ACCADEMIA NAZIONALE DEI LINCEI

CONVEGNO

GRAVITATIONAL WAVES AND THEIR COUPLING WITH LIGHT AND NEUTRINOS

24-25 OTTOBRE 2024

ABSTRACT

Comitato ordinatore: Marica BRANCHESI (Lincea, Astrofisica presso il Gran Sasso Science Institute (GSSI), L'Aquila), Monica COLPI (Lincea, Università di Milano Bicocca), Massimo DELLA VALLE (Linceo, Osservatorio Astronomico di Capodimonte Napoli - INAF), Giovanni LOSURDO (Linceo, INFN, Pisa), Francesca MATTEUCCI (Lincea, Università di Trieste), Marco TAVANI (Linceo, INAF)

PROGRAMMA

Detecting the vibrations of space-time from coalescing binary black holes and neutron stars allows us to probe gravity and matter under extreme conditions in a unique way. The gravitational wave (GW) signal from black holes contains precious information on their masses and spins, and geometry of space-time, inaccessible otherwise. Merging neutron stars are a laboratory to unveil how heavy elements are forged via r-process nucleosynthesis, and tidal signatures in their waveforms bring insight into the state of matter at ultra-high densities and temperatures. Combining these observations with coincident signals from neutrinos and light, even during core collapse supernova events, is paramount to answer key questions of fundamental physics and astrophysics. Detecting populations of binary black holes - from stellar to supermassive - illuminates the way they form and grow, from cosmic dawn to the present.

This *Convegno Linceo* is timely, considering the O4 LVK observational run, the recent adoption of the ESA's mission LISA, the development/implementation of the Einstein Telescope Observatory and neutrino detectors. Evidence of a stochastic GW background from Pulsar Timing Array experiments is now opening a new frontier. A novel astronomy comes into being, encompassing almost the entire GW Universe: a new probe into the cosmos.

This *Convegno Linceo* will provide a critical overview of the science of this emerging field. It is addressed to scientists, postdoctoral fellows and PhD students. It is meant to be an occasion to consolidate collaborations among Italian scientists working in this field.

Giovedì 24 ottobre

10.00 *Indirizzi di saluto*
Presidenza dell'Accademia Nazionale dei Lincei

10.10 Monica COLPI (Lincea, Università di Milano Bicocca): *Wellcome*

10.15 Dafne GUETTA (Ariel University and INAF-Napoli): *Neutrino emission from core collapse supernovae*

10.45 Albino PEREGO (Università di Trento): *Neutrino emission from compact binary mergers and the r-processes*

11.15 Maurice VAN PUTTEN (Seul University): *Gravitational wave emission from core-collapse supernovae*

11.45 Coffee break

12.00 Alberto SESANA (Università di Milano Bicocca): *Listening to the universe with a Galactic-size detector*

12.30 Giovanni LOSURDO (INFN, Pisa): *Updates from the O4 LVK run and plans for the future of Virgo*

14.30 Michele MAGGIORE (Genève University): *Key science with Einstein Telescope*

15.00 Giancarlo GHIRLANDA (INAF, Brera): *Multimessenger observation in the ET era*

15.30 Bill WEBER (Università di Trento): *LISA on track*

16.00 Coffee break

16.30 Marta VOLONTERI (IAP, Paris): *Key science with LISA*

17.00 Andrea POSSENTI (INAF, Cagliari): *The future of PTA*

17.30 *Discussion*

Venerdì 25 ottobre

9.30 Michela MAPELLI (University of Heidelberg): *What are we learning about binary black hole populations? A critical assessment*

10.00 Raffaella SCHNEIDER (Sapienza Università di Roma): *Massive Black Holes in the JWST era*

10.30 Walter DEL POZZO (Università di Pisa): *Fundamental physics with gravitational waves*

11.00 Coffee break

11.30 Arianna RENZINI (Università di Milano Bicocca): *LIGO gravitational wave backgrounds*

12.00 Jan HARMS (GSSI): *Lunar Gravitational Wave Antenna*

12.30 *Conclusions*

Il convegno è organizzato con il contributo dell'Istituto Nazionale di Astrofisica

