Proceedings of

Seminar on
"Discovery & Detection of Gravitational Waves"

September 14, 2024

organized by

JAIPUR NATIONAL UNIVERSITY, JAIPUR

in association with

Center for Excellence in Quantum Science (CEQS)

Indian Association of Physics Teachers (IAPT), RC-06, Rajasthan Chapter

&

National Academy of Sciences India (NASI), Rajasthan Chapter

A rendering of the LIGO India site in the state of Maharashtra (Curtsey: LIGO Caltech)

हरिभाऊ बागडे
राज्यपाल, राजस्थान

सत्यमेव जयते

Haribhau Bagde
Governor, Rajasthan

संदेश

मुझे यह जानकर प्रसन्नता हुई है कि जयपुर नेशनल यूनिवर्सिटी द्वारा 'गुरूत्वाकर्षण तरंगों की खोज और पहचान' विषयक संगोष्ठी का आयोजन किया जा रहा है।

भारतीय ज्ञान परम्परा सृष्टि के रहस्यों के साथ ही तत्व –ज्ञान से पूरी तरह आबद्व है। हमारी प्राचीन परम्पराओं और ज्ञान में सृष्टि के उद्‌भव, गुरूत्वाकर्षण, ब्रहमांड आदि सभी विषयों का विवेचन किया गया है। सुखद है भारतीय ज्ञान परम्परा के आलोक में यह आयोजन हो रहा है।

मेरी हार्दिक शुभकामनाएं हैं।

(हरिभाऊ बागडे)

राज भवन, सिविल लाइन्स, जयपुर–302006
Raj Bhawan, Civil Lines, Jaipur-302006
दूरभाष : 0141–2228716–19, 2228611–12, 2228722

JAIPUR NATIONAL UNIVERSITY, JAIPUR

Dear Participants, Esteemed Speakers, and Advisory Board Members,

It is a matter of great pride and honor for Jaipur National University to have successfully hosted this prestigious seminar on **"Discovery and Detection of Gravitational Waves."** This seminar has brought together some of the brightest minds in the field of astrophysics, allowing us to explore the frontiers of science and advance our understanding of the universe. I would like to extend my heartfelt congratulations and best wishes to all the participants.

I also want to express my deep gratitude to the distinguished members of the Advisory Board and our esteemed speakers. Your expertise, guidance, and insightful contributions have been instrumental in making this seminar a resounding success. The depth of knowledge and the range of perspectives shared during the discussions will extremely enrich us all and will continue to inspire future exploration in this exciting field.

We are incredibly proud to have organized such an important event, and I am confident that the ideas exchanged here will serve as a catalyst for new discoveries and collaborations in the years to come.

Once again, I extend my best wishes to all the participants as you continue your journey of learning, and sincerely thank the speakers and advisory board members for their unwavering support and guidance.

Warm regards,

Dr. Sandeep Bakshi
Chancellor

JAIPUR NATIONAL UNIVERSITY, JAIPUR

Dear Participants, Esteemed Speakers, and Advisory Board Members,

It is with immense pride and honor that Jaipur National University reflects on the successful completion of this esteemed seminar on "Discovery and Detection of Gravitational Waves." This event has gathered some of the most brilliant minds in astrophysics, fostering a collaborative environment to delve into the mysteries of the universe and expand our scientific horizons.

To all participants, I extend my heartfelt congratulations and best wishes. Your enthusiasm and dedication throughout the seminar have been inspiring and are essential to driving the progress of science. Your active engagement has truly brought this seminar to life.

I would also like to express my deepest gratitude to our distinguished speakers for their invaluable expertise, support, and thought-provoking insights in achieving the seminar's success. The knowledge shared has not only enriched our understanding but will also spark future innovation in this exciting field.

With my best wishes to each of you as you continue your pursuit of knowledge and discovery, I extend my sincere appreciation to the speakers and advisory board members for their unwavering support and guidance.

Warm regards,

Prof. H. N. Verma
Pro Chancellor

JAIPUR NATIONAL UNIVERSITY, JAIPUR

Dear Distinguished Speakers, Esteemed Advisory Board Members, and Valued Participants,

It is with profound pride and gratitude that Jaipur National University celebrates the successful conclusion of thetimely seminar on "Discovery and Detection of Gravitational Waves." The gathering has served as a vibrant platform for some of the brightest minds in astrophysics, providing an exceptional opportunity to delve into the mysteries of the universe and push the boundaries of our understanding.

We convey our deep appreciation to you all for your expertise, guidance, and thought-provoking insights have been instrumental in the success of this seminar. The perspectives you have shared have enriched us all, sparking fresh ideas and inspiring a deeper pursuit of knowledge in this dynamic field.

Our valued participants deserve special greetings for their enthusiasm and commitment. Their curiosity and active engagement made this event truly exceptional, highlighting the importance of collaborative learning in advancing science.

Thank you, all, once again for your invaluable contributions.

We wish you continued success in all your future endeavors!

Warmly,

Prof. R. L. Raina
Vice Chancellor

JAIPUR NATIONAL UNIVERSITY, JAIPUR

It gives me immense pleasure to extend my heartfelt congratulations and gratitude to all the participants, and esteemed speakers who contributed to the success of this seminar on gravitational waves. This event has been a remarkable confluence of minds, where curiosity, knowledge, and passion for science met to explore one of the most profound mysteries of the universe—gravitational waves. Your enthusiasm and engagement have truly made this seminar a memorable and enlightening experience.

A special note of gratitude is extended to our esteemed speakers, whose expertise and vision have guided the discussions and broadened our understanding of this cutting-edge field. Their commitment to advancing scientific inquiry has provided an invaluable learning opportunity for all of us. The insights shared will inspire you to delve deeper into the fascinating world of astrophysics and gravitational wave research.

We are also deeply thankful to our patrons for their unwavering support and guidance. We owe particular thanks to the Hon'ble Governor of Rajasthan for his gracious patronage, which has elevated this seminar and emphasized the significance of scientific exploration in our state and beyond.

May this event be a stepping stone for many toward future innovations and discoveries in science.

Warm regards,

Prof. (Dr.) Yogesh Chandra Sharma
Chair
Director, Research & Academic Development, Jaipur National University
Director, Center for Excellence in Quantum Science (CEQS), Jaipur
Vice President, IAPT-RC6; Treasurer, MRSI-Rajasthan Chapter
Mobile: 9664075093; email: director.res.acad.dev@jnujaipur.ac.in

Organizing Committee

Patron-in-Chief

Dr. Sandeep Bakshi
Chancellor
JNU, Jaipur

Patron

Prof. H. N. Verma
Pro-Chancellor, JNU, Jaipur
Chairman, NASI Rajasthan Chapter Jaipur

Patron

Prof. R. L. Raina
Vice-Chancellor
JNU, Jaipur

Chair

Prof. (Dr.) Yogesh Chandra Sharma
Director, Research & Academic Development
JNU, Jaipur

A. K. Jain, Roorkee

B. P. Tyagi, Dehradun

Bhupati Chakrabarti, Kolkata

D. C. Gupta, Kanpur

G. Venkatesh, Bangalore

H. C. Verma, Kanpur

K. N. Joshipura, Anand, Gujarat

M. S. Jogad, Kalburgi, Karnatak

Manjit Kaur, Chandigarh

Meenakshi Sayal, Jalandhar

P. D. Lele, National Coordinator, NCICP, IAPT, Ahmedabad

P. K. Ahluwalia, Shimla

Pradeep Kumar Dubey, Indore

R. S. Geetha, National Coordinator, NCIEP, IAPT, Bengaluru

Ranjita Deka, Guwahati

Ravi Bhattacharjee, Delhi

Rekha Ghorpade, General Secretary, IAPT, Thane

S. K. Joshi, National Coordinator, NCEWP, IAPT, Delhi

Sanjay Kr. Sharma, Kanpur

Sarmistha Sahu, Bangalore

Shivanand A. Masti, Hasarchampur, Maharashtra

U. S. Kushwaha, Chandigarh

Vijay A Singh, Mumbai

Ajayshree Sharma, Bhartiya Vidya Bhavan's Vidyashram School, Jaipur

Akash Shukla JNU, Jaipur

Anuj Shah JNU, Jaipur

Ashish Mittal JNU, Jaipur

Balram Tripathi, Subodh PG College, Jaipur

Dilip Srivastava, St. Xavier's School, Jaipur

Gaurav Jamwal, JNU, Jaipur

Hariom Ojha, Subodh School, Jaipur

K. S. Sharma, IIS University, Jaipur

Lokesh Lodha, Jnu, Jaipur

Mahesh Sharma, IIS University, Jaipur

Minal Bafna, Agarwal PG College, Jaipur

Mukesh Payak, Azeem Premji Foundation, Jaipur

Nitin Singh JNU, Jaipur

Pankaj Srivastava JNU, Jaipur

Preetam Singh JNU, Jaipur

R. K. Khanna, National Executive Member, IAPT, Rajasthan, Jaipur

R. K. Parashari, Jayashree Periwal School, Jaipur

Raj Bahadur Gupta, IIS School, Jaipur

Ramphal Sharma, IIS University, Jaipur

Ritu Jain, IIS University, Jaipur

Sanjay Pachori JNU, Jaipur

Vipin Jain, JKL University, Jaipur

Y. C. Bhatt, MNIT Jaipur

Y. K. Vijay, IIS University, Jaipur

Yogesh Bhatnagar, St. Xavier's School, Jaipur

ANNOUNCEMENT

JAIPUR NATIONAL UNIVERSITY, JAIPUR

in association with

Center for Excellence in Quantum Science (CEQS)
Indian Association of Physics Teachers (IAPT), RC-06, Rajasthan Chapter
&
National Academy of Sciences India (NASI), Rajasthan Chapter

organize

Seminar on
"Discovery & Detection of Gravitational Waves"

September 14, 2024

Aim: This seminar is organized to commemorate the historic detection of Gravitational Waves on September 14, 2015, a discovery that validated Einstein's General Theory of Relativity. This groundbreaking achievement was realized at the Laser Interferometer Gravitational Wave Observatory (LIGO) in the USA. The key contributors to this discovery, R. Weiss, B. C. Barish, and K. S. Thorne, were awarded the Nobel Prize in Physics in 2017 "for decisive contributions to the LIGO detector and the observation of gravitational waves." This seminar features lectures by eminent speakers aimed at enlightening young students and faculty members on the significance of Gravitational Waves and their detection in fundamental physics.

Topics:

1. Waves, Interference, Michelson's Interferometer: An in-depth exploration of wave properties, interference phenomena, and the working principles of Michelson's interferometer.
2. Michelson-Morley Experiment and Foundation for Einstein's Special Theory of Relativity: Understanding the pivotal Michelson-Morley experiment and its critical role in laying the groundwork for Einstein's Special Theory of Relativity.
3. Dark Energy, Gravitational Waves, and General Theory of Relativity: A comprehensive discussion on dark energy, the nature of gravitational waves, and how they fit into the framework of Einstein's General Theory of Relativity.
4. Discovery of Gravitational Waves and its Importance in the Verification of

General Theory of Relativity: Insights into the monumental discovery of gravitational waves and its profound implications for verifying the General Theory of Relativity.

Join us on September 14, 2024, to delve into the fascinating world of gravitational waves and celebrate the scientific achievements that have reshaped our understanding of the universe. Speakers will be renowned experts in the field who will share their insights and latest research on gravitational waves.

We look forward to your participation!

Use link to register https://forms.gle/86eoK5W6bhNUS9ZQ6

Contact:

Prof. (Dr.) Yogeshchandra Sharma

Director, Research & Academic Development, Jaipur National University

Vice President, IAPT-RC6

Treasurer, MRSI-Rajasthan Chapter

Jaipur (Rajasthan) India - 302 017.

Mobile: 9664075093

Gravitational Waves: Revolutionizing Our View of the Universe

Prof. (Dr.) Yogesh Chandra Sharma
Director, Research & Academic Development, Jaipur National University
Director, Center for Excellence in Quantum Science (CEQS), Jaipur
Vice President, IAPT-RC6; Treasurer, MRSI-Rajasthan Chapter
Mobile: 9664075093; email: director.res.acad.dev@jnujaipur.ac.in

Abstract

Gravitational wave astronomy is a revolutionary field that opens an entirely new way of observing the universe. Unlike electromagnetic radiation—such as light, radio waves, or X-rays—gravitational waves carry information about the dynamics of massive objects through ripples in spacetime itself. These waves are generated by cataclysmic events such as the merging of black holes, neutron star collisions, or supernova explosions, and they propagate through the universe almost unaffected by matter.

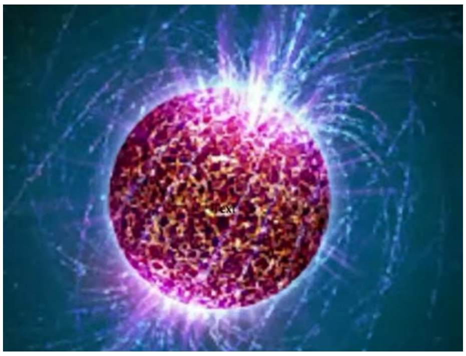
While gravitational waves were first predicted by Albert Einstein in 1916, their detection and study have only become possible in the last few decades due to advancements in highly sensitive detectors, such as LIGO and Virgo. The weak coupling of gravitational waves with matter makes them difficult to detect, but it also allows them to pass through the universe with little absorption or scattering, offering a pristine view of the most extreme and energetic events in the cosmos.

Introduction:

This article delves into key topics that shape human understanding of gravitational wave astronomy, including a comparison between Electromagnetic vs. Gravitational Radiation, the core principles of General Relativity and Spacetime Curvature, and a clear explanation of Gravitational Waves themselves. We will further explore how gravitational waves are produced in the section on the Generation of Gravitational Waves and take a Historical Perspective on how these theories evolved.

The significance of gravitational wave astronomy will become apparent with discussions like, Why Gravitational Wave Astronomy Matters and the methods of Detection of Gravitational Waves, focusing on How LIGO Detects Gravitational Waves. Different kinds of waves will be outlined in the Types of Gravitational Waves, followed by a discussion of the Advantages of Gravitational Wave Astronomy in contrast to traditional methods. Finally a forward-looking view at the Future Prospects of this exciting field will be taken.

Through this journey, one will discover how gravitational wave astronomy provides a unique and powerful tool for uncovering the hidden mysteries of the universe.

Gravitational radiation, much like electromagnetic radiation (which includes radio waves, infrared, visible light, and X-rays), transports energy through propagating waves or fluctuations in a field (a comparison given in table 1 below). While electromagnetic radiation involves fluctuations in the electromagnetic field, gravitational radiation pertains to fluctuations in the gravitational field. Both gravitation and electromagnetism are long-range forces that can exhibit radiative behavior. However, there are two key differences between them:

1. Strength of Forces: The electromagnetic force is significantly stronger than the gravitational force.
2. Charge Characteristics: Electromagnetic charge can be positive or negative, whereas gravitational "charge" (mass) only has one sign.

Table 1: Electromagnetic vs. Gravitational Radiation

	Electromagnetic Radiation	**Gravitational Radiation**
Origin	Generated by individual charged particles undergoing rapid acceleration.	Produced by the bulk motion of large masses.
Astrophysical Bodies	Typically electrically neutral due to the strong electromagnetic force and repulsion between like charges.	Large masses can accumulate because gravitational charge is always attractive.
Emission	The brightest sources emit a mix of high-frequency radiation from ionized materials.	Strongest at low frequencies due to coherent, large-scale motions.
Interaction with Matter	Easily absorbed and scattered, meaning we only observe radiation from the outer layers of sources.	Weakly interacts with matter, resulting in minimal absorption or scattering. The universe is nearly transparent to gravitational waves.
Information Gained	Provides insights into the thermodynamic state and material composition of the source.	Reveals the dynamics of the source, such as mass movements, rather than its thermodynamic state.

General Relativity and Spacetime Curvature

Einstein's General Theory of Relativity describes gravity not as a force but as a curvature of spacetime caused by mass, energy, and stress. Key concepts include:

- **Spacetime Curvature**: Massive objects cause spacetime to curve, influencing the motion of other objects.
- **Free-Falling Test Particles**: These particles follow the straightest possible paths in curved spacetime, known as geodesics.
- **Tidal Effects**: Manifestations of spacetime curvature, where objects initially moving parallel can converge or diverge due to gravitational gradients.
- **Propagation of Gravitational Fields**: Unlike Newtonian gravity, general relativity posits that gravitational changes propagate at a finite speed—the speed of light.

