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LA-UR -86-1216

CONF-851272 --2

RECEIVED BY OSTI MAY 12 1986

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LA-UR--86-1216

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SUBMITTED TO: Proceedings of the conference "RS Ophiuchi (1985) and the Recurrent Nova Phenomenon", Manchester, England, 12/16-18/85

3/25/86

Los Alamos

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FORM NO 836 R4
ST NO 2629 5/81

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To be published in the Proceedings of the conference "RS Ophiuchi (1985) and the Recurrent Nova Phenomenon" held in Manchester 1985 December 16-18 and edited by M.F. Bode. VNU Science Press, Utrecht.

INTENSE SOFT X-RAYS FROM RS OPHIUCHI DURING THE 1985 OUTBURST

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ABSTRACT

Intense soft X-ray emission with a characteristic temperature of a few million degrees has been detected from the recurrent nova RS Oph approximately two months after its January 1985 optical outburst. This is the first detection of X-rays from such a system at outburst. The X-radiation is interpreted as emission from circumstellar gas that is shock heated by the passage of the blast wave from the nova explosion. The rapid decline of the X ray flux between about 60 and 90 days after the outburst probably occurs because the blast wave has reached the edge of the volume filled, between outbursts, by the stellar wind of the red giant component of the binary system. Residual X-ray emission detected from RS Oph 250 days after the outburst is interpreted as coming from the surface of a white dwarf, at a temperature of ~300,000K, where thermonuclear burning is persisting.

1. INTRODUCTION

RS Ophiuchi is a recurrent nova which has outbursts approximately every 17 years. The system is a binary consisting of a red giant in orbit about a hot blue star (I. Rosino, this volume). The outburst of RS Oph in January 1985 provided the first opportunity to observe such an event in the X-ray band. The X-ray observations were made using the European X-ray astronomy satellite, EXOSAT. During the early stages of the optical outburst, RS Oph was too close to the Sun to be observed by the spacecraft. An observation was scheduled at the earliest available opportunity which was 1985 March 22, or 54 days after the peak of the optical outburst. A bright soft X-ray source was detected at the position of RS Oph, so a further series of EXOSAT observations, six in all, were made over the next few months to monitor the evolution of the X-ray flux.

2. OBSERVATIONS

Data on RS Oph were obtained with the Low Energy telescope (LE-1) and the Medium Energy proportional counter array (ME) on EXOSAT. The LE-1 telescope, with the CMA detector at the focus, was operated with various broadband filters to provide limited spectral information in its operational energy range of 0.04 to 2.0 keV. Additional spectral information is provided by the ME array which is sensitive in the energy range 1.5 to ~15 keV.

Figure 1 shows, on a logarithmic scale, the count rate measured by the LE-1 CMA detector with the Lexan 3000 filter as a function of time since the peak of the optical outburst. During the first observation, on March 22, a count rate of almost 0.5 per second was measured, making RS Oph one of the brightest sources recorded by the EXOSAT LE telescope. The source decayed over the next two months, slowly at first and then more rapidly. However, despite the steep decline in April and May, a significant residual emission was still detected during the final observation in 1985 October, 250 days after the peak of the optical outburst.

The background-subtracted count rate recorded as a function of energy by the ME detector on 1985 March 22 is illustrated in Figure 2. The count rate rises steeply towards low energies and the source is only detected below about 5 keV, implying a very soft spectrum. The total count rate recorded in the ME on this day was 0.5 counts per second per half array. We have attempted to fit various simple spectral models to the combined data from the ME and

