Evidence for inverse Compton emission from globular clusters

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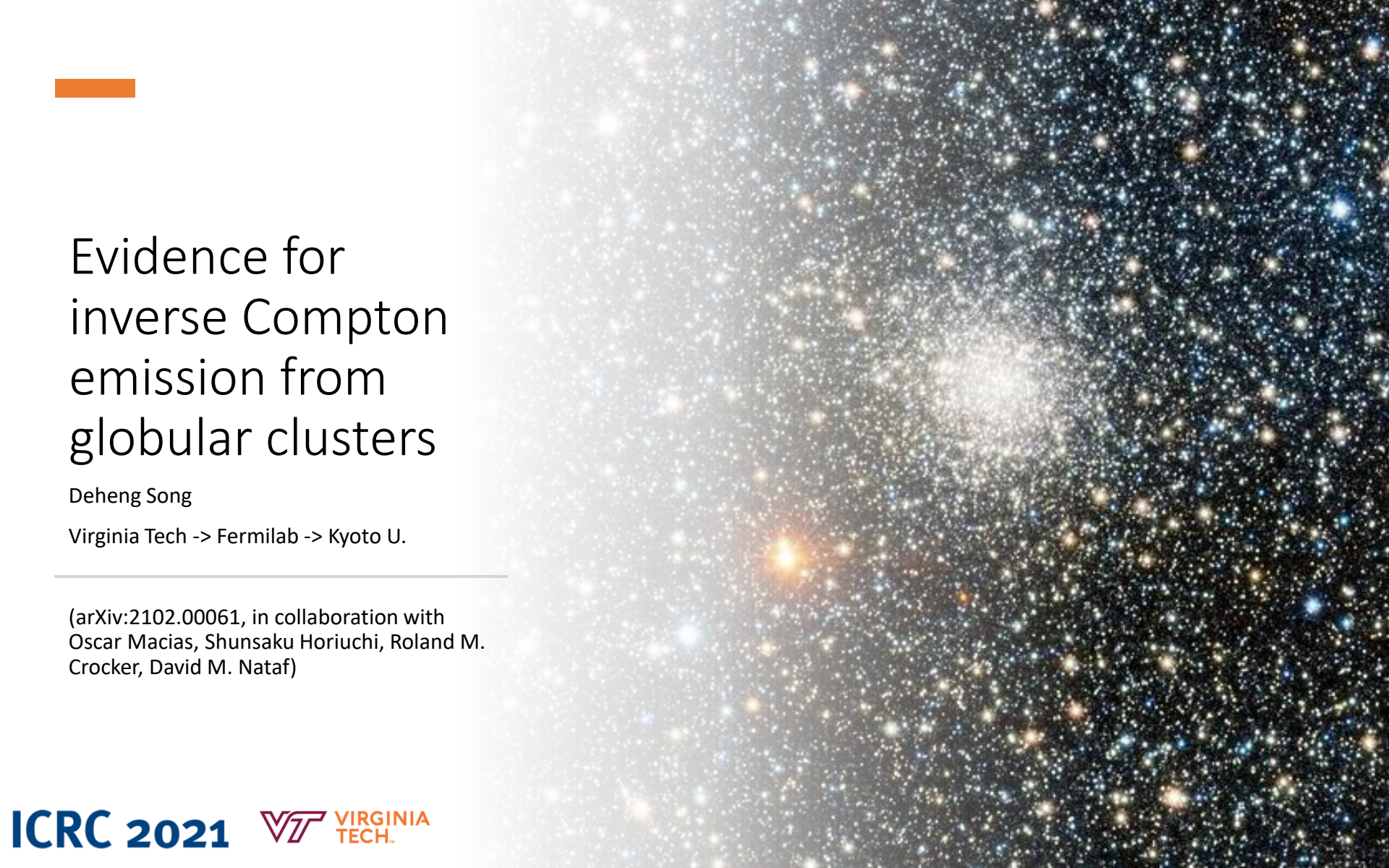
(arXiv:2102.00061, in collaboration with Oscar Macias, Shunsaku Horiuchi, Roland M. Crocker, David M. Nataf)



