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The paradigm of atypical HMXRBs: 4U 2206+54

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4U 2206+54 does not belong to any of the predefined classes of High Mass X-Ray Binary Systems (HMXRBs). It shows a mixture of behaviors between the wind-fed accretion systems with a supergiant optical companion, and those systems with a neutron star accreting from the disc of a main sequence Be star. The nature of the compact component to the system has been clarified only recently with the discovery of long 5560 s pulsations, with a highly variable pulse shape, both with time and with energy. Absorption lines resembling cyclotron resonant scattering features (CRSF) have been marginally detected by different missions, but only in specified times, being the non-detection the common rule. The values of he magnetic field derived from the possible CRSF and those needed to explain the long spin period differ considerably. This system may be representative of an early stage of evolution of HMXRBs, a very difficult phase to observe. We discuss the pulse period and its variability, the orbital period, and the high energy properties of the source and explore the possible connection with supergiant systems (2S 0114+650, GX 301-2, IGR J16358-4726) and main sequence/Be systems (X Per) which also posses highly magnetized neutron stars.

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1. Introduction

Wind-fed high mass x-ray binaries contain an early type supergiant star with an intense mass-loss in the form of a stellar wind, and a compact object, generally a neutron star, orbiting both around each other. The neutron star will capture wind matter leading to the well known high energy emission present in these systems. The neutron star can also be deeply immersed in the dense wind of the early type companion. Generally, it is said that the accretion takes place directly from the wind, however the final process is very likely modulated by the presence of a magnetic field in the neutron star In any case the angular momentum of the infalling matter will not be enough to form an accretion disk.

It can also happen that the optical companion is a Be star, a main sequence star developing a disk-like equatorial structure (or circumstellar decretion disk). The neutron star may pull matter form this disk, leading to the accretion process but, in this chance, matter will free-fall with enough angular momentum to form an accretion disk around the neutron star.

4U 2206+54 is a very complex source and it does not fit in any of the scenarios described above. In this review we will try to highlight the latest achievements in the understanding of its behaviour and how it is related to other atypical sources. We want to point out the following peculiarities of 4U 2206+54:

- it has got a main sequence star as a companion, but it is not a Be star (see [1])
- the optical companion posses some kind of disk like structure, very likely induced by a high magnetic field and settled around the magnetic equator (see [1])
- accretion takes place from a very slow and dense wind, unlike Be systems (see [11])
- very slow pulsations (see [9])
- orbital modulation detected at 9.6 and 19.2 d (see [5])

It has been proposed that the neutron star in 4U 2206+54 could have a high magnetic field (see [7] and [10]). We will review the two observational facts leading to this proposal, namely, the possible presence of a Cyclotron Resonant Scattering Feature (CRSF) in the spectra of 4U 2206+54, and the pulse period evolution of the source. We will discuss how reliable is to deduce the presence of a high magnetic field in 4U 2206+54 from these observational facts and also will compare the properties of 4U 2206+54 with a set of x-ray pulsars also reported to have long pulse periods or high magnetic fields.

2. The pulse period of 4U 2206+54, its evolution, and the expected magnetic field of the neutron star

The pulse period of 4U 2206+54 although it was suspected to be long (see [2]) was discovered only recently thanks to long term exposures of RXTE satellite (see [9]), it was difficult because the coincidence of the pulse period of this source with the orbital period of RXTE. INTEGRAL/ISGRI data was essential in the pulse period determination of the source with a detection during revolutions 510-512, which confirmed the non-RXTE-orbital origin of the modulation (see [3]).

Suzaku independently also determined the pulse period in a contemporaneous observation to that of RXTE ([7])

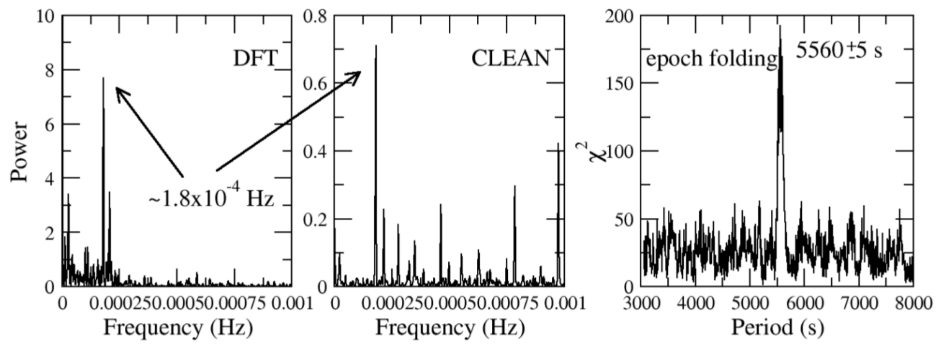

Figure 1: Power spectra of the light curve of 4U 2206+54 during INTEGRAL revolution 510. The peak corresponding to the pulse period of the source is clearly visible.

