

Understanding low X-ray polarization of HMXB pulsars through atmospheric temperature inversion and vacuum birefringence

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Recent Imaging X-ray Polarimetry Explorer (IXPE) observations of neutron stars in high mass X-ray binaries (HMXBs) report polarization degrees (PDs) significantly lower than the 60-80% values predicted by theoretical models. Additionally, more luminous sources tend to exhibit a comparatively higher PD than less luminous sources, suggesting that polarization properties are affected by the neutron stars' atmosphere profile. In this work, we investigate the effect of neutron stars' atmospheric structure on the propagation of radiation to explain these trends. Using magnetized radiative transfer calculations that include vacuum resonance and mode mixing, we construct a grid of atmospheric models with inverse temperature profiles and varying properties of the transition layer. Although the calculations cannot uniquely characterize the atmospheric structure, we find that the distinct PD classes occupy different regions of the parameter space. Specifically, stronger temperature inversion produces higher PD for X-mode dominated spectrum, whereas O-mode dominant spectrum shows a non-monotonic trend, with PD initially increasing and subsequently decreasing with temperature inversion. We then apply our models to IXPE observed HMXBs to constrain the allowed parameter space describing the temperature profile and transition layer. Our results suggest that variations in atmospheric structures incorporating vacuum resonance induced mode mixing could explain the diversity in observed PDs of HMXBs.