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Cross-correlation of X-rays for 4U 1608-52

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Abstract. We study the cross-correlation between X-rays of different energies for the atoll-type source 4U 1608-52 with *RXTE*, and find the cross-correlation evolutes along the different branches. The anti-correlation is reported from the Galactic black hole candidates and Z-type luminous sources in their hard states. Our results are a little different from the Z-type sources. Here we provide the first evidence that a similar anti-correlated feature can also be found in atoll-type source, and it is not corresponding to the lowest accretion rate.

Keywords. X-rays binary, accretion rate, cross-correlation

1. Introduction and Data Reduction

Most of neutron star low mass X-ray binaries can be divided into two classes viz. Z-type and atoll-type, based on their color-color diagram(CCD) or hardness-intensity diagram (HID)(Hasinger & van der Klis 1989). For each type of source, spectral/timing states are identified which are thought to arise from different inner flow configurations (e.g., Liu *et al.* 2007; di Salvo *et al.* 2009). For atoll sources, the main three states are the extreme island state (EIS), the island state (IS), and the banana branch, the latter subdivided into lower left banana (LLB), lower banana (LB), and upper banana (UB) states. 4U 1608-52 is a transient atoll-type source that shows outbursts with a recurrence time varying between 80 days and several years.

Anti-correlation of the soft and hard X-rays are often seen in the hard state of some BHXBs (e.g., Choudhury *et al.* 2005) and the horizontal branch (HB) and upper normal branch (NB) of two Z sources (Lei *et al.* 2008; Sriram *et al.* 2012). Detection of anti-correlation can help to know the radiative and geometrical structure of the accretion disk. The purpose of this work is to investigate whether the anti-correlation between the soft and hard X-rays exists as well in the atoll source of 4U 1608-52, and its evolution.

The observations of 4U 1608-52 analyzed in this paper are from the Proportional Counter Array (PCA) on board the *RXTE* satellite during the outburst of 1998 February 3 to September 29. In this work, only PCU2 data are adopted due to the longest observational duration. The XRONOS tool "*crosscor*" is used for estimating the cross-correlation between the soft X-rays (2-3.5 keV) and the hard X-rays (12-30 keV) for observations that containing segments longer than 2000 s. The data of X-ray burst are excluded. For CCDs analysis, the soft and the hard colors are defined as the count-rate ratio 3.5-6.0 keV/2.0-3.5 keV and 9.7-16 keV/6.0-9.7 keV. To obtain HID, we also calculate the intensity, the count rate in the energy band 2.0-16.0 keV.

2. Results and Discussion

We have studied the cross-correlation of 4U 1608-52 during 1998 outburst and find that it is evolutional along the different branches, and the anti-correlation of the soft and hard X-rays is detected (Fig. 1). ObsIDs 30062-01-01-03 and 30062-01-02-05 show the obvious anti-correlations between the soft and hard X-rays. Fig. 2 shows the light

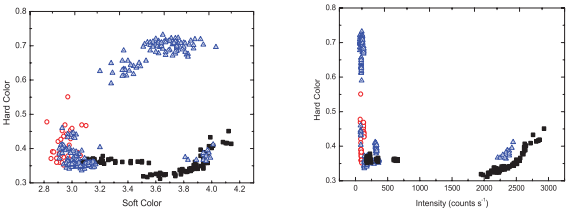

Figure 1. CCD and HID of 4U 1608-52 during the 1998 outburst. The square stands for the positive-correlation, the triangle corresponds to the ambiguous and the circle indicates the anti-correlation. Each point is on average of 512 s.

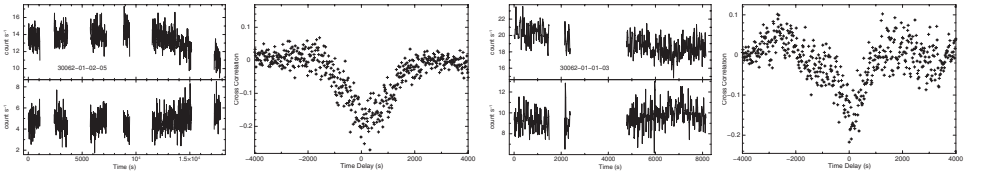

Figure 2. light curves with bin size of 16 s and cross-correlations of the observations with anti-correlation.

curves and cross-correlations between the soft(2.0-3.5 keV) and hard(12-30 keV) X-rays of the observations with anti-correlation detected, and no obvious time lag is detected in the two ObsIDs. In Fig. 1, we can see that, most of the observations with ambiguous-correlation are on the IS and LLB, the others are on the UB, the observations with positive-correlation are on the LB and UB, and the observations with anti-correlation are on LLB. On the IS, there are not obvious positive or anti-correlation detected.

It has been suggested that the accretion rate is connected with the position on the CCD and HID, Our results are a little different from the Z-type sources which the anti-correlations are detected at all three branches, but mostly on the vertical HB, HB and upper NB corresponding to the lower accretion rate. For the 4U 1608-52, there is not anti-correlated observation found in the IS corresponding to the lowest accretion rate. In the higher accretion rate(LLB), positive-correlation is dominative. In the UB which corresponds to the highest accretion rate, both the ambiguous-correlation and positive-correlation are detected. In the low hard state of BHXBs and Z-type source, the detected anti-correlation of the soft and hard X-rays suggests the existence of a truncated accretion disk. Such truncated accretion disk could be exist in atoll-type source, however the cause of its produce is not clear in detail. The more work is needed in the future for explaining the phenomenon and physical origin by studying the relationship of the timing and spectral properties with more data.

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