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

M.F. Bode

Astrophysics Research Institute, Liverpool JMU

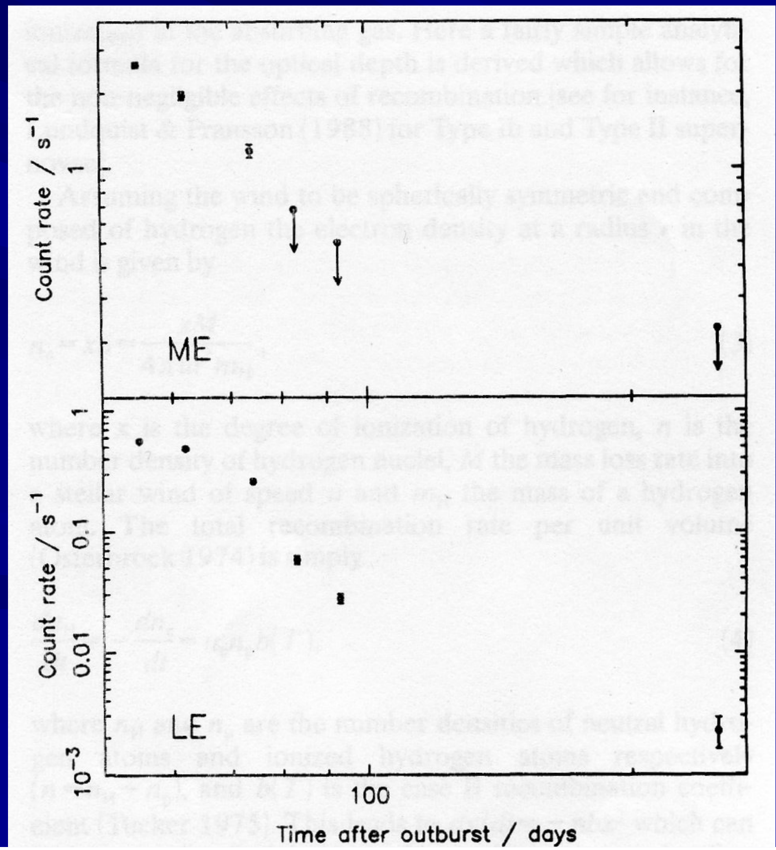
J.L. Osborne, K.L. Page, A.P. Beardmore, M. R. Goad (Leicester), T.J. O'Brien (Jodrell), F. Senziani G.K. Skinner (Toulouse), S. Starrfield, J-U. Ness (ASU), J.J. Drake (CFA), N. Gehrels (GSFC), G. Schwarz (West Chester), J. Krautter (Heidelberg) A.Evans (Keele), S.P.S. Eyres (Central Lancashire), M.J. Darnley (LJMU), P.Jean (CESR), G. Novara (INAF)

Vital Statistics

- Recurrent Nova – previous outbursts 1898, (1907), 1933, 1958, 1967, 1985
- 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)



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}
- Shock models by Bode & Kahn (1985), O'Brien, Bode & Kahn (1992)
- $M_{ej} = 1.1 \times 10^{-6}$ $M_\odot$, $\dot{M}_W = 2 \times 10^{-7}$ $M_\odot$ 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")*:

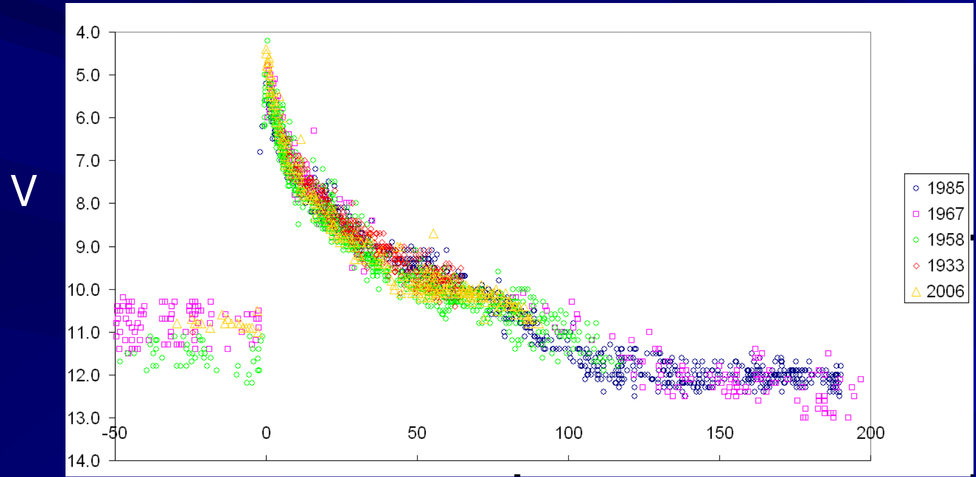
$$r_s \propto t^{1/2} \; ; \; v_s \propto t^{-1/2}$$

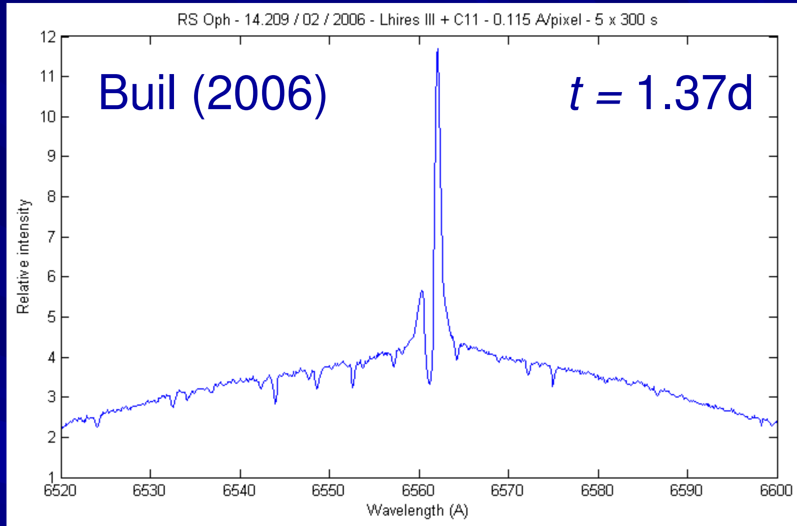
(also, for strong shocks, $T_s \propto v_s^2$)

