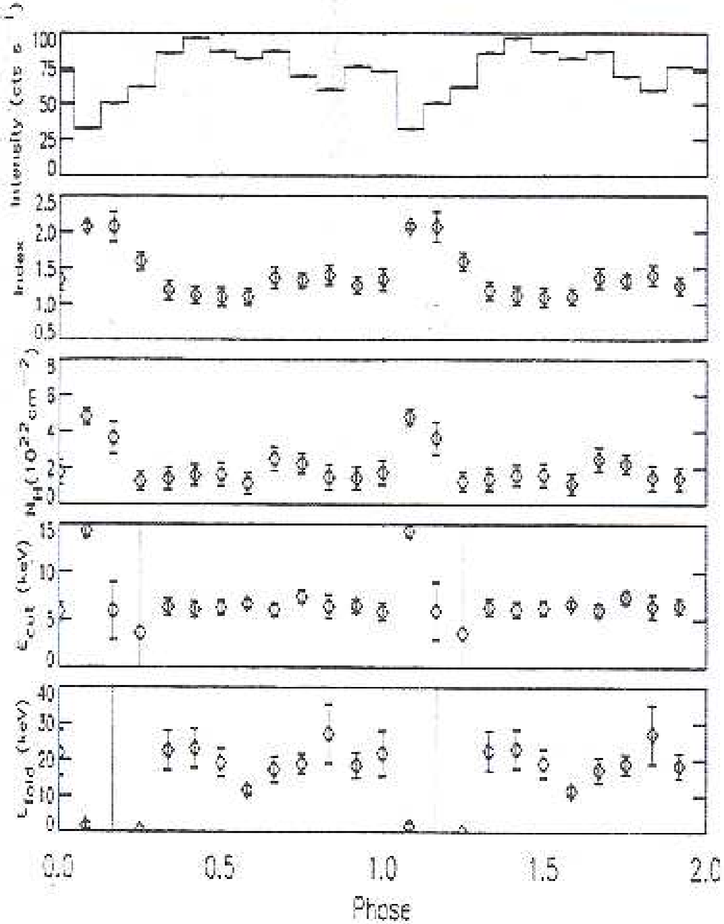

FIGURE 2. The pulse phase dependence of the February 5, 1998, PCA spectrum. The photon spectra in each of 12 phase bins were best fitted with a power law with low energy absorption and a high energy cutoff. The top panel shows the 2-30 keV intensity in each of the 12 bins. The photon index (2nd panel) and the absorption (3rd panel) showed significant pulse phase dependence. The cutoff (4th panel) and folding energies (5th panel) were not as well determined, so their phase dependence is less clear.

BeppoSAX Observation of the X–ray Pulsar 4U 1538–52

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Abstract. We report preliminary results of the temporal and spectral analysis performed on the X–ray pulsar 4U1538–52 out of eclipse observed by BeppoSAX. We obtain a new estimate of the pulse period of the neutron star $P = 528.24 \pm 0.01$ s (corrected for the orbital motion of the X–ray source): the source is still in the spin-up state, as since 1988. The broad band (0.12–100 keV) spectral analysys shows the presence of an absorption feature at ~ 21 keV is present, interpreted as due to cyclotron resonant scattering. Another absorption feature at ~ 51 keV seems also to be present (at 99% confidence level). If confirmed this might be interpreted as a cyclotron line, but its energy is not compatible with being double than the energy of the first line.

INTRODUCTION

4U 1538–52 is a wind–fed X–ray binary system formed by a massive B0 star and a neutron star spinning with a period of about 529 *s* ([1], [2]). The X-ray luminosity has been estimated $\sim 2\,10^{36}$ *erg/sec* for a distance of ≈ 6.4 *kpc* ([2]). The orbit, in an almost edge-on plane, is characterized by a period of ≈ 3.75 *days*, and a well defined X-ray eclipse lasting ≈ 0.6 *days* ([1], [2]). The pulse period measurements show that the neutron star was in a spin-down state before 1988 with a $|\dot{P}/P| \sim 10^{-11}\ s^{-1}$ and in a spin-up state with the same $|\dot{P}/P|$ after 1988 ([3]).

Before *Ginga* observations the X-ray spectrum has been well modeled by a power-law modified by a high-energy exponential cutoff and a weak iron line emission at 6.7 *keV* ($EW \sim 100$ *eV*). A phase-dependent absorption feature, in the X-ray spectrum, around 20 *keV* observed by *Ginga* ([4], [5]) is explained as a cyclotron resonance absorption. A cut-off in the spectrum above about 30 *keV* was interpreted as the second harmonic but the *Ginga* energy range precludes any definitive conclusion.

