New Insights Into Novae

A New class of Particle accelerators established by Fermi

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L. Chomiuk, K. Sokolovsky, B. Metzger, K. Mukai, K-L. Li, L. Izzo, J. Sokoloski, J. Linford, D. Buckley, A. Gordon, A. Stone, J. Monnier, G. Schaefer, ASAS-SN collabs, BRITE collabs, and friends…

11th Int. Fermi Symposium

September 2024

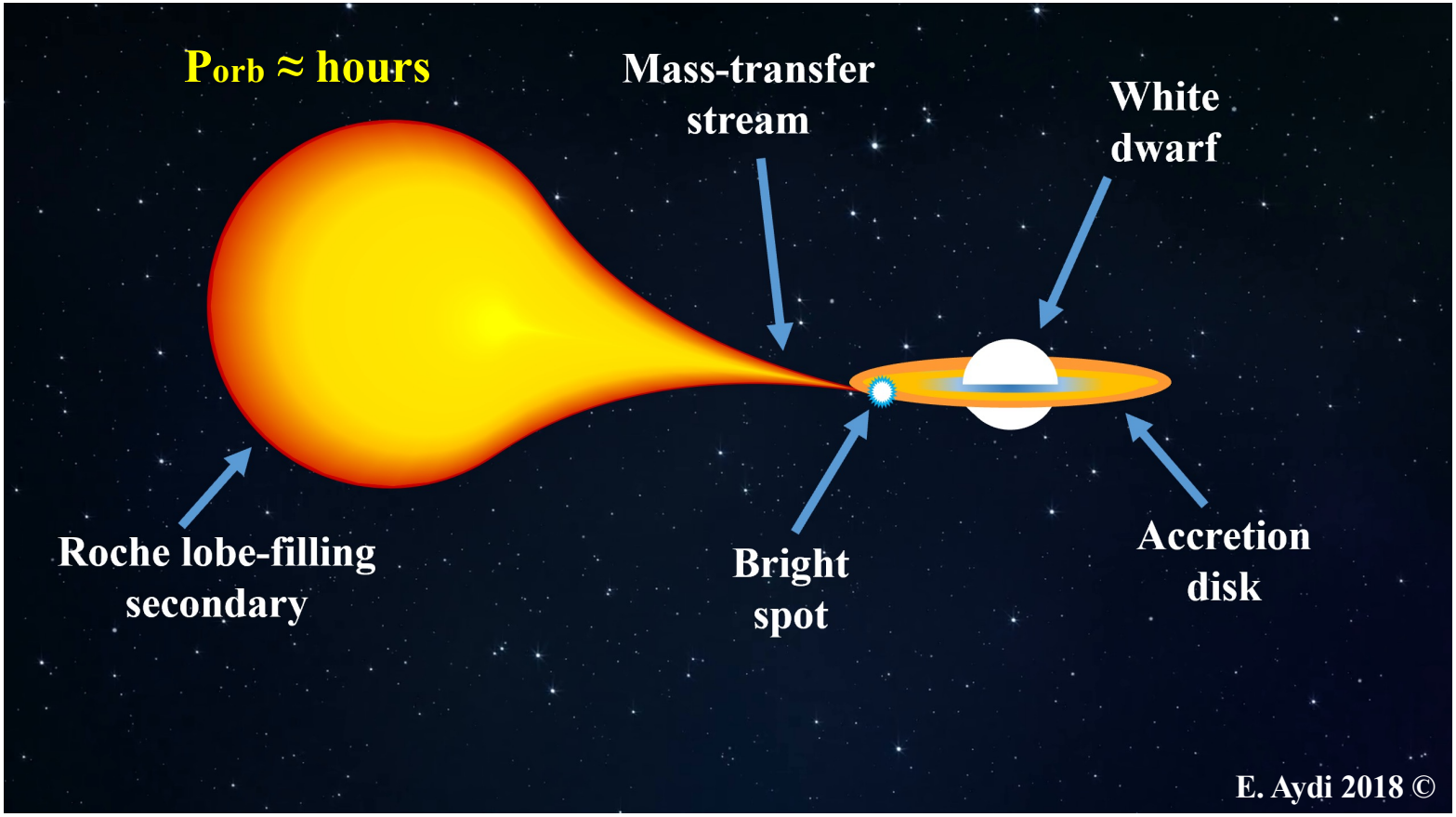
www.eliasaydi.com

NHFP NASA Hubble Fellowship Program

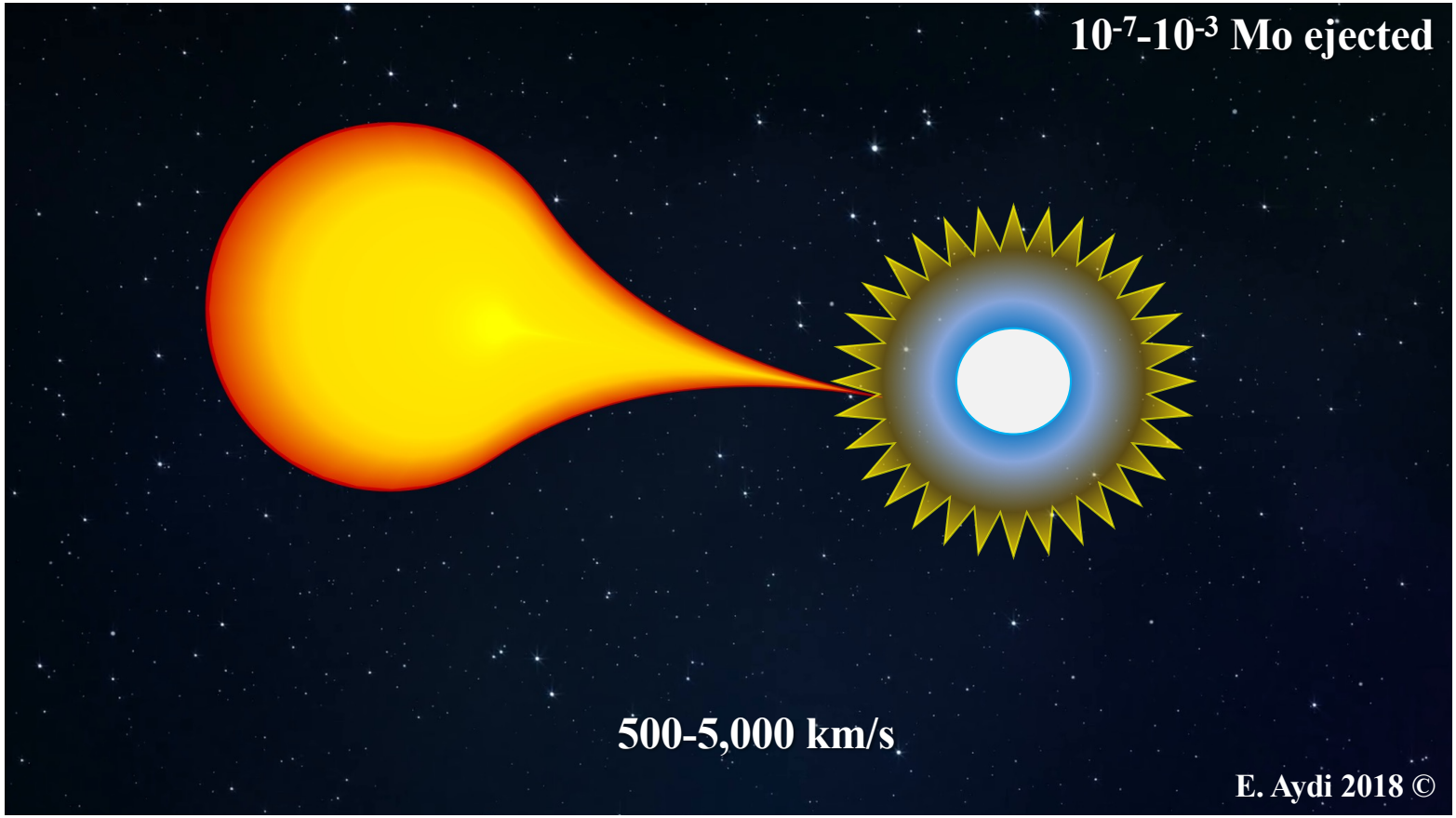
NASA

TEXAS TECH UNIVERSITY

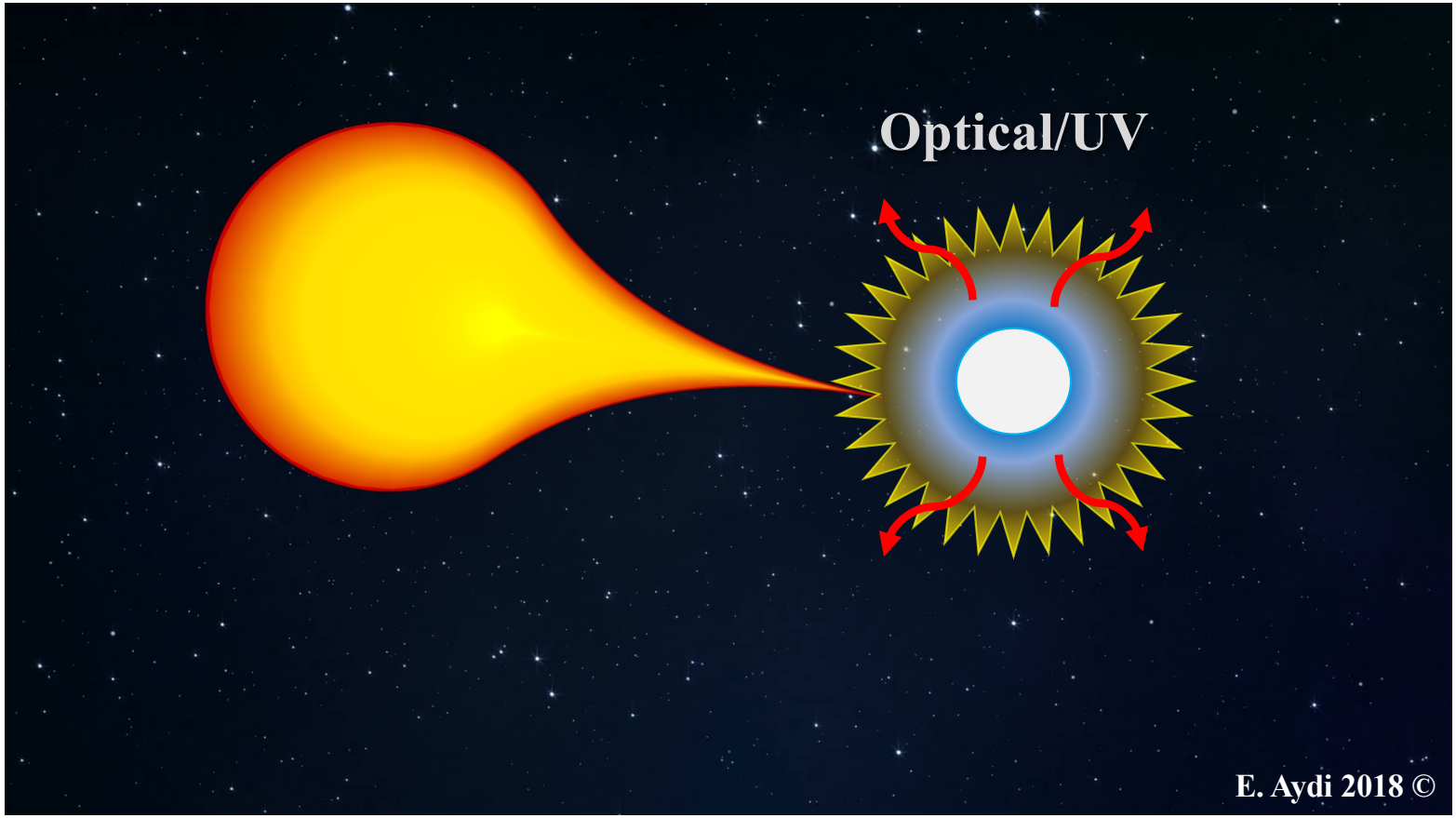
Novae – a brief summary



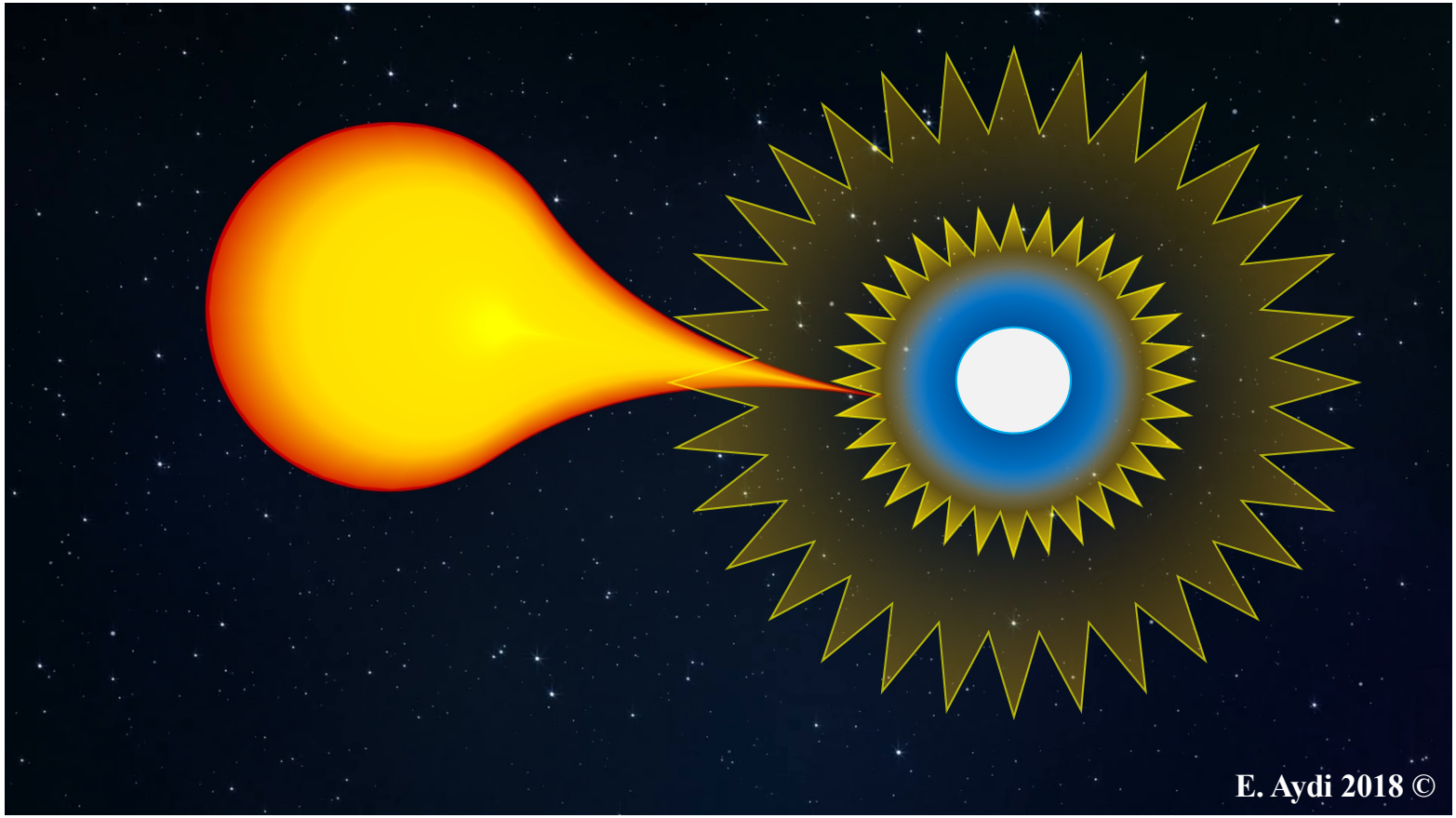
Novae – a brief summary



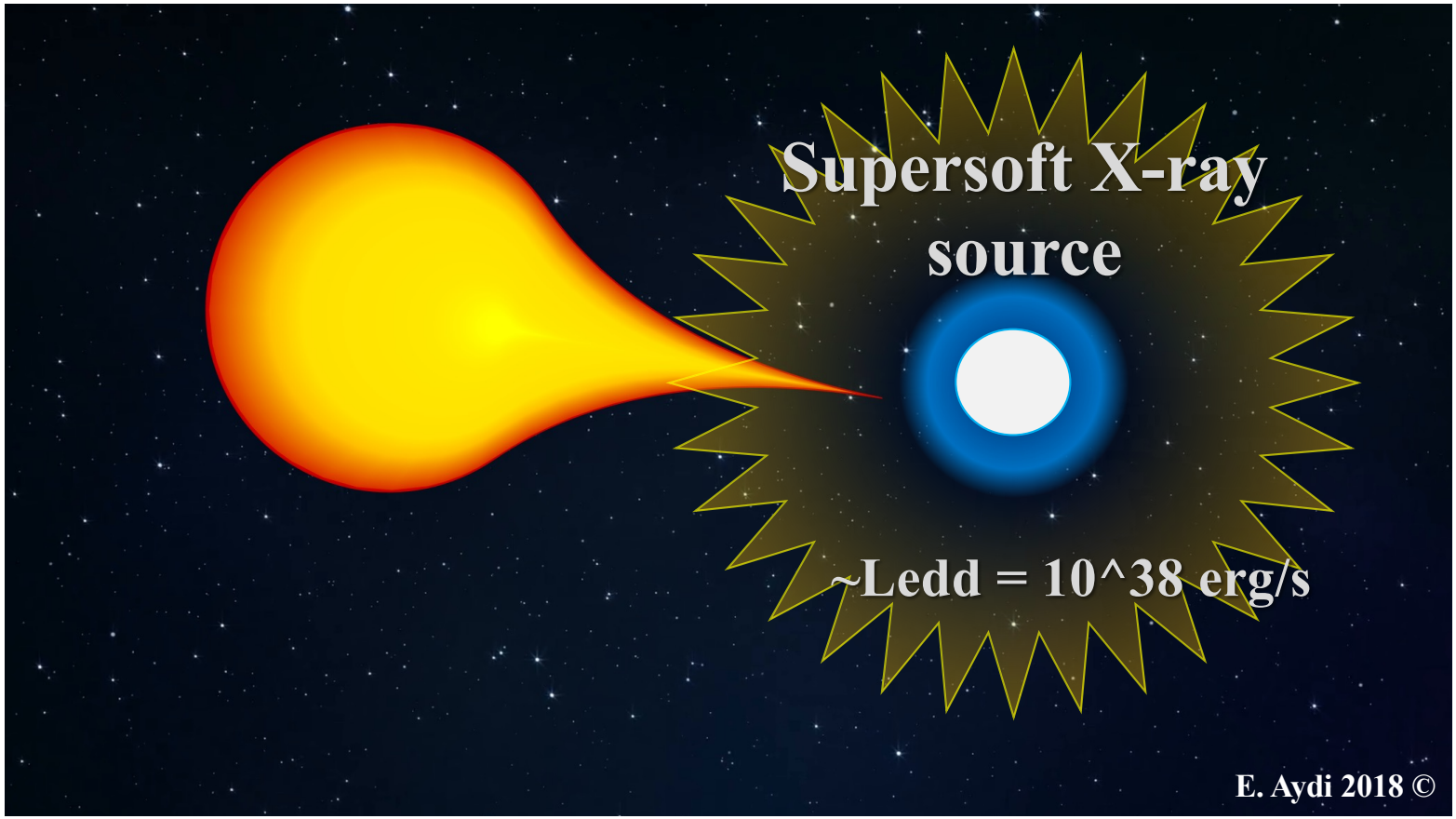
Novae – a brief summary



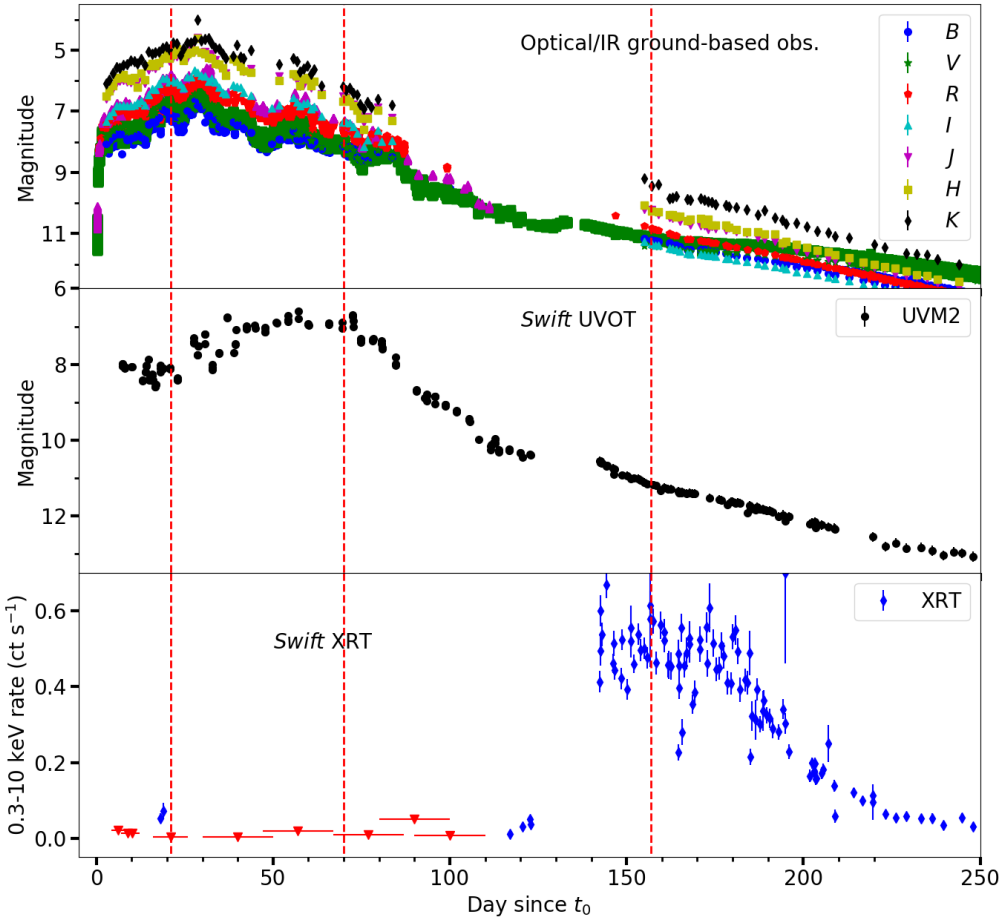
Novae – a brief summary



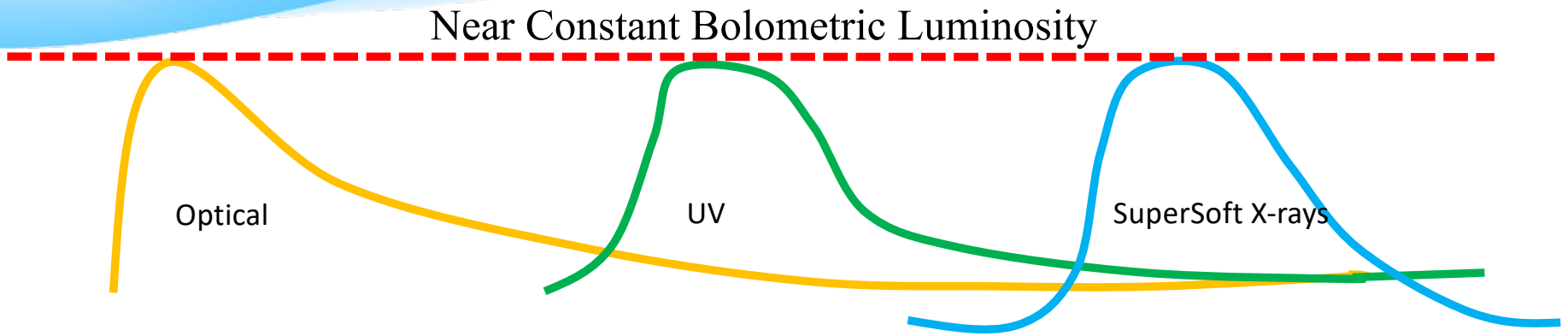
Novae – a brief summary

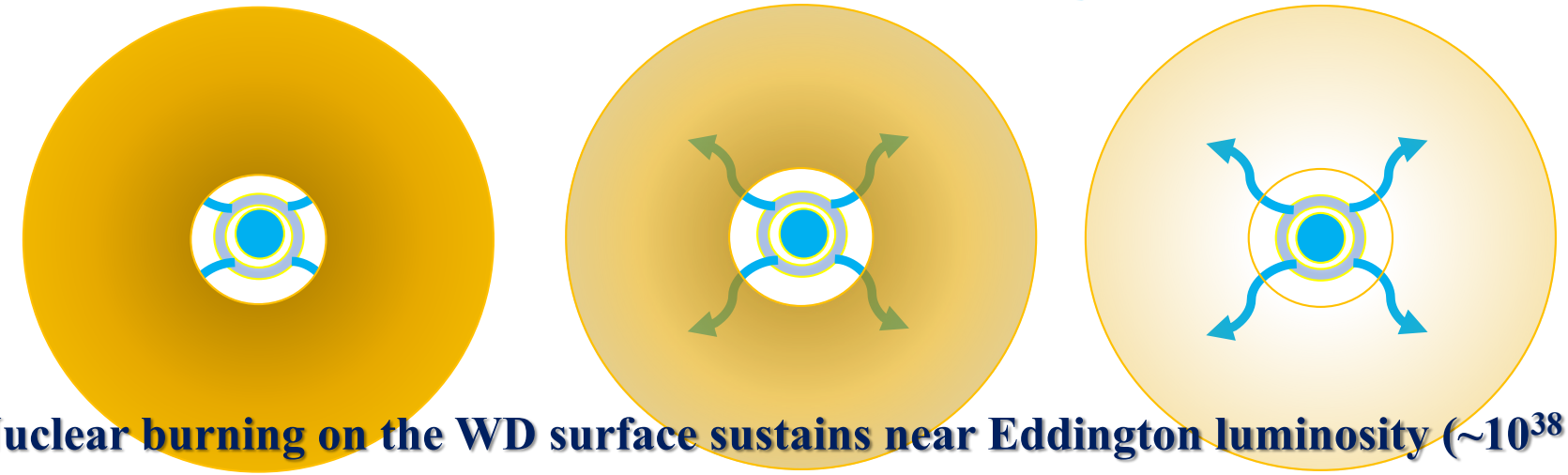


Novae – a brief summary



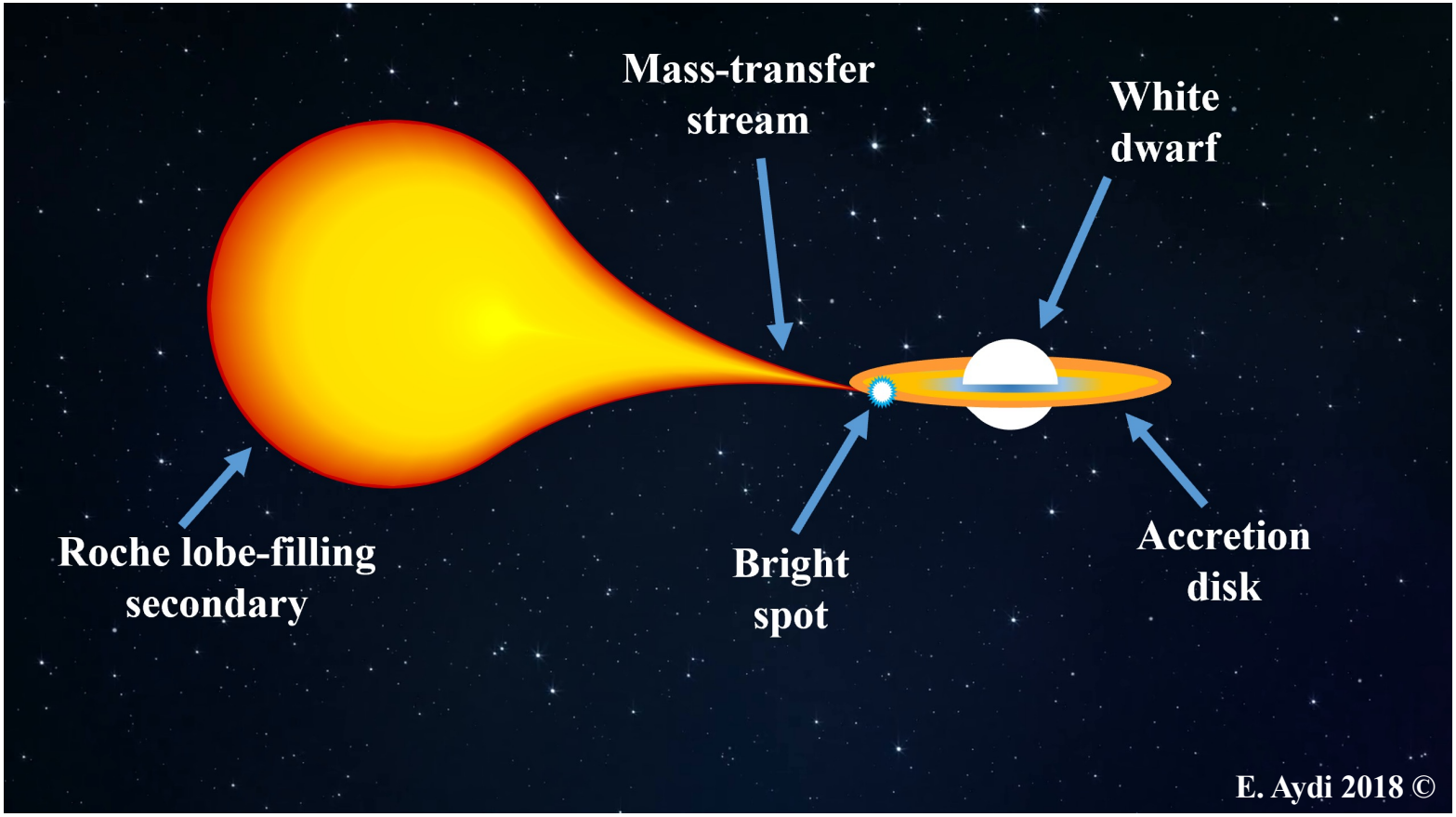
Novae – a brief summary



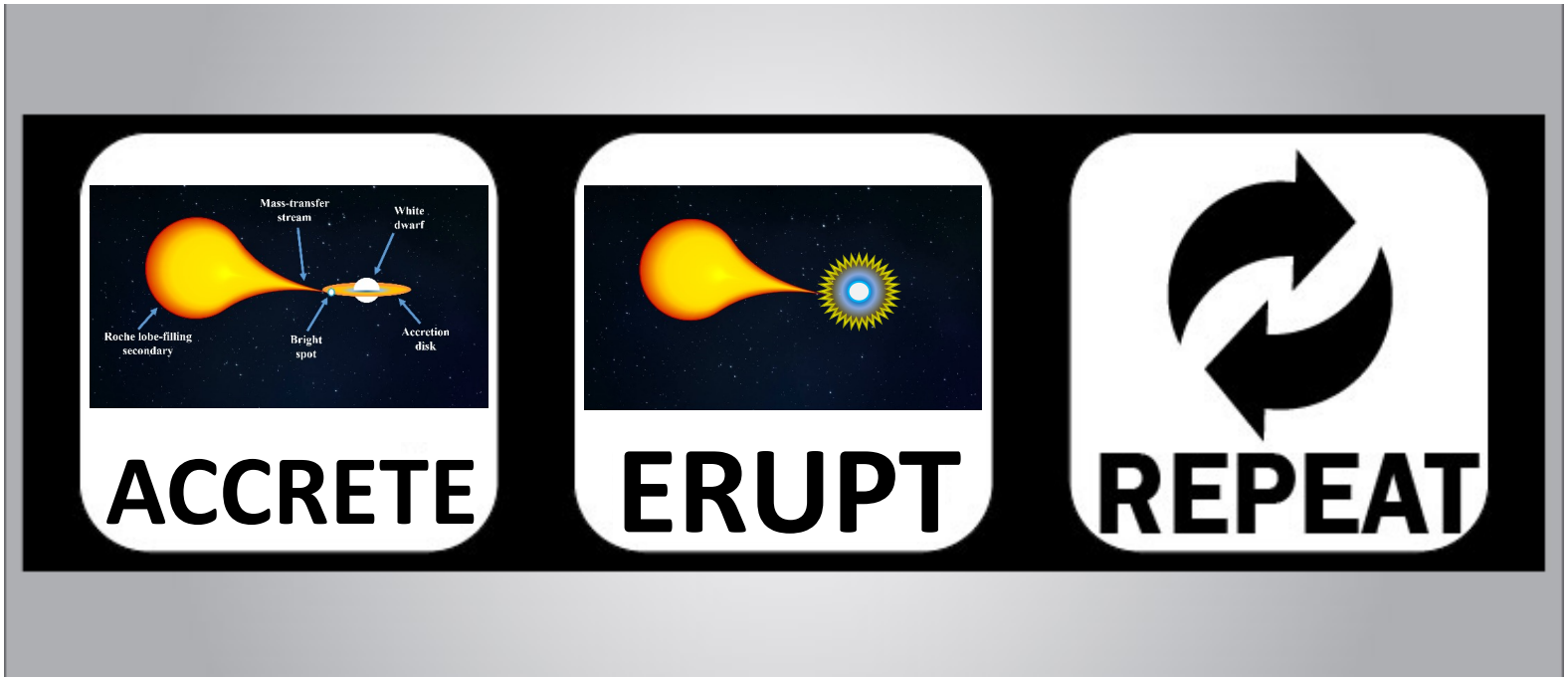


Nuclear burning on the WD surface sustains near Eddington luminosity (~10^{38} erg/s)

Novae – a brief summary

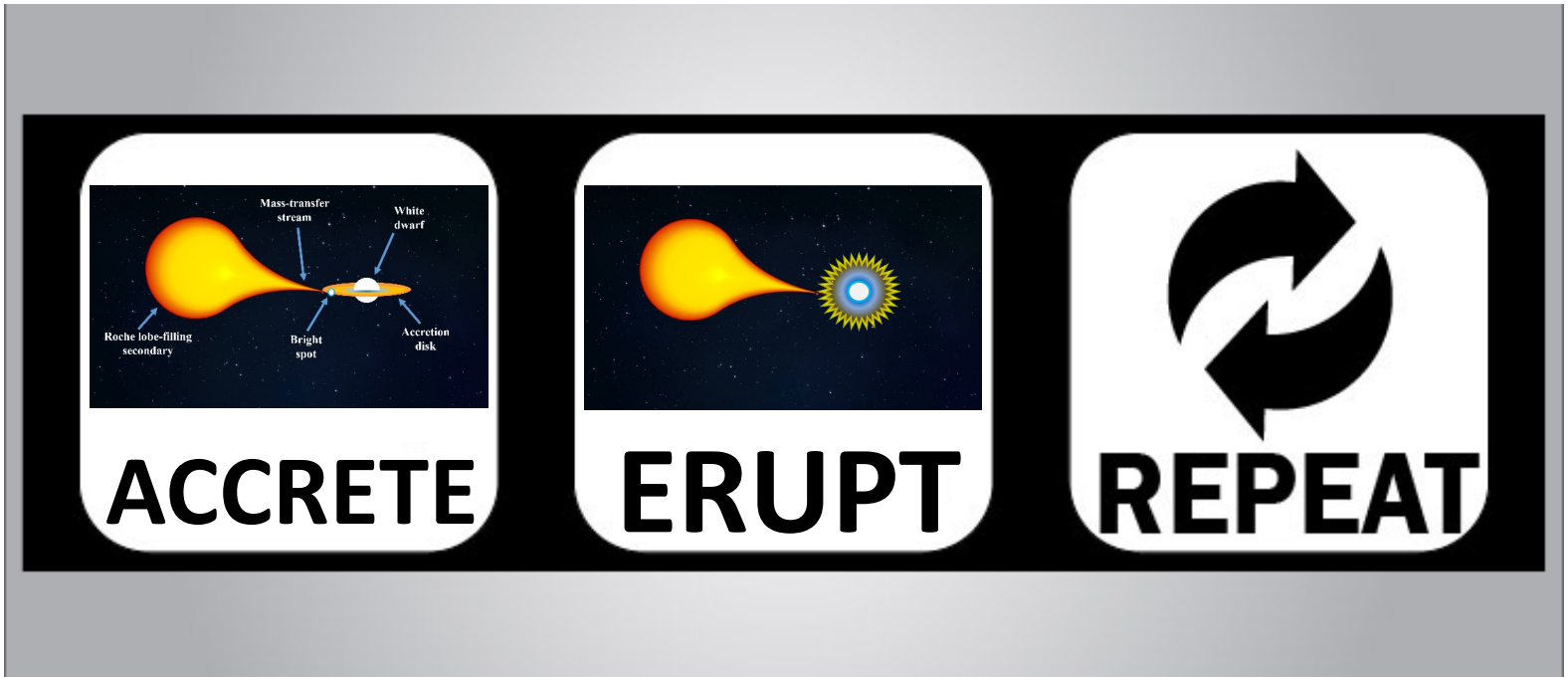


Novae in a nutshell



Recurrence period is typically 1000s of years, but some novae recur on much shorter timescales (decades)

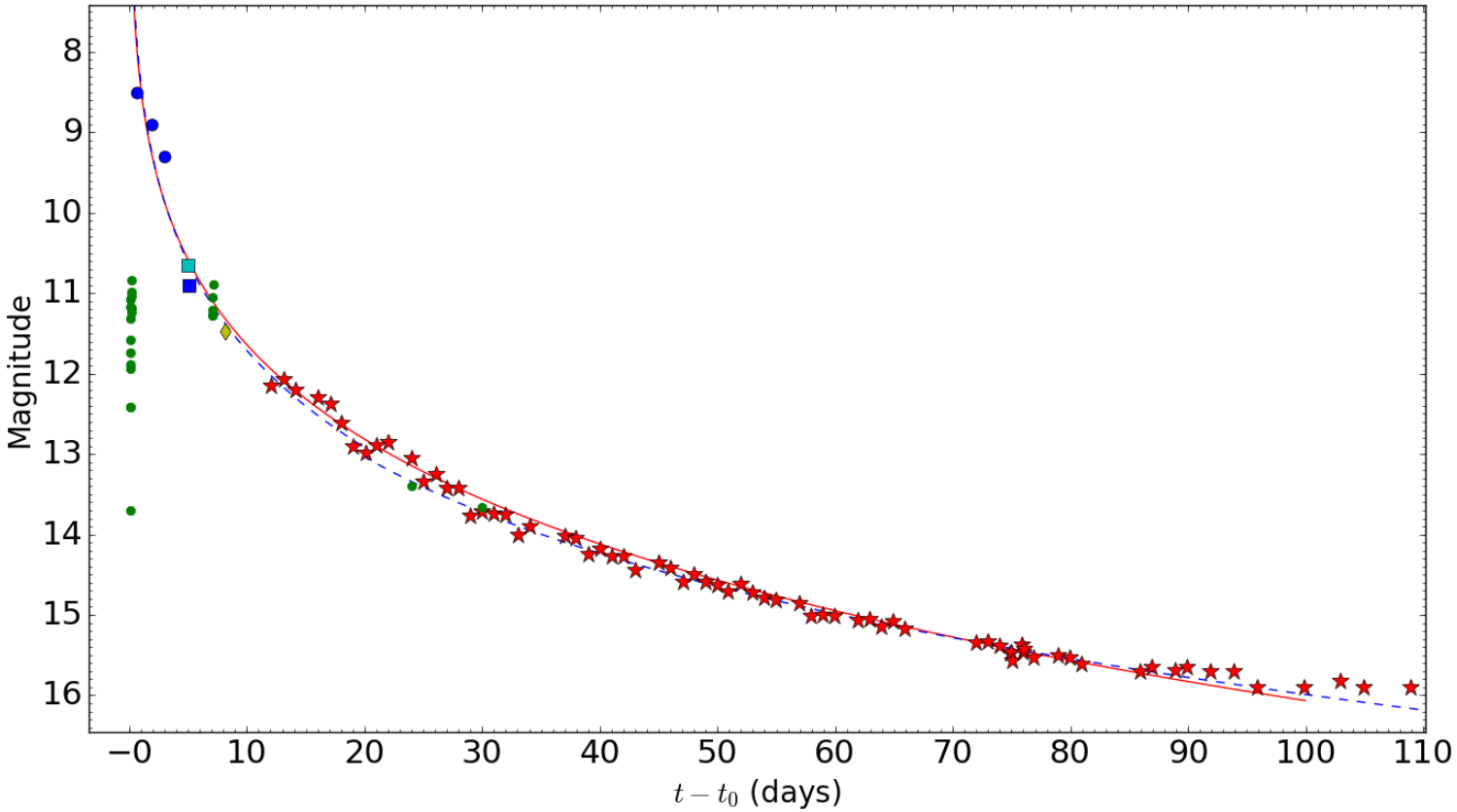
Novae in a nutshell



Around 10 novae are discovered in the Galaxy per year

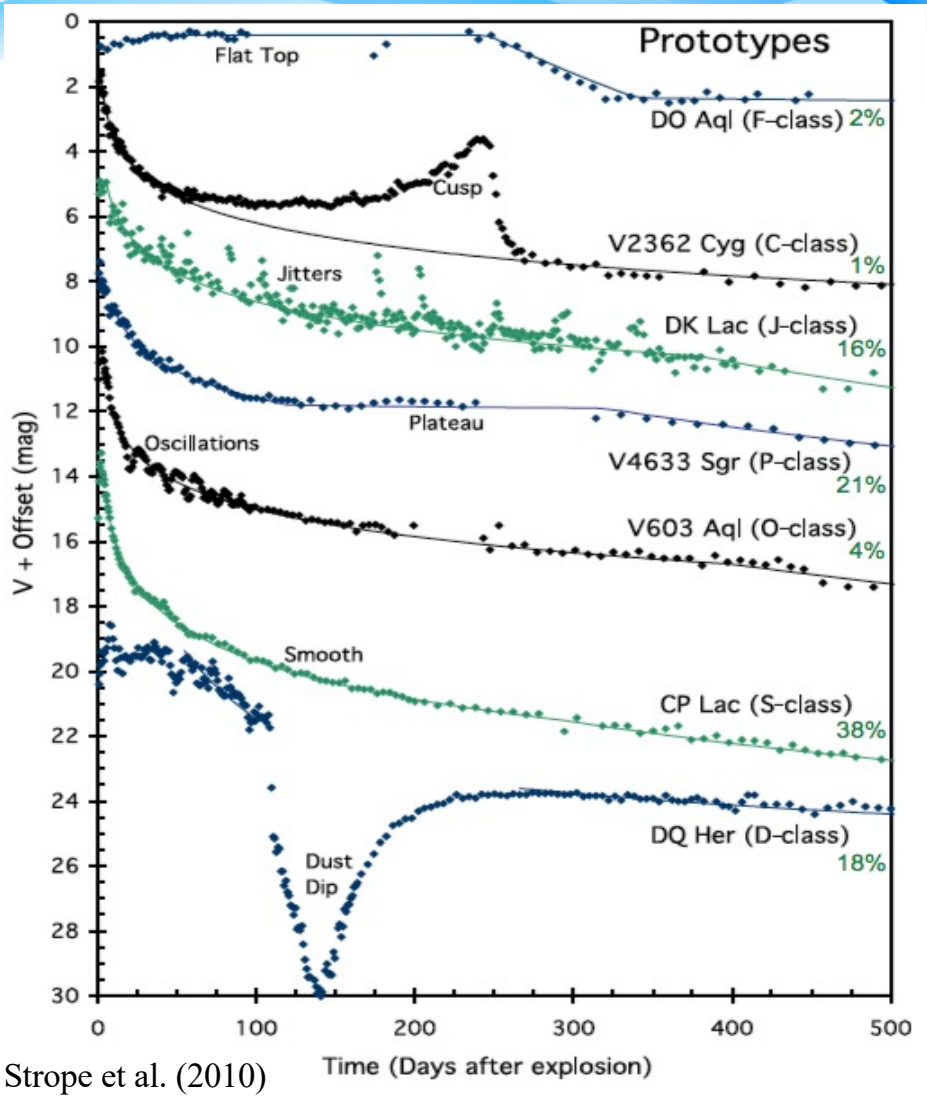
A typical visible light curve

Nova SMC 2016



Aydi et al. (2018a, MNRAS 474, 2679)

Not so typical



Strope et al. (2010)

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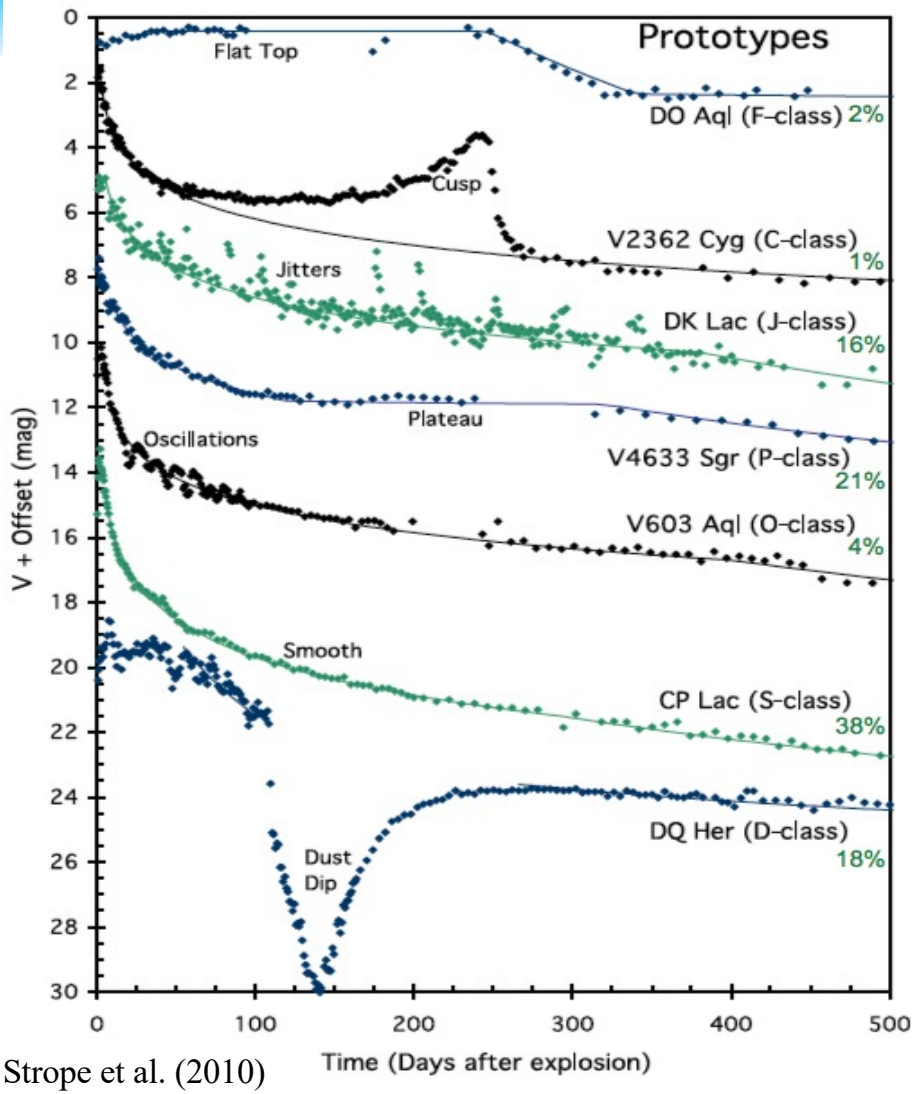
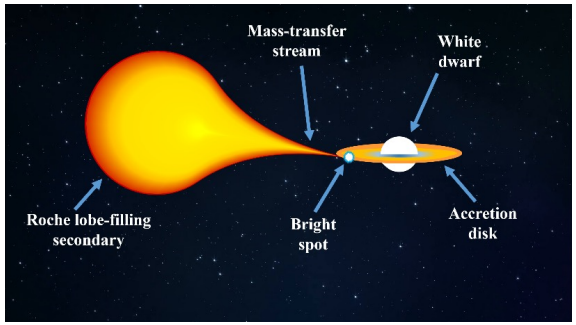
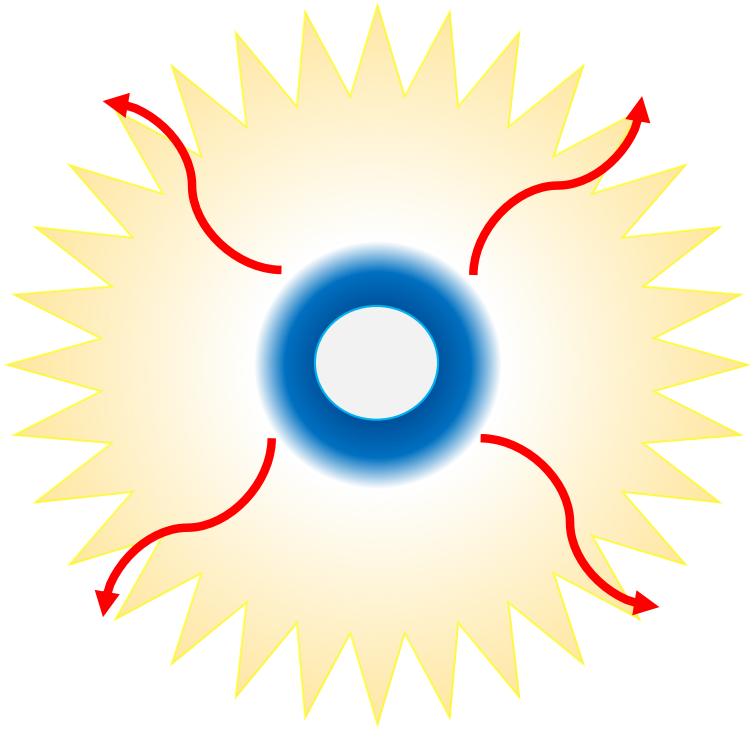


Strope et al. (2010)

Novae as we know them – Standard paradigm

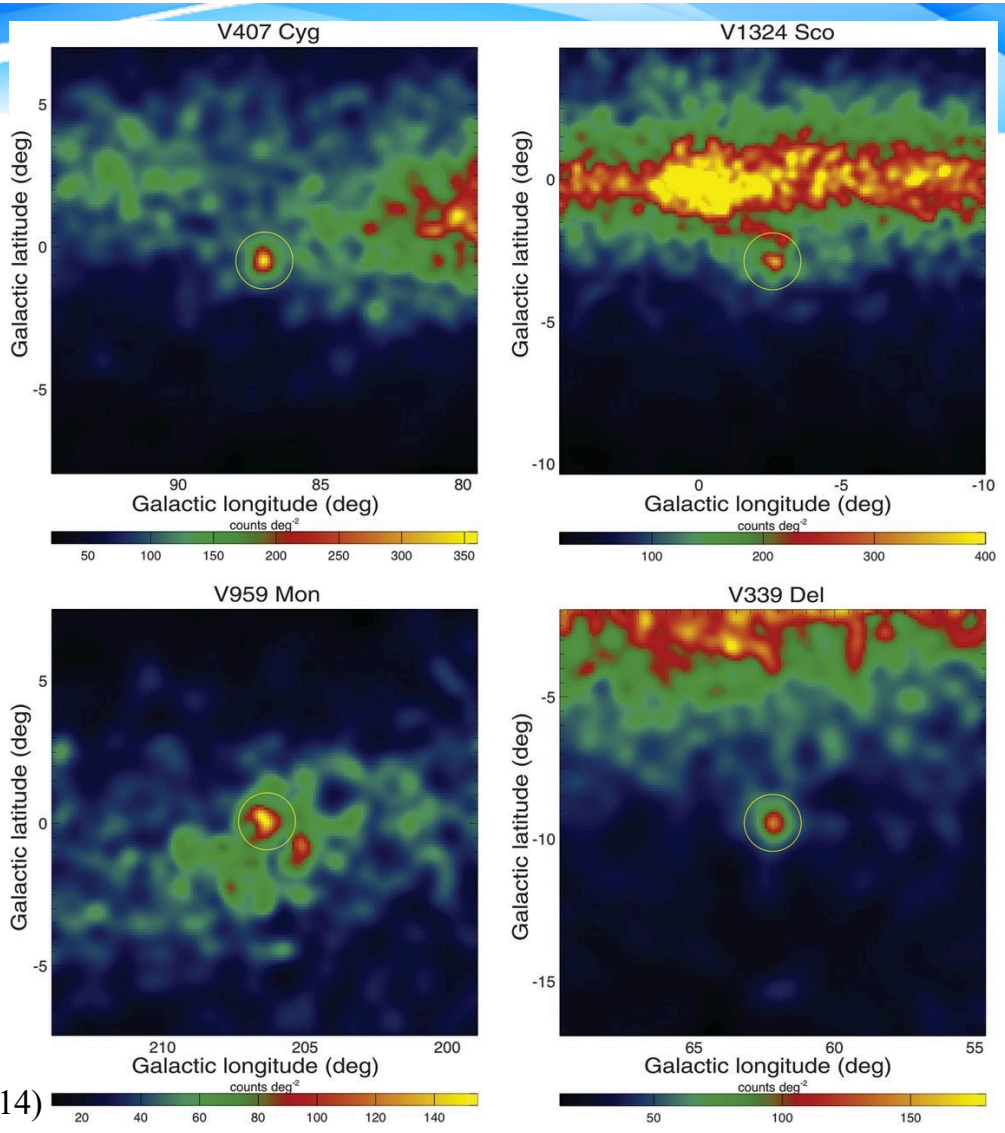




Luminosity powered by thermal emission from the hot WD

A shock!!

