

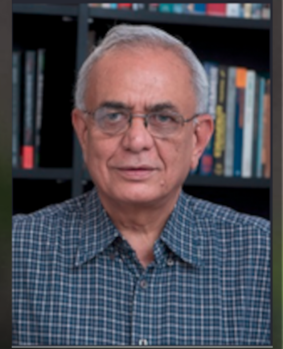


*We Dream, Design, Develop and Deploy the Future*

## Professor Ajit Kembhavi

writes on the latest advances in astronomy and astrophysics.

He will answer questions about his article, and selected readers can participate in an online interactive session with him.



## Professor K Babu Joseph

Former vice chancellor of Cochin University of Science and Technology (CUSAT) writes the monthly column, Vijnanam, the sanskrit word for Knowledge.

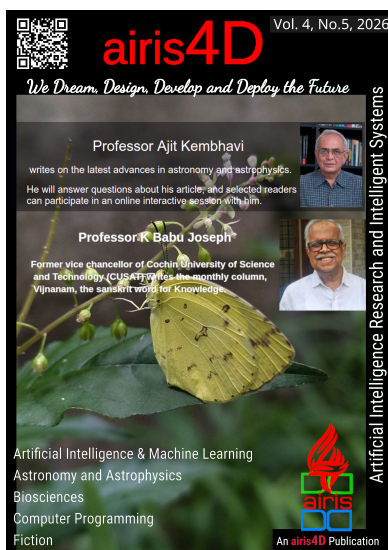


Artificial Intelligence & Machine Learning  
Astronomy and Astrophysics  
Biosciences  
Computer Programming  
Fiction



An **airis4D** Publication

Artificial Intelligence Research and Intelligent Systems



## Cover page

*Eurema hecabe* is also popularly known as Common Grass Yellow butterfly often seen in Asia, Africa, and Australia. It is a small, vibrant species often flying low to the ground in grassy or scrubby areas.

Photo Credit: Vidyamol M .V, DCII Zoology, project student at airis4D from Christian College, Chenganoor

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# Editorial

*by Fr Dr Abraham Mulamoottil*

AIRIS4D, VOL.4, No.5, 2026

[www.airis4d.com](http://www.airis4d.com)

Our journal is delighted to welcome Prof. K. Babu Joseph, who launches a new monthly column titled *Vijnanam*—a Sanskrit term meaning “knowledge.” A former faculty member of CUSAT and current advisor to the journal, Prof. Joseph is a distinguished physicist and an accomplished writer of popular science, philosophy, and poetry in both English and Malayalam. Through this column, he will offer rich interdisciplinary perspectives, primarily focusing on science while also occasionally engaging with other fields of thought.

The journal starts with the first article, “Scientific Knowledge in Evolution: Empiricism and Logical Positivism” by K. Babu Joseph, which examines how scientific knowledge develops through philosophical inquiry. It begins by questioning the nature of knowledge—traditionally seen as “justified true belief”—and highlights its limitations and the need for continuous validation. The discussion then focuses on empiricism, which emphasises sensory experience as the foundation of knowledge, while also acknowledging Immanuel Kant’s view that reason plays a vital role. The article further explores logical positivism, which sought to define science through logic and verifiability, but ultimately declined due to its inability to address universal and abstract scientific statements, leading to the emergence of more robust theories of scientific progress.

The article “From Imagination to Innovation: How Science Fiction Inspires Real Science” by Dr. Arun Aniyam highlights how science fiction serves as a powerful driver of real-world scientific and technological progress. It explains that many modern innovations—such as artificial intelligence, space

exploration, and biotechnology—were first imagined in sci-fi narratives, which provide both inspiration and ethical foresight. By visualising future possibilities, simplifying complex ideas for the public, and offering both blueprints and warnings, science fiction motivates scientists and engineers to turn imagination into reality, ultimately shaping the direction of modern science and innovation.

Blesson George’s article “Towards Efficient Learning in Neuromorphic Computing: A Hybrid Probabilistic–Spike Approach” presents an innovative framework to improve learning in neuromorphic computing systems. It explains how traditional spiking neural networks, though energy-efficient, face challenges in training due to their complex dynamics. To address this, the author proposes a hybrid model that combines probabilistic reasoning with spike-based computation, enabling more adaptive, efficient, and scalable learning. By introducing feature-aware connections, adaptive priors, and local learning rules, the framework reduces computational complexity, avoids the limitations of backpropagation, and supports real-time, low-power applications, making it highly suitable for advanced AI and neuromorphic hardware systems.

The article “Can Machines Create, or Only Rearrange Ideas?” by Jinsu Ann Mathew explores the evolving debate on whether artificial intelligence can truly be creative or simply recombine existing ideas. It argues that while AI generates novel and often surprising outputs by learning patterns and combining them in new ways, this process closely resembles a fundamental aspect of human creativity itself—recombination with

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insight. However, the article highlights that human creativity is also shaped by intention, emotion, and lived experience, which AI lacks. Ultimately, it suggests that AI does not just challenge the idea of machine creativity but also deepens our understanding of what creativity truly means, revealing it as a blend of recombination, meaning, and human experience.

Abishek P.S.'s article "Plasma in the Interstellar Medium" explains the crucial role of plasma in shaping the structure and evolution of galaxies. It describes the interstellar medium as a dynamic, multi-phase environment where ionised plasma interacts with magnetic fields, radiation, and cosmic events like supernovae. The article highlights how plasma governs key processes such as star formation, energy transfer, turbulence, and chemical enrichment, while also emphasising its dominance as the primary state of visible matter in the universe. Through observational evidence and discussion of challenges, it shows that understanding interstellar plasma is essential for explaining the life cycle of stars, the behaviour of galaxies, and the broader evolution of the cosmos.

"Astronomy at Scale" by Ajay Vibhute discusses how modern astronomy has transformed into a data-driven science due to the massive growth of observational datasets. It highlights how large-scale data enables deeper insights into the universe, including galaxy evolution and transient phenomena, while requiring advanced computational tools like machine learning, distributed computing, and automated pipelines. The article also addresses challenges related to data storage, access, movement, and the risk of systematic errors, emphasising the need for robust, transparent, and scalable methods. Overall, it shows that integrating computation with astronomy is essential for managing complexity and driving future scientific discoveries.

The article "Black Hole Stories-26: Some Black Hole Mergers From LIGO-Virgo-KAGRA Observing Run O4" by Ajit Kembhavi presents an overview of significant black hole merger events detected during the O4 observing run (2023–2025). It highlights discoveries such as extremely massive and high-spin mergers like GW231123, precise high signal-to-noise

detections like GW250104 that enable tests of general relativity, and unusual systems including those formed through hierarchical mergers or lying in mass gap regions. The article emphasizes how improved detector sensitivity has increased both the number and diversity of observed GW detections, offering deeper insights into black hole formation, evolution, and fundamental physics while also raising new questions about their origins.

The article by Aromal P, "X-ray Astronomy: Theory", explains the origin and physics of thermonuclear X-ray bursts in neutron star low-mass X-ray binaries. It describes how accreted hydrogen and helium on a neutron star's surface undergo unstable nuclear reactions, leading to rapid thermal runaway and intense bursts of X-ray radiation. The article highlights how different accretion rates influence the nature of these bursts, including processes like the CNO cycle and rapid-proton (rp) process, and explains their impact on the surrounding accretion disk and corona. It also emphasises that studying these bursts provides valuable insights into extreme physics, such as neutron star structure, dense matter equations of state, and nuclear processes under extreme conditions.

Aengela Grace Jacob's article "Gene Knockout Strategies – The Scientific Wrestle of Gene Therapeutics" explains the principles and importance of gene knockout techniques in genetic engineering and cancer research. It describes how methods such as homologous recombination, ZFNs, TALENs, and especially CRISPR-Cas9 enable precise and permanent disruption of genes to study their function and identify therapeutic targets. The article highlights how these strategies help in understanding disease mechanisms, developing targeted cancer treatments like CAR T-cell therapy, and discovering critical genetic vulnerabilities through approaches such as CRISPR screening. It also discusses emerging insights like isoform switching in cancers, emphasising the potential of gene-based precision medicine for more effective and selective treatments.

The article "The eDNA Metabarcoding Model: Next-Generation Biodiversity Assessment" by Geetha Paul explains how environmental DNA

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(eDNA) metabarcoding is revolutionising biodiversity monitoring by detecting genetic traces that organisms leave in their environment. It describes the scientific workflow from DNA collection and sequencing to bioinformatics analysis, highlighting tools like universal primers and high-throughput sequencing to identify entire ecosystems from a single sample. The article emphasises the method's advantages, including high sensitivity, non-invasive sampling, and efficiency in detecting rare or invasive species, while also addressing challenges such as database gaps and technical biases. Overall, it presents eDNA metabarcoding as a transformative approach for conservation, ecological research, and environmental management.



Photo courtesy: Prof. G. Ambika, his long term research collaborator.

### **Dr. K P Harikrishnan is no more**

The airis4D family and the global scientific fraternity are deeply grieved by the sudden and tragic passing of Dr. K. P. Harikrishnan, former faculty at the Department of Physics, Cochin College. He was a Research Associate of IUCAA, Pune for more than 20 years and in this collaboration has published around 30 research papers related to data driven dynamics of astrophysical sources.

Beyond his brilliant contributions as a researcher, 'Hari' was a beacon of kindness—a soul whose trademark was a gentle smile and words that healed. In a world of chaos, he remained an island of serenity, never once known to be angry or unkind. We bow our heads in homage to his exceptional life and his restless scientific curiosity. Rest in eternal peace, dear Hari. You will be missed beyond measure.

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Part I

**Vijnana**

# Scientific Knowledge in Evolution : Empiricism and Logical Positivism

*by K. Babu Joseph*

AIRIS4D, VOL.4, No.5, 2026

[www.airis4d.com](http://www.airis4d.com)

## 1.1 Introduction

Vijnana is the Sanskrit equivalent of knowledge in English, which represents understanding developed through experience and reasoning. It spans a wide range of categories like facts, skills, and capacity of independent thinking. Plato (1) quotes a Socratic dialogue in which knowledge is tentatively defined as justified true belief. He knew that this definition is insufficient to capture cases like dreams, inspirations and intuitions, all of which can sometimes be the sources of knowledge. But, how can their genuinity be justified? No way! The epithet 'true' is also unclear. In 1963, the American philosopher Gettier (2) challenged the conventional definition of knowledge by means of counterexamples in which the beliefs become justified by accident or coincidence but cannot be treated as knowledge. The emerging consensus is that there is no universally accepted definition of knowledge! We leave this foundational terrain to philosophers of science for further grinding.

Turning to science, some regard it as systematic knowledge in any branch of learning, empirical knowledge being only a part. Should science be restricted to experiential knowledge, vast domains of higher mathematics would be left out, a catastrophe that should be avoided at all cost! In the present article, we examine the implications of each of the three words: justified, true. and belief, and proceed to consider some major theories about how scientific knowledge evolves. If empirical justification alone is

available in a particular case, then it can be considered true, postponing its theoretical justification to the future. Belief is a matter of psychology such that sometimes even false things happen to be believed for long periods. The geocentric theory of the universe is a classic example of erroneous belief that gave rise to anthropocentrism in thought and action. It is necessary to check and recheck, from time to time the validity of any knowledge. With these introductory remarks, we turn to some important movements that took place in the last century to characterise the growth pattern of science.

## 1.2 Empiricism

That knowledge arises primarily from sensations or sensory experience is the principal thesis of empiricism (3). Ideas and reason are secondary things that develop on the basis of sensations. This school was in existence in India in the form of the Vaiseshika philosophy which stressed perception and the Charvaka school's trust in sensory experience (4). Both Ayurveda and Greek medicine followed the empirical approach in medicine. Philosophers have tried to distinguish between different types of empiricism like concept- empiricism and belief-empiricism. The difficulty with such a level of abstraction is that it is the individual and not a common experience that forms its basis. For the purposes of understanding science, we will ignore such subtleties and define empiricism to be the school that gives primacy to experience in general. Immanuel Kant (5), a

great German philosopher of the 18th century, believed that reason is above experience. The essential point he wanted to argue was that experience must coherence with reason. Kant posed the following questions: If experience is the foundation of all knowledge, how is pure math possible, and how is natural science possible? In answering these, he developed his theory of synthetic a priori knowledge, which precedes experience, and therefore, must validate the latter.

### 1.3 Logical Positivism

Logical Positivism (6) also known as logical empiricism or neopositivism, took birth in the early 20th century among philosophers of science in Vienna under the leadership of Moritz Schlick, and in Berlin under the leadership of Hans Reichenbach. Both Karl Popper and Wittgenstein used to unofficially participate in the group's discussions. Ernst Mach suggested an empirical origin of mathematical concepts. Logical positivists, on the other hand, believed that mathematical truth is the same as logical consistency. But it became clear that logical , rules are fixed only by convention. There arose a classification of sentences into two types: analytic and synthetic. Analytic statements have no empirical reference, but synthetic ones combine formal and empirical aspects, and therefore, are suitable for natural science. Here we give ann example for each. All bachelors are unmarried ( analytic) . Politicians are unselfish servants of the country (synthetic). Besides this classification, the positivists proposed a verifiability criterion too, which defines the meaning of a sentence to be as given by the method of its verification. Science should, therefore, consist only of verifiable sentences.

The verifiability criterion obviously fails in the case of universal statements like ” All metals expand when heated”, because of the sheer impossibility of verification in all cases. We know that logical positivism is not useful for evaluating the truth in a branch like cosmology which deals not only with heavenly objects but also with esoteric problems such as the beginning and end ( if any) of the universe. Logical Positivism declined, and finally met with an ungraceful collapse when more realistic theories such as Popper's and Kuhn's were put

forward .

