Journée LISA à Toulouse

Rapport sur les contributions

https://indico.in2p3.fr/e/36452

ID de Contribution: **1** Type: **Non spécifié**

Disentangling the Gravitational Symphony: Machine Learning for LISA's Global Fit

vendredi 20 juin 2025 14:00 (20 minutes)

The immense scientific potential of LISA hinges on solving an unprecedented data analysis challenge: the Global Fit problem. This involves the simultaneous inference of numerous overlapping signals and instrument noise, framed in a high-dimensional Bayesian setting.

Current approaches rely on computationally intensive Markov chain Monte Carlo (MCMC) techniques with block Gibbs sampling across source classes. Yet, these methods suffer from poor scalability and slow convergence, especially in the presence of source confusion and uncertainty in source number. To address these issues, we introduce GWINESS (Gravitational Wave Inference using NEural Source Separation), a machine learning-based framework inspired by music source separation. Using an encoder-decoder neural architecture, GWINESS aims to perform blind source separation of overlapping gravitational-wave signals—analogous to isolating vocals, drums, and bass in a song. By pre-processing LISA data and identifying distinct source components (e.g., MBHBs, EMRIs, GBs), we will try to accelerate convergence and to improve the initialization of classical MCMC pipelines.

This talk will present the core principles behind GWINESS, highlight the challenges of the Global Fit for LISA, and demonstrate how hybridizing physics-based inference with deep learning can dramatically reduce computational costs. We will discuss current limitations, and future directions for integrating ML methods in LISA's Global Fit.

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Classification de Session: Contributed talks and discussions

Classification de thématique: AI applications to LISA data analysis

ID de Contribution: **2** Type: **Non spécifié**

A parametrized test of General Relativity applied to LISA Massive Black Hole Binaries

vendredi 20 juin 2025 14:40 (20 minutes)

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 10^4 and $10^7 M_\odot$ produce inspiral signals in LISA's frequency band, well-modeled by the Post Newtonian (PN) approach, followed by loud merger-ringdown signals. We present a framework for parametrized inspiral GR tests with gravitational waves (GWs) from MBHBs, inspired by existing LIGO-Virgo-KAGRA (LVK) tools. This approach introduces generic deviations to the PN coefficients of the frequency-domain GW phase, effectively identifying potential GR violations by constraining deviations in the PN phasing formula.
Our results demonstrate that parameter constraints depend significantly on both mass and SNR, as LISA's sensitivity to different gravitational wave phases—inspiral, merger, and ringdown—varies across MBHB's parameter space. We also investigate the interplay between inspiral-only versus inspiral-merger-ringdown analyses in constraining deviation parameters.
Complementary analyses using Fisher matrix and full Bayesian approaches confirm that LISA observations could improve constraints on deviations from GR by at least two orders of magnitude compared to the most recent LVK measurements.
This work contributes to the development of robust tests of GR with LISA, enhancing our ability to probe the nature of gravity.

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Classification de Session: Contributed talks and discussions

Classification de thématique: Science with and for LISA

ID de Contribution: **4** Type: **Non spécifié**

Les défis optiques pour LISA

vendredi 20 juin 2025 09:40 (30 minutes)

LISA est une constellation de 3 satellites en orbite héliocentrique, située à environ 50 millions de kilomètres de la Terre. Les satellites formeront un triangle équilatéral, dont les bras mesurent 2,5 millions de kilomètres. Ainsi ils formeront un interféromètre optique orienté à 60° du plan de l'orbite terrestre.

Les charges utiles seront reliées 2 à 2 par des signaux lasers synchronisés, afin de mesurer les déplacements entre les masses de test en chute libre à l'intérieur de chaque instrument. Les perturbations de l'espace-temps, signes du passage d'une onde gravitationnelle, seront donc mesurées via la modification de distance entre ces masses d'épreuve. La sensibilité attendue est de 10 picomètres par million de kilomètres, sur un domaine de basses fréquences impossibles à mesurer avec les détecteurs terrestres LIGO et VIRGO.

