GLOBULAR CLUSTER SYSTEMS AS GEV–TEV TRACERS OF GALAXY ASSEMBLY

1st September, 2026 – TeVPA – Tendo, Japan

Artist's impression of the Globular Cluster system fo the Milky Way
Credit: ESA/Hubble, NASA, L. Calçada (2019)

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OUTLINE

- Globular cluster (GC) systems in evolving galaxies
  - Environmental dependency of GC GeV-TeV emission
  - Gamma-ray emission signatures from GC systems in galaxies
- Application to nearby galaxies
- Prospects to probe merger histories
- Summary

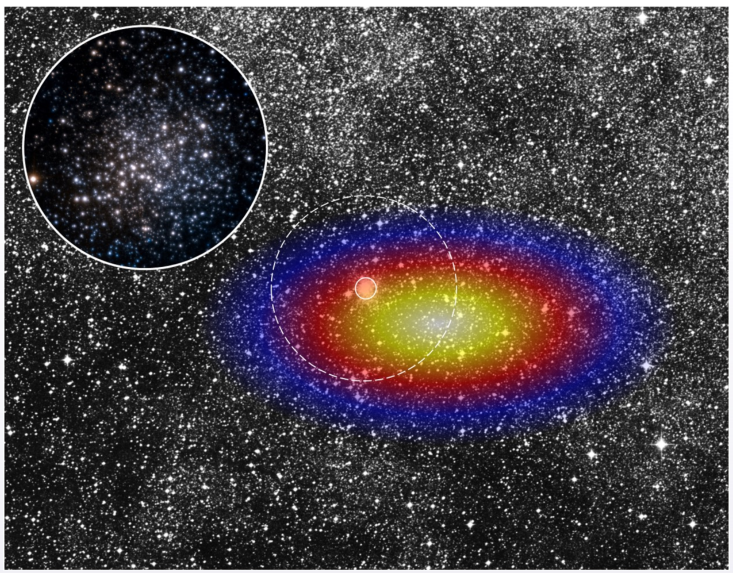
GLOBULAR CLUSTER SYSTEMS IN GALAXIES

- Galaxies can host hundreds of GCs (in the Milky Way, >150)
- Distributed through the bulge, disk and halo
- 2 types: **metal poor** (MP), and **metal rich** (MR): in-situ formation vs. minor merger/accretion

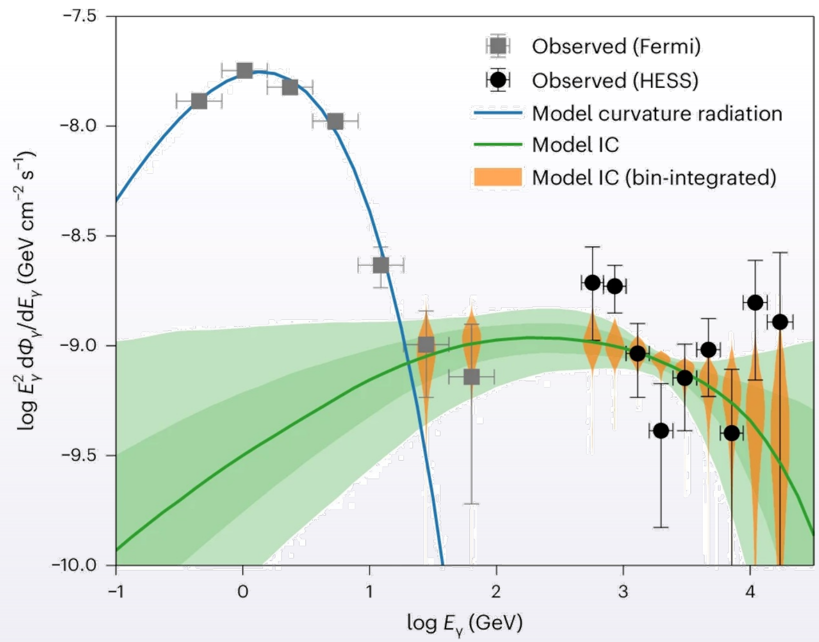
Artist's impression of the Globular Cluster system fo the Milky Way
Credit: ESA/Hubble, NASA, L. Calçada (2019)

VHE EMISSION FROM GLOBULAR CLUSTERS – TERZAN 5

- 45 GeV detections of GCs
- 1 confirmed at TeV energies with H.E.S.S. [Aharonian et al. 2011]
- TeV emission substantially offset from the cluster



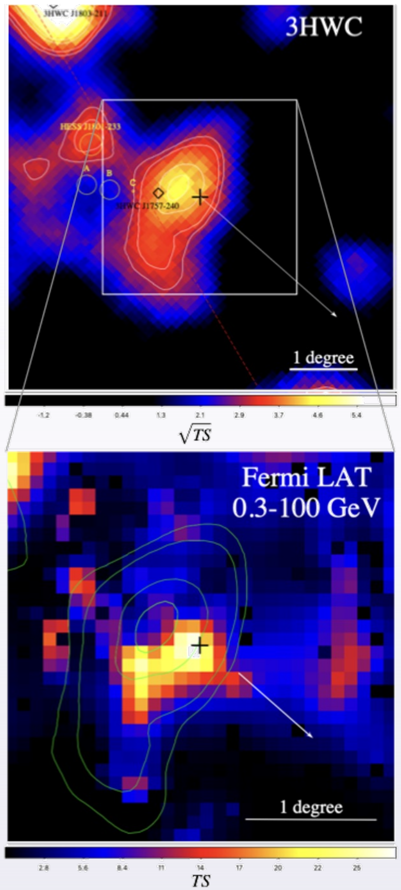
Terzan 5 in visible light and gamma-rays observed by H.E.S.S.
Credit: ESO/Ferraro and H.E.S.S. Collaboration/MPIK (2011)

