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BeppoSAX observation of the transient X-ray pulsar GS 1843+00

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Abstract. We present the results from both the timing and spectroscopic analysis of the transient X-ray pulsar GS 1843+00 observed by the *BeppoSAX* satellite on 1997 April 4, when the source was at a luminosity of $\sim 10^{37}$ erg s^{-1}. GS 1843+00 shows a very hard spectrum that is well fitted by an absorbed power law ($N_H \sim 2.3 \times 10^{22}$ cm^{-2}) modified by a high energy cut-off above 6 keV. The source shows a small pulse amplitude in the whole energy band. The pulse profile evolves with energy from a double-peaked to single-peaked shape. The barycentric pulse period is 29.477 ± 0.001 s.

Key words: stars: binaries: general – stars: neutron – stars: pulsars: individual: GC 1843+00 – X-rays: stars

1. Introduction

The transient X-ray pulsar GS 1843+00 was discovered on 1988 April 3 during a galactic plane scan observation near the Scutum region by the *Ginga* satellite (Makino et al. 1988a; Makino et al. 1988b). The Large Area Counter (LAC, Turner et al. 1989) on board *Ginga* (Makino et al. 1987) detected at a J2000 position of $\alpha = 18^{\rm h}45^{\rm m} \pm 1^{\rm m}$, $\delta = 0^\circ 55' \pm 7'$, a coherent pulsation with a period of 29.5 s and an 2–37 keV X-ray intensity of 50 mCrab (Koyama et al. 1990a). On 1988 April 19 and 20 *Ginga* carried out a pointed observation of GS 1843+00, measuring a highly variable X-ray flux on a wide range of time scales, ranging from 30 to 60 mCrab. In addition to a coherent oscillation with P$= 29.5056 \pm 0.0002$ s, an energy-dependent aperiodic variation was found (Koyama et al. 1990b).

On 1997 March 3, the Burst and Transient Source Experiment (*BATSE*) on board CGRO detected a new outburst from this peculiar source (Wilson et al. 1997). The mean 20–50 keV *rms* pulsed flux was 37 ± 2 mCrab while the mean barycentric pulse period at an epoch of March 6.0 was P$= 29.5631 \pm 0.0003$ s. The P variation during this observation implies a spin-up rate, $\dot{\rm P}$, of $(-3.65 \pm 0.11) \times 10^{-8}$ s s^{-1}. The data confirmed the low pulsed fraction ($\sim$7%) observed by *Ginga*.

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Between 1997 February 1 and March 19 the All Sky Monitor (ASM) on board the Rossi X-ray Timing Explorer (*RXTE*) observed the source to be at a flux level of $F_{2-10} \sim 15 - 30$ mCrab (Takeshima 1997).

A pointed observation carried out on 1997 March 5 with the *RXTE* Proportional Counter Array (PCA) detected the source at a 2–60 keV flux level of 62 mCrab, measuring a barycentric pulse period of 29.565 ± 0.002 s at an epoch of March 5.1712 UT (Takeshima 1997).

On 1997 April 4 the *BeppoSAX* Narrow Field Instruments (NFIs) performed a pointed observation of GS 1843+00 (Piraino et al. 1998). The source flux was $(2.9 \pm 0.3) \times 10^{-9}$erg cm^{-2}s^{-1} in the 0.3–100 keV energy range.

Using the capability of *BeppoSAX* imaging instruments, the 90% confidence J2000 position of GS 1843+00 was constrained to be within a $30''$ radius circular error region centered on $\alpha = 18^{\rm h}45^{\rm m}34^{\rm s}$, $\delta = 0^\circ 52'.5$ (Santangelo et al. 1997). On the same day, the source was also observed by the *ROSAT* High Resolution Imager (HRI) which found a J2000 position for the source of $\alpha = 18^{\rm h}45^{\rm m}36^{\rm s}.9$, $\delta = 0^\circ 51' 45''$ (90% confidence error radius $10''$, Dennerl & Greiner 1997).

In this *paper* we present the results of both a timing and spectroscopic analysis of the *BeppoSAX* observation of GS 1843+00.

