऱ्यांसारख्या स्वयंप्रकाशित इतर वस्तूही दिसतात — जसे गॅलेक्सी, नेब्युला, स्टार क्लस्टर इत्यादी. यातील गॅलेक्सी म्हणजे असंख्य ताऱ्यांचा समूह असून त्यांचा प्रकाश एकत्रितपणे आपल्याला दिसतो. गॅलेक्सीचा प्रकाश हा मुख्यतः त्या सर्व स्वयंप्रकाशित असंख्य ताऱ्यांपासून येतो.

मात्र काही गॅलेक्सींचा प्रकाश हा सर्व ताऱ्यांकडून येणाऱ्या प्रकाशाच्या तुलनेत तिच्या मध्यभागातून येणारा प्रकाश इतका प्रबळ असतो की तो संपूर्ण गॅलेक्सीच्या प्रकाशावर मात करतो. अशा गॅलेक्सींना सक्रिय गॅलेक्सी (Active Galaxies) म्हणून ओळखले जाते. त्यांचा प्रकाश ताऱ्यांमुळे नसून केंद्रस्थानी असलेल्या सुपरमॅसिव्ह ब्लॅक होलभोवती जमा होणाऱ्या पदार्थामुळे निर्माण होतो. पदार्थ ब्लॅक होलकडे आकृष्ट होताना प्रचंड गुरुत्वाकर्षणामुळे तापतो आणि आयोनाइज्ड स्पेक्ट्रमसह तीव्र प्रकाश उत्सर्जित करतो.

सामान्य गॅलेक्सी (उदा. आपली आकाशगंगा, अँड्रोमिडा गॅलेक्सी) यांच्या तुलनेत सक्रिय गॅलेक्सींचा प्रकाश हा 100 पट किंवा त्याहून अधिक असतो. या गॅलेक्सींचा आपल्याला दिसणारा प्रकाश जवळजवळ पूर्णपणे त्यांच्या मध्यभागातून येतो. त्या भागाला Active Galactic Nuclei (AGN) असे संबोधले जाते. आपल्या विश्वातील साधारणपणे 10% गॅलेक्सी या सक्रिय गॅलेक्सी आहेत.

सामान्य गॅलेक्सीच्या स्पेक्ट्रामध्ये प्रामुख्याने absorption lines दिसतात, तर सक्रिय गॅलेक्सींच्या केंद्रस्थानी असलेल्या आयोनाइज्ड गॅस (Ionized Gas) एक विशिष्ट Emission-Line Spectrum उत्सर्जित करते (Fig. Figure-1).

जसे माणसाचे किंवा प्राण्याचे जीवनचक्र असते तसेच ताऱ्यांचेही जीवनचक्र असते. तारे नेब्युलामधील हायड्रोजन वायूंपासून बनतात आणि त्याच वायूंच्या सूक्ष्मतेच्या वस्तूंमध्ये विलीन होऊन त्यांचा जीवनक्रम कसा असेल आणि पुढे काय

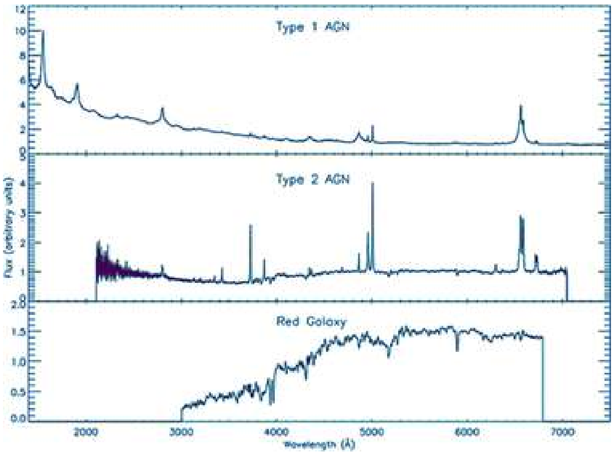

Fig-1: सक्रिय आणि सामान्य गॅलेक्सी या ऑप्टिकल स्पेक्ट्रम. Image Credit: Mickaelian 2015.

होईल यावर परिणाम करतात. कारण त्यांच्या केंद्रात सतत होणाऱ्या अणुविलयन प्रक्रियेतून ऊर्जा निर्माण होते. परंतु सक्रिय गॅलेक्सींच्या केंद्रातील असलेल्या Active Galactic Nuclei (AGN) हा भाग कसा आणि कशामुळे इतका प्रचंड ऊर्जावान आहे हे आपण या लेखात समजून घेण्याचा प्रयत्न करूयात.

ऐतिहासिक पार्श्वभूमी

- **1908:**
  ➤Edward A. Fath यांनी त्या काळी स्पायरल नेब्युला (ज्यांना आपण आता दीर्घिका किंवा गॅलेक्सी म्हणतो) यांच्या स्पेक्ट्रमचे अध्ययन केले.
  ➤ त्यांना एक विशिष्ट खगोलिय वस्तूचा स्पेक्ट्रम इतर दीर्घिकांपेक्षा वेगळा आढळला.
  ➤ त्यात सही emission lines दिसून आल्या.
  ➤ ती वस्तू होती NGC 1068.

- **1917 – 1926:**
  ➤ V. M. Slipher (1917) आणि Edwin Hubble (1926) यांनी NGC 1068, 4051, 4151 या गॅलेक्सींच्या स्पेक्ट्रामध्ये emission lines नोंदवल्या.

- **1943:**
  ➤Carl K. Seyfert यांनी एक महत्त्वाचा शोधपत्र प्रसिद्ध केला.

➤ त्यांनी काही विशिष्ट दीर्घिकांच्या स्पेक्ट्राचे निरीक्षण केले असता त्यात अनेक high-ionization emission lines आढळल्या.
➤ त्यांनी निरीक्षण केले की emission lines या सामान्य absorption lines पेक्षा अधिक रुंद (wider) आहेत आणि त्या खूप प्रकाशमान (luminous) आहेत.
➤ या रेड रेषा दर्शवतात की त्या दीर्घिकेच्या केंद्रात असलेला वायू अत्यंत वेगाने फिरत आहे.
➤ हेच एक सक्रिय दीर्घिकेचे केंद्र (Active Galactic Nuclei – AGN) लक्षण आहे.

- **दुसऱ्या महत्त्वपूर्ण शोध:**
➤ रेडिओ दुर्बिणींचा (Radio Astronomy) शोध लागला.
➤ त्यामुळे आकाशगंगेबाहेरील शोध लागला.
➤ त्यांचे ऑप्टिकल स्पेक्ट्रममध्ये पुन्हा Carl Seyfert यांनी ज्या दीर्घिकांचा शोध लावला त्या emission lines खूप मोठ्या absorption lines पेक्षा अधिक रुंद दिसल्या.
➤ यातील काही वस्तूंच्या ऑप्टिकल प्रतिमेमध्ये त्या वस्तू ताऱ्यासारख्या दिसतात, पण त्यांच्या स्पेक्ट्रममध्ये क्वासी-स्टेलर ऑब्जेक्ट्स (QSO) म्हणून ओळखले जाते.
➤ त्यांना क्वासार (quasar) किंवा नेब्युला म्हणत नव्हते.

- **1963**
➤Maarten Schmidt यांनी एक कोडे सोडवले.
➤ त्यांनी ताऱ्यासारख्या दिसणाऱ्या रेडिओ स्रोत 3C 273 चा स्पेक्ट्रम अभ्यासला.
➤ त्यात अनेक परिचित नेब्युलर emission lines आढळल्या.
➤ परंतु त्या redshift z =0.158z = 0.158z = 0.158 अवस्थेत त्यांना दिसल्या.
➤ त्यातून हे स्पष्ट झाले की हे ताऱ्यासारखे दिसणारे रेडिओ स्रोत आपल्या आकाशगंगेतील नसून extra-galactic वस्तू आहेत.
➤ म्हणजेच त्या आपल्यापासून खूप दूर असलेल्या तारामंडळांमध्ये आहेत.

ऊर्जा स्रोत – Accretion

क्वासी-स्टेलर ऑब्जेक्ट्स (QSO) खूप शक्तिशाली असतात आणि ते आपल्या आकाशगंगेतील ताऱ्यांच्या शोधापेक्षा त्यांचा एकत्रित प्रकाश अत्यंत प्रखर (luminous) दिसतो. या वस्तूंच्या केंद्रस्थानी प्रचंड गुरुत्वाकर्षणामुळे पदार्थाचा प्रवाह (accretion) होत असतो आणि त्यातून ऊर्जा निर्माण होते. याचा अर्थ असा की, त्या स्रोताचा आकार खूपच लहान असतो पण ते अत्यंत प्रखर प्रकाश उत्सर्जित करतात. कारण केलेल्या आवर्तनी वहनामुळे (variation) वेळेच्या मर्यादा असतात. म्हणजेच $R \leq c \cdot \Delta t$ जर एखाद्या वस्तूच्या आतल्या सर्व भागांमध्ये येणाऱ्या प्रकाशात वेळेचा अंतर असेल तर त्याचा आकार हा 1 light day पेक्षा कमी असला पाहिजे. यातून काही महत्त्वाचे प्रश्न निर्माण झाले:

- इतक्या छोट्याशा जागेत इतकी प्रचंड ऊर्जा कशी निर्माण होत असते?
- आयोनाइज्ड स्पेक्ट्रम मिळण्यासाठी नेमका कोणता ऊर्जा स्रोत असतो?

एखाद्या खगोलिय वस्तूची जास्तीत जास्त तेजस्विता (luminosity) ही एडिंग्टन तेजस्विता (Eddington Luminosity) असते. या अशी मर्यादा आहे जिथे त्या वस्तूच्या आत उत्पन्न होणाऱ्या radiation pressure बाहेर फेकण्याचा बल आणि गुरुत्वाकर्षणाचा बल यांच्यात संतुलन असते. ऊर्जा निर्मिती अशी होणे आवश्यक असते, ज्यात radiation pressure विरुद्ध गुरुत्वाकर्षण एक संतुलन ठेवेल आणि त्या वस्तूला spherically symmetric ठेवेल. अशा वस्तूसाठी एडिंग्टन स्थिती (Eddington condition) पूर्ण करणे आवश्यक आहे:

$$L \leqslant L_E$$

Eddington luminosity L_E :

$$L_E = \frac{4\pi c G m_H M}{\sigma_T} = 1.26 \times 10^{38} \frac{M}{M_\circ}$$

$$\frac{L}{L_\circ} \leqslant \frac{L_E}{L_\circ} = 3.22 \times 10^4 \frac{M}{M_\circ} \quad \text{......... (1)}$$

येथे σ_T : थॉमसन क्रॉस सेक्शन (Thomson cross section) $L_\circ$&$M_\circ$: सूर्याची तेजस्विता आणि वस्तुमान, L : कोणत्याही ताऱ्याची तेजस्विता, एका विशिष्ट AGN च्या तेजस्विता $10^{12}L_\circ$ इतकी असू शकते. ही कारण म्हणजे अशा वस्तूंच्या बाबतीत ऊर्जा स्रोत खूप महत्त्वाचा असतो. Equation 1 नुसार, $10^{12}L_\circ$ तेजस्विता असण्यासाठी AGN मध्ये मध्यवर्ती क्षेत्रात वस्तुमान $10^7 M_\circ$ पेक्षा जास्त असणे आवश्यक आहे. अशा वस्तूंमध्ये साधे नीहारिका किंवा $10^2 M_\circ$ वस्तुमानाचे तारे असू शकत नाहीत आणि त्यांची तेजस्विता साधारणपणे $10^5 M_\circ$ इतकी असते. अशा बाबतीत radiation pressure हा वायू दाबापेक्षा (gas pressure) जास्त असतो, ज्यामुळे ते स्थिर राहू शकत नाहीत. त्यामुळे त्यांच्या केंद्रातील अणुसंलयन (thermonuclear reactions) याचा मुख्य ऊर्जा स्रोत असू शकत नाही.

अशा प्रकारे, मोठ्या प्रमाणात ऊर्जा अत्यंत लहान

आकारमानात आणि मोठ्या वस्तुमानाच्या सानिध्यात उत्सर्जित होते. केंद्रकीय अभिक्रिया हे करू शकत नाहीत, परंतु गुरुत्वीय ऊर्जा उत्सर्जन (gravitational energy release) हे करू शकते. याचे सर्वात आश्वासक स्वरुप म्हणजे एका महाकाय कृष्णविवराभोवती (supermassive black hole) असलेली तबकडी (accretion disc). याचे सर्वात उपयुक्त उत्तर म्हणजे गुरुत्वाकर्षणाने ओढले जाणारे वस्तुमान/पदार्थ आणि त्यातून निर्माण होणारी ऊर्जा. या प्रक्रियेला Accretion म्हणतात.

हे समजून घेण्यासाठी खालील प्रतिमा पाहा:

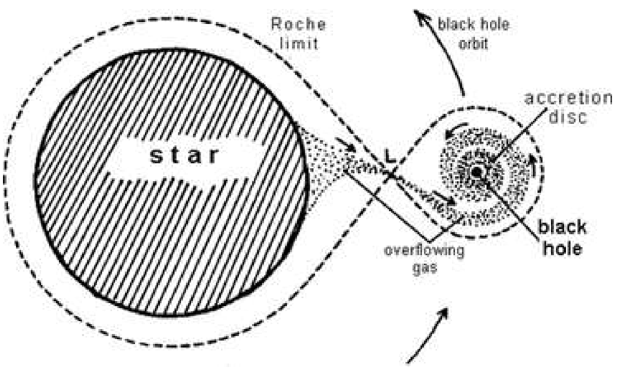

Fig-2: Binary Star System and formation of Accretion disc around the black hole. Image Credit: astronuclphysics.info

प्रतिमेत दाखविलेल्या कृष्णविवराच्या जोडीतील (Black Hole Binary) एक जड कृष्णविवर त्याच्या गुरुत्वाकर्षणामुळे दुसऱ्या कमी वजनाच्या ताऱ्याकडून वायू/पदार्थ खेचतो. या खेचलेल्या पदार्थांमुळे त्या जड कृष्णविवरभोवती भोवती एक तबकडी तयार होते, ज्याला Accretion of Matter म्हणतात.

सक्रिय गॅलेक्सींच्या मध्यभागी महाकाय कृष्णविवर (Supermassive Black Hole $10^8 - 10^9 M_\odot$) असू शकतो आणि तो अशाच प्रकारे पदार्थ ओढून ऊर्जा मिळवू शकतो असे शास्त्रज्ञांनी मांडले.

भौतिक मॉडेल (Physical model)

सध्याच्या समजुतीनुसार, AGN मध्ये एक घनदाट कोर असतो ज्याच्या केंद्रस्थानी एक सुपरमॅसिव्ह ब्लॅक होल (SMBH) असतो. या ब्लॅक होलवर पडणाऱ्या पदार्थांमुळे एक ॲक्रिशन डिस्क तयार होते, तसेच सापेक्षतावादी जेट्स, धुळीचा टोरस इत्यादी घटक असतात. बहुतेक AGN मध्ये खालील घटक आढळतात (Netzer, 2015):

ब्लॅक होल: आकाशगंगेच्या (AGN) मध्यभागी असलेली खूप मोठी आणि जड वस्तू.

ॲक्रिशन फ्लो: कृष्णविवराकडे फिरत जाणारा पदार्थांचा प्रवाह, जो AGN ला तेजस्वी बनवतो.

ब्रॉड-लाइन क्षेत्र: कृष्णविवराभोवती जवळपास असलेले ढग, जे वेगाने फिरतात.

टोरस: मध्यभागी असलेली धुळीची वलयाकार रचना.

नॅरो-लाइन क्षेत्र: टोरसच्या बाहेर पसरलेला विरळ वायू, जो दूरपर्यंत दिसतो.

जेट: कृष्णविवराच्या मध्यभागातून बाहेर फेकला जाणारा वेगवान रेडिओ प्रवाह.

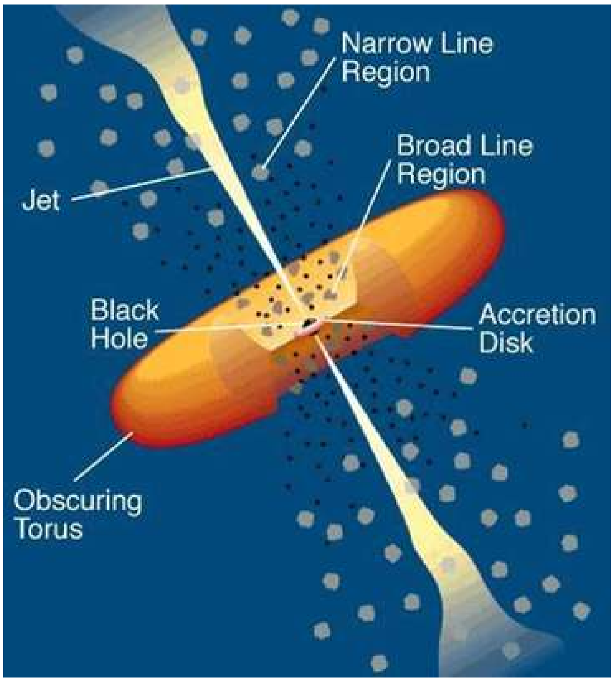

Fig-3: Schematic diagramof an AGN showing its key physical components (Urry & Padovani, 1995).

सक्रीय दीर्घिकांच्या (Active Galaxies) मध्यभागातून येणारा प्रकाश या Accretion disc सोबतच corona, broad-line, narrow-line region, dusty region, आणि relativistic jets सारख्या इतर घटकांमधूनही येतो.

जेव्हा आपण ताऱ्यांकडून येणारा प्रकाश सर्व तरंगलांबींमध्ये (wavelengths) मोजतो, तेव्हा आपल्याला एक विशिष्ट आकृती मिळते, जिला 'ब्लॅकबॉडी रेडिएशन कर्व्ह' म्हणतात.

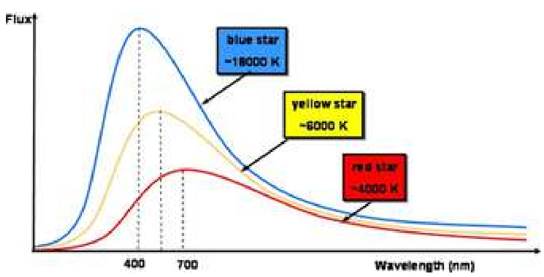

Fig-4: Blackbody Radiationcurve Credit: Swinburne

हा वक्र (उदा. Figure-4) दर्शवतो की ताऱ्याचे तापमान आणि त्यातून बाहेर पडणारी ऊर्जा यांचा एकमेकांशी संबंध असतो. सामान्य तारे हे जवळजवळ 'ब्लॅकबॉडी' प्रमाणे वागतात, म्हणजे ते एका ठराविक तापमानाला जास्तीत जास्त प्रकाश उत्सर्जित करतात.

याचप्रमाणे सक्रिय दीर्घिकांचा (Active Galaxies) प्रकाश मोजला असता त्याची आकृती सामान्य ताऱ्यांपेक्षा खूप वेगळी येते (उदा. Figure-5).

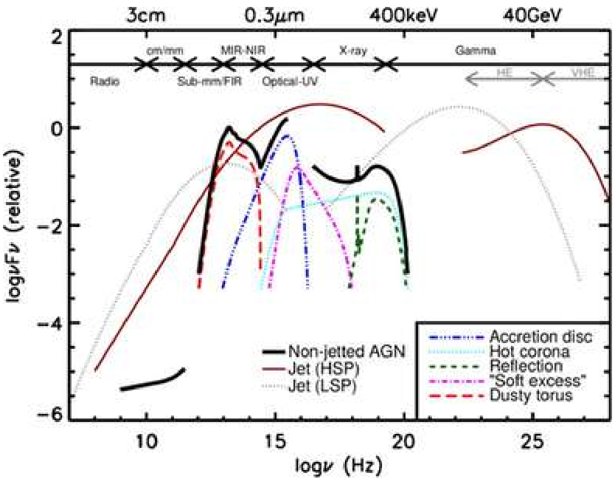

Fig-5: A schematic representation of an AGN spectral energy distribution (SED). Image credit: C. M. Harrison.

Fig-5: A schematic representation of an AGN spectral energy distribution (SED). Image credit: C. M. Harrison.

या दीर्घिकांच्या केंद्रस्थानी असलेले विशाल कृष्णविवर (Supermassive Black Hole) प्रचंड प्रमाणात ऊर्जा निर्माण करते. या दीर्घिका फक्त दृश्य प्रकाशच नाही, तर रेडिओ लहरींपासून ते गॅमा किरणांपर्यंत सर्व प्रकारच्या ऊर्जेमध्ये (energy spectrum) प्रकाश देतात.

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Three Earth-Sized Planets in a Binary System

Astronomers have discovered three Earth-sized planets in a binary star system, showing that planetary systems can exist even around two stars and expanding our understanding of planet formation in the universe.

Interstellar medium and star formation

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The interstellar medium (ISM) is the gas and the dust in between the stars and it consists of matter and radiation which is present throughout the Galaxy. Most of the interstellar medium gas consists of hydrogen (approx. 90%), helium (approx. 8%) and other trace elements. Small portion of carbon, oxygen, and higher Z elements are also found in the interstellar medium. The ISM constantly goes through the series of events called star formation, stellar evolution and feedback through mass loss through winds, supernova explosions. The stellar winds and supernova explosions return back the processed material into the ISM enriching it with the metals. The cycle of star formation and evolution impact the significant radiative and mechanical energy into the ISM making it very clumpy and filamentary.

Fig.1: Interstellar Medium (Credit: James Web Space Telescope (JWST) NASA, ESA, CSA, STScI)

The ISM has different phases such as hot ionised medium, warm neutral medium, cold neutral medium. The ISM consists of clumpy regions throughout the Galaxy with numerous stars in between them (See Fig.1). Hydrogen is present in different forms such as Molecular Hydrogen (H_2), Neutral Hydrogen (HI), Ionized Hydrogen (HII). The most abundant in the ISM, Neutral Hydrogen (HI) is detected at 21 cm (1420 MHz) wavelength with radio telescopes. When electron in the Neutral Hydrogen (HI) flips its spin, then a photon is emitted which can be detected at 21cm wavelength. Young stars ionize their local environment by removing an electron from hydrogen making it Ionized Hydrogen (HII) with their hot winds and UV radiation. Molecular Hydrogen (H_2) is the second most abundant gas in the interstellar medium after Neutral Hydrogen (HI), but H_2 has zero dipole moment so detection of H_2 is observationally challenging but it collides with the other interstellar molecules such as CO that helps astronomers to calculate the abundance of interstellar molecule with respect to H_2. Many rotational molecules such as CO and its isotopologues widely used to study kinematics of the molecular clouds.

