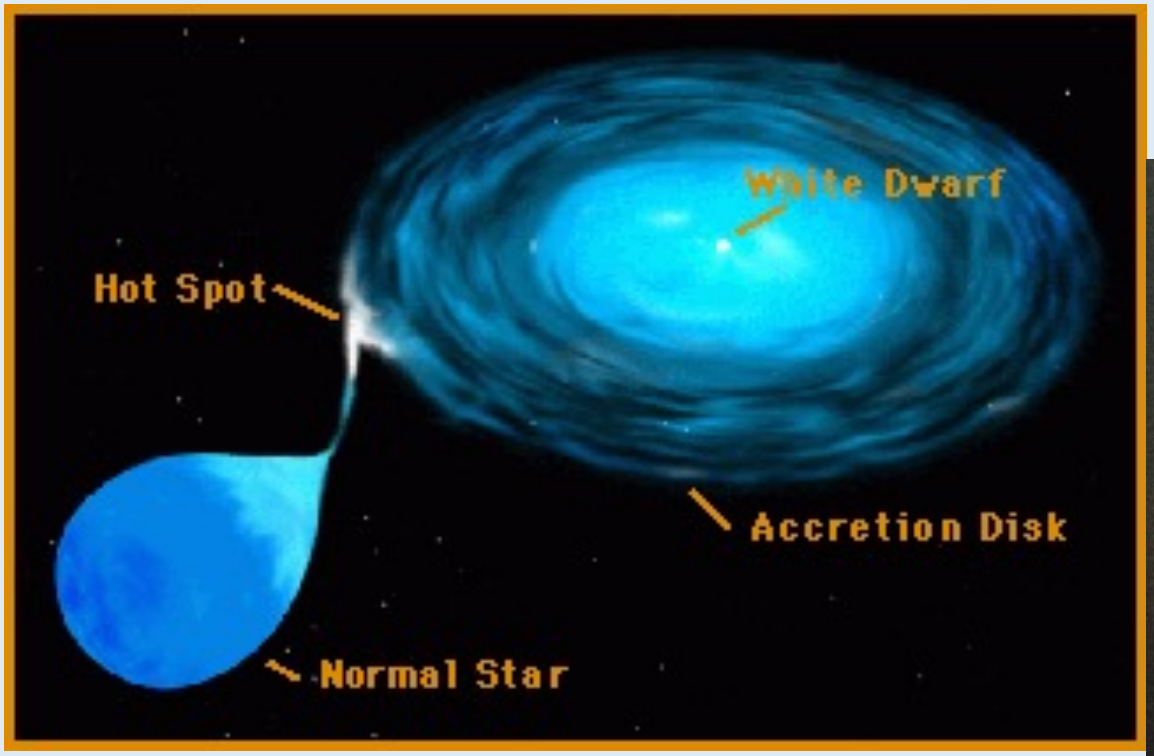
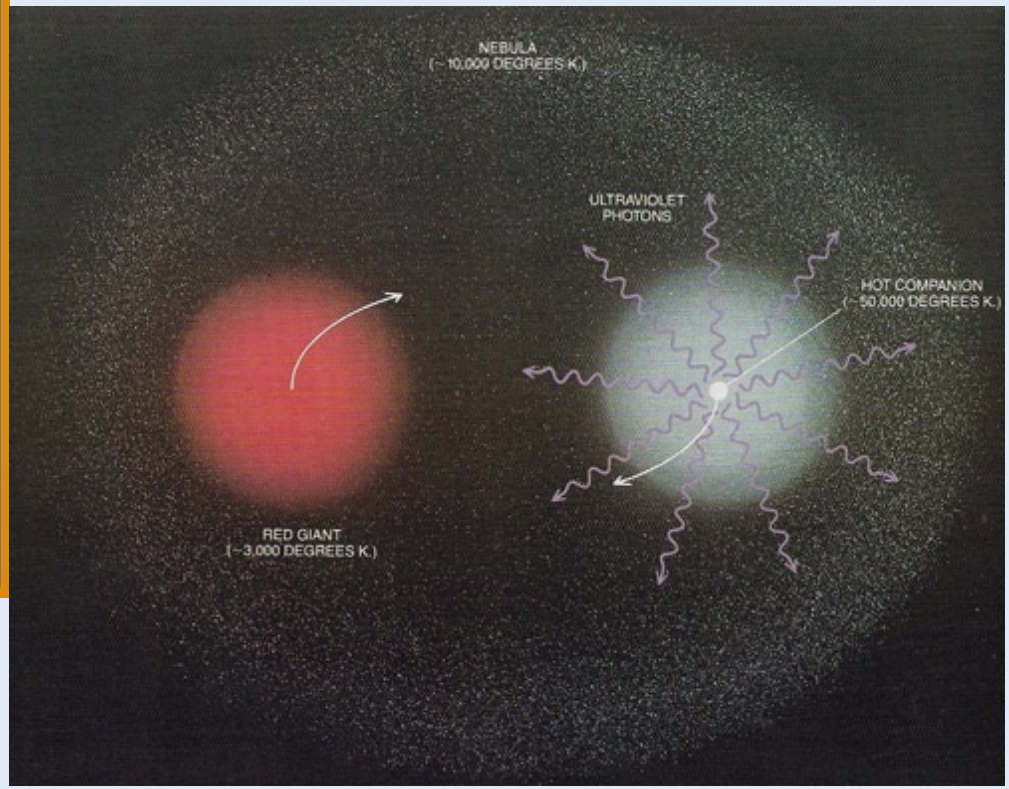
The legacy of Chandra/HRXS for novae

