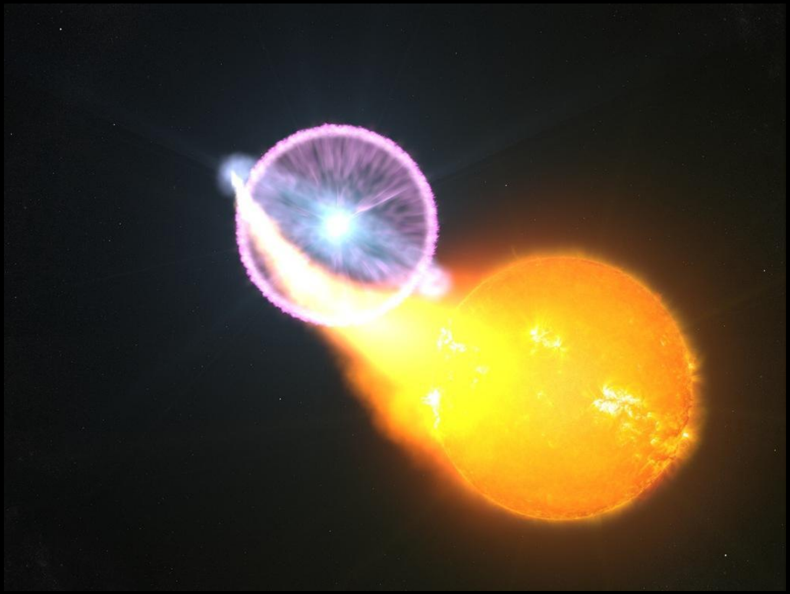


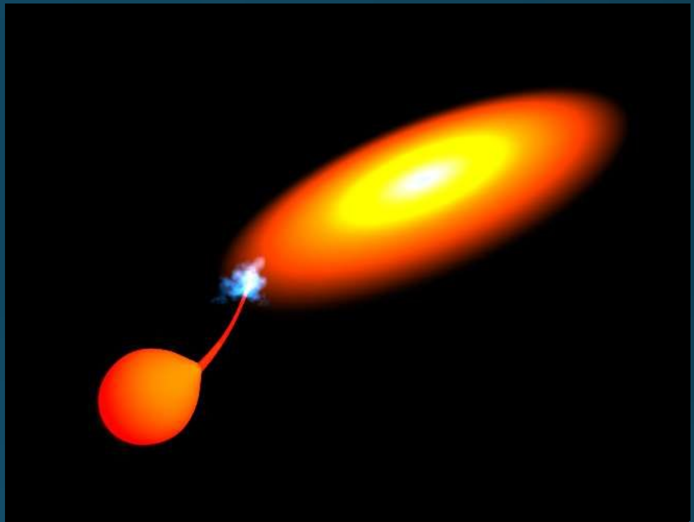
Accreting white dwarf science with *STROBE-X*

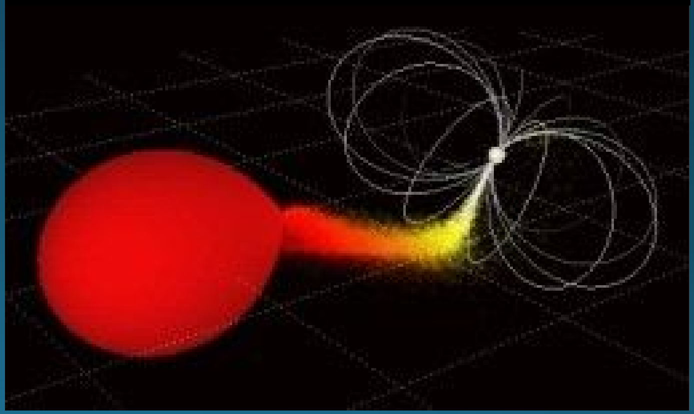
Tommy Nelson
University of Pittsburgh

Accreting white dwarf systems

Cataclysmic Variables

- Orbital periods 2 – 10 hours
- Mass donor is main-sequence (or slightly evolved star)
- Mass transfer driven by Roche Lobe Overflow through L1
- In low B-field systems ($B < 10^5$ G) a disk forms
- In strongly magnetic systems matter is channeled along B-fields, either completely (polars) or partially (intermediate polars)





Accreting white dwarf systems

Symbiotic Stars

- Donor is a red giant or AGB star
- Orbital periods 200 days to >10 years
- Mass transfer mode less clear:
  - Some donors may fill their Roche Lobes
  - Others may feed the WD via a wind (Bondi-Hoyle), or some combination of the two (wind Roche-Lobe Overflow)
- Only one magnetic symbiotic known but more should exist

R Aquarii

Accretion physics with *STROBE-X*

- **Accretion processes produce X-rays of various energy and flux in white dwarf binaries**
- *STROBE-X* will be a powerful instrument for studying accretion in both classes of white dwarf binaries
- Large collecting area in 0.3-30 keV regime of XRCA/LAD will allow high S/N spectroscopy and timing of both magnetic and non-magnetic CVs
- See white paper led by D. de Martino (arxiv 1501.02767) for details of accretion studies
  - XRCA will be an important complement to the LAD, especially for soft, bright sources (e.g. polars)
- I'm going to focus on what *STROBE-X* can tell us about nova eruptions today

LOFT Large Observatory For X-ray Timing

Nova eruptions

- **Nova eruption**: thermonuclear runaway in accreted shell
- Can eject most or all of accreted material, and in many cases dredge up WD material
- Typical optical outburst amplitude 8-12 mags; 5-12 discovered per year
- All accreting WDs should experience nova eruptions at some point
  - Unavoidable once critical mass of hydrogen has been accreted

