LISA data analysis: from classical methods to machine learning

Rapport sur les contributions

https://indico.in2p3.fr/e/27706

ID de Contribution: **1** Type: **In person talk**

The imprint of gas on gravitational waves from LISA intermediate-mass black hole binaries

mercredi 23 novembre 2022 16:45 (15 minutes)

We study the effect of torques on circular inspirals of intermediate-mass black hole binaries (IMBHBs) embedded in gas discs, wherein both BH masses are in the range 10^2-10^5~MSun, up to redshift z = 10. We focus on how torques impact the detected gravitational wave (GW) waveform in the Laser Interferometer Space Antenna (LISA) frequency band when the binary separation is within a few hundred Schwarzschild radii. Critically, the torques depend on the gas disc properties and whether the binary carves a gap or cavity in the disc. I will discuss how gas torques can lead to a substantial change in the inspiral or a negligible one, depending on the gas properties, and how this effect may arise in GW parameter estimation as a uniquely 'time-dependent' chirp mass. These sources may originate from gas-embedded merging BH seeds or dwarf galaxies, providing a possible probe of their environmental conditions at various redshifts.

Auteurs principaux: GARG, Mudit (University of Zurich); DERDZINSKI, Andrea; ZWICK, Lorenz; CAPELO, Pedro R.; MAYER, Lucio

Orateur: GARG, Mudit (University of Zurich)

Classification de Session: Conference session 1

ID de Contribution: **4** Type: **In person talk**

Progress towards a semi-coherent search for EMRI signals

vendredi 25 novembre 2022 10:00 (15 minutes)

The search for extreme mass ratio inspiral (EMRI) event signatures in the LISA data-stream necessitated new data analysis strategies to search for and to characterise EMRIs in parameter space. While elements of EMRI data analysis have been demonstrated before, they have typically involved simplifying assumptions and have tended to separate the 'search' and 'characterisation' parts of the analysis. The end-to-end analysis of EMRI signals remains a major open problem. We present some preliminary results using a semi-coherent likelihood to search for stellar mass binary black hole inspirals in LISA, which are a good analogue for EMRI signals from the perspective of data analysis. We show with a sufficiently high number of segments a stellar mass binary black hole signal can be localised from reasonably wide priors on the chirp mass and time of merger. A variant of particle swarm optimisation is also demonstrated as a solution to the problem of parameter degeneracy in the likelihood surface for EMRI signals.

Auteur principal: BANDOPADHYAY, Diganta (University of Birmingham)

Orateur: BANDOPADHYAY, Diganta (University of Birmingham)

Classification de Session: Conference session 4

ID de Contribution: **5** Type: **In person talk**

Identifying LISA verification binaries amongst the Galactic population of double white dwarfs

Double white dwarfs (DWDs) will be the most numerous GW sources for LISA. Most Galactic DWDs will be unresolved and will form a confusion noise foreground, the dominant LISA noise source around $\sim 0.5 - 3$ mHz. Around 1% of these sources will stand out from the background and be individually detectable. An even smaller fraction (approximately one in a million) will be known in advance from electromagnetic observations and are guaranteed LISA sources; these are known as verification binaries (VBs). In this talk I will present an update on recent work by the Birmingham group on VB sources aimed at exploring what we can learn from GW and joint EM/GW observations of VBs, estimating the time to detection for the loudest VBs in the early months of LISA operations, and analysing VBs in the presence of unknown numbers of other signals (both resolved and unresolved).

Auteur principal: MOORE, Christopher (University of Birmingham)

Orateur: MOORE, Christopher (University of Birmingham)

Classification de Session: Conference session 1

ID de Contribution: **6** Type: **In person talk**

LISA data analysis in the presence of environmental effects

mercredi 23 novembre 2022 16:15 (30 minutes)

While negligible for ground-based observatories, environmental effects (peculiar motion, accretion, etc.) will be detectable by LISA in a variety of sources. I will give on overview of the specific effects that are likely to be detected by LISA, the challenges these effects pose for parameter estimation and detection, and some ways to address them.

Auteur principal: SBERNA, Laura (Max Planck Institute for Gravit)

Orateur: SBERNA, Laura (Max Planck Institute for Gravit)

Classification de Session: Conference session 1

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

Towards a complete L0-to-L2 pipeline –Progress in simulation, processing and analysis (part 1)

jeudi 24 novembre 2022 09:00 (30 minutes)

LISA will allow the simultaneous observation and characterization of thousands of gravitational-wave sources, which presents unique data analysis challenges. Preparing for these challenges requires realistic simulations of the data streams entering the final astrophysical data analysis (L1 data).

First steps towards such demonstrations have been made as part of the LISA Data challenges (LDC), which showed that a number of data analysis techniques are able to perform good parameter estimations for individual or a small number of superimposed sources. Future challenges are expected to tackle more realistic datasets.

In parallel, significant progress is being made in the description and demonstration of the data processing steps required to produce the L1 data from the raw measurements provided by the spacecraft (L0 data). The most well-known of these processing steps is laser noise suppression by time-delay interferometry (TDI), which is already included in the LDC data generation. However, there are a number of additional processing steps required to reduce the impact of other noise sources and synchronize the final data streams to a common time frame.

We will present the current state-of-the-art in instrument simulations for LISA, which includes several effects currently not included in typical data analyses, such as realistic numerically optimized orbits, different time frames for L0 data, and a multitude of additional noise sources. In addition, we will discuss a possible implementation of the L0-L1 pipeline, which is able to reduce the most critical of the additional noise sources and provide synchronized data streams. We then inject this more realistic L1 data in a simple analysis pipeline (adapted from the LDC) to assess the impact of added complexity in the instrumental model and the additional processing steps on the scientific performance of LISA. This is achieved by combining multiple simulation (orbits, response to gravitational waves, instrument), processing (reduction of various noises), and analysis (parameter estimation) tools in a flexible pipeline structure.

