Classical and Recurrent Novae are Planetary Nebulae in Fast Forward AND Their Ejecta are Neither Spherical Nor Uniformly Filled

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(no grad student or postdoc was harmed in this study- yet)

Conclusions (just in case I get cut off early)

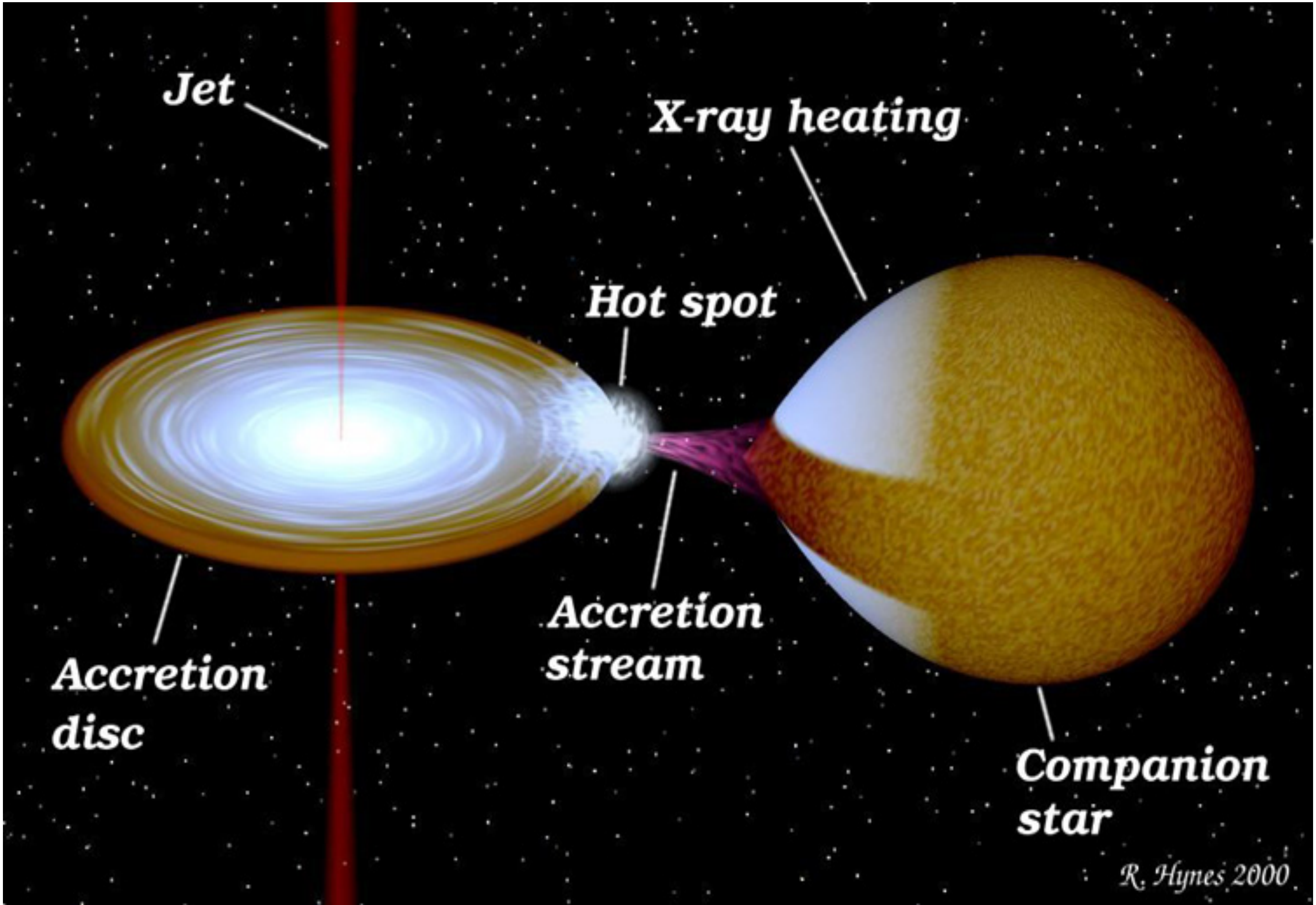
1) A nova outburst occurs in a binary system and is inherently asymmetric
2) The outburst properties depend on the viewing angle (pole on or equatorial).
3) Most studies have assumed that Classical and Recurrent Novae ejected gases are spherical and expanding in a Hubble flow (velocity increasing with radius)
4) But high resolution imaging shows that the material is far from spherical. (HST, Spitzer, LBT, VLT)
5) Spectroscopic studies show that the material is probably expanding in bi-polar jets or flows
6) The Maximum Magnitude Rate of Decline relationship (MMRD) is commonly used to obtain distances to Classical (or Recurrent) Novae
7) It assumes a single relationship between the peak brightness and rate of decline
8) This cannot be true because there are 5 parameters that affect the properties of the outburst.
9) Therefore, using it to get the distance to a single nova is wrong

THE CLASSICAL NOVA OUTBURST

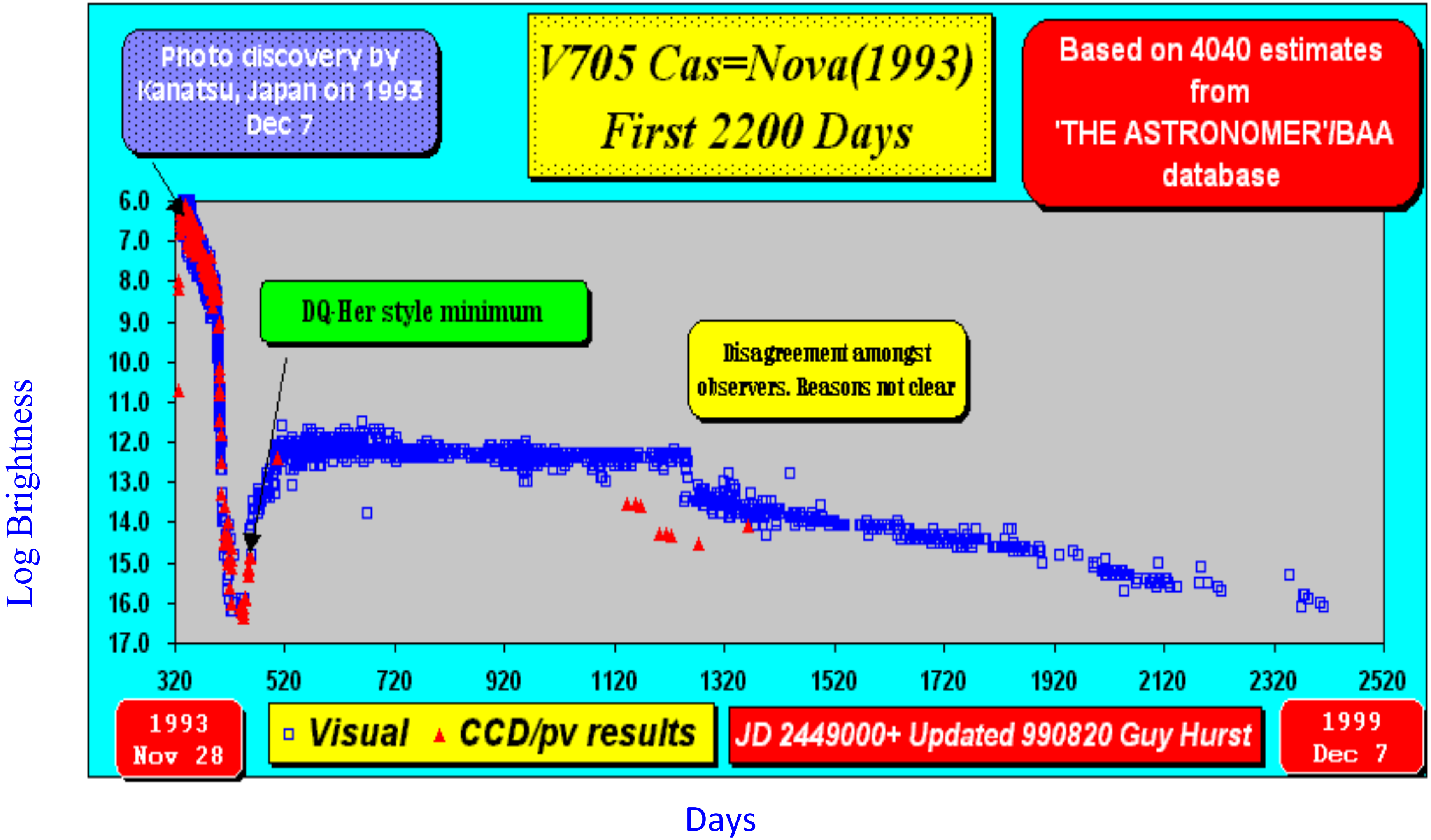
Degenerate Dwarfs Behaving Badly:

- Lasts about 1 year and radiates $\sim 10^{45}$ ergs
- Peak Luminosity ~ L_{Edd} **exceeds** L_{Edd} in the fastest novae.
- Ejects about 10^{28} to 10^{29} gm (QU Vul ejected about 10^{30} gm)
- Ejects at speeds from ~300 km/sec to 7000 km/sec (QU Vul)
- Abundances of ejected gases far from solar
  - Helium is **always** enriched
- Two composition classes:
  - Carbon-Oxygen Oxygen-Neon (Lots of Neon)
- A Class of novae that is not ejecting any hydrogen -mostly He and C
  - V445 Pup
- One recent CN occurred inside a Planetary Nebula Shell

Where Does the Explosion Occur?

