THE *ROSAT* VIEW OF THE MASSIVE ECLIPSING O-TYPE BINARY SYSTEM 29 UW CANIS MAJORIS

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Abstract. We have investigated a recently obtained *ROSAT* X-ray observation of the massive binary 29 UW Canis Majoris (HR 2781; HD 57060). This short-period binary (4.3934 d) consists of two eclipsing O-type stars and has been observed for about 9 days with the *ROSAT* PSPC. We discuss the origin of the X-ray emission in the close binary system 29 CMa in the context of the traditional colliding wind scenario as well as the scenario of X-ray emission from shock heated gas in the stellar winds.

Key words: stars: early-type – binaries – X-rays – stars individual: 29 UW CMa

1. Introduction

Observations with the *Einstein Observatory* (Chlebowski, Harnden & Sciortino 1989) and with *ROSAT* have conclusively shown that all single hot stars are soft X-ray emitters and only the sensitivity of the available detectors limits the discovery of fainter hot stars. The model for the X-ray generation of these stars is based on the phenomenological shock model of Lucy & White (1980) who pointed out that the radiatively driven winds of these stars are highly unstable. Detailed model calculations (Owocki, Castor & Rybicki 1988) have confirmed that the growth of instabilities in the stellar winds naturally leads to the production of strong shocks which heat wind material to temperatures of $10^6 - 10^7$ K with ensuing X-ray emission. New support for this scenario comes from two *ROSAT* results. First, with a detailed modelling of the X-ray opacity of the stellar wind and assuming that the X-ray emission arises from shocks uniformly distributed throughout the wind, Hillier *et al.* (1993) were able to explain the observed *ROSAT* PSPC pulse height spectrum of the O4f star ζ Puppis. They found that due to the high opacity in the energy range below 0.5 keV, the X-ray emission in this energy range must originate from far out in the wind and only the harder X-ray emission ($E > 0.5$ keV) comes from regions deeper in the wind. A second piece of evidence comes from our long-term X-ray variability studies (Berghöfer & Schmitt 1994) that have shown that X-ray time variability is not common among hot stars, with the interpretation that the observed X-ray emission is the average X-ray output of a larger number of shocks present at any given time.

Hot star binaries consists of at least two single hot stars and therefore we expect to observe X-ray emission from each individual star in such a system. On the other hand, in the case of hot star binaries, an additional X-

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ray emitting mechanism is possible: The colliding or interacting wind model (*e.g.,* Cherepashchuk 1976) predicts an excess in X-ray emission due to the presence of a shock region formed where the winds of the individual stars collide. Whether colliding winds are relevant for the observed X-ray emission from O-type binaries is open: This question can be addressed either by statistical studies of the properties of single stars *vs.* binaries, or by detailed case studies of individual systems.

2. *ROSAT* observations of 29 CMa

Here we present an analysis of a recently obtained *ROSAT* X-ray observation of the massive O-type binary system 29 UW Canis Majoris. This close binary system, consisting of two eclipsing O-type stars, is well studied (*e.g.,* Stickland 1989) in the optical and UV range. It has an orbital period of $P = 4.3934\,\mathrm{d}$ and an inclination $i \approx 70°$; some authors found evidence for an eccentricity of $e = 0.12$. The primary has been classified as an O8Iaf supergiant with a mass loss rate $\dot{M} = 4.4 \cdot 10^{-6} M_{\odot} yr^{-1}$ and a terminal wind velocity of $v_{\infty} = 1425$ km s^{-1}. The stellar properties of the secondary are not well known. Van Genderen *et al.* (1988) classified the secondary as an O9.5/B0 main sequence type star, whereas Wiggs & Gies (1993) argued that the UV spectra of 29 CMa point to a giant or supergiant secondary star of spectral type O9. They also found that the mass loss rate of the secondary's wind should not be smaller than the value of the primary.

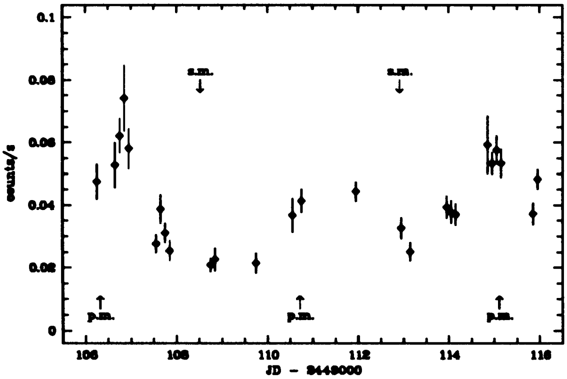

Fig. 1. *ROSAT* X-ray light-curve (0.6-2.4 keV) of 29 CMa; $P = 4.3934\,\mathrm{d}$; p.m. and s.m. indicate primary and secondary minimum.