ROMA – PALAZZO CORSINI- VIA DELLA LUNGARA, 10
Segreteria del convegno: convegni@lincei.it – http://www.lincei.it

Tutte le informazioni per partecipare al convegno sono disponibili su:
https://www.lincei.it/it/manifestazioni/gravitational-waves-and-their-coupling-light-and-neutrinos

Per partecipare al convegno è necessaria l'iscrizione online
Fino alle ore 10 è possibile l'accesso anche da Lungotevere della Farnesina, 10
I lavori potranno essere seguiti dal pubblico anche in streaming

L'attestato di partecipazione al convegno viene rilasciato esclusivamente a seguito di partecipazione in presenza fisica e deve essere richiesto al personale preposto in anticamera nello stesso giorno di svolgimento del convegno

Neutrino emission from core collapse supernovae

Dafne GUETTA (Ariel University and INAF-Napoli)

Over the last decade, choked jets have attracted particular attention as potential sources of high-energy cosmic neutrinos. However, testing this hypothesis is challenging because of the missing gamma-ray counterpart, such that the identification of other electromagnetic signatures is of paramount importance. A choked-jet source is expected, for instance, because of core-collapse supernovae with extended hydrogen envelopes (Type II SNe), leading to the release of ultraviolet (UV) and optical (O) emission for a few days. The UV band will be visible with an unprecedentedly large field of view by the future mission satellite ULTRASAT, for which we investigate the detection prospects in relation to the chocked source visibility in the O band with the currently operating telescope ZTF. By considering fiducial parameters of the source population, we estimate the maximum redshift up to which ULTRASAT will be able to detect UV signals from these explosions, finding that it will be able to double the volume of sky currently visible by ZTF for the same emitting sources, and consequently enlarge the sample of observed Type II SNe by 60%. Furthermore, we discuss coordinated multi-messenger observations among those instruments and high-energy neutrino telescopes. To optimize combined detections, we suggest a delay of 4 days between ν and ULTRASAT observations, with a subsequent follow-up by like-ZTF instruments about one week after.

Neutrino emission from compact binary mergers and the r-processes

Albino PEREGO (Università di Trento)

Compact binary mergers involving neutron stars are one of the cosmological forges where half of the heavy elements in the Universe are synthetized through the so called rapid-neutron capture process (r-process).

The precise prediction of the nucleosynthesis yields is crucial to assess the role of compact binary mergers in the chemical evolution of the Universe, as well as to interpret multimessenger observations, for example in shaping the light curves and spectra of kilonovae.

It is thus not surprising that compact binary mergers are primary targets of present and future gravitational wave telescopes, as well as of transient search campaign, with a dramatic increase of the detection rates expected in the next decade.

Neutrino eission is a key ingredient for all these processes, since the neutrinos that are copiously produced by the hot and dense nuclear matter resulting from these collisions set the relative amount of neutrons and protons.

In this talk, I will critically review the current status of neutrino emission and r-process nucleosynthesis as emerging from sophisticated, ab-initio simulations of compact binary mergers, with a special emphasis on the open questions and on theoretical and experimental perspective of the field.

Gravitational wave emission from core-collapse supernovae

Maurice VAN PUTTEN (Seul University)

Gravitational-wave observations now offer a direct window into the physical mechanisms driving supernovae from the core collapse of massive stars. The central engines of these events likely involve either a neutron star (NS) or a black hole (BH), depending on the progenitor's mass. BH central engines may produce long-duration gravitational-wave (GW) bursts emanating from a high-density disk or torus, harnessing an angular momentum reservoir far larger than that of an NS. Based on supernova event rates, associations of energetic events with long gamma-ray bursts (GRBs), and mass scaling from the GW170817B/GRB170817A event, these signals could be detectable with current instruments. GW170817B, a powerful descending GW chirp detected at a 5.5 σ significance during GRB170817A, was produced by the black hole remnant of the double neutron star merger GW170817. Conservatively, we anticipate several observational opportunities over the next decade within a range of 50–100 Mpc. Such observations promise to decisively break the degeneracy between NS and BH central engines in energetic core-collapse supernovae through detailed calorimetry of their gravitational-wave emission.

