Abstract. We present spectra for 34 accretion-powered X-ray and one millisecond pulsars that were within the field of view of the INTEGRAL observatory over two years (December 2002–January 2005) of its in-orbit operation and that were detected by its instruments at a statistically significant level ($> 8\sigma$ in the energy range 18–60 keV). There are seven recently discovered objects of this class among the pulsars studied: 2RXP J130159.6-635806, IGR/AX J16320-4751, IGR J16358-4726, AX J163904-4642, IGR J16465-4507, SAX/IGR J18027-2017 and AX J1841.0-0535. We have also obtained hard X-ray ($> 20$ keV) spectra for the accretion-powered pulsars A 0114+650, RX J0146.9+6121, AX J1820.5-1434, AX J1841.0-0535 and the millisecond pulsar XTE J1807-294 for the first time. We analyze the evolution of spectral parameters as a function of the intensity of the sources and compare these with the results of previous studies. © 2004 MAIK "Nauka/Interperiodica".

Key words: X-ray pulsars, neutron stars, spectra.

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INTRODUCTION

Accretion-powered X-ray pulsars were discovered more than 30 years ago (Giacconi et al. 1971), and some 100 such objects are known to date. A qualitative understanding of the nature of the observed pulsed emission came almost at once (see, e.g., Pringle and Rees 1972; Lamb et al. 1973). X-ray pulsars are rapidly rotating neutron stars with a strong magnetic field ($B > 10^{11}$ G) that are members of binary systems and that accrete matter from their stellar companion. As the plasma approaches a neutron star, it is stopped by the pressure of the magnetic field (which, to a first approximation, is in the form of a dipole), is frozen into the latter, and moves along the field lines toward the magnetic poles of the star to produce two hot spots (at these locations, the captured matter releases its gravitational energy in the form of X-ray and gamma-ray radiation). If the rotation axis of the neutron star does not coincide with its magnetic axis (an oblique rotator), then these spots will periodically cross the line of sight at a certain orientation of the binary relative to a remote observer and, thus, give rise to pulsed emission.

X-ray pulsars are a unique laboratory for studying the behavior of matter under extreme conditions – at high temperatures and in strong magnetic and gravitational fields. Analysis of their energy spectra gives an idea of the physical processes in the emitting region, the structure of the accreting matter, and the parameters of the compact object. For example, the detection of cyclotron lines in the spectrum of a pulsar allows the magnetic field of a neutron star to be measured (Gnedin and Sunyaev 1974). The magnetic field was first measured by this method for the pulsar Her X-1 (Truemper et al. 1978).

Many papers devoted to various sources of this class have been published over the period of research on X-ray pulsars; here, we mention only a few review articles in which particular properties of these objects were discussed. Such an attempt was first made by White et al. (1983), who summarized the spectra and pulse profiles for the then known X-ray pulsars and suggested an empirical model to describe their spectra. Subsequently, Nagase (1989) gave an overview of accretion-powered pulsars using new Hakucho, TENMA, EXOSAT, and GINGA observations. Based on data from the KVANT module, Gilfanov et al. (1989) analyzed the evolution of the pulsation periods for pulsars. GRANAT (Lutovinov et al. 1994) and ComptonGRO (Bildsten et al. 1997) data were used to investigate in detail the pulse profiles and the evolution of the pulsation periods. Coburn et al. (2002) and Orlandini and Dal Fiume (2001) used, respectively, RXTE and BeppoSAX data to analyze the pulsars whose spectra exhibited the cyclotron lines attributable to the resonant scattering of photons by electrons in a magnetic field; in certain cases, several harmonics were detected from objects.

Despite the long period of research, as yet there is no convincing theoretical model that would describe the spectra of accretion-powered X-ray pulsars. The most popular model used to fit the spectra yields a power-law spectral shape with an exponential cutoff (models (1) and (2) in the Section "Data Analysis"). For most sources, the photon index, the cutoff energy, and the e-folding energy lie within the ranges 0.3-2, 7-30 keV, and 9-40 keV, respectively. The sensitivity of the IBIS instrument at these energies is well suited for determining the e-folding
energy in the spectrum. The spectra also often exhibit the following: low-energy absorption that can be attributed both to the interstellar medium and to internal absorption in the binary system with the column density \( N_H \) varying within the range \( 10^{21} - 10^{24} \text{cm}^{-2} \); iron emission lines at 6-7 keV; and gyrolines at the energies corresponding to the electron cyclotron frequency and its harmonics. The INTEGRAL observatory, whose main instruments have a high sensitivity and a large fields of view, allows one not only to study known sources, but also to discover new objects, including X-ray pulsars, and to analyze their behavior over a wide energy range. In this paper, we provide an overview of the X-ray pulsars observed by the INTEGRAL observatory and construct their broadband spectra. Some 70 known and recently discovered pulsars were within the field of view of the INTEGRAL instruments. For 35 of these, we were able to reconstruct their energy spectra; the remaining sources were either not detected or detected, but the data on these are not publicly accessible at present (e.g., the pulsar 4U 0115+63 from which the INTEGRAL observatory detected an outburst in August 2004; Lutovinov et al. 2004a).

**OBSERVATIONS**

The international gamma-ray observatory INTEGRAL (Winkler et al. 2003) was placed in orbit by a Russian Proton launcher on October 17, 2002 (Eismont et al. 2003). It carries four instruments: the SPI gamma-ray spectrometer, the IBIS gamma-ray telescope, the JEM-X X-ray monitor, and the OMC optical monitor, which allow the emission from astrophysical objects to be analyzed over a wide wavelength range. In this paper, we use data from the ISGRI detector of the IBIS telescope (Ubertini et al. 2003) and from the JEM-X monitor. Both instruments operate on the principle of a coded aperture. The ISGRI effective energy range is 20–200 keV (the energy resolution is \( \sim 7\% \) at 100 keV), the field of view is \( 29^\circ \times 29^\circ \) (the fully coded zone is \( 9^\circ \times 9^\circ \)), and the nominal space resolution is \( \sim 12\' \) (the angular size of the mask element). A more detailed description of the detector can be found in Lebrun et al. (2003). The JEM-X monitor consists of two identical modules, JEM-X1 and JEM-X2 (Lund et al. 2003). Each of the modules of the telescope has the following technical characteristics: the energy range is 3 – 35 keV, the field of view (the fully coded zone) is \( 13.2^\circ \) (4.8\%) in diameter, the geometrical area of the detector is 500 cm\(^2\), and the nominal space resolution is \( \sim 3\' \). Here, we used the INTEGRAL observations from orbit 23 (MJD 52629, December 21, 2002) to orbit 239 (MJD 53276, September 28, 2004); these are the currently publicly accessible data and the data of the Russian quota obtained as part of the Galactic plane scanning (GPS), the Galactic center deep exploration (GCDE), and the observations in the General Program. Only the publicly accessible observations of the X-ray pulsar V0332+53 that were performed from orbit 272 (MJD 53376, January 6, 2005) to orbit 278 (MJD 53394, January 24, 2005) constitute an exception.
For all of the detected X-ray pulsars, we constructed light curves in the energy range 18–60 keV and analyzed their variability. We constructed average spectra for persistent sources and analyzed the dependence of the spectrum on the source’s state for pulsars with variable fluxes: if the spectrum did not change, we also provided an average spectrum; otherwise, we gave the spectra of different states. The fluxes from the pulsars determined from these light curves are given in mCrabs (1 mCrab = 1.36 × 10^{-11} erg cm^{-2} s^{-1} in the energy range 18–60 keV under the assumption of a power-law spectrum for the Crab Nebula with an index of 2.1 and a normalization of 10 at 1 keV). The image reconstruction method and the spectral analysis of the ISGRI/IBIS data used here were described by Revnivtsev et al. (2004) and Lutovinov et al. (2003a). Analysis of a large number of calibration observations for the Crab Nebula revealed that the method yields a systematic error in measuring the absolute flux from the source of 10% over a wide energy range and that the spectral shape is reconstructed with an accuracy up to 2−5%. To take into account this peculiarity, we added a systematic error of 5% when analyzing the spectra in the XSPEC package. As an example, Fig. 1 shows the energy spectrum for the Crab Nebula reconstructed by this method from the data of orbit 170. The response matrix was constructed from the data of orbit 102. In fitting this spectrum by a power law, we added a systematic error of 2% and obtained the following parameters: foton index $\Gamma = 2.13 \pm 0.02$ and $\text{Norm} = 11.27 \pm 0.35$. All of the errors given here are statistical and correspond to one standard deviation.

