8th Heidelberg International Symposium on High Energy Gamma Ray Astronomy

Milano 2nd-9th September 2024

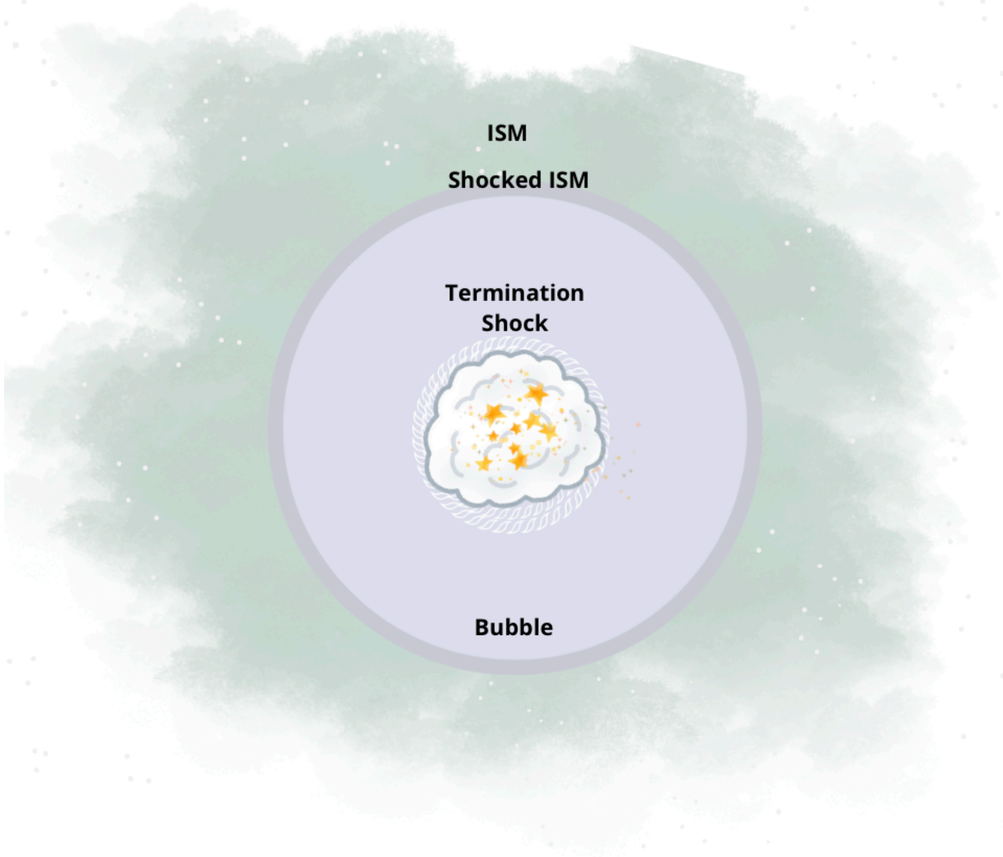
Massive Star Clusters in the Gamma-Ray Sky

Giada Peron — 04.09.2024

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Cosmic rays

The role of Star Clusters



- SCs have strong winds able to accelerate particles at their wind termination shock; $\mathscr{P}_w \approx 0.1\mathscr{P}_{SN}$
- The acceleration lasts for ~1 Myr, favoring the acceleration to the highest energies;
- The ambient is naturally rich of ^{22}Ne;

$$\epsilon_{winds} X_{winds} + (1 - \epsilon_{winds}) X_{ISM} = X_{CR} \rightarrow \epsilon_{winds} \simeq 16\,\%$$

- Several detections of regions towards SCs in gamma rays up to the highest energies;

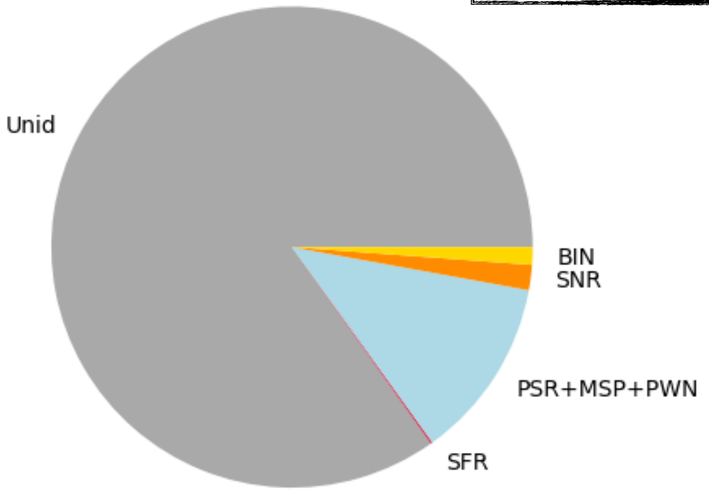
e.g. Bykov et al. 2020, Morlino et al. 2021, Vieu et al. 2022, Gabici et al. 2023,

