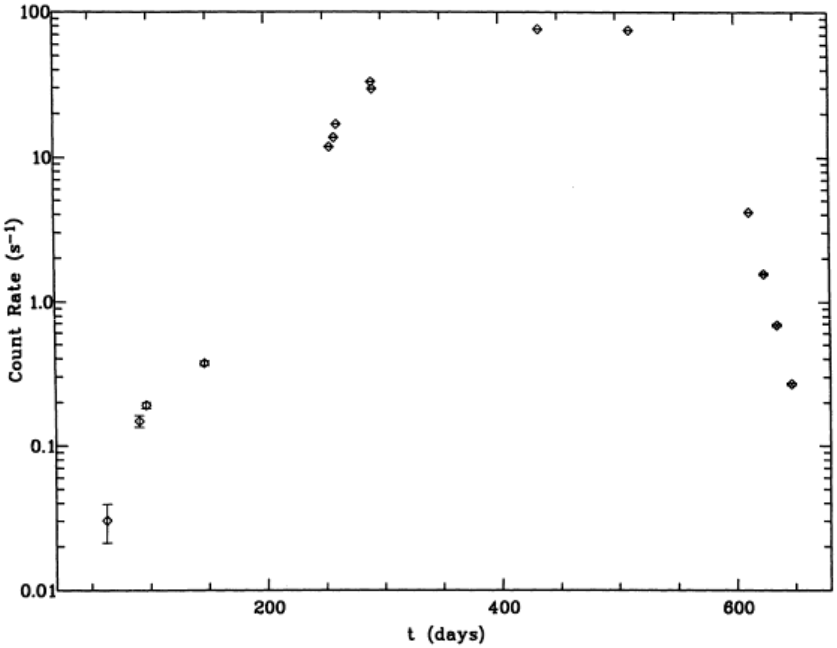
Previous best nova in X-rays



Krautter et al 1996

Nova Cyg 1992
(V1974 Cyg)

- Rosat PSPC
- 18 observations
- Super-soft Source lasts ~400 days

- Duration of SSS phase generally unknown – important constraint on WD mass ($t \sim M^{-6.3}$)

X-rays from novae

Potential sources of X-ray emission from classical/recurrent novae:

- Thermal emission from hot white dwarf
  - shock breakout
  - residual nuclear burning after ejecta dispersal
- High velocity shocks
  - internal shocks within the ejecta
  - shock of ejecta with shell from previous nova or planetary nebula
  - shock of later fast wind with earlier slower wind
- Re-established accretion
- Compton degraded e^- - e^+ annihilation (hard X-rays only)
  - not yet seen

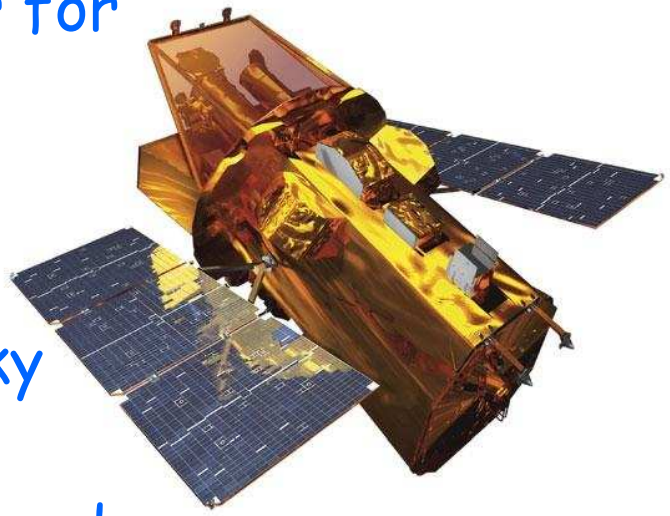
X-rays from novae

Potential sources of X-ray emission from classical/recurrent novae:

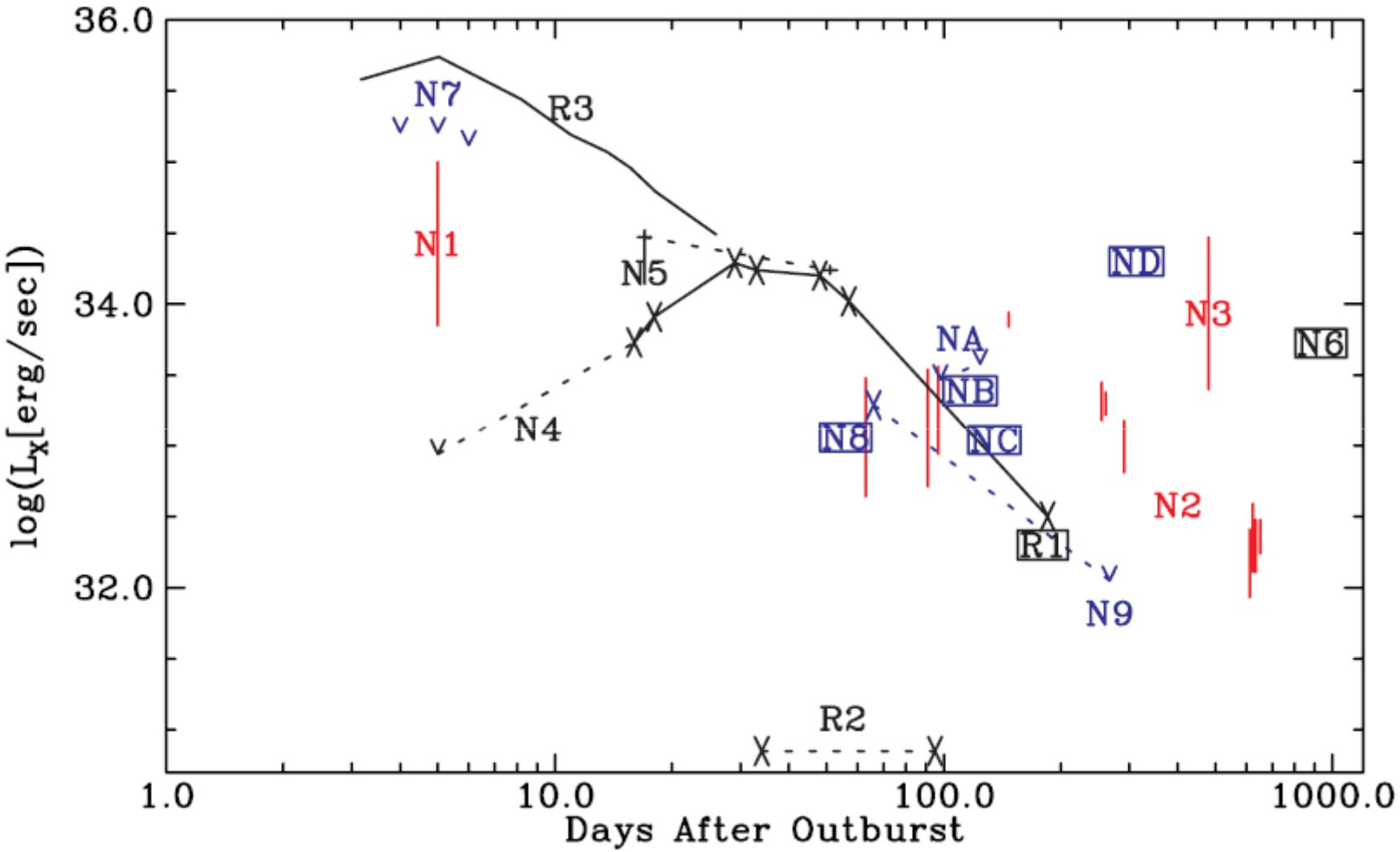
- Thermal emission from hot white dwarf
  - shock breakout
  - residual nuclear burning after ejecta dispersal — Swift
- High velocity shocks — Swift
  - internal shocks within the ejecta
  - shock of ejecta with shell from previous nova or planetary nebula
  - shock of later fast wind with earlier slower wind
- Re-established accretion — Swift
- Compton degraded gamma-ray emission from ^{22}Na
  - not yet seen

What is Swift?

- US/UK/Italian NASA small explorer for GRBs
- Low earth orbit
- Launched Nov 2004
- Large area, large FOV hard X-ray Sky survey: BAT
- 120 cm^2 X-Ray Telescope with auto-mode-switching CCD
- 30 cm UV-Optical Telescope, photon-counting, with filters & grisms; co-aligned with XRT
- Very rapid slewing, flexible daily scheduling; TOO; GI; fill-in programs



Pre/early Swift novae

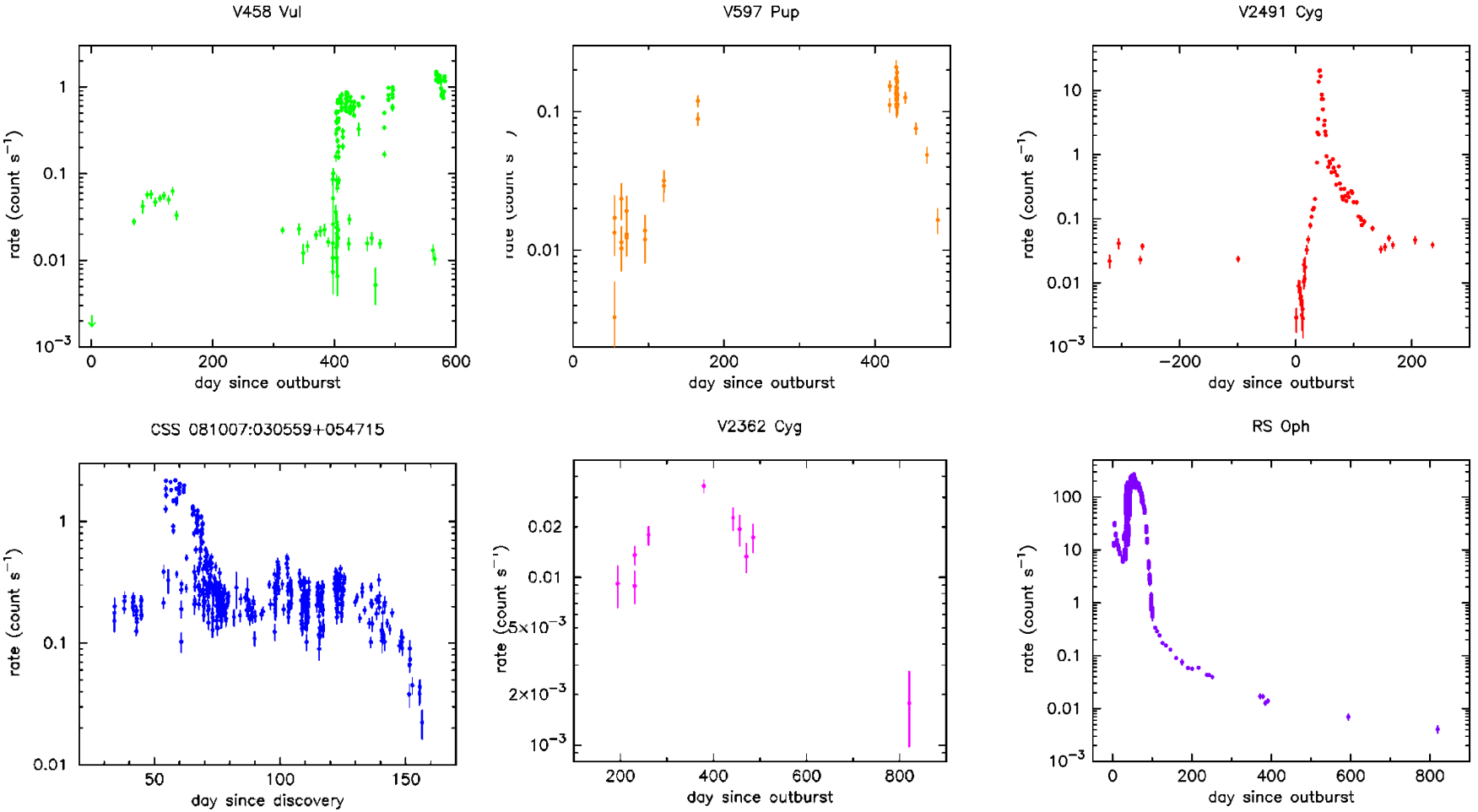


- Hard X-ray emission
- Sporadic coverage, mostly pre-Swift

Mukai, Orio & Della Valle ApJ (2008)

See also Ness et al ApJ (2007)

Nova X-ray light-curves

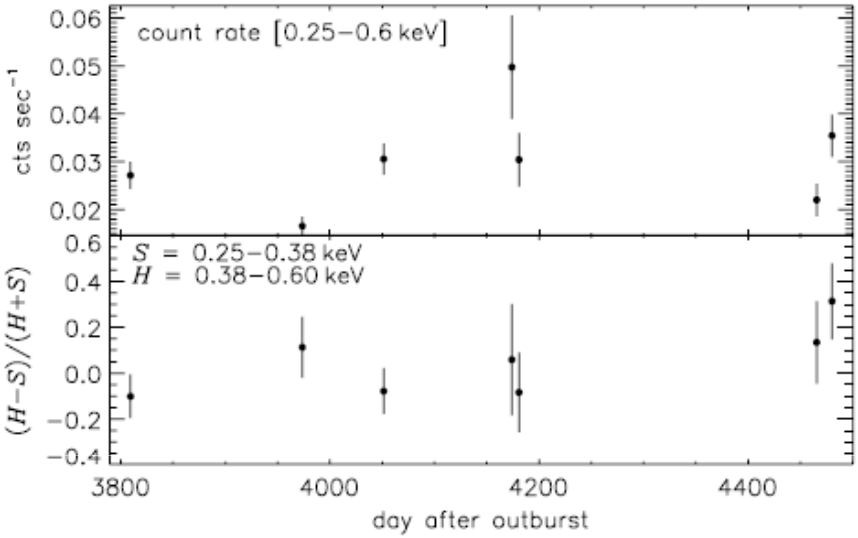


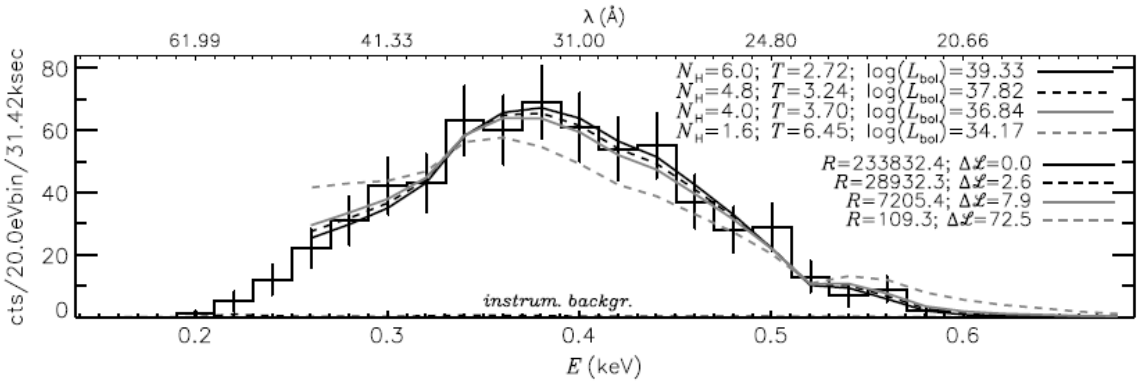
Swift novae stats

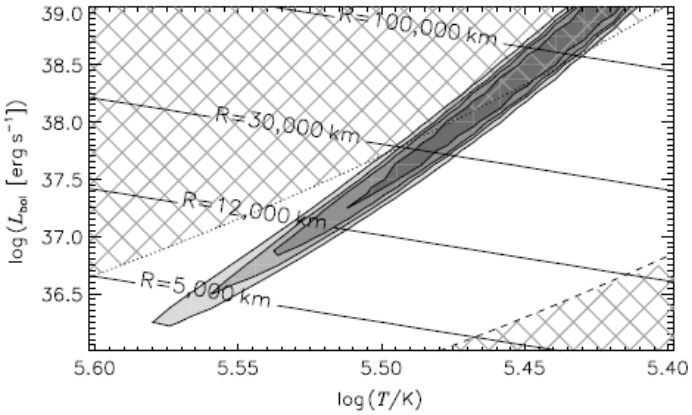
- Swift has observed 35 novae with 4000 days of outburst
- 19 detected in X-rays
- 1.5 Msec expended
- 11 ksec median exposure
- 4 novae have >100 ksec each: CSS 081007, V2491 Cyg, V458 Vul & RS Oph
- Observations start within 1 day (pre-nova for V2491 Cyg)

V723 Cas (N Cas 1995)

- Super-soft source still visible after 12 years
- Longest known activity
- Does not fit Greiner et al (2003) suggestion that short period systems have longer SSS phases
- Accretion playing a role?