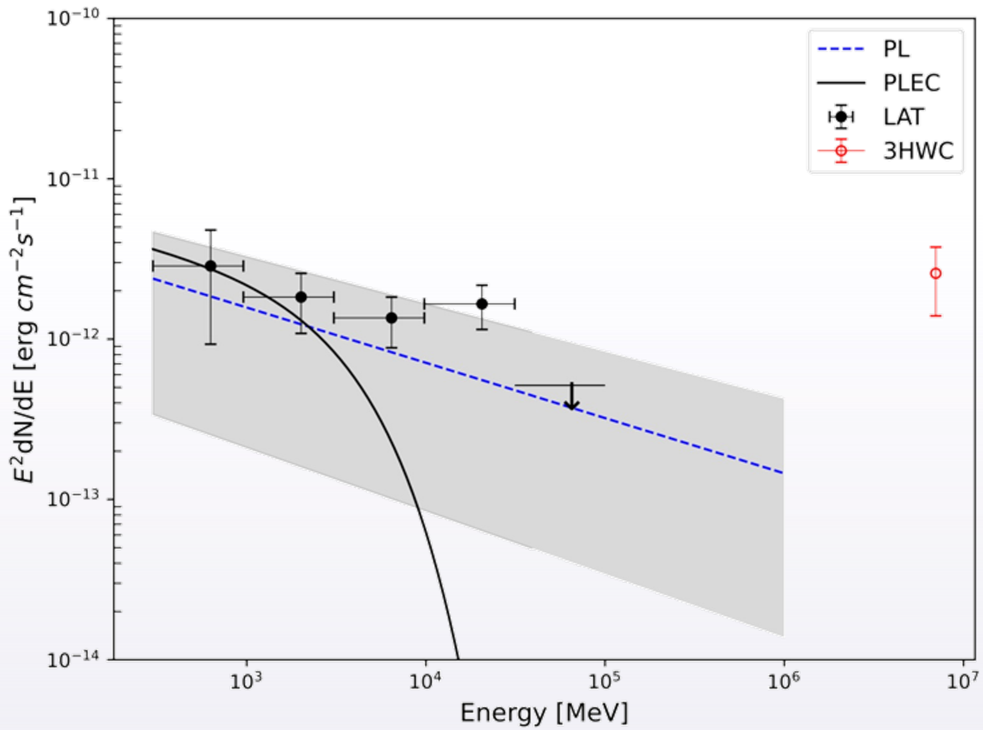


Krumholz et al. (2024)

VHE EMISSION FROM GLOBULAR CLUSTERS – UKS 1

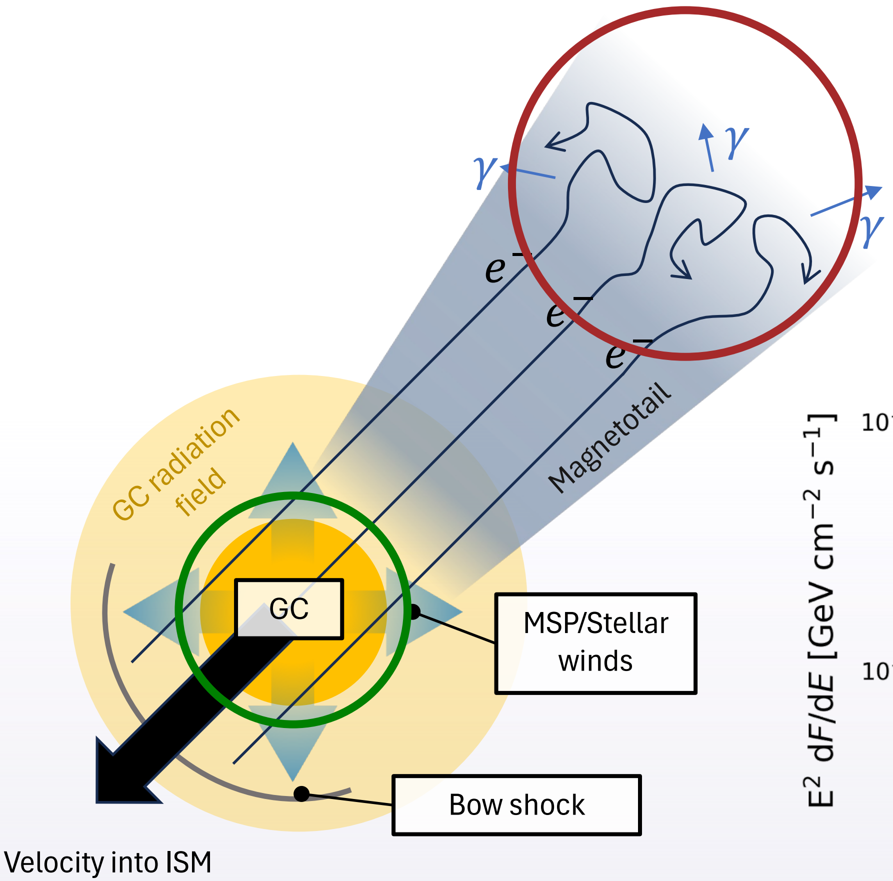
- **Possible** association reported at TeV energies in 3HWC data [Shin et al. 2025]
- Very powerful GeV emission; TeV peak also offset from the cluster