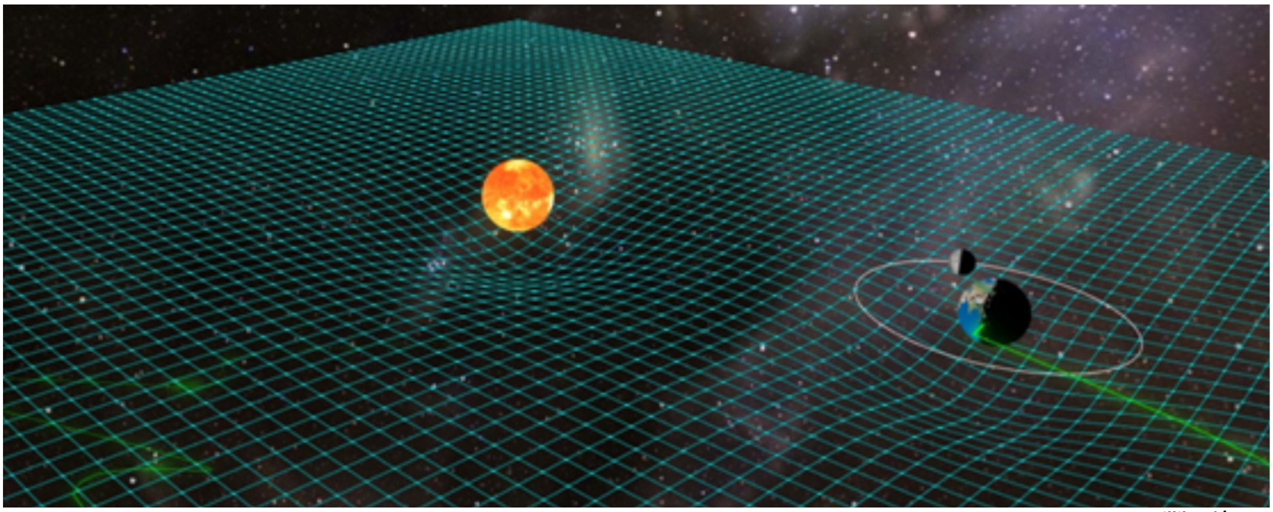


Image: Ben Gilliland/STFC

Fig. 1: Spacetime Curvature

Gravitational Waves Explained

Gravitational waves are ripples in spacetime curvature that propagate outward from their sources. They are characterized by:

1. **Oscillating Tidal Fields**: These cause periodic changes in the distance between nearby free-falling objects.

$$h = \frac{\Delta l}{l}$$

2. **Strain (h)**: Defined as the fractional change in distance between two free-falling objects separated by a distance “l” caused by a passing gravitational wave, calculated as:

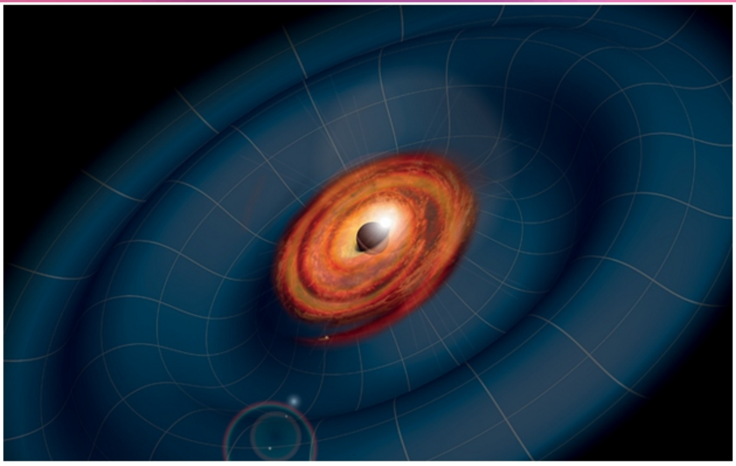


Image: Ben Gilliland/STFC

Fig. 2: Artist's impression of a black hole generating Gravitational waves.

3. **Polarizations**: General relativity predicts two types of gravitational wave polarizations, h_+ and $h_\times$, which cause displacements in perpendicular directions. The strain h on a particular pair of objects is a linear superposition of these two polarizations

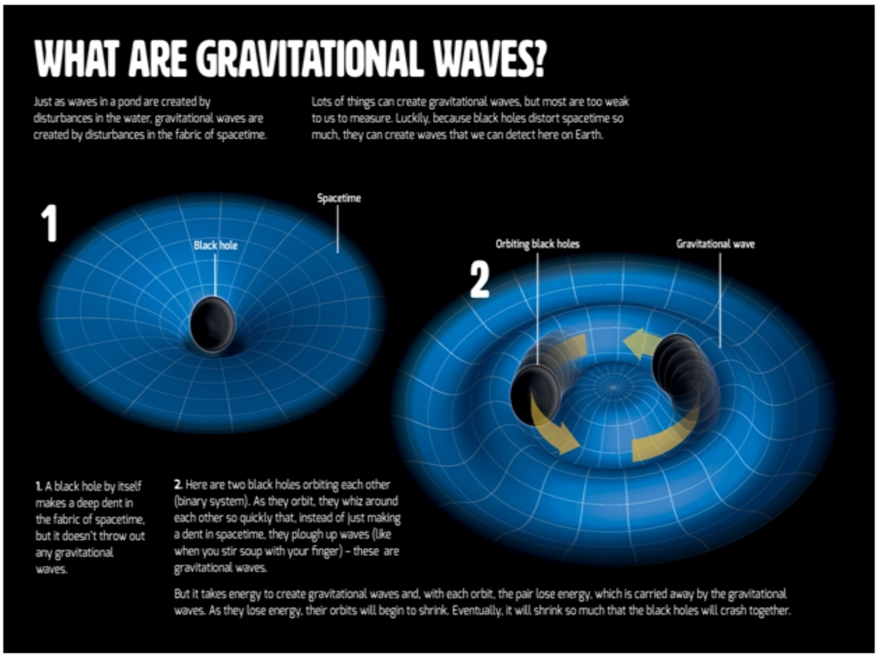


Image: Ben Gilliland/STFC

Fig. 3: Generation of Gravitational waves-I.

Generation of Gravitational Waves

According to Einstein's equations, gravitational waves are produced by accelerating masses. The most significant sources are systems with large masses undergoing rapid, nonsymmetric motions, such as:

- **Binary Systems**: Pairs of neutron stars or black holes orbiting each other.
- **Supernovae**: Explosive deaths of massive stars.
- **Early Universe**: Potentially from processes during the Big Bang.

Gravitational waves require changes in the quadrupole moment (or higher) of a mass distribution to be generated. Unlike electromagnetic waves, which can be produced by dipole (single charge) changes, gravitational waves do not exhibit dipole radiation due to the conservation of momentum and the equivalence of gravitational and inertial mass.

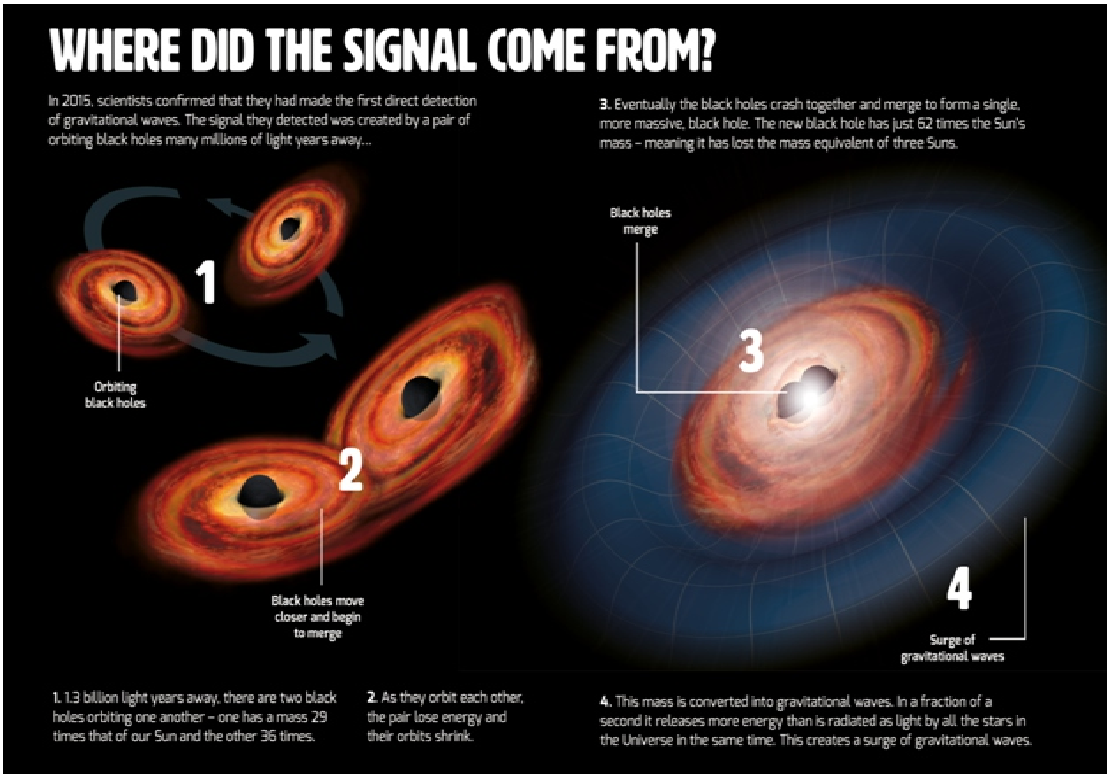


Image: Ben Gilliland/STFC

Fig. 4: Generation of Gravitational waves-II.

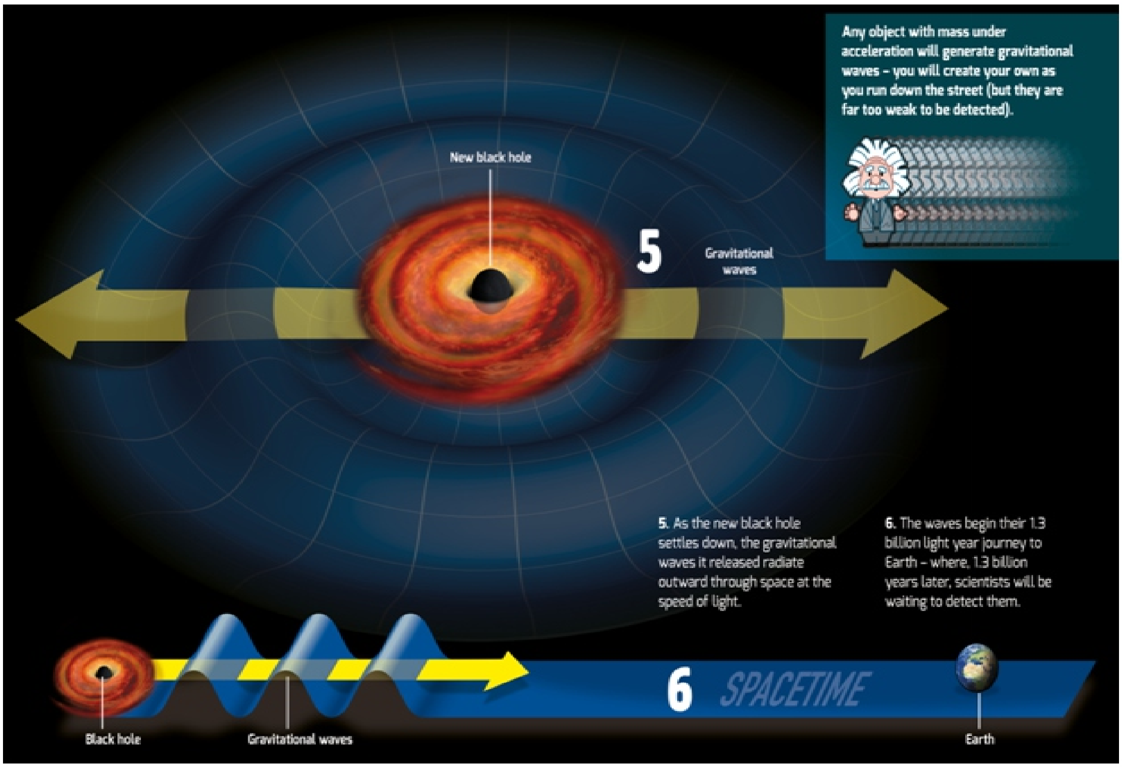


Image: Ben Gilliland/STFC

Fig. 5: Propagation of Gravitational waves-I.

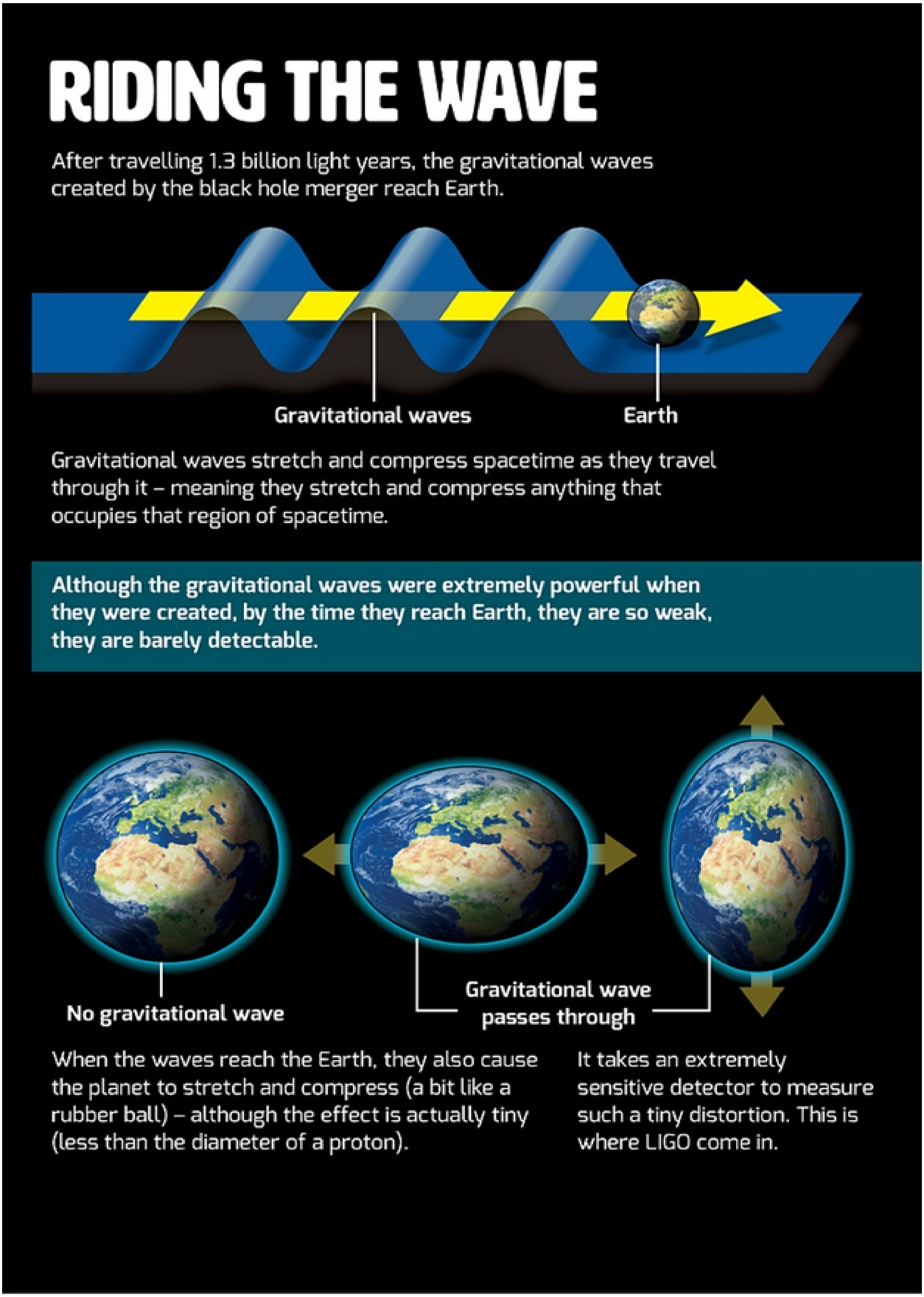


Image: Ben Gilliland/STFC

Fig. 6: Propagation of Gravitational waves-II.

Amplitude of Gravitational Waves

For weak gravitational fields and slow-moving sources, the strain "h" produced by a gravitational wave at a distance "D" from the source is approximately:

$$h \approx \frac{2G}{c^4 D^2} \frac{d^2 Q}{dt^2}$$

Where:

- G is Newton's gravitational constant.
- c is the speed of light.
- Q is the quadrupole moment of the mass distribution.
- $\frac{d^2 Q}{dt^2}$ represents the second time derivative of the quadrupole moment.

For astrophysical sources like those with solar masses ($M_{\odot}$) at megaparsec (M_{pc}) distances, the expected strain is on the order of 10^{-20}. Detecting such tiny strains requires highly sensitive instruments, which has only recently become feasible.

Historical Perspective

Until the 1960s, the scientific community debated the observability of gravitational waves due to the complexities in general relativity and distinguishing physical effects from mathematical artifacts. The strongest arguments supporting their physical reality come from the energy they carry:

- **Energy Transport**: Gravitational waves can perform work on objects, such as raising ocean tides through time-varying tidal fields.

Energy Loss in Systems: Systems emitting gravitational waves lose energy, causing observable changes in their motion (e.g., binary pulsars spiraling inward).

The energy carried by gravitational waves through an area "dA" over time "dt" is given by:

$$dE = \frac{c^3}{16\,\pi\,G}\left[\left(\frac{\partial\,h_+}{\partial\,t}\right)^2 + \left(\frac{\partial\,h_\times}{\partial\,t}\right)^2\right] dA\;dt$$

Within the quadrupole approximation, the rate of energy loss "dE/dt" from a source is:

$$\frac{dE}{dt} = \frac{G}{5\,c^5}\sum_{i,j=1}^{3}\left(\frac{d^3\,Q_{ij}}{\partial t^3}\right)^2$$

Where "Qij" is the quadrupole moment tensor, defined as:

$$Q_{ij} = q_{ij} - \frac{1}{3}\,\delta_{ij}\,q_{kk}$$

and:

$$q_{ij} = \sum_{\text{particles}} m\,x_i x_j$$

Here, m is the mass of a particle, and x_i are its position coordinates relative to an arbitrary origin.

Why Gravitational Wave Astronomy Matters

Gravitational wave astronomy opens a new window into the Universe, complementing traditional electromagnetic observations. Its significance includes:

New Observational Capabilities:

- Detecting phenomena invisible to electromagnetic telescopes, such as merging black holes.
- Providing insights into the dynamics of massive objects and extreme environments.

Unbiased Information:

- Gravitational waves travel through the Universe with minimal interaction, preserving the information from their sources without distortion.
- Unlike electromagnetic waves, they are not absorbed, reflected, or scattered by intervening matter.

Probing the Early Universe:

- Potential to detect relic gravitational waves from the Big Bang, offering a glimpse into the Universe's earliest moments.

Testing General Relativity:

- Providing empirical data to test and refine our understanding of gravity and spacetime.