- 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

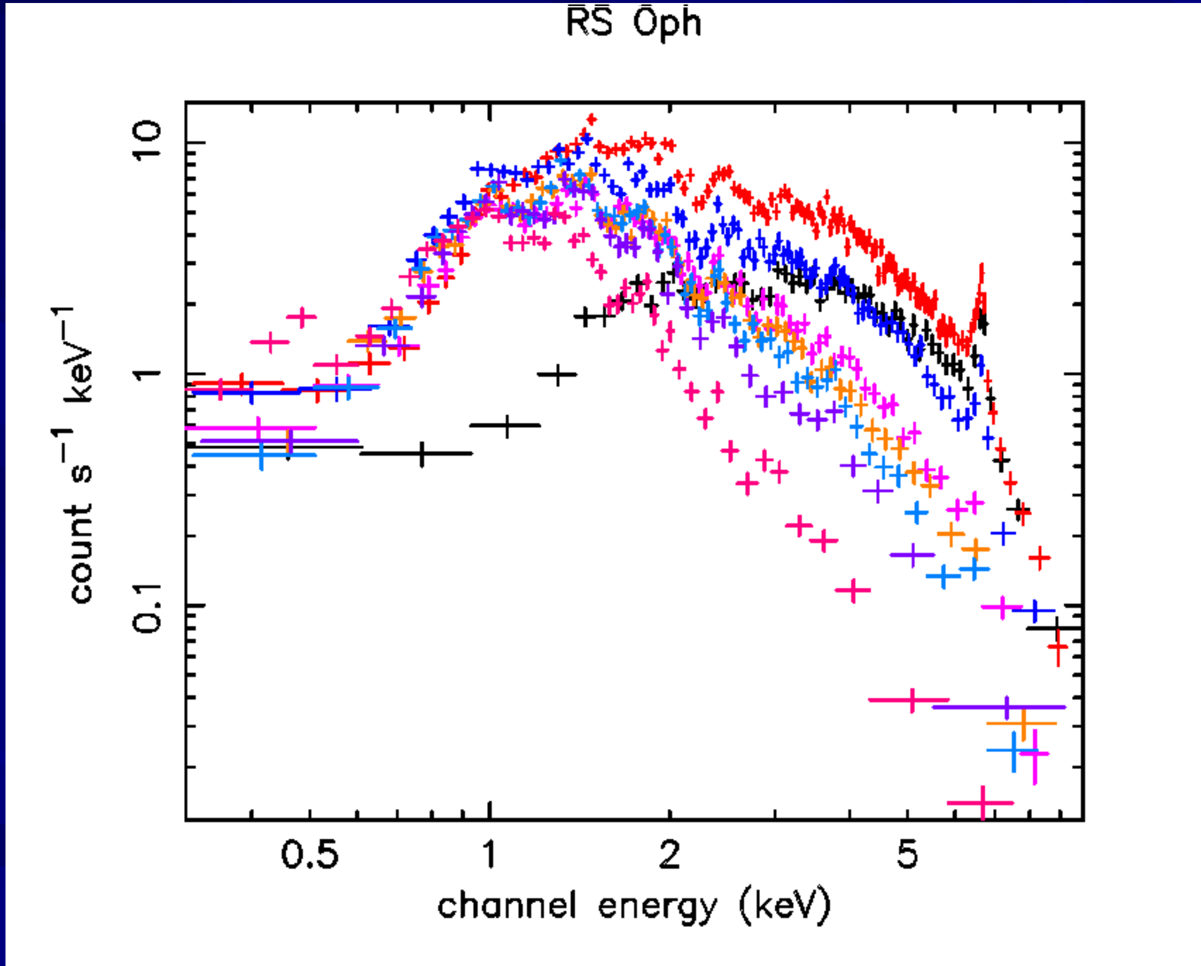




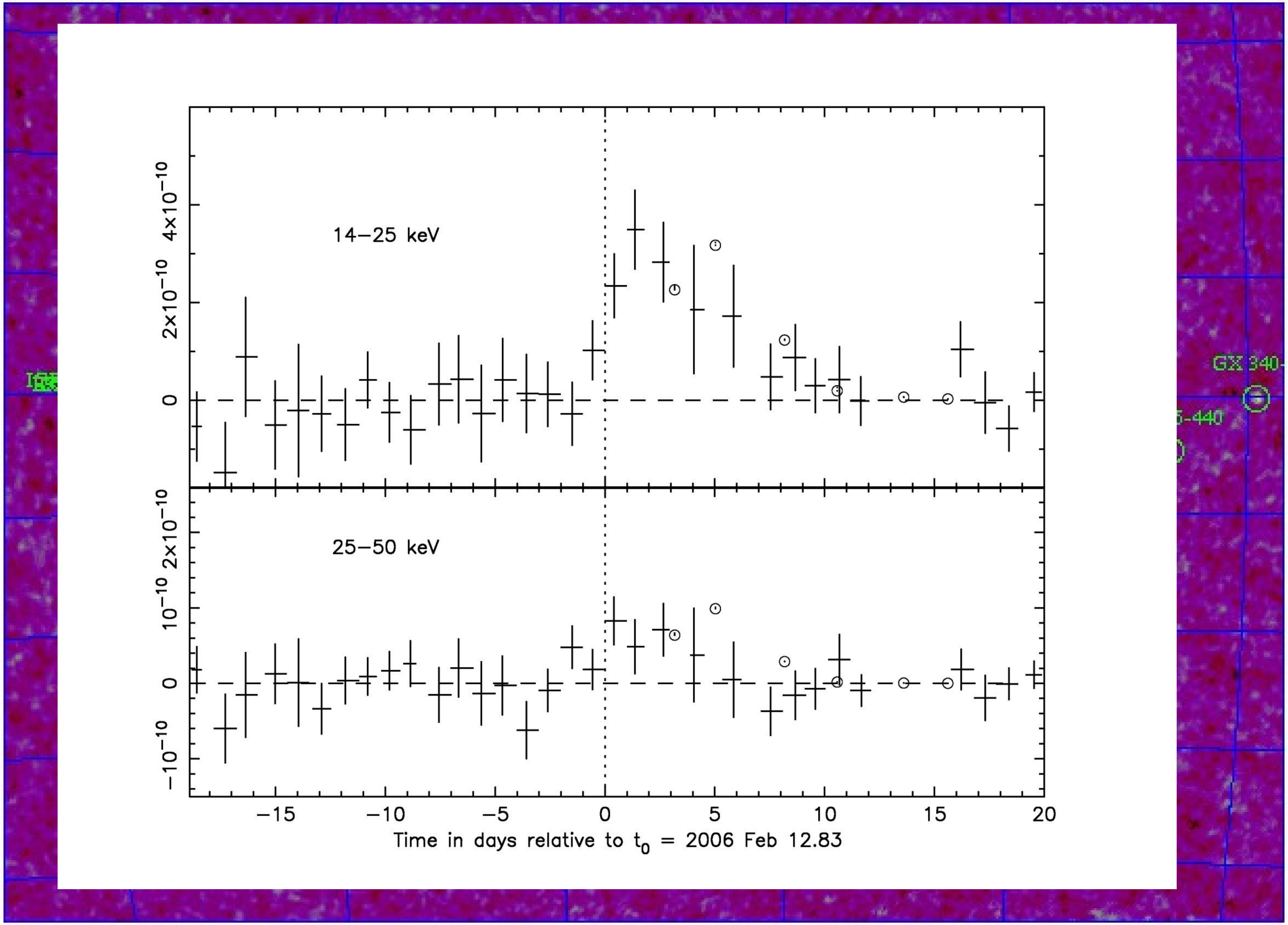
- Within 2 days, ToO's granted on *Swift, XMM, Chandra, RXTE, MERLIN, VLA, VLBA, EVN, LT, UKIRT*, plus *GMRT, Ryle, Spitzer* a few days later, + HST next week

