Swift Observations of the 2006 Outburst of the Recurrent Nova RS Ophiuchi

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Central system – high mass WD (1.2-1.4 $M_\odot$?) + Red Giant (M2III); $p = 455$ d

Outbursts due to TNR on WD surface (cf. Classical Novae)

Prior to 1985, spectroscopic evidence for red giant wind, systematic reduction in velocities post-outburst, and emergence of coronal lines, led to suggestion of ejecta ($v_0 \sim 4000$ km s$^{-1}$) interaction with RG wind ($u = 20$ km s$^{-1}$).
1985 Outburst

- Observed for first time in radio (from $t = 18d$) and X-rays (EXOSAT, from $t = 55d$).
- Bright and rapidly evolving source (Mason et al. 1987)

![Graph showing count rate over time](image)
1985 Outburst

- Observed for first time in radio (from $t = 18d$) and X-rays (EXOSAT, from $t = 55d$). Bright and rapidly evolving source (Mason et al. 1987)
- $d = 1.6 \pm 0.3$ kpc, $N_H = 2.4 \pm 0.6 \times 10^{21}$ cm$^{-2}$
- $M_{ej} = 1.1 \times 10^{-6}$ M$_\odot$, $\dot{M}_{W} = 2 \times 10^{-7}$ M$_\odot$ yr$^{-1}$
- $E = 1.1 \times 10^{43}$ erg
Phases of Remnant Evolution

- **Phase I:** Ejecta still important in supplying energy to shocked wind (+ reverse shock into ejecta)
- **Phase II:** Blast wave driven into wind ($\rho \propto r^{-2}$), not well cooled and effectively adiabatic (*Primakoff Solution*):
  \[ r_s \propto t^{2/3} ; \; v_s \propto t^{-1/3} \]
- **Phase III:** Forward shock well-cooled and momentum-conserving (*“Snow Plough”*):
  \[ r_s \propto t^{1/2} ; \; v_s \propto t^{-1/2} \]
  (also, for strong shocks, $T_s \propto v_s^2$)

- Bode & Kahn (1985) concluded that in the 1985 outburst, Phase I finished by $t = 6d$ and remnant in transition Phase II-Phase III at $t = 55d$ (first EXOSAT observation)
2006 Outburst

- Discovered Feb 12.83 UT ($t = 0$)
- Very similar optical behaviour to previous outbursts

Within 2 days, ToO’s granted on Swift, XMM, Chandra, RXTE, MERLIN, VLA, VLBA, EVN, LT, UKIRT, plus GMRT, Ryle, Spitzer a few days later, + HST next week
**Swift** XRT Observations: First 26 days

day
3.17
5.03
8.18
10.99
13.60
15.61
18.17
25.99
Detection with BAT at Outburst

- 14–25 keV
- 25–50 keV

Time in days relative to $t_0 = 2006$ Feb 12.83
UVOT Grism Spectra

First time U-grism deployed “in anger”

Simultaneous with XRT

Still undergoing calibration

Much slower evolution
Comparison with Models

Spectra fitted with single temperature *mekal* model. $v_s$ from $kT$; interstellar $N_H$ fixed and overlying wind $N_H$ free param. (expect $[N_H]_W \propto r_s^{-1}$ at these times - Bode et al. 2006, ApJ in press)

Appears to settle into stable pattern after $\sim$6 days (cf. end Phase I) but rapidly evolves to what looks more like Phase III behaviour.
First VLBA image – Day 13.8

Res’n ~ 3 mas

Peak $T_b$ $5 \times 10^7$K

Significant contribution from non-thermal synchrotron emission i.e. particles accelerated in shock wave.
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(O’Brien et al., 2006, Nature, in press)
Day 29: Emergence of a New Component!

The brightest Super-Soft Source Observed To-date
ROSAT Observations of V1974 Cyg

- Most extensive previous observations of nova SSS
- Unveiling of ongoing nuclear burning ($L \sim L_{\text{Edd}}$)
- Turn-off at $t \geq 511$ days (highly dependent on $M_{\text{WD}}$)
- Decline due to shrinkage back of extended atmosphere onto WD once nuclear burning ceases

(Krautter et al. 1996, Balman et al. 1998)
SSS Phase in RS Ophiuchi

- Starts at $t \approx 26$ days
- Initially highly variable
- “Plateau” phase, $t = 45 \sim 58$ days
- Linear decline to $t \sim 90$ days when SSS phase ends
- Very much compressed version of V1974 Cyg 
  (and other CN) evolution?

Osborne et al. (2006) in prep
Short Period Oscillation and Derived Parameters

- Duration of modulation and short period consistent with $\varepsilon$ (nuclear burning) instability on WD?
- $M_{WD} \sim 1.4 \, M_\odot$ from duration of SSS phase and $P$
- Mass burnt $\sim$ few % of $M_{\text{acc}}$
- $L_{\text{acc}} \sim 10^{36} \, \text{ergs s}^{-1}$ predicted between outbursts

$P \sim 36\,\text{s}$ modulation apparent during SSS phase prior to linear decline
Conclusions

- *Swift* (and other) observations are consistent with the basic shock model for $t < 1$ month, and this has potential applications to SNR.
- The radio source evolves to become bipolar – either the explosion is jet-like or is confined by an equatorially-enhanced red giant wind.
- The emergence of the SSS phase gives us a unique insight into nuclear burning on the WD.
- No conclusive evidence as yet of shock break out from the RG wind.
- The UVOT data will provide a unique dataset of UV-optical spectroscopy throughout the outburst.
- *Swift* will continue to monitor the source to investigate the late phases of remnant evolution and the re-establishment of both accretion and the RG wind.