

Novae at very-high-energy gamma rays: present and future

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VGGRS VI

April 12th-14th 2023



Outline

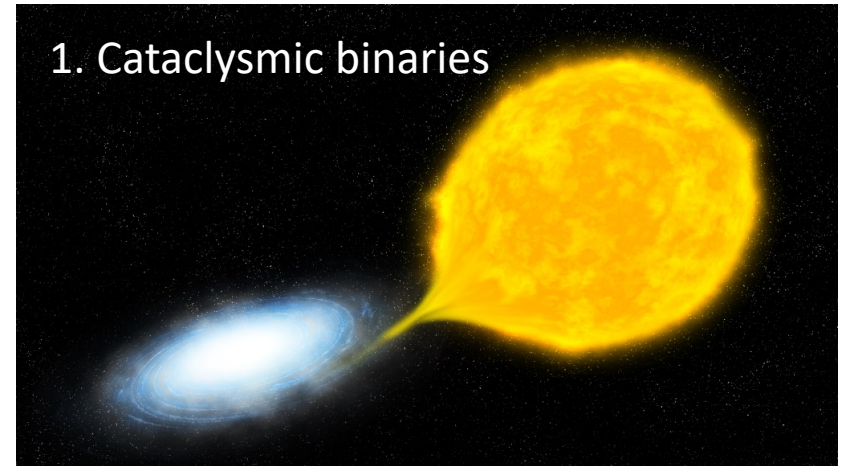
- Novae
- RS Ophiuchi at γ rays
- Novae detectability with CTA-N
- Conclusions and Outlook

Novae

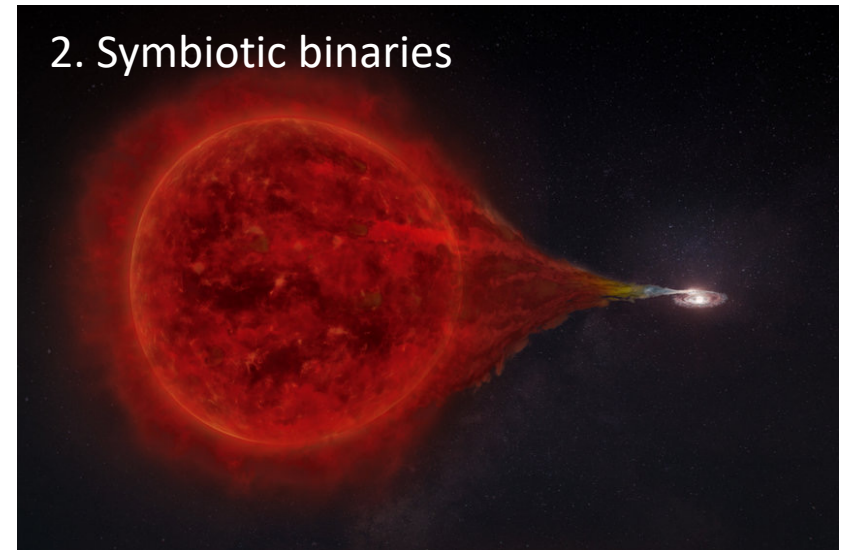
Nova (*stella nova*):

Thermonuclear runaway explosion at the surface of a white dwarf in a binary system

- Types of systems:
 1. Cataclysmic binaries (classical novae)
 - White dwarf and main sequence star
 2. Symbiotic binaries (symbiotic novae)
 - White dwarf and red giant (and Mira star)
- Mass transfer (Roche-lobe overflow and/or wind-driven)