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



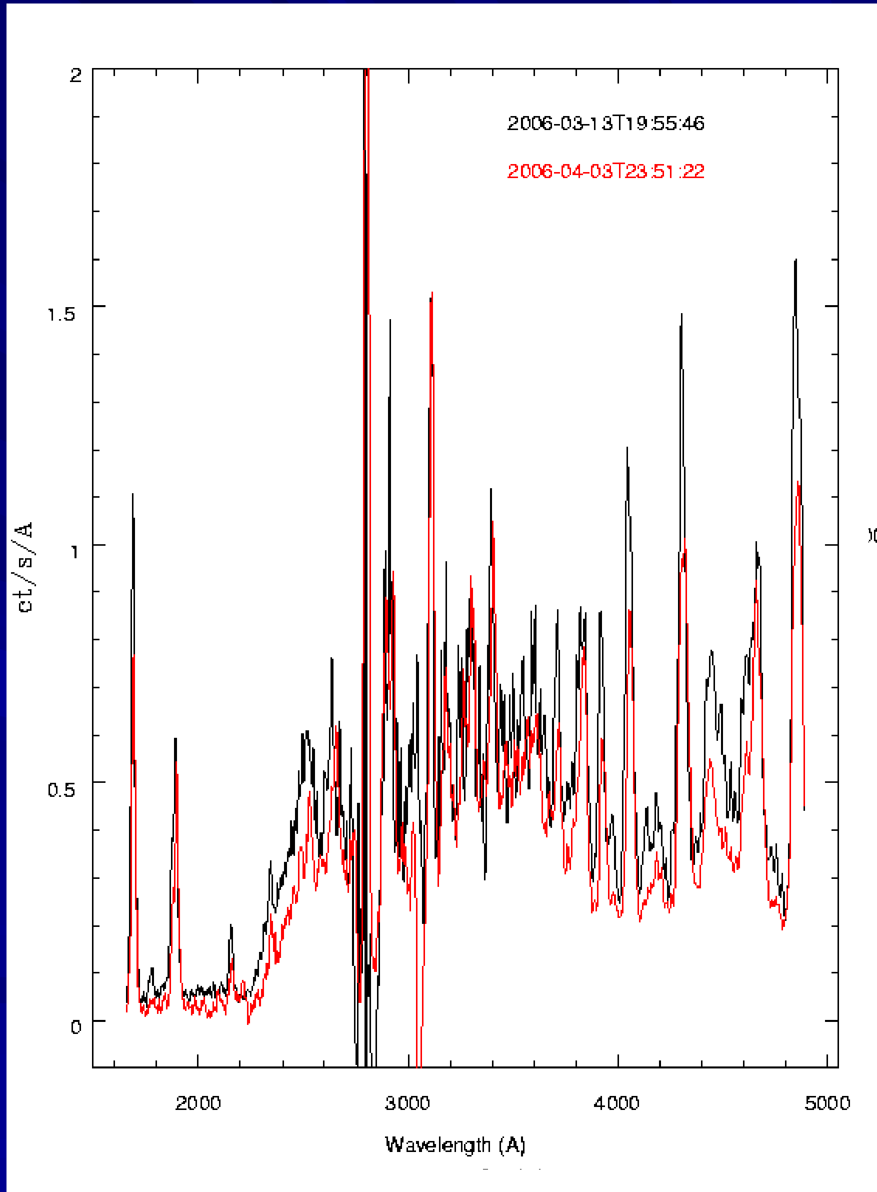
UVOT Grism Spectra

First time U-grism deployed “in anger”

Simultaneous with XRT

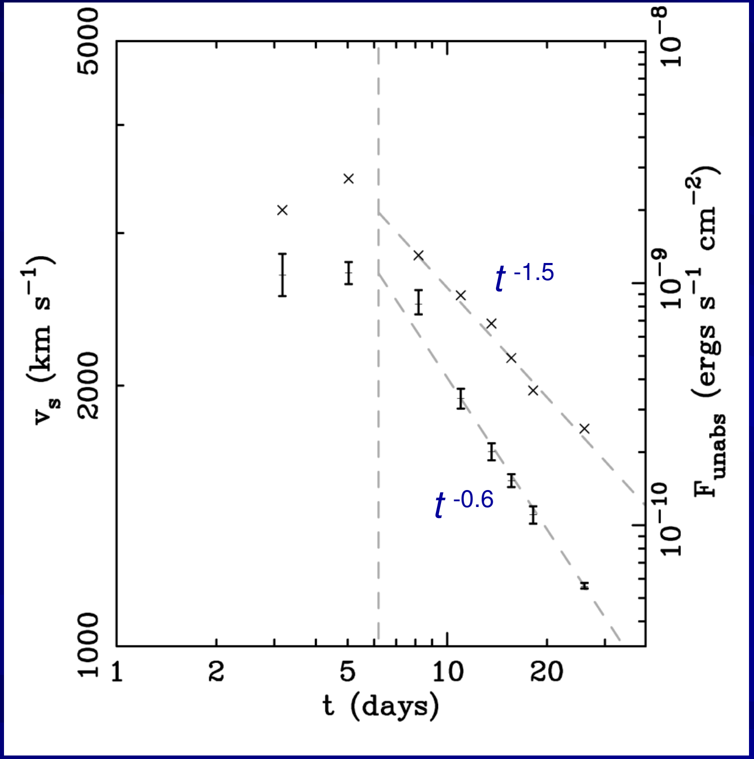
Still undergoing calibration

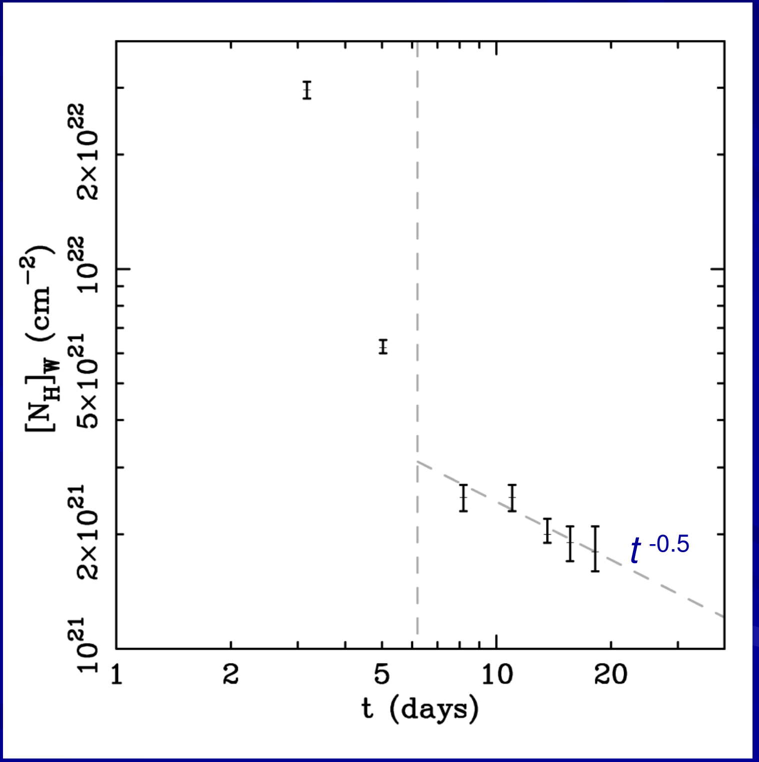
Much slower evolution



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)