Our new *ROSAT* PSPC observation of 29 CMa extended over a period of about ten days covering three primary minima and two secondary minima. During 82 ksec total observing time we obtained about 3000 source counts. In Fig. 1, we show the observed X-ray light-curve of 29 CMa in the energy range of 0.6-2.4 keV. Note that most of the X-ray emission in the lower energy range is absorbed by the interstellar medium ($N_H = 6.3 \cdot 10^{20}$ cm^{-2}). The observation of 29 CMa covered three primary minima and in each case we observed an enhanced X-ray count rate during primary minimum. These variations in X-ray count rate occurred periodically and the folding analysis of the X-ray light-curve confirmed a periodicity at the orbital period. In Fig. 2 we show the X-ray light-curve of 29 CMa folded with the 4.3934 d orbital period; orbital phase $\phi = 0.0$ corresponds to the primary minimum, the situation when the secondary is in front of the primary. As is clear from Figure 2, the X-ray light curve of 29 CMa reaches its maximum around primary minimum and its minimum during secondary minimum.

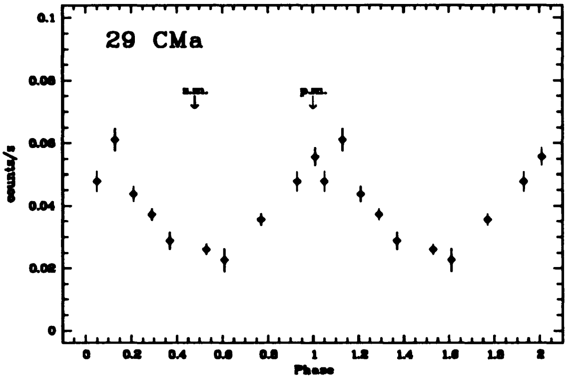

Fig. 2. Period-folded X-ray light-curve (0.6-2.4 keV) of 29 CMa; primary minimum at phase $\phi = 0.0$, 1.0 and 2.0, secondary minimum at $\phi = 0.0$ and 1.5.

3. Discussion and conclusions

According to Wiggs & Gies (1993) the stellar winds of the two components of 29 CMa should form a planar bow-shock region between the stars. In the case of an X-ray excess caused by such a shock region one would expect to observe half the orbital periodicity, since during one orbital period the interacting wind region between the two stars can be viewed twice. We emphasize that neither the observed X-ray light-curve nor the folding analysis gave any evidence for a periodicity at half the orbital period and therefore the observed periodicity of 29 CMa is the first strong argument against an X-ray excess due to a colliding wind scenario in this system.

In order to test whether we can explain the observed X-ray light-curve of 29 CMa by the X-ray emission of two single O-type stars, we compare the X-ray fluxes observed during primary and secondary minimum of 29 CMa with those of single O-type stars. During secondary minimum, when the dense wind of the primary totally eclipses the secondary's wind, we expect to observe the X-ray emission of the primary. In the case of primary minimum we expect that most of the observed X-ray emission comes from the secondary. Depending on the uncertain wind properties of the secondary we can not totally exclude to observe at least some of the primary's X-ray emission during primary minimum. In the following discussion we assign the whole X-ray count-rate observed during primary minimum to the secondary; this implies that we use the highest possible X-ray count-rate for the secondary and the derived X-ray luminosity is in fact an upper limit for the secondary of 29 CMa. Table 1 summarizes the observed X-ray count-rates, luminosities and L_x/L_{bol} values for the primary and secondary of 29 CMa as well as for four typical comparison O-type stars. The X-ray count-rates for ζ Pup, ζ Ori and σ Ori were corrected for the distance and the interstellar absorption of 29 CMa. Compared with these single O-type stars the primary of 29 CMa appears to be X-ray underluminous, while the X-ray luminosity of the secondary is in accordance with single O star X-ray emission. If we compare both stars of 29 CMa with the 52 X-ray brightest O and B stars detected in the *ROSAT* all-sky survey (Fig. 3 shows a histogram of the computed L_x/L_{bol} values), we also find no evidence for any additional X-ray emission in the binary system 29 CMa that cannot be explained by the X-ray emission of the individual stars. This is then the second strong argument against an X-ray excess in 29 CMa caused by a colliding wind. Note again that we used for our comparison of the X-ray luminosities the highest possible X-ray flux for the secondary. Any X-ray emission coming from the primary during primary minimum would lower the X-ray luminosity of the secondary.

