RXTE Broad Band X-ray Spectrum of the Burster 1E1724-3045

J. F. Olive¹, D. Barret¹, L. Boirin¹ and J. E. Grindlay²

¹CESR, CNRS/UPS, 9 Avenue du Colonel Roche, 31028 Toulouse Cedex 04, France (olive@cesr.fr)
²Harvard Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

ABSTRACT

The X-ray burster 1E1724-3045 located in the globular cluster Terzan 2 is known as one of the persistent (though variable) hard X-ray sources as shown by the SIGMA observations of the Galactic Center region. 1E1724-3045 was observed with the PCA and HEXTE experiments onboard the Rossi X-ray Timing Explorer (RXTE) on November 1996 for about 100 ksec. The broad band spectral capability and sensitivity of RXTE enables to study simultaneously the X-ray (3-20 keV) and hard X-ray components (E>20 keV) of this source. During the observation, this “Atoll” source was in its “Island” state characterized by a hard Comptonized spectrum with an electron temperature kT_e ∼ 29 keV, an optical depth τ ∼ 2.9 (spherical geometry) and a temperature of the “seed” photons of kT_W ∼ 1.2 keV. Below 5 keV, there is a soft excess which we fit with a blackbody of kT_BB ∼ 0.67 keV. The Comptonization temperature is significantly lower those observed for black holes candidates in their low luminosity state (kT_e > ∼ 50 keV). Finally, our observation allows us to associate the presence of an hard tail with a low luminosity X-ray state (1-20 keV luminosity of 1.0 × 10^{37} ergs s^{-1} at 7.7 kpc).

1 INTRODUCTION

It is now well known that, like black hole binaries, X-ray bursters (XRB, hence neutron star binary systems) can emit hard X-rays (see Tavani and Barret, 1997 and references therein). During the last few years, a dozen of such sources have been detected, mostly with the SIGMA and BATSE instruments. To investigate the conditions under which a neutron star can emit hard X-rays and the residual differences between black holes and neutron star systems (such as the position of the energy cutoff and luminosity) a high sensitivity broad band spectrum from X-rays to hard X-rays is necessary. Indeed, the hard X-ray data alone are inadequate to discriminate between thermal and non-thermal models. Furthermore, due to the moderate sensitivity of hard X-ray telescopes such as SIGMA and BATSE, only mean spectra, averaged over at least few weeks, are reliable.

The situation changed recently with experiments such as RXTE. This experiment allows to study these systems with a good sensitivity in a broad energy band (from 3 to 200 keV) by combining of the PCA and HEXTE instruments (Bradt et al., 1993). One of the most natural target for this study is 1E1724-3045. This source was one of the first X-ray burster detected above 100 keV. The detection came with SIGMA in the course its first observation of the Galactic Center region in March-April 1990 (Barret et al., 1991). At that time, this source was the third brightest hard X-ray source of the GC field (behind 1E1740-2942 and GRS1758-258) and was characterized by a very hard power law spectrum (photon index of 1.7 ± 0.5) extending up to 300 keV (Barret et al., 1991). Subsequently, over more than five years of GC observation by SIGMA, 1E1724-3045 was continuously detected with a flux ranging from 10 to 50 mCrab in the
35-75 keV band and a mean flux of $\sim 22$ mCrab (Goldwurm et al., 1995 and Churazov et al., 1997). The very hard spectrum of the first observation was never observed again. The time-averaged hard X-ray spectrum of the source can be approximatively fitted by a power law with a photon index of $3.0 \pm 0.3$, and is probably softer if the data of the March-April 1990 observation are excluded ($\alpha = 3.3 \pm 0.4$, see Goldwurm et al., 1995). Alternatively, this spectrum could also be fit with a Thermal Bremsstrahlung model of temperature $\sim 50$ keV (Churazov et al., 1997).

In the classical X-ray range (1-20 keV), the source has been repeatedly observed by various X-ray experiments since its discovery in 1977 by UHURU (Swank et al., 1977). The most reliable spectral observations of 1E1724-3045 (i.e. those performed with EXOSAT and TTM) showed that the source is characterized by a relatively hard power law type spectrum in X-rays (photon index of $\sim 2.0$). These observations, combined with the mean SIGMA spectrum suggested that a spectral break occurs somewhere below 100 keV. More recent observations with ASCA (Barret et al., 1998) and SAX LECS-MECS (Guainazzi et al., 1998) showed that the source spectrum can be fit with a Comptonized model ($kT_c \sim 30$ keV) and a soft blackbody component ($kT_{BB} \sim 0.6$ keV).