<u>Nova numbers</u>

t_{burn} = weeks to years

$M_{ej} = 10^{-7}$ to $10^{-4}\ M_{\odot}$

$V_{ej} = 300 – 4000\ km\ s^{-1}$

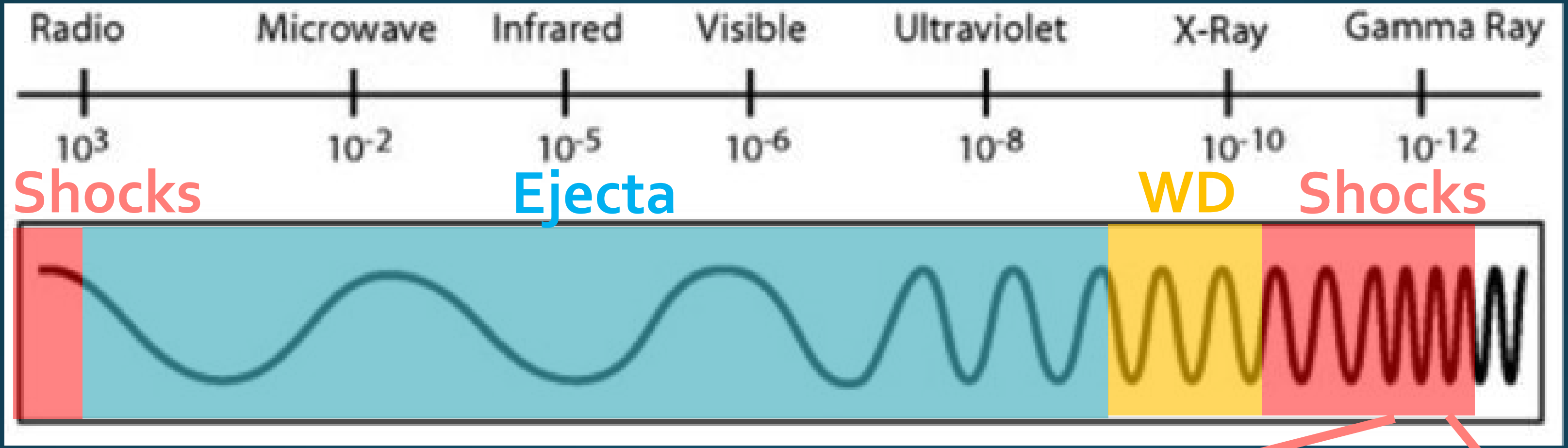
$E_{tot} = 10^{43-45}$ ergs

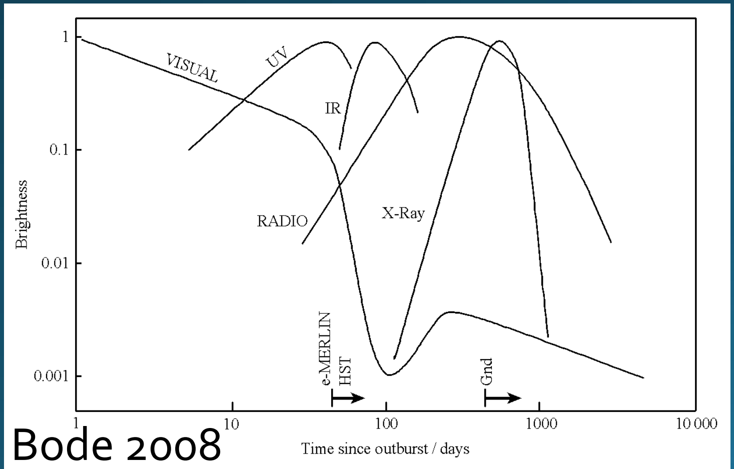
Classical or recurrent?

- ***Recurrent novae* (RN)** have more than one recorded outburst (the nature of the mass donor is not important)
- About 10 RN known in Milky Way, recurrence times of 10 to 50 years
- Several RN known in LMC and M31, including M31 N2008-12a, a system with a <1 year recurrence time
- ***Classical novae* are all other novae with one known outburst**

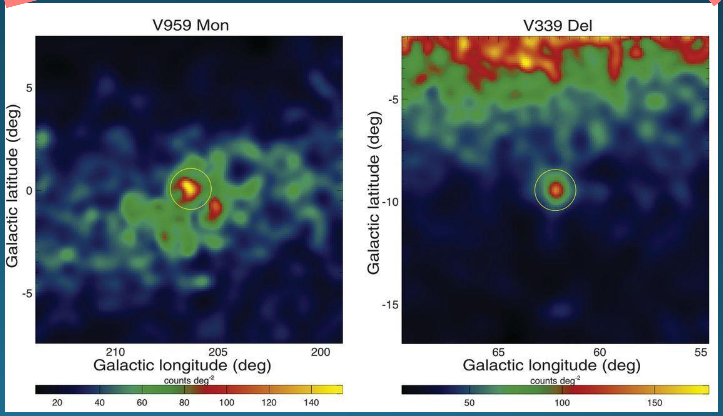
If accretion is re-established, all novae should experience another outburst in the future

Novae are panchromatic transients





Bode 2008



Ackermann et al. 2014

X-rays in novae probe shocks in the ejecta and the central white dwarf

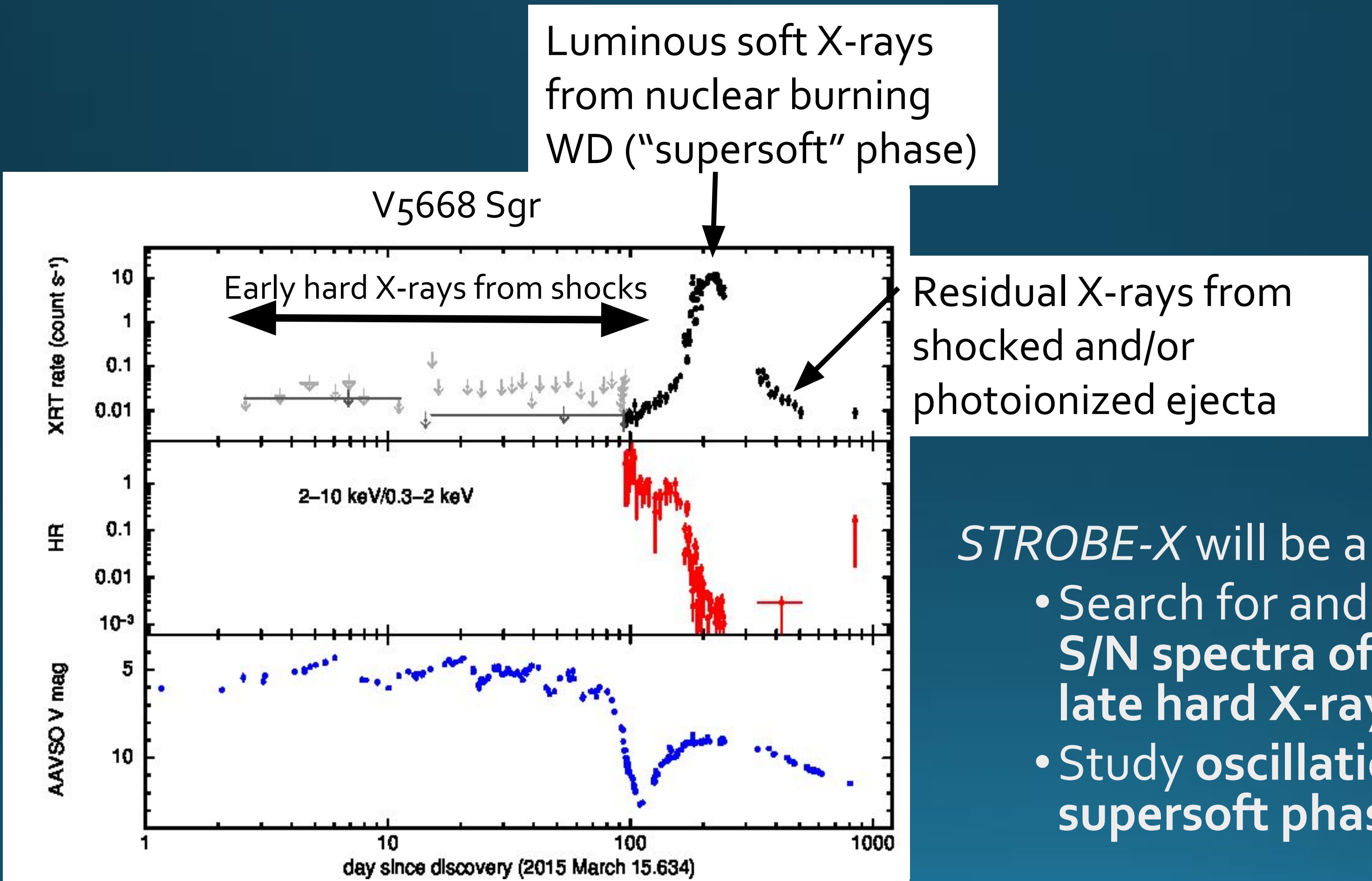


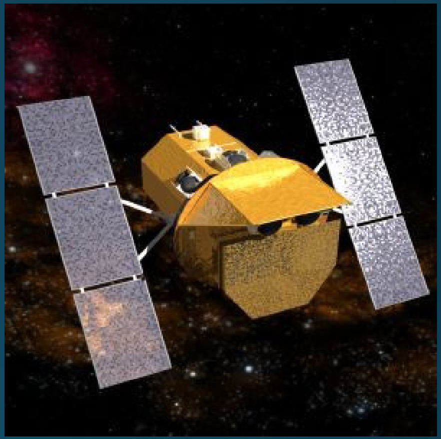
Figure courtesy K. Page for Swift Nova/CV group

