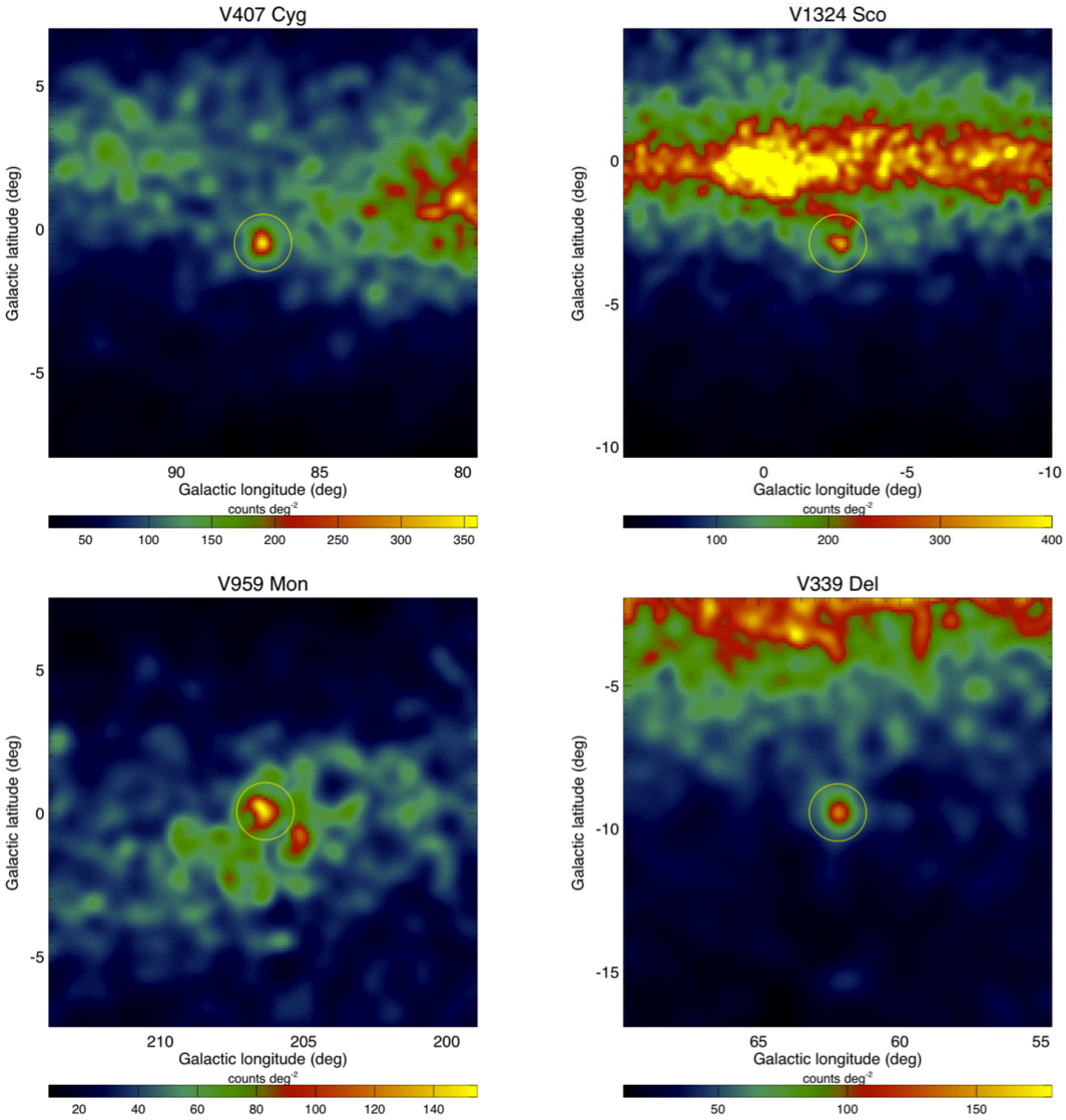
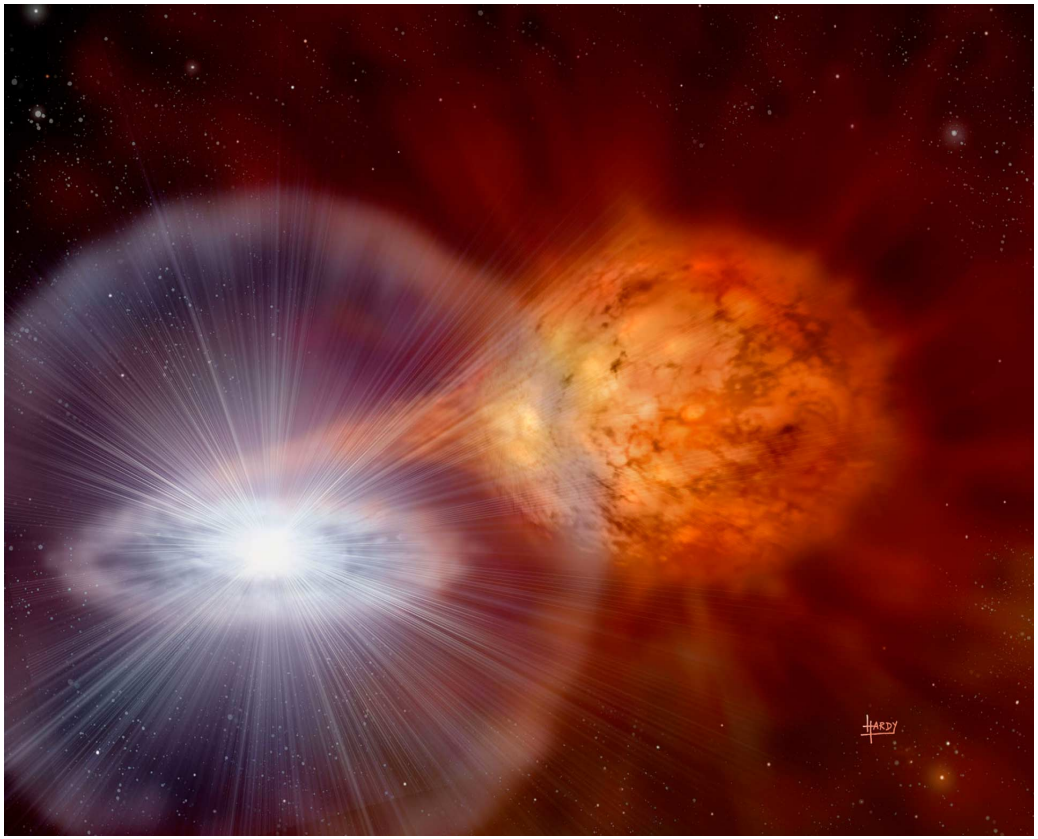


Gamma-ray novae

Pierrick Martin
on behalf of
the Fermi-LAT collaboration



Novae

Thermonuclear runaway burning of electron-degenerate material accreted on a WD

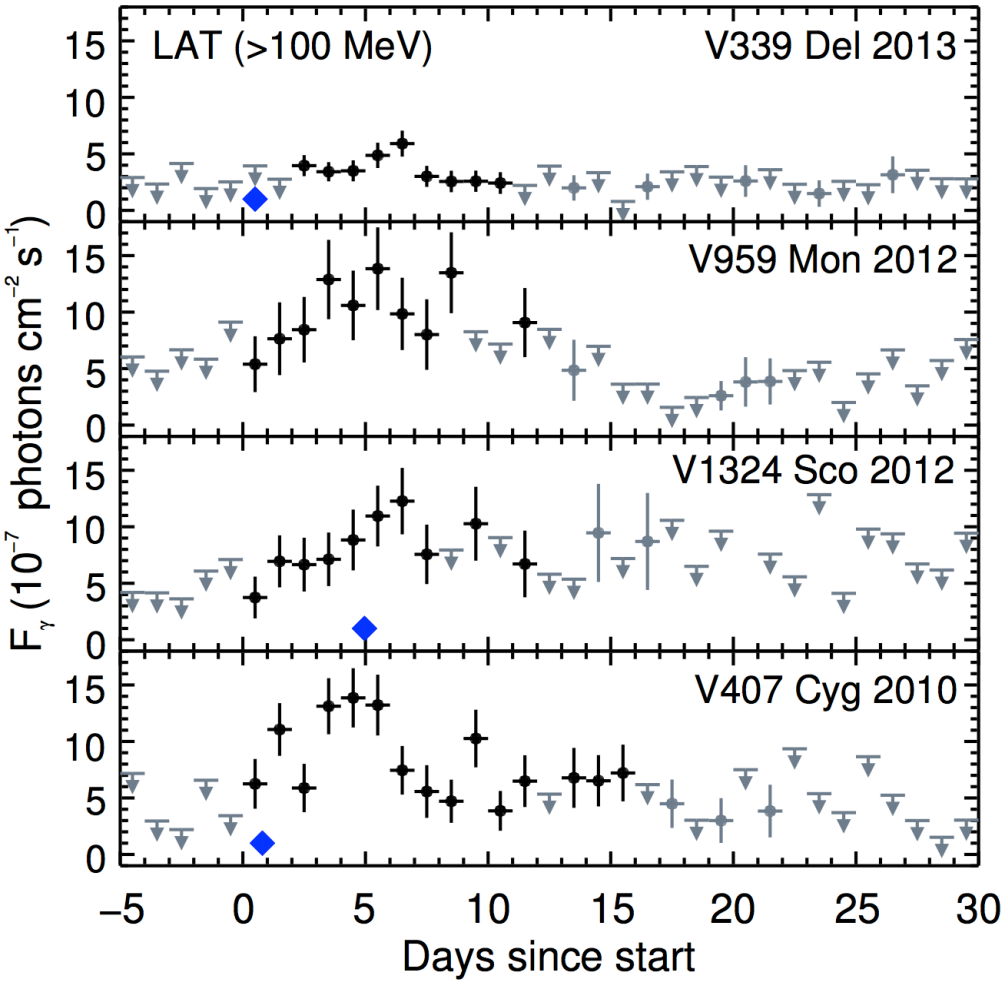
Violent 10^{-7}-10^{-4} $M_\odot$ ejection followed by continued burning at L_{Edd}~10^{38} erg/s