GeV gamma-ray emission from novae



Ackerman et al. (2014)

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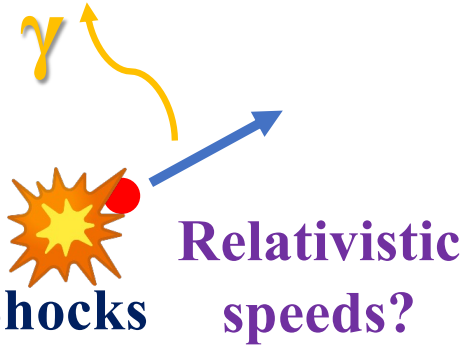
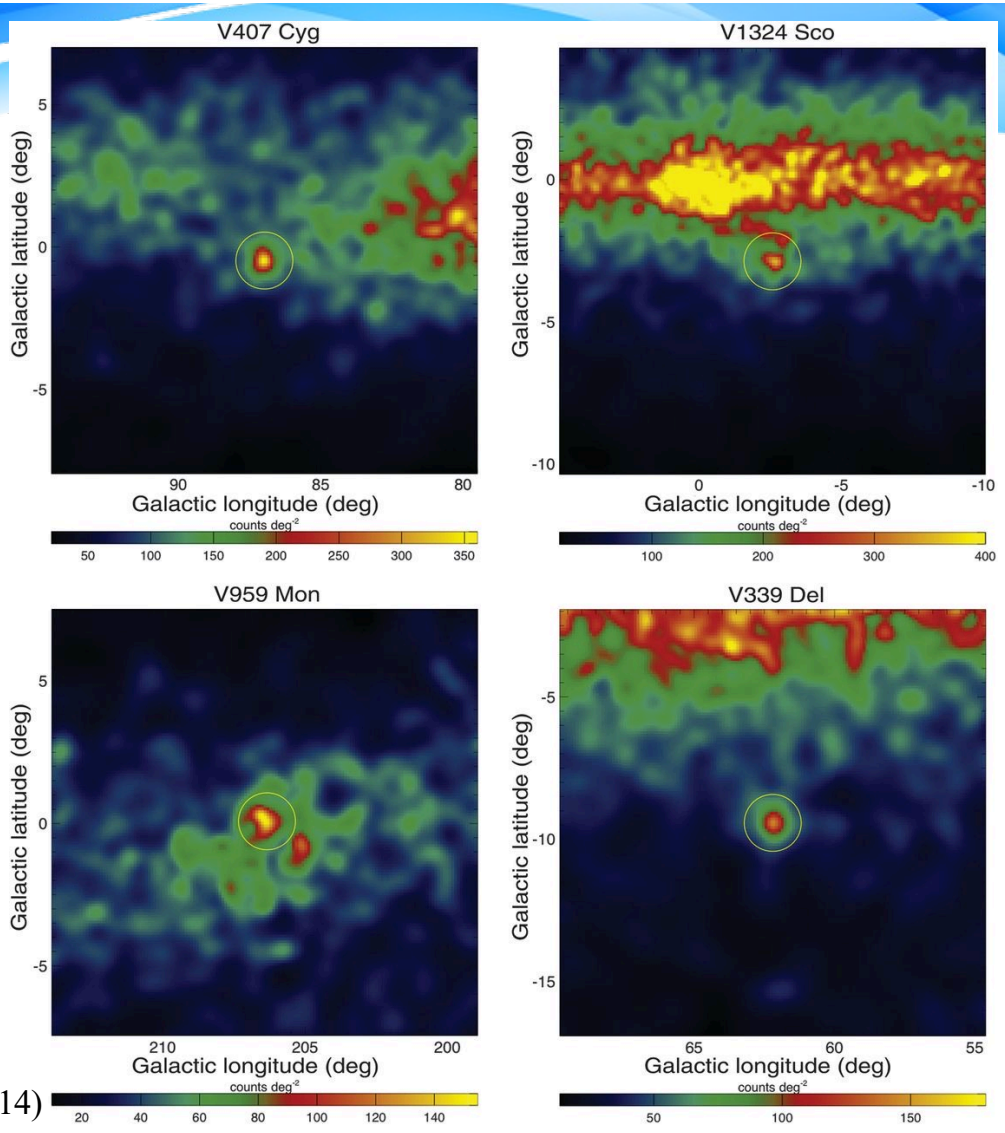




Ackerman et al. (2014)

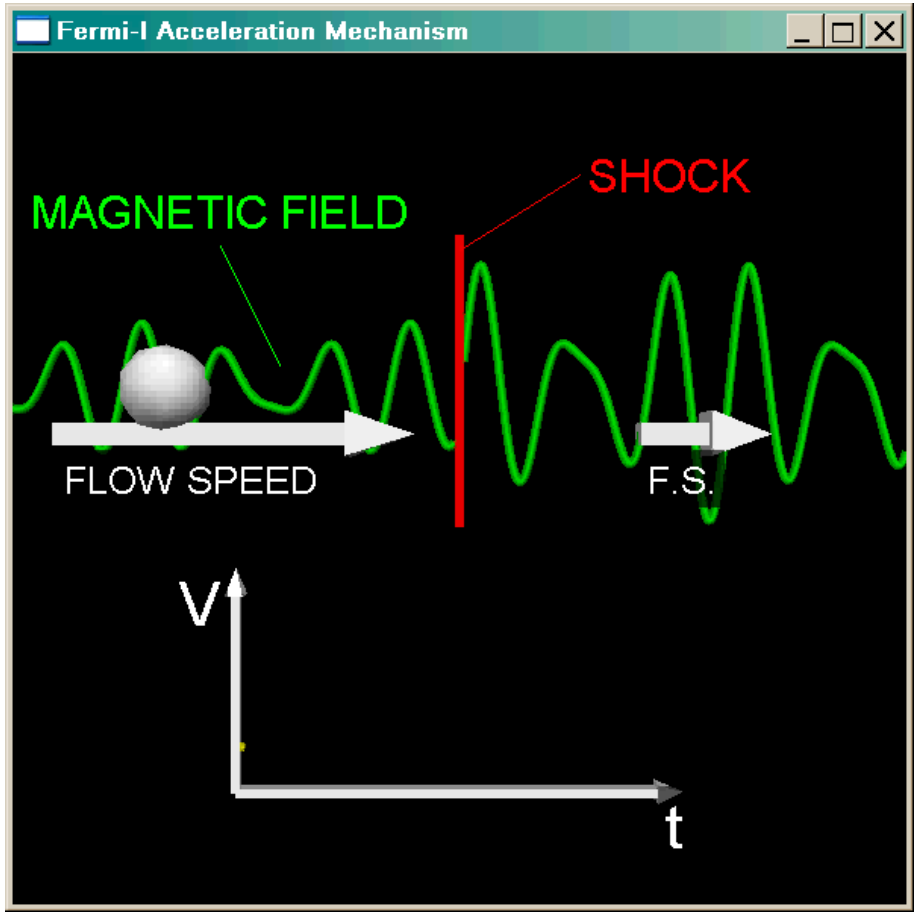
Particle acceleration in novae

Animation
by Andrey Vladimirov

Diffusive Shock Acceleration

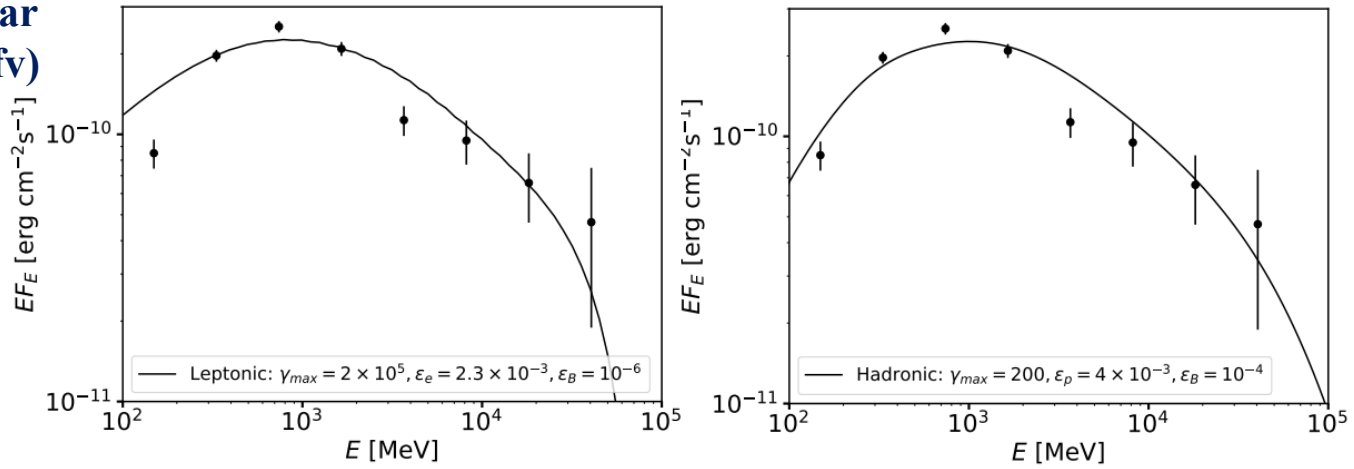
A charged particle traveling through the shock wave (from upstream to downstream). If it encounters a moving change in the magnetic field, this can reflect it back through the shock (downstream to upstream) at increased velocity.

If a similar process occurs upstream, the particle will again gain energy.



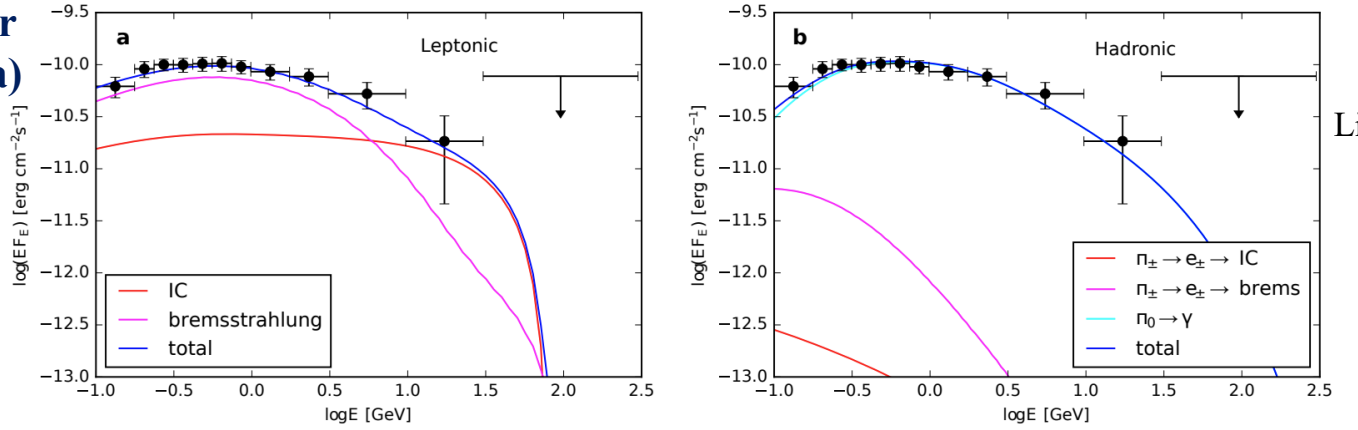
Gamma-rays from novae

Nova V906 Car (ASASSN-18fv)



Aydi et al. (2020a)

Nova V5856 Sgr (ASASSN-16ma)



Li et al. (2017)

Where are the shocks?

Where are the shocks?

Nova V407 Cyg Abdo et al. (2010)

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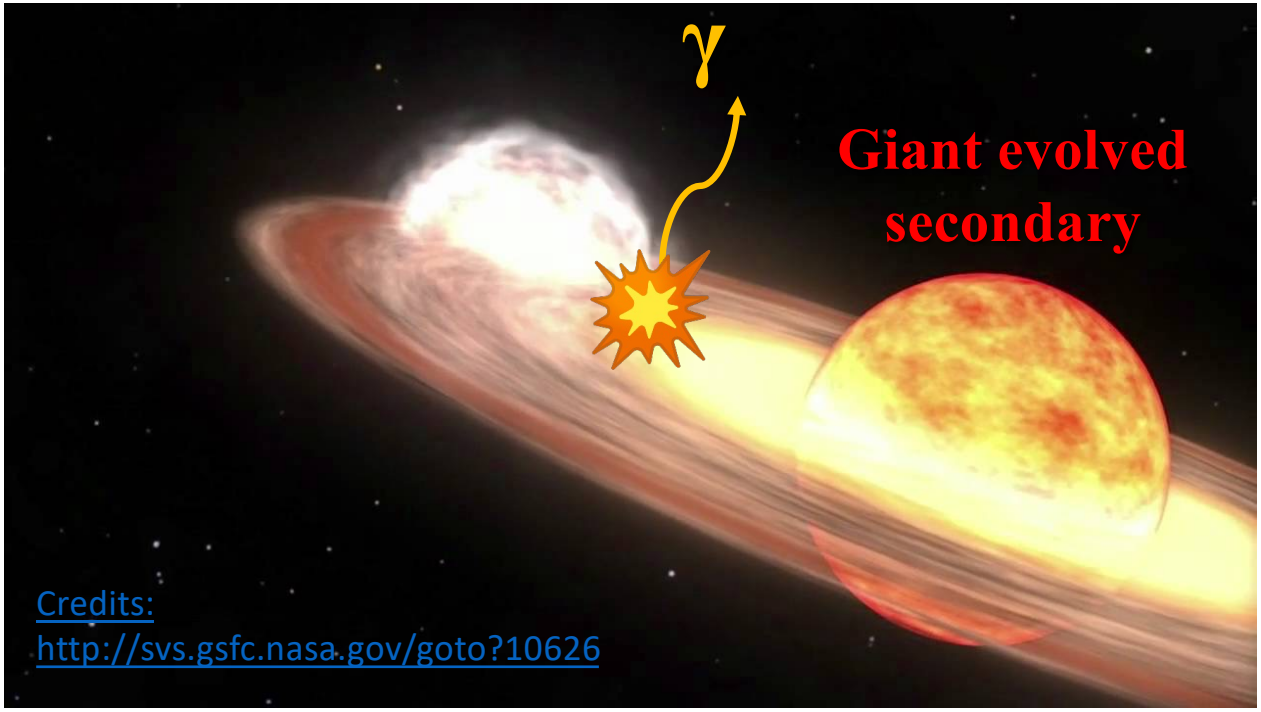
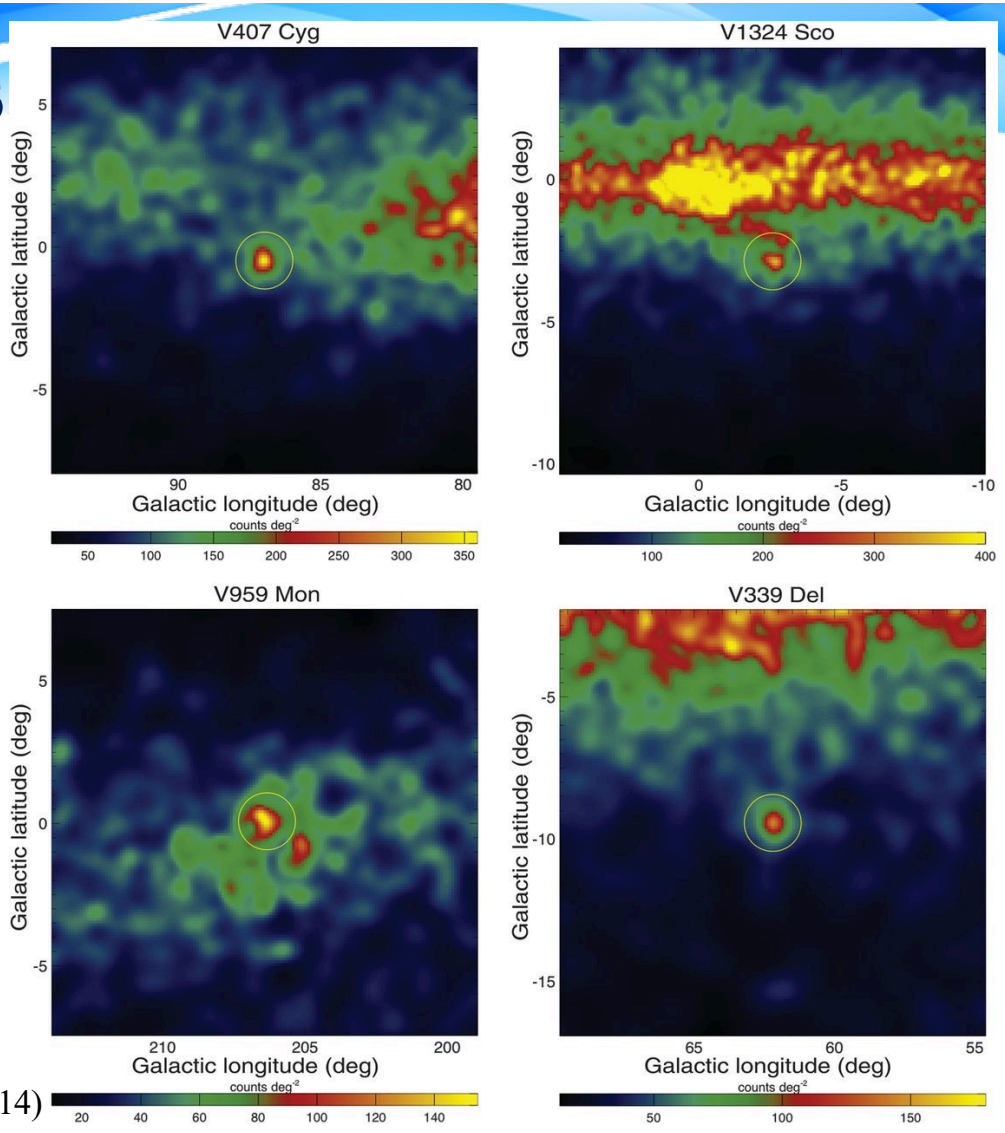


Where are the shocks

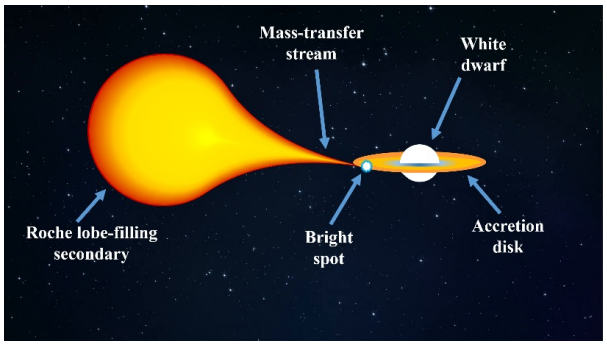
GeV gamma-ray emission from novae

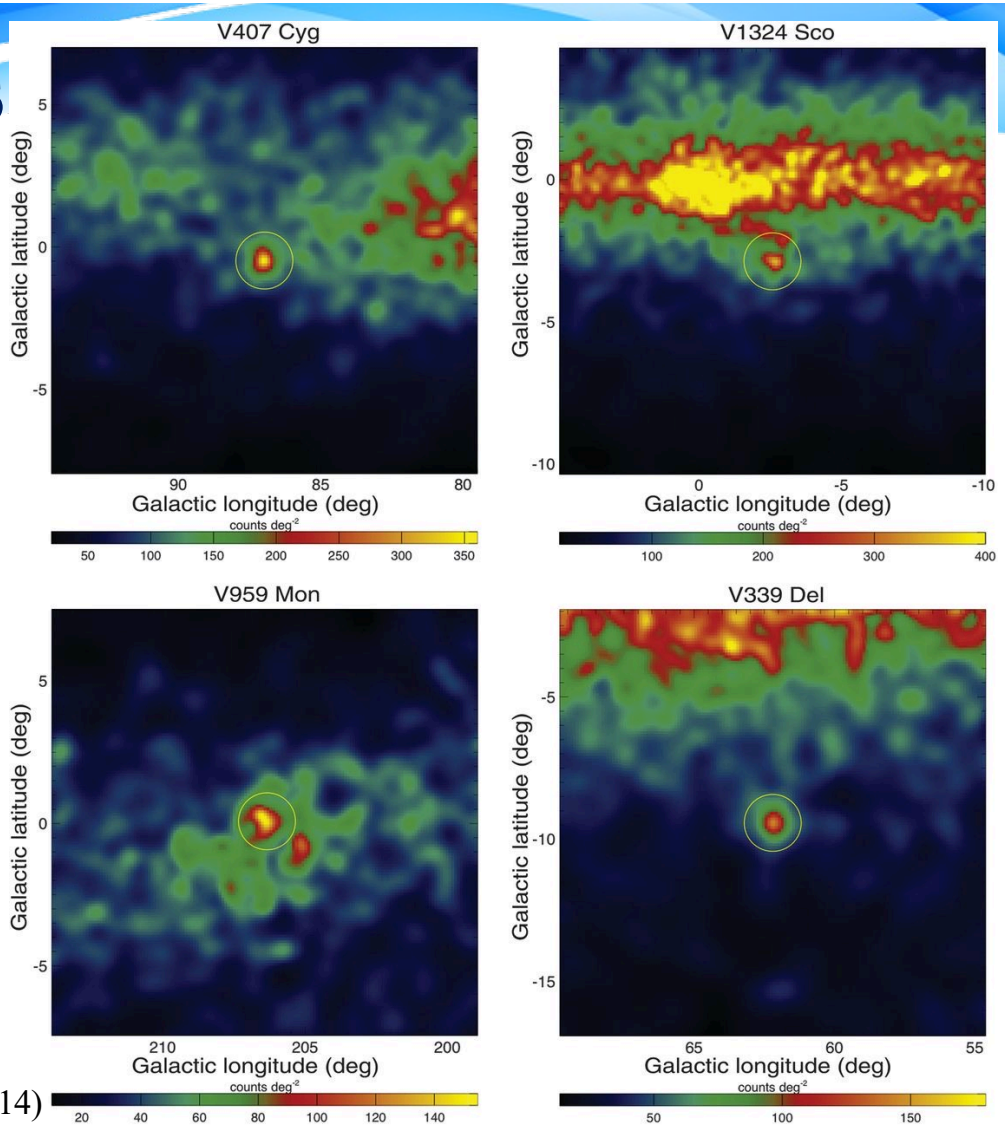


Ackerman et al. (2014)

Where are the shocks

GeV gamma-ray emission from novae

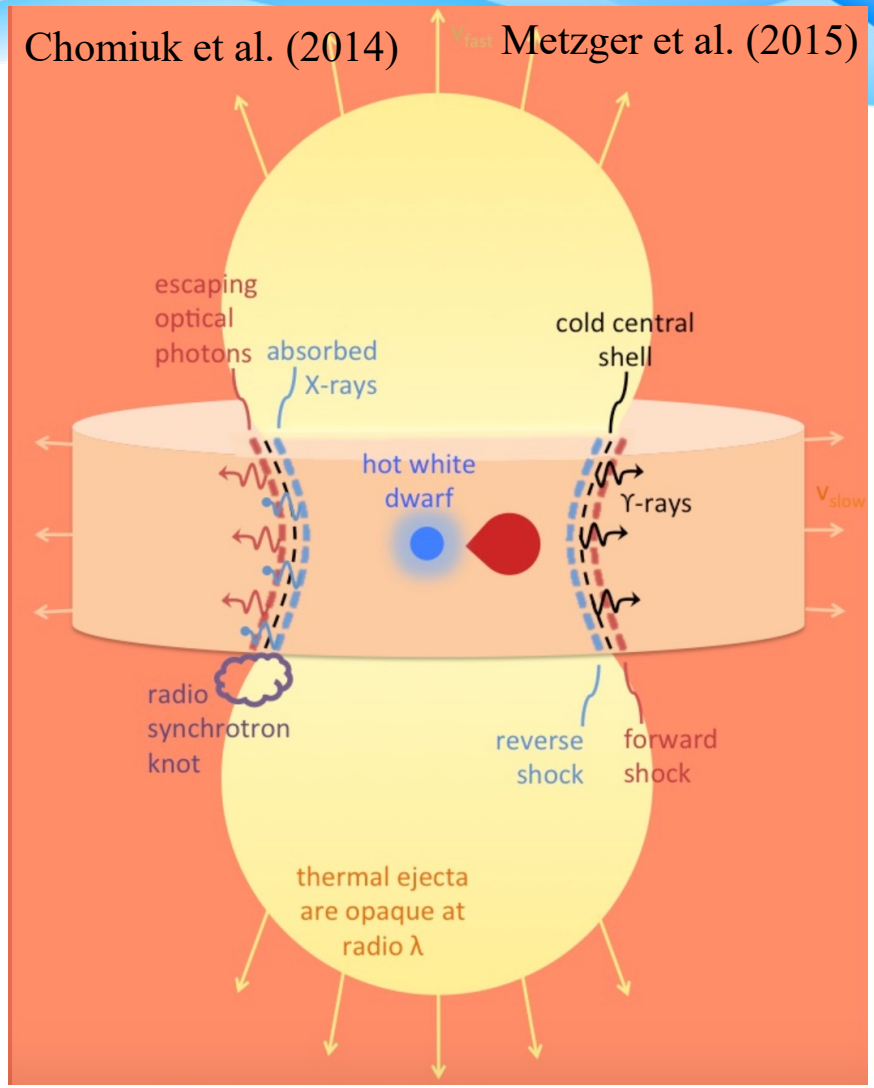




Ackerman et al. (2014)

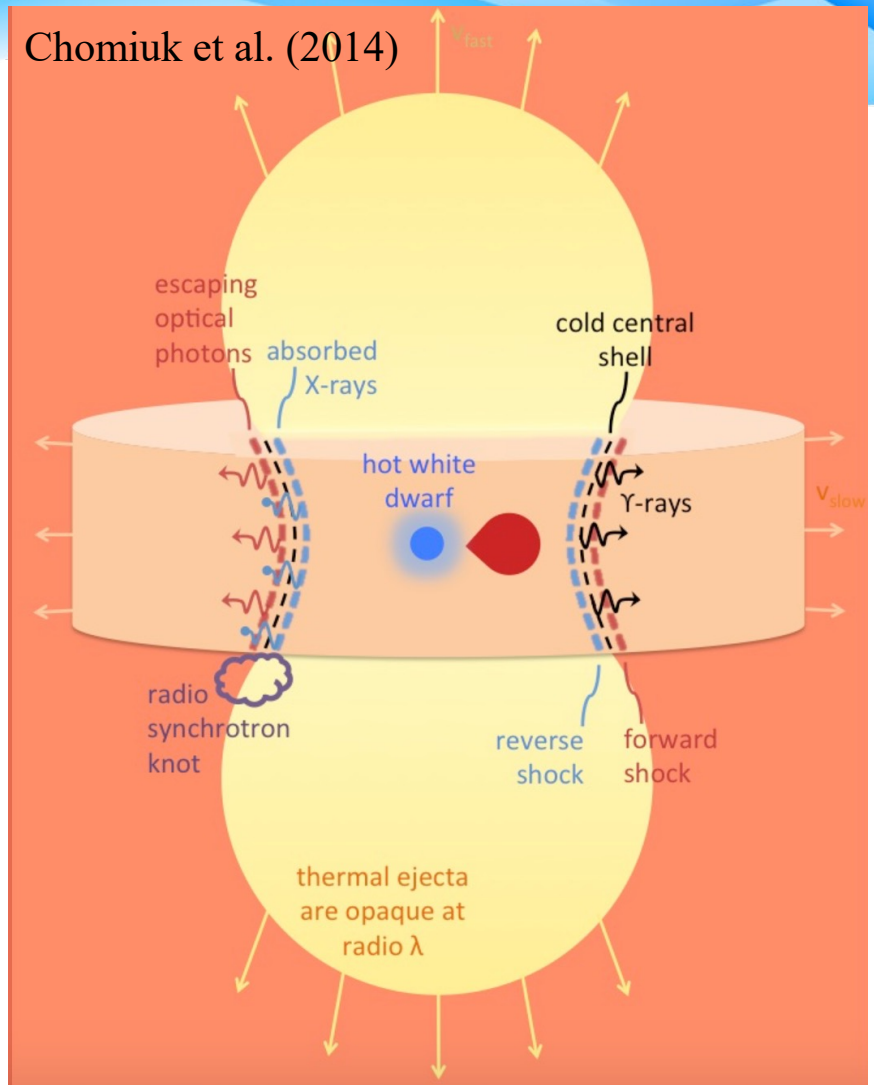
Shocks internal to the ejecta

Chomiuk et al. (2014) Metzger et al. (2015)



Shocks internal to the ejecta

Predicted $T \sim 10^6 - 10^7$ K



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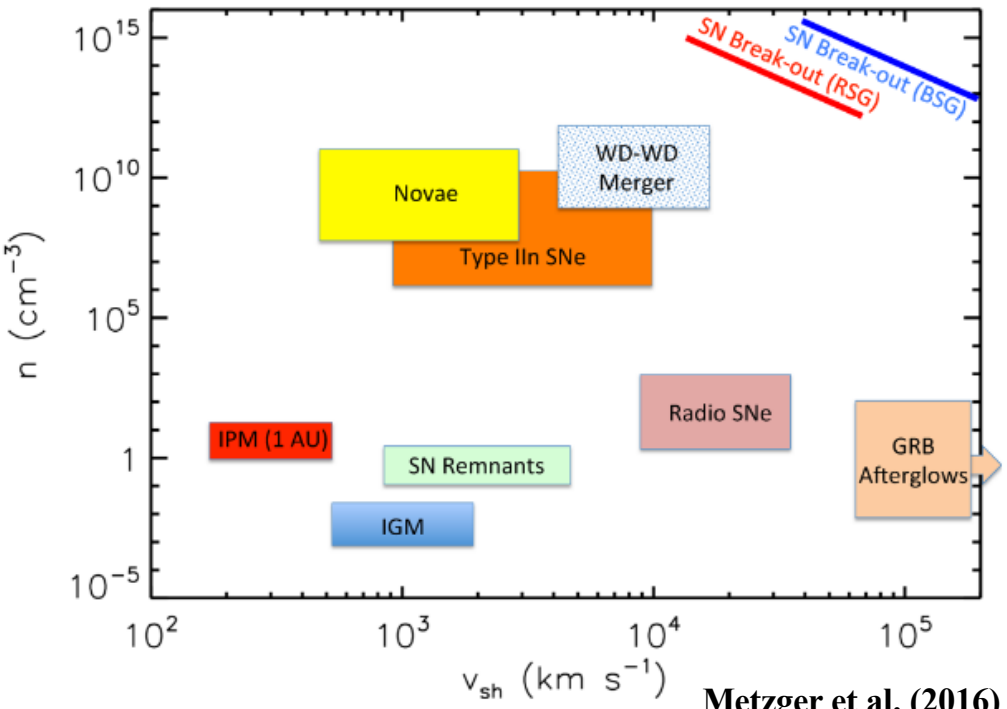
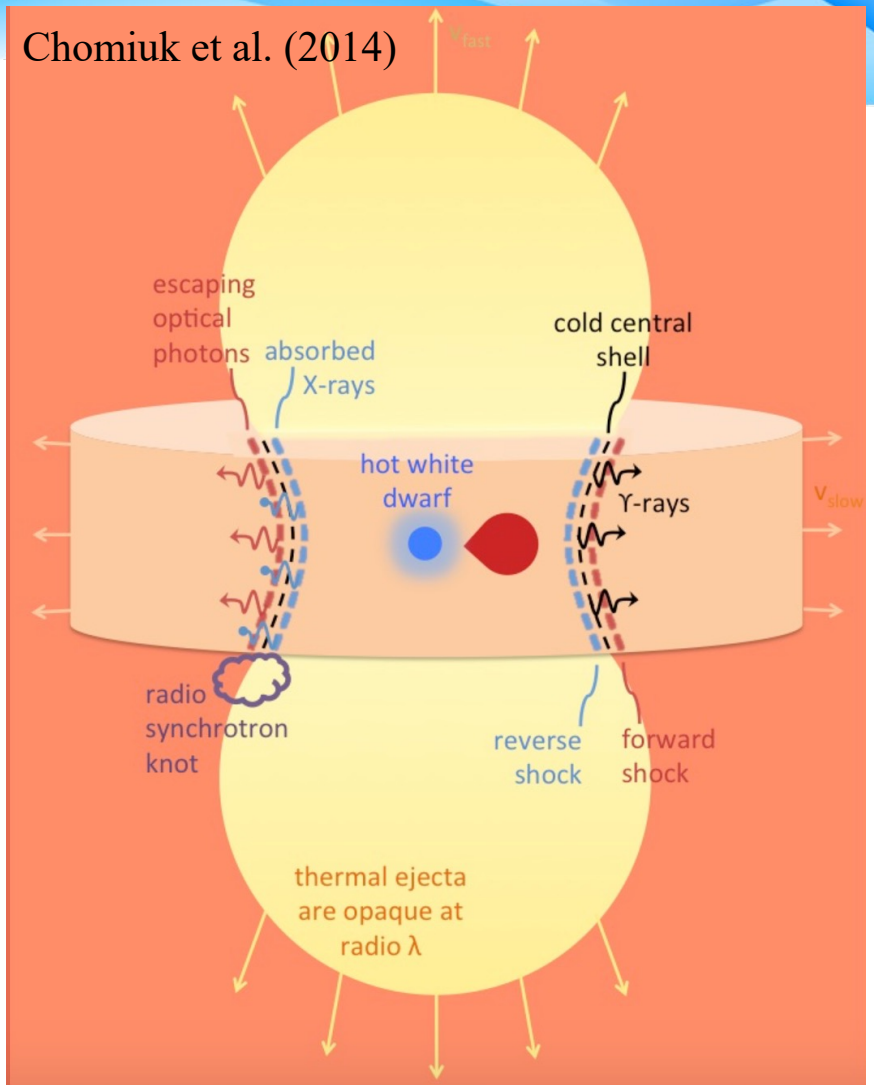


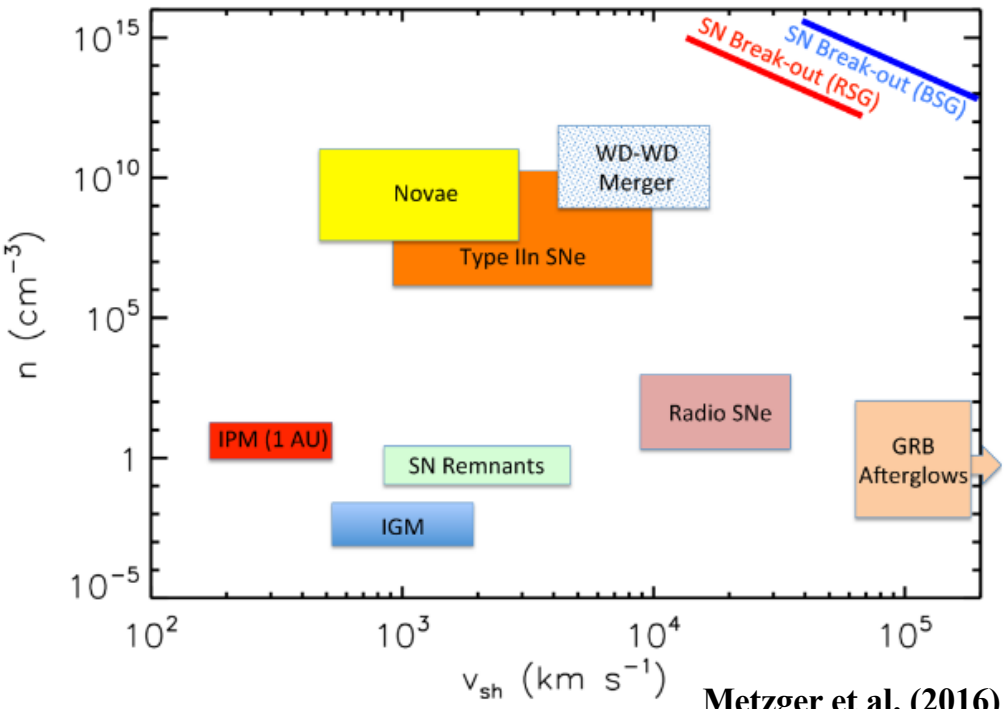
Metzger et al. (2016)

Chomiuk et al. (2014)



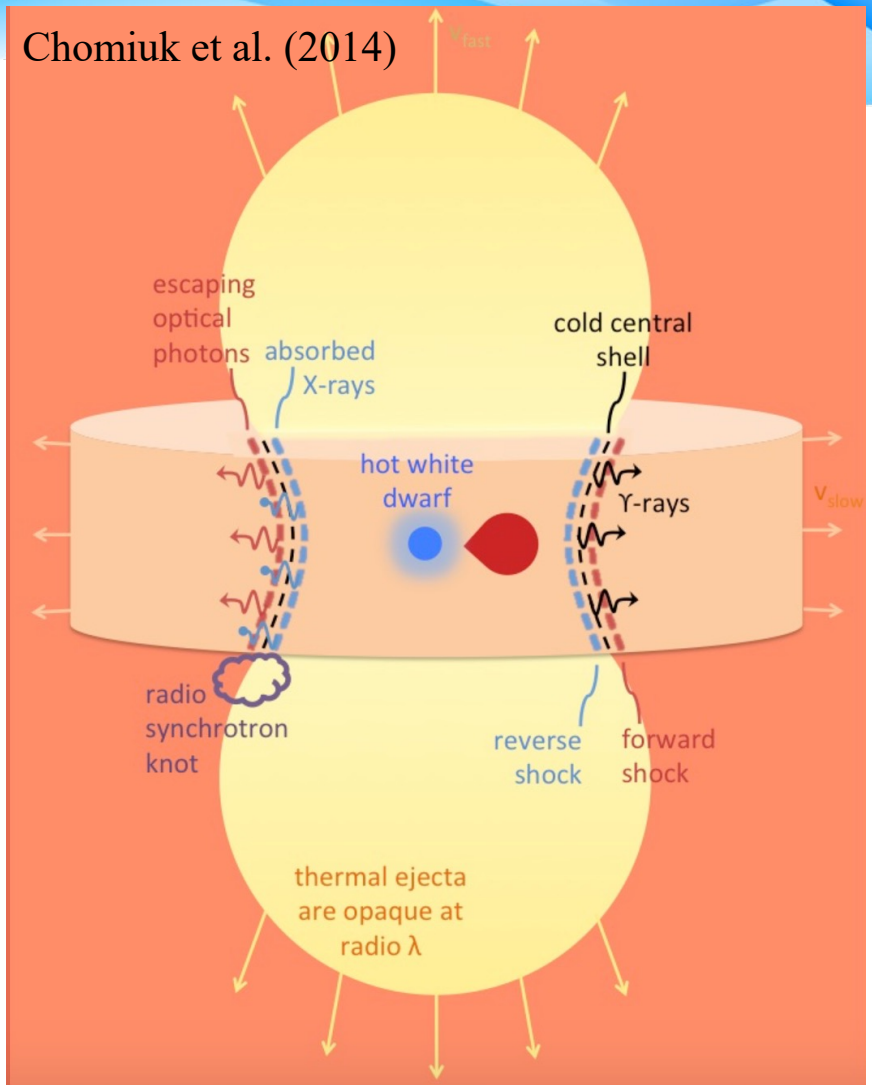
Shocks internal to the ejecta

Cooling time is short → radiative shocks



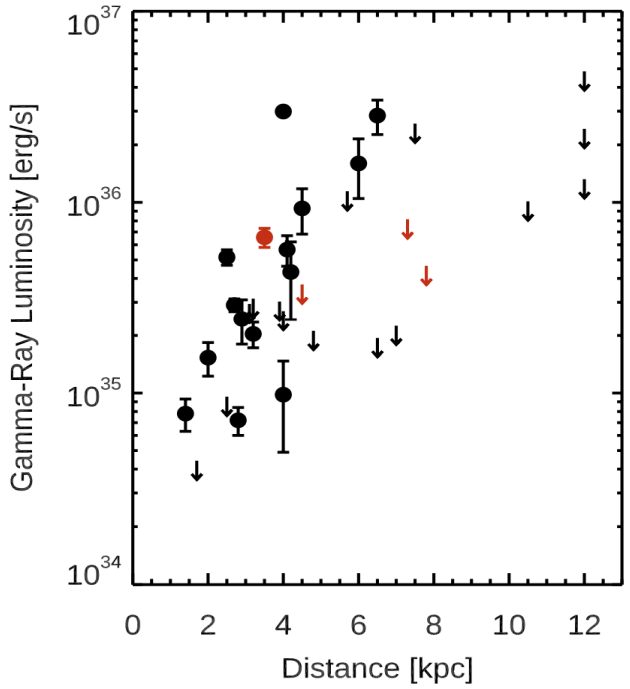
Metzger et al. (2016)

Chomiuk et al. (2014)



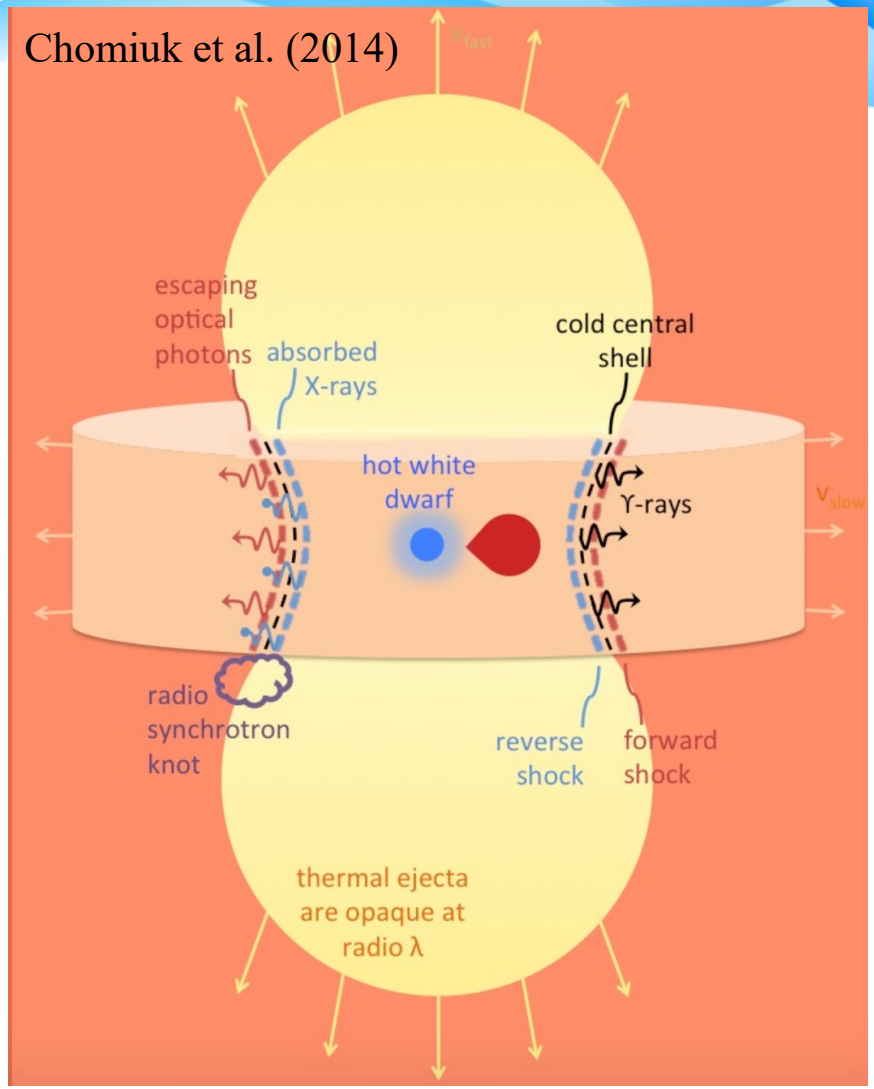
Shocks internal to the ejecta

Observed $L\gamma \sim 10^{35}$ -10^{36} erg/s



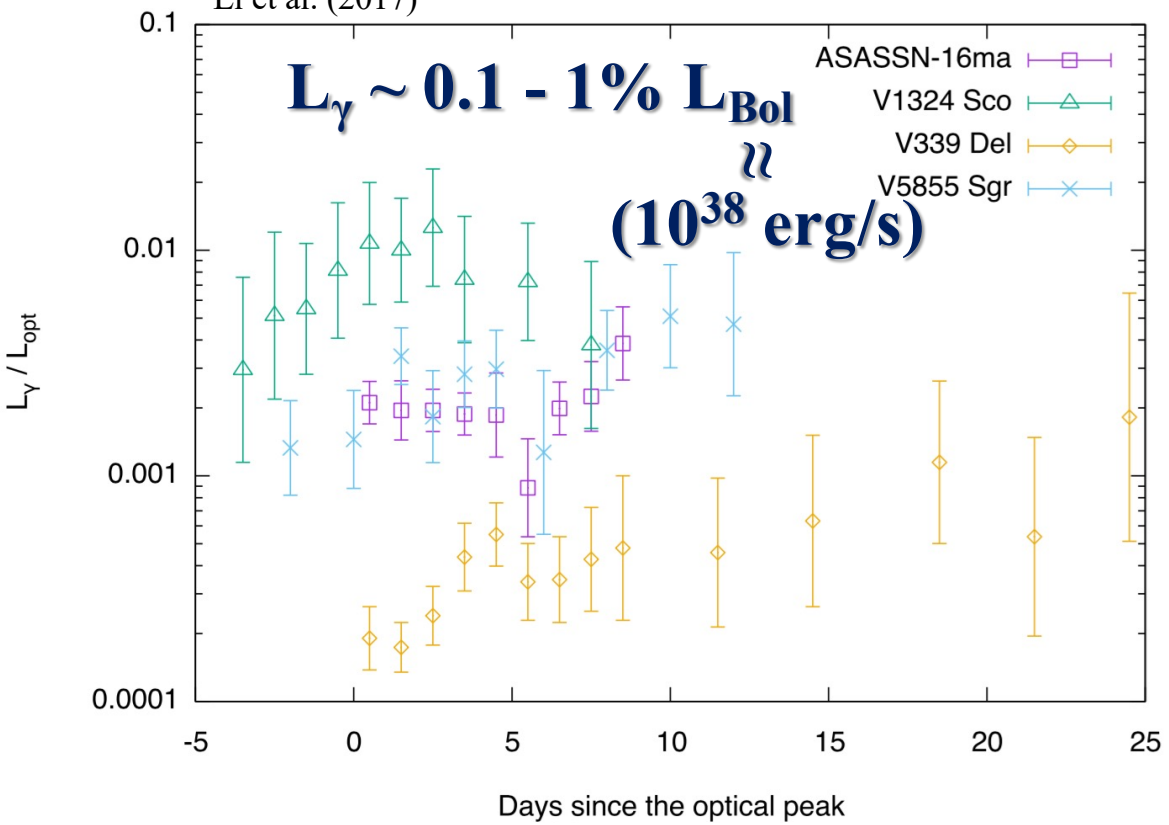
Chomiuk et al. (2021)

Chomiuk et al. (2014)



Gamma-rays from novae

Li et al. (2017)

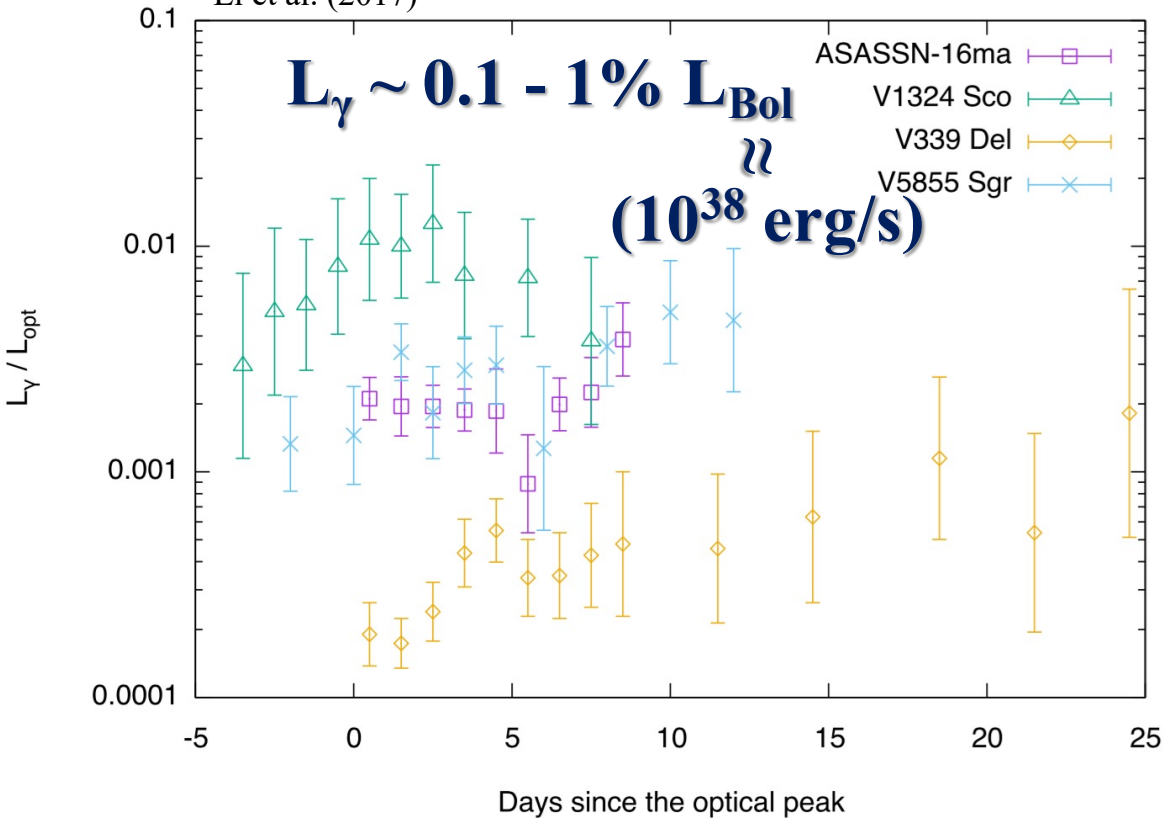


Gamma-rays from novae

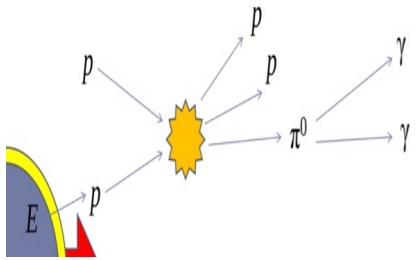
$L\gamma = L_{sh}\ \varepsilon_\gamma\ \varepsilon_{nth}$

Diffusive shock acceleration mechanism

Li et al. (2017)

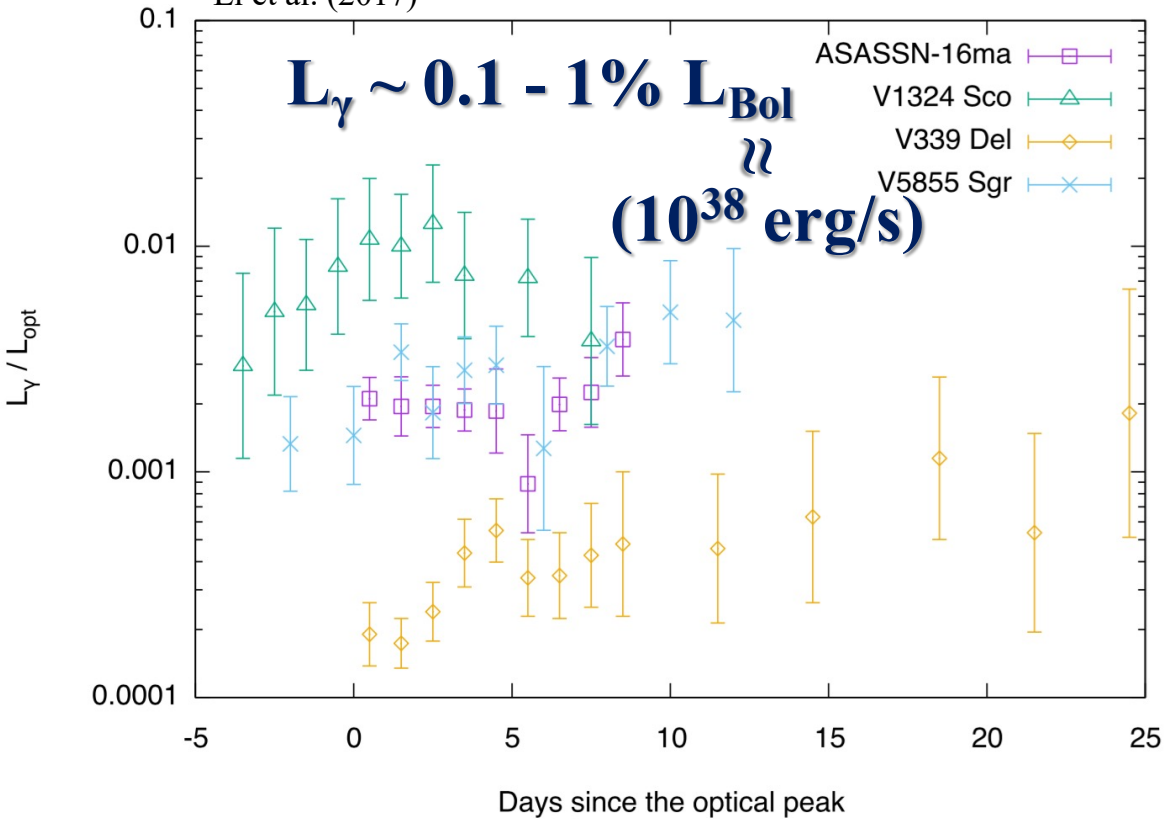


~5%



Gamma-rays from novae

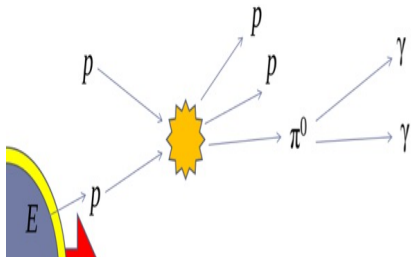
Li et al. (2017)



