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Investigating Δ-Resonances in Neutron Stars: Insights from Nuclear and Astrophysical Observations

This work conducts a thorough Bayesian analysis of neutron star matter, incorporating (Δ)-resonances alongside hyperons and nucleons within a density-dependent relativistic hadron (DDRH) model. By leveraging constraints from nuclear saturation properties, chiral effective field theory (χEFT), NICER radius measurements, and tidal deformability data from GW170817, we systematically examine the role of (Δ)-resonances in shaping the equation of state (EoS) and neutron star observables. Our findings indicate that while (Δ)-baryons soften the EoS at lower densities, they ensure sufficient stiffness at higher densities to sustain neutron stars with masses up to $(2M_{\odot})$. This provides a natural resolution to neutron star radius constraints and aligns well with the observed low-mass compact object in HESS J1731-347 while remaining consistent with GW170817 tidal deformability limits. Furthermore, we find that (Δ)-resonances preferentially populate the outer core of neutron stars, potentially influencing neutron star merger dynamics. Their presence could also play a significant role in neutron star cooling through the direct Urca process. Additionally, we explore quasi-normal (f)-mode oscillations within a fully relativistic framework, uncovering strong correlations between the (f)-mode frequency, neutron star compactness, and tidal deformability. By incorporating (Δ)-resonances and adhering to astrophysical constraints, we determine $(f_{1.4} = 1.97^{+0.17}_{-0.22})$ KHz and a damping time of $(\tau_{f_{1.4}} = 0.19^{+0.05}_{-0.03})$ s at the (1σ) confidence level.

Author: THAPA, Vivek Baruah (Bhawanipur Anchalik College, Assam, India)

Co-authors: Prof. BOMBACI, Ignazio (INFN, Sezione di Pisa, Largo B. Pontecorvo 3, I-56127 Pisa, Italy); Dr SINHA, Monika (Indian Institute of Technology Jodhpur, Rajasthan, India); Dr PARMAR, Vishal (INFN, Sezione di Pisa, Largo B. Pontecorvo 3, I-56127 Pisa, Italy)

Presenter: THAPA, Vivek Baruah (Bhawanipur Anchalik College, Assam, India)

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