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Reconstructing gravitational wave polarizations with bivariate signal processing and deep generative models

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This work addresses the inverse problem of the reconstruction of the impinging gravitational-wave (GW) polarizations $(h_+, h_\times)$ from the interferometric detector measurements. It is specifically focused on situations where the polarization pattern is non-stationary and evolves over the duration of the signal. For instance, this is the case for GW signals from compact binaries coalescence (CBC) subject to precession of their orbital plane; precession may be due to misaligned component spins. The GWTC-3 catalog (LIGO Scientific Collaboration et al., 2023) includes several such binaries like GW200129_065458.

Two new approaches are proposed that improve upon the methods available in the literature such as BayesWave (Cornish and Littenberg, 2015). BayesWave defines the GW signal model as a combination of wavelets with independent or constant elliptical polarization. It is therefore unable to capture both polarizations correctly or accurately.

1. The first approach builds on a previous work (Cano, 2022), that is based on the geometrical parametrization of the polarization content through Stokes parameters (Flamant, 2018). The regularization of the inversion is performed using a term to penalize the misalignment between reconstructed and predefined target Stokes parameters. This earlier work is restricted to constant Stokes parameters and suffers for the same limitations as BayesWave. The new approach enforces a variable but smooth evolution of the signal Stokes parameters in the reconstructed polarizations (Pilavci et al., 2024).
2. The second approach is based on the plug-and-play (PnP) method (Hurault, 2023) that exploits a deep generative model. PnP methods constitute the current state-of-the-art in image processing and consist in learning a prior from image examples. We apply this technique here on spectrograms of GW simulated signals.

The two proposed approaches are complementary. They resort to different levels of priors for the regularization. These priors are exploited in different ways in practice. The first approach is rather model-agnostic and encodes desirable characteristics of GW signals such as regularity or smoothness of the polarization evolution. In contrast, the second approach ensures that reconstructed GWs belong to the true GW spectrogram distribution learnt from the numerical model.

References

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