$L\gamma = L_{sh}\ \varepsilon_\gamma\ \varepsilon_{nth}$

Standard γ-gamma ray emission mechanism:

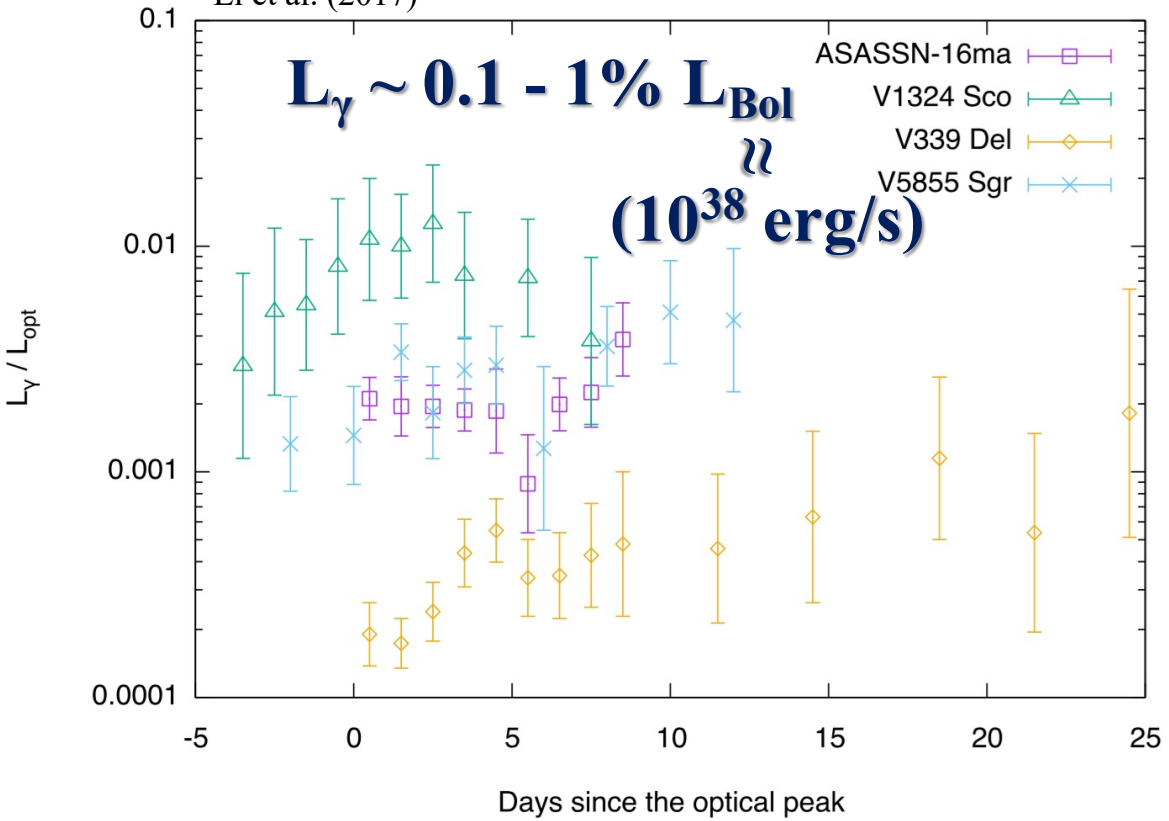
~5%



20%

Gamma-rays from novae

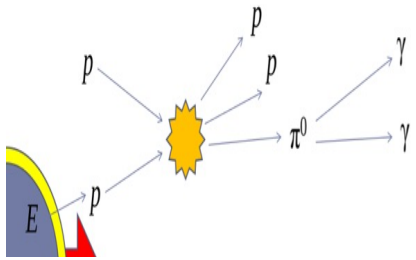
Li et al. (2017)



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

Standard γ-gamma ray emission mechanism:

~5%

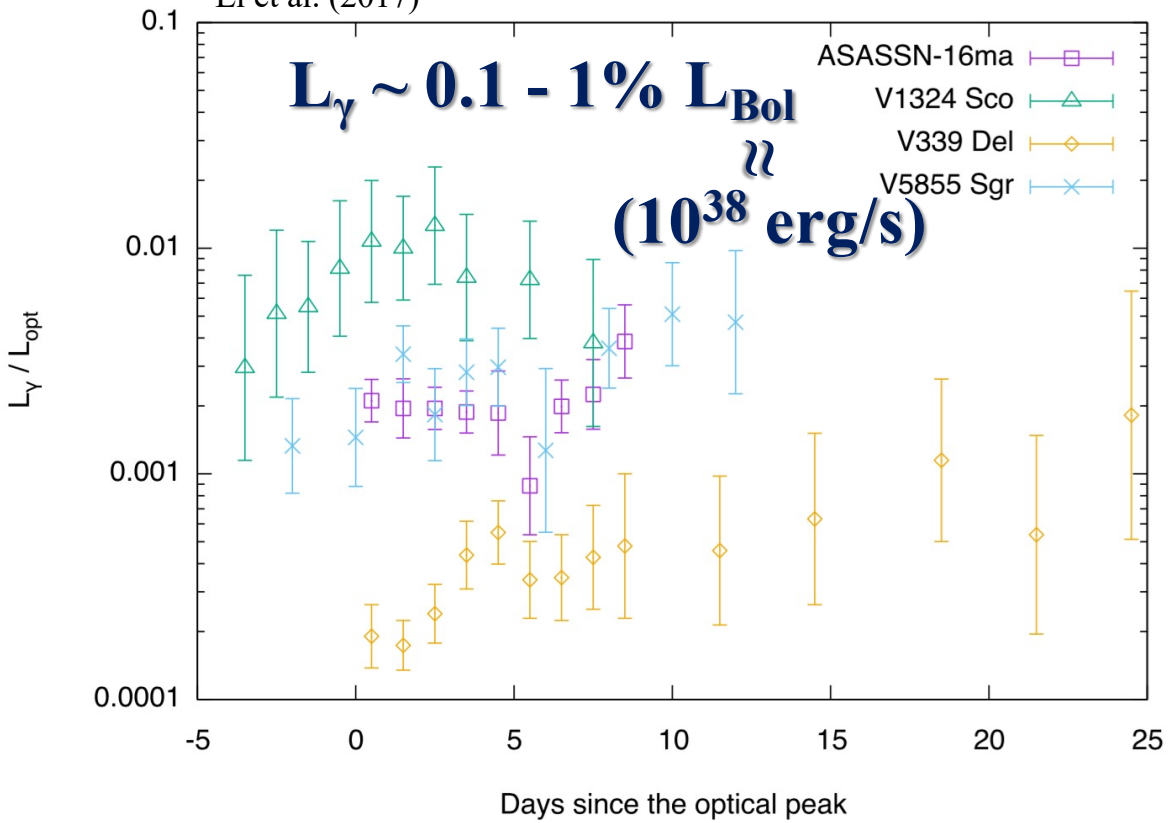


20%

$L_\gamma \sim 1\%\ L_{sh}$

Gamma-rays from novae

Li et al. (2017)



$L_\gamma \sim 1\%\ L_{sh}$

↓

$L_{sh} \approx 10^{38}$ erg/s

Rivaling the bolometric luminosity of the nova

Radiative shocks?

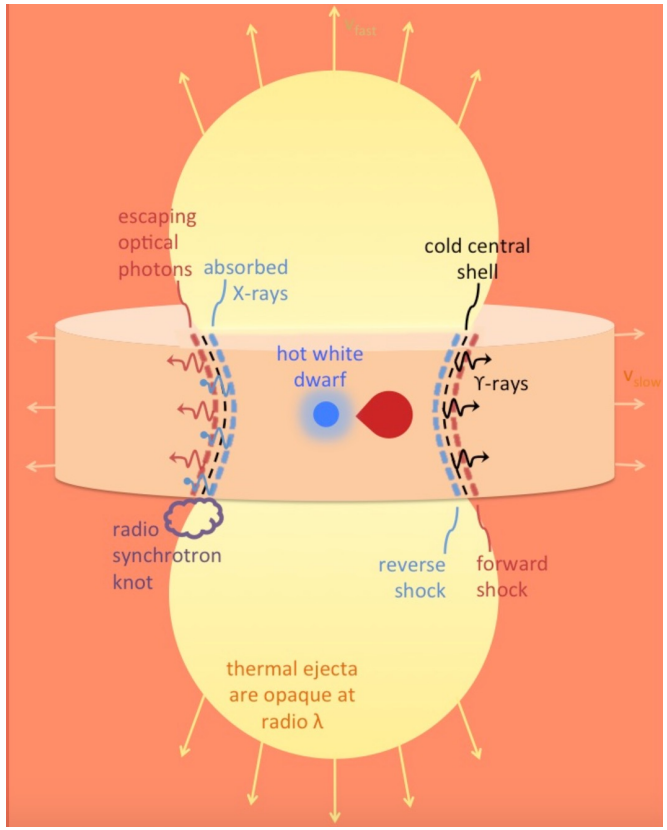
$L_{sh} \approx 10^{38}$ erg/s

Rivaling the bolometric luminosity of the nova.

Shock energy is radiated rather than being dissipated into adiabatic expansion

Shocks as an additional source of emission

Chomiuk et al. (2014)

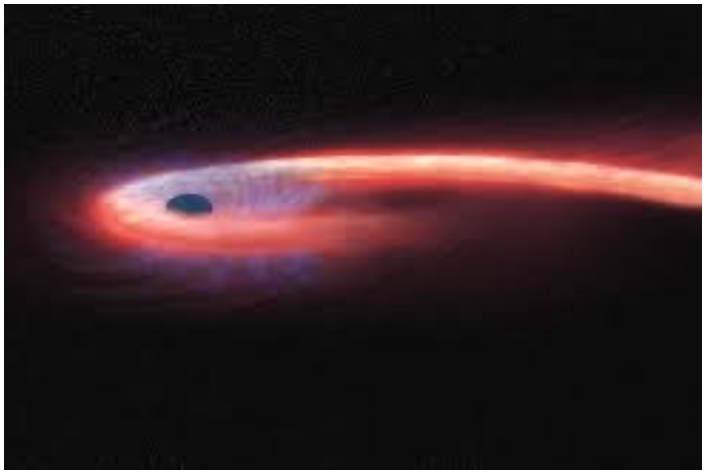


Shocks powering other stellar eruptions

Type IIn SNe

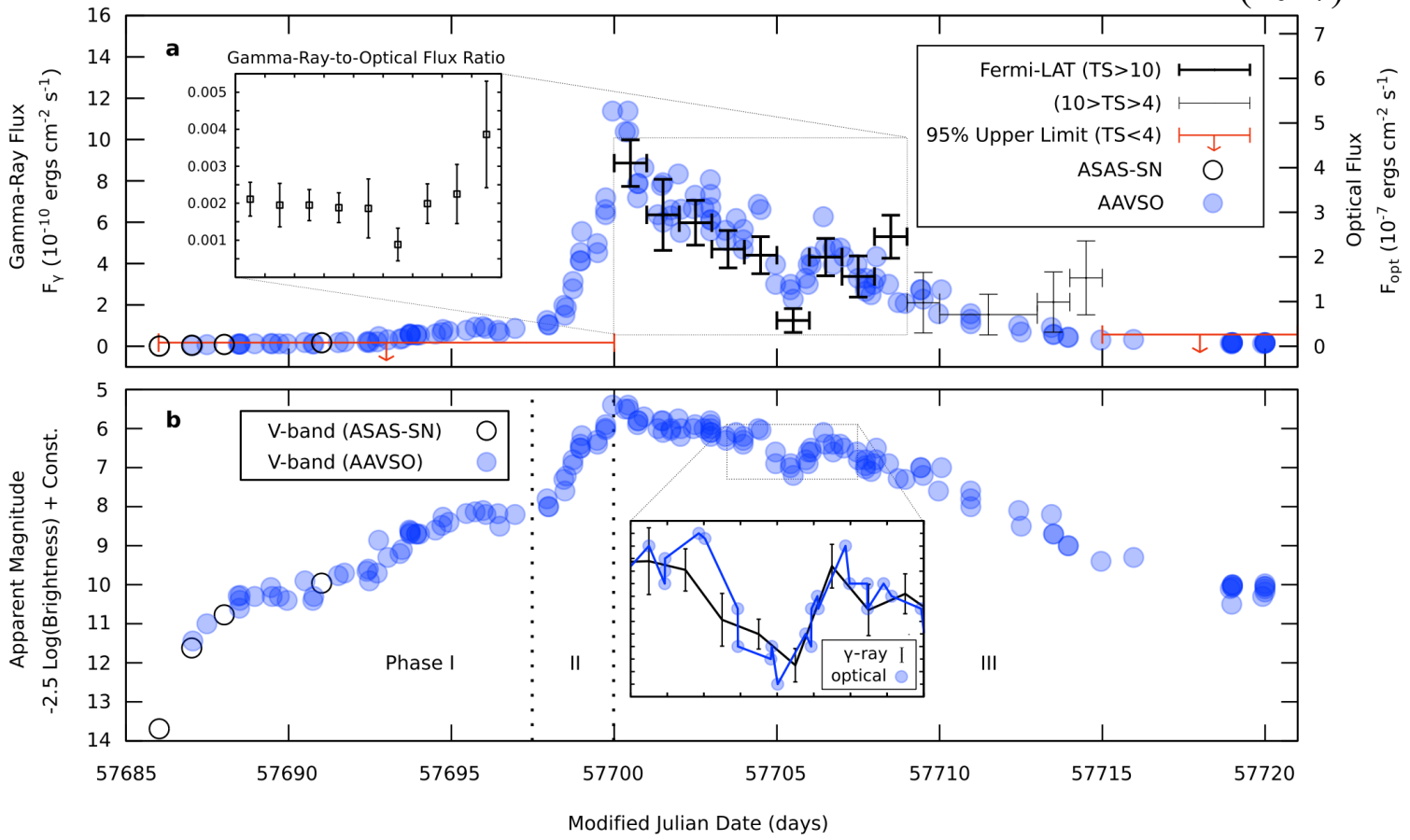
Stellar mergers

Tidal Disruption Events



Nova V5856 Sgr providing some evidence

Li et al. (2017)



Nova V906 Car seals the deal

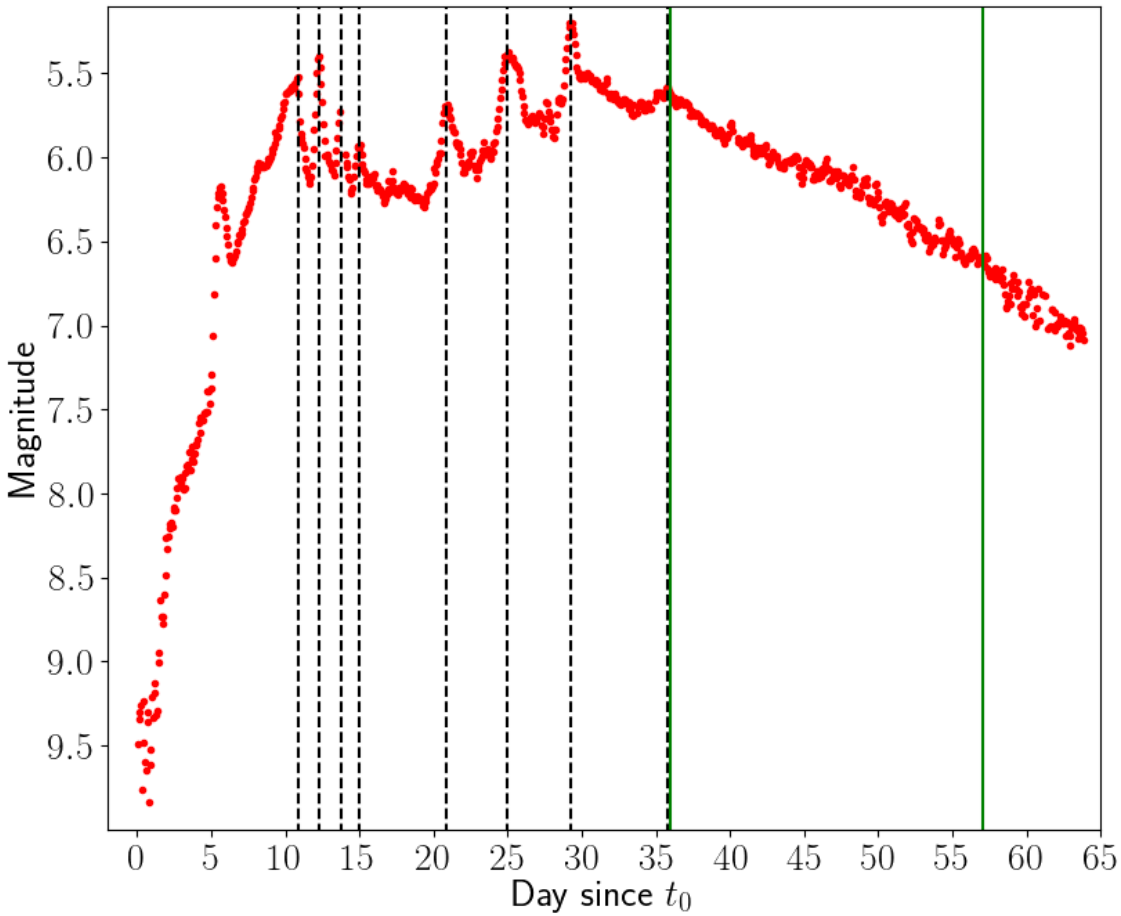
Nova V906 Car (ASASSN-18fv), discovered by the All-Sky Automated Survey for SNe (ASAS-SN) in March 2018 as a bright Galactic transients!

E. Aydi - MSU

Nova V906 Car seals the deal

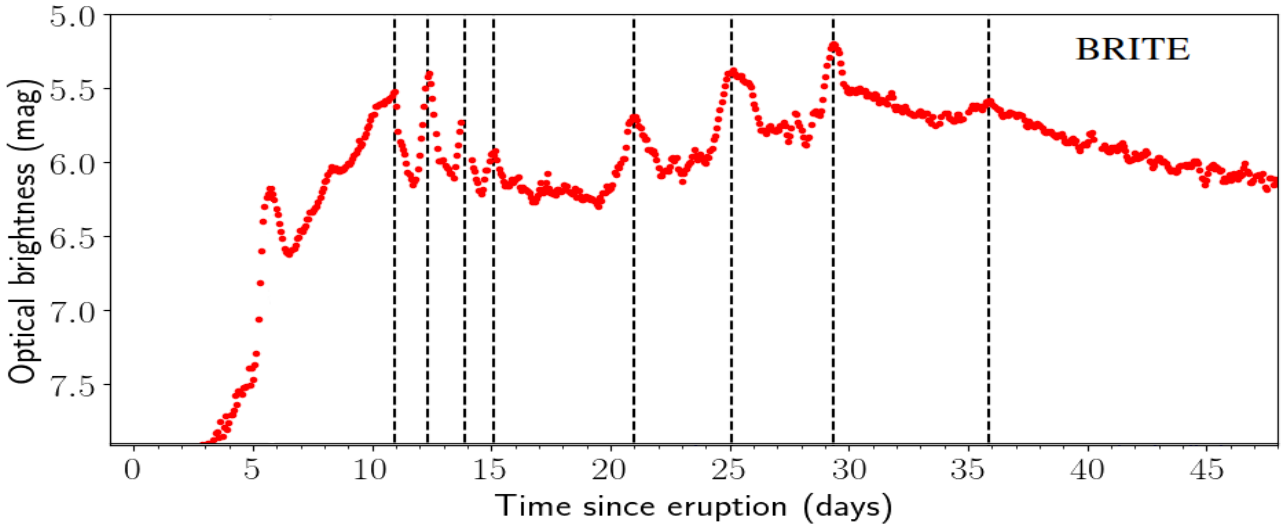
Nova V906 Car seals the deal

Aydi et al. 2020 (Nat Ast, 4, 776)



Nova V906 Car seals the deal

Aydi et al. 2020 (Nat Ast, 2, 697)



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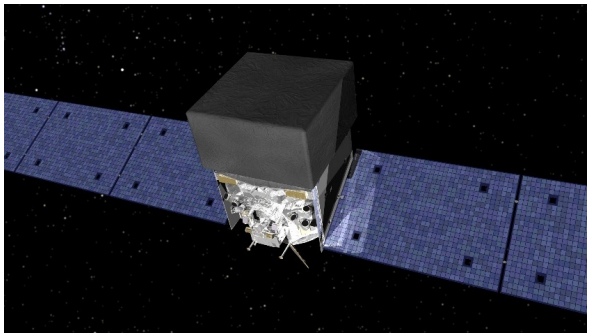
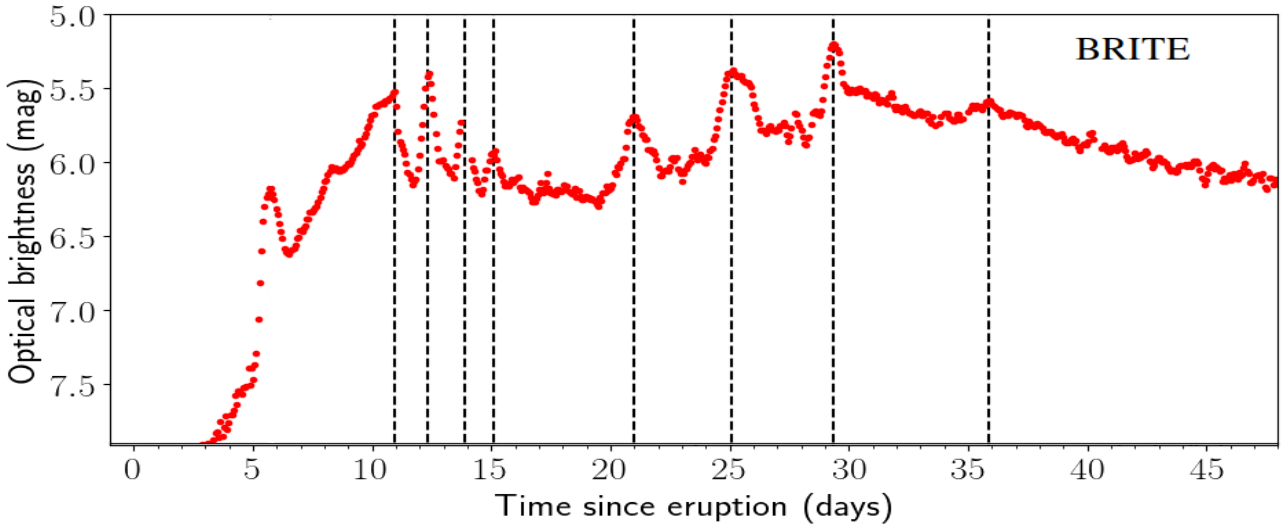


Fermi-LAT



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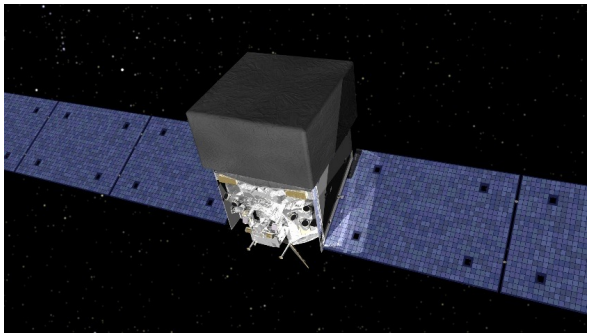
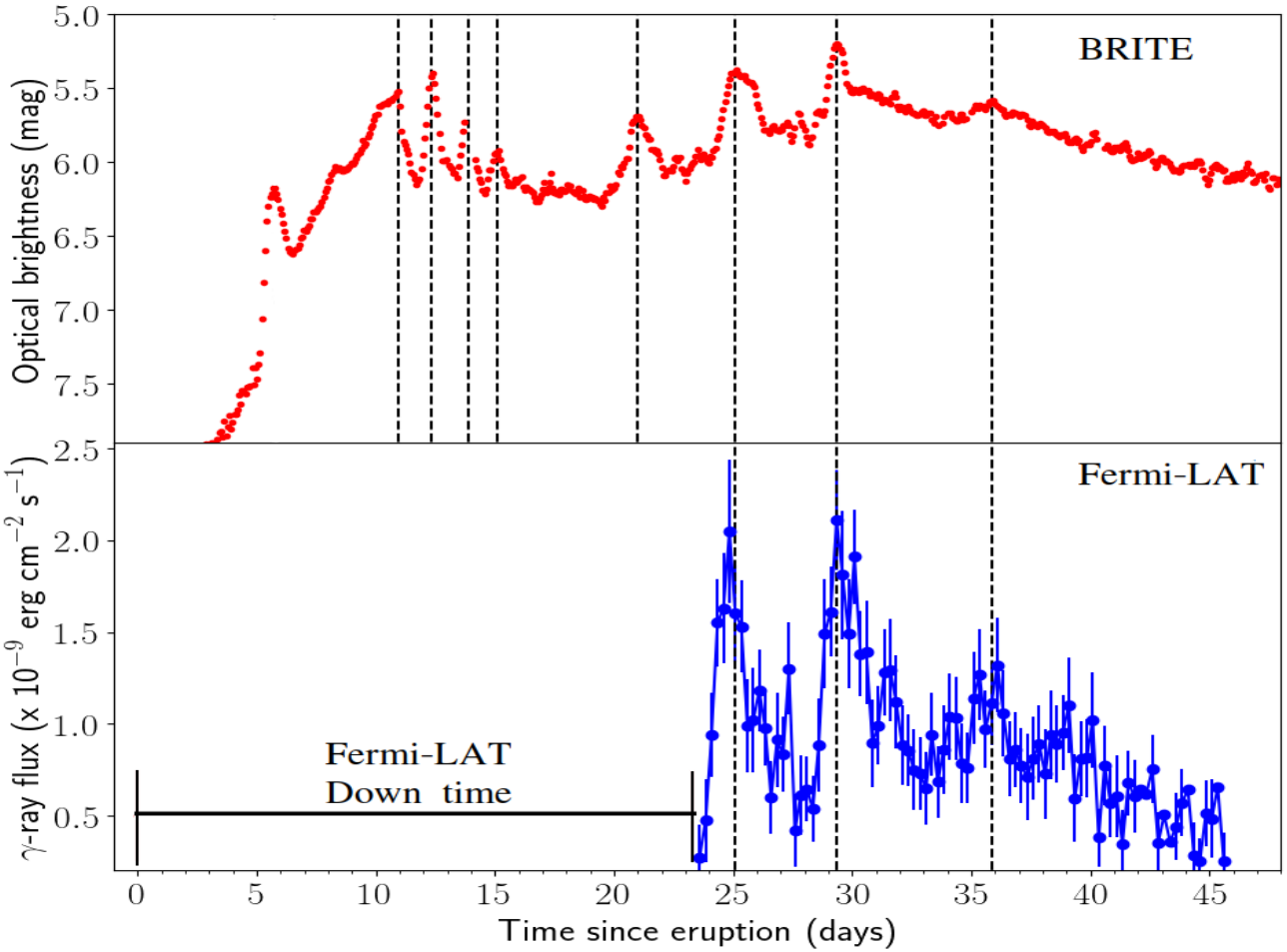


Fermi-LAT

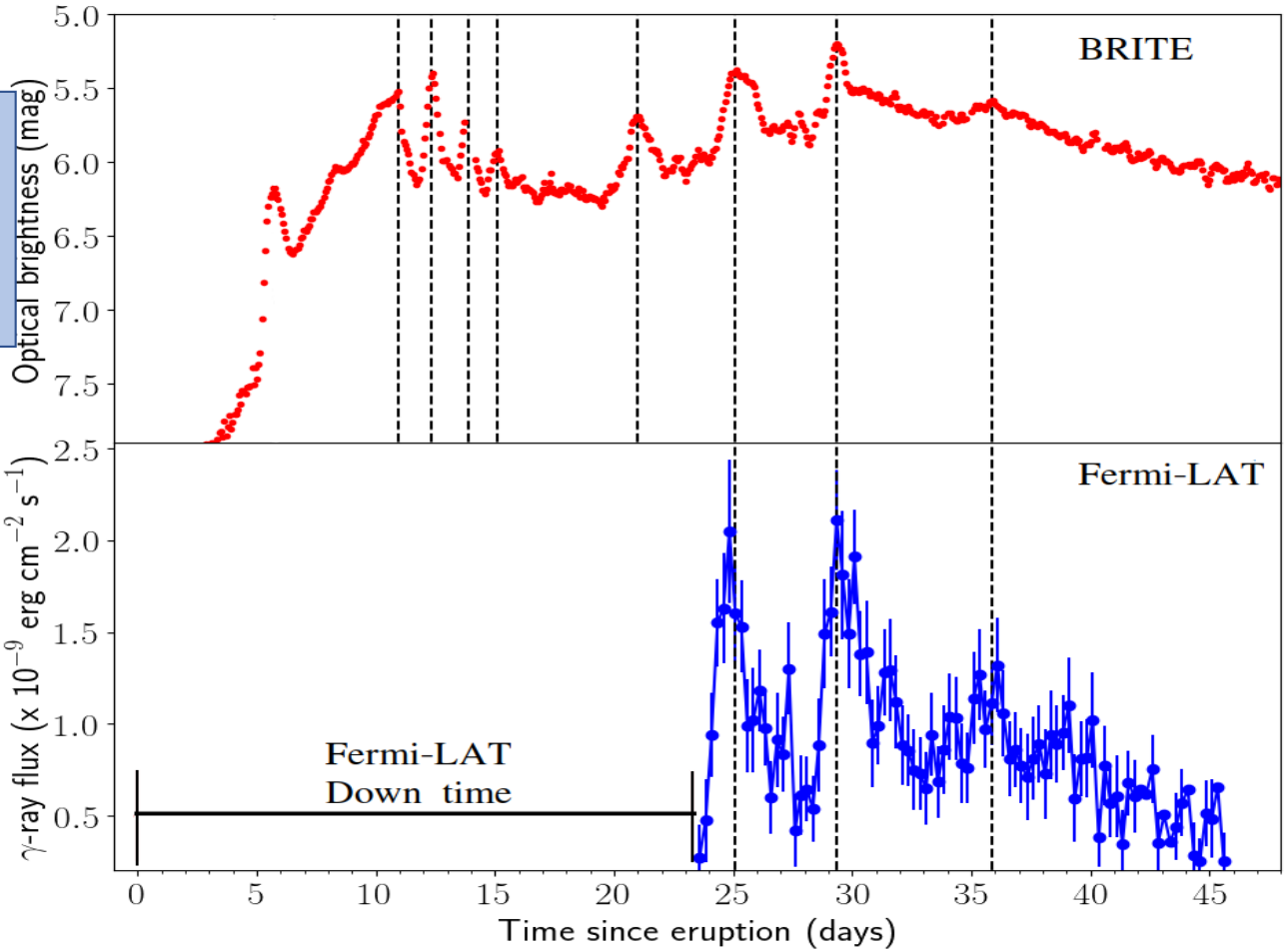


E. Aydi - MSU

Nova V906 Car seals the deal

Aydi et al. 2020 (Nat Ast, 4, 776)

Simultaneous flares → same origin (shocks)

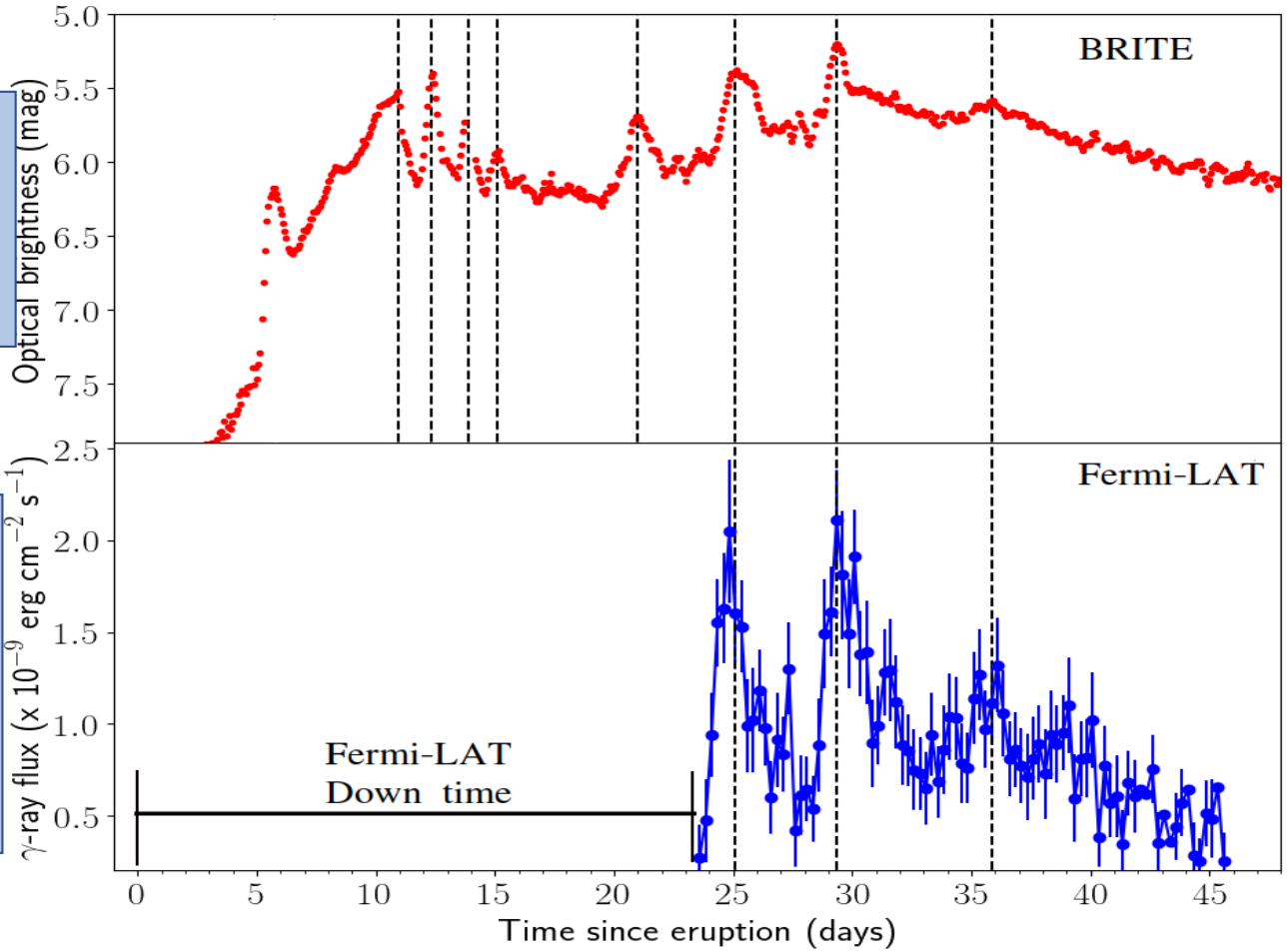


Nova V906 Car seals the deal

Aydi et al. 2020 (Nat Ast, 4, 776)

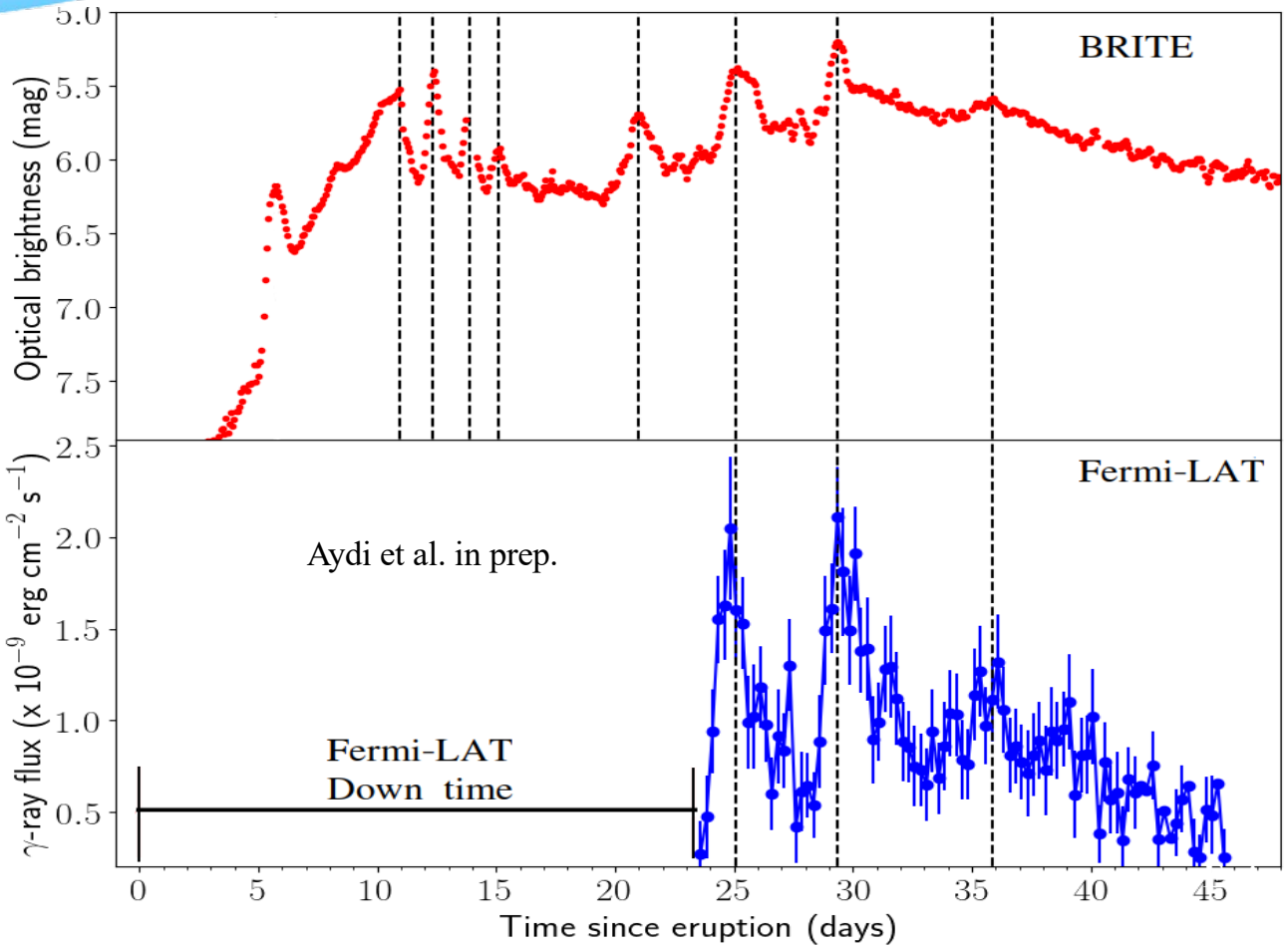
Simultaneous flares → same origin (shocks)

Luminosity doubled→ shocks radiate a large fraction of nova luminosity

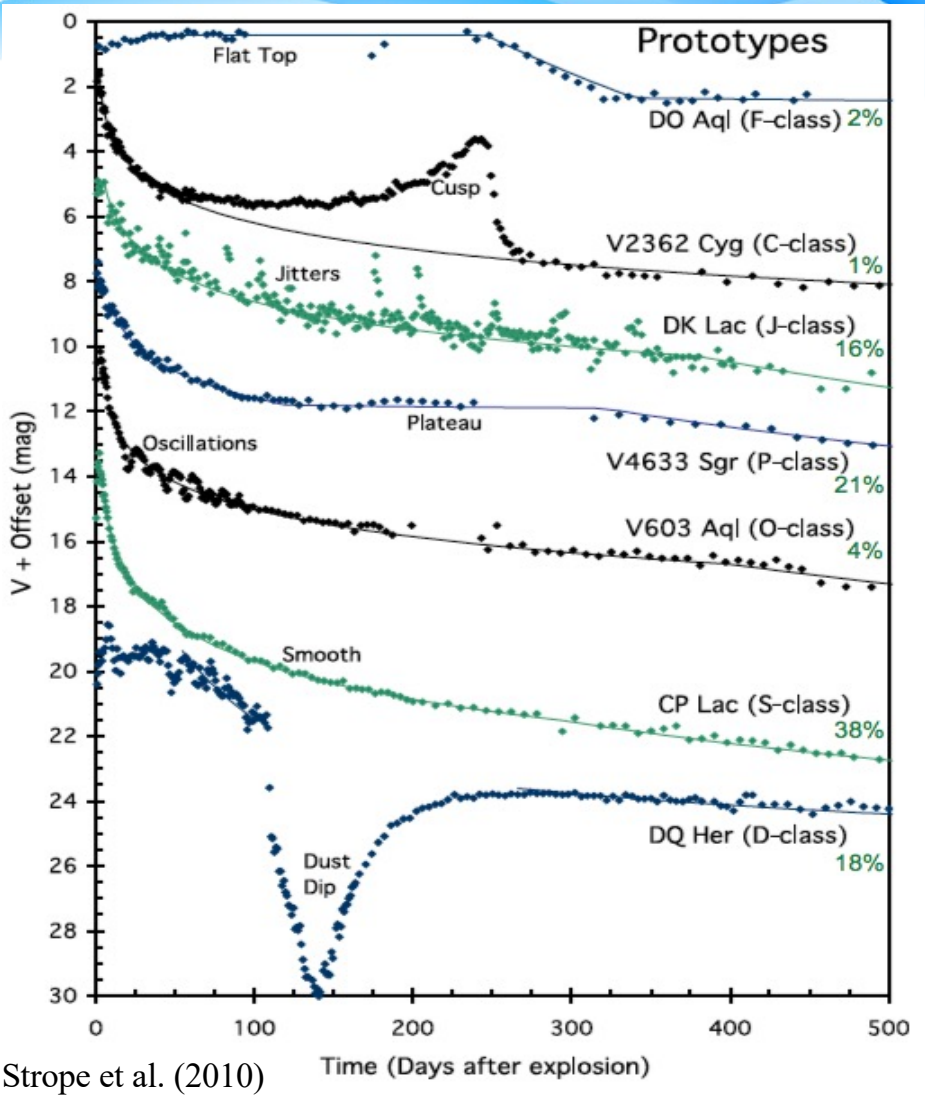


The first direct evidence!!!

Aydi et al. 2020 (Nat Ast, 4, 776)

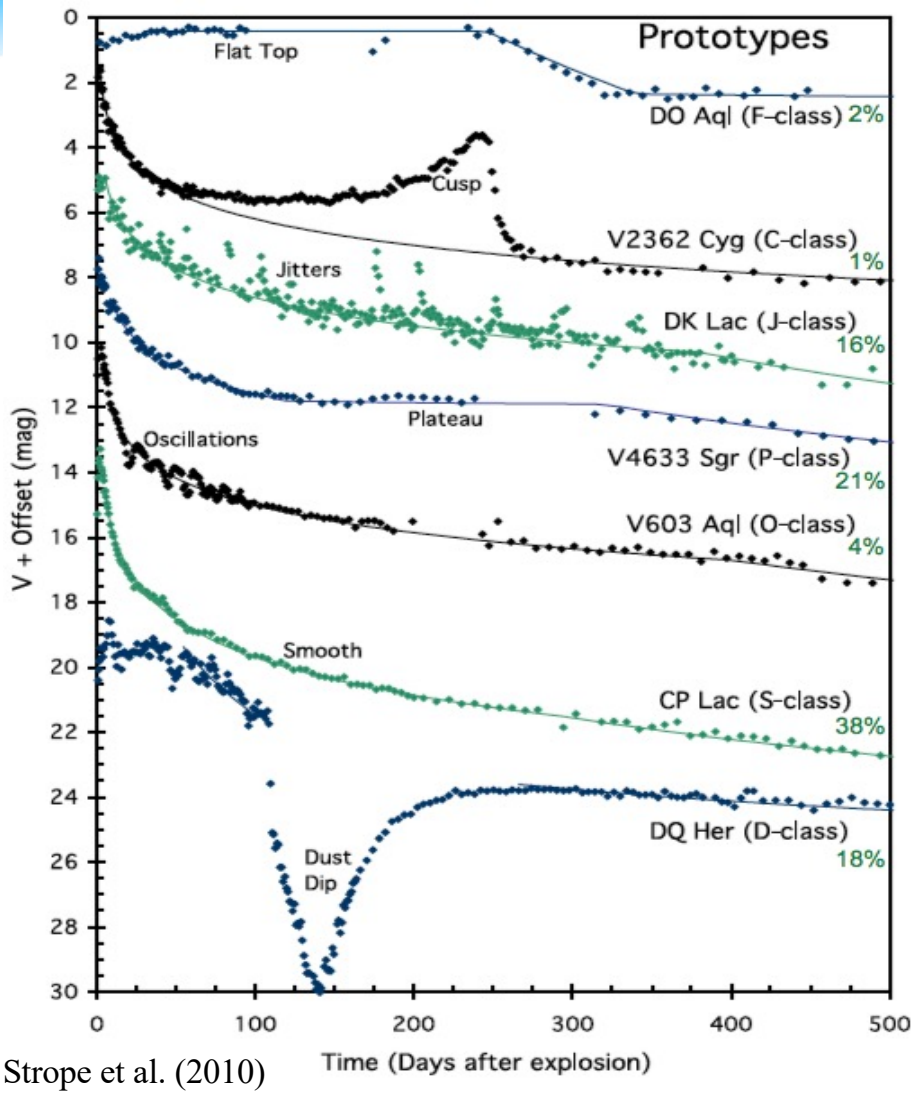


Some answers



Strope et al. (2010)

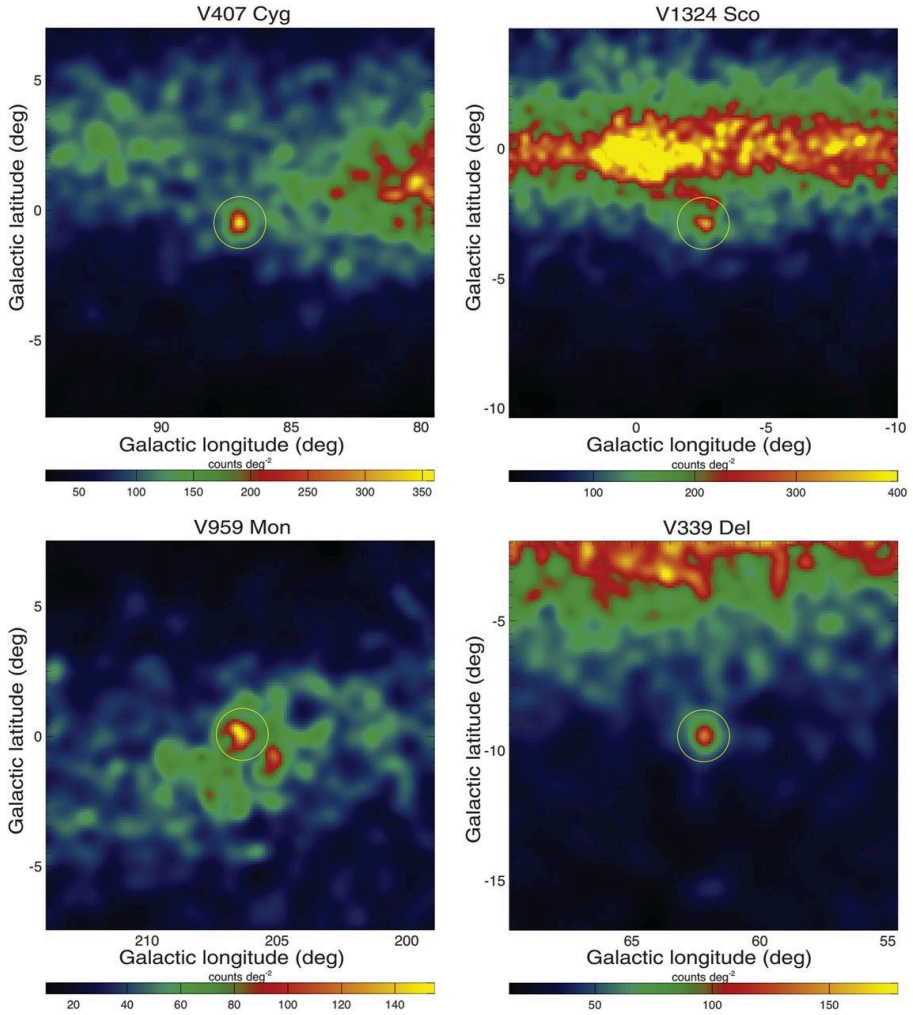
Some answers



Strope et al. (2010)

New insights into novae

GeV gamma-ray emission from novae



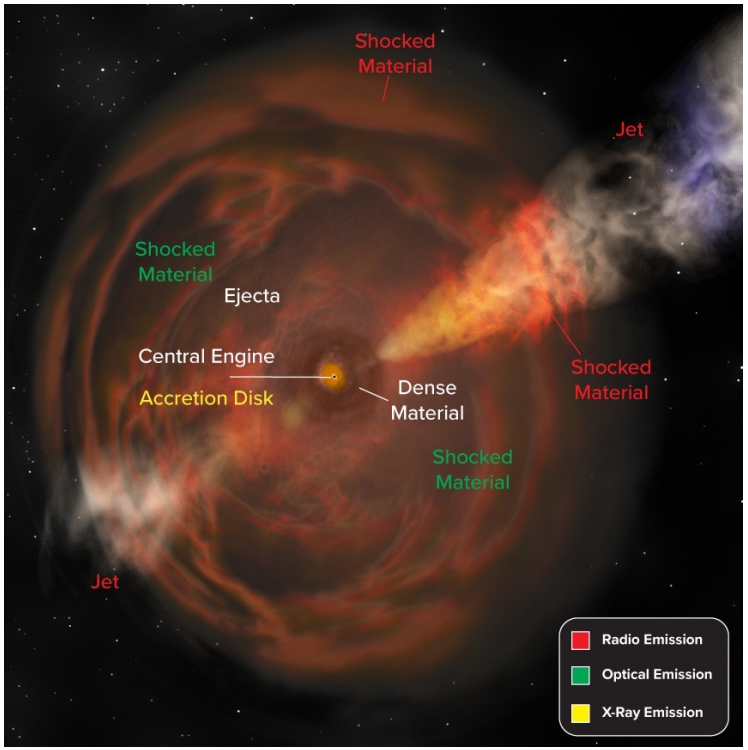
Ackerman et al. (2014)