Les aspects optiques de LISA sont majeurs et critiques, avec entre autres : des bancs optiques ultra-stables, une performance picométrique, une annulation des effets de tilt-to-length, de l'adhésion moléculaire, une faible lumière diffusée. Par ailleurs, les bancs de test au sol permettront de vérifier les performances de l'instrument, et doivent donc être aussi stable - voir meilleurs - que l'instrument lui-même.

Cette présentation aura donc pour objectif de présenter les défis optiques de LISA, sur l'instrument ainsi que sur les bancs de test.

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Classification de Session: Contributed talks and discussions

Classification de thématique: LISA Optical System

ID de Contribution: **5** Type: **Non spécifié**

Cosmology with the massive black hole population

vendredi 20 juin 2025 15:50 (20 minutes)

Features in the black hole population provide crucial information for measuring cosmology using only gravity. If this method is used for current gravitational wave observations, it has significant potential for applications to LISA sources. I present the first realistic population and spectral siren analysis using state-of-the-art catalogs of massive black hole mergers to infer both population and cosmological parameters simultaneously. We provide estimates of the constraints that LISA will be able to deliver, discussing specifics related to LISA and possible limitations of this approach with such sources.

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Classification de Session: Contributed talks and discussions

Classification de thématique: Science with and for LISA

ID de Contribution: **6** Type: **Non spécifié**

GWs in cosmology, the galaxy catalogue method

vendredi 20 juin 2025 16:10 (20 minutes)

Modern cosmology is confronted with a persistent tension over the value of the Hubble constant H_0, between local measurements (e.g. by SH0ES) and estimates from the cosmic microwave background (by Planck). Gravitational waves (GWs) offer a new way of assessing the expansion of the Universe, in particular by using *dark sirens*, which are gravitational sources with no electromagnetic counterpart.

In this context, I am working on the use of galaxy catalogues to constrain the Hubble constant on the basis of detections of *dark sirens*. The idea is to identify, statistically, the most likely host galaxy of the OG event, in order to associate a redshift z with it and to deduce H_0 from the luminosity distance measured directly at the time of detection.
The method is already well established for certain real catalogues such as GLADE. My aim is to adapt and evaluate these techniques for simulated catalogues that are better suited to sources that can be detected by LISA, such as supermassive black hole binaries (MBHBs). In particular, I am using *lightcone mocks* type catalogues, in order to test the robustness of cosmological inferences in more realistic contexts.

This work aims to anticipate the performance of LISA for cosmology with dark sirens, by exploring the impact of the characteristics of galactic catalogues on the accuracy of H_0 measurements.

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Classification de Session: Contributed talks and discussions

Classification de thématique: Science with and for LISA

ID de Contribution: **7** Type: **Non spécifié**

Inference of cosmological parameters from the stochastic gravitational wave background

vendredi 20 juin 2025 16:30 (20 minutes)

Gravitational waves (GWs) can be used to measure H_0 and help solve the Hubble tension since they provide us with an independent estimates of a source's luminosity distance and redshift. Future-generation detectors, such as LISA or ET, will contribute to this field both by improving the measurement of resolved events, and by providing measurement of the stochastic gravitational waves background (SGWB).

The SGWB is given by the superposition of unresolved GW events coming from all directions, and it is studied by cross-correlating the channels of an interferometer. The cross correlation is proportional to the energy density $\Omega_{\rm GW}$, whose dependence on astrophysical and cosmological parameters is well known, making it a starting point to infer the sources' population characteristics, and H_0.

The objective of the project I have been developing at the L2IT laboratory is using the estimate for the SGWB in LVK, given a catalogue of mock BBH sources, to infer via hierarchical inference both astrophysical and cosmological parameters. Even if my analysis is aimed at LVK, the method can be reapplied to LISA and ET, whose sensitivities will allow for the detection of the SGWB, making this topic of relevance for the future.

This work is relevant for two reasons. The first, is that studies have up to now relied on an analytic approach to compute Ω_{GW} from analytical models. I have instead developed my own Python pipeline for the generation of a catalogue of BBH sources, based on the standard LVK population models. The SGWB is therefore obtained through realistic waveform models that are directly projected onto the detector, leading to a more accurate simulation.

