High-Energy Observations of Novae

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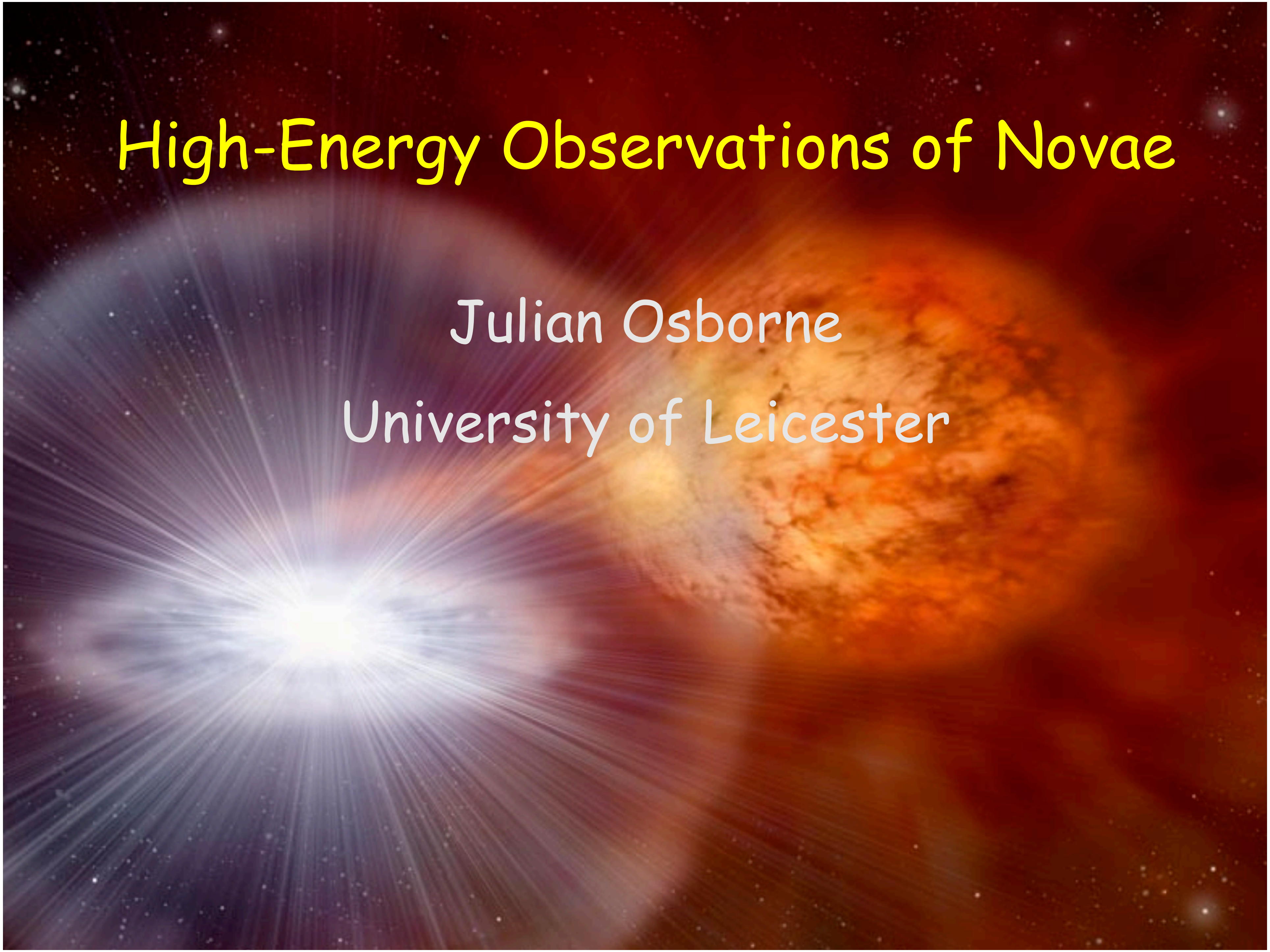
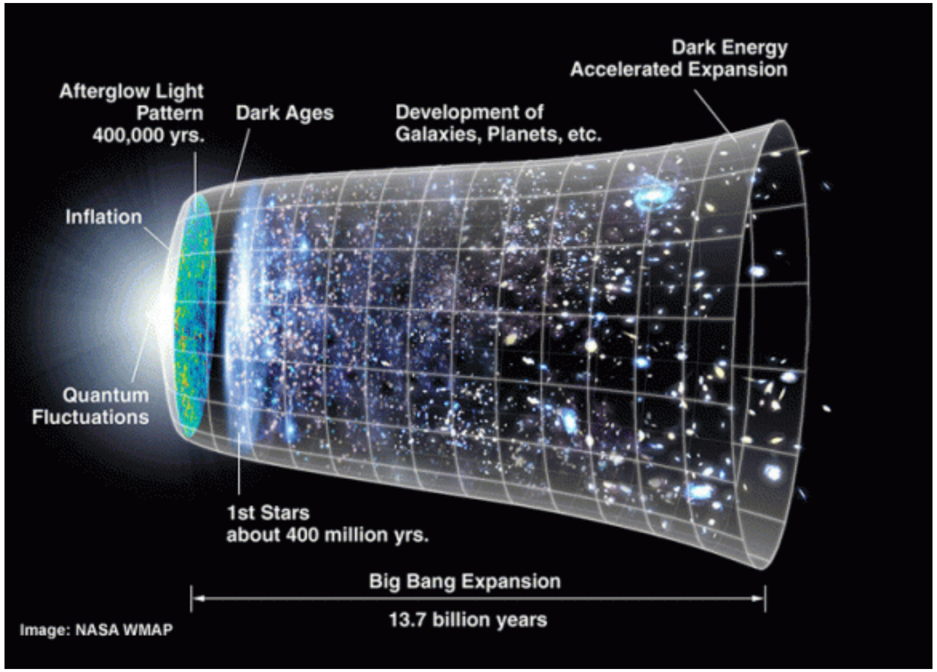


Novae: SN1a progenitors?

SN1a are key to measuring the acceleration of the Universe

- Thermonuclear explosion of a CO WD
- Progenitors are unknown (large literature!)
- Wang & Han 2012 review:
  - Single degenerate models:
    - WD+MS/RG/He
  - Double degenerate model:
    - WD+WD



- Gonzales-Hernandez+ 2012: lack of bright survivors means giant & subgiant companions excluded in SN1006
- Dilday+ 2012: PTF11kx circumstellar shells imply symbiotic nova prog.
- Broerson+ 2014: RCW86 is a remnant of a 1a that exploded in a 30 pc wind-blown cavity – requires an accretion wind, ie SD model
- Graur+ 2014: no HeII em before SN2011fe ➔ no high acc rate WD

Novae & X-rays

Novae:

- Thermonuclear runaway burning of accreted material on a WD
- Orbital period can be hours to decades
- Recurrent novae have human timescale eruption cycle
- Unclear if M_{WD} grows or declines over many eruptions

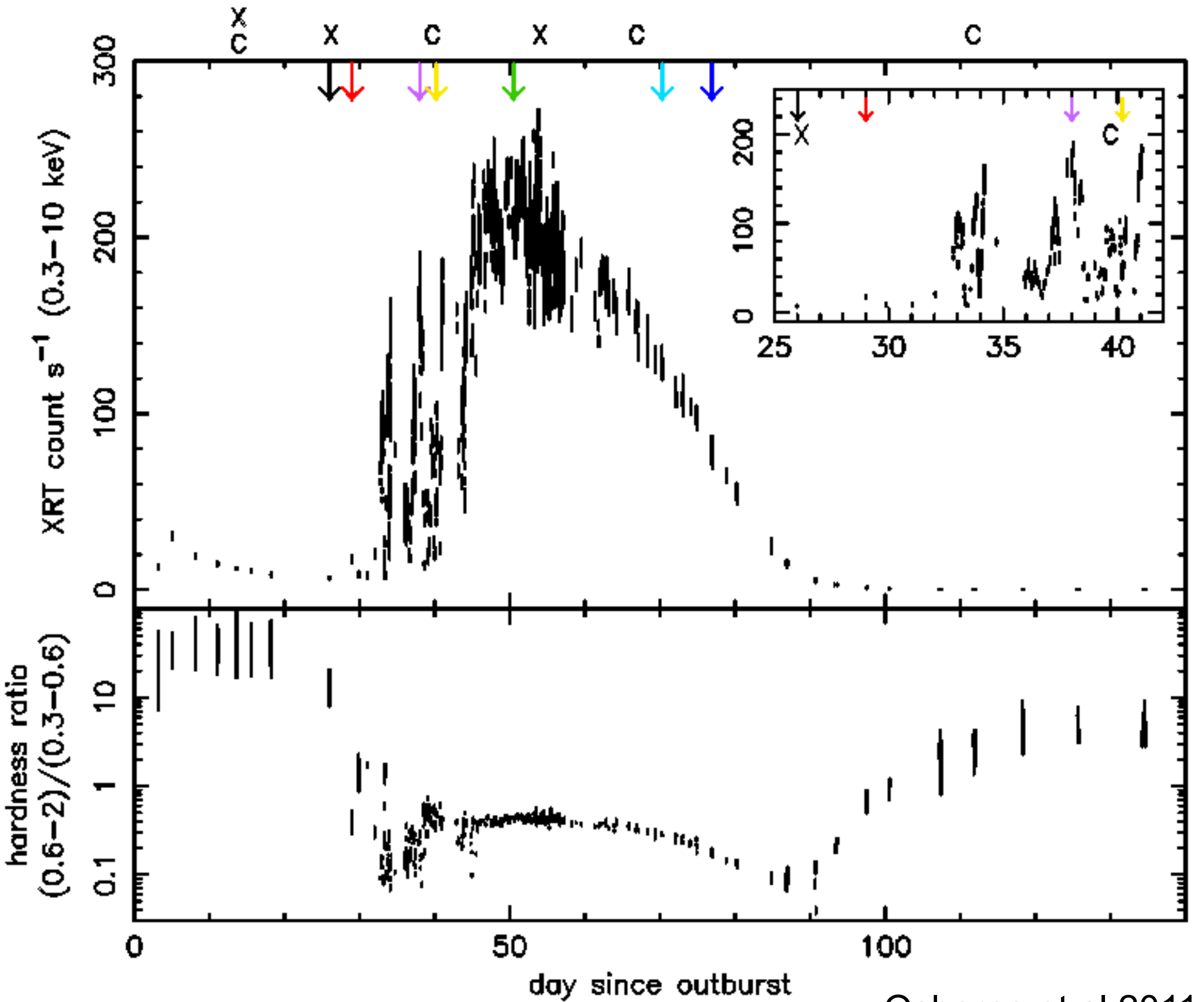
Potential sources of X-ray emission from novae:

- Thermal emission from hot white dwarf
  - shock breakout
  - residual nuclear burning after ejecta dispersal
- High velocity shocks
  - 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 novae stats

- Swift has observed 59 Galactic & MC novae within 4000 days of outburst, of which:
- 37 detected in X-rays
- 11 novae have >100 ksec each: V745 Sco, N Del 2013, N Mon 2013, 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)
- Extragalactic novae also observed

RS Oph

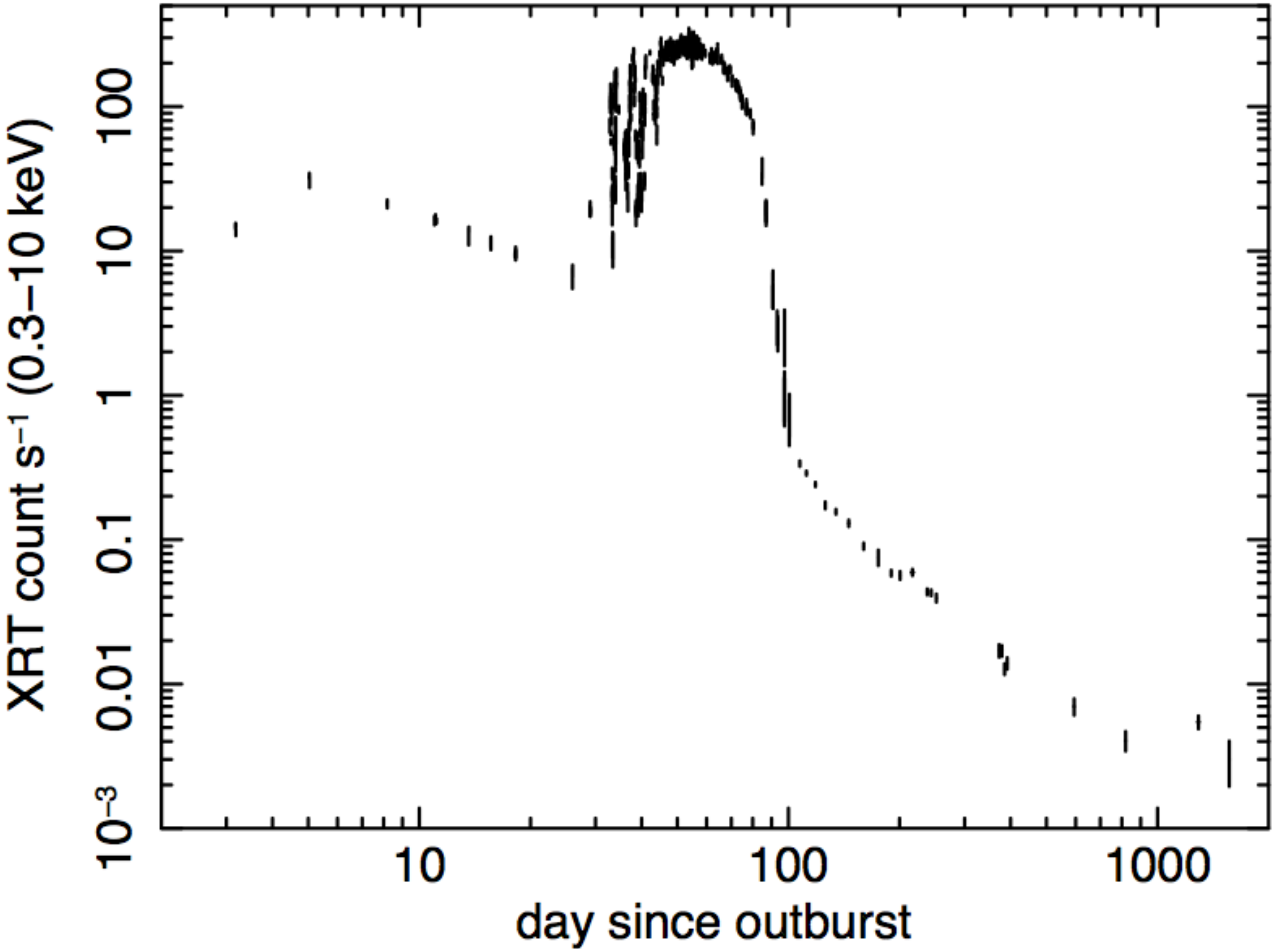


Osborne et al 2011

X-ray (0.3-10 keV) light curve shows:

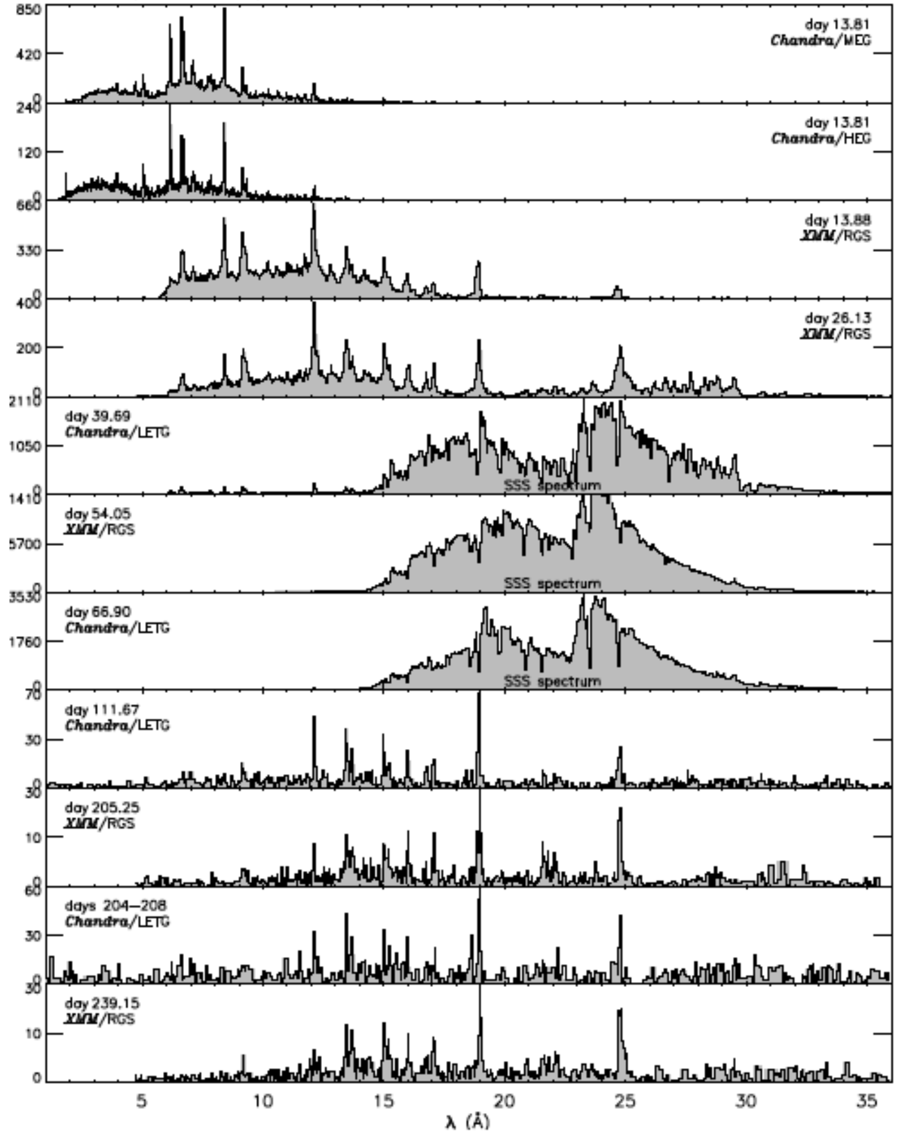
- Cooling hot gas emerging from red giant wind
- Noisy onset of super-soft phase, which lasts ~64 day in total
- Turnoff time → M_{WD}~1.35 $M_☼$

RS Oph



Osborne et al 2011

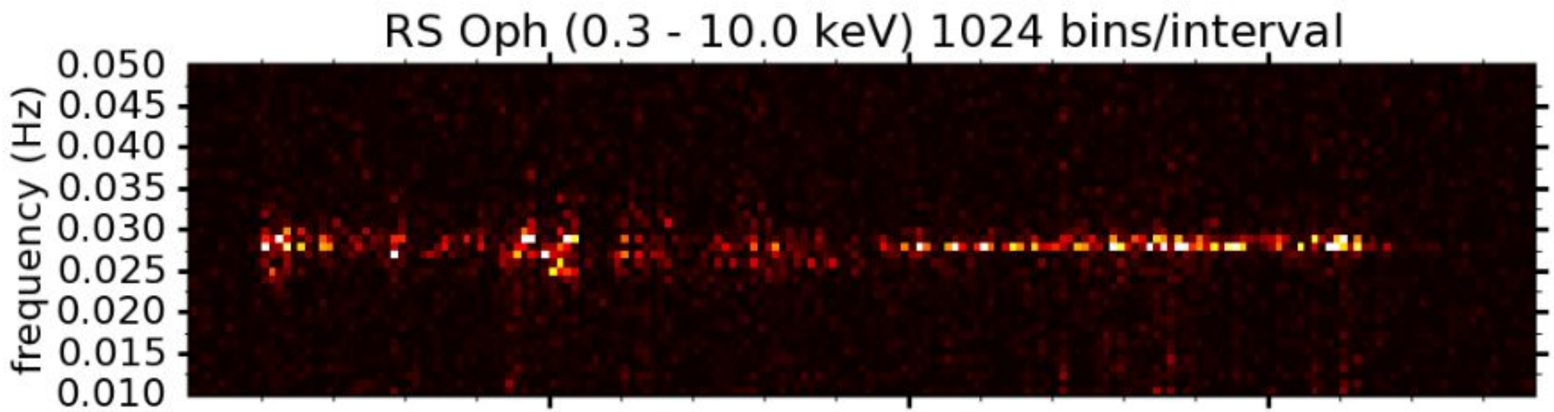
RS Oph

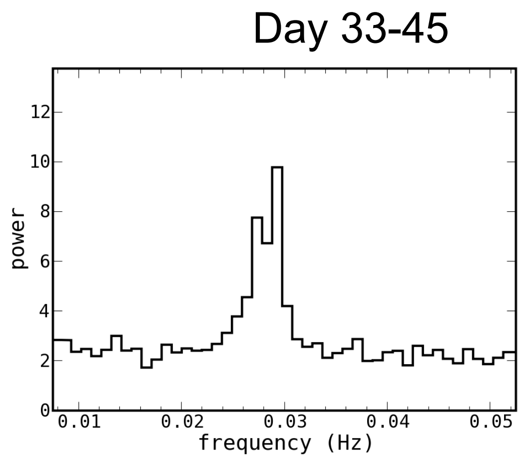


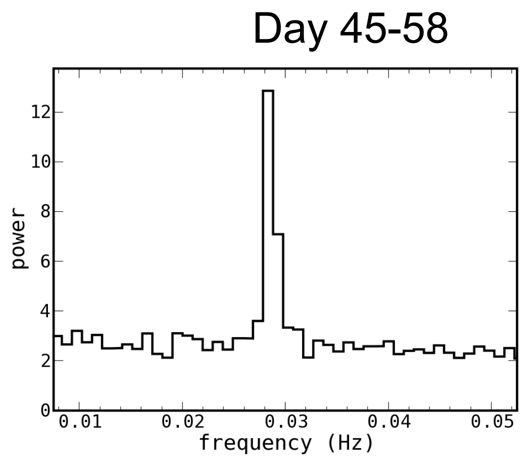
Ness et al 2009

RS Oph

A quasi-periodic modulation







Osborne et al 2011

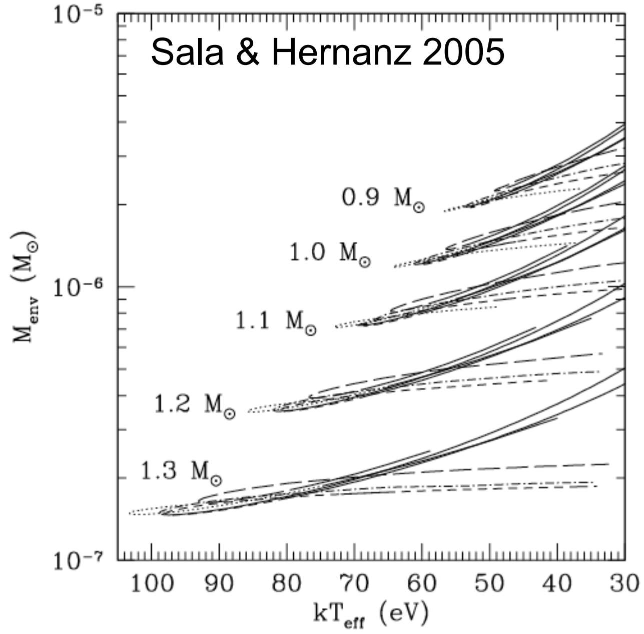
Period near 35s in soft X-rays between days 33-59

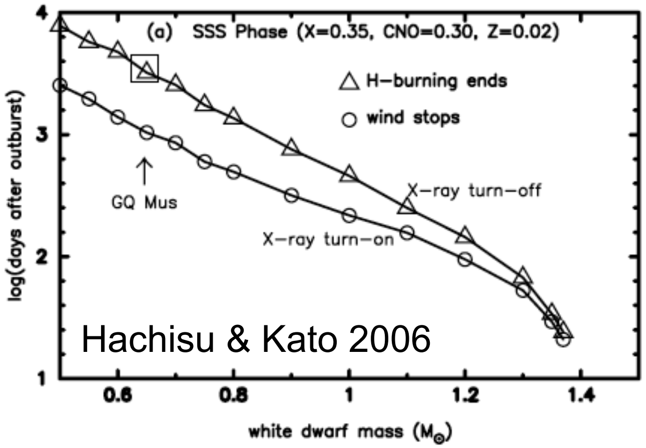
WD spin?

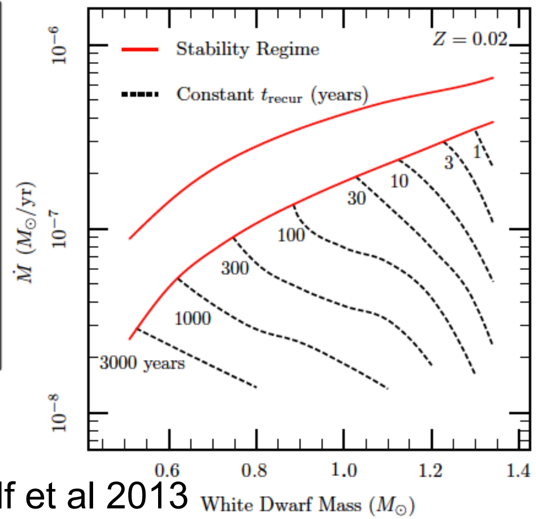
Nuclear burning instability?

What can we learn?