In Figure 1 we can see the Fourier analysis of the light curves of the INTEGRAL/ISGRI observations which contributed to the discovery of the pulse period of this source, which correspond to INTEGRAL revolution 510. The individual pulses can be seen in Figure 2. The light curve covers 3 days, which is one 7th of the orbital period (if its 20 days) or one third of the orbital period it its 9 days. The regularity of the arrival times is very significant, however the high inhomogeneity in pulse shapes is also remarkable.

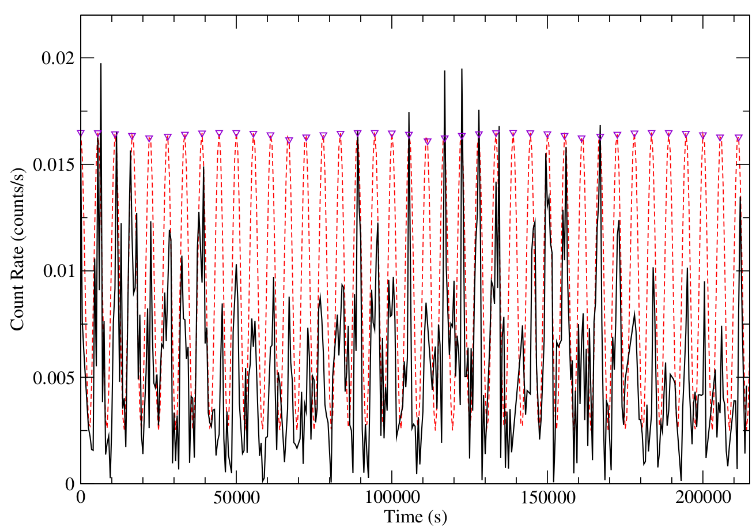

Figure 2: Light curve of 4U 2206+54 during INTEGRAL revolution 510. Superimposed, a sinusoidal variation with the periodicity of the X-ray pulsations of the source, shows the regularity in time of the individual pulses.

Thanks to the large amount of data present in the INTEGRAL/ISGRI archive, we can study the long term evolution of the pulse period of 4U 22067+54, see Figure 3. We see that for the long time spam which comprises INTEGRAL observations the pulse period is fluctuating around a mean value.

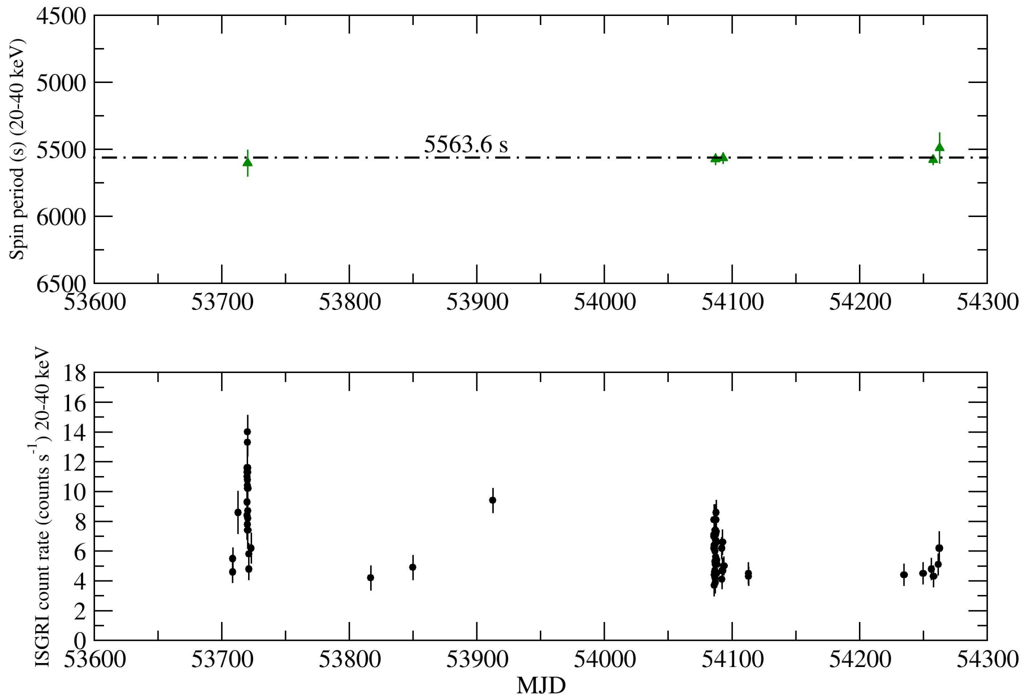

Figure 3: Long term light curve of 4U 2206+54 together with the spin period measurements in the 20-40 keV energy range.