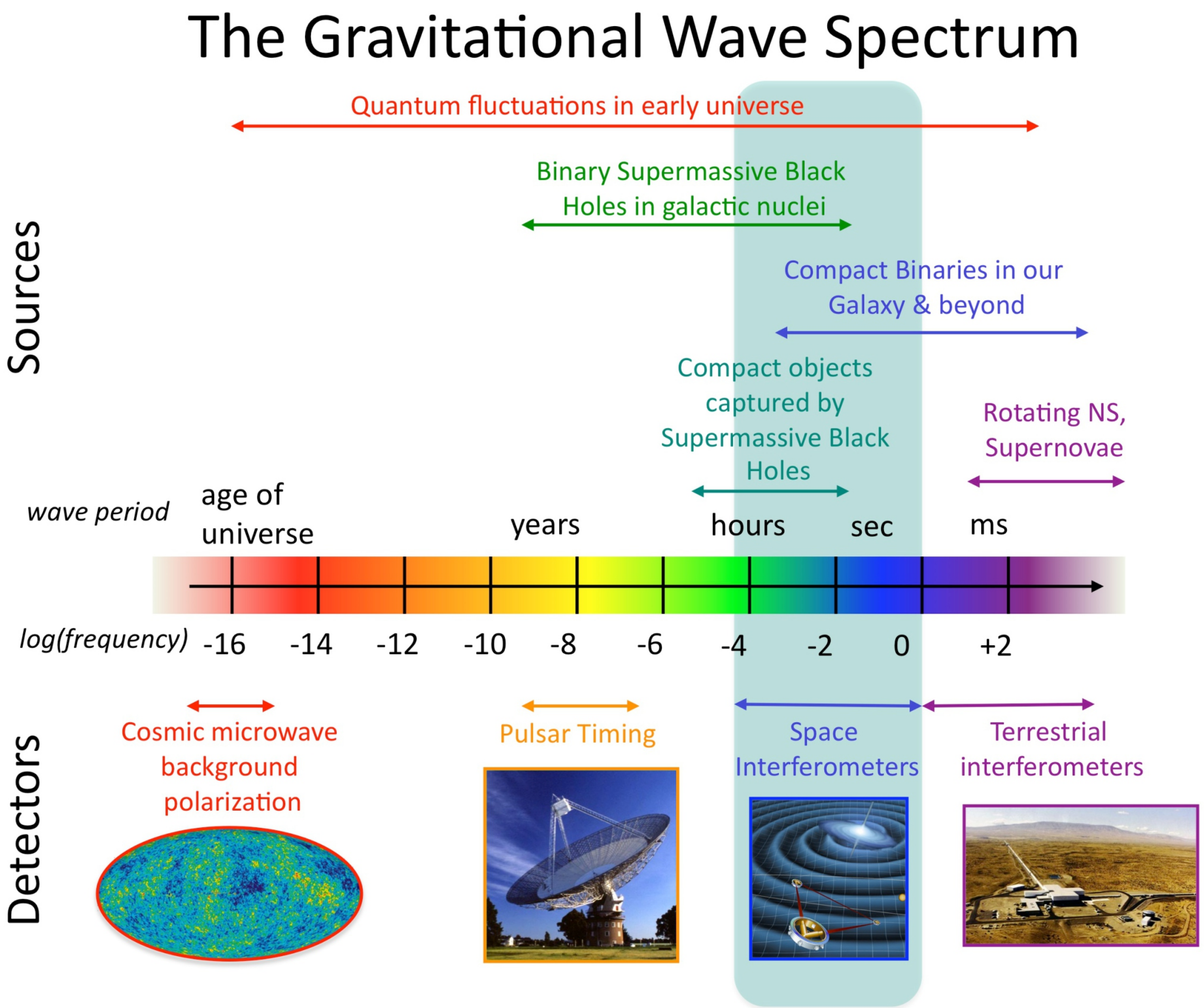


Fig. 7: The gravitational wave spectrum with sources and detectors. Credit: NASA Goddard Space Flight Center.

Detection of Gravitational Waves

The detection of gravitational waves is an extraordinary technological achievement, requiring instruments capable of measuring incredibly tiny strains in spacetime. Key milestones include:

Indirect Detection (1974):

- Russell Hulse and Joseph Taylor discovered a binary pulsar whose orbital decay matched predictions from gravitational wave emission, earning them the Nobel Prize in Physics in 1993.

Direct Detection (2015):

- The Laser Interferometer Gravitational-Wave Observatory (LIGO) made the first direct observation of gravitational waves from the merger of two black holes, confirming Einstein's century-old prediction.

How LIGO Detects Gravitational Waves

LIGO detects gravitational waves using laser interferometry, which measures the minute changes in distance between mirrors placed kilometers apart. When a gravitational wave passes through Earth, it slightly stretches and compresses spacetime, causing detectable shifts in the interference pattern of the lasers.

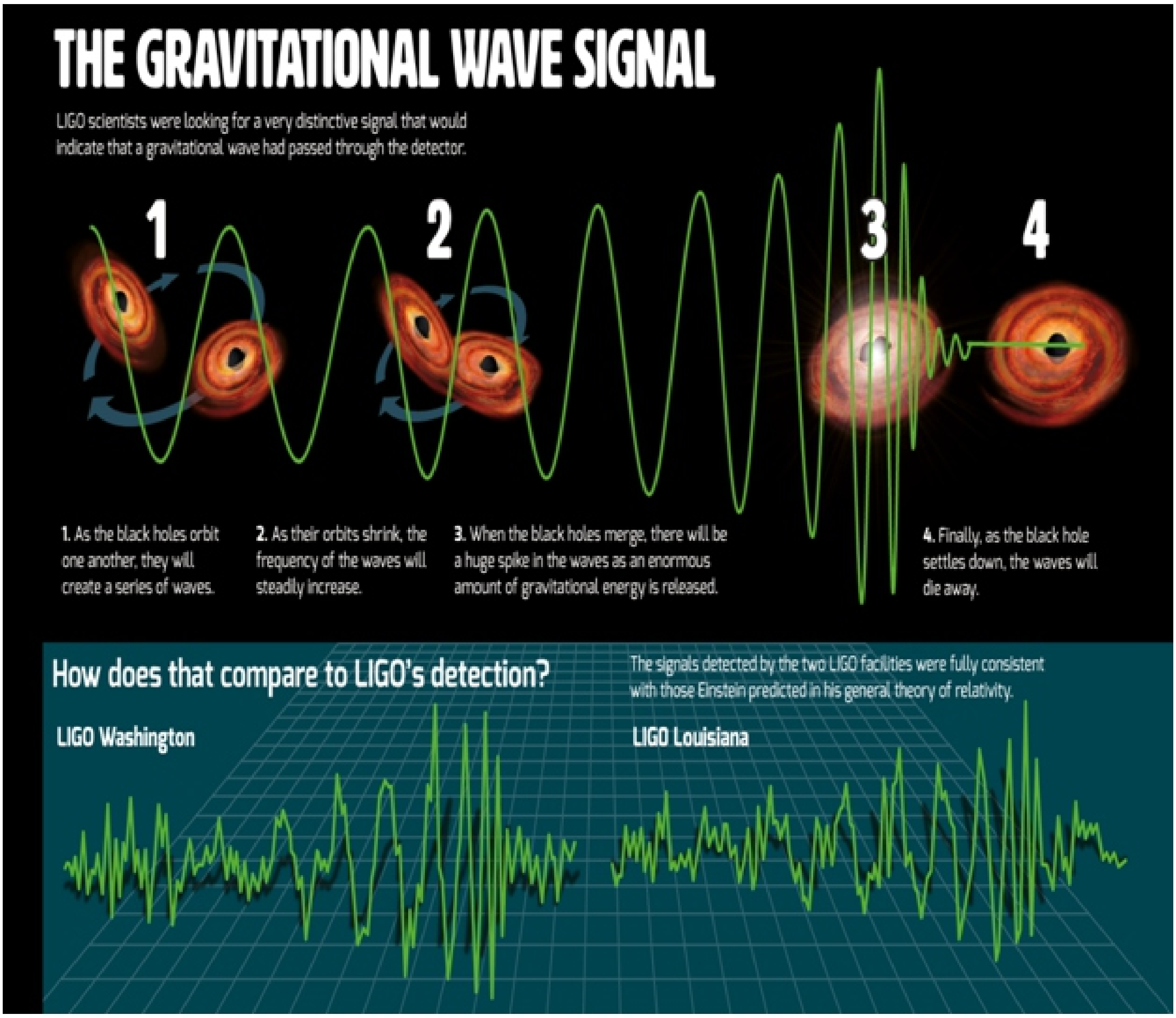


Image: Wikipedia

Fig. 8: LIGO and Gravitational wave detection-I.

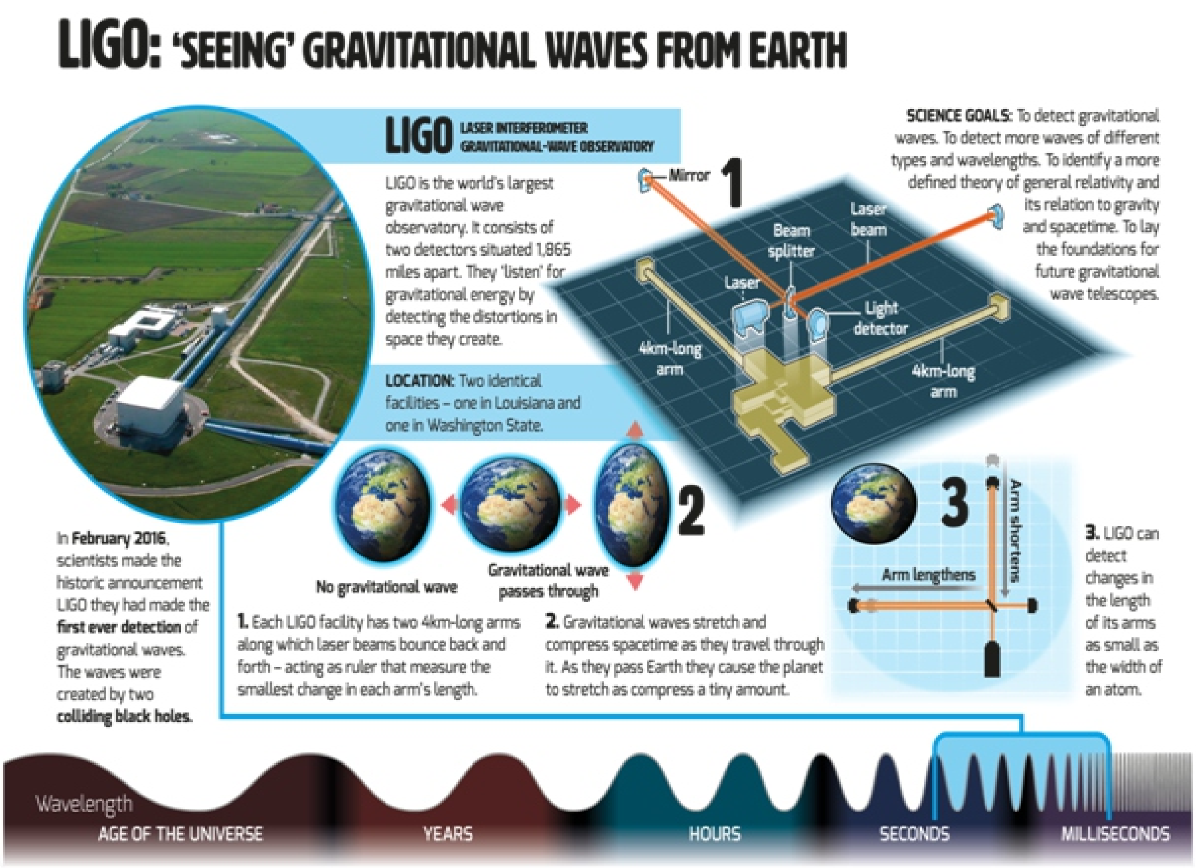


Image: Wikipedia

Fig. 9: LIGO and Gravitational wave detection-II.

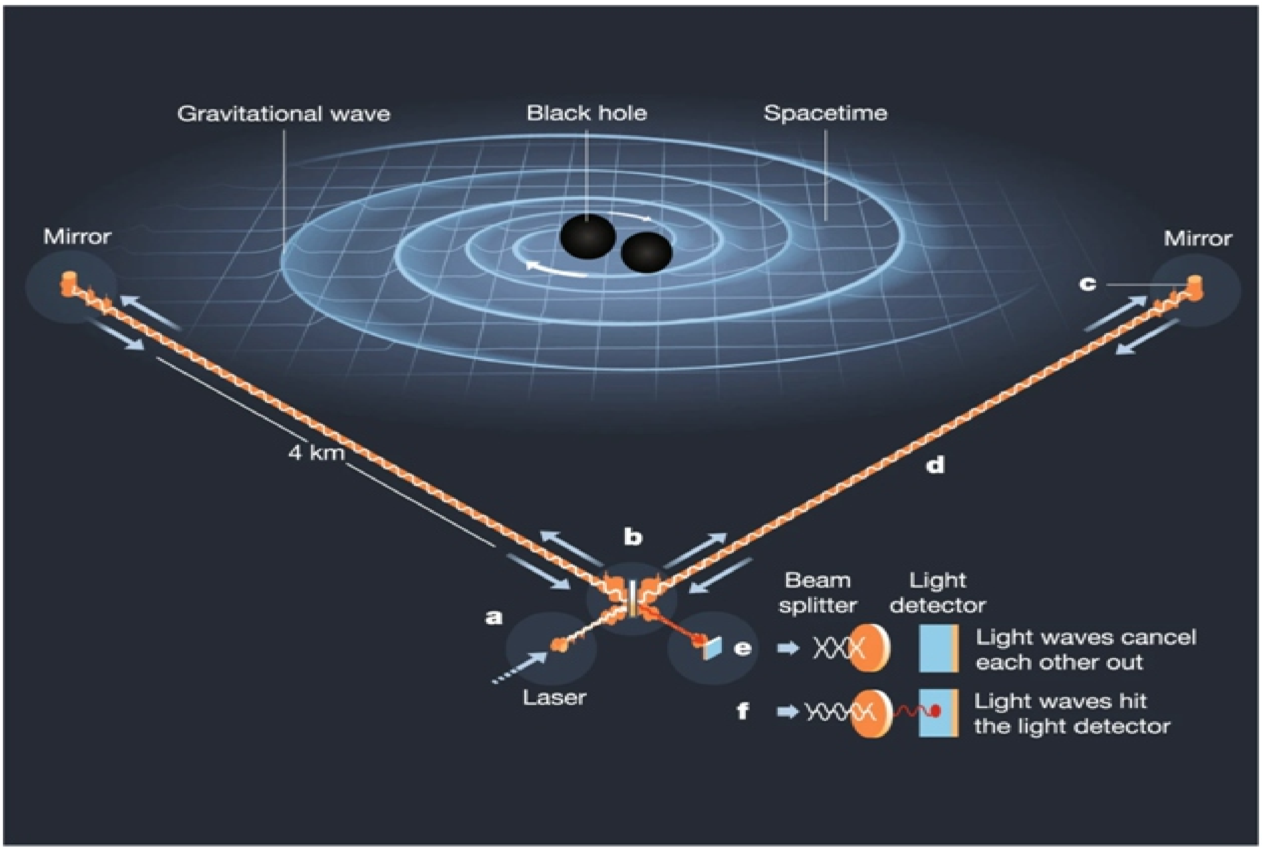


Image: Wikipedia

Fig. 10: LIGO and Gravitational wave detection-III.

Key Features:

- **Sensitivity**: LIGO can measure strains as small as 10−2010−20, which are 10,00010,000 times smaller than the nucleus of an atom.
- **Frequency Range**: Optimized to detect waves from events like black hole and neutron star mergers, which emit waves within LIGO's sensitive frequency band.

Types of Gravitational Waves

Gravitational waves are categorized based on their sources and characteristics, as given in table 2 below.

Table 2: Categories of Gravitational Waves

	Continuous GW	Compact Binary Inspiral GW	Stochastic GW	Burst GW
Source	Single, spinning massive objects like neutron stars with imperfections.	Pairs of compact objects (neutron stars or black holes) orbiting each other.	A superposition of many small, random gravitational waves from various sources, potentially including the Big Bang.	Short-duration, unanticipated events like supernovae or unknown cosmic phenomena.
Characteristics	Emit waves at a constant frequency and amplitude, analogous to a continuous musical note.	Waves increase in frequency and amplitude as the objects spiral inward, culminating in a merger.	Forms a random, background signal that requires statistical methods to detect.	Sudden and brief waveforms without a well-defined model.
Detection	Requires long-term observation to identify persistent signals.	Typically last from a fraction of a second to tens of seconds in LIGO's sensitive range.	Challenging due to the need to distinguish the stochastic background from noise.	Requires flexible analysis techniques to identify unexpected patterns.

Advantages of Gravitational Wave Astronomy

Gravitational wave astronomy provides several unique advantages:

- **Penetrating Power**: Gravitational waves pass through matter with minimal interaction, allowing us to observe events obscured by dust, gas, or other intervening materials.
- **Direct Information on Dynamics**: Offers direct insights into the motions and interactions of massive objects.
- **Complementary to Electromagnetic Observations**: Enhances our understanding by providing a different type of data, enabling multi-messenger astronomy when combined with electromagnetic and neutrino observations.

Future Prospects

The field of gravitational wave astronomy is rapidly evolving, with ongoing and future developments aimed at expanding our capabilities:

- **Enhanced Sensitivity**: Upgrades to detectors like LIGO and the development of new observatories (e.g., Virgo, KAGRA, and future space-based detectors like LISA) aim to increase sensitivity and detect a broader range of gravitational wave sources.
- **Multi-Messenger Astronomy**: Coordinating gravitational wave detections with electromagnetic and neutrino observations to gain a more comprehensive understanding of cosmic events.
- **Exploring Fundamental Physics**: Using gravitational waves to probe the nature of gravity, test general relativity in extreme conditions, and explore potential new physics beyond our current theories.

