55$^{\text{th}}$ **Rencontres de Moriond**

Gravitation

Virtual Conference, March 09 - 11, 2021

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Poster Session A

Laboratory tests of gravitation

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A01

New ideas and results in searches for ultra-low-mass dark matter and macroscopic topological defects

Yevgeny Stadnik (Kavli IPMU, University of Tokyo)

Ultra-low-mass bosonic dark matter may form a coherently oscillating classical field. These oscillating fields can in turn induce apparent temporal variations of the fundamental "constants" of nature, including fundamental interaction strengths and particle masses [1], as well as particle g-factors [2]. With the BASE collaboration at CERN, we proposed and performed a search for pseudoscalar (axionlike) dark matter interactions using antiprotons in a Penning trap, improving over astrophysical bounds by up to 5 orders of magnitude [2]. In another recent work [3], we identified novel signatures of scalar dark matter in laser-interferometric gravitational-wave detectors, such as LIGO/VIRGO and GEO600, the existing datasets of which may already be used to improve the sensitivity over current bounds from fifth-force searches by up to a factor of a few hundred. Ultra-low-mass bosons may also form macroscopic topological defects. In my recent work [4], I identified a number of novel signatures in previously-considered models of topological defects composed of scalar field(s) that interact with standard-model fields non-gravitationally. In particular, I have shown that the previously-overlooked back-action of ambient matter on the scalar field(s) results in an environmental dependence of the fundamental constants, as well as spatial variations of the fundamental constants in the vicinity of massive bodies such as Earth, due to the formation of a "bubble-like" defect structure surrounding the dense body [4]. Using existing data from torsion-pendulum experiments, clock comparison measurements at different heights and astrophysical spectra, I have derived new bounds on macroscopic domain walls that improve over previous bounds by up to 15 orders of magnitude [4].

References:

(1) Stadnik and Flambaum, Physical Review Letters 114, 161301 (2015); Physical Review Letters 115, 201301 (2015).
(2) Smorra, Stadnik et al., Nature 575, 310 (2019).
(3) Grote and Stadnik, Physical Review Research 1, 033187 (2019).
(4) Stadnik, arXiv:2006.00185; Physical Review D (In press).

A02

Are top sensitivity Sagnac gyroscopes suitable to fundamental physics, for Earth gravito-magnetism and Lorentz violation tests?

Angela Di Virgilio (INFN - Pisa)

The Earth rotation is a tool to investigate fundamental physics, since it contains general relativity terms, as de Sitter and Lense Thirring, and can provide unique data to investigate Lorentz violation. Its usefulness for fundamental physic is connected to sensitivity, which is quite often express in relative to the average Earth rotation rate; the boundary to be meaningful to fundamental physics is to reach 1 part in 10^9 and long term continuous operation. Present high sensitivity ring laser gyroscope have already fulfilled those requirements. The GINGER (Gyroscopes IN General Relativity) project is devoted to fundamental physics and based in an array of RLG. GINGERINO is a top sensitivity RLG built inside the underground Gran Sasso laboratory to validate the Gran Sasso laboratory for GINGER. Its sensitivity has been carefully investigated with standard statistical means, using 103 days of continuous operation and the available geodesic measurements of the Earth angular rotation rate. Sensitivity 0.1 frad/s appears, with 600s bandwidth at frequency of 40 days, indicating the feasibility of 1 part in 10^{12} of the Earth rotation rate, and accordingly for GINGER the Lense Thirring test on Earth at the 0.1% level or even better.

A03

Simulation of GBAR experiment at CERN: does antimatter fall or is there antigravity?

Olivier Rousselle (Laboratoire Kastler Brossel Paris)

One of the main questions of fundamental physics is the action of gravity on antimatter. We present here the simulation of the last part of the experiment GBAR at CERN, i.e. the measurement of the free fall acceleration $\overline{g}$ of antihydrogen atoms in the gravitational field of Earth. It includes the Monte-Carlo generation of trajectories and the analysis leading to the estimation of $\overline{g}$. A precision of the measurement beyond the % level is confirmed by taking into account the experimental design.

A04

Search for scalar field dark matter with the GEO 600 gravitational wave detector

Sander M. Vermeulen (Cardiff University)

Low-mass (sub-eV) scalar field DM may induce apparent oscillations of fundamental constants, where the frequency is determined by the field's mass, and the amplitude is set by the strength of the coupling to the SM and the local dark matter density. These oscillations of fundamental constants would produce corresponding oscillations of the size and the index of refraction of solids. Laser interferometers, such as gravitational wave (GW) detectors, are highly sensitive to changes in the size and index of refraction of the main beamsplitter. Therefore, examining data from GW detectors for the presence of continuous oscillatory signals allows for the exploration of previously unconstrained regions of the parameter space of scalar field DM. We present the motivation and methodology for a scalar field DM search in data from the GEO,600 GW detector, the results of which will be published soon.

A05

Observing quantum gravity effects with twin, co-located, tabletop 3D interferometers

William Griffiths (Cardiff University)

Theories of quantum gravity suggest space-time exhibits quantum fluctuations. The holographic principle further implies that these fluctuations are correlated in overlapping volumes of space-time. If observed, the correlated fluctuations would provide a hint to how gravity and quantum theories may be unified. Twin co-located interferometers would allow testing these theoretical models through their cross-spectrum to detect common-mode fluctuations of space-time. Cardiff University's Gravity Exploration Institute is building co-located tabletop interferometers with sufficient sensitivity to validate or exclude some theories of quantum space-time. The tabletop interferometers will not only be used for quantum gravity tests but will also be sensitive to MHz gravitational waves and dark matter candidates. To achieve unprecedented sensitivity, we will make use of highly squeezed vacuum states and a 200MHz bandwidth output mode cleaner.

A06

The DAMNED experiment !
Etienne Savalle (CNES and APC Paris)

The DAMNED experiment is a new type of experiment that compares the frequency of a clock to itself in the past, by "storing" photons in a fibre delay line. In ultra-light oscillating dark matter (DM) models, the coupling of DM to the standard model fields yields an oscillation of fundamental constants, which in turn leads to oscillations of the cavity and fibre lengths and of the fibre refractive index. Additionally, the sensitivity is significantly amplified around the mechanical resonance frequencies of the cavity. We present experimental result of such an experiment and report no evidence of DM for frequencies in the [10, 200] kHz region. Taking advantage of this sensitivity, we improve constraints on the involved coupling constants by one order of magnitude in a standard galactic DM model, at the mass corresponding to the resonant frequency of our cavity. Furthermore, in the model of relaxion DM, we improve on existing constraints over the whole DM mass range by about one order of magnitude, and up to six orders of magnitude at resonance. Based on the PRL accepted paper : https://arxiv.org/abs/2006.07055

A07

Production of Antihydrogen in pulsed mode
Antoine Camper (University of Oslo)

We report on the first production of antihydrogen in pulsed mode. Using a charge exchange reaction between a plasma of cold antiproton and a pulse of Rydberg positronium atoms, the AEgIS collaboration demonstrated the first production of antihydrogen with a precision on the time when the antiatoms are formed of a few hundreds of nanoseconds. We will present a detailed analysis of the antihydrogen production and outline the perspectives of this first step towards a test of the validity of the Weak Equivalence Principle for antimatter within the AEgIS collaboration.

A08

Measurement of Gravitational Coupling between Millimeter-Sized Masses
Jeremias Pfaff (University of Vienna)

Gravity is the weakest of all known fundamental forces and continues to pose some of the most outstanding open problems to modern physics: it remains resistant to unification within the standard model of physics and its underlying concepts appear to be fundamentally disconnected from quantum theory. Testing gravity on all scales is therefore an important experimental endeavour. Thus far, these tests involve mainly macroscopic masses on the kg-scale and beyond. Here we show gravitational coupling between two gold spheres of 1 mm radius, thereby entering the regime of sub-100 mg sources of gravity. Periodic modulation of the source mass position allows us to perform a spatial mapping of the gravitational force. Both linear and quadratic coupling are observed as a consequence of the nonlinearity of the gravitational potential. Our results extend the parameter space of gravity measurements to small single source masses and small gravitational field strengths. Further improvements will enable the isolation of gravity as a coupling force for objects below the Planck mass. This opens the way to a yet unexplored frontier of microscopic source masses, which enables new searches of fundamental interactions and provides a natural path towards exploring the quantum nature of gravity.

A09

Improved Limits for Violations of Local Position and Local Lorentz Invariance from Atomic Clock Comparisons
Nils Huntemann (PTB Braunschweig)

Searches for violations of Einstein's equivalence principle, such as tests of local Lorentz invariance and local position invariance, have become one of the leading applications of low-energy, high-precision experiments with laser-cooled atoms. In our laboratory, we operate microwave atomic clocks based on the ground state hyperfine splitting frequency of Caesium and optical clocks based on optical transitions of single trapped Ytterbium ions. The frequency ratio of an electric quadrupole and an electric octupole (E3) transition of Yb+ has been determined with 3E-17 fractional uncertainty, improving upon previous measurements by an order of magnitude. Using two caesium fountain clocks, we measured the E3 transition frequency at 642 THz with 80 mHz uncertainty, the most accurate determination of an optical transition frequency to date. Repeated measurements of both quantities over several years are analyzed for potential violations of local position invariance that would affect the atomic transition frequencies [1]. From the observed agreement and consistency of the clock data, we improve by factors of about 20 and 2 the limits for fractional temporal variations of the fine structure constant to 1.0(1.1)E-18/yr and of the proton-to-electron mass ratio to -8(36)E-18/yr. Using the annual variation of the Sun's gravitational potential at Earth, we improve limits for a potential coupling of both constants to gravity. Operating the two optical clocks both on the E3 reference transition with different orientations of the quantization axes enables an even more accurate comparison and allows us to improve previous limits on a Lorentz symmetry violation for electrons by two orders of magnitude [2].

(1) R. Lange, N. Huntemann, J. M. Rahm, C. Sanner, H. Shao, B. Lipphardt, Chr. Tamm, S. Weyers, and E. Peik, Phys. Rev. Lett. 126, 011102 (2021).
(2) C. Sanner, N. Huntemann, R. Lange, Chr. Tamm, E. Peik, M.S. Safronova and S.G. Porsev Nature 567, 204 (2019).

A10

ROYMAGE project: a transportable clock for geodetic and geophysical applications

Guillaume Lion (IPGP IGN Paris)

ROYMAGE (hoRloge Optique à Ytterbium Mobile Appliquée à l'exploration GEodésique) is a project funded by the French ANR dedicated to develop a transportable ytterbium (Yb) optical lattice clock. Connected to the fiber network REFIMEVE+, the clock will allow remote clock comparisons to perform chronometric geodesy applications and tests of gravitational time dilation. With a relative frequency uncertainty targeted in the low 10^{-17} (equiv. 10 cm in height) at a first step, the clock will provide geopotential measurements which are not directly available with traditional techniques (e.g. GNSS/levelling, InSar, gravimetry, gradiometry). This could revolutionize the determination of the gravity field and geodetic vertical references,the exploration of the Earth's internal dynamic and the connection between sea level measured either by tide gauges or by satellites. We present here the objectives and motivations for the 4-years project involving 4 partners in the consortium (Observatoire de Paris, IPGP, IGN and SHOM).

A11

The ORGAN Experiment: Status, and Future Plans

Ben McAllister (University of Western Australia)

We discuss the current status and future plans of the Oscillating Resonant Group AxioN (ORGAN) Experiment, a high mass axion dark matter detection experiment, designed to probe for axions in the 50-200 micro-eV mass range. Axions present as part of a compelling solution to the Strong CP problem in QCD, and are also a leading candidate to comprise dark matter. Despite their strong theoretical motivations, axions are yet to be observed directly in the lab. Most experiments which propose to detect dark matter axions rely on their coupling to photons. Confounding experimental efforts to detect axions is the fact that their mass is unknown, and thus the frequency of any photons generated via this coupling is unknown. Many recently theoretical predictions point to the high mass (>50 micro-eV) range as promising. However, owing to a host of technical concerns, this range is as yet largely unprobed experimentally. ORGAN made its first run in 2017, and is currently preparing for its second run, due to commence in 2021, when it will begin scanning this highly promising mass range. We discuss the results to date, the forthcoming run, and the future plans for the experiment, including the technologies which are in development to enhance its sensitivity.

A12

Determination of the fine-structure constant with an accuracy of 81 parts per trillion

Zhibin Yao (Laboratoire Kastler Brossel Paris)

Any discrepancies between standard model predictions and experimental results may reveal clues about the new physics. The fine-structure constant alpha is a crucial parameter in quantum electrodynamics theory especially for evaluating the magnetic moment of electron or muon predicted by the standard model. By using a matter-wave interferometer to measure the recoil velocity, we obtained recently a new value of the fine-structure constant with an accuracy of 81 parts per trillion.Using this value of the fine-structure constant we obtain the standard-model prediction of the anomalous magnetic moment of the electron with a relative uncertainty below 0.1 ppt, which is the most accurate prediction of the standard model. This result paves the way for testing the discrepancy observed in the magnetic moment anomaly of the muon in the electron sector.