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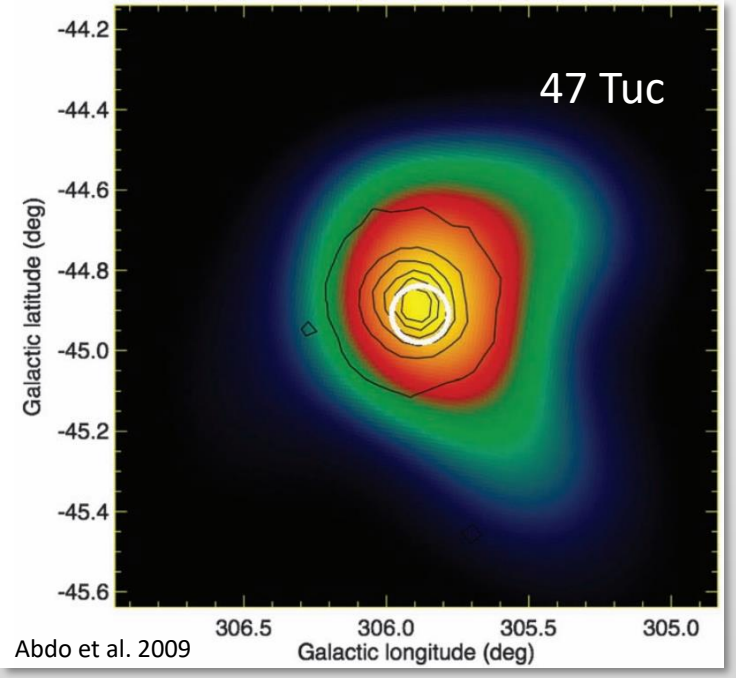
Gamma rays from globular clusters

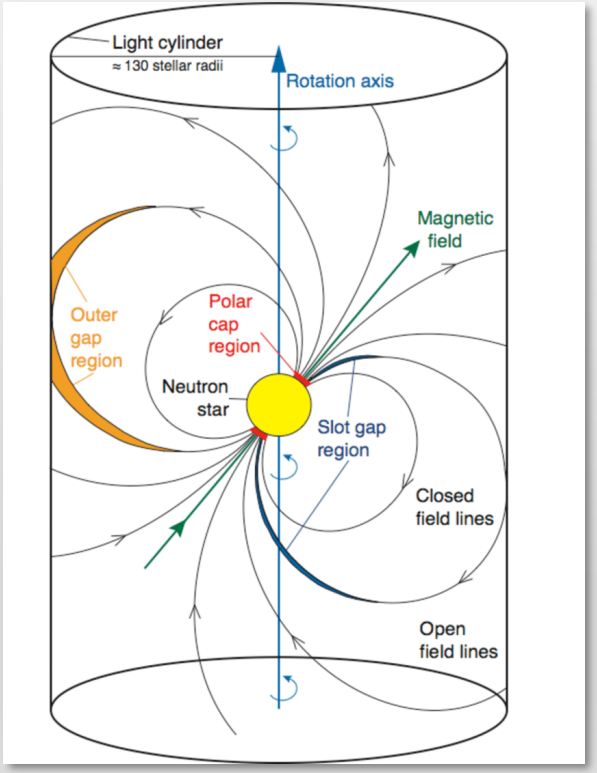


Abdo et al. 2009

- Globular clusters are spherical collections of old stars
- At least 30 globular clusters have been detected by Fermi LAT