2. Observation

The Satellite for X-ray Astronomy *BeppoSAX* is described in detail in Boella et al. 1997a. It carries a pay-load of four co-aligned Narrow Field Instruments: the Low Energy Concentrator Spectrometer (LECS, 0.1–10 keV; Parmar et al. 1997), the Medium Energy Concentrator Spectrometers (MECS, 1.6–10 keV; Boella et al. 1997b), the High Pressure Gas Scintillation Proportional Counter (HPGSPC, 4–100 keV; Manzo et al. 1997) and the Phoswich Detector System (PDS, 15–200 keV; Frontera et al. 1997).

The LECS and MECS are imaging instruments with an angular resolution of $\sim 1.2'$. The HPGSPC and PDS are collimated instruments with field of views (FOVs) of $1^\circ \times 1^\circ$.

The *BeppoSAX* Target Opportunity Observation Program of GS 1843+00 started at 1997 April 4 at 02:17 and ended at 15:00 UTC. Good data were selected from intervals when the

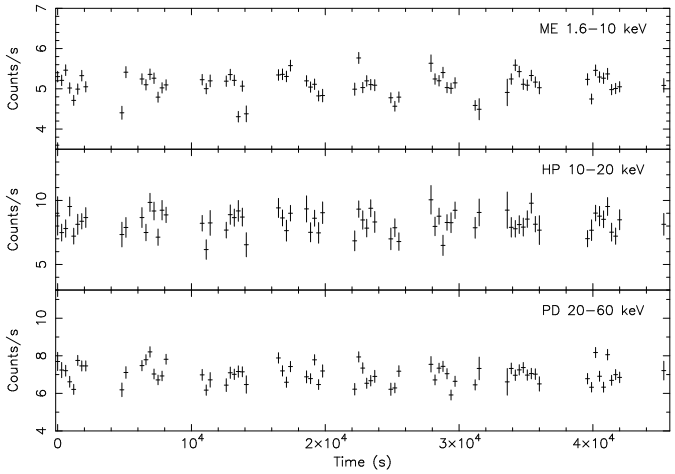

Fig. 1. GS 1843+00 background subtracted light curves in three energy ranges. The gaps are due to South Atlantic Anomaly passages and Earth occultations

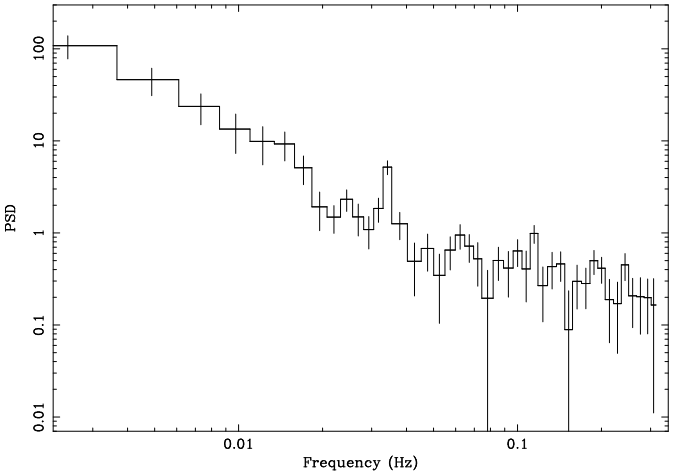

Fig. 2. GS 1843+00 power spectrum in the 1.6–10 keV energy range. The peak due to the fundamental frequency at 0.0339 Hz and the aperiodic variability are clearly visible

instrument configurations were nominal and the elevation angle, with respect to the Earth Limb, was greater then 5°. The total on-source exposure times were 8.5 ks for the LECS, which is operated only during night time, 22 ks for the MECS, 9.7 for the HPGSPC and 7.4 ks for the PDS.

The MECS light curves and spectra have been extracted, following the standard procedure, from a circular region, centered on the source with a $4'$ radius, while a $8'$ radius was used for the LECS.

For both LECS and MECS, the background subtraction, was performed using the background obtained from a long blank sky observations, rescaled by a correction factor obtained as the ratio of the count rates extracted from both the blank sky and the GS 1843+00 images, in a region of the detector far from the source location. As far as concerns the two collimated instrument, HPGSPC and PDS, the background was subtracted using the standard procedure (Segreto et al. 1997; Frontera et al. 1997) that uses the rocking collimator technique.

3. Temporal analysis

The arrival times of the photons were first converted to the solar system barycenter. In Fig. 1 we show the background subtracted X-ray light curves, obtained in three energy ranges, with 300 s time bin size. The maximum intensity variation is $\sim$30% in the 1.6–10 keV and 20–60 keV energy ranges, and 60% in 10–20 keV range.

