Shocks in Novae

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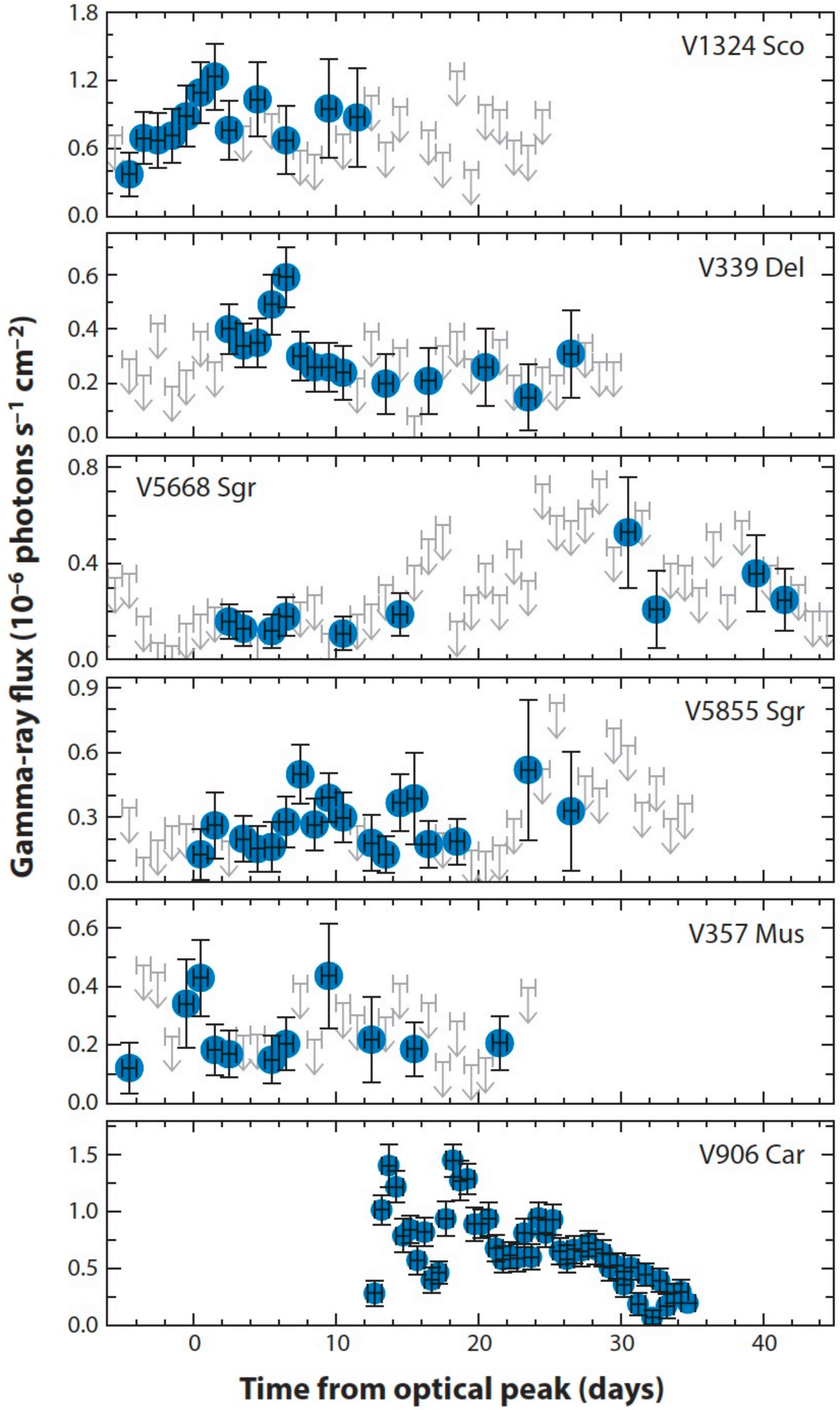
With input from Tatsuya Matsumoto and the ENova collaboration, including Koji Mukai, Laura Chomiuk, Elias Aydi, Kirill Sokolovsky, and Justin Linford.

See also review by Chomiuk, Metzger, & Shen (2021, ARAA).