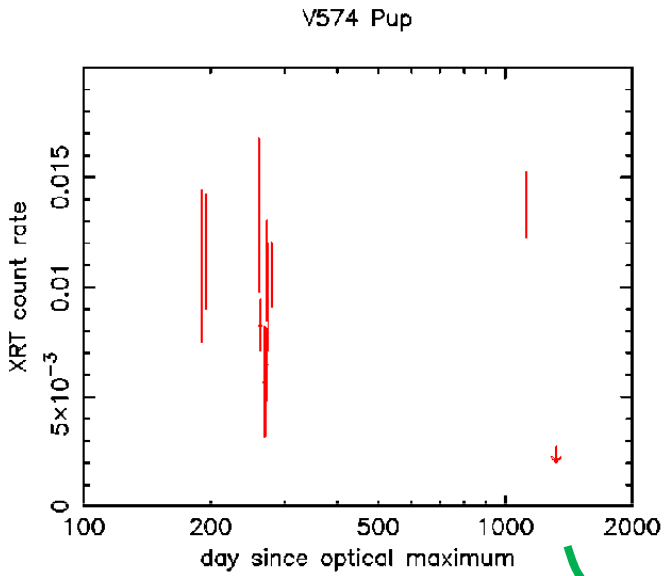


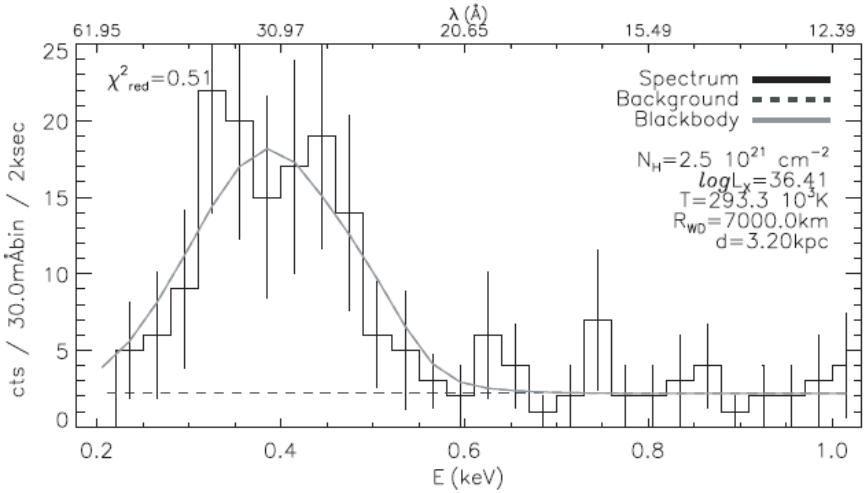


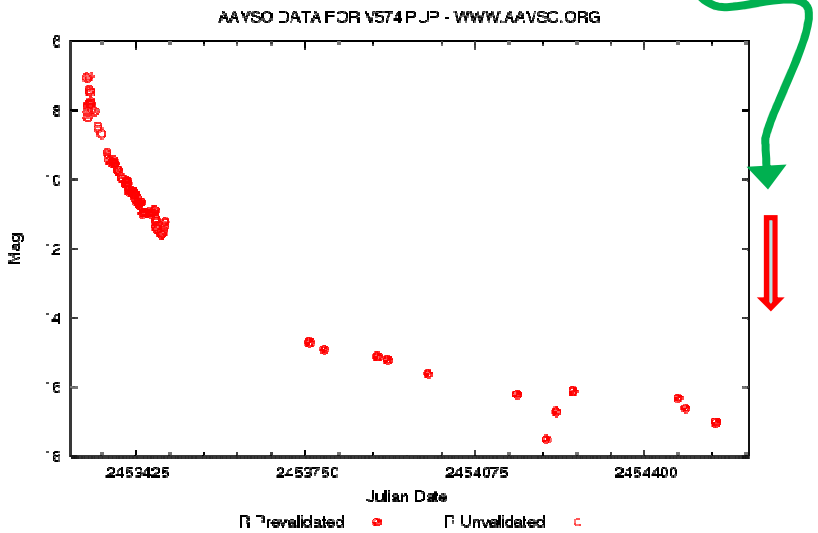
Ness et al AJ (2008)

V574 Pup (N Pup 2004)

- Variable super-soft source visible to ~3.5 years
- log $L_{X,BB}$ ~ 36.4



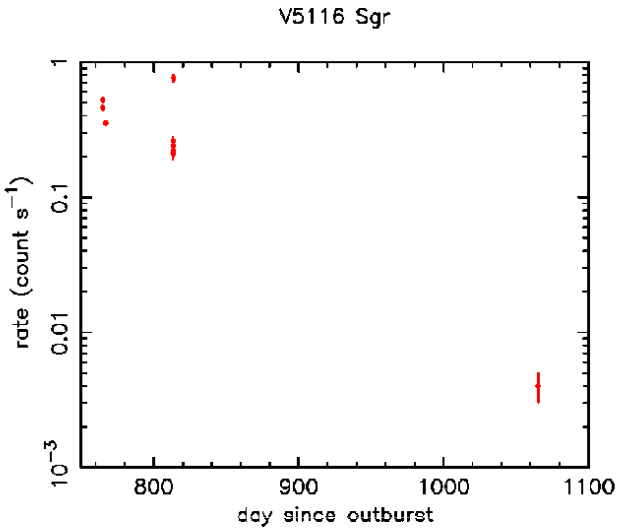


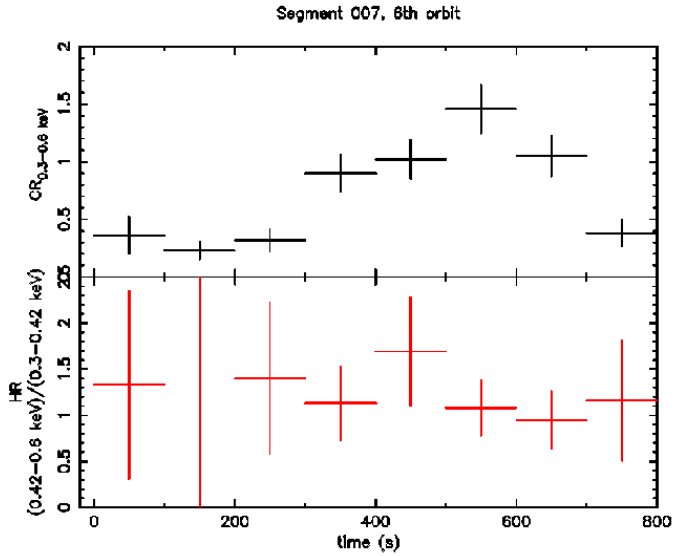


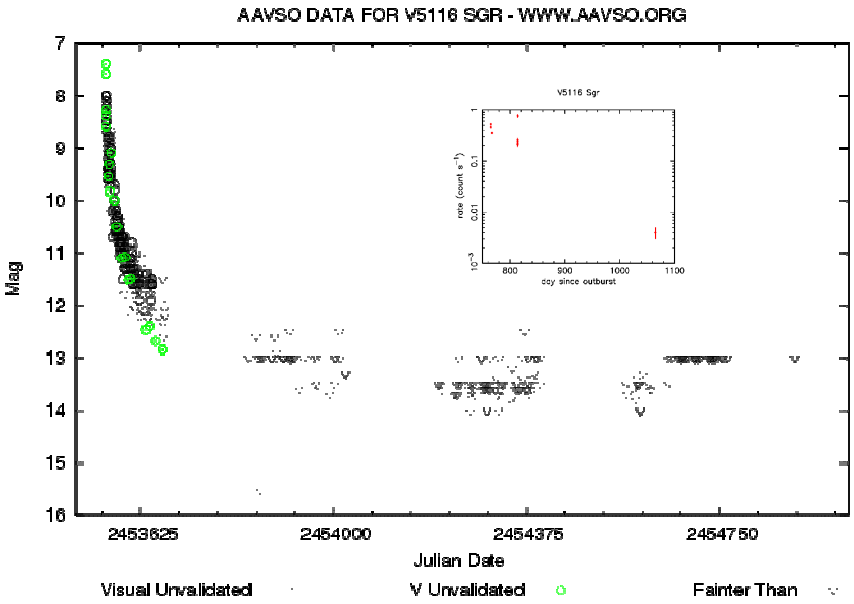
Ness et al AJ (2008)

V5116 Sgr (N Sgr 2005/2)

- Highly variable super-soft source visible to >2.9 years
- Chandra grating (ATEL 1202 Nelson et al) kT=40eV
- XMM: log L ~ 37.6 (ApJ 675, L93, Sala talk)

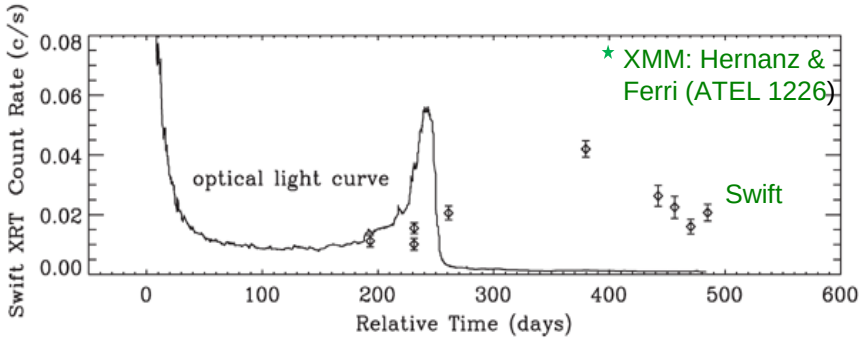




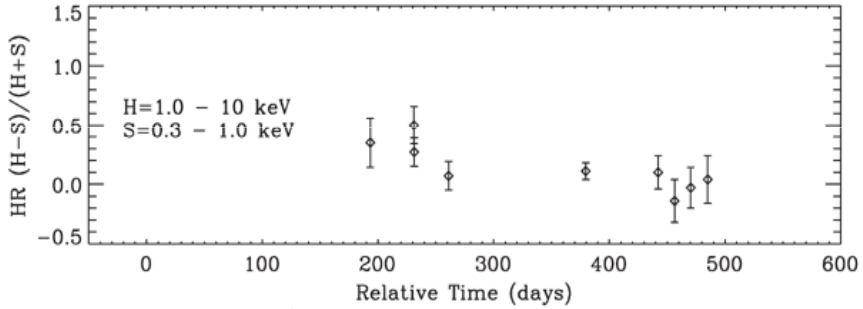


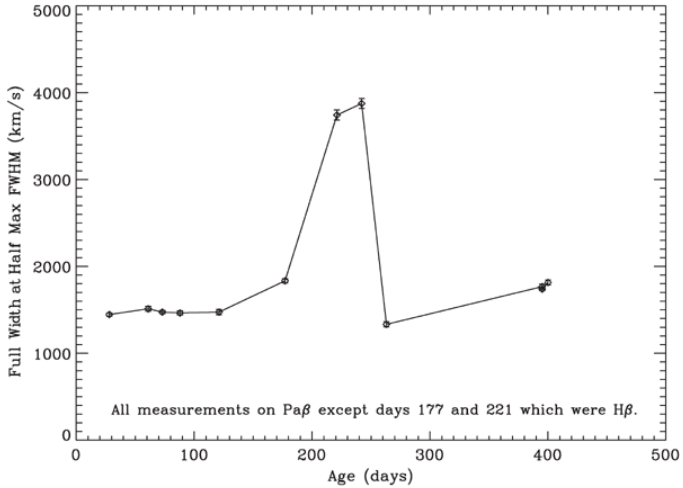
V2362 Cyg (N Cyg 2006)

- Remarkable optical rebrightening ~150 days, opt spec became low ionization & lines widths increased
- Variable soft optically thin 2-temperature X-ray source visible to >1.4 years, unaffected by dust formation at 243 days

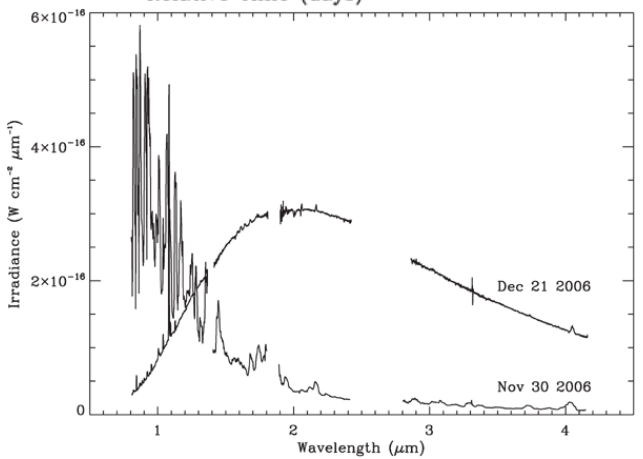


* XMM: Hernanz & Ferri (ATEL 1226)



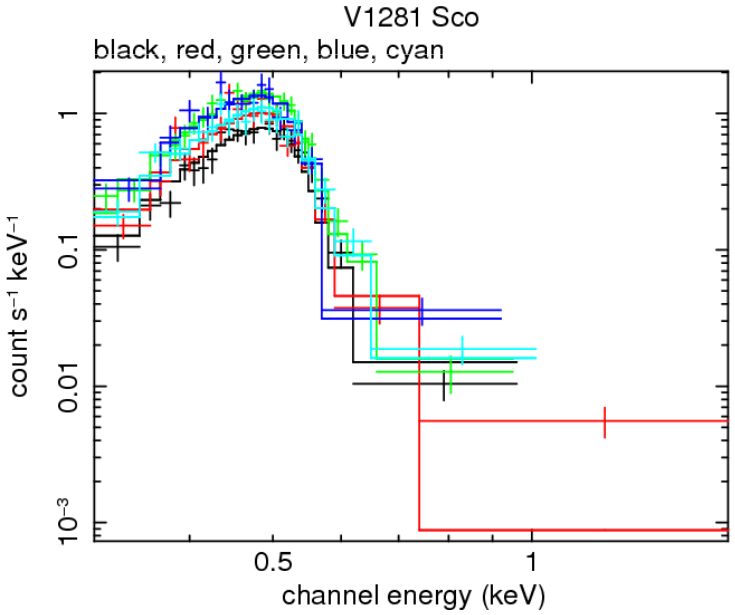


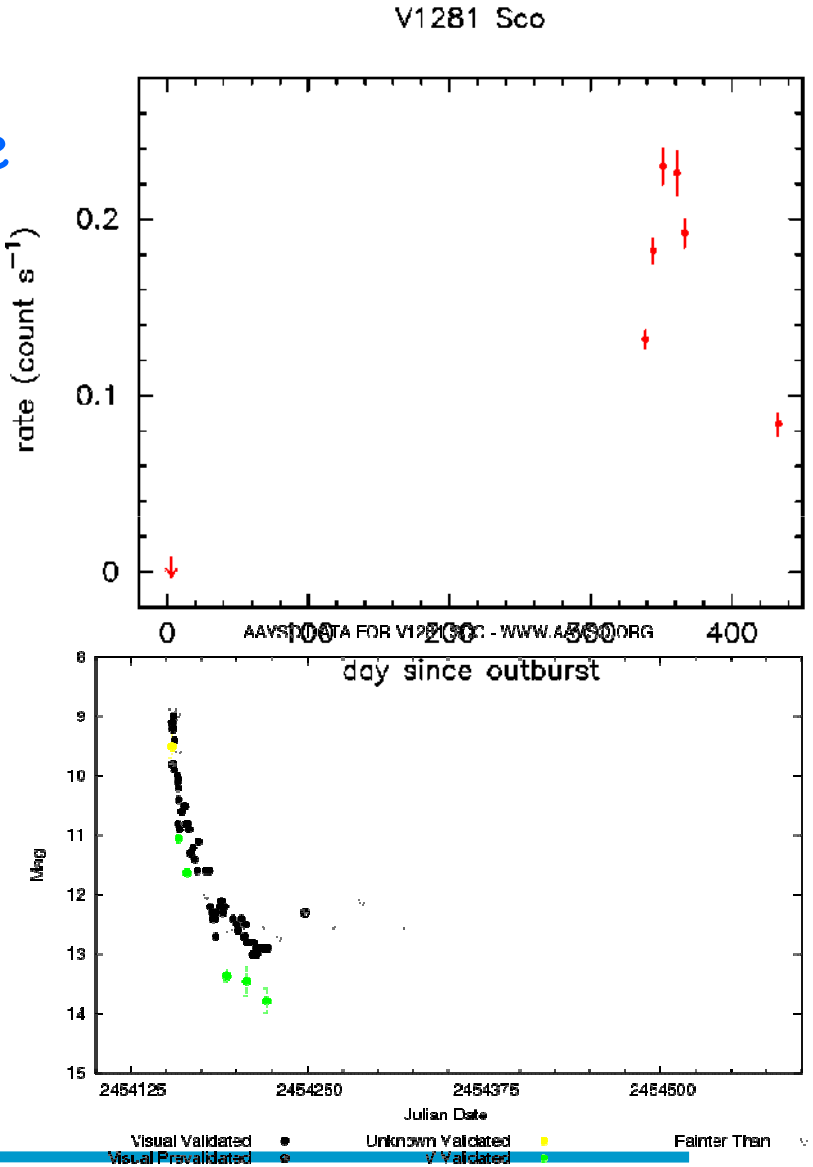
Lynch et al AJ (2008)



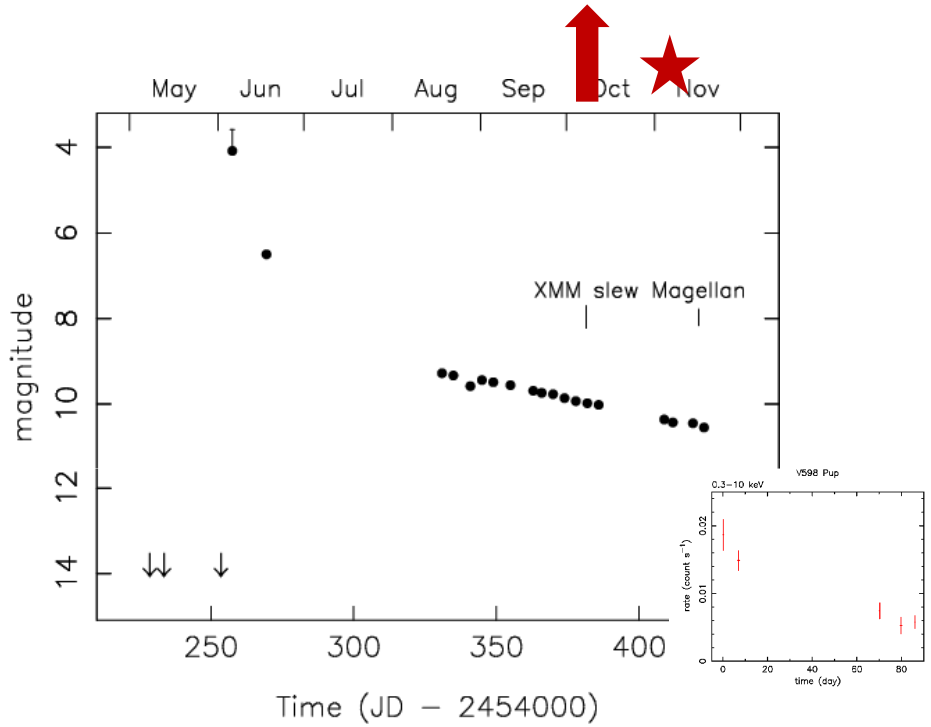
V1281 Sco (N Sco 2007/2)

