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The Temporal Phenomena of Black Hole Transient XTE J1650-500 in Its 2001-2002 Outburst† ⋆

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Abstract Using the data observed by *Rossi X-ray Timing Explorer*, a systematic study of temporal phenomena of the black-hole transient XTE J1650-500 in its 2001–2002 outburst is presented. By using the time lag in the Fourier frequency domain, three characteristic frequency ranges are analysed, namely the band limited noise, red noise, and QPOs (Quasi-Periodic Oscillations). The properties and evolution behaviours in these frequency ranges may be dominated by different accretion regions. It is commonly believed that the smaller timescale corresponds to the more inner region. The low-hard state and hard intermediate state are especially highlighted. The results of data analysis are discussed in the framework of Lense-Thirring precession. Results are in favor of the disturbance propagation model for explaining the observed time lags. Although the timing analysis in the frequency ranges of band-limited noise and red noise is carried out, and a possibly existed inflection point is found, the model to explain them is still not well established. More work is needed to understand the innermost accretion region.

Key words X-rays, binaries, accretion, accretion disks, quasi-periodic oscillations, time lags

1. INTRODUCTION

The Galactic X-ray radiation is mainly originated from the accretion process of compact stars in binary systems, the compact stars may be black holes or neutron stars. Most of

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black-hole X-ray binary systems are transient sources. Generally, the X-ray transients are situated in the low-luminosity state in a considerably long time, then they will experience an outburst period from several months to several years. In the outburst period, the X-ray luminosity may increase 2–3 orders of magnitude in several days, and the high-level luminosity may last ten and more days to several months, before it is gradually attenuated to the level previous to the outburst.

In the outburst period, a black-hole transient may have rich temporal phenomena and accretion state variations. According to the temporal and spectral variations, the whole outburst period can be divided into 5 different stages, namely the 5 states of transient sources, the quiet state, low-hard state, hard intermediate state, soft intermediate state, and high-soft state[1,2].

A complete X-ray transient outburst generally experiences the process of quiet state→low-hard state→hard intermediate state→soft intermediate state→high-soft state→soft intermediate state→hard intermediate state→low-hard state→quiet state. The X-ray luminosity at the quiet state of a Galactic black-hole transient ($L_{\rm X} = 10^{30.5} - 10^{33.5}$ erg $\cdot$ s^{-1}) is about $10^{-8.5}$–$10^{-5.5}$ $L_{\rm Edd}$. In the low-hard state (LHS, $L_{\rm X} \sim 0.01-0.08\ L_{\rm Edd}$), the X-ray spectrum is generally composed of the thermal component of standard thin-disc polychromatic blackbody radiation spectrum and the dominant power-law non-thermal component, the strong radio emission and strong X-ray light variation can be observed (a certain correlation exists between the two[3]), the relative rms amplitude (fractional rms) can attain ten and several percent to 40%, and occasionally the phenomenon of Quasi-Periodic Oscillation (QPO) can be observed[4]. The luminosity at the hard intermediate state (HIMS, $L_{\rm X} \sim 0.08-0.09\ L_{\rm Edd}$) is increased a little, because of the increase of the disk component, and the larger power-law index, the spectrum becomes gradually soft, the amplitude of light variation decreases, and the C-type QPO can be observed often. The soft intermediate state (SIMS, $L_{\rm X} > 0.2\ L_{\rm Edd}$) exhibits also strong thermal and non-thermal radiations, the spectrum becomes even softer, and the band-limited noise (BLN) in the power density spectrum is replaced by the power-law counterpart, the amplitude of light variation becomes smaller, and the B or A-type QPOs can be observed. The spectrum of the high-soft state (HSS, $L_{\rm X} \sim 0.09 - 0.5\ L_{\rm Edd}$) is dominated by the thermal component, the radio emission is weak, the amplitude of light variation is very small, and the QPO phenomenon generally does not occur[5,6].

The black-hole transient XTE J1650-500 was discovered in September 2001 by the All Sky Monitor (ASM) on the RXTE (Rossi X-ray Timing Explorer) satellite. From September 2001 to January 2002 it experienced a complete outburst. By the observation with an optical telescope, Orosz et al.[7] obtained that the compact star's companion is the K3 V-K5 V-type, the mass function is $(2.73 \pm 0.56)\,M_{\odot}$, the orbital inclination is $50^{\circ} \pm 3^{\circ}$, and the upper-limit mass of the compact star is $7.3\,{\rm M}_{\odot}$. In the whole outburst period, this source has exhibited rich spectral features and temporal variations, Miller et al.[8] found that in its energy spectrum exists a relativistically broadened iron line, and deduced hereby that