# OBSERVING AN EXOPLANET AROUND RX J2143.0+0654 USING THE TRANSIT METHOD

## 1 Abstract

Exoplanet transits are tested and confirmed methods for solar-type systems, but not yet for neutron star systems. RX J2143.0+0654 is an isolated neutron star with an observed periodic total loss of flux. These characteristics make RX J2143.0+0654 a good candidate for testing the relationship between changes in flux and changes in column density or absorption. Examining this relationship for such an extreme, yet regular, system will help to set a baseline for future observations of neutron stars with steep variations in flux. If a loss in flux correlating to increased column density can be observed using *XMM*, we may be able to confirm the existence of an exoplanet around RX J2143.0+0654.

## 2 Scientific Justification

For most of our history, one could only theorize that our solar system might not be the only one of its kind in the universe. However, with the discovery in 1984 of a planetary disc around the star Beta Pictoris, it became clear that there may be systems just like ours around other stars (NASA, 2025c). Using the Arecibo radio telescope, Polish astronomer Aleksander Wolszczan discovered the millisecond pulsar PSR B1257+12, in 1990 (Wolszczan, 1990). Millisecond pulsars are neutron stars that spin very rapidly ($\sim$ 100 rotations/s) (Center for Astrophysics, 2016). These neutron stars, remnants of the death of a roughly 10 solar mass star, emit electromagnetic radiation in a beam that sweeps past Earth at extremely regular intervals (Center for Astrophysics, 2016). Using observations of periodic fluctuations in the pulses of PSR B1257+12, a method called pulsar timing, Wolszczan, along with Canadian astrophysicist Dave Frail, discovered two exoplanets orbiting around PSR B1257+12: PSR B1257+12 A and B (Wolszczan and Frail, 1992). Non-pulsating neutron stars, however, do not have these regular fluctuations, and as such their systems cannot be probed for exoplanets using pulsar timing.

As of March 2025, 5867 exoplanets have been confirmed by NASA (NASA, 2024a). Only 0.03% of these exoplanets have been discovered using pulsar timing. Other techniques include, but are not limited to, direct imaging, radial velocity measurements, microlensing, and the transit method. 74.3% of confirmed exoplanets have been discovered using the transit method. The transit method consists of observing a star for a periodic change in its flux. As the transiting exoplanet moves in front of the host star, the amount of light measured from the star dips over the duration of the transit as the exoplanet blocks a fraction of the light. In most cases, the exoplanet is much smaller than its host planet, and so the light from the star will only be partially blocked (NASA, 2024b).

In the case of an exoplanet transit around a neutron star, however, the radius of the exoplanet will always be larger than the average (canonical) radius of a neutron star. Canonical neutron stars have a mass $M \approx 1.1 - 2.1\ M_\odot$ and a radius $R \approx 10 - 15$ km (Nättilä and Kajava, 2022). The resulting light curve will show a reduction in flux similar to that of a solar eclipse, wherein a changing fraction of the emitted solar flux is blocked as the Moon moves in front of the Sun (ingress), reaching the middle of its transit and covering the Sun (totality), and then moving away from the Sun (egress) in our field of view. This will be analogous to the exoplanet eclipsing its host star, as the exoplanet will move to completely cover the neutron star during its transit. A neutron star eclipse could therefore be observed similarly to exoplanet transits around a solar-type star.

RX J2143+0654 (J2143) is one of the "Magnificent Seven", an X-ray dim ($F_{0.05-10\ keV} = 3.5 \times 10^{-12}$ ergs cm$^{-2}$ s$^{-1}$) isolated neutron star (XDINS). It was detected by the *ROSAT* all-

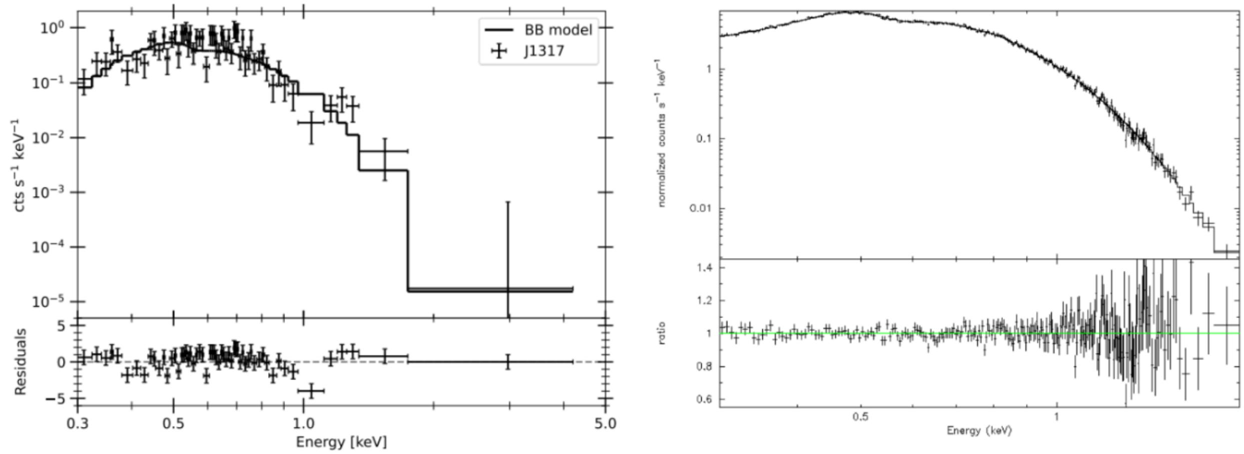


Figure 1: **Left:** The rebinned spectrum of J131716.9–402647 (Kurpas et al., 2023). J1317 was modelled as a blackbody with a temperature of $110^{+7}_{-7}$ eV. **Right:** The spectrum of J2143 modelled as a blackbody, along with absorption and power law components.

