INTEGRAL and Swift/XRT observations on IGR J18179-1621

J. Li\textsuperscript{1,2,⋆}, S. Zhang\textsuperscript{1⋆}, D. F. Torres\textsuperscript{2,3}, A. Papitto\textsuperscript{2}, Y. P. Chen\textsuperscript{1} and J. M. Wang\textsuperscript{1,4,5}

\textsuperscript{1}Key Laboratory for Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, 19B Yuquan Road, Beijing 100049, China
\textsuperscript{2}Institut de Ciències de l’Espai (IEEC-CSIC), Campus UAB, Torre C5, 2a planta, 08193 Barcelona, Spain
\textsuperscript{3}Institució Catalana de Recerca i Estudis Avançats (ICREA).
\textsuperscript{4}National Astronomical Observatories of China, Chinese Academy of Sciences, 20A Datun Road, Beijing 100020, China
\textsuperscript{5}Theoretical Physics Center for Science Facilities (TPCSF), Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

IGR J18179-1621 is a hard X-ray binary transient discovered recently by INTEGRAL. Here we report on detailed timing and spectral analysis on IGR J18179-1621 in X-rays based on available INTEGRAL and Swift data. From the INTEGRAL analysis, IGR J18179-1621 is detected with a significance of 21.6σ in the 18–40 keV band by JEM-X, between 2012-02-29 and 2012-03-01. We analyze two quasi-simultaneous Swift ToO observations. A clear 11.82 seconds pulsation is detected above the white noise at a confidence level larger than 99.99%. The pulse fraction is estimated as 22±8% in 0.2-10 keV. No sign of pulsation is detected by INTEGRAL/ISGRI in the 18–40 keV band. With Swift and INTEGRAL spectra combined in soft and hard X-rays, IGR J18179-1621 could be fitted by an absorbed power law with a high energy cutoff plus a Gaussian absorption line centered at 21.5 keV. An additional absorption intrinsic to the source is found, while the absorption line is evidence for most probably originated from cyclotron resonant scattering and suggests a magnetic field in the emitting region of \( \sim 2.4 \times 10^{12} \) Gauss.

Key words: X-rays: individual: IGR J18179-1621.

1 INTRODUCTION

One of the most effective techniques to estimate the strength of the magnetic field of a neutron star is the detection of cyclotron resonant scattering features (CRSF) in its X-ray spectrum. The fundamental electron cyclotron resonance energy is \( E = 11.6 \times 10^3 (1 + z_g)^{-1} \) keV, where \( B_{12} \) is the magnetic field strength of the neutron star in units of \( 10^{12} \) G, and \( z_g \) is the gravitational redshift. The surface magnetic field of neutron stars in accreting X-ray binaries can then be determined through the observation of the CRSF, which shows absorption lines at the fundamental electron cyclotron resonance and its high-energy harmonics.

So far, CRSF are identified in 17 X-ray binaries, and show hints in another 10 (Pottschmidt et al. 2001, Makishima et al 1999, Coburn et al 2001, Yamamoto et al 2011). All the X-ray binaries with identified or possible CRSF are high mass X-ray binaries, except for 4U 1626-67, and all host X-ray pulsars. 7 out of the 10 candidates host X-ray pulsars too, with the exceptions of XTE J1739-302, 4U 1700-377, and IGR 16318-4848, for which pulsations are not yet detected. The magnetic field strength of CRSF-identified X-ray binaries cluster in a relatively narrow range of \((1.1–6.2) \times 10^{12} \) Gauss (assuming the typical neutron star parameters, \( z_g \sim 0.3 \)).

