Timing and Spectral Study of IGR J19294+1816 with the RXTE: The Discovery of Cyclotron Features

Jayashree Roy1, Manojendu Choudhury2, and P. C. Agrawal2
UM-DAE Centre For Excellence In Basic Sciences, Vidyanagari, Santa Cruz (E), Mumbai-400098, India; jayashree.roy@cbs.ac.in
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Abstract

The Rossi X-Ray Timing Explorer/Proportional Counter Array (PCA) observations of IGR J19294+1816 covering two outburst episodes are reported. The first outburst happened during MJD 54921-54925 (2009 C.E.), and the second one happened during MJD 55499–55507 (2010 C.E.). In both cases, the PCA observations were made during the decay phase of the outburst, with the source exhibiting a temporal and spectral evolution with the change in flux. At the bright flux level, an absorption feature at 35.5 keV is detected in the spectra, which may be attributed to the Cyclotron Resonance Scattering Feature corresponding to a magnetic field of \( B = 4.13 \times 10^{12} \) Gauss. This is also detected at a lower significance in two other observations. In addition, an Fe line emission at 6.4 keV is prominently detected during the highest flux X-ray pulsations are detected in 9 out of 10 observations; no pulsations were found in the observation with the lowest flux level. During this observation with the lowest flux, the pulsation phenomenon becomes detectable only at the soft X-ray bands.

Key words: accretion, accretion disks – pulsars: general (IGR J19294+1816) – X-rays: binaries

1. Introduction

IGR J19294+1816 was discovered by the International Gamma-Ray Astrophysics Laboratory (INTEGRAL) using the IBIS/ISGRI camera at R.A. = 292.42 deg and decl. = +18.28 deg (±3’ at 68%, J2000) on 2009 March 27 (Turler et al. 2009). A follow-up analysis of the Swift archival data by Rodriguez et al. (2009b) led them to the conclusion that the source Swift J1929.8+1821, which was observed on 2007 December 9 and 13, was the same as IGR J19294+1816, with an improved position at J2000, R.A. = 19\(^{h}\)29\(^{m}\)55\(^{s}\)9 and decl. = +18 deg 18’ 39”(±3”5 at 90%). They detected a periodicity of 12.4 s from the power density spectrum, showing a feature at \( 8.04^{+0.02}_{-0.05} \times 10^{-2} \) Hz using Swift/XRT data. Their analysis of the timing and the spectral features suggested the source was an accreting pulsar. Strohmayer et al. (2009) confirmed IGR J19294+1816 was an accreting pulsar with the presence of 12.4 s pulsation from the source, using the Rossi X-ray Timing Explorer (RXTE)/Proportional Counter Array (PCA) observation on 2009 March 31. Corbet & Krimm (2009) suggested the source was a Be/X-ray class of a binary system based on its position on the pulse period versus the orbital plot of Corbet (1986). Rodriguez et al. (2009a) identified an infrared counterpart of the source. From the studies of infrared magnitudes dereddened with different values of the interstellar absorptions, they estimated the source to be at a distance of \( d \geq 8 \) Kpc. They suggested that the source could possibly be a supergiant, fast X-ray transient instead of a Be/X-ray transient because of the short (∼2000–3000 s) and intense flares that are more typical of supergiant fast X-ray transients. However, during the 2010 outburst of the source, the source showed a very smooth and gradual change in flux. Furthermore, the spectral parameters during the two months spanned by the Swift observations, along with its low spin period, seem to confirm that the source is a Be/X-ray transient (Bozzo et al. 2011). In this paper, we report the timing and spectral properties of the source during the decay phase of the 2009 and 2010 outbursts as observed by the RXTE/PCA. Our spectral analysis reveals the first ever detection of Cyclotron Resonance Scattering Features (CRSF) in the source.

