Broad band X-ray spectrum of KS 1947+300 with BeppoSAX

S. Naik¹,², P. J. Callanan², B. Paul³, and T. Dotani¹

ABSTRACT

We present results obtained from three BeppoSAX observations of the accretion-powered transient X-ray pulsar KS 1947+300 carried out during the declining phase of its 2000 November – 2001 June outburst. A detailed spectral study of KS 1947+300 across a wide X-ray band (0.1–100.0 keV) is attempted for the first time here. Timing analysis of the data clearly shows a 18.7 s pulsation in the X-ray light curves in the above energy band. The pulse profile of KS 1947+300 is characterized by a broad peak with sharp rise followed by a narrow dip. The dip in the pulse profile shows a very strong energy dependence. Broad-band pulse-phase-averaged spectroscopy obtained with three of the BeppoSAX instruments shows that the energy spectrum in the 0.1–100 keV energy band has three components, a Comptonized component, a ∼ 0.6 keV blackbody component, and a narrow and weak iron emission line at 6.7 keV with a low column density of material in the line of sight. We place an upper limit on the equivalent width of the iron Kα line at 6.4 keV of ∼ 13 eV (for a width of 100 eV). Assuming a spherical blackbody emitting region and the distance of the source to be 10 kpc, the radius of the emitting region is found to be in the range of 14–22 km, which rules out the inner accretion disk as the soft X-ray emitting region.

Subject headings: stars: neutron- Pulsars: individual: KS 1947+300 -X-rays: stars

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1. Introduction

Accretion powered X-ray pulsars are binary systems consisting of a neutron star and a stellar companion. The X-ray luminosity of these sources depends on the rate of mass accretion from the binary companion, and hence generally variable. Transient behavior is also observed in many X-ray binary pulsars, most of which have a Be star companion with an eccentric orbit (Bildsten et al. 1997). The mass donor in these Be binary system is a B star which is still on the main sequence and lying well inside its Roche surface. The energy spectra of the X-ray pulsars are generally described by a power-law continuum with a high energy cut-off. A fluorescent iron emission line at 6.4 keV has been observed in many X-ray pulsars which serves as a probe of the surrounding matter. As most of the X-ray pulsars are located in the Galactic plane with large interstellar absorption (Bildsten et al. 1997), they do not show the presence of a soft excess in the energy spectra, in contrast to those pulsars in the Small and Large Magellanic Clouds where the interstellar absorption is one to two orders of magnitude less. A systematic study of a sample of X-ray pulsars which show soft excess revealed that the soft excess is a common feature in the X-ray pulsar spectra and the possible origins of the soft excess are emission from accretion column, emission by a collisionally energized cloud, reprocessing by a diffuse cloud, and reprocessing by optically thick material in the accretion disk (Hickox et al. 2004). As broad-band X-ray spectroscopy has rarely been performed on transient X-ray binary pulsars, it is not clear whether the soft component is a common feature among these sources.

KS 1947+300 is an accretion powered X-ray pulsar consisting of a neutron star and a high mass stellar companion. The source was discovered on 1989 June 08 by the TTM coded-mask X-ray spectrometer aboard the Kvant module of the Mir orbiting space station (Borozdin et al. 1990). The source was again detected thrice in 1989 June and July but invisible in a 1989 August observation. The transient Be X-ray binary pulsar GRO J1948+32 was discovered with the Burst and Transient Source Experiment (BATSE) detectors on board the Compton Gamma Ray Observatory (CGRO) satellite in 1994 April 6 (Finger et al. 1994). The pulsar was detected when the 20–75 keV flux increased from about ∼25 mCrab to 50 mCrab: it decayed to below the detection threshold of the BATSE detectors within 25 days. During the outburst, 18.7 s pulsations were detected in the hard X-ray extending up to 75 keV. The 20–120 keV BATSE photon spectrum was described by a power-law spectral model with a photon index of $\gamma = 2.65 \pm 0.15$. RXTE observations of KS 1947+300 during an outburst in 2000 October revealed pulsations of 18.76 s which is consistent with the transient pulsar being identical with GRO J1948+32 having slowed down from the 1994 April spin period of 18.70 s at an average rate of 8 ms yr$^{-1}$ (Swank & Morgan 2000). This made the identity of KS 1947+300 with GRO J1948+32 virtually certain. 18.70 s pulsations were also detected in the BeppoSAX observations of the pulsar
during the declining phase of the 2000-2001 outburst (Naik et al. 2006).

