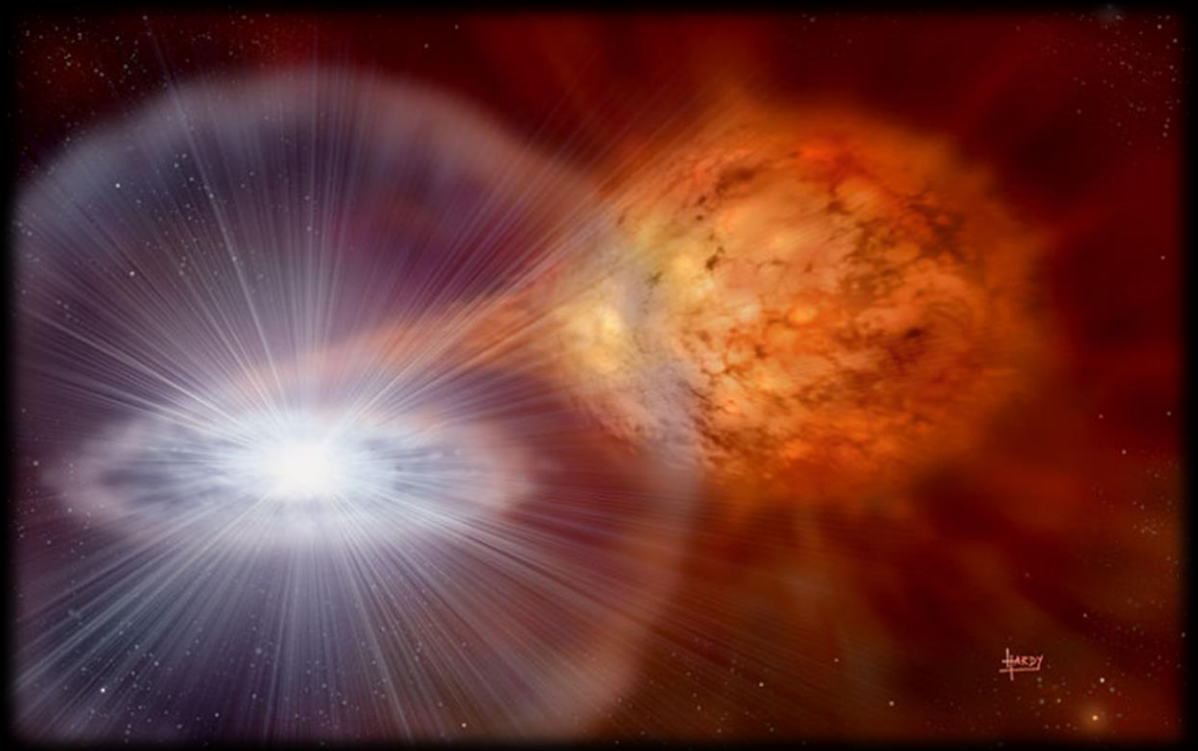
Recent Fermi novae analysis in a multi-wavelength context



Paul Fauverge, C.C. Cheung, P. Jean, on behalf of the *Fermi-LAT* collaboration, K.V. Sokolovsky, J.D. Linford, K. Mukai, J.L. Sokoloski

Introduction on Novae

Binary system with :

- 1 white dwarf
- 1 companion star

- https://www.youtube.com/wach?v=zYmd8EETy74
- Metzger et al. 2015

Introduction on Novae

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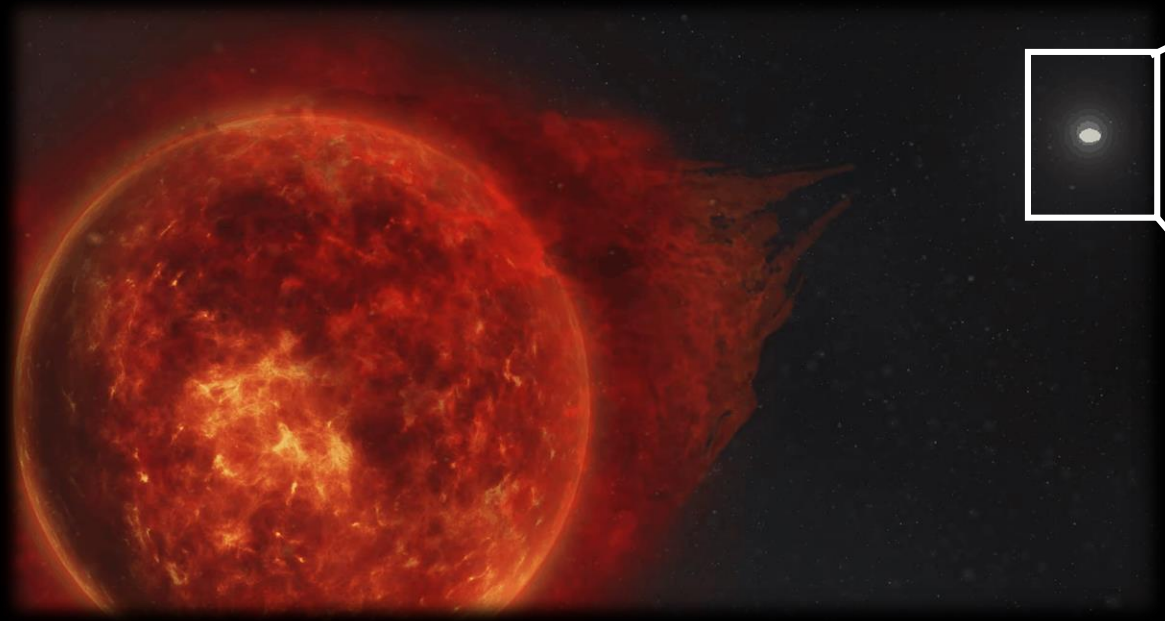
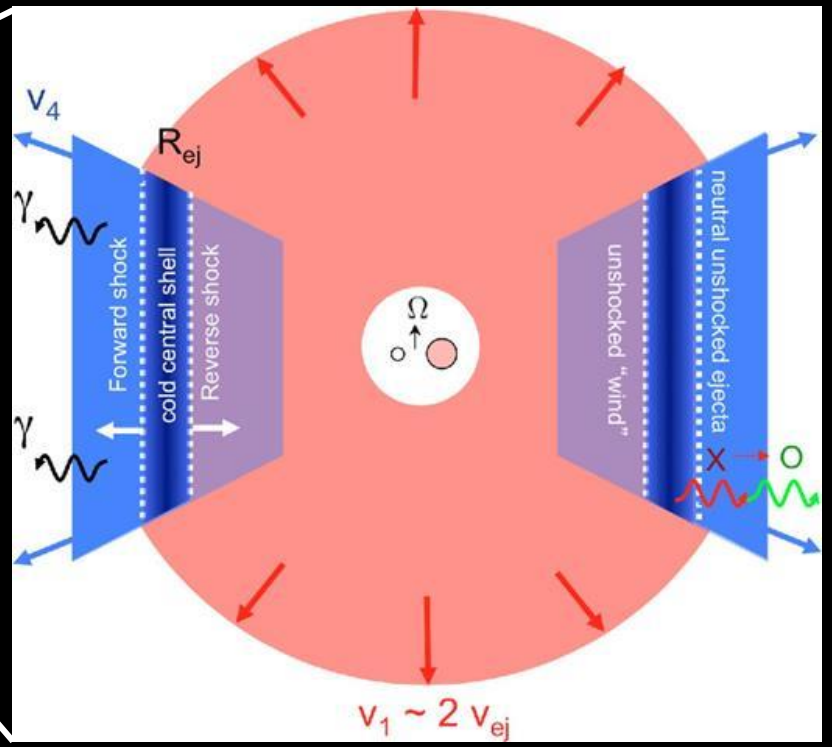