Marina Orio with many collaborators… including Jan-Uwe Ness, Ehud Behar, Sharon Mitrani, Jeremy Drake, Rico Ignace, Joy Nichols…



Nova in a cataclysmic variable

Symbiotic nova

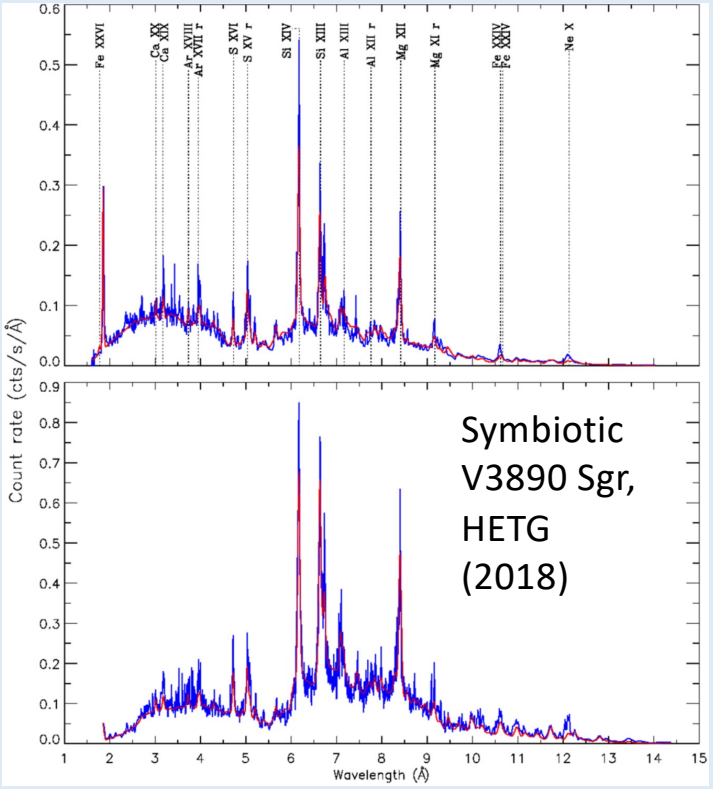


- These interacting binaries are candidate progenitors of type Ia Sne, either from single or from double degenerates
- Novae are fascinating astrophysical laboratories of many physical processes we need to understand better
- Novae enrich the interstellar medium of peculiar elements, important also in chemical evolution

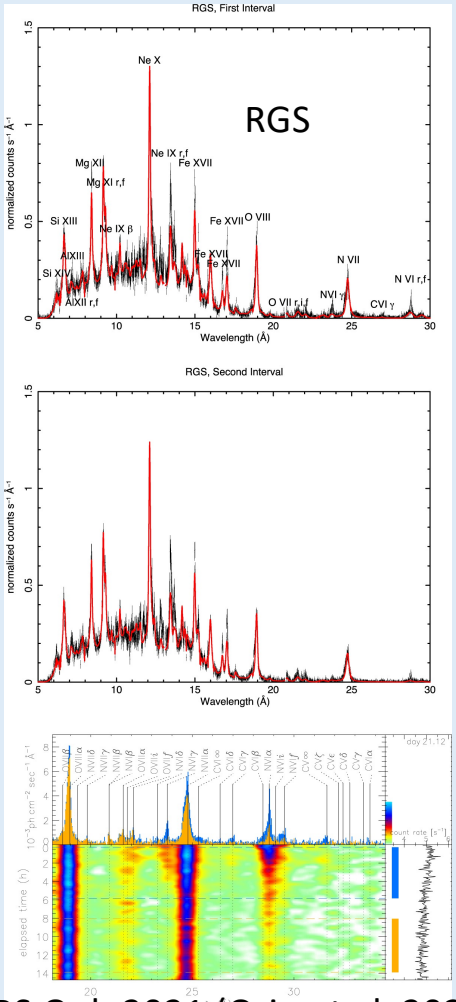
Novae in outburst emit at all wavelengths: the X-rays are the key to understanding their physics

- Novae outbursts are due to a thermonuclear runaway on a white dwarf (WD) that has accreted a hydrogen rich layer from a companion and ignited shell CNO burning in electron degenerate material. The WD mass is the most critical parameter.
- Mass outflows at velocity of 1000-7000 km/s, for weeks to many months
- Copious gamma/X-ray/UV/FUV/EUV fluxes, radio emission, IR (dust)…
- The "explosion" probably does not eject any matter… a radiation pressure driven super-wind seems to be the outflow cause, OR….
- Another mechanisms may occur in the common envelope (drag energy; Roche Lobe overflow, see Shen and Quaetert 2022)
- Powerful shocks (~$10^{33\text{-}34}$ erg/s in CV-type, $10^{36\text{-}38}$ erg/s in symbiotics) follow for wind episodes at different velocity, or collision with red giant wind, disk, etc.
- Shocks cause X-ray emission and, in dense environments, a secondary leptonic/hadronic gamma-ray emission (up to Cherenkov energy in symbiotics)
- In a dense environment: X-rays may be absorbed, reprocessed not only as gamma-rays, but also as optical light in different directions