Recurrent over
1-10^4 yrs time scales
50 (+30/-20) novae/yr in Galaxy

Wolf et al. (2013), Shafter (2016)

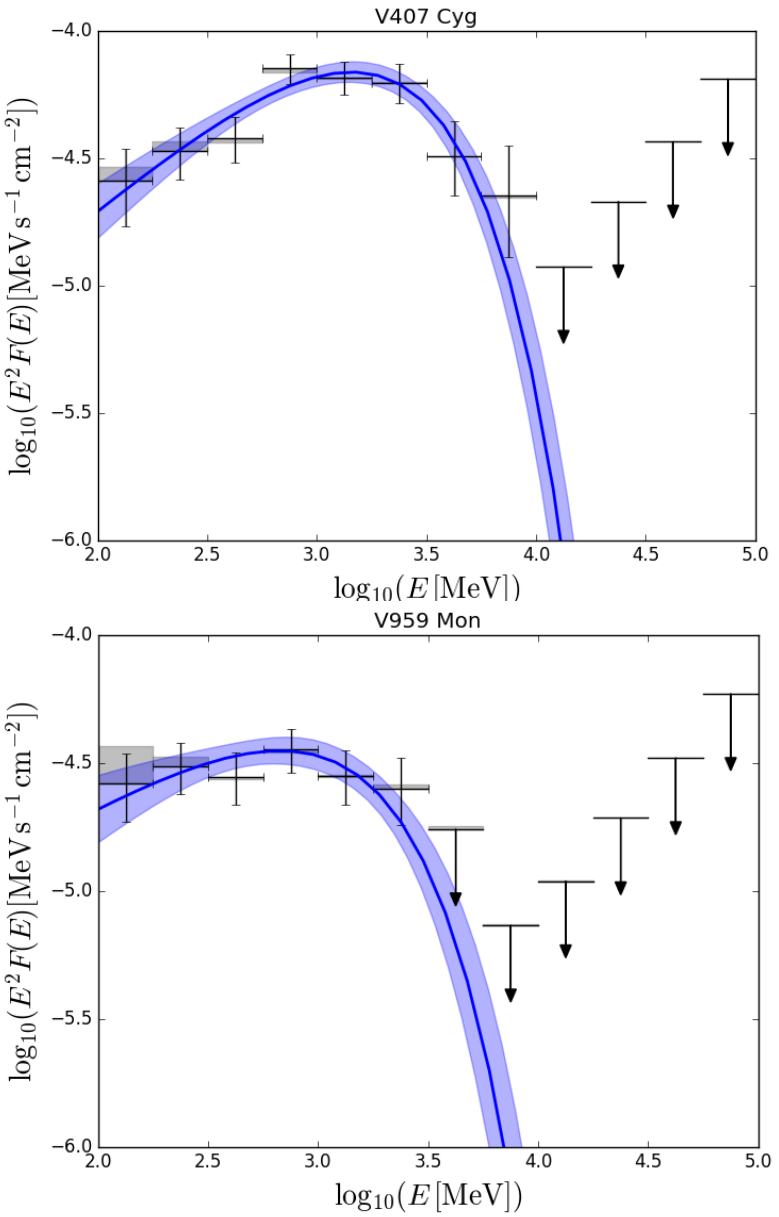
Multi-wavelength transient from radio to X-rays (**now gamma-rays**)
Variety of observed behaviors, at all stages

A new gamma-ray source class



Week/month-long transient
Most spectra cutting off at few GeV

Ackermann et al. (2014)



Current gamma-ray detection record

Year	Object	Discoverer
2010	V407 Cyg	Nishiyama/Kabashima
2012	V1324 Sco	MOA
	V959 Mon	**Fermi**
2013	V339 Del	Itagaki
	V1369 Cen	Seach
2014	V745 Sco	Stubbings
2015	V5668 Sgr	Seach
2016	V407 Lup	ASASSN
	V5855 Sgr	Itagaki
	V5856 Sgr	ASASSN
2017	V549 Vel	ASASSN
2018	Nova Mus 2018	Kaufman
	Nova Car 2018	ASASSN
	V392 Per	Nakamura

Classical and symbiotic novae

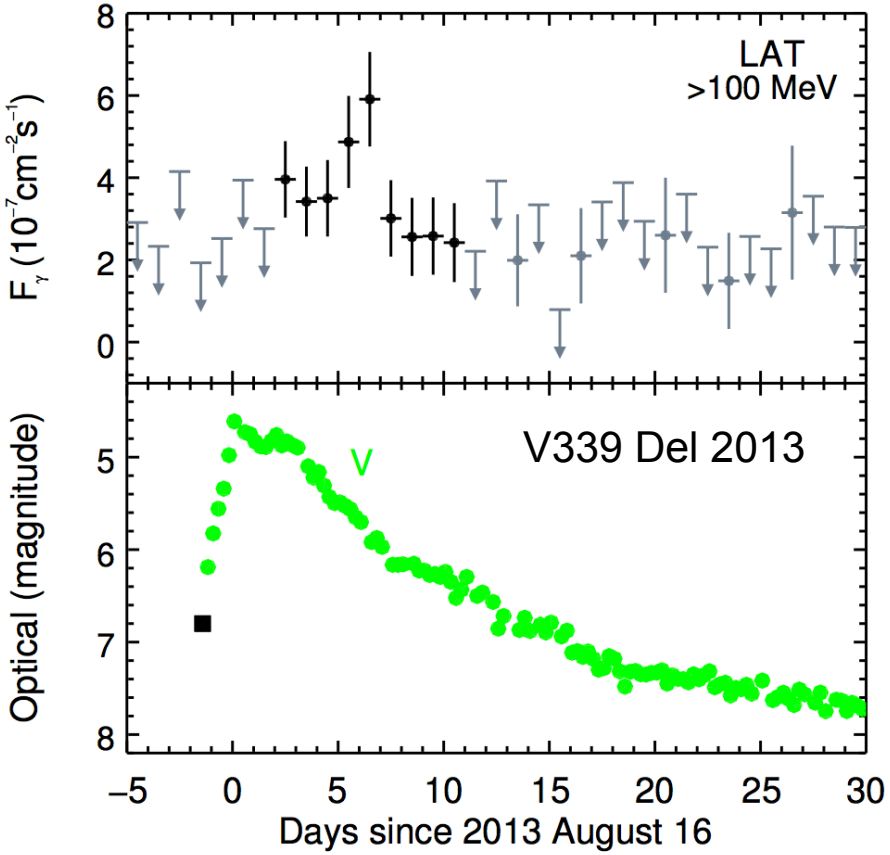
Low significance objects
(+2 from revisiting data with Pass 8)

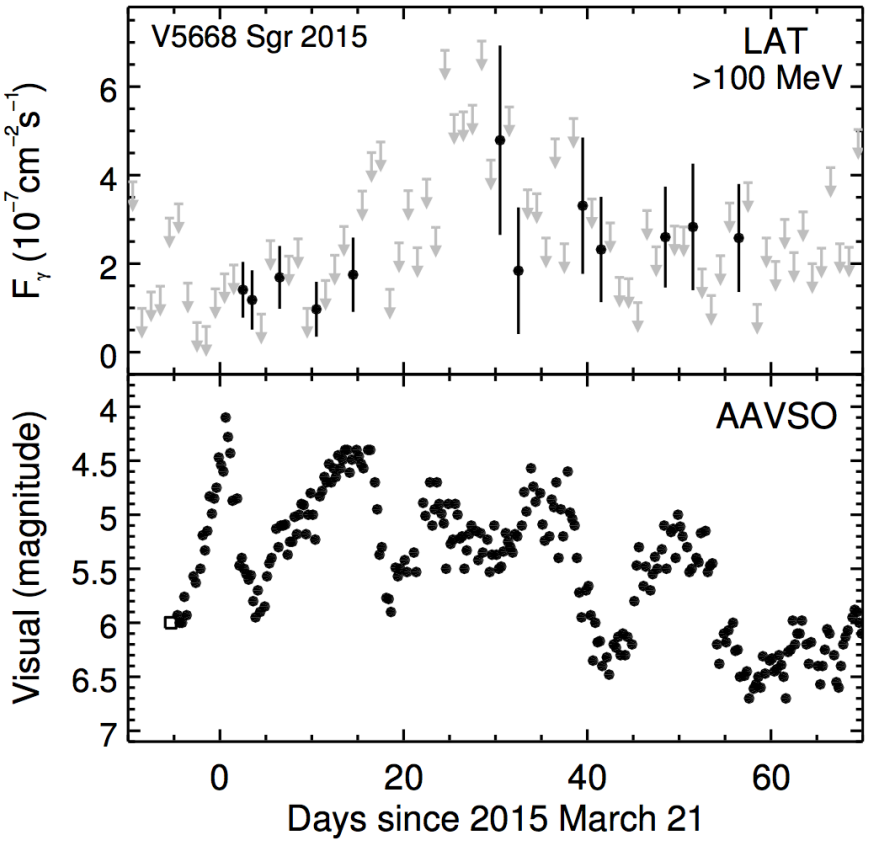
High significance objects

Variety of gamma-ray novae

Ackermann et al. (2014)
Cheung et al. (2016)