The stars form in these cold dense molecular clouds. Molecular clouds are the densest and the coldest regions in the ISM having temperatures in the range of 10K to 30K. Self-gravitating clouds often goes through a gravitational collapse when they reached the critical mass called Jean's mass to form stars but sometimes molecular clouds go through several instabilities and form dense clumps, filamentary structures in the ISM. High density regions always go through fragmentation and form small entities called clumps and cores. Dense clumps further fragments into prestellar cores which later leads to a protostar formation with series of events called infall, accretion and bipolar outflows through rotational axis of the protostar. Gravitational collapse of the prestellar core consists of different phases:(1) Free Fall Phase: The collapse is approximately isothermal, free-fall timescale. The central density of the sphere increases very fast compared to outer layer density. (2) Adiabatic Phase: The central density increases higher than the outer other layers, collapse is now not isothermal. Optically thick core formed inside the sphere. Internal temperature starts to increase (3) Hydrostatic Phase: Optically thick core will develop disk around it with accretion. Bipolar jets will show the evidences for the protostar formation. Magnetic field, turbulence, cosmic ray, radiation fields, metallicity in the ISM etc. affect the star formation process. Infall, Outflows can be observationally traced with submm and mm telescopes as well as infrared space based telescopes. Infrared wavelength probes the late phase of the star formation. There are a lot of contaminating sources like Active Galactic Nuclei (AGN), Galaxies at different redshifts etc. are seen with the Infrared but astronomers use different methods to remove those contaminating sources and extract only young stars. Young star clusters, young stars often seen in the infrared bands.

The process of star formation consists of different phases which can be observed in the timescales of 10,000 years to several Million years and that makes study of star formation process very complicated observationally. Astronomers use observational data as well as high performing computational power to test star formation theories and scaling relations. Observational study of various star forming regions is possible with current high resolution high sensitivity telescopes. From radio wavelength to X ray wavelength data is used to study the various phases of the star formation. Many star forming regions in our Milky Way Galaxy studied very extensively with multiwavelength data, two famous and well known regions are shown below.

1. Orion Nebula(M42) Region:

The Orion nebula is the most studied nebula in our Milky Way Galaxy (See Fig.2). The Orion nebula is visible in our sky in the constellation Orion. It is 414 pc away from the Earth (Menten et al.2007). The M42 is the part of two giant molecular clouds known as Orion A and Orion B. The mass of the Orion A cloud is approx. $1.0 * 10^5\ M_\odot$ whereas Orion B cloud is less massive than Orion A. Recent submm and mm as well as dust continuum maps showed the evidences for the ongoing star formation in the region. The region contains hot and cold star forming cores, various outflow signatures.

Fig.2: Orion nebula (Credit: MPE/ESO 2.2m Telescope, La Silla Observatory, Chile)

Fig.3: Rho Ophiuchi cloud complex (Credit: JWST NASA, ESA, CSA, STScI)

2. The Rho Ophiuchi cloud:

It is one of the closest star formation sites from the solar neighbourhood. Numerous young stars are detected in the region (See Fig.3). Large number of molecular outflows are seen in the image. Many young stars are present in the cloud; they carved this molecular cloud with their feedbacks in later stage of their formation. Many circumstellar disc systems are also detected in the region.

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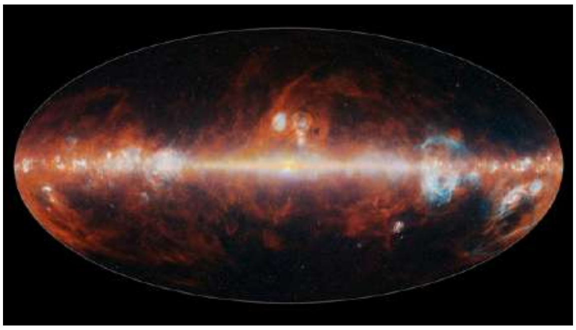

SPHEREx Completes First Full-Sky Infrared Map

The SPHEREx mission by NASA has completed its first full-sky infrared map, marking a major milestone in space astronomy. The mission surveys the entire sky in hundreds of infrared wavelengths to study the formation and evolution of galaxies. It will also help scientists trace water and organic molecules in the Milky Way, improving our understanding of cosmic history and planetary system formation.

SPHEREx will also play a crucial role in studying the large-scale structure of the universe by mapping the distribution of galaxies over cosmic time.

Waves in solar plasma: Can alfvén waves solve the coronal heating mystery?

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One of the most surprising facts about our Sun is that its outer atmosphere, known as the **corona**, is far hotter than its visible surface. While the solar surface(photosphere) has a temperature of about **6000 K**, the corona reaches temperatures of **one to three million kelvin.** This counterintuitive observation is known as the **coronal heating problem**, and despite decades of research, it remains one of the central unsolved questions in solar physics.

Over the years, scientists have proposed several mechanisms to explain this extreme heating. Among them, **waves in solar plasma**, particularly **Alfvén waves**, have emerged as one of the most promising candidates. Understanding how these waves transport and dissipate energy may be the key to solving this long-standing mystery.

The Sun as a Plasma Laboratory

The Sun is not a solid object; it is composed almost entirely of **plasma**, the fourth state of matter. In plasma, atoms are ionized, meaning electrons are free to move independently of ions. This makes plasma highly responsive to **electric and magnetic fields**, which dominate solar dynamics.

Because the Sun possesses strong and complex magnetic fields, its plasma supports a wide variety of wave motions. These waves can carry energy from the solar interior and lower atmosphere upward into the corona. Studying such waves allows us to treat the Sun as a natural plasma laboratory, far beyond what can be achieved on Earth.

Types of Waves in Solar Plasma

In a magnetized plasma like the solar atmosphere, several types of waves can exist:

- **Acoustic waves**, driven by pressure fluctuations, similar to sound waves.
- **Magnetoacoustic waves**, which involve both pressure forces and magnetic tension.
- Alfvén waves, which are purely magnetic in nature and involve transverse oscillations of plasma and magnetic field lines.

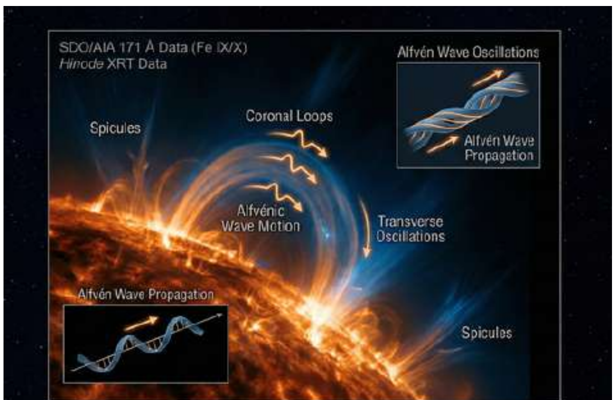
Among these, Alfvén waves are of particular interest because of their unique ability to transport energy over long distances with relatively little loss.

Understanding Alfvén Waves

Alfvén waves were first predicted by **Hannes Alfvén** in 1942. These waves are **transverse oscillations** where plasma particles move perpendicular to the direction of wave propagation, while the wave itself travels along magnetic field lines.

A useful analogy is that of a plucked string: the magnetic field lines act like stretched strings, and Alfvén waves are the vibrations traveling along them. Because they are **incompressible,** Alfvén waves do not easily lose energy through compression, allowing them to carry energy from the photosphere to the corona efficiently.

In the solar atmosphere, convective motions at the surface constantly shake magnetic field lines, naturally generating Alfvén waves. This makes them a realistic and continuous source of energy for the corona.



Observation of Alfvénic wave activity in coronal structures. (Figure adapted for research review).

Observational Evidence of Alfvén Waves

For many years, Alfvén waves were largely theoretical. However, modern space missions have provided strong observational evidence of their existence in the solar atmosphere.

Satellites such as **Hinode, Solar Dynamics Observatory (SDO), IRIS**, and **Solar Orbiter** have detected transverse oscillations in coronal loops, spicules, and solar wind streams. These observations show that Alfvén waves carry **significant amounts of energy**, potentially enough to account for coronal heating—at least in certain regions.

The challenge, however, is not just energy transport, but **energy dissipation.**

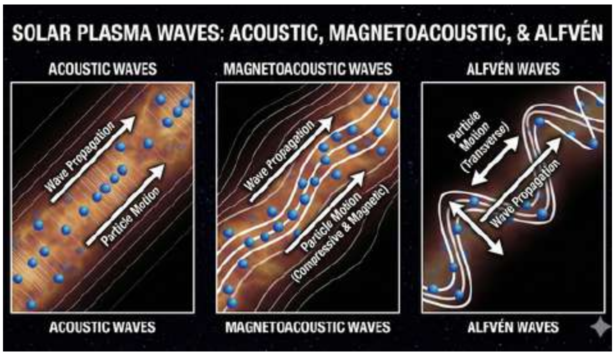
From Wave Energyto Heat: The Key Challenge

While Alfvén waves can transport energy into the corona, the crucial question is:

How is this energy converted into heat?

Several mechanisms have been proposed:

- **Phase mixing:** Waves traveling along neighboring magnetic field lines become out of phase, creating small-scale structures where energy can dissipate.
- **Resonant absorption:** Wave energy is transferred from large-scale oscillations to localized resonant layers.
- **Turbulent cascade:** Interacting waves transfer energy to smaller scales, where it is eventually converted into thermal energy.



Recent numerical simulations and high-resolution observations suggest that these processes can indeed lead to heating. However, whether they are sufficient to fully explain coronal temperatures remains an open question.

Why This Matters Beyond Solar Physics

Understanding coronal heating is not only important for theoretical astrophysics. It has practical implications for **space weather**, which affects satellite operations, communication systems, and power grids on Earth.

Moreover, the physics of plasma waves and energy dissipation is relevant to **laboratory plasma experiments** and **fusion research**, making solar studies valuable across multiple disciplines.

For students, solar plasma physics offers a rich field that combines theory, observation, computation, and real-world impact.

Conclusion

The Sun continues to challenge our understanding, and the coronal heating problem remains one of its most intriguing puzzles. Alfvén waves provide a compelling pathway for transporting energy into the corona, and modern observations strongly support their presence and importance.

While they may not be the sole solution, Alfvén waves are undoubtedly a crucial piece of the puzzle. With next-generation instruments such as the **Daniel K. Inouye Solar Telescope (DKIST)** and future space missions, we are closer than ever to uncovering how the Sun heats its atmosphere.

The answer may lie not in a single mechanism, but in the complex and beautiful interplay of waves, magnetic fields, and plasma.

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Discovery of Alaknanda at z ≈ 4: The Farthest Disc-Dominated Spiral Galaxy

The discovery of the **Alaknanda Galaxy** at a redshift of **z ≈ 4** marks a significant milestone in modern astrophysics. Identified by **Rashi Jain** and **Prof. Yogesh Wadadekar** from **NCRA-TIFR,** Pune, it is the farthest known disc-dominated spiral galaxy observed so far. At this redshift, the galaxy is seen as it existed when the universe was only about **1–1.5 billion years old.**

What makes this discovery remarkable is the presence of a well-formed, stable spiral disc at such an early cosmic time, challenging existing theories that predicted young galaxies to be irregular and chaotic. Enabled by advanced observational techniques, this finding provides crucial insights into early galaxy formation and suggests that organized structures may have developed much earlier than previously believed.

Further analysis of Alaknanda's structure and kinematics reveals that it is not only morphologically spiral but also dynamically mature, exhibiting ordered rotational motion similar to present-day disc galaxies. This suggests that the processes responsible for angular momentum buildup and disc stabilization—such as smooth gas accretion and minimal disruptive mergers—were already in place in the early universe. Such characteristics challenge hierarchical galaxy formation models, which predict that frequent interactions at high redshift should prevent the early emergence of well-settled discs.

The discovery also highlights the growing importance of next-generation observational facilities like the James Webb Space Telescope, whose deep infrared imaging allows astronomers to peer into the distant universe with unprecedented clarity. By studying galaxies like Alaknanda, researchers can refine models of star formation, dark matter distribution, and feedback processes in the early cosmos. Ultimately, this finding bridges the gap between primordial galaxy formation and the structured spiral systems seen in the present-day universe, offering a new perspective on how galaxies like the Milky Way came to exist.

The eclipse chasers: A remarkable experiment that blended astronomy with aviation to understand the solar eclipse better

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In the year 1973, two remarkably different teams tie up for one common quest i.e. pushing boundaries of human understanding and knowledge about universe. These teams were comprised of French and US astrophysicists, headed by Pierre Lena and Donald Liebenberg, met with a team of Concorde, a then anglo-french supersonic civilian airliner, comprised of expert French pilots Andre Turcat and Jean Dabo, to discuss a one-of-a-kind and unheard collaboration that remains one of the fascinating experiments by experts of two different fields. Here, the idea was to understand the solar eclipse better, but not from a boring stationary view-point on the earth, where the eclipse lasts only a few minutes, but from an ultra-fast aircraft at an altitude of 55,000 feet, where you can literally chase the eclipse over a lengthy time duration.

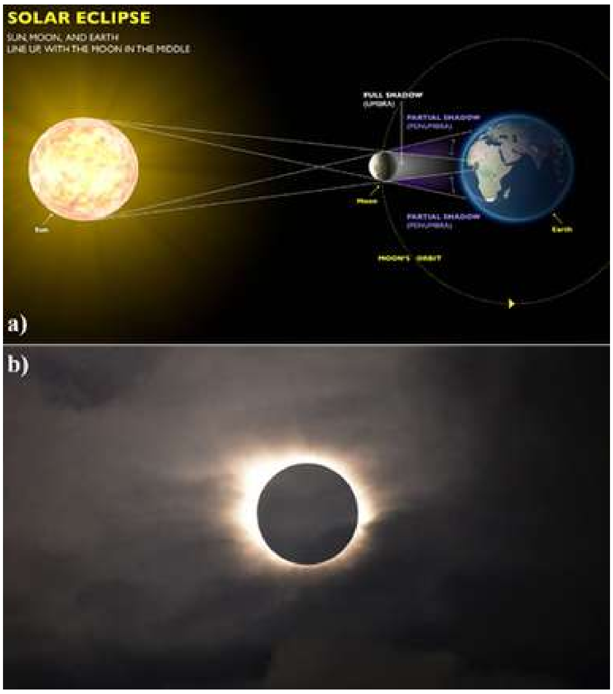

Fig.1: a) Schematics of the Solar Eclipse event. b) The actual total solar eclipse image. ©Oregon State University

This study of totality, i.e. the total time for which the Moon completely covers the Sun during the eclipse, on the day of 30th June 1973 across the Sahara Desert in Africa, added a great deal of knowledge in the field of Astrophysics and Astronomy, thanks to the lead taken by Dr. Pierre Lena.

Fig.2: a) Concorde Prototype 001. b) Fitting of the instruments on-board before experiment. ©space.com

Why the Quest?

Other than just looking impeccably fascinating from a child's view-point, the solar eclipse (Fig. 1) is equally important event for scientists as it adds a great deal of information on various parameters such as Sun's corona (i.e. outer atmosphere of the Sun) which is otherwise always hidden, testing of the astronomical theories, weather systems on earth etc. Another important fact is that the total solar eclipses are a rare natural phenomenon, hence astrophysicists need go to for such events in a war-ready mode. However, the short duration of solar eclipse makes all these studies and preparations incredibly difficult. Plus, the weather forecast on earth can be tricky at times. Hence, Dr. Lena wanted a robust but innovative solution and decided to "chase" the eclipse from the thin air.

The Aviator's Solution:

Even though fighter aircrafts are breathtakingly fast, they have extremely limited space on-board. Hence, a fastest commercial aircraft Concorde 001 (Fig. 2a) was selected as it offers a perfect blend of space and speed. This French-built proto-type was designed to fly at 60000 feet at supersonic speed of around Mach 2.07 (i.e. around 2,200 km/hr) and with ample space, many sensitive instruments (Fig. 2b) were carefully installed well before the experiment by removing seats and modifying electrical connections as well digging holes in the celling of the aircraft for eclipse observations.

For the eclipse on 30th June 1973, the width of path of the totality was calculated around 250 km. and with moon's shadow moving around 2400 km/hr, Concorde 001 proved perfect solution in studying the solar eclipse for a stunning 74 min compared to a mere 7 min 4 sec on ground.

The "Chase" Day:

On 30th June, around 10 GMT, Pilot Andre Turcat took off the Concorde 001 from Las Palmas of Canary Islands, Spain towards the precisely calculated trajectory of the solar eclipse.

Considering the multiple facts such that the path of solar eclipse was a curve (Fig. 3(a)), data recording needed to be uninterrupted and continuous, and to maintain the critical aircraft speed around 2180 km/hr, the pilot avoided the turns as well as tilts by choosing a straight flight trajectory (Fig. 3(b)). Hence, this straight path, considering the speed of the aircraft, would give them around 80 min to track the solar eclipse uninterrupted. Such was the precision of the flight plan as well as the eclipse calculation on paper and the skill of the pilot in the air, that the Concorde arrived at the rendezvous point up at 55,000 feet over Sahara Desert just 1 sec late and at the same time the total eclipse happened. And for next 74 min, one-of-a-kind experiments started taking never-seen-before measurements from the pre-installed equipments.

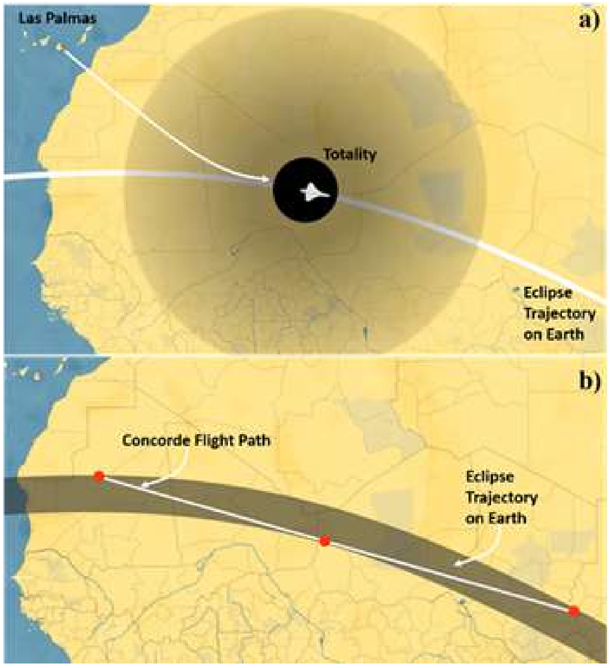

Fig.3: a) Schematics of the Solar Eclipse path and Concorde trajectory over Africa. b) The straight-line path taken by Concorde for continuous data recording

The result and Conclusions:

Considering the vitality of the experiment, the result obtained were equally amazing. First were the direct infra-red (IR) measurements of Sun's corona were studied. It was also observed and studied that the Sun throws acoustic shock waves outwards every 5 min which are complex compressive perturbations that contribute in the heating of the solar atmosphere around the sun. Furthermore, information they received on the space dust of solar system was also studied directly rather than indirect theoretical ways. The experiment equally created record such as the longest time spent in the totality phase and longest eclipse experienced by the humans. Considering the rarity of total solar eclipse and the audacity of this experiment performed, this record may take centuries to be broken. This experiment also implanted the thoughts of using the future unmanned vehicles for the astronomical events. Finally, not to mention the massive lasting impression it must have created on the people who experienced one of the nature's dazzling events at the elevated altitude and an ultra-high speed.

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Retirement of Sunita Williams

Sunita Williams, a veteran astronaut of NASA, announced her retirement after a remarkable career in human spaceflight. She participated in multiple missions to the International Space Station and spent over 300 days in space. Her contributions to space exploration and inspiration to aspiring scientists and astronauts around the world remain significant.

The sun: Source of solar activity

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1. Introduction

On the cosmic scale, the Sun is just another star; there are bigger and brighter stars in the universe. The Sun is, however, very important to us because it is the nearest and the only star in our planetary system and it provides almost all of our energy. A slight variation in the energy received from the Sun can threaten life on the earth!

Further, the Sun being the nearest star, we can study its structure, atmosphere, and other physical characteristics in greater detail.

The information so obtained can be used to test the theories of stellar structure and evolution. All the visible radiation from the Sun comes from its surface layer called the photosphere.

The photosphere is the atmosphere of the Sun, consisting of two distinct layers, namely the chromosphere and the corona.

Interaction of the Sun's magnetic field with highly mobile charged particles in it gives rise to a variety of observable events. These events are collectively known as solar activity.

2. Layers of the Solar Atmosphere

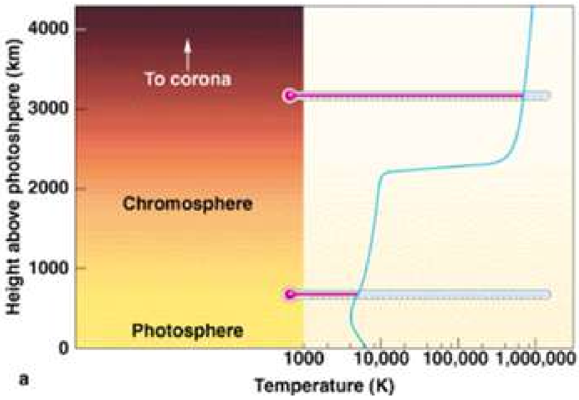

Fig. 1 :Layers of solar Atmosphere

3. The Sun's photosphere

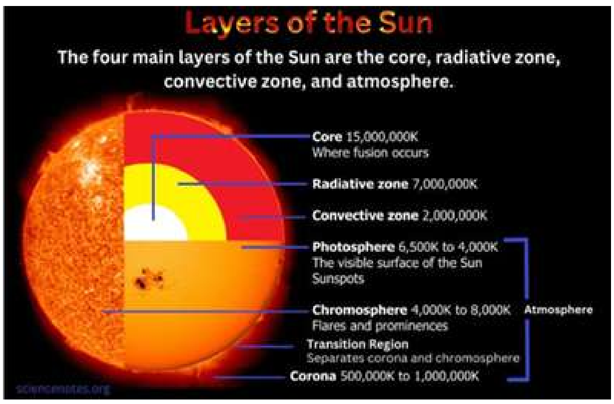

Fig. 2 : Layers of the Sun

The photosphere is the visible surface of the Sun. All the light received from the Sun, in fact, comes from the photosphere.

