Astrophys Space Sci (2012) 337:137–146
DOI 10.1007/s10509-011-0804-9

ORIGINAL ARTICLE

A systematic study on energy dependence of quasi-periodic oscillation frequency in GRS 1915+105

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Received: 1 April 2011 / Accepted: 16 July 2011 / Published online: 1 September 2011

Abstract Systematically studying all the *RXTE*/PCA observations for GRS 1915+105 before November 2010, we have discovered three additional patterns in the relation between Quasi-Periodic Oscillation (QPO) frequency and photon energy, extending earlier outcomes reported by Qu et al. (Astrophys. J. 710:836, 2010). We have confirmed that as QPO frequency increases, the relation evolves from the negative correlation to positive one. The newly discovered patterns provide new constraints on the QPO models.

Keywords Accretion · Accretion disks · Black hole physics · Stars: individual (GRS 1915+105) · Stars: oscillations

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1 Introduction

GRS 1915+105, discovered by WATCH instrument on board *GRANAT* in 1992 (Castro-Tirado et al. 1992) and located in our galaxy at an estimated distance of 9 ± 3 kpc (Chapuis & Corbel 2004), is a low-mass X-ray binary containing a spinning accreting black hole (Zhang et al. 1997) of mass about 14 ± 4 $M_\odot$ and a K-M III giant star of mass 0.8 ± 0.5 $M_\odot$ as the donor (Harlaftis & Greiner 2004; Greiner et al. 2001a). The orbital separation and period of this binary are, respectively, about 108 ± 4 $R_\odot$ and 33.5 days (Greiner et al. 2001b). Serving as a famous microquasar, GRS 1915+105 produces superluminal radio jets (Mirabel & Rodriguez 1994; Fender et al. 1999). It shows various X-ray light curves and complex timing phenomena. Based on the appearance of light curves and color-color diagrams, the behaviors of GRS 1915+105 can be classified into 12 classes. The variability of the source can be further reduced to transitions between three basic states (A, B, and C) (Belloni et al. 2000). Of these 12 classes, class χ (state) is most commonly observed (Belloni et al. 2000). It shows characteristics exclusively of state C, the state which is steady in the X-rays and lies in a rather hard part of the color-color diagram. It is the state when the low-frequency (∼0.5–10 Hz) QPOs (LFQPOs) are most frequently observed (e.g., Muno et al. 1999), providing an idea site for studying LFQPOs.