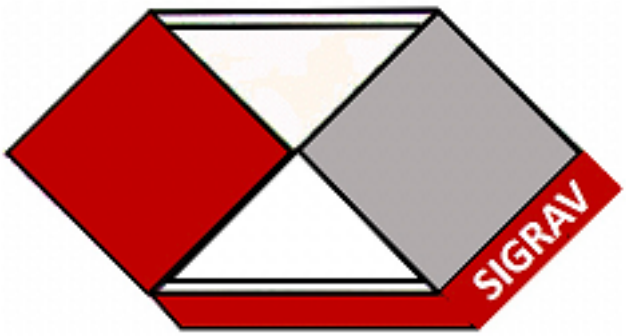
XXIV SIGRAV Conference on General Relativity and Gravitation

Tuesday, 7 September 2021 - Thursday, 9 September 2021

Urbino/Palazzo Battiferri



Book of Abstracts

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Spacetime effects on wavepackets of coherent light

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We investigate the interplay between gravity and the quantum coherence present in the state of a pulse of light propagating in curved spacetime. We first introduce an operational way to distinguish between the overall shift in the pulse wavepacket and its genuine deformation after propagation. We then apply our technique to quantum states of photons that are coherent in the frequency degree of freedom, as well as to states of completely incoherent light. We focus on Gaussian profiles and frequency combs and find that the quantum coherence initially present can enhance the deformation induced by propagation in a curved background. This further supports the claim that genuine quantum features, such as quantum coherence, can be used to probe the gravitational properties of physical systems. The results of this work can be tested with current satellite technologies.

Beyond Einstein's Gravity / 6

Self gravity affects quantum states

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We study how self gravitation of quantum systems affects the quantum coherence present in their state. Spatial superpositions of static, large, heavy systems tend to rapidly lose coherence, whereas light or massless particles are unaffected. Furthermore, large and heavy objects also rapidly localize into a single classical position. The ratio of the characteristic size of the system and its Compton length determines the onset of the effects, which become significant at a timescale that is inversely proportional to the system's gravitational self energy. Our results can explain two important aspects of physical systems: the possibility of coherently placing individual particles or photons in distant positions, and the difficulty of maintaining quantum coherence between massive objects.

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Amaldi medal talk

Gravitational Waves / **30**

GW networks of Advanced Detectors

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In 2015, the two LIGO detectors revealed for the first time a gravitational wave from the coalescence of two black holes. Two years later Virgo joined LIGO in a worldwide network of advanced gravitational wave detectors, and the detection of a gravitational wave from the coalescence of a neutron binary star in 2017 opened the era of multi-messenger astronomy. Today, the LIGO-Virgo Collaboration has already published about 50 events from the coalescence of binary black holes or binary neutron stars. In the meantime, in April 2020, the Japanese KAGRA detector joined the network, potentially increasing the future detection performance of the network by improving the ability to locate sources in the sky.
This talk will introduce the main technologies of advanced detectors in relation to the key noise sources that need to be addressed.
A summary of the network performance during the last observations and future perspectives will also be discussed.

Gravitational Waves / **31**

LISA and the origins of supermassive black holes

Massive black holes (MBHs) inhabit galactic centres, and power luminous quasars as those observed when the Universe was less than a billion of years old.
Their origins are a mystery, and the recent detection by LIGO/Virgo of a black hole of about 150

solar masses has revitalized the questions of as to whether there is
a continuum between 'stellar'and 'massive'black holes, and what the seeds of MBHs are. With LISA in synergy with third generation ground-based interferometers
as the Einstein Telescope we foresee the possibility of discovering avenues of their formation with observations deep into the distant Universe.
I will cover three main themes: the channels of black hole seed formation, the journey from seeds to MBHs, and the diagnostics on the origins in the realm of the
nascent gravitational wave astrophysics.

Cosmology / **34**

Primordial gravitational waves from CMB - observational perspectives

I will briefly review the impact of primordial gravitational waves into CMB polarization, and present some of the observational efforts in which I am involved.
I will describe the observational target and the most relevant measurement issues due to sensitivity, foreground emission and systematic effects.
In particular I will focus on the LSPE ground+balloon experiment, and on the LiteBIRD satellite.
LSPE is due in the next years, and aims at measure the large scales of the CMB polarization in the northern hemisphere.
LiteBIRD is a satellite devoted to CMB polarization to be launched in late 2020's. It is approved and coordinated by JAXA, with a strong involvement of European institutions (two of the three instruments on board are under European responsibility), and a relevant NASA contribution.

