



Contribution ID: 328

Type: **Talk in a parallel session**

First Detection of Soft-Lag in GRS 1915+105 at HFQPO during Soft State: A Multi-Mission Approach

Monday, 8 July 2024 17:35 (10 minutes)

The Galactic X-ray black hole candidate GRS 1915+105 exhibits high-frequency quasi-periodic oscillations (HFQPOs) at ~ 67 Hz only during the radio-quiet ‘softer’ variability classes. We have studied the long-term X-ray variability from 1996 to 2017 using observations from RXTE, AstroSat, NuSTAR and NICER. AstroSat observations reveal the first detection of a soft-lag for higher energy photons (6–25 keV) relative to soft photons (3–6 keV), associated with the ~ 67 Hz HFQPO, in the range from 0.40 to 1.68 milliseconds. We find a consistent lag-energy correlation, where the soft-lag increases with energy, peaking at ~ 18 keV across all variability classes (δ , ω , κ , and γ). An extensive study of the γ variability class reveals an evolution of HFQPOs from ~ 69 Hz to 66 Hz and then up to 71 Hz. We observed a transition from hard to soft lag using the RXTE and AstroSat observations. Broadband spectral analysis indicates a higher bolometric flux with a lower electron temperature (kTe) of the corona during observations without HFQPO. We confirmed from the NICER/NuSTAR observations that the observed soft-lag could be due to the presence of a reflection mechanism in accretion dynamics.

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Session Classification: A NICER view of extreme gravity from the International Space Station

Track Classification: Compact Objects and Stellar Evolution (CO): A NICER View of Extreme Gravity from the International Space Station