Physical Drivers and Radio Signatures of the Diversity of Nova Eruptions

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A Classical Nova

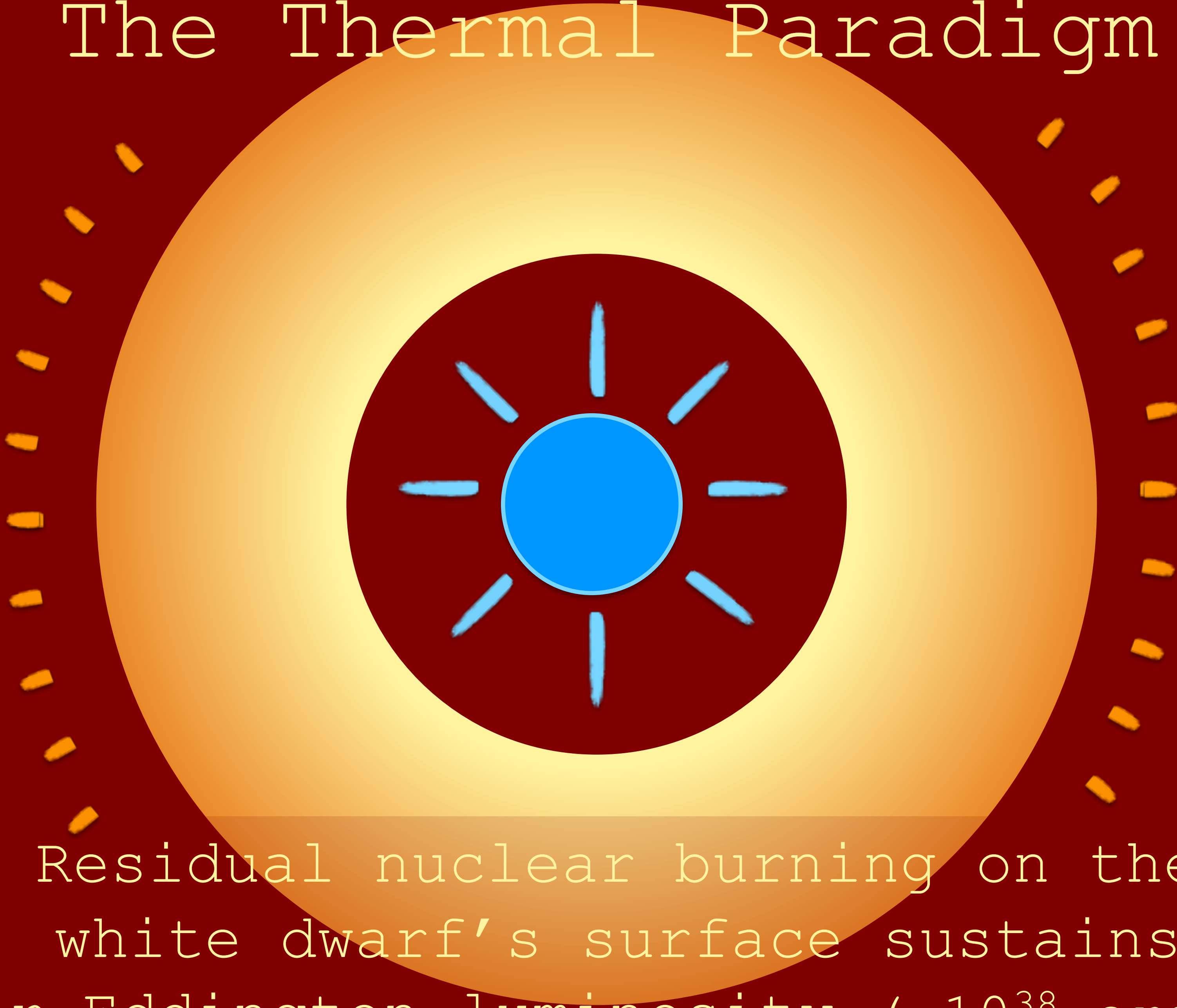
- marks a thermonuclear runaway on the surface of a white dwarf, in material accreted from a binary companion

- 10^{-7}-10^{-3} $M_{\odot}$ ejected at ~500-5,000 km/s

- Emits across the EM spectrum

- ~25 novae/yr in the Milky Way (~10 observed)

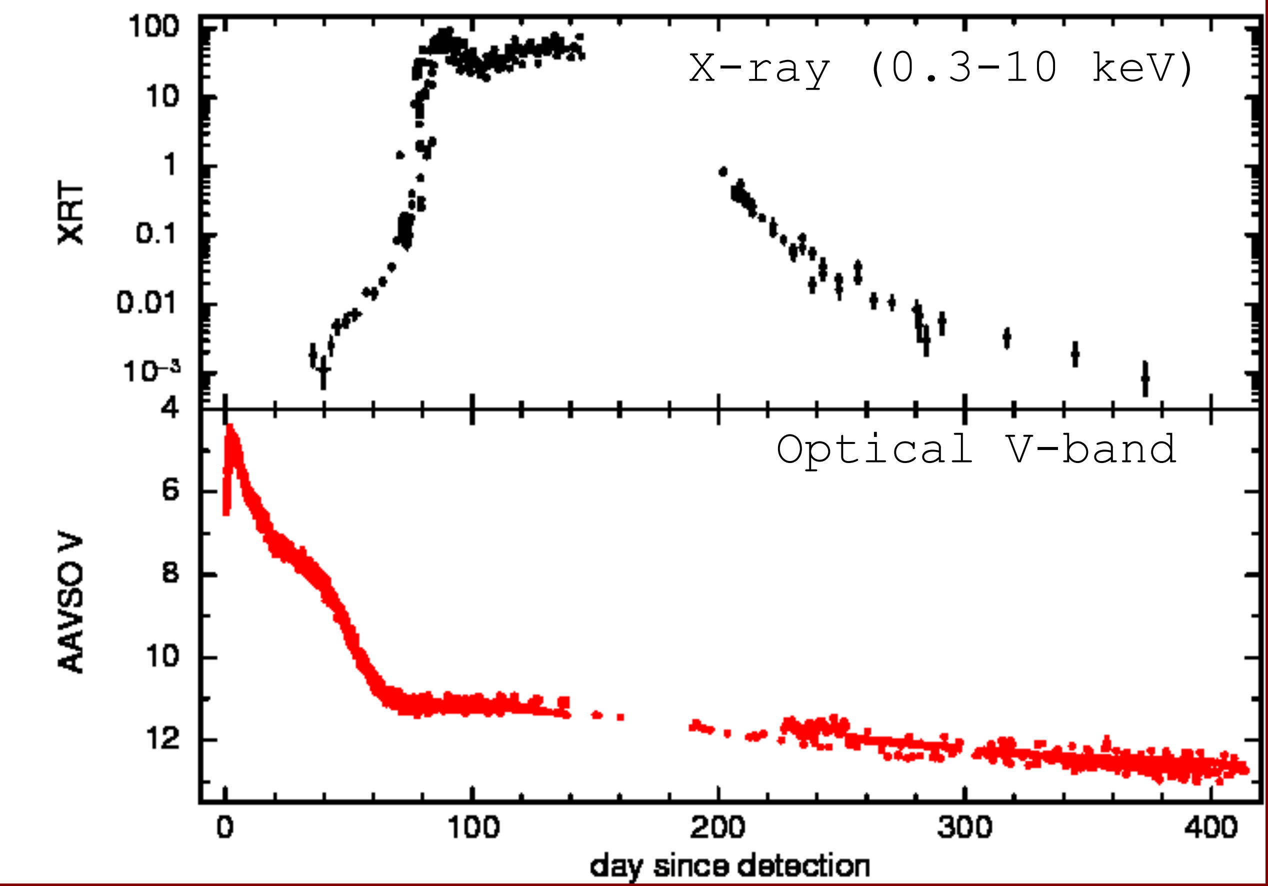
The Thermal Paradigm



Residual nuclear burning on the white dwarf's surface sustains near-Eddington luminosity (~10^{38} erg/s).

The Thermal Paradigm

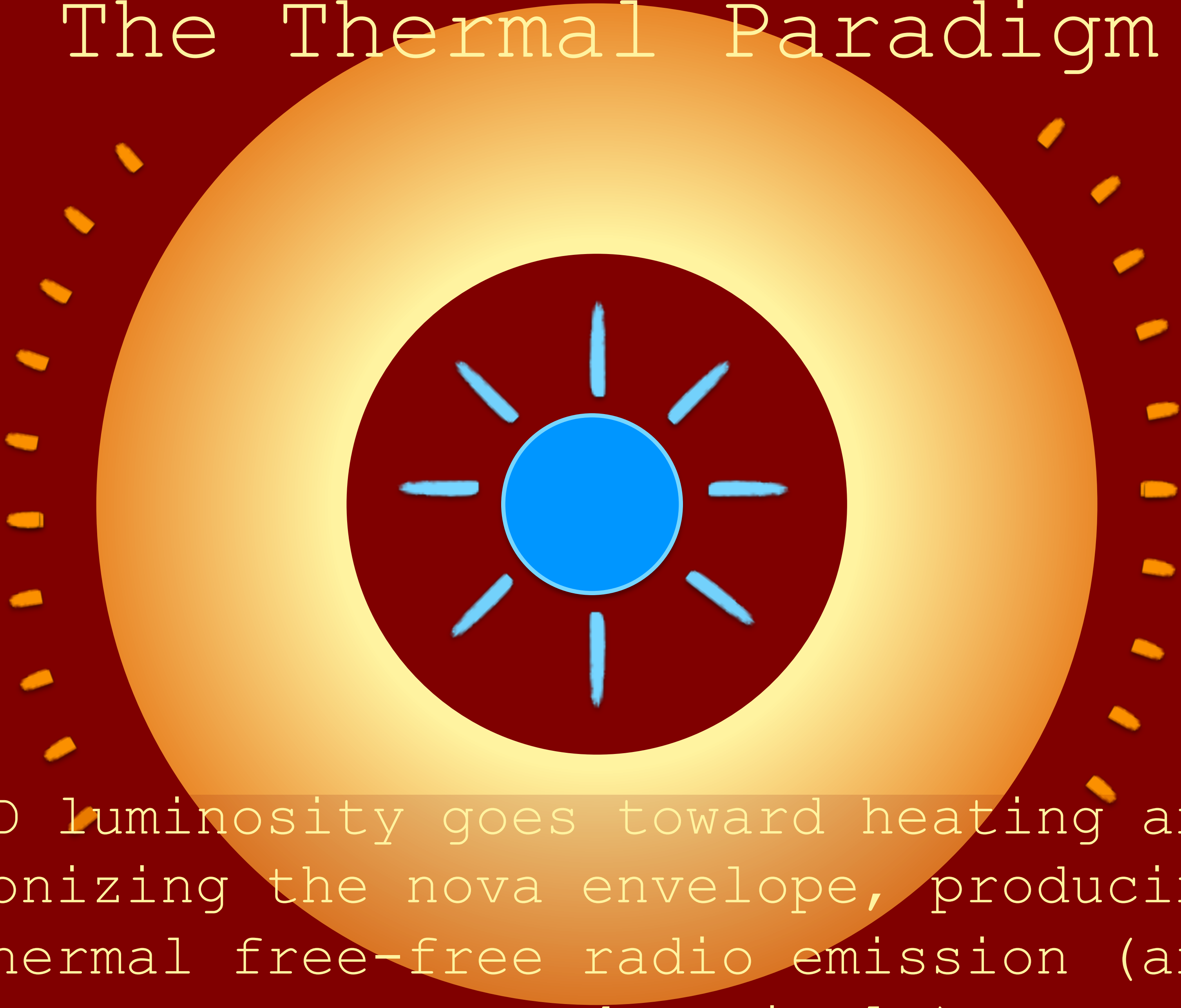
V339 Del (2013)



Near-constant luminosity emerges first in the optical, and later in the X-ray.