Star clusters

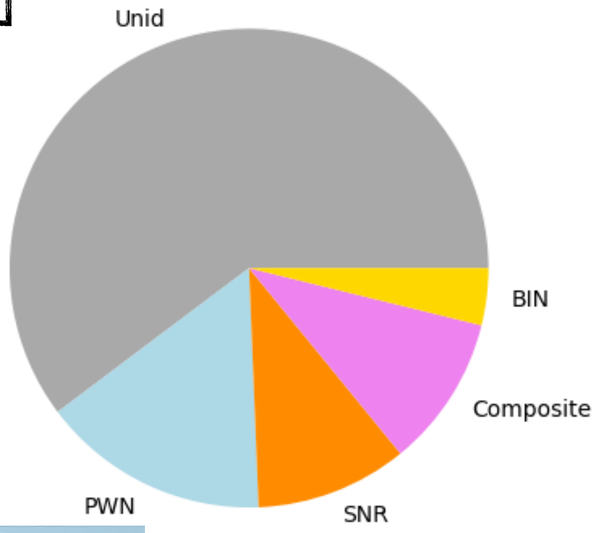
In the gamma-ray sky are only a handful

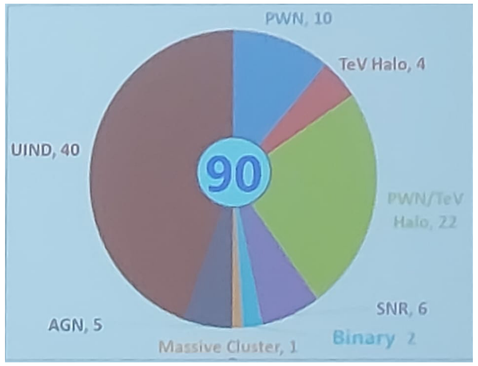
Gamma

Fermi-4FGL



HESS-HGPS



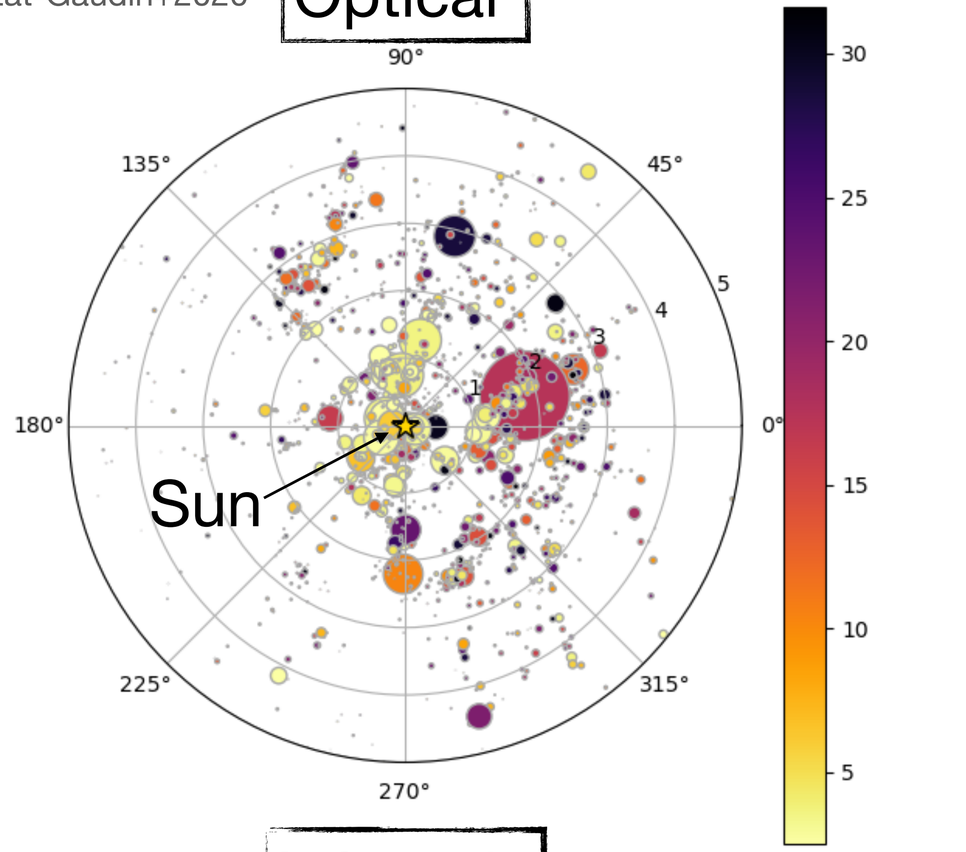


LHAASO 1st catalog

(Cao's slides)

