U.S. NAVAL RESEARCH LABORATORY

Fermi Gamma-ray Space Telescope

The Population of Gamma-ray Emitting Novae

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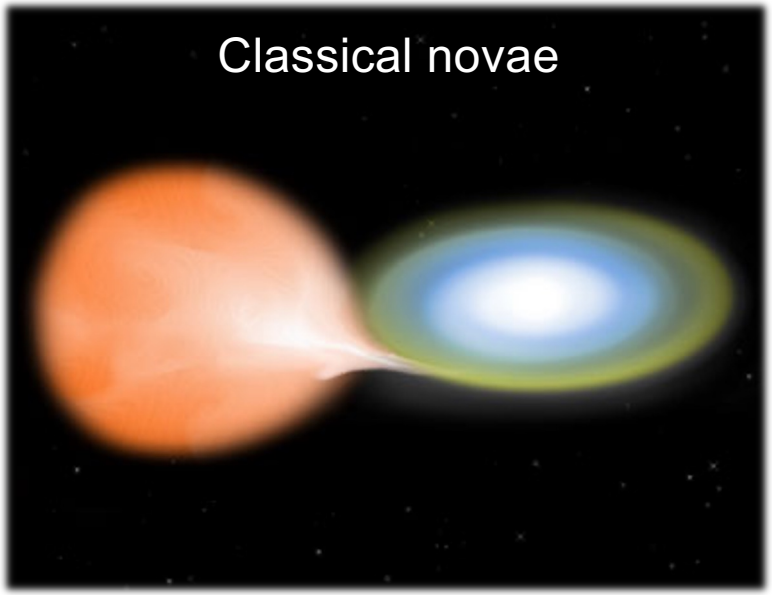
White Dwarfs in Close Binary Systems

Compact cataclysmic variable:

WD + Main Sequence

↓

Roche lobe overflow



- separations ~ $R_\odot$
- orbital periods ~ hours
- recurrence times $\gtrsim 10^4$ yr
- rate ~ 30 – 50 / yr in Galaxy

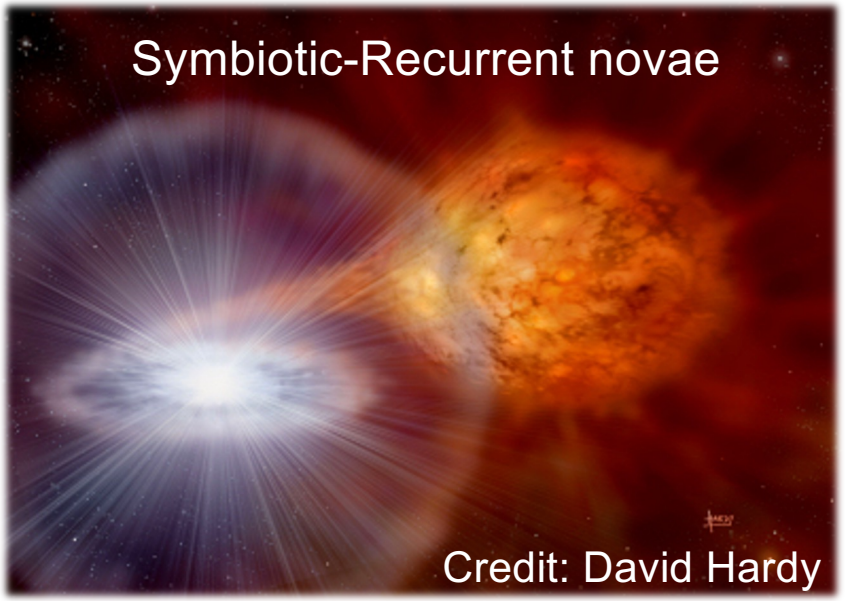
Hydrogen burning in degenerate conditions on top of the white dwarf

Symbiotic system:

Massive WD + Red Giant

↓

accretion from red giant wind



- separations ~ 100's $R_\odot$
- orbital periods ~ years
- recurrence times < 100 yrs
- ~10 known symbiotic/recurrents

Adapted from M. Hernanz, X-ray Universe 2011 talk

Fermi-LAT >0.1 GeV Novae: 2008 - 2015

Compact cataclysmic variable:

WD + Main Sequence

↓

Roche lobe overflow

(Ackermann+14, Cheung+16)

Symbiotic system:

Massive WD + Red Giant

↓

accretion from red giant wind

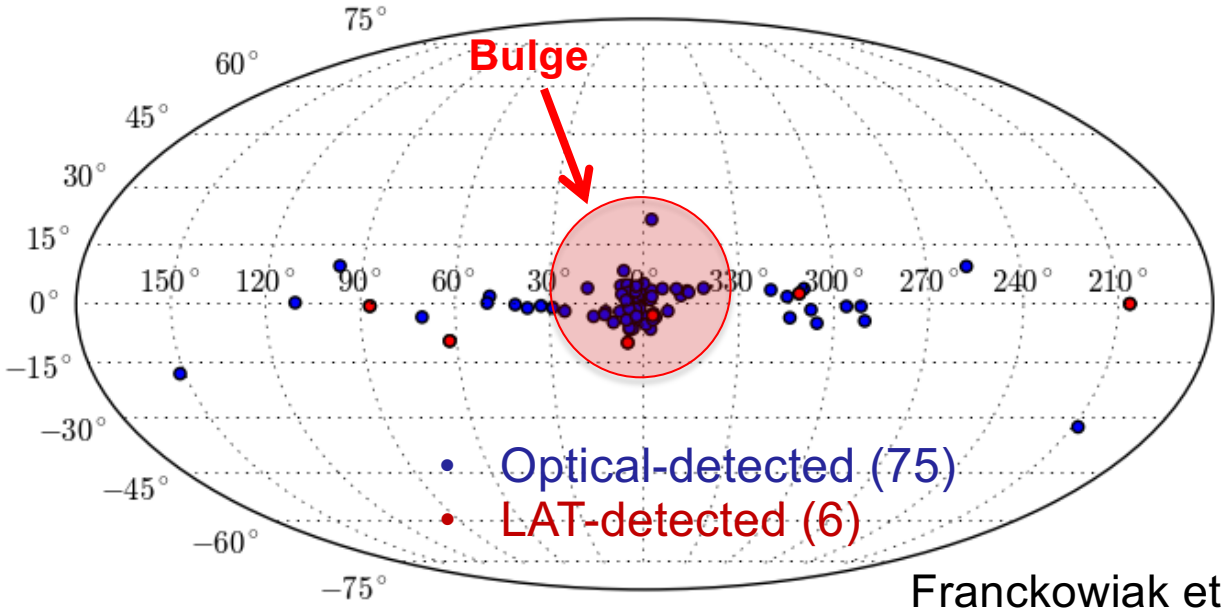
(Abdo+10)