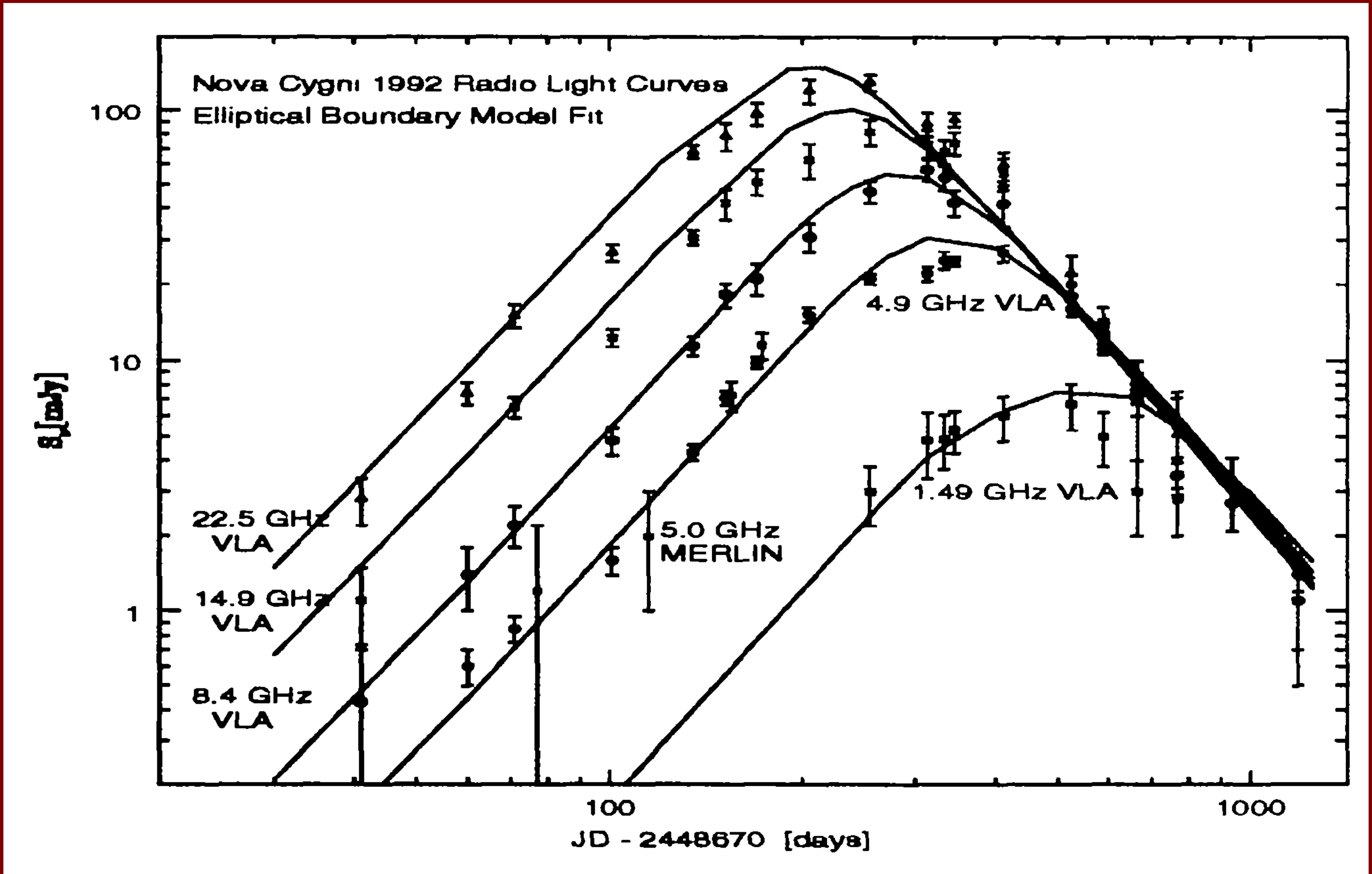
Nuclear burning “turns off” after weeks-years.

The Thermal Paradigm



WD luminosity goes toward heating and ionizing the nova envelope, producing thermal free-free radio emission (and X-rays, and optical…)

Thermal radio emission peaks >1 yr after eruption.



Hjellming+ 1996

Novae are quite unique as **thermal radio transients**!

Higher mass ejections peak at higher luminosities at later times.

$$f_{max} \approx 6.7 \left(\frac{\nu}{\mathrm{GHz}} \right)^{1.16} \left(\frac{T_e}{10^4\ \mathrm{K}} \right)^{0.46} \left(\frac{M_{ej}}{10^{-4}\ \mathrm{M}_\odot} \right)^{0.80} \left(\frac{D}{\mathrm{kpc}} \right)^{-2} \mathrm{mJy}$$

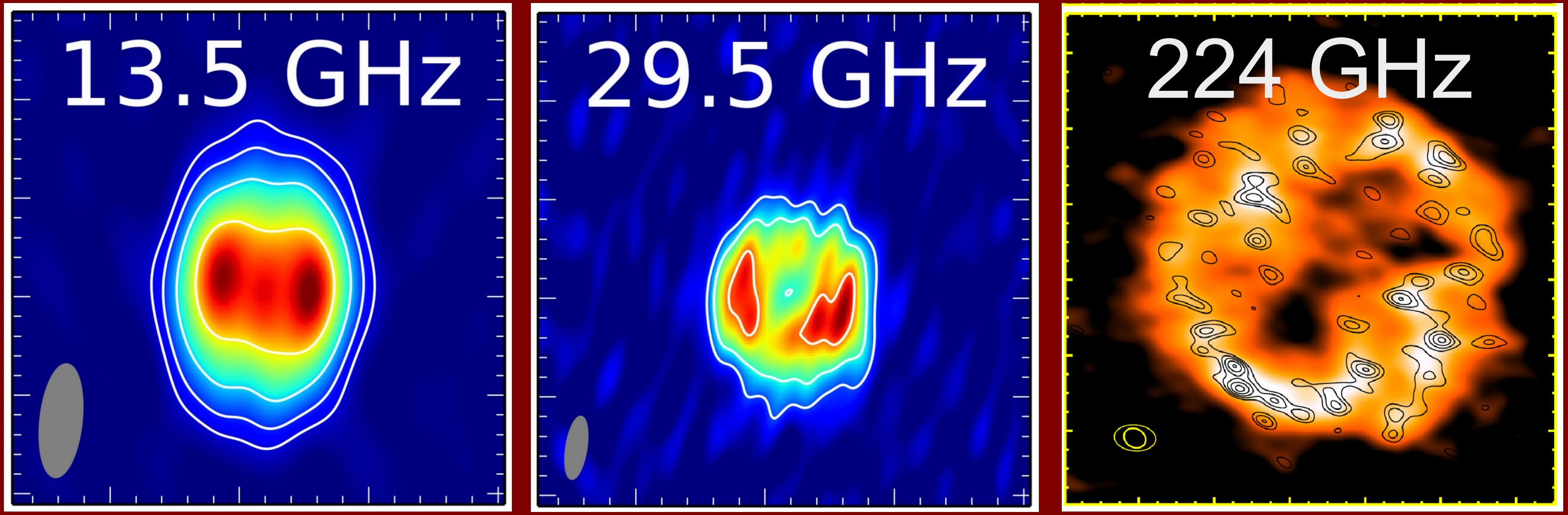
$$t_{max} \approx 2.6 \left(\frac{\nu}{\mathrm{GHz}} \right)^{-0.42} \left(\frac{T_e}{10^4\ \mathrm{K}} \right)^{-0.27} \left(\frac{M_{ej}}{10^{-4}\ \mathrm{M}_\odot} \right)^{0.40} \times \left(\frac{V_{ej}}{10^3\ \mathrm{km\,s^{-1}}} \right)^{-1} \mathrm{yr}$$

Seaquist & Bode 2008

Modelling light curves can yield ejecta mass.

10^4 K thermal ejecta can be imaged at radio (and mm!) wavelengths.

V5668 Sgr (2015)



1.7 yr after eruption w/VLA A config

2.5 yr after eruption w/ALMA (Diaz et al. 2018)

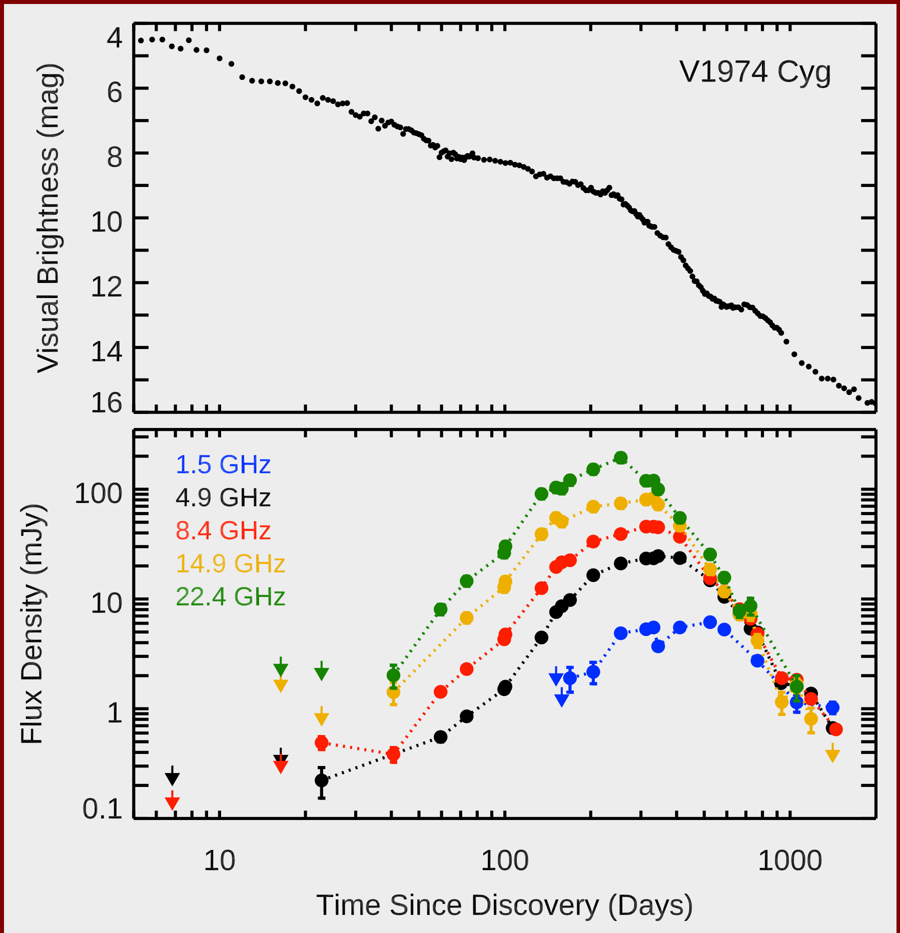
Name	Telescope	Date Range
HR Del	Combination[a]	1970 Jun 22–1978 Dec 12
FH Ser	Combination[b]	1970 Jun 22–1978 Dec 12
V1500 Cyg	Combination[d]	1975 Aug 31–1978 Dec 12
V1370 Aql	WSRT/VLA	1982 Mar 27–1987 Jan 24
PW Vul	VLA	1984 Aug 17–1987 Nov 28
QU Vul	VLA	1985 Jul 16–1988 Oct 24
V1819 Cyg	VLA	1987 Jan 17–1991 May 31
V827 Her	VLA	1987 Jul 2–1989 Feb 14
V838 Her	VLA	1991 Mar 28–1991 Oct 31
V351 Pup	VLA	1992 Mar 7–1995 Jan 7
V1974 Cyg	VLA	1992 Feb 25–1996 Feb 6
V705 Cas	VLA/Merlin	1993 Dec 24–1998 Dec 8
V1419 Aql	VLA	1993 Jun 19–1995 Jul 5
V723 Cas	Merlin	1996 Dec 13–2001 Oct 26
U Sco (1987)	VLA	1987 Jun 2–1987 Jul 5
U Sco (1999)	VLA	1999 Mar 4–1999 Apr 25
U Sco (2010)	GMRT	2010 Jan 29–2010 Mar 2
V4743 Sgr	VLA	2002 Oct 11–2003 Feb 21
V598 Pup	VLA	2007 Nov 18–2008 Aug 3
V2491 Cyg	VLA	2008 Apr 28–2008 Sep 19
V2672 Oph	VLA	2009 Sep 1 –2009 Nov 7
V1723 Aql	Jansky VLA	2010 Sep 25–2014 Mar 15
T Pyx	Jansky VLA	2011 Apr 22–2012 Sep 23
V5589 Sgr	Jansky VLA	2012 Apr 23–2013 Aug 26
V1324 Sco	Jansky VLA	2012 Jun 26–2014 Dec 18
V959 Mon	Jansky VLA	2012 Jun 30–2014 Feb 25
V809 Cep	Jansky VLA	2013 Feb 14–2016 Jan 28
V339 Del	Jansky VLA	2013 Aug 16–2017 Jul 8
V1369 Cen	ATCA	2013 Dec 5–2014 Apr 1
V5666 Sgr	Jansky VLA	2014 Feb 19–2017 Aug 22
V2659 Cyg	Jansky VLA	2014 Apr 5–2018 Sep 27
V5667 Sgr	Jansky VLA	2015 Feb 19–2019 Dec 22
V5668 Sgr	Jansky VLA	2015 Mar 17–2019 Dec 22
V5855 Sgr	Jansky VLA	2016 Nov 4–2021 Feb 9
V5856 Sgr	Jansky VLA	2016 Nov 11–2021 Feb 9
V357 Mus	ATCA	2018 Jan 18–2020 Sep 12
V906 Car	ATCA	2018 Apr 3–2020 Sep 12
V392 Per	Jansky VLA	2018 Apr 30–2020 May 15

