SoXS-WG4: Classical Novae, Recurrent Novae, Dwarf Novae and Nova Impostors

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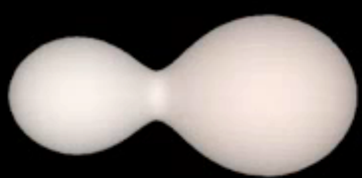
https://docs.google.com/document/d/1Eh7AOxgI8-syG6ACwKAVU7Z-vyrHuxPJJi_u1deyEsw/edit

This proposal deals with the study of several subclasses of semi-detached binaries

Detached binary:

neither of the stars fills its Roche Lobe



Contact binary:

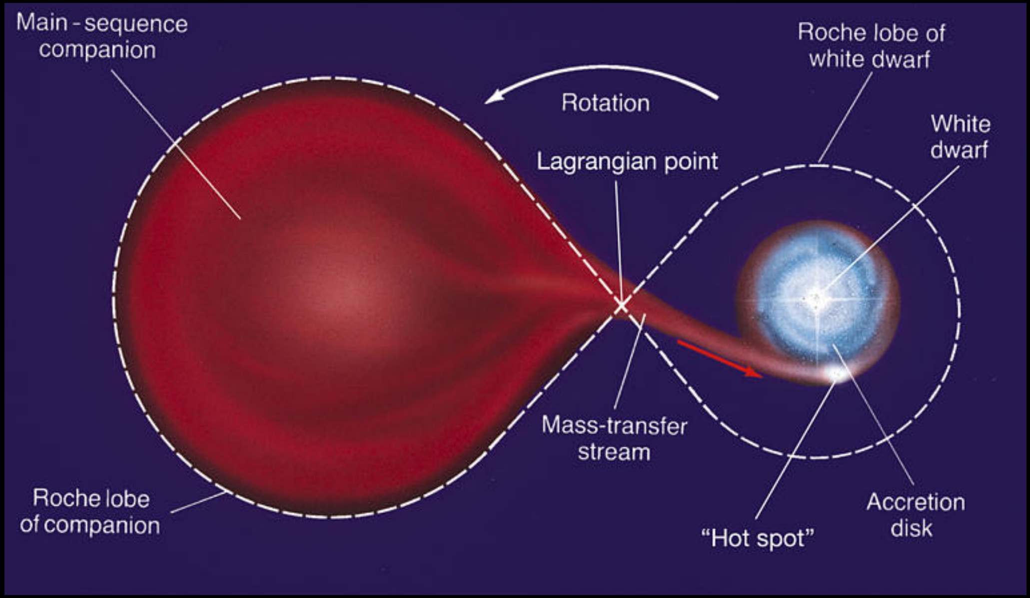
both stars fills their Roche Lobe

Semi-Detached binary:

one of the stars fills in its Roche Lobe

Roche Lobes

The star of the system which evolves second will fill in its roche lobe and since the stellar material at L1 is not longer bound to the star it can fall onto the companion.



Cataclysmic Variables

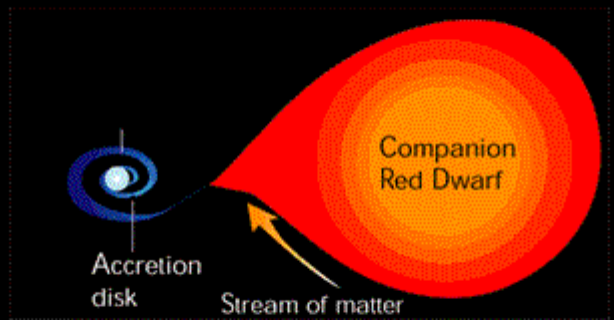
Semi-detached binaries in which the "receiving stars" are white dwarfs (WDs) are labelled as Cataclysmic Variables (CVs).

However CVs show a plethora of different phenomenology according to the nature of the "donor star". The targets of SWG4 are:

Classical Novae (CNe): when the donor star is a low mass MS star and the receiving star is a high (o relatively high) mass WD (0.8-1.2 $M_\odot$) and the stellar system is characterized by a relatively high M_dot (< ~10^{-9} $M_\odot$/yr)

Their outbursts exhibit amplitudes of the order of ~10-12 mag, and in some cases up to ~20. This fact makes CNe the most energetic events among CVs (~10^45 erg cfr. $10^{51/53}$ of SNe).

The Nova Outburst



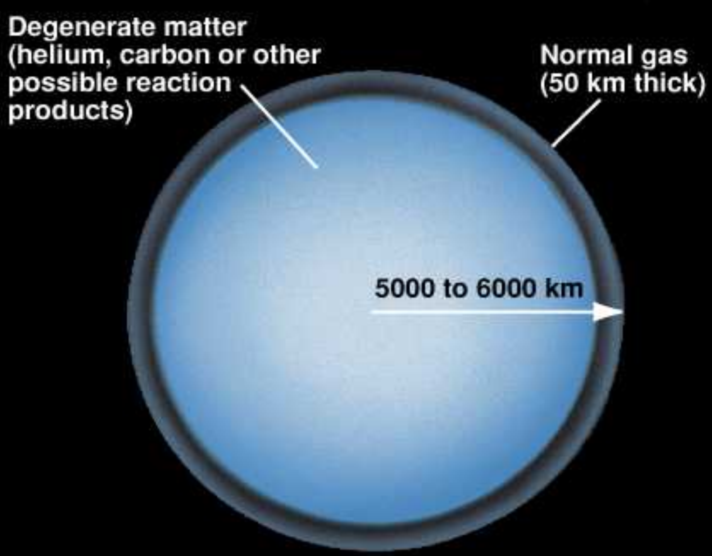
White dwarf siphons off matter from companion star, creating accretion disk.

When pressure at bottom of accreted layer (mostly H) is

$P > 10^{19}$ dyne cm^{-2}

→ Explosive H-burning
→ violent TNR
→ accreted shell ejected
(v ~ 1000-5000 km s^{-1})

$$\Delta m_{acc} \sim R^4_{WD}/M_{WD}$$



The strength of the outburst is primarily determined by the mass of the WD ('the more massive is the WD the more powerful is the outburst').

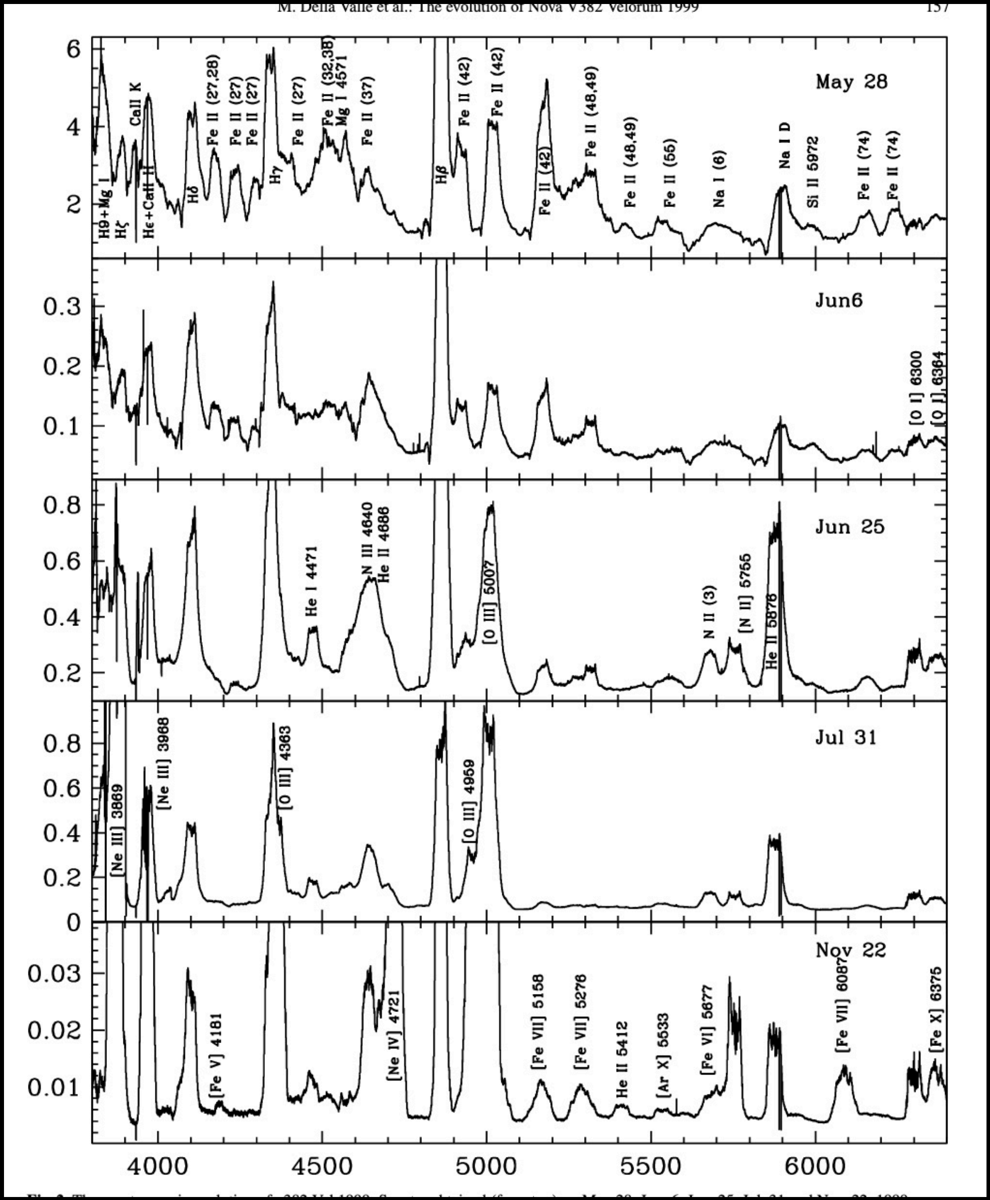
$$M_{B\,(max)} = -8.3 \times 10 \times \log M_{WD}$$