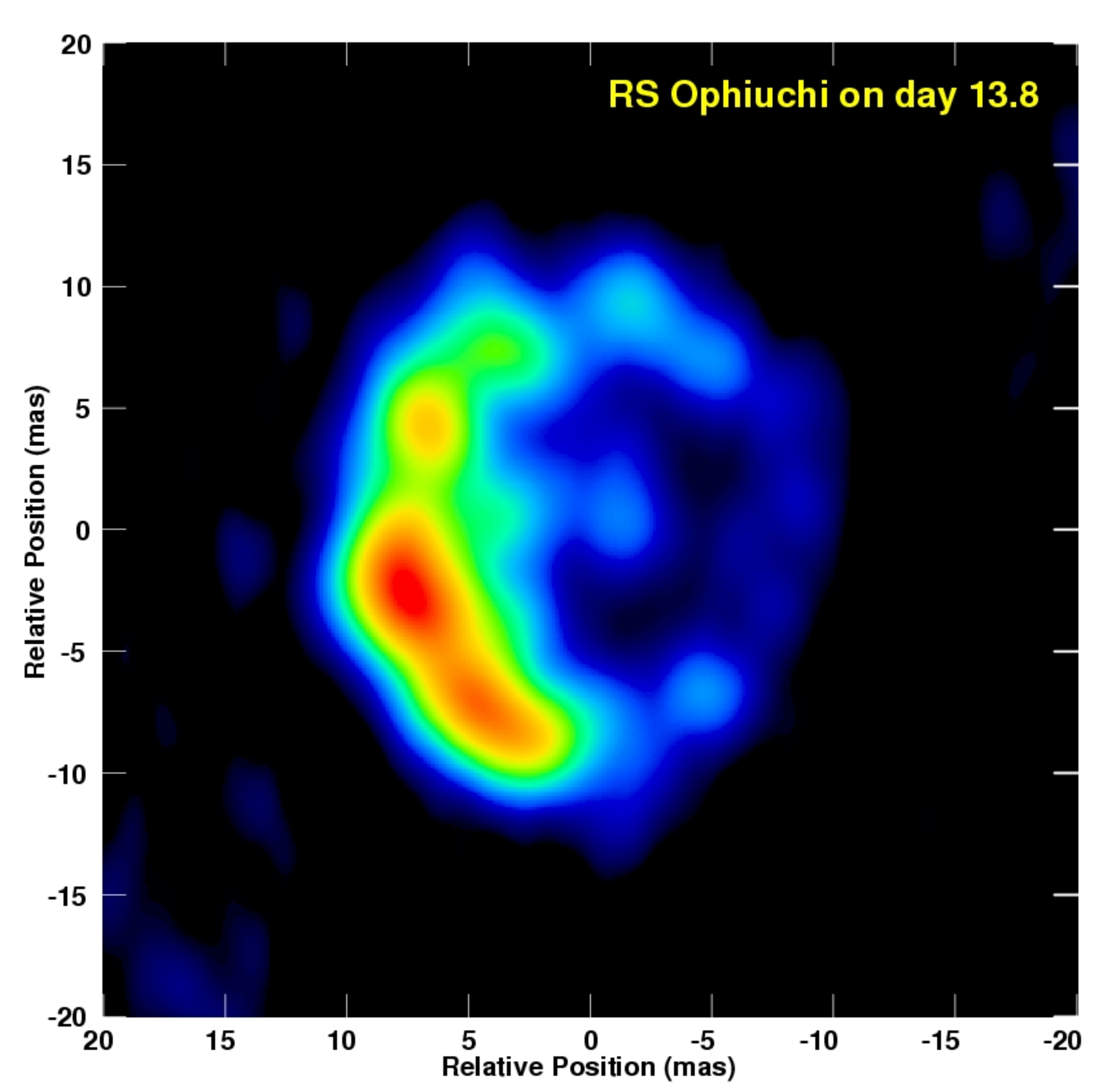
Appears to settle into stable pattern after ~6 days (cf. end Phase I) but rapidly evolves to what looks more like Phase III behaviour.

First VLBA image – Day 13.8

Res'n ~ 3 mas

Peak T_b $5x10^7$K

Significant contribution from non-thermal synchrotron emission i.e. particles accelerated in shock wave.