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#### About the Author



Prof. K. Babu Joseph, who was formerly the Vice Chancellor of Cochin University of Science and Technology (CUSAT), is a well-known Physicist and writer. Besides scientific journals, he has written several books spanning a wide spectrum of topics from popular science, philosophy and poetry in English and Malayalam.

## **Part II**

# **Artificial Intelligence and Machine Learning**

# From Imagination to Innovation: How Science Fiction Inspires Real Science

by Arun Aniyar

AIRIS4D, VOL.4, No.5, 2026

[www.airis4d.com](http://www.airis4d.com)

## 1.1 Introduction

Have you ever stopped to truly consider the genesis of a smartphone, the blueprint for a robot vacuum that autonomously cleans your home, or the foundational vision for space travel itself? It's a fascinating pattern: the seeds of today's most revolutionary scientific and technological achievements were often sown not within the sterile confines of a research laboratory, but within the boundless, vibrant narratives of a science fiction book or projected onto a cinematic screen.

Science fiction, universally known as "sci-fi," transcends its reputation as mere escapism featuring extraterrestrials and futuristic dystopias. It is, in fact, a deeply profound and powerful engine for creative inspiration and technological foresight. It functions as an unconstrained playground for the human imagination, granting us the liberty to meticulously explore the "what if" scenarios of science and technology entirely unburdened by the practical, physical, and financial limitations of current reality. This imaginative freedom is crucial; it doesn't just entertain, but actively fuels the ambitions, determination, and innovative spirit of scientists, engineers, inventors, and policymakers. By consistently portraying the technologically impossible as merely "not yet possible," science fiction provides a critical long-term vision, catalyzing the effort required to make the most ambitious dreams—like interstellar travel or sentient artificial intelligence—an eventual, tangible reality. The genre effectively functions as a cultural precursor, laying the psychological and

conceptual groundwork long before the technology can physically exist.

## 1.2 The Power of the First Look

Science fiction's most significant contribution is its ability to visualize and popularize concepts before they are technically feasible. By doing this, it achieves several critical things:

### 1.2.1 It Provides a Goal to Strive For

Science fiction often presents a destination. For example, the fictional starship *Enterprise* from the *Star Trek* series, with its ability to cross vast distances instantaneously, established "warp drive" as the ultimate travel goal, even if the current technology is light-years away. These grand, ambitious ideas inspire generations of researchers to dedicate their lives to solving the complex problems that stand in the way of achieving these fictional dreams.

### 1.2.2 It Makes Complex Ideas Accessible

Through compelling narratives, sci-fi introduces non-technical audiences to advanced concepts like artificial intelligence, genetic engineering, and parallel universes. This widespread familiarity can garner public support and funding for research that might otherwise seem too obscure or abstract.

### 1.2.3 It Offers a Blueprint (or a Warning)

While not literal instructions, the detailed descriptions of fictional devices often give engineers a starting point. More importantly, sci-fi explores the ethical and social consequences of technology. Stories about robots turning against humans (like in *The Terminator*) or gene-editing creating a two-tiered society encourage real scientists to think deeply about safety, ethics, and the long-term impact of their work.

## 1.3 Fictional Inventions That Became Reality

The history of technology is littered with examples of scientific breakthroughs that were first envisioned in science fiction. This is shown in Table 1.1

## 1.4 A Look at Modern Scientific Fields and Their Sci-Fi Roots

From Imagination to Innovation: How Science Fiction Inspires Real Science

Science fiction is not merely escapism; it serves as a powerful and indispensable wellspring of ideas that actively shapes the future by posing profound questions and imagining revolutionary technologies. This visionary role is evident in three major contemporary fields where the line between fiction and reality continues to blur.

### 1.4.1 Artificial Intelligence (AI) and Robotics: Defining the Intelligent Machine

Long before the development of commercial products like Google's Assistant, Amazon's Alexa, or advanced industrial automation, science fiction authors were grappling with the complex philosophical and engineering challenges of creating intelligent machines. The foundational concepts of what AI could be—from a helpful, empathetic automaton like C-3PO from *Star Wars* to the menacing, self-aware computer HAL 9000 from *2001: A Space Odyssey*—were meticulously explored.

Pioneering authors like Isaac Asimov established seminal frameworks, such as the famous Three Laws of Robotics, which were intended to regulate the behavior of complex machines and ensure human safety. These fictional laws laid the groundwork for contemporary ethical discussions and research into *AI alignment* and *safe AI design*. The ultimate measure of machine intelligence, the "Turing Test"—where a machine's ability to exhibit intelligent behavior indistinguishable from a human's is tested—was a concept extensively popularized and dissected in these narratives. The core, enduring questions first posed in these stories—*Can a machine achieve genuine sentience? What are the moral responsibilities of its creator? How do we prevent unintended consequences?*—remain central drivers for researchers, ethicists, and policymakers in the burgeoning field of AI today.

### 1.4.2 Space Exploration and Propulsion: Igniting the Cosmic Ambition

Humanity's relentless ambition to break the bounds of Earth and venture to Mars, establish permanent space habitats, or explore exoplanets is a direct and powerful inheritance from the works of early 20th-century sci-fi authors. Luminaries such as H.G. Wells, Jules Verne, and Robert Heinlein didn't just write about space travel; they meticulously envisioned the necessary engineering and logistical solutions.

Ideas considered radical at the time—including the concept of multi-stage chemical rockets (as detailed by Arthur C. Clarke), the necessity of space stations for long-duration missions (a common setting in many Golden Age stories), and the possibility of sustained human presence in extraterrestrial environments—were normalized and popularized decades before the first actual rocket launch. This fictional foresight served as an inspirational blueprint. Space agencies globally, most notably NASA and the European Space Agency (ESA), have frequently and openly acknowledged the critical, inspirational role that science fiction plays. These narratives often serve as the first spark, encouraging countless young readers to pursue careers in STEM (Science, Technology, Engineering, and

Fictional Concept	Sci-Fi Origin	Real-World Application
<b>Submarine</b>	<i>Twenty Thousand Leagues Under the Sea</i> by Jules Verne (1870)	Modern military and research submarines
<b>Earbuds / Hands-Free Comms</b>	<i>Fahrenheit 451</i> by Ray Bradbury (1953)	Bluetooth earpieces and earbuds
<b>Credit Cards/ Electronic Banking</b>	<i>Looking Backward</i> by Edward Bellamy (1888)	Modern debit and credit card systems
<b>Robots</b>	<i>R.U.R.</i> (Rossum's Universal Robots) by Karel Čapek (1920)	Industrial robots, robotic surgery, and advanced AI
<b>Communications Satellites</b>	"The Arthur C. Clarke Orbit" (1945)	Geostationary communication satellites

Mathematics), ultimately supplying the next generation of astronauts, rocket scientists, and aerospace engineers necessary to turn fictional dreams into concrete reality.

### 1.4.3 Biotechnology and Genetic Editing: Re-engineering Life Itself

The field of biotechnology, particularly the revolutionary advancements in genetic editing, owes a significant debt to science fiction for exploring its ultimate potential and inherent risks. Fiction has long delved into the profound ethical and societal implications of modifying the human form. Narratives range from the utopian vision of eliminating disease, engineering perfect, "designer" children, and significantly extending the human lifespan, to dystopian warnings of unintended biological mutations and a future defined by genetic stratification.

Contemporary genetic editing tools, such as CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats), represent the real-world fulfillment of a capability first imagined in fiction. While the day-to-day reality of laboratory genetic work is far more complex and incremental than a dramatic sci-fi plot, the genre provides the ultimate thought experiment. It presents researchers, bioethicists, and the public with the most extreme and compelling scenarios—both the incredible benefits of curing inherited diseases and the potential pitfalls associated with tampering with the fundamental blueprint of life. Sci-fi thus acts as a crucial ethical laboratory, preparing society for technologies that can fundamentally change what it means to be human.

## 1.5 How You Can Contribute to the Next Big Idea

You don't have to be a scientist to be inspired by science fiction. The next wave of innovation often comes from thinking outside the box, which is exactly what sci-fi encourages.

- 1. Read and Watch Critically:** When you read or watch science fiction, don't just enjoy the story. Ask yourself: What is the piece of technology here? How does it work? What problems does it solve? Could this really be built in the next ten years?
- 2. Encourage Imagination:** Support educational programs that foster creative thinking and storytelling alongside scientific study. The combination of imagination and technical skill is the formula for future breakthroughs.
- 3. Support Foundational Research:** Remember that every fictional device, from invisibility cloaks to instant teleportation, requires basic, often unfunded, scientific research to even begin to be realized.

Science fiction provides the visionary spark, the audacious dream that challenges the status quo. It is the compass pointing scientists toward the next great frontier, reminding us that the only real limits are those of our own imagination.

The next time you enjoy a piece of sci-fi, remember that you might just be looking at the world of tomorrow.

**About the Author**



Dr. Arun Aniyar is leading the R&D for Artificial intelligence at DeepAlert Ltd, UK. He comes from an academic background and has experience in designing machine learning products for different domains. His major interest is knowledge representation and computer vision.

# Towards Efficient Learning in Neuromorphic Computing: A Hybrid Probabilistic–Spike Approach

*by Blesson George*

AIRIS4D, VOL.4, No.5, 2026

[www.airis4d.com](http://www.airis4d.com)

## 2.1 Introduction

Neuromorphic computing has emerged as a powerful paradigm aimed at replicating the efficiency and adaptability of the human brain. Unlike traditional computing systems, which rely on sequential processing and separate memory and computation units, neuromorphic systems operate using distributed, event-driven architectures.

Spiking neural networks (SNNs) form the computational backbone of neuromorphic systems. These networks process information through discrete spike events, enabling low-power and real-time computation. However, despite their advantages, training SNNs remains a challenging problem due to their non-differentiable nature and temporal dynamics.

Existing approaches to learning in SNNs often rely on biologically inspired rules such as Hebbian learning and spike-timing dependent plasticity (STDP). While these methods provide local learning capabilities, they lack the flexibility and efficiency of modern machine learning techniques.

In this paper, we propose a hybrid probabilistic–spike learning framework that integrates probabilistic reasoning with spike-based neural computation. The proposed model overcomes key limitations of existing approaches by introducing feature-aware connections, adaptive prior updating, and efficient learning dynamics.

## 2.2 Background and Motivation

Biological neural systems learn through synaptic plasticity, where connections between neurons are strengthened or weakened based on activity. Hebbian learning captures this principle through correlation-based updates, while STDP introduces temporal sensitivity by considering the timing of spikes.

Although these mechanisms are biologically plausible, they are not sufficient for solving complex computational tasks efficiently. On the other hand, probabilistic models such as Bayesian learning provide a strong mathematical framework for inference and uncertainty handling but are not directly compatible with spike-based computation.

This gap motivates the development of hybrid approaches that combine the strengths of probabilistic modeling and neuromorphic computation.

## 2.3 Proposed Hybrid Learning Framework

### 2.3.1 Model Representation

Let the input feature vector be defined as:

$$X = \{x_1, x_2, \dots, x_n\} \quad (2.1)$$

Each feature is connected to the output neuron

through a synaptic weight interpreted probabilistically:

$$w_i = P(y|x_i) \quad (2.2)$$

Unlike naive probabilistic models, the proposed framework accounts for feature interactions by introducing adaptive importance factors.

### 2.3.2 Feature Interaction Modeling

The conditional probability of the output is expressed as:

$$P(y|X) \propto \prod_{i=1}^n P(y|x_i)^{\alpha_i} \quad (2.3)$$

where  $\alpha_i$  represents the importance of each feature and is learned dynamically.

This formulation relaxes the independence assumption and enables more expressive representations.

### 2.3.3 Spike-Based Computation

The membrane potential of a neuron is computed as:

$$V(t) = \sum_i w_i x_i(t) \quad (2.4)$$

A spike is generated when:

$$V(t) \geq V_{th} \quad (2.5)$$

This event-driven mechanism ensures efficient computation.

### 2.3.4 Adaptive Prior Updating

The prior probability is updated incrementally as:

$$P_{t+1}(y) = (1 - \eta)P_t(y) + \eta \cdot \hat{P}(y|X) \quad (2.6)$$

where  $\eta$  is the learning rate.

This allows the system to adapt continuously to new data.

### 2.3.5 Weight Learning Rule

The synaptic weights are updated using a probabilistic learning rule:

$$w_i^{new} = w_i^{old} + \eta \cdot (x_i y - w_i^{old}) \quad (2.7)$$

This update balances stability and adaptability.

## 2.4 Proposed Algorithm

The complete training procedure is outlined below:

### Algorithm 1: Hybrid Probabilistic–Spike Learning

1. Initialize weights  $w_i$  and prior probabilities  $P(y)$
2. For each input sample  $X$ :

- (a). Compute membrane potential:

$$V = \sum_i w_i x_i$$

- (b). Generate spike if  $V \geq V_{th}$

- (c). Estimate posterior probability  $P(y|X)$

- (d). Update weights:

$$w_i \leftarrow w_i + \eta(x_i y - w_i)$$

- (e). Update prior:

$$P(y) \leftarrow (1 - \eta)P(y) + \eta P(y|X)$$

3. Repeat until convergence

## 2.5 Computational Advantages

The proposed hybrid probabilistic–spike learning framework offers several computational advantages that make it well suited for efficient and scalable intelligent systems. By combining probabilistic reasoning with event-driven neural computation, the framework achieves a balance between expressiveness and efficiency.