IGR J18179-1621 is a newly discovered hard X-ray binary transient found by INTEGRAL during inner Galactic disk observations performed on 2012-02-29 – MJD 55986 (see the ATel by Tuerler et al. 2012). The significant detection of IGR J18179-1621 by INTEGRAL reveals an absorption line \( \sim 20.8 \) keV, which may result from cyclotron resonant scattering (Tuerler et al. 2012). In subsequent Swift/XRT and Fermi/GBM observations (see the ATels by Halpern et al. 2012, Li et al.2012, and Finger et al. 2012) a 11.82 s pulsation was discovered. The absorption line and the 11.82 s pulsation suggested that IGR J18179-1621 is a high mass X-ray binary hosting a pulsar. Due to the overlap between the Swift position of the X-ray source and 2MASS J18175218-1621316, Li et al. (2012) proposed the latter as the infrared counterpart of IGR J18179-1621. Such a correlation is compatible with the Chandra determination of the position, later obtained by Paizis et al. (2012). Here, we report on spectra and timing analysis of the INTEGRAL observations as well as on two quasi-simultaneous Swift ToO observations.

2 OBSERVATIONS AND DATA ANALYSIS

INTEGRAL (Winkler et al. 2003) is a γ-ray mission optimized to work between 15 keV–10 MeV. Its main instruments are the IBIS (15 keV–10 MeV; Ubertini et al. 2003) and the Spectrometer on
board INTEGRAL (SPI, 20 keV–8 MeV; Vedrenne et al. 2003). The INTEGRAL observations were carried out in individual Science Windows (ScWs), which have a typical time duration of about 2000 s.

For INTEGRAL analysis, we use IBIS/ISGRI and JEM–X data accumulated from the inner Galactic disk observations performed on 2012-02-29 (MJD 55986) and 2012-03-01 (MJD 55987). Our data set comprise 50 Science Windows covering revolution 1145, adding up to a total exposure time of 88.2 ks in IBIS/ISGRI and 39.4 ks in JEM–X (19.9 ks in JEM–X1 and 19.5 ks in JEM–X2). The data reduction is performed using the standard ISDC offline scientific analysis software version 9.0. We use the latest instrument characteristics in our analysis and follow the position of IGR J18179-1621 determined by Paizis et al. (2012). An IBIS/ISGRI image for each ScW is generated in the 18–40 keV energy band. The spectrum and lightcurve of IGR J18179-1621 from JEM–X observations are similarly produced following the standard steps using OSA 9.0.

Swift (Gehrels et al. 2004) is a γ-ray burst explorer launched on November 20, 2004. It carries three co-aligned detectors: the Burst Alert Telescope (BAT, Barthelmy et al. 2005), the X-Ray Telescope (XRT, Burrows et al. 2005), and the Ultraviolet/Optical Telescope (UVOT, Roming et al. 2005). The XRT uses a grazing incidence Wolter I telescope. XRT has an effective area of 110 cm², a FOV of 23.6 arcmin, an angular resolution (half-power diameter) of 15 arcsec, and it operates in the 0.2–10 keV energy range, providing the possibility of extending the investigation of the source to soft X-rays.

Following the discovery of IGR J18179-1621 (Tuerler et al. 2012) on 2012-02-29, we acquired two Swift ToO observations quasi-simultaneously with INTEGRAL, which were executed on 2012-02-29 (MJD 55986, ID 00032293002) and 2012-03-01 (MJD 55987, ID 00032293002) leading to an exposure of 19.9 ks in JEM–X1 and 19.5 ks in JEM–X2. Source events are accumulated within an annulus (inner radius of 4 pixels and ~2 ks, respectively. These two observations were carried out by Swift/XRT in Photon Counting (PC) mode. We select PC data with event grades 0-12 (Burrows et al. 2005). Due to the relatively high count rate observed by Swift/XRT (~1.9 counts/s), the observation is affected by pile-up. To correct for the pile-up effect we estimate the size of the Point Spread Function (PSF) core affected. By comparing the observed and nominal PSF (Romano et al. 2006; Vaughan et al. 2006), a radius of 4 pixels are determined and all the data within this radius from IGR J18179-1621 are excluded. Source events are accumulated within an annulus (inner radius of 4 pixels and outer radius of 30 pixels, 1 pixel ~ 2.36 arcsec). Background events are accumulated within a circular, source-free region with a radius of 60 pixels. For timing analysis, BARYCORR task is used to perform barycentric corrections to the photon arrival times using the Chandra position given by Paizis et al. (2012). We extract lightcurves with a time resolution of 2.5 seconds. XRTLCORR task is used to account for the pile-up correction in the background-subtracted light curves. For our spectral analysis, we extract events in the same regions as those adopted for the lightcurve creation. Exposure maps are generated with the task XRTEXPOMAP. Ancillary response files are generated with XRTMKARF, to account for different extraction regions, vignetting, and PSF corrections. We analyze the Swift/XRT 0.2–10 keV data by HEAsoft version 6.9 and spectral fitting is performed using XSPEC V.12.6.0. The error for timing and spectral analysis are estimated at 90% confidence level.

