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REVEAL THE NATURE OF IGR J17586–2129

D. Dehiwalage Don[1], M. Clavel[1], P.-O. Petrucci[1] and G. Henri[1]

Abstract. In the last couple of decades, the *INTEGRAL* satellite has been playing an important role in observing the high-energy sky. However, the nature of the faintest sources detected by *INTEGRAL* are considered to be mostly uncertain and multi-wavelength follow-up observations are generally needed to classify these sources. As part of this global effort, we have carried out a deep *XMM-Newton* observation to probe the nature of IGR J17586–2129. Our X-ray spectral and temporal analysis of this new observation reveal that the source could be a Symbiotic X-ray binary, a rare subclass of low-mass X-ray binaries in which matter is accreted via the winds of a cold giant companion onto a slowly rotating neutron star.

Keywords: X-ray binaries, IGR J17586–2129, XMM-Newton.

1 Introduction

The past twenty years of hard X-ray observations with the instruments of the international gamma-ray astrophysics satellite (*INTEGRAL*, Winkler et al. 2003) have provided a unique database for the exploration of the Galactic source populations. The latest all-sky catalogue has been published by Bird et al. (2016), detecting 939 sources including 369 extragalactic sources, but also 129 low mass X-ray binaries (LMXBs), 116 high mass X-ray binaries (HMXBs), and 56 cataclysmic variables (CVs)*. However, a large number of *INTEGRAL* sources remain poorly identified due to the scarce hard X-ray information and the lack of multi-wavelength follow-up studies.

IGR J17586–2129 was first reported in the third *INTEGRAL* IBIS/ISGRI catalogue (Bird et al. 2007). The short 2008 *Chandra* observation pinpointed its soft X-ray counterpart to be CXOU J181328.0–163548 (R.A. = $17^{\mathrm{h}}58^{\mathrm{m}}34.56^{\mathrm{s}}$, Dec. = $-21°23'21.6''$, Tomsick et al. 2009). This *Chandra* source has a hard and highly absorbed spectrum with $\Gamma = 0.23^{+0.59}_{-0.54}$ and $N_{\mathrm{H}} = 15.6^{+6.0}_{-5.0} \times 10^{22}\,\mathrm{cm}^{-2}$, implying a strong local absorption. Its unabsorbed 0.3–10 keV flux is $F_{0.3-10\mathrm{keV}} = 11.4 \times 10^{-12}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$. Based on this *Chandra* spectrum, Tomsick et al. (2009) excluded the LMXB hypothesis and claimed the source could be a CV or an HMXB. In 2009, the source underwent an outburst detected by both *Swift*/BAT and *INTEGRAL* IBIS/ISGRI (Krimm et al. 2009; Sanchez-Fernandez et al. 2009). The outburst properties did not help to distinguish the nature of this source. Using a VLT/ISAAC spectrum of IGR J17586–2129, Fortin et al. (2018) provided the strongest diagnostic on its stellar companion by detecting ^{12}CO and ^{13}CO absorption lines above 2.3 μm (suggestive of a K star) and only a faint Na I (suggestive of an evolved star), which ruled out the HMXB hypothesis. Fortin et al. (2018) identify the companion as a likely type KIII star, indicative of a Symbiotic system. Based on the strong intrinsic absorption, they argue that the source could be as close as 130–300 pc, in which case both the X-ray luminosity and the hardness of the *Chandra* spectrum would be compatible with a CV, and they propose IGR J17586–2129 as a likely Symbiotic CV. In 2020, we obtained a deep *XMM-Newton* observation of this source to test the CV identification proposed by Fortin et al. (2018).

2 XMM-Newton observations and data reductions

IGR J17586–2129 was observed with *XMM-Newton* (Jansen et al. 2001) on 2020 April 7, for a total exposure time of ∼25 ks (Observation ID: 0845060201). We performed standard data reduction with the science analysis

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[1] Univ. Grenoble Alpes, CNRS, IPAG, 38000 Grenoble, France

*These numbers include both firm and likely identifications (see Bird et al. 2016, for more details).

system (SAS) v.19.0.0, using the most up-to-date calibration files and following the analysis guidelines of each EPIC instrument. Both MOS and pn cameras were operated in Small Window mode. To extract the events to produce spectra and light curves of IGR J17586–2129, we used optimal extraction radii of 12.68″ and 23.80″ (respectively, for the pn and MOS cameras) centered on the *Chandra* coordinates of IGR J17586–2129. Background counts were obtained from larger circular regions (55.15″ and 78.90″) excluding any X-ray stray light[†] or point sources.

