Hard X-ray Views of Cataclysmic Variables and Symbiotic Stars

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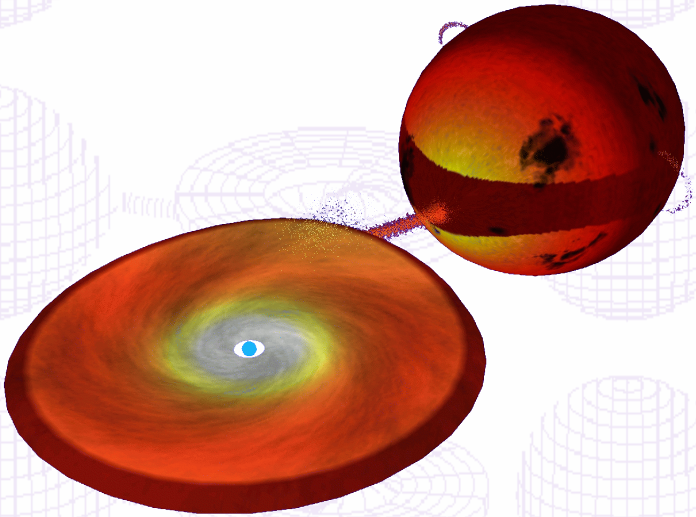
Summary

- Hard X-ray surveys with INTEGRAL and Swift/BAT have expanded our view of the population of CVs and Symbiotic Stars.
  - ✓ Now starting to combine with Gaia distances.
  - ✓ eROSITA will expand our view of the lower L_x populations.
- Nova eruptions have been shown to be unexpectedly powerful particle accelerators.
  - ✓ We now have the first contemporaneous detections of highly absorbed thermal X-rays from the shock responsible.
  - ✓ We still do not have reliable detection of non-thermal X-rays.
- Accretion disk boundary layer still manages to surprise us.
  - ✓ Paradigm derived from SS Cyg does not always work
  - ✓ Disk instability model predicts gradual X-ray luminosity increase during interoutburst intervals – this as never been observed
- Reflection has become a routine ingredient of spectral fitting for these objects.
  - ✓ This is both a complication and a tool.
- High resolution X-ray spectroscopy with XRISM and Athena will open new opportunities for the study of CVs and Symbiotic Stars.

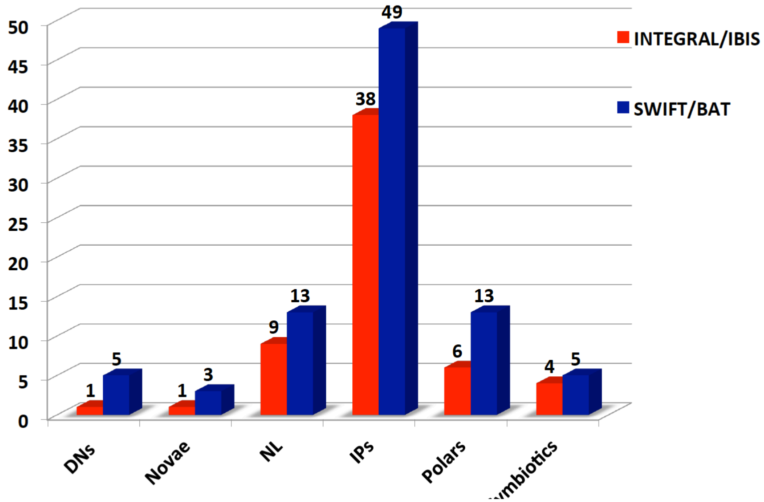
Cataclysmic Variables (CVs) and Symbiotic Stars

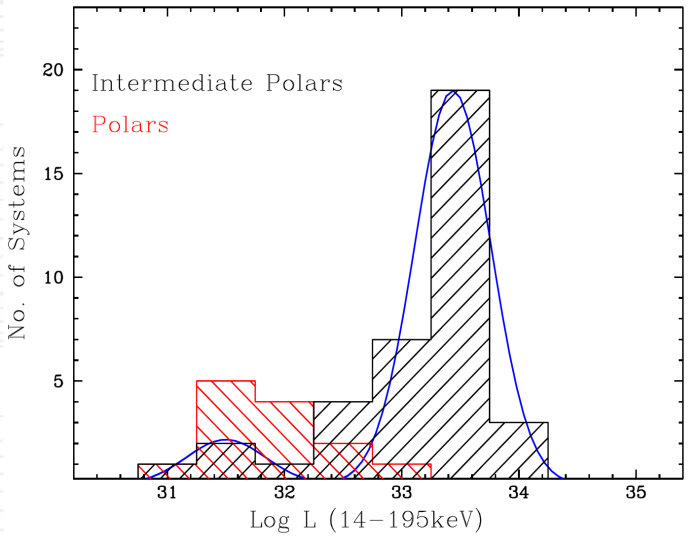


- CVs: Roche-lobe filling red dwarf and an accreting white dwarf
- In about 10-20% of CVs, the WD is sufficiently magnetic to control the accretion flow.
- The majority are non-magnetic, with the disk extending down to the WD surface.

- Symbiotic stars: red giant with strong wind and an accreting white dwarf.
- Many classic symbiotic stars have shell burning as the main energy source.
- Some are purely accretion powered.

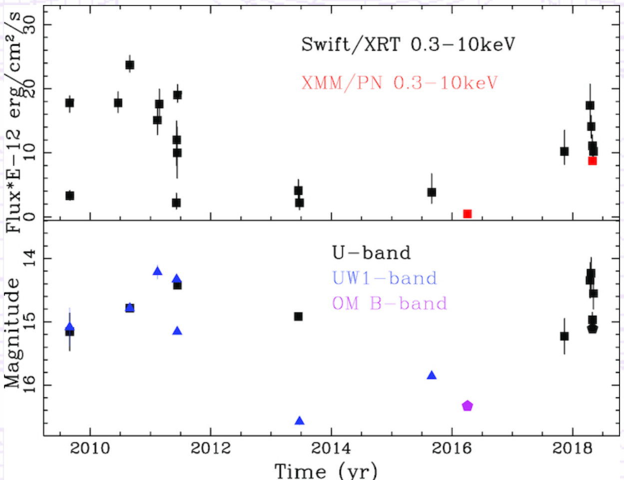
Hard X-ray Surveys

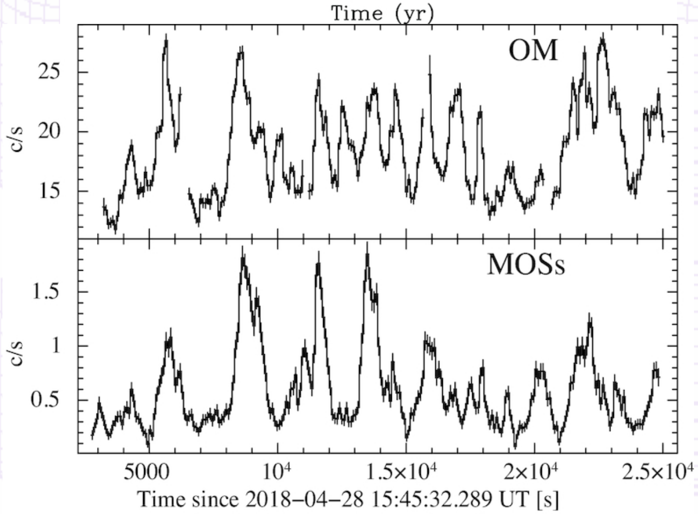




- We (de Martino et al., ASR, in press) have been conducting a systematic follow-up of INTEGRAL and Swift/BAT sources proposed to be CVs using XMM-Newton.
- Roughly 25% of the Galactic hard X-ray sources are CVs and Symbiotic Stars.
- In particular, magnetic CVs of intermediate polar (IP) subclass is the largest subclass, other types are also found.
- Combined with the Gaia DR2 distance, we can now construct reliable hard X-ray luminosity function of major subclasses.
- IPs are rare and individually luminous.