The data of the Russian quota for the pulsar were arbitrarily divided into two groups, before and after orbit 200, because our ISGRI response matrix was constructed from calibration measurements of the Crab Nebula. After orbit 200, the flux (in counts) from the Crab Nebula increased due to a change in the ISGRI operating parameters; our response matrix constructed from the data of orbit 239 changed accordingly. We reconstructed the spectra separately for each data group and analyzed the variability of their shape. For our spectral analysis of the JEM-X data, we used the standard OSA 4.2 software package provided by the INTEGRAL Science Data Center (http://isdc.unige.ch). It should be borne in mind that the JEM-X field of view is considerably smaller than the IBIS one. Therefore, the effective exposure for the observations of sources by this instrument is also shorter and, in certain cases, no sources fell within its field of view or the sensitivity of the instrument was not enough for their detection at a statistically significant level. Since the absolute fluxes from the sources are reconstructed from the JEM-X data not quite accurately, the normalization of the JEM-X data was left free when simultaneously fitting the JEM-X and ISGRI spectra of the sources in the XSPEC package. It is also worth mentioning that there are a number of features near energies 5–7 keV in the spectra reconstructed from the JEM-X data that are attributable to the flaws in the current response matrix of the instrument. These features make it difficult to study in detail a source’s spectrum, in particular, to identify the iron emission line and to determine its parameters.\footnote{Private correspondence with Carol Anne Oxborrow and Peter Kretschmar.}

To fit the spectra, we used a standard (for pulsars) empirical model that includes a power
law with a high-energy cutoff (White et al. 1983):

\[
PLCUT(E) = AE^{-\Gamma} \times \begin{cases} 
1 & (E \leq E_{\text{cut}}) \\
\exp\left(-\frac{E-E_{\text{cut}}}{E_{\text{fold}}}\right) & (E > E_{\text{cut}}),
\end{cases}
\]  

(1)

where \(\Gamma\) is the photon index, \(E_{\text{cut}}\) and \(E_{\text{fold}}\) are the cutoff energy and the e-folding energy, respectively. For several pulsars for which we failed to set a reasonable limit on the parameter \(E_{\text{cut}}\) when fitting their spectra by model (1), we used the following model:

\[
CUTOFF(E) = AE^{-\Gamma} \times \exp\left(-\frac{E}{E_{\text{fold}}}\right).
\]  

(2)

In certain cases, the standard model did not describe the pulsar’s spectral shape quite accurately. Therefore, we introduced additional components when fitting the spectrum:

– low-energy photoelectron absorption described by the formula

\[
WABS(E) = \exp(-N_H \times \sigma(E)),
\]  

(3)

\(\sigma(E)\) - is the cross section for the process (Morrison and McCammon 1983);

– an iron emission line described by a Gaussian profile

\[
GAUS(E) = \frac{A}{\sqrt{(2\pi)\sigma_{Fe}}} \times \exp\left(-\frac{(E - E_{Fe})^2}{2\sigma_{Fe}^2}\right),
\]  

(4)

where \(E_{Fe}\) is the line center, \(\sigma_{Fe}\) is the line width;

– a resonance cyclotron absorption line whose model is

\[
CYCL(E) = \frac{\exp\left(-\tau_{\text{cycl}}(\sigma_{\text{cycl}}/E_{\text{cycl}})^2\right)}{(E - E_{\text{cycl}})^2 + \sigma_{\text{cycl}}^2},
\]  

(5)

where \(E_{\text{cycl}}\) is the line center, \(\tau_{\text{cycl}}\) is the line depth, and \(\sigma_{\text{cycl}}\) is the line width.

To find features related to the resonance cyclotron absorption line in the radiation spectrum for those sources in which this feature was not observed previously, we added the corresponding component to the model fit (see above). The energy of the line center \(E_{\text{cycl}}\) was varied over the range 20 – 90 keV at 5 keV steps, while the line width was fixed at 5 keV. The choice of an energy range for the search of these lines was dictated by the presence of systematic features in the JEM-X response matrix and by the fact that the standard X-ray range has been well studied using data from other missions. We found the most probable position of the possible cyclotron line and its significance in units of the standard deviation using the \(\Delta\chi^2\) test.
RESULTS

The X-ray pulsars that fell within the field of view of the INTEGRAL observatory and that were detected at a statistically significant level by its instruments are listed in Table 1. This table also gives their parameters, the parameters of the corresponding binaries, and references to the papers from which these were taken (\( P \) is the spin period of the neutron star, \( P_{\text{orb}} \) is the orbital period of the binary, HMXB stands for a high-mass X-ray binary, and LMXB stands for a low-mass X-ray binary). The spectra of the sources are shown in Fig. 2, and the best-fit parameters for the spectra are presented in Tables 2 and 3. Table 2 gives the parameters for the standard model and lists the exposures of the observations from which the average spectrum was constructed and the fluxes from the pulsars in the energy ranges \( 6 - 20 \) and \( 18 - 60 \) keV determined by analyzing the spectra. Table 3 gives the parameters of the models that describe the features in the spectra of the pulsars, more specifically, the iron emission line and the cyclotron absorption line and its harmonics. Below, we briefly describe the results obtained for each of the pulsars.

A 0114+650. The X-ray pulsar A 0114+650 is one of the longest-period accretion-powered pulsars. The data from January through July 2003 (MJD 52653-52835) were used to analyze the source. The source was not detected in the observations performed from MJD 52653 to MJD 52655; the upper (1\( \sigma \)) limit on its 18 - 60 keV flux was 1 mCrab. In the remaining time, the mean flux in the same energy range was 8 mCrab. The pulsar’s average spectrum was reconstructed from these observations. Since JEM-X did not detect the source, we were able to reconstruct its spectrum only in the hard X-ray energy range. The pulsar’s spectrum is typical of this class of objects and is described in the soft X-ray energy range by a power law with a high-energy cutoff with the following parameters: \( \Gamma \sim 1.3, E_{\text{cut}} \sim 8 \text{ keV}, \text{ and } E_{\text{fold}} \sim 20 \text{ keV} \) (Hall et al. 2000). Since the IBIS exposure for the source was short, we failed to fit the spectrum obtained by models (1) or (2); therefore, it was fitted by a simple power law with an index of 2.3±0.4.

SMC X-1 (4U 0115-73). The source SMC X-1 was within the JEM-X/IBIS field of view during the observations of the Small Magellanic Cloud region from July 24 through July 27, 2003 (MJD 52843–52846).

We used the standard model (1) in our spectral analysis. Fitting the spectrum by this model yielded the parameters given in Table 2. Moon et al. (2003) showed the constancy of the spectral parameters with the source’s flaring activity, which is also confirmed by their agreement with our parameters. However, note a slightly higher e-folding energy in the source’s spectrum obtained from the INTEGRAL data. Based on our spectral analysis, we also obtained an upper limit on the presence of a resonance cyclotron absorption line in the source’s spectrum by the method described in the section ”Data Analysis”. No such feature was found at a confidence level higher than \( \sim 1\sigma \).

RX J0146.9+6121. To analyze the source RX J0146.9+6121, we used the publicly accessible INTEGRAL observations covering the period from MJD 52636 to MJD 53018. Because of the low flux from the source (in the energy range 18 – 60 keV, it was about 3 mCrab),
the JEM-X monitor did not detect the pulsar in this period. Since the source is weak, we used a simple power law with the estimated photon index $\Gamma = 2.9^{+1.1}_{-0.8}$ to fit its spectrum. It should be noted that the hard X-ray spectrum of the source has not been analyzed up until now.

