INTEGRAL OBSERVATION OF THE ACCRETING PULSAR 1E1145.1-6141

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ABSTRACT

We analyzed 1050 ks of INTEGRAL data regarding the X-ray binary pulsar 1E 1145-6141. We performed timing analysis, finding a spin period of $\sim 297\,s$, and spectral analysis as a function of the source luminosity. We find that the source spectrum can be modeled using an absorbed bremsstrahlung model in which the electron temperature is correlated with the luminosity while the height of the absorbing column is anti-correlated. We also find and discuss briefly a phase shift of the pulse profile peak with photon energy.

1. INTRODUCTION

In this paper we report on the observation of one of the least studied HMXRBs: 1E 1145.1–6141 located very close ($\sim 17'$) to the extensively studied HMXRB 4U 1145–61. Optical spectroscopy of the B2 supergiant companion of 1E 1145.1–614 yields a distance of 8.5 ± 1.5 kpc [3]. In Ref. [8] the measured column density was $\mathrm{N_H} = (3 \pm 2) \times 10^{22}\mathrm{cm}^{-2}$, value confirmed in Ref. [10], where the spectrum was modeled using an absorbed cut-off power law with index $\Gamma = 1.4$, cut-off energy $E_c = 6.4$ keV and e-folding energy $E_f = 18$ keV. The latter authors focused their analysis of RXTE data on the timing aspects: they measured the orbital parameters of the binary system finding an eccentric tilted orbit with a period $P = 14.365$ days and propose, also on the basis of previous observations, a moderate secular spin-up trend of $\sim 4 \times 10^{-4}$ Hz/year between 1975 and 2000 [10].

The neutron star (NS) presented a pulsed fraction of ∼50% in the 4–20 keV energy band and an X-ray luminosity of $\sim 10^{36}$ erg/s [6, 5, 10]. Such a low luminosity is inconsistent with Roche lobe overflow and indicates that the NS is almost certainly accreting from the companion wind. The pulse shape has been studied first in Ref. [5] where it was found evidence of a notch between the maximum and the minimum of the pulse; this feature appeared also in the typical pulse shape obtained with RXTE [10].

The paper is organized as follows: in Sect. 2 we describe the observations, in Sect. 3 we report on the scientific results which are briefly discussed in Sect. 4, and in Sect. 5 we draw our conclusions.

2. OBSERVATIONS AND DATA ANALYSIS

The European Space Agency's International Gamma-Ray Astronomy Laboratory (INTEGRAL), launched in October 2002, carries 3 co-aligned coded mask telescopes: the imager IBIS [12] made of CdTe detector ISGRI [9], sensitive in the 15–600 keV range, and of a CsI layer, PICsIT [7] for energies up to several MeV, the spectrometer SPI sensitive from 20 keV to 8 Me, and the X-ray monitor JEM-X (sensitive from 3 keV to 34 keV). The INTEGRAL observations are divided into short periods of ~ 2 ks called science windows (SCWs) during which the telescope maintains the same pointing.

In this paper we used the publically available INTEGRAL data from three high luminosity episodes of 1E 1145.1-6141 (H1, H2 and H3) and two low states (L1 and L2). We limit our analysis to data from ISGRI and JEM-X because the source is too weak to be studied with SPI. However, due to its small field of view, JEM-X detected the source only in a small subset of the used SCWs In Table 1 we summarize our observations and in Fig. 1 we show the light curves during the observation.

To analyze the JEM-X data we used the Off-line Science Analysis (`OSA`) software version 5.1; for the ISGRI data we exploited also the software described in [4, 11]. For the spectral analysis we used the standard `XSPEC` package version 12.2.

3. RESULTS

3.1. Timing analysis

For each time interval listed in Table 1 we performed timing analysis using the ISGRI data. Firstly, we transformed the event arriving times to the solar barycenter, secondly to the binary system barycenter using the parameters found in Ref. [10]. Finally we determined the pulse period in different time intervals (Table 2) with the

Table 1. Summary of the INTEGRAL *observations of 1E 1145.1-6141. In the table we show the name for the observational period, its start and end times, the exposure times and the corresponding source count rate. The lower exposure time of* JEM-X *compared to* ISGRI *is due to the smaller field of view of this instrument.*

name	start [MJD]	end [MJD]	exposure [ks]		count rate [cts/s]	
			ISGRI	JEM-X	ISGRI	JEM-X
L1	52 788.8384	52 791.3802	101.3	10.9	4.3±0.1	3.0±0.1
H1	52 795.6284	52 796.4538	29.2	13.7	14.4±0.2	6.2±0.1
H2	52 823.7611	52 824.9043	39.0		14.7±0.2	
L2	53 146.8561	53 162.3828	703.5		3.53±0.05	
H3	53 165.3538	53 169.1147	153.4	2.2	12.2±0.1	8.35±0.03

