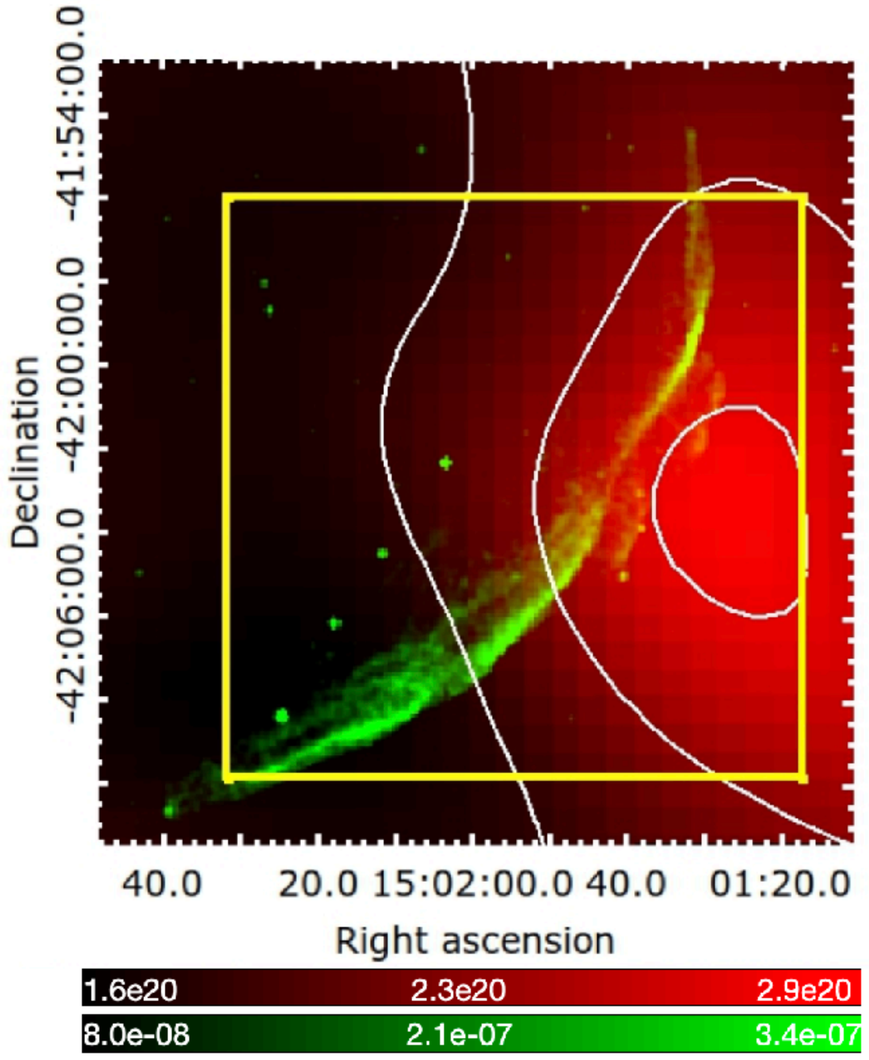
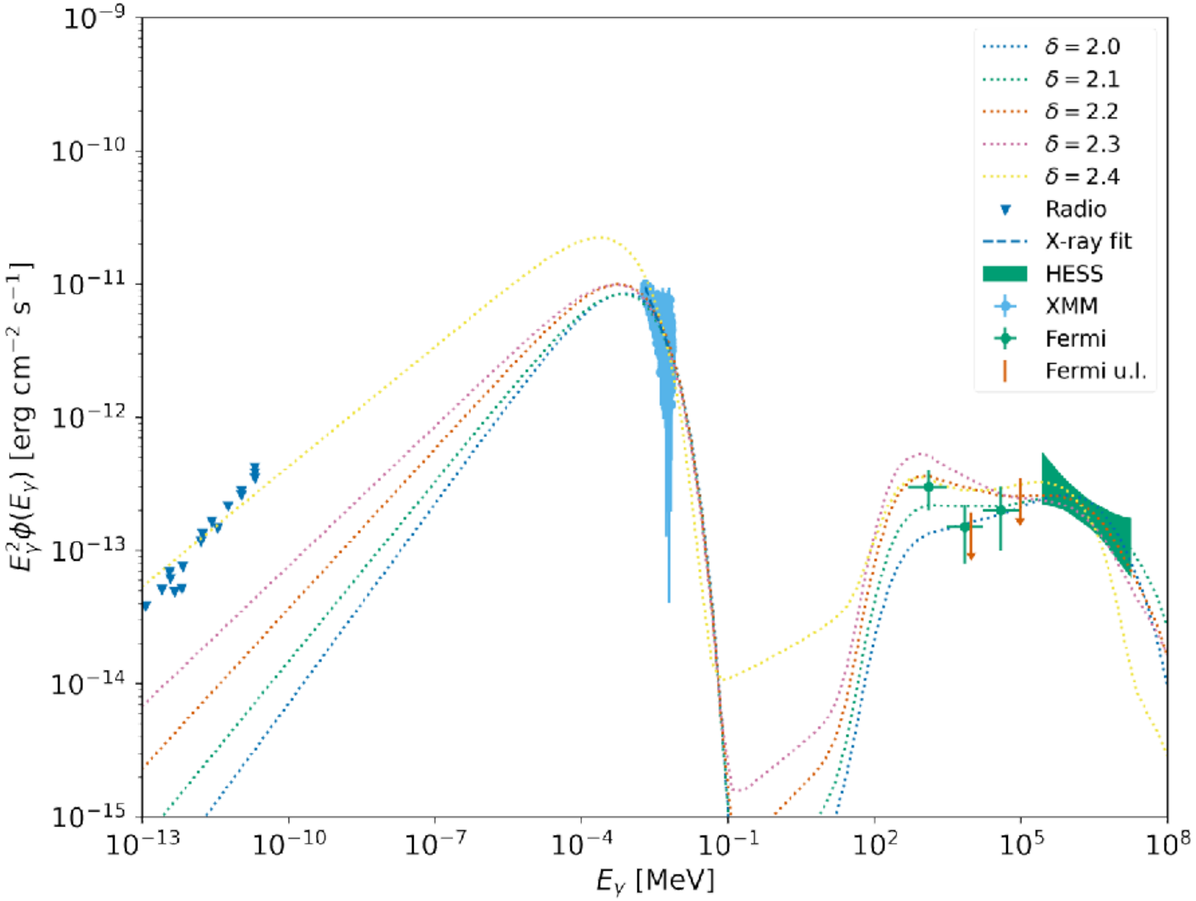
Transient gamma rays from the 2021 outburst of RS Ophiuchi

Vo Hong Minh Phan
Observatoire de Paris and Sorbonne University

with Enrico Peretti, Pierre Cristofari, Vincent Tatischeff and Andrea Ciardi

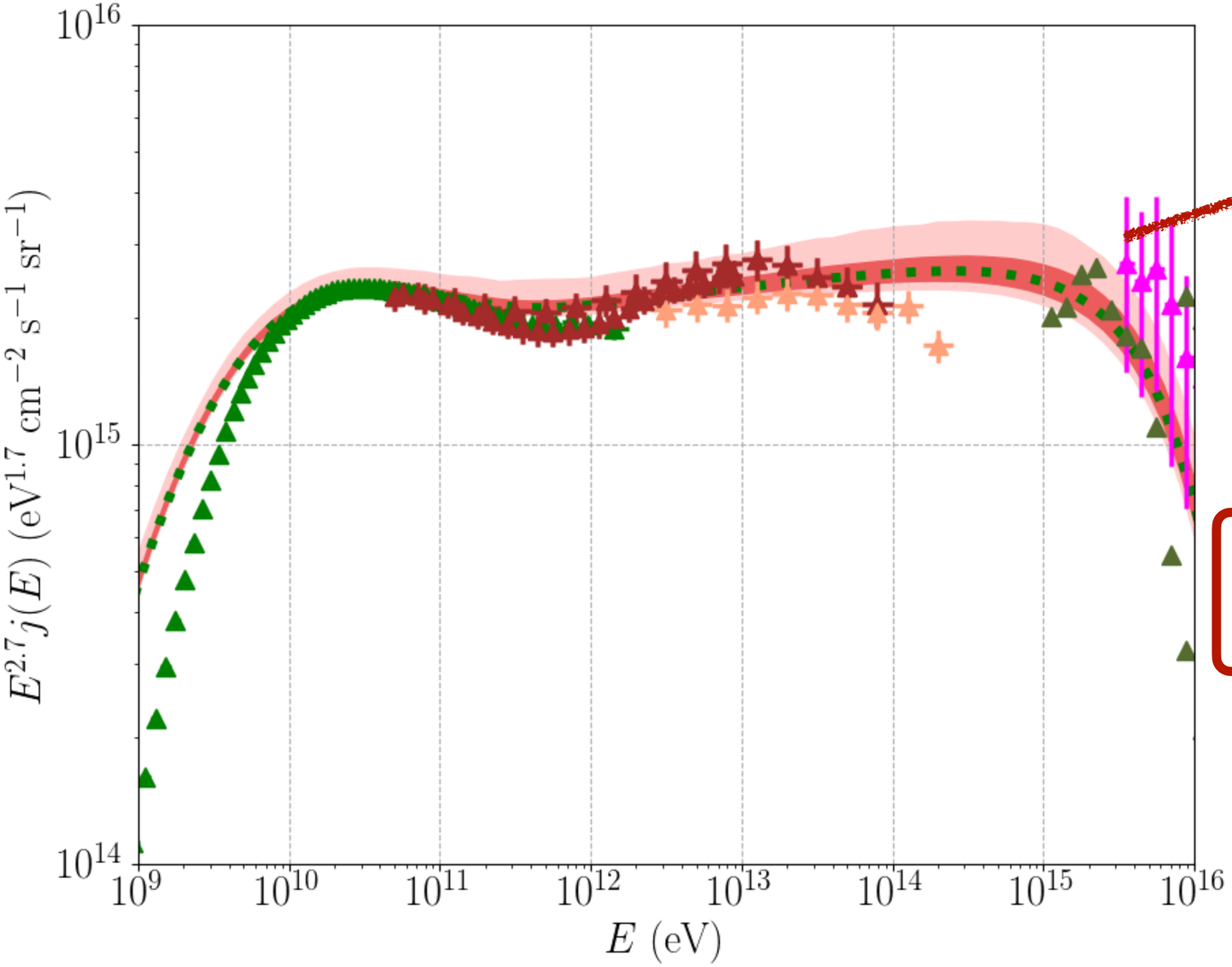
Motivation





Giuffrida (with **Phan**) et al. A&A 2024, see also **Phan** et al. A&A 2020 (for SNR W28)

Motivation

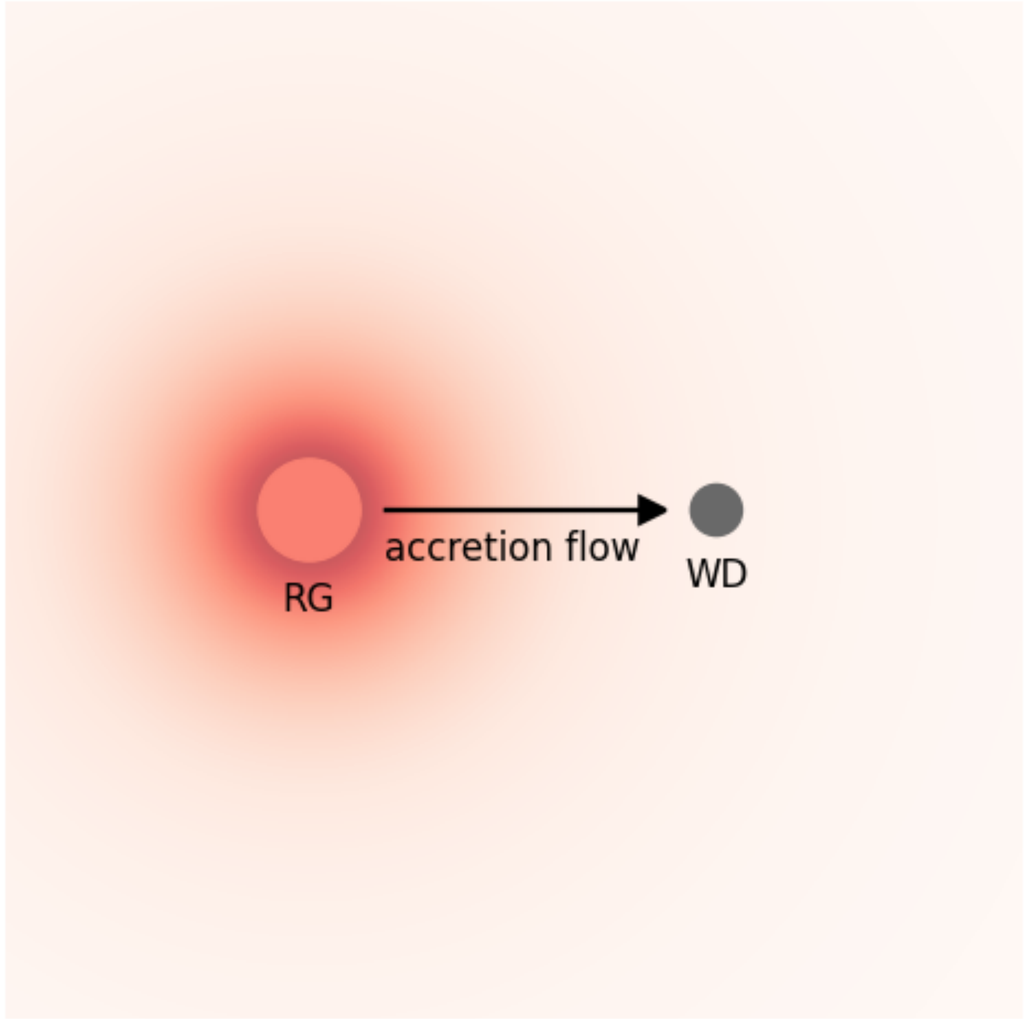


$E_{\mathrm{max}} \sim 3\,\mathrm{PeV}$

Alternatives to study cosmic particle acceleration?

Phan et al. Phys. Rev. Lett. 2021, **Phan** & Cristofari in preparation

Schematic view of RS Ophiuchi



- White dwarf embedded in red giant wind.