2. Data Analysis

RXTE/PCA (Jahoda et al. 2006) data of the source were obtained from High Energy Astrophysics Science Archive Research Center (HEASARC) data archive (http://heasarc.gsfc.nasa.gov), the details of which are presented in Table 1. The observed spectral parameters are presented in Tables 2 and 3. Among the five Proportional Counter Units (PCUs) sensitive in the 3–60 keV range, only the PCU 2 data (from all the layers) are reported in this paper, as it was the only common PCU consistently covering all the observations. The X-ray spectra were extracted using standard 2 mode data with 16 s binning, and the light curves were extracted from the event mode data. The data was filtered with data selection criteria that removed the stretches of the observation that had the South Atlantic Anomaly passage time and included the stretches of the observations for which the Earth elevation was >10° and the pointing offset was <0°.02. The faint background model was used for the background estimation of the spectral analysis, except for the observation on MJD 55499.46 (Obs.id.: 95438-01-01-00) when the source was just bright enough to warrant the strong background model. The background and dead time corrections were performed using the ftools task “fxbary” for all the timing analyses reported here. The source lies in the Galactic plane where the flux from the Galactic ridge needs to be included in the spectral modeling (Valinia & Marshall 1998). We have strictly followed the recipe of Rodriguez et al. (2009a), while adding the Galactic ridge spectrum to the instrumental background spectrum. The data reduction and the analysis were carried out using HEASOFT,\(^8\) which consists of (chiefly) FTOOLS for the general data extraction and analysis,

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1 NASI Research Associate.
2 NASI Senior Scientist.

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\(^8\) http://heasarc.gsfc.nasa.gov/docs/software/heasoft/
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| Observation ID | MJD   | Date                        | Exposure (s) | Phuls (nH) | Spectral Index (Γ) | Flux (3-60 keV) (10^{-10} erg cm^{-2} s^{-1}) | Power-law Flux (10^{-10} erg cm^{-2} s^{-1}) | Iron line Flux (10^{-12} erg cm^{-2} s^{-1}) |
|---------------|-------|-----------------------------|--------------|------------|-------------------|---------------------------------------------|-------------------------------------------|---------------------------------------------|
| 94103-01-01-00| 54921.32 | 2009 Mar 31 07:42:19.6      | 2533         | 0.32±0.08  | 1.56±0.14        | 1.48±0.04                                   | 1.47±0.04                                 | 1.48±0.57                                   |
| 94103-01-01-01| 54921.70 | 2009 Mar 31 16:53:26.6      | 3354         | 0.32±0.08  | 1.56±0.14        | 1.48±0.04                                   | 1.47±0.04                                 | 1.48±0.57                                   |
| 94103-01-01-03| 54922.82 | 2009 Apr 01 19:37:24.1      | 3371         | 0.32±0.08  | 1.56±0.14        | 1.48±0.04                                   | 1.47±0.04                                 | 1.48±0.57                                   |
| 94103-01-01-02| 54923.73 | 2009 Apr 02 17:36:24.8      | 1448         | 0.32±0.08  | 1.56±0.14        | 1.48±0.04                                   | 1.47±0.04                                 | 1.48±0.57                                   |
| 94103-01-02-00| 54925.83 | 2009 Apr 04 19:52:11.4      | 3335         | 0.32±0.08  | 1.56±0.14        | 1.48±0.04                                   | 1.47±0.04                                 | 1.48±0.57                                   |
| 95438-01-01-00| 55499.46 | 2010 Oct 30 11:03:58.2      | 9781         | 0.32±0.08  | 1.56±0.14        | 1.48±0.04                                   | 1.47±0.04                                 | 1.48±0.57                                   |
| 95438-01-02-00| 55501.16 | 2010 Nov 01 03:48:31.7      | 2935         | 0.32±0.08  | 1.56±0.14        | 1.48±0.04                                   | 1.47±0.04                                 | 1.48±0.57                                   |
| 95438-01-02-01| 55502.53 | 2010 Nov 02 12:43:54.3      | 2831         | 0.32±0.08  | 1.56±0.14        | 1.48±0.04                                   | 1.47±0.04                                 | 1.48±0.57                                   |
| 95438-01-03-00| 55505.16 | 2010 Nov 05 03:54:04.3      | 2328         | 0.32±0.08  | 1.56±0.14        | 1.48±0.04                                   | 1.47±0.04                                 | 1.48±0.57                                   |
| 95438-01-03-01| 55507.24 | 2010 Nov 07 05:44:38.1      | 3583         | 0.32±0.08  | 1.56±0.14        | 1.48±0.04                                   | 1.47±0.04                                 | 1.48±0.57                                   |