[Based on M.H.P.M. van Putten, M.A. Abchouyeh & M. Della Valle, 2024, ApJL, 972, L23; https://doi.org/10.3847/2041-8213/ad710f]

Listening to the universe with a Galactic-size detector

Alberto SESANA (Università di Milano Bicocca)

Last June several Pulsar Timing Array (PTA) collaborations reported evidence for a signal compatible with a gravitational wave (GW) origin. Although the significance did not yet cross the psychological '5sigma' threshold, we are likely witnessing the opening of a new window on the Universe: the nano-Hz GW window. I will discuss the principles of PTAs, the most likely origin of the observed signal and its implications for astrophysics and cosmology.

Key science with Einstein Telescope

Michele MAGGIORE (Genève University)

The Einstein Telescope (ET) is the European project for a next generation gravitational-wave detector. With an improvement in sensitivity by one order of magnitude and a significant enlargement of the bandwidth, both toward low and high frequencies, it will have extraordinary potential for discoveries in astrophysics, cosmology, and fundamental physics. In this talk we will summarize some of the most relevant aspects of the Science Case of ET.

Multimessenger observation in the ET era

Giancarlo GHIRLANDA (INAF, Brera)

The detection of the binary neutron star merger on August 17, 2017, marked the beginning of the multi-messenger era, combining gravitational wave (GW) and electromagnetic (EM) observations. This event revealed that the merger produced two ejecta components, with differing dynamical and angular structures, responsible for the gamma-ray burst and kilonova emissions. While ongoing GW detectors will continue to advance our understanding, the advent of the Einstein Telescope (ET), as a representative of the next-generation GW detectors, promises a transformative leap with hundreds of GW events detected per day reaching distances up and beyond the era of the peak of star formation. The challenge lies in identifying and following up on the EM counterparts across vast distances and wavelengths. In this talk, I will briefly describe key EM observational facilities expected to be operational by 2035, from high-energy observatories to radio telescopes arrays, and their roles in the multi-messenger study of compact binary mergers.

LISA on track

Bill WEBER (Università di Trento)

In January, the European Space Agency adopted the Laser Interferometer Space Antenna (LISA) as the second "Large Mission" of the Cosmic Vision program, scheduled for a launch in 2035. LISA aims to open a window of exploration of the gravitational wave sky, from 0.1 mHz to 1 Hz, that is only accessible from space and offers unprecedented opportunities to study the physics and astronomy of sources from collapsed stars in our own galaxy to distant supermassive black holes. LISA features free-falling test masses inside three spacecraft at the corners of an orbiting triangular constellation with 2.5 million km sidelength, with the tidal force of a passing gravitational wave detected in a laser interferometric measurement of the relative motion between the distant test masses. I will present here the LISA observatory measurement concept, hardware design, and the main experimental challenges that are being faced in developing this transformational observatory.

Key science with LISA

Marta VOLONTERI (IAP, Paris)

LISA, with a launch planned for the second half of 2030s, is slated to revolutionize our understanding of the Universe. In this presentation I will focus in particular on massive black holes — black holes with masses >10,000 solar masses. The most massive of such black holes, with masses above millions of solar masses, are known to inhabit the center of massive galaxies today, and to power Active Galactic Nuclei and quasars throughout the history of the Universe. Although we know that lighter massive black holes exist, as some examples have been detected in nearby dwarf galaxies, very little is known about them in the early Universe. We however expect then to be abundant in the first galaxies — the building blocks of the massive black holes we see today. LISA will be uniquely able to unveil this population and shed light on the formation and early growth of massive black holes.