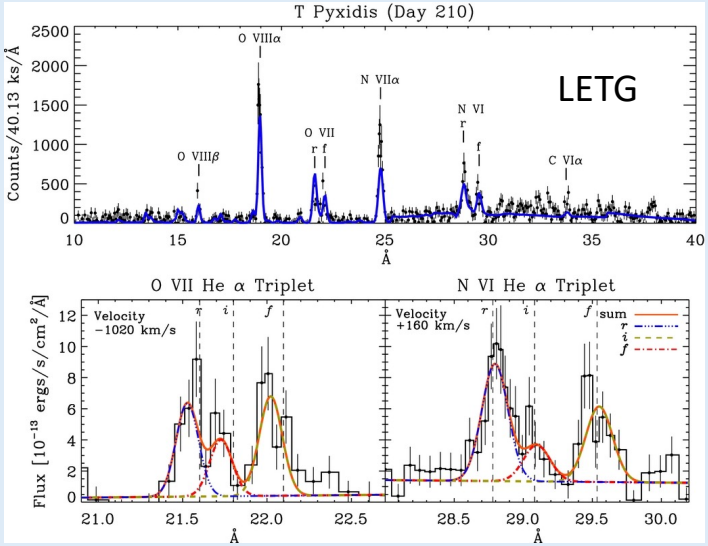
A wide variety of X-ray spectra from the ejecta



Orio et al. 2020



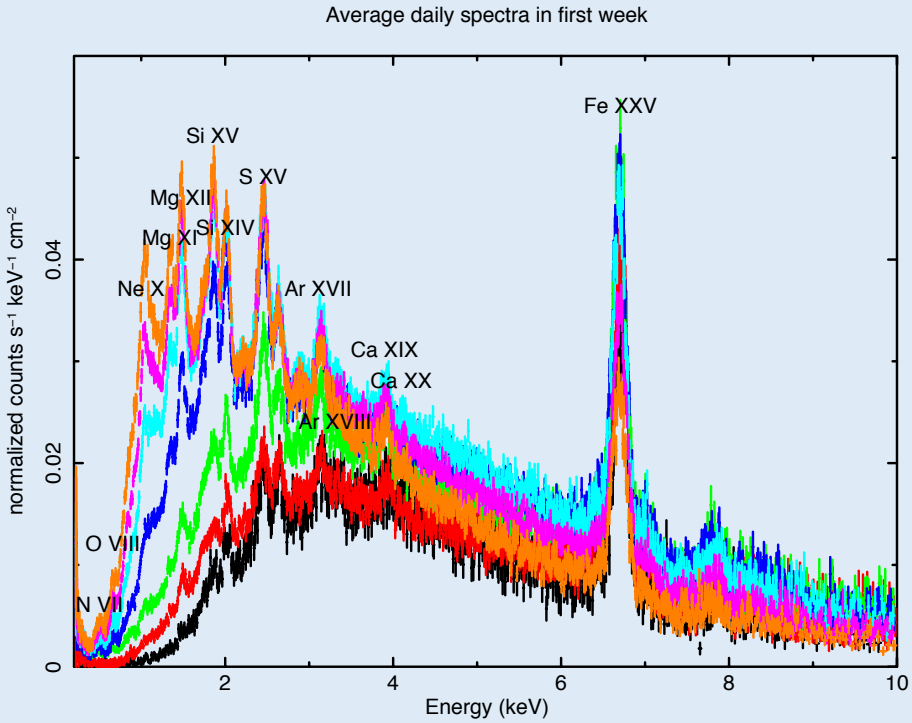
RS Oph 2021 (Orio et al. 2022)



Tofflemire et al. 2013

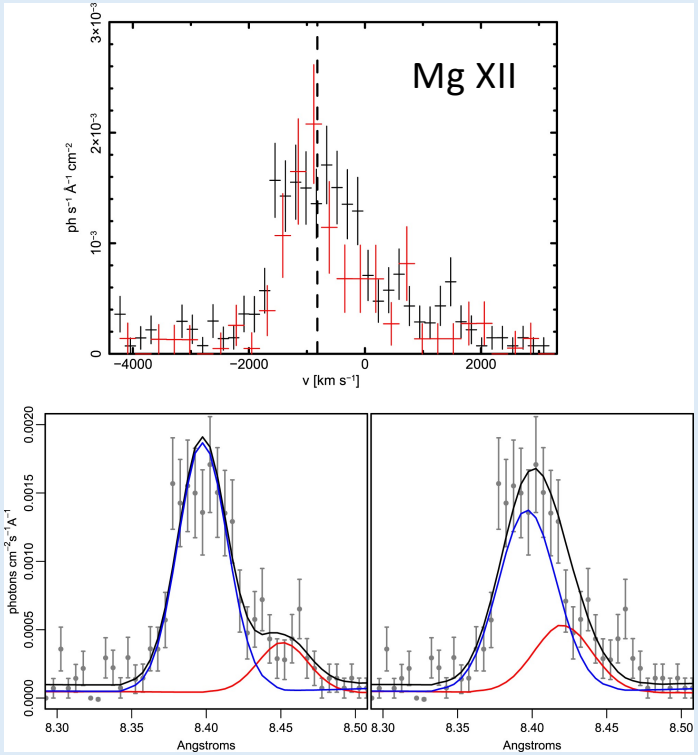
Connecting stellar binary evolution to the outburst physics: critically depending on X-rays – Part1:shocks

- kT_{sh}~1.2 keV (v/1000 km)^2
- Are there multiple shock sites, especially in symbiotics? Are we observing only some of them in the X-ray range?
- Diagnostics of temperature and electron density in the shock (=>clumping?)
- Chemical yields (e.g. aluminium)
- Early emission: if collisional equilibrium is not reached, difficulty in estimating maximum temperature and n_e
- High resolution spectra at early times precious to derive shocks physics and its evolution in the outburst

