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RANIERE DE MENEZES, ELENA ORLANDO, MATTIA DI MAURO, AND ANDREW STRONG

Superluminous stars with the Fermi-LAT: a probe to cosmic rays throughout the Galaxy

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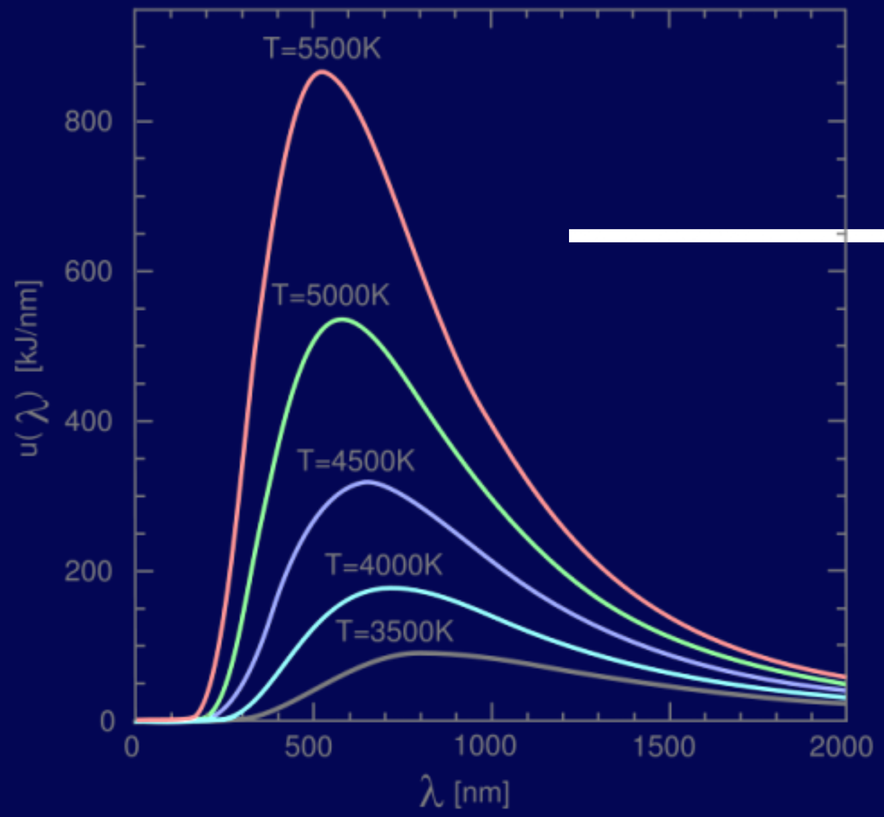
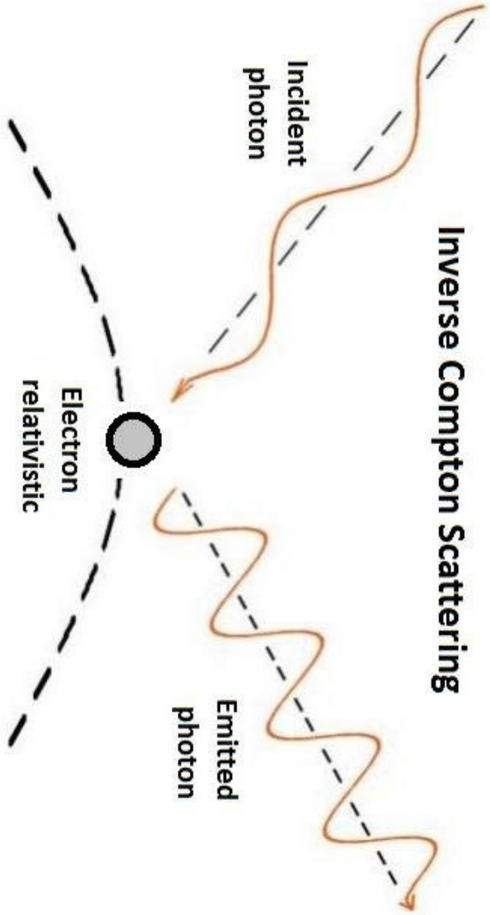
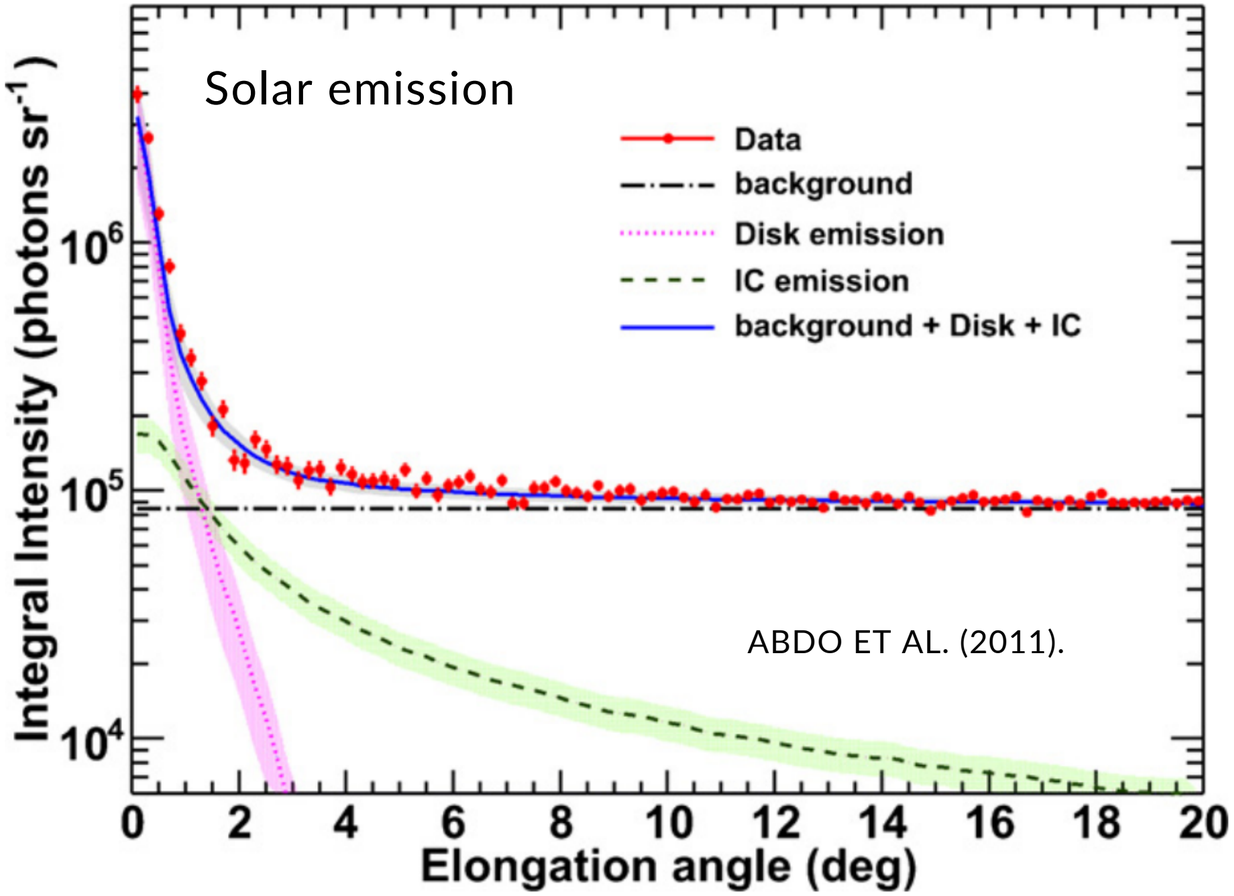
Stars emit thermal radiation: where do gamma-rays come from?





