Deducing Neutron Star Equation Of State From Telescope Spectra With Machine-Learning-Derived Likelihoods

The interiors of neutron stars reach densities and temperatures beyond the limits of terrestrial experiments, providing vital laboratories for probing nuclear and particle physics. While the star's interior is not directly observable, its pressure and density determine the star's macroscopic structure which, in turn, affects the spectra observed in telescopes. The relationship between the observations and the internal state is complex and partially intractable, presenting difficulties for inference. Previous work has focused on the regression from stellar spectra of parameters describing the internal state. In this study, we demonstrate a calculation of the full likelihood of the internal state parameters given observations, accomplished by replacing intractable elements with machine learning models trained on samples of simulated stars. Our machine-learning-derived likelihood allows us to perform {\it maximum a posteriori} estimation of the parameters of interest, as well as full scans. We demonstrate the technique by inferring stellar mass and radius from an individual stellar spectrum, as well as equation of state parameters from a set of spectra. Our results are more precise than pure regression models, reducing the width of the parameter residuals by 12% in the most realistic scenario. This research is in print with the Journal of Cosmology and Astroparticle Physics (JCAP).

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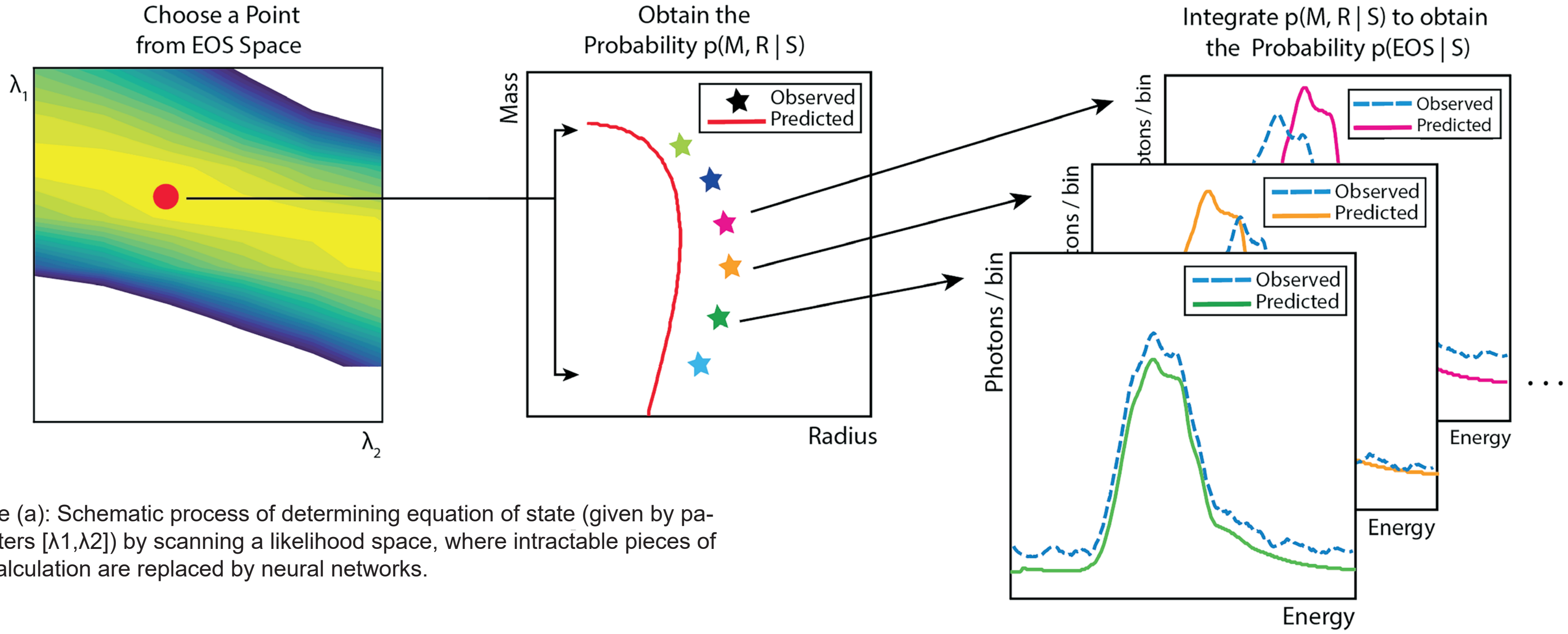

Figure (a): Schematic process of determining equation of state (given by parameters [λ1,λ2]) by scanning a likelihood space, where intractable pieces of the calculation are replaced by neural networks.