The (1.6–10 keV) GS 1843+00 power spectrum, is shown in Fig. 2. An outstanding peak at 0.0339 Hz is clearly observed. The GS 1843+00 pulse period was obtained with an epoch-folding technique using barycentric corrected 1.6–10 keV MECS data, while the (1σ) uncertainty was determined by fitting the arrival times of sets of 9 averaged profiles, each of 16 phase bins. The best-fit period is 29.477 ± 0.001. There is no evidence for any change in spin-period during the observation with a σ upper-limit of 7.5×10^{-8} s s^{-1}. Using this period value, we folded the light curves in different energy bands. The pulse profiles in five energy ranges are shown in Fig. 3. At lower energies the pulse profile is clearly asymmetric with a double peak shape, whilst at higher energies it becomes a simple sinusoid.

The variation with energy of the pulsed fraction, defined as the semi-amplitude of the modulation divided by the average intensity, is shown in Fig. 4. There is no evidence for an increase in the fractional periodic variation with energy.

In the *BeppoSAX* observation, GS 1843+00 may have opposite behavior than during *Ginga* observation, where the pulsed fraction was found to increase with energy and the pulse profile was clearly single peaked a lower energies and more structured at higher energies (Koyama et al. 1990b).

From *BATSE*[1], *RXTE* (Takeshima 1997) and *BeppoSAX* data a clear spin-up trend ($\dot{\mathrm{P}} = -3.79 \pm 0.10 \times 10^{-8}$ s s^{-1}) over 30 days is evident (Fig. 5). The mean spin-up timescale, $\mathrm{P}/\dot{\mathrm{P}}$, is a very rapid 24.6 years. However a difference of ΔP of 0.01 s is observed between the BeppoSAX period and the one expected from the BATSE data extrapolation. This could be due to a Doppler effect of orbital motion. Actually, the change of the pulse period, ΔP, due to orbital motion is constrained to be

$$\Delta P \leq \frac{P}{c} \frac{2 \sin i}{\sqrt{1-e^2}} \left[\frac{2\pi G}{P_{orb}} (M_{NS} + M_c) \right]^{\frac{1}{3}} \quad (1)$$

where P_{orb} is the orbital period, e the eccentricity, i the inclination angle, M_{NS} the mass of the neutron star, M_c the mass of the companion star, G is the gravitational constant and c the speed of light. Following Corbet (1986) relation to estimate the orbital period (50d) and assuming a mass of 15 $M_\odot$ for the companion star, typical of Be star, the upper limit of ΔP turns out to be ~ 0.02 for circular motion.

To study the aperiodic variability, firstly reported by Koyama et al. (1990b) the (1.6–10 keV) and (10–37 keV) power spectra were fitted with a power law. The Poisson white

[1] *BATSE* data are provided on line by *BATSE* pulsar team, at http://www.batse.msfc.nasa.gov/data/pulsar/sources

