Women & Gender Minorities @ FOE Gathering

Tomorrow (Thursday)

6pm

Mitch's Tavern

2426 Hillsborough

A Shocking Shift in Paradigm for Classical Novae

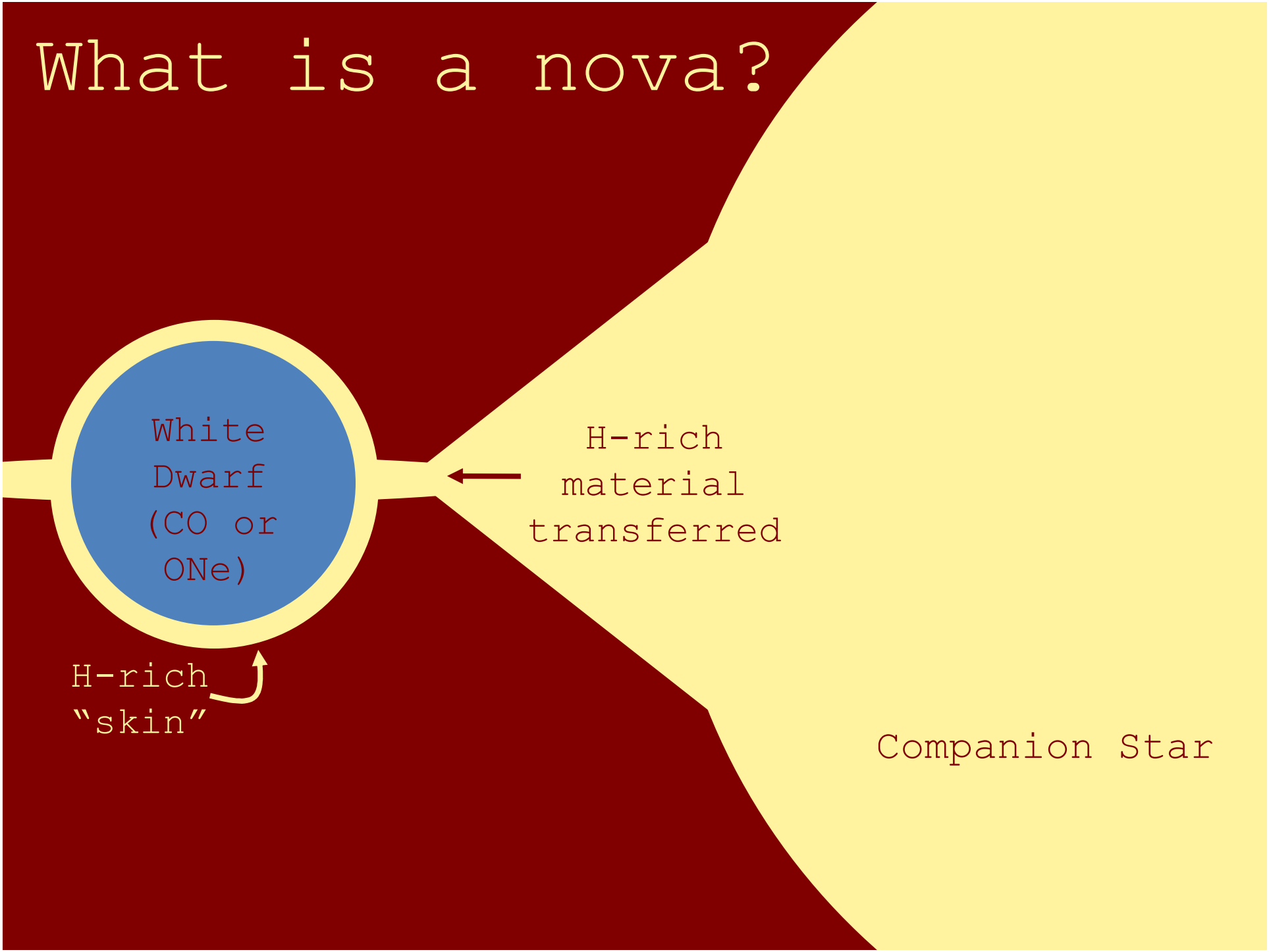
Laura Chomiuk
Michigan State University

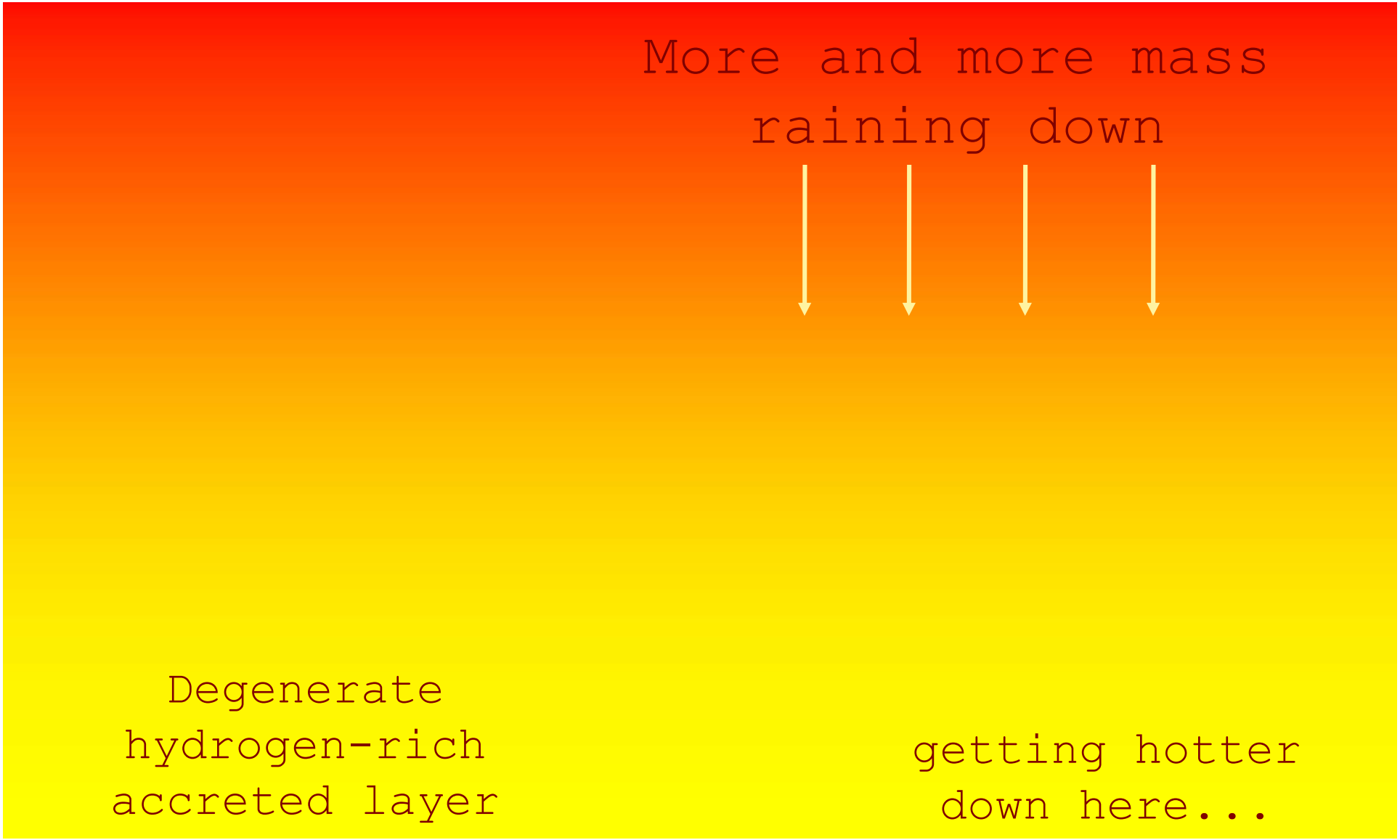
with:
Elias Aydi,
Ray Li,
Justin Linford,
Brian Metzger,
Koji Mukai,
Ondrej Pejcha,
Ken Shen,
Jeno Sokoloski,
Kirill Sokolovsky,
Elad Steinberg,
Indrek Vurm,
& friends

Why novae?

- Nearby, common, bright
- Potential progenitors of Type Ia supernovae
- The newest (and least understood) class of γ-ray sources
- Wonderful laboratories for understanding shock-powered and dusty transients (SNe IIn, SLSN, stellar mergers, SPRITEs…)

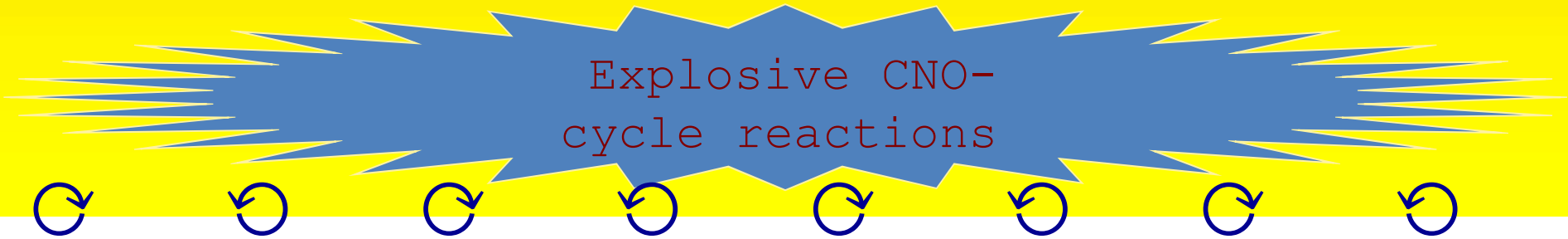
What is a nova?



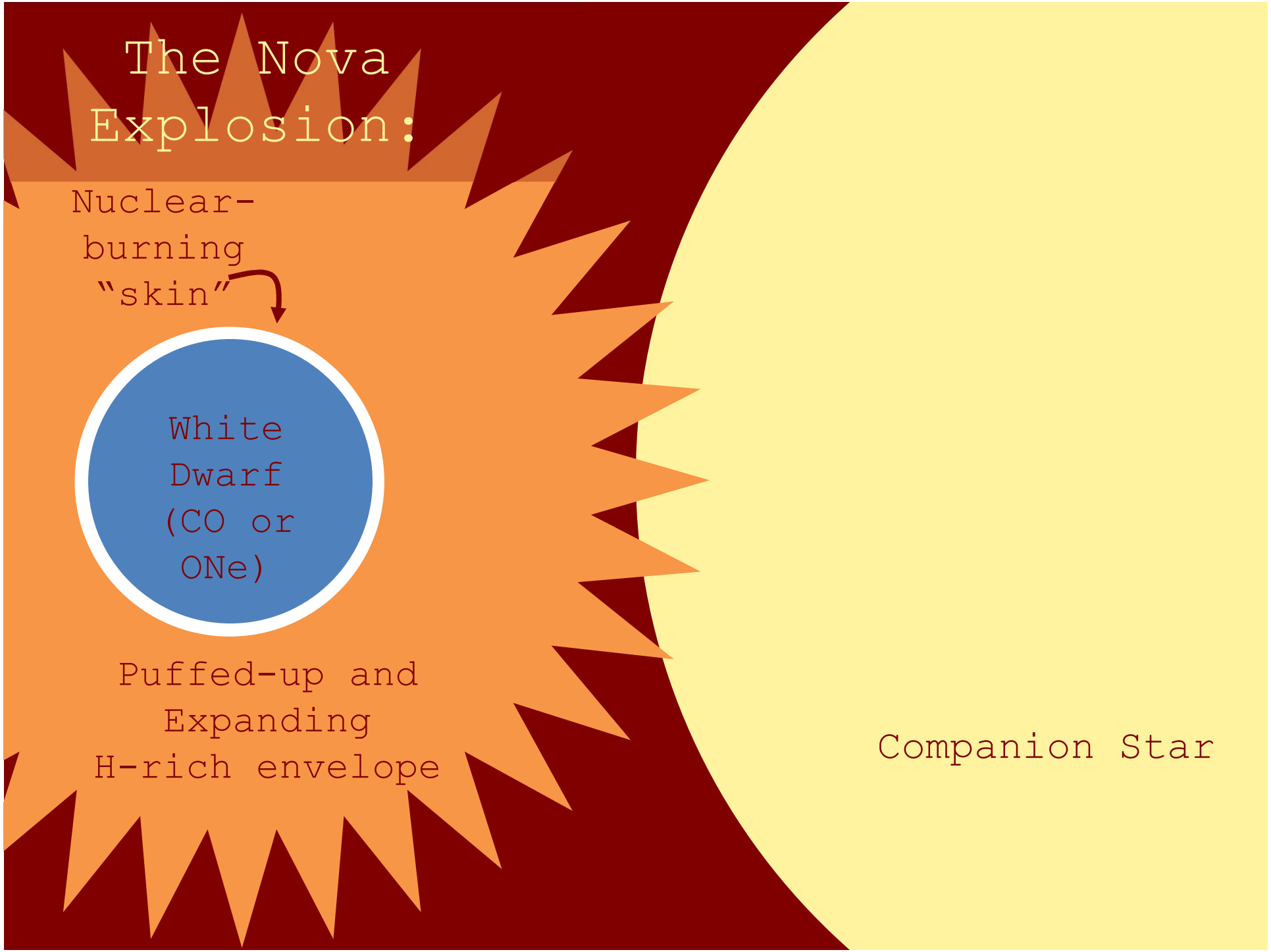

More and more mass
raining down
Degenerate
hydrogen-rich
accreted layer
getting hotter
down here...
White dwarf surface

Until... A nova is born!

Hydrogen-rich
accreted layer

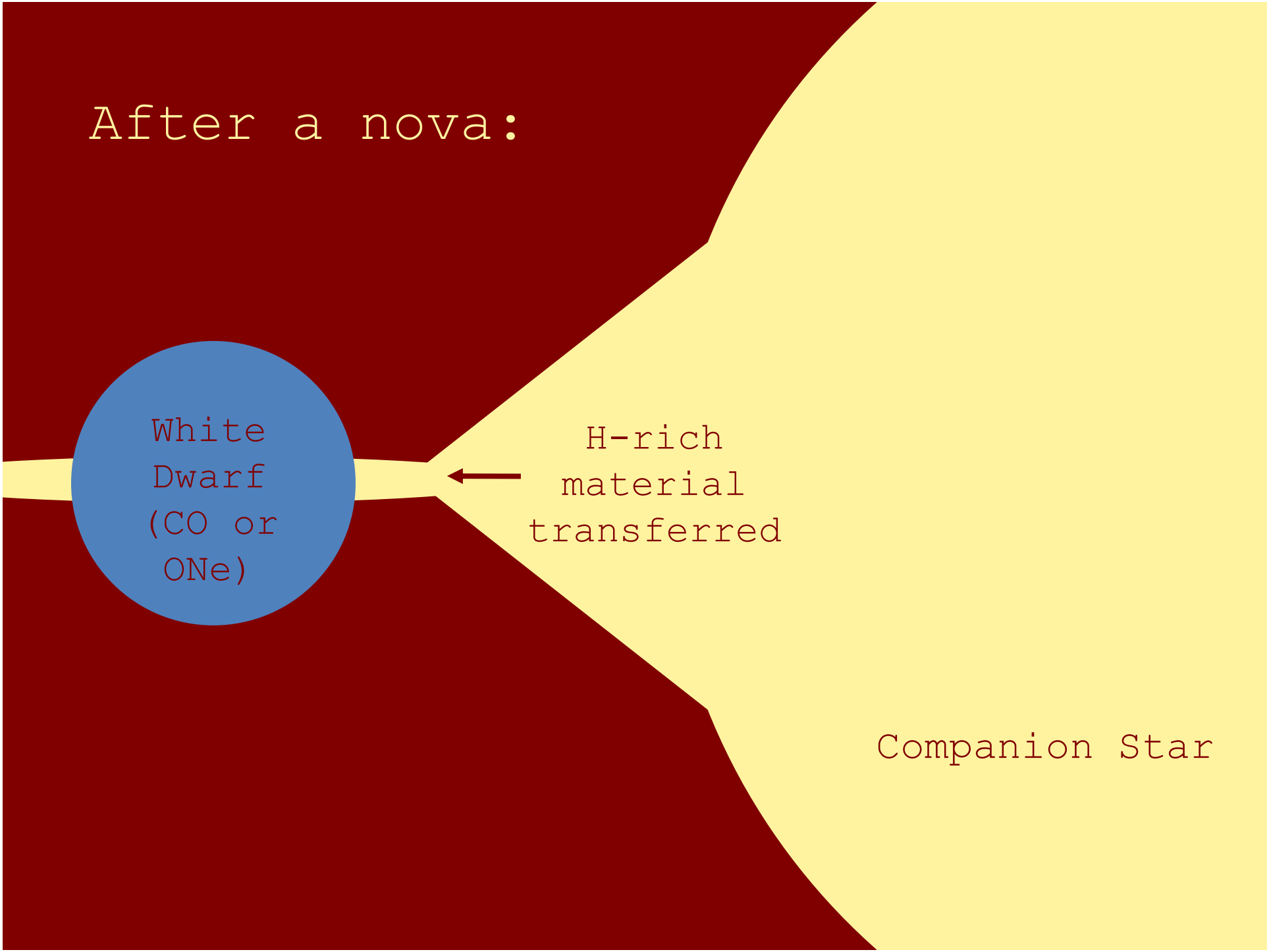


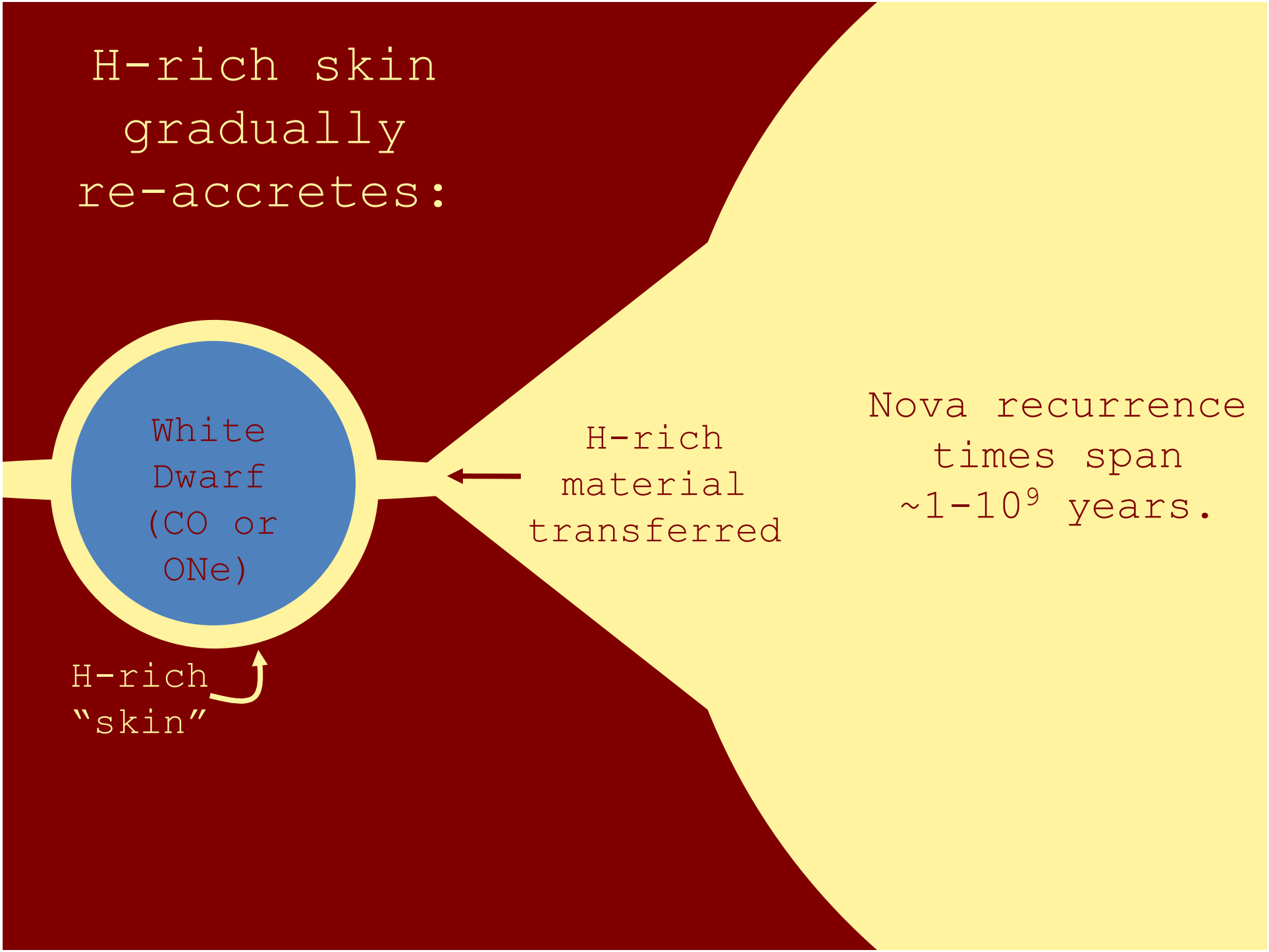
White dwarf surface


The Nova Explosion:
Nuclear-burning "skin"
White Dwarf (CO or ONe)
Puffed-up and Expanding H-rich envelope
Companion Star