A search through 5 years of RXTE/ASM data provided evidence for 41.7 day orbital periodicity of KS 1947+300 (Levine & Corbet 2000). A joint fit to the data obtained from a series of RXTE observations of KS 1947+300 during the 2000-2001 outburst and a smaller outburst in 2002 July, along with the BATSE measurement from the 1994 outburst, lead to an accurate measurement of the orbital parameters. The orbit is very close to being circular, quite unexpected for such an wide orbit with $a_x \sin i = 137$ lt-s. Assuming the mass of the neutron star in the binary system to be $1.4 M_\odot$, and using the derived orbital parameters, Galloway et al. (2004) estimated the lower limit on the mass of the companion to be $3.4 M_\odot$. The absence of eclipses in the ASM or RXTE-PCA light curves rules out an inclination $i \geq 85^\circ$. In one occasion during the 2000-2001 outburst, Galloway et al. (2004) found an increase in pulse frequency by $\sim 1.8 \times 10^{-6}$ Hz in $\leq 10$ hr over and above the mean trend without any indication of any large increase in X-ray flux. The luminosity dependence of the pulse profiles of the pulsar is found from the occasional presence of the pulsar in the field of view of the INTEGRAL observations of the Galactic plane (Tsygankov & Lutovinov 2005). Using the magnetized neutron star model, they have estimated the distance and magnetic field of the source to be $9.5 \pm 1.1$ kpc and $2.5 \times 10^{13}$ G respectively.

The optical counterpart to the transient X-ray source KS 1947+300 is a moderately reddened $V = 14.2$ early type Be star located at an approximate distance of $\sim 10$ kpc in an area of low interstellar absorption slightly above the Galactic plane (Negueruela et al. 2003). Assuming the intrinsic luminosity of the star to be normal for its spectral type, the X-ray luminosity during the peak of the 2000 October outburst reveals that it was a typical Type II outburst of a Be/X-ray transient. However, although the source has been observed several times with the BATSE and RXTE, the spectral properties of the pulsar at low energies are not well understood. In this paper, we present the timing and spectral properties of KS 1947+300 using data from the Low Energy Concentrator Spectrometer (LECS), the Medium Energy Concentrator Spectrometers (MECS), and the hard X-ray Phoswich Detection System (PDS) instruments of the BeppoSAX in the energy band of 0.1–100.0 keV during the decaying phase of a major outburst in 2000 November – 2001 June. We compare these properties of KS 1947+300 with those of other accreting binary X-ray pulsars.

2. Observations

Several X-ray outbursts of KS 1947+300 have been observed with the RXTE/ASM, including a prominent outburst in 2000 November – 2001 June followed by a few outbursts
of lower intensity. During the decline phase of the 2000 November – 2001 June outburst, the pulsar was observed with the BeppoSAX narrow field instruments on 2001 March 16, 2001 April 1 and 2001 April 13. The RXTE/ASM light curve of the source between 2000 September 23 and 2001 May 31 is shown in Figure 1. The arrow marks in the figure indicate the BeppoSAX observations of the pulsar. The details of the BeppoSAX observations are given in Table 1. We have used data from the LECS, MECS and PDS instruments on-board BeppoSAX satellite. The LECS, MECS, and PDS detectors are sensitive in 0.1–10.0 keV, 1.3–10.0 keV, and 15.0-300 keV respectively. The MECS consists of two grazing incidence telescopes with imaging gas scintillation proportional counters in their focal planes. The LECS uses an identical concentrator system as the MECS, but utilizes an ultra-thin entrance window and a driftless configuration to extend the low-energy response to 0.1 keV. The PDS detector is composed of 4 actively shielded NaI(Tl)/CsI(Na) phoswich scintillators with a total geometric area of 795 cm$^2$ and a field of view of 1.3$^\circ$ (FWHM). The time resolution of the instruments during these observations was 15.25 µs and energy resolutions of LECS, MECS, and PDS are 25% at 0.6 keV, 8% at 6 keV and ≤ 15% at 60 keV respectively. The effective area of LECS at 0.28 keV is 22 cm$^2$ and that of MECS detector at 6.4 keV is 150 cm$^2$. For a detailed description of the BeppoSAX mission, we refer to Boella et al. (1997) and Frontera et al. (1997).