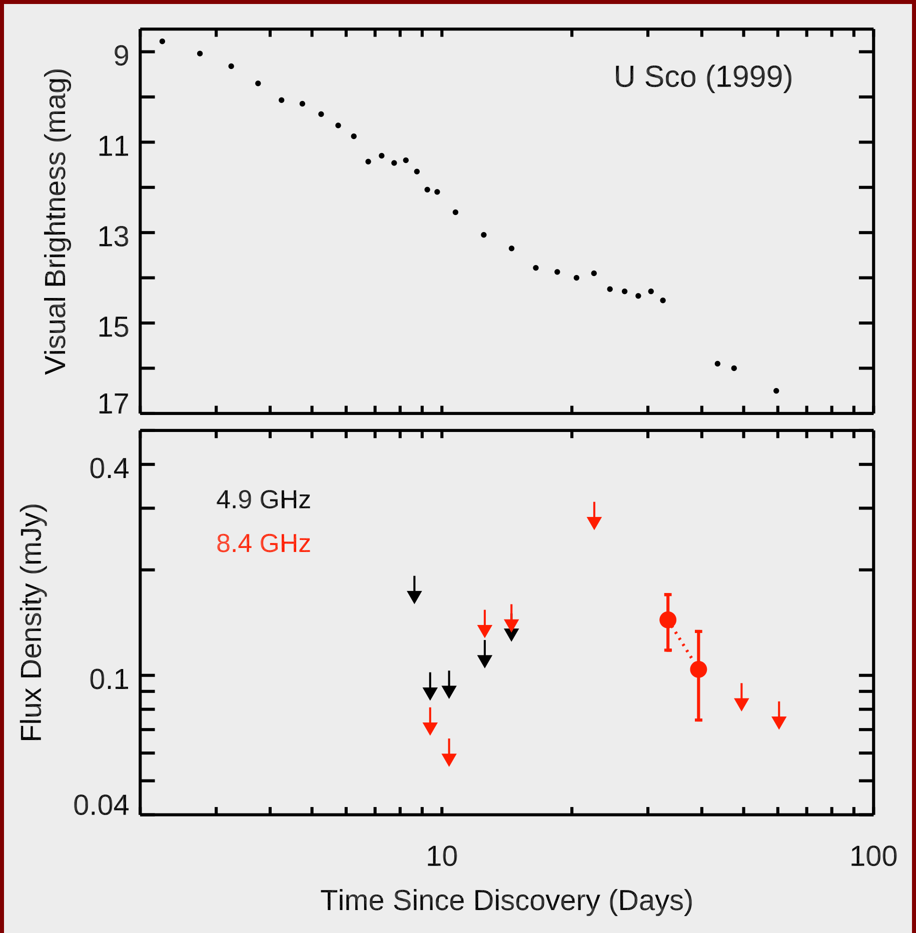
We analyzed and compiled radio data for 36 novae that erupted 1967-2018 (mostly VLA).

We focused on novae with main-sequence companions (and a few subgiants) – See **Bella Molina**'s talk on novae with giant companions.

Chomiuk+ 2021

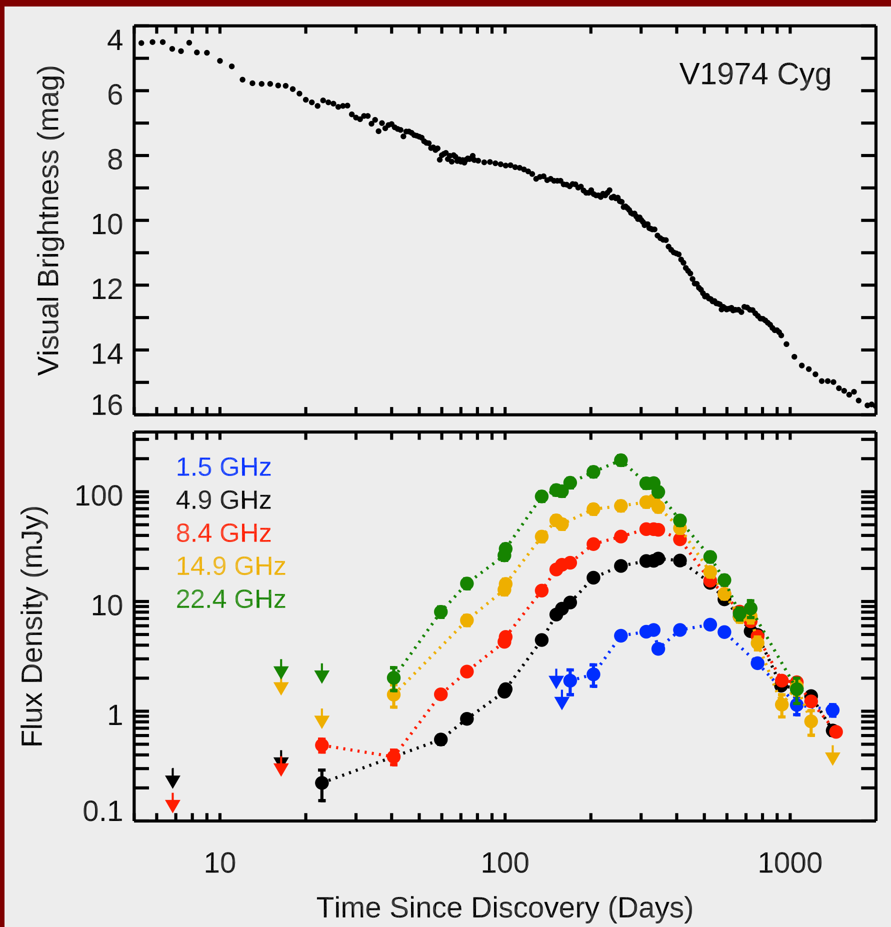
Some novae are among the brightest radio transients in the sky, others faint.

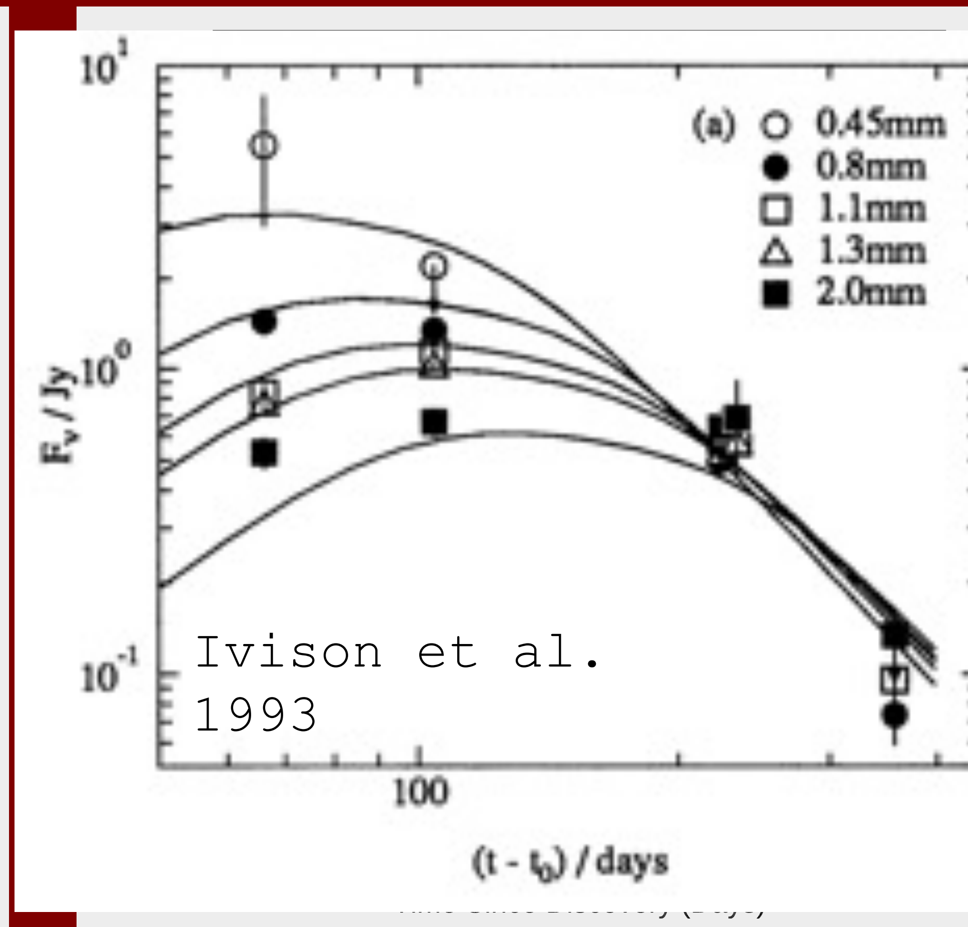




Chomiuk+ 2021

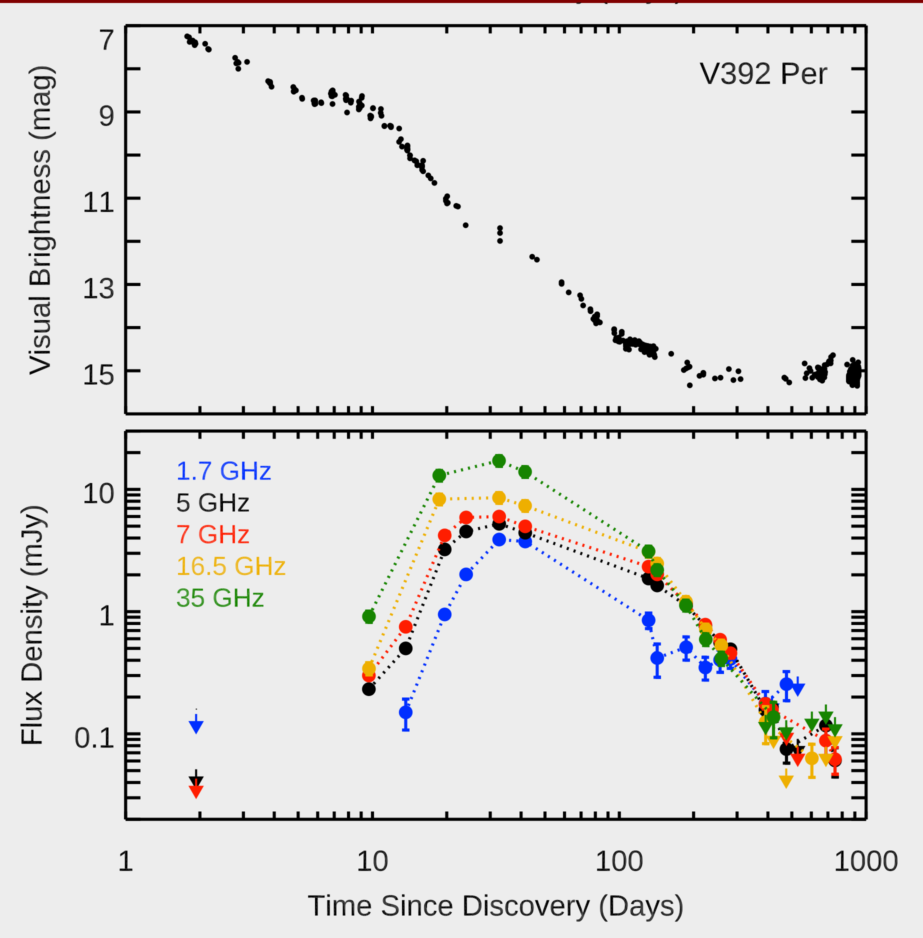
Novae should be bright mm transients, routinely reaching ≳100 mJy.

