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

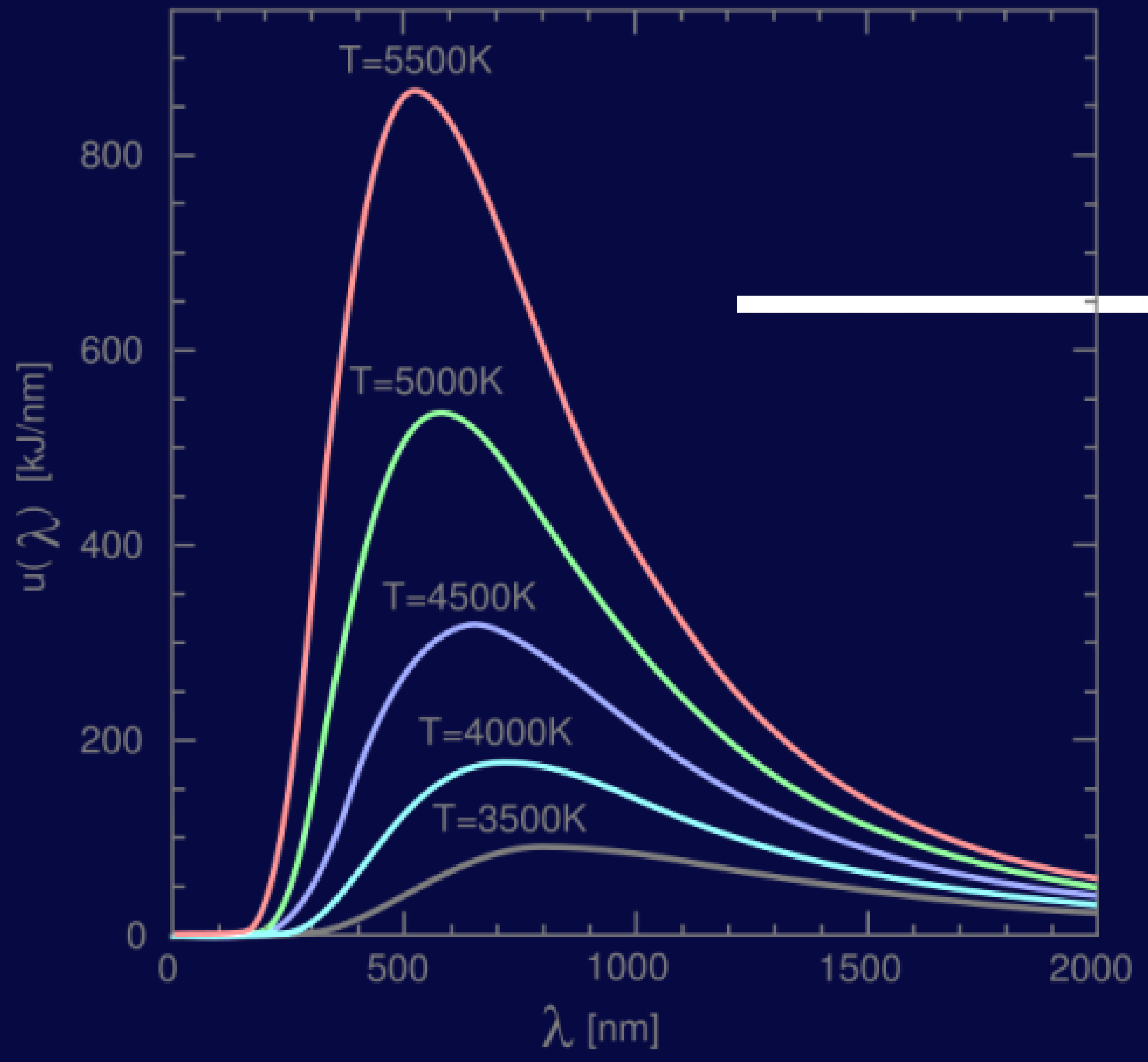
A study of super-luminous stars with the Fermi-LAT: a probe to cosmic rays throughout the Galaxy