### 3. Timing Analysis

We have used data from LECS, MECS, and PDS detectors for timing analysis. The arrival times of the photons collected in all detectors were first converted to those appropriate for the solar system barycenter. Light curves with a time resolution of 0.1 s were extracted from the LECS and MECS event data using circular regions of radius 4′ and 6′ around the source. Light curves in the energy band of 15-150 keV with same time resolution were extracted from the PDS data for all three BeppoSAX observations. For the measurement of the pulse period, pulse folding and a $\chi^2$ maximization method was applied to all the light curves. We have derived the pulse periods of KS 1947+300 to be

<table>
<thead>
<tr>
<th>Year of Obs.</th>
<th>Start Time (Date, UT)</th>
<th>End Time (Date, UT)</th>
<th>Exposure (ks)</th>
<th>LECS</th>
<th>MECS</th>
<th>PDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001 March</td>
<td>16, 18:12</td>
<td>17, 15:22</td>
<td>5</td>
<td>31</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>2001 April</td>
<td>01, 05:58</td>
<td>02, 05:07</td>
<td>13</td>
<td>39.5</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>2001 April</td>
<td>13, 01:50</td>
<td>14, 01:15</td>
<td>15.5</td>
<td>40</td>
<td>18.5</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 1.— The RXTE-ASM light curve of KS 1947+300 in 1.5-12 keV energy band, from 2000 September 23 (MJD 51800) to 2001 May 31 (MJD 52060). The arrows mark the dates of the BeppoSAX observations which are used for the analysis.

Fig. 2.— The MECS pulse profiles in 1.3-10.0 keV energy band, obtained by using corresponding pulse periods, of KS 1947+300 are shown for the three BeppoSAX observations; 2001 March observation at the top panel, 2001 April 01 observation at the middle panel, and 2001 April 13 observation at the bottom panel. Two pulses are shown for clarity. The epoch is adjusted for each observation to obtain the minimum at phase zero. The errors are estimated for 1 sigma confidence level.
18.70696(7) s, 18.70641(6) s, and 18.70969(5) s on 2001 March 16, 2001 April 01 and 2001 April 13 respectively. The quoted uncertainties (3σ confidence level) in the pulse periods represent the trial periods at which the χ² decreases from the peak value by three standard deviation of the χ² values over a wide period range far from the peak. The pulse period measurements have been corrected for the Doppler shift due to the orbital motion of the neutron star using orbital parameters determined by Galloway et al. (2004).

The pulse profiles obtained from the MECS data of the three BeppoSAX observations are shown in Figure 2 with 1 sigma errors. It is observed that the shape of the pulse profiles in the low energy band (0.1–10 keV) is different to that obtained from the BATSE observations in 20–75 keV energy band (Chakrabarty et al. 1995). The presence of a sharp peak at the rising part of the MECS profile followed by a dip like structure (Figure 2) is absent in the 20–75 keV profile obtained from BATSE. To study the energy dependence of the pulse profiles in KS 1947+300, we generated light curves in 8 different energy bands from the LECS, MECS and PDS event data of the 2001 April 01 observation. The pulse profiles obtained from these light curves are shown in Figure 3 with 1 sigma errors. It is found that the pulsations are detected in the light curves up to ∼ 100 keV, as seen in GX 1+4 (Naik et al. 2005). In the low energy band (0.1–3.0 keV of the LECS, top panel), the pulse profile is flat at the top and characterized by the absence of the narrow peak whereas the peak is very prominent in the 3.0–75.0 keV energy range. The peak disappears again in the 75.0–100 keV energy band. The light curve above 100 keV is mainly background dominated and pulsations are not detected above 100 keV.