- Shocks created at the interface of the slow ejecta and the fast wind

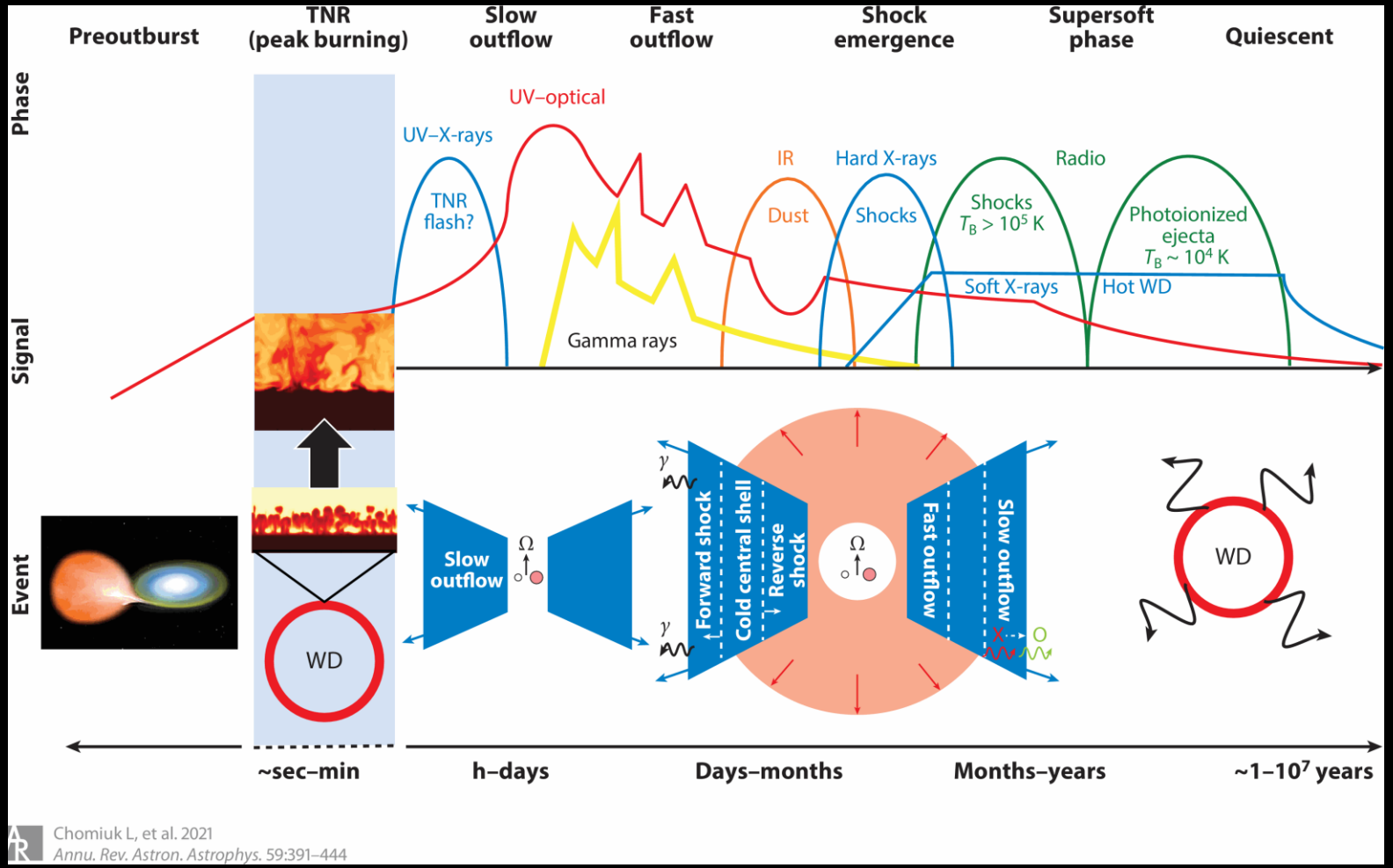


➔ **Diffusive shock acceleration**

- https://www.youtube.com/wach?v=zYmd8EETy74
- Metzger et al. 2015

Introduction on Novae

Schematic timeline of a nova (Chomiuk et al. 2021)



Chomiuk L, et al. 2021
Annu. Rev. Astron. Astrophys. 59:391–444

Study of the two last novae detected by the Fermi-LAT

V1723 Sco 2024

Days

- Previously unknown

- Binary system is an INTEGRAL source
- Not identified in the catalog but classified as mCV by Hare et al. 2021

Days

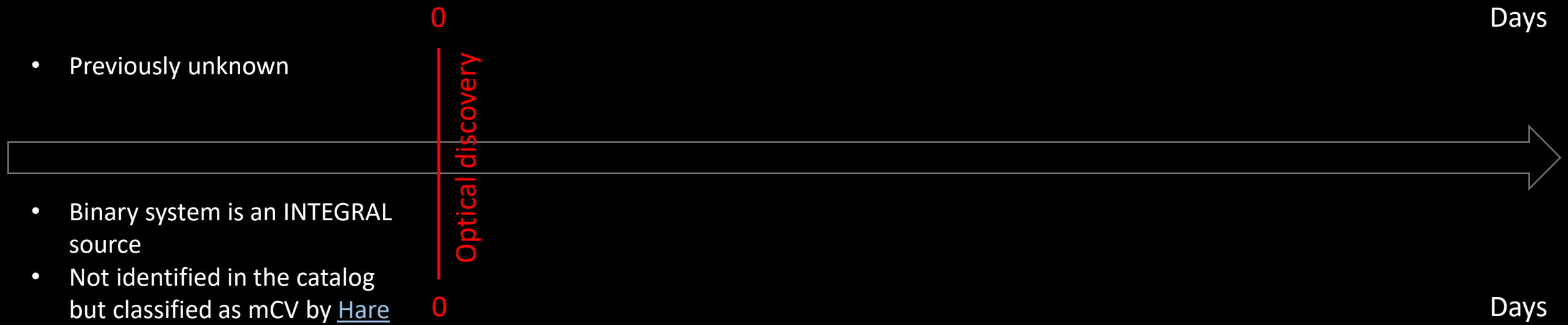
V6598 Sgr 2023

Study of the two last novae detected by the Fermi-LAT

2024-02-8.827

V1723 Sco 2024

Andrew Pearce on CBAT



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Andrew Pearce on CBAT

2023-07-15.459

V6598 Sgr 2023

Study of the two last novae detected by the Fermi-LAT

V1723 Sco 2024

2024-02-8.827

Andrew Pearce on CBAT
Cheung 2024 : ATel 16439

TS = 21

0

0.7 - 0.95

Days

- Previously unknown

Optical discovery

Fermi ATel period

- Binary system is an INTEGRAL source
- Not identified in the catalog but classified as mCV by Hare et al. 2021