A13

Tests of Lorentz invariance in the phonon sector using quartz BAW resonators

Zijun Zhao (University of Western Australia)

Tests of Local Lorentz Invariance Violation (LIV) in the phonon sector was implemented using quartz bulk acoustic wave (BAW) oscillators. Frequency shifts of rotating room temperature oscillators with state-of-the-art low phase noise are compared. Results of the improved precision in the limit of standard model extension (SME) coefficients in the matter sector after 1.7 years' worth of data will be presented.

A14

Some recent developments in 5th force searches

Ephraim Fischbach (Purdue University)

We discuss recent work that has drawn attention to the significance of composition-dependent effects in 5th searches. It has been shown that such searches require data from experiments in which the acceleration differences of 3 or more independent pairs of test samples of varying composition are determined. We illustrate the implications of the above observation by reference to both the original Eötvös experiment, and to a recent analysis of an experiment contemporaneous with Eotvos, which suggests a similar effect.

A15

Inertial sensing with quantum gases: A comparative performance study of condensed versus thermal sources for atom interferometry

Thomas Hensel (Leibniz University Hannover)

Quantum sensors based on light-pulse atom interferometers allow for measurements of inertial and electromagnetic forces such as the accurate determination of fundamental constants as the fine structure constant or testing foundational laws of modern physics as the equivalence principle. These schemes unfold their full performance when large interrogation times and/or large momentum transfer can be im- plemented. In this article, we demonstrate how interferometry can benefit from the use of Bose-Einstein condensed sources when the state of the art is challenged. We contrast systematic and statistical effects induced by Bose-Einstein condensed sources with thermal sources in three exemplary science cases of Earth- and space-based sensors.

A16

Ferromagnetic Gyroscopes for Tests of Fundamental Physics

Pavel Fadeev (Helmholtz Institute Mainz)

Is intrinsic spin affected by gravity the same way as orbital angular momentum? We propose how to measure general-relativistic precession of intrinsic spin, to test this question. In our concept a compass (a ferromagnet) is made to precess around, instead of pointing along, the direction of a magnetic field, due to its electrons' intrinsic spins. We seek to perform a proof-of-principle measurement in a ferromagnet levitating above a superconductor. We show that a bound on properties of dark matter candidate in such a setup is competitive with the current state of the art. https://arxiv.org/abs/2006.09334 https://arxiv.org/abs/2010.08731

A17

Transportable optical lattice clocks to test gravitational redshift in a broadcasting tower

Noriaki Ohmae (Fukuoka University)

State-of-the-art optical atomic clocks with an uncertainty of 10^{-18} allow measuring height differences of a centimeter via the gravitational redshift. We demonstrate an 18-digit-precision frequency comparison in a broadcasting tower, TOKYO SKYTREE, by developing transportable optical lattice clocks. The tower provides a 450 m height difference

to test gravitational redshift at $1.4(9.1) \times 10^{-5}$. Our experiment shows optical clocks resolving centimeters are technically ready for field applications, such as monitoring spatiotemporal changes of geopotentials caused by active volcanoes or crustal deformation and for defining the geoid. We present the details of our transportable clocks and the result of the gravitational redshift measurement.

A18

Dark matter Axion search with riNg Cavity Experiment DANCE: Development of control systems for long-term measurement

Hiroki Fujimoto (University of Tokyo)

Axion-like particles (ALPs) are pseudo-scalar particles that are candidates for ultralight dark matter. ALPs interact with photons slightly and cause the rotational oscillation of linear polarization. DANCE searches for axion dark matter by enhancing the rotational oscillation in a bow-tie ring cavity. The signal to noise ratio of DANCE can be improved by long-term observation, and we are planning 1-year observation for the final DANCE. In this poster session, I will report on the developed control systems of the ring cavity for the future long-term observation.

A19

Dark matter Axion search with riNg Cavity Experiment DANCE: Current sensitivity

Yuka Oshima (University of Tokyo)

We present the principle of Dark matter Axion search with riNg Cavity Experiment (DANCE) and the status of the prototype experiment, DANCE Act-1. To search for axion-like dark matter, we aim to detect the rotation and oscillation of an optical linear polarization caused by the axion-photon coupling. Optical path length is effectively increased with a cavity, and the rotation angle of the polarization can be amplified to be detected. In the case of a linear cavity, the rotation of polarization is inverted by reflection at the mirror and rotation effect is cancelled out. Our group proposed to use a bow-tie ring cavity to solve this issue. The final version of DANCE will improve the sensitivity to the axion-photon coupling constant for axion mass $< 10^{-10}$ eV by several orders of magnitude compared to the current best limits. A prototype experiment DANCE Act-1 with a cavity round-trip length of 1 m is underway to demonstrate the feasibility of our method and to investigate possible technical noises. Even with the shorter cavity round-trip length, smaller finesse and lower input power than the final DANCE, DANCE Act-1 can reach the sensitivity beyond the CAST limit. We have finished the assembly of the optics, obtained the data, and estimated current sensitivity. We are now trying to achieve the design sensitivity of DANCE Act-1 by hunting and reducing noises. In this session, we will report the current status of DANCE Act-1.

A20

Limits on fundamental constant oscillations from laser spectroscopy of molecular iodine

Nataniel Figueroa Leigh (Johannes Gutenberg Universität Mainz)

Approximately 85% of the matter content of the Universe is nonluminous, and composed by particles of unknown nature; this makes dark matter one of the biggest open questions in physics today. Among the promising candidates for dark matter, there are bosonic fields with small scalar coupling to standard-model particles. Here, we present a search for two such fields (dilatons and relaxions), that would manifest as oscillations of fundamental "constants". This would produce an oscillating frequency shift, δf, in the R(122) 2-10 I2 transition at 725 nm ($f_0 \approx 413$ THz), which we looked for using absorption spectroscopy. Oscillations were not observed at the $\delta f/f_0 < 10^{-14}$ level in the range between 0.1 to 100 MHz allowing us to put limits on the effects of potential dark matter-induced fundamental "constant" oscillations.

Poster Session B

Observational and space tests of gravitation

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B01

ACES/PHARAO: high performance space-to-ground and ground-to-ground clock comparison for fundamental physics

Marc Lilley (SYRTE, Observatoire de Paris)

The Atomic Clock Ensemble in Space (ACES) is a fundamental physics mission of the European Space Agency (ESA) to be launched in August 2021. It relies on a high-performance clock onboard the International Space Station (ISS), a network of high-performance clocks on ground, a dedicated two-way microwave link (MWL) enabling space-to-ground and ground-to-ground clock comparisons, as well as an optical link (ELT). PHARAO/SHM (Projet d'Horloge Atomique par Refroidissement d'Atomes en Orbite/Space Hydrogen Maser), the clock onboard the ISS, has a relative frequency accuracy at the 10^{-16} level, a relative frequency stability (Allan deviation) equal to $10^{-13}/\sqrt(\tau)$ (τ being the integration time in seconds) and a time deviation of 12 picoseconds after one day of integration. The MWL is designed to reach a time deviation below 7 ps after one day of integration. While space-to-ground clock comparisons will enable precise tests of the gravitational redshift, tests of deviations from General Relativity at the 10^{-6} level, and tests of local Lorentz invariance at the 10^{-10} level, ground-to-ground clock comparisons will enable a search of the time variation of fundamental constants with uncertainty at the 10^{-17} level after one year. In this contribution, we review the mission set up with a particular emphasis on the MWL, discuss the simulation and data analysis software developed to investigate mission performance, focusing on its primary scientific objective: the test of the gravitational redshift.

B02

Constraining modified theories of gravity using the latest LIGO-Virgo ringdown observations

Gregorio Carullo (University of Pisa and INFN Pisa)

Observations of binary black holes mergers from the LIGO-Virgo interferometers provide an unprecedented opportunity to glance into an unexplored dynamical regime of gravity, where spacetime curvature is several orders of magnitudes larger than the one probed by other experiments. We will start by reviewing the state of the art of black holes ringdown spectra observations. Next, we will show how requiring stringent, yet well-motivated, perturbative parametrisations of beyond-General Relativity (GR) effects, allows to extract observational constraints much stronger than those present in the literature on a variety

of classes of alternative theories of gravity. Such a boost brings observations close to the regime where corrections from Effective Field Theories of beyond-GR gravity may start to leave a detectable imprint, and translates into a much smaller number of signals needed to detect violations due to a modified theory of gravity. Finally, we will show what constraints can be placed on a class of specific theories, where a self-consistent, non-perturbative prediction can be tested against the data.

B03

Searching for new physics during gravitational waves propagation

Leïla Haegel (Laboratoire Astroparticules et Cosmologie Paris)

The direct detection of gravitational waves opened an unprecedented channel to probe the existence of new physics, including alternative theories of gravitation and violation of Lorentz invariance by low-energy manifestation of a possible theory of quantum gravity. The dispersion of gravitational waves during their propagation would be a clear flag for new physics, and would affect the signal morphology as well as the inferred luminosity distance of the source. This poster presents constraints on the gravitational waves dispersion using the LIGO and Virgo detection during the first three observational runs. It also outlines a novel study aiming at measuring the Standard Model Extension coefficients for polarisation-dependent dispersion due to spacetime birefringence.

B04

Gravitational wave lensing beyond General Relativity

Jose Maria Ezquiaga (University of Chicago)

Lensed gravitational waves (GWs) are natural laboratories to test the underlaying theory of gravity. Nonetheless, little has been explored about how GWs propagate in theories beyond General Relativity (GR) over generic space-times and their possible mixing with additional gravitational degrees of freedom. I will present a formalism to solve the lensed propagation beyond GR and identify the propagation eigenstates. I will then discuss how this leads to novel signatures such as birefringence, echoes or scrambled signals. Interestingly, these tests of gravity do not require electromagnetic counterparts. Applying our framework to Horndeski theories with screening, I will show how these new effects could be more constraining than GW170817.

B05

MICROSCOPE : new improvement on the systematic error

Océane Dhuicque (ONERA Chatillon)

MICROSCOPE is a space mission that aims to test the equivalence principle with an accuracy of 10^{-15} on the Eötvös parameter. The equivalence principle is the main postulate of general relativity, it states the equivalence of the inertial and the gravitational masses. The satellite was launched in 2016 and decommissioned in 2018. Its instrument T-SAGE is composed of two differential accelerometers. The first one, SUREF, is composed of two test masses both made of Platinum and is used to test the consistency of the experiment and the data process. The second one, SUEP, used for EP test, is composed of an internal mass of Platinum and of an external mass in Titanium. In case of an EP violation, a signal is expected to appear at the frequency of Earth's gravity field modulation, called F_{EP}, on the differential acceleration of the two test masses. The first result published in december 2017 showed no evidence of violation higher than 1.3×10^{-14} at 1 sigma. The upper bound of the systematic error was evaluated of 71×10^{-15} and was compatible with this statistic error. 94% of this systematic error came from the evaluation of the upper limit of the instrument thermal variations. The result was obtained with only 7% of the data, thus an improvement of the statistical error is excepted with the analysis of the whole data and it becomes important to be less conservative in the evaluation of the systematic error. Several sessions were dedicated to the in-orbit estimation of the thermal sensitivity at a f_{sti} frequency (close to the f_{EP} frequency) related to the sensor unit or to the electronic unit. I have analysed these sessions by the mean of two different methods which provide coherent estimations of the thermal sensitivity. I have demonstrated that for 3 parts of the instrument the thermal sensitivity doesn't depend on the frequency, while for one part of the SUEP instrument we note a frequency dependency that we modelize by a first order filter. After a brief presentation of the MICROSCOPE mission, I will present the result obtained with these methods.

B06

Testing General Relativity with black hole X-ray data: recent progress and future developments

Cosimo Bambi (Fudan University Shanghai)

The theory of General Relativity has successfully passed a large number of observational tests. The theory has been extensively tested in the weak-field regime with experiments in the Solar System and observations of binary pulsars. The past five years have seen tremendous progress in the study of the strong-field regime, which can now be tested with gravitational waves, X-ray data, and mm and sub-mm Very Long Baseline Interferometry observations. In my talk, I will summarize the state-of-the-art of the tests of General Relativity with black hole X-ray data, discussing its recent progress and future developments.