$V\ 0332+53$. As part of the Galactic plane scanning by the INTEGRAL observatory, its instruments detected an intense X-ray outburst from the source V 0332+53 that began at the very end of 2004 (Swank et al. 2004). In this paper, we analyze the observations performed by the INTEGRAL observatory from January 6 through January 24, 2005, (MJD 53376–53394) with a total exposure of 180 ks. In this period, the source was in a very bright state, and its 18 – 60 keV flux did not fall below $\sim 350$ mCrab.

In our analysis, the model fit was chosen using the results of previous studies and consisted of a power law with low-energy absorption (the hydrogen column density was taken from Makishima et al. 1990), a high-energy cutoff, and three resonance cyclotron absorption lines ($E_{\text{cycl}1} = 24.25$ keV, $E_{\text{cycl}2} = 46.8$ keV, $E_{\text{cycl}3} = 67.9$ keV). The derived positions of the cyclotron lines are confirmed by the analysis of RXTE data (Coburn et al. 2005) and the first 100 ks of INTEGRAL observations of the pulsar under study (Kreykenbohm et al. 2005).

As the X-ray luminosity of the pulsar decreased, we found a change in the shape of its radiation spectrum. Thus, for example, when the mean 3 – 100 keV luminosity of the source fell from $14.9 \times 10^{37}$ to $5.2 \times 10^{37}$ erg s$^{-1}$, the photon index in the model used slightly decreased (from $0.76 \pm 0.03$ to $0.59 \pm 0.03$), but the cutoff parameters remained the same, within the error limits. More detailed temporal and spectral analyses will be performed in a special paper.

$4U\ 0352+309\ (X\ Per)$. The pulsar was within the field of view of the IBIS X-ray telescope during the calibration observations of the Crab Nebula performed on August 14, 2003 (MJD 52865). The mean 20 – 100 keV flux from the source was $\sim 40$ mCrab. We used model (1) with the inclusion of a resonance cyclotron absorption line to fit the pulsar’s radiation spectrum. The source’s spectrum (Fig. 2) and the best-fit parameters (Tables 2 and 3) were taken from Lutovinov et al. (2004b).

$LMC\ X-4\ (4U\ 0532-664)$. The X-ray pulsar LMC X-4 was observed by the INTEGRAL observatory in January 2003 as part of the General program. The total exposure was more than a million seconds for both instruments of the observatory (IBIS and JEM-X). These observations covered almost the entire superorbital period ($\sim 30.5$ days) related to accretion disk precession.

Irrespective of the state in which the object under study was, its radiation spectrum was constant, within the error limits, although all of the main parameters are slightly lower than those obtained by other authors (see, e.g., La Barbera et al. 2001). Based on INTEGRAL data, Tsygankov and Lutovinov (2005a) studied the spectral properties of the pulsar LMC X-4 in more detail.

$A\ 0535+260$. The pulsar A 0535+260 is a transient source. On October 26, 2003 (MJD 52938), the INTEGRAL observatory detected an increase in its 18 – 60 keV flux to $\sim 10$
mCrab compared to the upper limit of $\sim 2$ mCrab during previous observations. On October 28, 2003, (MJD 52940), the flux reached $\sim 40$ mCrab in the same energy range. The subsequent observations of the source were interrupted due to solar flaring activity. Because of the short IBIS exposure for the pulsar, we constructed an average spectrum from all observations for this period during the outburst. The JEM-X monitor did not detect the source.

It follows from previous studies that the pulsar’s spectrum is one of the hardest and may extend to $\sim 200$ keV (Maisack et al. 1997). The INTEGRAL observatory detected the source at a statistically significant level up to 50 keV, which can be explained by its short exposure. The spectrum obtained was fitted by a power law with an index of $2.81 \pm 0.38$, with the reduced $\chi^2 = 0.6(5)$. Kendziorra et al. (1994) fitted the source’s spectrum in the energy range $3 - 200$ keV by model (1) with the following parameters: $\Gamma \sim 1.2$, $E_{\text{cut}} \sim 24$, and $E_{\text{fold}} \sim 20$ keV. We also fitted the spectrum by model (1) by fixing the photon index and the cutoff energy; the derived e-folding energy was found to be a factor of 1.5 lower than the value given in the above paper. For this model, the reduced $\chi^2 = 0.07(5)$.

_Vela X-1 (4U 0900-403)_ The pulsar Vela X-1 was regularly within the field of view of the instruments during the Galactic plane survey and during the observations of the region near the source as part of the General program. Preliminary results of the source’s study using INTEGRAL data were presented by Kretschmar et al. (2004). The observations from January through July 2003 (MJD 52644–52832) were used in this paper. The flux from the pulsar is highly variable and subjected to orbital modulations. A flux of $\sim 7$ mCrab was detected from the pulsar at a statistically significant level during X-ray eclipse (much as was observed by the GRANAT observatory; Lutovinov et al. 2000), and it reached 700 mCrab in the energy range $18 - 60$ keV at the maximum. We constructed the pulsar’s spectra for the eclipse phase and for various fluxes. Since the source was not detected by the JEM-X instrument during eclipses, we were able to construct its spectrum at these times only in the hard X-ray energy range. We fitted it by a simple power law with an index of $3.1 \pm 0.3$.

Since our analysis of the spectra outside eclipse revealed no marked differences in their shape, we give the pulsar’s average spectrum. A cyclotron line at $\sim 24$ keV and its harmonic at $\sim 50$ keV were detected in the source (Table 3), in agreement with previous results (see, e.g., Coburn et al. 2002). A prominent feature that can be described by a model iron emission line is also observed near an energy of $6 - 7$ keV. However, given the peculiarities of the JEM-X response matrix (see above), we treat this interpretation with great caution.

_Cen X-3 (3U 1118-60)_ We used the pointings from January through July 2003 (MJD 52668–52832) obtained both during the Galactic plane scanning and as part of the General program to analyze the pulsar’s spectrum. Using the known orbital parameters of the binary (Burderi et al. 2000), we determined the orbital phases for our observations and analyzed the emission from the source during and outside X-ray eclipse. The source was not detected during eclipse; the upper 1$\sigma$ limit on its $18 - 60$ keV flux was 2.5 mCrab. Outside eclipse, the mean flux from the pulsar was $\sim 17$ mCrab in the same energy range. Several outbursts during which the flux reached $\sim 90$ mCrab were detected against this background.
We constructed the pulsar’s radiation spectrum averaged over all outbursts and an average persistent spectrum for the source outside eclipse. Our study showed that the spectrum becomes softer during outbursts: the photon index increases from 0.87 to 1.16 (both spectra are shown in Fig. 2). In fitting the spectra, we attempted to introduce a component that describes the iron emission line in the model. Since we failed to do this properly due to the difficulties in reconstructing the spectra from JEM-X data mentioned above, we described the source’s spectrum in the standard X-ray energy range by a simple power law. Otherwise, our best-fit parameters for the spectrum (Table 2) are in good agreement with the values obtained by Burderi et al. (2000) and La Barbera et al. (2004).

4U 1145-619, 1E 1145.1-614. When analyzing the emission from 4U 1145-619, White et al. (1978) found pulsations from this pulsar at two close frequencies. This puzzle was solved using data from the Einstein observatory, whose instruments detected the second source, 1E 1145.1-614, at less than 20′ from the first source (Lamb et al. 1980).

The pulsar 4U 1145-619 is a transient from which regular outbursts with a duration of 10 days at intervals of 186.5 days are observed; this is assumed to be the orbital period in the binary. At the end of May 2003 (MJD 52788), the INTEGRAL observatory detected an outburst from it during which the mean 18 – 60 keV flux was ~ 26 mCrab. We used the available data in this time interval to construct the pulsar’s average spectrum. In the remaining time, the upper (1σ ) limit on the flux from the pulsar was 4 mCrab in the same energy range.