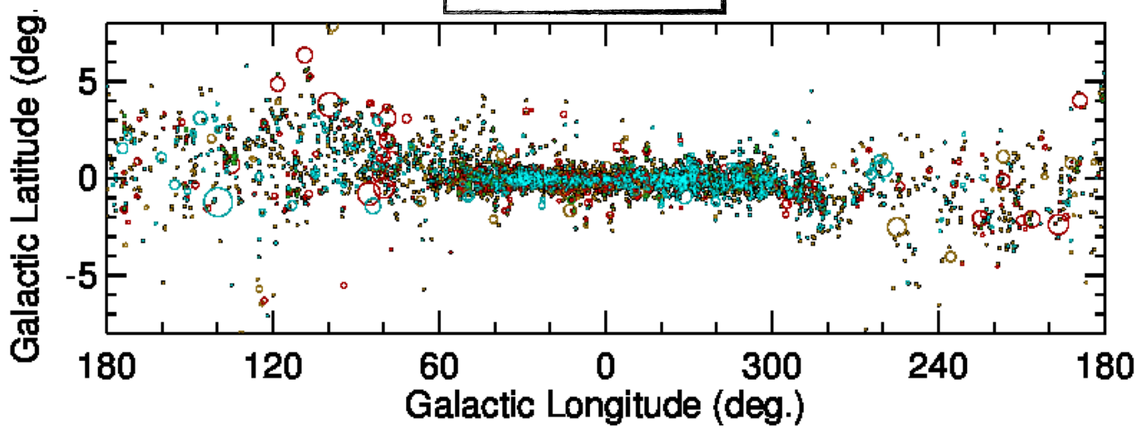
SC from Cantat-Gaudin+2020

Optical



Infrared

Anderson+2013

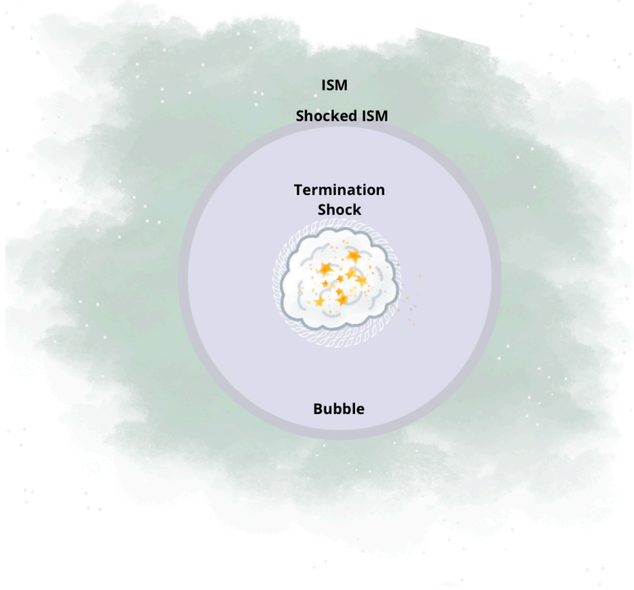


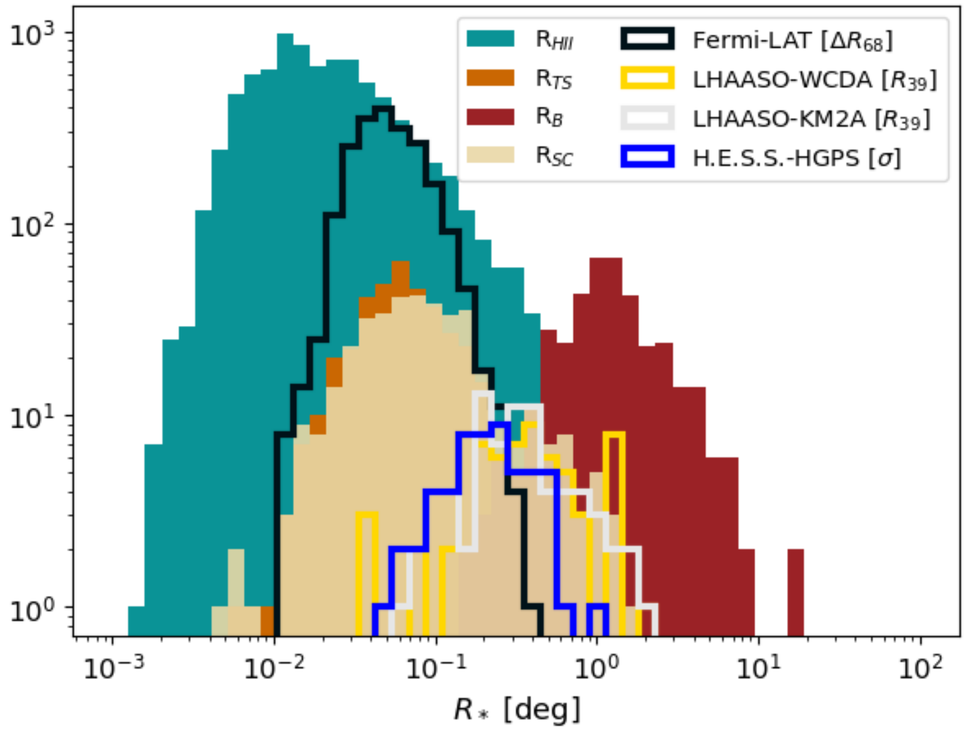
Star clusters

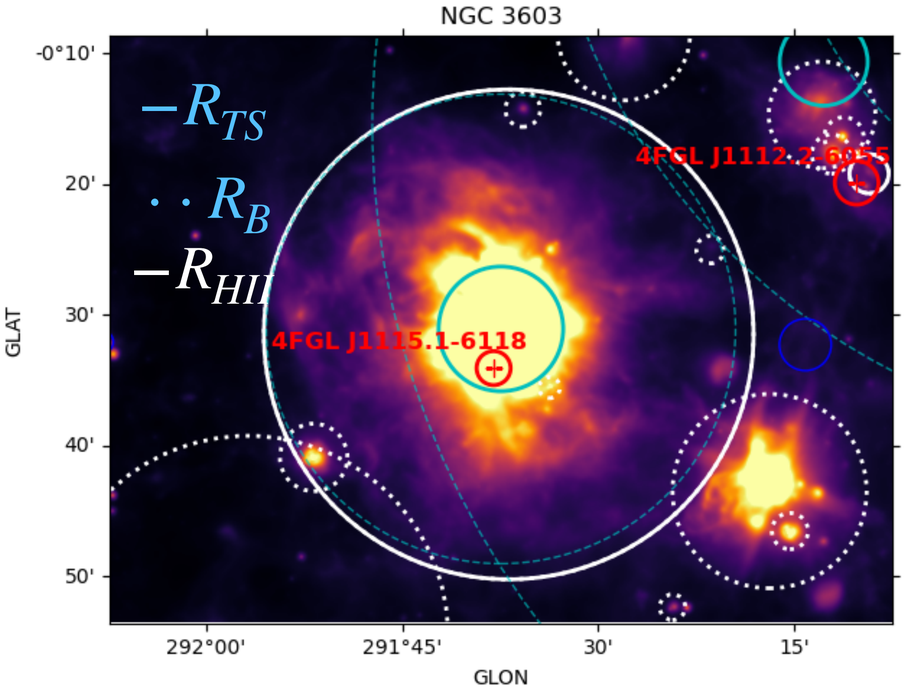
Matching with gamma-ray sources

The match is defined on a geometrical basis:
match if their distance < R*

R_*
- *R of the HII region*
- *R of the SCs (50% of stars)*
- *R of the termination shock*
- *R of the bubble*





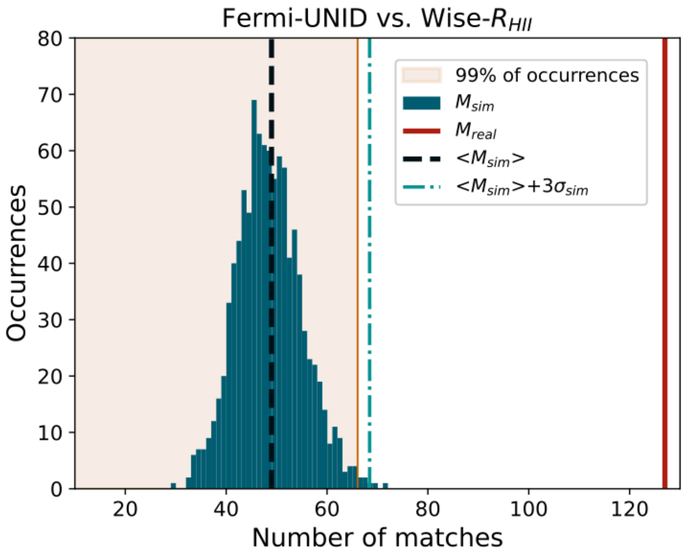


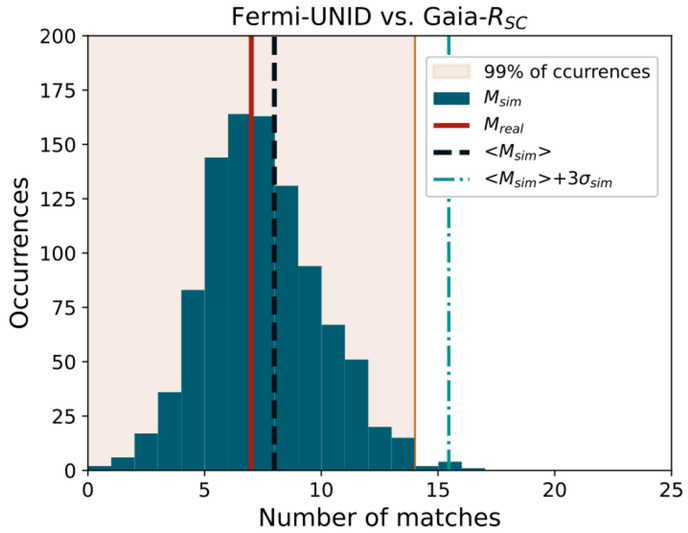
Star clusters

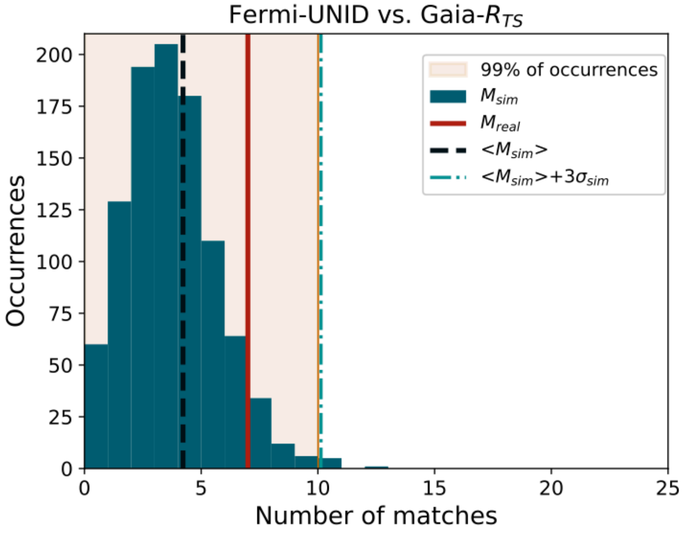
Matching significance

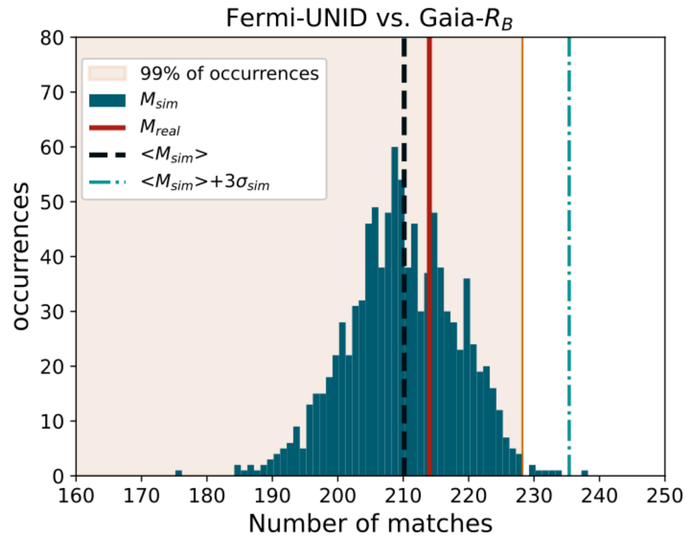
i. Calculate the number of matches with SC catalogs;
ii. Calculate the number and distribution of matches with 1000 randomly generated catalogs;
iii. Evaluate matching significance as:

$$\Sigma = \frac{N^{real}_{match} - < N^{sim}_{match} >}{\sigma(N^{sim}_{match})}$$

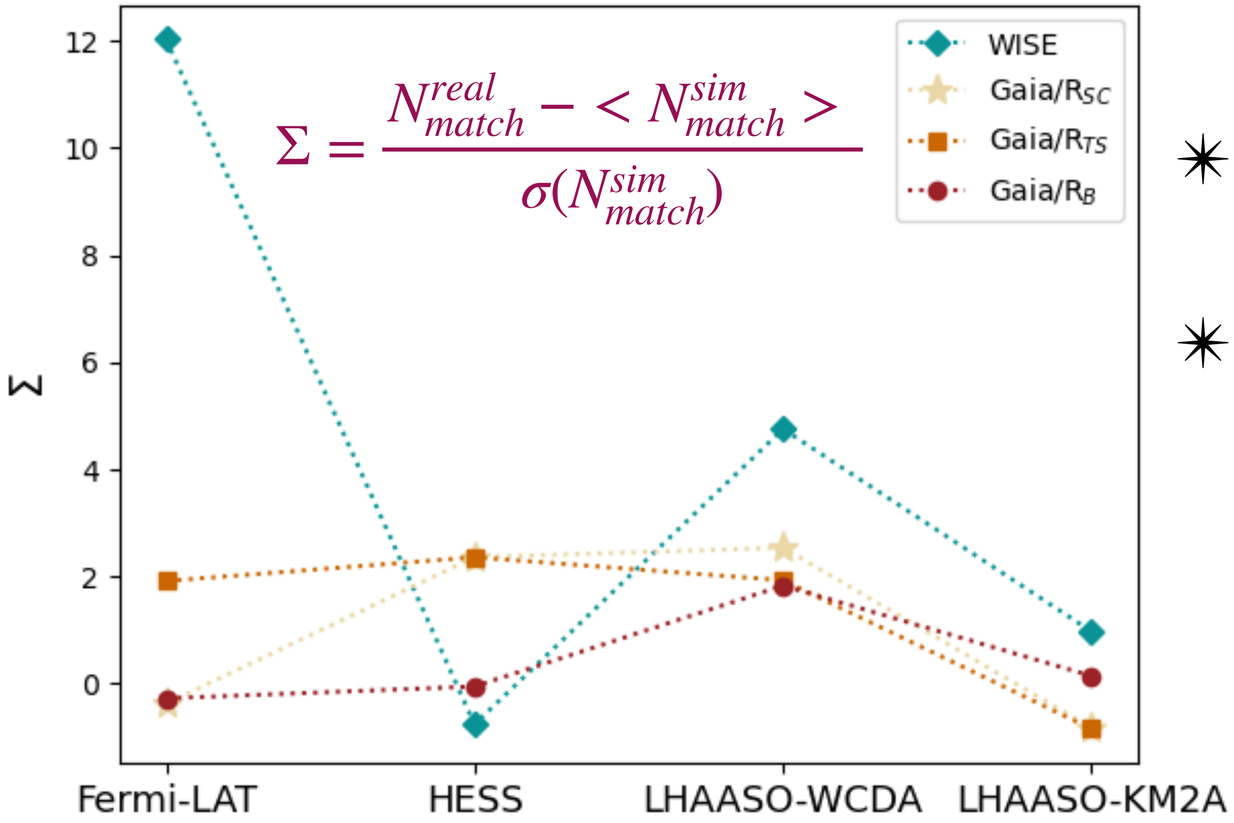




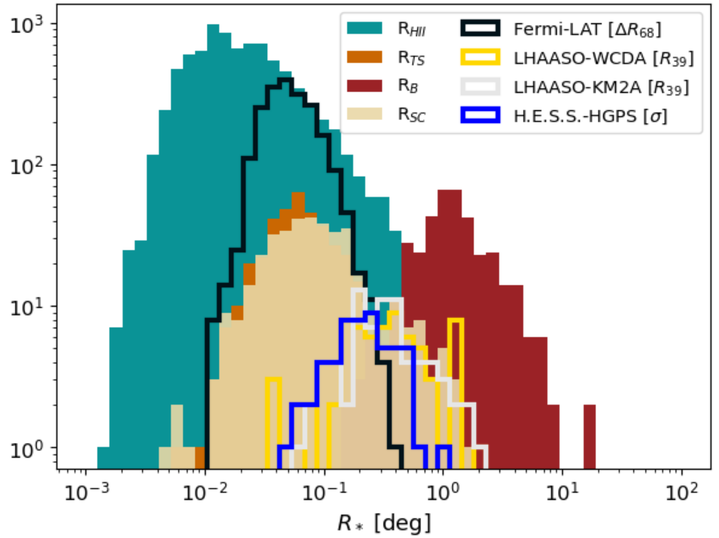




Star clusters Matching with gamma-ray sources



- Very good correspondence between **WISE** and **Fermi-LAT** sources
- The significance decreases for larger objects like Gaia's and TeV sources.
- Detection extended sources is challenged both by faintness and by source confusion