But this is true only at first order. Decades of investigations, mostly carried out on theoretical grounds (e.g Prialnik 1986, Prialnik & Kovetz 1995) have shown that the physical parameters of the outburst are also determined by the: Accretion rate; Temperature of the WD; Magnetic Field; Composition of the accreted material; Mixing Process between accreted envelope and underlying WD......

Optical/NIR photometry provides important information on the Nova speed which is related to the luminosity at max → mass of the WD.

All other parameters that I have mentioned in the previous slide can be investigated via spectroscopy, which allows the measurements of physical quantities that characterized the nova phenomenon, such as:

T , ρ and mass of the ejecta, chemical abundances of the ejecta → galactic nucleosinthesis, progenitors vs. environments (i.e. disk vs. bulge novae).



DV et al. 2002

Novae and nucleosynthesis

1 SN-*CC* x 100yr

~ 20 $M_{\odot}$ vs. 0.3 $M_{\odot}$

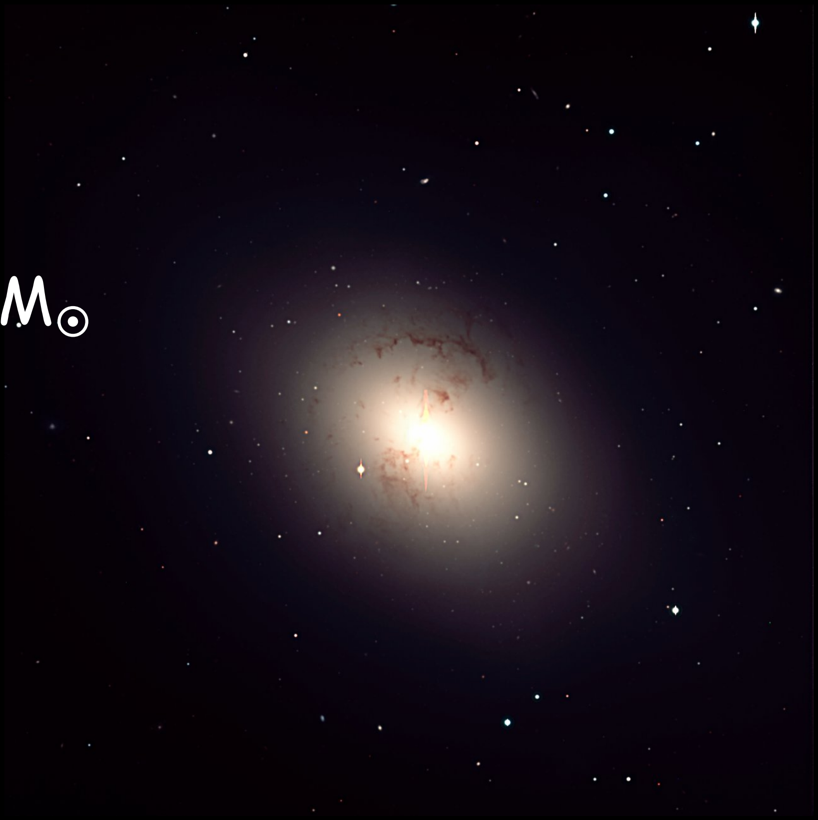
Only nuclei enriched in the nova ejecta by a factor ~100 can contribute significantly to the galactic nucleosynthesis

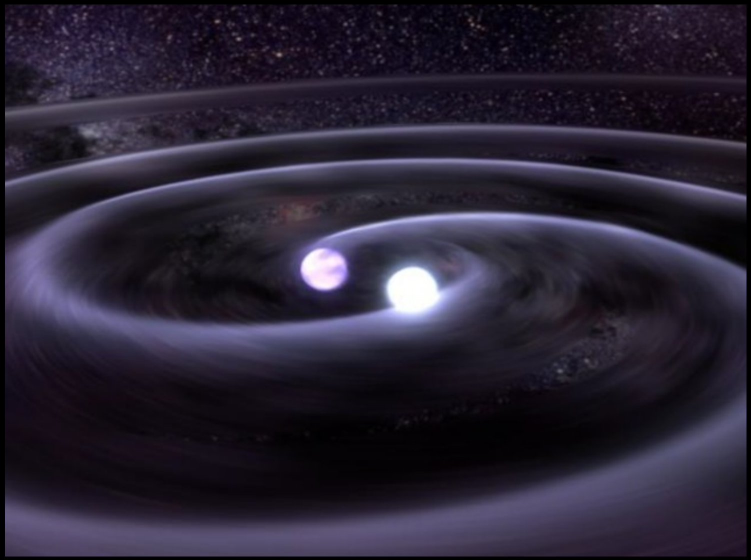
Novae can produce interesting concentrations of atomic species

(~ x 100 solar values)

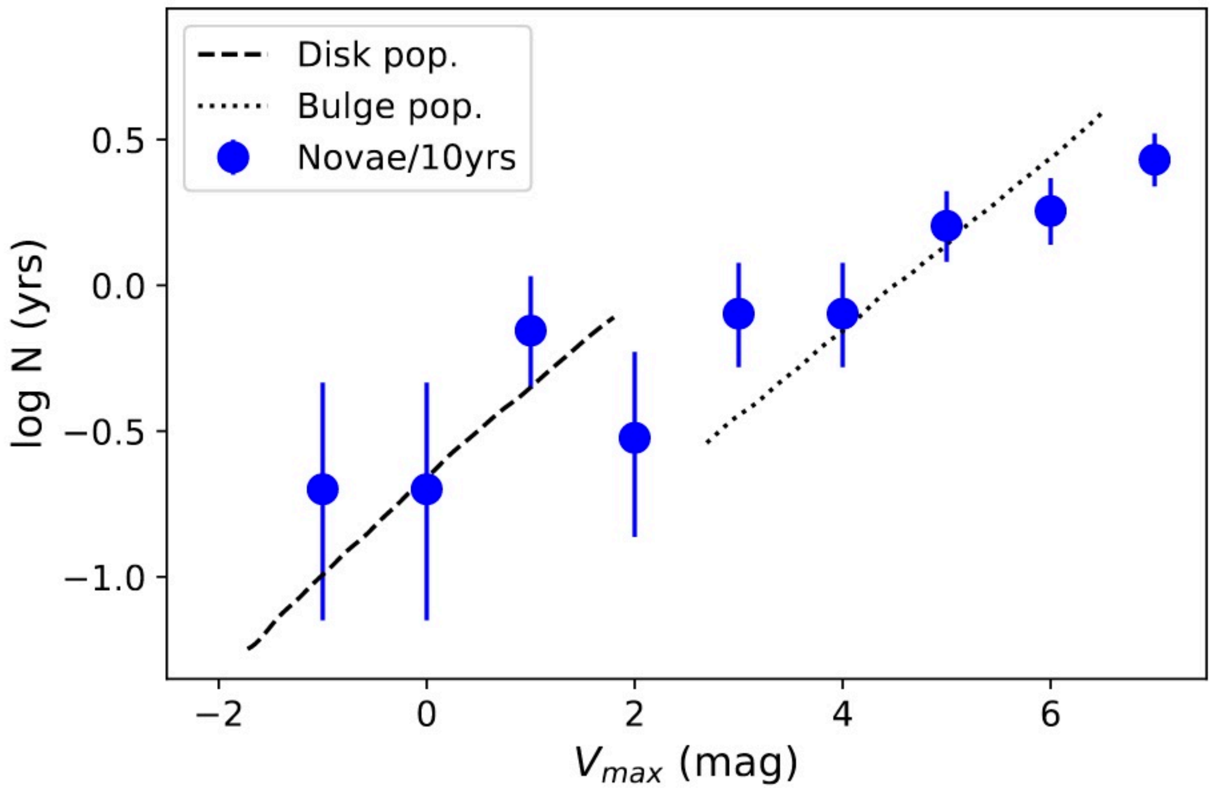
- ^{13}C; ^{15}N — Sparks, Starrfield, Truran (1978); Williams (1985);
- ^{7}Li — Arnould and Norghard (1975); Starrfield et al. (1978); Izzo et al. (2015);
- ^{22}Na; ^{26}Al — Hillebrandt and Thielemann (1982); Kolb and Politano (1997);
- Ne — Livio and Truran (1994);
- ^{7}Be — Izzo et al. 2018, Molaro et al. 2020