If we compare that to the work of [10], we can check that if we superimposse the same period depicted in our Figure 3, in their Figure 2, we clearly see that the measurements of the pulse period of 4U 2206+54 that they show are also compatible with a plateau of values fluctuating around an average pulse period. Very likely, the pulse period has not been monotonically increasing, but evolving irregularly with, at least, spin-up and plateau periods. The determination of the pulse period derivative by using very long time span tendencies can be dangerous and not advisable, see also [12].

3. The high energy spectrum of 4U 2206+54, the possible presence of a CRSF and implications on the neutron star magnetic field determination

A second way to infer the magnetic field of a neutron star is through the detection of CRSF.

A possible CRSF feature in the high energy spectrum of 4U 2206+54 has been reported by several authors, including from INTEGRAL/ISGRI data (see [2], [13], [8], and [14]). This CRSF was suggested to be at $\sim$30 keV, and, although reported by several instruments, has always been found with very low significance and at the limit of detection. It has not been reported again despite exhaustive searches. Is it really a CRSF?

3.1 Is there dependence of the detection of the possible CRSF with the luminosity?

We have selected high count rate detections and low count rate detections of 4U 2206+54 with INTEGRAL/ISGRI and extracted spectra of both sets of data independently. Figure 4 shows the spectra extracted for data with detections above 8 counts s^{-1} and for data with detections below this limit. No CRSF has been detected in any of those sets of data, therefore if there is a CRSF in the spectra of 4U 2206+54, its detection or not is not dependent, very likely, on the flux of the X-ray emission of the source.

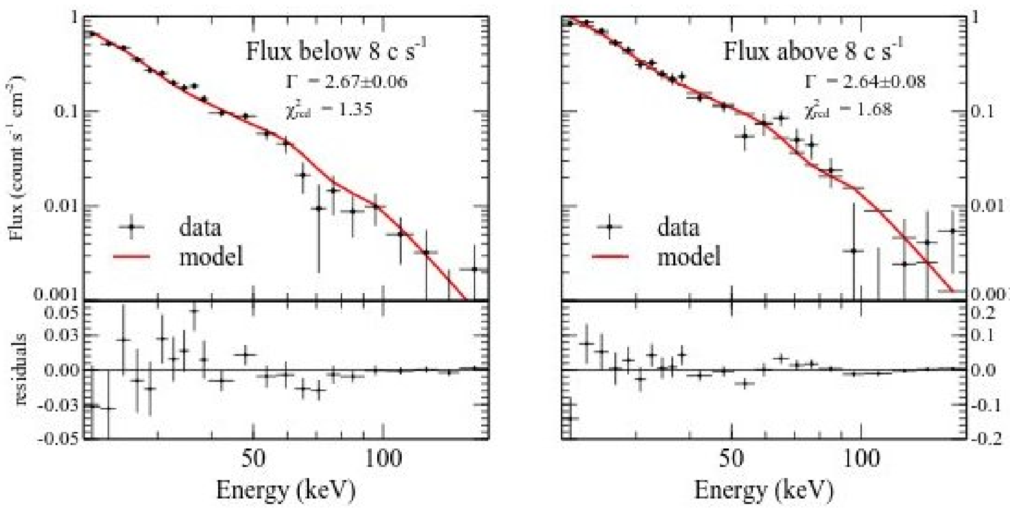

Figure 4: Spectra extracted for detections with higher flux values (above 8 counts s^{-}1, right panel) and for detections with lower flux values (below8 counts s^{-}1, left panel).

3.2 Is there dependence on the pulse phase of the neutron star?

We have performed intensive pulse phase resolved spectroscopy in data from revolutions 510, 67 and 68, i.e., those sets of data with enough consecutive observations to allow for this analysis.