- Symbiotic and classical
- Very fast to slow, variety of optical lightcurves
- Gamma-ray luminosities vary by >20, distances 1-7kpc
- Some very bright optical novae not detected in gamma-rays



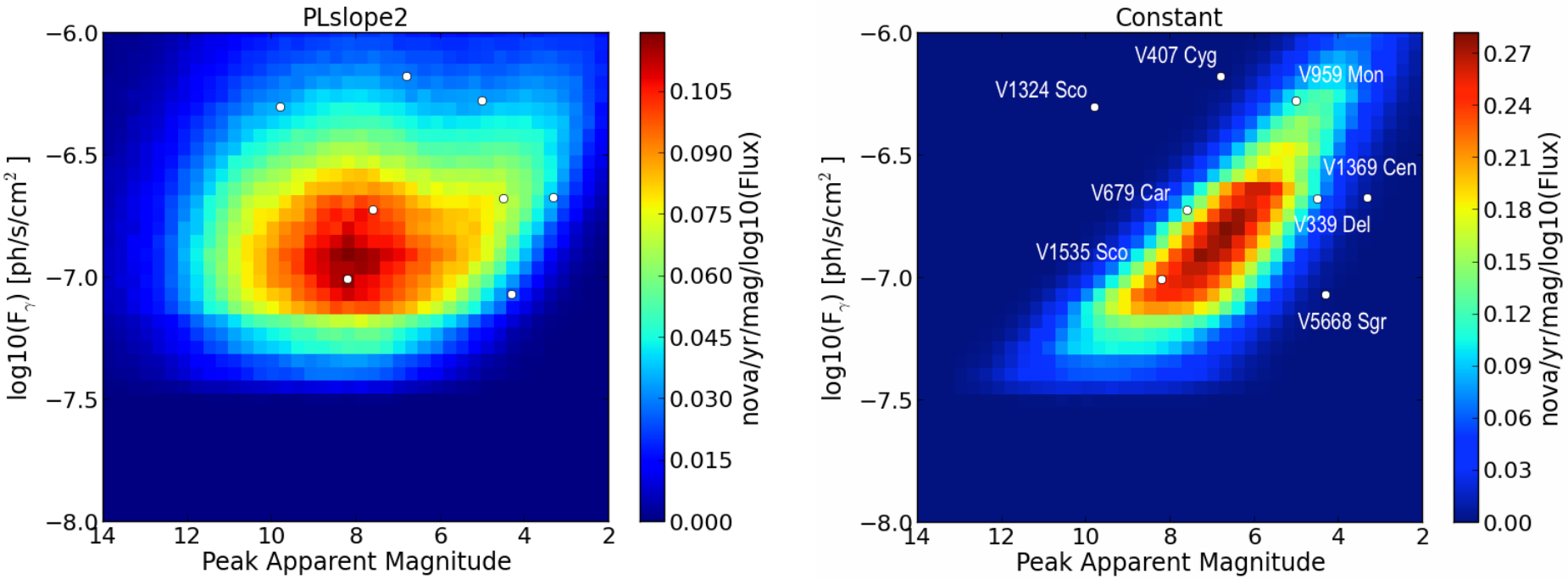


A first population study (Franckowiak et al., A&A, 2018)

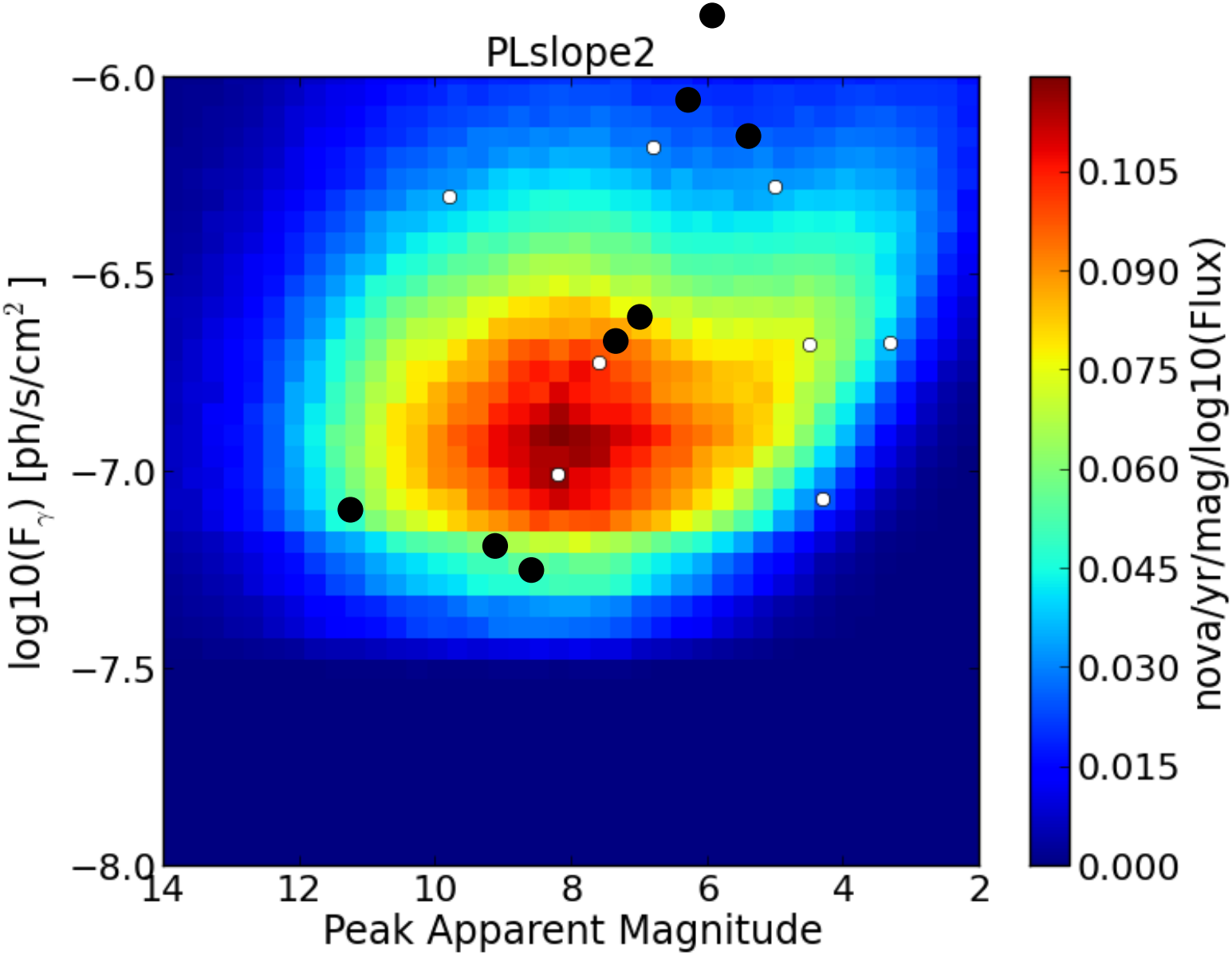
Search for gamma-rays from 75 optical novae in 7.4 yrs of Pass 8 data

- 2 novae candidates at ~2σ (V679 Car 2008, V1535 Sco 2015)
- Sub-threshold population at 3σ

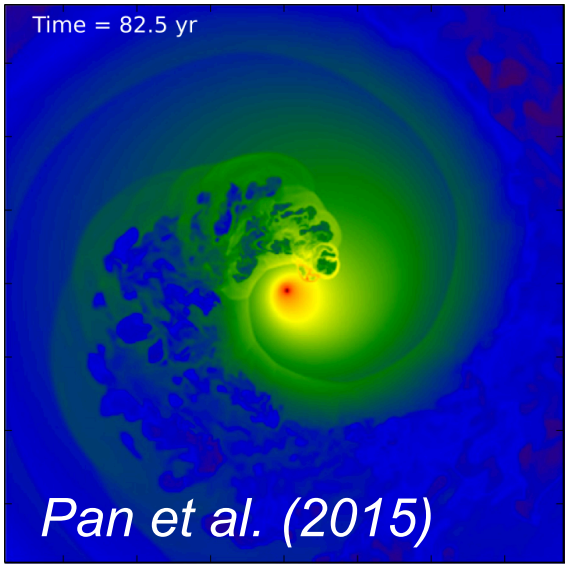
- Constraining gamma-ray emissivity distribution from population model
- Excluded: constant or correlated with maximum magnitude
- Favored: broader uncorrelated distributions



A first population study (updated approximately)

