The BeppoSAX Phase-resolved Spectra of the Anomalous X-ray Pulsar RX J170849-400910

Chang, H.-K.; Department of Physics and Institute of Astronomy, National Tsing Hua University, Taiwan
Email (HKC): hkchang@phys.nthu.edu.tw

Abstract

We report a phase-resolved spectral analysis of the anomalous X-ray pulsar RX J170849-400910 using archival data of a BeppoSAX observation conducted on 1999 March 31 – April 1. The model used is a power-law plus one blackbody plus a power-law plus two blackbodies. The model provides a good fit to the spectrum very well, but most of the flux is attributed to the nonthermal component for the former and to the thermal component for the latter. Photon power indices, blackbody temperatures, and estimated thermal and nonthermal fluxes all vary with phase. The necessity of involving a power-law component in spectral fitting, even in the case that most of the flux is thermal, poses severe challenges to those models involving only surface thermal emission as the nature of the radiation from anomalous X-ray pulsars.

1 Introduction

To explore the nature of AXPs, spectral information is crucial. For at least four among the five AXPs, a spectral model composed of a dominating power-law component plus a minor blackbody one was found to fit well by many authors. Such a model was also applied to RX J170849-400910 in Israel et al. (2001), in which phase-dependent power indices and blackbody temperatures were reported. A phase-varying temperature may indicate that we are observing the whole stellar surface with certain kind of temperature distribution in different aspects. In this regard, however, a blackbody spectral form is too idealized. Atmospheric effects and surface temperature distribution will cause the emergent spectrum to deviate significantly from that of a blackbody.

To model a realistic surface thermal spectrum from neutron-star-like objects is complicated. Theoretical work has been elaborated by several groups of authors. In this paper, we adopt a two-blackbody model to mimic the approximation to the atmospheric effect and the temperature distribution or the presence of a possible hot spot. We analyzed BeppoSAX archival data of RX J170849-400910. Equally good fits were found for different models: a steep power law; a steep power law plus a blackbody, and a flat power law plus two blackbodies. Models of simply two blackbody components without a power law do not fit well.

We note that Perna et al. (2001) also found good fits with a model composed of magnetar surface thermal emission plus a power law, as well as of a blackbody plus a power law, in the ASCA phase-averaged spectrum of RX J170849-400910. Our similar spectral fitting results with BeppoSAX data make these spectral models statistically equally reliable, in contrast to that in Israel et al., in which only one of the models involved only surface thermal emission as the nature of the radiation from anomalous X-ray pulsars. The manifestation of a possible hot spot or the hottest area of a distinct temperature distribution on the stellar surface. If these insights are correct, we expect to have higher temperature at phase 0.75 (and probably also 0.25), and to have larger nonthermal flux at phase 0 and 0.5 in phase-resolved spectral analysis.

2 Phase-dependent Pulse Profiles

The energy-dependent pulse profiles of RX J170849-400910 were reported in Israel et al. (2001). We reproduced them by folding the barycenter-corrected arrival times of extracted photon events at the reported period of 10.99915 s. A simple χ²-test on an epoch-folding search procedure confirmed this period. These profiles are plotted in Figure 1 in different energy bands.

In the low-energy band (1–4 keV), the profile shows a broad peak, typical of the modulation of surface thermal emission. However, a prominent second peak occurs in the high-energy band (6–10 keV), whose phase is defined as phase zero in Figure 1. This peak is relatively narrow, and there is a weak indication that at phase 0.55 there is another peak. If the peak at phase 0.55 is real, the separation between these two peaks is 0.45, a value similar to that for gamma-ray emission from the Crab, Vela, and Geminga pulsars (e.g. Ulmer 1994). The low-energy peak at about phase 0.75 remains in the high-energy band with a narrower width. It indicates that, if it is thermal in origin, this peak (phase 0.75) in 6–10 keV is

![Figure 1: Light curves folded at the period 10.99915 s in different energy bands. Phase zero is chosen to be the peak position in the high energy band (6–10 keV).](image)

3 Phase-resolved Spectral Analysis

According to the observation in the last section, we divided the whole period into four phase intervals centered at phase 0.0, 0.25, 0.5, and 0.75. They are referred to as P1, P2, P3, and P4 respectively. In such separation, we hoped to identify different spectral components as clear as possible. For example, the spectrum of P1 may contain a stronger contribution from a component which manifests itself as the peak in the 6–10 keV band, and that of P4 may be dominated by the component that gives the major peak in the 1–4 keV band.