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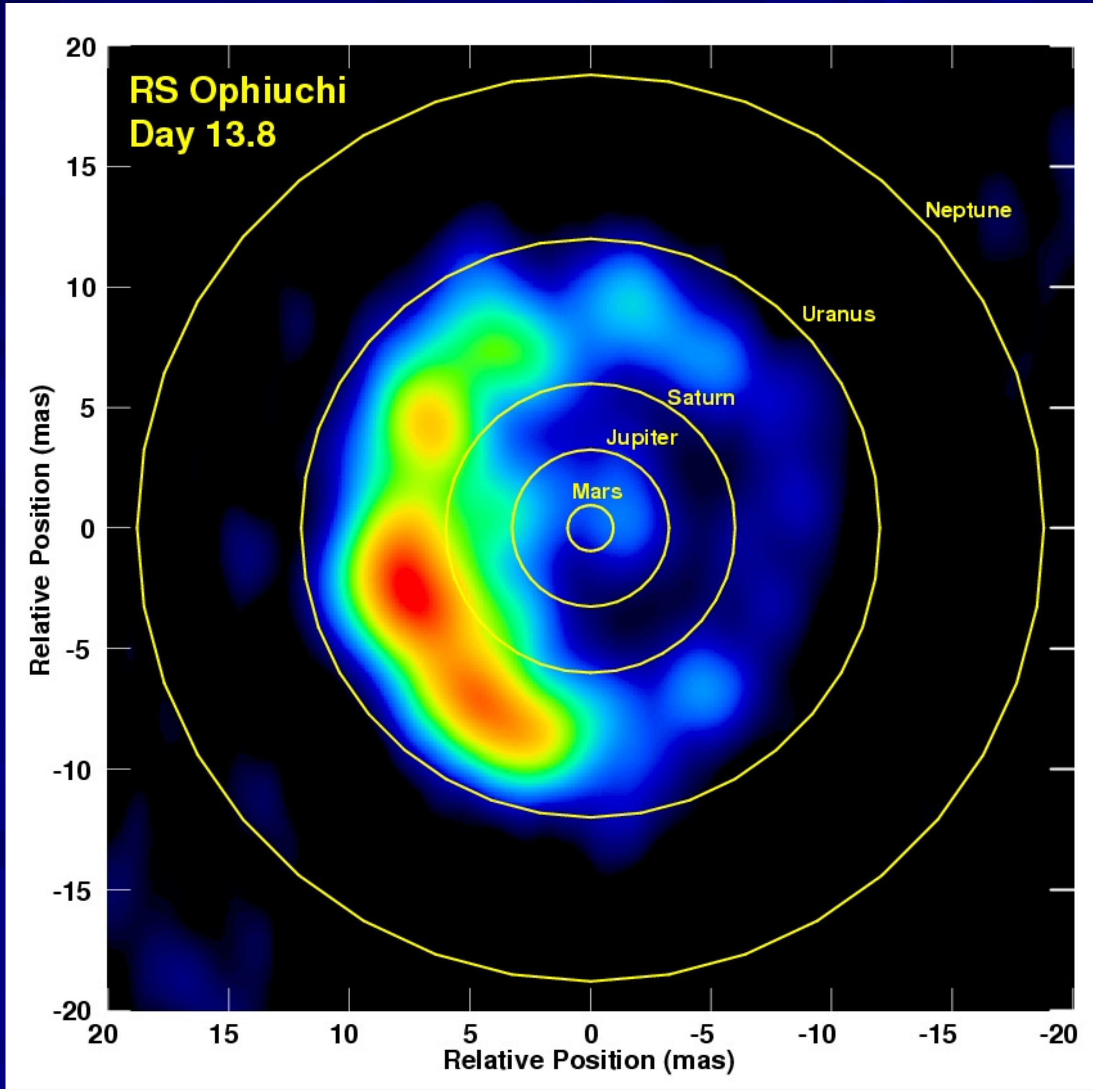