4. Spectral Analysis

4.1. Pulse phase averaged spectroscopy

For the spectral analysis, we have extracted LECS spectra from regions of radius 6′ centered on the object (the object was at the center of the field of view of the instrument). The combined MECS source photons (MECS 2+3) were extracted from circular regions with a 4′ radius. The response matrices released by BeppoSAX Science Data Center (SDC) in 1998 November were used for the spectral fitting. Background spectra for both LECS and MECS instruments were extracted from the appropriate blank-fields with annular regions around the source. We rebinned the LECS spectra to allow the use of the χ²-statistic. Events were selected in the energy ranges 0.1–4.0 keV for the LECS, 1.65–10.0 keV for the MECS and 15.0–100.0 keV for the PDS where the instrument responses are well determined. Combined spectra from the LECS, MECS and PDS detectors, after appropriate background subtraction, were fitted simultaneously. All the spectral parameters, other than the relative
Fig. 3.— The LECS, MECS, and PDS pulse profiles of KS 1947+300 during the declining phase of the 2000 December - 2001 April outburst (2001 April 01 BeppoSAX observation) are shown here for different energy bands with 32 phase bins per pulse respectively. The errors are estimated for 1 sigma confidence level. Two pulses in each panel are shown for clarity.
normalization, were tied for all three detectors.

Simultaneous spectral fitting of the broad-band energy spectrum (0.1–100 keV) of KS 1947+300 with a single power-law model and the line of sight absorption yielded a very poor fit. Addition of an iron emission line at \( \sim 6.7 \) keV and a high energy cutoff to the model, while improving the spectral fit slightly, produced an unacceptable reduced \( \chi^2 \) of \( \sim 3 \). As the broad-band continuum spectra of a few pulsars and also the medium and hard X-ray spectrum of KS 1947+300 (Galloway et al. 2004) are described by a Comptonized component, we subsequently fitted the combined spectrum of KS 1947+300 using a model consisting of a Comptonized continuum (compTT in XSPEC) with the geometry switch value equals to 1 (planar), along with a Gaussian function, and the interstellar absorption. We found that the above model requires a blackbody component for the soft excess to fit the broad-band energy spectrum of the pulsar with reduced \( \chi^2 \) in the range of 1.1–1.7.

In all the three BeppoSAX observations, the interesting results we found are:

- The hydrogen column density along the line of sight \( (N_H) \) is unusually low. The value of \( N_H \) is found to be in the range of \( 4.0-5.0 \times 10^{21} \) atoms cm\(^{-2} \) whereas in the direction of the source, the estimated value of hydrogen column density for the entire length of the galaxy is \( \sim 1.2 \times 10^{22} \) atoms cm\(^{-2} \). However, using the value of \( A_v = 3.38 \) (Negueruela et al. 2003) in the relation \( N_H/A_v = 1.79 \times 10^{21} \) atoms cm\(^{-2} \) mag\(^{-1} \) (Predehl & Schmitt 1995), we calculate the value of \( N_H \) to be \( 6 \times 10^{21} \) atoms cm\(^{-2} \), in good agreement with our X-ray measurements with BeppoSAX.

- The temperature of the soft blackbody component is found to be \( \sim 0.6 \) keV. The higher value of blackbody temperature for the soft excess compared to a value of 0.1-0.2 keV of the same in several other accreting pulsars (Paul et al. 2002) implies that the radius of the blackbody emission region (assuming a spherical geometry and the distance of the source as 10 kpc) is in the range of 14-21 km which is very small compared to the Alfven radius. This rules out the inner accretion disk as the possible soft X-ray emission region. The contribution of the blackbody flux to the total flux is estimated to be 8-9%. The blackbody radius at different pulse phases for the April 13 observation is in the range of 11-15.5 km while the phase averaged value is 14.5 km. The blackbody radius was calculated from the estimated blackbody flux by assuming a spherical emission zone.

- The detection of an iron emission line at \( \sim 6.7 \) keV and the absence of the iron \( K_a \) emission line at 6.4 keV. The 6.7 keV iron line flux is found to be decreasing along with the hard X-ray flux during the BeppoSAX observations of the pulsar whereas
the equivalent width of the emission line is found to be similar (within measurement errors).