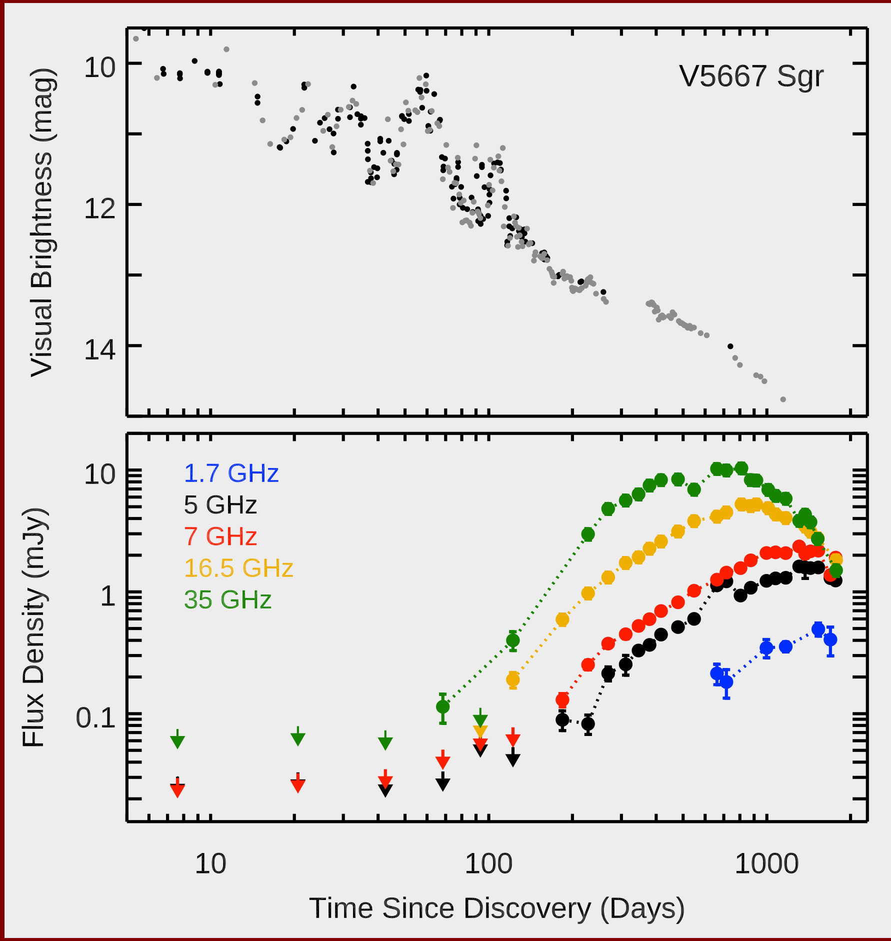




But mm behavior remains poorly explored.

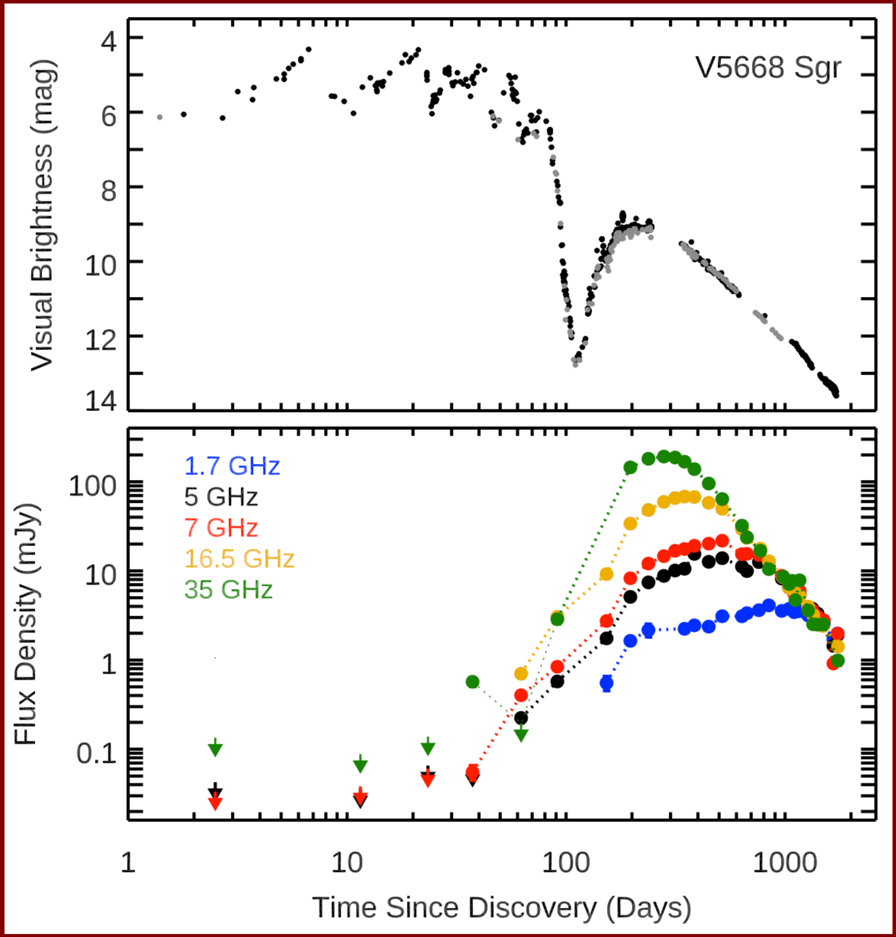
Some novae evolve over weeks, others evolve over years.

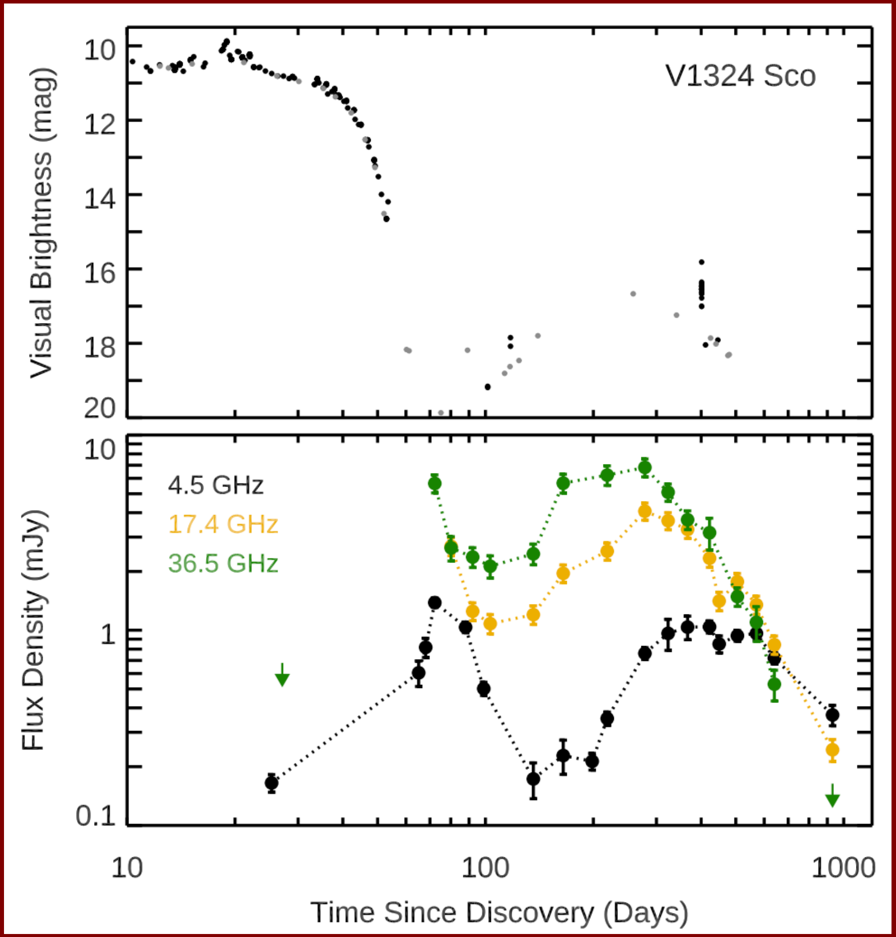




Chomiuk+ 2021

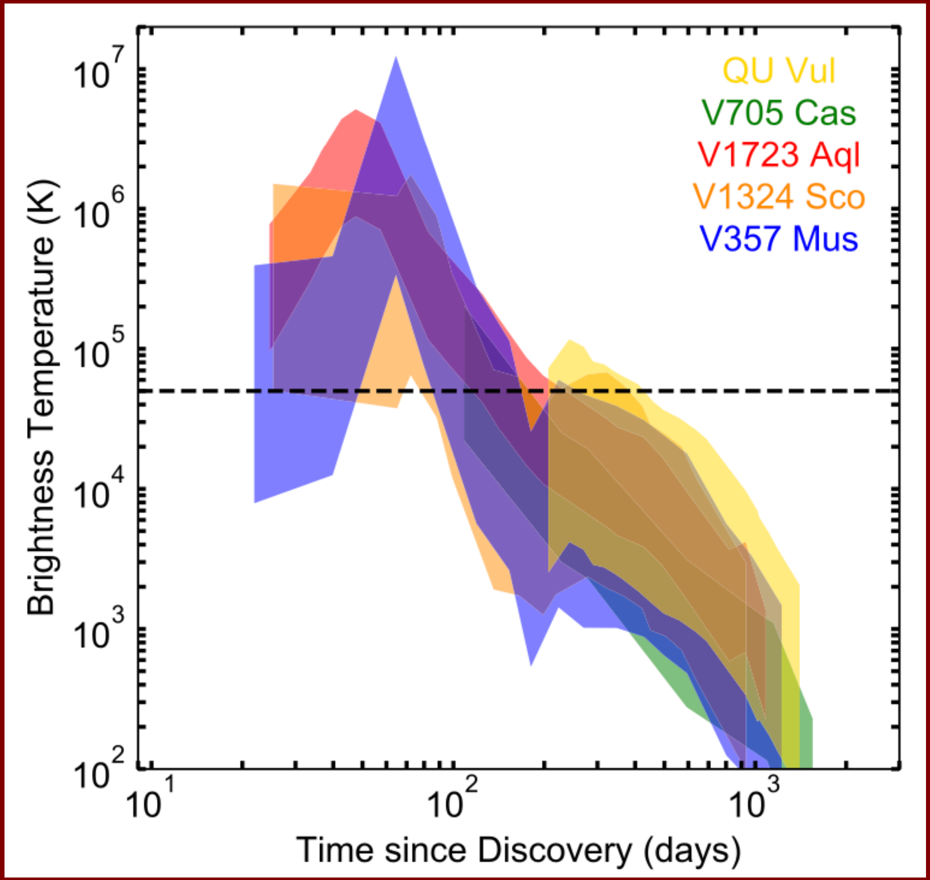
Many novae have one radio peak, some show two.

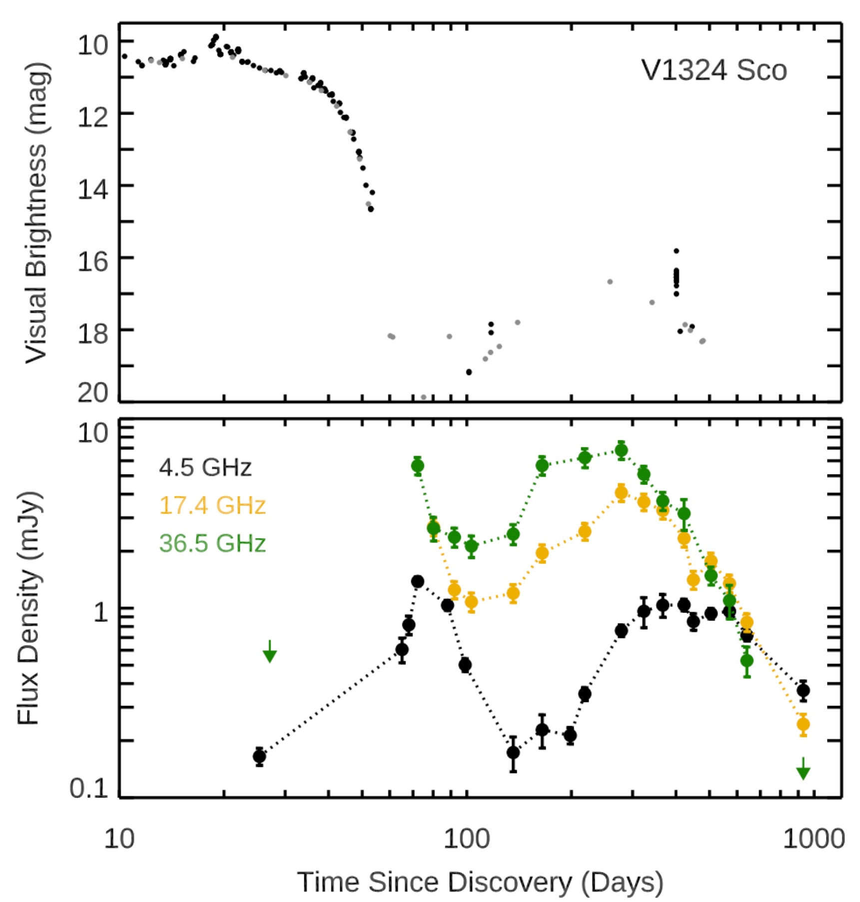




Chomiuk+ 2021

The first radio peak is synchrotron, the second thermal.

