Swift X-ray and UV Observations of Novae

Julian Osborne & the Swift nova-CV group

http://www.swift.ac.uk/nova-cv/

Significant input from Andy Beardmore, Mike Bode, Jeremy Drake, Jan-Uwe Ness, Kim Page, Greg Schwarz, Sumner Starrfield, Fred Walter, …

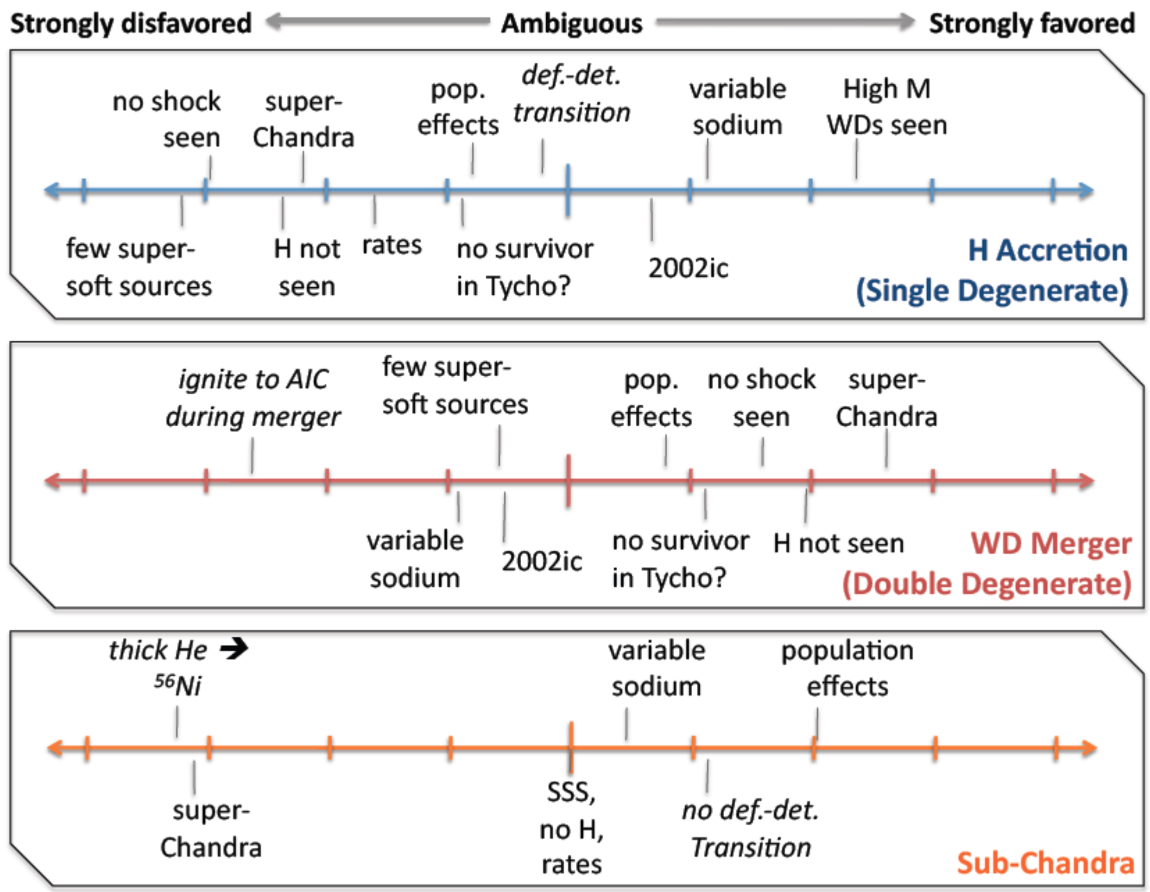
Outline

- Introduction
- A few selected highlights from Swift
- The super-soft sample
- Two objects not much discussed so far
- Summary & my questions

Why novae & why Swift?

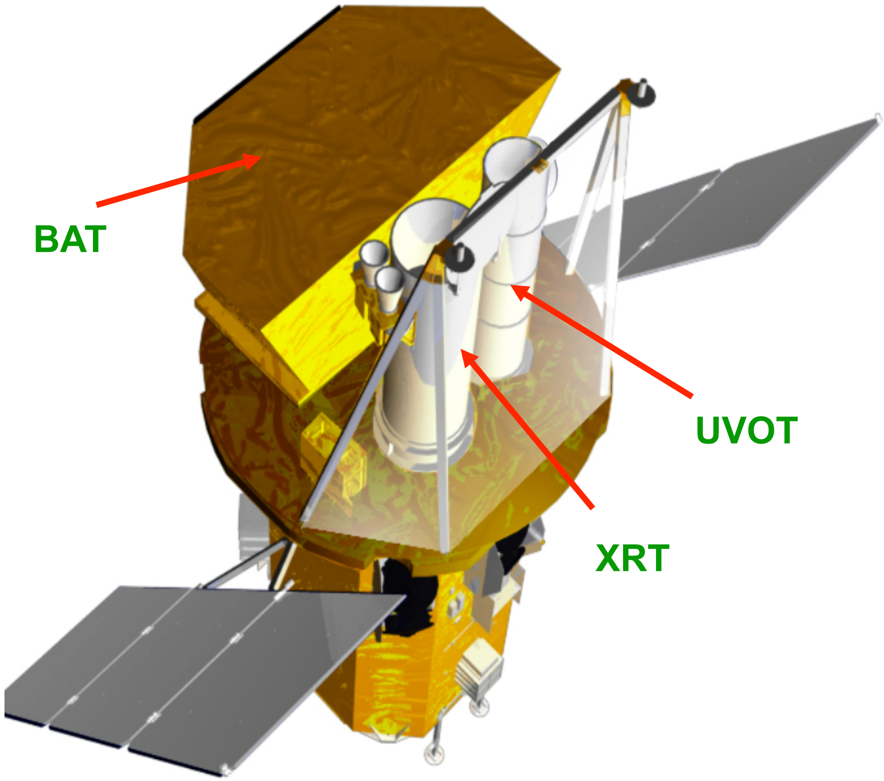
Novae:
- Some are possible SN1a progenitors
- Source of mid-weight elements: dust, planets
- Optically luminous (historically important), intrinsically interesting physics

Swift:
- Sensitive X-ray and UV/opt spectrometers
- Rapid reaction capability
- Readily available



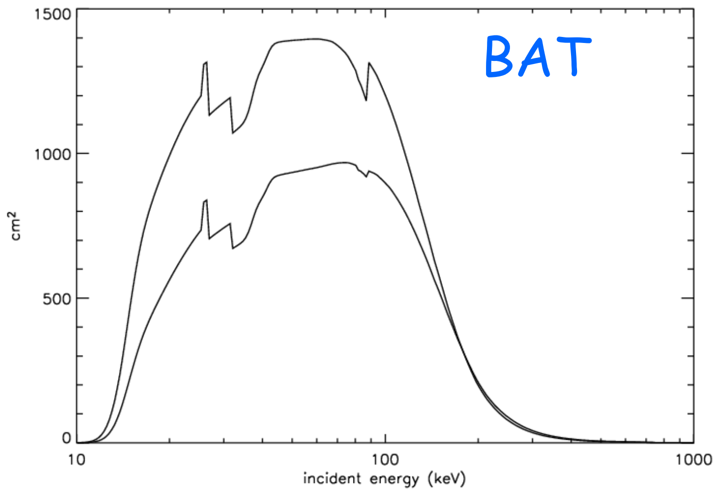
SN1a origin: weight of evidence. Howell 2011

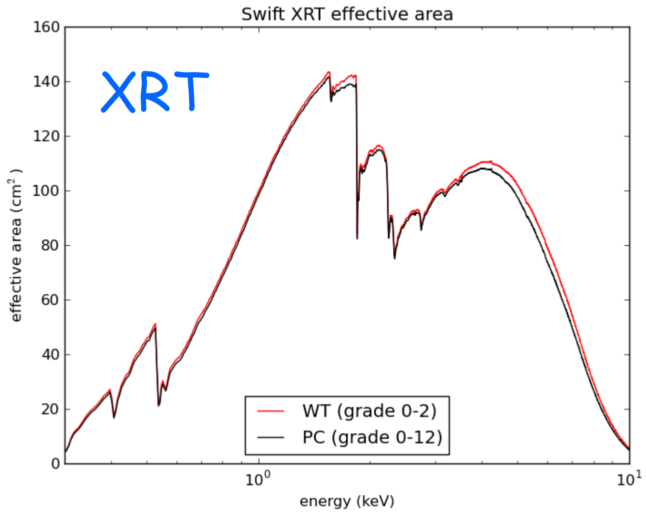
Swift Instruments

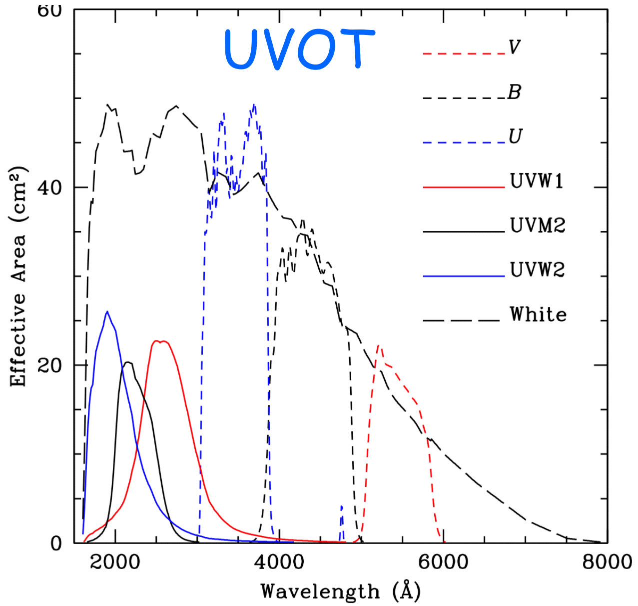


- Burst Alert Telescope (BAT)
  - Coded mask imager
  - 1 arcminute positions
  - New CdZnTe detectors
  - Detects ~90 GRBs per
  - Most sensitive gamma-ray imager
  - 15-350 keV
- X-Ray Telescope (XRT)
  - Arcsecond positions
  - CCD spectroscopy
  - 0.2-10 keV
- UV/Optical Telescope (UVOT)
  - Sub-arcsec imaging
  - Grism spectroscopy
  - 24th mag sensitivity (1000 sec)
  - 170-650 nm
- Spacecraft
  - Autonomous re-pointing in 1 min

Swift Effective Areas







X-rays from novae

Potential sources of X-ray emission from novae (Krautter 2008):

- Thermal emission from hot white dwarf
  - shock breakout
  - residual nuclear burning after ejecta dispersal — Swift

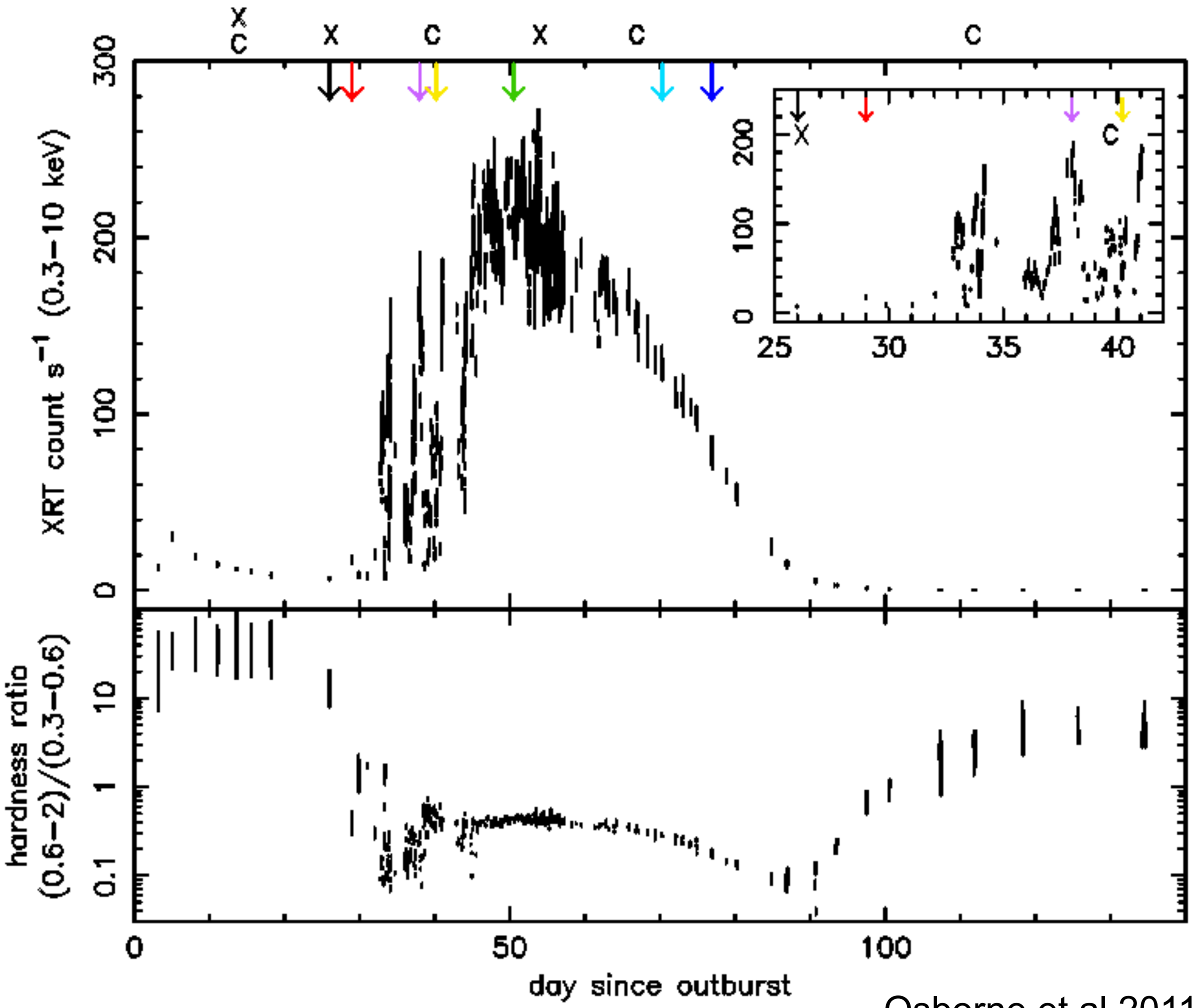
- High velocity shocks — Swift
  - internal shocks within the ejecta
  - shock of ejecta with shell from previous nova or planetary nebula
  - shock of later fast wind with earlier slower wind

- Re-established accretion — Swift

Swift novae stats

- Swift has observed 56 novae within 4000 days of outburst
- 35 detected in X-rays
- 9 novae have >100 ksec each: N Mon 2012, T Pyx, U Sco, KT Eri, N LMC 2009, HV Cet, V2491 Cyg, V458 Vul & RS Oph
- Observations start within 1 day (pre-nova for V2491 Cyg, U Sco & T Pyx)

Highlights: RS Oph

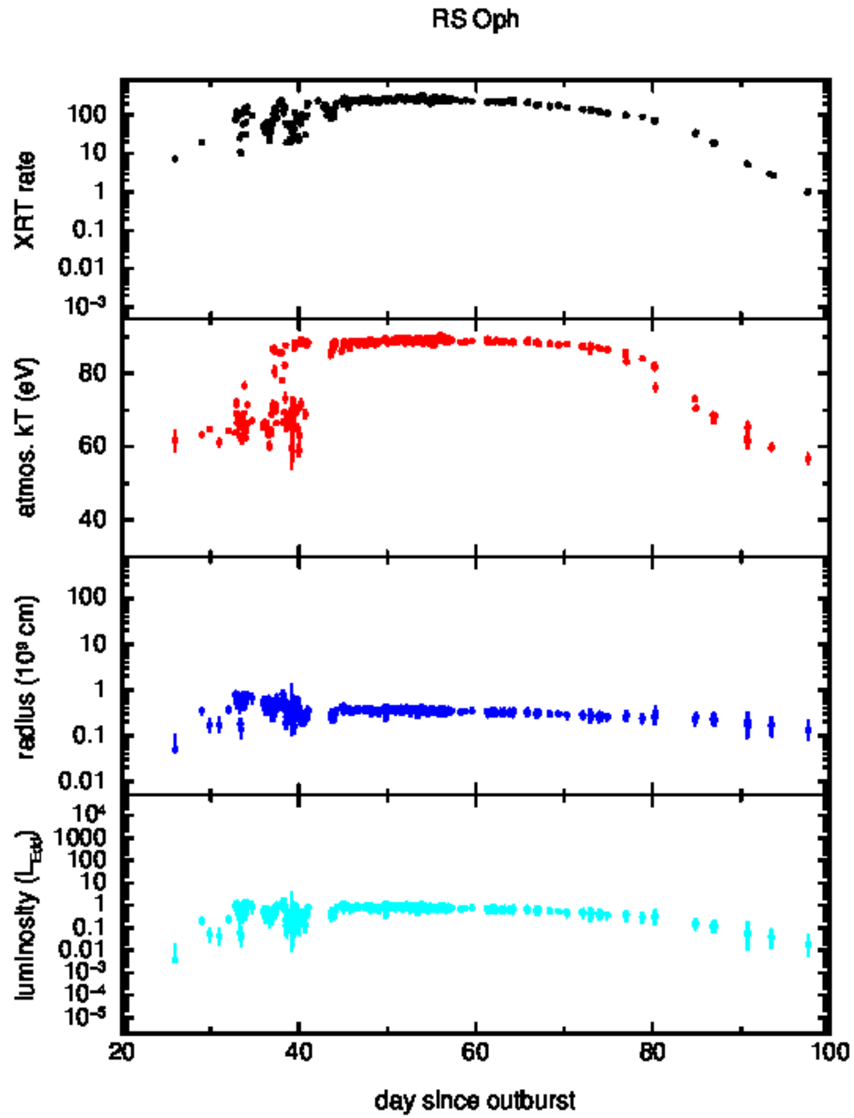


Osborne et al 2011

X-ray (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

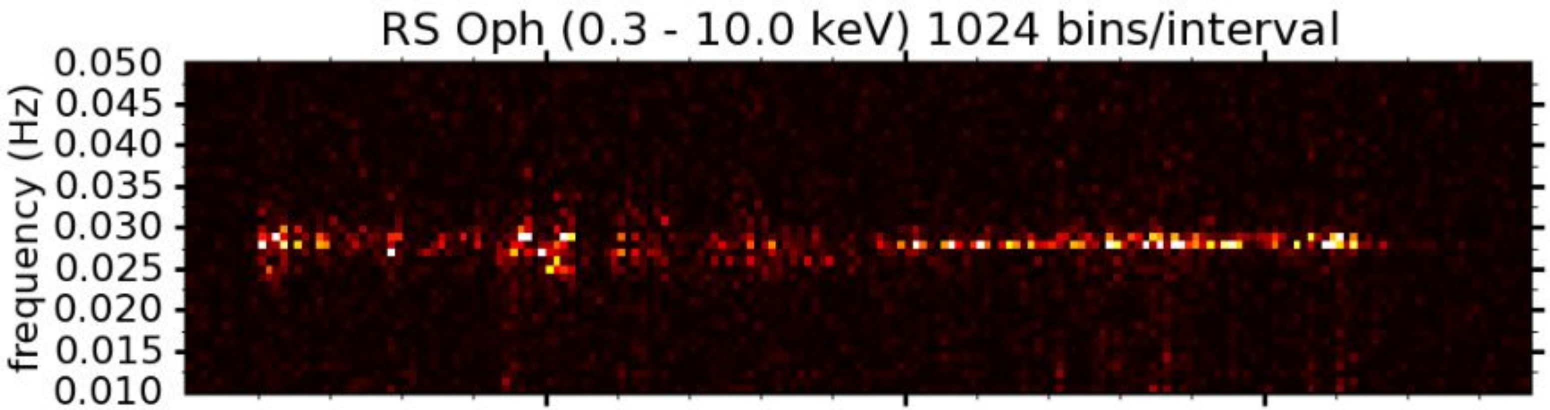


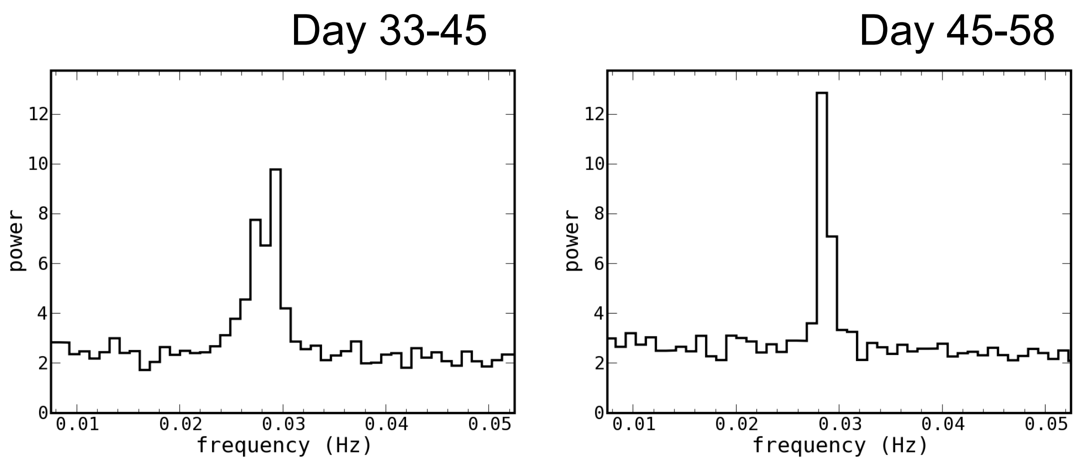
Rauch NLTE model fits assuming N_H model from expanding shock in red giant wind (Bode+ 2006)