Credit: NASA/SOFIA/L. Proudfit



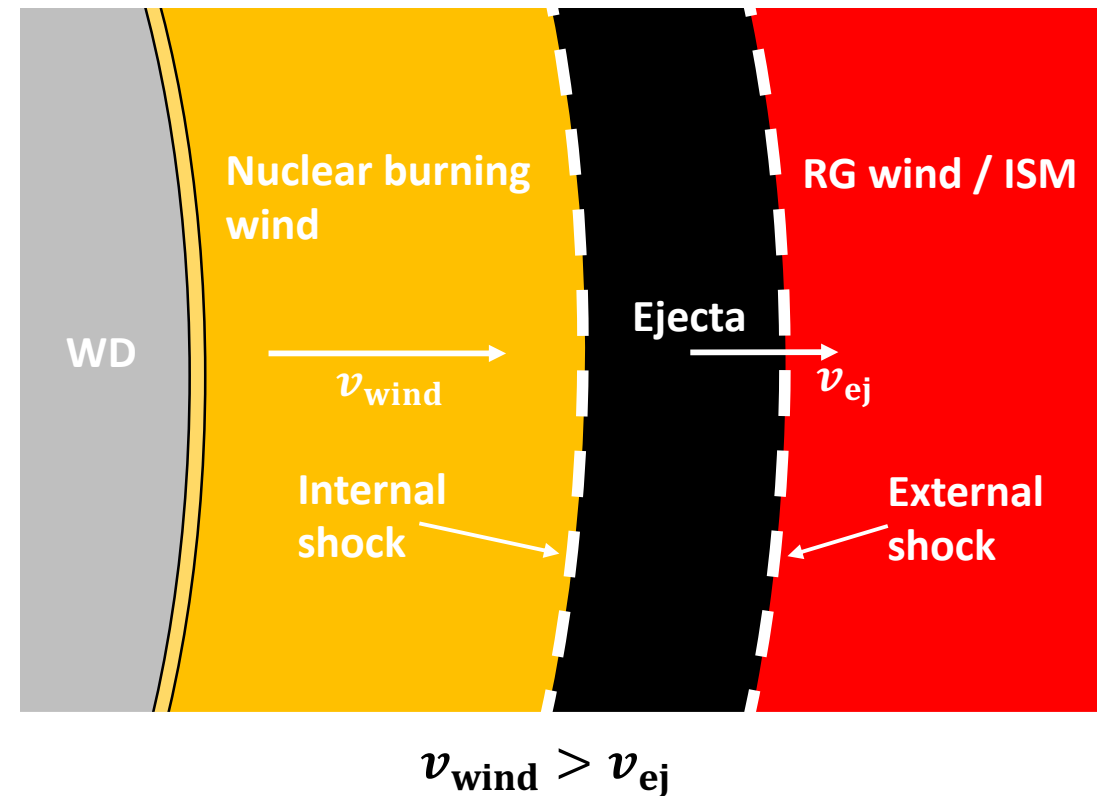
Credit: superbossa.com / MPP

Novae : Particle acceleration

- Particle acceleration in expanding shock waves

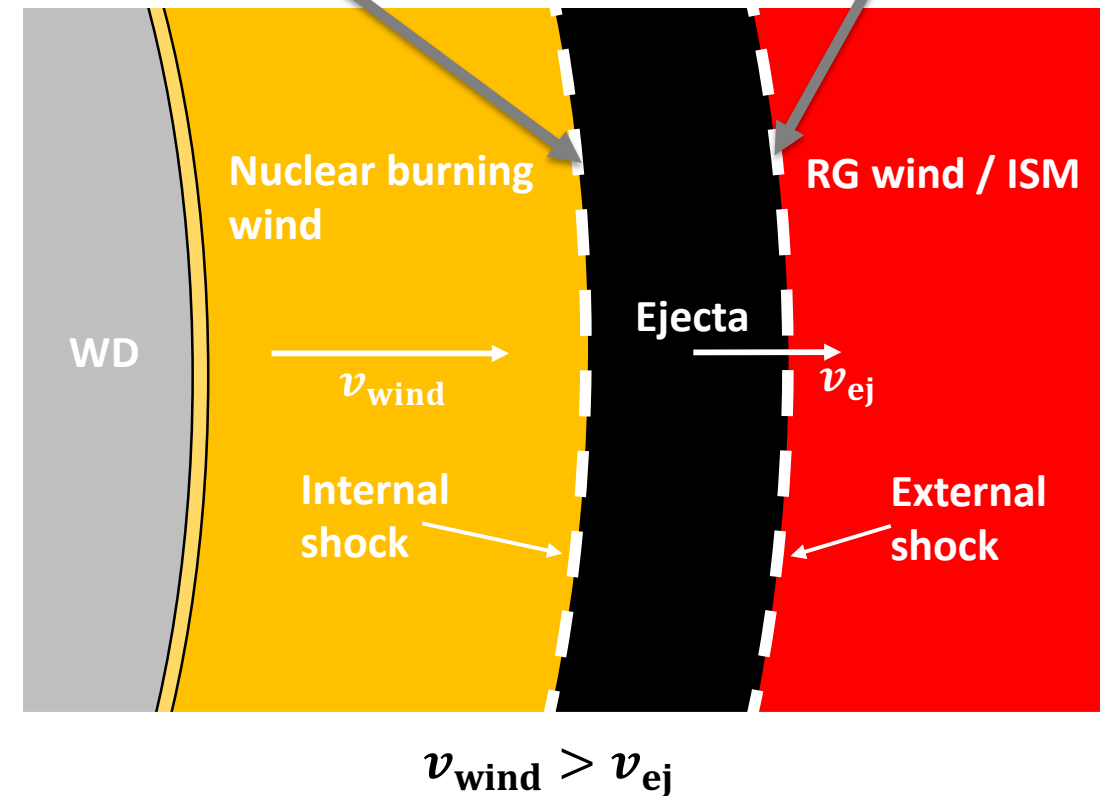
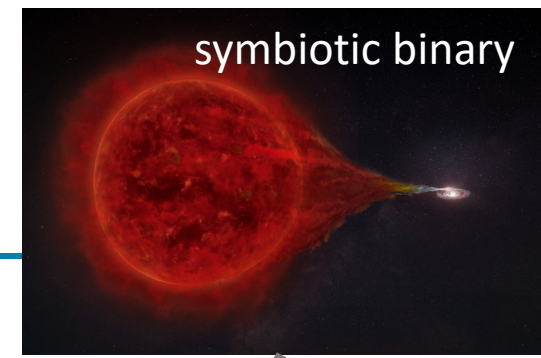
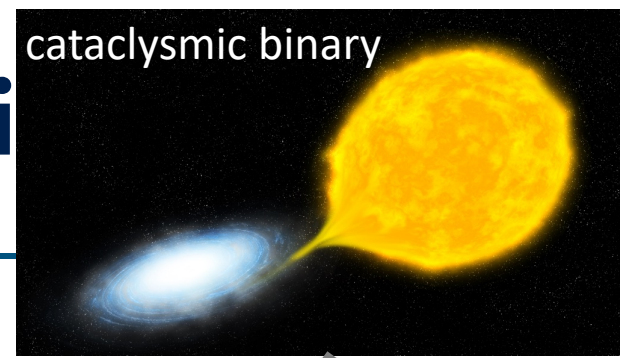
(Chomiuk et al. 2021 and reference therein)

 - Internal shocks:
 - Main ejection at the outburst (v_{ej}) is caught up by wind from steady H-burning (v_{wind})
 - External shocks:
 - Main ejection at the outburst interacts with the ISM and/or RG wind



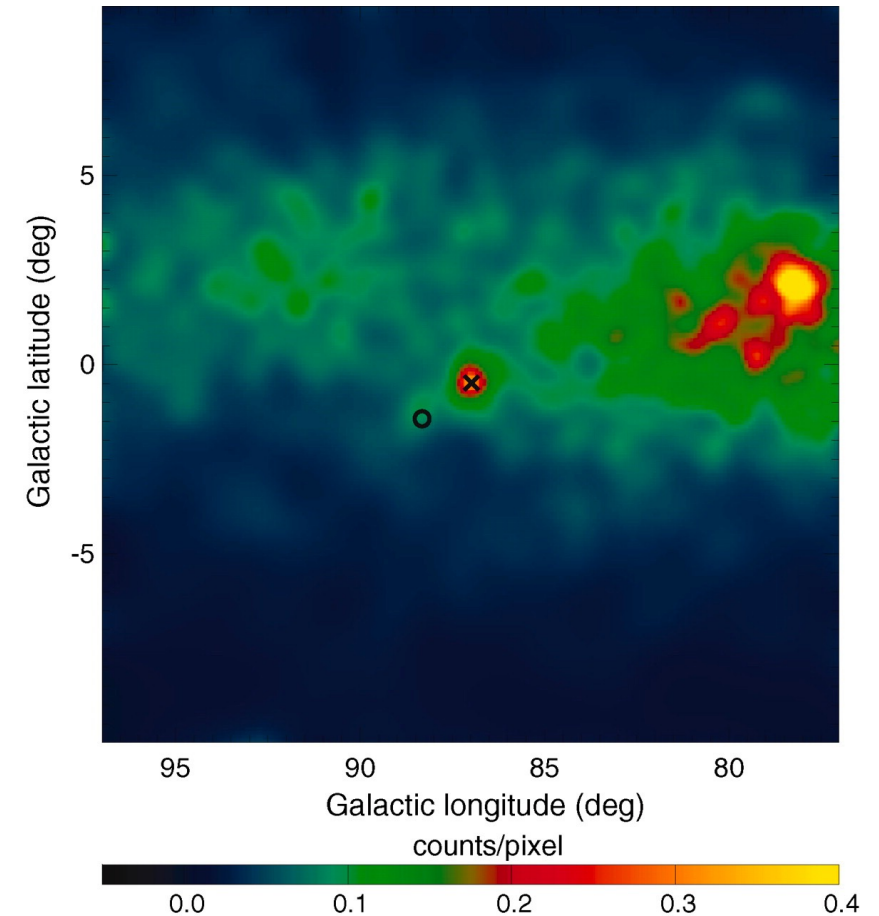
Novae : Particle accelerati

- Particle acceleration in expanding shock waves
 - (Chomiuk et al. 2021 and reference therein)
 - Internal shocks:
(dominant in cataclysmic binaries)
 - Main ejection at the outburst (v_{ej}) is caught up by wind from steady H-burning (v_{wind})
 - External shocks:
(dominant in symbiotic binaries)
 - Main ejection at the outburst interacts with the ISM and/or RG wind



