X-ray grating observations of novae

Marina Orio, Dublin, June 2014

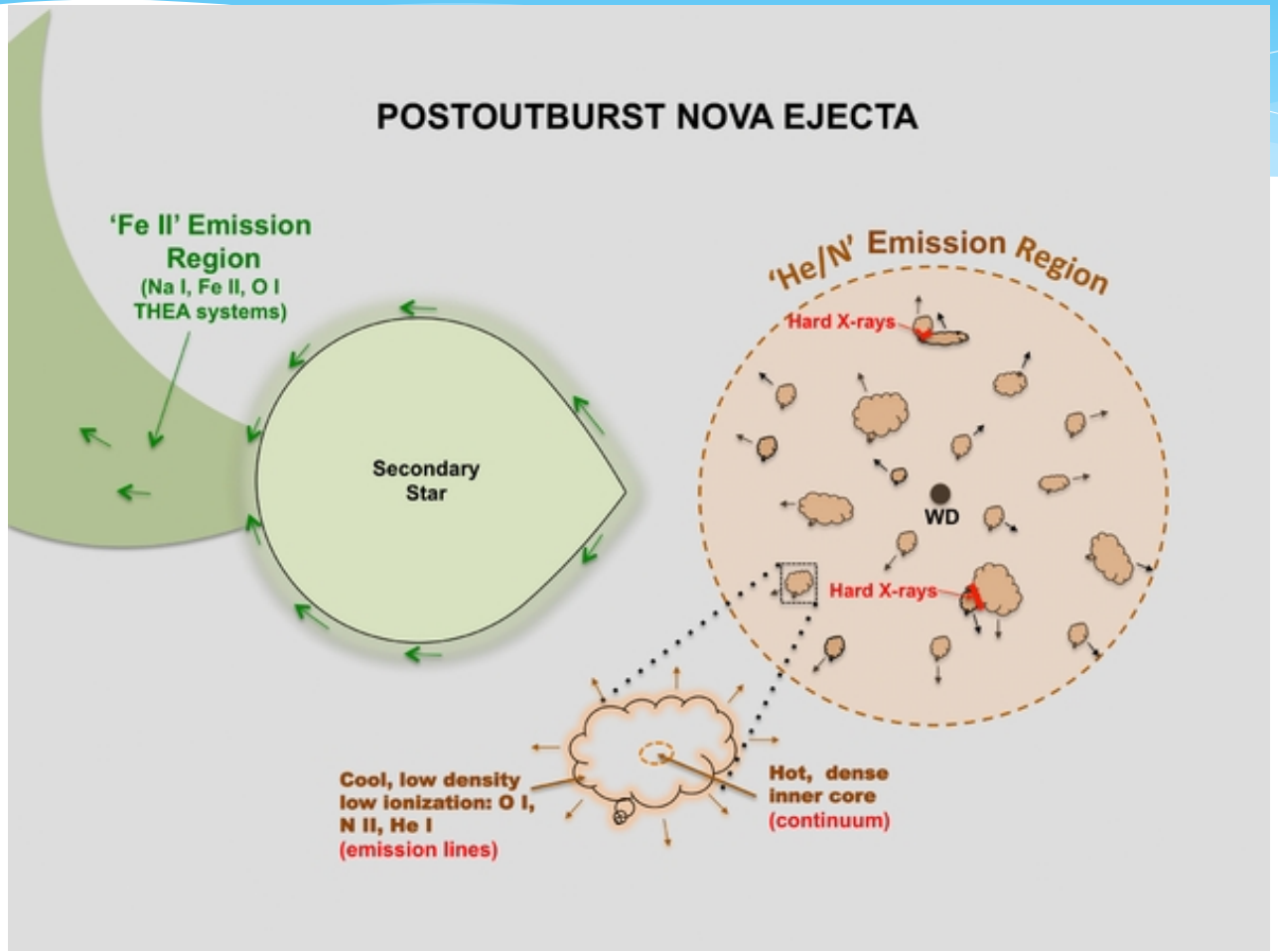
Two distinct components:

- The luminous supersoft component associated with the white dwarf atmosphere (up to a few 10^{38} erg/s)
- X-ray emission from the ejecta (up to 10^{36} erg/s)
- The initial motivation to study novae was to probe the white dwarf atmosphere and obtain the mass and chemical composition of the WD (Ögelman et al. 1983+)
- Immediately, it became clear that there may be X-ray emission from the ejecta and that broad band spectra may be insufficient to disentangle them (problem of N(H)).