- No X-rays at 2.9 days
- Variable super-soft source visible from day 339-433





V598 Pup (N Pup 2007/2)



- USNO A2 progenitor (R=15.9)
- Unresolved thermal radio source
- CNe emission line widths up to 1800 km/s

Read et al Atels 1282, 1301

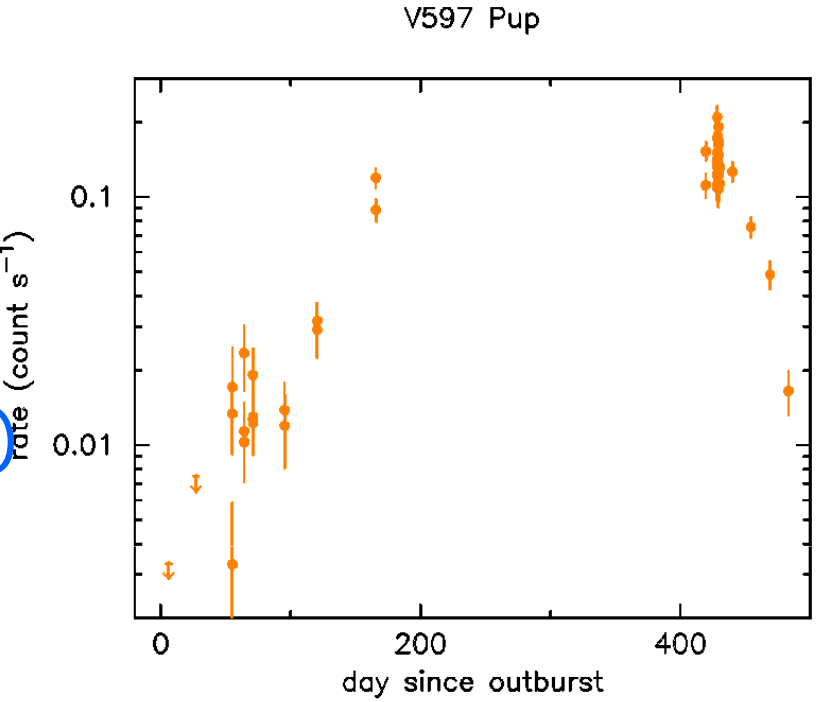
Torres et al Atel 1285

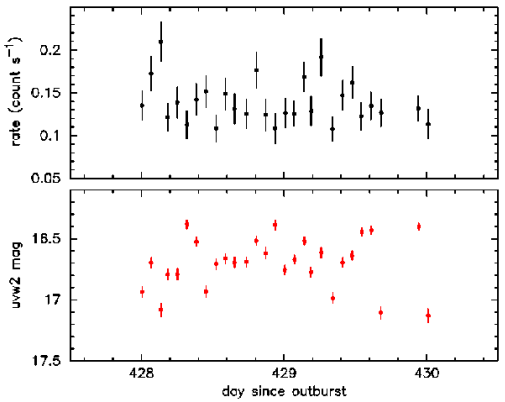
Rupen et al Atel 1305

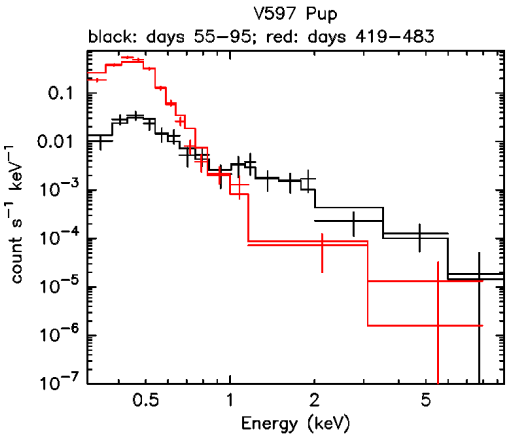
Read et al A&A (2008)

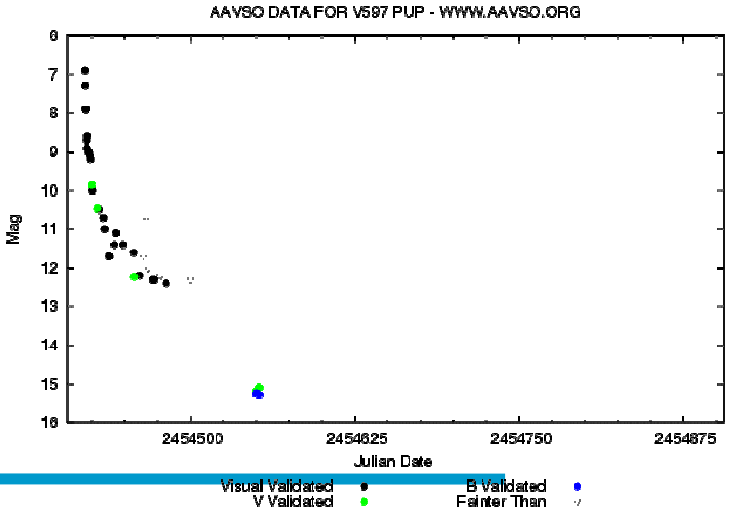
V597 Pup (N Pup 2007)

- HI & He I: 3500 km/s line widths on day 56
- He II 4686 seen (IAUC 8911)
- X-ray spectrum: hard optically thin and (strongly after day 100) soft blackbody-like components
- Rapid UV (& X-ray?) variability

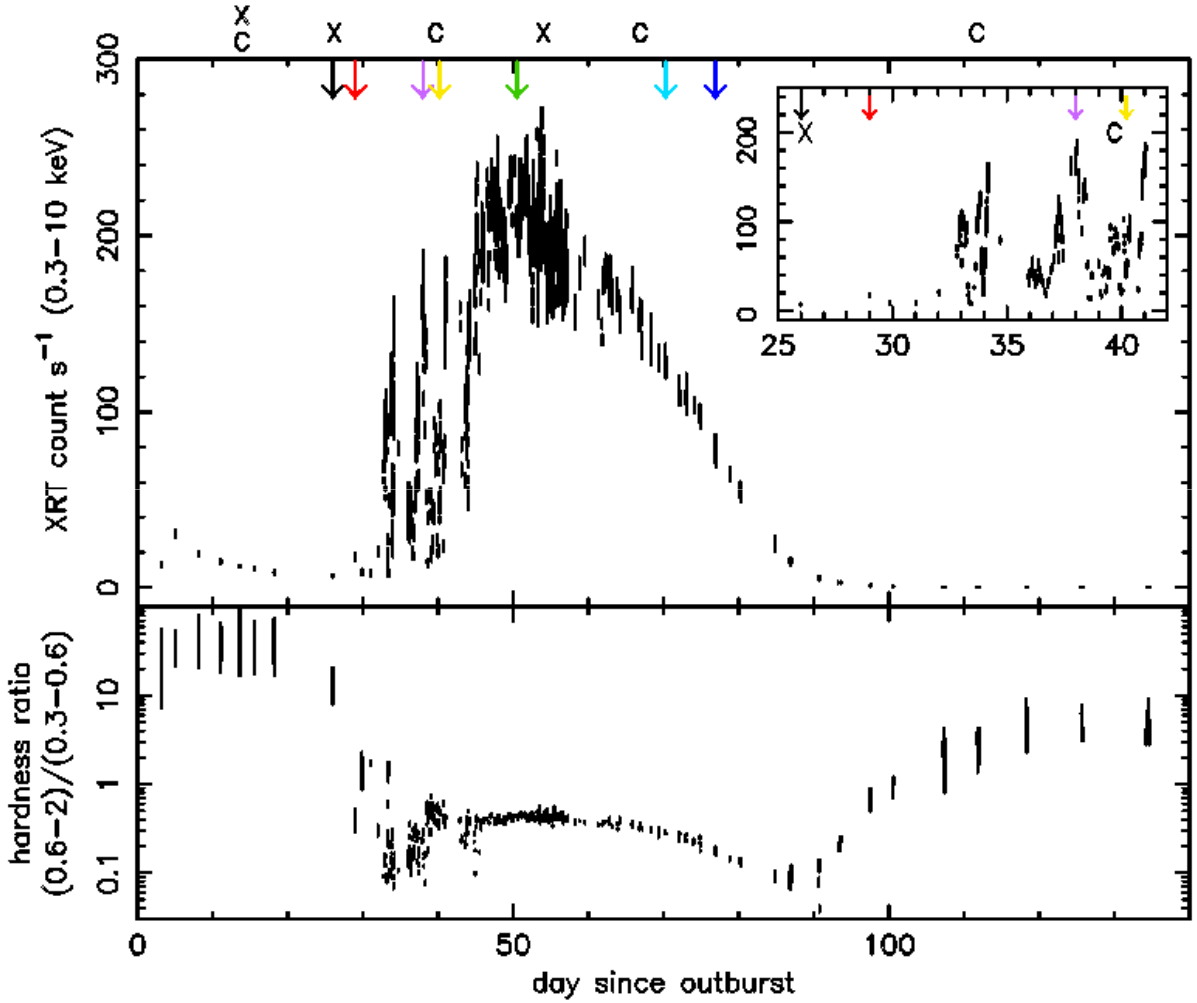








RS Oph: XRT light curve

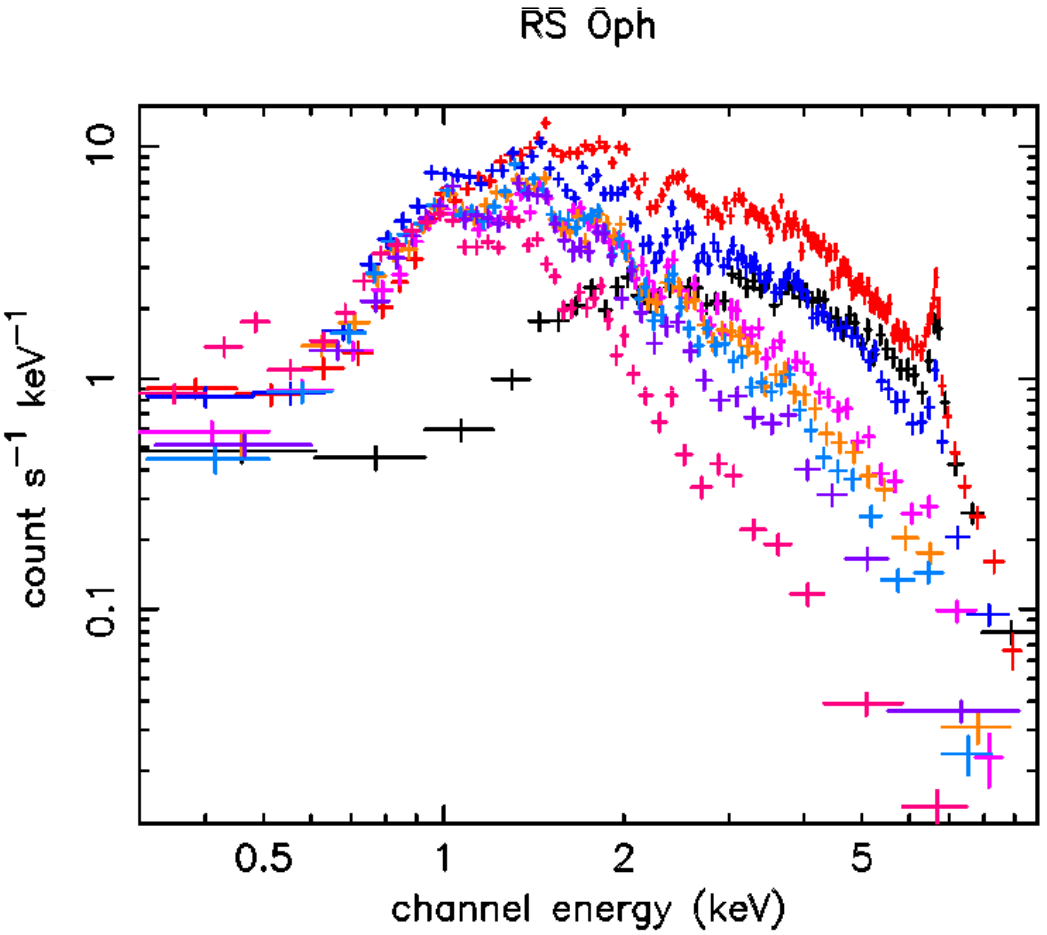


0.3-10 keV light curve shows:

- Cooling hot gas emerging from red giant wind
- Noisy onset of super-soft phase, which lasts ~64 day in total
- turnoff time → M_{WD}~1.35 $M_{\odot}$

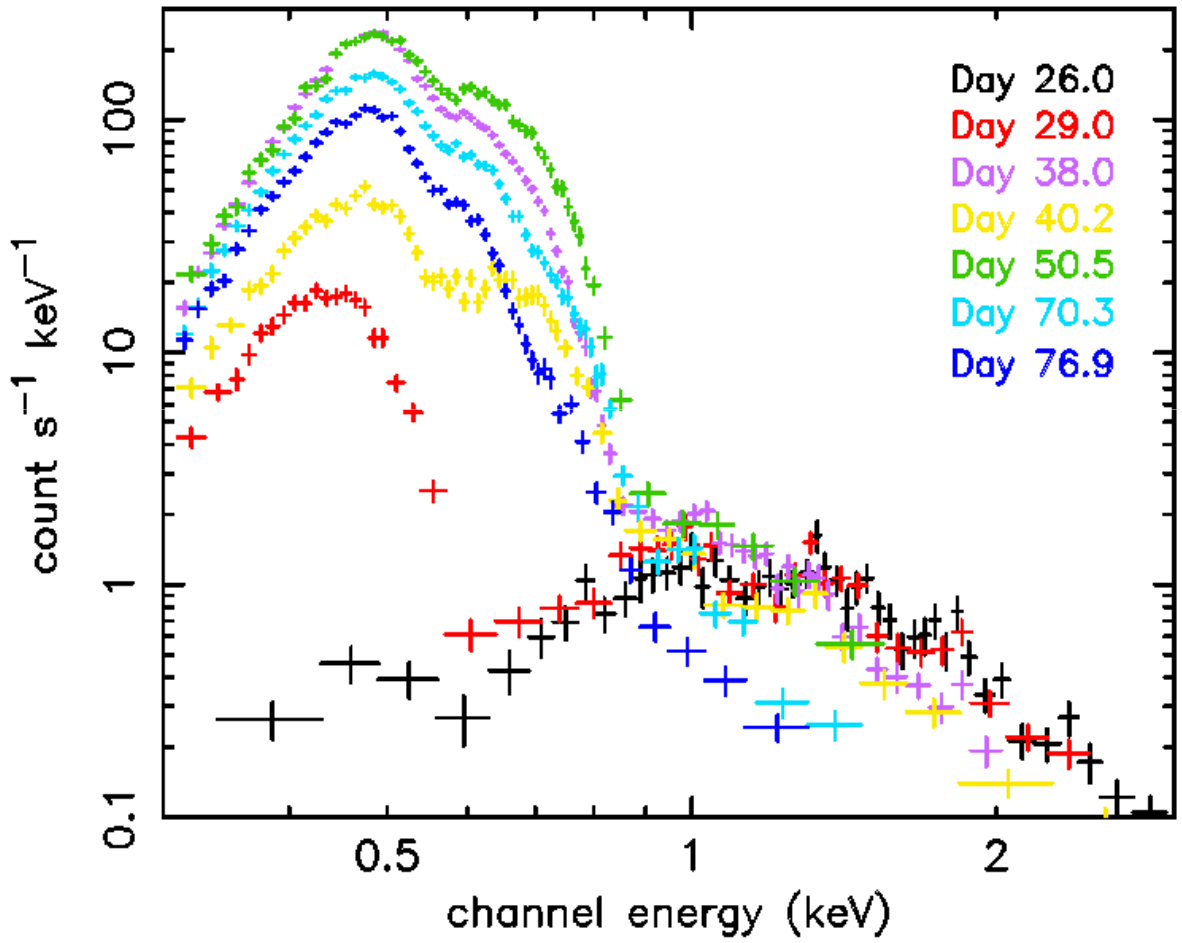
RS Oph: First 26 days

day
3.17
5.03
8.18
10.99
13.60
15.61
18.17
25.99



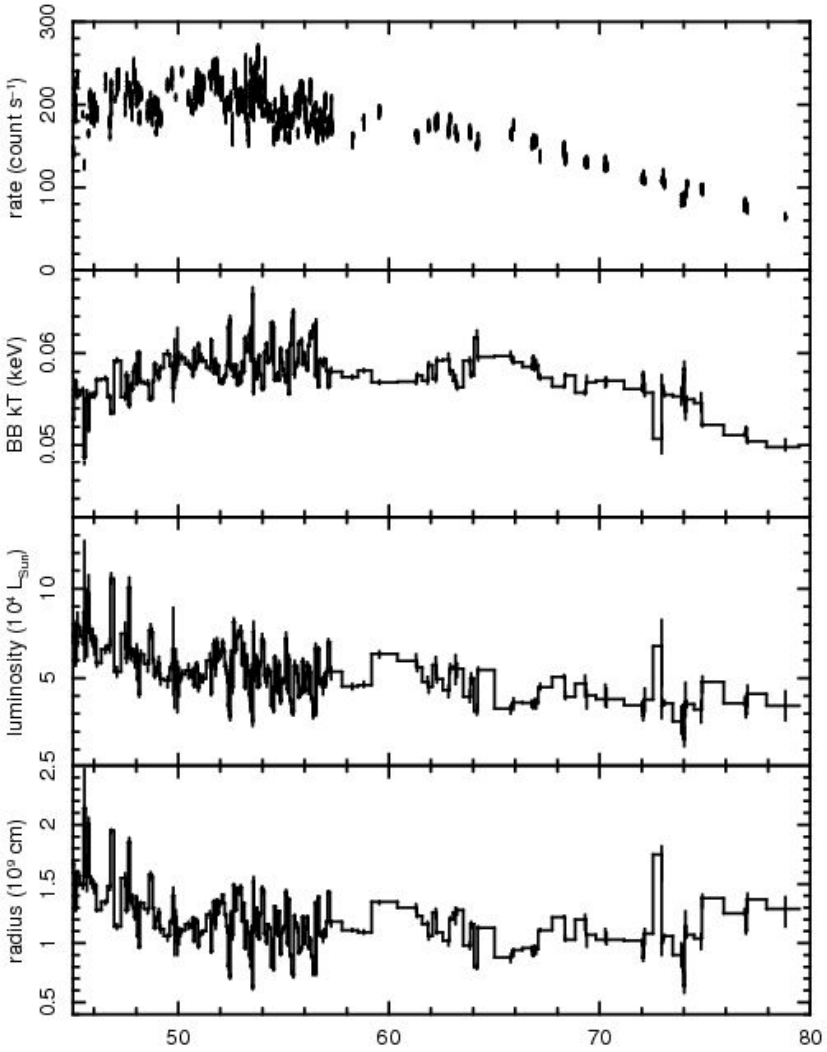
Bode et al 2006

RS Oph X-ray spectra



- 1st appearance of hot WD on day 26
- kT_{BB}=31 eV on day 29, = 56 eV on day 50.5
- Variable neutral oxygen absorption (0.54 keV)
- Late flux decline consistent with temperature drop to kT = 41 eV at day 76.9

