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UNIVERSITÀ DEGLI STUDI DI TRENTO

Young Massive Star Clusters as Galactic PeVatrons

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The SNR model and the YMSC model

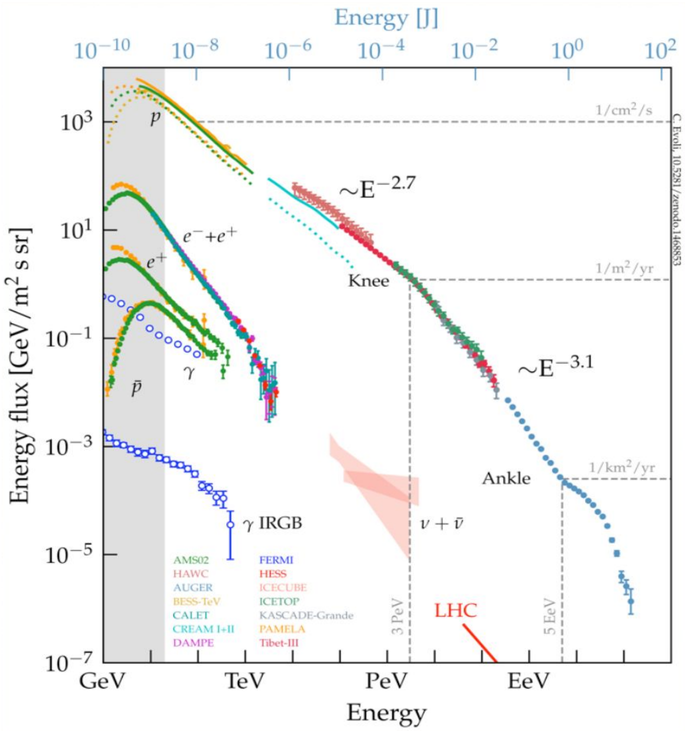
CONTRIBUTION OF SUPERNOVA REMNANT

- Enough power to sustain the CR flux (*10%* efficiency).
- Non-thermal emission.
- Compatible SNR-CR distributions.

CONTRIBUTION OF YOUNG STELLAR CLUSTERS

- Only rare, young SNR can reach high enough energies.
- Sources of accelerated photons above ~*100 TeV*.

Young Massive Stellar Clusters (YMSC) are a key component in the CR spectrum interpretation.



A YMSC Model

- $r < R_c$ **:** Cluster.
- $r < R_{ts}$ **:** Collective wind region ($v = v_w$).
- $r = R_{ts}$ **:** Supersonic wind - ISM impact.
- $r < R_b$ **:** Cavity excavated by the forward shock.

Hillas criterium:

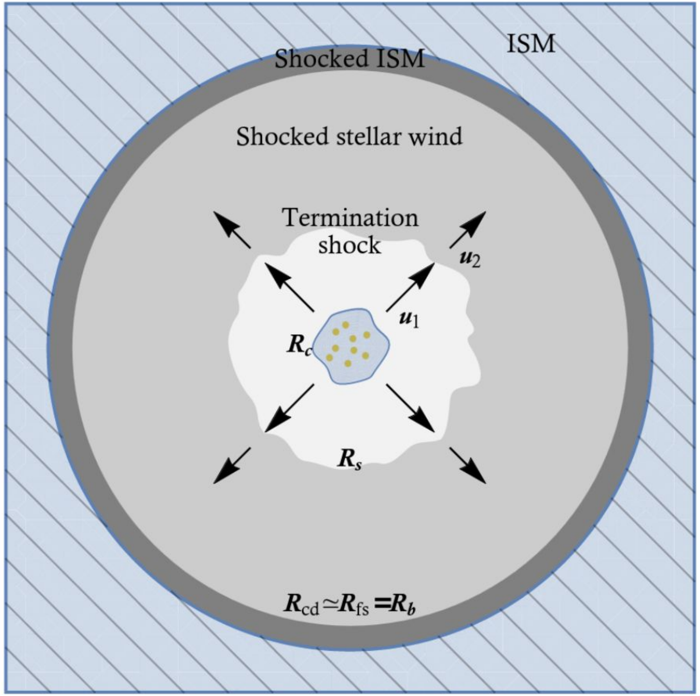
$$E_{max} \sim B\, u\, R_s\, q/c$$

SNR

- B ~100 μG
- R_S < 1 pc
- u > 5000 km/h
- E_{max} ~ 100 TeV

MSC

- B > 10 μG
- R_S ~ 10 pc
- u ~ 3000 km/h
- E_{max} ~ 1 PeV

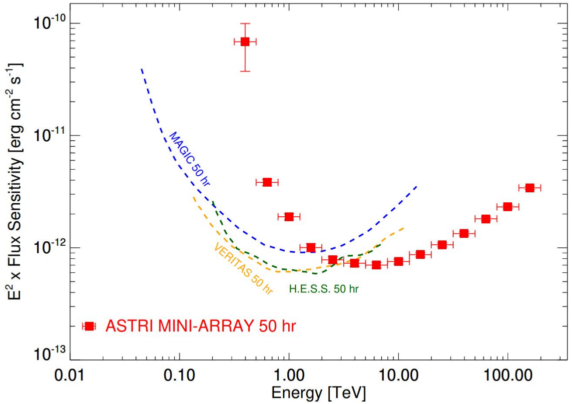


[G. Morlino et al., 2021]

YMSCs with CTAO and ASTRI

CTAO (*Cherenkov Telescope Array*) will have 37 telescopes in the south site, observing in the **5-300 TeV** range.

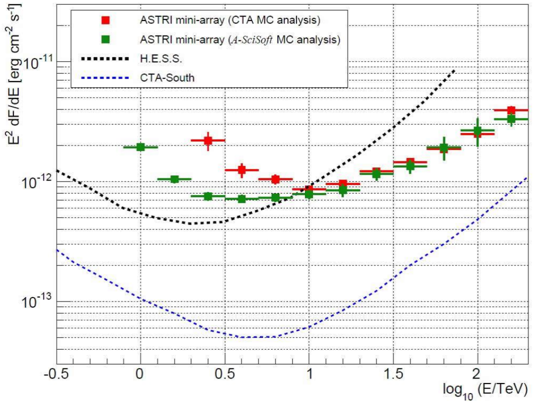
ASTRI-Mini Array (*Astrofisica con Specchi a Tecnologia Replicante Italiana*) will consist in 9 ground-based SSTs and will complement CTAO North.



Vast discovery space in extreme gamma-rays, **up to 100 TeV** and beyond.

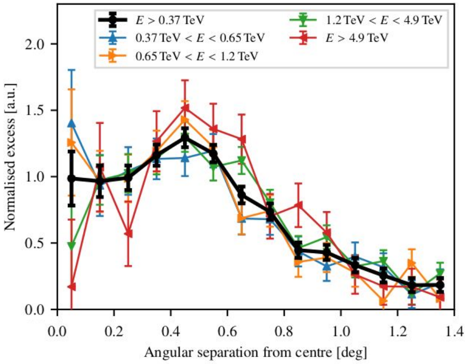
- Wide FoV.
- *2-3'* angular resolution.

Resolution and FoV useful to study YMSCs and their morphology (e.g. Cygnus OB2).



Analysis Methods and Simulations

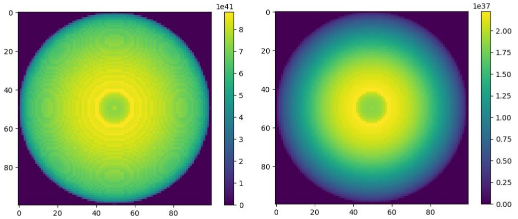
Gamma-ray emission can be used to study the **morphology** of YMSCs (*Cyg OB2* and *Wd 1*). Following what was observed e.g. in the case of *Westerlund 1* (Aharonian et al., 2022):

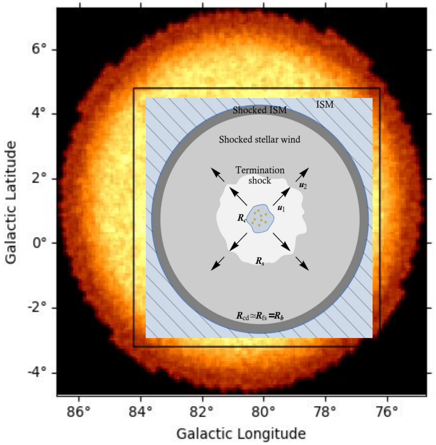


- we compute the **cosmic ray** (CR) distribution and the secondary **gamma-ray** emission around YMSCs across a 3d simulated region with model by Morlino et al. (2021).

- we produce gamma-ray emission **simulations** from hadronic models (Morlino et al., 2021) with the IRF.