Nova shocks as laboratory

SL SNe/ Type IIn SNe

Credit: NASA/Daana Berry/Skyworks Digital

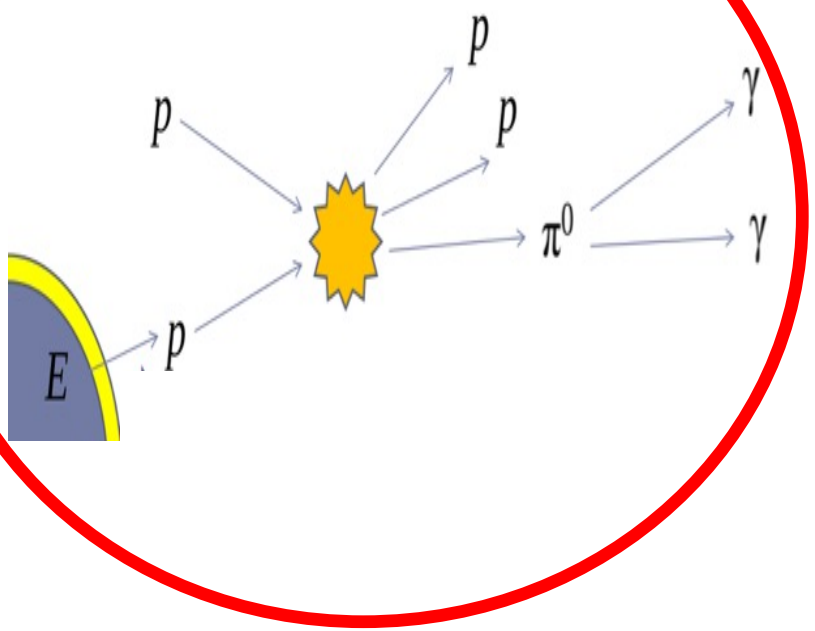
FBOTs



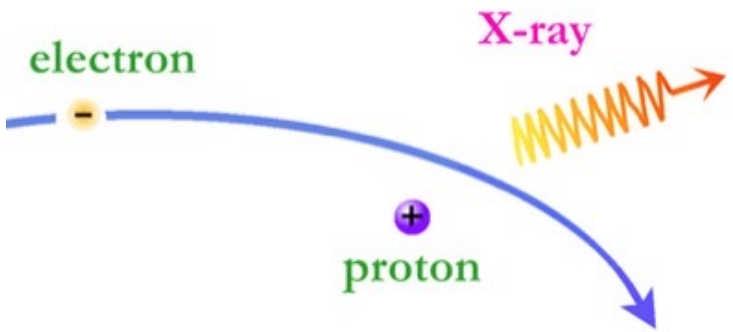
Credit: Bill Saxton, NRAO/AUI/NSF

Novae as neutrino sources

Hadronic

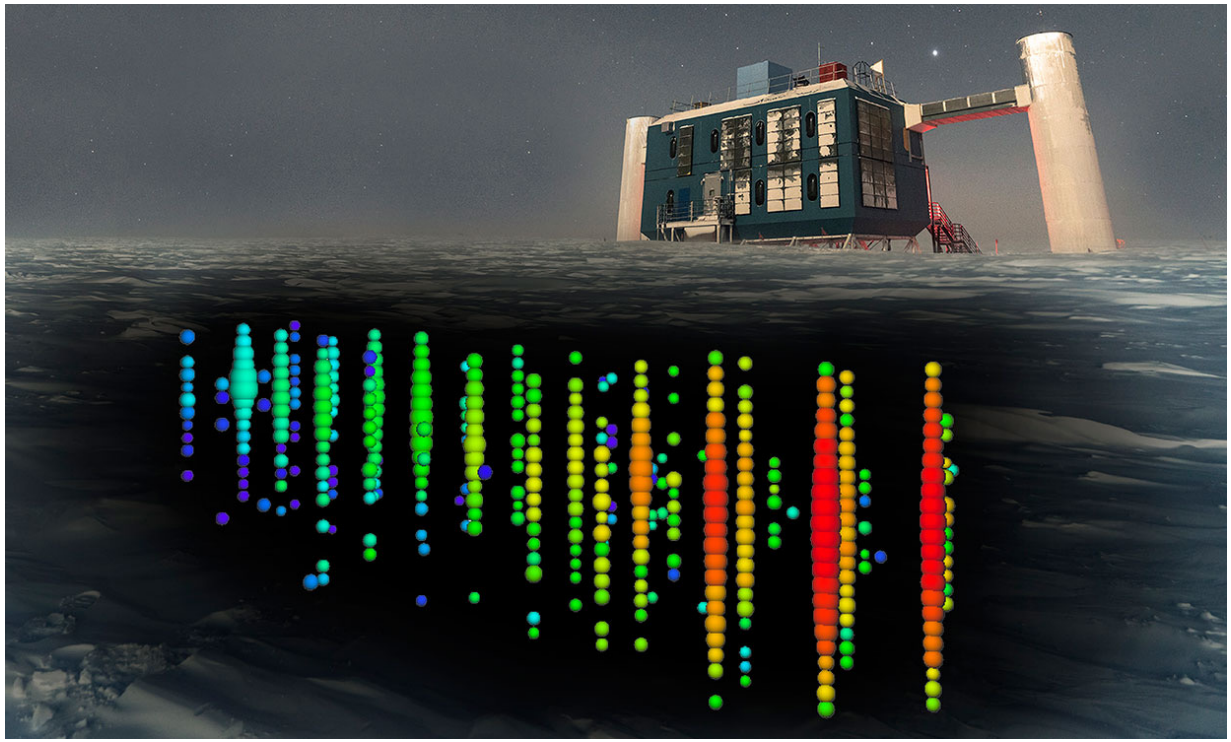


Leptonic



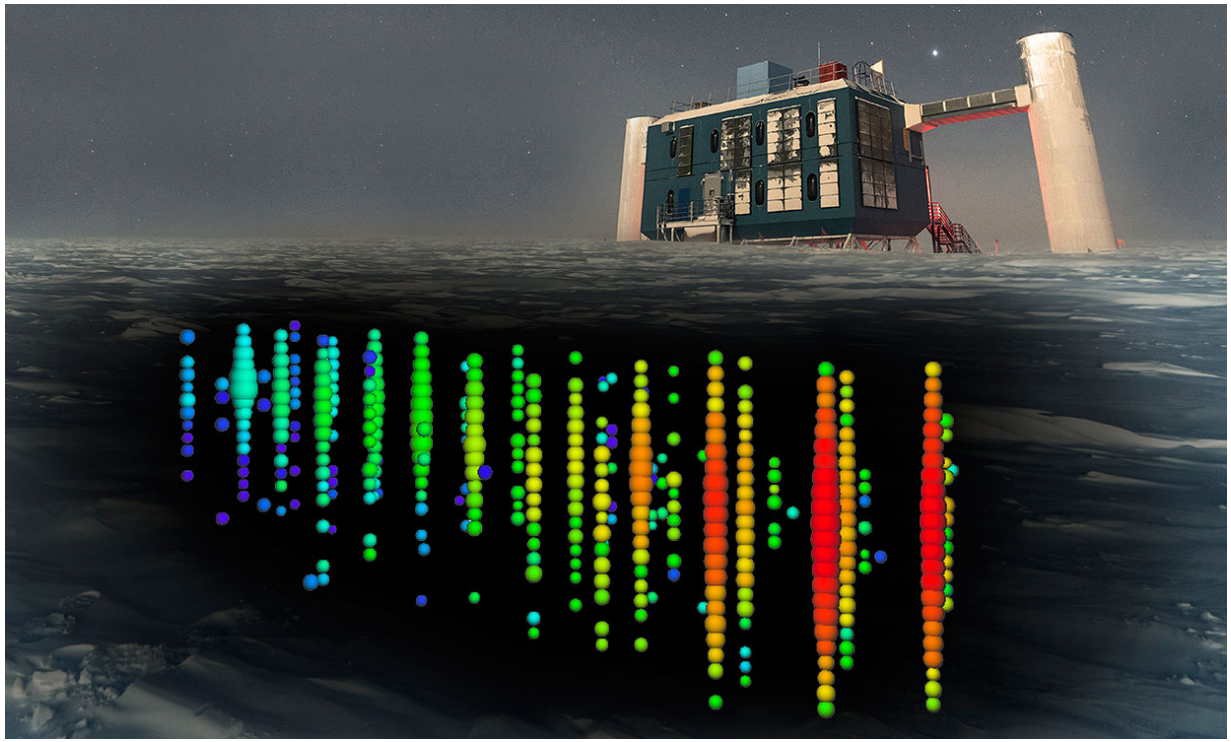
Novae as neutrino sources

IceCube



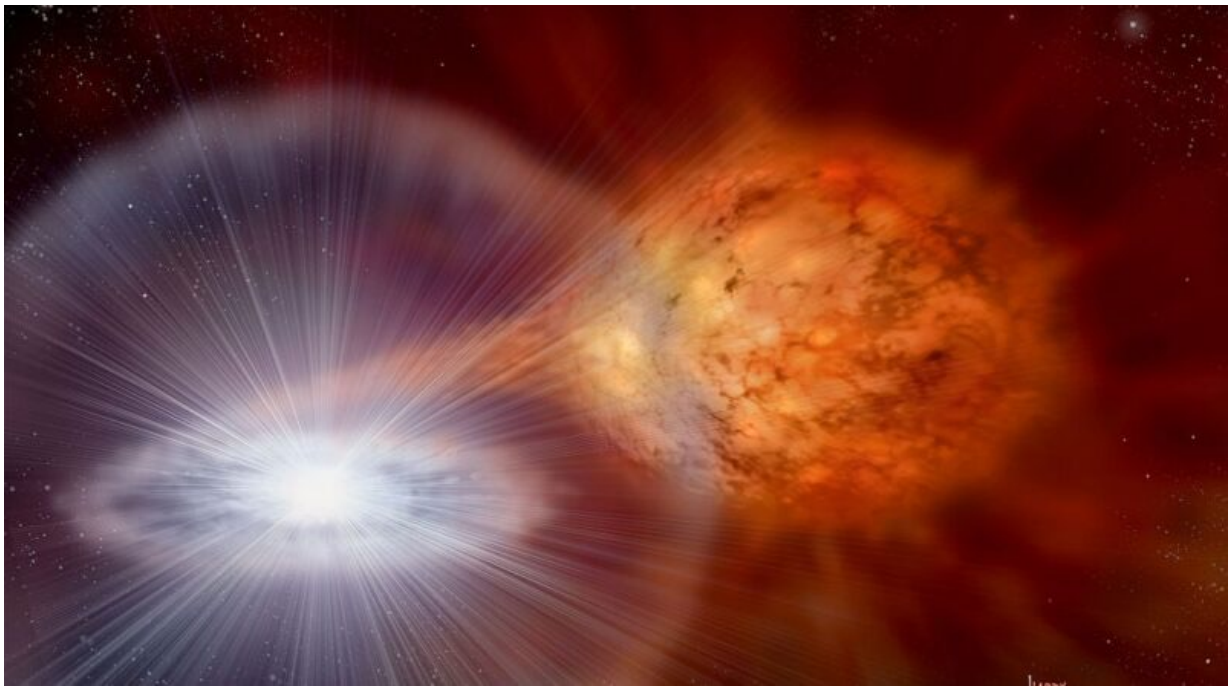
Novae as neutrino sources

IceCube – upgraded



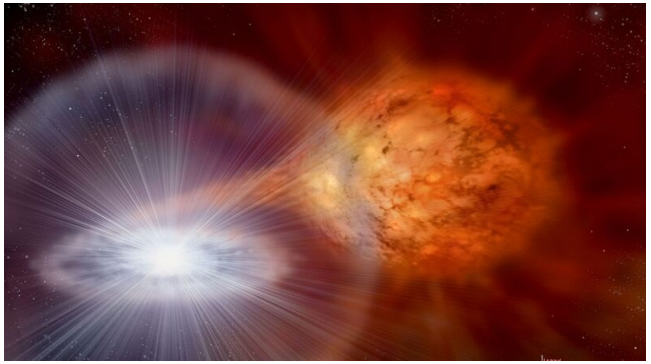
Novae as TeV sources

Nova RS Oph (2021)

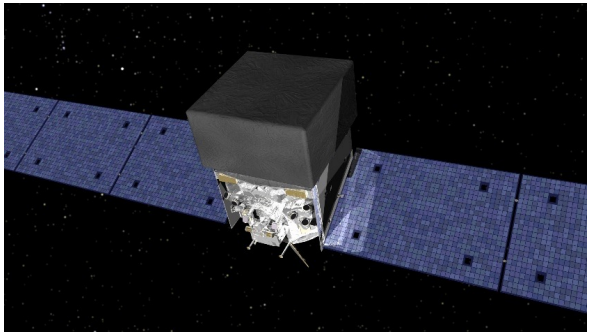


RS Oph is a Galactic recurrent nova with a recurrence period of 15-16 years.

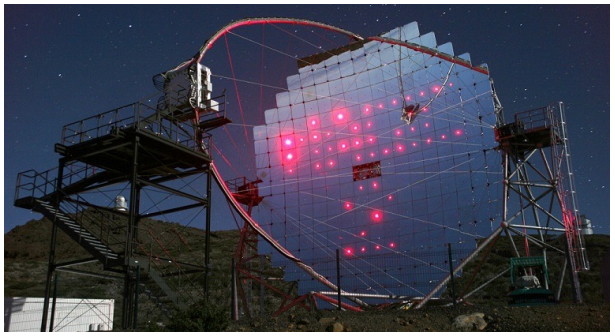
Novae as TeV sources



High Energy Stereoscopic System (HESS)



Fermi-LAT



Major Atmospheric Gamma-ray Imaging Cherenkov Telescope (MAGIC)

Novae as TeV sources

HESS Collab. (2022)

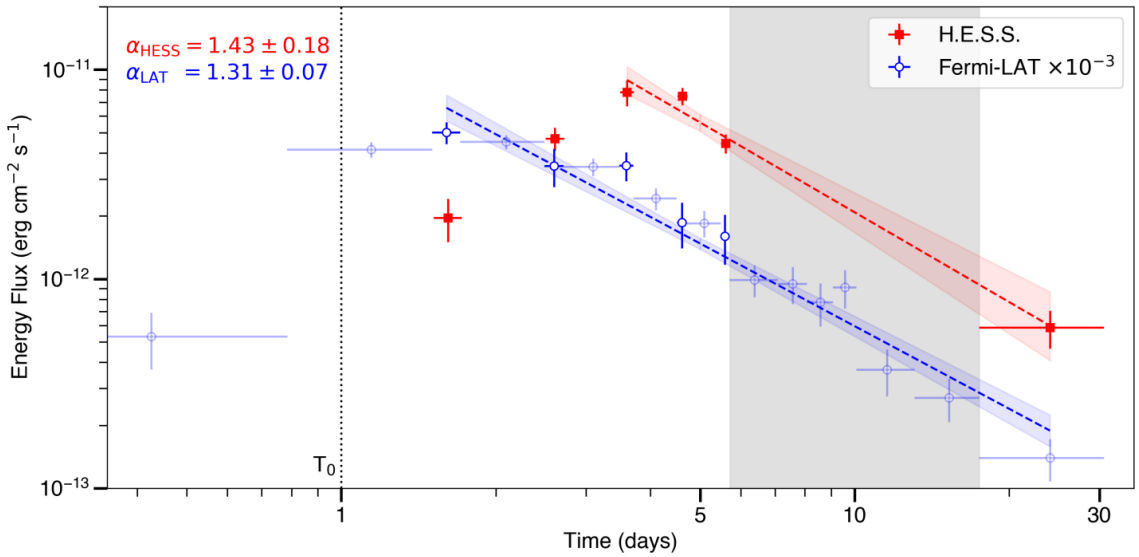
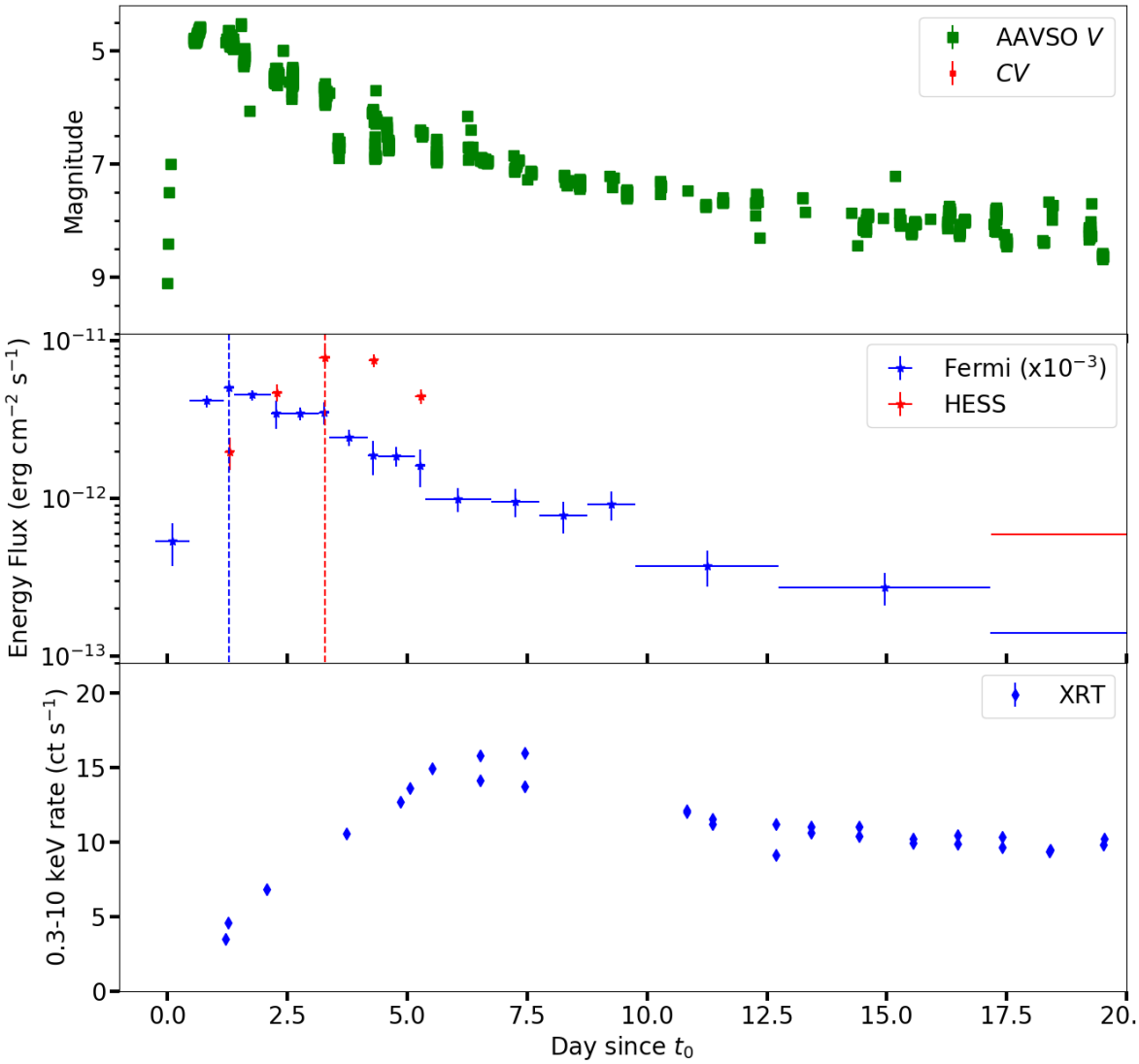


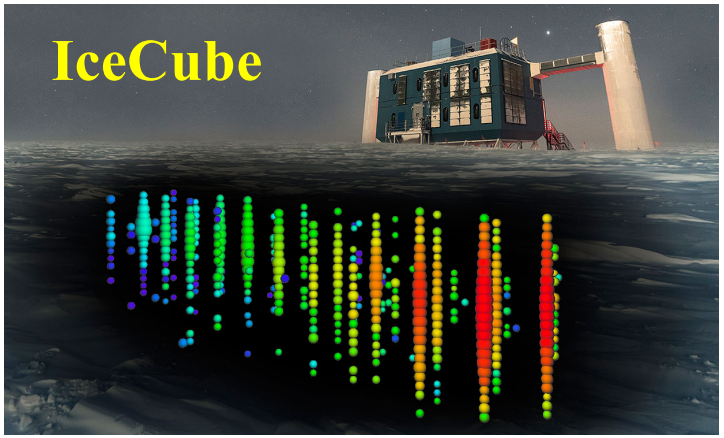
Figure 2: **Gamma-ray light curves of RS Oph.** Light curves of gamma-ray emission from RS Oph including data from *Fermi*-LAT and H.E.S.S. observations. The H.E.S.S. data (red squares) cover a period of five nights, after which observations ceased for ten days due to bright moonlight, marked by the shaded grey band, then recommenced for a period of 14 days. The H.E.S.S. flux is integrated from 250 GeV to 2.5 TeV, whilst the *Fermi*-LAT flux is integrated from 60 MeV to 500 GeV. *Fermi*-LAT data are shown in 6-hour bins (blue circles) corresponding to the time windows of the H.E.S.S. observations, and data outside of these times shown with semi-transparent markers. Error bars are 1 σ statistical uncertainties. A power-law slope model was fitted to the temporal decay after the time of peak flux for both instruments (red and blue dashed lines, with uncertainties indicated by the shaded regions). The vertical dotted black line indicates the peak of the outburst in the optical waveband, T_0.

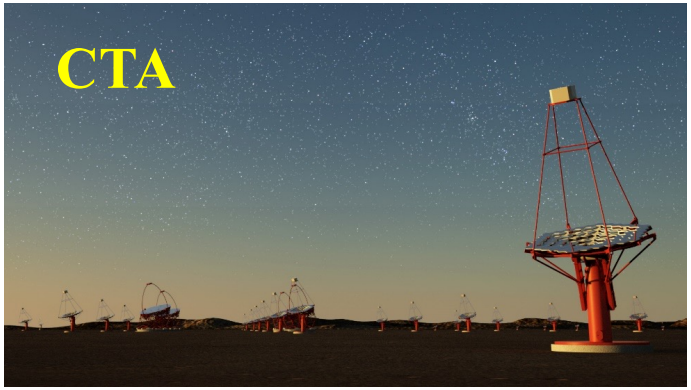
Novae as



E. Aydi

Novae as TeV sources





Particle accelerators in our Galactic backyard

E. Aydi - MSU

Nova T CrB will light up our sky

An artist's animation of what occurs when a red giant star and a white dwarf produce a nova.
By NASA

The Night Sky Will Soon Get 'a New Star.' Here's How to See It.

A nova named T Coronae Borealis lit up the night about 80 years ago, and astronomers say it's expected to put on another show in the coming months.

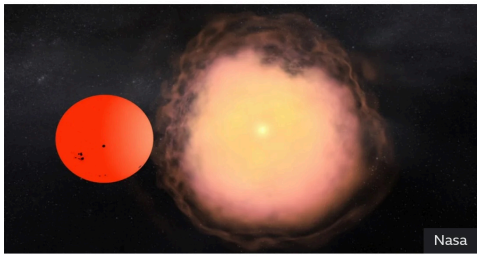
BBC Watch

Move over, solar eclipse: Scientists predict a once-in-a-lifetime nova explosion in the coming months

22 March 2024

Mia Taylor
Features correspondent

Share



CNN Live TV

World

Explosive star event will create once-in-a-lifetime sight in the sky. Here's how to see it

By Ashley Strickland, CNN
Updated 5:37 PM EDT, Tue March 19, 2024

NASA/Conceptual Image Lab/Goddard Space Flight Center

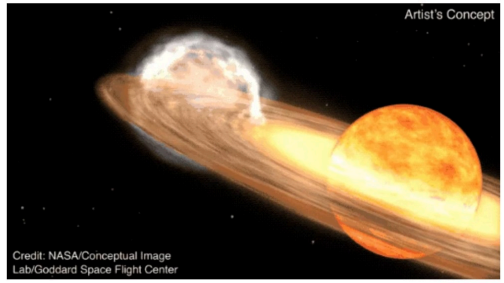
npr DONATE

SPACE

Never seen an exploding star? This year, you'll have your chance

UPDATED JUNE 18, 2024 · 8:58 AM ET

By Joe Hernandez

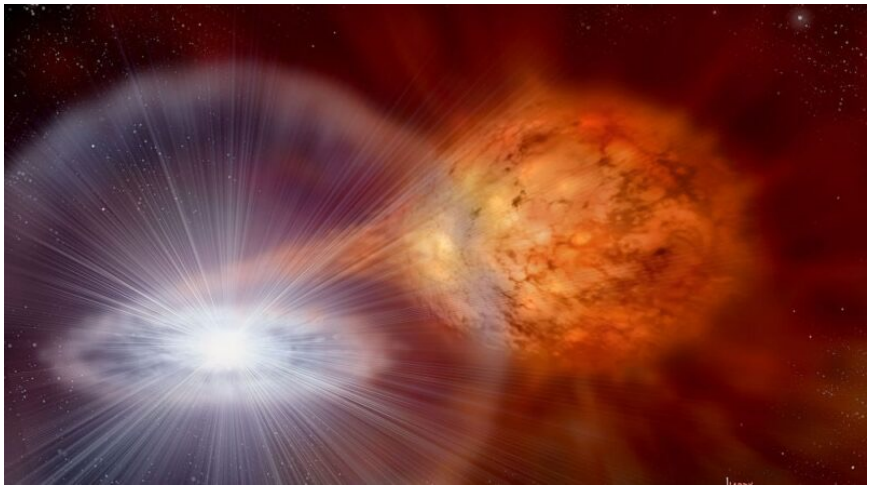


An artist's rendering shows the T Coronae Borealis star system, which contains a white dwarf and a red giant.
Conceptual Image Lab/Goddard Space Flight Center/NASA

E. Aydi - MSU

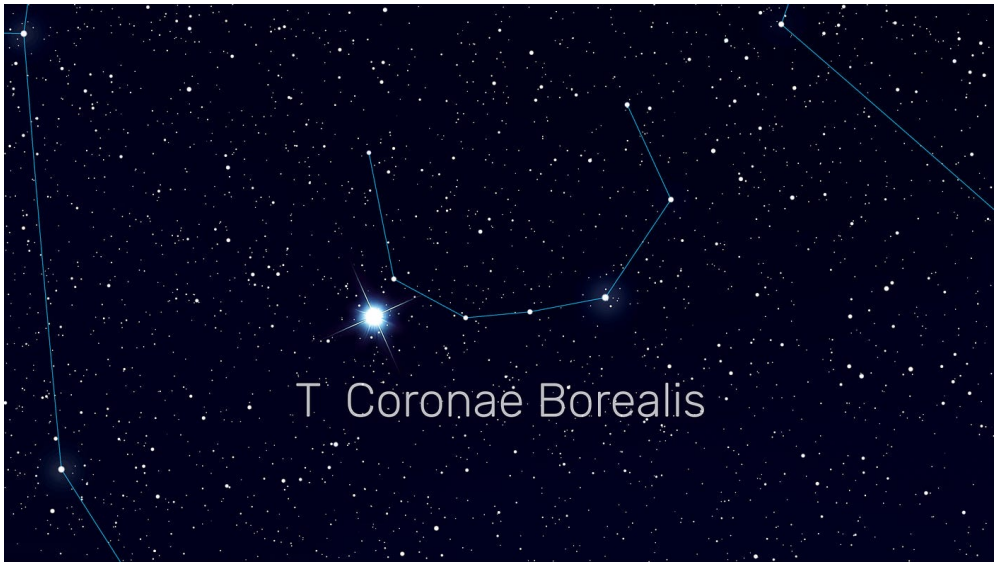
Nova T CrB will light up our sky

Recurrent Nova T Coronae Borealis

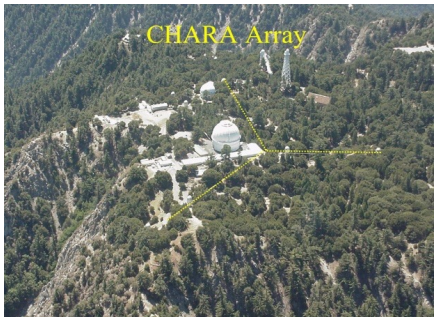


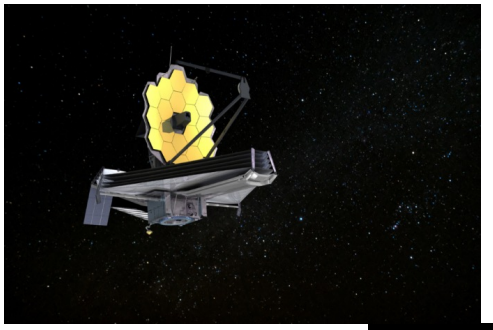
Distance ~ 0.8 kpc

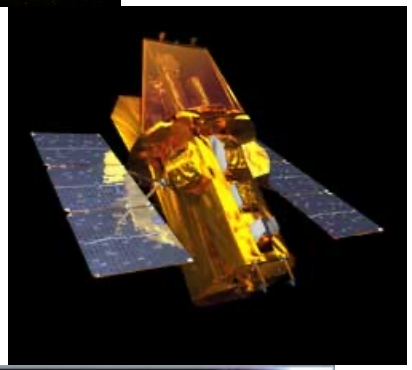
Predicted to erupt in 2024 +\- 1
And it will reach second magnitude

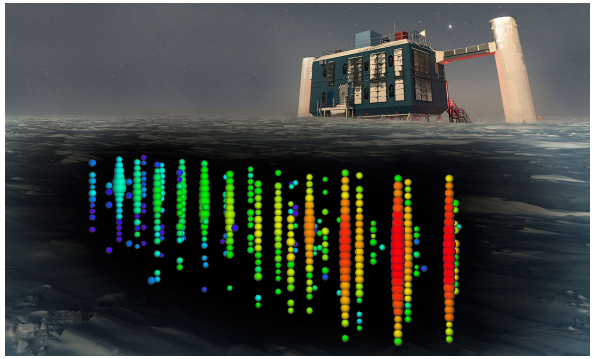


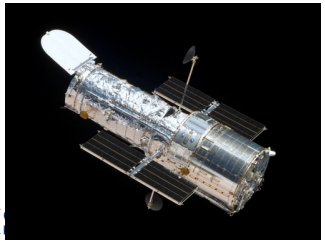
A rare opportunity!











Brace yourselves!

Summary

Shocks play a major role in powering nova luminosities.

Novae can serve as very valuable laboratories in our Galactic backyard to understand particle acceleration and shock interaction in other shock-powered transients.

Novae could be come the next multi-messenger Galactic sources – brace yourselves for T CrB!

www.eliasaydi.com

NHFP
NASA Hubble Fellowship Program

NASA

TEXAS TECH UNIVERSITY

Hiring opportunity!

Postdoc/PhD (graduate students) at Texas Tech University working on multi-wavelength observations of novae/transient phenomena with a focus on high-energies!

www.eliasaydi.com

NHFP
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NASA

TEXAS TECH UNIVERSITY

Summary

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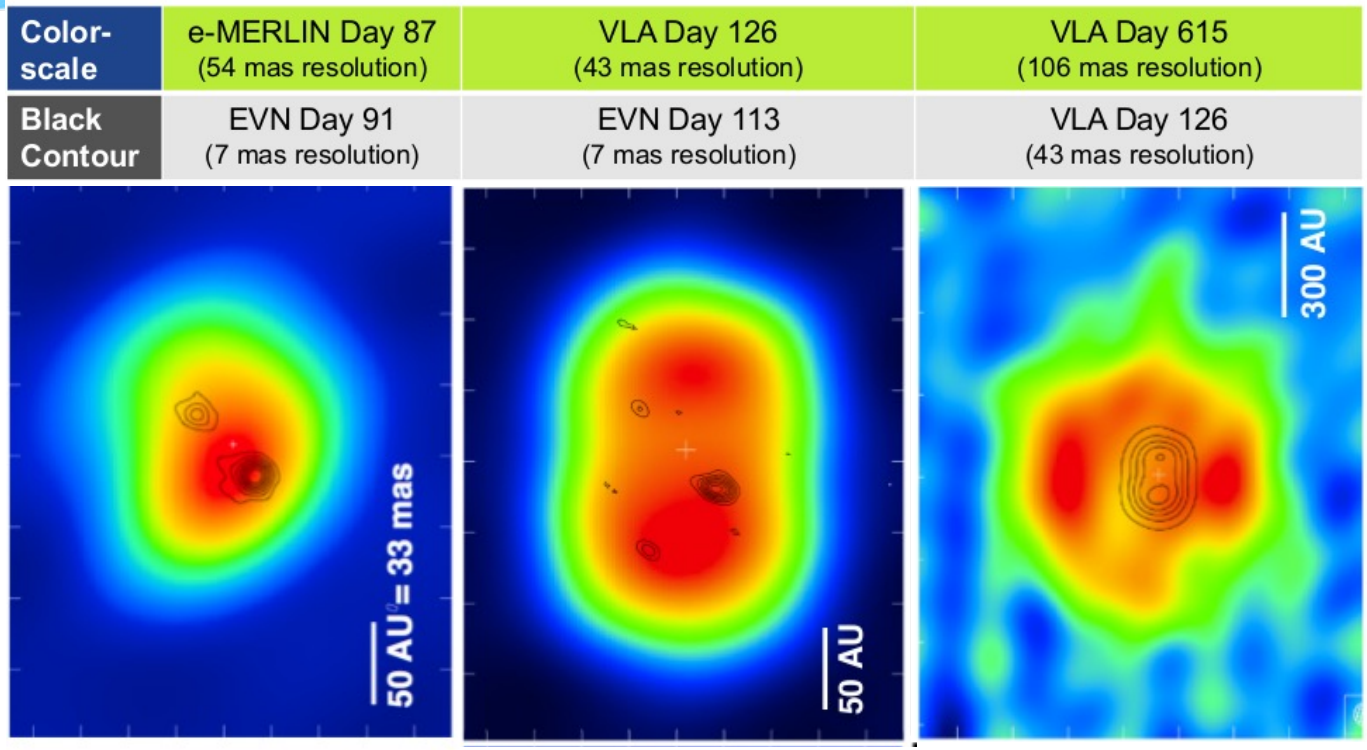
Extra slides

Novae in the radio

Chomiuk et al. (2014)



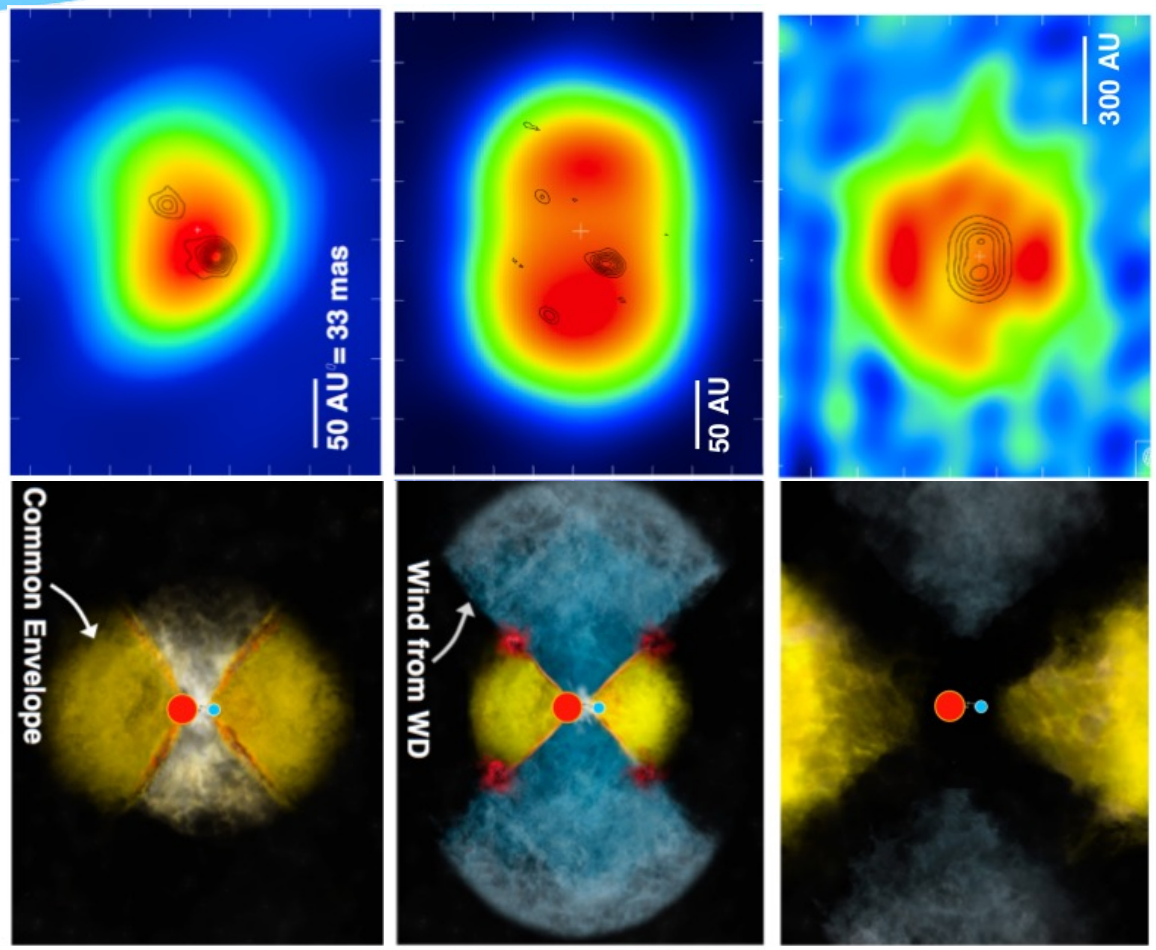
V959 Mon

black: synchrotron from EVN
color: thermal from VLA

Symmetry axis "flips" by 90 degrees in 2 years following explosion.

Radio imaging reveals two interacting outflows

Chomiuk et al. (2014)

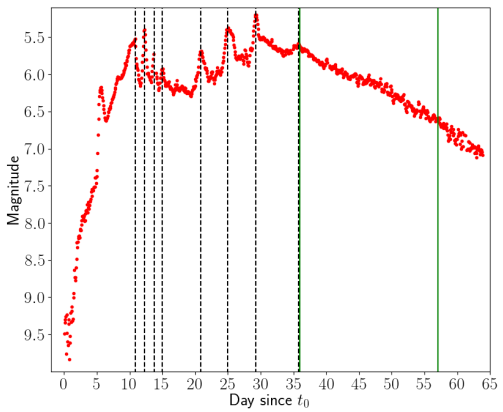


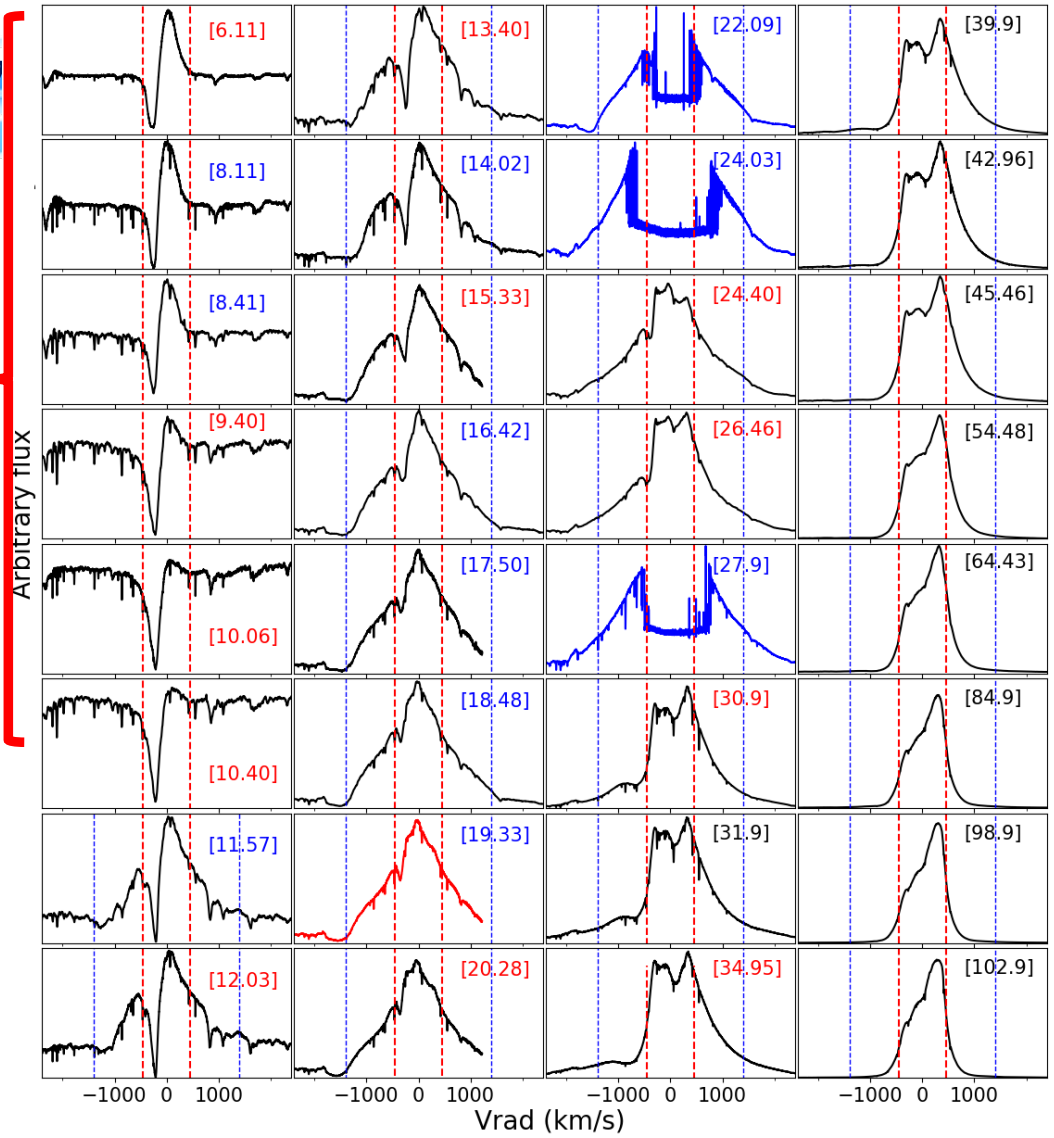
V959 Mon

Bill Saxton / NRAO / AUI / NSF

E. Aydi - MSU

Spectra rev



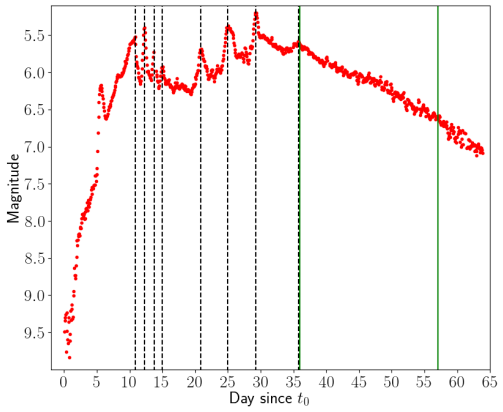


Halpha line profiles evolution

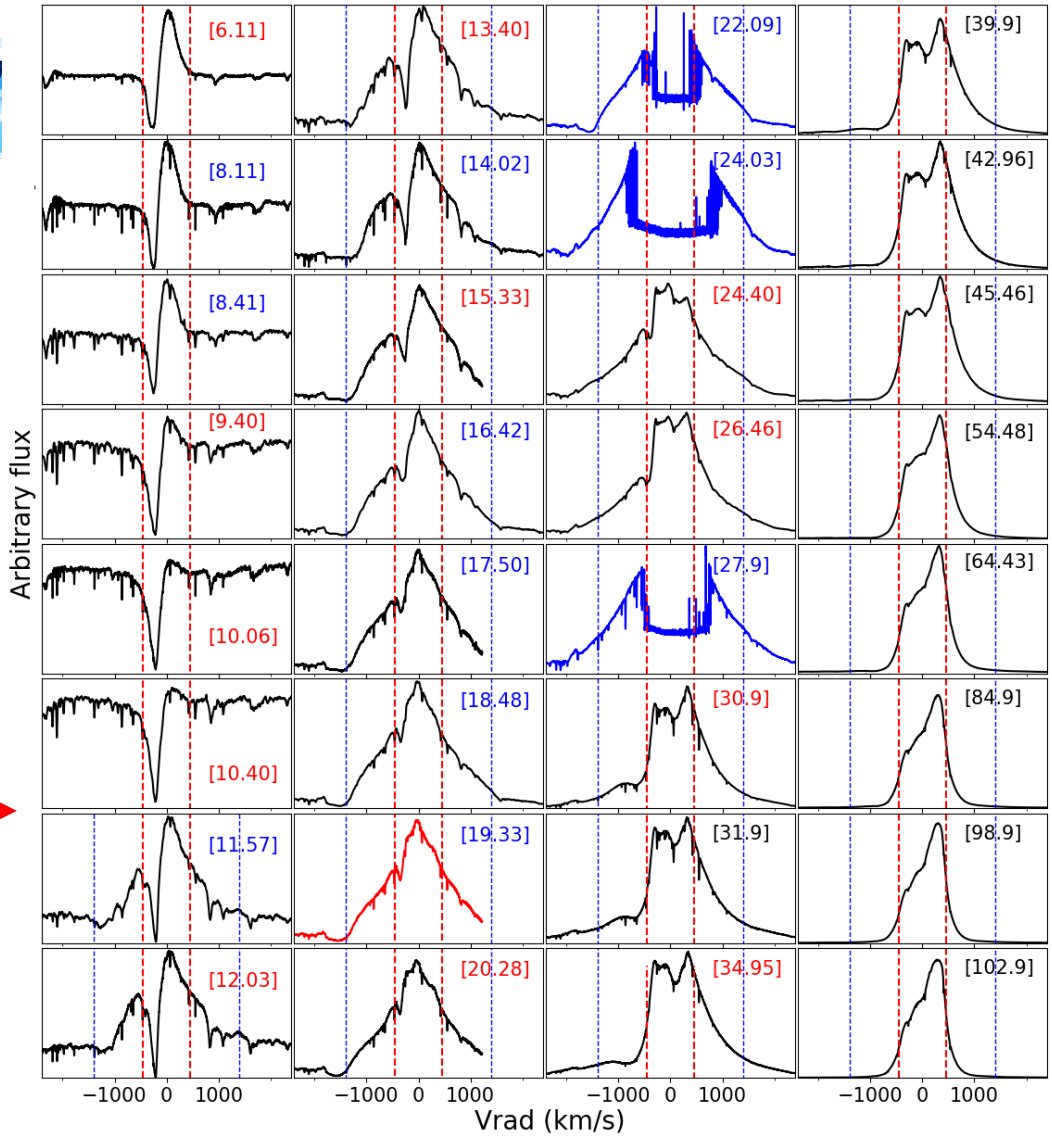
Aydi et al. 2020 (Nat Ast, 4, 776)

E. Aydi - MSU

Spectra rev



Peak

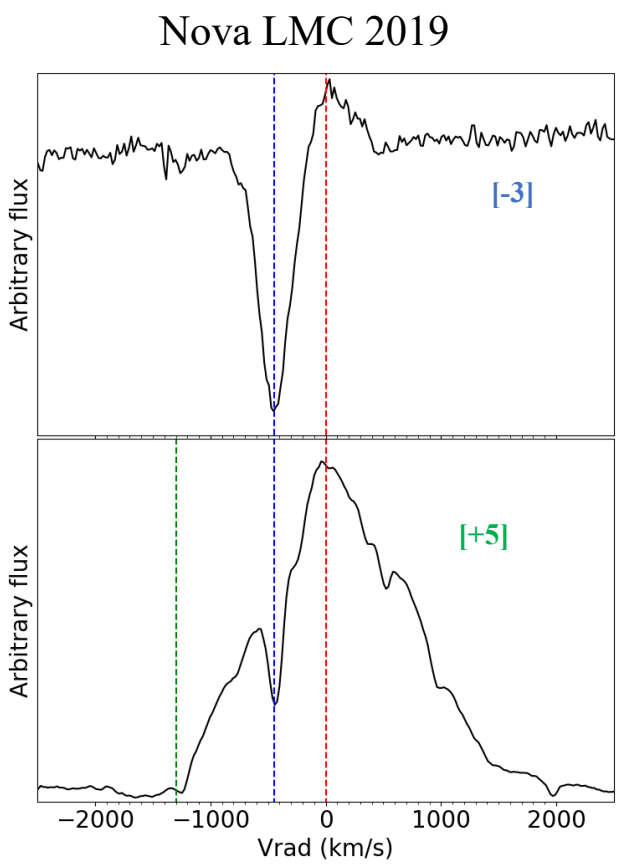


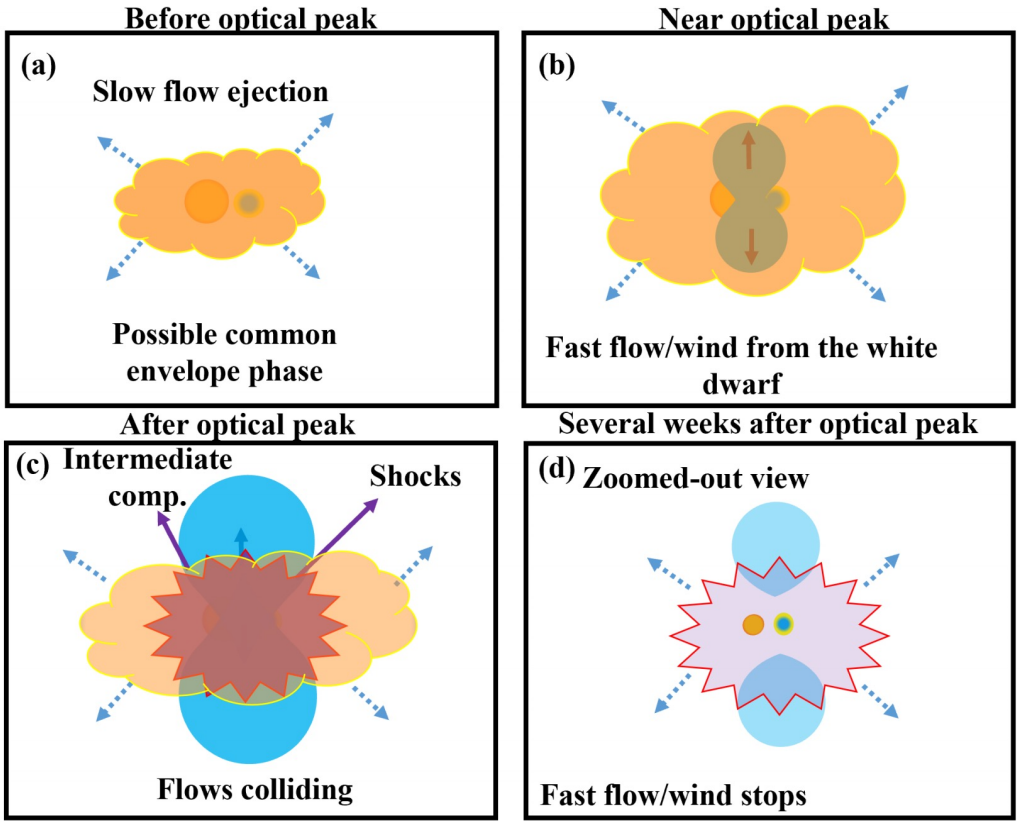
Halpha line profiles evolution

Aydi et al. 2020 (Nat Ast, 4, 776)

E. Aydi - MSU

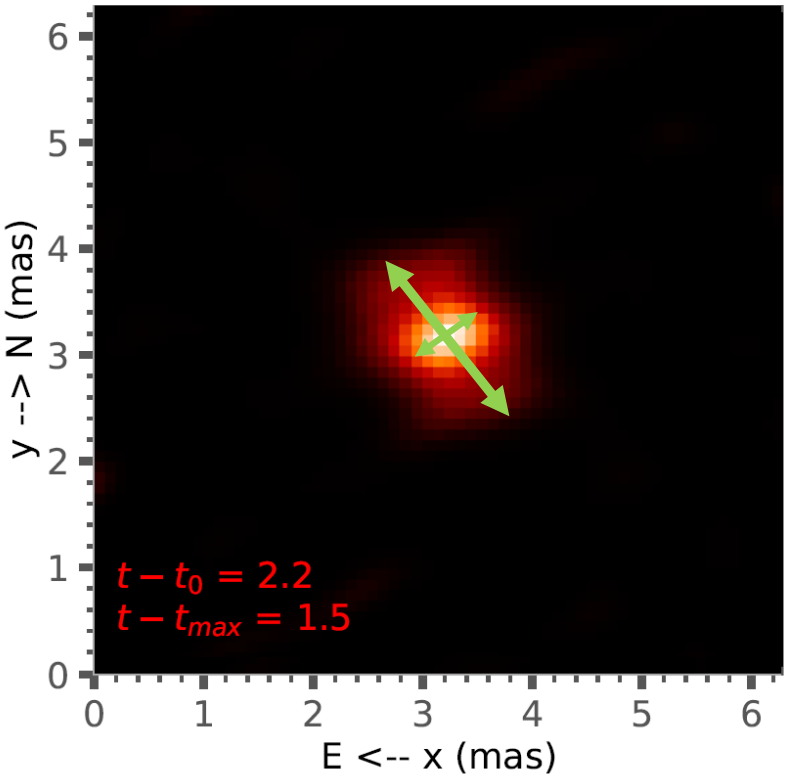
Spectra reveals two outflows

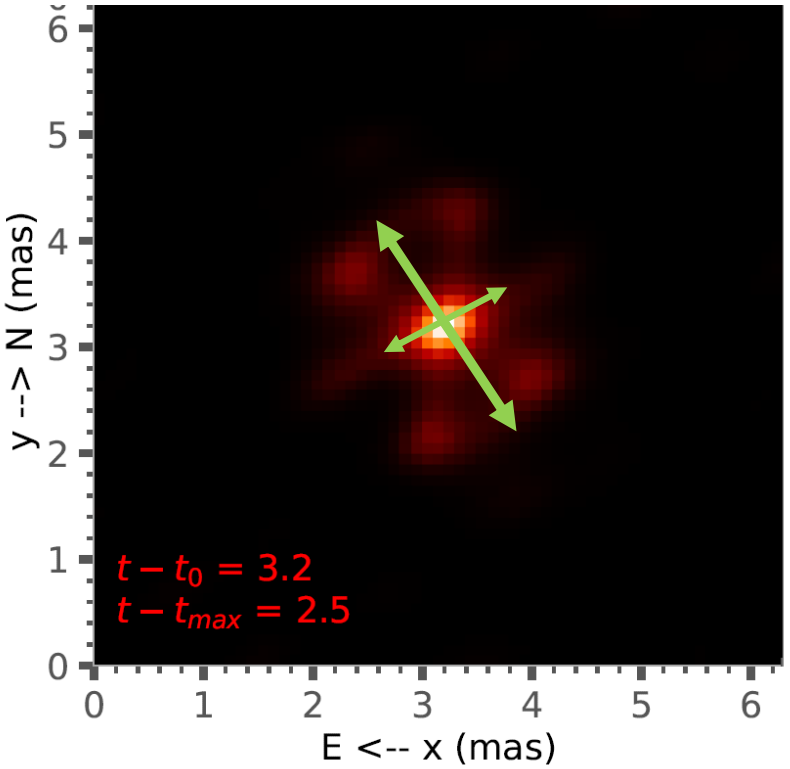




Aydi et al. 2020, ApJ, 905, 62

Imaging with CHARA

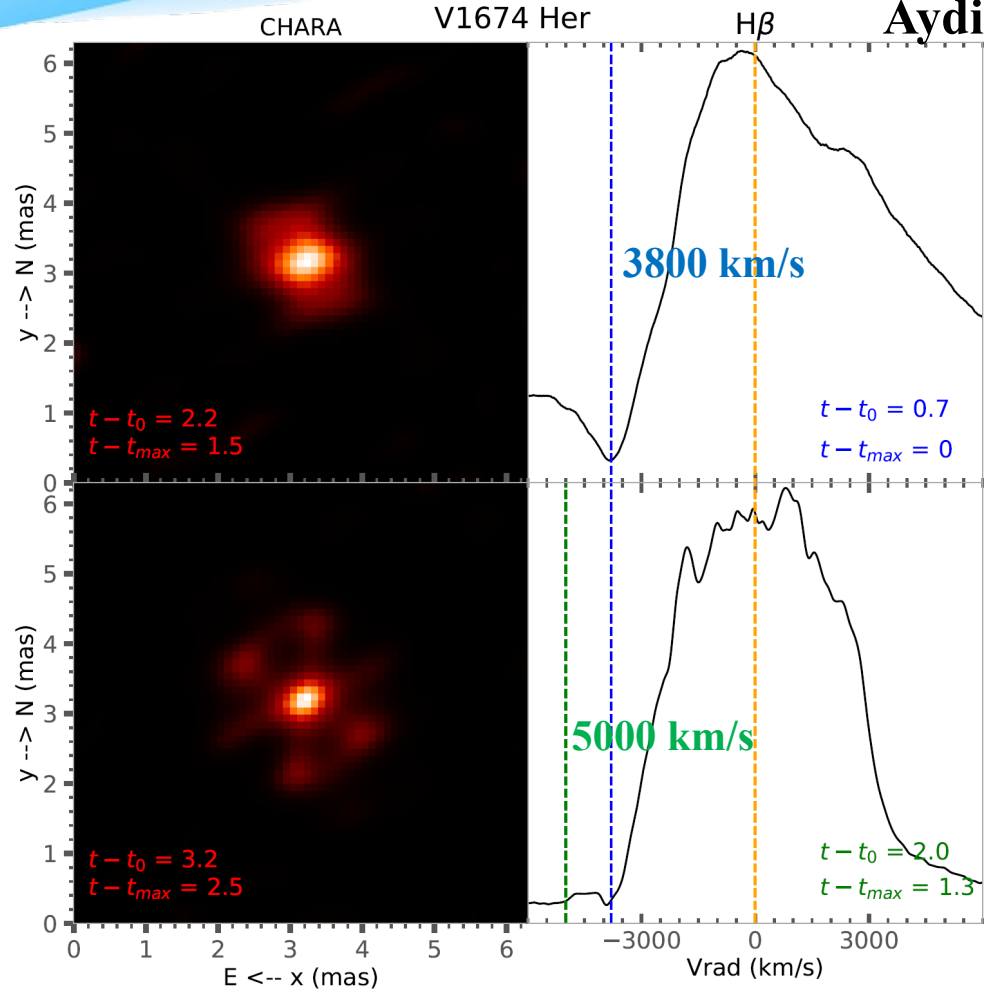




Aydi et al. in perp.