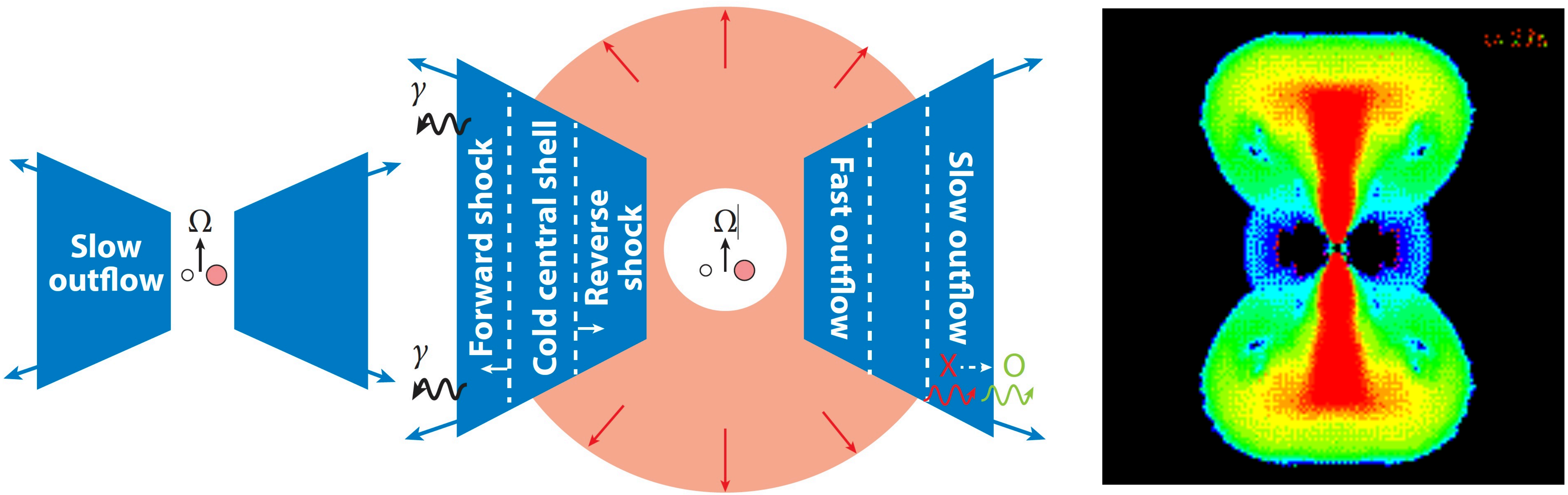
Chomiuk+ 2021

Novae as γ-ray transients

- Ubiquity: majority of classical novae within several kpc detected by Fermi
- Similarity of γ-rays: spectrum, timing
- Differences: luminosities vary from one object to another by > 2 orders of mag (Franckowiak+ 2018)
- Robustness: γ-rays detected from embedded and non-embedded novae

➡ See talk today at 4pm by Tekeba Olbemo on N Her 2021.

