

# The peculiar O9.5V star BD+53°2790, the massive counterpart to the X-ray binary system 4U 2206+54

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**Abstract:** The X-ray binary system 4U 2206+54 hides many mysteries. Among them, the surprising behavior of both of its components: the O9.5 dwarf star BD+53°2790 and a slowly rotating neutron star. BD+53°2790 misled the astronomers, exhibiting characteristics reminiscent of Be stars. However, a deeper spectral analysis and more intense monitoring revealed that the real picture was a bit more complicated: a) Although it shows evidence of a circumstellar envelope, its observable properties differ from those typical of envelopes in Be stars. b) Comparison with spectral standards and models indicates a possible over-abundance in He. This would open the possibility to link the behavior of BD+53°2790 to the He-rich class of stars. c) UV spectra show an abnormally slow and dense wind for an O9.5V star. d) Spectral classification in the IR wavelength region suggest a more likely supergiant nature of the source, in contradiction with the optical classification. e) The presence of an intense magnetic field is under investigation. BD+53°2790 stands as a perfect laboratory for testing stellar structure, as well as wind and evolutionary theories. The observable properties of this source in a wide range of spectral bands are discussed, and some interpretations outlined.

## 1 Introduction

X-ray binary systems consist of two stellar bodies orbiting each other and emitting high energy photons as the result of mass transfer from one onto the other. BD+53°2790 is the massive companion of one of such systems, namely 4U 2206+54. Although initially BD+53°2790 was mis-classified as a Be star, Negueruela & Reig (2001) and Blay et al. (2006) show reasons to discard this classification and suggest that BD+53°2790 is instead a very peculiar main sequence O9.5 star. We will briefly review its peculiarities, from a wide point of view only achieved with a multiwavelength approach. In X-ray binary systems, each part of the electromagnetic spectrum gives us information from a very specific part of the system. While optical data show us what kind of massive companion is contained in 4U 2206+54, as well as its stellar parameters and properties, infrared data indicate the properties of the very close neighborhood of this massive star, UV bands tell us how the mass-transfer takes place, and high energy and radio data helps to unveil what kind of accretor is hosting 4U 2206+54. Only a complete multiwavelength approach will help to comprehend BD+53°2790 and its compact companion.

## 2 High energy data: The compact companion

X and  $\gamma$ -ray measurements lead to the conclusion that 4U 2206+54 hosts a neutron star. Its pulse period has only been determined recently, by Reig et al. (2009) and Finger et al. (2010), to be 5560s. It is one of the longest pulse periods for a High Mass X-ray Binary System (HMXRB). INTEGRAL detection of the pulse period is shown on the two plots of Figure 1. The high energy light-curve of 4U 2206+54 (Figure 2) is reminiscent of that of a HMXRB hosting a supergiant star and a wind-fed accreting compact companion (see Ribó et al. 2006).

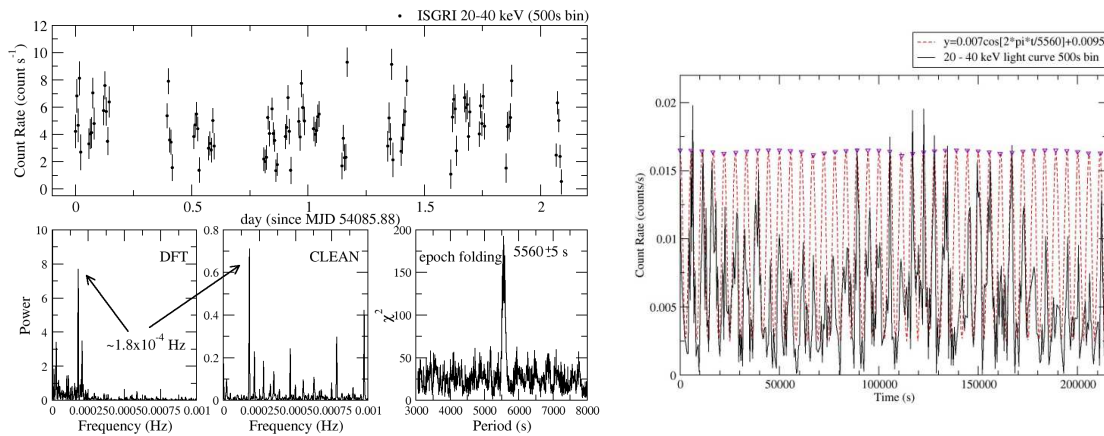


Figure 1: Left panels: 500s binned light curve (upper plot) and periodograms (lower plots) showing the pulse period detection from 4U 2206+54 by INTEGRAL/ISGRI data in the 20-40 keV energy range. A clear periodic variation at  $1.8 \cdot 10^{-4}$  Hz (5560s) is shown. Right panel: Pulsed emission from 4U 2206+54 compared to a sinusoidal-like variation with a 5560s periodicity. The irregularity of the pulse profile is evident and striking.