Recent Examples





- Highest flux hard X-ray sources were dominated by standard IPs. We probably have a complete census of such systems to beyond 1 kpc.
- As we push our efforts to lower hard X-ray fluxes, other subtypes of CVs are showing up.
- 2PBC J0658.0-1746 is an eclipsing polar at ~200 pc; most polars are soft X-ray bright and har
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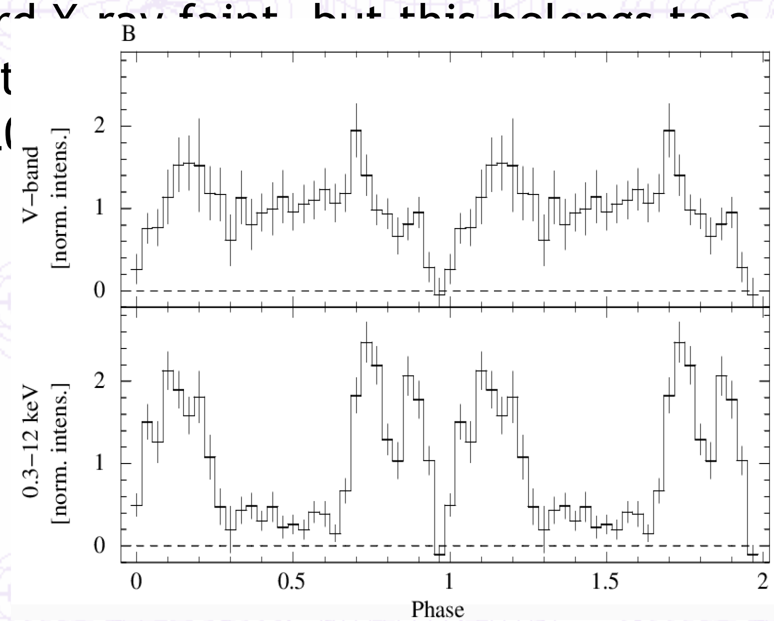
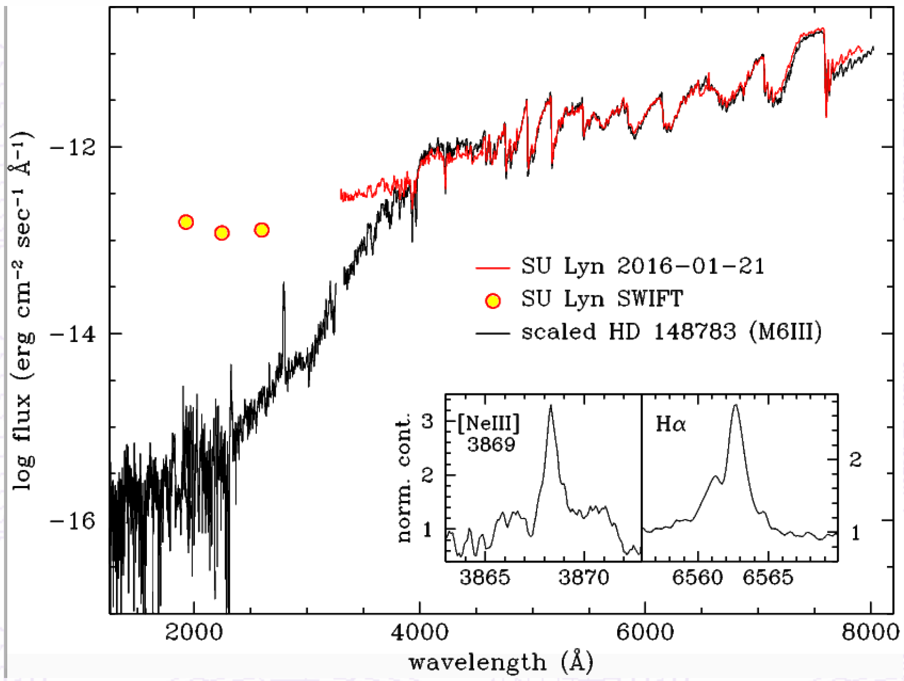


- Swift J0746.3-1608 has high and low states and unusual light curves, and is probably an IP (Bernardini et al. 2019, MNRAS, 484, 101).

Symbiotic Stars as hard X-ray sources

- A surprise from the early BAT survey: 4 symbiotic stars (T CrB, RT Cru, V648 Car, and CH Cyg) were detected.
- A new surprise: SU Lyn, a previously obscure red giant in an obscure constellation was also detected - a newly recognized, purely accretion-powered, symbiotic star
- A Skymapper search for similar objects under way.

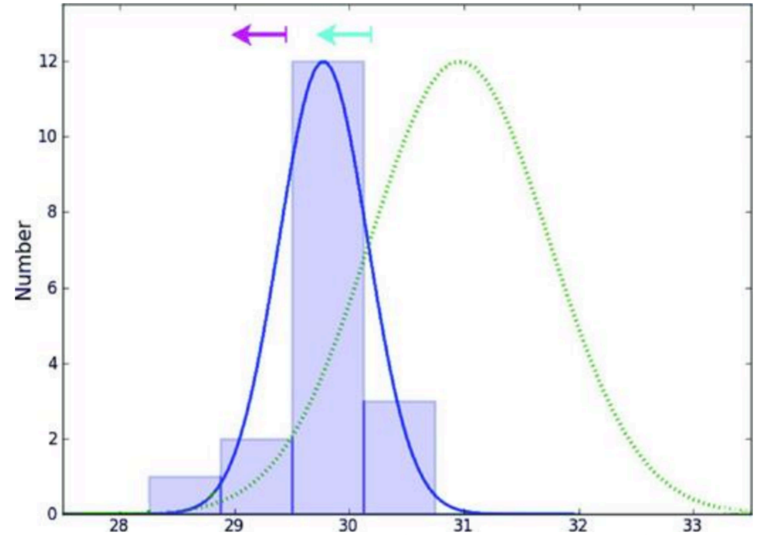


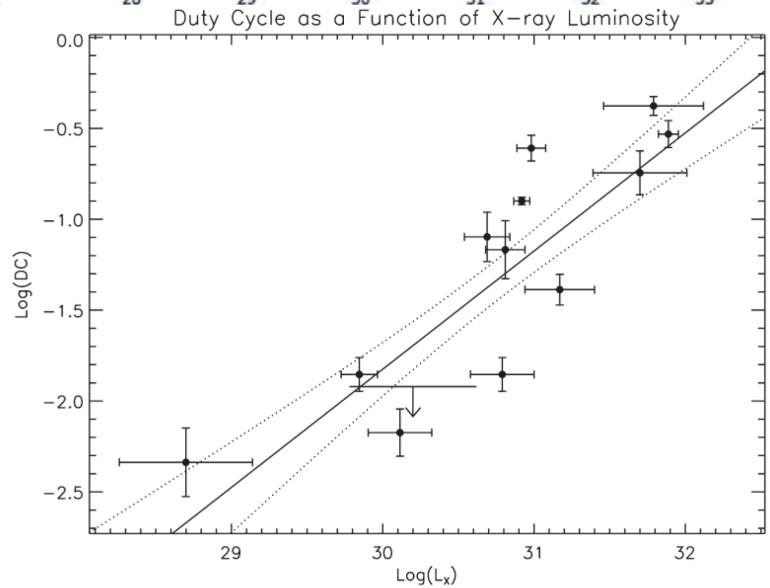
Composite UV-optical SED of SU Lyn, a BAT-detected hard X-ray source. Low resolution optical spectroscopy cannot reveal the symbiotic nature: high resolution spectra and/or UV data are necessary