Auteurs principaux: BAYLE, Jean-Baptiste (University of Glasgow); HARTWIG, Olaf (SYRTE, Observatoire de Paris)

Orateurs: BAYLE, Jean-Baptiste (University of Glasgow); HARTWIG, Olaf (SYRTE, Observatoire de Paris)

Classification de Session: Conference session 2

ID de Contribution: **8** Type: **In person talk**

Trans-dimensional sampling methods: current status and future prospects

mercredi 23 novembre 2022 14:30 (30 minutes)

Trans-dimensional Bayesian sampling algorithms have been extensively used in the analysis of simulated LISA data. So far, tools based on Reversible Jump MCMC methods, have been proven to be a good candidate for tackling the LISA *global fit problem*. In this talk, I will summarize the success of the techniques that have been used to date, as well as their current limitations. These limitations will also become our starting point for discussing the future prospects of such algorithms, during the emerging era of Machine Learning techniques.

Auteur principal: KARNESIS, Nikolaos (AUTh)

Co-auteurs: Dr GAIR, Jonathan (AEI); Dr KATZ, Michael (AEI); Dr KORSAKOVA, Natalia (APC Paris); Prof. STERGIOULAS, Nikolaos (AUTh)

Orateur: KARNESIS, Nikolaos (AUTh)

Classification de Session: Conference session 1

ID de Contribution: **9** Type: **In person talk**

Merger-ringdown test – A novel test of GR using a machine learning implementation

jeudi 24 novembre 2022 17:15 (15 minutes)

The gravitational waves emitted during the coalescence of binary black holes are an excellent probe to test the behaviour of strong gravity. We propose a new test called the merger-ringdown consistency test‘ that focuses on probing the imprints of the dynamics in strong-gravity around the black-holes during the plunge-merger and ringdown phase. We demonstrate the feasibility of our test on a simulated population of events using a deep learning framework, setting a precedence for performing precision tests of gravity with neural networks. Additionally, testing consistency of QNM amplitudes and phases in the ringdown to GR predictions provide a complimentary null-test to the traditional black hole spectroscopy.

Auteur principal: BHAGWAT, Swetha (University of Birmingham)

Orateur: BHAGWAT, Swetha (University of Birmingham)

Classification de Session: Conference session 3

ID de Contribution: **10** Type: **In person talk**

Characterizing Anisotropic Stochastic Gravitational Wave Backgrounds and Foregrounds with the Bayesian LISA Pipeline (BLIP)

jeudi 24 novembre 2022 16:00 (15 minutes)

LISA data is expected to feature at least one significant anisotropic stochastic gravitational wave (GW) signal: a galactic foreground comprised of the GW contribution from millions of unresolved double white dwarf (DWD) binaries throughout our galaxy. However, the Milky Way itself is not the only local host of such systems. For instance, the Large Magellanic Cloud (LMC) is expected to contain ~2 million unresolved DWDs; the resulting GW signal may therefore comprise an anisotropic GW background in LISA. We use the Bayesian LISA Pipeline (BLIP) to simulate realistic, population-derived stochastic signals from unresolved DWDs in both the Milky Way and LMC, and apply BLIP's all-sky spherical harmonic analysis to perform anisotropic searches for each. We present the results of these searches alongside new insight into the angular resolution of the spherical harmonic search, and discuss directions of further development in the area of anisotropic stochastic searches with LISA.

Auteur principal: CRISWELL, Alexander (University of Minnesota)

Co-auteurs: LAWRENCE, Jessica (Texas Tech University); Prof. ROMANO, Joseph (Texas Tech University); BLOOM, Malachy (Carleton College); BANAGIRI, Sharan (Northwestern University); RIECK, Steven (University of Minnesota); Prof. MANDIC, Vuk (University of Minnesota)

Orateur: CRISWELL, Alexander (University of Minnesota)

Classification de Session: Conference session 3

ID de Contribution: **11** Type: **Remote talk**

Detecting gravitational waves from extreme mass ratio inspirals using convolutional neural networks

vendredi 25 novembre 2022 09:30 (15 minutes)

Extreme mass ratio inspirals (EMRIs) are among the most interesting gravitational wave (GW) sources for space-borne GW detectors. However, successful GW data analysis remains challenging due to many issues, ranging from the difficulty of modeling accurate waveforms, to the impractically large template bank required by the traditional matched filtering search method. In this work, we introduce a proof of principle approach for EMRI detection based on convolutional neural networks (CNNs). We demonstrate the performance with simulated EMRI signals buried in Gaussian noise. We show that over a wide range of physical parameters, the network is effective for EMRI systems with a signal-to-noise ratio larger than 50, and the performance is most strongly related to the signal-to-noise ratio. The method also shows good generalization ability toward different waveform models. Our study reveals the potential applicability of machine learning technology like CNNs toward more realistic EMRI data analysis.