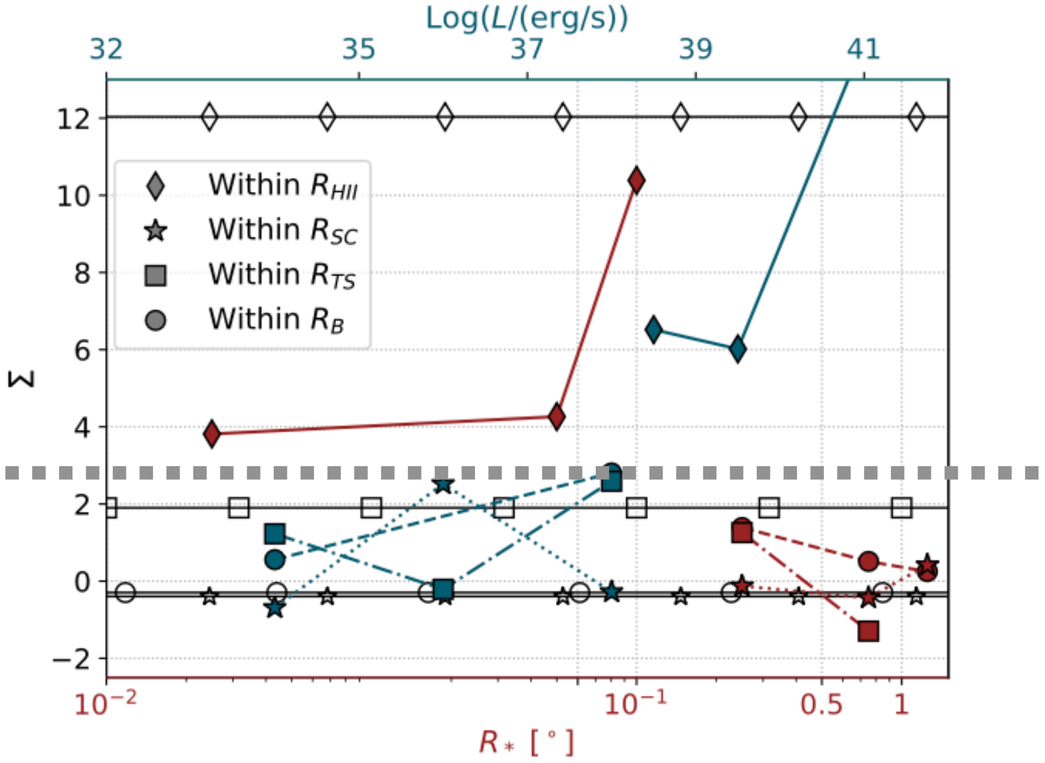
Peron et al. 2024 (ApJL, in press.) arXiv:2408.04973v1

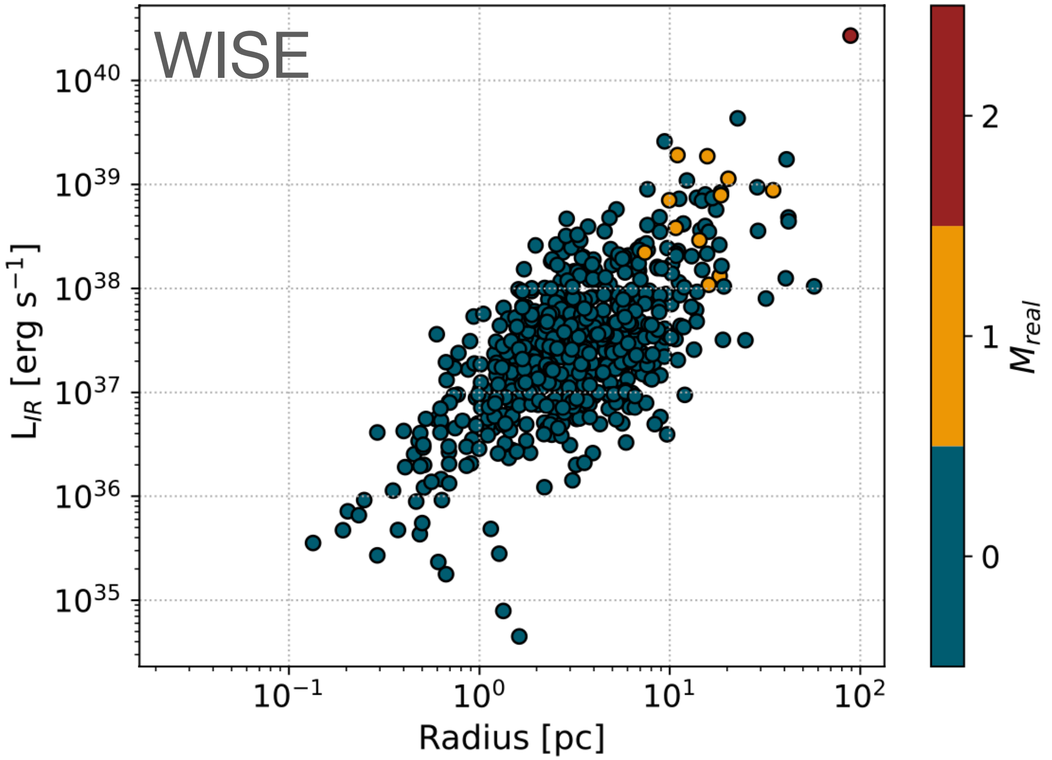
Star clusters from WISE

Matching with gamma-ray sources: Fermi-LAT (50 MeV — 1 TeV)