The study of 1E 1145.1-614 is severely complicated by the proximity of its twin, which becomes much brighter during outbursts, and the standard collimator X-ray instruments do not allow these sources to be observed separately. The pulsar could be studied in more detail after its discovery only several years later using ART-P (Grebenev et al. 1992) and RXTE data, when its twin was in quiescence (Ray and Chakrabarty 2002). In our paper, we used the observations from March 2003 through September 2004 (MJD 52710–53276) to analyze 1E 1145.1-614. In this period, its flux was constant and had a mean value of ~ 20 mCrab, except the following times: 52795 MJD, when the flux from the pulsar increased to ~ 100 mCrab; 53196 MJD, when the source flared up again (Bodaghee et al. 2004); and the outburst time of the pulsar 4U 1145-619, when the mean flux from 1E 1145.1-614 rose to 40 mCrab. However, we found no clear correlations of the flux rises between the two sources; therefore, we concluded that these events were independent. We constructed the source’s spectra during and outside these outbursts. The source was not within the JEM-X field of view during the outbursts and was not detected by the instrument outside these, except the outburst period of 4U 1145-619. Since no clear differences were found in the spectral shape of 1E 1145.1-614, we give here only an average spectrum for all observations. The derived best-fit parameters for the average spectrum of 1E 1145.1-614 are in good agreement with the values from Ray and Chakrabarty (2002), who analyzed the source’s spectrum using RXTE data, except the photon index, which proved to be slightly smaller. The parameter $N_H$ was fixed at the value given in the paper mentioned above.

During the outbursts in 1984 and 1985, the mean photon index for the pulsar 4U 1145-619
was equal to one, the low-energy absorption changed from $26 \times 10^{22}$ \text{sm}^{-2} to $3.1 \times 10^{22}$ \text{sm}^{-2}, the cutoff energy remained constant $\sim 6$ keV, and the e-folding energy rose from $\sim 12$ keV during the 1984 outburst to $\sim 17$ keV during the 1985 outburst (Cook and Warwick 1987). Our analysis showed that the pulsar’s spectrum became softer, $\Gamma = 1.5 \pm 0.1$, while the e-folding energy increased to $30 \pm 4$ keV. The sensitivity of the JEM-X detector is too low to determine the low-energy absorption, while its spread does not allow it to be fixed at a particular value; therefore, we did not introduce this component in the standard model when fitting the spectrum.

**GX 301-2 (3A 1223-624)**. To analyze the source, we used the publicly accessible INTEGRAL observational data obtained from January through July 2003. Over this period, the IBIS telescope made about 250 pointings at the object under study, which included two times close to the periastron passage by the neutron star. Therefore, all of the data obtained were arbitrarily divided into low and high (periastron passage) states. For the high state, we had some 10 IBIS pointings at our disposal (we took into consideration the pointings for which the orbital phase was within the range from 0.87 to 0.92), while for the low state, we were able to reconstruct the broadband spectrum using also 23 JEM-X pointings. A preliminary analysis based on the first several IBIS pointings was performed by Kreykenbohm et al. (2004).

Tsygankov et al. (2004) showed that the shape of the source’s radiation spectrum and its hardness were subjected to random variations on a time scale of the order of several thousand seconds. In this paper, we failed to analyze these variations due to the lack of JEM-X data in the high state and insufficient statistics in the low state. In our spectral analysis of the low state for the pulsar GX 301-2, we corrected significantly the model fit (1): low-energy absorption (many authors pointed out a significant hydrogen column density that strongly depends on the object’s orbital phase and that reaches $\sim 2 \times 10^{24}$ atoms cm$^{-2}$ (Endo et al. 2002), an iron line, and a resonance cyclotron absorption line were added to the power law with a high-energy cutoff. The latter feature whose existence was mentioned by various authors (see, e.g., Orlandini et al. 2000; Coburn et al. 2002) has a confidence level higher than $3\sigma$ and improves significantly the quality of the fit. In our case, for the low state (the mean $3 - 100$ keV flux from the source was $1.9 \times 10^{-9}$ erg cm$^{-2}$ s$^{-1}$), we obtained the energy $E_{\text{cyc}} = 47.4 \pm 1.9$ keV for the cyclotron absorption line that is closest to the value given by Orlandini et al. (2000) (the line width was fixed at the value taken from this paper). Within the error limits, our results are also in good agreement with the results of other authors.

As was mentioned above, we had only the IBIS data at our disposal for the high state. Nevertheless, the quality of the spectrum allowed us to detect a statistically significant change in the photon index, which slightly increased compared to the low state (Table 2), but was slightly lower than that in Borkus et al. (1998), while the remaining model parameters were in good agreement. When this parameter is fixed at 0.3 obtained in the low state, the quality of the fit deteriorates sharply. In this case, we also added the resonance cyclotron absorption line at energy $\sim 49$ keV whose confidence level was about $2\sigma$ (Table 3) to the standard model (1).
2RXP 130159.6-635806. Hard X-ray emission from the region of the sky containing this object was detected by the INTEGRAL observatory during its outburst in late January–early February 2004 (Chernyakova et al. 2004), when the 20–60 keV flux from the source reached \( \sim 15 \) mCrab. Subsequently, XMM-Newton data revealed X-ray pulsations from it with a period of \( \sim 700 \) s. The spectral and temporal properties of the new pulsar were analyzed in detail by Chernyakova et al. (2005) using both current XMM-Newton and INTEGRAL data and archival ASCA and BeppoSAX data. The source’s spectrum and its best-fit parameters over a wide energy range (1–70 keV) presented in Fig. 2 and Table 2, respectively, were taken from the same paper.

4U 1538-522. The pulsar 4U 1538-522 is a persistent source. Over the period of our observations from February 2003 through September 2004 (MJD 52671–53260), its mean 18–60 keV flux was \( \sim 15 \) mCrab. We constructed the pulsar’s average spectrum from all of the available data in the energy range 4–80 keV. The derived best-fit parameters for the spectrum are in good agreement with the values from Robba et al. (2001) \((N_H\) was taken from the same paper), who analyzed the pulsar’s spectrum using BeppoSAX data.

4U 1626-67. To study the pulsar 4U 1626-67, we used the observations from March through October 2003 (MJD 52699–52915) performed as part of the Galactic plane scanning and the deep Galactic center survey. The light curve of the source exhibited no statistically significant variations in the flux, whose mean value was \( \sim 12 \) mCrab in the energy range 18–60 keV; therefore, we constructed an average spectrum of the pulsar. Since the source was far from the Galactic plane \((b = -13.1)\), it was not within the JEM-X field of view, which did not allow us to reconstruct its spectrum in the soft X-ray energy range. Preliminary results of the pulsar’s analysis based on INTEGRAL data were presented by Denis et al. (2004), who described the source’s spectrum by a simple power law with an index of 3.4. In our paper, the exposure of the available observations is a factor of 10 longer; therefore, we were able to fit the spectrum by the standard model (1) by fixing the photon index at the value given in Orlandini et al. (1998), who analyzed the pulsar’s spectrum over a wide energy range \((0.1–100 \text{ keV})\). Our values of \(E_{cut}\) and \(E_{fold}\) are in good agreement with those given in the same paper.

IGR/AX J16320-4752, IGR J16358-4726, AX J163904-4642, IGR J16465-4507. These recently discovered long-period pulsars (with pulsation periods of several hundred seconds) belong to the class of strongly absorbed sources discovered by the INTEGRAL observatory. These are not detected by the JEM-X monitor because of significant absorption. Therefore, Lutovinov et al. (2005c) analyzed their spectra over a wide energy range using data from the RXTE, ASCA, and XMM-Newton observatories in the standard X-ray energy range and from the ISGRI detector at energies above 18 keV; We used model (2) to fit the spectra. The spectra of the sources (Fig. 2) and their best-fit parameters (Table 2) were taken from Lutovinov et al. (2005c).