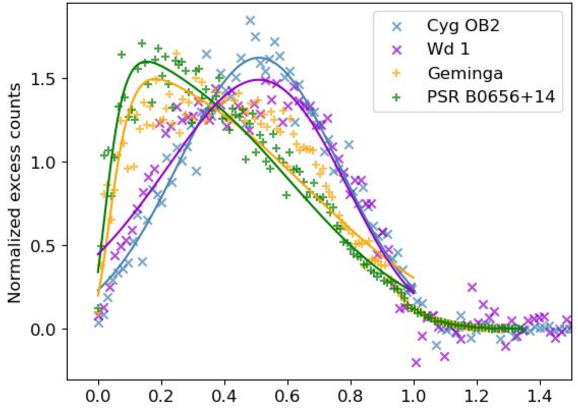
- we are performing morphology studies and radial **excess profile** modellization.

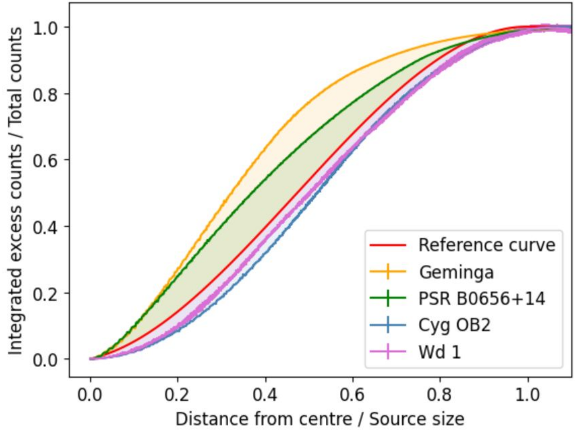




On the right: Computed proton number at 1 TeV and 100 TeV in the case of Cygnus OB2 (*top*) and spherical symmetry. Observation simulation with the ASTRI IRF (*bottom*) compared with the size of the Cygnus OB2 system according to the Morlino et al. model.

Simulations (Spherical Symmetry)





We looked for methodologies to study **the surface brightness variations** and identify **unknown TeV extended sources** (YMSCs and TeV halos).

- Through the **excess counts** modelization and fit:
  - high/low peak **anisotropy**.
  - central/distanced position of the emission **peak**.

- With the **incremental excess counts**:
  - Distance from a reference function (**area**) to evaluate how clearly YMSCs and TeV halos can be distinguished.
  - With **spherical symmetry** the reference curve is near.

On the left: Simulated normalized radial excess profiles (above) and incremental excess profiles (below) of two YMSCs and two TeV Halos (ASTRI) in the case of spherical symmetry.

MCs Modeling

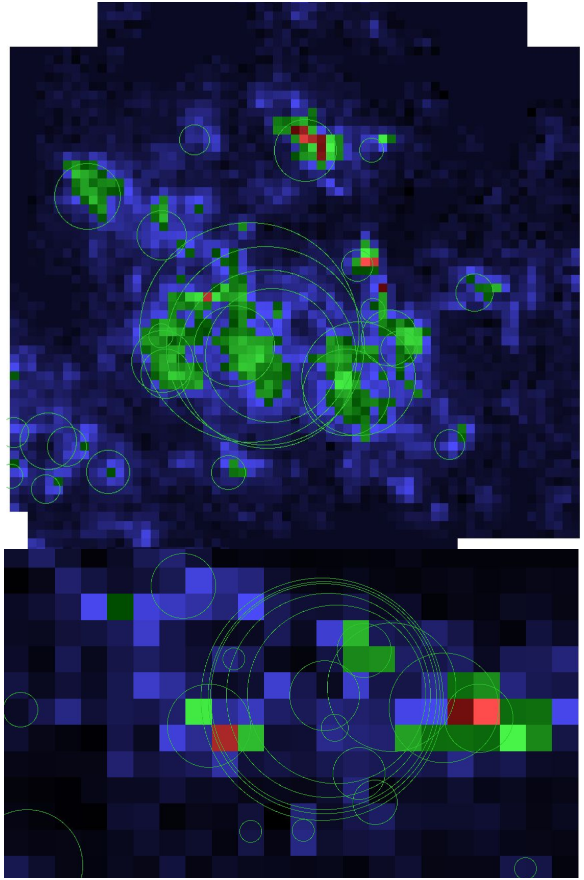
We used 3d maps from CO surveys to compute the **density and position** of MCs.

We used dendrogram techniques (Rosolowsky et al., 2008) to topologically represent the topology of Nd data.