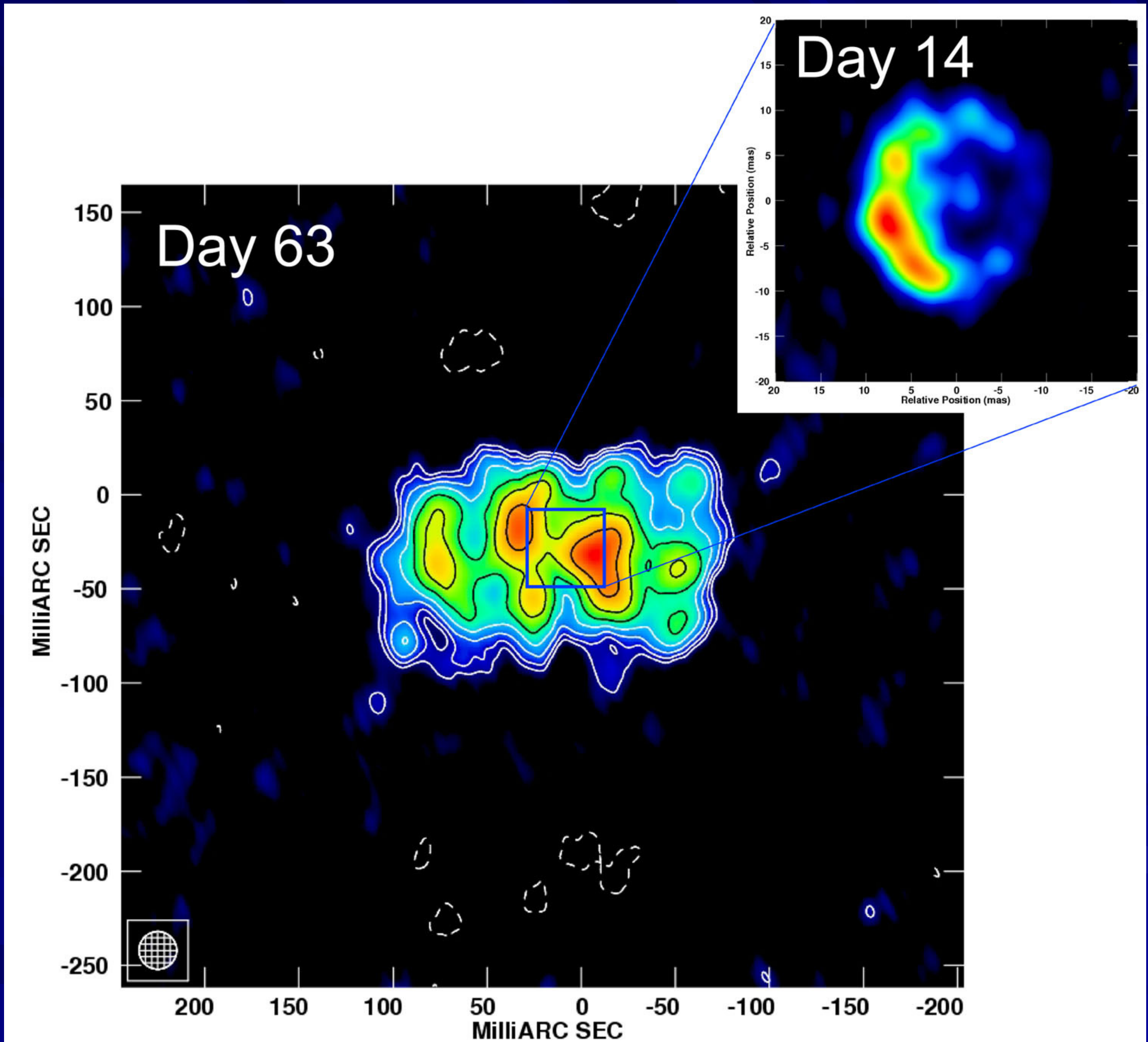
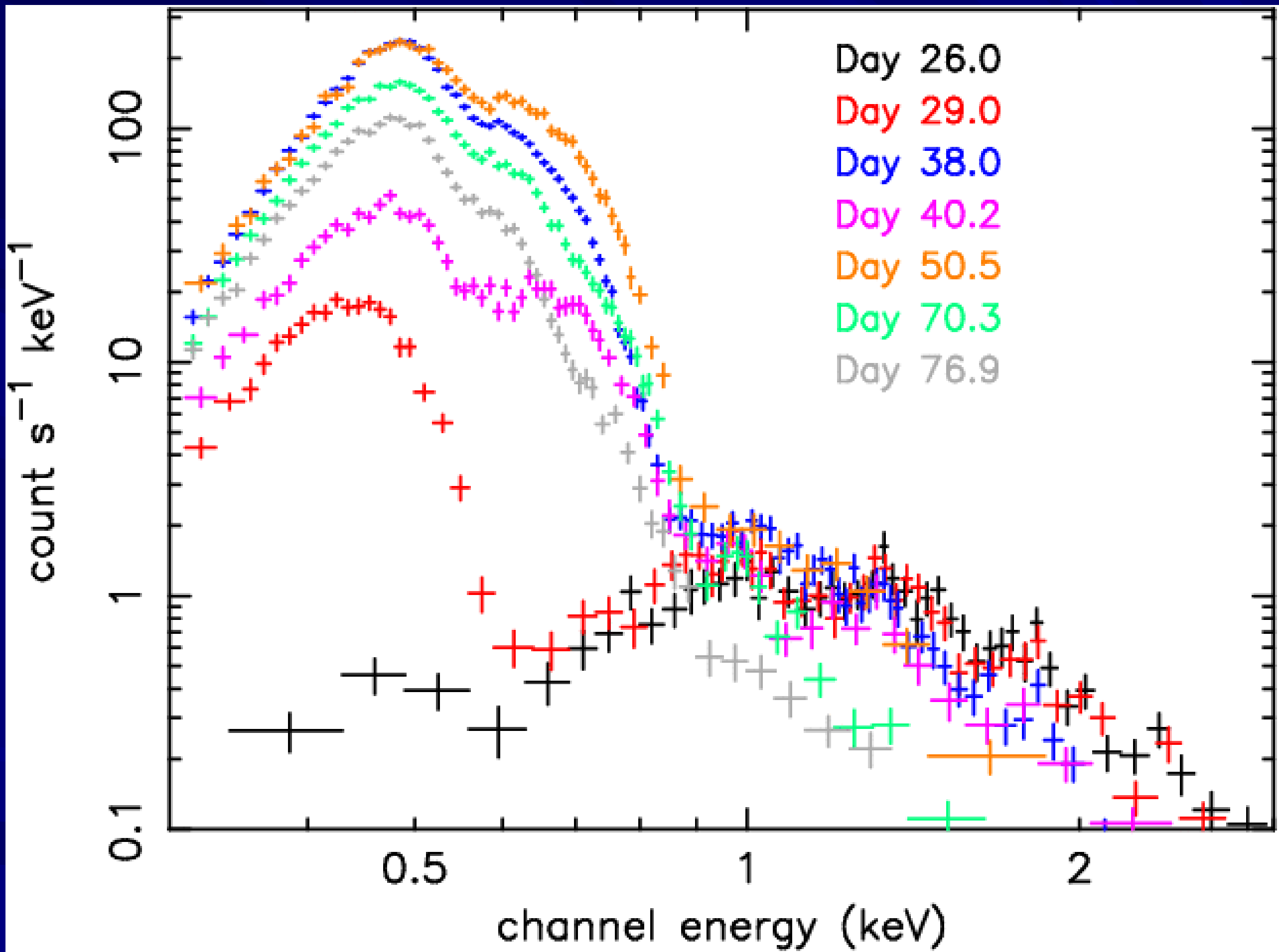