At the centre of the Sun, the energy is generated in the form of high energy photons called gamma rays. As these photons travel outwards, they collide with particles of matter and lose energy continuously.

The density of the photosphere is 3400 times less than the density of the air we breathe. The thickness of the photosphere is about 500 km.

The photosphere shows a **granular structure** and irregularly shaped granules; each granule is surrounded by dark edges.

It has been found that these granules are very hot and their typical size is 1500 km.

Granulation of the photosphere is **caused by convection.** The centre of the granule is hotter, and it emits more radiation and looks brighter in comparison to the edges, which are relatively cooler and emit less radiation.

The chemical composition of the photosphere - It consists of 79 % hydrogen and the remaining 21% consists of nearly 60 other chemical elements.

Interestingly, all the elements of the photosphere **are known elements** and their proportion in the earth is more or less the same as that in the photosphere.

This similarity in the chemical compositions of the photosphere and the earth is of utmost important **for understanding the formation of the solar system.**

These layers can be seen and probed, and valuable information about their physical characteristics can be obtained. Let us learn about the various layers of the solar atmosphere.

4. Chromosphere

Chromosphere lies above the photosphere and extends up to ~ 2000 km. This layer of the solar atmosphere is normally not visible from the Earth because of its faintness. However, it can be seen during a solar eclipse.

The temperature in the chromosphere increase with height because of the hot gas, in the form of jets called **spicules**, is observed throughout the chromosphere.

These spicules extend upward in the chromosphere up to a height of 10000 km and last for as long as 15 minutes.

This implies that the lower part of the chromosphere is highly turbulent and the spicules transport energy and matter from the photosphere to the chromosphere.

This causes heating of the chromosphere. It appears to be caused by the Sun's magnetic field.
The transition region links the chromosphere with corona, the outermost part of the solar atmosphere.

5. Corona

Corona, the outermost layer of the Sun's atmosphere, is named after the Greek word for crown. Like the chromosphere, the corona can be observed only during a total solar eclipse when the Moon completely covers the solar disc (Fig.3).

we cannot see the corona at normal times- The fact is that the density of matter in both the chromosphere and corona is very low (see Fig. 3).

They emit very little light and, as a result, they are very faint. In the bright light of the photosphere, they are not visible.

Fig. 3 : The solar corona

6. SOLAR ACTIVITY

Astronomers have observed a variety of short-lived events, collectively known as solar activity, occurring on or near the surface of the Sun.

The root cause of all these activities is the existence of a strong and localised magnetic field in the photosphere.

Studies of these events provide valuable information about the Sun and the nature of its magnetic field. You will now learn about some of these short-lived events.

7. Sunspots

The Sun, has dark spots on its visible surfaces. These dark spots are called **sunspots.**

Sunspots can be seen sometimes even with the unaided eye at sunrise or sunset. Naked eye observations of sunspots date back to 2000 years in China.

It was in the seventeenth century that Galileo, using the telescope which he himself had fabricated, observed sunspots and found that these dark spots were in motion. This led him to suggest that the Sun was spinning in space.

Galileo also observed that the sizes and shapes of the sunspots kept changing as they rotated with the Sun.

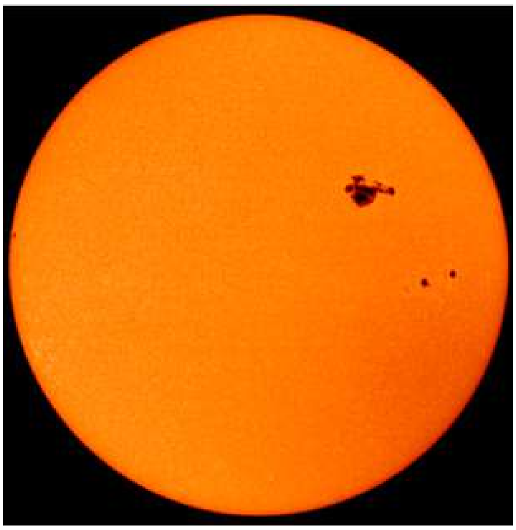

Fig. 4 : The Sunspots

The sunspot temperature is 4000 K. Sunspots appear darker because they are cooler than their surrounding areas in the photosphere that have an effective temperature of 6000 K.

A typical picture of a large sunspot is shown in Fig. 4. And Fig. 5.

Note that it consists of a dark central region, **called umbra**, surrounded by a less dark region, called **penumbra**.

We do not see such details in the picture of smaller sunspots.

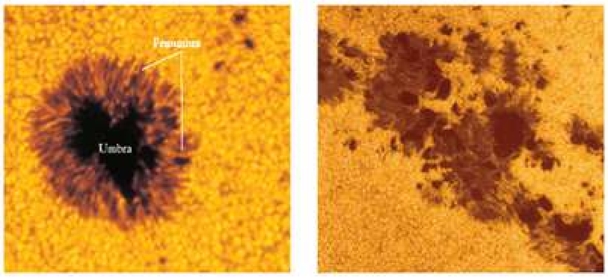

Fig.5: Sunspot structure

The temperature of the sunspots lower than their surroundings,

It is due to the existence of strong magnetic fields in the sunspots.

In the presence of a magnetic field, a spectral line emitted by an atom at a single wavelength is split into three lines. **This is called the Zeeman Effect**. Such Zeeman splitting is observed in the spectrum of sunspots.

Since the line separation, **$\Delta\lambda$** is proportional to the applied magnetic field, a magnetic field up to 3000 Gauss has been estimated in sunspots.

The presence of strong magnetic fields in sunspots restrains the flow of hot material from layers below the photosphere. Therefore, within a sunspot, less heat comes up, and they (sunspots) are cooler/darker than the surrounding region.

Within a sunspot, the umbral magnetic field is quite intense 3000 Gauss. It spreads like an umbrella and weakens in the penumbral region. The field strength in the penumbra is estimated to be 1000 Gauss.

8. Sunspot Cycle

The observed motion of the sunspots indicates that the Sun is spinning in space.

In 1843, Heinrich Schwabe, a German who observed the sky for fun, discovered a periodic variation in the numbers of visible sunspots.

He found an interval of 5.5 yrs between the time when maximum number of sunspots **(sunspot maxima)** were observed and the time when the minimum number of sunspots **(sunspot minima)** were observed.

Over the last two centuries, sunspot observations clearly suggest a periodic variation of about 11 years between two successive sunspot maxima.

Another important observation pertaining to sunspot is that the sunspot zones migrate along solar latitude.

It is observed that the first sunspot zone appears **at latitude of 35°** in, say, the northern hemisphere and it migrates to lower latitudes. It lasts till it reaches a latitude of 10°.

This is the famous butterfly diagram which shows a period of 11 years between the successive occurrences of a sunspot at a given latitude.

It is believed that the sunspot cycle is caused due to differential rotation of the Sun; it rotates faster at the equator compared to higher latitudes.

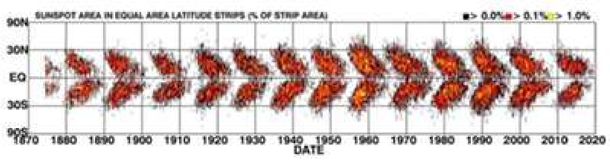

Fig. 6 : Butterfly diagram

Fig.6 Shows butterfly diagram - the migration of sunspots from higher to lower latitudes.

9. Solar Flares

Yet another form of solar activity is called **solar flare**. Solar flares are sudden eruptive events which occur on the Sun (Fig. 7), Each event may involve energy in the range of 1022 to 1025 Joules.

Usually the flares last anywhere between a few minutes to more than an hour. A large flare may have linear dimension as large as 10 km and may be seen as a short-lived storm on the Sun. Thus, the most likely places of occurrence of solar flare are the regions of closely packed sunspots.

The tremendous amount of energy carried in solar flare is released in the form of X-rays, ultraviolet and visible radiation, high speed electrons and protons.

Fig.7: Solar flare

10. Conclusion

All kinds of solar activities i.e., the sunspots, prominences, flares etc., are possibly linked to the release of stored magnetic energy. It is believed that the energetic solar eruptions are caused due to coming together and merging of magnetic fields in the active regions (the phenomenon is known as magnetic field reconnection) and thereby releasing the stored magnetic energy.

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The 500,000-pound moon mystery: Our newest junkyard?

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Imagine standing on the Moon. Beyond the silver dust and craters, you would find discarded cameras, gold-plated golf balls, and over 70 abandoned spacecraft. As of 2025, humans have left approximately 500,000 pounds (227,000 kg) of material on the lunar surface. To save fuel for the return journey, missions often "ditch" heavy equipment, creating a permanent footprint of human waste.

The Science of Permanence

Unlike Earth, the Moon has no atmosphere, wind, or rain. On our planet, nature eventually breaks down or buries waste through erosion and weather. On the lunar surface, however, a piece of metal, a plastic shard, or even a footprint remains perfectly preserved for millions of years. This lack of geological activity means the Moon has no way to "clean" itself. Every mission adds a new layer of technological fossils that will stay there forever unless we intervene.

The Danger of "Kinetic Bullets"

In the Moon's low gravity, these discarded items pose a significant threat. When new rockets land, their powerful engines kick up tiny shards of old debris and lunar dust (regolith). Without air resistance to and lunar dust (regolith). Without air resistance to slow them down, these particles can travel at thousands of miles per hour across the horizon. These "kinetic bullets" are fast enough to puncture the multi-layered fabric of space suits or destroy the sensitive solar panels and sensors of new equipment. This creates a dangerous cycle: old waste makes new missions riskier.

The Kessler Risk and Future Solutions

If the lunar orbit becomes too crowded with debris, we face the Kessler Syndrome—a domino effect where one collision creates thousands of new pieces of junk, eventually making lunar travel impossible. To prevent this, global agencies are now prioritizing sustainability. Through the "Zero Debris Charter," missions are being designed for "In-Situ Recycling." This involves using advanced 3D-printing technology to melt down abandoned aluminum hulls and repurpose them into structural shielding for new lunar habitats.

Sustainable exploration is a necessity. As we reach for the stars, our responsibility is to ensure the Moon remains a laboratory for science rather than a landfill for history.

Revealing the galactic dynamics

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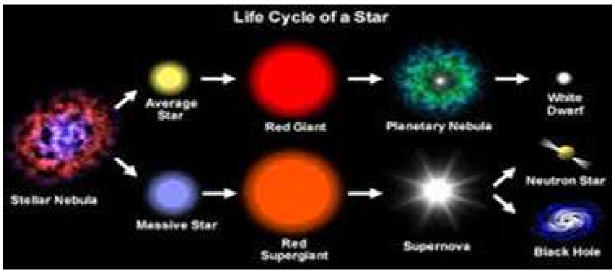
Don't everyone always think about what happened to this cosmos causing its birth. I will tell the topic of the history of this galaxy, as we all know THE BIG BANG was the cause of the birth this universe. Large amount of energy was created due to this collision. The Solar System began as a giant cloud of gas and dust which was Solar Nebula (SOLAR NEBULA HYPOTHESIS). Atoms collided with one another at tremendous speed. This event led to the generation of enormous heat and glowing celestial bodies which were Stars. Rocky and dust particles formed Rocky Planets and gaseous particles formed

Gas Giants. In this process several galaxies were formed, our galaxy is called Milky Way also known as Akash Ganga. Our neighboring and closest galaxy is Andromeda Galaxy. It is 2.5 million light years away from us. In ancient and medieval India many astronomers took interest in such explorations. In the world there were other scientists who were able to discover celestial bodies and created different theories. Like the great scientist Galileo Galilei and father of astronomy Nicholas Copernicus.

Stars are one of the lightening celestial bodies formed due to the BIG BANG. After the cooling of the matter formed in BIG BANG, the atoms of Helium and Hydrogen formed massive clouds resulting in illuminating celestial bodies, stars (Population III) . These stars lived short and exploded creating several elements in the gas for the next generation of stars .There are different types of stars- red giant, white dwarf etc. Here no stars collapse immediately as they radiate energy (loss), they shrink making them hotter.

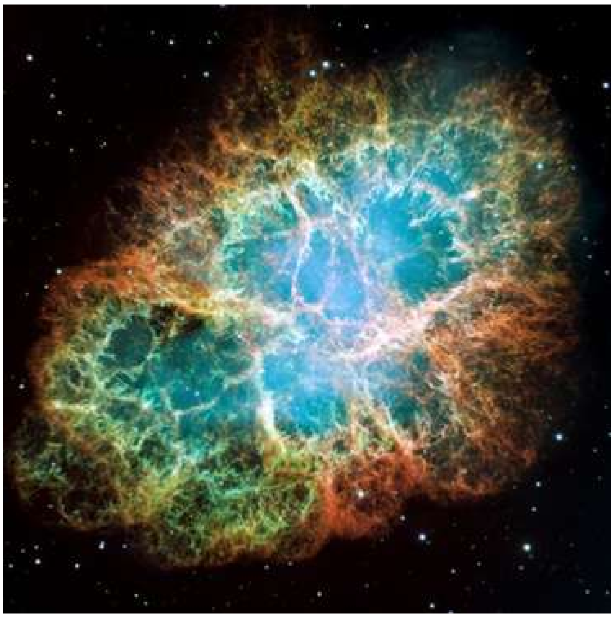
FORMULA: $2T + V = 0$ (VIRIAL THEOREM BY RUDOLF CLAUSIUS) Relate star's internal kinetic energy to its gravitational potential energy.



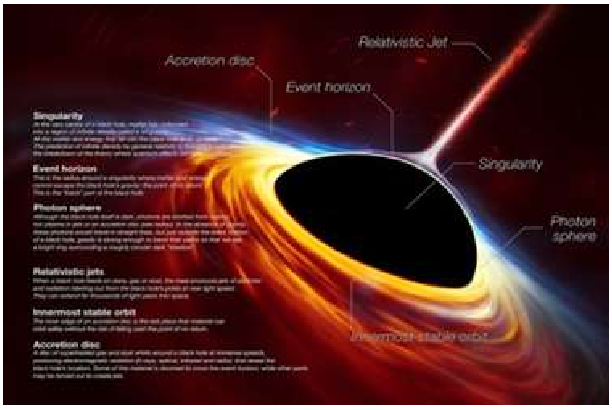
(How stars form: life of stars in six stages)

Supernova is considered last stage of a stars life, it explodes and leaves behind its traces – remnants by either forming a Black Hole or further stage of Neutron Star.

The Supernovas explode due to the exhausting nuclear fuel. The collision of two Neutron Stars also leads to the formation of Black Holes. The Black Holes slowly evaporate to form Photons and other particles. The larger mass Black Holes take more time to evaporate than the smaller mass Black Holes. Black Holes evaporate over the timescales of (HAWKING RADIATON). A Black Hole is considered dead when it losses all its mass and disappears completely.



These Black holes slowly disappear with time but when it exists it takes in the matter present at the event horizon. Even light cannot escape from the massive gravity of the Black hole. All the laws of physics break down at the center of the Black Holes due to the presence of singularity. Here in the singularity, the matter breaks down into infinite density ending space-time. Due to this, none of the theory or law can state or describe it. Here therefore, need to have quantum realm.



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Do black holes forget? : The information paradox and the true nature of gravity

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1. Introduction

Imagine writing your thoughts in a diary and then burning it. The pages disappear, the ink vanishes, and the words seem lost forever. Yet physics tells us something subtle: the information was not truly destroyed. It was transformed into heat, smoke, and ash. In principle, if every particle could be tracked perfectly, the information could still be recovered. At a fundamental level, nature does not forget.

Black holes challenge this idea.

Predicted by the General Theory of Relativity, black holes are regions where gravity becomes so intense that spacetime itself bends inward. When quantum effects are considered near these objects, an unsettling question arises: can gravity permanently destroy information? This question lies at the heart of the **Black Hole Information Paradox.**

2. Black Holes in Classical Gravity

According to classical General Relativity, a black hole forms when matter collapses beyond a critical size known as the Schwarzschild radius:

$$r_s = 2GM / c^2$$

Once this boundary is crossed, an event horizon appears. Beyond this surface, no signal can travel back to the outside universe.

A simple real-world analogy is a waterfall. A swimmer can escape upstream while the current is weak, but after crossing a certain point, return becomes impossible. Classical gravity treats the event horizon in the same way: anything that crosses it is lost forever from the perspective of an outside observer.

Within this framework, information loss seems unavoidable—and unproblematic.

3. Hawking Radiation: A Turning Point

This calm picture was disrupted when Stephen Hawking demonstrated that black holes are not perfectly dark. Quantum fluctuations near the event horizon allow black holes to emit radiation, now known as Hawking radiation.

The temperature associated with this radiation is:

$$T_h = \hbar c^3 / (8\pi GMk_\beta)$$

This result implies that black holes slowly lose mass over time.

A helpful analogy is a heated metal object placed in a cooler room. Even though it absorbs energy from its surroundings, it also radiates heat and gradually cools down. Similarly, black holes slowly evaporate through Hawking radiation.

4. Where the Paradox Appears

The paradox does not arise from evaporation itself, but from the nature of the emitted radiation.

Hawking radiation is thermal—it appears random and does not seem to carry detailed information about the matter that originally formed the black hole. If a black hole forms from a particular star, the outgoing radiation does not preserve the unique features of that star.

Returning to the diary example, this would be like burning a diary and finding that the resulting smoke contains no trace of whether the diary held poetry, equations, or personal memories.

Quantum mechanics strongly disagrees with this outcome. It requires that physical processes preserve information through unitary evolution:

$$|\psi\_{initial}\rangle \rightarrow |\psi\_{final}\rangle$$

However, black hole evaporation appears to produce:

$$|\psi\_{initial}\rangle \rightarrow \rho\_{thermal}$$

This apparent transition from a pure quantum state to a mixed thermal state violates a core principle of quantum theory. This conflict defines the Black Hole Information Paradox.

5. Rethinking Gravity

Most physicists do not believe quantum mechanics is flawed. Instead, the paradox suggests that classical gravity is incomplete.

General Relativity assumes spacetime is smooth at all scales. Yet near a black hole horizon, gravity reaches extreme strengths. Just as air appears smooth until examined at the molecular level, spacetime itself may possess microscopic structure that classical gravity cannot describe.

If spacetime has hidden degrees of freedom, information may be stored and transferred in subtle ways invisible to classical theory.

6. Entropy as a Clue

A crucial insight comes from black hole thermodynamics. The entropy of a black hole is proportional to the area of its event horizon:

$$S\_{BH} = k_B c^3 A / (4G\hbar)$$

This behaviour is unusual. For ordinary systems, entropy scales with volume, not area.

A useful comparison is digital data storage. Information on a hard drive is not stored throughout empty space but on a thin surface of microscopic structures. Similarly, black hole information appears to be associated with the horizon rather than the interior.

7. Proposed Resolutions

Several ideas attempt to resolve the paradox.

Black hole complementarity suggests that information behaves differently for distant observers and infalling observers, without contradiction. Holographic approaches propose that gravitational systems may be equivalent to information-preserving quantum theories defined on boundaries.

Firewall models argue that the event horizon may not be smooth, challenging classical gravity. Soft-hair proposals suggest that black holes carry subtle quantum imprints that slowly leak information.

While no single solution is universally accepted, most modern approaches agree that information is not truly lost.

8. Why This Matters

The information paradox is not just a theoretical puzzle. It reshapes how physicists think about black holes, spacetime, and gravity itself. Black holes may not be cosmic destroyers of information, but highly complex systems that process and encode it in unfamiliar ways.

9. Conclusion

The Black Hole Information Paradox reveals that gravity is more than a force of attraction—it is deeply connected to information and entropy. Black holes do not simply erase the past; they challenge our classical understanding of spacetime and push us toward a deeper theory of gravity.

By asking whether black holes forget, we may ultimately learn how gravity remembers.

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The illusion of time – From daily life to depths of space

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What is time really? Is it just the ticking of the clock? Or something beyond just some fat and slim needles changing positions. Maybe time is just our way of making sense of something we call a 'change'. Sometimes a minute feels like an hour, and an hour passes in a few minutes . That is because our brain's sense of time isn't perfect; it stretches and shrinks based on how much attention we pay and how engaged we are. Scientists call this psychological time – it's our personal experience, not the clock's. Unlike the speed of light, time depends on the frame of reference; it can bend, stretch, and even freeze in certain cases. The relativity of time isn't bound to just the interstellar space but also our everyday life, yet only a few notice.

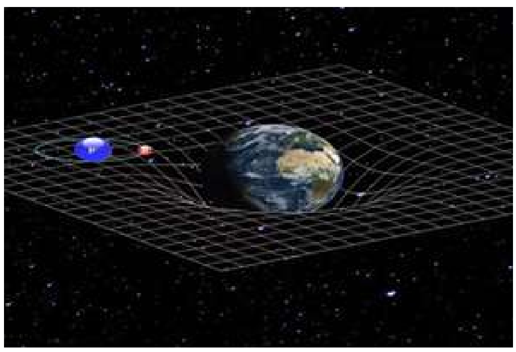
Time is a relative- the illusion of space–time

The understanding of physics shows that even at everyday speeds and conditions, time is not absolute but relative. A well-known example involves travelers moving at high speeds, such as passengers on a fast-moving train.

Suppose both the traveller and the stationary observer on the platform carry precise watches that seem to tick normally from their perspectives. Yet, when the traveler returns, their watch will record slightly less elapsed time than the stationary observer's. This phenomenon, called ***Time Dilation***, arises because time slows down for objects in motion relative to the stationary observer. But time's strange tricks don't stop on Earth – out in the vast cosmos, where speeds race close to the universe's ultimate limit, this time dilation get more and more affective, and time slow down . Relative speed race close to the universe's ultimate speed limit.

Gravity -The Game Changer

Gravity to our understanding, is often limited to the idea of some force pulling us towards ground and something pulling massive objects together. However, as I learned more about this occurrence, my understanding of gravity has slightly evolved. I realized that gravity is far more and complex than just a pull initially taught by Sir Isaac Newton – it's a fundamental aspect that changes the fabric of space-time.



According to Einstein, time and space are connected in something called space-time. The speed of light is constant for everyone, in the whole universe as its not limited to the frame of reference and individual perception. This speed is not just for photons but for all those particles which have zero rest mass. Imagine space-time as a trampoline. When a massive object, like a planet or a star, sits on the trampoline, it causes a dip or curve in the fabric.