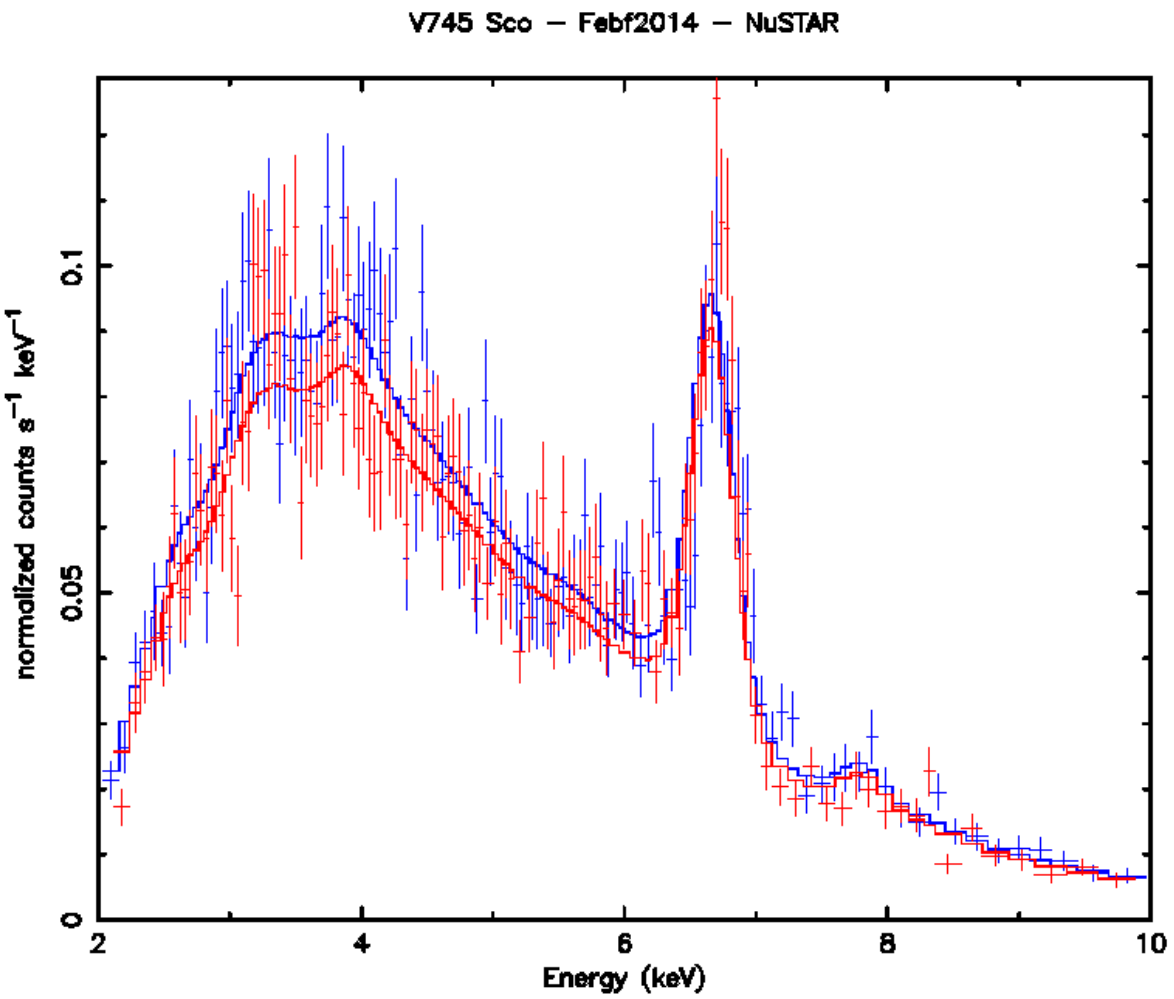
Hard X-ray emission as a way to test how mass loss occurs:

- Is hard X-ray emission correlated with the gamma ray emission - is it just a later phase as the plasma cools down?
- Is it Comptonized gamma-ray emission? (Optical depth dependent on mass and expansion velocity of the ejecta. A continuum spectrum should be observed).
- Are the hard X-rays produced in the material flowing from the WD, while a large part of the ejecta are instead from the secondary? (Bob Williams 2013)
- Question of iron lines at all wavelengths – there should not be iron lines in the ejecta X-ray spectrum, example of V382 Vel.
- Connection with "soft" emission line spectrum observed at later phases – again, is it just the same region which is cooling?

Bob William's view of nova ejecta (based on V382 Vel)



NuSTAR can observe "prompt" (or later) hard X-rays:

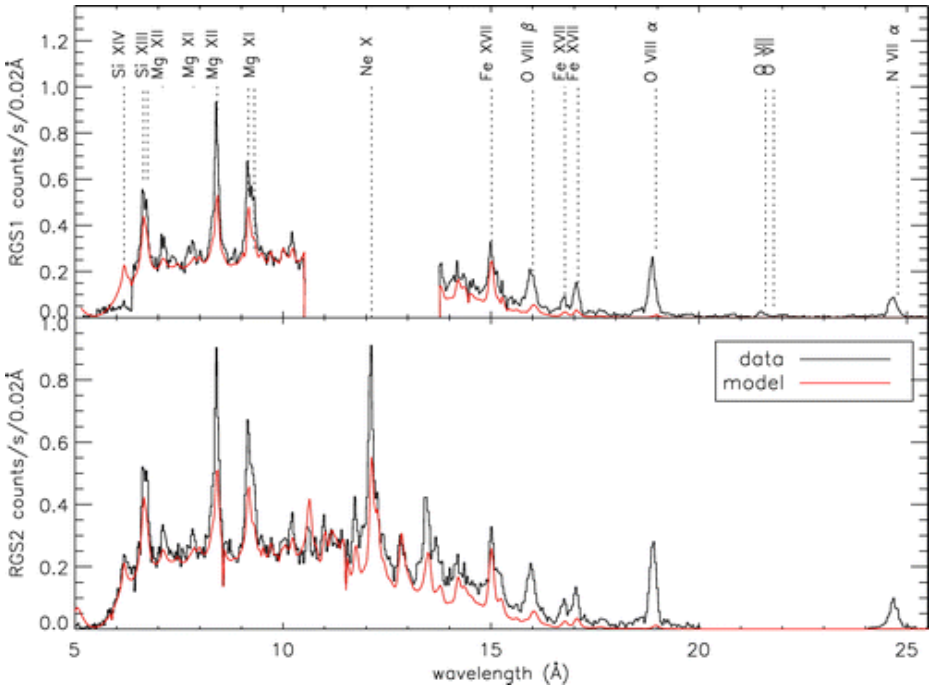


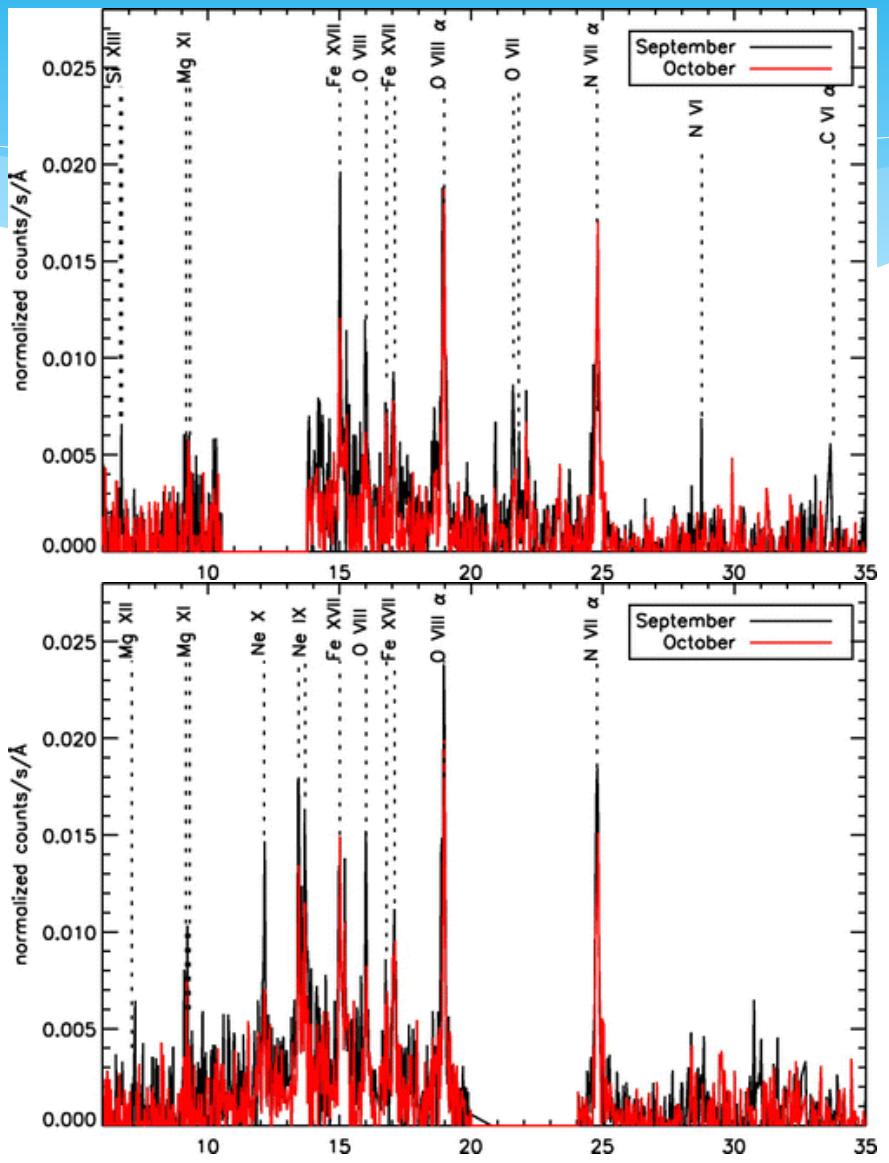
This prominent Iron feature seems to rule out both the Comptonization of gamma rays, and the use of hard X-rays as a probe of the two-ejecta model