Constant temperature phase clearly apparent

RS Oph

A quasi-periodic modulation



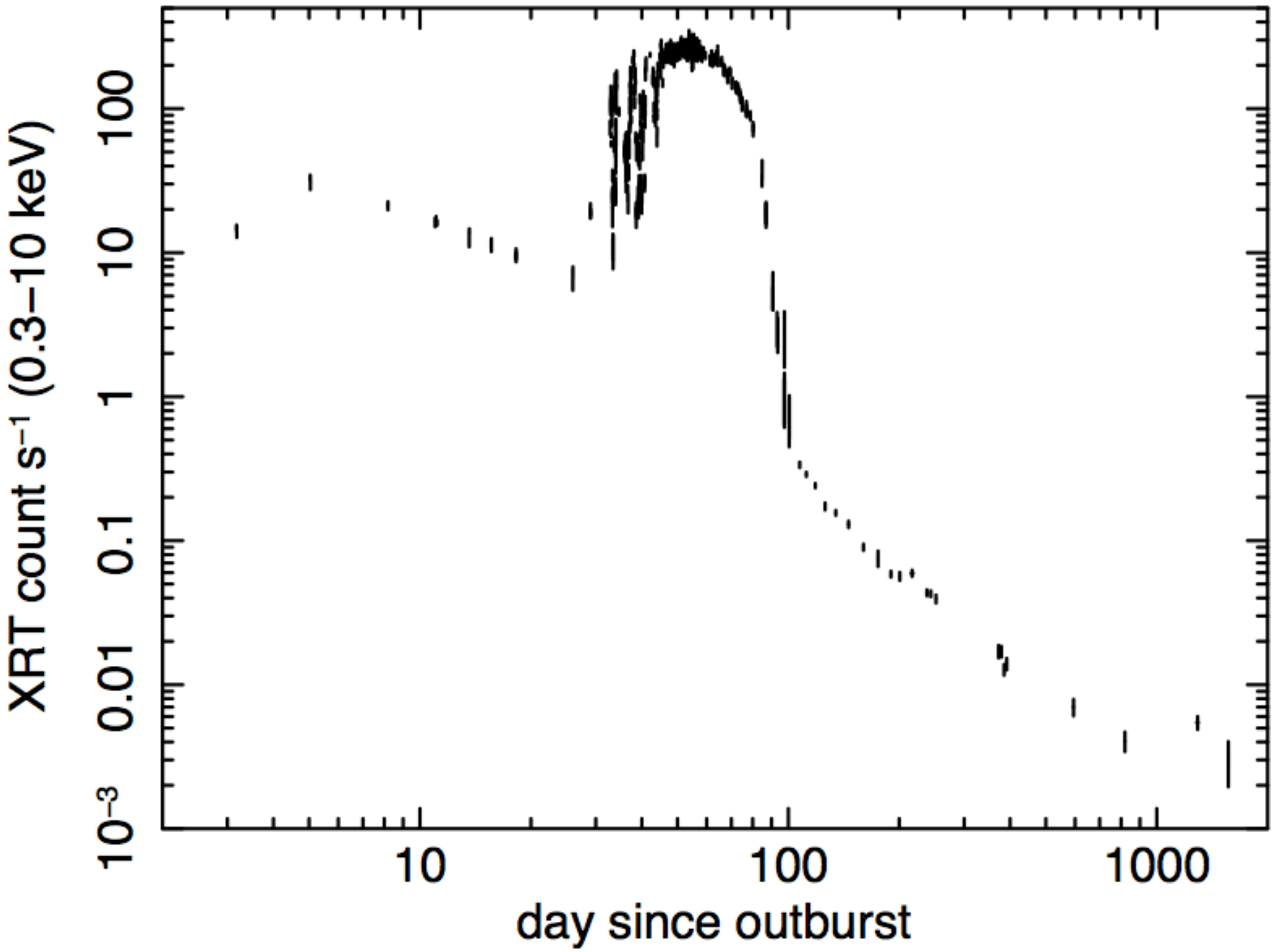


Osborne et al 2011

Period near 35s in soft X-rays between days 33-59 (discontinuous time-series)

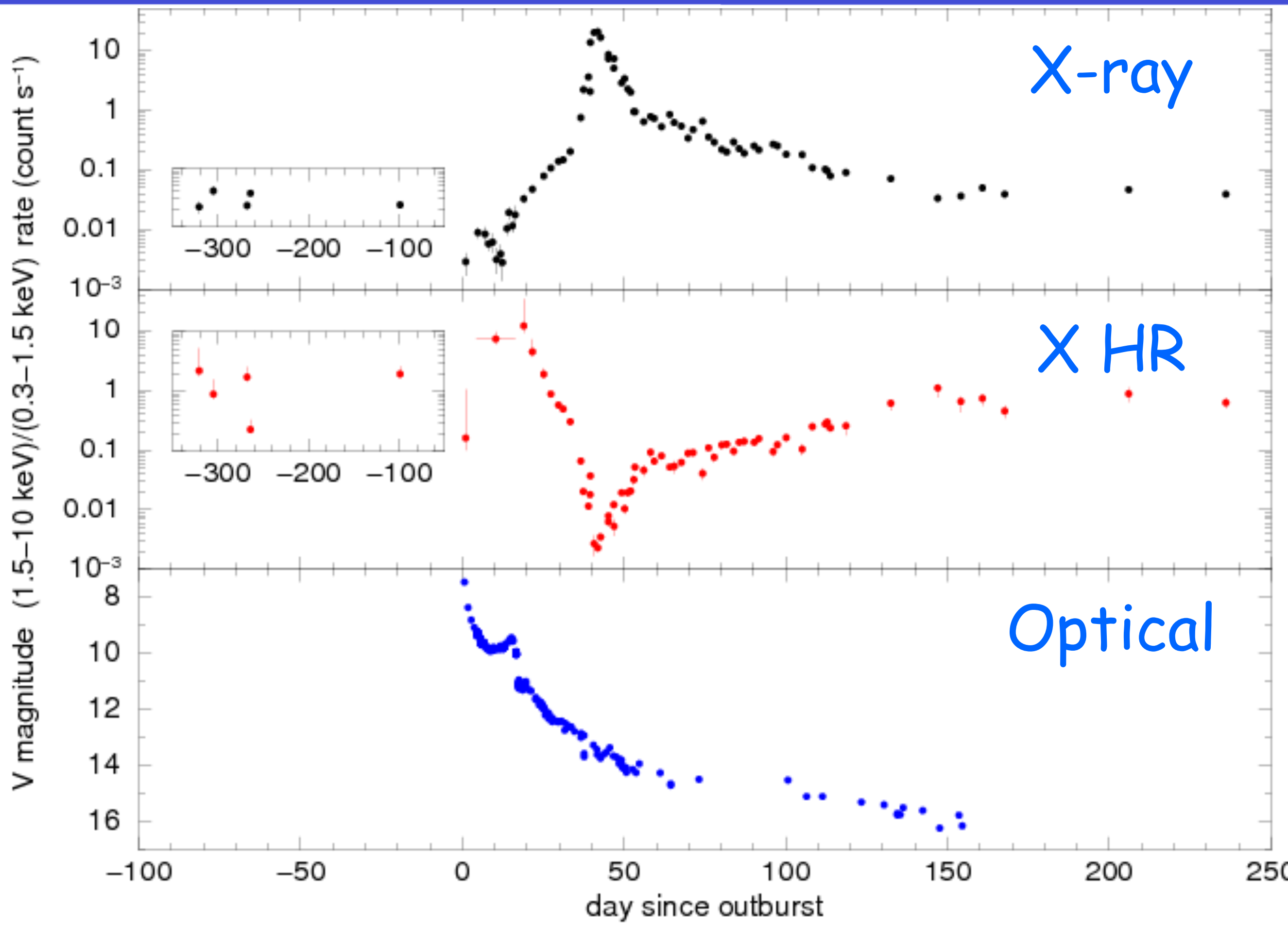
- WD spin?
- Nuclear burning instability?

RS Oph



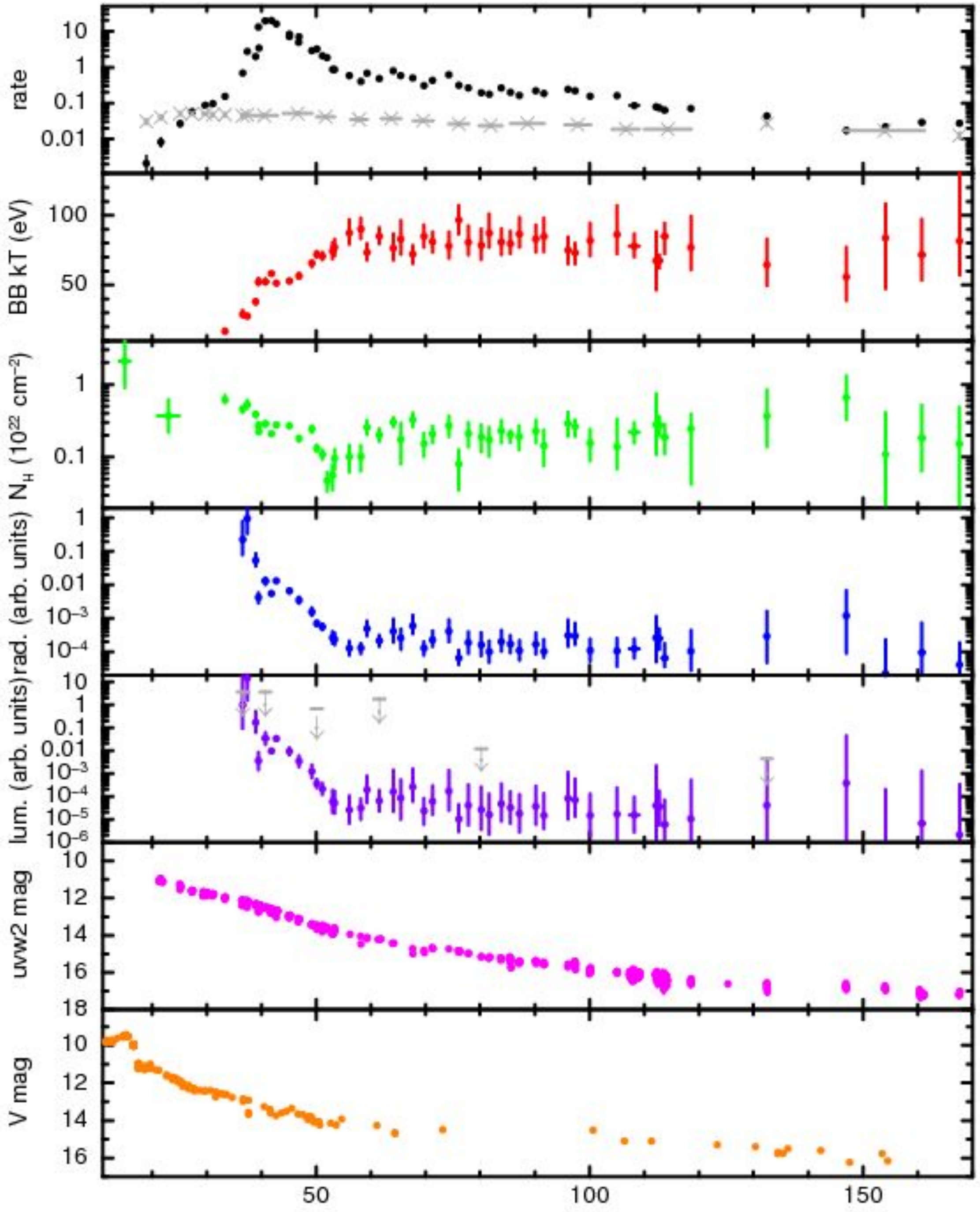
Late hard X-ray phase not yet modelled

Highlights: V2491 Cyg



Page et al 2010

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.



Blackbody fit parameters while the super-soft source was visible

Absolute values probably not reliable

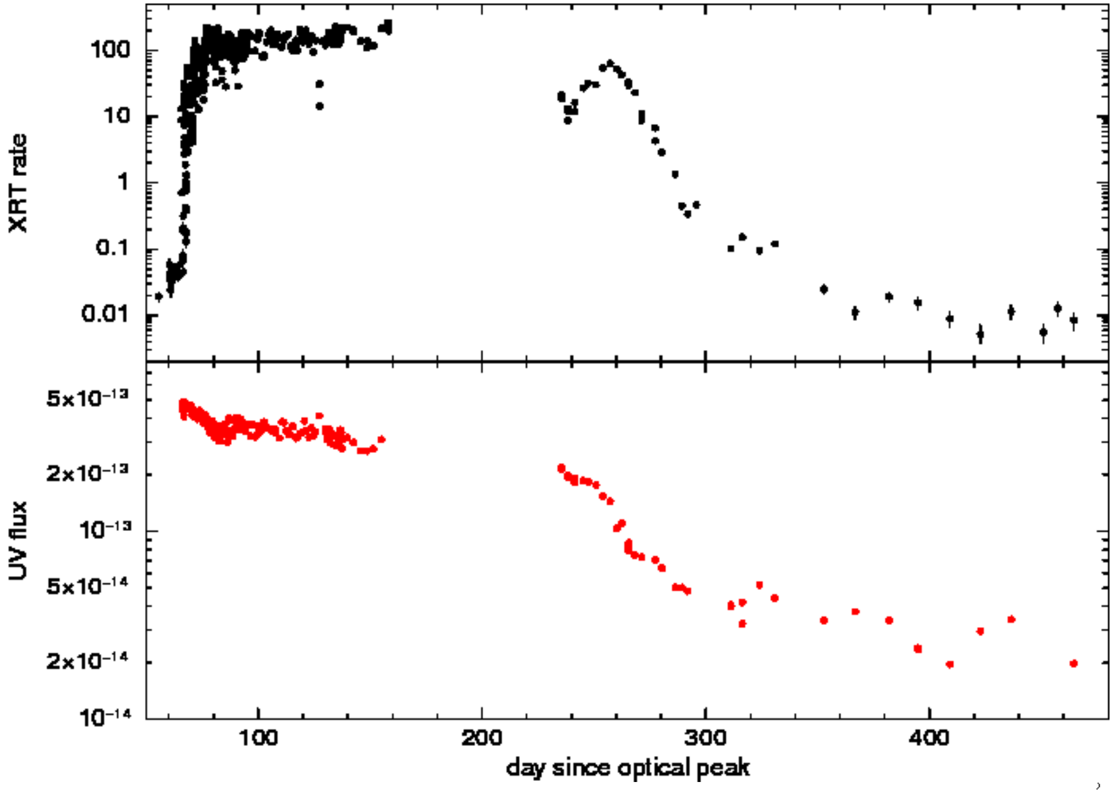
A rising temperature and shrinking radius are seen between days 30 - 57

Where is the expected constant luminosity nuclear burning phase?