Gamma rays from globular clusters

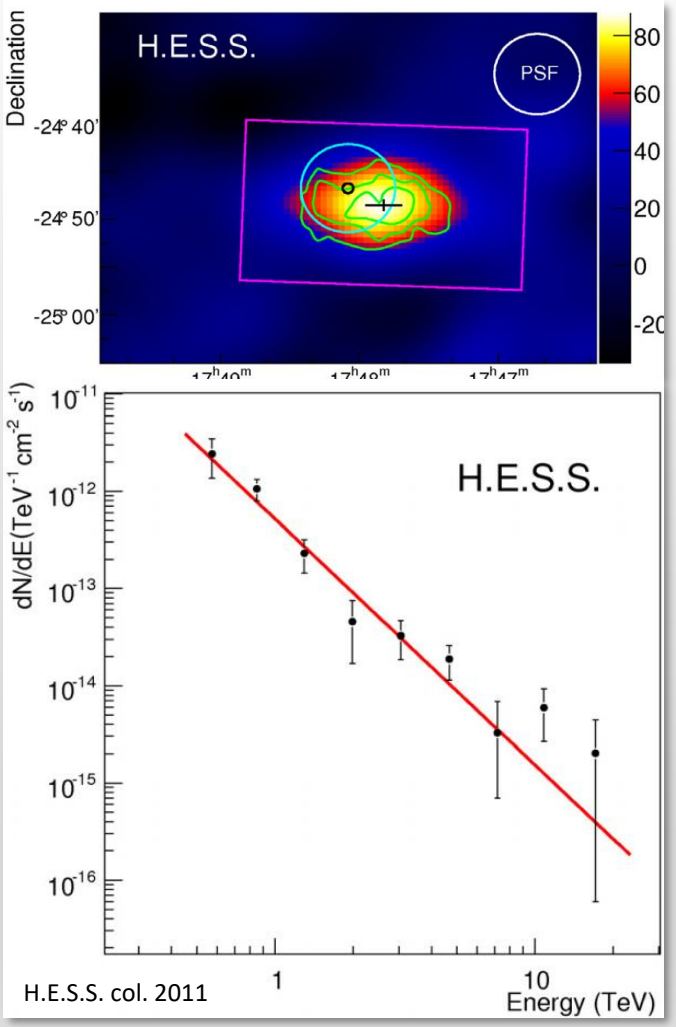
- Millisecond pulsars hosted by the globular clusters are the most likely source:
  - Curvature radiation from pulsar magnetosphere
  - Inverse Compton from e+/- propagated in the globular clusters
- How important is the inverse Compton emission?



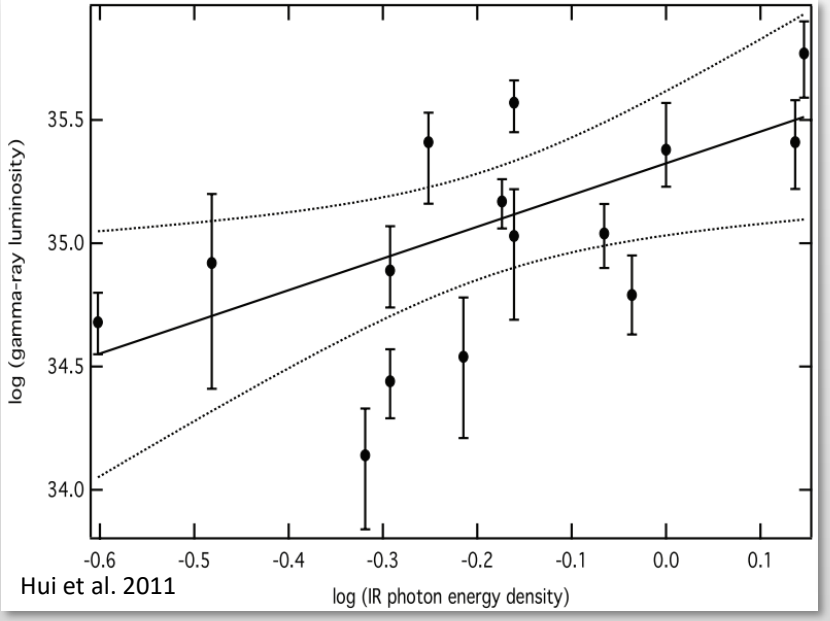
MAGIC col. 2008

Terzan 5: a TeV example?