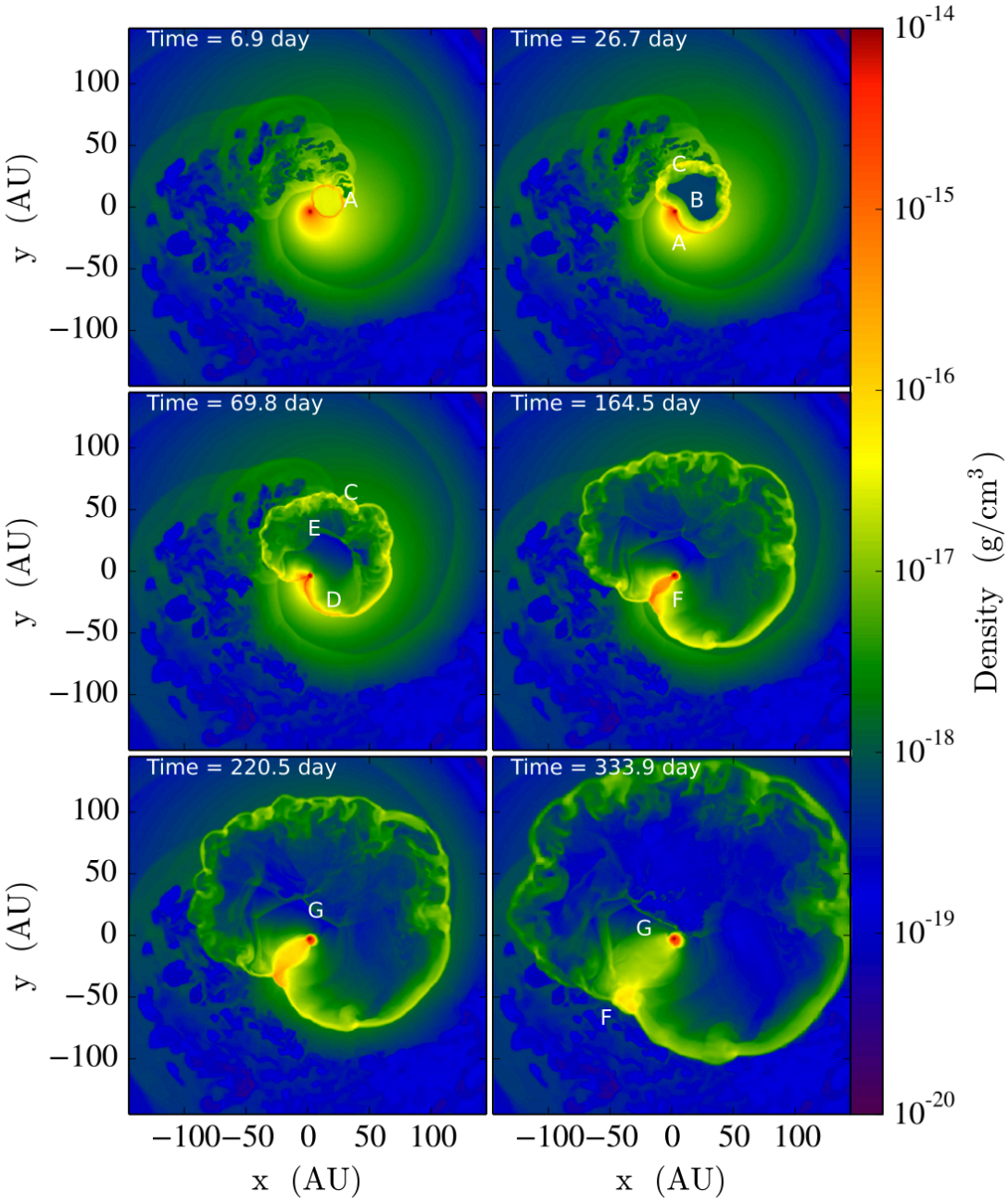


Novae as particle accelerators – symbiotic systems



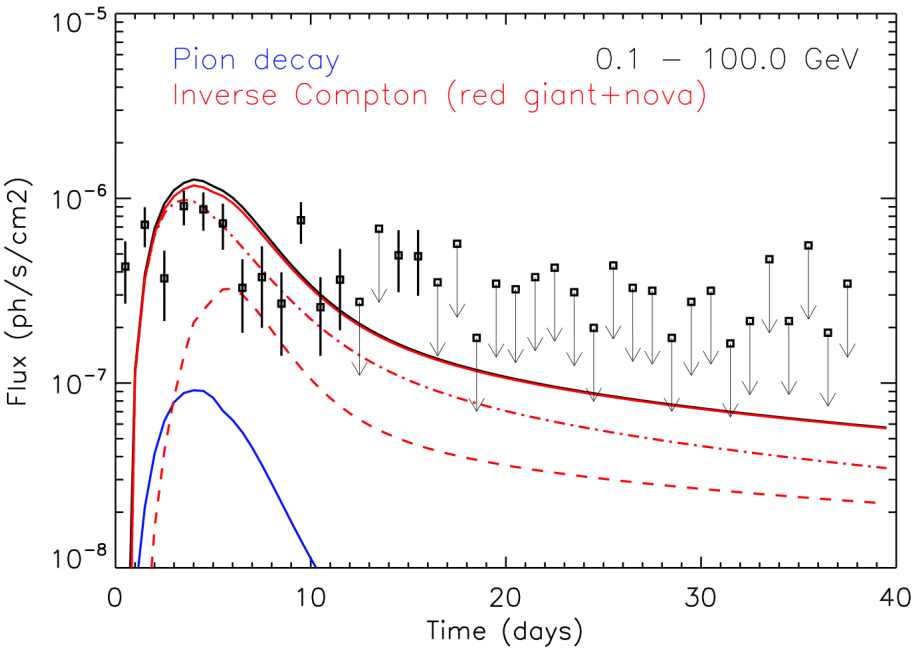
WD + RG companion
(RS Oph,V407 Cyg,V745 Sco)

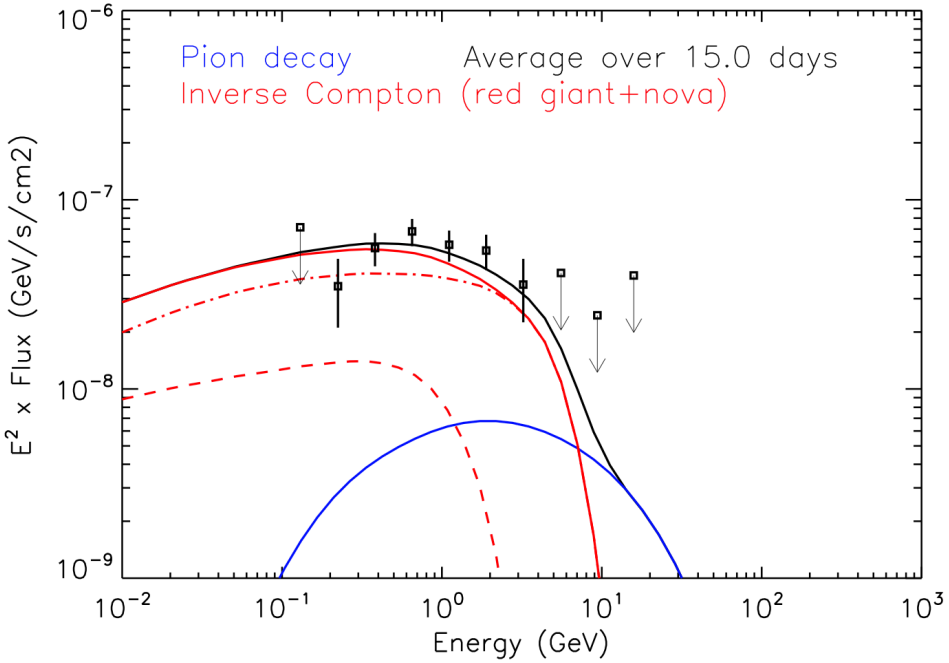
Shock in dense stellar wind
Scaled-down SN/SNR
(10^{44} erg, 3000km/s, weeks)



Novae as particle accelerators – symbiotic systems

- LAT data reproduced from typical assumptions for shock acceleration
- Mass amount and distribution are **key to reproduce the light curve**
- Martin & Dubus (2013)





V407 Cyg: **(if)** shock propagating in matter accumulated around WD
gamma-rays mostly inverse-Compton in nova+RG light

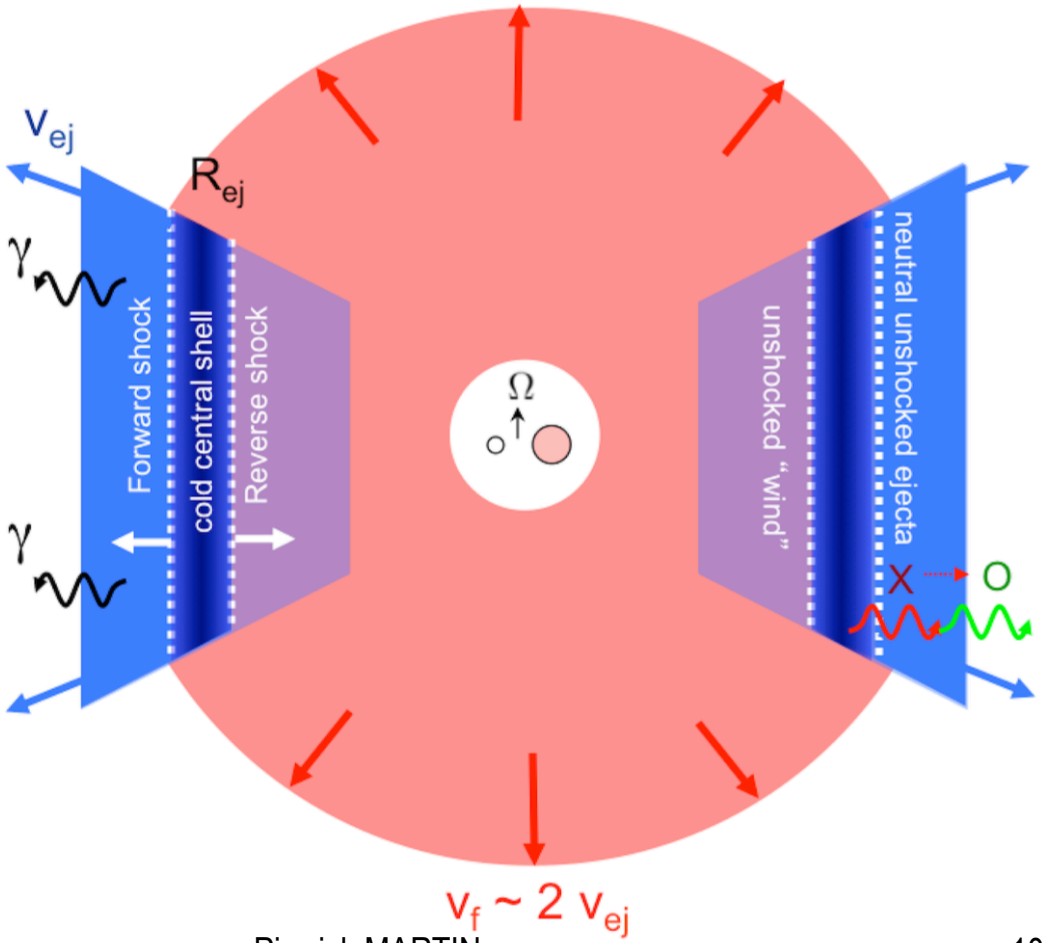
Novae as particle accelerators – classical novae