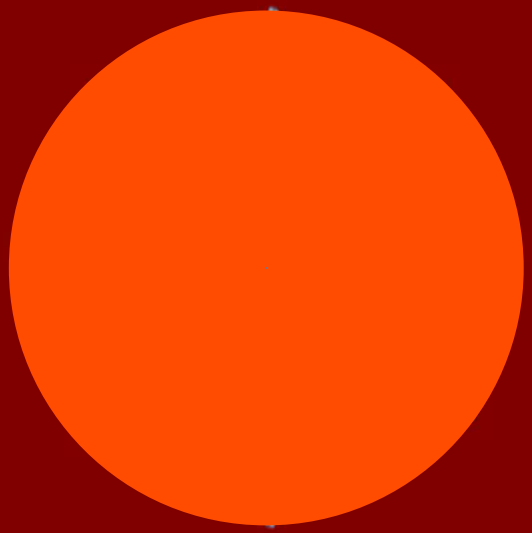
Some Nova Stats:

- 10^{-7}-10^{-3} $M_\odot$ ejected
- At 500-5,000 km/s
- 10^{44}-10^{46} erg
- ~10 novae observed each yr in Milky Way

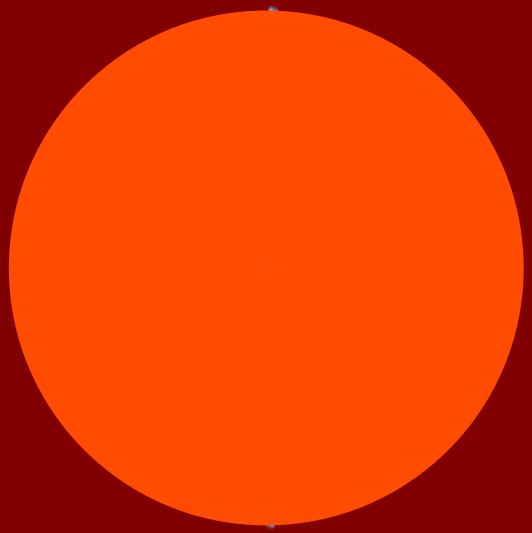

After a nova:
White Dwarf (CO or ONe)
H-rich material transferred
Companion Star


H-rich skin gradually re-accretes:
White Dwarf (CO or ONe)
H-rich material transferred
Nova recurrence times span ~1-10^9 years.
H-rich "skin"

The Paradigm (abridged)

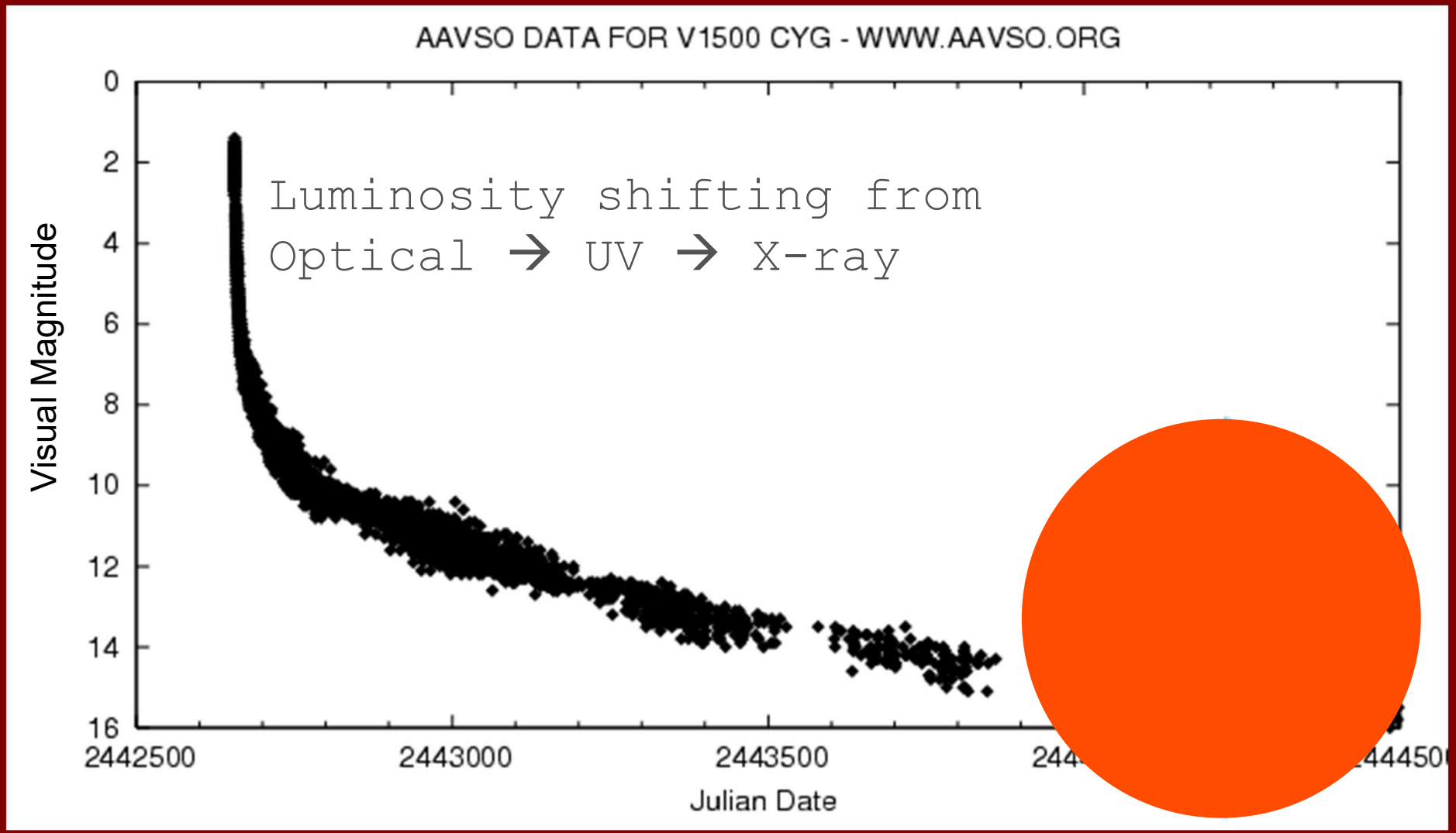


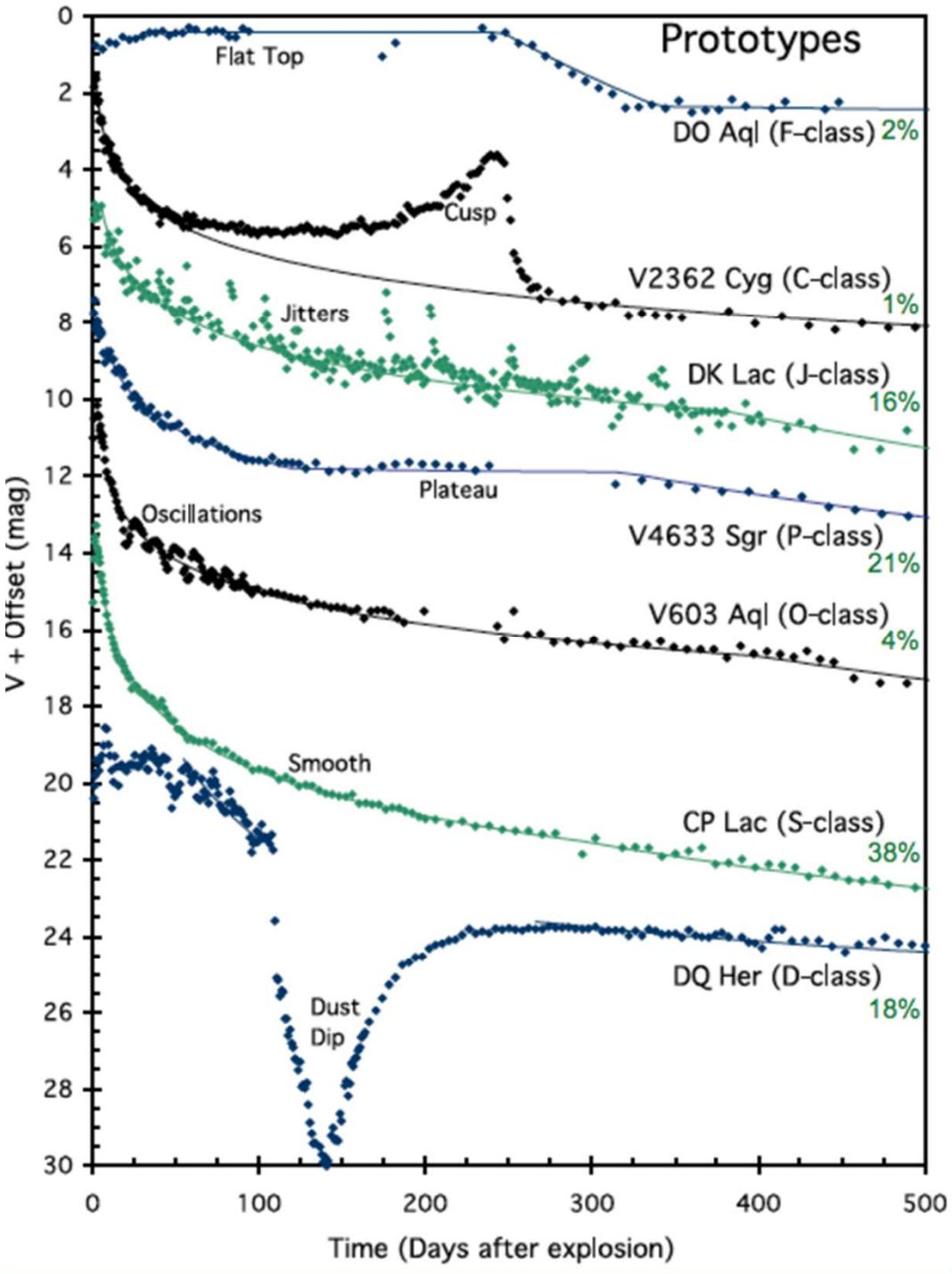
The Paradigm (abridged)



A nova has constant luminosity ($\sim L_{edd,wd}$), powered by the hot white dwarf.

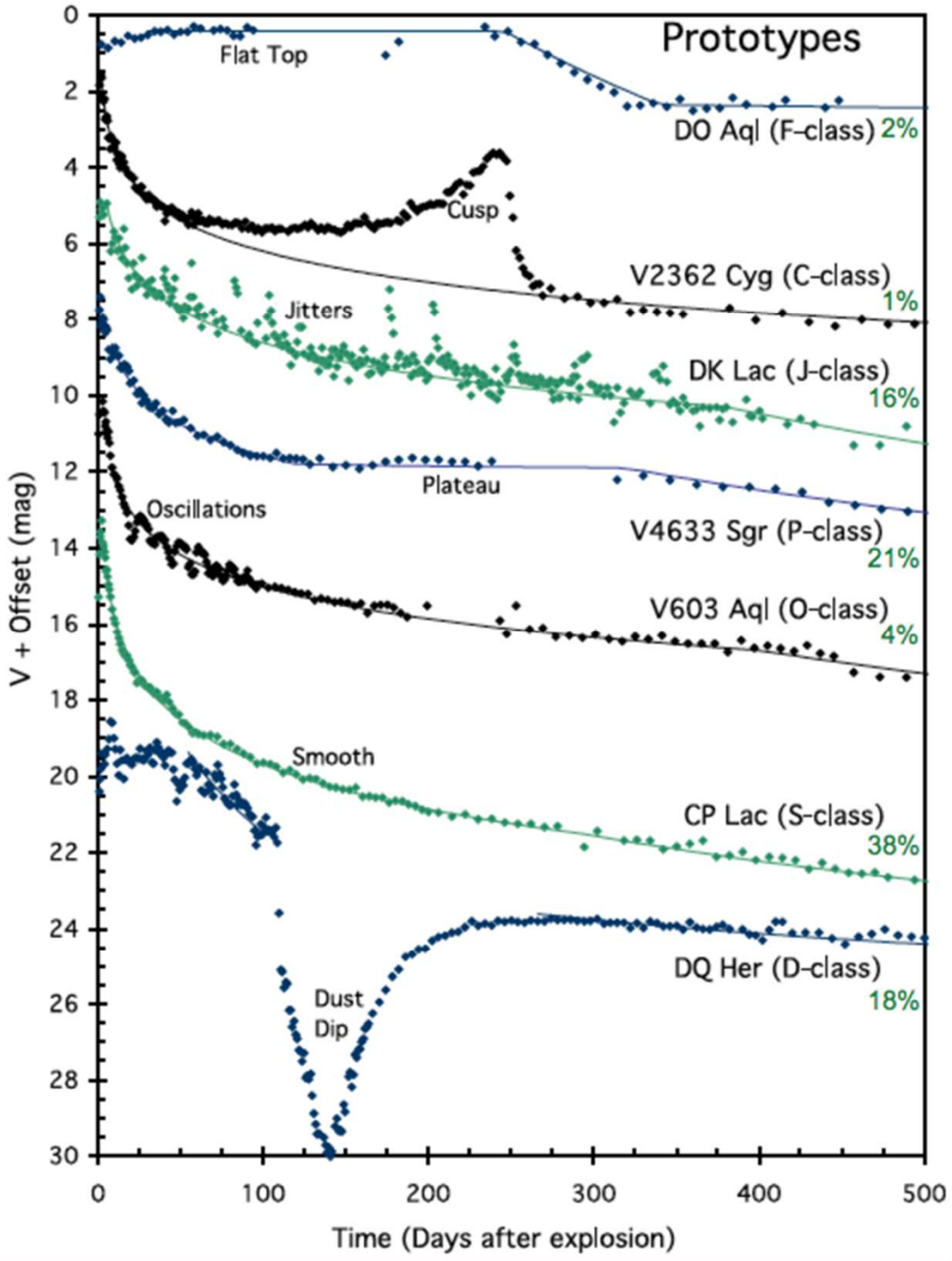
A Well-Behaved Nova Light Curve





But there's a lot of funny business.