Cosmology / **35**

Neutrino Cosmology: current status and future prospects

Neutrino unknowns are clear gateways to new physics. Cosmology offers a unique arena to unveil neutrino secrets in a way that is separate from, but complementary to astrophysical and terrestrial searches. The next generation of cosmological surveys will supersede the current, which is already highly sensitive to neutrino fundamental properties. I will present the state of the art, summarise future prospects and comment on the main challenges in neutrino cosmology.

Cosmology / **36**

Models of galaxy formation and evolution constrained by gravitational-wave events

The recent detection of gravitational waves (GW) by the LIGO/VIRGO Collaboration opened a new era of gravitational astronomy with an unavoidable impact on theoretical models of galaxy formation and evolution. The astrophysical nature and origin of compact objects generating GW events are in fact deeply connected with the property of the galactic environment in which their stellar progenitors form, while their statistical relevance strictly depends on the progress of cosmic star formation. In this talk I will introduce recent semi-analytic and hydrodynamical simulations tak-

ing advantage from the emerging statistics of GW events already provided by LIGO/VIRGO. Results of recent investigations focusing on the high redshift Universe will be also introduced to show how GW signals originating from massive black hole binary mergers can shed some light on star forming galaxies in the epoch of cosmic Reionizaton.

Gravitational Waves / 40

Broadband quantum noise reduction in Advanced Virgo Plus

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Quantum noise is limiting the sensitivity of ground based gravitational wave detectors both at high and low frequency. Carlton Caves in 1980s proposed to introduce particular quantum states of lights, called vacuum squeezed states, from the output port of the detector to reduce this noise. In O3, the injection of frequency independent squeezing improved Virgo and LIGO sensitivities at high frequency, slightly worsening the performance at low frequency. A broadband quantum noise reduction can be achieved using frequency dependent squeezing, i. e. rotating the vacuum squeezed ellipse below 100 Hz by reflecting the squeezed vacuum off a Fabry–Perot cavity. Once the frequency dependent squeezing is produced, it has to be injected in Virgo with a non trivial interface of additional benches and a 285 meters cavity. The installation and pre-commissioning of infrastructure and optics have been completed. The commissioning is ongoing and we will soon have this new technique working.

Experimental Gravitation / 41

GINGER

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Precision measurements of the Earth rotation make it possible to investigate fundamental physics, as they contain general relativity terms, such as de Sitter and Lense Thirring, and can provide unique data to investigate possible Lorentz violations. These measurements require high sensitivity, usually parametrised as the fraction of the average Earth rotation rate; the limit to be reached to study fundamental physics is 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 focuses on fundamental physics, using an array of Ring Laser Gyroscopes (RLG). The GINGER apparatus and its potentiality will be described. Present study indicates that sensitivity of 1 part 10^12 is feasible using ring lasers.

Gravity Theory / 42

Canonical Analysis of Brans-Dicke Theory Addresses Hamiltonian Inequivalence between Jordan and Einstein Frames

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We analyze the Brans-Dicke theory with a Gibbons-Hawking-York(GHY) boundary term and perform ADM decomposition both in Jordan and Einstein frames. For ω≠-3/2, we show that, at the Hamiltonian level, the Weyl (conformal) transformations from the Jordan to Einstein frames are not canonical transformations (in Hamiltonian sense). A set of canonical transformations is found. These are Anti-Gravity or Anti-Newtonian transformations and are different respect to the transformations from the Jordan to the Einstein frames. The case for ω=-3/2 with GHY boundary term is studied as well. The presence of the conformal invariance too in the Jordan frame, the Dirac's constraint algebra of secondary first-class constraints is different in the Jordan frame respect to the Einstein frame. This inequivalence of the Dirac's algebra between the two frames addresses, more strongly respect to the case ω≠-3/2, the non (Hamiltonian)-canonicity of the transformations from the Jordan to the Einstein Frames.