B07

Weighing spacetime along the line of sight using precise astrometry

Mikolaj Korzynski (CFT PAN Warsaw)

I will present a new method of determining the mass density along the line of sight by comparing the results of two types of astrometric distance measures to a single luminous object: the angular diameter distance or luminosity distance with the parallax distance. The difference between them is a spacetime curvature effect and, for short distances, it can expressed as an integral of the matter density along the LOS. The derivation of the effect assumes the geometric optics approximation, but otherwise it is very general and valid in any spacetime.

B08

Constraining the Hubble constant and modified GW propagation with LIGO/Virgo dark sirens

Michele Mancarella (Université de Genève)

The recent detections and data releases from LIGO/Virgo allow the first concrete applications of statistical methods for constraining cosmological parameters with Gravitational Waves (GWs). Moreover, they open the possibility of new tests of General Relativity, based on the fact that GW signals are standard sirens and that modified gravity models predict non-standard GW propagation. I will present the hierarchical bayesian framework for constraining the Hubble parameter and modified GW propagation with "dark sirens" (namely, compact binary coalescences without an electromagnetic counterpart) and galaxy catalogues, focussing in particular on relevant improvements to the treatment of the latter, such as their completeness, and on the correct treatment of selection bias. I will then show results that make use of the recent O3a data release, presenting the most accurate measurement of H0 from dark sirens alone, new bounds on modified GW propagation, commenting on the role of EM counterparts and on relevant systematics. I will also present the python code used to produce these results, that will be shortly publicly available, making it the first open source tool to date to constrain H0 and modified GW propagation.

B09

Novel atom-optics sensors for future satellite gravity missions

Hu Wu (IfE Leibniz Universität Hannover)

The advancements of atom-optics technology bring new opportunities to develop novel sensors and measurement concepts for accelerometry, gradiometry and chronometry. The atomic sensors, which utilize cooled atoms as test masses to observe accelerations or gravity gradients in a free-falling condition, show a very high sensitivity and long-term stability. These properties are very beneficial for their application in future satellite gravity missions. Another promising new technique for geodesy, i.e., optical clocks, use the electron transition frequency in the optical range of the electromagnetic spectrum of atoms as frequency standard. Today optical clocks can provide the frequency information with an uncertainty level of one part in 10^{18}. According to Einstein's theory of general relativity, one can observe the gravitational redshift effect through the comparison of clock frequencies, and thus obtain the gravity potential differences between the clock stations. In addition, laser interferometer ranging with nanometer accuracy – which has been realized in the GRACE-FO mission – belongs to these novel sensors where future missions may benefit from atomic optics. We will illustrate how gravity field determination can potentially benefit from these novel atom-optics sensors and show future perspectives for Earth's gravimetric observations in various scenarios. Clocks on-board orbiting satellites are proposed to obtain gravity potential values through the

comparison to reference clocks on ground or in space. An atomic accelerometer, or its hybridization with a classical electrostatic accelerometer, is expected to largely improve the measurement of non-conservative forces in space. This will contribute to precisely reduce the non-conservative perturbations in GRACE-like measurements. In addition, gravity gradiometry can be realized based on cold atom interferometry. Full-scale simulations are performed to map the sensitivities of these types of measurements to gravity field coefficients. The benefit of these novel sensors for the determination of different gravity field parts and gravity variations over time are quantitatively evaluated.

We gratefully acknowledge the financial support by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy EXC-2123 "QuantumFrontiers" (Project-ID: 390837967). The study is also funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Project-ID 434617780 – SFB 1464. A. Knabe acknowledges initial funding for the DLR Institute by the Ministry of Science and Culture of the German State of Lower Saxony from "Niedersächsisches Vorab".

B10

Progress on the Astrometric Gravitation Probe concept

Mario Gai (INAF Osservatorio Astrofisico di Torino)

The Astrometric Gravitation Probe (AGP) mission is a modern version of the 1919 Dyson-Eddington-Davidson experiment, based on a space-borne telescope with a coronagraphic system implementing a permanent eclipse. The expected improvement on current experimental bounds to General Relativity and competing gravitation theories is by at least two orders of magnitude. The science is briefly recalled, and the measurement principle is reviewed: Fizeau-like combination of a set of individual inverted coronagraphs, simultaneously feeding a common telescope. A novel optical design has been recently introduced, minimising the sensitivity of the optical performance to perturbations.

B11

Testing Modified Gravity theory (MOG) with Type Ia Supernovae, Cosmic Chronometers and Baryon Acoustic Oscillations

Siusama Landau (Buenos Aires University)

We analyse the MOdified Gravity (MOG) theory, proposed by Moffat, in a cosmological context. We use data from Type Ia Supernovae (SNe Ia), Baryon Acoustic Oscillations (BAO) and Cosmic Chronometers (CC) to test MOG predictions. For this, we perform $\times 2$ tests considering fixed values of H0 and VG, the self-interaction potential of one of the scalar fields in the theory. Our results show that the MOG theory is in agreement with all data sets for some particular values of H0 and VG, being the BAO data set the most powerful tool to test MOG predictions, due to its constraining power

B12

An Experiment Exploring Gravitational Effects on CP Violation

Giovanni Maria Piacentino (Nettuno University Rome)

We suggest a new experiment sensitive to a possible difference between the amount of CP violation as measured on the surface of the Earth and in a lower gravity environment, i.e., to measure a dependence in the magnitude of CP violation as a function of gravitational field intensity. An experiment on the surface of the Moon, in Leo orbit, or in a Lagrangian point orbit would provide an environment with $g_{Moon} \approxeq 0.165 g_{Earth}$, $g_{LEO} \approxeq 0.9 g_{Earth}$, or $g_{L.P.O} \approxeq 0.0$, respectively. In our model-independent experiment we intend to explore the connection between CP violation and gravity. We note that, should it exist, gravity-induced CP violation could help explain the cosmic baryon asymmetry. Sakharov's conditions are satisfied (in SM) [14, 15, 16], while many non-SM theories imply a large CP violation and antigravity [6, 17, 18]. In 1961, Good [19] calculated that a repulsive gravitational interaction of antimatter should cause CP violation, at that time still unknown. Chardin [17] reformulated Good's argument and showed that the gravitational field on the surface of the Earth is of the required order of magnitude to cause CP violation during the mixing time. Specifically, the mixing time of the $K^0 - \overline{K^0}$ system, $\Delta\tau = 5.9 \times 10^{-10}$ "s" $\approxeq 6\tau_{K_S}$ is long enough for the gravitational field of the Earth to induce a separation, $\Delta\zeta = g(\Delta\tau^2$, between matter and antimatter components of the K meson. When compared to the kaon's Compton wavelength, we

obtain an adimensional CPV parameter, $\chi = \Omega \times 0.88 \times 10^{-3}$ which is O(epsilon). On the Moon's surface, we expect χM to be $\sim 97\%$ less than χE, in LEO we expect χLEO to be $\sim 10\%$ less than χE , and in the Lagrangian point orbit it should be negligible, assuming a linear dependence of ϵ with the gravitational acceleration ([17], [19]). Taking advantage of the cosmic proton flux as measured by AMS-02 [23] and PAMELA [24], both in LEO and aboard the Lunar Reconnaissance Orbiter [21, 22], our detector would consist of a PbWO4 target to produce a flux of neutral Kaons. By measuring the number of KL decays inside a 1 m radius 4 m deep cylindrical tracking volume with an offset between the target and the tracking volume of 2 m to allow the K_S to decay we can measure $R = \Gamma(K_L \to \pi^+\pi^-)/\Gamma(K_L \to \pi^+\pi^-\pi^0)$. Any difference of this value from the value measured on Earth's surface would indicate a dependence of CPV on the the Gravitational field.

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B13

Constraining massless dilaton theory at solar system scales with the planetary ephemeris INPOP

Agnès Fienga (Geoazur Observatoire de la Côte d'Azur Nice)

In this poster we present the results obtained with the INPOP planetary ephemerides in term of constraining the phenomenology of the massless dilaton theory in the Solar system. We expose the phenomenology of the massless dilaton theory in the Solar system for a non universal quadratic coupling between the scalar field which represents the dilaton, and the matter: modified post-Newtonian equations of motion of an N-body system and the light time travel are derived from the action of the theory. We use the physical properties of the bodies of the Solar system to reduce the number of parameters to be tested to 3 in the linear coupling case, and 6 in the quadratic coupling case. In the linear case, we have an universal coupling constant α_0 and two coupling constants α_T and α_G related respectively to the telluric bodies and to the gazeous bodies. In the quadratic case, the 3 supplementary constants are β_0, a quadratic universal coupling constant, and β^T and β^G, quadratic non universal coupling constants related respectively to the telluric bodies and the gazeous bodies. Then we use the last version of our planetary ephemeris, INPOP19a, in order to constrain these constants.

B14

Intermediate mass black holes search using gravitational microlensing.

Tristan Blaineau (IJCLab Orsay)

Gravitational microlensing constrains massive compact object abundance within the Galactic halo. Past surveys (MACHO, EROS, OGLE, MOA) excluded objects lighter than 10 solar masses as a major component of Galactic dark matter. Recent detections of coalescences of heavier black holes by LIGO/Virgo rekindled the interest in compact objects dark matter. The efficiency of the past microlensing surveys was limited in lens mass by their duration. As they cover several distinct time periods, combining all their databases allows us to obtain very long timescale light curves. As a consequence, we can increase our sensitivity to lenses of mass up to several hundreds of solar masses. I will present preliminary results from the combination of MACHO and EROS surveys.

B15

The Most Stringent Test of the Strong Equivalence Principle with Gravitational Waves

CS Unnikrishnan (TIFR Mumbai)

The Strong Equivalence Principle (SEP) holds the full essence and meaning of the General Theory of Relativity as the nonlinear relativistic theory of gravitation. It asserts the universal coupling of gravity to all matter and its interactions including the gravitational interaction and the gravitational self energy. We point out that the confirmation of the gravitational coupling to gravitons, and hence to the gravitational waves, is the most direct test of the SEP. We show that the near simultaneous detection of gravitational waves and gamma rays from the merger of binary neutron stars provides a unique and the most stringent test of the SEP, better than a part in 10^9, which is also the only test of the SEP in the radiation sector. This direct test surpasses the previous tests from Lunar Laser Ranging (10^{-4}) and the Triple compact star system (10^{-5}). Further, several more instances of similar detections are expected, which will improve the precision and the reliability of this unique test. (with George T. Gillies of University of Virginia).

B16

Strong field tests of gravity with electromagnetic and gravitational waves: successes and challenges

Sourabh Nampalliwar (Eberhard Karls University of Tübingen)

Einstein's theory of gravity has been the standard theory for describing gravitational phenomena in our universe for several decades now. Along with its successes, there have been some questions, e.g., singularities, dark matter, dark energy, that have emerged for which it does not provide a satisfactory answer. This has led to proposals that modify or supersede Einstein's theory, and testing these theories against data, especially from the strong-field regime, has emerged as a new paradigm in physics in recent years. Along with the completely new avenue of gravitational waves, new and improved techniques based on electromagnetic waves are being used to test GR ever more stringently. As the realm beyond GR is unknown, a popular approach is to look for theory-agnostic deviations from GR/predictions of GR. I will describe constraints on some of these theory-agnostic deviations obtained up to now, and mention some of the challenges and opportunities going forward.

Poster Session C

Gravity theories

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- **C13 Shadows and precession in the black hole and naked singularity spacetimes**
  Parth Bambhaniya (Charotar University Anand) 20
- **C14 Hawking temperature and phonon emission in acoustic holes**
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- **C15 Impact of multiple modes on the black-hole superradiant instability**
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- **C16 (P)reheating Effects of a Constrained Kähler Moduli Inflation**
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- **C17 Exact solution for wave scattering from black holes**
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- **C18 Superradiance in deformed Kerr black holes**
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- **C19 Gravity waves in parity-violating Copernican Universes**
  Pavel Jirousek (CEICO Czech Academy of Sciences) 22
- **C20 Losing the trace to find dynamical Newton or Planck constants**
  Alexander Vikman (CEICO Czech Academy of Sciences) 23

C01

Neutron stars and white dwarfs as tools for the detection of a photonic mass.

Abel Quintana (Universidad Autónoma Metropolitana-Iztapalapa)

In the present work we consider a rotating neutron star or white dwarf and, introducing the Proca Lagrangian, analyze the effects that a photonic mass has upon the corresponding energy-momentum tensor of the involved electromagnetic field. In addition, the consequences on the gravitomagnetic field of this mass is studied. The order of magnitude of the deduced effects is considered and the detectability discussed.