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

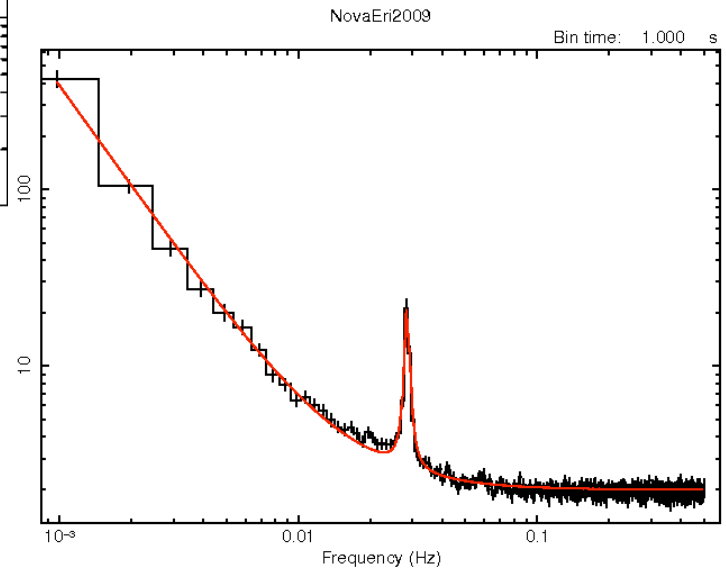
V2491 Cyg - Page et al 2010

Highlights: KT Eri



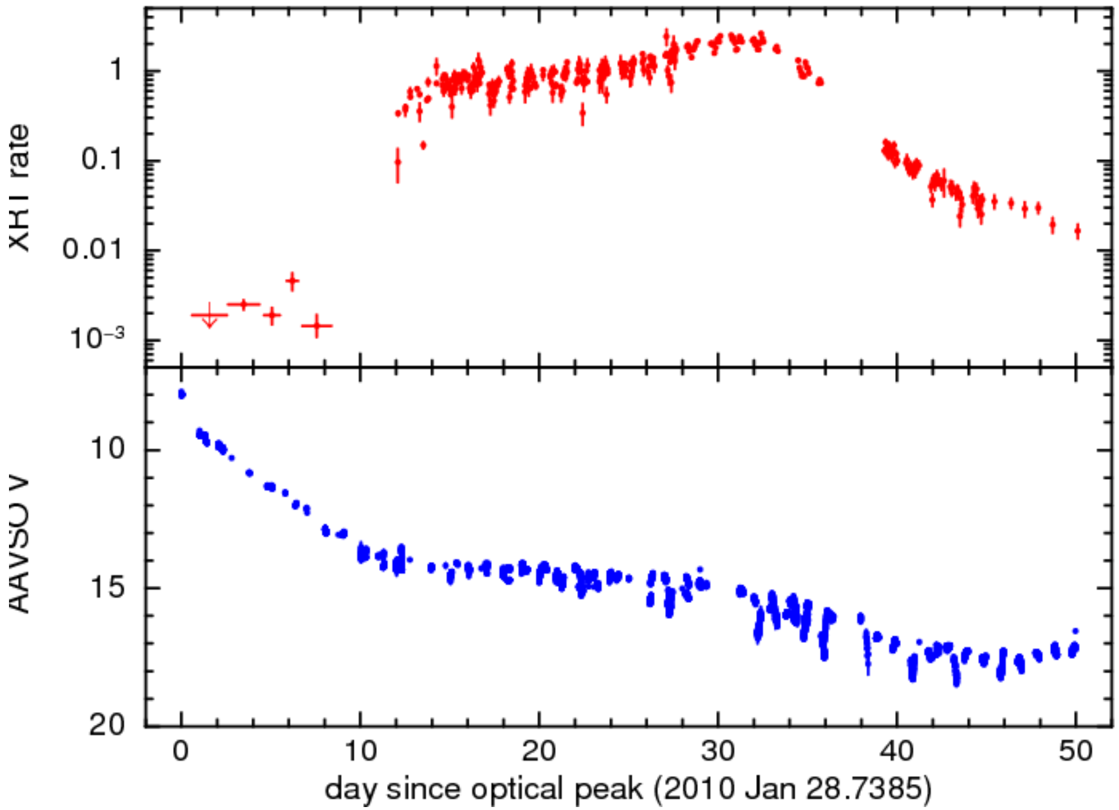
Schwarz et al 2011

P = 35 sec



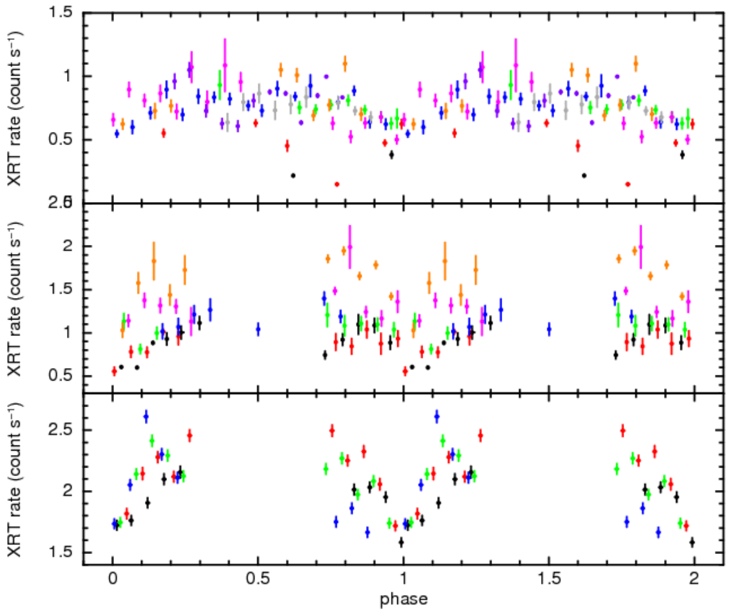
Beardmore et al 2010

Highlights: U Sco



LC: Schwarz et al 2011

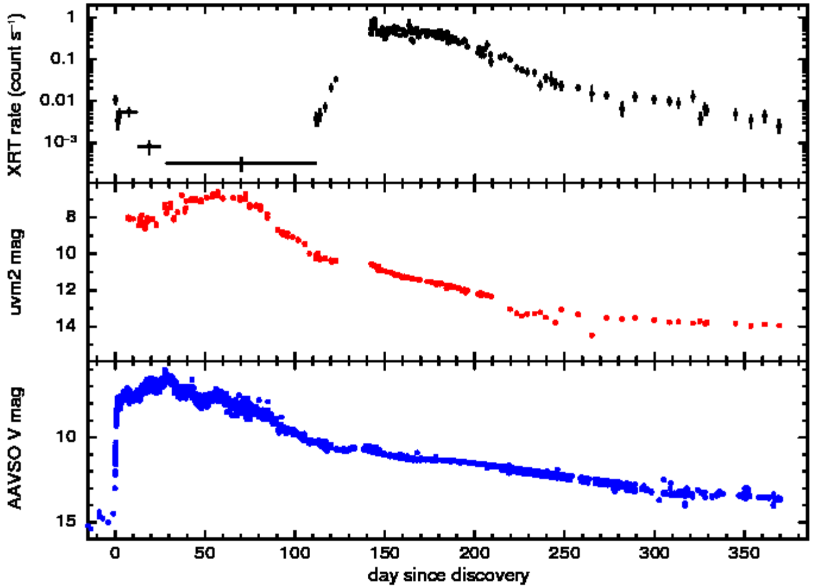
- Only eclipsing RN
- Broad eclipses
- Pagnotta et al in prep



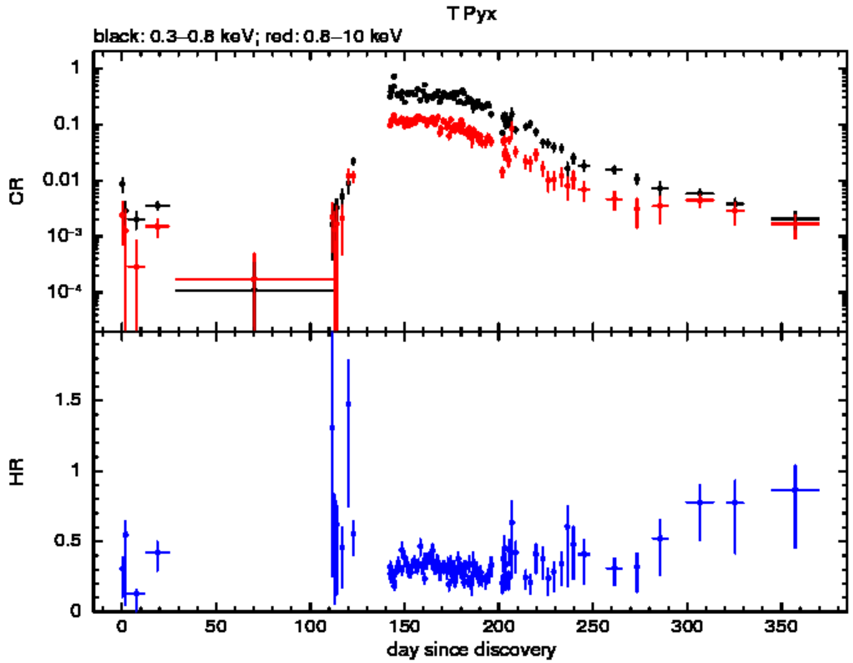
XMM LCs in Ness et al 2011

- Re-forming disk witnessed

Highlights: T Pyx



- Slower nova (unusual for Swift)
- Odd high accretion rate (P=1.83 hr, below the CV period gap)



This is not a typical SSS

- Harder flux falls & rises with SSS
- Delayed ejection (Nelson+ arXiv: 1211.1312)

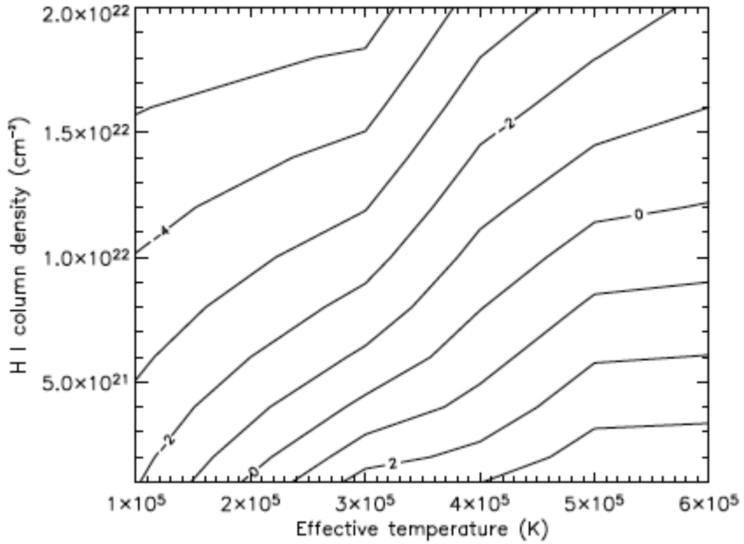
X-ray nova samples

Pre-Swift samples:

- Orio, Covington & Ögelman (2001) 108 novae observed by Rosat, >50% were hard sources, but just 3 were SS. Showed $T_{SS, off}$ <10 yrs
- Greiner, Orio & Schartel (2003) compiled 9 SS novae with limits on $T_{SS, off.}$ Anti-correlations: $T_{SS, off}$-V_{exp}, $T_{ss, off}$-P_{orb}, & poss correlation of $T_{SS, off}$- un-ejected mass.

Ness et al 2007 (paper 1):

- 12 Swift CNe, obs'd few x10 – few x100 days
- 5 faint X-ray sources, 2 of which were SS

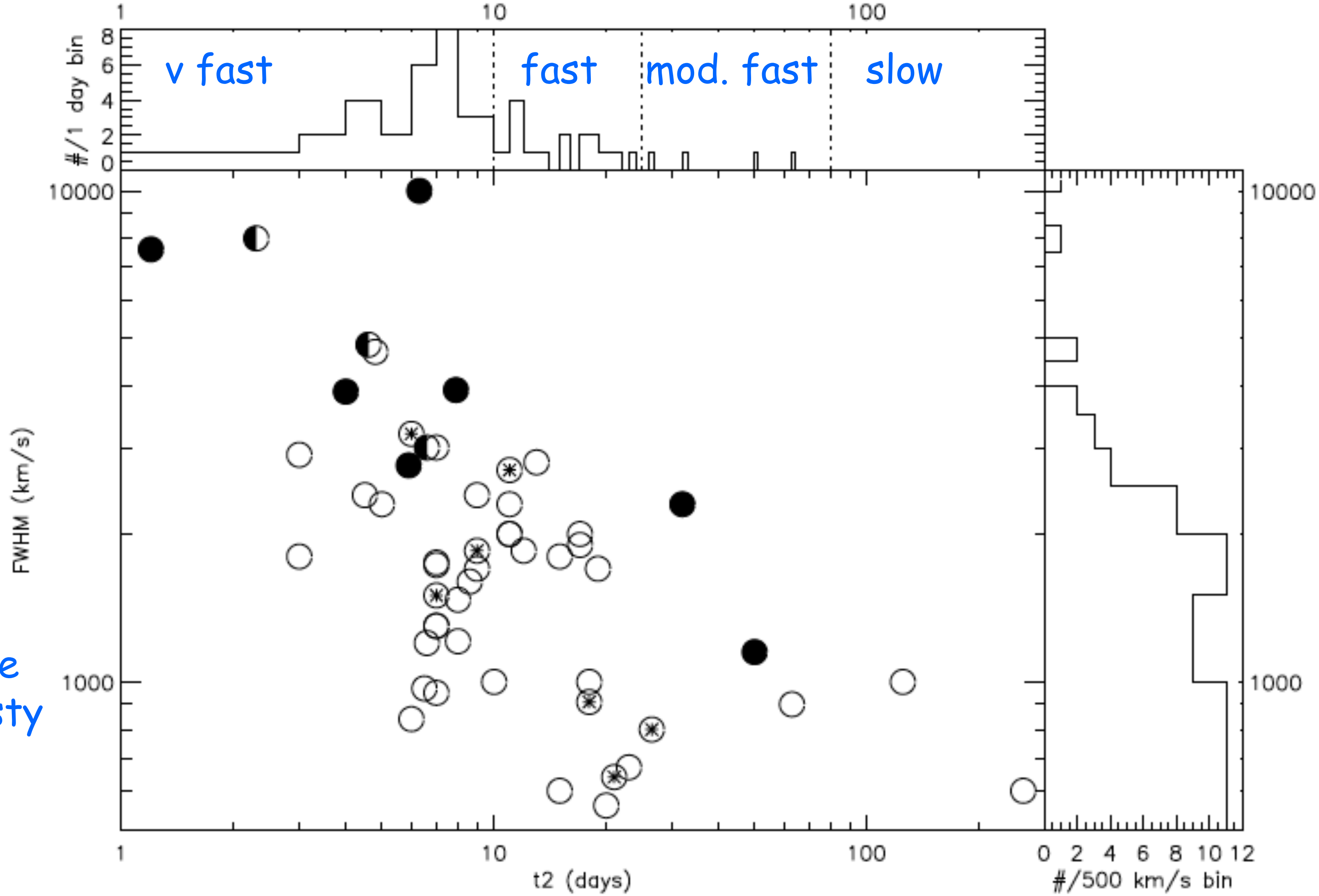


Log flux contours (NH, T)
Ness et al 2007

Schwarz+2011 ApJS super-soft sample

- All public pointed X-ray observations of novae to 1 Aug 2010
    - Rosat, BeppoSax, ASCA, RXTE, XMM-Newton, Chandra
    - but most data from Swift
- By far the largest exposure time on X-ray data on novae to date
- 57 Galactic & 5 Magellanic Cloud novae
- 7 – 10 recurrent novae
- 26 novae seen as Super Soft Sources
- Not an un-biased sample:
    - mostly TOO observations of recent optically & X-ray bright novae (observations continuing)
    - biased towards fast novae
- Expansion velocities, decline rates, orbital periods, etc taken from literature

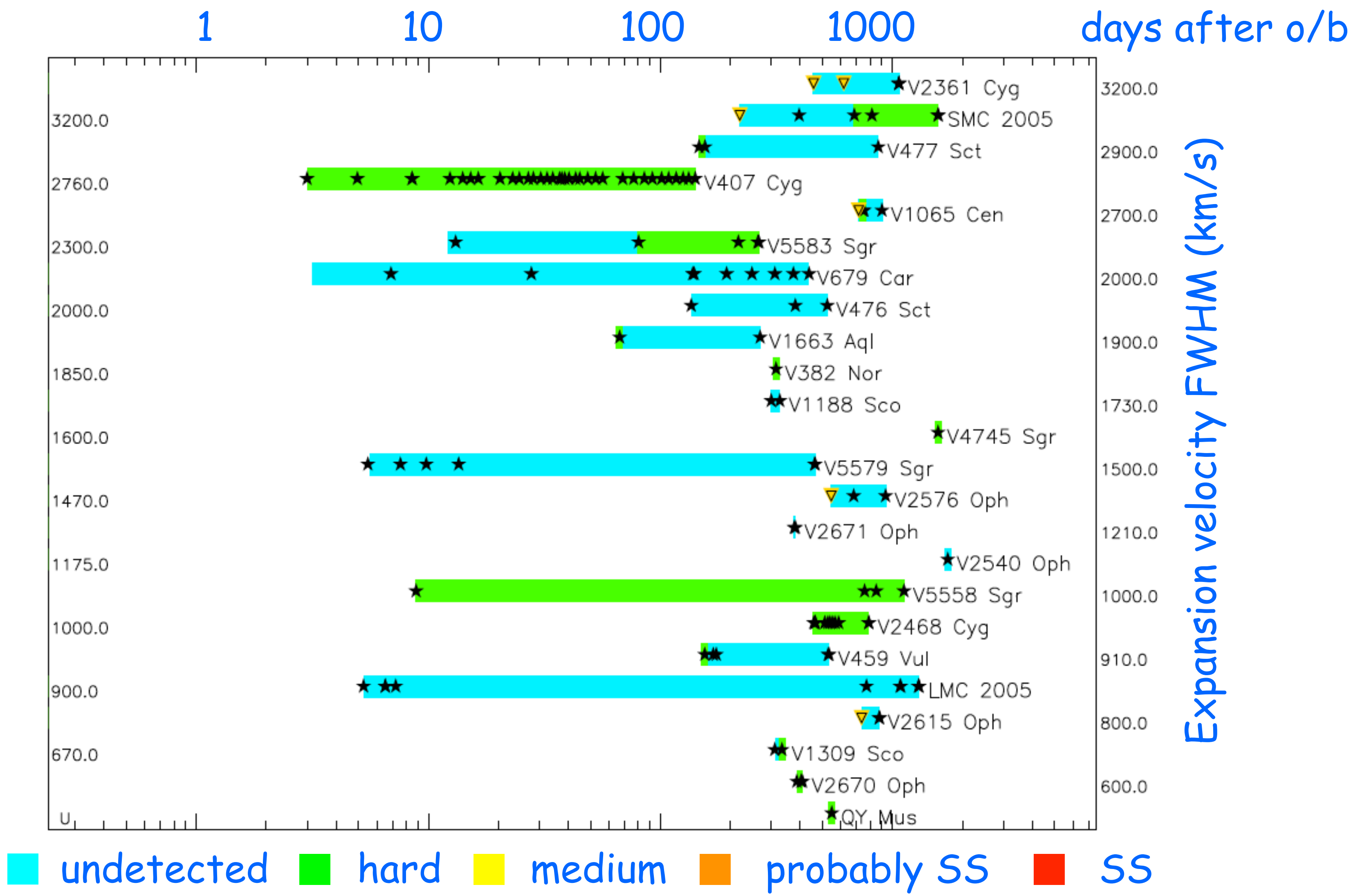
Sample mostly very fast



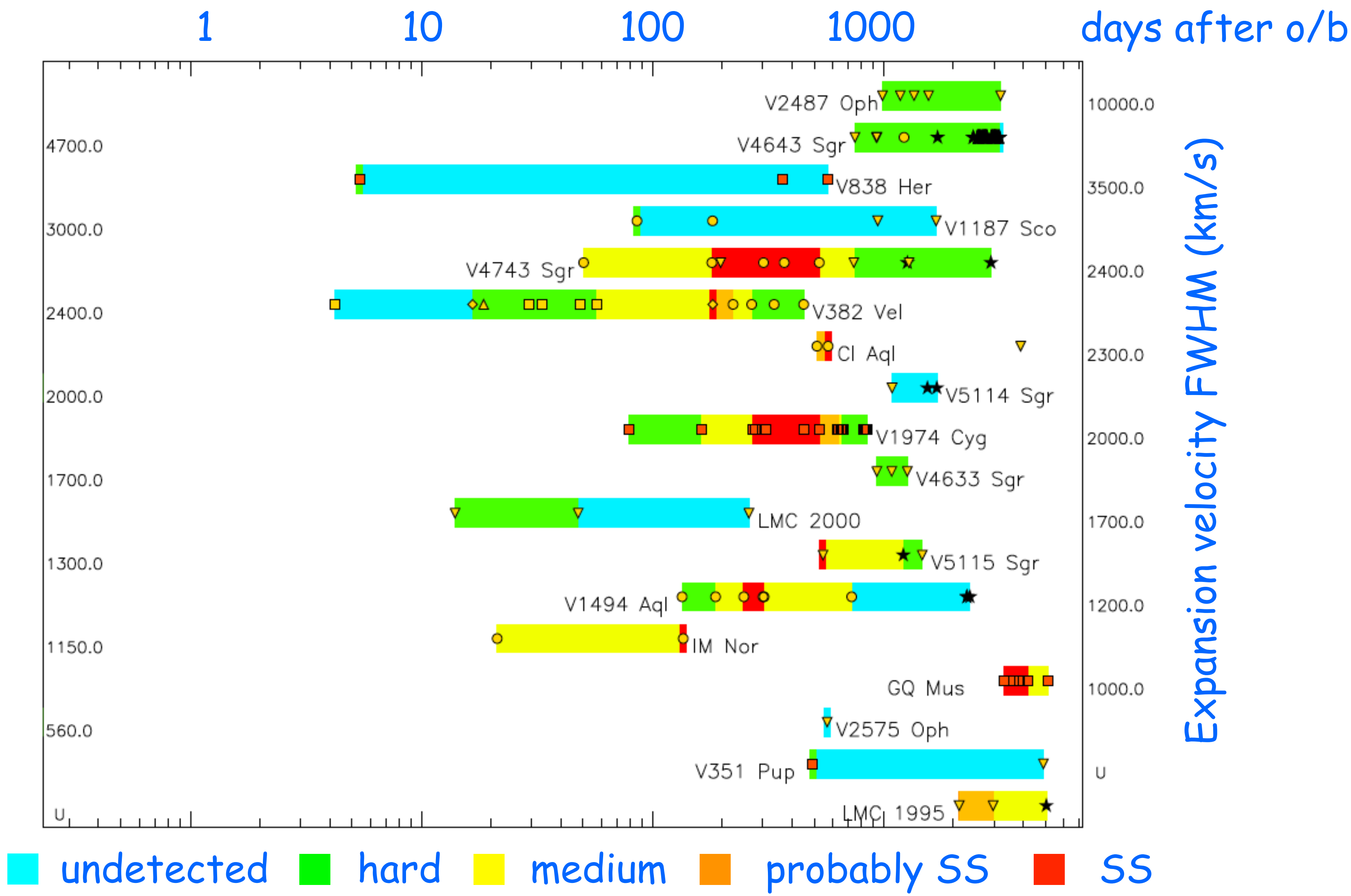
● RNe
× dusty

Super Soft Swift Novae

Non-SS Swift Novae



Pre-Swift Novae



SS Novae stats

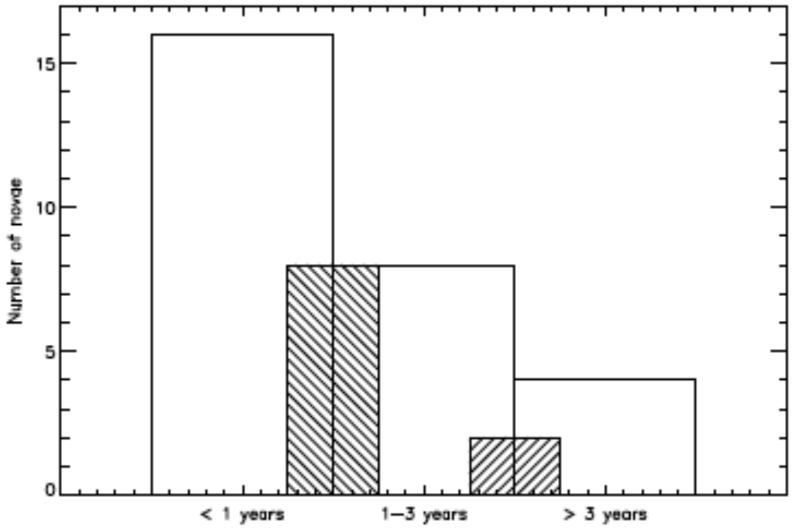
SS (& prob SS) defined as (H-S)/(H+S) < -0.3, where H=1.0-10 keV c/s & S=0.3-1.0 keV c/s