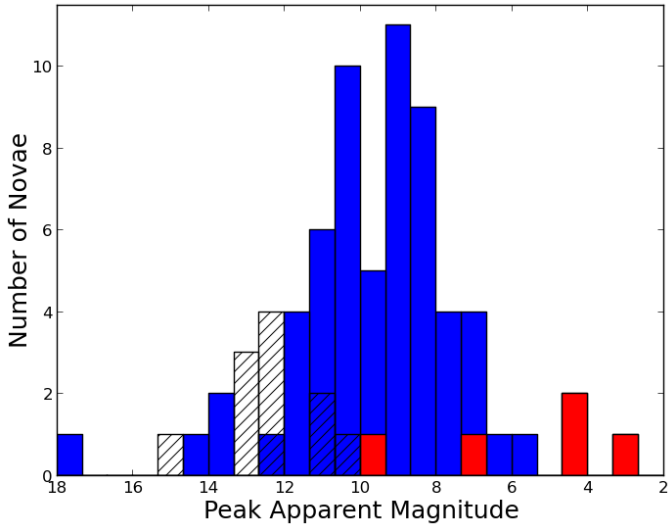
• Other systems at 2σ (Franckowiak+18)

• Non-symbiotic recurrents were ***not*** detected (Franckowiak+18)

Fermi-LAT >0.1 GeV Novae: 2008 - 2015

- Fermi-LAT search of 75 Galactic novae from Aug 2008-Dec 2015
- **LAT** detected 6 total (**average ~1 per year**)





Franckowiak et al. 2018 ("1st LAT nova catalog")

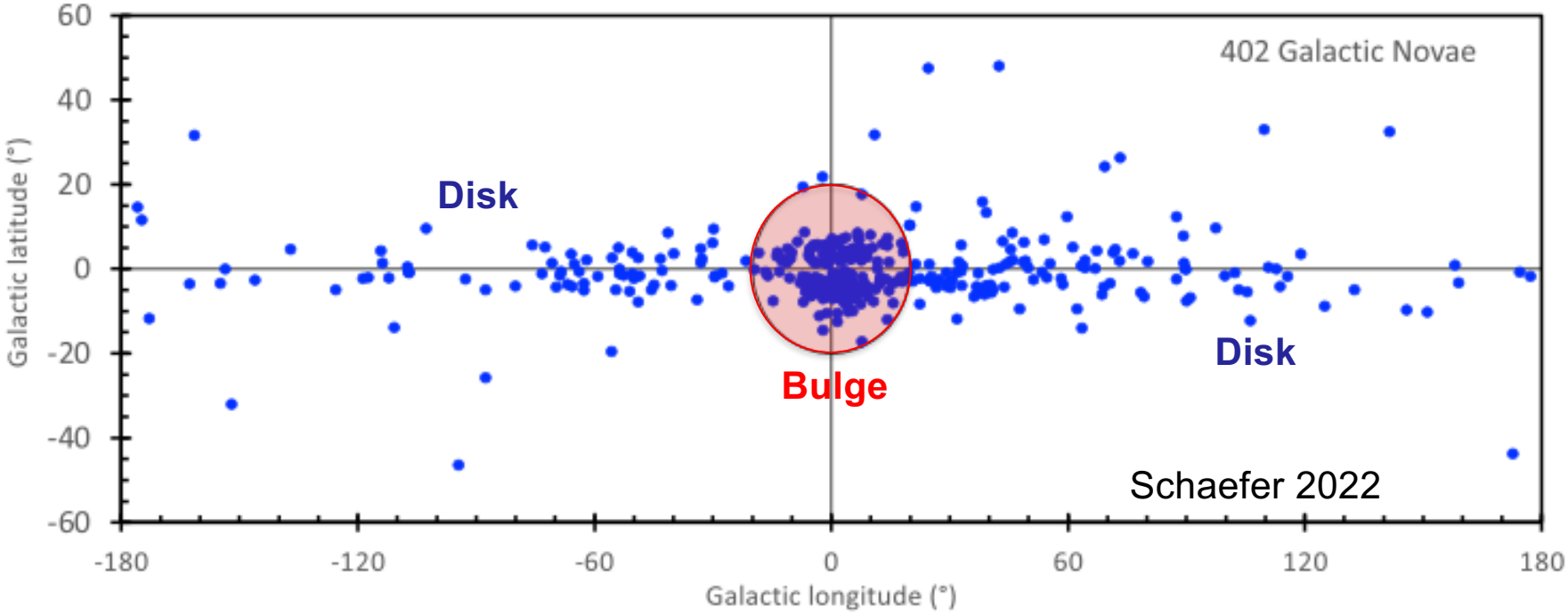
- **Average ~10 novae detections per year** in optical/IR surveys

(ASAS-SN, OGLE-IV, Palomar-IR, NEOWISE; Mroz+2015, De+2020, Kawash+ 2021, 2022)

- **Galactic nova rate ~30-50 per year implied by detection rates**

(depends on spatial distribution models adopted; e.g., Shafter 1997, 2017)

New: Distances to Galactic Novae



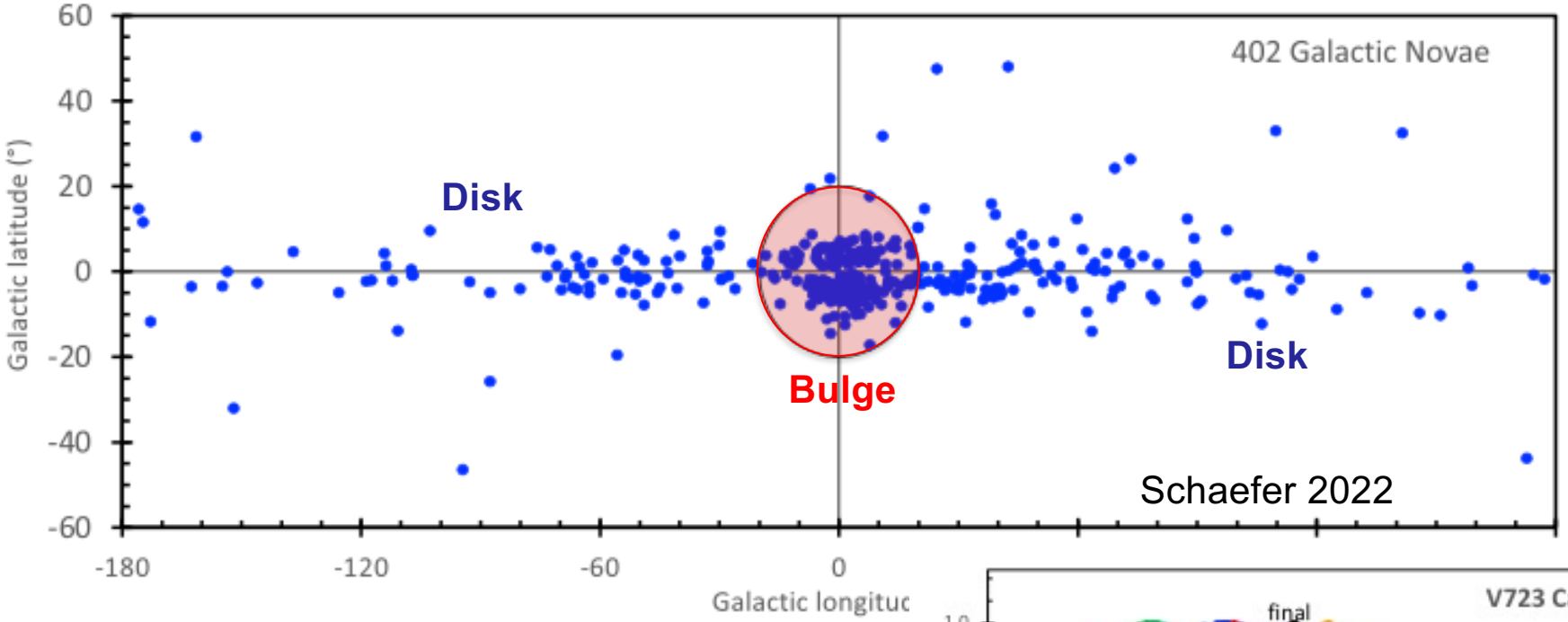
Bayesian distances to 402 Galactic novae (Schaefer 2022)