The future of PTA

Andrea POSSENTI (INAF, Cagliari)

Thanks to the rotational stability of the underlying neutron star, a subsample of the so-called “recycled” pulsars are magnificent cosmic instruments not only to perform high precision tests of the gravity theories, but also to constitute of a galactic scale gravitational wave detector, dubbed Pulsar Timing Array (PTA). Recent publications from the various PTA experiments have been very promising, reporting the first evidence for a detection of ultra-long period gravitational waves, to be corroborated by additional analysis. After briefly reviewing the major results, the talk will describe the perspectives of these experiments, with a particular focus on the impact of the SKA radio telescope.

Massive Black Holes in the JWST era

Raffaella SCHNEIDER (Sapienza Università di Roma)

Understanding the nature of the first black holes and their growth mechanisms through gas accretion and mergers with other black holes are some of the most important open problems in modern astrophysics. Progress in this field has been limited by the fact that our observational knowledge at redshifts greater than 6 has been confined to the supermassive black holes powering luminous quasars, which are just the tip of the iceberg of a much larger but observationally inaccessible population of black holes. The extraordinary discoveries of the JWST are allowing, for the first time, an extension of our exploration to much smaller mass black holes, reaching down to seed black holes, and understanding their relationship with their host galaxy and the physical conditions present in the nuclear regions. In this talk, I will provide a personal perspective on our current understanding of the origin and early growth of nuclear black holes in the first few hundred million years of cosmic history, highlighting how JWST observations have offered both confirmations and many surprises.

Fundamental physics with gravitational waves

Walter DEL POZZO (Università di Pisa)

Gravitational waves have revolutionised our ability to observe the universe, opening an entirely new window into its most extreme phenomena. Since LIGO and Virgo first detected the mergers of binary black holes, these observations have provided groundbreaking insights into gravity, confirming key predictions of general relativity. Compact binary systems, such as black hole

and neutron star mergers, generate gravitational waves that allow us to directly test general relativity in its most intense, strong-field environments. Beyond confirming current theoretical frameworks, gravitational wave astronomy offers the potential to explore uncharted territories in physics, including the nature of black holes, dark matter, the behaviour of matter at extreme densities, and possibly even quantum gravity.
In this talk, I will examine the fundamental physics revealed through the study of compact binary mergers, showcasing the innovative methods used to investigate novel phenomena. I will conclude with a review of the most significant discoveries so far and an outlook on the promising future of this rapidly evolving field.

LIGO gravitational wave backgrounds

Arianna RENZINI (Università di Milano Bicocca)

Abstract: Gravitational-wave backgrounds (GWBs) encompass a multitude of signals across the wide gravitational-wave (GW) frequency spectrum, and represent key targets in the panorama of gravitational-wave data analysis. Typically, GWBs are considered to be the collection of GW signals that lie just beneath the threshold of detection. In this talk, I will broadly introduce GWBs and various ongoing or near-future detection efforts, focusing on ground-based interferometers such as LIGO and Virgo. I will specifically focus on the astrophysical GWB from binary black holes and neutron stars, as it is expected to be the main background source in the LIGO-Virgo-KAGRA (LVK) frequency range. I will describe the flagship LVK GWB searches and outline their key implications beyond GWs: The GWB power spectrum includes information on binary formation history and mass distribution, while its angular power spectrum is a tracer of large-scale structure, and many other potential sky distributions. I will also present exciting new detection prospects for the non-Gaussian binary black hole background, which we can target with tailored search methods.

Titolo: Scavando sotto la superficie: Fondi di onde gravitazionali in LIGO-Virgo-KAGRA