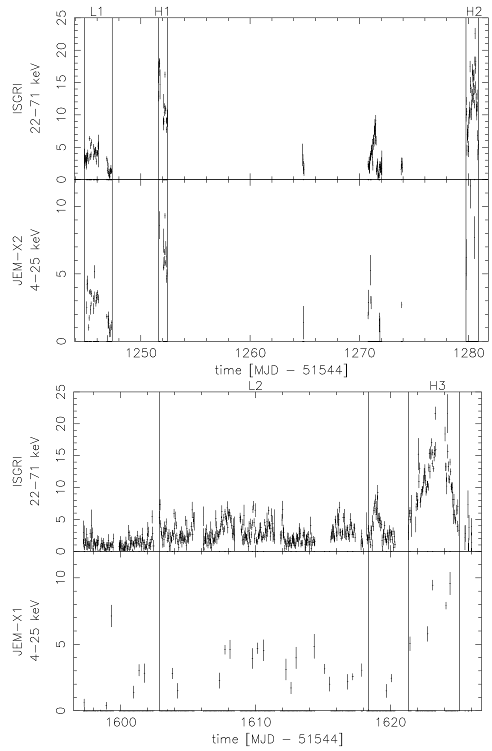

Figure 1. The ISGRI *(22–71 keV) and* JEM-X *(4–25 keV) light curves of 1E 1145.1-6141 during the* INTEGRAL *observations (From* `http://isdc.unige.ch/?Data+sources`*). The time intervals in which we performed the analysis are indicated in the figure between vertical solid lines and listed in Table 1; day 1250 is 3 June 2003, day 1600 is 18 May 2004.*

Table 2. The measured spin periods (P) computed in the time intervals specified in Table 1. At the reference time the pulse profile has a minimum in the 15–25 keV energy range. The errors are at 1σ level.

name	reference time [MJD]	P [s]
H1	52 795.662215	296.76 ± 0.03
H2	52 823.760794	296.62 ± 0.02
L2+H3	53 146.848143	296.6901 ± 0.0003

phase shift method described in Ref. [4]: we found a tentative pulse period from the Fourier analysis of the light curve. Then, using this value we accumulated a pulse profile in each science window and determined the phase of the pulse maximum. Finally, from a linear fit of the phase of the pulse maximum as a function of time, we found the optimal pulse period. We note that the spin periods that we measure in this work are slightly higher than the extrapolation of the trend proposed by [10].

Using the values of Table 2 we produced pulse profiles setting arbitrarily the phase zero at the pulse minimum in the 15–25 keV energy range. The pulse profiles of all the considered observational intervals look very similar: a single broad peak which moves to earlier phase for increasing energy. However, in the pulse profiles of H1 and H2, there is also a hint of a second peak at $\sim$ 50 keV which disappears above 60 keV. This is reminiscent of the notch between the pulse maximum and minimum reported in Ref. [5, 10].

To investigate the evolution of the pulse profile with energy we used the first high state (H1) in which the JEM-X exposure is long enough to accumulate good pulse profiles below 20 keV. We used a model with a Gaussian profile plus a constant as shown in Fig. 2. For each profile the model is quite good yielding a reduced χ^2 between 0.8 and 1.4 for 35 degrees of freedom. From the analysis, we found a shift of the Gaussian centroid from pulse phase 0.55 between 2 and 20 keV to pulse phase 0.4 at $\sim$ 35 keV, reaching pulse phase 0.2 above 80 keV.

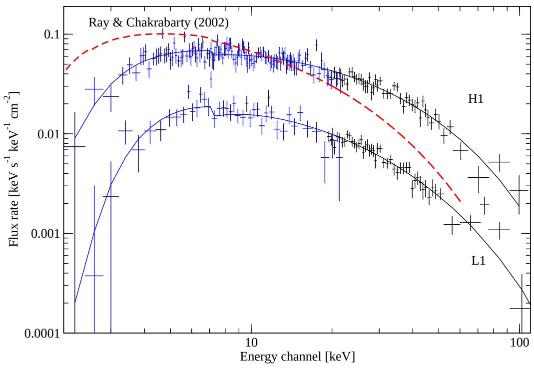

Figure 3. Broad band observed energy spectra for the first high state (H1) and the first low state (L1). Below ∼*20 keV data are from* JEM-X*, above value* ∼*20 keV from* ISGRI*. The model in both cases is absorbed bremsstrahlung. The dashed line is the model used by [10].*