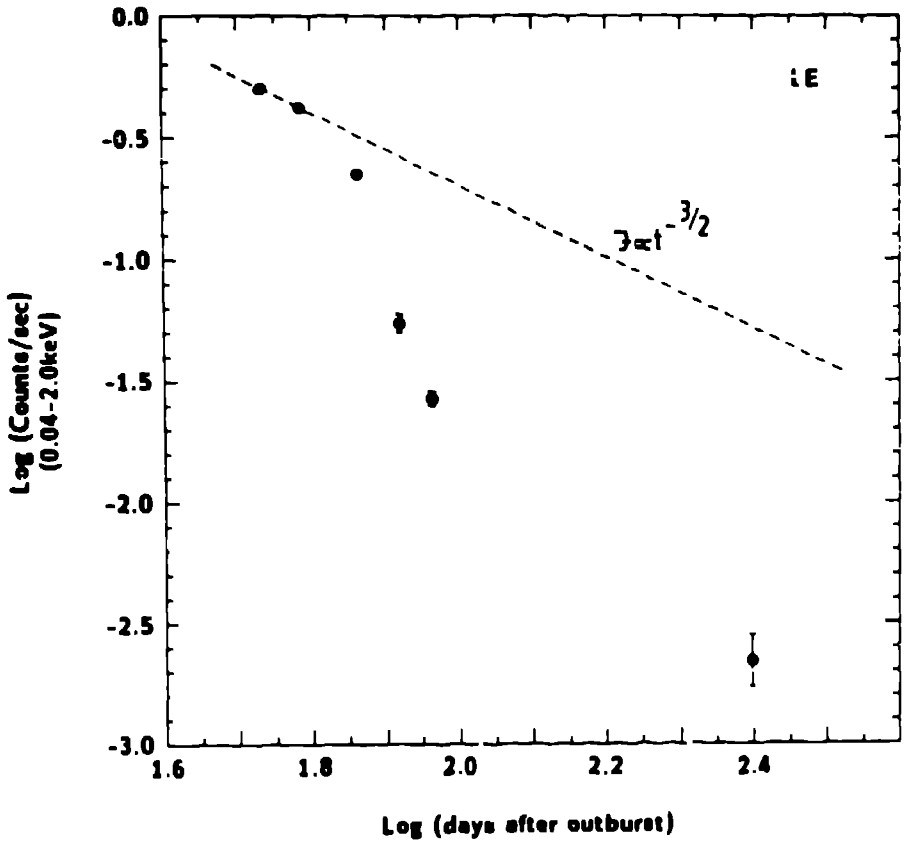

Figure 1: EXOSAT CMA+Lexan 3000 count rate as a function of time since the optical outburst plotted on a logarithmic scale. The dashed line is the expected decay rate of the X-ray flux according to the model of Bode and Kahn (1985) in Phase III (see text).

LE-1 detectors, including hydrogen bremsstrahlung, power-law, and blackbody spectra, and the spectrum of an optically thin line-emitting plasma (Raymond and Smith 1977). None of these provided an acceptable fit. A statistically acceptable representation of the data was provided by a combination of two hydrogen bremsstrahlung models with temperatures of 0.3 and 0.8 keV respectively (3.5 million and 9 million degrees). However, this model required an unacceptably low value of the interstellar absorption column (9×10^{20} H atoms cm^{-2}) compared to the most recent estimates from the radio and ultraviolet data of 3-4×10^{21} H atoms

cm^{-2} (R.J.Davis and M.A.J.Snijders, this volume). Nevertheless, we can use this fit to estimate that the total flux detected from RS Oph between ~1 and 6 keV is about $1.5x10^{-10}$ erg cm^{-2} s^{-1} on March 22. Because the source is so soft, this is probably no more than about 10% of the flux emitted in this band by the source, the rest being absorbed by the interstellar medium.

In Figure 3 we plot the source count rate detected by the LE-1 instrument against that recorded by the ME for the first five EXOSAT observations of RS Oph. The source was significantly detected above background in the ME during the first three observations only. The data are consistent with there being a constant ratio between the count rates in the two instruments