STROBE-X will be able to

- Search for and obtain **high S/N spectra of early and late hard X-ray emission**
- Study **oscillations during supersoft phase**

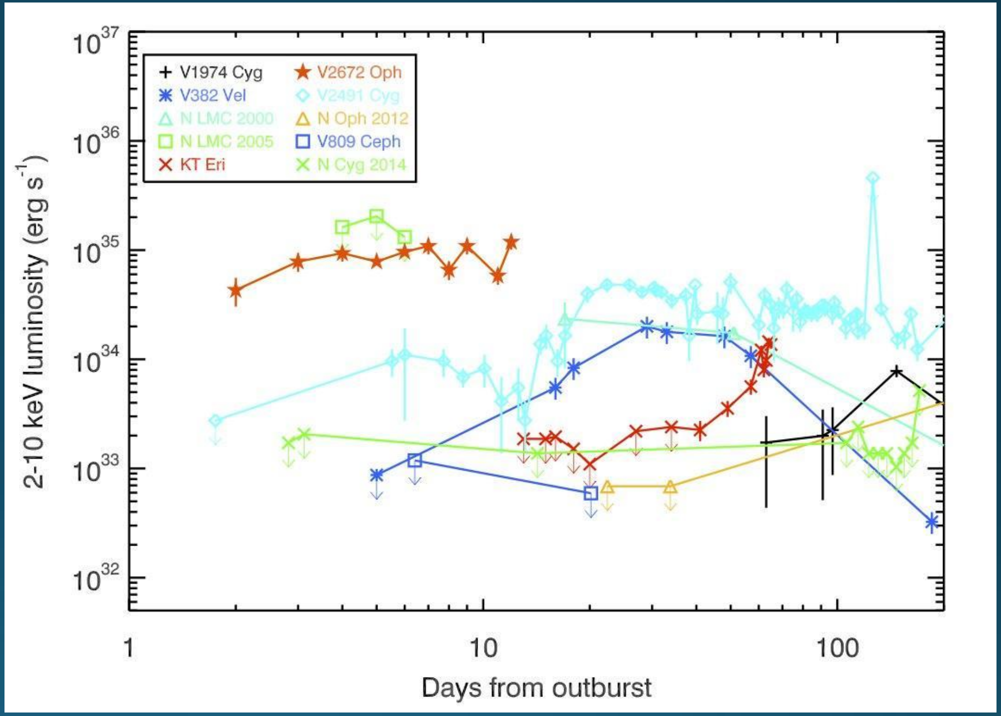
Observing assumptions

- *Swift* is currently the workhorse of nova monitoring
  - Obtains anywhere from a few to hundreds of snapshots, usually 500-2000 s exposures
  - See e.g. Schwarz et al. 2011 for review of *Swift* studies of novae
- Assume that *STROBE-X* will monitor in a similar way
  - All spectral simulations assume 2ks exposure time unless otherwise noted
- Plots shown are for 128 XRCA units and 200 eV LAD resolution (unless noted)
- **What improvements do we get with *STROBE-X?***



X-rays from nova shocks

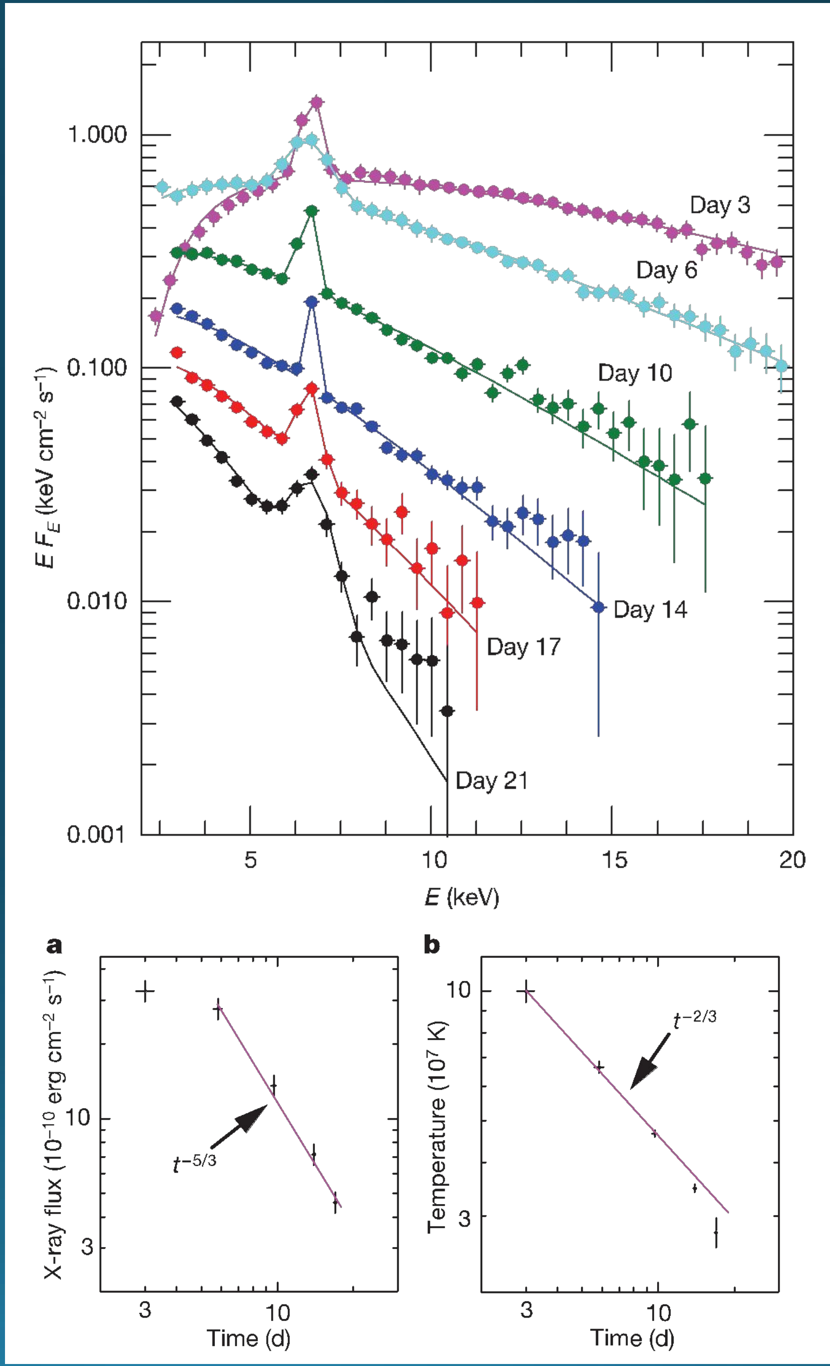
- 2-10 keV X-rays are often detected in novae within days to weeks of eruption
- In symbiotic systems, luminous X-rays originate in blast wave driven into companion wind (e.g. **RS Oph,** V407 Cyg)
- In CV-type systems, X-rays are thought to originate in internal shocks (e.g V382 Vel**, V959 Mon, T Pyx)**



Selection of novae in 2-10 keV band.
Count rates in range 0.001 – 0.05 cts/s with *Swift*