Gravitational Waves / **43**

Bayesian parameter estimation of stellar-mass black-hole binaries with LISA

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Co-authors: Antoine Klein [2]; Elinore Roebber [2]; Christopher J. Moore [2]; Eliot Finch [2]; Davide Gerosa [2]; Alberto Vecchio [2]

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In this talk I will present a fully Bayesian parameter-estimation pipeline to measure the properties of inspiralling stellar-mass black hole binaries with LISA.
Our strategy (i) is based on the coherent analysis of the three noise-orthogonal LISA data streams, (ii) employs accurate and computationally efficient post-Newtonian waveforms –accounting for both spin-precession and orbital eccentricity–and (iii) relies on a nested sampling algorithm for the computation of model evidences and posterior probability density functions of the full 17 parameters describing a binary. We demonstrate the performance of this approach by analyzing the LISA Data Challenge (LDC–1) dataset.
In addition, we report on the successful recovery of an eccentric, spin-precessing source at signal-to-noise ratio 15 for which we can measure an eccentricity of 3×10^{-3} and the time to merger to within ~1 hour.

Gravity Theory / **44**

Hydrodynamics of the Gross-Pitaevskii equation in general Riemannian metric

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Here we show that the standard 3D Gross–Pitaevskii equation (GPE) [1,2] for Bose-Einstein condensates (BECs) admits hydrodynamic interpretation in a general Riemannian metric. This is done by deriving the corresponding Euler and Navier-Stokes forms in full generality. We also show [3] that in this metric the momentum equation has a new term that is associated with local curvature

and density distribution profile. This work may find applications in analogue gravity models in cosmology.

This is joint work with Alice Roitberg (UniMiB).

[1] Gross E.P. 1961 Structure of a quantized vortex in boson systems. *Il Nuovo Cimento* **20**, 454-477.
[2] Pitaevskii L.P. 1961 Vortex lines in an imperfect Bose gas. *Sov. Phys. JETP* **13**, 451-454.
[3] Roitberg A. & Ricca R.L. 2021 Hydrodynamic derivation of the Gross-Pitaevskii equation in general Riemannian metric. *J. Phys. A: Math. Theor.* **54**, 315201.

Gravity Theory / **45**

On a new Einstein field equation with possible application to black hole cosmology

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Here we consider the hydrodynamic form of the momentum equation associated with the Gross-Pitaevskii equation (GPE) in general Riemannian metric [1] and show that, under particular steady state conditions, a new Einstein field equation can be determined in presence of negative scalar curvature. Since GPE vortex defects in Bose-Einstein condensates are useful, analogue models in cosmology, a relativistic form of GPE is also considered on generic metric, in order to show connection with models of analogue gravity, thus providing physical background for mathematical modeling, and rigorous grounds for future investigations of black hole dynamics, Hawking radiation and curvature effects on physics [3].

This is joint work with Renzo L. Ricca (UniMiB).

[1] Roitberg, A. & Ricca, R.L. (2021) *J. Phys. A: Math. Theor.* **54**, 315201.
[2] Roitberg, A. (2021) *J. Phys.: Conf. Ser.* **1730**, 012017.
[3] Barceló, C., Liberati, S. & Visser, M. (2001) *Class. Quantum Grav.* **18**, 1137.

Beyond Einstein's Gravity / **47**

A quantum state for black holes and the late Universe

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We present a simple quantum description of black holes and the late Universe in which the effective Schwarzschild-de Sitter spacetime geometry emerges from a coherent state of background gravitons. Once localised baryonic matter is added consistently, such quantum states are shown to describe regular black holes and to contain the necessary components to describe MoND phenomenology at galactic scales. The tension between values of the Hubble parameter measured from the CMB and supernovae data can also be addressed with this approach.

Beyond Einstein's Gravity / **48**

Exact solutions in statistical quantum field theory

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An exact form of the stress-energy tensor in quantum field theory (QFT) with a local equilibrium statistical operator would be a crucial ingredient of the semiclassical Einstein equation, with non-trivial quantum corrections to the equation of state. While a solution in a curved background is still unknown, much can be learned from solving related problems in flat space-time. In this talk, I will present some recent results in statistical QFT obtained with equilibrium and non-equilibrium density operators. A general method to calculate the exact mean value of the stress-energy tensor at equilibrium with rotation and acceleration without solving PDE's in curvilinear coordinates is introduced and the quantum corrections to the ideal fluid form discussed. In the second part, the exact solution for an expanding velocity field with longitudinal boost invariance is presented along with the quantum corrections to free-streaming.