Strope et al. 2010

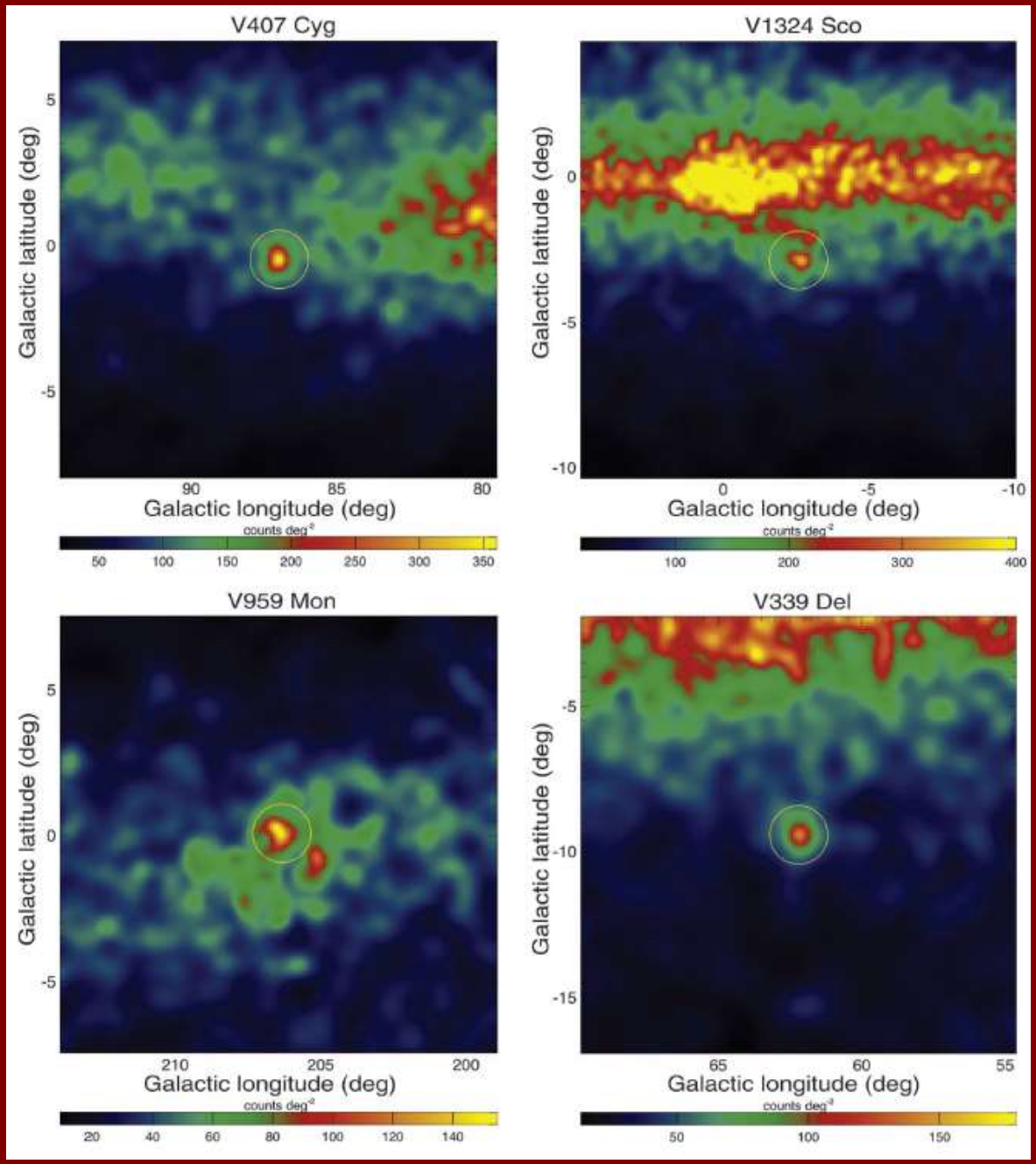


"We understand novae"

Strope et al. 2010

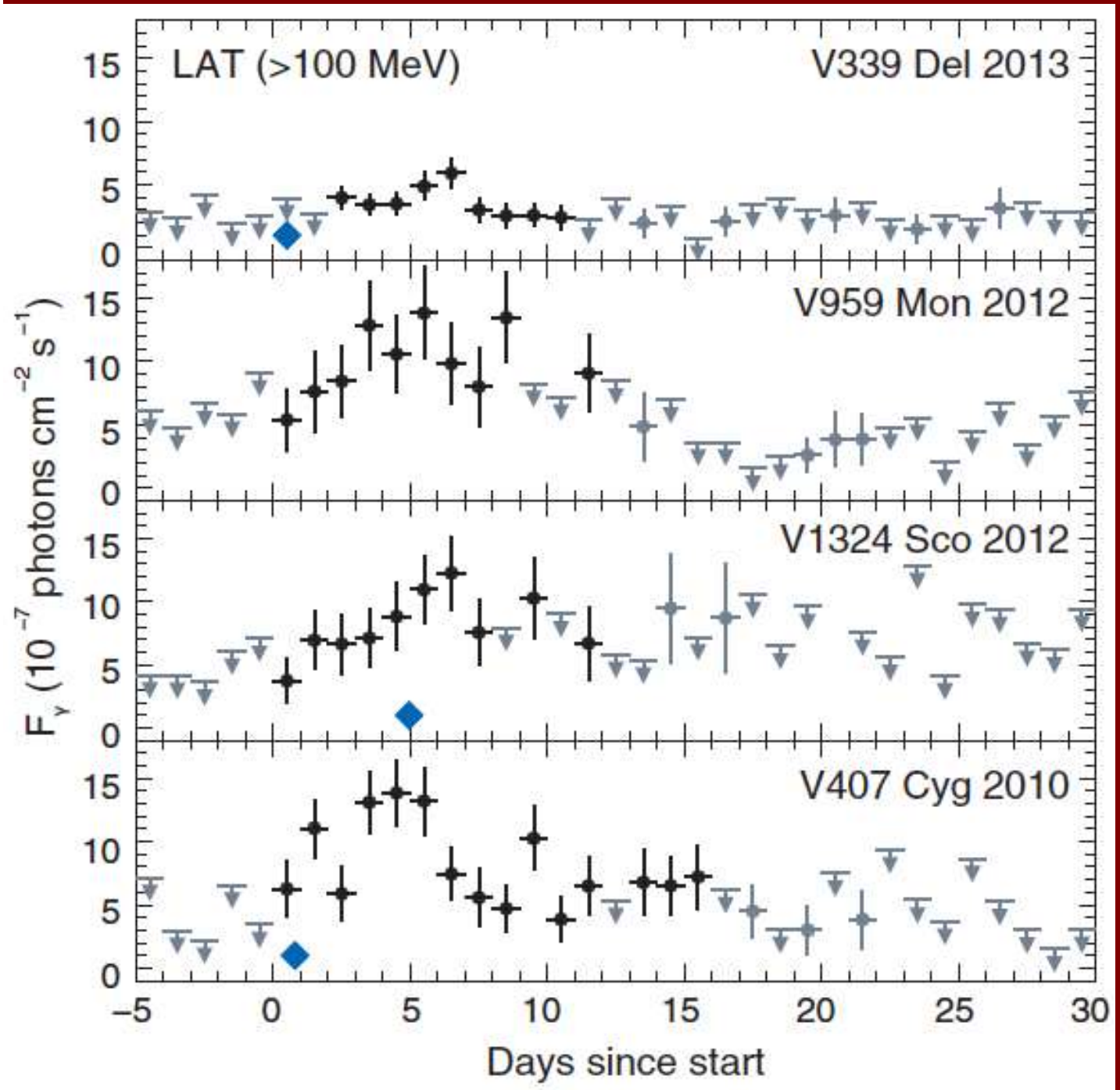
Surprise!

Fermi
Gamma-ray
Space Telescope



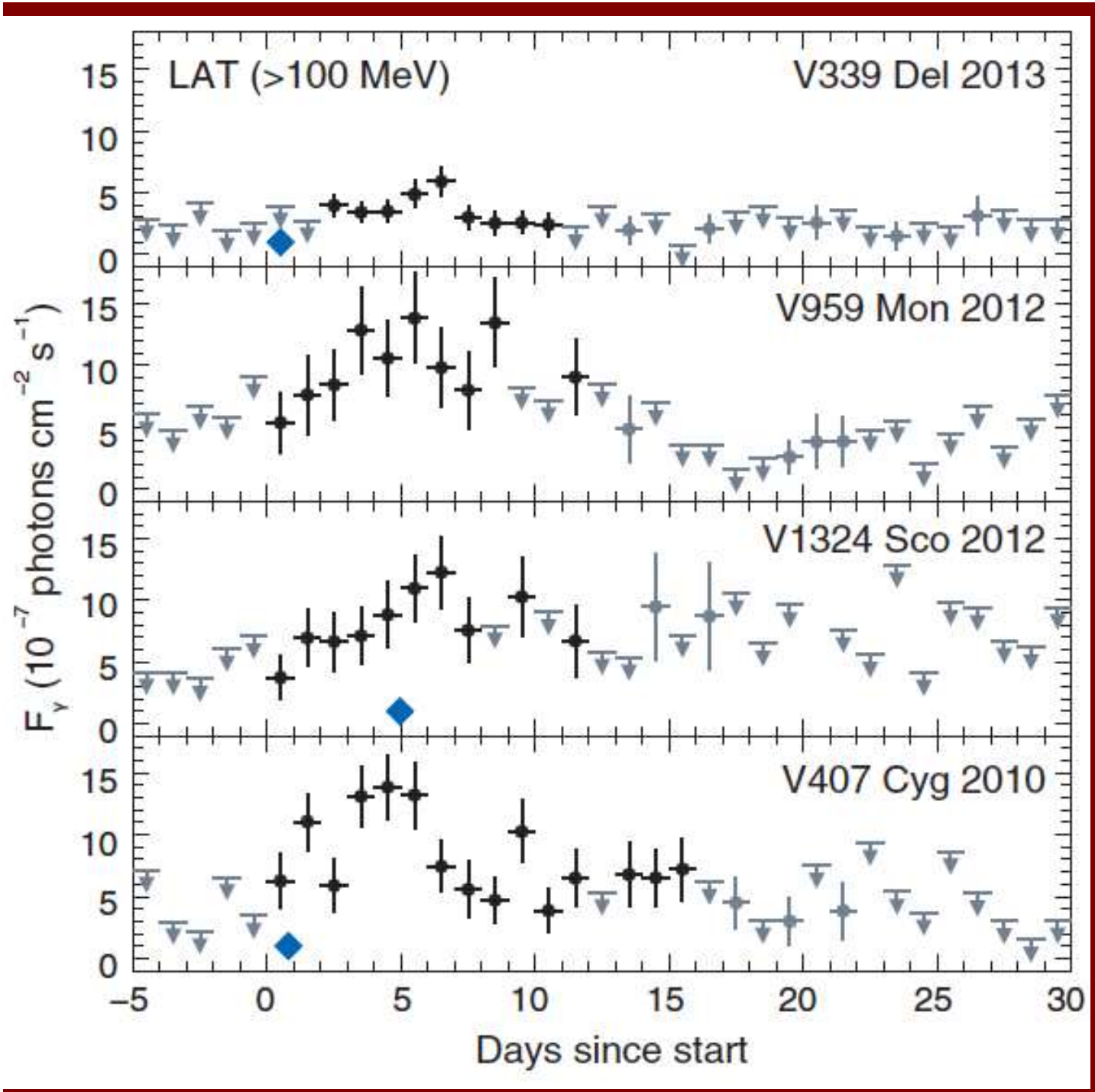
GeV γ-rays detected from 13 novae detected since 2012 with *Fermi*/LAT.

Ackermann et al. 2014



γ-ray duration ~15-55 days around optical max

Ackermann et al. 2014

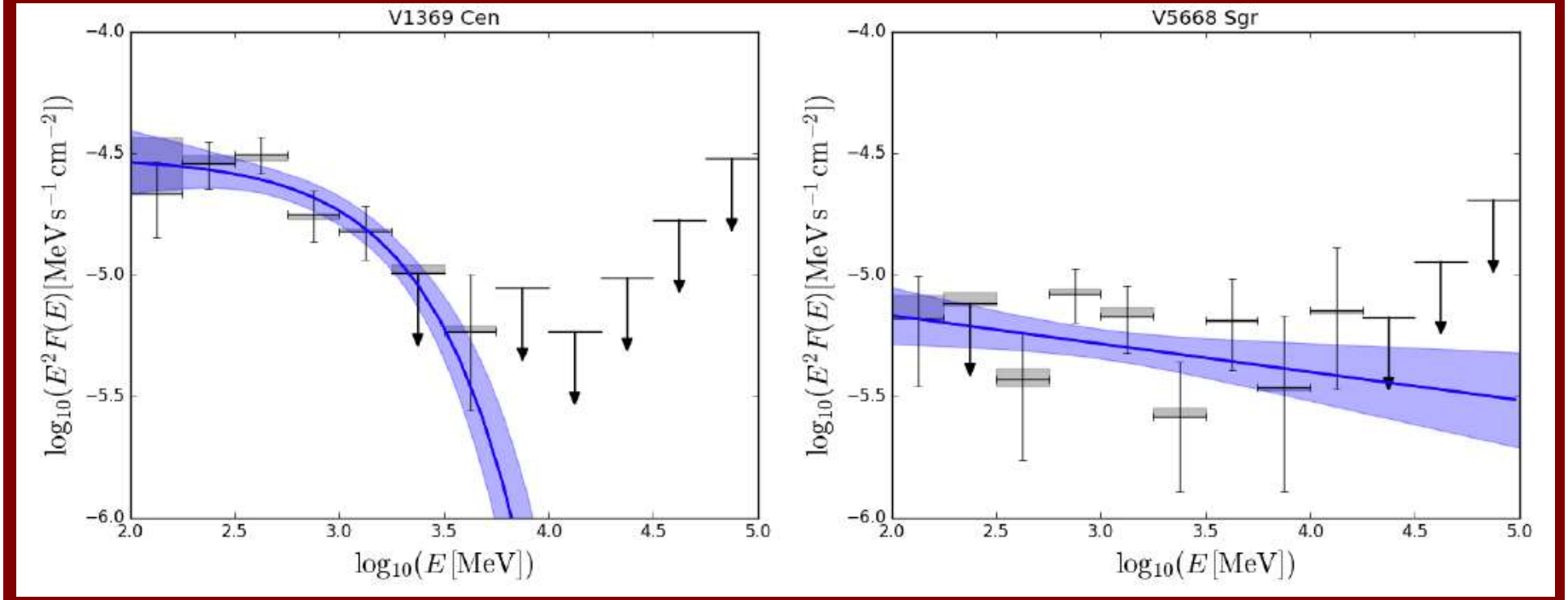


Typical $L_\gamma \approx 10^{35}$–10^{36} erg/s

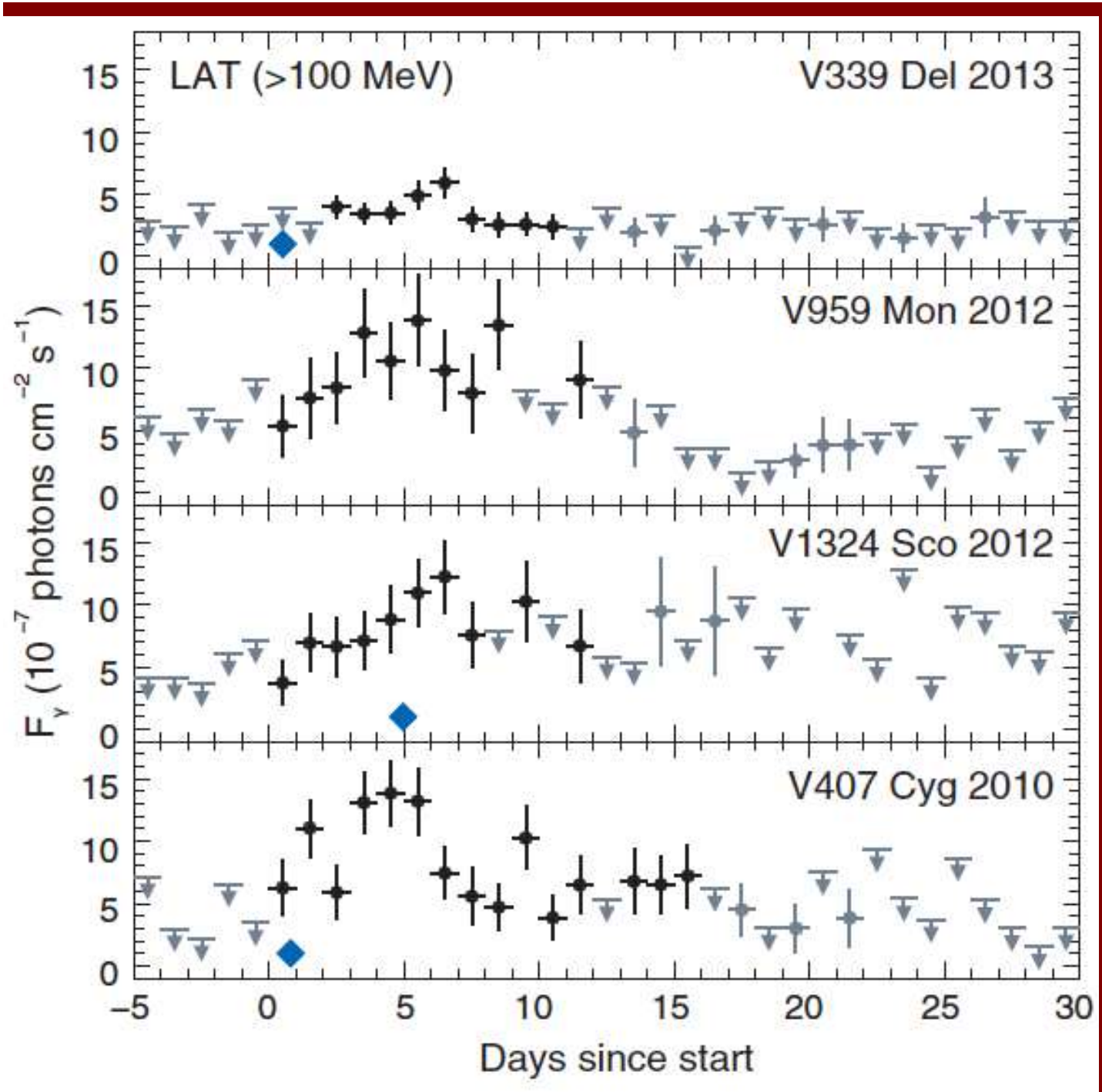
Ackermann et al. 2014

Nova γ-ray spectra extend to ~100 GeV.

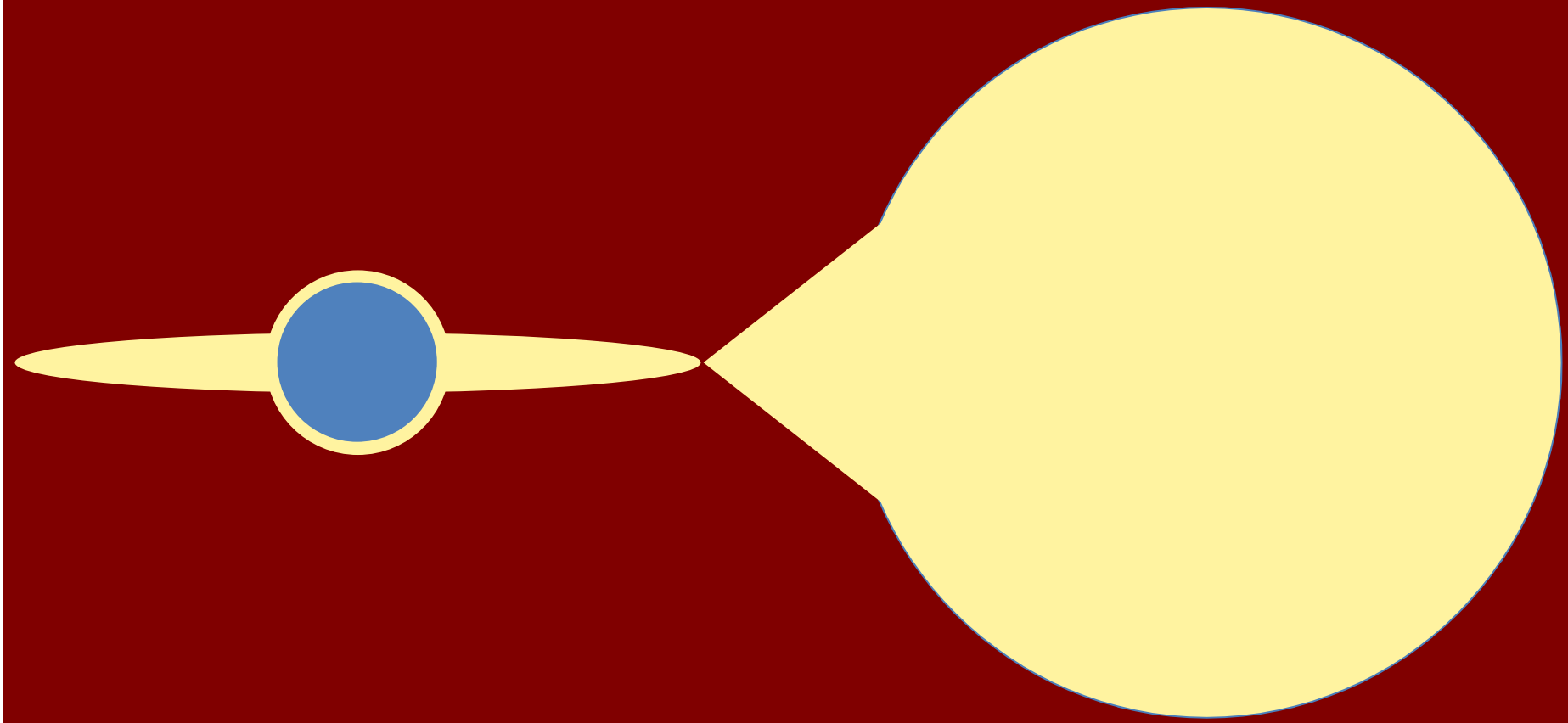
Consistent with leptonic or hadronic origin.