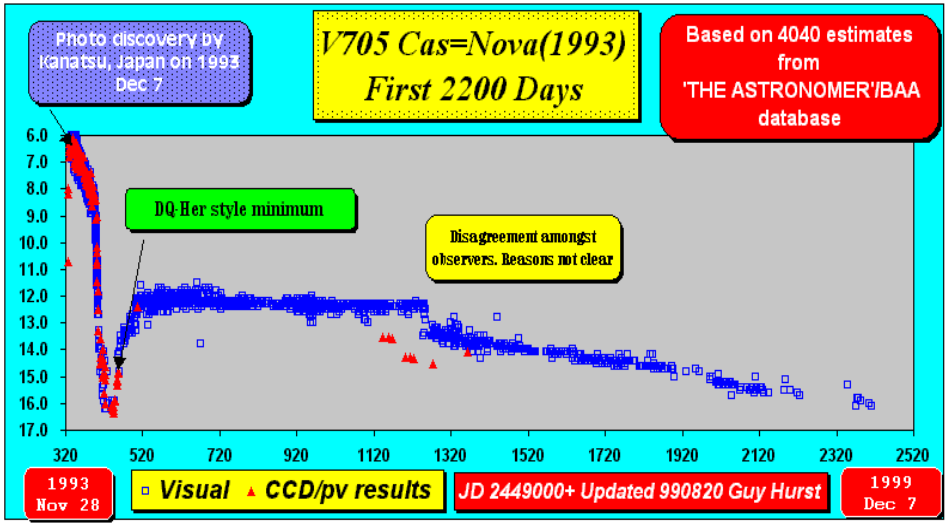


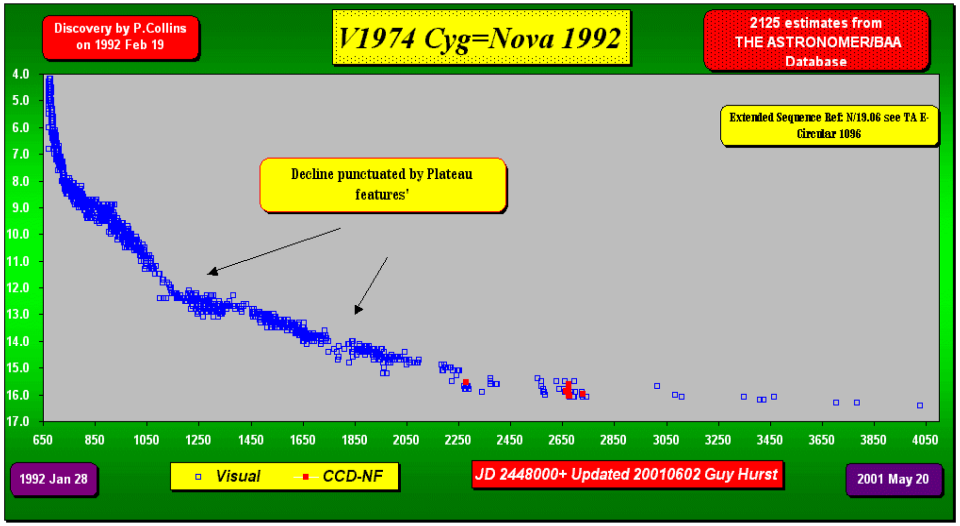
We Follow the Light Curve:

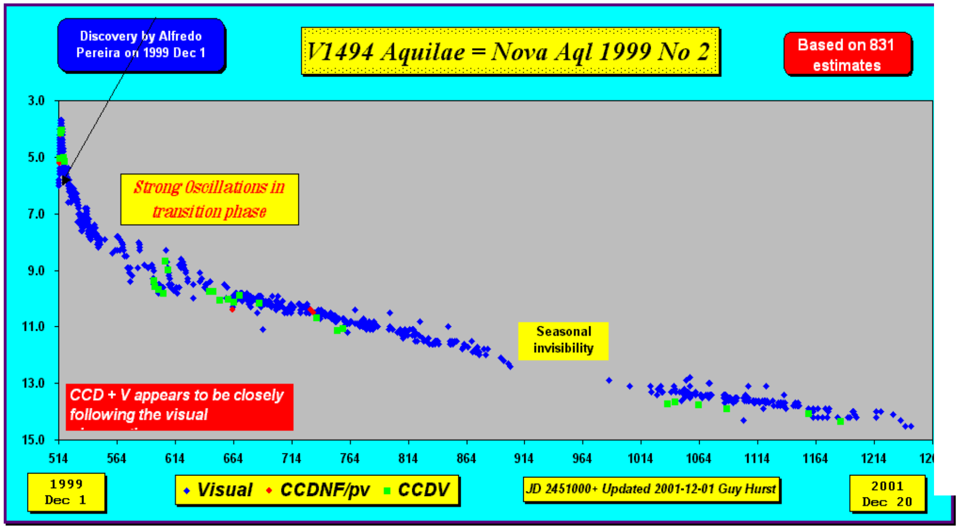


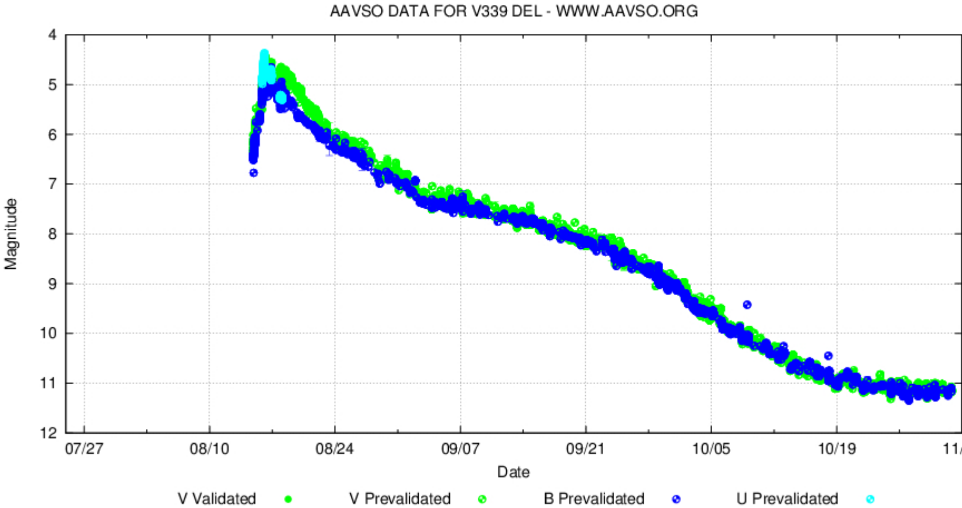
(Outburst occurs on a Grad student or Post Doc time scale NOT tenured professors {like PNe})

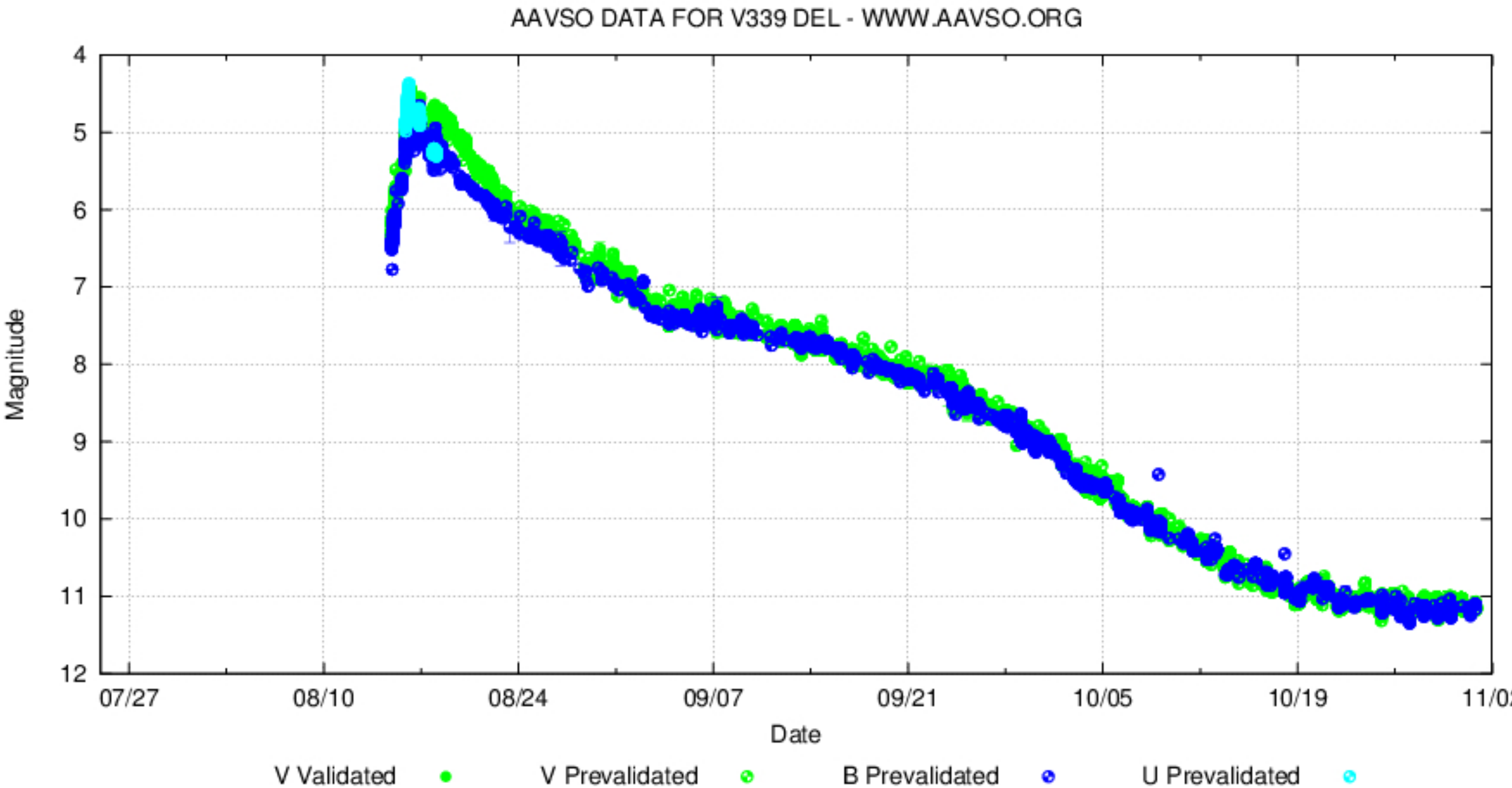
Novae Do Not All Evolve in the Same Way:









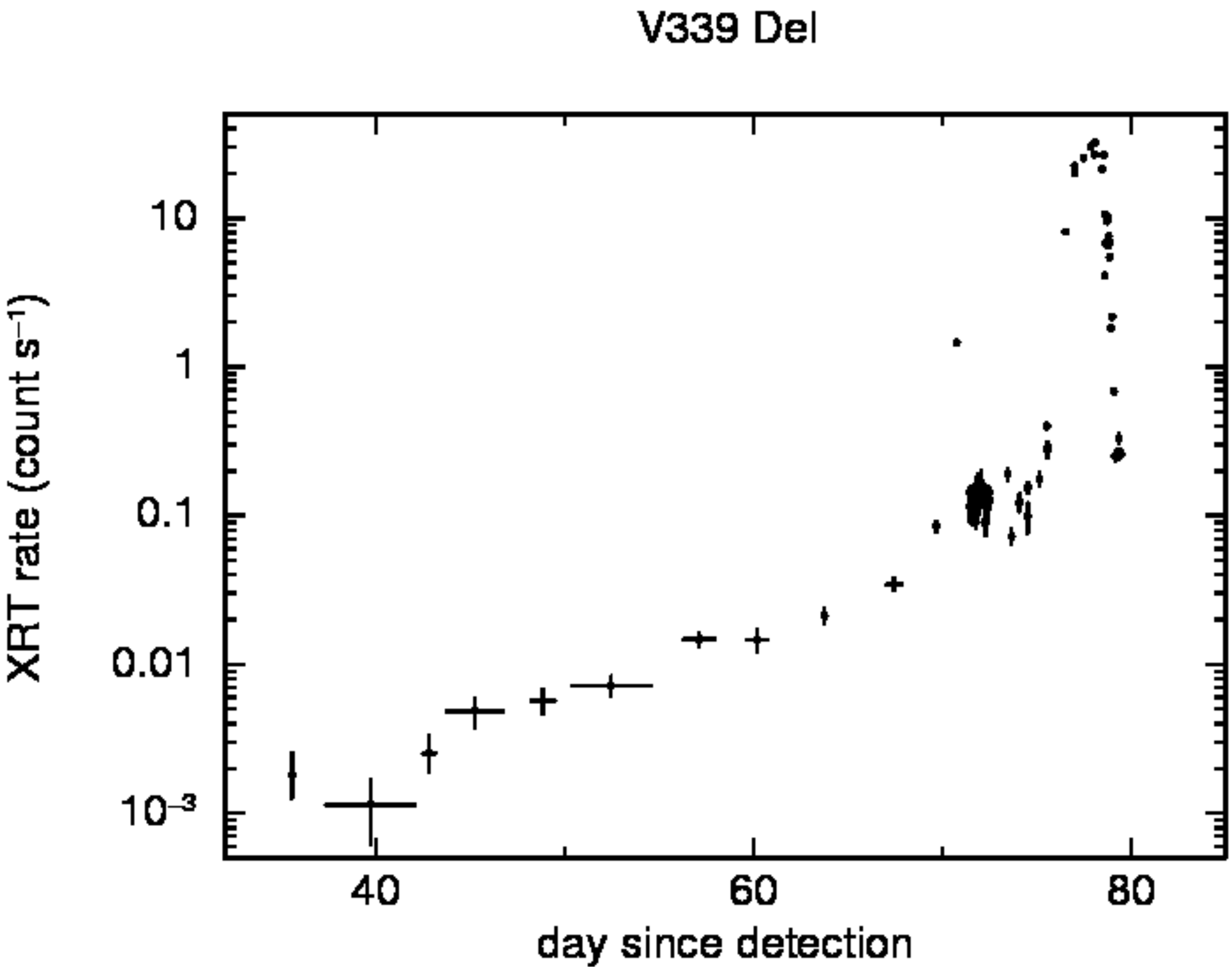


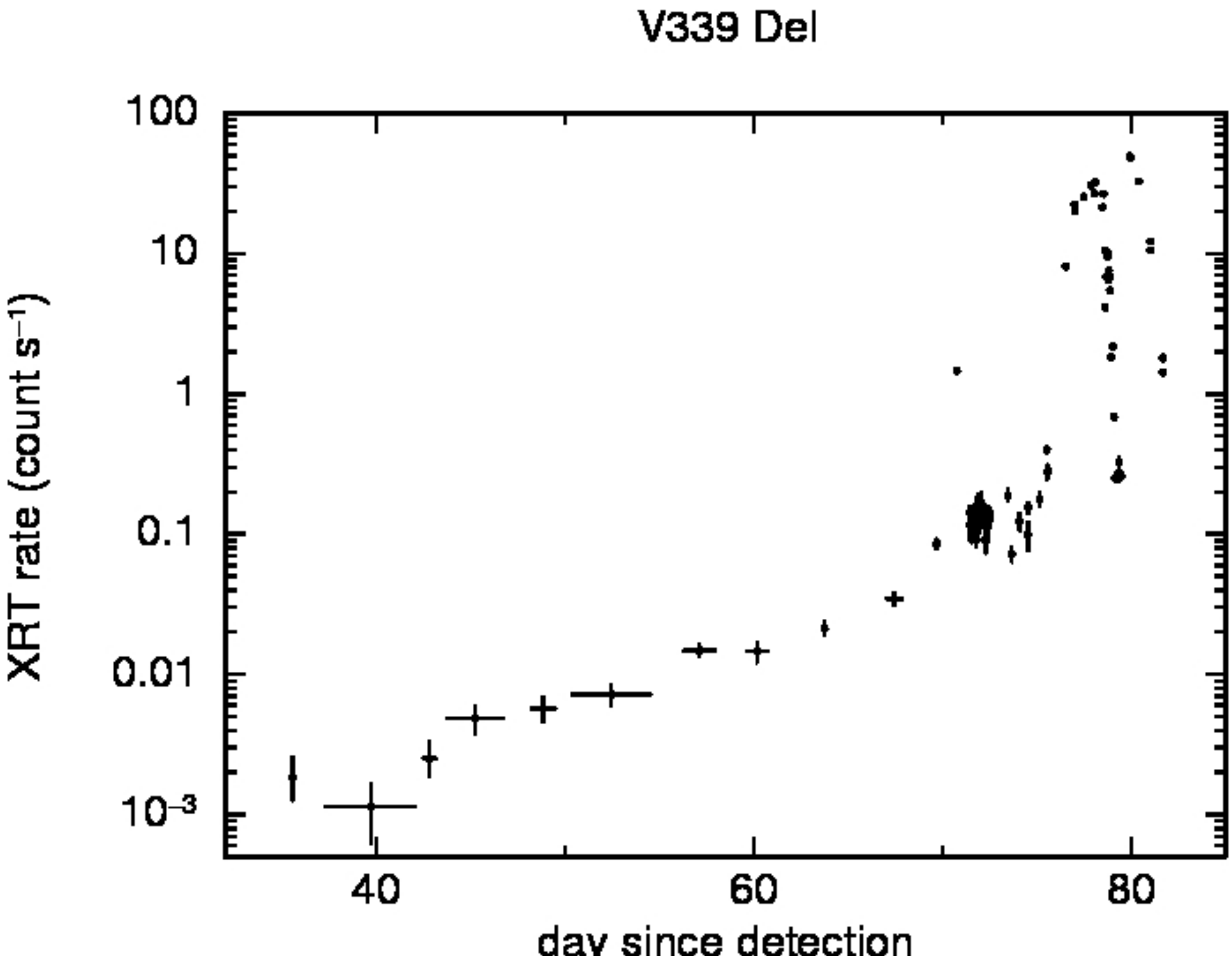
Nova Del 2013 the 4th nova detected in γ-rays by FERMI/LAT

No sign of dust formation as of November 1, 2013:

The first CO nova to be seen as a Super Soft Source (Kim Page et al.)

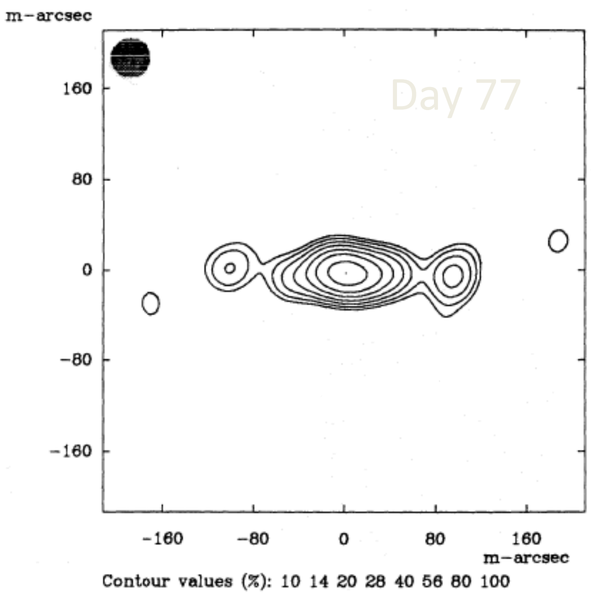
Kim Page et al. (Nov 1, 2013) [counts below 0.5 keV]