- Derived 220 distances with <30% uncertainty
- Combined Gaia DR3 parallaxes (74 w/ <30% uncertainty) & non-parallax methods
- **124 novae during Fermi era (2008 – 2021.6)**

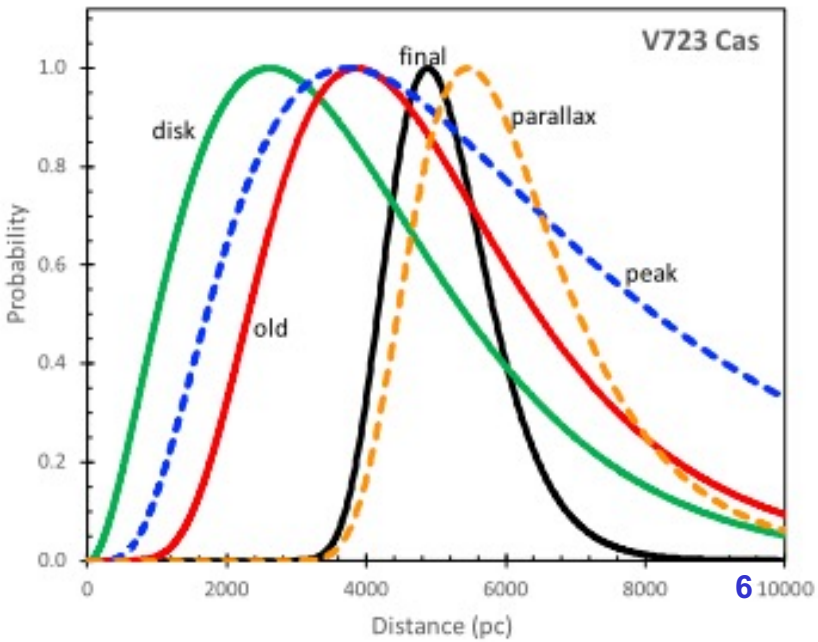
Two populations:

- ~40% in Galactic Bulge (D ~ 8.0±0.8 kpc)
- ~60% in Galactic Disk (scale height 140±10 pc), i.e., local population to Earth

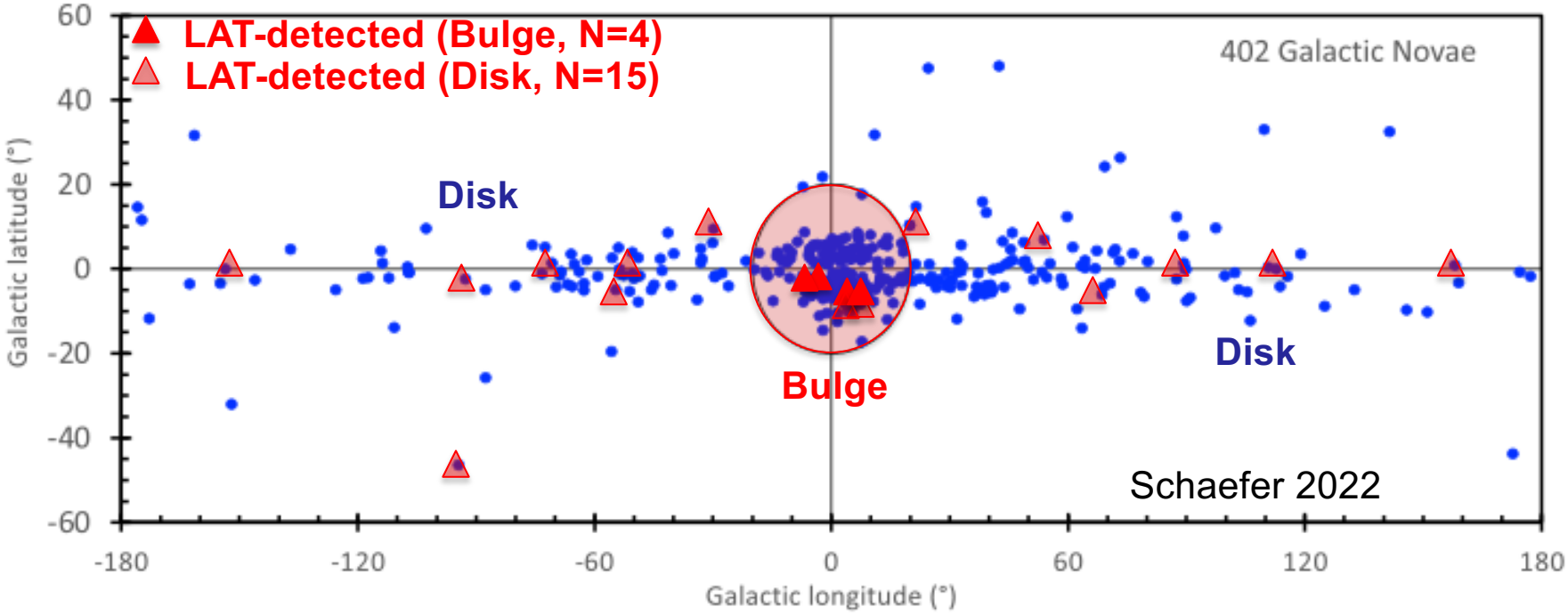
New: Distances to Galactic Novae



- 74 with <30% uncertainty from Gaia DR3 parallaxes; 215 total Gaia DR3 counterparts
- 29 expansion parallax distances (Downes & Duerbeck 2000; also Schaefer 2018)
- 81 ISM extinction-based distances (Ozdonmez et al. 2018)
- 68 peak-mag / lightcurve shape distances (Hachisu & Kato 2021)
- Handful of blackbody distances for companions
- Few from other methods



Fermi-LAT GeV Novae Population



N =19 total LAT detections from 2008 – 2022:

- N=15 LAT detections in Galactic disk (2/15 seen through the sightline of the bulge)
- N = 4 LAT detections in Galactic Bulge (including symbiotic-recurrent V3890 Sgr 2019)

* Triangles placed using powerpoint

Fermi-LAT GeV Novae: 2008 - 2022

N=19 LAT detections, 0-3 novae each year, average ~1.3 per year

Nova	D (kpc)	t_γ^a (days)	Γ^b	E_c^c (GeV)	F_γ^d (10^{-7} cm^{-2} s^{-1})	Refs	
V407 Cyg 2010	3.5 ± 0.3	22	1.3 ± 0.2	2.0 ± 0.5	3.5 ± 0.4	1,14,20	
V1324 Sco 2012	7.1 – 8.6	17	1.9 ± 0.2	7.7 ± 4.7	4.4 ± 0.9	2,14,21	
V959 Mon 2012	2.5 – 4.1	22	1.5 ± 0.3	1.3 ± 0.5	2.6 ± 0.5	2,14,22	2008 - 2015
V339 Del 2013	1.3 – 2.9	27	1.7 ± 0.2	3.0 ± 1.8	1.5 ± 0.2	2,14,23	
V1369 Cen 2013	0.53 – 1.0	39	2.0 ± 0.3	2.0 ± 1.0	2.5 ± 0.5	3,14,24	
V5668 Sgr 2015	1.0 – 1.9	55	2.1 ± 0.1	-	0.6 ± 0.1	3,14,5	"First six"
V407 Lup 2016[e]	2.3 – 4.7	3	2.2 ± 0.3	-	1.6 ± 0.7	4,5	
V5855 Sgr 2016	7.3 – 8.8	26	2.3 ± 0.1	-	3.0 ± 0.8	6	
V5856 Sgr 2016[f]	2.3 – 6.0	15	1.9 ± 0.1	5.9 ± 2.6	5.4 ± 0.5	7,5	
V549 Vel 2017[g]	1.8 – 5.1	33	1.8 ± 0.2	-	0.4 ± 0.2	8,5	2016 - 2020
V357 Mus 2018	2.5 – 5.1	27	2.2 ± 0.1	-	1.3 ± 0.2	5	
V906 Car 2018[h]	2.9 – 7.6	> 20[i]	1.8 ± 0.1	5.9 ± 1.1	12.2 ± 0.4	9	
V392 Per 2018	3.1 – 4.2	$\gtrsim 8$[j]	2.0 ± 0.1	-	2.2 ± 0.4	10,25	From Chomiuk+21, ARAA
V1707 Sco 2019	7.3 – 8.8	5	2.1 ± 0.2	-	2.9 ± 1.0	11,12	
YZ Ret 2020	2.2 – 2.6	18	2.2 ± 0.1	-	2.6 ± 0.2	12,13,26	

V1405 Cas 2021 1.6 – 1.8
V1674 Her 2021 2.5 – 5.4
RS Oph 2021 2.6 – 2.9

2021 - onward

V1716 Sco, **V6598 Sgr 2023; V1723 Sco 2024 (P. Fauverge's Tuesday talk)**

V3890 Sgr 2019 8.1 – 9.1

See Koji Mukai's updated list: https://asd.gsfc.nasa.gov/Koji.Mukai/novae/novae.html

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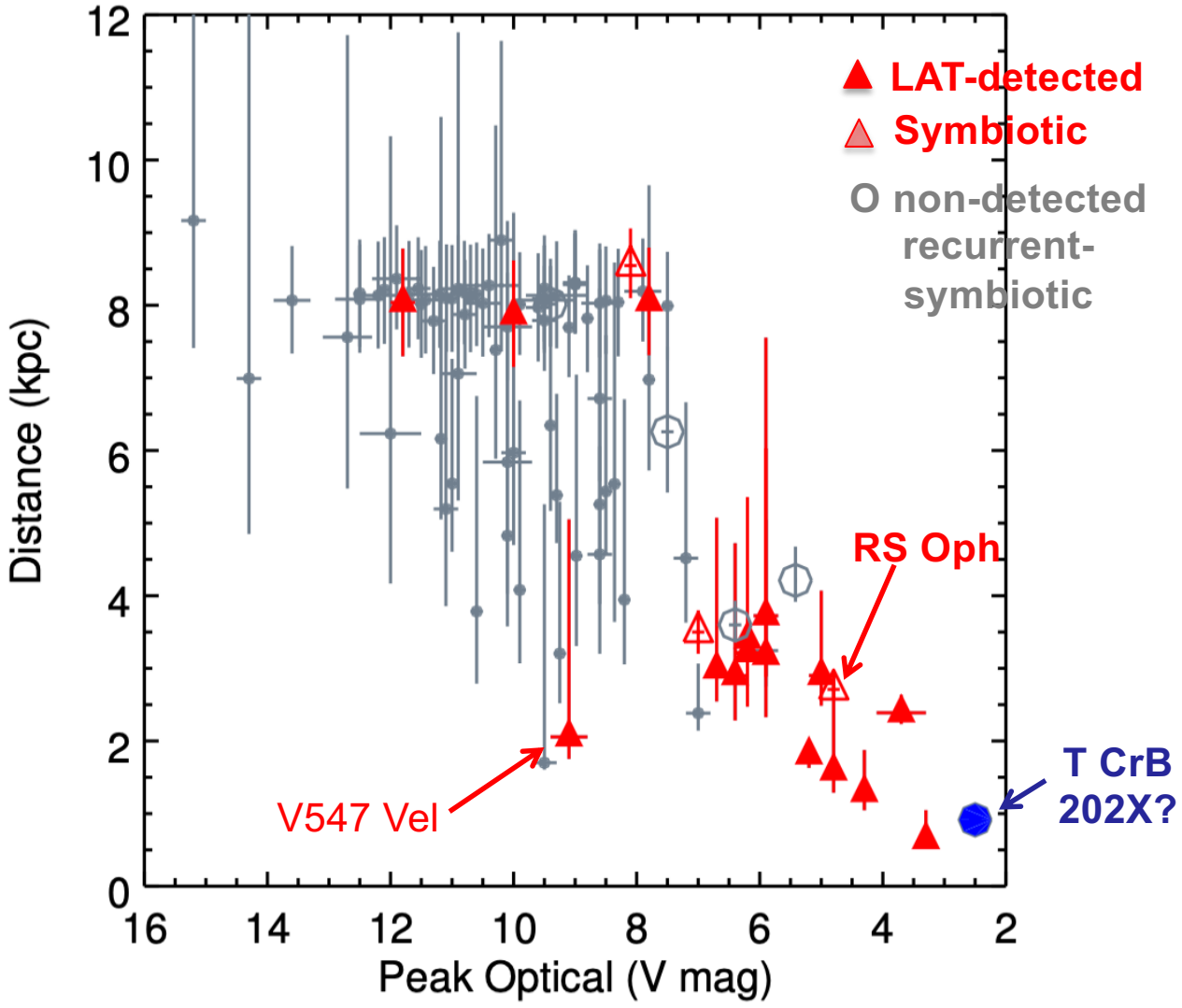