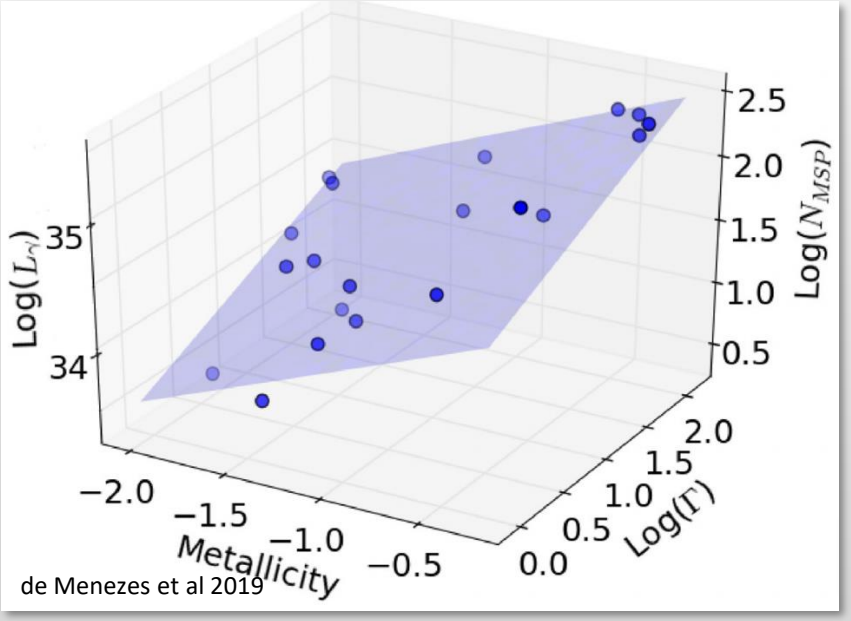
- VHE gamma-ray emission above TeV is evidence for inverse Compton
- Terzan 5 is the only globular cluster plausibly seen by TeV instruments
- The center of the source is misaligned