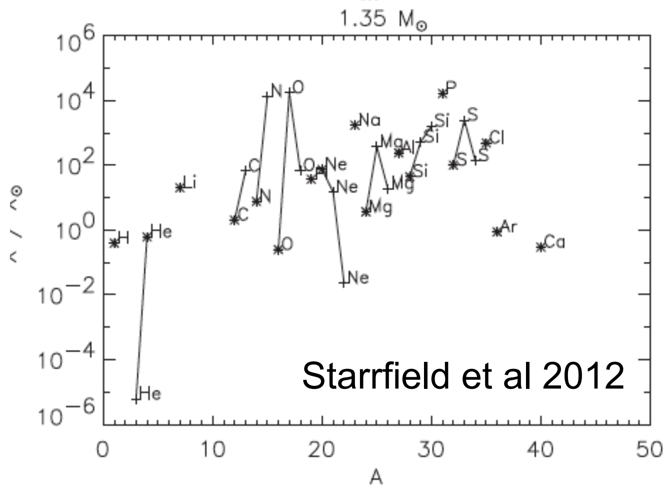
- kT_{max} gives M_{WD}
- T_{recurr} gives M_{WD}, acc rate
- T_{SS} gives M_{WD}
- Ejecta abundances give level of WD mixing, and so whether WD is gaining or loosing mass



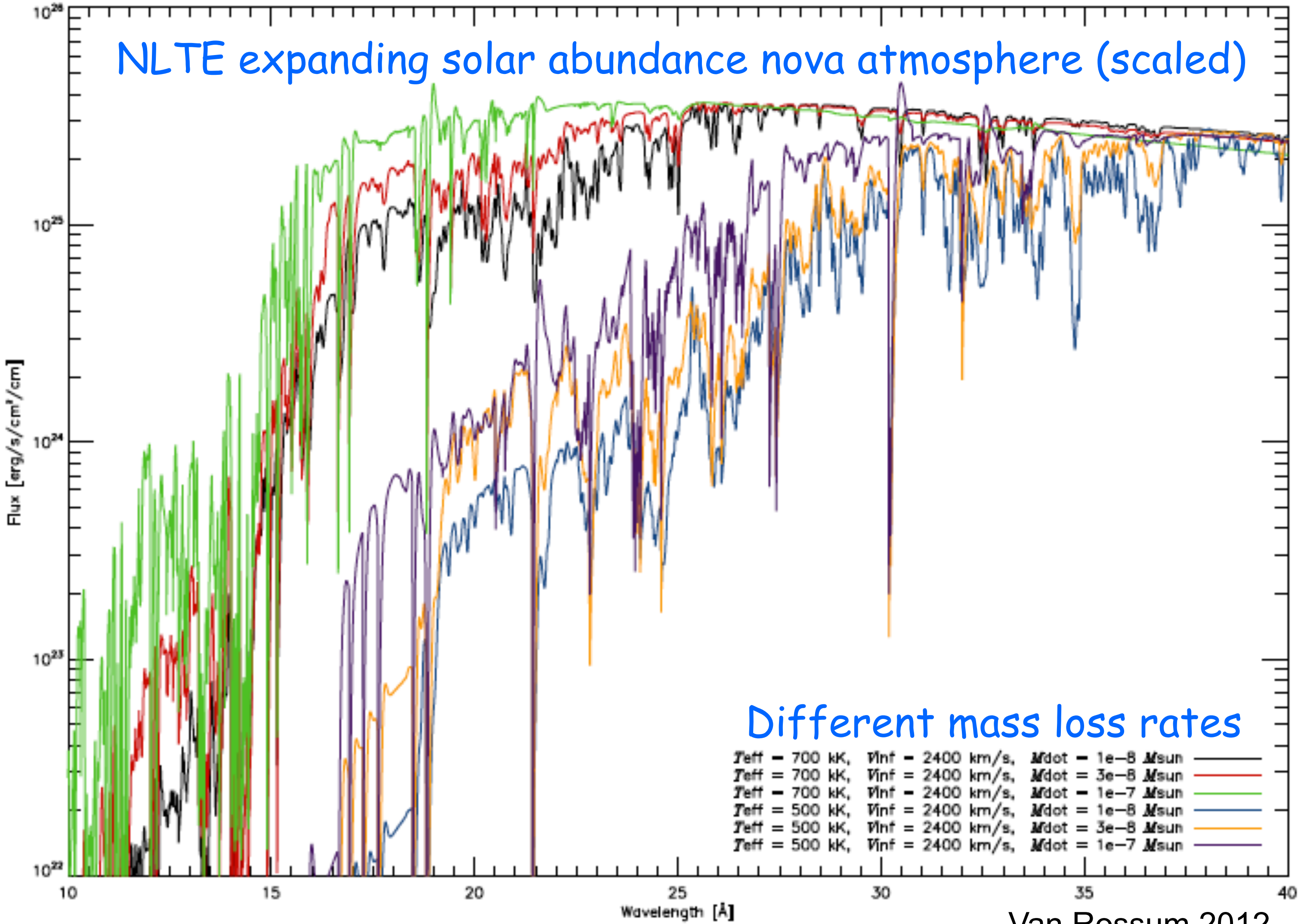




Wolf et al 2013

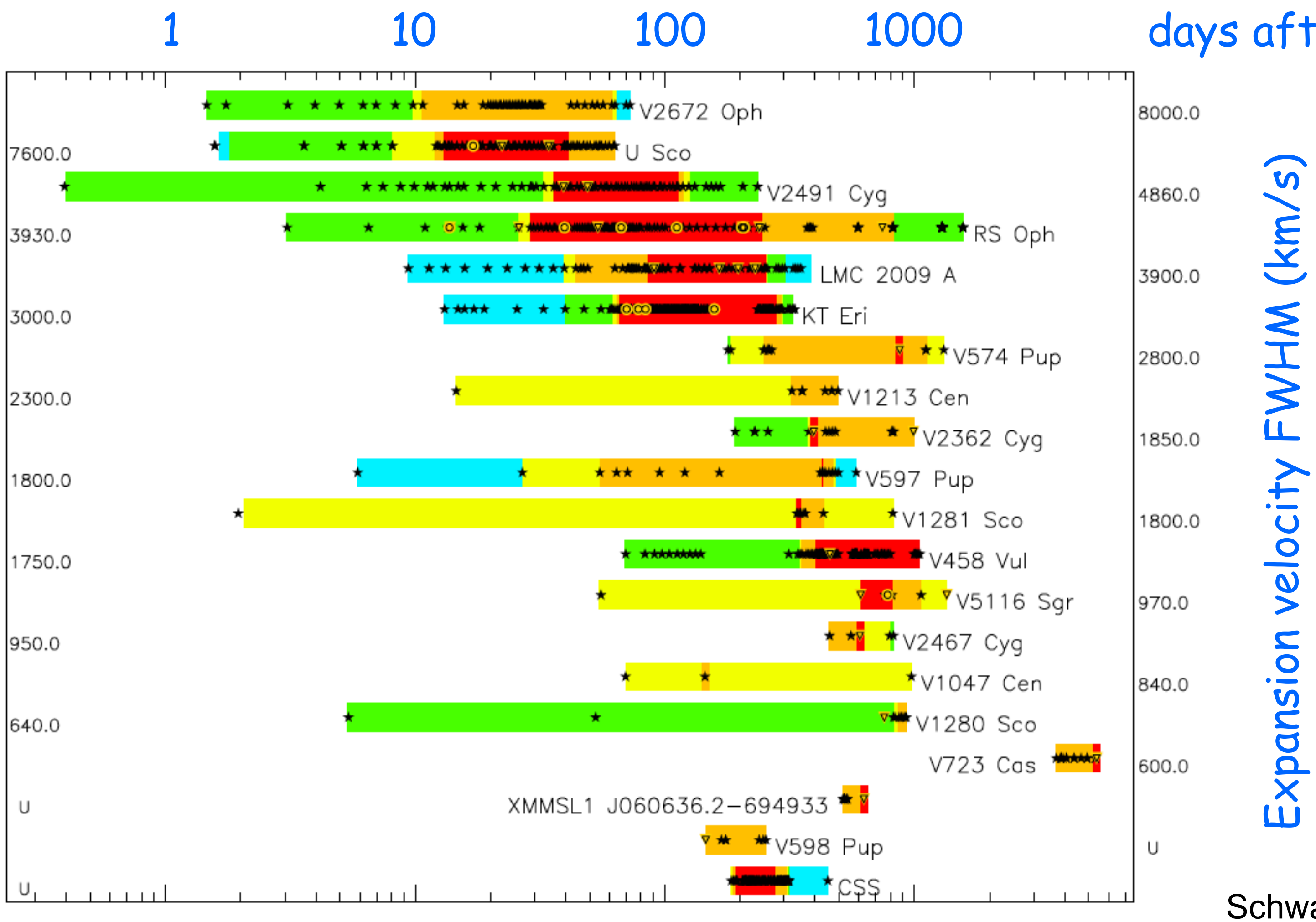


What can we learn?