- High expansion velocity ➔ high WD mass
- High expansion velocity ➔ early & short SS phase
  - Absorption & a strong hard component can be confusing
- The fastest novae have an early hard phase
  - Internal shocks in ejecta: $kT_{shock} = (3/16)\langle m \rangle V^2$
- Lack of SSS in previous samples due to observations being insufficiently early or late

Super Soft Duration

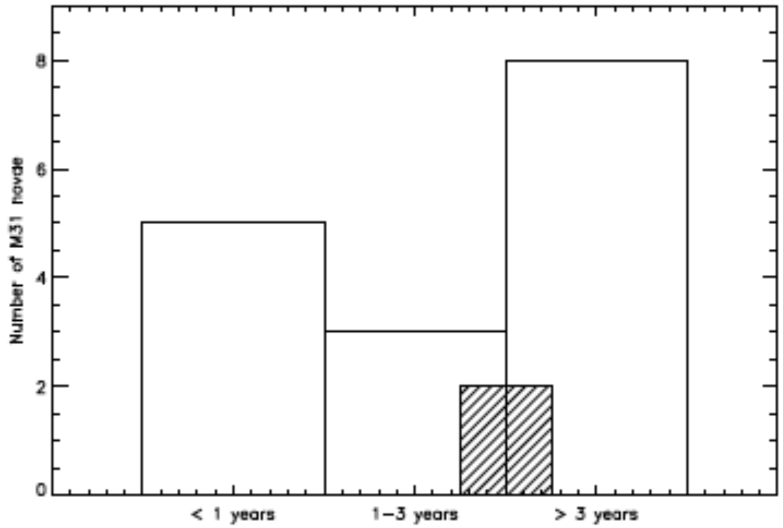
Galaxy/MC

This sample



M31

Heinze+ 2010



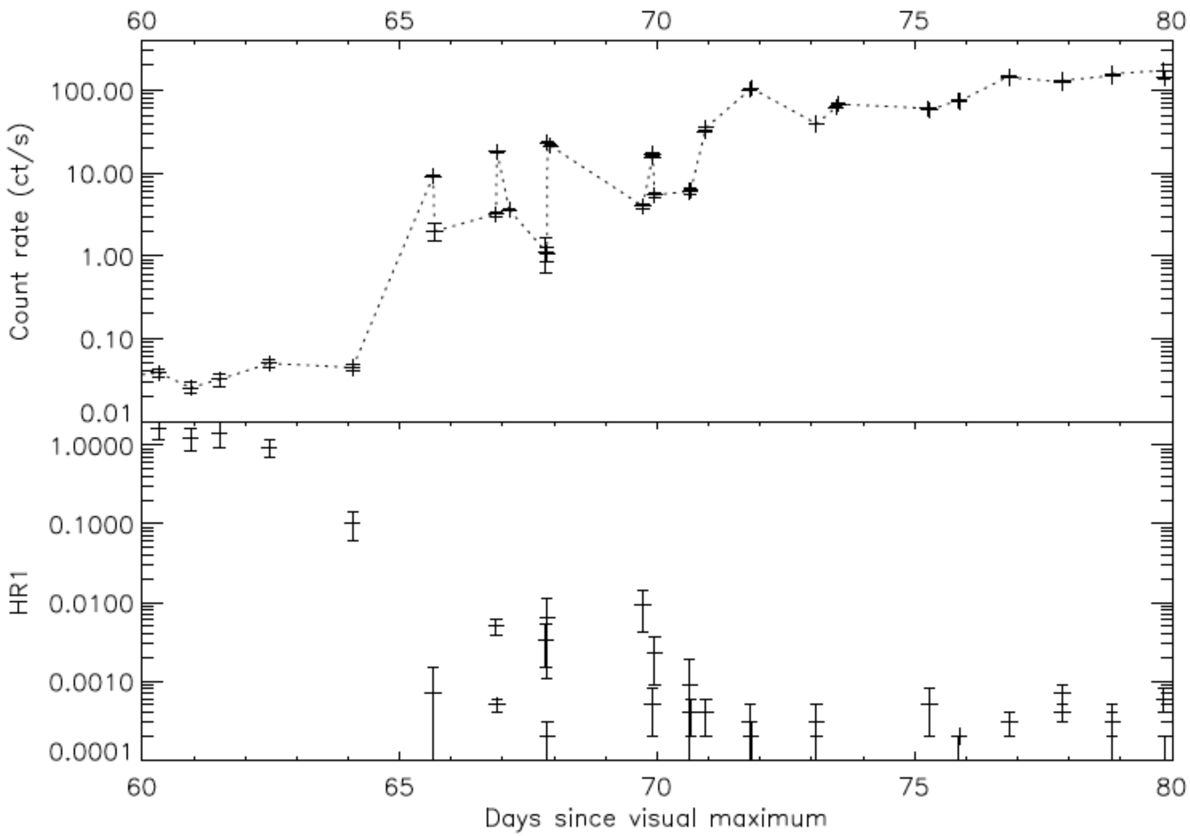
<1 yr 1-3 yr >3 yr

<1 yr 1-3 yr >3 yr

Selection effect!

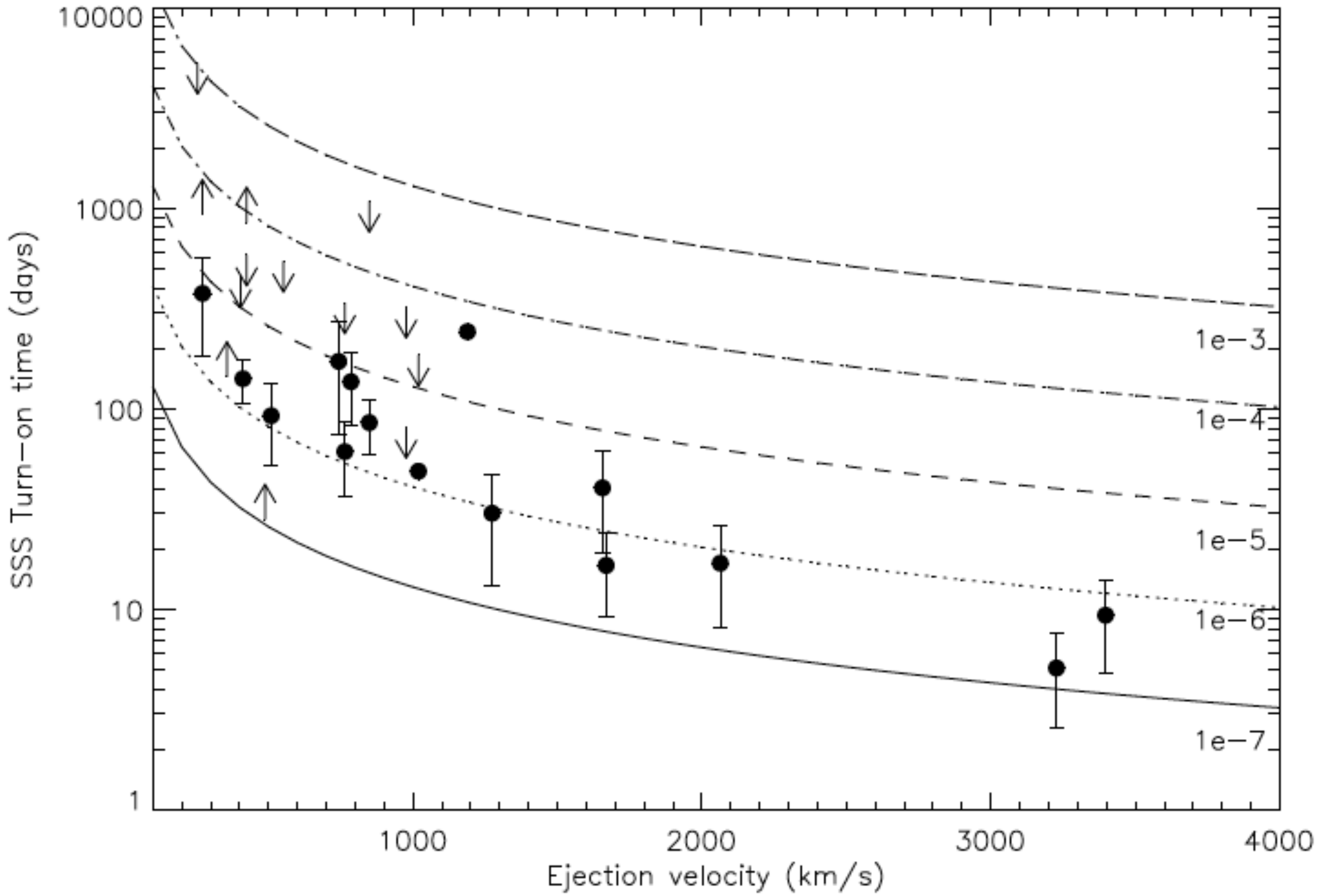
Our sample is biased to fast novae

KT Eri: chaotic SS turn-on



Chaotic turn-on of SSS seen in 7 novae: 3 RNe and 2 poss RNe, but also in the less-energetic V458 Vul. Origin unclear: could be L, T, N_H or ξ.