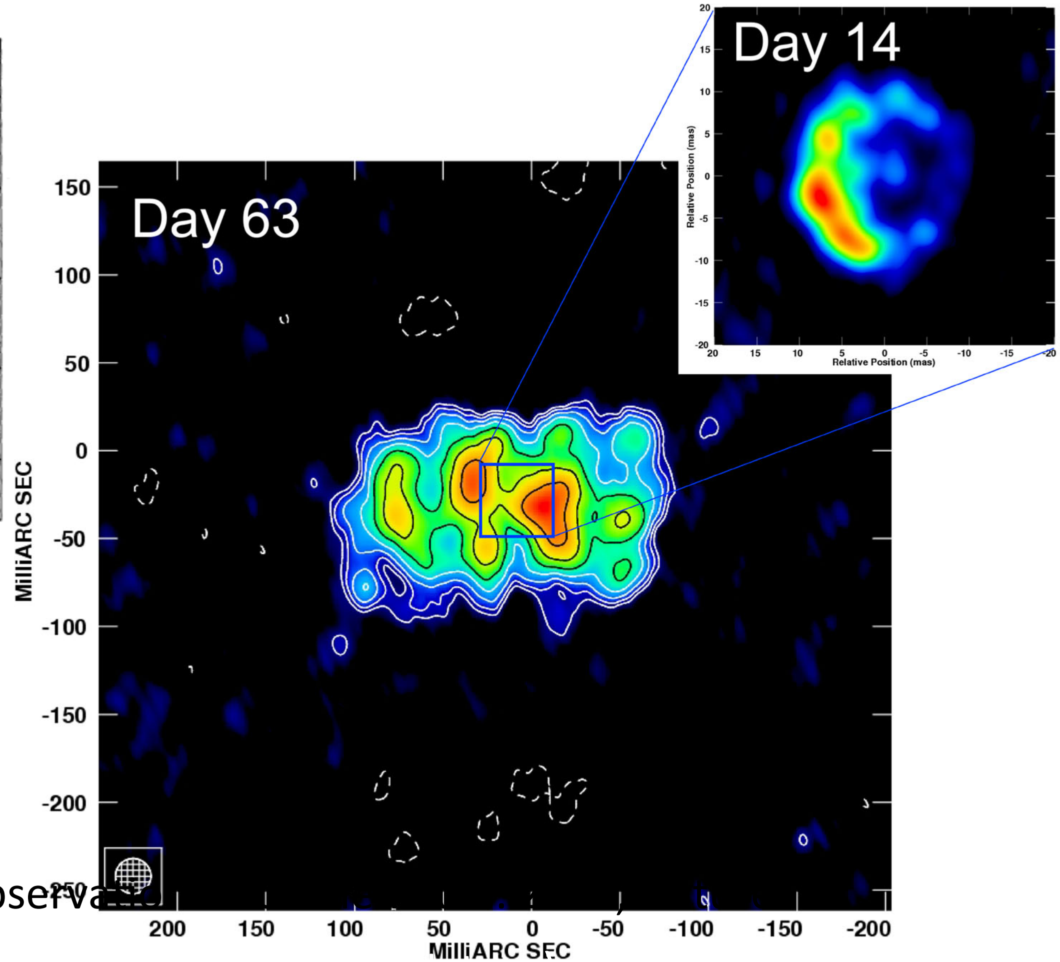




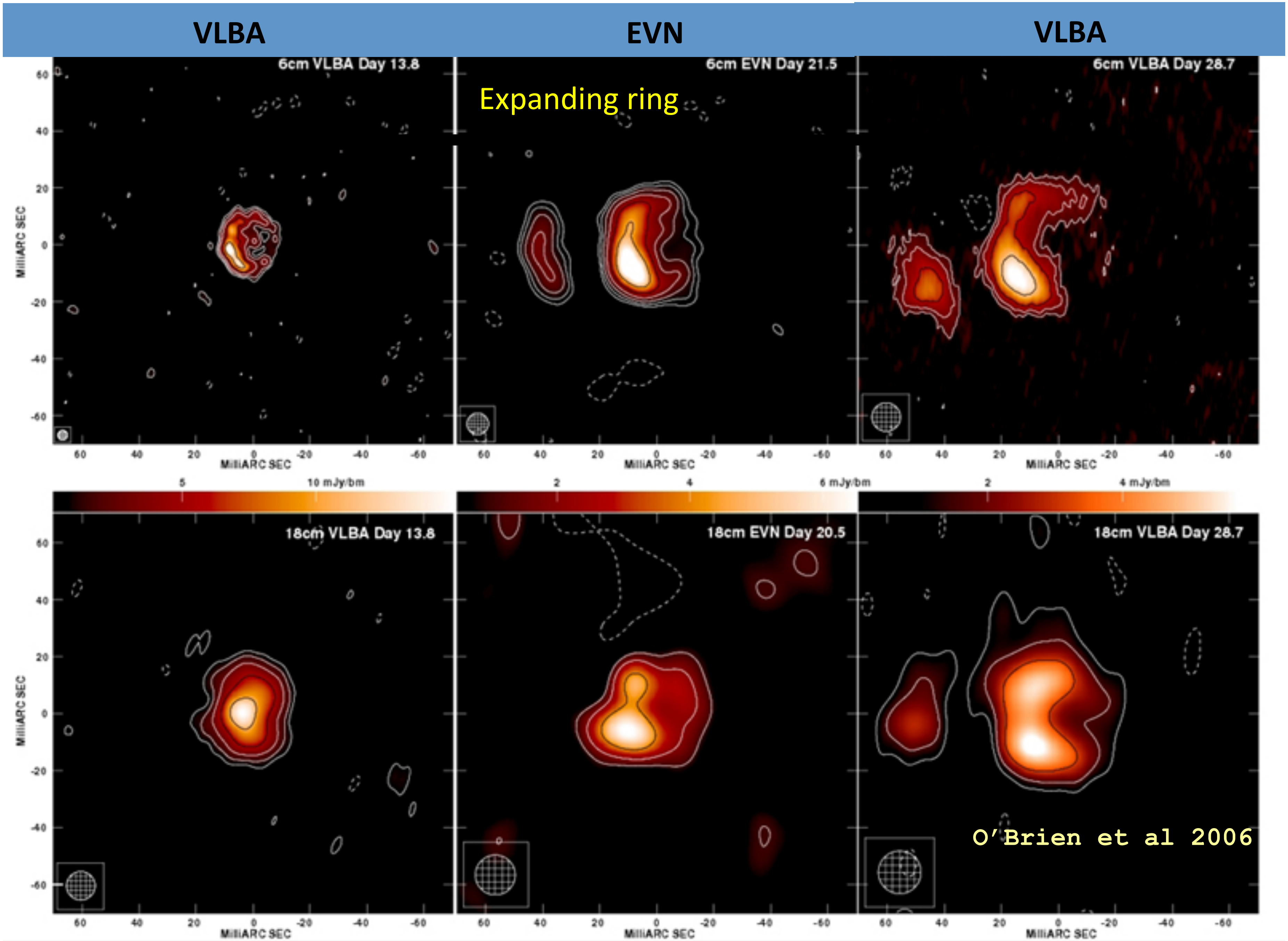
V339 Del
100
10
1
0.1
0.01
10^{-3}
XRT rate (count s^{-1})
40
60
80
day since detection

The Evolving Radio Remnant of RS Oph in 2006

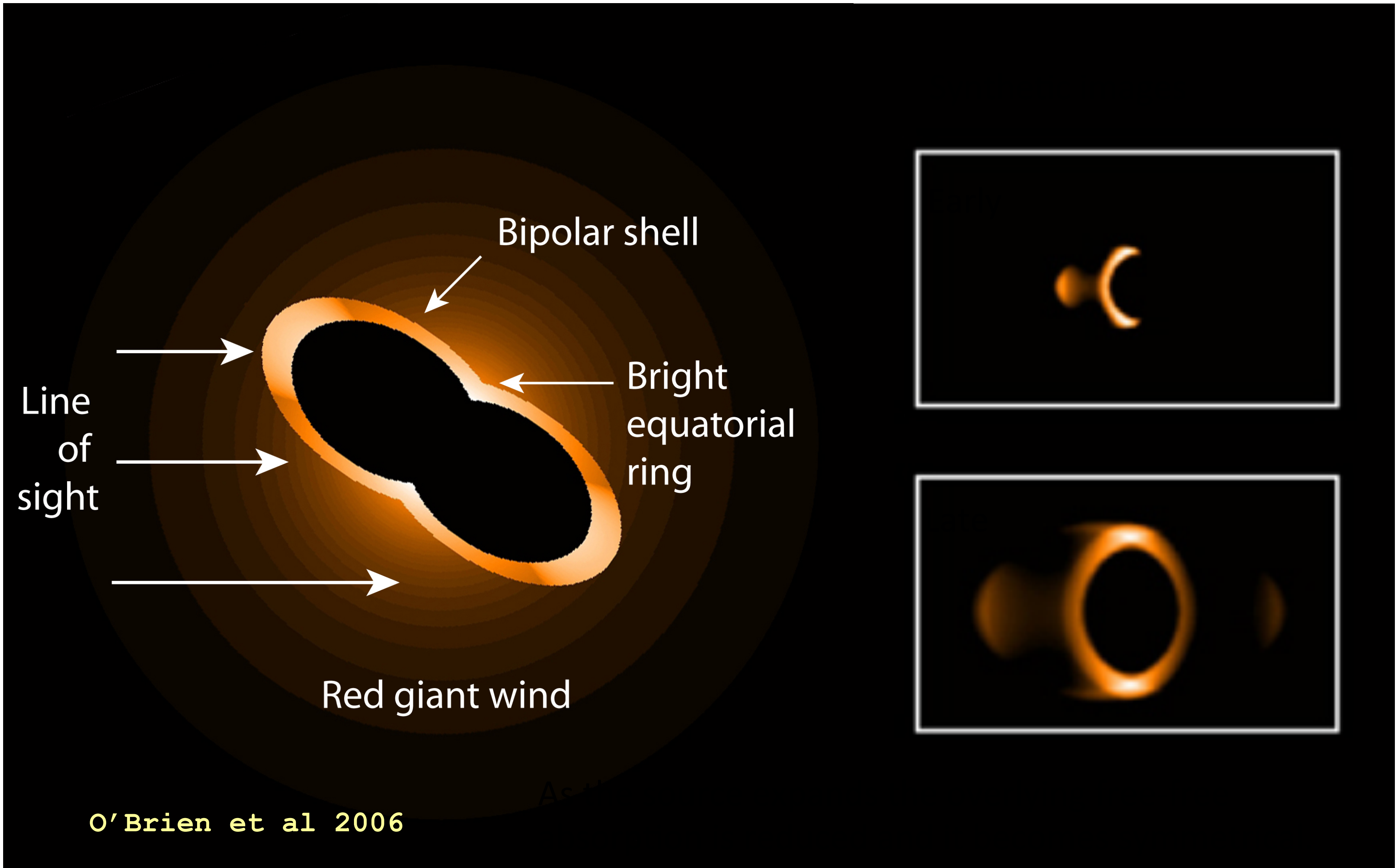




VLBI observa

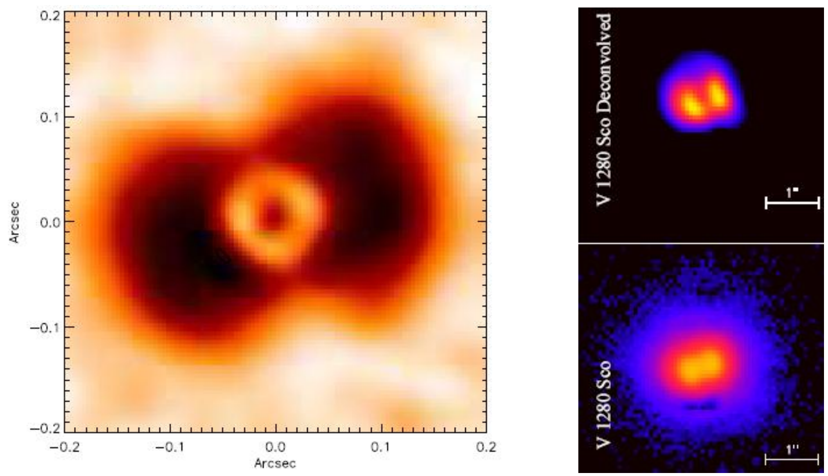

VLBA
EVN
VLBA
6cm VLBA Day 13.8
6cm EVN Day 21.5
Expanding ring
6cm VLBA Day 28.7
MilliARC SEC
5
10 mJy/bm
2
4
6 mJy/bm
2
4 mJy/bm
18cm VLBA Day 13.8
18cm EVN Day 20.5
18cm VLBA Day 28.7
O'Brien et al 2006

A model


Bipolar shell
Bright
equatorial
ring
Line
of
sight
Red giant wind
O'Brien et al 2006

V1280 Sco – a deep dust forming CO Nova Chesneau et al. [not seen in soft X-rays]

In 2009, NACO and VISIR observation were obtained that revealed a striking bipolar nebula whose expansion was then regularly monitored between 2009 and 2011 (Chesneau et al. submitted). The expansion of the nebula in the major axis direction is 0.39±0.03mas day^{-1}, a value close the estimate from VLTI measurements. By chance, most of the baselines used for the VLTI observations were closely aligned with the major axis direction. The dimensions of the nebula will be 0.93" x 0.61" in Jun. 2013 and the inclination is probably large. Most of the dust seems to reside in the caps of the nebula, and to date no clear emission is observed near the equatorial plane. Signatures of hydrogenated carbon compounds were observed in the infrared (Sitko et al. 2009).



Left: NACO K (2.2 micron) band image obtained in June 2010 (inverted colors, central source subtracted). Right: VISIR image obtained in burst mode (short exposures) at 8.59 micron in June 2011. Bottom: raw image. Up: deconvolved (Chesneau et al. submitted).