Franckowiak et al. 2018

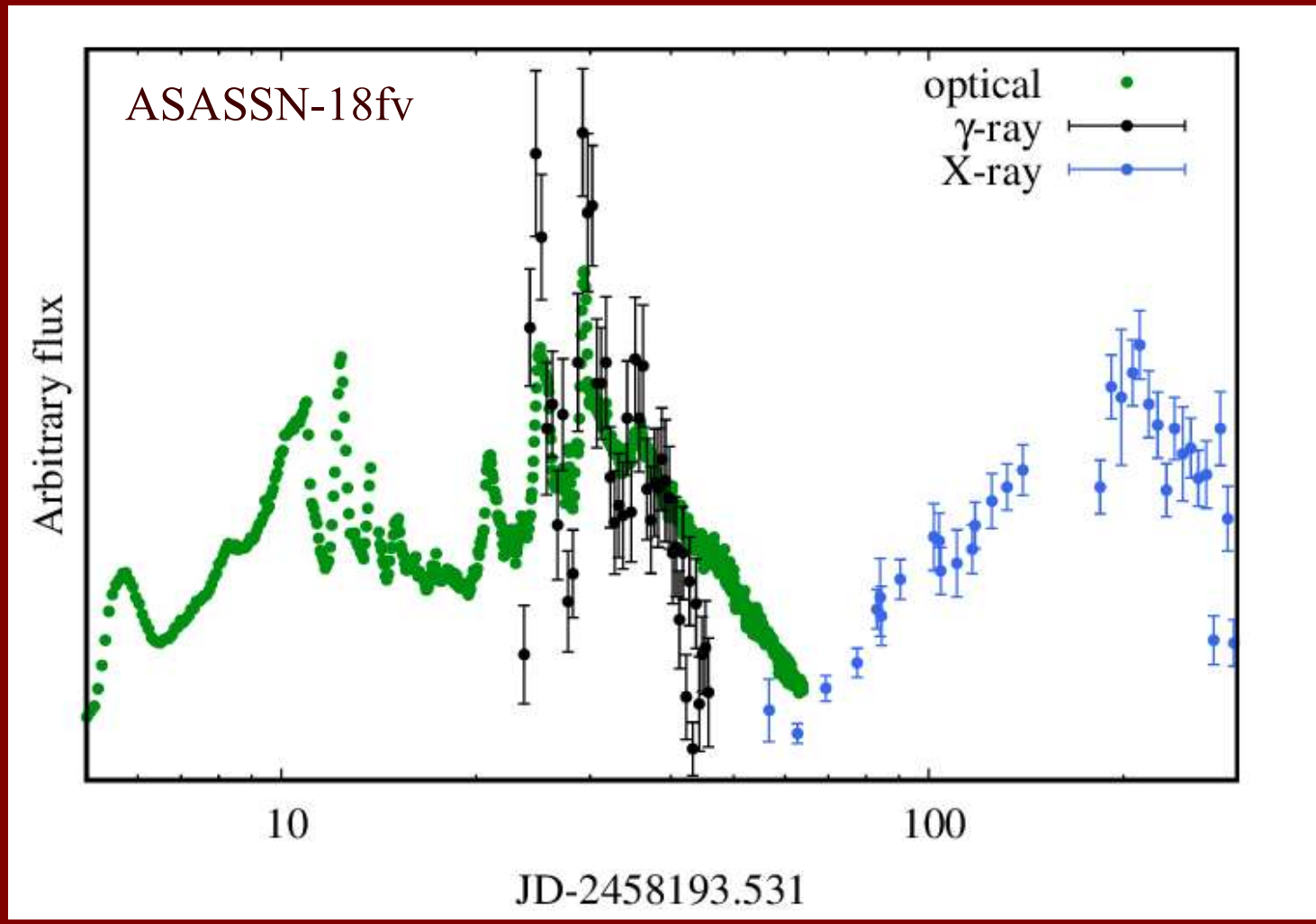

LAT (>100 MeV)
V339 Del 2013
V959 Mon 2012
V1324 Sco 2012
V407 Cyg 2010
F_γ (10^{-7} photons cm^{-2} s^{-1})
Days since start
Main Sequence
Main Sequence
Main Sequence
Mira Giant
Ackermann et al. 2014

WD + Main Sequence binaries
have clean environments.

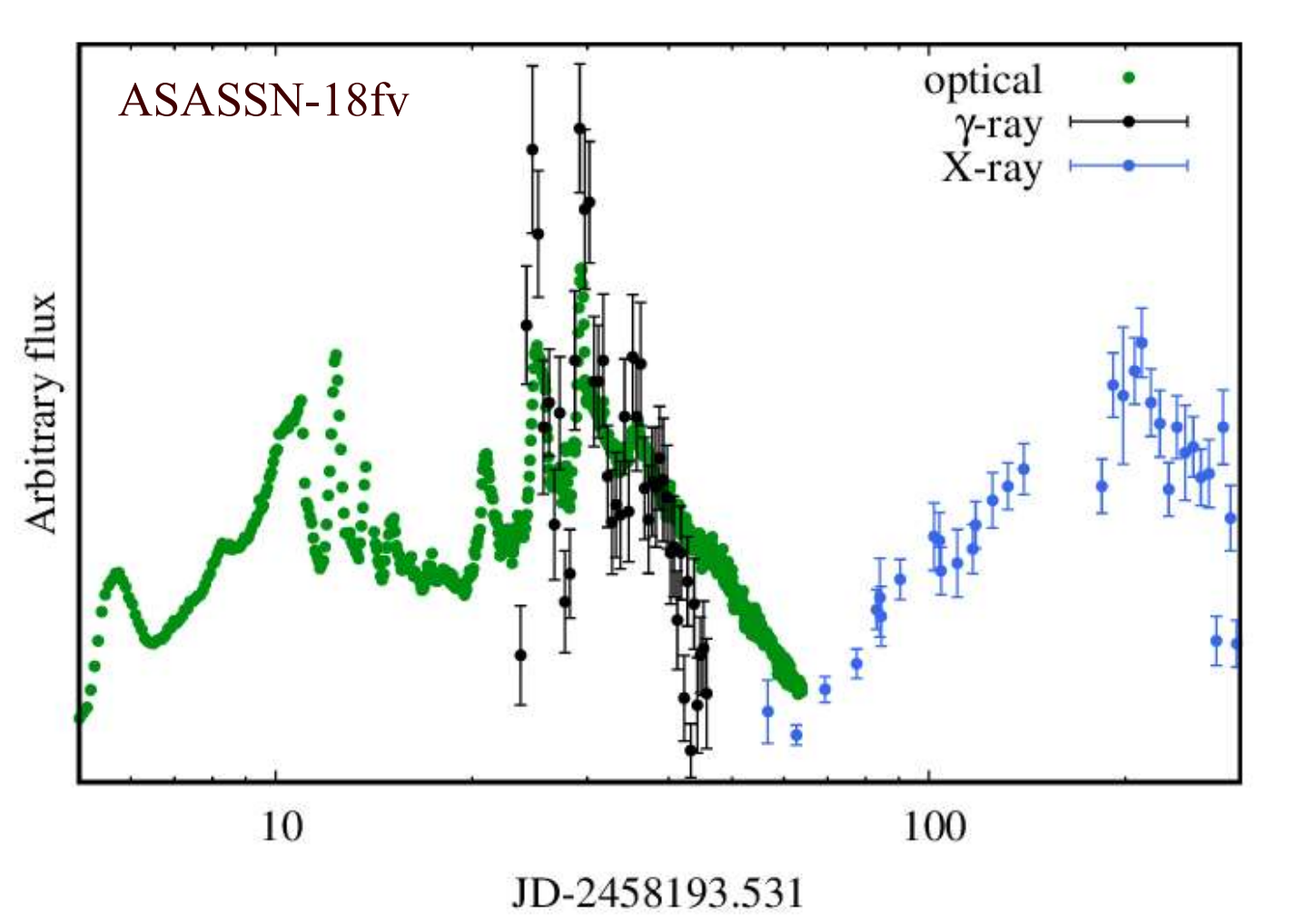


The γ-ray producing shocks are
likely **internal** to the nova ejecta.

No X-rays seen coincident with γ-rays.

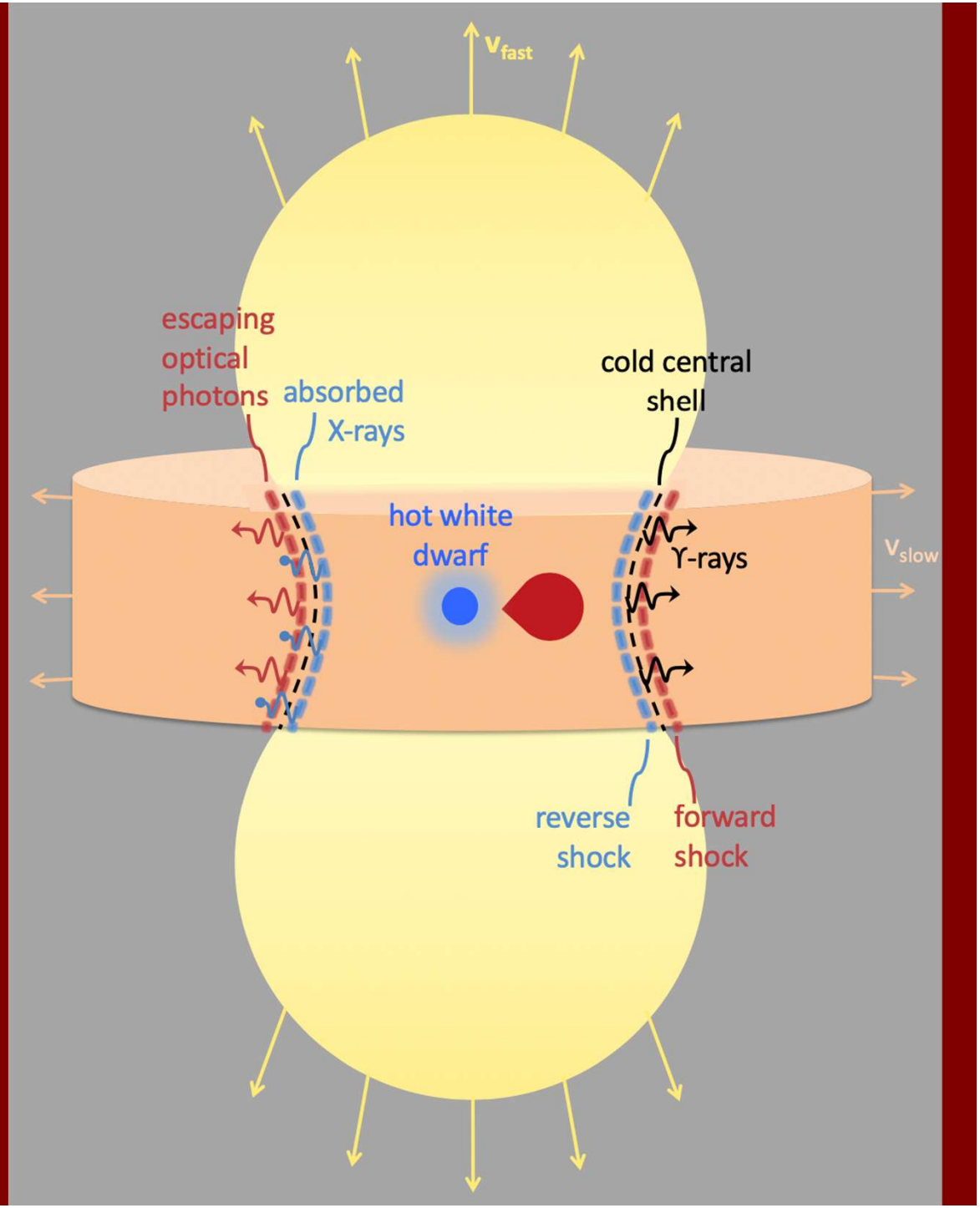


No X-rays seen coincident with γ-rays.



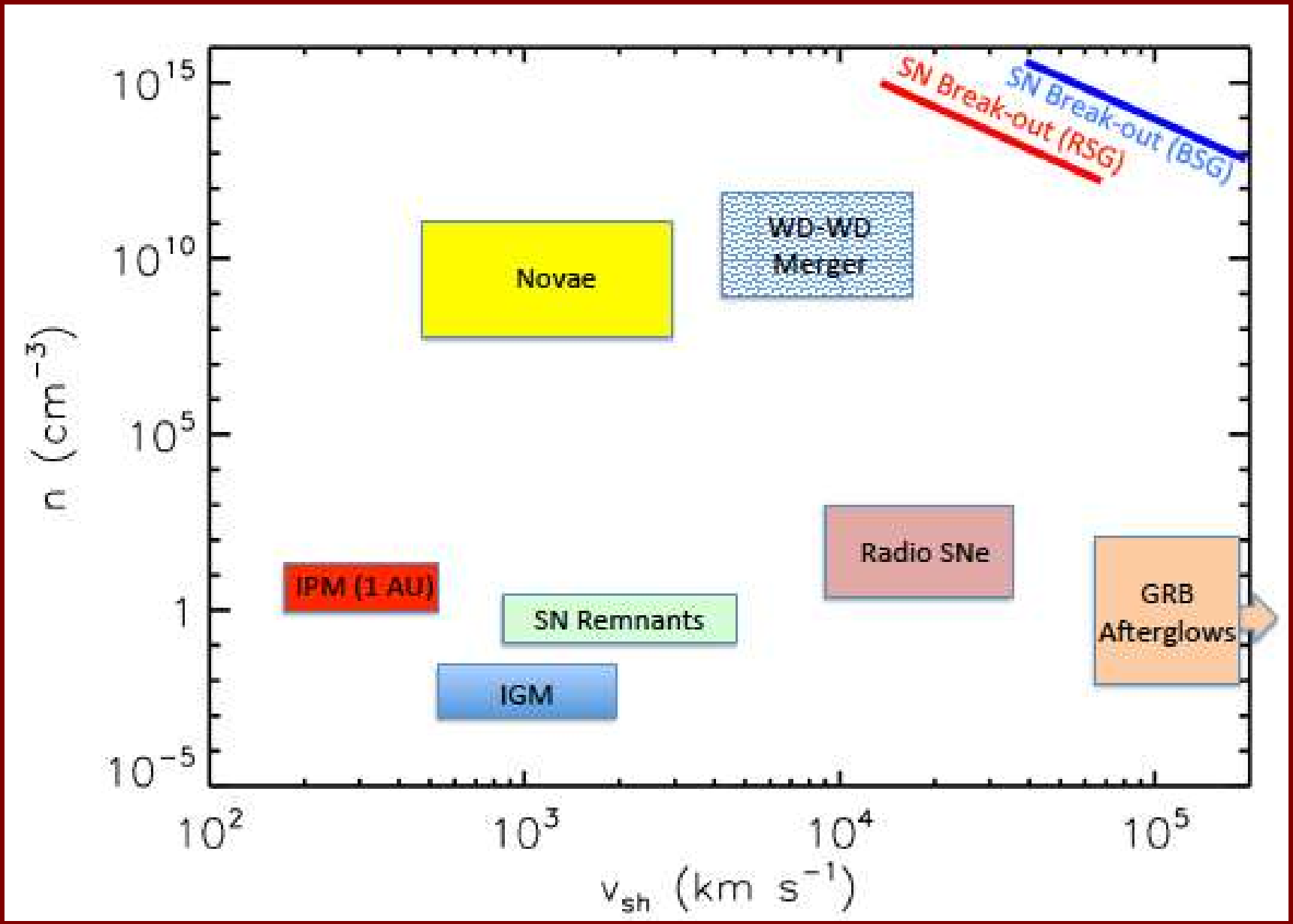
The shocks are deeply embedded and **internal** to the nova ejecta.