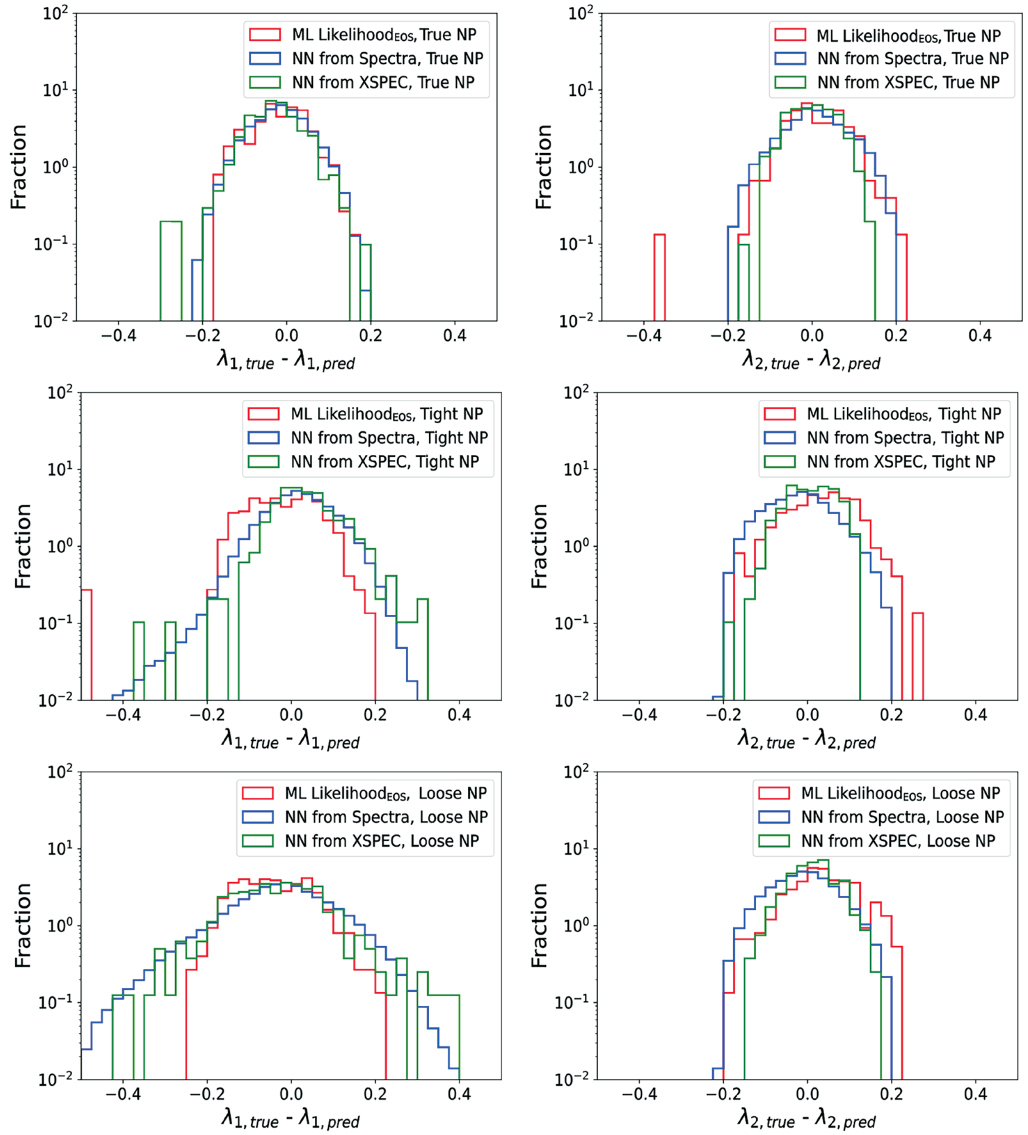

Figure (b): Residual plots for EOS parameters λ1 and λ2, where the likelihood method, ML Likelihood, is compared to previous best methods using machine learning. Results are shown for three different uncertainty bands:

- Top row: additional parameters are known exactly, "true"
- Middle row: uncertainty of additional parameters is small, "tight"
- Bottom row: uncertainty of additional parameters is large, "loose"