Auteurs principaux: CHAN, Man Leong (Fukuoka University); MESSENGER, Chris (University of Glasgow); ZHANG, Jian-dong (Sun Yat-sen University); KORSAKOVA, Natalia (APC); ZHANG, Xue-Ting (School of Physics and Astronomy, Sun Yat-sen University); HU, Yi-Ming (Sun Yat-sen University)

Orateur: ZHANG, Xue-Ting (School of Physics and Astronomy, Sun Yat-sen University)

Classification de Session: Conference session 4

ID de Contribution: **12** Type: **In person talk**

On the effectiveness of null TDI channels as instrument noise monitors in LISA

jeudi 24 novembre 2022 10:00 (15 minutes)

I will present a recent paper we submitted on the use and limits of the Time-Delay Interferometry null channels for in flight estimation of the Laser Interferometer Space Antenna instrumental noise. In the talk I will consider how the two main limiting noise sources, test-mass acceleration noise and interferometric phase measurement noise, propagate through different Time-Delay Interferometry channels: the Michelson combination X that is the most sensitive to gravitational waves, then the less-sensitive combinations α, and finally the null channel ζ. We note that the null channel ζ, which is known to be equivalent to any null channel, not only has a reduced sensitivity to the gravitational waves, but also feature a larger degree of cancellation of the test mass acceleration noise relative to the interferometry noise. This severely limits its use in quantifying the low frequency instrumental noise in the Michelson X combination, which is expected to be dominated by acceleration noise. However, we show that one can still use in-flight noise estimations from ζ to put an upper bound on the considered noises entering in the X channel, which allows to distinguish them from a strong stochastic gravitational wave background.

Auteurs principaux: VETRUGNO, Daniele (UNITN); HARTWIG, Olaf (SYRTE, Observatoire de Paris); VITALE, Stefano (UNITN); WEBER, William Joseph (UNITN)

Orateur: MURATORE, Martina (AEI (Potsdam))

Classification de Session: Conference session 2

ID de Contribution: **13** Type: **In person talk**

GPry - Fast Bayesian inference with Gaussian Processes

vendredi 25 novembre 2022 11:00 (15 minutes)

LISA will offer a window into many different, simultaneously observed sources in a long, narrow band signal. Inferring source parameters will - for complex waveforms - require computationally expensive simulations, especially if those waveforms are generated in time domain.
This in turn makes Bayesian inference using such codes extremely expensive: typical sampling algorithms like Markov chain Monte Carlo or nested sampling usually take many tens of thousands of evaluations of the likelihood/posterior distribution. Hence it requires many signal-generations and subsequent comparisons to data. Likelihood-free approaches circumventing this problem have lately gained some attention. However, these come with their own set of challenges such as managing biases and often require methods tailored to the problem at hand. With our Python package "GPry"we introduce a new tool keeping the simplicity and robustness of likelihood-based inference, while drastically reducing the number of samples required for getting an MC sample of the posterior. This approach is based on interpolating the posterior distribution with a suitable Gaussian process and a deterministic, sequential acquisition of likelihood samples inspired by Bayesian optimization. We show the performance of the algorithm on test distributions and how this algorithm could be applied to sources in the LISA band.

Auteur principal: EL GAMMAL, Jonas (University of Stavanger)

Co-auteurs: NARDINI, Germano (University of Stavanger); TORRADO, Jesus; Dr BUSCICCHIO, Riccardo (Universitá di Milano-Bicocca)

Orateur: EL GAMMAL, Jonas (University of Stavanger)

Classification de Session: Conference session 4

ID de Contribution: **14** Type: **Remote talk**

Determining the Individual Masses of Accreting White Dwarf Binaries

jeudi 24 novembre 2022 17:45 (15 minutes)

Accreting binary white dwarf systems are among the sources expected to emanate gravitational waves that will be detectable by LISA. We attempt to ascertain whether the individual masses of such a binary can be determined from LISA's measurements of the frequency and frequency time derivative of gravitational waves emanated by the binary. We present analytic expressions for the gravitational wave frequency and its derivative in terms of the individual masses, which we derive using prior knowledge of mass accreting mechanisms for low-mass helium core white dwarfs. We then perform a Fisher analysis to reveal the accuracy with which we expect to be able to constrain the individual masses given LISA's measurements.

Auteur principal: YI, Sophia (University of Virginia)

Co-auteurs: Prof. YAGI, Kent (University of Virginia); Prof. ARRAS, Phil (University of Virginia); LAU, Shu Yan (University of Virginia)

Orateur: YI, Sophia (University of Virginia)

Classification de Session: Conference session 3

ID de Contribution: **15** Type: **In person talk**

FastEMRIWaveforms: New tools for millihertz gravitational-wave data analysis

vendredi 25 novembre 2022 09:45 (15 minutes)

The observations of gravitational wave signals from extreme-mass-ratio inspirals (EMRIs) have a huge scientific potential for the LISA mission because the system's parameters will be constrained to unprecedented precision. However, high precision comes with new challenges. EMRIs are the only sources that combine the challenges of strong-field complexity with that of long-lived signals. The rapid generation of such signals is hindered by computing the $10^3 - 10^5$ harmonic modes in a fully relativistic waveform. In this talk, I will present the FastEMRIWaveforms (FEW) package, a collection of tools to build and analyze EMRI waveforms. I will discuss the construction of the overall framework; constituent modules; and the general methods used to accelerate EMRI waveforms, such as the exploitation of graphics processing units (GPUs). Finally, I will show that the FEW package enables the generation of fully relativistic waveforms on timescales useful for direct implementation in LISA data analysis algorithms.

Auteurs principaux: SPERI, Lorenzo (Max Planck Institute for Gravitational physics (Albert Einstein Institute, AEI Potsdam)); KATZ, Michael (AEI)

Orateur: SPERI, Lorenzo (Max Planck Institute for Gravitational physics (Albert Einstein Institute, AEI Potsdam))

Classification de Session: Conference session 4

ID de Contribution: **16** Type: **In person talk**

On the edge of quantum black holes

jeudi 24 novembre 2022 17:30 (15 minutes)

Black holes are potential gateways to groundbreaking discoveries. Black hole astrophysics has undergone an observational renaissance in the past 6 years. Notably, the observation of gravitational waves has provided an exciting new window to probe as close as possible to the event horizon of observed binary black hole mergers. In this talk, I will provide an overview of the strong motivations for why quantum black holes may be radically different from their classical counterparts in Einstein's General Relativity. Then I will review the observational searches for quantum black holes, focusing on gravitational wave echoes as smoking guns for quantum horizons (or exotic compact objects), which have led to significant recent excitement and activity. Finally, I will discuss the future observational landscape for unraveling the "Quantum Black Holes"in light of the next generation of gravitational wave detectors such as LISA.