Van Rossum 2012

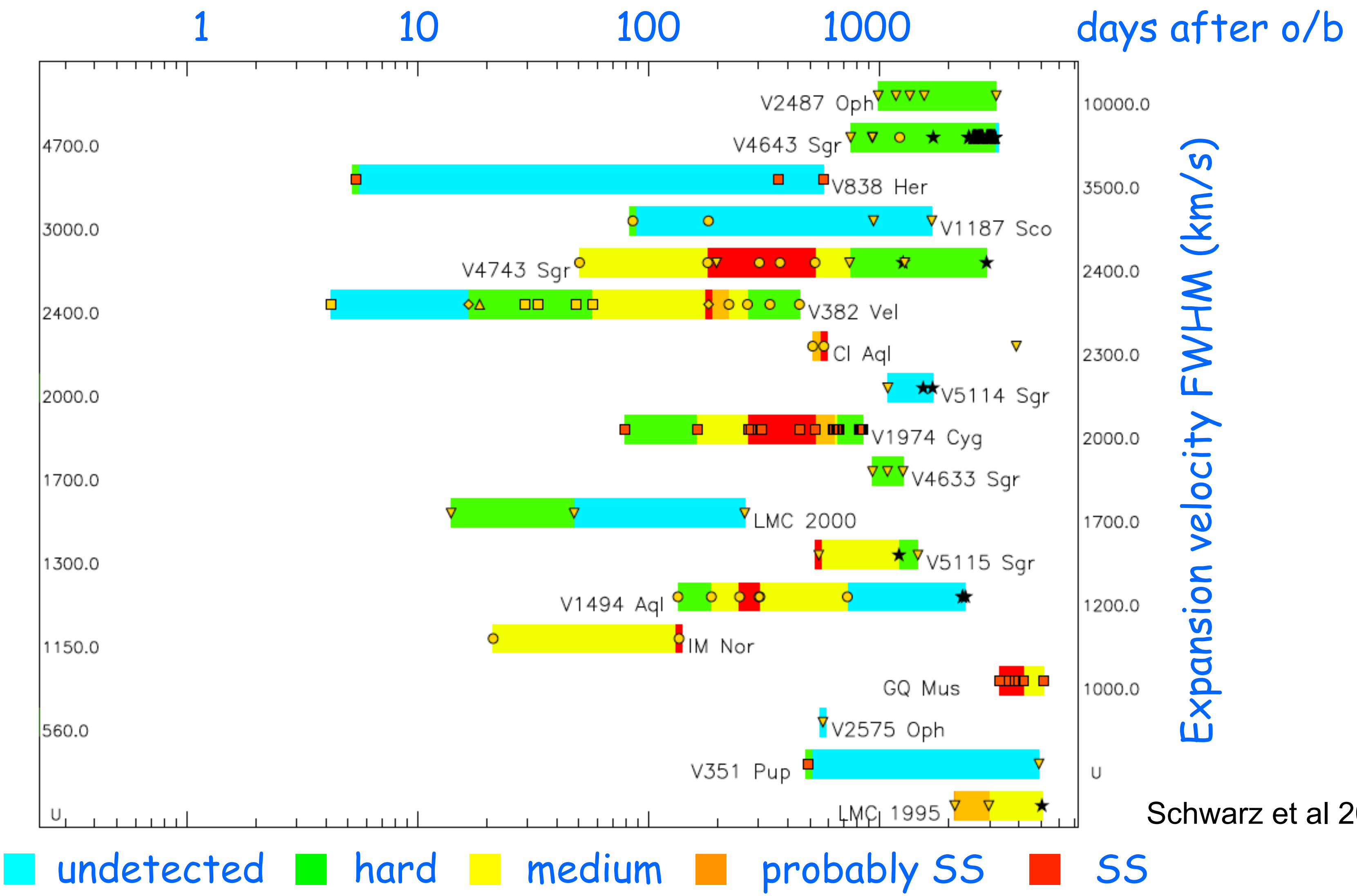
Super Soft Swift Novae



Schwarz et al 2011

undetected hard medium probably SS SS

Pre-Swift Novae



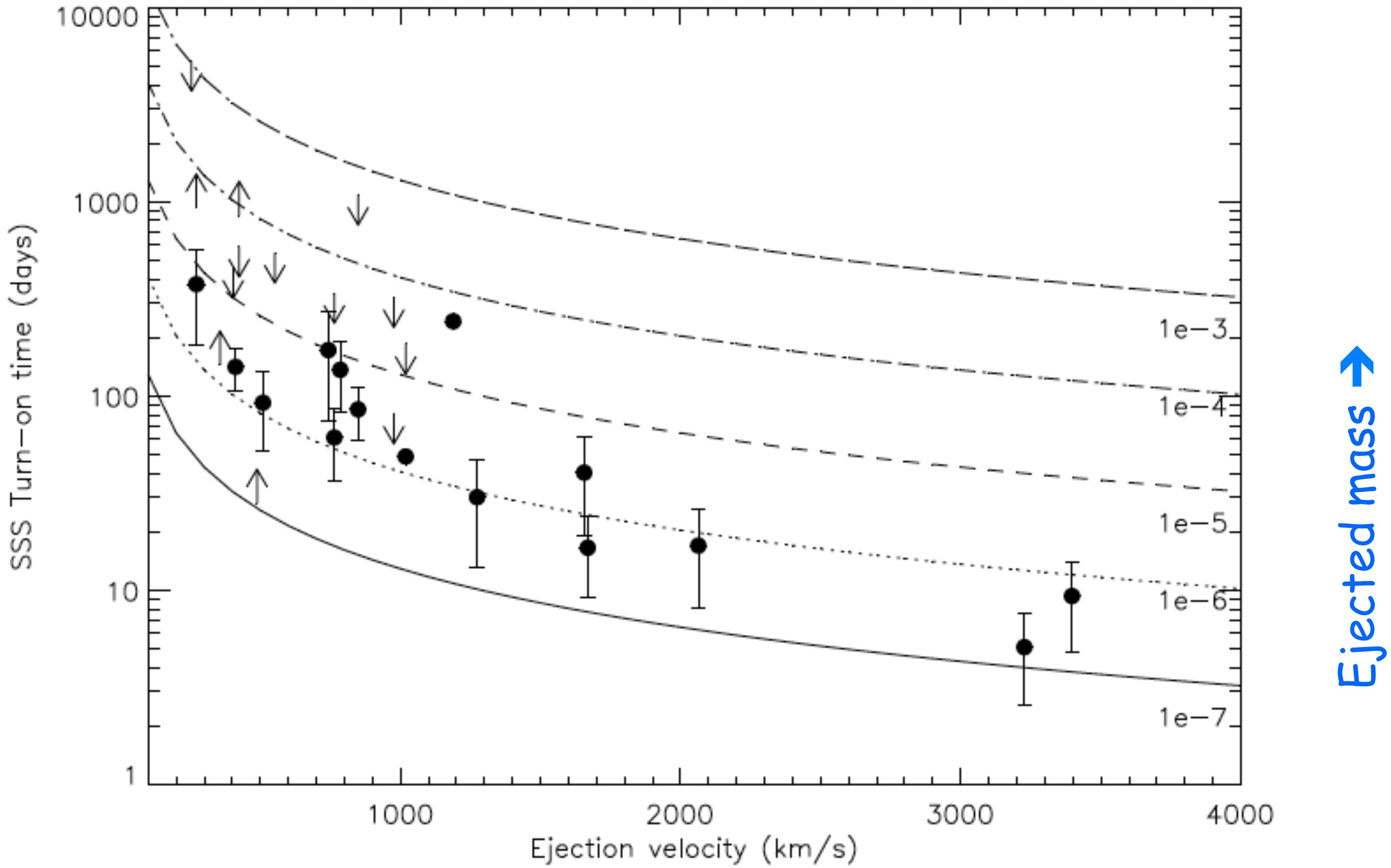
Schwarz et al 2011

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

SS novae turn-on times

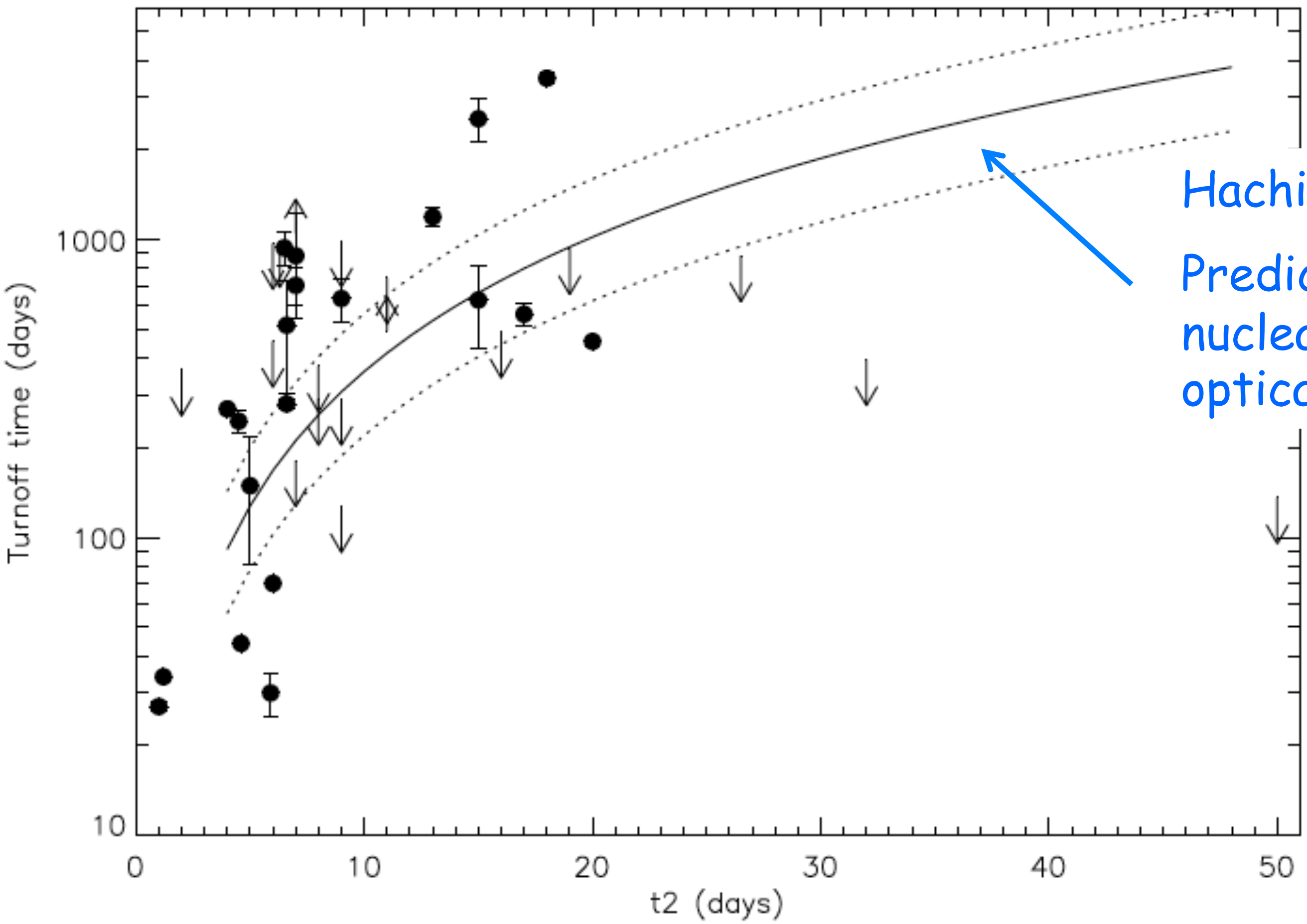


The fastest novae eject the least mass

Schwarz et al 2011

They become SSS early as the ejecta thin out quicker

SS novae turn-off times



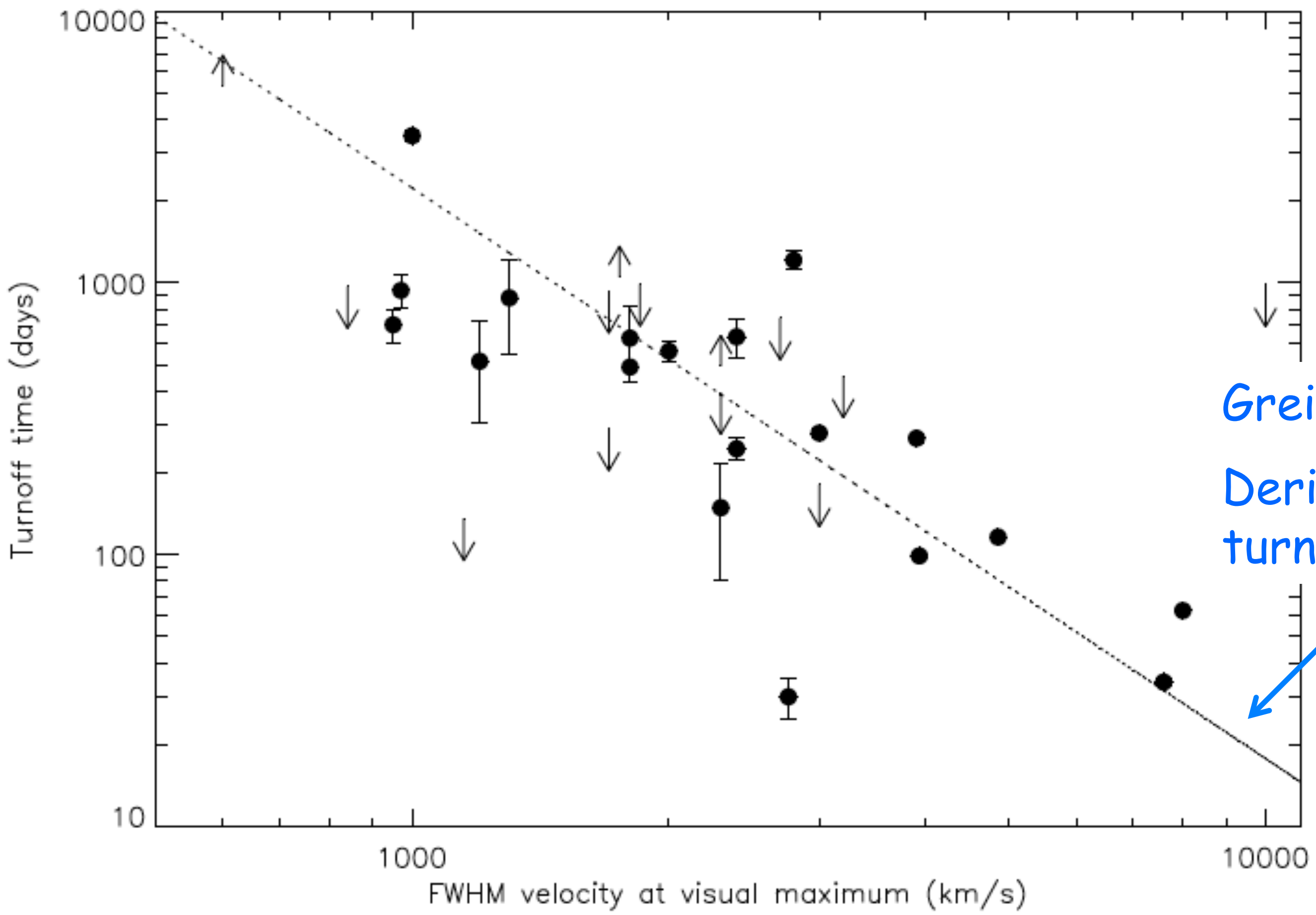
Hachisu & Kato 2010

Predicted end of nuclear burning from optical LC break time

Days to decline 2 magnitudes

Schwarz et al 2011

SS novae turn-off times



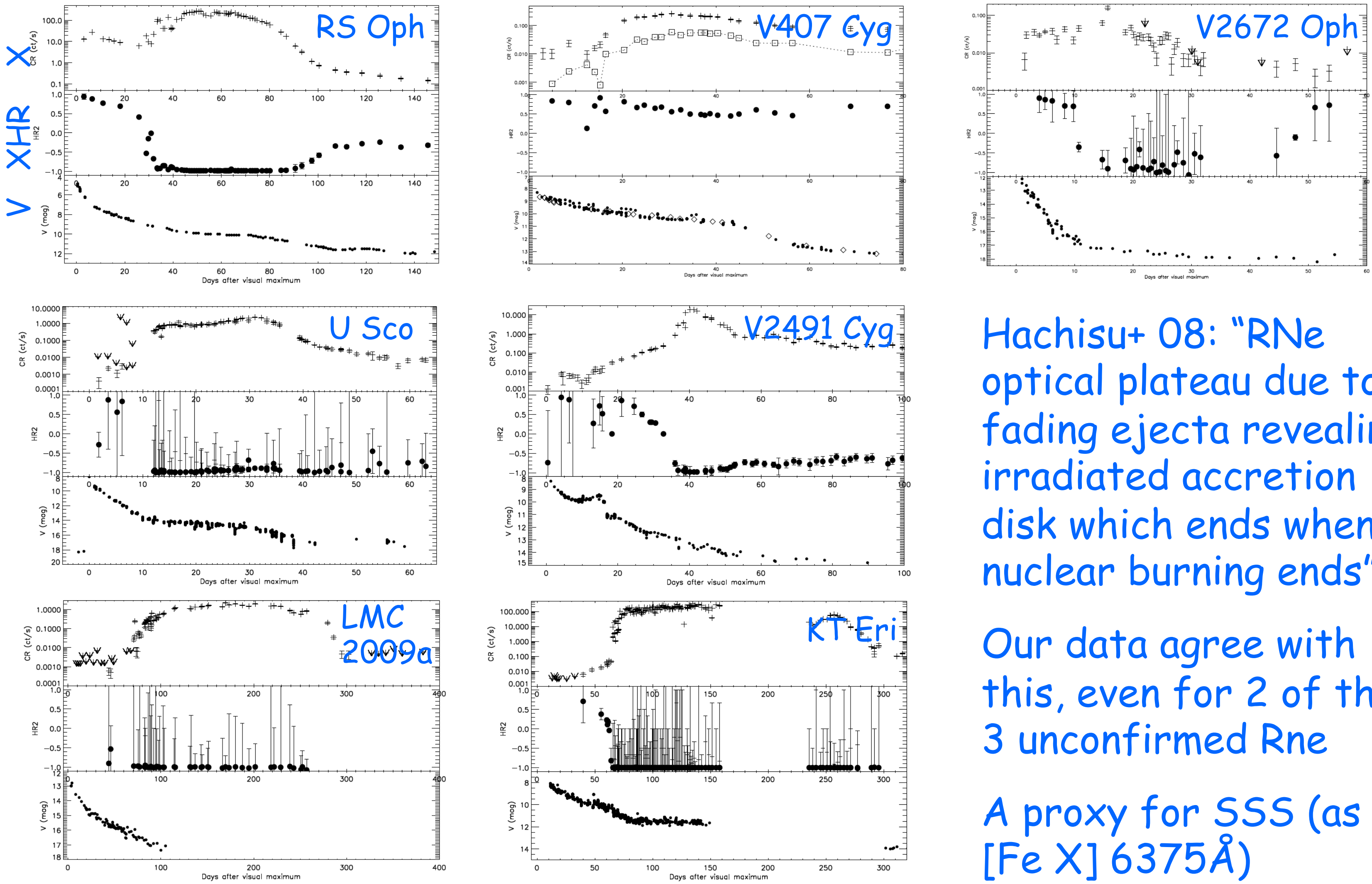
Greiner+ 03

Derived from 4 SS turn-offs

Ejecta velocity

Schwarz et al 2011

SSS = optical plateau?