The gamma-ray emission from stars has two main components



- Emission from the stellar disk due to CR cascades in the star's atmosphere.
- Extended emission from IC scattering of CR electrons on stellar thermal photons.

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We can use the gamma-ray emission from stars to constrain the density of cosmic-ray electrons throughout the Galaxy

Gamma-ray intensity:

$$I(E_\gamma) = \frac{1}{4\pi}\int \epsilon(E_\gamma)\mathrm{d}x$$

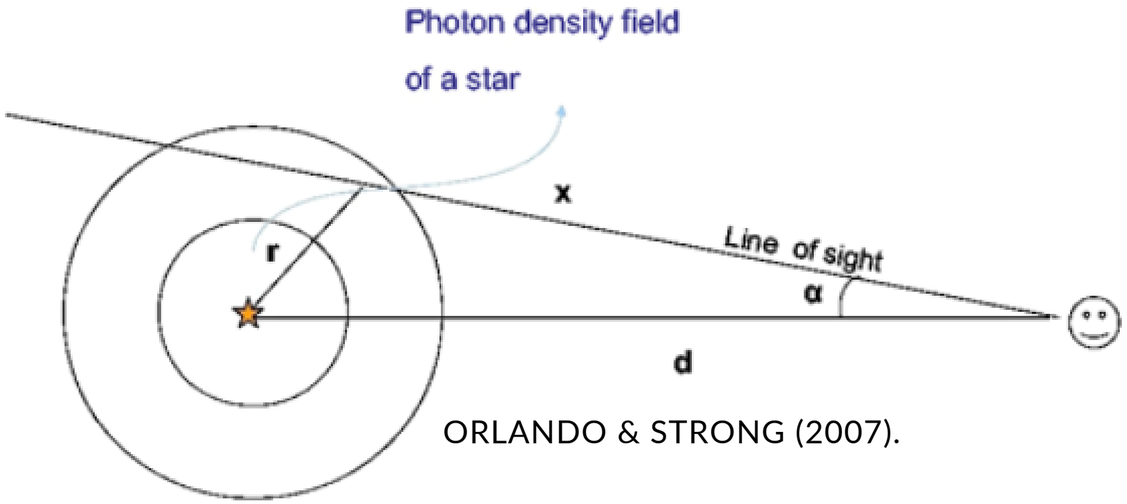
$$\varepsilon(E_\gamma) = \int dE_e \int \sigma(\gamma, E_{ph}, E_\gamma) n_{ph}(E_{ph}) c N(E_e)\, dE_{ph}$$

Emissivity

CR e⁻ spectrum

Photon density

K-N cross sec.



ORLANDO & STRONG (2007).

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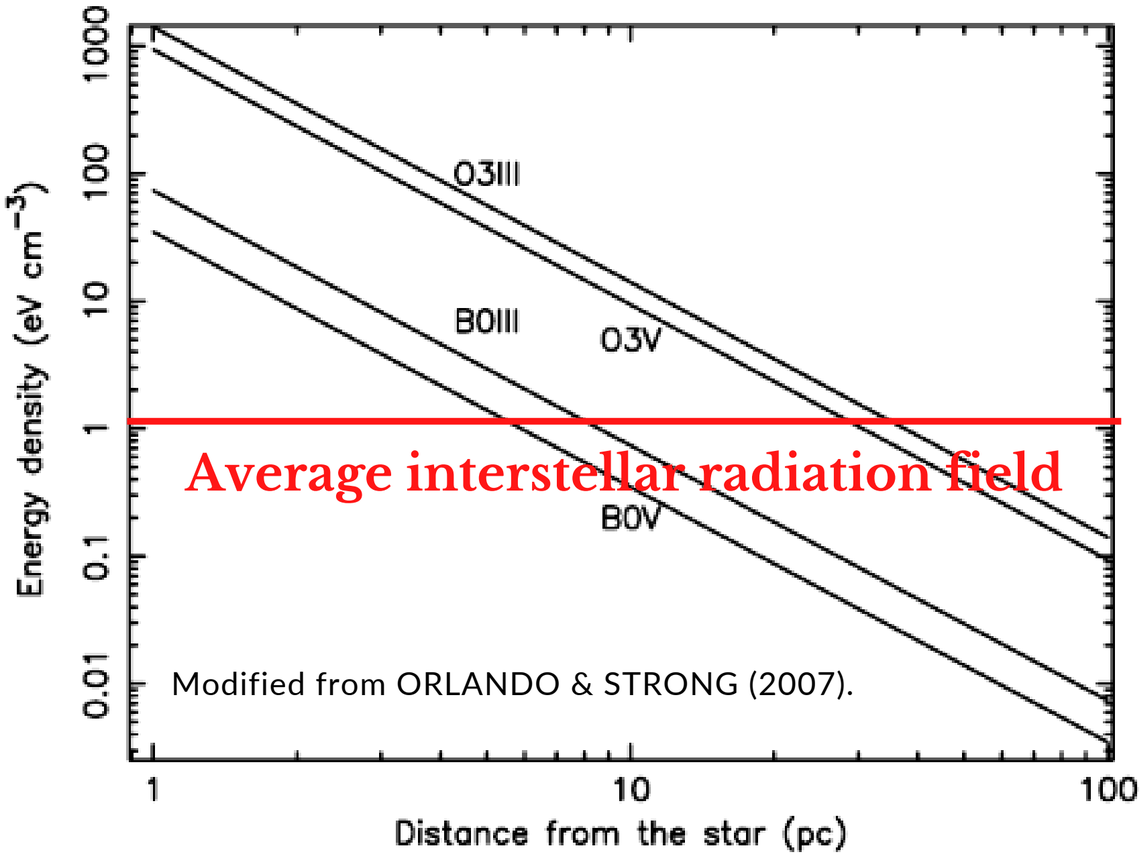
Nearby superluminous stars are expected to be observed as extended gamma-ray sources