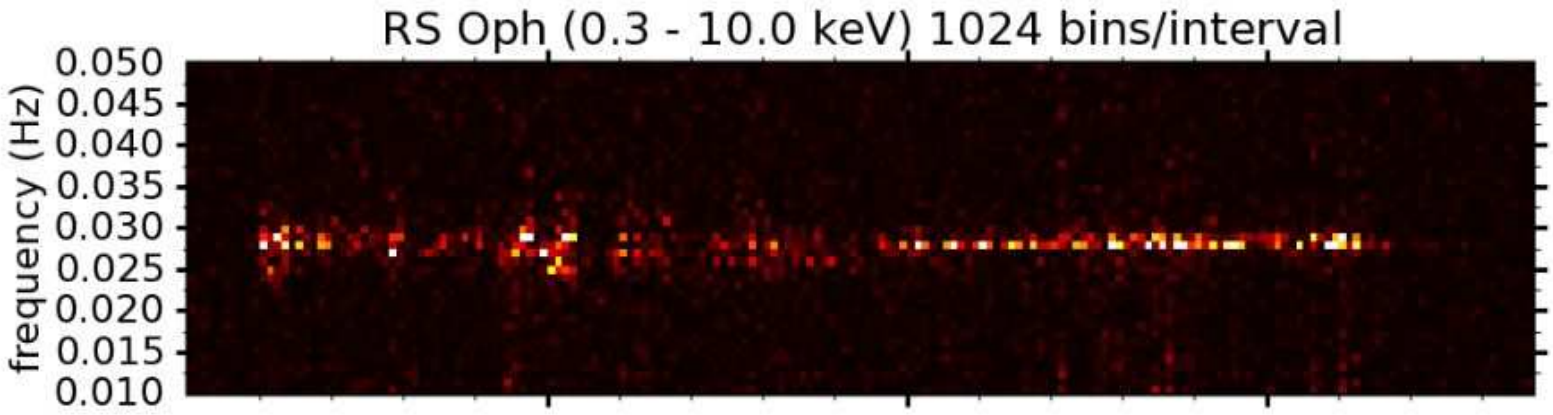
RS Oph X-ray spectra

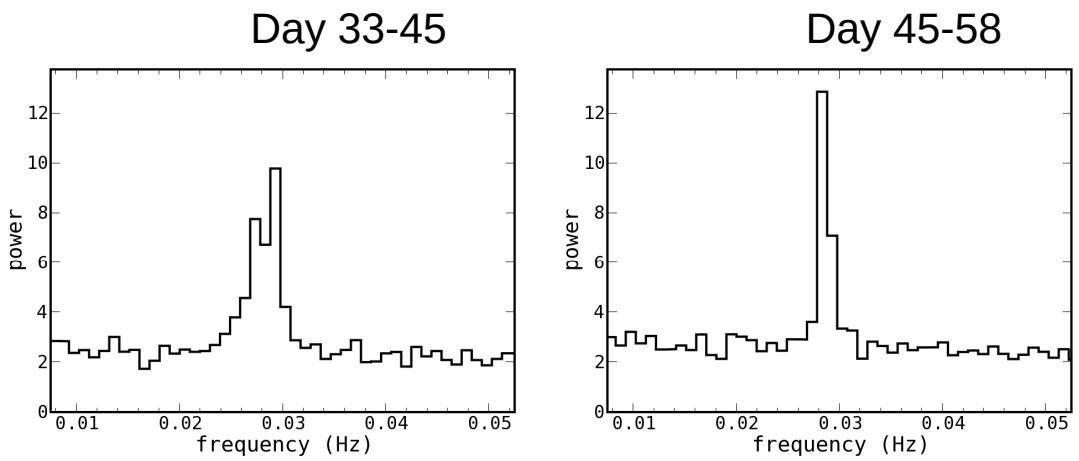


Page et al 09

- Blackbody spectral fits (declining wind absorption with $O=O_{Sun}/3$, Ness et al 07)
- Shrinking radius and rising temperature seen to day 50-60
- Then $L \sim L_{Edd}$ (but beware L_{BB})
- Later count rate decline due to cooling
- A rising temperature until the end of nuclear burning was predicted by Starrfield et al (1991)

A quasi-periodic modulation





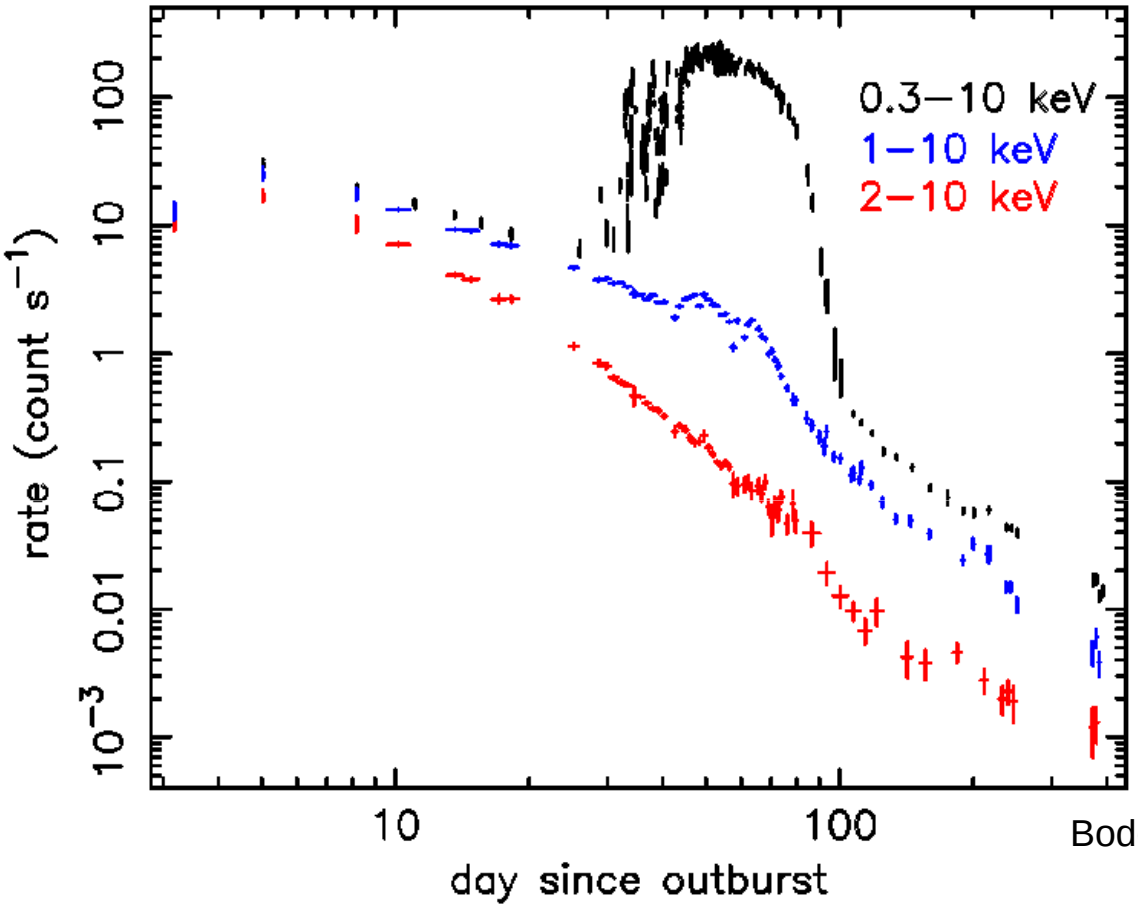
Beardmore et al 2009

Period near 35s in soft X-rays between days 33-59

WD spin?

Nuclear burning instability?

RS Oph shock evolution



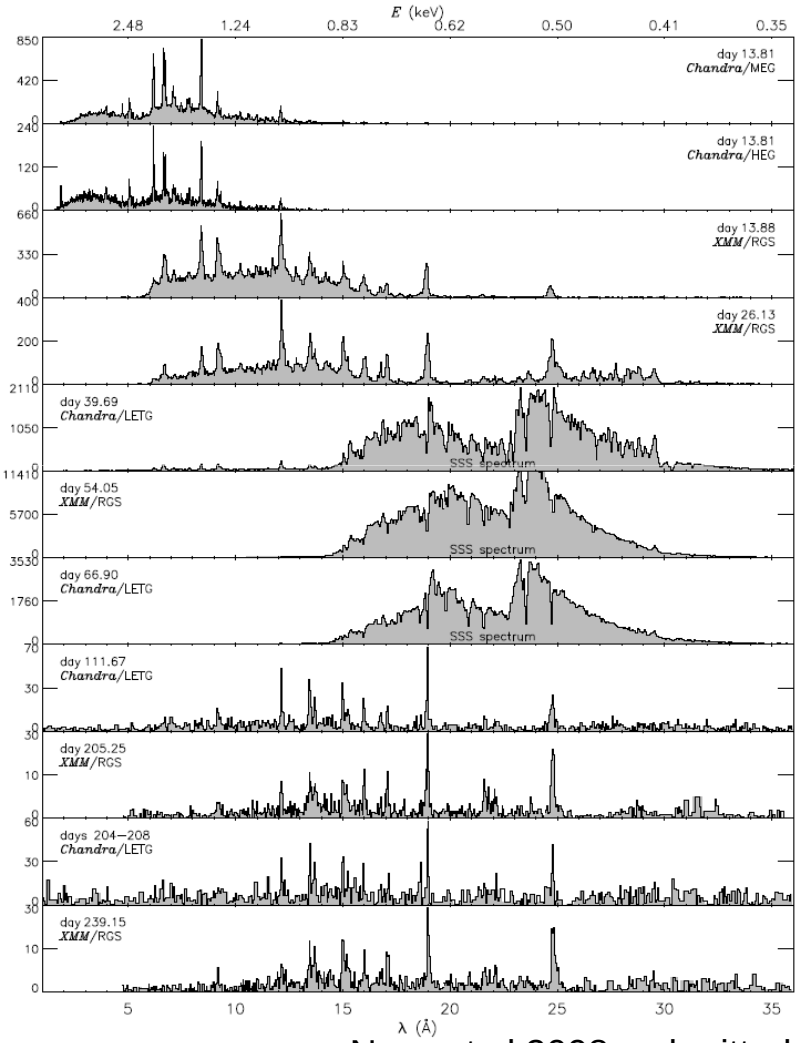
Bode et al 2009

Hard X-ray emission from the shock shows accelerating decline until ~day 100

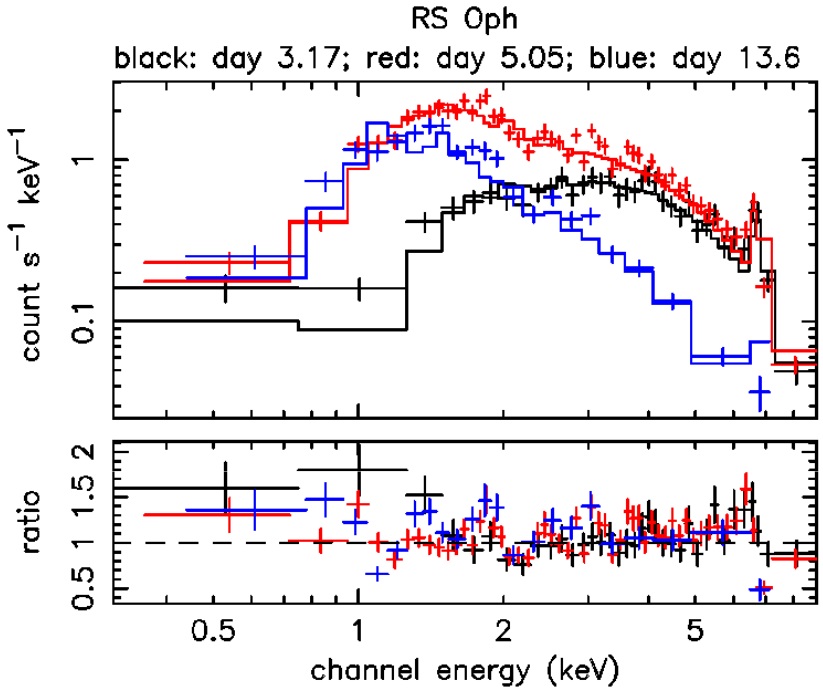
Shock breakout not expected until ~1000 days

Detailed shock evolution modelling required

RS Oph spectra



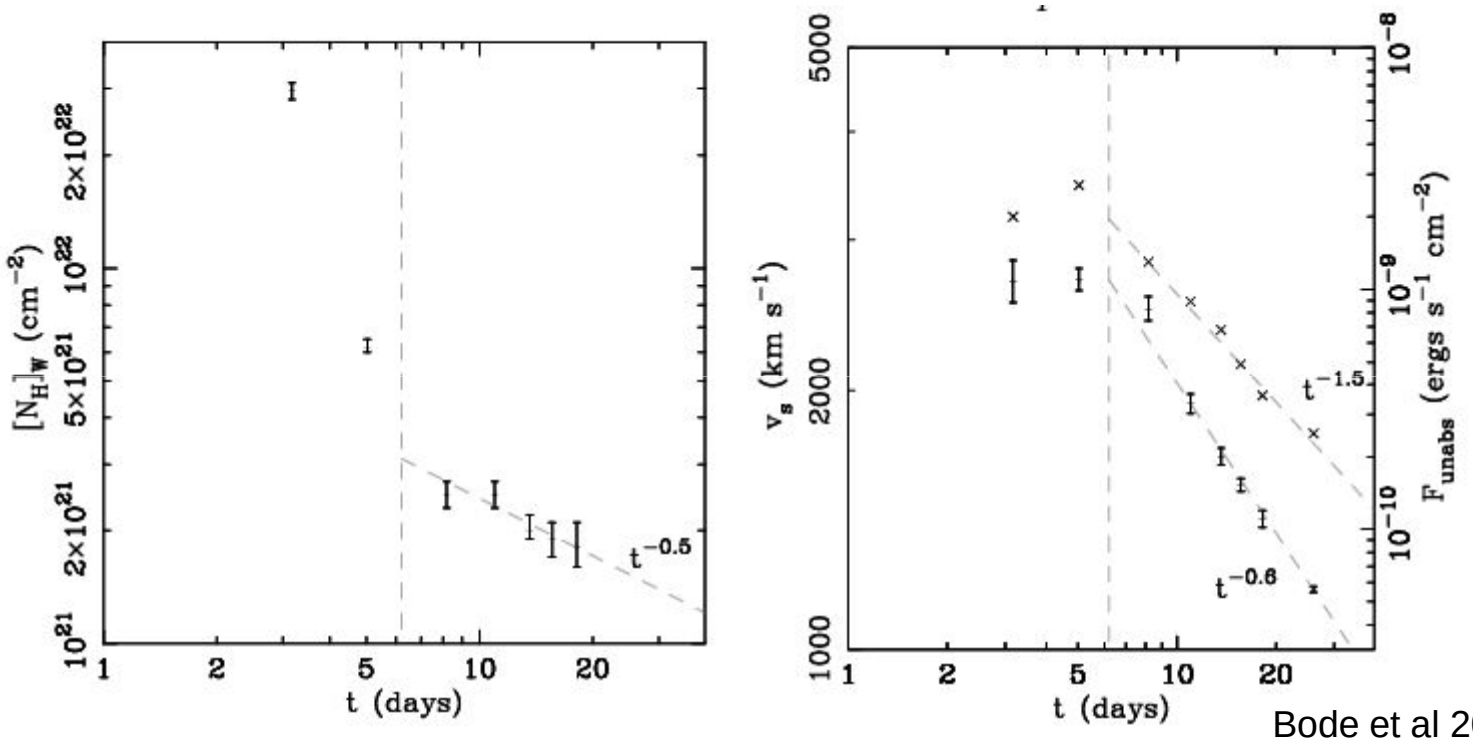
Ness et al 2008, submitted



Need to monitor the hard X-ray spectrum to understand shock evolution.

Frequent observations complementary to rarer grating spectra.