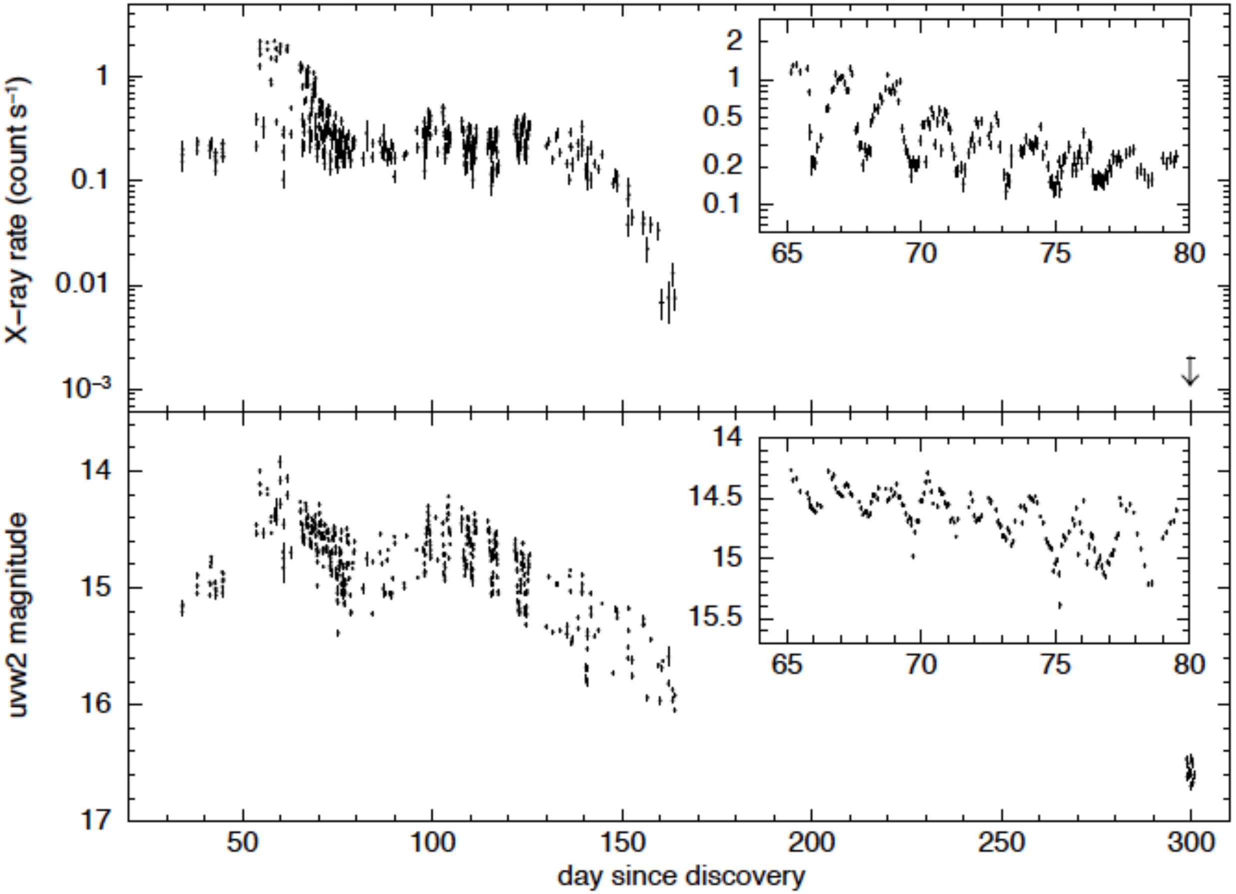
Hachisu+ 08: "RNe optical plateau due to fading ejecta revealing irradiated accretion disk which ends when nuclear burning ends"

Our data agree with this, even for 2 of the 3 unconfirmed Rne

A proxy for SSS (as is [Fe X] 6375Å)

CSS 081007… = HV Ceti

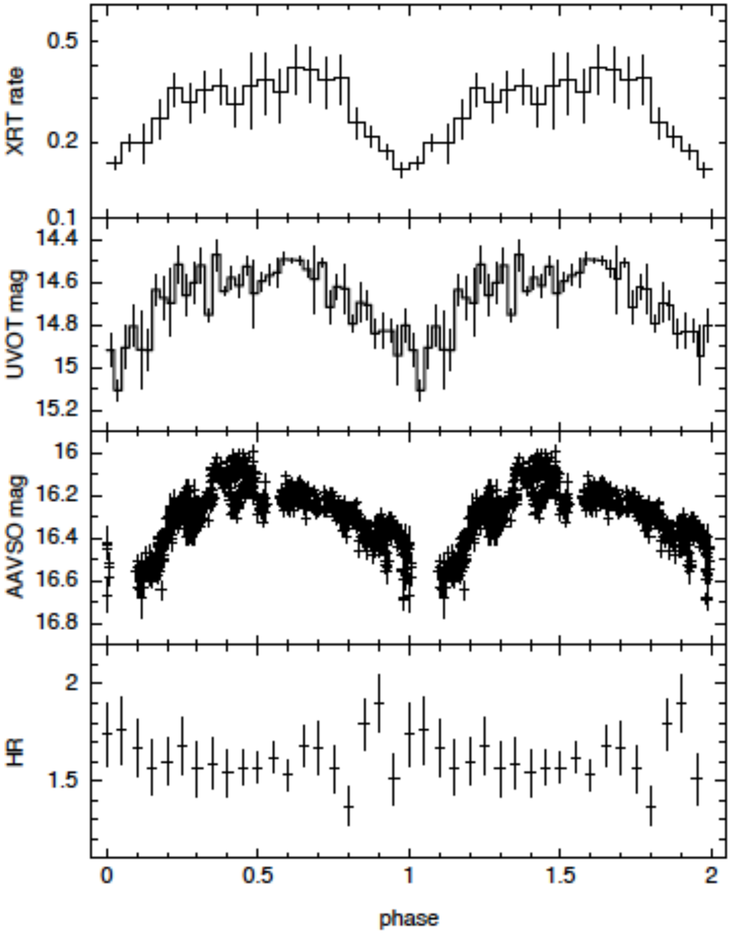
- Beardmore et al 2010: initial summary in AN
- Beardmore et al 2012: full paper - A&A 545, A116

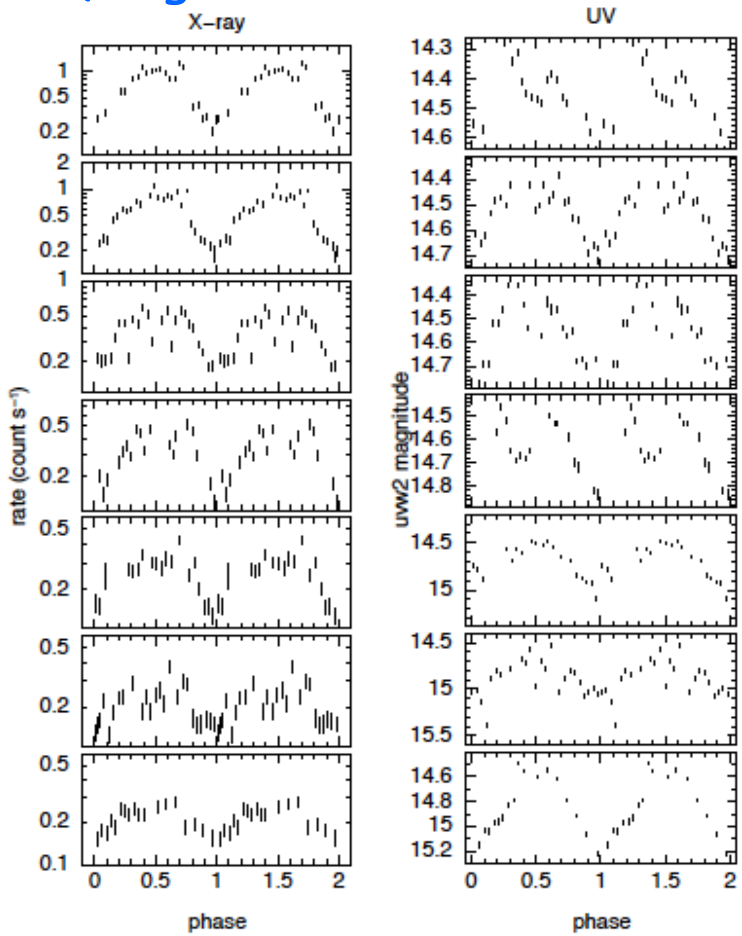


- $\Delta V > 4$
- Ha vel ~ 1500 km/s
- Strong [Ne V]
- Pre-o/b rise ~ 1-2 mag
- Gal latitude = -44°
- Time of optical peak poorly constrained

HV Ceti

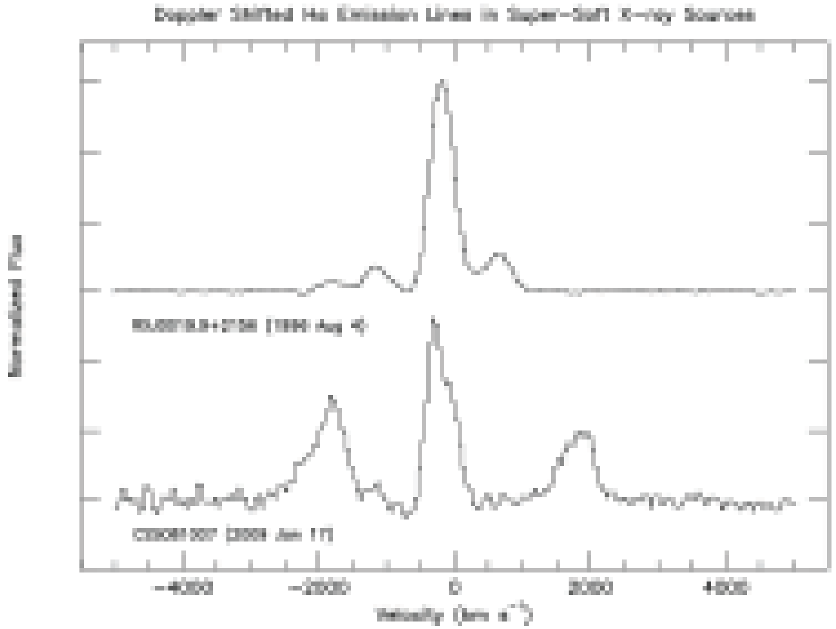
- 1.77 day modulation: orbital (cf GK Per) or poss precession
  - Broad modulation suggests large emission region
  - UV peak dips like SSS Cal 87 (bright inner accretion disk?)





