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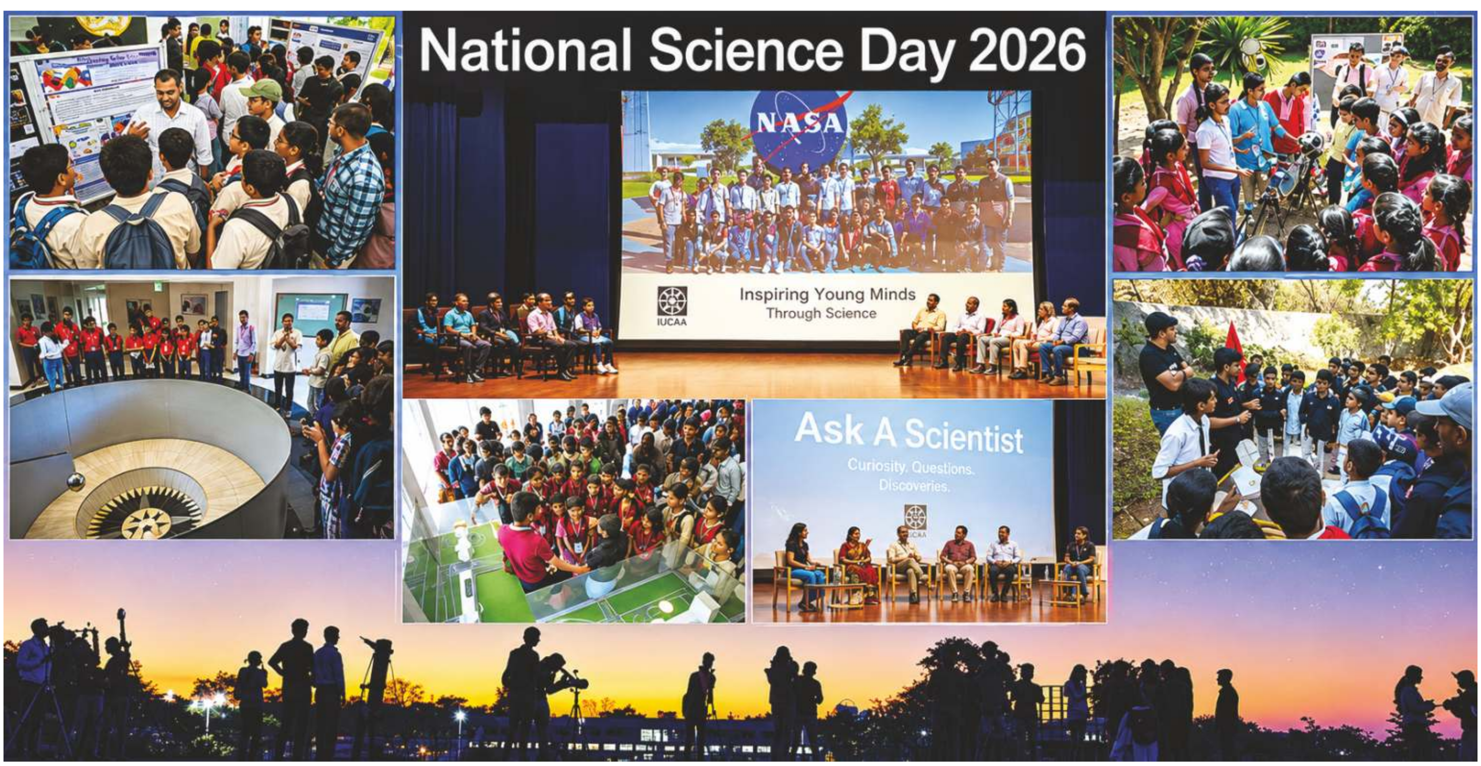
Contents...



Listening for binary mergers: Compact binary coalescence searches in gravitational-wave data

Introduction

On 14 September 2015, at 09:50:45 UTC, the two LIGO detectors — one in Hanford, Washington and the other in Livingston, Louisiana — registered a transient ripple in spacetime almost simultaneously. The signal lasted barely 0.2 seconds, swept upward in frequency from about 35 Hz to 150 Hz, and vanished. This was GW150914, the first direct detection of gravitational waves (GW), produced by the inspiral and merger of two stellar-mass black holes (BH) roughly 1.4 billion light-years away [1]. That detection made headlines worldwide — and rightly so. But what often does not make headlines is the question of *how* the signal was found.

The peak strain amplitude was $h \sim 10^{-21}$ — a fractional length change of one part in a thousand billion billion across a 4 km arm. Less than a thousandth the diameter of a proton. Despite this, GW150914 was one of the *louder* events in the catalogue with a network signal-to-noise ratio (SNR) of about 24. Most detections sit between SNR 8 and 12. Finding such signals in non-stationary, non-Gaussian detector noise — filled with artefacts from seismic activity, electronic glitches, and scattered laser light — requires a carefully designed detection strategy. That strategy is *matched filtering*, and built around it are signal-consistency vetoes, significance estimation methods, and astrophysical classification tools that together form the backbone of all compact binary coalescence (CBC) searches by the LIGO-Virgo-KAGRA (LVK) collaboration.

As of August 2025, LVK has published GWTC-4.0 cataloguing **218 confident GW detections** across O1 through O4a, with roughly 250 more candidates from O4b and O4c undergoing offline analysis [2, 3]. This is a far cry from the single event that started it all. Highlights from O4 include GW231123, the most massive BBH merger ever observed — producing an intermediate-mass black hole of $\sim 225\,M_\odot$, with both progenitors in the pair-instability mass gap [4] — and GW250114, the loudest GW signal ever recorded at a network SNR of ≈ 80, enabling the first confident identification of two ringdown quasi-normal modes in a single event [5]. This article walks through the search methods that find them all.

1. The Signal and the Noise

A compact binary — two neutron stars (NS), two BHs, or one of each — loses energy to GW emission as it spirals inward. The orbital frequency increases, and so does the gravitational-wave frequency (twice the orbital frequency). The result is a characteristic frequency-sweeping waveform called a *chirp*. In the inspiral regime, the phase evolution to leading order depends entirely on the *chirp mass*,

$$\mathcal{M} = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}, \qquad (1)$$

with corrections from the symmetric mass ratio $\eta = m_1 m_2/(m_1 + m_2)^2$ and component spins. Waveform models from families like `IMRPhenom` [6, 7, 8, 9] or `SEOBNR` [10, 11, 12, 13, 14] or `TEOB` [15, 16, 17] extend the signal through merger and ringdown, giving a complete template over the detector band.

The detector output is $d(t) = n(t) + h(t)$, where $n(t)$ is noise and $h(t)$ is the GW strain (if a signal is present). Advanced LIGO's noise power spectral density (PSD), $S_n(f)$, rises steeply below $\sim$20 Hz from seismic and suspension noise, plateaus in a thermal noise floor at intermediate frequencies, and is dominated by quantum shot noise above $\sim$100 Hz. This frequency-dependent sensitivity defines a natural *noise-weighted inner product*,

$$\langle a \mid b \rangle = 4\,\mathrm{Re} \int_0^\infty \frac{\tilde{a}^*(f)\,\tilde{b}(f)}{S_n(f)}\,df, \qquad (2)$$

where tildes denote Fourier transforms. Whitening the data by dividing in frequency domain by $\sqrt{S_n(f)}$ renders the noise approximately stationary and Gaussian. Every detection statistic, every error estimate, and every template placement criterion follows from Eq. (2).

2. Matched Filtering as Maximum-Likelihood Estimation

Treating $n(t)$ as a zero-mean stationary Gaussian process, the log-likelihood ratio for a template $h(t;\boldsymbol{\theta})$ is

$$\ln \Lambda(\boldsymbol{\theta}) = \langle d \mid h(\boldsymbol{\theta}) \rangle - \tfrac{1}{2}\langle h(\boldsymbol{\theta}) \mid h(\boldsymbol{\theta}) \rangle. \qquad (3)$$

The first term is the projection of data onto the template; the second normalises for amplitude. This is exactly the *maximum-likelihood estimator* (MLE) for the signal parameters under Gaussian noise [18]. Maximising analytically over the two extrinsic parameters that enter linearly — the coalescence time t_c and reference phase ϕ_0 — the detection statistic reduces to the *matched-filter SNR*,

$$\rho(t_c;\, \boldsymbol{\theta}) = \frac{|\langle d \mid h(\boldsymbol{\theta}; t_c) \rangle|}{\sqrt{\langle h \mid h \rangle}}. \qquad (4)$$

This is evaluated efficiently over all t_c via an inverse FFT. The Neyman-Pearson lemma guarantees that Eq. (4) is the *optimal* linear detection statistic in Gaussian noise: nothing else extracts more SNR from the data. The luminosity distance d_L and inclination ι enter only through the overall amplitude and are absorbed into a combined *quadrature SNR* $\rho^2 = \rho_+^2 + \rho_\times^2$ from two template polarisations [19].

Fig. 1 illustrates this for a GW151226. The top row shows band-passed, whitened strain data, with the best-matched templates shown in black. The second and third rows show the accumulated matched-filter SNR and SNR time series. The last row shows the time-frequency representation.

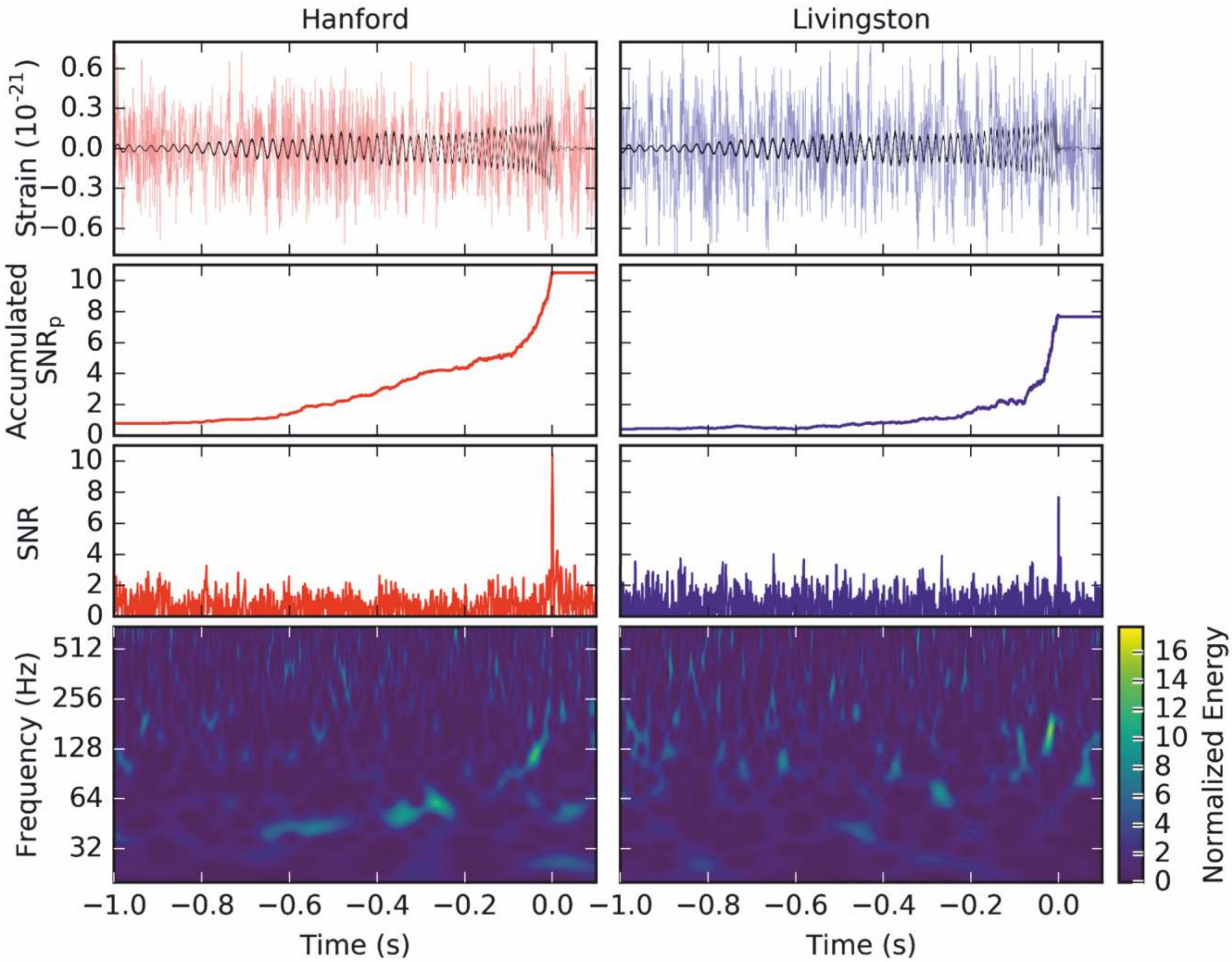


Figure 1. Matched filter in action GW151226 observed by the LIGO Hanford (left column) and Livingston (right column) detectors. First row: Strain data from the two detectors, filtered with a 30–600 Hz bandpass. Also shown in black is the best-match template. Second row: The accumulated peak signal-to-noise ratio ($\mathrm{SNR_p}$) as a function of time from 30 Hz. Third row: Signal-to-noise ratio (SNR) time series produced by time shifting the best-match template waveform. Fourth row: Time-frequency representation where the signal is not clearly visible as it is weak. [20]

3. Composite Hypothesis and Template Banks

The matched filter in Eq. (4) is optimal for a *known* template. In reality, we test a *composite* hypothesis: a signal may be present with some unknown parameters $\boldsymbol{\theta}$ anywhere in a multi-dimensional family. We therefore compute ρ over a discrete *template bank* and report the maximum SNR over all templates and all times.

How densely must the bank sample the parameter space? The fractional SNR loss when the true signal falls between two templates is the *mismatch* $\mu = 1 - \rho^2_{\max}/\rho^2_{\rm opt}$. The *Fisher information matrix*,

$$\Gamma_{ij}(\boldsymbol{\theta}) = \left\langle \frac{\partial h}{\partial \theta^i} \middle| \frac{\partial h}{\partial \theta^j} \right\rangle, \qquad (5)$$

whose inverse gives the Cramér-Rao bound on parameter estimation errors at high SNR [18, 21], also defines a Riemannian metric on waveform space: the mismatch between neighbouring templates is $\mu \approx \frac{1}{2}\Gamma_{ij}\delta\theta^i\delta\theta^j$. Template placement is therefore a covering problem in this metric, with the standard criterion $\mu \leq 3\%$.

Two strategies implement this covering. *Geometric placement* [22] tiles the space with a regular lattice — typically hexagonal — in coordinates where the metric is nearly flat, such as the chirp-time pair (τ_0, τ_3). It is efficient but breaks down when spin degrees of freedom are included, since the metric topology becomes complex in higher dimensions. *Stochastic placement* [23] avoids this entirely: it proposes random template points and rejects those within mismatch μ of any accepted template. It works in arbitrary dimensions, respects the true metric geometry, and over-covers the geometric optimum by only ∼30–50%. In O3 and O4, PyCBC used stochastic banks with $\mathcal{O}(10^5\text{–}10^6)$ templates covering the full BBH, NSBH, and BNS parameter spaces.

Fig. 2 shows the template density in the (m_1, m_2) plane. The density scales roughly as $\mathcal{M}^{-5/3}$: the BNS corner requires far more templates per unit area than the high-mass BBH region, making BNS searches computationally the most expensive.

4. Signal-Consistency Vetoes

The matched filter is optimal against Gaussian noise. Real detector noise is not Gaussian. It contains *glitches* — transient, non-Gaussian artefacts from violin-mode resonances, scattered light,

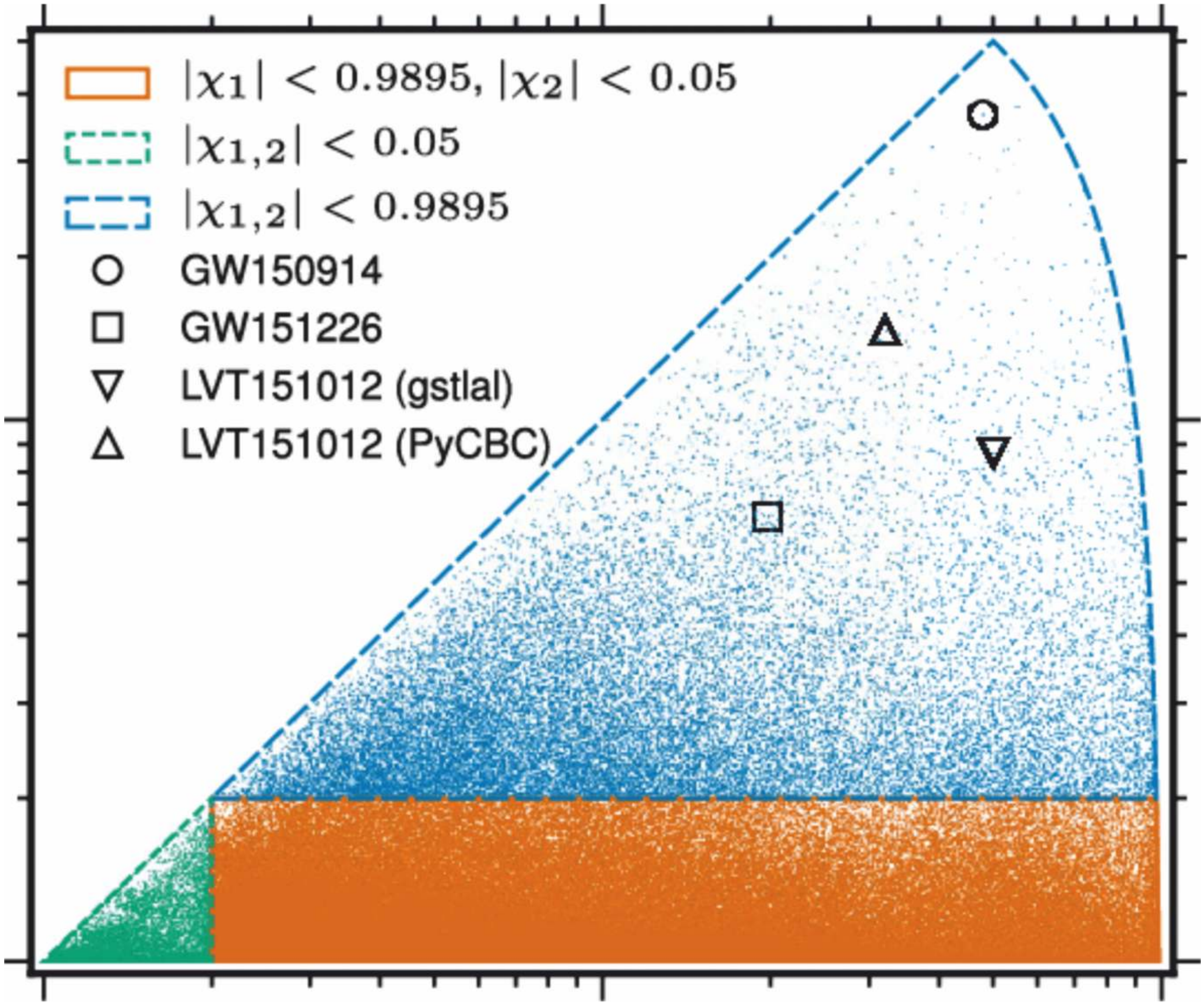


Figure 2. Template bank in the (m_1, m_2) plane. Colours separate BNS, NSBH, and BBH sub-banks at m_i=3 $M_\odot$; dashed diagonal marks m_1=m_2. Bank covers the O1 parameter space [19, 23].

and control-system coupling. Some glitch families, like the "blip" class in Advanced LIGO data [24], are well-localised in time and overlap strongly with short CBC templates, producing large SNR excursions, despite bearing no physical resemblance to an inspiralling binary.