0

-0.5 - 1.5

Days

4σ detection

Andrew Pearce on CBAT
Jean et al. 2023 : ATel 16151

2023-07-15.459

V6598 Sgr 2023

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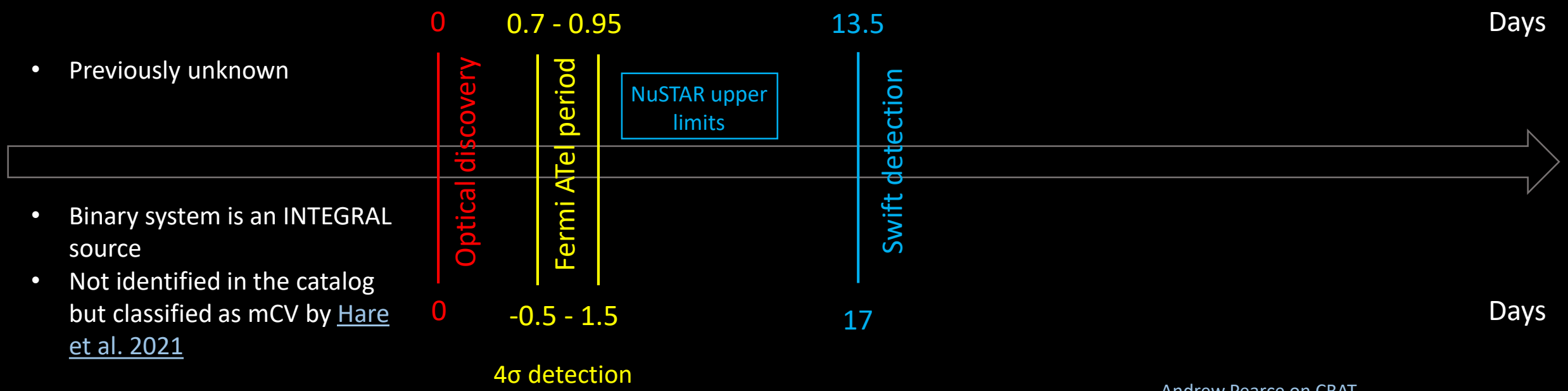
2024-02-8.827

TS = 21



4σ detection

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Andrew Pearce on CBAT
Cheung 2024 : ATel 16439
Sokolovsky et al. 2024 : ATel 16444
Sokolovsky et al. 2024 : ATel 16484

V6598 Sgr 2023

2023-07-15.459

Andrew Pearce on CBAT
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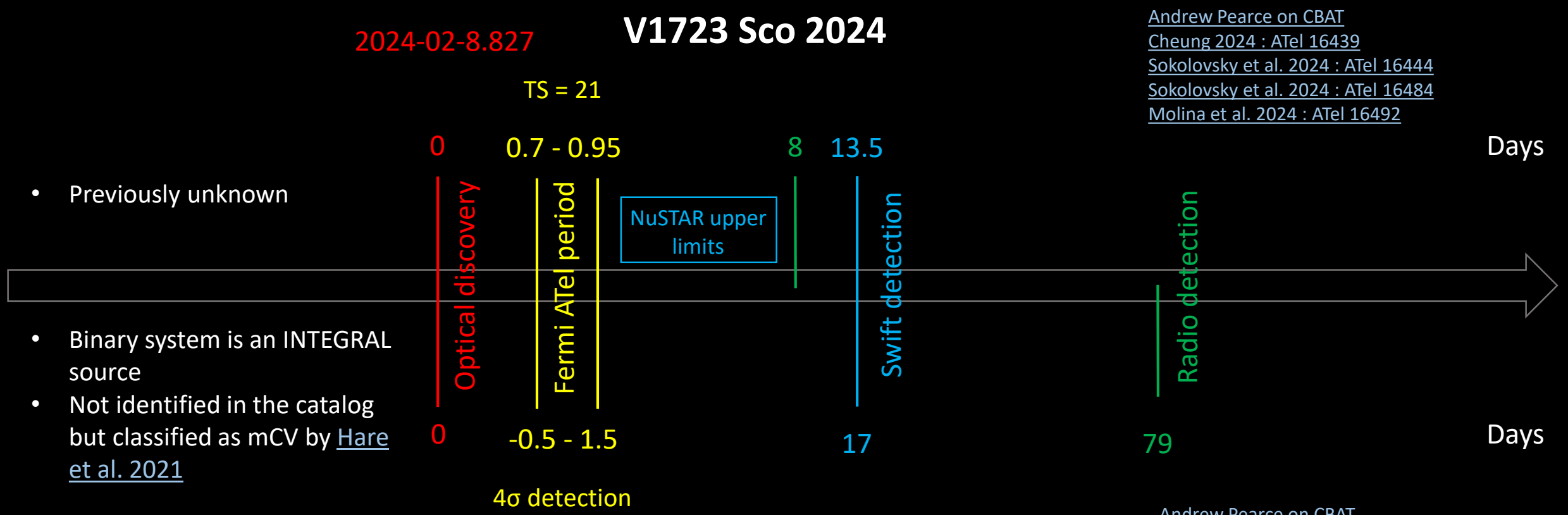
Nesci et al. 2023 : ATel 16172

Study of the two last novae detected by the Fermi-LAT



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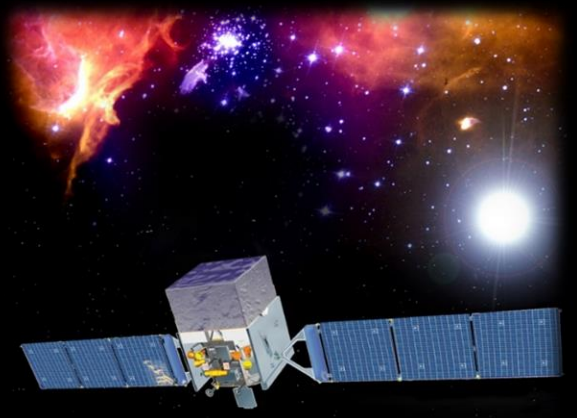
Andrew Pearce on CBAT
Jean et al. 2023 : ATel 16151
Nesci et al. 2023 : ATel 16172
Dobie et al. 2023 : ATel 16383

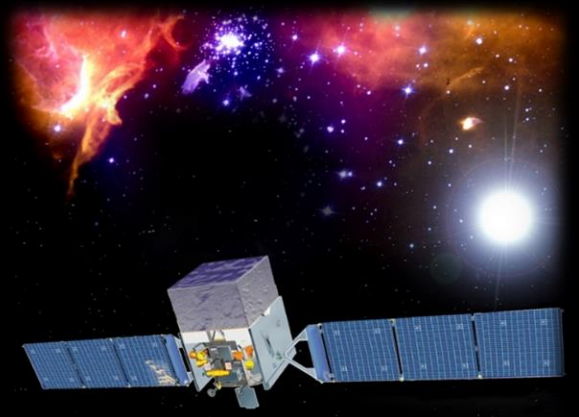
Method of LAT data analysis



- Analysis 1-year before the outburst :
  - ➔Model of the ROI (bright sources, galactic and isotropic components)
- Light curve :
  - ➔Determine the time period of analysis
- Localization of the peak in gamma-ray data
  - ➔Offset or no with respect to the optical position
- Spectral analysis
  - ➔ Calculation of the SED and find the best fit model