RS Oph: an example

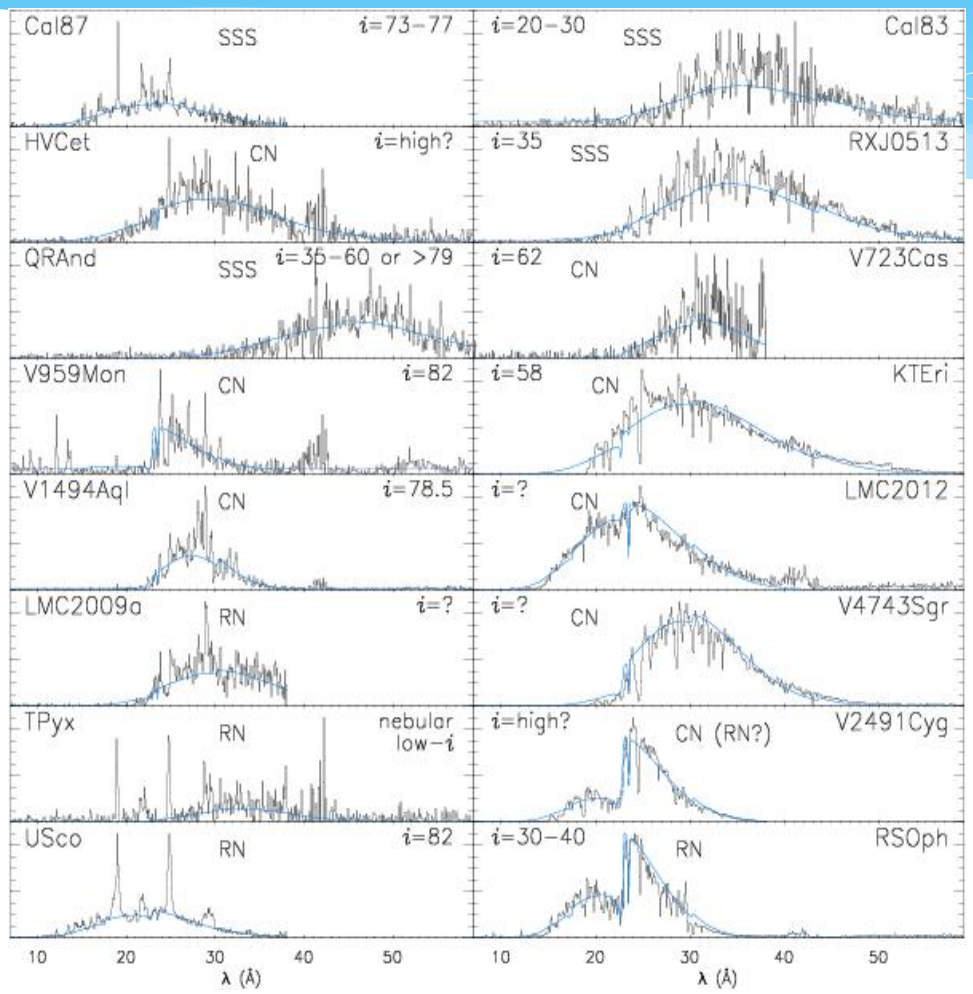
How do we go from this ➔

To this ➔





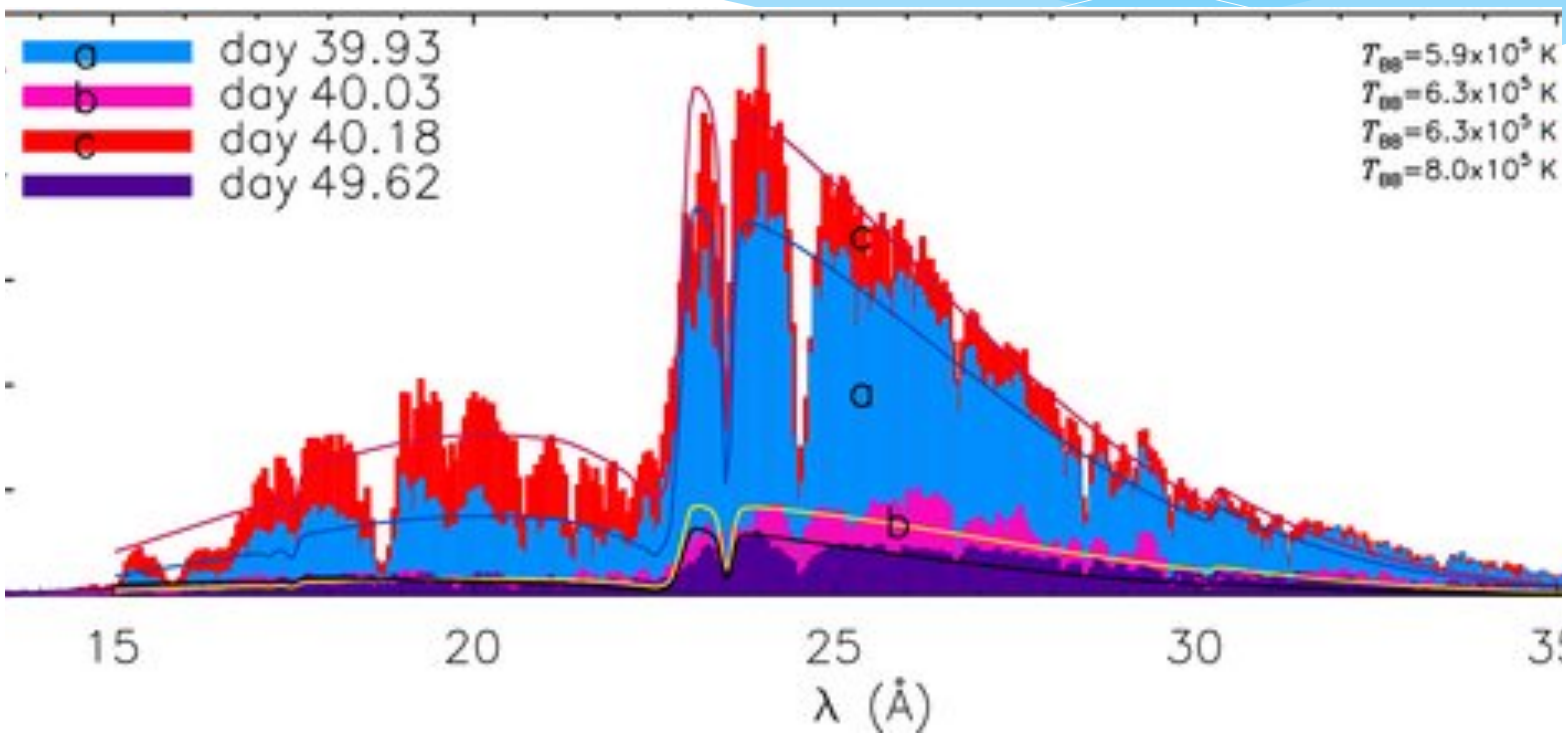
Hypothesis of inclination dependence does not explain two types of spectra in the same nova: RS OPh., and N LMC 2009 changed spectrum, T Pyx had low inclination



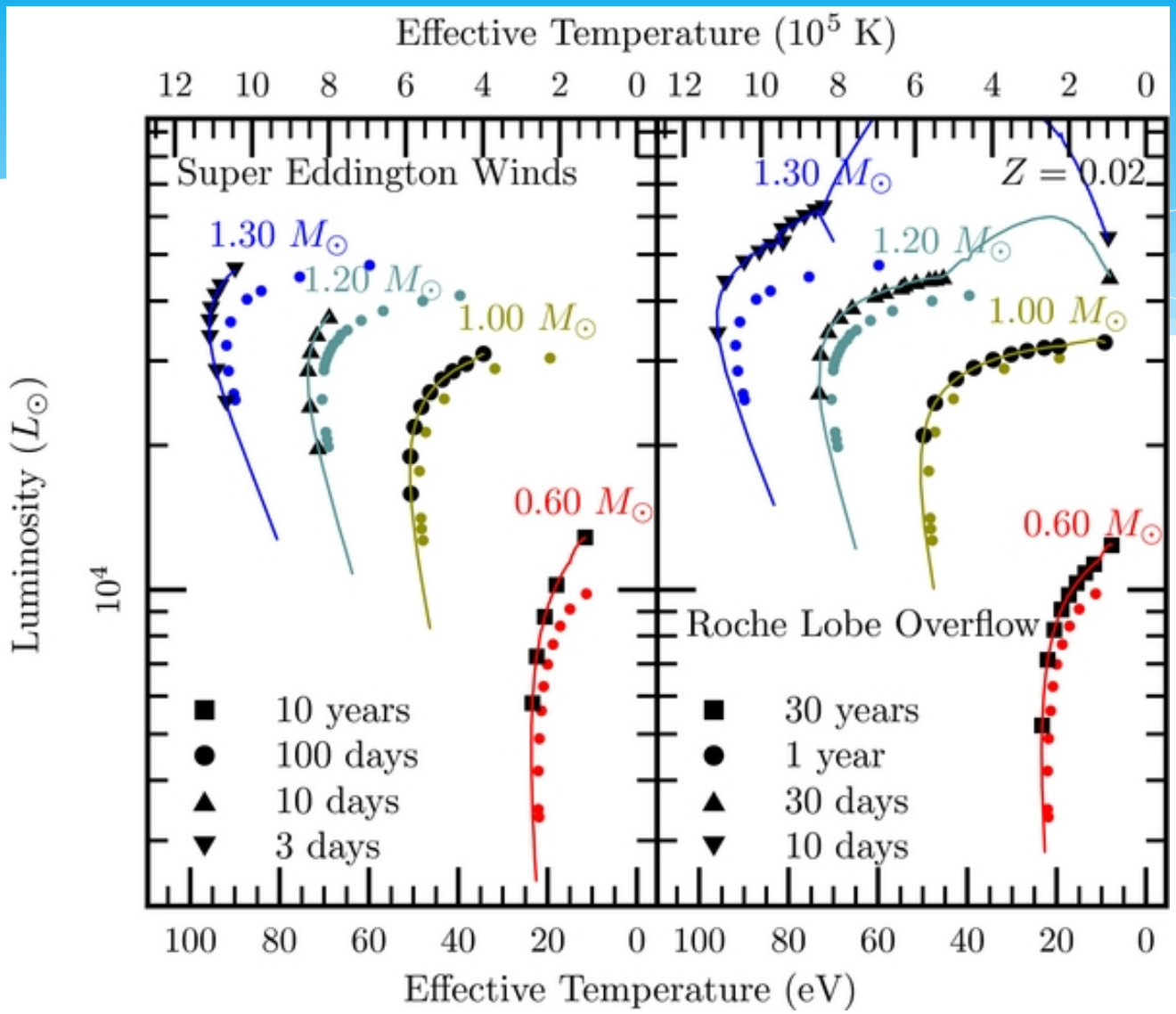
The X-ray emission in the ejecta is (usually) not photoionized:

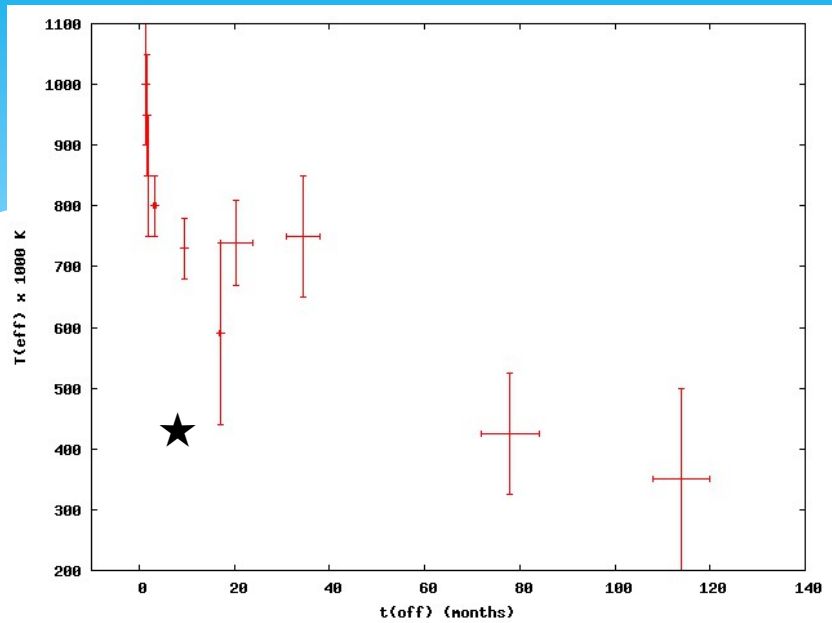
- "Smoking gun" of RRC (radiative recombination continua) is usually absent
- Line ratios MOSTLY (not always) consistent with collisional ionization
- Plasma temperature appears to be cooling with time
- Shocked ejecta, also when no red giant wind or symbiotic nebula is present (changing wind velocity, different episodes of mass ejection?)
- The emission lines are BROAD and blue-or red-shifted

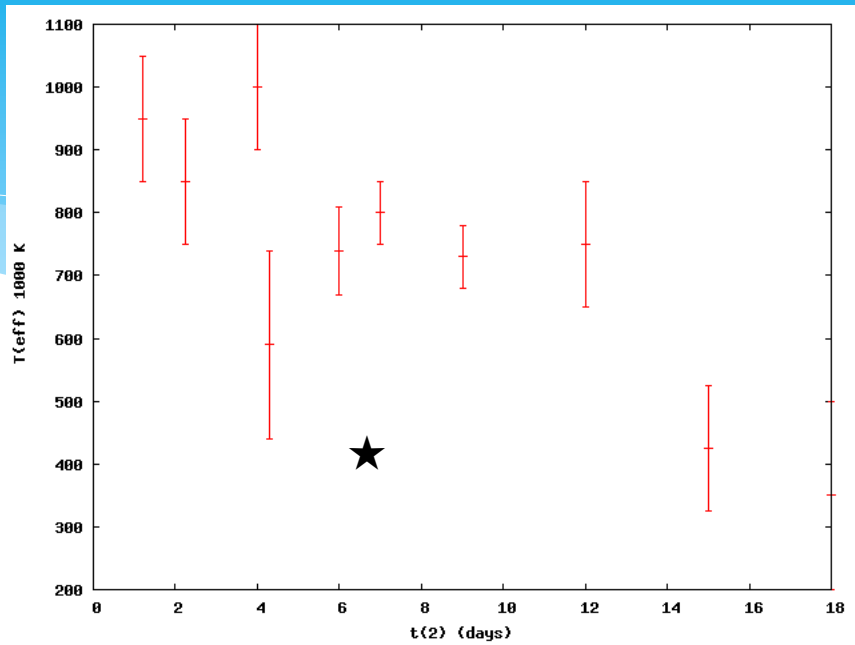
V2491 Cyg one of the best examples of the WD atmosphere and its large variability:



Ness et al. 2011: XMM-Newton RGS gratings spectra of Nova 2491 Cyg in 2010


Effective Temperature (10^5 K)
12 10 8 6 4 2 0 12 10 8 6 4 2 0
Super Eddington Winds
1.30 $M_\odot$
1.20 $M_\odot$
1.00 $M_\odot$
0.60 $M_\odot$
$Z = 0.02$
Roche Lobe Overflow
10 years
100 days
10 days
3 days
30 years
1 year
30 days
10 days
Luminosity ($L_\odot$)
10^4
100 80 60 40 20 0 100 80 60 40 20 0
Effective Temperature (eV)