- Circumbinary medium mostly **empty**
- …the ejecta is the mass reservoir !
- Internal shocks revealed by hard X-rays (ROSAT…Swift)
- Multiple ejecta components from lines

Impulsive ejection
followed by
fast radiatively driven wind

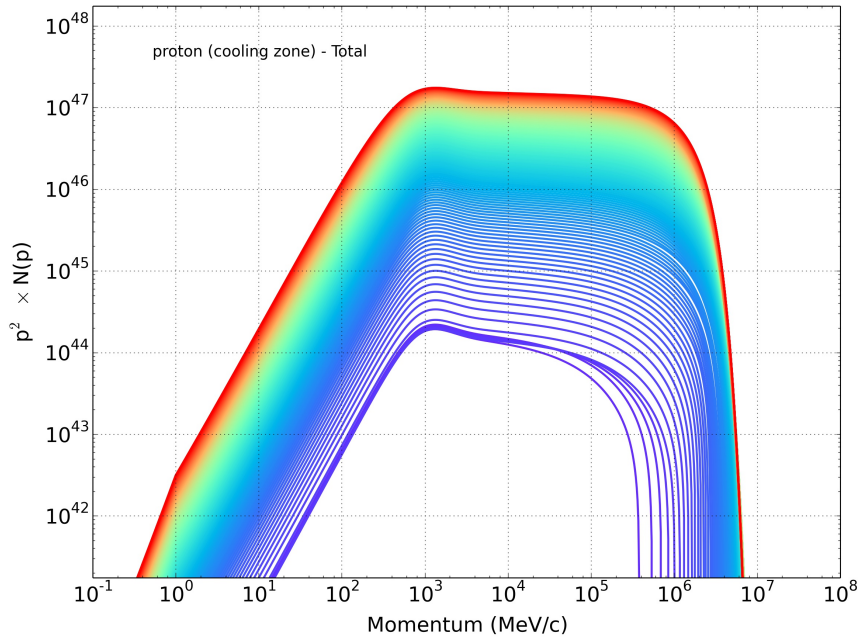
Radiative forward and
reverse **shocks** separated
by cold dense shell

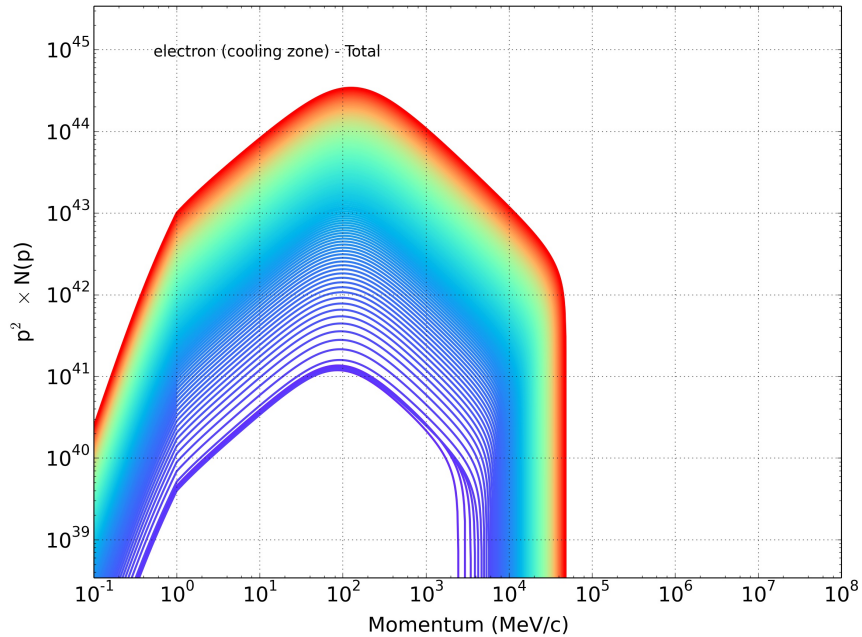
Variations on the geometry
Metzger et al. (2014,2015)
Martin et al. (2018)



Novae as particle accelerators – classical novae

- Diffusive shock acceleration with values typical of SNRs
  - Particle injection fraction ~10^{-4} and e/p ratio ~10^{-2}
  - Amplified upstream magnetic field = 10^{-4}-10^{-2} the ram pressure
  - Particles diffusing in Bohm limit



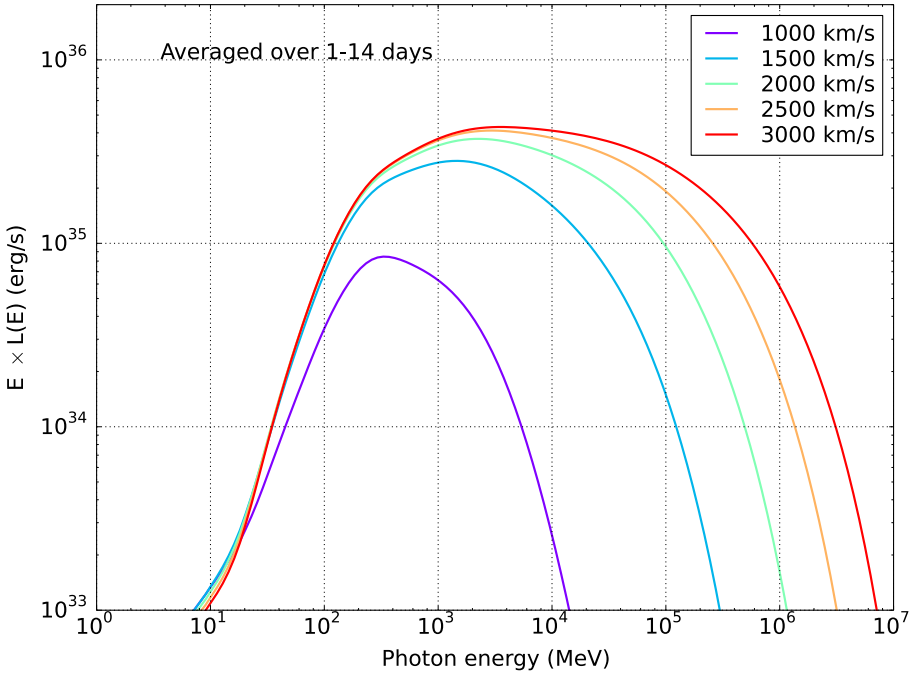


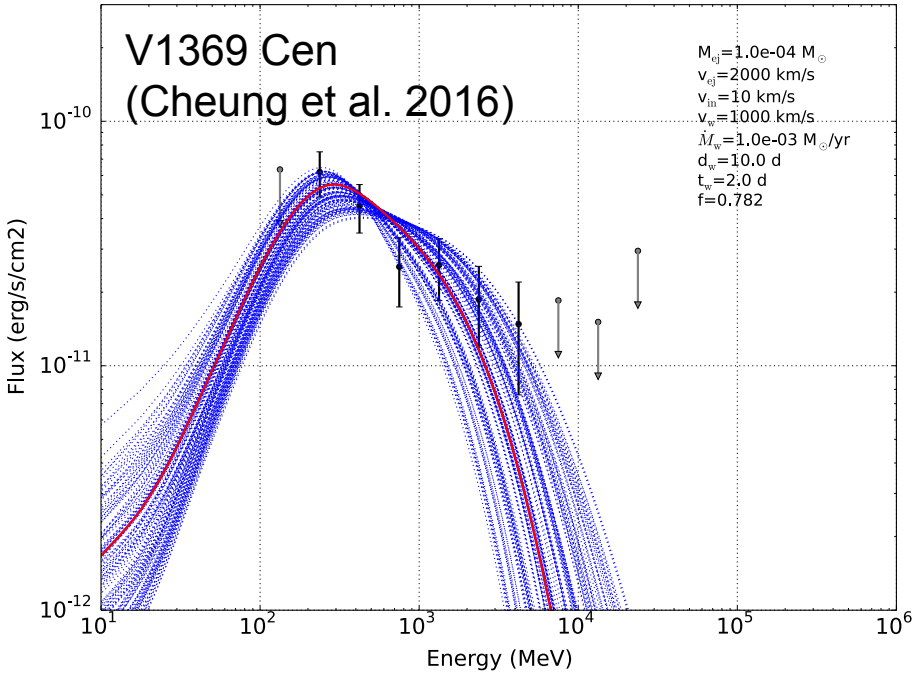
Protons accelerated **<TeV**
Electrons exhausted by synchrotron losses
Gamma-rays > 100MeV dominated by **pion decay**