Analyses done using `fermipy 1.2`

Method of LAT data analysis



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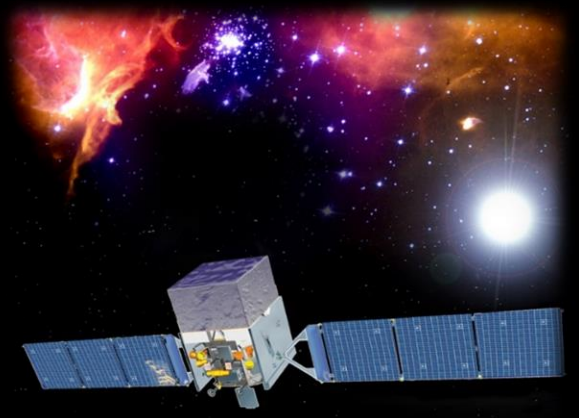

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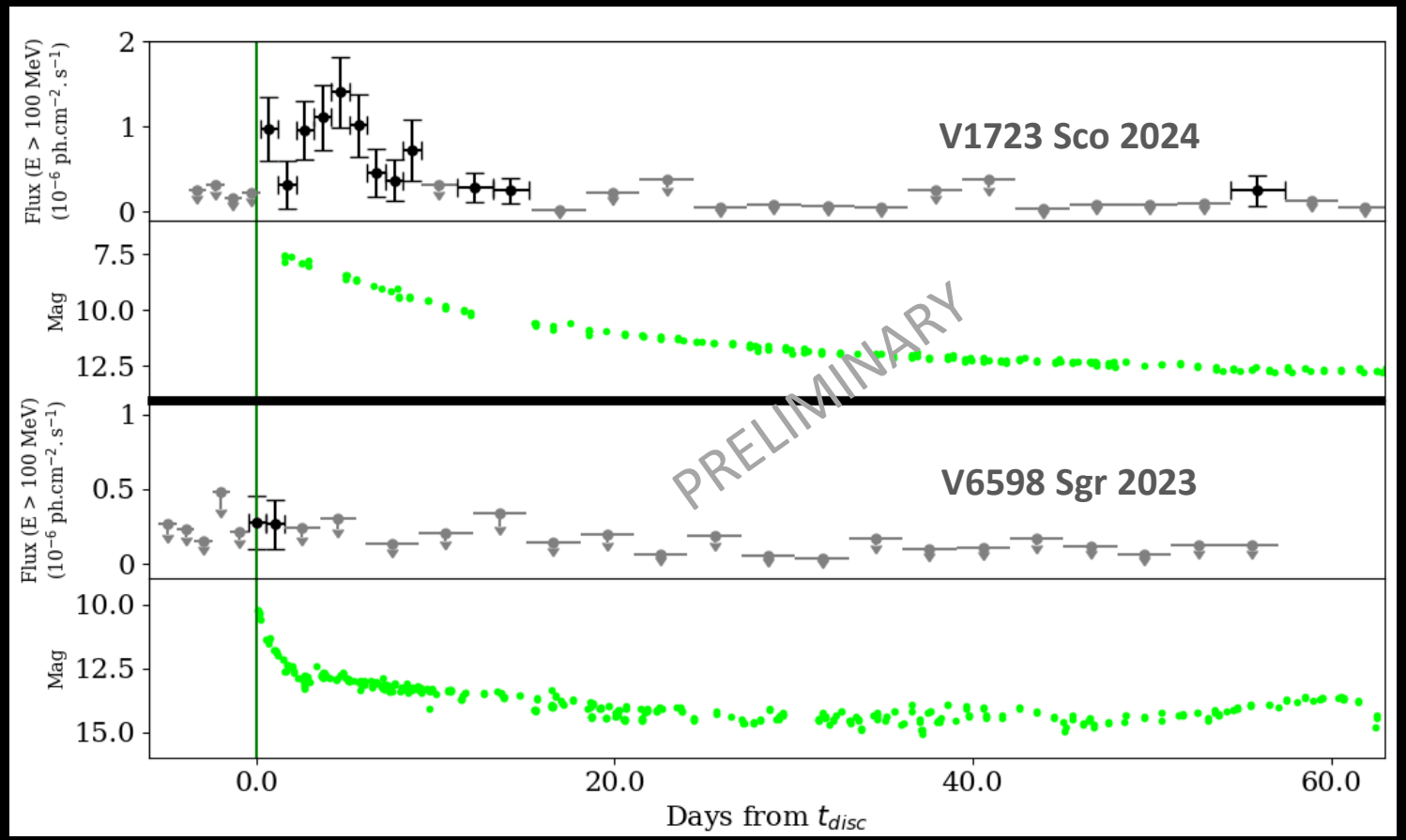
Light curves from the LAT and AAVSO

Fermi-LAT analysis :

- Analysis on ~ 60 days
- Model by a PL with Norm free to evolve
- Adapted time intervals
- Points when TS and N_{pred} > 4, 95% ULs
- t_{disc} is the time of discovery

Optical magnitude taken from the AAVSO database in the V-Band



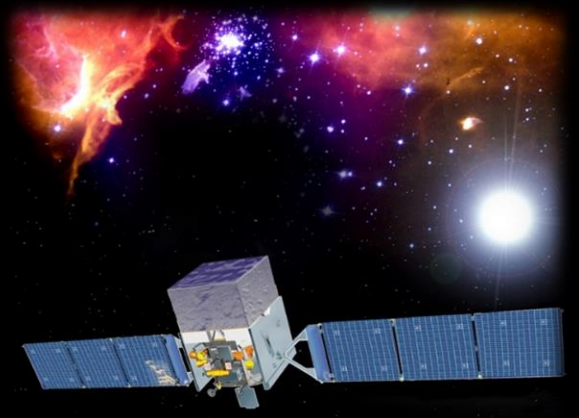
V1723 Sco 2024

Analysis period : 15 days

V6598 Sgr 2023

Analysis period : 2 days

Method of LAT data analysis



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Localization of the γ-ray peak

TS MAP :

- 15° region centered on the optical nova position
- Only the isotropic diffuse free to evolve

Localization :

- Point source with the best fit model (see spectral analysis)
- `gta.localize()` to find the peak in the γ–ray data