X-ray Luminosity Function of Dwarf Novae

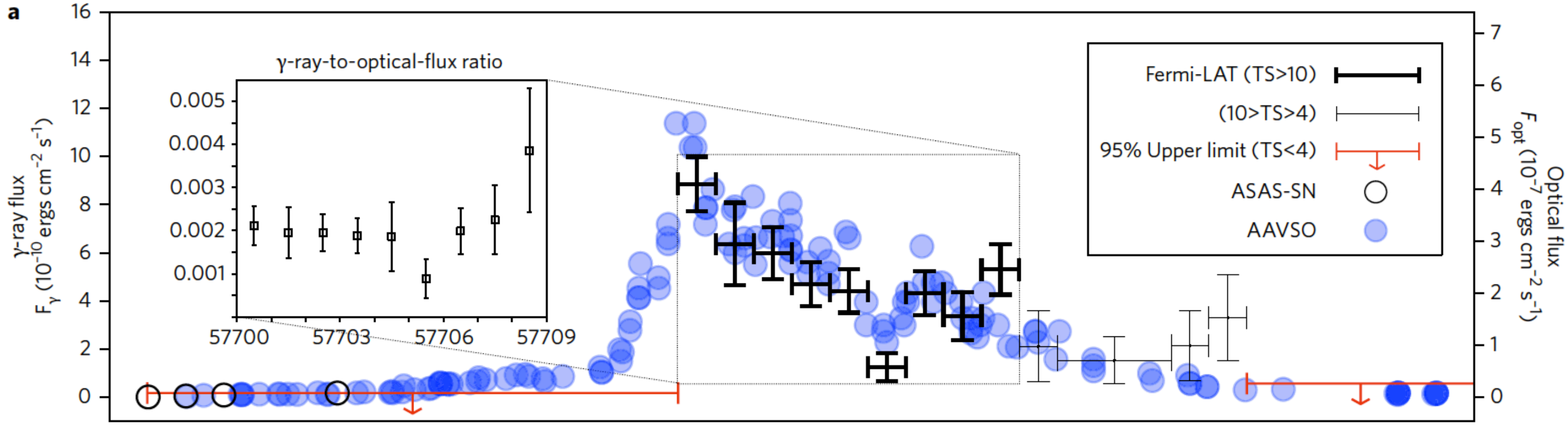
- Our current census of even the nearby (d=100-300 pc) dwarf novae are probably woefully incomplete. WZ Sge subtype has low accretion rate, faint during quiescence in the optical and in the X-rays, and outbursts are rare.
- For example, TCP J21040470+4631129 was discovered in outburst this past July, and Gaia DR2 parallax puts it at 109 pc away.
- Well-known dwarf novae have $L_x=10^{30}$-10^{32} ergs/s (Byckling et al. 2010, MNRAS, 408, 2298); SDSS discovered optically-faint population have lower L_x (Reiss et al. 2013, MNRAS, 430, 1994)
- Britt et al. (2015, MNRAS, 448, 3455) found correlation between outburst duty cycle and X-ray luminosity

eROSITA will discover many, many



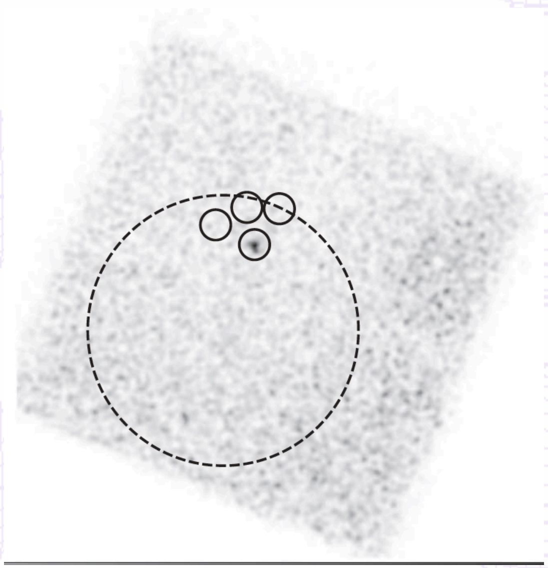


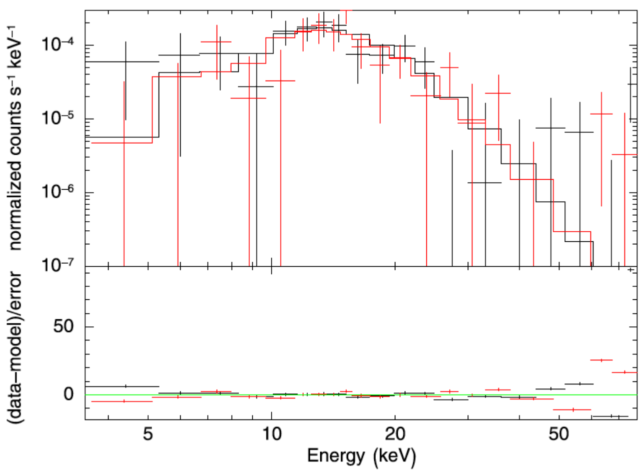
Novae as GeV gamma-ray sources



- Nova eruptions are the consequence of violent mass ejection due to thermonuclear runaway of material accreted on the white dwarf surface.
- Fermi/LAT has discovered 14 or so novae (depending on the significance threshold) as transient source of GeV gamma-rays.
- In one spectacular case of V5856 Sgr, Li et al. (2017, Nature Astronomy, 1, 697) reported a striking correlation between gamma-ray and optical flux of the nova, leading to the speculation that a significant part of the nova emission may be shock-powered.
- Such shocks should also emit thermal X-rays; non-thermal emission should extend down from GeV to hard X-ray energies.