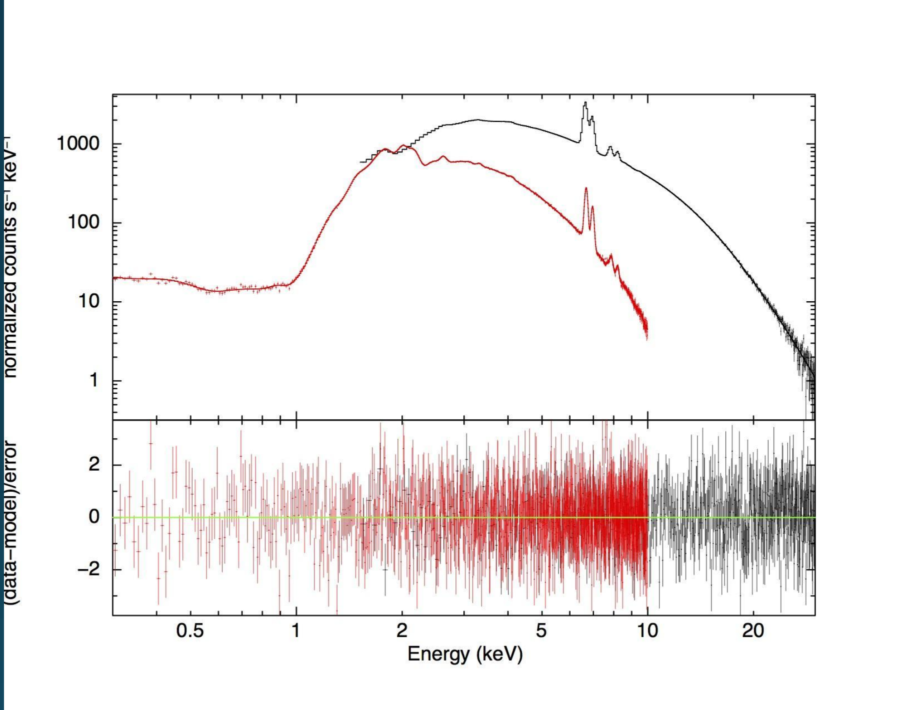
RS Oph

- Recurrent nova. t_{rec} 10-20 yrs, last outburst in 2006 (may hold off for *STROBE-X!)*
- Bright, hard X-ray transient immediately after eruption (F_x > 10^{-9} erg/s/cm^2)
- Temperature and luminosity evolution of blast wave used to constrain M_{ejecta}
- Discrepancy between *RXTE* and *Swift* fits on same day led to different interpretation of shock evolution



RXTE spectra and derived properties from Sokoloski et al. 2006

RS Oph with *STROBE-X*

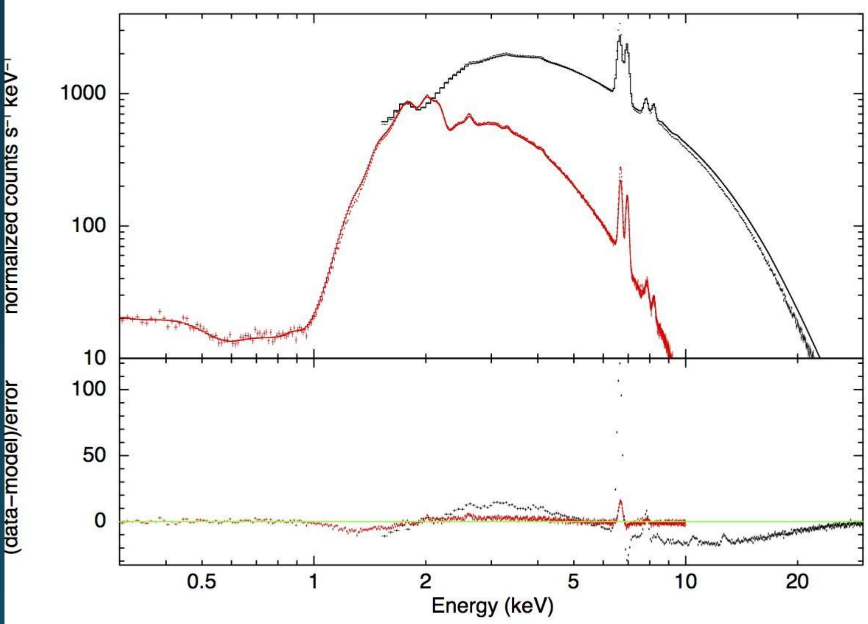


2ks observation of 8.44 keV mekal absorbed by 2.96 x 10^{22} cm^{-2}
XRCA = 2240 cts/s; LAD = 11760 cts/s

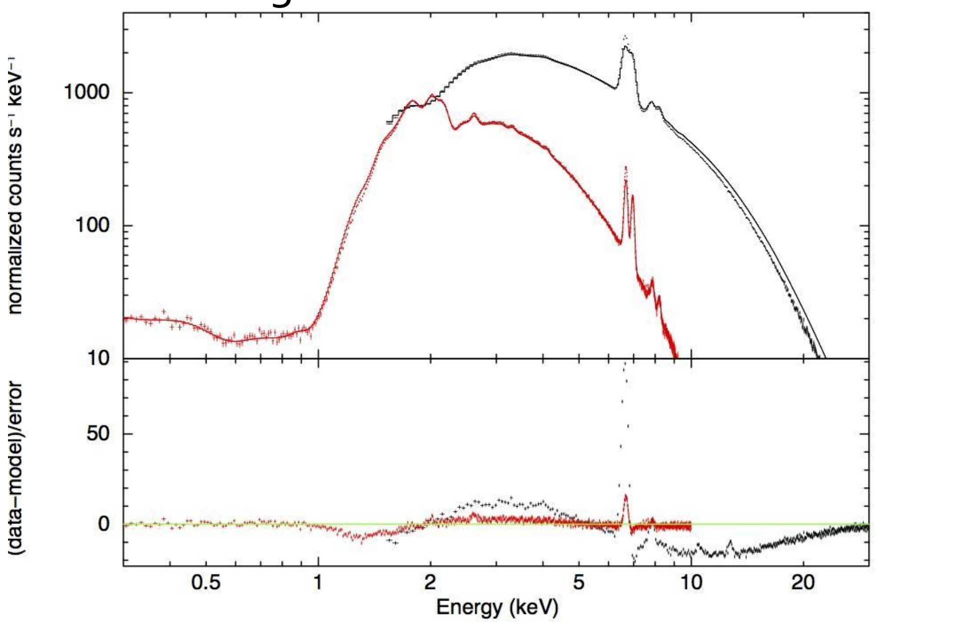
- Extremely high S/N spectra with both XRCA and LAD
- Combination of soft and hard responses crucial to constrain both N(H) and temperature
- Well-resolved, high S/N Fe complex crucial for good temperature constraints
- RS Oph type spectra could be observed out past 10 kpc