OAO 1657-415. The intensity of the pulsar OAO 1657-415 is subjected to strong orbital modulations and varies between a few mCrab (during X-ray eclipse) and 100–150 mCrab in the energy range 18–60 keV. Since our study of the source’s spectrum at various orbital
phases (the orbital parameters of the binary were taken from Baykal (2000)) revealed no marked differences in its shape, we constructed an average spectrum from all of the available data from March 2003 until April 2004 (MJD 52699–53097). The pulsar’s spectrum is one of the hardest spectra for X-ray pulsars in binaries, extending to 100 keV (see Table 2 and Fig. 2), and strong absorption with $N_H \sim 10^{23} \text{cm}^{-2}$ is observed at low energies. The pulsar will be analyzed in detail using INTEGRAL and RXTE data in a special paper.

EXO 1722-363. The flux from the pulsar EXO 1722-363 is subjected to orbital modulations (Markwardt and Swank (2003); Lutovinov et al. 2004b) and changed from a few to 50 mCrab in the energy range $18 – 60$ keV over the period of our observations from March 2003 through April 2004 (MJD 52698–53097). Based on INTEGRAL data, Lutovinov et al. (2004b, 2004c) improved the localization accuracy of the object and showed that the shape of the hard part of the pulsar’s spectrum remains constant, although the flux is highly variable, while the shape of its soft part analyzed using RXTE data strongly depends on the orbital phase of the binary, and the photoabsorption can reach $N_H \sim 10^{24} \text{cm}^{-2}$.

We failed to reconstruct the source’s spectrum from JEM-X data, since it was within the field of view of this instrument only during states with low fluxes. Our analysis showed that the pulsar is detected at a statistically significant level up to $60$ keV, and its hard X-ray spectrum can be described either by a power law with an index of 3.5 or by model (2), from which it follows that the e-folding energy is $\sim 15$ keV. However, both models describe the source’s spectrum poorly, and further studies over a wide energy range are required to improve its parameters.

GX 1+4 ($4U$ 1728-247). To analyze the radiation spectrum of the X-ray pulsar GX 1+4, we used the currently publicly accessible data that cover the interval from late February through late September 2003. The total exposure for the IBIS telescope was 2400 ks; the source was within the JEM-X field of view much more rarely.

Our analysis showed that the spectral parameters of the pulsar’s radiation depend on its flux. When constructing average spectra for the object under study, we took into account the pulsar’s intensity in the time interval where the averaging was performed. Therefore, we identified three segments (MJD 52698–52700, MJD 52710–52753, and MJD 52874–52910) in the light curve with mean $18 – 60$ keV fluxes from the source of $\sim 130$, $\sim 11$ and $\sim 6$ mCrab, respectively. In the latter case (low state), the source’s spectrum was best fitted by a simple power law. Despite significant errors, we see from Table 2 that as the intensity of the radiation from the object under study decreases, its spectrum becomes slightly softer, as confirmed by the studies of other authors (Paul et al. 1995).

IGR/SAX J1802.7-2017. The INTEGRAL spectrum of the new X-ray pulsar IGR/SAX J1802.7-2017 was analyzed by Lutovinov et al. (2005a), from which we took its best-fit parameters.

XTE J1807-294. Formally, this source is not an accretion-powered X-ray pulsar and belongs to the class of millisecond pulsars. Campana et al. (2003) showed that the source’s XMM-Newton radiation spectrum at low energies is best fitted by the combination of an absorbed blackbody and Comptonization models or a power law without absorption or emission
Because of its transient nature, the pulsar under study was detected by the IBIS telescope at a statistically significant level only in the period between February 20 and May 1, 2003, (MJD 52690–52760), without being detected by the JEM-X monitor. It should be noted that this source is the only millisecond pulsar in our sample, which is why we pay special attention to choosing the model fit. To analyze the spectral properties of the pulsar’s radiation, we used models (1) and (2) and a simple power law; for the composite models, the power-law index was fixed at the value taken from Campana et al. (2003). Based on $\Delta \chi^2$ statistics, we established that model (1) with the parameters from Table 2 is in best agreement with the experimental data. Such high values of $E_{\text{cut}} \sim 48$ keV and $E_{\text{fold}} \sim 76$ keV are not a rarity for flaring millisecond pulsars (see, e.g., Heindl and Smith 1998).

AX J1820.5-1434. The pulsar AX J1820.5-1434 was discovered in 1997 during the Galactic plane scanning by the ASCA observatory (Kinugasa et al. 1998); these authors also analyzed the source’s spectrum in the soft X-ray energy range. The INTEGRAL observatory first detected the source in the hard X-ray energy range (Lutovinov et al. 2003b). The available observations can be arbitrarily divided into two groups: from March through April 2003 (MJD 52699–52759), during which the flux from the source did not change appreciably and was $\sim 8$ mCrab in the energy range $18–60$ keV, and from September through October 2003 (MJD 52909–52929) when the source was not detected at a statistically significant level and the upper $1\sigma$ limit on its flux was $0.3$ mCrab in the same energy range. We constructed an average spectrum from all of the data when the source was detected and used model (1) to fit it; the photon index was fixed at 0.9 given in Kinugasa et al. (1998). We see from Fig. 2 that the pulsar was detected at a statistically significant level up to $\sim 70$ keV.

AX J1841.0-0535. The pulsar AX J1841.0-0535, discovered by the ASCA observatory (Bamba et al. 2001), was detected during observations of the Sagittarius arm region performed by the INTEGRAL observatory in the spring of 2003. A preliminary analysis of the INTEGRAL data showed that the source position is differ from the position obtained by the ASCA observatory, therefore it was named as a new source IGR J18406-0539 (Molkov et al. 2004a). A new outburst from the same sky region was detected in November 2004. It was again assigned to a new source IGR J18410-0535 at first (Rodriguez et al. 2004), but later it was identified with the source IGR J18406-0539 (Hallpen et al. 2004).

The following analysis showed, that in the spring of 2003 the source was significantly detected during 2 pointings, and its flux reached $\sim 40$ mCrab in the $18–60$ kev energy range. The increase of the source flux up to $\sim 10$ mCrab in the same energy range was also registered in October 2003. In the remaining time the upper $1\sigma$ limit on its flux was $\sim 1$ mCrab ($18–60$ keV). Here we present for the first time a hard source’s spectrum, which was averaged over the source high states. Because of the low statistics of the data we fitted the source’s spectrum by a simple power-law with an index of $2.2 \pm 0.3$.

GS 1843+009. An average spectrum for the transient pulsar GS 1843+009 in the hard X-ray energy range ($20–100$ keV) was constructed from the data obtained in early May 2003 (MJD 52759–52760), when an outburst was detected from the source (Cherepashchuk
and its $18 - 60$ keV flux during the outburst was $\sim 7$ mCrab. The JEM-X monitor did not detect the pulsar.

Because of the lack of data in the softer part of the spectrum, when describing it by model (1), we fixed the following parameters obtained from BeppoSAX data over a wide energy range during the outburst from the source in April 1997: $\Gamma = 0.34$, and $E_{\text{cut}} = 5.95$ keV (Piraino et al. 2000). The derived e-folding energy $E_{\text{fold}} = 17.4 \pm 1.4$ keV is in good agreement with the value given in Piraino et al. (2000). This may suggest that the shape of the source’s radiation spectrum is constant irrespective of its luminosity.

A 1845-024. Soffitta et al. (1998) identified the pulsar A 1845-024 with the sources GS 1843-02 and GRO J1849-03. To analyze its spectrum, we used the publicly accessible observations from March through October 2003 (MJD 52699–52930). Over this period, one outburst was detected from the pulsar during which the $18 - 60$ keV flux reached $\sim 7$ mCrab; the outburst began approximately on MJD 52728 and lasted for $\sim 40$ days. We constructed the pulsar’s average spectrum for this period from ISGRI data; the JEM-X instrument did not detect the source. In the remaining time, the upper $1\sigma$ limit on the flux from the source was 0.4 mCrab in the same energy range. The pulsar’s $18 - 90$ keV spectrum was fitted by a simple power law with a photon index of $\Gamma = 2.62 \pm 0.19$, in agreement with that obtained by Zhang et al. 1996, whose used ComptonGRO data.