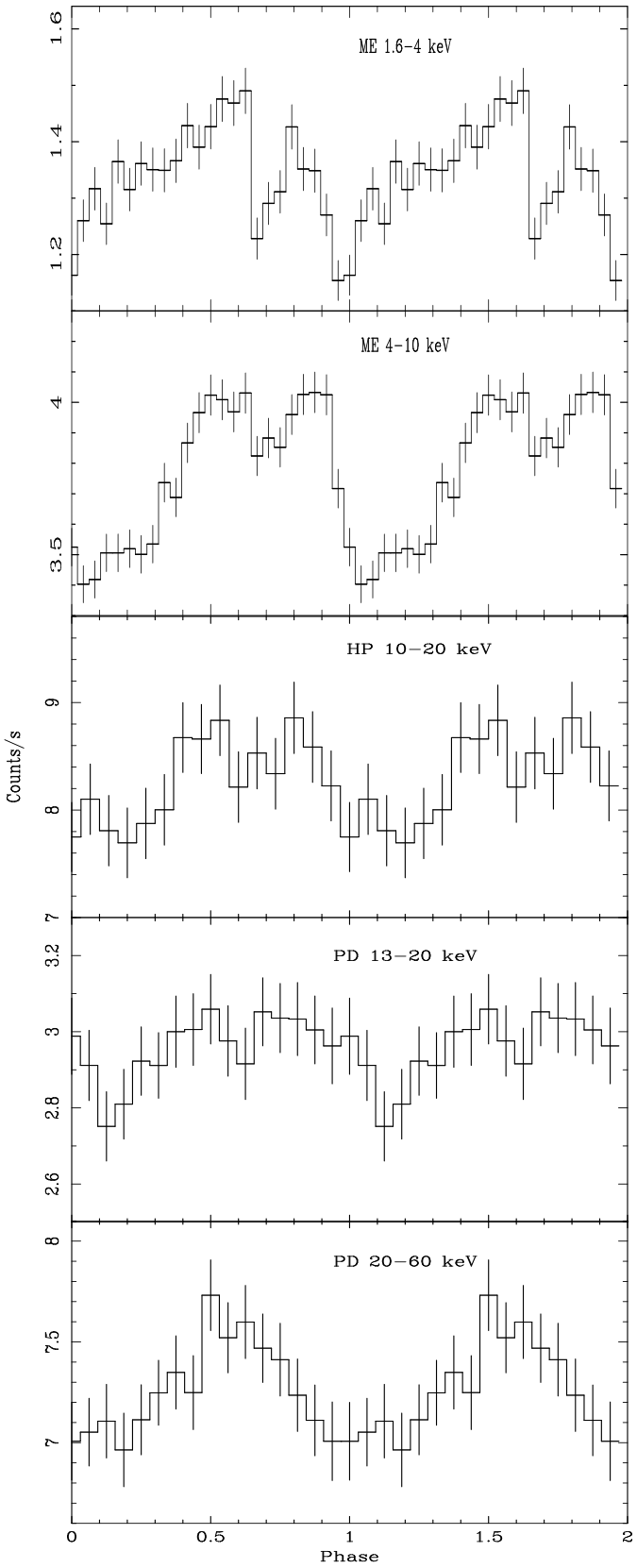

Fig. 3. GS 1843+00 pulse profiles in five energy ranges. 1σ uncertainties are shown

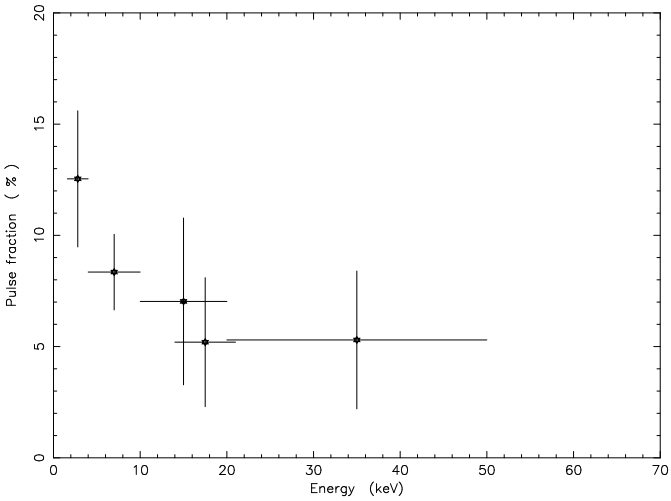

Fig. 4. The GS 1843+00 Pulsed fraction versus energy

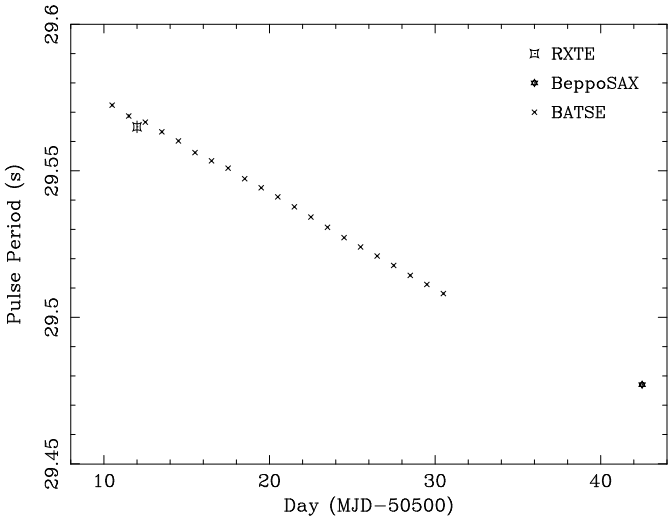

Fig. 5. The period history of the GS 1843+00 outburst between early 1997 March to early April obtained from *BATSE*, *BeppoSAX* and *RXTE*. All the data points are consistent with a smooth rapid spin-up trend

noise was subtracted from Leahy normalized power spectra (Leahy et al. 1983). The power indices, 1.44±0.17 and 0.9±0.25 respectively, are consistent with those found in the *Ginga* Observation (Koyama et al. 1990b). The relative amplitude of the aperiodic variation, calculated dividing the root square of the integrated PDS over 4×10^{-3} Hz to 10 Hz by an average intensity, is larger in the lower energy band (18%) than in the higher energy band (2%).