RS Oph with *STROBE-X*

200 eV LAD resolution

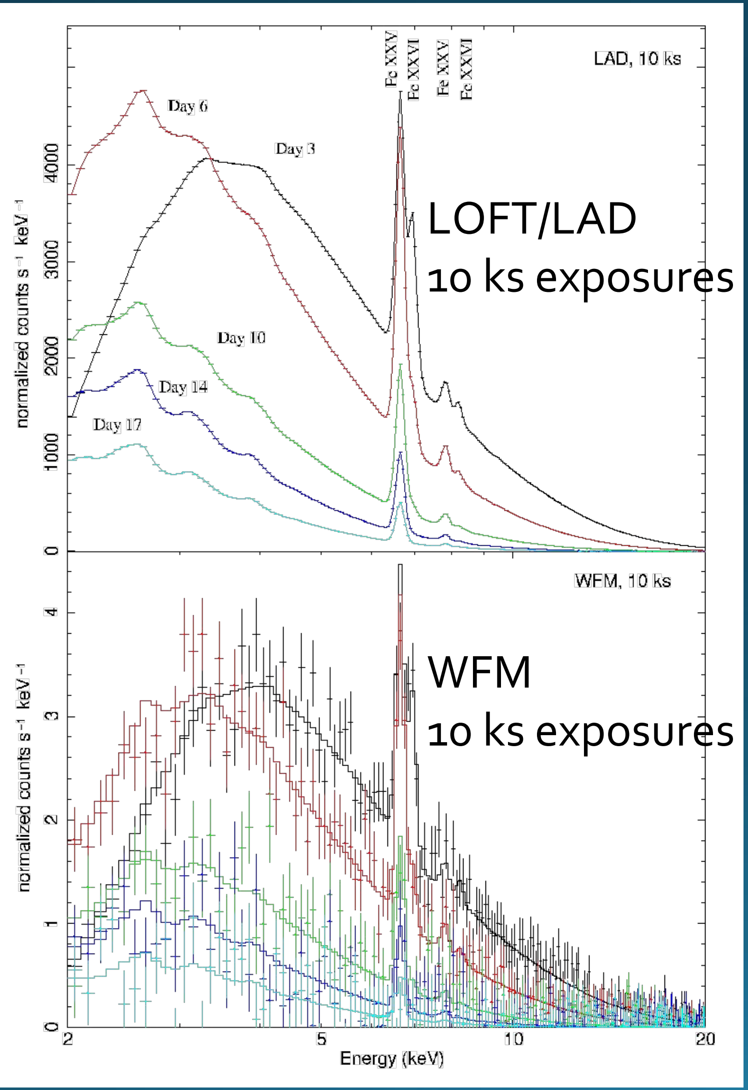


300 eV LAD resolution



Fe line and 10-20 keV coverage better constrain temperature than *RXTE* or *Swift*

RS Oph with *STROBE-X*



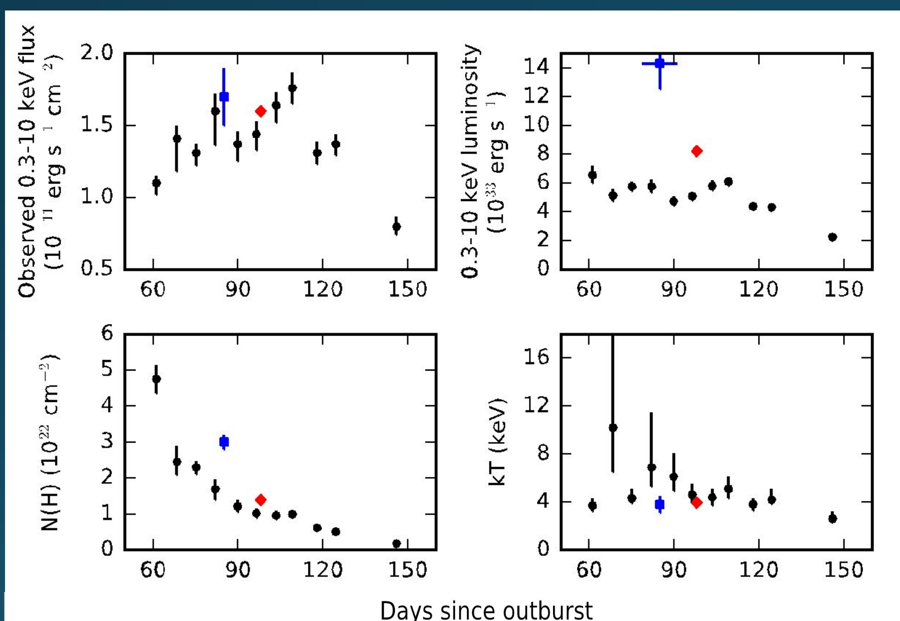
- RS Oph would trigger the WFM out to distances of 5 kpc (RS Oph at 2.4 kpc)
- See LOFT accreting white dwarf white paper for more details…

LOFT simulations of RS Oph from de Martino et al. 2015

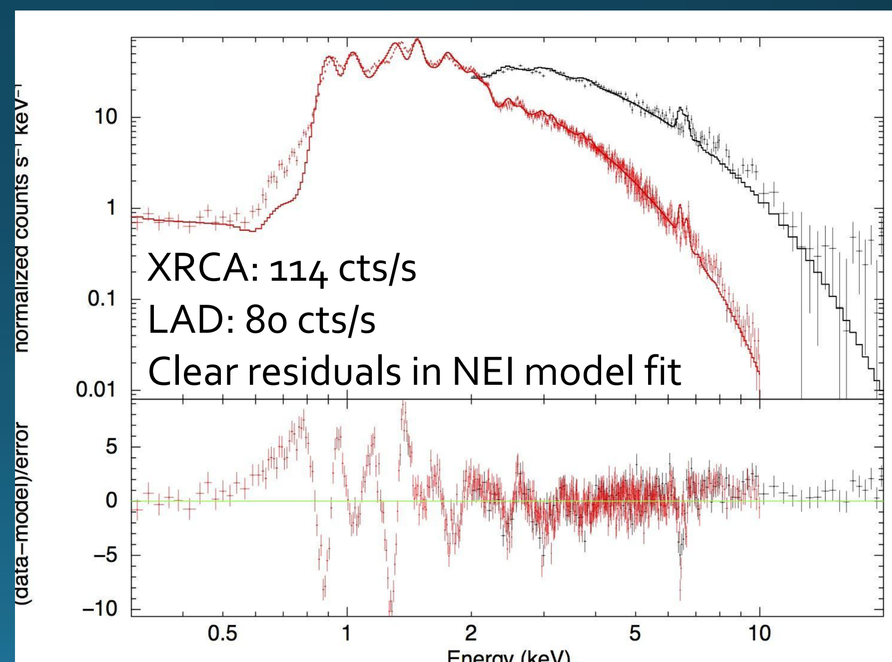
X-rays from CV novae

- Most CV-type systems show much lower X-ray fluxes at early times than RS Oph
- Some nearby novae will be ideal *STROBE-X* targets (e.g V959 Mon) and will enable searches for NEI line ratios in spectra

Nelson et al. in prep



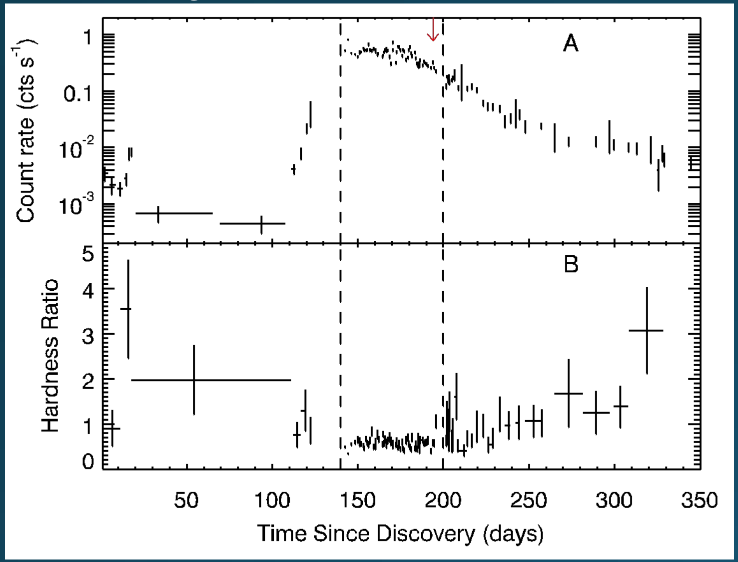
Swift XRT, *Suzaku* and *Chandra* model parameters