Auteur principal: ABEDI, Jahed (University of Stavanger)

Orateur: ABEDI, Jahed (University of Stavanger)

Classification de Session: Conference session 3

ID de Contribution: **18** Type: **In person talk**

LISA Data Analysis - A Deep Learning Approach

jeudi 24 novembre 2022 15:15 (15 minutes)

With LISA Mission being now in phase B1, its requirements have been consolidated and we are more and more able to tailor the mission, including the methods to scientifically analyse the data during operations.
Also, to fulfil one of LISA's role as an actor in enabling multi-messenger astronomy, we need to analyse the data in a fast and reliable way in order to quickly identify important gravitational wave events and emit low-latency alerts towards all the available observatories.
To obtain a quick and accurate analysis of the LISA data, we opted for an approach based on deep learning techniques. We have developed several deep learning models and trained to detect and characterize LISA-like waveforms.
In this presentation we will show our results concerning tests and benchmarks performed on these models. We will also present our preliminary results on the analysis of the data produce by the LISA/LDC group using these techniques.

Auteur principal: Mlle PISLAN, Florentina-Crenguta (Institute of Space Science, Faculty of Physics)

Co-auteurs: Dr CARAMETE, Ana (Institute of Space Science); Dr CARAMETE, Laurentiu Ioan (Institute of Space Science); M. BASCEANU, Vlad-Andrei (Institute of Space Science, Faculty of Physics)

Orateur: Mlle PISLAN, Florentina-Crenguta (Institute of Space Science, Faculty of Physics)

Classification de Session: Conference session 3

ID de Contribution: **19** Type: **In person talk**

Accelerating parameter estimation of Galactic binaries in the full LISA frequency band using Gaussian Process Regression

mercredi 23 novembre 2022 16:00 (15 minutes)

We present an end-to-end pipeline using Gaussian Process Regression to model the log-likelihood function for parameters of Galactic binaries. It is expected that tens of millions of Galactic binaries will be the dominant sources of observed gravitational waves, emitting quasi monochromatic gravitational waves, which will be constantly measured by LISA. To resolve as many Galactic binaries as possible is a central challenge of the upcoming LISA data set analysis. It is estimated that tens of thousands of these overlapping gravitational wave signals are resolvable, and the rest blurs into a galactic foreground noise. Extracting these tens of thousands of signals using Bayesian approaches is computationally expensive. We developed and tested a novel pipeline using Gaussian Process Regression in order to rapidly compute Bayesian posterior distributions. The Gaussian Process Regression offers a significant speed-up over the full evaluation of the likelihood function, e.g. using Metropolis Hastings methods. Using the pipeline we are able to solve the Lisa Data Challenge (LDC) 1-3 consisting of noisy data as well as further challenges with overlapping signals in the full LISA frequency band as being the focus of LDC 1-4 containing millions of overlapping signals.

Auteur principal: STRUB, Stefan (ETH Zurich)

Co-auteurs: FERRAIOLI, Luigi (ETH Zurich); Dr SCHMELZBACH, Cedric (ETH Zurich); Dr STÄHLER, Simon (ETH Zurich); Prof. GIARDINI, Domenico (ETH Zurich)

Orateur: STRUB, Stefan (ETH Zurich)

Classification de Session: Conference session 1

ID de Contribution: **20** Type: **Remote talk**

Detecting Gravitational Waves from Cosmic Strings with LISA

jeudi 24 novembre 2022 16:30 (15 minutes)

The detection of a stochastic gravitational wave background (SGWB) by LISA is an exciting prospect, especially in the light of the recent NANOGrav results. One of the many possible sources of cosmological SGWB signals which could be detected by LISA is cosmic strings. An important ingredient in the calculation of this contribution is the loop power spectrum which characterizes the emission from a cosmic string loop of a given length as a function of the harmonic (mode). The existing analytic approximations to the computation focus on certain points on the cosmic string loops and are valid for very high modes. Since these loops span a wide range of lengths from zero to a fraction of the horizon size, we require a formalism to compute the power emitted at different ranges of modes and hence bridge the gap between the numerical methods at low modes and the existing analytical methods at very high modes. In my talk, I will explore a new approach to achieve this which accounts for larger regions of the loop that play an important role in emission at lower modes. Our approach, in combination with the numerical approaches can be used to build a complete model of the loop power spectrum. The calculation can be extended to multiple string loops to model the total contribution to the SGWB. Detection of this signal would not only validate the existence of these exotic objects but would also provide an avenue to explore models in superstring theory!

Auteur principal: SURESH, Namitha (Cornell University)

Co-auteur: CHERNOFF, David (Cornell University)

Orateur: SURESH, Namitha (Cornell University)

Classification de Session: Conference session 3

ID de Contribution: **21** Type: **Remote talk**

A neoclassical approach to coherent gravitational-wave search

vendredi 25 novembre 2022 09:00 (30 minutes)

The low instantaneous signal-to-noise ratio for most classes of gravitational-wave source necessitates the use of coherent search, which looks for signals in some length of data through phase comparisons against modeled templates. Such comparisons are statistics of the data, defined as functions on the model space. Coherent statistics suffer from uncontrolled variations over the space, which result from non-local signal correlations as well as the manifestation of detector noise. These variations severely hinder search algorithms when the model space itself has large volume and high complexity, as in the case of certain source classes for the next generation of gravitational-wave detectors.

