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Spectral and Timing Properties of the Galactic X-Ray Transient Swift J1658.2–4242 Using *Astrosat* Observations

V. Jithesh[1], Bari Maqbool[1], Ranjeev Misra[1], Athul. R. T[2], Gitika Mall[3], and Marykutty James[4]
[1] Inter-University Centre for Astronomy and Astrophysics (IUCAA), Post Bag No. 4, Ganeshkhind, Pune 411007, India; vjithesh@iucaa.in
[2] Department of Physics, Cochin University of Science & Technology, Kochi 682022, India
[3] Department of Physics, Banaras Hindu University, Varanasi-221005, India
[4] Department of Physics, St. Thomas College, Ranni, Pathanamthitta 689673, Kerala, India
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Abstract

We present the X-ray timing and spectral analysis of the new Galactic X-ray transient Swift J1658.2–4242 observed with the Large Area X-ray Proportional Counter and Soft X-ray Telescope instruments on board *Astrosat*. We detect prominent C-type quasi-periodic oscillations (QPOs) of frequencies varying from ∼1.5 to ∼6.6 Hz along with distinct second harmonics and subharmonics. The QPO detected at ∼1.56 Hz drifts to a higher centroid frequency of ∼1.74 in the course of the observation, while the QPO detected at ∼6.6 Hz disappeared during hard flarings. The fractional rms at the QPO and the subharmonic frequencies increases with photon energy, while at the second harmonic frequencies the rms seems to be constant. In addition, we have observed soft time lag at QPO and subharmonic frequencies up to a timescale of ∼35 ms; however, at the second harmonic frequencies there is weak/zero time lag. We attempt spectral modeling of the broadband data in the 0.7–25 keV band using the doubly absorbed disk plus thermal Comptonization model. Based on the spectral and timing properties, we identified the source to be in the hard-intermediate state of black hole X-ray binaries. To quantitatively fit the energy- and frequency-dependent fractional rms and time lag, we use a single-zone fluctuation propagation model and discuss our results in the context of that model.

Unified Astronomy Thesaurus concepts: Stellar accretion disks (1579); Black hole physics (159); X-ray transient sources (1852); X-ray sources (1822); X-ray binary stars (1811); Accretion (14)

1. Introduction

Black hole transients (BHTs) spend most of their lives in quiescence and are primarily discovered when they enter into outbursts characterized by abrupt changes in their X-ray luminosity by several orders of magnitudes. During typical outbursts, BHTs undergo a transition from the low hard state (LHS) to the high soft state (HSS) through short-lived hard and soft intermediate states (HIMS, SIMS), then again back to the LHS via the intermediate states (Remillard & McClintock 2006; Belloni 2010; Belloni et al. 2011). In the LHS, the source is characterized by a hard spectrum with high (∼30%) fractional rms variability (Belloni 2005) and sometimes show low-frequency quasi-periodic oscillations (LFQPOs) in the power density spectrum (PDS). A soft thermal component modeled with multicolor disk blackbody component dominates in the HSS, while the fractional rms reduces down to a few percent and PDS shows weak power-law noise.

The intermediate states identified in the black hole systems are rather complex and the observed behaviors are difficult to interpret. In these states, the energy spectrum contains both disk and power-law components, while the PDS mainly contains LFQPOs with a centroid frequency ranging from a few mHz to ∼30 Hz. LFQPOs are identified in several sources and they are classified into types A, B, and C (Remillard et al. 2002; Casella et al. 2005). Type-C QPOs are mainly identified in the HIMS, while type A and B QPOs are detected in the SIMS (Wijnands et al. 1999; Casella et al. 2005; Motta et al. 2011). Although the origin of the LFQPOs is still under debate, several models have been proposed to explain the origin and evolution of LFQPOs in X-ray binaries. The proposed models are generally based on the two different mechanisms: instabilities (e.g., Tagger & Pellat 1999; Titarchuk & Osherovich 1999; Titarchuk & Fiorito 2004; Cabanac et al. 2010) and geometrical effects (Stella & Vietri 1998; Stella et al. 1999; Ingram et al. 2009; Ingram & Done 2011). LFQPOs are widely detected in BHTs and their detailed studies provide essential information regarding the accretion flow around the black hole and geometry of the system. In addition, it is important to examine the energy-dependent properties of quasi-periodic oscillations (QPOs) such as fractional rms and time lag, which also provide the link between the spectral and timing variability properties of BHTs.

Swift J1658.2–4242 is a new Galactic X-ray transient source discovered by the Burst Alert Telescope instrument on board *Swift* on 2018 February 16 (Barthelmy et al. 2018). The Imager on Board the *INTErnational Gamma-Ray Astrophysics Laboratory (INTEGRAL)* Satellite/ISGRI instruments on board *INTEGRAL* detected the source to be in the hard state during their observations of the Galactic center field performed from 2018 February 13 to 16 (Grebenev et al. 2018). The reported position of the source from the *Swift* X-Ray Telescope observation is R.A. = 16:58:12.58, decl. = −42:41:55.7 (equinox J2000.0) with an uncertainty of ∼4″ (D'Avanzo et al. 2018). Radio observation with the Australia Telescope Compact Array (ATCA) identified a radio source at a position consistent with the *Swift* XRT position, and the radio emission was consistent with a flat radio spectrum from a compact jet implying that the source is a black hole X-ray binary (BHXRB) at a distance >3 kpc (Russell et al. 2018). In the positional uncertainty of *ATCA*, an optical source has been observed in the archival imaging observation and the optical spectroscopy observation with SOAR telescope suggest this source is a normal, mid to late-type K star with no signatures of accretion (Bahramian et al. 2018). The *Swift* XRT observation taken with Window Time (WT) mode reports the presence of a peak at