The key observation is that an astrophysical CBC signal must distribute its power across frequency in a precise, predictable way determined by the orbital phase evolution. The χ^2 *time-frequency veto* [25] quantifies this. The template's frequency band is divided into p sub-bands, each expected to contribute equally (ρ^2/p) to the total SNR for a real signal. A glitch concentrates its power in a narrow frequency range. The statistic

$$\chi^2 = \sum_{k=1}^{p} \left(\rho_k - \frac{\rho}{p} \right)^2 \tag{6}$$

follows a χ^2 distribution with $2(p-1)$ degrees of freedom for an astrophysical signal and is inflated for a glitch. The *reweighted SNR*,

$$\hat{\rho} = \begin{cases} \rho\left[\frac{1}{2}(1 + (\chi_r^2)^3)\right]^{-1/6} & \chi_r^2 > 1, \\ \rho & \chi_r^2 \leq 1, \end{cases} \tag{7}$$

where $\chi_r^2 = \chi^2/[2(p-1)]$, penalises loud but morphologically inconsistent triggers. This $\hat{\rho}$ is the primary single-detector ranking statistic in PyCBC [19, 26].

Two further vetoes complement the χ^2. A *sine-Gaussian veto* targets narrow-band, high-Q transients that are common in LIGO data but inconsistent with a broadband CBC template. An *auto-correlation veto* checks whether the matched-filter time series near the peak is consistent with the template's own auto-correlation function — a test that finite-duration glitches routinely fail.

5. Coincident Search and Multi-Detector Consistency

An astrophysical GW must arrive at each detector within the inter-site light-travel time ($\leq$ 10 ms for Hanford–Livingston; $\leq$ 27 ms including Virgo). The *coincident search* [19] requires single-detector triggers above $\hat{\rho}$ threshold to overlap in both time and template parameters across detectors within this window. The network ranking statistic combines reweighted SNRs in quadrature: $\hat{\rho}_{\rm net}^2 = \hat{\rho}_H^2 + \hat{\rho}_L^2 + \cdots$

Two multi-detector consistency tests further suppress accidental coincidences. *Phase and time consistency*: for a given sky position, the GW must arrive with a specific time delay and phase difference between detectors, fixed by the antenna pattern functions $F_+(\alpha, \delta, \psi)$, $F_\times(\alpha, \delta, \psi)$. Trigger pairs with differences inconsistent with every sky position are suppressed [27]. *Amplitude consistency*: the ratio $\hat{\rho}_H/\hat{\rho}_L$ constrains the sky position through the effective distance ratio; amplitude ratios incompatible with any sky position reduce the ranking. These checks together ensure that a highly ranked candidate is not merely two independent glitches that happened to overlap within the light-travel window.

6. Significance from Time Slides

Once triggers are ranked by $\hat{\rho}_{\rm net}$, the critical question is: how often does noise alone produce a trigger this loud? An analytical answer is unreliable because detector noise is non-Gaussian and non-stationary. The solution is *time slides*: one detector's stream is shifted relative to another by a large time offset (much greater than the light-travel time) and the coincident search is re-run. This destroys coincidences for astrophysical GW signals while preserving individual detector noise statistics. Repeating over $\mathcal{O}(10^2$–$10^3)$ offsets generates a background distribution extending to equivalent false-alarm rates of $\mathcal{O}(1/10^4\,\mathrm{yr})$ from only months of data [19]. GW150914 had a false-alarm rate of < 1 in 200,000 years from this method, $> 5\sigma$ [1].

In GWTC-4.0, most BBH events carry FAR $\lesssim 1\,\mathrm{yr}^{-1}$ from offline time-slide searches, with many far lower. Fig. 3 illustrates the background distribution and the distribution of foreground events at different significance levels.

7. Astrophysical Probability, $p_{\rm astro}$

A FAR is a noise statement: how often a detection statistic value would be exceeded by chance. But what we often want is: what is the probability that *this specific trigger* is a real astrophysical event? This is the *astrophysical probability* $p_{\rm astro}$ [28],

$$p_{\rm astro} = \frac{R_s\, p(\hat{\rho}_{\rm net} \mid \mathcal{H}_s)}{R_s\, p(\hat{\rho}_{\rm net} \mid \mathcal{H}_s) + R_n\, p(\hat{\rho}_{\rm net} \mid \mathcal{H}_n)}, \tag{8}$$

where R_s, R_n are the expected rates of signals and noise triggers, and the likelihoods are evaluated from the observed ranking statistic. The signal rate prior R_s is calibrated from confirmed detections in previous runs, separately for BBH, BNS, and NSBH.

In GWTC-4.0 the catalog threshold is $p_{\rm astro} \geq 0.5$, yielding 218 confident detections through O4a. For population studies, FAR $< 1\,\mathrm{yr}^{-1}$ is used ($\sim$161 events); for tests of general relativity, FAR $\leq 10^{-3}\,\mathrm{yr}^{-1}$ (91 events); for cosmology, FAR $< 0.25\,\mathrm{yr}^{-1}$ (142 events) [2]. This tiered scheme reflects different contamination tolerances for each science case. A trigger with FAR $= 10\,\mathrm{yr}^{-1}$ can still carry $p_{\rm astro} > 0.5$ if the astrophysical rate is high in that region of parameter space. Conversely, $p_{\rm astro}$ is sensitive to the population prior — a cautionary note, especially for NSBH events sitting in a sparsely sampled parameter region.

8. Low Latency and Early Warning

The BNS merger GW170817 demonstrated the power of multi-messenger astronomy in the most vivid way possible: gravitational waves followed 1.7 s later by a short gamma-ray burst, then optical, infrared, UV, X-ray, and radio counterparts over subsequent days [29]. That observation required rapid sky localisation and rapid alerts. The offline pipeline described above takes hours to days. PyCBCLive [30] achieves real-time detection by streaming data continuously, estimating the PSD online with a running median, and issuing a preliminary alert within $\sim$30–60 seconds post-merger. During O4a, four low-latency pipelines (PyCBCLive, GstLAL, MBTA, SPIIR) achieved a median preliminary alert latency of about 29.5 seconds, with 1,697 alerts issued over the course of O4a [31].

Going further still, *early-warning searches* [32] exploit the finite inspiral duration of BNS systems. A $1.4 + 1.4\,M_\odot$ BNS spends $\sim$15 minutes above 20 Hz before coalescence. By monitoring the accumulating matched-filter SNR against a partial template truncated 10–60 seconds before merger, a pipeline can issue an alert *before* the stars collide — giving telescopes time to slew before the kilonova onset. During O4, PyCBCLive issued pre-merger alerts with a median lead time of $\approx$ 3 seconds; for brighter events, the lead time extends to tens of seconds. The tradeoff is a smaller accumulated SNR, higher FAR at a fixed threshold, and coarser sky localisation. But for a nearby BNS within $\sim$200 Mpc, the science return — catching the earliest kilonova emission or the prompt gamma-ray burst for an on-axis event — justifies both the operational complexity and the follow-up bandwidth.

9. A Problem of Plenty: The Next-Generation Challenge

LVK detected 90 events through O3; O4 alone nearly tripled the catalogue. O5 (planned 2028–2031) will detect thousands more per year. The third-generation detectors in development — the *Einstein Telescope* (ET) [33], a triangular underground 10 km facility, and *Cosmic Explorer* (CE) [34], a 40 km L-shaped detector — will be an order of magnitude more sensitive, extending the BNS merger horizon to $z \gtrsim 5$ and yielding $\mathcal{O}(10^4$–$10^5)$ CBC detections per year.

This is not just a quantitative increase — it is a qualitative change in the data analysis challenge. At any given moment in an ET or CE data stream, there will be not one but *tens to hundreds* of overlapping CBC signals simultaneously in band: long BNS inspirals lasting hours, BBH mergers, NSBH events, all superimposed on each other. This is the *signal confusion regime* [35], and it breaks the assumptions underlying every method described above.

The first casualty is time-slide background estimation. Time slides work because true signal coincidences are rare: shifting a stream by a few seconds destroys real events. In ET/CE data, a time-shifted stream will contain independent real signals from other sources, polluting the background with signal–signal coincidences and systematically underestimating the FAR [35]. There is no signal-free baseline to work from.

Second, recovering weak, high-redshift BNS mergers from beneath the foreground will become exceedingly difficult. The unresolved superposition of all distant mergers forms a stochastic GW background acting as an effective noise floor. Extracting a BNS at $z \sim 3$–5 from this foreground requires iterative *global subtraction*: removing the loudest events, re-estimating the noise, searching again. Convergence is not guaranteed, and waveform-modelling errors in subtracted signals propagate into the noise estimate for subsequent searches.

Third, the χ^2 and related vetoes will

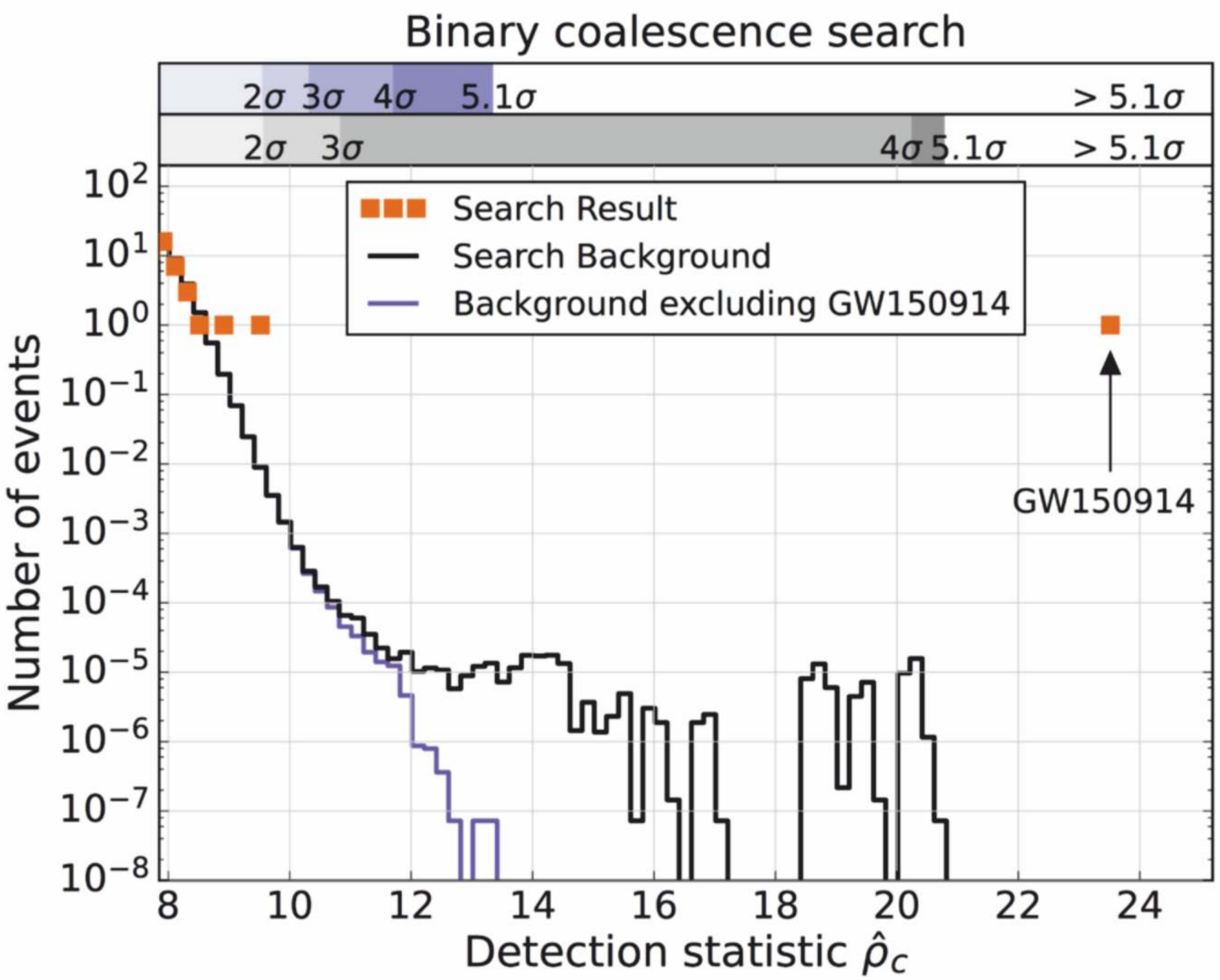


Figure 3. Background from time slides and foreground events. Black and violet histograms: noise trigger rate vs. reweighted network SNR $\hat{\rho}_{\rm net}$ from $\sim 10^4$ yr equivalent background. An exponential tail is expected for coincident Poisson noise. The tail in the black-line background of the binary coalescence search is due to random coincidences of GW150914 in one detector with noise in the other detector. (This type of event is practically absent in the generic transient search background because they do not pass the time-frequency consistency requirements used in that search.) The purple curve is the background, excluding those coincidences, which is used to assess the significance of the second strongest event.

produce unreliable rankings when data contains multiple overlapping signals. The χ^2 sub-band contributions for a target template will be contaminated by the overlapping waveform of another binary with a different chirp evolution, causing the veto to downrank true foreground events. New veto architectures are needed: multi-signal χ^2 statistics that jointly fit several templates, or deep neural-network classifiers [**?**] trained to assess signal consistency in a crowded foreground. In a very real sense, the data analysis challenge inverts entirely: today we search for *signals in noise*; with ET and CE we will be searching for *noise in signals*.

Fig. 4 illustrates this concretely. A simulated hour-long segment of CE data containing many overlapping mergers. This shows that the time-frequency plane is never truly empty, and the matched-filter SNR for a single target template sits on a continuously elevated floor between coalescences — making both background estimation and veto assignment fundamentally harder than today.

Conclusion

The search for compact binary coalescences rests on a logical chain: the matched filter, derived from the likelihood as the optimal MLE in Gaussian noise; the Fisher metric, which dictates template bank density; the χ^2 and related vetoes, which exploit the detailed morphology of CBC signals to reject glitches; multi-detector coincidence tests, which leverage antenna-pattern geometry; time slides, which empirically characterise the non-Gaussian noise background; and $p_{\rm astro}$, which folds in population knowledge for a Bayesian classification of each event.

Together, these tools delivered 218 confident detections through GWTC-4.0, including the most massive BBH merger observed, the loudest GW signal on record, and the first detection of a mass-gap object merging with a neutron star. The fourth-generation detectors — ET and CE — will probe the universe to depths unimaginable today, but will simultaneously stress-test every assumption in the current search toolbox. Developing the analysis methods for the signal-confusion regime is one of the most important open problems in gravitational-wave data analysis today, and the foundation for tackling it is the machinery described in this article.