Not to scale

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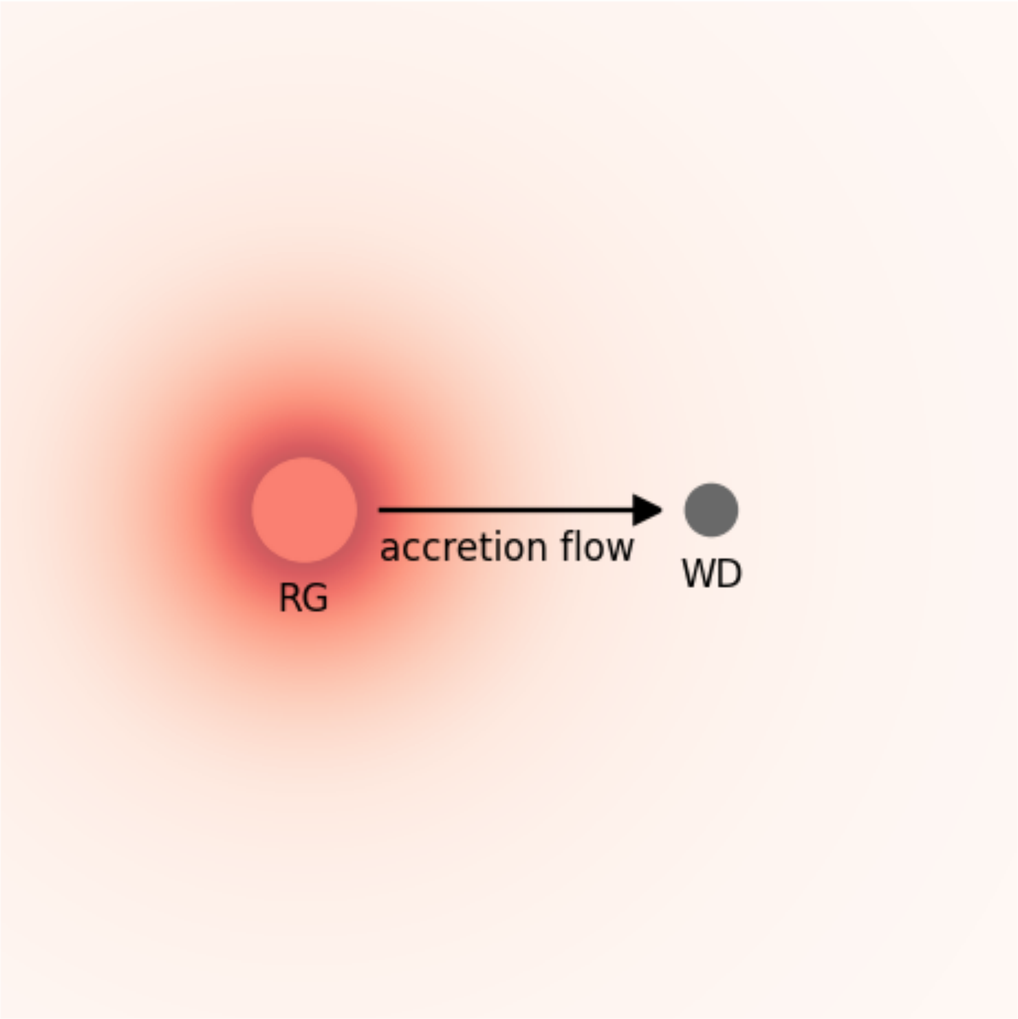

- White dwarf embedded in red giant wind.
- Distance to Earth $\sim 1.5\,\mathrm{kpc}$ or $2.5\,\mathrm{kpc}$?
- Size of the system $\sim 1.5\,\mathrm{au}$.
- B-field close to red giant $\sim 1\,\mathrm{G}$ to $10\,\mathrm{G}$.
- Gas density close to red giant $\sim 10^{8}\,\mathrm{cm}^{-3}$.

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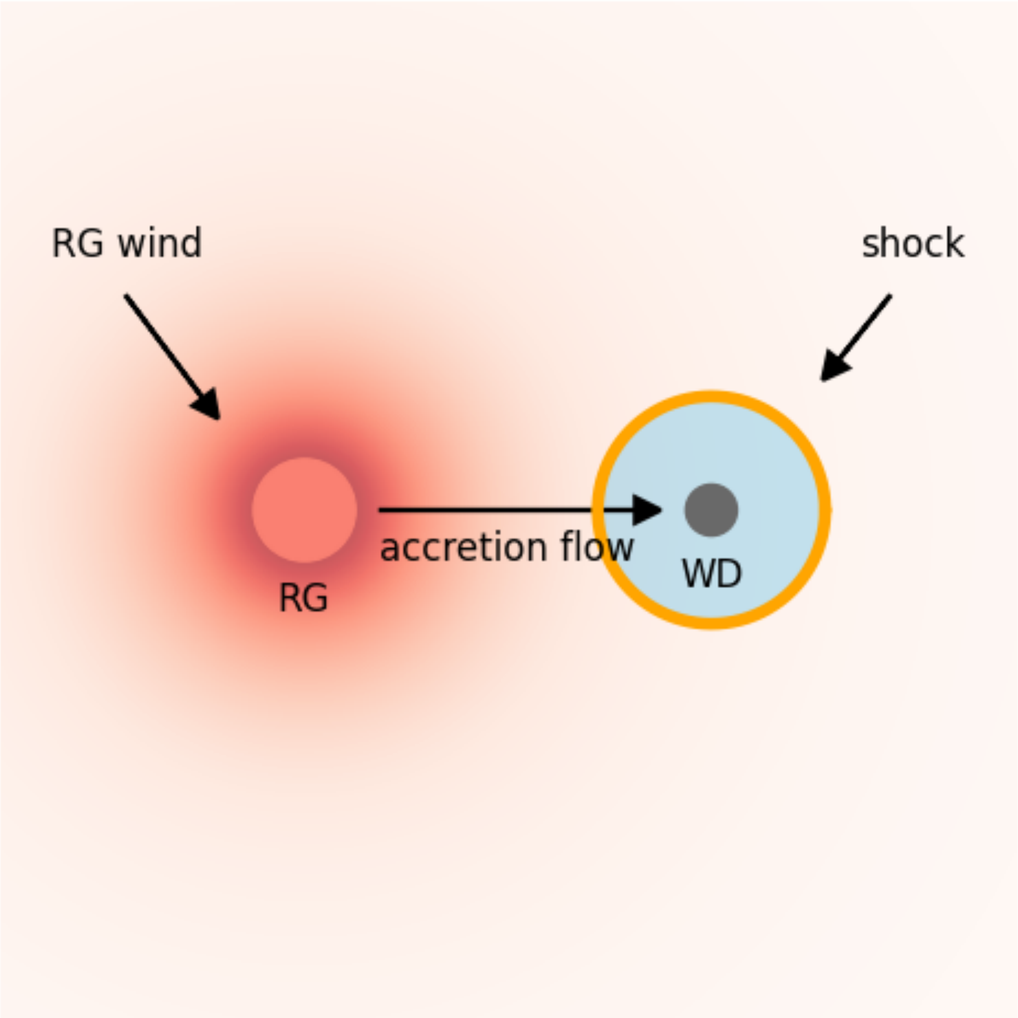

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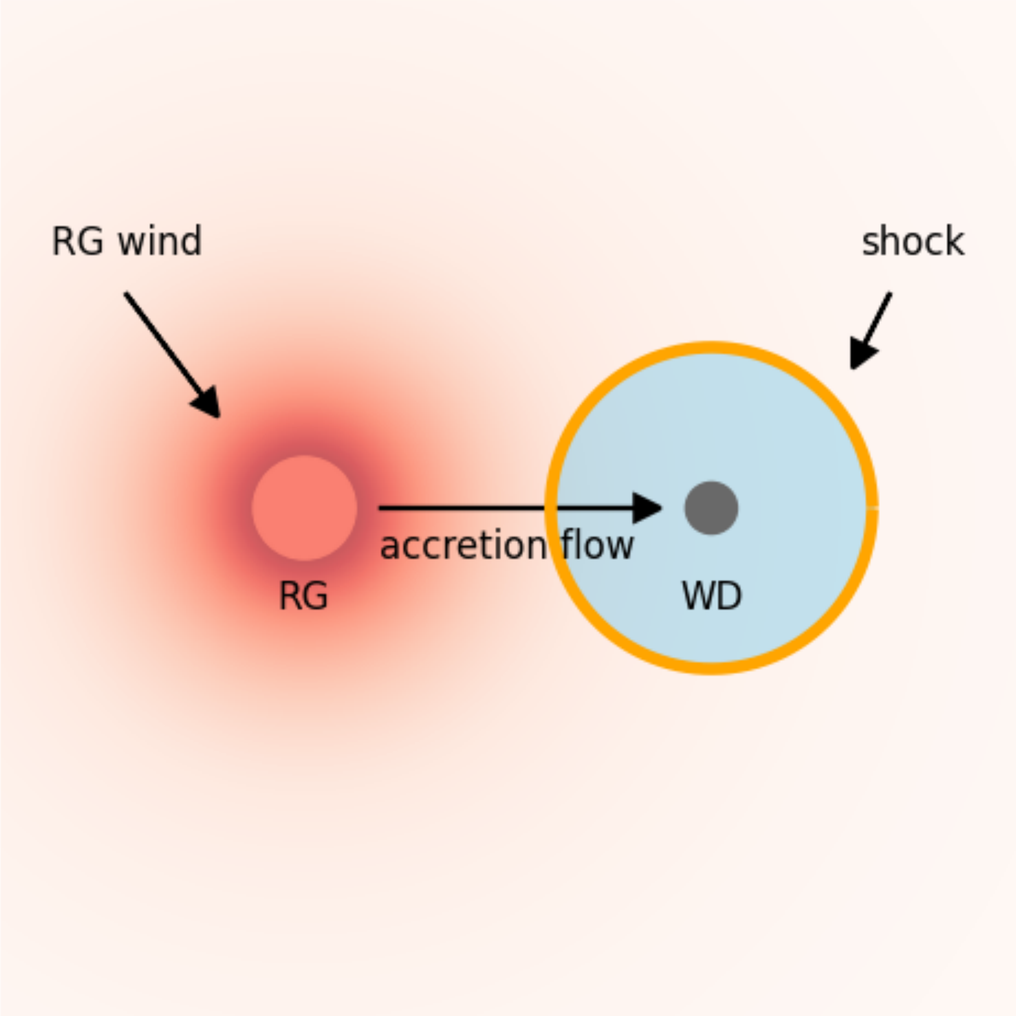

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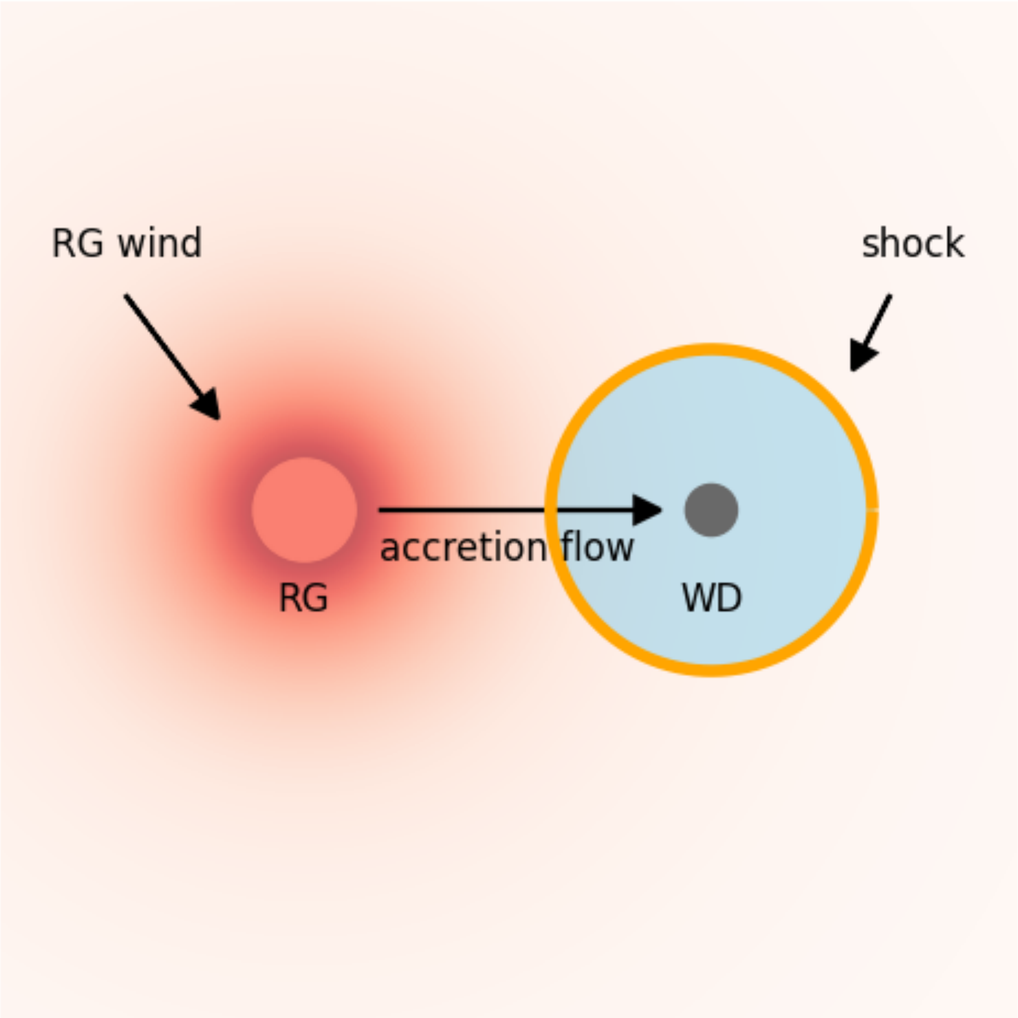
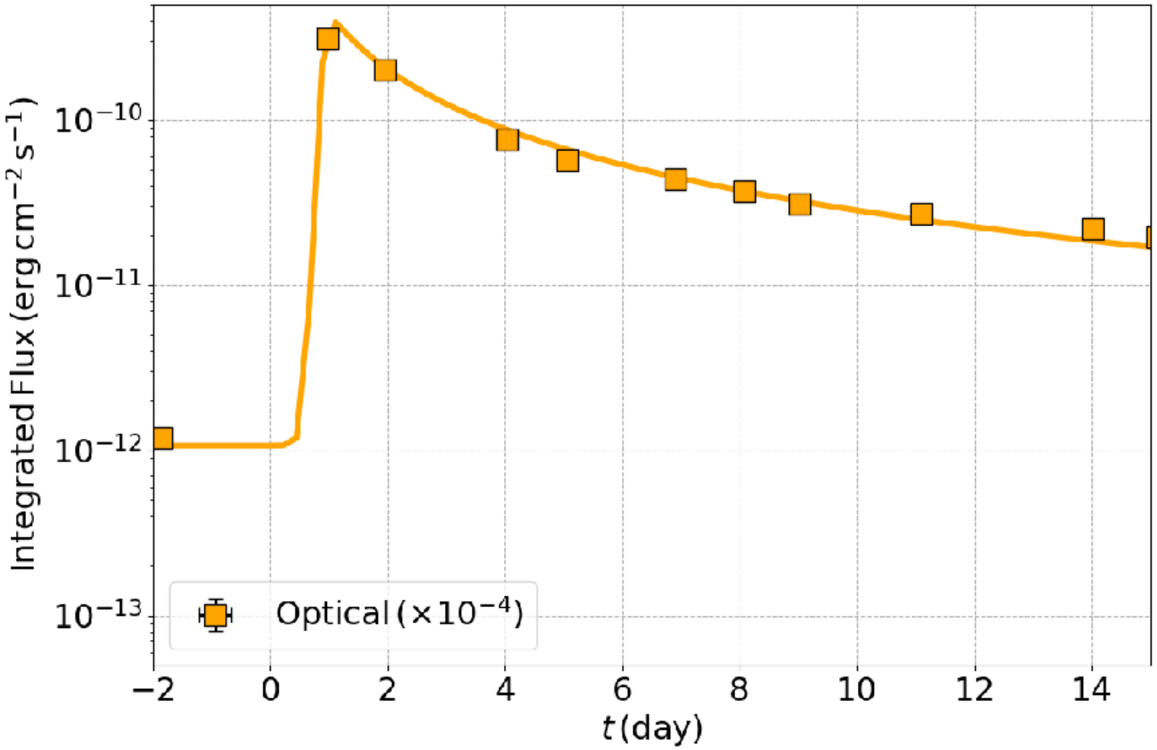
Optical light curve