Conclusion

Gravitational waves have revolutionized our ability to observe and understand the Universe. By detecting these subtle ripples in spacetime, scientists have unlocked a new method for probing the cosmos, revealing phenomena that were previously invisible to traditional electromagnetic observations. As technology advances and our detection capabilities improve, gravitational wave astronomy promises to deepen our comprehension of the fundamental forces and the most enigmatic and powerful events in the Universe

References and Bibliography:

1. Miller, M.C., Yunes, N. The new frontier of gravitational waves. *Nature* **568**, 469–476 (2019).
2. Bailes, M., Berger, B.K., Brady, P.R. *et al.* Gravitational-wave physics and astronomy in the 2020s and 2030s. *Nat Rev Phys* **3**, 344–366 (2021).
3. Barish, B. C., and R. Weiss. 1999. LIGO and the detection of gravitational waves. Physics Today 52(10):44–50.
4. Brady P. R. and Creighton J. D.E., Gravitational Wave Astronomy, p 33-48; Poggiani R., Gravitational Wave Detectors, p 49-65; Kokkotas K. D., Gravitational Wave Physics p 67-85; Hariharan P., Optical Interferometry p 371 -379; Anderson J. L., General Relativity, p 93-116; 2003 (Ed.: Robert A. Meyers), Encyclopedia of Physical Science and Technology (Third Edition), Academic Press.
5. Lyne, A. G., M. Burgay, M. Kramer, A. Possenti, R. N. Manchester, F. Camilo, M. A. McLaughlin, D. R. Lorimer, N. D'Amico, B. C. Joshi, J. Reynolds and P. C. C. Freire. 2004. A double-pulsar system: A rare laboratory for relativistic gravity and plasma physics. Science 303:1153–1157.
6. Saulson, P. R. 1994. Fundamentals of Interferometric Gravitational Wave Detectors. Singapore: World Scientific.
7. Schutz, B. S. 2003. Gravity from the Ground Up. Cambridge, U.K.: Cambridge University Press.
8. Taylor, J. H., and J. M. Weisberg. 1982. A new test of general relativity: Gravitational radiation and the binary pulsar PSR 1913+16. Astrophysical Journal 253:908–920.
9. Will, C. M. 1993. Was Einstein Right? Putting General Relativity to the Test. New York: Basic Books.
10. Will, C. M. 1999. Gravitational radiation and the validity of general relativity. Physics Today 52(10):38–43.
11. https://www.ligo.caltech.edu/page/why-detect-gw
12. "Gravitational Astrophysics Laboratory". science.gsfc/nasa.gov.

PROGRAM

S. No.	Name	Affiliation	Title
1	Prof. Gabriela Gonzalez	LSU Boyd Professor Physics and Astronomy Louisiana State University, LA, USA	International Collaboration in gravitational wave detection
2	Prof. K. N. Joshipura	Sardar Patel University, Anand, Gujarat	QUANTUM MECHANICS - AT A GLANCE
3	Prof. Sarah Shandera	Director, Institute for Gravitation and the Cosmos, Davey Laboratory University Park, Penn State, USA	Gravitational Waves and Dark Matter Discovery
4	Prof. P. C. Deshmukh	IIT, Tirupati & RV University, Bengaluru	Unriddling the General Theory of Relativity
5	Prof. T. Souradeep	Director, Raman Research Institute, Bangalore	Quests & conquests: Gravitational wave science
6	Prof. Manjari Bagchi	The Institute of Mathematical Sciences, Chennai	Hunting low-frequency gravitational waves through Pulsar Timing Arrays: The role
7	Dr. Suvodip Mukhrjee	Tata Institute of Fundamental Research (TIFR), Mumbai	Gravitational Wave Astronomy: A New Frontier
8	Dr. S. Sunil	Scientific Officer at Institute for Plasma Research (IPR), Gandhinagar.	Role of vacuum in gravitational wave detection
9	Mr. Saurabh Salunkhe	Senior outreach coordinator for LIGO-India Inter- University Centre for Astronomy and Astrophysics, Pune	LIGO-India Educational and Career Opportunities

10	Prof. Patrick Das Gupta	University of Delhi, Delhi	Extragalactic sources of Gravitational Radiation
11	Dr. Suresh Doravari	Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune	An Introduction to Advanced LIGO Detectors
12	Prof. Sudip Bhattacharyya	Tata Institute of Fundamental Research (TIFR), Mumbai	Many incarnations of neutron stars
13	Prof. Anand Sengupta	IIT Gandhinagar	Highlights from the Gravitational Wave Songbook
14	Prof. Arunava Mukherjee	Saha Institute of Nuclear Physics, Kolkata	Aspects of Fundamental Physics and Astrophysics with Compact Objects in Gravitational Waves
15	Prof. Y C Sharma	JNU	Vote of thanks

JAIPUR NATIONAL UNIVERSITY, JAIPUR

in association with

Center for Excellence in Quantum Science (CEQS)

Indian Association of Physics Teachers (IAPT), RC-06, Rajasthan Chapter

&

National Academy of Sciences India (NASI), Rajasthan Chapter

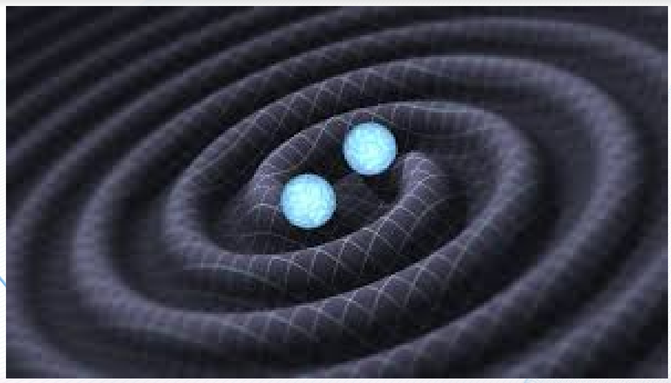
organize

Precursor to Seminar on "Discovery & Detection of Gravitational Waves"

September 13, 2024

Virtual Tour of LIGO Livingston Detector

The U.S. National Science Foundation Laser Interferometer Gravitational-wave Observatory (NSF LIGO) was established to pioneer the field of gravitational-wave astrophysics by directly detecting gravitational waves, as predicted by Einstein's General Theory of Relativity. Using advanced laser interferometry, LIGO's large-scale detectors, located in Hanford, Washington, and Livingston, Louisiana, measure tiny disturbances in space-time caused by events like colliding neutron stars or black holes. LIGO made the groundbreaking first detection of gravitational waves in 2015. This historic achievement marked the beginning of a new era in astronomy. The LIGO Laboratory, based at Caltech and MIT, oversees detector operations, research, and public outreach, all under the funding and guidance of the U.S. National Science Foundation.



JAIPUR NATIONAL UNIVERSITY, JAIPUR

in association with

Center for Excellence in Quantum Science (CEQS)

Indian Association of Physics Teachers (IAPT), RC-06, Rajasthan Chapter

&

National Academy of Sciences India (NASI), Rajasthan Chapter

organize

Precursor to Seminar on "Discovery & Detection of Gravitational Waves"

September 13, 2024

Philately Exhibition on the theme "Unfolding Mysteries of the Cosmos"

"Unfolding Mysteries of the Cosmos" is a philatelic exhibit and audiovisual journey exploring humanity's evolving view of the universe, from ancient cosmologies to modern space technology and its cultural impacts. Discover the cosmos through rare postage stamps and covers.

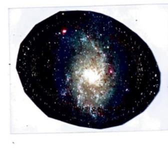
***Triptych pair**-Large Magellanic Cloud-earliest recorded satellite galaxy of milky way*

Pleiades Cluster-0r *seven sister-* open star cluster in Taurus consist hot blue and luminous stars

Whirlpool Galaxy-interacting grand design spiral galaxy in Cancer

Sombrero(hat) galaxy-is a lenticular galaxy with dust lane with supermassive blackhole inside

Rose galaxy-is pair of interacting galaxies with large galaxy distorted into rose like shape



***Triangulum Galaxy**-pinwheel galaxy* local group of spiral galaxies

Cigar Galaxy-is a starburst galaxy with new stars born at centre 1o time faster rate than milky way

View of milky way from the Earth

Spiral galaxy and Hubble Telescope

Pyramid of Giza and Abu Simble temple of Egypt are perfectly aligned with coordinal points

Joint issue – se-tenant pair- ancient observatories- Chomsongdae (Korea) and stone observatory -Jantar Mantar. (Jaipur, India)

Advisory Board

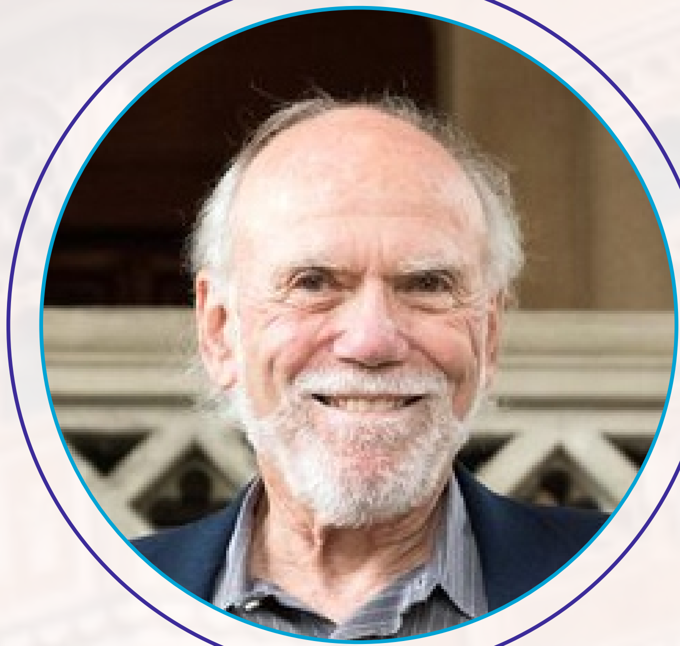
CHIEF PATRONS

2017 Physics NOBEL Laureates

PROF. RAINER WEISS
Professor of Physics (Emeritus)
Massachusetts Institute of Technology (MIT),
Cambridge, USA

PROF. KIP S. THORNE
Richard P. Feynman Professor of
Theoretical Physics (Emeritus)

PROF. BARRY C. BARISH
Ronald and Maxine Linde Professor of
Physics (Emeritus)



The Division of Physics, Mathematics and Astronomy

Advisory Board

PATRONS

PROF. RICHARD H. PRICE
Cambridge, USA

PROF. SARAH SHANDERA
PennState, USA

PROF. T. SOURADEEP
Bangalore

PROF. A. C. PANDEY
New Delhi

PROF. A. BHARDWAJ
Ahmedabad

MEMBERS

PROF. H. C. VERMA
Kanpur

PROF. P. C. DESHMUKH
Bengalore

PROF. K. N. JOSHIPURA
Anand

PROF. ARCHANA PAI
Bombay

PROF. PATRICK DAS GUPTA
Delhi

DR. WILLIAM KATZMAN
Livingston, LA, USA

PROF. GABRIELA GONZÁLEZ
Louisiana, LA, USA

PROF. JORGE PULLIN
Louisiana, LA, USA

PROF. S. BHATTACHARYYA
Mumbai

PROF. MANJARI BAGCHI
Chennai

JAIPUR NATIONAL UNIVERSITY

NAAC A+

Prof. Rainer Weiss, born on September 29, 1932, in Berlin, Germany, is a physicist who was awarded the 2017 Nobel Prize in Physics for his decisive contributions to the development of the LIGO detector and the observation of gravitational waves. His family fled Nazism and settled in the United States, where Weiss later earned his doctorate from the Massachusetts Institute of Technology (MIT) in 1962. After brief stints at Tufts and Princeton, he returned to MIT, where he has had a long career. Weiss played a pivotal role in the design of the LIGO detector, which uses laser technology to measure tiny changes caused by gravitational waves, a prediction of Einstein's theory of relativity. His work was instrumental in the first detection of gravitational waves in 2015.

2017 Physics NOBEL Laureate

CHIEF PATRON

PROF. RAINER WEISS

Professor of Physics (Emeritus)
Massachusetts Institute of Technology (MIT),
Cambridge, USA

International Seminar on "Discovery & Detection of Gravitational Waves"

JAIPUR NATIONAL UNIVERSITY

Prof. Kip S. Thorne, born on June 1, 1940, in Logan, Utah, is a renowned physicist who was awarded the 2017 Nobel Prize in Physics for his pivotal contributions to the development of the LIGO detector and the observation of gravitational waves. He earned his doctorate from Princeton University in 1965 and has since been affiliated with the California Institute of Technology (Caltech), where he has played a central role in advancing theoretical physics. Thorne's work focuses on Einstein's general theory of relativity, particularly the prediction and detection of gravitational waves, which are ripples in spacetime caused by accelerating masses. His efforts were instrumental in the 2015 detection of these waves, marking a groundbreaking moment in physics. Beyond his academic work, Thorne has contributed to popular science, notably consulting on the 2014 film Interstellar.

2017 Physics NOBEL Laureate

CHIEF PATRON

PROF. KIP S. THORNE

Richard P. Feynman Professor of Theoretical Physics (Emeritus)

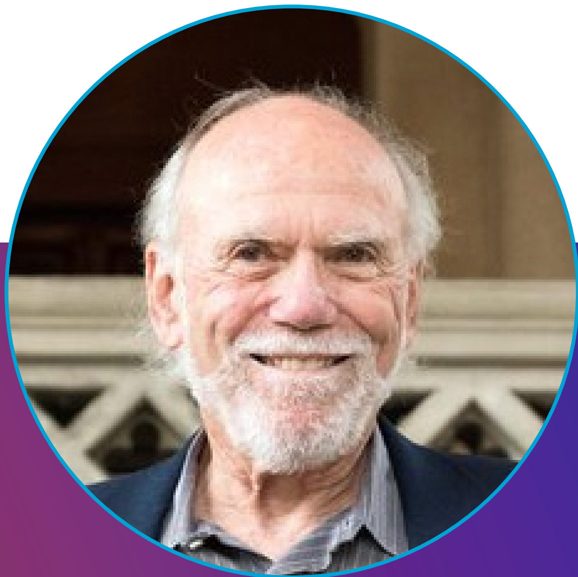
The Division of Physics, Mathematics and Astronomy

International Seminar on "Discovery & Detection of Gravitational Waves"

JAIPUR NATIONAL UNIVERSITY

Prof. Barry C. Barish, born on January 27, 1936, in Omaha, Nebraska, is a distinguished physicist who was awarded the 2017 Nobel Prize in Physics for his decisive contributions to the development of the LIGO detector and the observation of gravitational waves. Raised in Los Angeles after his family emigrated from Poland, Barish earned his doctorate from the University of California, Berkeley, in 1962. He joined the California Institute of Technology (Caltech) in 1963, where he became a key figure in the LIGO project. Barish's leadership from 1994 onward was instrumental in advancing the detector's ability to capture gravitational waves, a phenomenon predicted by Einstein's theory of relativity. His work culminated in the first successful detection of gravitational waves in 2015.

2017 Physics NOBEL Laureate



CHIEF PATRON

PROF. BARRY C. BARISH

Ronald and Maxine Linde Professor of Physics (Emeritus)

The Division of Physics, Mathematics and Astronomy

International Seminar on "Discovery & Detection of Gravitational Waves"

JAIPUR NATIONAL UNIVERSITY

Richard Price is a distinguished theoretical physicist specializing in relativistic astrophysics, black hole dynamics, and gravitational radiation. His research uses mathematical methods, computer modeling, and approximations to tackle complex problems in black hole dynamics and general relativity, applying intuition to uncover insights into astrophysical phenomena.

Price earned his PhD in theoretical physics from Caltech in 1971 under the guidance of Kip Thorne, after completing his Engineering Physics degree at Cornell University in 1965. His research contributions include work on perturbations of relativistic gravitational collapse and gravitational wave equations for binary neutron stars.

Price has authored numerous publications, including a pivotal paper on nonspherical perturbations of gravitational collapse, and contributed to popular science, editing "The Future of Spacetime" alongside leading physicists like Stephen Hawking and Kip Thorne.

PATRON

PROF. RICHARD H. PRICE

Professor of Physics, Cambridge, USA

JAIPUR NATIONAL UNIVERSITY

NAAC A+

Prof Avinash Chandra Pandey was Director, Institute of Interdisciplinary Studies, University of Allahabad since 2016 before joining IUAC as Director. He was Vice Chancellor of Bundelkhand University from 2012 to 2015. He has earlier been Professor at University of Allahabad. He is accredited with the development of the Nanotechnology Application Centre (NAC) besides setting up of High Fluence Ion Beam Facility: a state of art Ion Implanter facility in the premises of University of Allahabad and Innovation Center, Weather Station, Animal Research Facility at Bundelkhand University. He has earlier been Professor & Founder Head, Department of Atmospheric & Ocean Sciences and Co-ordinator of K Banerjee Centre of Atmospheric & Ocean Studies, M N Saha Center of Space Studies at University of Allahabad. He is also an Adjunct Professor at Michigan Tech, USA. His researches have focused in developing novel nonmaterial for various real life applications from LED, PDP, biomedical and diagnostics and a new fluorescent carbon material besides non-linear dynamics and surface modification using ion beams.

Prof Avinash Chandra Pandey has been an Associate of ICTP, Trieste, Italy (2004- 2009). He has been member of governing boards and academic councils/courts of many institutes such as INST, Mohali ARIES, Nanital, Dr H S Gour University, Saugor and University of Allahabad. He is a member of many academic societies such as American Physical Society, Ion Beam Society of India, Indian Meteorological Society, Computer Society of India, IETE, Biotechnology Research Society of India etc.

PATRON

PROF AVINASH CHANDRA PANDEY

Director, Inter University Accelerator Consortium (IUAC)
New Delhi

JAIPUR NATIONAL UNIVERSITY

Prof. Anil Bhardwaj is a distinguished scientist and an expert in planetary and space sciences. He received his M.Sc. from Lucknow University (1987) and Ph.D. from IIT-BHU (1992), joining the Indian Space Research Organisation (ISRO) in 1993 at the Vikram Sarabhai Space Centre (VSSC). He has held prominent positions, including Head of the Planetary Science Branch and Director of the Space Physics Laboratory. Since 2017, he has served as the Director of the Physical Research Laboratory (PRL), Ahmedabad.

Prof. Bhardwaj has played a pioneering role in developing planetary science programs at ISRO, contributing significantly to India's major space missions. He was the Principal Investigator for experiments on Chandrayaan-1, Mars Orbiter Mission, Chandrayaan-2, Chandrayaan-3, and the Aditya-L1 mission, advancing our understanding of the solar system.