Traditional approaches in gravitational-wave data analysis address the difficulties of coherent search by defining statistics that are "smoother" in some way; these generally involve either maximizing the original statistic over some degrees of freedom, or annealing it through simple rescaling. In this talk, I advocate for a third alternative - the exponential suppression of variations - and introduce a realization of this strategy for extreme-mass-ratio-inspiral searches.

Auteur principal: CHUA, Alvin (National University of Singapore)

Orateur: CHUA, Alvin (National University of Singapore)

Classification de Session: Conference session 4

ID de Contribution: **22** Type: **In person talk**

Inference for LISA with Normalising flows and data representation through source separation

jeudi 24 novembre 2022 12:00 (30 minutes)

In my talk I am going to concentrate on the models of machine learning which allow us to learn the probability distributions and apply it to the important unsolved problems in the LISA data analysis.
The most common approach to do parameter estimation is through defining the likelihood function and producing posterior samples with some form of sampling technique. The disadvantage of sampling methods is that they are slow. We propose the Bayesian parameter estimation method which is based on Normalising flows – a technique which allows to make an extremely fast mapping from the base sample distribution to the posterior conditioned on the data. This is implemented by learning this mapping in advance on the training dataset and then applying the trained map to the real data. We apply this method to the data from the first LISA Data Challenge (LDC) in order to evaluate how the estimated posteriors agree with the standard approaches. The main purpose of the fast parameter estimation is to use it for the multi-messenger observations and to be able to alert other observatories to perform follow-ups.
Another challenge for the extraction of LISA sources from the data stream will be the presence of the multiple signals simultaneously in the data stream. To solve this problem we propose to use different data representations which project the data on the new basis. One of the methods which allows to do that is called Autoencoders (AE). In the simples case AE can be viewed as a non-linear mapping, which maps the original signal to the lower dimensional representation and then recovers it back to the original number of dimensions. We project the data in such a way that we are sensitive to one or the other type of the signal.
We will finish by discussing how we can combine these approaches in the effort to tackle more realistic LISA data analysis problems.

Auteur principal: KORSAKOVA, Natalia (APC)

Orateur: KORSAKOVA, Natalia (APC)

Classification de Session: Conference session 2

ID de Contribution: **23** Type: **In person talk**

Learning-based models for gravitational wave analysis

jeudi 24 novembre 2022 15:00 (15 minutes)

The LISA space-interferometer will simultaneously acquire gravitational waves emitted from thousands of sources through three time series.
The disentanglement of these signals poses a challenging underdetermined source separation problem.
To isolate signals based on their individual signatures, we introduce a new source separation algorithm based on learning signal representations in a similar fashion to autoencoders.
Our method makes it possible to efficiently extract physically meaningful signals from the entangled data.
This will be illustrated on realistic simulations of the LISA data.

Auteur principal: LEROY, Elie (DRF-IRFU)

Orateur: LEROY, Elie (DRF-IRFU)

Classification de Session: Conference session 3

ID de Contribution: **24** Type: **In person talk**

LISA Data Challenge for the Galaxy

mercredi 23 novembre 2022 15:00 (30 minutes)

The Laser Interferometer Space Antenna will open a window to gravitational waves (GW) between 0.1 mHz and 1 Hz. The instrument will monitor the entire sky and observe a variety of overlapping signals. GWs from the population ultra compact binaries, numbering millions in our Galaxy, are predicted to dominate the milli-Hertz frequency band. Galactic binaries are millions of years from merger, and consequently their signals will simultaneously persist for the duration of the LISA mission. This wealth of sources will contribute to an unresolved foreground which will be the main source of noise between 1-3 milli-Hertz. However, a few tens of thousands are expected to be resolvable. Extracting these overlapping galactic signals is a central challenge in LISA data analysis. I will give a brief introduction to the GBMCMC pipeline applied to the global fit of Galactic white dwarf binaries. Then we'll review the application of GBMCMC to the Radler galaxy, from the LISA Data Challenges, and the production of catalog data. We'll explore the post-analysis and science of the resulting catalog and quantify the efficacy of the pipeline search. And finally, I'll discuss my ongoing work to use machine learning to develop a new method for transforming MCMC samples into catalog data, namely converting an L2 data product to an L3 product for the end user.

Auteur principal: LACKEOS, Kristen (Max Planck Institute for Radio Astronomy)

Co-auteur: Dr LITTENBERG, Tyson (NASA MSFC)

Orateur: LACKEOS, Kristen (Max Planck Institute for Radio Astronomy)

Classification de Session: Conference session 1

ID de Contribution: **25** Type: **In person talk**

Towards a complete L0-to-L2 pipeline –Progress in simulation, processing and analysis (part 2)

jeudi 24 novembre 2022 09:30 (30 minutes)

This is the second part of the talk 'Towards a complete L0-to-L2 pipeline –Progress in simulation, processing and analysis' proposed by J.-B. Bayle.

Auteurs principaux: BAYLE, Jean-Baptiste (University of Glasgow); HARTWIG, Olaf (SYRTE, Observatoire de Paris)

Orateurs: BAYLE, Jean-Baptiste (University of Glasgow); HARTWIG, Olaf (SYRTE, Observatoire de Paris)

Classification de Session: Conference session 2

ID de Contribution: **26** Type: **In person talk**

Massive Black Hole Binary parameter estimation using Masked Autoregressive Flows

jeudi 24 novembre 2022 14:45 (15 minutes)

One of the sources which we expect to be detected by the Laser Interferometer Space Antenna (LISA) are Massive Black Hole Binaries (MBHBs). Detection for these sources should be relatively easy, since their signal to noise ratio (SNR) will be large.