4. Spectral analysis

Data were selected in the energy ranges 0.1–4 keV, 1.6–10 keV, 8–40 keV and 15–40 keV, respectively for the LECS, MECS, HPGSPC and PDS, where the instrument responses are well determined and there are sufficient counts. All spectra have been rebinned to at least 20 counts for energy channel, in order to ensure the applicability of χ^2 test in the spectral fits.

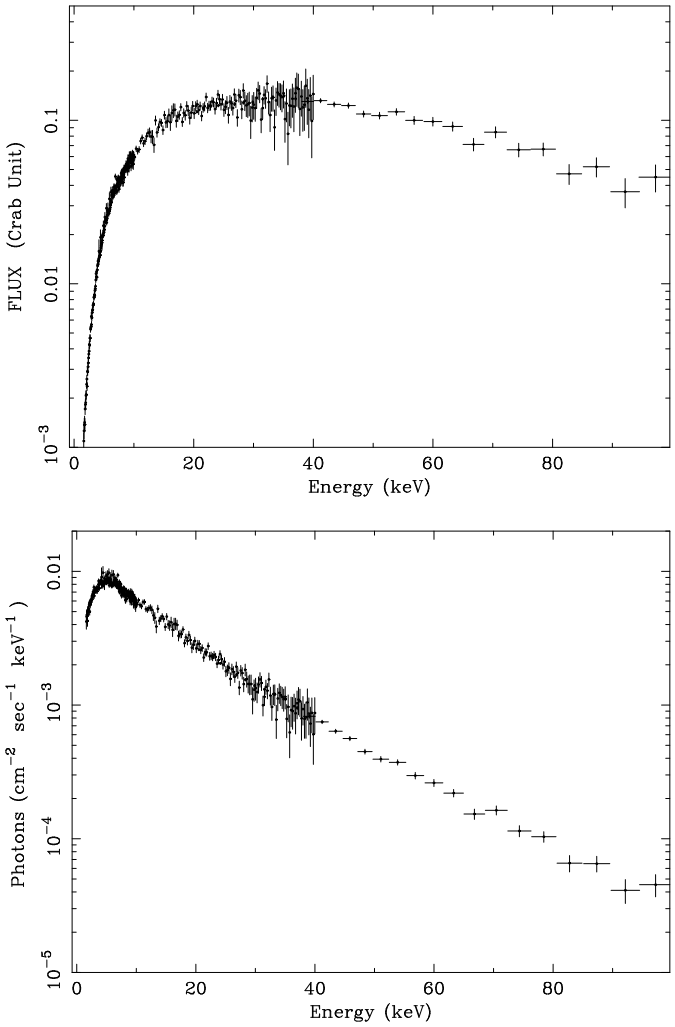

Fig. 6. Upper panel: ratio between the GS 1843+00 and Crab spectra. Lower panel: Crab ratio times the functional form of the Crab spectrum, $E^{-2.1}$

Exploiting the *BeppoSAX* spectral capability we were able to obtain the simultaneous broad band spectrum (0.1–200 keV) of GS 1843+00. The source shows a very hard spectrum strongly absorbed at lower energies. No deviation from a smooth continuum is observed. This can be seen in Fig. 6 in which the Crab ratio, upper panel, and the ratio times the functional form of the Crab (a featureless power-law with $\alpha = 2.1$ in this energy range), lower panel, are reported. To extract more physical information we fitted the phase averaged spectra obtained from the four co-aligned instruments simultaneously. The conventional model used to describe the spectrum of X-ray pulsar (Pravdo et al. 1978; White et al. 1983) is an absorbed power law with exponential cut-off at higher energies, i.e. a photon spectrum of the form