RS Oph shock modelling

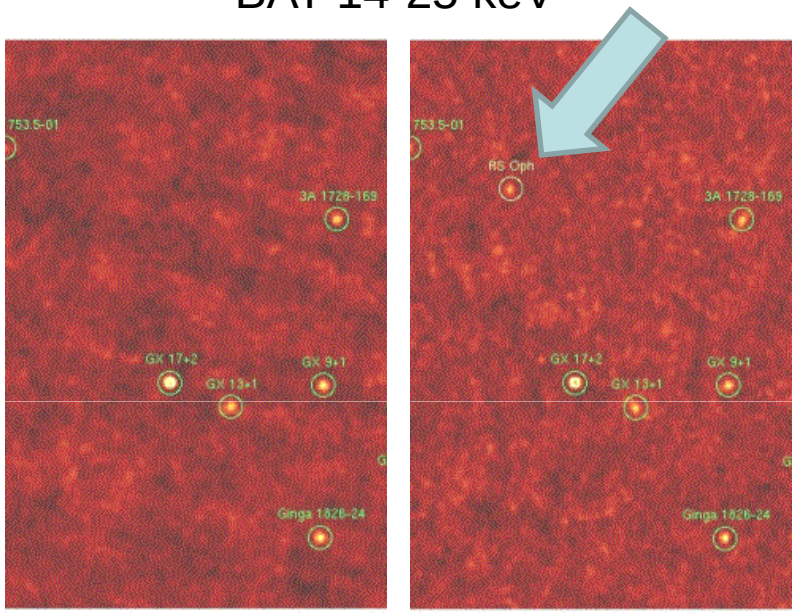


Bode et al 2006

- Decrease in absorption due to expansion of ejecta
- Flux (& temperature) decline due to cooling & slowing shock

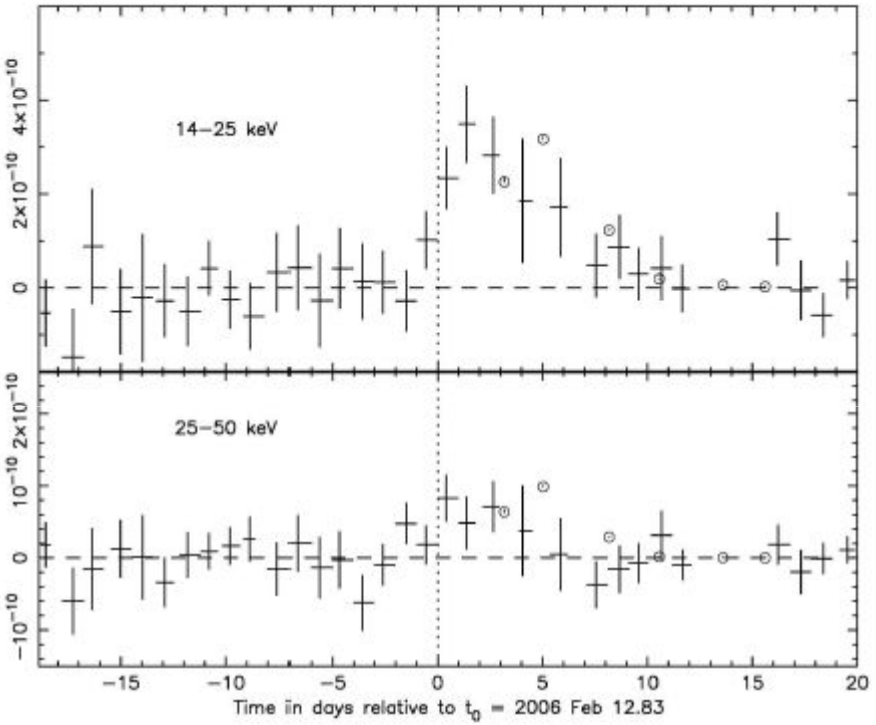
RS Oph BAT detection

BAT 14-25 keV



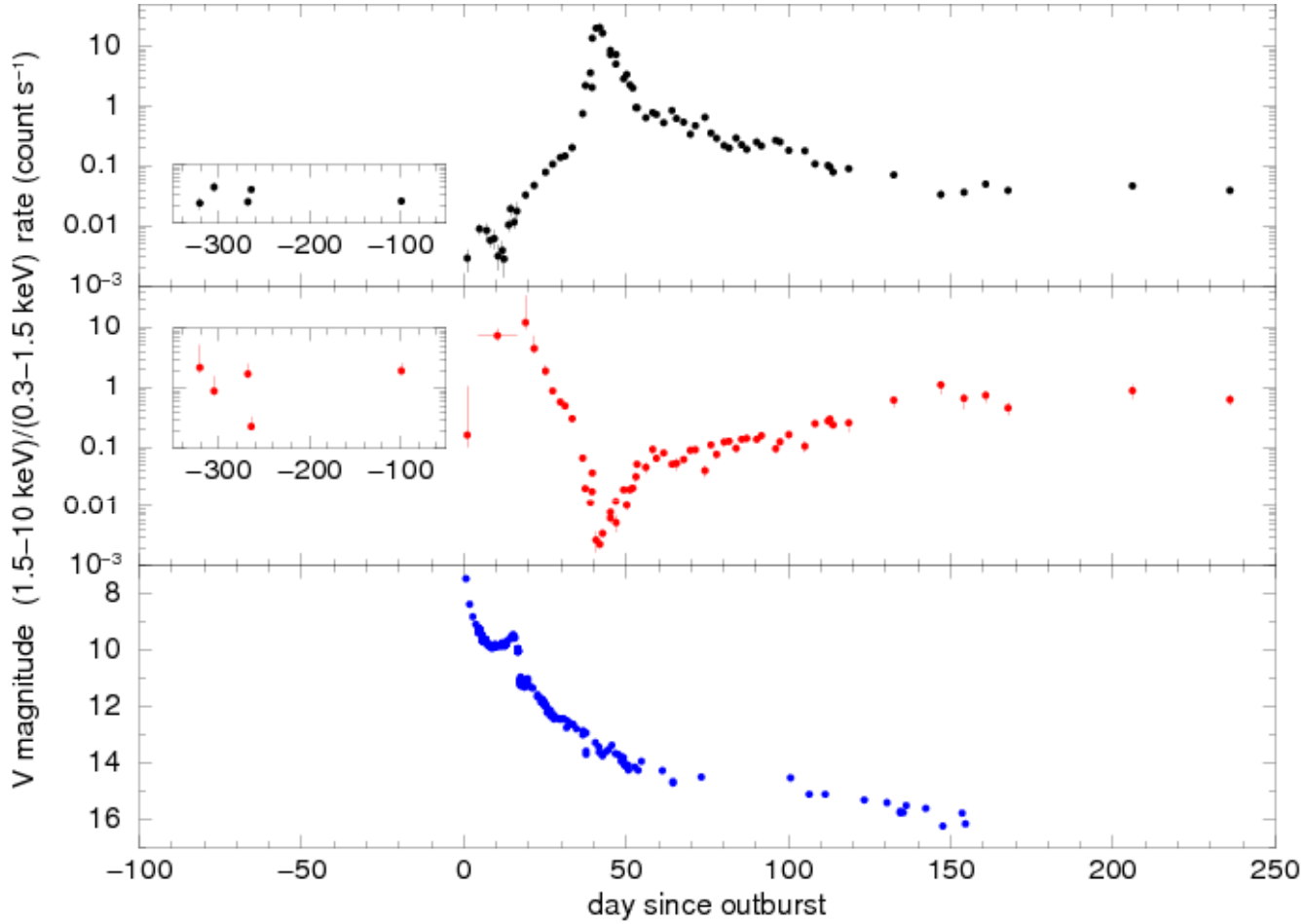
2006 Feb 11-12

2006 Feb 13-14



- RS Oph was detected by the BAT in the softest band
- Emission was likely thermal rather than compton degraded radioactivity

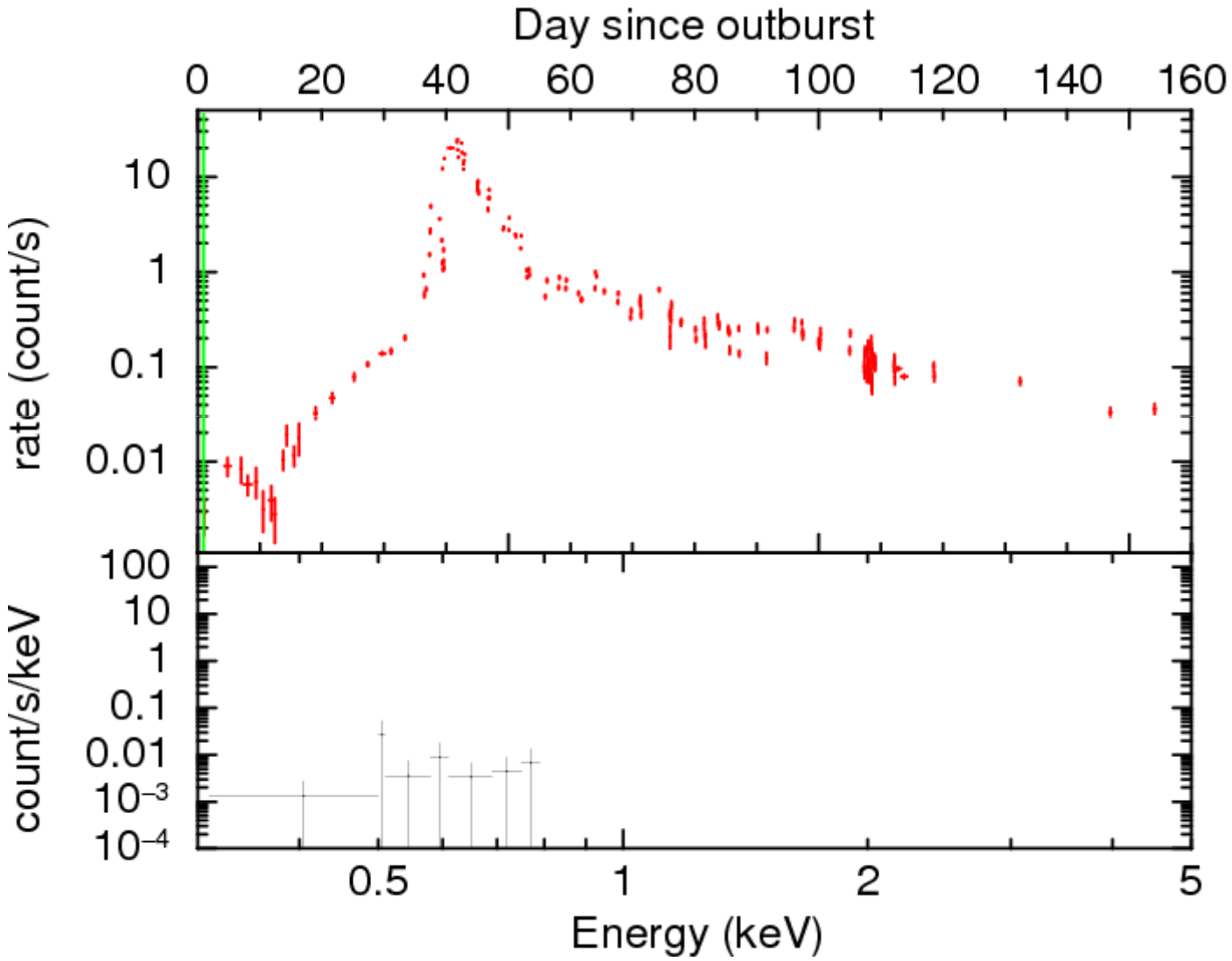
V2491 Cyg



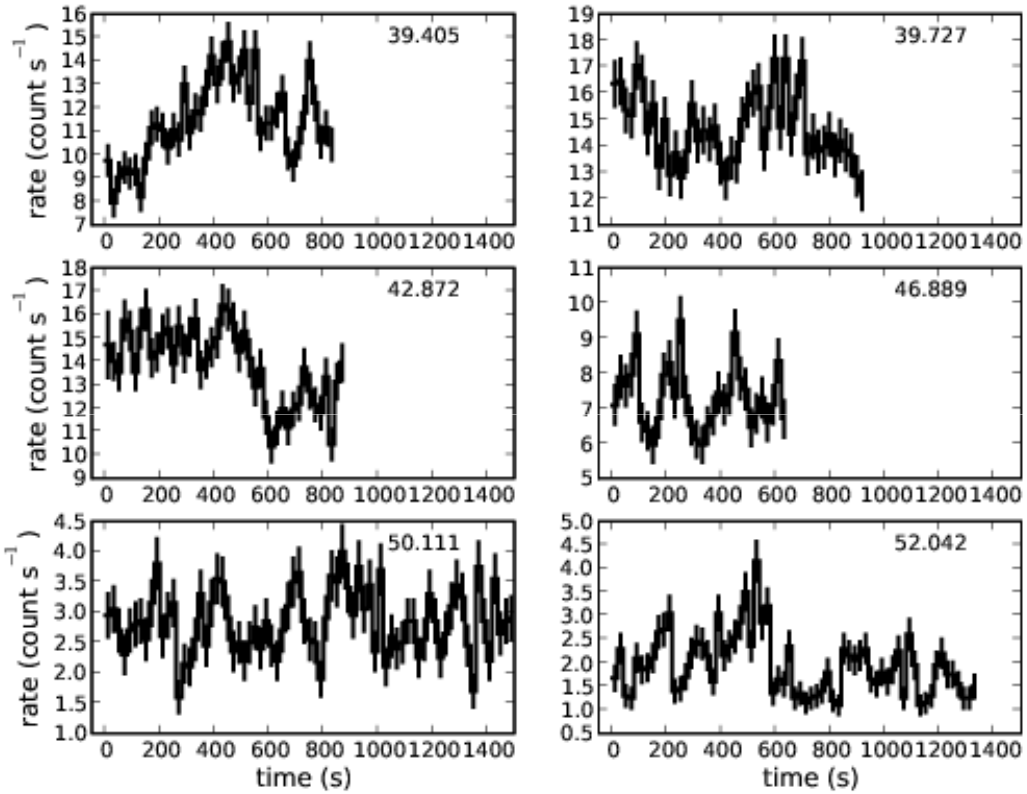
Page et al, subm

V2491 Cyg was observed – and detected - pre-outburst as part of the BAT survey follow-up. The source may have been the X-ray counterpart of the BAT source.

V2491 Cyg


Day since outburst
0
20
40
60
80
100
120
140
160
rate (count/s)
10
1
0.1
0.01
100
count/s/keV
10
1
0.1
0.01
10⁻³
10⁻⁴
0.5
1
2
5
Energy (keV)

V2491 Cyg

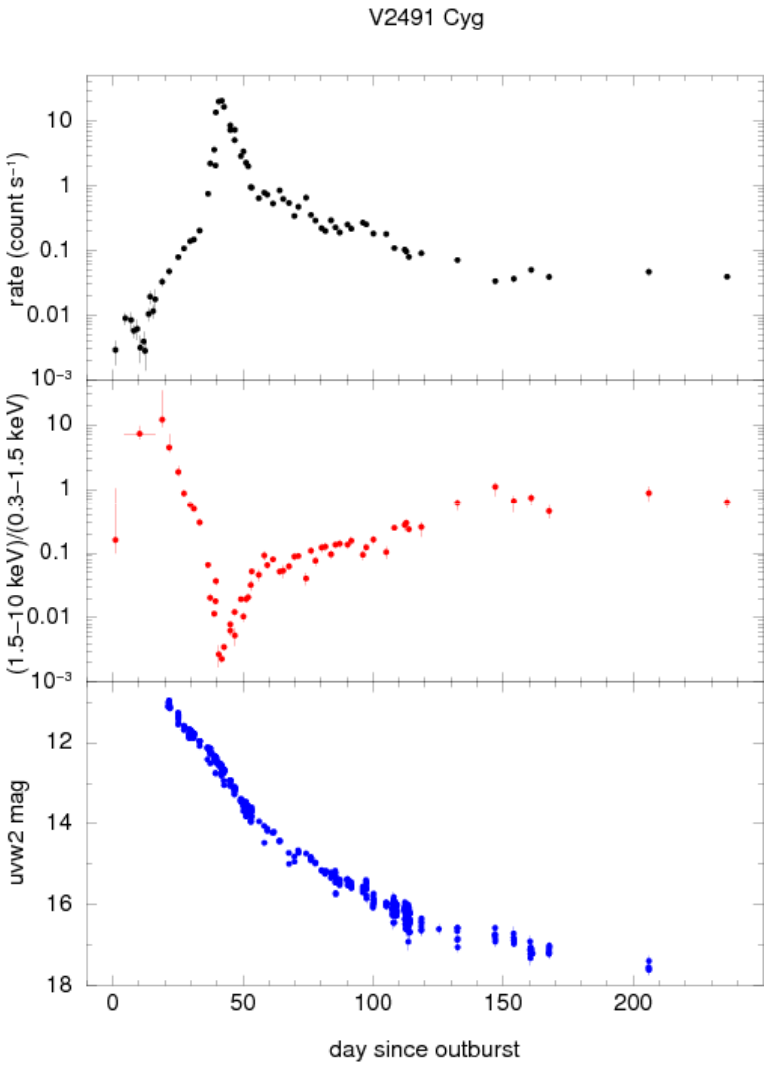


Numbers in the top right corner indicate the day after outburst.

Short-term X-ray variability is seen, though there is no strict periodicity.