SS novae turn-on times



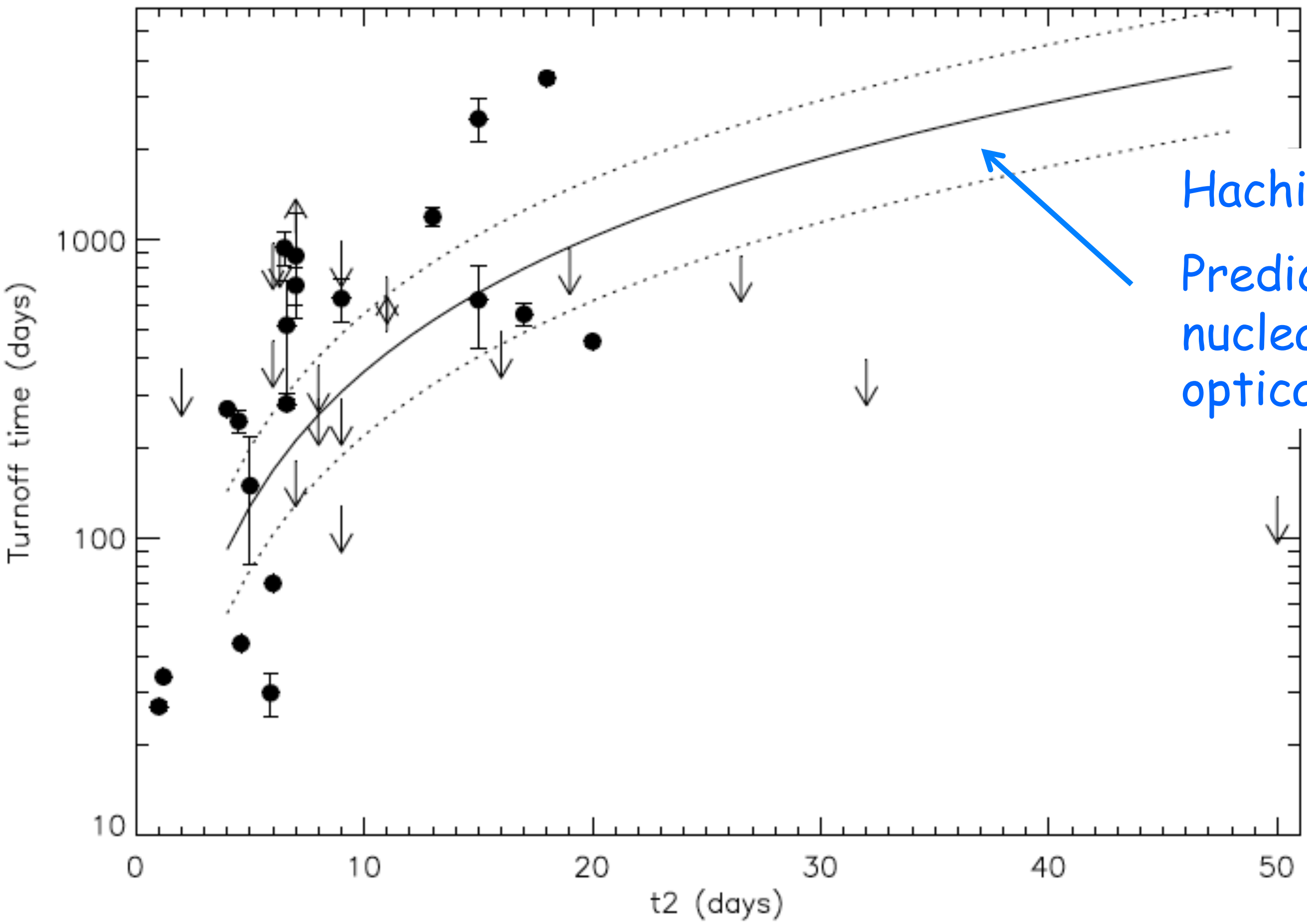
Ejected mass ↑

Shore (2008): Mej ~ $N_H.V_{exp}{}^2.t_{on}{}^2$

The fastest novae eject the least mass

They become SSS early as the ejecta thin out quicker

SS novae turn-off times

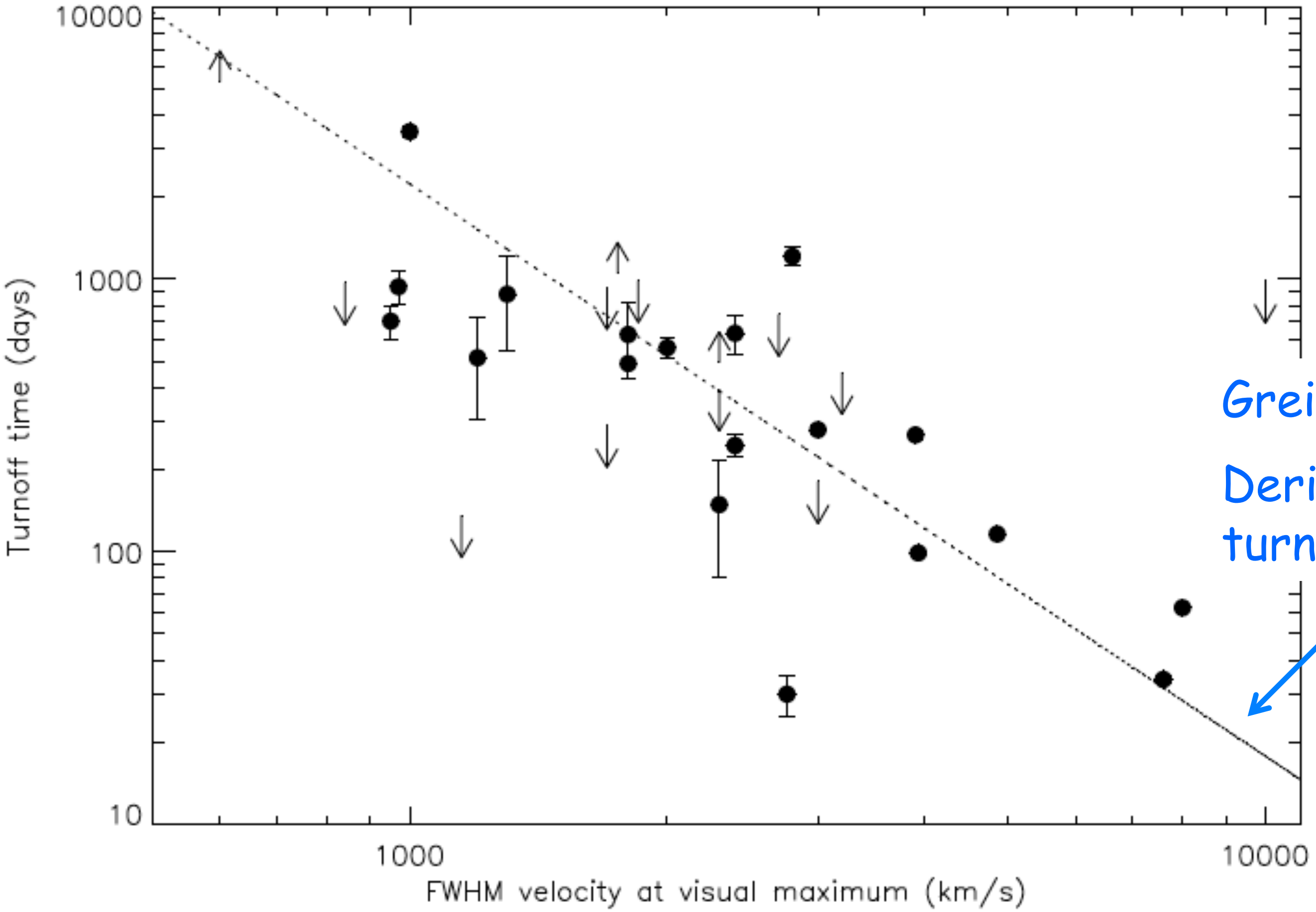


Hachisu & Kato 2010

Predicted end of nuclear burning from optical LC break time

Days to decline 2 magnitudes

SS novae turn-off times

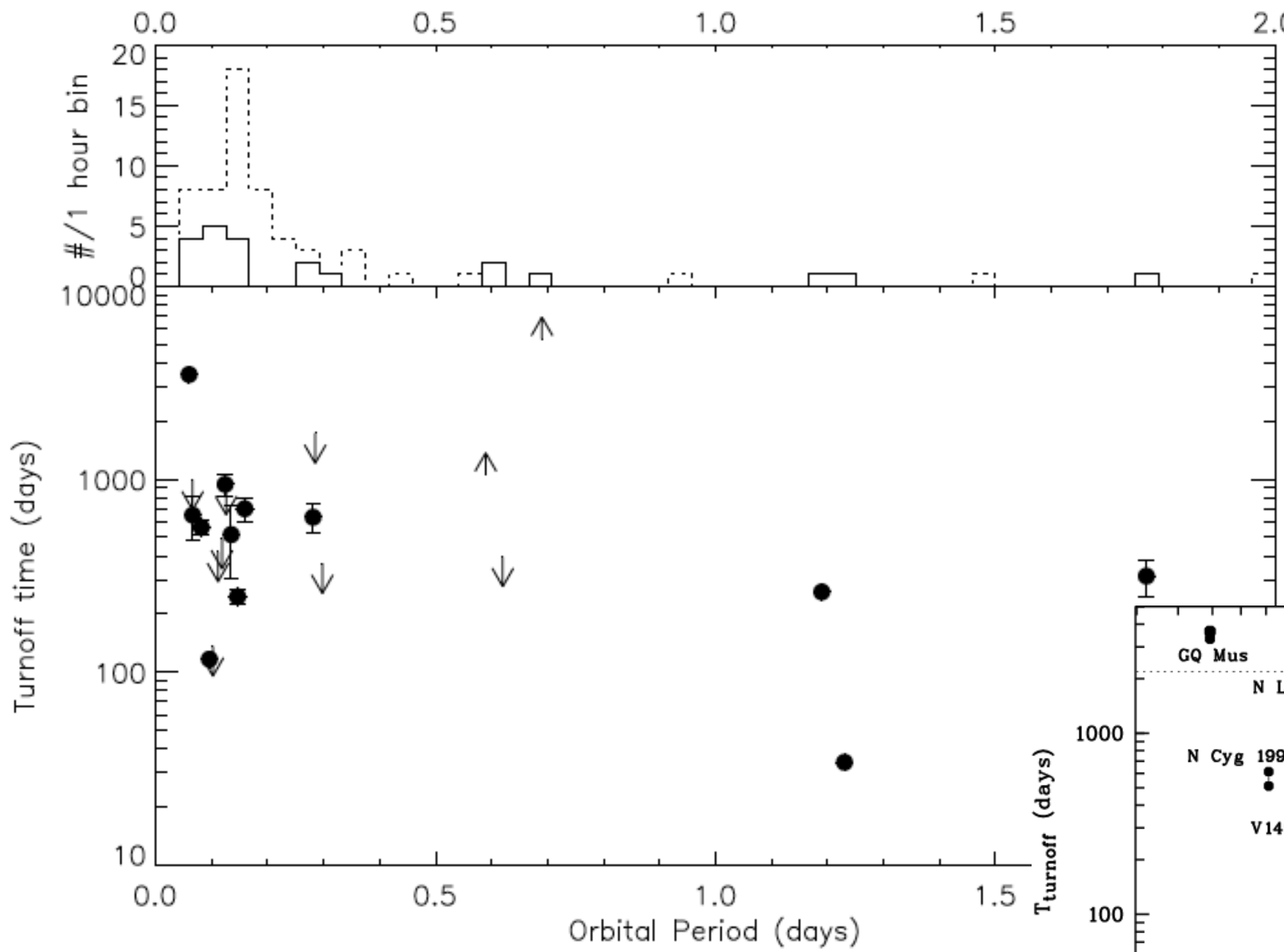


Greiner+ 03

Derived from 4 SS turn-offs

Ejecta velocity

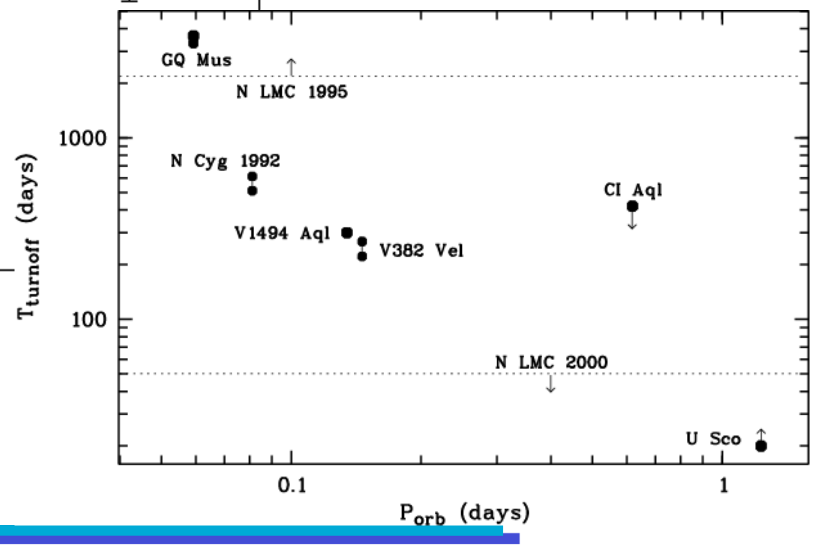
T_{off} - P_{orb}



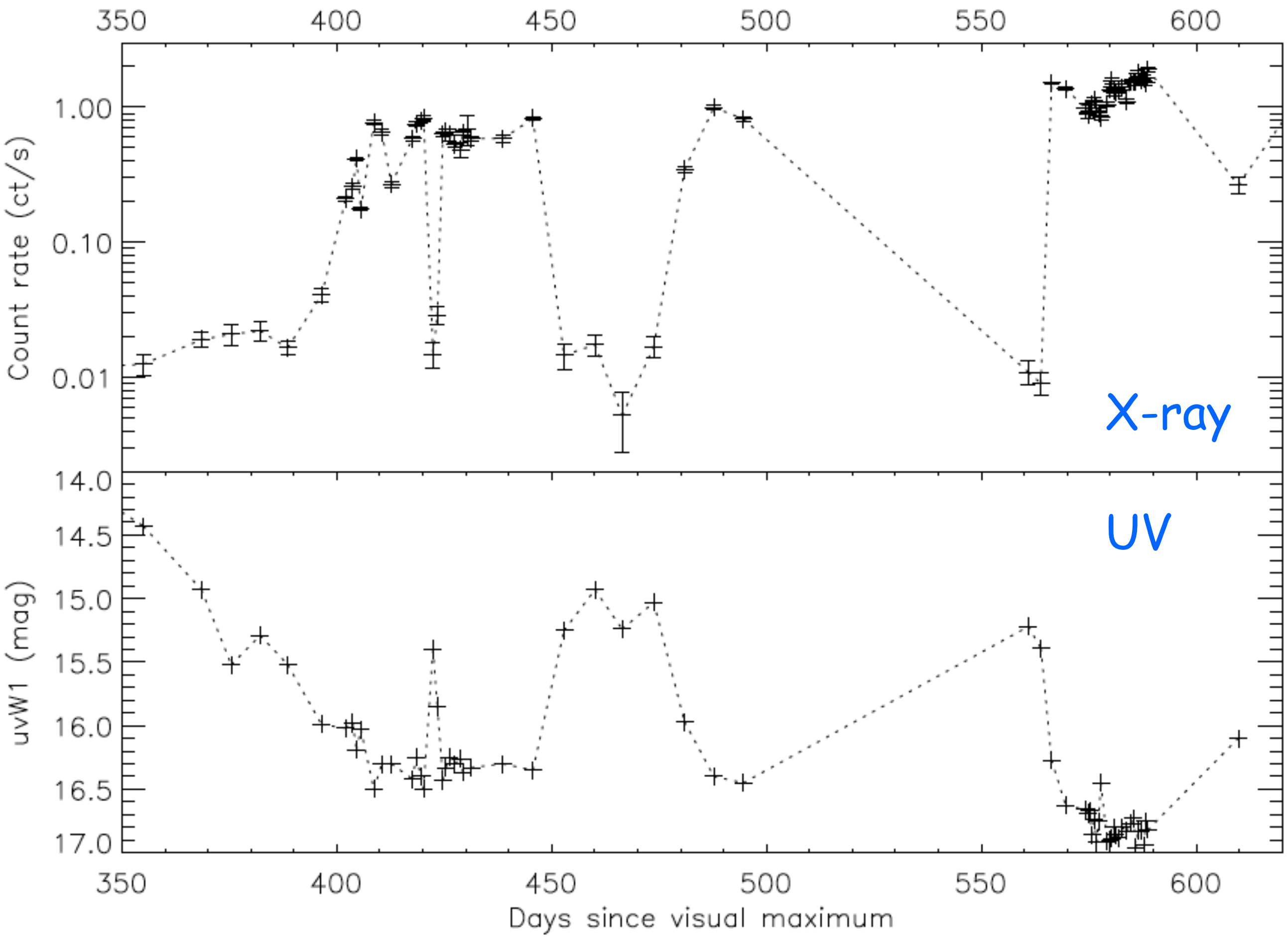
No correlation seen

No SS heating of secondary. Disk shielding?

cf Greiner+ 03: smaller sample, dominated by limits above 0.2 days



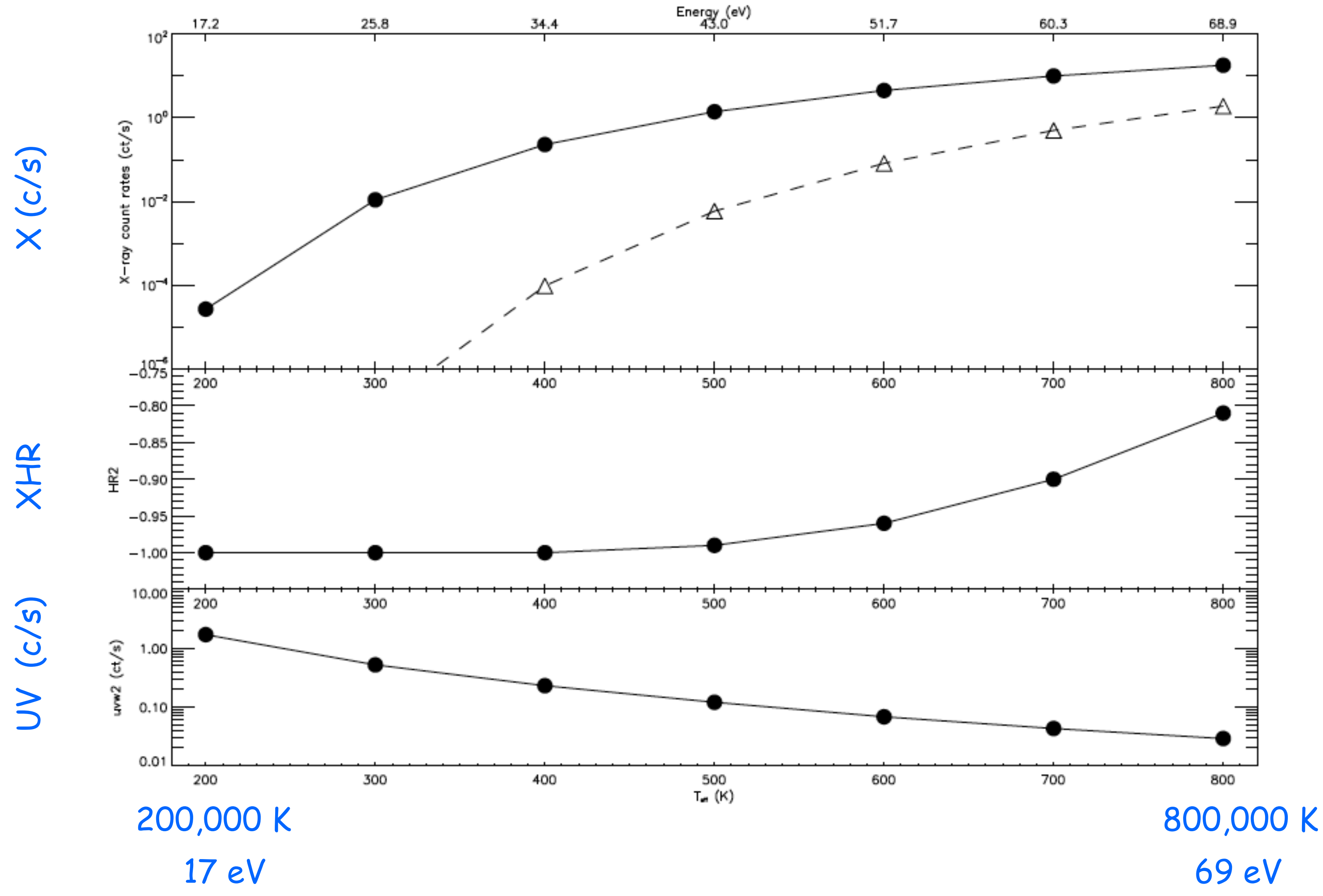
V458 Vul: X-UV anti-corr



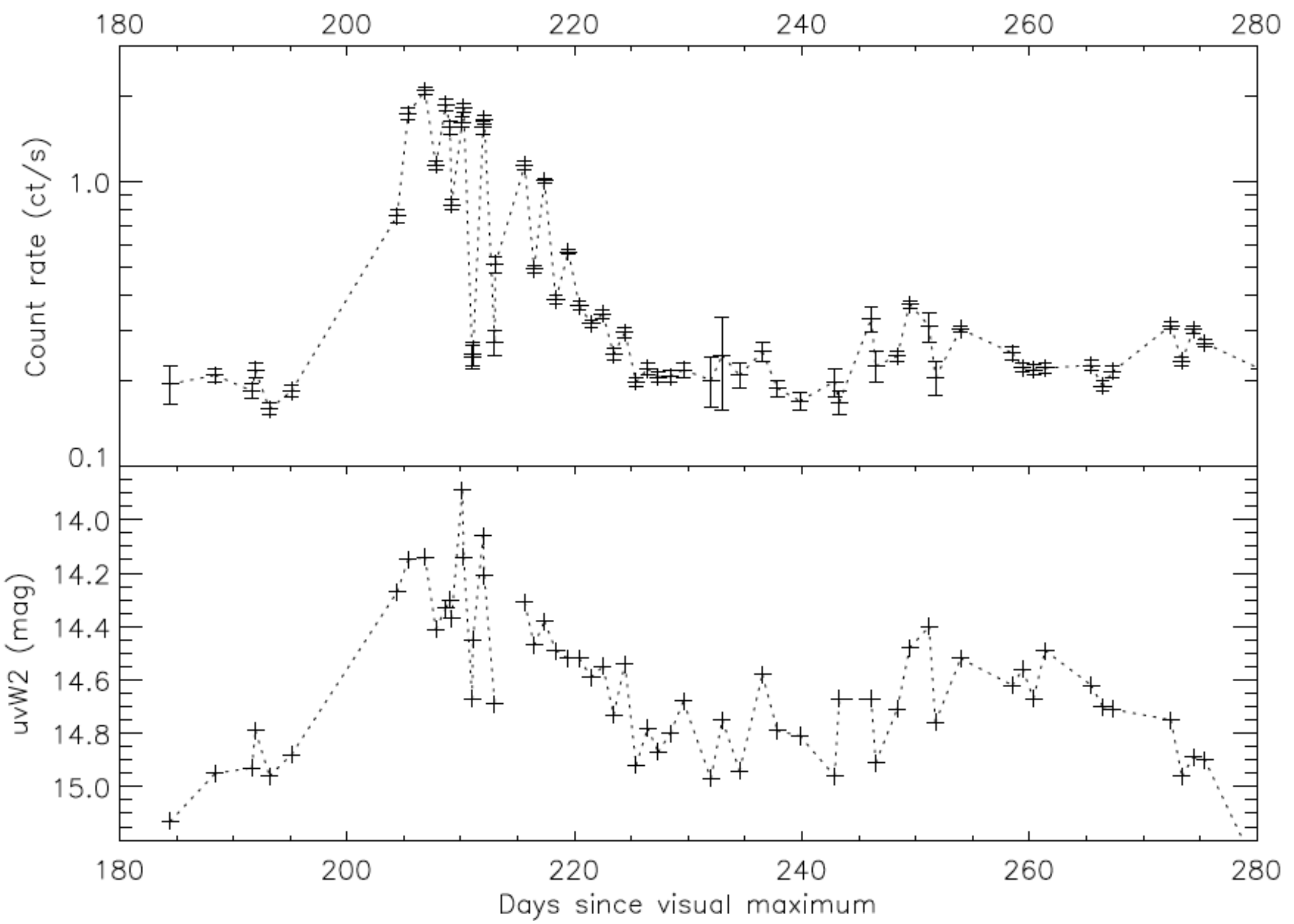
X-ray – UV anti-correlation is similar to that seen in the SSSs Cal 83 (Greiner & di Stefano 02) & RX J0513.9-6951(Reinsch+ 00)

Effect can in principle be achieved by T decline from 700 kK (60eV) to 500 kK (43 eV)

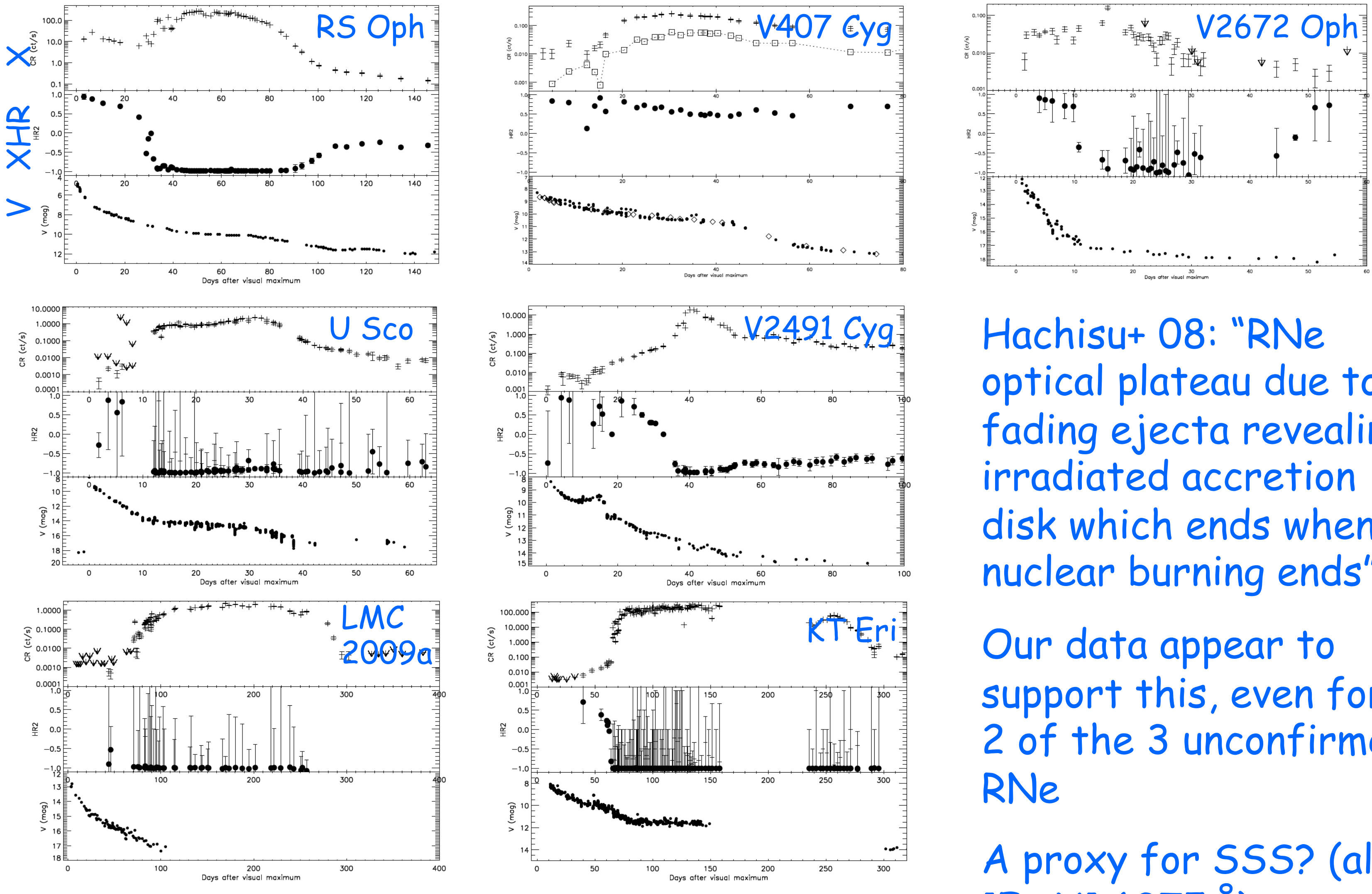
Swift T_{BB} dependance



CSS 081007: X - UV corr



SSS = optical plateau?