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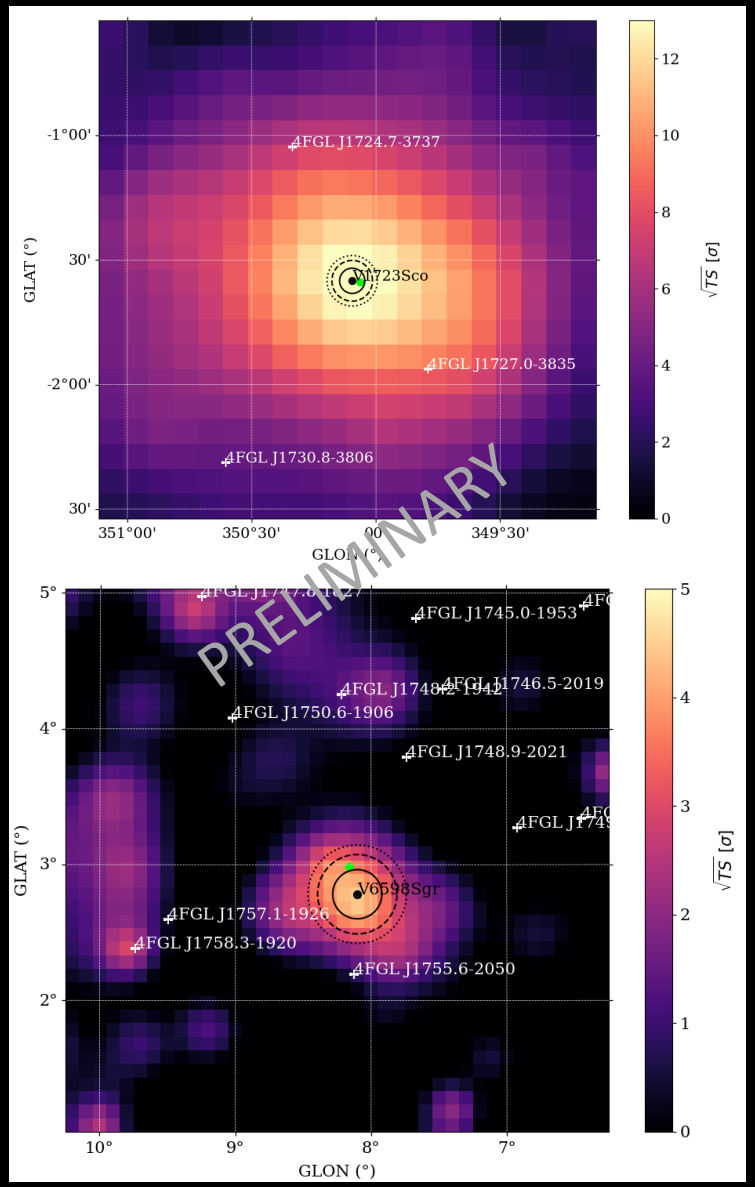

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V1723 Sco 2024

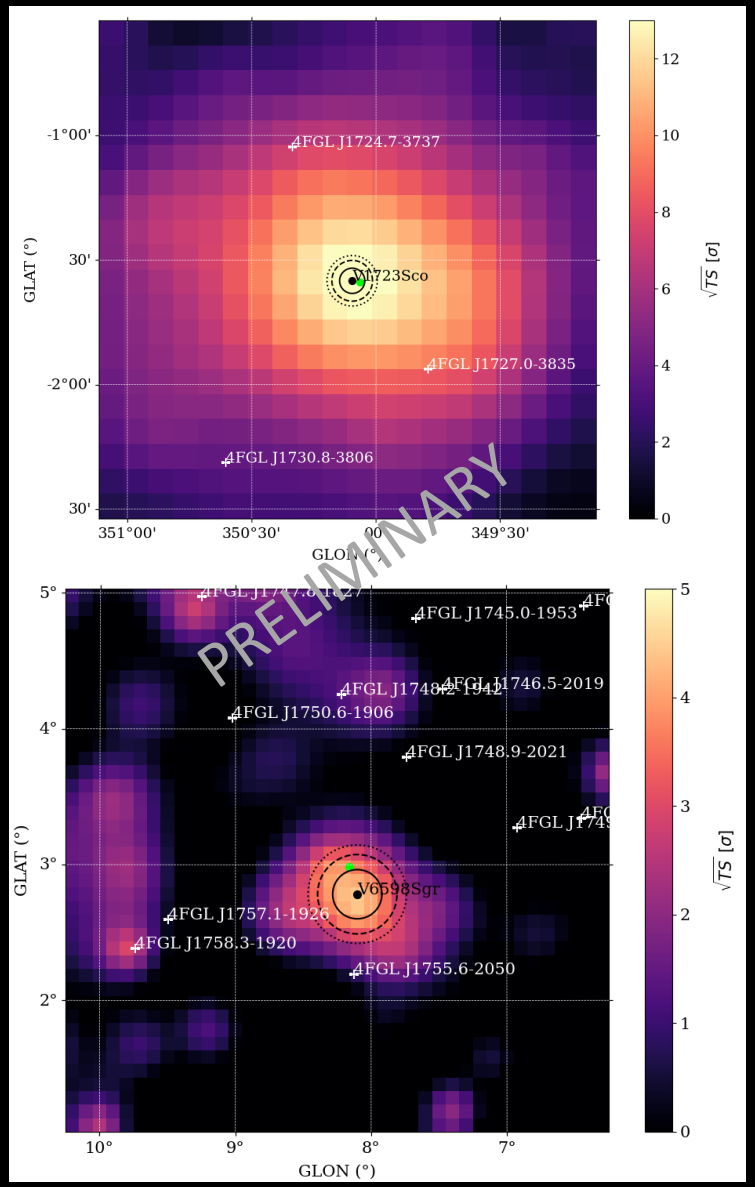
- ΔTS_{reloc} = 0.3
- Offset = 0.03°
- 95% error radius = 0.08°

Optical position for spectral analysis

V6598 Sgr 2023

- ΔTS_{reloc} = 5.8
- Offset = 0.22°
- 95% error radius = 0.29°

New position for spectral analysis



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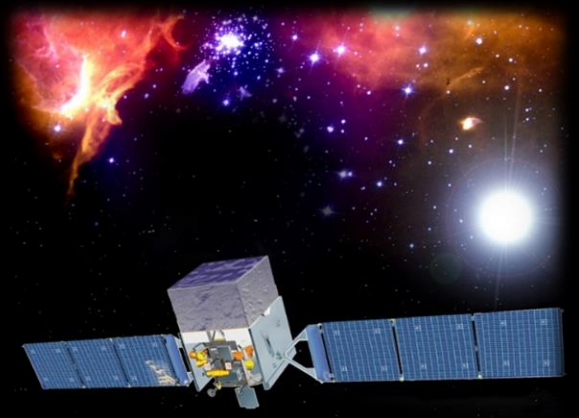

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Spectrum from the LAT

SED :

- Calculated for a PL with an index = 2
- Errors :
  - Black : statistical only
  - Red : quadratic sum of systematic and statistical errors
  - Systematics dominated by uncertainties in the galactic diffuse model
  - Points when TS and N_{pred} > 2, 95% ULs

Best Fit model :