3 TIMING AND SPECTROSCOPY

Swift imaging analysis shows a single source detected at soft X-rays. Using the online Swift tool, we find a position for IGR J18179-1621 at RA = 274.4675 (18h 17m 52.20s), DEC = -16.3589 (-16°21'31.9") (J2000), with a 90% confidence error of 2.2 arcsec, consistent with the position measured by INTEGRAL/JEM–X (Tuerler et al. 2012) and Chandra (Paizis et al. 2012). This position determination uses a Point Spread Function fit, with bad column and pile-up correction built in. For the enhanced positions the absolute astrometry is corrected using field stars in the UVOT. We have used the XRT/UVOT alignment, and matching UVOT field sources to the USNO-B1 catalogue (Evans et al. 2009). With all INTEGRAL/ISGRI data combined, IGR J18179-1621 is detected with a significance level of 21.6 σ in the 18–40 keV energy band, over an 88.2 ks exposure. Figure 1 shows the INTEGRAL/ISGRI significance mosaic image of IGR J18179-1621 sky region, derived from combining all INTEGRAL/ISGRI data in the 18–40 keV energy band. The significance level is given by the color scale which is linear. Corresponding significance and color could be found in the lower color bar. The contours of significance start at 9 σ, and following steps of 4 σ. X-axis and Y-axis are RA and DEC in the unit of degree.

For timing analysis, we use sphinx3 software and the XRTLCCORR tool to cross-correlate the Swift and INTEGRAL lightcurves. Using this method, we find a robust correlation between the Swift and INTEGRAL lightcurves with a significance level of 21.6 σ in the 18–40 keV energy band. Combining all INTEGRAL/ISGRI data, IGR J18179-1621 is detected with a significance level of 11.4 σ in the 3–10 keV band, 15.9 σ in the 10–25 keV band, and 15.3 σ in the 3-25 keV band, under a exposure of 19.9 ks. JEM–X2 detects IGR J18179-1621 at a similar level. The significant detection of IGR J18179-1621 by Swift/XRT and INTEGRAL allows for a detailed spectral and timing analysis in both soft and hard X-rays.

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1 Please see http://www.swift.ac.uk/pileupthread.shtml for more information.

2 Please see http://www.swift.ac.uk/user_objects/ for more information.
3.1 Timing analysis

Swift/XRT lightcurves in 2.5 seconds bin are produced in the 0.2–10 keV band for the two ToO observations mentioned above. A constant fit to the lightcurve yields an average count rate of 0.91±0.03 counts/s and a reduced χ² of 1.03 for 1238 d.o.f. In order to search for any periodic signal in the Swift/XRT lightcurve, we use the Lomb–Scargle periodogram method (Lomb 1976; Scargle 1982). Power spectra are generated for the lightcurve using the PERIOD subroutine (Press & Rybicki 1989). The 99.99% white noise significance levels are estimated using Monte Carlo simulations (see e.g. Kong, Charles & Kuulkers 1998). A significant signal at 11.82±0.03 s is detected above the white noise at a confidence level larger than 99.99% (figure 2, upper panel). The pulsation exhibits a single peak profile and pulse fraction of 22±8% (figure 2, middle panel). The signal we detect is consistent with the results reported by Halpern et al. (2012), Li et al. (2012), and Finger et al. (2012).