Among the three BeppoSAX observations, the source was brightest on March 16 with a 0.1–100.0 keV flux of $\sim 4.3 \times 10^{-9}$ ergs cm$^{-2}$ s$^{-1}$ and faintest on April 13 with a flux of $\sim 2.0 \times 10^{-9}$ ergs cm$^{-2}$ s$^{-1}$ in above energy band. Assuming a distance of 10 kpc for the source, the total broad band (0.1–100 keV) X-ray luminosity of the X-ray pulsar is 5.1, 3.3, and 2.4 times $10^{37}$ ergs s$^{-1}$ during the three observations made with BeppoSAX respectively. Though the source intensity varies by a factor of 3, no systematic changes are observed in the spectral parameters. Over about 30 days, even the equivalent width of the iron emission has remained same within the measurement errors. The spectral parameters of the Comptonized continuum model obtained from the simultaneous spectral fitting to the LECS, MECS, and PDS data of the three BeppoSAX observations are given in Table 2. The count rate spectra of all observations are shown in Figure 4 along with the residuals to the best-fit Comptonization model in the bottom panel.

### 4.2. Pulse phase resolved spectroscopy

The presence of a significant energy dependent dip in the rising part of the pulse profile of KS 1947+300 prompted us to make a detailed study of the spectral properties at different pulse phases of the neutron star. To estimate the change in the spectral parameters at different pulse phases, we have carried out pulse phase resolved spectroscopy during 2001 April 13 observations in which the all three instruments had long exposures. The LECS and MECS spectra were accumulated into 10 pulse phase bins by applying phase filtering in the FTOOLS task XSELECT. The LECS and MECS background spectra, used for phase-averaged spectroscopy, were used for the phase-resolved spectral fitting. The PDS phase resolved spectra were accumulated into 10 pulse phases from the corresponding event file by using the program "pdproduct". Appropriate LECS, MECS, and PDS response files were used for the phase-resolved spectral fitting.

The phase resolved spectra were fitted with the same model used to describe the phase averaged spectra of KS 1947+300 keeping the iron emission line energy and width fixed at the phase averaged values. The results obtained from the phase resolved spectral analysis did not show any significant variation of $N_H$ over the pulse phase. This suggests that the column density is not coupled with the rotation of the neutron star in the binary system. The blackbody temperature ($kT_{BB}$) of the soft excess was also found to have similar value within the measurement error throughout the spin phases. As the optical depth ($\tau$) and the temperature of the Comptonizing plasma ($kT$) are anti-correlated, we therefore froze...
Fig. 4.— Energy spectra of KS 1947+300 obtained with the LECS, MECS and PDS detectors of 2001 March 16 (left panel), April 01 (middle panel), and April 13 (right panel) BeppoSAX observations, along with the best-fit model comprising a blackbody component, Comptonized continuum model and a narrow iron line emission. The data in 0.1–4.0 keV, 1.65–10.0 keV, and 15.0–100.0 keV ranges are used for the LECS, MECS, and PDS detectors respectively. The individual spectral components are also shown in the top panels. The bottom panels show the contributions of the residuals to the $\chi^2$ for each energy bin for each observations.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>16 March</th>
<th>01 April</th>
<th>13 April</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_H$</td>
<td>4.3±0.1</td>
<td>4.5±0.1</td>
<td>4.3±0.3</td>
</tr>
<tr>
<td>$kT_{BB}$ (keV)</td>
<td>0.65±0.01</td>
<td>0.62±0.01</td>
<td>0.63±0.01</td>
</tr>
<tr>
<td>Line Energy (keV)</td>
<td>6.7±0.1</td>
<td>6.62±0.11</td>
<td>6.60±0.26</td>
</tr>
<tr>
<td>Line width (keV)</td>
<td>0.01±0.13</td>
<td>0.01±0.13</td>
<td>0.01±0.50</td>
</tr>
<tr>
<td>Eqw. width (eV)</td>
<td>30±9</td>
<td>29±9</td>
<td>19±12</td>
</tr>
<tr>
<td>Line Flux$^2$</td>
<td>4.3±1.2</td>
<td>2.7±1.0</td>
<td>1.3±0.8</td>
</tr>
<tr>
<td>$kT_0$ (keV)</td>
<td>1.6±0.1</td>
<td>1.64±0.02</td>
<td>1.75±0.04</td>
</tr>
<tr>
<td>kT (keV)</td>
<td>12.4±0.1</td>
<td>13.22±0.04</td>
<td>13.7±0.5</td>
</tr>
<tr>
<td>$\tau$</td>
<td>2.64±0.01</td>
<td>2.45±0.01</td>
<td>2.33±0.11</td>
</tr>
<tr>
<td>Reduced $\chi^2$</td>
<td>1.7 (184)</td>
<td>1.2 (184)</td>
<td>1.1 (178)</td>
</tr>
<tr>
<td>Blackbody flux$^3$</td>
<td>3.8</td>
<td>2.1</td>
<td>1.6</td>
</tr>
<tr>
<td>(0.1-10.0 keV range)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CompTT flux$^3$</td>
<td>39.3</td>
<td>25.4</td>
<td>18.9</td>
</tr>
<tr>
<td>(0.1-100.0 keV range)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$kT_{BB} =$ Blackbody temperature, $kT_0 =$ Input spectrum temperature
kT = plasma temperature,$^1$ : $10^{21}$ atoms cm$^{-2}$
$^2$ : $10^{-4}$ photons cm$^{-2}$ s$^{-1}$, $^3$ : $10^{-10}$ ergs cm$^{-2}$ s$^{-1}$
the $N_H$, $kT_{BB}$, and $kT$ to the pulse phase averaged values and repeated the pulse phase resolved spectroscopy. The parameters obtained from simultaneous spectral fitting to the LECS, MECS, and PDS phase resolved spectra are plotted in Figure 5. The errors shown in the figure are estimated for a 90% confidence level. The smooth variation of the blackbody normalization over the pulse phase (second panel from top) explains the absence of the dip feature in the pulse profiles of the soft X-ray energy bands. The variation of the blackbody normalization component over the pulse phase also indicates the pulsating nature of the soft component. The variation of the normalization of the Comptonized component over the pulse phase is shown in the third panel of Figure 5. The presence of a dip like structure at the same phase bin to that of the pulse profile (top panel) confirms that the dip which is absent at the soft X-rays ($<3$ keV) is prominent in the hard spectral component. However, the variation of the other spectral components is not significant enough to get any clear understanding of the nature of the dip in the pulse profile.