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)

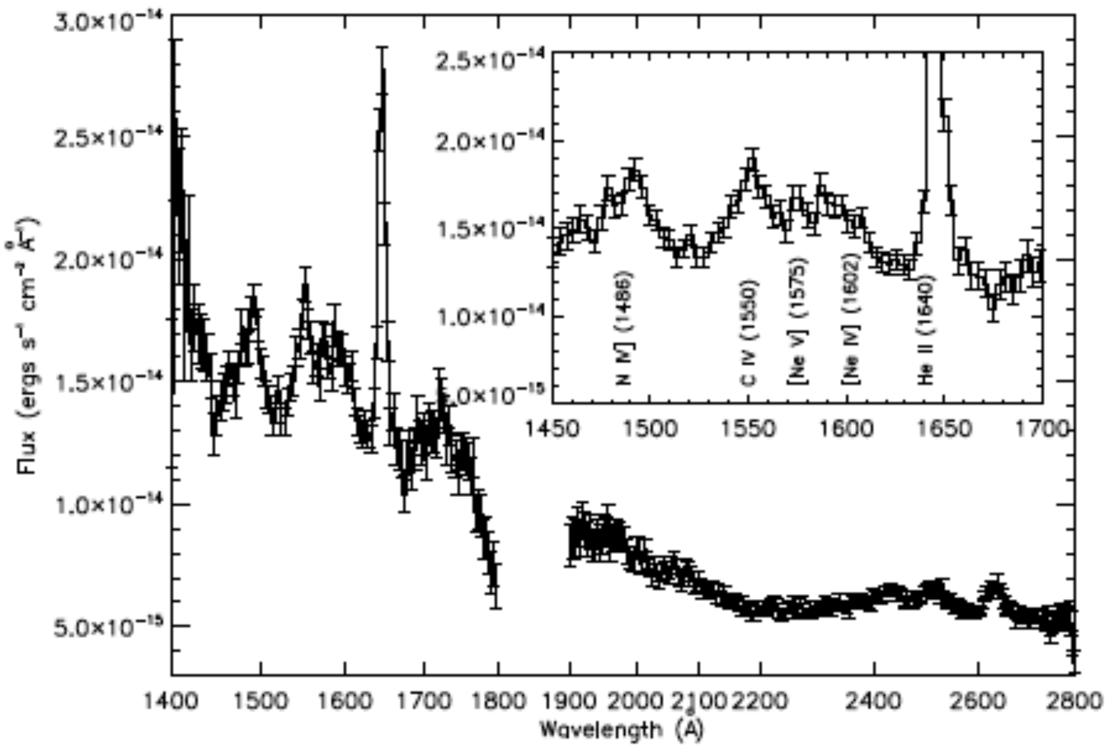


Wagner et al 2011

HV Ceti

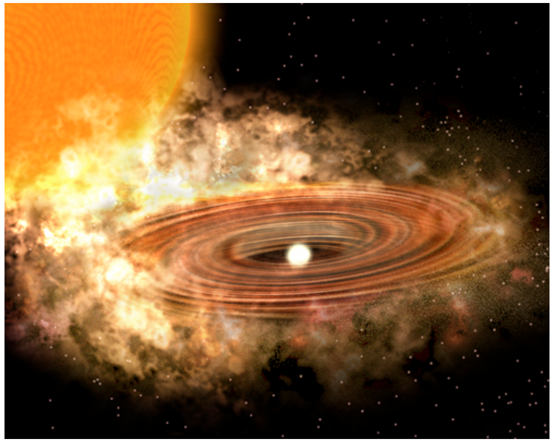
Galex spectra:

- 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

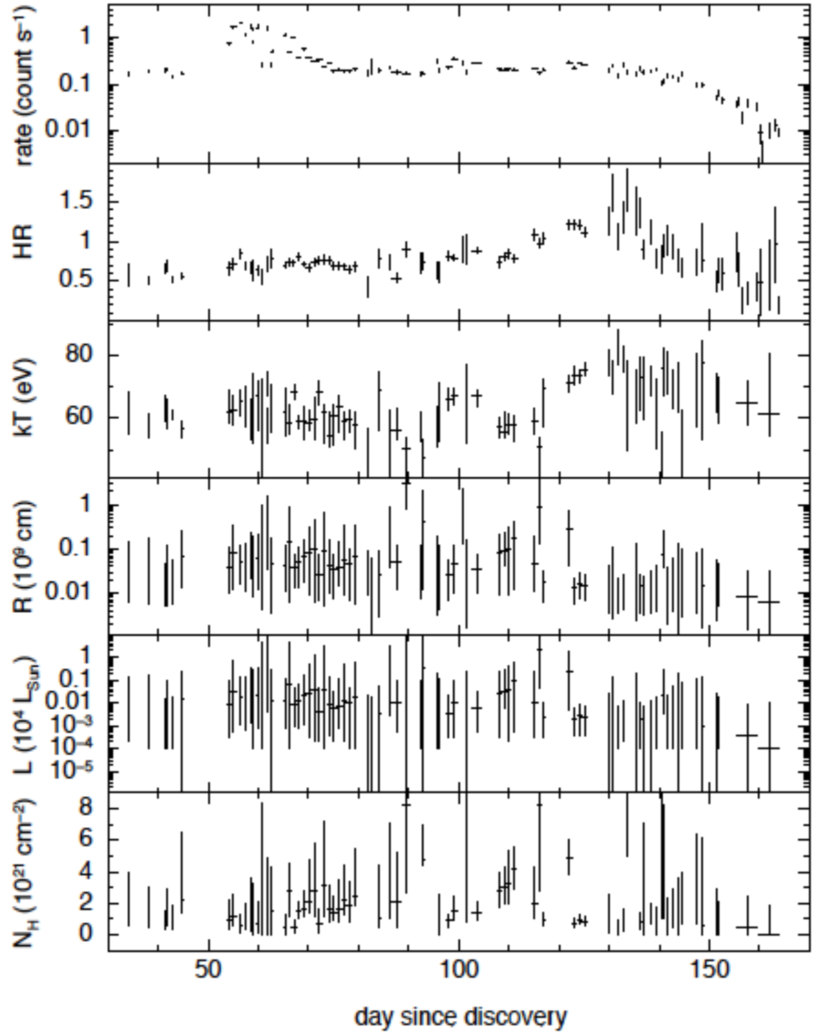


HV Ceti

- 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) – Well below expected ~10^9 cm



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

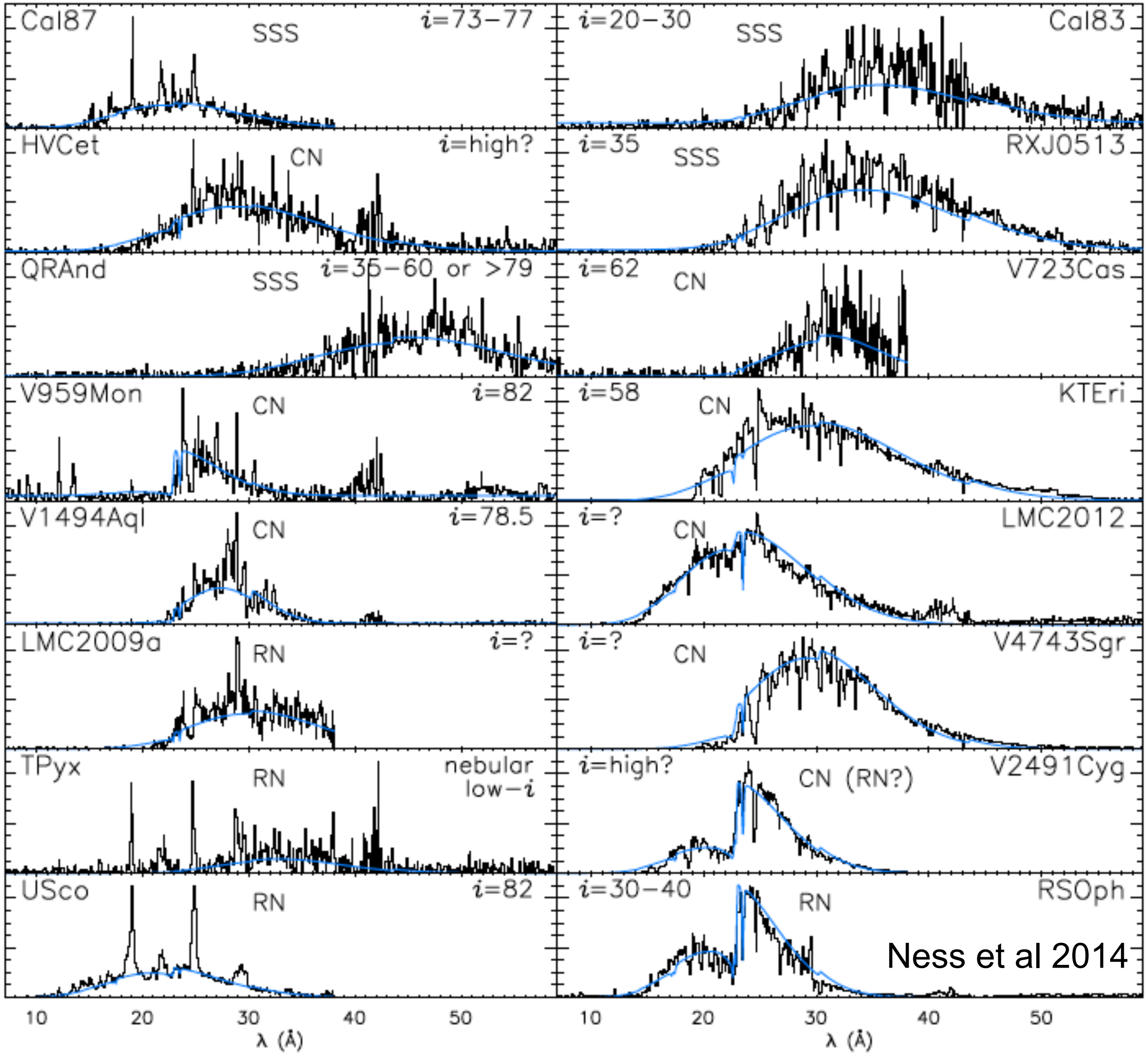
- Cannot be due to changes in disk rim height or size of inner scattering region

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

SSS obscuration

Mostly novae

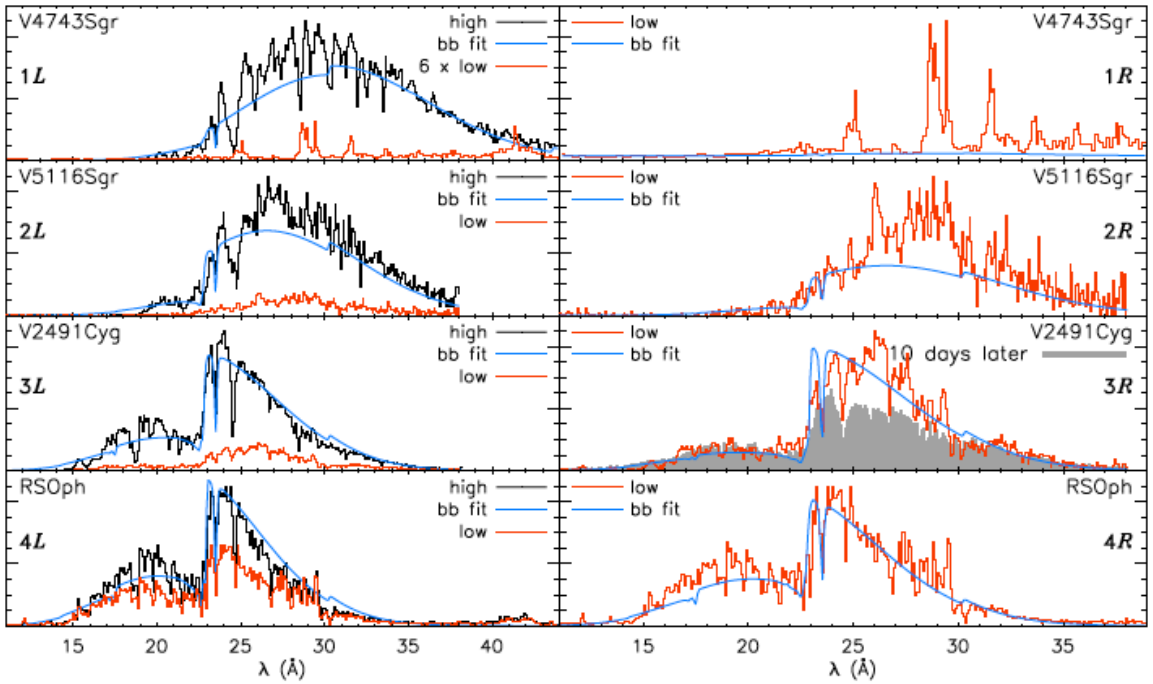
- High inclination SSSs are emission line dominated
- Low inclination systems dominated by continuum & absorption lines



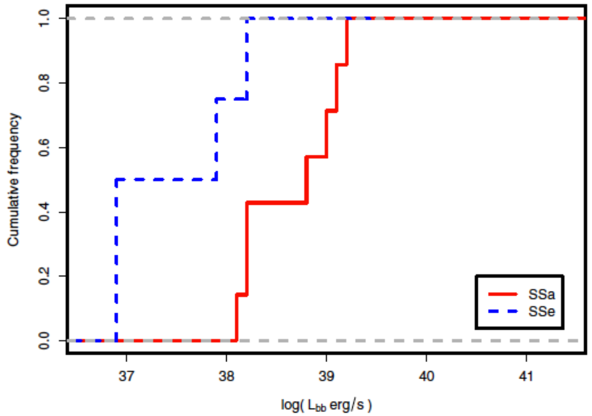
SSS obscuration

Sources are:
- continuum dominated when bright
- emission line dominated when faint