Table 2

Table 3

| MJD   | Energy (keV) | Cyclab | Depth Dγ | Width Wγ (keV) | Iron line Energy (keV) | norm (×10^{-3}) | χ² (df) without cyclabs | χ² (df) without Fe line |
|-------|--------------|--------|----------|---------------|------------------------|-----------------|--------------------------|-------------------------|
| 54921.32 | 35.5         | 0.01±0.01 | ...      | 5.45          | 6.40±0.27              | 1.42±0.07       | 51.7 (84)                 | 51.7 (85)                |
| 54921.70 | 35.5         | 0.1±0.01  | ...      | 5.45          | 6.55±0.27              | 1.03±0.06       | 68.6 (82)                 | 68.4 (85)                |
| 54922.82 | 35.5         | 2±0.01   | ...      | 5.45          | 6.21±0.24              | 1.73±0.07       | 68.5 (84)                 | 71.3 (85)                |
| 54923.73 | 35.5         | 0.5±0.01  | ...      | 5.45          | 6.50±0.27              | 1.28±0.08       | 59.7 (85)                 | 59.7 (85)                |
| 54925.83 | 35.5         | ...       | ...      | 5.45          | 6.65±0.27              | 0.96±0.39       | 62.2 (82)                 | 62.3 (85)                |
| 55499.46 | 35.5±1.17    | 2.10±2.0  | ...      | 5.45±1.10     | 6.40±1.15              | 2.13±0.04       | 77.9 (82)                 | 216.0 (85)               |
| 55501.16 | 38.2±4.2     | 3.5±1.6  | ...      | 5.45          | 6.38±0.24              | 1.5±0.07        | 82.6 (82)                 | 114.8 (84)               |
| 55502.53 | 41.9±9.8     | 4.2±2.0  | ...      | 5.45          | 6.31±0.24              | 2.1±0.09        | 68.1 (84)                 | 102.7 (86)               |
| 55505.16 | 35.0±14      | 2.9±2.8  | ...      | 5.45          | 6.15±0.30              | 1.5±0.08        | 58.4 (84)                 | 62.3 (86)                |
| 55507.24 | 35.5         | 1.1±1.1  | ...      | 5.45          | 6.62±0.23              | 0.73±0.35       | 59.8 (83)                 | 60.5 (84)                |

Note. All values without errors are frozen values. All uncertainties are expressed as a 90% confidence.

XRONOS (Stella & Angelini 1992) for the timing analysis, and XSPEC (Arnaud 1996) for the spectral analysis.

The source was observed for a total of 10 PCA pointings, of which 5 were during the 2009 outburst (MJD 54921.32-54925.83), and 5 were during the 2010 outburst (MJD 55499.46-55507.24). As evident from the flux evolution in Table 2, on both occasions, the observations are during the decay phase of the outburst. The flux values, measured from the extracted wide band 3–60 keV spectra, are comparatively lower during the 2009 outburst (Table 2). The details of the timing and spectral analysis are discussed in the following subsections.

