Evidence for Centrifugal Barrier in X-ray Pulsar GRO J1744-28

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Abstract. We present further observational evidence of the effects of a centrifugal barrier in GRO J1744-28, based on continued monitoring of the source with RXTE.

INTRODUCTION

The magnetosphere of an accreting X-ray pulsar expands as the mass accretion rate decreases. As it grows beyond the co-rotation radius, centrifugal force prevents material from entering it. Thus, accretion onto the magnetic poles ceases, and, consequently, X-ray pulsations cease. This phenomenon has recently been observed, for the first time, in GX 1+4 and GRO J1744-28 with RXTE [1]. Here, we present further evidence to show that the phenomenon repeated itself for GRO J1744-28 during the decaying phase of its latest X-ray outburst.

OBSERVATIONS AND RESULTS

The ASM light curve (as shown in the top panel of Fig. 1) reveals that there have been two episodes of X-ray outburst in GRO J1744-28, separated by roughly one year. The source has been extensively monitored by the main instruments aboard RXTE since its discovery [2]. For detailed analyses, we have selected a number of PCA observations, based on the ASM light curve, to cover the decay phase of the outbursts. Fig. 1 (bottom panel) shows the pulsed fraction \( \equiv \frac{f_{\text{max}} - f_{\text{min}}}{f_{\text{max}}} \) measured with each observation. For comparison, the published results [1] for the first outburst are also presented here. A striking feature is the precipitous drop of the pulsed fraction as the source became "quiescent" both times.

GRO J1744-28 was generally not so quiet after the first outburst. In previous work [1], we happened to catch a brief period (as indicated in Fig. 1) when the pulsed emission became very weak or was not detected at all in some observations. Following the latest outburst, the source has shown little activity. Its presence (at about 20-30 mCrab) has, however, been firmly established by the PCA slew data. This provides a good opportunity to verify our previous interpretation of the
phenomenon. We have searched for the known 2.14 Hz pulse frequency, employing various techniques including FFTs and epoch-folding, but have failed to detect it since the end of June 1997 (as marked in Fig. 1). The results therefore argue strongly that the centrifugal barrier is active in this source during such faint period, as we have concluded previously [1].

The source also shows interesting spectral evolution during the decay. The observed X-ray spectrum can be characterized by a simple power law with an exponential high-energy cutoff. As the quiescent state is approached, the spectrum softens significantly: the power-law becomes steeper, and more prominently, the cutoff energy decreases by roughly a factor of 2 (see Fig. 2). At the end of the first “quiescent” period, the spectrum would recover to the bright-state shape. We have proposed before that the X-ray emission probably consists of two components: the emission from a large portion of the neutron star surface (thus unpulsed), due to the “leakage between field lines” [3], and that from “hot spots” near the poles (pulsed plus unpulsed). When the source was bright, the latter dominated, so the spectrum was hard (corresponding to a much higher temperature of the hot spots). However, as soon as the centrifugal barrier took effect in the quiescent state, the observed X-rays were all due to the surface emission and their spectrum was therefore softer.

It is interesting to note that the pileup of accreting matter on the neutron star surface might also cause unstable thermonuclear burning and produce type I bursts
like in X-ray bursters. The lack of such (or does it?) in GRO J1744-28 may be due to the suppression of this process by a significantly higher field [5].

GRO J1744-28 does produce X-ray bursts [6], unlike any other X-ray pulsars. The bursts are thought to be the product of accretion instability [7]. They occurred at a rate of one to two dozen per hour near the peak of the outbursts [6,8], and the rate decreased as the X-ray flux decayed. At the start of the first quiescent period, the bursting activity ceased entirely [9] for weeks before resuming again near the end [10]. Fig. 3 (the top panel) shows an example of such activity (with 7 major bursts) on MJD 50260 (∼ 26 June 1996). We have separated the light curve of 26 June 1996 into burst and non-burst intervals. The X-ray pulsation is detected during the bursts but is not detected outside of them (see Fig. 3). This is again consistent with the presence of the centrifugal barrier in GRO J1744-28. A sudden surge in the mass accretion rate that produces a burst would also momentarily push the magnetosphere inside the co-rotation radius and thus, the accretion to the poles would resume to produce the pulsed emission. As the system relaxes following a burst, the magnetosphere expands again; the inhibition of accretion by the centrifugal barrier again suppresses the pulsation.

CONCLUSIONS

We conclude by summarizing the main results as follows:
The results support our previous conclusion that the cessation of pulsed emission when the source becomes faint is a manifestation of the centrifugal barrier.

For GRO J1744-28, the X-ray emission in the quiescent state (unpulsed) likely comes from a large portion of the neutron star surface, due to the penetration of accretion flows through the magnetosphere.

Accretion instability can still occur in the quiescent state (less frequently), and produce type II bursts. The pulsed emission was apparent during the bursts, presumably due to the resumption of accretion to the magnetic poles because of the momentary shrinkage of the magnetosphere. The pulsation stopped as the system recovered to the quiescent state.

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