Journées LISA France

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Off-centre supermassive black holes in bright central galaxies

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Supermassive black holes (SMBHs) are believed to reside at the centre of massive galaxies such as brightest cluster galaxies (BCGs). However, as BCGs experienced numerous galaxy mergers throughout their history, the central BH can be significantly kicked from the central region by these dynamical encounters. By combining the Illustris-TNG300 simulations and orbital integrations, we demonstrate that mergers with satellite galaxies on radial orbits are a main driver for such BH displacements in BCGs. BHs can get ejected to distances varying between a few parsecs to hundreds of kiloparsecs. Our results clearly establish that SMBH offsets are common in BCGs and more precisely a third of our BHs are off-centred at z=0. This orbital offset can be sustained for up to at least 6 Gyr between z=2 and z=0 in half of our BCGs. Since the dense gas reservoirs are located in the central region of galaxies, we argue that the consequences of off-center SMBHs in BCGs are to quench any BH growth and BH feedback.

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A test for LISA foregrounds Gaussianity and stationarity. II. Extreme-mass-ratio inspirals

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Extreme Mass Ratio Inspirals (EMRIs) are key targets expected to be observed by the Laser Interferometer Space Antenna (LISA) mission. Unresolvable EMRI signals contribute to forming a gravitational wave background (GWB).
Characterizing the statistical features of the GWB from EMRIs is of great importance, as EMRIs will ubiquitously affect large segments of the inference scheme.
In this work, we apply a frequentist test for GWB Gaussianity and stationarity, exploring three astrophysically-motivated EMRI populations. We construct the resulting signal by combining state-of-the-art EMRI waveforms and a detailed description of the LISA response with first-generation time-delay interferometry variables.
Depending on the brightness of the GWB, our analysis demonstrates that the resultant EMRI foregrounds show varying degrees of departure from the usual statistical assumptions that the GWBs are both Gaussian and Stationary.
If the GWB background is non-stationary with non-Gaussian features, this will challenge the robustness of Gaussian-likelihood model, when applied to global inference results, e.g. foreground estimation, background detection, and individual-source parameters reconstruction.

Science / 3

Probing General Relativity with the inspiral of Massive Black Hole Binaries

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LISA observations of Massive Black Hole Binaries (MBHBs) will provide high signal-to-noise ratio (SNR) data, ideal for testing General Relativity (GR) in the strong field regime. MBHBs with masses between 10^3 and 10^6M* produce extended inspiral signals in LISA's frequency band, well-modeled by the Post Newtonian (PN) approach.
We present a framework for parametrized GR tests with gravitational waves (GWs) from MBHB inspirals, inspired by existing LIGO-Virgo tools. This approach introduces generic deviations to the PN coefficients of the frequency-domain GW phase while accounting for the time- and frequency-dependent instrument response. This method effectively identifies potential GR violations by constraining deviations in the PN phasing formula.
The extended inspiral signals from MBHB detections significantly enhance parameter inference. Complementing Fisher matrix studies, preliminary full Bayesian analyses show promising results, with projected constraints with approximately two orders of magnitude improvement compared to the most recent LIGO-Virgo-Kagra (LVK) analysis.
Accurate GR tests require highly precise waveform templates to minimize systematic errors and avoid misinterpretations, particularly crucial given the high SNRs expected in LISA observations. By using different waveform models for signal recovery, we aim to investigate the impact of waveform systematics and determine the required PN accuracy for precision tests in the LISA context.

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Extra-galactic Double White Dwarfs Gravitational Waves Background Synthesis for LISA: DWDs Cosmic Synthesis

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We estimate the stochastic background for LISA originating from extra-galactic double white dwarf binaries, building on the foundational work by Farmer & Phinney (2003) and recent calculations by Staelens & Nelemans. By using the COSMIC code for binary population synthesis, we explore various stellar synthesis models with different assumptions, including improved models for tidal interactions between DWDs. Our approach within a cosmological framework, produces background estimates across metallicity, star formation rates and redshift bins.

Through this study, we reproduce the background estimates reported by Staelens & Nelemans and Farmer & Phinney (2003). I will also provide new insights into the potential impact of anisotropies on future LISA observations, demonstrating significant variability in stochastic background predictions based on different astrophysical, cosmological, and stellar synthesis assumptions. This work highlights both the uncertainties in current predictions and the potential for discovering anisotropic features in the stochastic background during future LISA observations.

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La mécanique du TMS

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La précision demandée sur les réglages du miroir du TMS (Test Mass Simulator) est particulièrement exigeante. Pour y parvenir, la mécanique du système s'appuie sur des éléments flexibles qui seront présentés lors de cette intervention.