Colliding-flows picture

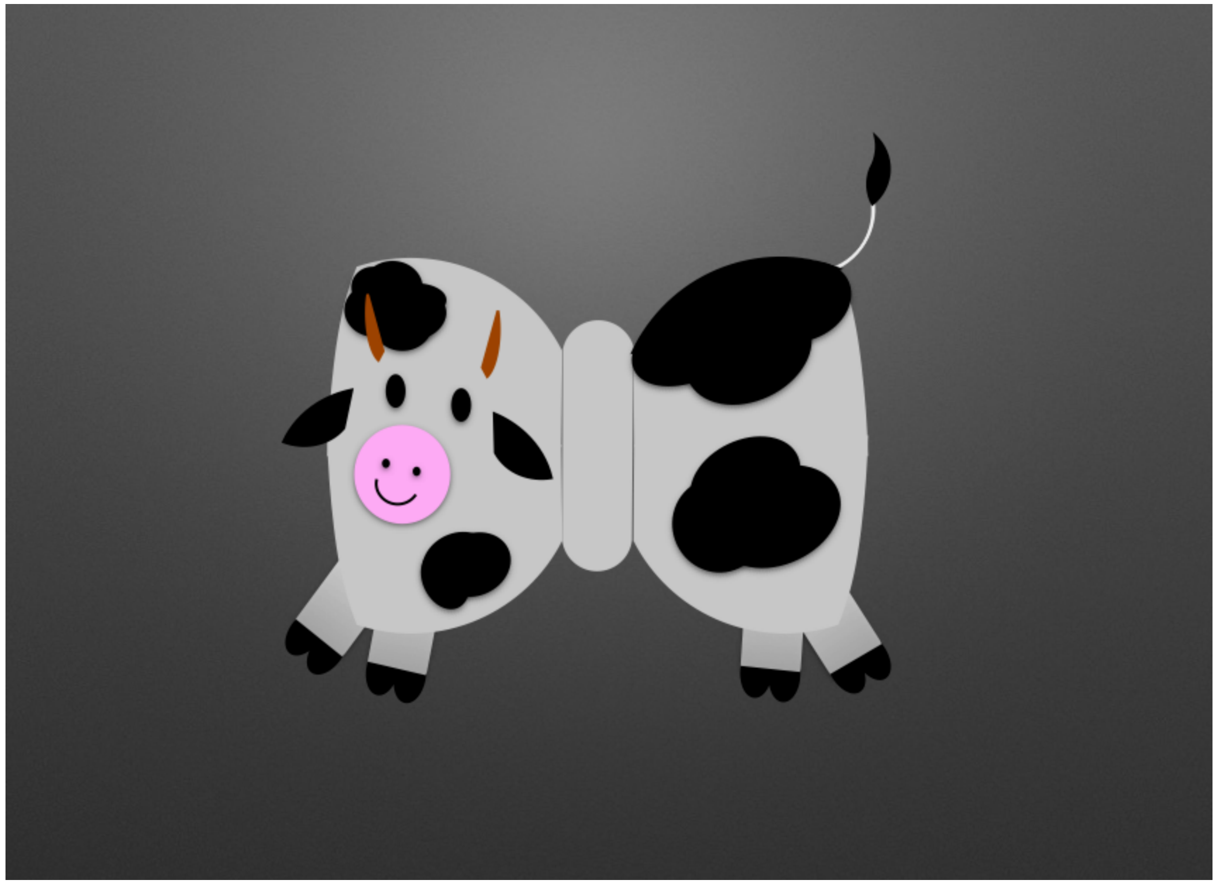


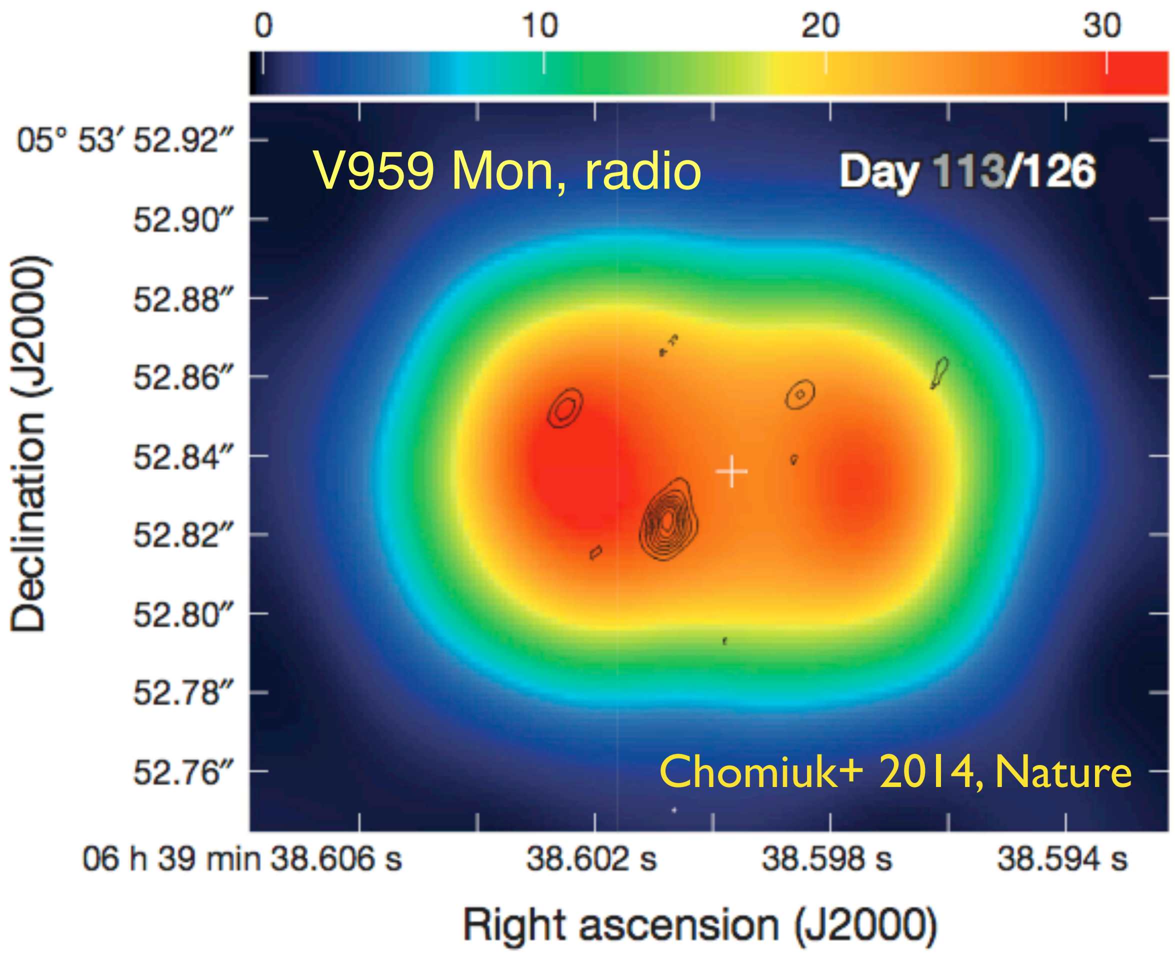
First two panels from Chomiuk+ 2021

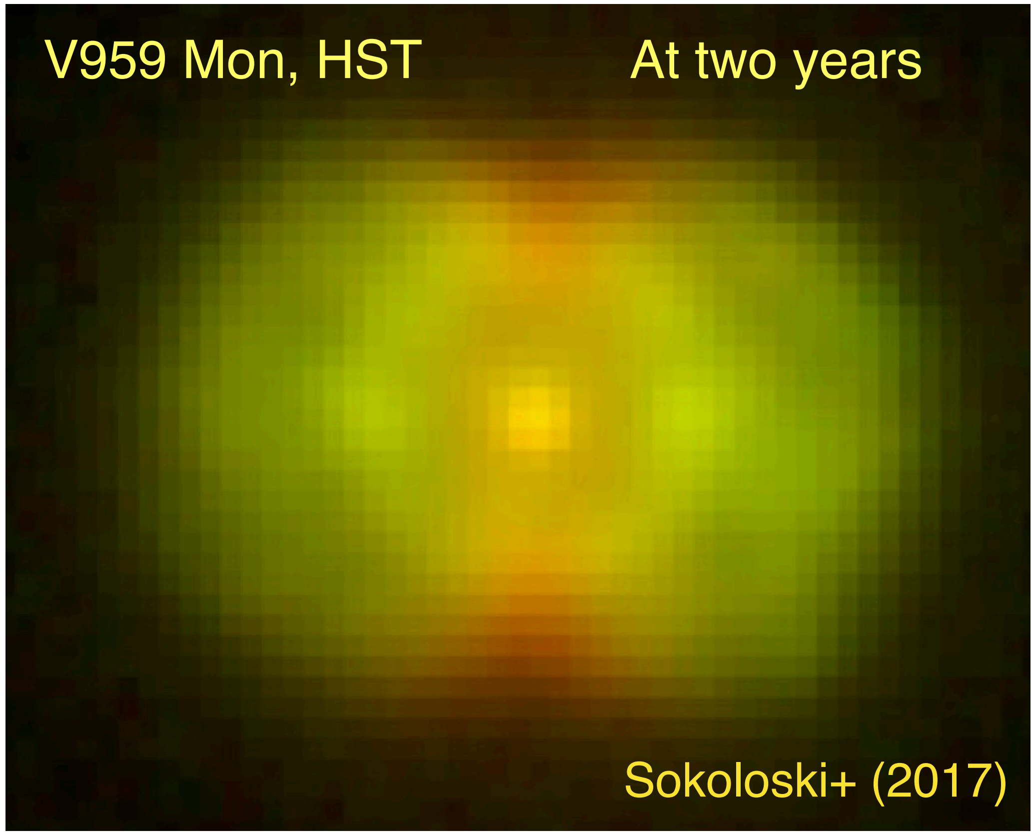
Time

➡ Diffusive shock acceleration produces populations of relativistic particles, which most likely generate γ-rays via π^0 decay.