Abstract: I fondi di onde gravitazionali comprendono una moltitudine di segnali attraverso l'ampio spettro di frequenze delle onde gravitazionali, e rappresentano obiettivi chiave nel panorama delle analisi dati di onde gravitazionali. Tipicamente, i fondi sono costituiti dall'insieme di segnali che si trovano appena sotto la soglia di rilevamento. In questo intervento, introdurrò i vari fondi di onde gravitazionali e gli sforzi di rilevamento in corso o di prossima realizzazione, concentrandomi sugli interferometri terrestri come LIGO e Virgo. Mi focalizzerò specificamente sul fondo astrofisico proveniente da buchi neri binari e stelle di neutroni, poiché si prevede che sia la principale fonte di fondo nella gamma di frequenze LIGO-Virgo-KAGRA (LVK). Descriverò le ricerche di punta sui fondi all'interno della collaborazione LVK e ne delineerò le principali implicazioni: lo spettro di potenza del fondo include informazioni sulla storia della formazione delle binarie e sulla distribuzione delle masse dei buchi neri, mentre il suo spettro di potenza angolare è un tracciante della struttura su larga scala dell'Universo.

Presenterò anche nuove ed entusiasmanti prospettive di rilevamento per il fondo di buchi neri binari, sfruttando la sua caratteristica temporale intermittente.

Lunar Gravitational Wave Antenna

Jan HARMS (GSSI)

Gravitational-wave (GW) observations with the Virgo and LIGO detectors have revolutionized astronomy and physics. With more than 100 detections today, we can start to study in greater detail the properties of black holes and their distribution in our Universe. The observation of the merger of two neutron stars in 2017 has led to the greatest astronomical campaign in human history with numerous publications dedicated to its study. Despite these outstanding achievements, the field is only in its infancy, and new revolutionary instruments are underway like the space-based LISA mission or the proposed Einstein Telescope. Even then, GW detectors will only observe a small portion of all possibly detectable GW sources in our Universe, and researchers have started to develop new detector concepts to further extend the scientific reach of GW detectors. Among these concepts is the Lunar Gravitational-wave Antenna (LGWA). The Moon itself acts like an antenna to GWs by starting to ring like a bell when a GW passes. A transducer needs to be built to read out the vibrations of the Moon. These transducers are being developed by an international team. The LGWA mission creates a tight connection between astrophysical observations and the properties of the Moon, which determine how it responds to GWs. The LGWA pathfinder mission Soundcheck was recently selected by ESA to study a possible LGWA deployment site. The Moon provides an ideal environment for LGWA, and it might well be the only place in our solar system where a detector like LGWA can ever be realized.

L'antenna lunare per onde gravitazionali

Le osservazioni delle onde gravitazionali (gravitational waves; GW) con i rivelatori Virgo e LIGO hanno rivoluzionato l'astronomia e la fisica. Con oltre 100 rilevazioni oggi, possiamo iniziare a studiare più in dettaglio le proprietà dei buchi neri e la loro distribuzione nel nostro Universo. L'osservazione della fusione di due stelle di neutroni nel 2017 ha portato alla più grande campagna astronomica nella storia dell'umanità con numerose pubblicazioni dedicate al suo studio. Nonostante questi risultati eccezionali, il campo è solo agli inizi e si sta lavorando a nuovi strumenti rivoluzionari come la missione spaziale LISA o il progetto Einstein Telescope. Anche quando questi saranno operativi, i rivelatori GW osserveranno solo una piccola parte di tutte le possibili sorgenti GW rivelabili nel nostro Universo. I ricercatori hanno quindi iniziato a sviluppare nuovi concetti di rivelatori per estendere ulteriormente la portata scientifica dei rivelatori GW. Tra questi concetti c'è Lunar Gravitational-wave Antenna (LGWA). La Luna stessa può essere un'antenna per le GW iniziando a risuonare come una campana quando è attraversata una GW. È necessario costruire un trasduttore per leggere le vibrazioni della Luna. Questi trasduttori sono in fase di sviluppo da parte di un team internazionale. La missione LGWA unirà le osservazioni astrofisiche alle proprietà della Luna, permettendo di studiare l'universo e l'interno della luna. La missione pathfinder Soundcheck è stata recentemente selezionata dall'ESA per studiare un possibile sito di distribuzione LGWA. La Luna fornisce un ambiente ideale per LGWA e rappresenta l'unico posto nel nostro sistema solare in cui un rilevatore come LGWA potrà mai essere realizzato.