Only SNe-Ia ~ 1.4 $M_\odot$ vs. 0.3 $M_\odot$



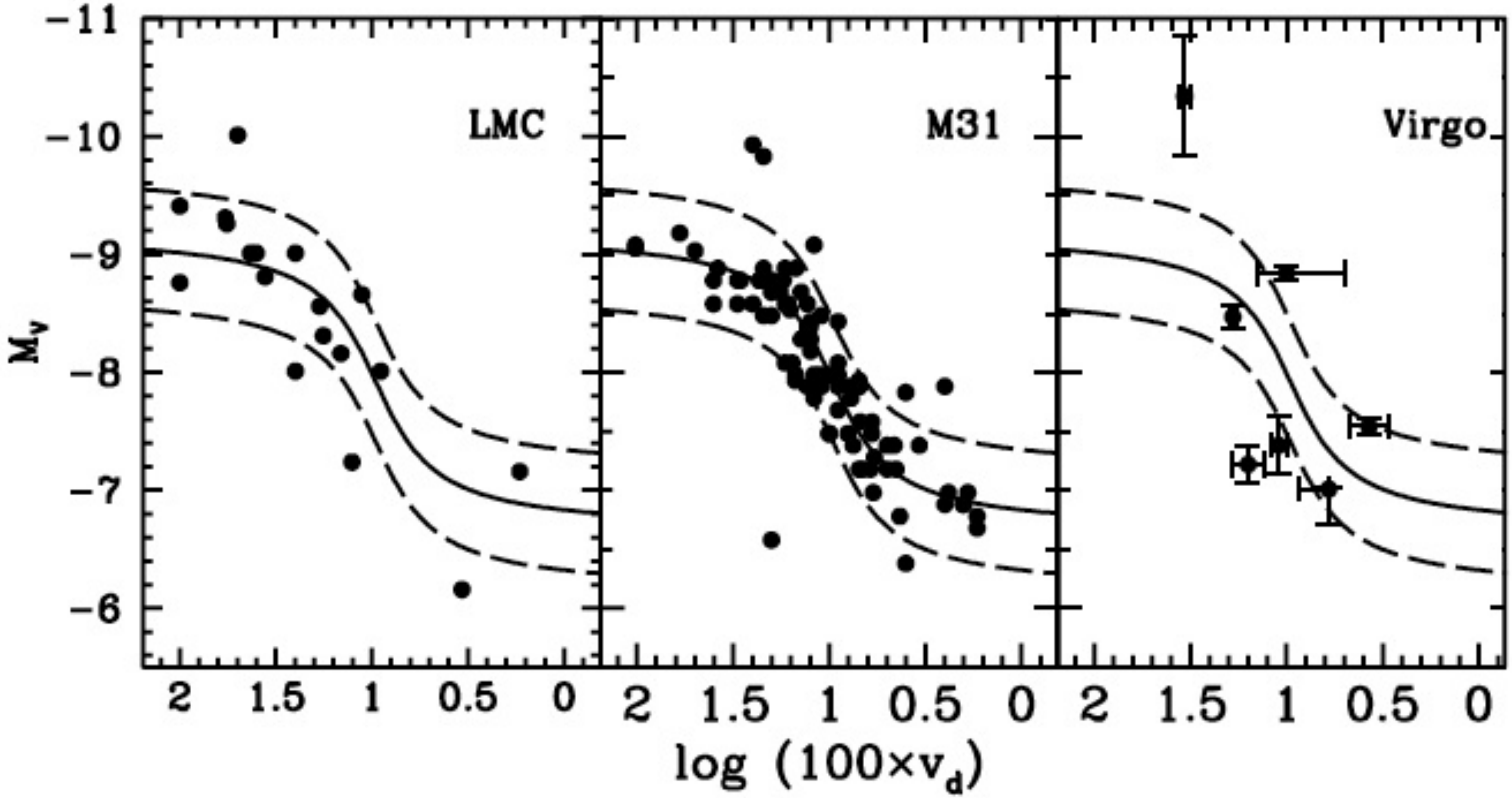


Nova explosion parameters vs. environments



DV & Izzo 2020

Nova explosion parameters vs. environments

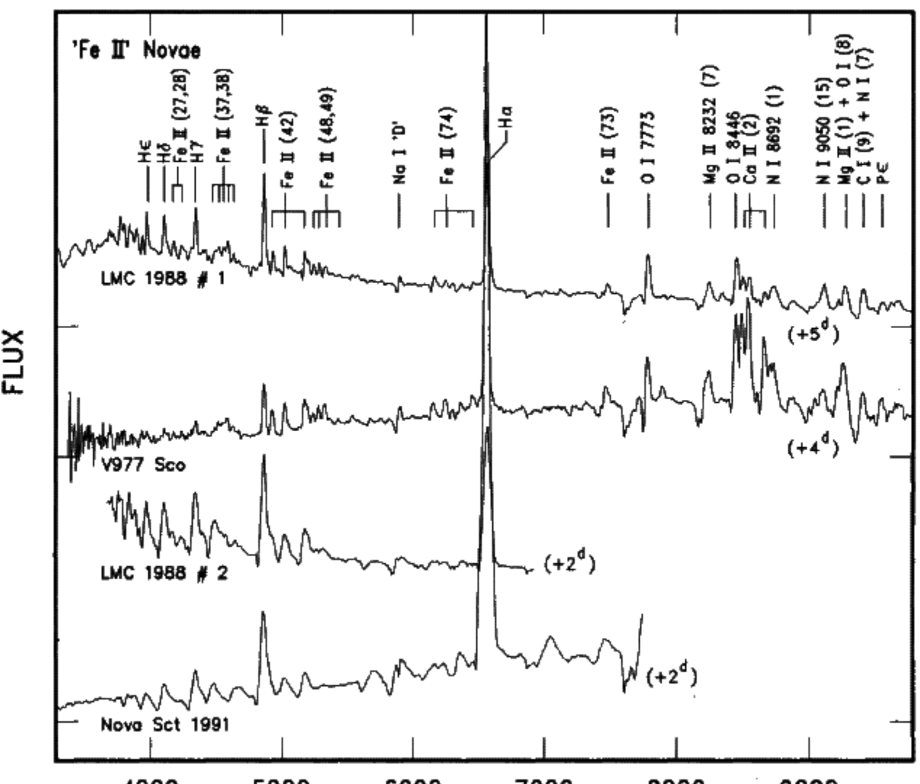


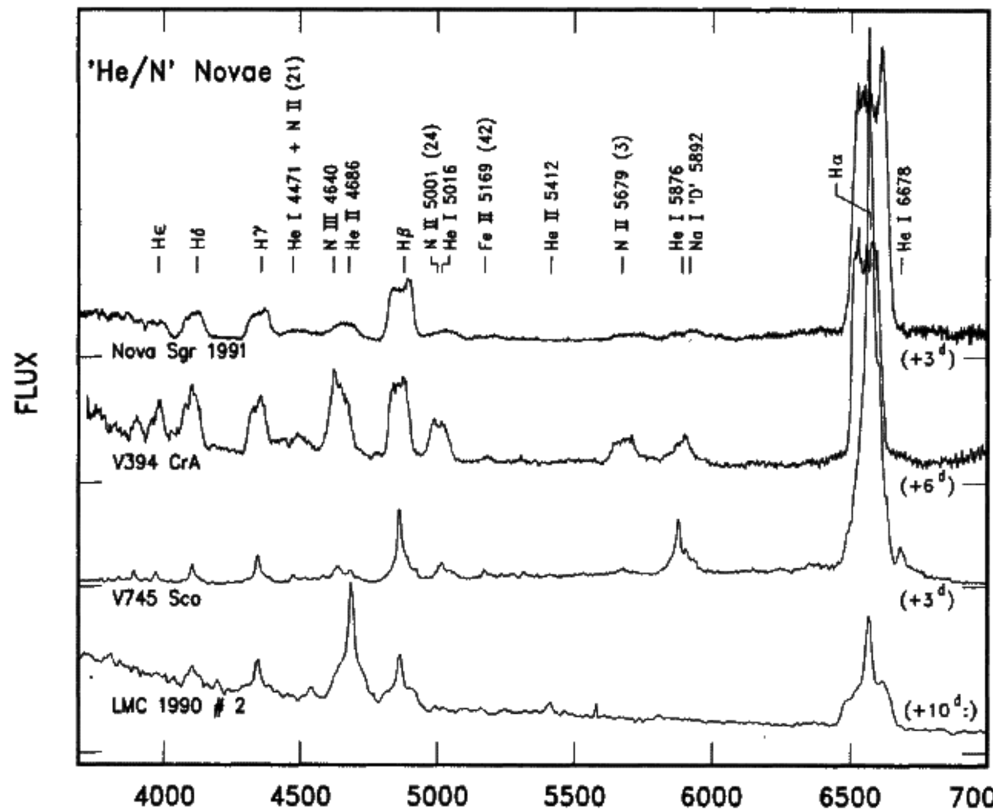
Disk Disk + Bulge only Bulge

Mass of the WD →

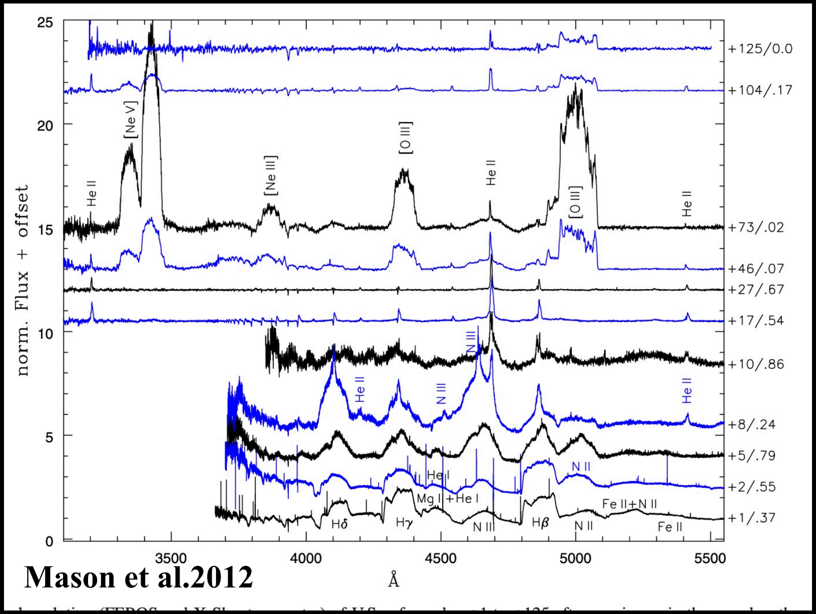
Williams 92

'Fe II' Class	'He/N' Class
Narrower lines (HWZI < 2,500 km/sec)	Broad lines (HWZI > 2,500 km/sec)
Frequent P Cygni absorption profiles	Flat-topped line peaks with little absorption