The spectra were grouped so that each bin has a signal-to-noise ratio greater than 5σ. The *XMM-Newton* spectra were fitted using XSPEC v.12.10. All model uncertainties and upper limits are given at 90 % confidence for the best fit parameters. For the light curves, the photon arrival times were corrected from the Solar system barycentre and the 2–10 keV background subtracted light curves were derived with a bin time of 10 s.

3 Spectral analysis

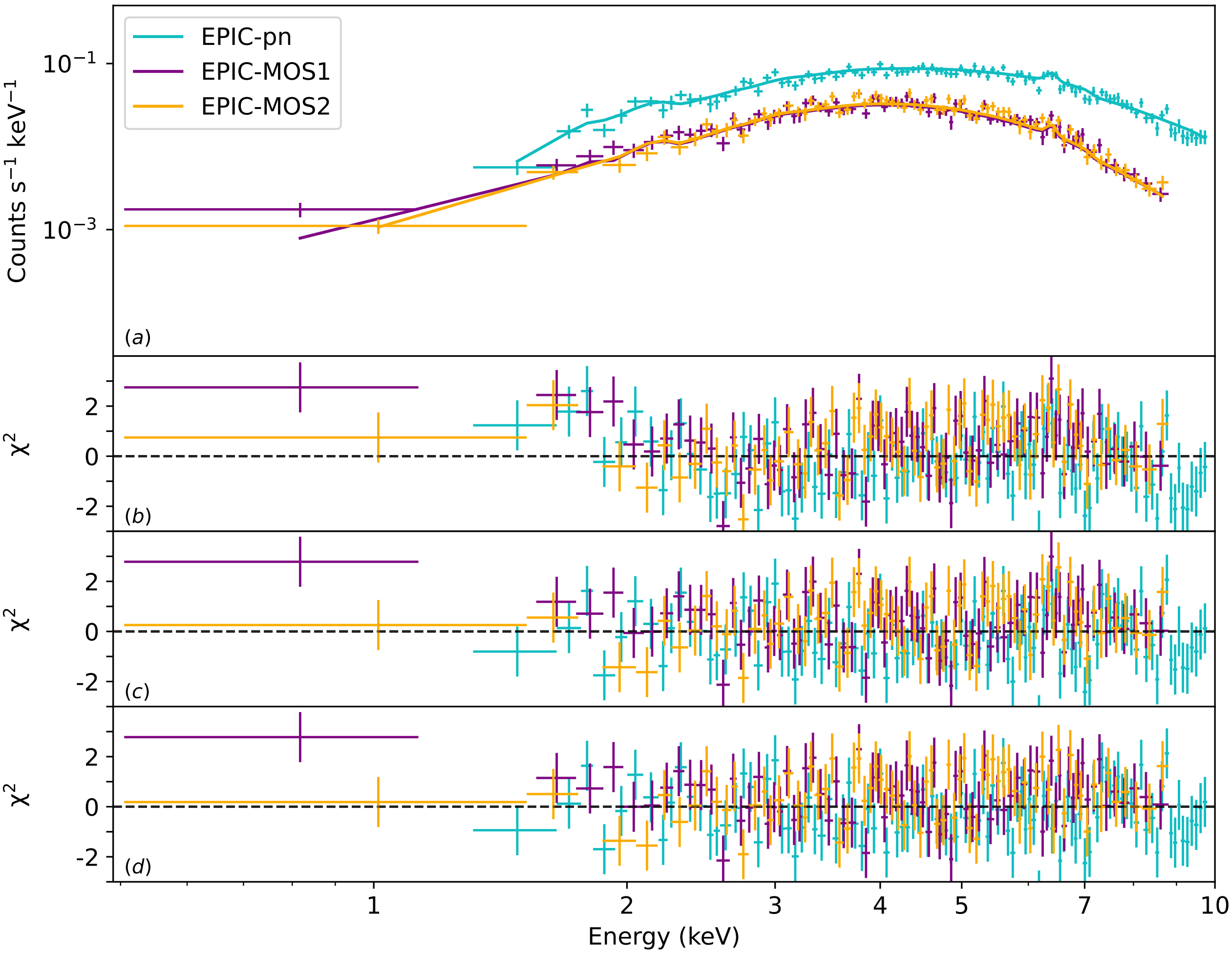

Fig. 1. The simultaneous fit of the *XMM-Newton* EPIC data with three different models. (*a*) Data and best fit model (i.e. `tbabs*pcfabs*(powerlaw+gaussian)`). (*b*) Residuals for the absorbed power-law model. (*c*) Residuals for the absorbed power-law model, including a partial absorption component. (*d*) Residuals for the absorbed power-law model, including a partial absorption and a Gaussian emission line (best fit model).

[†] X-ray stray light in EPIC is produced by rays which are singly reflected by the mirror hyperbolas and which reach the sensitive area of the camera (xmm 2022). In our observation, stray light is present in MOS1 and MOS2, but is not contaminating the source region.

The pn, MOS1 and MOS2 spectra of IGR J17586–2129 are shown in Figure 1. We jointly fitted these three *XMM-Newton* spectra in the 0.5-10 keV energy range. First, the spectra were simultaneously fitted with an absorbed power-law model. All parameters were left free to vary, but fixed to be the same between the three instruments, and the best fit model yielded to $\chi^2/\nu = 1.17$ for $\nu = 276$ degrees of freedom. The source shows $N_{\rm H} = 10.91^{+0.67}_{-0.63} \times 10^{22}\,{\rm cm}^{-2}$ and $\Gamma = 1.34 \pm 0.09$, which is significantly softer than the spectrum reported by Tomsick et al. (2009). Residuals for this model can be seen in Figure 1 (b), and we noted significant residuals at low energy. Introducing a partial absorption to the absorbed power-law model provided a significant improvement, with $\chi^2/\nu = 0.99$ for $\nu = 274$ degrees of freedom. Looking at Figure 1 (c), we see a significant reduction of the residuals, notably at low energies[‡]. This additional component allows to get values of the photon index $\Gamma = 1.72^{+0.17}_{-0.15}$, closer to what can be observed in some LMXBs.

The CV identification proposed by Fortin et al. (2018) would imply to have strong iron emission lines in the *XMM-Newton* spectrum of IGR J17586–2129, while the residuals shown in Figure 1 (c) show very limited residuals in the corresponding energy range (6–7 keV). We therefore decided to assess the presence of the 6.4 keV line by adding a Gaussian line to the best fit model. The *XMM-Newton* spectra were simultaneously fitted with this new XSPEC model (`tbabs*pcfabs*(powerlaw+gaussian)`), leaving all parameters free to vary except for the energy and the width of the Gaussian line, which were fixed at 6.4 keV and 10 eV, respectively. The best fit gives a new $\chi^2/\nu = 0.96$ for $\nu = 273$ degrees of freedom. Figure 1 (d) shows the residuals for this model, while panel (a) shows this best fit model overlaid to the data. Note that, none of the power-law and absorption parameters are significantly affected by this new component compared to the one obtained from previous model (`tbabs*pcfabs*(powerlaw)`). The emission line appears to be significant, with a flux which is $N_{{\rm FeK}\alpha} = (8.4 \pm 3.9) \times 10^{-6}\,{\rm ph\,cm^{-2}s^{-1}}$, significantly above 0. The line equivalent width corresponding to the best fit is 90 eV. This value is very low compared to what is anticipated for CVs seen in hard X-rays but could correspond to a line as seen in some LMXBs.

4 Timing analysis

Figure 2 shows the light curves for the three EPIC cameras (however, we used only EPIC-pn data for the timing analysis). The strong variability seen over the duration of the *XMM-Newton* observation motivates investigation on the temporal behaviour of IGR J17586–2129 and its possible periodicity.