WISE

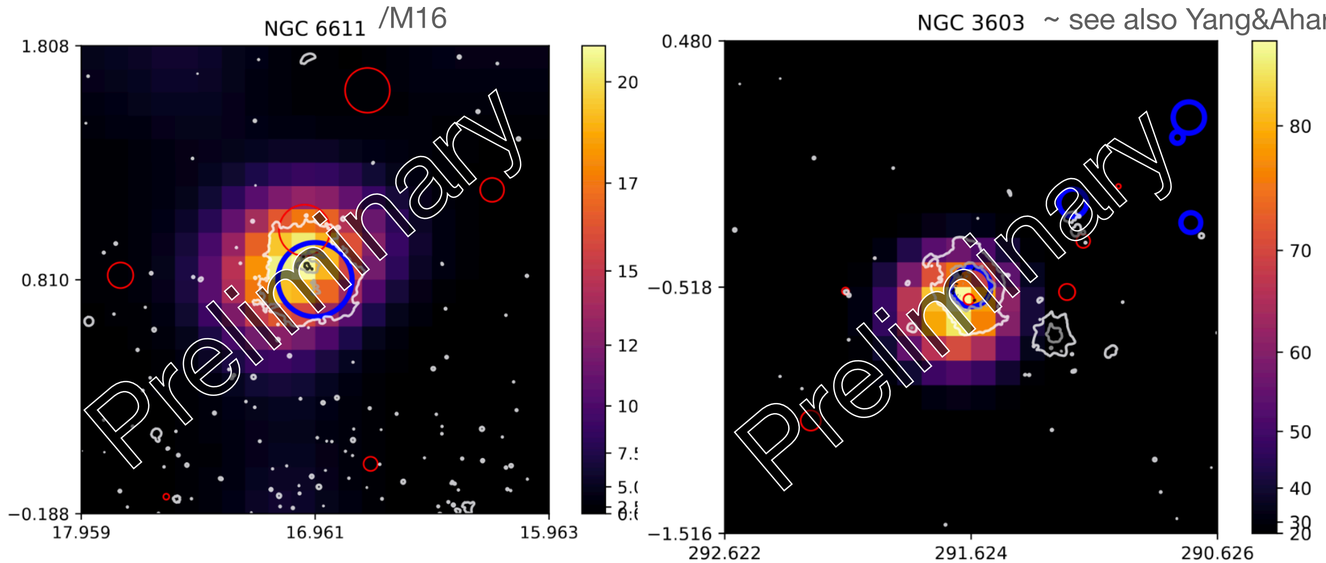
Gaia

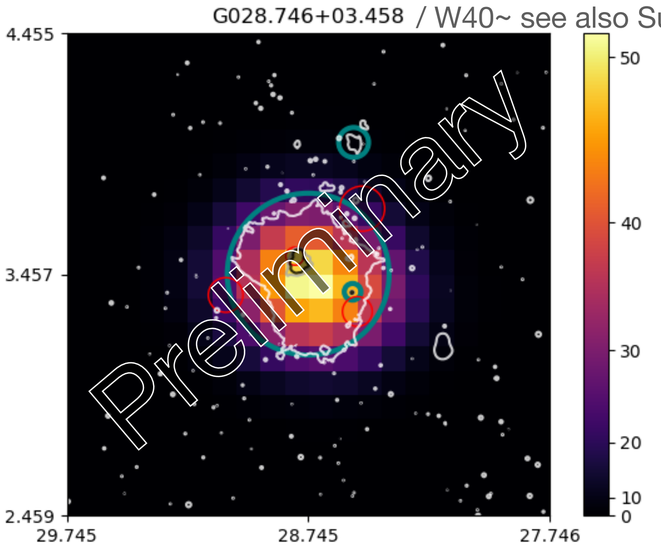


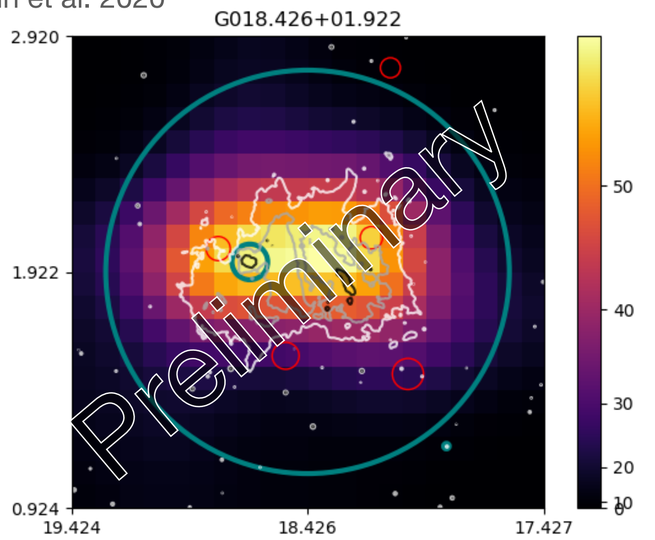


Matching significance and number of matching sources **increase** with **luminosity** and **radius**

Star clusters seen by Fermi-LAT







Map: Fermi-LAT TS (>1 GeV)