Slower spectral evolution (weeks)	Faster spectral evolution (days)
Initial forbidden lines:	Initial forbidden lines:
N and O auroral transitions	[Fe X] λ6375 and [Fe VII] λ6087
[O I] λ6300	[Ne III] or [Ne V]
Low ionization fluorescence lines in red	

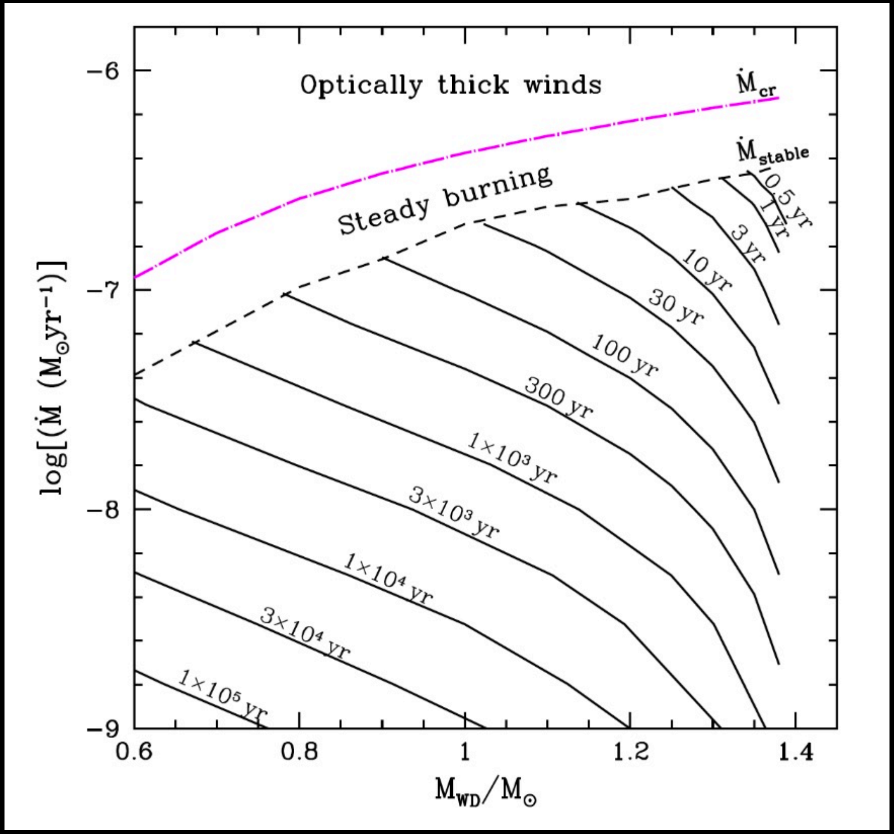


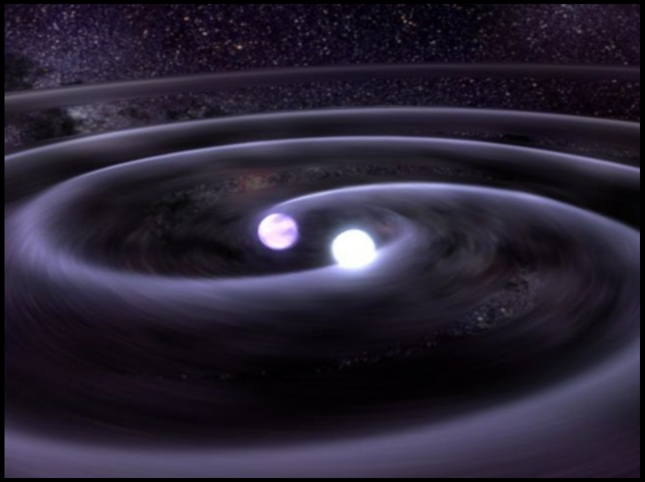


Recurrent Novae (RNe): when the donor star is a MS star or a sub-giant or a giant and the receiving star is a very high mass WD (1.3 $M_\odot$) , close to the Chandrasekhar limit, and the stellar system is characterized by a very high M_dot (< ~$10^{-7/8}$ $M_\odot$/yr)