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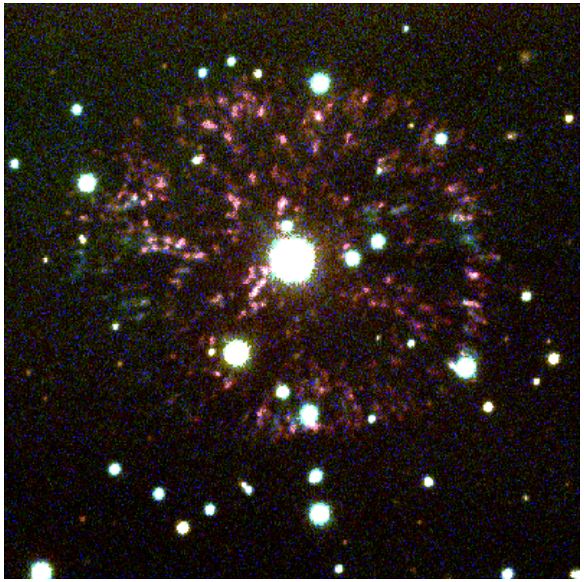
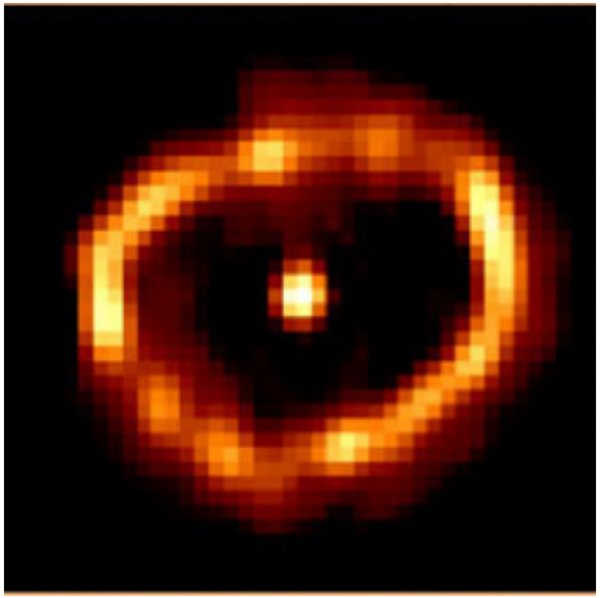
[1] http://www.eso.org/public/news/eso0822/

A nova ejects ~10 to 100 Earth masses (10^{28} gm to 10^{29} gm) at speeds from 300 km/sec to 7000 km/sec

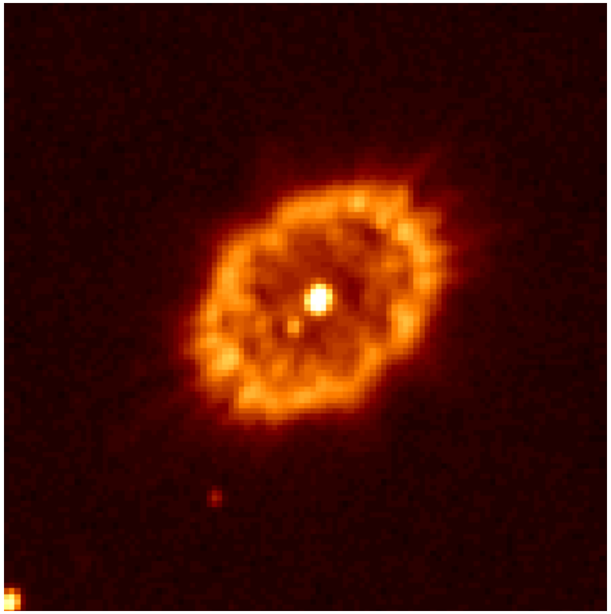
GK Per (1901)



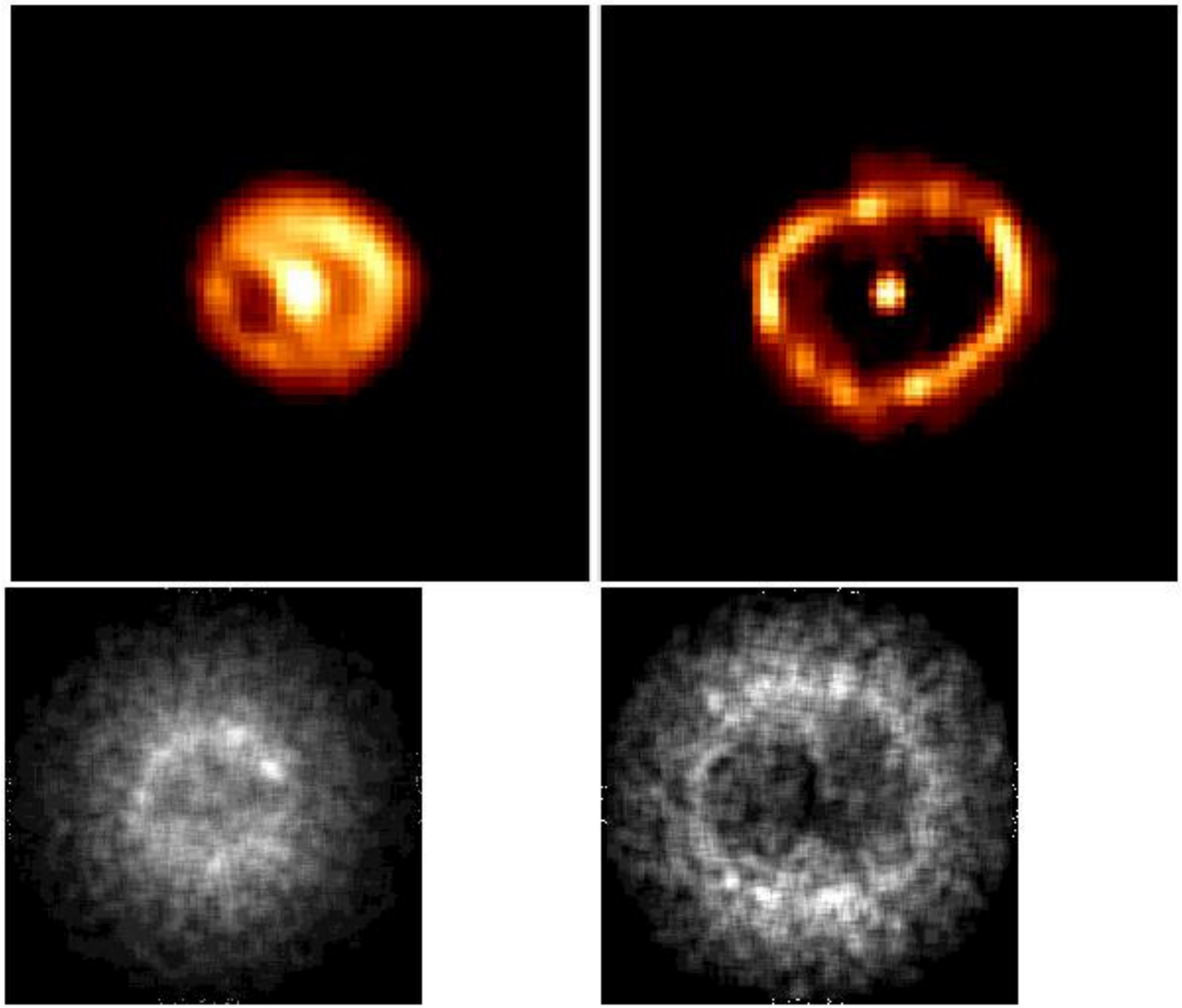
V1974 Cyg (1992)



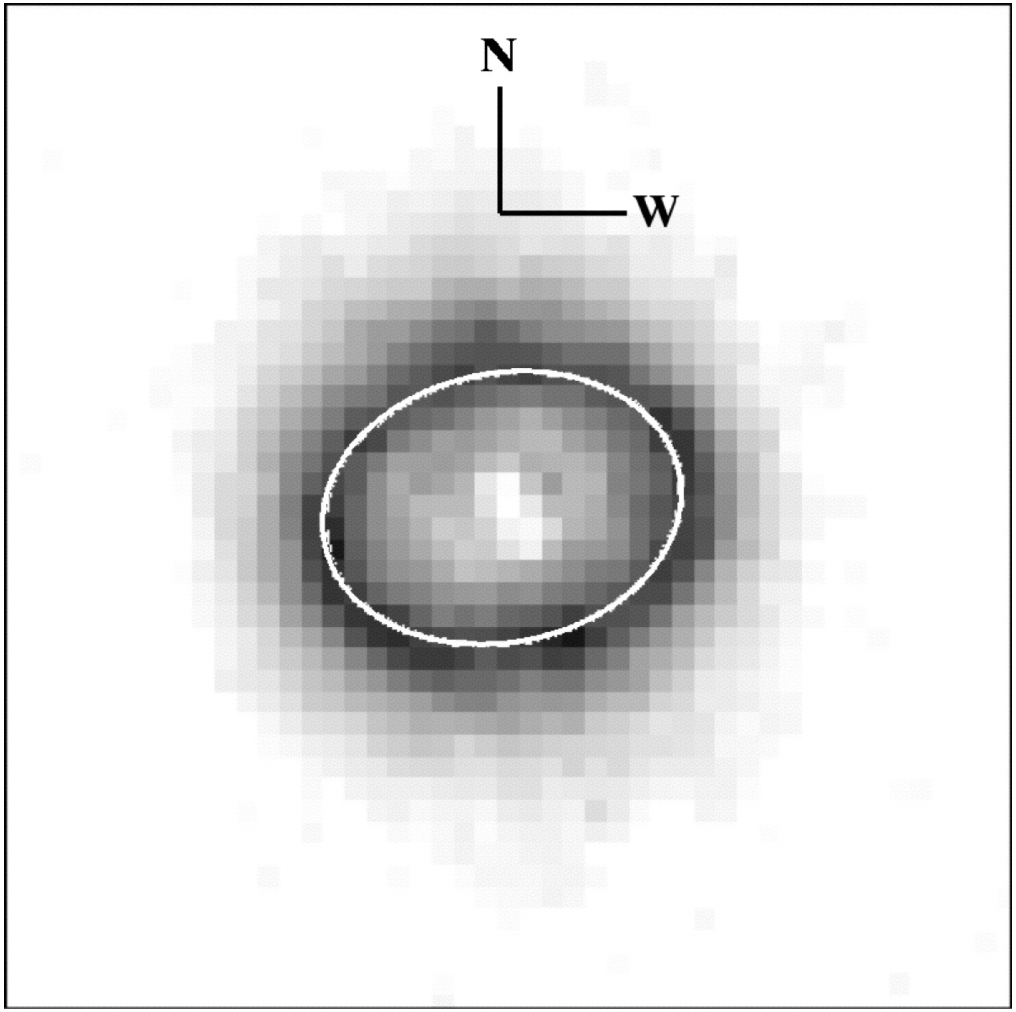
DQ Her (1934)