This curvature in space-time is what we perceive as gravity. This occurrence certainly changes the "rules" of how objects really move and also how time flows as Sir John wheeler said 'it not only affects the motion of celestial objects but also it directs the path of light and the passage of time'. Gravity slows down time, stronger the gravity, slower the time. This effect known as ***gravitational time dilation***. It has been measured on earth with ultra precise atomic clocks at different heights–the one closer to the ground ticks a tiny bit slower.

Reaching a speed closer to the speed of light or to be around a gravitationally dense body like a black hole, slows down time for you as compared to the person far away standing still. Even on earth, where speeds are much slower than the speed of light, time still behaves in a relative way.

Astronauts on the International Space Station experience measurable time dilation. Their high orbital speed causes their clocks to run slower due to special relativity, while being farther from Earth's gravity causes their clocks to run faster due to general relativity. Over a six-month mission, the net effect is that astronauts age about 0.005 seconds less than people on Earth—tiny, but exactly as Einstein's theory predicts.

Time dilation in other celestial bodies

With only 16% of Earth's gravity, time on the surface of Moon runs slightly faster than on Earth. But even if gravity and time are related, the difference in time is fractions of seconds over years. But here comes the bigger picture. What if we are talking about super-distant objects not belonging to a solar system ?

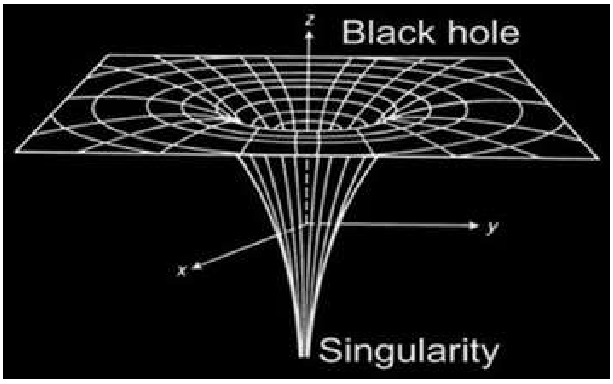
Let's imagine a planet, "C", in a neighboring solar system of the Milky Way. And through photometry or spectroscopy, we can observe its rate of rotation and, when combined with orbital data or physical models, estimate its mass, which gives us an idea of its gravity. Those planets in the neighboring solar system could have surface gravities higher or lower than the strongest or weakest planets in our solar system. For example, some supermassive exoplanets may have gravity stronger than Jupiter, while smaller ones may have gravity, weaker than Mercury. For example, astronomers have discovered exoplanets like ***Kepler-22b*** in other solar system. We can observe its orbit and estimate its mass, but we can't directly measure its surface gravity or how time would flow there locally. So any time dilation calculations would carry quantified uncertainties based on observational limitations.

As we shift our observation to a different solar system, it might feel like a place with different physical behavior related to ours for sure, but not exactly the 'exact' we define in our earthly language.

In a different galaxy- Lets imagine cosmos farther than Voyager 1. A different galaxy might as well seem like a whole new universe from a human perspective. Even though we haven't explored it the way we have explored our solar system, time still vary place to place. Time depends on two main things; a speed related to the speed of light and the strength of gravity. Understand that gravity itself depends on mass. The bigger or denser an object, the stronger its gravity and the more it can slow down time. But there is always room for one or more contradictions in science. Just by observing the outer structure of an interstellar body, we can't directly assume its mass. Take black holes before they are finally observed. They might look smaller than the tiniest moon to ever exist, but yet their mass would be greater than many stars.

Who's to say there aren't other mysterious bodies like this in space waiting to challenge our intuitive expectations about our knowledge of size, mass, gravity, certainty, and uncertainty like black holes did over the centuries?

Black hole and its strong gravity - And now talking about black holes, the strangest, yet incredibly fascinating frontier of time dilation. The gravity near a black hole is considerabely insane. So intense that even light cannot escape, and particles of light being mass-less suggests how strong its gravity is. Imagine putting a 15kg iron ball in a stretched trampoline. The trampoline takes a huge dip and stretches. Now imagine something millions of times heavier. That's how a black hole bends space and time around it. Now in this case, the trampoline would surely break. But space isn't a trampoline, instead, It reacts in an unbelievably strange way. The dip caused by a black hole is so extreme that it reshapes every rule of physics for anything moving around it.



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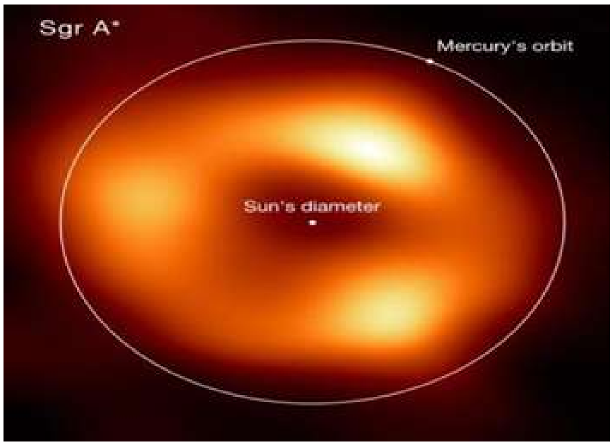
And that's why time starts showing significant variations near the curve.

Earlier we were talking about time dilation in tiny fractions, milliseconds, seconds, maybe days, for as far it could go. But now we're entering a realm when time could stretch into thousands or even millions of years, depending on how close you dare to get to a black hole's gravity. This is where we witness the most extreme gravity that humanity has ever explored. Nothing in our solar system or even nearby stars come close to the sheer strength of black holes.

Let's take an example of a real-life black hole and surprisingly in order to find one,We don't have to cross galaxies or travel through intergalactic spaces. Right at the heart of our very own Milky Way, lies a supermassive black hole known as ***Sagittarius A.***

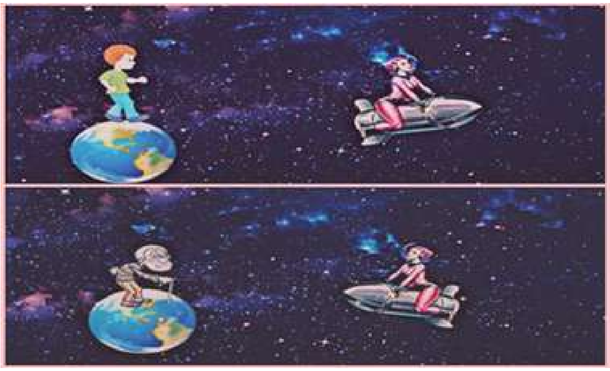


Located approximately 27,000 light years from Earth, having mass about 4 million times than that of Sun, yet its diameter is approximately about 17 times larger than the Sun. Perhaps its monstrous size and mind bending effects it remains quiet.

So, the question arises, what is it like to experience the traumatic time dilation in a black hole?

Getting eaten by a black hole - Imagine you are in two positions, yourself A and yourself B. A, standing at a safe distance, observing the black hole Sagittarius A, slowly moving towards the event horizon. From A's perspective, everything about B slows down. As he moves towards the event horizon, he watches B wave in almost frozen slow motion, gradually getting blurry, and eventually seeming to vanish.

But for B, time feels normal. Seconds tick like usual. Hypothetically considering B to be immune to everything, If B could look back, he would see years of centuries or even thousands of years pass in the universe in what feels like moments depending on how close B is to the event horizon. To B, it's like watching a Cosmos video in 2x speed or even faster, just before being swallowed into the pool of nothingness as the black hole's gravity takes hold. And that's how time works in these bodies. In their own frames, both A and B experience time normally. However, B sees A's time running slower, while A and B's time running faster. If A crosses the event horizon, he is lost from B's view, since even light cannot escape the black hole. According to general relativity, the information about A appears lost, leading to the black hole information paradox, because quantum mechanics suggests that information can never be completely destroyed.



From tiny dilatations in ISS, to slightest slowdowns on planets, and all the way to mind-bending stretches of time in black holes, the universe shows us that time is never absolute, but an illusion. No matter how much we explore, the truth is real for we never get past exploring even 1% of what the universe conveys.

Maybe there is a cosmic body with completely different rules. Even beyond that, we assume reality to be, perhaps, in a different universe.What I have written may sound like a wild rant in a different universe, but to my limited human brain, black holes remain the section of the cosmos that makes time dilation truly fascinating.

The most intense magnets in the universe: The life and times of a magnetar

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In the vast zoo of celestial objects, few are as terrifying or as fascinating as the magnetar. A specialized subspecies of neutron star, a magnetar possesses a magnetic field so powerful that it defies conventional terrestrial physics. To put their strength in perspective: if a magnetar were located halfway to the Moon, it would instantly wipe the data from every credit card on Earth and strip the atoms from your body.

The life cycle of these "magnetic monsters" is a brief, violent, and brilliant journey through the extremes of space and time.

1. The Violent Birth: A Supernova Preamble

The story of a magnetar begins not at its birth, but at the death of a massive star—specifically one about 10 to 25 times the mass of our Sun. When such a star exhausts its nuclear fuel, it can no longer support its own weight against gravity. The core collapses in a fraction of a second, while the outer layers are blasted away in a Type II supernova.

What remains is a neutron star: an object the size of a city but with the mass of a sun. However, for a neutron star to become a magnetar, specific conditions must be met during this collapse. Scientists believe the progenitor star must be rotating extremely rapidly. As the core shrinks, a "dynamo" effect occurs. Through a combination of rapid rotation, convection, and heat, the internal magnetic field is amplified by a factor of a thousand, reaching strengths of up to 10^{15} Gauss.

2. The Anatomy of Power

Once formed, the magnetar is a dense ball of neutrons wrapped in a solid "crust" of iron nuclei. Its defining characteristic is its magnetic field, which is roughly a trillion times stronger than Earth's. This field is so intense that it compresses the electron clouds of atoms into long, thin cylinders, fundamentally changing the chemistry of matter.

Unlike "normal" pulsars, which are powered by their rotation, a magnetar is powered by the decay of this magnetic field. The field lines are inextricably "frozen" into the ultra-dense crust. As the magnetic field evolves, it exerts a mechanical stress on the crust, leading to the magnetar's most famous—and dangerous—behavior.

3. The "Active" Years: Starquakes and Giant Flares

A magnetar's youth is marked by extreme volatility. Because the magnetic field is under immense tension, it occasionally snaps or rearranges itself, much like tectonic plates on Earth. This causes a "starquake."

When the crust cracks, it releases a gargantuan amount of energy in the form of X-rays and gamma rays. These are known as Soft Gamma Repeaters (SGRs). In 2004, a giant flare from the magnetar SGR 1806-20 was so bright that it actually physically affected Earth's upper atmosphere, despite being 50,000 light-years away. In a tenth of a second, it released more energy than the Sun emits in 150,000 years.

4. The Brief Prime

One of the most tragic aspects of a magnetar is how quickly it burns out. Because they radiate so much energy through their magnetic fields and wind, they "brake" very quickly. While a standard neutron star might spin hundreds of times per second, magnetars typically rotate once every 2 to 12 seconds.

The energy required to maintain such a monstrous magnetic field is finite. The very field that makes the magnetar special is also the engine of its own destruction, constantly bleeding energy into space. Consequently, the "active" phase of a magnetar—where it emits these brilliant X-ray bursts—only lasts about 10,000 years. In cosmic terms, that is the blink of an eye.

5. Retirement: The Quiet Fade

As the magnetar ages, its magnetic field decays and stabilizes. The starquakes cease, and the brilliant flares go dark. It doesn't disappear, but it becomes "dead" to our telescopes. It transforms into a cold, dark neutron star, drifting through the galaxy as a silent tombstone of the violent star it once was.

Because their active life is so short, astronomers estimate there are millions of "extinct" magnetars in the Milky Way, even though we have only identified about 30 active ones to date.

6. Why Magnetars Matter

Studying the life cycle of magnetars isn't just about cataloging weird space objects; it is about testing the limits of physics. Magnetars are the only laboratories in the universe where we can observe how matter behaves under extreme magnetic pressure. They are also leading candidates for the source of **Fast Radio Bursts (FRBs)**—mysterious signals from deep space that have baffled scientists for years.

The magnetar reminds us that the universe is not just a collection of quiet stars and planets, but a place of dynamic, high-energy transitions where the laws of nature are pushed to their breaking point.

Gigantic Intergalactic Gas Bridge Connects Two Galaxies

Astronomers have discovered a gigantic bridge of gas connecting two distant galaxies, stretching across vast intergalactic space. This enormous structure is mainly composed of hydrogen gas and extends for hundreds of thousands of light-years between the galaxies.

Such bridges form when galaxies interact gravitationally, pulling streams of gas from each other. These gas flows can trigger new star formation and influence the evolution of the galaxies involved.

Black holes: From stellar death to the geometry of spacetime

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Astronomy reminds us how little we truly know. For every question answered, several new ones arise. What exactly is dark matter? Will the expansion of the universe continue indefinitely, or will future dynamics alter its fate? Among the most compelling objects that raise such questions are black holes, where known physical laws are pushed to their limits.

What Is a Black Hole?

A black hole is a region of spacetime in which gravity is so intense that no form of matter or radiation can escape once it crosses the event horizon. This extreme gravitational field arises when a massive amount of matter is compressed into a very small volume, causing spacetime curvature to diverge. Black holes are solutions to Einstein's field equations and represent a fundamental prediction of general relativity rather than hypothetical objects.

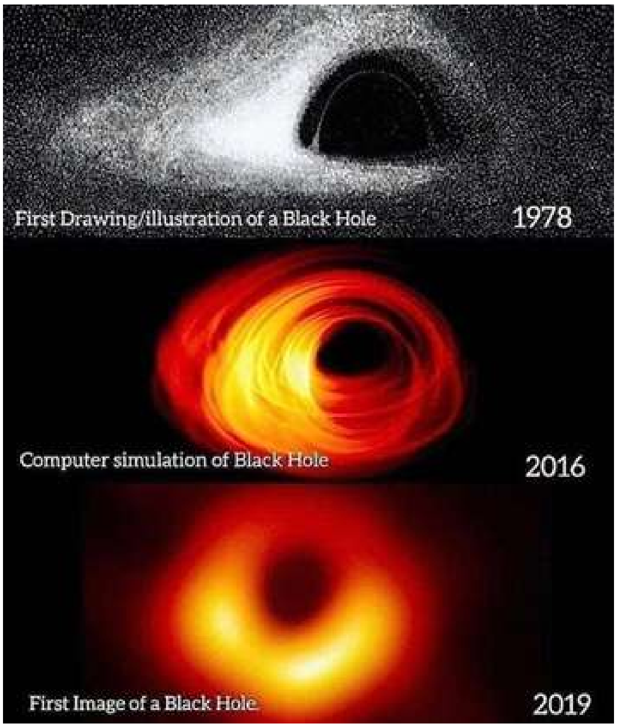
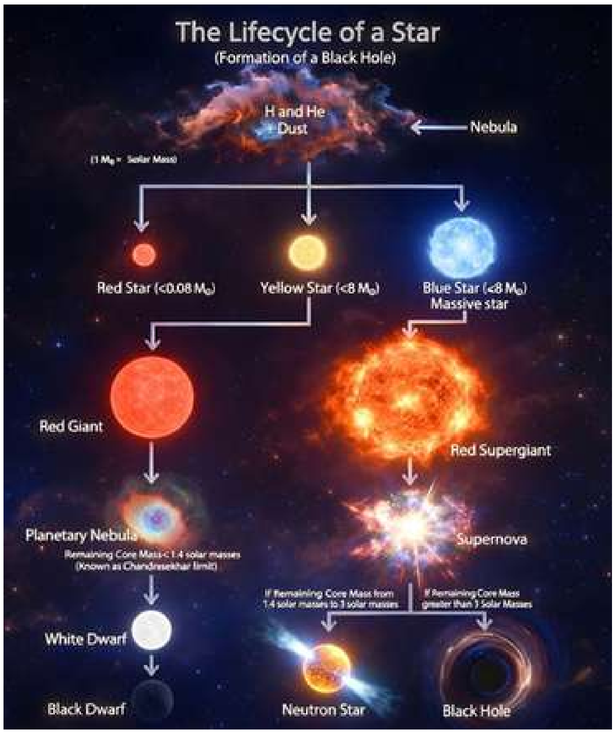


Photo source : Google

Life Cycle of a Star and Supernovae

Stars form from collapsing clouds of gas and dust and spend most of their lifetimes fusing hydrogen into helium. This nuclear fusion provides outward pressure that balances gravitational collapse. When a massive star exhausts its nuclear fuel, this balance is disrupted, leading to core collapse. The outer layers are expelled violently in a supernova explosion, while the core may collapse into a neutron star or, if sufficiently massive, a black hole.



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Pulsars

Pulsars are rapidly rotating neutron stars formed after supernovae. They emit narrow beams of electromagnetic radiation due to their strong magnetic fields. As the star rotates, these beams sweep across space, producing highly regular pulses. Pulsars serve as precise cosmic clocks and provide valuable insights into strong gravity, dense matter, and relativistic effects, often acting as observational precursors to black hole formation.

Sagittarius A and the Milky Way

At the center of the MilkyWay lies Sagittarius A, a supermassive blackhole with a mass millions of times that of the Sun. Its presence is confirmed through the precise measurement of stellar orbits near the galactic center. These observations provide one of the strongest pieces of evidence for black holes and offer an exceptional opportunity to test general relativity in the strong-field regime.

Why Time Behaves Like Space Near a Black

Near the event horizon of a black hole, spacetime curvature becomes so extreme that the roles of space and time effectively interchange. Outside the horizon, motion through space is optional while motion through time is inevitable. Inside the horizon, the radial direction becomes time- like, meaning movement toward the singularity is unavoidable, just as the passage of time is unavoidable in normal spacetime. This behavior is a geometric consequence of general relativity rather than a force-driven effect.
Hole

Laws of Black Hole Mechanics

Black holes obey a set of laws analogous to thermodynamics, revealing deep connections between gravity, energy, and entropy.

1. **Zeroth Law :** The surface gravity $\varkappa$ is constant over the entire event horizon of a stationary black hole. $\varkappa$ = constant

2. F**irst Law :** The change in mass of a black hole is related to changes in horizon area, angular momentum, and electric charge.
$dM = (\varkappa / 8\pi G)\, dA + \Omega\, dJ + \Phi\, dQ.$

   where M is mass, A is horizon area, J is angular momentum, Q is charge, Ω is angular velocity, and Φ is electric potential.

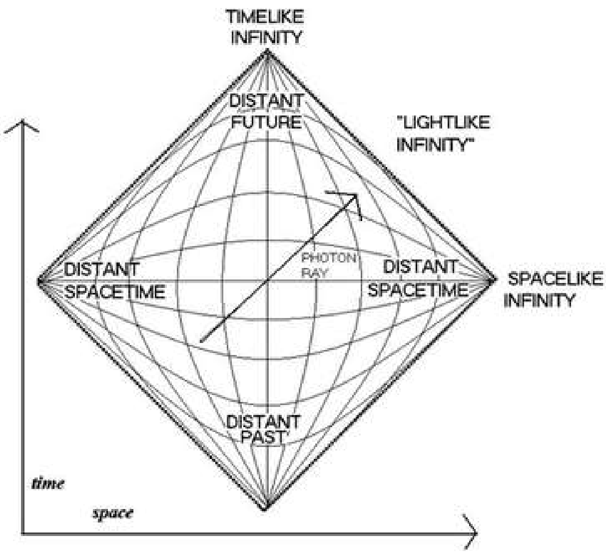
3. **Second Law :** The area of the event horizon never decreases in any classical physical process.

   $dA \geq 0$. This mirrors the second law of thermodynamics, suggesting that horizon area corresponds to entropy.

4. **Third Law :** It is impossible to reduce the surface gravity of a black hole to zero through any finite physical process. These laws form the foundation of black hole thermodynamics.

Penrose Diagram and Theory

Penrose diagrams provide a compact representation of spacetime that preserves causal structure. They allow infinite regions to be visualized on a finite diagram and clearly illustrate event horizons, singularities, and light paths. Penrose's work was crucial in understanding gravitational collapse and proving the inevitability of singularities under general conditions.



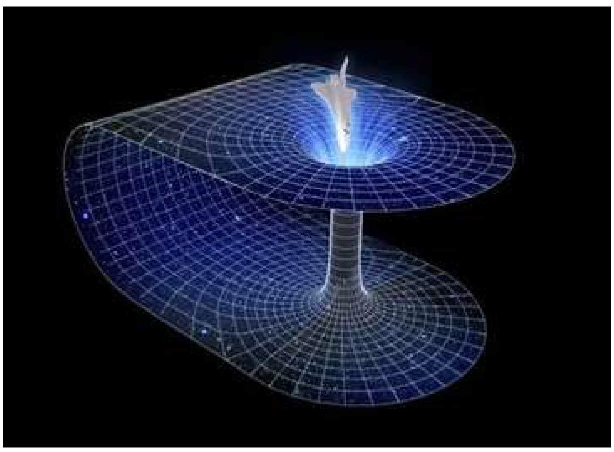


Photo source : Google

Minkowski Spacetime

In the absence of gravity, spacetime is described by Minkowski geometry, where space and time form a flat four-dimensional continuum. Black holes arise when mass-energy curves this spacetime significantly. General relativity extends Minkowski spacetime to curved geometries, allowing black holes to exist as exact solutions.

Conclusion

Black holes are among the most extreme and informative objects in the universe. They are born from stellar death, dominate galactic centers, and obey precise mathematical laws that connect gravity, thermodynamics, and quantum theory. Yet they also conceal regions where existing physical theories fail.

In this way, black holes act as both confirmations of known physics and signposts toward new discoveries. Each observation, whether through stellar motion, pulsars, or gravitational waves, refines our understanding while revealing deeper mysteries. Studying black holes is not merely about understanding collapse and gravity, but about uncovering the fundamental structure of spacetime itself.

[**Acknowledgement :** The concepts discussed in this article are partly based on insights gained during an academic workshop attended at the Indian Institute of Science (IISc), Bangalore. Additional understanding was developed through standard texts such as A Brief History of Time by Stephen Hawking and A First Course in General Relativity by Bernard Schutz.]