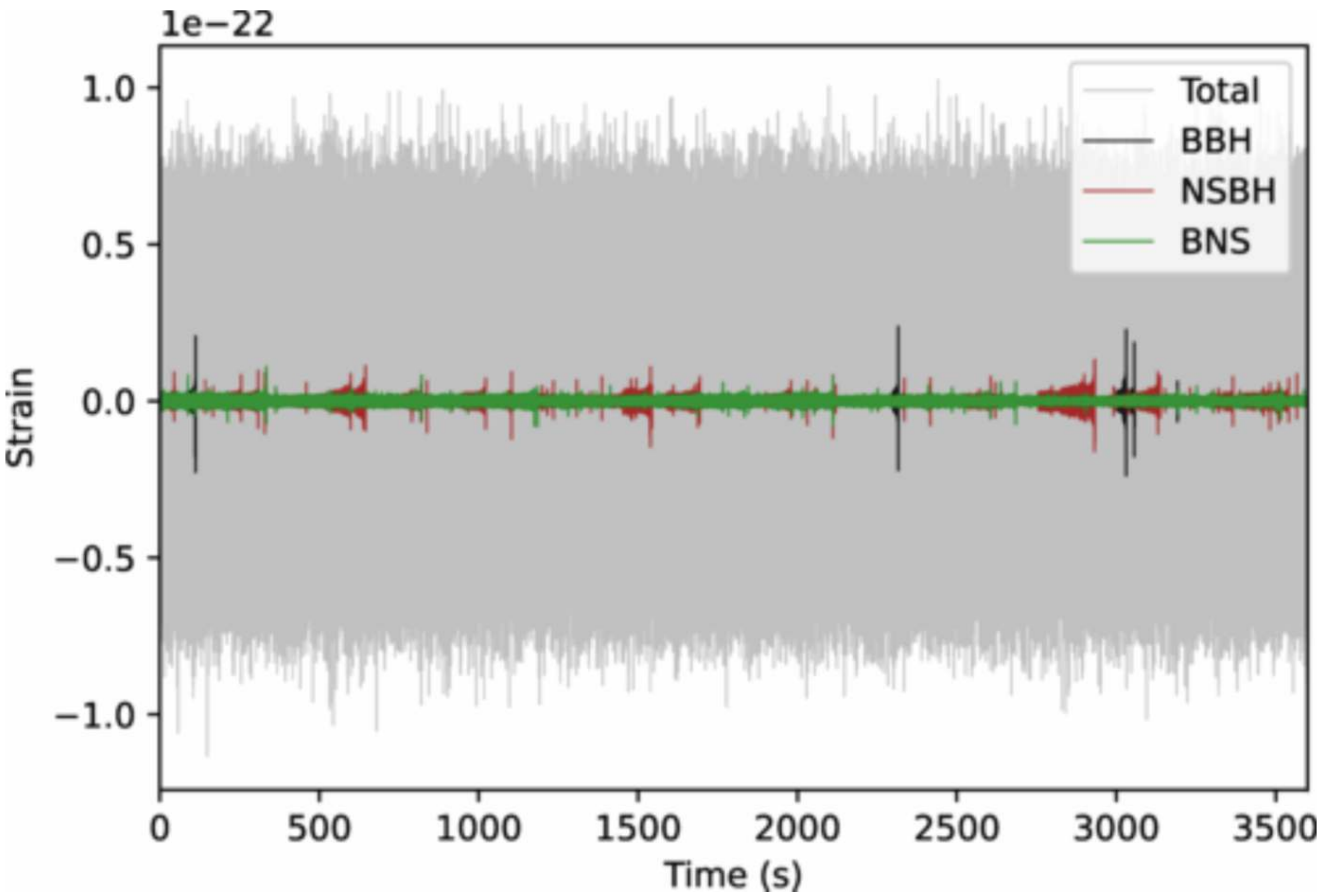


Figure 4. Signal confusion in the Einstein Telescope/ Cosmic Explorer era. An hour of simulated data for CE/ET data. The gray line represents the sum of all GW signals and detector noise. The black, brown, and green lines represent the injected BBH, NSBH, and BNS signals, respectively. [36].

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Can gravitational wave astronomy identify the existence of wormhole?

The hypothetical astrophysical entity namely wormhole (WH), a consequence of Einstein general relativity is speculated to be the short cut passage in space travel [1]. The criteria of traversability of the wormhole requires exotic matter (i.e. matter violating null energy condition) in the vicinity of the throat [2]. The first theoretical prediction of wormhole was due to Flamn [1], immediately after the formulation of general relativity. Subsequently, Einstein and Rosen [3] gave a bridge like solution which is usually known as Einstein-Rosen bridge. However, the idea of traversable wormhole (TWH) due to morris and Throne [2] is widely used in the literature due to its simplicity, transparent nature [4, 5] and gravitationally stable from perturbative point of view. As a result, it is possible to have an imprint of time-like or null test particles passing through traversable wormhole in finite time and these responses can be deleted as wave scattering and quasinormal ringing.

In analogy to black holes (BH), wormholes behave similarly for the light deflection in strong and weak deflection limit [6]. So in context of black hole/wormhole, a photon trajectory may be scattered to infinity or may fall into it (may pass through the throat) or be critical photon orbits separating the other two sets and named as unstable photon orbits which appear to a distant observer as shadow [7]. In black hole context such shadows of *M 87*$_*$ and *SgrA** have been detected by Event horizon Telescope (EHT) [8]. Hence astrophysicists are very optimistic about observational evidences for other compact objects (including wormhole). Thus indirect evidences through gravitational lensing, unique signatures in quasinormal models (QNMS) and anomalous energy distributions inconsistent with black hole models, it is possible to have detection of wormholes.

The detection of gravitational waves (GW) by LIGO and VIRGO collaborators [9, 10] 100 years after its predictions by Einstein, is due to collision of black holes. The final stage of the ringdown phase is characterized by the QNMS [11] which are also possible for wormholes. Thus detection of gravitational waves not only prove the existence of black holes but also may indicate a distinction between a black hole and a wormhole (or a compact object) [11]. In fact the real part of the quasi normal models (QNMs) are related to the angular velocity of the last circular null geodesics and hence there is a correspondence between the QNMs and the strong lensing limit. Further, the gravitational wave astronomy is related to the shadow of compact objects as shadow radius is determined by the real part of QNMs for static or rotating compact object. Mathematically, gravitational waves from a compact object behaves to a distant observer as massless scalar field propagating along the last unstable null orbit and gradually approaching to spatial infinity.

A general spherically symmetric static wormhole space-time of Morris Thorne traversable form has the line element

$$dS^2 = -e^{2\Phi(r)}dt^2 + \frac{1}{1-\frac{b(r)}{r}}dr^2 + r^2 d\Omega^2 \qquad (1)$$

with r ∈ [r_0, ∞], b(r) the shape function and Φ(r), the red shift function. The restrictions on b(r) are the following:

(I) b(r) < r for r > r_0 (metric condition) and b(r_0) = r_0 (the throat condition)

(ii) b(r) − rb′(r) > 0 ∀ r ∈ [r_0, ∞] (flairing out condition/ traversability condition)

(iii) $\frac{b}{r}$ → 0 as r → ∞ (asymptotic flatness)

For convenience, let us suppose that two distant space-time regions are connected by a traversable wormhole. Suppose one of the distant regions is illuminated by a light source while there is no such light source near the throat of the other region. Then the photon trajectories in the first region are divided into two clasess: [12, 13]

(i) Photon trajectories go to the other side through the throat.

(ii) Photon trajectories scatter away from the wormhole to infinity.

Thus a distant observer in the first region will visualize only the scattered photons and the trans-mitted ones appear to him as black spot and is termed as shadow of the wormhole. For the scattered photons the trajectories must have a turning point which is mathematically characterized by $\frac{dr}{d\lambda}$ = 0 i.e. V_{eff} = 0. Moreover, the critical orbit between the scattered one and the plunged orbits, corre-sponds to maximum of the effective potential. Thus the critical orbit should be spherical in nature and is determined by the restrictions

$$V_{\text{eff}} = 0 = \frac{dV_{\text{eff}}}{dr} \text{ and } \frac{d^2V_{\text{eff}}}{dr^2} \leq 0.$$

Thus in wormhole geometry, the radius (r_{ph}) of the photon sphere located at the apparent image of the photon rings is characterized by [13, 14]

$$r\Phi'(r) = 1 \;\; \text{i.e.} \;\; e^{\Phi(r)} = \Phi_0 r \qquad (2)$$

So if (r_{ph} denotes the largest root of the above equation then the shadow radius r_{sh} is determined as

$$r_{sh} = re^{-\Phi(r)}|_{r=r_{ph}}. \qquad (3)$$

Now due to distant Observer the above shadow radius can be determined in the observer's frame as [13]

$$r_{sh} = r_{ph}e^{-\Phi(r_{ph})} = \sqrt{X^2+Y^2} \qquad (4)$$

where (X, Y) in observer's frame are identified as the Celestial co-ordinates. On the otherhand if (r_0, ϑ_0) identifies the observer with respect to the wormhole then the apparent shape of the shadow i.e. the boundary curve of the wormhole shadow is characterized by [13, 14]

$$X = \lim_{r_0\to\infty} \left(-r_0^2 \sin\theta_0\right) \frac{d\phi}{ds}$$
$$Y = \lim_{r_0\to\infty} \left(r_0^2 \frac{d\theta}{dr}\right).$$

Using (4) one obtains the Celestial co-ordinates as

$$X = -\frac{\mu}{\sin\theta_0} \quad , \quad Y = \sqrt{\nu - \frac{\mu^2}{\sin^2\theta_0}}$$

where μ and ν are called impact parameters [13, 14] and the asymptotic limit of the red-shift function0i.e. $\lim_{r\to\infty} e^{-2\Phi(r0)}$ = constant has been taking into account. Thus shadow diagram is nothing but2the plot of Y against X (with $\vartheta_0 = \frac{\pi}{2}$ i.e. equatorial plane for convenience).

Moreover, in the context of wave dynamics in curved space-time the idea of quasi normal mod-els (QNMs) and grey body factors (GBFs) are very important as they describe the behaviour of gravitational waves near a compact astrophysical object [15, 16]. The response of the space-time to perturbations and its observational characteristics are identified by the study of QNMs and GBFs. Specifically, QNMs are the characteristic oscillations of a compact object due to perturbataion while GBFs detect how incoming radiation from a compact object is partially transmitted and partially reflected due to curvature of space-time near the compact object. GBFs are highly stable in the distorted region near the compact object while the overtones of QNMs are highly sensitive to such deformations. As the boundary conditions are identical for compact objects like black hole/wormhole so the correspondence between QNMs and GBFs are obtained using WKB method. However, there is a basic difference in the asymptotic limit of the tortoise co-ordinates (r_T T):

BH: −∞ < r_T < +∞ : event horizon to one side of the asymptotic region in a black hole.

WH: −∞ < r_T < +∞ : between the two asymptotically flat space-time regions of a wormhole.

The QNMs represent the damped oscillations of the space-time and are uniquely characterized by the geometry of the wormhole and boundary conditions. The GBFs on the otherhand, measure the transmission probability of waves propagating through the wormhole's effective potential barrier. Thus QNMs and GBFs may be possible mechanism to distinguish wormholes from black holes in the context of gravitational wave astronomy and related observational studies.

The perturbation of the wormhole geometry (given by (1)) may be considered either by small deviations in the above background space-time geometry or equivalently by considering the evolution of test fields in the underlying geometry. So the Schro¨dinger like wave equation for the perturbation field takes the form

$$\left[\frac{d^2}{dr_T^2}+\omega^2-V(r_T)\right]\Psi(r_T)=0 \tag{7}$$

where the effective potential V is given by

$$V(r)=\begin{cases} e^{2\Phi}\left[\frac{l(l+1)}{r^2}-\frac{(rb'-b)}{2r^3}+\frac{\Phi'(r)}{r}(1-\frac{b}{r})\right], & \text{for massless scalar field} \\ e^{2\Phi}\frac{l(l+1)}{r^2}\ , & \text{for electromagnetic field,} \end{cases} \tag{8}$$

the tortoise co-ordinate has the expression

$$r_T(r)=\int\frac{dr}{e^{\Phi}\sqrt{1-\frac{b(r)}{r}}} \tag{9}$$

rand ω represents the oscillation frequency. In the present context the angular momentum quantum no. 'l' represents the multipole number.

The QNMs [Re[ω] + iIm[ω_k]] give information about the evolution of the perturbed field with purely outgoing boundary conditions at infinity i.e. $\Psi[r_T] \simeq \Psi_0 e^{i\omega r_T}$, as $r_T \to \pm\infty$. More specifically, Re[ω] indicates the oscillation of the signal while the imaginary part (i.e. Im[ω]) measures the damping factor for the energy loss of gravitational radiation. For the above boundary condition one has

$$\left.\begin{array}{l} \mathrm{Im}(\omega)<0, \\ \quad \text{unstable perturbation} \\ \quad \text{with exponential growth} \\ \mathrm{Im}(\omega)>0, \\ \quad \text{stability of the} \\ \quad \text{perturbative field} \end{array}\right\} \begin{array}{l}\text{for} \\ \Psi(r_T)\simeq\Psi_0 e^{i\omega r_T} \\ \text{as } r_T\to\pm\infty\end{array}$$

and

$$\left.\begin{array}{l} \mathrm{Im}(\omega)>0\ ; \text{unstable perturbation} \\ \mathrm{Im}(\omega)<0\ ; \text{stable perturbation} \end{array}\right\} \begin{array}{l}\text{for} \\ \Psi(r_T)\simeq\Psi_0 e^{-i\omega r_T} \\ \text{as } r_T\to\pm\infty.\end{array}$$

Using the standard WKB technique the QNM frequency ω near the throat of the wormhole takes the form

$$\omega=\frac{e^{\Phi(r_0)}}{r_0}\left(l+\frac{1}{2}\right)-i\left(n+\frac{1}{2}\right)\frac{e^{\Phi(r_0)}}{\sqrt{2}r_0}+\mathcal{O}\left(l^{-1}\right) \tag{10}$$

The definition of shadow radius shows that the real 'ω' can be written as

$$Re(\omega)=\frac{1}{r_{sh}}(l+\frac{1}{2} \tag{11}$$

Note that (i) the above result is exact in the eikonal limit (i.e. large l) and it is very close for small values of l and (ii) due to identical real 'ω' in the eikonal limit for both scalar field and electromagnetic field, the interrelation between shadow radius and the real part of the QNMs will be identical for propagation of scalar field/ electromagnetic field. Further, the shape of wormhole can be associated with the imaginary part of QNMs as

$$\mathrm{Im}(\omega)=\frac{\sqrt{\frac{(b_1-1)}{(b_0\Phi_1-1)}}}{\sqrt{2}r_{sh}} \tag{12}$$

where due to smoothness of b(r) and Φ(r) in the vicinity of the throat one has the Taylor series expression for b(r) and Φ(r) as

$$\begin{aligned} b(r) &= b_0+b_1(r-r_0)+b_2(r-r_0)^2+... \\ \Phi(r) &= \Phi_0+\Phi_1(r-r_0)+\Phi_2(r-r_0)^2+... \end{aligned} \tag{13}$$

Note that Im[ω] which characterizes the damping on decay of wave amplitude depends reciprocally with the shadow radius.

In context of GBFs one has to take into account of the wave scattering process in the vicinity of the wormhole. Due to interaction of waves with potential barrier surrounding the wormhole, waves are partially reflected off the barrier and partially transmitted through it and GBFs take care of both these events, no matter whether the wave originates in the asymptotic region of the other Universe or it arrives from spatial infinity. So the modified boundary condition for GBFs are as follows

$$\Psi=\begin{cases} e^{-i\Omega r_T}+Re^{i\Omega r_T}\ , & r_T\to+\infty \\ Te^{-i\Omega r_T}\ , & r_T\to-\infty \end{cases} \tag{14}$$

where *R* and *T* are respectively reflection and transmission coefficients and the frequency Ω is real and continuous for scattering phenomena. The transmission coefficient (*T*) is usually termed as the grey body factor due to its measurement of the fraction of the wave traverses the potential barrier and hence it measures the emission of radiation from the wormhole. So the GBF for the angular momentum no. 'l' can be written as (using WKB approximation)

$$\Gamma_l(\Omega)=|T|^2=1-|R|^2=\frac{1}{1+e^{2\pi ik}} \tag{15}$$

Now due to eikonal approximation from the first order WKB expansion one gets

$$\Omega=l\sqrt{V_{00}}-ik\sqrt{\frac{-V''_{00}}{2V_{00}}}+\mathcal{O}(l^{-1}) \tag{16}$$

where the effective potential has been expanded in powers of 'l' as

$$V(r_T)=l^2V_0(r_T)+lV_1(r_T)+l^{-1}V_2(r_T)+...$$

and V_{00} is the value of V_0 at its maximum and Vóó is the second derivative of $V_0(rT)$. Thus k can be V ″−1 expressed as a function of the real frequency Ω as

$$-ik=\frac{\Omega^2-l^2V_{00}}{l\sqrt{-2V_{00}}}+\mathcal{O}(l^{-1})=\frac{-(\Omega^2-Re^2(\omega_0))}{4Re(\omega_0)Im(\omega_0)}+\mathcal{O}(l^{-1}). \tag{17}$$

Hence the GBF is related to the fundamental mode ω_0 by the relation

$$\Gamma_l(\Omega) = |T|^2 = \left(1 + e^{2\pi\frac{\Omega^2 - Re^2(\omega_0)}{4Re(\omega_0)Im(\omega_0)}}\right), \qquad [18]$$

which is exact in the eikonal limit $l \to \pm\infty$ and is an approximate one for small 'l'.

The use of the Taylor series expansions [13] one gets

$$V_{00} = e^{2\Phi}\left[\frac{4l(l+1)}{2r_0^4}\{2r_0^2(\Phi_1^2+\Phi_2)-1\}+\frac{b_2}{r_0^3}(1-2\Phi_1 r_0)-\frac{3b_2}{r_0^2}\right]. \qquad [19]$$

Choosing the restrictions (for simplicity)

$$\Phi_2 + \Phi_1^2 = \frac{1}{2r_0^2} \quad \text{and} \quad \frac{3b_2}{r_0^2} - \frac{b_2}{r_0^3} = 0 \qquad [20]$$

one obtains

$$V_0'' = -l(l+1)b_2^2\left(\frac{e^{\Phi_0}}{r_0}\right)^2.$$

Hence

$$\Gamma_l(\Omega) = 1 + e^{\Lambda} \quad \text{with} \quad \Lambda = \frac{\pi}{\sqrt{2}}\left[\frac{\Omega^2 - \frac{l^3(l+1)}{r_{sh}^2}}{\frac{b_2}{r_{sh}}\sqrt{l^3(l+1)}}\right]. \qquad [21]$$

The above expression for GBF shows that as the clamping increases (i.e. the radius of the shadow decreases) one has $\Omega^2 < \frac{l^2(l+1)}{r_{sh}^2}$ so that $\Lambda < 0$ and hence as $\Lambda \to -\infty$, $\Gamma_l \to 1$ i.e. lesser is the radius of the shadow, more is the effect of damping and GBF tends to be unity.

The above analysis shows that QNMs and GBFs depend on prolongation of perturbations along geodesics near the wormhole space-time and wormhole can mimic black hole shadows but have distinct QNMs due to absence of an horizon. Therefore, one may conclude that the study of QNMs and GBFs in gravitational wave astronomy are promising candidates to identify traversable wormhole observationally.