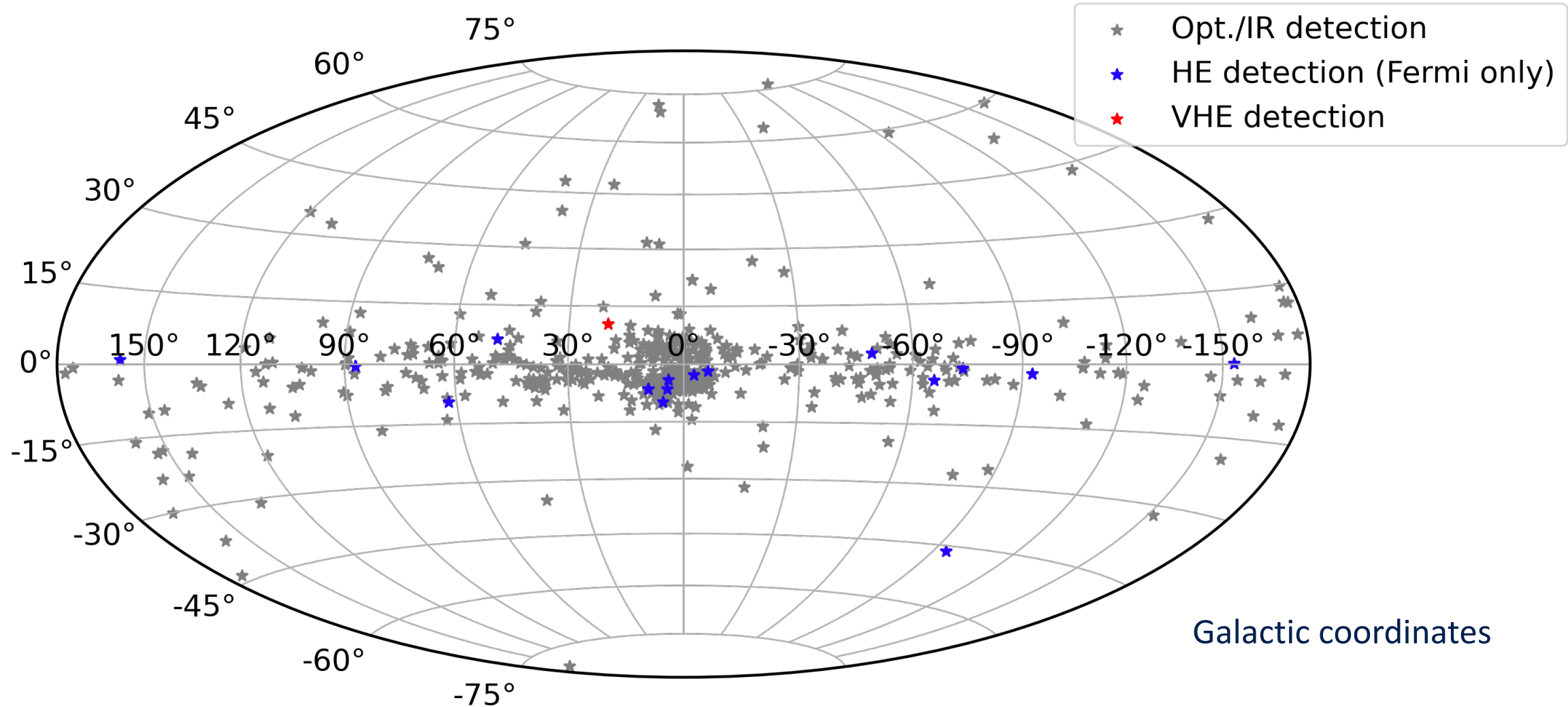
Novae at γ rays : Detection

- Predictions of HE γ -ray emission for symbiotic binaries
(Tatischeff & Hernanz 2007, Hernanz & Tatischeff 2012)
- Novae detections at HEs with *Fermi*-LAT:
 - First detection: symbiotic nova V407 Cygni
(Abdo et al. 2010)
 - Unexpected detection of classical novae
(Ackermann et al. 2014, Cheung et al. 2016)
- First nova detection at VHE γ rays with MAGIC and H.E.S.S.: symbiotic nova RS Oph
(Acciari et al. 2022, H.E.S.S. Collaboration et al. 2022)



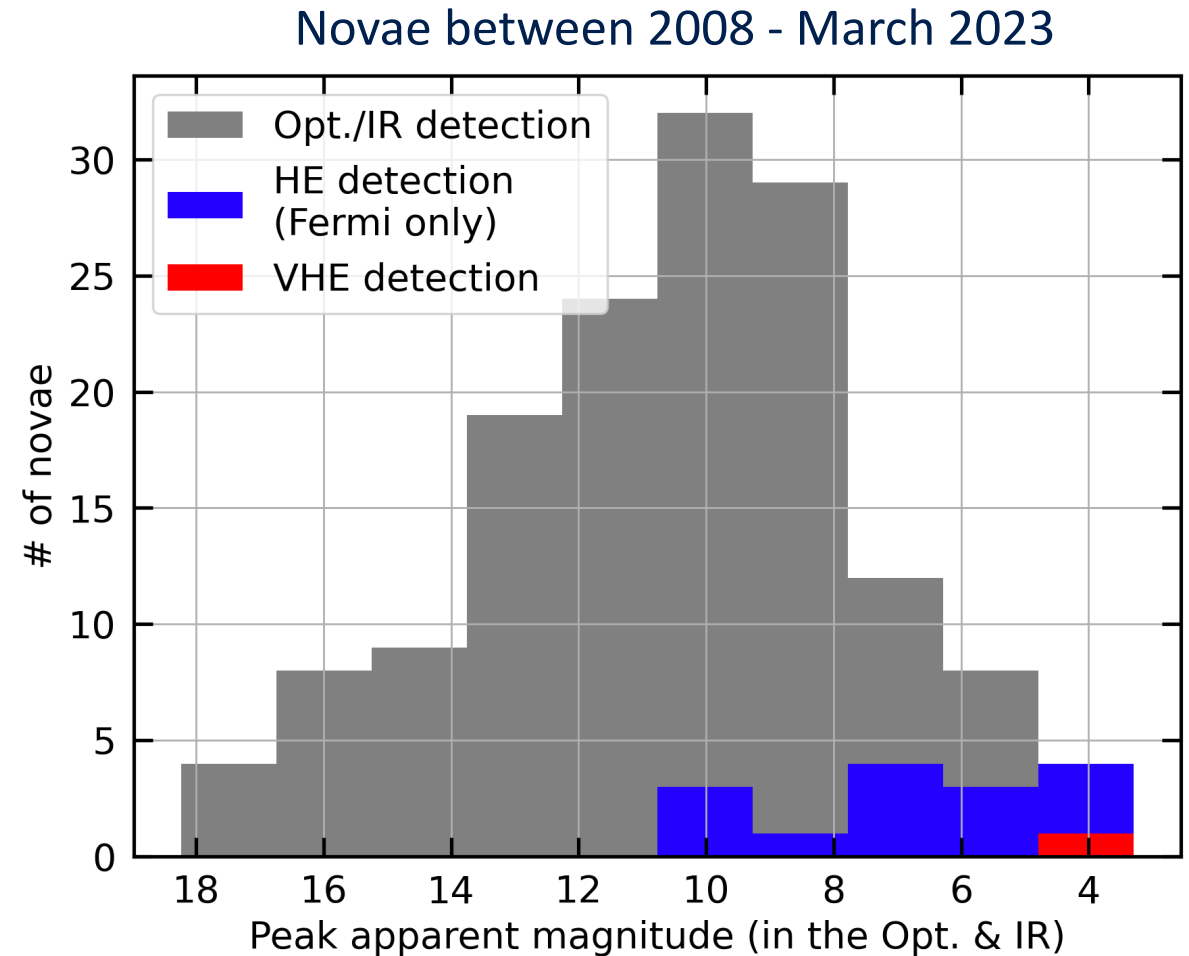
Source: Abdo et al. 2010

Novae at γ rays : Historical novae (as of March 2023)



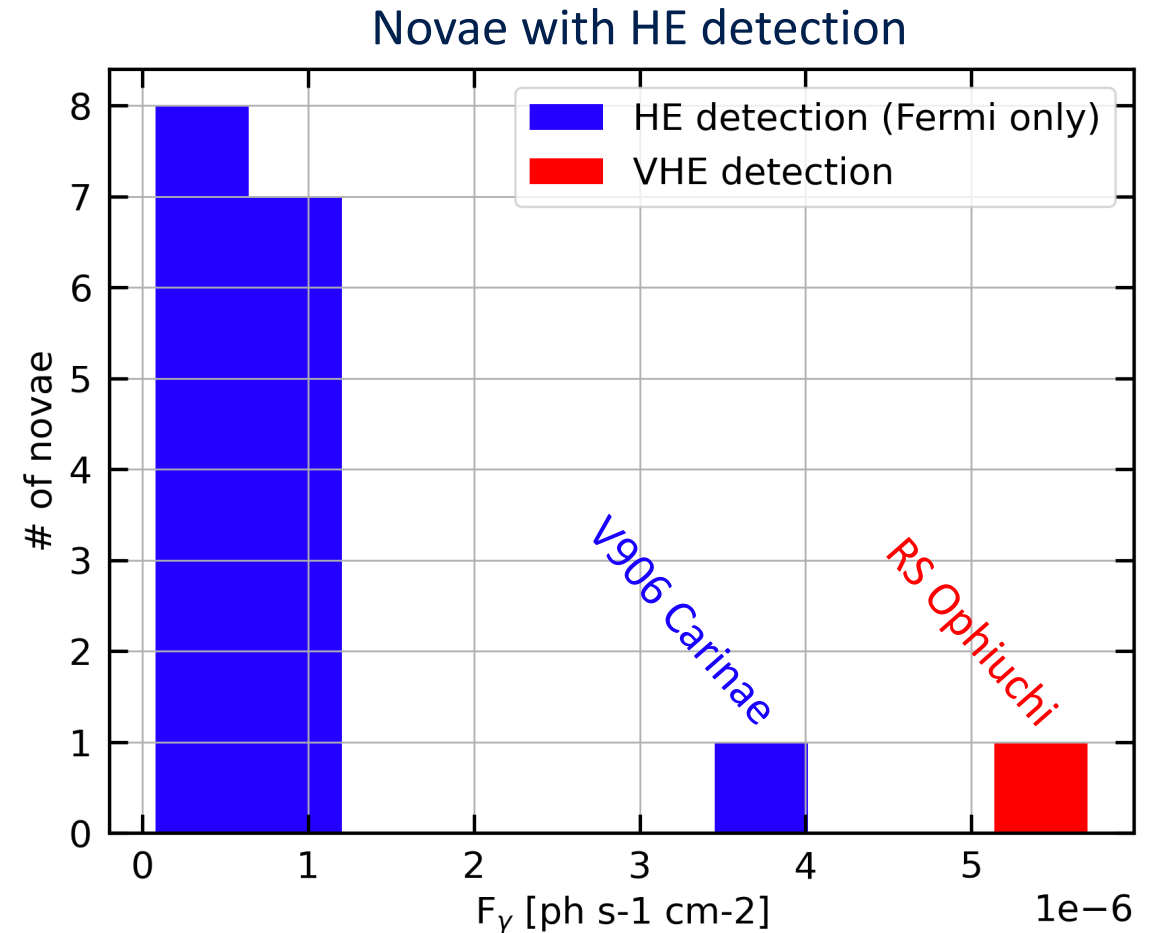
Novae at γ rays

- What makes them special?
 - Novae detected at HE & VHE γ rays are optically bright
 - The VHE detection is at the (bright) edge of the distribution
 - Intrinsic brightness
 - Distance