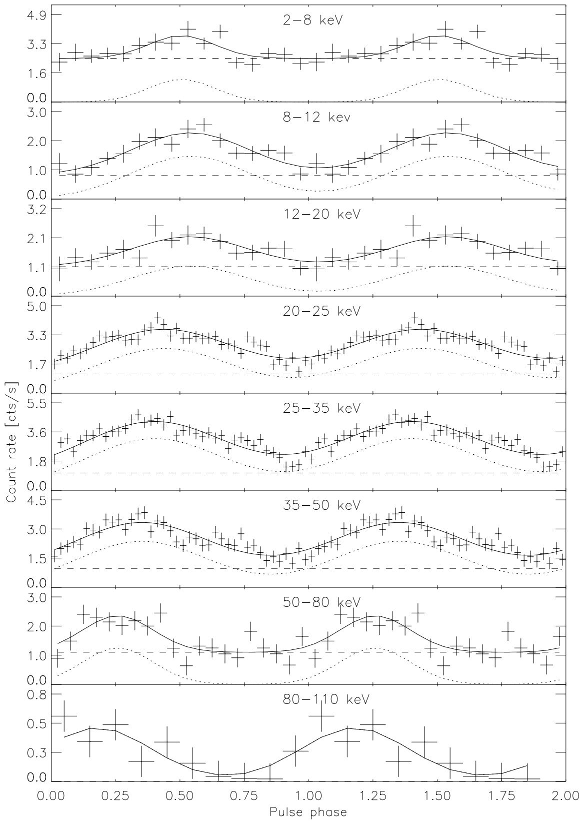

Figure 2. The background subtracted pulse profiles of H1. The data below 20 keV are from JEM-X *, above 20 keV from* ISGRI *. In each panel the solid line is the best fit pulse profile obtained adding a Gaussian (dotted line) to a constant (dashed line). The exposure time is listed in Table 1, the reference time and spin period are listed in Table 2.*

3.2. Spectral analysis

The source spectrum can be fitted very well using a bremsstrahlung model plus low energy absorption (PHABS). In this low luminosity HMXRB the emission is thus produced by a non shocked medium in accordance with the models [1, 2]. The best fit parameters are reported in Table 3 and the spectra in the low and high states are shown in Fig. 3 together with the model by [10]. We note that the present spectrum is considerably different from the previous one, therefore the source underwent some kind of evolution since the latest observations.

We also find a decrease of the low energy absorption and an increase of the plasma temperature with luminosity except for the highest luminosity point. However, the points at highest and lowest luminosity are obtained using the ISGRI data alone and therefore the continuum model can be biased by the relatively narrow energy range.

4. DISCUSSION

The proposed emission models show that several mechanisms can be responsible for the pulse shape and its energy dependence: the emission in a slab of a cylindrical accretion column or from the walls of a hollow accretion column, the presence of fan and pencil beams, of a scattering halo, the light bending around the NS, the interaction with the magnetic field etc. Combining the various mechanisms for different geometries, accretion rates and emission models it is possible to obtain virtually any observed pulse profile. On the other hand it is very difficult to discriminate which set of mechanisms determines the pulse profile of a particular system.

Table 3. Results of the spectral fits with a bremsstrahlung model. The exposures are reported in Table 1, the fluxes are computed using the 20-50 keV and 5-15 keV energy intervals and are expressed in units of $10^{-10}\mathrm{erg\,s^{-1}\,cm^{-2}}$. *The* hardness ratio *is computed in these energy bands. For comparison the flux of the Crab Nebula in the 20-50 keV energy band is* $10^{-8}\mathrm{erg\,s^{-1}\,cm^{-2}}$. *When* JEM-X *data were available (in L1, H2 and H3) we made a simultaneous fit otherwise we used just the* ISGRI *data. The errors are at 90% confidence level for one parameter of interest (*$\chi^2_{\rm min}+2.7$*).*

parameter	L1	H1	H2	L2	H3
N_H [$10^{22}\,\mathrm{cm^{-2}}$]	15.7 ± 2.2	10.9 ± 0.9	N/A	N/A	9.2 ± 2.5
kT [keV]	27.6 ± 1.4	31.3 ± 0.9	27.6 ± 0.9	25.6 ± 0.9	31.3 ± 0.8
χ^2/d.o.f.	220/216	230/216	45/65	74/60	213/212
flux(20–50 keV)	2.54 ± 0.05	8.35 ± 0.08	8.6 ± 0.1	2.02 ± 0.03	7.46 ± 0.06
flux(5–15 keV)	4.1 ± 0.1	7.9 ± 0.2	N/A	N/A	9.5 ± 0.1
hardness ratio	0.62 ± 0.02	1.06 ± 0.03	N/A	N/A	0.78 ± 0.01

For 1E 1145.1-6234 we found that the position of the main peak drifts with energy, therefore different components dominate at different phases. But, whether they are due to an accretion column, a scattering halo or due to the beams from the two poles appearing alternately and forming a unique blended peak cannot be distinguished with this observation.

5. CONCLUSIONS

From the analyzed data of 1E 1145.1–6141 we find that:

- the spectrum can be modelled using a bremsstrahlung model showing that the emission from this low luminosity HMXRB originates from non shocked plasma;
- the plasma temperature is higher and the emission is less absorbed when the source is brighter;
- the pulse profile maximum shifts by ~ 0.4 in phase from 20 and 100 keV;
- the spin period of the source is not constant at 98% confidence level and is higher than expected on the basis of the spin–up trend proposed by [10], the spin period variations between different observing periods can be due to stochastic variations of the torque on the NS.

1E 1145.1–6141 is a typical low luminosity neutron star accreting material directly from the companion wind showing, on an irregular basis, states of higher luminosity. The hardening of the spectrum with luminosity and the reduction of the absorbing column indicate that, enhancing the accretion, the emitting region becomes hotter and thus absorbs less efficiently in accordance with the HMXRB standard picture.

ACKNOWLEDGMENTS

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