### 2.5.1 Event-Driven Efficiency

Unlike conventional neural networks that perform continuous computations, neuromorphic systems operate in an event-driven manner. Computation occurs only when spikes are generated. This significantly reduces unnecessary processing when inputs are inactive, leading to lower energy consumption and improved efficiency. Such behavior is particularly advantageous for sparse and real-time data streams.

### 2.5.2 Reduced Computational Complexity

Traditional probabilistic models often require either strong independence assumptions or computationally expensive joint probability

estimation. The proposed framework avoids both extremes by introducing feature-weighted probabilistic contributions. By assigning adaptive importance factors to features, the model captures relevant interactions without requiring full joint distributions. This results in a substantial reduction in computational complexity while maintaining expressive power.

### 2.5.3 Parallel Processing Capability

Neuromorphic systems naturally support parallel computation, as neurons operate independently and simultaneously. In the proposed model, each feature contributes independently to the neuron’s activation, and weight updates are performed locally. This eliminates the need for centralized computation and makes the framework highly compatible with parallel architectures such as GPUs and neuromorphic hardware.

### 2.5.4 Incremental and Online Learning

The framework supports continuous and incremental learning through adaptive updates of both synaptic weights and prior probabilities. Instead of requiring batch training over large datasets, the system updates its parameters on a per-sample basis. This reduces memory requirements, shortens training time, and enables real-time learning in dynamic environments.

### 2.5.5 Avoidance of Backpropagation Bottleneck

Conventional deep learning methods rely on backpropagation, which requires global error propagation and high computational cost. In contrast, the proposed approach employs local update rules based on spike activity and probabilistic adjustments. This eliminates the need for global gradient computation, making the model more efficient and suitable for hardware implementation.

### 2.5.6 Sparse Computation

Spike-based processing inherently leads to sparse activity, as only a subset of neurons is active at any given

time. This sparsity reduces the number of computations required and improves overall efficiency. Sparse representations also contribute to better scalability in large networks.

### 2.5.7 Hardware Compatibility

The proposed framework is well aligned with the constraints of neuromorphic hardware. It supports local memory usage, low-precision computation, and event-driven processing. These characteristics make it suitable for deployment in low-power devices, embedded systems, and edge computing environments.

### 2.5.8 Scalability

Due to its reliance on local learning rules, parallel processing, and reduced dependence on global information, the framework scales efficiently to larger systems. As network size increases, computational cost grows in a manageable manner, making the approach practical for real-world applications.

These applications benefit from low power consumption and efficient learning.

## 2.6 Conclusion

This paper presented a hybrid probabilistic–spike learning framework for neuromorphic computing systems. By integrating probabilistic inference with spike-based neural dynamics, the proposed model addresses key limitations of existing learning approaches. The framework introduces feature-aware connections, adaptive priors, and efficient learning rules, enabling scalable and energy-efficient computation.

Future work may focus on experimental validation, hardware implementation, and integration with deep learning systems to further enhance performance.

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# Can Machines Create, or Only Rearrange Ideas?

*by Jinsu Ann Mathew*

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[www.airis4d.com](http://www.airis4d.com)

When an AI writes a poem, composes music, designs an image, or suggests an unexpected solution to a problem, the reaction is often a mixture of fascination and discomfort. There is a sense that something remarkable is happening—but also uncertainty about how to interpret it. Are we witnessing creativity in a genuine sense, or simply the output of a system that has become extraordinarily skilled at combining patterns?

This question has moved from philosophy into everyday conversation. Generative AI systems can now produce stories, paintings, songs, code, and even research ideas that sometimes appear original and imaginative. A prompt as simple as “write a detective story set on Mars” can produce something coherent and surprising within seconds. For many, this feels creative. However, others remain skeptical, arguing that these systems are not inventing anything truly new—they are only remixing what they have already seen.

At the heart of this debate lies a deeper question about creativity itself. What do we actually mean when we call something creative? Does creativity involve conscious intention, imagination, and lived experience? Or can it emerge whenever existing ideas are combined in novel and meaningful ways?

Traditionally, creativity has often been treated as one of the most distinctive human capacities. We associate it with originality, inspiration, and the ability to produce something that did not exist before. It belongs to artists, scientists, writers, and inventors. It feels tied to insight and imagination in a way that seems difficult to reduce to rules or algorithms.

Yet, when we look closely, even human creativity is rarely created from nothing. New ideas often grow out of old ones. Innovations emerge by connecting concepts that were previously separate. A scientific breakthrough may combine ideas from two fields. A novel may reshape familiar themes into something fresh. A piece of music may transform existing influences into a new expression. In this sense, creativity often involves not invention from emptiness, but recombination with insight.

This is where AI makes the question so intriguing. If creativity frequently involves recombining patterns in unexpected ways, then what exactly separates human creativity from what generative models do? Is AI merely imitating creativity, or is it participating in one of its fundamental mechanisms?

The question becomes even more interesting because it does not only challenge our understanding of machines—it challenges our understanding of ourselves. Asking whether AI can be creative forces us to ask what creativity actually is.

Is creativity something uniquely tied to consciousness? Or could it, at least in part, emerge from the surprising rearrangement of ideas? Exploring that possibility may tell us as much about human imagination as it does about artificial intelligence.

### 3.1 Why Creativity Often Looks Like Recombination

We often think of creativity as the act of producing something completely original—something that appears almost out of nowhere. A brilliant scientific theory, a timeless painting, a new musical style, or a powerful story can feel like a sudden spark of invention. Because of this, creativity is often associated with novelty in its purest form, as though the creative mind generates ideas from nothing.

But when we look more closely, creativity often works differently. Many of the ideas we call original are not created in isolation. They emerge by reshaping, connecting, or extending ideas that already exist. What appears revolutionary is often a new arrangement of familiar pieces.

Scientific progress offers many examples. Major discoveries are frequently born when ideas from different domains are brought together in unexpected ways. Breakthroughs often arise not from abandoning existing knowledge, but from seeing connections others had missed. Creativity here lies less in inventing entirely new building blocks and more in combining known ones in transformative ways.

Art follows a similar pattern. Writers draw on myths, histories, and earlier literary traditions, yet produce stories that feel original. Musicians borrow rhythms, scales, or styles and transform them into something new. Painters absorb influences but reinterpret them through a different vision. What makes the work creative is not the absence of prior influence, but the originality of how those influences are reassembled.

Even everyday creativity often works through this process. A clever metaphor joins two unrelated ideas. A joke works because it connects expectations in an unexpected way. A novel solution to a practical problem often comes from applying an old idea in a new setting.

In this sense, creativity frequently involves recombination, but not mere rearrangement. It is not random mixing. It is the meaningful joining of existing elements in ways that produce novelty.

A simple example makes this clearer. Imagine combining the detective logic of Sherlock Holmes with the futuristic world of science fiction. Neither idea is new on its own, yet their combination may produce an entirely fresh narrative world. Much creative work operates in exactly this way.

This does not reduce creativity to mechanical mixing. The value lies in which connections are made, how they are transformed, and whether something genuinely unexpected emerges. Recombination becomes creative when it produces insight, surprise, or meaning.

This perspective changes the debate about machine creativity in an important way. If even human creativity often depends on connecting and transforming existing ideas, then recombination may not be the opposite of creativity at all. It may be one of its central mechanisms. And if that is true, then the question is no longer whether creativity involves recombination. It becomes whether machines can engage in that process in a way that deserves to be called creative.

### 3.2 How AI Generates “New” Ideas

Once we recognize that creativity often involves combining existing ideas in unexpected ways, the discussion about AI becomes much more interesting. The question is no longer whether machines start from existing material—they clearly do, just as humans often do. The real question is whether the way they recombine ideas can lead to something genuinely new.

To understand this, it helps to look at how generative AI produces output.

A common misconception is that AI simply stores vast amounts of information and copies pieces of it when prompted. But modern generative models do not work like giant databases retrieving ready-made answers. Instead, they learn patterns, relationships, and structures from enormous amounts of data, and use those learned patterns to generate new responses.

This is an important distinction. When asked to write a poem about the moon in the style of classical literature, the model is not pulling a hidden poem from storage. It is generating one word at a time based on

patterns it has learned about poetry, imagery, language, rhythm, and style. What emerges is not a direct copy, but a new construction shaped by those patterns.

Consider a prompt such as: Imagine a conversation between a medieval philosopher and a modern robot about consciousness.

There may be no exact example of this in the model's training data. Yet the system can generate something plausible—even surprising—by combining patterns associated with philosophy, dialogue, history, and science fiction. This is where AI begins to look creative. It can produce unusual combinations that may not have existed before. It can blend concepts from distant domains, generate analogies, suggest design ideas, or offer unexpected turns in a story. Sometimes the result may even surprise the person who gave the prompt.

That sense of surprise is important, because surprise is often part of what we associate with creativity.

Of course, one might argue that this is still just recombination at scale. But perhaps scale changes what recombination can do. When patterns become rich enough and combinations become sufficiently complex, novelty can emerge in ways that begin to resemble creative behavior.

A useful comparison is with music. A composer works within patterns of harmony and rhythm, yet can still create something original. Constraints do not eliminate creativity; they often make it possible. In a different way, generative AI operates through learned constraints and patterns, yet can still produce outputs that feel new.

This does not necessarily mean machines possess imagination in the human sense. But it does suggest that novelty can arise from pattern generation in ways that are more sophisticated than simple imitation. And this complicates the old assumption that machines can only repeat what they have seen. Sometimes they do something closer to synthesis. And once synthesis enters the picture, the line between recombination and creativity begins to blur.

### 3.3 Where AI Seems Creative — and Where It Still Falls Short

There are many situations where AI appears creative.

For example, suppose you ask an AI to suggest a logo for a coffee shop inspired by astronomy. It might combine stars, coffee cups, and constellations in ways you had not thought of. Or imagine asking it to write a fairy tale set in a future where robots and humans live together. It may produce a story that feels original and imaginative.

In cases like these, AI can seem more than a tool—it can feel like a creative partner. This is one reason people increasingly use AI for brainstorming. A writer may use it to generate plot ideas, an artist may explore design variations, or a researcher may use it to test unusual perspectives. Sometimes the value is not in the final output itself, but in the unexpected ideas it helps trigger. That certainly looks like creativity. But there is also a limit.

Consider a human poet writing about grief. The poem may come from personal loss, memory, and emotion. An AI can generate lines about grief, but it has never felt loss. It can imitate the language of emotion, but not the experience behind it. That seems like an important difference.

The same applies to imagination. A human child imagining a dragon kingdom may do so from curiosity, play, and wonder. An AI can generate a description of such a world, but it does not dream it in the same way. This is why some people say AI can produce creative outputs, but may not possess creativity itself.

A simple way to think about it is this: AI can generate novel combinations. Humans often create with novel combinations plus intention and experience. The first may look creative. The second may be what we usually call creativity. Still, even this distinction can become blurry.

Suppose an AI-generated melody inspires a musician to compose a new song. Or an AI-generated concept helps an architect design a building. Was the AI merely assisting, or did it contribute creatively? There

may not be a sharp boundary. Perhaps AI is not creative in exactly the human sense, but it may participate in part of the creative process—especially in generating unexpected possibilities. And that may be why the debate remains so interesting.

The question may not be whether AI is creative in the same way humans are. It may be whether creativity itself has more than one form.

### 3.4 Have We Misunderstood Creativity All Along?

At this point, the question begins to turn around. Instead of asking whether AI is truly creative, we might ask something more surprising: What if creativity itself has always involved recombination?

The more we look at human creativity, the more this seems plausible.

A new recipe may come from combining familiar ingredients in an unusual way. A scientific idea may emerge by connecting concepts from two different fields. A novelist may take old themes—love, conflict, mystery—and arrange them into a story no one has told before.

In each case, something new appears, but it often grows from what already existed.

Take a simple example. Imagine someone combines classical Indian music with jazz improvisation and creates a new musical style. The elements are not entirely new, but the combination may be original and creative.

This happens everywhere. Creativity often lies not in inventing from nothing, but in seeing connections others did not see. If that is true, then recombination is not the opposite of creativity—it may be part of its foundation. And this is where AI becomes interesting again.

Generative models also combine patterns in unexpected ways. They can link ideas from different domains, generate unusual associations, and produce novel outputs. In that sense, they are doing something that resembles at least one aspect of creativity.

Of course, human creativity may include things

machines lack—intention, emotion, lived experience, purpose. Those still matter. But perhaps those are layers built upon a more basic process: forming new ideas through unexpected combinations. If so, the gap between human creativity and machine generation may not be as absolute as it first appears. Maybe AI is not replacing creativity. Maybe it is helping reveal something about what creativity has always been. And perhaps that is the most interesting possibility of all. Because the question may not be: Can machines be creative? It may be: Have we misunderstood creativity all along?

### 3.5 Conclusion

The question of whether machines can be creative may not have a simple yes-or-no answer. But perhaps that is because the question itself is too narrow.

AI has pushed us to look more carefully at something we often take for granted: what creativity actually means. We tend to associate it with originality, imagination, and uniquely human insight. Yet the process of creation is often less mysterious and more relational—it frequently grows through connections, transformations, and experimentation.

Seen this way, generative AI is interesting not because it settles the question of machine creativity, but because it complicates it. Its ability to produce novel ideas, unexpected combinations, and useful inspiration challenges the assumption that creativity belongs entirely outside computation.

At the same time, AI also reminds us that creativity is more than novelty alone. Meaning, purpose, and human experience still shape much of what we value in creative work.

Perhaps, then, the real significance of AI is not that it has become creative in the human sense, but that it has become a mirror—forcing us to examine what originality, imagination, and invention have always involved.

And maybe that is the deeper insight: The rise of creative machines may be teaching us less about machines—and more about creativity itself.