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Testing Extended Theories of Electro-Magnetism and the absence of expansion at local scales with space interferometry

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We face the dichotomy of an ad-hoc dark Universe compatible with General Relativity (GR) but lacking experimental evidence and unsupported by the Standard Model (SM), while we record continuous successes of GR that undermine the efforts the reformulations of gravitation. We are aware that, despite neutrinos, cosmic rays and now gravitational waves, photons remain by large the main messengers of the cosmos. Thus, we analyse signals and see whether Extended Theories of Electro-Magnetism (ETEM) induce a (partial) reinterpretation of physics laws. The SM Extension (SME) induces a mass to a photon [1,2], the only free massless particle, compatible to the upper limits by Fast Radio Bursts [3-5] and solar wind [6,7]. Group velocity dispersion birefringence are the most widely searched ETEM effects. Further, all photons –massive as from the SME or from the de Broglie-Proca theory, or non-linear from the Born-Infeld, Heisenberg-Euler types - undergo a frequency shift in presence of an electromagnetic and/or Lorenz Symmetry Violation background [8,9]. This shift, added to expansion redshift, determines new cosmological scenarios, e.g., without recurring to dark energy [10-12] and possibly to dark matter. We discuss what interferometry could hopefully test beside the running experiments, e.g., BMV Toulouse, γ-γ CERN, DeLLight Paris.
For the LISA configuration, there would be an ETEM frequency change of about 10 mHz for each transmission between spacecraft, that is ideally around 100 Hz in a day.
Cosmology tell us that there isn't expansion at sub-galactic level and this could be tested with LISA. Concerning a null-test on the expansion, 70 km/s per Mpc (apart from the Hubble tension [13-14]) corresponds to 3 x 10-18 m/s per metre and thus LISA could in principle carry out this test too.

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L3 data production in Nice

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In this presentation I will overview the context of the L3 data production within the DDPC. I will detail the efforts undertaken in Nice towards the production of LISA catalogs.

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SL-OGSE measurements on the ZIFO optical bench and results interpretation

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The LISA optical bench is a complex system, hosting several optical elements and interferometers. To analyze the stray light contributions to the different beams and photoreceivers, and check whether the stray light allocation is exceeded in the LISA noise budget, a dedicated instrument and method are required. We developed for that purpose the SL-OGSE instrument, which will be coupled to the LISA optical bench during the IDS measurements. It will inject in the LISA OB a frequency swept laser and record the signals from the LISA photoreceiver during the frequency scan. A Fourier transform will reveal stray light contributions, in the form of a fringe pattern dependent on their optical pathlength difference (OPD) to the nominal beam. We use ray tracing simulations to link the measured OPDs to the actual stray paths present in the system. We have already tested the instrument capabilities (noise floor of 1e-6 in fractional amplitude, 2mm OPD resolution) with a measurement campaign on the ZIFO optical bench. Here we will show the results of that campaign and the efficacy of the procedure in the individuation of stray light paths.

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Galactic binaries and neural density estimators in global fit

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In this talk we are going to discuss how the Normalising Flow (a type of neural density estimator) can help us in doing the global fit. We will look at the ways it can be incorporated as a proposal and as a prior in the process of parameter estimation. We will follow up with the discussion of how the model of the Galaxy can be included in the analysis to perform the population inference.

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Présentation du GWOSC (Gravitational Wave Open Science Center)

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La collaboration LIGO-Virgo-Kagra a mis en place une politique de science ouverte avant même les premières détections d'ondes gravitationnelles. Cette politique est assurée par le Gravitational Wave Open Science Center (GWOSC) qui permet d'une part d'accéder aux données et propose d'autre part des ressources (documents, tutoriels, formations) pour apprendre à les utiliser et à les traiter.

Cette contribution vise à présenter quelques aspects techniques et organisationnels du GWOSC ainsi que les réalisations concrètes de la science ouverte dans le domaine des ondes gravitationnelles.

La collaboration LISA peut s'inspirer de cette expérience pour mettre en place une politique de science ouverte.

Science / **11**

Search for dark matter with space based gravitational waves detectors

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In this talk, I will present you some on going work on searches for ultra light dark matter fields with space based gravitational waves detectors. In the first part of the talk, I will present the result of a numerical study on the feasibility of breaking the degeneracy between scalar dark matter and monochromatic gravitational waves in LISA. In the second part, I will discuss a recent proposal of a slight modification of space based GW detectors' optical benches in order for them to be sensitive to axion dark matter.

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Comment vérifier les performances de l'instrument LISA sur Terre? - La contribution bord de LISA-France

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Présentation du setup de test en cours de développement par la collaboration LISA-France pour vérifier les performances de l'instrument LISA sur Terre. Introduction sur les éléments complexes de ce setup de test (Beams Simulator, Structure Stable, TestMass simulator). Positionnement de LISA-France au sein du projet IDS (Interferometric Detection System).