V1974 Cyg on Day 464 (left) and Day 723 (right)
Spectra Modeled on the Bottom



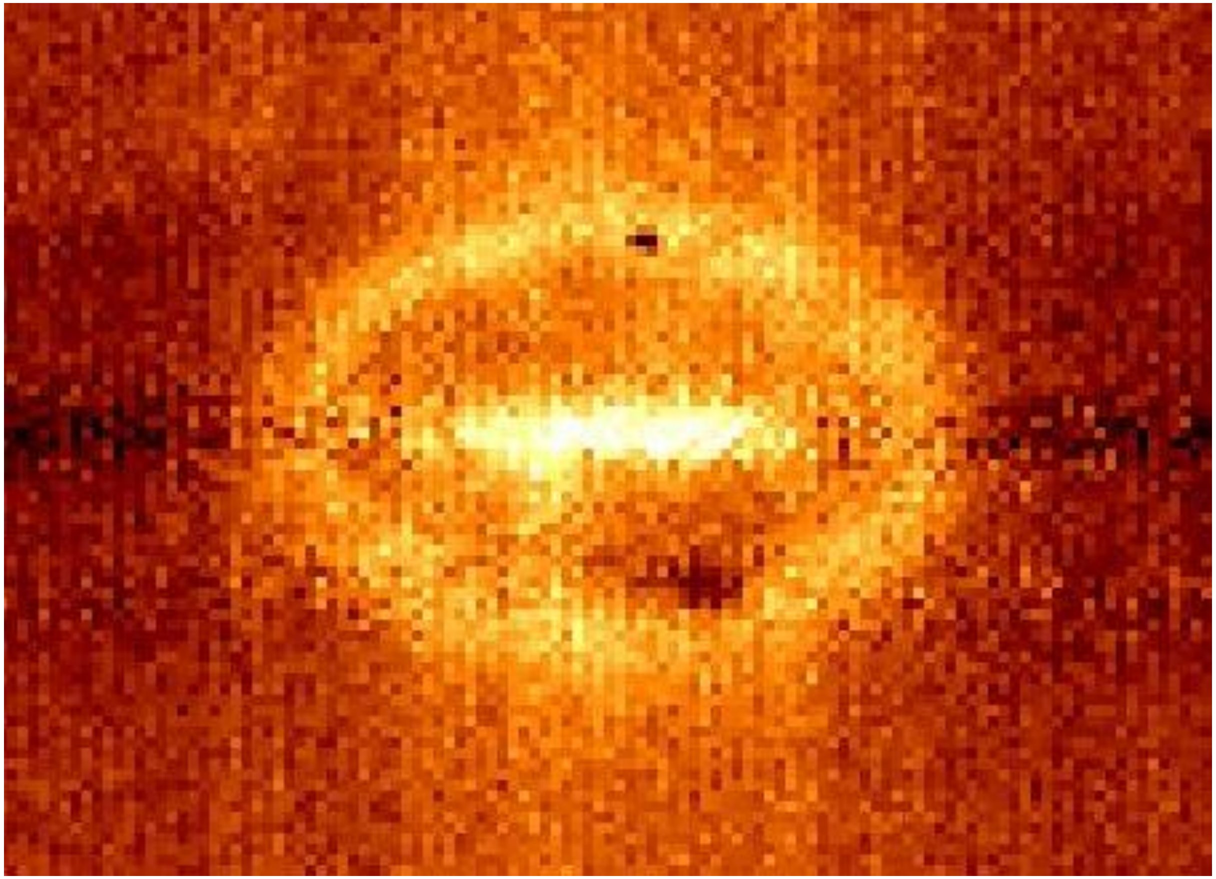
V1974 Cyg taken with HST/NICMOS on 10 Feb 1998
Long axis diameter about 1”



Krautter et al. 2002

V1974 Cyg (1992) taken with MODS on the LBT Oct 31, 2013

Long axis diameter about 5”



Wagner, Starrfield, et al. 2014, in prep

V445 Pup (2000)

Ejected only H and He

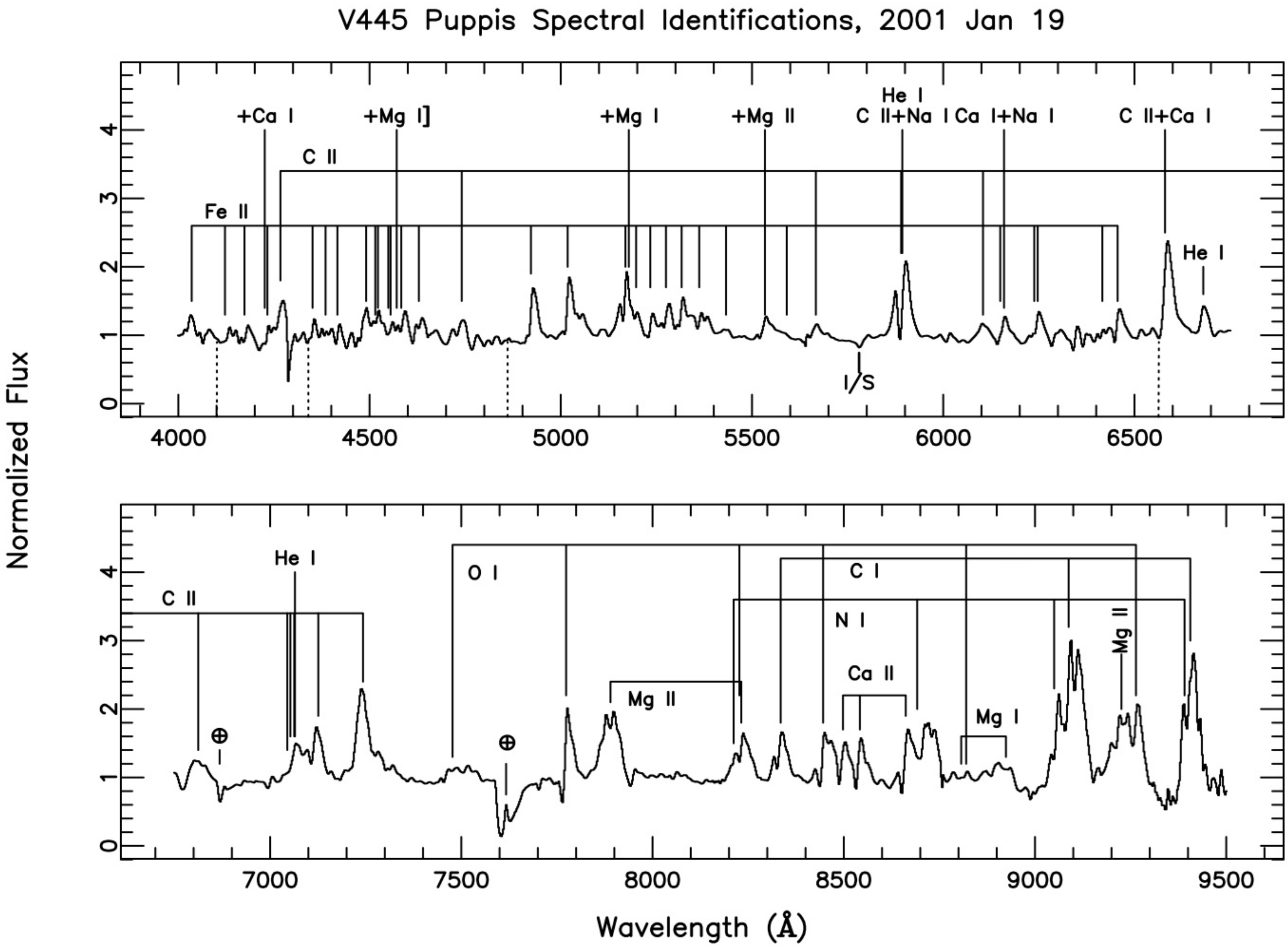
It may be a SN Ia progenitor:

SN Ia provide a fraction of the iron group elements in the Solar System;

And are useful in Cosmology

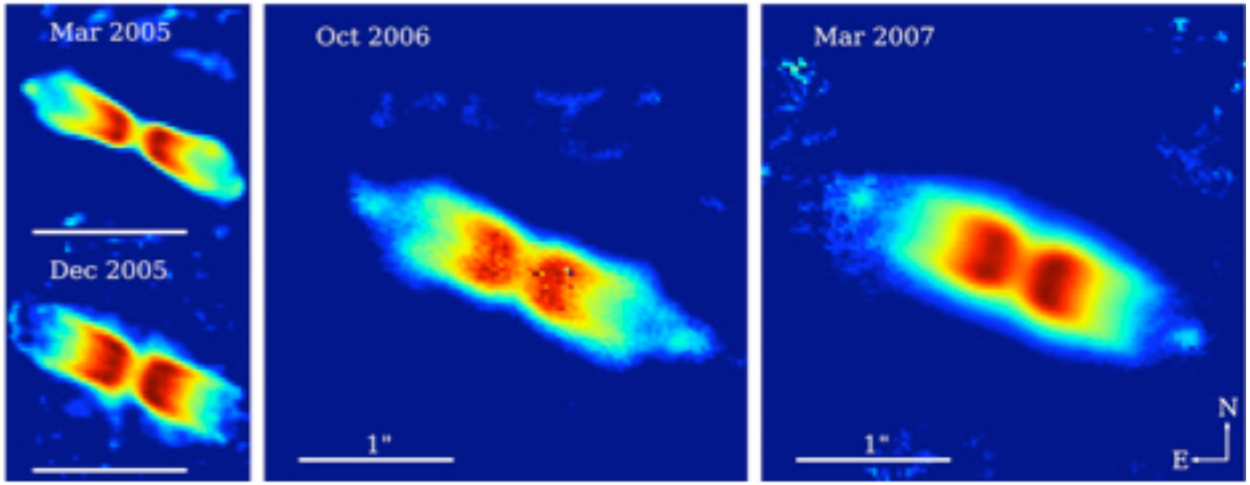
SN Ia show neither H or He in their spectra