Regions: Fermi-LAT 4FGL sources

Region: Gaia RTS

Region : WISE (22 micron) HII regions

Contours: WISE (22 micron) emission

The morphology of the Fermi emission well matches with the HII region contours

..and more examples

Peron et al. 2024, in prep

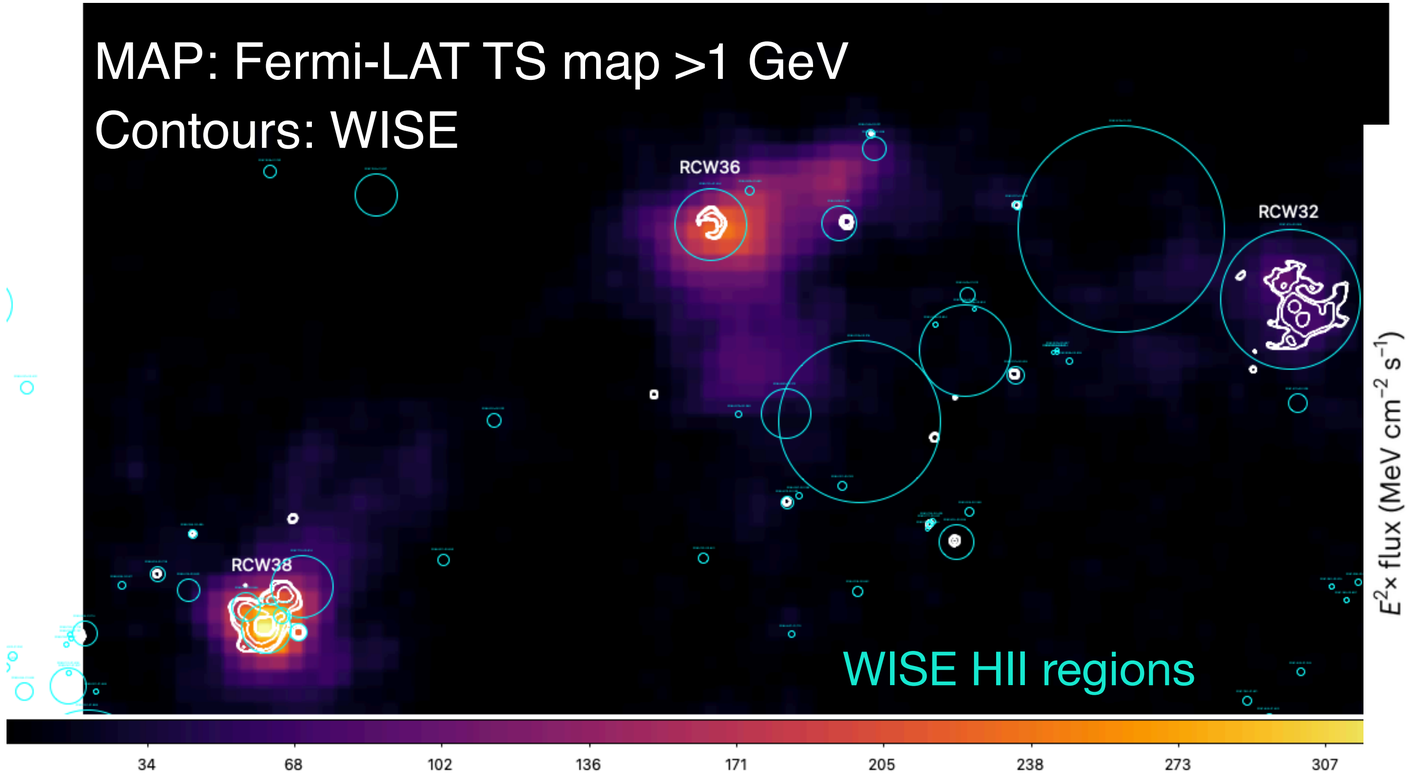
Star clusters seen by Fermi-LAT

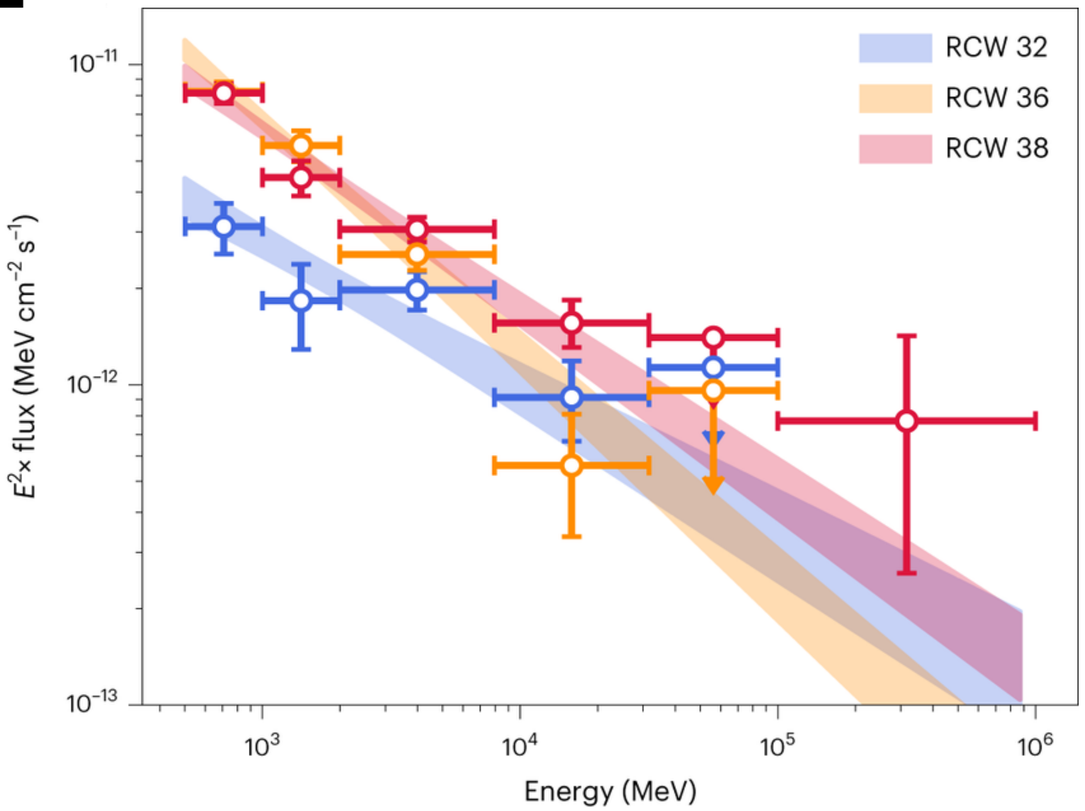
In the Vela Molecular cloud Ridge

Star forming complex at ~1-2 kpc

✳SC of Age ~ 1 Myr —> No Supernovae

✳Embedded in dense medium ~ 1000 cm^{-3}





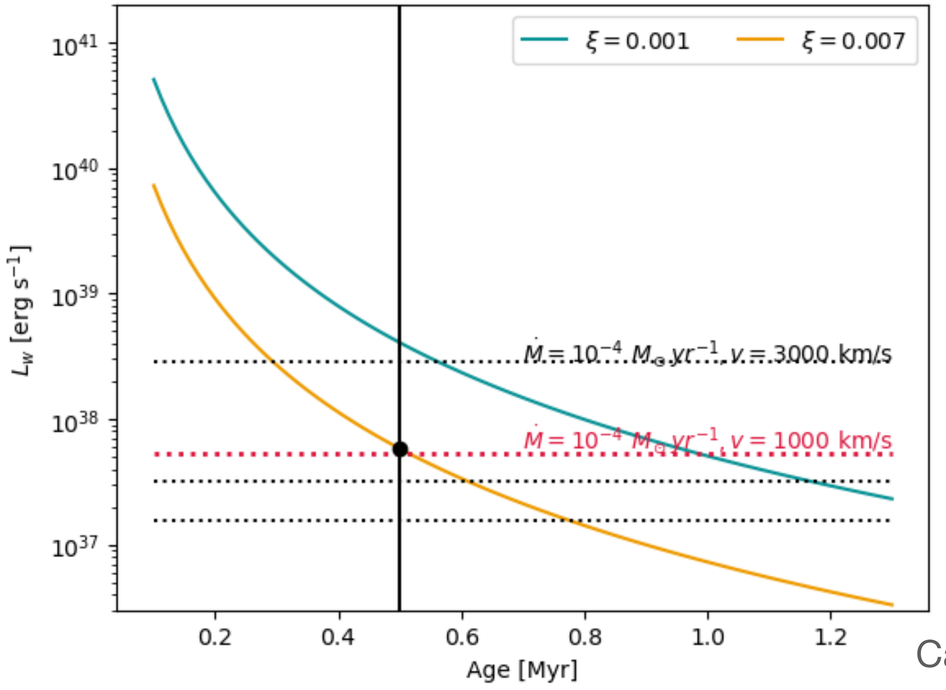
Star clusters

Acceleration efficiency

$$\eta = \frac{L_{CR}}{L_w}$$

L_{CR} from full confinement $L_{CR}[measured] << L_{CR}[real]$

A fraction, ξ , of L_w goes to blown the bubble of radius R



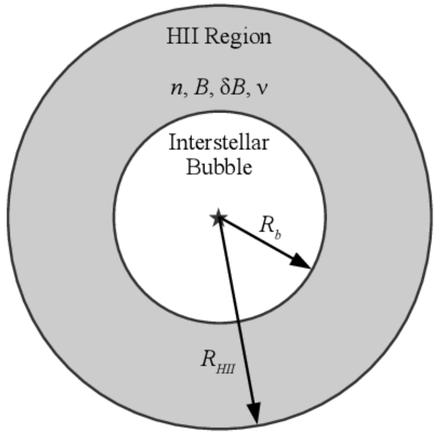
Canto' et al. 2000 [Simulations]

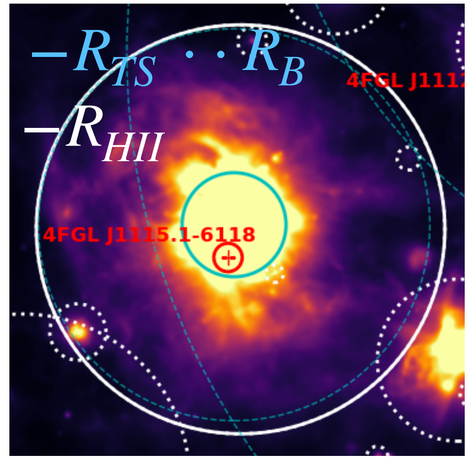
$$\dot{M} \sim 10^{-4} M_\odot yr^{-1}$$

$$v \sim 1000 \text{ km s}^{-1}$$

$$R \sim R_{HII} \sim R_\gamma$$

Maurin et al. 2016





$$R \simeq R_{HII} = \left(\frac{\xi L_w}{n}\right)^{\frac{1}{5}} t^{\frac{3}{5}}$$

Weaver et al. 1977

Star clusters

Acceleration efficiency

$$\eta = \frac{L_{CR}}{L_w}$$

$$L_{CR}[measured] << L_{CR}[real]$$

$$< \eta > \sim 0.5\,\% << \eta[real]$$

Source	Age [Myr]	N [1E3 cm-3]	Efficiency [%]
RCW 32	2	1.9	0.85
RCW 36	1.1	2.6	0.79
RCW 38	0.5	2.1	4E-03

$$\epsilon_w = \frac{\mathscr{P}^w_{CR}}{\mathscr{P}^{tot}_{CR}} = \frac{0.0005 \times 10^{41} \mathrm{erg\ s^{-1}}}{7 \times 10^{40} \mathrm{erg\ s^{-1}}} \simeq 1\,\% << \epsilon_w[real]$$