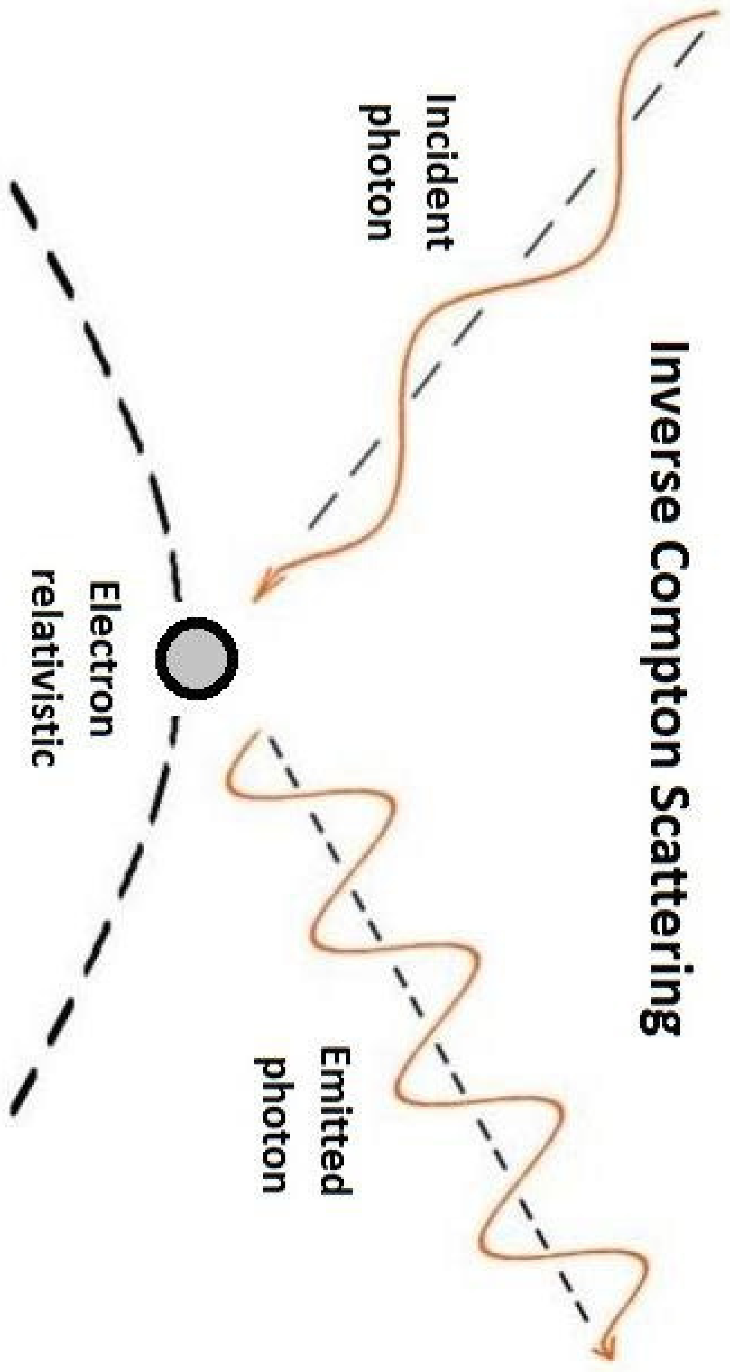
UNIVERSITÀ DI TORINO

INFN Istituto Nazionale di Fisica Nucleare
SEZIONE DI TORINO

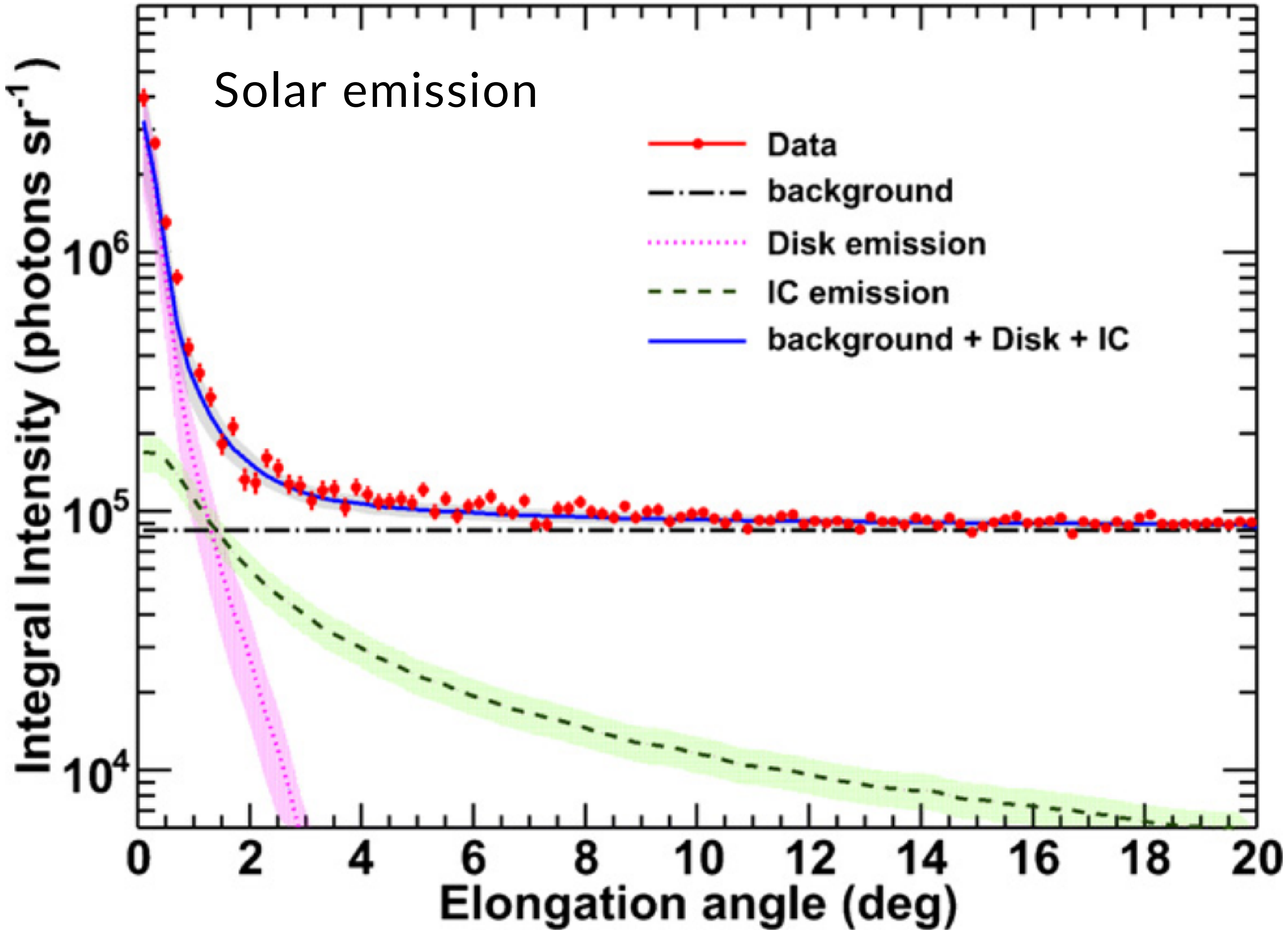
September, 2023

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.

FIGURE: ABDO ET AL. (2011).

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

K-N cross sec.

Photon density

CR e⁻ spectrum

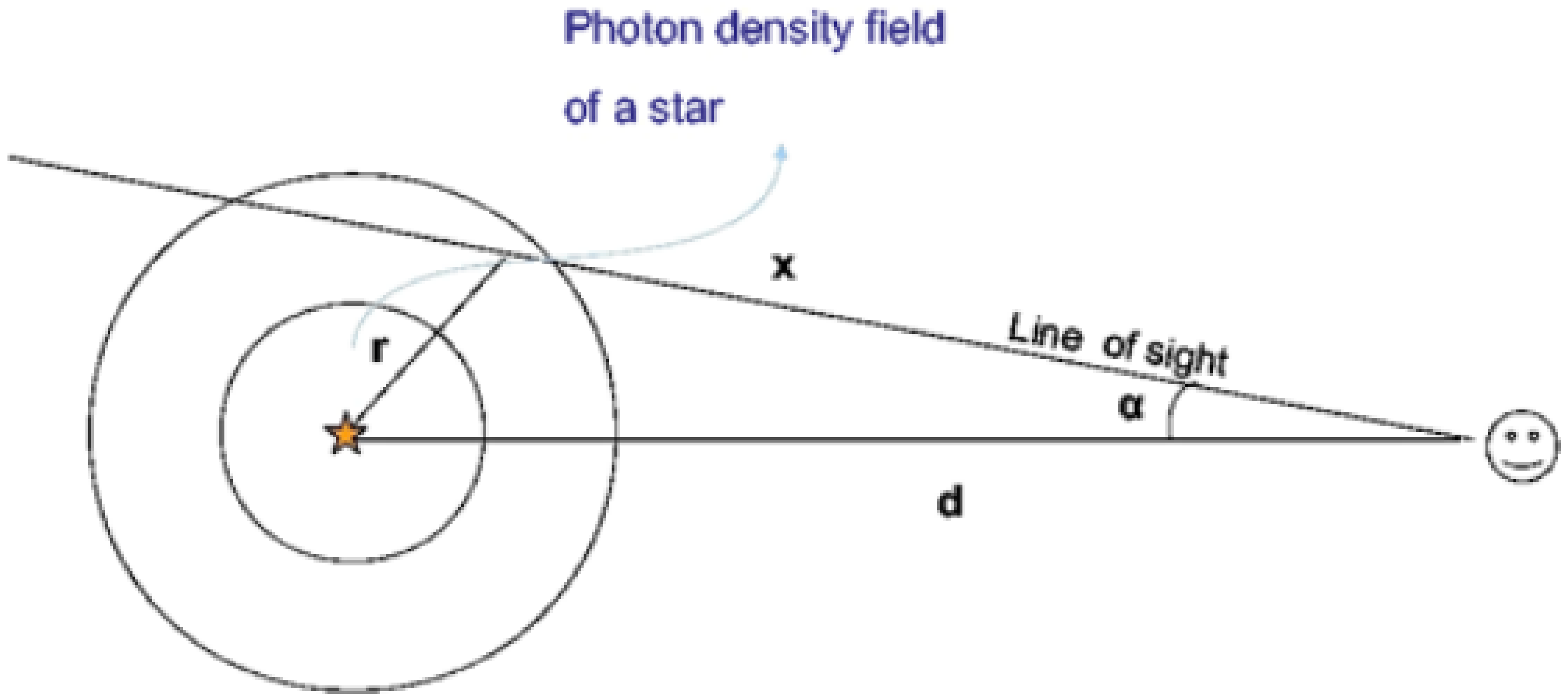


FIGURE: ORLANDO & STRONG (2007).