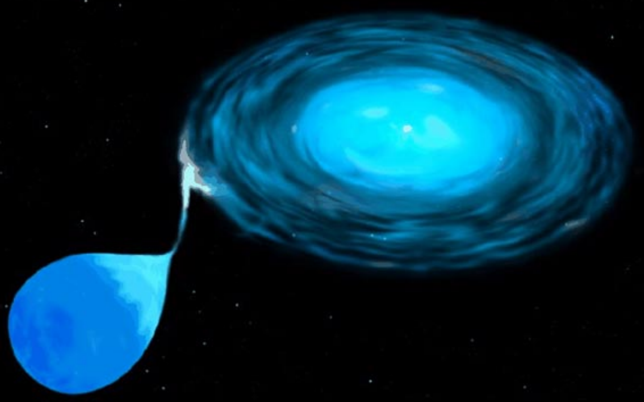


Mason et al.2012





VS

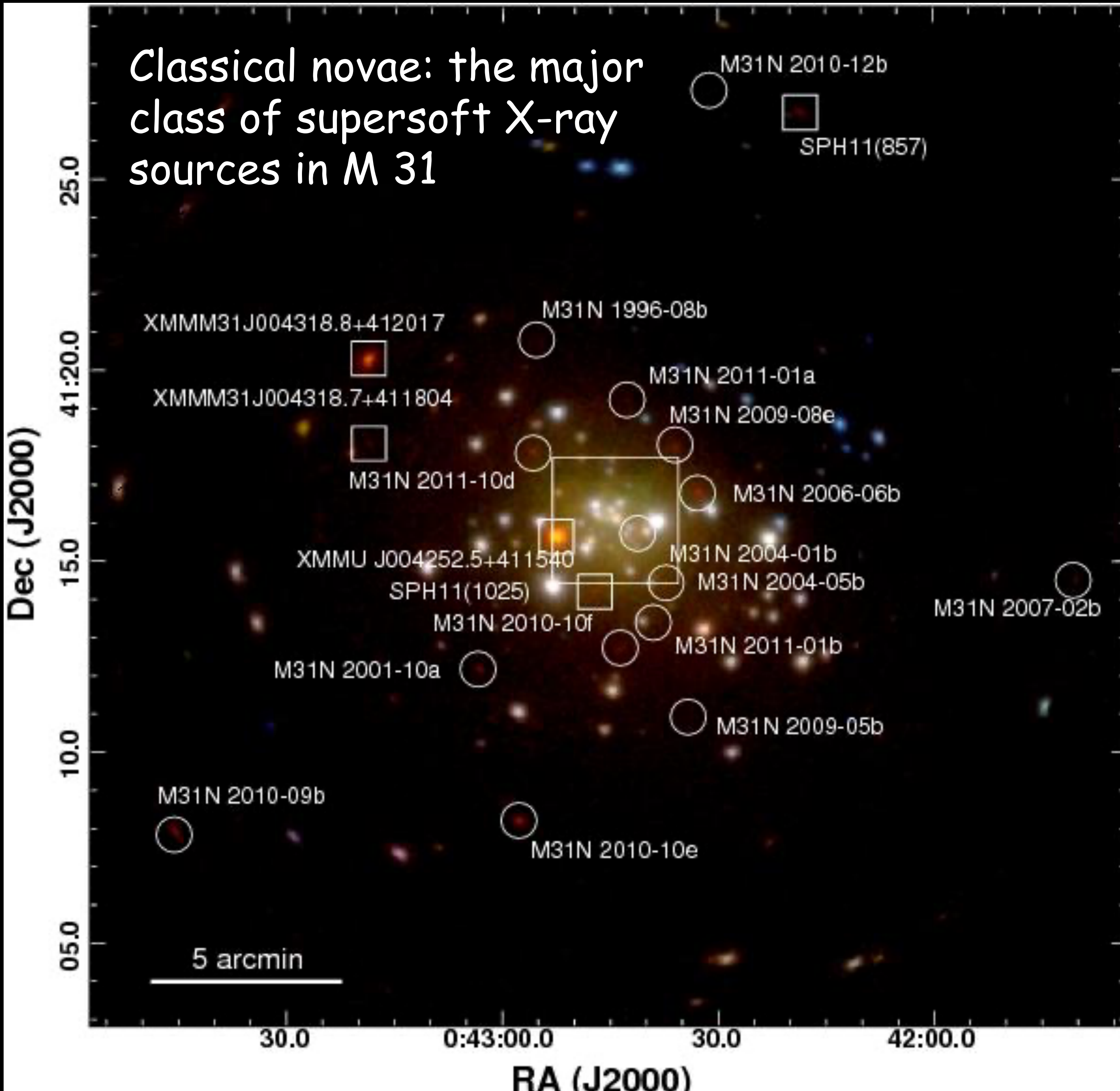


Double degenerate: where two C-O WDs in a binary systems make coalescence as result of the lost of orbital energy for GWs

Single Degenerate i.e.Cataclysmic-like systems:

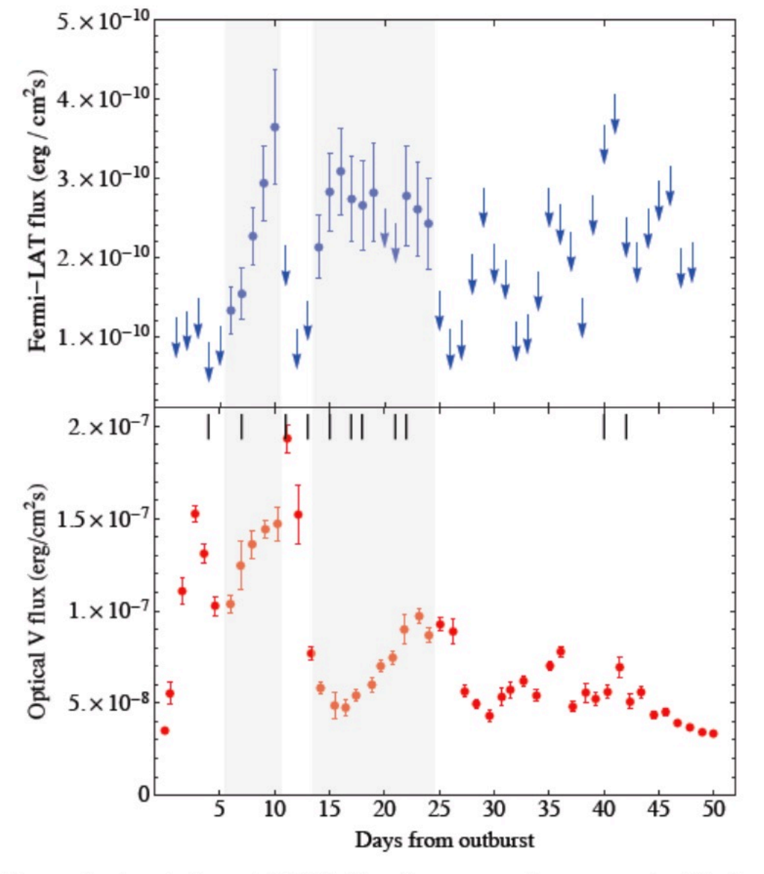
Recurrent Novae (WD+giant, WD+He)