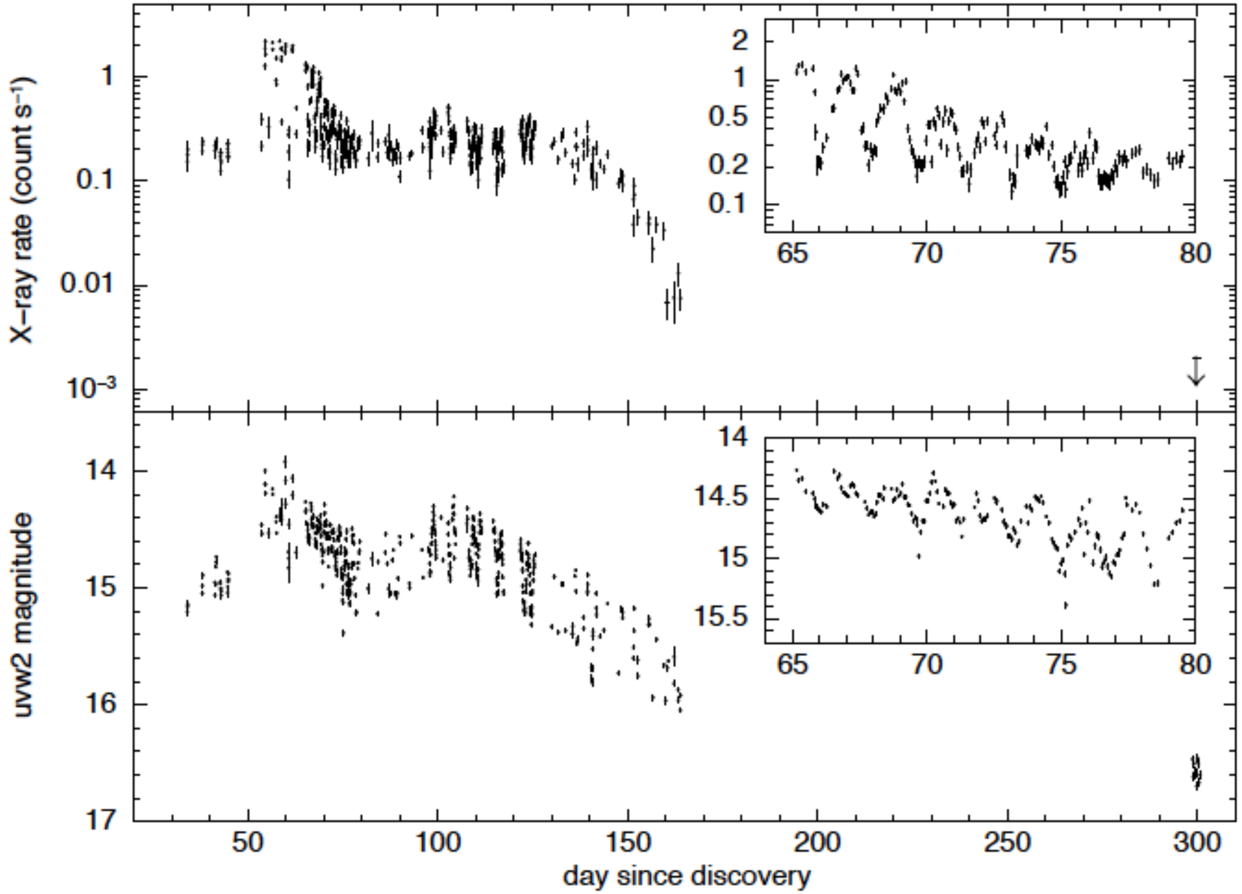
Hachisu+ 08: "RNe optical plateau due to fading ejecta revealing irradiated accretion disk which ends when nuclear burning ends"

Our data appear to support this, even for 2 of the 3 unconfirmed RNe

A proxy for SSS? (also [Fe X] 6375Å)

CSS 081007… = HV Ceti

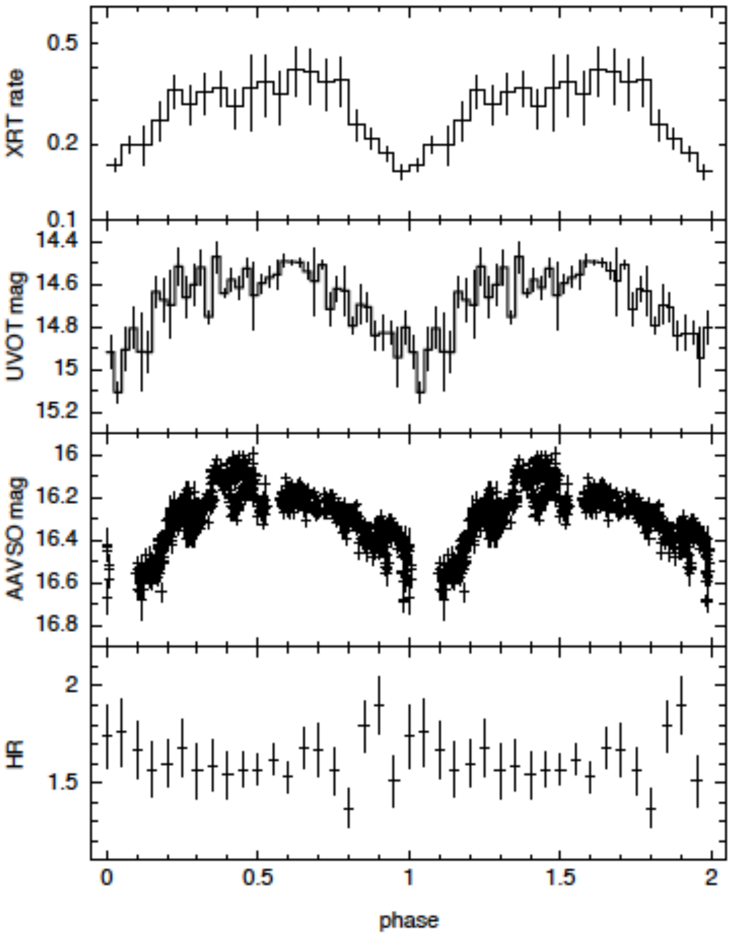
- Beardmore et al 2010: initial summary in AN
- Beardmore et al 2012: full paper - A&A 545, A116

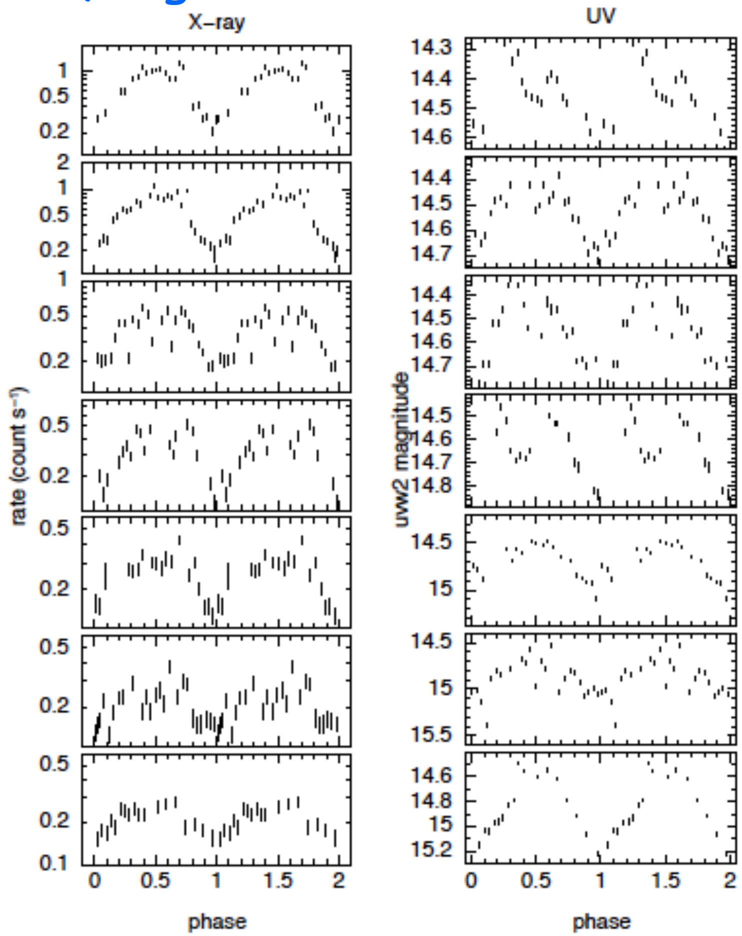


- ΔV > 4
- Ha vel ~ 1500 km/s
- Strong [Ne V]
- Pre-o/b rise ~ 1-2 mag
- Gal latitude = -44°
- Time of optical peak poorly constrained

HV Ceti

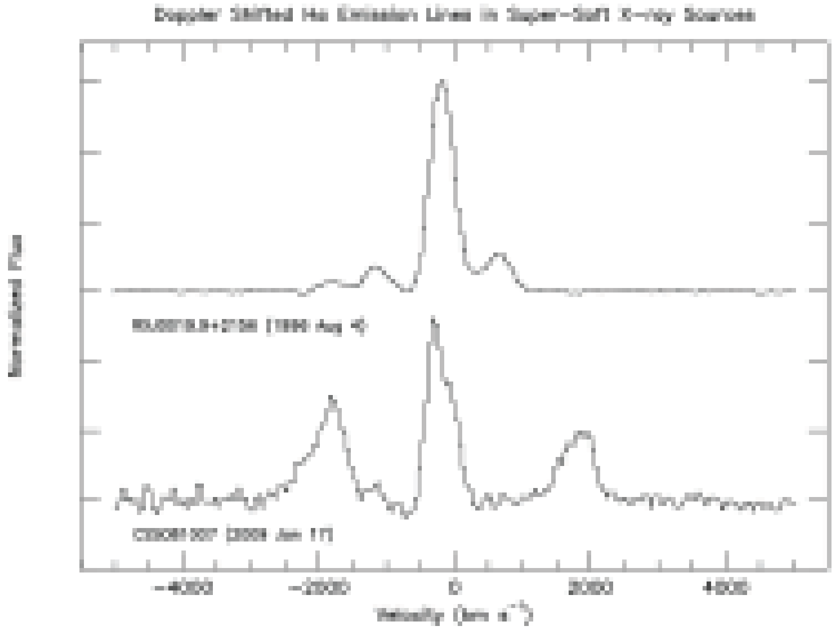
- 1.77 day modulation: orbital (cf GK Per) or poss precession
  - Broad modulation suggests large emission region
  - UV peak dips like SSS Cal 87 (bright inner accretion disk?)





HV Ceti

- Tri-peaked optical emission lines – which move
- Also seen in some Compact Binary SSS
- 'jet emission' / bipolar ejecta / accretion disk ??
- Hard to get both disk edge and high velocity jets in line of sight (unless they are broad)

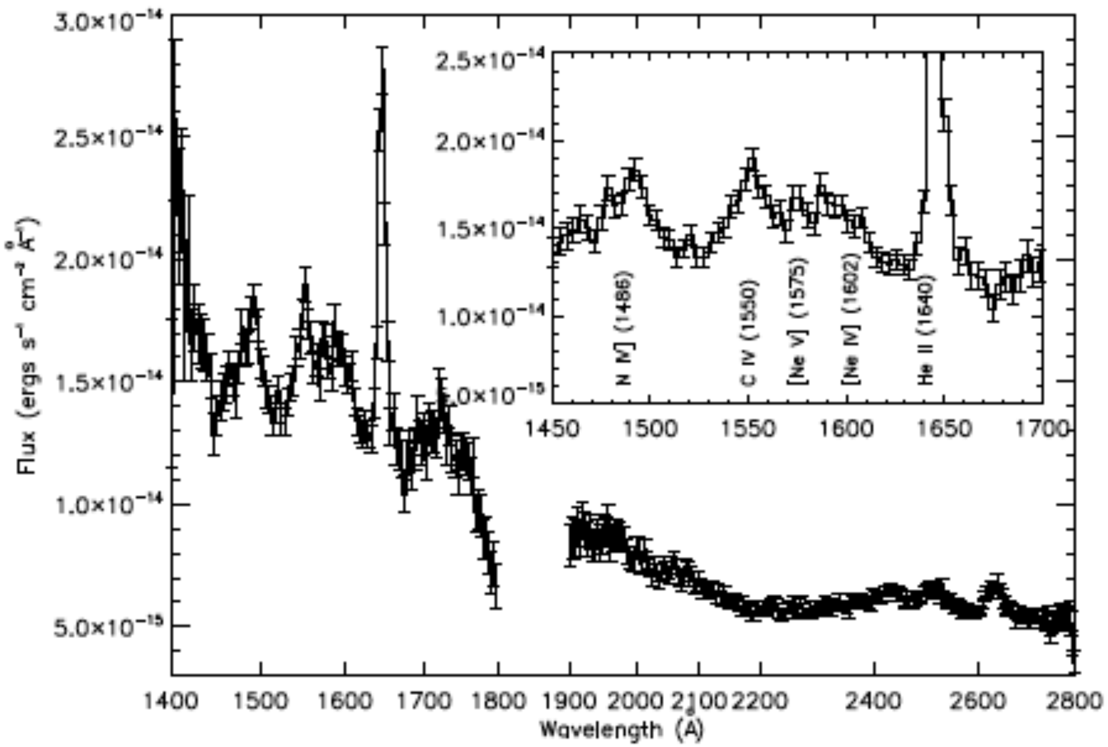


Wagner et al 2011

HV Ceti

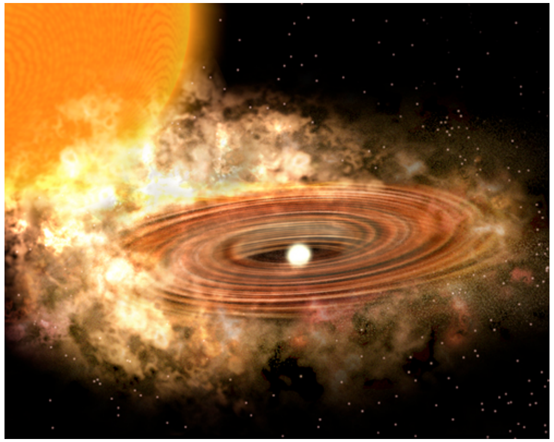
Galex spectra:

- no spectral variation
- few thousand times extrapolated X-ray spectrum
- but we know UV is modulated at 1.77 d like X-rays
- UV must come from inside accretion disk

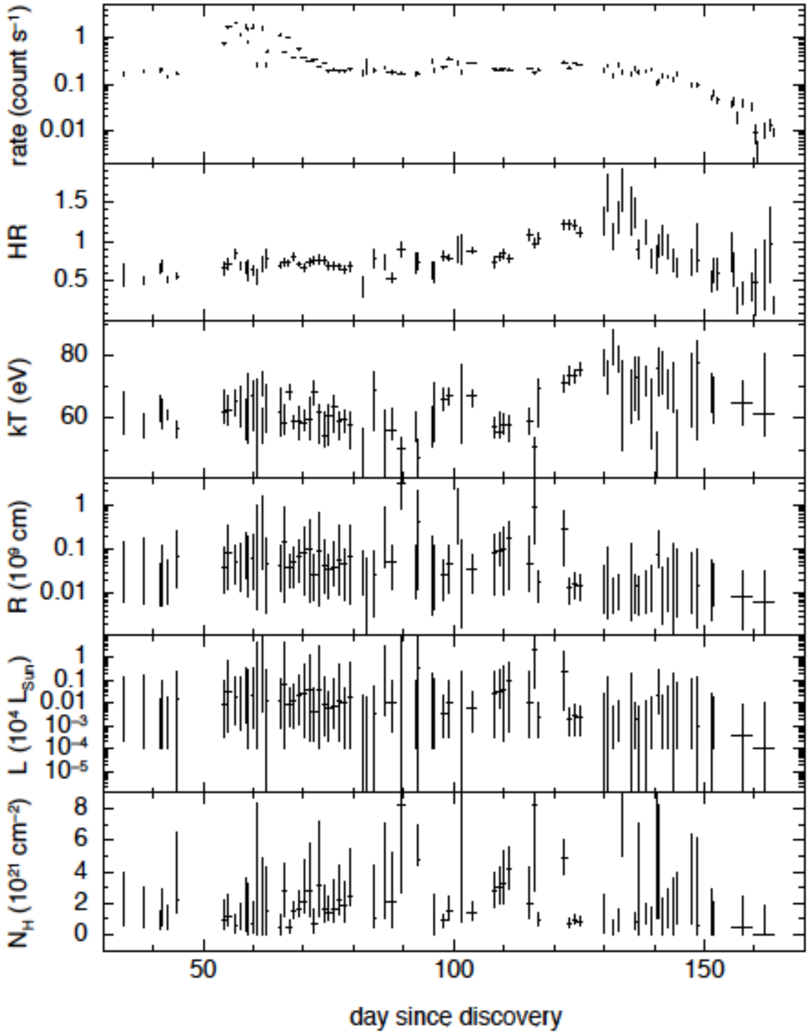


HV Ceti

- Suggests we see only scattered X-rays ($\tau << 1$), while UV reflector sees hot WD directly



- Helps to explain R ~ few 10^7 cm from X-ray spectral fits (Rauch atmosphere model) – See P&O poster



HV Ceti

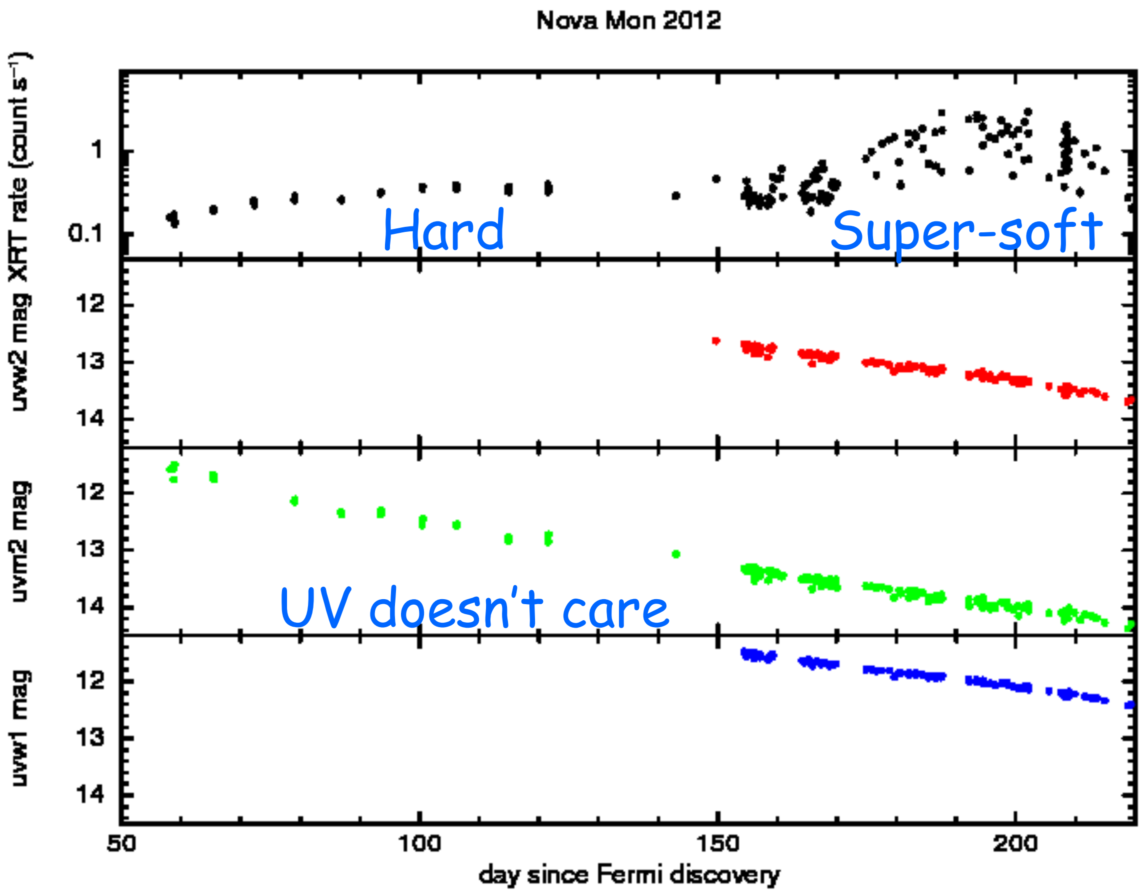
- What about the trend in the periodic X & UV photometric variation?