Novae at γ rays

- What makes them special?
 - Novae detected at HE & VHE γ rays are optically bright
 - The VHE detection is at the (bright) edge of the distribution
 - Intrinsic brightness
 - Distance
 - The VHE detection has the highest HE flux



Data: <https://asd.gsfc.nasa.gov/Koji.Mukai/novae/latnovae.html>,
last view on March 13th, 2023.

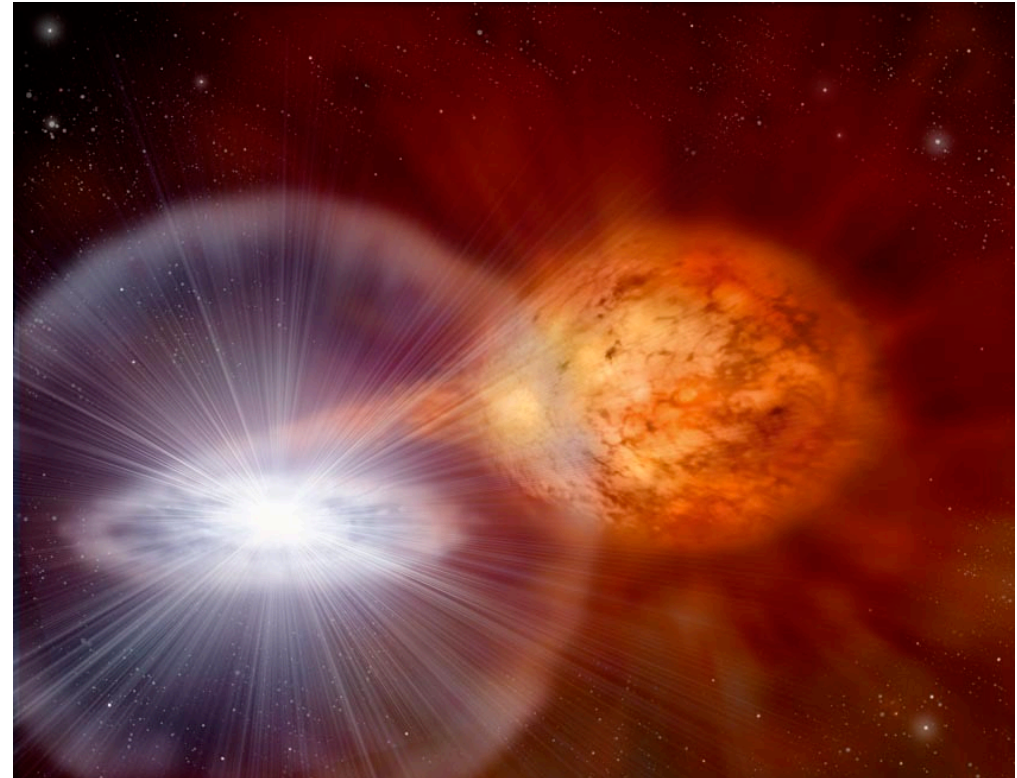
Novae : RS Ophiuchi

- Symbiotic binary at $d \sim 2.45$ kpc
- Recurrent nova outbursts every ~ 15 years

Recurrent nova

- August 2021 outburst: the first detection of a nova at VHEs

(H.E.S.S. Collaboration 2022, Acciari et al. 2022)

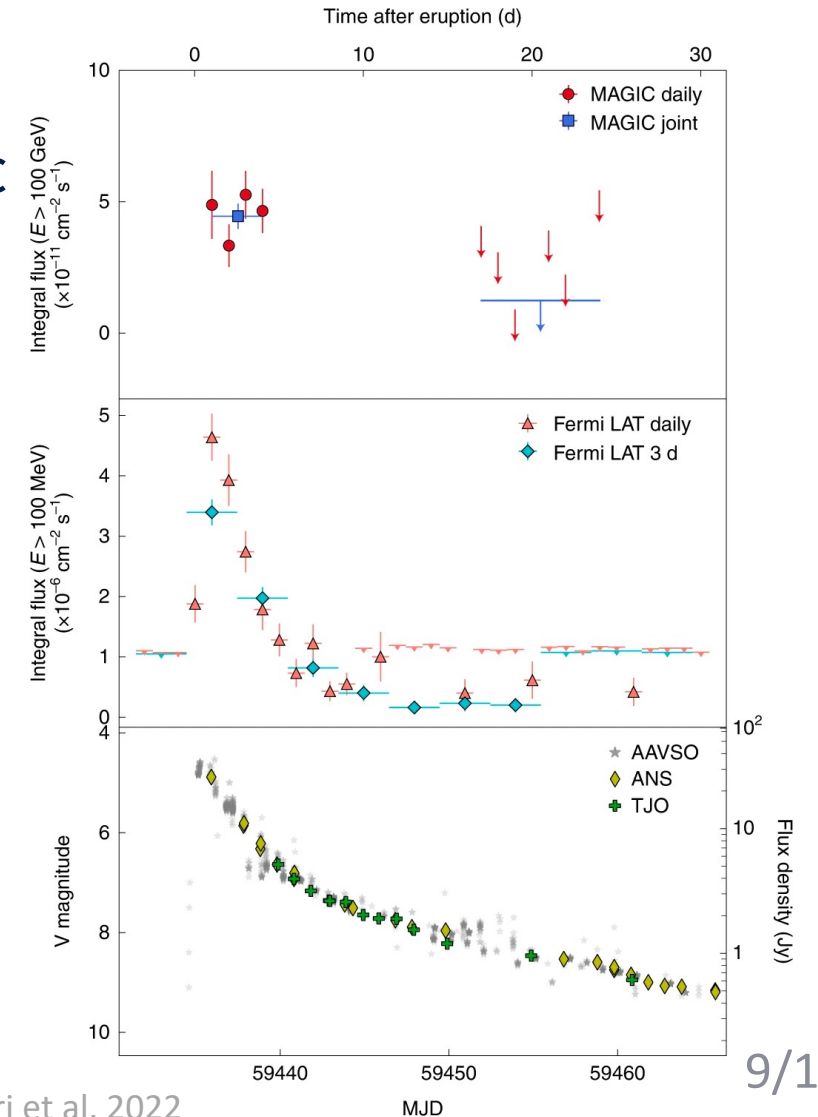
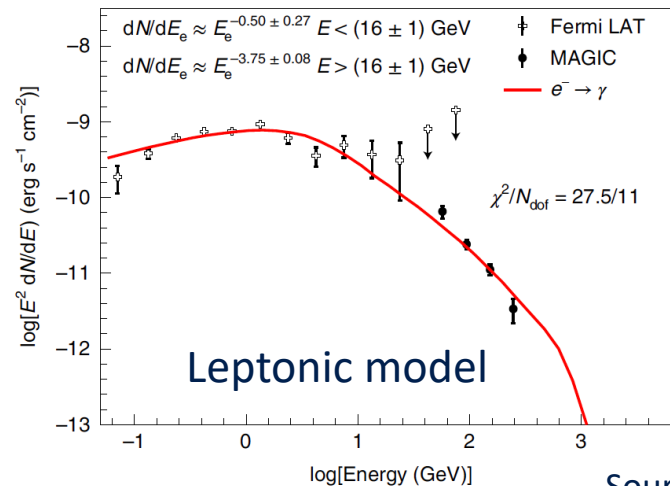
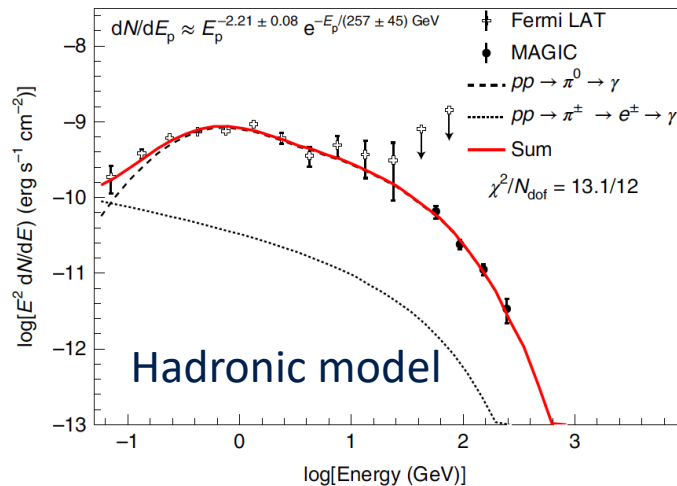