Novae as particle accelerators – classical novae

- Gamma-rays as a **probe of mass ejection**
- LAT data favour nova wind < 2000 km/s
- Poor prospects for detection at TeV energies (CTA)

Martin et al. (2018)



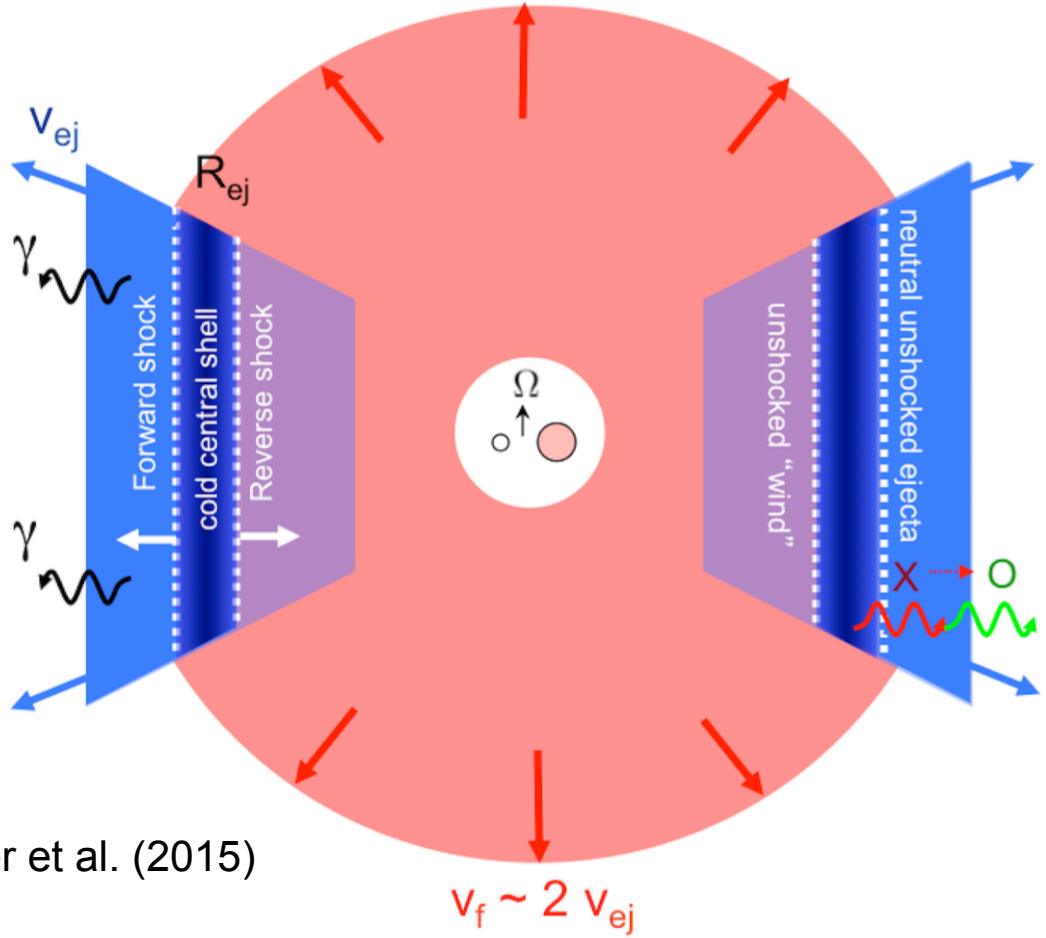


Most other parameters of internal shock scenario **poorly constrained**
Need additional information on shock dynamics from X-rays/optical

The light from novae

- Internal **shocks dissipate $10^{37\text{-}38}$ erg/s** at peak, primarily in X-rays
- Observed $L_X \leq 10^{35}$ erg/s
- High X-ray opacity in early stages…**reprocessing into optical** light !

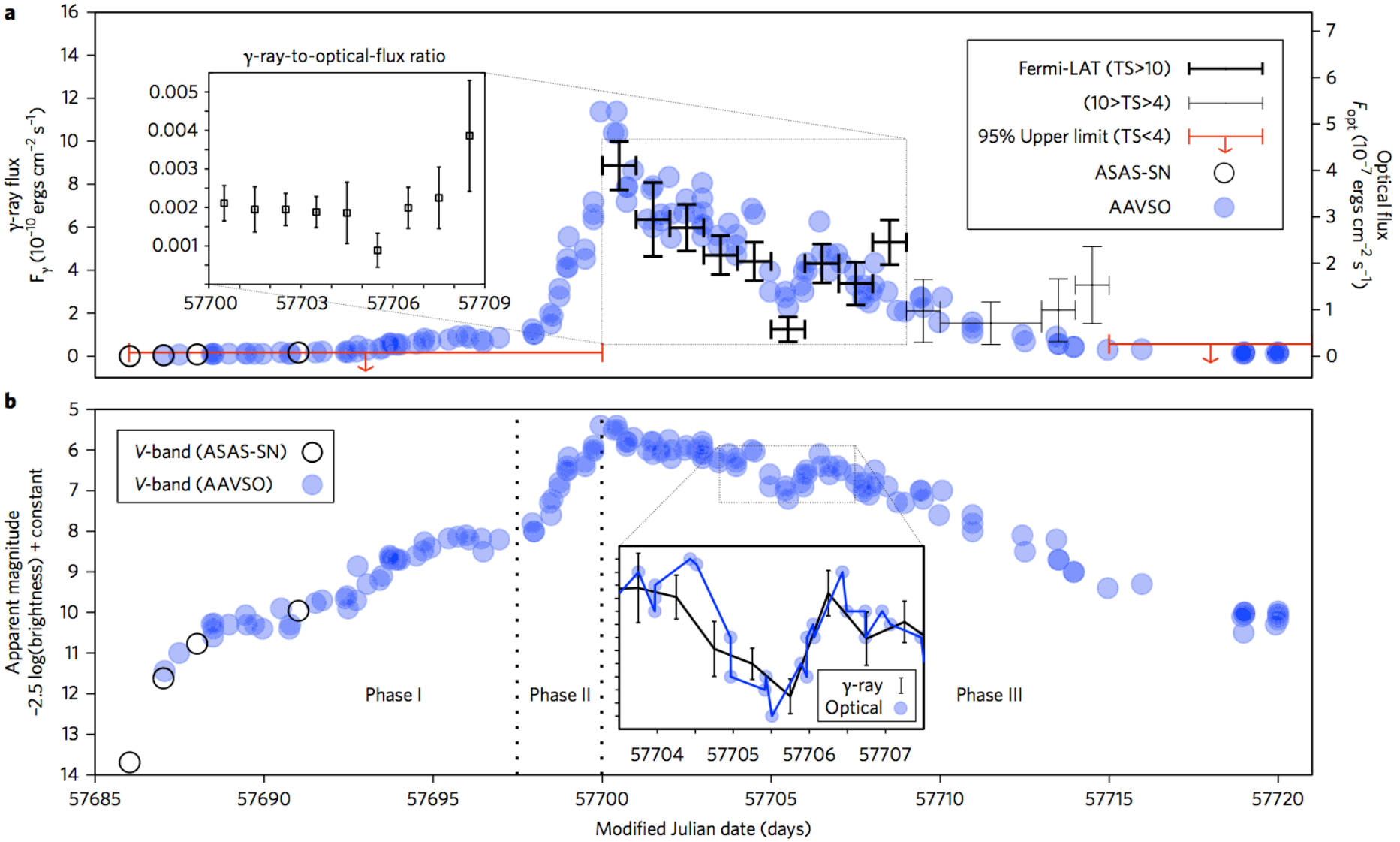
- Additional contribution to optical lightcurve (secondary maxima, plateaus)



Metzger et al. (2015)

The light from novae

- ASSASN-16ma = V5856 Sgr (Li et al. 2017)