Observational evidence — imaging



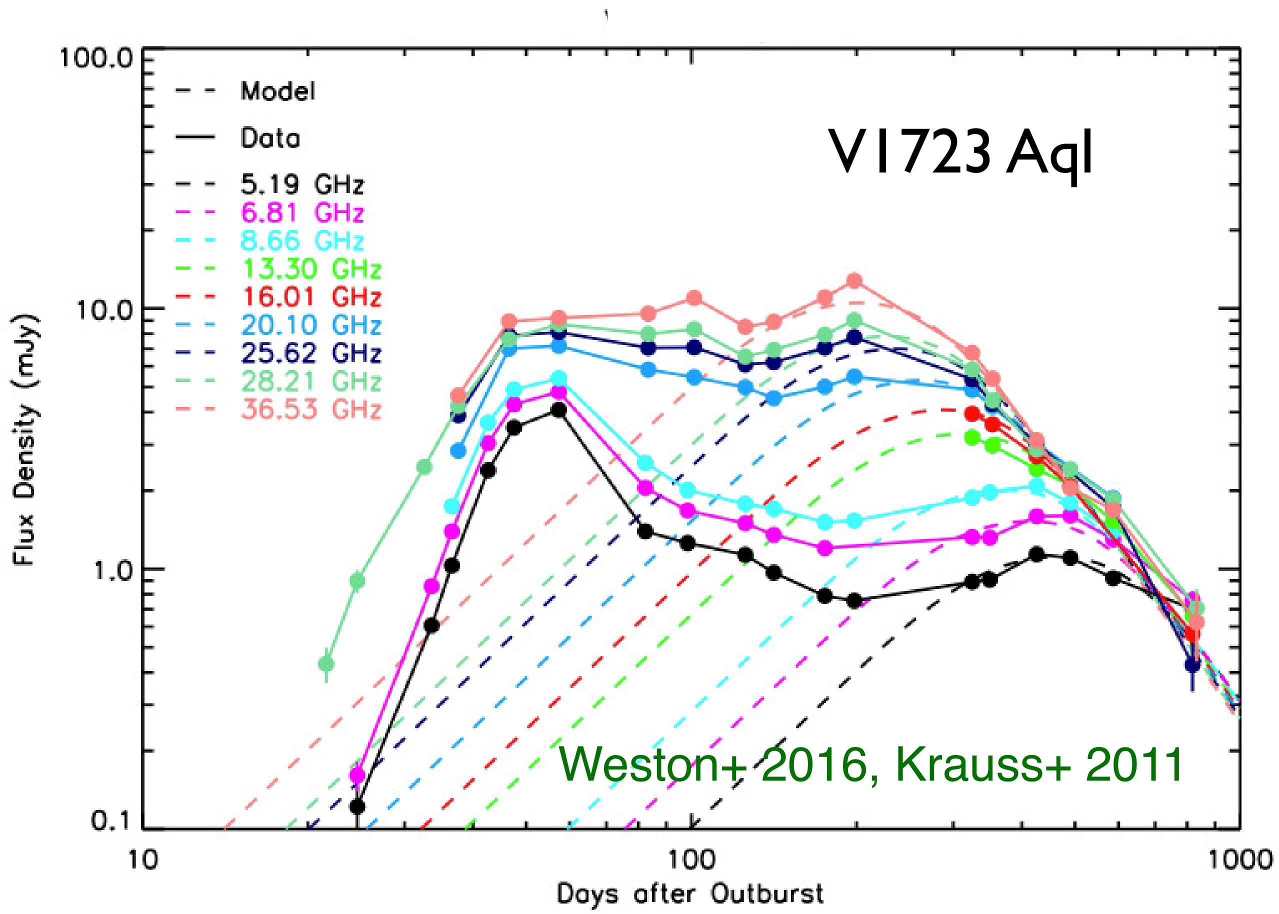




See also: Page+ 2013, Ribeiro+ 2013, Linford+ 2015 for V959 Mon, plus many old HST nova shells

Additional observational evidence

- Early-time radio flares consistent with radio synchrotron



- Optical spectroscopy → multiple flows and rings (e.g., Aydi+ 2020, Shore+ 2013, Wade 2000, Friedjung 1966abc, 1987; Hutchings 1972, McLaughlin 1947, Russell 1936)

- γ-ray spectral shape and L_{γ}/L_{opt} → π^0 decay (e.g., Li+ 2017, Metzger+ 2015, Martin+ 2018, Chomiuk+ 2021)

Theoretical support

Early ejecta form slow torus — Theoretical work by Shen & Quataert (2022) strengthens arguments for multi-stage ejection, with the first stage slow loss through L2 into a circumbinary torus.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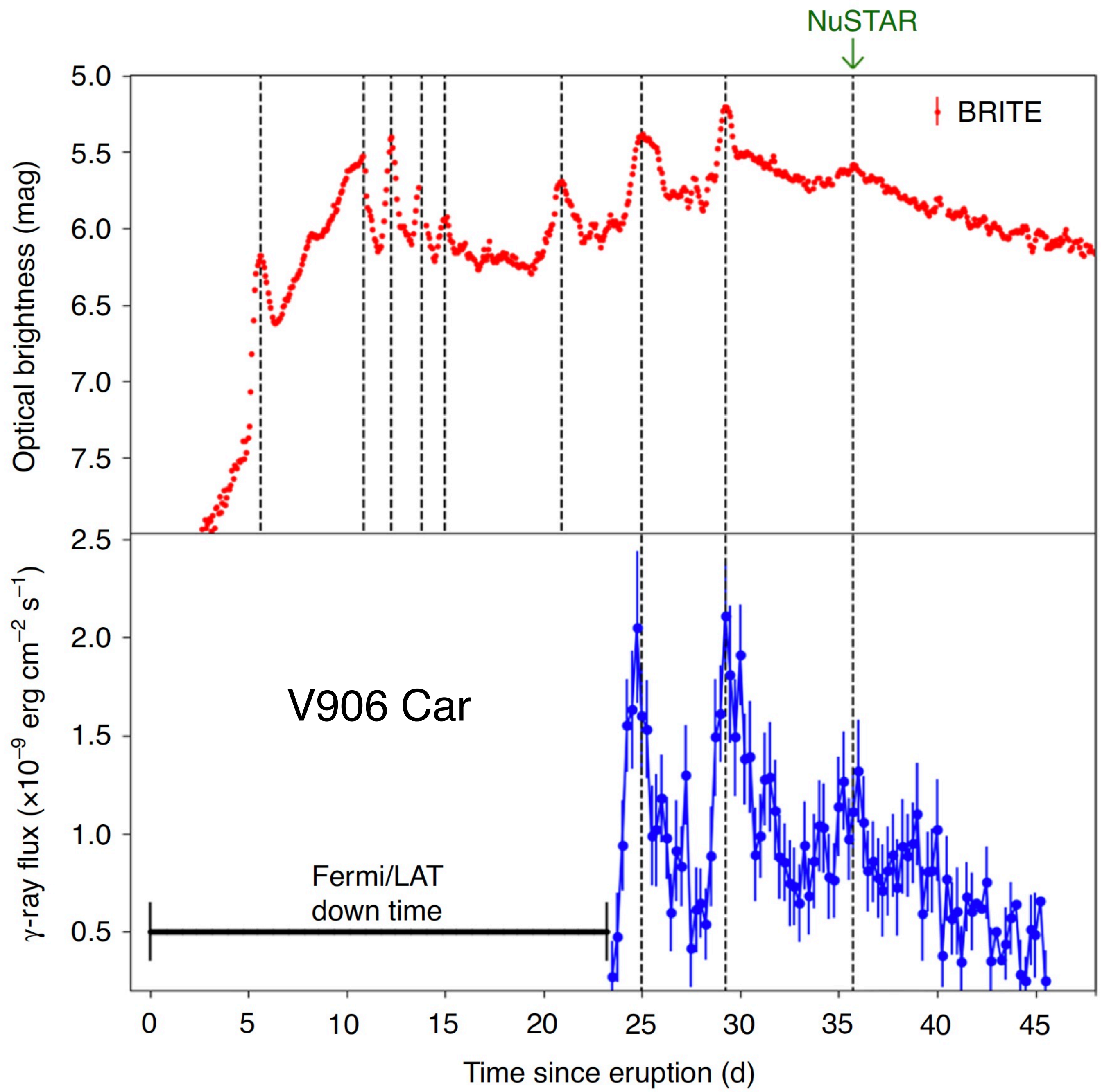
Shocks power some optical emission