Credit: David A.Hardy/ www.astroart.org & PPARC.

RS Ophiuchi at gamma rays : MAGIC



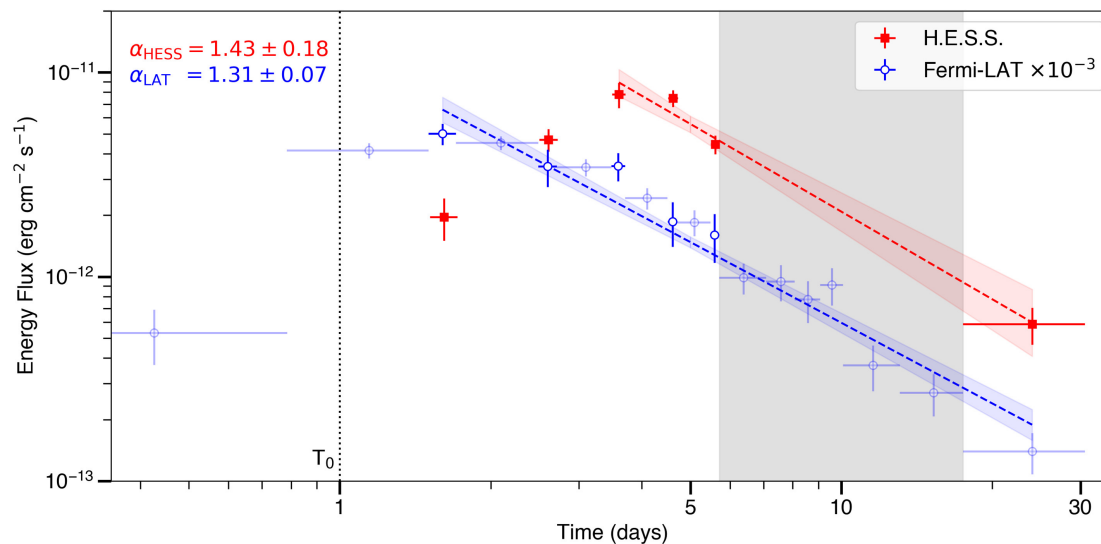
- *Fermi*-LAT & MAGIC joint analysis:
Hadronic scenario is preferred over the leptonic
 - Increase of $E_{p,max}$ with time (p-p mild cooling)
 - Simpler injection spectrum and better spectral fit
- Flat light curve
 - Migration of gamma rays to higher energies



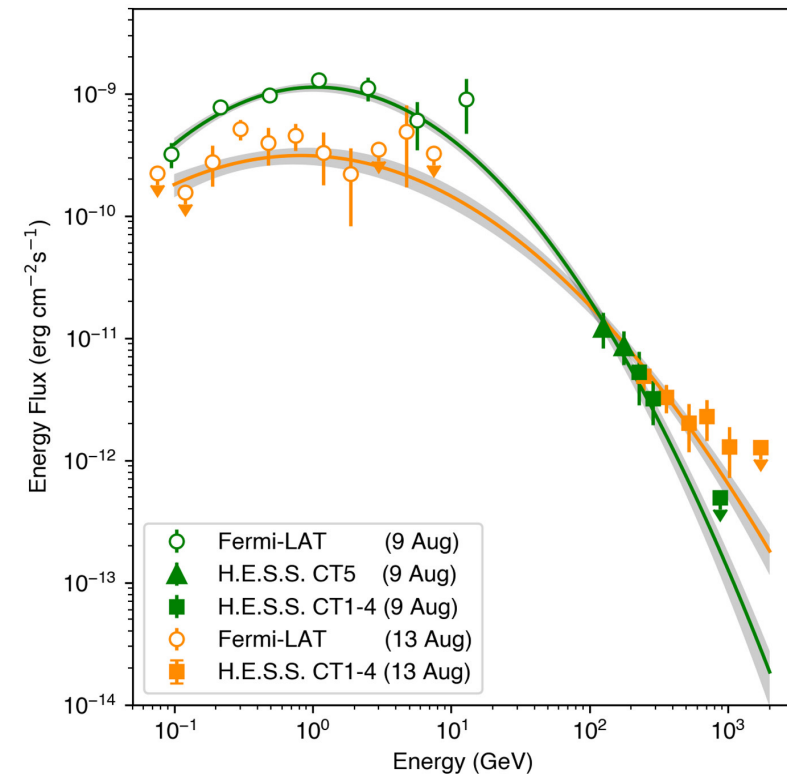
Source: Acciari et al. 2022

RS Ophiuchi at gamma rays : H.E.S.S.

- *Fermi*-LAT & H.E.S.S. combined analysis
 - Finite acceleration time of VHE protons (delayed VHE peak)
 - Single γ -ray component (similar temporal profiles & spectra)
- The hadronic scenario is preferred as well
 - Efficient acceleration up to $E_{p,max} \approx 10$ TeV



Source: H.E.S.S. Collaboration 2022



Cherenkov Telescope Array (CTA)

- Cherenkov Telescope Array Observatory (CTAO)
 - Future observatory at VHEs with the next generation of Cherenkov telescopes
 - Northern hemisphere (CTA-N): La Palma
 - Southern hemisphere (CTA-S): Paranal
 - LST-1: Large Size Telescope prototype
 - Currently under commissioning phase
 - Good sensitivity at tens to hundreds of GeVs
 - Fast re-positioning speed to follow-up transient sources



Credit: Tomohiro Inada

RS Ophiuchi at gamma rays : LST-1



- LST-1 also observed RS Ophiuchi outburst in 2021 !

Date (yyyy/mm/dd)	T-T0 (days)	Zenith angle (deg)	Atmospheric transmission 9km* (%)	Observation time after cuts (h)
2021-08-09	0.97	36-41	> 90	1.43
2021-08-10	1.97	36-56	> 90	2.69
2021-08-12	3.97	36-48	> 90	2.27
2021-08-13	4.99	37-51	15 - 90	
2021-08-14	5.97	37-51	65	
2021-08-15	7.03	41-54	55	
2021-08-29	21.01	36-41	> 80	0.97
2021-08-30	21.97	36-41	> 80	1.52
2021-09-01	24.05	61-64	> 90	0.32
2021-09-02	24.98	61-64	> 90	1.28

Right after outburst

Bad atmospheric transmission

After moon break

T0 = 59434.93 MJD

* MAGIC LIDAR measurements

RS Ophiuchi at gamma rays : LST-1



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- Analysis using observations right after the outburst