Left panel of Figure 5 shows the results of the imaging techniques of OSA 9 software[1] applied to the phase intervals defined to perform the phase resolved spectroscopy in the data from INTEGRAL revolution 510. The averaged pulse shape is outlined, indicating that the pulse phase division used is correct. The values of the photon index from a powerlaw fit to the phase resolved spectra obtained for these phase intervals are also annotated in the plot, along with the count rate measurement. The right panel of Figure 5 show the plot of the extracted phase resolved spectra. We find no variations in spectral shape dependent on pulse phase, and no traces of a feature around $\sim$30 keV.

We have performed the same analysis for revolutions 67 and 87, those used by [2]. Table 1 summarizes the photon index measured from powerlaw fits to the phase resolved spectra extracted i both cases. As in the case of revolution 510, the spectral shape show no changes with respect to the pulse phase.

[1]http://www.isdc.unige.ch/integral/analysis

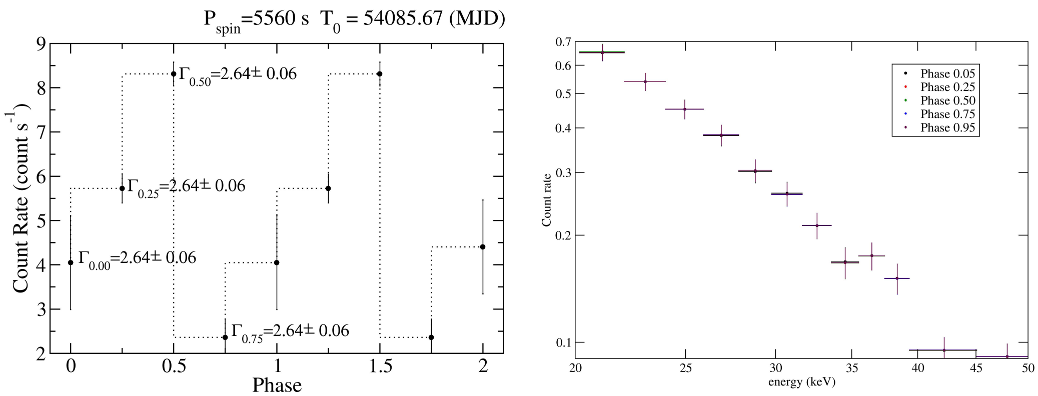

Figure 5: Left: Count rate from 4U 2206+54 as extracted from the imaging procedure applied to the phase intervals used to produce the phase resolved spectroscopy for revolution 510. The values of the photon index corresponding to the spectrum extracted in each interval is annotated along the count rate measurement. **Right:** Phase resolved spectra at phases 0,05, 0.25, 0.50, 0.75, and 0.95 for the data from INTEGRAL revolution 510.

Rev 67		Rev 87	
Γ	Phase	Γ	Phase
2.46±0.12	0.05	2.37±0.13	0.05
2.46±0.12	0.25	2.34±0.13	0.25
2.46±0.12	0.50	2.28±0.14	0.50
2.48±0.12	0.75	2.34±0.12	0.75
2.45±0.11	0.95	2.32±0.12	0.95

Table 1: Photon indexes obtained from phase resolved spectroscopy measurements for revolutions 67 and 87.

Despite intensive searches, the CRSF has not been reported again, and no dependence with flux or pulse phase can be established. Therefore the question of the association of the reported ∼30 keV absorption feature to a CRSF is still open and the magnetic field derived from this assumption may not be valid.

4. Discussion and conclusions

Both types of analysis, pulse period evolution and searching for a CRSF in 4U 2206+54 have been shown to be insufficient for the determination of the magnetic field of the neutron star in this X-Ray binary system. However, the relationship of 4U 2206+54 and a few other sources with slow spin periods or also reported to have high magnetic fields have already been spot by several authors (see, for example [10] and [6]).

These sources are, namely, 2S 0114+650, GX 301-2, IGR J16358-4726, and X Per, and they share this peculiarities: a) slow pulsations, b) persistent low luminosity, c) wind accretion, d) slow and dense wind e) spin down dominates in the long term

In particular, the only main sequence in the group, other than 4U 2206+54, is present in X Per. This BeX system has shorter pulse period but it seems to share this properties with 4U 2206+54 (see [6]): a) emission twice per orbit, b) accreting from the wind and not the Be disk due to the large orbital distance.

4U 2206+54 and X Per have main sequence companions, while the others are supergiant systems. The possible evolutionary link between these two subgroups arises naturally. Some authors have linked the Supergiant Fast X-Ray Transients to the group of highly magnetized neutron stars, or magnetar-alike sources (see [4]), by relating the eruptive variability of SFXTs to the gated mechanism produced by a high magnetic field, which would modulate the accretion of matter onto the neutron star magnetic poles.

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