Our cartoon picture of internal shocks in novae



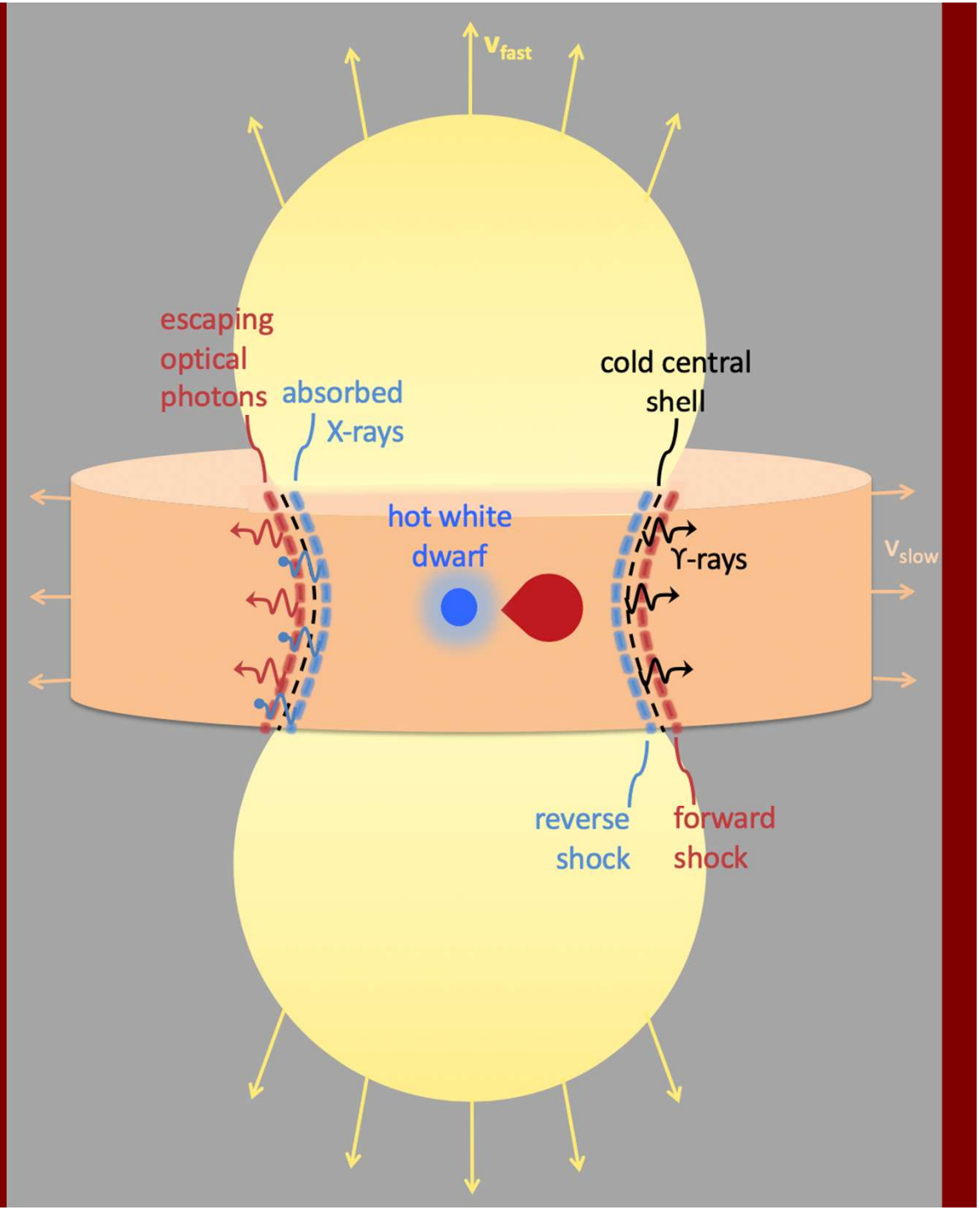
Chomiuk et al. 2012

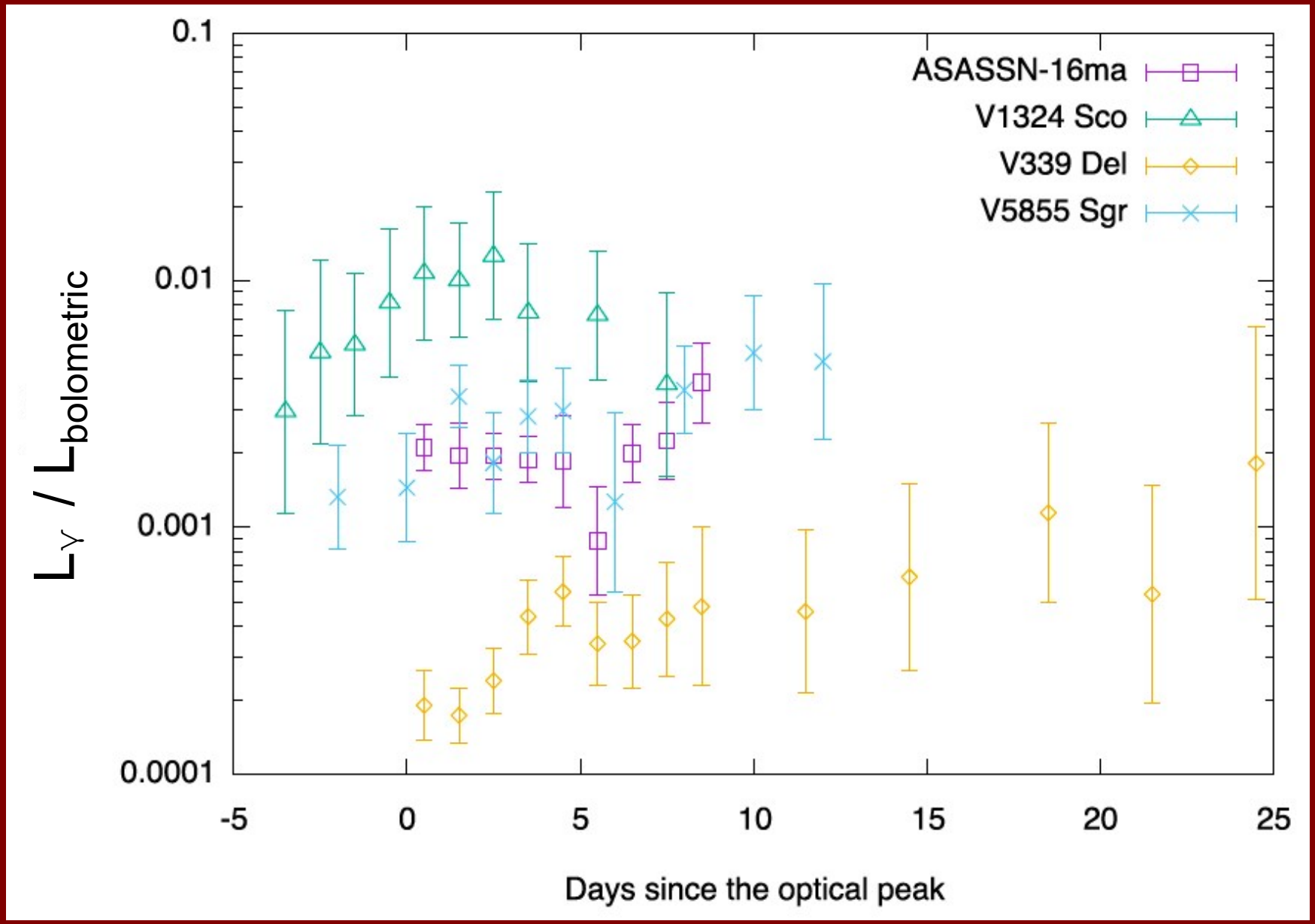
Nova shocks are **dense.**



Metzger et al. 2015

Shocked X-rays are absorbed and re-emitted as optical photons.





Li et al. 2017

0.1-1% of bolometric luminosity in γ-rays.
This is a LOT.

$$L_\gamma = L_{shock}\ \varepsilon_\gamma\ \varepsilon_{nth}$$

For standard γ-ray emission mechanisms, ε_γ ~ 20% of energy in relativistic particles emerges in Fermi/LAT bandpass.

Metzger et al. 2015

$$L_\gamma = L_{shock}\ \varepsilon_\gamma\ \varepsilon_{nth}$$

For standard γ-ray emission mechanisms, $\varepsilon_\gamma \sim 20\%$ of energy in relativistic particles emerges in Fermi/LAT bandpass.

And $\varepsilon_{nth} \lesssim 5\%$ of shock energy expected to go into relativistic particles.

Metzger et al. 2015

$$L_\gamma = L_{shock}\ \varepsilon_\gamma\ \varepsilon_{nth}$$

For standard γ-ray emission mechanisms, $\varepsilon_\gamma \sim 20\%$ of energy in relativistic particles emerges in Fermi/LAT bandpass.

And $\varepsilon_{nth} \lesssim 5\%$ of shock energy expected to go into relativistic particles.

Implying $L_\gamma \lesssim 1\%\ L_{shock}$

Metzger et al. 2015

$$L_\gamma = L_{shock}\ \varepsilon_\gamma\ \varepsilon_{nth}$$

For standard γ-ray emission mechanisms, $\varepsilon_\gamma \sim 20\%$ of energy in relativistic particles emerges in Fermi/LAT bandpass.

And $\varepsilon_{nth} \lesssim 5\%$ of shock energy expected to go into relativistic particles.

Implying $L_\gamma \lesssim 1\%\ L_{shock}$

But, we see $L_\gamma = 1\%\ L_{bol}$ in some novae.

Metzger et al. 2015

$$L_\gamma = L_{shock}\ \varepsilon_\gamma\ \varepsilon_{nth}$$

For standard γ-ray emission mechanisms, $\varepsilon_\gamma \sim 20\%$ of energy in relativistic particles emerges in Fermi/LAT bandpass.

And $\varepsilon_{nth} \lesssim 5\%$ of shock energy expected to go into relativistic particles.

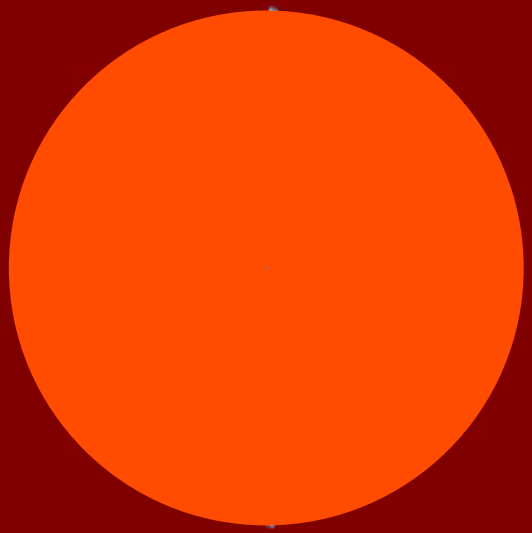
Implying $L_\gamma \lesssim 1\%\ L_{shock}$

But, we see $L_\gamma = 1\%\ L_{bol}$ in some novae.

So, $L_{bol} \approx L_{shock}$
L_{bol} can be dominated by shocks!

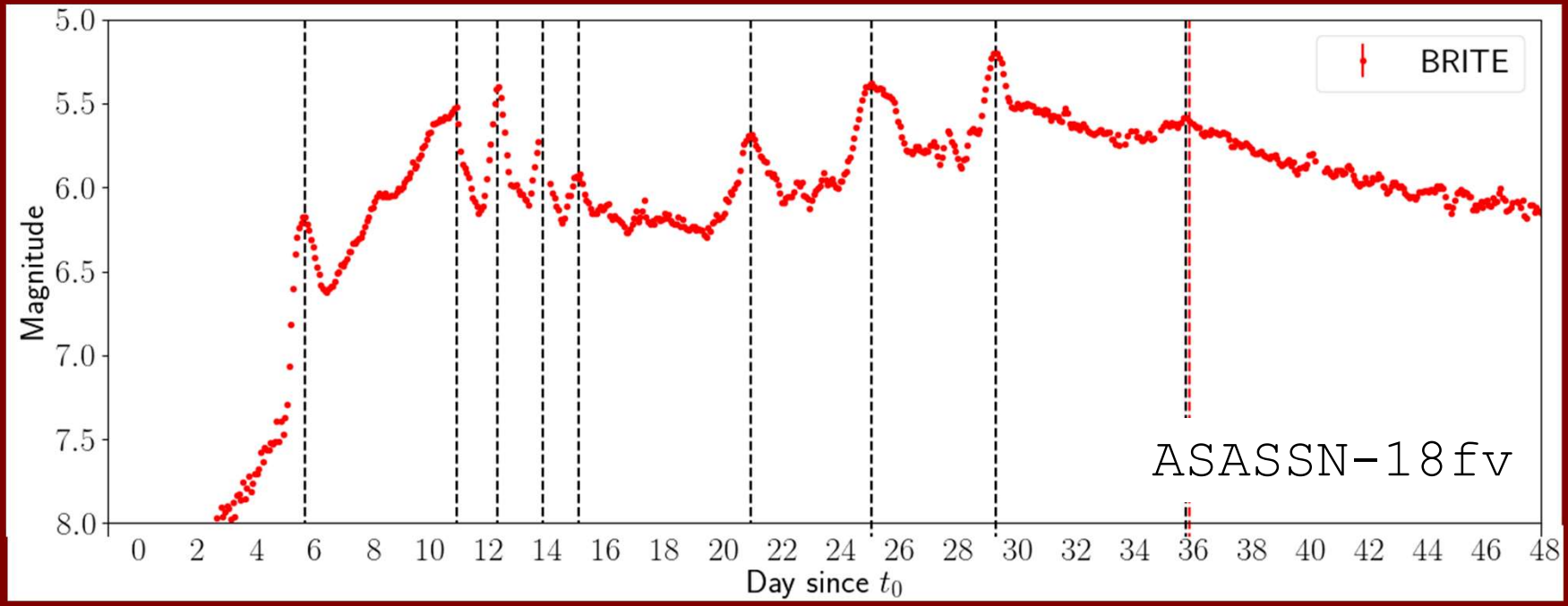
Metzger et al. 2015

Shocks powering classical novae would be a new paradigm

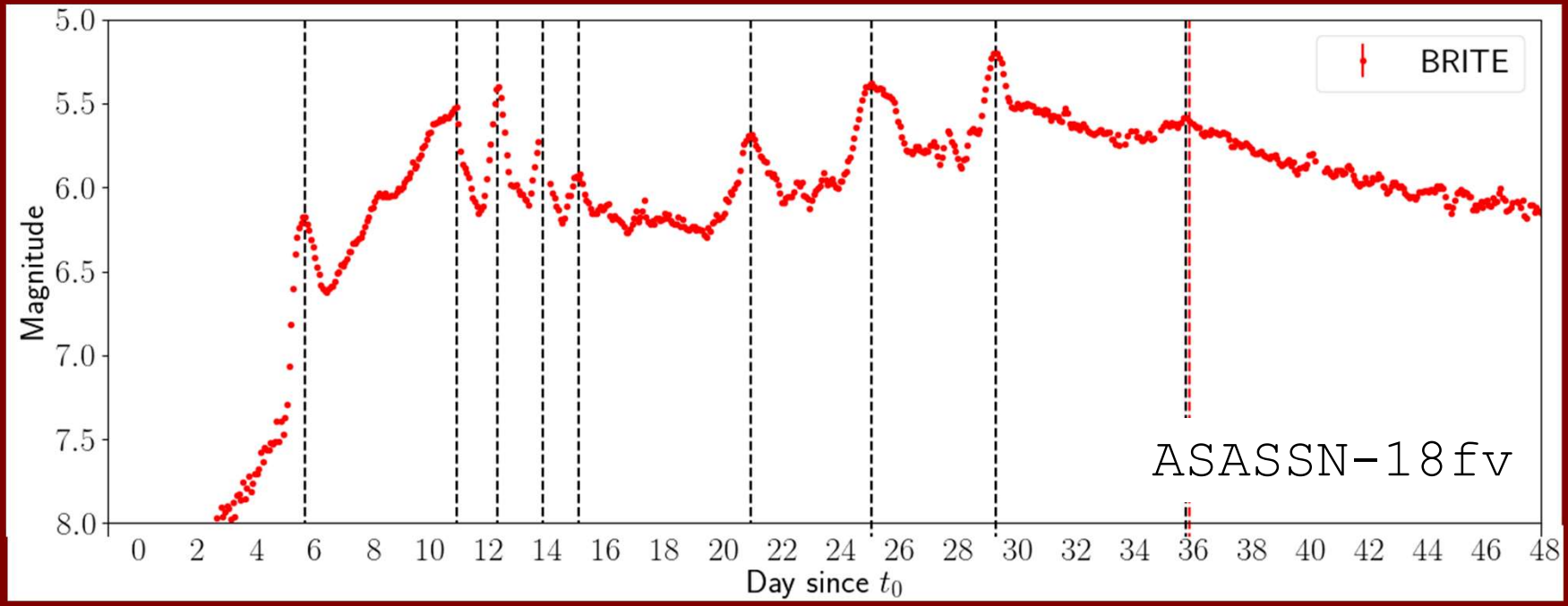


Challenging the picture of constant L_{bol} novae powered by hot white dwarfs.

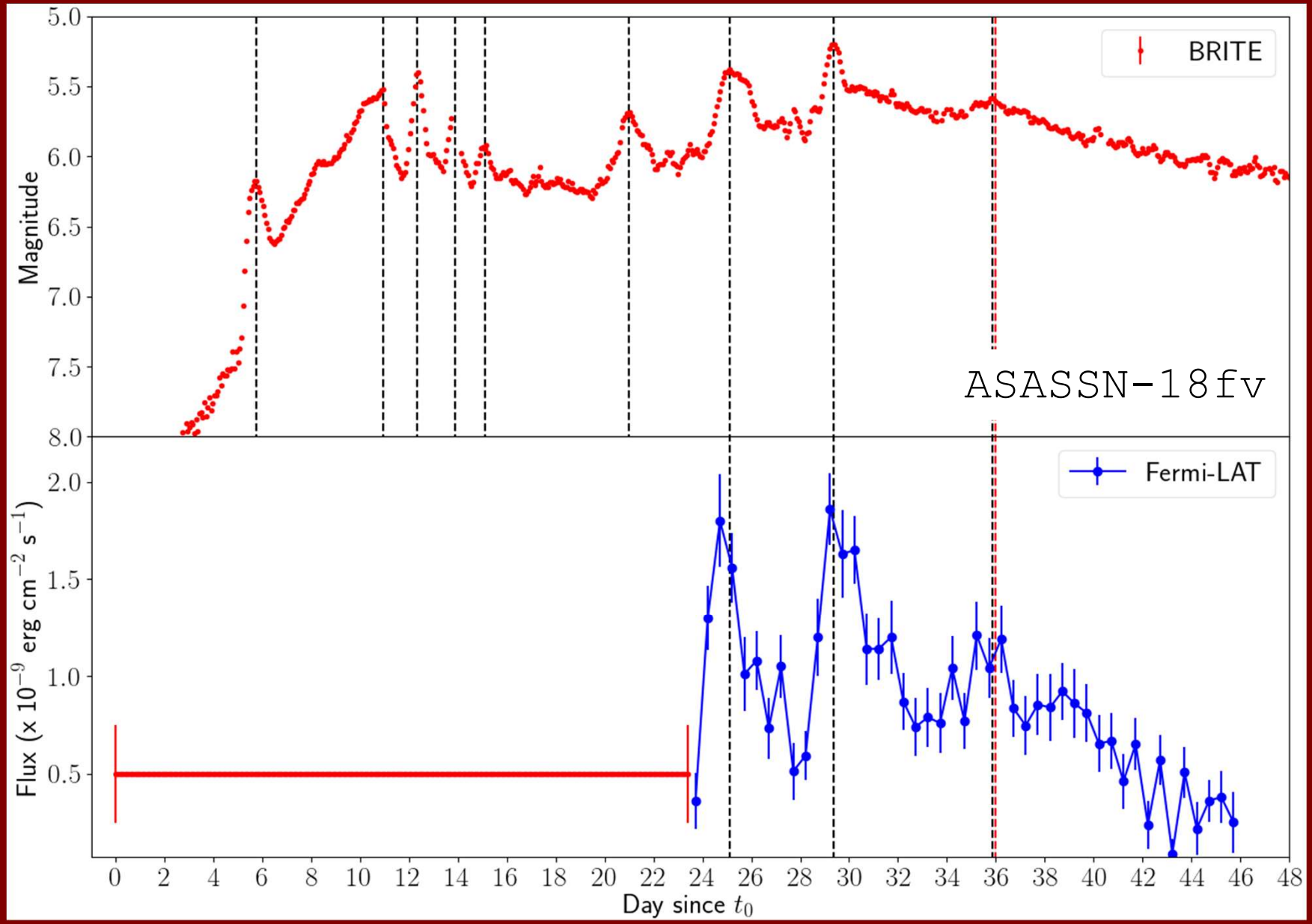
Is the optical correlated with the γ-ray?



