The phases of X-ray emission of RS Oph

Jan-Uwe Ness\textsuperscript{1,}\textsuperscript{*} Sumner Starrfield\textsuperscript{1}, Kim L. Page\textsuperscript{2}, Julian P. Osborne\textsuperscript{2}, Andy P. Beardmore\textsuperscript{2}, Jeremy J. Drake\textsuperscript{3}

\textsuperscript{1}School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-1404, USA
E-Mail: [Jan-Uwe.Ness,sumner.starrfield]@asu.edu

\textsuperscript{2}Department of Physics & Astronomy, University of Leicester, Leicester, LE1 7RH, UK

\textsuperscript{3}Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

Abstract The recurrent symbiotic nova RS Oph reoccurred after 21 years on 12 February 2006. In contrast to the 1985 outburst, much denser coverage with X-ray observations was achieved. \textit{Swift} observed RS Oph up to several times a day while \textit{Chandra} and \textit{XMM-Newton} observed two to four times during each phase of evolution. While the \textit{Swift} observations provide high resolution in time, the \textit{Chandra} and \textit{XMM-Newton} observations provide high spectral resolution. Refined models can be constrained by the grating spectra, and interpolation of the model parameters can be constrained by the wealth of \textit{Swift} observations. We compared the \textit{Swift} light curve with six X-ray observations taken with \textit{EXOSAT} during the 1985 outburst. We found that the decay from the supersoft X-ray binary (SSS) phase had been observed.

1 Introduction

RS Oph is a Symbiotic Recurrent Nova (RN) that recurs on time scales of \(\sim 20\) years. The explosion occurs in a binary system consisting of a white dwarf (WD) near the Chandrasekhar limit and a red giant companion orbiting with a period of \(455.72 \pm 0.83\) days (see Dobrzycka & Kenyon, 1994; Shore et al., 1996; Fekel et al., 2000). On the surface of the WD a layer of hydrogen-rich material is built up by accretion of material from the red giant. When enough material is accreted, a thermonuclear explosion occurs, and an optically thick shell of ejected material initially blocks all high-energy radiation produced by nuclear burning. The radiative energy output occurs primarily in optical light until the shell clears. During this early phase, all X-ray emission from RS Oph originates from a shock produced by the expanding shell colliding with the pre-existing wind of the red giant (Ness et al., 2006c; Bode et al., 2006; Sokoloski et al., 2006). After the shell has cleared, X-ray emission from the WD dominates the shock emission, and X-ray observations allow a view deep into the outflow (Ness et al., 2006d; Osborne et al., 2007; Ness et al., 2006a). The X-ray spectrum during this phase resembles that of the supersoft X-ray binary sources (SSS: van den Heuvel et al., 1992; Kahabka & van den Heuvel, 1997). After nuclear burning on the WD surface has turned off, residual X-ray emission from the shock and from the ionized surrounding material is observed (Ness et al., 2006b).

*Chandra Fellow at ASU; Any opinions, findings, and conclusions or recommendations expressed in this article are those of the author[s] and do not necessarily reflect the views of SAO or NASA.
2 X-ray Observations

The first X-ray observations of RS Oph were carried out during the 1985 outburst with EXOSAT. In contrast, the 2006 outburst was monitored in X-rays by RXTE and Swift, (Bode et al., 2006; Osborne et al., 2007; Sokoloski et al., 2006), while twelve observations were carried out with Chandra and XMM-Newton, using the high spectral resolution of the grating spectrometers.

X-ray observations with Swift started three days after outburst, and the evolution was followed until day 251 (2006, October 22). A total of 386.5 ksec of exposure were obtained, and in Fig. 1 we show the X-ray Telescope (XRT) light curve as presented by Osborne et al. (2007). Until day $\sim 30$ an emission level between 10 and 30 counts per second was detected with a hard spectrum from the shock (Bode et al., 2006). The ascent into the SSS phase occurred very rapidly with an increase in count rate by an order of magnitude, followed by strong variations in brightness (Osborne et al., 2006). The decay occurred after day 55, and in Fig. 1 we compare the Swift light curve with observations of the 1985 outburst carried out with the Low Energy (LE; 0.05-2 keV) Imaging Telescopes aboard EXOSAT (black triangles; Mason et al., 1987). We rescaled the EXOSAT count rates with the constant factor given in the legend. With this factor the rescaled count rate and the XRT count rate are the same on day 55.