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Extending coronagraphic time-delay interferometry to more realistic scenarios

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The Laser Interferometer Space Antenna (LISA) will be a space-borne gravitational wave (GW) detector to be launched in the next decade. Central to LISA data analysis is time-delay interferometry (TDI), a numerical procedure which drastically reduces otherwise overwhelming laser frequency noise. LISA data analysis is usually performed on subsets of TDI variables which form a basis, e.g. Michelson variables (X, Y, Z). We investigate a less standard TDI variable, denoted κ, which depends on time and two parameters (β, λ). For any GW source located at sky position (β_0, λ_0), κ has the singular property of canceling GW signal when (β, λ) tend to (β_0, λ_0), very much like a coronagraph. This TDI variable has been briefly discussed in the LISA literature [1,2,3], but on theoretical grounds. From a data analysis perspective, the study of κ is relevant to low latency detection of massive black hole mergers (MBHBs). Because the method is based on the response of the detector and not on GW templates, it has the potential to be a fast and model agnostic alternative to other data analysis techniques. After assessing the applicability of this method to LISA data analysis—particularly for sky localization in an idealized scenario [4]—we now turn to more realistic settings. Specifically, we investigate κ's response to simulated instrumental noise and examine cases involving noisy simulations of Galactic binaries and MBHBs. Additionally, we consider scenarios with the superposition of two signals. These findings highlight the challenges that arise in less idealized scenarios and suggest directions for the future development of data analysis techniques based on coronagraphic TDI.

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ZIFO's Insights on Optical Pathlength Stability for LISA

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Within the framework of the French collaboration for the LISA , a series of optical demonstrators have been developed as a part of the Interferometric Detection System (IDS) Test Set-Up, to characterise the foreseen complexity and technologies to be employed in the optical systems of LISA. The IDS, consisting of LISA's optical bench, the lasers and phase-meters, have to be rigorously tested on ground to verify their operational efficiency.

The Zerodur Interferometer (ZIFO) ultra-stable optical metrology bench was developed by APC (Laboratoire Astroparticule et Cosmologie) in collaboration with CNES and other French laboratories to acquire expertise in low-frequency heterodyne interferometry and demonstrate the ability to reduce acquisition chain noise (alongside other requirements).

The ZIFO successfully completed a campaign at the Laboratoire Astrophysique Marseille (LAM) in October 2023. The campaign showcased a remarkable optical path stability, surpassing the predefined benchmark of 10 pm/√Hz in the interferometric measurement within the 10 mHz - 1 Hz band.

In my presentation, I will explore the elements and methodologies employed in the ZIFO campaign. I will put emphasis on to the conclusions drawn regarding the impact of the test environment on measurement accuracy and its coupling to the optical path noise.

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Beams Simulator optical bench

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Lors de cette présentation, je fournirai une vue d'ensemble du banc optique Beams Simulator, en expliquant son rôle dans le dispositif de test IDS et son utilisation pour valider les performances des versions EM et QM de l'IDS. J'aborderai également le concept optique du banc, les tests prévus et l'état d'avancement de sa conception.

DDPC / **16**

Tools for assessing the impact of gaps on LISA data analysis

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In this talk, we will discuss the impact of data gaps on the data analysis of the Laser Interferometer Space Antennae (LISA). The LISA data stream will be interrupted by both scheduled and unscheduled gaps due for instance to repointing of the antennae, or instrumental disturbances. Developing data analysis pipelines for LISA will require us to take into account these data gaps in our

parameter estimation algorithms. In this talk, we will discuss a direct and quite general method that can be used to account for data gaps in LISA data, both in time and Fourier domain, and evaluate the impact of using improper statistical characterization of the noise properties when recovering source parameters. Albeit powerful, this approach is limited to short data segments, and as a result we will focus on short mergers of Massive Black Hole Binaries. This tool provides us with a test bed to quantify the impact of various approximations in our modelling of the noise, and will inform the development of methods aiming at covering longer data segments. We explore the impact of mismodelling the non-stationarity induced by the gaps themselves, of mismodelling the noise level in the underlying stationary process, and of mismodelling the independence between segments.

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Modèle de performance du setup de test

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Les essais de performance de l'IDS sont parmi les plus importants prévus pour la campagne de tests menés par la collaboration française. L'un des enjeux principaux du setup de test en développement est d'avoir un niveau de bruit assez faible pour ne pas fausser les mesures de performances interférométriques de l'IDS.
Un bilan de performance du setup de test a donc été développé afin d'estimer son plancher de bruits, basé les exigences de la mission et de la campagne de test, et des modèles de bruits.