Shin et al. (2025)

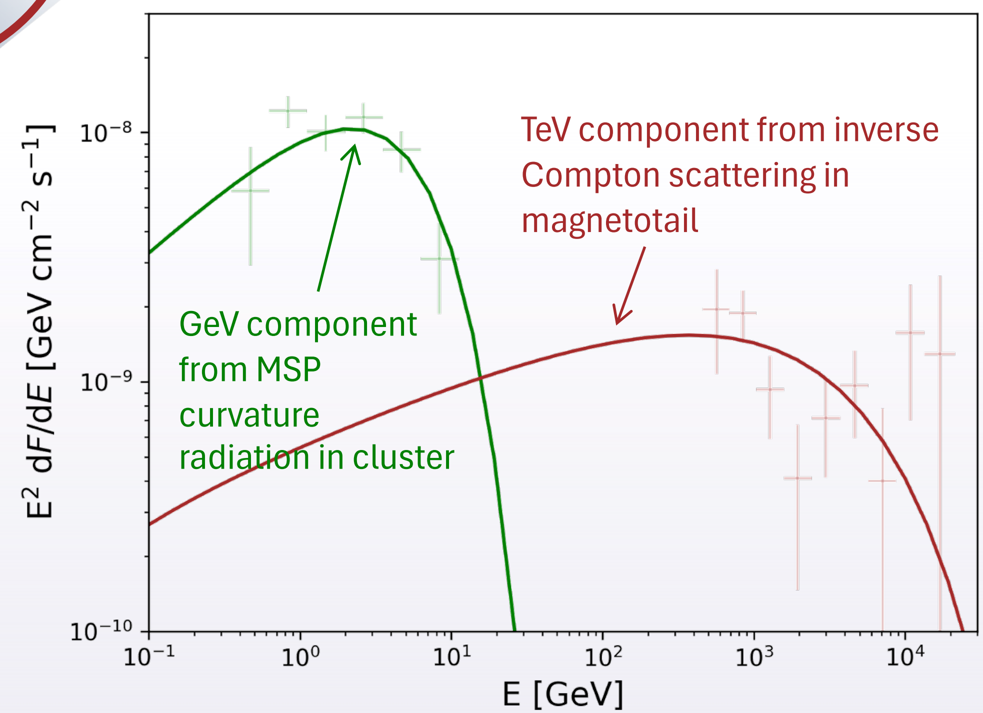
GAMMA-RAY EMISSION SPECTRA OF GCs



Krumholz et al. (2024) model

ICS emission origin from self-scattering electrons in magnetotail

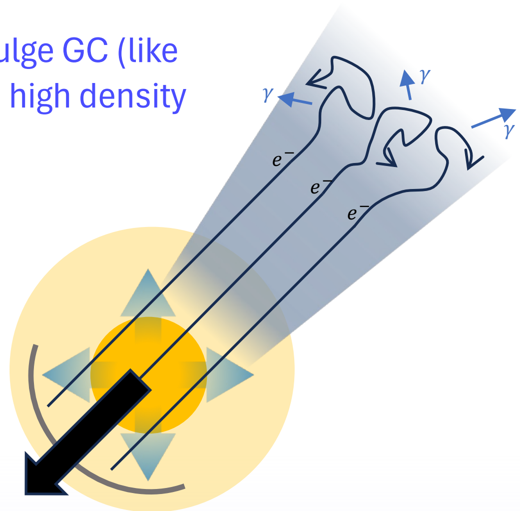
Model configured to emulate Terzan 5

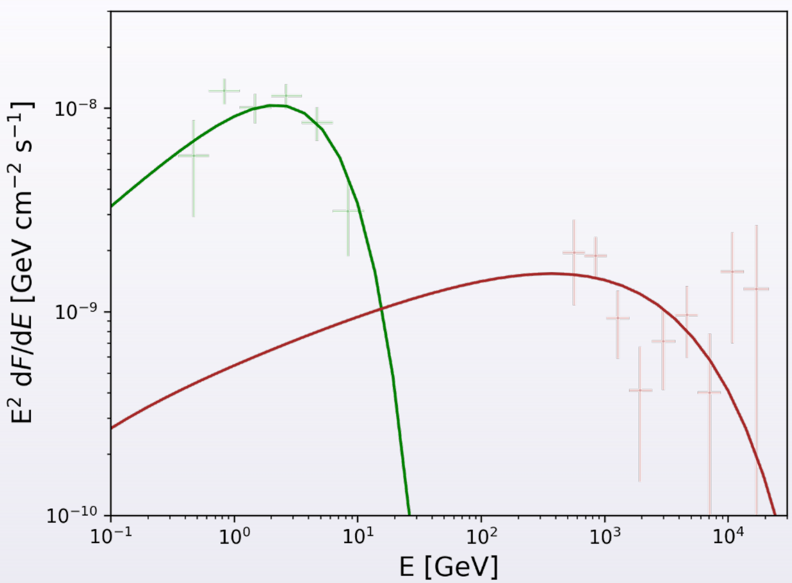


Data points: GeV from *Fermi*-LAT [Song et al. 2021]
TeV from H.E.S.S. [Aharonian et al. 2011]