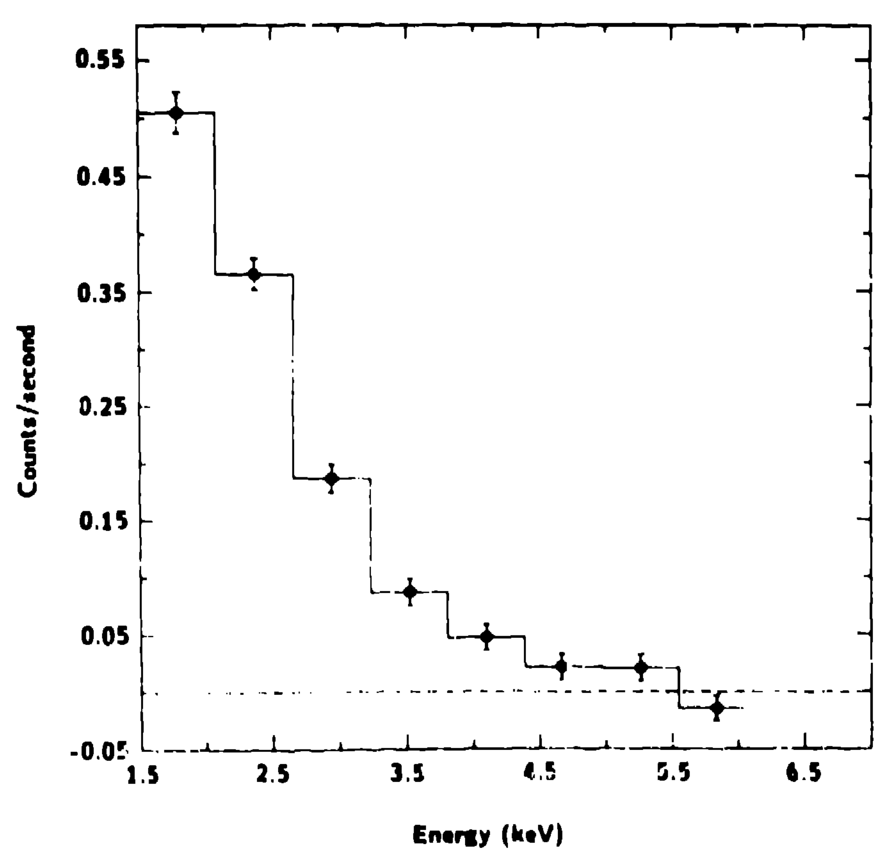

Figure 2: EXOSAT ME background-subtracted count spectrum of RS Oph on 1985 March 22.

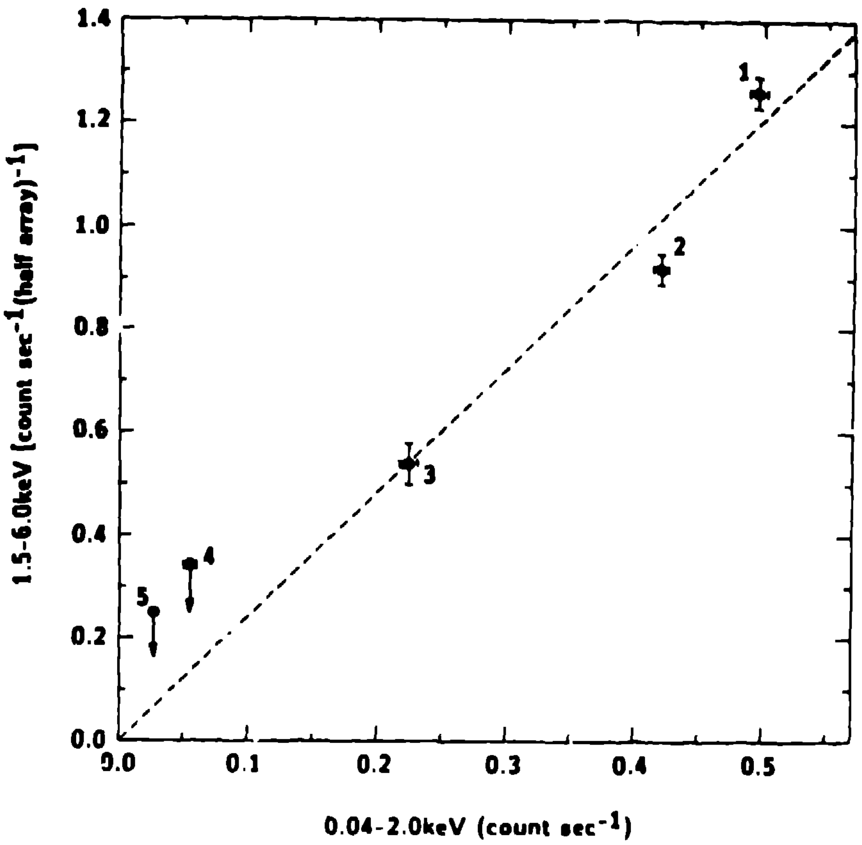

Figure 3: EXOSAT ME 1.5-6.0 keV count rate versus CMA+Lexan 3000 count rate for the first five EXOSAT observations of RS Oph. The observations are labeled in time order.

suggesting that there is no substantial change in the overall spectrum of the X-ray source as it decays.

3. DISCUSSION

3.1 The Blast Wave Model

Soon after the beginning of RS Oph's optical outburst, emission lines appear in the optical spectrum whose breadths indicate velocities of ~3000 km/s. These lines become narrower with time and it has been inferred that they are associated with a blast wave from the nova explosion which sweeps up, and is strongly decelerated by, the pre-existing circumstellar wind of the red giant companion (Pottasch 1967). About 20 to 30 days into the outburst strong coronal lines appear, including those due to [FeX] and Fe[XIV], indicative of gas at a temperature of a few million degrees (Gorbatskii 1972).

A number of properties of the X-ray emission recorded from RS Oph suggest that it too originates in gas shock heated by the nova blast wave. These are:

(i) Strong X-ray emission is seen a long time after the optical outburst.

(ii) There is no short timescale variability detected in the X-ray flux, consistent with emission from an extended source.

(iii) Optical line widths indicate velocities of about 500 km/s fifty days after the outburst. If this is the velocity of the blast wave, Vs, the temperature of the shock heated gas is expected to be $1.2(Vs/1000\ km\ s^{-1})^2$ keV ~ 0.3 keV. This is consistent with the observed characteristic temperature of the X-ray spectrum.