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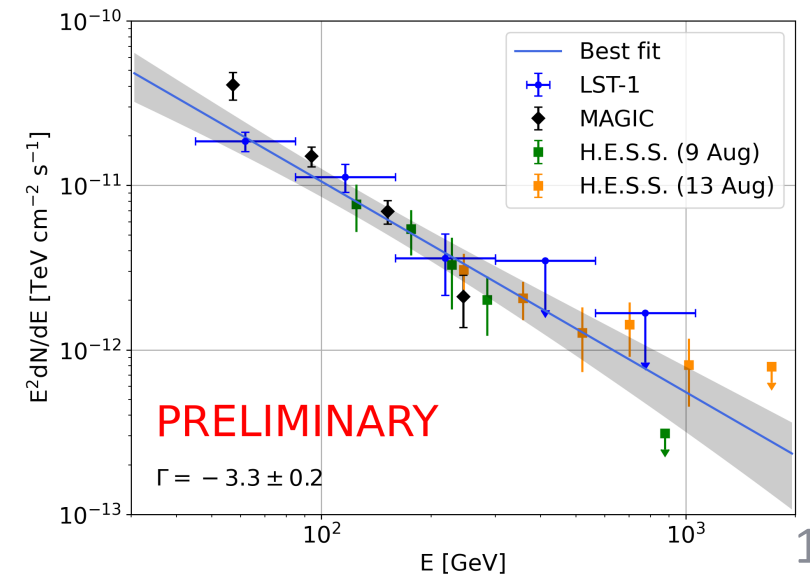
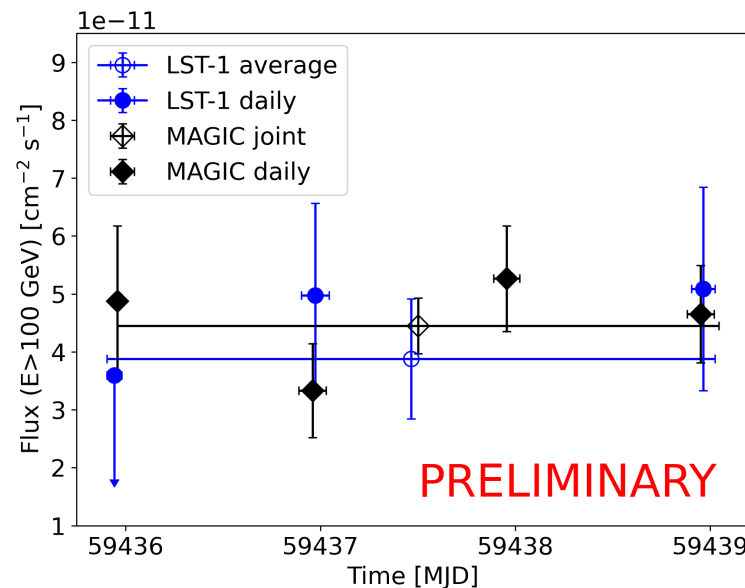
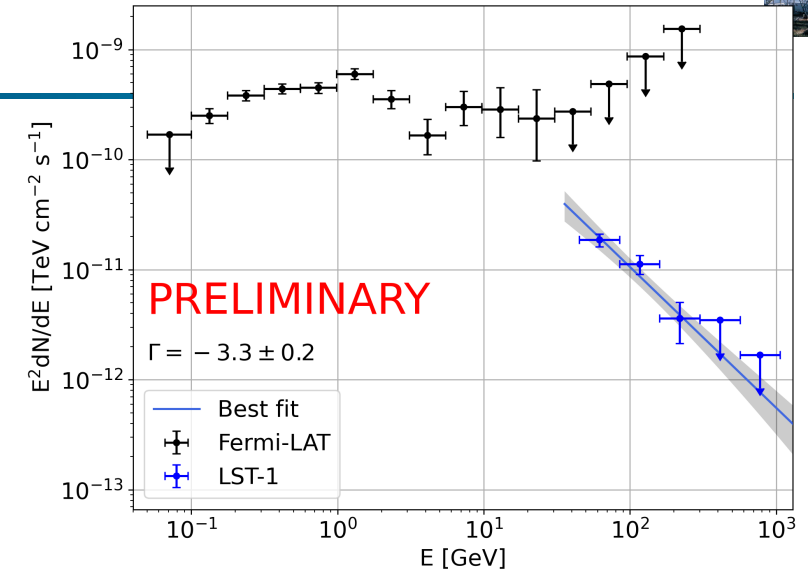
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RS Ophiuchi at gamma rays : LST-1



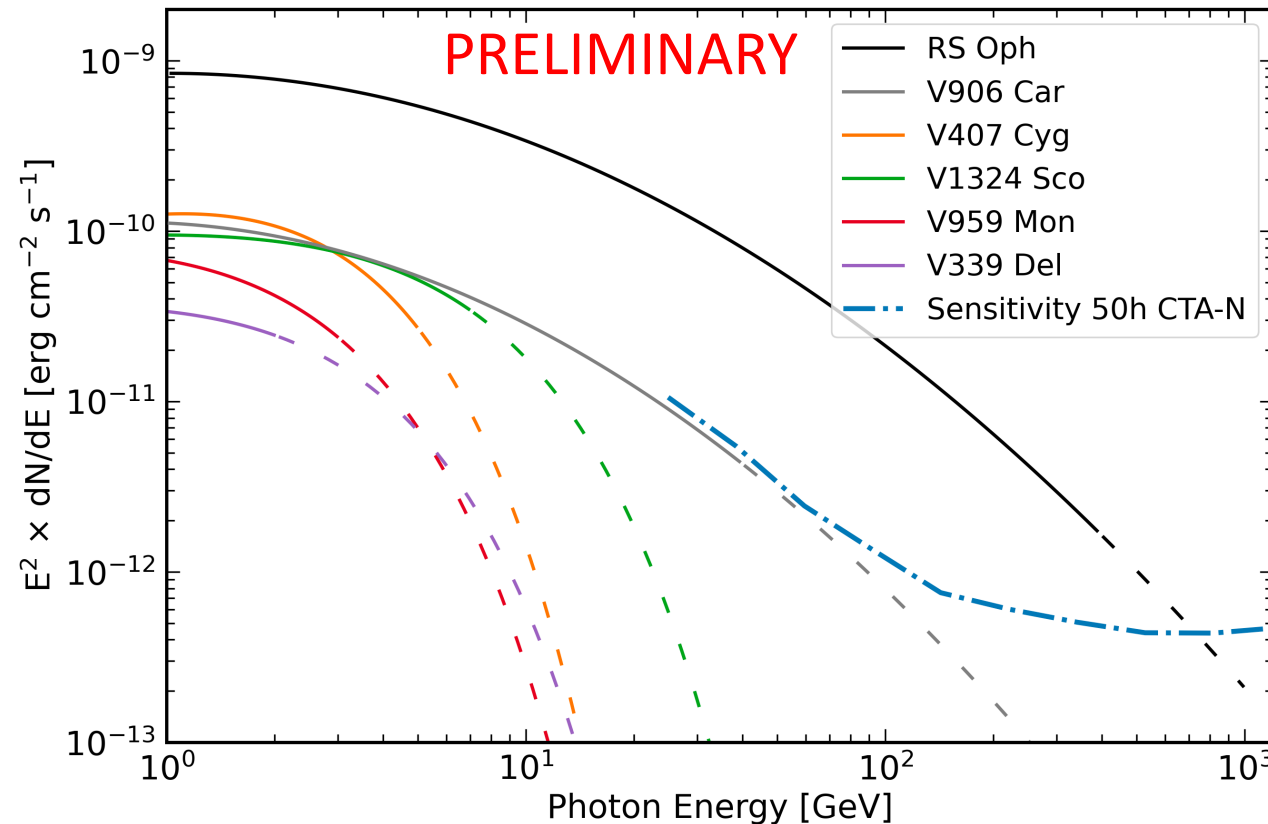
- Clear detection of RS Oph with LST-1 (6.4 h)
 - Det. significance of $\sim 7.5\sigma$ & S/N of $\sim 4.8\%$
- \sim Smooth transition from HE to VHE range
 - Spectral analysis down to ~ 45 GeV
- Preliminary results compatible with other IACT facilities