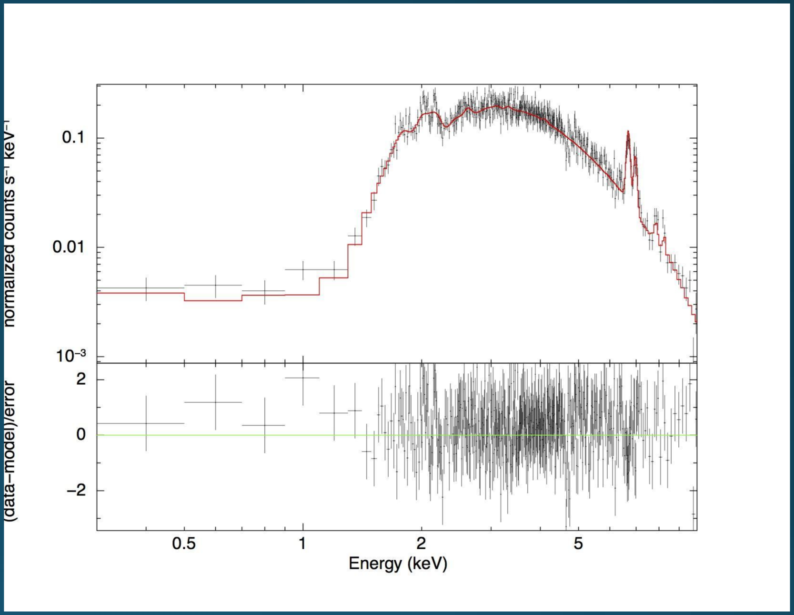


2 ks simulation of V959 Mon, Day 98

Characterizing early faint X-rays

T Pyx *Swift*/XRT (Chomiuk et al. 2014)





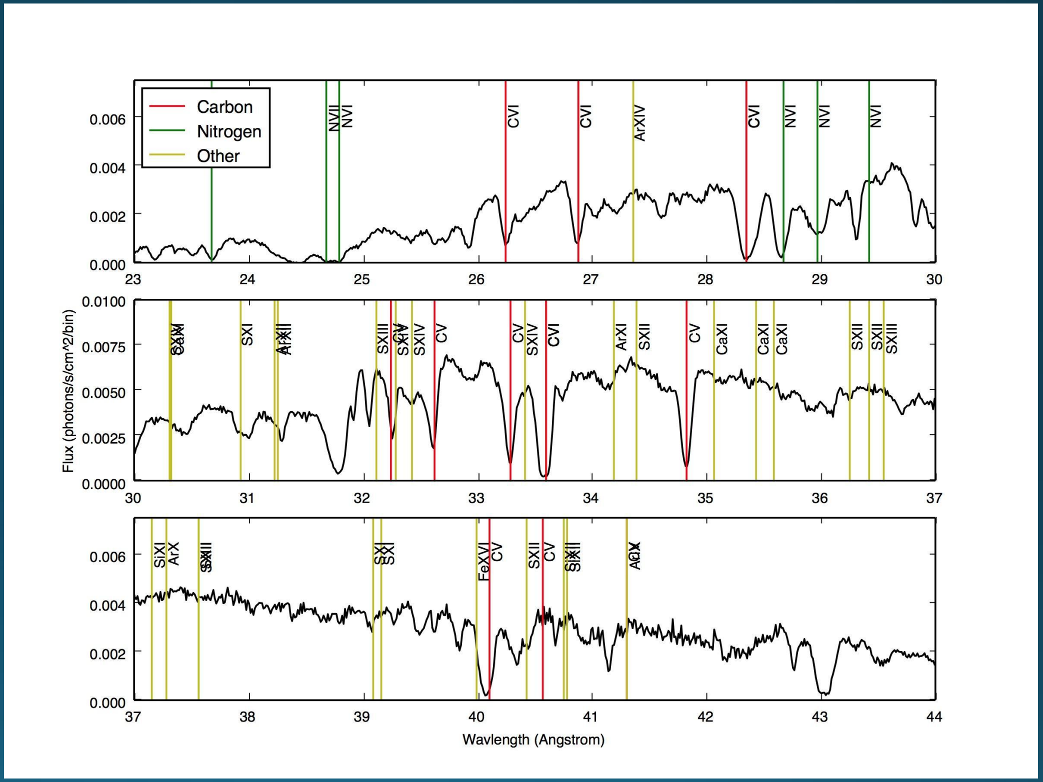
- Very faint X-ray emission seen in many novae at early times
- XRCA will offer better characterization of this emission depending on final background levels

20 ks XRCA observation assuming 10 keV thermal plasma absorbed by 5e22 cm^{-2} and 0.3-10 keV flux of 5.3e-13 erg/s/cm^{2}

XRCA count rate is 0.7 cts/s - mayne too faint to detect above background?

X-rays from nuclear burning

- Many novae become bright, supersoft sources
- Emission originates in still-burning white dwarf photosphere
- $20 < kT < 100$ eV
- $10^{36} < L_x < 10^{38}$ erg s^{-1}
- Generally modeled as blackbody in short *Swift* exposures, but known from grating observations to show complex absorption line systems