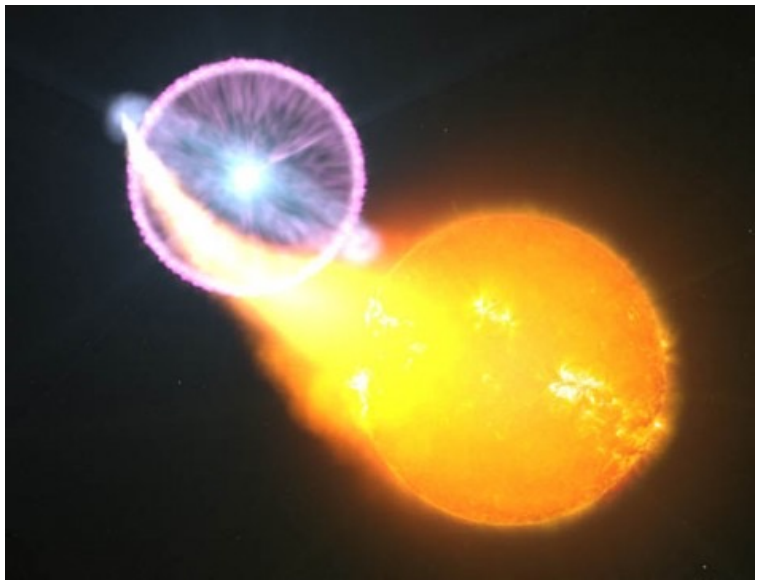
Thanks to Gail Schaefer and John Monnier

Imaging with CHARA



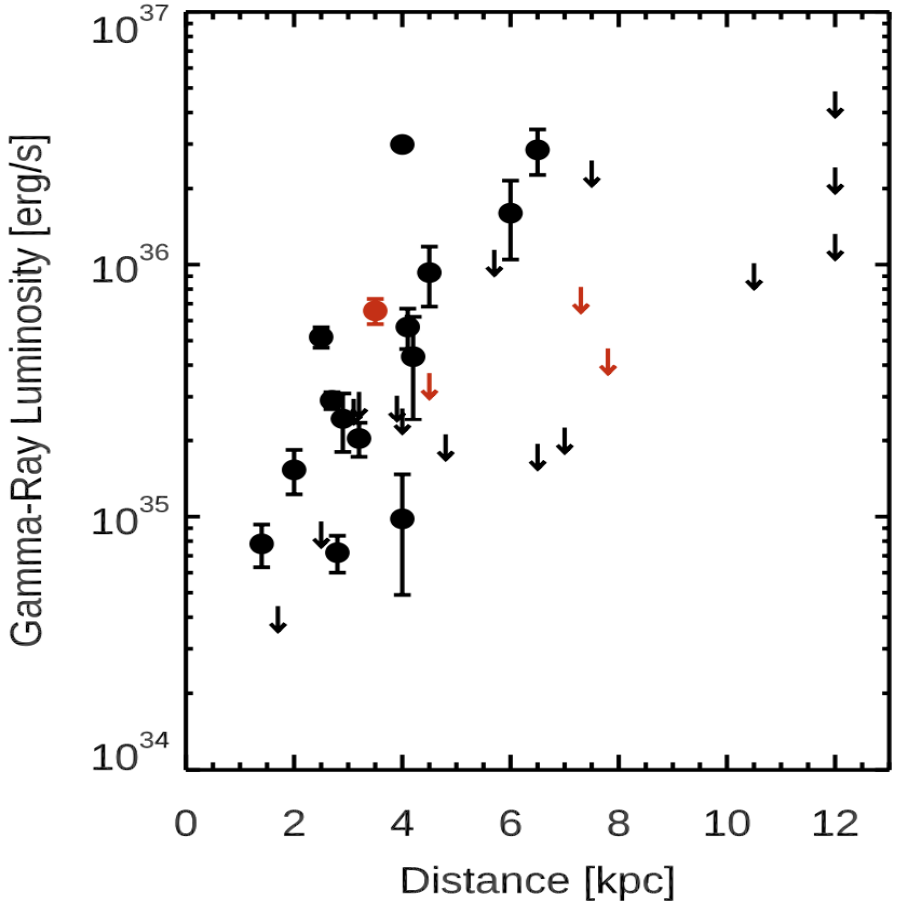
Aydi et al. in perp.

What determines the shock power in novae?



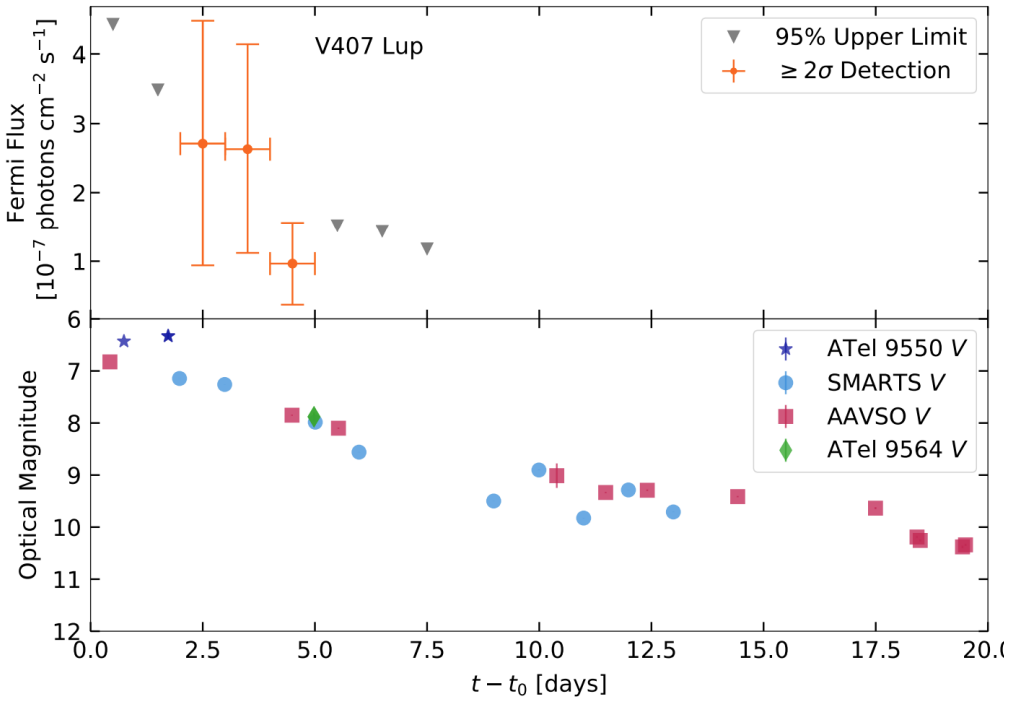
2 to 3 novae are detected with Fermi each year

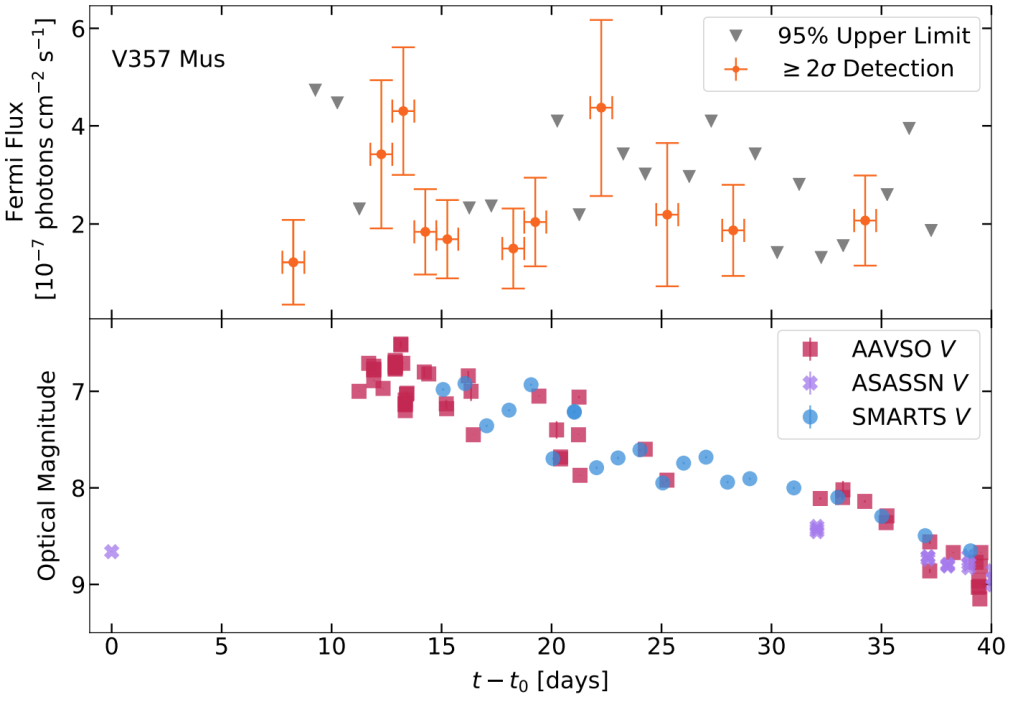
What determines the shock power in novae?



Chomuik et al. (2021)

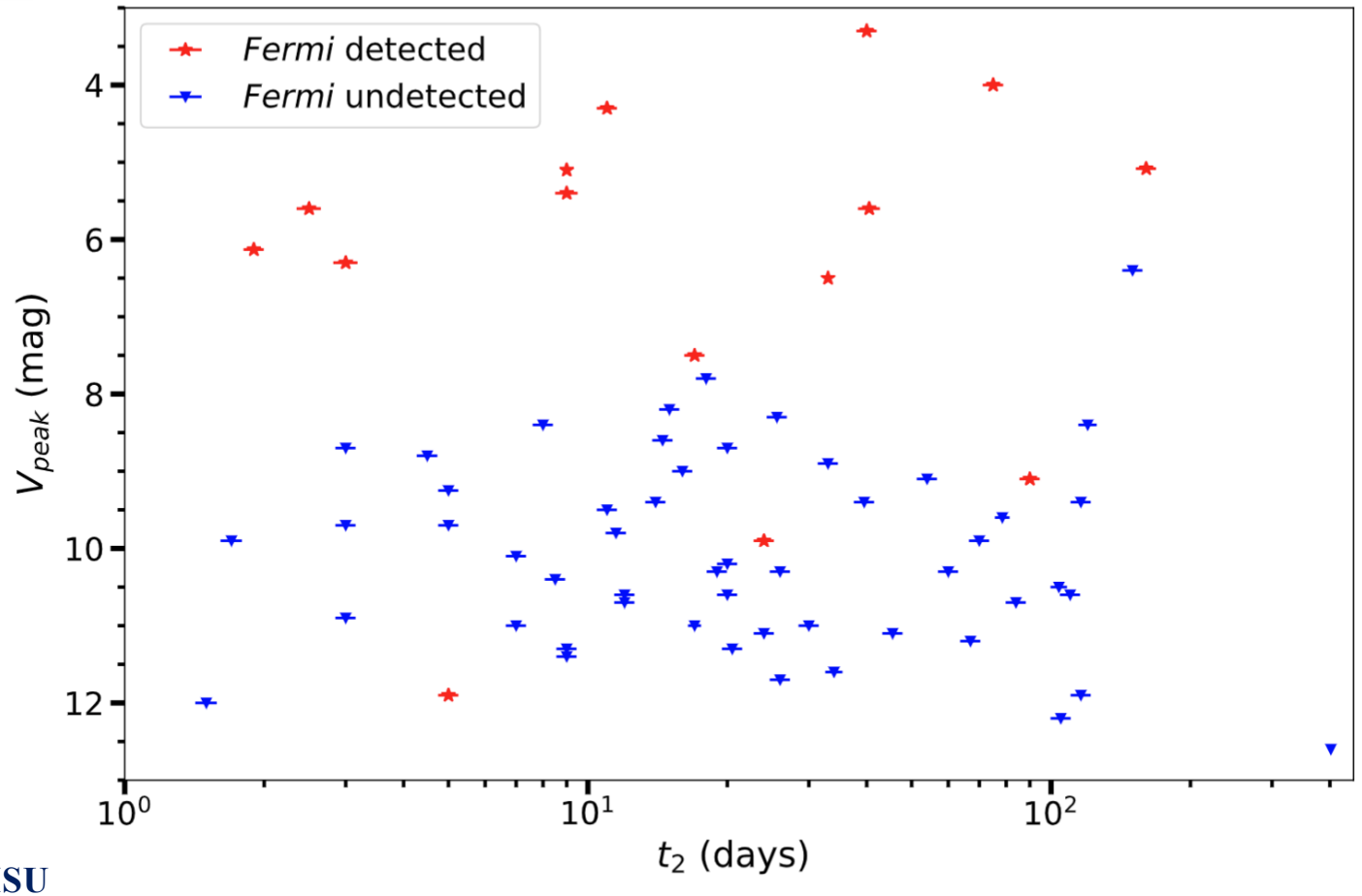
What determines the shock power in novae?





Gordon et al. (2021)

What determines the shock power in novae?

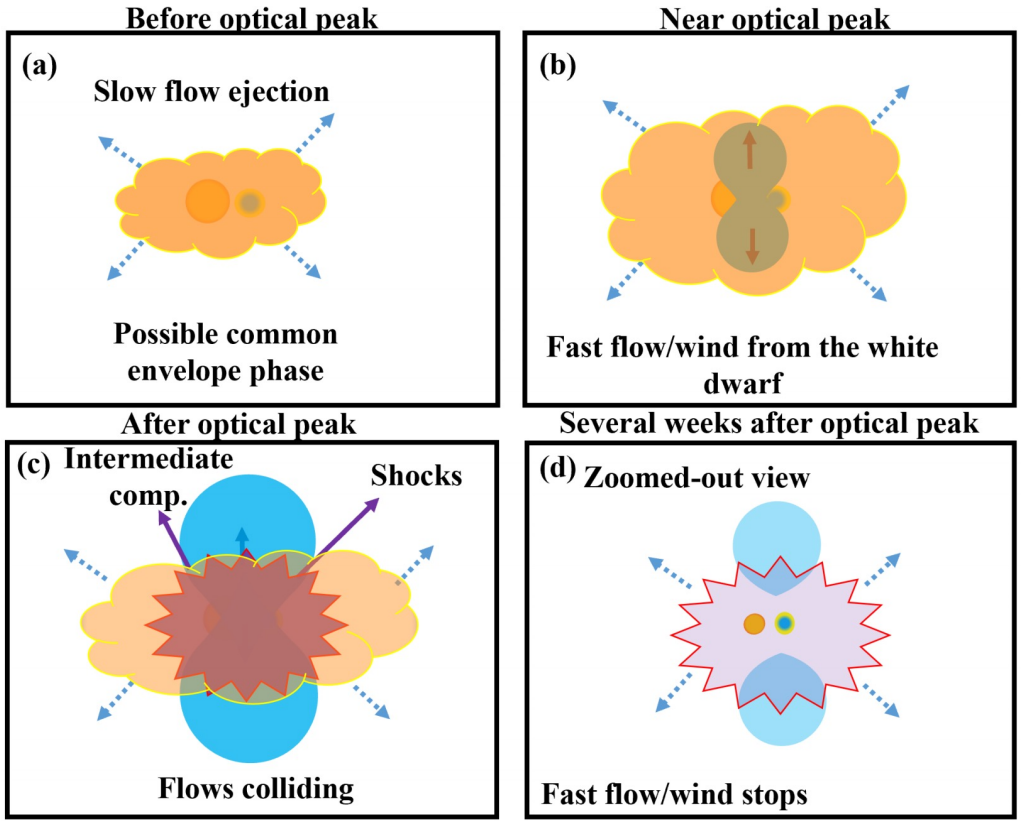


Ashley Stone

Stone et al in prep.

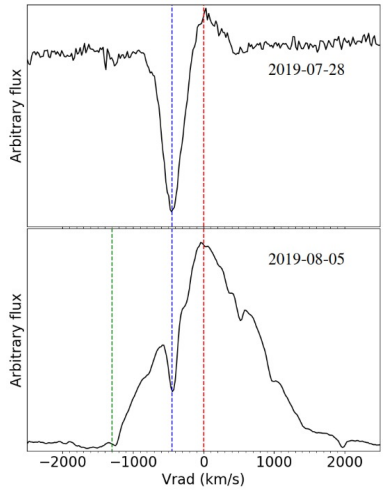
Luminosity of the shocks??

$L_{sh} \propto \rho v^2$

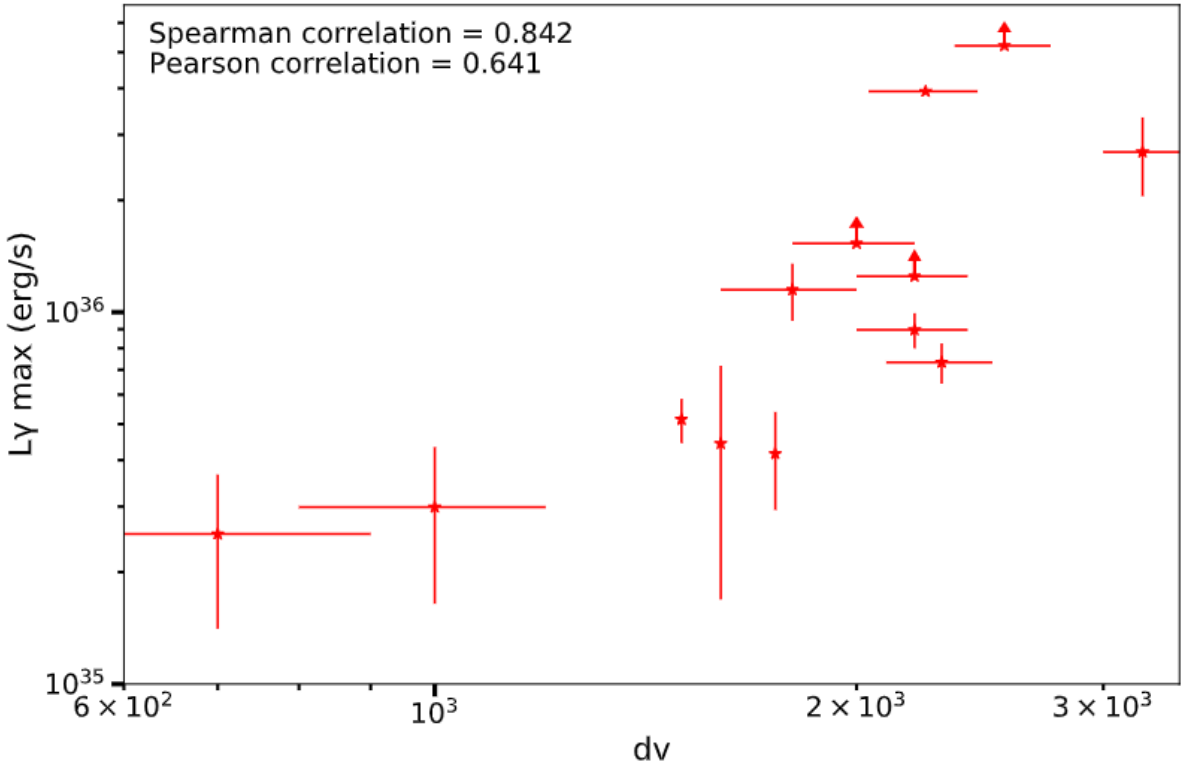


Aydi et al. 2020, ApJ, 905, 62

Parameter space to determine Lgamma



Stone et al in prep.

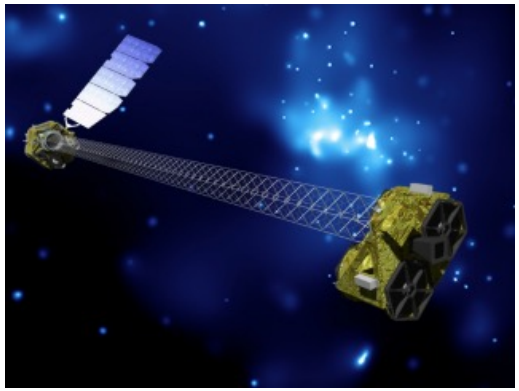


Ashley Stone

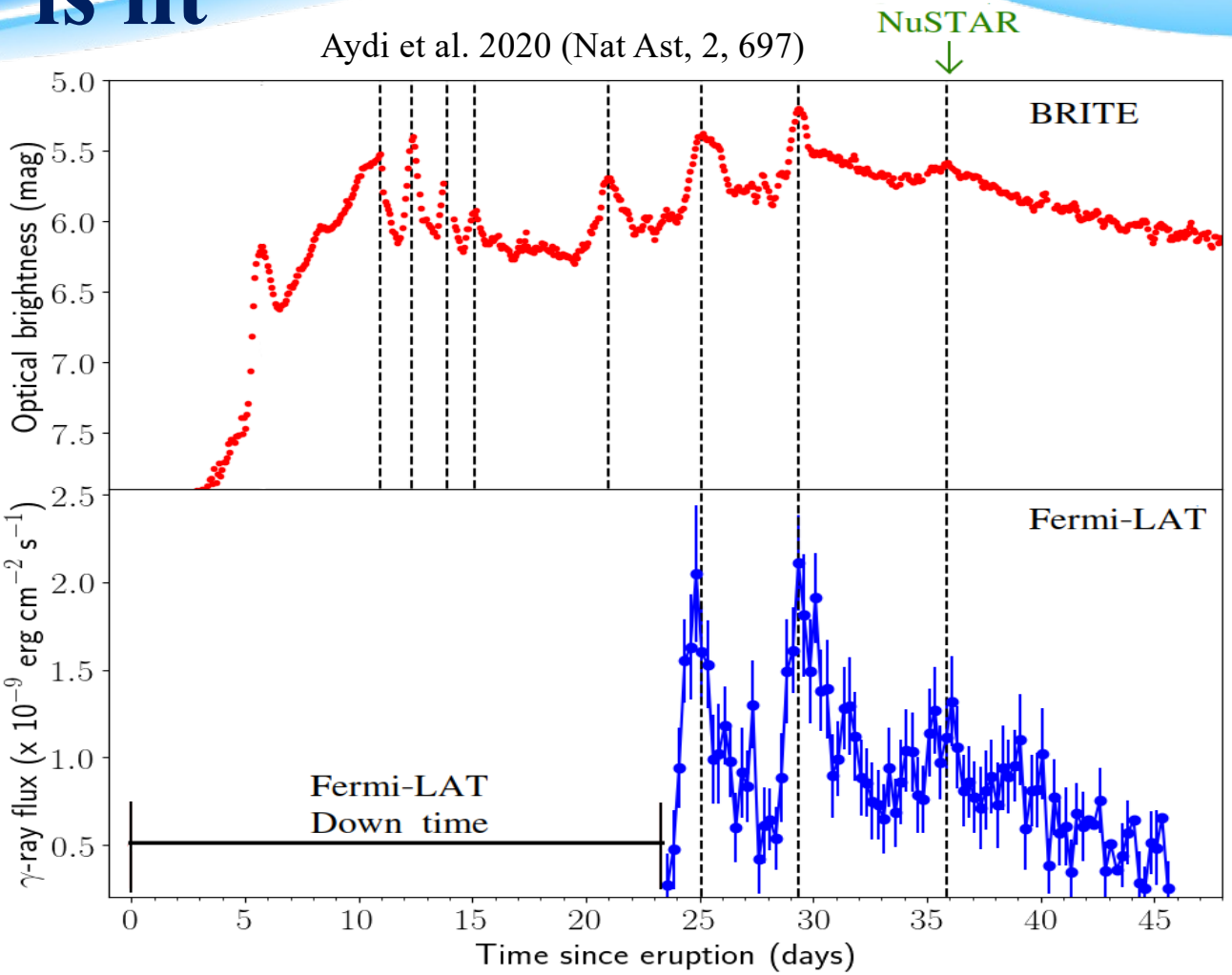
E. Aydi - MSU

Nova V906 Car is lit

NuSTAR



Aydi et al. 2020 (Nat Ast, 2, 697)



E. Aydi - MSU

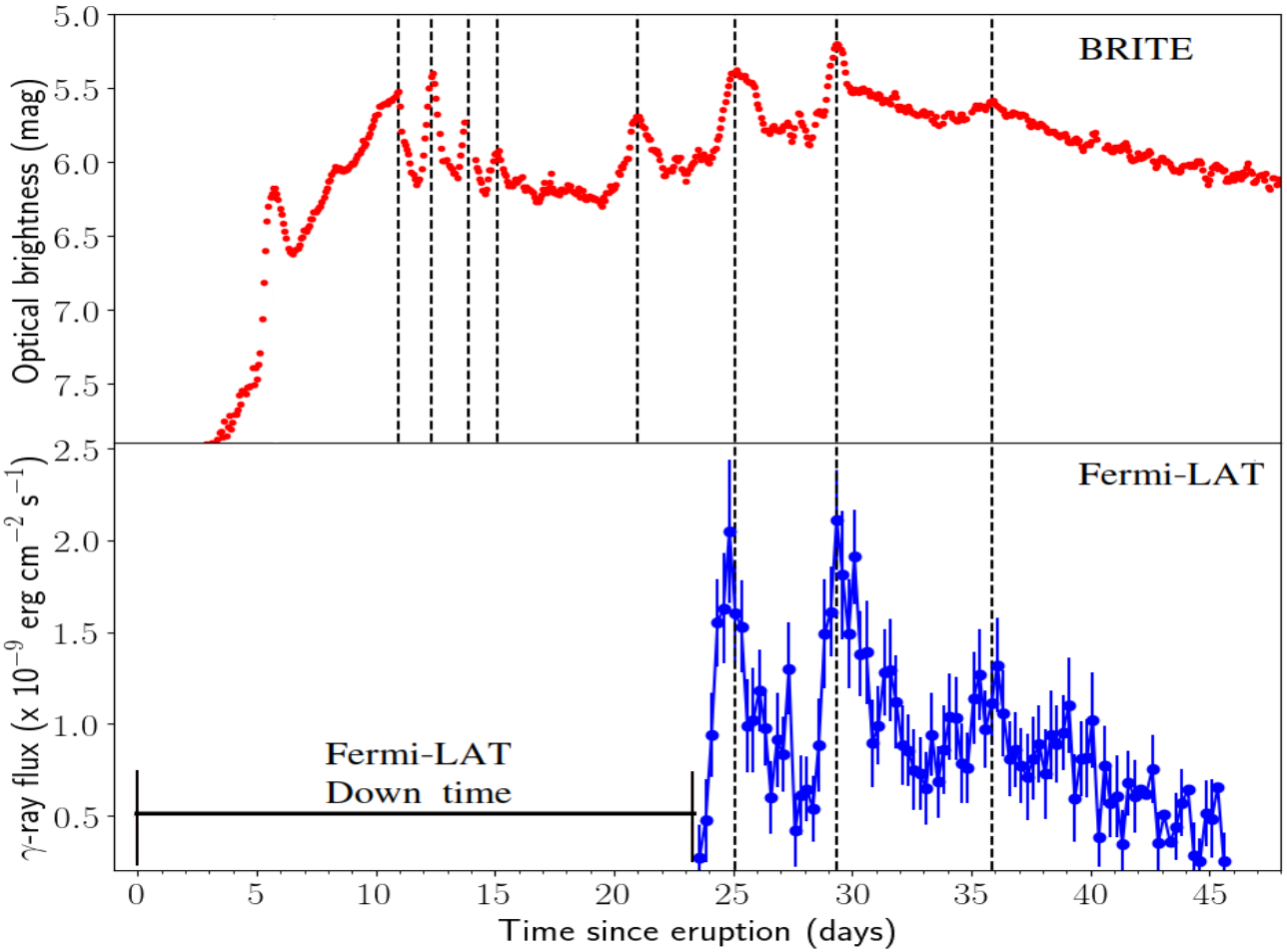
Nova V906 Car is lit

Aydi et al. 2020 (Nat Ast, 2, 697)

X-ray coming From deeply Embedded shocks

L_X ~ 10^34 erg/s

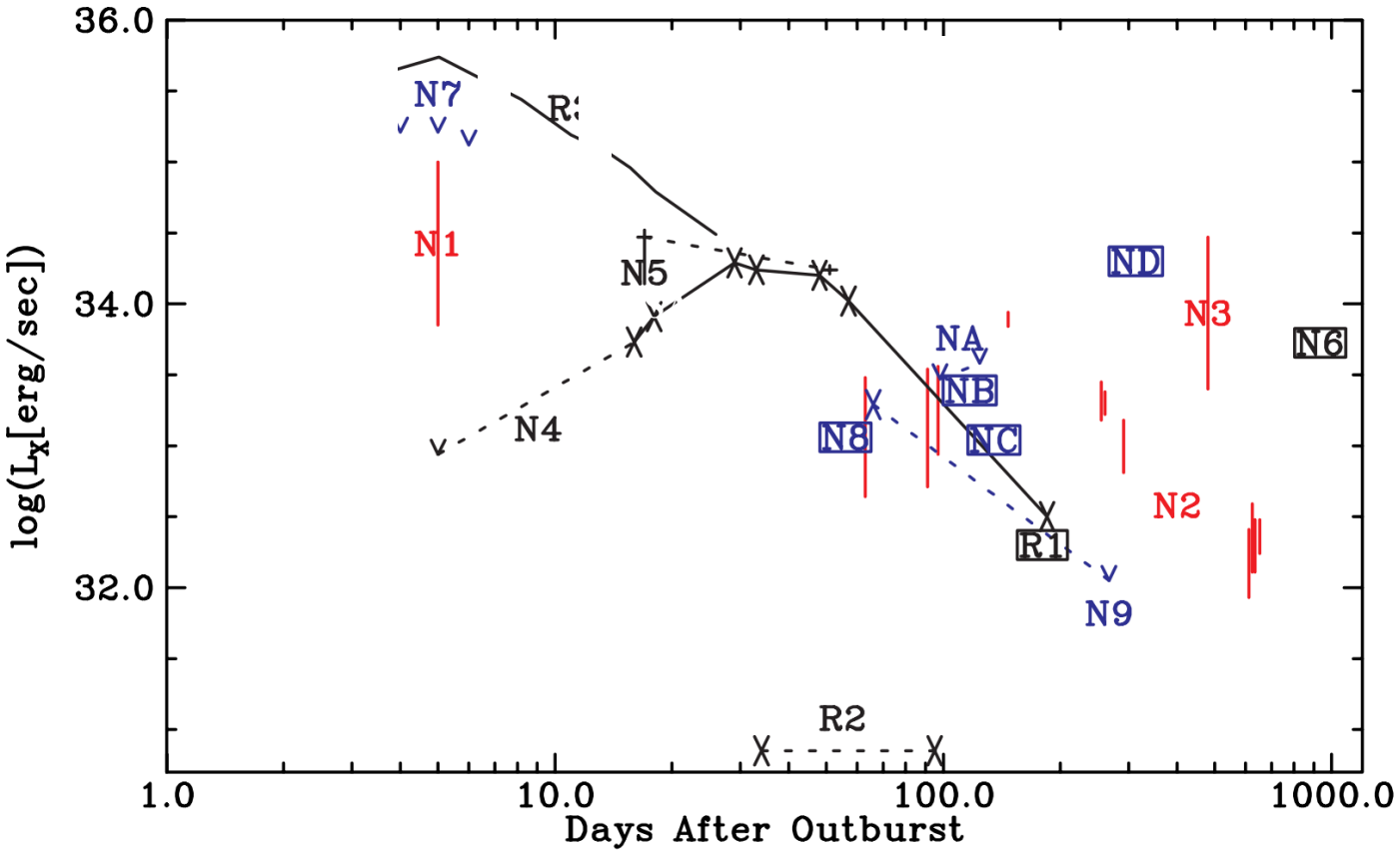
X-rays are absorbed/suppressed



Shock signatures in the X-rays

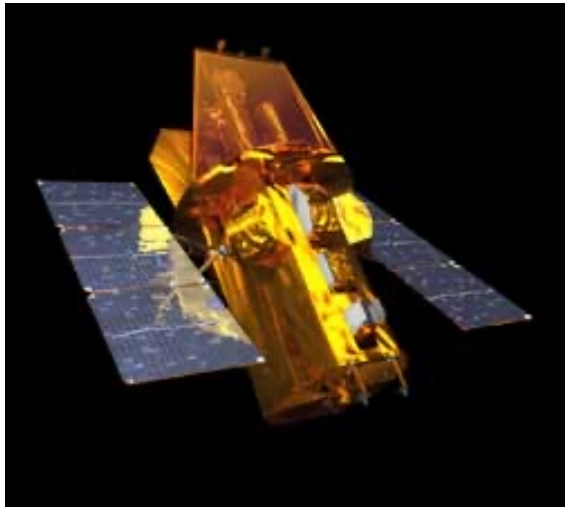
Early hard X-rays from shocks

MUKAI, ORIO, & DELLA VALLE (2001)



Surveying the X-ray Behavior of novae

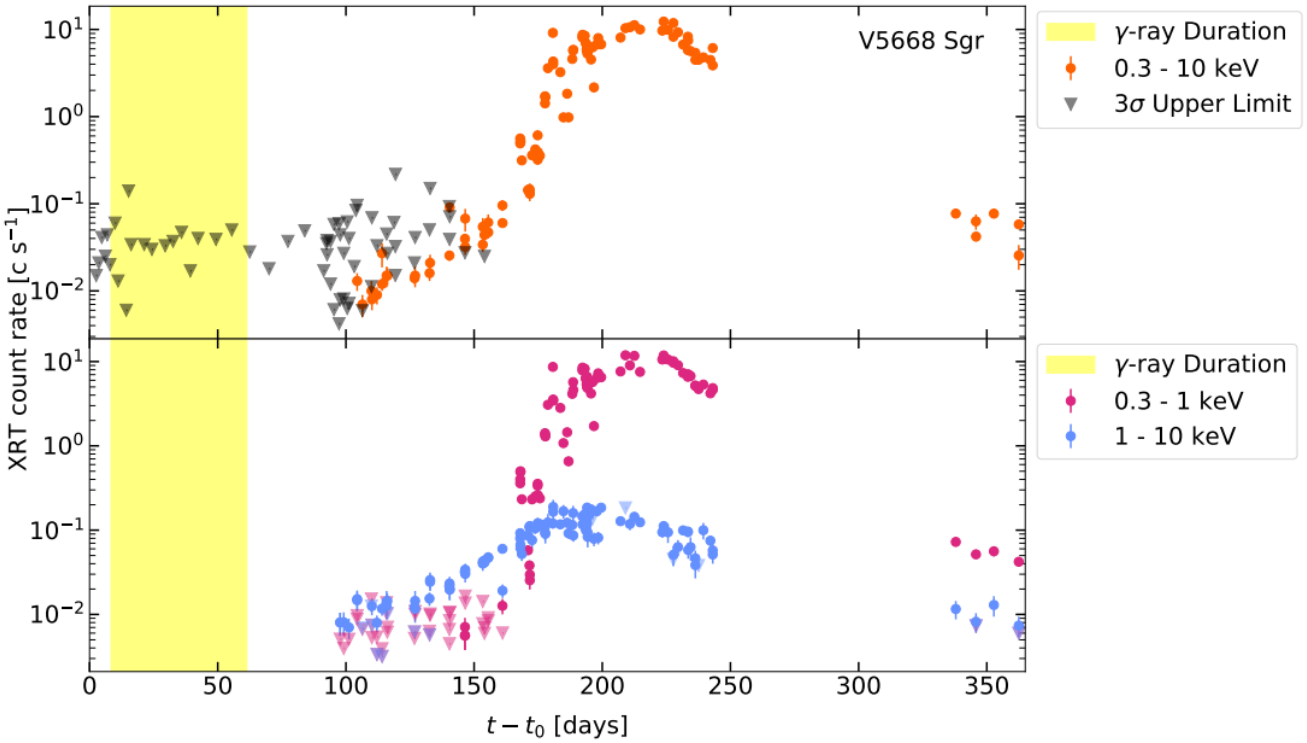
Alexa C. Gordon



***Swift* Grant – PI: Aydi**

E. Aydi - MSU

Gordon et al. (2021, ApJ, 910, 134)



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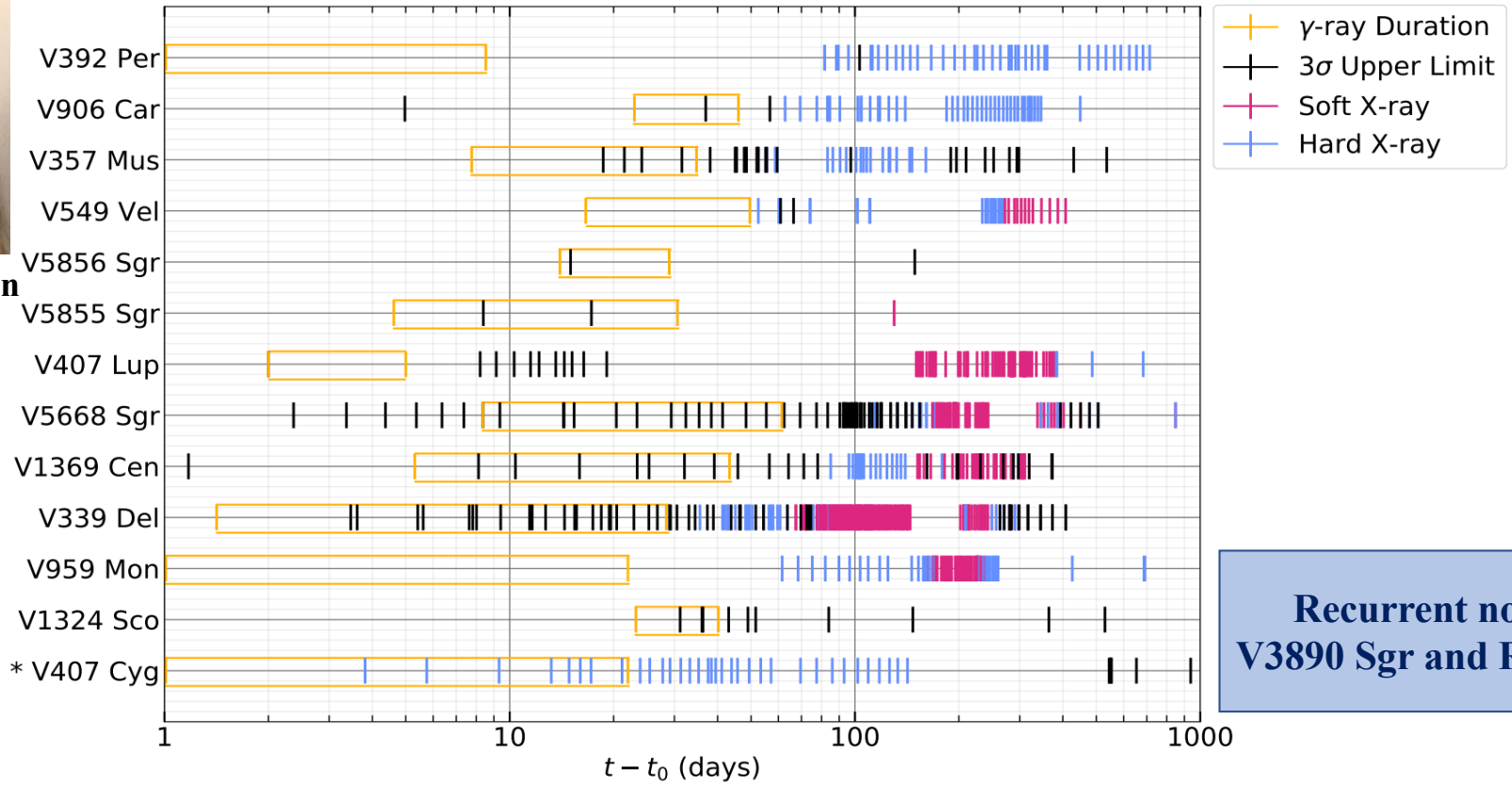

Recurrent novae
V3890 Sgr and RS Oph

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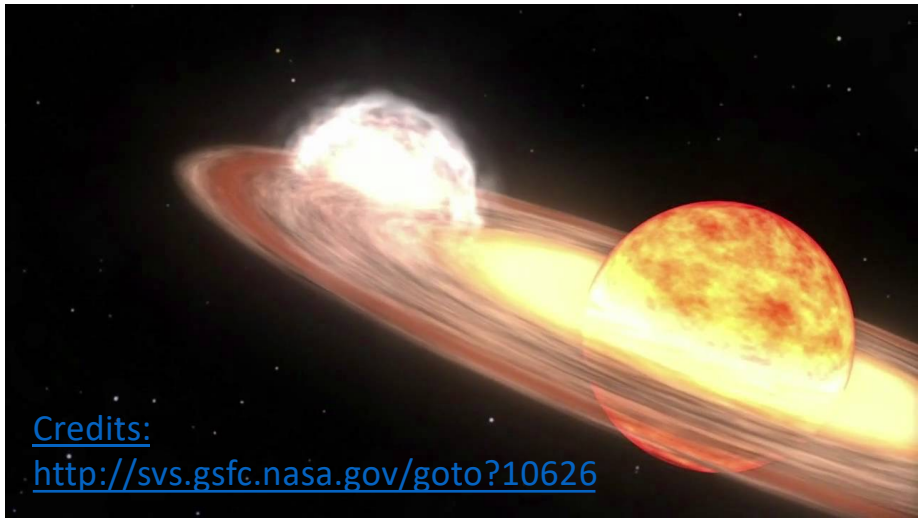
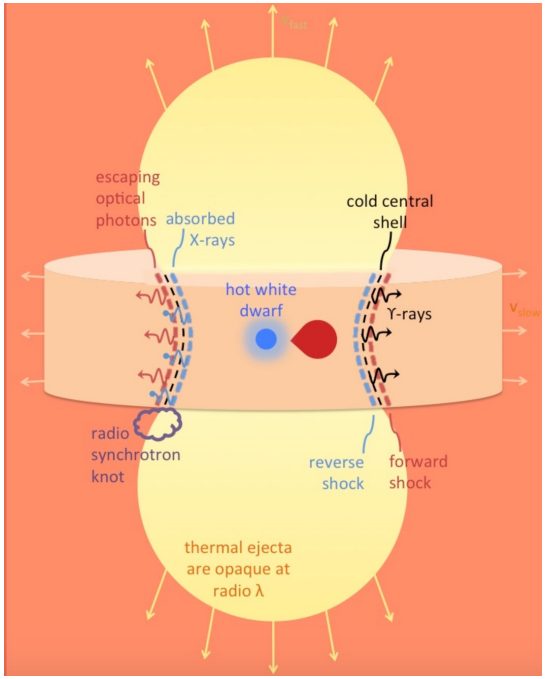
Gamma-rays from novae

External shocks

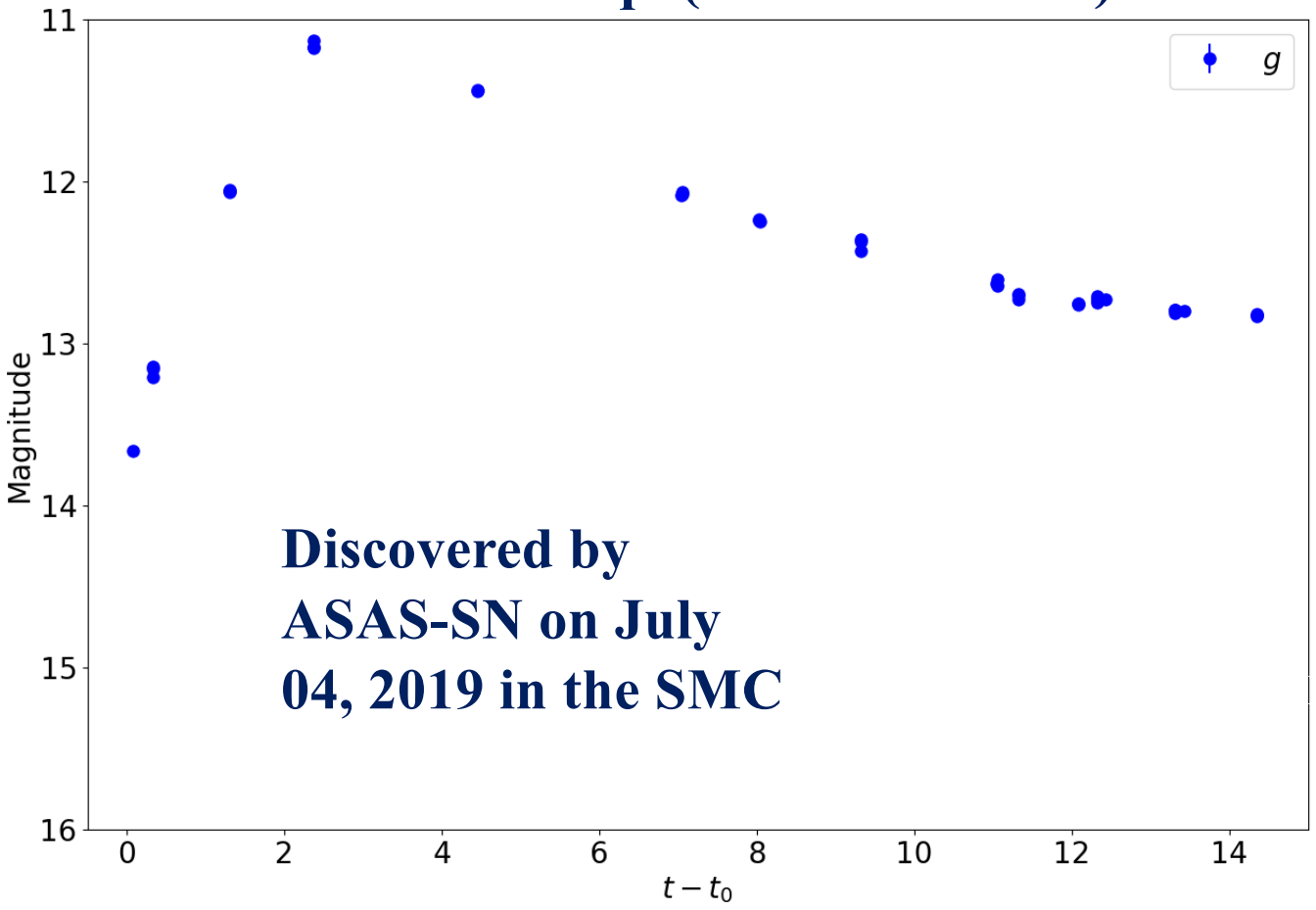


Internal shocks



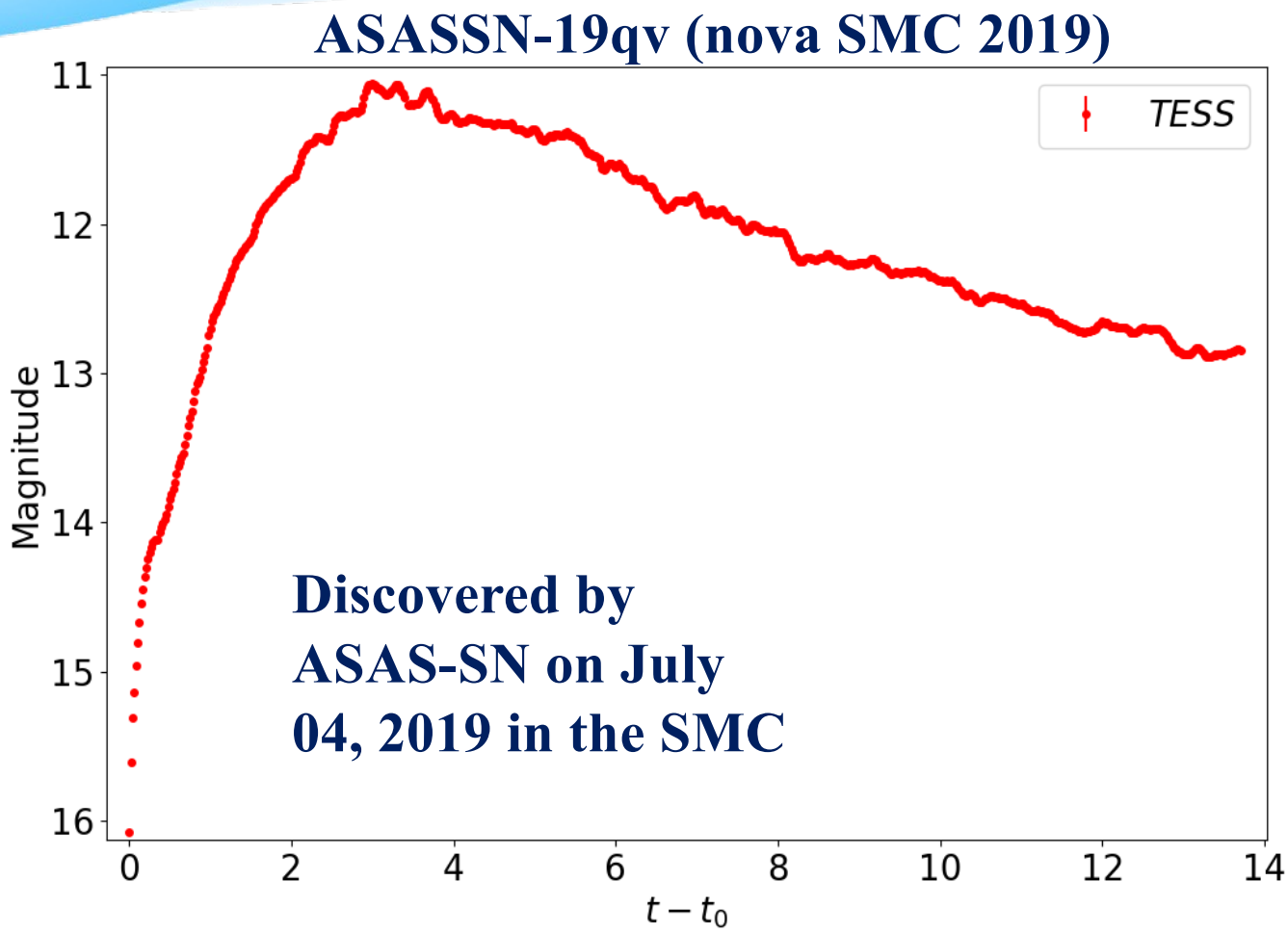
TESS as a tool to study Novae

Aydi et al. in prep.