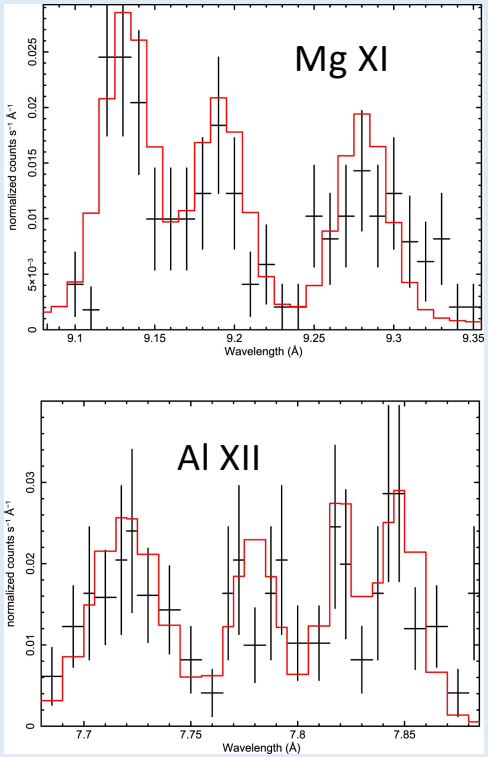


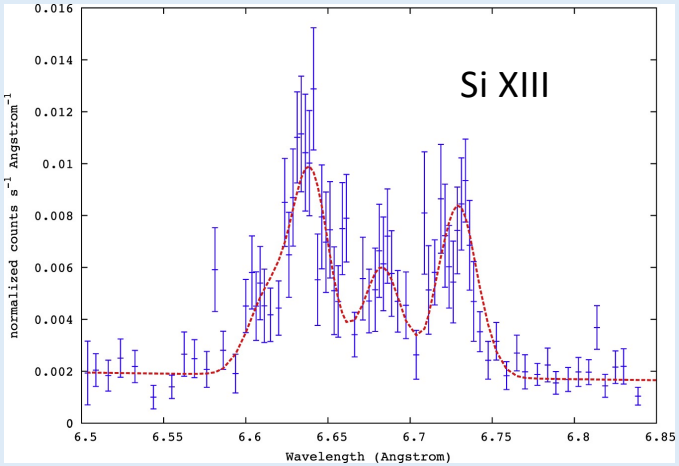
RS Oph with NICER (Orio et al. 2023): no HRX spectra obtained in 1st and 2nd week

The importance of high spectral resolution for emission line diagnostics (G and R ratios, etc.)



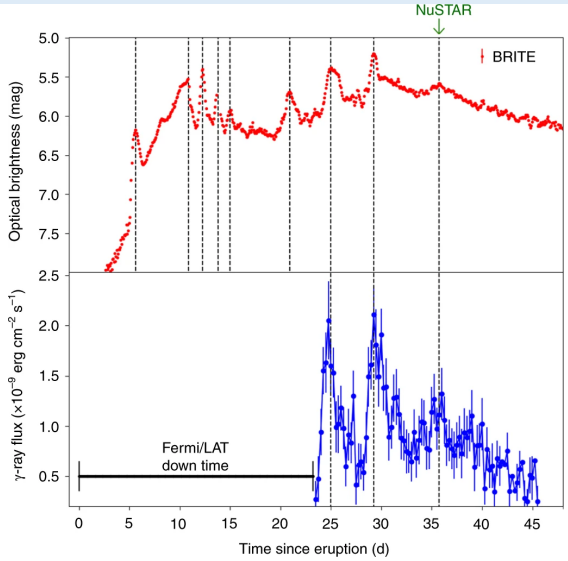
Peretz et al. 2016: 2 components only in H-like lines, different velocity





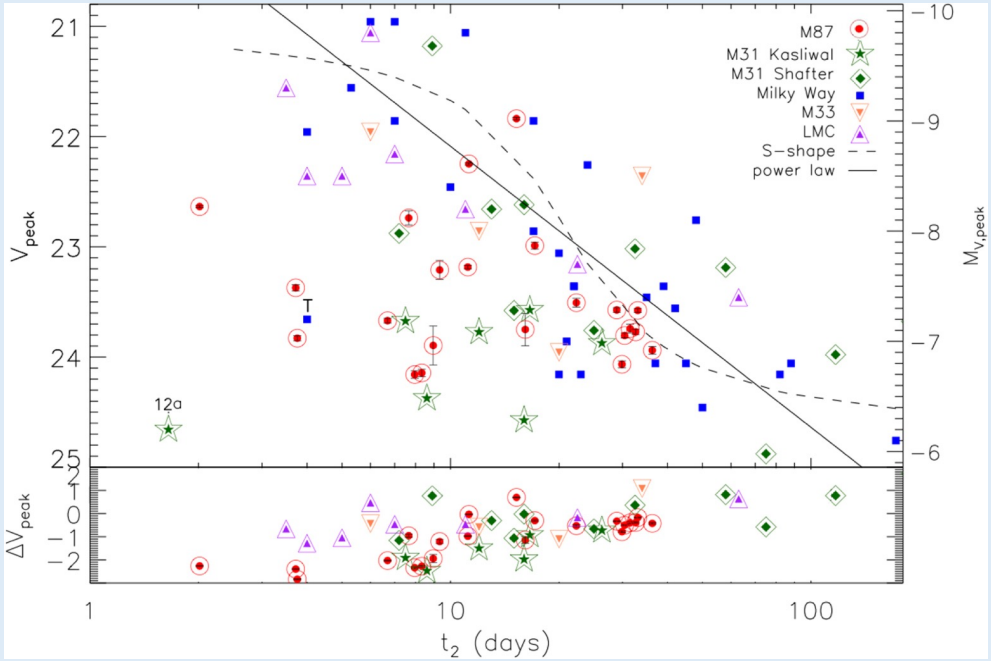
Peretz et al. 2016 (left), Orio et al. 2020 (right): line ratios in triplets to assess collisional ionization vs. photoionization