It finds the local maxima and the isosurfaces of constant intensity in the map.

We generated the **dendrograms** of the CO maps of CygOB2 and Wd1 from Dame et al. (2001) and we found:

- 29 structures in the CygOB2 region.
- 23 structures in the Wd1 region.



On the right: CO maps and contours of MCs (modelled as spheres) obtained with *astrodendro*. The dendrograms of the structure of the MCs are also shown for CygOB2 (*top*) and Wd1 (*bottom*).

MCs in the CygOB2 Region

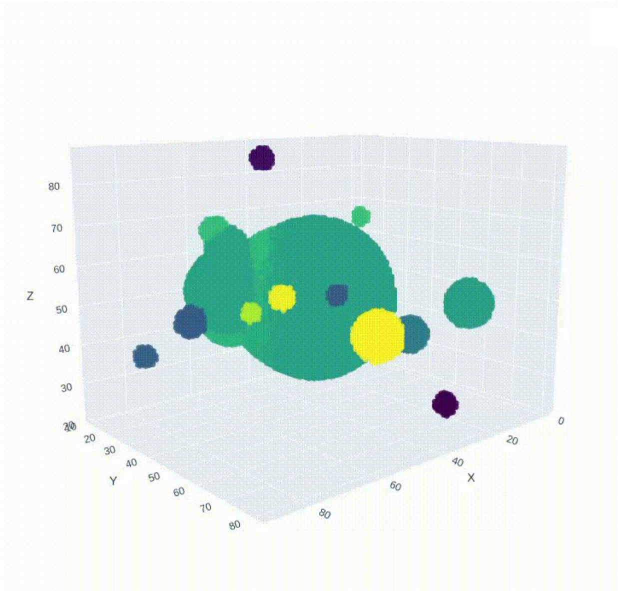
We used CO survey maps (H.O. Keung & P. Thaddeus, 1991) in the case of CygOB2.

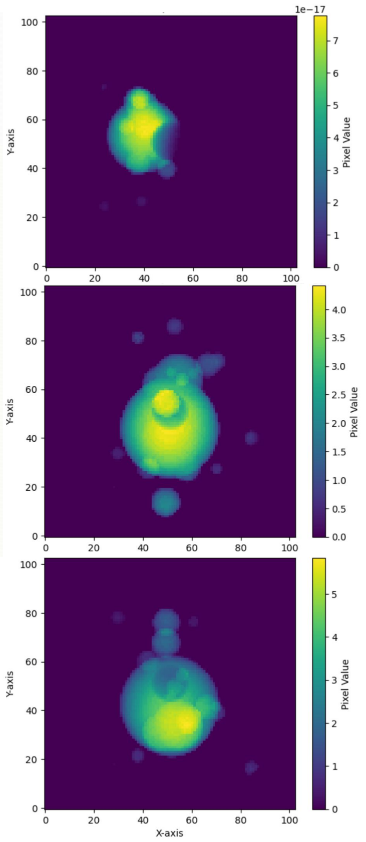
We modelled the MCs as **spheres** with a mass contained in each 3d pixel computed as:

$$M_{H_2} = \alpha_{CO-H_2} \cdot L_{CO} = \alpha_{CO-H_2} \cdot T_{pixel} V_{pixel}$$

where $\alpha = 4.35\, M_\odot\, pc^{-2} (km\, s^{-1})^{-1}$.

We generated 3d **temperature** and hydrogen **density** maps to realistically evaluate the gamma-ray emission.





On the right: 3d density map of clouds around Cygnus OB2 and the 2d pixel maps of the computed gamma-ray emission.

MCs in the Wd1 Region

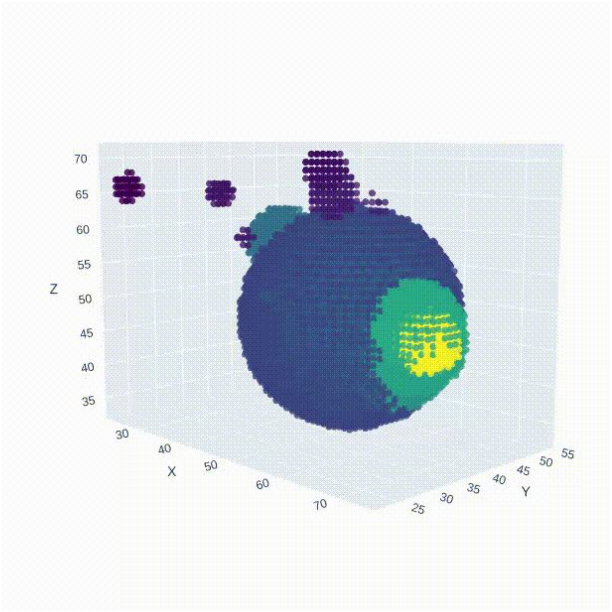
We used CO survey maps (L. Bronfmanet et al., 1989) in the case of Wd1.