His research in solar system X-ray astronomy has led to groundbreaking discoveries, including X-rays from the rings of Saturn and X-ray flares from Jupiter, recognized by NASA, ESA, and ISRO. With over 220 peer-reviewed publications, he has made remarkable contributions to space science.

PATRON

PROF. A. BHARDWAJ

Director, Physical Research Laboratory
Ahmedabad

JAIPUR NATIONAL UNIVERSITY

Prof. H C Verma is a renowned Indian physicist and educator, best known for his contributions to physics education. He retired from the Department of Physics at the Indian Institute of Technology (IIT) Kanpur, where he served as a professor. He is widely recognized for his textbooks in physics for school and college students, especially his Concepts of Physics volumes, which have become essential learning resources. Prof. Verma has developed more than 600 physics experiments for classroom demonstrations and created 45 video lectures in Hindi to support school-level physics education.

Prof. Verma is the founder of Shiksha Sopan, an NGO that provides educational support and promotes Indian values among underprivileged families around IIT Kanpur. Prof. Verma is actively involved in the Indian Association of Physics Teachers (IAPT), through National Anveshika Network of India (NANI) which benefits students and teachers in 22 cities across India. The National Anveshika Experimental Skill Test (NAEST), initiated by him, encourages students to develop experimental skills in science. He has trained over 8000 school teachers in India, transforming the way physics is taught. His annual workshops, supported by the National Academy of Sciences India (NASI), have created a network of senior resource persons who help propagate innovative teaching methods. Prof. Verma also explores India's ancient scientific traditions, delivering talks on topics like ancient mathematics, surgery, and computational sciences. His lectures have been widely appreciated for bridging the past with contemporary science education. Prof. Verma's tireless efforts to democratize science education have left a profound impact on India's academic landscape.

MEMBER

PROF. H. C. VERMA

Professor of Physics (Retd.), IIT, Kanpur

JAIPUR NATIONAL UNIVERSITY

NAAC A+

William Katzman, as the Project Manager at the LIGO (Livingston Laser Interferometer Gravitational-Wave Observatory) developed Science Education Center (SEC) under the California Institute of Technology. The SEC was responsible for the Education and Public Outreach component of LIGO Livingston Observatory, with three main focus areas:

1. Utilizing lab facilities and cross-institute collaborations, the SEC provided opportunities for educators to enhance their teaching of science, particularly related to gravitational-wave science.
2. Targeting grades 5-9 and extending from K-16, the SEC organized on-site field trips to the LIGO Lab and Science Education Center and conducted off-site presentations to engage students in science education.
3. The SEC offered tours and educational experiences for the general public and community groups through its interactive exhibits and presentations. It also supported press and documentary filmmakers in sharing the "LIGO story" to inspire future scientists.

He has contributed immensely making Gravitational Science more popular through his endeavors.

MEMBER

DR. WILLIAM KATZMAN

Program Leader of LIGO Science Education Center,
California Institute of Technology (Caltech)
Livingston, LA, USA

JAIPUR NATIONAL UNIVERSITY

Prof. Jorge Pullin is a distinguished physicist renowned lot his research in gravity and black holes. His work focuses on bridging the gap between Einstein's theory of general relativity and quantum mechanics, expiating modifications to make gravity more compatible with quantum principles. Prof. Pullin's research extends to the study of gravitational waves waves-ripples in spacetime generated by the collision of black holes. Al the LIGO Prof. Pullin's role is In predict the characteristics of the spacetime distortions Gravitational Waves would produce. His extensive research encompasses both classical and quantum aspects of gravitational physics, contributing significantly to our understanding of these fundamental phenomena.

MEMBER

PROF. JORGE PULLIN

Horace Hearne Jr. Institute for Theoretical Physics Center for Computation and Technology , Department of Physics & Astronomy Louisiana State University, LA, USA

JAIPUR NATIONAL UNIVERSITY

Prof Archana Pai is a professor at the Department of Physics at IIT Bombay and a PI of the pan-India LIGO-India Scientific Collaboration. Her broad research focus is Gravitational Wave Astronomy with ground-based gravitational wave detectors and multi-messenger astronomy. Her group at IIT Bombay works on gravitational wave transient searches, probing astrophysics from a wide range of gravitational wave sources such as black hole mergers, compact objects such as neutron stars, gamma-ray bursts, supernovae, etc. Her group worked on Testing Einstein's GR for the gravitational wave discovery event GW150914 as part of the LIGO Scientific Collaboration. She shares the Special Breakthrough Prize in Fundamental Physics and the Gruber Prize in Cosmology with the LIGO Scientific Collaboration. In addition, she is the recipient of the N. R. Sen Young Scientist Award, the Vaidya-Raychaudhuri Endowment Lecture Award, and the Prof. Peraiah Foundation Lecture Award.

MEMBER

PROF ARCHANA PAI

Professor, Department of Physics, IIT Bombay
and
PI of the pan-India LIGO-India Scientific Collaboration

JAIPUR NATIONAL UNIVERSITY

NAAC A+

Prof. Tarun Souradeep is a globally acclaimed scientist whose groundbreaking contributions have significantly advanced our understanding of cosmology and gravitation. His work has been pivotal in two of the most celebrated confirmations of Einstein's theory of gravitation: the observation of Cosmic Microwave Background (CMB) fluctuations in 1992 and the discovery of gravitational waves in 2016. These milestones have reshaped our view of the universe and solidified the importance of Einstein's theories in modern physics.

His contributions have been recognized with several prestigious awards in India, including the Swarnajayanti Fellowship, NASI-Scopus Award, B.M. Birla Prize, and the Vikram Sarabhai Research Award. Souradeep is also a distinguished Fellow of the Indian Academy of Sciences and the National Academy of Sciences, India, underscoring his influence and leadership in the scientific community.

Invited Speaker

MEMBER

PROF. T. SOURADEEP

Director, Raman Research Institute, Bangalore

International Seminar on "Discovery & Detection of Gravitational Waves"

JAIPUR NATIONAL UNIVERSITY

Professor P.C. Deshmukh, a distinguished physicist, served the Indian Institute of Technology (IIT) Madras for over three decades. He earned his Ph.D. from Nagpur University and pursued post-doctoral research at institutions like the University of Aarhus, the University of Notre Dame, and Georgia State University. His research focuses on quantum collision physics, specifically atomic photoionization through relativistic many-body theory.

Professor P.C. Deshmukh is a distinguished academic and researcher, currently associated with IIT Tirupati and RV University. With a career spanning several decades, he is recognized for his significant contributions to theoretical and computational physics, particularly in atomic and molecular physics, quantum mechanics, and spectroscopy. Dr. Deshmukh has held key academic positions and has been instrumental in establishing research programs and educational frameworks that advance scientific inquiry and innovation.

Professor Deshmukh's dedication to education extends to his work at RV University, where he supports interdisciplinary physics research. His authored books on Classical and Quantum Mechanics, published by Cambridge University Press, are highly valued for their comprehensive treatment of these fields, bridging foundational principles with advanced concepts, and underscoring his commitment to academic excellence. In addition to publishing extensively in premier journals and guiding numerous Ph.D. students, Professor Deshmukh actively engages undergraduate students in research projects. His group is a leading contributor to studies on attosecond time-delay in atomic photoionization.

At IIT Tirupati, he has played a crucial role in developing the institution's research profile, fostering a culture of scientific excellence, and mentoring young scholars. His work at RV University further underscores his commitment to higher education and the interdisciplinary advancement of physics, where he guides research in cutting-edge areas of science and technology. He is also well-regarded for his online lecture series, which make complex topics in both introductory and advanced physics accessible to a broader audience. Renowned for his research acumen and teaching excellence, Professor Deshmukh continues to influence the fields of physics and education through his leadership, scholarly work, and dedication to nurturing the next generation of scientists.

Invited Speaker

MEMBER

PROF. P. C. DESHMUKH

IIT, Tirupati
&
RV University, Bengalore

International Seminar on "Discovery & Detection of Gravitational Waves"

JAIPUR NATIONAL UNIVERSITY

Professor Patrick Das Gupta is an accomplished physicist with extensive expertise in the fields of astrophysics and theoretical physics. A respected figure at the University of Delhi's Department of Physics & Astrophysics, he has a strong background in mathematical modeling, computational physics, data analysis, and spectroscopy. Dr. Das Gupta's academic journey includes a Ph.D. from the Tata Institute of Fundamental Research (TIFR), Mumbai, with a focus on general relativity, astrophysics, and quantum theory.

His career began with a National Science Talent award in 1976, followed by a master's degree from BITS Pilani in 1981. He subsequently engaged in research at premier institutions like IISc Bengaluru, TIFR Mumbai, and IUCAA Pune. As a TWAS Postdoctoral Fellow and Senior Research Fellow, he expanded his research internationally, including visits to the University of Cardiff and Observatoire de Paris. Dr. Das Gupta joined the University of Delhi as a lecturer in 1993 and rose through the ranks to become a full professor in 2004. His career is marked by a dedication to advancing scientific knowledge, making significant contributions to both theoretical and observational cosmology.

Invited Speaker

MEMBER

PROF. PATRICK DAS GUPTA

Department of Physics & Astrophysics
University of Delhi, New Delhi

JAIPUR NATIONAL UNIVERSITY

Prof. Sarah Shandera is an accomplished physicist with a focus on the intersection of particle physics, gravity, and cosmology. Her research delves into the foundational principles of particle physics and gravity, employing cosmological data to address fundamental questions. Prof. Shandera's work spans quantum systems, quantum information, and out-of-equilibrium systems, leveraging these tools to tackle long-standing problems in cosmology. She is also a key member of the CMB-S4 collaboration, where she has previously served on the Executive Committee. This collaboration is dedicated to developing advanced ground-based instruments aimed at providing next-generation constraints or detecting primordial gravitational waves.

Invited Speaker

MEMBER

PROF. SARAH SHANDERA

Director, Institute for Gravitation and the Cosmos
Davey Laboratory, PennState, USA

JAIPUR NATIONAL UNIVERSITY

Prof. Gabriela Ines González has made significant contributions to the field through her work at the LIGO Livingston Observatory in Livingston, LA. Her research includes detailed studies on the limitations imposed by Brownian motion on detector sensitivity, and she has published several influential papers on this topic. As a founding member of the LIGO Scientific Collaboration (LSC), Prof. González has played a crucial role in the commissioning and operational excellence of the LIGO detector at Livingston Observatory since joining Louisiana State University in 2001. Her expertise extends to alignment sensing, control, and the instrumental characterization and calibration of data from the LIGO Science Runs.

Invited Speaker

MEMBER

PROF. GABRIELA GONZÁLEZ

LSU Boyd Professor, Physics & Astronomy
Louisiana State University, LA, USA

Prof. K. N. Joshipura is a distinguished physicist with a remarkable career spanning several key roles in academia and science education at Sardar Patel University (SPU) Vallabh Vidyanagar, Gujarat. Prof. Joshipura is the Immediate Past General Secretary of the Indian Association of Physics Teachers (IAPT) and is a Fellow of the Gujarat Science Academy. He is also noted for his scholarly work on atomic and molecular ionization. His book, "Atomic-Molecular Ionization: Electron Scattering Theory and Applications," published by Cambridge University Press, is a valuable resource in the field.

Invited Speaker

MEMBER

PROF. K. N. JOSHIPURA

Department of Physics,
Sardar Patel University, Anand Gujarat

JAIPUR NATIONAL UNIVERSITY

Dr. Suresh Doravari is R&D Scientific & Technical Officer-F at the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, India. Dr. Suresh is involved building experiments to test the fundamental laws of nature. During his PhD at the Indian Institute of Astrophysics he built an apparatus to measure the Casimir-Polder force and used that to test deviations from Newtonian law of gravity at sub-millimeter scales. He has worked at the Univ of Pisa, Imperial College London, Caltech and the Albert Einstein Institute at Hannover pursuing a variety of tests of gravity and the particle physics. He is an active member of the LIGO Scientific Collaboration and presently works as a part of the team at IUCAA, which plans to build LIGO-India.

Invited Speaker

DR. SURESH DORAVARI

R&D Scientific & Technical Officer-F
IUCAA, Pune

International Seminar on "Discovery & Detection of Gravitational Waves"

JAIPUR NATIONAL UNIVERSITY

Dr. Anand Sengupta has received his Ph.D. in 2005 from IUCAA, Pune. Prof. Anand is interested in developing efficient algorithms for extraction of gravitational waves embedded in the noisy data from a network of gravitational wave detectors, and solving the corresponding inverse problem to reconstruct the sources responsible for these signals. The area of research is detection of gravitational waves, Aspects of CMB data analysis and predictive modelling of ecological data using a variety of data-science techniques.

Invited Speaker

DR. ANAND SENGUPTA

Department of Physics,
IIT, Gandhinagar

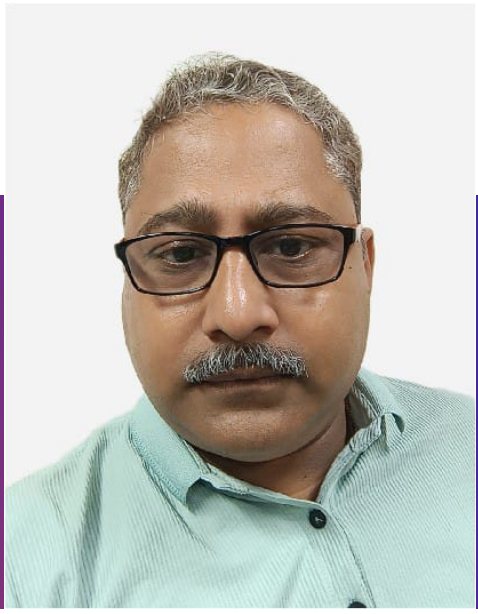
JAIPUR NATIONAL UNIVERSITY

Dr. Sunil. S is a Scientific Officer at Institute for Plasma Research (IPR), Gandhinagar. IPR contributes towards fundamental and applied research in plasma physics – the fourth state of matter. Sunil in his earlier days at IPR was involved in characterizing laser produced plasma and its interaction with tokamak plasma. His research work also involves study and control of conditions leading to parametric instabilities in a gravitational wave detector. Sunil presently is a team member of LIGO-India and is contributing towards the vacuum requirement of Gravitational wave detector.

Invited Speaker

DR. S. SUNIL

Scientific Officer,
Institute for Plasma Research (IPR), Gandhinagar.



International Seminar on "Discovery & Detection of Gravitational Waves"

JAIPUR NATIONAL UNIVERSITY

Dr. Sudip Bhattacharyya is an esteemed astrophysicist recognized for his significant contributions to the field of black holes and neutron stars. He earned his Ph.D. in Astrophysics in 2002 and has since been a prominent figure in the scientific community. In 2007, he was honored with the NASA Space Science Achievement Award, reflecting his notable achievements in astrophysics. His research and contributions extend to major projects such as the first dedicated Indian astronomy satellite AstroSat, where he heads the team of the Soft X-ray Telescope aboard this very successful space observatory.

Invited Speaker

PROF. SUDIP BHATTACHARYYA

Payload Manager or PI,
Soft X-ray Telescope, AstroSat Space Mission,
Department of Astronomy and Astrophysics, TIFR, Mumbai

International Seminar on "Discovery & Detection of Gravitational Waves"

JAIPUR NATIONAL UNIVERSITY

Prof. Manjari Bagchi is a distinguished astrophysicist with a broad research focus that spans neutron stars, black holes, and globular clusters, among other celestial phenomena. Her expertise reflects her comprehensive approach to understanding the complexities of the universe. In addition to her primary interest in neutron stars, Dr. Bagchi's research encompasses various aspects of particle physics, further enhancing her multidisciplinary approach to astrophysical investigations.

Invited Speaker

PROF. MANJARI BAGCHI

The Institute of Mathematical Sciences, Chennai

International Seminar on "Discovery & Detection of Gravitational Waves"

Prof. Suvodip Mukherjee is leading the group at the Tata Institute of Fundamental Research (TIFR), which works in the interface of theory and data analysis in astrophysics, cosmology, and gravitational waves. This group is actively involved in various scientific collaborations such as CMB-S4, LIGO/ Virgo/ KAGRA/LIGO-India, LISA, and LGWA. Key areas of his research include Astrophysical properties of GW sources, Cosmology with GW sources, Fundamental, Physics using GW, Gravitational lensing of GW, Stochastic GW Background-- astrophysical and cosmological, Secondary CMB anisotropies, Search of Axions/Axion-like particles using multi-frequency observations, The epoch of cosmic reionization.

Invited Speaker

PROF. SUVODIP MUKHERJEE

Tata Institute of Fundamental Research, Mumbai

International Seminar on "Discovery & Detection of Gravitational Waves"

JAIPUR NATIONAL UNIVERSITY

Prof. Arunava Mukherjee is associated with the Centre for Astroparticle Physics, Saha Institute of Nuclear Physics, Kolkata. His area of interests is Gravitational Waves & Multi-messenger Astronomy, High Energy Astrophysics, and Physics & Astrophysics of Compact Objects: Neutron Stars and Black Holes and Equation of State of Neutron Stars and Nuclear Matter. Prof. Mukherjee had worked in UK and Germany in the field of gravitational waves.

Invited Speaker

PROF. ARUNAVA MUKHERJEE

Saha Institute of Nuclear Physics, Kolkata

International Seminar on "Discovery & Detection of Gravitational Waves"

JAIPUR NATIONAL UNIVERSITY

Saurabh Salunkhe is a Senior Outreach Coordinator at LIGO India and a dedicated astrophysics educator. With a profound passion for astronomy and gravitational wave detection, he plays a pivotal role in advancing public understanding of these complex subjects. Prof. Salunkhe is committed to inspiring the next generation of astrophysicists by making intricate topics in astronomy and astrophysics accessible to young learners. His research enthusiasm drives him to explore the profound mysteries of the universe, contributing both to educational outreach and to the broader field of astrophysics.