New analysis with improved MC is ongoing



Perspective of novae detections with CTA

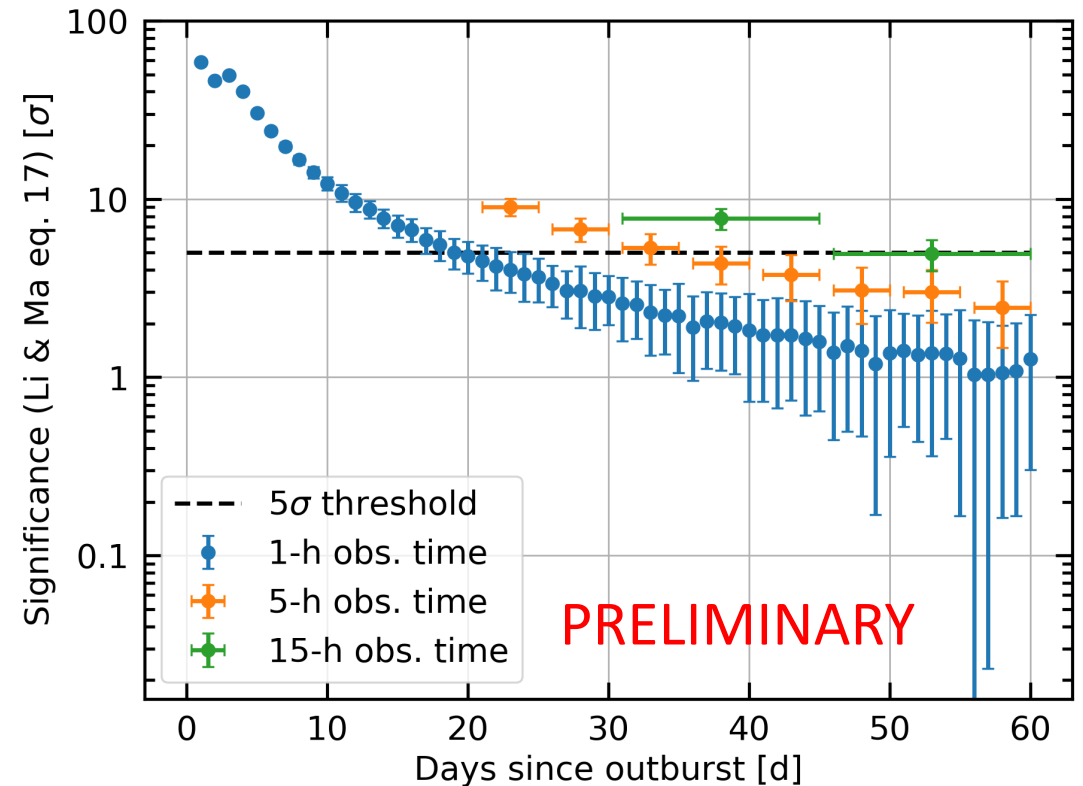
- Spectral energy distribution for RS Ophiuchi, V906 Carinae and the first novae detected with *Fermi*-LAT



- Solid lines: fit to data
- Dashed lines: fit extrapolation

Perspective of novae detections with CTA

- Simulation of RS Ophiuchi with CTA-N
 - 1-h daily observations for 60 days
 - Spectral properties (Acciari et al. 2022)
 - Temporal profile (H.E.S.S. Collaboration et al. 2022)
 - Clearly detected right after the outburst
 - Daily detection for 20 days !

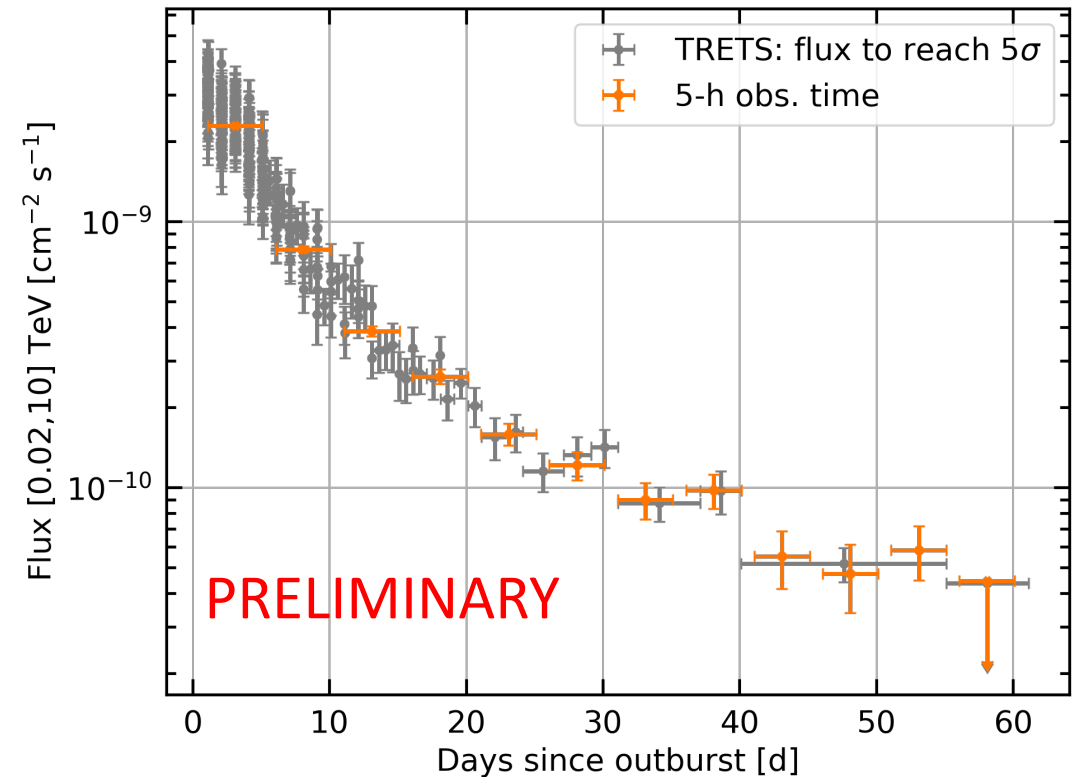


Source: CTA consortium in prep.

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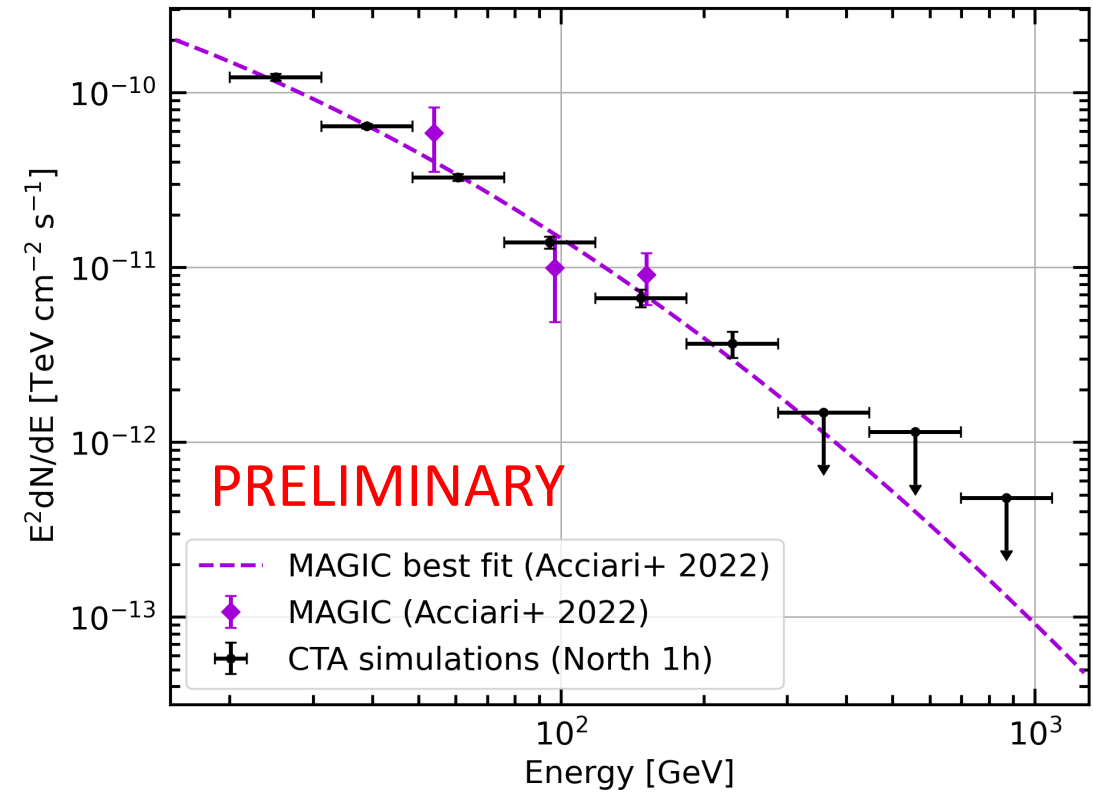
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Take a look at our poster during the coffee break: TRETs (Aguasca-Cabot et al.)