Data from Schaefer (2022), except V~5 inferred in V959 Mon 2012; added V407 Cyg 2010

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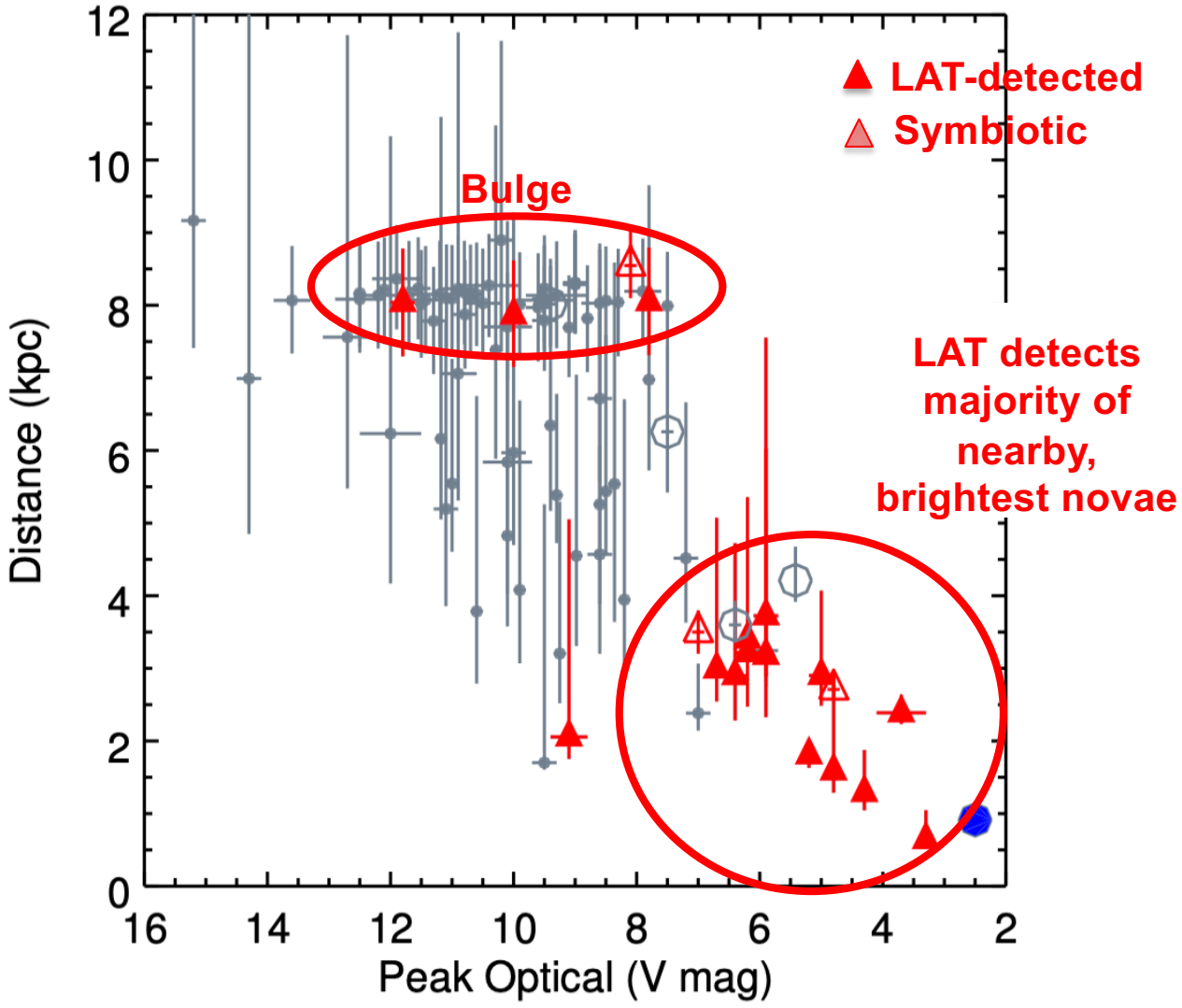

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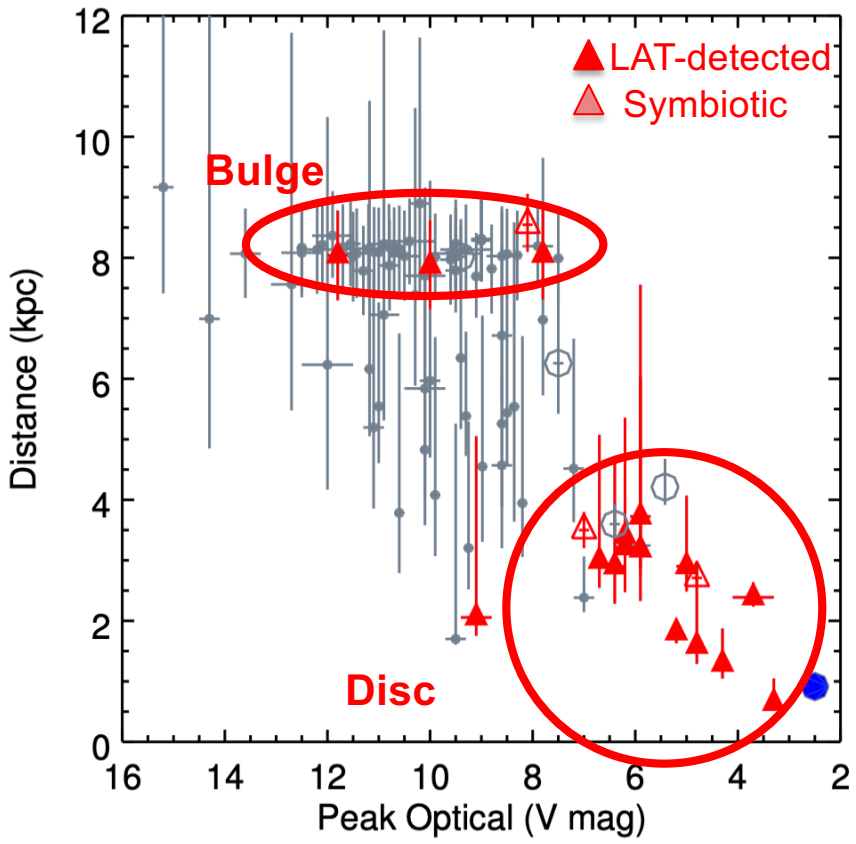
Fermi-LAT GeV Novae: 2008 - 2022

Observational Summary

- **LAT-detected novae in Galactic disc tend to be closest and brightest !**
- LAT detected 13/17 of the optically brightest novae during Fermi era. Exceptions:
  - KT Eri (V = 5.4), T Pyx (V = 6.4) are non-symbiotic (recurrent) novae
  - FM Cir (V = 5.9) – greater distance and multi-peaked; possible LAT detection in Wang+2024
  - V5583 Sgr (V = 7) viewed thru bulge