Invited Speaker

SAURABH SALUNKHE

Senior Outreach Coordinator for LIGO-India
IUCAA, Pune

International Seminar on "Discovery & Detection of Gravitational Waves"

Speakers

PROF. T. SOURADEEP
Bangalore

PROF. P. C. DESHMUKH
Bengalore

PROF. PATRICK DAS GUPTA
Delhi

PROF. SARAH SHANDERA
PennState, USA

PROF. G. GONZÁLEZ
Louisiana, LA, USA

PROF. K. N. JOSHIPURA
Anand

DR. SURESH DORAVARI
Pune

PROF. S. BHATTACHARYYA
Mumbai

DR. S. SUNIL
Gandhinagar

PROF. ANAND SENGUPTA
Gandhinagar

PROF. MANJARI BAGCHI
Chennai

PROF. SUVODIP MUKHERJEE
Mumbai

PROF. A MUKHERJEE
Kolkata

SAURABH SALUNKHE
Pune

Report

The Seminar on Gravitational Waves, held on September 14, 2024 and its precursor events, held on September 13, 2024, represented a remarkable convergence of experts from various fields, all of whom came together to discuss the cutting-edge advancements in gravitational wave science. This interdisciplinary events focused on the profound implications of gravitational wave detection across fields such as quantum mechanics, general relativity, and astrophysics These events underscored the significance of gravitational wave research in unraveling the mysteries of the universe, from the detection of black hole mergers to understanding the fundamental forces of physics. Throughout the presentations, several critical themes emerged, including the interdisciplinary nature of the field, the crucial role of international collaboration, technological advancements, and the importance of public outreach and education. The goal was to foster a deeper understanding of the evolving landscape of gravitational wave research and its potential to revolutionize our understanding of the universe.

Overview of Gravitational Wave Science

Gravitational waves, first predicted by Albert Einstein in 1916 as part of his general theory of relativity, are ripples in the fabric of spacetime generated by massive cosmic events. These waves propagate outward from their sources, similar to the way waves spread across a pond when a stone is thrown into the water. The discovery of gravitational waves not only confirmed Einstein's theory but also opened up an entirely new way of observing the universe. Unlike traditional astronomy, which relies on electromagnetic radiation (such as light, radio waves, or X-rays), gravitational wave astronomy allows us to study cosmic phenomena that are otherwise invisible, such as the mergers of black holes or neutron stars.

The detection of gravitational waves in 2015 by the Laser Interferometer Gravitational-Wave Observatory (LIGO) marked a historic moment in astrophysics. It was the first time humanity had directly observed these cosmic ripples, originating from the merger of two black holes over a billion light-years away. Since then, gravitational wave astronomy has grown rapidly, with numerous detections providing new insights into the behavior of matter and energy under extreme conditions. This seminar delved deeply into these themes, exploring the latest advancements in gravitational wave science, the technology behind it, and its future potential.

Key Presentations

The seminar featured several prominent speakers who provided deep insights into various aspects of gravitational wave research. Their presentations highlighted both the theoretical and practical challenges of detecting gravitational waves and the broader implications for physics and cosmology.

PROF. GABRIELA GONZÁLEZ
LSU Boyd Professor, Physics & Astronomy
Louisiana State University, LA, USA

International Collaboration in GRAVITATIONAL WAVE DETECTION

Prof. Gonzalez, a renowned physicist who played a key role in the first direct detection of gravitational waves in 2015 at the Laser Interferometer Gravitational-Wave Observatory (LIGO). Prof. Gonzalez's talk offered a comprehensive overview of the groundbreaking discovery of gravitational waves, emphasizing their transformative impact on modern physics.

She explained how the detection confirmed a key prediction of Einstein’s theory of general relativity and introduced a revolutionary method for observing the universe. Unlike electromagnetic waves, gravitational waves are not absorbed or blocked by matter, which allows us to observe previously inaccessible events. Prof. Gonzalez also stressed the importance of global collaboration in advancing this field, highlighting initiatives like LIGO (USA), Virgo (Europe), and KAGRA (Japan) as prime examples of how international efforts enhance the detection accuracy of gravitational waves.

She concluded by discussing the exciting future of gravitational wave science, particularly the upcoming space-based observatories like the Laser Interferometer Space Antenna (LISA) and projects like LIGO-India, which aim to expand the global network of gravitational wave detectors.

International Seminar on “Discovery & Detection of Gravitational Waves”

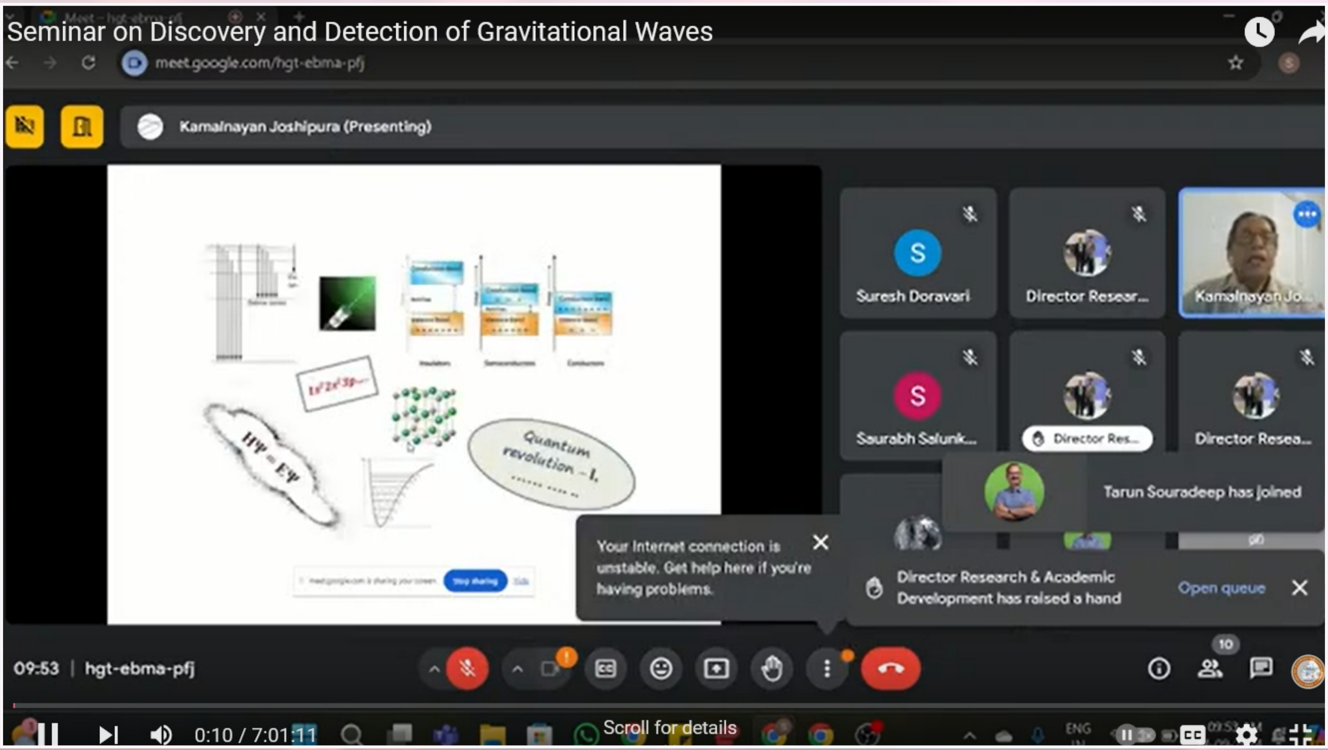
PROF. K. N. JOSHIPURA

Sardar Patel University, Anand

Quantum Mechanics –

AT A GLANCE

Prof. Joshipura, appreciated the efforts of the Center for Excellence in Quantum Science in organizing the Seminar, and gave an outline of quantum mechanics. He explored the key quantum concepts like wave-particle duality, uncertainty principle, quantum entanglement etc, and mentioned how the quantum phenomena occurring at the micro-scales, have implications in a number of applications and devices of today.



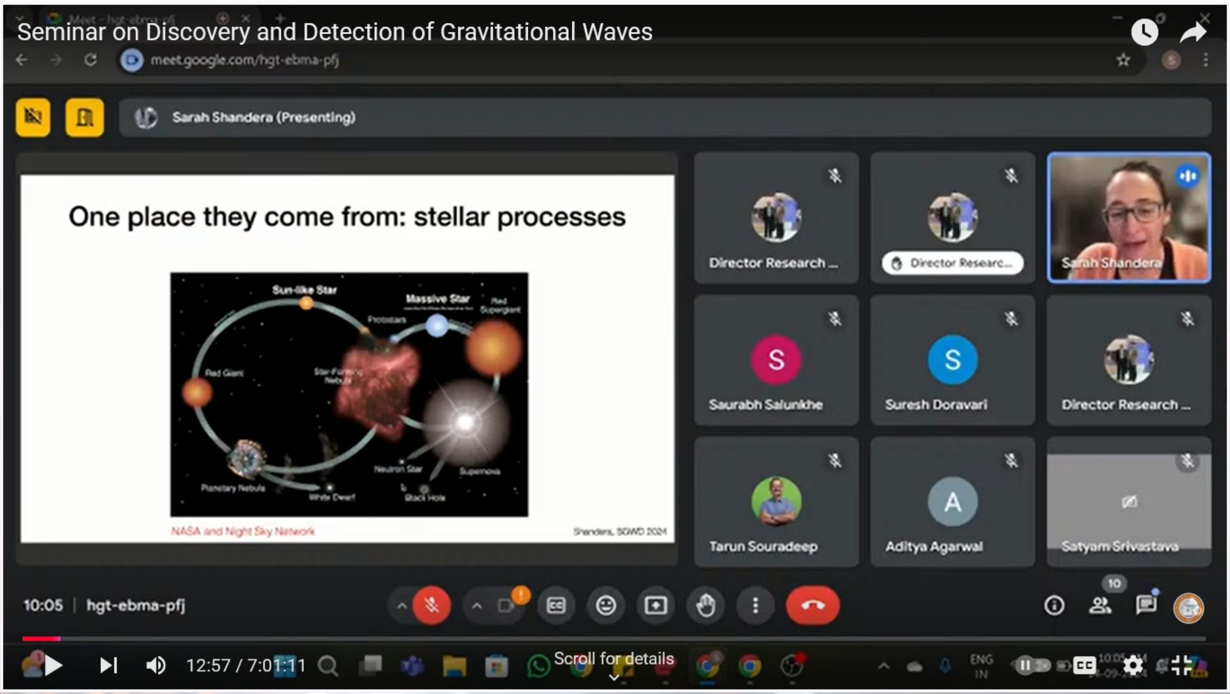
PROF. SARAH SHANDERA
Director, Institute for Gravitation and the Cosmos
Davey Laboratory, PennState, USA

Gravitational Waves and
DARK MATTER DISCOVERY

Prof. Shandera, explored the role of gravitational waves in the search for dark matter—a substance that constitutes roughly 85% of the matter in the universe yet is detectable only through its gravitational effects.

Prof. Shandera discussed how gravitational wave astronomy might offer indirect evidence of dark matter, presenting it as a new tool to investigate this mysterious aspect of the universe. She introduced theoretical models suggesting that dark matter could influence the propagation of gravitational waves or even interact directly with them.

The possibility that certain dark matter candidates, such as axions or primordial black holes, might leave detectable signatures in the gravitational waves observed by LIGO and Virgo was also proposed. These investigations offer a fresh perspective on solving the dark matter puzzle, one of the major unsolved problems in modern astrophysics.



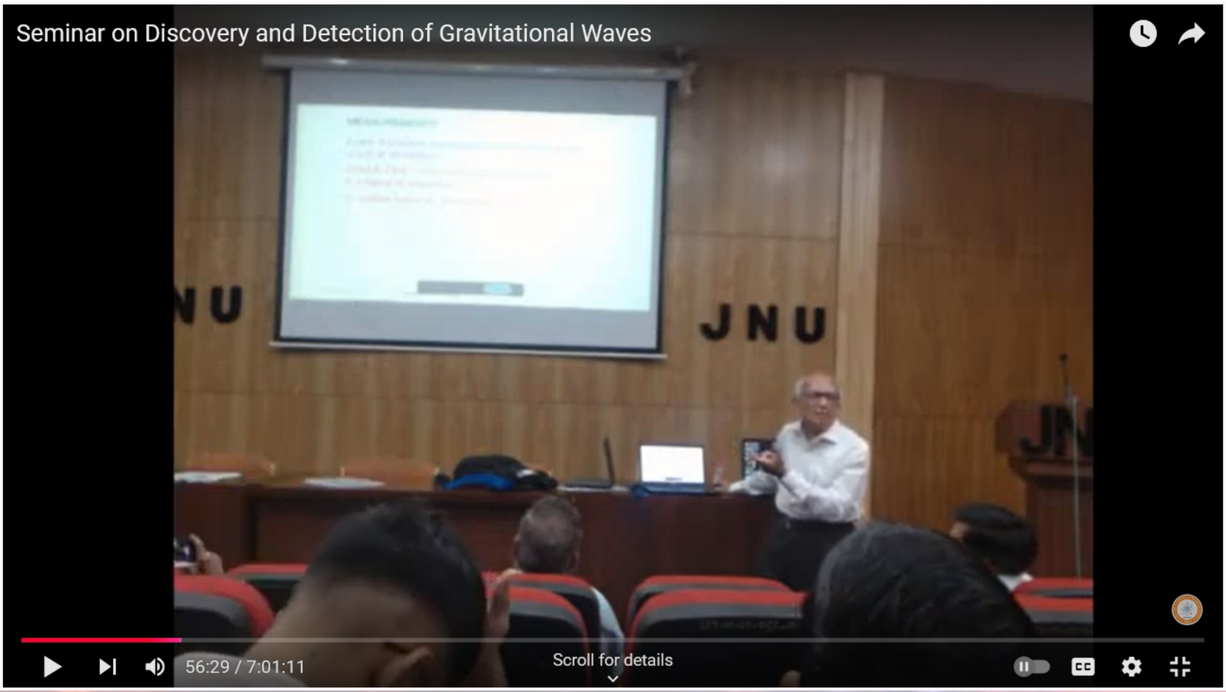
PROF. P. C. DESHMUKH
IIT, Tirupati &
RV University, Bengalore

Unriddling
THE GENERAL THEORY OF RELATIVITY

Prof. Deshmukh, presented an in-depth discussion on Einstein’s General Theory of Relativity, the theoretical foundation for studying gravitational waves during his lecture on “Unriddling General Relativity”.

Prof. Deshmukh eloquently demystified the complexities of general relativity, explaining how gravity is not a force in the traditional sense but rather a curvature of spacetime caused by mass and energy. He demonstrated how this curvature affects the motion of objects, the propagation of light, and other energy forms.

Gravitational waves, as he explained, are a direct consequence of this theory, and their detection serves as powerful validation. Additionally, Prof. Deshmukh discussed the challenges of reconciling general relativity with quantum mechanics, a frontier in theoretical physics that remains unresolved. This dichotomy between the two theories is one of the most significant challenges for physicists in the pursuit of a unified understanding of the universe.



International Seminar on "Discovery & Detection of Gravitational Waves"

PROF. T. SOURADEEP
Director, Raman Research Institute, Bangalore

Quests & Conquests: GRAVITATIONAL WAVE SCIENCE

The keynote address, delivered by Prof. Souradeep, on the topic "Quests and Conquests in Gravitational Wave Science", provided a historical perspective on the evolution of gravitational wave science, from Einstein's early predictions to LIGO's first detection in 2015.

Prof. Souradeep highlighted the key technological advancements, including laser interferometers, vacuum systems, and vibration isolation technologies, that have been crucial to detecting the faint distortions in spacetime caused by passing gravitational waves. These advancements have propelled the field forward, enabling precise measurements of these waves and expanding our ability to observe the universe.

Looking ahead, Prof. Souradeep emphasized the potential of future projects to further enhance detection capabilities, including space-based detectors such as LISA. These developments aim to broaden the range of gravitational wave frequencies scientists can observe, providing new insights into distant cosmic events.

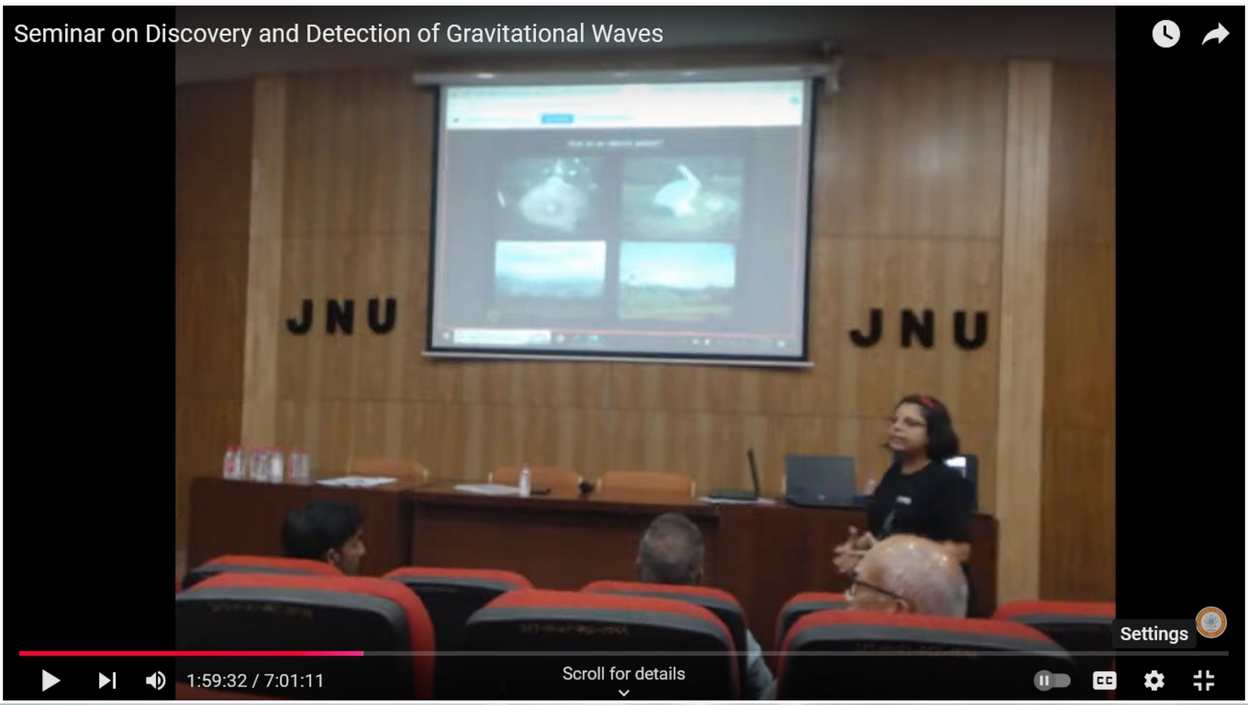
PROF. MANJARI BAGCHI
The Institute of Mathematical Sciences, Chennai

Hunting low-frequency gravitational waves

through Pulsar Timing Arrays: THE ROLE OF INDIAN PULSAR TIMING ARRAY

Prof. Manjari, introduced the detection of low-frequency gravitational waves through Pulsar Timing Arrays (PTAs). Pulsars, which are highly magnetized rotating neutron stars, emit beams of electromagnetic radiation. The precise timing of these emissions allows scientists to detect deviations caused by the passage of gravitational waves. Prof. Bagchi discussed how PTAs, such as the Indian Pulsar Timing Array, are playing a vital role in the global effort to detect low-frequency gravitational waves produced by massive cosmic events, like the mergers of supermassive black holes.