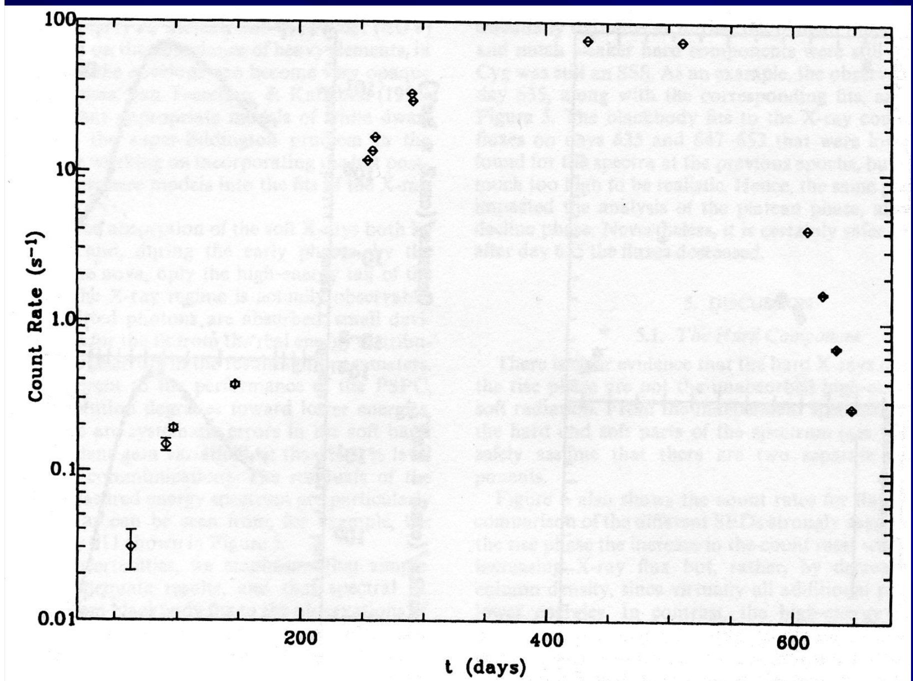
(O'Brien et al., 2006, Nature, in press)

Day 29: Emergence of a New Component!