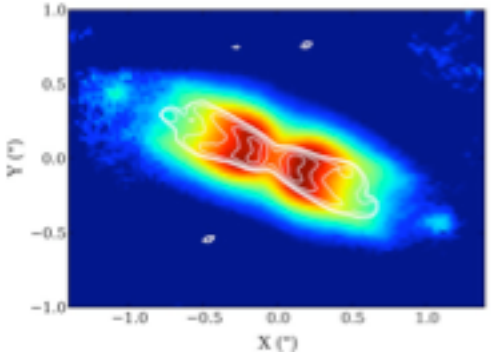
At any time



Wagner and Starrfield

Woudt et al. 2009, ApJ, 706, 738



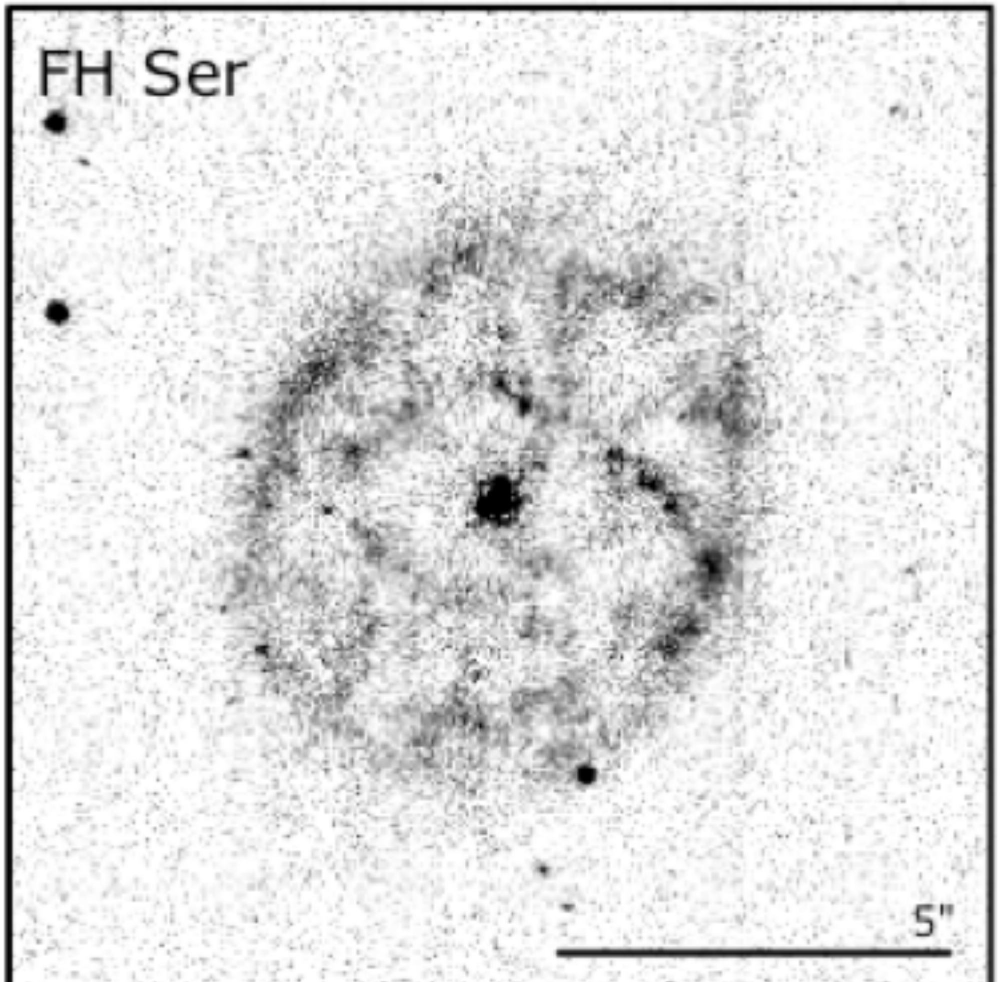


V445 Puppis - Discovered in 2000 - imaged with Active Optics

No Hydrogen detected in the ejected gases - mostly helium and carbon

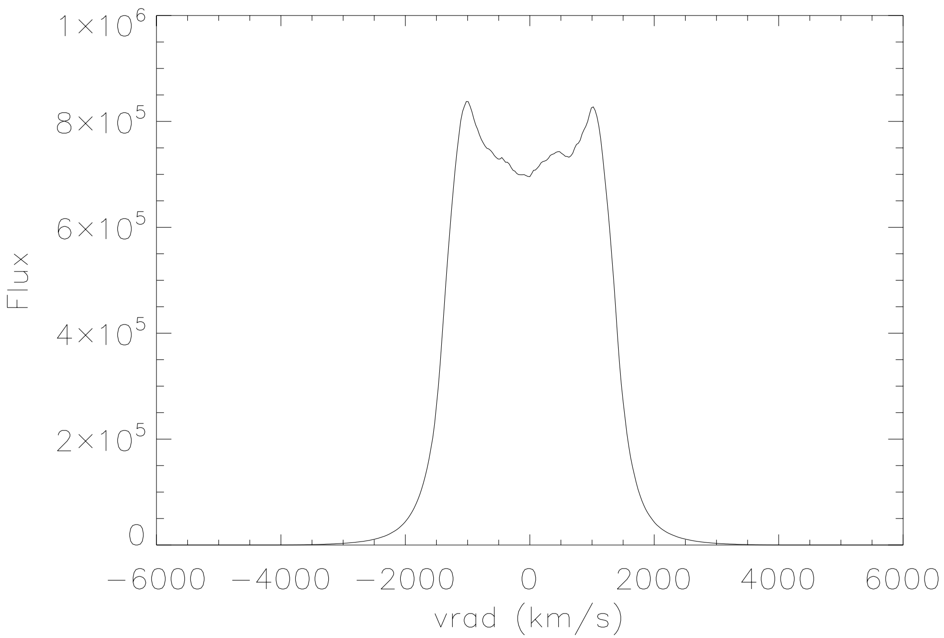
White Dwarf accreting from a Hydrogen Deficient Carbon star

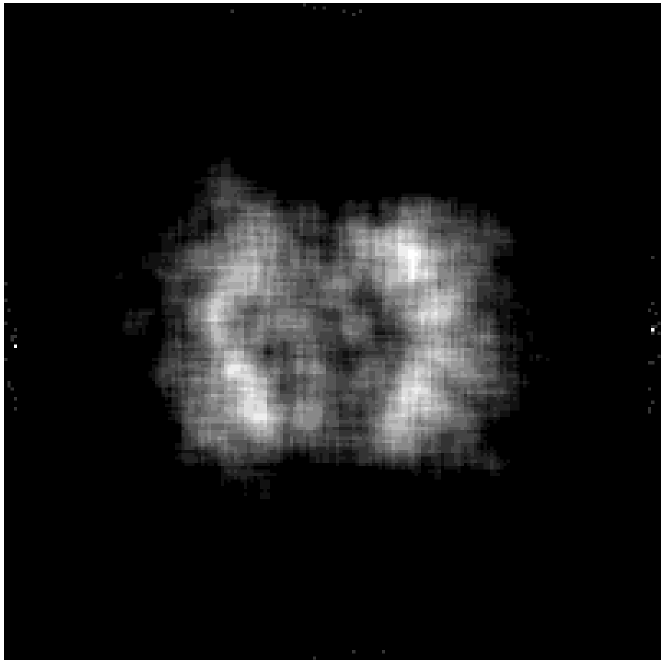
FH Ser HST WFPC2 imaging
Gill and O'Brien MN



Nova Mon 2012: Model spectral profile on the left: Pseudo image taken from the profile on the right

(Shore et al. 2013)





Why should you worry about the MMRD?

It is used to determine distances to single novae when it is a statistical relationship

In fact, an important parameter is the Viewing angle.

