UNIVERSITÀ DI TRENTO

IUSS Scuola Universitaria Superiore Pavia

PhD SST Space Science and Technology

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Young and Massive Star Clusters as Galactic PeVatrons

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PeVatrons Introduction

PeVatrons are CR factories accelerating protons and electrons to PeV energies.

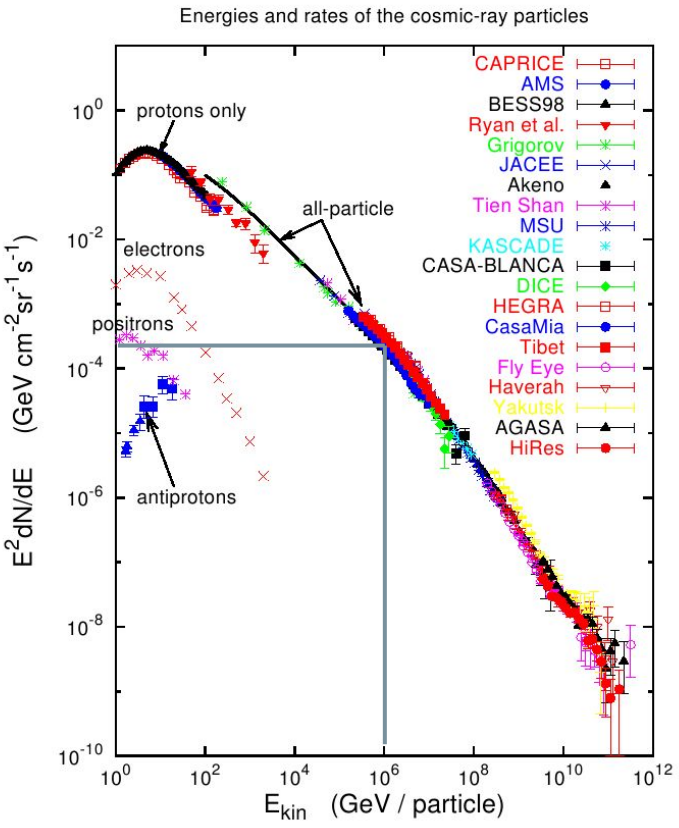
The **SNR Paradigm** explains CRs below the knee:

- Enough power for the CR flux
- Compatible SNR-CR distributions.

SNRs struggle to reach PeV energies.

LHAASO identified other classes of PeVatron candidates:

- PWNe
- YMSCs (CygOB2)



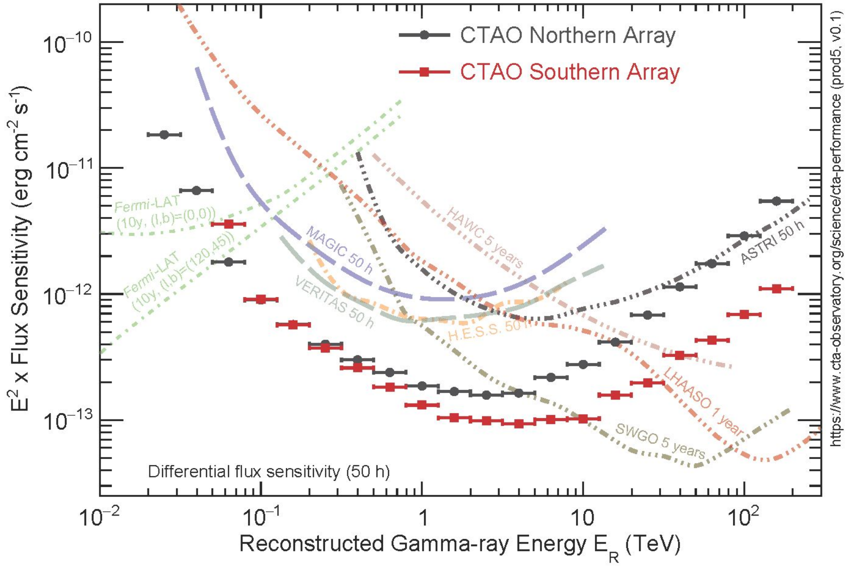
Next-Generation IACT Telescopes - I

CTAO (*Cherenkov Telescope Array Observatory*) will consist of two arrays of telescopes with (*alpha configuration*):

- LSTs and MSTs in the northern site (20 GeV - 5 TeV).
- MSTs and SSTs in the southern site (150 GeV - 300 TeV).

It will have **more than 60 telescopes** located across the two hemispheres.

- ~ *5 − 10%* energy resolutions.
- ~ *few arcmin* angular resolution.