As shown in Table 1, all three models fit spectra of P2 and P4 very well with a reduced χ² of about 0.9. The fits for P1 are not as good, but still quite acceptable with χ² of about 1.1. The phase-dependent photon power indices reported in Israel et al. (2001) are also clear in our results. In Israel et al. (2001) only the model of PL+BB was applied. From our analysis, we can see even with the PL+BB+BB model the photon power index also shows significant variation in different phases. Derived unabsorbed fluxes for all these model fits are also shown in Table 1. In PL+BB models thermal fluxes only give a minor contribution, while in PL+BB+BB models thermal fluxes dominate. We note that in the PL+BB+BB

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model fits, the temperature of the hard blackbody component for P2 and P4 is higher than that for P1 and P3, and the thermal flux is highest for P4, nonthermal highest for P1. To illustrate the partition of thermal and nonthermal power and also the fitting residuals, the unfolded spectrum and fitting model (PL+BB+BB) for P4 is plotted in Figure 2. For other phase intervals, unfolded spectra are similar to that in Figure 2 but with different normalizations for thermal and nonthermal components.

Table 1: Phase-resolved spectral fit of RX J170849-400910

<table>
<thead>
<tr>
<th>Parameter</th>
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<th>P2</th>
<th>P3</th>
<th>P4</th>
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<tbody>
<tr>
<td>$N_H$ (10$^{22}$ cm$^{-2}$)</td>
<td>1.45±0.20</td>
<td>1.76±0.24</td>
<td>2.09±0.20</td>
<td>1.92±0.18</td>
</tr>
<tr>
<td>$R_e$ (kpc)</td>
<td>2.56±0.17</td>
<td>3.31±0.23</td>
<td>3.57±0.19</td>
<td>3.47±0.16</td>
</tr>
<tr>
<td>$\Gamma$ (d.o.f.)</td>
<td>1.22(43)</td>
<td>0.97(43)</td>
<td>1.25(70)</td>
<td>0.85(43)</td>
</tr>
<tr>
<td>Flux</td>
<td>7.25±2.62</td>
<td>6.98±2.74</td>
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Note: All fluxes are unabsorbed ones (derived by setting $N_H$ equal to zero) in the energy band of 1–10 keV and in units of 10$^{-11}$ erg cm$^{-2}$ sec$^{-1}$. P1, P2, P3, and P4 stand for adjacent phase intervals centered at phase 0.0, 0.25, 0.5, and 0.75 respectively.

4 Discussion

A broad peak in the low-energy pulse profile gives some hint of a thermal origin. If the PL+BB+BB model is closer to the reality, from our fitting results and the derived thermal and nonthermal fluxes for different phases, we may infer that P2 and P4 correspond to the locations of the two magnetic poles, where the temperature is the highest on the whole stellar surface. Besides, the magnetic inclination, that is, the angle between the magnetic and the spin axes, and the viewing angle – the angle between observer’s line of sight and the spin axis – both should not be too close to zero degree or too close to 90 degrees, otherwise the thermal flux in P2 would not be that small and the low-energy pulse profile would show two peaks or simply no significant features. Combining temporal and spectral information can potentially derive relevant geometry. Such kind of attempt has been made for high-energy pulsars (Harding & Muslimov 1998; Chang 2001).

In addition to showing the model of surface thermal emission plus a flatter power law can describe the spectrum of RX J170849-400910 very well, one of the most important results of this study is that a power law component with phase-dependent power indices, either steep or flat, is necessary. In PL+BB models, the power-law flux dominates the total flux. Even in PL+BB+BB models or the magnetar+PL model (Perna et al. 2001), the power-law flux is still negligible, typically at a level of about 25% or 10%–30% for different phases. Models of how to power an X-ray can be grouped into two categories according to whether accretion is invoked or not. For those without accretion, a ‘magnetar’ (Duncan & Thompson 1992) model is assumed with either magnetic field decay (Thompson & Duncan 1996; Heyl & Kulkarni 1998) or the residual thermal energy (Heyl & Hernquist 1997) as the energy source to power the AXPs. Although these kinds of models can naturally provide required energy source, the necessity of a power-law component in fitting the spectrum renders them incomplete. Unless a certain mechanism, which could convert thermal energy into nonthermal radiation, can be devised, emission processes in stellar magnetospheres due to other origins, for example, accretion, seem necessary.

Up to date, there is no evidence of any Doppler shifts from binary motion for AXPs. Many models invoking accretion have been proposed, for example, from a very low mass binary companion (Mereghetti & Stella 1995), or from a circumstellar disk, which could be the remnant of a common-envelope evolution (van Paradijs, Taam, & van den Heuvel 1995) or the falling-back ejecta after a supernova explosion (Chatterjee, Hernquist, & Narayan 2000; Alpar 2001; Marsden et al. 2001). These accretion models may stand a better chance to explain the spectral behavior of RX J170849-400910. Besides, a power-law tail at higher energies is often seen in the spectra of accreting neutron stars at low luminosities, for example, Cen X-4 (Asai et al. 1996) and Aql X-1 (Zhang, Yu, & Zhang 1998; Campana et al. 1998). As shown in this paper, to know how significant the thermal component is in the total flux, spectral behavior above 10 keV will be very helpful. To understand the nature of AXPs, a model with a convincing emission mechanism accounting for the power-law radiation is very much desired.

Acknowledgements

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References


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