2.1. Timing Properties

The daily averaged All-Sky Monitor (ASM) light curve of IGR J19294+1816 from MJD 50087 to MJD 55906 in the energy range from 1.5–12 keV is shown in Figure 1(a). PCA observations during 2009 and 2010 outbursts are indicated by
arrows. The light curve shows the presence of small flares in every ∼350 days. Figure 1(b) presents the 2009 outburst of the source starting from MJD 54796 to MJD 55100 covering 298 days, which is the efolding time of the outburst. At the onset of the outburst on MJD 54796, the ASM count rate was 2.12 ± 0.76 counts/s. PCA observed the source in the decay phase of the 2009 outburst on five different occasions from MJD 54921.32 to MJD 54925.82, during which the average PCA flux varied from 6.19 ± 0.15 counts/s to 3.71 ± 0.13 counts/s. Similarly, Figure 1(c) shows the ASM light curve of the 2010 outburst that started from MJD 55490 (ASM flux = 0.61 ± 0.34 counts/s). This outburst decayed comparatively faster in the ∼29 days, and the ASM count rate declined to 0.14 ± 0.90 counts/s on MJD 55522. The PCA observations were made on five occasions, starting from MJD 55499.46 to MJD 55507.24, during which the average PCA

Figure 1. Top panel (a) shows the ASM light curve of the source IGR J19294+1816 in the 1.5–12 keV energy range. Panel (b) shows the faint long 2009 outburst profile of the ASM light curve, and panel (c) shows the 2010 outburst of the source. The bottom panel (d) shows the 2009 and 2010 light curve of the source observed in 15–50 keV by SWIFT/BAT hard X-ray transient monitor from MJD 54831–55559. The PCA pointed mode observations are indicated with arrows in all the panels.
flux varied from 21.22 ± 0.87 counts/s to 6.80 ± 0.13 counts/s. Figure 1(d) shows the Swift/BAT hard X-ray transient monitor daily averaged light curve (Krimm et al. 2013) for IGR J19294 +1816 in the 15–50 keV energy band during MJD 54831–55559.

Light curves with the 0.01 s binning were used to generate the power density spectra (PDS) (using ftools task “powspec”) from all the 10 PCA observations. The light curves were divided into stretches of 16384 bins per interval. PDS from all the segments were averaged to produce the final PDS for each observation. The PDS of the source exhibits a continuum that is best fit by a power law in the frequency range 5 mHz to 50 Hz; in addition, there is a strong peak at ~0.0803 ± 0.0021 Hz, which is attributed to the pulsation from the source. The error values are obtained following the standard procedure in XRONOS. A Lorentzian model component is the best fit for the observed pulsation peak and its harmonic whenever it is present. During the 2009 outburst, the pulsations were clearly detected on three occasions and marginally on one occasion on MJD 54921.70, while no pulsation peak was detected at the lowest flux level on MJD 54925.83. During the 2010 outburst, prominent pulsation peaks were detected in the PDS in all five observations. The details of the parameters pertaining to the pulsation are presented in Table 1.

PDS obtained from the light curves of the five observations of the 2009 outburst are shown in the left column of panels of Figure 2, and those from the 2010 outburst are shown in the right column of panels. PDS corresponding to the highest flux value in the top panel with other PDS corresponding to progressively lower flux values are shown in the lower panels, as shown in Table 2 below. On occasions where the total flux (3–60 keV) is higher than $2.12 \times 10^{-10}$ ergs cm$^{-2}$ s$^{-1}$, a second peak at ~0.160 ± 0.004 Hz, representing the first harmonic of the pulsation peak, is observed.

A better estimate of the pulsation period is obtained by the $\chi^2$ maximization method after folding the light curves around an approximate period of ~12.44 s (as obtained from the PDS) using the ftools task “efsearch.” The light curves with a binning of 5 ms were folded with 25000 different periods around 12.44 s, with a resolution of 1 ms with 32 phase bins per period. This pulsation peak was fit with a Gaussian model whose width provided the error on the observed periodicity. The results of this search for the pulsation periodicity from all of the observations of the two outbursts in 2009 and 2010 are
Figure 3. Best pulse period of the source IGR J19294+1816, which was estimated using ftool “efsearch” on 10 PCA observations during 2009 (left panel) and 2010 (right panel) for the source IGR J19294+1816. The panels are arranged by the highest to lowest fluxes in both outbursts.