TESS as a tool to study Novae

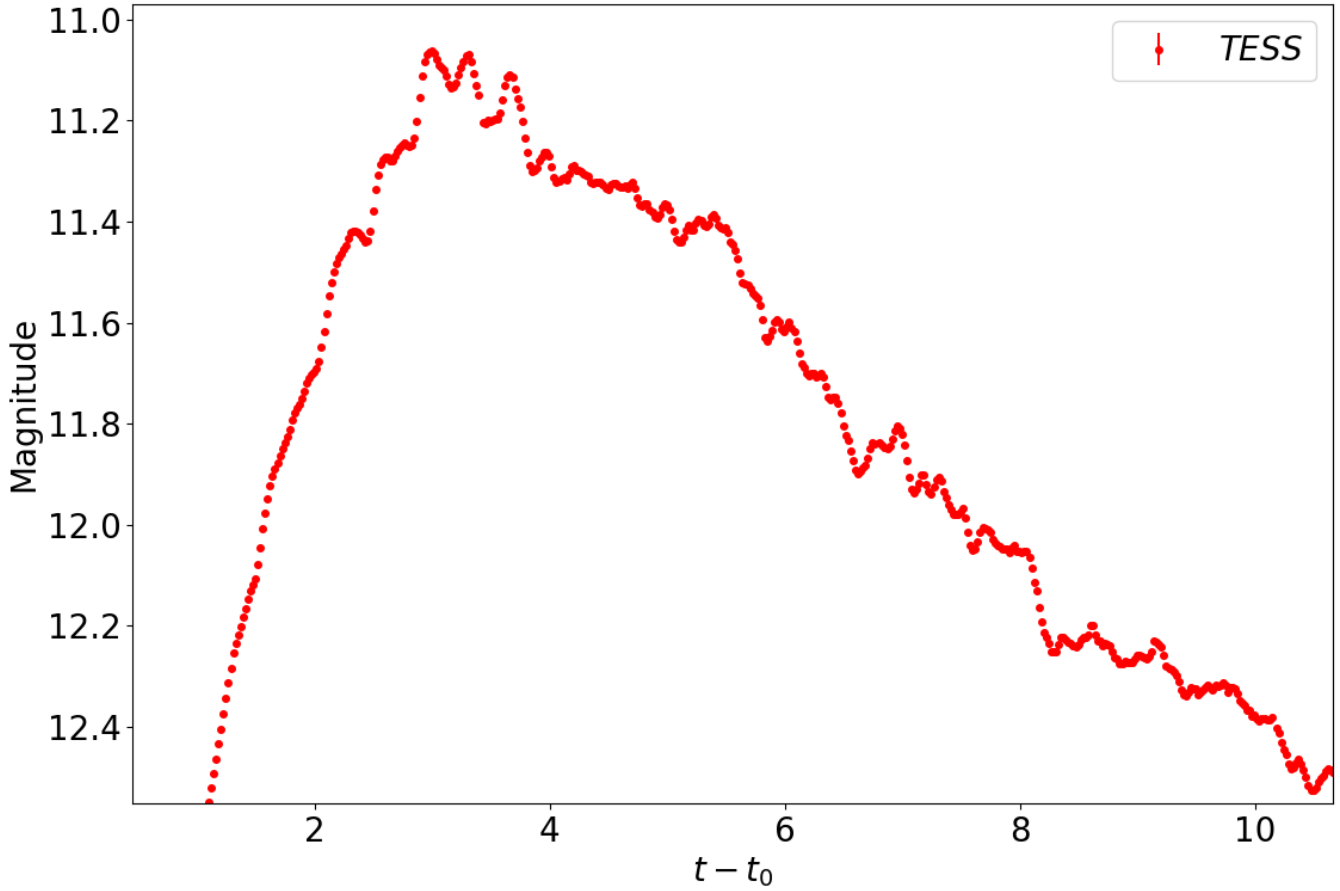
Aydi et al. in prep.



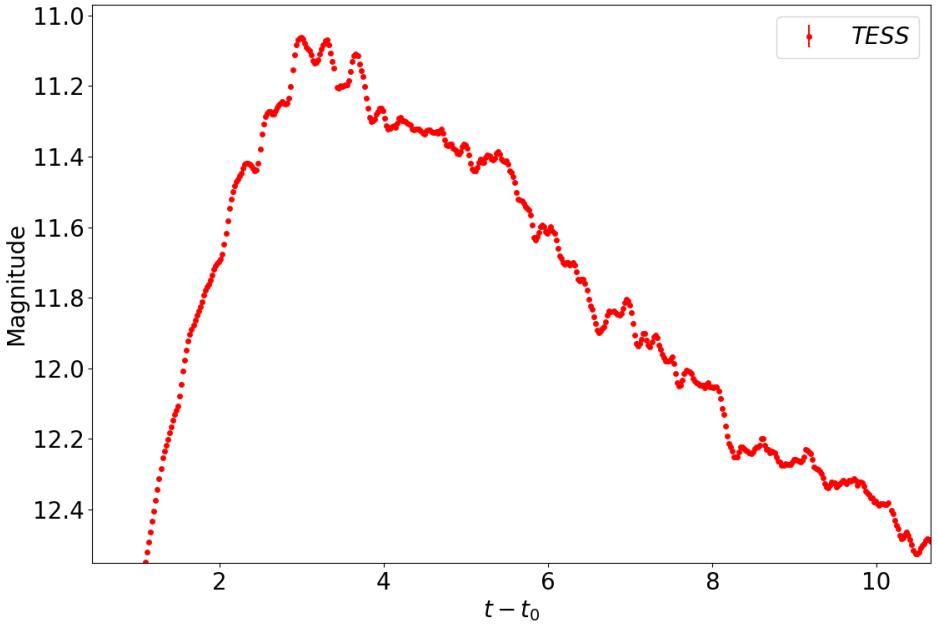
TESS as a tool to study Novae

ASASSN-19qv (nova SMC 2019)

Aydi et al. in prep.



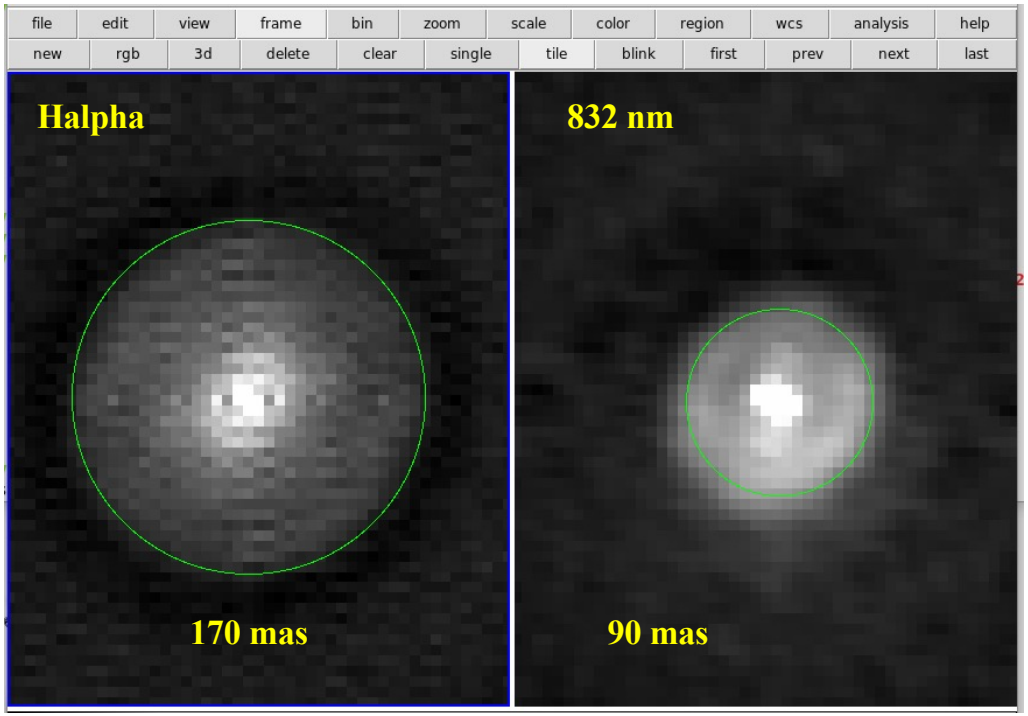
TESS as a tool to study Novae



Imaging years into the eruption

Nova V906 Car ≈ 2 years after eruption with Zorro on Gemini

Preliminary results:
Thanks to Ricardo Salinas
And Eliott Horch



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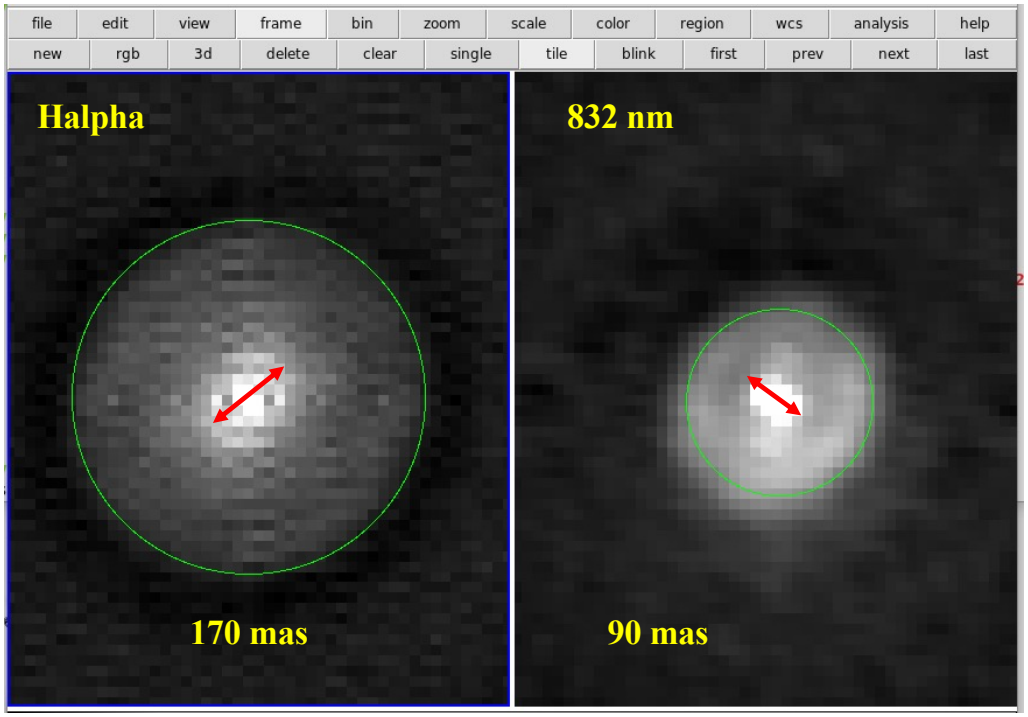
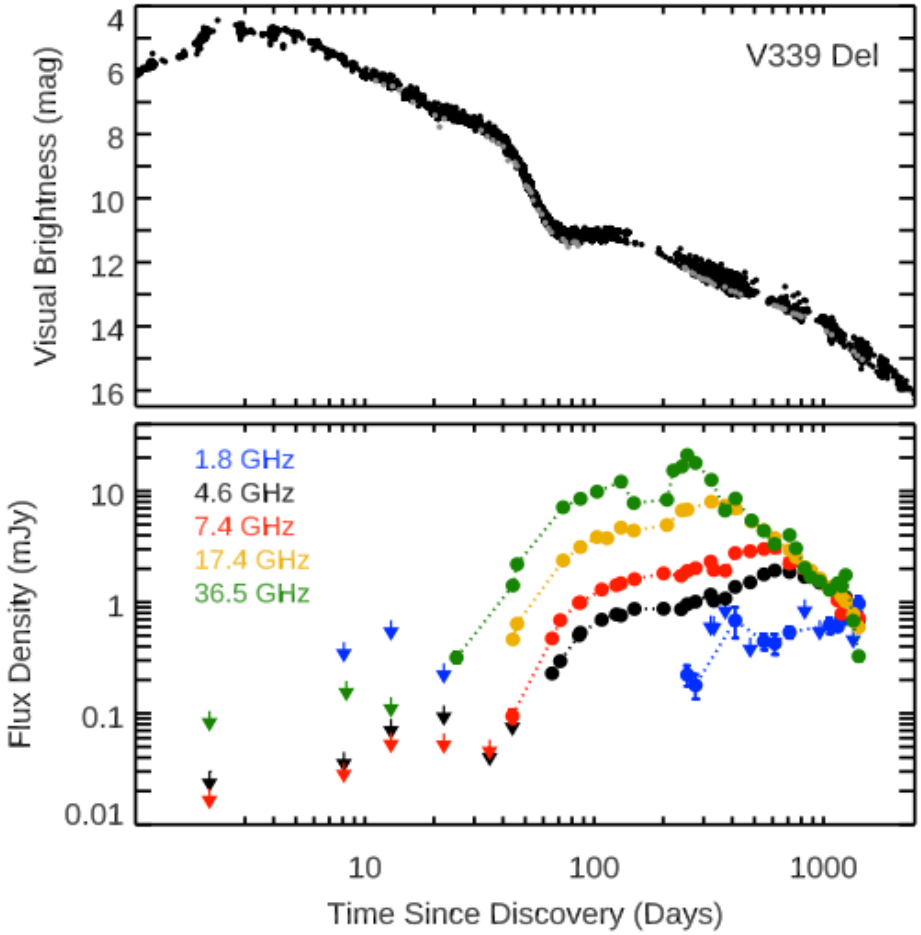
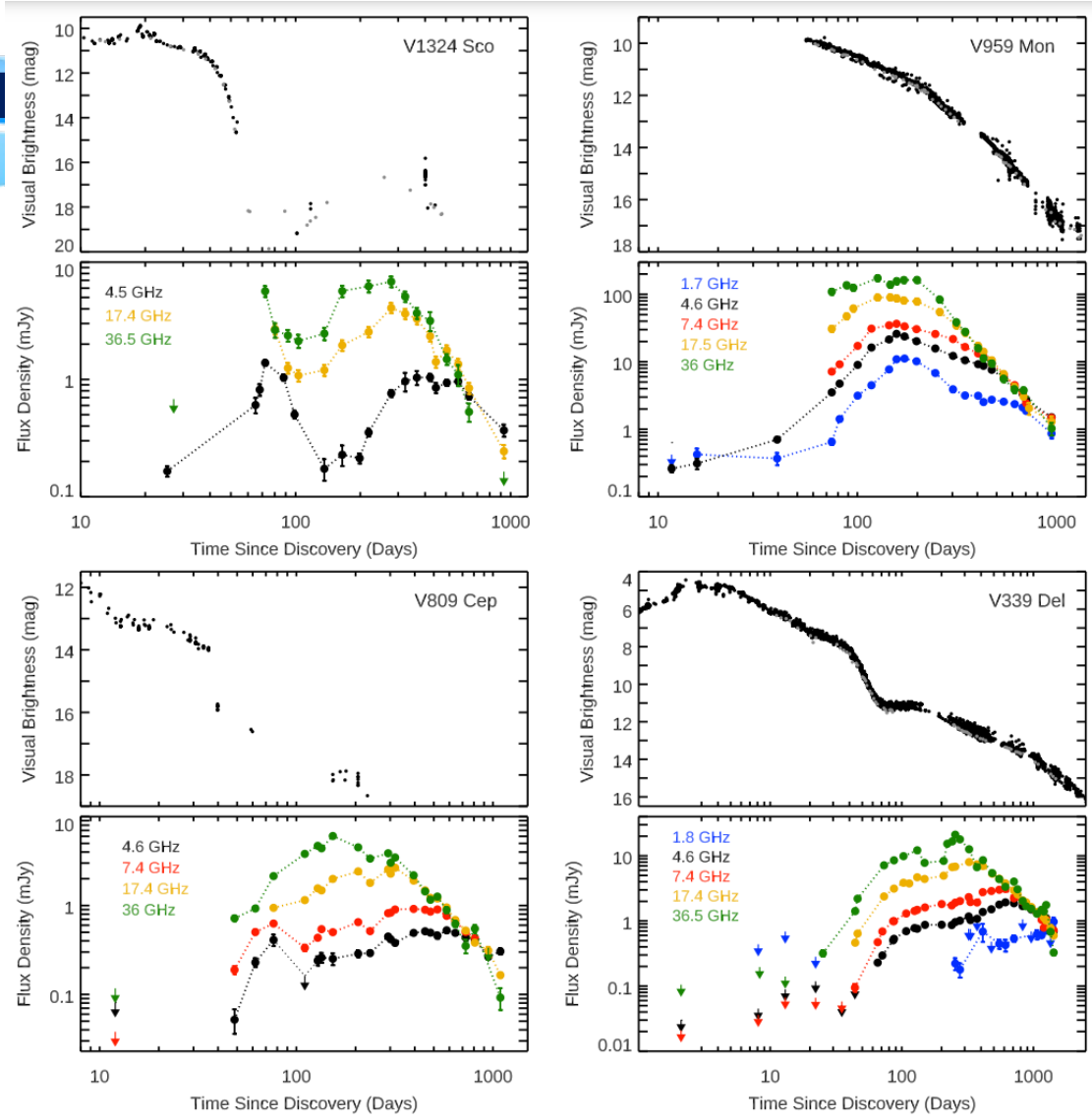


Novae in the radio

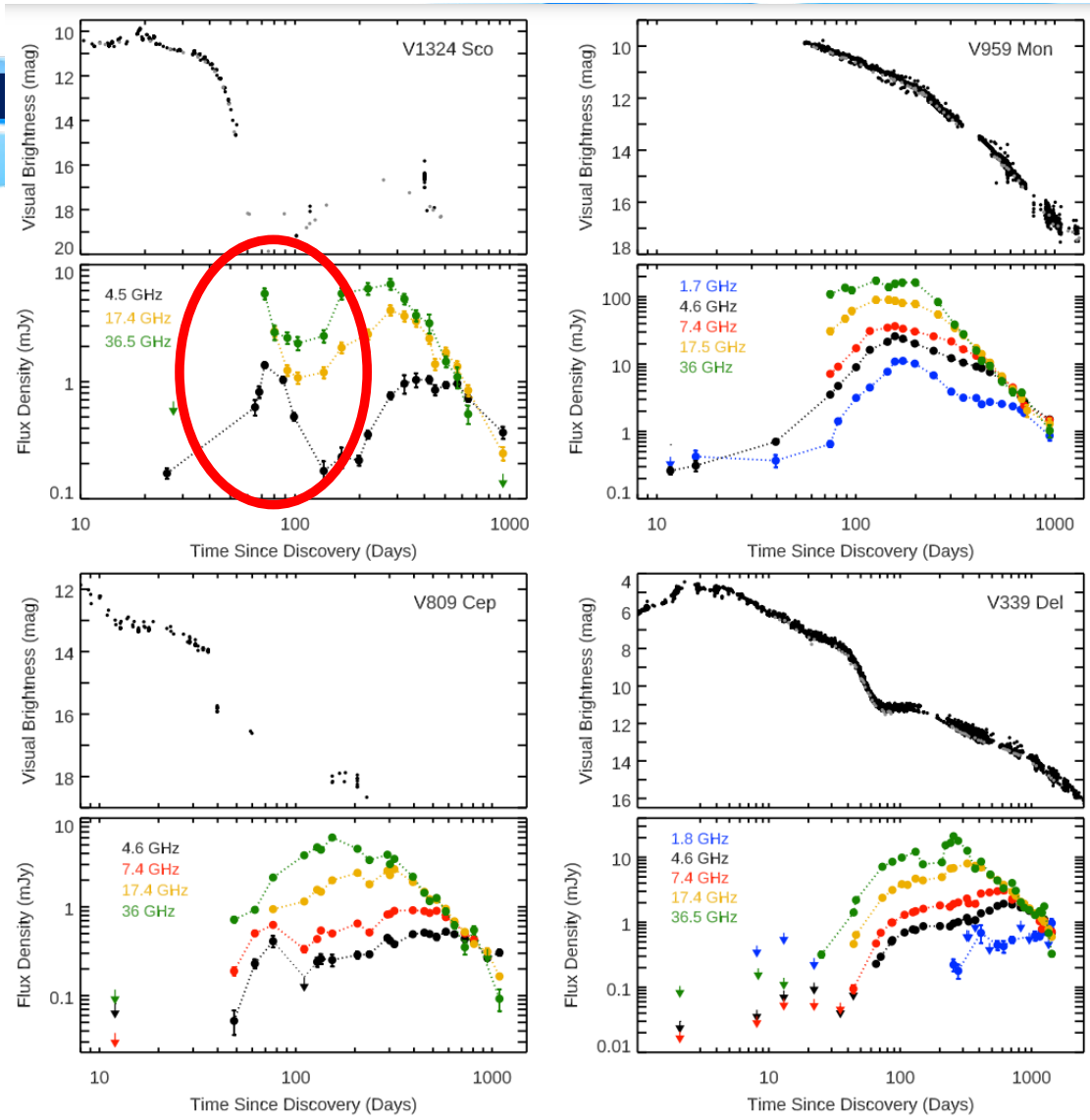
Typical radio light curve of novae



Typical r


V1324 Sco
Visual Brightness (mag)
Flux Density (mJy)
4.5 GHz
17.4 GHz
36.5 GHz
Time Since Discovery (Days)
V959 Mon
1.7 GHz
4.6 GHz
7.4 GHz
17.5 GHz
36 GHz
V809 Cep
4.6 GHz
7.4 GHz
17.4 GHz
36 GHz
V339 Del
1.8 GHz
4.6 GHz
7.4 GHz
17.4 GHz
36.5 GHz

Typical r


V1324 Sco
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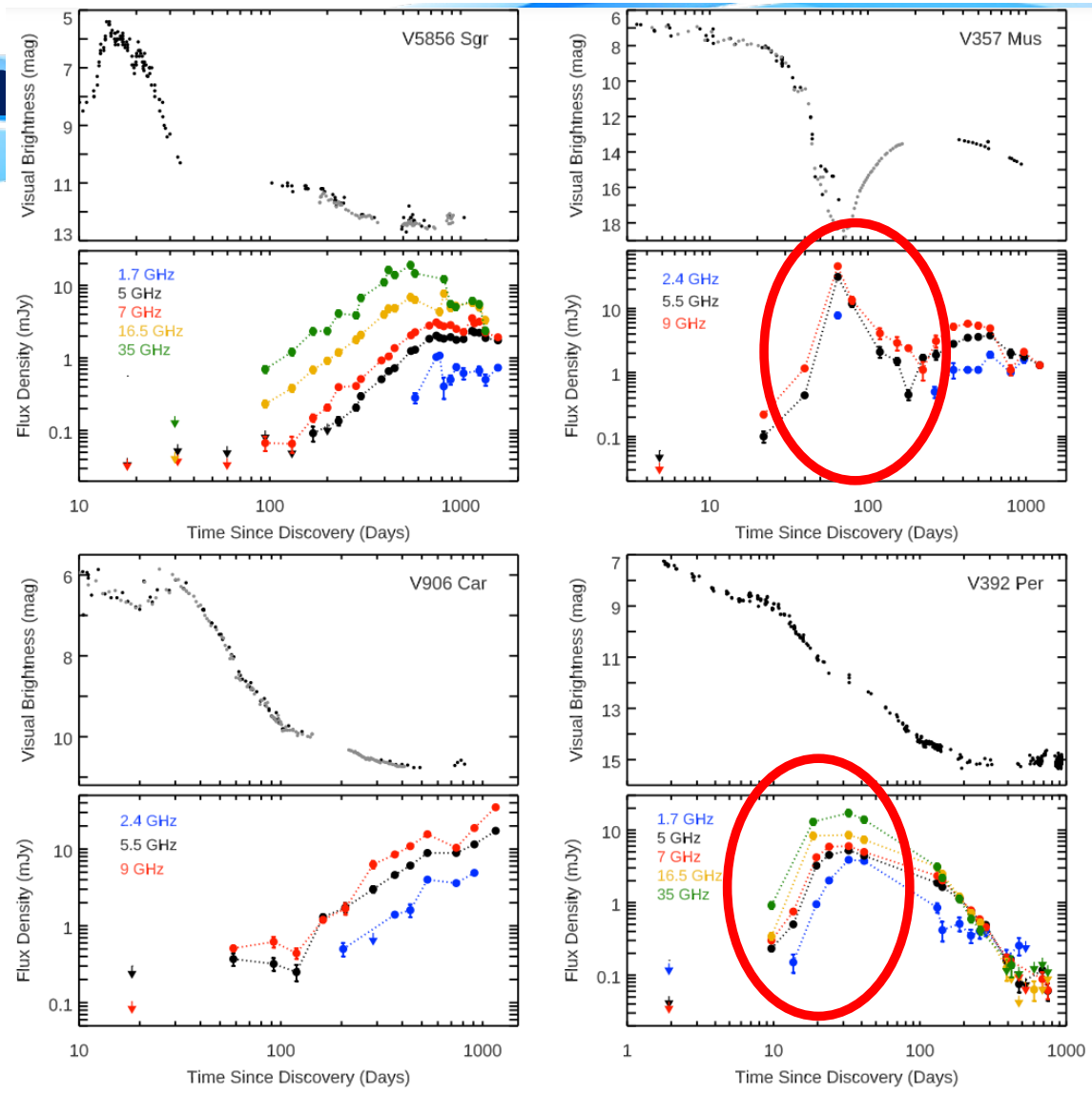
4.6 GHz
7.4 GHz
17.4 GHz
36 GHz
V339 Del
1.8 GHz
4.6 GHz
7.4 GHz
17.4 GHz
36.5 GHz

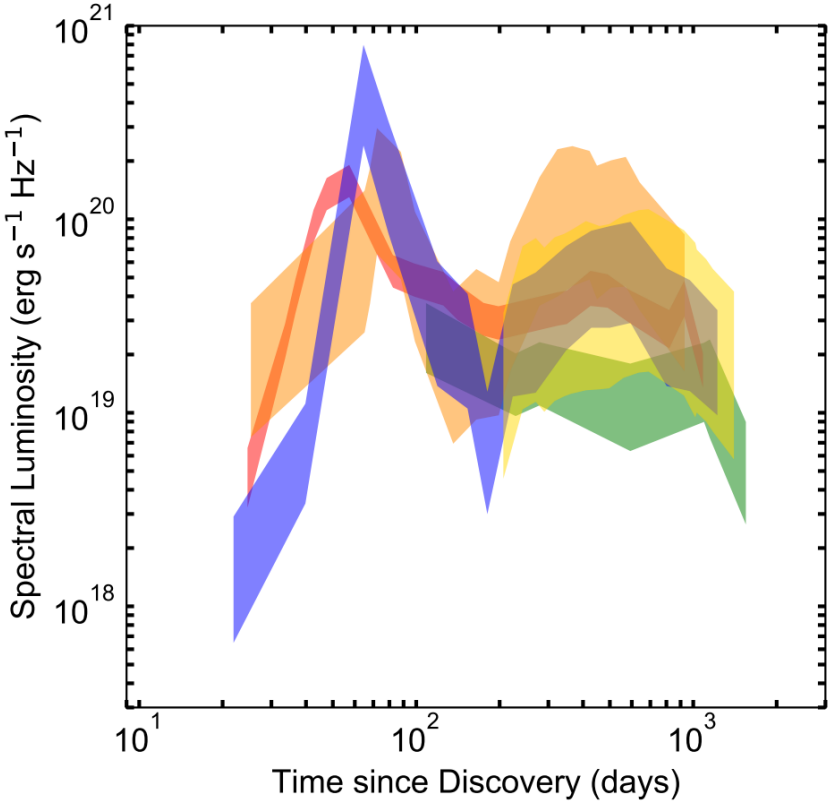
Novae in

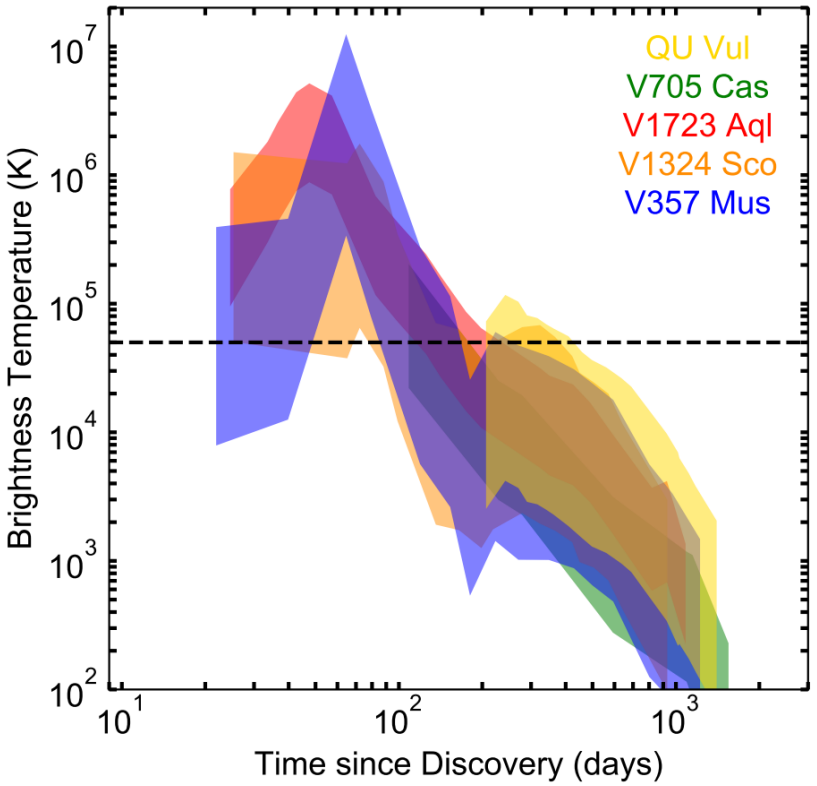


Chomiuk et al. 2021, ApJ, 257, 49

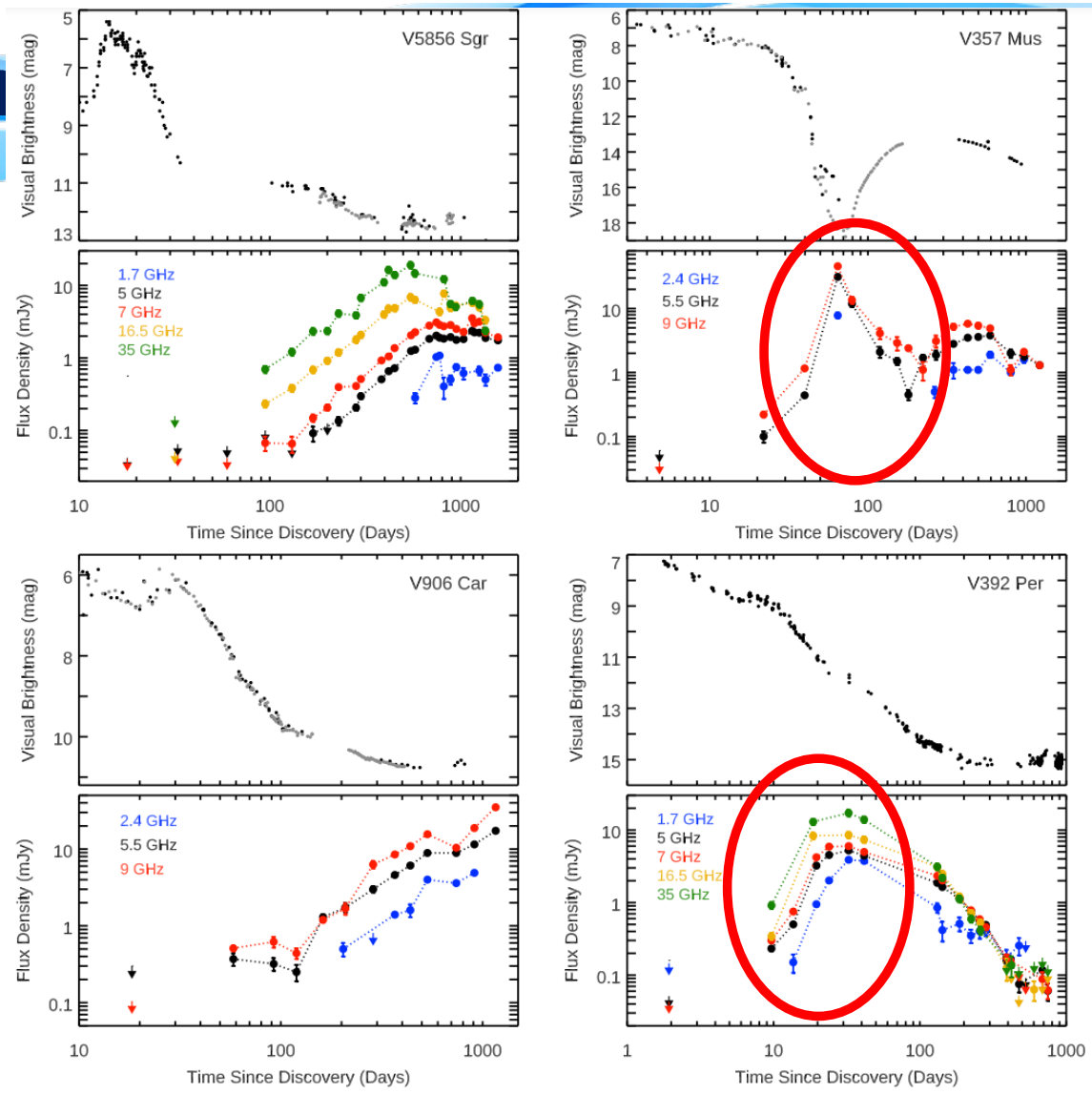
Novae in the radio

Chomiuk et al. 2021, ApJ, 257, 49





Novae in



Chomiuk et al. 2021, ApJ, 257, 49

Novae across the spectrum

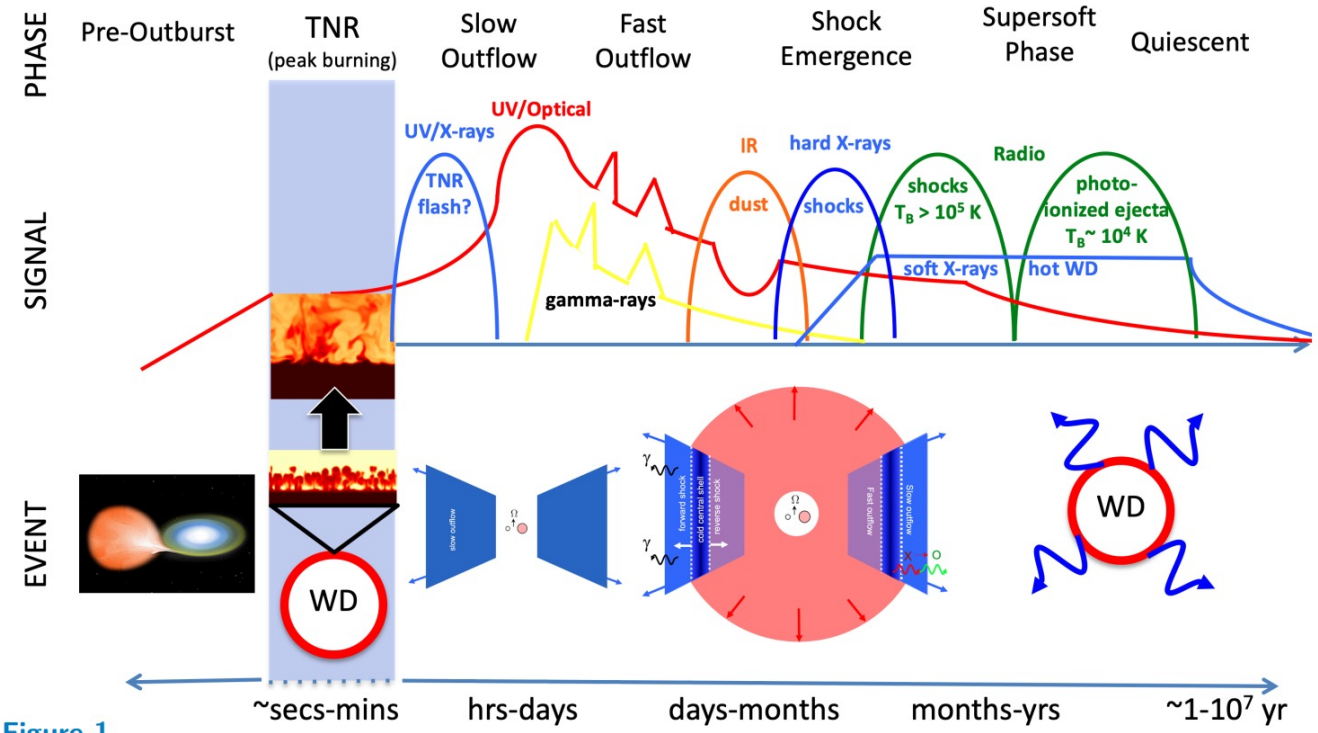
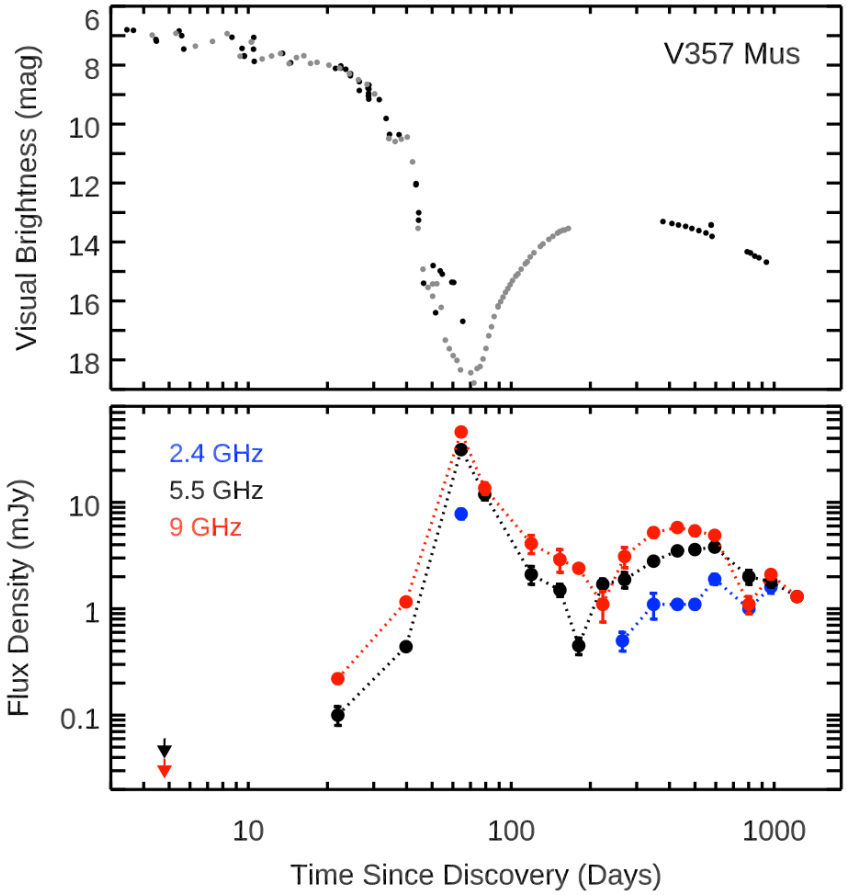


Figure 1

Schematic timeline of the physical processes and electromagnetic signals from novae. The figure includes modified images of convection/mixing during the thermonuclear runaway from Casanova et al. (2016, reproduced with permission ©ESO) and internal shocks from Metzger et al. (2015).

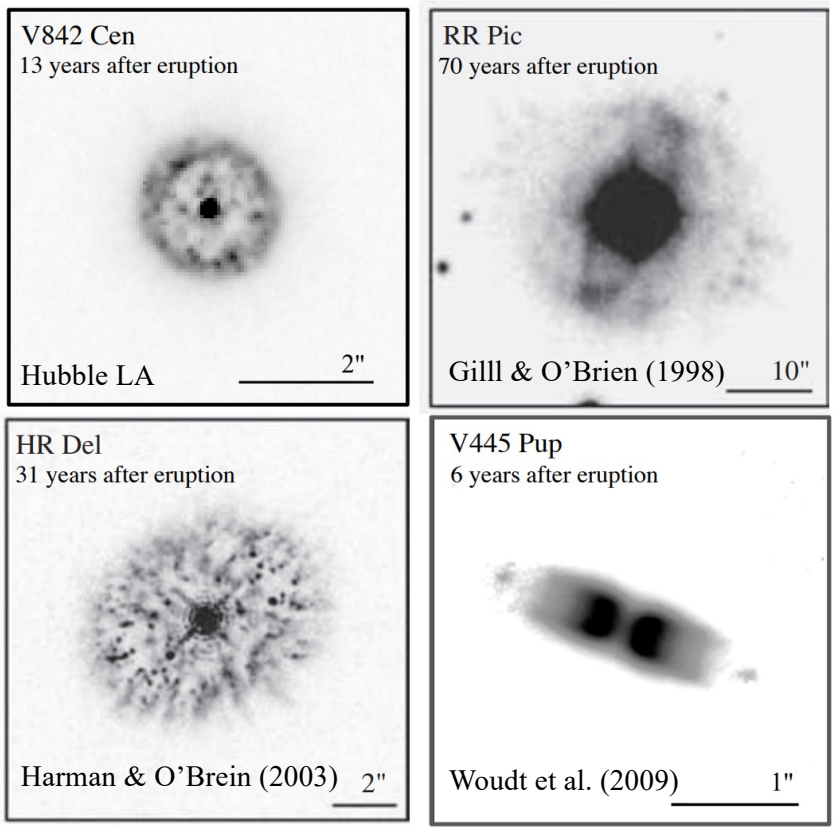
How and where dust forms?



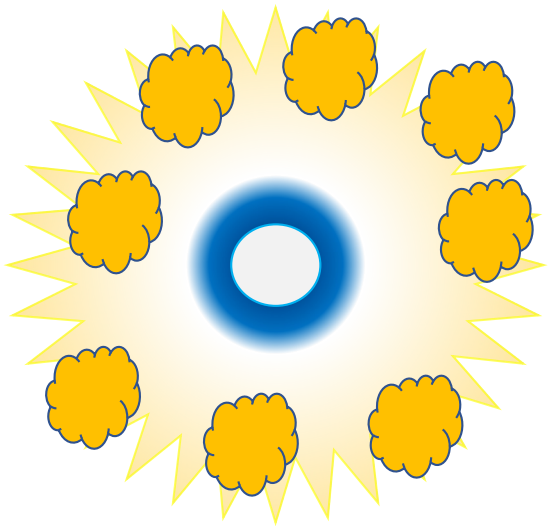
Chomiuk et al. 2021, ApJ, 257, 49

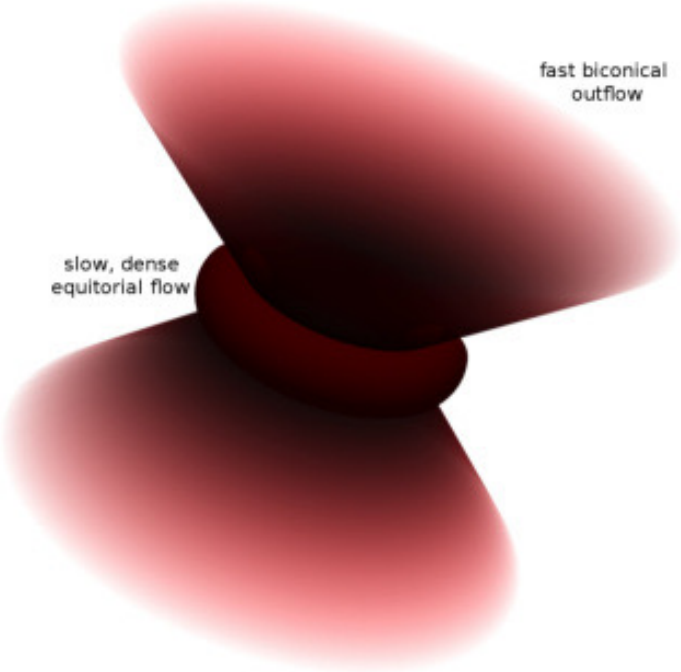
Single ejection vs multiple ejections?

From Chomiuk et al. (2021)

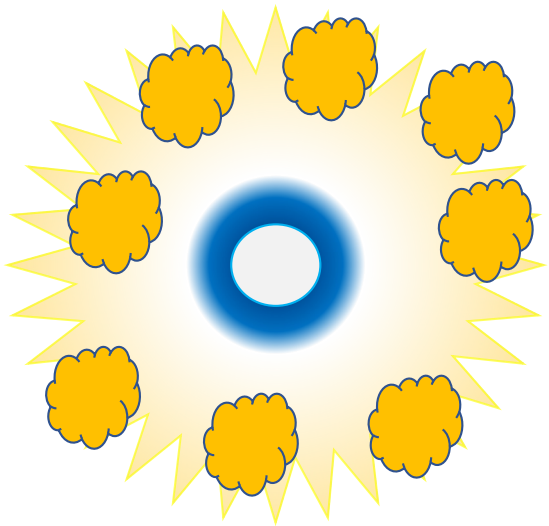


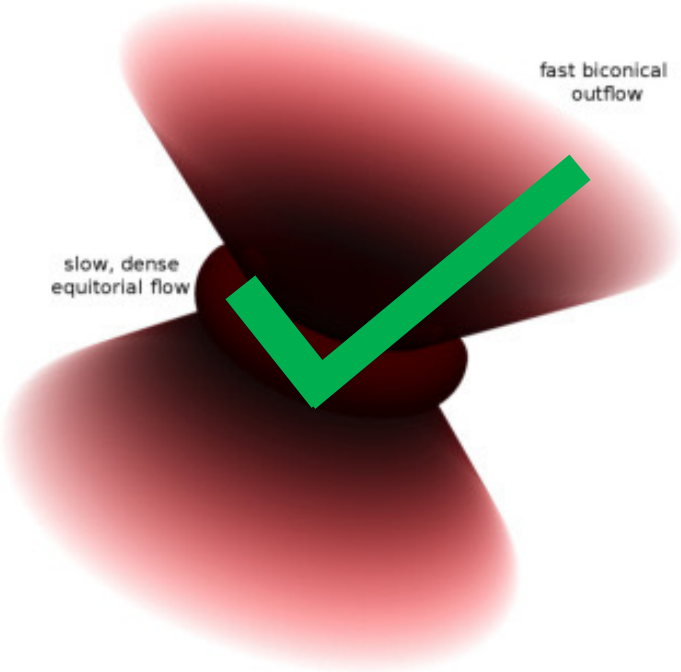
Single ejection vs multiple ejections?





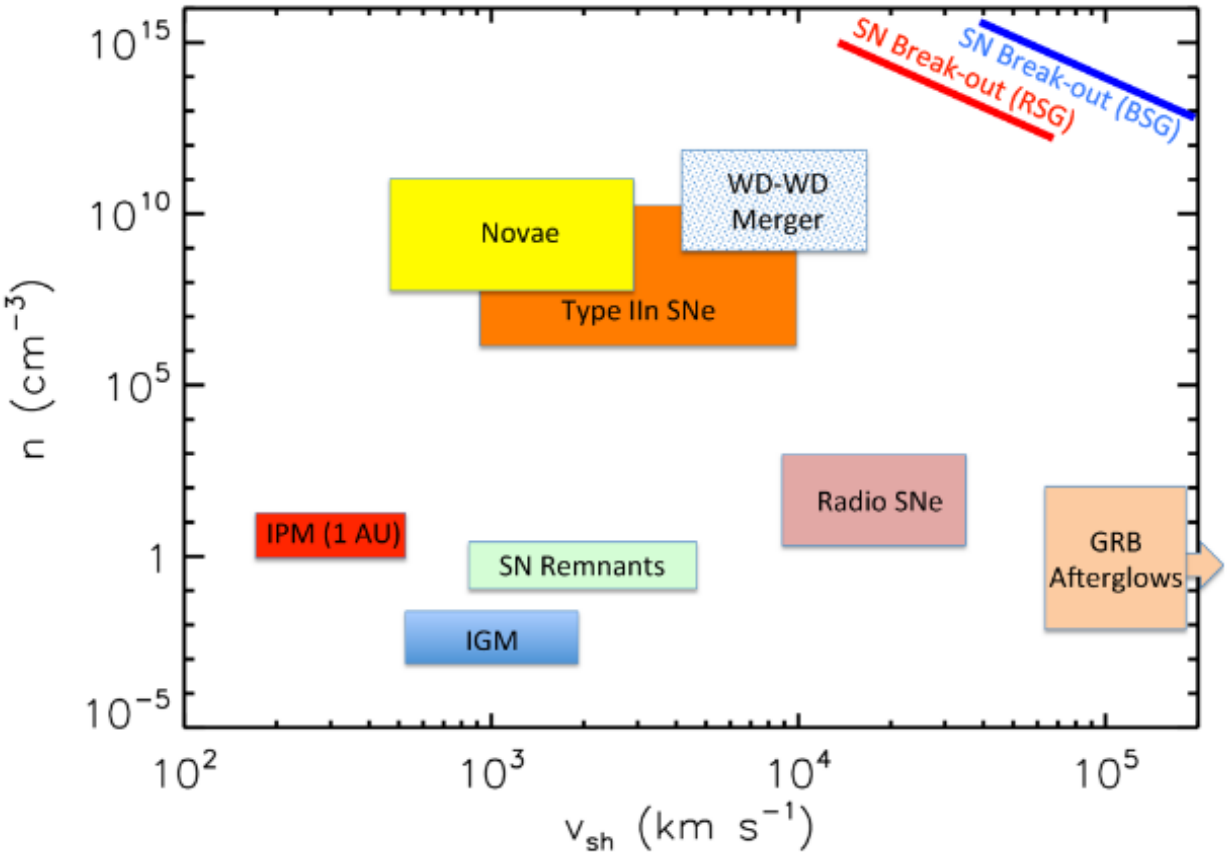
Single ejection vs multiple ejections?





Shock parameter space

Metzger et al. (2016)



Novae as laboratory

High-Energy Neutrinos and Gamma-Rays from Non-Relativistic Shock-Powered Transients

Ke Fang,[1,2] Brian D. Metzger,[3,4] Indrek Vurm,[5] Elias Aydi,[6] Laura Chomiuk,[6]

[1] *Kavli Institute for Particle Astrophysics and Cosmology (KIPAC), Stanford University, Stanford, CA 94305, USA*
[2] *NHFP Einstein Fellow*
[3] *Department of Physics and Columbia Astrophysics Laboratory, Columbia University, Pupin Hall, New York, NY 10027, USA*
[4] *Center for Computational Astrophysics, Flatiron Institute, 162 5th Ave, New York, NY 10010, USA*
[5] *Tartu Observatory, Tartu University, 61602 Tõravere, Tartumaa, Estonia*
[6] *Center for Data Intensive and Time Domain Astronomy, Department of Physics and Astronomy, Michigan State University, East Lansing, MI, USA*

ABSTRACT

Shock interaction has been argued to play a role in powering a range of optical transients, including supernovae, classical novae, stellar mergers, tidal disruption events, and fast blue optical transients. These same shocks can accelerate relativistic ions, generating high-energy neutrino and gamma-ray emission via hadronic pion production. The recent discovery of time-correlated optical and gamma-ray emission in classical novae has revealed the important role of radiative shocks in powering these events, enabling an unprecedented view of the properties of ion acceleration, including its efficiency and energy spectrum, under similar physical conditions to shocks in extragalactic transients.