Correlation with gamma rays



Hui et al. 2011



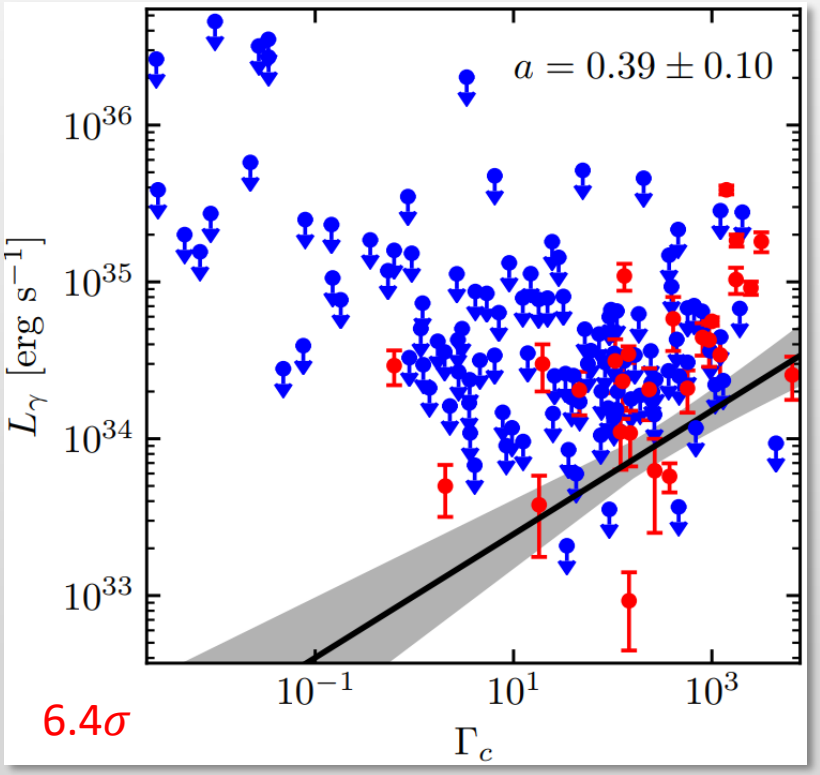
de Menezes et al 2019

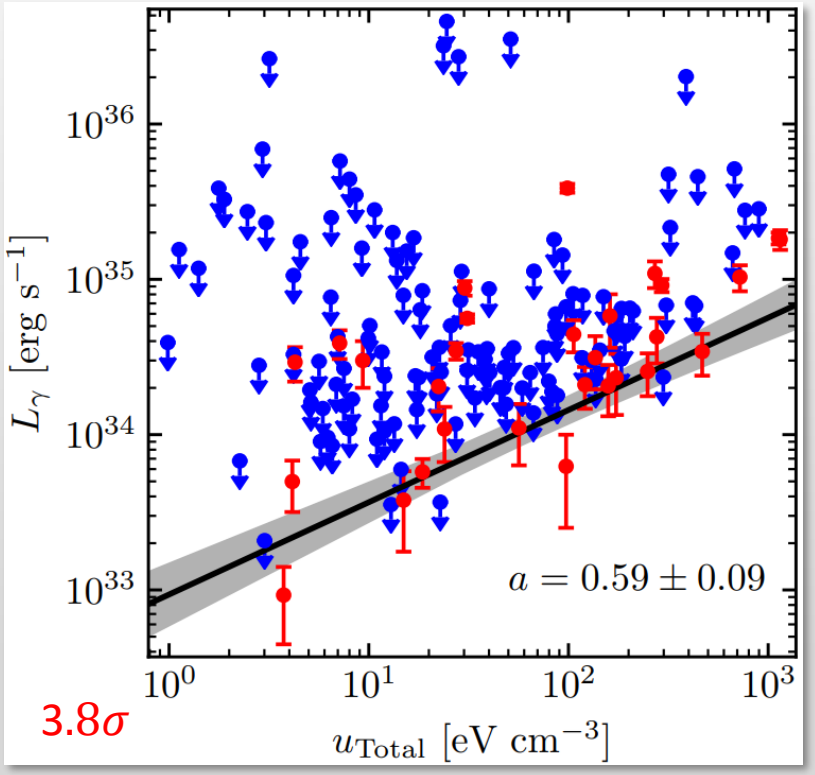
- Correlations between gamma-ray emission and other properties of the globular clusters have been used to probe the origin of the gamma rays

Correlation with gamma rays (this work)

- Thorough correlation analysis with 4FGL Fermi LAT data:
  - Considering the stellar encounter rates, metallicity and radiation field energy densities in the globular clusters
  - Including 30 detections and 100+ upper limits in Fermi LAT
  - Using an expectation–maximization (EM) algorithm to study the correlations and estimate their statistical significance with MC simulations
    - Similar approaches have been adapted in the literature to study star-forming galaxies, AGNs, etc. (Ackermann et al. 2012; Di Mauro et al. 2014; Ajello et al. 2020)

Correlation with gamma rays (this work)