NuSTAR detection of V5855 Sgr





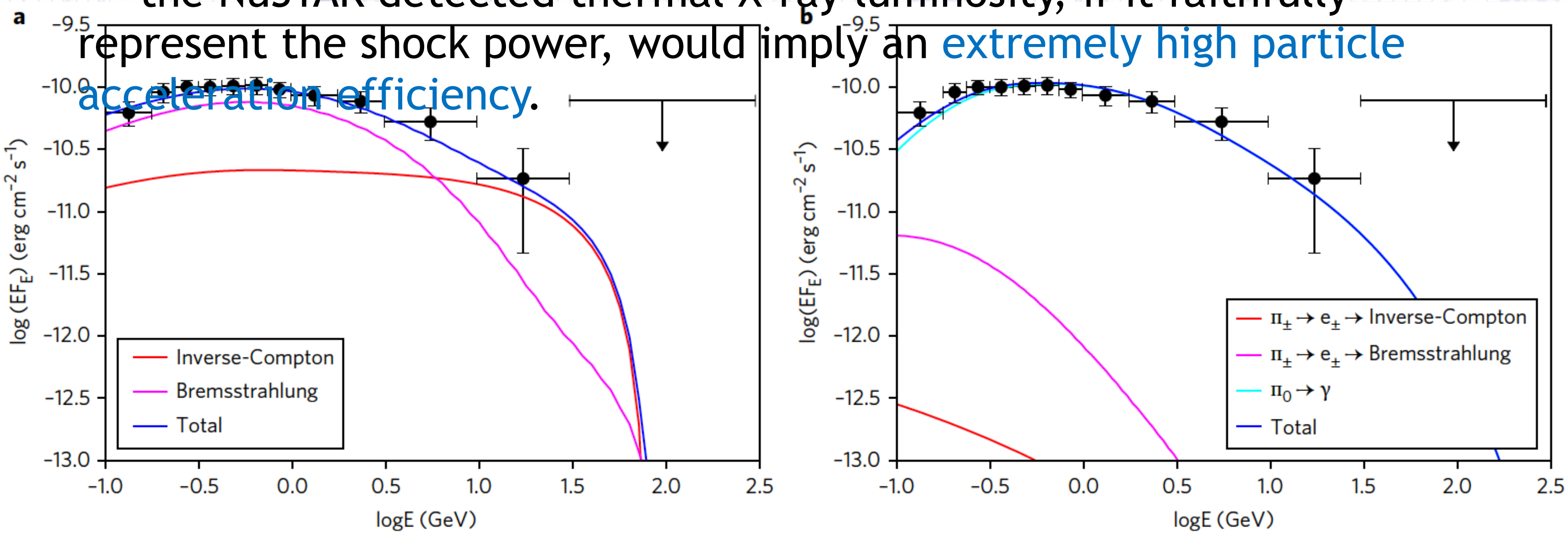
X-rays from shocks in novae have been well known but previously detected with a significant delay relative to optical peak. In contrast, GeV emission is usually reported within days of optical peak, lasting for a week or two.

- ➢ Nelson et al. (2019, ApJ, 872, A86) reported the first contemporaneous detection of X-rays during the GeV emission phase of a nova eruption.
- ➢ The spectrum was highly absorbed, requiring the high energy capability of NuSTAR.
- ➢ Non-thermal emission has not been detected with NuSTAR, although a couple of claims exist obtained using non-imaging hard X-ray instrument.

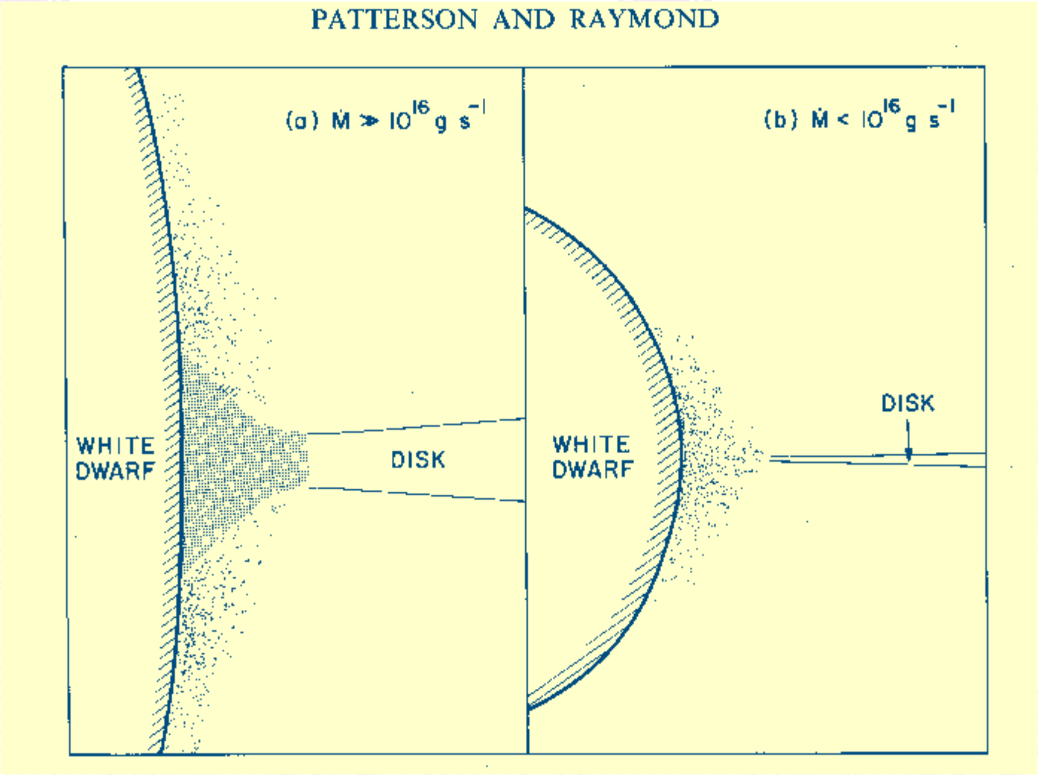
Watch out for forthcoming results on V906 Car (=ASASSN-18fv).

Hadronic or Leptonic?

- With the right combination of circumstances (bright, nearby novae in the right part of the sky at the right time), we may be able to detect non-thermal hard X-rays from novae while Fermi/LAT is detecting GeV gamma-rays.
- This is likely a good diagnostic of whether the gamma-ray emission process is leptonic or hadronic, which, so far, we have not been able to determine.
- In addition, the overall efficiency of particle acceleration is in question --- the NuSTAR detected thermal X-ray luminosity, if it faithfully represent the shock power, would imply an extremely high particle acceleration efficiency.



X-rays from non-magnetic WDs



Schematic diagram of the boundary layer, the site of X-ray emission for accreting non-magnetic white dwarfs, from Patterson & Raymond (1985).

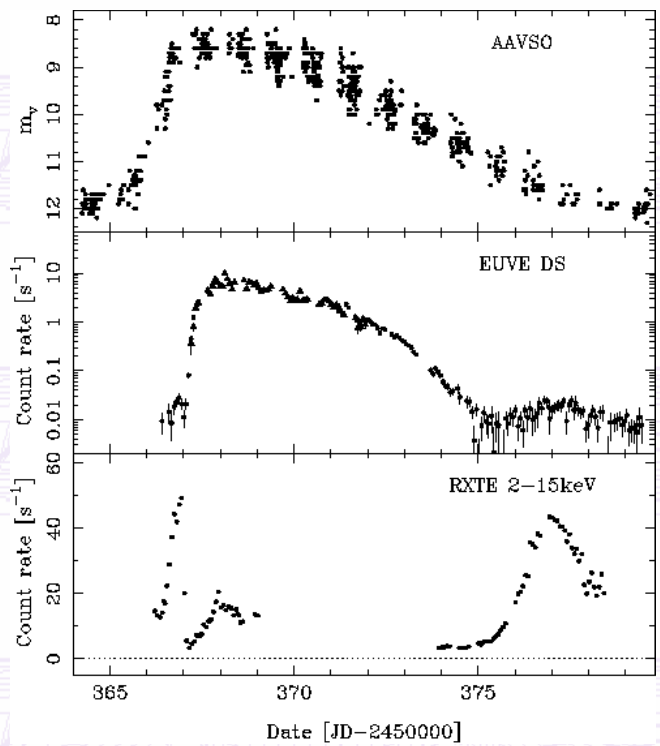
An X-ray astronomer might think that CVs and symbiotic stars are the same, since X-rays are generated in the immediate vicinity of the white dwarf. However:

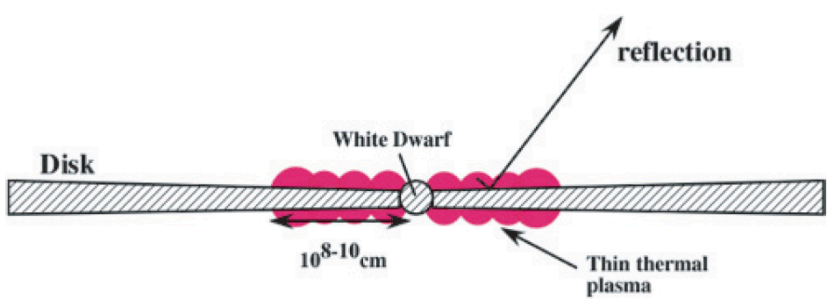
- Evolutionary paths and current evolutionary drivers differ
- Symbiotic stars are embedded in the wind of the donor
- IR/optical/UV characteristics differ greatly
- Accretion disk time scales differ greatly as well

Textbook Case: SS Cyg

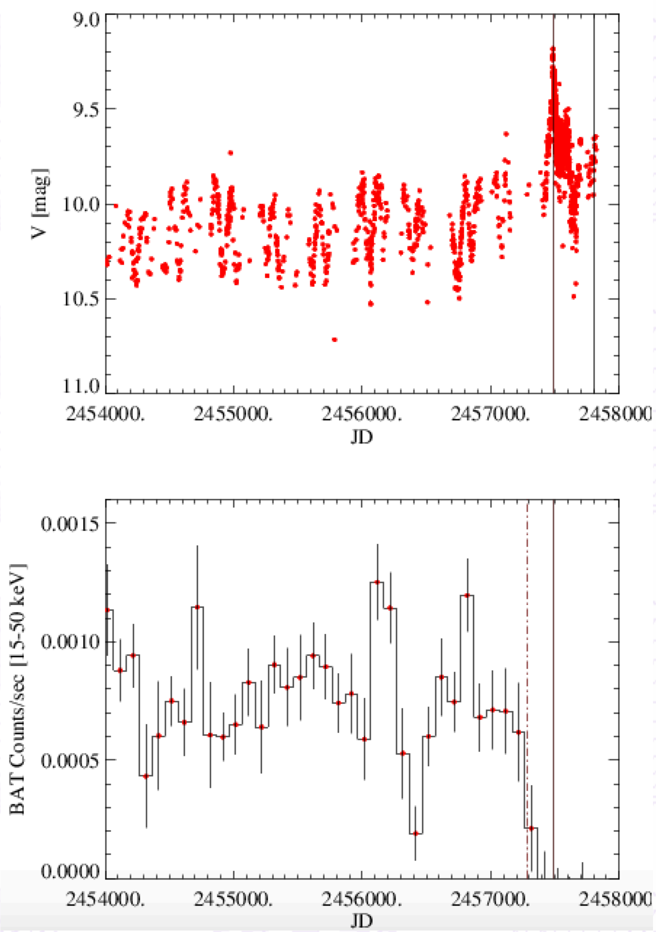
Note: SS Cyg is a textbook case, i.e., it's not necessarily typical in all its aspects.

- ❖ SS Cyg in quiescence has an optically thin boundary layer, emitting ~10^{31} ergs s^{-1} of optically thin X-rays in the 0.5-~30 keV range
- ❖ In outburst, the boundary layer switches to a mostly optically thick state, emitting blackbody-like soft (<0.5 keV) X-rays while optically thin emissions remain
- ❖ There is a hysteresis effect – rise and decay are not identical
- ❖ There is a residual, weaker and softer, optically thin component during outburst.
- ❖ Ishida et al. (2009, PASJ, 61, 877) proposed an accretion disk corona origin for this component.