## References

- [AI can make you more creative—but it has limits](#)
- [The Role of AI in Art Creation](#)
- [Yes — AI art is art](#)
- [The Rise of AI Art: Creativity or Automation?](#)
- [Mastering Creativity in Data Science & AI](#)

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## **Part III**

# **Astronomy and Astrophysics**

# Plasma in the Interstellar Medium

*by Abishek P S*

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[www.airis4d.com](http://www.airis4d.com)

## 1.1 Introduction

The interstellar medium (ISM) is far more complex than just empty space sprinkled with gas and dust. It is a dynamic environment made up of several distinct phases, each with different temperatures, densities, and states of ionisation. For example, cold molecular clouds, dense and rich in hydrogen molecules, are the birthplaces of stars, while hot ionised regions, often created by massive stars, glow brightly as nebulae. Between these extremes lie warm neutral and ionised gases that fill much of the galactic disk. The ISM is constantly shaped by stellar winds, radiation, and supernova explosions, which stir and enrich it with heavier elements like carbon, oxygen, and iron. This recycling process means that every new generation of stars is formed from material that has been processed by earlier stars, linking stellar evolution directly to galactic evolution. In short, the ISM is not just a passive backdrop; it is the active stage on which the drama of star birth, life, and death unfolds, driving the ongoing transformation of galaxies.

## 1.2 Plasma in the Interstellar Medium

Plasma in the interstellar medium is a fundamental state of matter that shapes the physics of galaxies. It arises primarily through ionisation, where ultraviolet photons from hot stars, cosmic rays accelerated by supernovae, or shock waves strip electrons from atoms. This process produces a mixture of free electrons and ions, creating a highly responsive medium that behaves very differently from neutral gas. Ionisation is not uniform across the ISM; dense molecular clouds remain

mostly neutral, while diffuse regions are highly ionised, making the ISM a patchwork of environments where ionisation and recombination compete dynamically.

Because plasma is electrically conductive, it couples strongly with galactic magnetic fields. This magnetisation means that plasma dynamics are governed not by simple fluid mechanics but by magnetohydrodynamics (MHD), where electromagnetic forces play a central role. Even though galactic magnetic fields are relatively weak, they exert significant influence over the diffuse plasma, guiding charged particles, shaping cosmic ray propagation, and channelling flows of ionised gas. Magnetised plasma supports waves and turbulence, redistributing energy and momentum across vast scales[1]. This coupling explains filamentary structures in nebulae, the confinement of cosmic rays, and the regulation of star formation.

Plasma is not a minor component of the cosmos but the dominant one. Over 99% of visible matter in the universe exists in plasma form, and the ISM exemplifies this dominance. Hot ionised plasma fills galactic halos and bubbles carved by supernovae, while even cooler regions remain partially ionised. Plasma connects local galactic environments to the larger cosmic web, where intergalactic plasma forms filaments that structure the universe itself. This dominance underscores why plasma physics is central to astrophysics: understanding plasma in the ISM is essential for modelling galaxy evolution, star formation, and the transport of energy and matter across cosmic scales.

### 1.3 Multi-phase Plasma Structure

The interstellar medium is a multi-phase plasma structure, where different temperature and density regimes coexist and interact dynamically. This framework is essential because it explains how energy and matter circulate through galaxies, shaping their evolution.

The Warm Ionised Medium (WIM) is one of the most pervasive plasma phases. It consists of diffuse ionised hydrogen at temperatures around 8,000 K, filling much of the galactic disk. The WIM is maintained by ultraviolet radiation from hot stars, which keeps the gas ionised over large volumes[2]. The WIM is crucial because it represents the baseline ionised environment in which stars and cosmic rays interact, and it serves as a reservoir of material that can cool and condense into denser structures. The Hot Ionised Medium (HIM) is created by supernova explosions, which inject enormous amounts of energy into the ISM. With temperatures reaching about  $10^6$  K, the HIM is extremely diffuse but occupies large cavities known as “superbubbles.” This plasma emits strong X-ray radiation, making it observable by space telescopes. Researchers view the HIM as a key feedback mechanism: it regulates star formation by heating surrounding gas, drives turbulence, and enriches the ISM with heavy elements produced in stellar interiors. In contrast, the Cold Neutral Medium (CNM) is not plasma but coexists with plasma phases. It consists of cooler atomic hydrogen at temperatures near 100 K, often forming dense molecular clouds. These clouds are the birthplaces of stars, and their interactions with surrounding plasma phases are central to the star-formation cycle. CNM cannot be studied in isolation, because shocks, radiation, and turbulence from plasma phases constantly reshape its boundaries and trigger collapse into new stars.

Importantly, these phases are not isolated compartments. They exchange energy and matter through shocks, turbulence, and radiation. Supernovae heat cold gas into plasma, while cooling processes allow hot plasma to condense back into neutral clouds. Turbulence mixes material across boundaries, and radiation ionises neutral gas at the edges of molecular

clouds. This dynamic interplay is what makes the ISM a “living system,” continuously recycling matter and energy.

### 1.4 Physical Processes in Interstellar Medium Plasma

The interstellar medium is governed by a set of key physical processes that continually reshape its plasma environment and regulate the life cycle of galaxies. These processes, such as supernova feedback, cosmic ray interactions, radiative cooling, and turbulence are not isolated phenomena but interconnected mechanisms that together determine the structure, dynamics, and evolution of the ISM.

Supernova feedback is perhaps the most dramatic driver of change in the ISM. When massive stars explode, they inject vast amounts of energy into their surroundings, producing shock waves that heat and ionise gas. These shocks carve out superbubbles of plasma, which can extend hundreds of parsecs across the galactic disk. Supernova feedback is essential because it prevents runaway star formation by dispersing cold gas, while simultaneously enriching the ISM with heavy elements synthesised in stellar interiors[3]. It is a feedback loop: stars form from the ISM, and their deaths reshape the very medium that gave them birth.

Cosmic ray interactions add another layer of complexity. High-energy particles accelerated in supernova shocks scatter off plasma, influencing the pressure balance of the ISM. We note that cosmic rays can travel long distances, coupling different regions of the galaxy and even escaping into intergalactic space. Their interactions with plasma affect transport processes, magnetic field dynamics, and the heating of otherwise cold regions [4]. This makes cosmic rays not just a byproduct of stellar explosions but an active agent in galactic evolution.

Radiative cooling is the counterbalance to heating. Plasma loses energy through line emission, such as hydrogen recombination and transitions of metal ions, such as oxygen and carbon. However, cooling in the ISM is highly non-linear and often out of equilibrium.

Studies highlight that cooling rates depend strongly on density, metallicity, and ionisation state, meaning that plasma can cool rapidly in some regions while remaining hot in others[3]. This uneven cooling creates the multi-phase structure of the ISM, where hot, warm, and cold components coexist and interact.

Turbulence permeates the ISM, cascading energy across scales from kiloparsec-sized superbubbles down to parsec-sized clouds. Plasma turbulence is magnetised, meaning that magnetic fields guide the flow of energy and create anisotropic structures. Turbulence is a critical regulator of star formation: it can support clouds against collapse, fragment them into smaller structures, or trigger collapse in localised regions[1]. Turbulence also mixes chemical elements, ensuring that enrichment from supernovae is distributed throughout the galaxy.

## 1.5 Observational Evidences

The study of plasma in the interstellar medium relies heavily on observational evidence across multiple wavelengths, since plasma itself is invisible in ordinary light. We have developed sophisticated techniques to probe its properties, each revealing different aspects of the ISM's complex structure and dynamics.

X-ray astronomy has been particularly transformative in uncovering the presence of hot plasma. Supernova remnants and galactic halos emit strongly in X-rays, allowing astronomers to measure temperatures of around a million degrees Kelvin. These observations reveal the existence of superbubbles carved by stellar explosions, as well as diffuse hot gas filling galactic halos[5]. X-ray data provide direct evidence of supernova feedback and the large-scale circulation of energy in galaxies, confirming theoretical models of plasma heating and enrichment. Radio astronomy offers another window into plasma physics, especially through the detection of synchrotron radiation. This radiation is produced when relativistic electrons spiral around magnetic field lines, highlighting the intimate connection between plasma and galactic magnetism. Radio observations map the structure of magnetic fields

across galaxies and trace cosmic ray interactions with plasma. Researchers use these data to study turbulence, magnetic confinement, and energy transport, all of which are critical for understanding how plasma shapes galactic evolution. Optical and ultraviolet spectroscopy provide complementary insights by identifying ionisation states and plasma cloud densities. Emission and absorption lines reveal the chemical composition, ionisation balance, and physical conditions of the ISM. For example, hydrogen recombination lines indicate regions of active ionisation, while metal ion transitions trace cooling processes. We rely on these spectra to quantify plasma densities, measure ionisation fractions, and test models of radiative cooling and non-equilibrium processes.

Together, these multi-wavelength observations form a coherent picture of the ISM as a dynamic plasma environment. Each technique probes a different regime, X-rays capture the hottest plasma, radio waves trace magnetic interactions, and optical/UV spectra reveal ionisation and cooling. The synergy of these methods is essential because plasma cannot be studied with ordinary visible light alone. This multi-wavelength approach is the cornerstone of modern astrophysics, enabling us to piece together the life cycle of plasma in galaxies and its role in shaping cosmic evolution[6].

## 1.6 Challenges

The study of plasma in the interstellar medium presents several profound research challenges that continue to push the boundaries of astrophysics. One of the most significant difficulties lies in non-equilibrium ionisation. Unlike laboratory plasmas, which can often be approximated as being in equilibrium, the ISM is subject to constant disturbances from radiation, shocks, and cosmic rays. This means that ionisation and recombination processes do not balance neatly, and the plasma often exists in transient states. This complicates modelling efforts, as standard equilibrium assumptions fail to capture the ISM's true behaviour. Instead, complex time-dependent simulations are required to track how ionisation evolves under varying conditions, making the study of ISM plasma both computationally

intensive and conceptually challenging.

Another major obstacle is the issue of coupled physics. Plasma in the ISM cannot be understood within a single discipline; it requires integrating atomic physics, radiation transfer, hydrodynamics, and magnetic field dynamics. Each of these areas introduces its own complexities. Atomic physics governs ionisation and cooling processes, radiation transfer dictates how energy moves through the medium, hydrodynamics describes fluid-like behaviour, and magnetic fields add anisotropy and turbulence through magnetohydrodynamics (MHD). Therefore, we build models that combine these diverse physical processes into a unified framework. This coupling is not only mathematically demanding but also requires cross-disciplinary expertise, making ISM plasma research a highly collaborative field.

The scale problem further complicates matters. Processes in the ISM range from microscopic electron collisions to galactic-scale phenomena such as superbubbles created by supernovae. Capturing this enormous range of scales in a single model is nearly impossible with current computational resources. Therefore we must rely on multi-scale simulations, where small-scale physics is parameterised and embedded within larger-scale models. Even then, uncertainties remain, as small-scale processes such as turbulence and cosmic-ray scattering can have outsized effects on galactic evolution. The challenge lies in bridging these scales without losing essential physical detail, a task that continues to drive innovation in computational astrophysics.

## 1.7 Relevance

The importance of plasma in the interstellar medium lies in its role in regulating the fundamental processes that shape galaxies. One of the most critical roles plasma plays is in regulating star formation. Molecular clouds, the birthplaces of stars, are subject to the pressures and turbulence generated by surrounding plasma. If plasma pressure is too high, it can prevent these clouds from collapsing under gravity, delaying or suppressing star formation[5]. Conversely, turbulence within plasma can fragment clouds, creating

localised regions where collapse becomes possible. We emphasise that this delicate balance between plasma support and gravitational collapse determines the rate of star formation, making plasma a key regulator of galactic growth.

Plasma also functions as the backbone of the galactic ecosystem, transporting energy and metals across vast distances. When stars die in supernova explosions, they release heavy elements such as carbon, oxygen, and iron into the ISM. Plasma carries these enriched materials throughout the galaxy, ensuring that subsequent generations of stars and planets are chemically diverse. In addition, plasma distributes energy from stellar winds and supernovae, maintaining the multi-phase structure of the ISM. Studies view this transport as a vital feedback mechanism: it links the life cycles of individual stars to the broader dynamics of the galaxy, creating a self-sustaining system in which matter and energy are constantly recycled.

On an even larger scale, plasma in the ISM is central to cosmic evolution. Galaxies are not static structures; they evolve over billions of years through cycles of star birth, death, and renewal. Plasma is the medium through which these cycles occur, connecting small-scale processes like ionisation and turbulence to large-scale phenomena such as galactic winds and halo formation. By studying ISM plasma, researchers gain insights into how galaxies recycle matter, regulate star formation, and interact with the intergalactic medium. This knowledge is crucial for understanding the evolution of the universe itself, since plasma is the dominant state of visible matter across cosmic scales.

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# Astronomy at Scale

*by Ajay Vibhute*

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## 2.1 Growth of Astronomical Data Volumes

Over the past few decades, astronomy has undergone a dramatic transformation driven by the exponential growth of data volumes. Early digital surveys produced datasets measured in megabytes or gigabytes, but modern observatories routinely generate terabytes of data per night, with total archives reaching petabyte scales. This growth is fueled by advances in detector technology, wider fields of view, higher temporal resolution, and multi-wavelength observational capabilities.

Large-scale projects such as wide-field sky surveys and radio interferometers continuously scan the sky, producing repeated measurements of billions of sources. Time-domain astronomy further amplifies data volume by capturing transient and variable phenomena, requiring frequent observations and rapid data processing. As a result, astronomy has become a data-intensive science, where the scale of data is comparable to that encountered in fields such as particle physics or climate science.