The INTEGRAL/ISGRI lightcurve is produced by running the pipeline to LCR level and binned with 1800 seconds. Fitting a constant to the INTEGRAL/ISGRI lightcurve yields an average count rate of 3.10±0.16 counts/s and a reduced χ² of 1.01 for 53 d.o.f. For timing analysis in hard X-ray, we extracted all INTEGRAL/ISGRI photon events from IGR J18179-1621 in the 18–40 keV band. For a larger signal-to-noise ratio, only photons from fully illuminated pixels (Pixel Illuminated Factor=1) are included. Barycentric corrections are applied to the photon arrival times using the Chandra position given by Paizis et al. (2012), and the pulsation is searched for by using the Kronos routine efssearch. Fourier period resolution (FPR), δP = P²/2Tobs, is used as search resolution. With P = 11.82 s and 2Tobs = 2 d, we obtain δP = 4 × 10⁻⁴ s. To search within the interval defined by the 3 σ error on the Swift/XRT determination of the period (i.e., 2×3×0.01 = 0.06 s), we perform 150 period trials. The trail periods are sampled using 8 phase bins. For a χ² distribution with 7 degrees of freedom (see, e.g. Leahy et al. 1983) the detection at a 3 σ confidence level for a single trial is χ² = 21.8. Considering the number of trials performed, 3 σ confidence level increases to χ² = 33.9. The results are shown in the lower panel of figure 2. The most significant peak has a χ² = 20.6, which therefore does not allow to draw a signal in the INTEGRAL/ISGRI events. This is most probably the result of background dominated nature of INTEGRAL/ISGRI data. We also note how this analysis assumes that the possible orbital period of the system does not significantly affect the frequency of the signal, over the considered time-interval (i.e., is > 20 d).

3.2 Spectral analysis

INTEGRAL and Swift observations of IGR J18179-1621 are quasi-simultaneous within continuous two days. Consequently it provides a chance for simultaneous spectral analysis in soft and hard X-rays. Combined with Swift/XRT and INTEGRAL/JEMX & ISGRI, we carry out systematic spectral analysis for MJD 55986 (2012-02-29) and MJD 55987 (2012-02-29) separately. We checked a posteriori that the analysis on the two days separately gave consistent results. The spectra from the two consecutive days are then combined to increase the statistics and better constrain the parameters. To fit simultaneously the spectra of various instruments –Swift/XRT (0.2–10 keV), INTEGRAL/JEMX-1 (5–30 keV), JEMX-2 (5–30 keV) and ISGRI (18–50 keV)– we introduce normalization constants, which are fixed to 1 for the JEMX-1 spectrum, and free to vary for the others. Using an absorbed power-law model, we obtained a reduced χ² = 4.02 over 118 degrees of freedom, which is far from being acceptable. To improve the fitting, we followed Coburn et al. 2002, adding a high energy cutoff (PLCUT; White et al. 1983) to the absorbed powerlaw. The analytic form of the model is:

\[
\text{PLCUT}(E) = A E^{-\Gamma} \times \begin{cases} 1 & (E \leq E_{\text{cut}}) \\ e^{-(E-E_{\text{cut}})/E_{\text{fold}}} & (E > E_{\text{cut}}) \end{cases}
\]

where Γ is the photon index, and Ecut and Efold are the cutoff and folding energies, respectively. Applying PLCUT model an apparent structure locate at ~20 keV in the residuals (Figure 3, lower panel), which indicates the presence of a CRSF. To model the pos-

![Figure 2](https://example.com/figure2.png)
We present timing and spectral analysis of IGR J18179-1621 from Swift/XRT and INTEGRAL/JEMX–1 (black), JEMX–2 (red) and ISGRI (green). The spectra are fitted with PLCUT plus GABS model and residuals between data and model are shown. Lower: residuals between data and model in the case of PLCUT only. A structure at ∼20 keV indicates the presence of a CRSF.

![Figure 3](https://via.placeholder.com/150)

**Figure 3.** Upper: Combined folded spectra from Swift/XRT (blue), INTEGRAL/JEMX–1 (black), JEMX–2 (red) and ISGRI (green). The spectra are fitted with PLCUT plus GABS model and residuals between data and model are shown. Lower: residuals between data and model in the case of PLCUT only. A structure at ∼20 keV indicates the presence of a CRSF.