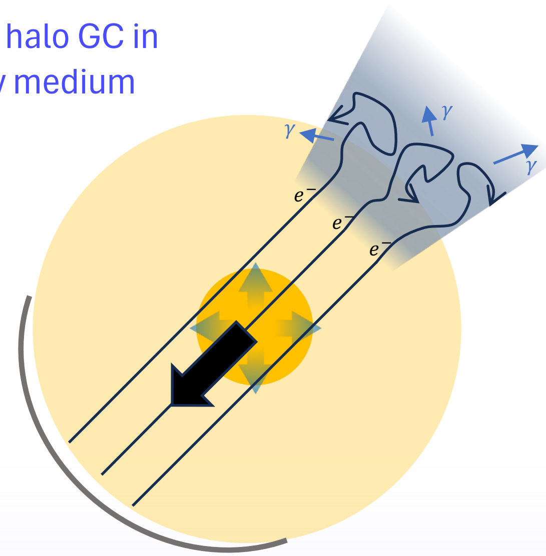
ENVIRONMENTAL EFFECTS

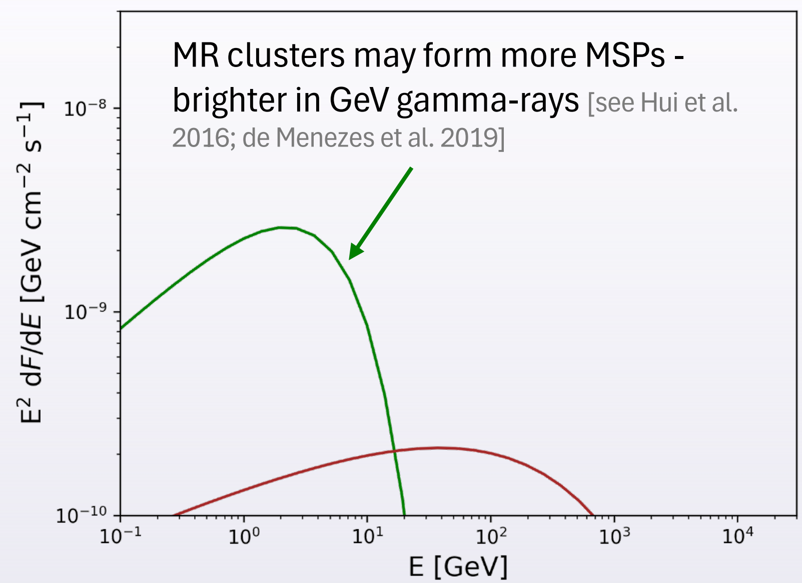
Metal Rich bulge GC (like Terzan 5) in a high density medium





Metal poor halo GC in low density medium

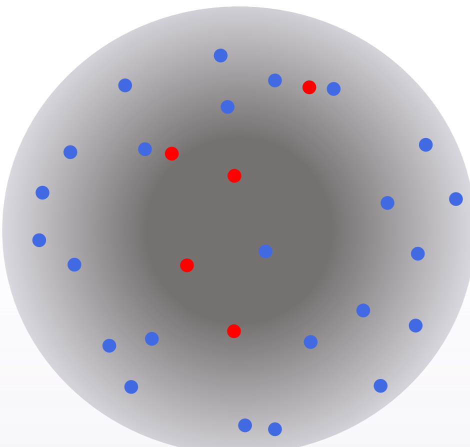




GC SYSTEMS IN GALAXY MERGERS

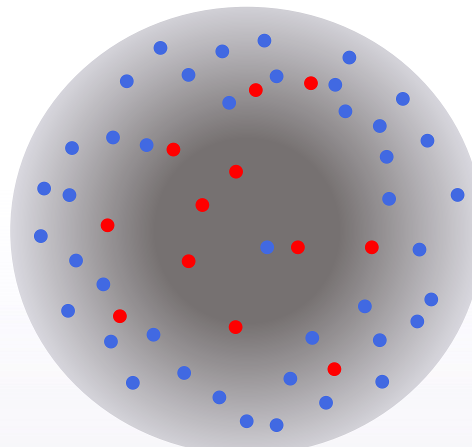
GC distribution depends on a galaxy's formation history

NO MERGER HISTORY



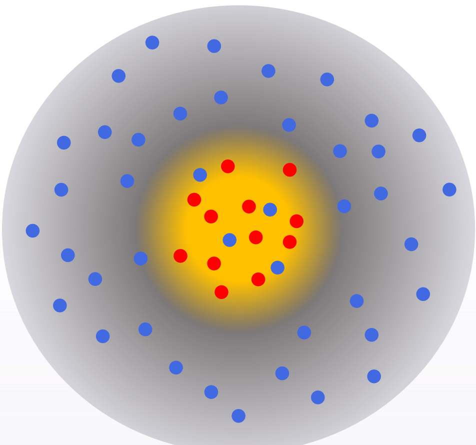
- Low overall GC count
- Emission dominated by in situ GCs
- Metal-poor GCs may be more abundant
- Follows the gas density profile

MINOR MERGERS



- A few more GCs
- Old, metal poor GCs from accretion of satellites
- Extended, flatter profile

MAJOR INTERACTIONS



- More GCs, including metal rich (young) ones
- Central bulge boosts metal rich GC abundance