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

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

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

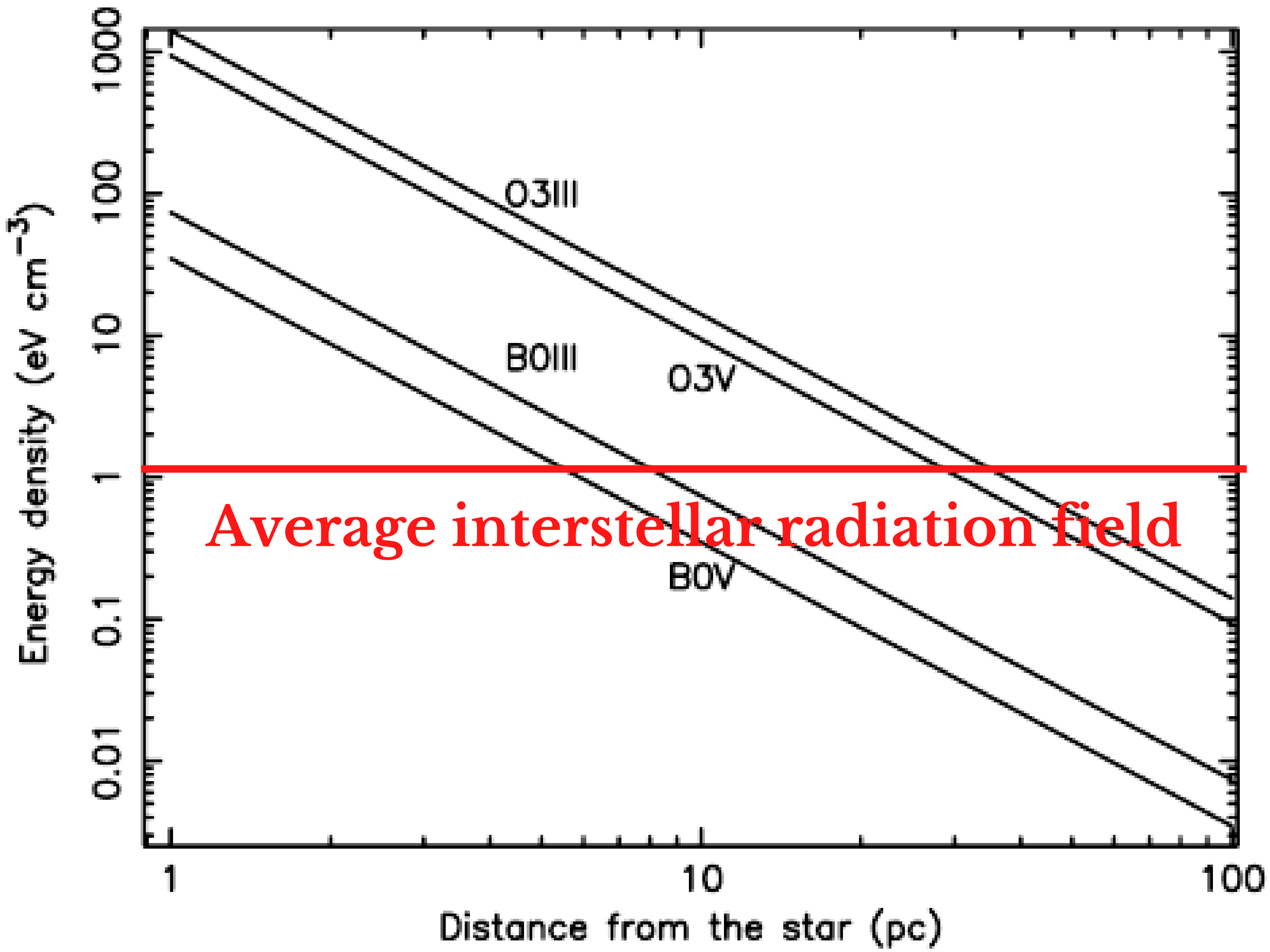
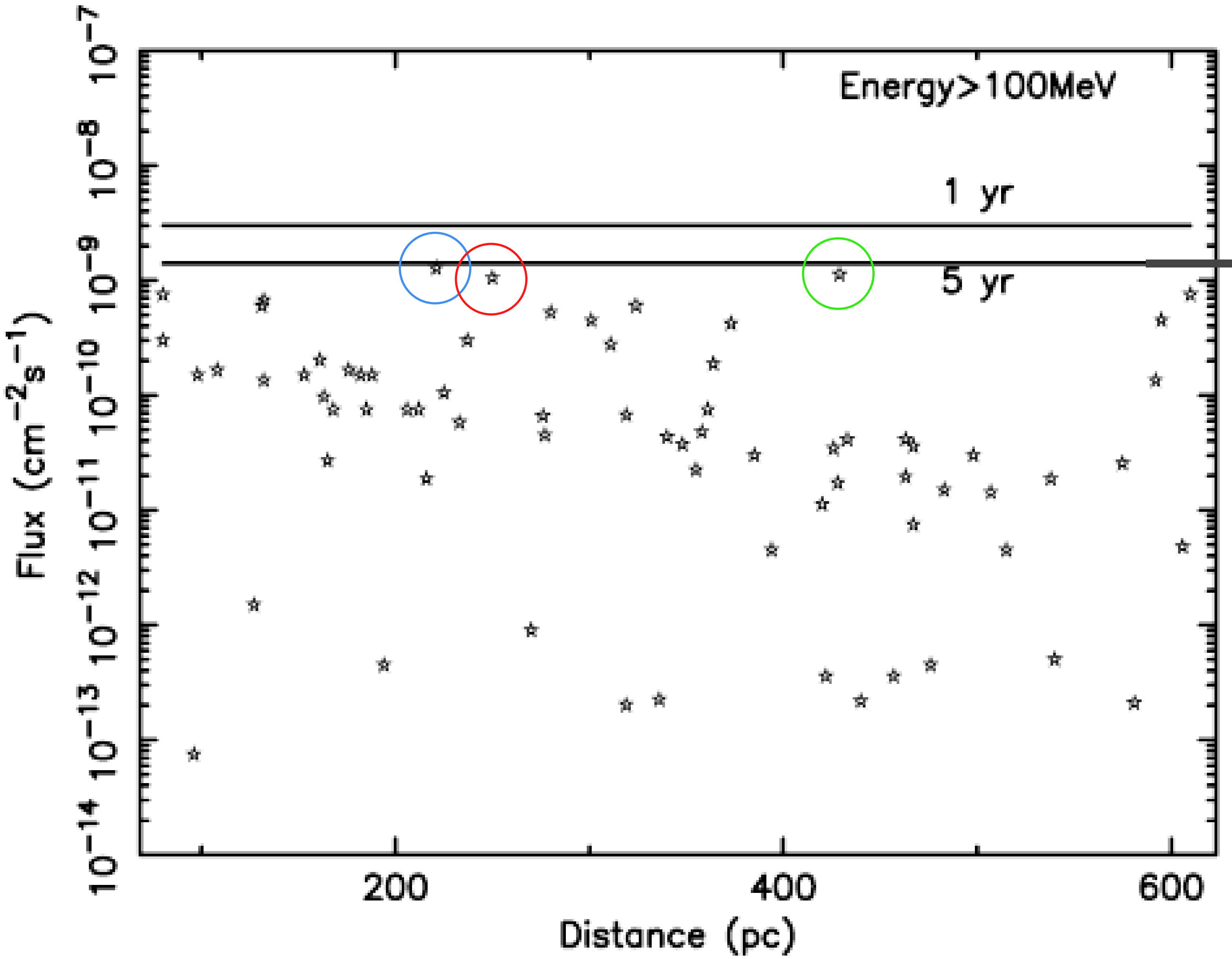