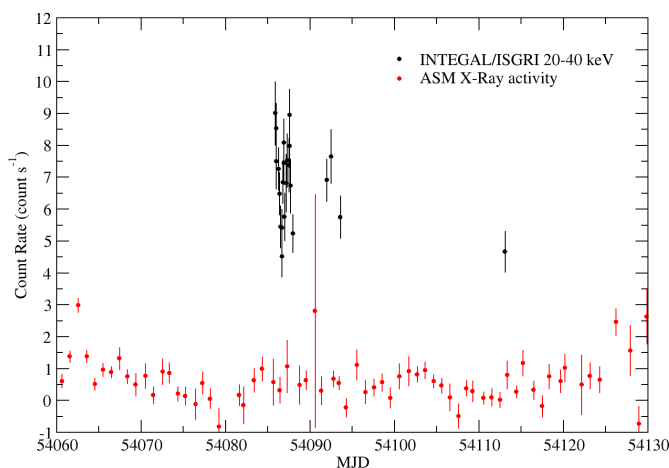


Figure 2: X-ray light curve of 4U 2206+54 in the 2-10 keV (RXTE/ASM) and 20-40 keV (INTEGRAL/ISGRI) energy ranges. The flaring-like variability typical of wind fed HMXRBs is shown in both energy ranges.

Although a 9.56d periodicity was previously considered as the orbital period of the system (see Ribó et al. 2006), more recent high energy data indicate that most likely the orbital period is almost double this value, namely 19.25d (see Corbet, Markwardt, & Tueller 2007).

## 3 UV data

There are very few data in the UV range for BD 53°2790. Two low resolution and one high resolution spectra are available in the IUE (International Ultraviolet Explorer) database. They are described in

detail in Negueruela & Reig (2001) and Blay, Ribó & Negueruela (2009). Ribó et al. (2006) found that the stellar wind from BD+53°2790 was slower and denser than expected for a O9.5V star. However, this peculiar wind could explain the observed behavior in the X-ray ranges if wind-fed accretion takes place in an moderately eccentric ( $e \sim 0.15$ ) orbit.

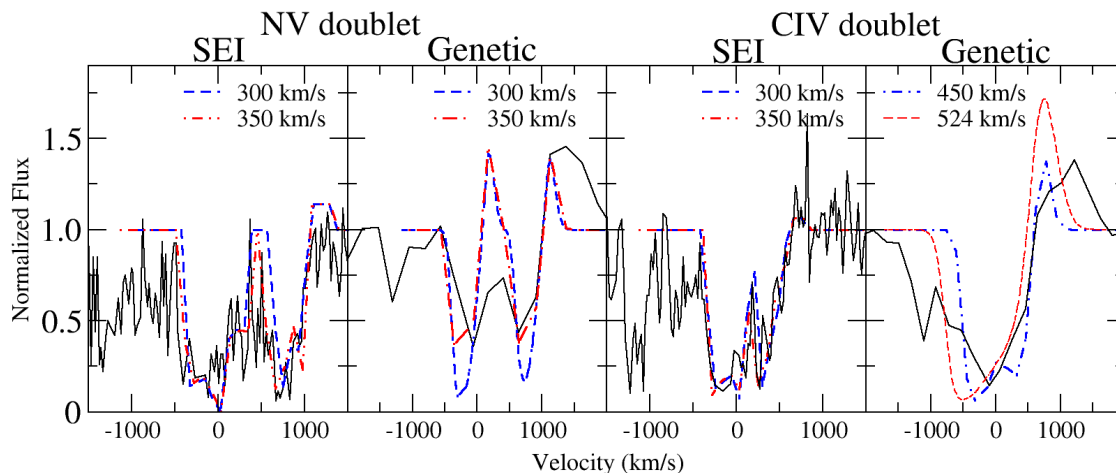


Figure 3: Fit to the observed N V and C IV doublets profiles by using a genetic algorithm and the SEI code as explained in the text. All fits yield terminal wind velocities in the range 300-500  $\text{km s}^{-1}$ . The two fits shown in each plot represent the lower and upper limits of the range of possible solutions (see Ribó et al. 2006).