Next-Generation IACT Telescopes - II

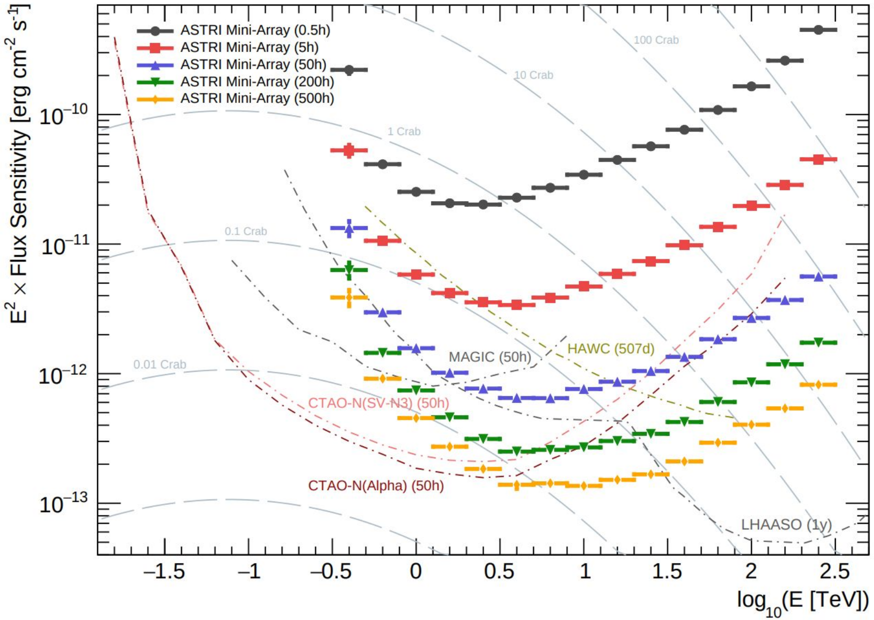
The <u>ASTRI Mini-Array</u> (*Astrofisica con Specchi a Tecnologia Replicante Italiana*):

- 9 SSTs in the northern hemisphere (Teide Observatory - Tenerife).

Vast discovery space in the extreme gamma-rays, **up to 100s of TeV**.

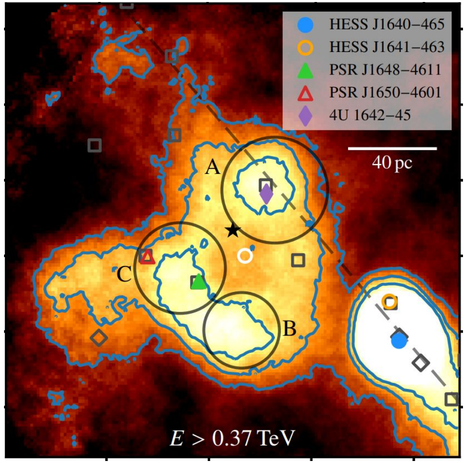
- *3.5x* H.E.S.S. spectral resolution.
- Wide FoV.
- *3'* angular resolution.

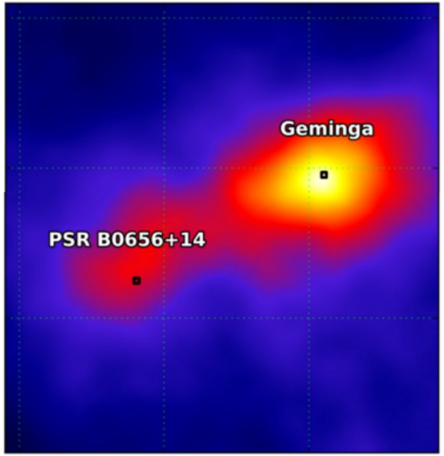
Its **resolution and FoV** make it particularly useful to study YMSCs and their morphology.



The Sample of YMSCs and TeV Halos

We study the morphology of known diffuse sources
to define classification methodologies of unidentified sources.





We simulated **5 YMSCs:**

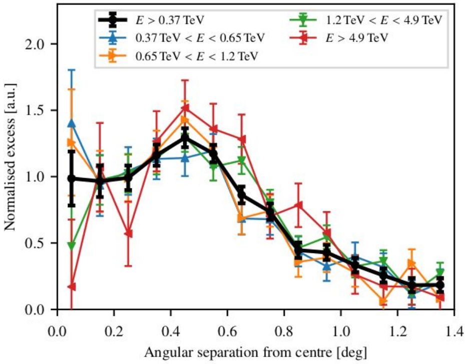
- 2 in the **northern** sky (CygOB2, Mk50).
- 3 in the **southern** sky (Wd1, Dk1-2).

We simulated **2 TeV Halos:**

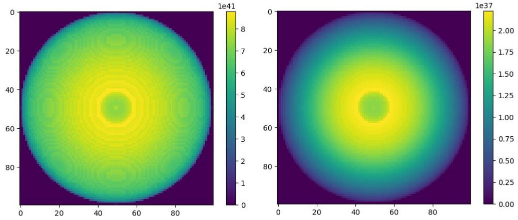
- Geminga and Monogem (PSR J0659+1414).