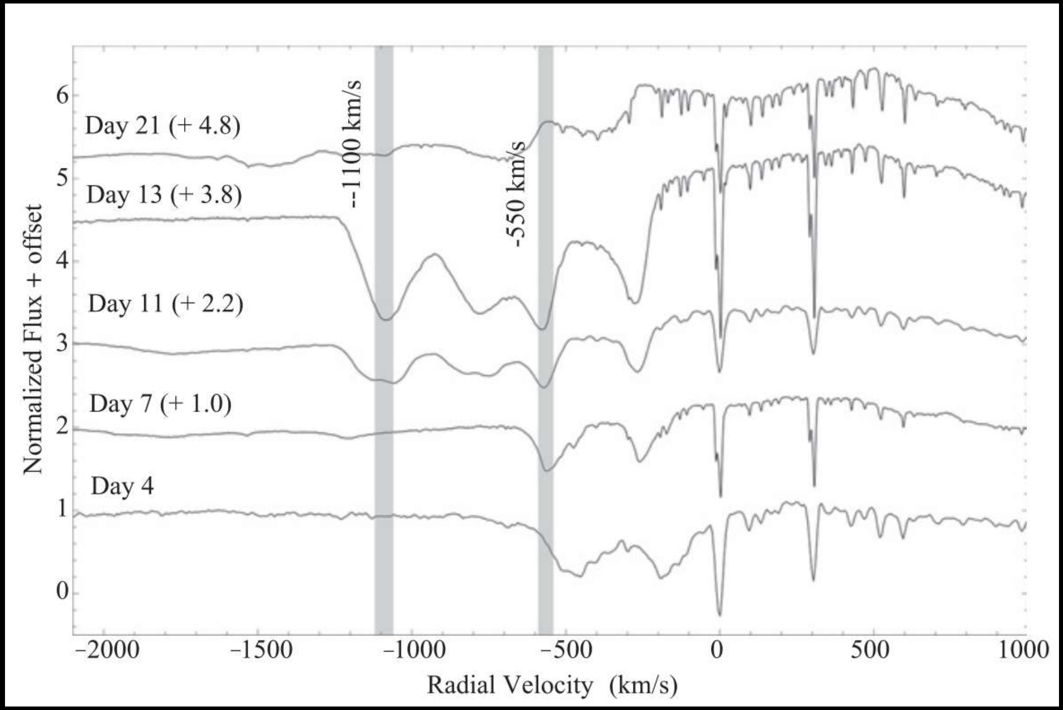
Symbiotic systems (WD+Mira or red giant)



Henze et al. 2014, 2011, 2010

From 2014, CNe were definitely revealed **as a new class of gamma-ray sources** (Ackermann et al 2014, see also Abdo et al. 2010). To date about a dozen of novae and symbiotic systems have been detected in gamma



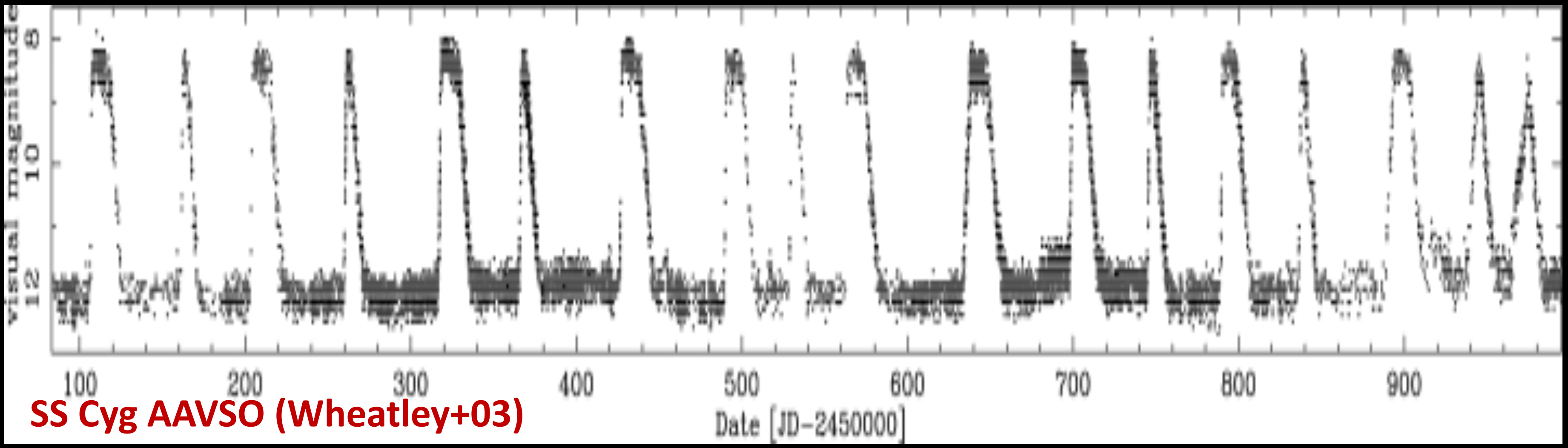


Optical emission of V1369 Cen (lower panel) compared with the emission detected by the Fermi-LAT detector (upper panel, Kovacevic et al. 2019) . Grey regions mark the time intervals corresponding to a positive detection of Fermi-LAT.

Dwarf Novae (DNe): when the donor star is a low mass MS star and the receiving star is a low mass WD and the stellar system is characterized by low M_dot (<~ 10^{-11} $M_\odot$/yr)

- *Optical Brightening (2-5mag)*

- *Duration ~ days-week(s)   &   Duty cycle ~ months to yrs*



SS Cyg AAVSO (Wheatley+03)

CNe vs. DNe

	Novae	**Dwarf Novae**
Amplitudes	$\Delta V \approx$ 10-15mag	$\Delta V \approx$ 2-6mag
Outb. Duration	years	days-weeks
Recurrence	10^{3-5} yrs (CNe) 10-100yrs (RNe)	Majority Weeks-years
Energetics	$10^{38} - 10^{39}$ erg/s	$10^{34} - 10^{35}$ erg/s
Mass ejection	$M_{out} \approx 10^{-7} - 10^{-4}\ M_{\odot}/yr$ $V \approx$ a few 10^2-10^3 km/s	$M_w \approx 10^{-11} - 10^{-8}\ M_{\odot}/yr$ $V \approx 1\text{-}4\times10^3$ km/s
Mechanism	TNR onto the WD	Disc and/or mass transfer rate instability

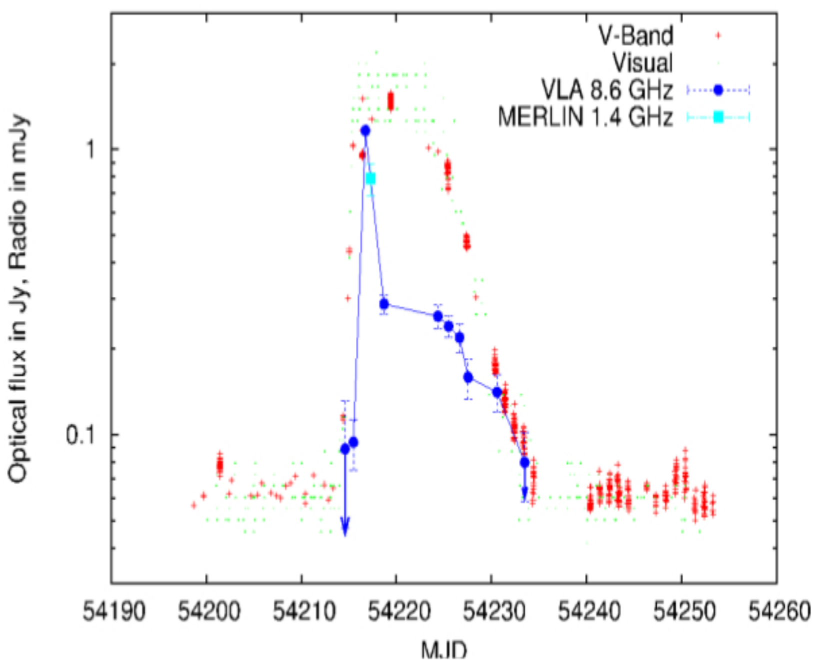
Outburst mechanisms are different

Outflows in Dwarf Novae

CVs believed to be unable to power jets !

but………

SS Cyg   2007 Outburst



(Koerding et al. 2008, Science)