Once a detection has been made, parameter estimation is typically done with Bayesian sampling methods, such as nested sampling or variations of Markov Chain Monte Carlo (MCMC). These can be reliable methods, but are also very slow and computationally expensive —for each of the many thousands of samples one wants to produce, one has to evaluate the likelihood function, which in turn involves making forward simulations.

We are looking at ways to speed up the inference process. Using Machine Learning techniques, one can incur the computational cost in the training process, done beforehand, then very quickly analyze the real data. The way we are doing this is by replacing our desired likelihood function with a Masked Autoregressive Flow (MAF), which bijectively maps it via a neural network with some masked weights to a very simple distribution. We can then sample this base distribution very quickly.

In this talk, I will explain how this method works, how we produced our training dataset of MBHB data to be as close as possible to the first LISA Data Challenge (LDC), and show some preliminary results.

Auteur principal: MARTIN VILCHEZ, Ivan (Institute of Space Science (ICE, CSIC and IEEC))

Co-auteur: Dr F SOPUERTA, Carlos (ICE, CSIC and IEEC)

Orateur: MARTIN VILCHEZ, Ivan (Institute of Space Science (ICE, CSIC and IEEC))

Classification de Session: Conference session 3

ID de Contribution: **27** Type: **In person talk**

Extracting gravitational-wave backgrounds in noise of unknown spectral shape

jeudi 24 novembre 2022 11:00 (30 minutes)

Measuring stochastic gravitational-wave backgrounds (SGWBs), particularly primordial ones, is one of LISA's most hoped-for outcomes. However, this task is difficult with a single flying detector because it requires an accurate characterisation of the instrumental noise. Assuming that its shape is known or highly constrained is a dangerous bet. In order to make any discovery possible, it is necessary to have a robust criterion for distinguishing gravitational-wave signals and instrumental stochastic processes. We address this problem by presenting a flexible approach based on two ingredients: a matrix formulation of both SGWB and noise transfer functions and a generic B-splines model of the interferometers'noise spectra. We show that the detection of power-law SGWBs is possible within this framework, with a threshold corresponding to scale-independent energy densities of about 2×10^{-13}.

Auteur principal: BAGHI, Quentin (CEA Saclay)

Co-auteurs: BAYLE, Jean-Baptiste (University of Glasgow); BESANCON, Marc (CEA-Saclay/DSM/Irfu/SPP); Dr KARNESIS, Nikolaos (AUTh)

Orateur: BAGHI, Quentin (CEA Saclay)

Classification de Session: Conference session 2

ID de Contribution: **28** Type: **In person talk**

Importance nested sampling with nessai for gravitational-wave inference

jeudi 24 novembre 2022 14:30 (15 minutes)

Nested sampling is a crucial tool for gravitational-wave data analysis. However, it is often computationally expensive, especially for high-dimensional and complex parameter spaces. This poses a challenge for applications to LISA data analysis. It has been shown that *nessai*, a nested sampling algorithm that incorporates normalising flows, can accelerate gravitational-wave inference four-fold compared to *dynesty* whilst producing statistically identical results.

In this talk, we present an improved version of *nessai* which addresses the main computational bottlenecks. To achieve this, we draw on previous work and modify the core nested sampling algorithm to incorporate importance weights. We demonstrate that these modifications eliminate the aforementioned bottlenecks and that the new algorithm is an order of magnitude faster than *dynesty* when applied to gravitational-wave inference.

Auteur principal: WILLIAMS, Michael (University of Glasgow)

Co-auteurs: MESSENGER, Chris (University of Glasgow); Dr VEITCH, John (University of Glasgow)

Orateur: WILLIAMS, Michael (University of Glasgow)

Classification de Session: Conference session 3

ID de Contribution: **29** Type: **In person talk**

Love and EMRIs in SPA

vendredi 25 novembre 2022 10:15 (15 minutes)

The capture of stellar-mass compact objects by a supermassive black hole is one of the most exciting sources detectable by future space-borne interferometers like LISA. The parameters of these extreme-mass-ratio inspirals (EMRIs) binaries are expected to be inferred with excellent accuracy, allowing for unprecedented tests on the nature of their components. Measuring the tidal Love number of the central object, which encoded its response to tidal deformabilites, could distinguish black holes from exotic compact objects. Unlike black holes, a horizonless compact object might have a tiny but not vanishing tidal deformability due to quantum-gravity corrections at the horizon scale.

In this talk, I will present the results of a Fisher-matrix error analysis of the tidal Love number of the supermassive black hole in an EMRI binary for circular, equatorial orbits. In the extreme-mass ratio limit, the tidal deformability of the central object enters at leading order in the mass-ratio expansion of the gravitational wave phase. We used kludge waveforms at adiabatic order, including the effects of the tidal deformability of the supermassive body and the spin of the smaller companion. Using the Stationary Phase Approximation (SPA), we also developed a new method to compute Fisher matrices in the extreme-mass ratio limit in a fast and accurate way.

Our analysis shows that the error on the tidal Love number for a supermassive black hole with reduced spin $a = 0.9 (a = 0.99)$ is $\sim 10^{-2} (10^{-3})$. These bounds are roughly 5 to 6 orders of magnitude more stringent than current ones on neutron stars. Thus, an EMRI detection by LISA could potentially probe putative quantum corrections down to the Fermi or even Planck scale.