5. Discussion

5.1. Pulse period evolution and energy dependence of the Pulse profile

The spin-down of the pulsar KS 1947+300 was observed at an average rate of 8 ms yr$^{-1}$ (Swank & Morgan 2000). BeppoSAX measurements of the spin period of KS 1947+300 on three occasions in 2001 March-April (present work) shows that the pulsar has spun-up rapidly within about 4 months. The X-ray luminosity of the pulsar during the BeppoSAX observations in 2001, when the source was in the decaying phase of the outburst, is in the range of 2–5 times $10^{37}$ ergs s$^{-1}$. The additional torque due to the accretion of the matter which triggered the X-ray outburst in this transient X-ray pulsar, therefore has caused a transient spin-up of the pulsar. However, the spin evolution of the pulsar is studied in more detail from regular RXTE monitoring in 2000 November 21 - 2001 June 18 and 2002 March 29 - 2002 May 17 (Galloway et al. 2004). Pulse timing analysis of above two sets of RXTE observations showed that the rate of increase in the pulse frequency is approximately proportional to the X-ray flux of the pulsar.

During the BeppoSAX observations of KS 1947+300 when the MECS pulse profile was characterized by a narrow peak and a broad peak as was seen in RXTE-PCA profiles at higher flux levels (Galloway et al. 2004), the energy resolved pulse profiles, as shown in Figure 3, are found to be strongly energy dependent. At low energies (0.1–3.0 keV band), the profile is characterized by a flat top without the narrow peak. At higher energies, a sharp peak followed by a dip appears at the rising part of the profile. This feature is seen in the pulse profiles in the energy band of 3.0–75.0 keV beyond which the feature
Fig. 5.— Spectral parameters obtained from pulse phase resolved spectroscopy of 2001 April 13 BeppoSAX observation of KS 1947+300. The smooth variation of the blackbody normalization (second panel from top) indicates the absence of the narrow dip in soft X-rays which is clearly seen in 15-75 keV pulse profiles (Figure 3).
disappears as the X-ray light curves are background dominated. Pulse phase resolved spectral analysis confirmed the absence/presence of the narrow dip in the pulse profiles because of the absence of the notch in the blackbody component which is seen in the hard Comptonised component. The observed change in shape of pulse profiles of KS 1947+300 with energy is also seen in some binary pulsars such as 4U 1626-67 (Angelini et al. 1995; Chakrabarty et al. 1997), LMC X-4 (Naik & Paul 2004a), SMC X-1 (Naik & Paul 2004b), EXO 053109-6609.2 (Paul et al. 2004) etc.