sky survey (Voges et al., 2000). XDINSs have very soft ($kT \lesssim 0.1$ keV) X-ray spectra (Rigoselli, 2024), with no indication of non-thermal components (Kondratiev et al., 2009). J2143 itself has a temperature given by $kT = 0.102$ keV (Haberl, 2013). The spectrum of J2143 is fitted (Fig. 1) using absorption (`tbabs`), blackbody (`bbodyrad`) and power law components. Using the given $kT$, the galactic column density with extinction ($N_H/A(V) \sim 0.2 \times 10^{22}$ atoms/cm$^2$/mag) (Swinburne University of Technology, 2025), and a photon index of $\Gamma = 2.0$, the spectrum of J2143 was modelled in the 0-5 keV range, to compare with the spectrum of J1317 in the same energy range (Fig. 1). This comparison was done to test the usage of the absorption component and power law in order to better model the full energy range including the hard excess ($2 - 8$ keV). As a result of the additional components, the hard X-ray tail is fit closer to the data.

In previous observations (Reyno et al., 2025), the flux was found to vary over a 100-day period, decreasing and increasing very quickly. We believe these observations are indicative of an unknown object obscuring the star. The object was found to have an orbital radius of $7.05 \times 10^{12}$ cm and a transit time of 0.39s, which excludes the possibility that the object is a distant and slow-moving interstellar object. This implies a fast moving in-system object that is large enough to eclipse the neutron star. An exoplanet in transit is a possible candidate for this object, as any exoplanet would be large enough to fully eclipse J2143, giving a potential explanation for the total flux loss at the midpoint of the transit time (Reyno et al., 2025).

Measurement of the flux and column density at $t = 0$s, 0.0975s, and 0.195s into the transit would be able to show the flux at the beginning of transit, at the midpoint of ingress, and at totality, respectively. The resulting flux and column density variations, and subsequent modelling, would be able to provide insight into the nature of the obscuring object around J2143.

## 3 Technical Justification

In order to observe J2143, we propose the use of *XMM-Newton* (Jansen et al., 2001). *XMM* is advantageous because of its large effective area in the soft X-ray band (1550 cm$^2$ at 1.5 keV energy) (ESA, 2025, Section 3.1). The general specifications of *XMM* include 3 Wolter type-1 X-ray telescopes and a 30-cm optical/UV telescope for optical monitoring (ESA, 2025, Section 3). Of interest to this proposal is the EPIC-pn instrument, which has a sensitivity of $\sim 10^{-14}$ in the range