The enigma of ‘oumuamua

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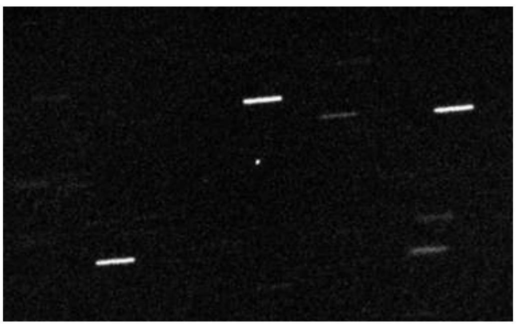
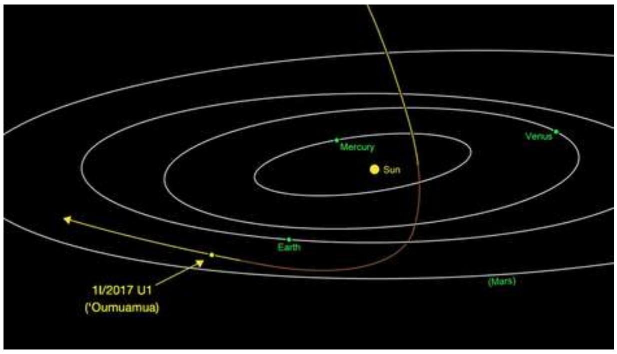
For centuries, interstellar objects were only theoretical. On October 19, 2017, the Pan-STARRS telescope in Hawaii detected a faint object moving across the sky. Nothing about it seemed extraordinary until its orbit was calculated. Instead of following a closed ellipse around the Sun, its path was hyperbolic. Its eccentricity was about 1.2, well above 1.0, confirming an unbound trajectory. This was enough to conclude that the solar system was not its home. By the time astronomers realized what they were tracking, ‘Oumuamua, Hawaiian for “messenger from afar,” was already fading into darkness.



Real detection frame from Pan-STARRS/Hubble: a faint object moving.

Image Credit: Alan Fitzsimmons / QUB / ING / IAC Source: NASA APOD



Oumuamua's hyperbolic trajectory through the solar system
Credits: NASA/JPL-Caltech/IAU

Most asteroids are roughly spherical, lumpy like potatoes. Instead, ‘Oumuamua was like a cigar, ten times longer than it was wide. Its extreme elongation with an aspect ratio exceeding 10:1 was far beyond typical asteroids. Its brightness varied by a factor of 10, strongly suggesting an extreme shape that was unlike typical Solar System bodies.

As it passed the Sun, ‘Oumuamua was accelerating. But not only due to gravity. Conventionally, this means outgassing: ice heating up and venting gas acts like thrust. But this wasn’t the case here. No gas plume, no dust, and no thermal emission were detected. These observations challenged conventional models of small-body behaviour.

Comets accelerate as ice vaporizes and provides thrust, leaving behind a tail, ice cloud, or observable jets. Asteroids do not accelerate this way. So ‘Oumuamua did two things that shouldn't happen together: acceleration and absence of tail. It sped up like a comet but looked clean like an asteroid. These anomalies demanded explanation. Each anomaly alone might have been explainable. Together, they broke the rules.

One of the most controversial interpretations came from Avi Loeb, founding director of Harvard's Black Hole Initiative and former chair of Harvard's astronomy department. He presented a thesis that proposed ‘Oumuamua as a piece of extraterrestrial debris: a light sail or a fragment of it. A light sail works like a sailboat's sail but catches photons instead of wind, using radiation pressure for thrust. Loeb proposed ‘Oumuamua as a light sail due to its elongated, flat shape that maximized surface area for photon pressure. This explained two anomalies: shape and acceleration. The hypothesis quickly became a global headline given it came from a credentialed Harvard astronomer. Scientists disagreed. Citing Carl Sagan’s principle, ‘extraordinary claims require extraordinary evidence.’ Loeb had anomalous observations, but not proof.

Other astronomers considered a simpler possibility: ‘Oumuamua was just an unusual comet with outgassing we couldn't detect. Some proposed natural alternatives that didn’t involve extraterrestrial technology. In 2020, Darryl Seligman and Gregory Laughlin proposed a hydrogen ice hypothesis. Hydrogen would evaporate invisibly as the object warmed near the Sun, creating thrust. In 2021, Alan Jackson and Steven Desch proposed ‘Oumuamua was a chunk of nitrogen ice from a Pluto-like exoplanet. Nitrogen could sublimate in a way that produces little visible dust. This explained the oddities of acceleration and absence of a comet tail.

Scientists preferred the natural explanations. It’s simple: when you have two competing hypotheses- a natural rare phenomenon vs. a first-ever alien artifact, you go with the precedented one. Loeb’s critics referred to Occam’s razor: simpler explanations beat extraordinary ones without extraordinary [OA1] proof. Loeb had anomalies; his critics had the entire history of astronomy finding natural answers to cosmic mysteries.

The Vera Rubin Observatory in Chile
Credits:
RubinObs/NOIRLab/SLAC/NSF/DOE/AURA

‘Oumuamua is long gone, hurtling back into interstellar space, and the questions it raised remain unanswered. But it revealed something important. It exposed how blind we were to interstellar passersby; how primitive our detection systems were and how slow our response times were. But we've evolved. The Vera Rubin Observatory now scans the entire sky every three nights with automated detection systems built to catch what we once missed. We found a second visitor: 2I/Borisov in 2019. We actually studied it this time. Protocols now exist, and telescopes are better prepared for the next visitor. We’re ready. Somewhere in the galaxy, another interstellar traveller has begun its journey through the void. When it arrives, we will study it for what science represents: a way of reaching beyond ourselves.

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Navigating invisible maps: When planetary magnetism guides life

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Reaching a destination has become one of the most routine acts of modern human life & rarely needs an understanding of direction. A location typed into a phone is enough to guide movement through unfamiliar streets and cities. Navigation, once a skill shaped by memory, intuition, and environmental awareness, is now outsourced to technology that continuously interprets the planet on our behalf.

Long before humans learned to locate themselves using Earth-orbiting satellites, navigation was already embedded within the living world. Today, our dependence on GPS systems and digital maps feels natural, almost invisible, yet these technologies rely on principles that are far older than human innovation. At their foundation lies Earth's magnetic field — an invisible planetary force that has shaped the behaviour, movement, and survival of life for millions of years.

Earth's magnetic field provides a global framework for orientation, allowing direction and position to be defined consistently across space and time. Human technology does not invent this framework; it merely decodes it. Stars, galaxies, and planets all generate magnetic fields through the movement of electrically conductive material.

On Earth, this field arises from the geodynamo — the convective motion of molten iron within the Earth's outer core, sustained by heat from radioactive decay and residual energy from the planet's formation. Without a stable magnetic field, Earth may have evolved in a significantly different manner, as suggested by comparisons with planets like Mars.

Yet the magnetic field is not only a planetary shield. It is also a source of information.

For certain organisms, Earth's magnetic field is not an abstract geophysical phenomenon but a biologically meaningful signal — one that can be sensed, interpreted, and used to guide behaviour. Among the most compelling examples of this intimate relationship between planetary physics and biology are sea turtles.

Sea turtles (Superfamily: Chelonioidea) are among the most striking examples of how a planetary physical force can become biologically meaningful. Their survival, migration, and evolutionary success reveal how life can adapt to forces operating on planetary — and ultimately cosmic — scales.

Figure 1: Hawksbill Turtle (*Eretmochelys imbricata*)

Navigational Framework

Sea turtles inhabit vast oceanic environments where visual landmarks are scarce and chemical cues disperse rapidly. Species such as the Loggerhead Sea Turtle (*Caretta caretta*), Green Sea Turtle (*Chelonia* *mydas*), Hawksbill Turtle (*Eretmochelys imbricata*), and Leatherback Turtle (*Dermochelys coriacea*) undertake migrations across open oceans.

After hatching on sandy beaches, young turtles disperse into the open ocean, often travelling thousands of kilometres before returning — sometimes decades later — to reproduce near their natal sites. Despite differences in ecology and size, all share a life history defined by long-distance migration. These journeys raise a fundamental question: how do sea turtles navigate such vast, featureless spaces with remarkable precision?

Such navigational precision is difficult to explain using conventional sensory cues alone. Research over the past several decades has demonstrated that sea turtles possess a magnetic sense, allowing them to detect variations in Earth's magnetic field and use these variations as a global positioning system.

From a physical perspective, Earth's magnetic field varies predictably in two key parameters: intensity and inclination. Together, these parameters form a spatial grid across the planet. Sea turtles can detect both, effectively providing them with positional information across ocean basins.

Biological Basis of Magnetoreception

Sea turtles do not consciously "read" magnetic fields. Instead, magnetism is translated into biological signals through specialised sensory mechanisms — a phenomenon known as magnetoreception.

Although the precise sensory structures responsible for magnetoreception in sea turtles remain under investigation, two main mechanisms have been proposed based on animal research. The first involves magnetite-based receptors, microscopic iron-containing particles that physically align with magnetic fields and exert mechanical forces on surrounding cells. The second is a light-dependent chemical mechanism, in which magnetic fields influence photochemical reactions within light-sensitive proteins, altering neural signalling.

The influence of magnetism begins early in a sea turtle's life. Hatchlings of Loggerhead Sea Turtle (*Caretta caretta*) entering the ocean face a high risk of mortality, with correct orientation determining survival. Research shows that juvenile turtles respond to geomagnetic cues, allowing them to orient toward oceanic regions that enhance growth and reduce predation [1].

At this stage, magnetism functions as a directional guide rather than a detailed map. Nevertheless, it provides a crucial survival advantage. Individuals who fail to interpret these cues correctly are less likely to survive, ensuring that sensitivity to geomagnetic information becomes subject to natural selection.

Behaviour Across the Life Cycle

Magnetic navigation plays different roles at different stages of a sea turtle's life, shaping behaviour from birth to reproduction.

For hatchlings, magnetic cues guide offshore movement, reducing the risk of remaining in predator-rich coastal waters. Newly emerged Leatherback hatchlings (Dermochelys coriacea) enter the ocean under low-light conditions with minimal visual guidance, relying largely on Earth's magnetic field to orient offshore during their earliest and most vulnerable life stage. (Fig. 2)

During juvenile stages, turtles use magnetic information to maintain their position within favourable ocean currents, avoiding displacement into unsuitable habitats. As adults, turtles rely on the same magnetic sensitivity to undertake long-distance migrations between feeding grounds and nesting beaches.

Notably, sea turtles do not navigate to a single fixed point. Instead, they navigate to magnetic regions — areas defined by particular combinations of magnetic intensity and inclination. This strategy provides flexibility, allowing turtles to reach suitable habitats even as coastlines shift and environmental conditions change over time.

Navigation, therefore, is not a single behaviour but a lifelong process shaped by ecological demands, integrated across development, physiology, and environment.

Figure 2: Baby Leatherback Hatchling

Evolutionary Shaping of Magnetic Navigation
The ability to use Earth's magnetic field did not arise suddenly. Over evolutionary time, natural selection acted on behavioural outcomes such as survival, successful migration, and reproduction.

Sea turtles take several decades to reach sexual maturity. Individuals unable to navigate effectively were less likely to survive early dispersal, locate feeding grounds, or return to nesting areas. In contrast, turtles that responded appropriately to magnetic cues had higher reproductive success, gradually refining magnetoreceptive abilities across generations. As a result, Earth's magnetic field acts as an evolutionary constraint, shaping behaviour and population structure [2].

Because Earth's magnetic field remains relatively stable over geological timescales, it provides a reliable environmental framework for such navigation systems to evolve. Magnetism thus acted as an evolutionary constraint that life learned to exploit.

Sea turtles represent the outcome of this long evolutionary dialogue between biology and planetary physics.

Breaks in a Magnetically Structured Life Cycle
While Earth's magnetic field has remained stable for millions of years, the biological systems built upon it are vulnerable. Human activities increasingly disrupt the biological systems that depend on them. Coastal development, artificial electromagnetic noise, and habitat alteration interfere with navigation and nesting. Among the most direct threats is the illegal trade of sea turtles.

Sea turtles are particularly sensitive to disruption because their life cycle depends on precise timing, long-distance movement, and delayed reproduction. Illegal hunting and trade — for meat, shells, eggs, and traditional products — remove individuals from populations that rely on long-term survival to remain stable.

Because sea turtles take decades to mature, the loss of adults has disproportionate consequences. Individuals removed from populations are not merely lost organisms; they represent the loss of navigational knowledge embedded through development and evolution. Magnetic imprinting cannot fulfil its role if turtles are harvested before completing reproductive migrations.

Illegal trade thus disrupts more than population numbers. It breaks an evolved relationship between planetary-scale physical cues and biological behaviour.

Research from the Caribbean coast of Costa Rica shows that this disruption is not driven primarily by tradition, but by socioeconomic vulnerability, including poverty, unemployment, drug dependency, and weak enforcement. Poaching and egg theft are often concentrated among a small subset of marginalized individuals, highlighting how human social systems can fracture biological processes rooted in planetary physics [3].

Applications & Implications
While sea turtle magnetoreception has not yet been directly translated into everyday technology, it already plays an important role in conservation science, helping researchers identify migratory corridors and protect critical nesting regions. At the same time, the remarkable ability of turtles to navigate using Earth's magnetic field continues to inspire studies in neuroscience and bio-inspired navigation, with potential future applications in low-energy navigation systems and sensitive magnetic sensors.

Beyond Earth, these findings also inform astrobiology by highlighting how stable planetary magnetic fields may be essential for supporting complex, mobile life.

Conclusion: Reading the Invisible

Sea turtles do not simply move through the ocean — they read the planet. Their survival, migration, and evolution are shaped by an invisible magnetic field generated deep within the Earth and influenced by cosmic forces.

In following magnetic lines across open oceans, sea turtles remind us that the forces shaping the universe also shape life — quietly, invisibly, and with remarkable precision.

Through magnetoreception, neural processing, behaviour, and evolution, sea turtles transform Earth's magnetic field from a physical phenomenon into a biological guide. In doing so, they bridge scales from the planetary to the neural, from astrophysics to zoology, and reveal a profound truth: life does not merely exist on a planet; it adapts to its physics.

As we search for life beyond Earth and work to conserve life upon it, sea turtles offer a quiet but powerful lesson: to understand life fully, we must understand the worlds that shape it.

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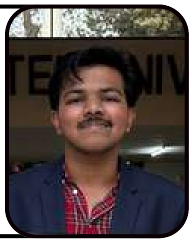
Measuring time in ancient India: A space-time-motion approach



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Ancient Indian scholars developed a sophisticated system of timekeeping based on astronomical observations, geometric principles, and precise instrumentation. Central to this system were experiments conducted during solar (*Suryagrahan*) and lunar (*Chandragrahan*) eclipses, which were regarded as critical junctures for temporal and spatial measurements. These experiments, rooted in mathematical rigor and empirical validation, began two days prior to the actual eclipse to ensure accuracy.

The Shankhu: A Geometric Instrument for Time Measurement

The primary instrument used was the ***Shankhu***, a conic-shaped device modelled after the conch shell. This instrument embodied advanced mathematical concepts, including conic sections, analytical geometry, and algebraic principles. The *Shankhu* stood 24 *angulas* (an ancient unit of measurement) in height, with 6 *angulas* embedded underground and 18 above, ensuring stability. Its surface was polished to a mirror-like finish to reflect sunlight accurately.

A critical feature of the *Shankhu* was its vertical axis, aligning precisely with the zenith and nadir. This alignment established a coordinate system where the horizontal plane (x-axis) intersected the vertical axis (y-axis) at a perfect right angle, an early application of Cartesian geometry. On equinox(comes twice a year in India during Diwali and *Gudi Padwa* festival) the sun, moon and earth are in a straight line which forms a linear equation. The credit for linear algebra goes to German Mathematician H. Grassmann and Hamilton who did this work. When sunlight struck the *Shankhu*, it cast shadows that helped determine direction and time.

The Experimental Procedure

Experiments commenced at sunrise, but the first reliable measurement was taken at *Ardha Suryodaya* (when half of the Sun's disc was visible) rather than at the first ray, ensuring greater precision. Similarly, evening measurements were recorded at *Ardha Astamana* (half-sunset). Along with sun, half moon and half earth is also as there is spatiotemporal geometrization on eclipses it is similar to what Dr Albert Einstein said in general and special theory of relativity which was done much before in India.

To establish cardinal directions, four observers were stationed at the east, west, north, and south, with a fifth individual overseeing the process from the centre. The following steps were undertaken:

1. **Shadow Tracing:** The morning shadow of the *Shankhu* fell westward, while the evening shadow extended eastward.

2. **Directional Calibration:** Since a 12-hour gap (though not exactly 12 hrs every time as Earth's axis is tilted) between morning and evening introduced errors, circles were drawn from the shadow points, intersecting to determine true north and south (akin to a Venn diagram). From finding southwest direction the north and south was determined.

3. F**our-Dimensional Considerations:** Practically Earth is 3 dimensional but 4^{th} dimension which is of time (theoretically) is necessary as here we are dealing with time. It has been done by Riemann, Gauss, Einstein and Minkowski. Earth's axial tilt necessitated a spherical, dynamic model incorporating zenith, nadir, and all cardinal directions.

Philosophical and Mathematical Foundations

The methodology was deeply influenced by Aryabhata, Varahmira, Vedic and Yogic thought.

Patanjali's Yoga Sutra (3.15) states:
"Kramanyatvam parinamanyatve hetuh"
("The succession of changes is the cause of different modifications.")

This principle underscores that changes in direction, time, and motion are interconnected. Time was not measured directly but inferred through spatial observations—a fusion of geometry, topology, complex numbers and astronomy.

The **Bhagavad Gita (8.26)** further elaborates on this duality:
"Shukla-krishne gate hyete jagatah shashvate mate, ekaya yaty anavrittim anyayavartate punah."
("There are two paths in this world—the path of light and the path of darkness. One leads to liberation, the other to rebirth.")

This binary framework (light/dark, day/night, solstices) formed the semantic basis for calendars used in agriculture, Indian festivals, architecture, and governance.

Cosmological Implications

The model extended beyond Earth, encompassing the motion of the Moon, Sun, and other celestial bodies. The Vedic concept of two eternal paths—light (devayana) and darkness (pitriyana)—mirrored the cyclical nature of time, from daily sunrises to annual solstices.

Conclusion

Ancient India's timekeeping system was a holistic integration of mathematics, astronomy, and philosophy. The ***Shankhu*** experiments exemplify an early scientific approach where space, time, and motion were studied interdependently. This framework not only structured calendars but also influenced diverse fields, from metaphysics to civil engineering, demonstrating the profound interconnectedness of knowledge in India's intellectual tradition.

(*This article is based on discussions with Dr. S.N. Bhavsar (PhD) and Reinhard Bögle of the Yoga Forum Munich.*)

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Understanding galaxy evolution through stellar populations

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Introduction

When we look at a galaxy, we are often drawn to its beauty, spiral arms stretching outward, or a soft elliptical glow spread across space. But a galaxy is far more than what we see. It is a system that has been evolving for billions of years, shaped by processes like star formation, mergers, and gradual chemical change.

The real challenge is not just observing galaxies, but understanding their history.

One of the most powerful ways to do this is by studying their stars, not individually, but as groups known as **stellar populations**. These populations act like records of the past. By examining them carefully, we can begin to reconstruct how galaxies formed, evolved, and reached their present state.

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Galaxy Evolution

Galaxies did not always exist in their current form. In the early universe, small regions of matter slowly came together under gravity. Over time, these regions merged and grew into the galaxies we see today.

Even after formation, galaxies continue to evolve through several processes:

- **Star formation:** where gas turns into new stars
- **Mergers:** which reshape galactic structure
- **Explosions like supernovae:** which influence future star formation
- **Chemical enrichment:** where elements heavier than hydrogen and helium are created

These processes leave behind subtle but important clues. The key is learning how to read them.

Stellar Populations

Not all stars in a galaxy are the same. They differ in age, chemical composition, and location. Based on these properties, astronomers classify them into different **stellar populations**.

- **Population I stars** are relatively young and rich in heavy elements. They are commonly found in the disks of galaxies.
- **Population II stars** are older and contain fewer heavy elements. They are often located in the halo and globular clusters.
- **Population III stars,** though not yet directly observed, are believed to be the first generation of stars formed in the universe.

This classification reflects different stages in the life of a galaxy. A mix of populations suggests ongoing evolution, while dominance of older stars indicates a quieter, more evolved system.

Visualizing a Galaxy

A nearby spiral galaxy like the **Andromeda Galaxy** clearly shows how different stellar populations coexist. Its bright disk contains younger stars, while older, metal-poor stars are spread throughout its outer regions. Galaxies like Andromeda contain diverse stellar populations that preserve clues about their evolution.

Processed image of the Andromeda Galaxy, with enhancement of H-alpha to highlight its star-forming regions

How Stars Tell the Story

Each star carries information about the conditions under which it formed. By studying many stars together, patterns begin to emerge.

One key property is **metallicity**, which refers to the amount of elements heavier than hydrogen and helium. ***Older stars*** tend to have low metallicity because they formed when the universe had not yet been enriched with heavy elements. ***Younger stars***, formed later, contain higher metallicity.

Another important factor is **stellar age**. By analyzing the distribution of stellar ages, we can understand a galaxy's star formation history. For example:

- A galaxy with continuous star formation will contain stars of many different ages
- A galaxy that stopped forming stars long ago will be dominated by older stars

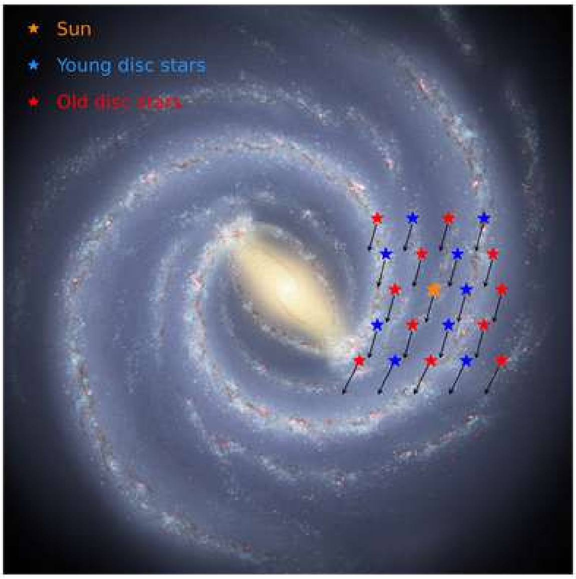
What makes this particularly fascinating is how much information can be extracted from what initially appears to be just a distribution of stars.

Why Stellar Populations Matter

Stellar populations are important because they act as tracers of a galaxy's history.

- **Chemical clues:** The distribution of elements across stars reveals how a galaxy has evolved chemically over time.
- **Stellar motions:** The movement of stars can indicate past interactions or merger events.
- **Spatial distribution:** Younger stars are typically found in galactic disks, while older stars are more common in halos.