$$L_{IC} \propto r\ L_{STAR}$$

$$flux_{IC} \propto L_{STAR}\ \alpha/d$$



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We selected a sample of 9 nearby superluminous stars expected to be on the edge of Fermi-LAT sensitivity

κ *Ori*

ζ *Pup*

ζ *Ori*

Betelgeuse

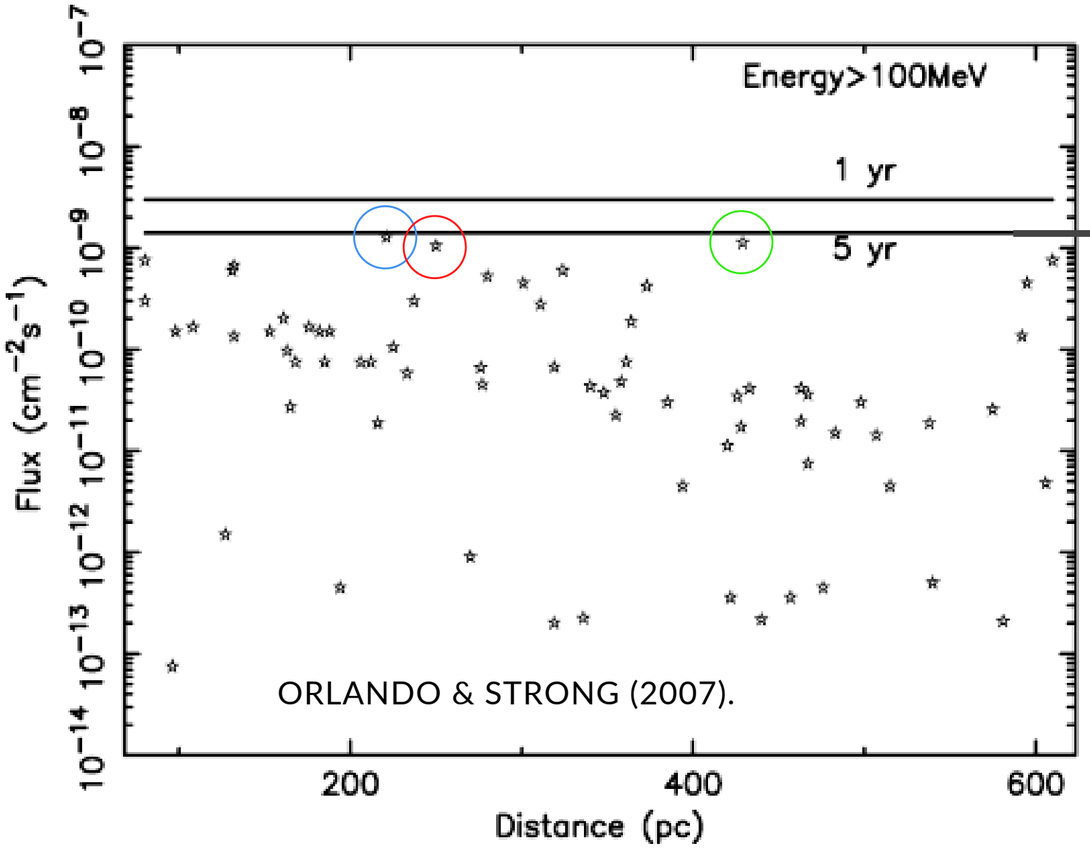
δ *Ori*

Rigel

ζ *Per*

λ *Ori*