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ASASSN-24fw: A rare stellar dimming event

I saw the alert for the event ASASSN-24fw on 16th September 2024 (ATel No. 16833), issued by the All-Sky Automated Survey for SuperNovae (ASAS-SN). This is a survey with a dedicated network of telescopes in Hawaii, Chile, South Africa, the USA, and China managed by the Ohio State University. The star, located in the Monoceros constellation, was stable around V~12.8 mag, then suddenly underwent a steep brightness decrease up to ~16.8 mag. I continued monitoring the light curve of this event every day for the next several months. I, Prof. Eswar Reddy (then Dean, IIA), Prof. Ramaprakash (Dean, IUCAA), and Prof. Ashish Mahabal (Professor, Caltech) were already working on detecting specific stellar dimming events, and we expected the light curve that we saw in the initial months for ASASSN24fw. However, as we delved deeper, we found that the star lies on the main-sequence, actually, and has an F-type spectral type. We also verified this candidature using astroseismology from the TESS data. Astroseismology, or the science of measuring stellar quakes, is a powerful tool to separate different classes of stars.

After modeling the SED using Kurucz stellar atmospheric models, we found an infrared excess of 10-11% in the WISE bands, which is very unusual for a main-sequence star. So the next important question we had is: Is this a Young Stellar Object (YSO) with massive protoplanetary material around it? Or it is an older star, evolved off the main sequence, with a debris disc. The third question we asked was whether the dimming and the infrared excess are related. In the process of answering these questions, we made an important discovery. For example, the location of the star at 1kpc, close to the Monoceros star-forming region in the sky, hints that it is likely to be an associated YSO. However, thanks to the astrometry and proper motion information from Gaia DR3, we found out that they are not associated, and the star lies in the thick disc, indicating an older star. Therefore, it is likely that the infrared excess is caused by a debris disc rather than a proto-planetary disc.

There are various reasons for a star to dim, e.g., intrinsic factors such as pulsation, chromospheric activity, and stellar spots may cause regular or irregular dimming episodes. Thanks to surveys like Kepler and TESS, with high-cadence observations, these intrinsic factors that cause a star to dim are well documented and actively studied. However, external factors such as planetary transits, exocomets, debris discs, and random occulters along the line of sight may cause regular or irregular dimming episodes. While thousands of instances of planetary transits (on a scale of a few days) have been discovered, the long-duration dimming phenomena are rarely observed or studied, even though they provide direct insight into theories of planetary formation, evolution, and destruction.

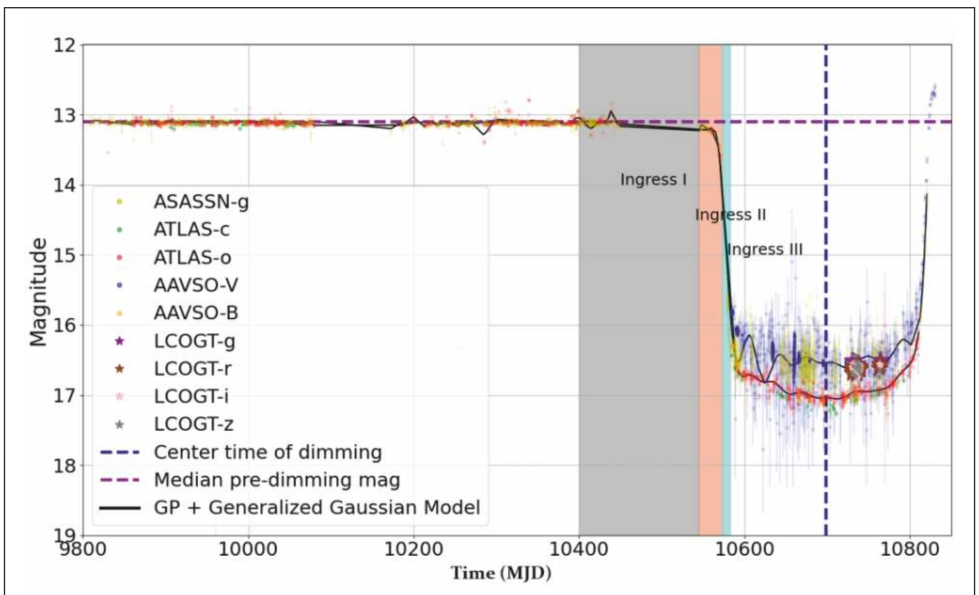


Figure 1: The lightcurve of ASASSN24fw showing various stages of dimming. The central dotted line corresponds to the mid-point of the dimming, while the horizontal line is the median brightness of the star before dimming.

A couple of months after the alert was issued, Astronomer's Telegram posted by Nair & Denishenko (ATel No. 16919) stated that this dimming occurred twice in the past 2 years, in 1981 and 1937, i.e., it has an orbital period of ~43 years. So we started our follow-up observations to extract as much information as possible about the dimming using the Keck II and Palomar Telescopes. We recorded a low-resolution optical spectrum on 29th October 2024, a low-resolution NIR spectrum on 21st December 2024, and another high-resolution optical spectrum on 25th January 2025. Meanwhile, I came in contact with a researcher from ASIAA, Taiwan, who is an expert in debris discs around stars - Dr. Jonathan Marshall, and we immediately wrote a DDT proposal to LCOGT to study the change in reddening vector during dimming. LCOGT observed this event from February to May 2025. Using multi-wavelength photometric data, it is possible to calculate the specific reddening vector towards a local target and, hence, the possible compositions of the materials responsible for causing it. Towards the end of May 2025, the brightness of the star began to return to normal, and the light curve was nearly symmetric, U-shaped. If we consider a single body causing a transit, there is no such massive dark body known to us (although we know black holes; no way a star would be so stable around one). Hence, my first conclusion was that it should be a planet with a massive ringed system. Although we had straightforward evidence of a 43-year periodicity, translating to an orbital separation range of 14-17 au, another piece of evidence was the lack of accretion activity (H-alpha emission line) in the optical spectra. This meant that the circumstellar material generating the infrared excess was not accreting onto the star, providing another evidence that the circumstellar material and the occulter are unrelated.

When we modeled the light curve from a ringed planet's perspective (Figure 1), we found that our model not only fits the light curve but also yields physical parameters that are realistic and consistent with expectations. Moreover, our models also state that the dimming was not a single event but occurred in three stages. It started around March 2024, when the outermost layers of the rings came into view. During this time, the gradual dimming was not evident, so alert systems would notify. However, the second stage of the dimming, which started in the last week of August 2024, was short and followed immediately by the third stage, which caused a noticeable change in the star's brightness. The benefits of lightcurve modeling are that it gives direct evidence of what could be happening near any star. A rendering of the possible situation mid-way during dimming is shown in Figure 2, and the evidence-based imagination of the circumstellar environment is shown in Figure 3 when the dimming is over.

Now we are left with an interesting puzzle. Our models suggest that the minimum mass of the planet should be >3.4 MJup. This is the mass range of super-Jupiters and some low-mass brown-dwarfs. A brown-dwarf holding a massive ring system is more plausible than a gas-giant like super-Jupiter, naturally, due to similar size and more mass. Also, our knowledge of such massive ring systems is limited, as we have found only a handful. This makes ASASSN-24fw very interesting for follow-up studies. We have already conducted a set of post-dimming follow-up observations: optical and NIR spectral observations using the 6.5m Magellan Telescope and the 3.6m Devasthal Optical Telescope, multi-band photometric observations using the 1.3m Devasthal Fast Optical Telescope, and multi-band polarimetric observations using the 1.04m Sampurnand Telescope. In the next phase of the study, we are investigating the properties of the star and its circumstellar environment. This will shed light on the theoretical aspect of planetary evolution around main-sequence Sun-like stars

Figure 2: Rendering of the possible situation during the dimming. The central planet is assumed to be point-like in comparison to the massive rings, and the darkness of the ring is proportional to the density of the material in that layer of the ring. The red-dwarf companion is also shown in the vicinity.

Figure 3: The F-type Sun-like star surrounded by the circumstellar material (most likely a debris-disc), causing an infrared excess. This is an imagination rendered into an image that reflects a post-dimming situation.

Dr Sarang Shah completed his Ph.D. in 2020 from the University of Canterbury, New Zealand, where he worked on detecting exoplanets using the technique of gravitational microlensing. During this period, he developed a strong interest in writing and debugging Python codes for big data and high-performance computing.

He later applied this skill set during his first postdoctoral position at the Indian Institute of Astrophysics, Bengaluru, where he developed a methodology and a Python-based public package to generate a partial infrared guide-star catalog for adaptive optics observations with the Thirty Meter Telescope.

Subsequently, he worked at the Nicolaus Copernicus Astronomical Center in Warsaw, utilizing big data to identify potential binary Cepheids. This work has since evolved into a larger, multi-year radial velocity study of Cepheids using 8m-class telescopes.

He joined IUCAA in December 2025 as a postdoctoral researcher and is currently working with Prof. Anupam Bharadwaj in the field of variable stars, contributing to the Rubin LSST project as an in-kind effort, in addition to working on ASASSN-24fw.

Events at IUCAA

Theoretical Aspects of Relativistic Jets (THOR) Workshop

The Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, organized a five-day advanced workshop on "*Theoretical Aspects of Relativistic Jets (THOR)*" from *January 5–9, 2026*. The workshop was coordinated by *Vaidehi S. Paliya* (IUCAA) and was aimed at Ph.D. students, postdoctoral fellows, and faculty members working in the area of relativistic jets. The primary objective of the workshop was to provide Indian researchers with exposure to the theory of active galactic nuclei (AGN) jets, along with hands-on experience in numerical simulations of relativistic jet emission. A total of 50 participants, including 16 female participants, from across the country attended the workshop.

The workshop featured lectures by eminent speakers, including Markus Böttcher (North-West University, South Africa), Banibrata Mukhopadhyay (Indian Institute of Science, Bengaluru), Bhargav Vaidya (Indian Institute of Technology, Indore), Dipanjan Mukherjee (IUCAA), and Sunder Sahayanathan (Bhabha Atomic Research Centre, Mumbai). The morning sessions were devoted to lectures covering various aspects of jet physics. These included radiative processes such as Doppler boosting, leptonic synchrotron emission, and inverse Compton scattering in both Thomson and Klein–Nishina regimes; particle acceleration mechanisms, hadronic processes, high-energy polarization, and neutrino production; accretion disk physics including Keplerian (soft state) and advective (hard state) disks, spectral properties, efficiency, and the role of magnetic fields in driving outflows and jets; jet launching, dynamics, composition, and interaction with the ambient medium along with their observational signatures; and high-energy emission processes from kiloparsec-scale AGN knots, including SSC and IC-CMB models, constraints from Fermi upper limits, and the two-population hypothesis.

The afternoon sessions were dedicated to hands-on training, focusing on the development of a one-zone leptonic radiative model. Participants worked on numerical solutions for synchrotron, synchrotron self-Compton, and external Compton emissivity functions involving anisotropic photon fields, and applied these models to observed broadband spectral energy distributions. They also derived approximate analytical solutions and compared them with detailed numerical results, thereby gaining deeper insights into the modeling of relativistic jet emission.

The workshop concluded with a vote of thanks and participant feedback, which highlighted the usefulness and relevance of the program. The coordinator, Vaidehi S. Paliya (IUCAA), expressed gratitude to the IUCAA Director for providing the necessary support and resources, acknowledged the IUCAA staff for their excellent organizational assistance, appreciated the speakers for their detailed and lucid presentations on complex theoretical concepts, and thanked all participants for their enthusiastic participation throughout the workshop.

4th IAGRG School on Gravitation and Cosmology

The 4th annual school was organized by the *Indian Association for General Relativity and Gravitation (IAGRG)* during *January 12–23, 2026*. This two-week programme offered advanced pedagogical lectures and discussions for young researchers in gravitation and cosmology. The school was coordinated by *Shasvath Kapadia* (IUCAA), with *Susmita Adhikari* (IISER Pune), *Sumanta Chakraborty* (IACS Kolkata), *Sudipta Das* (Visva-Bharati, Santiniketan), *Rajeev Kumar Jain* (IISc Bengaluru), and *Sudipta Sarkar* (IIT Gandhinagar) serving as co-organizers. Approximately 40 students and postdoctoral researchers attended the school.

The programme covered a range of topics, including Primordial Black Holes in the Early Universe by *Juan García-Bellido* (Instituto de Física Teórica, Madrid, Spain); Black Hole Mechanics and Thermodynamics in Effective Field Theories of Gravity by *Nilay Kundu* (Indian Institute of Technology, Kanpur, India); Neutrinos in Structure Formation and Cosmology by *Arka Banerjee* (IISER, Pune, India); and Effective Field Theory Approach and Post-Minkowskian Expansion in General Relativity by *Alok Laddha* (Chennai Mathematical Institute, Chennai, India).

In addition, tutorial sessions were conducted by *Chiranjeeb Singha* (IUCAA), *Nilanjandev Bhaumik* (ICTP-AP, Beijing), and *Shuvayu Roy* (IIT Gandhinagar). The school was very well received and garnered positive feedback from the participants.

Symposium for Communicating Astronomy in India (SCAI) 2026

The *ASI 006 Symposium for Communicating Astronomy in India 2026 (ASI SCAI–26)*, hosted by IUCAA from *January 22-24, 2026*, marked a significant national milestone in strengthening astronomy outreach efforts across India. Conceived as a platform to foster dialogue between researchers and science communicators, the symposium brought together a diverse community at the IUCAA campus. The event was dedicated to the memory of Late Prof. Jayant Vishnu Narlikar, whose visionary leadership at IUCAA established public communication as an integral part of astronomy in India.

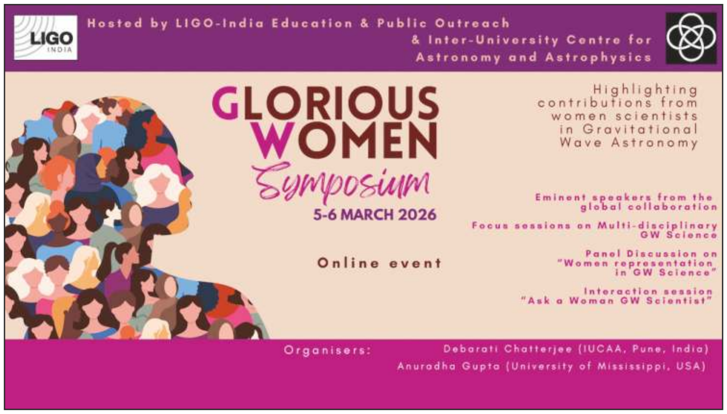
As the host institution, IUCAA played a central organizational role by providing the academic environment, campus facilities, hospitality, and logistical support necessary for the successful conduct of the symposium. *Samir Dhurde and Nishant Singh* served as IUCAA coordinators, with support from the Scientific Organising Committee (SOC) and Local Organising Committee (LOC). The symposium witnessed participation from over 300 attendees, both in person and online, reflecting its inclusive nature. Participants represented research institutions, universities, amateur astronomy groups, independent communicators, planetariums, schools, NGOs, media, and students.

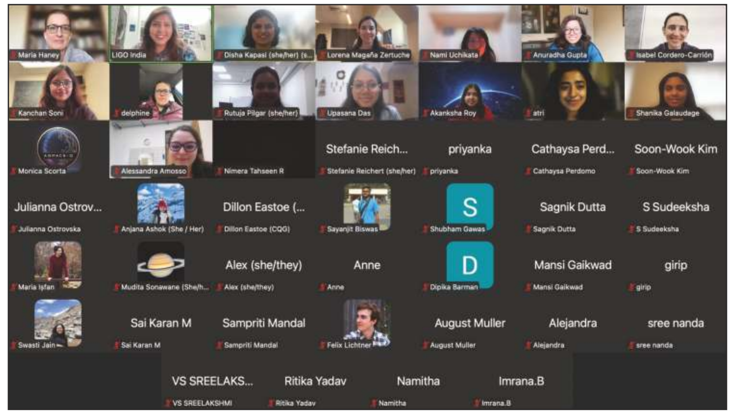
The scientific and outreach programme highlighted the diversity of astronomy communication in India, featuring 8 plenary talks, 49 contributed talks, 51 posters, and 11 demonstrations. A key feature was the memorial session on the science communication legacy of Prof. J. V. Narlikar, accompanied by an exhibition on his work. Additional highlights included sessions on India's astronomy mega-projects, a smart telescope demonstration, a public lecture on a recent scientific discovery, and a theatrical presentation on Galileo by the IUCAA team, showcasing the integration of science with cultural engagement. The symposium concluded with a field visit to the Giant Metrewave Radio Telescope (GMRT) on *January 25, 2026*.

A significant outcome of the symposium was its forward-looking focus on collaboration and sustained outreach. Breakout discussions on curriculum development, regional languages, institutional communication, inclusive content, and dark-sky preservation led to proposals for thematic working groups under the ASI Public Outreach and Education Committee.

Supported by IUCAA, the Astronomical Society of India, the Indian Institute of Astrophysics, the Aryabhatta Research Institute of Observational Sciences, and the National Centre for Radio Astrophysics, the symposium is expected to have a lasting impact by fostering a coordinated national network for astronomy communication and by laying the foundation for a regular biennial forum in India.

Glorious Women Symposium





The first international symposium titled *"Glorious Women"*, dedicated to celebrating women scientists in the field of gravitational wave (GW) astronomy, was held online on *March 5–6, 2026*. The primary objective of the symposium was to highlight accessible, real-world role models and to inspire young women to pursue careers in astronomy and astrophysics. The two-day event brought together women scientists at various stages of their careers to share their expertise in gravitational wave science across multiple collaborations and research domains. The symposium witnessed participation from more than 300 registrants, including international and national invited speakers, faculty members, research scholars, and postdoctoral researchers.

The first day featured a plenary session with leading researchers representing major global collaborations in gravitational wave astronomy, including the LIGO–Virgo–KAGRA collaboration, the LISA Consortium, and the International Pulsar Timing Array. The speakers presented overviews of their respective collaborations, highlighting their scientific goals, contributions of women scientists, and future prospects in the field. The day concluded with a panel discussion on "Women's Representation in GW Science", which addressed issues such as gender balance, challenges faced by women, and opportunities for greater inclusion in the field.

The second day began with a focus session featuring leading women experts who presented overviews of their research areas within the multidisciplinary domain of gravitational wave science. Topics included instrumentation, fundamental physics, multi-messenger astronomy, data analysis and search techniques, as well as theoretical modeling and numerical relativity simulations. An interactive session titled *"Ask a Woman Scientist"* provided participants with an opportunity to engage directly with early-career researchers, seek career guidance, and gain valuable insights. All sessions were conducted via an online platform and were made accessible to registered participants, with recordings subsequently made available on the LIGO-India YouTube channel.