Figure 4. Evolution of the pulse profile of all 10 observations of the RXTE/PCA pointings during the 2009 and 2010 outbursts of the source IGR J19294+1816 in panels for the (a) 2–7 keV, (b) 7–15 keV, (c) 15–25 keV, (d) 25–60 keV, and (e) 2–60 keV energy bands with a clear detection of the pulsation folded with their estimated pulse periods and with eight phase bins/period.
The pulse profiles for each PCA observation were generated by folding the light curve using the tool “efold” over the exact pulsation period obtained above. The pulse profiles were generated with eight phase bins per period. Energy dependent pulse profiles were also generated in the ranges of $2-7$ keV, $7-15$ keV, $15-25$ keV, $25-60$ keV, and overall $2-60$ keV, using the best estimated periods that correspond to different observations. Energy dependent pulse profiles of all of the 10 PCA observations are shown in Figure 4. We observed single peaked pulse profiles in $2-7$ keV, $7-15$ keV, $15-25$ keV, and $2-60$ keV in nine of the observations (see Figure 4). While the pulsation was not observed in one case (MJD 54925.83), the pulse profile was obtained by folding the light curves at $12.44$ s.

This pulse profile was then used to obtain the pulse fraction of the emitted radiation using the traditional method for obtaining the pulse fraction given by $\frac{C_{\text{min}} - C_{\text{eff}}}{C_{\text{min}} + C_{\text{eff}}}$ (Harding & Muslimov 1998). The evolution of the pulse fraction with the flux of the source in different energy bands, for both the outbursts, is shown in Figure 5. The pulse fraction shows a logarithmically increasing trend with an increasing flux in the energy ranges of $2-7$ keV, $7-15$ keV, $15-25$ keV, and $2-60$ keV, which is a commonly reported pattern for the accretion powered pulsars (Inam et al. 2004, 2009). In the $2-60$ keV energy band, the pulse fraction is very low for all of the observations (Figures 4 and 5). This results in the overall $2-60$ keV pulse profile having a comparatively lower pulse fraction (Figure 5) in all the nine observations, as compared to the soft X-ray emissions less than $25$ keV. Evidently, as shown in Figures 2–5, the pulsation is not detected for MJD 54925.83 in the total $2-60$ keV energy band when the flux was at its lowest. Nevertheless, during this observation, the emission in the ranges of $2-7$ keV and $7-15$ keV do exhibit a weak single peaked pulse profile when the light curve is folded with the average periodicity of $12.44$ s.

### 2.2. Spectral Properties

The $3-60$ keV wide band continuum X-ray spectrum of the source is fit by a simple “power-law” model (Table 2), with an absorption component for the Galactic interstellar medium parameterized by the spectral model component “phabs” (available in XSPEC package), which provides the measure of absorption as the effective equivalent hydrogen column density (in units of $10^{22}$ atoms/cm$^2$), using the photoelectric absorption cross-section of Balucinska-Church & McCammon (1992). In addition, we used a Gaussian line to account for the statistically significant presence of the $6.4$ keV iron fluorescence line produced in the accretion process. The width of the iron line is fixed at $0.01$ keV. On MJD 55499.46, corresponding to the maximum value of the measured flux, the fit to the simple model yielded a high chi-square, and the residuals indicated a possible absorption feature at about $\sim 35$ keV (MJD 55499.46 is indicated in bold in Table 3). The spectrum of this particular observation is shown in Figure 6. The top panel shows the ratio of the spectrum to the best-fit power-law model, and the residual absorption feature is best modeled by the “cyclabs” model component, which signifies the physical presence of CRSF. The middle panel of Figures 6 depicts the XSPEC’s unfolded spectra. The bottom panel shows the model that best fits the spectrum of this observation. For consistency, we have used the same model (phabs*(powerlaw + Gaussian)*cyclabs), in the XSPEC