ϵ *CMa*



LAT 5 years sensitivity

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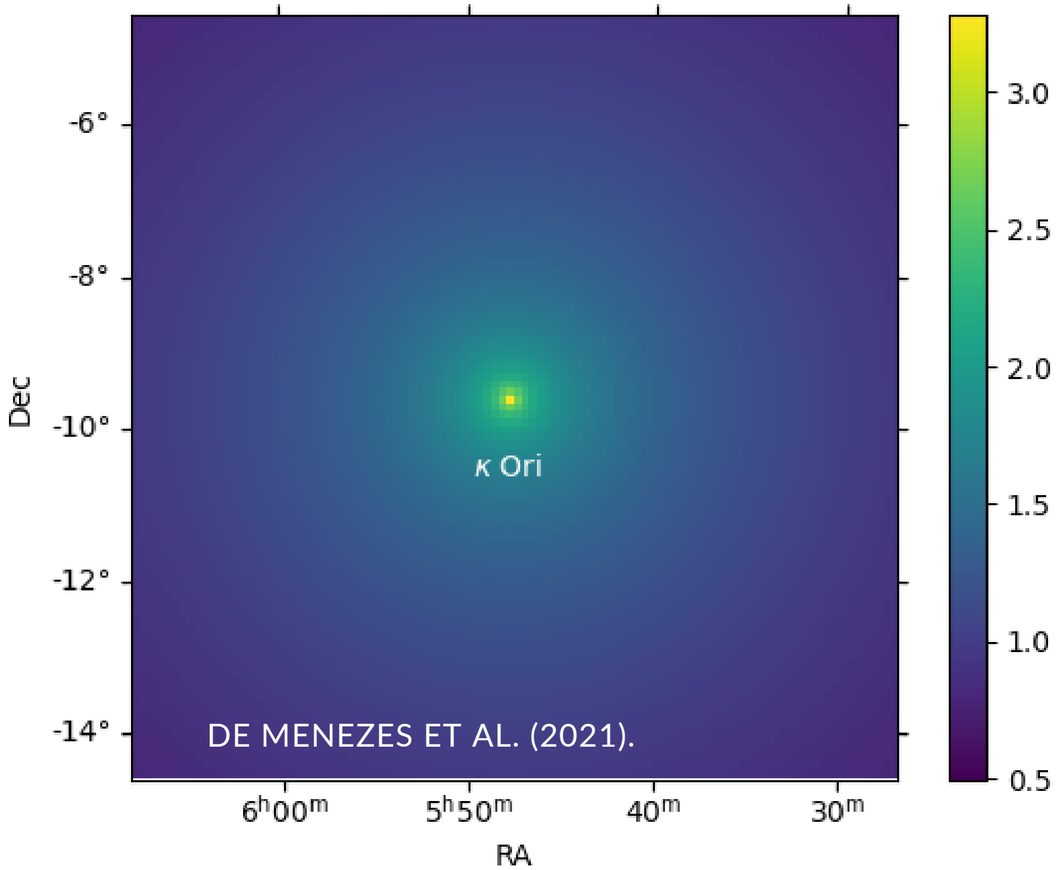
Each star was modeled as an extended gamma-ray halo



Spectral models computed with StellarICS (Orlando & Strong, 2021)

→ Gamma-rays from each star give us information about the density of CR electrons in its surroundings