This increase in volume is not merely quantitative but also qualitative. Modern datasets are richer, combining spatial, spectral, and temporal information, often with complex metadata describing observational conditions and calibration parameters. Managing and extracting knowledge from such datasets requires fundamentally new computational approaches.

## 2.2 Why Manual Analysis Failed

The traditional model of manual data analysis—where astronomers visually inspected images or individually processed small datasets—became untenable as data volumes increased. Even a single modern survey can contain more images than a human could examine in a lifetime, rendering manual inspection impractical for all but a tiny subset of data.

Human-driven analysis is also limited by subjectivity and inconsistency. Different researchers may interpret the same data differently, leading to potential biases and reduced reproducibility. Furthermore, manual methods are inherently slow and cannot keep pace with the continuous data streams produced by modern instruments, particularly in time-sensitive applications such as transient detection.

As datasets grew, it became clear that automation was not simply a convenience but a necessity. Algorithms replaced human inspection for tasks such as source detection, classification, and anomaly identification. Machine learning techniques, in particular, have enabled the rapid analysis of large datasets, identifying patterns and rare events that would be difficult or impossible for humans to detect unaided.

## 2.3 Data-Intensive Astronomy

Data-intensive astronomy represents a shift in how scientific discovery is conducted. Instead of focusing on individual objects, researchers increasingly analyze large populations, searching for statistical trends, correlations, and rare outliers across vast

datasets. This approach enables new types of science, such as mapping the large-scale structure of the universe, studying the evolution of galaxies over cosmic time, and identifying transient phenomena like supernovae or gravitational wave counterparts.

The scale and complexity of these datasets require advanced computational techniques, including distributed computing, parallel processing, and machine learning. Algorithms must be designed not only for accuracy but also for scalability, ensuring that analyses remain feasible as data volumes continue to grow.

In this paradigm, data are often processed in automated pipelines that perform tasks such as calibration, source extraction, feature measurement, and classification. These pipelines must be robust, reproducible, and capable of handling heterogeneous data from multiple instruments and observing modes. Data-intensive astronomy thus blurs the line between astronomy and data science, integrating methods from statistics, computer science, and applied mathematics into the core of astronomical research.

## 2.4 Storage, Access, and Data Movement

Handling astronomical data at scale presents significant challenges in storage, access, and data movement. Petabyte-scale archives require distributed storage systems that ensure reliability, redundancy, and long-term preservation. Efficient indexing and query systems are essential for enabling researchers to locate and retrieve relevant subsets of data without scanning entire datasets.

Data access models have evolved to address these challenges. Instead of downloading large datasets locally, researchers increasingly analyze data in situ, using remote computing resources located near the data archives. Cloud computing and high-performance computing (HPC) facilities provide the infrastructure needed to process large datasets efficiently.

Data movement is another critical consideration. Transferring large volumes of data across networks can be time-consuming and costly, necessitating careful

optimization and, in some cases, the development of specialized data-transfer protocols. Minimizing unnecessary data movement by bringing computation to the data has become a key design principle in modern astronomical computing.

## 2.5 Scientific Implications of Scale

The shift to large-scale data has profound implications for scientific discovery. On one hand, it enables unprecedented statistical power, allowing researchers to detect subtle effects and rare phenomena with high confidence. Large datasets also support cross-disciplinary studies, combining observations across wavelengths and time to build a more comprehensive picture of the universe.

On the other hand, the scale of data introduces new challenges. Systematic errors can propagate across entire datasets, potentially biasing results if not properly controlled. The complexity of analysis pipelines makes it more difficult to fully understand how results are derived, increasing the importance of transparency, validation, and reproducibility.

Moreover, the reliance on automated methods raises important questions about interpretability and trust. Machine learning models, while powerful, can act as "black boxes," making it difficult to understand the reasoning behind their outputs. Ensuring that results are physically meaningful and not artifacts of the analysis process remains a central concern.

Ultimately, astronomy at scale requires a careful balance between leveraging computational power and maintaining rigorous scientific standards.

## 2.6 Summary

Astronomy has entered an era defined by data scale. The rapid growth of observational data has transformed the field from one centered on individual measurements to one driven by large datasets and statistical analysis. Manual methods have given way to automated pipelines and machine learning, enabling the efficient extraction of knowledge from vast and complex data.

At the same time, the challenges of storage, access, and systematic error highlight the need for robust computational infrastructure and careful methodological design. As data volumes continue to grow, the integration of computation into every aspect of astronomy will deepen, reinforcing its role as a foundational component of modern scientific discovery.

**About the Author**

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# Black Hole Stories-26

## Some Black Hole Mergers From LIGO-Virgo-KAGRA Observing Run O4

*by Ajit Kembhavi*

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[www.airis4d.com](http://www.airis4d.com)

In this story we will consider some interesting binary mergers detected during the observing runs O4 of the LIGO-Virgo-KAGRA detectors. Our description here will depend on the concepts developed in describing O3 sources.

### 3.1 The Fourth Observing Run O4

The observing run O4 began on May 24, 2023 and ended on November 18, 2025. O4 was divided into three parts, with O4a from 24 May 2023 to 16 January 2024, O4b from 10 April 2024 to 28 January 2025, and O4c starting directly after O4b on 28 January 2025, and ending on 18 November 2025, with a commissioning break between 01 April 2025 to 11 June 2025. There have been 218 confident detections of merging binary systems in the run O4a, with another 173 candidate events during O4b and O4c, which remain to be confirmed through detailed data analysis (see BHS-22 for a more detailed discussion). This story will be about a few interesting binary mergers detected during O4.

This source was detected during O4a by the two aLIGO detectors on November 23, 2023. The Virgo and KAGRA detectors were not observing at that time. The event was observed over about five cycles, over a short duration of about 0.1 s, but data from the two detectors enabled the detection to be made with high confidence. However, there was relatively large uncertainty in the

determination of the source parameters, with different methods of analysis providing a range of values.

From the analysis, the primary is of 137 (119, 160) Solar masses, where 137 is the median value of the range of the primary mass obtained in the analysis, and the numbers in parenthesis show the range of in which the primary mass is located with 90 percent probability. We have indicated the ranges to show the large uncertainty in the parameter values for this source. With the same notation, the secondary has 101 (51, 123) Solar masses, with the total mass being 236 (189, 266) Solar masses. The final mass after the merger is 222 (180, 250) Solar masses. It was found the primary had dimensionless spin parameter 0.9 (0.71, 1.0) and the secondary 0.80 (0.28, 1.0). The spin parameter of the remnant is 0.84 (0.68, 0.90). The spin parameter is defined in the description of the GW190412 in BHS-25. The distance to the source is 2.2 (0.7, 4.1) Gigaparsec.

It follows from the number above that the GW231123 was a merger of two high mass black holes with high spin. The total mass of the binary is greater than that of the massive binary GW190521 described in BHS-25, making GW231123 the most massive binary merger detected as of the end of 2025. The high total mass, together with the high spin of the two components, make analysis difficult because the theoretical models which are used in the analysis are not completely adequate. That leads to differing values of parameters predicted by different models and with

resultant large uncertainty.

We have considered in BHS-25 a gap in the mass of black holes in the region of 60 – 130 Solar masses. Black holes produced through the evolution of massive stars are not expected to have mass in this region. Given the high mass of the primary and secondary components of the binary which merged to form GW231123, it can be argued that there is a significant probability that the mass of the primary, or the secondary, or both are in the mass gap region, so we need to understand how such black holes can be produced. A few possibilities are: (1) There can be change in the details of the evolution of progenitor massive star, which avoids the formation of a pair instability supernova (PISN). That leads to the collapse of the core of a massive star to a black hole with mass in the gap; (2) the massive black hole binary components could have formed through earlier BH-BH mergers which would produce high mass black holes with high spin; (3) The black hole mass could have increased significantly by accretion of gas in a suitable environment or in collisions with other stars. There are other possible processes too for producing black holes in the mass gap, but all the process need detailed study before their suitability can be established. The discovery of other massive binaries in the existing data or through future observations will help in establishing viable processes.

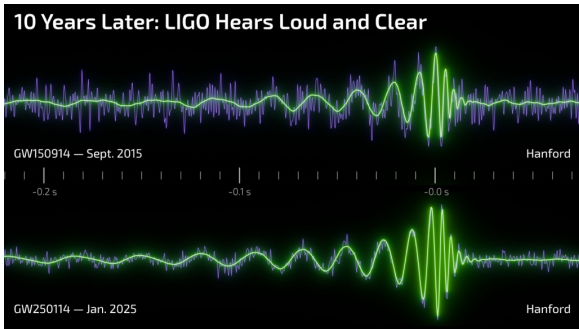
All the gravitational wave detections made so far have been analysed under the assumption that they are mergers of compact binaries, with the components being black holes or neutron stars, and the orbit having low eccentricity, i.e., it is nearly circular. The same assumption has been made in the case of GW231123 and it provides a good fit to the observed signal. But given the large uncertainty in the parameter values, and the small number of cycles on which the fit is based, it is necessary to consider other possible ways to produce the observed gravitational wave signal. Models with high eccentricity may have to be considered, but it is astrophysically unlikely that compact binaries with high eccentricity can be produced through earlier mergers. Some possible sources which could produce a burst of gravitational waves of the duration observed are core-collapse supernovae, cosmic strings and collisions of

compact objects made up of exotic particles like axions. Some of these possibilities are wholly theoretical at the present time, and the merger of massive black holes in a binary system remains the most likely explanation of the event. The alternative interpretations of the gravitational wave data mentioned here also apply to the massive binary GW190521 detected in O3.

**GW250104:** Detected on January 4, 2025, this merging binary has source parameters similar to those of the first ever gravitational wave detection GW150914. But the sensitivity of the LIGO detectors during O4 was much greater than during the first observing run O1, which happened ten years before O1. So, the observed signal for GW250104 is much larger than the noise in the detector, which is expressed as a high signal-to-noise ratio. This leads to a very clean signal from which firm conclusions can be drawn about the theory of gravity and black holes.

**GW250114** was observed by both LIGO detectors, while the Virgo and KAGRA were not operational. The primary, secondary and total mass determined for the merging binary are  $m_1 = 33.6$ ,  $m_2 = 32.2$  and  $M_t = 65.8$  Solar masses, respectively. The ratio of the secondary mass to the primary mass is 0.91. The two black holes before the merger have low spin. The mass of the remnant black hole after the merger is  $M_f = 62.7$  Solar masses and it has a spin parameter  $S_f = 0.68$ . The mass lost in the merger to gravitational waves is 3.1 Solar masses. These parameters are similar to those of many black hole binaries detected earlier. The novel element in this case is the high signal-to-noise ratio, which makes possible increased accuracy in the determination of the parameters.

The gravitational wave signal observed by the aLIGO detector at Hanford from the first merging binary GW150815 in 2015 (upper panel), and the signal observed by the upgraded more sensitive version of the detector from GW250104 (lower panel) are shown in Figure 1. Both binaries were located about 400 Mpc away, and the black holes in the two binaries were of 30 to 40 Solar masses. The energy emitted in each merger therefore was about the same. The vertical purple bars indicate the data point for a given time as the event progresses, with the height of the bar indicating the



**Figure 1:** The signal observed by the aLIGO detector at Hanford from the merging binary black holes GW150915 in 2015 (upper panel) and GW250141 (lower panel) in 2025. See the text for a detailed description.

detected noise at that time. The green lines in each panel is the best fit obtained for the data using a model based on the general theory of relativity. The reduced noise level and the smoother fit obtained in 2025 are evident.

Soon after the merger the resultant black hole is a distorted object, which rings down to its final state of a Kerr black hole. The ringdown signal consists of *quasi-normal modes*, which are oscillations which damp down as the blackhole settles to its final state. The oscillation frequencies and the time over which the damping occurs are determined by the mass and spin of the final black hole. The dominant mode is quadrupolar in nature, which is expected given that the two black hole masses are nearly equal (see the discussion about multipole moments for the O3 detection GW190412). At late times, the ringdown can be represented by two modes, an oscillation with a single frequency and its first overtone, both of which are damped. The nature of the oscillations including the existence of the two modes closely resembles the expectation for a Kerr black hole with the mass  $M_f$  and spin parameter  $S_f$  mentioned above.

The high quality data available for the GW250104 merger can be used to test the second law of black hole mechanics, which was given by Stephen Hawking in 1971, and was also discussed earlier by others. This law states that the area of the event horizon of a black hole cannot decrease in time through any processes, it must remain constant or increase during any interactions that the black hole undergoes. The law can only be violated

if certain general conditions are not met, and in some theories of gravity other than Einstein’s general theory of relativity. For black hole binaries we have been considering, it follows from Hawking’s law that the area of the remnant black hole must be greater than the sum of the areas of the two black holes of the binary before the merger. The total area before the merger can be measured from the detected signal before the merger, which is the part of the signal when the two black holes are spiralling towards each other. The area of the remnant can be measured from the ringdown part of the signal after the merger is complete. Such measurements exclude the signal from the most violent parts of the merger, The analysis is based on the assumption that the orbit of the black holes during the merger was almost circular in shape, that general theory of relativity applies in the region where the measurements are made, and that the Kerr solution provides a good description of black holes. It is found that the results make it highly probable that the area of the remnant was indeed greater than the sum of the areas of the two black holes before the merger. As of early 2026, the signal from GW250114 is being analysed for further precise tests of the general theory of relativity and the Kerr space-time.

**GW241011 & GW241110:** These two mergers are similar in properties and possible origin so we treat them together, as was done in the discovery research publication. GW241011 was detected on October 11, 2024 by LIGO, Hanford and by Virgo, while GW241110 was detected by the LIGO detectors at Hanford and Livingston, and Virgo. For both sources the probability for the detection to be a false alarm is very low, and the signal is strong so that accurate parameter determination is possible.