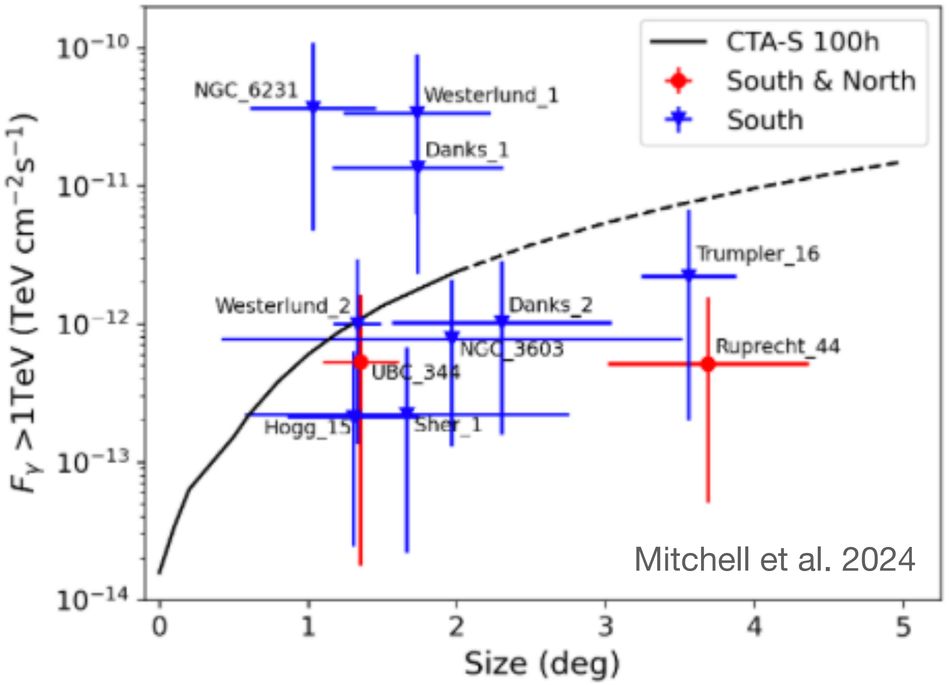
From isotopic ratio:

$$\epsilon_{winds} X_{winds} + (1 - \epsilon_{winds}) X_{ISM} = X_{CR} \rightarrow \epsilon_{winds} \simeq 16\,\%$$

Star clusters

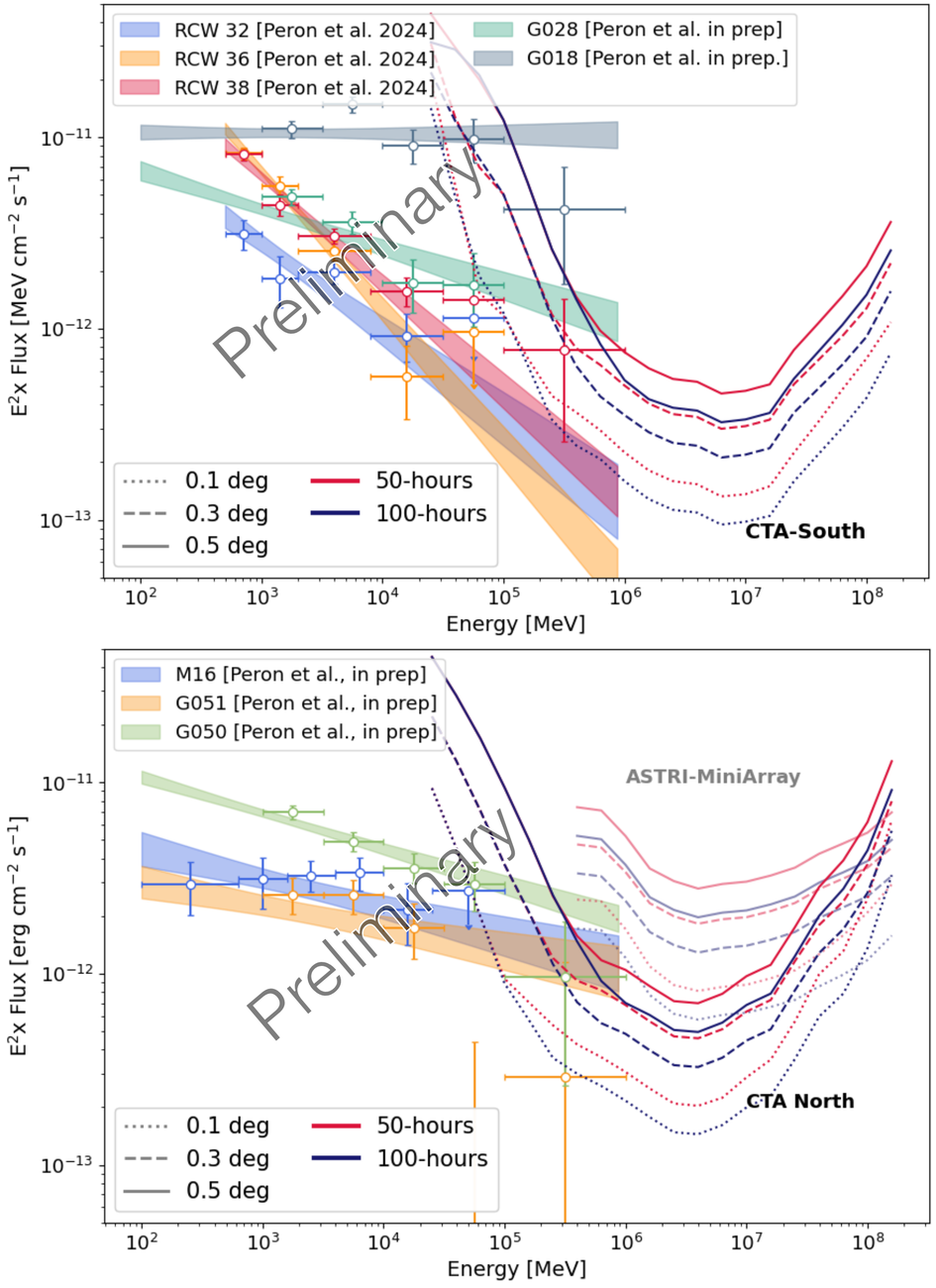
Prospect for future observations

Visibility of suberbubbles challenged by their extension



Sensitivity curves from Celli & Peron, A&A (in press.) 2024

HII regions are much more compact



Conclusions

✳ We detected **GeV gamma-ray** emission in correspondence of a few **embedded star clusters**;

✳ We showed that the coincidence is **statistically significant** and is interpreted as a consequence of the enhanced target around these regions and their compactness; Conversely, no significant emission with Gaia SCs.

✳ Embedded clusters are **young** therefore they are not influenced by SN explosions;

✳ The derived efficiency suggests that a small **part of galactic cosmic rays is contributed by stellar winds**, consistently with the estimate based on composition;

✳ The real **efficiency is larger** as it should account also for escaped particles;

✳ More observations will come to help constraining these values and to shed light on the TeV energy band.