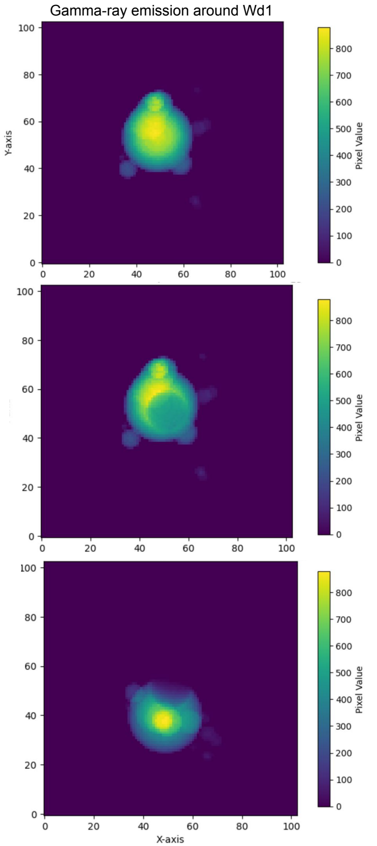
We modelled the MCs as **spheres** with a mass contained in each 3d pixel computed as:

$$M_{H_2} = \alpha_{CO-H_2} \cdot L_{CO} = \alpha_{CO-H_2} \cdot T_{pixel} V_{pixel}$$

where $\alpha = 4.35\, M_\odot\, pc^{-2} (km\, s^{-1})^{-1}$.

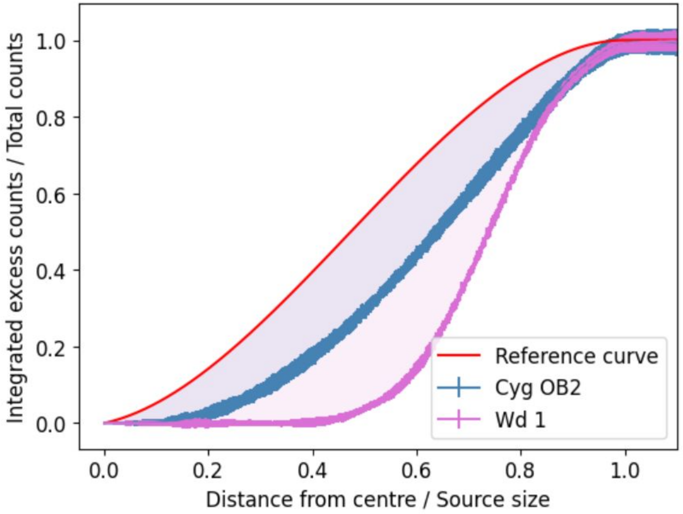
We generated 3d **temperature** and hydrogen **density** maps to realistically evaluate the gamma-ray emission.





On the right: 3d density map of clouds around Westerlund 1 and the 2d pixel maps of the computed gamma-ray emission.

Simulations (MCs)



On the left: Simulated incremental excess profiles of the two YMSCs (ASTRI) without spherical symmetry.

We look for **differences and similarities** between the spherically symmetrical case and the MC model:

- The curves occupy the same **plane region** (correct reference curve).
- The peak **anisotropies** are small and positive.

- Even larger **peak** values.
- Normalized **areas** are larger (clearer source identification).

The emission intensity strongly depends on the **positions** of the clouds.

Final Remarks

- Young massive stellar clusters can be a valid explanation for the CRs at the knee of the spectrum.
- **Features** of radial profiles (peak position, anisotropy, incremental counts area) of gamma-ray radiation are a useful and fast way to **identify and characterise** young massive star clusters.
- Spherical symmetry in the model is not realistic and identification of sources can be **uncertain**, so different and better model characterization for the fit..

- The **dendrogram technique** identifies and parametrizes well complex structures to produce a 3d model of molecular clouds in the region of interest.
- Observation simulations that account for molecular clouds and their position further allow **better identification** of sources.
- Cygnus OB2 as a prototype for other stellar clusters, **others to come (South)!**