PTAs complement observatories like LIGO and Virgo by offering a method to observe gravitational waves that occur on much longer timescales, broadening the scope of gravitational wave astronomy.

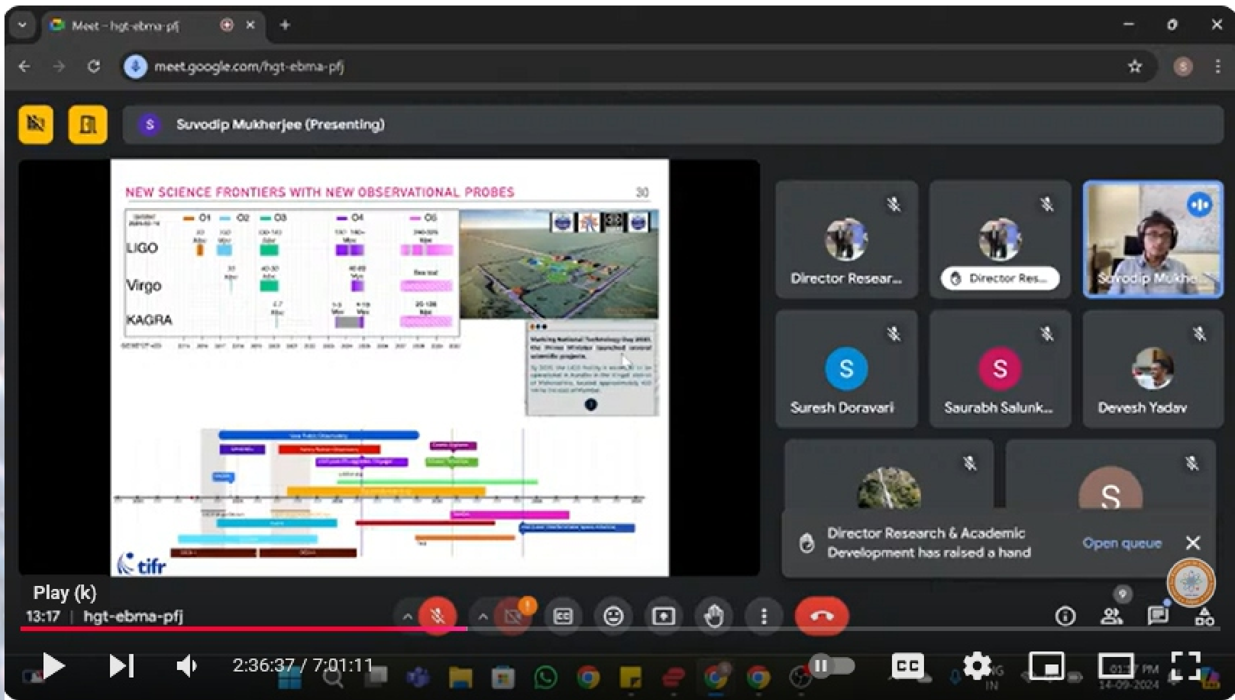


PROF. SUVODIP MUKHERJEE
Tata Institute of Fundamental Research, Mumbai

Gravitational Wave Astronomy: A New Frontier

Dr. Suvodip discussed the transformative potential of gravitational wave astronomy. He emphasized how gravitational wave observations allow us to study cosmic phenomena that do not emit light, such as black hole mergers and neutron star collisions.

Dr. Mukherjee discussed the importance of developing more sensitive detectors to capture fainter and more distant gravitational wave events, as well as the prospects for future observatories like LISA, which will detect gravitational waves from sources that are currently beyond our observational reach, including those from the early universe. He also touched on the potential of multi-messenger astronomy, where gravitational wave data is combined with electromagnetic observations to provide a more comprehensive picture of cosmic events.



International Seminar on "Discovery & Detection of Gravitational Waves"

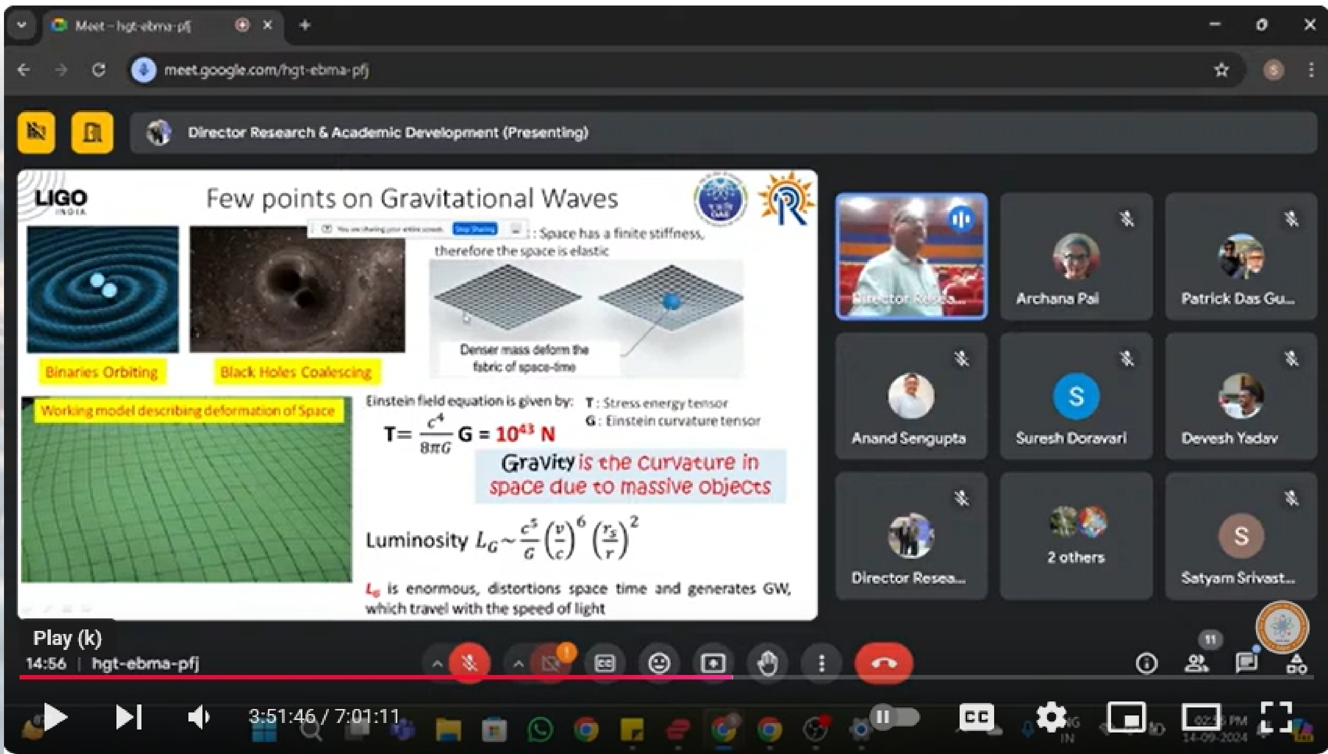
DR. S. SUNIL

Scientific Officer at Institute for Plasma Research (IPR), Gandhinagar.

Role of Vacuum in GRAVITATIONAL WAVE DETECTION

Dr. Sunil provided a technical overview of the critical role that vacuum systems play in gravitational wave detection. Detectors like LIGO require an environment free from noise and interference to detect the minute distortions in spacetime caused by gravitational waves. This is achieved by maintaining vacuum chambers around the laser interferometers, isolating them from external disturbances.

Dr. Sunil discussed the technological challenges in creating and maintaining these vacuums, which are among the most demanding requirements in modern physics. This isolation is crucial for the precise measurement of gravitational waves, allowing detectors to capture signals that are incredibly faint.

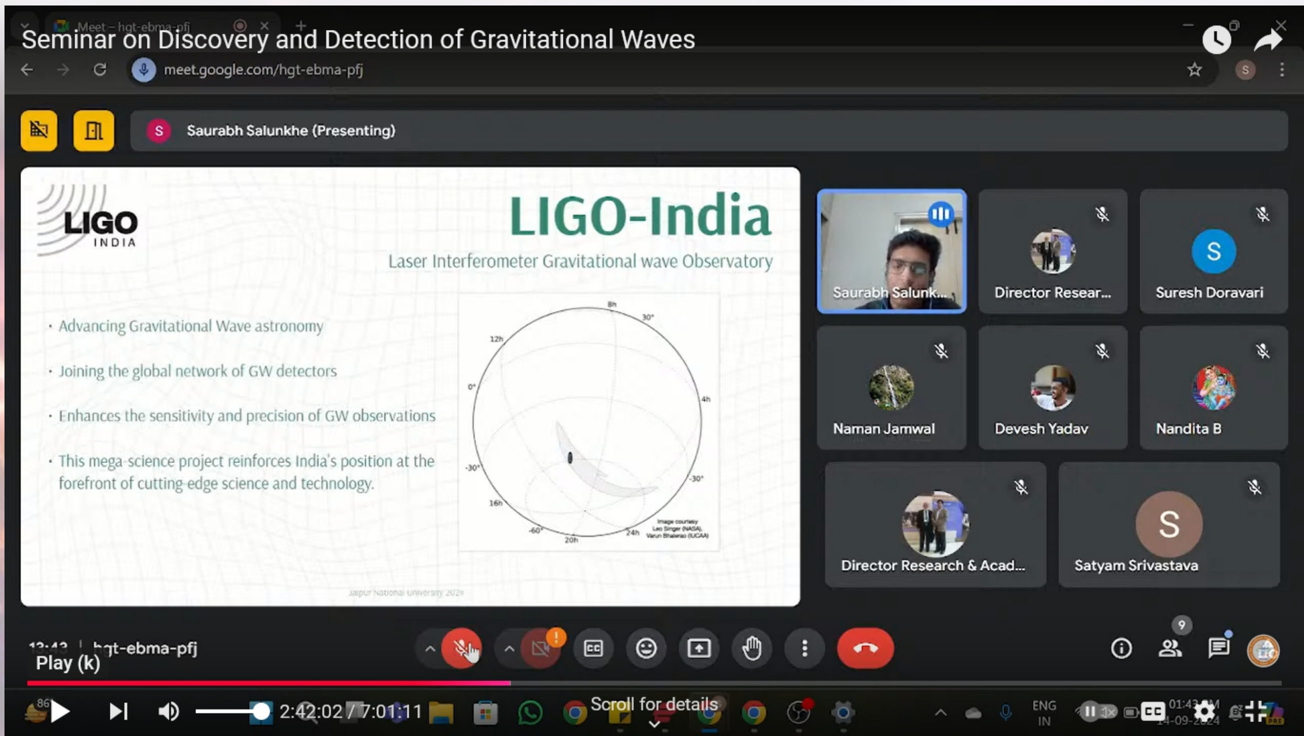


SAURABH SALUNKHE
Senior Outreach Coordinator for LIGO-India
IUCAA, Pune

LIGO-India and its
EDUCATIONAL AND CAREER OPPORTUNITIES

Mr. Saurabh spoke on the educational and career opportunities associated with LIGO-India, which is part of the global network of gravitational wave detectors. LIGO-India will play a significant role in expanding the capability to detect and analyze gravitational waves in India and beyond.

Mr. Salunkhe discussed various educational programs, internships, and outreach initiatives aimed at inspiring the next generation of Indian scientists and engineers. He emphasized the importance of training young researchers in cutting-edge technologies like laser interferometry, data analysis, and vacuum systems. LIGO-India offers a unique opportunity for Indian students and researchers to participate in one of the most exciting fields in modern science.



PROF. PATRICK DAS GUPTA
University of Delhi, Delhi

Extragalactic Sources of GRAVITATIONAL RADIATION

Prof. Gupta's presentation focused on the extragalactic sources of gravitational waves, particularly cosmic events such as black hole and neutron star mergers occurring outside our galaxy. These extragalactic sources are of particular interest because they provide a wealth of information about the large-scale structure of the universe and test the limits of general relativity. Prof. Das Gupta emphasized that gravitational wave astronomy is still in its early stages, and much remains to be discovered about these distant cosmic events.

One of the key points he raised was the importance of studying gravitational waves from extragalactic sources to search for new physics beyond Einstein’s theory. While general relativity has passed every experimental test to date, there are still unresolved questions about its validity in the most extreme conditions, such as near black holes or during neutron star mergers. Gravitational waves offer a unique way to probe these extreme environments and potentially discover phenomena that challenge our current understanding of physics. Prof. Das Gupta also discussed how the detection of gravitational waves from extragalactic sources allows scientists to explore the behavior of matter and energy under the most extreme conditions, offering new insights into the forces that shape the universe.

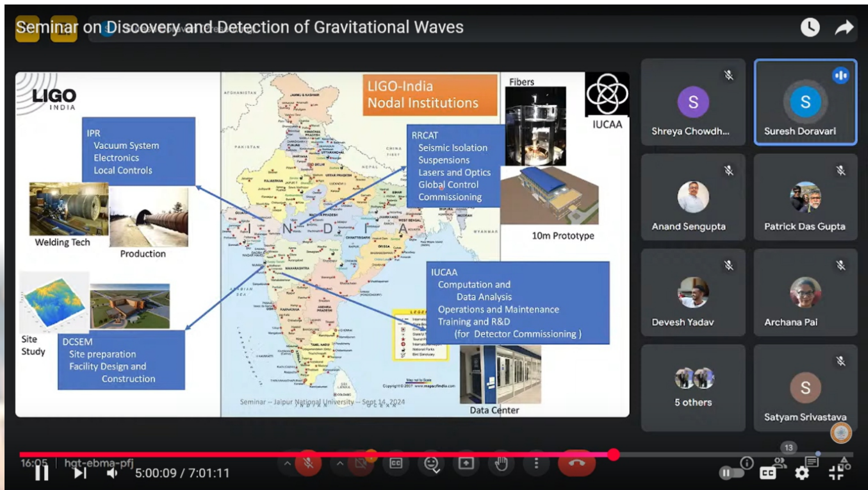
DR. SURESH DORAVARI
R&D Scientific & Technical Officer-F
IUCAA, Pune

An Introduction to ADVANCED LIGO DETECTORS

Dr. Doravari delivered a talk titled "An Introduction to Advanced LIGO Detectors", which provided a deep dive into the intricate engineering behind the LIGO detectors. These detectors are among the most sensitive instruments ever constructed, capable of detecting disturbances in spacetime that are smaller than a fraction of the width of a proton. Dr. Doravari explained how LIGO’s laser interferometers work, using highly reflective mirrors, advanced vacuum systems, and precision lasers to measure tiny distortions in spacetime caused by passing gravitational waves.

One of the key points of his presentation was the technological milestones achieved since LIGO’s first detection of gravitational waves. The engineering behind the detectors has seen continuous improvements, with future upgrades aiming to enhance detection capabilities even further. He emphasized the interdisciplinary nature of this work, combining expertise in physics, engineering, and computational science to push the boundaries of what is possible in gravitational wave detection. Dr. Doravari also discussed the challenges of isolating the detectors from environmental noise and the ways in which LIGO’s technology is advancing to meet these challenges, paving the way for even more precise measurements in the future.

Dr. Doravari also mentioned the various opportunities available within the LIGO-India training program for motivated students, who would like to explore career opportunities in instrument science related to these extraordinary detectors.



PROF. SUDIP BHATTACHARYYA
Payload Manager or PI,
Soft X-ray Telescope, AstroSat Space Mission,
Department of Astronomy and Astrophysics, TIFR, Mumbai

Many incarnations of NEUTRON STARS

Prof. Bhattacharyya's presentation, titled "Many Incarnations of Neutron Stars", explored the varied and fascinating nature of neutron stars, the ultra-dense remnants of supernova explosions. Neutron stars are of particular interest in gravitational wave research because they are one of the primary sources of these waves, especially during neutron star mergers. Prof. Bhattacharyya explained that neutron stars can take on different forms, such as pulsars and magnetars, each with unique properties and behaviors.

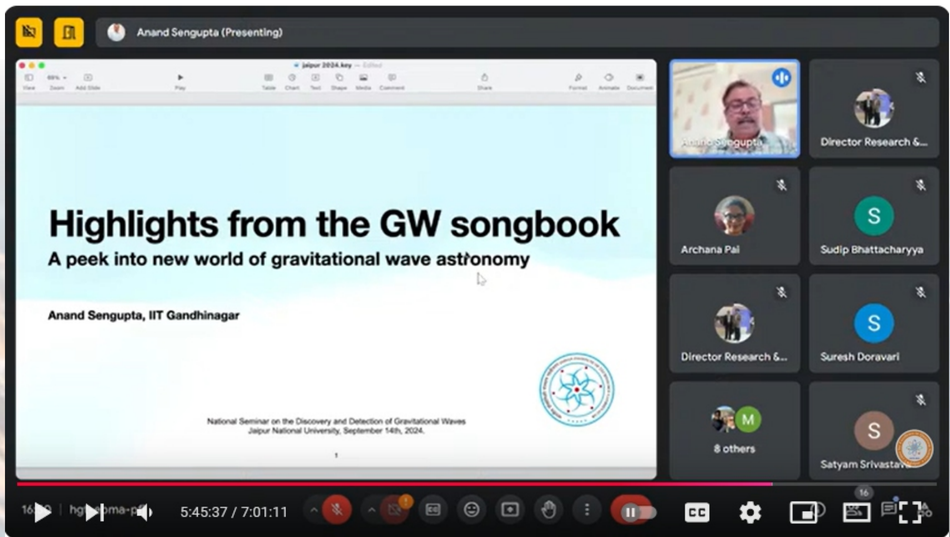
His talk delved into how neutron stars provide valuable insights into the extreme states of matter, where nuclear forces dominate. These stars offer a rare opportunity to study matter under conditions that cannot be replicated on Earth, such as densities several times greater than that of an atomic nucleus. Gravitational wave observations from neutron star mergers are particularly valuable for advancing our understanding of nuclear physics, offering a laboratory for studying matter under extreme pressures and densities. Prof. Bhattacharyya emphasized that studying neutron stars not only helps us understand gravitational waves but also provides critical information about the behavior of matter at the fundamental level.