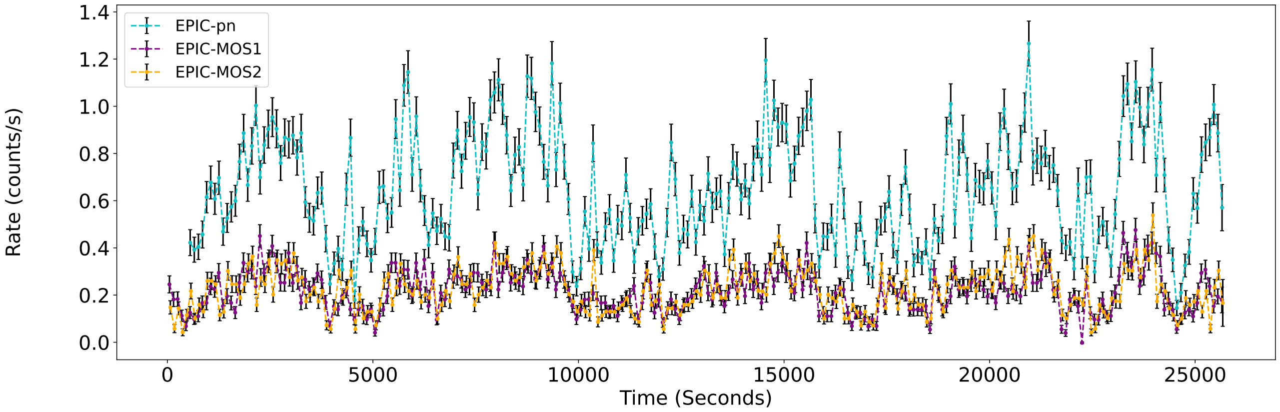

Fig. 2. IGR J17586–2129 2–10 keV light curves for MOS1, MOS2, and pn data. The Y axis is the photon count rate and the X axis is the time starting from the beginning of the *XMM-Newton* observation.

To investigate whether the apparent modulation is real and to search for possibly shorter timescale variations, we analyse the power spectrum density (PSD) created by the XRONOS powspec tool[§]. The overall PSD seems flat towards high frequencies with a power increase towards lower frequencies, which could be due to the limited

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[‡] We also tried to fit the data with different XSPEC models (`bbody`, `diskbb`, `bremss`) without obtaining a substantial decrease in the reduced χ^2 value and they were not successful at fitting IGR J17586–2129 low-energy spectrum.

[§] `https://heasarc.gsfc.nasa.gov/lheasoft/ftools/fhelp/powspec.txt` duration of the observation ($\sim$ 25 ks). Searching the PSD with the XRONOS efsearch tool[¶], we find a best fit period of 5883 s.

A Monte-Carlo (MC) simulation procedure was carried out to verify the significance of the periodicity detection. The strong variability seen in Figure 2 is often described as flickering or $1/f$ fluctuations (where f is the frequency). Based on the spectral estimation theory, we used the algorithm proposed by Timmer & Koenig (1995) to generate non deterministic linear time series with $s(\omega) \approx (1/\omega)^\beta$ (where $\omega = 2\pi f$ and $\beta = 0.4$ is the spectral slope the IGR J17586–2129 Fourier spectrum) to simulate PDS with the same observational constraints as the IGR J17586–2129 light curve. After randomizing the phase and amplitude of the simulated Fourier transform of the data according to its stochastic nature, we generated 1000 random Fourier spectra and carried out a systematic MC simulation to verify the detection. The MC simulation provided evidence that the 5883 s period detection of IGR J17586–2129 is significant to 99.7% (or 3σ) level.

5 Conclusions

Based on our results, the Symbiotic CV hypothesis is ruled out, but IGR J17586–2129 could instead be a Symbiotic X-ray binary (SyXB). The first SyXB was identified more than forty years ago (Davidsen et al. 1977), and since then, there has been an increasing number of Symbiotic systems detected. These X-ray binaries represent a relatively small subclass of long-period Galactic LMXBs consisting of a late-type giant (K1-M8) and an accreting magnetized neutron star (Sazonov et al. 2020), with spin periods typically between one hundred and several thousands of seconds (Kuranov & Postnov 2015). Therefore, such classification for IGR J17586–2129 would agree with the X-ray and the NIR constraints obtained on this source. In this context, if confirmed, the 5883 s pulse period could correspond to the spin of the neutron star, making this system very similar to another *INTEGRAL* source, IGR J16358–4724 with a very close spin period of 5880 s (Patel et al. 2004).

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