The light from novae

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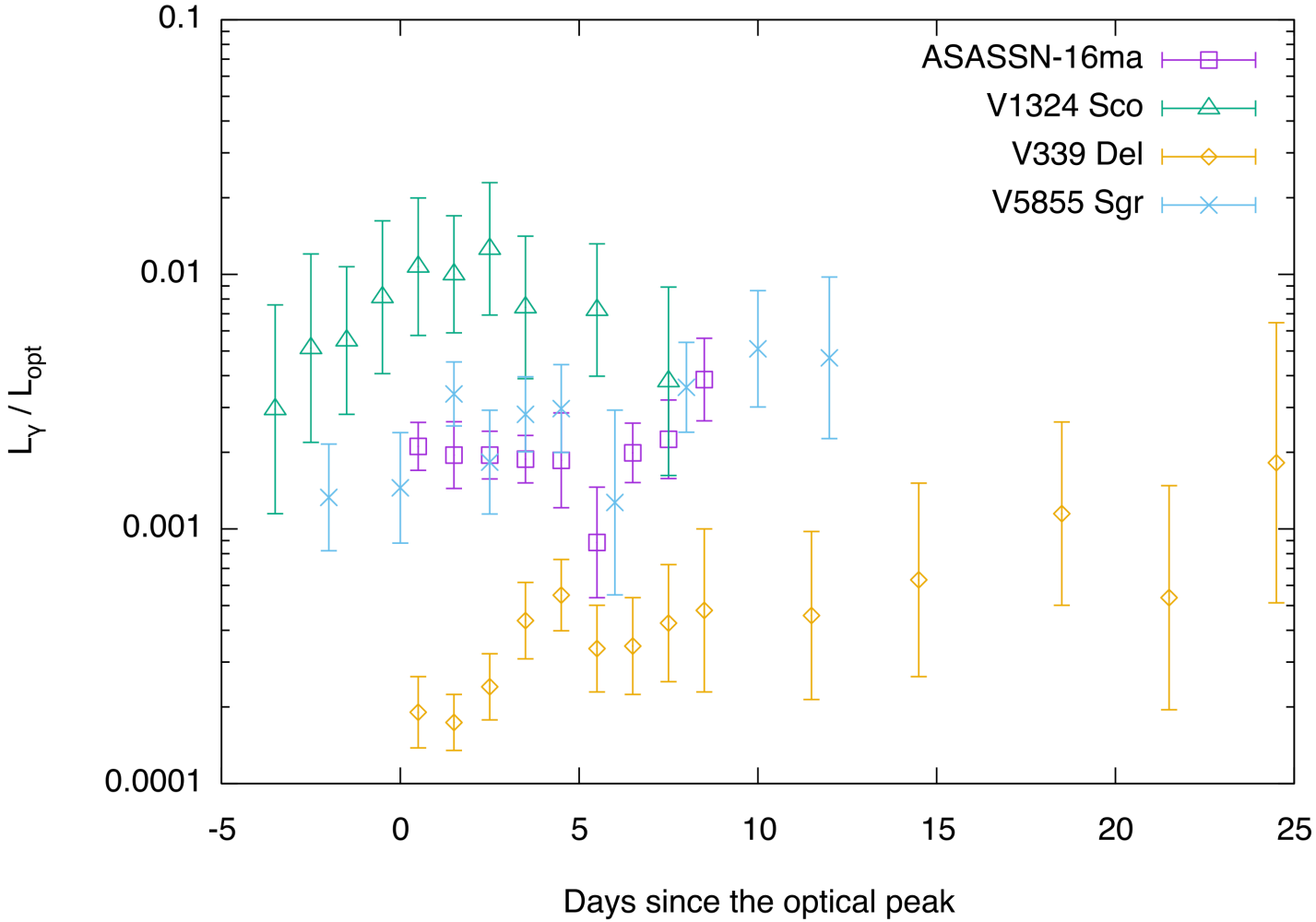
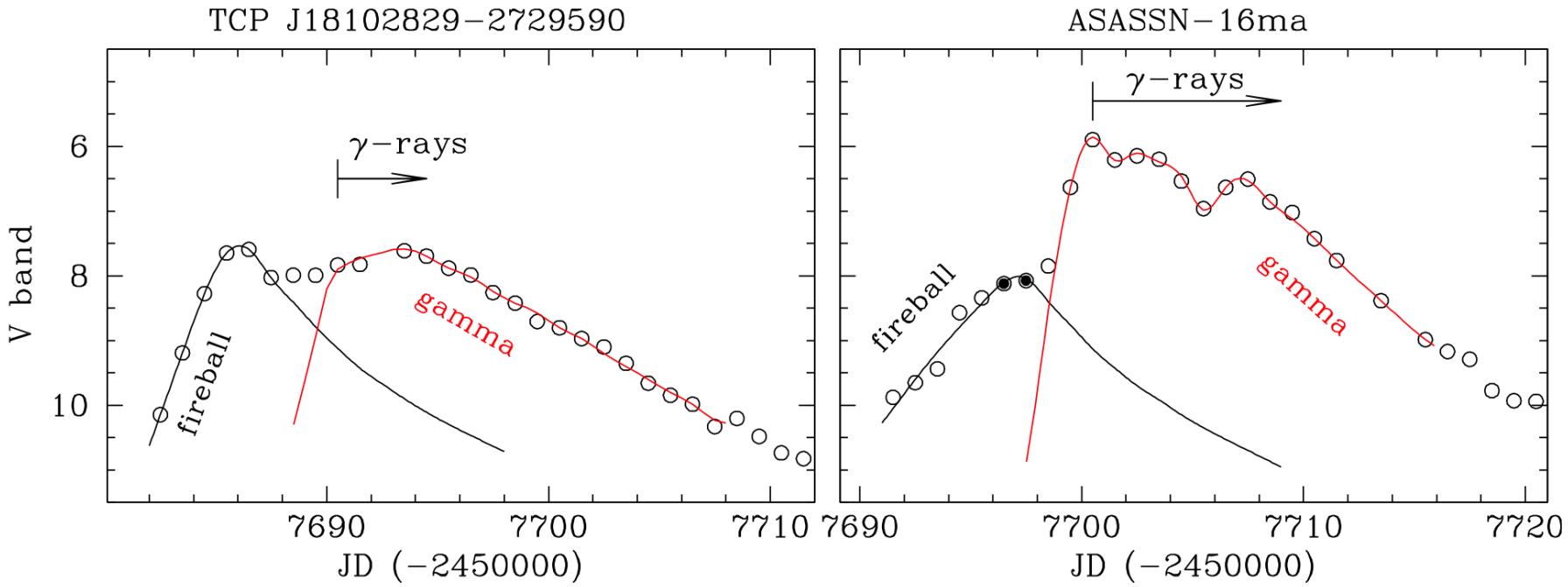


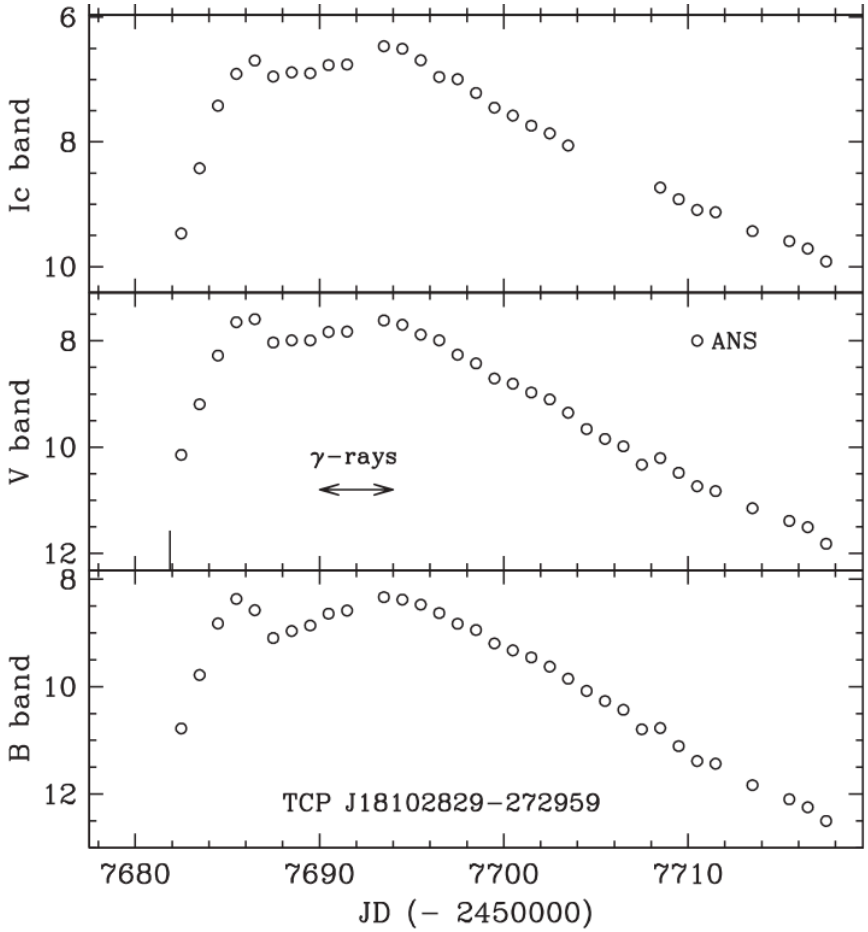
The light from novae

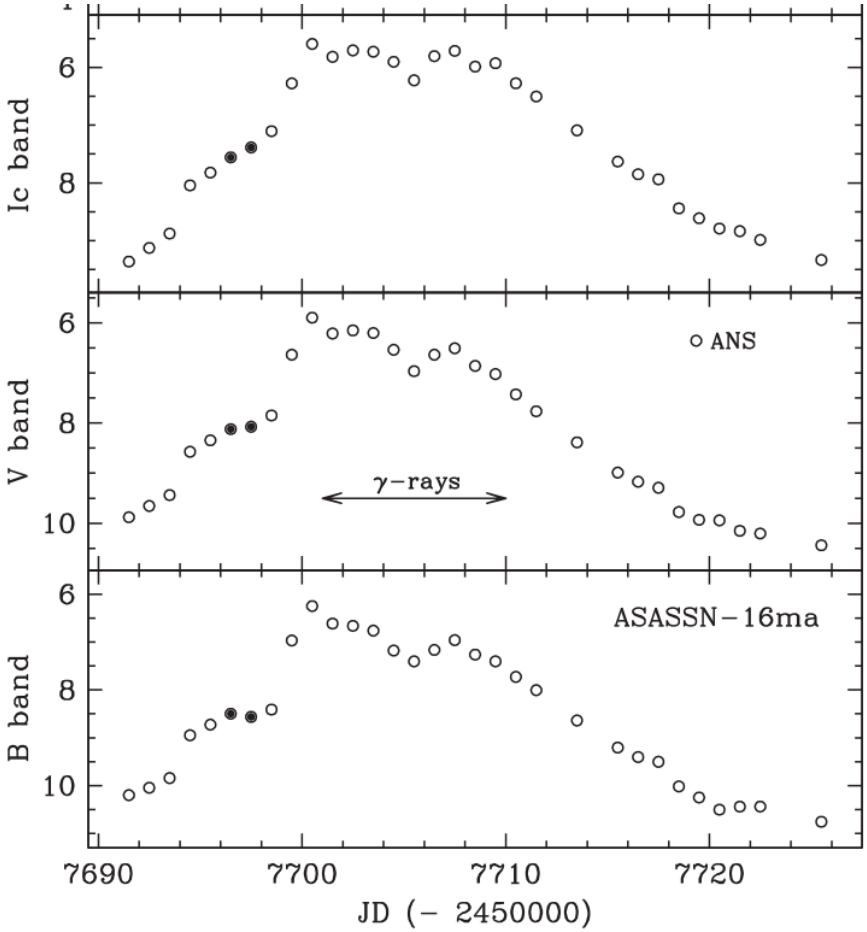
- Another possible example V5855 Sgr (Munari et al. 2017)