Perspective of novae detections with CTA

- Simulation of RS Ophiuchi with CTA-N
 - 1-h daily observations for 60 days
 - Spectral properties (Acciari et al. 2022)
 - Temporal profile (H.E.S.S. Collaboration et al. 2022)
 - Clearly detected right after the outburst
 - Daily detection for 20 days !
 - Better spectral resolution !

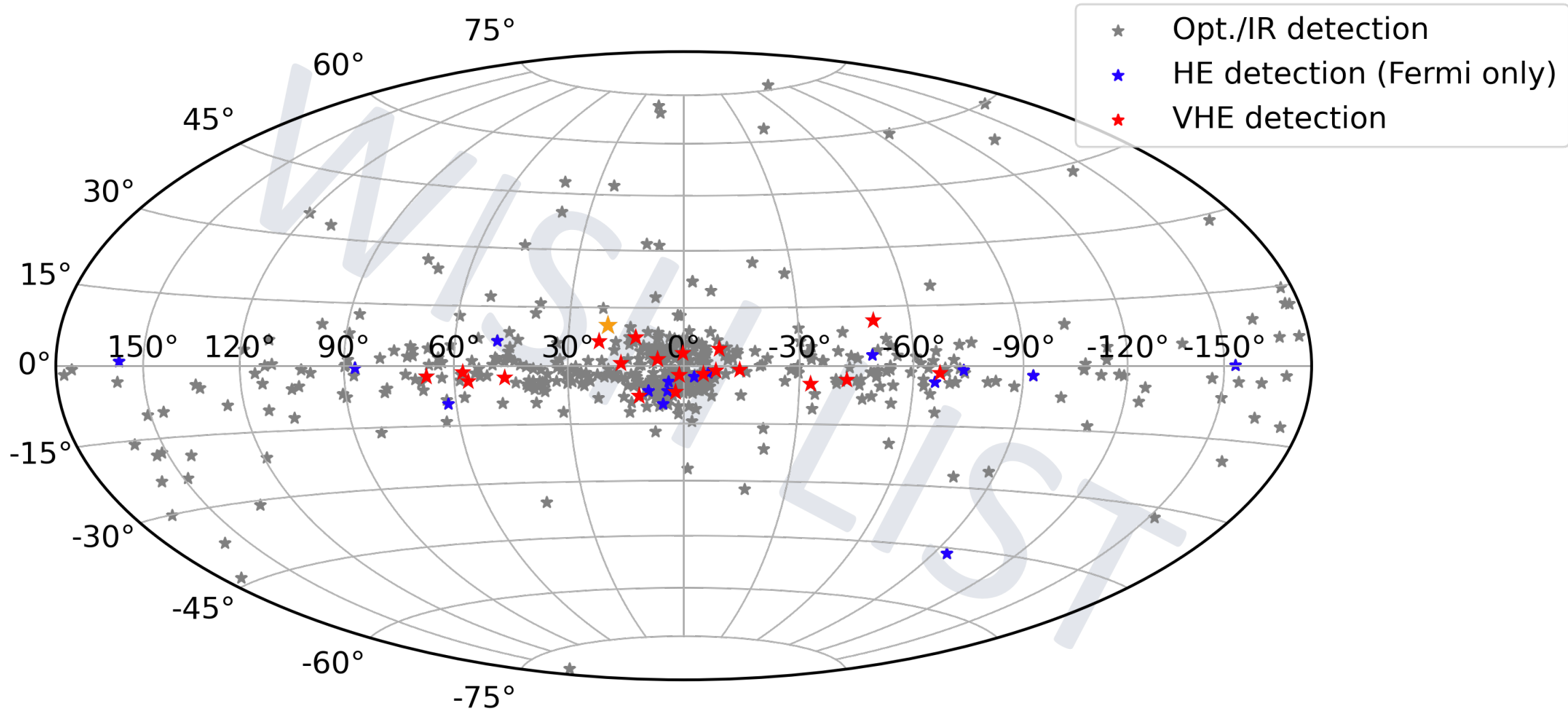


Source: CTA consortium in prep.

Conclusions and Outlook

- RS Ophiuchi: first nova detected at VHEs
 - γ -ray emission likely produced in hadronic processes
 - Finite acceleration time for VHE protons
- The first nova detected with the first LST of CTA
 - Soft spectrum for the first days after the outburst
 - Compatible results with MAGIC & H.E.S.S. within errors
- The high sensitivity of CTA will be crucial for understanding novae
 - Good sensitivity at low energies is critical!

Novae at γ rays: wish list sky map (as of 20XY)



Novae at very-high-energy gamma rays: present and future

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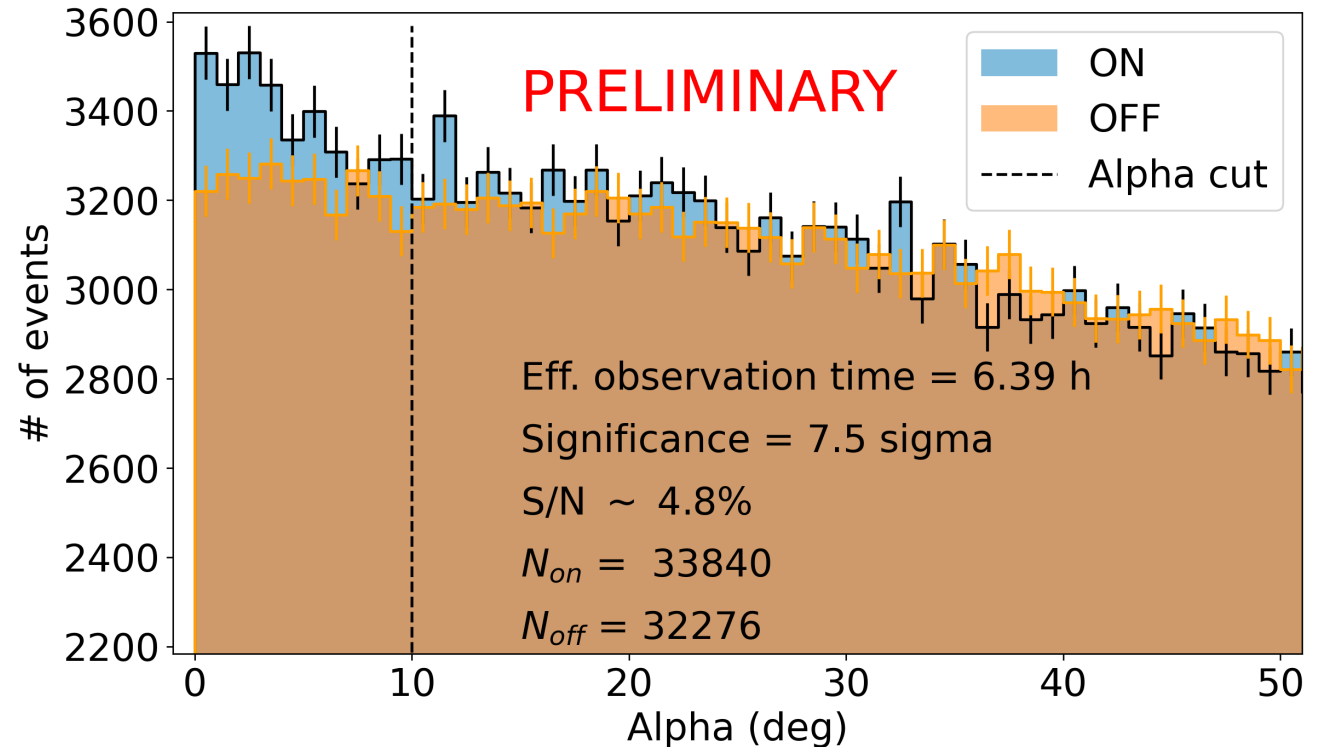
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backup

backup: Alpha plot

- Detection right after the outburst (Aug. 9, 10 and 12)
 - Alpha plot: angle distribution between event's major axis and:
 - Nominal source position (ON)
 - Reflected background positions (OFF)
 - Li & Ma significance*
 - 7.5
 - Signal-to-noise ratio
 - 4.8 %



* Equation 17, Li & Ma 1983