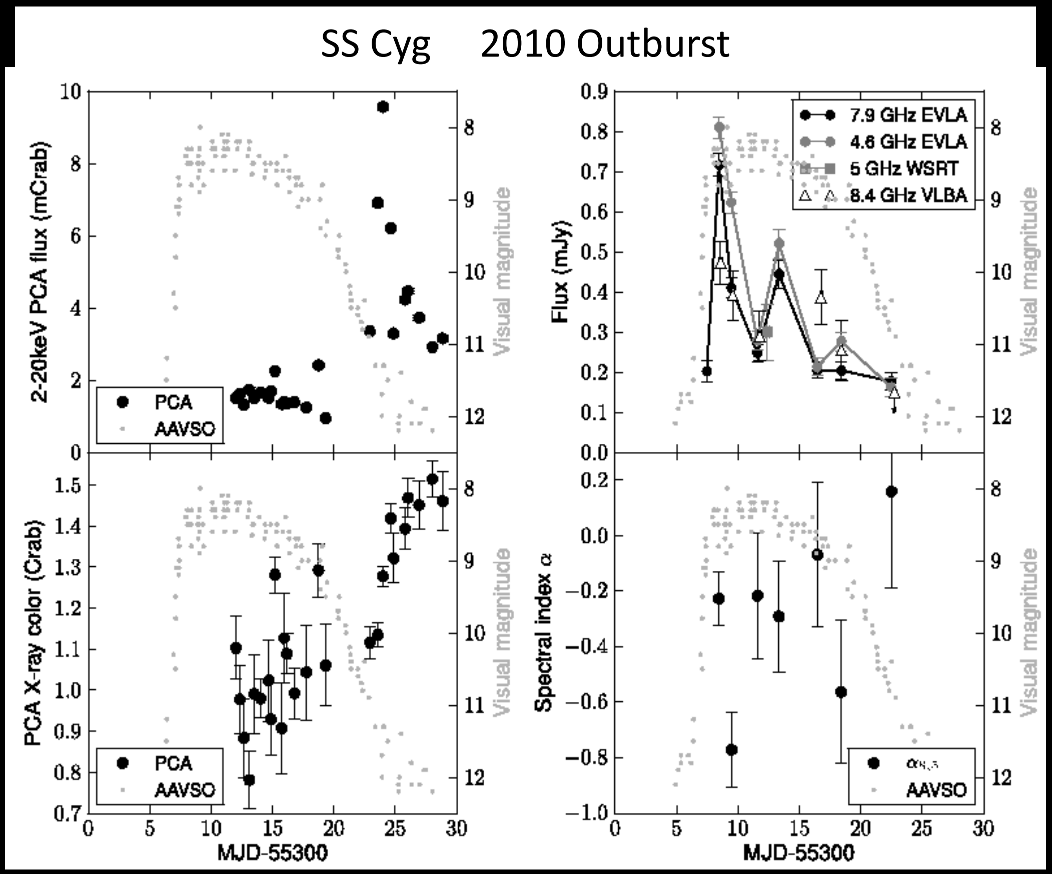
- *Radio detections in Outburst*
- *Spectrum $S_\nu \approx \nu^{\alpha}$; $\alpha \approx 0.3$*

  → *Synchrotron emission*

Outflows in Dwarf Novae

CVs believed to be unable to power jets !

but………



- *Confirmation in other outbursts*
- *Radio onset with optical rise*
- *Similarities with NS & BH LMXBs, Common jet-launching process ?*

Jet in Dwarf Novae ?

(Miller-Jones et al. 2011; Russell et al. 2016)

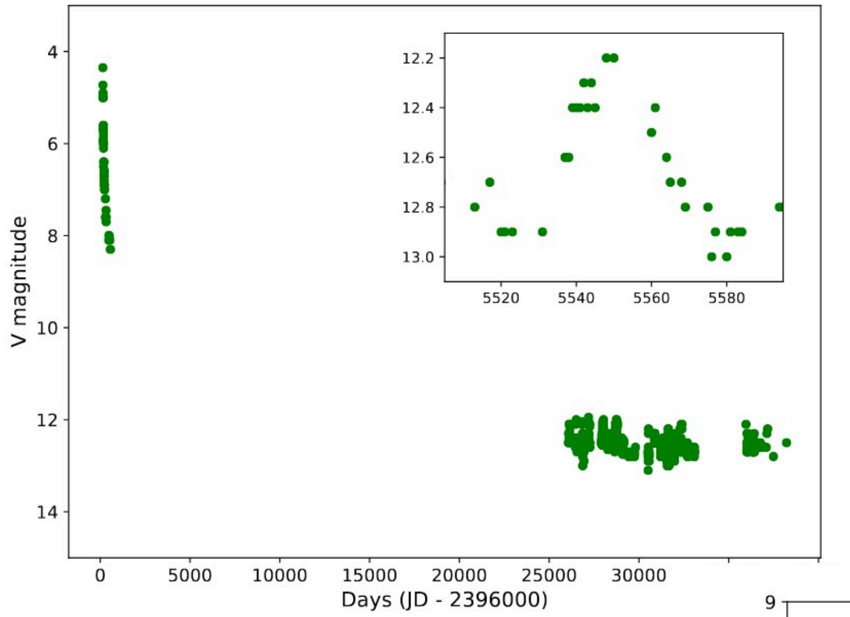
Linking Novae - Dwarf Novae

Increasing number of Dwarf Novae found to show Nova shells

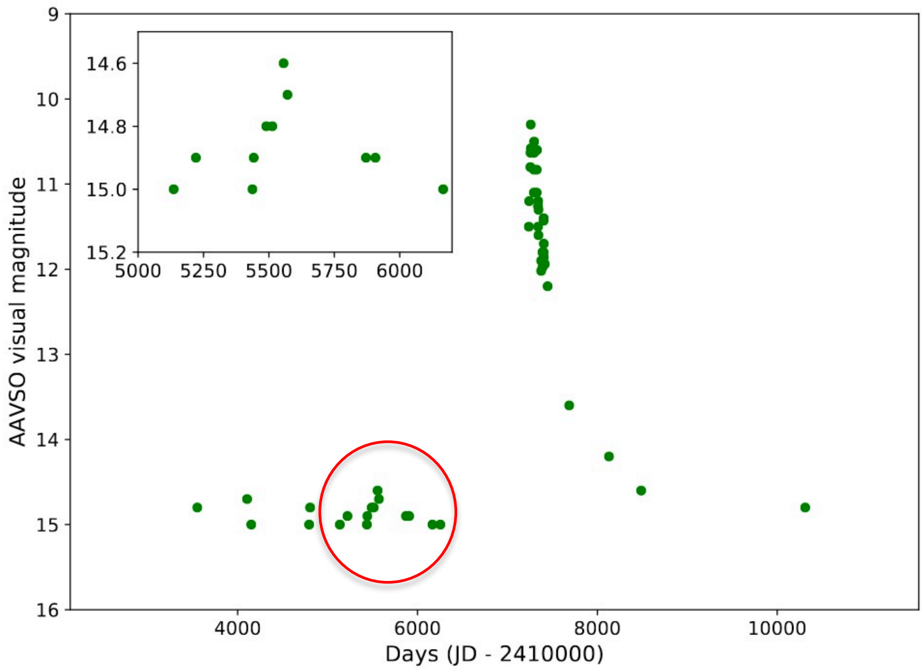
An ancient nova shell around the dwarf nova Z Camelopardalis

Michael M. Shara, Christopher D. Martin, Mark Seibert, R. Michael Rich, Samir Salim, David Reitzel, David Schiminovich, Constantine P. Deliyannis, Angela R. Sarrazine, Shri R. Kulkarni, Eran O. Ofek, Noah Brosch, Sebastien Lépine, David Zurek, Orsola De Marco & George Jacoby

Nature **446**, 159–162(2007) | Cite this article



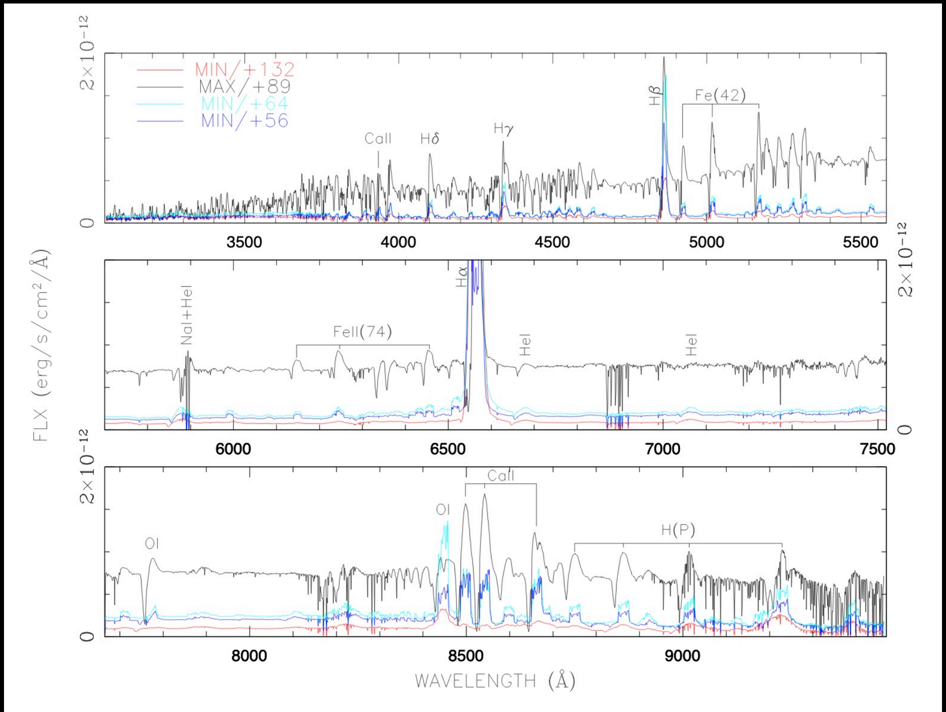
DN activity in pre-Nova and post-Nova stages