Here we introduce a model for connecting the radiated optical fluence of non-relativistic transients to their maximal neutrino and gamma-ray fluence. We apply this technique to a wide range of extra-galactic transient classes in order to place limits on their contributions to the cosmological high-energy gamma-ray and neutrino backgrounds. Based on a simple model for diffusive shock acceleration at radiative shocks, calibrated to novae, we demonstrate that several of the most luminous transients can accelerate protons up to 10^{16} eV, sufficient to contribute to the IceCube astrophysical background. Furthermore, several of the considered sources—particularly hydrogen-poor supernovae—may serve as "gamma-ray- hidden" neutrino sources due to the high gamma-ray opacity of their ejecta, evading

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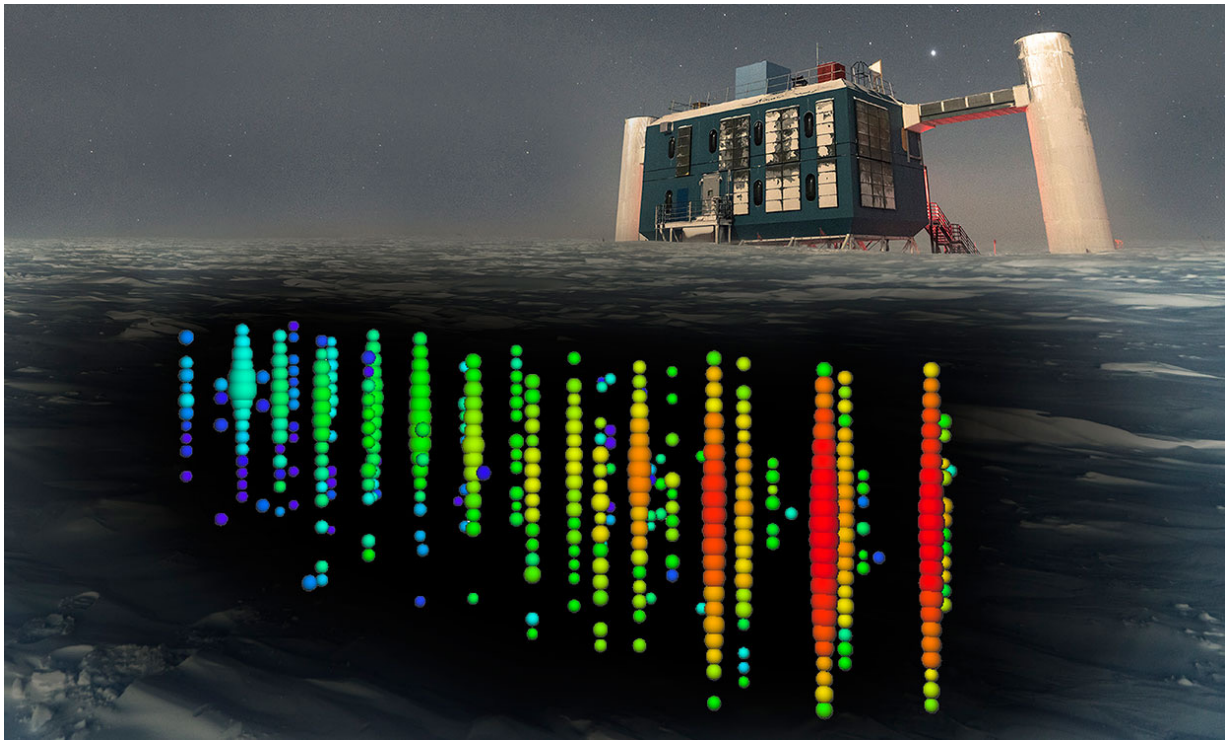
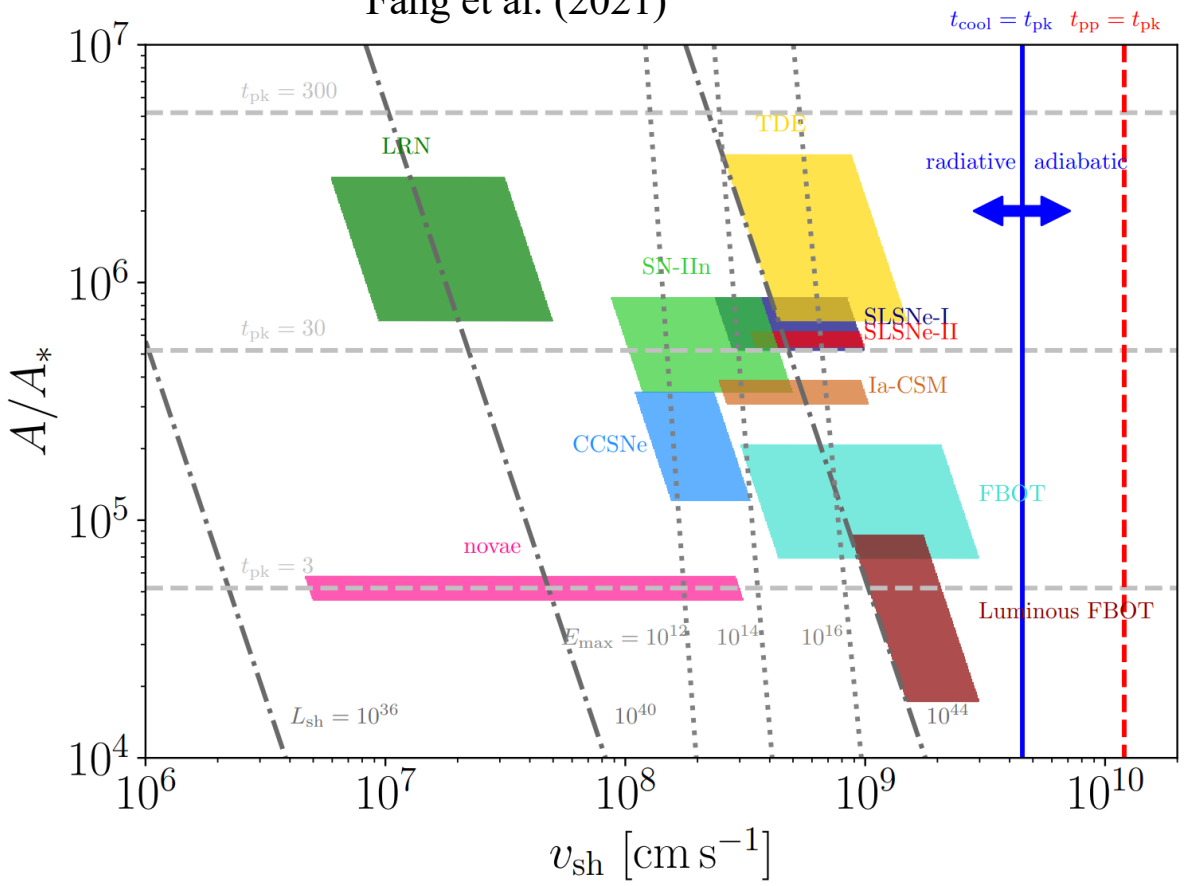
Novae as laboratory

Cosmic neutrino background?



Novae as laboratory

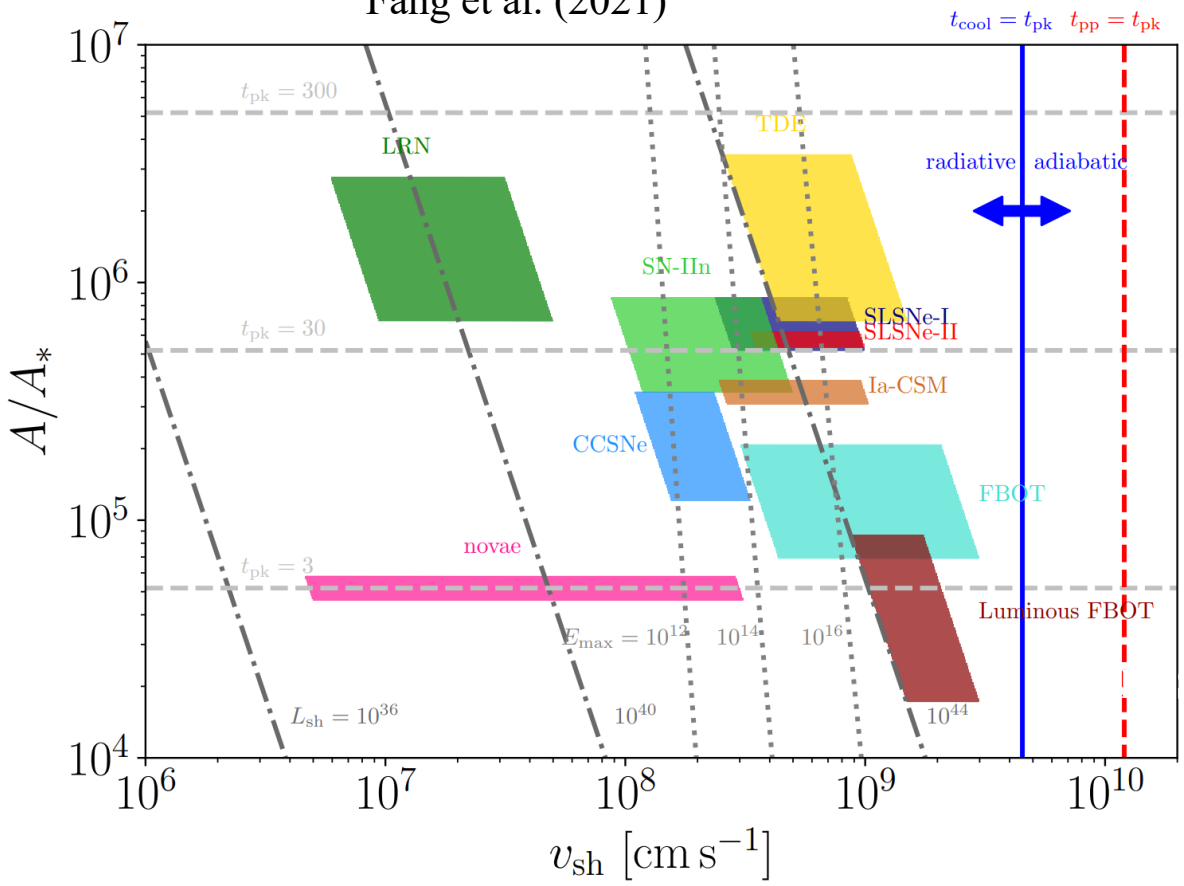
Fang et al. (2021)



Novae as laboratory

Contribute a few % of the total IceCube background

Fang et al. (2021)

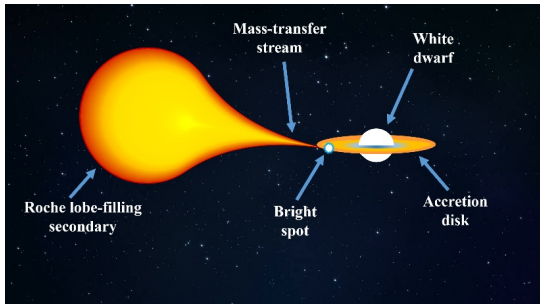


Novae as TeV sources

New insights into classical novae!!

- **Are novae potential multi-messenger sources?**
- **How novae expel their envelopes?**
  Novae can be used as miniature common envelope events.
- **What is the parameter space that determines the luminosity of shocks in stellar explosions?**
- **How is dust formed around novae and stellar explosions?**
  Any role for the shocks?

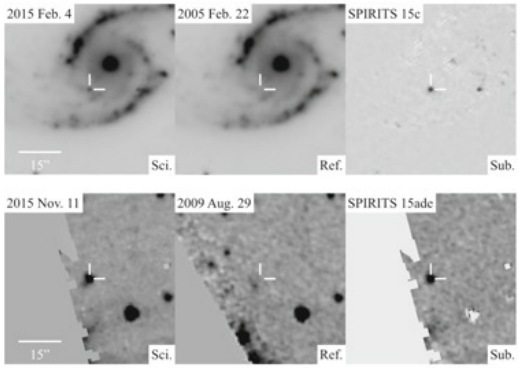
Laboratory to study shocks and dust formation



Type IIn SNe

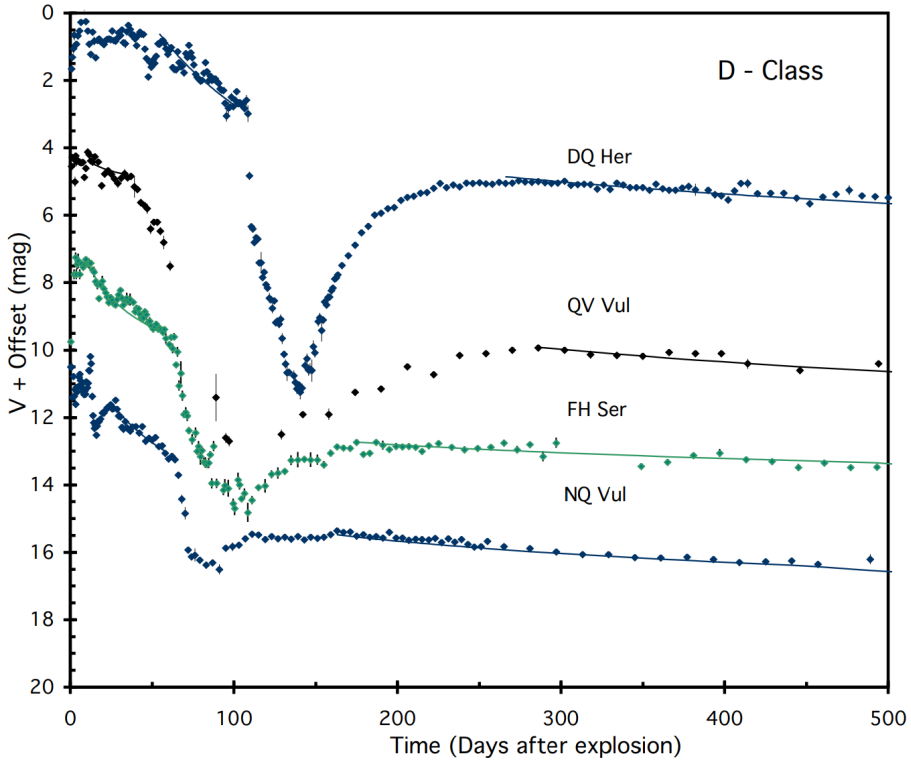
Stellar mergers

IR transients

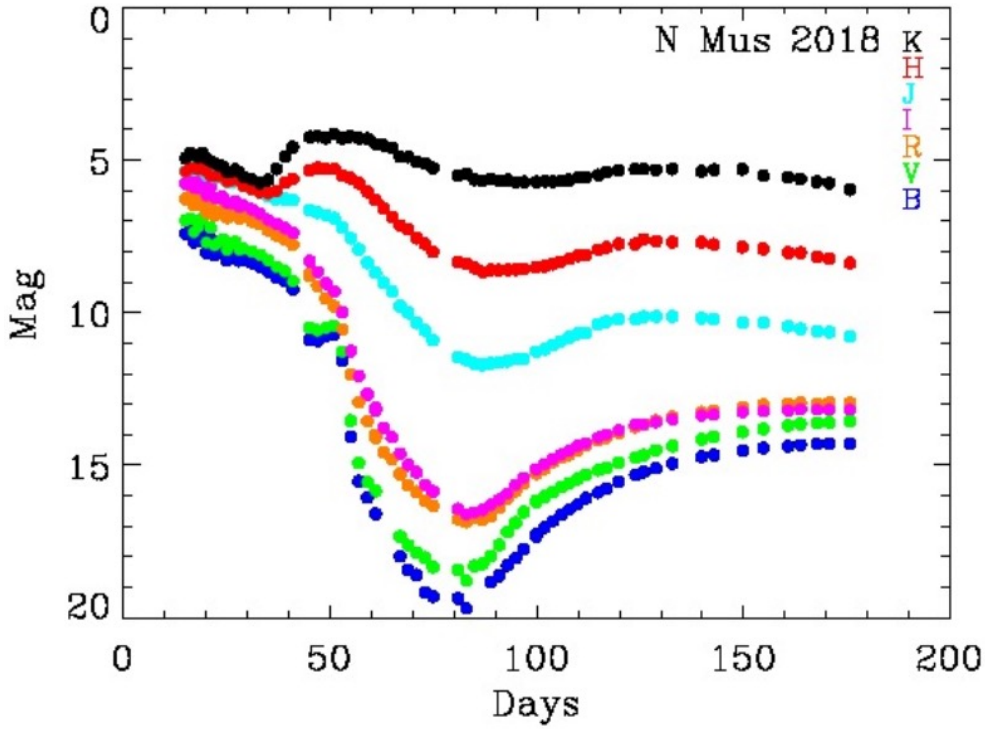


How and where dust forms?

Strope et al. (2010)



SMARTS Consortium (Walter 2012)



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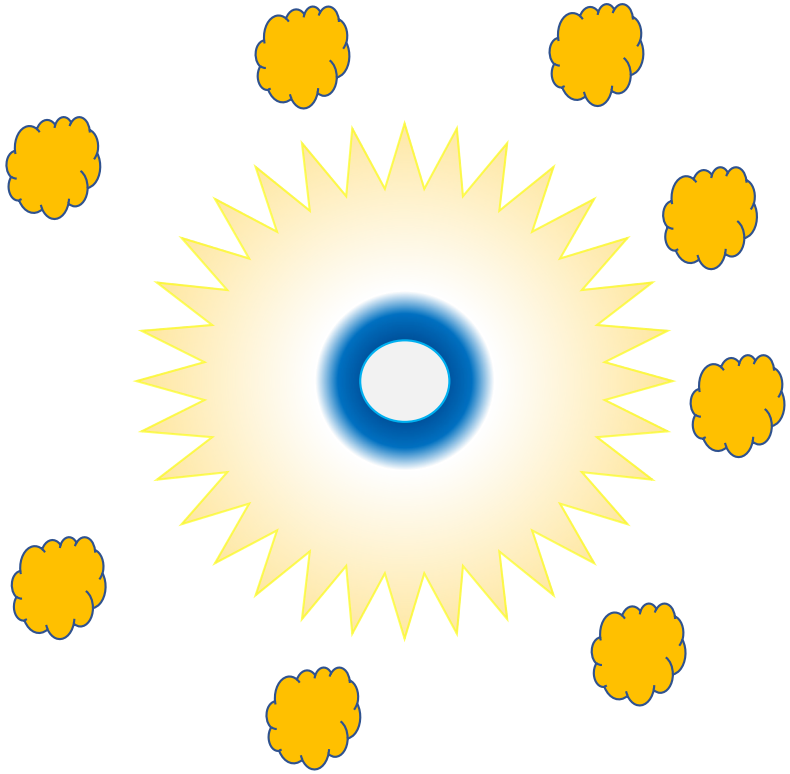
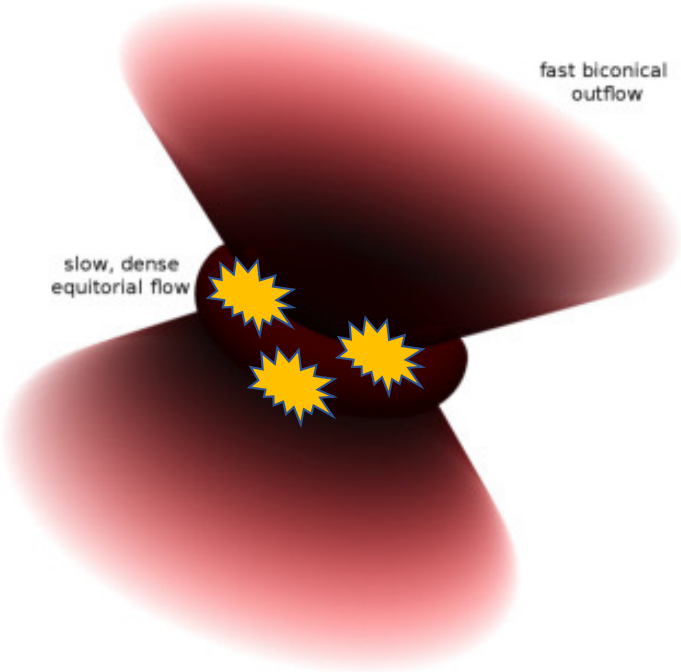


Derdzinski et al. (2017)



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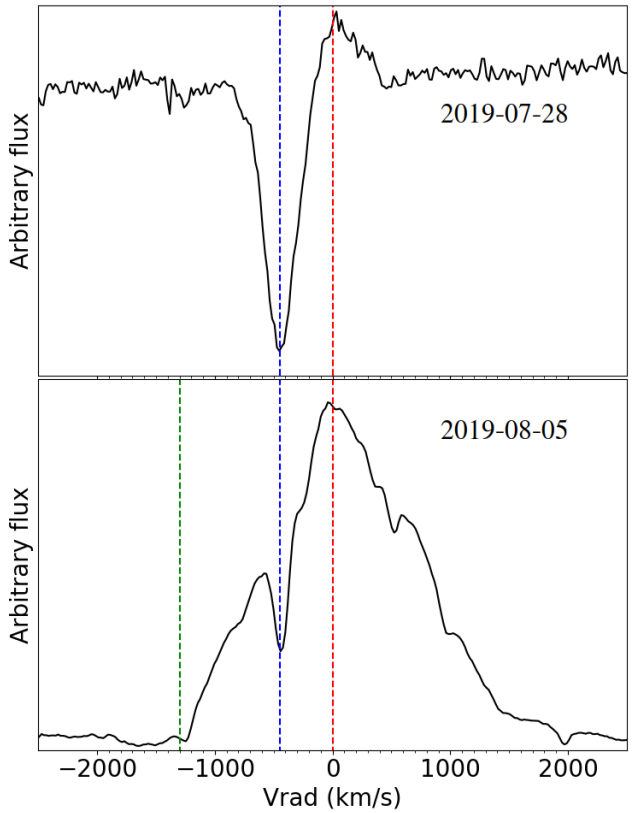

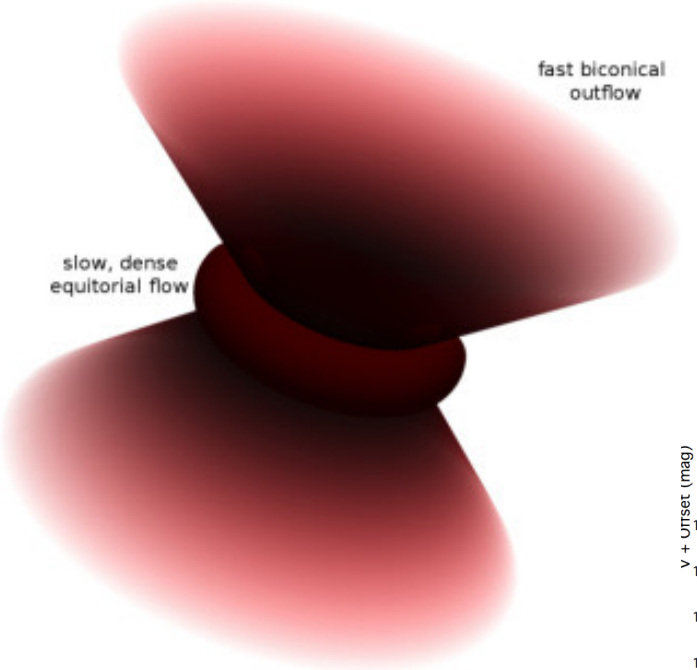

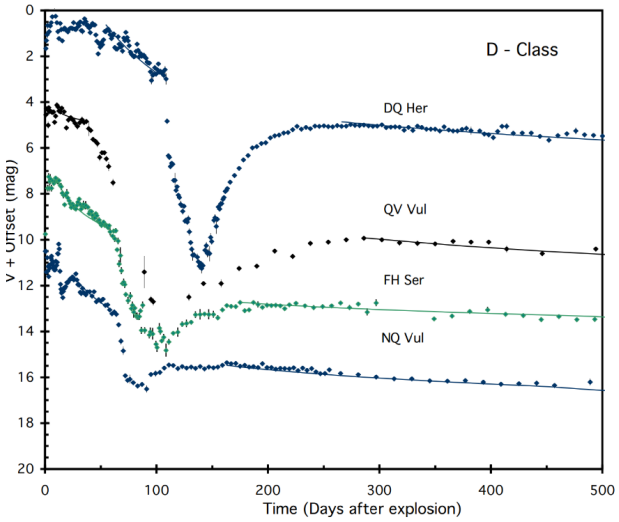

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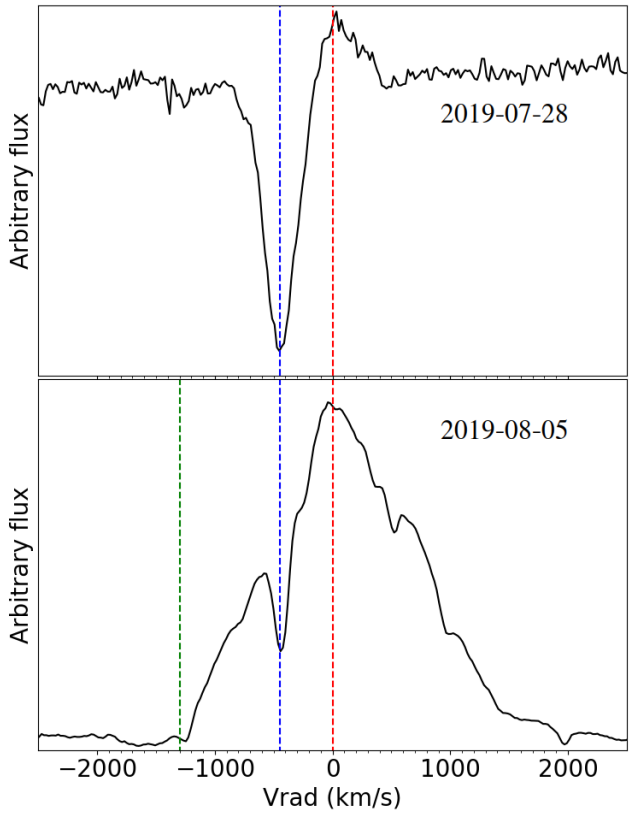
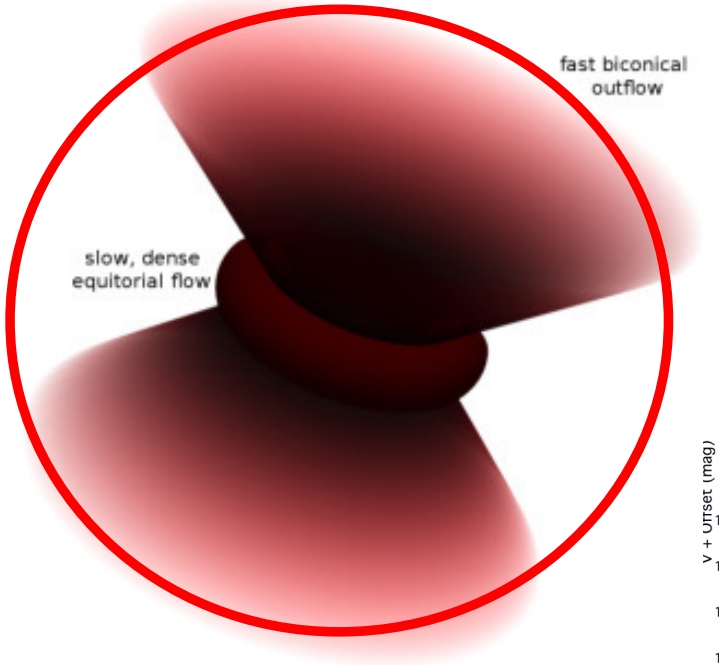
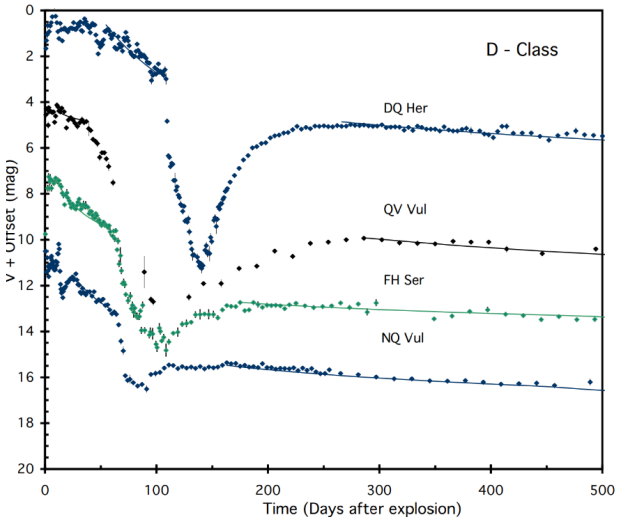
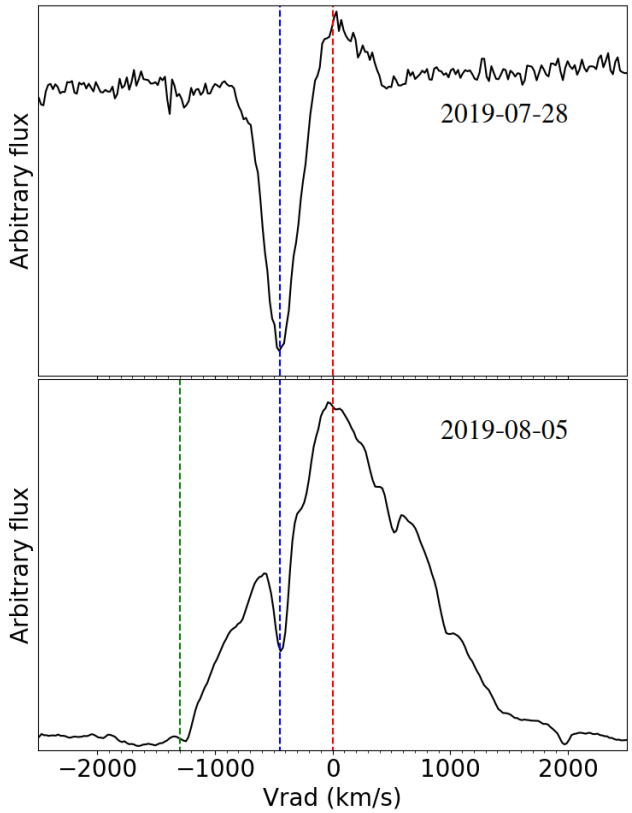
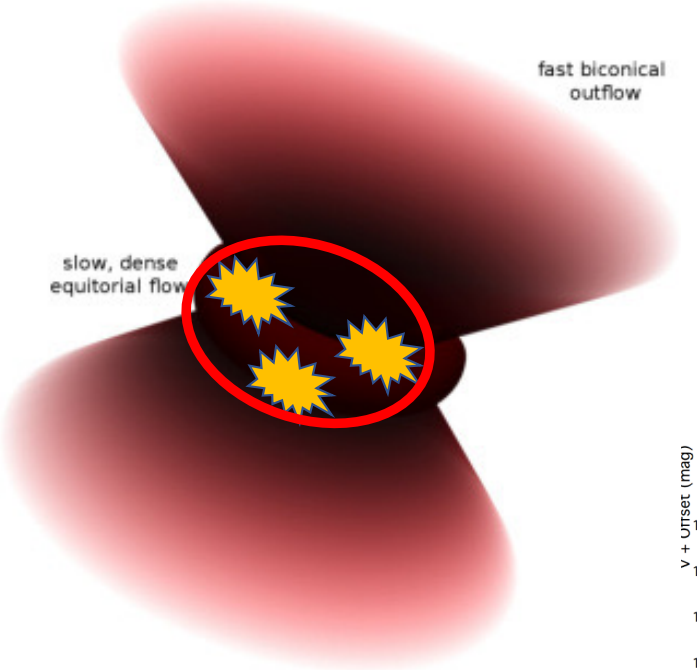


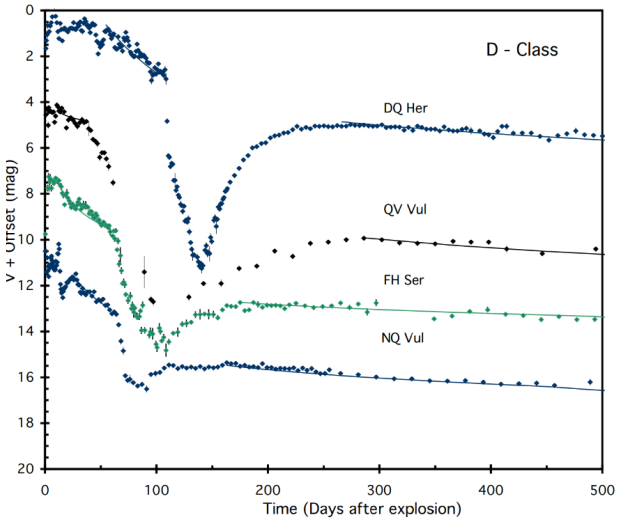




How and where dust forms?

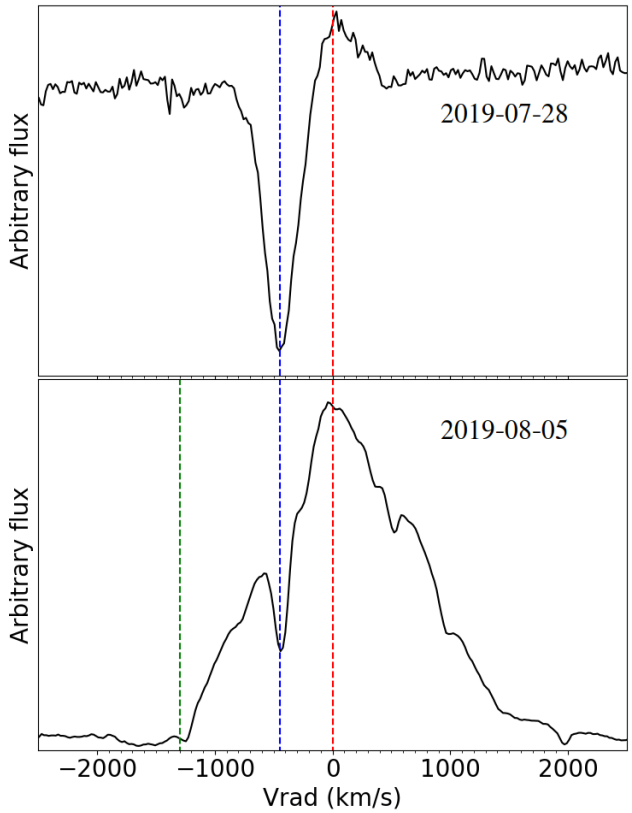


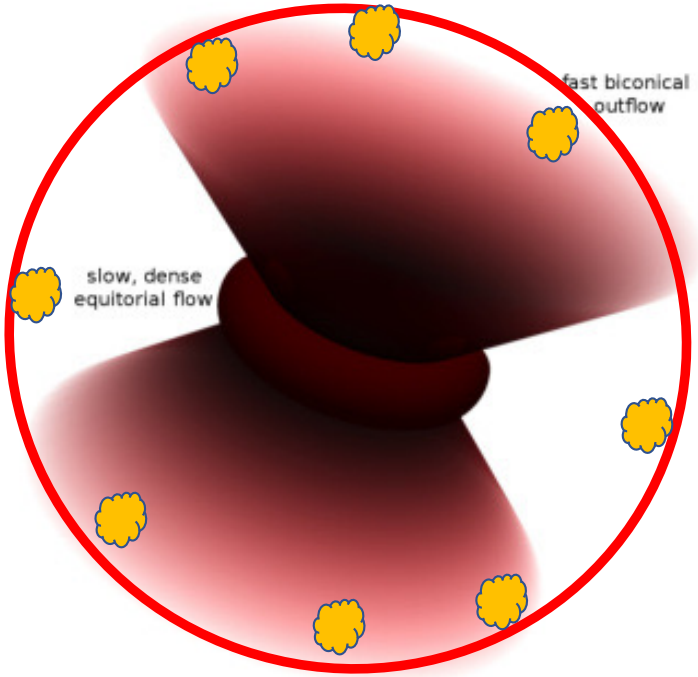


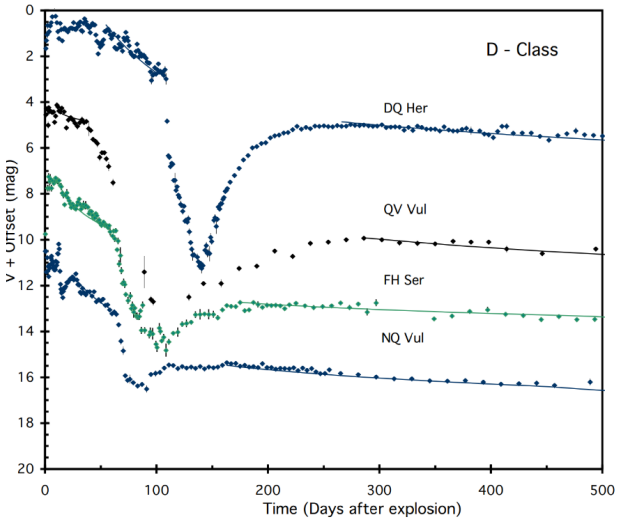


E. Aydi - MSU

How and where dust forms?

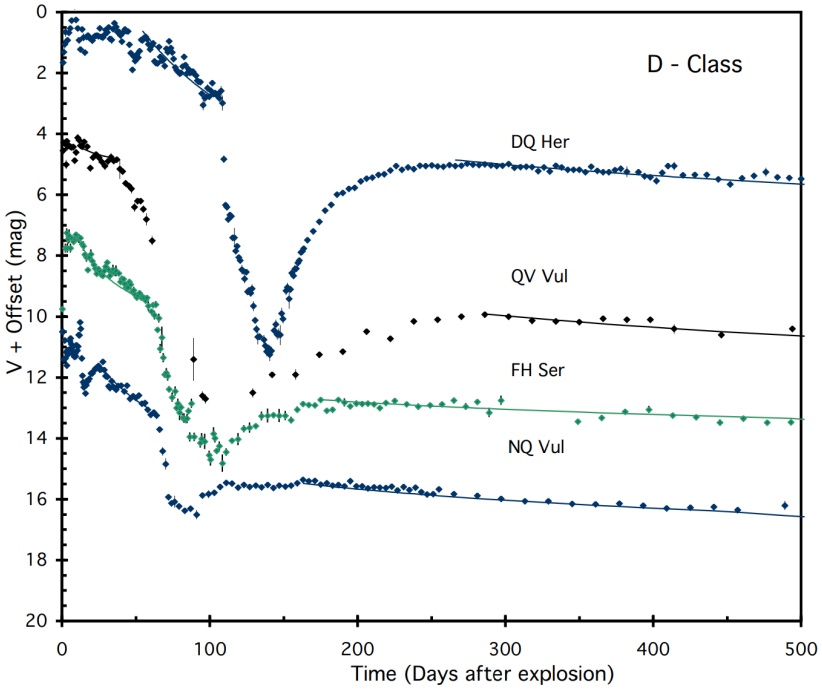


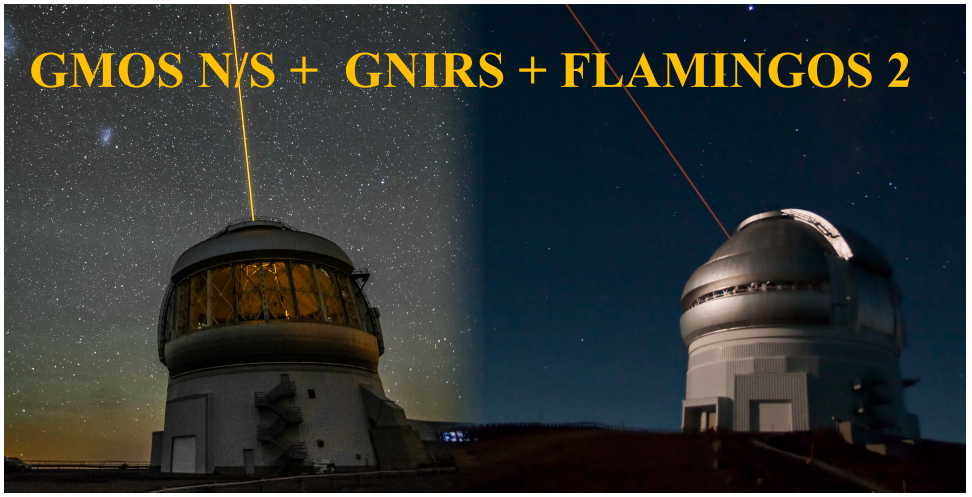




How and where dust forms?

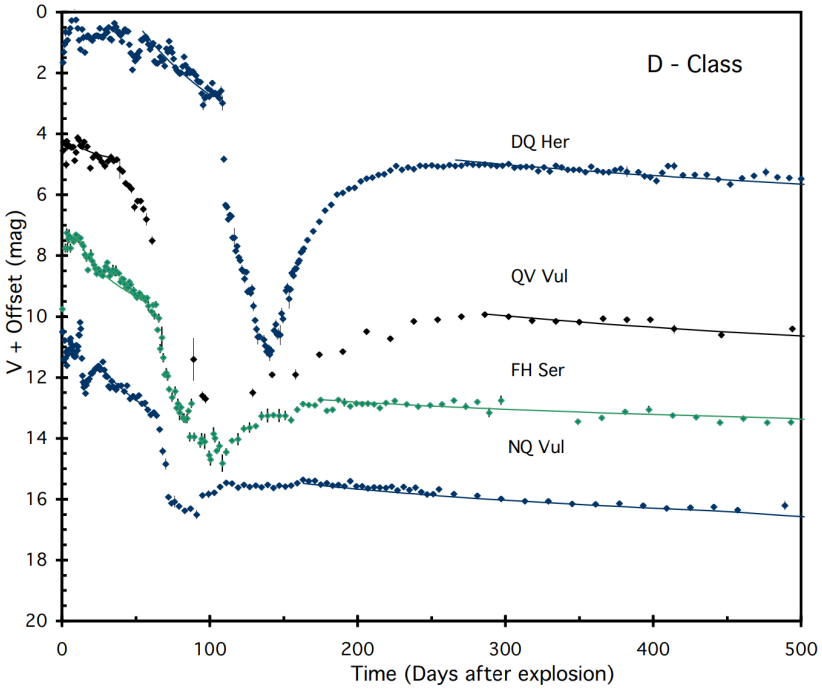
Strope et al. (2010)

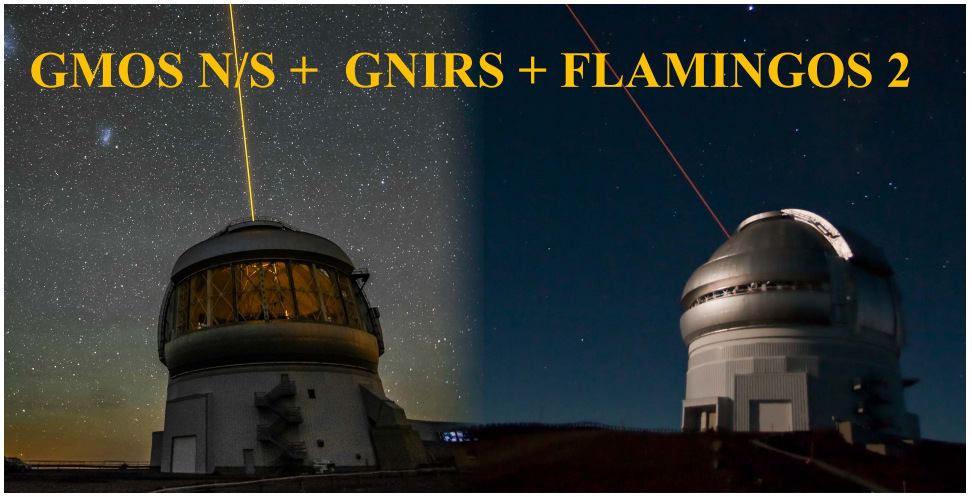


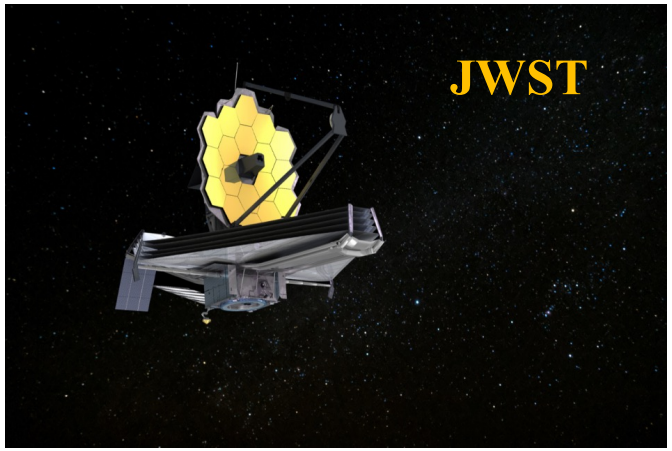


How and where dust forms?

Strope et al. (2010)



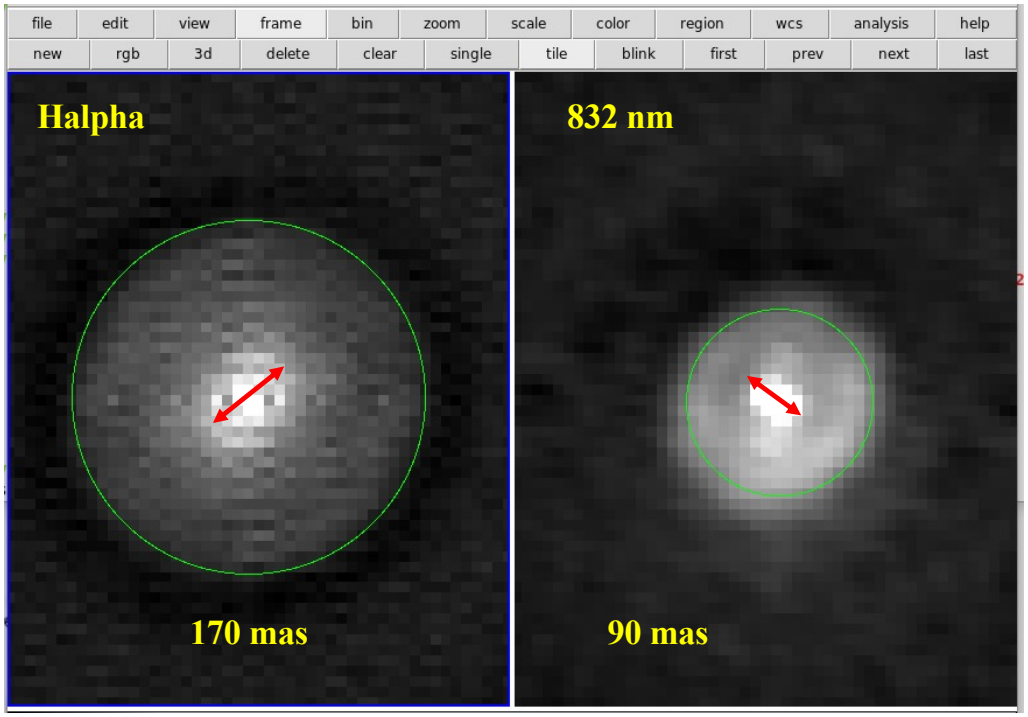




How and where dust forms?

Nova V906 Car ≈ 2 years after eruption with Zorro

Preliminary results:
Thanks to Ricardo Salinas
And Eliott Horch



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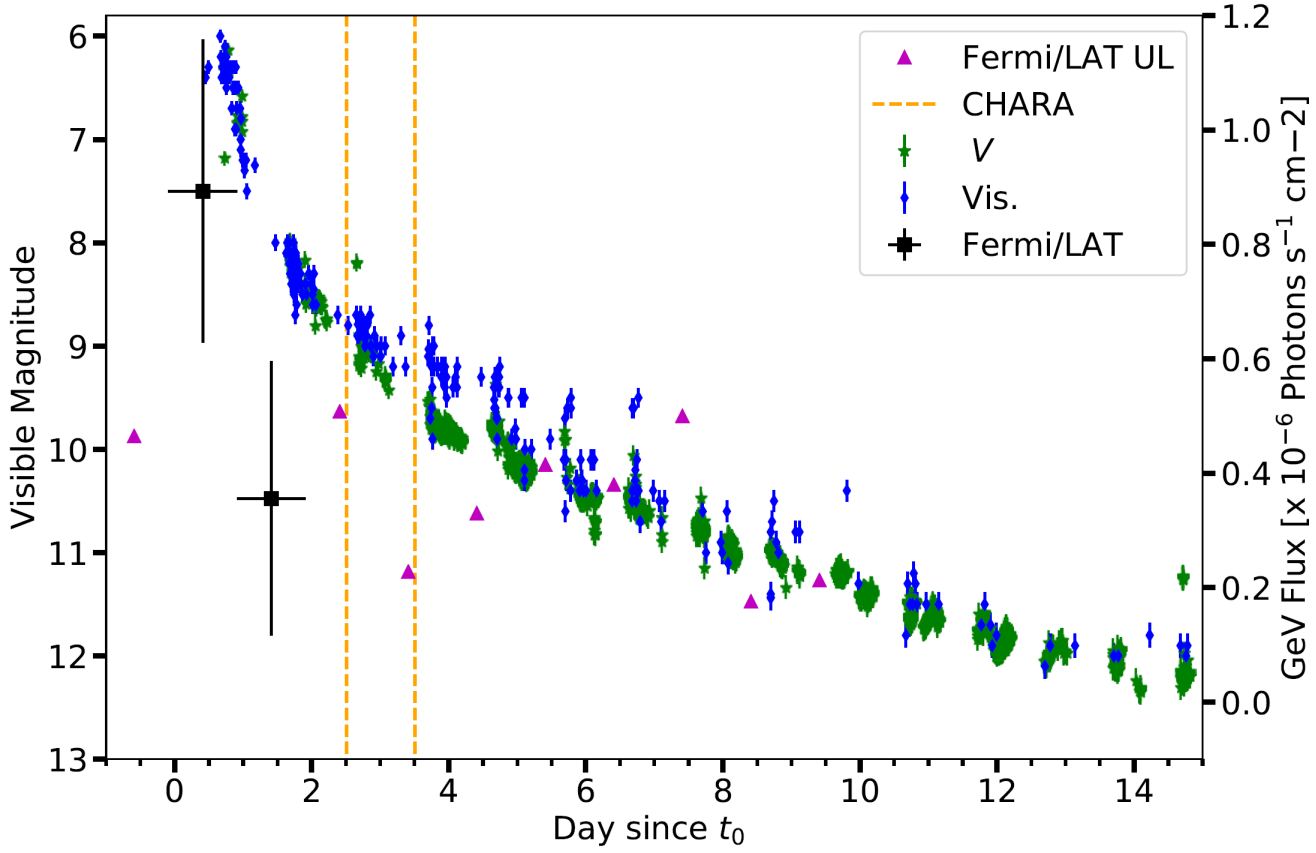
Nova V1674 Her - Discovered on June 12, 2021

Aydi et al. in perp.