Shocks=> optical light => revisiting the assumption of thermonuclear burning dominating optical decay



The black dashed lines represent the dates of the post-maximum flares. The green arrow indicates the date of the first NuSTAR X-ray observation. The black solid bar indicates the period of Fermi/LAT down time due to technical issues. Fermi entered another observing gap between days 46 and 57. The error bars in the BRITE light curve are 1σ uncertainties. The point-to-point scatter of the binned BRITE measurements is ~2 mmag and therefore the size of the error bars is smaller than the symbol size. The error bars in the Fermi light curve are 1σ uncertainties. The eruption start is on 2018 March 16.03 UT (see Methods for more details).

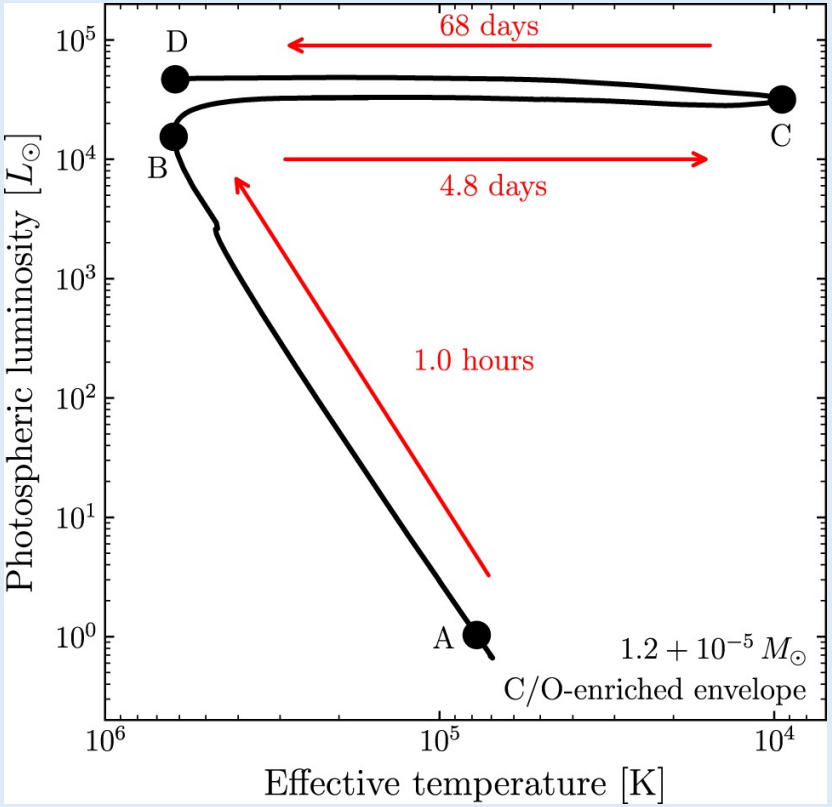
Aydi et al. 2020: shocks vs. optical brightening