The symposium was organized and coordinated by *Debarati Chatterjee* (IUCAA) in collaboration with *Anuradha Gupta* (University of Mississippi, USA), with support from IUCAA and LIGO-India. The event received an enthusiastic response from both invited speakers and participants, as reflected in the feedback collected following the symposium.

Events outside IUCAA

Workshop on General Relativity, Cosmology and Gravitational Waves at Malda College, West Bengal

A three-day workshop on *General Relativity, Cosmology and Gravitational Waves* was organised by the Department of Physics, Malda College, under the aegis of ICARD, Malda College, from *January 8-10, 2026* at *Malda College, West Bengal*. The programme was sponsored by the IUCAA, Pune. The workshop was coordinated by Shyam Das and Apratim Ganguly (IUCAA) The workshop aimed to provide participants with an overview of both the classical foundations and recent developments in gravitation, cosmology, and gravitational-wave astronomy.

The workshop was inaugurated by *Ashis Bandopadhyay*, Hon'ble Vice-Chancellor of the University of Gour Banga. The inaugural session was dedicated to the memory of Prof. J. V. Narlikar and Prof. N. Dadhich in recognition of their remarkable contributions to gravitation and cosmology. The programme began with the ceremonial lighting of the lamp. In his address, the Vice-Chancellor highlighted the growing importance of astrophysics and encouraged students and young researchers to explore emerging research areas.

The welcome address was delivered by *Manas Kumar Baidya*, Principal of Malda College, who emphasised the importance

of IUCAA-supported programmes in strengthening research activities in regional institutions. *Subrata Sarkar*, Head of the Department of Physics at the University of Gour Banga, spoke about the academic objectives of the workshop, while *Apratim Ganguly* (IUCAA) introduced the structure of the programme. The inaugural session was conducted by *Moumita Das*, Head of the Department of Physics, Malda College, and concluded with a vote of thanks by *Shyam Das*, Coordinator of ICARD, Malda College.

The workshop was attended by thirty-eight participants, including students, research scholars, and early-career faculty members from Malda College and other institutions. The academic programme featured invited lectures covering key topics in general relativity, cosmology, gravitational waves, and related theoretical and observational aspects.

Sumanta Chakraborty (IACS, Kolkata) delivered lectures on the geometric foundations of general relativity, Einstein's field equations, and black hole physics, with special emphasis on gravitational waves from inspiralling compact binaries and their observational signatures. *Tanmoy Paul* (Visva-Bharati University) discussed modern cosmology, including the standard model of the universe, cosmic inflation, reheating, and the role of primordial gravitational waves in probing the early universe. *Apratim Ganguly* (IUCAA) introduced the principles of gravitational-wave detection and data analysis, including hands-on sessions using GWOSC tutorials to familiarise participants with publicly available gravitational-wave data. *Farook Rahaman* (Jadavpur University) delivered lectures on gravitational lensing and the theoretical aspects of wormhole geometries.

In addition to the lectures, selected participants presented short talks on their academic and research work. Interactive discussions and problem-solving sessions enabled participants to engage closely with the speakers and gain deeper insights into the topics discussed.

A cultural programme was organised on the evening of the first day, featuring music and dance performances that highlighted the local cultural traditions of Malda. The programme provided an opportunity for informal interaction among participants and speakers.

The workshop concluded with a valedictory session in which participants shared feedback and discussed possible future research directions and collaborations. Overall, the workshop successfully achieved its objectives by strengthening conceptual understanding and promoting research-oriented learning in the fields of gravitation and cosmology.

Most of the lectures delivered during the workshop were recorded and have been made available on YouTube for the benefit of participants.

Poster Exhibition: "Forces Unleashed" at Fergusson College, Pune

A poster exhibition titled *"Forces Unleashed"* was organised on *January 16 and 17, 2026*, at the Bamboo Garden, Fergusson College, Pune, under the coordination of *Raka Dabhade (ICARD)* along with undergraduate students.

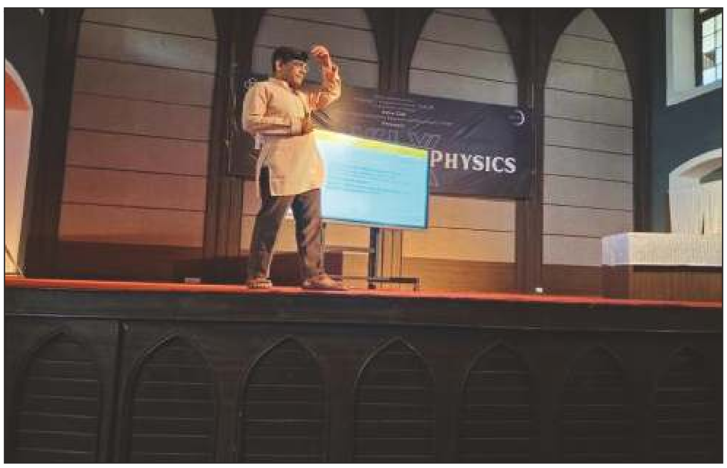
The exhibition was structured around ten sub-themes under the central theme "Forces Unleashed," namely: Forces; Electromagnetic Forces; Applications and Instrumentation of Electromagnetism; Standard Model and Beyond; Weak Nuclear Force; Strong Nuclear Force; Applications and Instrumentation of Weak and Strong Nuclear Forces; Newtonian Gravity; Einsteinian Gravity; and Unification of Forces.

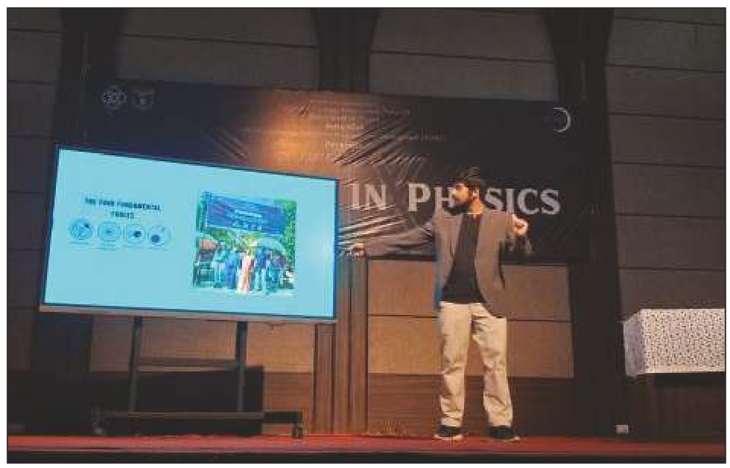
Each sub-theme involved approximately five undergraduate students who prepared

posters and models related to their respective topics. The exhibits were explained primarily by first-year B.Sc. students, who engaged in detailed study of the subjects and held discussions with their senior peers to develop a clear understanding.

In total, 52 students actively participated in the exhibition. The event attracted over 650 visitors from within and outside the college, making it a highly engaging and educational experience for both participants and attendees.

Frontiers in Physics XIX: National Students' Seminar at Fergusson College, Pune





The nineteenth edition of *Frontiers in Physics*, a national students' seminar, was held *on February 20 and 21, 2026*, at the Amphitheatre, Fergusson College, Pune. The event was coordinated by *Raka Dabhade* (ICARD) in collaboration with undergraduate students.

The seminar witnessed enthusiastic participation, with a total of 161 registered participants and 27 non-registered attendees from 11 different institutions. The programme featured a series of invited lectures by distinguished speakers from leading research institutions, along with student poster presentations.

The inaugural lecture was delivered by Yogesh Wadadekar (NCRA), titled "Alaknanda – the Spiral Galaxy that Shouldn't Exist." This was followed by a lecture by Anuradha Misra (Emeritus Professor, CEBS Mumbai) on "Inside the Heart of Matter – From Quarks and Gluons to Quantum Chromodynamics."

A poster presentation session showcasing student projects was also organised. The session was evaluated by Vrushali Limaye (Department of Mathematics, Fergusson College) and Aniruddha Pranjapaye (S.P. College, Pune).

Shekhar Mande (President, INSA) was scheduled to deliver a talk on "Recent Developments in AI"; however, due to health reasons, he was unable to present. The session was subsequently continued by Raghav Verma (Former Professor, IIT Bombay), who spoke about his project on river cleaning.

Other invited talks included Bhas Bapat (IISER Pune, Alumnus) on "The Aditya L1 Solar Observatory," Priyanka Chaturvedi (Alumnus, TIFR Mumbai) on "Hide and Seek of the Distant Worlds," Swarnim Shirke (Alumnus, IUCAA Pune) on "Exotic States of Matter in Neutron Stars," and Mukul Maske and Pritesh Ranadive (HBCSE Mumbai), who jointly presented "Bridging Research and Classroom Science Education in Practice."

Overall, the seminar provided an engaging platform for students to interact with experts, present their work, and gain exposure to current developments in physics, thereby fostering academic exchange and scientific curiosity.

School on Stellar and Solar Astronomy at Chungathara, Nilambur, Kerala

The Department of Physics, Mar Thoma College, *Chungathara*, in collaboration with the Inter-University Centre for Astronomy and Astrophysics, organized a *five-day School on* Stellar and Solar Astronomy: *A Skill-Building Programme for Undergraduate Learners in Space-based Data Analysis* from *January 12 to 16, 2026*. The programme was attended by 30 undergraduate students enrolled in four-year degree courses from various parts of Kerala.

The lecture sessions were delivered by Anupam Bhardwaj (IUCAA), Joe Jacob, and Sreejith P. The project sessions were conducted by Shubh Mittal and Prashant Nishad, along with Adithya H. N., Munjiba M. M., and Harshvardhan Hegde.

The primary objective of the school was to provide undergraduate students with a strong foundation in both theoretical concepts and practical skills in astronomical data analysis. The programme covered key topics such as solar astronomy, solar structure, star formation, stellar evolution, and the dynamics of solar and stellar systems. It also included discussions on contemporary research, with special emphasis on space missions such as Aditya-L1 and Gaia.

In addition to the lecture sessions, participants actively engaged in hands-on, project-based activities using real observational data, which enhanced their understanding of modern research methodologies. The school also provided ample opportunities for interaction between the resource persons and participants, fostering meaningful academic discussions.

The programme was coordinated by Anupam Bhardwaj (IUCAA) and Nishant Singh (IUCAA), along with Sheelu Abraham.

Introduction to Astronomical Data Analysis and Machine Learning Applications at Bengaluru

St. Francis de Sales College (Autonomous), Bengaluru, organised a *three-day national-level workshop titled "Introduction to Astronomical Data Analysis and Machine Learning Applications"* from *January 15 to 17, 2026*, with sponsorship from IUCAA, Pune. The workshop aimed to introduce participants to modern observational astronomy, astronomical data analysis, and emerging machine learning techniques used in astrophysical research. It was primarily designed for undergraduate and postgraduate physics students, while also attracting research scholars and early-career researchers from institutions across the country. Approximately 45 participants attended the workshop, including around 25 from various universities, colleges, and research institutes across India.

The workshop commenced on January 15, 2026, with an inaugural session. Savithri H. Ezhikode delivered the welcome address and provided an overview of the workshop. This was followed by the Principal's address by Rev. Binu Edathumparambil. Ranjeev Misra (IUCAA), the Chief Guest, delivered the inaugural lecture on AI and Astronomy Research, highlighting the transformative role of artificial intelligence in astronomical investigations. The session concluded with a vote of thanks by Gisa Grace Ninan.

The academic programme included lectures on Stellar Astronomy by Blesson Mathew and X-ray Astronomy by Jithesh V (both from CHRIST). The first day concluded with a hands-on session on the Astropy package, conducted by Cysil Tom Baby (CHRIST), which provided participants with practical exposure to astronomical data analysis tools.

The second day focused extensively on practical training. Participants engaged in hands-on sessions on aperture photometry using Photutils and stellar cluster analysis, guided by Cysil Tom Baby, Prasoon Ashok Singh, and Arun Roy (CHRIST). These sessions enabled participants to work directly with real astronomical datasets, thereby strengthening their computational and analytical skills. The day concluded with a lecture on Introduction to Machine Learning by Vivek M (IIA, Bengaluru), who explained the fundamental concepts and applications of machine learning in astronomy.

The final day, *January 17, 2026*, was dedicated entirely to machine learning applications in astronomy. Hands-on sessions were conducted by Rachana, Arihant Tiwari, and Khushi Jirawala (IIA, Bengaluru), focusing on the practical implementation of machine learning techniques for astronomical data analysis. The workshop concluded with a valedictory session, during which participants shared their feedback and reflected on the knowledge gained.

Overall, the workshop was highly informative and interactive, effectively bridging the gap between theoretical concepts and practical applications in astronomy and machine learning. It significantly enhanced participants' understanding of data-intensive astronomy and equipped them with essential computational skills required for astrophysical research. The event also received wide media coverage in several newspapers across South India and on digital platforms, and successfully met its objectives while providing an enriching learning experience for all participants.

Workshop on Introduction to Astronomy and Astrophysics at IIT and IISER, Tirupati

The *Workshop on Astronomy and Astrophysics* was jointly organized by the Department of Physics at the *IIT Tirupati* and the *IISER, Tirupati* on *January 24–25, 2026*. This two-day academic event was attended by 38 outstation students from various states across India, along with approximately 45 students from the IIT and IISER Tirupati campuses. The workshop introduced participants to both fundamental and advanced topics in astronomy and astrophysics. Notably, female participation was significant, with 25 of the 38 outstation participants being women. Accommodation for all female participants was generously provided by IISER Tirupati.

On the first day, the inaugural session was addressed by K. N. Satyanarayana, Director of IIT Tirupati. He emphasized the importance of building a strong foundation in space sciences, encouraged students to pursue research, and highlighted the promising future of astronomy and related research areas. Following the inaugural session, the lecture series commenced, focusing on developing a strong conceptual foundation in astrophysics.

The first day covered a wide range of topics, including astronomical scales, radiation processes, and instrumentation, progressing to stellar astrophysics and compact objects. The sessions were delivered by R. Srianand (IUCAA), Adarsh K., Rajeshwari Dutta (IUCAA), and Aniket Jogalekar. These lectures introduced key concepts such as hydrostatic equilibrium, nuclear energy generation in stars, angular resolution, diffraction limits, and the physics of white dwarfs, neutron stars, and black holes. A career guidance session titled "What to Do in Astronomy and Space Sciences", delivered by R. Srianand (IUCAA), provided valuable insights into future scope and career prospects.

The second day began with lectures on the interstellar medium, star formation, galaxies, dark matter, active galactic nuclei, and cosmology. These sessions were conducted by Rajeshwari Dutta, Arunima Banerjee, Main Pal, and Vikram Khaire. Further sessions on exoplanets and multimessenger astronomy were delivered by Jessy Jose. A hands-on session on optical data analysis of galaxies, conducted by Adarsh K., enabled participants to work with real observational data and gain practical experience in astronomical data analysis using relevant coding techniques.

Towards the end of the workshop, an interactive session was held, providing participants with an opportunity to engage directly with the lecturers and discuss various topics. The feedback received from participants was overwhelmingly positive, with appreciation for the quality of lectures, the breadth of topics covered, and the effectiveness of the hands-on session.
Overall, the workshop successfully covered key foundational and contemporary topics in astronomy and astrophysics and encouraged active participation among students.

11th Southern Regional Astronomy Meeting (RAM-XI): Research in Astronomy: Opportunities and Challenges at CHRIST (Deemed to be University), Bengaluru

The *11th Southern Regional Astronomy Meeting (RAM-XI)*, titled *"Research in Astronomy: Opportunities and Challenges,"* was held from *February 5-7, 2026*. The event was hosted by the Centre of Excellence in Astronomy and Astrophysics at the Department of Physics and Electronics, CHRIST (Deemed to be University), Bengaluru, in collaboration

with the IUCAA, Pune. The meeting served as an important platform for the astronomical community in Southern India, attracting 160 applicants. From this pool, 90 participants were selected, representing a diverse group of faculty members, postdoctoral researchers, PhD scholars, and postgraduate students from Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Telangana, and Maharashtra. Over the course of three days, the conference featured 10 technical sessions, 6 invited talks, 39 participant presentations, and 27 poster sessions.

The inaugural ceremony commenced with a one-minute silent tribute in memory of the late Prof. Jayant Vishnu Narlikar, founder-director of IUCAA. Jithesh V., Associate Professor and PhD Coordinator at CHRIST (Deemed to be University), delivered the welcome address. This was followed by an address from T. V. Joseph, Dean of the School of Sciences, who highlighted the growth of the Department of Physics and Electronics since its inception. Ranjeev Misra, Dean of Visitor Academic Programmes at IUCAA, delivered a keynote address emphasizing the significance and evolution of the RAM series. The highlight of the inaugural session was the address by Annapurni Subramaniam, Director of the Indian Institute of Astrophysics. The session concluded with a vote of thanks delivered by Kenath Arun, Associate Professor at CHRIST (Deemed to be University). The technical programme commenced immediately after the inaugural ceremony. This meeting was coordinated by Jithesh. V., Kenath Arun (CHRIST) and Ranjeev Misra (IUCAA)

The technical sessions on Day 1 covered topics including stars and star formation, machine learning applications, gravitational waves, and cosmology. On Day 2, sessions focused on compact objects and the solar system. The second day concluded with a panel discussion moderated by Joe Jacob. The panel included Ranjeev Misra, A. N. Ramaprakash, Arun Kenath, Jithesh V., Ravikumar, and Blesson Mathew. The discussion began with A. N. Ramaprakash outlining major ongoing programmes in Indian astronomy and encouraging young researchers to actively engage with these opportunities. A key outcome was his proposal to establish a formal working group to coordinate regional research efforts.