$$\mathrm{f(E)} = \mathrm{AE}^{-\alpha} \exp\{-\mathrm{N_H}\sigma(\mathrm{E}) - \mathrm{H(E)}\} \quad (2)$$

where E is the photon energy, α is the power-law photon index, $\mathrm{N_H}$ is the absorbing column and $\sigma(\mathrm{E})$ is the photoelectric absorption cross sections due to cold matter (Morrison & McCammon 1983). The high-energy cut-off is modeled by the function of the form:

$$\mathrm{H(E)} = \begin{cases} 0 & E < E_c \\ \frac{E-E_c}{E_f} & E > E_c \end{cases} \quad (3)$$

where $\mathrm{E_c}$ is the cut-off energy and $\mathrm{E_f}$ is the e-folding energy.

Table 1. Spectral Parameters for the GS 1843+00 broad band fit. All quoted uncertainties are at 90% confidence for a single parameter ($\Delta\chi^2 = 2.7$)

Parameter	Value	Units
$\mathrm{N_H}$	2.30± 0.13	10^{22} cm^{-2}
α	0.34± 0.04	
$\mathrm{E_c}$	5.95± 0.45	(keV)
$\mathrm{E_f}$	18.4± 0.6	(keV)
χ^2_ν (dof)	1.08(477)	

Using this model, we obtained a χ^2_ν of 1.08 for 477 degrees of freedom (dof). The best-fit parameters are summarized in Table 1. The spectrum together with the best-fit model are shown in the upper panel of Fig. 7. Fit residuals in terms of σ are reported in the lower panel and its show no clear evidence of any absorption or emission features. Normalization factors, between the instruments, were left free in the fits. Setting the MECS as reference, the relative normalizations are 0.83 for the LECS, 1.02 for the HPGSPC and 0.79 for the PDS. These values are in good agreement with the ones obtained from the intercalibration analysis of the four Narrow Field Instruments (Fiore et al. 1999). The inclusion in the model of a gaussian line gives a marginal improvement in fit quality (at less then 90% confidence level) for a fluorescent K_α line at 6.4 keV with a flux level of $(2.4 \pm 1.0) \times 10^{-4}$ photons cm^{-2} s^{-1}.

5. Discussion

After its discovery in 1988, GS 1843+00 was detected again in 1997 March as a bright (0.3–100 keV) $\sim 2.9 \times 10^{-9}$ erg cm^{-2}s^{-1} X-ray source. Due to the spatial capabilities of the *BeppoSAX* imaging instruments an improved position was obtained. The *BeppoSAX* position is within the *Ginga* (Koyama et al. 1990b) and RXTE (Chakrabarty et al. 1997) error boxes, and is also consistent with that measured by the *ROSAT* HRI (Dennerl & Greiner 1997). Accurate measurement of the position of the source is important in order to carry out a systematic search for the still unidentified optical counterpart. Pulsations with a period $P = 29.477 \pm 0.001$ s together a mean pulse period change $\dot{\mathrm{P}}/\mathrm{P} = -4.1 \times 10^{-2}$ yr^{-1}, which is in good agreement with the one measured by *Ginga* were found. Koyama et al. (1989) suggested that such a high spin up rate could be due, at least partly, to an orbital Doppler motion. Pulse period variations observed in the 30 days monitoring obtained by combining data from *BATSE*, *RXTE-PCA* and *BeppoSAX* , confirmed the presence of a high intrinsic spin-up rate. Moreover, assuming a Be transient system having an orbital period between 50 and 60 days, inferred from the pulse-orbital periods relation of Cor-