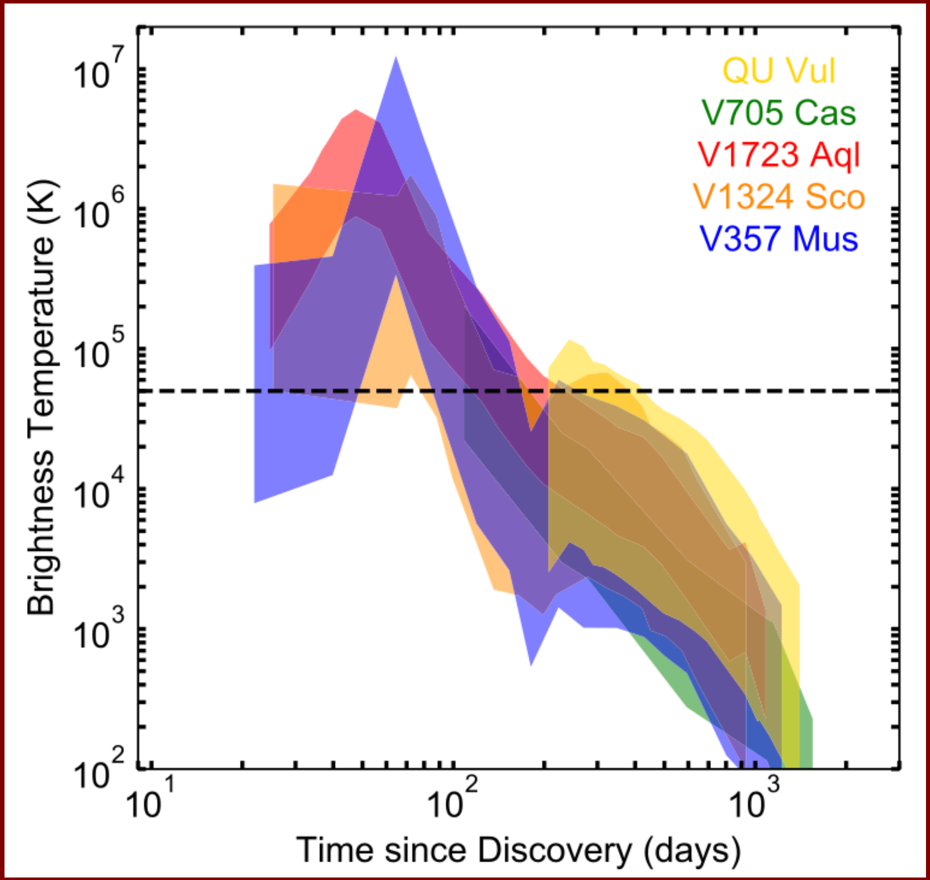


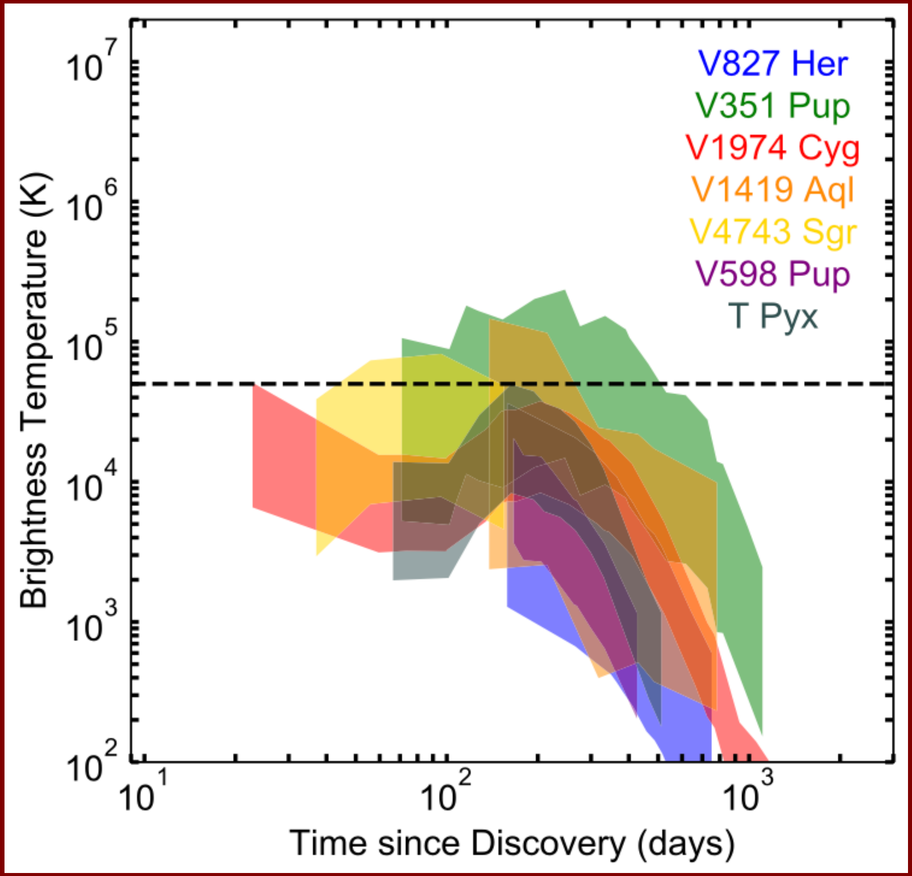


$$T_B = 1765.8 \text{ K} \left(\frac{\nu}{\text{GHz}}\right)^{-2} \frac{S_\nu}{\text{mJy}} \left(\frac{\theta}{\text{arcsec}}\right)^{-2}$$

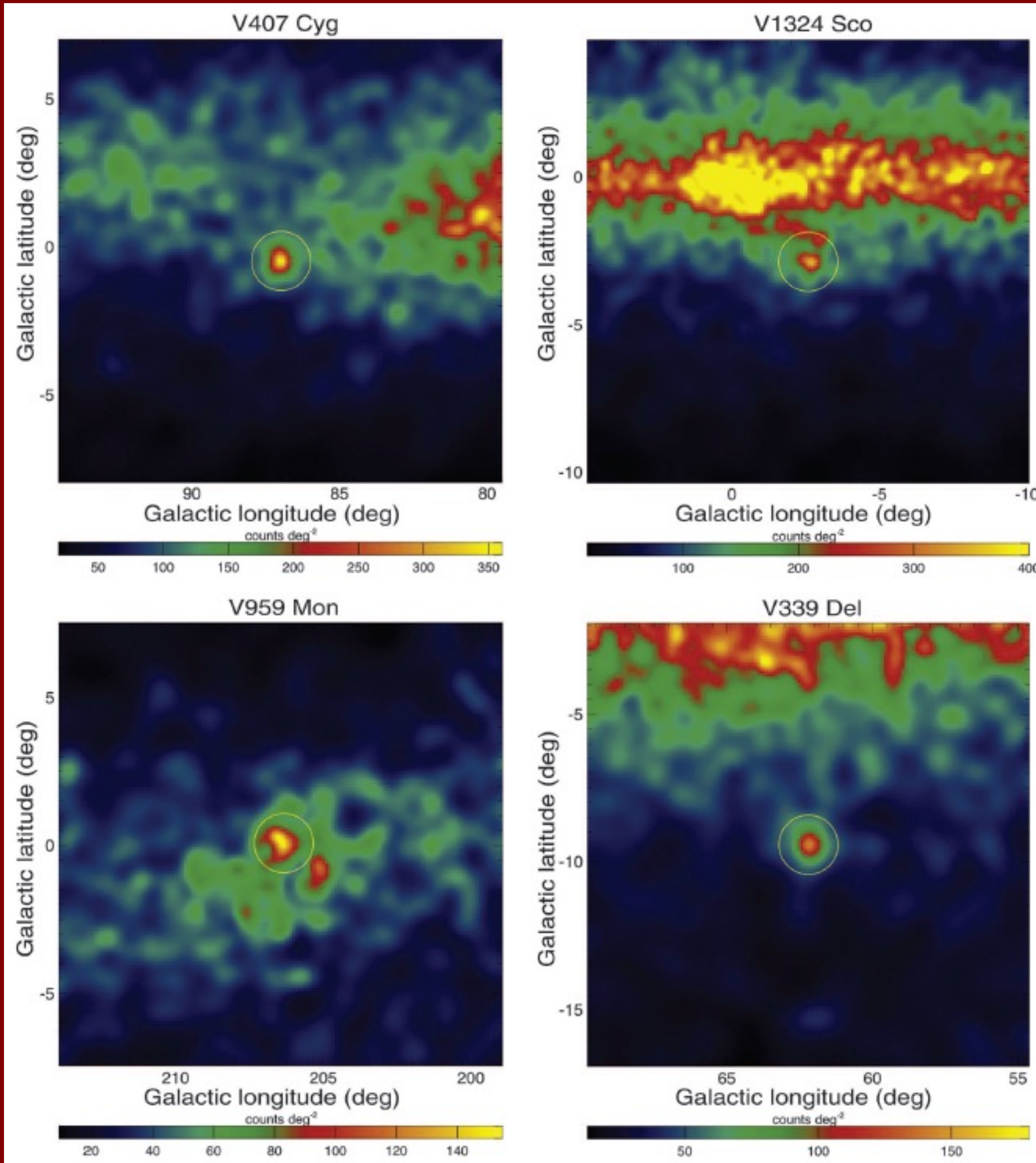
Upper limit estimated from expansion velocity & time, plus distance.

25% of all novae show evidence for non-thermal emission ($T_B > 5x10^4$ K).





Chomiuk+ 2021

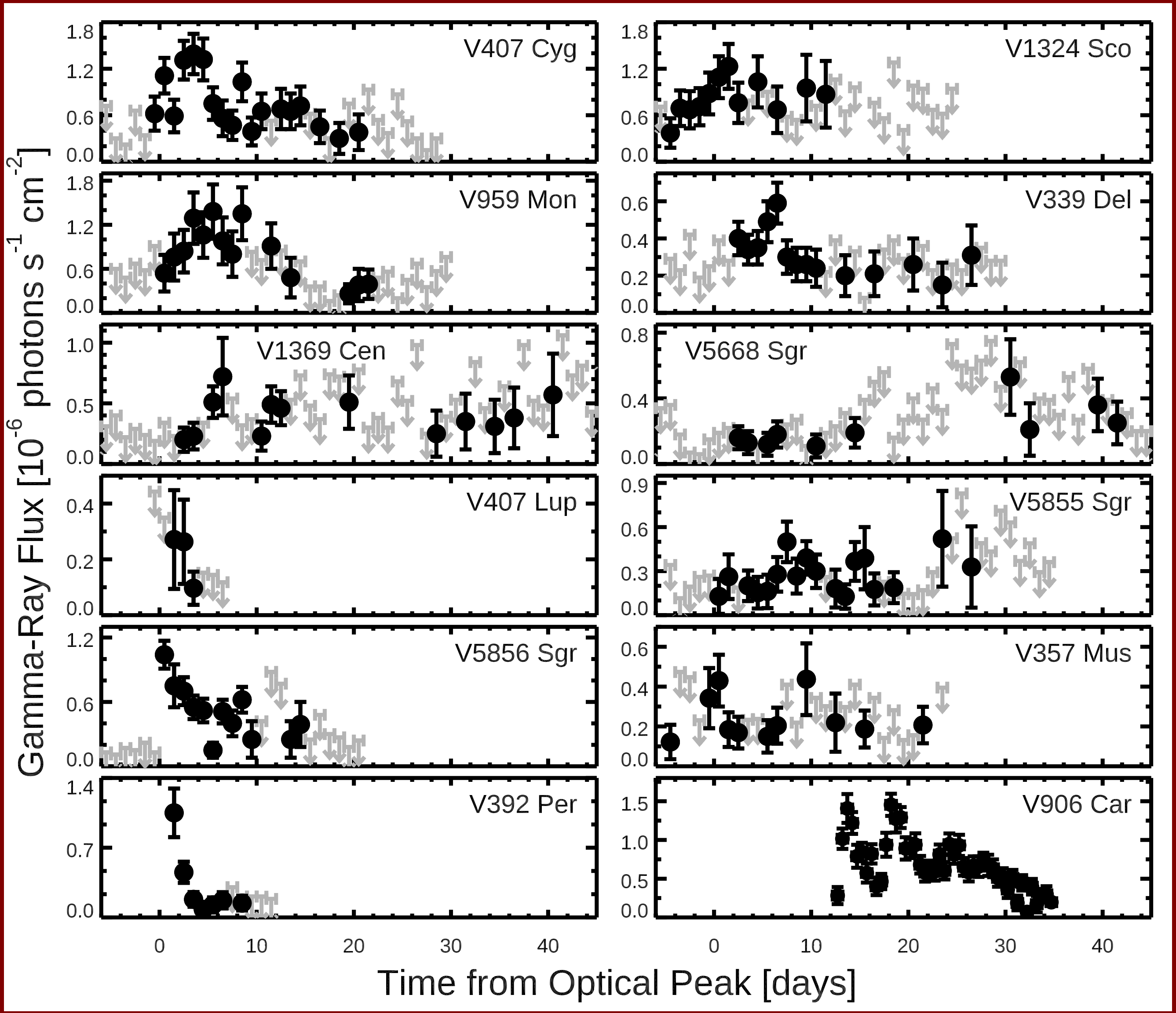


GeV γ-rays detected from novae!