Figure 3 shows the result of fitting the IUE high resolution spectrum by using the SEI code (Sobolev with Exact Integration, Lamers, Cerruti-Sola & Perionotto 1987) and a genetic algorithm developed by Georgiev & Hernández (2005). Terminal wind velocities in the range 300-500  $\text{km s}^{-1}$  are found, as explained in more detail in Ribó et al. (2006) and Blay et al. (2009).

## 4 Optical data: a very intriguing star

Negueruela & Reig (2001) and Blay et al. (2006) describe the optical peculiarities of BD +53°2790. The adopted spectral type and luminosity for this massive star are O9.5Vp. There are still some peculiarities to be explained in the optical spectra of BD +53°2790: a) the presence of metallic lines which is reminiscent of those of later types (see Negueruela & Reig 2001); b) when compared to standard stars of the same or very similar spectral type, BD +53°2790 seems to be overabundant in He (Blay et al. 2006 suggest the possibility to link BD +53°2790 to the group of He-rich stars). When comparing the He profiles to those of standard stars which are broadened rotationally, a rotational velocity of 315  $\text{km s}^{-1}$  is found for this object. Figure 4 depicts the variability of the  $H\alpha$  line. Although the double peaked profile is always present, with the red peak always higher than the blue one, the variability is evident on short and long time scales. V magnitude variability is shown in Figure 5. The average V magnitude remains fairly constant over time, but on shorter time scales it is clearly variable, with no coherent variability detected so far.

## 5 IR data: the circumstellar environment

Infrared magnitudes and colors obtained during a long-term monitoring campaign (1987-2001) are described and analyzed in Blay et al. (2006). No coherent variability is shown by the IR data. However

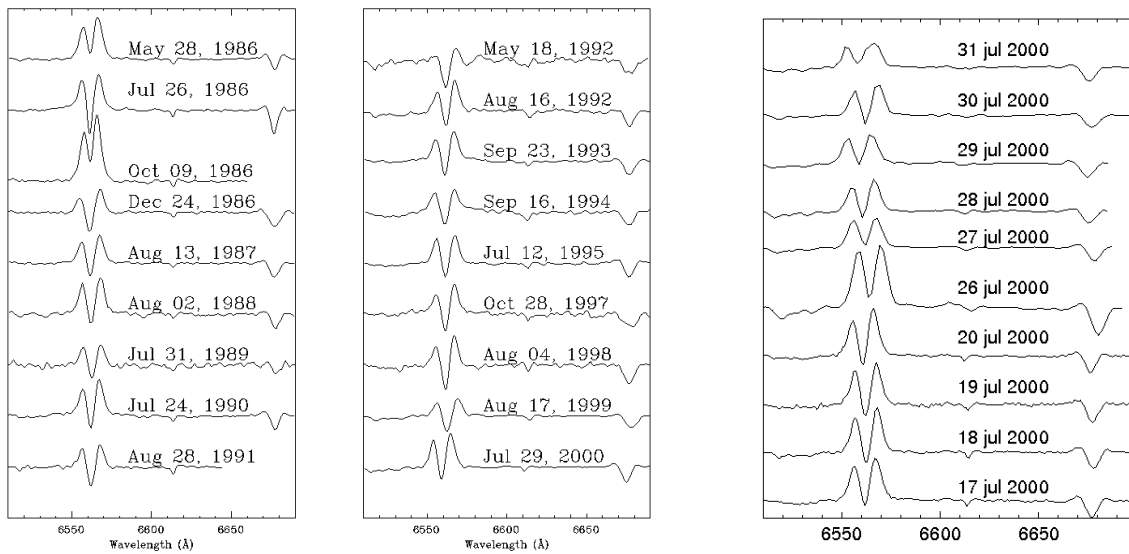


Figure 4:  $H\alpha$  line variability on long time scales (left panels) and shorter time scales (right panel). See Blay et al. (2006).