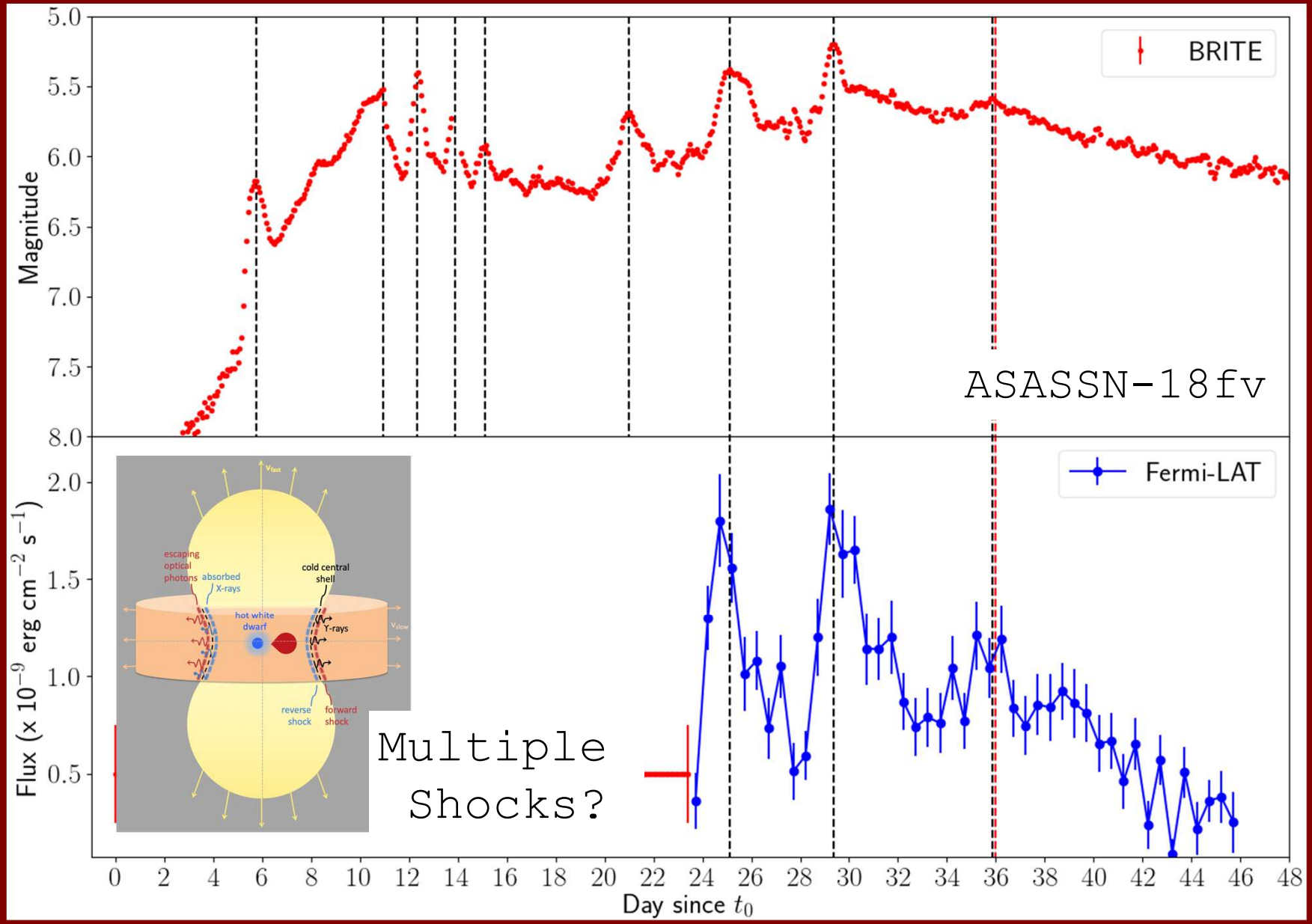
Is the optical correlated with the γ-ray?



Is the optical correlated with the γ-ray?

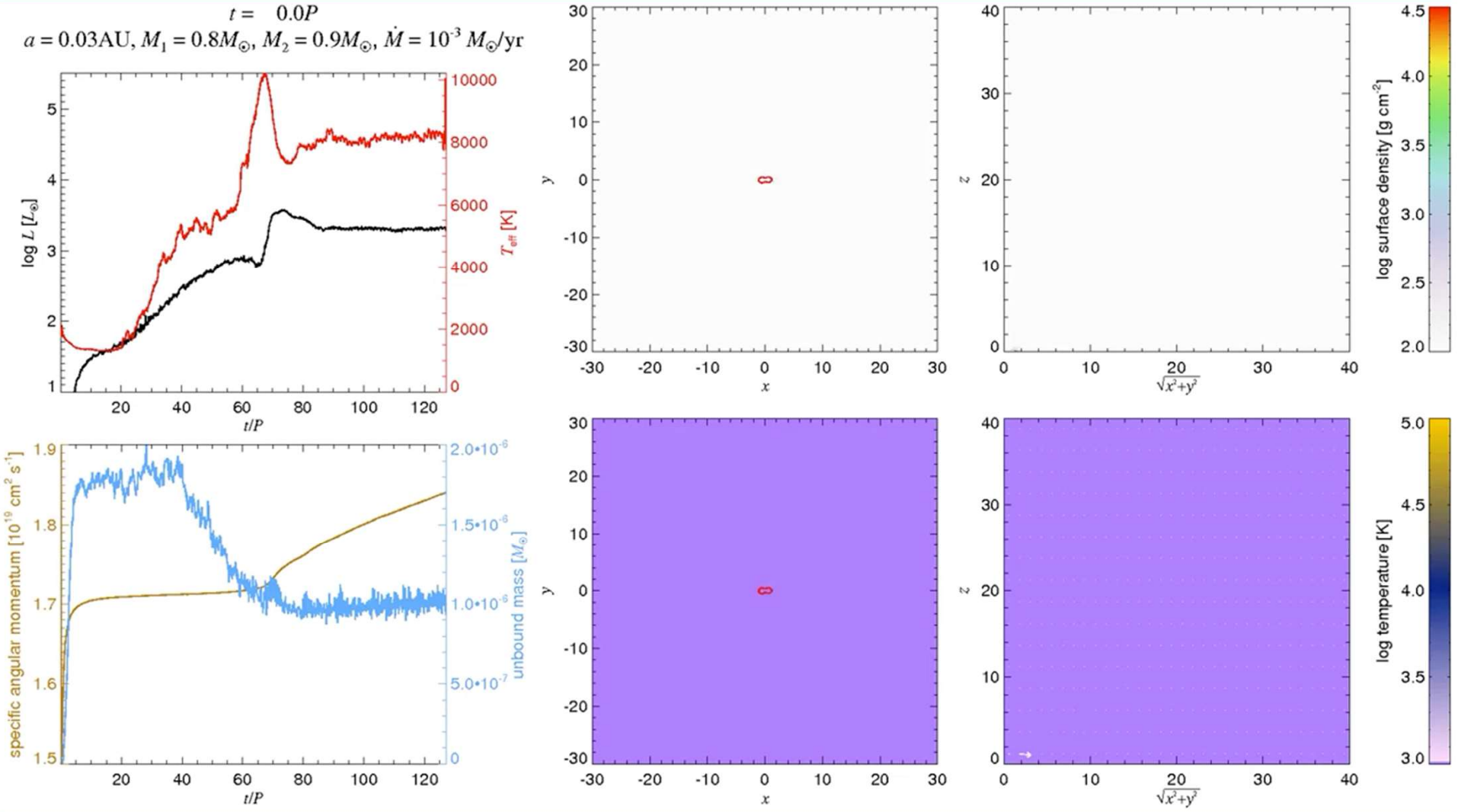


What creates these flares?



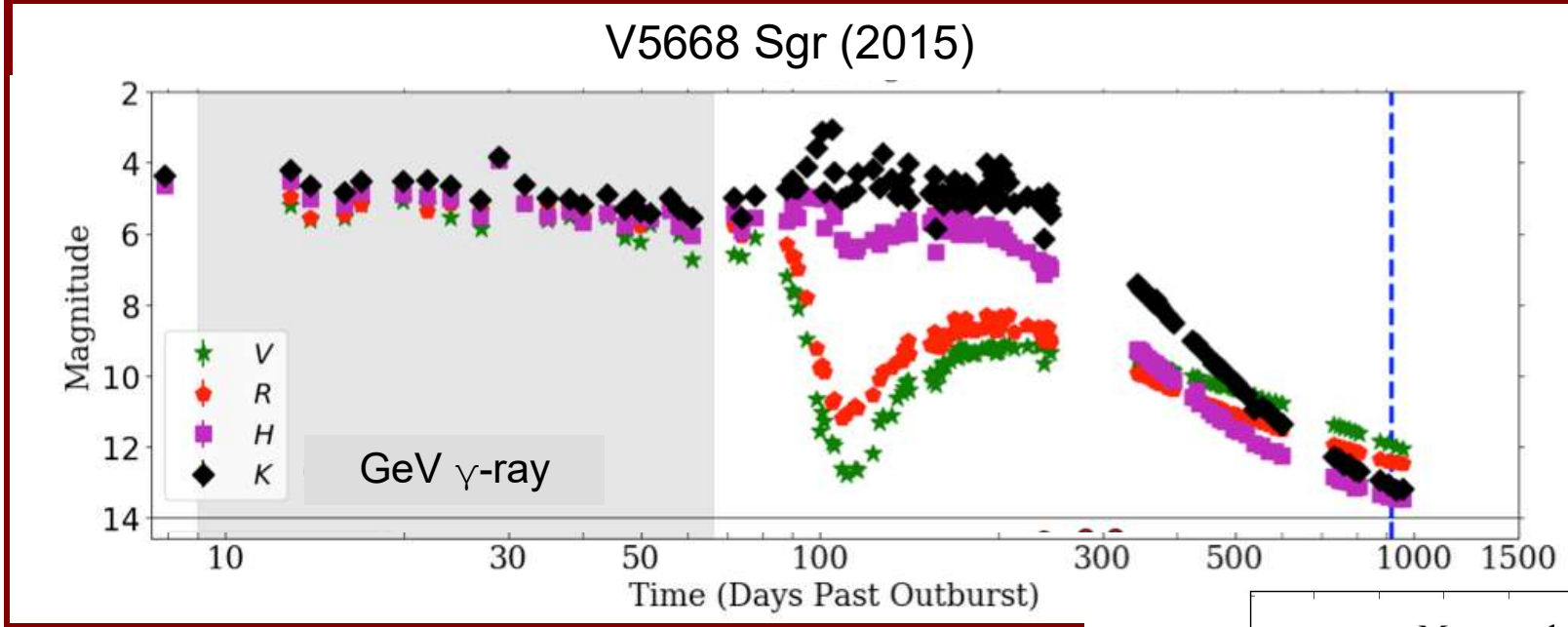
Novae can act like little common envelope events

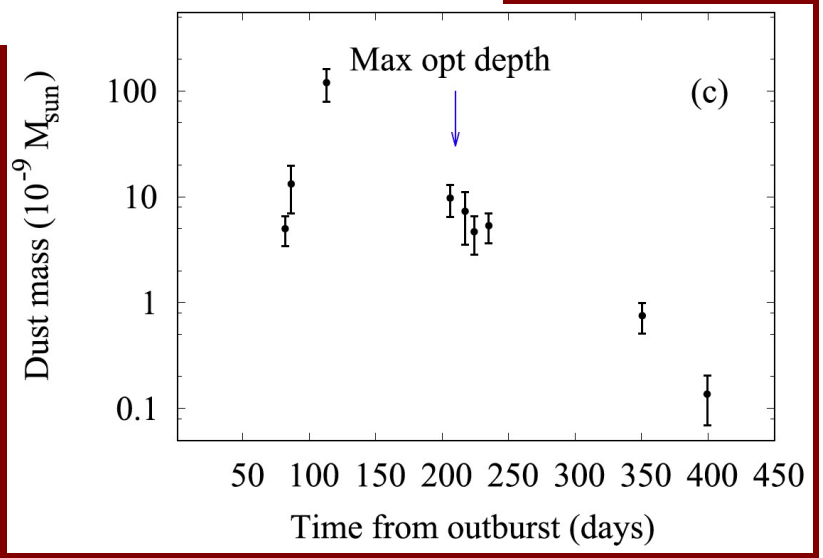
The unbinding and ejecting of the CE may be a chaotic process.



Pejcha et al. 2016

Dense radiative shocks in novae could be great sites for dust formation.





Derdzinski et al. 2016,
Gehrz et al. 2018

Conclusions

- Recent observations challenge a decades-old paradigm by showing that shocks are energetically important in classical novae.
- Shocks can produce γ-rays, power bolometric luminosity, and form dust.
- Novae are convenient laboratories for stellar mergers and shock-powered transients (we can **image** novae!)

Women & Gender Minorities @ FOE Gathering

Tomorrow (Thursday)

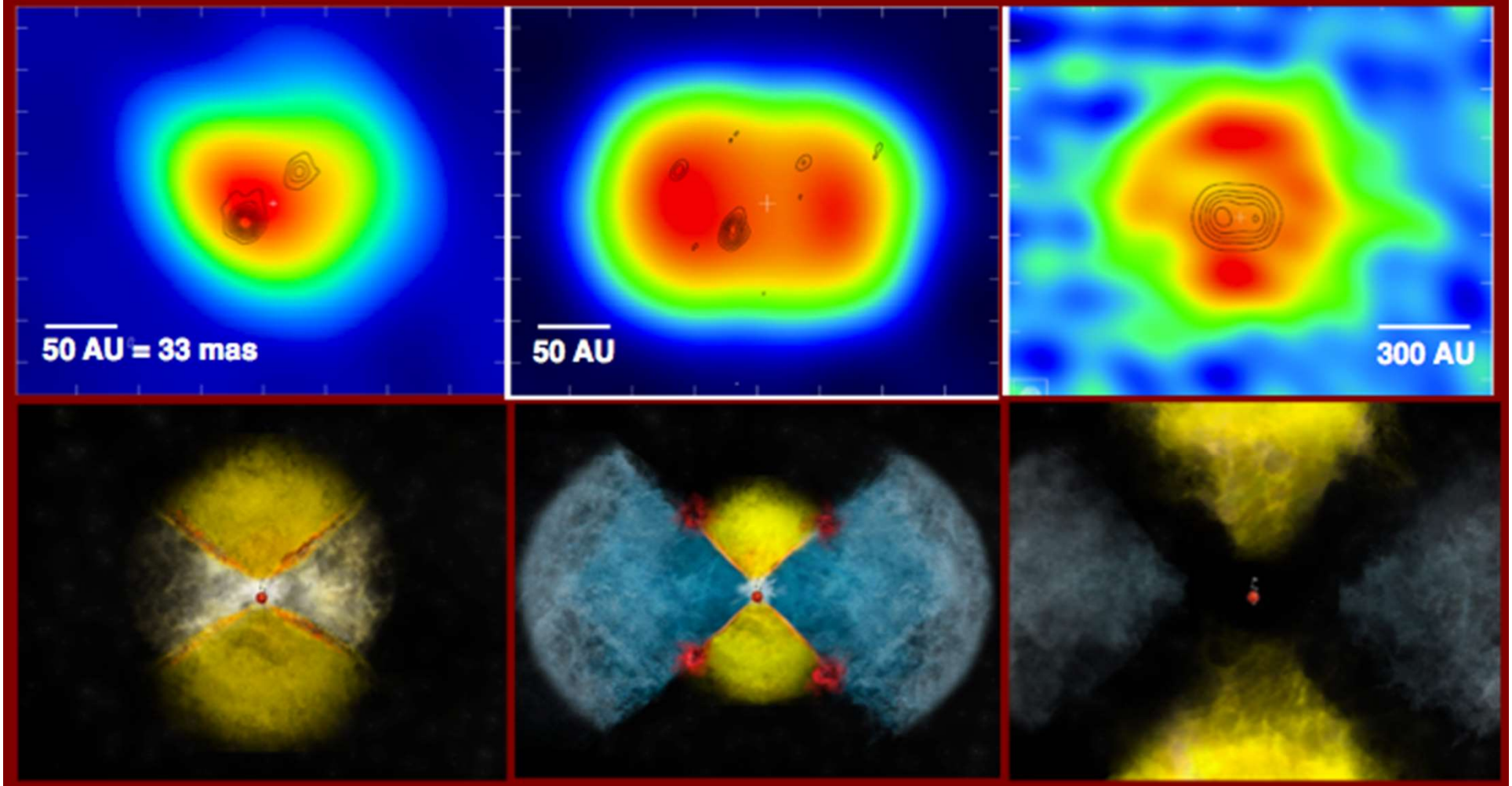
6pm

Mitch's Tavern

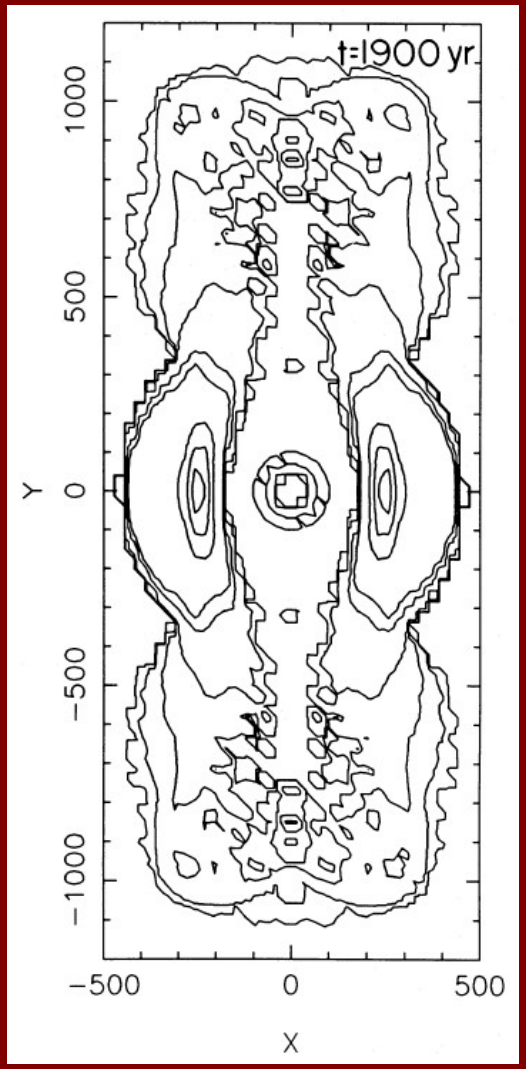
2426 Hillsborough

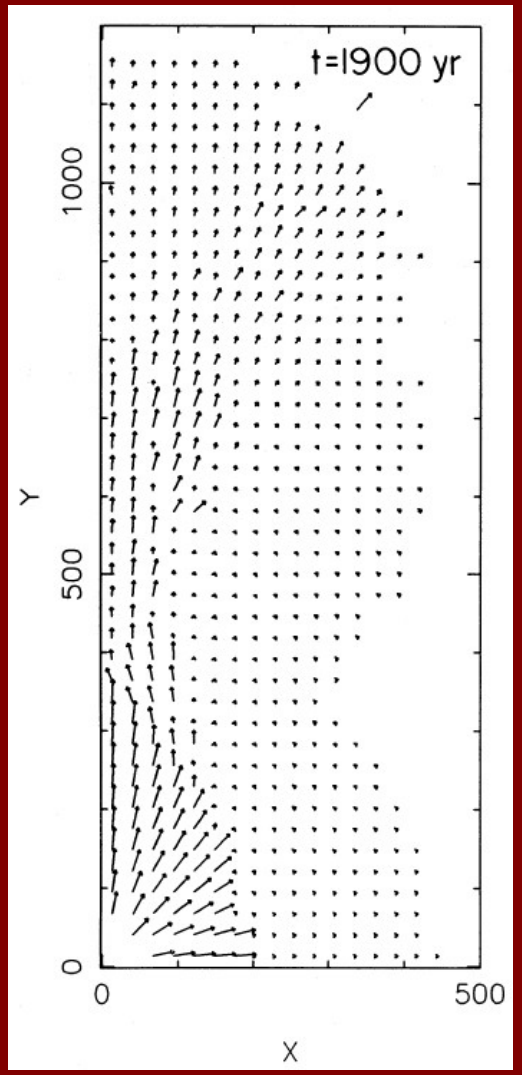
Future talk- could add something about diversity of gamma-ray properties.