R. Misra (IUCAA) addressed challenges faced by amateur astronomers, particularly the lack of structured guidance for beginners, and suggested the creation of dedicated support platforms such as online forums or messaging groups. The panel also discussed the demand for a Young Astronomers Meet and proposed an associateship model for allocating supercomputing resources, similar to telescope time allocation. In terms of career guidance, panellists advised students to align their research interests with emerging facilities and emphasized the growing importance of instrumentation in astronomy. The discussion also highlighted the importance of maintaining work–life balance and promoting outreach initiatives, especially in rural areas, to counter pseudoscience. An exclusive session for IUCAA Associates was also conducted to discuss regional activities and future directions, with 14 associates in attendance.

The final day featured sessions on stars, artificial intelligence in astronomy, and galaxies. A dedicated session for poster presentations and flash talks enabled in-depth, one-on-one technical discussions among participants, ranging from undergraduate and master's students to PhD scholars. This session provided valuable networking opportunities for early-career researchers.

The three-day meeting concluded with a formal valedictory session on on *February 7, 2026*. The session was presided over by the conference coordinators, Jithesh V. and Arun Kenath, who presented a summary of the event. The organisers expressed their sincere gratitude to CHRIST (Deemed to be University) and IUCAA, Pune, for their continued support and contribution to the success of the conference.

New Frontiers in Astronomy and Astrophysics at NIT Rourkela

The IUCAA-sponsored workshop titled *"New Frontiers in Astronomy and Astrophysics"* was successfully conducted from February 06-10, 2026 at the *Pranakrushna Parija Auditorium, NIT Rourkela*. The workshop was organized by the Department of Physics & Astronomy, NIT Rourkela, with the objective of exposing participants to cutting-edge developments in astronomy and astrophysics.

The workshop witnessed participation from across India, including the Eastern, Western, Northern, Southern, and Central regions, with a total of 103 participants. The programme was structured with morning lecture sessions followed by afternoon hands-on/tutorial sessions, along with a special public lecture aimed at engaging a wider audience. The workshop was coordinated by Ananta C. Pradhan (NIT Rourkela) and Gulab Chand Dewangan (IUCAA).

A total of 15 lectures were delivered covering a wide range of topics. Ajit Kembhavi (IUCAA, Pune) delivered lectures on "AI with Applications to Astronomy" and also presented the public lecture on "Black Holes – Finding Them, Measuring Them, Seeing Them." Abhishek Sharma (IUCAA) spoke on "Searches of Compact Binaries from Gravitational Wave Data." Abhay Pratap Yadav (NIT Rourkela) delivered a lecture on "Formation, Evolution and Final Fate of Stars." Liton Majumdar (NISER Bhubaneswar) presented lectures on "Discovering New Worlds: How We Find Planets Beyond the Solar System" and "Exploring Alien Skies: What Exoplanet Atmospheres Reveal About Other Worlds." Lalit Pathak (IUCAA) spoke on "Source Reconstruction from Gravitational Wave Data." Durgesh Tripathi (IUCAA) delivered two lectures on "Solar Astronomy 1" and "Solar Astronomy 2." Gulab Chand Dewangan (IUCAA) delivered lectures on "X-ray Astronomy and AstroSat" and "X-ray in Active Galactic Nuclei." Jagabandhu Panda (NIT Rourkela) spoke on "Mars and its Atmospheric Characteristics." Bharat Kumar (NIT Rourkela) delivered a lecture on "Multimessenger Probes of Neutron Star Matter." Ananta Charan Pradhan (NIT Rourkela) presented a lecture on "Ultraviolet Views of the Galaxies."

In addition, three hands-on/tutorial sessions were conducted by IUCAA faculty members and postdoctoral researchers, including Lalit Pathak, Abhishek Sharma, Durgesh Tripathi, Nived N., Gulab Chand Dewangan, and Tanuman Ghosh. These sessions provided practical exposure to data analysis techniques in astronomy, including gravitational wave data analysis and solar observations.

Overall, the workshop was highly successful in achieving its objectives. It provided a comprehensive learning experience through expert lectures, interactive sessions, and hands-on training, while fostering academic interaction and inspiring participants toward advanced research in astronomy and astrophysics.

Introductory Workshop on Astronomy & Astrophysics at Bhattadev University, Bajali, Assam

An *IUCAA-sponsored Introductory Workshop on Astronomy and Astrophysics* was successfully organized on February 16-17, 2026 at *Bhattadev University, Bajali, Assam*. The workshop was conducted through a joint collaboration between Bhawanipur Anchalik College and Bhattadev University. This two-day in-person programme aimed to introduce students and young researchers to the fundamental concepts and emerging areas of astronomy and astrophysics, while fostering scientific curiosity and critical thinking, particularly among participants from the western Brahmaputra belt of Assam.

The programme commenced with an inaugural session and a welcome address delivered by the Hon'ble Vice Chancellor of Bhattadev University, marking the formal beginning of the workshop. The event was coordinated by Vivek Baruah Thapa (Bhawanipur Anchalik College) and Debajyoti Dutta (Bhattadev University), with Kanak Saha (IUCAA) serving as the IUCAA coordinator. The organizers emphasized the importance of bridging academic and infrastructural gaps in access to advanced scientific disciplines in rural and semi-urban regions, in alignment with the vision of NEP 2020 for inclusive and equitable science education.

The workshop featured a series of invited lectures delivered by distinguished resource persons, including Sukanta Deb (Cotton University), Rupjyoti Gogoi (Tezpur University), Biman Jyoti Medhi (Gauhati University), and Debasish Borah (IIT Guwahati). The lectures covered a broad range of topics, including stellar and galactic astronomy, observational techniques, cosmology, and the connections between astrophysics and fundamental physics. These sessions were designed to provide both conceptual understanding and exposure to modern research methodologies in astronomy and astrophysics. The programme also included an interactive session on career prospects and research opportunities in the field, along with participant engagement activities such as discussions and feedback sessions.

The workshop attracted around 40 participants, including M.Sc. Physics students, final-year B.Sc. students, and early-stage Ph.D. scholars selected based on academic merit and interest in the field. The participation reflected strong academic engagement from institutions across the region, fulfilling the objective of extending scientific outreach to a wider student community.

The programme concluded with a valedictory session during which participants shared their feedback, and certificates were distributed. The workshop successfully achieved its intended objectives by enhancing awareness, motivating students toward higher studies in astrophysics, and laying the groundwork for future academic collaborations and outreach initiatives in the region.

The workshop was financially supported by IUCAA, Pune. The organizers expressed their sincere gratitude to IUCAA for its generous support, which played a pivotal role in the successful organization of the event. The programme also received strong institutional support from Bhattadev University and Bhawanipur Anchalik College, whose coordinated efforts contributed significantly to its effective execution. The successful conduct of the workshop highlights the importance of collaborative initiatives among higher educational institutions in promoting scientific outreach and capacity building in emerging areas such as astronomy and astrophysics.

Evolved Stars to Compact Objects: Tracing Stellar Evolution and Explosions at Panjab University, Chandigarh

A two-day workshop titled *"Evolved Stars to Compact Objects: Tracing Stellar Evolution"* was successfully organized on *February 16–17, 2026*, by the *Department of Physics, Panjab University, Chandigarh*, in collaboration with the IUCAA, Pune. The workshop aimed to introduce participants to the fundamental concepts of stellar evolution, including star formation, the life cycle of stars, nucleosynthesis processes, and the formation of compact objects such as neutron stars and black holes.

The programme was attended by approximately 60 undergraduate and postgraduate students from the Department of Physics, Panjab University, along with participants from several regional institutions, including Himachal Pradesh University, Shimla; the Central University of Punjab; IISER Mohali; and DAV College, Chandigarh. The primary objective of the workshop was to familiarize students with the basics of astronomy and astrophysics while also exposing them to recent developments and ongoing research in the field. It also aimed to strengthen conceptual understanding and motivate participants to pursue higher studies and research careers in astrophysics and related areas.

The inaugural session commenced with opening remarks by Meenakshi Goyal, Director of the Research and Development Cell, Panjab University, followed by an address by S. K. Tripathi, Head of the Department of Physics. Anupam Bhardwaj, Workshop Coordinator (IUCAA), provided an overview of IUCAA and outlined the objectives of the workshop. The keynote address, titled "End-to-End Journey of Stars," was delivered by B. K. Agrawal, Raja Ramana Chair at the Saha Institute of Nuclear Physics, Kolkata. The session witnessed active participation from faculty members and students, including non-registered attendees, and concluded with a vote of thanks delivered by Sakshi Gautam, Workshop Coordinator at Panjab University.

The academic programme comprised ten pedagogical lectures delivered by eminent experts, covering a wide range of topics, including the significance of stars in understanding the Universe and stellar evolution across different stages, the formation and survival of Population III stars, stellar populations in the Milky Way, pulsating stars, neutron stars and black holes, classical and quantum aspects of black holes, the role of telescopes in studying compact objects, and the origin of planetary systems. The sessions were highly interactive, with participants actively engaging in discussions and posing insightful questions, reflecting their keen interest and enthusiasm.

An observational session on night-sky viewing was also conducted, during which participants were introduced to the practical aspects of observational astronomy, including the setup and operation of an 11-inch telescope. They had the opportunity to observe celestial objects such as Jupiter and Saturn, providing a valuable hands-on learning experience that complemented the theoretical lectures.

The workshop also served as an important platform for academic networking and peer learning. Participants interacted with experts and fellow students from different institutions, fostering collaborative learning and the exchange of ideas. A feedback session was conducted on the final day, during which participants shared their suggestions and experiences. Many expressed a strong interest in future workshops incorporating hands-on training in astronomical data analysis and software tools.

Overall, the workshop proved to be highly beneficial in enhancing participants' understanding of astrophysical concepts and in inspiring them toward research-oriented thinking. Given the enthusiastic response and the relative scarcity of such specialized academic events in the region, it was strongly felt that similar workshops should be organized regularly to provide sustained exposure and opportunities for students in the field of astronomy and astrophysics.

Innovative Training Programme on Gravitational Waves and LIGO-India at SIT, Siliguri

An innovative *five-day training programme on Gravitational Waves (GW) and LIGO-India* was sponsored by the Inter-University Centre for Astronomy and Astrophysics, Pune, and conducted from *February 16 - 20, 2026*. The programme was jointly organized by the *University of North Bengal and the Siliguri Institute of Technology, Siliguri*. It was conducted in two phases: February 16–18 at the SIT Siliguri campus, and February 19–20 at the University of North Bengal campus.

The programme aimed to provide Master's and Ph.D. students in Physics and Mathematics, along with final-year B.Tech. students in Engineering, with a comprehensive introduction to gravitational waves and recent scientific and technological developments related to their detection. Gravitational wave astronomy is emerging as a transformative frontier in modern science, creating a growing demand for interdisciplinary expertise in physics, mathematics, engineering, data science, and instrumentation.

The first phase of the programme, held at SIT Siliguri, focused on foundational concepts, theoretical frameworks, and introductory technical sessions. In the second phase, participants moved to the NBU campus for advanced discussions, collaborative interactions, and specialized lectures in a research-oriented environment. This dual-campus format reflected strong institutional collaboration aimed at strengthening scientific engagement in eastern India.

The resource persons included *Bhoosan Gadre, Apratim Ganguly, Shivaraj Kandhasamy, Sandip Joshi, and Saravanan T. R.* from IUCAA, Pune. They delivered lectures, conducted hands-on training using a prototype detector brought from IUCAA, and introduced participants to computational methods and instrumentation related to the upcoming LIGO-India mega project.

The programme witnessed the enthusiastic participation of around 40 students from different parts of eastern India, along with one international participant who was visiting India at the time. By bringing together leading scientists and aspiring researchers across two prominent campuses, the initiative significantly contributed to strengthening the scientific ecosystem in eastern India and inspired young scholars to engage in the rapidly advancing field of gravitational wave astronomy.

The programme was coordinated by *Apratim Ganguly* (IUCAA), *S. Dey* (SIT, Siliguri), and *B. C. Paul* (ICARD, NBU).

Workshop on Data Science in Astronomy at UPES, Dehradun

As the scientific community continues to navigate the era of Big Data where the ability to handle, interpret, and analyze astronomical data has become an essential skill for researchers a National Workshop on *Data Science in Astronomy* was organized at *UPES, Dehradun*, from *February 24–26, 2026*. The event was jointly organized by the Applied Science Cluster, School of Engineering, UPES–Bidholi, and IUCAA, Pune.

The workshop aimed to advance knowledge and foster collaboration in astronomical data handling and data-driven methodologies. It was coordinated by Nitesh Kumar (UPES) and Anupam Bhardwaj (IUCAA). The programme commenced with inaugural addresses by UPES representatives and the Hon'ble Vice Chancellor, who welcomed the participants to the Bidholi campus.

The workshop was attended by around 60 participants, including nearly 50 students and faculty members from the host institution, along with participants from various regions of the country. The audience comprised individuals from physics/astrophysics and engineering backgrounds, including undergraduate and postgraduate students keen to engage with modern astronomical surveys.

The three-day programme featured lectures on modern astronomy, solar physics, stellar evolution, and machine learning applications in galaxy and stellar classification. Practical hands-on sessions

on machine learning techniques and data science applications in solar astronomy significantly enriched the learning experience. These sessions were conducted by distinguished resource persons, including H. P. Singh (University of Delhi), Ajit Kembhavi (IUCAA), Bhuwan Joshi (PRL Ahmedabad), Kaushal Sharma (FSL, Uttar Pradesh), Aasheesh Raturi (PG Dolphin, Dehradun), and Kuntal Misra (ARIES Nainital).

To provide direct exposure to observational techniques, a special telescope session titled "Sun and Sunspots" was organized at the Old Amphitheatre and conducted by a team of researchers. In addition, an interactive poster session held at the AB1 Quadrangle facilitated active academic exchange among participants and experts. The workshop also highlighted the importance of interdisciplinary education and research, particularly in the context of the recent initiation of observational astronomy activities at UPES. The programme concluded with a valedictory session led by the coordinators, marking the successful completion of the workshop.

Overall, the workshop was highly successful in achieving its objectives of introducing participants to the fundamentals of astronomical data analysis and providing an enriching and collaborative learning experience.

VO4EDU – Virtual Observatories for Education at Hyderabad

The workshop titled *VO4EDU – Virtual Observatories for Education* was organised from *March 23 to 25, 2026*, and was coordinated by *Priya Hasan* (Maulana Azad National Urdu University) and *Surhud More* (IUCAA). The workshop aimed to train Master's students, research scholars, teachers, and young researchers to access, analyse, and develop scientific use cases from astronomical data available from observatories across the globe.

Astronomy has evolved significantly over the years from a data-poor to a data-rich science. Modern ground-based observatories and space telescopes such as the Hubble Space Telescope, James Webb Space Telescope, and GAIA are generating vast amounts of data, ranging from terabytes to petabytes. To effectively utilise this wealth of data, the concept of Virtual Observatories (VO) has been developed.

The International Virtual Observatory Alliance (IVOA), established in June 2002 with 20 participating alliances, currently comprises 17 Virtual Observatory initiatives worldwide. Its mission is to facilitate international coordination and

collaboration for the development and deployment of tools, systems, and organisational frameworks that enable seamless access to and utilisation of astronomical data archives as an integrated and interoperable virtual observatory.

The core functions of the Virtual Observatory framework include the development of standards and protocols such as the Table Access Protocol (TAP) and VOTable for efficient data access and sharing; ensuring interoperability among various data centres and archives; organising working groups and interoperability meetings; and promoting FAIR data principles (Findable, Accessible, Interoperable, and Reusable). These efforts aim to make astronomical data accessible for scientific research and education under the broader vision of "science for all."

The workshop featured experts from China, Russia, the United Kingdom, and India, who

delivered approximately 20 lectures covering data access, analysis techniques, and the application of machine learning and programming tools in astronomy. The programme included both lectures and hands-on sessions, enabling participants to gain practical experience in working with real datasets. A sky-watching event was also organised as part of the workshop activities.

The workshop witnessed the participation of over 40 offline attendees from various universities and institutes, including IITs, IISERs, the University of Delhi, JNU, the University of Hyderabad, Osmania University, and BITS Hyderabad, among others. Conducted in a hybrid mode, the workshop also engaged a large number of online participants through Zoom.

All sessions were livestreamed and are now available on YouTube for wider access:

https://youtube.com/playlist?list=PLGf1ijrdazzGYuWv62Iz6g0xy2FjcMiiw&si=IeUgK4xhjLJstoPD

Further details about the workshop can be accessed on the official website:

https://bricsastronomy.org/vo4edu/

Overall, the workshop successfully achieved its objectives by equipping participants with the necessary skills to access and analyse astronomical data and by promoting the effective use of Virtual Observatory tools in research and education.

Welcome to...

IUCAA welcomes **Sanjay Yadav**, **Ashmita Roy**, **Subhajit Kar**, **Abhishek Sharma**, **Akriti Singh**, **Dipanjan Mitra**, **Anirban Chakraborty**, and **Sreejith Naie**, who have joined as Post-Doctoral Fellows.

Farewell to...

The institute bids farewell to **Saikruba Krishnan**, who has completed his tenure as a Post-Doctoral Fellow.

IUCAA also bids farewell to **Rajendra Prasad Bhatt** upon the completion of his association as a Research Associate.

Awards & Recognitions (January–March 2026)

Congratulations to...

- **Anupam Bhardwaj** on being selected as a **Young Associate of the Indian Academy of Sciences,** January 2026.
- **Eshita Banerjee** on receiving the **Young Astronomer Award** for the best publication from the Astronomical Society of India (ASI), March 2026.
- **Meenakshi** on receiving an **Honorable Mention** for the **Justice Oak Award** for **Outstanding Thesis in Astronomy** from the Astronomical Society of India (ASI), March 2026.