Auteur principal: PIOVANO, Gabriel Andres (University College Dublin)

Co-auteurs: Prof. MASELLI, Andrea (Gran Sasso Science Institute (GSSI)); Prof. PANI, Paolo (Sapienza, University of Rome)

Orateur: PIOVANO, Gabriel Andres (University College Dublin)

Classification de Session: Conference session 4

ID de Contribution: **30** Type: **In person talk**

Investigation of Tidal Disruption Events through gravitational waves

mercredi 23 novembre 2022 17:00 (15 minutes)

Stars tidally disrupted (TDEs, Rees 1988) by massive black holes (BHs) represent an unprecedented powerful tool to unveil the presence of otherwise quiescent compact objects in the cores of galaxies. More recently, the scientific community has become aware also of the potential of these events as gravitational wave (GW) sources (Kobayashi et al. 2004, Stone et al. 2013, Toscani et al. 2019, 2020, 2022, Pfister et al. 2022). In particular, they generate a monochromatic burst during the disruption of the star, with typical frequencies from milli-Hertz to deci-Hertz, where LISA and future deci-Hertz observatories will work. With the detection of this burst, together with the electromagnetic counterpart produced along the circularisation of the debris, we will obtain more precise information about the dynamical properties of the BH-star system and also more accurate estimates of the BH mass, which can help us in the identification of BHs in the intermediate-mass range regime.
In this talk, I will illustrate the main features of the gravitational signal produced by TDEs and we will investigate the effects of gravitational lensing on these systems.

Auteur principal: TOSCANI, martina (L2I Toulouse, CNRS/IN2P3, UT3)

Orateur: TOSCANI, martina (L2I Toulouse, CNRS/IN2P3, UT3)

Classification de Session: Conference session 1

ID de Contribution: **31** Type: **Non spécifié**

Bayesian inference methods in cosmology with LISA standard sirens

jeudi 24 novembre 2022 16:45 (15 minutes)

One of the main scientific objectives of LISA is to probe the expansion rate of the Universe. In this talk, we examine the problem of measuring cosmological parameters through gravitational wave observations using LISA standard sirens. We discuss a Bayesian framework to do cosmological parameter inference with LISA dark and bright sirens, presenting forecasts based on simulated catalogs of extreme mass-ratio inspirals and massive black hole binaries having an observable electromagnetic counterpart.

Auteur principal: Dr LAGHI, Danny (CNES, L2I Toulouse, CNRS/IN2P3, UT3)

Orateur: Dr LAGHI, Danny (CNES, L2I Toulouse, CNRS/IN2P3, UT3)

Classification de Session: Conference session 3

ID de Contribution: **32** Type: **Remote talk**

Modified Gravity Forecasting with Large Scale Structure in the LISA era, including a Machine Learning analysis

jeudi 24 novembre 2022 17:00 (15 minutes)

In the present work we explore how modified gravity theories affect the propagation of gravitational waves produced by the merger of binary massive black holes (MBH) and also by a stochastic background. For this purpose we developed a mock of catalogs that are expected to be observed in the operating frequency band of the Laser Interferometer Space Antenna (LISA). For this proposal we develop both a Bayesian and Machine Learning analysis, the latter in order to obtain information independent of the physical model. In light of LISA's forecasts we will present preliminary results on the main parameters that deviate from general relativity, however, we can announce that LISA will provide a unique way to test, with good accuracy, the nature of gravity up to very large cosmic distances.

Auteur principal: BONILLA RIVERA, Alexander (UFJF)

Orateur: BONILLA RIVERA, Alexander (UFJF)

Classification de Session: Conference session 3

ID de Contribution: **33** Type: **In person talk**

The impact data gaps have on parameter estimation

jeudi 24 novembre 2022 10:15 (15 minutes)

For the LISA instrument, data gaps are entirely unavoidable. We will expect to have scheduled data gaps due to antennae repointing or enforced data gaps to mask out instrumental artefacts. It is absolutely essential that the probabilistic models used to describe the data must be consistent with the data generating process itself. By including gaps in the data stream, the resultant noise process can no longer be treated as a stationary process, and thus the usual likelihood used throughout GW astronomy will be violated. In this talk, we will argue that familiar statistical quantities (SNR, Fisher matrix, likelihood etc.) must be generalised to account for such non-stationary features. We will show, using a toy model for illustrative purposes, the detrimental effect mis-modelling the masked noise as a stationary process has on parameter estimation. If time permits, we will conclude by demonstrating our formalism on MBHs in the presence of data gaps.

Auteur principal: BURKE, Ollie (L2I Toulouse, CNRS/IN2P3, UT3)

Orateur: BURKE, Ollie (L2I Toulouse, CNRS/IN2P3, UT3)

Classification de Session: Conference session 2

ID de Contribution: **34** Type: **In person talk**

Searching for primordial features with LISA

jeudi 24 novembre 2022 16:15 (15 minutes)

Observational constraints and prospects for detection of features, i.e. physically motivated oscillations in the primordial power spectrum, have so far concentrated on the CMB and Large Scale Structure surveys. Probing these features could, for instance, establish the existence of heavy particles beyond the reach of terrestrial experiments, and even test the inflationary paradigm or point to alternatives to it.
In this talk, I will discuss the ongoing effort to assess the detection prospects of such features with LISA.