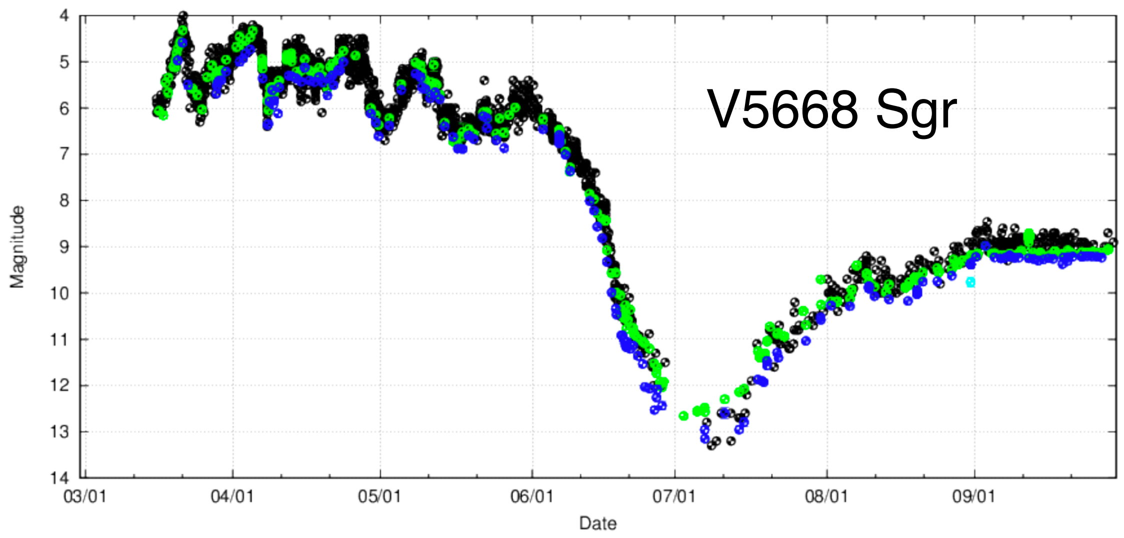
Why do some nova optical light curves have jitters and flares?



Optical emission can be shock powered, w/ flares from the shock hitting high-density structures (Aydi+ 2020; see also Li+ 2017, Metzger+ 2015)

Dust

How can dust form in the hostile environment of nova ejecta?



➡Support: Correlated timing of some shock signatures and dust formation (e.g., Kumar+ 2022).