→ CR electrons cannot penetrate closer than 0.025°

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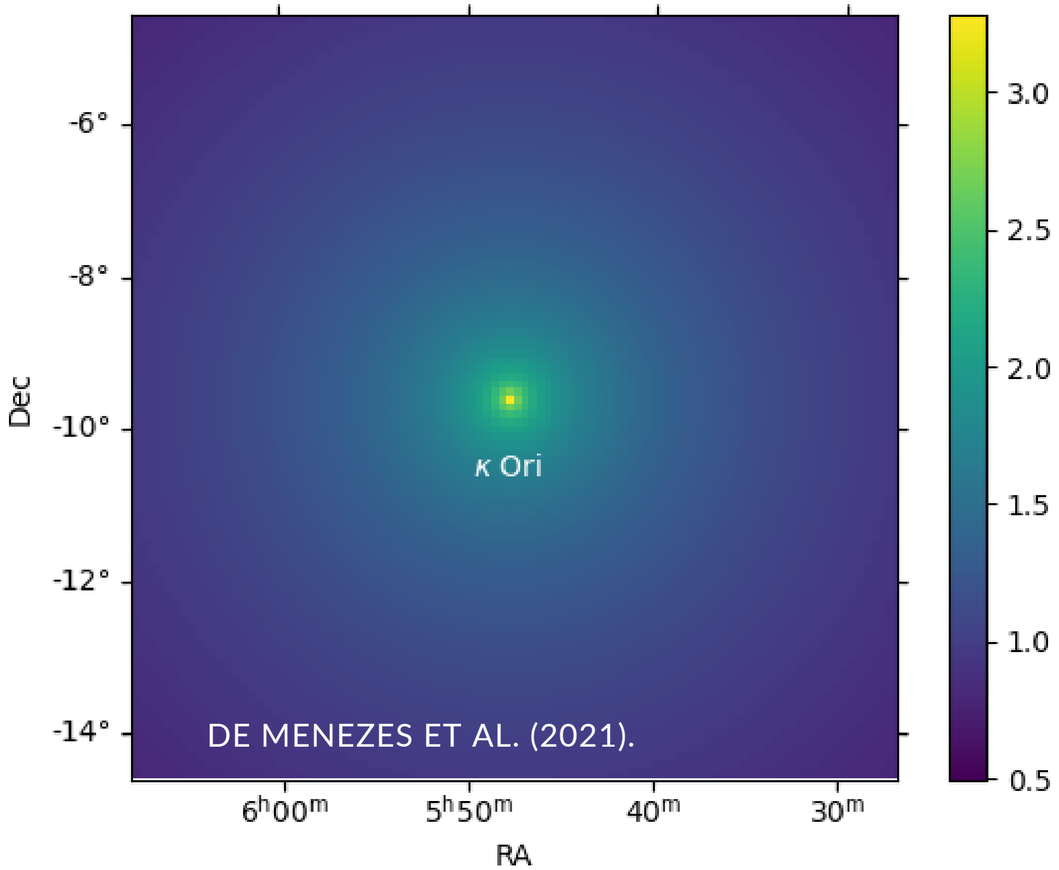

- By knowing the optical and gamma-ray luminosities of stars, we can map the density of CR electrons around the Galaxy
- Superluminous and non-variable stars are better suited for this

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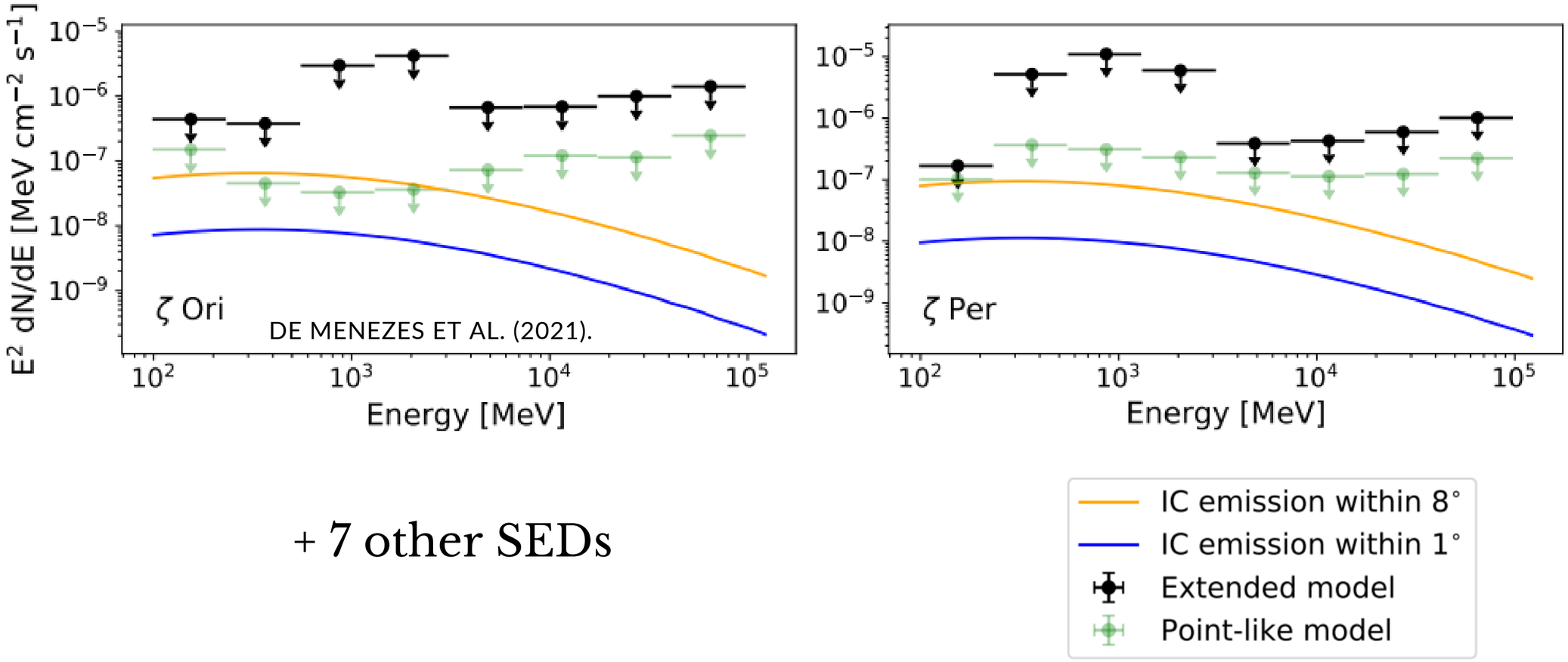
We found no significant gamma-ray emission coming from the stars