Through these clues, we are not directly observing galaxy evolution, but we are reconstructing it from evidence that still exists today.



Different regions of a galaxy contain stars with varying ages and chemical compositions.

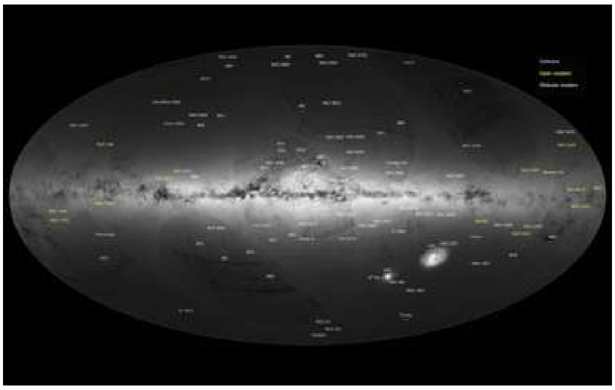
A Modern Perspective: From Observation to Data

Astronomy today is undergoing a major shift. Instead of studying a few stars at a time, we now work with data from millions or even billions of stars.

Organizations such as the European Space Agency have enabled detailed mapping of stellar positions, motions, and properties. This has transformed astronomy into a more data-driven science.

What makes this approach especially powerful is that we are no longer limited to observing individual stars and we can now study entire stellar populations as structured datasets. Within these datasets, hidden patterns can reveal events that are otherwise impossible to observe directly, such as past mergers or the presence of rare stellar groups.

In this way, stellar populations are not just physical objects and they also become patterns in data, offering new ways to understand galaxy evolution.



An all-sky view of stars in our Galaxy – the Milky Way – and neighbouring galaxies, based on the first year of observations from ESA's Gaia satellite

Modern sky surveys provide large-scale maps of stars, allowing astronomers to study galaxies in unprecedented detail.

Conclusion

Understanding galaxy evolution is like solving a puzzle without ever seeing the full picture directly. We cannot watch galaxies change over billions of years, but we can study the traces they leave behind.

Stellar populations provide some of the most reliable and meaningful clues. They reveal how galaxies formed, how they evolved, and what processes shaped them over time.

In a universe filled with billions of stars, it is not just their number that matters, but the patterns they form. Stellar populations are not random collections and they are records of cosmic history. By studying them, we are not just observing galaxies as they are today, but uncovering how they became what they are.

In that sense, every galaxy is not just an object in space, but a story written in stars and waiting to be understood.

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Really, in our own backyard?!!

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The study of astronomy has always been a subject of great interest since ancient times. Around the world there are proofs of its study from some very old civilizations such as the Indus Valley, Babylonian, Egyptian, Mayan, etc., primarily for devising calendars and navigation maps. Today, with the advancement of science and technology, we know a lot more about the world of stars in the sky.

Now, if we call Earth our home, then we can safely refer to the Solar System as our own backyard. Here are some amazing facts that might make you say, "Really, in our own backyard?!!"

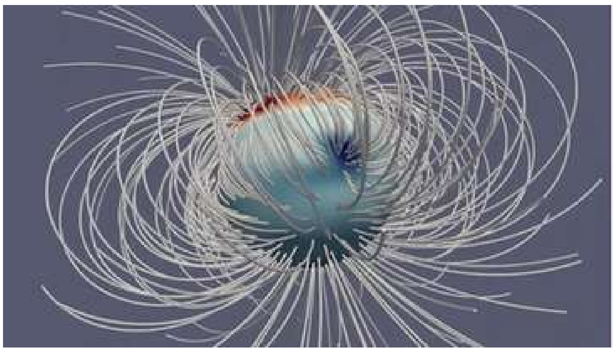
Lemon-shaped Moon

Although it appears round to us in the sky, the Moon is shaped like a lemon with flattened poles and a bulged equator. It is thought that this shape was caused by the interactions with Earth soon after its formation.

Venus & Mercury: Days longer than a year
Venus takes 243 Earth days for a spin on its axis (called a sidereal day) but takes only 225 Earth days to orbit the Sun. Mercury's case is quite different. Similar numbers for Mercury are 59 Earth days and 88 Earth days, respectively. However, its solar day (period between two sunrises) is 176 Earth days, i.e. the double of a Mercury year. This is because Mercury's orbit is highly eccentric.

Venus: The Sun rises on the west
Venus spins in the opposite direction with an axial tilt of ~177°. This makes the Sun rise in the west and set in the east on the planet. The dwarf planet Pluto also spins backwards with an axial tilt of ~120°. Uranus has a very peculiar case. It will be touched upon when Uranus is discussed later.

Jupiter's enormous magnetosphere



Magnetosphere is the region in which the magnetic field of a mass dominates. Jupiter has the biggest magnetosphere in our solar system. Here are the primary reasons:

- Jupiter has a vast ocean of electrically conducting metallic hydrogen, which spins rapidly, causing a very strong internal magnetic field.

- One of Jupiter's moons, Io is highly volcanic and continuously expels tons of sulphurous materials into space every second. This leads to the formation of an ionised plasma ring around Jupiter called Io plasma torus. This ring inflates the Jupiter's magnetosphere significantly.

- Jupiter's rotation is very rapid. One spin takes less than 10 hours. This rapid rotation drags the internal magnetic field and the heavy plasma around it, causing strong electric currents. This makes the whole magnetosphere enormous.

Jupiter's magnetosphere is so big that it even reaches Saturn's orbit. In fact, the width of the magnetosphere can fit 15 to 20 Suns in it. Had it been visible, it would have appeared bigger than the Moon despite being 1500 times farther away than the Moon.

Neptune orbited only once since we got to know it
Neptune was discovered in 1846. It takes 165 Earth years for it to complete a full orbit around the Sun. It was only in 2011 that Neptune completed one full orbit since its discovery. Interestingly, the dwarf planet Pluto's full orbit period is 248 Earth years and it was discovered in 1930. So, it is a long time away from accomplishing a similar feat.

Is the Sun doing Zumba?
The Sun's upper atmosphere is so very hot and energetic that part of it is continuously leaving it to enter space as solar wind. The Sun sheds around one billion (10^9) kilograms every second. At this rate, it will take around 185 million years to shed mass equivalent to Earth's mass.

Saturn can float
Earth is the densest of the planets and Saturn has the least density. In fact, Saturn, being made up primarily of gases, is the only planet that has density less than that of water. It means that if we could arrange a

water body to accommodate Saturn, it would have floated on it.

Venus is the hottest planet

Mercury is the closest to the Sun, yet Venus is the hottest planet. Venus has a thick atmosphere mostly composed of carbon dioxide, which is a greenhouse gas. It absorbs radiation both ways, from the Sun as well as its own. The result is that heat gets trapped and the planet gets hotter and hotter. Mercury, on the other hand, has a very thin exosphere, so it is cooler despite being the nearest to the Sun.

Total solar eclipse – Earth-only miracle

A total solar eclipse is exclusive to Earth. It is not seen on any other planets. It is all because of a cosmic coincidence that the Sun is 400 times bigger than the Moon in size, while at the same time it is 400 times farther. This makes them appear almost the same size in Earth's sky, making a total solar eclipse possible. However, it will not remain this way forever as our distance to the Moon is changing. You will know about it soon.

Uranus is the coldest planet

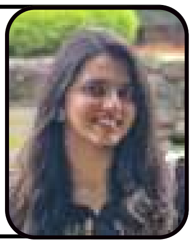
Neptune is the farthest of the planets and its average temperature is -214 °C. Uranus is the second farthest planet and yet its average temperature is -224 °C, making it the coldest of the planets. Scientists are yet to ascertain the reasons behind it, but there are a few theories. One theory says that the planet lost its primordial heat (the thermal energy of the planet at formation) very early. Another says that it is because of its axial tilt of around 97° (almost perpendicular to the orbital plane's normal), making it almost roll along the orbit path. It is thought that an object of almost the size of Earth may have collided with it in the early days of the Solar System, which caused the loss of primordial heat and the peculiar axial tilt.

The Moon is getting farther and Earth is getting slower

The Moon and Earth, being so close, have continuous gravitational pulls on each other. The Moon makes the ocean bulge, causing tides. Earth rotates much faster than the Moon (24 hours vs. ~28 days). As Earth's bulge moves ahead with its spin with respect to the Moon's position, the Moon's gravitational pull tries to resist it. This gradually makes Earth's rotation slower over a period of time ($1/500^{th}$ of a second over a century) and Earth loses its energy in the process. The Moon gains that energy, causing it to expand its orbit. In effect, the Moon is moving away about 3.8cm every year.

Note on references: The primary reference for this article is BBC Sky at Night Magazine website (https://www.skyatnightmagazine.com). Both the pictures used here are also taken from the same website.

Dark, the invisible mystery of the universe



Isha Vala

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Knowing ourselves, our lives, and everything we understand is the main goal of astrophysics. While studying astrophysics, I have learned about many wonders of the universe. I want to share some fascinating aspects of the darkness of the universe here.

When we look at the night sky, it feels like we are seeing the cosmos. The stars, the moon, and distant galaxies all seem vast and complete. However, we can only see about 5%, while the rest remains hidden. According to current astrophysics, dark matter and dark energy, two mysterious and unseen components, make up over 95% of the universe. They are invisible to us, and we cannot touch them. Yet, without them, the universe as we know it would not exist. It is intriguing to think that an unseen force governs the cosmos. Let's try to solve this puzzle.

Dark Matter: Its History and Mysteries

The story of dark matter begins with data, not theory. In the 1930s, astronomers researching galaxy clusters made an unusual finding. The galaxies were moving too quickly. According to Newton's laws, they should have flown apart, but they didn't. An unseen force was holding them together. Vera Rubin confirmed this finding in the 1970s. While studying the rotation of spiral galaxies, he made a groundbreaking discovery. Classical physics suggested that, like planets farther from the Sun moving more slowly, stars farther from the galactic center should also move more slowly. However, Rubin found that stars on the outskirts of galaxies were moving at the same speed as those near the center. This was surprising. The motion could not be explained by the visible matter such as dust, gas, and stars. We needed extra mass that we could not see. This invisible material is called dark matter. One way to understand dark matter is as a glue that holds galaxies together. Dark matter neither emits nor reflects light, nor does it absorb light. It interacts very little with regular matter, likely only through gravity. But its gravitational pull is undeniable.

Current estimates suggest that dark matter makes up about 27% of the universe. It provides the gravitational framework for the formation and evolution of galaxies, acting like a cosmic scaffold. Without dark matter, galaxies might not have formed at all. However, we still do not fully understand what dark matter is. Some physicists propose new fundamental particles like axions and WIMPs (Weakly Interacting Massive Particles). These particles are being searched for in space and deep underground experiments. Dark matter remains a mystery and an enigmatic concept.

Dark Energy: The Greater Mysteries

If dark matter holds the cosmos and galaxies together, dark energy does the exact opposite. In 1998, two separate groups of astronomers made an amazing discovery while studying distant supernovae. They expected gravity to slow down the expansion of the universe, which started with the Big Bang. Instead, they found that the universe's expansion is speeding up. This was completely unexpected. To explain this acceleration, scientists proposed dark energy, an unknown type of energy that fills space and pushes the cosmos apart.

Dark energy is thought to be the main component of the universe, making up around 68% of it. But what exactly is it? One theory suggests that dark energy is a property of space itself and relates to Einstein's cosmological constant. In this view, energy exists even in empty space. As the universe expands, more space forms, leading to more dark energy and further expansion. Another theory proposes that dark energy might be a dynamic field that changes over time. However, current observations are not detailed enough to confirm which explanation is correct.

These Mysteries' Mysteries

It is natural to wonder why dark energy and dark matter matter if they are invisible. The key lies in understanding our cosmic origins. Dark matter played a role in shaping the early universe. After the Big Bang, tiny density fluctuations grew under gravity. Dark matter enhanced these variations, allowing clusters and galaxies to form. Without it, the universe might have existed only as a thin, uniform cloud of particles. However, the fate of the universe is determined by dark energy. Will the expansion continue forever? Will it slow down? Could it eventually destroy stars, galaxies, or even individual atoms? The true nature of dark energy will provide the answer. Studying these mysterious components goes beyond filling gaps in textbooks. It involves understanding the makeup, development, and future of everything.

What we know about dark matter and dark energy is intriguing, as is what we do not know. Astronomy is at an exciting crossroads. On one side, we have precise readings from satellites, particle detectors, and telescopes. On the other side, we face major unresolved issues about the nature of reality. It humbles us to realize that most of the universe is out of our sight. As physics students, we often solve equations about motion, fields, and energy. Yet dark energy and dark matter remind us that nature is far more mysterious than what we currently understand. We hope that future experiments will allow us to detect dark matter particles directly. Maybe new physics beyond the Standard Model will emerge, or perhaps we will need to rethink our understanding of gravity. The universe is a puzzle, and dark matter and dark energy are its largest missing pieces. When we look at the night sky, we may see stars shining quietly. However, between them lies an invisible cosmic ocean, shaping galaxies and accelerating space itself toward infinity.

In the end, the greatest discovery may not be what dark matter and dark energy are, but how much they teach us about curiosity, persistence, and the courage to question the unknown. Could this invisible matter have an atomic structure similar to the visible?

The unraveling of space-time

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Physicists discovered strange supersolids, constructed new kinds of superconductors, and continued to make the case that the cosmos is far weirder than anyone suspected.

Will 2024-25 be remembered as a banner year in the quest to understand the universe, or just an average one? That depends on whether a result from this spring turns out to be real.

In April, physicists detected a hint of a signal suggesting that dark energy, the mysterious energy of space itself, "Hint" is the preferred term because the sign in the heavens isn't quite robust enough to be called "evidence," to say nothing of "discovery." Astrophysicists used the Dark Energy Spectroscopic Instrument (DESI)to map millions of galaxies at different distances in space and time, and from this map they inferred how the universe has expanded over its history. The data confirmed — as we've known since 1998 — that the cosmos's expansion is accelerating, driven by what we call dark energy. But DESI's data hints that the rate of acceleration has been dropping.

If dark energy is an energy source that can get diluted, it would upend and deepen physicists' understanding of the fundamental laws of the universe. "If true, it would be the first real clue we have gotten about the nature of dark energy in 25 years," Adam Riess, one of the Nobel Prize–winning discoverers of dark energy, told Quanta. Theoretical physicists are busy trying to explain dark energy change while DESI logs more data for a more definitive assessment in the coming years.

Dark Matter Is Dead, Long Live Dark Matter

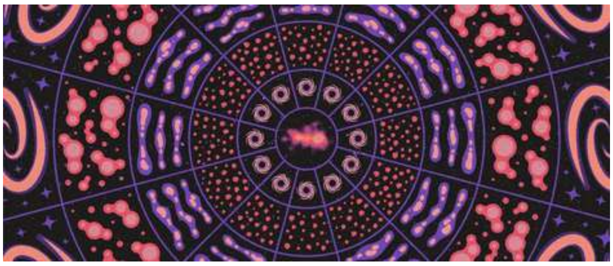
In the search for the invisible components of the universe, dark matter reached a discouraging milestone. (Fuzzy on the difference between dark energy and dark matter? Read our from May.) Experimenters hunting for hypothesized dark matter particles known as WIMPs — heavy, inert particles that were long considered the top candidate for the nonreflective stuff floating in and around galaxies — hit a limit. Detectors have become so sensitive that they're now which blinds them to any subtler signals. "So that's kind of the end of the WIMP detection era," the Stanford University physicist Natalia Toro told us.

She and other dark matter hunters have switched gears and now especially lightweight but abundant particles that would come in multiple species. "The most common hypothesis is that this is somehow simple. Why on Earth should we expect that?" said Philip Schuster, also a Stanford physicist, voicing an increasingly common sentiment among specialists

Lest you suspect that dark matter is the of the 21st century — a long- believed but convoluted and ultimately erroneous model of the universe — astronomers discovered a new reason to think it's really out there. The finding, an object called **MACS J0018.5**, has proved so compelling that people are referring to it as **the new Bullet Cluster**. In the original Bullet Cluster — long considered one of the single most persuasive pieces of evidence for dark matter's existence — we see two enormous clusters of galaxies crashing together. The colliding gas glows brightly in the center of the crash site, but most of the matter has sailed right through, forming heavy, light-distorting blobs on either side. That's how dark matter particles would behave, because they don't (or barely) interact.

MACS J0018.5 is similar, except the galaxy clusters are merging along our line of sight. Researchers effectively pointed a radar gun at them and found that their visible gas has slowed as it collides while the majority of the mass moves faster, unimpeded by the collision.

These merging clusters are hard to explain without invoking the kind of invisible particles we're looking for.



Astronomical Discoveries

The night sky holds many secrets. The flagship of modern astronomy, beamed down a few more this year, particularly in its observations of Banana-shaped galaxies, little red dots, grape-like clusters, shockingly big young black holes: Astrophysicists are reveling in the "beautiful confusion" of that formative epoch of cosmic history.

The Webb telescope also enabled a precise new measurement of the universe's expansion rate, known as the Hubble tension. Meanwhile, other telescopes revealed

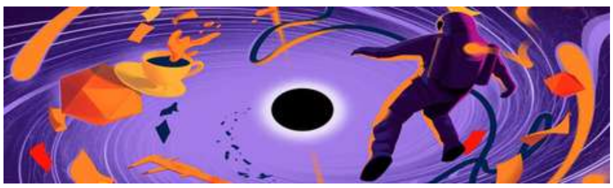
Happy Days in the Lab

Moving from the largest stage to the very smalle stone, physicists who manipulate atoms, molecules and crystals in the lab have also spent 2024 in the throes of discovery, having achieved astonishing levels of precision and control over their quantum quarries. A team in Innsbruck created and even imaged the hallmark "quantum tornadoes" that formed when they stirred an otherwise rigid crystal of dysprosium atoms. Astrophysicists suspect that this supersolid phase might arise inside incredibly dense, fast-spinning stars called pulsars.

Meanwhile, condensed matter physicists studying two-dimensional materials — that is, crystalline sheets of atoms — this year, while also mulling over a strange quantum phase of matter in which flow around the crystal's edge. No telling yet whether these phases will prove technologically useful, but that's always the dream.

Other labs made progress in encoding and manipulating information in arrays of atoms. Once an underdog approach to quantum computing, these so-called seem to have suddenly shot to the front of the pack. The ascendant devices yielded a landmark result in November, achieving a noise-resistant.

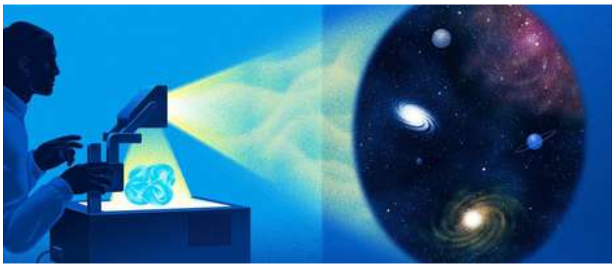
Moreover, for decades, physicists have sought to pinpoint the energy of a special nuclear transition in thorium, knowing it could serve as a tool to probe the fundamental forces that bind the universe. This year, three different groups which they plan to monitor to look for variations in the strength of those fundamental forces.



A Peek Beneath Space-Time

Theoretical physicists have made progress of a more abstract kind. They've developed for predicting the outcomes of particle interactions. Traditionally, they use equations that describe these interactions as dynamical events playing out in space and time according to quantum rules. Using the new method, answers seem to flow from sets of curves on surfaces. These breakthrough insights are part of an effort to discover the fundamental underpinnings of space and time themselves — the subject of a nine-part special issue we published in September.

For another deep dive into a deliciously profound subject, check out our which examines how the evolving understanding of this quantity has reframed the purpose of science and our role in the universe.



All Riled Up

Physics-related discussions on X (formerly known as Twitter) are pale shadows of what they used to be, but lively chatter did ensue from one bit of physics news, when *Scientific American* reported that What, exactly, is that supposed to mean? Had something really taken less than no time at all? Not exactly. In the quantum world, words often fail.

What happened was that physicists at the University of Toronto shot photons toward a cloud of rubidium atoms. Each photon might excite an atom in the cloud, or go straight through without interacting, or both. These quantum possibilities interfered like two waves. Then the researchers could determine that some photons went through the atom cloud faster when they got absorbed and reemitted than when they didn't, implying a "negative dwell time," as if these photons excited the atoms for a negative amount of time — but again, these are just words. "We are measuring a duration, not something finishing before it starts," one of the researchers involved Eyebrows also shot up in October when the 2024 Nobel Prize in Physics— a technology that seems, on its face, unrelated to the laws of nature. "I'm flabbergasted," one of the recipients, the computer scientist Geoffrey Hinton, told Science. Yet in the 1980s, he and the other winner, John Hopfield, their rudimentary artificial neural network son systems in statistical physics.

Some statistical physicists were pleased by the attention given to their obscure research on the behavior of systems of many parts. "For us, it's super-great," Aurélien Decelle "It's recognition at the broader level that what we're doing matters a lot."

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From starlight to science: The growth of astronomy into astrophysics

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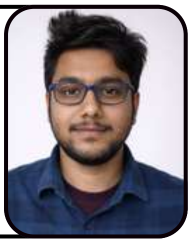

Since ancient times, human beings have been fascinated by the night sky. Long before modern science existed, people observed the Sun, Moon, and stars to understand seasons, time, and direction. What began as simple sky-watching gradually developed into astronomy, and later evolved into astrophysics, a field that uses the laws of physics to explain celestial phenomena. This transformation reflects the growth of human curiosity and scientific thinking.

In early civilizations, astronomy was mainly observational. Ancient Egyptians used the rising of certain stars to predict floods of the Nile, while Babylonian astronomers carefully recorded planetary movements. Greek scholars later attempted to explain these observations through models. Ptolemy's geocentric system, which placed Earth at the center of the universe, remained accepted for centuries despite its inaccuracies.

A major change came during the Renaissance.

Nicolaus Copernicus proposed that the Sun, not Earth, lies at the center of the planetary system. Although controversial at the time, this idea simplified the understanding of planetary motion. Galileo Galilei strengthened this theory using telescopic observations. His discovery of Jupiter's moons and the phases of Venus provided strong evidence against the geocentric model.

The real connection between astronomy and physics was established by Isaac Newton. His law of universal gravitation showed that the same force governing motion on Earth also controls the movement of planets and stars. This unified approach marked the beginning of astrophysics.