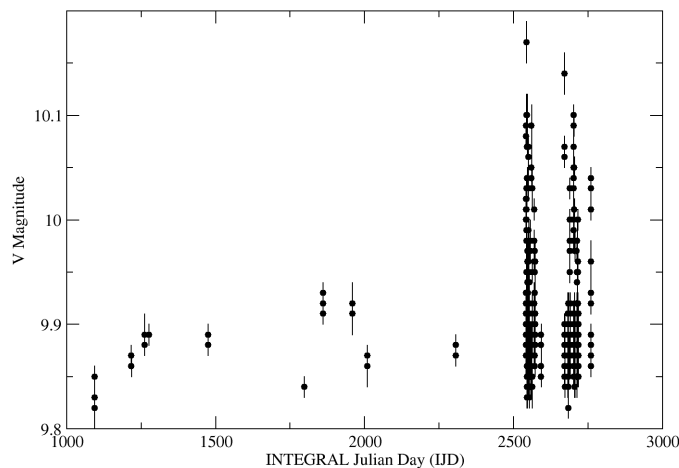


Figure 5: V magnitude observations of the OMC (Optical Monitoring Camera) on board the high energy satellite INTEGRAL. The OMC works in the V filter range. Large amplitude variability is seen at some epochs, however, in the long term, the V magnitude average remains fairly constant.

a long-term trend seems to be present in the J and H magnitudes, but not shared by the K magnitude. On the other hand, as shown in Figure 6, the (J-H), (J-K) and (H-K) colors show a long-term trend which seems to be correlated with RXTE/ASM X-ray data (in the 2-10keV energy range) in the case of the two former colors, but not so well correlated when the latter colour is considered. This is an indication that X-ray emission could be proportional to the IR excess, i.e., to the amount of available circumstellar matter. Spectroscopic classification in the IR band indicates a more evolved nature of BD+53°2790 (see Negueruela & Reig, 2001).

## 6 Radio data: as expected for a neutron star.

Radio emission from 4U 2206+54 was analyzed in Blay et al. (2005). An image was obtained with the VLA at 8.4 GHz after concatenation of observations from 2 runs during May 2003, with no radio emission detected at a significant level. According to Gallo, Fender & Pooley (2003) the presence of a Black Hole would imply radio emission in the 4-15 GHz frequency range. As stated by Blay et al. (2005), the expected radio emission from 4U 2206+54 (if hosting a black hole) would be 60 times greater than the  $3\sigma$  upper limit given by the VLA observation.

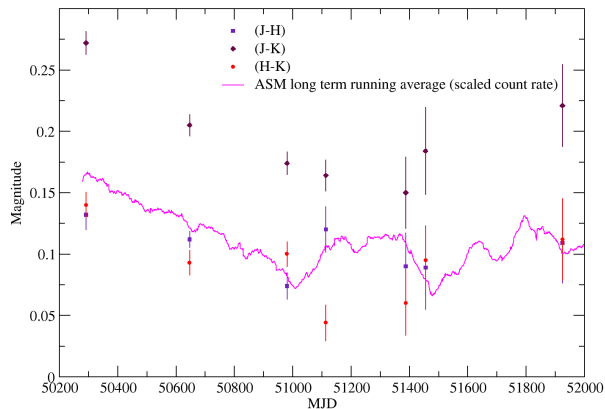


Figure 6: Comparison of the long term IR colours (J-H), (J-K) and (H-K) with the long-term trend of the RXTE/SAM count rate as a running average over 300 days. RXTE/ASM count rate has been scaled for plotting purposes.

## 7 Conclusions

Given the peculiarity of both of its components, 4U 2206+54 shows up as a unique type of X-Ray binary system. There are only two known High Mass X-Ray Binary systems showing wind-fed accretion from a main sequence star. One of them is 4U 2206+54, the other system is the microquasar LS 5039, which hosts a black hole and a O6.5V star. These systems are of great importance as they are presumably the progenitors of Supergiant HMXRBs. 4U 2206+54 also shows similarities with the supergiant systems 2S 0115+54, which also hosts a slowly rotating Neutron Star (2.78 h), and IGR J16358-4726, with a 1.6 h X-ray pulsar. BD+53°2790 is a very active peculiar star, possibly belonging to the class of He rich stars. It very likely hosts a magnetically driven equatorial disk-like envelope, but its existence is still to be confirmed by the detection of intense magnetic field, by magnitude variations modulated by its rotational motion, or both.

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