The second reason is that for third generation detectors, the inference process will have to take into consideration both resolved sources and the background. Up to now, all studies have relied on the independence of the two sources to model their two likelihood separately. A likelihood model that takes into account their interaction is yet to be derived. This work also aims at setting the theoretical framework for the future developmente of this computation, approaching the subject from a theoretical point of view.

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Classification de Session: Contributed talks and discussions

Classification de thématique: Science with and for LISA

ID de Contribution: **8** Type: **Non spécifié**

Assessing the impact of mismodeled gaps in LISA data analysis

vendredi 20 juin 2025 11:40 (20 minutes)

The LISA data stream will have interruptions, both scheduled and un-scheduled, due to repointing of the antennae or other instrumental disturbances. These data gaps must be taken into account in our data analysis algorithms. In this talk, we discuss a direct method that can account exactly for data gaps in LISA data, both in time and Fourier domain, although computationally expensive and limited to short data segments, such as short mergers of Massive Black Hole Binaries. The method can also evaluate the impact of using improper statistical characterization of the noise properties when recovering source parameters, including for longer signals when assessing statistical consistency. These tools give us a way to quantify the impact of various approximations in our modelling of the noise. We explore the effect of mismodeling the non-stationarity induced by the gaps themselves, of mismodeling the noise level in the underlying stationary process, and of mismodeling the independence or coherence between data segments.

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Classification de Session: Contributed talks and discussions

Classification de thématique: Data analysis and DDPC

ID de Contribution: **9** Type: **Non spécifié**

The influence of the acceleration produced by the third celestial body on black hole binaries

vendredi 20 juin 2025 15:00 (20 minutes)

Ground-based gravitational wave detectors have observed dozens of binary black holes. Some of them may have formed in dynamic environments, such as globular clusters or active galactic nuclei (AGN) disks. In this case, third-body interactions with (super-)massive, and possibly intermediate mass BHs will imprint clear signatures on observed GW signals due in particular to the gravitational pull of the more massive BH. As a preliminary attempt, we estimate the parameters of the massive binary black hole signal affected by acceleration based on LISA-beta, study the detectable minimum acceleration, and investigate the influence of acceleration on other parameters.

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Classification de Session: Contributed talks and discussions

Classification de thématique: Science with and for LISA

ID de Contribution: **10** Type: **Non spécifié**

Algorithmic breakthroughs for the acceleration of LISA's data processing

vendredi 20 juin 2025 14:20 (20 minutes)

The LISA mission is a space-based interferometer designed to detect gravitational waves at frequencies on the order of millihertz. LISA will detect numerous types of sources, such as compact binary systems: EMRIs, MBHBs, and GBs.

Data processing is a major challenge for this mission, as several thousand sources will need to be analyzed simultaneously due to their overlap in both the time and frequency domains. This is especially true for Galactic Binaries (GBs), which will be the most numerous sources (several tens of thousands).

Current methods, which are based on Bayesian inference, are not efficient enough to process the data flow related to GBs, due to their large number and overlapping signals. The projects I am working on aim to accelerate data processing by using new methods based on artificial intelligence. For example, I am exploring the use of Normalizing Flow techniques to determine the physical parameters of GBs, with the goal of fully characterizing a GB in significantly less computational time compared to traditional methods.

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Classification de Session: Contributed talks and discussions

Classification de thématique: AI applications to LISA data analysis

ID de Contribution: **11** Type: **Non spécifié**

Presentation and status of the LISA DDPC

vendredi 20 juin 2025 11:10 (30 minutes)

This talk will provide an overview of the LISA Distributed Data Process Center (DDPC) and will present the current status of its implementation.

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Classification de Session: Contributed talks and discussions

Classification de thématique: Data analysis and DDPC

ID de Contribution: **12** Type: **Non spécifié**

Q&A and discussion on LISA optical design and challenges

vendredi 20 juin 2025 10:10 (30 minutes)

Classification de Session: Contributed talks and discussions

ID de Contribution: **13** Type: **Non spécifié**

Discussion on LISA data analysis and DDPC

vendredi 20 juin 2025 12:00 (30 minutes)

Classification de Session: Contributed talks and discussions

ID de Contribution: **14** Type: **Non spécifié**

Welcome and introduction

vendredi 20 juin 2025 09:30 (10 minutes)

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Classification de Session: Contributed talks and discussions