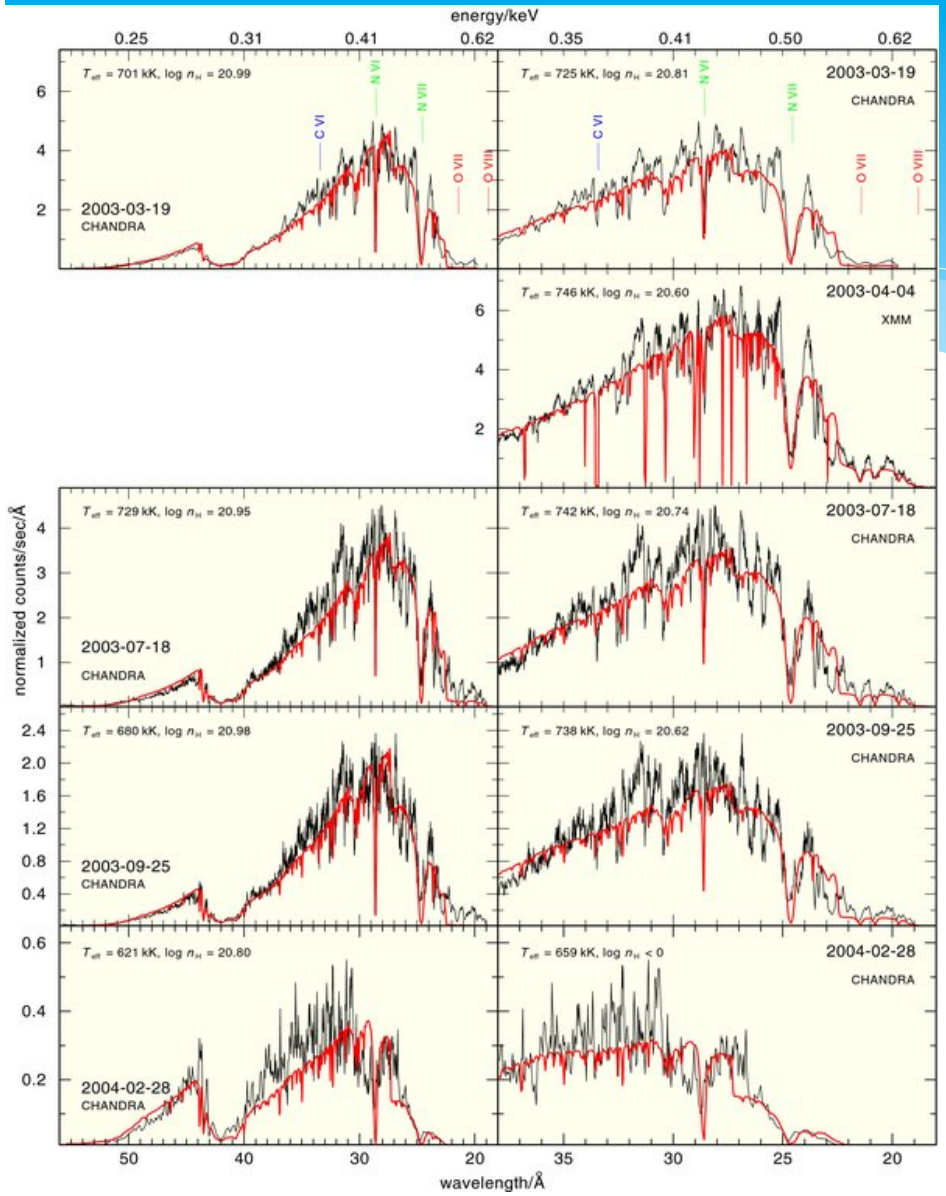




- Peak effective temperature obtained with Rauch's models' fits shows expected dependence on t(turn-off) and t_2. The spread with respect to a linear relationship is expected to be due to mdot,
- PLAN: try an evaluate mdot for the novae in the plot as they return to quiescence. BUT: is mdot constant? Can it be? We should be able to use T_{eff} as a proxy for the mass: it is very important to test the models and paths towards SN Ia evolution.
- T Pyx does not fall "well" in these plots.

Atmospheric models

* Problem of detangling the two components: can be done. WD atmosphere may have some emission lines as well.
* At least up to a certain post-outburst epoch, the absorption lines are blue-shifted! By as much as ~2000 km/s.
* Rauch's Tuebingen models: static, non LTE plane parallel approximation yields the lines we observe with realistic broadening and abundances… no blue shift
* van Rossum's wind-atmosphere expanding atmosphere model very interesting but still only grid witht solar abundances: does not fit obsservations.
* Problem of blue-shifts: observed when theory and "other observations" indicate or prescribe that the NOVA WIND has ceased. Why this residual low mdot wind?



Comparison with Van Rossum

T_{eff} =550 K, log(g)=8.18

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T_{eff} =550 K, log(g)=8.44

T_{eff} =475 K, log(g)=8.48

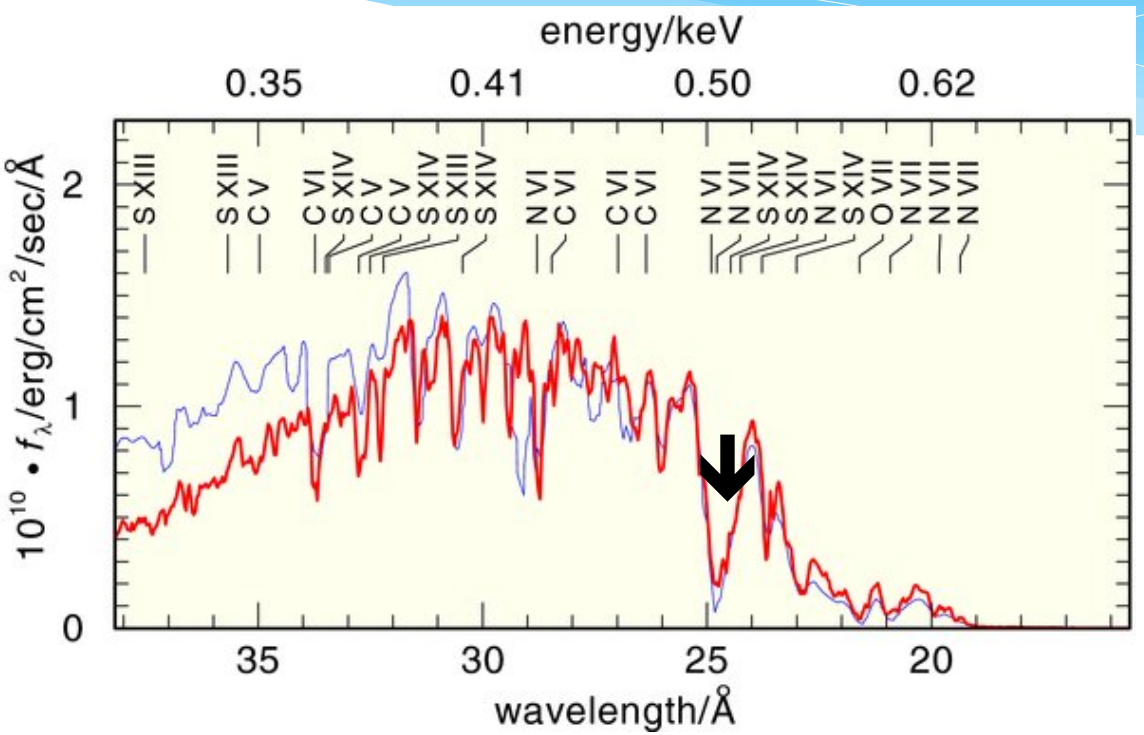
If the atmosphere is expanding:

* T(WD) at max still depends on m(WD), but there is a “mass degeneracy”: the same T(eff) is reached at more than one value of effective gravity
* mdot(wind) additional parameter
* No real handle on mdot, since the few pseudo-P-Cyg profiles observed seem to be due to a chance almost-superposition of red-shifted lines in the ejecta
* So, hard to quantify the effect of atmospheric expansion… late observations doen when blue-shift ceases

In two cases we did NOT measure a near Eddington luminosity from the WD continuum:

* U Sco: eclipse observed in X-rays shows low luminosity (~10^{36} erg/s instead of a few 10^{37} erg/s) continuum eclipsed by disk, emitting region very extended: Thomson scattering corona (it preserves the spectrum).
* T Pyx: not an eclipse system, but X-ray flux much reduced: is part of the view to the WD blocked by highly inhomogeneous ejecta with peculiar geometry?

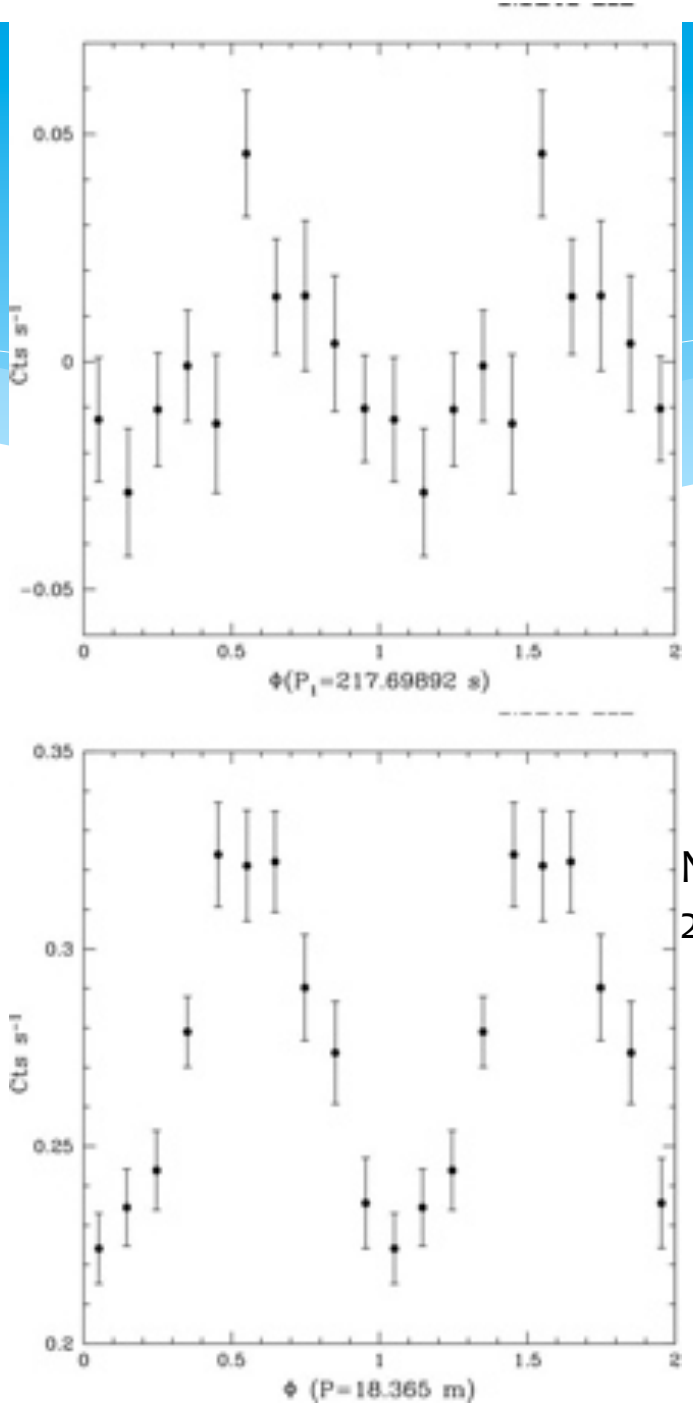
Abundances: clearly non-solar, only one "clear"ONe WD, extremely low C/N