The light from novae

- Another possible example V5855 Sgr (Munari et al. 2017)
  - Wavelength-dependent maximum time for fireball component
  - …not the case for gamma component: different origin !



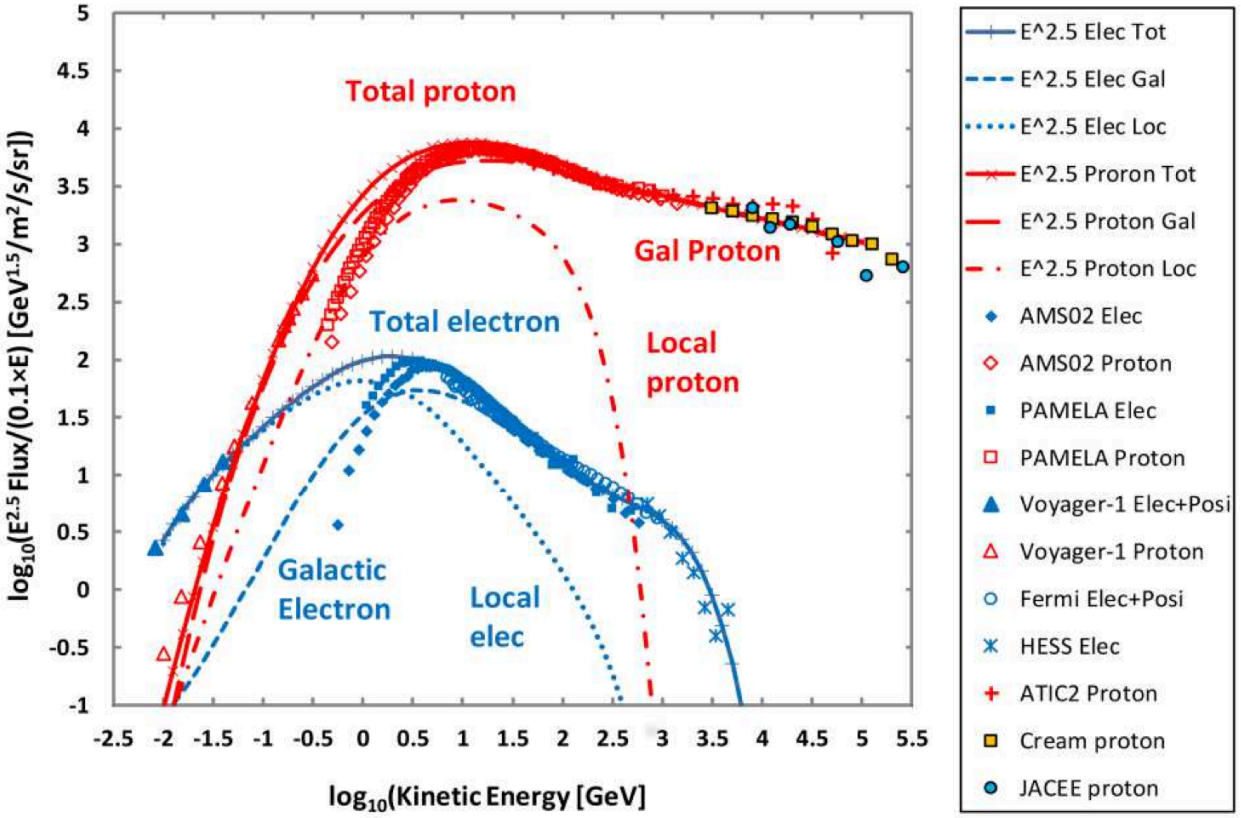


Novae as cosmic-ray sources ?

- Globally, negligible
  - Kinetic energy= $10^{44\text{-}45}$ erg/nova
  - Eruption rate 50~ novae/yr
  - At least 2000x below SNe

Novae as cosmic-ray sources ?

- Possible local effects ?
  - Kamae et al., PASJ, 2018
  - Higher WD density in solar neighborhood
  - CR trapping in local bubble
  - Explains hardening in CR spectra (and GeV hump in inner Galaxy)



Open issues (personal selection)

- Mass ejection in nova eruptions
  - What is the typical pattern for mass ejection in novae (if any) ?
  - Role of asymmetry/inhomogeneities/geometry ?
  - Which progenitor properties drive the mass ejection sequence ?

- Radio emission
  - Can we fully account for the early non-thermal radio emission ?
  - Radiation from secondaries from hadronic interactions ?
  - See Justin Linford's talk

Relation of gamma-ray novae to the whole population

- What drives the gamma-ray sample selection ?
- Can we predict gamma-ray emission from other bands ?

The way forward

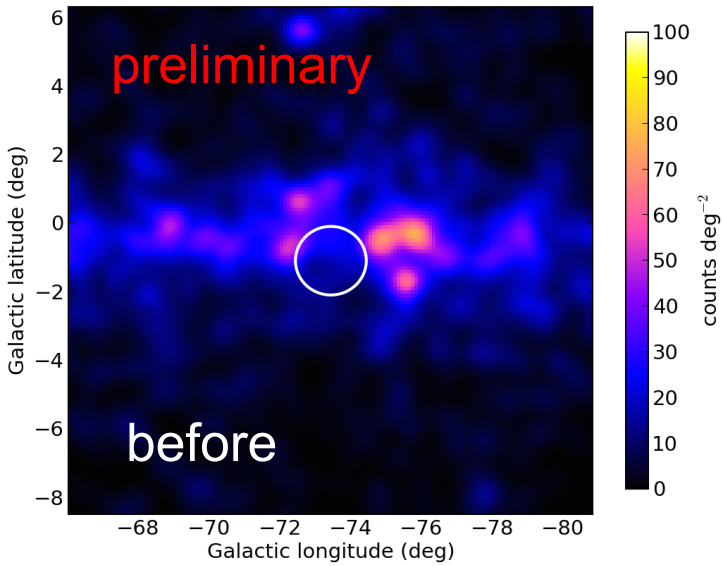
- Radiation transfer calculations
  - What kind of outflow can result from steady nuclear burning on the WD ?
  - What fraction of the internal shock power is reprocessed into optical ?

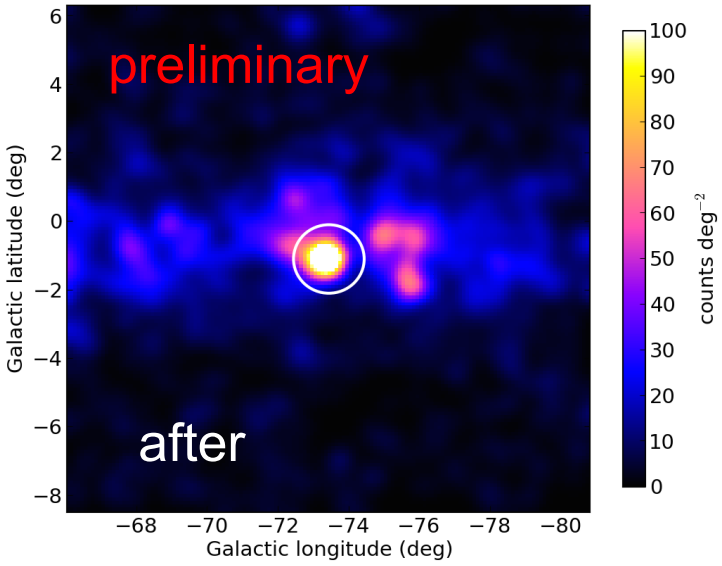
- **Fermi-LAT**
  - Expanding the detected population
  - More **high significances** objects à la ASASSN-16ma and Nova Car 2018
  - Eruption of nearby symbiotic **RS Oph and TCrB in mid-2020** !

- Associated multi-wavelenth coverage
  - X-rays (Swift, Nustar,…)
  - High cadence optical follow-up
  - Early and late radio follow-up
  - Mid-term: MeV and TeV exploration

Vurm et al. (2018), Metzger et al. (2016)

Fermi-LAT shed a new light on the nova phenomenon
… by probing the heart of the mass ejection process
… and helping connect various observables into a coherent picture





Nova Car 2018
Most significant
Highest-energy photons