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OBSERVATIONS AND ANALYSIS

BeppoSAX observed 4U 1538-52 with its Narrow Field Instruments (NFI) on 1998 from 29th July to 1st August. The source was in its eclipse state during the first ~ 52 ks and out of eclipse in the last ~ 177 ks. In this paper we concentrate our analysis on data out of eclipse. Adopting a distance of 6.4 kpc ([2]), the source luminosity out of eclipse is $\sim 4.7 \times 10^{36}$ ergs/s in the whole range 0.1 - 100 keV.

We used MECS data, which have a better statistics, to perform a temporal analysis. The arrival times of all the events were reported to the solar system barycentre. Moreover we corrected the arrival times for the orbital motion of the source. We performed a folding search for the best pulse period on these corrected arrival times. The best period obtained was 528.24 ± 0.01 s, demonstrating that the source is still in a spin-up state. Figure 1 shows the pulse profiles during the post-egress phase in different energy bands, namely 0.1–1.8 keV (upper panel), 1.8–10.5 keV (middle panel), 15–100 keV (lower panel). A double peaked pulse profile is present in the 1.8–10 keV band, progressively disappearing at lower energies. Indeed the secondary peak is almost absent in the soft range 0.1–1.8 keV. In the PDS range (15–100 keV) the emission is pulsed without significant variations in shape, although the secondary peak is less pronounced.

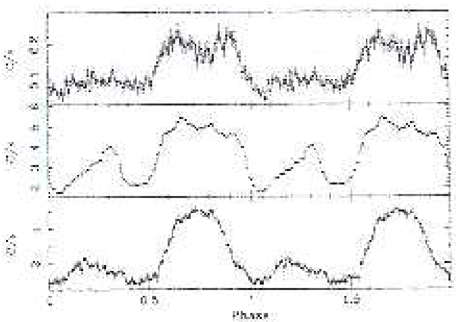

FIGURE 1. Pulse profiles during the post-egress phase in different energy bands, namely 0.1–1.8 keV (LECS, upper panel), 1.8–10.5 keV (MECS, middle panel), 15–100 keV (PDS, lower panel).

We performed spectral analysis on the post-egress energy spectrum of 4U 1538–52 in the energy range 0.12–100 keV. The high energy part of the spectrum (above ~ 10 keV) is not well fitted by a power law modified only by two absorption features as proposed by [4] in the analysis of *Ginga* data. The broader band of the BeppoSAX instruments unambiguously demonstrates that *both* an absorption feature and an exponential cutoff are needed to adequately model the spectrum.

We fit the spectrum with an absorbed power-law continuum modified by a high energy rollover and by an absorption cyclotron line of gaussian shape plus a gaussian iron emission line at ~ 6.4 keV. This model gave a good fit with a $\chi^2/d.o.f.$ = 733/700. The best fit parameters are shown in Table 1 (model 1); the observed spectrum and the residuals (in units of σ) are shown in Figure 2, upper and lower panel respectively. With respect to this model a residual is still visible in the PDS range, between 40 and 60 keV. Since this is the range of energy in which we expect to find harmonics of the cyclotron line we added another cyclotron line to the model above. In this way we obtain a reduction of the χ^2 to 721/697. An F–test gives a probability of 99% that the improvement is real. The results with this model are also show in Table 1 (model 2).

TABLE 1. Results of the fit of the pulse averaged spectrum in the energy range 0.1-100 keV. Uncertainties are at 90% confidence level for a single parameter.

Parameter	Model 1	Model 2
$N_H \times 10^{22}$ cm^{-2}	1.632 ± 0.040	1.636 ± 0.040
Photon index	1.125 ± 0.013	1.127 ± 0.012
E_{cut} (keV)	15.41 ± 0.72	$14.1^{+2.4}_{-0.56}$
E_{fold} (keV)	10.06 ± 0.47	$11.39^{+0.15}_{-0.80}$
$A_{cyc,1}$	0.491 ± 0.038	$0.412^{+0.035}_{-0.027}$
$E_{cyc,1}$ (keV)	21.09 ± 0.21	$21.49^{+0.25}_{-0.44}$
$\sigma_{cyc,1}$ (keV)	3.46 ± 0.27	$2.82^{+0.35}_{-0.41}$
$A_{cyc,2}$	-	$0.86^{+0.17}_{-0.34}$
$E_{cyc,2}$ (keV)	-	$51.87^{+4.2}_{-3.6}$
$\sigma_{cyc,2}$ (keV)	-	$4.4^{+3.3}_{-2.3}$
E_{Fe} (keV)	6.374 ± 0.057	6.374 ± 0.057
σ_{Fe} (keV)	< 0.2	< 0.2
Fe Equiv. Width (eV)	58	58
χ^2/d.o.f.	733/ 700	721/697

DISCUSSION AND CONCLUSIONS

We performed temporal and broad band (0.1–100 keV) spectral analysis on the out-of-eclipse data of 4U 1538–52 observed by BeppoSAX NFIs. We obtained a new measurement of the spin period P_{spin} = 528.24 ± 0.01 s, which indicates that the neutron star is still spinning–up.