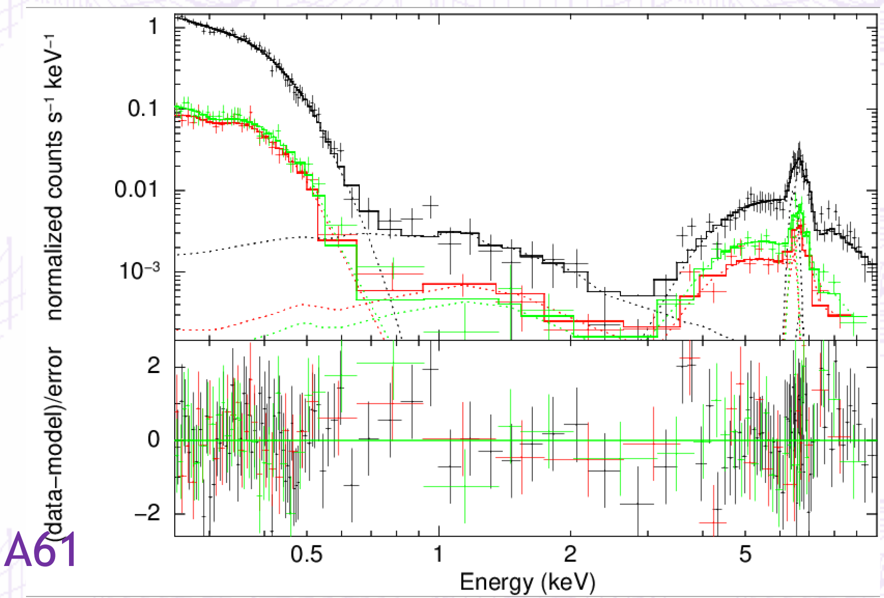




Recent Activity of T CrB

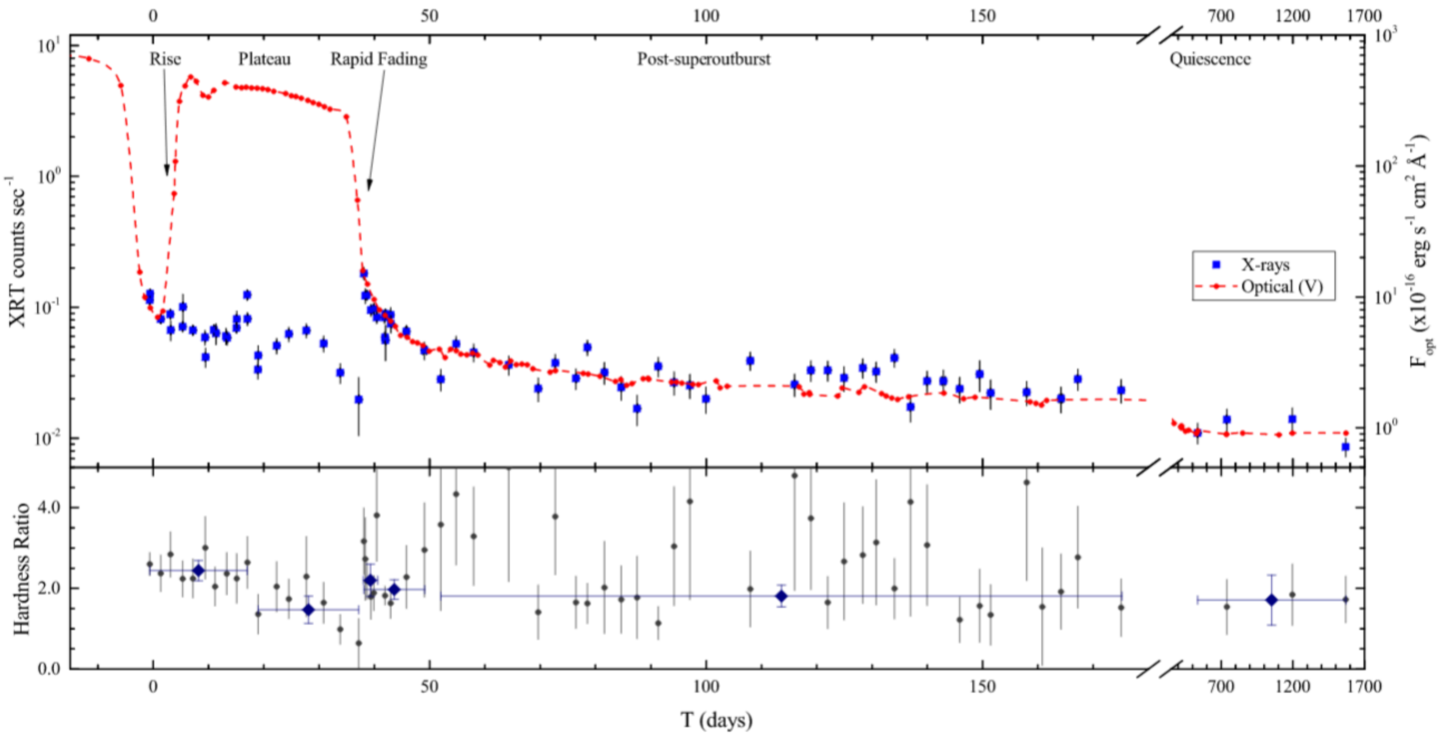


- ➢ Since 2015, T CrB has gone into an optically bright state – sign of a large, bright, disk
- ➢ The hard X-ray flux dropped
- ➢ The *XMM-Newton* spectrum confirms the softening and dimming of hard X-rays with a dramatic soft component



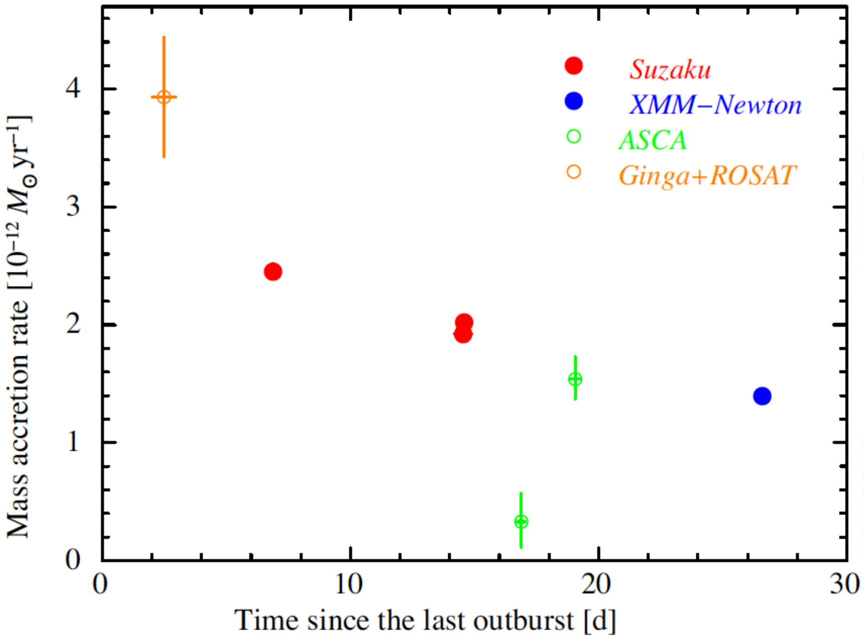
From Luna et al. 2018, A&A, 619, A61

SSS J122221.7-311520 and co.



- ➢ Neustroev et al. (2018, A&A, 611, A13) presented an extensive Swift/XRT campaign on the WZ Sge-type dwarf nova, SSS J122221.7-311520.
- ➢ No soft component was detected, simply an elevated level of hard X-ray emission.
- ➢ Recent snapshot Swift/XRT observations of WZ Sge-type dwarf novae in outburst similarly reveal increased hard X-ray luminosity (e.g., TCP J21040470+4631129; Sokolovsky et al. 2019, Atel 13009)

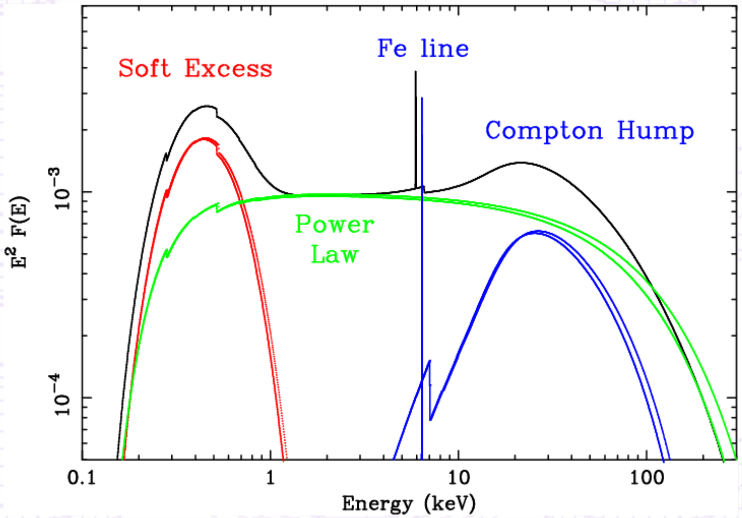
Inter-outburst X-ray Luminosity Evolution