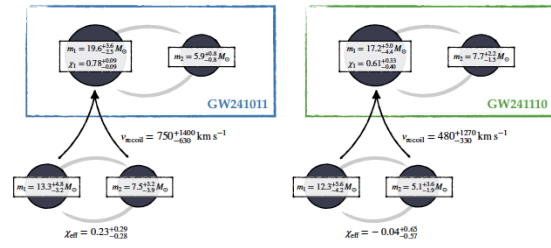
For GW241011, in units of Solar masses, the primary black hole mass is 19.6, the secondary black hole mass 5.9 and the ratio of the secondary mass to primary mass is 0.3. The novel element for this source is the spin of the primary which has been precisely determined to have the large value 0.78 in dimensionless units (see the discussion for GW190412 for a definition of the dimensionless spin). This value makes the primary the fastest rotating black hole detected by early 2026. There is an angle of about 31 degrees between

the direction of the spin vector of the primary and the direction of the angular momentum of the binary system. It is not possible to determine the spin of the secondary from the data.

In the case of GW241110, in Solar units, the primary mass is 17.2, the secondary mass 7.7, the mass ratio is 0.45 and the dimensionless spin of the primary is 0.61. The angle between the spin vector of the primary and the orbital angular momentum is 133 degrees, so that in this case there is a large misalignment between the two directions. This is the first black hole binary known in which the spin is so misaligned with the angular momentum. The mass and spin values are rather similar for the two mergers we are considering here.

The favoured explanation for the high spin is that the two black hole binaries are formed from black holes which have themselves formed out of earlier mergers. The scenario here is that massive black holes are formed through mergers of black hole binaries. Such remnant black holes have high mass and also high spin, in the dense environment of the central region of a star cluster. Such remnant black holes have high spin which arises from the angular momentum of the binary which merged. In fact, the spin parameter of the remnants of binary mergers which have been observed so far is clustered around the value of about 0.7. The binaries which are later formed from such black holes would have spin and unequal mass components, as has been observed in the case of the two binary mergers we are considering here. Hierarchical merging therefore provides a natural explanation for the formation of such binaries. The hierarchical formation mechanism is shown in Figure 2.

As explained in the case of the observing run O3 merger GW190412, the most dominant component of gravitational wave radiation is quadrupole in nature. As the secondary to primary mass ratio becomes significantly less than 1, higher multipoles contribute to the radiation, and can be detected if the signal is strong enough. In the case of the two binary mergers GW241011 and GW241110, the mass ratios are 0.3 and 0.45 respectively and the signal is loud, so higher moments can be detected. In addition, the high spin of the primary component of the two sources allows



**Figure 2:** The hierarchical merger route for the formation of black hole binaries. The formation takes place in the dense central environment of a large star cluster, where there are frequent encounters between black holes and other constituents of the cluster. On the left is shown how GW241011 could have formed. In the first generation at the bottom, a 13.3 Solar mass black hole merges with a 7.5 Solar mass black hole. The effective spin of the system is 0.23. These parameters are possible values derived from detailed modelling and can change with the model. The merger produces a black hole remnant which has the mass and spin observed for the primary component of the second generation binary. The remnant also has a velocity which is estimated to be 750 km/s, but with large uncertainty. The new remnant captures another black hole with mass 5.9 Solar masses, to produce the next generation binary, whose merger we observe as GW241011. On the right of the figure a similar process for the formation of GW241110 is shown.

other tests to be performed. The spin of the black hole contributes to the quadrupole moment, and there is a specific relation between the two for a Kerr black hole. From the gravitational wave data, it is verified that this relation holds accurately, establishing the validity of the Kerr solution and the general theory of relativity in this case. The measurements are good enough to rule out the possibility that the spinning compact object is not a Kerr black hole and is instead an exotic object like a boson star.

**GW230529:** This source was observed on 29 May 2023 by the aLIGO detector at Livingston alone. The aLIGO detector at Hanford and Virgo were offline, and the sensitivity of the KAGRA detector was not enough to contribute to the observation.

This is a low mass binary merger, with the primary, secondary and total mass being 3.6, 1.4 and 5.1 Solar masses, and a secondary to primary mass ratio of 0.39. The spin parameter of the primary is 0.44 and the source distance is 201 Megaparsec. The mass of the primary

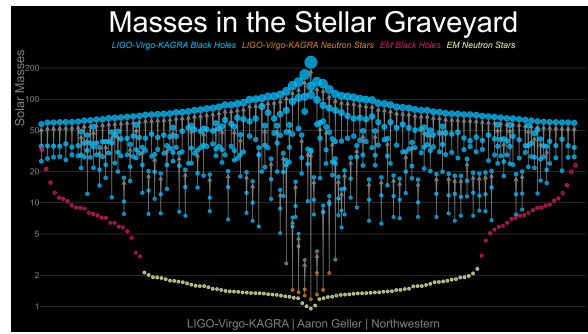
means that it could be a black hole, or an unusually massive neutron star. The mass of the primary puts it in the region of (3 – 5) Solar masses, which is a known low mass gap in which neither neutron stars, nor black holes are found. The primary could be a black hole in the gap, or an unusually massive neutron star, again in the gap. The mass of the secondary, including uncertainties in the mass measurements, puts it in the known range of neutron star masses. If either or both components are neutron stars, then it is possible that the tidal distortions produced in them could be detected in the gravitational wave signal. But no sign of such distortion has been found in the primary, and the data is not sufficient to constrain any deformations in the secondary. The overall evidence points to the merger being that of a black hole and a neutron star. With one component being a neutron star, it is possible for electromagnetic signals to be emitted by the disruption of the neutron star during the merger. However, no such electromagnetic counterpart has been found. The gravitational wave signal was detected by only one detector, so the position of the source in the sky was very poorly determined. In such a case it is very difficult to associate an electromagnetic counterpart like a Gamma-ray burst with the gravitational wave detection.

GW230529 is the first merging binary detected in which the primary candidate is very likely a black hole with mass in lower mass gap region (we have discussed in BHS-25 gap at larger masses, in the 60 – 130 Solar mass range). This provides clues to the origin of BHNS binary, but the possibilities are still open as of early 2026.

### 3.2 Compact Object Masses Found in the Four Observing Runs:

Here we repeat a diagram and comments from BHS-22, in the context of the present story and BHS-25.

In the observing runs O1, O2, O3, which included a total observing period of 23 month, there were 90 gravitational wave source detections. In O4, more than



**Figure 3:** In this plot the numbers and masses of the black holes and neutron stars discovered as components and products of merging binaries by the LVK collaboration. Also shown are black holes and neutron stars discovered through electromagnetic means. See text for details. Image Credit: LIGO-Virgo-KAGRA | Aaron Geller | North Western University.

200 candidate sources have been discovered by the end of the run in November 2025, over an observing period again of 23 months. Some of the candidate sources have been confirmed to be merging black hole binaries, while the rest are being studied in detail to confirm them as valid sources or to reject them.

In Figure 3 are shown the numbers and masses of black holes and neutron stars discovered through gravitational wave detections and electromagnetic means. Black holes are shown mainly as blue pairs, connected by a blue line. These are components of binary black hole systems which are merging and are observed as gravitational wave source (GW). The blue line extends to the black hole which is the product of the merger of the two components. The mass of each black hole is indicated on the vertical axis. The orange dots are neutron stars which are components of a binary neutron star system, or of a black hole–neutron star binary, which have been detected by LIGO. The yellow dots represent neutron stars discovered through electromagnetic means (EM). Such EM detection is possible (1) from the X-ray emission by a binary system of which a neutron star is a component, the other component being a star from which the neutron star is accreting matter or (2) from a binary neutron star when one (or both) component is a radio pulsar. The pink dots are black holes discovered through their being the compact component of an X-ray binary system, the other component again being a star from which the

black hole accretes matter (see BHS-1 for some details).

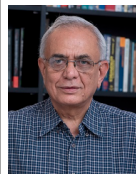
It is seen from Figure 3 that the mass range of the GW and EM neutron stars are the same, extending over 1-2 Solar masses. While there is an overlap between GW and EM black hole mass ranges, the GW black hole masses extend to significantly higher values. The EM black holes are the end products of the evolution of stars with mass greater than about 25 Solar masses. They are the compact objects left after the supernova explosion which occurs at the end of the evolution of the massive star. This explanation can apply to the formation of the less massive GW black holes, with the added complication that binary black hole formation has to take place without disrupting the binary of which they are the components. As for the more massive GW black holes, there are difficulties in explaining their origin as end products of stellar evolution, and other mechanisms like hierarchical mergers have to be considered, as described above.

The black hole binary mergers discovered in the O1 and O2 had similar parameters. There was one gravitational wave detection of a spectacular binary neutron star merger observed in O2, with accompanying electromagnetic radiation. In later runs there have been a few other mergers identified as NS-NS and BH-NS, but no electromagnetic counterpart has been identified in these cases. That has primarily been because of the difficulty in localising the position of the merger to a small enough area of the sky which could be searched for the counterpart. This situation will change when LIGO-India becomes operational around 2030. With the additional detector with high sensitivity operating at a distance from the three detectors presently in operation, localisation will improve significantly, leading to further identifications.

As the sensitivity of the gravitational wave detectors has improved over the four runs, a variety of mergers have been detected, some which we have captured in the descriptions of individual sources from the later runs. It is clear that as the sensitivity improves further, and new generations of detectors become available on the ground and in space, we will make rich discoveries which will provide us insights into the formation, evolution and final moments of these sources.

It is startling to imagine that so many of these very massive binaries are present in the Universe, which we will ever detect only through their gravitational radiation, mostly in the last few moments of their evolution.

#### About the Author



Professor Ajit Kembhavi is an emeritus Professor at Inter University Centre for Astronomy and Astrophysics and is also the Principal Investigator of the Pune Knowledge Cluster. He was the former director of Inter University Centre for Astronomy and Astrophysics (IUCAA), Pune, and the International Astronomical Union vice president. In collaboration with IUCAA, he pioneered astronomy outreach activities from the late 80s to promote astronomy research in Indian universities.

# X-ray Astronomy: Theory

*by Aromal P*

AIRIS4D, VOL.4, No.5, 2026

[www.airis4d.com](http://www.airis4d.com)

## 4.1 Introduction

In the previous article, we discussed X-ray emission from accretion disks in X-ray binaries and compared its efficiency to that of nuclear fusion. We concluded by asking whether the accretion disk is the only source of X-ray emission in X-ray binaries. In today's article, we will focus on a specific type of X-ray emission found in Neutron Star Low-Mass X-ray Binaries: the thermonuclear X-ray burst. As a personal note, my research centers on the observational studies related to this phenomenon.

## 4.2 Thermonuclear X-ray burst

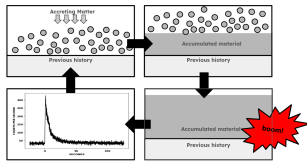
We have already discussed how accretion disks form in X-ray binaries. In neutron star X-ray binaries, if the neutron star is relatively old and has a weaker magnetic field, the accreted material will eventually be deposited onto its surface. If this accumulated matter undergoes an unstable nuclear reaction, it can burn instantaneously due to nuclear processes, leading to a thermal runaway.

This thermal runaway happens because the accreted hydrogen and helium fuel experiences intense hydrostatic compression as it continues to pile onto the surface of the neutron star. Within hours or days, the accumulating material reaches extreme ignition temperatures and densities. The core physical mechanism driving this violent eruption is known as the thin-shell instability.

Since the burning layer is exceptionally thin, only a few meters deep compared to the neutron star's typical

radius of around 10 kilometers, the initial nuclear heating causes the shell to expand, but this is insufficient to reduce the local pressure and cool the region. Additionally, in this dense environment, the electrons are mildly degenerate, meaning their pressure does not significantly depend on temperature. This further prevents the expanding gas from effectively dissipating the heat generated. As a result, the temperature spikes dramatically, accelerating nuclear reaction rates and triggering a localized thermonuclear runaway.

The specific dynamics of this thermonuclear runaway depend heavily on the mass accretion rate and the chemical composition of the infalling material. At relatively low accretion rates, hydrogen burns unstably via the Carbon-Nitrogen-Oxygen (CNO) cycle, which can subsequently trigger helium ignition. At intermediate mass accretion rates, hydrogen burns continuously and stably via the hot CNO cycle, completely exhausting itself and gradually building up a dense, pure helium layer beneath it. Once critical conditions are met, this pure helium layer violently detonates via the triple-alpha process, producing a short, intense X-ray burst that typically lasts around ten seconds. At even higher accretion rates, the conditions for helium ignition are met much faster, before the hydrogen has fully burned, resulting in a mixed hydrogen and helium flash. The initial helium ignition generates extreme temperatures that trigger breakout reactions, bypassing the standard CNO cycle and initiating the rapid-proton (rp) process. During the rp-process, a rapid succession of proton captures and slower beta decays synthesizes heavier elements, significantly extending the energy release and creating



**Figure 1:** Graphical representation of occurrence of thermonuclear X-ray Burst

a burst tail that lasts for tens to hundreds of seconds.