FIGURE (MODIFIED): ORLANDO & STRONG (2007).

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

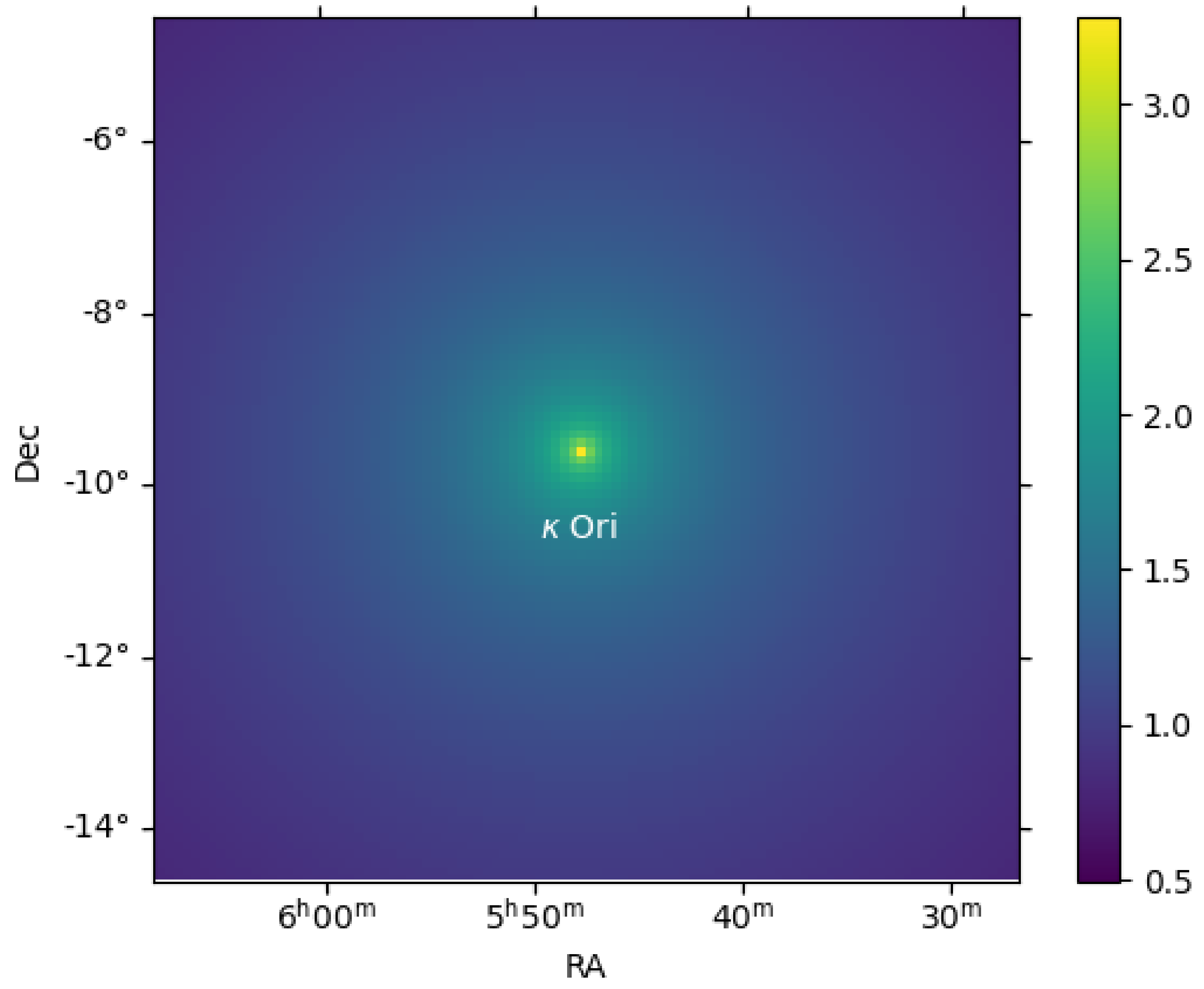
- κ Ori
- ζ Pup
- ζ Ori
- Betelgeuse
- δ Ori
- Rigel
- ζ Per
- λ Ori
- ϵ CMa



LAT 5 years sensitivity

FIGURE: ORLANDO & STRONG (2007).