Fermi Gamma-ray Space Telescope

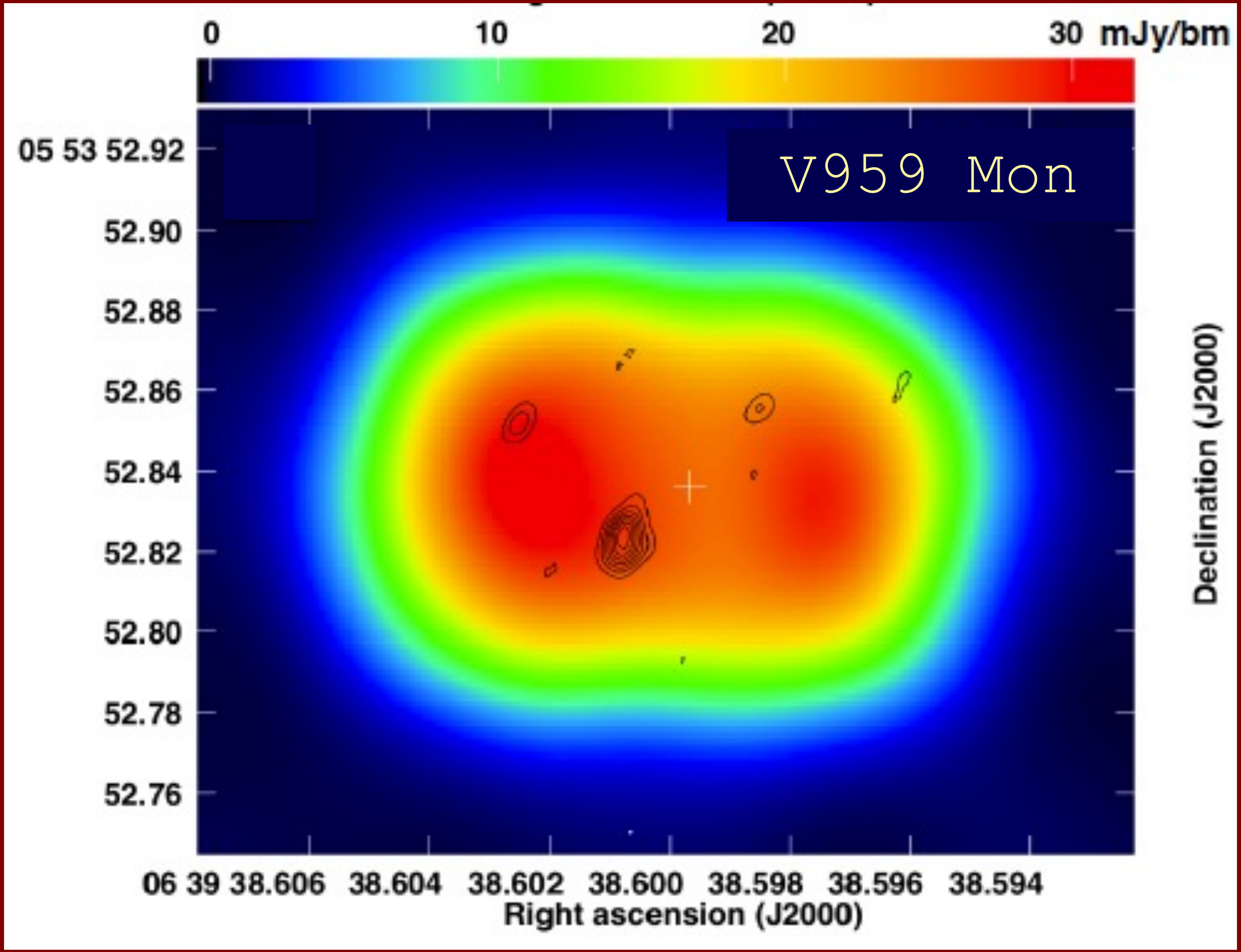
Abdo et al. 2010, Ackermann et al. 2014

21 novae detected by *Fermi*/LAT since 2010



Chomiuk, Metzger, & Shen 2021

VLBI is only sensitive to higher T_B ($>10^6$ K).

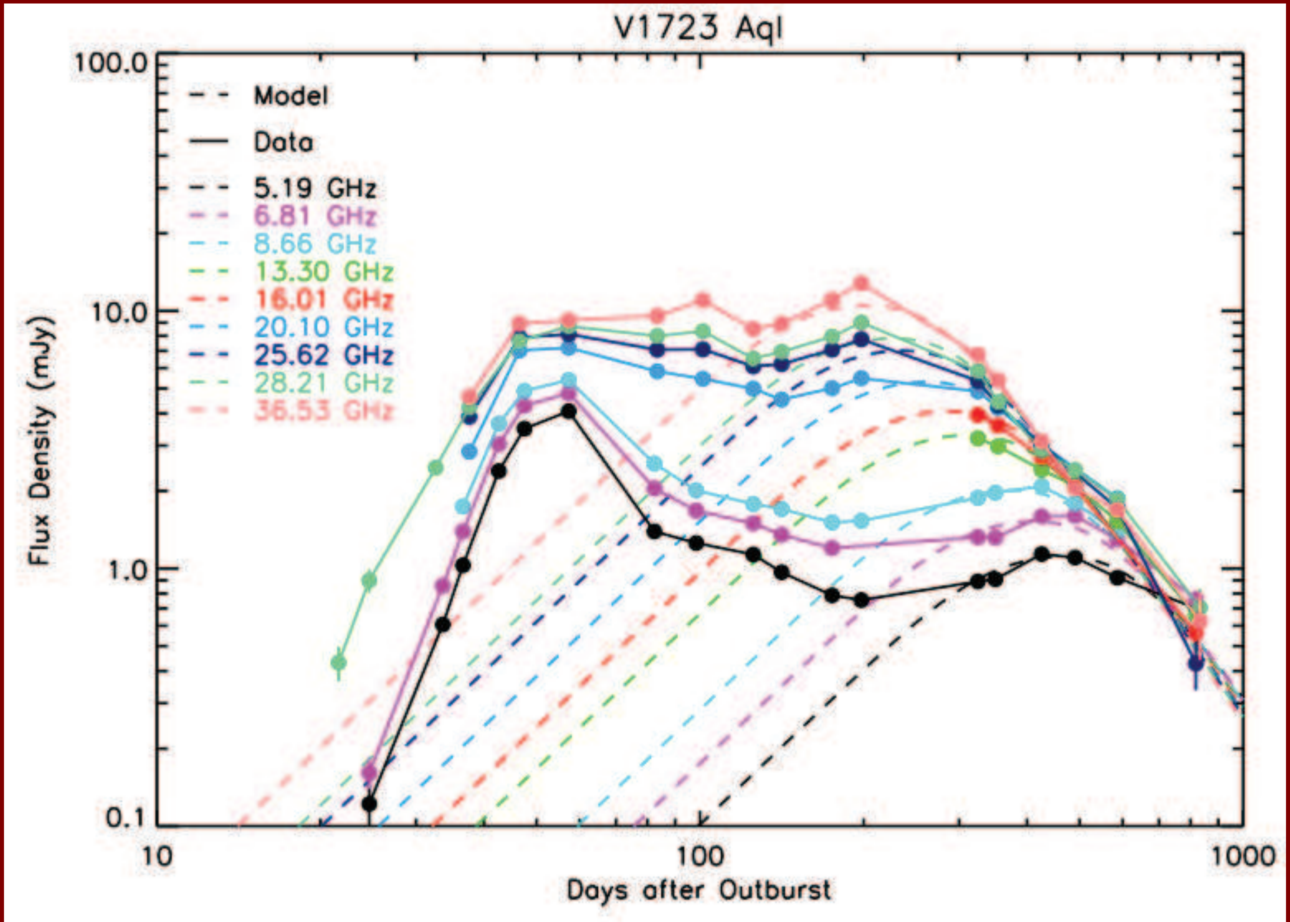


black: 5 GHz synchrotron from EVN (VLBI)
color: 36 GHz thermal from VLA

Nova shocks are internal to the ejecta

(low density CSM for main-sequence companions)

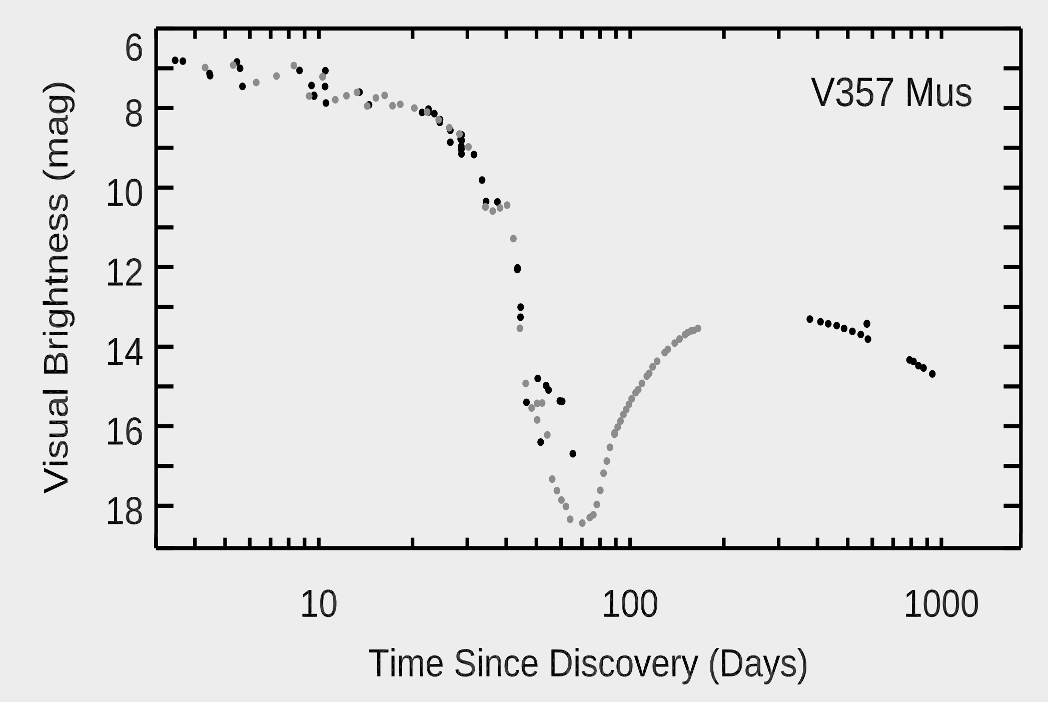
Next steps:

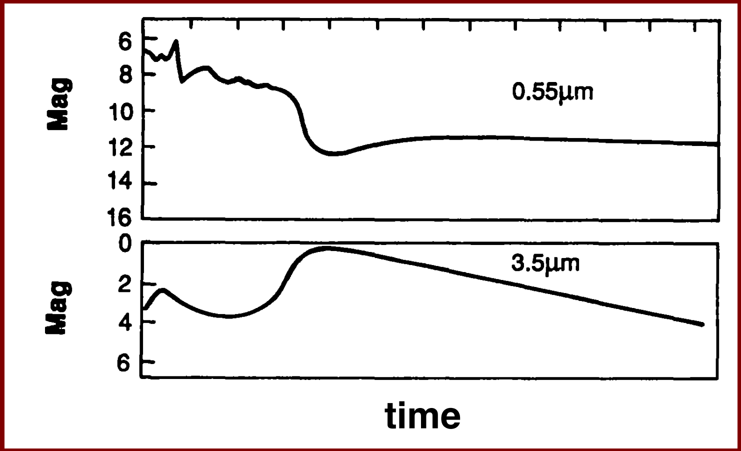


Weston+ 2014

1) Fit thermal models
2) Measure ejecta mass
3) Determine synchrotron luminosity
4) Compare with γ-ray luminosity/duration

How do novae form dust in the warm, irradiated ejecta?