- More luminous sources are continuum dominated
- Less Luminous source are emission line dominated



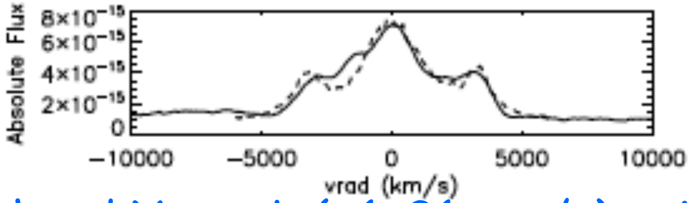
Ness et al 2014



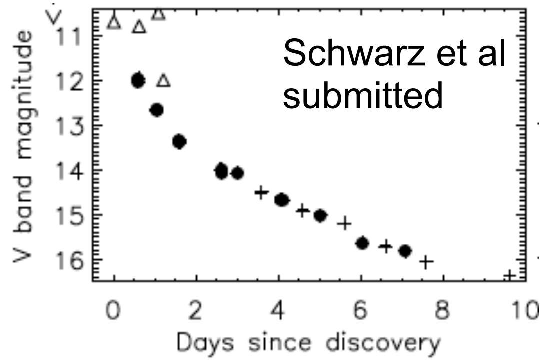
- Line of sight to WD is blocked at i>~70°
- Residual continuum seen via scattering
- Emission lines stronger where continuum is stronger ➔ photo-excitation
- Accretion disk exists at time of SS in novae

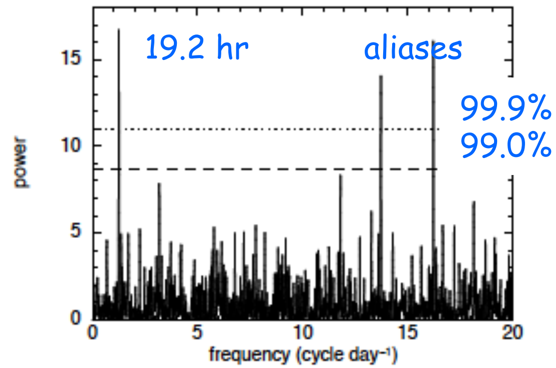
Nova LMC 2012

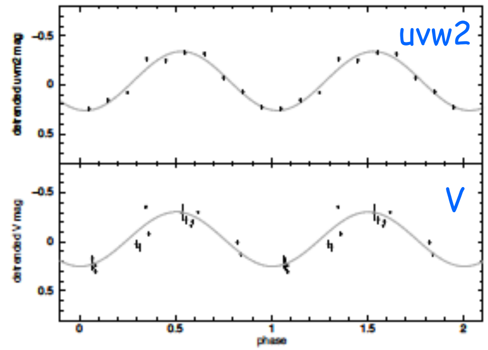
- Very fast decline: t_2 ~ 2 days (~ fastest ever seen)
- $P_{UV,\ opt,\ NIR}$ = 19.2 hr, not present in X-rays
- Emission line Chandra grating spectrum & optical emission line modelling suggests inclination ~55°



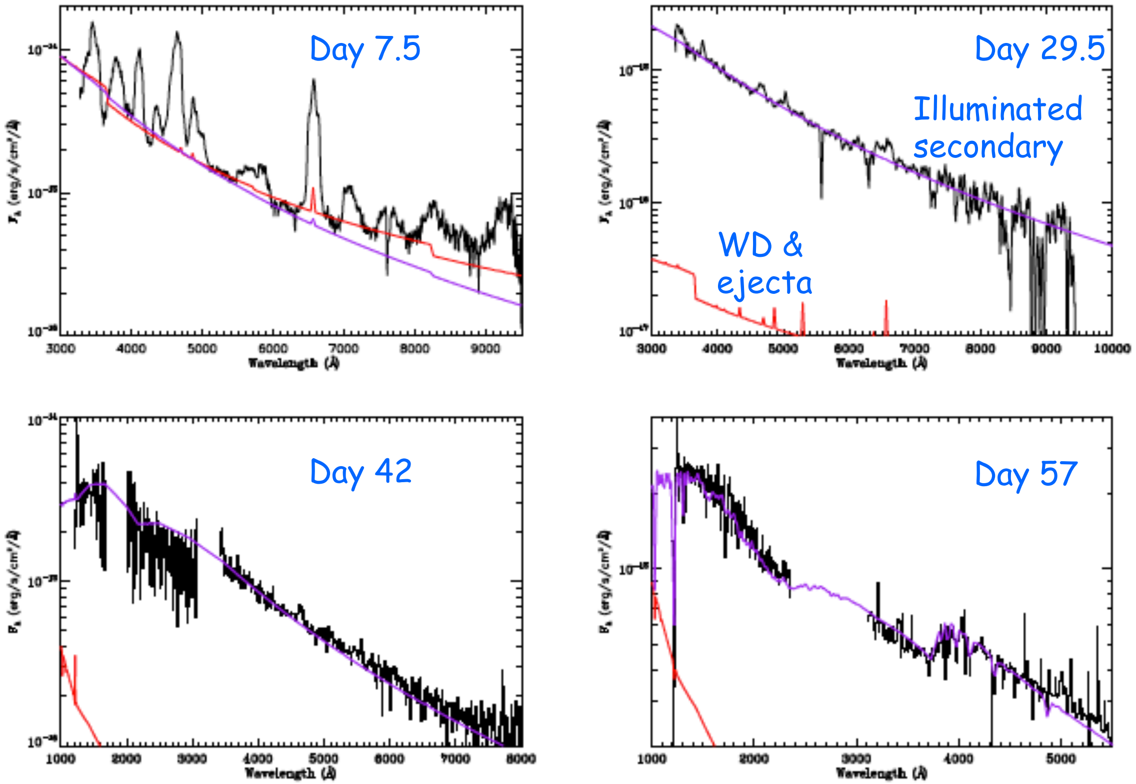
- Very low hard X-ray L (~1e31 erg/s) points to low M_{ej} (~1e-6 $M_{\odot}$)
- Short T_{SS} (= 50 d) at 1MK, high V_{ej} (~5000 km/s), low M_{ej} all point to a high M_{WD}







Nova LMC 2012

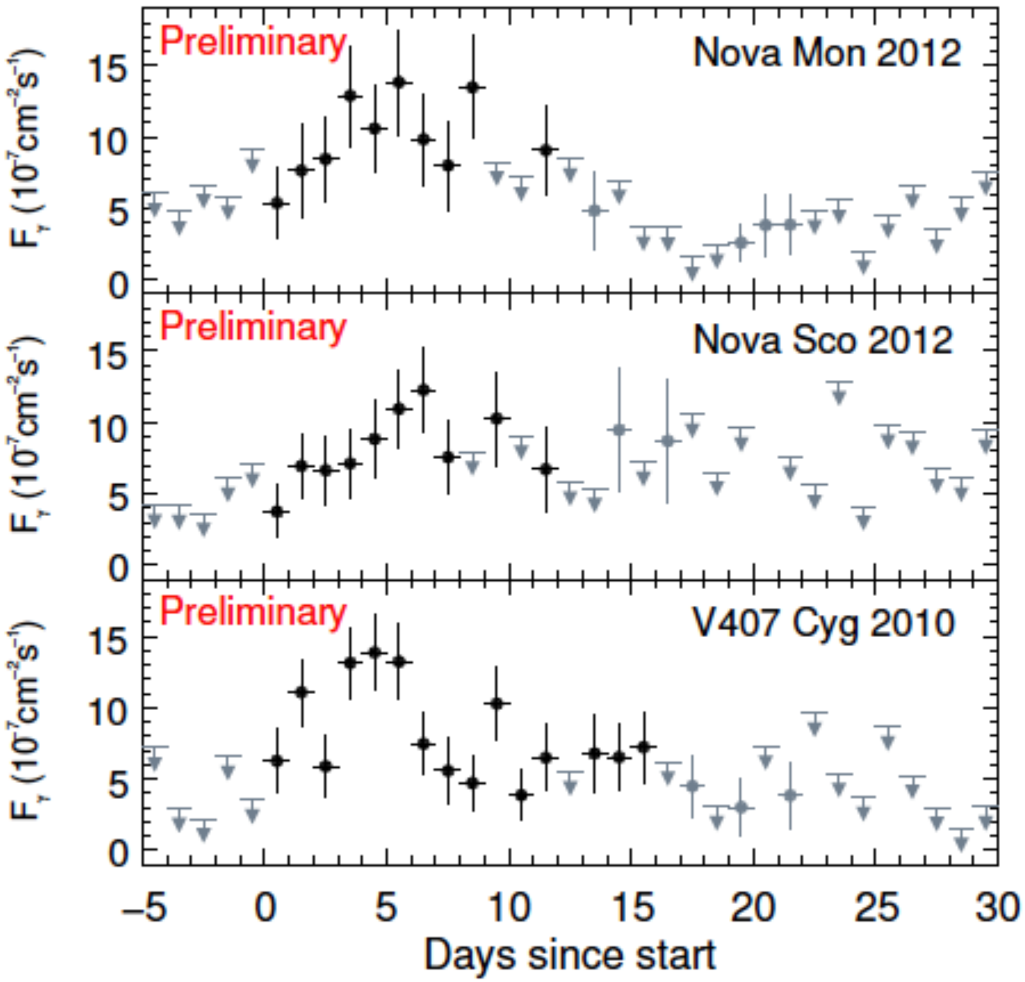


Schwarz et al submitted

- Optical/UV & X-ray spectroscopy constrain Rauch WD and Cloudy ejecta models, leading to the need for a 2nd UV/optical source:
    - Consistent with illuminated secondary, T ~ 20,000 K
    - Optical light curve is not due to ejecta
- Probable RN, gaining mass: SN1a progenitor – hard to find with t_2 ~ 2 days

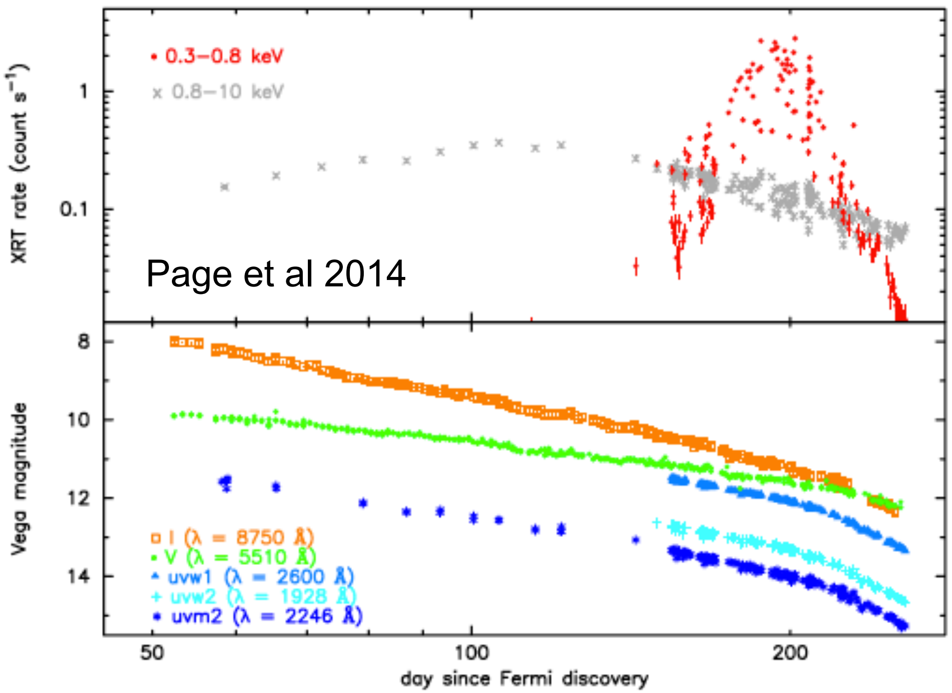
Fermi-LAT novae

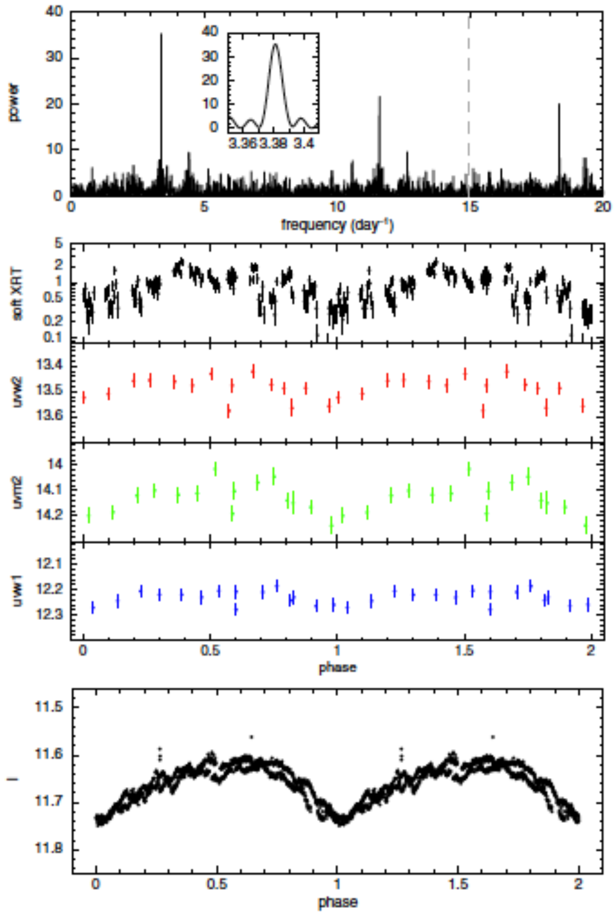
- 6 >100 MeV novae
- V407 Cyg: red giant (P_o~40-50y)
- N Sco = ?
- N Mon = K dwarf
- Emission peaks a few days after optical
- Discovery not widely expected: MeV line emission predicted, but not GeV continuum
- 1st had dense companion wind, good target for shock
    - photo-pion or IC origin
    - LAT novae would be rare
- No wind in N Mon 2012