  - X-ray max declines, min stays constant
  while
  - UV max stays constant, min declines

- Cannot be due to changes in disk rim height or size of inner scattering region

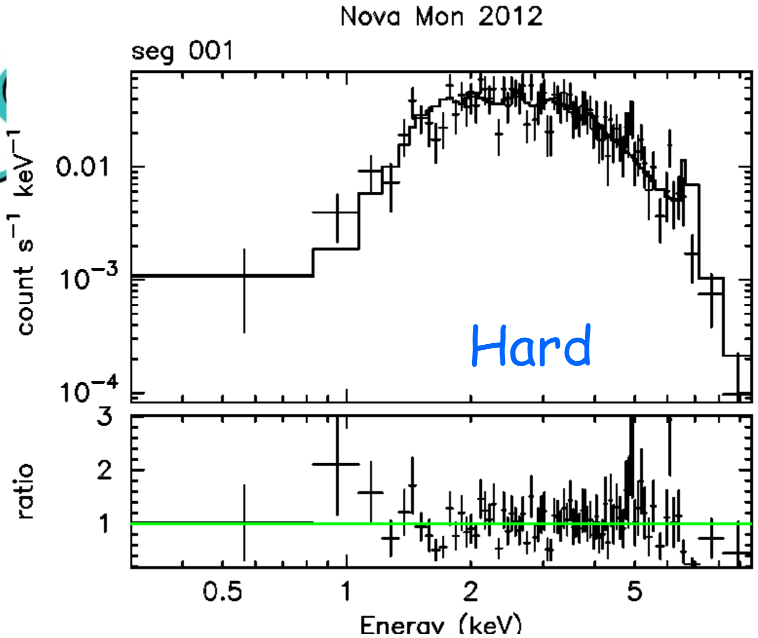
- No explanation to hand: worry about scattering cloud – UV reflection - disk obscuration concept?

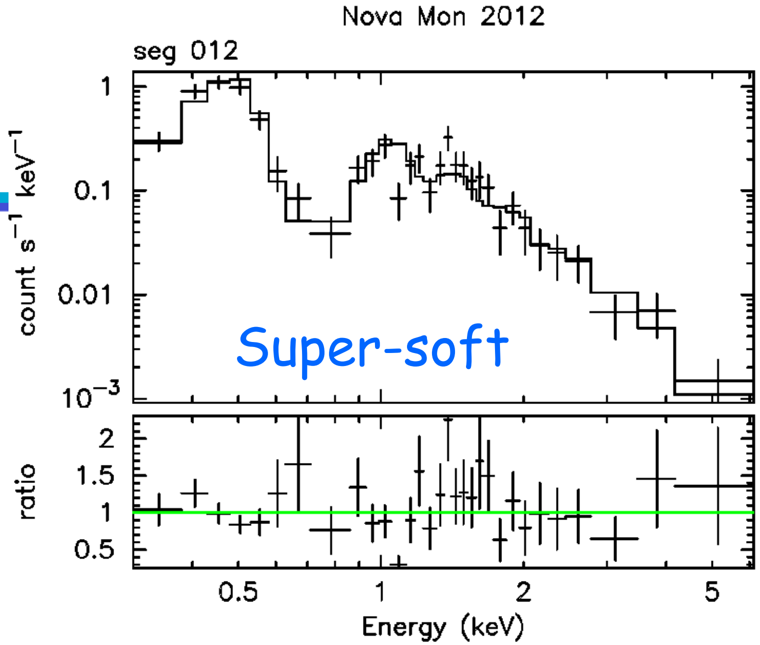
Nova Mon 2012

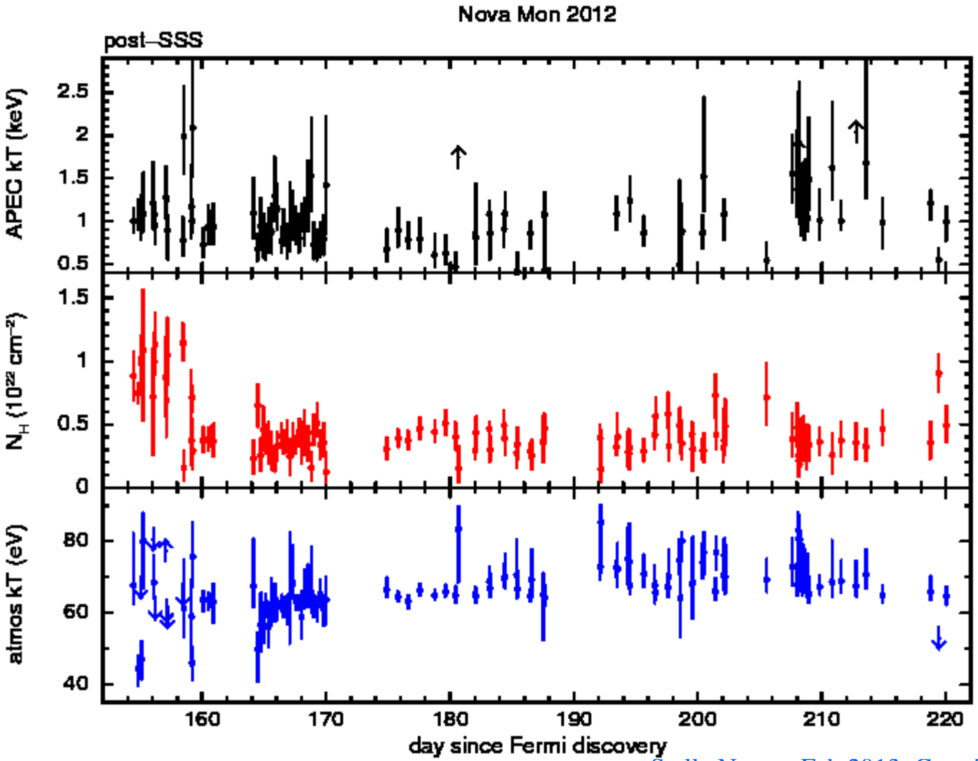


N Mon 2012:

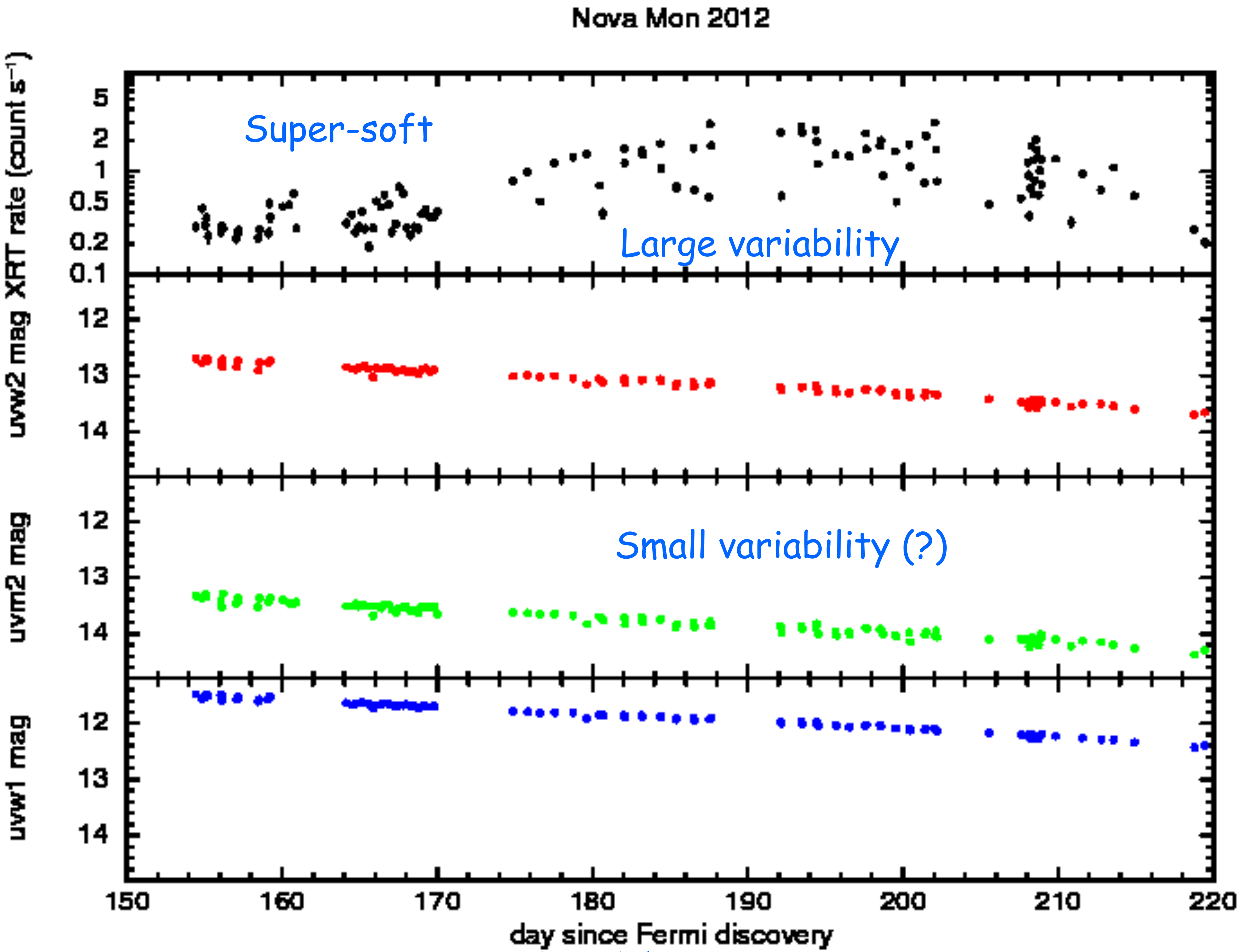
- Fermi gamma-ray source (Cheung+)
- Double radio source (O'Brien+)
- Ne nova (Munari)
- SSS (Nelson+)
- X-ray grating spectra when harder (Ness+, Orio+)





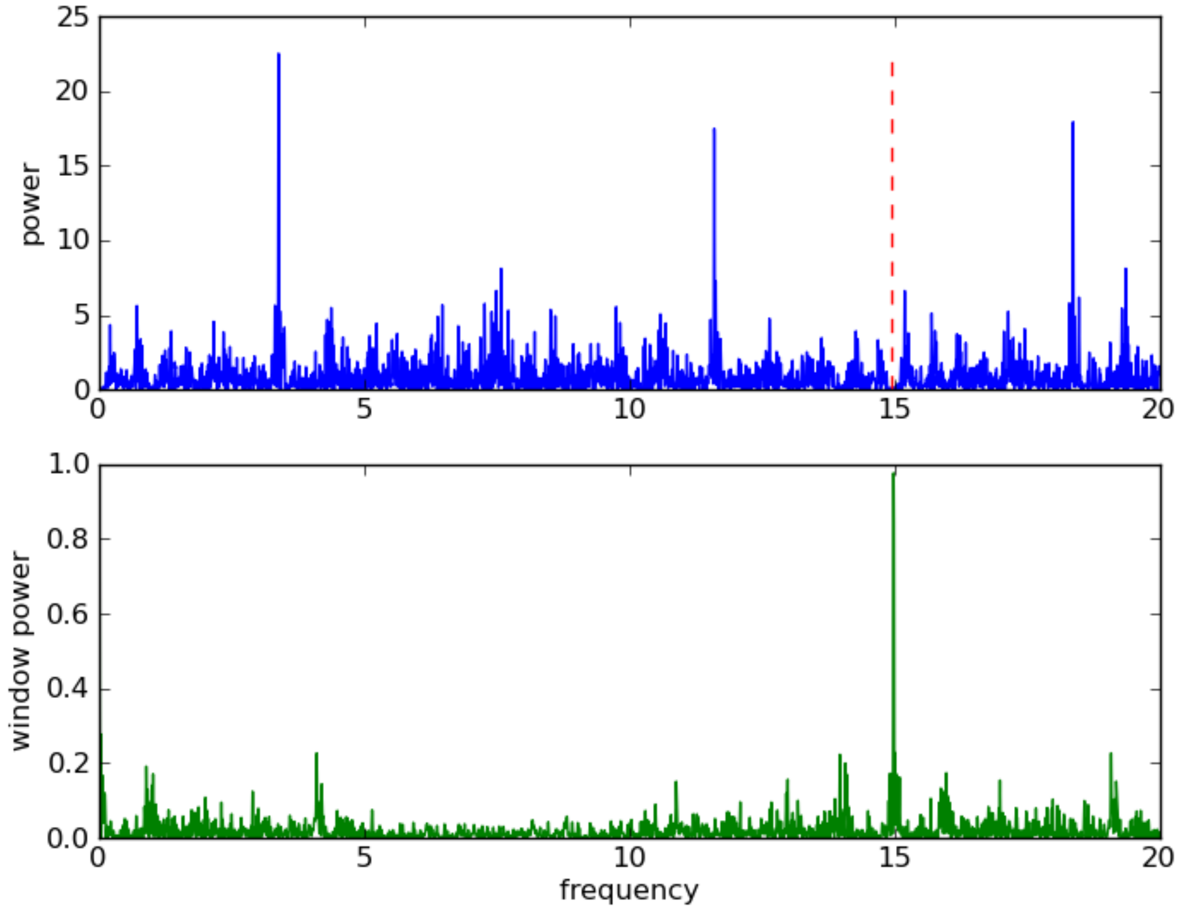


Super-soft spectrum has not changed so far



Nova Mon 2012
Super-soft
Large variability
Small variability (?)
XRT rate (count s^{-1})
uvw2 mag
uvm2 mag
uvw1 mag
day since Fermi discovery

Nova Mon 2012

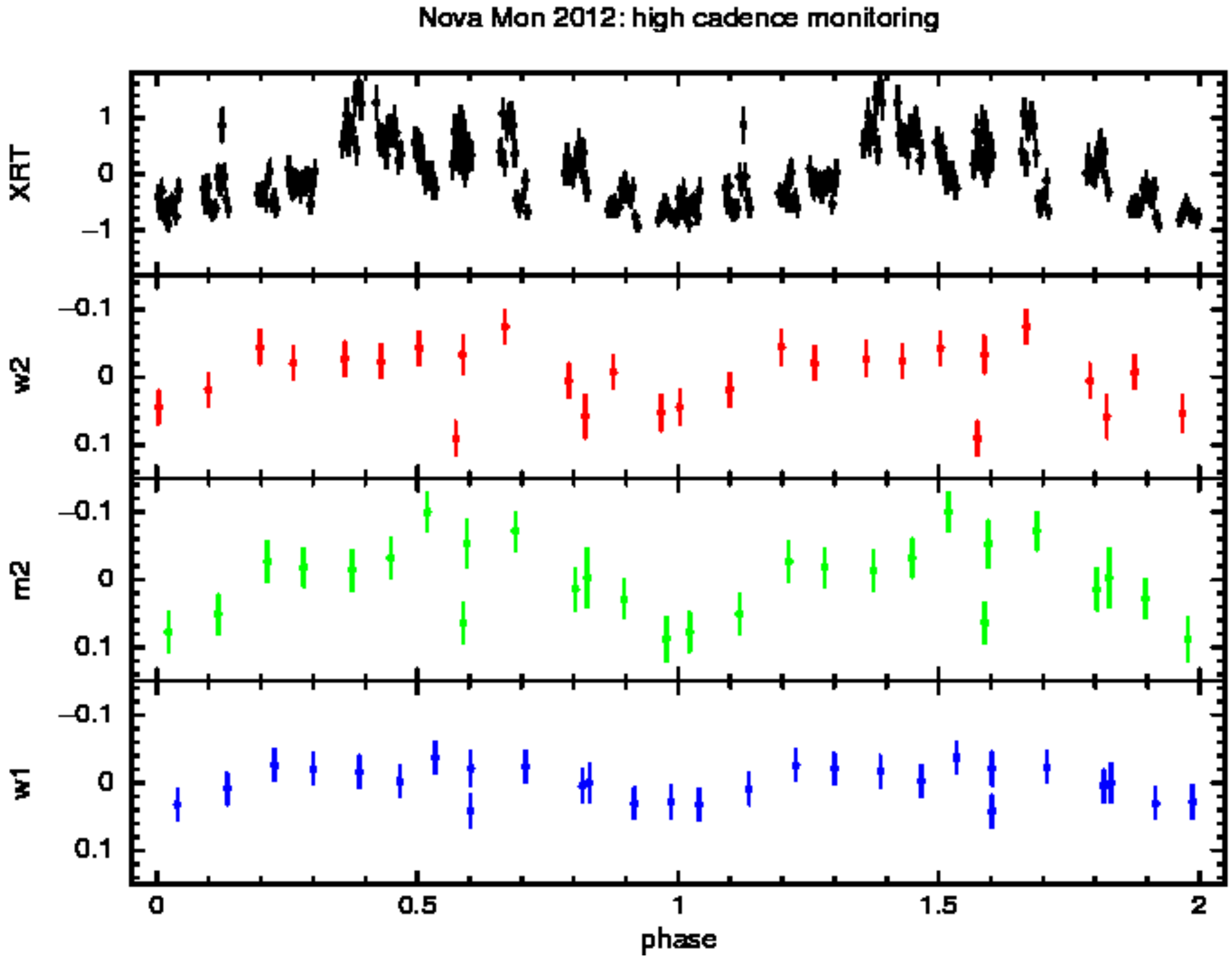


Lomb-Scargle periodogram of SSS-phase UVOT data (all filters look the same):

Period is 0.2957 days (ATEL 4722)