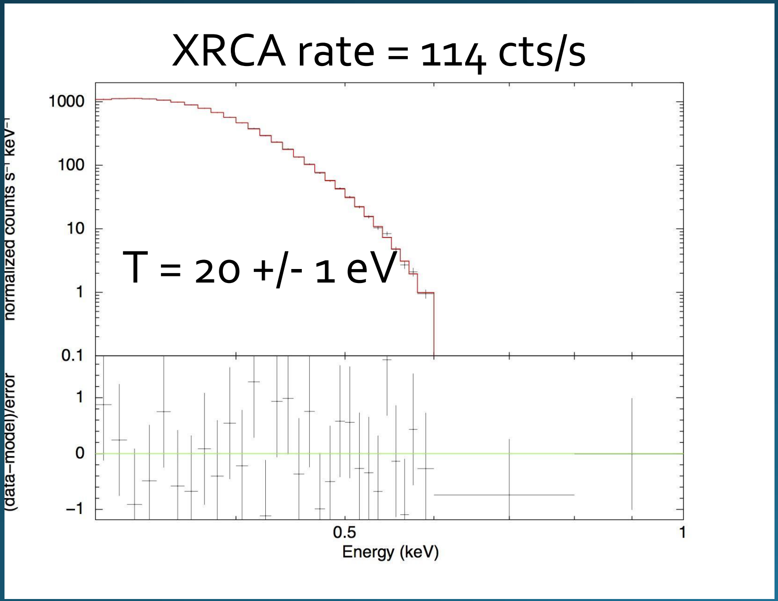


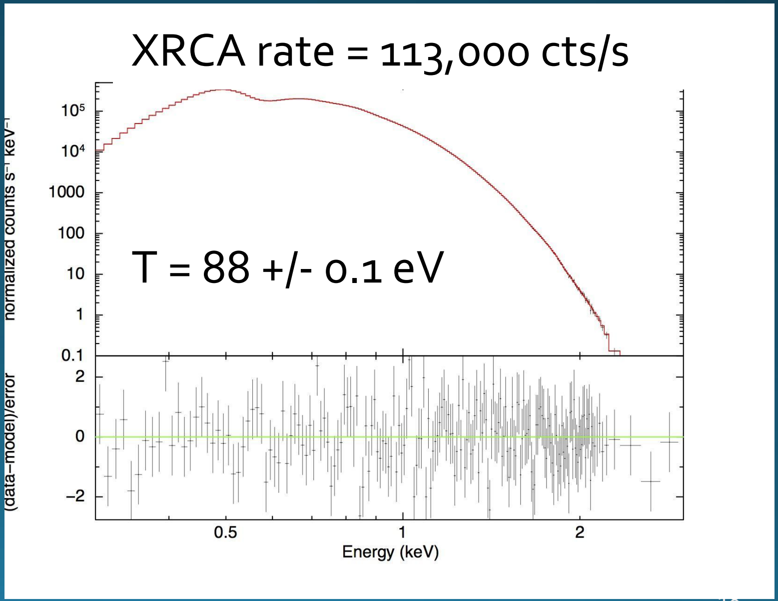
Chandra/LETG spectrum of V339 Del

Expected count rates with XRCA

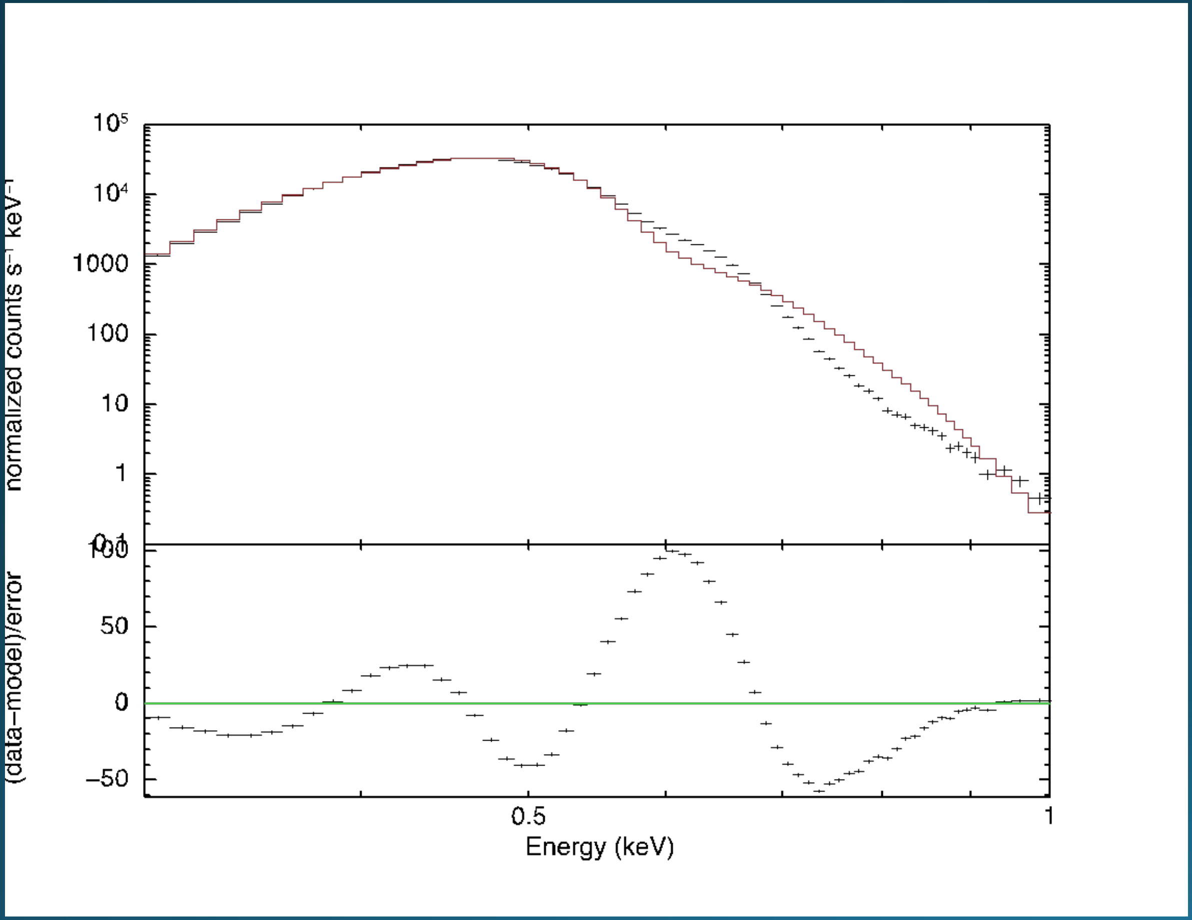
- "Faint" Swift SSS
  - $F_x = 10^{-11}$ erg/s/cm^2
  - kT = 20 eV
  - N(H) = $2e^{21}$ cm^{-2}
  - XRT rate = 0.5 cts/s

- RS Oph 2006
  - $F_x = 6 \times 10^{-9}$ erg/s/cm^2
  - kT = 88 eV
  - N(H) = $3e^{21}$ cm^{-2}
  - XRT rate = 250 cts/s





Detecting atmosphere features



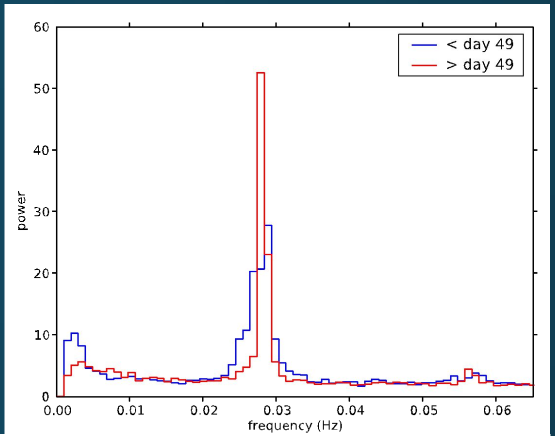
Rauch model atmosphere
kT = 70 eV
F_x = 2.4e^{-10} erg/s/cm^2