XTE J1855-026. For the pulsar XTE J1855-026, we were able to construct a broadband spectrum in the energy range $4 - 100$ keV using the 9-ks-averaged JEM-X data obtained on October 18, 2003, and the IBIS data averaged over all of the available observations (March 2003–April 2004).

We used model (1) to fit the INTEGRAL data; because of the low flux from the source ($2.68 \times 10^{-10}$ erg cm$^{-2}$ s$^{-1}$ in the energy range $3 - 100$ keV), the quality of the soft ($< 20$ keV) X-ray spectrum did not allow us to detect an iron line and low-energy absorption. It should be noted that there is a discrepancy between our best-fit parameters and those given in Corbet et al. 1999: according to the INTEGRAL data, the spectrum is slightly softer, while the e-folding energy is larger by about 10 keV.

XTE J1858+034. The pulsar XTE J1858+034 is a transient source, which was discovered during outburst in 1998 by RXTE observatory (Remillard et al. 1998). INTEGRAL observations of the Sagittarius arm region (MJD 53116 – 53128) allowed to detect a new outburst from the source and improve the accuracy of its localization (Molkov et al., 2004b).

In the period MJD 53116 – 53119 the mean $18 - 60$ keV flux from the source was about 6 mCrab then it increased and reached $\sim 83$ mCrab on MJD 53128 in the same energy range. For lack of the INTEGRAL data, the further behaviour of the source was analyzed using data of the ASM monitor of the RXTE observatory in the $1 - 12$ keV energy range, which are available from [http://xte.mid.edu](http://xte.mid.edu). It was found that flux from the pulsar remained stable on the same level for $\sim 4$ days, and then began to decrease.

No significant dependence of the pulsar’s spectrum shape on its flux was revealed in our analyses, therefore we constructed an average spectrum of the source. It was fitted by the
model (1) with the absorption on the low energies; the following parameters were obtained: 

\[ N_H = (14.3 \pm 0.7) \times 10^{22} \text{ cm}^{-2}, \quad \Gamma = 1.38 \pm 0.02, \quad E_{\text{cut}} = 25.16 \pm 0.33 \text{ keV}, \quad E_{\text{fold}} = 7.92 \pm 0.22 \text{ keV}. \]

Paul and Rao (1998) analyzed the pulsar’s spectrum in the 2–50 keV energy range using the RXTE observatory data, however they failed to obtain its meaningfully constrained best-fit parameters. Thus our results are the first reliable measurements of the source spectrum parameters in the broad energy range. More detailed analysis of the pulsar behavior during the outburst in 2004 will be perfomed in a separate paper.

*X 1901+03.* The X-ray pulsar X 1901+03 was observed by the INTEGRAL observatory during its outburst in the spring of 2003 (Galloway et al. 2003). The spectrum and its best-fit parameters based on model (1) were taken from Molkov et al. (2003), who performed spectral and temporal analyses of the pulsar’s behavior.

*4U 1907+097.* To construct the spectrum for the pulsar 4U 1907+097, we used the publicly accessible observational data from March through May 2003 (MJD 52705–52762 MJD). The mean 18–60 keV flux from the source in this period was \( \sim 20 \text{ mCrab} \); however, we observed episodes with a duration of \( \sim 1 \) day when the flux dropped by a factor of 2 and detected one outburst during which the flux doubled compared to its mean value.

Roberts et al. (2001) analyzed the source’s soft X-ray spectrum in detail using ASCA data, which were fitted by a simple power law with low-energy absorption, and RXTE data in the range 2.5–20 keV, which were fitted by model (2). This analysis showed that the best-fit parameters for the pulsar’s spectrum change only slightly with flux, except the absorption, which changes from \( \sim 2 \times 10^{22} \text{ cm}^{-2} \) to \( \sim 8 \times 10^{22} \text{ cm}^{-2} \) throughout the orbital cycle.

We constructed the source’s average spectrum from all of the available observations and fitted it by model (1). Our photon index agrees with the values given in Roberts et al. (2001) and Cusumano et al. (1998) (in this paper, the source’s spectrum was analyzed over a wide energy range using BeppoSAX data and was fitted by model (1)). At the same time, the e-folding energy proved to be a factor of 1.7 lower than the values given in these papers.

Cusumano et al. (1998) detected a cyclotron line at 19 keV and its harmonic in the pulsar’s spectrum. Our analysis did not reveal these features in the source’s spectrum.

*KS 1947+300.* The transient X-ray pulsar KS 1947+300 was within the IBIS/INTEGRAL field of view from December 2002 until April 2004 \( \sim 700 \) times, with the total exposure being \( \sim 1.5 \) million s. Because of its flaring activity, several states differing in intensity for which independent spectral analyses were performed using INTEGRAL and RXTE data (Tsygankov and Lutovinov 2005b) can be identified in the source’s light curve.

Here, we provide the INTEGRAL spectrum of the source obtained on April 7, 2004, when it was detected at a statistically significant level by both the IBIS telescope and the JEM-X monitor. The pulsar’s spectrum (Fig. 2) and its best-fit parameters (Table 2) were taken from Tsygankov and Lutovinov (2005b).

*EXO 2030+375.* The INTEGRAL observations of the transient pulsar EXO 2030+375 prior to MJD 52650 were analyzed in several papers (see, e.g., Kuznetsov et al. 2004; Camero
Arranz et al. 2004; and references therein). Over the period from MJD 52650 to MJD 52838, three outbursts (MJD 52717, MJD 52761, MJD 52805) were detected from the source, during which the 18 – 60 keV flux reached \(\sim 80\) mCrab. In the remaining time, the upper 1\(\sigma\) limit on its flux was 2 mCrab in the same energy range. Because of the scarcity of data, we failed to analyze the spectra for each outburst separately; therefore, we constructed an average spectrum for all outbursts. Our best-fit parameters based on model (1) agree with those given in Kuznetsov et al. (2004) and Reynolds et al. (1993a) for the hard and soft X-ray energy ranges, respectively.

**SAX J2103.5+4545.** The source SAX J2103.5+4545 was within the field of view of the INTEGRAL instruments during the calibration observations of the Cyg X-1 region in December 2002 (MJD 52629–52632 and MJD 52636–52637); a detailed analysis of these observations can be found in our previous paper (Filippova et al. 2004). The data obtained later during the Galactic plane scanning were analyzed by Sidoli et al. (2004). The pulsar’s spectrum shown in Fig. 2 and its best-fit parameters (Table 2) were taken from Filippova et al. (2004).

**CONCLUSIONS**

We have presented a catalog of spectra for 34 accretion-powered X-ray pulsars and one millisecond pulsar that were observed by the INTEGRAL observatory and that were detected by its instruments at a statistically significant level in the period from MJD 52629 to MJD 53276. For 18 of the 35 sources, we were able to reconstruct their broadband spectra. The sources under study include one millisecond pulsar, XTE J1807-294, and seven recently discovered X-ray pulsars: 2RXP J130159.6-635806, IGR/AX J16320-4751, IGR J16358-4726, AX J163904-4642, IGR J16465-4507, SAX/IGR J18027-2017 and AX J1841.0-0535. Hard X-ray spectra have been obtained for the pulsars A 0114+650, RX J0146.9+6121, AX J1820.5-1434, AX J1841.0-0535 and XTE J1807-294 for the first time.

For variable sources, we analyzed the flux dependence of the spectral shape. For example, the spectrum of the pulsar GX 1+4 becomes harder with increasing intensity of the source. We also compared our best-fit parameters with the results of previous studies and discussed their evolution.

A hard X-ray spectrum has been obtained for the pulsar Vela X-1 for the first time during an eclipse of the source by its optical companion. We were able to reconstruct it only in the hard X-ray energy range, since the JEM-X instrument did not detect the pulsar at this time. The spectrum was described by a simple power law with an index of 3.1.