In this paper, we report on the joint spectral analysis of the PCA and HEXTE data on 1E1724-3045. In the last section, we make a brief comparison with black hole candidates. For a full description of the observation and the timing analysis of the source variability, we refer to Olive et al. (1998).

## 2 The RXTE observation and data analysis

The RXTE observation took place on November, 4th to 8th, 1996 for a total exposure time of about 100 kiloseconds. The data have been filtered out for elevation greater than $10^\circ$ (as recommended) and source pointing offset less than 0.02$^\circ$. We have also excluded data recorded during the SAA passage (and 30 minutes after it) using the FTOOLS 4.1 version of xtefilt.

### 2.1 The PCA data

First, using the PCA standard 2 data, we have built light curves, color-color, and hardness-intensity diagrams with various time resolution. The FTOOLS used for PCA background estimation was the latest pcabacest version 2.0c. Along the RXTE observation, no time or spectral variability could be inferred from this analysis. So we decided, for spectral analysis, to consider the mean spectra over the whole observation. The spectra of each PCA unit (PCU0 to PCU4) have been extracted separately and PCU response matrices have been made for each PCU using the FTOOLS pcarsp 2.36. Then we have combined the 5 PCU data and matrices using the FTOOLS addspec 1.2.0. In order to investigate the possible systematics in the PCA data we have first analyzed a 15 ksec Crab observation (March 22, 1997, similar modes of observation). Provided that 1% systematics are added to the data, the Crab spectrum was correctly fitted, so we decided to add, before fitting the 1E1724-3045 data, the same 1% systematics to the data.

### 2.2 The HEXTE data

We have also used the HEXTE standard mode data. The data were corrected for background measurement duty cycle and for the 40% to 60% deadtime effects (using version 0.0.1 of hxtdead). Once again, using light curves, color-color, and hardness-intensity diagram analysis, no spectral or intensity variation could be inferred. Therefore, we have combined the mean spectra of the two HEXTE clusters (using
Figure 1: Unfolded combined PCA and HEXTE spectra of 1E1724-3045 for a power law fit. A clear spectral break occurs around 50 keV and the fit is not satisfactory below 10 keV.

3 Spectral analysis of 1E1724-3045

For spectral fitting, we have used XSPEC version 10.0. When fitting simultaneously PCA and HEXTE spectra, we found that the optimum energy ranges for the fit were 3–20 keV for the PCA and 20–150 keV for HEXTE. In a combined fit, the relative normalization between the PCA and HEXTE spectra has been left as a free parameter of the models.

3.1 Fit by a power law

An absorbed power law is the simplest model we have tested (see results in table 1). The reduced chi-squared of the fit is $\chi^2_{\text{red}} \sim 5.1$ for 82 dof. Figure 1 shows why the fit is not satisfactory. At low energy, the spectrum is flatter. If this flattening goes down to 2.5 keV, the residuals suggest the presence

\[\text{http://mamacass.ucsd.edu:8080/hexte/hexte_calib.html}\]
of a soft excess. At higher energy a clear cutoff or break in the HEXTE spectrum around 50-60 keV appears. On the other hand, the column density \((3.7 \times 10^{22} \text{ cm}^{-2})\) is significantly larger than what has been previously observed with ASCA and SAX. These results are suggestive of the following features: (1) a spectral break in the HEXTE range, (2) a harder spectrum below say 10 keV, (3) a possible soft excess below 5 keV.

For comparison with SIGMA data, it was interesting to fit the HEXTE data alone in the nominal SIGMA range of 35–150 keV with a single power law model. The index we derived was 2.7 ± 0.1 consistent with the SIGMA mean value \((3.0 \pm 0.3)\). However the power law fit was not satisfactory \((\chi^2_{\text{red}} = 1.84 \text{ for 61 dof})\) and the ∼ 50 keV break was readily visible, even in this restricted energy range.

### 3.2 Fit with a Comptonized model and a Blackbody

In the light of recent observations of the source with ASCA and SAX, we have fit the broad band spectrum with a recently developed Comptonization model (the so-called “comptt” in XSPEC) which can produce spectra with a high energy cutoff and a flatenning below few keV. Both characteristics were observed in the 1E1724-3045 spectra. The Comptonization parameters are: the electron temperature \(kT_e\), optical depth of the electron cloud \(\tau\) and a temperature of the “seed” photons of \(kT_W\) assuming a Wien-type distribution (Titarchuk, 1994). This model inputs two different geometries: disk and sphere. Despite these interesting properties, it is clear that the “Comptt” model alone could not take into account the low energy soft excess (below 5 keV). So, we have tried to fit our spectra with a composite model of a blackbody plus a Comptonized spectrum (see results in table 1).