Joint Fermi, NOIRLab, NOAO project
PI: Aydi

E. Aydi

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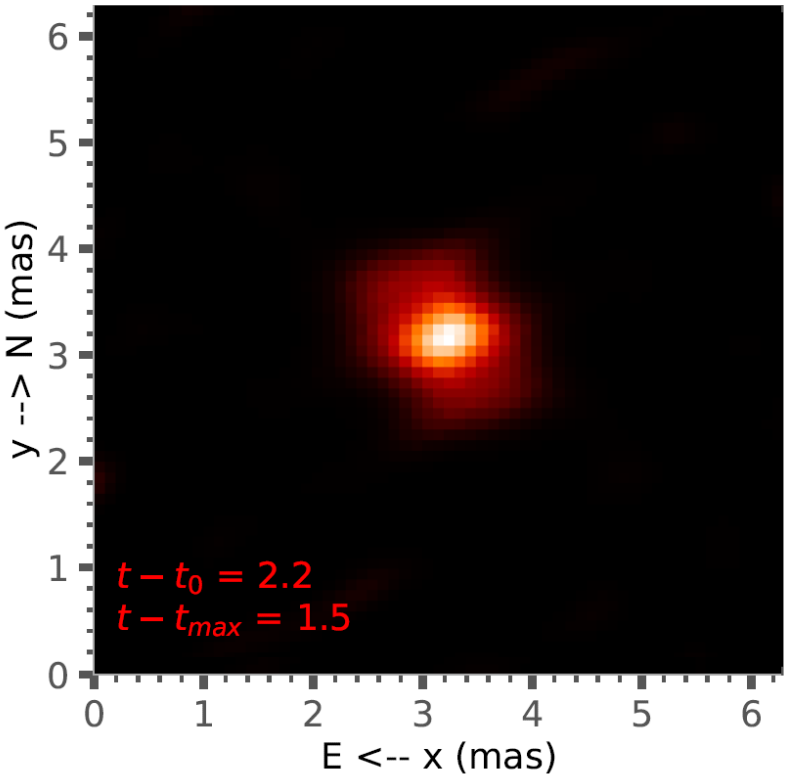

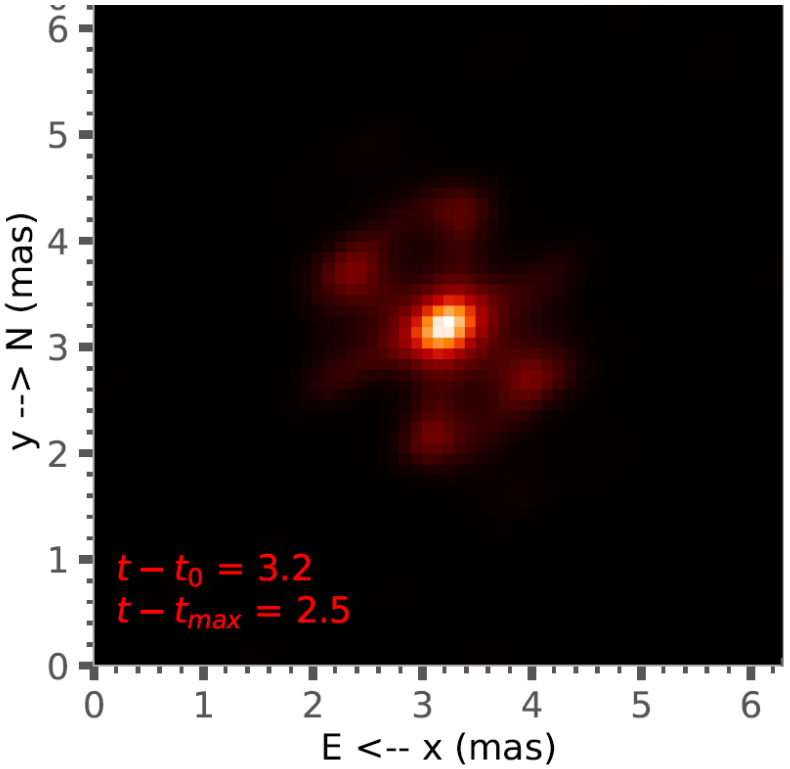

Aydi et al. in perp.

Thanks to Gail Schaefer and John Monier

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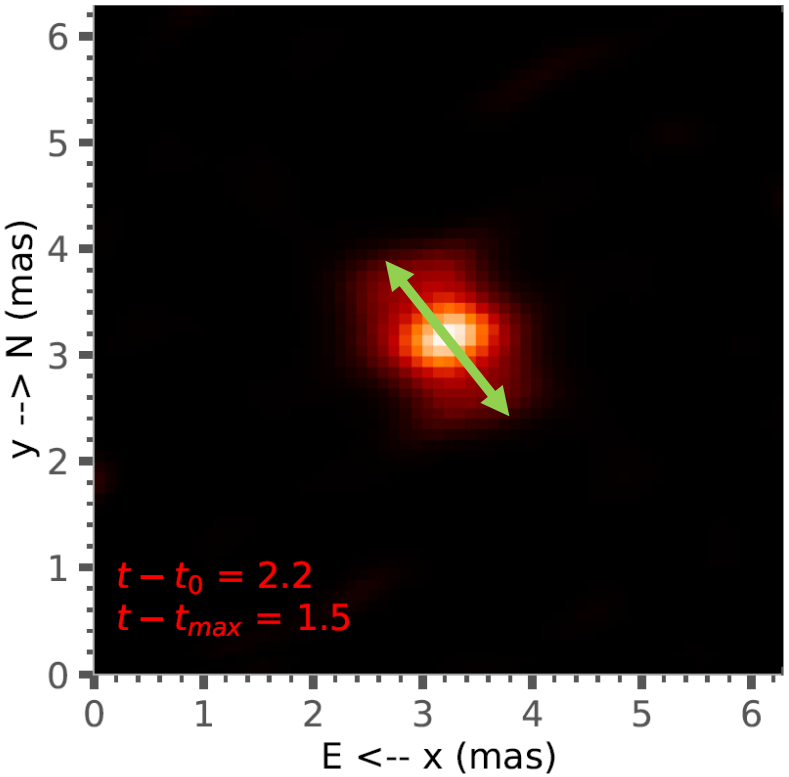

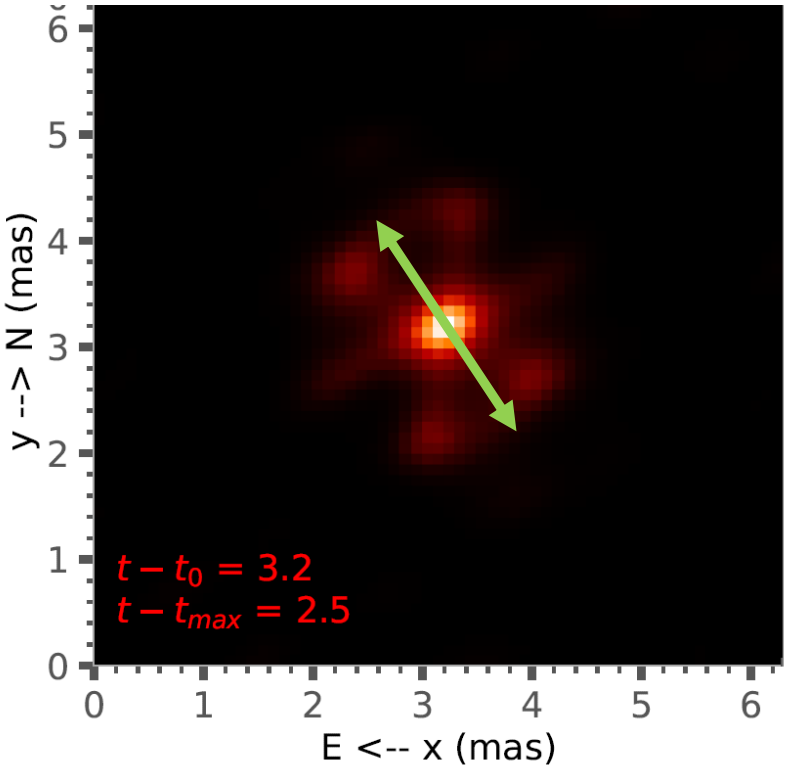

Aydi et al. in perp.

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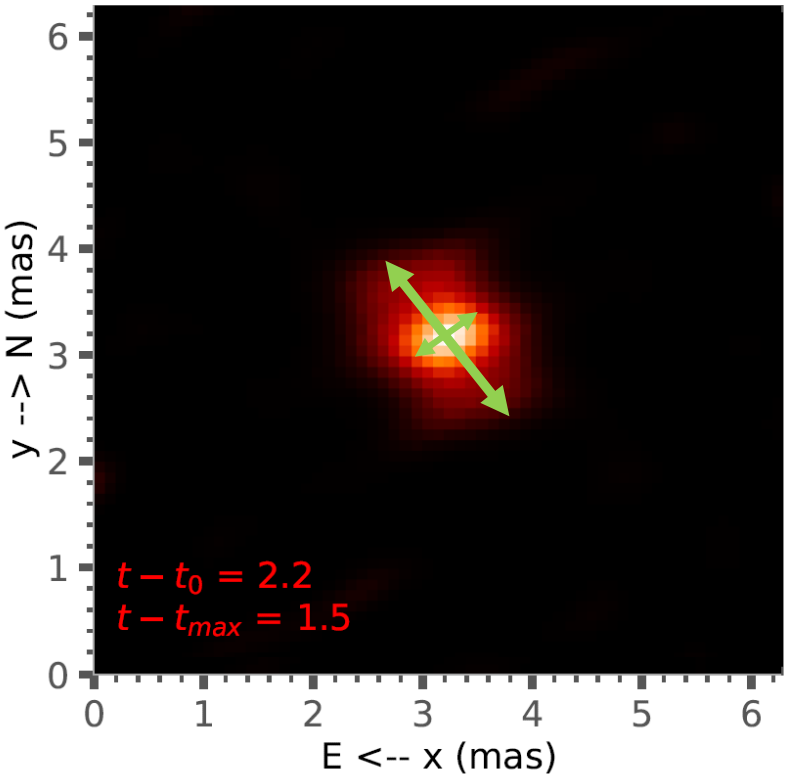
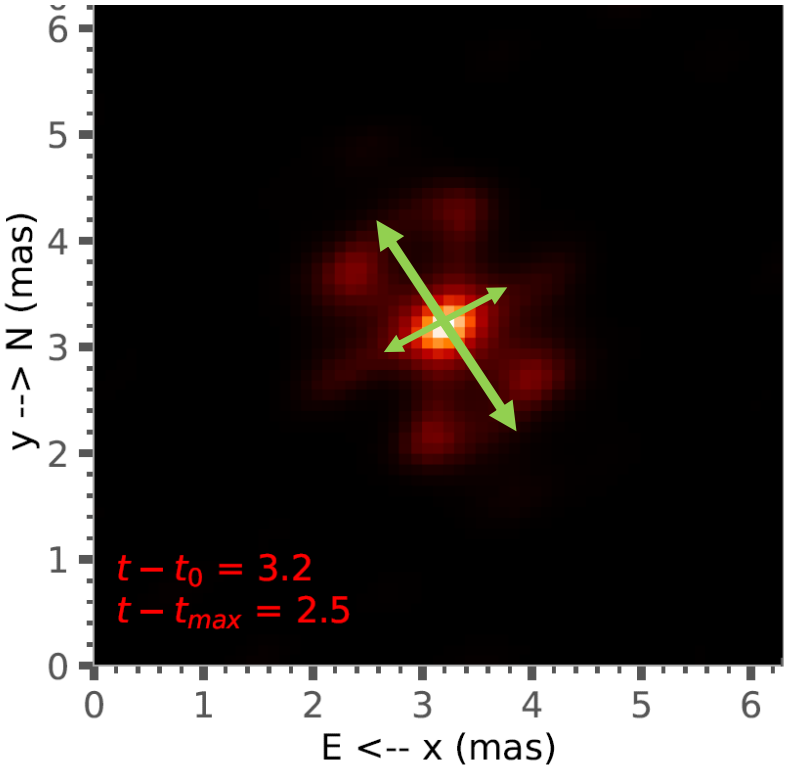
Imaging with CHARA





Aydi et al. in perp.

Thanks to Gail Schaefer and John Monnier

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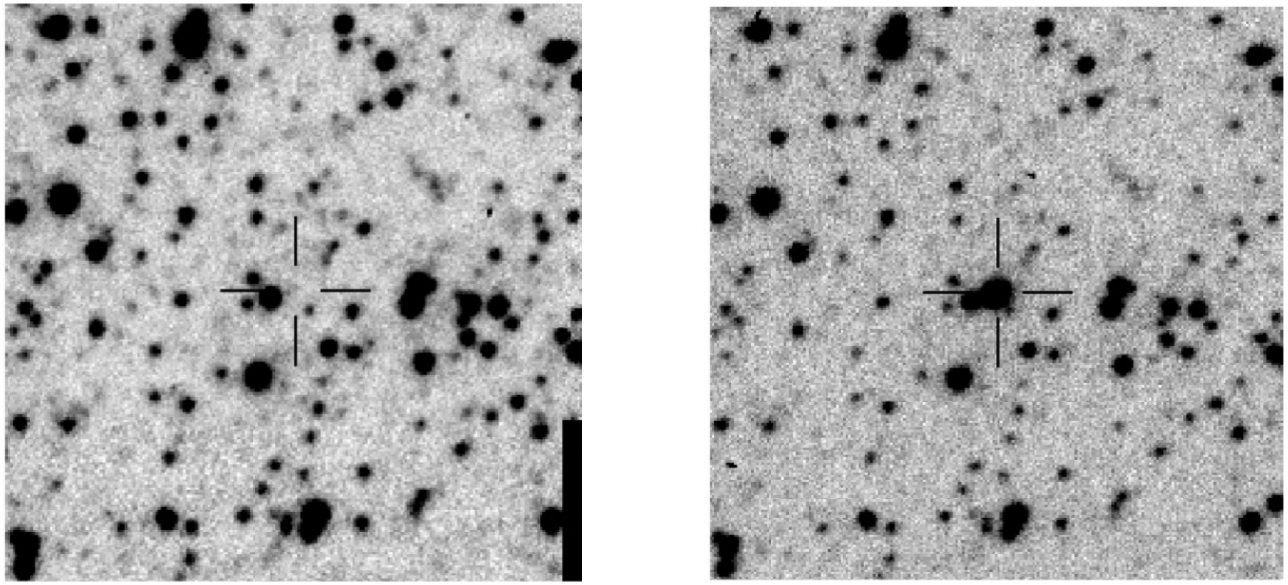
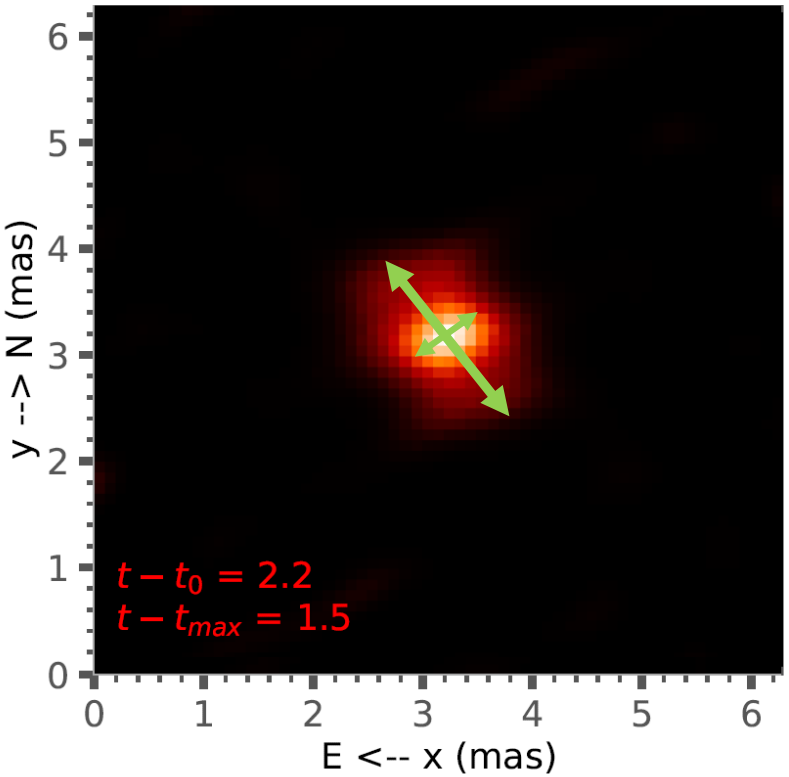
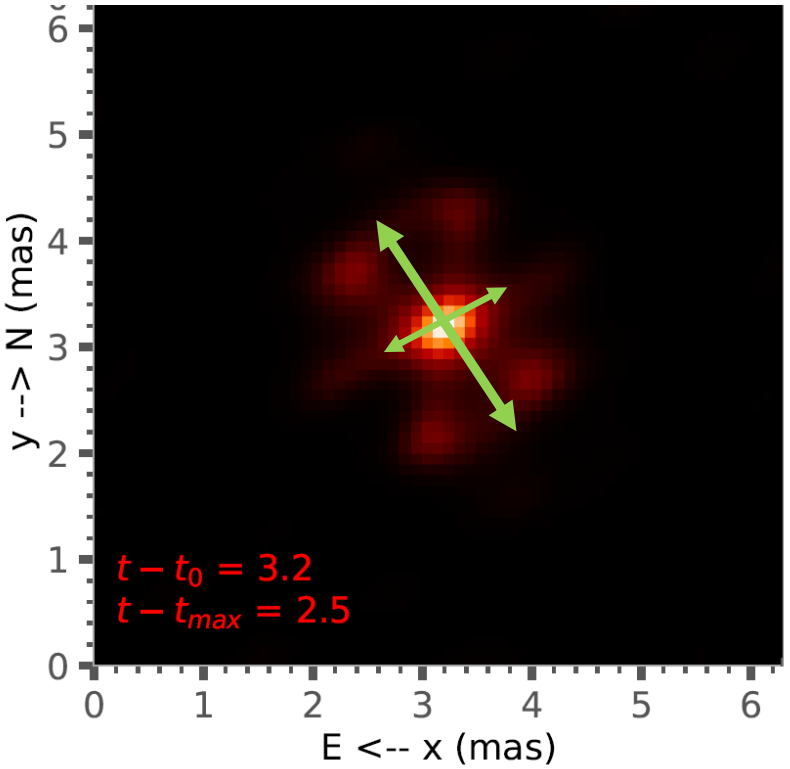


Nova V5852 Sgr Aydi et al. (2016)

Imaging with CHARA

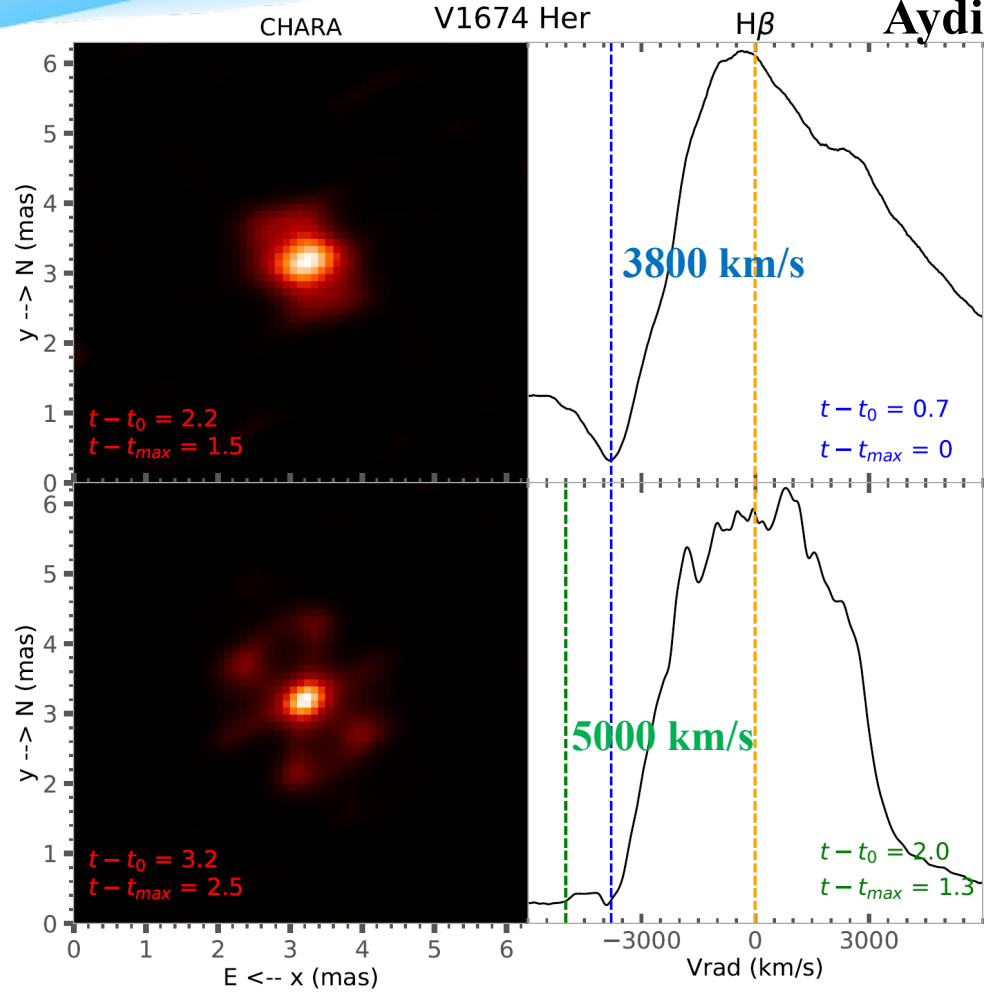




Aydi et al. in perp.

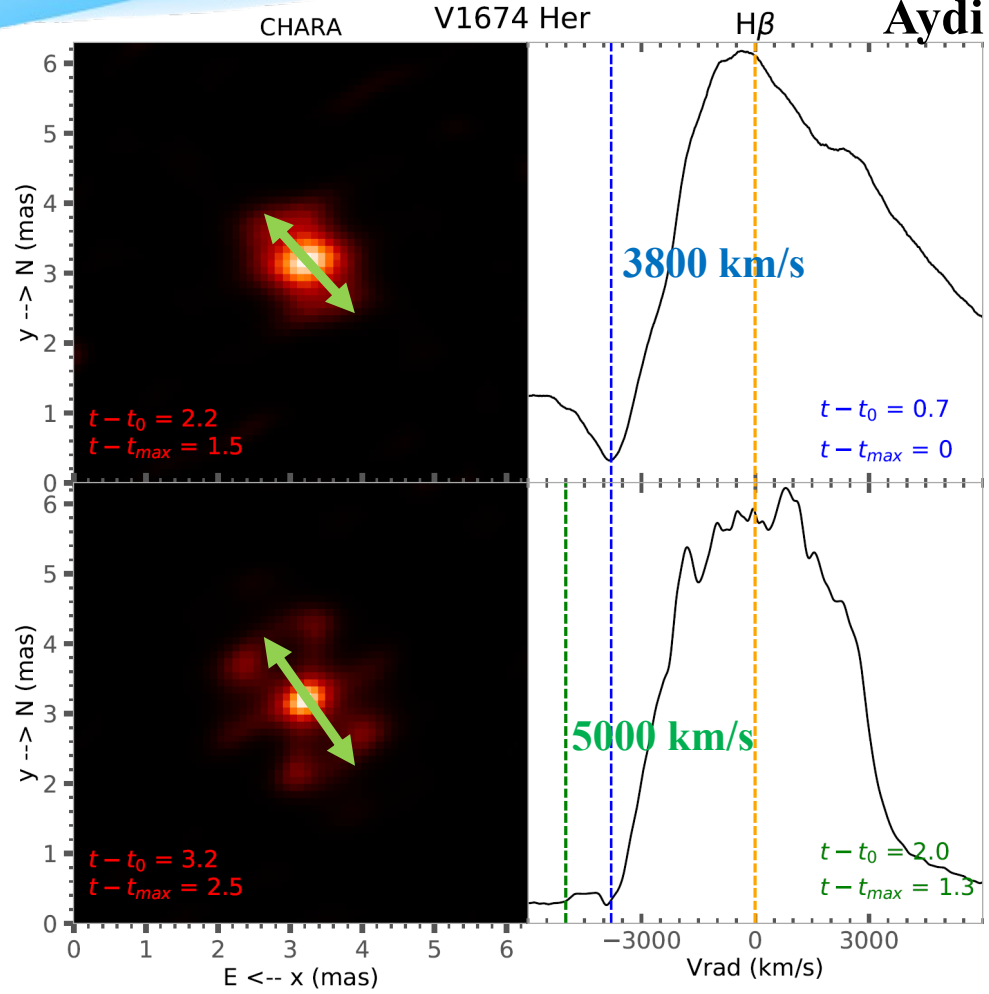
Thanks to Gail Schaefer and John Monnier

Imaging with CHARA



Aydi et al. in perp.

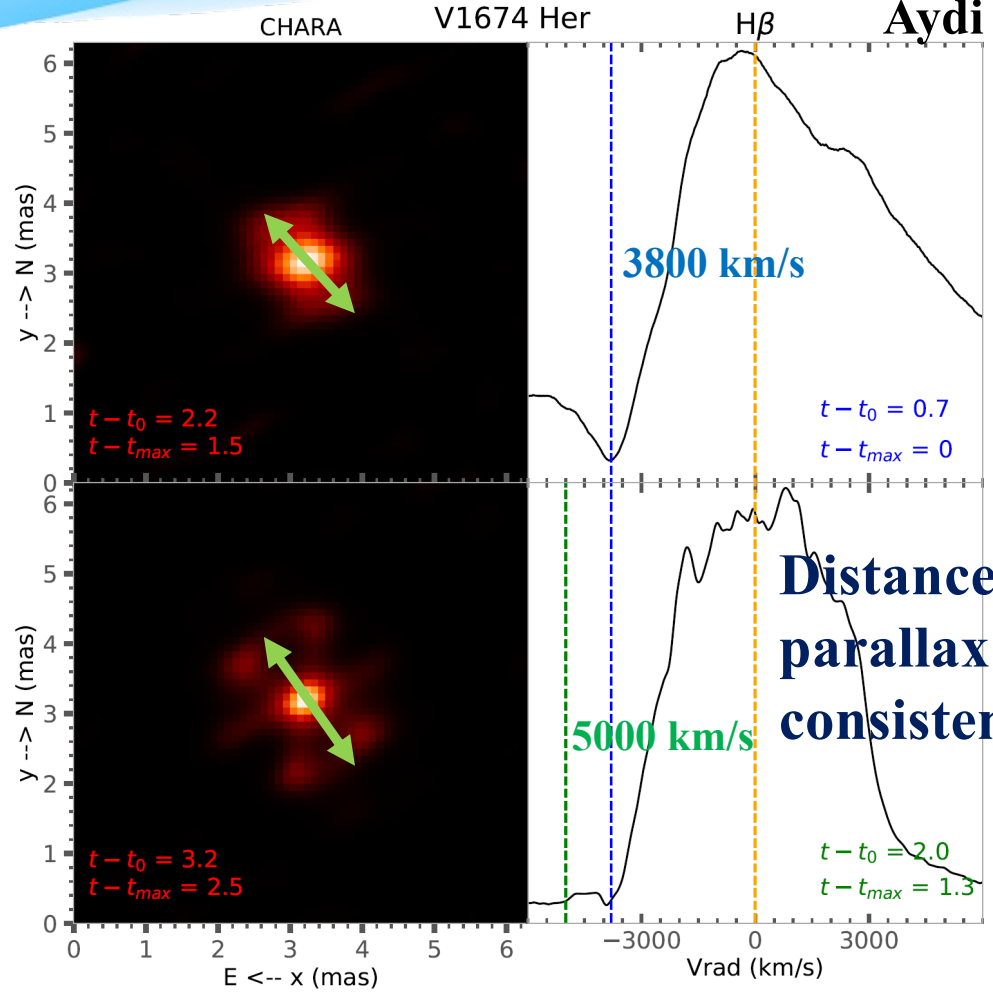
Imaging with CHARA



Aydi et al. in perp.

Imaging with CHARA

Aydi et al. in perp.



Distance from expansion parallax is around 5-6 kpc, consistent with other methods.

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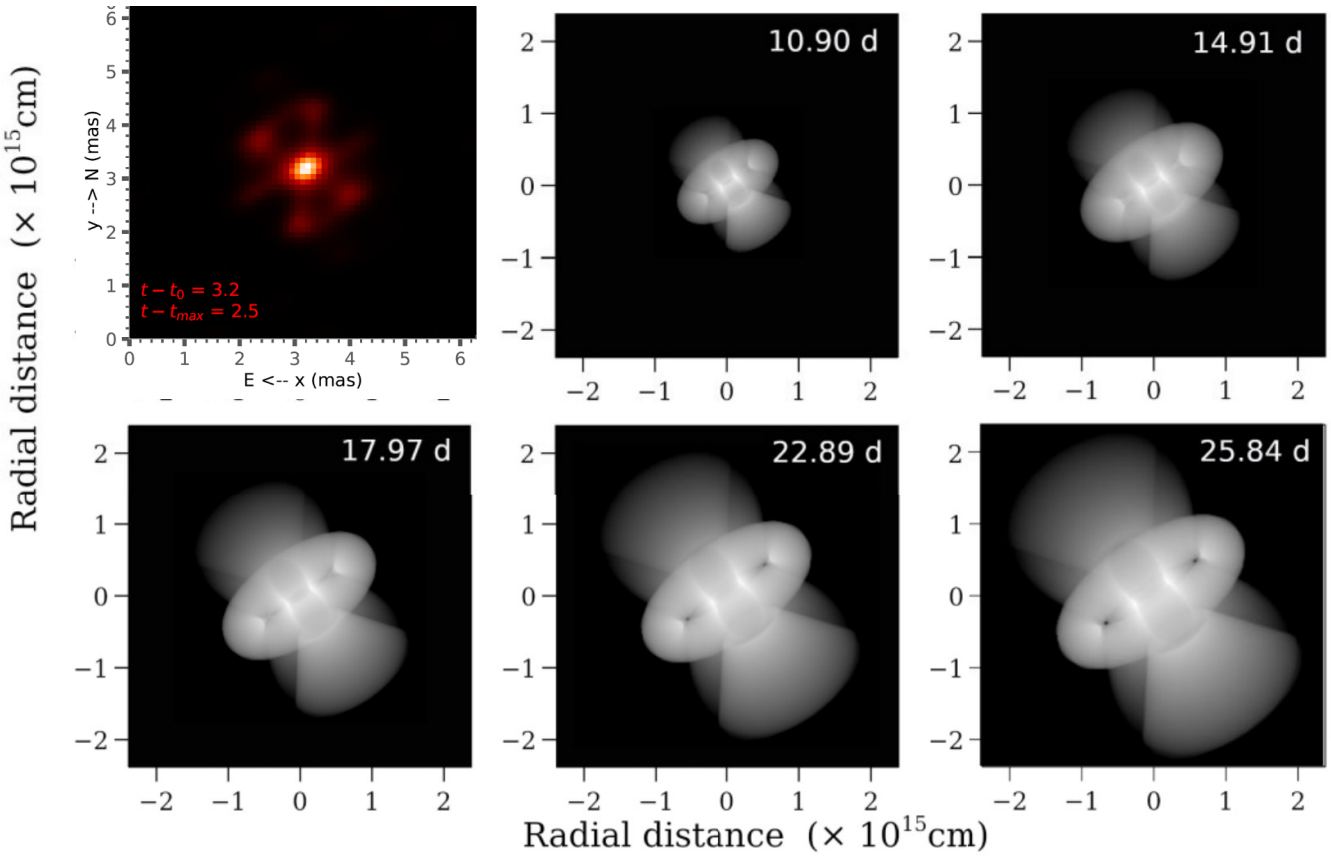
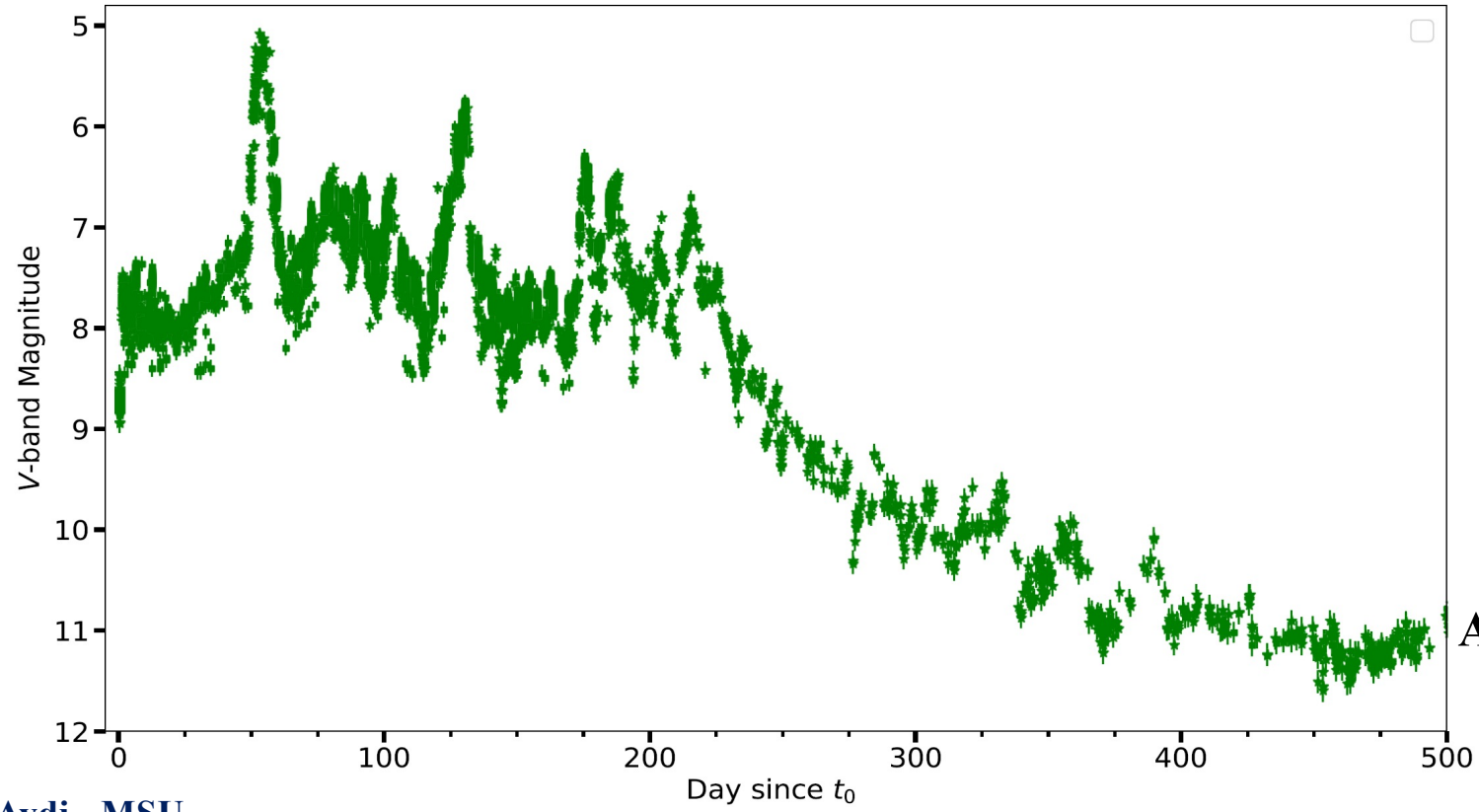
Habtie et al. (2024, MNRAS 527, 1405)



Imaging with CHARA

Nova V1405 Cas- Discovered on March 18, 2021



Aydi et al. in perp.

Imaging with CHARA

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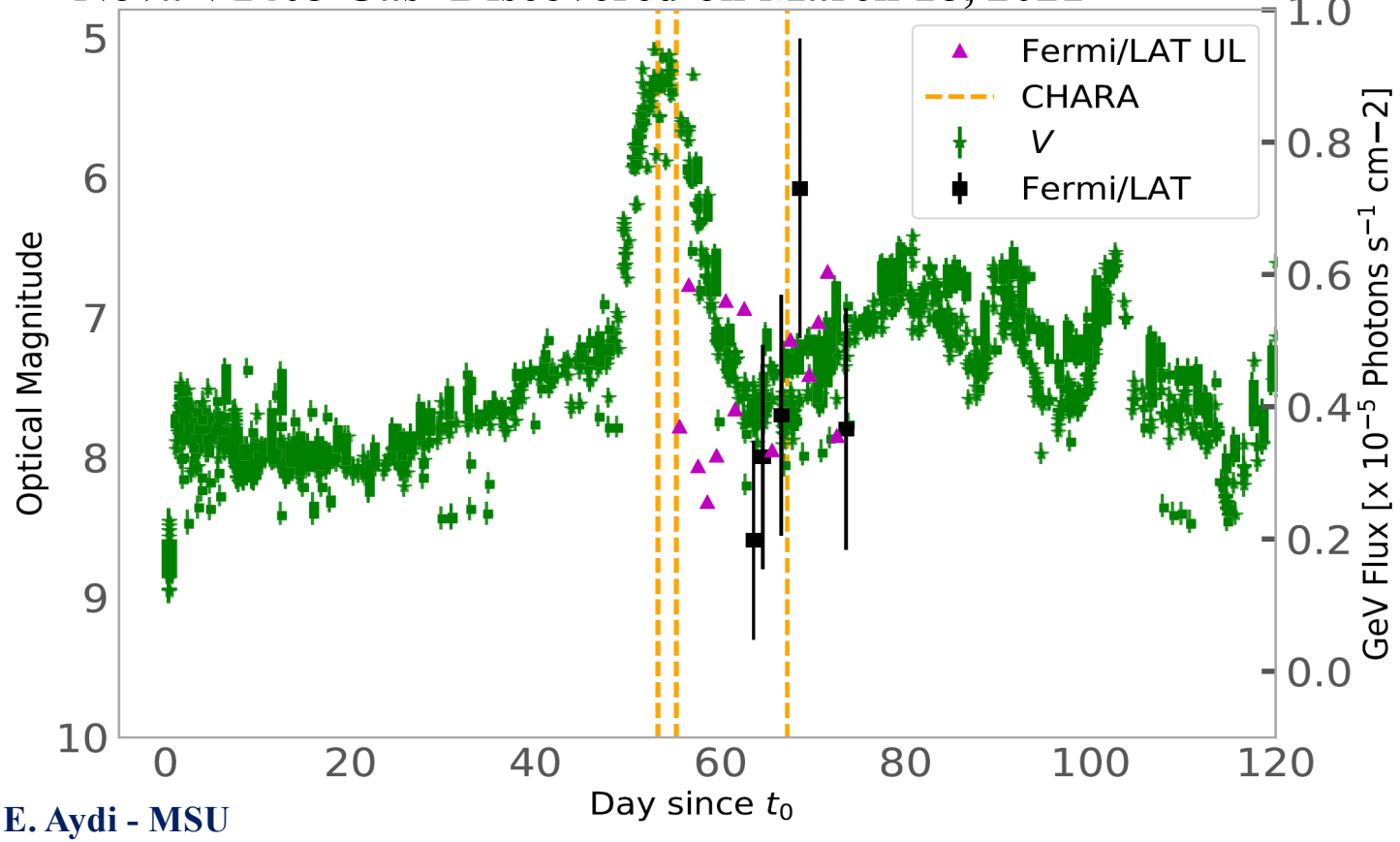

Aydi et al. in perp.

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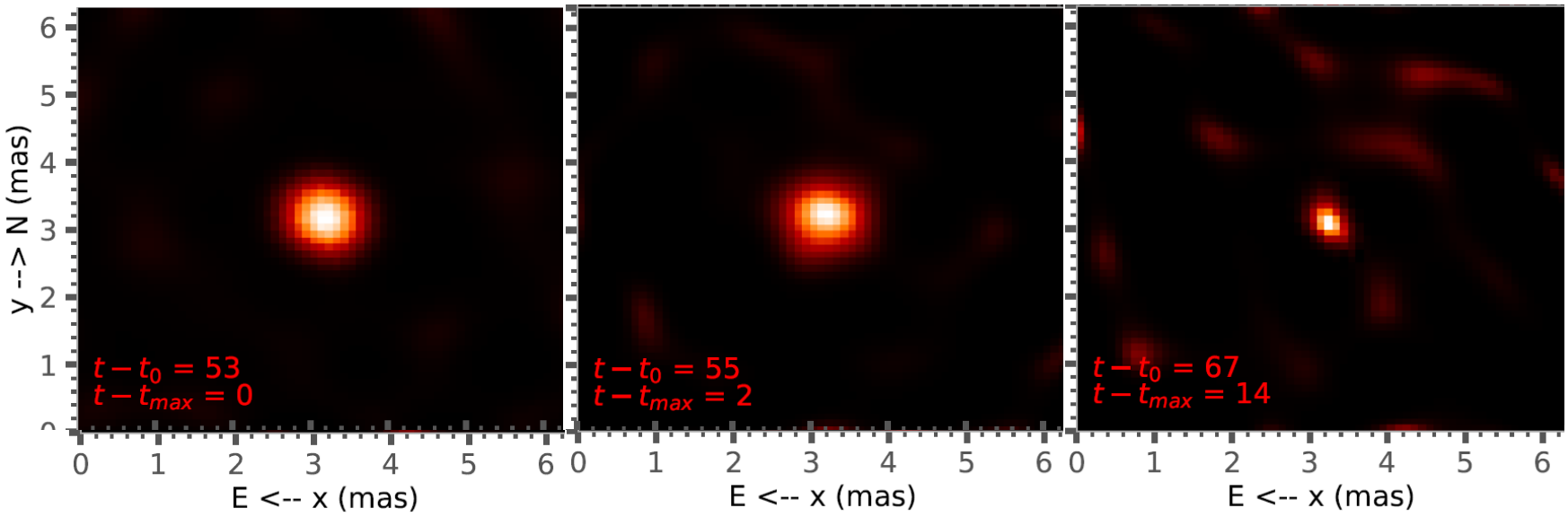
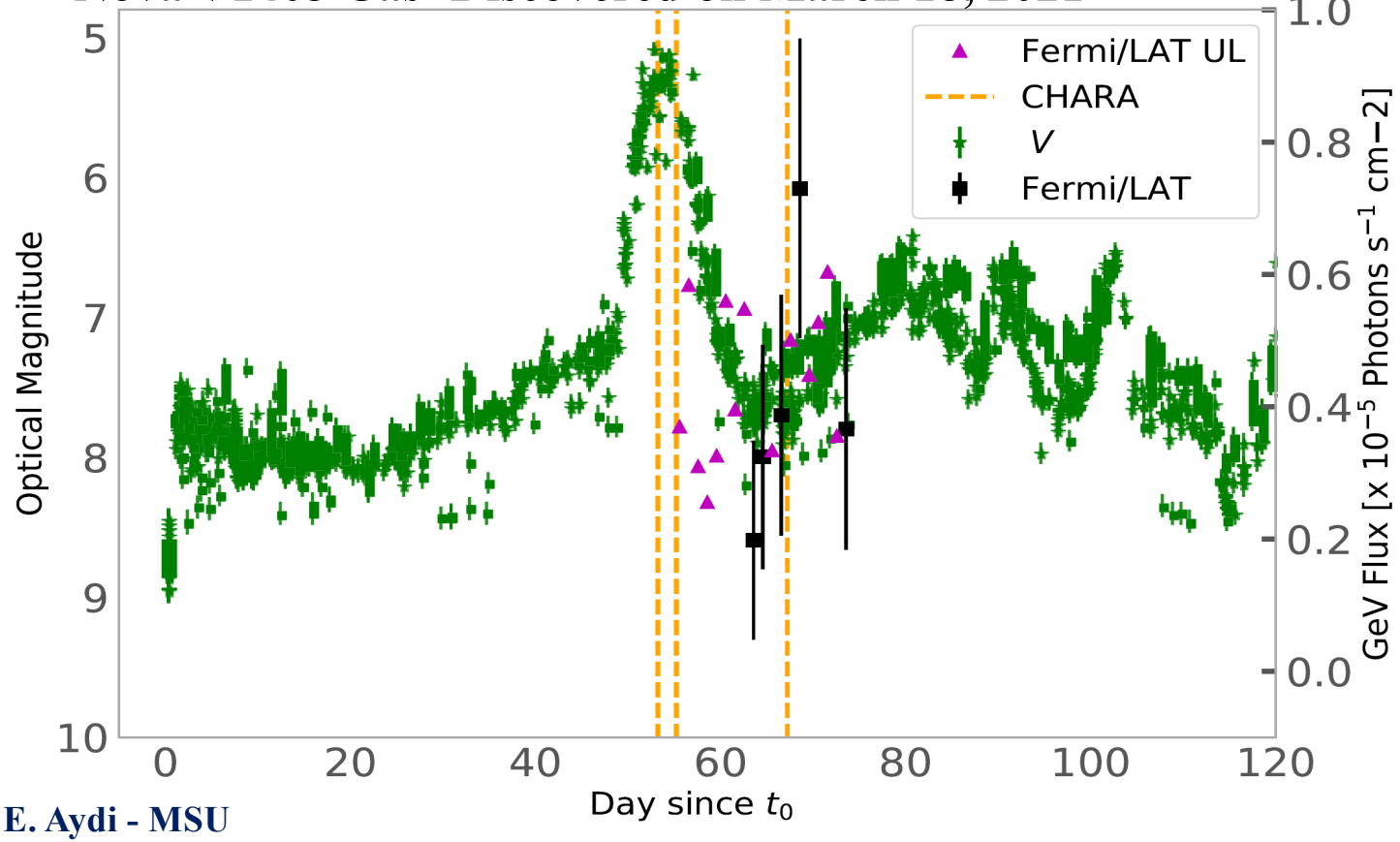


Aydi et al. in perp.

Thanks to Gail Schaefer and John Monnier

Imaging with CHARA

Nova V1405 Cas- Discovered on March 18, 2021



Aydi et al. in perp.

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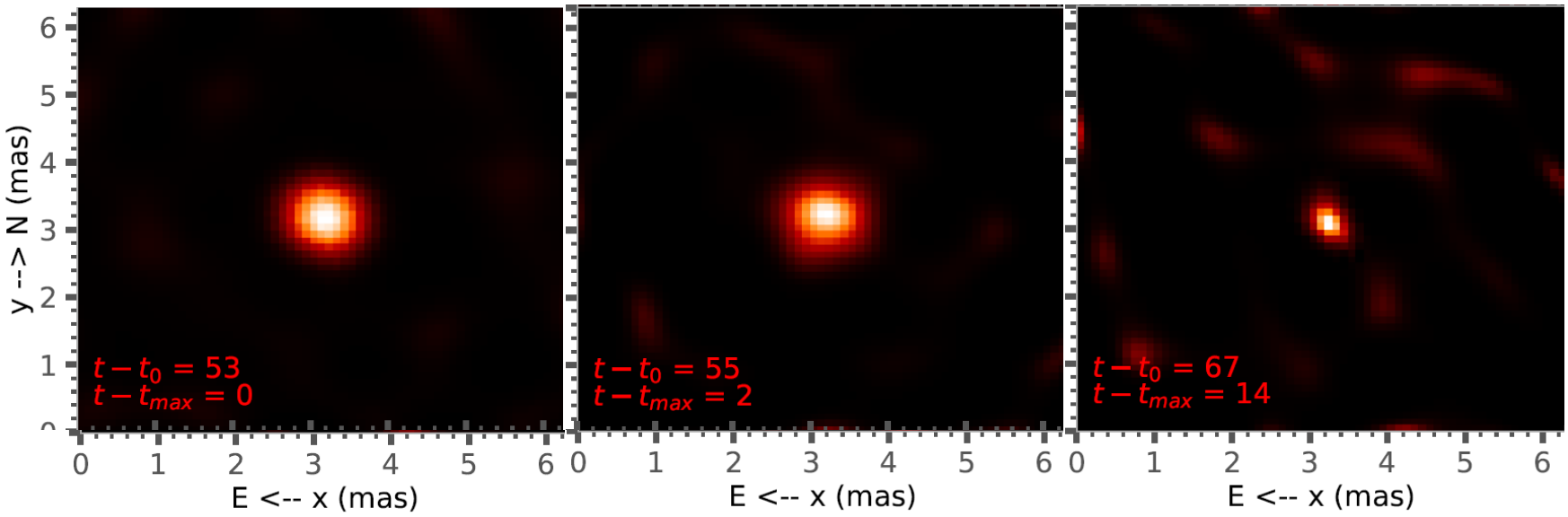

Aydi et al. in perp.

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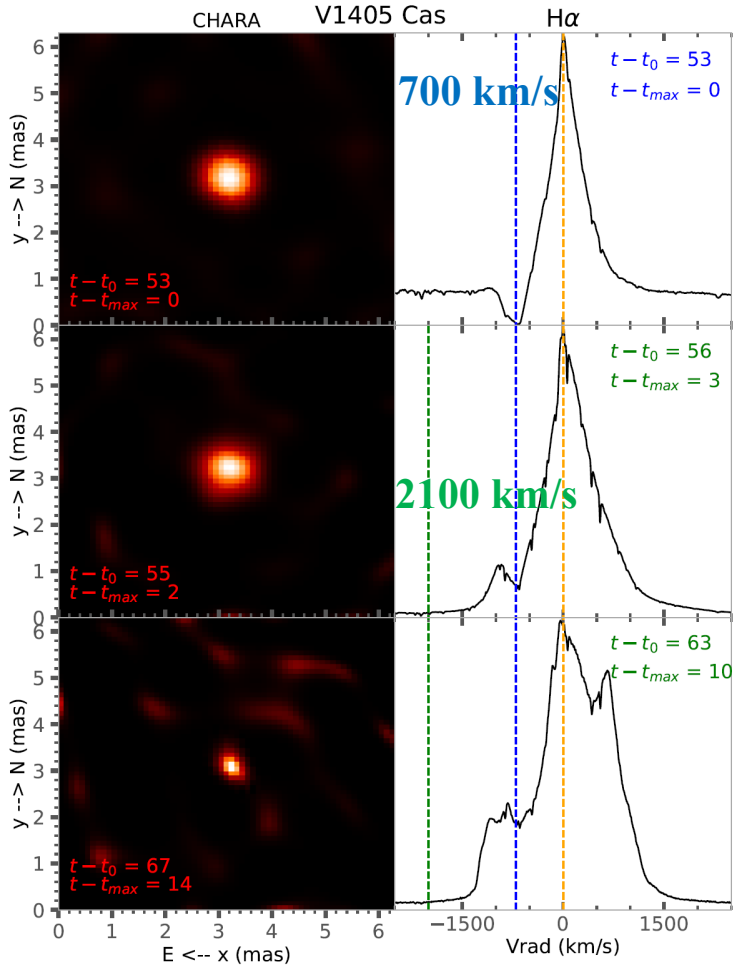

Aydi et al. in perp.

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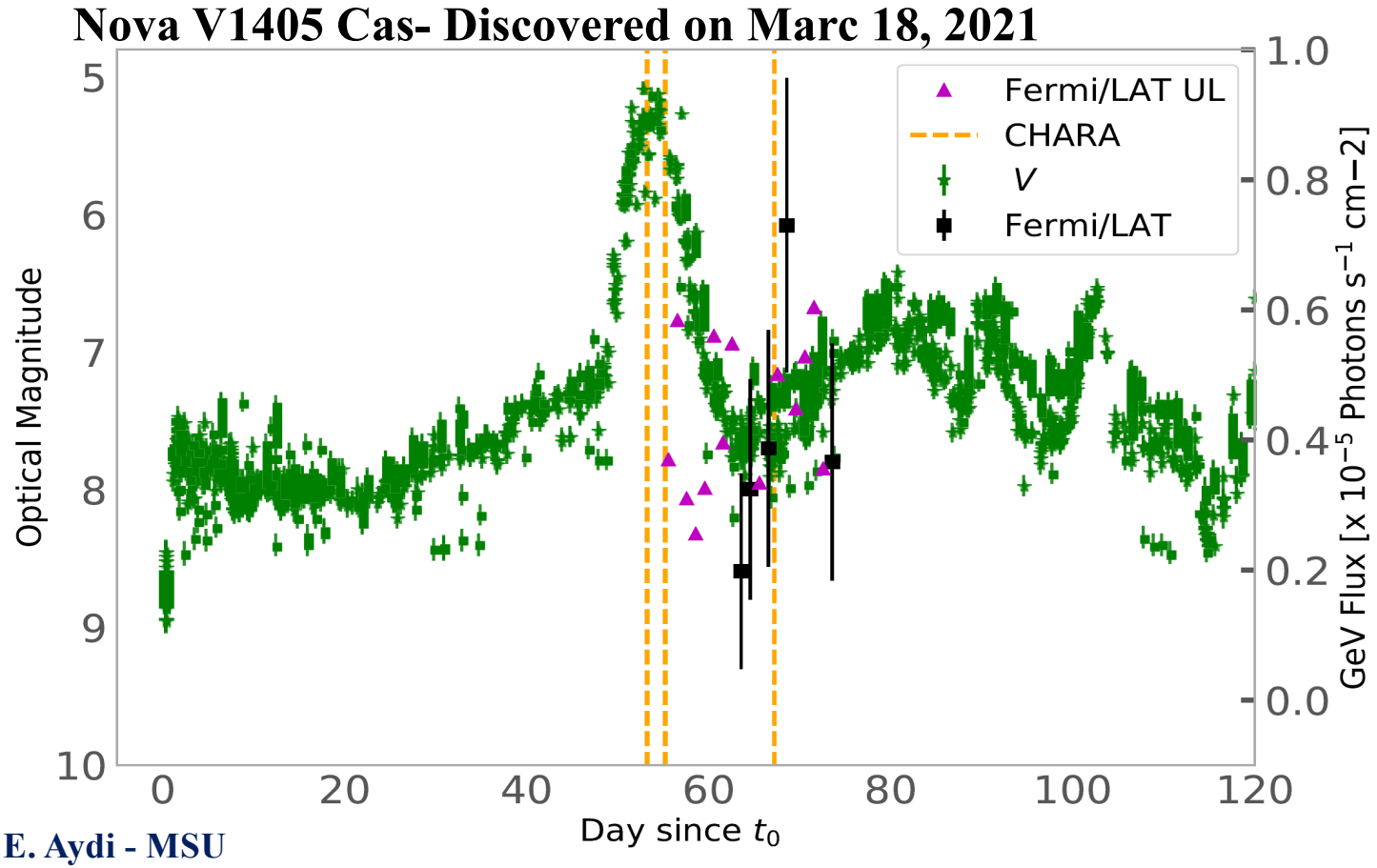

Aydi et al. in perp.