Cosmology / **49**

FLRW quantum cosmology from a tomographic point of virw

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The introduction of a perfect fluid source in quantum cosmological models has permitted to write down the Wheeler De Witt equation in a form similar to the Schroedinger equation, by the introduction of a fiducial time. In the first part of the talk I introduce the formalism and discuss the nature of this fiducial time. In the second part I introduce the corresponding tomograms in order to analyze the properties of these models

Beyond Einstein's Gravity / **50**

New equations for relativistic cosmology

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We propose a model where, in the Einstein equations, the right-hand side is modified by the addition of a term proportional to the symmetrized partial contraction of the Ricci tensor with the energy-momentum tensor. Bearing in mind the existence of a natural length scale given by the Planck length, dimensional analysis shows that such a term yields a correction linear in hbar to the classical term that is instead just proportional to the energy-momentum tensor. One then obtains an effective

energy-momentum tensor that consists of three contributions: pure energy part, mechanical stress, and thermal part. The pure energy part has the appropriate property for dealing with the dark sector of modern relativistic cosmology. Such a theory coincides with general relativity in vacuum, and the resulting field equations are here solved for a Dunn and Tupper metric, for departures from an interior Schwarzschild solution as well as for a Friedmann-Lemaitre-Robertson-Walker universe.

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Social dinner

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New directions for quantum field theory in curved spacetime

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Spontaneous symmetry breaking is a transversal concept in modern physics, being pivotal for our understanding of mass generation in particle physics, topological defects formation in cosmology and the appearance of condensed phases of matter. I will discuss some recent results about the way symmetry breaking occurs for systems embedded in a curved background, when curvature acts as an effective mass that, depending on the sign, enhances or suppresses the mechanism responsible for phase transitions.

Experimental Gravitation / 53

Gravity with Gaia

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The ESA Gaia mission measures directly positions and velocities of more than 1.5 billion stars to create the largest, most precise 6D kinematical map of the Milky Way (MW). High accurate measurements in space force fundamental astronomy to move from the "classical" paradigm, responding to Newton's gravity, to that of Einstein's General Relativity (GR). Then, GR must be at the very core of the Gaia data reduction to guarantee the quality of the scientific products that span from the fraction-of-a-parsec scale of the Solar System to the two tens of kpc of that of the MW to comprise also GR tests. Indeed, any reconstruction of our Galaxy should be consistent with the relativistic-compliant astrometry delivered by Gaia to assure a coherent local cosmological laboratory for the predictions of the Lambda-CDM model at z=0. Besides that, a GR treatment of the local line-of-sight allows to devise an astrometric antenna for detecting with unmatched precision the GW incoming direction.

The future of Gravitational waves astronomy / 54

The Einstein Telescope and its vacuum system

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Einstein Telescope is the European third-generation gravitational waves detector.
This new detector will detect GW sources in a Universe volume that is a thousand times bigger compared to the volume surveyed by the present detectors, reaching sources at cosmological distances. The promise, among the others, is to unveil new insight on compact objects like neutron stars and black holes, to study the matter in extreme density conditions, and possibly to study primordial BH and stochastic GW background. Such ambitious scientific goals, require a cryogenic, underground detector 10x bigger than second-generation ones. However, the upscaling in size can be not straightforward. For example, the vacuum system is the biggest volume in ultra-high vacuum ever conceived and his realization will require a huge R&D to find the proper solutions and allow the realization of such gigantic infrastructure. In the talk, we will present the ET project with an emphasis on the vacuum system.

Cosmology / **55**

Cosmology with LIGO/Virgo dark sirens and galaxy catalogs

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Co-authors: Andreas Finke [2]; Stefano Foffa [2]; Michele Maggiore [2]; Michele Mancarella [3]

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We will briefly present a detailed study of the methodology for correlating "dark sirens" (compact binaries coalescences without electromagnetic counterpart) with galaxy catalogs. Several improvements on the current state of the art will be examined and applied to the published LIGO/Virgo gravitational wave (GW) detections, studying several sources of systematic errors. We will give the best result measurement of H_0 from dark sirens alone, as well as combining with the counterpart of GW170817. We will also discuss the application of this formalism to the study of modified GW propagation (which is a smoking gun of dark energy and modifications of gravity at cosmological scales). Current observations of dark sirens already start to provide interesting limits, and we will show the results using them alone for the measurement of the parameter Ξ_0, which measures deviations from GR. If time permits, we will also briefly present other ways of obtaining information on this parameter.