+ 7 other SEDs

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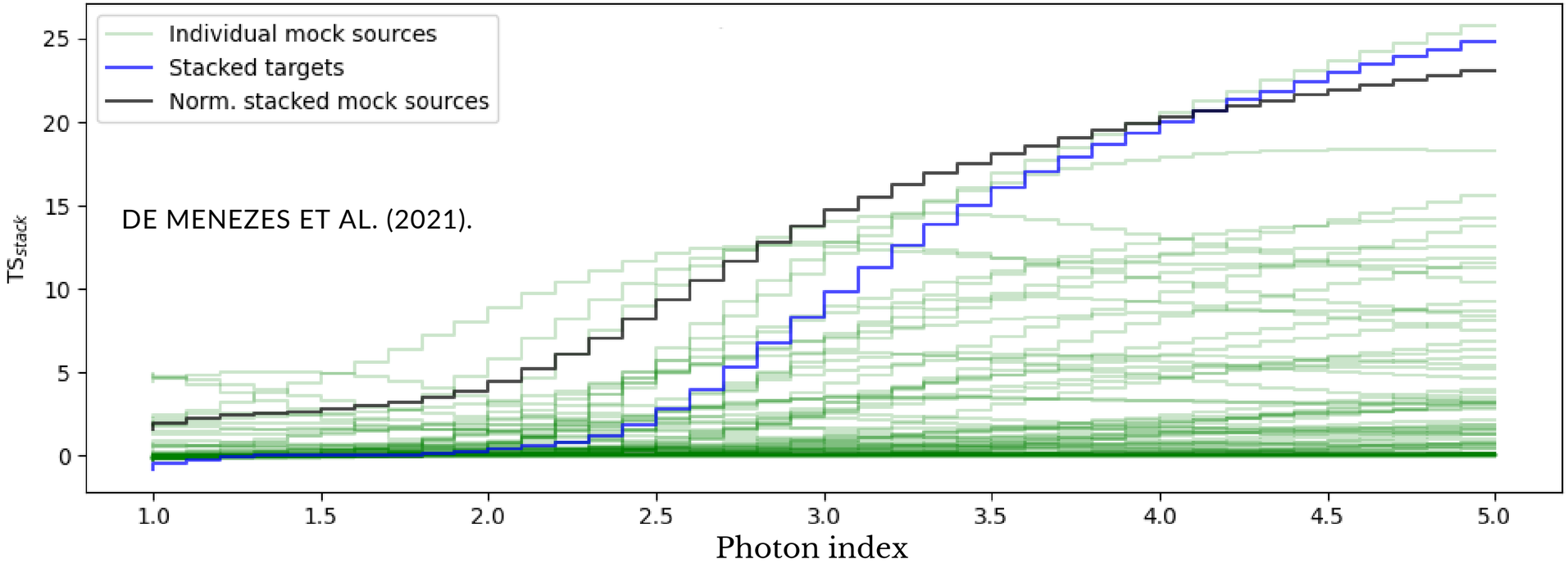
We stacked the Fermi-LAT data from all 9 stars



The population of stars as a whole is not emitting gamma-rays at a significant level