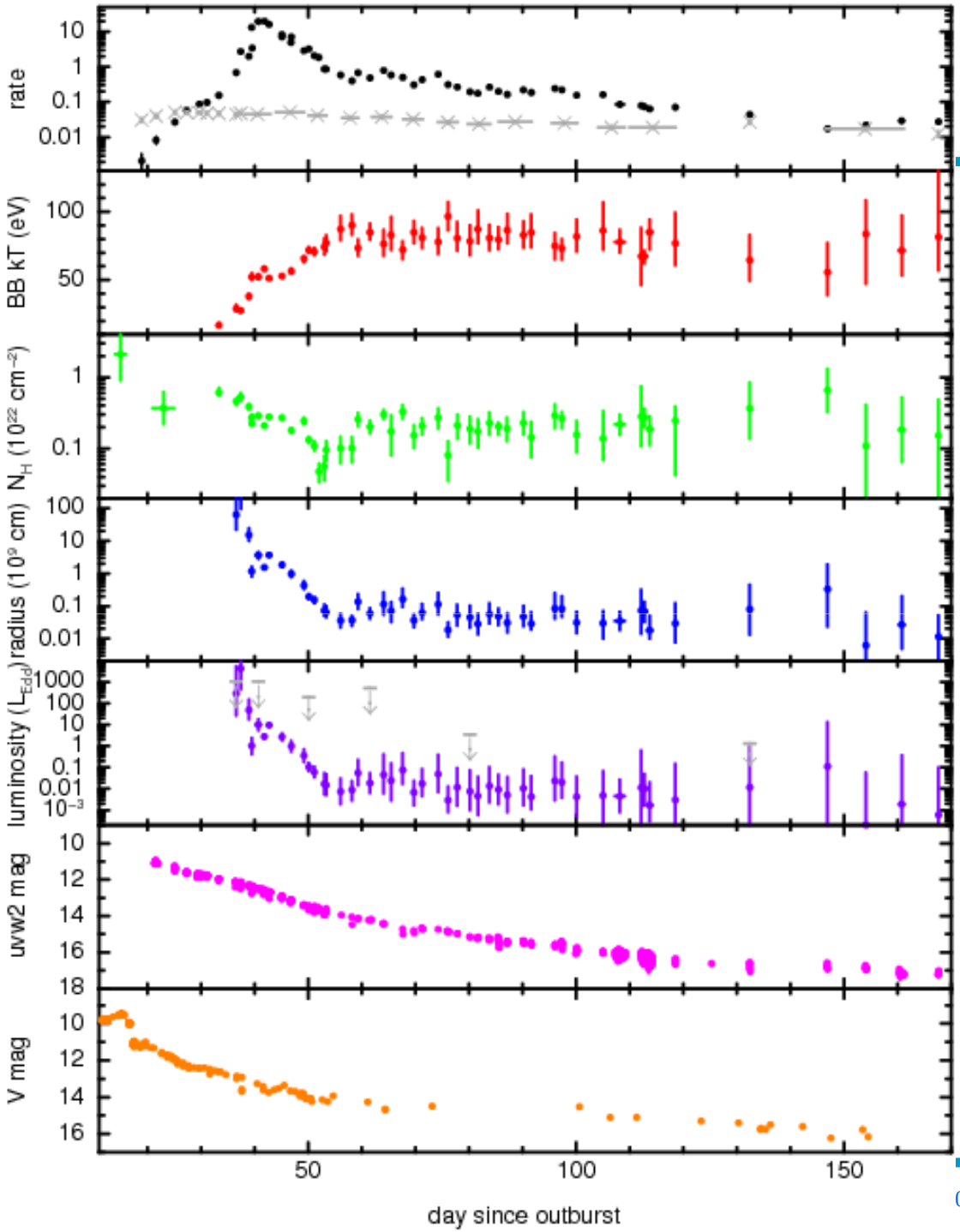
Similar (unexplained) variability has been seen in other SS novae.

V2491 Cyg



The UV (1928 Å) evolution is very different from that seen in X-rays, showing a fading trend beyond at least 20 days after the outburst. Earlier observations were saturated.

The UV curve has inflections at ~40 and ~57 days, at the times of the X-ray peak and the end of the rapid decline.



University of Leicester

Blackbody fit parameters while the super-soft source was visible

Absolute values probably not reliable

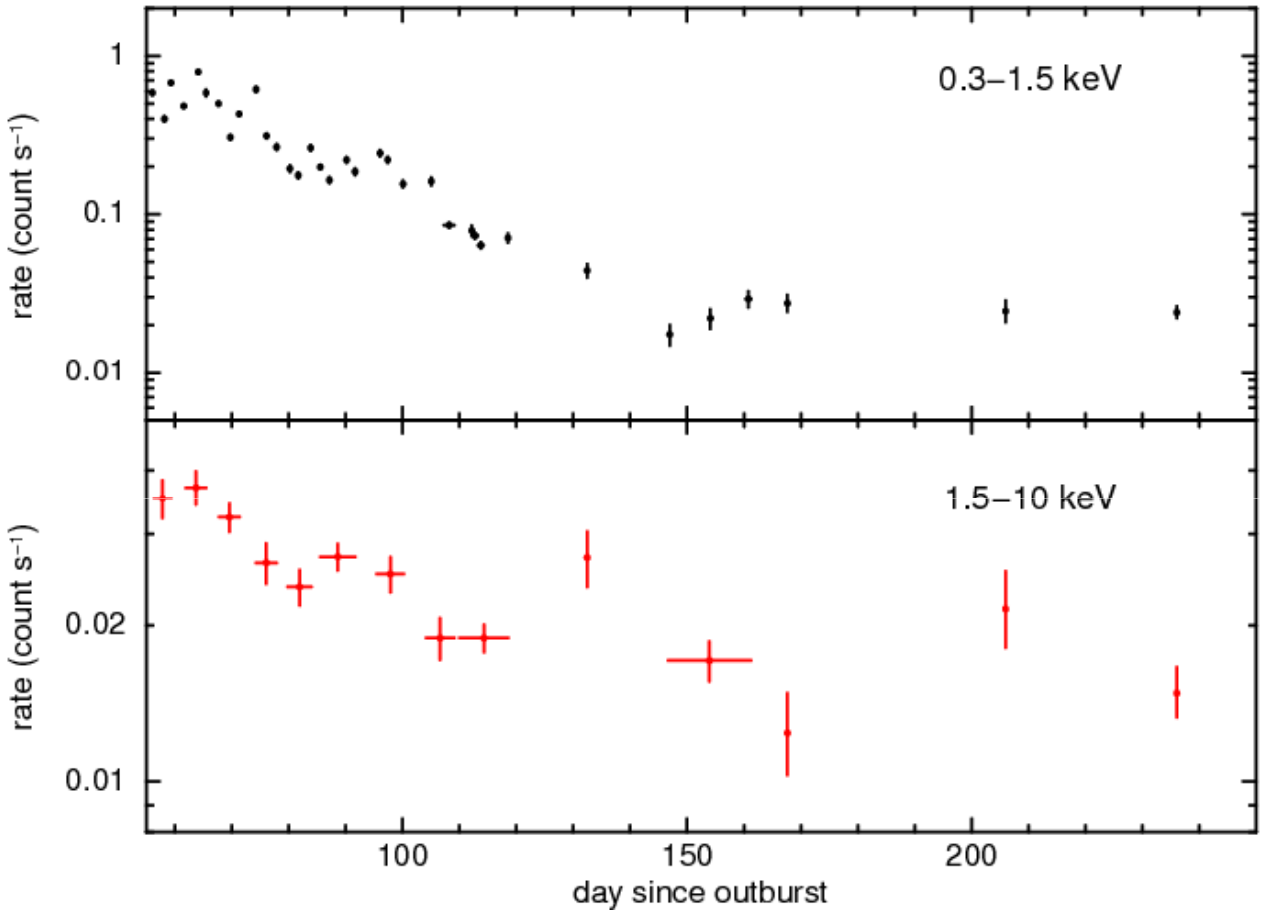
A rising temperature and shrinking radius are seen between days 30 - 57

Where is the expected constant luminosity nuclear burning phase?

Grey points show luminosity upper limits from linking X-ray to UV.

Page et al, subm

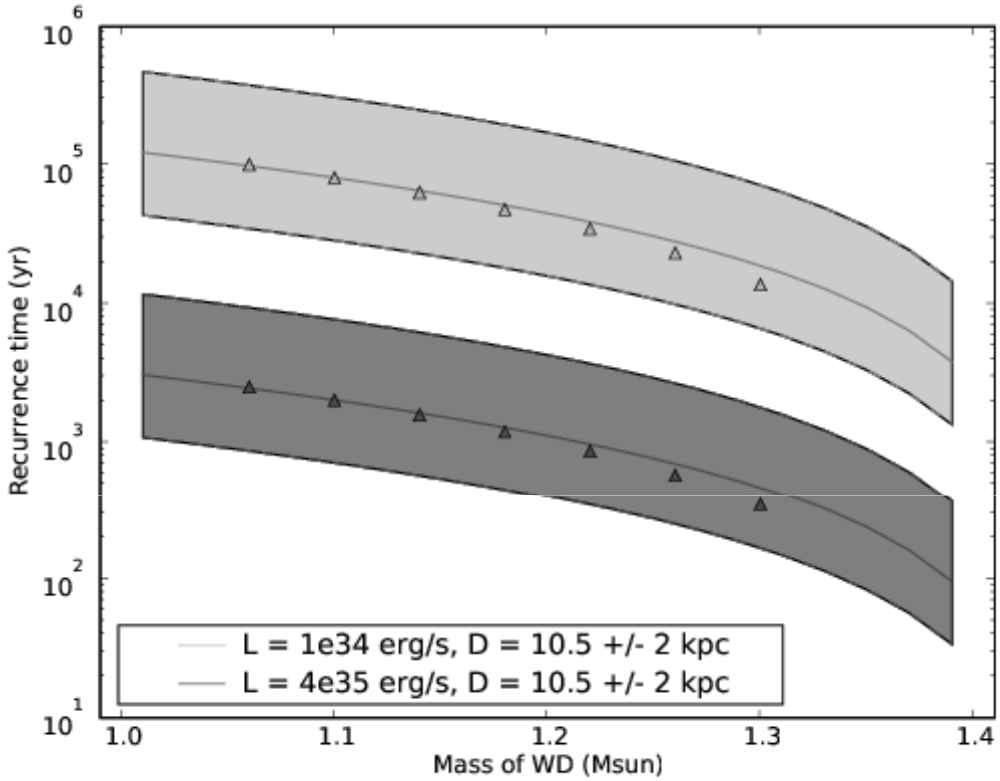
V2491 Cyg



Page et al, subm

Flickering is visible after day ~57. If this is the recovery of accretion due to viscous expansion of a disk, then disk was removed to 2×10^{10} cm. With Porb=0.96 days, Rdisk ~ 3×10^{10} cm. Inner disk only destroyed by nova

V2491 Cyg

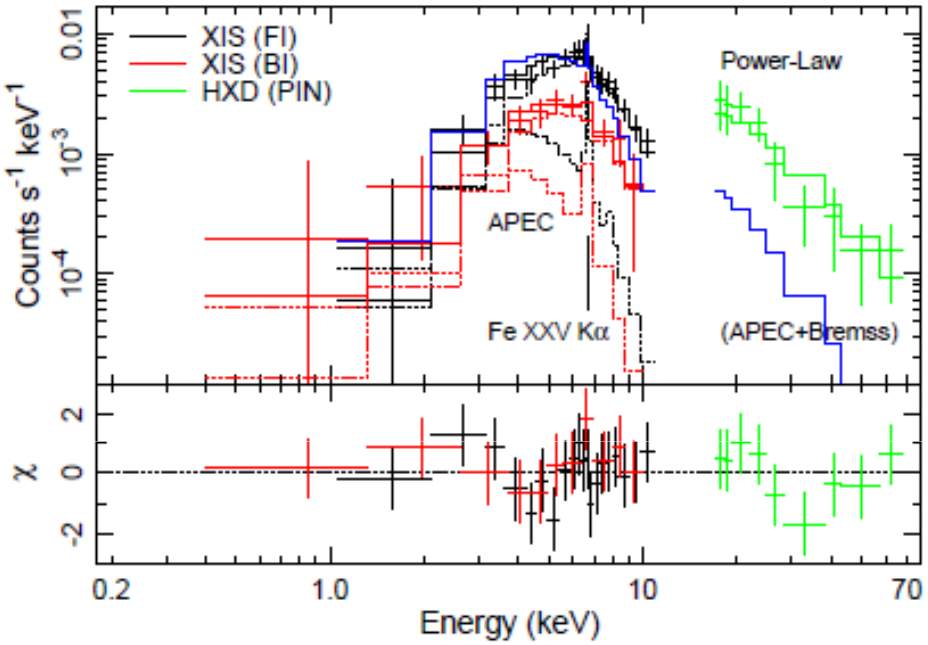


Page et al, subm

Estimates of the time to reach ignition pressure for V2491 Cyg derived from the observed pre-nova luminosities of Ibarra et al (2009).

Curves are from the Nauenberg (1972) WD M-R relationship (points from Althaus et al 2005), ranges reflect distance and accretion efficiency uncertainties.

V2491 Cyg



Takei et al, subm

Detection of very hard X-rays up to 70 keV by Suzaku 9 days after outburst.

Requires very hard power law (photon index ~ 0) which dominates thermal luminosity by ~100x

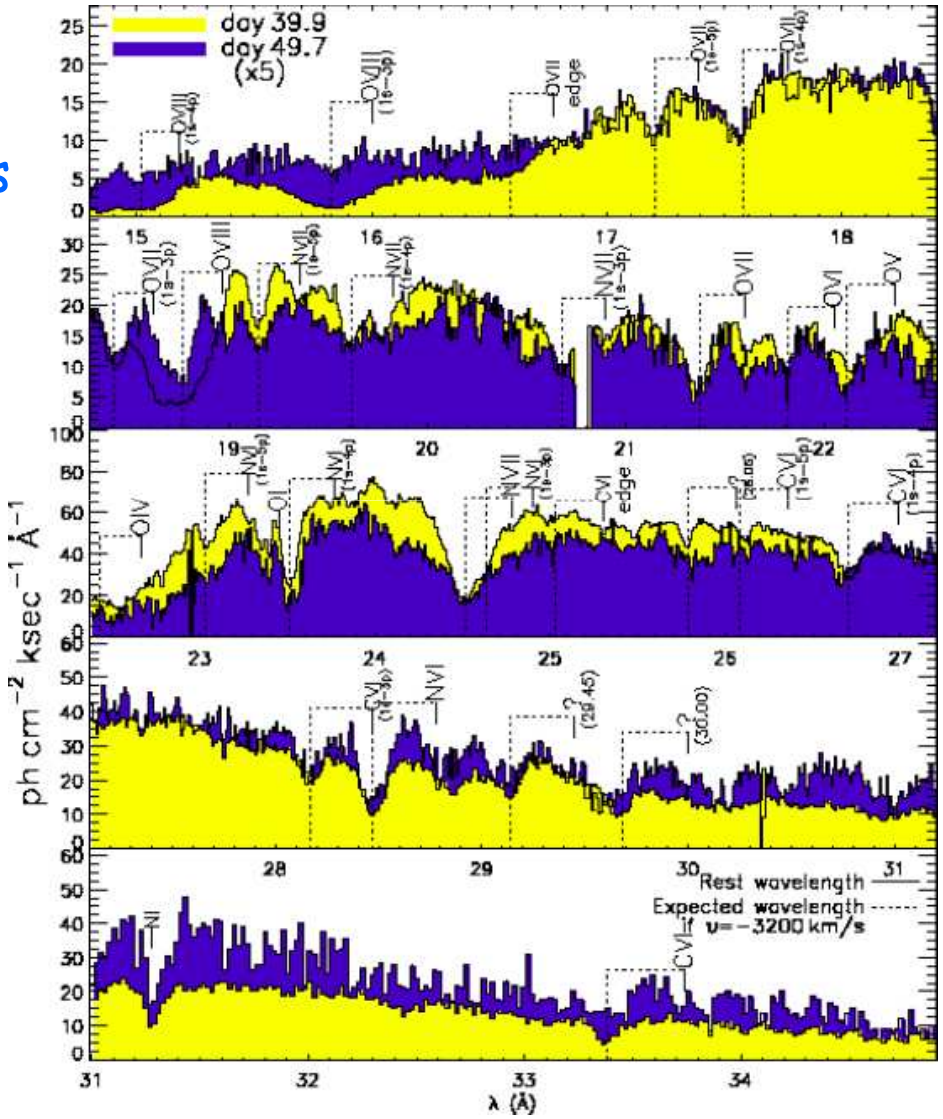
Very hard X-rays absent on day 24

Decay too fast for ^{22}Na, spectrum too hard for shock. IC or reconnection?

