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Emulating gravitational wave spectra from sound waves during the cosmological FOPT

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We present DeepSSM, an open-source code powered by neural networks (NNs) to emulate gravitational wave (GW) spectra produced by sound waves during cosmological first-order phase transitions in the radiation-dominated era. The training data is obtained from an enhanced version of the Sound Shell Model (SSM), which accounts for the effects of cosmic expansion and yields more accurate spectra in the infrared regime. The emulator enables instantaneous predictions of GW spectra given the phase transition parameters, while achieving agreement with the enhanced SSM model within 10% accuracy in the worst case scenarios. The emulator is highly computationally efficient and fully differentiable, making it particularly suitable for direct Bayesian inference on phase transition parameters without relying on empirical templates, such as broken power-law models. We demonstrate this capability by successfully reconstructing phase transition parameters and their degeneracies from mock LISA observations using a Hamiltonian Monte Carlo sampler.

Primary author(s) : Prof. TIAN, Chi; Dr WANG, Xiao; Prof. BALÁZS, Csaba

Presenter(s) : Prof. TIAN, Chi

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