C02

Little rip and hyperbolic models in modified theory of gravity

Bivudutta Mishra (Birla Institute of Technology and Science-Pilani, Hyderabad Campus)

we have presented two cosmological models of the Universe in the framework of f(R; T) gravity theory, where we have considered a minimal coupling between the matter and geometry appearing inside the gravitational action. We chose an anisotropic metric for our investigation. Two different models one with little rip behavior and the other with a hyperbolic form of the Hubble parameter are constructed. The models provide accelerating behavior of the Universe at late time of the evolution. For the both the model, we have discussed the dynamical behavior of the EoS parameter. More or less, the physical behavior of both models appear to be the same at least at late times. However, at an initial phase, the hyperbolic model shows some interesting behavior. It is observed that, both the models evolve in the phantom-like cosmic phase and at late times overlap with Lambda CDM model. The coupling constant of the f(R; T) gravity theory affects the dynamics of the models in deciding the path history of the EoS parameter. We have also carried out a geometrical diagnosis of the model to show the viability of the models.

C03

Bifurcations of a soliton model of dark matter towards natural inflation

Eckehard Mielke (Universidad Autonoma Metropolitana Iztapalapa Mexico)

Axion-like scalar fields with a periodic potential provide a solitonic model of dark matter halos of galaxies. Here we point out that their stability analysis bridges over, via bifurcations, to natural inflation. Then the (pseudo-) scalar part of the Lagrangian can be mapped into a gravity model mildly nonlinear in the scalar curvature. In the case of an axionic periodic potential, the equivalent Lagrangian L(R) exhibits a combination of swallow tail cusps with transitions of stability, well-known from catastrophe theory. The resulting almost Einsteinian branches indicate a 'unification' of dark matter, dark energy and inflation. (Physics Letters B)

C04

Phenomenological model explaining Hubble Tension origin

Gennagy Bisnovatyi-Kogan (Space Research Institute RAS Moscow)

One of the problem revealed recently in cosmology is a so-called Hubble tension (HT), which is the difference between values of the present Hubble constant, measured by observation of the universe at redshift $z \lesssim 1$, and by observations of a distant universe with CMB fluctuations originated at $z \sim 1100$. In this paper we suggest, that this discrepancy may be explained by deviation of the cosmological expansion from a standard Lambda-CDM model of a flat universe, during the period after recombination at $z \lesssim 1100$, due to action of additional variable component of a dark energy of different origin. We suppose, that a dark matter (DM) has a common origin with a variable component of a dark energy (DEV). DE presently may have two components, one of which is the Einstein constant Λ, and another, smaller component DEV (Λ_V) comes from the remnants of a scalar fields responsible for inflation. Due to common origin and interconnections the densities of DEV and DM are supposed to be connected, and remain almost constant during, at least, the time after recombination, when we may approximate $\rho_{DM} = \alpha rho_{DEV}$. This part of the dark energy in not connected with the cosmological constant Λ, but is defined by existence of scalar fields with a variable density. Taking into account the influence of DEV on the universe expansion we find the value of α which could remove the HT problem. In order to maintain the almost constant DEV/DM energy density ratio during the time interval at $z < 1100$, we suggest an existence of a wide mass DM particle distribution.

C05

On the quantum origin of a dark universe

Saurya Das (University of Lethbridge)

It has been shown beyond reasonable doubt that the majority (about 95%) of the total energy budget of the universe is given by the dark constituents, namely Dark Matter and Dark Energy. What constitutes Dark Matter and Dark Energy remains to be satisfactorily understood however, despite a number of promising candidates. An associated conundrum is that of the coincidence, i.e. the question as to why the Dark Matter and Dark Energy densities are of the same order of magnitude at the present epoch, after evolving over the entire expansion history of the universe. In an attempt to address these, we consider a quantum potential resulting from a quantum corrected Raychaudhuri/Friedmann Equation in presence of a cosmic fluid, which is presumed to be a Bose-Einstein condensate (BEC) of ultralight bosons. For a suitable and physically motivated macroscopic ground state wavefunction of the BEC, we show that a unified picture of the cosmic dark sector can indeed emerge, which also resolves the issue of the coincidence. The effective density of the Dark energy component turns out to be a cosmological constant, by virtue of a residual homogeneous term in the quantum potential. Furthermore, comparison with observed data give an estimate of the mass of the constituent bosons in the BEC, which is well within the bounds predicted from other considerations.
Authors: Saurya Das (University of Lethbridge), Mohit Kumar Sharma (University of Delhi), Sourav Sur (University of Delhi) Presenter: Saurya Das

C06

Symmetries of black hole perturbations

Adam Solomon (Carnegie Mellon University Pittsburg)

We discuss symmetries of the action for perturbations around Schwarzschild, their origins, and their implications for gravitational-wave observations. This is motivated in particular by two special aspects of black hole perturbation theory in four dimensions – isospectrality of quasinormal modes and the vanishing of tidal Love numbers – which seem ripe for an explanation in terms of symmetries. We report a novel symmetry of general relativity around Schwarzschild, which on-shell reproduces the famous Chandrasekhar duality and therefore underlies isospectrality, and further show that this is an extension of electric-magnetic duality to black hole backgrounds. We further discuss a zoo of "hidden symmetries" present whenever there are Killing vectors, including the symmetries of Ehlers and Geroch, and their potential implications for Love numbers.

C07

A multiverse model generalization of Penrose CCC cosmology as to how to obtain high frequency Gravitational waves from the onset of inflation and the starting Planckian regime of space-time

Andrew Beckwith (Chongqing University)

Starting from a multiverse generalization of Penrose Cyclic Conformal cosmology, as a feed into the starting point for inflation, we re do a standard energy density of a bosonic field calculation $\sim \overline{h} \times k^4$ which is proportional to 2×10^{71} times GeV to the 4th power, whereas the standard result for DE, if commensurate to experimental observations is $1/10^{120}$ times smaller. If we look at $k \sim 2 * \pi/\lambda$, whereas λ is the wavelength, we find that the wavelength initially would have to be 10^{30} times larger than the wavelength which yielded the bosonic field value of 2×10^{71} times GeV to the 4th power. The aim of this paper is to discuss a pre inflationary geometry as for how this could come about, using the work done by the author in the publication Using "Enhanced Quantization" to Bound the Cosmological Constant, (for a Bound-on Graviton Mass), by Comparing Two Action Integrals (One Being from General Relativity) at the Start of Inflation" which is in the Fundamental Physics and Physics Education Research springer Verlag Publication(2021). Upon obtaining this value of the cosmological constant and factoring in, its connections to a Pre Planckian space-time geometry, we then specify that if the cosmological constant is proportional to the square of the mass of a graviton, we can then specify a vacuum energy density of 10^{120} times larger than that of the free space DE which would then be used, to specify an enormous initial Frequency for gravitons of mass m(graviton) as specified by also assuming an initial entropy of about 10^{30} or more from the Planckian regime of space-time to the electroweak. regime of space-time. The DE/ cosmological constant energy would be specified within a bubble of space time with feed in from a multiverse , with the multiverse allowing for 10^{30} times larger initial wavelength prior to energy being fed into a near singularity of space-time which would have a dramatically decreased value of $k \sim 2 \times \pi/\lambda$, which in turn if the singularity were built up could, if 10^{30} times energy density of DE lead to initially very high frequency Gravity waves

C08

General Relativity from Scattering Amplitudes

Pierre Vanhove (Institut de Physique Théorique CEA Saclay)

We outline the program to apply modern quantum field theory methods to calculate observables in classical general relativity through a truncation to classical terms of the multi-graviton two-body on-shell scattering amplitudes between massive fields. Since only long-distance interactions corresponding to non-analytic pieces need to be included, unitarity cuts provide substantial simplifications for both post-Newtonian and post-Minkowskian expansions. We illustrate this quantum field theoretic approach to classical general relativity by computing the interaction potentials to second order in the post-Newtonian expansion, and deriving the static Schwarzschild-Tangherlini metric by extracting the classical contributions from the multi-loop vertex functions of a graviton emitted from a massive scalar field.

C09

A New Effective Spin for Modelling Precessing Higher Modes in the Strong-Field

Lucy M. Thomas (University of Birmingham)

Gravitational wave data analysis relies on accurate and efficient waveform models which incorporate physical phenomena such as precession and higher-order modes. Current semi-analytical models for precessing binary black holes are not calibrated to numerical relativity in the precessing sector, in part due to the high-dimensionality of the parameter space. One possibility lies in dimensional reduction of the precessing spin-space, previously done with χ_p, but it has been shown that χ_p does not accurately represent precessing higher-order modes, which are crucial for modelling a complete precessing waveform. This poster presents an alternative 2D effective precession spin $\vec{\chi}_{perp}$, and shows that it reproduces the precession dynamics and higher-order modes of strong-field precessing waveforms much more accurately than χ_p, as well as the remnant spin. This could be a promising avenue towards meaningful calibration of semi-analytic precessing, higher-order mode waveforms to numerical relativity.

C10

Black Holes Lessons from Multipole Ratios: A New Window into Black Holes

Daniel Mayerson (IPhT CEA Saclay)

We compute gravitational mass and angular momentum multipole moments for four-dimensional black holes and fuzzball geometries thereof. For Kerr and for supersymmetric black holes many multipole moments vanish, but we show that an infinite number of ratios of vanishing multipoles are constant. We calculate these ratios for the first time, using two very different methods; the results agree spectacularly for certain black holes. Hence our work establishes that ratios of vanishing multipoles are intrinsic properties of four-dimensional black holes. For the Kerr black hole these ratios pose strong constraints on the parameterization of possible deviations from the Kerr geometry that should be tested by future gravitational wave interferometers.

C11

Axisymmetric equilibrium models for magnetised neutron stars in scalar-tensor theories

Jacopo Soldateschi (Università degli Studi di Firenze)

Among the most promising "alternative theories of gravity", one of the most studied class is that of "scalar-tensor theories of gravity" (STTs), because they are the most simple extensions of general relativity (GR), they don't lead to pathologies in the spacetime properties, and show behaviours that look promising in the context of cosmological constraints. Some of these theories predict a phenomenon known as "spontaneous scalarisation", which produces strong deviations from GR in compact objects, like neutron stars (NSs), while fulfilling the strong observational constraints in the weak gravity regime. Such phenomenon is potentially observable in this new era of gravitational wave astronomy. We present here, for the first time, the results of numerical multi-dimensional modelling of NSs in STTs, with the inclusion of magnetic fields, accomplished by the simultaneous solution of the coupled scalar-Einstein-Maxwell equations. We show how global quantities, like mass, inertia moments and magnetic deformation, which are potentially observable, deviate from GR. We show that it is possible to provide a simple parametrisation of the magnetic deformation and of the power emitted in scalar and tensor gravitational waves by NSs in terms of just their baryonic mass, circumferential radius and scalar charge. We demonstrate that a universal scaling exists between these quantities and the magnetic deformation, independently of the magnetic field geometry, of the parameters of the STT and of the (realistic) equation of state, potentially providing new tools to both test STTs and probe the equation of state of NSs, with the hope of disentangling the known degeneracy between their effects.

C13

Shadows and precession in the black hole and naked singularity spacetimes

Parth Bambhaniya (Charotar University Anand)

It is now known that the shadow is not only the property of a black hole, it can also be cast by other compact objects like naked singularities, gravastars, etc. However, there exist some novel features of the shadow of the naked singularities which are elaborately discussed in some recent articles. In the earlier literature, it is also shown that a naked singularity may admit negative precession of bound timelike orbits which cannot be seen in Schwarzschild and Kerr black hole spacetimes. This distinguishable behavior of timelike bound orbit in the presence of the naked singularity along with the novel features of the shadow may be useful to distinguish between a black hole and a naked singularity observationally. However, in this talk, I will explain that deformed Kerr spacetime can allow negative precession of bound timelike orbits when the central singularity of that spacetime is naked. I will also show that negative precession and shadow both can exist simultaneously in deformed Kerr naked singularity spacetime. Therefore, any observational evidence of negative precession of bound orbits, along with the central shadow may indicate the presence of a deformed Kerr naked singularity.

C14

Hawking temperature and phonon emission in acoustic holes

Silvia Trabucco (Università di Pisa)

Acoustic holes are the hydrodynamic analogue of standard black holes. Featuring an acoustic horizon, these systems spontaneously emit phonons at the Hawking temperature. We derive the Hawking temperature of the acoustic horizon by fully exploiting the analogy between black and acoustic holes within a covariant kinetic theory approach. After deriving the phonon distribution function from the covariant kinetic equations, we reproduce the expression of the Hawking temperature by equating the entropy and energy losses of the AH and the entropy and energy gains of the spontaneously emitted phonons. Differently from previous calculations we do not need a microscopical treatment of normal modes propagation. Our approach opens a different perspective on the meaning of Hawking temperature and its connection with entropy, which may allow an easier study of non stationary horizons beyond thermodynamic equilibrium, including dissipative effects.