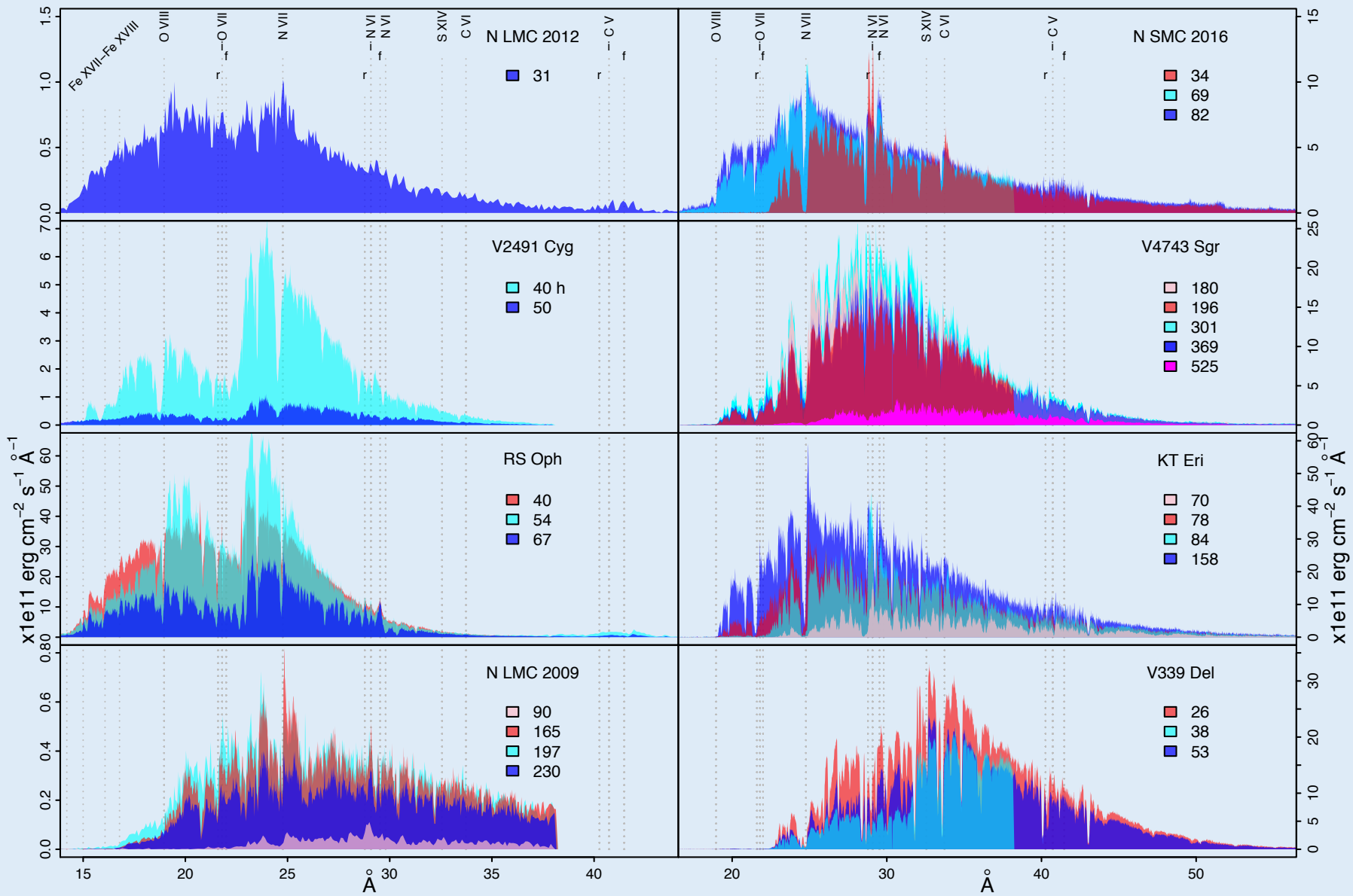


Shara et al. 2017: does the Maximum-Magnitude-Rate-of Decline-Relationship hold? … Is it just determine by the TNR physics?

Part 2: Supersoft X-rays: a window into the WD

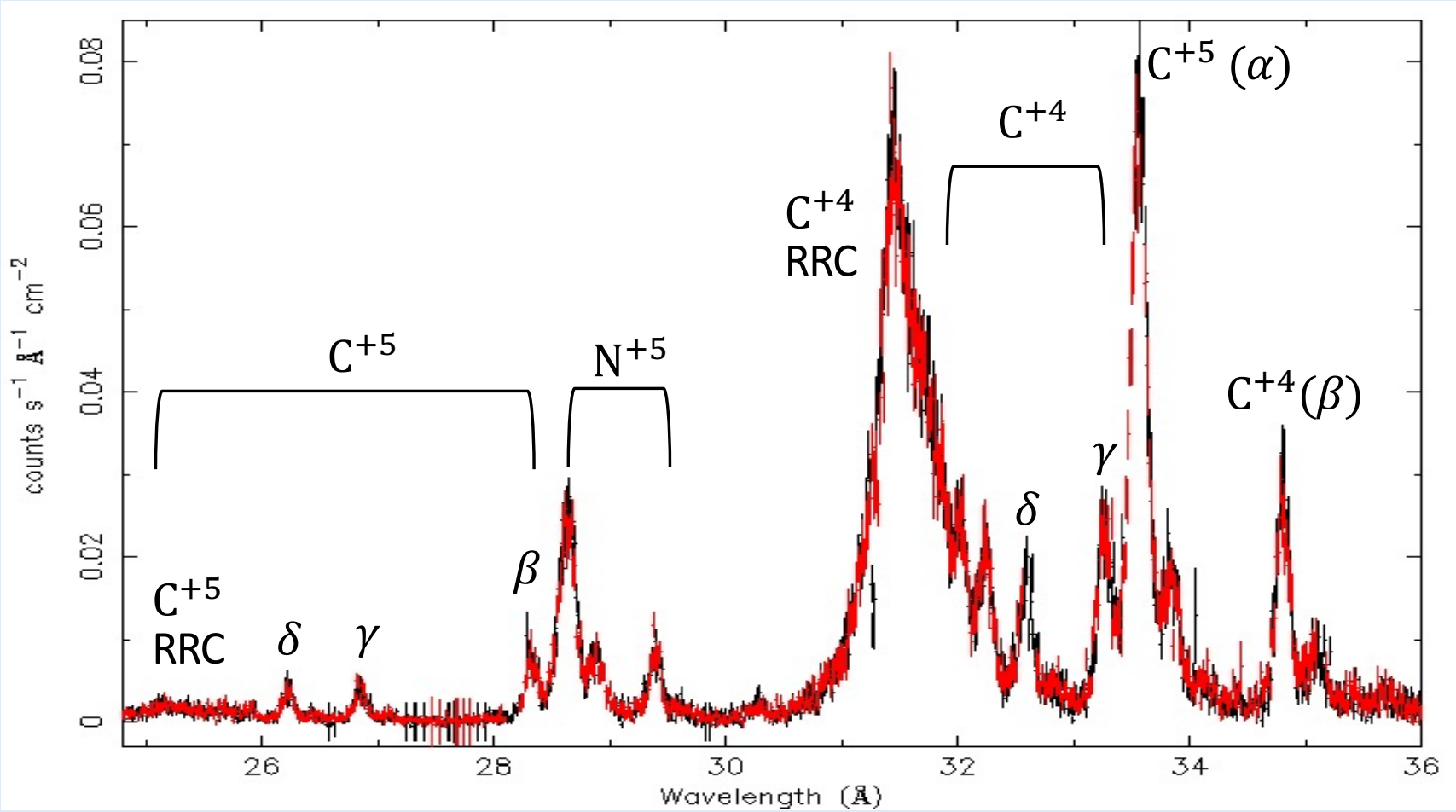
- Very soft X-rays from the WD as it shrinks again while shell burning is still ongoing (Eddington luminosity ~10^{38} erg/s)
- The supersoft X-rays are the only mean of WD diagnostics ("forget" about optical spectrum…)
- But novae are complicated: we are looking into moving (blue-shifted) layer(s) and not into a static atmosphere





