MONITORING THE WIND INTERACTION IN HD 93403 WITH XMM-NEWTON

G. Rauw[1], J.-M. Vreux[1], I.I. Antokhin[1], I.R. Stevens[2,1], E. Gosset[1⋆], H. Sana[1⋆⋆], C. Jamar[3], and K.O. Mason[4]

[1]Institut d'Astrophysique, Université de Liège, Allée du 6 Août, Bât B5c, B-4000 Liège (Sart Tilman), Belgium
[2]School of Physics & Astronomy, University of Birmingham, Edgbaston Birmingham B15 2TT, UK
[3]Centre Spatial de Liège, Université de Liège, Avenue du Pré-Aily, B-4031 Angleur, Belgium
[4]Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Dorking, Surrey, RH5 6NT, UK

Abstract

We report the first results of a campaign aimed at the study of early-type binaries with the XMM-Newton observatory. Phase resolved EPIC spectroscopy of the eccentric binary HD 93403 reveals a clear modulation of the X-ray flux as a function of the orbital phase. We find that the variations of the EPIC count rates in the 1.0 – 2.5 keV band are consistent with a colliding wind scenario.
Beside some diffuse emission from the Carina Nebula, the EPIC images centered on HD 93403 reveal also X-ray emission from the open cluster Trumpler 15 as well as a number of discrete sources. We briefly discuss the properties of one of these sources.

Key words: binaries: close – Stars: early-type – Stars: individual: HD 93403 – Stars: winds, outflow – X-rays: stars

1. Introduction

Massive O-stars lose substantial amounts of matter ($\dot{\mathrm{M}} \sim 10^{-5}$ $\mathrm{M}_{\odot}\,\mathrm{yr}^{-1}$) through their highly hypersonic stellar winds ($v_\infty \sim 3000$ km s^{-1}). In binary systems consisting of two O-type stars, the stellar winds of both stars collide and the plasma in the wind interaction region is heated to temperatures of a few times 10^7 K (e.g. Stevens et al. 1992). The hot, shocked plasma is expected to contribute to the total X-ray emission of the binary and, as a result, many early-type binary systems display larger $\mathrm{L_X}/\mathrm{L_{bol}}$ ratios than single stars of the same spectral type (e.g. Chlebowski & Garmany 1991).

Some early-type binaries exhibit a phase-locked modulation of the X-ray flux (e.g. Willis et al. 1995, Corcoran 1996) that can result from:

- the variation of the circumstellar opacity along the observer's sightline through the winds provided that the orbital inclination is large enough;
- the variation of the intrinsic properties of the wind collision shock as a function of the changing separation between the binary components in an eccentric system.

Multi-wavelength studies of the colliding wind phenomenon yield precious information about $\dot{\mathrm{M}}$ and the hydrodynamical processes in stellar winds.

In this contribution, we focus on the eccentric binary HD 93403 (O5.5 I + O7 V) in the Carina complex. Using EINSTEIN data, Chlebowski & Garmany (1991) reported a rather large X-ray excess luminosity above the empirical $\mathrm{L_X}/\mathrm{L_{bol}}$ relation for single O-stars.
Rauw et al. (2000) derived a large orbital eccentricity ($e = 0.234$) and a probably rather low orbital inclination ($i \simeq 32°$, $25° < i < 58°$) for HD 93403. Therefore, one expects the X-ray emission from the wind interaction region to vary mainly as a function of orbital separation.

2. Observations and data reduction

Four pointings of HD 93403 were obtained with XMM-Newton as part of the guaranteed time programme of the XMM-OM consortium. The average exposure times per observation were 9.4 and 5.0 ksec for the EPIC-MOS and -pn instruments respectively. The observations were scheduled at binary phases 0.26, 0.52, 0.75 and 0.01 (phase 0.00 corresponding to the periastron passage, see Rauw et al. 2000). The EPIC-MOS and-pn cameras were operated respectively in the full frame and the extended full frame mode. The data were processed with SAS version 5.0.1.
We extracted the EPIC spectra of HD 93403 over a radius of 1′ and the background spectra over an annulus around the source region.