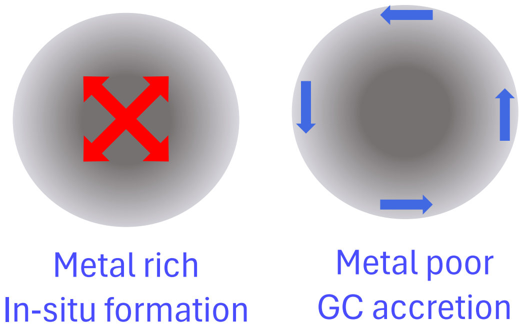
● = metal poor, older GC

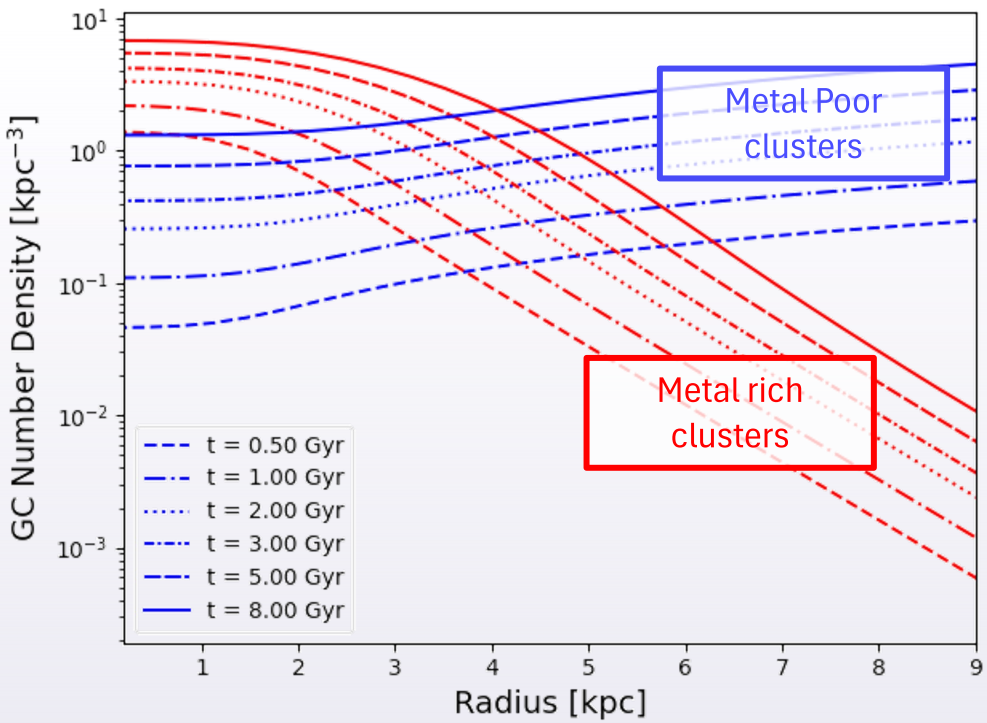
● = metal rich, younger GC

EVOLUTION OF GC SYSTEMS

- Evolution of GC system (MP vs. MR)

$$\underbrace{\frac{dN_i}{dt}}_{\text{Evolution}} = \underbrace{\frac{N_{i+1}}{t_{\rm df}(r_{i+1})} - \frac{N_i}{t_{\rm df}(r_i)}}_{\text{Dynamical friction}} + \underbrace{\Gamma_{\rm diss}(r_i)}_{\text{Dissipation}} + \underbrace{S_i(t)}_{\text{Formation term}}$$

