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Deducing Neutron Star Equation of State From X-ray Telescope Spectra with Machine Learning

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Neutron stars provide a unique laboratory for studying matter at extreme pressures and densities. While there is no direct way to explore their interior structure, X-rays emitted from these stars can indirectly provide clues to the equation of state (EOS) of the nuclear matter within through the inference the star's mass and radius. However, inference of EOS directly from a star's X-ray spectra is extremely challenging from systematic uncertainties in observation. The current state of the art is to use simulation-based likelihoods in a piece-wise method, which first infer the star's mass and radius to reduce the dimensionality of the problem, but likely sacrifice some information, and from those quantities infer the EOS. We demonstrate a series of enhancements to the state of the art, in terms of realistic uncertainty quantification and improved regression of physical properties with machine learning. We also demonstrate the first inference of the EOS directly from the high-dimensional spectra of observed stars, avoiding the intermediate mass-radius step. Our network is conditioned on the sources of uncertainty of each star, allowing for natural and complete propagation of uncertainties to the EOS.

Primary authors: GHOSH, Aishik (University of California Irvine (US)); STEINER, Andrew (UTK/ORNL); Mr KAVITKAR, Atharva; WHITESON, Daniel (University of California Irvine (US)); FARRELL, Delaney; WEBER, Fridolin (University of California at San Diego, La Jolla, California, USA); Dr OTT, Jordan (University of California, Irvine); Dr LINDBLOM, Lee (University of California, San Diego); Dr BALDI, Pierre (University of California, Irvine)

Presenter: FARRELL, Delaney