During the nineteenth century, spectroscopy revolutionized astronomy. Scientists learned that light from stars carries information about their composition. By studying spectral lines, astronomers discovered that stars contain elements such as hydrogen and helium, the same elements found on Earth.

The twentieth century witnessed rapid progress in astrophysics. Albert Einstein's theory of general relativity changed the understanding of gravity and predicted phenomena such as black holes and gravitational waves. Edwin Hubble's observations revealed that distant galaxies are moving away from us, leading to the concept of an expanding universe.

Advancements in technology further accelerated research. Radio telescopes, space-based observatories, and multi-wavelength studies allowed scientists to observe objects invisible to the naked eye.

In conclusion, the journey from ancient astronomy to modern astrophysics represents centuries of observation, experimentation, and theoretical development. As technology improves, astrophysics will continue expanding our understanding of the universe.

The cosmic paradox: are we already inside a black hole, just looping back to ourselves?

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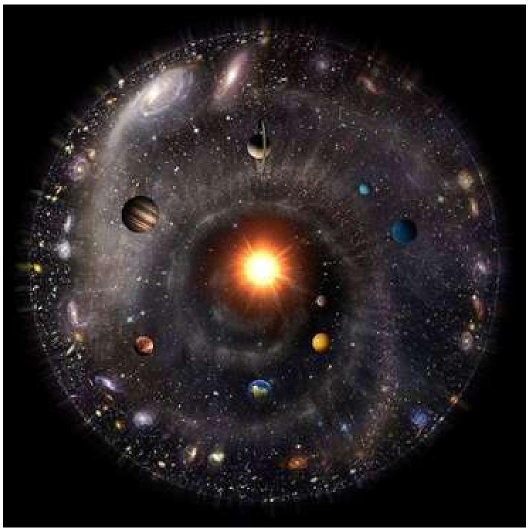
The mysteries of the cosmos never cease to spark our imagination, but sometimes, the biggest answers come from asking even bigger questions.



(Image Source: Pinterest)

What if this is a black hole and we're already inside it?
This could be just one of countless black holes, each holding an entire universe like ours. We might be living in one without even knowing it and there could be many more, far beyond what we can see.

A Universe Born in the Dark!!
What if our **entire universe is inside a black hole?**

It sounds like science fiction, but some cosmologists have proposed that the **Big Bang** might have been a **"Big Bounce,"** the result of a black hole in another universe collapsing in on itself and spawning our own.

In this scenario, we wouldn't just be observers of black holes we would be **living inside** one. Our entire reality, wrapped within an event horizon, would be part of a far greater cosmic structure. A paradox in itself.

But that leads to another question:
What about the black holes **we** observe in our universe?

Could each of them be a **gateway** to another universe with its own laws of physics, time, galaxies, or even **life?**

Infinite Loops & Mirror Universes!
Here's where things get even more mind-bending.

If every black hole leads to a new universe, **what if falling into one doesn't take us somewhere new**, but instead…

…loops us back to our own universe, just in a different place, or at a different time?

Imagine black holes not as exits to something beyond, but as **curved paths through space-time**, cosmic shortcuts that warp us back into the same reality, just **shifted**.

So perhaps we're not escaping anything.
Maybe we're just **re-entering** again and again the very universe we're already in.

A paradox: No matter how many black holes we fall into, we never leave we just arrive somewhere else… in the same story.

Are we exploring something new?
Or are we simply seeing **familiar space through unfamiliar coordinates?**

Are Black Holes Time Machines?
Many physicists suggest that black holes could act like **time travel devices**. The gravitational pull is so intense that time itself slows dramatically. If you were to cross a black hole's event horizon, some theories suggest you could leap far into the **future** or even potentially into the **past**, depending on the geometry of space-time.

That would make black holes not just the **endpoints of stars**, but the **highways of time** cosmic narrative twists that don't just warp where we go… but **when**.

Every black hole might not just be a tunnel to somewhere it might be **a story waiting to be told**.

A Final Twist: Are We Just One of Many?
If black holes spawn universes, what lies within those realms?

New physics? New timelines?
Perhaps even **new life?**

It's possible that somewhere, in some distant black hole, there's **another version of us** asking these same questions.

Another consciousness is wondering, "Are we inside something much bigger than we thought?"

The Universe as a Mirror?
What if every time we stare into the dark heart of a black hole, we're not seeing emptiness, but a **cosmic mirror?**

Not one that reflects light, but one that reflects **possibilities.**

What if our universe isn't a standalone story but one **chapter in an infinite cosmic library,** where black holes are the gateways between volumes?

Maybe, just maybe, we're not meant to escape.
Maybe we're meant to realize **we've always been inside.**
The End!

This article may have come to an end, but **our thinking shouldn't.**
The cosmos invites us not only to **wonder,** but also to **explore deeper** to imagine, question, and, most importantly, to work toward **real answers.**

Because every idea opens the door to many more.
And who knows? The next breakthrough might begin with a question just like this one!!

This article is a thought experiment, inspired by recent discussions in astrophysics and cosmology! Reflections in this article are my own. If you're curious to explore more about the idea that our universe could be inside a black hole, here are recent articles that inspired this reflection:

- **Is Our Universe Inside a Black Hole? New Research Says It Could Be Possible -** By Charlotte Phillipp, March 23, 2025 https://people.com/is-our-universe-inside-a-black-hole-new-research-shares-answer-11698196
- **Is the Universe inside a Black Hole? -** By Paul M. Sutter, April 1, 2025 https://www.scientificamerican.com/article/do-we-live-inside-a-black-hole/
- **Are We Inside a Black Hole? New Study Challenges the Big Bang Theory -** https://www.livemint.com/science/news/are-we-inside-a-black-hole-new-study-challenges-the-big-bang-theory-we-are-not-special-11749703241547.html

Implications of radioadaptive response from lab to space: A radioadaptive mechanism in astronauts

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Chennai, Tamil Nadu

Space radiation exists in three forms with either the cosmic rays trapped in the intrinsic magnetic field of Earth, or during solar particle events, or outside the solar system. Galactic cosmic radiation comprising high-energy charged particles (protons, helium, and heavier atomic nuclei) reacts with Earth's atmosphere and produces secondary radiation, which is enormous in space, and happens to be the main source for astronauts travelling to space.

Astronauts receive an effective radiation dose within the range of 50-2000 millisievert over a long-term interplanetary space travel. Radiation induces genotoxic stress and poses serious health implications such as cognitive impairment, loss of vision, bone resorption, cardiovascular diseases, psychological disorders, skin injuries, compromised immune system and most significantly, an increased risk of cancer .

A personalized countermeasure such as shielding against radiation is required for minimizing their exposure to the chronic galactic cosmic radiation. Radiation shielding refers to the process of limiting the radiation exposure to astronauts in space by blocking via effective barrier materials by the "attenuation" principle. This is performed via either active shielding to deflect charged particles or passive shielding by lead or concrete to protect from high-energy particles and secondary radiation to a limited extent, despite a maximum absorption in astronauts. This shielding is expensive and poses limitations in the quantity of radiation absorption, thereby requiring the need to encounter the exposure levels biologically.

"Radiation-induced adaptive response" is a biological phenomenon and a non-targeted effect of ionizing radiation that is found to minimize the harmful biological effects to cells upon low/priming doses followed by higher/challenging doses of radiation exposure. The low-dose induced radioadaptation has been widely explored in areas such as COVID-19 disease, Alzheimer's disease, epidemiological studies in high-level natural radiation areas, cancer radiotherapy, and is of timely relevance in space radiation research due to amelioration in novel space missions.

Space radiobiology poses a need for evaluating this phenomenon in astronauts, as this may enhance radiation tolerance or mitigate the radiation effects received from exposure. Low doses upregulate DNA repair pathways, antioxidant defenses, and stress response systems after subsequent higher dose exposures. In turn, it leads to an influx of acute solar particle events.

The radioadaptive response seems to have a decreased effect in contrast to the synergistic effect, where the level of aberrations and DNA damage is higher. This adaptation may lead to a protection against cancer, the most stochastic effect of ionizing radiation, whose probability of occurrence is radiation dose-dependent, but dose increase does not relate to the severity of the disease.

The genetic constitution of every individual is found to vary greatly hence, the astronauts with a higher radio-adaptive response are selectively designated for long-term space missions only after testing their cytogenetic effects, namely, DNA damage either by gamma-H2AX biomarker-associated early DNA damage or micronucleus biomarker-associated late DNA damages, and chromosomal aberrations by the dicentric assay via exposing their lymphocytes and skin fibroblast cells to low radiation dose, followed by higher radiation doses under laboratory conditions. Evaluating this phenomenon using these assays is regarded as the gold standard in radiobiological methods. Analysing the DNA damage levels of astronauts can succour to an increased awareness of the phenomenon at the radiobiological level operating in space and its associated mechanisms, in turn leading to altering low doses, that can impart better radiological safety apart from merely sequencing their DNA and editing genes in space.

Ordinarily, these responses are not exhibited under all experimental conditions, and therefore, this biological phenomenon is "not regarded as universal".This phenomenon confers efficient radioprotection via the effective DNA repair mechanisms, leading to a reduction in DNA damage and gene mutations, thereby decreasing the risk of cancer in astronauts. It also increases antioxidant levels leading to a reduction in inflammatory effects. The chronic low-dose-rate galactic cosmic radiation activates specific signalling pathways/mechanisms like DNA damage response and DNA repair (Non-Homologous End Joining or Homologous Recombination Repair) pathways that confer radioprotection against higher space radiation doses in astronauts during long-term space travel. Variations in the occurrence of these responses in space exist due to factors such as the type of radiation particle, dose, dose-rate, microbiome co-adaptation, time of exposure, and microgravity.

These responses are considerably found to be observed in astronauts exposed to galactic radiation for long-term during space travel, but the manifestations of these responses are heterogeneous, and the magnitude of response also varies to a greater extent due to their individual variability. This inter-individual variability exists fundamentally due to their varying radio-sensitivities, which are found to be different among the subtypes of lymphocytes. Therefore, astronaut selection on the basis of radioadaptation is a prerequisite for space travel. The occurrence of these responses is dependent upon multiple factors, especially with the constant-dose rate at which they are exposed to chronically elevated levels during space travel. The trend of radioadaptive response seems to attain a saturation phase only with a constant dose rate. Astronauts receive a radiation dose of around 0.3–0.6 milligray/day. There are also biophysical and mathematical models being designed to explicitly describe the doses by the physicist to evaluate this phenomenon with a parameter of dose- and time-related mathematical function in astronauts. Fixing or modifying radiation doses by evaluation from a combination of biological aspects, biophysical and mathematical models will aid in improving space radiation research. Also, delving into this phenomenon in various ISRO-associated research laboratories will enhance our nation's contribution to space research.

Exposure to prior low-dose ionising radiation or radiofrequency radiation before travelling to space may cause this phenomenon in astronauts, resulting in beneficial effects that reduce the adverse health effects of radiation. This can target to lessen radiosusceptibility and enhance radioresistance, resulting in refining the risk assessment protocols and radioprotection standards for astronauts. Therefore, it is essential to extensively elucidate the biological mechanisms of this phenomenon using low doses via space radiobiological studies in astronauts can lead to enhanced radioprotection, thereby reducing the need for heavy radiation shielding of the vehicle and space suit during long-term space travel.

Insights into the black hole physics: Recent trends and developments


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The underlying physics of the gravitational field, epitomised to understand the motion of celestial bodies, has elucidated the crucial role of the structure of spacetime in the dynamical motion of these bodies. The well-established theoretical framework, known as the theory of general relativity (GR) [1,2], has been corroborated through various accurate predictions and rigorous experiments. The anomalous precession of Mercury's perihelion [3], gravitational lensing by massive bodies [4,15], gravitational redshift [5], orbital decay of the Hulse-Taylor binary pulsar [6,7], imaging of the supermassive black hole (BH) shadow at the heart of the galaxy M87 by the EHT (Event Horizon Telescope) [8], and the detection of gravitational waves by LIGO (Laser interferometer Gravitational-wave Observatory) [9] are some of the notable experimental proofs of the GR. One of the most influential solutions in the GR literature is the concept of BHs, defined as regions in spacetimes with singularities from which even light cannot escape. The first exact solution of Einstein's field equation in vacuum, given by Karl Schwarzschild, has laid the foundation of the structure of BHs [10]. Whereas, the work by Hans Reissner and Gunnar Nordström, and Roy Patrick Kerr delivers the solutions for BHs with the essence of charge [11,12] and spin [13], respectively. The most general classical solution of the BH in asymptotically flat spacetime has the effect of both charge and spin and is known as the Kerr-Newman BH [14]. These developments gave rise to a new era of understanding the dynamics of the particle moving in the vicinity of a gravitationally intense regime, BH, sparking widespread interest among theoretical astronomers. This interest is being further amplified due to recent advancements in the observational domains of BH physics, which reconstruct theories and fill the gaps within our understanding of BHs and their phenomenology. Here, we dedicated each paragraph to understanding how observational astronomy reconstructed the various theoretical aspects of BH physics and compiled a recent pattern of study implemented by many theoretical astronomers.

In this context, gravitational lensing, defined in GR as light being attracted by matter, was the first experimental proof of GR and a historical dramatic event [15]. An expedition led by Arthur Eddington, a British scientist, in 1919 measured the apparent positional shift of background stars near the solar limb during a solar eclipse. The observed deflection was consistent with the predictions of GR contributing to its widespread acceptance. The key concept of gravitational lensing is the variation of path-defining spacetime due to compact massive sources, such as a galaxy, cluster, or BH, leading to intriguing observable effects, including image deflection, magnification, multiple imaging, and time delays. The study of photon trajectories by null geodesics provides a powerful tool for theoretical physicists, enabling them to identify strong field features such as photon spheres, critical impact parameters, and relativistic images formed by light undergoing multiple deflections near the event horizon. Experimentally, lensing by a BH provides a strong way to investigate their mass, spin, and surrounding spacetime geometry, and has direct relevance to observations of supermassive BHs and compact objects. Advances in lensing modelling, numerical simulations, and relativistic ray-tracing techniques have enabled scientists to conduct fundamental tests of various gravity models, probing the nature of BHs and dark matter through increasingly accurate comparisons between theory and data.

Another phenomenon, BH shadows, is described as a purely relativistic marvel arising from the extreme bending of light in the strong gravitational field near the event horizon, encompassing BHs as a dark region in the observable sky corresponding to photon trajectories. Theoretical studies based on null geodesics show that for a non-rotating Schwarzschild BH, the shadow appears as a perfectly circular silhouette whose angular size depends only on the BH mass and observer's distance. In contrast, for the most general rotating (Kerr) BHs, frame-dragging effects distort the shadow, leading to asymmetry and displacement that encode direct information about the BH spin and viewing angle [16]. For several decades, shadow studies remained largely exploratory and model dependent due to the lack of observational constraints, however this situation changed dramatically with the advent of millimetre-wavelength Very Long Baseline Interferometry (VLBI) culminating in the EHT's first horizon-scale image of the supermassive BH in M87 [8,17], followed by the shadow of Sagittarius A* at the centre of the Milky Way [18]. These observations transformed shadow studies from a largely qualitative theoretical exercise into a precision tool with clear observational direction. Today, shadows are investigated through relativistic ray-tracing, enabling a direct comparison between theoretical results and observed brightness patterns near the horizon. This study is especially important because it provides a direct way to examine the spacetime very close to the event horizon. This makes shadows a powerful tool for testing GR, deviations from the GR and understanding the description of Kerr BH in the strong field regime. In addition, shadow observations enable the estimation of important physical parameters, such as BH mass, spin, and orientation. In this sense, shadow imaging forms a natural and complementary counterpart to gravitational lensing studies and has become an integral component of contemporary BH physics, linking theoretical modelling with high-resolution observations.

Another proven prediction of GR is gravitational waves (GW), analogous to electromagnetic waves, that are described as ripples in spacetime created from the dynamical motion of celestial bodies [9]. Thereby correlating the motion of a celestial object into an astrophysically observable entity. Even with recent advancements in the GW detectors, existing studies are still largely limited to probing motion in a strong gravitational region. However, there also exists another influential class of celestial-BH systems for the formation of GWs, known as extreme mass ratio systems (EMRs) [19], where the smaller test particle (a star or any celestial compact body) in an EMR is orbiting under the strong gravitational influence of the central supermassive BHs. In adiabatically approximated EMRs, the orbiting particle loses its angular momentum and energy gradually, so its GWs can be enumerated by solving the timelike geodesics of spacetime. As the test body in EMRs loses energy and angular momentum, it spirals closer to the BHs, which can take thousands to millions of years. This characteristic of EMRs with slow orbital evolution makes the GWs associated with it detectable over a long period of time. Hence, leverages the observational advantages. Future space-based GW detectors, including Laser Interferometer Space Antenna (LISA) [20], Taiji [21], TianQin [22], and DECi-heltz Gravitational-wave Observatory (DECIGO) [23], will target such systems due to their long period of observation and high event rates. The theoretical study of GWs associated with the trajectory of adiabatically approximated EMRs provides an underlying potential, explaining the nature of physical BHs in association with the observational data provided by future space-based GW observatories.

In conclusion, the arduous study of BHs has been an interest of many physicists and mathematicians, which is further amplified by recent technological advancements in the field. The concept of comparing real data with theoretical models allows parameterisation, constraining, and further understanding of some of the unknown mysteries, such as the nature of time, dark matter, dark energy, and the quantum involvement in macroscopic phenomena of the universe. The excitement of involving observational restrictions in theory can be seen in the recent publications, with astronomers dedicating one session to the observational correlation of their theoretical model and providing a range of permissible limits to their parameters. With its mystery and dynamics, the study of BHs have attracted many early physicists and astronomers, but one can still ask the question of why the great minds of humankind puzzle themselves with something that has no current applications to humanity. And the answer to this lies in the past, the same way the study of electricity was once seen as mere madness, and now is the fundamental requirement of humans. In the same way, it was science fiction to colonise the moon, becoming a nearby reality. The evolution of humans from curiosity to reality and then to dependency makes it clear how the current development of BH will be promising.

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The first imagery from the **Vera C. Rubin Observatory** marks a significant step in modern astronomy, showcasing its powerful wide-field imaging capabilities. Designed for the **Legacy Survey of Space and Time (LSST),** it can capture deep images of the sky and detect faint, distant objects. This milestone opens new possibilities for studying **galaxy evolution, cosmic structure,** and **transient events,** while honoring the legacy of **Vera Rubin.**

Cosmic extremes: AGN, quasars, blazars and pulsars — When the universe pushes physics to its limits

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The universe is often imagined as calm and silent, filled with distant stars shining steadily through the darkness. Yet, beneath this apparent stillness lies a realm of extreme phenomena where matter, energy, gravity, and time behave in ways that challenge our understanding of physics. Objects such as Active Galactic Nuclei (AGN), quasars, blazars, and pulsars represent the most energetic and exotic expressions of the cosmos. Studying them is not merely an exercise in observation, but an exploration of the limits of nature itself.

Active Galactic Nuclei: The Powerhouses at Galactic Centres

At the heart of many galaxies lies a region that emits enormous amounts of energy, far more than can be explained by stars alone. These regions are known as Active Galactic Nuclei (AGN). Despite their compact size, AGN can outshine the combined stellar light of their host galaxies.

The central engine of an AGN is believed to be a supermassive black hole, with a mass millions to billions of times that of the Sun. As surrounding gas and dust fall toward the black hole, they form an accretion disk. Friction and gravitational forces heat this disk to extremely high temperatures, causing it to radiate across the electromagnetic spectrum.

AGN are not isolated phenomena; they actively influence their host galaxies. The energy released can heat interstellar gas or drive powerful outflows, suppressing or triggering star formation. In this way, AGN play a crucial role in galaxy evolution, acting as regulators of cosmic growth.

Quasars: Light from the Distant Past

Among the AGN family, quasars are the most luminous and distant members. They are visible from billions of light-years away, making them some of the earliest observable structures in the universe. Observing a quasar is equivalent to looking back to a time when the universe was young and galaxies were still forming.

What makes quasars extraordinary is the efficiency with which they convert gravitational energy into radiation. A quasar, confined to a region comparable in size to the Solar System, can emit more energy than an entire galaxy containing billions of stars. This immense luminosity arises from rapid accretion onto a growing supermassive black hole.

Quasars are invaluable tools for cosmology. As their light travels through space, it interacts with intervening gas clouds, leaving absorption signatures that reveal the composition and structure of the early universe. Thus, quasars act as cosmic backlights, illuminating the large-scale structure of the cosmos.

Blazars: Relativistic Jets Aimed at Earth

Blazars represent one of the most dramatic manifestations of AGN activity. What distinguishes blazars from other AGN is orientation. In blazars, one of the relativistic jets produced near the black hole is pointed almost directly toward Earth.

This alignment leads to striking observational effects. Due to relativistic beaming, radiation from the jet appears intensely amplified and highly variable. Blazars can change brightness within hours or even minutes, making them among the most unpredictable objects in the universe.

Blazars emit radiation across the entire electromagnetic spectrum, including high-energy gamma rays. This makes them natural laboratories for studying particle acceleration, magnetic fields, and relativistic plasma physics. They demonstrate how geometry alone can drastically alter our perception of cosmic phenomena.

Pulsars: Precision Born from Stellar Death

While AGN, quasars, and blazars originate from supermassive black holes, pulsars arise from the remnants of massive stars. When a massive star ends its life in a supernova explosion, its core may collapse into a neutron star, an object so dense that a teaspoon of its material would weigh billions of tons.

Pulsars are rapidly rotating neutron stars with extremely strong magnetic fields. Radiation emitted along their magnetic poles sweeps across space as the star rotates. If this beam intersects Earth, it is detected as a pulse of radiation, giving pulsars their name.

Some pulsars rotate hundreds of times per second and maintain astonishing stability, rivaling atomic clocks in precision. This regularity allows pulsars to be used as tools for testing general relativity, detecting gravitational waves, and probing matter at nuclear densities.

Despite their violent origins, pulsars represent order and precision emerging from cosmic catastrophe.

A Unified View of Cosmic Extremes

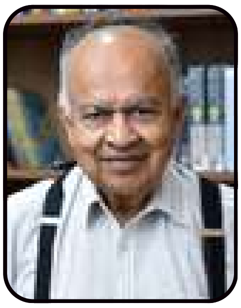
AGN, quasars, blazars, and pulsars may differ in scale and origin, but they share a common theme: they exist at the boundaries of physical law. They involve extreme gravity, intense magnetic fields, relativistic motion, and enormous energy release.