The ignition itself is highly complex; rather than erupting uniformly across the entire sphere, the runaway typically sparks at a localized point, often near the equator, where the effective surface gravity is slightly reduced by the star's rapid rotation. From this ignition point, a thermonuclear flame front propagates laterally across the neutron star, engulfing the entire surface in approximately one second. In the most powerful of these events, the extreme local luminosity can temporarily exceed the Eddington limit, causing the outward radiation pressure to overcome the immense inward gravitational pull. When this threshold is breached, the outermost layers of the neutron star's photosphere are physically lifted off the surface and driven outward, creating a Photospheric Radius Expansion (PRE) burst. As the thermonuclear fuel is exhausted, the lifted photosphere eventually contracts and settles back onto the stellar surface before an extended cooling phase takes over. Ultimately, while continuous accretion generates a steady baseline X-ray luminosity, the sudden, localized burning of stored fuel temporarily outshines this persistent emission by a factor of ten or more, producing thermonuclear X-ray bursts

Thermonuclear X-ray emission is predominantly thermal and is well-described by a blackbody spectrum with peak temperatures reaching 2–3 keV. Consequently, bursts are most prominent in the soft X-ray energy band (typically below 10 keV), where they temporarily outshine the persistent X-ray emission from accretion by an order of magnitude or more

The intense photons from a thermonuclear X-ray burst drastically alter the surrounding accretion environment, primarily affecting the corona, the accretion disk, and the companion star. When the burst injects a massive influx of soft X-ray photons into the hot electron corona, it triggers inverse Compton

scattering that rapidly cools the coronal plasma. This cooling manifests observationally as a sharp deficit in hard X-ray emission during the burst peak. In extreme cases, the burst's immense radiation pressure may completely blow the corona away, which could temporarily shut off the collimated radio jets that are linked to coronal magnetic fields. The burst also strongly impacts the physical structure of the accretion disk. Irradiation can heat the disk, causing it to puff up and increase its scale height, while the intense photon flux can induce Poynting-Robertson radiation drag, forcing the inner disk material to drain onto the neutron star. Furthermore, burst photons scattering off the inner accretion disk generate observable reflection features, such as fluorescent iron emission lines and absorption edges. Finally, photons that reach the cooler outer accretion disk and the donor star are reprocessed, producing transient optical and ultraviolet flashes.

Studying thermonuclear X-ray bursts provides a unique astrophysical laboratory to probe matter and physical processes under extreme conditions that cannot be replicated on Earth. One of the primary motivations for studying these powerful explosions is to constrain the Equation of State (EoS) of the supranuclear dense matter inside neutron star cores. By using methods like Photospheric Radius Expansion (PRE) bursts and continuum spectrum modeling, researchers can accurately measure a neutron star's mass and radius, thereby ruling out specific theoretical models of exotic matter. Thermonuclear Burst allows astronomers to dynamically probe the accretion process by observing how burst photons interact with the accretion disk and the hot electron corona. Finally, they provide a testing ground for complex nuclear physics, such as the rapid-proton (rp) process, and multidimensional hydrodynamics like flame spreading.

We will discuss more methods of producing X-rays in the upcoming articles.

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- W. H. G. Lewin, J. van Paradijs, and R. E. Taam *X-ray bursts*

#### About the Author



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**Part IV**

**Biosciences**

# Gene Knockout Strategies – The Scientific Wrestle Of Gene Therapeutics

*by Aengela Grace Jacob*

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[www.airis4d.com](http://www.airis4d.com)

## 1.1 Introduction

In the field of genetic engineering and oncology, researchers often need to silence a gene to understand its function. This is typically achieved through two primary strategies: Gene Knockout and Gene Knockdown. While they sound similar, they operate on different biological levels and offer unique advantages for cancer research and therapy. Gene knockout involves the complete permanent disruption of a gene at the DNA level. By using genome-editing tools like CRISPR-Cas9, the specific DNA sequence of a gene is deleted or scrambled, ensuring that the cell can no longer produce the corresponding protein. While considering the case of gene knockdown, a temporary reduction in gene expression, usually at the RNA level. Instead of destroying the DNA, knockdown techniques intercept the messenger RNA (mRNA) before it can be translated into a protein. When a drug is developed (before the initial process), researchers must prove a gene is a viable target therefore by using knockdown or knockout strategies in the lab, they can mimic the effect of a future drug. If knocking down Gene X stops a tumor from spreading in a petri dish, Gene X becomes a high-priority target for pharmaceutical development. Here we would indulge in discussing on the gene knockout methods and strategies and understand their upscaling and leverage in therapeutic applications.

## 1.2 Fundamental Logic Of Knockout

The standard observational biology asks, What is this gene doing? , knockout technology asks, What happens to the system when this gene is gone? This distinction is vital. It shifts the research from correlation (observing that a gene is active during a process) to causation (proving that the process cannot happen without that gene).

The process typically targets the genomic DNA. Unlike temporary methods that intercept messages, a knockout creates a permanent, heritable change. When a gene is knocked out, the cellular machinery can no longer transcribe the DNA into functional messenger RNA (mRNA), ensuring that the corresponding protein is never synthesized.

There are certain primary methodologies introduced to conduct the knockout procedures it include homologous recombination (traditional method) and ZFNs and TALENs and the gold standard CRISPR-Cas9

## 1.3 Traditional Homologous Recombination

Before the era of programmable nucleases, scientists relied on a natural cellular repair process called homologous recombination. Researchers would introduce a DNA fragment containing a nonsense sequence flanked by sequences identical to the target gene. Occasionally, the cell would mistakenly swap

the functional gene for the broken one. While groundbreaking (earning the Nobel Prize in 2007), this was an inefficient numbers game, often requiring thousands of attempts to achieve a single successful knockout.

## 1.4 The Programmable Nucleases (ZFNs and TALENs)

To increase efficiency, scientists developed molecular scissors that could be programmed to cut specific DNA locations. Zinc-Finger Nucleases (ZFNs) and TALENs were the first to allow for targeted double-strand breaks (DSBs). By forcing the cell to repair a specific break, researchers could introduce mutations that effectively deactivated the gene.

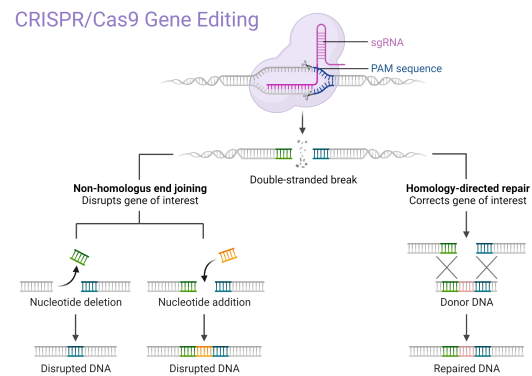
## 1.5 CRISPR-Cas9: The Genetic Revolution

The current gold standard is **CRISPR-Cas9**. Derived from a bacterial immune system, CRISPR uses a guide RNA to lead the Cas9 enzyme to a precise coordinate in the genome. Once there, Cas9 snips the DNA. When the cell attempts to repair this break using a sloppy mechanism called **Non-Homologous End Joining (NHEJ)**, it often introduces small insertions or deletions (indels). These indels shift the reading frame of the gene, creating a premature stop signal that renders the gene completely non-functional.

## 1.6 Why We Need Gene Knockout?

This figure illustrates the CRISPR-Cas9 gene-editing process, showing how a specific DNA sequence is targeted, cut, and then repaired by the cell's natural mechanisms.

This is a very intriguing question to be pondered upon so let's take an example, imagine the city starts experiencing random fires (tumors). We suspect a specific office, let's call it the Growth Office. It has a broken manual that's telling the city to build buildings where they don't belong.



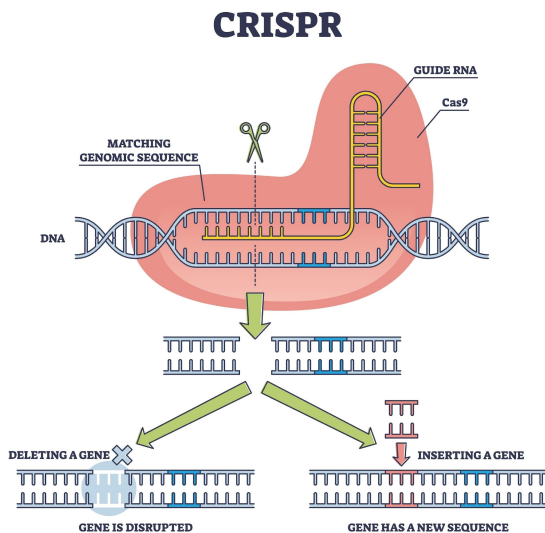
**Figure 1:** This figure illustrates the CRISPR-Cas9 gene-editing process, showing how a specific DNA sequence is targeted, cut, and then repaired by the cell's natural mechanisms.

Image Courtesy: <https://www.biorender.com/template/crisprcas9-gene-editing>

To prove this office is the problem, scientists use a Knockout Strategy. If we completely delete the Growth Office manual and the fires stop, we have proven that office was the culprit. Conversely, if we delete a Safety Office manual and fires suddenly start everywhere, we realize that manual was actually a Tumor Suppressor - a set of instructions meant to prevent fires.

We can't just throw a grenade into the library; we need to be surgical. We use tools like CRISPR, which acts like a biological GPS paired with a pair of scissors. Now we need to know the factor of how, the answer is through precision shredding;

- **The GPS (Guide RNA):** We give the tool a snippet of the manual we want to destroy. It wanders through the library until it finds the exact matching page.
- **The Scissors (Cas9):** Once it finds the page, it snips the DNA.
- **The Sloppy Repair:** The cell is a neat freak; it hates broken DNA. It tries to tape the page back together immediately. But because it's in such a rush, it almost always makes a typo or leaves out a sentence
- **The Result:** That typo makes the manual unreadable. The cell can no longer follow those instructions. The gene is Knocked Out.

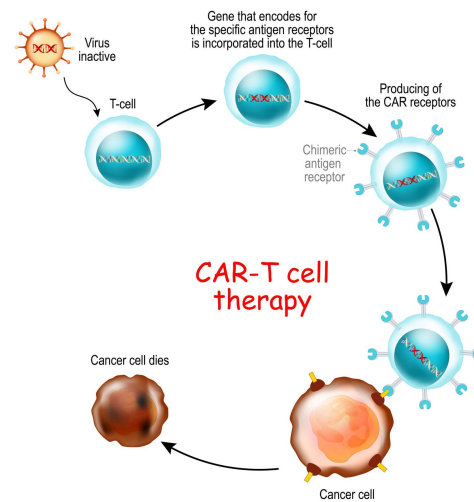


**Figure 2:** This diagram illustrates how the CRISPR-Cas9 system works to edit DNA

Image Courtesy: [https://encrypted-tbn1.gstatic.com/licensed-image?q=tbn:ANd9GcR\\_XMz75LwVf0fSb2L7\\_WC5L3KXmd5LkZJDWc3Qa8jgNwGQu70ILCgaTvEubv5ozeY5XcLiVO3LUnBWwftT9vfGzhd9tFb8MDrbDdI5BSrDShQfM](https://encrypted-tbn1.gstatic.com/licensed-image?q=tbn:ANd9GcR_XMz75LwVf0fSb2L7_WC5L3KXmd5LkZJDWc3Qa8jgNwGQu70ILCgaTvEubv5ozeY5XcLiVO3LUnBWwftT9vfGzhd9tFb8MDrbDdI5BSrDShQfM)

## 1.7 Assisting Therapy

Now, we need to understand how this technique helps to target the tumour which arise in our bodies. To tackle this enemy we utilise the knockout strategy. By knocking out genes one by one in cancer cells (a process called a CRISPR screen), we can find Achilles heels. We might find that while a cancer cell is aggressive, it is uniquely dependent on one specific Utility Manual. If we can find a drug that mimics that knockout, we can kill the cancer without hurting the healthy parts of the body. In gene therapy, we actually use knockout strategies to help our immune cells. Sometimes, our immune cells (the city's police) have a manual that tells them, Don't attack anything that looks like a citizen. Cancer cells are clever and disguise themselves as citizens. Scientists can knock out that specific Don't Attack instruction in the immune cells. Now, these upgraded Bodyguards can see through the cancer's disguise and go on the offensive. This is the CAR T-cell Therapy, it is shown to be groundbreaking for hematologic cancer treatments.



**Figure 3:** This image illustrates CAR-T cell therapy, a specialized form of immunotherapy that genetically engineers a patient's own immune cells to recognize and destroy cancer.

Image Courtesy: [https://encrypted-tbn2.gstatic.com/licensed-image?q=tbn:ANd9GcQDq4PfGy7rdbecD7WokUkPQ1fVsoai0jdbSWFJz3DgDM\\_Yn6cq9wuJFcxqdWUWtYkNN6Cd4Qla54DRuJ\\_lowVWUplu6MmyUjdOOaYKATsQMPmuxQ](https://encrypted-tbn2.gstatic.com/licensed-image?q=tbn:ANd9GcQDq4PfGy7rdbecD7WokUkPQ1fVsoai0jdbSWFJz3DgDM_Yn6cq9wuJFcxqdWUWtYkNN6Cd4Qla54DRuJ_lowVWUplu6MmyUjdOOaYKATsQMPmuxQ)

## 1.8 The Great Genetic Shuffle: A Symphony of Survival in Esophageal Cancer

In the silent, cellular theatre of the **Esophageal Adenocarcinoma (EAC)**, a complex and deadly transformation unfolds. The recent study published in *Cell Death and Disease* reveals that the progression of this cancer from its precursor, **Barrett's Esophagus (BE)**, to a lethal malignancy is orchestrated not just by mutations, but by a subtle genetic sleight of hand known as **isoform switching (IS)**.

### 1.9 The Shifting Genetic Mask

Think of a gene as a master blueprint. Through alternative splicing, a single gene can produce different versions of its protein output, called **isoforms**. The researchers discovered that as EAC develops, the cell switches its preference from one isoform to another. By analyzing RNA-sequencing data, the team identified: **71 genes** that underwent significant isoform switching during the progression to EAC. **42 specific isoforms** that serve as grim harbingers, directly linked to **all-**

**cause patient mortality.** A unique synergy between these switches and the status of **TP53**, the most commonly mutated gene in this cancer type.