Colloquium

08.01.2026	Prof. Markus Boettcher on ***Multi-wavelength Polarization as a Probe of Astrophysical Relativistic Jets***
22.01.2026	Dr. Kelly Blumenthal on ***The IAU and the astronomy communication ecosystem***
02.02.2026	Prof. David A.H. Buckley on ***Science Highlights from SALT Transient Studies and the Future Prospects for Optical Transient Science***
05.02.2026	Prof. Vadim Burwitz on ***New X-ray Observatories: calibration and testing of X-ray Optics and Detectors at PANTER***
10.02.2026	Prof. Prasenjit Saha on ***Imaging the unimagable with the Hanbury Brown and Twiss effect***
12.03.2026	Prof. Rajeeva Karandikar on ***Beyond the Black Box: Why Mathematics Still Matters in the Age of AI***

Seminars

06.01.2026	Dr. Shikhar Mittal on ***New Approaches in Modelling and Interpretation of the Cosmic Dawn 21-cm Signal***
09.01.2026	Prof. Nikku Madhusudhan on ***The search for life beyond the solar system***
13.01.2026	Dr. Sreekanth Harikumar on ***Lensing of gravitational waves by Globular clusters and dark matter***
14.01.2026	Prof. Niranjan Thatte on ***The Extremely Large Telescope (ELT) and its near-infrared integral field spectrograph HARMONI***
16.01.2026	Dr. Dimple Panchal Jha on ***Understanding the Gamma-Ray Burst Diversity with Data-Driven Methods***
20.01.2026	Dr. Samik Mitra on ***A Hybrid Framework for Magnetohydrodynamic Accretion Disks: Analytical and Simulation Perspectives***
21.01.2026	Dr. Anupam Ray on ***Decoding the Mystery of Dark Matter with Celestial Objects***
27.01.2026	Dr. Samrat Sen on ***From current sheet instabilities to post-flare coronal rain in the solar atmosphere: Insights from MHD modeling and synthetic observations***
29.01.2026	Dr. Ramon Brasser o**n *The Solar System's Great Divide***
12.02.2026	Dr. Divya Singh on ***Constraining Dark Matter with Gravitational Wave Observations***
24.02.2026	Prachi Prajapati on ***Vz-GAL: Probing Cold Molecular Gas in Dusty Star-forming Galaxies at z=1-6***
05.03.2026	Dr. Harsh Kumar on ***Massive stars through the prism of hydrogen-poor superluminous supernovae***
10.03.2026	Dr. Atanu Koley on ***Probing Magnetic Fields and Turbulence in Massive Protoclusters Using ALMA***

Public Outreach Activities

Special Outreach Programs

The Zilla Parishad, Pune (ZPP) school outreach programme: IUCAA is preparing students for the second round of scientific exposure visits under the rural education initiative, conducted in collaboration with the ZPP for underserved rural schools in the district. In addition, IUCAA has conducted several programmes for the ZPP Education Department.

IUCAA – ZPP Teachers' Training Programme (March–April 2026): A total of six teacher training sessions are being organized on *March 16, 18, 23 and 25*, and on *April 02 and 04, 2026*, for ZP teachers across 13 talukas in Pune district. As of March 2026, around 350 teachers from ZP Pune schools have participated in these workshops.

IUCAA – ZPP Students' Online Informative Sessions (March 2026): Four online sessions were conducted on *February 25* and *March 10, 17, and 24*, receiving more than 4,000 views.

IUCAA – ZPP Students' Online Science Content Creation Training (March–April 2026): Four online sessions held on *March 13, 20 and 27*, and *April 01* focused on helping students understand science toys and create high-quality short online content. These sessions were conducted for students selected for various exposure visits in 2025.

Ambegaon Taluka Panchayat Samiti and the Education Department collaborated with IUCAA to organize the "Super 23" educational visit programme. The participating students were from ZPP schools in rural and tribal areas around the IUCAA Girawali Observatory. IUCAA personnel conducted interviews to select 23 students from a pool of nearly 1,200 students from the taluka.

Accompanied by a few teachers, the selected students visited Mumbai many for the first time in their lives. Their educational sessions were conducted under the OAE India Centre for Astronomy Education at HBCSE-TIFR, where they were also accommodated. The three-day visit (*February 26–28*), coordinated by *Samir Dhurde and Nilesh Pokharkar*, included special interactions at the Nehru Planetarium and Nehru Science Centre, along with visits to notable landmarks in Mumbai. On the final day, the group visited Raj Bhavan, the residence of the Governor of Maharashtra, where they had interactions with several officials.

Educonclave 3.0 was organized by the Pune Knowledge Cluster (PKC) in collaboration with Salaam Bombay as an in-person conference on January 30, with the theme *"Rewiring STEM Education for Future-Ready Classrooms."* R. Srianand (Director, IUCAA) delivered the keynote lecture to students and teachers from various districts of Maharashtra and also encouraged participants at the science exhibition held during the event. Samir Dhurde moderated a panel discussion on "Enabling Future-Ready Classrooms: Ground Realities, Impact, and Possibilities." Rupesh Labade also conducted a talk-cum-demonstration session for teachers.

Dr. Kelly Blumenthal, Director of the International Astronomical Union's Office for Astronomy Outreach (IAU OAO), visited IUCAA during *January 16–25, 2026*. During her visit, she participated in several meetings and discussions related to astronomy public outreach in India and explored opportunities for collaboration with the IAU OAO. Samir Dhurde, serving as the IAU National Outreach Coordinator for India, scheduled her visit to coincide with the SCAI 2026 conference hosted at IUCAA, enabling her to interact with key stakeholders from across the region and the country. She also visited and appreciated the activities of the IUCAA MVS Science and Astronomy Outreach Centre.

As part of her visit, she delivered a colloquium on *January 22* titled "The IAU and the Astronomy Communication Ecosystem."

National Science Day 2026

National Science Day 2026 at IUCAA was not just a celebration of science, but a bridge connecting the scientific community with the general public. IUCAA marked the occasion with an inspiring series of events held throughout February, culminating in an engaging and educational Open Campus Day on February 28. The celebrations attracted more than 7,000 science enthusiasts of all ages from various parts of Maharashtra and highlighted the theme "Science & Innovation at IUCAA."

The highlight of the festivities was the Open Day on *February 28*, during which IUCAA staff and faculty welcomed the public to explore its scientific landscape. A variety of interactive exhibits, live demonstrations, and lectures were held across multiple locations on campus, each offering a glimpse into the fascinating world of astronomy and astrophysics.

At the Aryabhata and Kund areas, visitors marveled at the Foucault Pendulum and sculptures of iconic scientists, while solar telescopes provided real-time views of the Sun. A special aeromodelling shows by Madhav Khare kept children spellbound. The Bhaskara area featured themed presentations on LIGO-India, demonstrations of gravitational waves, and detailed displays on the Aditya-L1 solar mission. Models and interactive sessions on quantum science and AstroSat were also presented.

The Chandrasekhar Auditorium hosted a full day of public talks. Speakers including *Shubham Sati, Sourav Das, Susmita Das, Bhooshan Gadre, Apratim Ganguly, and Sourabh Magare* presented highly informative topics. Special lectures were delivered by *Jennifer Gupta* (University of Portsmouth, UK) on "Studying the Skies with Satellites and Spectra," and by *Rashi Jain and Yogesh Wadadekar* (NCRA-TIFR) on the "Discovery of the Alaknanda Galaxy." Notable highlights included the "Ask a Scientist" session and special interactions with ZPP rural students who had participated in exposure visits in 2025. Sessions were conducted in English, Marathi, and Hindi to ensure inclusivity and wider participation.

The Muktangan Vidnyan Shodhika area

served as the exhibit hub for school astronomy activities, including hands-on demos, amateur radio astronomy, and outreach project displays.

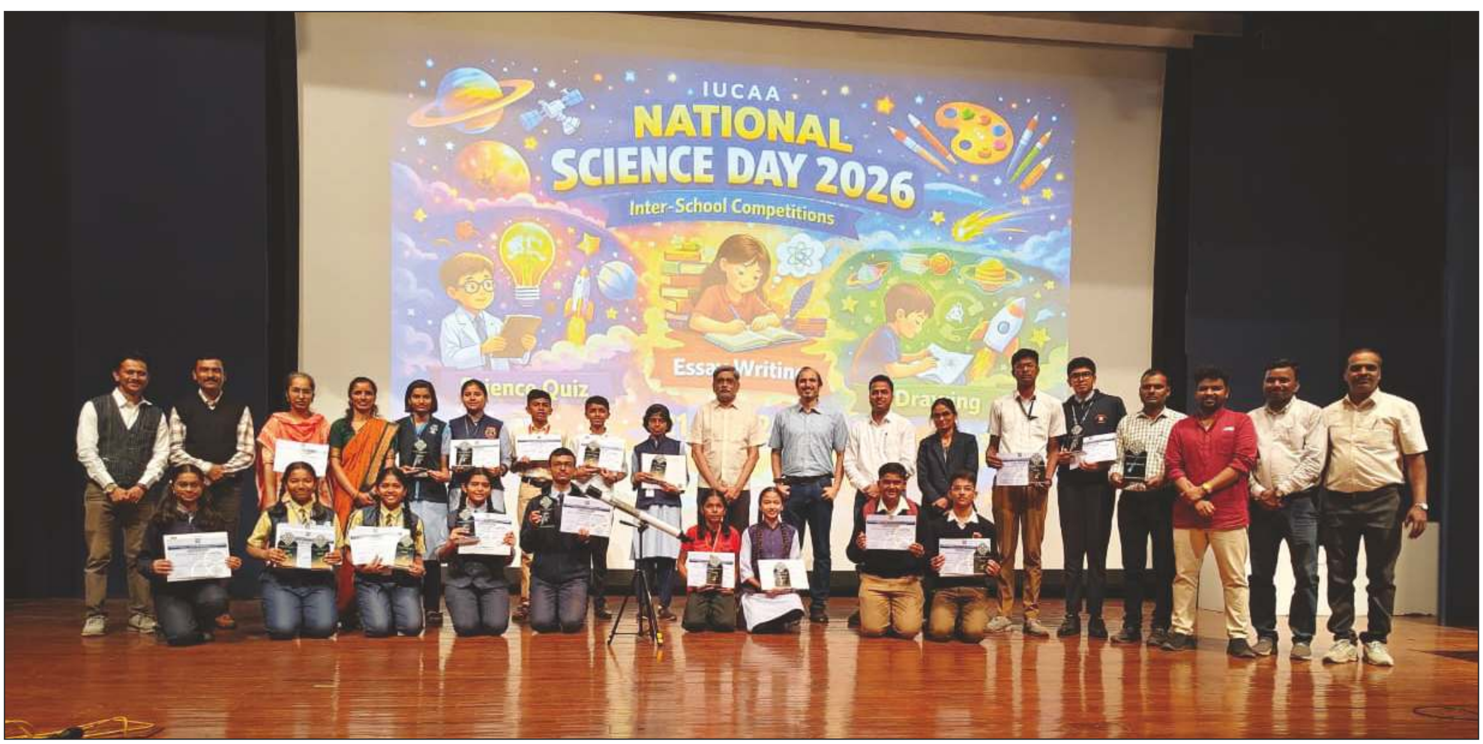
In the evening, the celebrations continued at the Savitribai Phule Pune University sports ground with a public skywatch event from 7:00 pm to 10:00 pm. Using telescopes, attendees enjoyed guided observations of celestial objects, deepening their connection with the cosmos.

As part of the tradition, several events for school students were organized prior to the Open Day. IUCAA Public Outreach personnel conducted science quiz, essay writing, and drawing competitions for rural students in Ambegaon Taluka on *February 14, 2026*. *Saurabh Magare, Sudhir Gholap, and Sarang Shah*, with support from *Nilesh Pokharkar* and the outreach staff, encouraged enthusiastic participation from students representing 26 rural schools. The event was hosted at the Government Polytechnic, Awasari.

On *February 21, 2026*, around 180 students from 36 schools in Pune city participated in inter-school competitions organized by IUCAA. Students from Classes VIII to X took part in drawing, essay writing, and science quiz competitions. These events were coordinated by *Rajeshwari Dutta, Anupreeta More, Anupam Bhardwaj, and Subhadeep De*. During the day, *Surhud More* delivered an engaging talk titled "Exploring the Universe" for accompanying teachers. Following the quiz finals, prizes were awarded to the winners by the IUCAA Director, including special invitees from rural schools.

Through these celebrations, IUCAA successfully ignited curiosity and fostered a deeper appreciation for science among students and the general public, many of whom valued the opportunity to interact directly with IUCAA scientists.

Winners of the National Science Day Competitions



Results of Competitions – National Science Day 2026

Rural Schools

A) Quiz Competition

First Prize:

Krutika Bansod, Vedant Dabhade, Sarthak Pingale (New English School, Landewadi)

Second Prize:

Ojas Jadhav, Devraj Kolhe, Tanish Kasbe (R. P. Sabnis Vidyamandir, Narayangaon)

Third Prize:

Snehal Dukare, Swarnima Dongre, Anushka Langhi (New English School, Ghodegaon)

B) Essay Competition

First Prize:

Aishwarya Auti (R. P. Sabnis Vidyamandir, Narayangaon)

Second Prize:

Anushka Badhekar (Shri Sangameshwar Vidyalaya, Pargaon (Shingave))

Third Prize:

Riddhi Nighot (Mahatma Gandhi Vidyalaya, Manchar)

Honourable Mention:

Kartik Kanaskar (Kamalaja Devi Vidyalaya, Kalamb)

Honourable Mention:

Mahi Dhobale (New English School, Landewadi)

C) Drawing Competition

First Prize:

Arshin Shaikh (Shri Bhairavnath Vidyalaya, Awasari Khurd)

Second Prize:

Aafiya Sutar (Mahatma Gandhi Vidyalaya, Manchar)

Third Prize:

Antara Shinde (Pandit Jawaharlal Nehru Vidyalaya, Nirgudsar)

D) Best School Trophy

G. R. P. Sabnis School, Narayangaon

Pune City Schools

A) Quiz Competition

First Prize:

Amarth Mishra, Vidushi Joshi, Ayan Gantayat (Army Public School)

Second Prize:

Tanay Pai, Shradchandra Sarode, Vihan Bhagwat (Symbiosis Secondary School)

Third Prize:

Arnav Patil, Pragyan Patil, Chinmay Lokhande (Tree House High School, Pune)

B) Essay Competition

First Prize:

Lavisha Shrivastava (Army Public School)

Second Prize:

Advay Joshi (Loyola High School)

Third Prize:

Sharvani Sardesai (BVB Sulochna Natu Vidyalaya)

Honourable Mention:

Mihika Singhai (Delhi Public School)

C) Drawing Competition

First Prize:

Anandita Dash (Air Force School, Chandan Nagar)

Second Prize:

Sanvi Patnekar (MES Bal Shikshan Mandir English Medium School)

Third Prize:

Rishit Mehta (VP's Vinodkumar Gujar Bal Vikas Mandir, Baramati)

Honourable Mention:

Prachiti Patil (D.E.S. Secondary School)

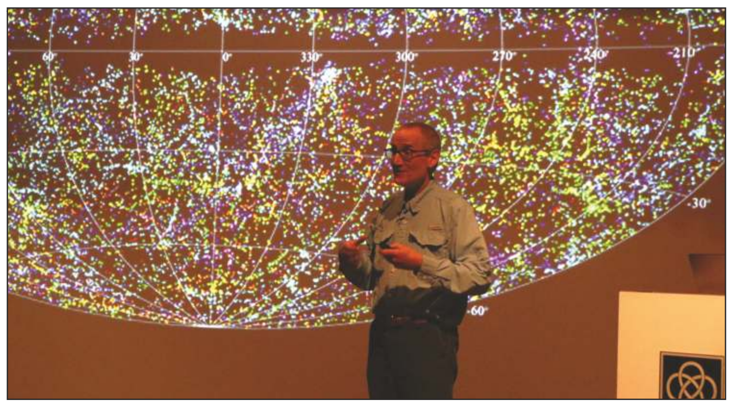
D) Best School Trophy

Army Public School, Pune

Chandra Public Lecture

As part of IUCAA's public engagement initiatives, one *Chandra Public Lectures* were delivered

Duncan Lorimer (West Virginia University) presented a lecture titled "The Brightest Pulsars in The Universe" on *January 22, 2026.*



2nd Saturday Lectures

IUCAA continued its monthly Second Saturday public engagement series with the following talks and demonstrations

Samir Dhurde & Rupesh Labade **(IUCAA, Pune) presented a lecture titled "Science of Bicycles with the Velodyaneshwari" on *January 10, 2026***

Workshops, Visits, and Other Outreach Events:

(The following sessions had various members of the IUCAA SciPop team as organisers or resource persons.)

1. *LGP-IISER Telescope Making workshop (January 3)* – Attended by 80 Students.

2. *Telescope Making workshops in Chhattisgarh*. (*January 5-7*) at Raipur & Kavarda – attended by 115 students participated and a Sky watch for 2000 people was also conducted.

3. *Carmel College for Women, Goa, students visit* (*January 8*) - 16 Students participated in this educational visit.

4. *Talk at ZP, Pune District Level Science exhibition* by *Surhud More*, IUCAA (January 9) - 60 teachers and many students attended this talk.

5. "*Galileo in Modern Times*" stage show in the India Science Festival at IISER, Pune (*January 11*) - 400 people attended this show.

6. *Telescope Making workshop* for students of *Nayanta University*, Pune (*January 16*)

7. *Skywatching event at T.C College, Baramati* (*February 2*) - 350 students attended this event

8. *Science and Astronomy talk at New English School, Landewadi* by *Sarang Shah*, IUCAA (*February 14*) - 200 students attended the talk

9. *Christ University Students' visit and skywatch session* (*February 17*)

10. *Young Investigators' Meeting (YIM 2026) (March 4) - Samir Dhurde* was a part of a panel discussion on the topic "Science Engagement at Research Institutions", conducted by IndiaBioscience

11. *Science and Astronomy talk for Zilla Parishad School, Dharashiv* (*March 12*) - 200 students attended the talk

12. *Skywatching session for Awasara Academy* (*March 17*) - 60 students attended the session

13. *Educational visit by Savitribai Phule school*, Pune (*March 24*) - 20 students attended

Astronomy Centre for Educators Activities

School on Optical Astronomy Techniques

A School on Optical Astronomy Techniques was organized by the Astronomy Centre for Educators at the Inter-University Centre for Astronomy and Astrophysics from *February 3 to 13, 2026*. Approximately 220 applications were received, from which 16 educators and 16 students were selected to participate. The educators—comprising faculty members, research scholars, postdoctoral fellows, and scientific staff—were keen to incorporate optical astronomy projects and hands-on experiments into their undergraduate teaching. The student participants, primarily third- and fourth-year undergraduates, were largely encountering optical astronomy techniques for the first time.