**4 DISCUSSION**

We present timing and spectral analysis of IGR J18179-1621 from quasi-simultaneous observations made by Swift/XRT and INTEGRAL. A 11.82 s pulsation is discovered in Swift/XRT lightcurve in the 0.2–10 keV band, which is consistent with previous reports by Halpern et al. 2012, Li et al. 2012, and Finger et al. 2012. Because of more data being included in our analysis, a higher significance detection is obtained when compared with that of Tuerler et al. 2012. The 11.82 s pulsation is searched within 4U 0115+63 is a transient X-ray pulsar too with 3.6 s pulsation and 24-d orbit. It have a similar cutoff energy (10 keV) and folding energy (9.3 keV) than IGR J18179-1621. However, since little is known about IGR J18179-1621, we cannot draw further conclusions on the similarity between these two sources. Though IGR J18179-1621’s 2.61 keV width of CRSF is not uncommon, its optical depth of 6.3 is the largest –about ten times that of other sources. A correlation between CRSF relative width (σc/Ec) and optical depth (τc) is observed (Coburn et al. 2002). However, because of the unusually large CRSF optical depth, IGR J18179-1621 is far from the correlation. On the contrary, IGR J18179-1621 follows another two correlations with other sources, CRSF width (σc) versus centroid energy (Ec), and cutoff energy (Ec) versus centroid energy (Ec) (Coburn et al. 2002). An absorption (12.3 × 10^22 cm^-2) which is much larger than the Galactic column density (1.2 × 10^22 cm^-2) at IGR J18179-1621’s position is obtained. This possibly indicates an additional absorption intrinsic to the source. Li et al. 2012 proposed 2MASS J18175218-1621316 as the infrared counterpart for IGR J18179-1621. This source is obscured and it is well measured only in the Ks band: Ks magnitude=11.14. Both may indicate a complicated surrounding of IGR J18179–1621.

Given the value of the spin period, the detection of an absorption feature compatible with a CRSF, and the proposed optical counterpart, IGR J18179-1621 is most plausibly an accreting pulsar. In general, the transient behavior of X-ray binaries is powered by accretion of matter from the companion to the magnetic poles of the neutron star. The accretion flow onto the magnetic pole will be modulated as a fan beam coming out from the bottom region of the shock and peaked perpendicular to the magnetic axis. In a lower accretion rate, while luminosity is less than 10^{33} erg s^-1, a CRSF is significantly detected at 21.5 keV, which is consistent with, but more precise and constrained than the results by Tuerler et al. 2012, obtained using INTEGRAL data only. Among those X-ray binaries which show CRSF and which are fitted by the same model (Coburn et al. 2002), IGR J18179-1621 have a moderate slope. Ec and E_c are low comparing with other sources. 4U 0115+63 is a transient X-ray pulsar too with 3.6 s pulsation and 24-d orbit. It have a similar cutoff energy (10 keV) and folding energy (9.3 keV) than IGR J18179-1621. However, since little is known about IGR J18179-1621, we cannot draw further conclusions on the similarity between these two sources. Though IGR J18179-1621’s 2.61 keV width of CRSF is not uncommon, its optical depth of 6.3 is the largest –about ten times that of other sources. A correlation between CRSF relative width (σc/Ec) and optical depth (τc) is observed (Coburn et al. 2002). However, because of the unusually large CRSF optical depth, IGR J18179-1621 is far from the correlation. On the contrary, IGR J18179-1621 follows another two correlations with other sources, CRSF width (σc) versus centroid energy (Ec), and cutoff energy (Ec) versus centroid energy (Ec) (Coburn et al. 2002). An absorption (12.3 × 10^22 cm^-2) which is much larger than the Galactic column density (1.2 × 10^22 cm^-2) at IGR J18179-1621’s position is obtained. This possibly indicates an additional absorption intrinsic to the source. Li et al. 2012 proposed 2MASS J18175218-1621316 as the infrared counterpart for IGR J18179-1621. This source is obscured and it is well measured only in the Ks band: Ks magnitude=11.14. Both may indicate a complicated surrounding of IGR J18179–1621.