Each star was modeled as an extended gamma-ray halo



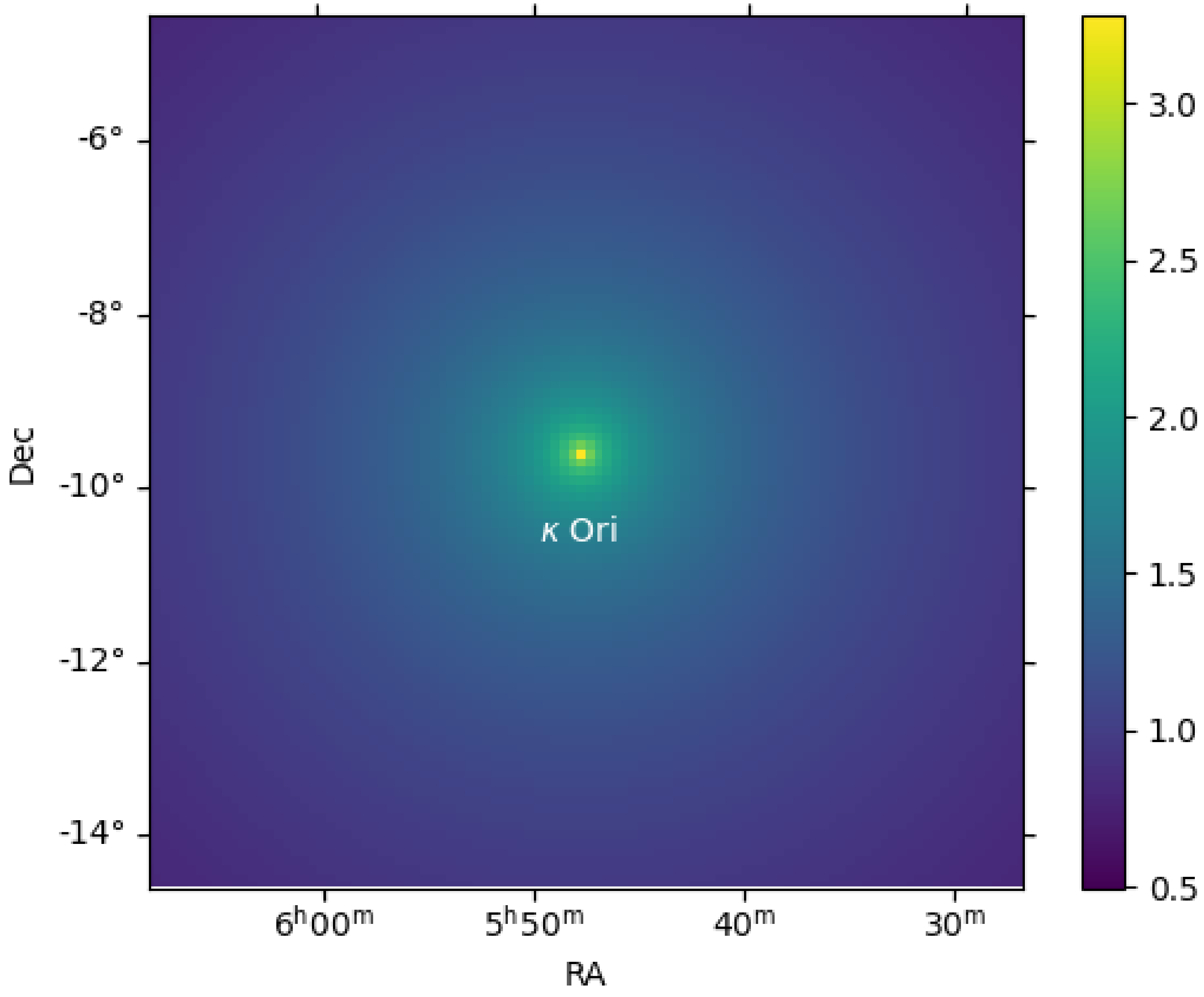
Spectral models computed with StellarICS (Orlando & Strong, 2021)

→ Gamma-rays from each star give us information about the density of CR electrons around them

→ CR electrons cannot penetrate closer than 0.025°

FIGURE: DE MENEZES ET AL. (2021).

Each star was modeled as an extended gamma-ray halo

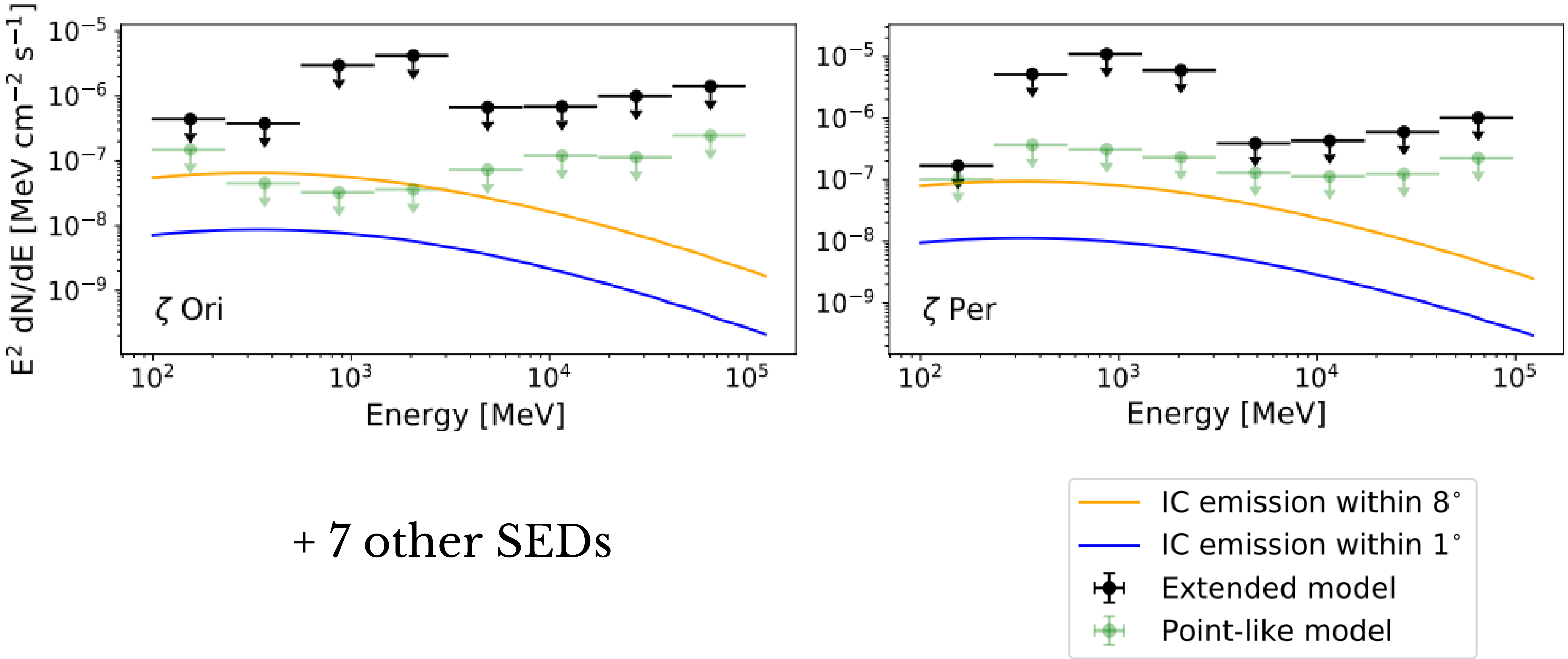


→ By knowing the optical and gamma-ray luminosities of stars, we can map the density of CR electrons around the Galaxy

→ Superluminous and non-variable stars are better suited for this

FIGURE: DE MENEZES ET AL. (2021).