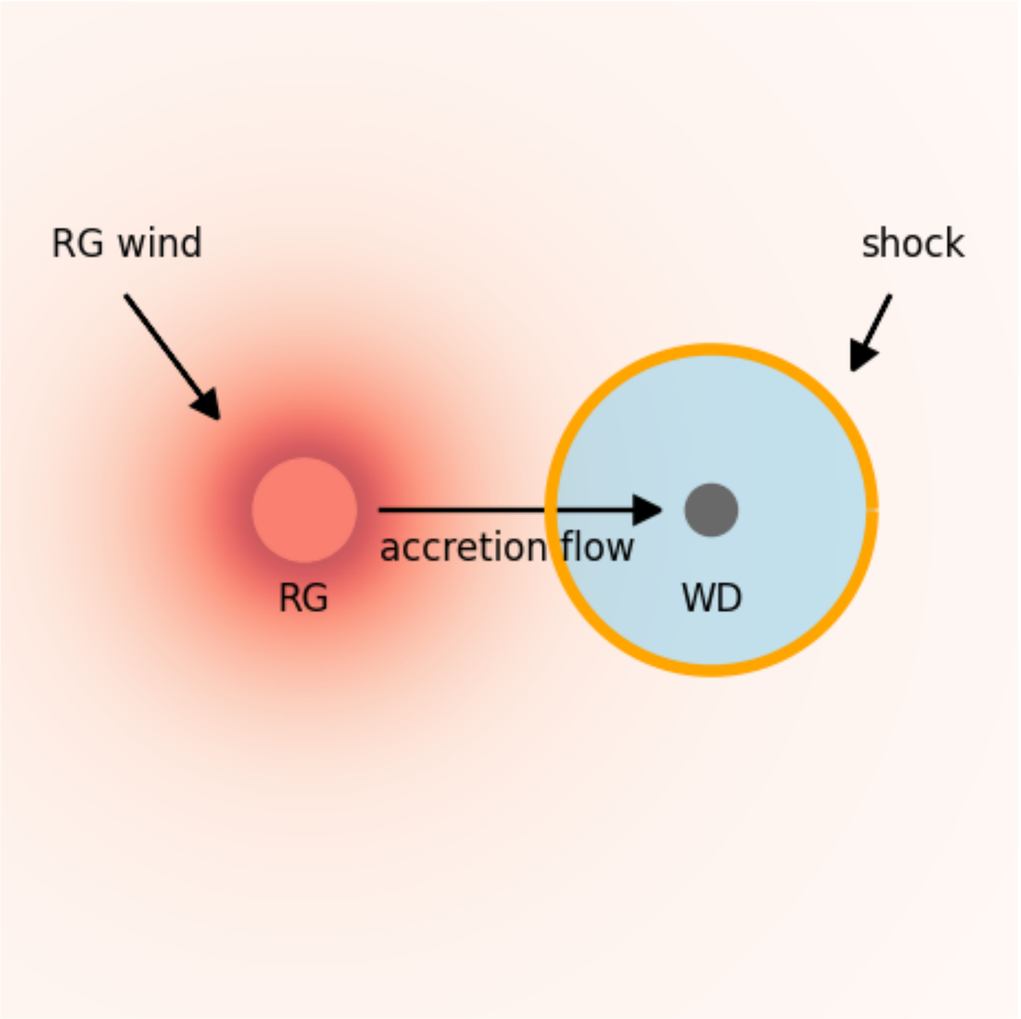


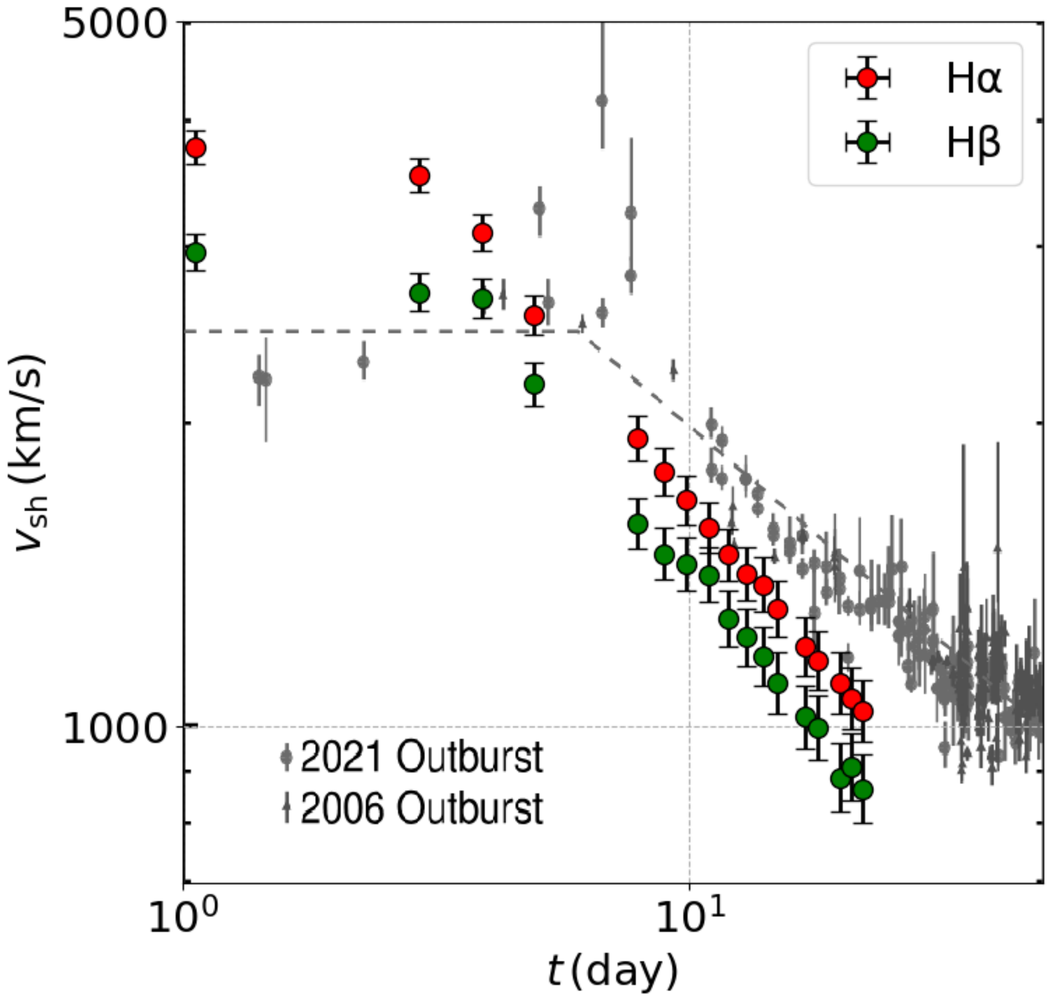
$t = 0\,\mathrm{day}$ at 2021 August 8.25 in Coordinated Universal Time



Not to scale, optical flux derived from Cheung et al. ApJ 2022

Shock dynamics





Not to scale, shock speed from Cheung et al. ApJ 2022 and Pandey et al. MNRAS 2022

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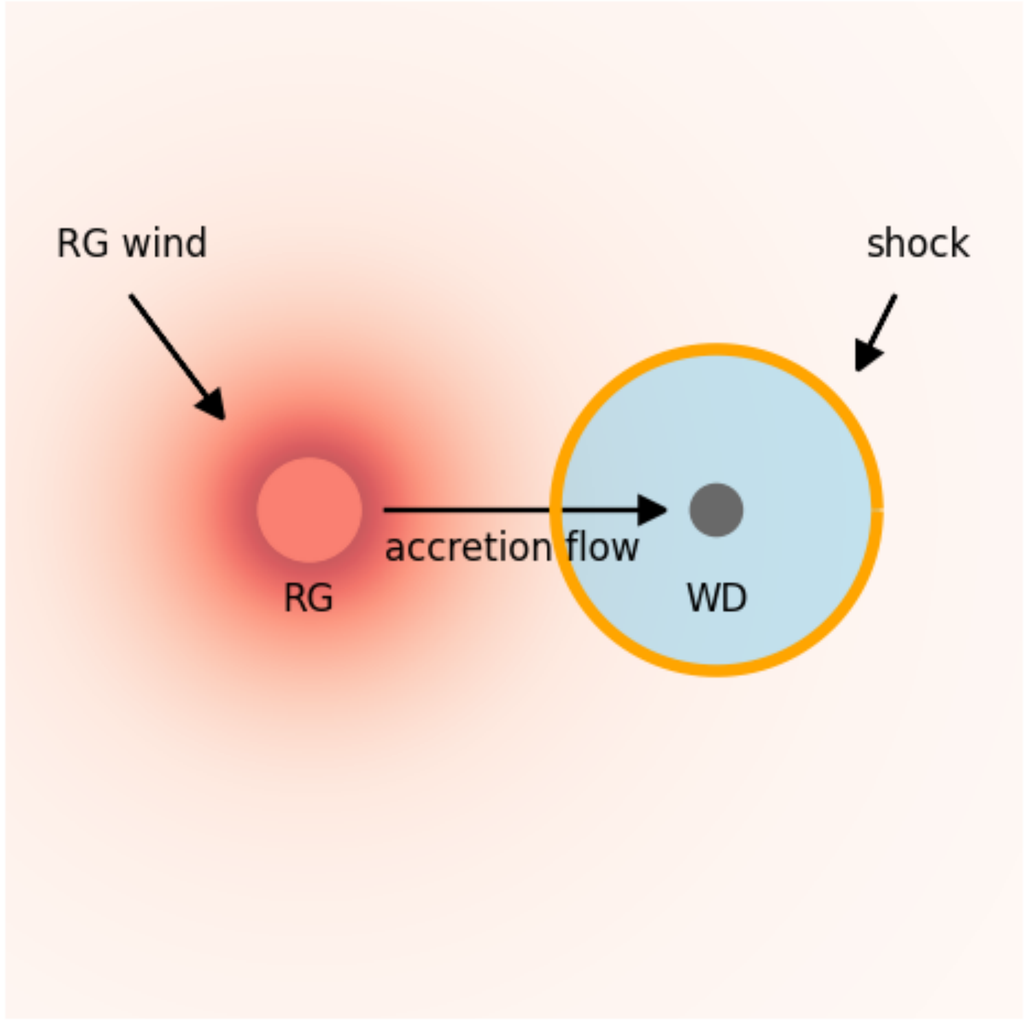
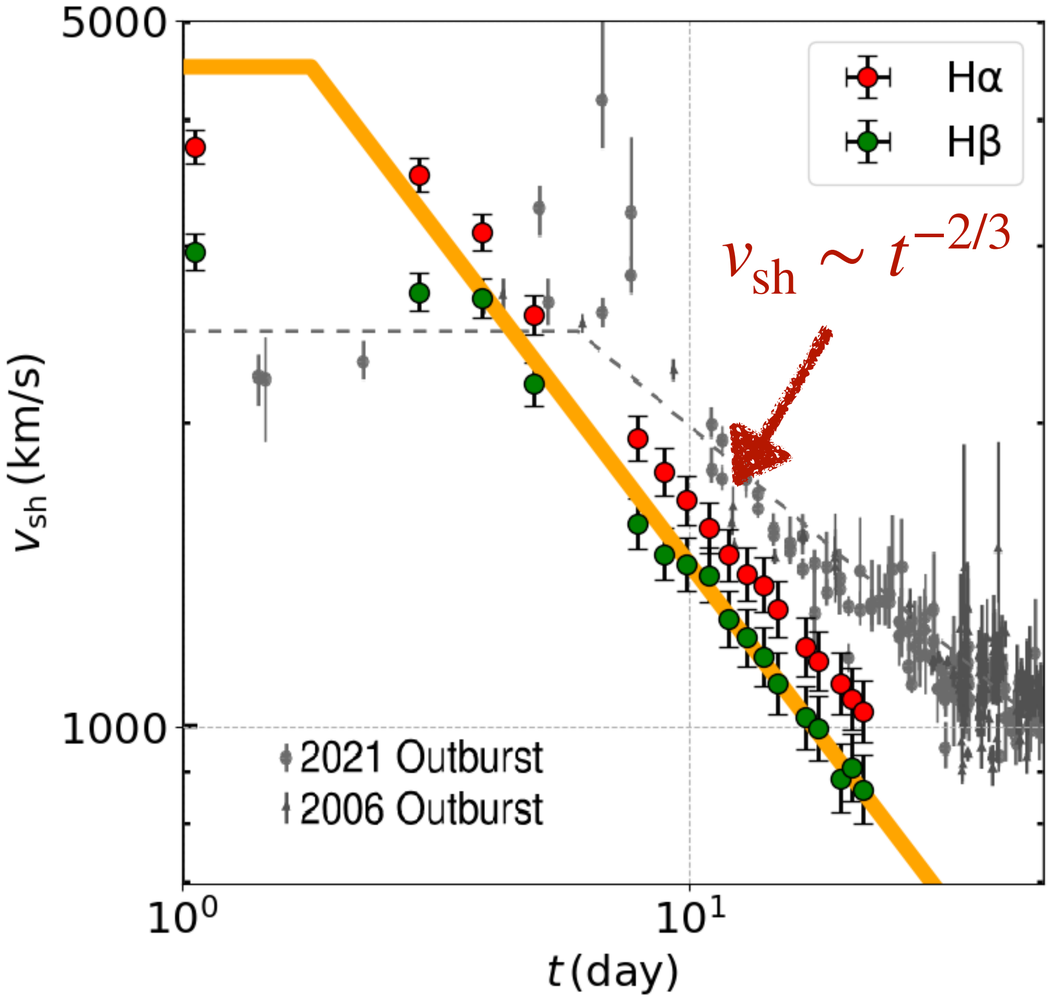
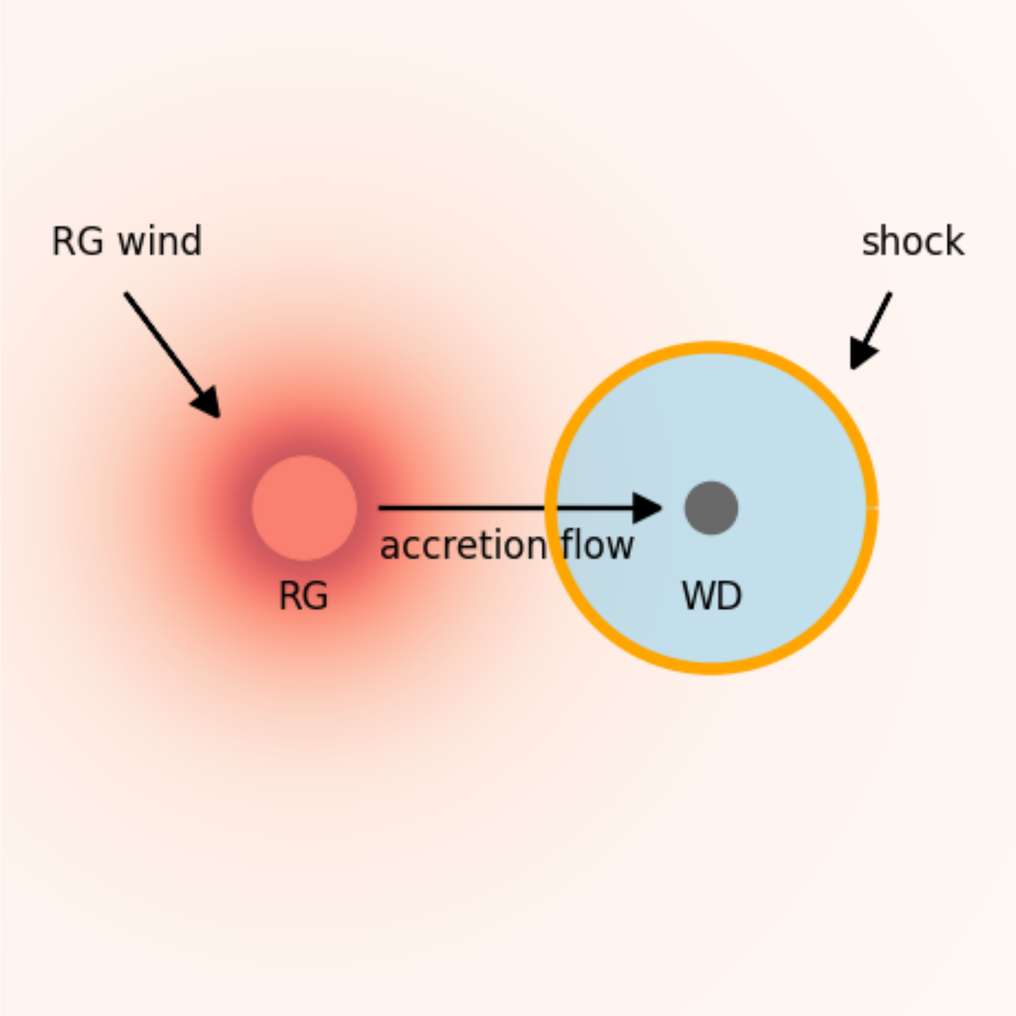
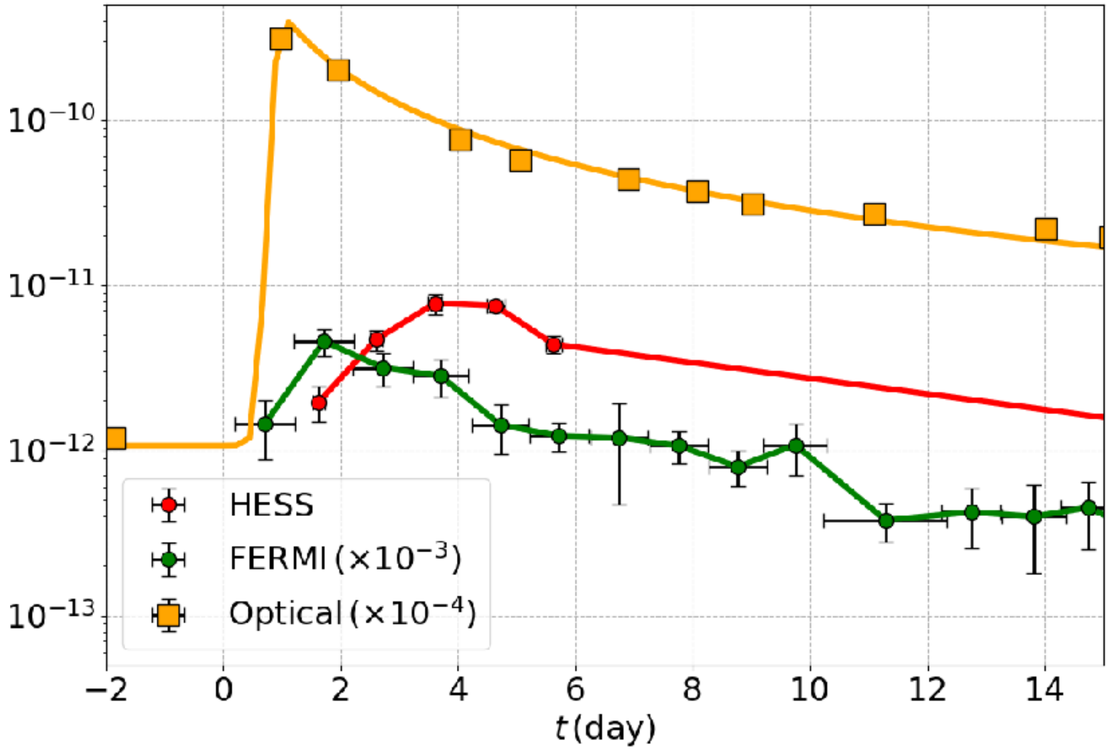