Chomiuk et al. 2021, Gehrz et al. 1988

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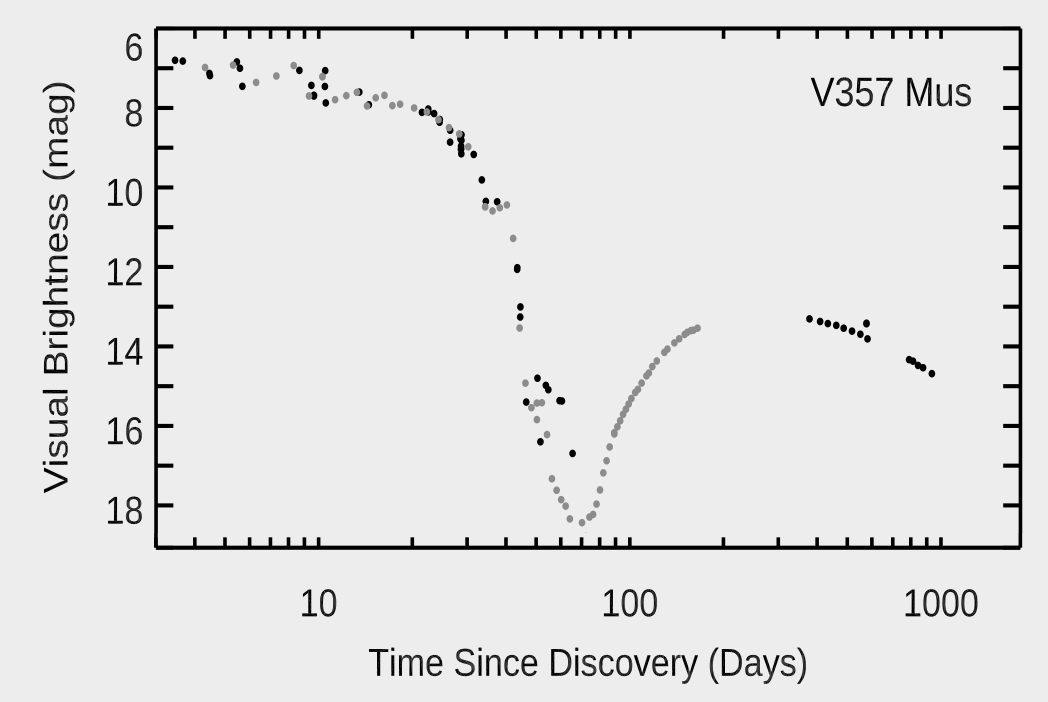
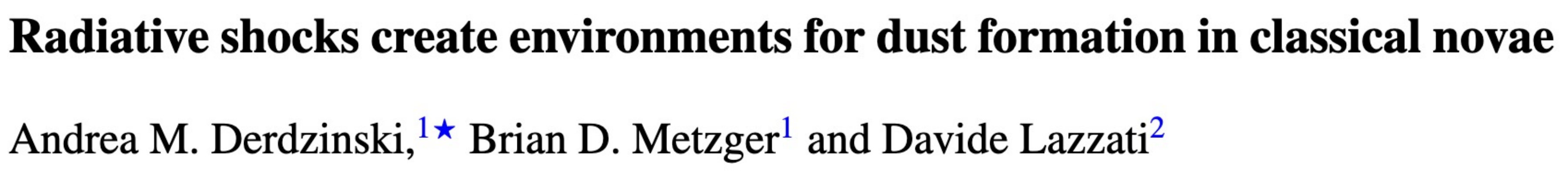
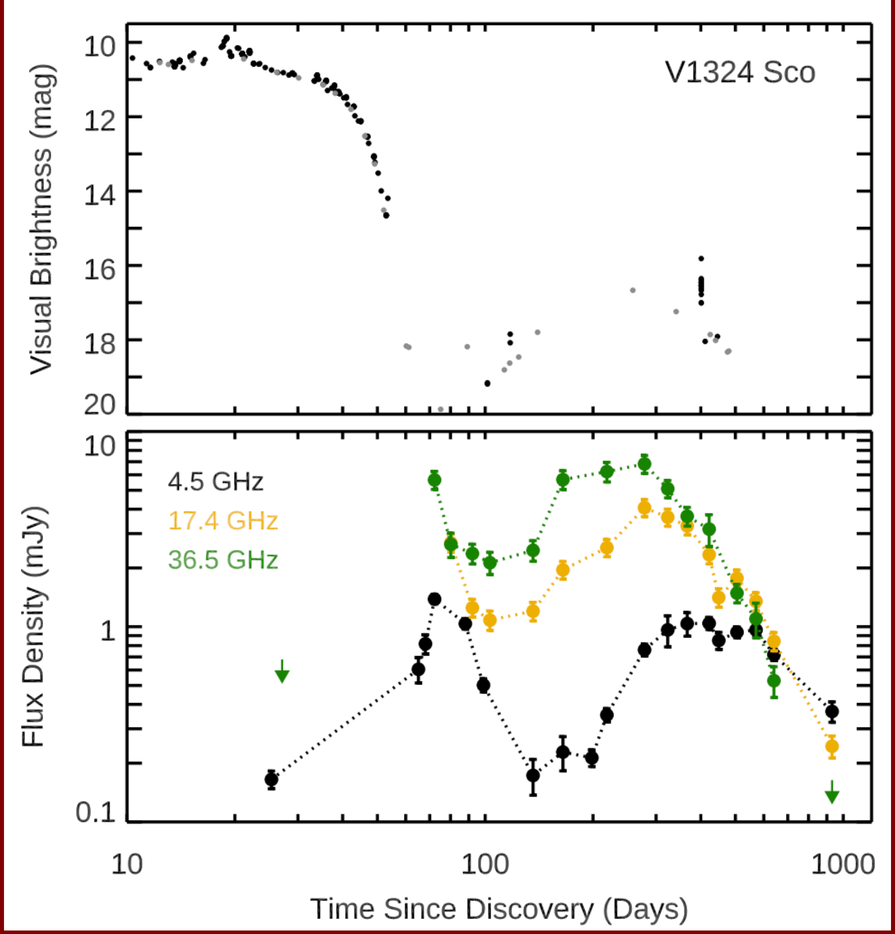


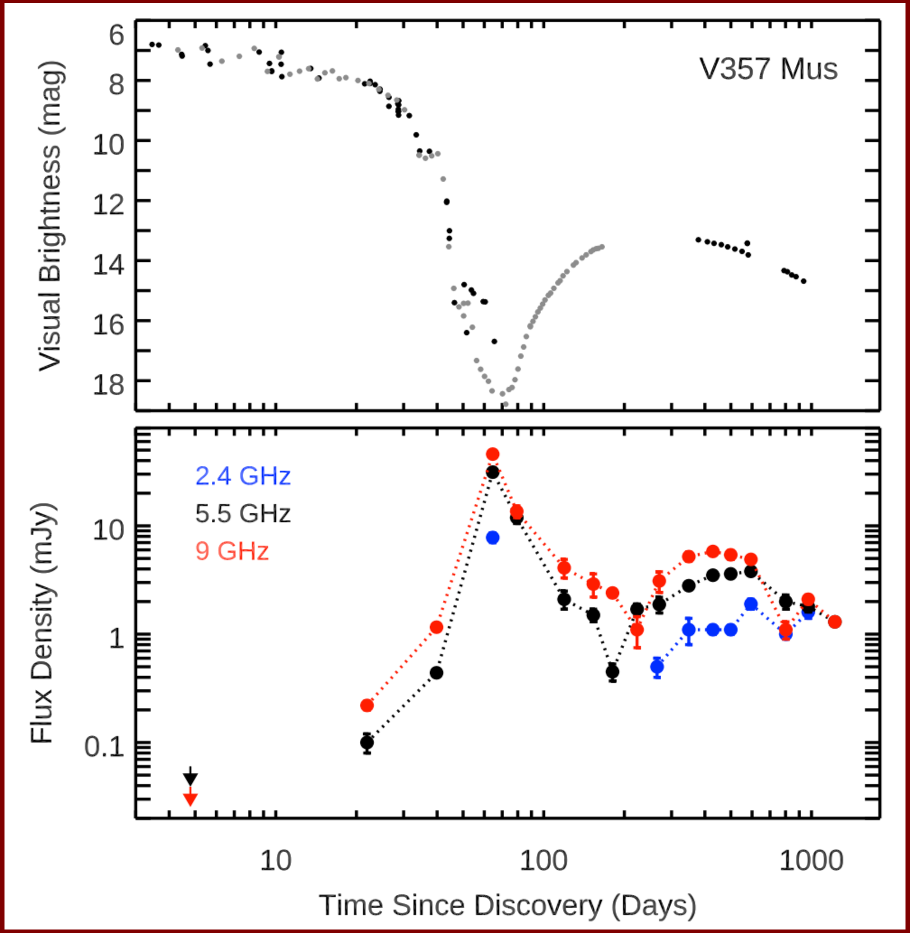
A theoretical prediction:


Radiative shocks create environments for dust formation in classical novae

Andrea M. Derdzinski,[1★] Brian D. Metzger[1] and Davide Lazzati[2]

Synchrotron radio peaks (sometimes) coincide with dust dips!