Figure 1: Light curve of the 2006 outburst taken with Swift XRT (grey; Osborne et al., 2007), compared to EXOSAT (LE) count rates measured during the 1985 outburst (black; Mason et al., 1987) and Chandra/XMM-Newton grating fluxes (blue; Table 1). The count rates and fluxes were rescaled with a constant factor (given in the legend) to reproduce the XRT count rate on day 55.
In Table 1 we summarize all grating observations of RS Oph taken in 2006 with observation date, day after outburst, instrumental setup, observation ID, and net exposure time. We extracted effective areas for each spectral bin from the calibration of Chandra and XMM-Newton using the respective analysis software packages CIAO and SAS. Since the grating spectrometers have very little photon redistribution, the values of measured count rates in each spectral bin can be converted to photon fluxes by division by the effective areas. Energy fluxes are then obtained using the wavelength of the corresponding grid points. This approach is more accurate than defining a model over which to integrate the fluxes. In the last column of Table 1 we list the measured fluxes integrated over the wavelength range 7–38 Å (0.33–1.8 keV). We include these values in Fig. 1, rescaled in the same way as the EXOSAT count rates.

Table 1: Grating observations of RS Oph in 2006

| Date (start–stop) | day[a] | Mission | Grating/detector | ObsID | net time (ksec) | flux[b] |
|-------------------|--------|---------|------------------|-------|----------------|---------|
| Feb. 26, 15:20–18:46 | 13.8 | Chandra | HETG/ACIS | 7280 | 9.9 | 9.0 ± 0.20 |
| Feb. 26, 17:09–23:48 | 13.9 | XMM | RGS | 0410180101 | 23.8 | 9.1 ± 0.05 |
| Mar. 10/11, 23:04–02:21 | 26.1 | XMM | RGS | 0410180201 | 11.7 | 8.8 ± 0.05 |
| Mar. 24, 12:25–15:38 | 39.7 | Chandra | LETG/HRC | 7296 | 10.0 | 138 ± 0.25 |
| Apr. 07/08, 21:05–02:20 | 54.0 | XMM | RGS1/2 | 0410180301 | 9.8/18.6 | 414 ± 0.21 |
| Apr. 20, 17:24–20:28 | 66.9 | Chandra | LETG/HRC | 7297 | 6.5 | 321 ± 0.48 |
| June 04, 12:06–18:08 | 111.7 | Chandra | LETG | 7298 | 19.9 | 0.62 ± 0.008 |
| Sept. 06, 01:59–17:30 | 205.3 | XMM | RGS | 0410180401 | 30.2 | 0.11 ± 0.002 |
| Sept. 04, 10:43–22:26 | 203.6 | Chandra | LETG/HRC | 7390 | 39.6 | 0.085 ± 0.001 |
| Sept. 07, 02:37–14:29 | 206.3 | Chandra | LETG/HRC | 7389 | 39.8 | 0.099 ± 0.001 |
| Sept. 08, 17:58–23:36 | 207.9 | Chandra | LETG/HRC | 7403 | 17.9 | 0.10 ± 0.002 |
| Oct. 09/10, 23:38–13:18 | 239.2 | XMM | RGS | 0410180501 | 48.7 | 0.07 ± 0.001 |

[a] after outburst (2006, Feb. 12.83)  
[b] over 7–38 Å [10⁻¹¹ erg cm⁻² sec⁻¹]

3 Conclusions

The best coverage in X-rays was obtained with Swift, providing data on an almost daily basis. The X-ray spectra obtained with Swift can be used to study the evolution of the temperature and the luminosity. More detailed spectral information can be obtained from the Chandra and XMM-Newton spectra, however, more sophisticated models are required in order to fully explore the grating spectra. For example, the SSS spectra need to be modeled with atmosphere codes like PHOENIX [Petz et al. 2005]. In a later step, the model parameters obtained from the grating spectra can be interpolated, using the Swift spectra as a constraint. In that way the interplay of both missions can achieve a full description of the evolution of the outburst.

The EXOSAT measurements during the 1985 outburst were interpreted as residual
shock emission by O'Brien et al. (1992), however it is now clear that the LE observed the decline of the SSS phase. The comparison between the XRT and the LE count rates reveals that the decay occurred in exactly the same way. The spectrum was also very soft, and the Medium Energy (ME; 1-50 keV) Proportional Counter has measured only upper limits after day 80. O'Brien et al. (1992) suspected that the SSS emission may contaminate the shock emission, however, the XRT and the XMM-Newton and Chandra grating data show that the SSS spectrum is far brighter compared to the shock emission at that stage than had been expected.

Acknowledgments

J.-U.N. gratefully acknowledges support provided by NASA through Chandra Postdoctoral Fellowship grant PF5-60039 awarded by the Chandra X-ray Center, which is operated by SAO for NASA under contract NAS8-03060. Any opinions, findings, and conclusions or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of SAO or NASA. S.S. received partial support from NSF and NASA grants to ASU. K.L.P., J.P.O. acknowledge support by the Particle Physics and Astronomy Research Council.

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