C15

Impact of multiple modes on the black-hole superradiant instability

Giuseppe Ficarra (King's College London)

Ultralight bosonic fields in the mass range $\sim (10^{-20} - 10^{-11})$ eV can trigger a superradiant instability that extracts energy and angular momentum from an astrophysical black hole with mass $M \sim (5, 10^{10}))M_odot$, forming a nonspherical, rotating condensate around it. So far, most studies of the evolution and end-state of the instability have been limited to initial data containing only the fastest growing superradiant mode. By studying the evolution of multimode data in a quasiadiabatic approximation, we show that the dynamics is much richer and depend strongly on the energy of the seed, on the relative amplitude between modes, and on the gravitational coupling. If the seed energy is a few percent of the black-hole mass, a black hole surrounded by a mixture of superradiant and nonsuperradiant modes with comparable amplitudes might not undergo a superradiant unstable phase, depending on the value of the boson mass. If the seed energy is smaller, as in the case of an instability triggered by quantum fluctuations, the effect of nonsuperradiant modes is negligible. I will discuss the implications of these findings for current constraints on ultralight fields with electromagnetic and gravitational-wave observations. I will also present results of my ongoing work on the evolution of a scalar field in a binary black-hole environment.

C16

(P)reheating Effects of a Constrained Kähler Moduli Inflation

Islam Khan (Washington State University)

Inflation has been one of the most important paradigms in modern cosmology, while investigating dark energy's nature remains one of its main challenges. We study the predictions of the string-theory-motivated Kähler Moduli Inflation I (KMII) potential coupled to a light scalar field with its minimum constrained to provide a source for today's dark energy density. We use Floquet analysis and numerical lattice simulations to analyze the observable effects of the model's (p)reheating phase. We specifically focus on the phenomena of tachyonic instability and resonant reheating effects during the inflaton field oscillations. The model is consistent with the measured Cosmic Microwave Background data when the KMII potential's minimum is constrained to a value equivalent to the cosmological constant; however, it suffers from fine-tuning and predicts a high reheating temperature, which we use to obtain bounds on the inflaton field's mass. We do not observe any tachyonic instability or resonance effects in either our Floquet analysis or lattice simulation results. Finally, we compute stochastic gravitational-wave backgrounds generated during the inflaton field oscillations that would be observable today in the $10^9 - 10^{10}$ Hz frequency range.

C17

Exact solution for wave scattering from black holes

Hayato Motohashi (Kogakuin University)

Scattering theory is a powerful tool to explore black hole physics. We establish an exact formulation for wave scattering of a massless spin-s field by Kerr-Newman-de Sitter black hole. Our formulation is based on the exact solution of the Teukolsky equation in terms of the local Huen function, and does not require any approximation. It serves simple exact formulae with arbitrary high precision, which realize fast calculation without restrictions on model parameters. We highlight several applications including the quasinormal mode, the cross section, the reflection/transmission rate, and the Green function.

C18

Superradiance in deformed Kerr black holes

Mauro Oi (INFN Sezione di Cagliari)

Recent strong-field regime tests of gravity are consistent with general relativity. In particular, astrophysical black holes seem to be all described by the Kerr spacetime, but the statistical error on the observations allows for small yet detectable deviations from this description. In this talk we discuss superradiance of scalar and electromagnetic test fields in deformed Kerr spacetimes and we observe that for large deformations superradiance is highly suppressed with respect to the Kerr case. Surprisingly, for small deformations there exists a range of values for the deformation parameter for which the maximum amplification factor is larger than the Kerr one. We also provide a first result about the superradiant instability of these deformed spacetimes against massive scalar fields.

C19

Gravity waves in parity-violating Copernican Universes

Pavel Jirousek (CEICO Czech Academy of Sciences)

In recent works a minimal theory of varying cosmological constant has been proposed. This was achieved by admitting a nontrivial background torsion, which, in case of homogeneous and isotropic solutions, may contain a parity violating piece. In this talk I will present findings from our recent paper DOI:10.1103/PhysRevD.102.044039. There we analyzed the linear tensor perturbations of these models. We demonstrated that the propagation of gravitational waves is dramatically different in the parity violating branch. Right and left handed gravitons acquire an effective mass and propagate with different speeds. In certain exotic limits their evolution is left undetermined. By comparing our findings with observations we put constraints on these theories.

C20

Losing the trace to find dynamical Newton or Planck constants

Alexander Vikman (CEICO Czech Academy of Sciences)

I will discuss e-Print: 2011.07055 where we showed that promoting the trace part of the Einstein equations to a trivial identity results in the Newton constant being an integration constant. Thus, in this formulation the Newton constant is a global dynamical degree of freedom. As usual this global degree of freedom is a subject to quantization and quantum fluctuations. This is similar to what happens to the cosmological constant in the unimodular gravity where the trace part of the Einstein equations is lost in a different way. In this e-print above, we introduced a constrained variational formulation of these modified Einstein equations. Then, drawing on analogies with the Henneaux—Teitelboim action for unimodular gravity, we constructed different general-covariant actions resulting in these dynamics. It turned out that, the inverse of dynamical Newton constant is canonically conjugated to the Ricci scalar integrated over spacetime. Surprisingly, instead of the dynamical Newton constant one can formulate an equivalent theory with a dynamical Planck constant. Finally, I will speculate that an axion-like field can play a role of the Newton constant or the Planck constant.

Poster Session D

Binary sources of Gravitational Waves and cosmology

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D01

Primordial black holes

Juan Garcia-Bellido (IFT Universidad Autonoma de Madrid)

More than twenty years ago, we predicted that massive primordial black holes (PBH) would form via the gravitational collapse of radiation and matter associated with high peaks in the spectrum of curvature fluctuations, and that they could constitute all of the dark matter (DM) today. In 2015, we predicted the clustering and broad mass distribution of PBH, which peaks at several Msun, and whose high-mass tails could be responsible for the seeds of all galaxies. Since then, AdvLIGO/Virgo interferometers have detected gravitational waves from at least fifty merger events of very massive and spin-less black hole binaries, and we propose that they are all PBH. We have recently understood that a universal mechanism associated with rapid changes in the number of relativistic species in the early universe could have been responsible for the formation of PBH at specific scales and thus have a very concrete prediction for the mass spectrum of DM-PBH, with broad peaks at 10^{-5}, 2, 80, and 10^6 Msun. In particular, the QCD quark-hadron transition could be responsible for the efficient production of baryons over antibaryons at PBH collapse, thus explaining the presence of baryons today and the relative abundance of DM. We predict that within a few years a less than one solar mass PBH will be detected by AdvLIGO/Virgo, and that an array of GW detectors could be used to determine the mass and spin distribution of PBH dark matter with 10% accuracy. Thus, gravitational wave astronomy could be responsible for a new paradigm shift in the understanding of the nature of dark matter and galaxy formation.

D02

Probing SMBH with LISA

Srija Chakraborty (Scuola Normale Superiore Pisa)

We study hydrodynamical simulations of galaxy formation, based on the GADGET-3 code, and investigate supermassive black hole binaries coalescence at $5.5 < z < 14$ and the expected gravitational waves emitted from the binary mergers for different AGN feedback models. A fraction of the accreted rest-mass energy is radiated away by each BH. Furthermore, a fraction of this radiated energy is coupled to the surrounding gas as feedback energy. We consider the cases of thermal feedback, kinetic feedback,which includes AGNcone and AGNsphere,where in the former case the kinetic BH feedback is distributed inside bi-cone (45°half opening angle) and in latter the kinetic feedback is distributed in spherical geometry(90°half opening angle). We further consider the case in which no AGN feedback is implemented in the simulation. We find the merger rates for the kinetic feedback for two cases of AGNsphere and cone and for the thermal feedback two cases of no AGN feedback and with thermal AGN feedback. We stress the comparisons to be made between simulations of the same resolution: kinetic with smoothing length, R_{smooth}= 1ckpc/h and thermal with smoothing length, R_{smooth}=0.5 ckpc/h. For each model, we estimate the expected characteristic strain of gravitational waves emitted by supermassive black hole binary mergers, the time to coalesce, and the expected number of resolved events and compare our predictions with the LISA sensitivity and resolution. We further investigate the host galaxy properties for the events detectable by LISA and make predictions of the electromagnetic counter parts expected events to be detected by various electromagnetic facilities and present a panoramic view of merger events through different detectors.

D03

Gravitational radiation from MHD turbulence in the early universe

Alberto Roper Pol (Laboratoire APC Paris)

The generation of primordial magnetic fields and its interaction with the primordial plasma during cosmological phase transitions is turbulent in nature. We perform direct numerical simulations of magnetohydrodynamic (MHD) turbulence in the early universe and the resulting stochastic gravitational wave background (SGWB). In addition to the SGWB, the primordial magnetic field evolves up to our present time and its relics can explain indirect observations of weak magnetic fields coherent on very large scales. We apply the numerical results to magnetic fields produced at the electroweak (and the QCD) phase transitions and show that these signals may be detectable by the planned Laser Interferometer Space Antenna (and by Pulsar Timing Array). The detection of these signals would lead to the understanding of cosmological phase transition physics, which can have consequences on the baryon asymmetry problem and on the origin seed of observed magnetic fields coherent over very large scales at the present time.

D04

The cosmic merger rate density of compact binaries

Filippo Santoliquido (University of Padova)

With the recent publication of the second gravitational wave transient catalog by the LIGO-Virgo collaboration (LVC), the number of binary compact object mergers has risen dramatically, from a dozen to ~ 50 events. From these detections, the LVC inferred the merger rate density both in the local Universe and as a function of redshift. It is then of foremost importance to compare the merger rate density predicted with different astrophysical models with the value inferred by LVC. In my poster, I will present a semi-analytic model that evaluates the cosmic merge rate density, by taking into account the cosmic star formation rate density and the metallicity evolution of stars across cosmic time. These are then combined with catalogues of merging compact binaries. I have considered binaries that form in isolation versus dynamical binaries. My results indicate that dynamical binaries are much less sensitive to metallicity than isolated binaries (Santoliquido et al. 2020 - 2004.09533). Furthermore, I have explored the impact of various binary evolution processes on the merger rate density. For example, when I vary the common envelope ejection efficiency parameter from $\alpha_{CE} = 7$ to 0.5, the local merger rate density of binary neutron stars varies from 10^3 to 20 $Gpc^{-3}yr^{-1}$, whereas the local merger rates of binary black holes and black hole - neutron star binaries vary just by a factor of $\sim 2-3$. I will also show that by propagating the uncertainties of the metallicity evolution model on the merger rate density, the binary black hole merger rate can change by one order of magnitude within 50% credible interval (Santoliquido et al. 2021 - 2009.03911).

D05

Implications for first-order cosmological phase transitions from the third LIGO-Virgo observing run

Alba Romero-Rodríguez (IFAE Barcelona)

We place constrains on the normalised energy density in gravitational waves from first-order strong phase transitions using data from Advanced LIGO and Virgo's first, second and third observing runs. First, adopting a broken power law model, we place 95% confidence level upper limits simultaneously on the gravitational-wave energy density at 25 Hz from unresolved compact binary mergers, and strong first-order phase transitions . We then consider two more complex phenomenological models, limiting at 25 Hz the gravitational-wave background due to bubble collisions and the background due to sound waves at 95% confidence level for temperatures above 10^8 GeV.

D06

Searches for Compact Binary Coalescence Events using Neural Networks in LIGO/Virgo Second Observation Period

Alexis Menendez Vazquez (IFAE Barcelona)

We present results on the search for the coalescence of compact binary mergers using convolutional neural networks and the LIGO/Virgo data, corresponding to the O2 observation period. Two-dimensional images in time and frequency are used as input, and two sets of neural networks are trained separately for low mass (0.2 - 2.0 solar masses) and high mass (25 - 100 solar masses) compact binary coalescence events. We explored neural networks trained with input information from a single or a pair of interferometers, indicating that the use of information from pairs leads to an improved performance. A scan over the full O2 data set using the convolutional neural networks for detection demonstrates that the performance is compatible with that from canonical pipelines using matched filtering techniques. No additional events with significant signal-to-noise ratio are found in the O2 data.

D07

Topsy-turvy binary black hole spins in numerical relativity

Matthew Mould (University of Birmingham)

Spin precession occurs in binary black holes whose spins are misaligned with the orbital angular momentum. Otherwise, the spin configuration is constant, and the subsequent binary dynamics and gravitational-wave emission is much simpler. But, aligned-spin binaries in the 'up-down' configuration are unstable when perturbed; at a critical point in the inspiral the black hole spins begin to tilt wildly as precession takes over. We show for the first time that this prediction, derived with post-Newtonian techniques, holds in full numerical relativity. We perform 12 new simulations of the stable and unstable configurations for different spin perturbations, each lasting about 100 orbits before merger and featuring several precession cycles. Precession induced by the spin instability of up-down black-hole binaries can tilt the spins by as much as 90 degrees from near-alignment and leaves a notable imprint in the emitted gravitational-wave signal.