Not to scale, shock speed from Cheung et al. ApJ 2022 and Pandey et al. MNRAS 2022

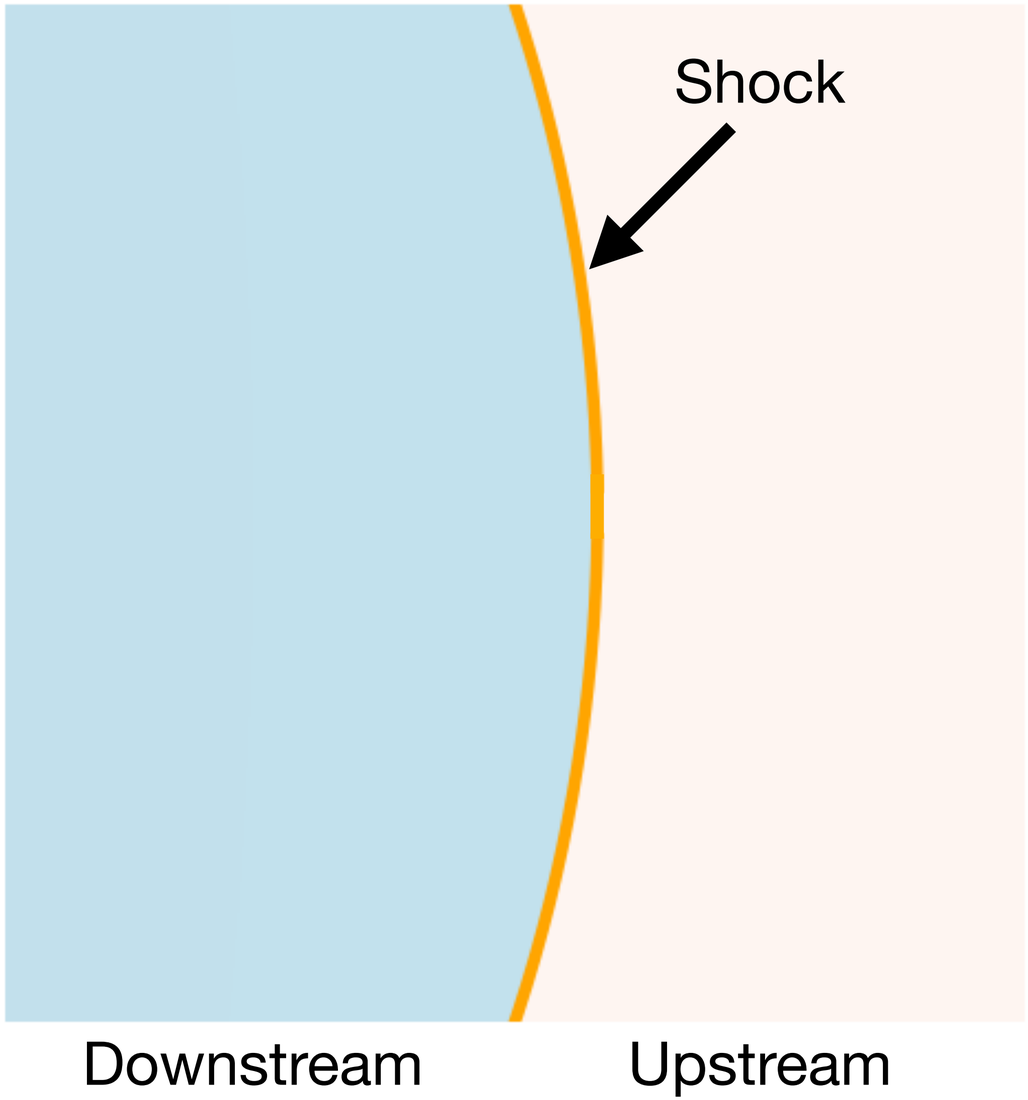
Gamma-ray light curves





Not to scale, optical and gamma-ray flux from Cheung et al. ApJ 2022 and HESS Collaboration Science 2022

Particle acceleration in nova shocks



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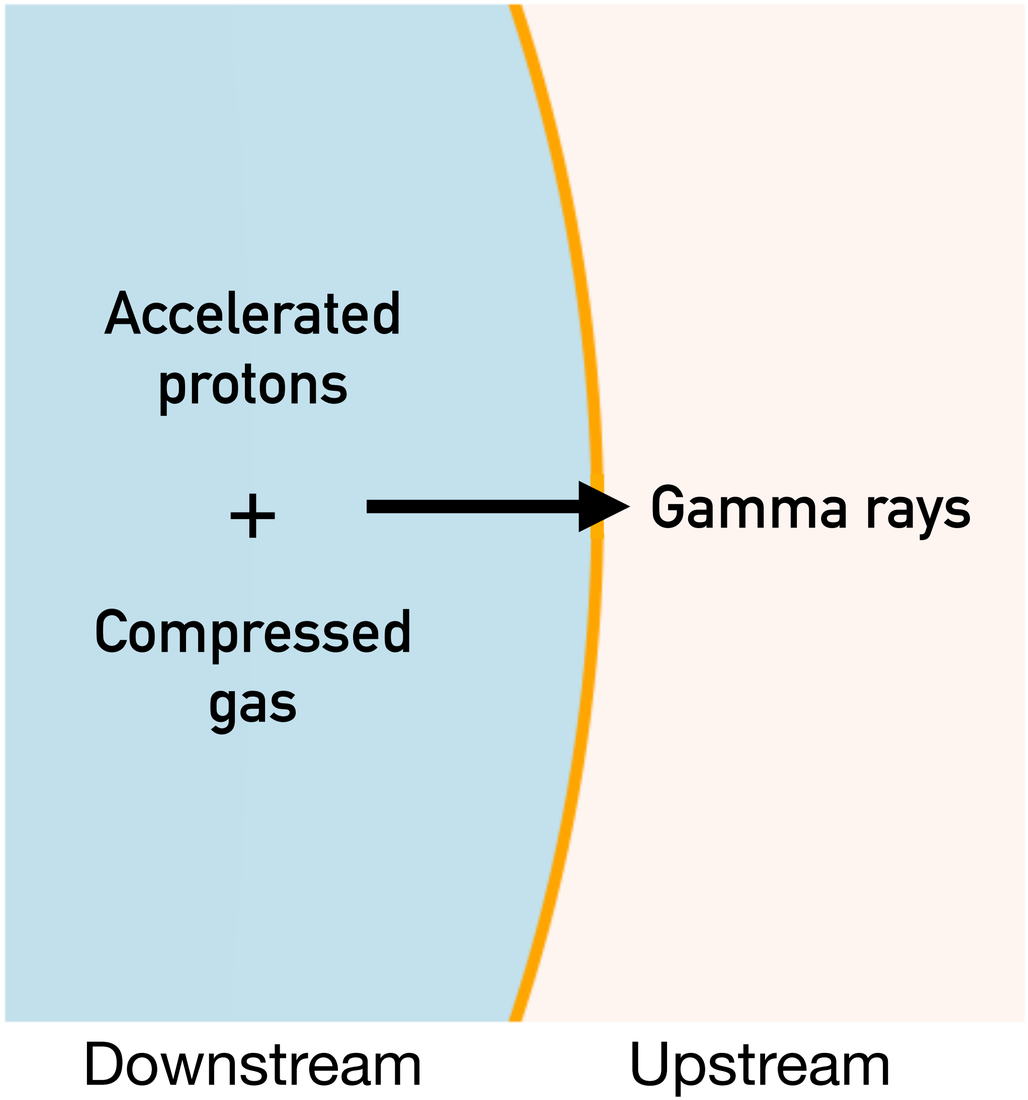

$$\frac{\partial N(E,t)}{\partial t} = \pi R_{\rm sh}^2(t) v_{\rm sh}(t) \; f_{\rm p}(E,t),$$