Cyclotron lines and their harmonics were detected in the spectra of several pulsars: one harmonic in 4U 0352+309, one harmonic in both low and high states in GX 301-2, two harmonics in Vela X-1, and three harmonics in V 0332+53.
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| Name                  | Binary type | $P_s$    | $P_{orb}$, days | Companion type | References          |
|-----------------------|-------------|----------|-----------------|----------------|---------------------|
| A 0114+650            | HMXB        | 10008    | 11.6            | B1 Ia          | [1],[2],[3]         |
| SMC X-1               | HMXB        | 0.71     | 3.89            | B0             | [4],[5],[6]         |
| RX J1016.9+6121       | HMXB        | 1408     |                 | B5IHe          | [7],[8]             |
| V 0332+53             | HMXB        | 4.4      | 34.25           | O8-9Ve         | [9],[10]            |
| 4U 0352+309           | HMXB        | 837      |                 | Be(XPer)       | [11]                |
| LMC X-4               | HMXB        | 13.5     | 1.4             | O7 III-V       | [12],[13],[14]      |
| A 0355+260            | HMXB        | 103      | 111             | O9.7 I1He Be   | [15],[16],[17]      |
| Vela X-1              | HMXB        | 283      | 8.96            | B0.5lb         | [18],[19]           |
| CEN X-3               | HMXB        | 4.82     | 2.1             | O6-8f          | [20],[21]           |
| 4U 1145-619           | HMXB        | 292      | 187             | B1Vne          | [22],[23]           |
| 1E 1145.1-6141        | HMXB        | 297      | 14.365          | B2Iae          | [24],[25]           |
| GX 301-2              | HMXB        | 680      | 41.5            | Be             | [26],[27]           |
| 2RXP J130159.6-635806 | HMXB?       | 704      |                 |                | [28]                |
| 4U 1538-52            | HMXB        | 528      | 3.7             | B0Iab          | [29],[30]           |
| 4U 1626-67            | LMXB        | 7.66     | 0.0289          | low-mass dwarf | [31],[32]           |
| IGR/A X J16320-4751   | HMXB        | 1300     |                 |                | [33],[34]           |
| IGR J16358-4726       | HMXB        | 5980     |                 |                | [35],[36]           |
| AX J163904-4642       | HMXB        | 900      |                 |                | [37]                |
| IGR J1645-4507        | HMXB        | 228      |                 |                | [35]                |
| OAO 1657-415          | HMXB        | 37.7     | 10.4            | B0-6Iab        | [38],[39]           |
| EXO 1722-363          | HMXB        | 413      | 9.7             | Be?            | [40],[41]           |
| GX 1+4                | LMXB        | 115      | 303.8           | M6III          | [42],[43],[44]      |
| SAX/IGR J18027-2017   | HMXB        | 139      | 4.6             |                | [45],[46]           |
| XTE J1807-294         | LMXB        | 0.00255  | 0.0278          |                | [47],[48]           |
| AX J1820.5-1434       | HMXB        | 152.3    |                 | Be?            | [49]                |
| AX J1841.0-0535       | HMXB        | 4.74     |                 | Be             | [50],[51]           |
| GS 1843-009           | HMXB        | 29.477   |                 | B0-B2 IV-Ve    | [52],[53],[54]      |
| A 1845-024            | HMXB        | 94.8     | 242             |                | [55],[56],[57]      |
| XTE J1855-026         | HMXB        | 360.741  | 6.067           |                | [58],[59]           |
| XTE J1858+034         | HMXB        | 221      |                 |                | [60]                |
| X 1901+031            | HMXB        | 2.763    |                 |                | [61],[62]           |
| 4U 1907-097           | HMXB        | 438      | 8.38            | B1              | [63],[64],[65]      |
| KS 1947-300           | HMXB        | 18.7     | 40.415          | B0Ve           | [66],[67],[68],[69] |
| EXO 2030+375          | HMXB        | 41.7     | 46              | Be             | [70],[71]           |
| SAX J2103.5+4545      | HMXB        | 355      | 12.68           | O-B            | [72],[73]           |

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### 2. Exposure times, fluxes, and best-fit parameters for the spectra of the pulsars