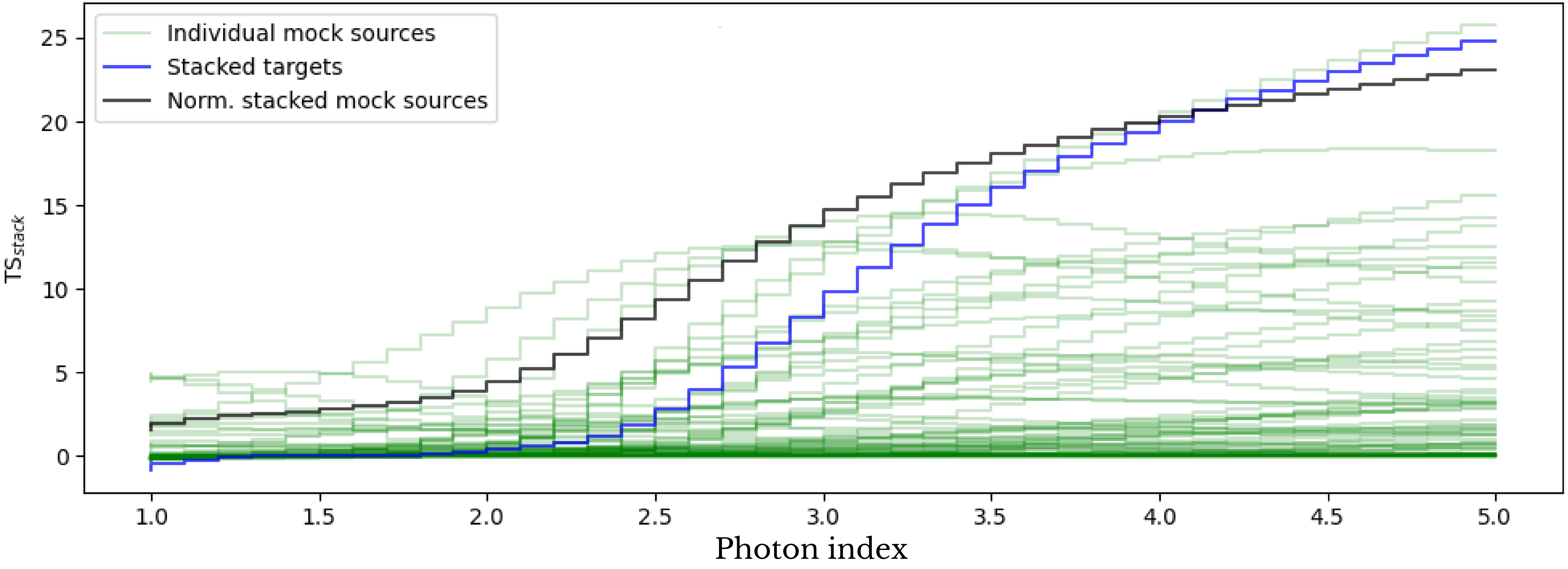
We found no significant gamma-ray emission coming from the stars



+ 7 other SEDs

FIGURE (MODIFIED): DE MENEZES ET AL. (2021).

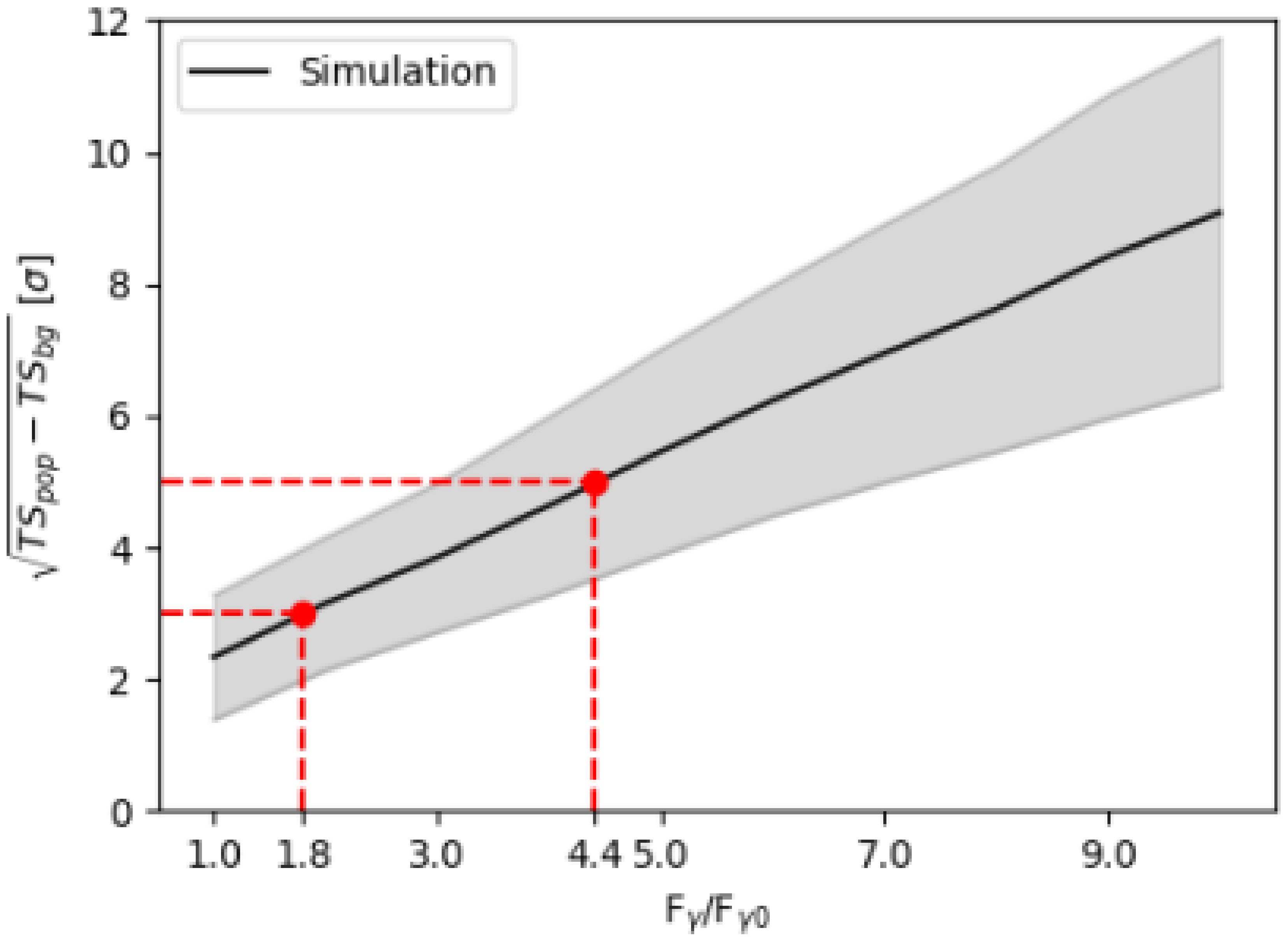
We stacked the Fermi-LAT data from all 9 stars



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

FIGURE (MODIFIED): DE MENEZES ET AL. (2021).

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

FIGURE: DE MENEZES ET AL. (2021).

Before concluding

Links to install easyFermi:

https://pypi.org/project/easyFermi/

https://github.com/ranieremeneze
s/easyFermi

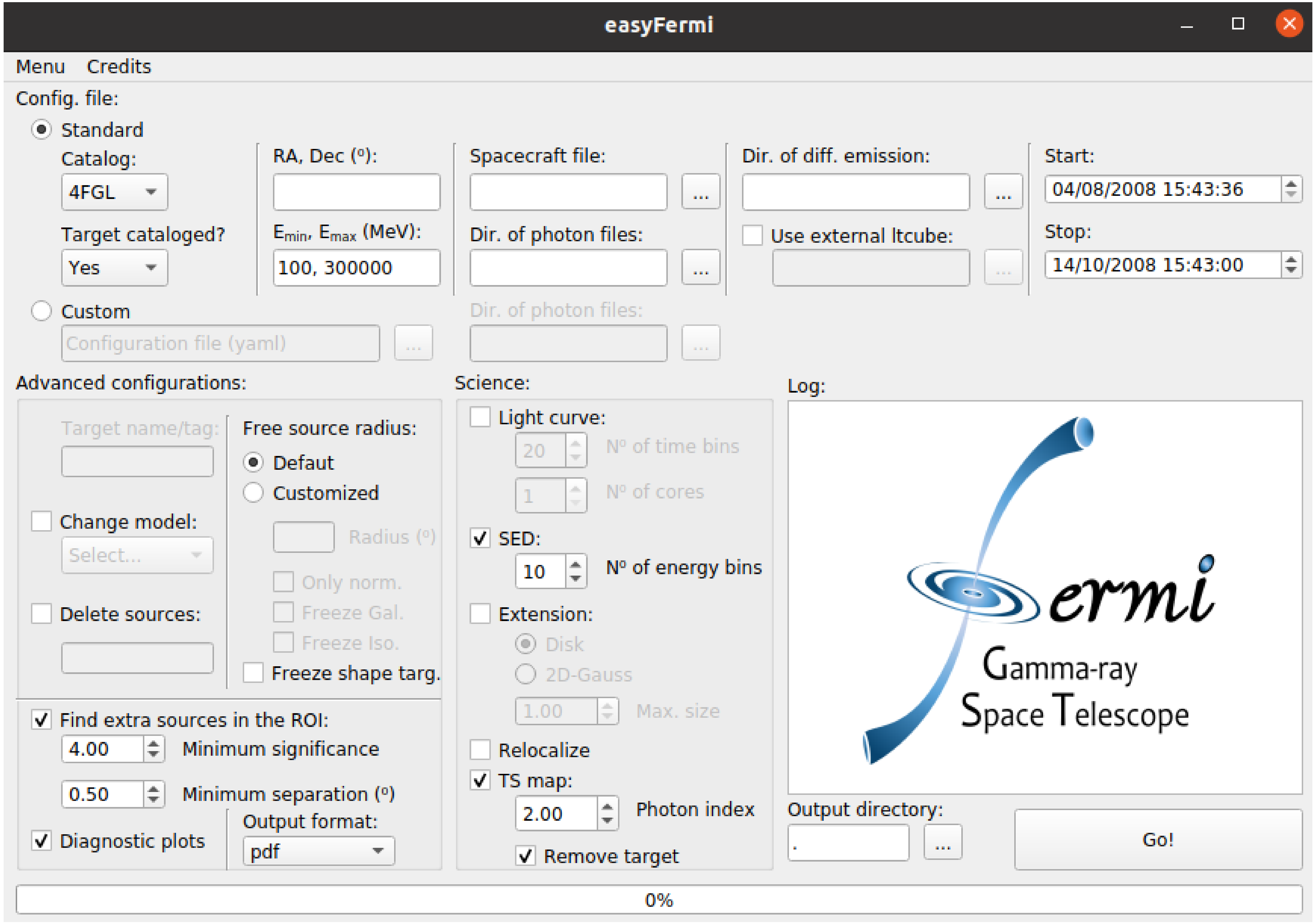
Tutorials:

https://www.youtube.com/channel
/UCeLCfEoWasUKky6CPNN_opQ

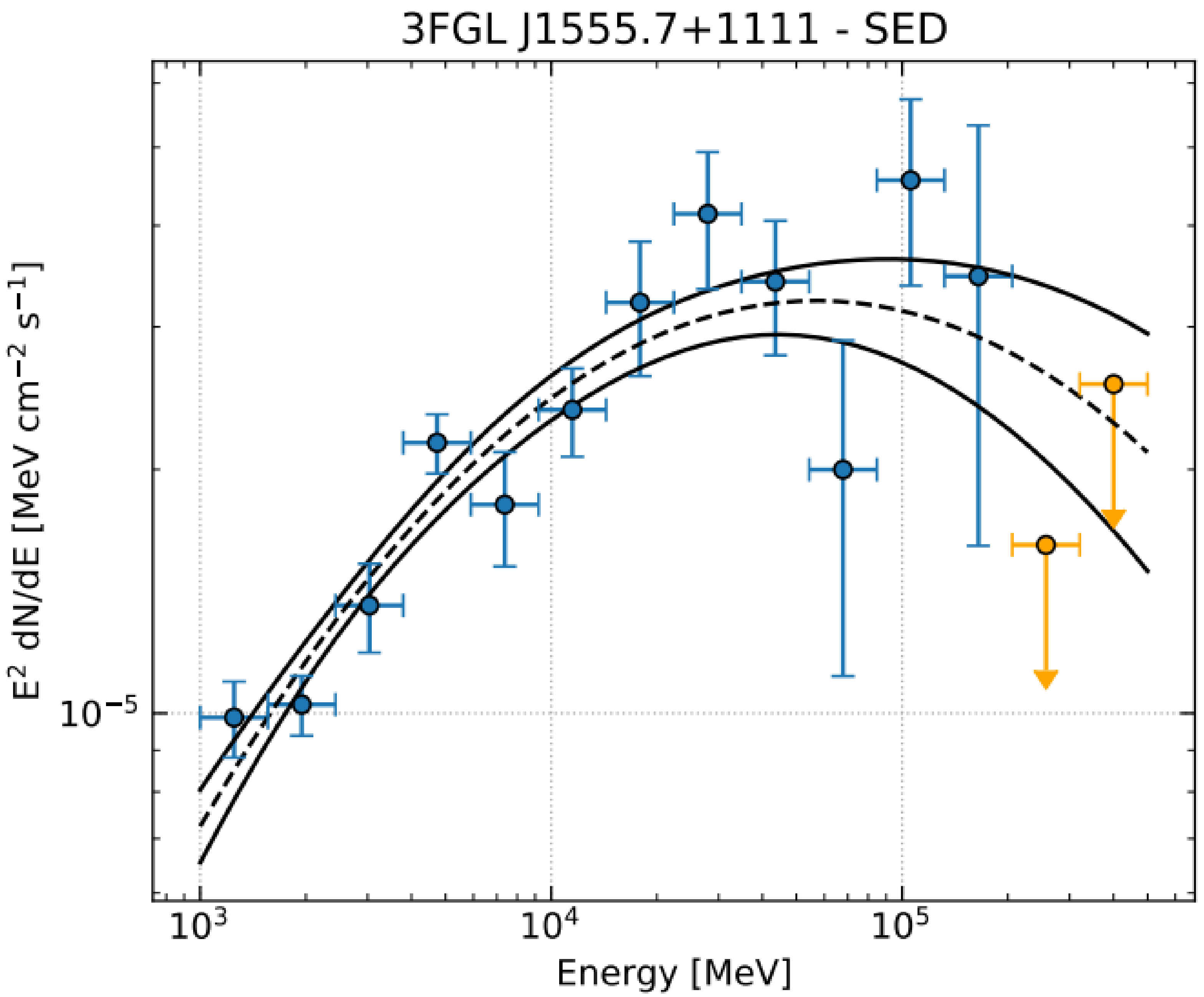
Binned likelihood
Fermipy on background

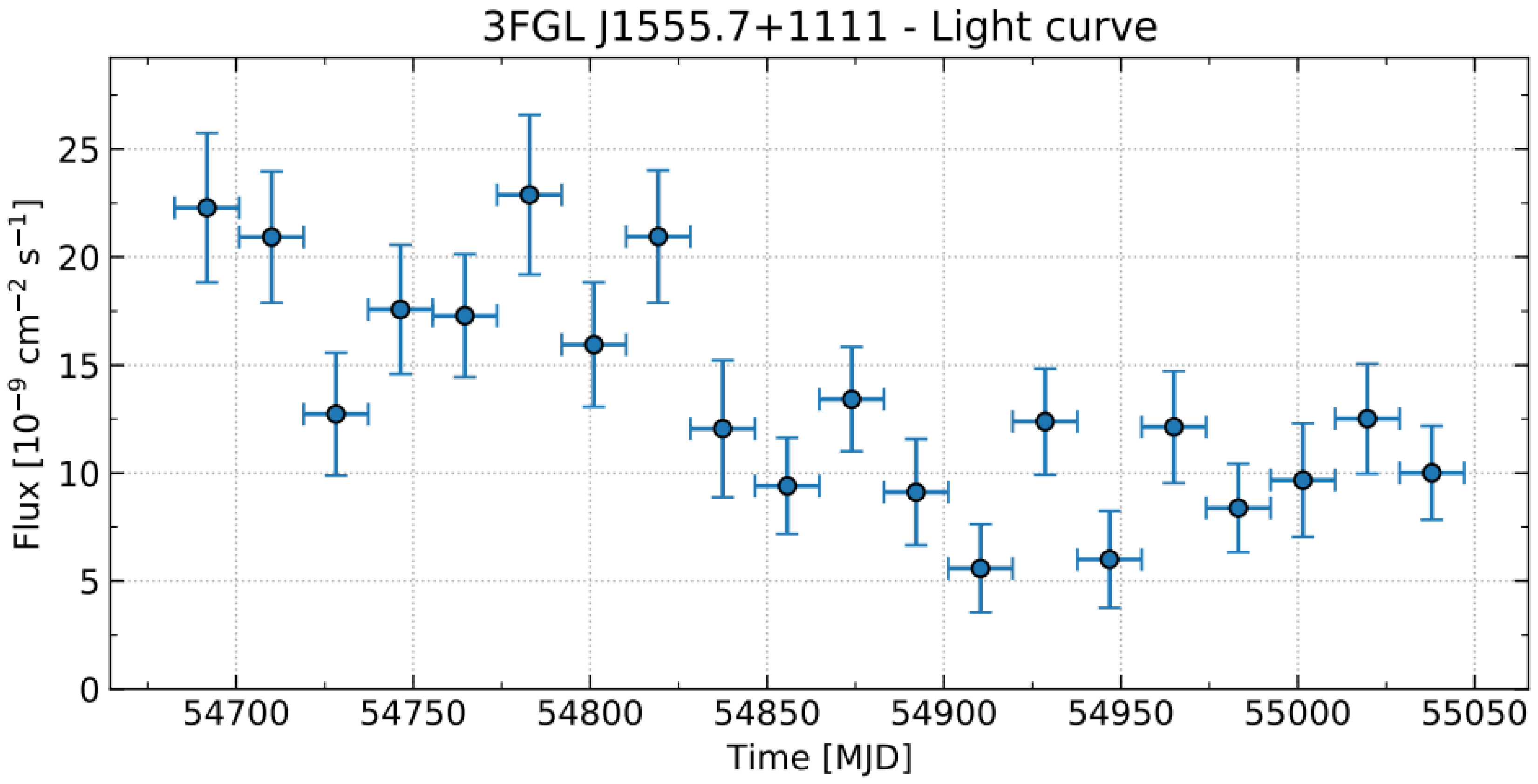
Paper:

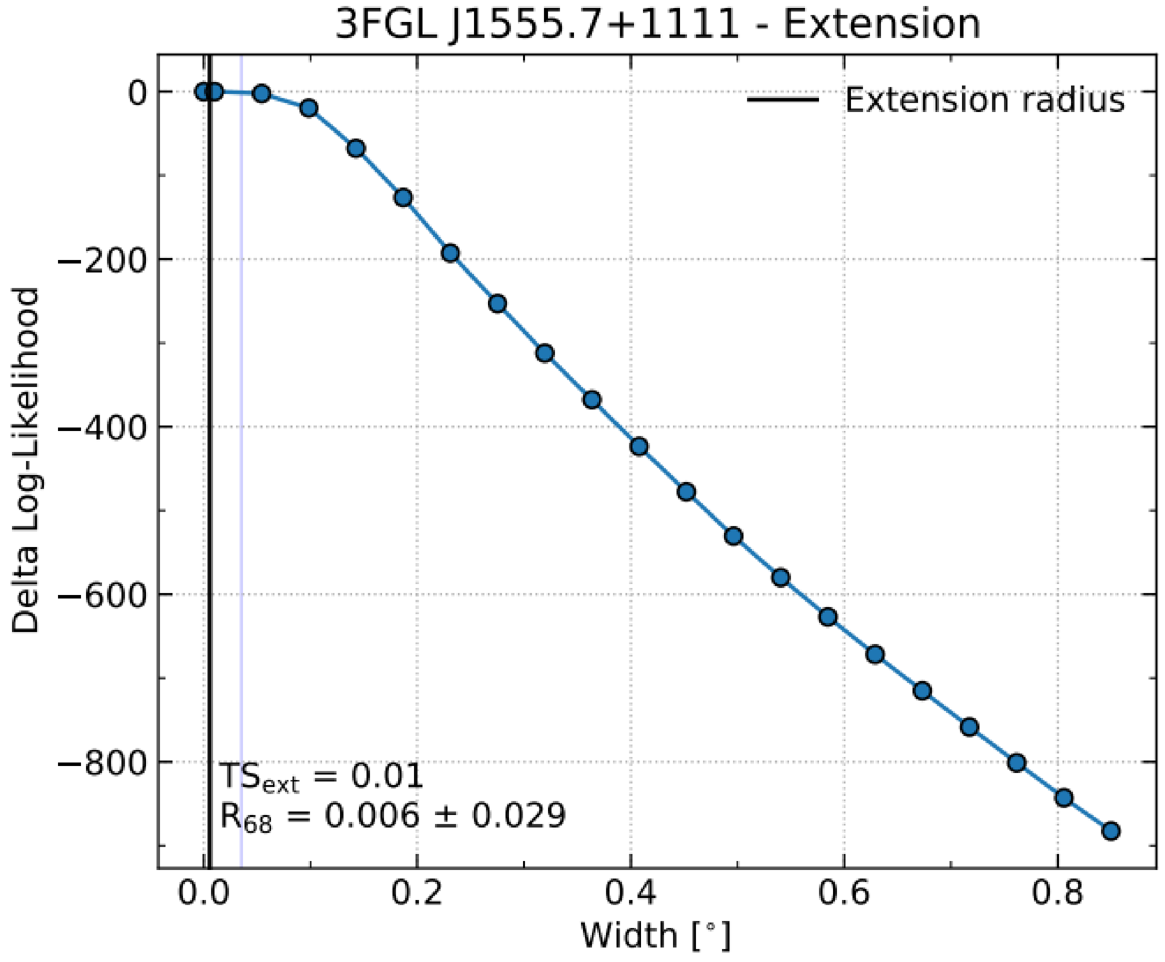
de Menezes, R (2022).



Main results







FIGURES: DE MENEZES, R. (2022).

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.
- **easyFermi** is powerful. Give it a try!

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **507,** 680–686 (2021) https://doi.org/10.1093/mnras/stab2150
Advance Access publication 2021 July 26

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*

*ranieremaciel.demenezes@unito.it

Thanks!