D08

The effect of dynamics on BBH populations

Stefano Torniamenti (University of Padova)

The early evolution of young star clusters, the common birthplace of massive stars, leaves a deep imprint on their binary population. This imprint is inherited by the resulting binary black holes (BBHs), which turn out to present distinctive signatures with respect to the case of isolated evolution. Understanding the peculiarities of dynamically-formed BBHs is now of fundamental importance, because it can shed light on the formation channels of the merging events that are being observed through gravitational wave detection by LIGO/VIRGO interferometers. In my poster, I will show the properties of the BBH population from a new sample of N-body simulations of young star clusters. The simulated stellar systems present fractal initial conditions to mimic the clumpiness of the observed star forming regions and include a realistic primordial population of binaries, characterized by observation-based orbital properties and a mass-dependent binary fraction. In order to take into account all the possible dynamical effects, the star clusters are evolved for 1500 Myr. I will describe the distributions of the masses, mass ratios and orbital properties of all BBHs and of those that merge within a Hubble time. In particular, I will focus on the differences between BBHs from original and dynamically exchanged binaries. Also, I will show how the dynamical interactions can affect the distribution of merging BBHs after the first 100 Myr, even though a large part of the stellar system has dissolved. In fact, my results suggest that, if we stopped the simulations after only the first 100 Myr, almost all of the mergers with high primary black hole mass (>40 Msun) would not take place.

D09

Suppression of Ultra Slow-Roll Primordial Black Holes from Inflaton momentum

Ashley Wilkins (Newcastle University)

Inflation is a period of accelerated expansion in the early universe, driven by a scalar field called the inflaton, that solves the horizon and flatness problems. Crucially it also provides a method by which small scale quantum fluctuations can be grown to super-Hubble size, classicalise and cause density perturbations that act as the seeds for large-scale structure formation. If these density perturbations are sufficiently overdense then they can collapse to form Primordial Black Holes (PBHs), a possible dark matter candidate. It has been shown that the standard Slow-Roll version of inflation does not produce enough sufficiently overdense density perturbations to form enough PBHs to make up a significant proportion of dark matter. One method to enhance the number of PBHs formed is to consider the Ultra Slow-Roll regime characterised by a plateau in the inflaton potential where quantum diffusion is the dominant effect on the inflaton. Previous calculations have indicated that a sufficiently wide plateau could enhance the density fluctuations sufficiently for PBHs to form all or a substantial quantity of dark matter. We revisit these calculations taking into account the velocity of the inflaton as it enters the plateau and its backreaction on the expansion rate. We find that it can significantly supress the formation of PBHs. We derive analytic formulae for the mass fraction $\beta(M)$ of PBHs formed due to the inflaton entering a USR region and plot the dependence of $\beta(M)$ on the inflaton's momentum as it enters the plateau and the width of the plateau itself. This allows us to put new constraints on how wide a plateau region could be without overproducing PBHs.

D10

Exploring gravitational-wave detection and parameter inference using Deep Learning methods

Osvaldo Freitas (University of Minho)

We explore machine learning methods to detect gravitational waves (GW) from binary black hole (BBH) mergers using deep learning (DL) algorithms. The DL networks are trained with gravitational waveforms obtained from BBH mergers with component masses randomly sampled in the range from 5 to 100 solar masses and luminosity distances from 100 Mpc to, at least, 2000 Mpc. The GW signal waveforms are injected in public data from the O2 run of the Advanced LIGO/Virgo detectors, in time windows that do not coincide with those of known detected signals. We demonstrate that DL algorithms, trained with GW signal waveforms at distances of 2000Mpc, still show high accuracy when detecting closer signals, within the ranges considered in our analysis. Moreover, by combining the results of the three-detector network in a unique RGB image, the single detector performance is improved by as much as 70%. Furthermore, we train a regression network to perform parameter inference on BBH spectrogram data and apply this network to the events from the GWTC-1 and GWTC-2 catalogues. Without significant optimization of our algorithms, we obtain results that are mostly consistent with published results by the LIGO-Virgo Collaboration. In particular, our predictions for the chirp mass are compatible (up to 3σ) with the official values for 90% of events.

D11

Search for Black Hole Merger Families

Doga Veske (Columbia University)

The origin, environment, and evolution of stellar-mass black hole binaries are still a mystery. One of the proposed binary formation mechanisms is manifest in dynamical interactions between multiple black holes. A resulting framework of these dynamical interactions is the so-called hierarchical triple merger scenario, which happens when three black holes become gravitationally bound, causing two successive black hole mergers to occur. In such successive mergers, the black holes involved are directly related to each other, and hence this channel can be directly tested from the properties of the detected binary black hole mergers. Here we present a search for hierarchical triple mergers among events within the GWTC-1 and GWTC-2 catalogs of LIGO/Virgo, the eccentric localization of GW190521 and those found by the IAS-Princeton group. We perform our analysis for different upper bounds on the mass distribution of first generation BHs. Our results demonstrate the importance of the mass distributions' properties for constraining the hierarchical merger scenario. We present the individually significant merger pairs. The search yields interesting candidate families and hints of its future impact.

D12

Galaxy Clustering and Systematics Mitigation with the Dark Energy Survey Year 3 data

Martin Rodriguez Monroy (CIEMAT Madrid)

We are now in the era in which cosmological surveys will be able to answer the remaining questions about the formation and evolution of the Universe. Among them it is the Dark Energy Survey (DES), an international collaboration whose main goal is to unveil the nature of dark energy. For this purpose, it has performed a 6-year photometric survey from the Blanco Telescope at Cerro Tololo (Chile), covering nearly 5000 deg^2 of the southern sky with the filters g, r, i, z and Y and reaching magnitudes up to i = 23.7 and redshifts of about 1.2. One of DES's most powerful probes to constrain cosmological parameters is the angular galaxy clustering, described by the two point angular correlation function, $w(\theta)$, especially when combined with weak lensing measurements, the so called 3x2pt probe. As part of the measurement, we must take special care of any spurious signal introduced by spatially varying observing conditions and survey properties, such as exposure time and seeing, or astrophysical sources of contamination, like galactic extinction or stellar density. The aim of this contribution is to introduce the systematic decontamination procedure focusing on the analysis of the first three years of data (Y3), and to showcase the measurement of $w(\theta)$ in two different galaxy clustering samples used in the DES 3x2pt Y3 Key Project, and its validation in their corresponding simulations. I will show new, preliminary results from clustering for Y3 data.

D13

Search of gravitational waves from mergers of stellar-mass compact objects and sub-solar mass black holes in the second observing run of Advanced LIGO.

Khun Sang Phukon (Nikhef Amsterdam)

We report a search of gravitational waves from the coalescences of stellar-mass compact objects and sub-solar mass black holes with masses between [1.95 - 11] Solar Mass and [0.19 - 1] Solar Mass, respectively, in the second observing run of Advanced LIGO. The observation of sub-solar mass black holes could provide evidence for the existence of primordial origin black holes and a possible component of dark matter. We find no significant candidate gravitational-wave candidate for stellar-mass compact object and sub-solar mass black hole merger. Using the null result, we derive model-independent limits on primordial black hole mergers and confort them to two recent scenarios in which primordial black holes constitute up to the totality of dark matter.

D14

Gravitational wave cosmology with extreme mass-ratio inspirals

Danny Laghi (University of Pisa and INFN Pisa)

The Laser Interferometer Space Antenna (LISA) will open the mHz frequency window of the gravitational wave (GW) landscape. Among all the new GW sources expected to emit in this frequency band, extreme mass-ratio inspirals (EMRIs) constitute a unique laboratory for astrophysics and fundamental physics. We investigate the prospect of using the loudest EMRIs detected by LISA as dark standard sirens, statistically matching their sky localisation region with mock galaxy catalogs. Assuming a ΛCDM model we obtain constraints on the Hubble constant at the 1% (4%) level at 90% confidence level in our best (worst) case scenario, while assuming a time-evolving dark energy equation of state we show that in our best (worst) case scenario the equation-of-state parameter w0 can be measured with 6% (12%) accuracy at 90% confidence level. EMRI measurements will be affected by different systematics compared to both electromagnetic and ground-based GW observations, hence they will be of great importance for cosmology, providing additional independent validation of our present understanding of the Universe.

Poster Session E

Astrophysics and Gravitational Waves

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E01

Formation Rate of Extreme Mass Ratio Inspirals in Active Galactic Nucleus

Zhen Pan (Perimeter Institute Toronto)

Extreme Mass Ratio Inspirals (EMRIs) are important sources for space-borne gravitational wave detectors, such as LISA (Laser Interferometer Space Antenna). Previous EMRI rate studies have focused on the "loss cone" scenario, where stellar-mass black holes (sBHs) are scattered into highly eccentric orbits near the central massive black hole (MBH) via multi-body interaction. In this work, we calculate the rate of EMRIs of an alter- native formation channel: EMRI formation assisted by the accretion flow around accreting massive black holes. In this scenario, sBHs and stars on inclined orbits are captured by the accretion disk, and then subsequently migrate towards the MBH, under the influence of density wave generation and head wind. By solving the Fokker-Planck equation incorporating both sBH-sBH/sBH-star scatterings and sBH/star-disk interactions, we find that an accretion disk usually boosts the EMRI formation rate per individual MBH by $O(10^2 \sim 10^3)$ com- pared with the canonical "loss cone" formation channel. Taking account of the fraction of active galactic nuclei (AGNs) $\sim O(10^{-2})$, where the MBHs are expected to be rapidly accreting, we expect EMRI formation assisted by AGN disks to be an important channel for all EMRIs observed by LISA. These two channels also predict distinct distributions of EMRI eccentricities and orbit inclinations, which can be tested by future gravitational wave observations.

E02

Neutron Stars Mass-Radius relationship and Electromagnetic follow-up of Kilonovae

David Barba González (Universidad de Salamanca)

Authors: D. Barba, C. Albertus, M. A. Pérez-García Neutron Stars (NSs) are compact objects that arise in the aftermath of a Supernova explosion. When these objects ,usually found in binaries, merge they may form another NS or a Black Hole. A Kilonova (KN) is a transient event that is thought to take place in a merger event of two compact objects. Electromagnetic emission arises from microscopic decay reactions of heavy elements being ejected in the bulk of matter in the dynamical process. In this contribution we study how, in the case of two NSs, the mass-to-radius ratio can be determined from optical radiation obtained with accurate measurements. This will shed light on the characteristics

of this emission and provide new, complementary probes in addition to the gravitational wave (GW) emission expected.

E03

Black hole kicks - a tool to measure the accuracy of gravitational-wave models

Angela Borchers (Albert Einstein Institute Hannover)

Gravitational-wave models of merging binary systems have become fundamental to detect potential signals and estimate the parameters of observed sources. As the interferometers' sensitivity is enhanced in current and future detectors, gravitational waveform models will have to be further improved. Asymmetric binary systems lose linear momentum through the emission of gravitational waves, leading to the recoil of the merger remnant. Black hole kicks have attracted much attention due to their astrophysical implications. However, with the observations made by LIGO and Virgo so far, the value of the kick velocity cannot be well constrained. Future events will carry richer information that will allow determining its value with more accuracy. In this work, we discuss how the gravitational recoil can be used to test the accuracy of waveform models. Current gravitational-wave models do not include the mode asymmetries responsible for black hole kicks. For this reason, we investigate whether applying simple adjustments to existing higher-mode models can improve their accuracy and, in turn, can allow us to extract meaningful information about the kick in future observations.

E04

Systematic uncertainty of standard sirens from the viewing angle of binary neutron star inspirals

Hsin-Yu Chen (Massachusetts Institute of Technology)

The joint detection of gravitational-wave and electromagnetic-wave emissions from neutron star mergers GW170817 allowed for the first standard-siren measurement of the Hubble constant. Future standard sirens will potentially shed light on the tension between the local distance ladders and Planck experiments. Therefore, thorough understanding of the sources of systematic uncertainty for the standard siren method is crucial. In this poster, I will discuss a systematic uncertainty of the standard siren method introduced by the aspherical electromagnetic emission of neutron star mergers. Depending on the observational strategies and the understanding of the electromagnetic emissions, the systematics originated from the geometry of electromagnetic emissions of neutron star mergers may be a major challenge before the standard sirens can resolve the tension in Hubble constant.