TABLE I

X-ray properties of the primary and secondary of 29 CMa compared with single O-type stars (X-ray count-rates are corrected for the distance and the interstellar absorption of 29 CMa)

star	spectral type	PSPC (counts/s)	$log L_x$ (erg/s)	$log(L_x/L_{bol})$
29 CMa (primary)	O8Iaf	0.025	31.8	-7.28
29 CMa (secondary)	O9I	0.05	32.1	-6.75
τ CMa	O9Ib	0.118	32.5	-7.05
ζ Puppis	O4f	0.081	32.4	-7.03
ζ Orionis	O9.7Ib	0.105	32.7	-6.75
σ Orionis	O9.5V	0.022	31.9	-6.80

In summary, in the 29 CMa system we detected orbit-related variations in X-ray count-rate that can naturally be explained by the eclipsing winds of the individual stars. We find no evidence for any X-ray excess caused by a colliding wind. If anything has to be explained in the 29 CMa system, it

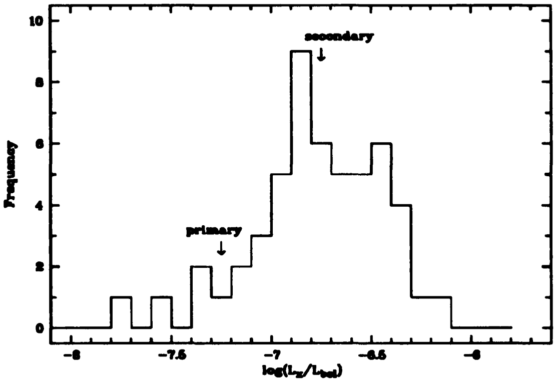

Fig. 3. Histogram of the computed L_x/L_{bol} values for the 52 X-ray brightest O and B stars detected in the *ROSAT* all-sky survey.

is the relative weakness of the X-ray emission from the primary.

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DISCUSSION:

Stickland: Responding to the question as to whether 29 CMa is unique, one should recall the spectra taken by Struve and Sahade and shown in the Stars and Stellar Systems book. When the secondary is approaching, there is a clear signature of the secondary which is absent when the secondary is going away. I find this effect also in IUE data. This implies some very asymmetrical geometry and gas distribution.

Marchenko: If you are talking about the lack of any X-ray variability in the O and WR stars, you are limited by ~ few kiloseconds exposure time. You cannot deny the possible presence of short-timescale events (some kine of flaring) with much shorter duration. We cannot make the exposure time shorter due to count rate limits. Have you any possibility to check the presence of the short-time variability during processing of data?

Berghöfer: Our long-term X-ray variability studies of early-type stars provide no evidence for X-ray time variability on all observable timescales. The only limiting factor is the photon statistics which, in the case of these low X-ray count rate sources, do not allow us to study time variability on very short timescales. However, in the case of the X-ray brightest O stars we can exclude X-ray time variability down to several hundred seconds.

Owocki: Over the last few years, we have been establishing dynamical models of the line-driven instabilities in winds from single hot stars. Glenn Cooper a graduate student working with me, will later be defending his PhD thesis on X-ray emission from the instability generated shocks. There is generally good agreement with observations of luminous supergiants, massive winds, e.g. ζ Pup, but not enough X-rays for lower density B star winds. It would be interesting to apply these instability models to your data for this binary system as well.

Gies: Two comments: 1. Our recent tomographic study of this system (Dagnuob et al. 1993) suggests the secondary is a supergiant.

2. The light curve strongly suggests that the primary is tidally distorted and presumably locked in synchronous rotation. I wonder if this property is related to the low L_x of the primary star.

Berghöfer: If the secondary is a supergiant then the L_x/L_{Bol} is lower than we calculated and this reduces again the chance for any X-ray excess due to colliding winds. Some words about the spectral properties of 29 CMa: during our ROSAT observations of 29 CMa we observed no significant variations in the hardness ratio. If we take into account the different interstellar absorption the ROSAT PSPC pulse height spectrum of 29 CMa during primary minimum is similar to the pulse height spectrum of our comparison star σ Orionis. This star is of spectral type 09.5V and has similar wind properties.

Pollock: Are you sure that you can exclude a significant contribution from a colliding wind shock? The highest count rate is at a phase both significantly different from conjunction and at just the time you might expect to be looking at a shock.

Berghöfer: We don't think that the somewhat higher count rate in this data point is significant. This data point has the largest error bar and contains the smallest number of counts. As Douglas Gies told us in his talk, the shock front of the colliding winds is expected to form between both stars and therefore can be viewed twice during one orbital period at phases 0.25 and 0.75. However, during phases 0.25 and 0.75 we do not observe any excess in X-ray emission that we cannot explain by the X-ray emission of the two eclipsing winds.