Studying these objects allows us to test theories under conditions that cannot be reproduced on Earth. They also remind us that the universe is dynamic, evolving, and far more energetic than it appears to the naked eye.

Why These Objects Matter?

These extreme cosmic objects are not just curiosities; they are keys to understanding the universe. They reveal how black holes grow, how galaxies evolve, how matter behaves at extreme densities, and how space and time respond to intense gravity.

For a student of physics, exploring AGN, quasars, blazars, and pulsars is an invitation to witness nature at its most powerful. They show us that the universe is not only vast, but also deeply intricate: a place where even the most violent processes follow elegant physical laws.



Prof. Jayant Narlikar (Vigyan Ratna)

Jayant Narlikar was honored with the prestigious **Vigyan Ratna,** India's highest science award, in recognition of his lifelong contributions to astrophysics and cosmology. His groundbreaking work on alternative cosmological models, along with his dedication to science communication and education, has made a lasting impact on the scientific community. This honor celebrates his role in advancing Indian science and inspiring future generations.

Prof. Surhud More (Vigyan Yuva)

Surhud More was honored with the **Vigyan Yuva** award in recognition of his outstanding contributions to astrophysics and cosmology at a young age. His research, particularly in large-scale structure of the universe and gravitational lensing, has significantly advanced our understanding of cosmic evolution. This award highlights his impactful work and his role as a promising young scientist in India.

Astrophotographs are clicked by Dr. Sumeet Kulkarni.

Dr. Sumeet Kulkarni is an astrophysicist and award-winning science communicator with a PhD in astrophysics. His research focuses on gravitational waves and black holes, including work with LIGO data and machine learning techniques. Beyond research, he is widely recognized for his science writing and outreach, with contributions to platforms like *Nature*, the *Los Angeles Times*, and *Veritasium*. He is also passionate about engaging the public in science through education, journalism, and visual storytelling, including astrophotography.

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Lunar Eclipse 2022: Light from a millions sunrises and sunsets from around the globe.

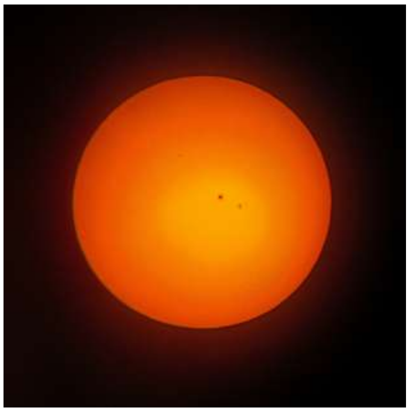
Lagoon and **Trifid nebulae** setting behind **The Grand Teton**

The dark **Horsehead** and illuminated **Flame nebulae** on the side of **Orion's Belt.** 35 minute exposure using **canonm50** and **rokinon135mm** lens, tracked.

Both **Star Trails** above are captured using Remi Note 13 Mobile

Moon

Jupiter



Sun-Spots

Images Clicked by: Swayam Tirlotkar.

All the images above are clicked by him using my Redmi Note 13 mobile and corresponding telescope also all the images are captured by Manually tracking as he do not own tracking system.

College: St. Xavier's College, Mumbai

Orion Constellation

Image shot at : Mudumalai Tiger Reserve part, Tamil Nadu.

Images Clicked by: Prassanna from Tamil Nadu.

He is an engineering graduate, an astronomy educator, and an amateur astrophotographer. He have been working as a science communicator.

Prof. Govind Swarup: Architect of India's radio astronomy revolution

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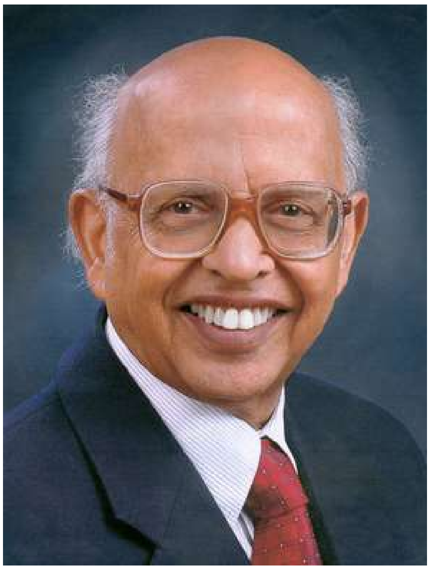


Prof. Govind Swarup a global pioneer in radio astronomy. He is known as **"Father of Radio Astronomy in India".** In research he contributed in multiple areas of astronomy and astrophysics. He also played a pioneering role in establishing radio telescope infrastructure in India.

Born in the town of **Thakurdwara** in **Uttar Pradesh** on **23rd March 1929.** Swarup received his BSc degree in 1948 and MSc in Physics 1950. Swarup spent several years at the **National Physical Laboratory** in Delhi with **K. S. Krishnan (1950–53),** measuring the spin resonance of electrons. In March 1953 on a 2-year fellowship he joined the **CSIRO Division** of Radio-physics in Sydney. He worked there with other Radio-physicists where he worked on building and using radio interferometers to study radio emissions from the sun and other cosmic sources.

Interferometers:
Radio waves are much longer than visible light so to see fine details one will need the dish kilo-meters wide, which is physically impossible to build, so astronomers use interferometry. Interferometers use two or more smaller antennas separated by a distance, where antennas are pointed at same cosmic object. The signals from all antennas are sent to correlator (a powerful computer) which combines the waves, and then they are studied.

While at CSIRO he and along with him **R. Parthsarathy** converted a **L-shaped grating radio interferometer telescope** to an operating wavelength of **500MHz.** [An L-shaped grating radio interferometer is a type of antenna array used to achieve high-resolution images of the Sun.]

Swarup went to United States, where he worked as research associate at the **Radio Astronomy Station of Harvard University at Fort Davis, Texas (1956-57).** He then became a research assistant at **Stanford University (1957–60)** in California, completing his doctoral thesis with **Ron Bracewell.** Swarup received his PhD from Stanford University in 1961 and became an assistant professor at Stanford University (1961-1963).

Sun has its own magnetic field any charged particle there due to its magnetic field would spin in circle or spiral. Any charged particle changing its direction must give off energy, so when charged particle (like electron) is spinning the energy release is gyro-radiation. (radiation can be categorized according to the speed of charged particle here it is gyro-radiation because the speed here of charged particle is moderate) At Stanford Swarup continued to make studies of radio emissions from the Quiet Sun and developed a gyro-radiation model of solar emissions of microwave radiation. He explained the emission mechanism of sunspots in terms of gyro-resonance processes.

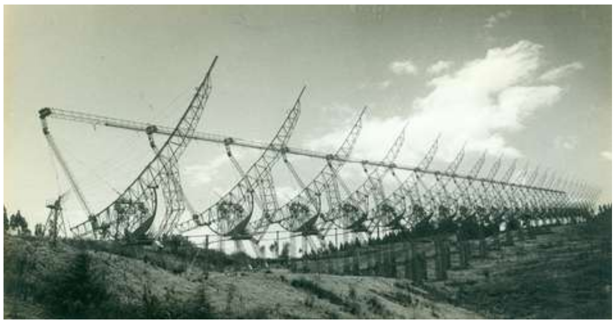
In 1959, Swarup developed a technique for the round-trip transmission of phase measurements that enabled the phase equalization of all 32 antennas in an array to be carried out in minutes rather than weeks. Published in 1961, this technique has been used in radio interferometers world-wide.

Cygnus A is a massive galaxy that acts like a powerful radio station in space. While it looks like a normal group of stars, a supermassive black hole at its centre shoots out invisible beams of energy. These beams create two giant "clouds" of radio waves that are much larger than the galaxy itself. In 1962 Swarup used the Stanford compound-grating interferometer to examine Cygnus A. Previous researchers had shown that the radio galaxy contained two distinct radio lobes. In 1963 Swarup reported the presence of a continuous bridge of radio emissions between the two lobes, the first instance of a steep spectrum bridge. Such bridges are used to estimate the age of a radio galaxy.

Kalyan Radio Telescope

Swarup returned to India on **2nd April 1963.** And he began to assemble a group at the **Tata Institute of Fundamental Research** near Mumbai. With the antennae from Potts Hill, they constructed the **Kalyan Radio Telescope,** was the first modern radio telescope in India. It was completed in 1965. The site was located at the southern end of the abandoned Kalyan Airstrip. Completed in 1965, the Kalyan telescope was a "solar grating interferometer." It was designed to study the Sun. Its primary purpose was to pinpoint exactly where radio waves were coming from in the solar atmosphere.

Swarup's next major installation was the **Ooty Radio Telescope (ORT)** at Ooty in South India. Completed in 1970, ORT was an Indian Indigenous engineering. It is 530 meters long and 30 meters wide. The long axis of the cylinder parallel to the Earth's rotation axis, the telescope acts as an equatorial mount.



Ooty Radio Telescope

This allows it to track a celestial object for up to 9.5 hours simply by rotating the cylinder from east to west. In its early years, **ORT** used the **Lunar Occultation technique** (observing radio sources as they are eclipsed by the Moon) to provide evidence that supported the Big Bang model over the Steady State theory. It is currently a world leader in studying **Interplanetary Scintillation (IPS).** That is, it monitors the solar wind the stream of charged particles from the Sun, to help predict magnetic storms that can affect Earth's satellites. It has been used to discover and time, several pulsars (rapidly rotating neutron stars), including studies on pulse nulling, where a pulsar's emission mysteriously disappears and reappears. It has mapped over 1,000 radio galaxies and quasars with high precision. [The telescope has recently undergone a massive digital upgrade known as the **Ooty Wide Field Array (OWFA).** This upgrade converts the telescope into a 264-element interferometer.]

Giant Metrewave Radio Telescope (GMRT)

Beginning in 1985, Swarup began construction of the

Giant Metrewave Radio Telescope (GMRT), at Khodad near Pune. The telescope was completed in 1997. The GMRT is an interferometer consisting of 30 massive parabolic dishes, each of them 45m in diameter, arranged in a **Y-shape array** over a **25 km area.** Using a novel **SMART (Stretched Mesh Attached to Rope Trusses)** design concept, GMRT is highly versatile. Originally it was the world's largest radio telescope for the operating in the frequency range of **130–1430 MHz** and has been used by researchers from over 40 countries. GMRT was recognized as a key historical achievement in electrical and electronic engineering and given **IEEE** Milestone status in 2020. One of the concerns behind the development of the GMRT was the question of dark matter and the nature of the universe. A sensitive radio telescope at an appropriate frequency (327 MHz) was needed to test predictions about whether the universe contained **hot dark matter (HDM)** or **cold dark matter (CDM).** Swarup has used the GMRT to observe the emission and absorption of atomic hydrogen from objects in the early Universe, examine the cosmic cold spot, and study radio emissions from Venus.

Major Discoveries of GMRT:

- In 2018, it discovered a galaxy located 12 billion light-years away.
- It helped observe the Ophiuchus Supercluster explosion, the biggest blast in the universe since the Big Bang.
- It recently detected radio signals from atomic hydrogen in a galaxy 8.8 billion light-years away a massive feat for low-frequency astronomy.
- It is a key player in the InPTA (Indian Pulsar Timing Array), searching for the hum of the universe caused by nanohertz gravitational waves. (The "hum" is the collective vibration of space-time caused by millions of pairs of supermassive black holes dancing across the universe.)
- The GMRT was recently upgraded to the uGMRT (upgraded GMRT), making it 3 times more sensitive than before. The uGMRT is currently the world's most sensitive radio telescope array operating at low frequencies. (for this 300 MHz – 1.4 GHz frequency.)

Throughout his career Prof. Govind Swarup received multiple awards. He was awarded the Padma Shri (1973) and the Shanti Swarup Bhatnagar Prize (1972), India's highest science award. He received the prestigious Grote Reber Medal (2007) from Australia and the Herschel Medal (1987) from the Royal Astronomical Society, UK. He was honoured with the H. K. Firodia Award and the M. N. Saha Birth Centenary Award for his role in making India a global hub for radio astronomy. He was also a Fellow of the Royal Society of London and all three major science academies in India (INSA, IASc, and NASI). He served as the President of the Astronomical Society of India and played a pivotal role as a member of the International Astronomical Union (IAU). He was a key member of the International Union of Radio Science (URSI) and the person behind the initial conceptualization of the Square Kilometre Array (SKA), the world's largest radio telescope project.

Prof. Govind Swarup was more than just a scientist, he was a visionary who proved that India could build world class technology with limited resources. By creating masterpieces like the Ooty Radio Telescope and the GMRT, he put India on the global map of space exploration. His legacy continues to inspire young scientists to dream big and build indigenous solutions for the mysteries of the universe.

ARIES: India's gateway to observational astronomy

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The **Aryabhatta Research Institute of Observational Sciences (ARIES)** is one of India's leading research institutes dedicated to the study of astronomy, astrophysics, and atmospheric sciences. Located at **Manora Peak** near the scenic town of **Nainital** in the state of **Uttarakhand,** ARIES plays a significant role in advancing observational astronomy in India. The institute operates under the **Department of Science and Technology** and serves as an important center for scientific research, advanced instrumentation, and training in space sciences.

History and Establishment

ARIES was formally established in **2004** when the earlier **Uttar Pradesh State Observatory (UPSO),** which had been functioning for nearly **50 years,** was transformed into an autonomous research institute. The transformation allowed the institute to expand its research capabilities and infrastructure in astronomy and atmospheric sciences. Since then, ARIES has developed into a premier institution contributing significantly to observational research and technological development in astronomy.

Location and Importance

The location of ARIES is particularly advantageous for astronomical observations. Situated in the Himalayan region at a high altitude with relatively dark skies and stable atmospheric conditions, the observatory provides excellent viewing conditions for celestial observations. Additionally, its geographical longitude places it strategically between observatories in **Europe** and **Australia,** allowing continuous monitoring of astronomical events that might otherwise be missed.

Research Areas

ARIES conducts research in several major areas of astronomy and atmospheric science. In astronomy and astrophysics, scientists study a wide range of cosmic phenomena, including:

- Solar and planetary systems
- Stellar evolution and variable stars
- Star clusters and galaxies
- Quasars and active galactic nuclei
- High-energy events such as supernovae and gamma-ray bursts

The institute also carries out research in atmospheric sciences, focusing on aerosols, trace gases, and the lower layers of Earth's atmosphere. These studies contribute to understanding climate processes and atmospheric dynamics.

Observational Facilities

One of the major strengths of ARIES is its advanced observational infrastructure. The institute operates several powerful telescopes and instruments for astronomical observations. Among the important facilities are:

- **1.04-meter Sampurnanand Telescope** – Used for photometric and spectroscopic observations.
- **1.3-meter Devasthal Fast Optical Telescope (DFOT)** – Designed for monitoring variable and transient astronomical sources.
- **3.6-meter Devasthal Optical Telescope (DOT)** – One of the largest optical telescopes in Asia, capable of high-resolution imaging and spectroscopy.
- **4-meter International Liquid Mirror**

Telescope (ILMT) – A unique telescope designed for deep-sky surveys.

These telescopes are located at the **Devasthal observatory site,** about **60 km** from **Nainital,** where the dark sky conditions are ideal for advanced astronomical observations.

Scientific Contributions

ARIES has made important contributions to observational astronomy. Scientists at the institute have successfully observed and studied various astronomical phenomena, including the optical afterglow of gamma-ray bursts, gravitational microlensing events, and variability in quasars. These observations have helped improve our understanding of high-energy cosmic events and distant galaxies.

In addition to astronomy, ARIES has contributed to atmospheric studies in the Himalayan region, providing valuable data for climate and environmental research.

Education and Training

ARIES is also involved in training and education programs for students and young researchers. The institute organizes workshops, training schools, and research internships in observational astronomy and atmospheric sciences. These programs help students gain hands-on experience with telescopes, instruments, and data analysis techniques.

Conclusion

The Aryabhatta Research Institute of Observational Sciences stands as a major pillar of astronomical research in India. Through its advanced telescopes, strategic location, and active research programs, ARIES continues to expand our understanding of the universe. It also plays an essential role in training the next generation of astronomers and contributing to global scientific collaborations in space science and astrophysics.

Institute Images

ARIES Main Building

aries

आर्यभट्ट प्रेक्षण विज्ञान शोध संस्थान

Aryabhatta Research Institute of Observational Sciences

Institute Logo

ARIES Devasthal Campus

Nainital Observatory

Image Courtesy: ARIES Institute

BHOUTIKI Pradnya 4th issue release & recognition ceremony & reel competition result announcement

BHOUTIKI Physics Club
Department of Physics, MES's Nowrosjee Wadia College, Pune - 411 001

The **BHOUTIKI Pradnya 4th Issue Release and Recognition Ceremony & Reel Competition Result Announcement** was successfully organized on **22nd December 2025** with great enthusiasm and academic spirit. The **Nuclear Physics** issue of **BHOUTIKI Pradnya** was officially released by **Chief Guest Dr. Sanjay Dhole, Department of Physics, Savitribai Phule Pune University.**

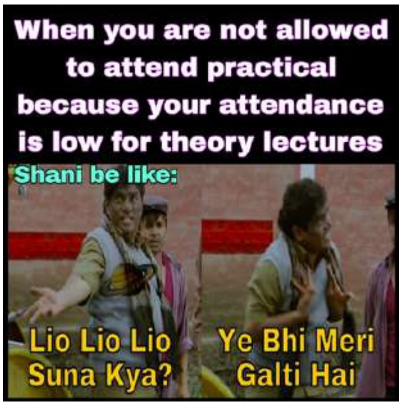
The event was graced by the presence of **Prof. Manisha Hawaldar, President of IAPT SRC-08 C,** who announced the results of the **Reel Competition**. Distinguished dignitaries including **Dr. B. B. Bahule, Principal of MES's Nowrosjee Wadia College, Dr. Subhash Ahire, Vice-Principal,** and **Prof. S. G. Jamdade, Head of the Department of Physics,** were also present.

During the ceremony, contributors to the fourth issue were honored with **Letters of Appreciation** in recognition of their valuable efforts. The program also featured an insightful and motivating talk by **Dr. Sanjay Dhole,** inspiring students to actively engage in scientific exploration and research. The event concluded on a celebratory note, marking another successful milestone for **BHOUTIKI Pradnya.**

Astronomy memes

Shubham Jadhav
Department of Physics, MES's Nowrosjee Wadia College, Pune - 411 001

Resolutions.... 🙂



Event Horizon: The boundary around a black hole beyond which nothing—not even light—can escape.

Venus and Uranus are the planets in our solar system that rotate clockwise.

The universe is infinite yet we can live on only one(known) planet.

Eclipses do not change food chemistry.

When matter and antimatter collide, they annihilate each other, converting their mass entirely into energy, usually as gamma-ray photons.

Year of activities by BHOUTIKI physics club

BHOUTIKI Physics Club
Department of Physics, MES's Nowrosjee Wadia College, Pune - 411 001

Winners - State Level Avishkar Research Competition

Ms. Vidhi Baldota

Mr. Anurag Mehta

We are proud to celebrate the remarkable achievement of our **TYBSc Physics** students, **Ms. Vidhi Baldota** and **Mr. Anurag Mehta**, who secured **3rd Rank** at the prestigious **18th Maharashtra State Inter-University Aavishkar Research Convention.**

The competition was hosted at **Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani,** where they represented **Savitribai Phule Pune University (SPPU.)**

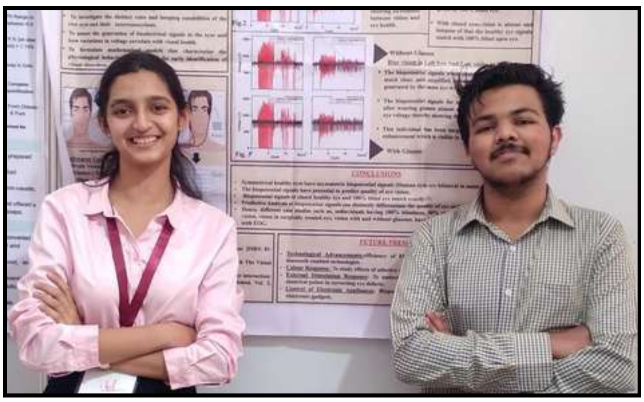
Their project, titled **"Predictive Analysis of Human Vision using Biopotential Signals,"** focused on integrating biomedical signal processing with predictive analytics to explore innovative approaches in understanding human vision. Their work stood out for its interdisciplinary approach, combining physics, biology, and data science.

In the Undergraduate category, **78 research posters** were presented, out of which only the **top 15 projects** were shortlisted for podium presentations. Among these highly competitive finalists, their project earned an impressive **3rd Rank**, reflecting both the quality and impact of their research.

This achievement is the culmination of a rigorous selection journey, progressing through **College Level**, **Zonal Level**, **University Level**, and **Post-Training Evaluation**, before reaching the **State Level.**

In addition to this honor, they were also awarded a **State-Level Research Fellowship**, recognizing their potential for continued contribution to research and innovation. Their success also contributed to the outstanding performance of the university contingent-out of **48 participating projects from SPPU**, **11 projects secured prizes**, helping the university achieve the **1st Runner-Up position** at the State Level.

This accomplishment highlights not only their dedication and teamwork but also the growing culture of research and innovation among undergraduate students. Their journey stands as an inspiration for aspiring researchers to pursue interdisciplinary ideas and push the boundaries of scientific exploration.



PHYSICS REEL COMPETITION!

PHYSICS IN MOTION, REEL IT, FEEL IT!

Winners
High School & Jr. College Category

1st Prize
Radhika Sawant
(9^{th} - Vidyaniketan School)
Physics of Motion - Leaf Floats on Water

2nd Prize Shared
Sambhav Waghresha
(11^{th} - Nowrosjee Wadia College, Pune)
Taylor Coutte Law of Liquid

2nd Prize Shared
Parinita Nigade
(8^{th} New Bal Vikas Mandir, Baramati)
Physics is Everywhere

Winners
UG - PG Category

1st Prize
Diganta Hazaarika
(MSc - I Physics, Nowrosjee Wadia College, Pune)
Physics Behind Different Sounds in Guitar

2nd Prize Shared
Harsh Tekawade
(MSc - I, Fergusson College, Pune)
Physics Behind Ukulele

2nd Prize Shared
Soham Sawant
(BSc, Fergusson College, Pune)
Matter-Antimatter Asymmetry

Upcoming Edition

PHOTONICS

June Issue

Submission Open!

Articles

Illustration

Memes

Submit on : bhoutiki_physics@nowrosjeewadiacollege.edu.in

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