The squares indicate post maximum days elapsed

Not only the WD: Nova YZ Reticuli 2020 (Mitrani et al 2023)

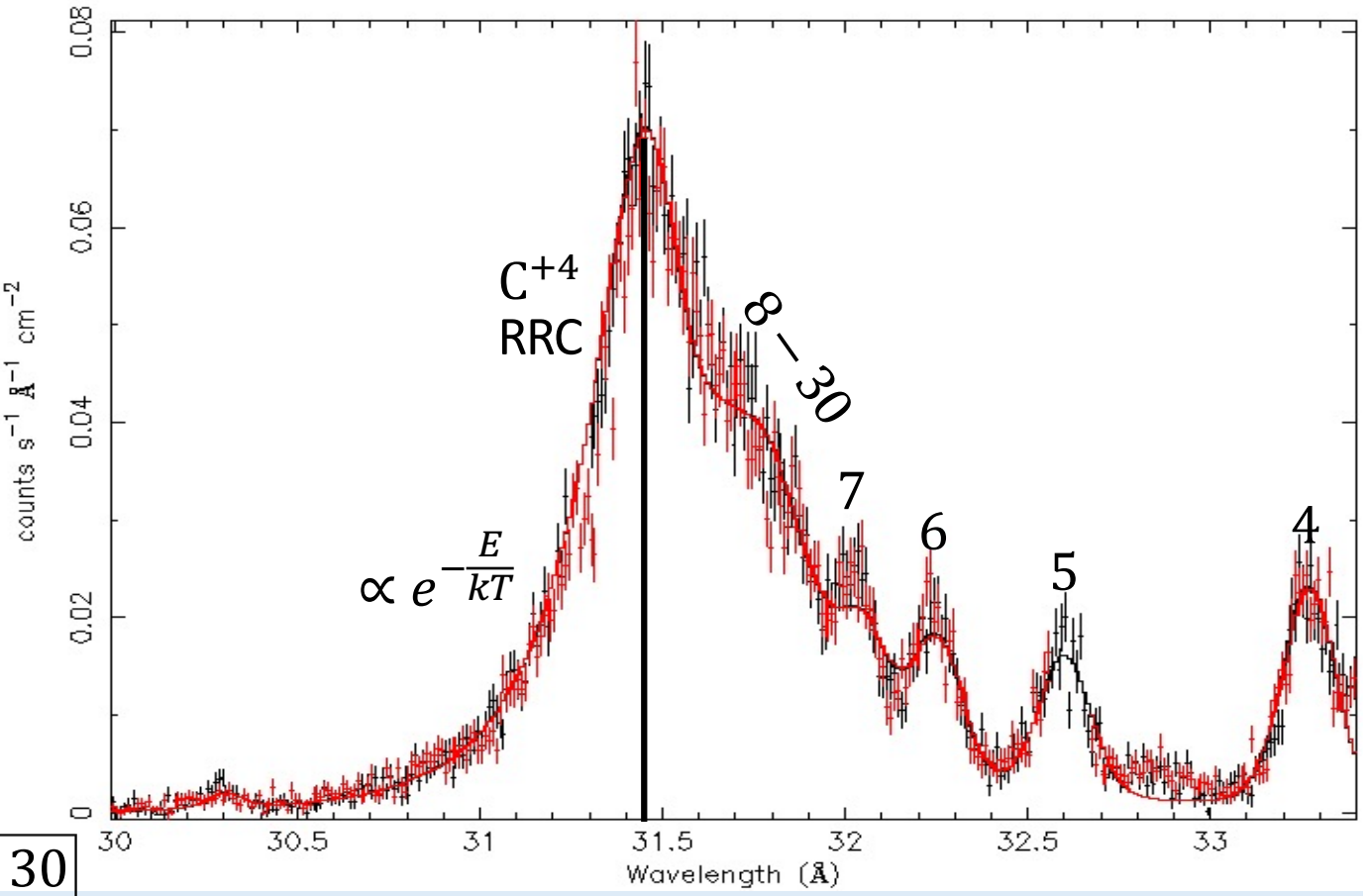


C^{+4} Radiative Recombination Continuum (RRC), along with $n = i \rightarrow 1$ transition lines .
Blueshift indicates a velocity of $v \cong 1500\ km/s$