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**Figure 5.** Variation of the pulse fraction in different energy bands: (a) $2-7$ keV, (b) $7-15$ keV, (c) $15-25$ keV, (d) $25-60$ keV, and (e) $2-60$ keV with flux of all the observations (the total 10 PCA pointings) during the 2009 and 2010 outbursts of the source IGR J19294+1816. The solid line shows the logarithmic fit to the data.

**Figure 6.** Spectra of the observation on MJD 55499.46; Obs. Id.: 95438-01-01-00. The absorption at $35.5^{\pm 1.1}$ keV and the Fe line at $6.40^{\pm 0.19}$ keV are the two prominent features of the observation on this particular day.
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terminology, to fit all 10 observations during the 2009 and 2010 outbursts (i.e., including the iron line and cyclotron line). The folded energy spectrum of IGR J19294+1816, which was obtained with the five PCA/RXTE observations each during the 2009 and 2010 outbursts of the source along with the best-fit model indicated by solid line, are shown in Figures 7 and 8, respectively. The bottom panel of each of the spectrum of Figures 7 and 8 give the residuals to the best-fit model for each observed spectra.

To estimate the flux and error on the flux in the 3–60 keV range, an additional model component “cflux” (convolution model in XSPEC) is used to obtain the overall flux, as well as the flux pertaining to the individual modeled component, viz unabsorbed power law, Gaussian line, etc. The best-fit values of the model and the flux obtained from the spectra are tabulated in Tables 2 and 3. In Table 3, the value of \( \chi^2 \) and the degree of freedom without the inclusion of “cyclabs” model used for modeling the CRSF are also reported. We observed that the inclusion of the cyclotron line model in the spectra of the three bright observations (MJD 55499.46, 55501.16, and 55502.53) during the 2010 outburst showed a significant improvement in \( \chi^2 \) and the degree of freedom. Similarly, the value of \( \chi^2 \) and the degree of freedom without the inclusion of the Gaussian model are also reported in the Table 3. This provides an estimate

Figure 7. Energy spectrum of IGR J19294+1816 obtained with the five PCA/RXTE observations (MJD 54921.32, 54921.70, 54922.82, 54923.73, and 54925.83) during the 2009 outburst of the source along with the best-fit model phabs*(powerlaw + Gaussian)*cyclabs, as indicated by solid line. The bottom panel shows the residuals to the best-fit model for each observation.
of the significance of the respective model components for each spectra.

The variation of different spectral parameters with the total flux in 3–60 keV energy range is shown in Figure 9. We obtained Pearson’s correlation coefficient to quantify the strength of the relation of the spectral parameters with respect to the total flux. There seems to be an increase in the absorption in the source, as parameterized by the nH value (Figure 9(a)), with increase in the flux, with a correlation coefficient of 0.59 (the obvious assumption is that the properties of ISM does not change in tandem with the source). Figure 9(b) shows that the photon index (Γ) shows a spectral hardening with the increasing 3–60 keV flux with a relatively strong anticorrelation, as the Pearson’s coefficients have a value of −0.72. A logarithmic function is used to fit the trend of the spectral index variation with the flux. This anticorrelation suggests that the source is in a horizontal branch of the hardness intensity diagram (Reig & Nespoli 2013), which further strengthens the hypothesis that the nature of the binary system is that it is a Be/X-ray binary type. The flux corresponding to the spectral component “power law” (Figure 9(c)) is mostly the unabsorbed flux for this source, which is consistently higher by about
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Figure 9. Variation of spectral parameters: (a) the hydrogen column density (in units of $10^{22}$ atoms cm$^{-2}$), (b) the photon index ($\Gamma$), (c) the power-law flux (in the units of erg cm$^{-2}$ s$^{-1}$), (d) the Iron line normalization, (e) the Iron line flux (in the units of erg cm$^{-2}$ s$^{-1}$), and (f) the Cyclotron line depth with an 3–60 keV absorbed total flux from the 10 observations. The solid lines indicate the fit of the linear trend in panels (a), (c), (d), and (e). The solid line in Panel (b) shows a logarithmic trend used to fit the spectral correlation.