Morning sessions were devoted to lectures that established a strong foundation in optical astronomy techniques, followed by discussions on a wide range of astronomical objects and the insights provided by optical observations. Topics included the Sun, stellar structure and evolution, the interstellar medium, extragalactic astronomy, and cosmology. Additional focus areas included time-domain astronomy, cosmological measurements, computational astrophysics, and the applications of artificial intelligence and machine learning in astronomy. Several sessions also placed optical observations within the broader framework of modern multi-messenger astronomy, linking them to radio, X-ray, and gravitational-wave studies.

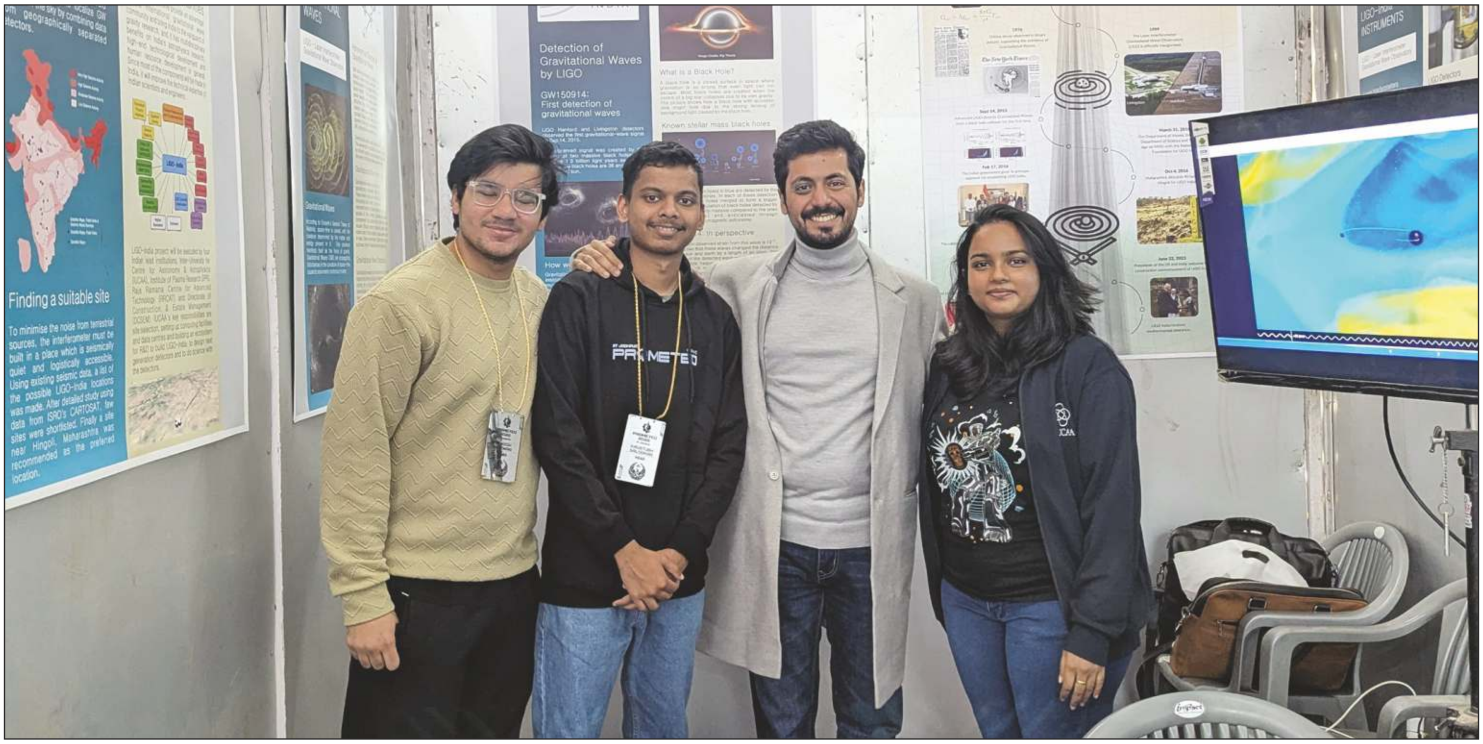
Afternoon sessions emphasized intensive hands-on training through laboratory experiments, observations, and data analysis. The programme began with an introduction to aperture photometry, followed by advanced instrumentation experiments such as optical polarimetry using a Wollaston prism, Michelson interferometry with feedback control and phase locking, characterization of focal ratio degradation in optical fibers, and adaptive optics corrections using a Hartmann mask. Participants also conducted solar observations to measure limb darkening and performed stellar photometry. These practical sessions were designed and guided by a dedicated team of scientific staff, postdoctoral fellows, research scholars, and project students: Namita Uppal, Sarang Shah, Deepa Modi, Nishant Patil, Arya Papal, Chaitanya Rajarshi, Abhay Kohok, Saravanan T. R., Ajinkya Naik, Sneha Pandit, Khushi Lalit, Sourav Das, Shreya Mukherjee, and Jameer Manur.

A highlight of the school was a visit to the IUCAA Girawali Observatory, where participants received a guided tour of the observatory's design and operations. On the final day, participant groups presented their work based on selected experiments.

The school witnessed enthusiastic participation from both students and educators, making it a highly engaging, collaborative, and educational experience. The programme was coordinated by the Astronomy Centre for Educators, with A. N. Ramaprakash serving as the faculty coordinator.

LIGO-India Education & Public Outreach (LIEPO) Activities

IIT Jodhpur Tech Carnival: Prometeo 2026



LIGO-India Education and Public Outreach (LI-EPO) participated in IIT Jodhpur's Tech Carnival, Prometeo, held from *January 16-18, 2026*. The team engaged the public by spreading awareness about the LIGO-India project and popularising gravitational wave science through interactive and hands-on exhibits.

Gravitational Wave (GW) research scholars Rutuja Pilgar and Ankur Chhabra from BITS Pilani volunteered on behalf of LIGO-India EPO. A large number of visitors interacted with the researchers, learning about the upcoming mega-science project and exploring multidisciplinary aspects of gravitational wave science.

ASI Symposium for Communicating Astronomy in India (SCAI), IUCAA, Pune

SCAI 2026 during *January 22-24, 2026* was the first symposium of its kind dedicated to communicating astronomy in India. LIGO-India Senior Outreach Coordinator *Saurabh Salunkhe* participated in the symposium and delivered a presentation on the mega-science project, gravitational wave science, and the outreach activities conducted by LI-EPO.

Behind the Scenes Interview & "Glorious Women" Feature

On the occasion of the International Day for Women and Girls in Science, LIGO-India EPO organised an interview with Debnandini Mukherjee, a postdoctoral researcher at the University of Birmingham (UK) and one of the key researchers behind the recent discovery of the GW event GW231123.

She shared insights into her daily life as a woman researcher in the LIGO-Virgo-KAGRA collaboration, along with inspiring advice for aspiring scientists. The interview was conducted by Rutuja Pilgar, a research scholar from BITS Pilani on *February 11, 2026.*

National Science Day

On the occasion of National Science Day on *February 28, 2026*, a LIGO-India booth was set up during the open day at IUCAA. The exhibit presented gravitational wave astronomy along with information about the mega-science project.

The booth featured demonstrations, posters, and live experiments, including the space-time continuum model, a scaled-down LIGO-India model, Mercury's orbit, a GW generator, the Michelson interferometer, and a quadruple suspension system model, all explaining fundamental concepts of gravity and gravitational waves.

In line with the National Science Day 2026 theme, "Women in Science: Catalysing Viksit Bharat," contributions by women GW researchers were highlighted. The online international symposium "Glorious Women" celebrating these contributions was also promoted.

A special themed exhibition titled "Fundamental Physics with Gravitational Waves" was organised in collaboration with students from Fergusson College, Pune. A Sci-Art exhibition showcased winning entries from the astrophotography workshop and contest *"Cosmic Canvas"* organised by LI-EPO.

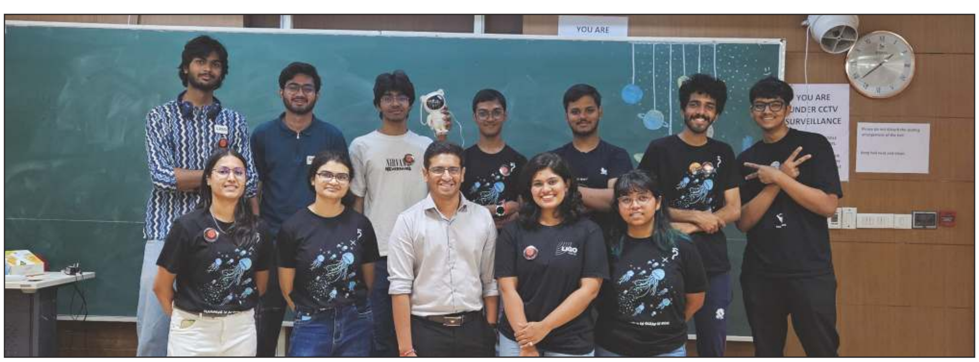
Additionally, a Marathi screening of the virtual tour of the LIGO Livingston Laboratory (USA) was conducted. An interaction session was also organised for students and teachers from Hingoli, the site of the LIGO-India detector

IISER Pune Science Festival: Mimamsa SciCon

LIGO-India EPO was invited to participate in the IISER Pune Science Festival, Mimamsa SciCon, held on *March 22, 2026.*

LI-EPO Senior Outreach Coordinator Saurabh Salunkhe delivered a popular talk on LIGO-India and gravitational waves, providing insights into the project and related career opportunities.

LI-EPO interns and volunteers Aarya Thuse, Harsh Satam, and Shivam Banerjee interacted with students, explaining gravitational wave science through engaging, hands-on exhibits and models.



Visitors

[January – March 2026]

Naveena Kumara A., Abhishek A.S., Abhishek Abhang, Soham Acharya, Sushmita Agarwal, Apoorwa Agrawal, Ashad Ahmad, Syed Ishtiyaq Ahmad, Arkajit Aich, Shahzada Akhter, Heena Ali, Kewal Anand, Mywish Anand, Ananya Anandharaman, Dorje Angchuk, Remya B.S., Shubha B.S., Shylaja B.S., Chitranshi Bakshi, Arit Bala, Arunima Banerjee, Samuzal Barua, Deepika Baruah, Manthan Bhagat, Aditya Bhalla, Sumukha Bharadwaj, Parth Bhargava, K.T.N. Bhaskaran, Debbijoy Bhattacharya, Parag Bhattacharya, Darshan Bhattacharyya, Sree Bhattacherjee, Nilanjandev Bhaumik, Soumadip Rabindranath Bhowmick, Sougata Bhunia, Kunzong Nima Bhutia, Promila Biswas, Ritabrata Biswas, Shauvik Biswas, Kelly Blumenthal, Sajad Ahmad Boked, Hritwik Bora, Zafri Ahmed Borboruah, Pragyan Pratim Bordoloi, Mary Bosco, Markus Bottcher, David Buckley, Vadim Burwitz, Nand Kumar Chakradhari, Kabir Chakravarti, Sreelakshmi P. Chakyar, Hum Chand, Krishan Chand, Surajit Chattopadhyay, Shivani Chaudhary, Aditya Chauhan, Suraj Kumar Chaurasia, Harshita Chavan, Laxmikant Chaware, Sheetal Chopde, Rasheshwari Paul Chowdhury, Aravindaraja D., Pratik Dabhade, Athar Ahmad Dar, Sikandar Akbar Dar, C. Annal Deva Priya Darshini, Avik Kumar Das, Kaustav Das, Nilava Das, Nirmali Das, Nutan Das, Susmita Das, Anirban Dasgupta, Prasanna Deshmukh, Vadiraj Deshpande, Reshma Dessai, Tribeni Deuri, Laishram Saroda Devi, Ankit Dey, Puskar Dey, Tulika Dey, Ruchika Dhaka, Suraj Dhiwar, Rahul Dhyani, Aman Dobhal, Ishika Dubey, Nitesh Kumar Dubey, Sukanya Dutta, Sreeraj E., Yadu E., Vinuta G., Yuvasri G., Jayant Ganguly, Piyali Ganguly, Juan Garcia-Bellido, Sunay S. Gavandalkar, Yash Ghatwai, Abir Ghosh, Nihar Ranjan Ghosh, Shubhrangshu Ghosh, Suprovo Ghosh, Sushant G. Ghosh, Manish Kumar Gond, Jennifer Gupta, PrateEK Gupta, Sarvesh Gupta, Soumya Gupta, Suresh Kumar Gupta, B.R. Guruprasad, Sreekanth Harikumar, Priya Hasan, Syed Najamul Hasan, Brenjit Hazarika, Anisha Hazra, Gopal Hazra, Muhammed Irshad, Md. Sariful Islam, Mohamed Jahim, Sonam Jorphail, Dhyan Kaushik Joshi, Jaimin Joshi, Manish R. Joshi, Joel Joy, Hridika K., Rajarajeswari K., Yashaswini K.S., Pallavi Kajrekar, Shubham Kala, Usha Kalive, Sammi Kamal, Rajeeva Karandikar, Chrisphin Karthick, Suresh Karthik, Siddharth Kasthurirangan, Tejpreet Kaur, Sahela Khalid, Ahamadullah Khan, Farhan Khan, Istiak Khan, Renuka Khanvilkar, Passang Norbu Khrimey, Atanu Koley, Harshit Krishna, Krithi Krishna, Usha Kulkarni, Harsh Kumar, Pankaj Kumar, Raj Kumar, Subhash Kumar, Sudesh Kumar, Nilay Kundu, Sayan Kundu, Pankaj Kushwaha, Sudharani L., Alok Laddha, H. Lalthantluanga, Jeremie Lasue, Naval Kishor Lohani, Duncan Lorimer, Kaamesh M.G., Mahesh M.B., Anand M.Y., Druthi Madhavaraj, Nandini Madhukar, Ashish Mahabal, Aman Mahnoori, Soumak Maitra, Prajjwal Majumder, Lekhika Malhotra, Manzoor A. Malik, Sweta Malik, Zahoor Ahmad Malik, Subhrajyoti Mallick, Sukanya Mallik, Ankush Mandal, Bhaswati Mandal, Alok Mandavgane, Jagadeeswaran Mani, Goutam Manna, Shevin Sunil Mathew, Ananya Matta, Suraj Kumar Maurya, Jalak Mehta, Thokchom Yaiphaba Meitei, Parthiv A. Menon, Sapna Mishra, Anuradha Misra, Indranil Mitra, Patrlekha Mitra, Samik Mitra, Meenakshi Mohan, Ram Mohan, Abhisek Mohapatra, Aurindam Mondal, Soumen Mondal, Atanu Mukherjee, Sutirtha Mukherjee, Banibrata Mukhopadhyay, Aditya Nagare, Akshatha Nagari, Suhas Naik-Satam, Akhil U. Nair, Barasarani Nayak, Mohith Nigam, Shamik Niyogi, Brian O'Reilly, Nityendra Oke, Aromal P., Naseef Mohammed P.N., Sreebala P.S., Main Pal, Satyajit Pal, Subhajit Pal, Dimple Panchal, Rajat Kumar Panda, Arvind Paranjpye, Rutu Parekh, Bina Jalak Patel, Palak Patel, Mayank Pathak, K.D. Patil, Nishant Patil, Nupur Paul, Suvankar Paul, Devraj Pawar, Ninan Sajeeth Philip, Bikram Phookun, Privatus Pius, Anupama Pradeepan, Anirudh Pradhan, Arbind Pradhan, Bikram Pradhan, Prachi Prajapati, Raj Prince, Raajabirami R., Abhirami S. Raghu, Anisur Rahaman, Suvendu Rakshit, Bhera Ram, Niruj Mohan Ramanajun, Divya Rana, Pritesh Ranadive, Arshi Rastogi, Aasheesh Raturi, Akhilesh Ray, Anupam Ray, Shankar Ray, Tulip Ray, Mohd. Rehan, Lal Rinkimi, Shuvayu Roy, Sanjana S.P., Pramodh S., Sankar S., Soundarya Meenakshi S., Sonali Sachdeva, Margarita Safonova, Pameli Saha, Prasenjit Saha, Priyanka Saha, Sudipta Saha, Supriyo Saha, Asmi Saharay, Sunder B. Sahayanathan, Siddharth Kumar Sahoo, Niraj Kumar Sahu, Sahil Saini, Subrata Sarangi, Janmejoy Sarkar, Subir Sarkar, Suchira Sarkar, Tamal Sarkar, Seema Satin, Gargi Sen, Samrat Sen, Muhammed Shafeeque, Mohd Shahalam, Hafsa Shaikh, Emmanuel K. Shaji, Aadya Sharma, Aditya Sharma, Chanchal Sharma, Himanshu Sharma, Isha Sharma, Khushboo Sharma, Paryag Sharma, Pranav Sharma, Subah Sharma, Vaibhav Sharma, Ravi Kiran Sheth, Sai Shetye, Sai Shetye, Mahmoodur Rahman Shihab, Sheeshram Siddh, Abhijeet Singh, Archana Singh, Divya Singh, Prabhav Singh, Ramanshu P. Singh, Rishabh Kumar Singh, Meghanil Sinha, Preksha Siwach, Sohail Sk, Divyesh Solanki, Arnav Soni, Kanchan Soni, S. Sridhar, Kavuri Srimohith, Amogh Srivastav, Ajit Srivastava, Rashmi Srivastava, C.S. Stalin, Madhu Sudan, Babasaheb Sutar, Mumtaz Syed, Ajay Talwar, Ashis Tamang, Tagtshen Tamang, Rupali Tamrakar, Garima Tyagi, Sanil Unnikrishnan, Namita Uppal, Jithesh V., Bhargav Pradeep Vaidya, P.B. Vanlalzarliana, T.V. Venkateswaran, Sankaranarayanan Viswanathan, Faheem Aalijah Wani, Kiran Wani, Munior Ahmad Wani, Kanak Wasnik, Zak Yacoob, Virendra Yadav, Rauf Zargar, Andrzej Antoni Zdziarski, Anita, Megha, Sameera.

Khagol (the Celestial Sphere) is the quarterly bulletin of IUCAA

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