- Test for PL, LogParabola, PLExpCutoff

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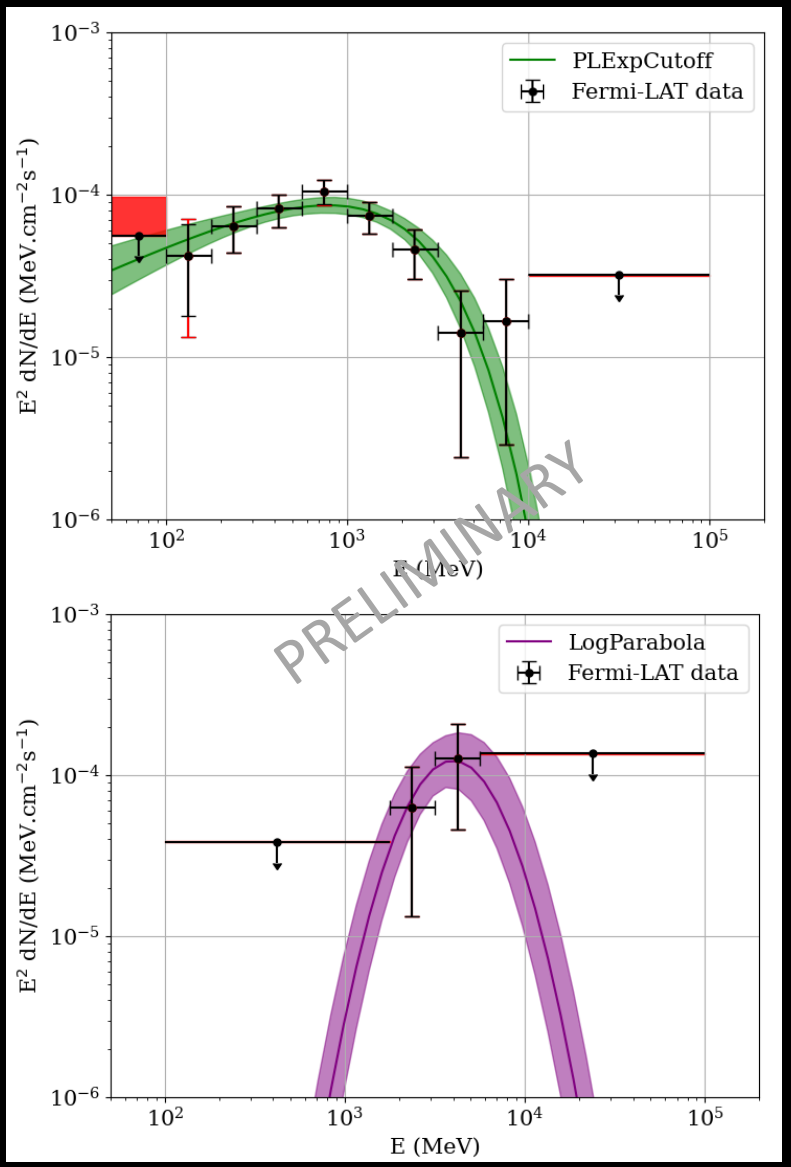
V1723 Sco 2024

- PLExpCutoff preferred with 4.8σ
- E_{cutoff} =1.6±0.6 GeV

V6598 Sgr 2023

- LogParabola preferred with 2.1σ
- TS_{total} = 24.5 (~4σ)



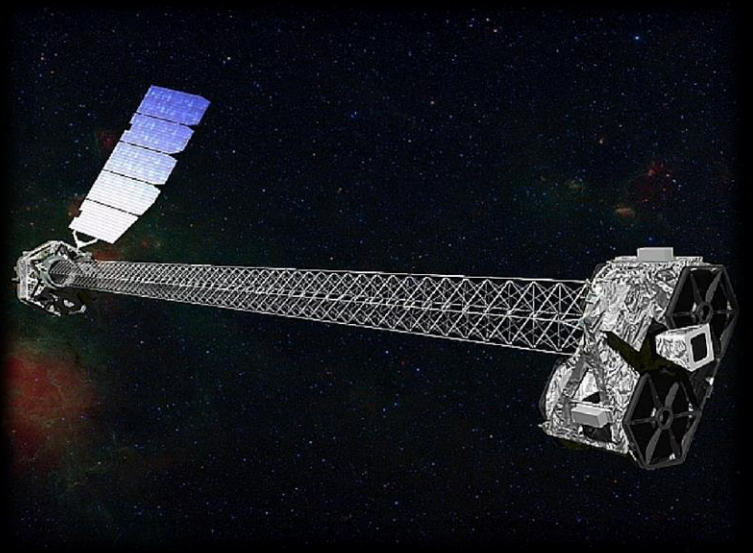
V1723 Sco 2024

V6598 Sgr 2023

L_X/L_γ ratio in V1723 Sco

- Most of the soft X-rays absorbed
- E > 10 keV could be observed with NuSTAR
- In a leptonic scenario hard X-rays from:
  - Inverse Compton
  - Bremsstrahlung

  ➔ Continuity between the γ-range and the X-range



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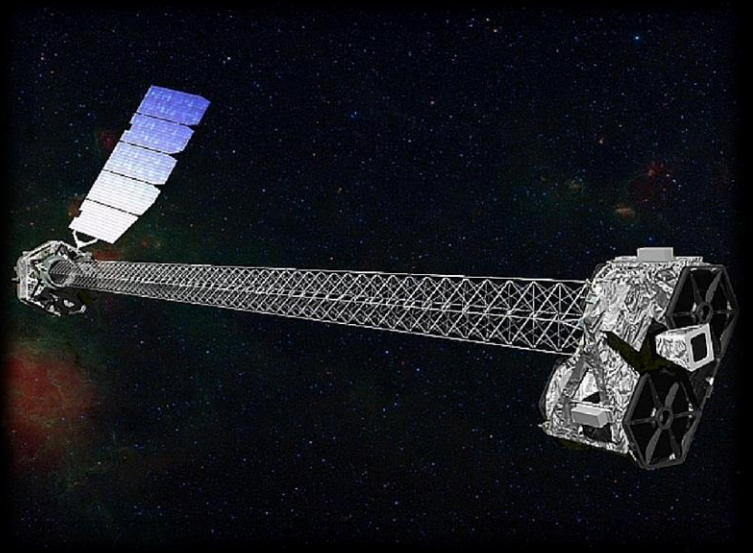
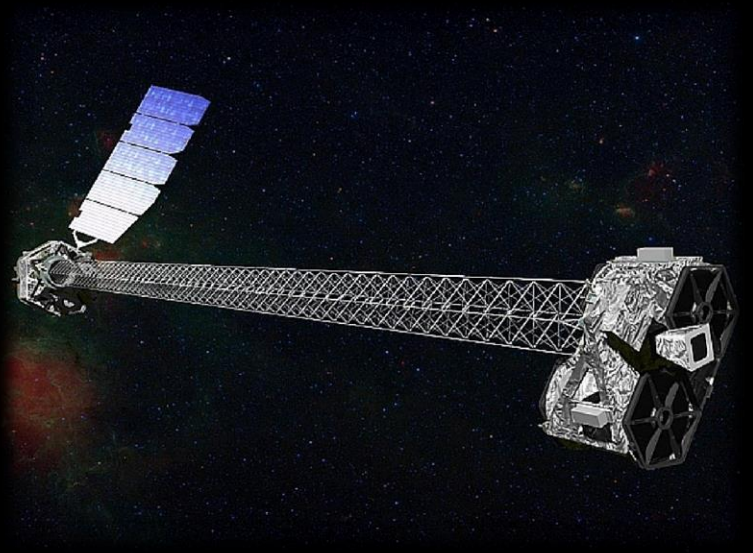


- NuSTAR data during 68 ks (between t_0 + 1.5 and t_0 + 3 days)
- Upper limits : 6×10^{-14} erg.cm^{-2} .s^{-1} between 3 and 78 keV

L_X/L_γ ratio in V1723 Sco



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- Upper limits : 6×10^{-14} erg.cm^{-2} .s^{-1} between 3 and 78 keV