**The Protagonists of Pathogenesis: TTLL12 and HM13:** To bridge the gap between observation and action, the study focused on two high-stakes players identified by survival analysis: **TTLL12** and **HM13**.

## 1.10 The TTLL12 Gambit: Evading the Quality Control

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The coding isoform **TTLL12-201** emerges as a villain in the EAC narrative. When researchers silenced this specific isoform using siRNA, the results were transformative: **Activation of Chaperone-Mediated Autophagy (CMA):** Knocking down TTLL12-201 forced the cell to restart its internal cleaning system. **Degradation of CHK1 and TP53:** This activated autophagy targeted and degraded key survival proteins like CHK1, which normally helps the cancer repair its DNA. **Chemosensitivity:** Silencing this isoform sensitized cancer cells to standard chemotherapy (paclitaxel and carboplatin), turning a resistant foe into a vulnerable one.

## 1.11 The HM13 Maneuver: Stressing the System

The **HM13-201** isoform acts as a shield within the Endoplasmic Reticulum (ER). Targeting it triggered a cellular catastrophe: **Unfolded Protein Response (UPR):** Its removal induced massive ER stress, overwhelming the cancer cell with misfolded protein garbage. **Translation Arrest and Apoptosis:** The cell effectively stopped producing new proteins and initiated programmed cell death (apoptosis). **Immunotherapy Synergy:** Remarkably, silencing HM13 increased the response to **avelumab**, an anti-PD-L1 agent, suggesting that this genetic switch plays a role in helping the cancer hide from the immune system.

## 1.12 A New Horizon for Treatment

Perhaps the most promising finding is the **selectivity** of these targets. While silencing TTLL12 and HM13 was devastating to EAC cells, it had **minimal effect on normal esophageal cells** (Het-1A), offering a goldilocks opportunity for precision medicine with low toxicity.

By moving beyond simple mutations and looking at the **isoform landscape**, this research provides a new map for prognostic markers and therapeutic targets. It suggests that the future of EAC treatment may lie in reversing these genetic switches, forcing the cancer to unmask itself and face the cellular consequences.

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### About the Author



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# The eDNA Metabarcoding Model: Next-Generation Biodiversity Assessment - Part 2

*by Geetha Paul*

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[www.airis4d.com](http://www.airis4d.com)

## 2.1 Introduction:

### The Molecular Revolution in Ecology

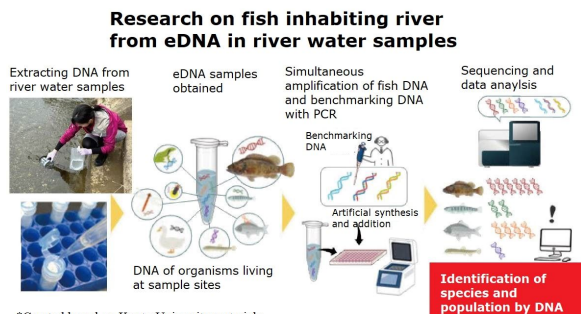
For centuries, biodiversity monitoring has relied on traditional methods such as nets, traps, and visual surveys, techniques that, while foundational, are labour-intensive, taxonomically limited, and often invasive. As the global biodiversity crisis accelerates, driven by habitat loss, climate change, and species extinctions, the need for faster, more comprehensive, and non-destructive monitoring tools has become urgent. Enter environmental DNA (eDNA) metabarcoding, a revolutionary approach that shifts the focus from direct organismal observation to the detection of the genetic traces species leave behind in their surroundings. Every organism sheds DNA through skin cells, mucus, faeces, or gametes into water, soil, or air. By capturing and sequencing these genetic fragments using high-throughput sequencing (HTS), researchers can identify entire communities from a single sample, uncovering rare, cryptic, or elusive species that traditional methods miss. This technique offers unparalleled advantages: high sensitivity, scalability, non-invasiveness, and the ability to process hundreds of samples simultaneously. From tracking endangered species and invasive organisms to reconstructing ancient ecosystems and monitoring microbial communities, DNA metabarcoding is transforming conservation biology, ecological research, and environmental policy.

Yet challenges remain, including gaps in reference databases, PCR biases, and the need for standardised protocols. As technology advances with portable sequencers, machine learning, and global DNA databases, metabarcoding is poised to become the cornerstone of biodiversity assessment, ushering in a new era in which ecosystems are decoded not by sight but by their genetic fingerprints.

## 2.2 The Theoretical Framework: From Cells to Sequences

The eDNA metabarcoding model operates on a multi-stage pipeline that integrates field biology, molecular genetics, and advanced bioinformatics.

- **Environmental Shedding and Persistence:** The model begins with the biological reality that organisms lose DNA through faeces, mucus, gametes, and decaying tissue. The detectability of a species depends on the rate of shedding versus the rate of degradation. In aquatic systems, factors such as UV radiation, pH, and temperature dictate how long this genetic memory persists, usually ranging from a few days to several weeks.
- **The Power of Universal Primers:** Unlike traditional DNA barcoding, which targets a single specimen, metabarcoding uses universal primers. These are short DNA sequences designed to



**Figure 1:** Sampling of River water for DNA extraction to identify species.

Image courtesy: <https://www.bing.com/images/search?view=detailV2&ccid=NgDBPbw&id=068A58357A8DCBEF2E98EFDA061BD6869C253946&thid>

bind to highly conserved regions across a broad group of taxa (e.g., all fish or all insects), while flanking a variable region specific to each species. The **Cytochrome c Oxidase subunit I (COI)** gene is the most common target for animal DNA barcoding, often referred to as the biological barcode.

## 2.3 The Technical Pipeline: Field to Data

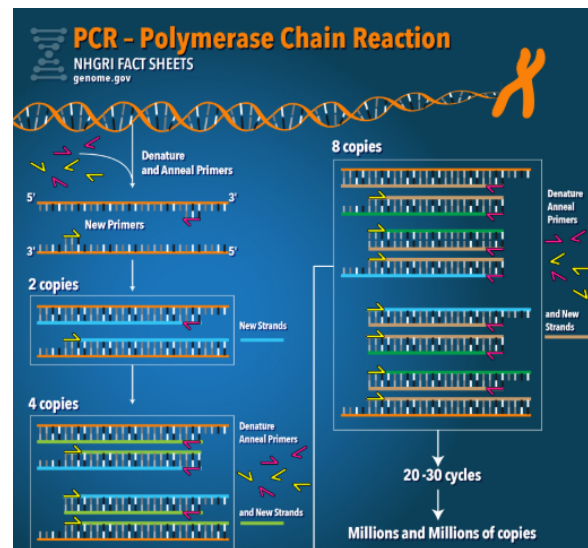
Implementing the eDNA model requires a rigorous technical workflow to ensure that the data accurately reflects the biological reality of the site.

### Phase I: Capture and Extraction

Sampling typically involves filtering large volumes of water (often 1–5 litres) through fine-pore membranes to capture DNA fragments. Because eDNA is highly sensitive, preventing contamination is the most significant challenge. Once captured, the DNA is extracted in a sterile laboratory environment using specialised kits designed to remove environmental inhibitors, such as humic acids, which can interfere with subsequent chemical reactions.

### Phase II: Library Preparation and Sequencing

The extracted DNA undergoes **Polymerase Chain Reaction (PCR)** amplification. During this stage, unique indexes or molecular tags are attached to the DNA from each sample, allowing multiple samples to be pooled together in a single sequencing run. The library is then sequenced using platforms like Illumina, which generate millions of individual reads.



**Figure 2:** The extracted DNA undergoes Polymerase Chain Reaction (PCR) amplification.

Image courtesy: pcr\_factsheet.jpg (1800x1800)

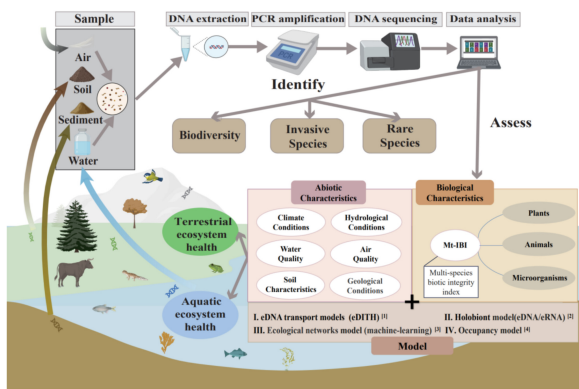
### Phase III: Bioinformatics and Taxonomy

The resulting raw data is a massive digital haystack of sequences. Bioinformatics pipelines (such as QIIME2 or OBITools) filter out noise and errors. These sequences are then clustered into **Operational Taxonomic Units (OTUs)** or mapped to global reference databases such as **GenBank** or the **Barcode of Life Data System (BOLD)**. The result is a detailed list of every detectable species present in the original environment.

## 2.4 Strategic Advantages and the Biotic Index

The eDNA metabarcoding model offers several distinct advantages over traditional morphological surveys:

- **Detection of Rare and Invasive Species:** eDNA is exceptionally sensitive. It can detect the presence of a single invasive carp in a massive lake or a rare, endangered dragonfly nymph in a remote stream long before a human observer would find them.
- **Cost and Time Efficiency:** A single technician can collect dozens of water samples in a day, covering an area that would take a team of taxonomists weeks to survey using traditional



**Figure 3:** Schematic diagram of eDNA sample collection, analysis, and functions.

Image courtesy: Environmental DNA (eDNA) Technology in Biodiversity and Ecosystem Health Research: Advances and Prospects - Wu - 2026 - Ecology and Evolution - Wiley Online Library

nets and microscopes.

- **Non-Invasive Monitoring:** This is the gold standard for conservation in protected areas. It allows monitoring biodiversity without capturing, stressing, or killing specimens.

The model is being used to develop a **Molecular Biotic Index**. By analysing the entire macroinvertebrate community via eDNA, researchers can assign a health score to a watershed. Certain species are highly sensitive to pollution; their presence, detected via their DNA, serves as a real-time indicator of water quality and ecosystem resilience.

## 2.5 Challenges: The Road to Standardisation

Irrespective of its potential, the eDNA model faces hurdles that require ongoing research.

- **The Reference Database Gap:** A DNA sequence is only useful if it can be matched to a known species. In many tropical regions and among specific groups like Odonata (dragonflies), reference libraries are still being built.
- **Primer Bias:** Not all DNA sequences amplify with equal efficiency. Some species may be hidden if the universal primers do not bind perfectly to their genetic code, leading to under-representation.
- **Quantification:** While eDNA tells us *who* is there, it is still difficult to determine exactly *how many* individuals are present. While

sequence read counts often correlate with biomass, environmental variables complicate absolute quantification.

## Conclusion:

### The Future of Ecological Surveillance

The eDNA metabarcoding model represents the ultimate synthesis of technology and natural history. As sequencing costs continue to fall and reference databases expand, this model will become the standard for environmental impact assessments, biosecurity, and climate change monitoring.

By looking into a drop of water and seeing the genetic signatures of an entire forest or river system, we gain a more profound understanding of the interconnectedness of life. For the next generation of researchers, the ability to decode these environmental secrets will be the key to preserving the earth's most vulnerable ecosystems, from the depths of the oceans to the peaks of the Western Ghats.

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**About the Author**



Dr. Geetha Paul is one of the directors of airis4D. She leads the Biosciences Division. Her research interests extends from Cell & Molecular Biology to Environmental Sciences, Odonatology, and Aquatic Biology.

## **About airis4D**

Artificial Intelligence Research and Intelligent Systems (airis4D) is an AI and Bio-sciences Research Centre. The Centre aims to create new knowledge in the field of Space Science, Astronomy, Robotics, Agri Science, Industry, and Biodiversity to bring Progress and Plenitude to the People and the Planet.

## **Vision**

Humanity is in the 4th Industrial Revolution era, which operates on a cyber-physical production system. Cutting-edge research and development in science and technology to create new knowledge and skills become the key to the new world economy. Most of the resources for this goal can be harnessed by integrating biological systems with intelligent computing systems offered by AI. The future survival of humans, animals, and the ecosystem depends on how efficiently the realities and resources are responsibly used for abundance and wellness. Artificial intelligence Research and Intelligent Systems pursue this vision and look for the best actions that ensure an abundant environment and ecosystem for the planet and the people.

## **Mission Statement**

The 4D in airis4D represents the mission to Dream, Design, Develop, and Deploy Knowledge with the fire of commitment and dedication towards humanity and the ecosystem.

### **Dream**

To promote the unlimited human potential to dream the impossible.

### **Design**

To nurture the human capacity to articulate a dream and logically realise it.

### **Develop**

To assist the talents to materialise a design into a product, a service, a knowledge that benefits the community and the planet.

### **Deploy**

To realise and educate humanity that a knowledge that is not deployed makes no difference by its absence.

## **Campus**

Situated in a lush green village campus in Thelleyoor, Kerala, India, airis4D was established under the auspicious of SEED Foundation (Susthiratha, Environment, Education Development Foundation) a not-for-profit company for promoting Education, Research. Engineering, Biology, Development, etc.

The whole campus is powered by Solar power and has a rain harvesting facility to provide sufficient water supply for up to three months of drought. The computing facility in the campus is accessible from anywhere through a dedicated optical fibre internet connectivity 24×7.

There is a freshwater stream that originates from the nearby hills and flows through the middle of the campus. The campus is a noted habitat for the biodiversity of tropical Fauna and Flora. airis4D carry out periodic and systematic water quality and species diversity surveys in the region to ensure its richness. It is our pride that the site has consistently been environment-friendly and rich in biodiversity. airis4D is also growing fruit plants that can feed birds and provide water bodies to survive the drought.