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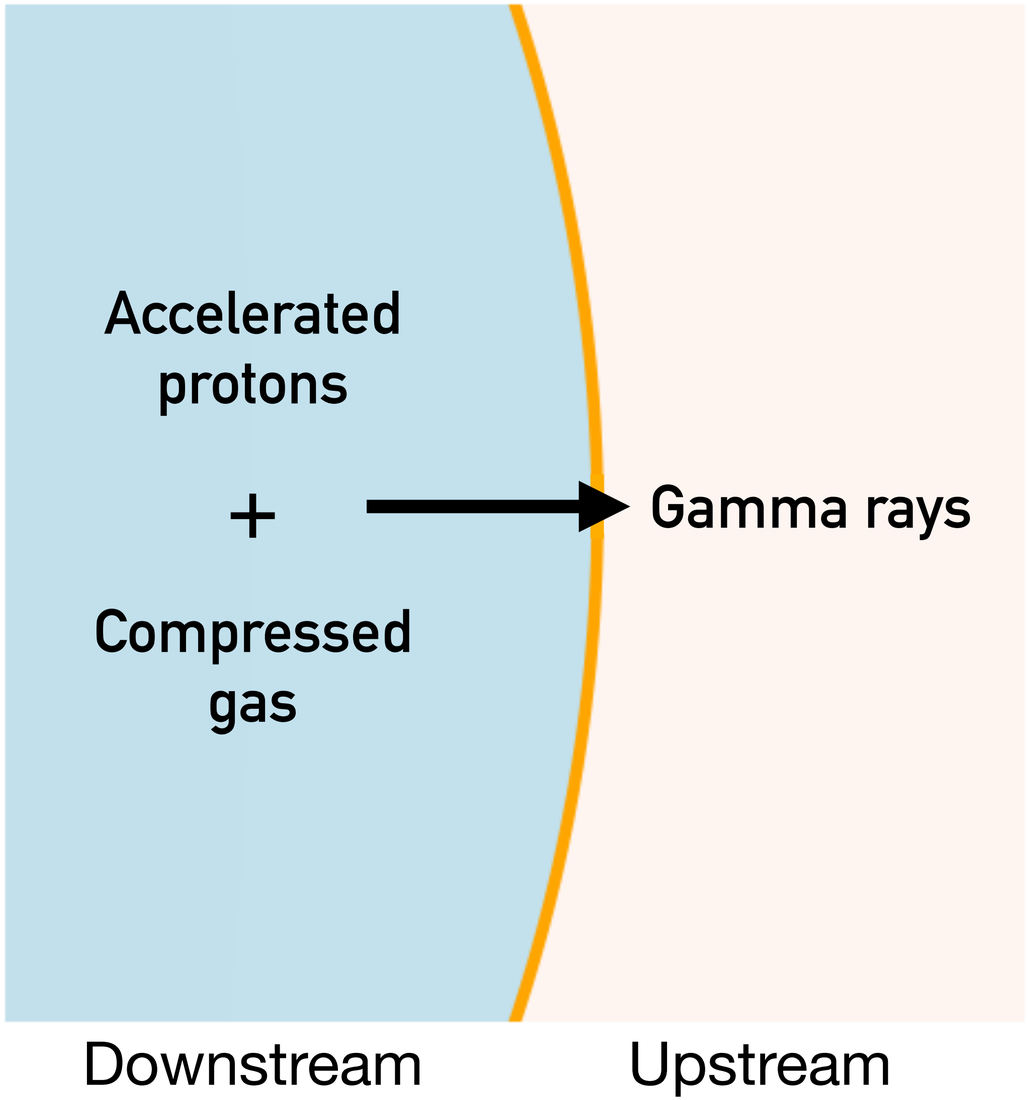

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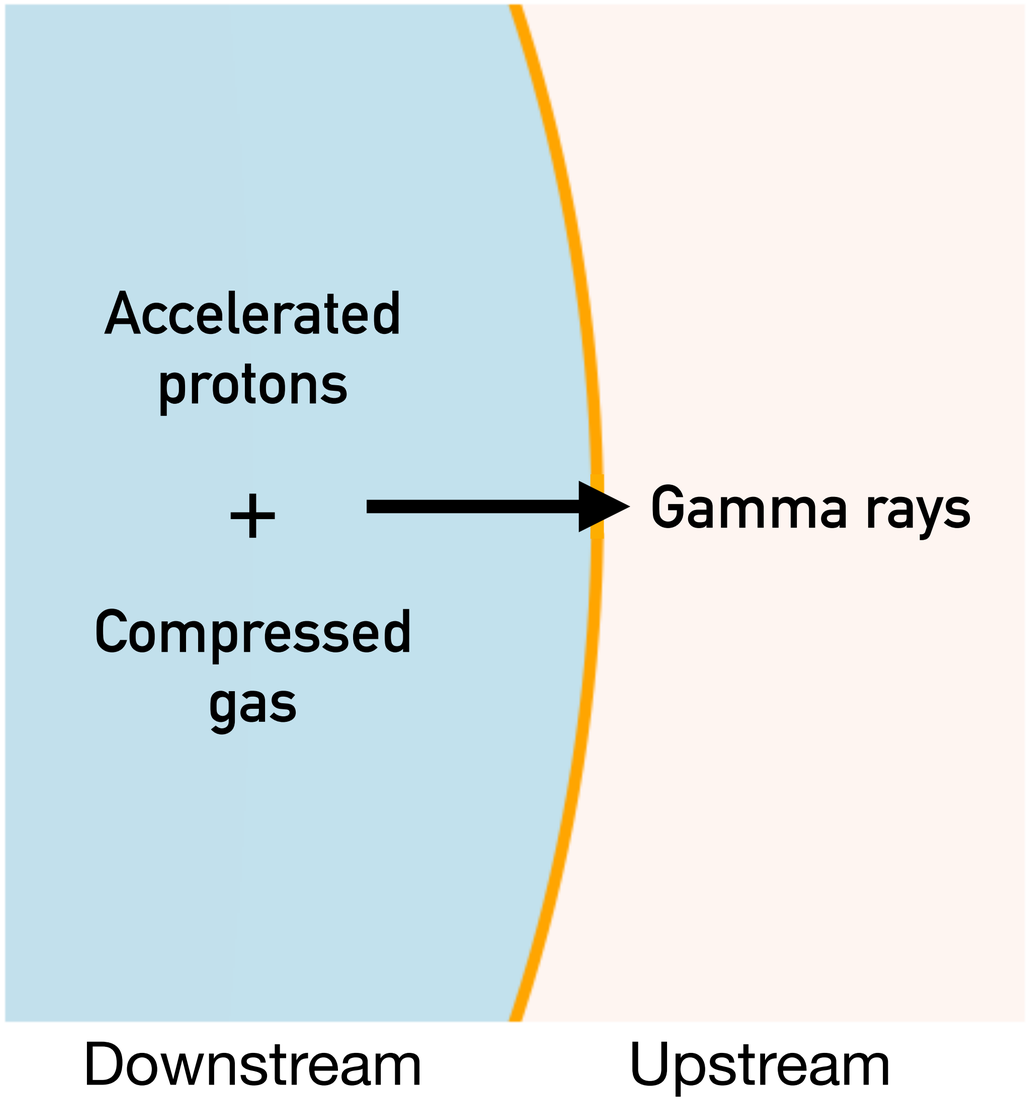

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Shock injection spectrum

$$f_p(E,t) \sim E^{-2.2} \exp\left(-\frac{E}{E_{\rm max}(t)}\right)$$

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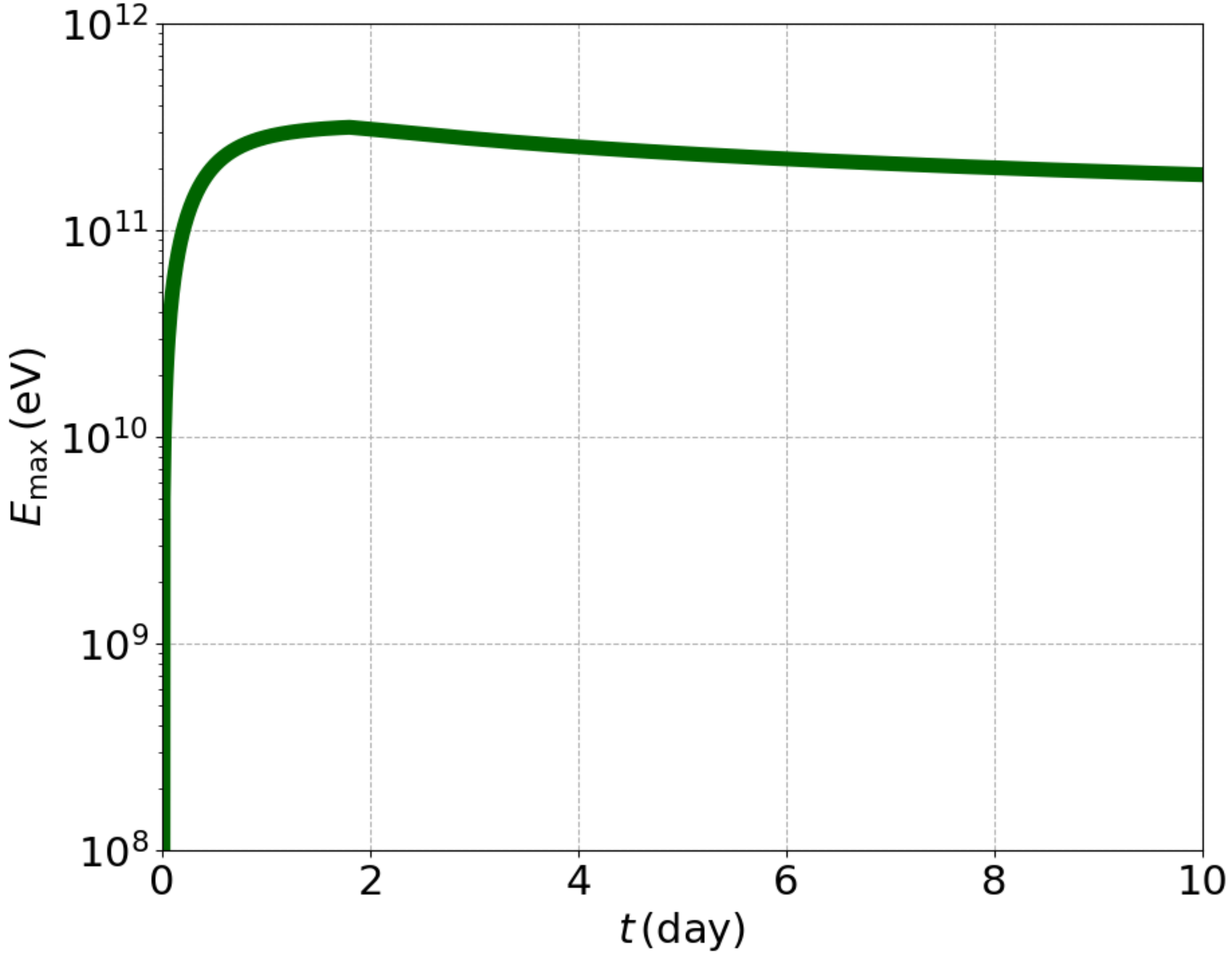

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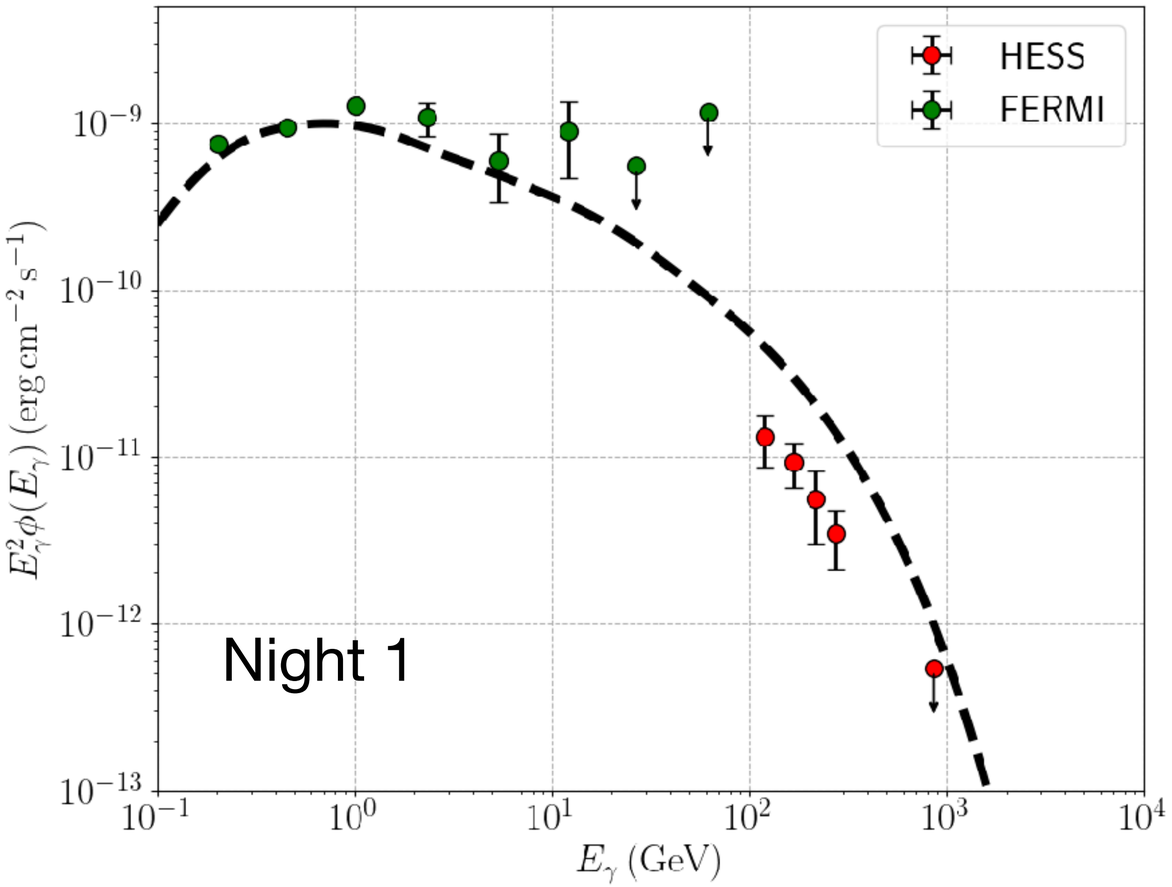
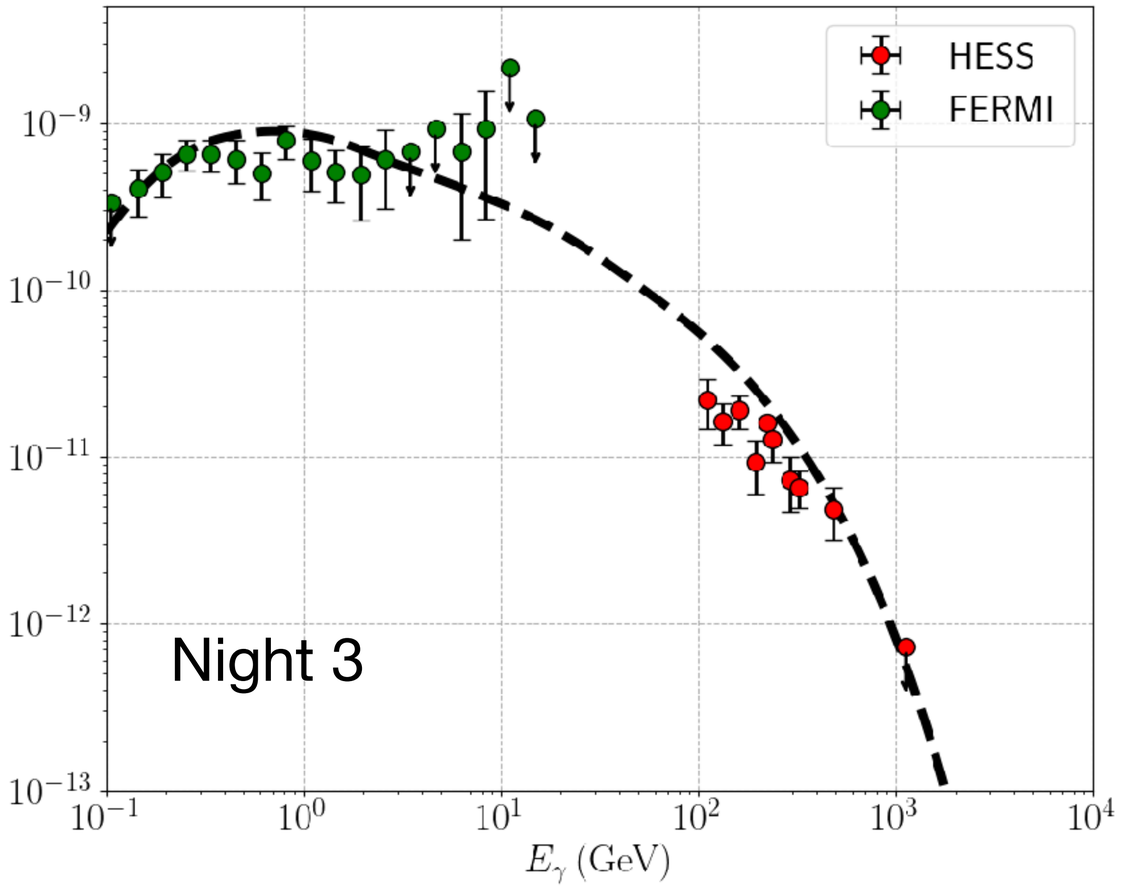
Gamma-ray emission