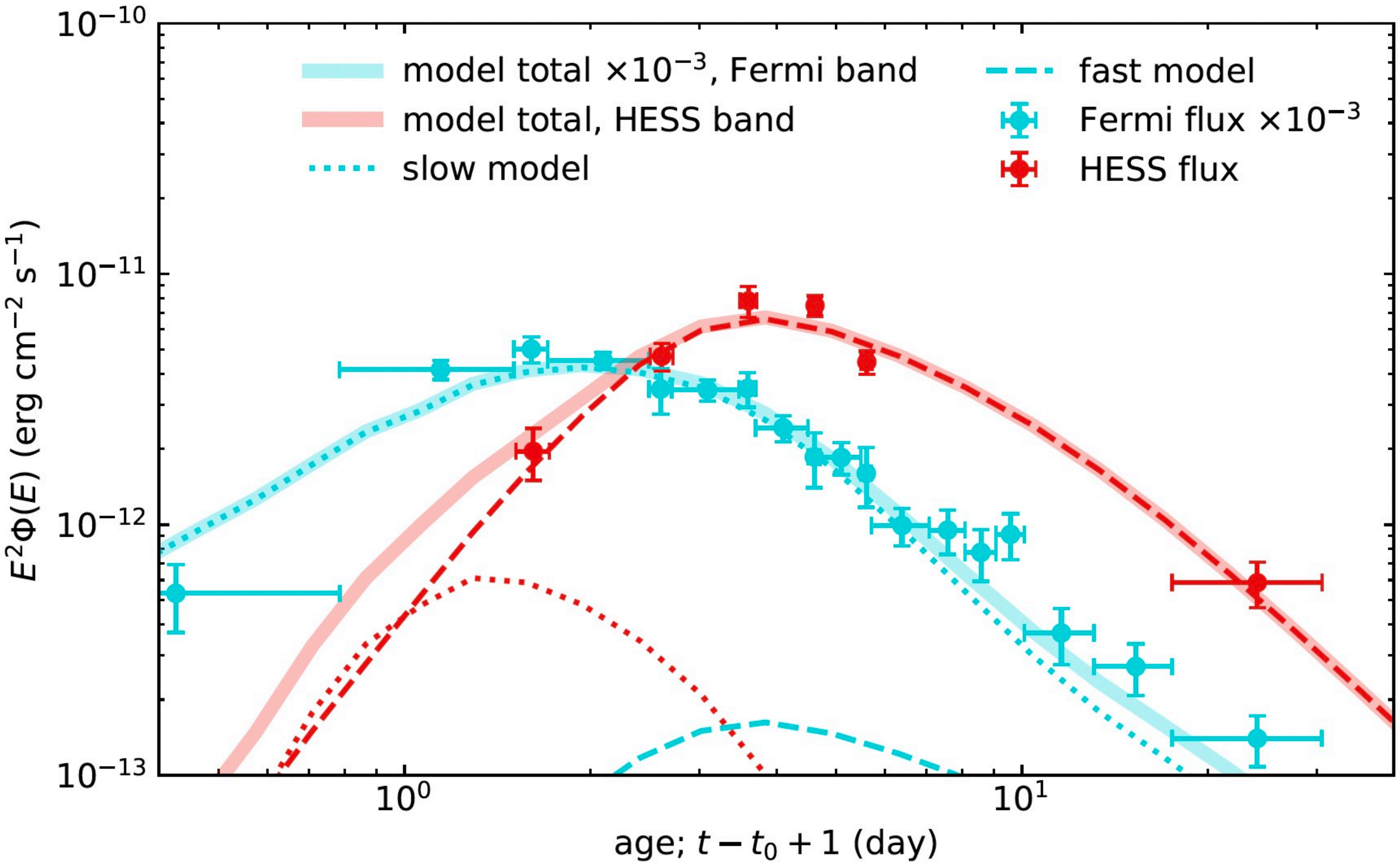
➡Support: Radio spectral evolution suggests dust-producing synchrotron shock emerging from behind free-free absorption (e.g., Babul, Matsumoto+ in prep).

➡Support: spectropolarimetry shows tranient dust aligned w/ bipolar flow and then equatorial plane in RS Oph (Nikolov+ submitted).

Idea: Catastrophic cooling in dense layer between radiative shocks creates environment conducive to dust formation (Derdzinski+ 2017)

TeV emission!

From embedded nova RS Oph



Diesing+ (2022)

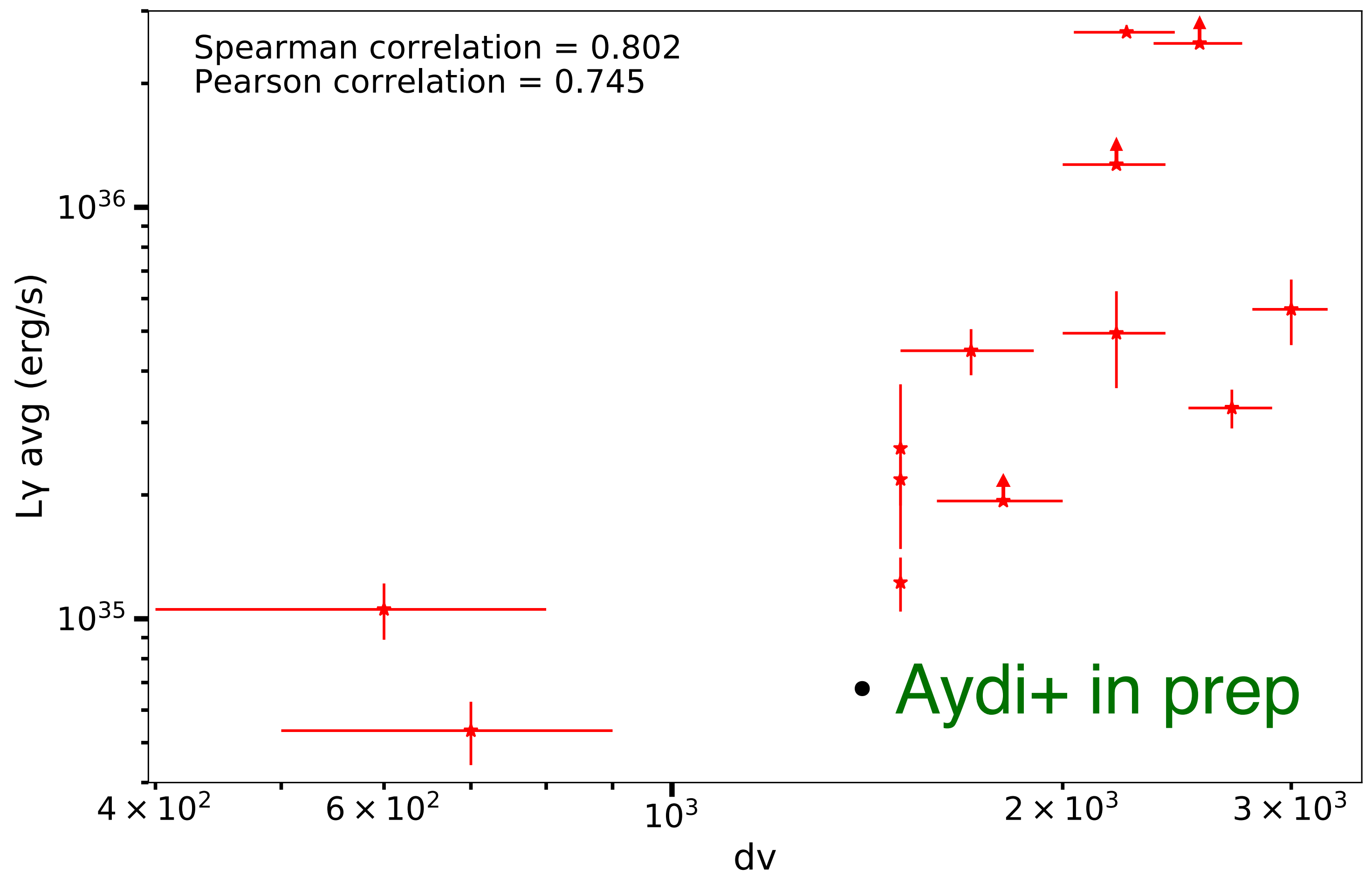
- RS Oph detected in GeV, 60-250 GeV, and 0.1-1TeV γ-rays by Fermi (Cheung+ 22), MAGIC (Acciari+ 22) and H.E.S.S. (H.E.S.S. Collaboration 2022), respectively.
- VHE emission peaked later than LAT-band emission — could be from a different shock.
- Detection out to 250 GeV strongly supports neutral pion decay over inverse-Compton scattering as source of γ-rays.