The brightest Super-Soft Source Observed To-date

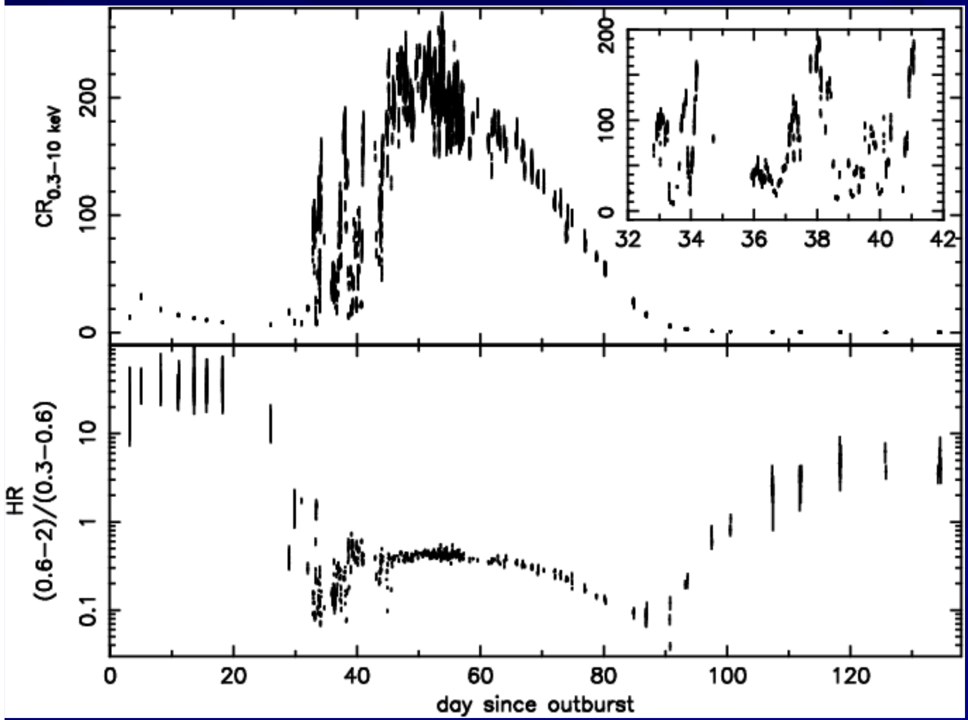
ROSAT Observations of V1974 Cyg



(Krautter et al. 1996, Balman et al. 1998)

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

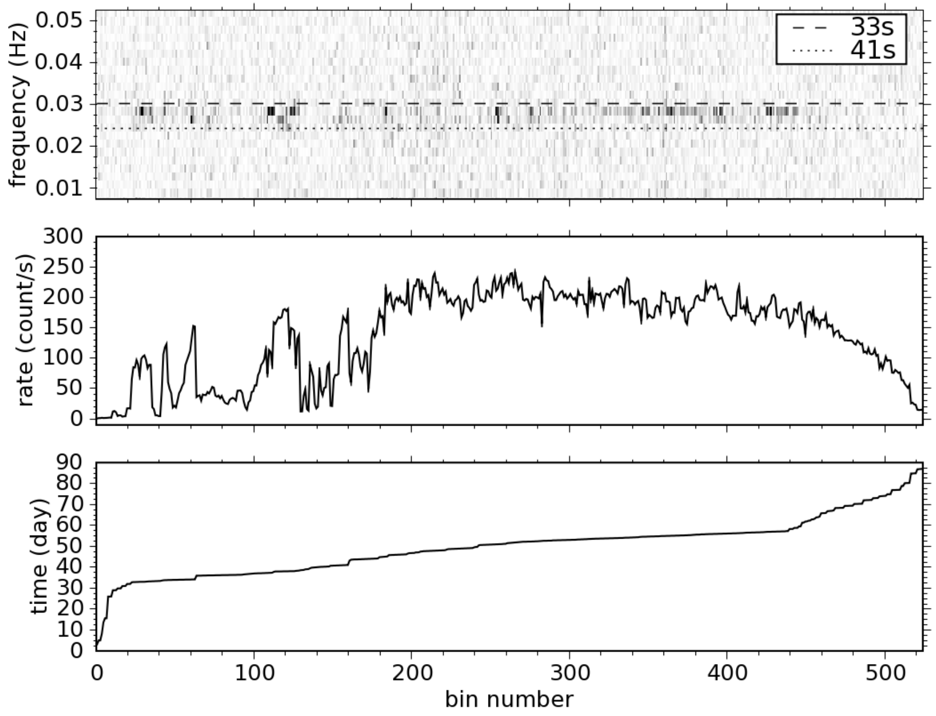
SSS Phase in RS Ophiuchi



Osborne et al. (2006) in prep

- Starts at *t* ~ 26 days
- Initially highly variable
- "Plateau" phase, *t* = 45 – 58 days
- Linear decline to *t* ~ 90 days when SSS phase ends
- Very much compressed version of V1974 Cyg (and other CN) evolution?

Short Period Oscillation and Derived Parameters



P ~36s modulation apparent during SSS phase prior to linear decline

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

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.