(iv) Preliminary comparison indicates that the flux and evolution of the optical coronal emission lines is consistent with them originating in the same hot gas that produces the X-ray emission. For example, Kenyon and Wade (1985, private communication) find that the flux in the [Fe XIV] 5300Å line on March 18 was $6x10^{-12}$ erg cm^{-2} s^{-1}. Using the coronal line emissivities given by Woodgate et al. (1975), this corresponds to an X-ray flux of between $1.5x10^{-9}$ and $3x10^{-8}$ erg cm^{-2} s^{-1}, where the extremes correspond to gas with a temperature of 2 million and 4 million degrees respectively. This compares favourably with the X-ray flux observed on March 22, given the uncertainty in the amount of flux absorbed by the interstellar medium.

Despite the above, there are problems with the simple blast wave model. The most important are the rapid decay of the X-ray flux, and the lack of change in the slope of the X ray spectrum during the decay. Bode and Kahn (1985) have calculated the expected behaviour of a blast wave expanding into a medium whose density falls as r^{-2} (the expanding stellar wind of the red giant star)

They find that the X-ray luminosity of the shock heated envelope should decay as $t^{-1/3}$ or $t^{-3/2}$ depending on whether the nova remnant is in Phase II or Phase III of its evolution (see J.E.Dyson, this volume). Moreover, the temperature of the emission should decrease as $t^{-2/3}$ or t^{-1} respectively as the blast wave is decelerated by the circumstellar material. A line corresponding to $F \propto t^{-3/2}$ is plotted in Figure 1, and while the first two X-ray observations are consistent with this slope, subsequent points fall away much more steeply than predicted.

The most likely explanation for the departure of the observations from the simple model is that, about two months after the outburst, the blast wave reaches the edge of the cavity filled, between outbursts, by the stellar wind of the red giant companion. The widths of optical emission and absorption lines of RS Oph in quiescence suggest that the velocity of the red giant's wind is about 20 km/s. Thus, in the ~17 years between outbursts, the wind fills a sphere of radius ~10^{15} cm. The blast wave will reach the furthest extent of the wind in two months if its time averaged velocity is ~2000 km/s. This compares favourably with the velocities deduced from the optical emission lines, which range from ~3000 km/s just after outburst, to ~500 km/s two months after outburst. When the blast wave reaches the edge of the stellar wind, the density drops off much more rapidly than r^{-2} with a corresponding reduction in the X-ray flux emitted. The blast wave thereafter expands comparatively unhindered into interstellar space.

3.2 Thermonuclear Burning on the White Dwarf

It is apparent from Figure 1 that weak, but significant, residual X-ray emission is still detected from RS Oph with EXOSAT more than two hundred days after the outburst. By this stage, the X-ray source is too weak to be detected in the ME, and we have a flux measurement in the LE with a single filter only (Lexan 3000). The amount of residual flux detected with the LE is consistent with an origin on the surface of a white dwarf. For $N_H \sim 3\times10^{21}$ cm^{-2} (consistent with IUE and 21cm line measurements), a white dwarf radius of 10^9 cm and a distance of 1.6 kpc, the blackbody temperature implied is $\sim 3.5\times10^5$ K, and the total luminosity is approximately 10^{37} erg s^{-1}. This interpretation would imply that thermonuclear burning was still taking place on the surface of the white dwarf (cf. Starrfield et al. 1978; W.Sparks, this volume). The values for the temperature and luminosity derived are in line with those found by Ogelman et al. (1984) for the soft X-ray emission from the central remnant of the classical nova Muscae 1983 (see also H.Ogelmann and J.Krautter, this volume).

4. CONCLUSION

We have detected a strong flux of soft X-rays from RS Oph about two months after outburst which we interpret as thermal emission from circumstellar gas which is shock heated by the passage of the blast wave from the nova explosion. The environs of RS Oph are thus in many ways like a supernova remnant in miniature, and offer a fascinating opportunity to examine the evolution of such an event on a timescale of months rather than thousands of years. The rapid fall-off in the X-ray flux can be explained if the blast wave has reached the edge of the cavity filled by the stellar wind of the red giant star since the last nova explosion. We also find evidence of continued thermonuclear burning on the surface of the white dwarf in the form of weak residual emission detected 250 days after the outburst. A number of further tests of the model can be made. Most important of these is a detailed comparison of the X-ray and optical coronal line light curves, which awaits the availability of calibrated optical line fluxes.

ACKNOWLEDGEMENTS

We thank the EXOSAT observatory team for their efforts in scheduling the RS Oph observations as targets of opportunity. This work was supported by the Royal Society (KOM), the US Department of Energy (FAC), and the SERC (KOM and MFB).

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