Della Valle and Livio
ApJ 1995

M31 and LMC Novae

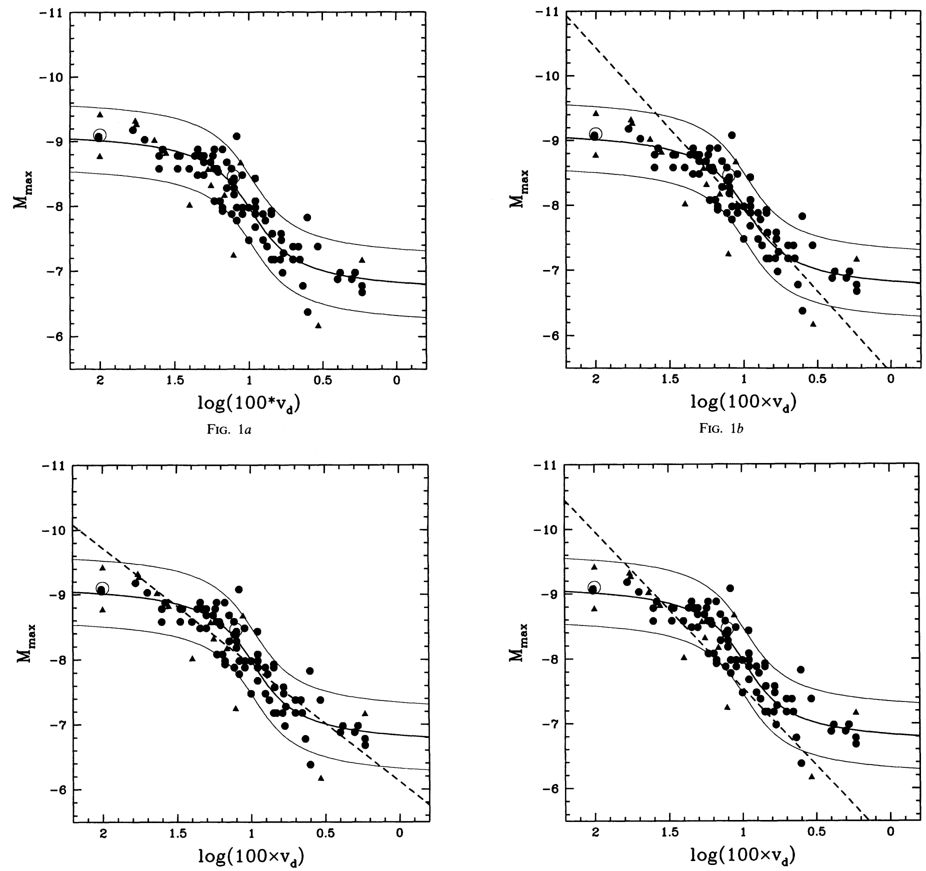


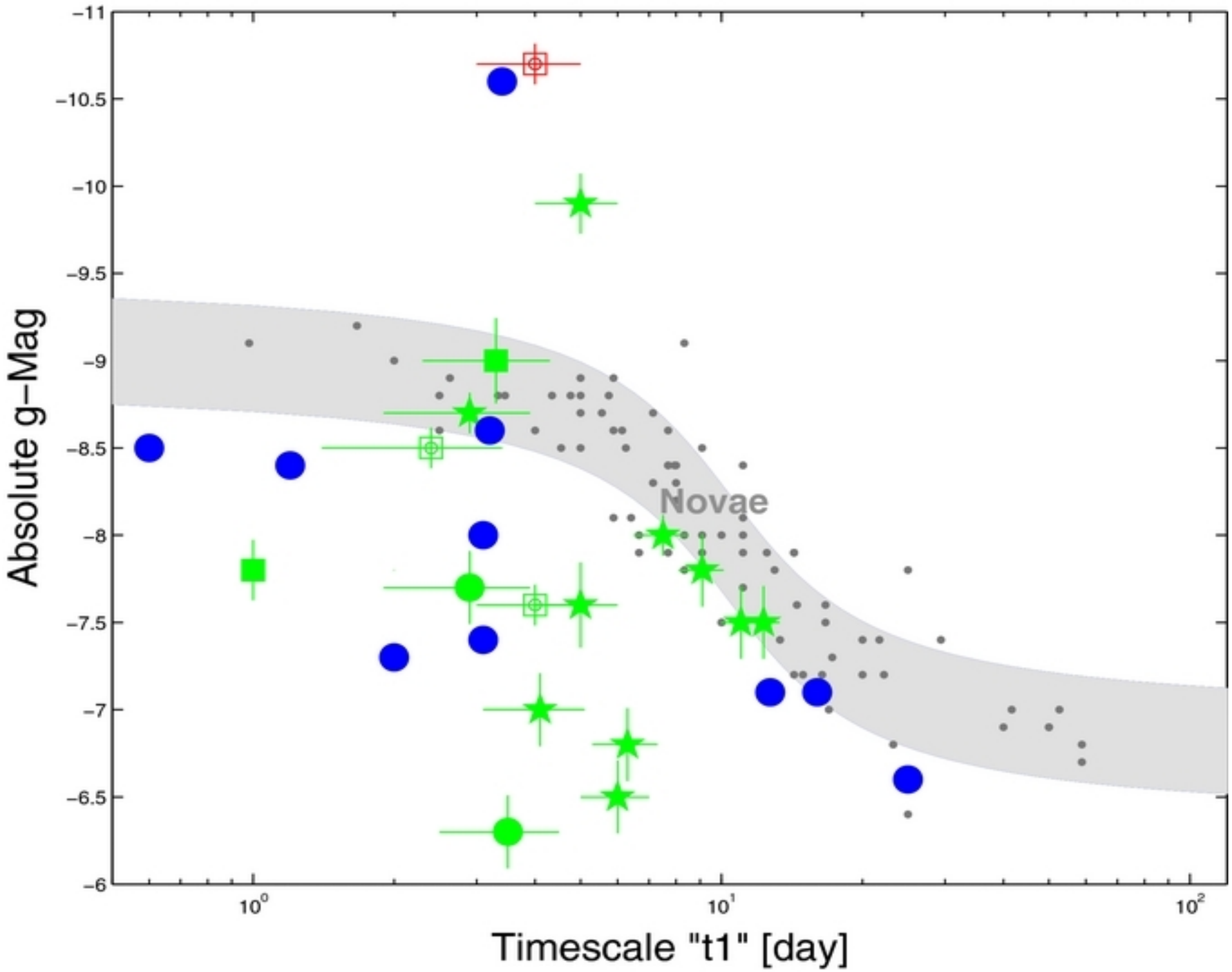
FIG. 1.—(*a*) Maximum magnitude vs. rate of decline relationship for novae in M31 (*filled circles*) and the LMC (*triangles*). Each apparent magnitude has been transformed to an absolute *V* magnitude by using the different distance moduli and absorptions for M31 and the LMC. The "best" fit is indicated by the solid curve. Open circles represent the positions of Nova Cyg 1992 and Nova Her 1991. Upper and lower curves are located $\pm 3\,\sigma$ above and below the relation of eq. (2). (*b*) Same data as in (*a*), but with the phenomenological relation of Schmidt (1957). (*c*) Same data as in (*a*), but with the phenomenological relation of Pfau (1976). (*d*) Same data as in (*a*), but with the phenomenological relation of Cohen (1985). (*e*) Same data as in (*a*), but with the theoretical relation of Livio (1992).

the magnitudes and rates of decline that have been used. The fit has been performed for over 84 novae of M31 and 15 novae of the LMC, without using the overluminous objects which deviate from the main relation by at least $5\,\sigma \gtrsim 1$ mag (Della Valle 1991) and the two subluminous ones (patchy absorbed or recurrent novae). The minor differences with the fit performed by Capaccioli et al. (1990) are caused by the fact that the latter fit was based only on novae of M31. The main advantage of adding the LMC novae to the original sample is that the LMC nova population is rich in bright and fast objects (e.g., Della Valle et al. 1994). Consequently, we have substantially increased (by a full factor of 2) the number of bright and fast novae which are suitable to calibrate the bright shoulder of the relationship.

The best fit (indicated in Fig. 1*a* by the continuous curve) yields (the value of arctan is in radians)

$$M_V = -7.92 - 0.81 \arctan \frac{1.32 - \log(t_2)}{0.23} . \qquad (2)$$

Kasliwal et al. 2011: M31 and M82 Novae from the PTF



On What Do the Peak Luminosity and Rate of Decline (expansion speed) Depend?

1. The White Dwarf Mass: The higher the WD mass the smaller the amount of accreted and ejected mass. So the expanding gases go optically thin more rapidly

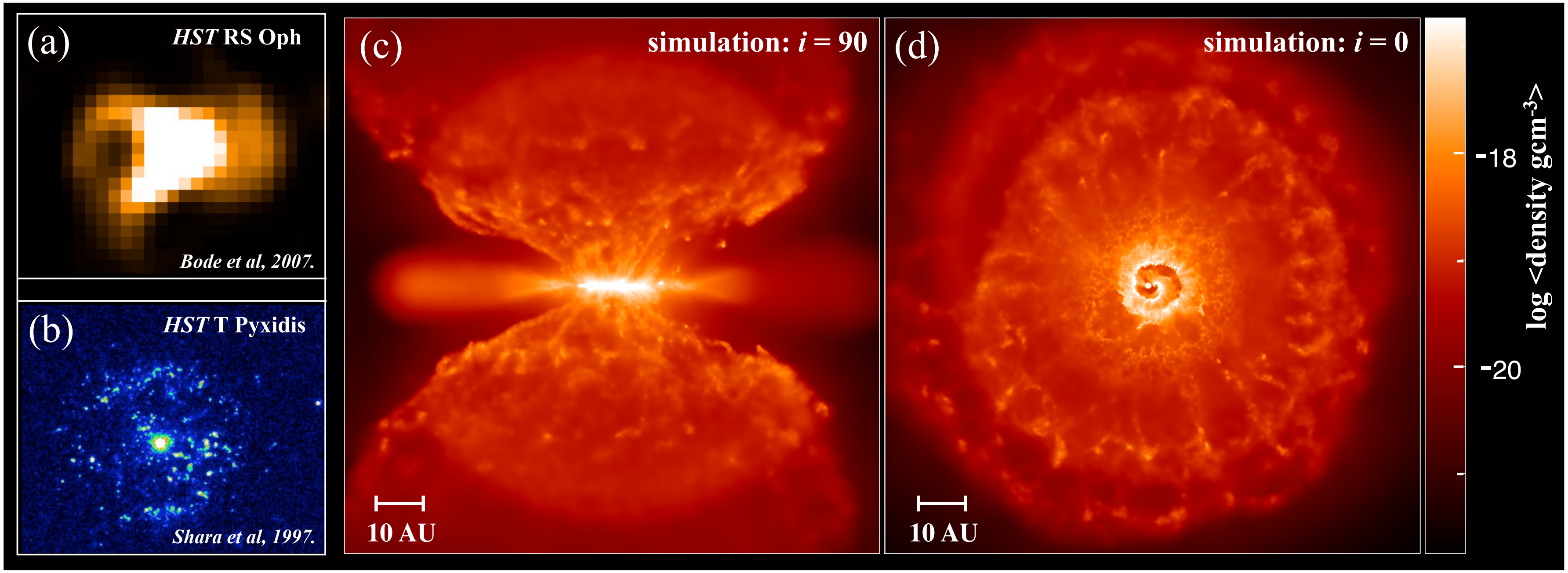
2. The White Dwarf Luminosity: The more luminous the WD - the more rapidly the accreting material reaches the TNR: so less mass is accreted.

3. The Rate of Mass Accretion: The higher the rate of mass accretion, the more energy is liberated in the accreted layers and the more rapid the rise to the TNR.

4. The Composition: ^{12}C is the most reactive of the CNO elements. ONe novae have less carbon and can accrete more material than CO novae. We also need to be concerned about mixing of accreted and WD core material. What is the composition of the material being transferred by the secondary?

5. The Viewing angle: Following a pole-on explosion will give different properties than an edge on explosion and any inclination angle in between.

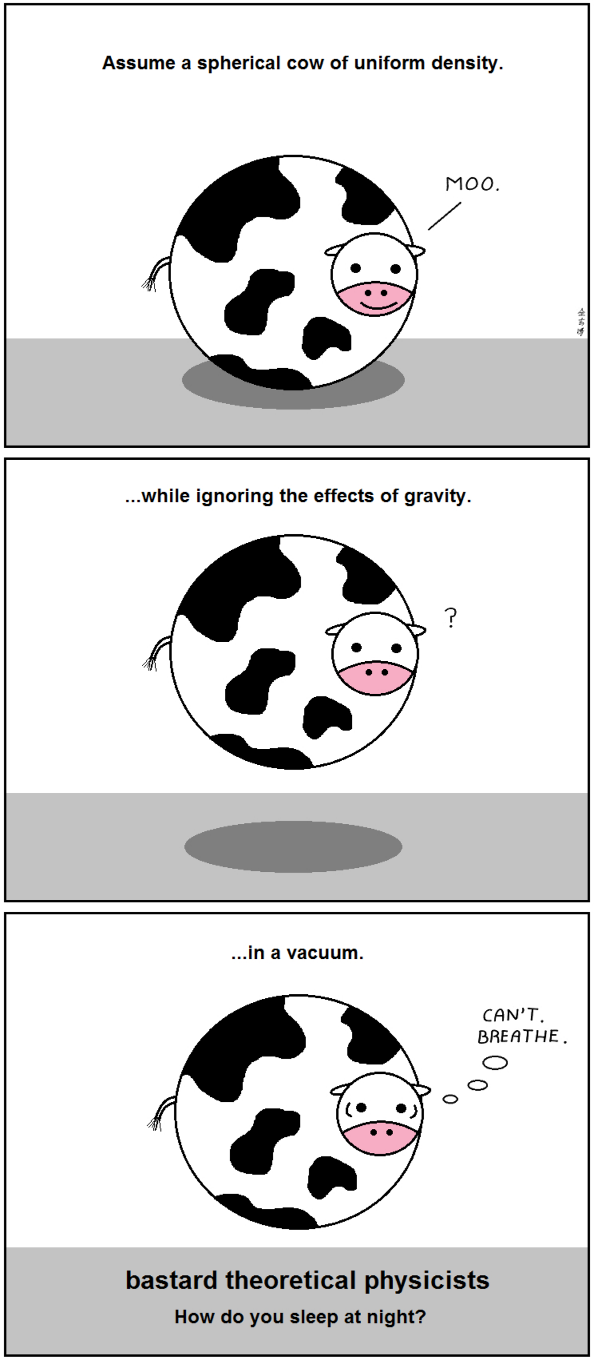
This figure shows us estimating the CO emission from CNe in outburst using SPH modeling and then running the results through the LIME radiative transfer code and the CASA simulator. These results show that the ALMA observations will allow us to obtain the velocity structure and improve the determinations of the mass of the ejected gases. Knowing the velocity and mass we can then estimate the white dwarf mass and determine if the white dwarf is growing or losing mass as a result of the outburst.



From Shazrene Mohamed's Talk –with thanks

Conclusions:

1. Classical and Recurrent Novae are Binaries
2. They have survived Common Envelope Evolution
3. There are two composition classes: CO and ONe
4. The shaping of the ejecta occurs almost immediately
5. The ejecta are asymmetric and their observed shape may, in some cases, depend on how we are viewing the ejecta
6. The ejected gases start off as hot, adiabatically cool until neutral, and then are slowly ionized again by the hot White Dwarf –on time scales of WEEKS (not centuries)



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Recurrent Nova ejecta
are neither
Spherical
Nor
Uniformly filled

Novae Hate Theorists