$0.51 \pm 0.02 \times 10^{-10}$ erg cm$^{-2}$ s$^{-1}$ in nearly all observations and is linearly increasing with the increase in the total flux of the source, with a strong positive correlation of 0.96. Figure 9(d) shows a trend of the linear increase of the iron line normalization with the total flux, and the correlation coefficient is 0.76. The iron line flux shows a positive correlation coefficient of 0.82 (Figure 9(e)) with an increasing total flux. A reprocessing of the hard X-ray continuum in relatively cool matter, which produces the fluorescent iron K$\alpha$ line feature, does not vary with the flux, as observed from Table 3. The CRSF parameters were not significant enough in all of the observations, and hence a correlation test was not possible for the most important spectral feature detected.

3. Results and Conclusion

In this work, we have studied the timing and spectral properties of the Be/X-ray binary IGR J19294+1816 using RXTE/PCA data. RXTE/PCA observed the evolution of the source in the decaying phase for both outbursts in 2009 and 2010. The overall spectral and timing features are very similar during these two outbursts, suggesting that the physical processes in the accretion region during the two outbursts, separated by ~600 days, are similar. We observed that the significance of the detection of the pulsation peak decreases with the decrease in the flux. Furthermore, the pulse fraction showed a logarithmically increasing trend with the flux in all of the energy ranges (as seen in Figure 5).

The spectral study reveals a detection of a CRSF for the first time in the source IGR J19294+1816 at 35.5$^{+3.2}_{-2.3}$ keV. In addition, an Fe line at $6.40^{+0.12}_{-0.14}$ is also reported to be present in the source. Cyclotron absorption features originate in the X-ray spectrum due to the resonance scattering of photons with quantized electrons in the presence of the magnetic field. The presence of the cyclotron absorption lines enable the direct measurement of the magnetic field of the pulsar, as given by the following relation (see p. 471 of Ghosh 2007):

$$E_c = 11.6B_{12}(1 + z)^{-1}keV,$$

where $E_c$ is the energy of the cyclotron absorption line, $z$ is the gravitational redshift at the neutron star surface, and $B_{12}$ is the magnetic field in units of $10^{12}$ Gauss. Typically, the value of $z$ is 0.35 for neutron stars of a mass in the range 1.4–2 $M_\odot$ (Cottam et al. 2002; Zhao & Jia 2014). Hence, using the value of $E_c = 35.5$ keV (corresponding to the most significant observation of the CRSF), the value of the magnetic field obtained is $B = 4.13 \times 10^{12}$ Gauss.

The detection of the CRSF at lower flux values is marginal at the best fit, and as a result there is no clear correlation between the energy of the cyclotron line and the X-ray luminosity (Table 3), which is similar to sources like 1A 0535+262 (Caballero et al. 2007). Although there is a mild positive correlation (a coefficient of 0.41) between the cyclotron line depth and the total flux (it may be noted that in most of the cases, the energy of the CRSF is frozen; see Table 3), it is not much of a consequence, as the error on the best-fit value shows that the statistically significant detection of the CRSF occurs only at the highest flux value. Since the power law hardens as the flux increases, one factor for the significant detection of the CRSF at a high flux is that the comparatively harder spectra provide the better continuum baseline above the background noise, which enables a statistically significant detection of the CRSF.

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ORCID iDs
Jayashree Roy @ https://orcid.org/0000-0002-2329-5863
Manojoendu Choudhury @ https://orcid.org/0000-0002-3021-6190

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