Given the value of the spin period, the detection of an absorption feature compatible with a CRSF, and the proposed optical counterpart, IGR J18179-1621 is most plausibly an accreting pulsar. In general, the transient behavior of X-ray binaries is powered by accretion of matter from the companion to the magnetic poles of the neutron star. The accretion flow onto the magnetic pole will be decelerated in a radiative shock above the neutron star surface when the luminosity reaches 10^{37} erg s^-1 (Basko & Sunyaev 1976). Radiation will be modulated as a fan beam coming out from the bottom region of the shock and peaked perpendicular to the magnetic axis. In a lower accretion rate, while luminosity is less than 10^{37} erg s^-1, radiation will be formed into a pencil–beam, which the maximum direction is along the magnetic axis. During a transient outburst similar with the one lead to discovery of IGR J18179–1621, the fan–beam and pencil beam will influence the pulse profiles in the lightcurve. In a high (low) accretion phase, the fan–beam (pencil) component is dominating the emission region, leading to a double (single) peak pulse profile. The transition point between these two different phases is ~ 10^{37} erg s^-1. A demonstration of the pulse profile transformation from two peaks to a single peak accompanying the luminosity evolution is seen in V0332+53 (see, e.g., Zhang et al. 2005). IGR J18179-1621 is characterized with a single peak pulse profile and its unabsorbed flux in 1.5–50 keV is ~ 1.3 × 10^4 erg cm^-2 s^-1. If we apply L < 10^{37} erg s^-1 as the threshold of pulse profile shift, we obtain a upper limit on the IGR J18179-1621 distance at d < 8 kpc.

From the combined Swift and INTEGRAL spectra CRSF of IGR J18179-1621 is identified at 21.5 keV and no high energy harmonics are discovered. If the fundamental electron cyclotron resonance energy is 21.5 keV, this will indicate a magnetic field of ~2.4 × 10^2 Gauss in the emitting region. Under a magnetic field of ~ 10^11 Gauss, the ratio of cyclotron absorption coefficient between the fundamental absorption line and first harmonic is ~ 10^{-1} – 10^{-2} (You et al. 1997), which means that the chance of producing the fundamental absorption line is 10–100 times larger than producing...
the first harmonic. In case of a relatively low accretion rate, there may not be sufficient electrons near the surface of the neutron star to produce the first harmonics in the spectrum. If the accretion rate is high and more electrons are available, the first harmonic may appear in the spectrum, and even the second or third harmonics might. IGR J18179-1621 only shows fundamental absorption line and there is no sight of any harmonics, which hints to a relatively low state of accretion. In addition to its single peak pulse profile, this is another indication that IGR J18179-1621 is not in a very high accretion state during this outburst.

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Table 1. Fitting Parameters of the combined spectra from Swift and INTEGRAL

| Hydrogen column density | Photon Index | Cutoff Energy $E_{\text{cut}}$(keV) | Folding Energy $E_{\text{fold}}$(keV) | Centroid Energy $E_{\text{c}}$(keV) | Absorption Line $\sigma_{\text{c}}$(keV) | Absorption Line $\tau_{\text{c}}$ | reduced $\chi^2$ (D.O.F) |
|-------------------------|--------------|------------------------------------|---------------------------------|---------------------------------|-----------------------------------|--------------------------------|--------------------------|
| $12.3^{+1.8}_{-1.7}$   | $0.59^{+0.25}_{-0.25}$ | $9.97^{+0.97}_{-0.94}$ | $6.10^{+0.70}_{-0.58}$ | $21.5^{+1.1}_{-1.0}$ | $2.61^{+1.14}_{-0.88}$ | $6.93^{+2.44}_{-2.11}$ | 0.923 (113) |

Normalization factors

| INTEGRAL JEM X–2/JEM X–1 | ISGRI JEM X–1 | Swift XRT/JEM X–1 |
|---------------------------|--------------|-------------------|
| $1.21^{+0.08}_{-0.08}$   | $1.17^{+0.21}_{-0.25}$ | $0.67^{+0.07}_{-0.06}$ |

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