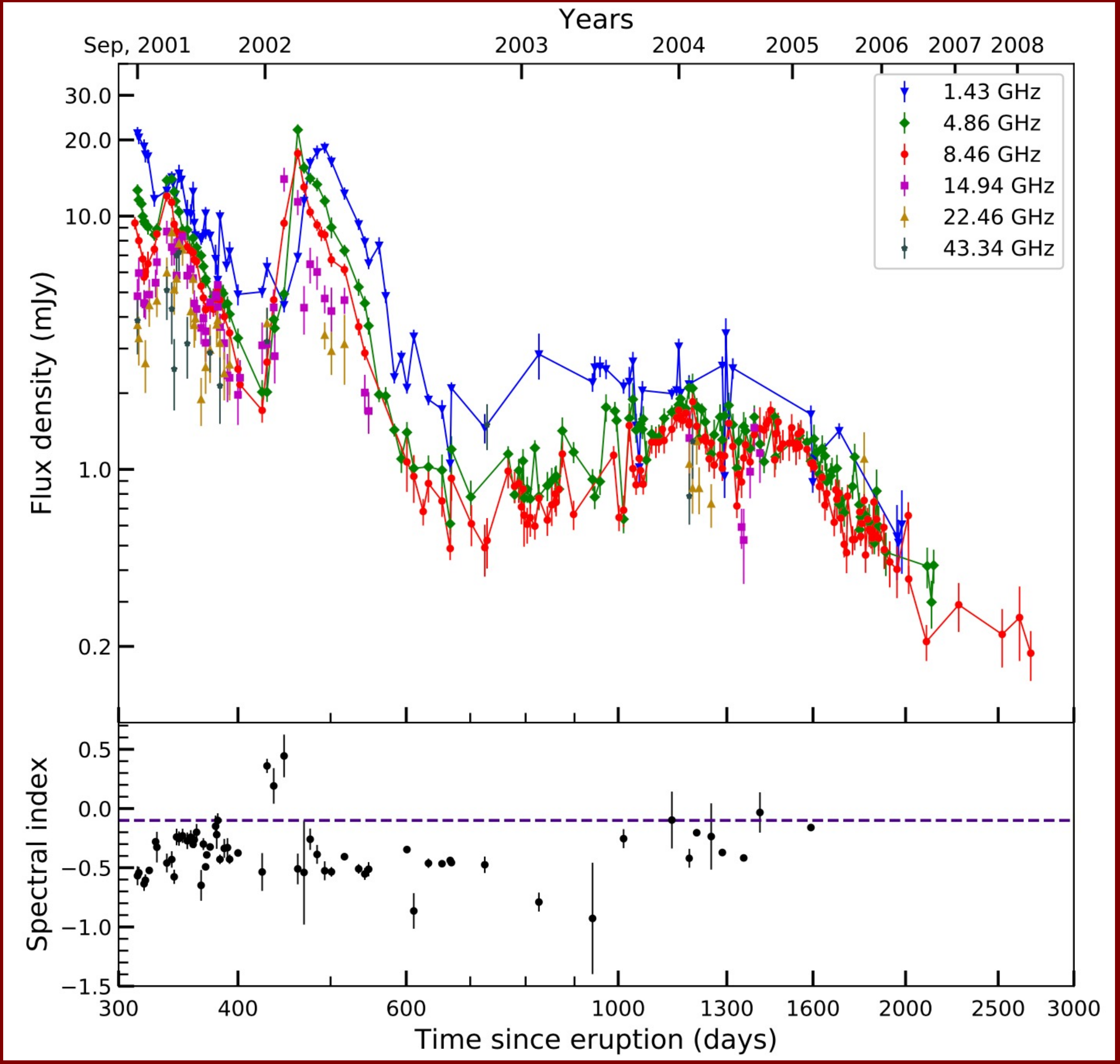




Radiative shocks create environments for dust formation in classical novae

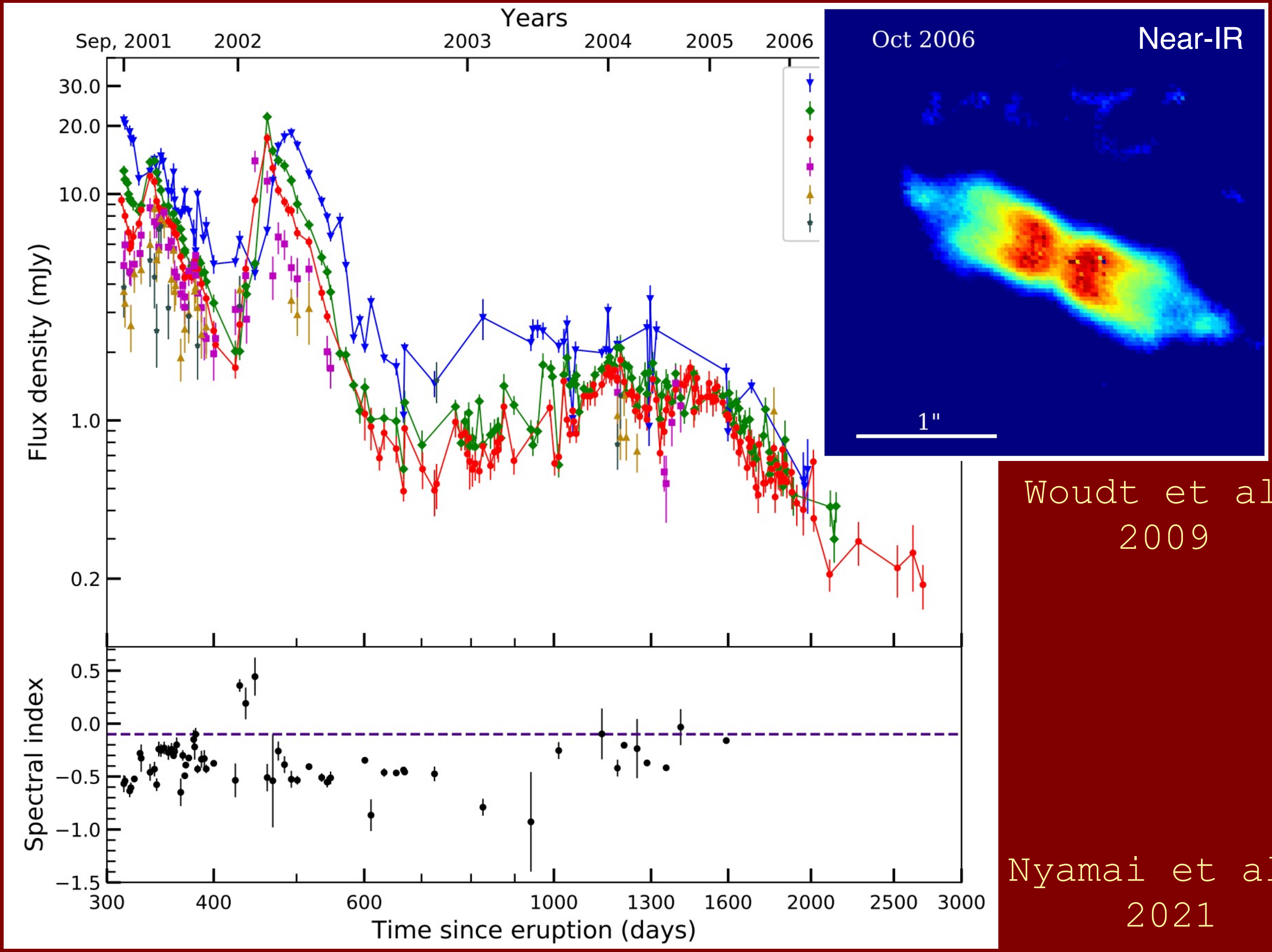
Andrea M. Derdzinski,[1★] Brian D. Metzger[1] and Davide Lazzati[2]

The unique synchrotron-dominated light curve of the unique He nova V445 Pup



Nyamai et al. 2021

The unique synchrotron-dominated light curve of the unique He nova V445 Pup



Woudt et al. 2009

Nyamai et al. 2021

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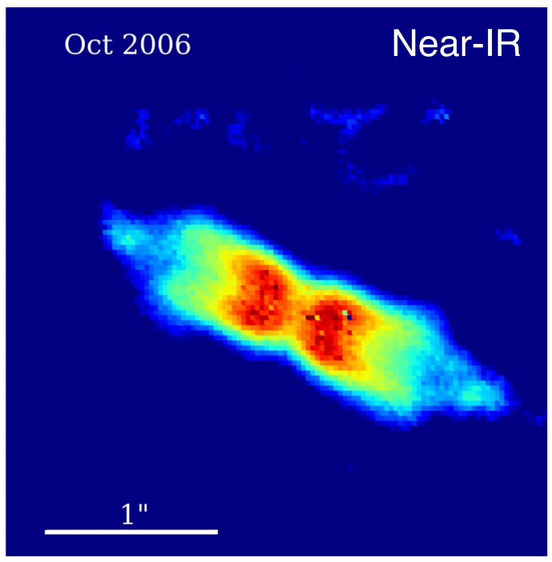
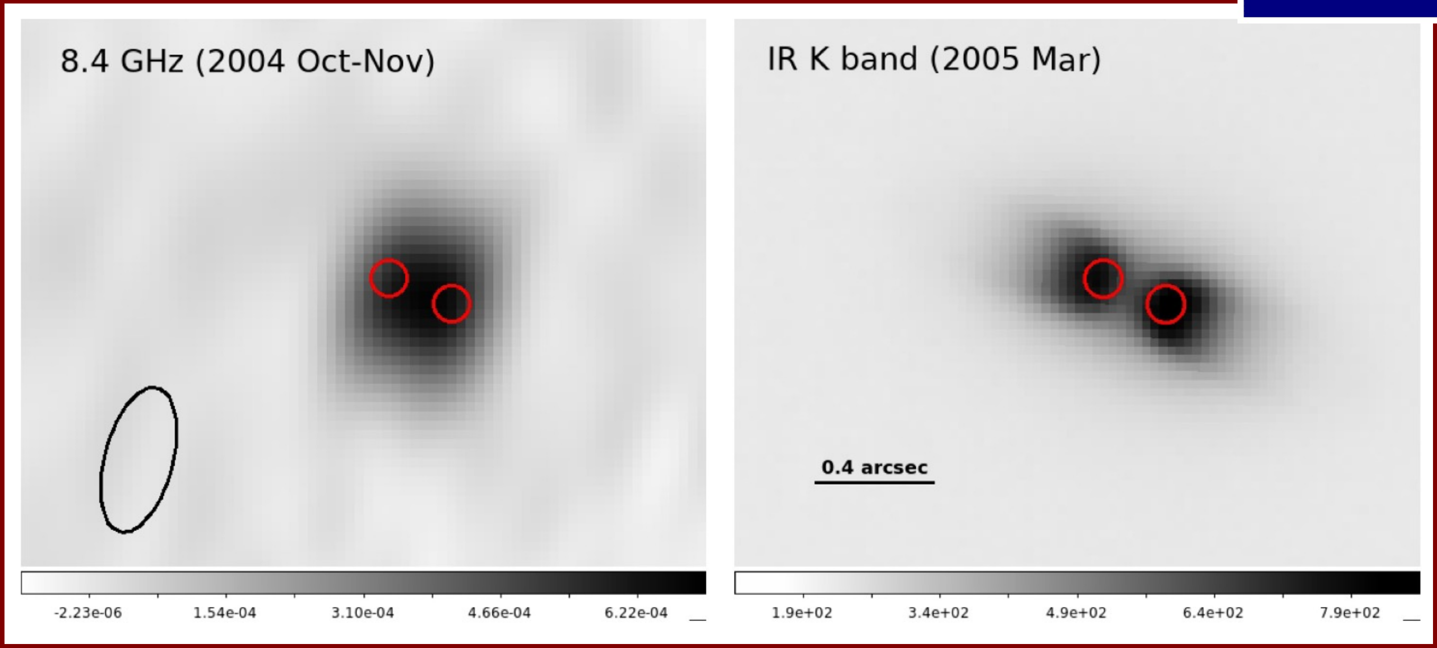
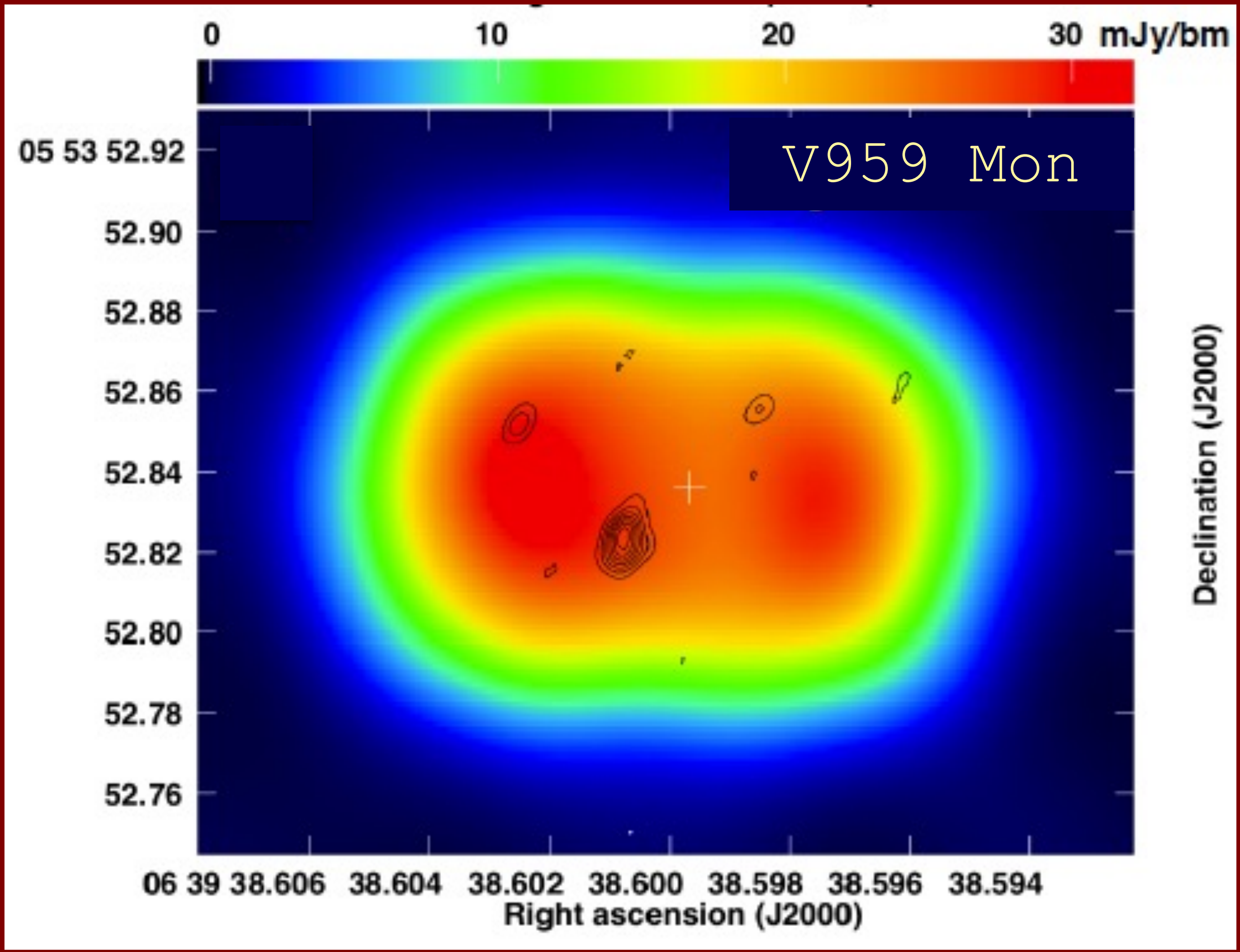


Woudt et al. 2009



Nyamai et al. 2021

Next steps:



Do this better & regularly, all in one go with ngVLA!