The broad band energy spectrum is well fitted by a power–law with high energy cutoff continuum (the typical continuum of the HMXB systems), with low energy absorption by cold matter, an emission line due to fluorescence from iron in low ionization states, and an absorption feature around 20 keV that we interpreted as due to cyclotron scattering (in agreement with [4]). Another absorption feature seems to be present around 50 keV (at 99% confidence level). If confirmed, this feature might be interpreted as the second harmonic of the 20 keV cyclotron line.

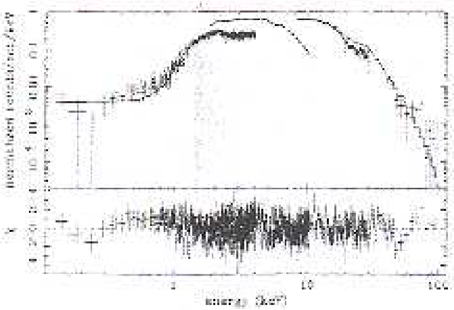

FIGURE 2: Data and model with one absorption line (upper panel) and residuals in units of σ with respect to this model (lower panel).

However the energy of this second feature ($51.9^{+4.4}_{-3.3}$ keV) is not compatible with being double than that of the first line ($21.49^{+0.29}_{-0.31}$ keV). Considering that the optical depth of the fundamental and second harmonic are different we expect that the two lines should form at different heights. In particular the fundamental, with a larger cross section, will form higher in the atmosphere where the magnetic field is weaker. We calculate that a difference in the heights of ~ 0.07 neutron star radii are sufficient to explain the difference in the energy. Another possibility is that we see two different lines coming from the two magnetic poles. A displacement of the magnetic dipole momentum by about 0.15 neutron star radii from the center is sufficient to explain the difference of energy of the two lines produced at the two magnetic poles. In this case we expect a phase dependence of the strength of these two lines. The phase resolved spectral analysis that we performed (whose results we will present elsewhere) are not conclusive as regard the second line (because of the low statistics). Further observations are needed to address the question of the presence of this second high energy absorption feature.

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Bright X-ray bursts from 1E1724-3045 in Terzan 2

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ABSTRACT. During about 3 years wide field monitoring of the Galactic Centre region by the WFC telescopes on board the *BeppoSAX* satellite, a total of 14 type-I X-ray bursts were detected from the burster 1E 1724-3045 located in the globular cluster Terzan 2. All the observed events showed evidence of photospheric radius expansion due to Eddington-limit burst luminosity, thus leading to an estimate of the source distance (~7.2 kpc). Preliminary results of the analysis of the bursts are presented.

INTRODUCTION

Since its discovery [14], the globular cluster source 1E 1724-3045, has been repeatedly studied by several satellite experiments both in the "classical" (~1-20 keV) X-ray energy band (e.g. *EINSTEIN, EXOSAT, TTM, ROSAT, BeppoSAX, RXTE, ASCA*) and in the hard X-rays (*GRANAT, BeppoSAX, RXTE*).

The source is persistently bright, though variable, and is one of the few X-ray bursters showing persistent emission up to the soft Gamma-rays [1],[17],[16].

Type-I X-ray bursts from 1E 1724-3045 were observed since the very first observations performed with OSO-8 [14]. In particular, *EINSTEIN* detected a bright burst showing photospheric radius expansion [7],[15], allowing an estimate of the source distance (~7 kpc) which is consistent with what is obtained taking into account the measured reddening of the globular cluster Terzan 2 [13].

Bursting activity identifies the source as a weakly magnetized neutron star in a low mass binary (*LMXB*) system.

Soft X-ray observations have shown that the persistent spectrum is best-fitted by a power law of photon index ~2.0-2.4 [9],[12],[18]. A higher spectral index (~3.0) is obtained in the hard X-rays by *SIGMA* [5],[6]. More recently, simultaneous *SAX* and *RXTE* observations demonstrated that the wide band (1-200 keV) spectrum of 1E 1724-3045 is actually power law below ~30 keV, attenuated at high energies by an exponential cutoff at ~70 keV [8],[2]. This is interpreted as the result of the Comptonization of soft photons in a spherical scattering region of electron temperature ~30 keV and optical depth ~3. Besides that, the *RXTE* and *SAX*

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