3. Phase-resolved EPIC spectroscopy of HD 93403

The EPIC spectra of HD 93403 above 0.5 keV were analyzed using the XSPEC software. Acceptable fits were obtained with two-temperature `mekal` models (see Fig. 1). Our phase resolved observations of HD 93403 indicate little variability of the spectral parameters. The best fitting models yield temperatures of $\mathrm{kT_1} = 0.23$ and $\mathrm{kT_2} = 1.06$ keV for the softer and the harder component respectively.

We find that the overall X-ray luminosity changes as a function of orbital phase (see Fig. 2). This behaviour is phase-locked since it is also found in older ROSAT-HRI archive data (though the HRI data have large error bars

⋆ Research Associate FNRS (Belgium)
⋆⋆ Research Fellow FNRS (Belgium)

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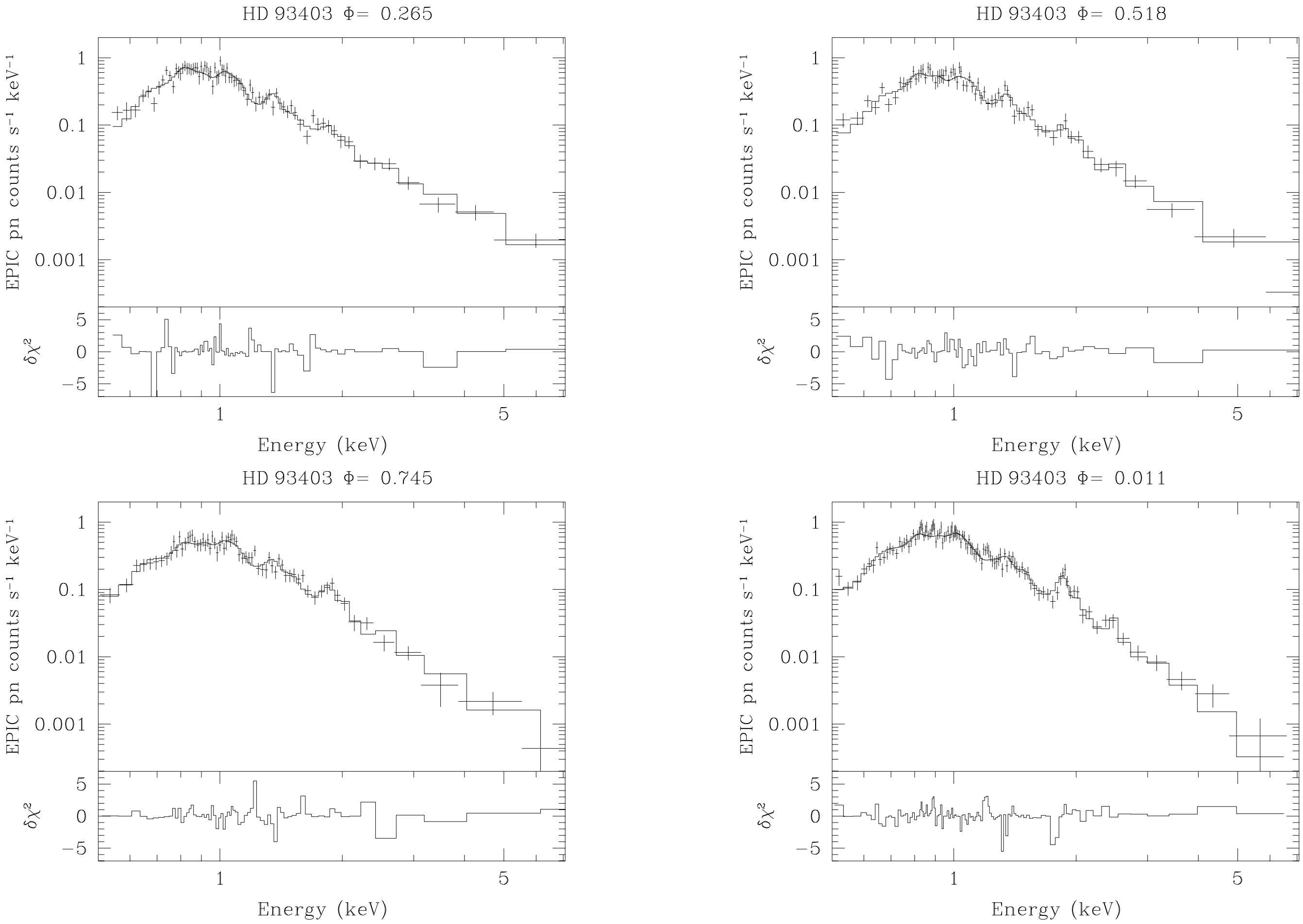