Hill et al 1308.6281
3σ detections marked

Fermi-LAT novae

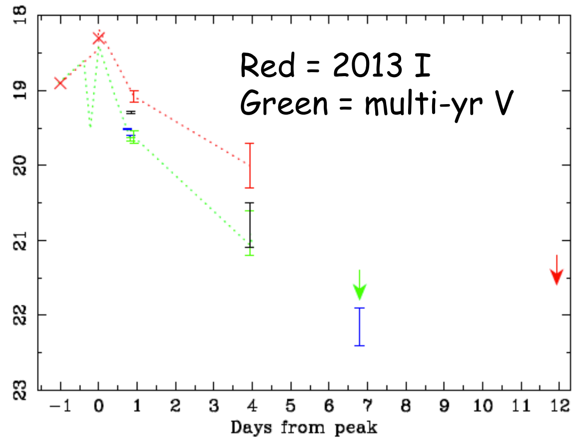




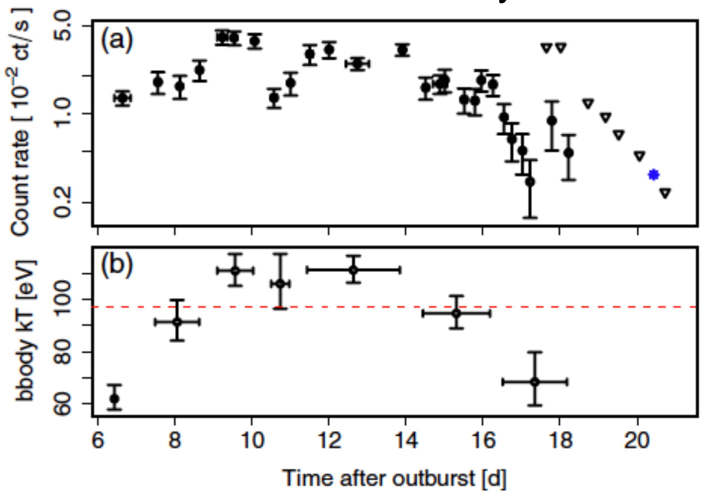
- N Mon 2012 seen in VHE-γ before optical
- 7.1 hr period in phase in X-ray, UV & I-band
    - Modulation due to disk rim obscuration?
- Presumed orbital period ➔ Msec ~ 0.8 $M_{\odot}$, rules out wind shock VHE-γ
- Martin & Dubus 2013 model: shock in gas around accretion disk

M31 nova: T_{recurr} ~ 1 yr

- M32N 2008-12a outbursts in: 2008/12, 2011/10, 2012/10, 2013/11
- Shortest Galactic nova T_{recurr} ~ 8 yr (U Sco)
- Very fast V-band decline (t_2 ~ 4 days)
- Very high M_{WD} (~1.4 $M_\odot$) and accretion rate (log Mdot ~ -7 to -8)
- Very short SS phase seen by Swift (T_{SS} ~ 20 days) ➔ high M_{WD}
- T_{BB} ~ 97 eV ➔ very high M_{WD}
- Also found by Rosat as SSS in 1992/2 & 1993/1 and by Chandra HRC in 2001/9
- If this is a CO WD, it is a good SN1a progenitor candidate

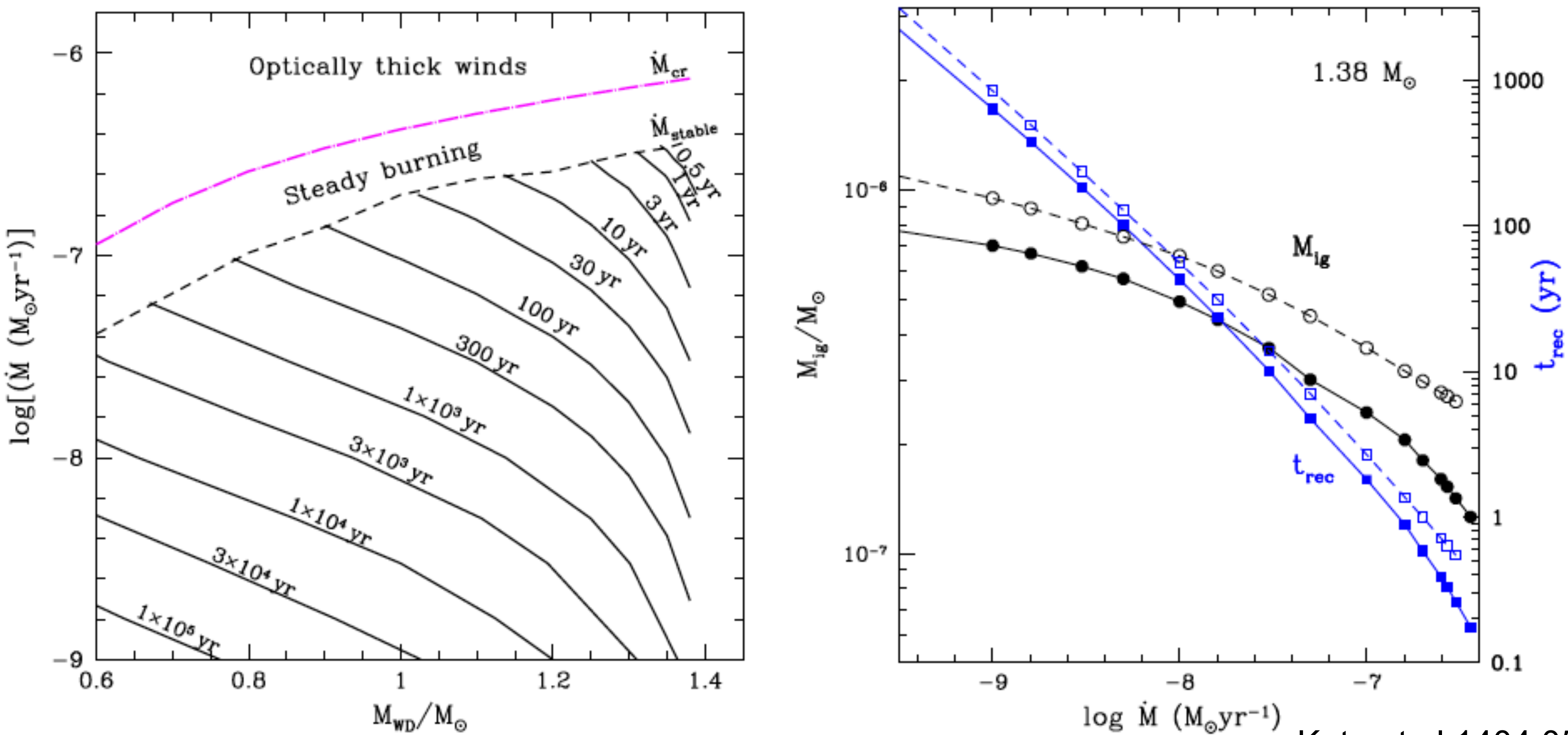


Darnley et al 2014



Henze et al 2014

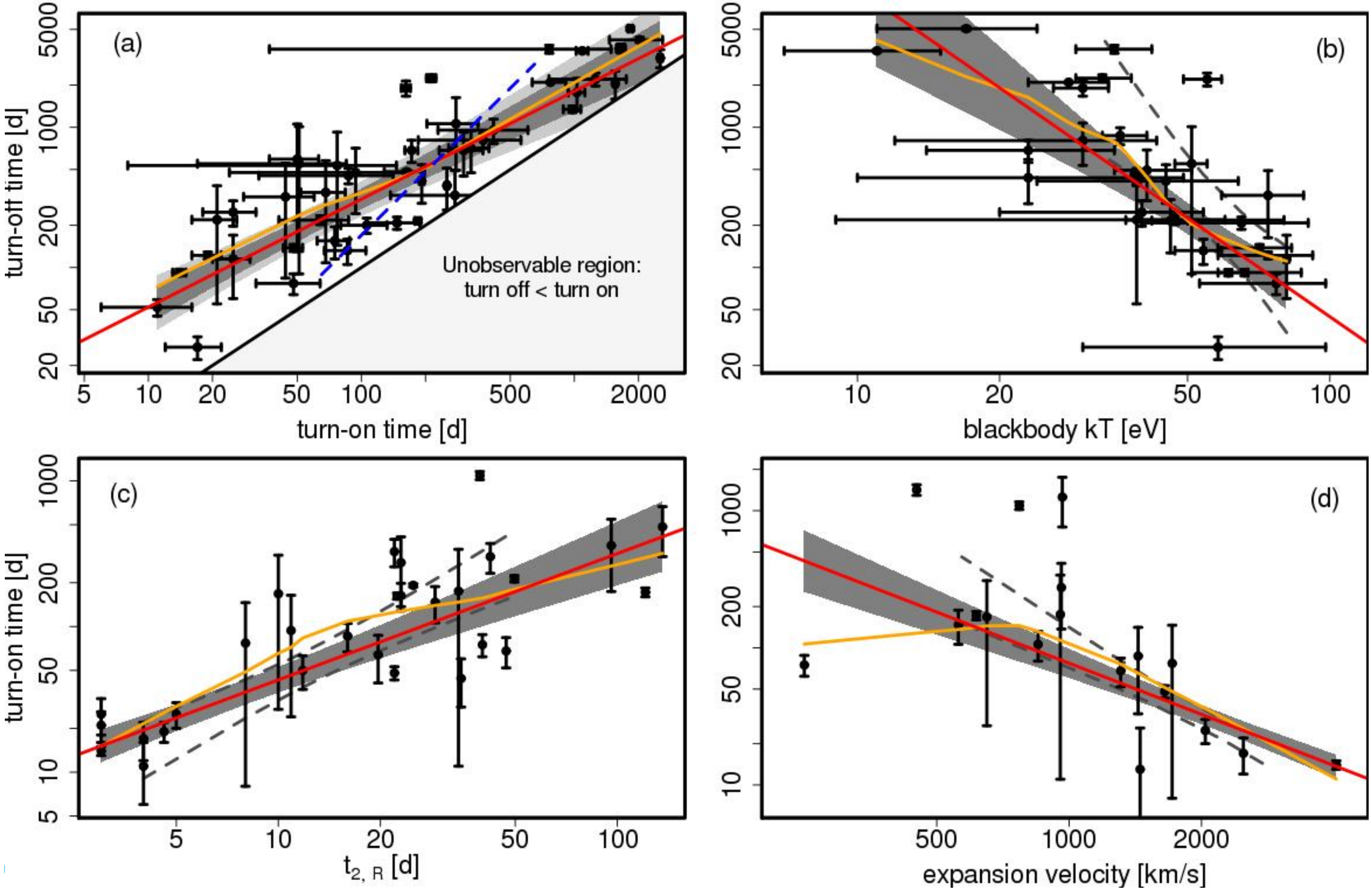
M31 nova: T_{recurr} ~ 1 yr



Kato et al 1404.0582

- M_{WD} > 1.3 M & acc rate > 1.5x10^-7 M/yr
- Min poss T_{recurr} ~ 2 months (for non-rot 1.38 M_{WD})

M31 Henze+14



(a)
turn-off time [d]
turn-on time [d]
Unobservable region:
turn off < turn on
(b)
blackbody kT [eV]
(c)
turn-on time [d]
$t_{2,R}$ [d]
(d)
expansion velocity [km/s]

Summary

- High energy nova observations have revealed surprises
- Not really understood:
  - Large amplitude variability of early super-soft phase ('clumps'?)
  - 30-60 sec QPO (WD spin or oscillation?)
  - GeV emission origin
- Perhaps understood:
  - High mass WDs lead to fast novae
  - Irradiation can play a large role in optical light curve formation
  - Accretion disk can be present during residual nuclear burning phase
  - X-rays from inner regions can be scattered into line of sight
  - Completeness of nova samples may be very poor
- Fuller knowledge will lead to progress in understanding the origin of SN1a