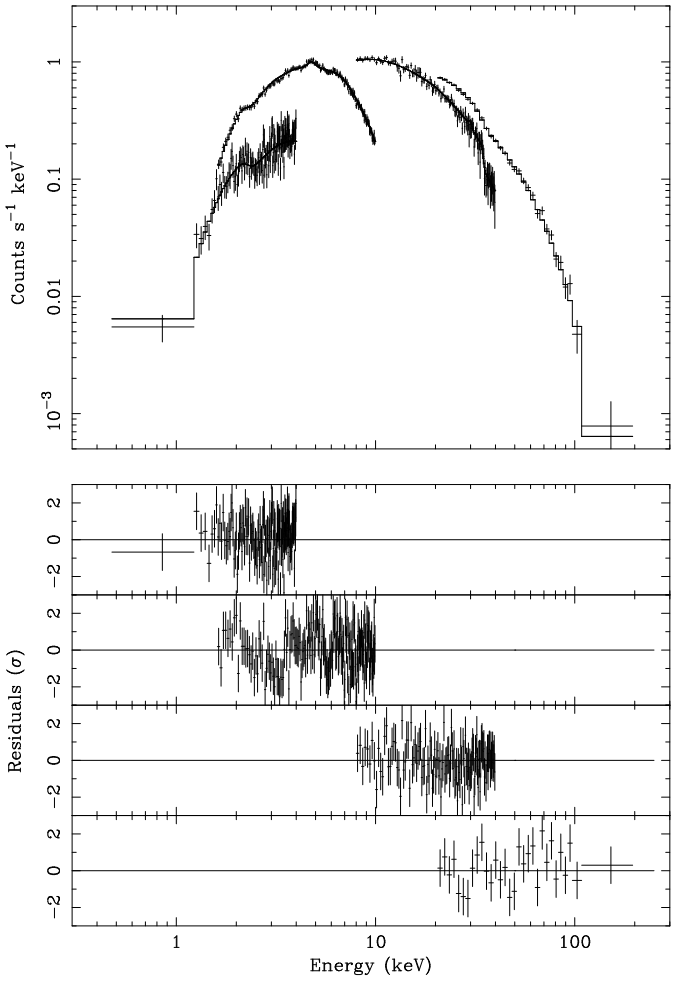

Fig. 7. Broad band LECS(0.1–4 keV), MECS(1.6–10 keV), HPGSPC(8–40 keV) and PDS(20–200 keV) X-ray spectra of GS 1843+00 during outburst fitted with model (1). The lower panel shows the residuals in terms of sigmas with error bars of size one.

bet (1986), a possible Doppler effect may be overlapped to this intrinsic spin-up rate.

The source spectrum, which is well described by an absorbed power law with high energy cut-off, is typical of accreting X-ray pulsars. The very high absorption, $N_H = 2.3 \times 10^{22} cm^{-2}$ is consistent with that reported by Koyama et al. (1990b). The hypothesis that the absorption is mainly interstellar rather then circumstellar (Koyama et al. 1990a) is supported by the marginal detection of a fluorescent K_α iron line in the source spectrum.

Assuming a distance of 10 kpc (Koyama et al. 1990a; Hayakawa et al. 1977) the 0.3–100 keV luminosity is $\sim 3 \times 10^{37}$ erg s^{-1}.

It is unclear if cyclotron resonance scattering features are present in the hard X-ray spectrum of the source. Koyama et al. (1990b) suggested that the cut-off in the spectrum observed at $\sim$18 keV could be related to a very intense magnetic field typical of this class of source. Moreover, Mihara (1995), fitting the phase resolved spectrum with an absorption-like feature at $\sim$20 keV, classified GS 1843+00 as a possible cyclotron source. Although the spectrum is observed with good statistics up to $\sim$100 keV, no evidence of any cyclotron feature is observed in the *BeppoSAX* pulse phase averaged spectrum of GS 1843+00. Also the "crab-ratio technique"(Dal Fiume et al. 1998), successfully exploited in detecting Resonance Cyclotron Features (RCFs) in other X-ray pulsars, does not display any sign of cyclotron features. Moreover no evidence of cyclotron absorption features was found in the phase resolved spectra below 100 keV. However, we found an upper limit on the depth of 0.15 for the possible 20 keV feature. This value is compatible with that found by Mihara (1995).

Manchanda (1999), using data from the LASE experiment, a balloon-born large area scintillation counter, recently suggested the possibility of an absorption feature around 100 keV or an emission at 140 keV. Unfortunately, statistics of *BeppoSAX* spectra is quite low at that energy and a much deeper analysis, which is underway, is required.

There are $\sim$80 known accreting X-ray pulsars (see Bildsten et al. 1997 for a recent review). Until recently only the relatively bright nearby pulsars were visible due to the limited sensitivity of previous detectors. This is changing with the discovery by *ASCA*, *ROSAT*, *BeppoSAX* and *RXTE* of a population of faint, absorbed pulsars (e.g., Angelini et al. 1998; Kinugasa et al. 1998, Torii et al. 1998). The search for faint pulsars is one of the main scientific objectives of the *ASCA* galactic plane survey (e.g., Sugizaki et al. 1997; Torii et al. 1998).

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