Figure 1. EPIC-pn spectra of HD 93403 and best-fitting 2-T `mekal` *models. The different panels are labelled with the corresponding orbital phases.*

and provide no spectral information). Figure 2 clearly illustrates that the count rates do not vary the same way over the entire energy range covered by the EPIC instruments. HD 93403 appears brightest around periastron passage ($\Phi = 0.0$) in all energy bands. However, the count rates in the softer band are minimum around the conjunction when the O5.5 I primary is 'in front' ($\Phi \simeq 0.75$), whereas those in the harder energy range are minimum around apastron ($\Phi = 0.5$). These different behaviours suggest that the variations in the soft energy band are dominated by opacity effects whilst the harder energy band actually reflects the changes in the properties of the wind collision as a function of orbital separation.

On the one hand, the circumstellar opacity along the direction of the observer's line of sight is likely to change as a function of orbital phase since the primary of spectral type O5.5 I is expected to have a larger mass loss rate and hence a more opaque wind than the O7 V secondary. This asymmetry in the wind properties combined with the orbital inclination leads to a moderate eclipsing effect. On the other hand, a dependence of the harder X-ray count rate on the orbital separation is expected if a colliding wind interaction contributes to the hard X-ray flux. In fact, if the shocked plasma cools adiabatically, then the X-ray emission from the wind collision should scale as $v^{-3.2}\,r^{-1}$ (Stevens et al. 1992) where v and r stand for the pre-shock velocity and the relative orbital separation respectively. At periastron passage, the stars are closest and the accelerating stellar winds do not have the time to reach large velocities before they collide. On the other side, the separation and the pre-shock velocities are largest at apastron and the X-ray emission is thus expected to be minimum around $\Phi = 0.5$. A detailed discussion of the EPIC light curve will be presented elsewhere (Rauw et al. 2002, in preparation).

4. Other X-ray sources in the EPIC FOV

The combined EPIC-MOS three colour image of the field of view around HD 93403 reveals a number of point sources as well as X-ray emission from the small open cluster Trumpler 15 and some soft diffuse emission arising in the

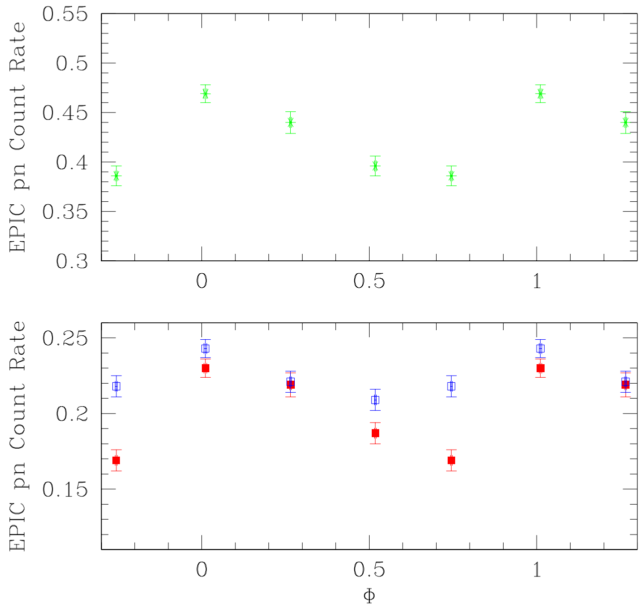

Figure 2. EPIC-pn light curves of HD 93403. The upper panel yields the overall pn count rate above 0.5 keV whilst the lower panel displays the count rates in two separate energy bands: 0.5 – 1.0 keV (filled red symbols) and 1.0 – 2.5 keV (open blue squares). 1-σ error bars are indicated. Note that the MOS light curves indicate a very similar behaviour.

outer regions of the Carina Nebula (see Fig. 3).