Adding a blackbody component makes impossible to leave the \(N_H\) as a free parameter because of the strong correlation existing with this parameter and the amplitude of the blackbody. Furthermore, the points constraining their values are restricted to a narrow energy range. Consequently, the \(N_H\) was fixed to its nominal ASCA value of \(1.0 \times 10^{22} \text{ cm}^{-2}\) (Barret et al., 1998).

Figure 2 shows the unfolded spectrum and residuals. It shows that the wave shape below 5 keV has been removed while the fit has accomodated an acceptable \(\chi^2_{\text{red}}\) value (See table 1). Using a disk instead of a sphere geometry yields essentially the same value for \(kT_e\) and \(kT_W\); the main effect being on the optical depth which decreases from ∼ 3 to ∼ 1.

<table>
<thead>
<tr>
<th>Model</th>
<th>Parameters</th>
<th>(\chi^2_{\text{red}}) (d.o.f.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Law</td>
<td>(N_H) (\pm 0.1)</td>
<td>5.12 (82 dof.)</td>
</tr>
<tr>
<td></td>
<td>(\alpha) (\pm 0.05)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(\chi^2_{\text{red}}) (d.o.f.)</td>
<td></td>
</tr>
<tr>
<td>BB+Comptt</td>
<td>(N_H) (\times 10^{22} \text{ cm}^{-2})</td>
<td>1.0 (fixed)</td>
</tr>
<tr>
<td></td>
<td>(kT_{BB}) (\pm 0.07) keV</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>(kT_{W}) (\pm 0.17) keV</td>
<td>1.19</td>
</tr>
<tr>
<td></td>
<td>(\tau) (\pm 0.2)</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>(\chi^2) (d.o.f.)</td>
<td>1.10 (79 dof.)</td>
</tr>
</tbody>
</table>

Table 1: Best fit spectral parameters (Comptt=Comtonization model from Titarchuk (1994), BB=Black body). Error are give at the 90% confidence level for variation of one single parameter.
4 Discussion

1E1724-3045 belongs to the class of bright and persistent LMXBs located in globular clusters. We observed this “Atoll” source in its hard state, during which it emits hard X-rays. The source did not show any spectral variability. The RXTE spectrum could be well described by a hard Comptonized component (\(kT_e \sim 30\) keV, \(kT_W=1.2\) keV, \(\tau \sim 3\)), plus a soft component which could be fit by a Blackbody (\(kT_{BB}=0.7\) keV, \(R_{BB}=10^{-11}\) km). The origin of the soft component is unclear (neutron star surface or optically thick boundary layer). The fact that our RXTE spectrum is consistent with the SAX LECS-MECS (Guainazzi et al., 1998) and ASCA (Barret et al., 1998) ones suggests that this source spends most of its time in such a hard state.

Barret, McClintock and Grindlay (1996) proposed that X-ray bursters (XRBs) can be distinguished in two ways from black hole candidates (BHCs) using luminosity criteria. First, no XRBs seem to be able to emit hard X-ray tails when their 1-20 keV luminosity is larger than \(\sim 2 \times 10^{37}\) ergs s\(^{-1}\). During our observation, the 1-20 keV luminosity was \(1.0 \times 10^{37}\) ergs s\(^{-1}\) at 7.7 kpc. So the hard X-ray emission is indeed associated with a low X-ray intensity state. Second, no XRBs have hard tails brighter than \(\sim 2 \times 10^{37}\) ergs s\(^{-1}\). Again, this criterion is satisfied for 1E1724-3045 as the 20-200 keV luminosity was...
\[ 6.4 \times 10^{36} \text{ ergs s}^{-1} \]

Recently it has been suggested that the Comptonization temperature could also be used as a criterion to discriminate between BHCs and XRBs: the former would have temperature \( kT_e \gtrsim 50 \text{ keV} \), whereas for the latter it would be \( \lesssim 30 \text{ keV} \) (Zdziarski et al., 1998). Our result fits in this scheme.

5 Conclusions

It is already well known that “Atoll” sources have timing properties similar to BHCs (Van der Klis, 1995, see also Olive et al. 1998 for 1E1724-3045). The present result demonstrates that they also share similarities with respect to their spectral properties. Both systems emit hard X-rays and Comptonization seems to be the dominant emission mechanism. Further broad band observations are needed to test the luminosity criteria over a larger sample of sources, and to definitely assess whether BHCs and XRBs can indeed be distinguished on the basis of the electron temperature of the Comptonizing cloud.

6 References

Churazov, E., et al., 1997, Advances in Space Research, v. 19 Issue 1, 55
1E1724-3045
Abs. Power Law

Energy (keV)

Photons cm$^{-2}$ s$^{-1}$ keV$^{-1}$

$N_\sigma$