- Monochromatic flux at 20 keV and 100 MeV

$$L_X/L_\gamma < 1.3\ 10^{-4}$$

➔ **Hadronic** scenario is preferred (Vurm and Metzger 2018)

Pion Decay emission of V1723 Sco

- Distance estimated using MMRD :
  1.9 ± 1.1 kpc for V1723 Sco
- Environment :
  Density of target $n_H \sim 4\ 10^{11}\ cm^{-3}$

Fit of the parameters of the particle distribution :

- Test of a PowerLaw
- Naima used MCMC optimization
- Parameters : Maximum Likelihood ones
- 1σ errors

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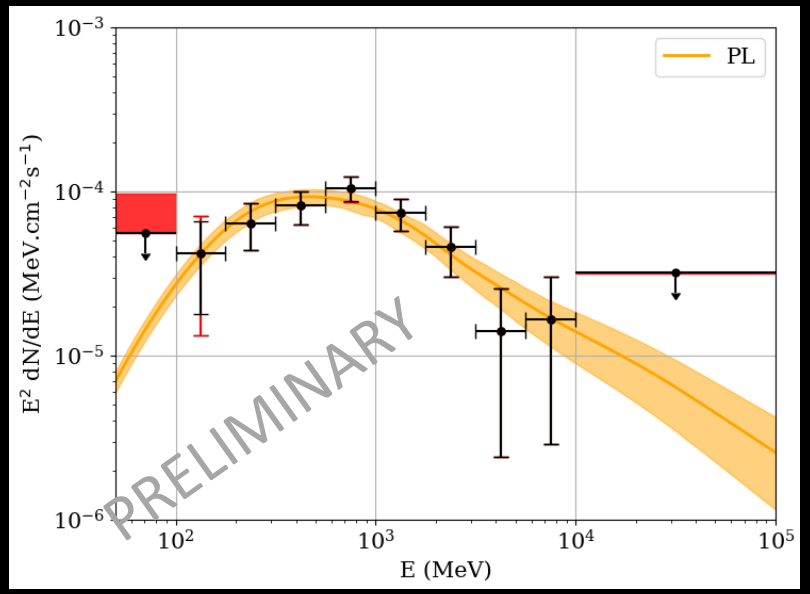

PowerLaw

- Index = 2.9 ± 0.2
- W_p = 6 ± 5 × 10^{39} erg

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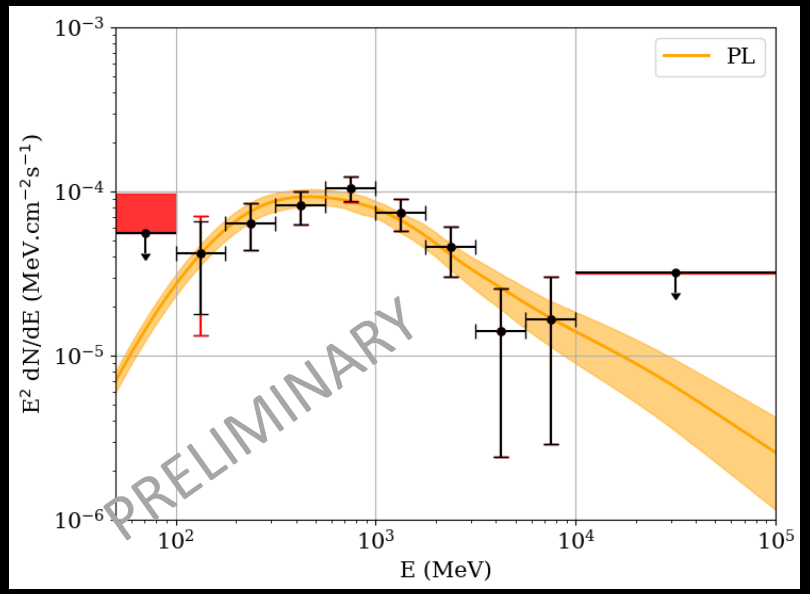
- $W_{sh} = W_{opt}$ ~ 10^{43} erg



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➔ ~ 0.1% of energy go in acceleration of non-thermal protons (in agreement with Metzger et al. 2015)

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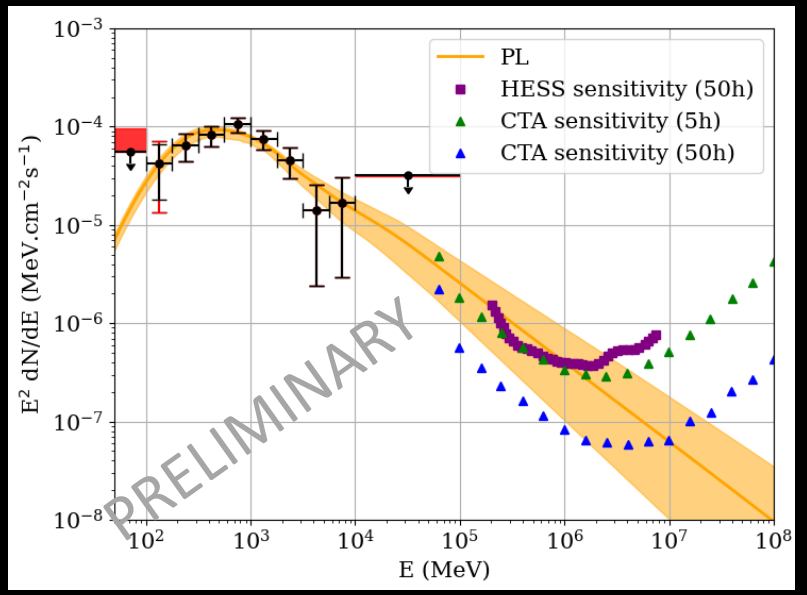

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Conclusion

For V1723 Sco 2024 :

- One of the brightest nova in γ-rays
- L_X/L_γ ratio upper limit in favor of a hadronic scenario
- γ-ray data can be modeled using Pion Decay emission model
  ➔ Can be improved by adding a cutoff in energy
- W_p/W_{opt} also supports a hadronic scenario

For V6598 Sgr 2023 :

- ~ 4σ detection with the LAT
- Offset between γ-rays and optical
- Unclassical environment with an mCV and peculiar shape of the gamma-ray spectrum
  ➔ More data needed to constrain their relation

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Thank you for your attention !