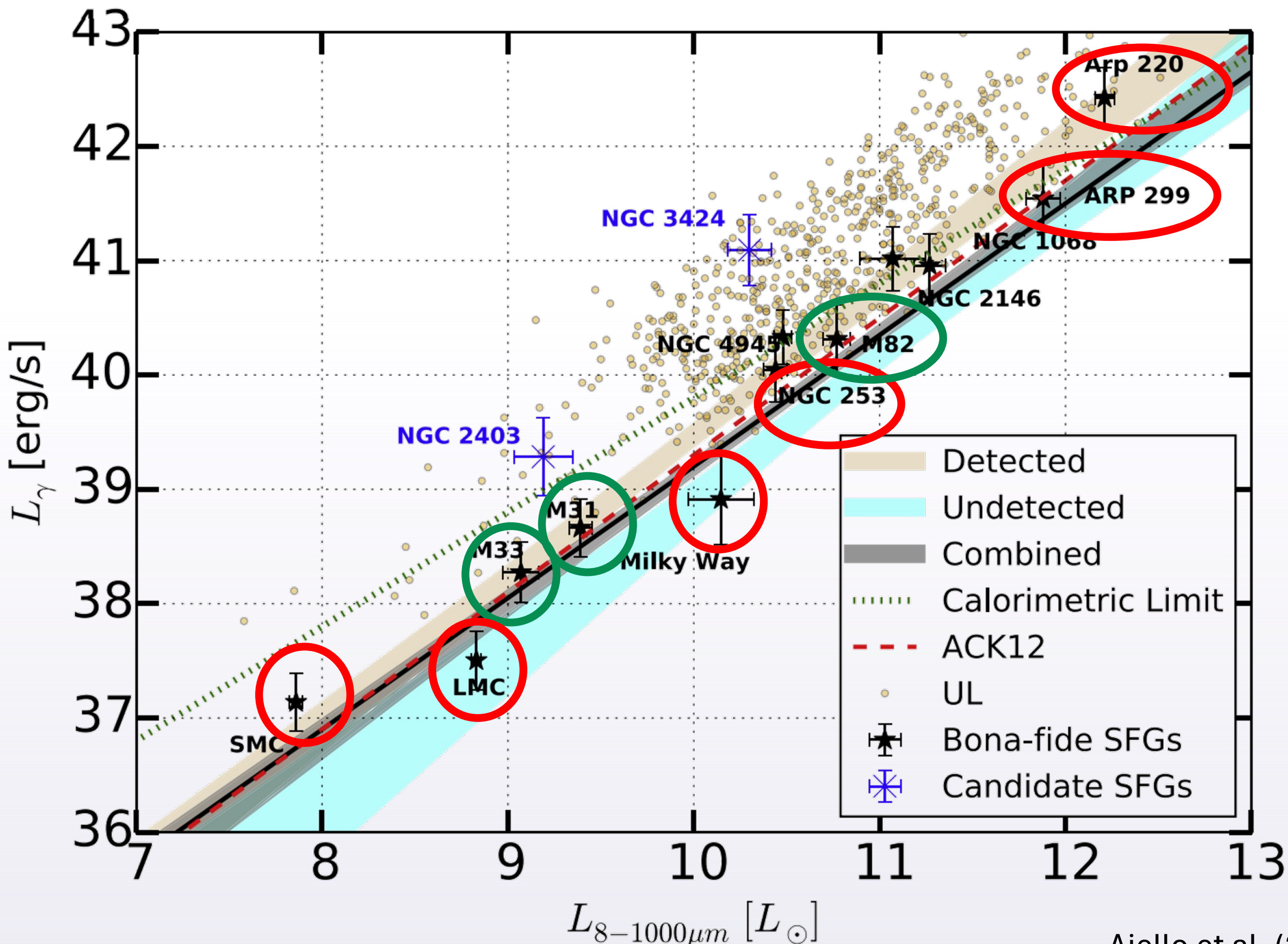




Metal poor GCs slowly fall inwards over Gyr timescales, MR ones build-up in-situ

VHE GAMMA-RAY SIGNATURES

Compare 3 gamma-ray detected galaxies with different merger histories

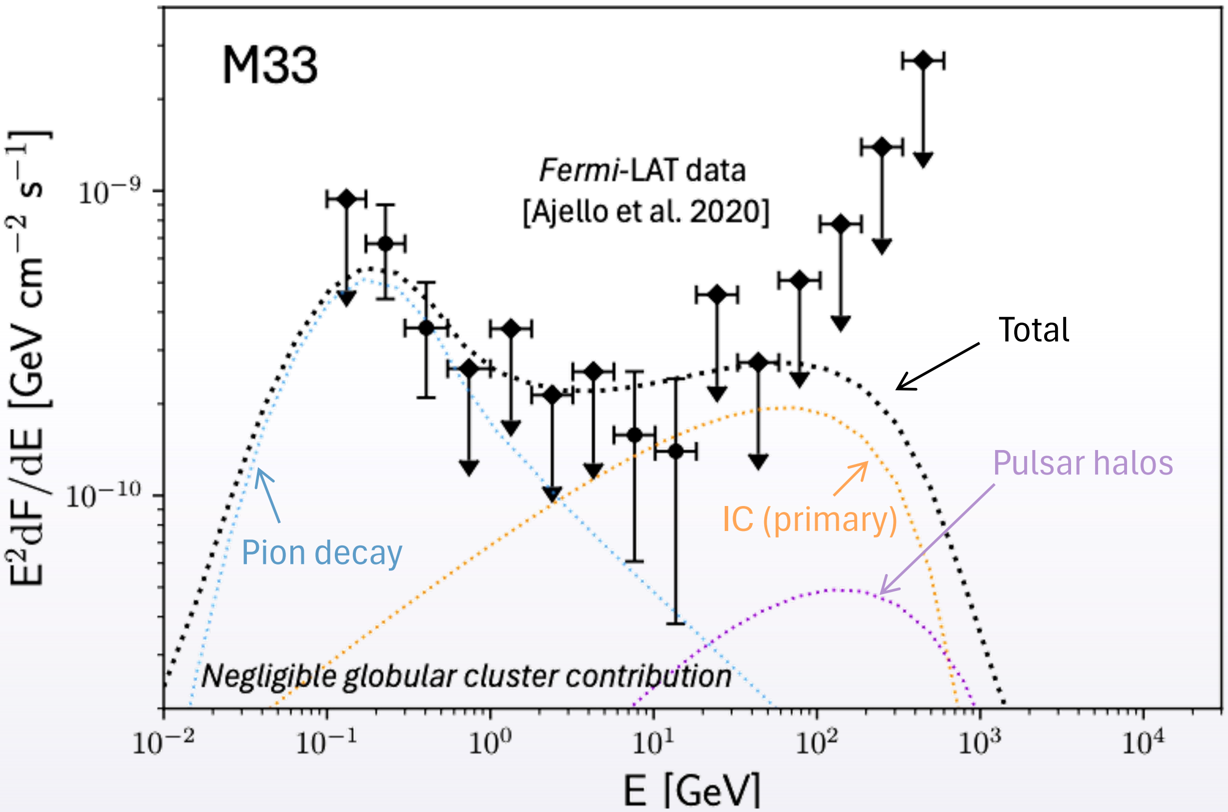


Ajello et al. (2020)

Select systems with well understood formation histories **in clean environments as laboratories** (no Seyfert activities, ongoing mergers)

A TALE OF 3 GALAXIES – SECULAR EVOLUTION [M33]