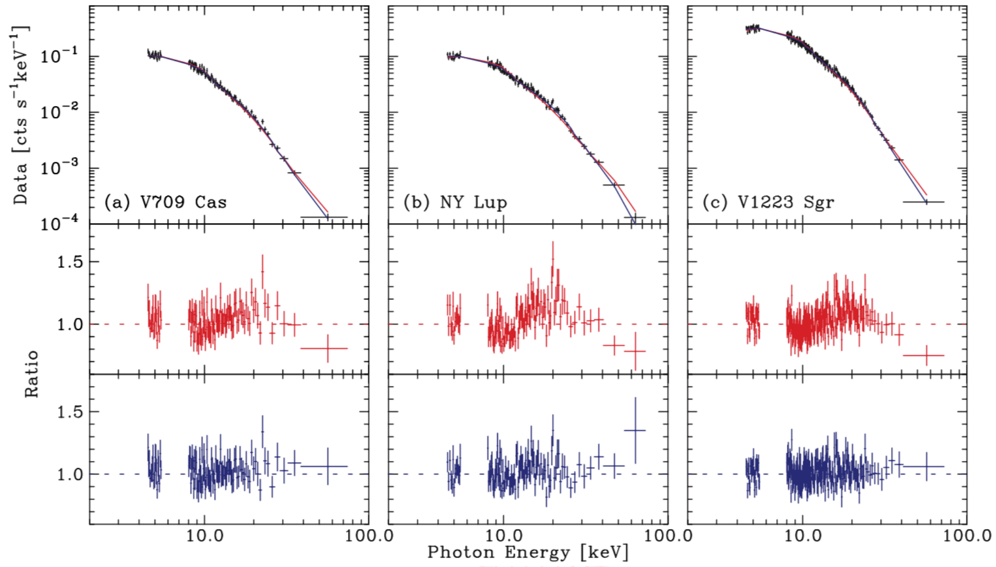
Accretion rate of the dwarf nova VW Hyi as inferred from X-ray observations, as a function of time since last outburst (Nakaniwa et al. 2019, MNRAS, 488, 5104)

- Dwarf novae are supposed to be the manifestation of disk instability.
  - ✓ Mass transfer rate from the donor is sufficiently low to keep the disk in a low viscosity state.
  - ✓ Mass builds up in the disk, until suddenly it transitions to a hot, viscous state (=outburst).
- A general prediction of disk instability model is that, during the course of the quiescence, the accretion rate onto the central objects gradually increases.
- This has never been observed in dwarf novae (SS Cyg, SU UMa, and now VW Hyi). Quite the contrary.

Reflection in IPs



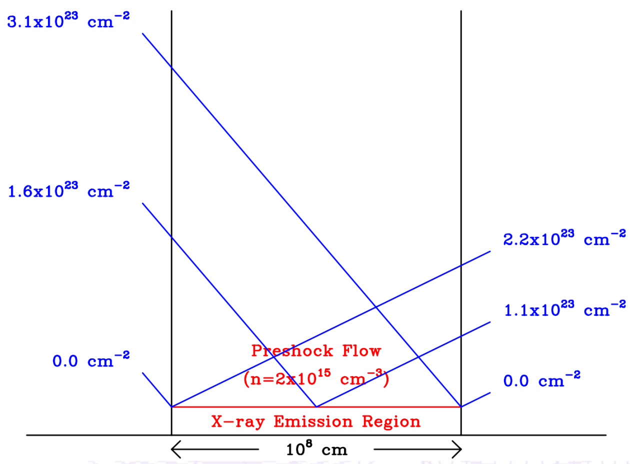
(Schematic AGN spectrum)

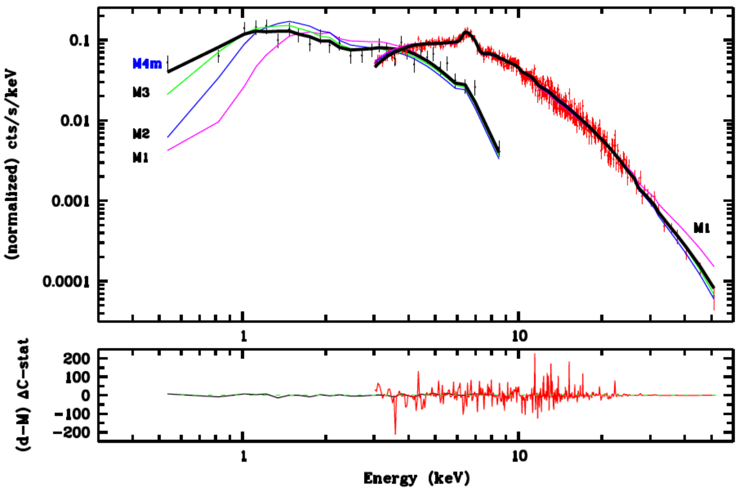


- “Reflection” (really backscatter) modifies the spectrum of X-ray sources that are near cold, Compton-thick surfaces (accretion disk, white dwarf).
- Spectral shape of the reflection component is determined by the competition between photoelectric absorption (highly effective at E<10 keV) and Compton scattering (E>10 keV), and leads to continuum bump & fluorescent 6.4 keV lin.
- The sensitivity of NuSTAR allowed Mukai et al. (2015, ApJ, 807, L30) to achieve unambiguous detection of reflection component in 3 IPs.

NuSTAR legacy survey of IPs led by Shaw will produce many M_{wd} estimatest

Spectral Complexities

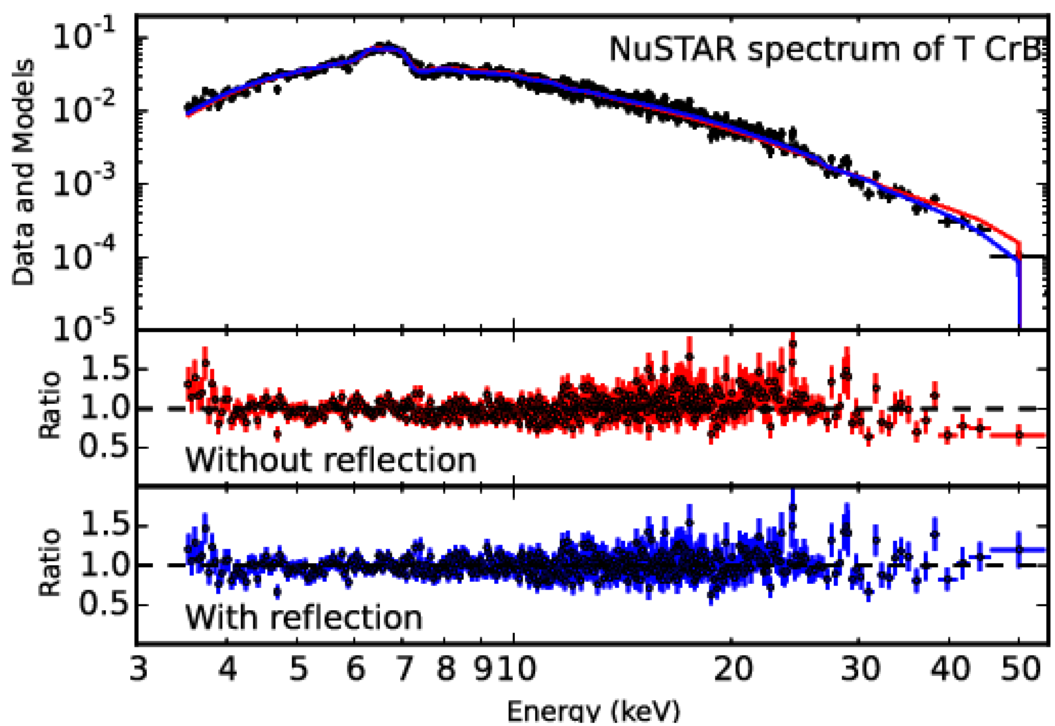




- Given the available bandpass and S/N limitations, kTmax and reflection amplitude are correlated in the fit results
- Reflection produces Fe edge at 7 keV – but so does the complex absorber in the case of IPs
- The complex absorber also modifies the spectral curvature in the 1-6 keV range (see the case of TV Col, from Lopes de Oliveira & Mukai 2019, ApJ,)
- Additional complications exist: soft, blackbody-like component from the heated surface, ionization of the complex absorber, abundances, …
- Spin modulation can help break the degeneracy
- Side benefit: WD mass estimate