Experimental Gravitation / **57**

SaToR-G: an experiment to test gravity theories in the field of the Earth with laser-tracked satellites

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SaToR-G (Satellite Tests of Relativistic Gravity) is a fundamental physics experiment of the National Scientific Committee 2 (CSN2) of the Italian National Institute for Nuclear Physics (INFN). SaToR-G aims at testing gravitation beyond the predictions of General Relativity (GR) in its weak-field and slow-motion limit, searching for effects foreseen by alternative theories of gravitation and possibly connected with "new physics". The predictions of General Relativity on the orbits of laser-tracked satellites such as the two LAGEOS and LARES – which play the role of proof masses – will be compared with those of other metric and non-metric theories of gravity. The analysis of the orbital residuals of the satellites will be presented with the activities related to the development of perturbative models to better determine their orbital dynamics together with new preliminary constraints to some alternative theories of gravitation.

The future of Gravitational waves astronomy / 58

Einstein Telescope and the future of ground-based GW detection

Author: Ettore Majorana[1]

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Einstein Telescope was conceived fifteen years ago, significantly before the first observations of gravitational waves. The concept was strongly characterized by the aim of constituting an European pole of development for a new observational branch of astrophysical science, ranging from fundamental interactions studies to cosmology. Many facts happened since that time. Given the quantity and the quality of the observations, the most relevant aspect is relevance and the value of networked operation of the detectors. Beyond that, the target of reaching all the CBC throughout the whole universe or studying extreme conditions of matter through space-time and multimessenger observations rekindled the purposes of ET community. The project is now among the most appealing European scientific infrastructures (ESFRI) and the preparatory phase, leading to constitute a wide international collaboration, is ongoing. The status and the perspective of ET will be presented.

Gravitational Waves / 59

GRMHD Simulations of Compact Object Binaries

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I will present the results of numerical relativity simulations of compact object binaries. I will focus in particular on the effects that magnetic fields can have in two different scenarios: binary neutron stars and supermassive black hole binaries. In the first one, magnetic fields can affect the post-merger evolution of the remnant and in particular its gravitational and electromagnetic emission. In the latter, we expect the mergers of supermassive black holes to happen in regions where the presence of magnetized plasma can give rise to relativistic jets and electromagnetic radiation. Both binary neutron stars and supermassive black hole binaries are strong sources of gravitational waves for current and future detectors. Understanding their electromagnetic emission can provide further information on the binary properties when combined with their gravitational wave signals.

Beyond Einstein's Gravity / **60**

Generalizing the coupling between spacetime and matter

Author: Sante Carloni[1]

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We construct a new class of extension of General Relativity starting from the idea that the coupling between spacetime and matter is the key to understand dark phenomenology. We then focus on one of the simplest examples of such a class of theories which contains only one additional parameter dubbed "MEMe model". We show that this theory is able to offer a unified framework for dark energy and inflation. The MEMe model requires an extension of the classical Post-Newtonian expansion to be analyzed in the weak field, slow-motion approximation. We find that in the context of the MEMe model the structure of compact objects can be different from the ones of GR, whereas, if one considers only one type of fluid, the circular orbits of the fluid particles differ significantly from the usual ones only in the center of the matter distribution.

Experimental Gravitation / **61**

The MBTA Pipeline for Detecting Compact Binary Coalescences in the Third LIGO-Virgo Observing Run

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As the sensitivity of existing ground-based detectors increases and new detectors appear, the number of gravitational-wave detections from compact binary mergers is also increasing. A low latency detection of these sources is primordial to increase the chances of observing counterparts, and an offline search allows for better exploitation of the data. In this talk, I will present how the Multi-Band Template Analysis (MBTA) online and offline pipelines have contributed to detections during the third LIGO-Virgo observing run (O3). These two searches must deal with a network of detectors with heterogeneous sensitivities and non-stationarities. I will discuss the solutions we have chosen to face these challenges and talk about the performance of the analysis during O3.

Beyond Einstein's Gravity / **62**

Precision tests of the AdS/CFT correspondence

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I will review recent non-trivial tests of the AdS/CFT correspondence which provides a dual description of the 4D quantum gravity in terms of 3D Chern-Simons-matter superconformal field theories. After a general discussion, I will focus on BPS Wilson loops that represent one of the best playgrounds to match exact field theory results with dual gravity predictions.

Gravity Theory / 63

Beyond the shadow

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Even from the very name, the international collaboration Event Horizon Telescope may suggest that the stellar objects hidden within the observed shadow are necessarily black holes safely covered inside a trapped region. However, on a purely classical level, one can exhibit models determining a shadow without a horizon. Recent speculations on possible alternative interpretations of the objects as those analyzed by the EHT collaboration will be discussed.