Auteur principal: FUMAGALLI, Jacopo (IAP)

Orateur: FUMAGALLI, Jacopo (IAP)

Classification de Session: Conference session 3

ID de Contribution: **35** Type: **In person talk**

Introduction to machine learning

lundi 21 novembre 2022 11:00 (1h 30m)

Orateur: CAILLOU, Sylvain (L2I Toulouse, CNRS/IN2P3, UT3)

Classification de Session: Introductory lectures

ID de Contribution: **36** Type: **In person talk**

Introduction to LISA data analysis

lundi 21 novembre 2022 09:00 (1h 30m)

Orateur: LE JEUNE, Maude (APC)

Classification de Session: Introductory lectures

ID de Contribution: **37** Type: **In person talk**

GW Detection with Traditional vs Machine Learning Techniques - Part 1 (theory)

lundi 21 novembre 2022 14:00 (1h 30m)

Orateur: BAYLEY, Joseph (Univ. of Glasgow)

Classification de Session: Training session 1

ID de Contribution: **38** Type: **Remote talk**

GPU Techniques to Accelerate GW Waveforms and Data Analysis Computations - Part 1 (theory)

lundi 21 novembre 2022 16:00 (1h 30m)

Orateur: KATZ, Michael (AEI)

Classification de Session: Training session 1

ID de Contribution: **39** Type: **In person talk**

GW Detection with Traditional vs Machine Learning Techniques - Part 2 (tutorial)

mardi 22 novembre 2022 09:00 (1h 30m)

Orateurs: BAYELY, Joseph (Univ. of Glasgow); WILLIAMS, Michael (University of Glasgow)

Classification de Session: Training session 2

ID de Contribution: **40** Type: **In person talk**

GW Detection with Traditional vs Machine Learning Techniques - Part 2 (tutorial)

mardi 22 novembre 2022 11:00 (1h 30m)

Orateurs: BAYELY, Joseph (Univ. of Glasgow); WILLIAMS, Michael (University of Glasgow)

Classification de Session: Training session 2

ID de Contribution: **41** Type: **In person talk**

GPU Techniques to Accelerate GW Waveforms and Data Analysis Computations - Part 2 (tutorial)

mardi 22 novembre 2022 09:00 (1h 30m)

Orateurs: SPERI, Lorenzo (Max Planck Institute for Gravitational physics (Albert Einstein Institute, AEI Potsdam)); KATZ, Michael (AEI)

Classification de Session: Training session 2

ID de Contribution: **42** Type: **In person talk**

GPU Techniques to Accelerate GW Waveforms and Data Analysis Computations - Part 2 (tutorial)

mardi 22 novembre 2022 11:00 (1h 30m)

Orateurs: SPERI, Lorenzo (Max Planck Institute for Gravitational physics (Albert Einstein Institute, AEI Potsdam)); KATZ, Michael (AEI)

Classification de Session: Training session 2

ID de Contribution: **43** Type: **Non spécifié**

GW Parameter Estimation with Bayesian Machine Learning - Part 1 (theory)

mardi 22 novembre 2022 14:00 (1h 30m)

Orateur: GREEN, Stephen (Albert Einstein Institute Potsdam)

Classification de Session: Training session 3

ID de Contribution: **44** Type: **In person talk**

Gaussian Process Regression - Part 1 (theory)

mardi 22 novembre 2022 16:00 (1h 30m)

Orateur: BABAK, Stanislav (APC)

Classification de Session: Training session 3

ID de Contribution: **45** Type: **Non spécifié**

GW Parameter Estimation with Bayesian Machine Learning - Part 2 (tutorial)

mercredi 23 novembre 2022 09:00 (1h 30m)

Orateurs: KORSAKOVA, Natalia (APC); GREEN, Stephen (Albert Einstein Institute Potsdam)

Classification de Session: Training session 4

ID de Contribution: **46** Type: **Non spécifié**

GW Parameter Estimation with Bayesian Machine Learning - Part 2 (tutorial)

mercredi 23 novembre 2022 11:00 (1h 30m)

Orateurs: KORSAKOVA, Natalia (APC); GREEN, Stephen (Albert Einstein Institute Potsdam)

Classification de Session: Training session 4

ID de Contribution: **47** Type: **Non spécifié**

Gaussian Process Regression - Part 2 (tutorial)

mercredi 23 novembre 2022 09:00 (1h 30m)

Orateur: BABAK, Stanislav (APC)

Classification de Session: Training session 4

ID de Contribution: **48** Type: **Non spécifié**

Gaussian Process Regression - Part 2 (tutorial)

mercredi 23 novembre 2022 11:00 (1h 30m)

Orateur: BABAK, Stanislav (APC)

Classification de Session: Training session 4

ID de Contribution: **49** Type: **In person talk**

LISA status and data processing organisation

mercredi 23 novembre 2022 14:00 (30 minutes)

Orateur: PETITEAU, Antoine (CEA/IRFU/DPhP)

Classification de Session: Conference session 1

ID de Contribution: **50** Type: **In person talk**

LISA data analysis: status and challenges

jeudi 24 novembre 2022 11:30 (30 minutes)

Orateur: BABAK, Stanislav (APC)

Classification de Session: Conference session 2

ID de Contribution: **51** Type: **In person talk**

Infrastructure for Lisa Data Analysis

vendredi 25 novembre 2022 11:15 (30 minutes)

Orateurs: TRAN, Antoine (CNES); NGUYEN, Hong-Nga; MATTHIEU, Marseille (CNES)

Classification de Session: Conference session 4

ID de Contribution: **52** Type: **In person talk**

MCMC parameter estimation methods for LISA massive black holes

jeudi 24 novembre 2022 14:00 (30 minutes)

Orateur: MARSAT, Sylvain (L2I Toulouse, CNRS/IN2P3, UT3)

Classification de Session: Conference session 3

ID de Contribution: **53** Type: **Non spécifié**

Final remarks

vendredi 25 novembre 2022 11:45 (30 minutes)

Classification de Session: Conference session 4