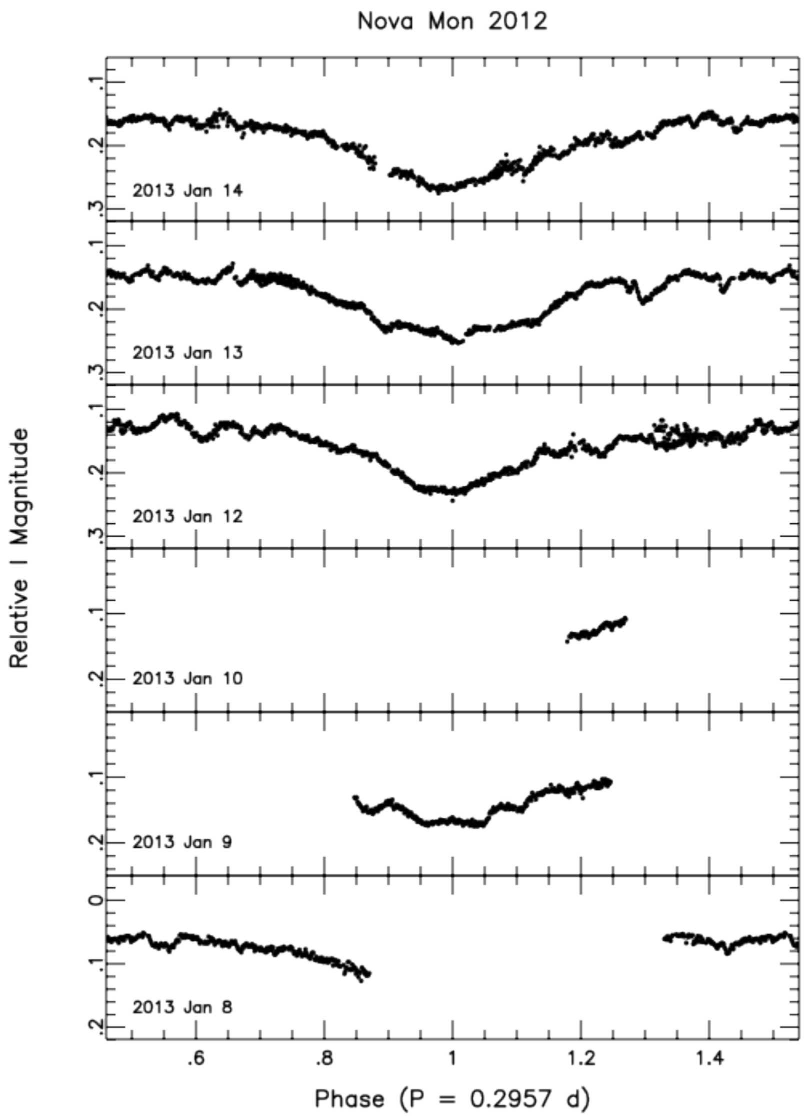
Window function

Nova Mon 2012



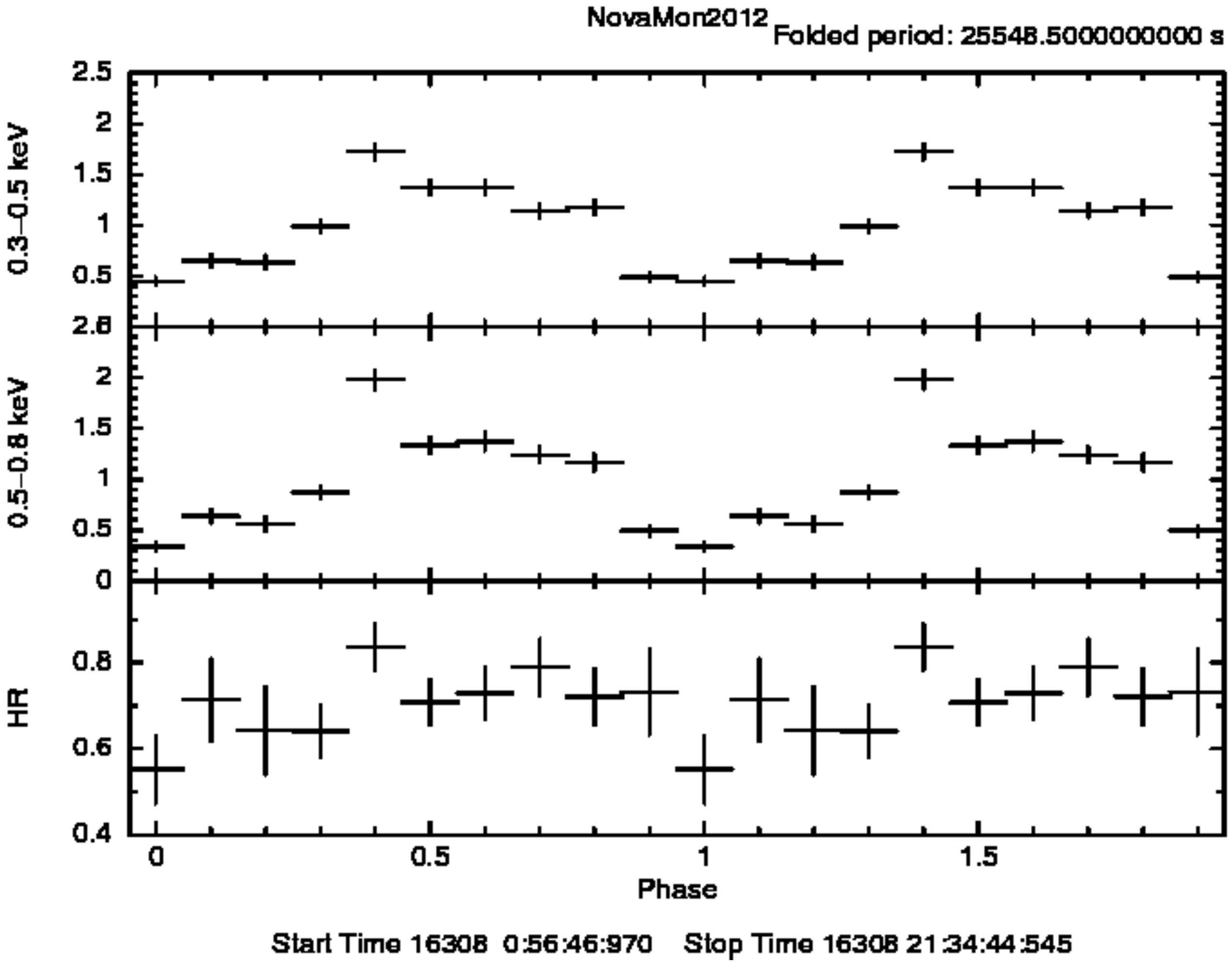
X-ray & UV vary in phase

Nova Mon 2012



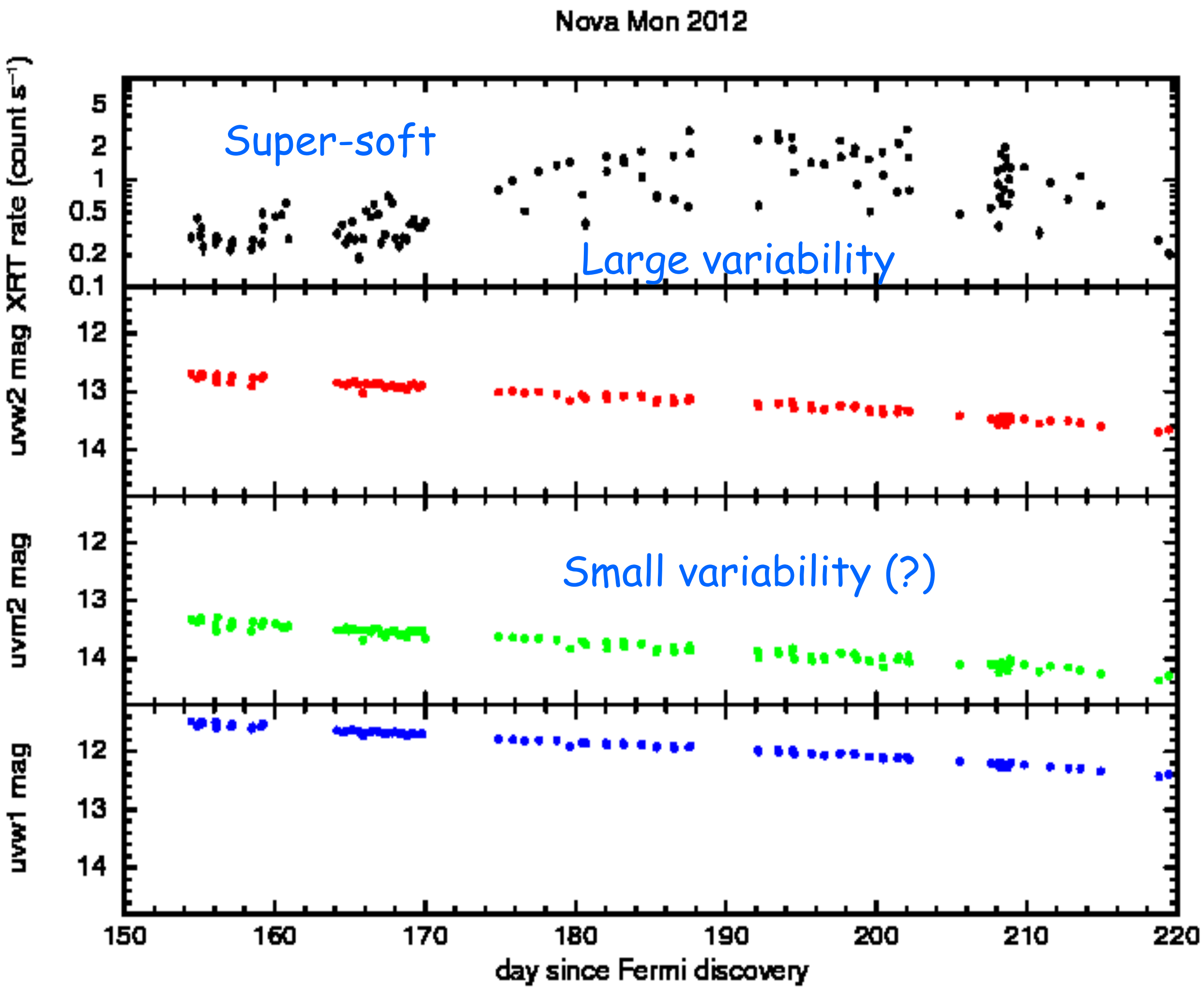
I-band photometry by Mark Wagner using 1.3m at Kitt Peak (Wagner+)

Nova Mon 2012



No spectral signature of 7.1 hour period in soft X-rays

Nova Mon 2012



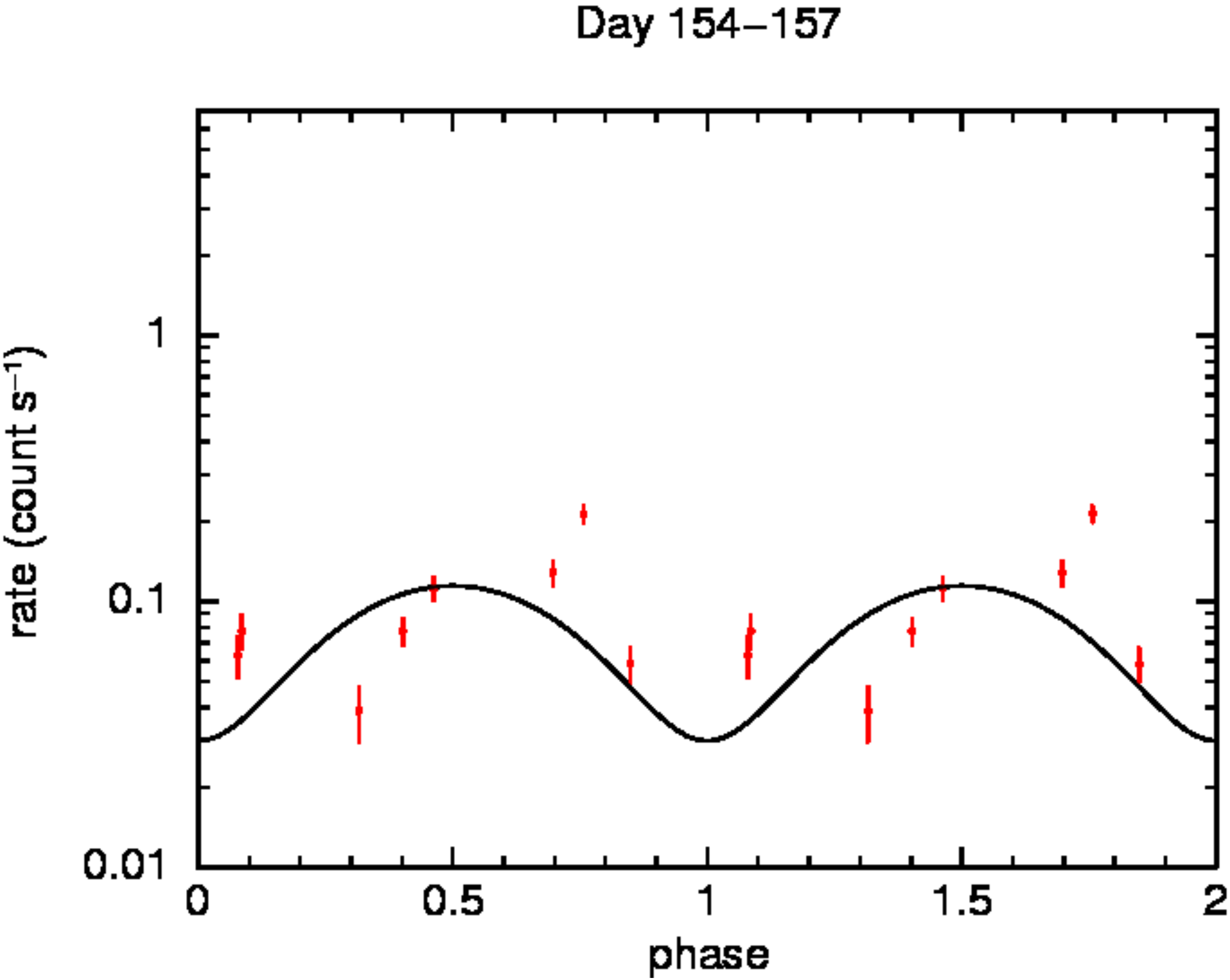
Is the large variability like that of RS Oph, or is it due to periodicity?

X-rays appear to have constant range of variability

Fit with:

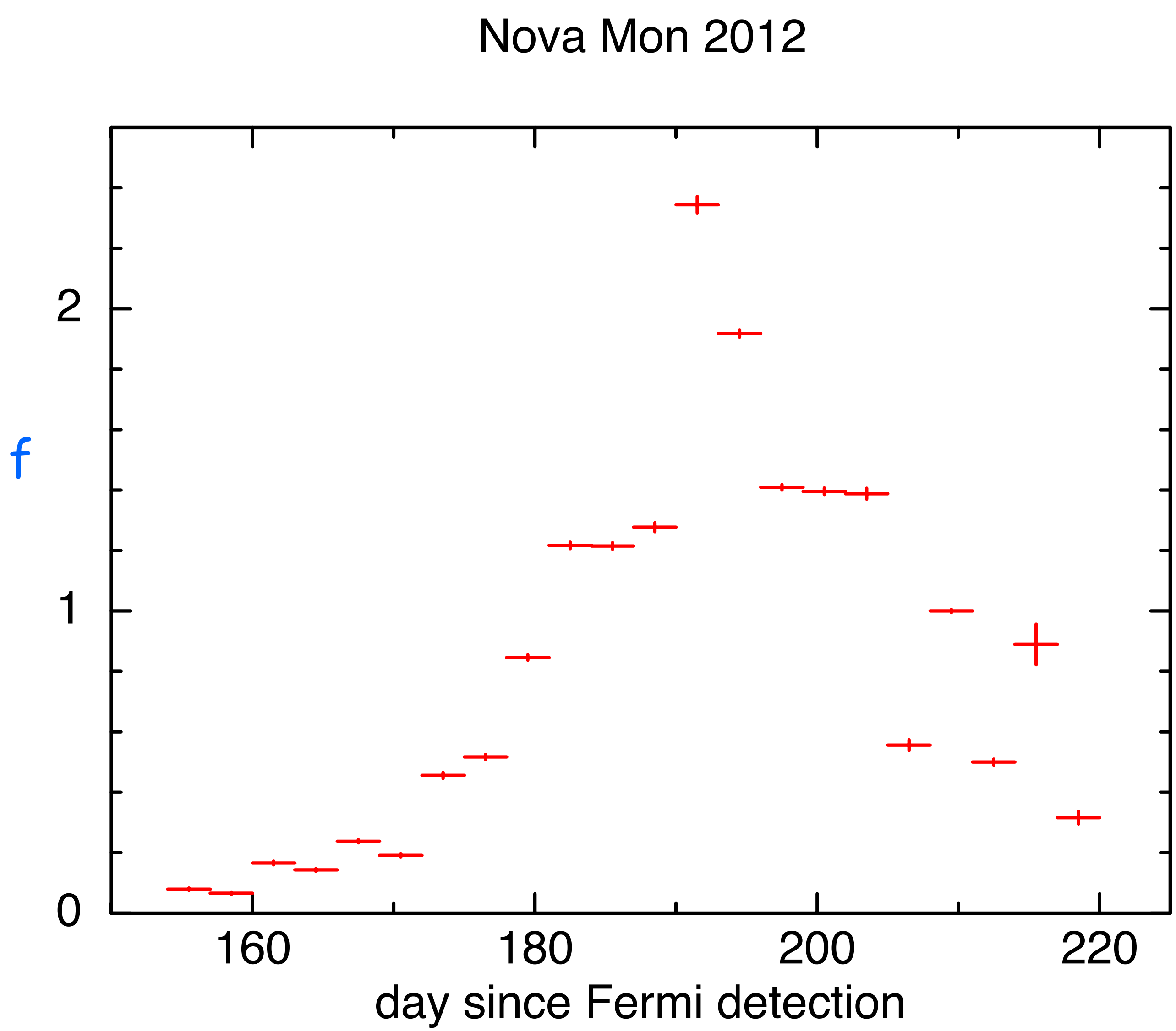
rate = f(a+b.sin(c.t))

a, b & c fixed from high cadence data



Day 154–157
rate (count s^{-1})
1
0.1
0.01
0
0.5
1
1.5
2
phase

Nova Mon 2012



Most of the large variability may be due to secular rise and fall of SSS

Summary & Questions 1/2

- Swift has transformed novae studies with prompt, dense, and extensive X-ray spectral & UV monitoring
- Sample is biased to faster novae
- Models are still catching up
- Model atmosphere fits through the SS phase show ~L_{Edd} and constant temperature
- The super-soft phase starts & ends earliest in fast novae (high M_{WD})
- Super-soft phase turn-on can show large rapid variability
- RS Oph & KT Eri show qpo ~35 sec
- Fast novae have an early hard X-ray phase
- SSS T_{off} not correlated with P_{orb}
- SS X-ray flux is correlated, anti-correlated, or uncorrelated with UV
- Some novae show optical plateau during SS phase (as per Hachisu+08)

Summary & Questions 2/2

- HV Ceti has a very sub-luminous SS spectrum, a smooth 1.77 d modulation with the X-rays & UV in phase, and a strong UV excess. All points to disk rim obscuration of inner scattering region
- Ne nova Mon 2012 entered SS phase ~150 days after Fermi detection. It has a 7.1 hr optical/UV/X-ray period with variations in phase. SS variability due to random phase sampling of slow rise & fall

Questions:

- What is the cause of the early high-amplitude variability in RS Oph & others?
- What is the origin of the ~35 sec period in RS Oph & KT Eri?
- Does the SSS live because it is fed by the re-formed accretion disk?
- Are compact binary SSSs just unrecognised low M_{WD} novae?
- How can we get more X-ray grating data?