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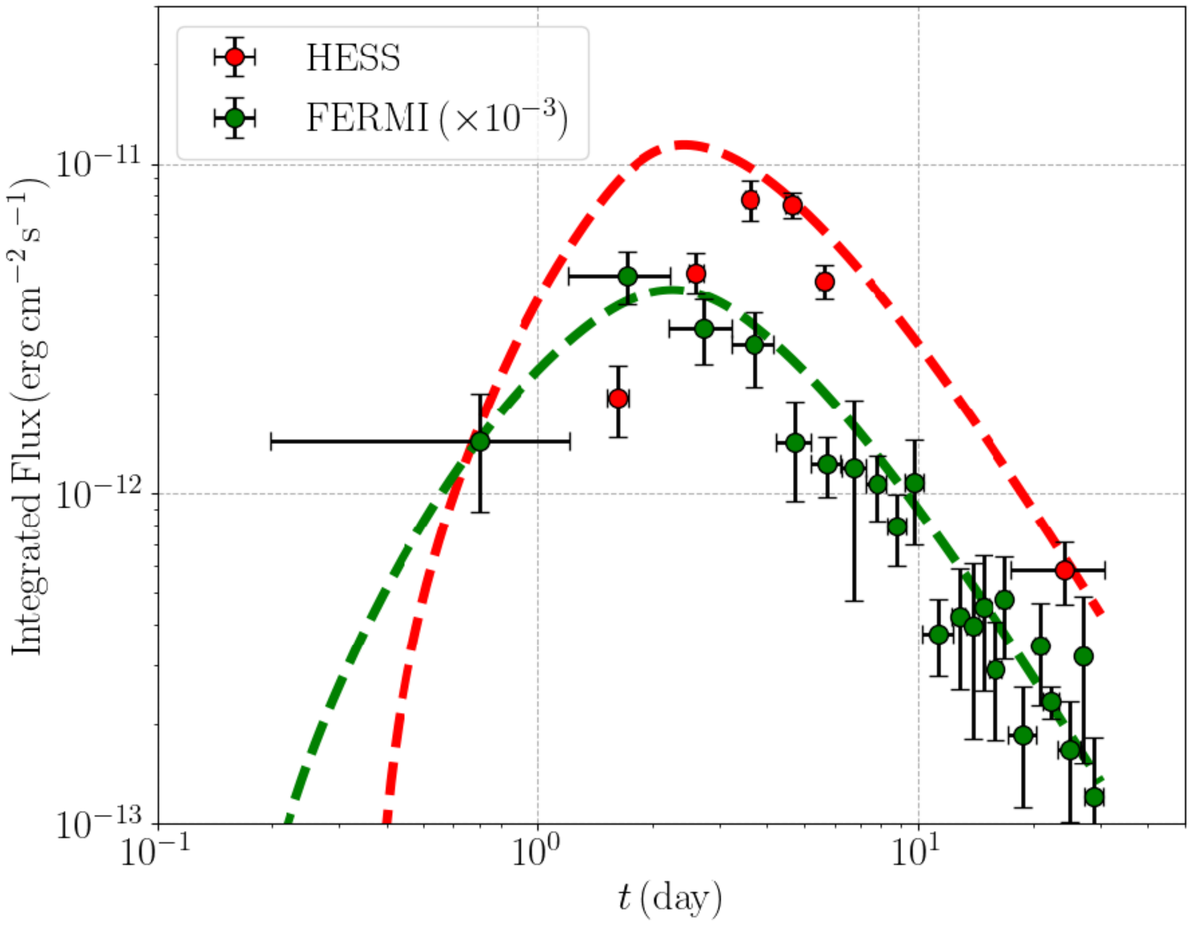

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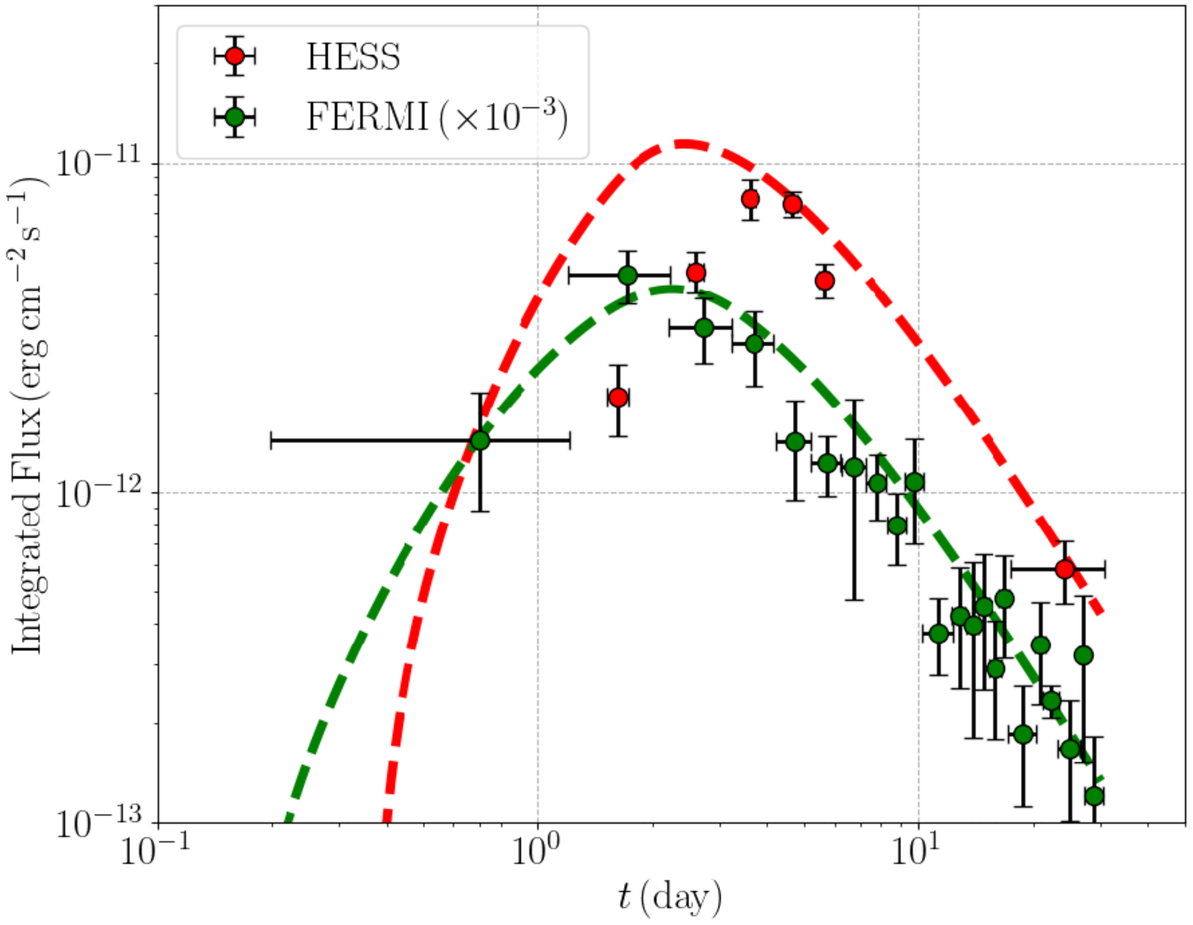