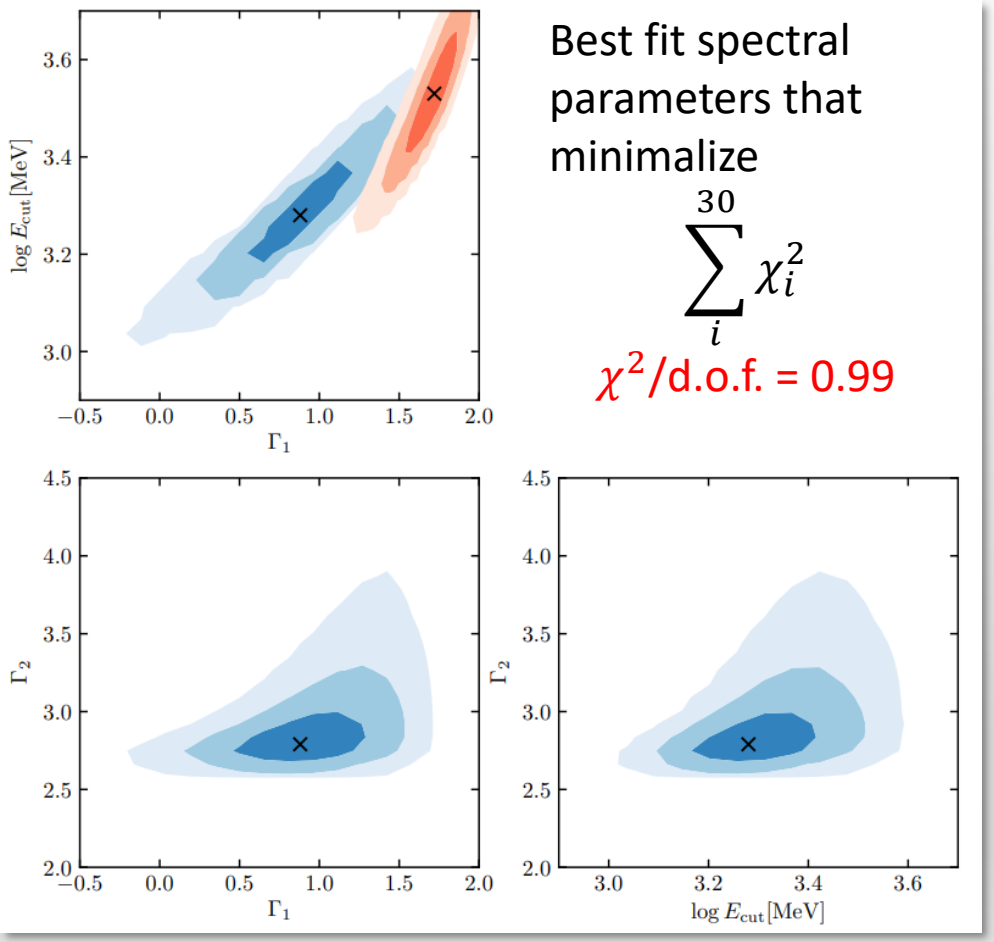


Gamma-ray luminosities are correlated with encounter rates and total radiation field

Inverse Compton signal in energy spectra

- The high energy tail of Fermi data may probe the inverse Compton
- Model:
  - $\frac{dN}{dE} = \left[\frac{dN}{dE}\right]_{CR} + \left[\frac{dN}{dE}\right]_{IC} = N_1 \left(\frac{E}{E_0}\right)^{-\Gamma_1} \exp\left(-\frac{E}{E_{cut}}\right) + N_2 \left(\frac{E}{E_0}\right)^{-\Gamma_2}$
- Data: 30 globular clusters, 300 MeV to 500 GeV
- Require the globular clusters to share the same spectra shape

