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

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The upcoming ESA mission LISA (Laser Interferometer Space Antenna), scheduled for launch in 2037, will usher in a transformative era in astrophysics by detecting gravitational waves from space. Unlike traditional observatories limited to the electromagnetic spectrum, LISA will directly probe the fabric of space-time, revealing a new and complex landscape of astrophysical signals from galactic binaries, massive black hole mergers, and extreme mass ratio inspirals (EMRIs). However, 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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