| Name                      | Exposure,ks | JEM-X Flux, $10^{-9}$erg cm$^{-2}$s$^{-1}$ | IBIS 6-20 | IBIS 18-60 | $N_H$,10$^{22}$ cm$^{-2}$ | Photon index, $\Gamma$ | $E_{cut}$,keV | $E_{fold}$, keV | $\chi^2$ |
|---------------------------|-------------|------------------------------------------|-----------|------------|---------------------|-----------------|-------------|----------------|--------|
| A 0114+650                | 2           | 40.4                                     | 0.09      | –          | –                   | 2.3±0.4        | –           | –              | 0.42(6) |
| SMC X-1                   | 70          | 104                                      | 1.05      | 0.76       | –                   | 1.48±0.02      | 20.5$^{+1.0}_{-1.8}$ | 12.9$^{+0.6}_{-0.7}$ | 0.98(124) |
| RX J0146.9+6121           | –           | 250                                      | 0.03      | –          | –                   | 2.9$^{+1.1}_{-0.8}$ | –           | –              | 0.31(3) |
| V0332+53                  | 178         | 187.4                                    | 17.87     | 6.22       | 4$^a$               | 0.77±0.02      | 24.3$^{+0.5}_{-0.7}$ | 14.0$^{+5.0}_{-0.7}$ | 0.35(127) |
| 4U 0352+309               | –           | 50                                       | 0.56      | –          | –                   | 1.92±0.19      | 50±16       | 77±27         | 0.36(9) |
| LMC X-4                   | 93          | 176                                      | 0.79      | 0.78       | –                   | 0.2±0.15       | 9.1±0.8      | 11.0±0.6      | 0.93(117) |
| A 0535+26                 | –           | 77                                       | 0.24      | –          | –                   | 1.2$^a$        | 24$^a$       | 13.8$^{+4.5}_{-3.2}$ | 0.07(5) |
| Vela X-1(eclipse)         | –           | 203.6                                    | 0.1       | –          | –                   | 3.1±0.3        | –           | –              | 0.83(7) |
| Vela X-1(outside eclipse) | 897.2       | 560                                      | 3.2       | 3.6        | –                   | 0.88±0.01      | 25.5±0.2     | 13.0±0.1      | 0.34(131) |
| CEN X-3(quiet state)      | 266.1       | 250                                      | 0.39      | 0.2        | –                   | 0.87±0.06      | 16.4±0.6     | 7.1±0.2       | 1.5(120) |
| CEN X-3(outbursts)        | 15          | 47                                       | 1.57      | 0.66       | –                   | 1.16±0.04      | 15.3±0.2     | 7.8±0.2       | 1.4(116) |
| 4U 1145-619               | 11          | 77.3                                     | 0.39      | 0.33       | –                   | 1.5±0.1        | 6.7±1.4      | 30±4          | 1(142) |
| 1E 1145.1-614             | 11          | 345.2                                    | 0.39      | 0.4        | 3.3$^a$            | 1.08±0.07      | 8±1         | 21.9$^{+1.8}_{-0.8}$ | 0.98(139) |
| GX 301-2 (high state)     | –           | 31                                       | –         | 6.04       | –                   | 0.74$^{+0.32}_{-0.09}$ | 23.3$^{+0.3}_{-0.5}$ | 8.3±0.7      | 0.74(8) |
| GX 301-2 (low state)      | 62          | 710                                      | 0.96      | 0.99       | 10.6±2.5           | 0.30±0.06      | 17.8±0.2     | 9.7±0.7       | 0.9(118) |
| 2RXP130159.6-635806       | –           | 10.3                                     | 0.2       | –          | 2.5$^a$            | 0.69$^a$       | 24.3±3.4     | 8.5±0.2       | d |
| 4U 1538-52                | 23          | 894.4                                    | 0.46      | 0.2        | 1.63$^a$           | 1.37±0.06      | 28.7±0.8     | 9.9±0.7       | 0.94(119) |
| 4U 1626-67                | –           | 218.2                                    | 0.15      | –          | –                   | 0.87$^a$       | 23.9$^{+1.0}_{-1.4}$ | 7±1        | 1.25(5) |
| IGR/AX J16320-4752$^b$    | –           | 1000                                     | 0.2       | 18$^a$     | –                   | 0.7±0.2        | –           | 13±1          | d        |
| IGR J16358-4726$^b$       | –           | 1000                                     | 0.04      | 40&0.7±0.5 | –                   | 16±5           | d           |               |         |
| AX J163904-4642$^b$       | –           | 1000                                     | 0.06      | 58&1.3±1.0 | –                   | 11±1           | d           |               |         |
| IGR J16465-4507$^b$       | –           | 1000                                     | 0.12      | 72&1.0±0.5 | –                   | 30$^a$         | d           |               |         |
| OAO 1657-415              | 29          | 1663.7                                   | 0.8       | 1.03       | 15.2$^{+0.7}_{-1.4}$ | 1.57±0.02 | 26.3$^{+0.7}_{-1.8}$ | 29.2$^{+1.2}_{-0.5}$ | 0.73(119) |
| EXO 1722-363              | –           | 2960.9                                   | 0.6       | –          | 3.5$^a$            | –              | –           | 2.7(5)        |         |
| GX 1+4 (low state)        | 9           | 2315                                     | 0.08      | 0.07       | –                   | 2.24$^{+0.06}_{-0.12}$ | –        | –             | 0.93(126) |
| GX 1+4 (intermediate state) | 3.5       | 385                                      | 0.11      | 0.14       | –                   | 1.54$^{+0.35}_{-0.22}$ | 24.8$^{+5.8}_{-3.0}$ | 47.0$^{+15.2}_{-10.7}$ | 1.16(125) |
| GX 1+4 (high state)       | 5           | 164                                      | 0.76      | 1.62       | –                   | 0.93$^{+0.12}_{-0.14}$ | 25.1$^{+1.1}_{-1.7}$ | 30.4±2.4     | 1.19(136) |
| IGR/SAX J18027-2017$^b$   | –           | 1274                                     | 0.06      | –          | –                   | 0.1$^a$        | –           | ~10           |         |
|        | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| XTE J1807-294 | –   | 711 | –   | 0.11| –   | 1.96| 48.1$^{+7.6}_{-9.9}$ | 75.7$^{+28.1}_{-24.5}$ | 0.92(7) |
| AX J1820.5-1434 | –   | 2322.3 | –   | 0.1 | –   | 0.9$^a$ | 25.3±3 | 17.0±2.7 | 0.37(9) |
| AX J1841.0-0535 | –   | 77.19| –   | 0.11| –   | 2.2±0.3 | –        | –        | 0.42(5) |
| GS 1843+009 | –   | 62  | –   | 0.17| –   | 0.34$^a$ | 5.95$^a$ | 17.4±1.4 | 1.2(8) |
| A 1845-024 | –   | 691.8 | –   | 0.06| –   | 2.62±0.19 | –        | –        | 0.46(7) |
| XTE J1855-026 | 9   | 652 | 0.16| 0.17| –   | 1.69±0.23 | 23.99$^{+2.88}_{-6.73}$ | 38.49$^{+10.35}_{-7.38}$ | 1.08(112) |
| XTE J1858+034 | 137 | 360 | 1.13| 0.99| 14.3±0.7 | 1.38±0.02 | 25.16±0.33 | 7.92±0.22 | 0.95(144) |
| X 1901+031 | 150 | 330 | 6.1 | 1.8 | –   | 2.035±0.015 | 11.27±0.19 | 13.22±0.11 | 0.82(127) |
| 4U 1907+097 | 180 | 478.3 | 0.6 | 0.18| –   | 1.26±0.07 | 7.0±0.3 | 9.0$^{+0.3}_{-0.6}$ | 0.75(131) |
| KS 1947+300 | 2   | 6   | 1.09| 1.17| –   | 1.07$^{+0.24}_{-0.13}$ | 8.6$^{+3.4}_{-1.2}$ | 23.6$^{+5.3}_{-2.3}$ | 1.18(104) |
| EXO 2030+375 | 2   | 25.3 | 0.84| 0.85| –   | 1.71±0.09 | 25.2$^{+2.5}_{-3.7}$ | 33$^{+6}_{-4}$ | 1.06(137) |
| SAX J2103.5+4545 | 33  | 196.6 | 0.38| 0.38| 0.9$^a$ | 1.04±0.15 | 8.5±2.4 | 21.37±2.75 | 1.21(120) |

$^a$The parameter is fixed  

$^b$The cutoffpl model was used to fit the spectrum  

In the energy range 20–60 keV  

$^d$Lutovinov et al. (2005c) fitted the pulsar’s spectrum over a wide energy range together with data from other observatories (see the text).
3. Other best-fit parameters for the spectra of the pulsars

| Binary               | Fe line center, keV | Fe line width, keV | Fe line Intensity, Fe, photons s$^{-2}$ s$^{-1}$ | $E_{\text{cycl}}$, keV | $\tau_{\text{cycl}}$ | $\sigma_{\text{cycl}}$, keV |
|----------------------|---------------------|-------------------|-----------------------------------------------|------------------------|----------------------|--------------------------|
| V0332+53             | –                   | –                 | –                                             | 24.25$^{+0.07}_{-0.14}$ | 1.98$^{+0.02}_{-0.04}$ | 7.10$^{+0.10}_{-0.09}$ |
| 4U 0352+309          | –                   | –                 | –                                             | 28.8$^{+2.5}_{-2.3}$   | 0.33$^{+0.12}_{-0.09}$ | 9                        |
| Vela X-1             | 6.64$^{+0.10}_{-0.11}$ | 0.31$^{+0.16}_{-0.15}$ | (4.7$^{+0.8}_{-0.8}$)$\times10^{-3}$          | 24.0$^{+0.3}_{-0.3}$   | 0.38$^{+0.01}_{-0.01}$ | 5.3$^{+0.5}_{-0.5}$    |
| GX 301-2 (high)      | –                   | –                 | –                                             | 49.2$^{+4.2}_{-2.1}$   | 0.60$^{+0.13}_{-0.09}$ | 18                       |
| GX 301-2 (low)       | 6.54$^{+0.17}_{-0.11}$ | 0.52$^{+0.22}_{-0.14}$ | (2.54$^{+1.02}_{-1.02}$)$\times10^{-3}$       | 47.4$^{+2.2}_{-1.1}$   | 0.87$^{+0.17}_{-0.17}$ | 18                       |

\(^a\) Two more features were found in the pulsar spectrum, the second and third harmonics of the cyclotron line:

\[
E_{\text{cycl} 2} = 46.8^{+0.2}_{-0.1} \ , \ \tau_{\text{cycl} 2} = 1.94^{+0.06}_{-0.07} \ , \ \sigma_{\text{cycl} 2} = 8.9 \pm 0.4
\]

\[
E_{\text{cycl} 3} = 67.9^{+3.2}_{-4.3} \ , \ \tau_{\text{cycl} 3} = 2.60^{+0.25}_{-0.35} \ , \ \sigma_{\text{cycl} 3} = 26.9 \pm 5.4
\]

\(^b\) The parameter is fixed.

The second harmonic of the cyclotron line with

\[
E_{\text{cycl} 2} = 50.2 \pm 0.5 \ , \ \tau_{\text{cycl} 2} = 0.95 \pm 0.03 \ , \ \sigma_{\text{cycl} 2} = 12.2 \pm 0.5 \text{ keV}
\]

was detected in the pulsar.
Fig. 1: Energy spectrum for the Crab Nebula. The solid line represents the power-law best fit to the spectrum with the following parameters: $\Gamma = 2.13 \pm 0.02$, $Norm = 11.27 \pm 0.35$. The errors correspond to one standard deviation.
Fig. 2: INTEGRAL energy spectra for the X-ray pulsars. The solid lines represent the best fit to the spectrum. The errors correspond to one standard deviation.
Fig. 2: Contd.
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