- **4 LAT detections are in the Galactic bulge with range of V peaks consistent with general bulge population** (includes symbiotic-recurrent V3890 Sgr)

(These 4 would be very unusual novae if placed in the disk)



Recurrent Novae

- Red giant wind in symbiotic systems have **outsized** role in γ-ray production, e.g., RS Oph and T CrB
- Interesting subset of optical novae in non-symbiotic recurents were not detected by LAT (U Sco 2010, 2022; T Pyx 2011, KT Eri 2009)

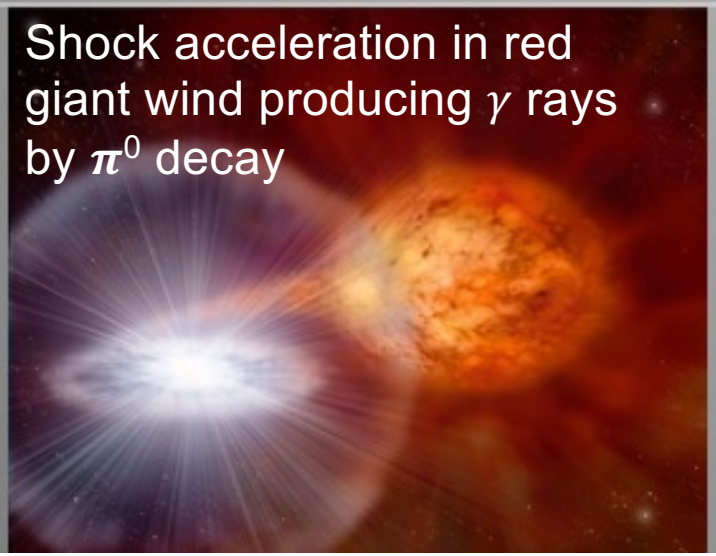
T CrB, RS Oph, V3890 Sgr, V745 Sco

Red giant secondary, P ~ few 100d

M_{WD} ~ M_{Ch}

Very fast optical decline, v_{ej} >~4000 km/s

M_{ej} ~ 10^{-7} – 10^{-6} $M_\odot$



U Sco, V394 CrA , Cl Aql (+V2487 Oph?)