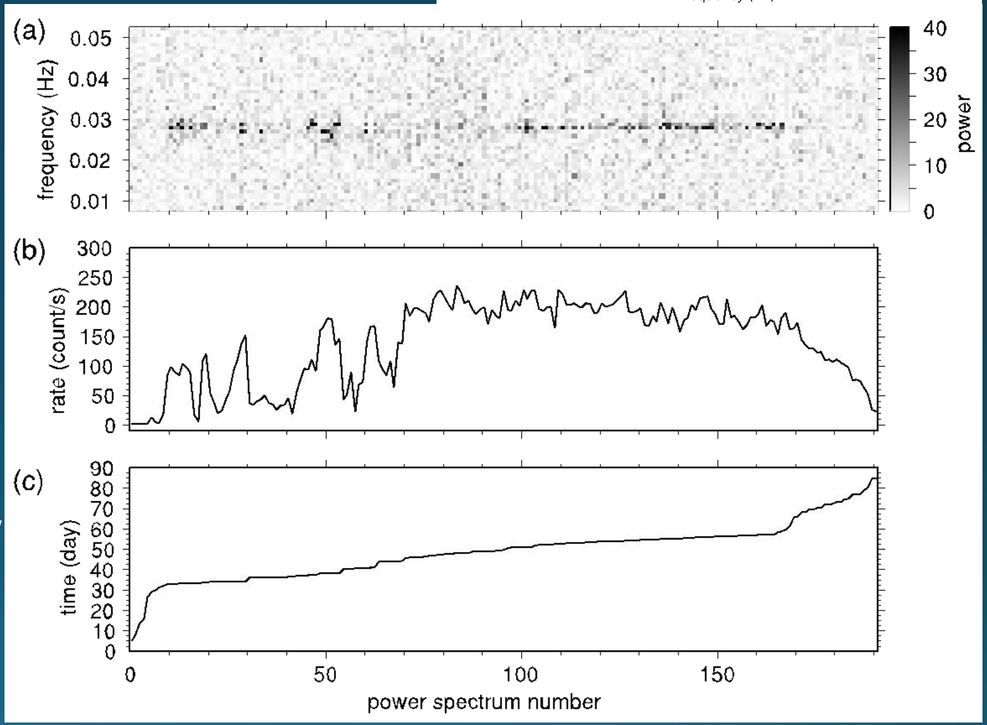
XRCA rate= 5120 cts/s

Clear departures from blackbody spectrum in short observations

Supersoft oscillations

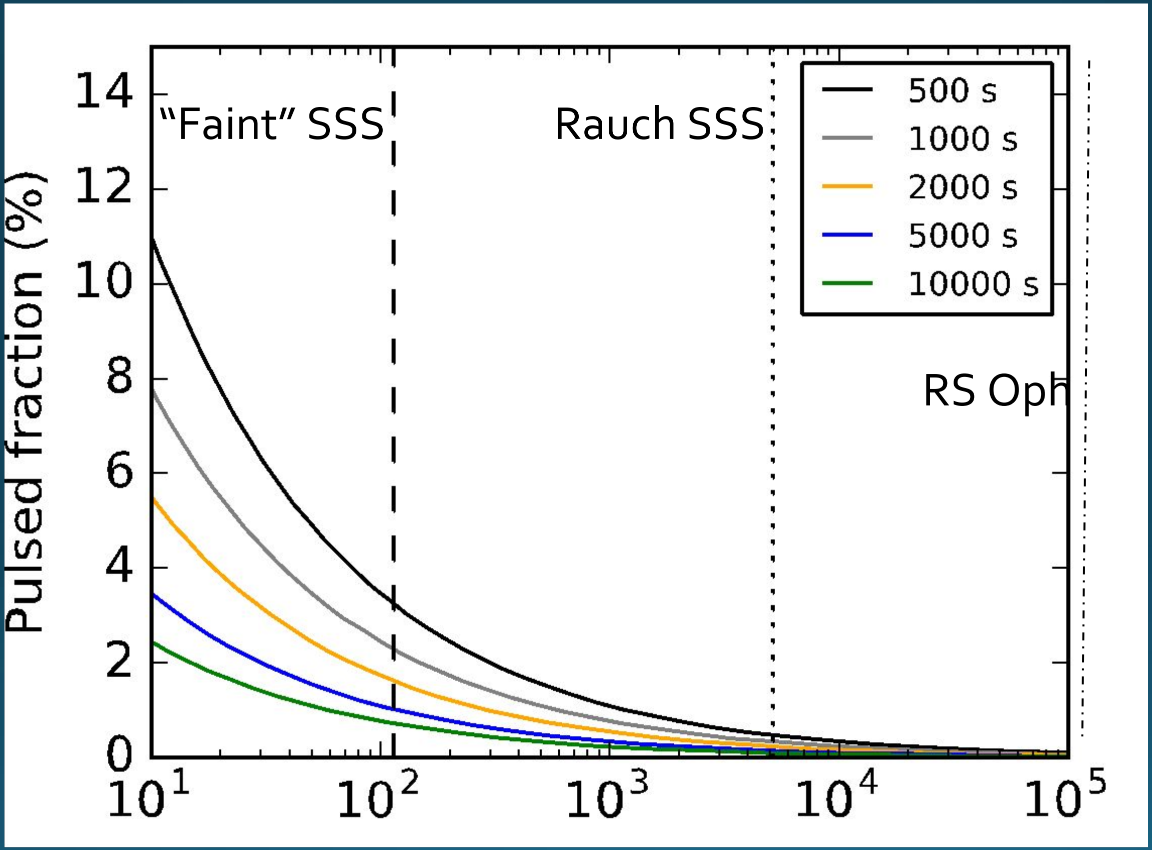
- Short period oscillations have been found in several novae during the supersoft phase
- Periods in range 30-60 s
- Pulse fractions 1.5-10%
- Duty cycle 10—50%
- Periods vary over the course of the nova outburst (e.g. RS Oph)
- Origin unclear: white dwarf spin, or g-modes excited by nuclear burning (epsilon mechanism)





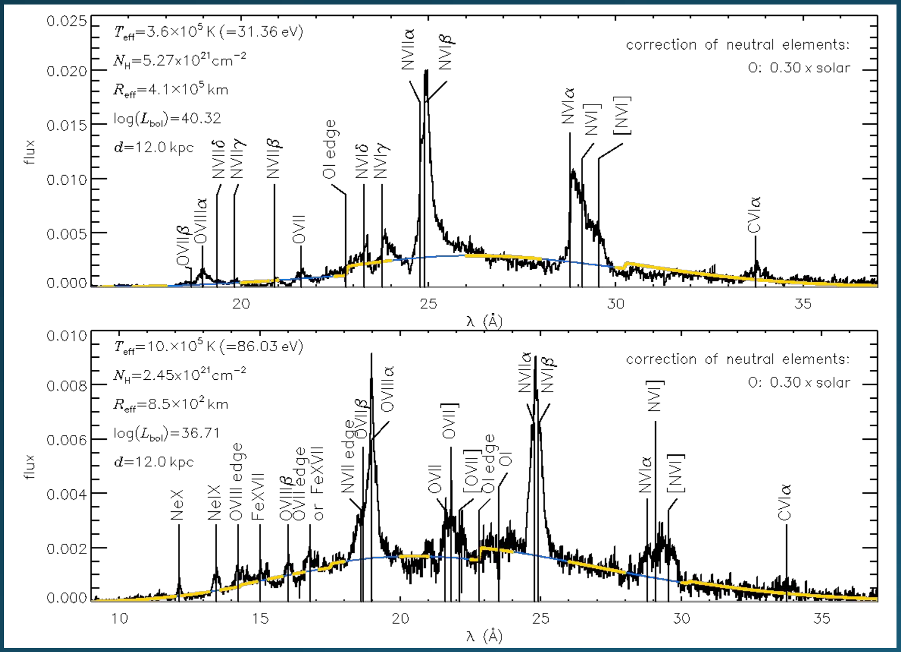
SSS oscillation evolution in RS Oph 2006 from Osborne et al. 2011

Sensitivity to periodic oscillations



XRCA observations of novae offers real opportunity to study these oscillations in a wider number of systems

Dilution by Thomson scattering



Chandra/LETG spectrum of U Sco in 2011; XRCA observations may be able to detect SSS oscillations that are suppressed by scattering in the ejecta

- Oscillations to date have been found in continuum-dominated supersoft novae
- Many “fainter” SSS show primarily emission line spectrum, with suppressed continuum, in grating observations (e.g. U Sco)
- Oscillations are suppressed by Thomson Scattering in nova ejecta

Biggest concerns

- XRCA background for fainter sources
  - Once background models are available, can work more carefully on simulations of faint sources
- Optically bright source issues (e.g. optical loading?)
  - Swift XRT is subject to optical loading for bright sources, and has proven to be an issue for studies of novae and symbiotic stars
  - Will we be able to observe V < 5 objects?
- Source confusion for galactic plane novae
  - Most novae are discovered in the galactic plane; many near the galactic center
  - Source confusion will be an issue for LAD observations; will impact sensitivity on source-by-source basis

Conclusions

- Large effective area and good energy resolution will allow many novae to be efficiently followed up
- Hard X-rays trace shocks: STROBE-X will be able to obtain more accurate temperatures, absorbing columns and abundance constraints for many novae compared to Swift
- Some nova eruptions will trigger WFM
- XRCA will be able to probe oscillations in many more supersoft sources than we can currently