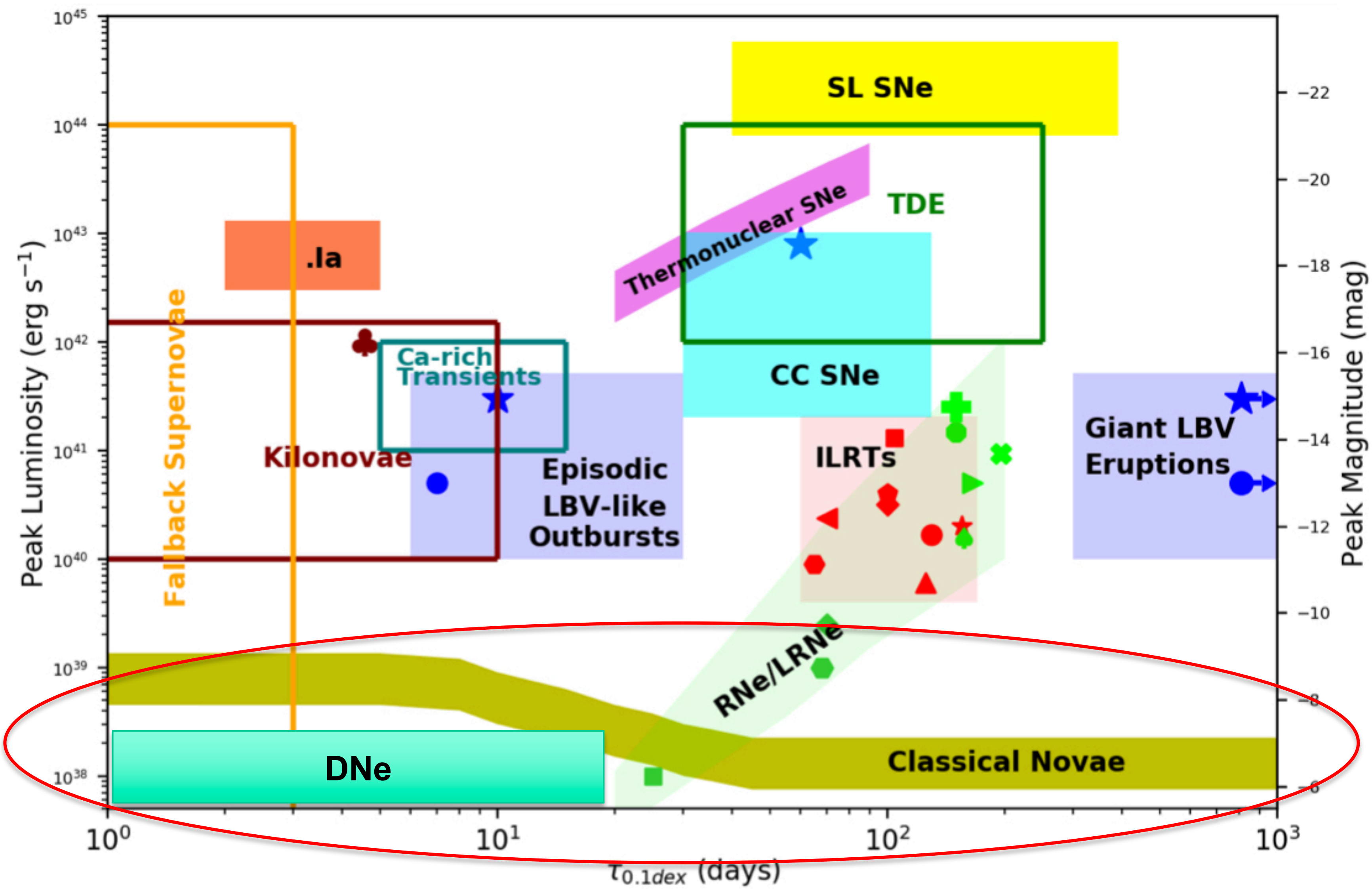
DV & Izzo 2020

Nova Impostors (NIs): is a very heterogeneous class of objects which includes "nova-like" events and they are often labelled as "luminous red novae" (see for recent cases Pastorello et al. 2020) .

This "Impostors" class includes also peculiar events such as the Sakurai object or v605 Aql (1921) or the more recent ASASSN-17hx (Mason et al. 2020). This case is particularly interesting:



The mass of the ejecta is ~ 10^{-3} $M_\odot$


SL SNe
TDE
Thermonuclear SNe
.Ia
CC SNe
Ca-rich Transients
Fallback Supernovae
Kilonovae
Episodic LBV-like Outbursts
ILRTs
Giant LBV Eruptions
RNe/LRNe
DNe
Classical Novae
Peak Luminosity (erg s^{-1})
Peak Magnitude (mag)
$\tau_{0.1dex}$ (days)
10^{45}
10^{44}
10^{43}
10^{42}
10^{41}
10^{40}
10^{39}
10^{38}
10^{0}
10^{1}
10^{2}
10^{3}
−22
−20
−18
−16
−14
−12
−10
−8
−6

Summary of science cases for CVs

Spectroscopic observations are relevant:

i) to assess the contribution of nova ejecta to the chemical evolution of the host galaxies;

ii) to investigate the connection between properties of CNe/ RNe outbursts vs. environments (by studying the spectroscopic properties of Novae produced in different parent stellar populations, e.g. disk, bulge or halo);

iii) to study the intimate relation between DNe and CNe (e.g. hibernation scenario) through spectroscopic observations of old/post-novae at minimum

iv) to provide the synergy between optical and high energy (X-ray and Gamma-ray) observations;

v) to trace accretion/outflows in DNe, through time-resolved spectroscopy over a broad range of wavelengths;

vi) to explore the disc-jet connection for DNe

vii) to study the possible link between the progenitors of CNe and Supernovae-Ia; (e.g. mass of CN ejecta vs. mass of RN ejecta → is the WD eroded after each burst? Or is increasing in mass ?)

viii) to provide the first systematic study of Nova Impostors aimed at clarifying if we are observing a new class of transients or we are just observing objects belonging to an heterogeneous family of stellar explosions due to the weird nature of the donor or thermal pulse of a post-asymptotic giant branch star which undergoes a He-flash events, a merger event that is the merger of two main sequence stars, or planetary capture event in which the Impostor may have swallowed its giant planets; or a common envelope event, in which the receiving object is engulfed into the envelope of the donor, then the two objects spiral towards one another inside this common envelope which is expelled as soon as the two objects get merged.

Synergies with SKA, LSST, Swift, Fermi, XMM, Chandra… are essential

Requested time in the 5yr SOXS time-frame:

CNe and RNe
Requested time 6h per object (classification and follow-upon average): 4 galactic CNe/RNe/yr; 2 Magellanic CNe/RNe/yr.
TOTAL TIME: 180h

DNe and Novalikes:
Requested time per 6 objects (3 DNe+3 Nova-like)
TOTAL TIME: about 48h

Nova Impostors
Requested time 6h per object, 3 objects/yr
TOTAL TIME: about 90h

Objects at minimum light a dozen of objects/yr, about 1.5h per target
TOTAL TIME: about 75h

Therefore our request is a grand total of 450h over 5yrs (including 15% overheads) that is 90h/yr (~ 13 nights/yr, for a 7h night).