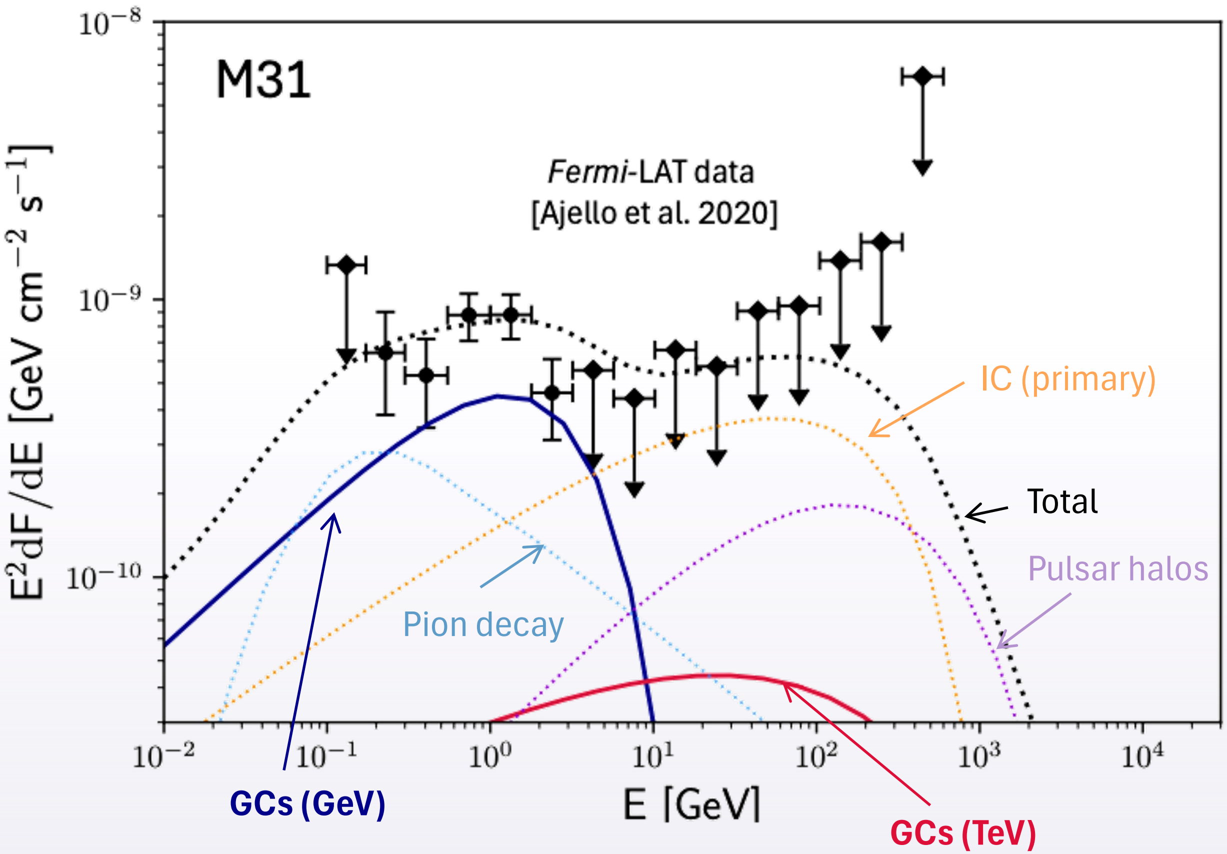
Reference case – negligible GC contribution

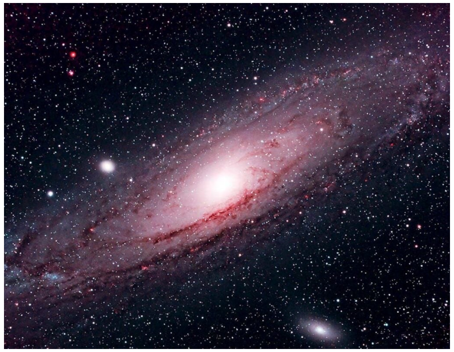


M33 optical image.
Credit: Makrem Larnaout (2023)

No minor mergers, no major mergers for the last 10 Gyr

A TALE OF 3 GALAXIES – MINOR MERGER DOMINATED [M31]