Inverse Compton signal in energy spectra

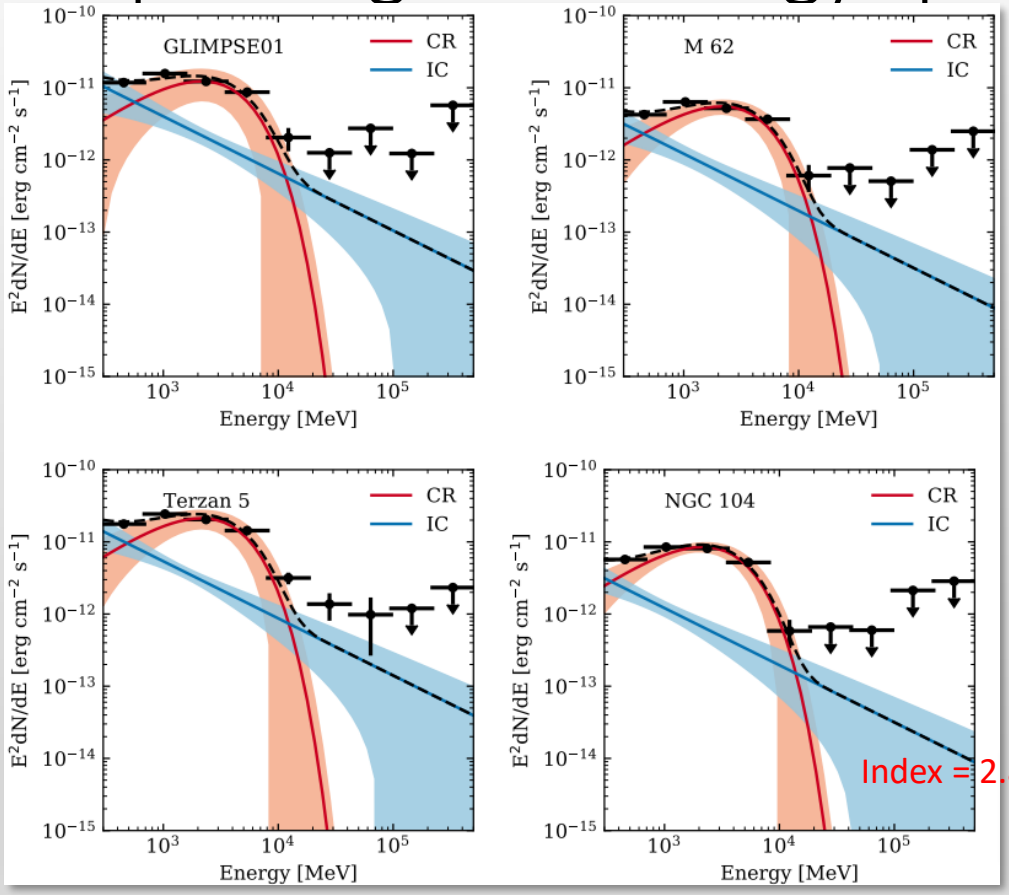


Best fit spectral parameters that minimalize

$$\sum_{i}^{30} \chi_i^2$$

χ^2/d.o.f. = 0.99

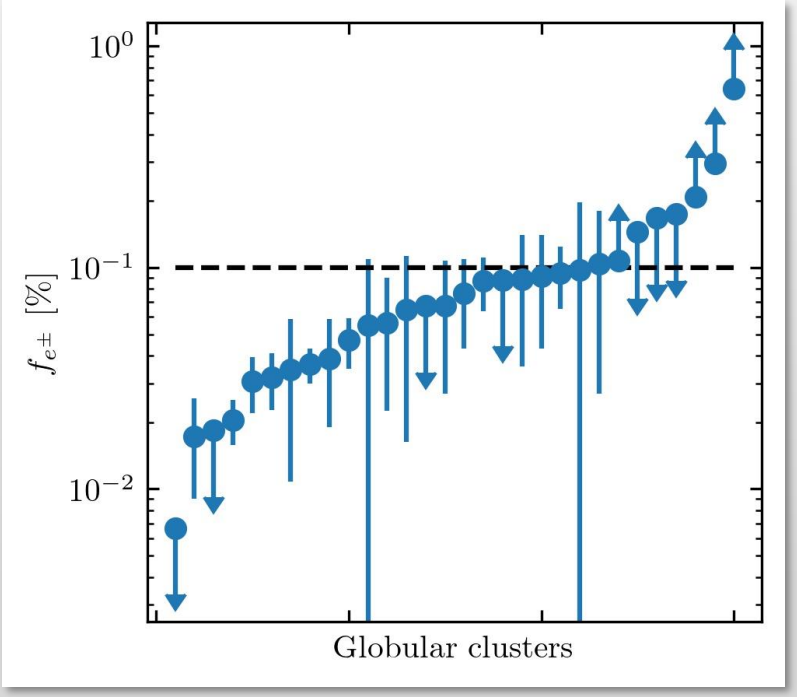
Inverse Compton signal in energy spectra



A soft inverse Compton component is preferred by 8.2σ!

Millisecond pulsar e+/- efficiency

- Pulsar spin-down to e+/- efficiency is hard to measure
- Based on inverse Compton component in the spectra, the e+/- efficiency is slightly smaller than 10%
- Consistent with other estimates:
  - Galactic center (Bednarek & Sobczak 13)
  - Nearby pulsars (Hooper et al. 17)
  - Quiescent galaxies (Sudoh et al. 20)



Summary

- We analyze 4FGL Fermi LAT data for more than 150 Milky Way globular clusters:
  - Their gamma-ray luminosities are correlated with the stellar encounter rates and total radiation field in the globular clusters
  - An inverse Compton signal with a power index of 2.8 is found in the energy spectra of gamma-ray detected globular clusters
  - The e+/- efficiency of the millisecond pulsars is estimated to be close to 10%

Thank you!