Evolved/sub-giant secondary, P ~ day

M_{WD} ~ M_{Ch}

Very fast optical decline, v_{ej} ~10,000 km/s

M_{ej} ~ 10^{-7} $M_\odot$

T Pyx, IM Nor, KT Eri

MS/sub-giant secondary, P ~ hrs - day

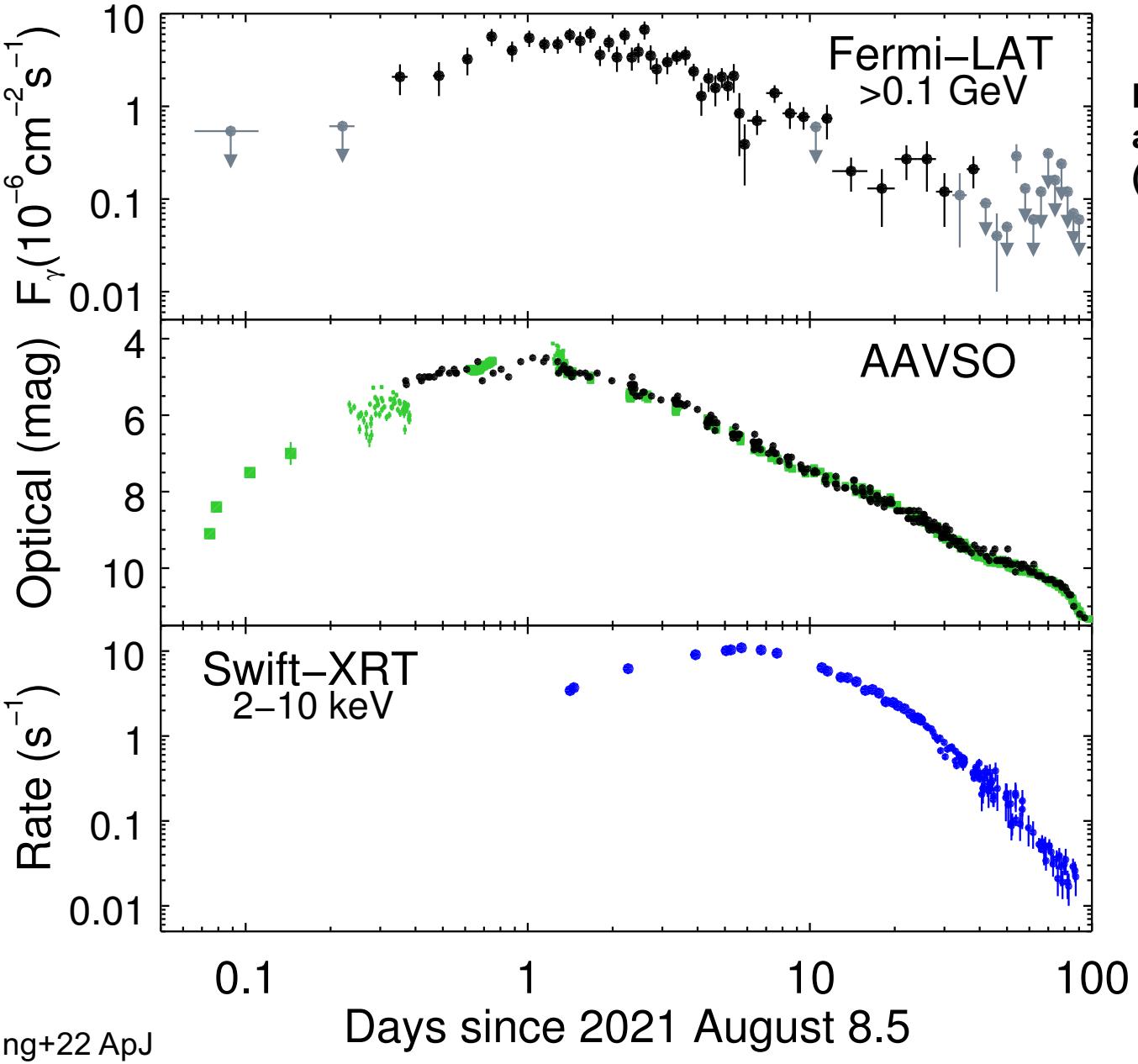
M_{WD} < M_{Ch}

Slower optical decline, v_{ej} ~800-2500 km/s

M_{ej} ~ 10^{-5} $M_\odot$, spectral development as CN

5

RS Oph 2021

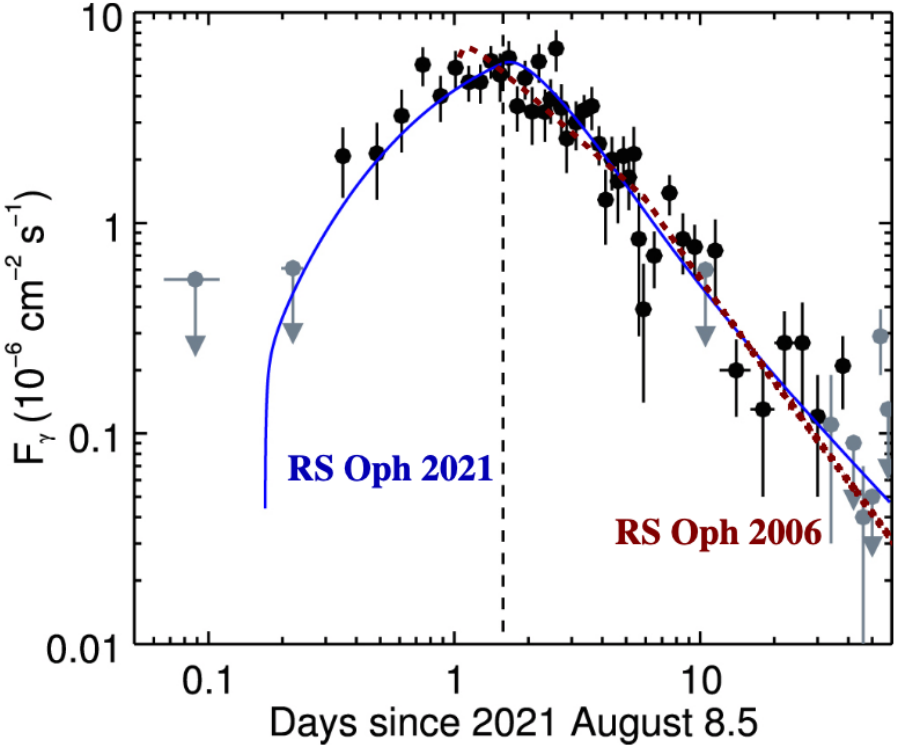


First nova detected at VHE gamma rays (HESS, MAGIC) !