The brightest X-ray source aside from HD 93403 is the very hot O3 V star HD 93250 near the edge of the field of view. HD 93250 is a suspected non-thermal radio emitter (Leitherer et al. 1995). The EPIC light curve of HD 93250 displays some slight variability between the four pointings, whilst most of the other sources (apart from HD 93403) do not show significant variability. The EPIC spectra of HD 93250 can be fitted with a two-temperature `mekal` model with temperatures around 0.60 keV and 1.08 – 1.74 keV.
Although more data are needed before we can draw any firm conclusion, we note that these results, i.e. the existence of a relatively hard thermal component, the slight X-ray variability and the possible non-thermal radio emission, suggest that HD 93250 might be another interacting wind binary. It should be mentioned however that so far optical spectroscopy failed to reveal the signatures of binarity for this star.

5. Summary and future work

Our EPIC data of HD 93403 provide the most complete phase-resolved X-ray spectroscopy of any colliding wind O-star binary so far. We find that HD 93403 displays phase-locked variations of the X-ray count rate: the system appears brightest around periastron. The X-ray light curve in the 1.0 – 2.5 keV band is consistent with a colliding wind interpretation, while the modulation of the flux in the soft band (0.5 – 1.0 keV) is probably due to the changing circumstellar opacity along the direction of the observer's line of sight.
As a future step, we will compare the X-ray data with an extensive set of optical spectra in order to provide a multi-wavelength picture of the wind interaction. Further insight into the properties of stellar winds will be gained through a comparison of the EPIC spectra of HD 93403 and other early-type binaries to hydrodynamic simulations (e.g. Pittard & Stevens 1997).

Beside some soft diffuse emission from the outer skirt of the Carina Nebula, the EPIC field of view around HD 93403 reveals also a number of point sources, some of which are coincident with other early-type stars. Together with other observations of the Carina complex, we will use these data to derive the X-ray luminosity function of early-type stars.

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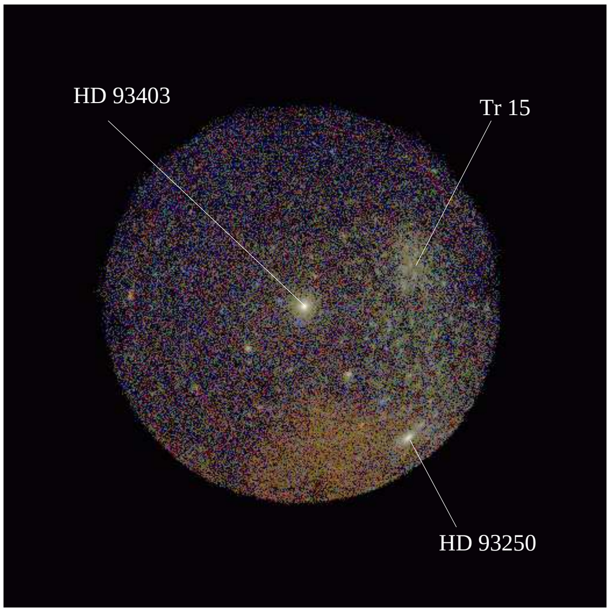

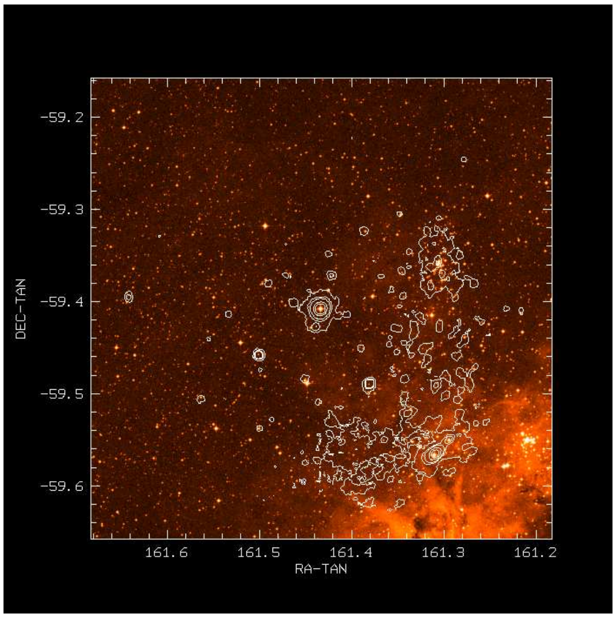

Figure 3. Left: three colour image of the Carina region around HD 93403. Red, green and blue colours correspond to average energies of 0.7, 1.5 and 2.5 keV (north is up and east is left). η Carina is located outside the image near the south-west corner. Right: X-ray contours overlaid on an optical image taken from the Digital Sky Survey.