Reflection in Symbiotic Stars

- We detect the reflection signature in a NuSTAR observation of T CrB (similarly for RT Cru and V648 Car; inconclusive for SU Lyn)
- Reflection amplitude varies among them and is >1.0 in V648 Car
- Reflection from WD surface only or from disk only should peak at amplitude of 1.0

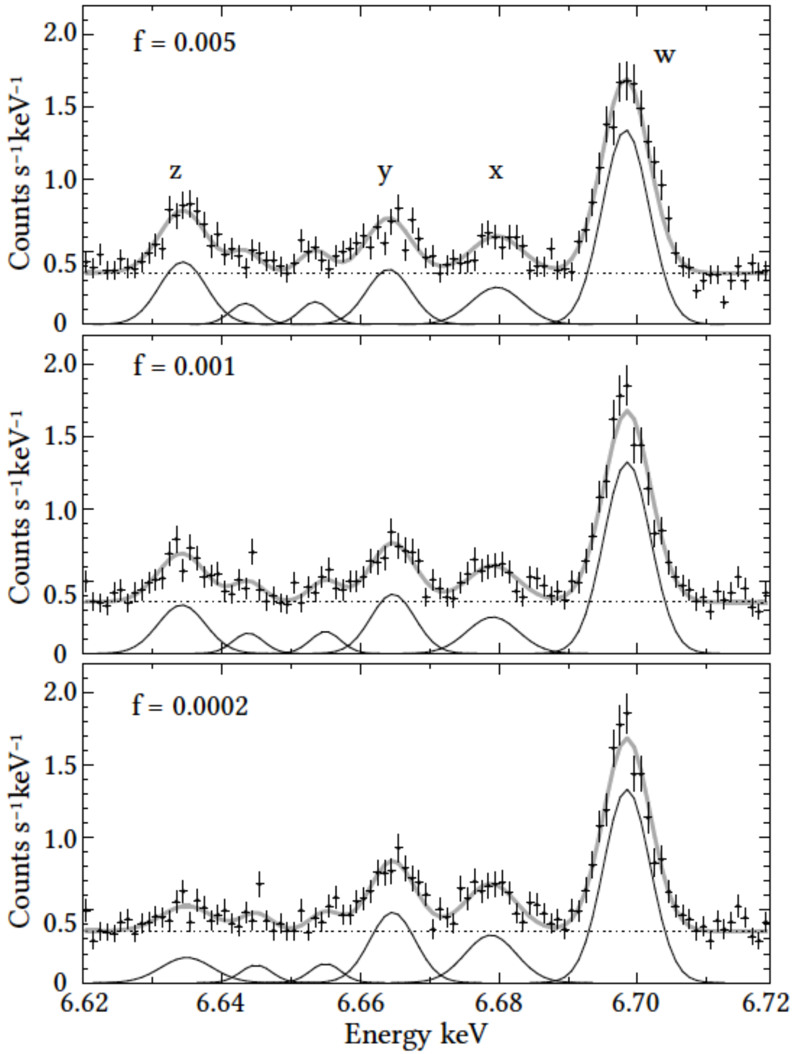


Combined with the high ratio of L_{UV} to L_X, it's likely that some of these symbiotic stars (at least some of the time) have a partially optically thick boundary layer, yet has hard and luminous optically thin X-ray emission. Reflection can be from both the WD surface and the disk.

Promise of High Resolution X-ray Spectroscopy

XRISM and Athena will open up the power of high resolution X-ray spectroscopy for CVs and Symbiotic Stars. Possible objectives include:

- ➢ Density diagnostics for magnetic CVs, allowing us to measure the size of the accretion column, hence that of the magnetospheric interaction region.
- ➢ Density diagnostics for non-magnetic CVs, allowing us to measure the size of the boundary layer in quiescence and in outburst.
- ➢ Dynamical information on the post-shock regions
- ➢ Gravitational redshift of the 6.4 keV line from the surface of the white dwarfs.



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Magnetism & Accretion
A conference in Cape Town, South Africa,
16 – 20 November 2020
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National Research Foundation
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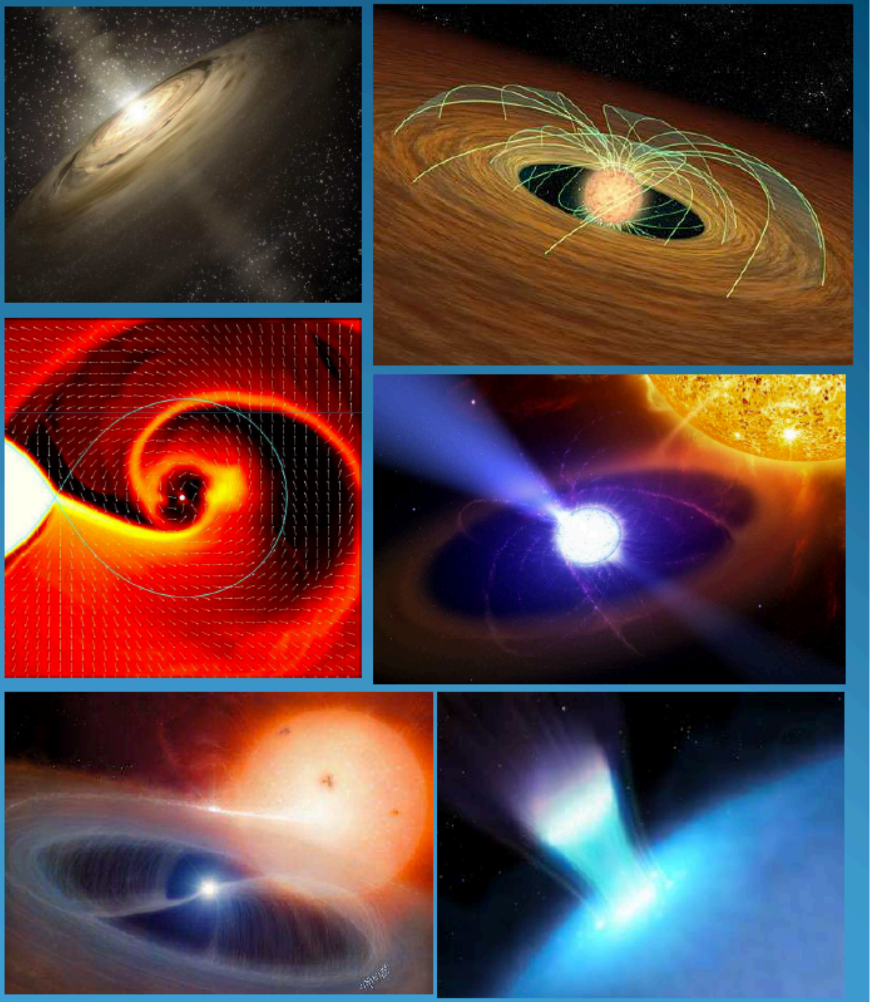
Magnetism & Accretion

The physics of magnetically influenced accretion throughout the Universe, covering:

- compact binaries with accreting white dwarfs, neutron stars or black holes
- disk/jet connections
- AGN and blazars
- proto-stellar systems, YSOs & planets
- GRBs



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First announcement expected October 2019