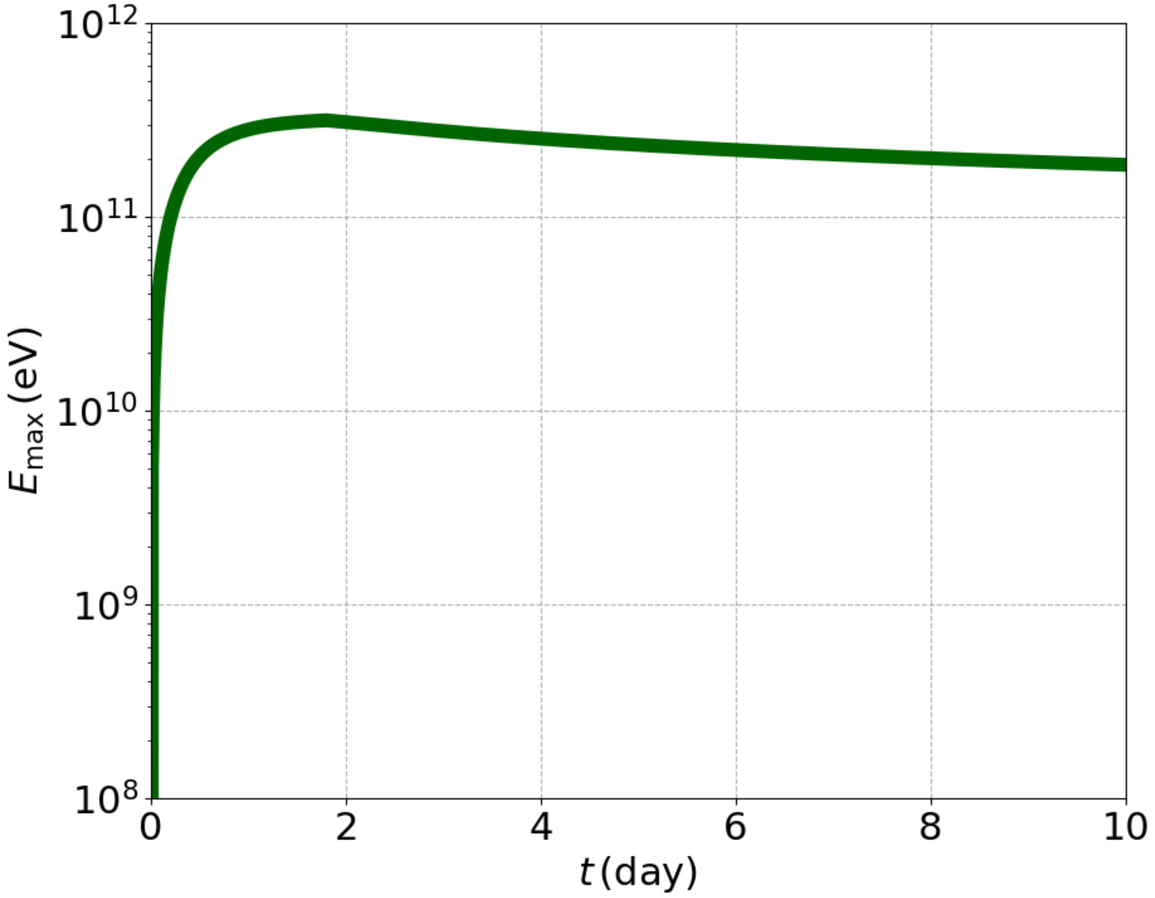

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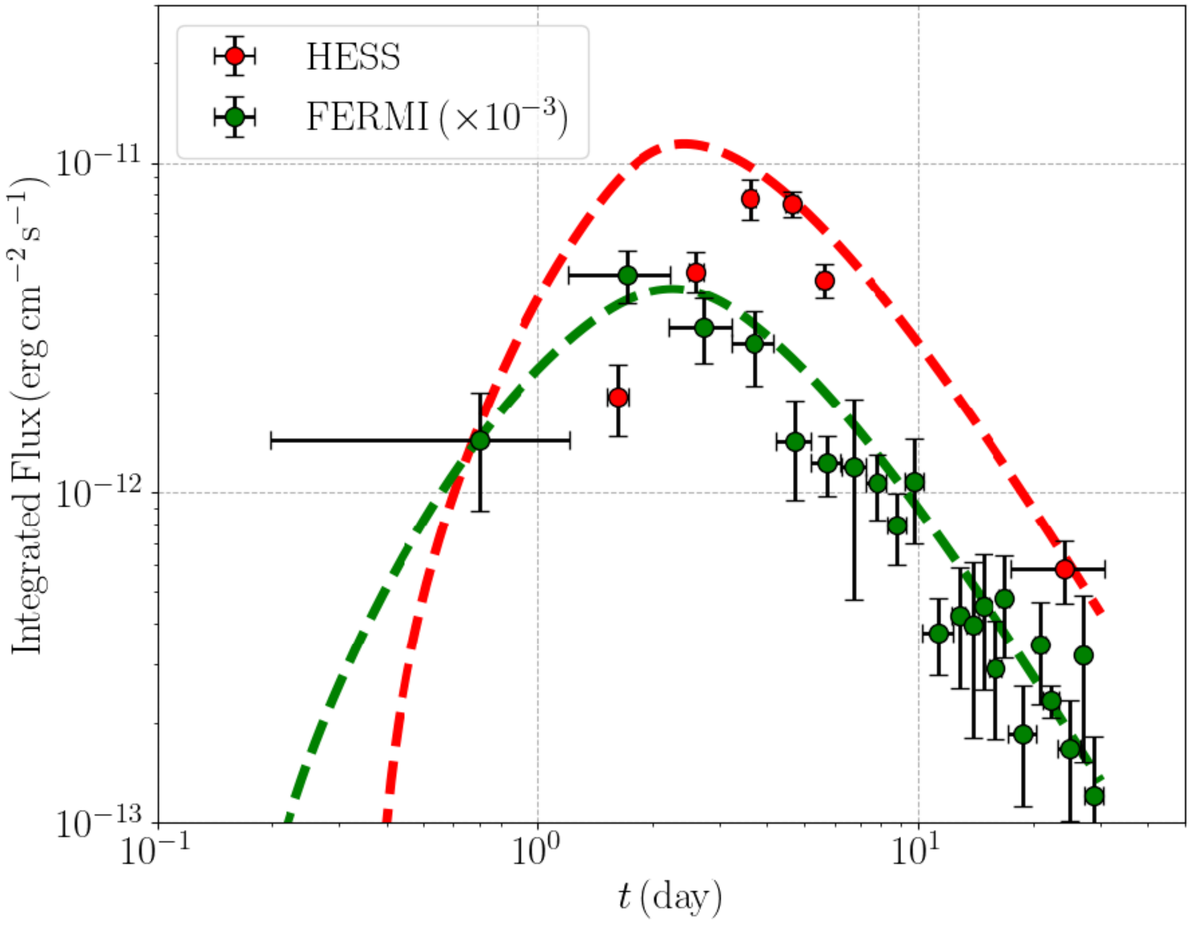
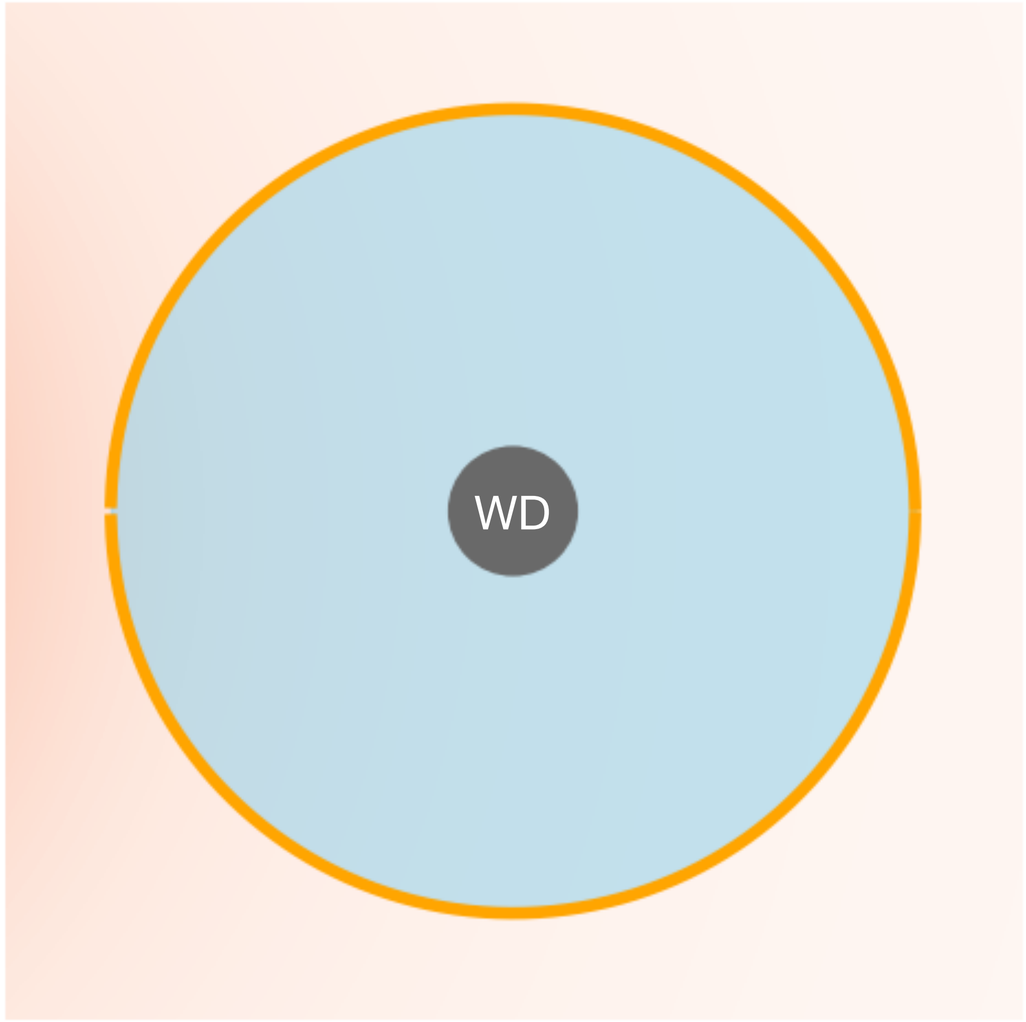


- Models proposed for this delay:
  - Changes in injection spectrum,
  - Multiple shocks,
  - Leptonic gamma rays,
  - … ?

HESS Collaboration Science 2022, Zheng et al. Phys. Rev. D 2022,
Diesing et al. ApJ 2023, De Sarkar et al. ApJ 2023

Gamma-ray absorption



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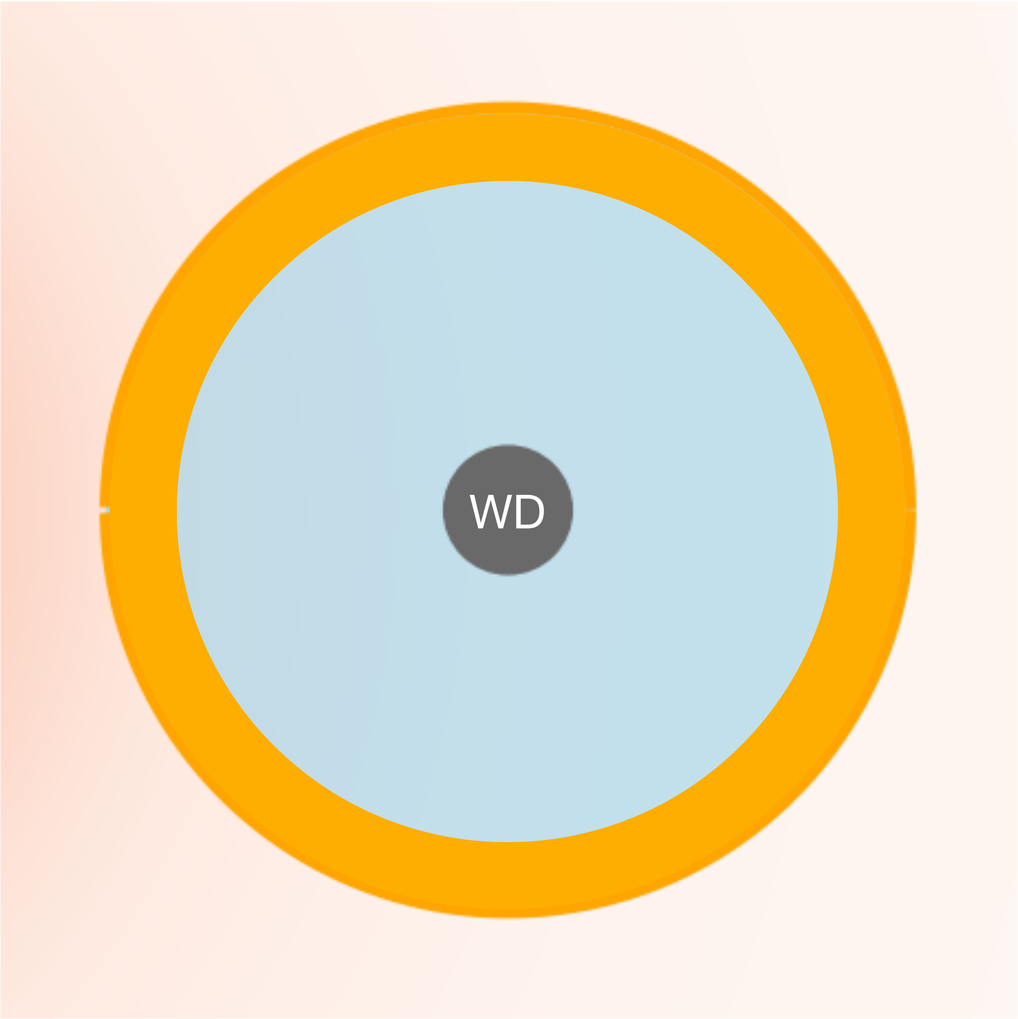

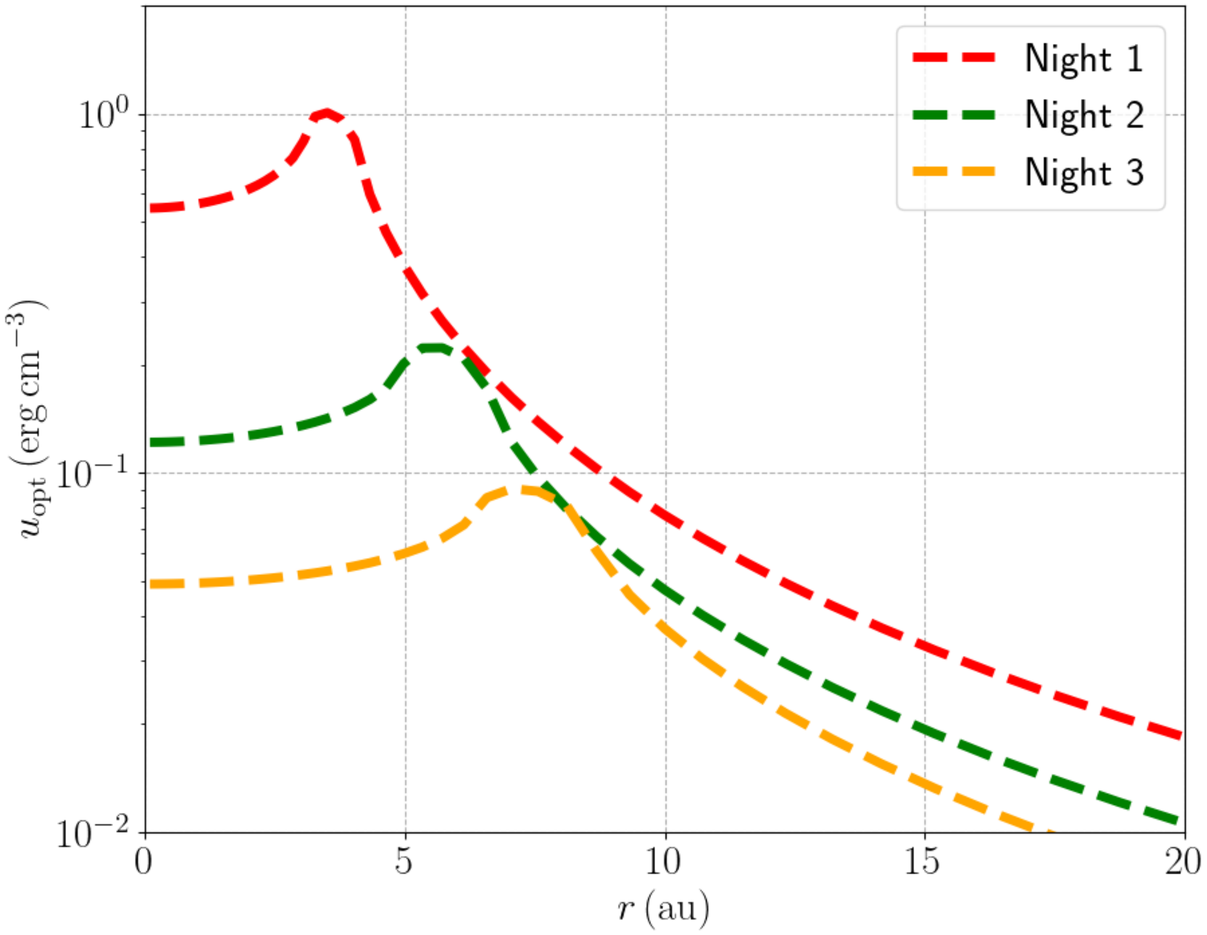

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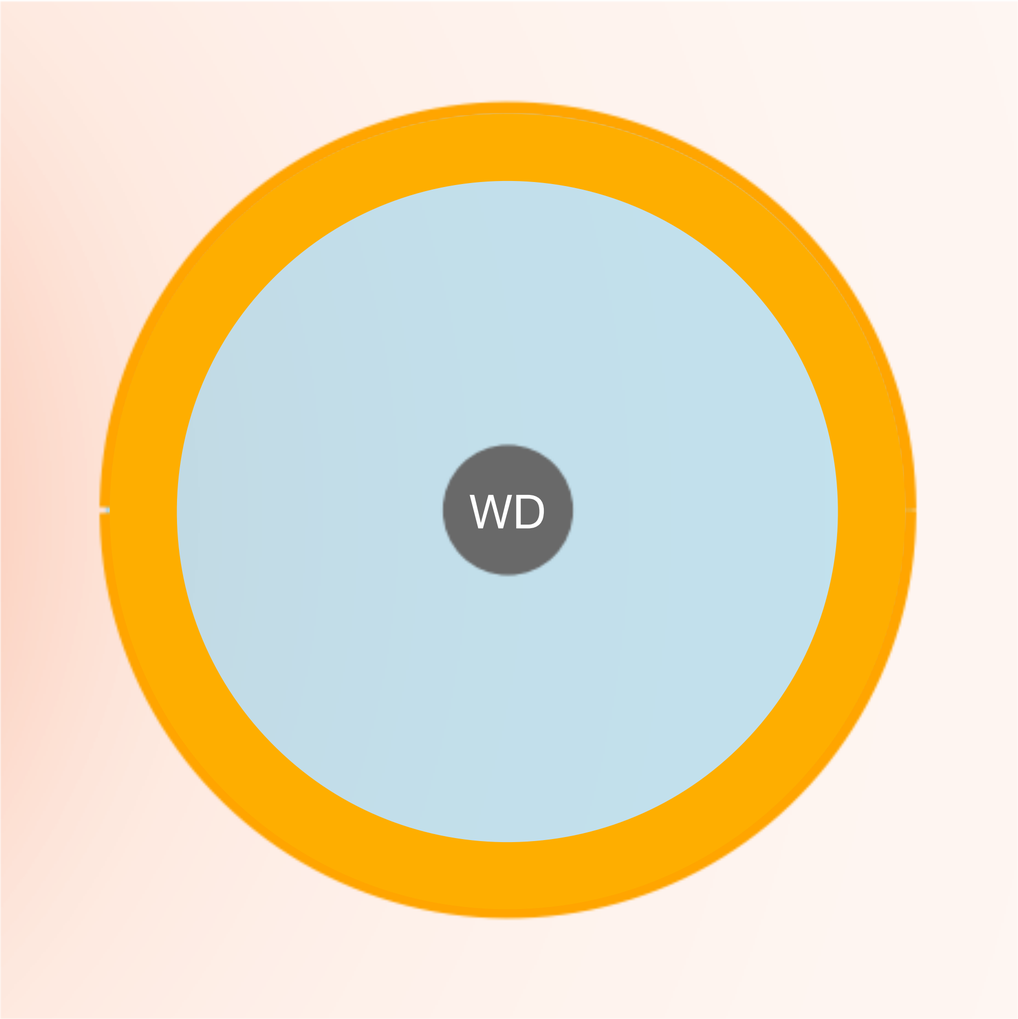


- **Gamma-ray flux with absorption**

$$\phi(E_\gamma, t) \simeq \frac{\phi_0(E_\gamma, t)}{2}\left(e^{-\tau_1(E_\gamma,t)} + e^{-\tau_2(E_\gamma,t)}\right).$$