PROF. ANAND SENGUPTA
IIT, Gandhinagar

Highlights from THE GRAVITATIONAL WAVE SONGBOOK

In a creative and engaging presentation titled "Highlights from the Gravitational Wave Songbook", Prof. Sengupta used the metaphor of a songbook to describe the distinct waveforms generated by cosmic events like binary black hole mergers and neutron star collisions. Each of these events produces a unique gravitational wave signal, or “song,” which scientists can use to identify the astrophysical sources that created them.

Prof. Sengupta demonstrated how sophisticated computational techniques are used to interpret these waveforms and extract valuable data about the universe. He explained that by analyzing the frequency, amplitude, and shape of a gravitational wave signal, scientists can infer key information about the cosmic event, such as the masses of the objects involved and their distance from Earth. His presentation highlighted the diverse and informative nature of gravitational wave data, illustrating how these “cosmic songs” are helping scientists gain a deeper understanding of the universe. Prof. Sengupta also touched on the potential for machine learning and artificial intelligence to play a significant role in future gravitational wave data analysis, as the volume of data continues to grow.



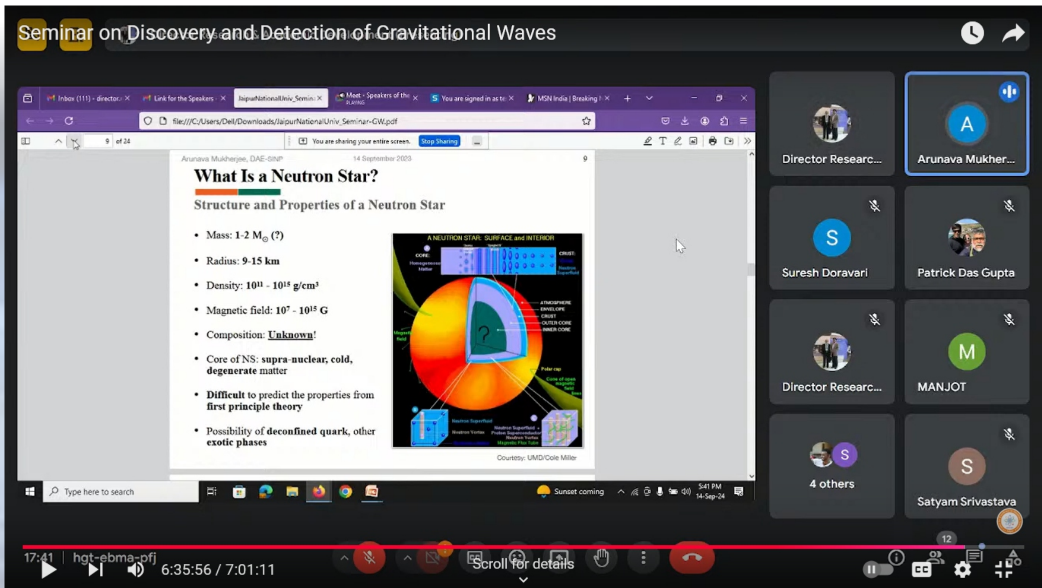
PROF. ARUNAVA MUKHERJEE
Saha Institute of Nuclear Physics, Kolkata

Aspects of Fundamental Physics and

ASTROPHYSICS WITH COMPACT OBJECTS IN GRAVITATIONAL WAVES

Prof. Mukherjee delivered an insightful talk on "Aspects of Fundamental Physics and Astrophysics with Compact Objects in Gravitational Waves". His presentation focused on the profound astrophysical and fundamental physics revelations that arise from studying compact objects such as black holes and neutron stars through gravitational wave observations. These compact objects act as natural laboratories for testing theories such as general relativity and quantum mechanics under conditions of immense gravitational forces.

Prof. Mukherjee emphasized that gravitational wave research has the potential to uncover new physics. For example, the study of black hole mergers may reveal discrepancies in general relativity or offer insights into the nature of dark matter. He discussed how gravitational waves provide a new way to probe the strong-field regime of gravity, where the effects of general relativity are most pronounced. His presentation offered a window into some of the most profound mysteries of the universe, including the nature of spacetime, the behavior of matter at the quantum level, and the limits of current physical theories.



Conclusion and Panel Discussion

The seminar concluded with a panel discussion that brought together the speakers for an engaging debate about the future of gravitational wave research. The discussion covered a range of topics, including the potential for space-based detectors like the Laser Interferometer Space Antenna (LISA), which would be able to detect gravitational waves at lower frequencies than ground-based detectors like LIGO. The panelists also discussed the role of artificial intelligence in gravitational wave data analysis, as the increasing sensitivity of detectors will lead to a flood of data that will require new methods of processing and interpretation.

One of the key takeaways from the panel discussion was the critical importance of international collaboration in advancing the field. The global nature of gravitational wave research, with collaborations like LIGO-Virgo and initiatives such as LIGO-India, is essential for making significant progress. The panelists emphasized that the future of gravitational wave astronomy depends on the continued integration of expertise from around the world, as well as from different scientific disciplines.

At the end Prof. Y. C. Sharma thanked all the speakers and participants for their time and valuable inputs towards the success of the seminar

Quiz Event Overview

The quiz was design by Prof. Y C Sharma in consultation with Dr. William Katzman, LIGO, Caltech and Mr. Saurabh Salunkhe, LIGO-India. The quiz was conducted online via Google Forms, it featured 3 categories school students. undergraduate and postgraduate students and faculty/research scholars. Participants' knowledge was tested, and the quiz engaged them in crucial conversations about their understanding of quantum mechanics and gravitational waves.

The quiz attracted over 800 registrations from more than 50 institutions across 21 states, including prominent names like IISc, TIFR, IITs, IISERs, NITs, and carious Central and state Universities.

The precursor events on September 13, 2024

The precursor events held on September 13, 2024, ahead of the highly anticipated seminar on “Discovery and Detection of Gravitational Waves,” were a vibrant amalgamation of educational

activities, interactive sessions, and engaging exhibitions. These events aimed at creating awareness about gravitational wave science and its profound implications on our understanding of the universe. Targeted primarily at students and educators, the day's proceedings were designed to foster curiosity, inspire future generations of scientists, and create a broader understanding of cutting-edge Gravitational Wave research.

1. Student Sessions and Workshops

The day commenced with specialized workshop and interactive session for school and undergraduate students. Hosted by Jaipur National University, the sessions focused on fundamental physics concepts leading up to the discovery of gravitational waves. Students from various institutions, along with visiting schools, participated enthusiastically in this workshop.

Session Highlights:

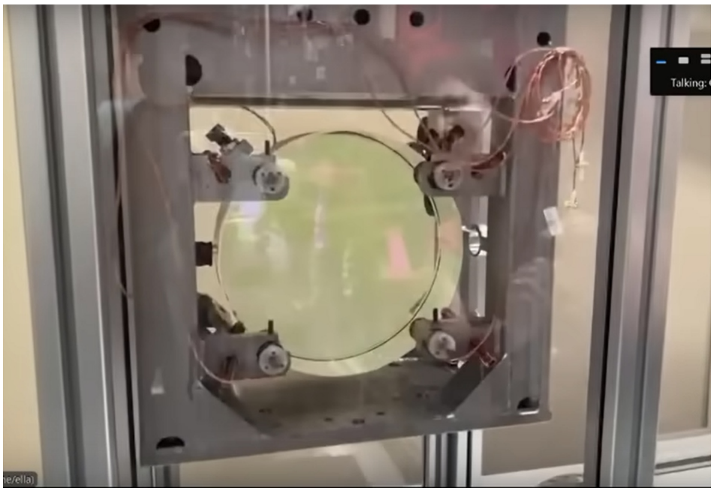
- Introduction to Gravitational Waves: The first session aimed at providing an introduction to gravitational waves and the science behind their discovery. Using visual aids, animations, and simplified explanations, Prof. Y C Sharma the speaker ensured that even students unfamiliar with complex physics could grasp the basics. Students learned about the origins of gravitational waves, the general theory of relativity, and how gravitational waves propagate through spacetime.

- Hands-On Activities: In this session, students were invited to experiment with wave patterns and observe the simulations on how different astronomical events—like black hole mergers and neutron star collisions—generate specific gravitational waveforms. The hands-on activities allowed them to visually comprehend how these cosmic events send ripples through spacetime, making an abstract concept far more accessible.
- Career Guidance and Mentorship: Towards the end of the workshop, the focus shifted to discussing the academic and career pathways available in the field of astrophysics, gravitational wave science, and related disciplines. Experts from the university and visiting speakers offered valuable insights, motivating students to consider a future in scientific research and engineering. Emphasis was placed on the interdisciplinary nature of the field, combining physics, mathematics, computer science, and engineering.

2. Virtual Field Trip to LIGO Livingston

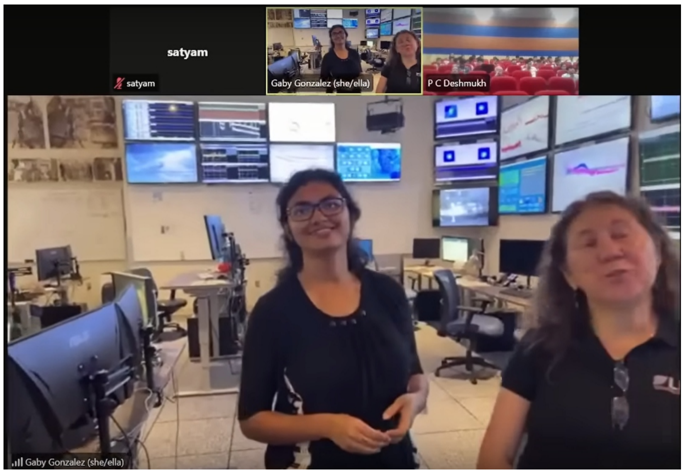
A major highlight of the day was the virtual field trip to the Laser Interferometer Gravitational-Wave Observatory (LIGO). Students and faculty embarked on a captivating guided tour of one of the world's leading gravitational wave detectors, located in Livingston, Louisiana. This immersive experience, designed to replicate an actual visit, allowed participants to explore the observatories and gain insight into the cutting-edge technology behind gravitational wave detection.

The virtual tour was both visually engaging and highly educational. Accompanied by insightful audio commentary from Professor Gabriela González, LSU Boyd Professor of Physics and Astronomy at Louisiana State University, and Debasmita Nandi from the Experimental Relativity Group at LSU, along with Gaurav Waratkar, a visiting Indian scientist from the LIGO-India Scientific Collaboration at IIT Bombay, the participants learned about the intricate laser systems, advanced mirror configurations, and vacuum tubes that enable LIGO to be one of the most sensitive instruments ever constructed. This unique experience offered students a deep understanding of the complexity and precision required in gravitational wave detection and highlighted the vital role technological innovation plays in advancing modern scientific research.




Talking: Gaby Gonzalez
LIGO


Talking:


satyam
satyam
Gaby Gonzalez (she/ella)
P C Deshmukh
Gaby Gonzalez (she/ella)


satyam
satyam
Gaby Gonzalez (she/ella)
P C Deshmukh
Gaby Gonzalez (she/ella)

3. Science and Philately Exhibition

In a bid to connect science with culture and history, a unique Science and Philately Exhibition was organized in collaboration with the Philatelic Society of Rajasthan (PSR). In the exhibition Sh. Yogesh Bhatnagar, President of the society, showcased an impressive collection of stamps, postal covers, and memorabilia related to major scientific breakthroughs, focusing on physics, astronomy, and space exploration.

One of the central themes of the exhibition was "Science through Stamps", illustrating key moments in the history of physics—from Einstein's theory of general relativity to the discovery of the Higgs boson—through beautifully curated stamp collections from around the world. A special section was dedicated to gravitational waves, featuring postal stamps issued by various countries. This exhibit offered a unique intersection of art, history, and science, illustrating how scientific achievements have been celebrated globally.

Attendees marveled at the rare collection of stamps commemorating notable physicists such as Isaac Newton, Albert Einstein, and Stephen Hawking. Additionally, the exhibit included stamps celebrating major space exploration milestones, such as the moon landing, the Voyager missions, and the Hubble Space Telescope. The exhibit emphasized how science is not only an intellectual pursuit but also a cultural and historical phenomenon that transcends borders.

4. Lecture for Teachers and Educators

Recognizing the pivotal role educators play in nurturing scientific curiosity, a special lecture and discussion were held, led by Prof. P. C. Deshmukh, an esteemed figure in quantum science and physics education. His talk centered on the active participation of undergraduate (UG) students in pedagogical and research projects, highlighting their immense potential as a reservoir of fresh and innovative ideas.

Prof. Deshmukh emphasized that undergraduates enter college with dreams, questions, and an ambitious drive, making it both exciting and challenging to prepare them for advancements in science, engineering, and technology. He noted how critical fields such as data processing, communication, navigation, and even designing trajectories for vehicles, aircraft, rockets, and satellites rely heavily on a deep understanding of fundamental physics principles. He also pointed out the growing significance of emerging technologies like driverless cars, robotic surgery, and quantum computation, all of which depend on the strategic application of physical laws.

Engaging undergraduates in projects that explore these fundamental concepts, according to Prof. Deshmukh, offers students early exposure to advanced studies and real-world applications. Such projects also provide a unique opportunity for both teachers and students to experience the joy of theoretical and experimental methods, fostering a deeper connection to scientific discovery. His talk was filled with personal reflections on the rewarding experience of collaborating with undergraduate students, illustrating the fulfillment that comes from mentoring and inspiring the next generation of scientific thinkers.

The precursor events held on September 13 were a resounding success, setting the stage for the main seminar on gravitational waves. By combining education, culture, and public engagement, these events created an environment that fostered scientific curiosity, encouraged collaboration, and inspired future generations to continue exploring the mysteries of the universe. From hands-on workshop to public lecture, the day offered a multitude of ways for participants to engage with one of the most exciting fields in modern science—gravitational wave research.

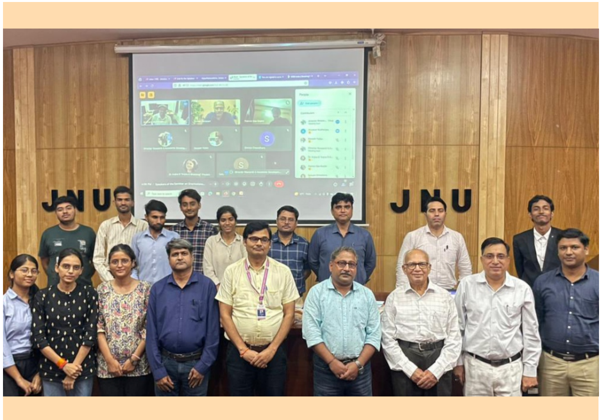
The seminar and precursor events on gravitational waves successfully brought together a wide range of perspectives on this rapidly evolving field. From the latest advancements in detector technology to the theoretical frameworks that underpin gravitational wave science, the presentations provided a comprehensive overview of the current state of the field and its future possibilities. One of the most striking themes of the seminar was the interdisciplinary nature of gravitational wave research. It is a field that requires expertise from multiple areas, including physics, engineering, mathematics, and computer science, and its success depends on the integration of these diverse disciplines.

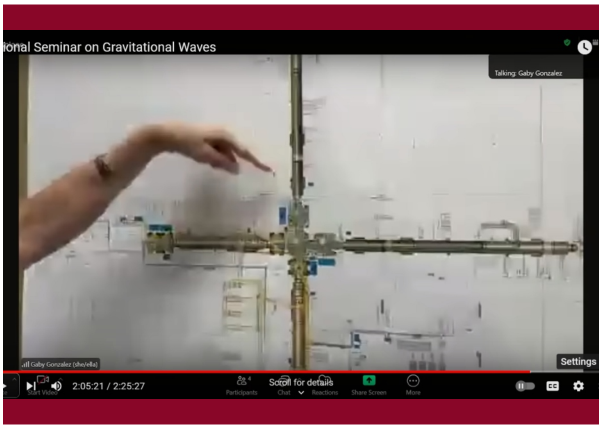
The event also highlighted the global nature of gravitational wave research, with international collaborations playing a key role in driving the field forward. Initiatives like LIGO-India and future space-based detectors like LISA are set to expand our understanding of the universe, offering new ways to explore the most extreme and mysterious phenomena in the cosmos.

Finally, the seminar emphasized the importance of public outreach and education in ensuring the continued growth of gravitational wave research. By inspiring young scientists and engineers to contribute to this transformative field, the event set the stage for the next generation of discoveries in astrophysics, quantum mechanics, and fundamental physics. The interdisciplinary, collaborative, and forward-looking nature of gravitational wave research ensures that it will continue to be a critical area of scientific inquiry for years to come.

Total 800 participants registered for the event. Around 300 participated offline and others have attended it online.

Some Glimpses





JAIPUR NATIONAL UNIVERSITY

NAAC A+

Jaipur-Agra Bypass, Near New RTO Office,
Jagatpura, Jaipur, Rajasthan 302017

Web. : www.jnujaipur.ac.in | E-mail: admissions@jnujaipur.ac.in
Ph. No. : +91-141 719 7070 | Toll Free No. : 1800-102-1900