5.2. The broad band X-ray spectrum of KS 1947+300

Since the first detection of KS 1947+300, it has been observed with the BATSE, RXTE, BeppoSAX, and INTEGRAL observatories. Though pulse phase averaged spectral studies of KS 1947+300 have been done in the 20–75 keV energy range using X-ray data from the BATSE instruments (Chakrabarty et al. 1995), broad band X-ray spectroscopy in 0.1–100 keV energy range is reported here for the first time. The 20–75 keV BATSE spectra were described by a power-law with spectral index of 2.65 when the source was bright. However, during quiescence, the RXTE/PCA spectra of KS 1947+300 above 2 keV was described by a cutoff power-law spectrum with a photon index of about 0.6 and e-folding energy of 10 keV above a cut-off energy of 6 keV with a small column density (< $10^{21}$ cm$^{-2}$) (Swank & Morgan 2000). Galloway et al. (2004) also carried out a spectral study of the pulsar using RXTE data during the 2000-2001 and 2002 July outbursts. A Comptonized continuum component along with a blackbody component and a Gaussian representing the fluorescent Fe K$_\alpha$ emission was used to describe the source spectrum in 2–80 keV energy range (2–25 keV RXTE-PCA spectrum and 15–80 keV RXTE-HEXTE spectrum). A blackbody component with kT $\sim$ 3–4 keV (at the peak of the outburst) or an additional broad Gaussian component (\$\sigma$ $\sim$ 10 keV) was also required by these authors to achieve the best fit to the X-ray spectra. Though the energy range used for spectral fitting is 2–80 keV, Galloway et al. (2004) estimated the value of the column densities of neutral matter to be consistent with the line-of-sight value i.e. $\sim 10^{22}$ atoms cm$^{-2}$. In the hard X-ray band, the best spectral measurements reported so far are with the INTEGRAL, and the X-ray spectrum in the 5–90 keV band is fitted well with an exponentially cut-off power law with cut-off energy at 8.6 keV (Tsygankov & Lutovinov 2005).

These are the only occasions when a study of the X-ray properties of KS 1947+300 has been attempted. Though a power-law continuum component was used to describe the spectrum of KS 1947+300 in some of the earlier spectral studies in relatively narrow energy bands, it is found to be unsuitable when fitted to the broad-band BeppoSAX spectra. A
Comptonization continuum component, as used to describe the spectrum of a few other accretion powered X-ray pulsars, along with a high energy cutoff and an iron emission line is found to provide the best broad-band spectral fit. Even though Galloway et al. (2004) fitted the energy spectra of KS 1947+300 using a Comptonized component, the significant differences in results obtained from 2.0–80.0 keV RXTE spectral fitting and broad-band spectral fitting in 0.1–100.0 keV energy range of BeppoSAX data are

- the temperature of the blackbody component used to explain the soft excess is much less (\(\sim 0.6\) keV) compared to that of 3–4 keV which was required to fit the RXTE spectra (Galloway et al. 2004).

- the value of the column density measured from BeppoSAX data is found to be significantly lower than that estimated from the RXTE observations, and

- the iron emission line is found to be located at \(\sim 6.7\) keV in 0.1–100.0 keV BeppoSAX spectra although it was reported earlier to be iron K\(\alpha\) emission line from the RXTE observations.

The value of the hydrogen column density estimated from the broad-band spectral fitting of the three BeppoSAX observations is found to \(\sim 4-5 \times 10^{21}\) atoms cm\(^{-2}\), which is about one half of the integrated value of the Galactic column density in this direction. This indicates a very low absorption by material close to the X-ray binary. Optical observations of the counterpart of KS 1947+300 also suggest that the binary system is located in an area of low interstellar absorption slightly above the Galactic plane (Negueruela et al. 2003).