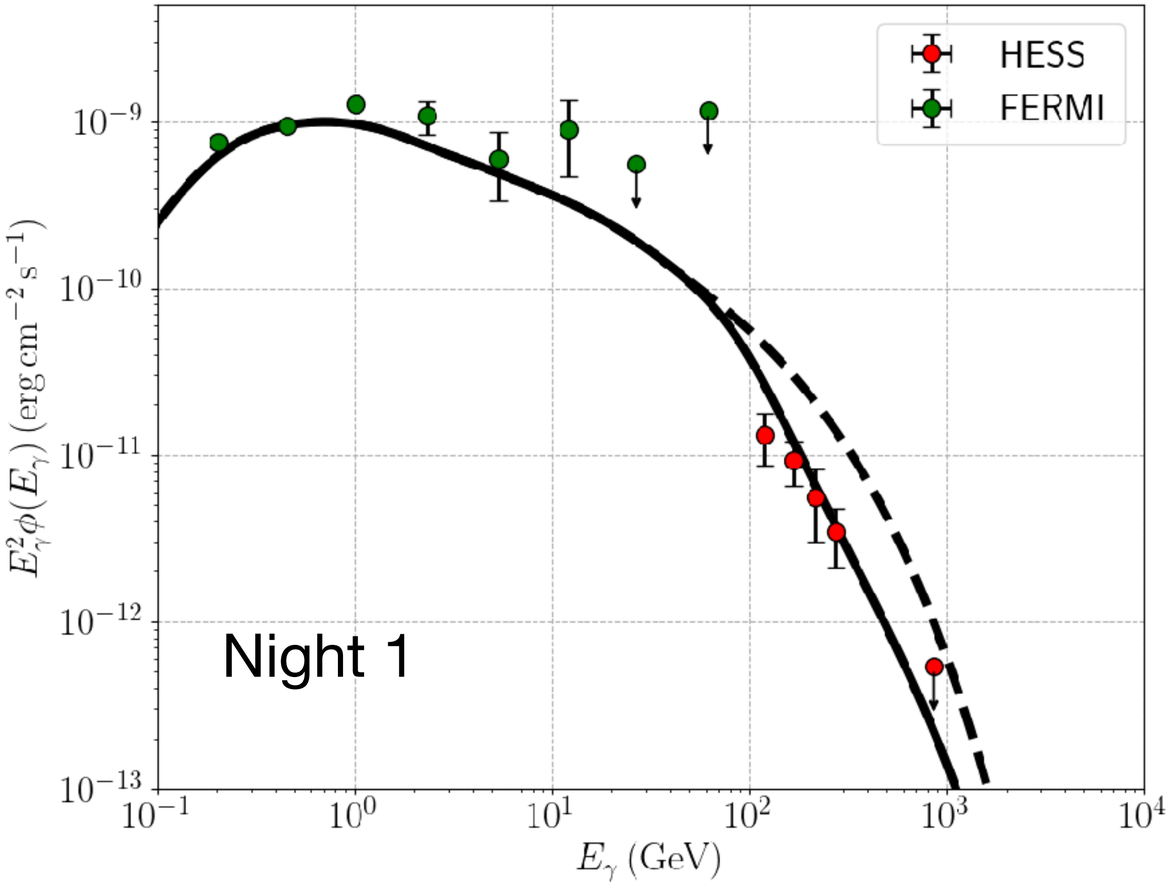
- **Opacities from the two sides**

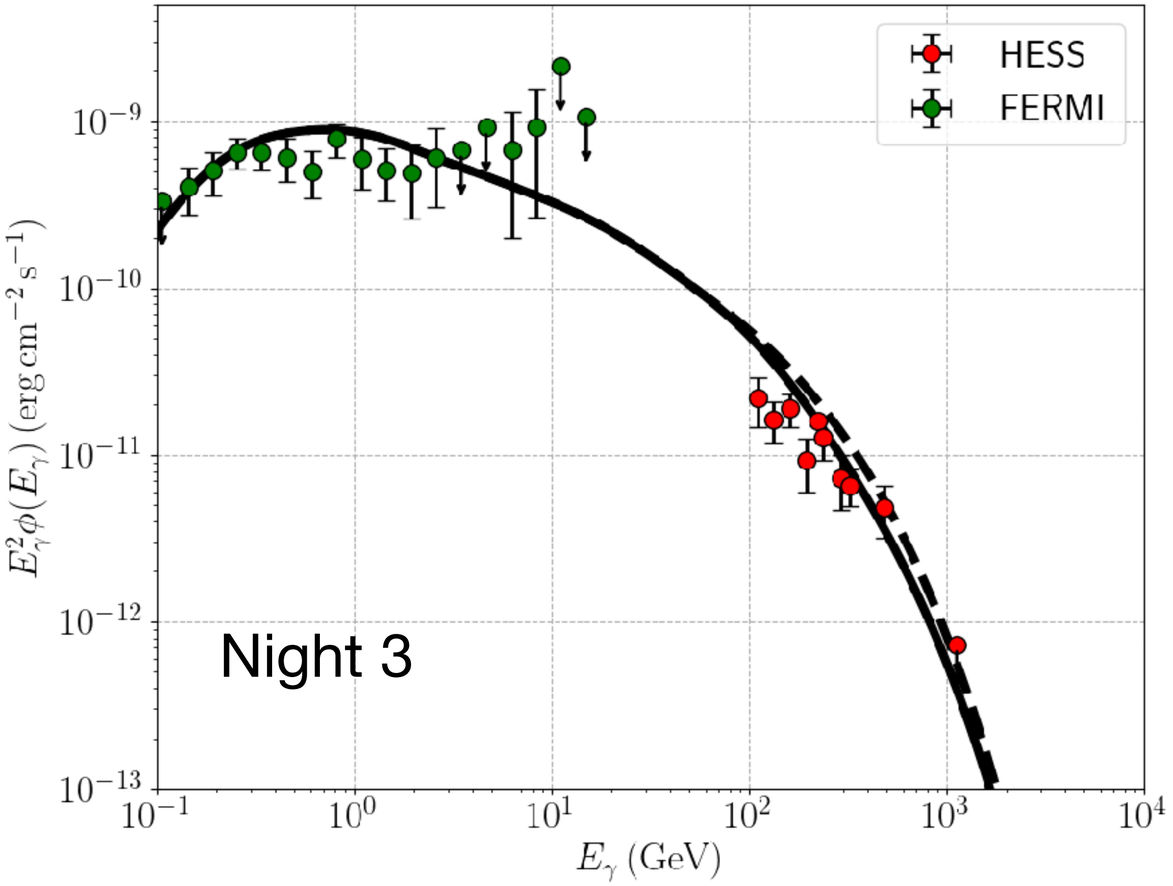
$$\tau_1(E_\gamma, t) = \int_{R_{\rm sh}(t)}^{d_s} {\rm d}r \int_0^\infty {\rm d}E_{\rm ph} f_{\rm opt}(E_{\rm ph}, r, t)\sigma_{\gamma\gamma}(E_\gamma, E_{\rm ph}),$$

$$\tau_2(E_\gamma, t) = \tau_1(E_\gamma, t) + 2\int_0^{R_{\rm sh}(t)} {\rm d}r \int_0^\infty {\rm d}E_{\rm ph} f_{\rm opt}(E_{\rm ph}, r, t)\sigma_{\gamma\gamma}(E_\gamma, E_{\rm ph})\,.$$

Phan & Peretti et al. in prepararion

Preliminary results





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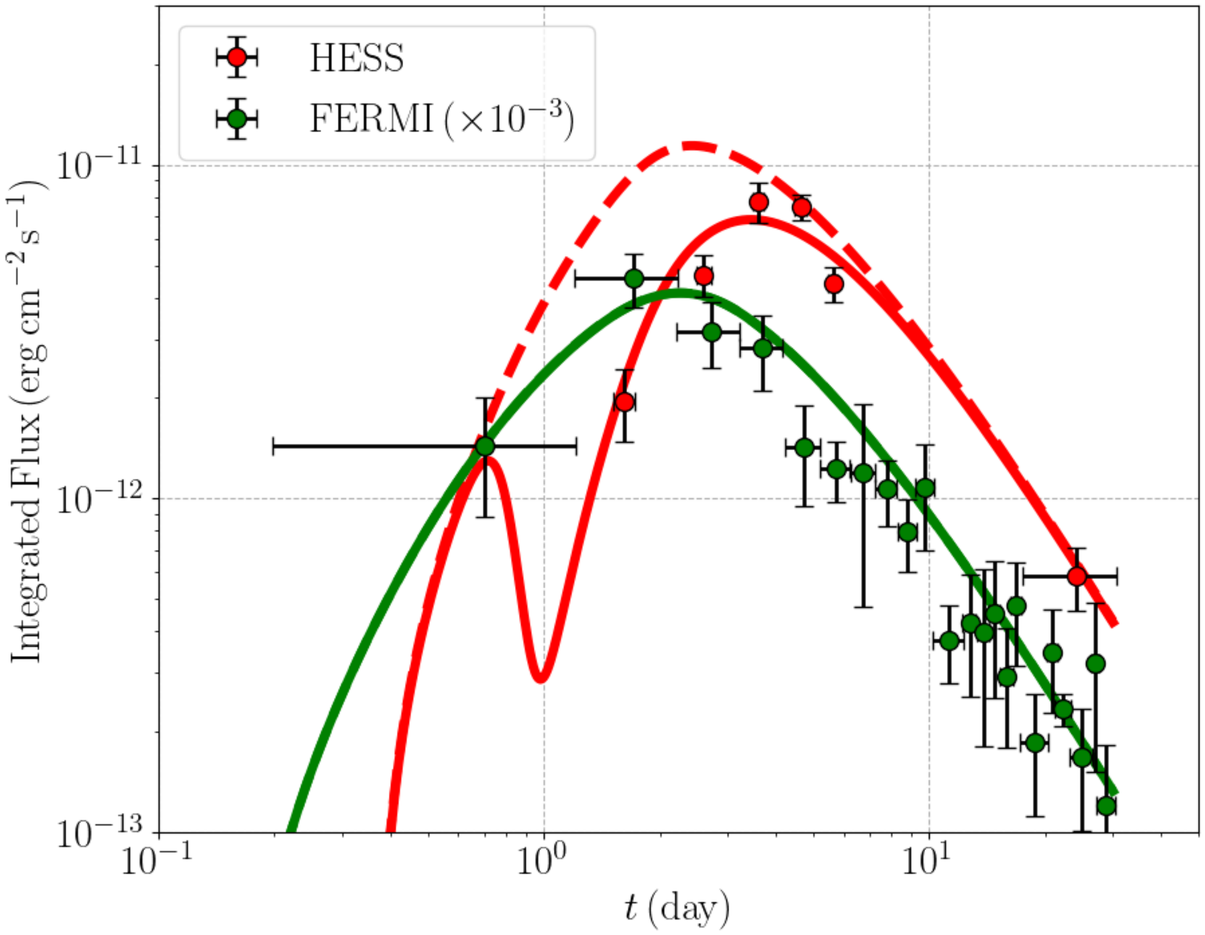
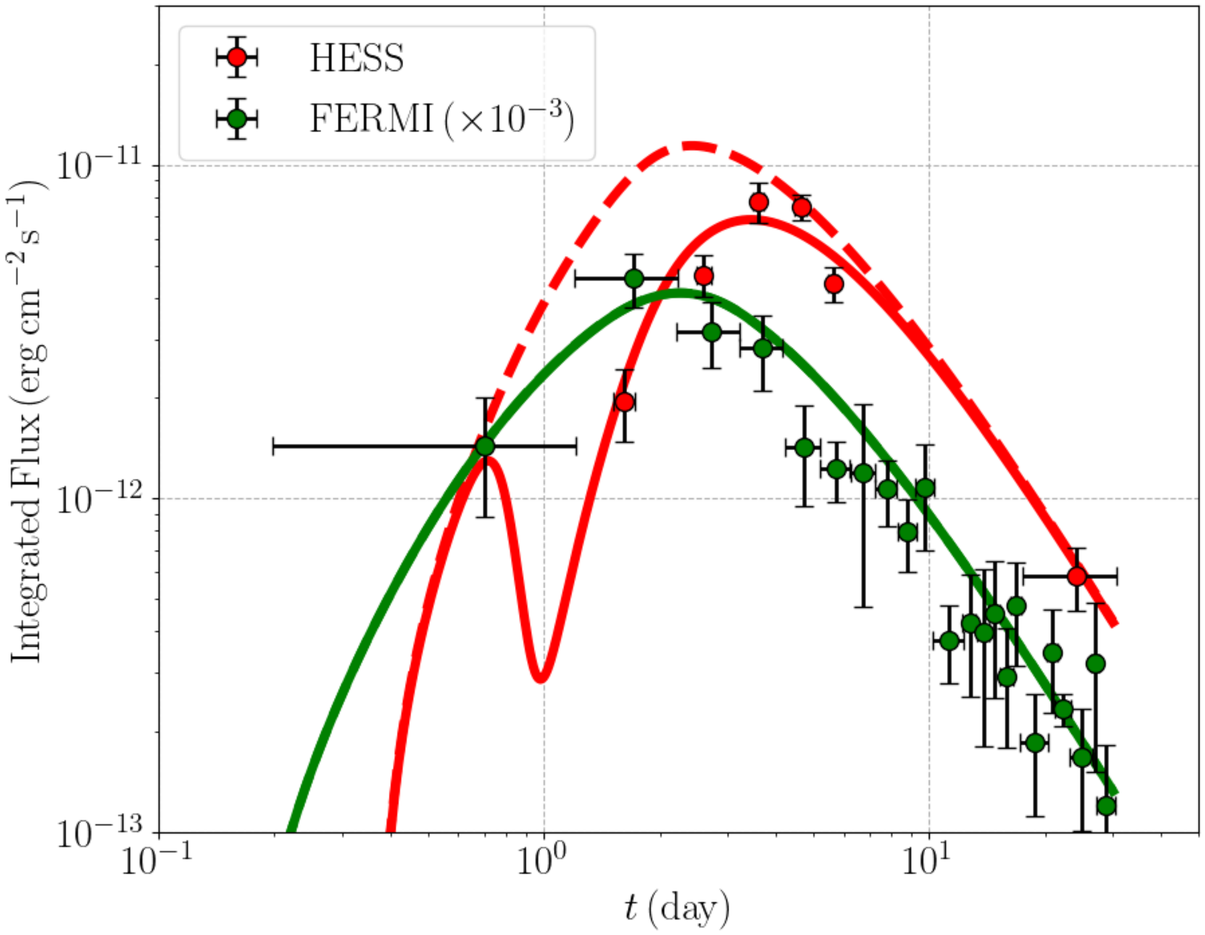


Phan & Peretti et al. in preparartion

Conclusion and outlook



- Novae are ideal labs for particle acceleration.
- High-energy gamma rays from novae can be partially absorbed by optical photons in the first few days of the explosions.
- This can lead to a delay between GeV and TeV light curves.
- These models maybe tested with neutrino telescopes in the future?

Phan & Peretti et al. in preparartion