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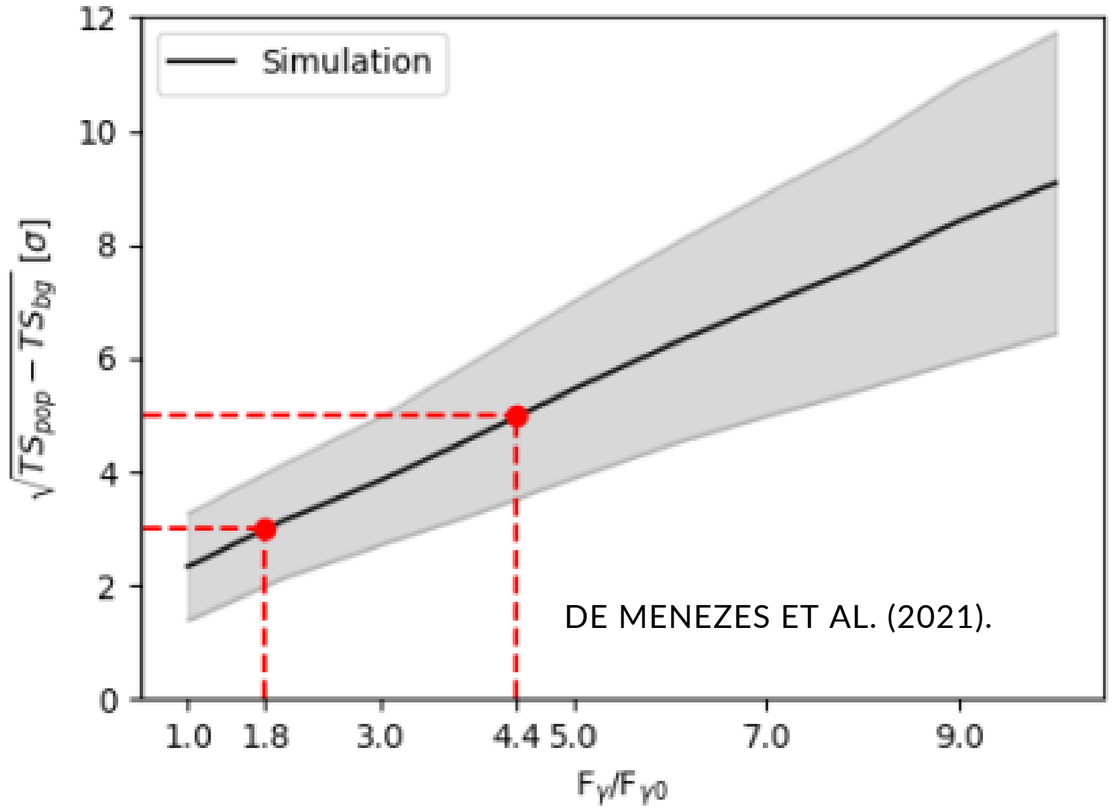
We constrain the average density of CR electrons surrounding these stars



The average flux for each star has to be

$$< 3.3 \times 10^{-11}\ \mathrm{ph\ cm^{-2}\ s^{-1}}$$

Otherwise we should detect them as a population at the 3σ level

The density of CR electrons has to be less than ~2 (~4) times that observed in the Solar System at the 3σ (5σ) level

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Summary

- Stars can be used as CR e^- detectors throughout the Galaxy.
- Fermi-LAT has insufficient sensitivity to detect the gamma-ray emission from nearby superluminous stars.
- The stacked analysis allowed us to constrain the gamma-ray emission from the population to be < 3.3E-11 ph cm^{-2} s^{-1} (500 MeV to 100 GeV).
- We constrain the density of CR electrons to be less than 2 that observed in the Solar System at the 3σ level.

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A study of superluminous stars with the *Fermi*-Large Area Telescope

Raniere de Menezes,[1★] Elena Orlando,[2,3] Mattia Di Mauro[4] and Andrew Strong[5]

[1]*Departamento de Astronomi, Universidade de São Paulo, Rua do Matão, 1226, São Paulo SP 05508-090, Brazil*
[2]*INFN Sezione di Trieste, Università degli Studi di Trieste, Via Valerio 2, I-34127 Trieste, Italy*
[3]*Kavli Institute for Particle Astrophysics and Cosmology and Hansen Experimental Physics Laboratory, Stanford University, 94305-4085 California, CA, USA*
[4]*INFN Torino, Physics Department, Via Pietro Giuria 1, I-10125 Torino, Italy*
[5]*Max-Planck-Institut für extraterrestrische Physik, Germany*

Thanks!