It has been proposed that all/most of the accretion powered X-ray pulsars have an excess soft X-ray emission, the origin of which varies from source to source mainly due to the intrinsic X-ray luminosity (Hickox et al. 2004). Sources located in the Galactic plane are usually subjected to strong X-ray absorption and the soft excess is usually not detectable. The soft component is detectable only in those pulsars which do not suffer from strong absorption by material along the line of sight, such as LMC X-4 (\(N_H \sim 6 \times 10^{20}\) atoms cm\(^{-2}\); Naik & Paul 2004a, Paul et al. 2002), SMC X-1 (\(N_H \sim 2-5 \times 10^{21}\) atoms cm\(^{-2}\); Naik & Paul 2004b, Paul et al. 2002), EXO 053109-6609.2 (\(N_H \sim 0.6-3.0 \times 10^{21}\) atoms cm\(^{-2}\); Paul et al. 2004), Her X-1 (\(N_H \sim 4 \times 10^{21}\) atoms cm\(^{-2}\); Endo et al. 2002), 4U 1626-67 (\(N_H \sim 1 \times 10^{21}\) atoms cm\(^{-2}\); Orlandini et al. 1998), Cen X-3 (\(N_H \sim 2 \times 10^{22}\) atoms cm\(^{-2}\); Burderi et al. 2000), XTE J0111.2–7317 (\(N_H \sim 2 \times 10^{21}\) atoms cm\(^{-2}\); Yokogawa et al. 2000) etc. The column density measurement for these X-ray pulsars have been made by observatories with good sensitivity at low energies, such as BeppoSAX and ASCA.
In the high luminosity systems, the soft excess emission is likely to be from the inner part of the accretion disk with a temperature of about 0.1-0.2 keV. In the quiescent states of some accretion-powered X-ray pulsars, a higher temperature (kT~1.0 keV) blackbody component has been detected (Mukherjee & Paul (2005) and references therein). A blackbody component with a temperature of about 0.5 keV is quite common in the anomalous X-ray pulsars (Paul et al. 2000). However, the area of the emission zone in the two later cases are about a few km$^2$ and are, therefore, likely to be from the surface of the neutron star. The soft excess emission zone in KS 1947+300 has a size of more than 10 km$^2$ and the accretion column is a more likely origin. The pulsation detected in the blackbody component also suggests the accretion column origin of the soft excess. However, we note that Hickox et al. (2004) have argued against a accretion column origin of the soft excess from the point of view of brightness temperature.

Broad-band phase-averaged spectroscopy of KS 1947+300 shows the presence of a weak and narrow 6.7 keV iron emission line with equivalent width in the range of 55–85 eV. It is interesting to note that the 6.7 keV iron line is present in all three BeppoSAX spectra of KS 1947+300 while the 6.4 keV emission line is absent. The 6.7 keV line is identified as emission from helium like iron. This emission line might be regarded as due to the radiative recombinations of H-like iron followed by cascade processes in a relatively hot corona (Hirano et al. 1987). Similar iron emission at 6.67 keV with an equivalent width of 107 eV was detected in the absence of the 6.4 keV emission line in the BeppoSAX spectrum of the high mass X-ray binary pulsar Cen X-3 (Burderi et al. 2000). The Ginga observation of Cen X-3 also showed the presence of 6.7 keV line during mid-eclipse, when the 6.4 keV line was relatively weak (Nagase et al. 1992). This line was interpreted as the emission from He-like iron ions in a hot plasma emitting resonance and fluorescence lines at 6.63, 6.67 and 6.70 keV. By taking into account the heating of an X-ray irradiated plasma by Compton scattering and photoionization and cooling by thermal bremsstrahlung and line emission, Hirano et al. (1987) showed that the emission lines with energies ≥ 6.63 keV are emitted by recombination and subsequent cascades, whereas the lines with energies ≤ 6.63 keV are due to X-ray fluorescence.

As the MECS detectors of BeppoSAX do not have sufficient spectral resolution to identify the exact ionization state of iron by separating the lines at energies 6.63 keV, 6.67 keV and 6.70 keV as seen in LMXBs, X-ray observations of KS 1947+300 with instruments having better spectral resolution (Chandra) are required to investigate the presence of such lines in the energy spectrum. These observations may also explain the absence/presence of the soft excess over the Comptonized continuum model at the peak of the outburst. The absence of any cyclotron resonance absorption feature in the phase averaged spectra of KS 1947+300 implies the cyclotron line lies outside the 0.1-100.0 keV energy band. This
suggests the magnetic field of the pulsar is very high ($\geq 10^{13}$ G).

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