Gravity Theory / 64

Massive scalar field in de Sitter space:a two-loop calculation and a comparison with the stochastic approach

Authors: Alexander Kamenshchik[1]; Alexei Starobinsky[2]; Tereza Vardanyan[3]

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We examine the long-wavelength correlation functions of massive scalar fields in de Sitter space. For the theory with a quartic self-interaction, the two-point function is calculated up to two loops. Comparing our results with the Hartree-Fock approximation and with the stochastic approach shows that the former resums only the cactus type diagrams, whereas the latter contains the sunset diagram as well. We also demonstrate that the long-wavelength expectation value of the commutator of two fields is equal to zero both for spacelike and timelike separated points.

Cosmology / 65

Primordial black hole formation

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Primordial black holes can form in the early Universe from the collapse of cosmological perturbations after the cosmological horizon crossing. They are possible candidates for the dark matter as well as for the seeds of supermassive black holes observed today in the centre of galaxies. In calculations of spherically symmetric collapse, a Lagrangian relativistic hydrodynamical code is used to follow the non linear evolution. If the perturbation is larger than a threshold depending on the equation of state and on the specific shape of the perturbation, a black hole is formed. In this talk I will discuss the dependence of PBH formation from the initial shape of the curvature profile, showing the relation with the shape of the inflationary power spectrum. This allows to compute consistently the abundance

of PBHs. Depending on the model, a proper calculation shows that the abundance of PBHs might be significantly increased by several order of magnitudes compared to previous estimations.

Experimental Gravitation / **67**

Technologies for a GW astrometric antenna

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After recalling its working tenets, the contribution introduces to the technological (including computational) challenges facing

the actual realization of a compact antenna in space that, complementary to current or future facilities, utilizes (sub)-micro-arcsecond

astrometry to estimate strength and pin-point direction of GWs, i.e., by using suitable natural star-like close pairs as antenna "arms".

Finally, some of the designs, reduction strategies, and lab activities carried out by the ASTRA Team are presented.

The future of Gravitational waves astronomy / **68**

Experimental challenges for space-based gravitational wave detectors: overview of LISA

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In this talk we address the measurement concept and the main experimental challenges for LISA, the first space-based GW observatory, to be launched in 2034. The task of using laser interferometry to measure the GW tidal deformation of a constellation of free-falling test masses is discussed, both in the context of heritage from the preparatory single-spacecraft mission - LISA Pathfinder - and for the unique remaining challenges to be met by the first orbiting GW observatory, whose location will allow the exploration of the mHz frequency band only accessible from space.

The future of Gravitational waves astronomy / **69**

Liquid Activated Gravity Experiment - an update

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Gravity at short distances is still an open field for investigation. The measurement scheme we propose, with fluid source masses, overcomes some of the main limitations of torsion pendulum experiments. We overview the scientific motivations for such a search, outline the experimental apparatus

and present a progress report on the activities, with the first experimental demonstration of the working principle.

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SIGRAV during the pandemia era

Gravity Theory / **72**

Probing new physics with Ginger experiment

Author: Gaetano Lambiase[1]

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The possibility of testing Gravitomagnetism effects in a terrestrial laboratory has been explored in recent years. In particular, the GINGER (Gyroscopes In General Relativity) experiment relies on the use of light for testing Gravitomagnetism and, more in general, post-Newtonian effects, in a terrestrial laboratory by means of an array of ring lasers (a ring laser is a rotation sensor based on the Sagnac effect, that is the shift of the interference pattern arising when an interferometer is set into rotation, with respect to what is observed when the device is at rest). In this framework, I will review the behaviour of a quantum system in a gravitational field, and the possibility to test modified gravity and Lorentz invariance violation.

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On the nature of the supermassive compact object in SgrA

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In a campaign to acquire astrometric data on the stars orbiting the compact source at the Galaxy center, Sgr~A*, the groups led by R. Genzel at Max Planck, and by A. Ghez at University of California, have used the most advanced observational techniques of European (GRAVITY instrument at VLT), and US based (Keck, Gemini North and Subaru), to reach an unprecedented precise determination of the orbits of the S-cluster stars. This observational results have allow to start a new astrophysical endeavour to identifying the theoretical model which can consistently satisfy all the existing observational constraints. It is so that the following interesting models for Sgr~A* arise: a classical source by a Schwarzschild Black Hole [Hoanian and Ruffini, PRD, 1974], and a quantum self-gravitating DM system of neutral

fermions. These two scenarios fulfilling all the current observational data, are discussed in light of Richard Feynman considerations of classical versus quantum theories.