Color-scale	e-MERLIN Day 87 (54 mas resolution)	VLA Day 126 (43 mas resolution)	VLA Day 615 (106 mas resolution)
Black Contour	EVN Day 91 (7 mas resolution)	EVN Day 113 (7 mas resolution)	VLA Day 126 (43 mas resolution)



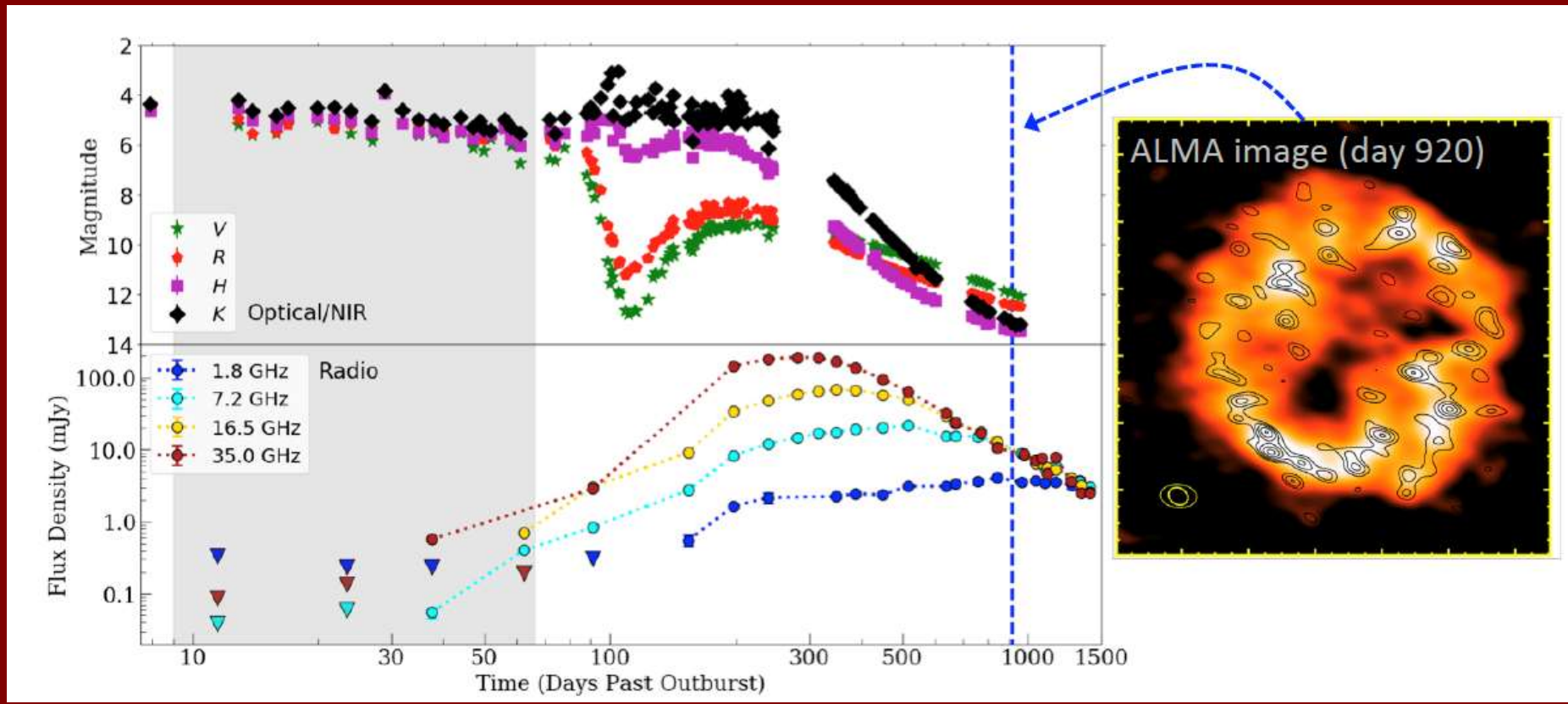
Shaping mechanism also seen in planetary nebulae.



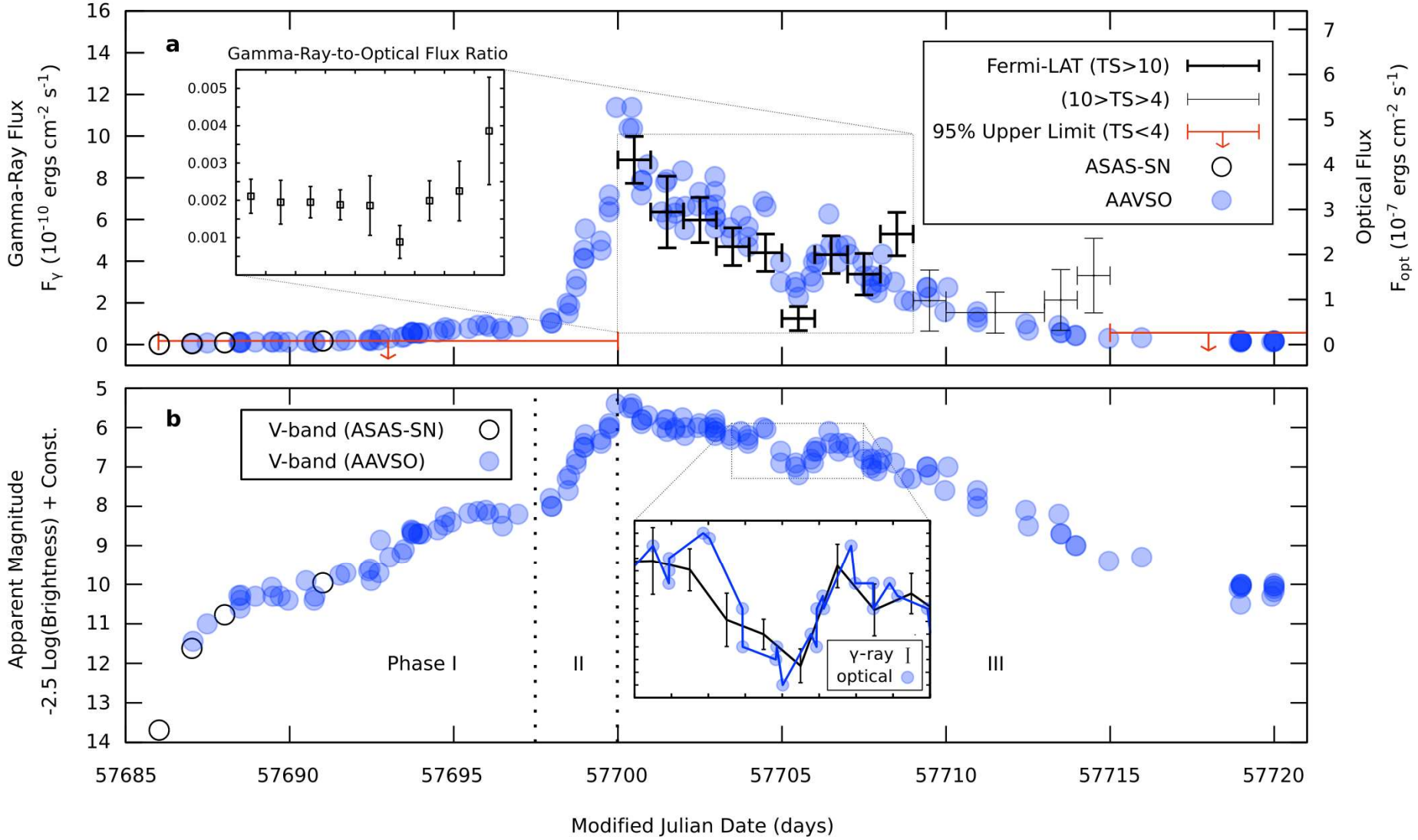


Soker & Livio 1989

Planetary Nebula M2-9

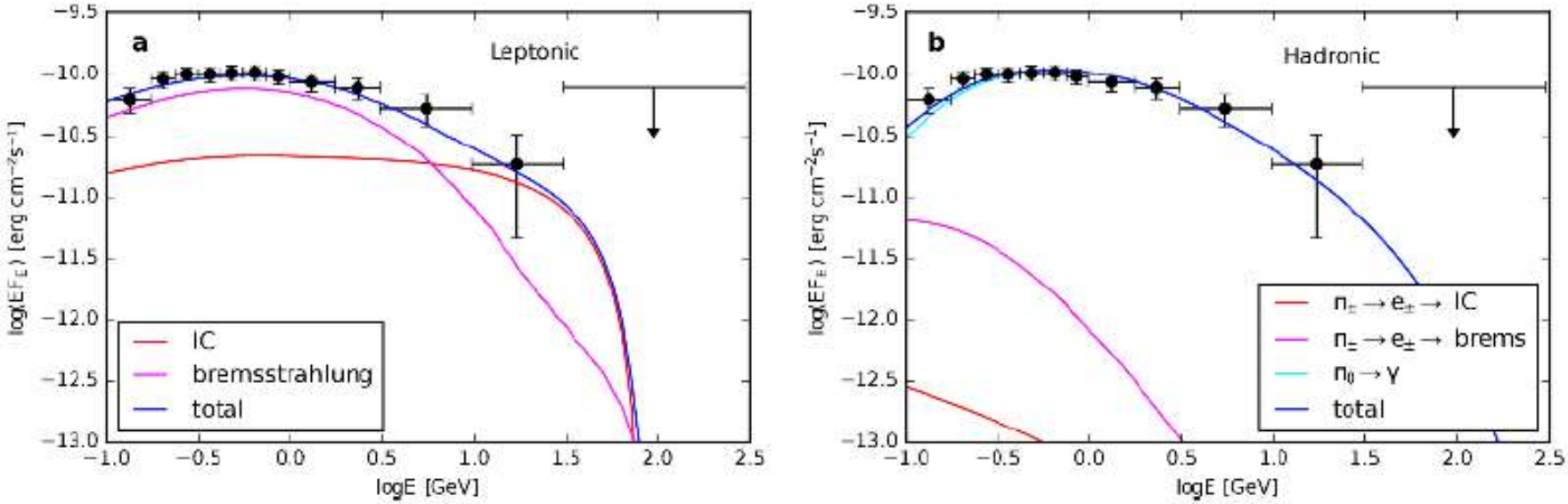

Magnitude
V
R
H
K
Optical/NIR
Radio
1.8 GHz
7.2 GHz
16.5 GHz
35.0 GHz
Flux Density (mJy)
Time (Days Past Outburst)
ALMA image (day 920)

Nova ASAS-SN 16ma



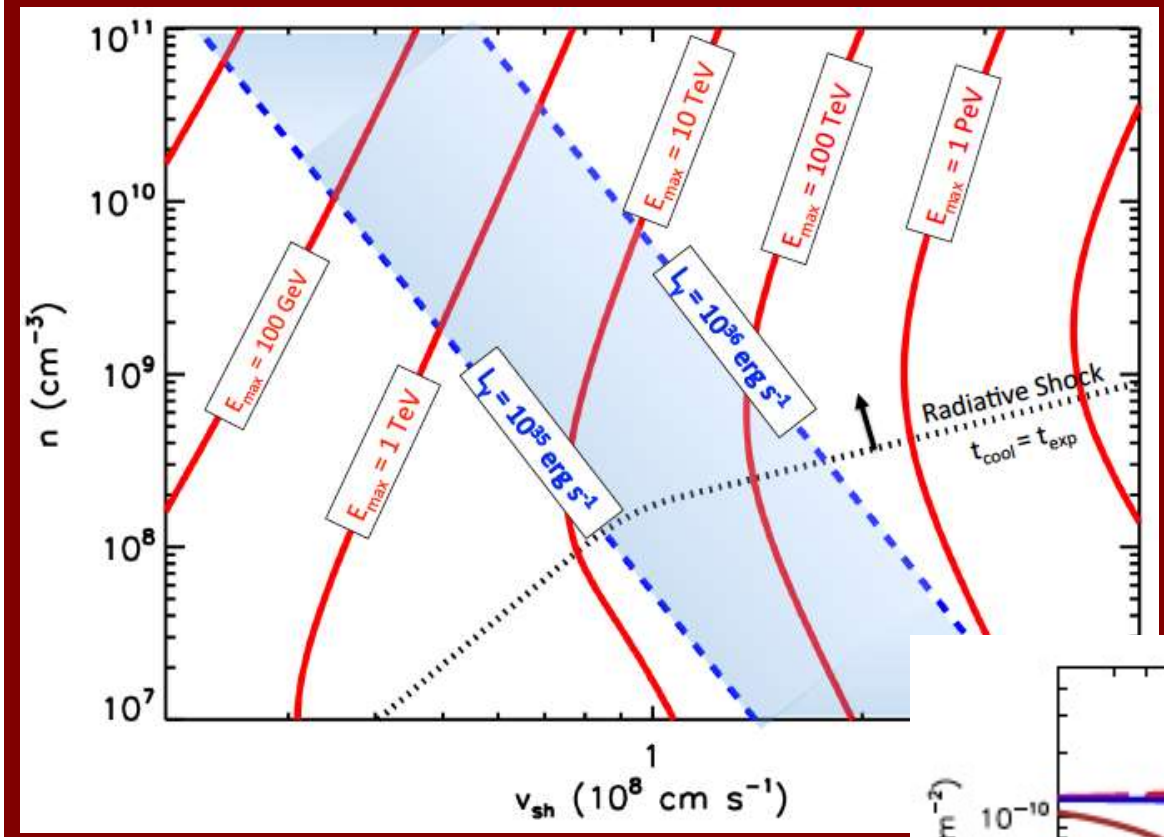
Li et al. 2017

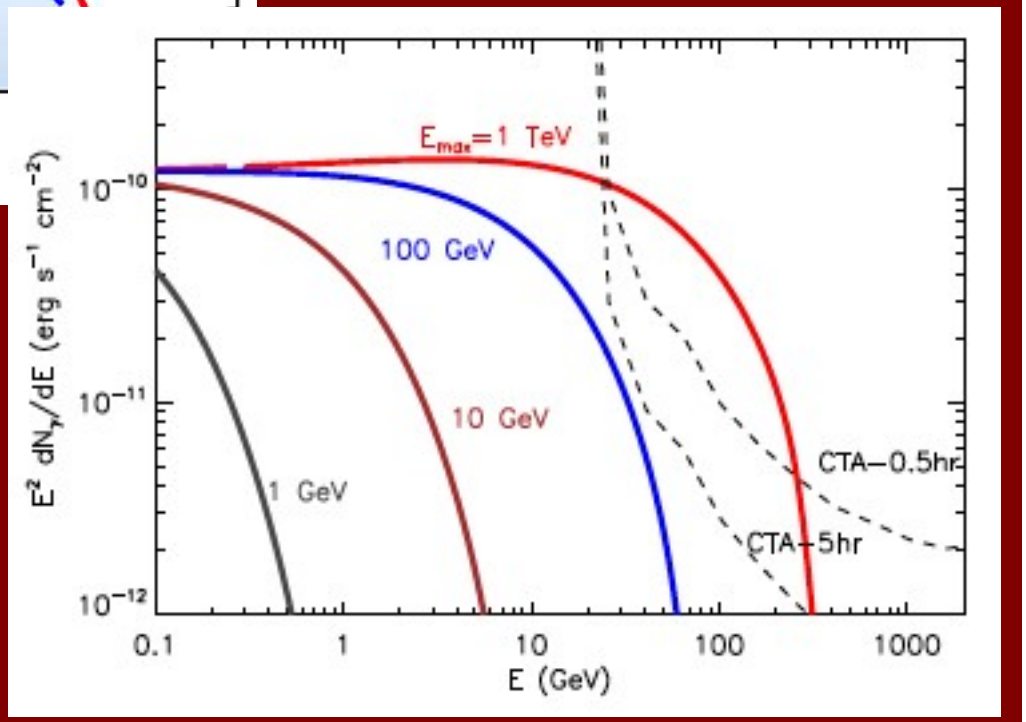
V5856 Sgr: γ-ray Emission Mechanism



The leptonic model requires a very high electron acceleration efficiency ($\epsilon_e \approx 2.5 \times 10^{-3}$)

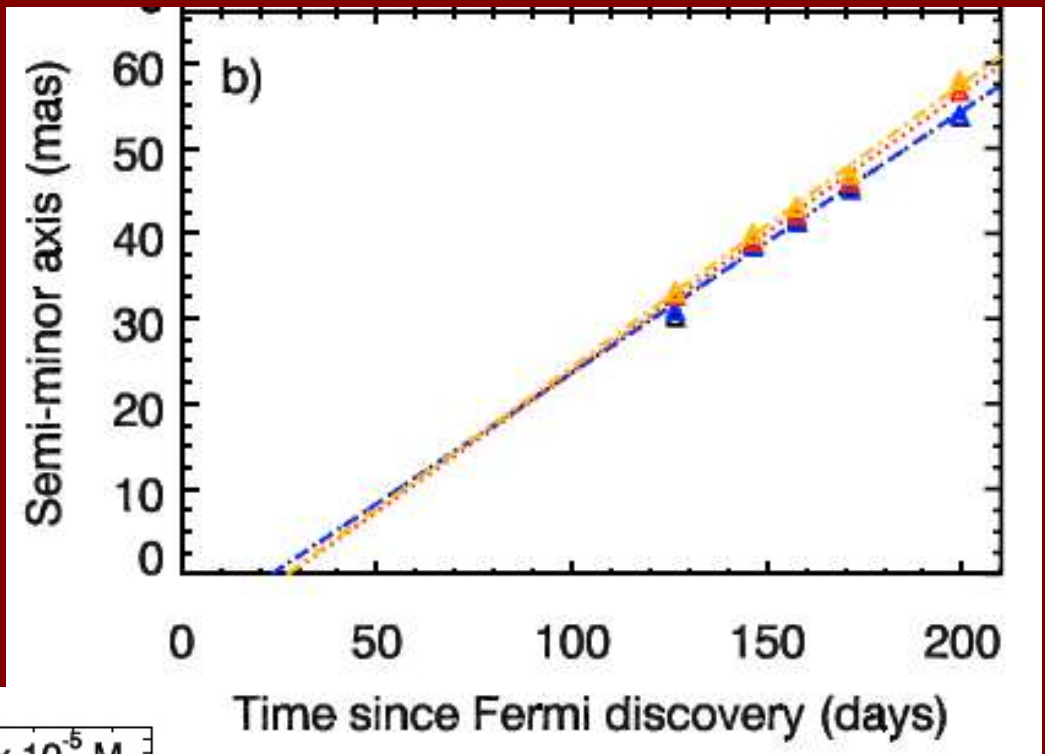
Both the hadronic and leptonic models invoke a high ejecta mass rate ($10^{-4}\ M_\odot$/week)