E05

The morphology of the X-ray afterglows and of the jetted GeV emission in long GRBs

Remo Ruffini (ICRANet Rome)

We recall evidence that all short and long gamma-ray bursts (GRBs) have binary progenitors and give new detailed examples. We focus on the binary progenitors of long GRBs, the binary-driven hypernovae (BdHNe), that consist of a carbon-oxygen core (CO core) and a binary neutron star (NS) companion. For binary periods of the order of 5 min, the energetic subclass BdHN I originates when the CO core collapses. They are characterized by: 1) an outstanding energetic supernova (the "SN-rise"); 2) a newborn black hole (BH) originating from the SN hypercritical accretion onto the NS companion. Only in some cases, the newborn BH via the "inner engine"' mechanism, is observed to lead to GeV emission characterized by an isotropic power-law luminosity $L_{GeV} = A_{GeV} \times t^{-\alpha_{GeV}}$. 3) The new NS ($\nu$NS), created at the SN center, accretes matter from the SN ejecta originating the X-ray afterglow with $L_X = A_X \times t^{-\alpha_X}$, always present in all BdHN I. We analyze 378 BdHN I and, among them, select four prototypes: GRB 130427A, GRB 160509A, GRB 180720B and GRB 190114C using a time-resolved spectral analysis and derive 1) the spectra, the luminosities and the duration of the SN-rise; 2) the amplitude A_X, the power-law index $\alpha_X = 1.48\pm0.32$ of their X-ray afterglows, 3) the time-evolution of the νNS spin, and 4) A_{GeV} and $\alpha_{GeV} = 1.19 \pm 0.04$. From the latter, we infer for the first time the mass and spin of the BH powering long GRBs. We also deduce that there is a special morphology which explains why the GeV emission is present only in some BdHN I, and it is confirmded by dedicated three-dimensional smoothed-particle-hydrodynamics simulations of BdHN I. We conclude that the GeV radiation is observed only when emitted within a cone of half-opening angle of nealry 60 degrees from the normal to the orbital plane. The mass and spin of the Kerr BHs are obtained based upon the GRB "inner engine" originating the GeV emission by extracting the BH rotational energy. We obtain initial BH masses $2.3 < M/M_{sun} < 8.9$ and spins $0.27 < a/M < 0.87$, and from their time evolution, we verify, for the first time, the validity of the BH mass-energy formula.

E06

Inferences of GRB 190114C for the Crab pulsar and the supernova remnant
Simonetta Filippi (ICRANet Rome)

Authors: R. Ruffini, R. Moradi, J. A. Rueda, C. L. Bianco, C. Cherubini, S. Filippi, L. Li, N. Sahakyan, Y. Wang The understanding of binary-driven hypernovae of type I (BdHNe I) has identified the central role of the explosion of the supernova ("SN-rise") as well as of the role of the hypercritical accretion of the SN ejecta onto the binary companion neutron star (NS) and onto the newborn NS (νNS) in determining the GRB dynamics. We model the νNS through the equilibrium sequence of Maclaurin spheroids. By requiring that the νNS period extrapolated on 1000 yr coincides with the one of PSR B0531 + 21 (the Crab pulsar), we determine the initial spin of the νNS to be 0.9 ms, and follow the subsequent rotational and gravitational evolution of the eccentricity. The observed changes in the braking index are proposed to be correlated to pulsar glitches, whose intensities are predicted to be strongly correlated with the pulsar spin. We propose that the progenitor of the Crab nebula and of the Crab pulsar is a GRB very similar to GRB 190114C.

E07

The Emergence of Structure in the Binary Black Hole Mass Distribution
Vaibhav Tiwari (Cardiff University)

I report an emerging structure in the binary black-hole mass distribution. We use the mixture model framework VAMANA on the observations in LIGO and Virgo's catalog GWTC-2 to reconstruct the underlying mass and spin distributions of the population of merging black holes. Our analysis identifies a structure in the chirp mass distribution, specifically, we identify peaks in the chirp mass distribution at 7.1, 13.5, 25.3, and 45.3 M, and a complementary structure in the component mass distribution. Intriguingly, the location of subsequent peaks are separated by a factor of around two and there is a lack of mergers with chirp masses of 10-12 M. We argue in favour of the hierarchical merger scenario as the source of the observed structure. In simplest terms, these features can be explained when at least one of the black hole binary formation channels suffers a mass-gap near 13 M causing black-holes to pile-up at the first peak combined with the scenario in which lower mass black-holes hierarchically merge to produce higher mass black-holes. The results are limited by statistics but if confirmed by future observation the observed structure in the mass spectrum has far-reaching implications.

E08

Binary black holes from globular clusters- the impact of IMBH
Dorota Gondek-Rosinska (Astronomical Observatory University of Warsaw)

Stellar mass binary black holes are the most important sources of gravitational waves for ground based interferometric detectors. We analyze about a thousand globular cluster (GC) models simulated using the MOCCA Monte Carlo code for star cluster evolution to study black hole - black hole interactions in these dense stellar systems that can lead to gravitational wave emission. We extracted information for all coalescing binary black holes (BBHs) that merge via gravitational radiation from these GC models and for those BHs that collide due to 2-body, 3-body and 4-body dynamical interactions. By obtaining results from a substantial number of realistic star clusters evolution model, that cover different initial parameters (masses, metallicities, densities etc) we have an extremely large statistical sample of two black holes which merge or collide within a Hubble time. The existence of Intermediate Mass Black Hole strongly influences the results. We discuss the importance of BBH originating from GC for gravitational waves observations.

E09

Primordial Black Holes: insights and constraints from Gravitational-Wave observations.
Sébastien Clesse (University of Brussels ULB)

I will review some recent developments in the field of primordial black holes, in particular models with extended mass distributions in the stellar-mass range imprinted by thermal history. These will be confronted to the latest gravitational-wave observations from LIGO/Virgo with a focus on GW190425, GW190814 and GW190521, and to the possible hint at a stochastic gravitational wave background at nanohertz freqency from NanoGRAV.

E10

Wavefronts of gravitational waves partially trapped in ultracompact stars

Marek Abramowicz (Göteborg University)

Using a standard first-order perturbation theory (Teukolsky's equation) but expressed in a conformally scalled "optical geometry", we derive, for the first time, analytic formulae describing gravitational waves partially trapped inside constant density ultracompact stars – in particular frequencies and wavefunctions of their normal modes, and their damping ("ringdowns") and echoes. They are qualitatively different from those corresponding to the black hole case. This has direct consequences for interpretation of the the LIGO-Virgo data. Authors: Jiri Horak (Institute of Astronomy, Prague, CZ), Marek Abramowicz (Göteborg University, SE)

E11

GW190521 formation via three-body encounters in young massive star clusters

Marco Dall'Amico (University of Padova)

With a mass of $100 - 10^5$ Msun, intermediate-mass black holes (IMBHs) bridge the gap between stellar-mass black holes (BH) and super-massive BHs. Their existence has been confirmed with the detection of GW190521, the most massive binary black hole (BBH) merger observed by LIGO and Virgo to date. The formation of massive BBHs and IMBHs is matter of intense debate. In my poster, I will present the effects of three-body encounters on the formation of massive BBHs and IMBHs in young (<100 Myr) massive ($10^3 - 3 \times 10^4$ Msun) star clusters. I will show the results of 10^5 dynamical interactions between a BBH and a massive (M>60 Msun) BH simulated with ARWV: a direct N-body code that implements Mikkola's algorithm regularization, post-Newtonian parameters up to the 2.5 order, and a relativistic kick prescription for merger remnants. Particular importance will be given to the discussion of our initial conditions. All the resulting BBHs from the simulations have, on average, higher total and chirp masses and lower mass ratios than the initial conditions, and have eccentricities close to one. Moreover, dynamical encounters increase the number of massive (>60 Msun) BBH mergers from $\sim 0.3\%$ up to $\sim 2.5\%$ and the number of IMBH binary mergers from $\sim 0.1\%$ up to $\sim 0.6\%$. I will discuss how these features may be exploited to infer the dynamical origin of BBHs. Lastly, $\sim 11\%$ of the merging BBHs have the components in the same mass range of GW190521 BHs, 3 of these binaries are second-generation BBHs (i.e. a BBH born from a previous merger). This implies that hierarchical mergers may be at work in young massive star clusters and that the GW190521 event could have been caused by a 2nd generation binary coalescence.

E12

Improved Gravitational Radiation Timescales

Lorenz Zwick (University of Zurich)

Peters' formula is an analytical estimate of the time-scale of gravitational wave (GW)-induced coalescence of a binary system. It is used in countless applications, where the convenience of a simple formula outweighs the need for precision. However, many of the most promising sources of the Laser Interferometer Space Antenna (LISA), such as supermassive black hole binaries and extreme mass-ratio inspirals (EMRIs), are expected to enter the LISA band with highly eccentric (e ~ 0.9) and highly relativistic orbits. These are exactly the two limits in which Peters' estimate performs the worst. With this poster, we present a simple analytical formula to quantify how the inspiral time-scale is affected by the 1.5 post-Newtonian (PN) hereditary fluxes and spin-orbit couplings. We discuss several cases that demand a more accurate GW time-scale and show how this can have a major influence on quantities that are relevant for LISA event-rate estimates, such as the EMRI critical semi-major axis or the Kozai-Lidov quenching radius. We further discuss two types of environmental perturbations that can play a role in the inspiral phase: the gravitational interaction with a third massive body and the energy loss due to dynamical friction and torques from a surrounding gas phase ubiquitous in galactic nuclei. With the aid of PN corrections to the time-scale in vacuum, we find simple analytical expressions for the regions of phase space in which environmental perturbations are of comparable strength to the effects of any particular PN order, being able to qualitatively reproduce the results of much more sophisticated analyses.

Poster Session F

Gravitational Wave detectors and other sources

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F01

Search for R-Modes Gravitational Signals from PSR J0537-6910

Alessio Zicoschi ("La Sapienza" University of Rome)

PSR J0537-6910 is known for its rather significant glitching activity, hinting to the possible presence of r-modes excitations. These are likely to be a promising source of detectable continuous GWs. I would like to present a search methodology developed to detect this kind of signals that has been recently applied to gravitational data produced in the LIGO O3 run. The underlying idea in this search is to use a semi-coherent procedure due to the presence of glitches during the studied data timespan: a coherent search has been performed on each intra-glitch period, while results are later incoherently combined. On one hand, the coherent part of the analysis is slightly adapted from the already tried-and-tested narrow-band 5-vector procedure. However, this search requires to study a broad range of frequencies (approx. 13Hz, compared to the usual fractions of Hz for this type of searches). Thus, interesting physical considerations have been outlined, in order to explore the parameters space in an efficient way. On the other hand, the incoherent combination procedure has been developed from scratch, exploiting techniques used in continuous targeted searches. The implementations developed for this search might be useful for future r-modes searches and for other investigations in which glitches play a key role.

F03

Lunar Gravitational-Wave Antenna

Jan Harms (Gran Sasso Science Institute)

Monitoring of vibrational eigenmodes of an elastic body excited by gravitational waves (GWs) was one of the first concepts proposed for the detection of GWs. At laboratory scale, these experiments became known as resonant-bar detectors first developed by Joseph Weber in the 1960s. Due to the dimensions of these bars, the targeted signal frequencies were in the kHz range. Weber also pointed out that monitoring of vibrations of Earth or Moon could reveal GWs in the mHz band. His Lunar Surface Gravimeter experiment deployed on the Moon by the Apollo 17 crew had a technical failure, which made it impossible to carry out a search for GWs. In this poster, we present the Lunar Gravitational-Wave Antenna (LGWA) concept recently submitted in response to the ESA call for ideas for a lunar exploration from the European Large Logistic Lander (EL3) and expanded in a paper (https://arxiv.org/abs/2010.13726). There are significant technical challenges of realizing its science payload, i.e., a high-performance seismometer, and of the deployment and operation of the experiment. Key to the planning of LGWA is our understanding of the lunar interior and the lunar surface conditions. The lunar interior structure determines the Moon's response to GWs. Surface conditions can have a great impact on the seismometer performance. For example, regions with temperatures constantly below 40K were found in permanent shadows near the lunar south pole by the Diviner Lunar Radiometer Experiment, which might enable the implementation of superconductor technology. In such environments, even vibration-free Helium sorption cooling might be an option to further stabilize and reduce the temperature of the system and thereby increase the seismometer sensitivity. The LGWA science case has potential for breakthrough discoveries like the direct association of a double white-dwarf merger with a supernova type Ia due to a potentially superior 0.1-1Hz sensitivity compared to other GW detectors that will or might be realized in the coming two decades, and excellent source-localization capability since a distributed seismometer network can be deployed, and also the month-long rotation period of the Moon gives an advantage over the year-long period of the LISA detector orientation. Like LISA, LGWA would be able to see massive binary black-hole mergers out to high redshift, and could potentially form an efficient tandem with LISA or other potential LISA-type detectors for observations of such signals. A distributed seismometer network would also make it possible to measure the polarization content of a GW and to carry out novel tests of general relativity.