Periodic variability

r2-12

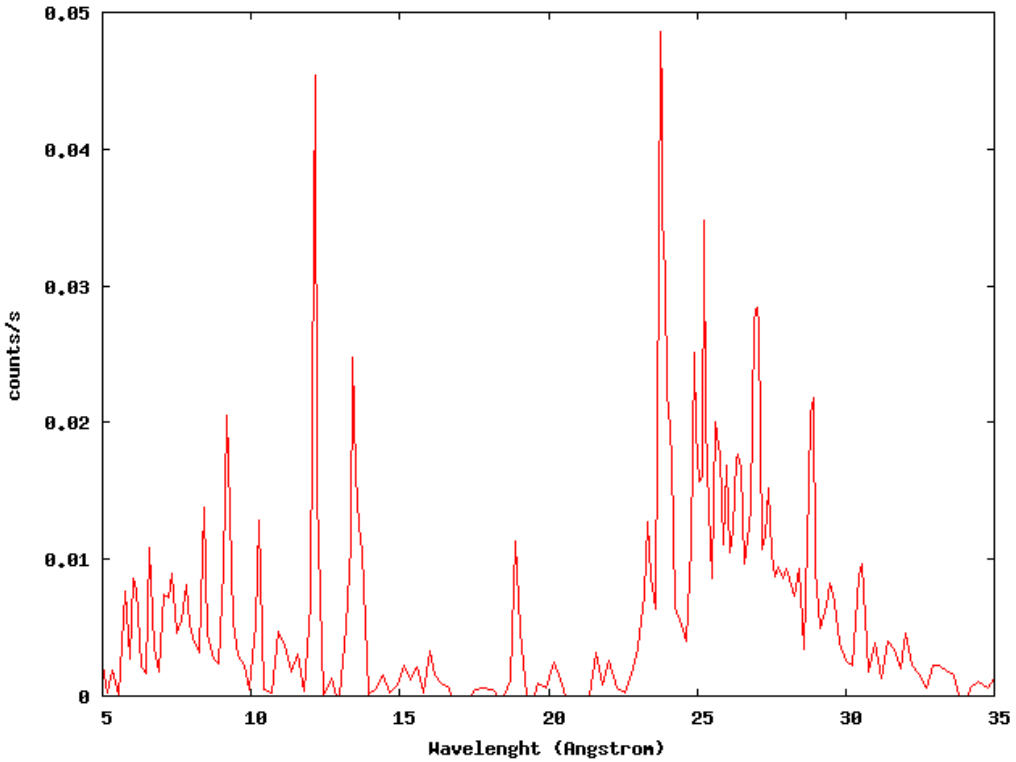
* ~half hour periods (e.g. previous slide): non-radial g-mode oscillations?
* Period due to the WD rotation (V4743 Sgr seems to show both)
* In RS Oph, KT Eri, and perhaps V1974 Cyg, periods of ~35 sec are observed: very short WD spin. Is this the spin of the WD spun up by accretion?
* Orbital variability: hours (up to 1.5 days). Are the magnetic fields playing a role in this variability?
* Flares repeated at each orbital period: are they common?
* Note two M31 SSS in plots on the right, with same periods as Galactic sources!



N M31 2007-12b

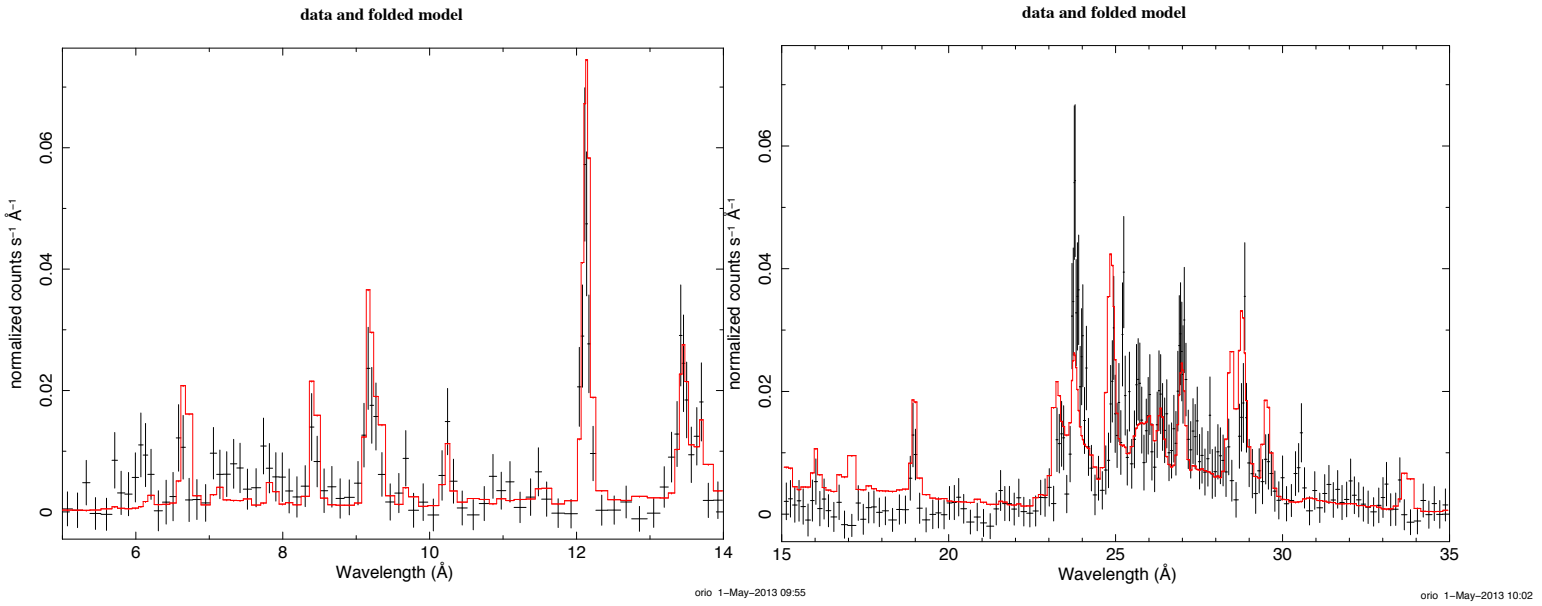
Nova Mon 2012: another "Fermi nova" with initially hard X-rays

- Relatively slow development with SSS emerging only after 5 months, off after 2 months
- Near main sequence secondary
- NeO nova
- Bipolar outflows (Shore et al. 2012)
- 7.1 hours period detected with Swift XRT and UVOT (Page 2013)
- "Beautiful" collisionally ionized plasma



Spectral fits:

* Like RS Oph, started with a "hard" spectrum
* Shifted to lines of lower and lower ionization potentials in December (our LETG spectrum)
* Can be fitted with ~ atmosphere at ~600,000 K + 80 eV + ~600 eV plasma



Importance of XMM-Newton for these studies

- Possibility to observe broad-band and high resolution simultaneously
- => Obtain high S/N light curve with EPIC and better understand the root cause of the variability
- Larger effective area: not all novae are luminous enough, and EPIC-pn is the only broad band instrument that may distinguish a “scattered-reflected” or partially obscured WD aymosphere from the “soft” ejecta