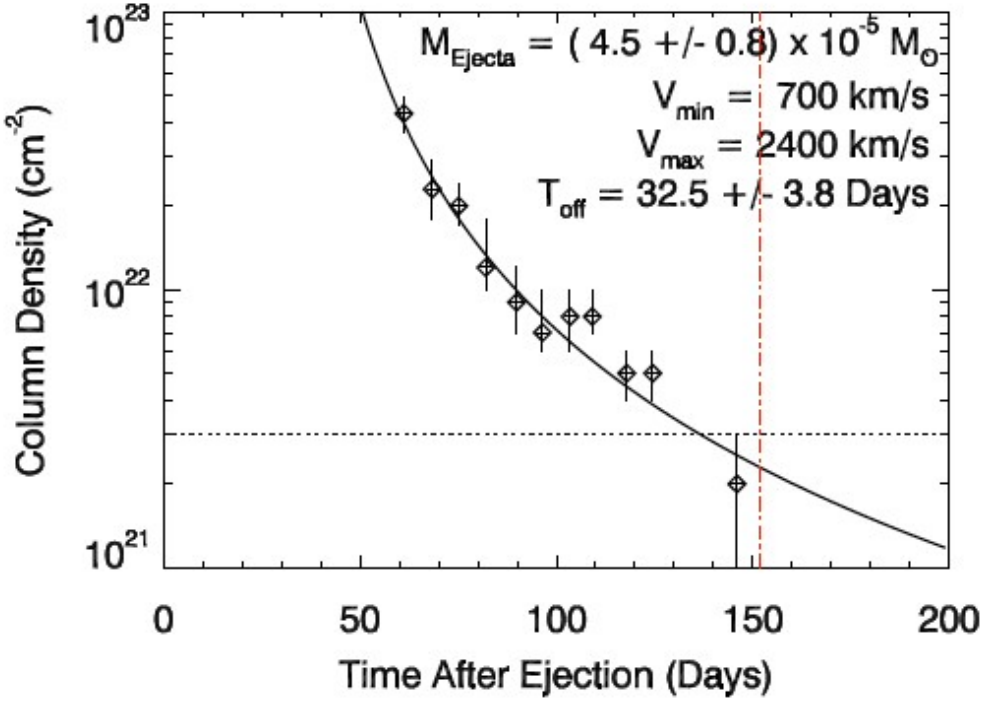




Metzger et al. 2015

The nova envelope hung around V959 Mon for ~30 days before it was expelled.





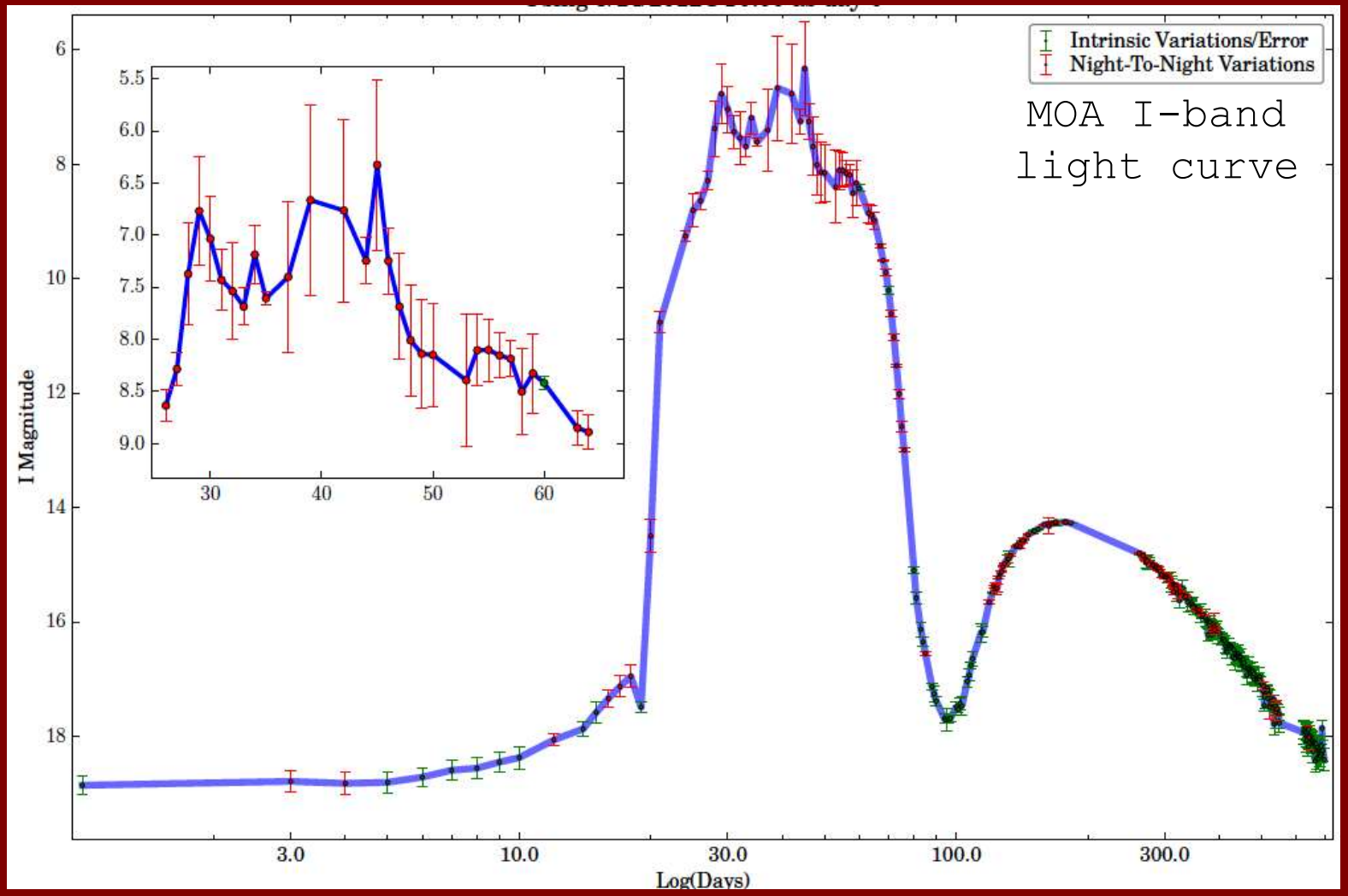
radio

⟵ X-ray

See also our studies of T Pyx; Nelson et al. (2014); Chomiuk et al. (2014

γ-ray Nova #3: V1324 Sco

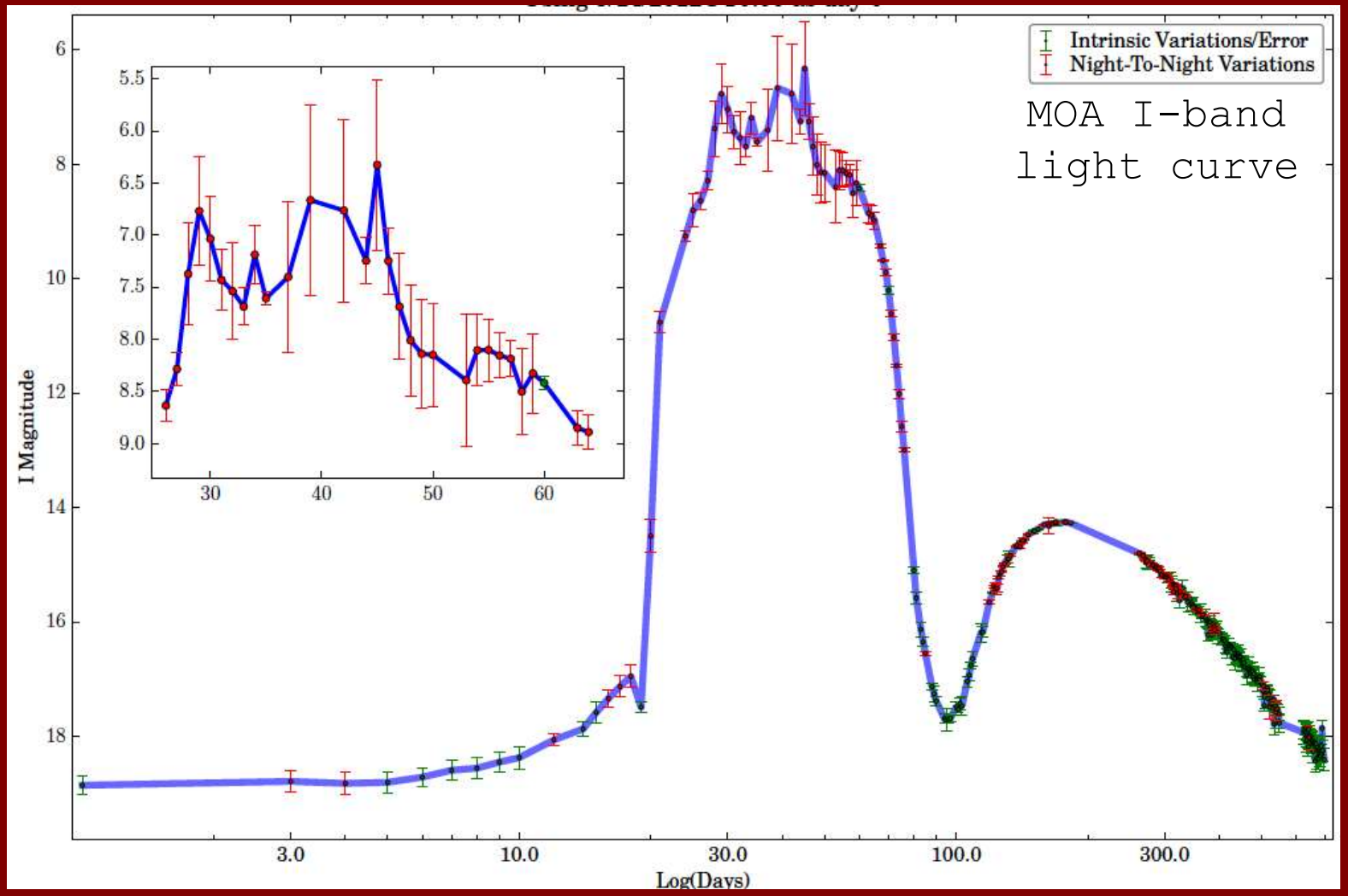
γ-rays, but no X-rays!



Metzger et al. 2014

γ-ray Nova #3: V1324 Sco

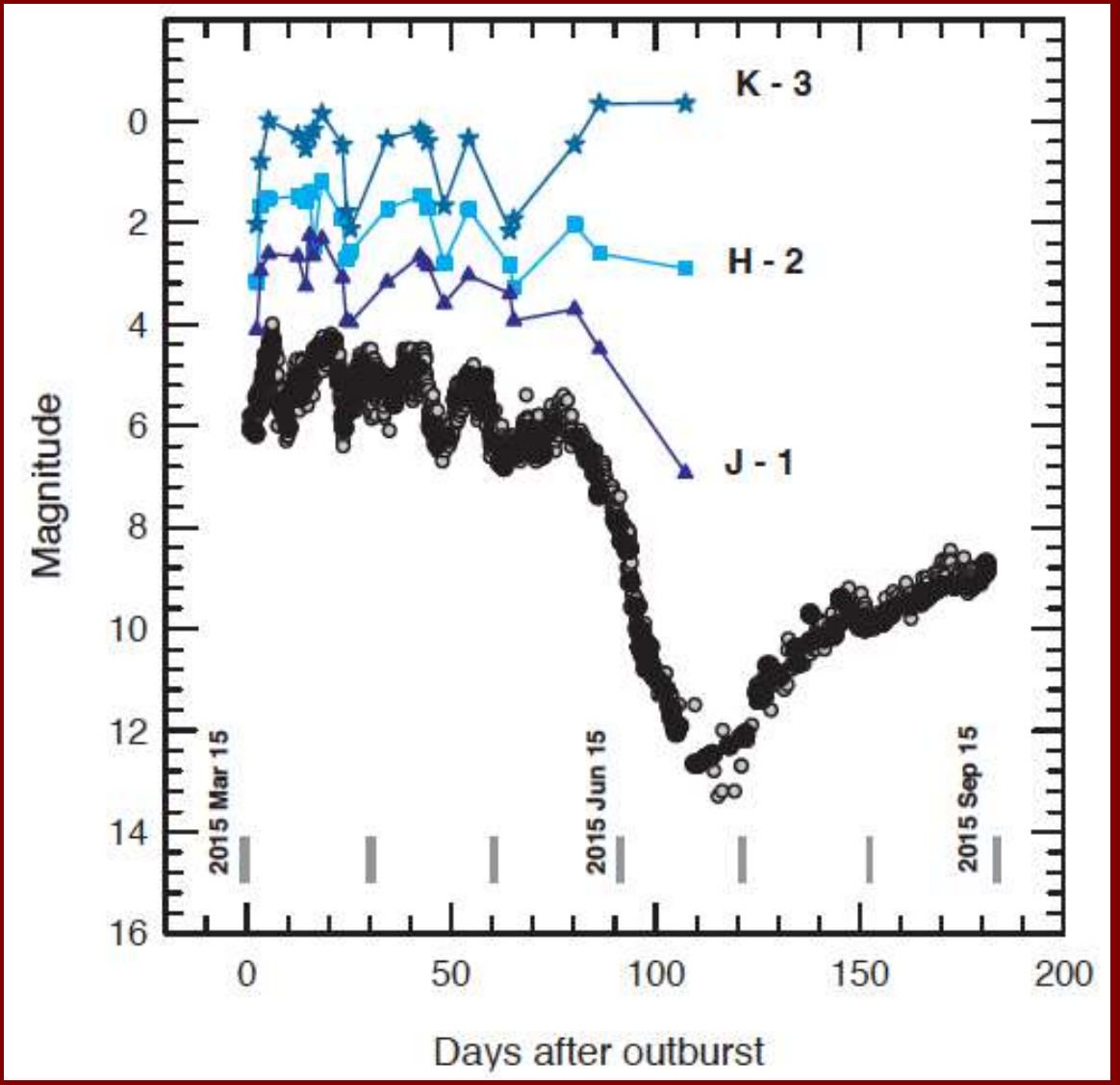
γ-rays, but no X-rays!



X-rays absorbed by a dense, radiative shock?

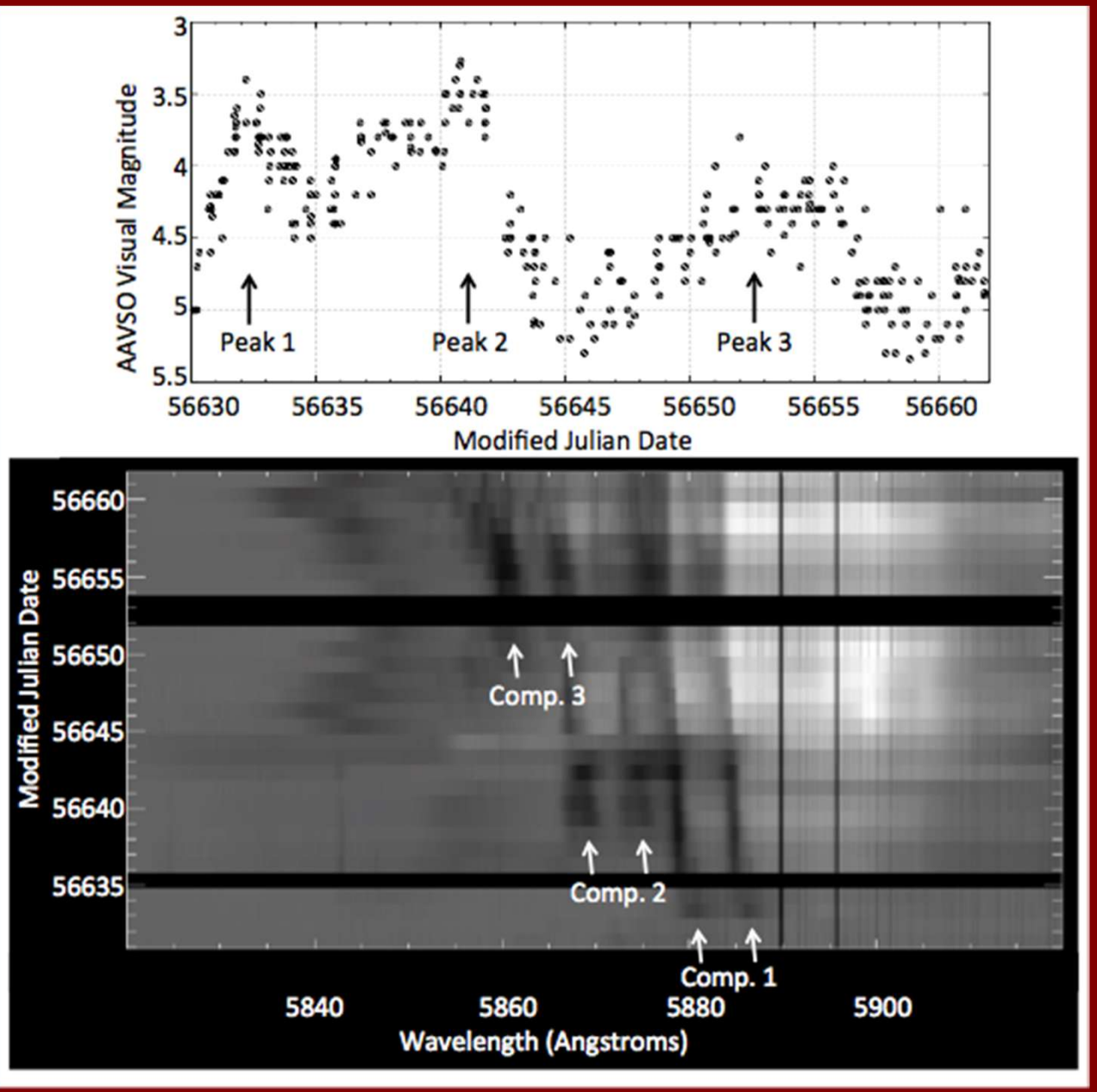
Metzger et al. 2014

γ-ray Nova V5668 Sgr (another dust former)



Banerjee et al. 2015

Any funny business is just frosting(?).



Optical light curve for V1369 Cen (2013)

Dynamic Na I D profiles for V1369 Cen

F. Walter