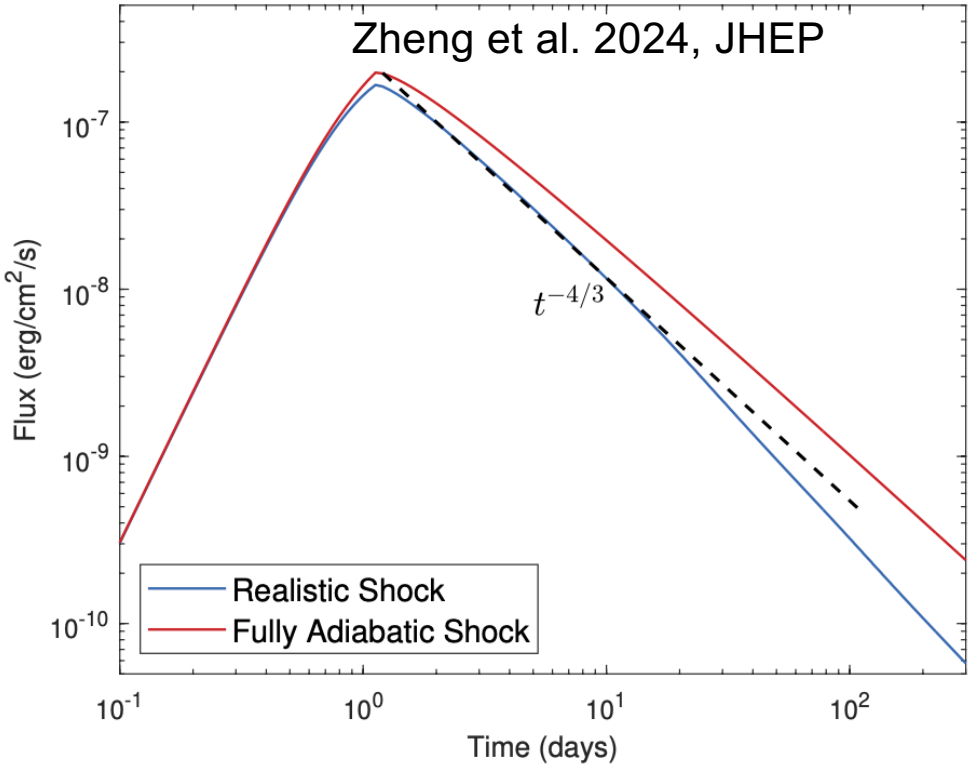
Cheung+22 ApJ

Hadronic Emission from RS Oph, T CrB

RS Oph LAT lightcurve w/ Hadronic model



Expected Fermi-LAT lightcurve for T CrB

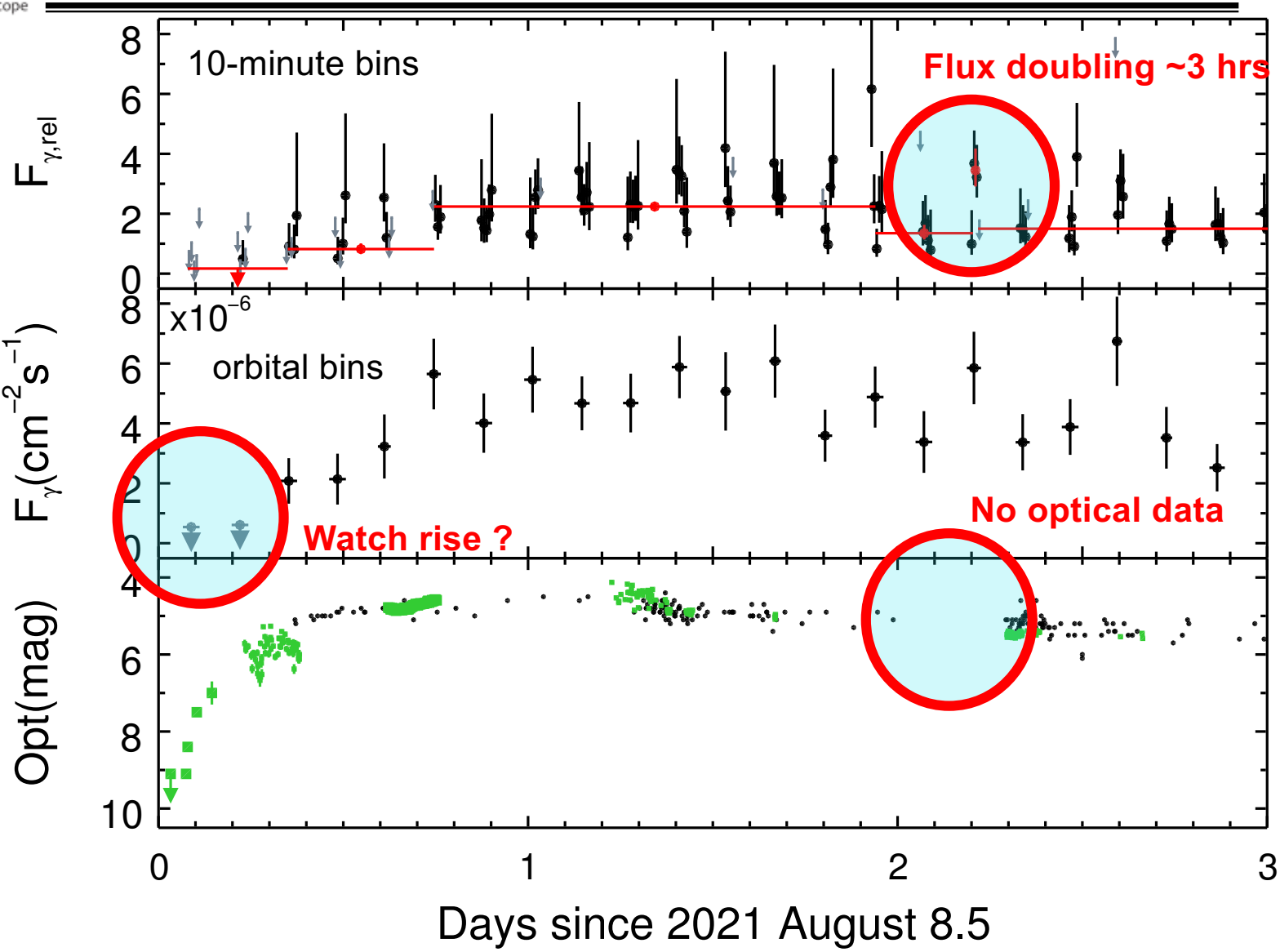


Tatischeff & Hernanz arXiv:2302.01276
Original predictions from 2006 outburst:
Tatischeff & Hernanz (2008 ApJL)

Naively scale by distance (d~ 0.9 kpc):

- **T CrB peak >100 MeV flux ~ (1-2) x 10^-5 ph/cm2/s (~1-2x Vela flux)**
- **Detectable for ~100 days**

RS Oph 2021 in detail

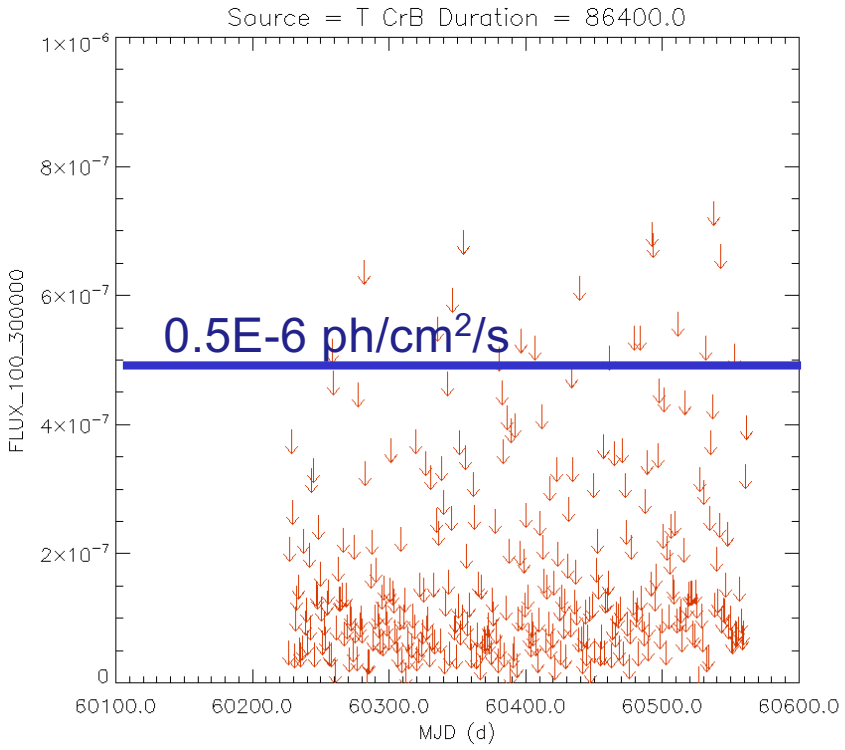


T CrB (D~0.9 kpc) will be 3-4x brighter

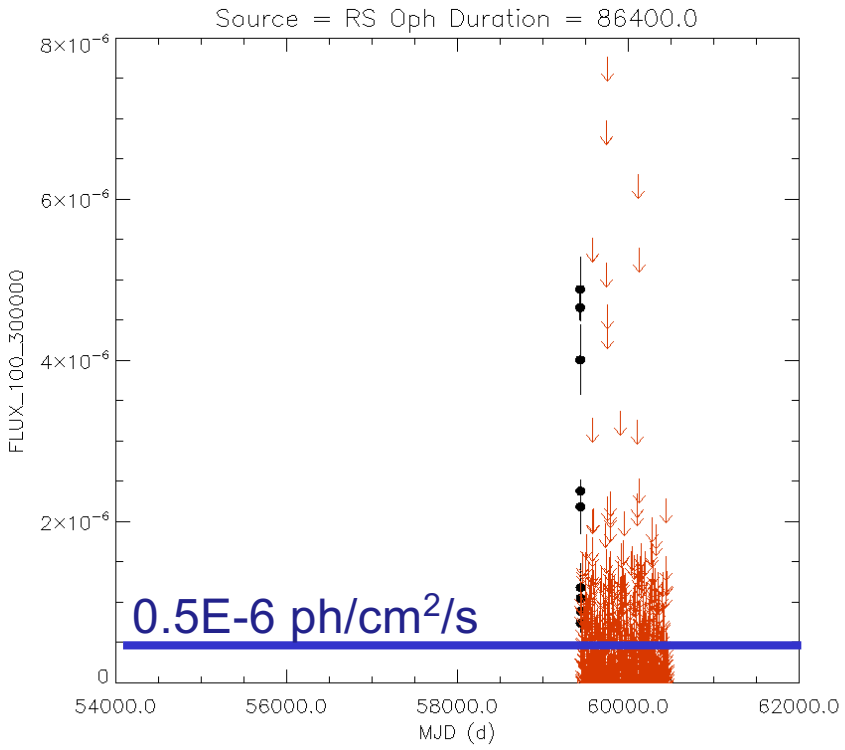
Cheung+22 ApJ

T CrB Watch: public LAT aperture lightcurve

T CrB Daily



RS Oph Daily



https://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/source/T_CrB

See Cheung et al. ATel #16336

Gamma-ray Novae

- **What we know now: are all novae GeV gamma-ray sources ?**
  - **Yes.** LAT detected majority of novae within D~4 kpc; subset of 4 novae within Galactic bulge (D~8 kpc)

- **Symbiotics (and recurrents) as keystone systems**
  - RS Oph 2021 gamma-ray data (LAT+VHE) well-matched to hadronic emission model (Tatischeff & Hernanz 2007); likely explains other symbiotics
  - Expect remarkable outburst from T CrB (D~0.9 kpc)
  - Additional outbursts from other symbiotics (RS Oph 203X?) and other recurrents

Classical novae have wide-ranging LAT properties (E. Aydi's talk)