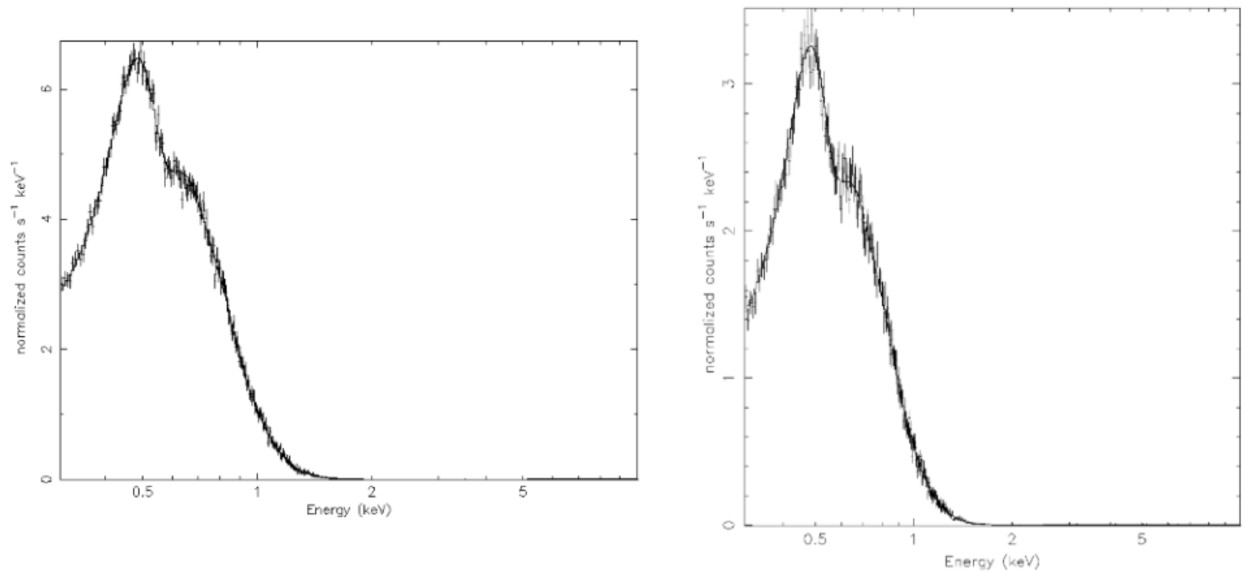


Figure 2: The spectra are focused in the low end of the spectrum, as expected from a faint source. The blackbody emission is clear in the low energy band ($0.3-1$ keV), and there is evidence of a high energy tail fitted with the power law from $2-10$ keV. **Left:** The spectrum of J2143 modelled from $0-10$ keV, using a partial fraction of zero percent. **Right:** The spectrum of J2143 modelled from $0-10$ keV, using a partial fraction of 50 percent.

0.15-12.0 keV and a field of view of 30 arcseconds (ESA, 2025, Section 3.1). The EPIC background components will be analyzed using *XMM*'s Background Analysis tables (XMM-Newton Science Operations Centre, 2023).

We select *XMM*'s EPIC-pn camera with the thin filter, as J2143 can be treated as a point source with faint thermal emission (ESA, 2025, Section 3.3.6). Using EPIC-pn Timing mode, we will be able to resolve the ingress and egress of the transit, although closer attention will have to be paid to the background fluctuations (ESA, 2025, Section 3.3.2).

To obtain sufficient counts over the duration of the transit events, we request three 50ks observations using *XMM*, for a total of 150ks. This exposure length will accumulate enough counts to detect small flux variations with adequate precision, producing spectra comparable to those obtained in Reyno et al., 2025. The observations should be made with regular intervals, in order to ensure observation of any irregularities that may arise due to either the transits or other unforeseen phenomena. The visibility of J1243 was evaluated using the XMM-Newton Target Visibility Checker. There are 4 viewing periods between April 2025 to December 2026, each with $\sim 16$ periods with visibility lasting longer than 70ks. J1243 is located at RA $= 21^{\mathrm{h}}43^{\mathrm{m}}02.0^{\mathrm{s}}$ and DEC $= +06^{\circ}54'26''$ (J2000) (Zampieri et al., 2001). It has been observed by *ROSAT* and *CHANDRA* in X-ray, and the Keck, VLT, Blanco and Magellan telescopes in optical and infrared wavelengths (Rea et al., 2007).

To check the feasibility of an exoplanet detection, we simulated the transit using the partial covering fraction absorption component in XSPEC (`pcfabs`) (Arnaud, 1996). The values for the absorption, blackbody and power law components used for Figure 1 were used again for Figure 2. A column density of $1 \times 10^{28}$ atoms cm$^{-2}$ (the maximum value for the column density in XSPEC) was modelled for the planet. A partial covering fraction of zero percent would occur at $t = 0$ s (Fig. 2, left) and 50 percent at $t = 0.0975$ s (Fig. 2, right).

The predicted flux across various bands is shown in Table 1. The predicted values across the

Table 1: Expected $F$ for Each Covering Fraction

| Covering Fraction (%) | $F_{0-10}$ ($10^{-12}$ ergs cm$^{-2}$ s$^{-1}$) | $F_{0.3-1}$ ($10^{-12}$ ergs cm$^{-2}$ s$^{-1}$) | $F_{2-8}$ ($10^{-15}$ ergs cm$^{-2}$ s$^{-1}$) |
|---|---|---|---|
| 0 | 3.5 | 3.3 | 3.3 |
| 50 | 1.7 | 1.6 | 0.51 |

entire energy range are in the same order of magnitude of those obtained in Haberl (2013). Those in the hard X-ray band match the order of magnitude in (Dessert et al., 2020) at zero percent coverage. The soft X-ray band has no comparison. At 50 percent coverage, the diminished flux is clear. The flux across the entire spectrum, as well as the soft X-ray flux, is $\sim 0.5$ times lower. The hard X-ray flux is even more diminished, $\sim 6.5$ times lower than with no coverage. Actual observations may be able to detect a proportional relationship between the actual column density and amount of hard X-ray emission reaching the detector. At 100 percent coverage, there is no flux expected, and the observation at totality will be used to confirm the strength of the absorption as the object fully eclipses. In this model, we assume that the entirety of the absorption is being caused by the planet's radius. If there is flux detected at totality, it may indicate that the object has an atmospheric component, where some X-ray photons can make it past the absorber.

# 4 Conclusion

Exoplanets are an intriguing explanation for the periodic loss of flux from RX J2143.0+0654. *XMM* observations may provide insight into the nature of the transiting object and its characteristics. *XMM*'s EPIC-pn instrument is well-suited to this kind of rapidly varying fluctuation, and 150ks of observing time will meet the immediate scientific goal of understanding the properties of this neutron star system. Simulations show that the transit properties are observable, but they also raise questions that can only be answered with real data. If the transit method using flux and column density can confirm the existence of a planet, or a planet-like object, with a possible atmosphere, we will be able to turn our telescopes to other neutron stars with flux variability to better understand the nature of the systems they form.

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