F04

All-sky search in early O3 LIGO data for continuous gravitational-wave signals from unknown neutron stars in binary systems

Rodrigo Tenorio (University of the Balearic Islands)

Rapidly spinning neutron stars are promising sources of persistent, continuous gravitational waves. Detecting such a signal would allow probing of the physical properties of matter under extreme conditions. A significant fraction of the known pulsar population belongs to binary systems. Searching for unknown neutron stars in binary systems requires specialized algorithms to address unknown orbital frequency modulations. We present a search for continuous gravitational waves emitted by neutron stars in binary systems in early data from the third observing run of the Advanced LIGO and Advanced Virgo detectors using the semicoherent, GPU-accelerated, BinarySkyHough pipeline. The search analyzes the most sensitive frequency band of the LIGO detectors, 50 - 300 Hz. Binary orbital parameters are split into four regions, comprising orbital periods of 3 - 45 days and projected semimajor axes of 2 - 40 light-seconds. No detections are reported. We estimate the sensitivity of the search using simulated continuous wave signals, achieving the most sensitive results to date across the analyzed parameter space. (This contribution is given on behalf of the LIGO Scientific Collaboration and the Virgo Collaboration),

F05

A search algorithm for long duration gravitational wave transients

Adrian Macquet (ARTEMIS Observatoire de la Côte d'Azur Nice)

PySTAMPAS is a new data analysis pipeline designed to search for long transient gravitational wave signals in ground-based interferometers data. Long transient GW refer to a class of signals with duration in the range of 1-1000s . Such signals could originate from a wide range of astrophysical processes : accretion disk instabilities around black holes, deformations in magnetars, BNS post-merger emission, core-collapse supernovae... As these processes are still poorly modelized, searches have to rely on unconstrained detection methods that make few or no assumptions on the signal morphology. The search algorithm consists in looking for excess power in cross-correlated data from a network of GW detectors. It is implemented in a computationally efficient way adapted to all-sky, all-time searches on year-long data and intends to maximize detection sensitivity for a wide range of signal morphologies. Monte-carlo studies and the re-analysis of LIGO second observing run done with this pipeline show an increase in detection sensitivity by factors 1.3 - 2 compared to previous long-duration searches. Following the recent identification of a sample of Gamma-Ray Bursts with potential Magnetar Giant Flare origin (Burns et. al 2021), we present results of a follow-up study for long duration GW emission targeting 3 of these magneta giant flares.

F06

First search for r-mode gravitational waves from J0537-6910

Liudmila Fesik (Albert-Einstein-Institut Hannover)

We report results of the first search to date for continuous gravitational waves from unstable r-modes from the pulsar J0537-6910. We use data from the first two observing runs of the Advanced LIGO network. We find no significant signal candidate and set upper limits on the amplitude of gravitational wave signals, which are within an order of magnitude of the spin-down values. We highlight the importance of having timing information at the time of the gravitational wave observations, i.e. rotation frequency and frequency-derivative values, and glitch occurrence times, such as those that a NICER campaign could provide. Based on the paper https://arxiv.org/abs/2001.07605. published in The Astrophysical Journal, Volume 895, Number 1, 2020

F07

LIGO-Virgo detector characterization and data quality: from the O3 performance to the preparation of O4

Nicolas Arnaud (IJCLab Orsay and EGO Pisa)

Detector characterization and data quality – in short "DetChar" – activities are key to optimize the performance of data-taking periods ("runs") and to turn gravitational-wave (GW) candidates into confirmed events. The LIGO and Virgo DetChar groups are active from the detector to the final analysis and cover various latencies: online first, to tag the data that search pipelines can analyze in real-time; then, the quick vetting (few tens of minutes at most) of the open public alerts targeting the broad astronomer community for follow-up observations; finally, offline work to define the final datasets and the final lists of GW events to be published and released publicly. This poster summarizes the DetChar performance during the O3 run (April 2019 - March 2020) and describes the main improvements and upgrades that are foreseen for the O4 run that should start during Summer 2022 and include a fourth detector: KAGRA.

F08

Searching for High Frequency Gravitational Waves with Bulk Acoustic Wave Resonators

William Campbell (The University of Western Australia)

We present the operation of a High Frequency Gravitational Wave (HFGW) detector based on a cryogenic acoustic cavity and report observation of rare events at MHz frequencies during 153 days of operation. Utilising a piezoelectric quartz bulk acoustic wave resonator as a resonant mass HFGW antenna, three strong events are observed as transients responding to energy deposition within acoustic modes of the cavity. The first event occurring on 12/05/2019 (UTC) has a footprint only on one mode, whereas the second and third events, separated by 13 minutes occurring on 27/11/2019(UTC), are observed via the simultaneous monitoring of two modes. Timing of thee events is checked against available environmental observations and well as data from other detectors. Various possibilities explaining the origins of these events are discussed. With the possibility of simultaneously monitoring many overtone modes across multiple resonators, quartz

BAW based HFGW detectors could provide an efficient solution to gravitational wave astronomy at MHz frequencies. Employing natural techniques such as coincident analysis and cross correlation will allow future generations of this experiment to probe for exotic transient sources as well as a stochastic background of HFGWs

F09

Spectral Separation of the SGWBs for LISA

Guillaume Boileau (ARTEMIS Observatoire de la Côte d'Azur Nice)

In the context of the orbital modulated waveforms from the white dwarf binary gravitational foreground and the stochastic gravitational wave background (SGWB) in the LISA observation band, the Fisher Information and Markov Chains Monte Carlo methods give an estimation of the LISA noise and the parameters of the three backgrounds (galactic, astrophysical, cosmological). We simulate a complex waveform of the galactic foreground with 35 000 000 binaries. We extract an understanding of the effect of the distribution population across masses and positions in our galaxy, the stellar core type, and the orbital frequency distribution. We also predict the detectable limits for the future LISA measurement of the SGWB in the spectral domain with the three LISA channels A, E and T. We predict detectable limits for the future LISA measurement of the SGWB. Adaptive Markov chain Monte-Carlo methods are used to produce estimates with the simulated data from the LISA Data challenge (LDC). We also calculate the Cramer-Rao lower bound on the variance of the SGWB parameter uncertainties based on the inverse Fisher Information using the Whittle Likelihood. We simultaneously estimate the noise using a LISA noise model. Assuming the expected astrophysical background, a cosmological background and a galactic foreground energy density of around $\Omega_{GW} \approx 1 \times 10^{-12} to 1 \times 10^{-13}$ can be detected by LISA.

F10

External environmental noise influences on Virgo during O3

Irene Fiori (EGO Pisa)

Sources of geophysical and anthropogenic noise, such as wind, sea, earthquakes, local traffic, etc. can impact gravitational wave interferometers by causing sensitivity drops and lock losses. During the 1-year long O3 observation run, the Virgo Collaboration collected a statistically significant sample of data to study the response of the detector to a variety of environmental conditions. We used this dataset to correlate various environmental parameters to quantities that monitor detector performance, such as its observation range and duty cycle. Where possible, we identified weaknesses in the detector and worked out strategies to be implemented to improve Virgo robustness against external environmental disturbances for the next observing run O4, planned for summer 2022. The lessons learned could provide useful insights for the design of the next generation of ground-based interferometers.

F11

BRiSTOL - a Band-limited RMS Stationarity Test Tool for Gravitational Wave Data

Francesco Di Renzo (University of Pisa and INFN Pisa)

Common techniques in Gravitational Wave data analysis assume, to some extent, the stationarity and Gaussianity of the detector noise. These assumptions are not always satisfied because of the presence of short duration transients, namely glitches, and other slower variations in the statistical properties of the noise, which might be related to malfunctioning subsystems. We present here a new technique to test the stationarity hypothesis with minimal assumptions on the data, exploiting the band-limited root mean square and the two-samples Kolmogorov-Smirnov test. The outcome is a time-frequency map showing where the hypothesis is to be rejected. This technique was used as part of the event validation procedure for assessing the quality of the LIGO and Virgo data during O3. We also report on the applications of the test to both simulated and real data, highlighting its sensitivity to various kinds of non-stationarities.

F12

Interactive Glitch Web Catalogue: an on-line application for glitches characterization in the Virgo interferometer

Nunziato Sorrentino (University of Pisa and INFN Pisa)

The rapid analysis of transient gravitational wave signals is becoming more and more challenging for the LIGO and Virgo collaborations. During the last observation run (O3), the rate of gravitational wave candidates has grown significantly with respect to the previous ones. In preparation for the next run, fast and effective analysis tools will be very useful to distinguish correctly the astrophysical signals from the transient noise events (i.e. the glitches). We present here the Interactive Glitch Web Catalogue, a web application focused on exploring glitches in Virgo. One of the main features of the tool is related to the classification of transient signals, together with integrated interactive tools for investigating the glitch characteristics. This tool is expected to be ready for the next run (O4), that should start in summer 2022.

F13

Challenges and Opportunities of Ultra High-Frequency Gravitational Waves

Francesco Muia (University of Cambridge)

The first direct measurement of gravitational waves by the LIGO and Virgo collaborations has opened up new avenues to explore our Universe. Currently operating and planned gravitational wave detectors mostly focus on the frequency range below 10 kHz, where signatures from know astrophysical sources are expected to be discovered. However, based on what happens with electromagnetic waves, there should be interesting physics to be discovered at every scale of gravitational wave frequencies. In particular, any discovery of gravitational wave signatures at frequencies higher than 10 kHz would correspond either to exotic astrophysical objects (such as primordial black holes or boson stars) or to cosmological events in the early Universe, such as phase transitions, preheating after inflation, oscillons, cosmic strings, etc. Hence, the search for high-frequency gravitational waves is a promising and challenging search for new physics and it provides a unique opportunity to test many theories beyond the Standard Model that could not be tested otherwise. In this poster, I will review the state of the art about ultra high-frequency gravitational wave physics, both from the theoretical point of view - summarising the most promising known sources and their features - and from the experimental point of view - presenting the state of the art in terms of experimental proposals in this frequency range and what are the possible ways forward.

F14

GPE: GPU-accelerated parameter estimation for gravitational waves

Yun-Jing Huang (Acadamia Sinica Taiwan)

We present GPE, a GPU-accelerated parameter estimation package for gravitational waves from compact binary coalescence sources. This stand-alone program is adapted from the nested sampling flavor of LALInference. Two main parallelization methods are implemented: (1) the frequency-domain waveform and likelihood calculations, (2) and the prior sampling portion in the nested sampling algorithm. We show that GPE can produce consistent results compared to LALInference, while demonstrating a 200-400 times speedup on one GPU compared to LALInference on one CPU. The high acceleration of GPE can facilitate the data-analysis of detected events, simulations for detector observing scenarios, and production of sky localization regions for EM follow-up.

F15

Silica Fibers for large masses upgrade on Advanced Virgo Plus

Matteo Montani (INFN Firenze)

The observation of gravitational waves is highly influenced by the detectors sensitivity, that is limited at low frequencies (10 -100 Hz) by the thermal noise. For this reason, the monolithic suspensions are one of the most important upgrades of the interferometric detectors including Advanced Ligo (aLigo) and Advanced Virgo (AdV). The target sensitivity for the new updates of Advanced Virgo Plus (AdV+) pass through larger reference masses, and this choice requires, among other things, a re-design of the silica fibers, and a new capability to produce and test them, in order to minimize the thermal noise in the band of interest and to fit the load constrains. This work will present the mechanical design of the silica fibers for large mass update and the desired features in terms of mechanical stress, thermal noise and resonant frequencies. Moreover some preliminary measures of the fibers profile and the breaking stress will be shown and compared with the design constrains. Finally the impact of the new silica fibers on the sensitivity of the Virgo interferometer will be discuss.

F17

Application of space-time spectral analysis for detection of seismic waves in gravitational-wave interferometer

Denys Mateusz (AstroCeNT Nicolaus Copernicus Astronomical Center)

Mixed space-time spectral analysis was applied for the detection of seismic waves passing through the west-end building of the Virgo interferometer. The method enables detection of every single passing wave, including its frequency, length, direction, and amplitude. A thorough analysis aimed to improving sensitivity of the Virgo detector was made for the data gathered by 38 seismic sensors, in the two-week measurement period, from 24 January to 6 February 2018, and for frequency range 5–20 Hz. Two dominant seismic-wave frequencies were found: 5.5 Hz and 17.1 Hz. The possible sources of these waves were identified, that is, the nearby industrial complex for the frequency 5.5 Hz and a small object 100 m away from the west-end buiding for 17.1 Hz. The obtained results are going to be used to provide better estimation of the newtonian noise near the Virgo interferometer.