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A stochastic propagation model to the energy dependent rapid temporal behaviour of Cygnus X-1 as observed by *AstroSat* in the hard state

Bari Maqbool,[1★] Sneha Prakash Mudambi,[2★] R. Misra,[1★] J. S. Yadav,[3] S. B. Gudennavar,[2] S. G. Bubbly,[2] A. Rao,[4] S. Jogadand,[5] M. K. Patil,[5] S. Bhattacharyya[3] and K. P. Singh[6]

[1]*Inter-University Centre for Astronomy and Astrophysics, Ganeshkind, Pune 411007, India*
[2]*Department of Physics and Electronics, CHRIST (Deemed to be University), Hosur Road, Bengaluru 560029, India*
[3]*Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400005, India*
[4]*Department of Physics and Astronomy, Faculty of Physical Sciences and Engineering, University of Southampton, Southampton SO17 1BJ, UK*
[5]*Swami Ramanand Teerth Marathwada University, Nanded 431 606, India*
[6]*Indian Institute of Science Education and Research Mohali, Knowledge City, Sector 81, SAS Nagar, Manauli 140306, India*

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ABSTRACT

We report the results from analysis of six observations of Cygnus X-1 by Large Area X-ray Proportional Counter (LAXPC) and Soft X-ray Telescope (SXT) onboard *AstroSat*, when the source was in the hard spectral state as revealed by the broad-band spectra. The spectra obtained from all the observations can be described by a single-temperature Comptonizing region with disc and reflection components. The event mode data from LAXPC provides unprecedented energy dependent fractional root mean square (rms) and time-lag at different frequencies which we fit with empirical functions. We invoke a fluctuation propagation model for a simple geometry of a truncated disc with a hot inner region. Unlike other propagation models, the hard X-ray emission (>4 keV) is assumed to be from the hot inner disc by a single-temperature thermal Comptonization process. The fluctuations first cause a variation in the temperature of the truncated disc and then the temperature of the inner disc after a frequency dependent time delay. We find that the model can explain the energy dependent rms and time-lag at different frequencies.

Key words: accretion, accretion discs – black hole physics – X-rays: binaries – X-rays: individual: Cygnus X-1.

1 INTRODUCTION

In the last two decades, there have been extensive studies on the rapid temporal behaviour of X-ray binaries primarily using *Rossi X-ray Timing Explorer (RXTE)* data. These studies have considerably broadened the understanding of behaviour of matter in the strong gravity regime of innermost regions of accretion disc. The X-ray variability of these sources are characterized by their power density spectra (PDS) which show broad-band continuum noise like features and sometimes peaked features known as quasi-periodic oscillations (QPOs). The origin of the broad-band continuum noise could be due to perturbations which occur throughout the disc and propagate inwards causing the X-ray variation (Lyubarskii 1997). Since these variations occurring at different radii are expected to have a multiplicative effect on the accretion rate of inner disc, the scenario provides an explanation for the linear relationship of the rms variability with the flux (Uttley & McHardy 2001; Gleissner et al. 2004). Additionally, the model also makes predictions on energy dependent temporal properties of the system. In particular, the variation of the fractional rms and time-lag as a function of energy can provide clues to the geometry of the system within this paradigm (Böttcher & Liang 1999; Misra 2000; Kotov, Churazov & Gilfanov 2001). The origin of QPOs is not yet clear as to whether they are arising due to resonances in the disc or precision of inner regions.

Recently, there have been efforts to develop simple models based on propagation of fluctuations which attempt to make quantitative predictions for the energy dependent PDS and time-lag (Ingram & Done 2011, 2012; Ingram & van der Klis 2013; Rapisarda et al. 2016). The time-lag between the different energy bands is attributed to the time taken for the fluctuations to propagate, which is taken to be of the order of the viscous timescales. To explain the frequency dependence of the observed time-lags, these models generally invoke that photons of different energies arise primarily from the

★ E-mail: bari@iucaa.in (BM); sneha.m@res.christuniversity.in (SPM); rmisra@iucaa.in (RM)

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