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Probing magnetic fields and accretion physics through pulsed emission in accreting X-ray pulsars

We analyze all NuSTAR observations of the accreting X-ray pulsar 4U 1538−52 to investigate the energy-dependent pulse profiles and the phase-dependent spectral variability of its fundamental cyclotron resonant scattering feature (CRSF). Fourier decomposition of energy-resolved pulse profiles reveals a broad bump in the pulsed fraction spectrum (PFS) near the CRSF energy, contrasting with the dip-like features observed in other systems (Ferrigno et al. 2023). Phase-resolved spectroscopy shows that the CRSF depth varies strongly with spin phase, becoming deeper during low-flux intervals and shallower at pulse maximum. We interpret the PFS morphology across different sources as the result of the interplay between spin-dependent flux variations and phase-dependent CRSF behavior. These findings establish the PFS as a sensitive, model-independent diagnostic for CRSF detection and characterization, providing new constraints on the magnetic field structure and accretion geometry of X-ray pulsars. To interpret the observations, we perform physical modeling of the pulsed X-ray emission from a neutron star, favoring a geometry with high inclination, large magnetic obliquity, and a ~15° asymmetry between magnetic poles. This configuration naturally reproduces the observed pulse profiles and PFS features, offering a framework linking CRSF behavior, system geometry, magnetic topology, and potential jet activity. Given the possible existence of jets in strongly magnetized HMXBs (van den Eijnden et al. 2021), detailed knowledge of magnetic field configurations through model-independent methods such as the PFS and pulse profile modeling is essential to understand jet-launching mechanisms in these systems.

Affiliation

INAF - IASF Pa

E-mail

dimitrios.maniadakis@inaf.it

Author: Mr MANIADAKIS, Dimitrios Konstantinos (Istituto Nazionale di Astrofisica (INAF))

Presenter: Mr MANIADAKIS, Dimitrios Konstantinos (Istituto Nazionale di Astrofisica (INAF))

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