$kT = 2$ eV ($\cong 10^4$ K) by fitting RRC model $F \propto e^{-\frac{E}{kT}}$

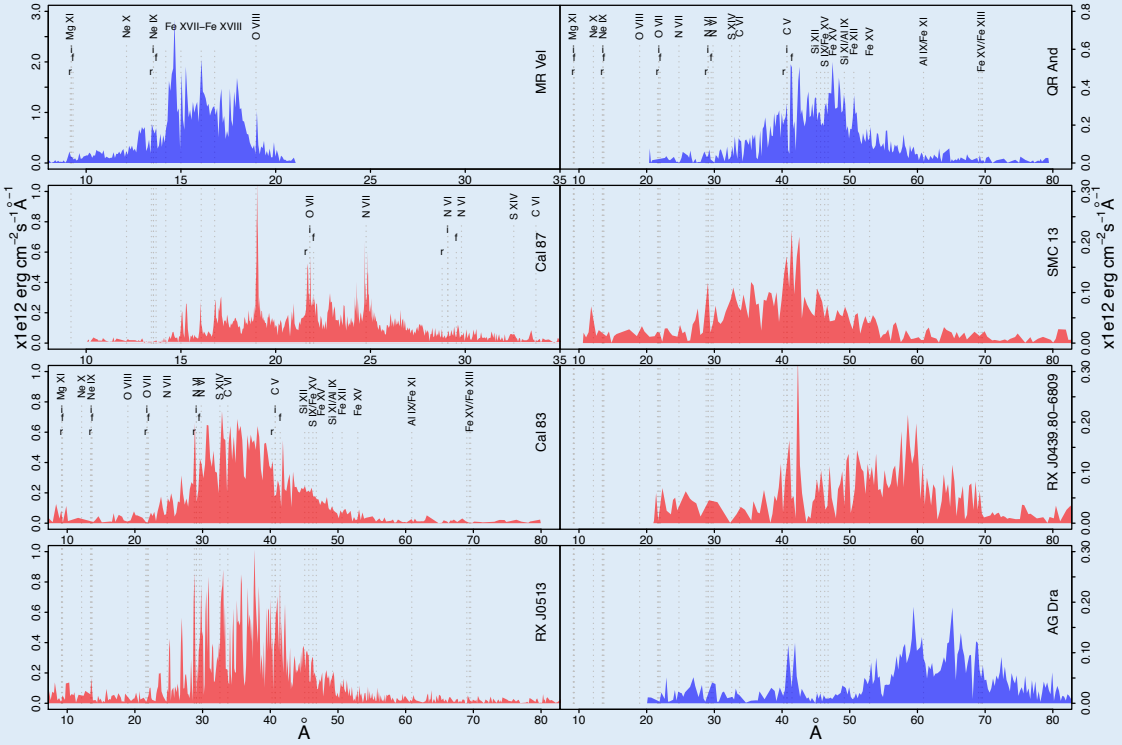
The maximum observed emission line n provides an electron density measurement:
$A_{n+1,1}/\alpha_{n+1}^{CI} < n_e < A_{n,1}/\alpha_n^{CI}$

The maximum observed line is $n = 30$
$\Rightarrow n_e = (2-3)\times 10^{12}\mathrm{cm}^{-3}$

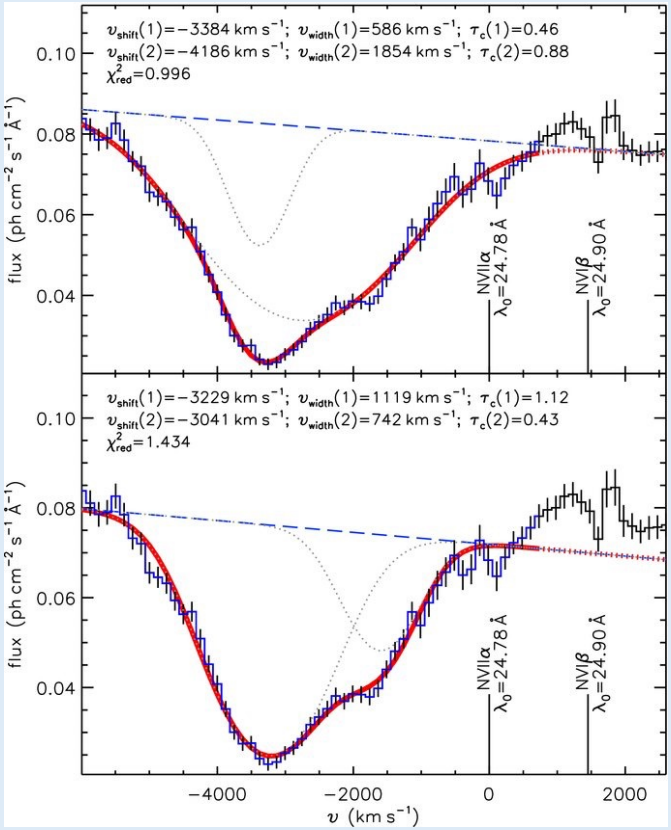


And not only novae in outburst…

- Quiescent “SSS” accreting binaries have rich X-ray emission line spectra from which white dwarf mass and mass accretion rates can be estimated
- “Non-ejecting novae” and other shell burning WDs have intricate, rich luminous supersoft X-ray spectra with many lines longwards of 40 Angstrom, in emission and in absorption



Many reasons for which we want high spectral resolution



(Ness et al 2011).

- A working model is to assume a shell (or shells) of photoionized material very close to the WD
- But… it is only an empirical model
- Static atmospheres reproduce lines depth and even profiles
- We would like to measure even the weakest lines in absorption
- The overlap with the shocks component makes some novae not very feasible for SSS studies