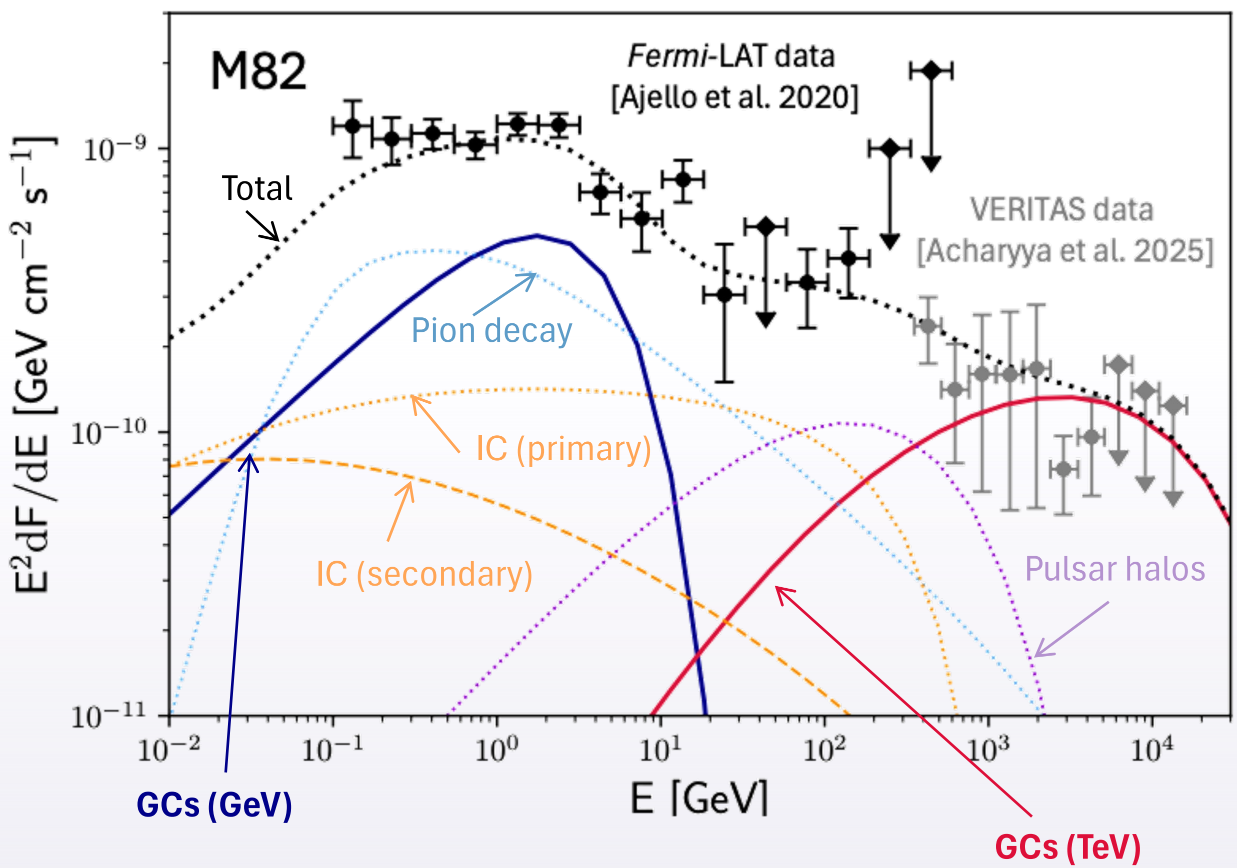




M31 optical image.
Credit: Klaus Brasch (2024)

Minor merger rate of 0.33 Gyr^{-1}, no major mergers for the last 10 Gyr

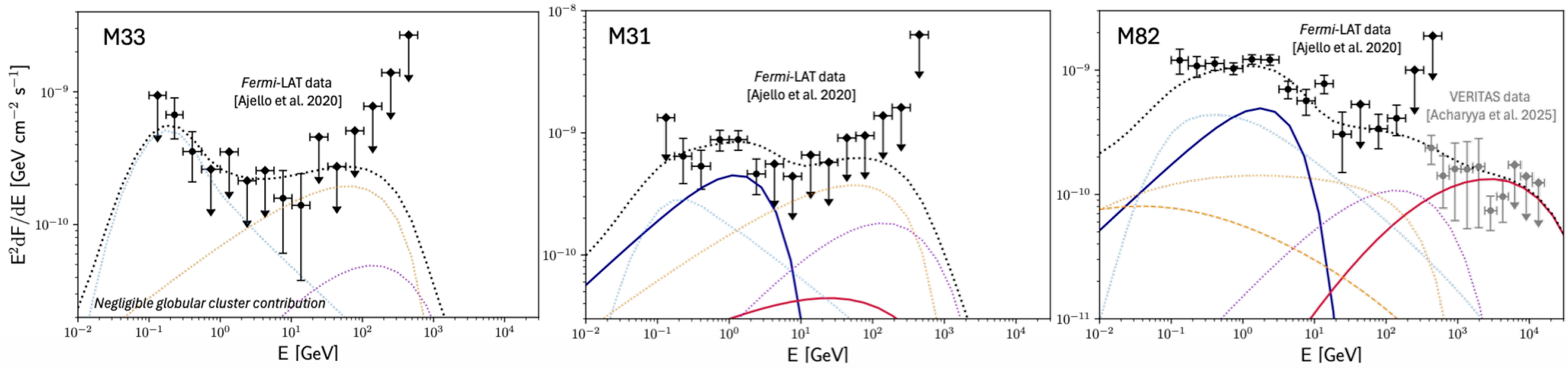
A TALE OF 3 GALAXIES – INTERACTION DOMINATED [M82]



M82 (HST image). Credit: NASA/ESA.

No minor mergers, but successive interaction events at a rate of 1 Gyr^{-1}

PROSPECTS FOR PROBING GALAXY ASSEMBLY HISTORY



- Strong differences in spectral features under different assembly histories
- Steady over Gyr, providing record of a galaxy's history
- Potential as a complementary way to trace galaxy evolution
  - Reach into regions like the bulge that are often hidden from conventional observational methods, especially in dusty galaxies
  - Bypasses reliance on stellar evolution modelling
- Future CTAO TeV studies: high-energy tail, spatial distribution, more systems

SUMMARY

- Galaxies with **different assembly histories** develop different distributions and properties of globular cluster systems

- Their **GeV and TeV emission** is sensitive to their GC distribution

- The overall GeV-TeV emission spectrum from a galaxy therefore **encodes information about how it formed** over the last ~10 Gyr

- Potential to use GeV-TeV spectral features with near-future data as a new probe of a **galaxy's history** that can **bypass limitations and degeneracies** of traditional UV/optical methods and stellar population models