V2491 Cyg

J-U Ness Poster #81:

- 2 XMM grating spectra (days 40 & 50, at X-ray peak and near end of rapid decline)
- Blue-shifted high excitation C, N & O lines seen in absorption
- 3200 km/s blue-shift
- Some lines appear saturated but do not go to zero flux



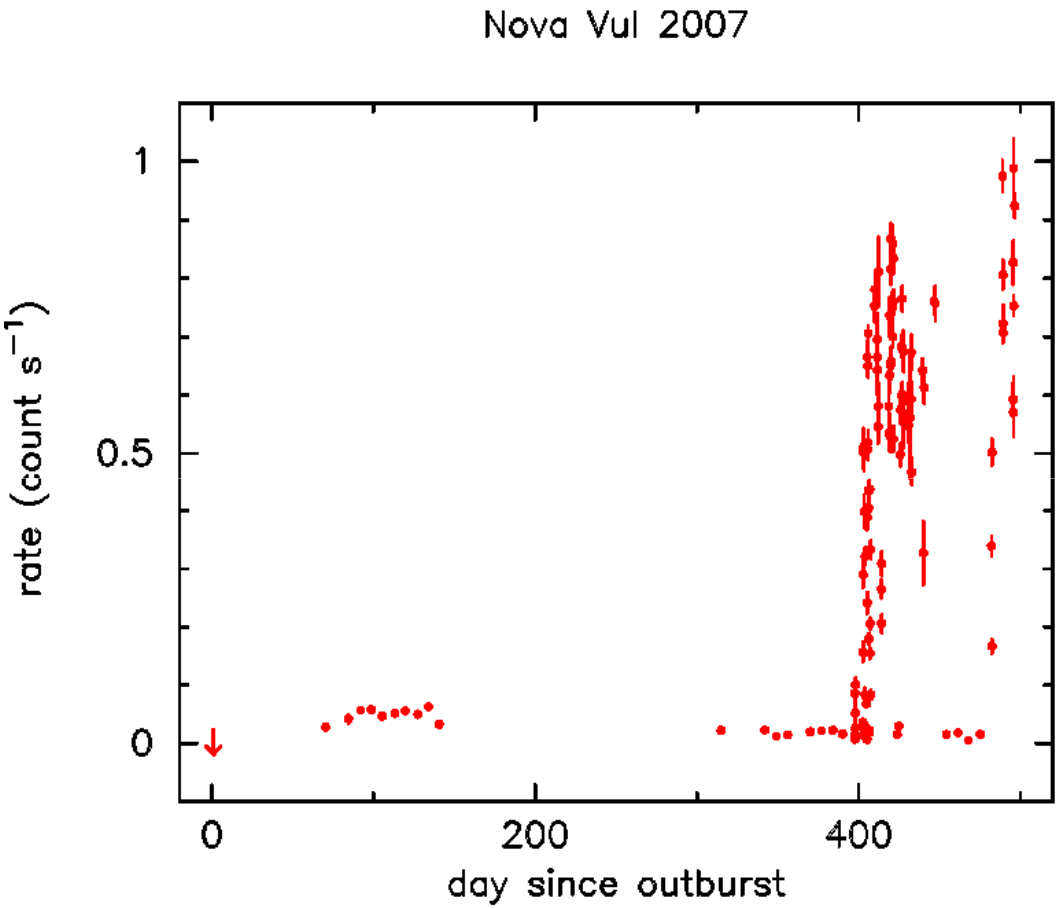
V2491 Cyg

It is highly unusual to see a nova in X-rays pre-outburst. The only others which have been detected pre/inter-outburst have actually been recurrent novae (e.g. RS Oph and V2487 Oph).

A high inter-outburst accretion rate is expected if a nova is to be observably recurrent.

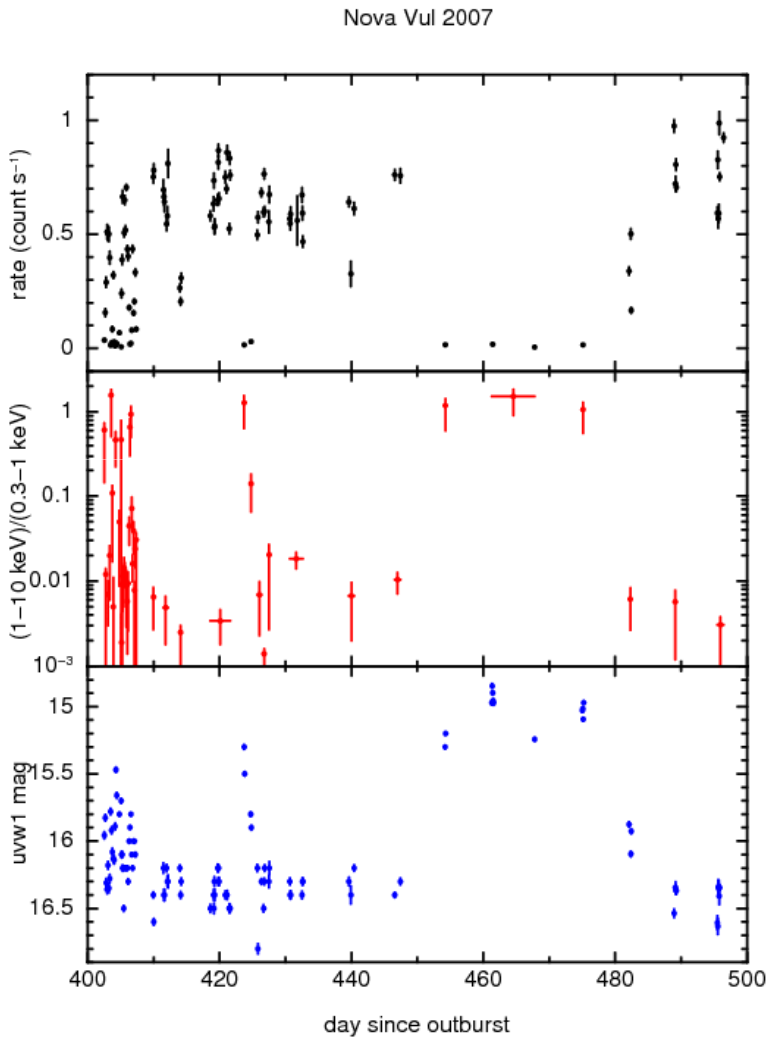
It seems possible that V2491 Cyg will be a recurrent nova.

V458 Vul

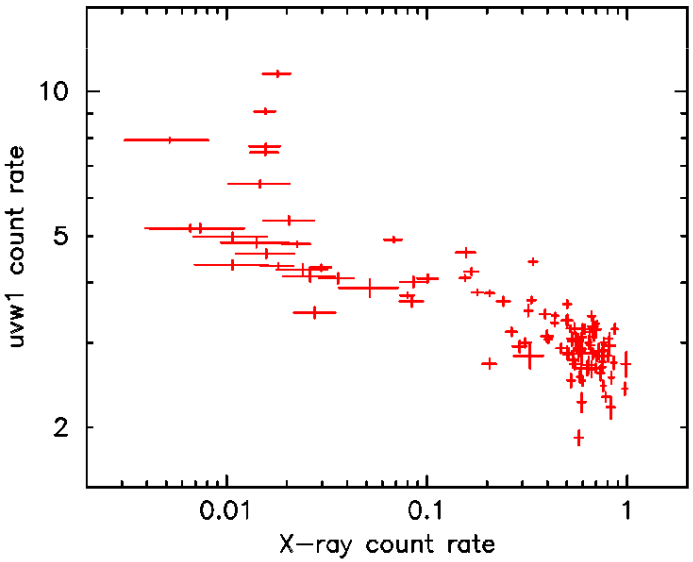


V458 Vul remained at a relatively low X-ray count rate until about 400 days after outburst, at which point rapid variability began.

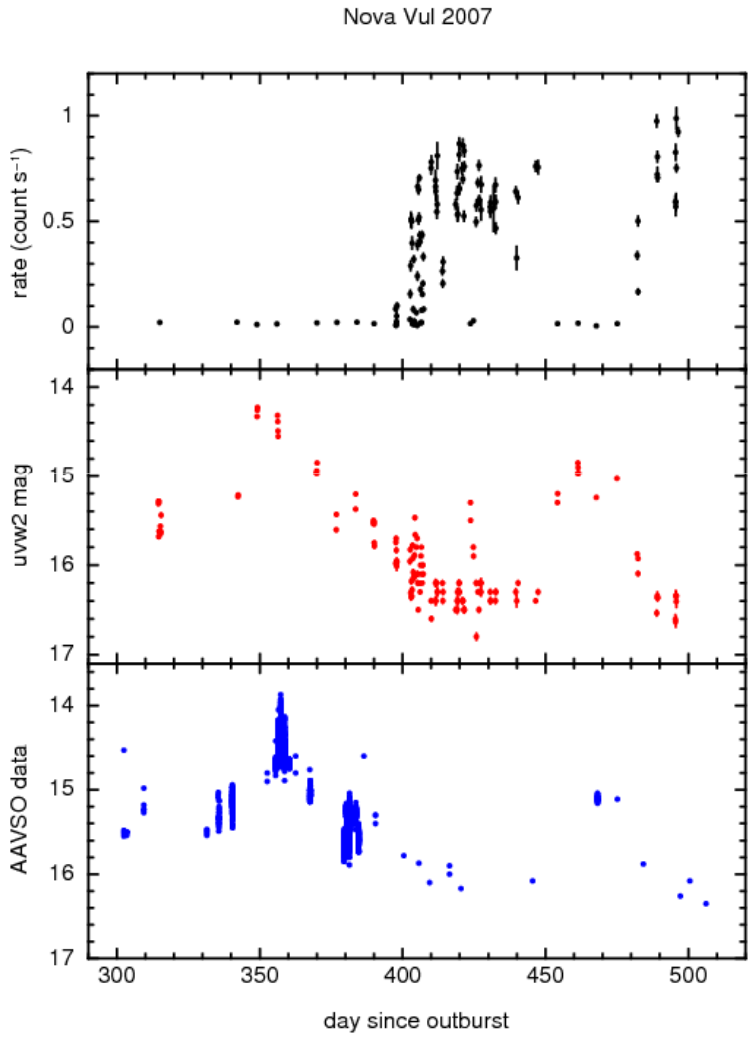
V458 Vul



The X-ray data are softest when brightest, with the X-ray and UV data being approximately anti-correlated. This could be due to an effective temperature change at constant L_{bol}.



V458 Vul



Optical data from AAVSO show the same trends as the UV data.

See also Wesson et al MNRAS 2008 & talk

CSS 081007

ATEL 1825: 4 mag increase in 1 yr. Em line vel spread 2900 km/s, tri-peaked Hα. CNe are ~3 mags more luminous if peak was seen. b = -44°

ATEL 1835: Blue spectrum similar to very fast nova 4160 Sgr, strong [Ne V] emission (5x Hα) suggests ONe nova. Fading

ATEL 1847: super-soft X-ray emission

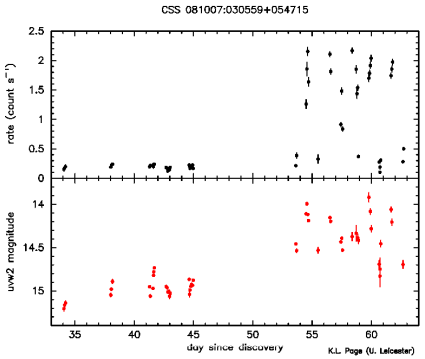
ATEL 1873: large X-ray flux increase, and 1.77 day period

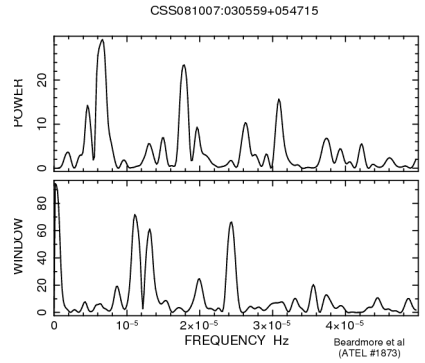
ATEL 1901: Chandra grating spec shows N VII & O VII

ATEL 1938: 1.69 & 0.61 day optical periods reported

ATEL 1940: >1 mag pre-outburst variation

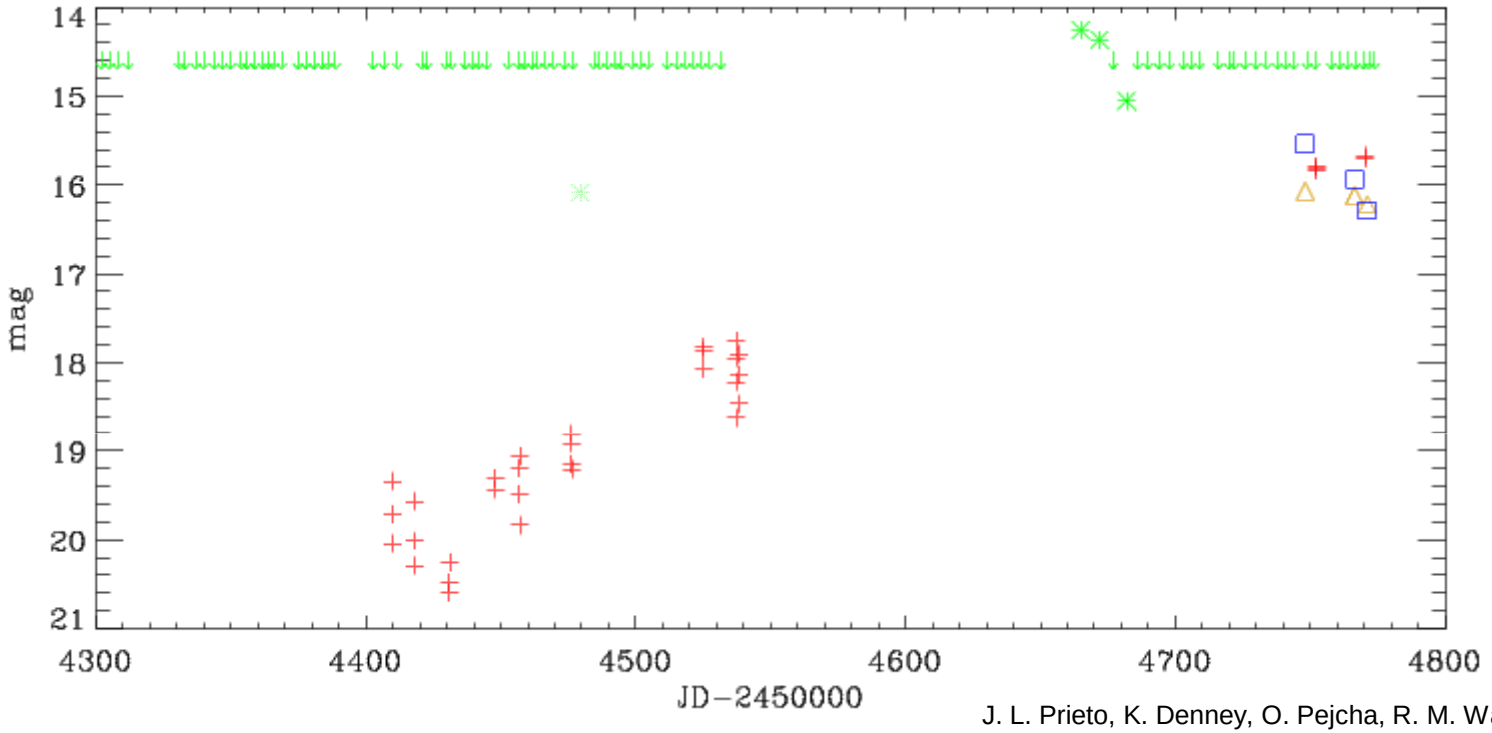
ATEL 1942: 1.77 day X-ray period confirmed & seen in UV & optical. Poss ~45 day period. Flux in Rosat <0.1% current





Beardmore et al 2008: ATEL 1873

CSS 081007



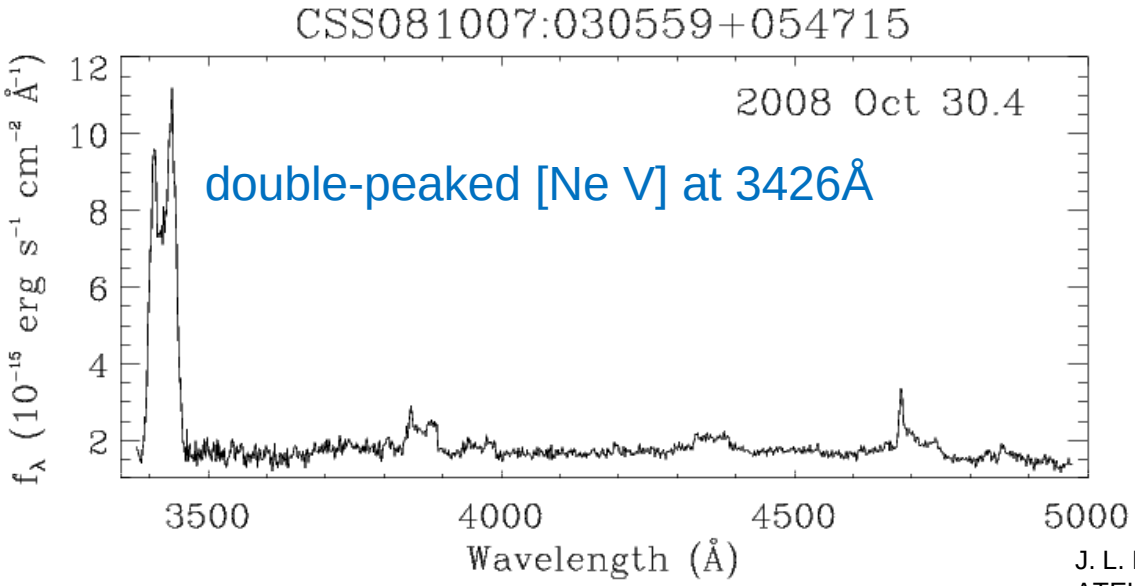
J. L. Prieto, K. Denney, O. Pejcha, R. M. Wagner
ATEL 1835

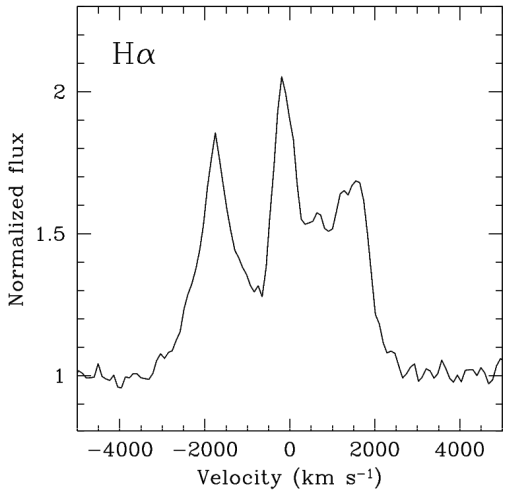
Optical evolution of CSS 081007

Main outburst only partly seen (?)