More shock physics & ejecta structure

- Radio spectral evolution shows synchrotron initially absorbed by shock-ionized material w/ steep density gradient (Babul+ 2022, 2023 in prep).

- Radio synchrotron shock is forward shock approaching outermost part of slow flow.

- L_γ correlated w/ $(v_{fast} - v_{slow})$ (Aydi+ in prep)

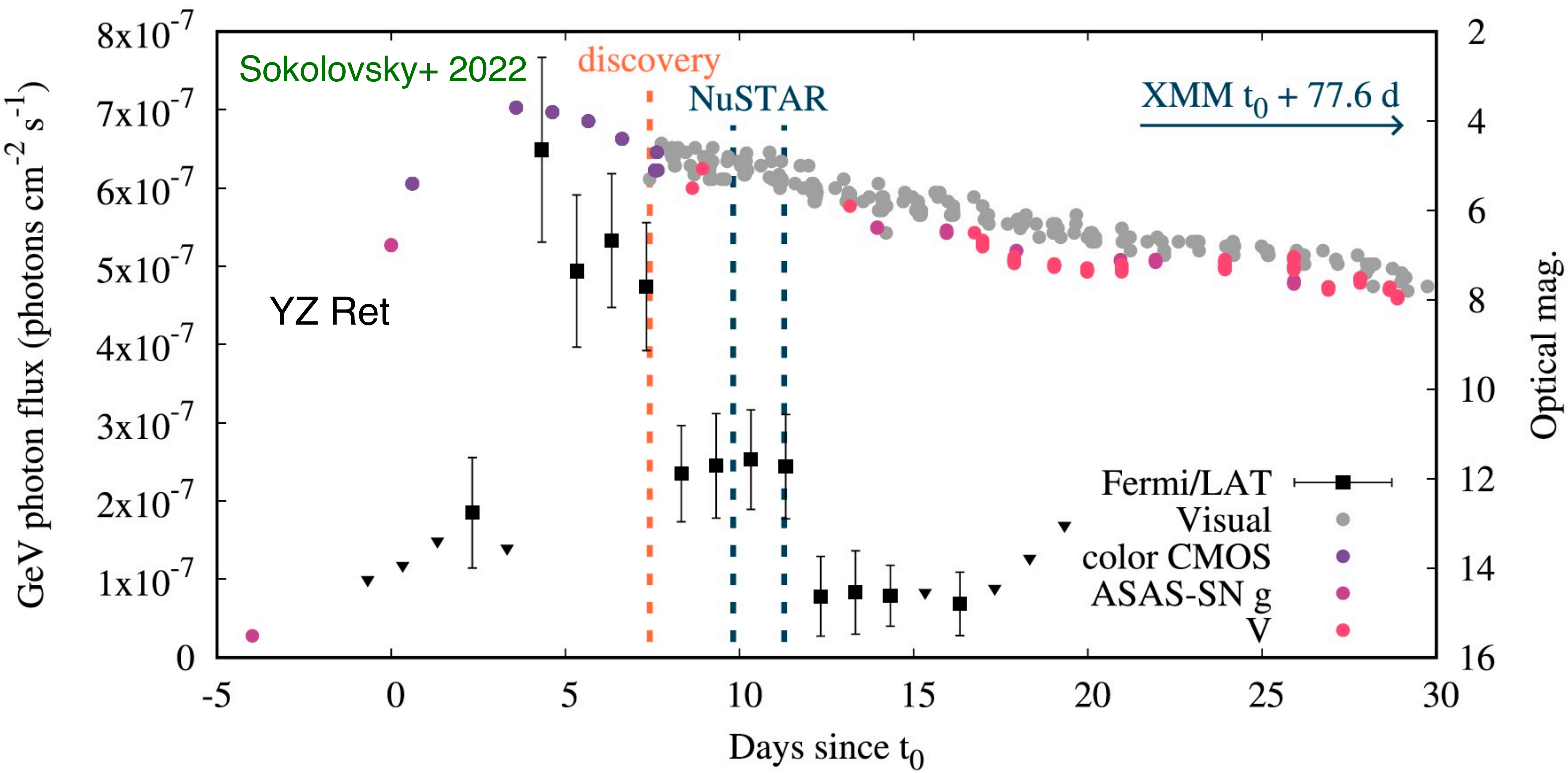


- Aydi+ in prep


A.C. VOLTS

Challenge: Faint X-rays

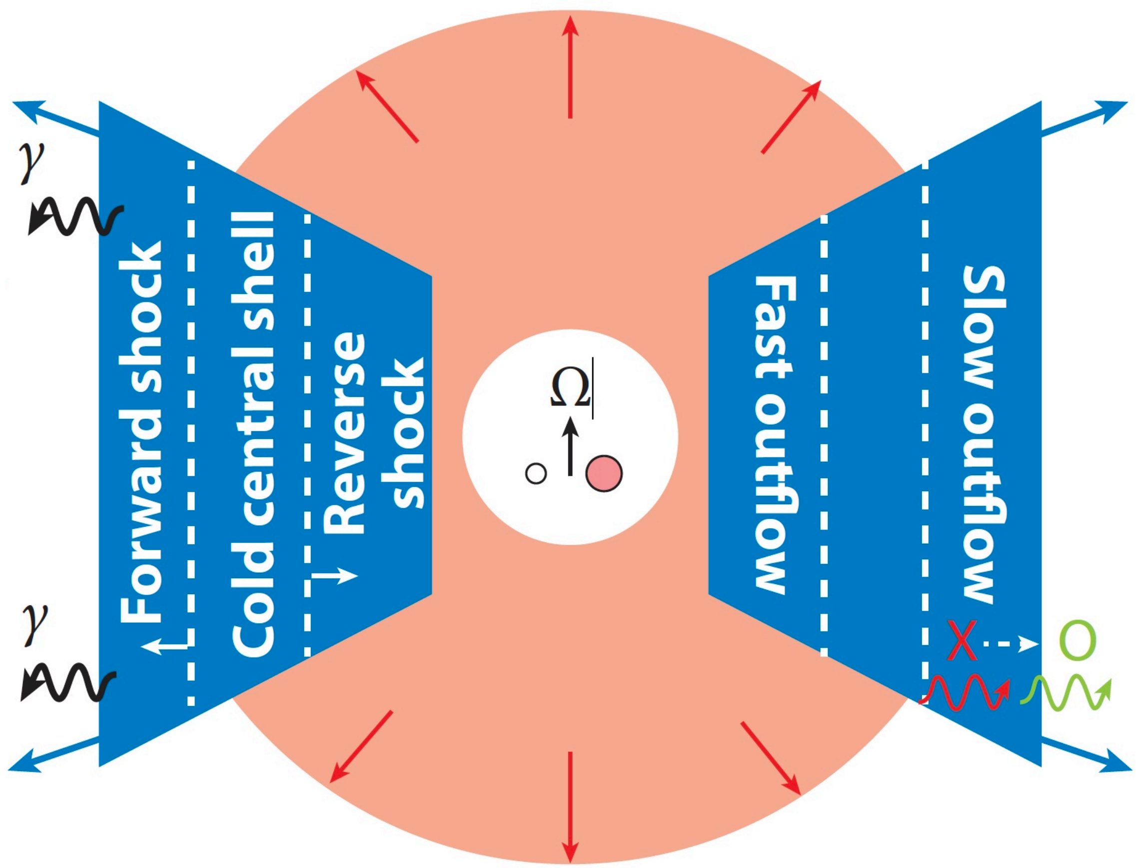
Much work on this topic led by Kirill Sokolovsky.



X-ray emission is two orders of magnitude fainter than expectations for plasma behind the radiative, γ-ray producing shock (see also Chomiuk+ 2021)

γ-rays from forward or reverse shocks?

This question closely related to that of the faint X-rays.



- Early radio synchrotron flares from forward shocks.
- Dominant source of hard X-ray emission may be reverse shock in some novae (Nelson+ 2021)
- Associated w/ polar flows, like synch spots in V959 Mon?

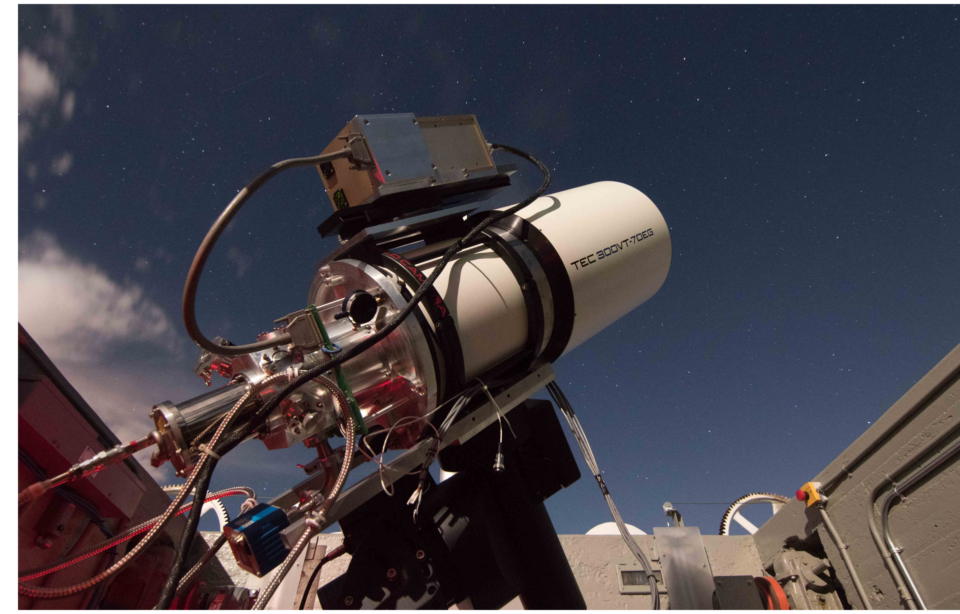
➡ Promising path to resolving these questions — multi-wavelength imaging.

Other open questions

- How much mass is ejected? How does M_{WD} evolve?
- Why is there a month-long delay between the TNR and ejection in some novae?
- Where are all the normal novae w/ red-giant donors?

➡Finding more novae, across all parts of parameters space, and performing strategic multi-wavelength monitoring, will drive progress.

Survey science



Wide-field surveys have been a boon, e.g.:

- Improved discovery rates and coverage (ASASSN, Gaia, ZTF, PGIR);
- Pre-eruption light curves; orbital periods;
- Galactic nova rate (De+ 2021)

Going forward, coordination of community efforts is vital.

LSSTC — an alliance of ~30 institutions using private philanthropy to prepare for Rubin/LSST. Illinois is well represented, with Northwestern already taking a leadership role. We recently launched >$20M of interconnected programs called LINCC.

Your institution can still join!

Conclusions

- Observations and theory suggest that in novae, the WD envelope is ejected in multiple stages, leading to collisions between fast winds and slow, equatorial flows.
- These collisions give rise to powerful (~10^{38} erg/s) shocks that can accelerate particles, generating detectable GeV continuum emission for weeks.
- These shocks help resolve long-standing problems.
- Multi-wavelength imaging and wide-field surveys are likely to answer open questions about nova shock physics, ejecta structure, and the evolution of WDs in CVs.
- If you are here, your department should join LSSTC.