References

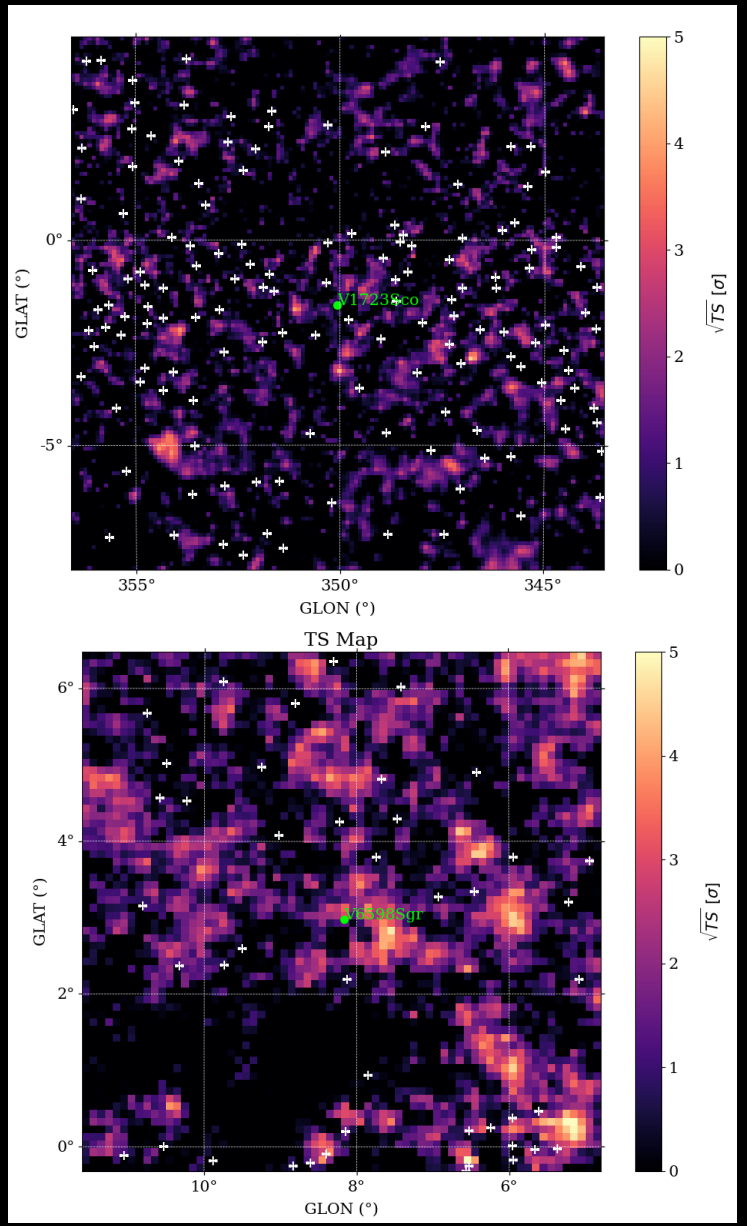
ATel V1723 Sco : 16439, 16440, 16442, 16444, 16454, 16484, 16492, 16641
ATel V6598 Sgr : 16135, 16141, 16151, 15172, 16383

Metzger et al. 2015
Vurm and Metzger 2018
Chomiuk et al. 2021

1-year period analysis

- 15° region centered on the optical nova position
- Energy range : 50 MeV – 300 GeV
- Energy dispersions bins = -2
- 4FGL catalog
- `gll_iem_v07.fits` and `iso_P8R3_SOURCE_V3_v1.txt`
- All the bright sources are free to evolve
- Fit the region for each nova

In the following, this model is taken as a reference



MMRD and density of target calculation

$$M_{V,peak} = -7.6 + 1.5 \log\left(\frac{t_3}{30 \text{ days}}\right) \pm 1.3$$

Section 7.2 Schefer 2022

$$R_{ej} = v_{ej} t \approx 4 \times 10^{13} \left(\frac{v_{ej}}{2000 \text{ km.s}^{-1}}\right) \left(\frac{t}{2.3 \text{ days}}\right) \text{cm}$$

$$n_H = \frac{M_{ej}}{4\pi R_{ej}^3 f_\Omega \mu m_p} \approx 4 \times 10^{11} \left(\frac{M_{ej}}{10^{-4} M_\odot}\right) \left(\frac{f_\Omega}{0.5}\right)^{-1} \left(\frac{\mu}{0.74}\right)^{-1} \text{cm}^{-3}$$

Metzger et al. 2015

Look on other novae

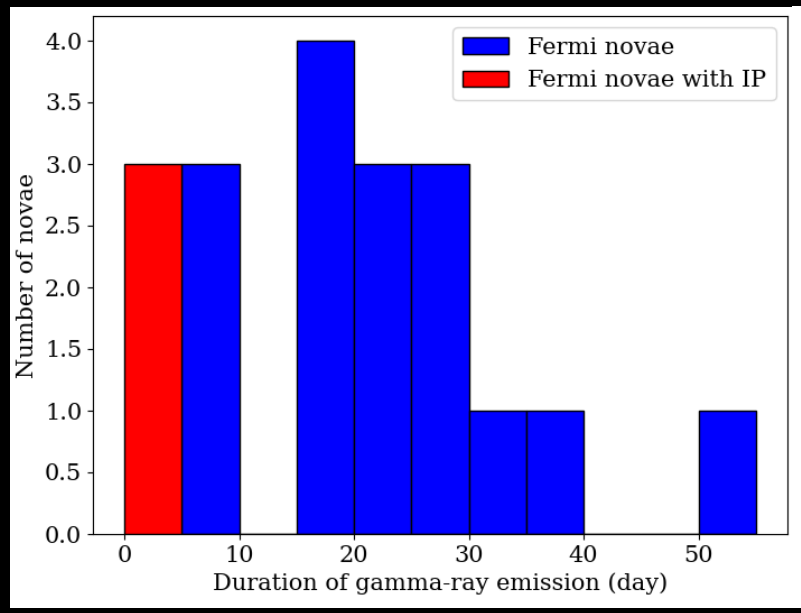
L_X/L_γ from Vurm and Metzger 2018 :

- V339 Del : $< 4 \times 10^{-3}$
- V5668 Sgr : $< 1.7 \times 10^{-3}$

Classical novae : L_{opt} ~10^{37} – 10^{38} erg.s^{-1}
Chomiuk et al. 2021

Fermi novae with IP:

- V1674 Her 2021(Sokolovsky et al. 2023)
- V407 Lup 2016 (Gordon et al. 2020)
- V6598 Sgr 2023



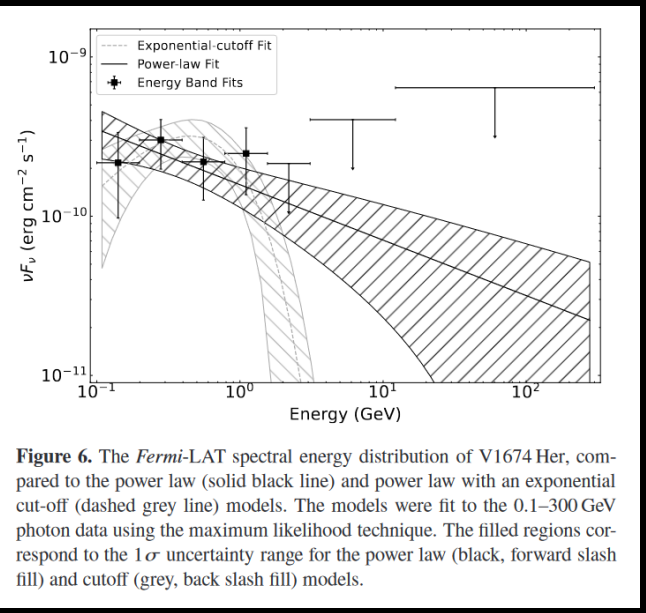


Figure 6. The *Fermi*-LAT spectral energy distribution of V1674 Her, compared to the power law (solid black line) and power law with an exponential cut-off (dashed grey line) models. The models were fit to the 0.1–300 GeV photon data using the maximum likelihood technique. The filled regions correspond to the 1σ uncertainty range for the power law (black, forward slash fill) and cutoff (grey, back slash fill) models.