Pre-nova brightening occasionally seen in other novae

CSS 081007



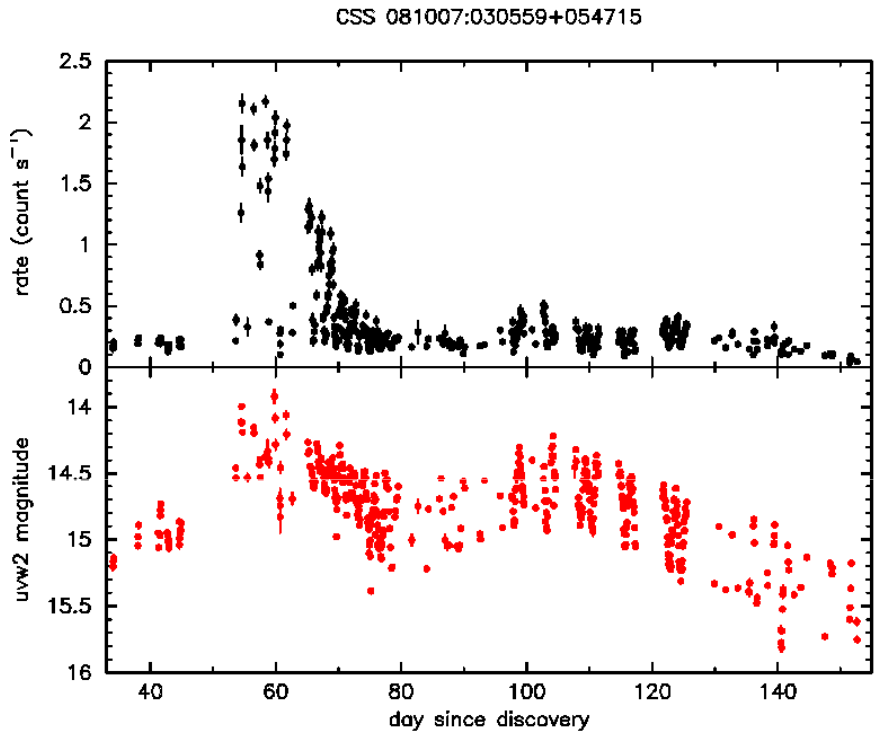


J. L. Prieto, K. Denney, O. Pejcha, R. M. Wagner
ATEL 1835

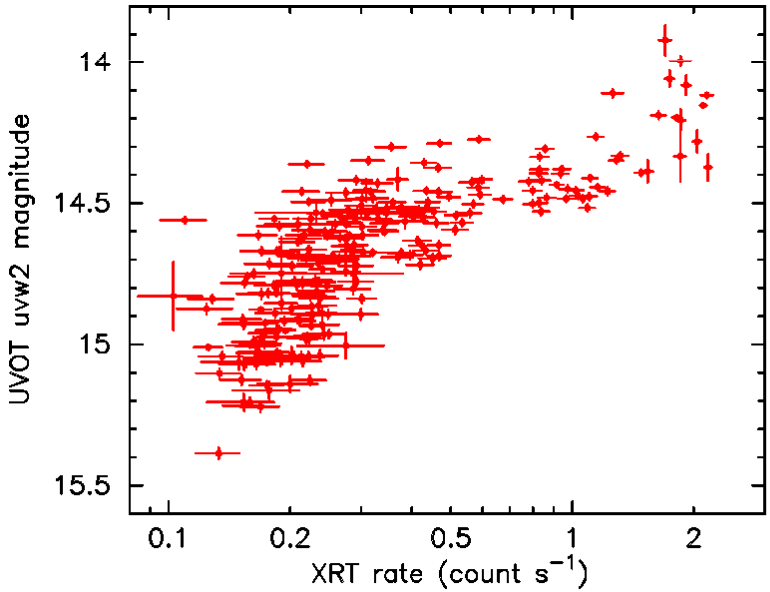
The strong Ne line lead to the suggestion of a ONe nova

Ha tri-peaked on day 23

CSS 081007

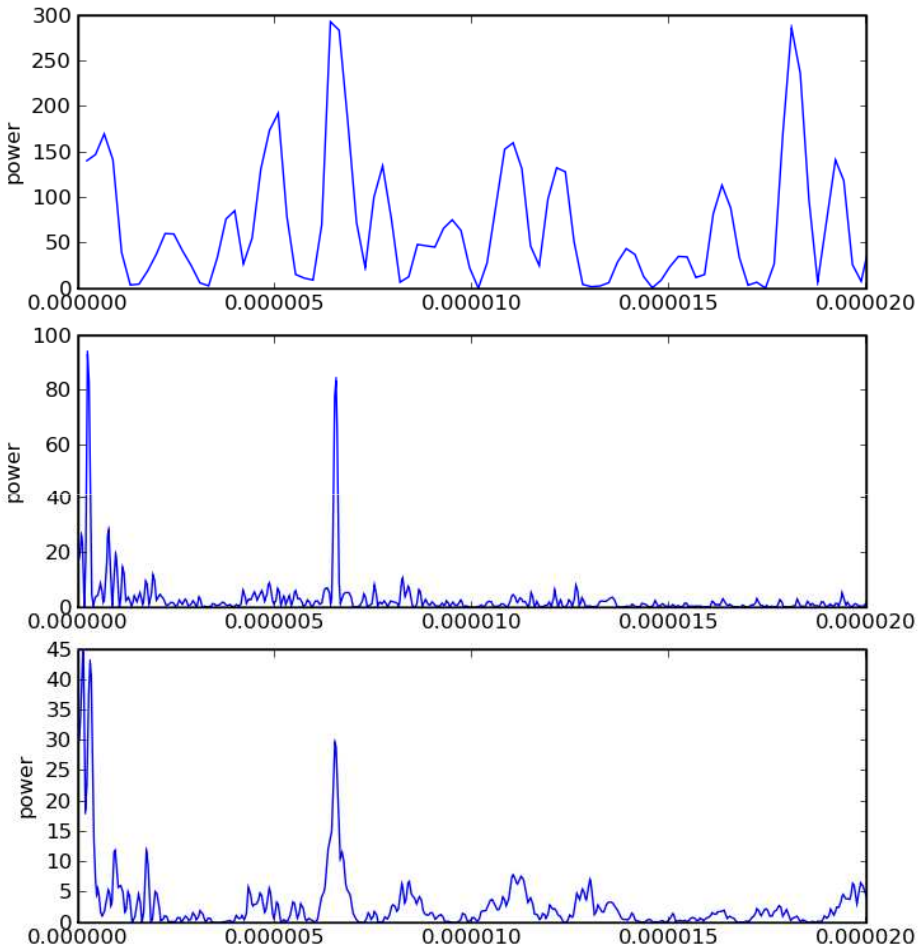


Large X-ray flux increase around 50 days, with 2nd peak around 100 days. More clearly seen in the UV flux.



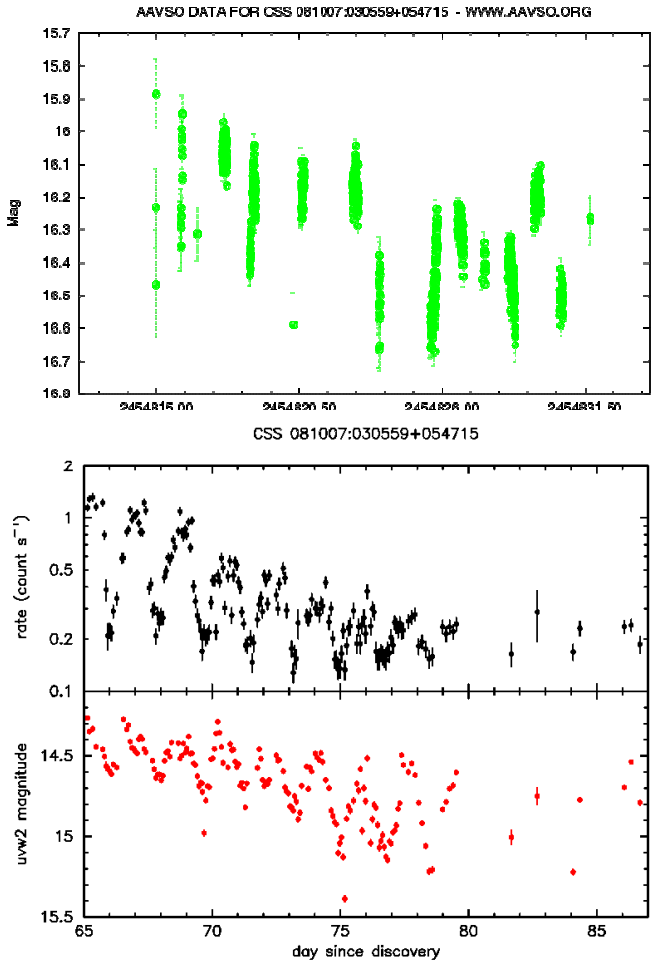
Differently from V458 Vul, the XRT and UVOT emission is more-or-less correlated in CSS 081007.

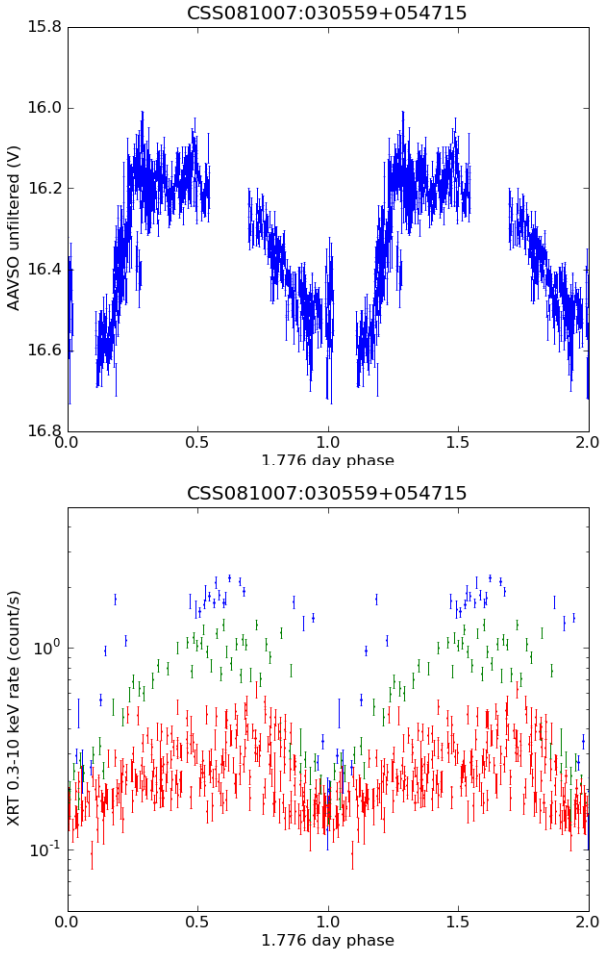
CSS 081007



AAVSO (V band), UVOT (uvw2), X-ray (0.3-10 keV) Lomb-Scargle periodograms showing the 1.77 day period

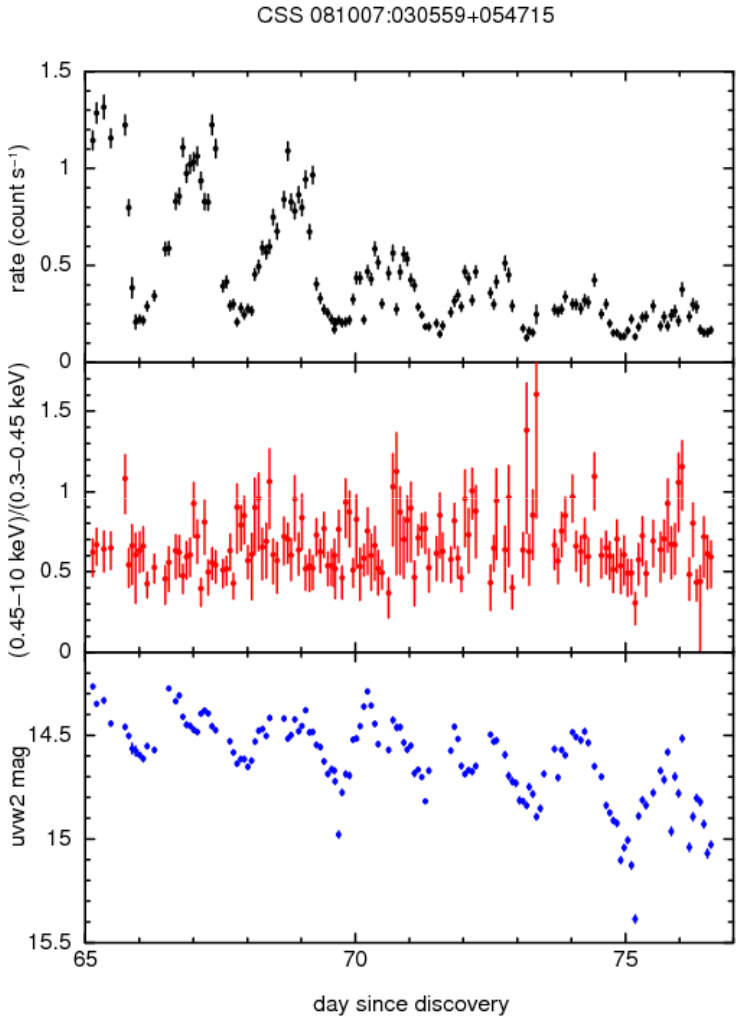
CSS 081007





AAVSO (V band), UVOT (uvw2), X-ray (0.3-10 keV) Lomb-Scargle periodograms showing the 1.77 day period

CSS 081007



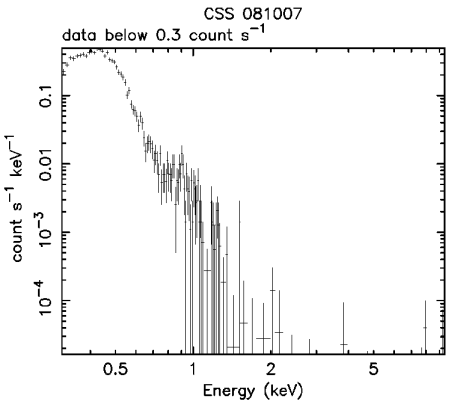
Beardmore et al, in prep

We see a ~1.77 day period in both the X-ray and UV data.

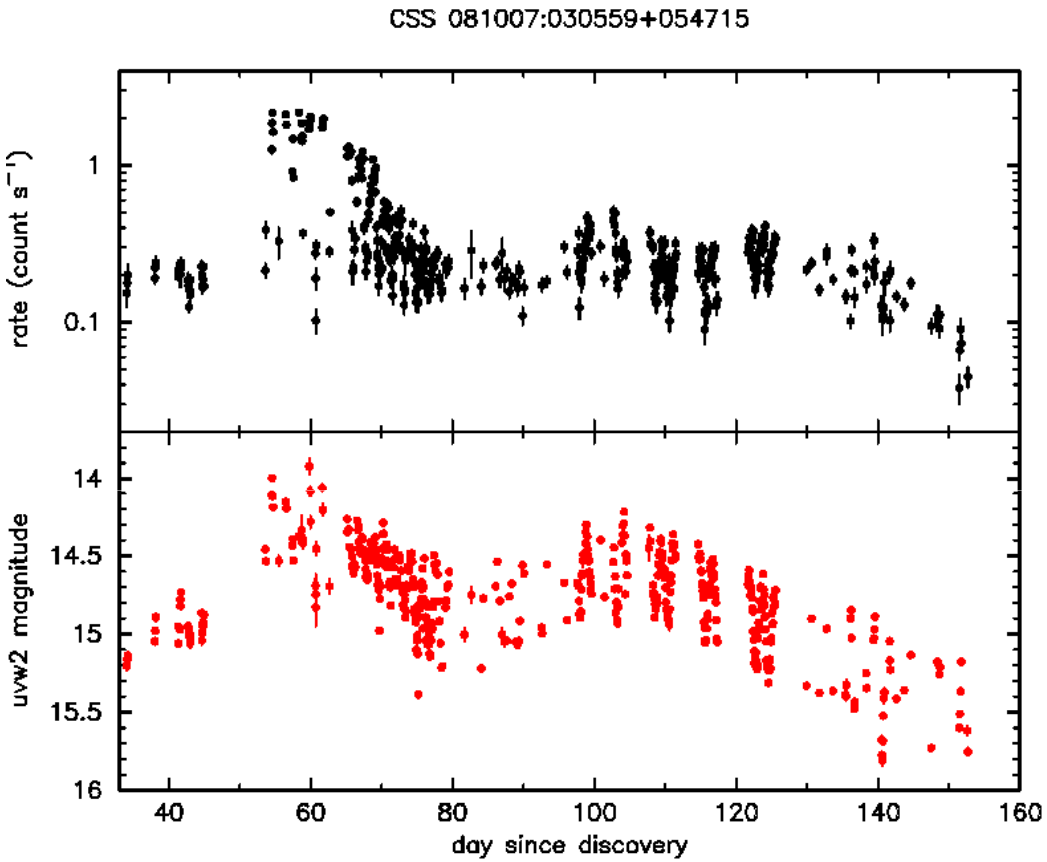
X-ray spectral shape is always soft and well fitted by a blackbody alone.

1.77 d period much longer than typical nova Porb (but GK Per), but is similar to those of the persistent SSSs

CSS is not a persistent SSS (Rosat non-detection), and Δmag~6 is much greater than pSSS range.



CSS 081007



The amplitude of the X-ray oscillations has decreased, while the UV data continue to vary strongly. The overall brightness was suggestive of a ~45 day oscillation, which we speculated might be due to a precessing disk, but recently it has been fading fast.

Summary

- The scheduling flexibility and multi-wavelength capability of Swift make it the best rapid-response nova observing facility

- Extensive datasets are obtained when novel behaviour is seen

- The short SS phase durations measured lead to high M_{WD}

Nova	SSS years
V723 Cas	>12
V574Pup	3.5
V5116 Sgr	2.9
V1281 Sco	1.2
V597 Pup	1.4
RS Oph	0.25
V2491 Cyg	0.16
V458 Vul	>1.4
CSS 081007	0.41

- Blackbody fits raise the question of the definition of SSS end (count/s vs const L at end of rising temperature phase)

- Only one X-ray bright nova (V2362 Cas) did not show a SSS (up to 2 yrs)
  - a dusty nova
  - X-rays apparently unaffected by dust formation

- CSS 081007 appears to be an unusual object