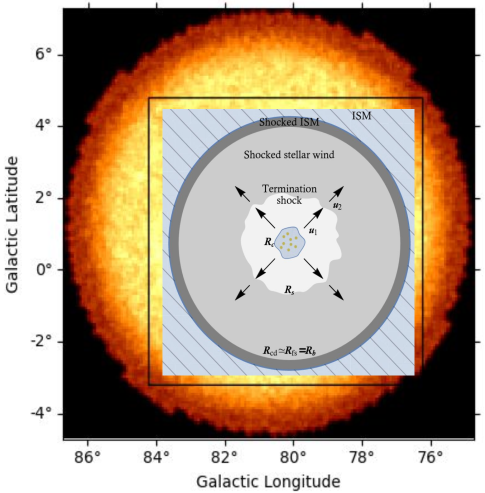
Analysis Methods and Simulations

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



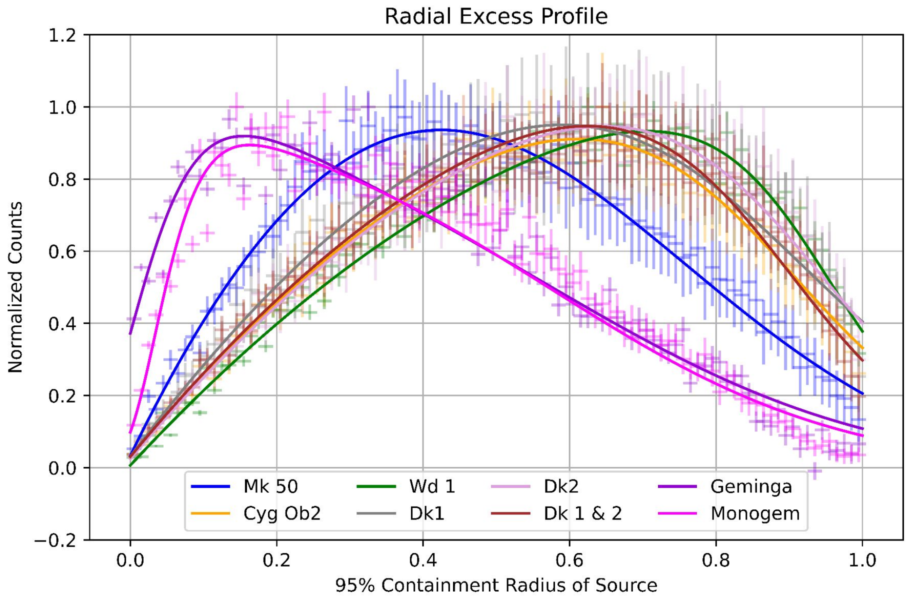
- **CR** distribution and **gamma-ray** emission around YMSCs with model by Morlino et al. (2021).
- Gamma-ray emission **simulations** with the ASTRI Mini-Array and CTAO IRFs.
- Morphology studies and radial **excess profile** modellization.





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 Mini-Array IRF (*bottom*) compared with the size of the Cygnus OB2 system according to the Morlino et al. model.

Radial Profile Models - I



Modified Gaussian Function

$$f(x; N, x_0, a, w) = N\, e^{-\left[\left(1+e^{a(x-x_0)}\right)\frac{x-x_0}{w}\right]^2}$$

Polynomial-Asymmetric Function

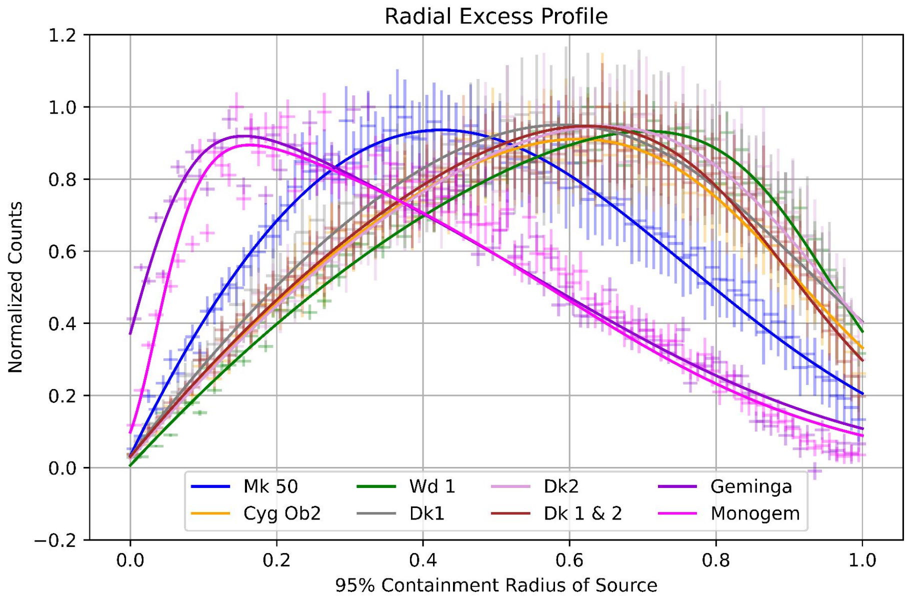
$$f(x; N, x_0, s, w) = N \underbrace{\left(1 - \left(\frac{x - x_0}{w}\right)^2\right)}_{\text{Parabola}} \underbrace{\frac{1}{1 + e^{\frac{x-x_0}{s}}}}_{\text{Sigmoid}}$$

Parabola *Sigmoid*

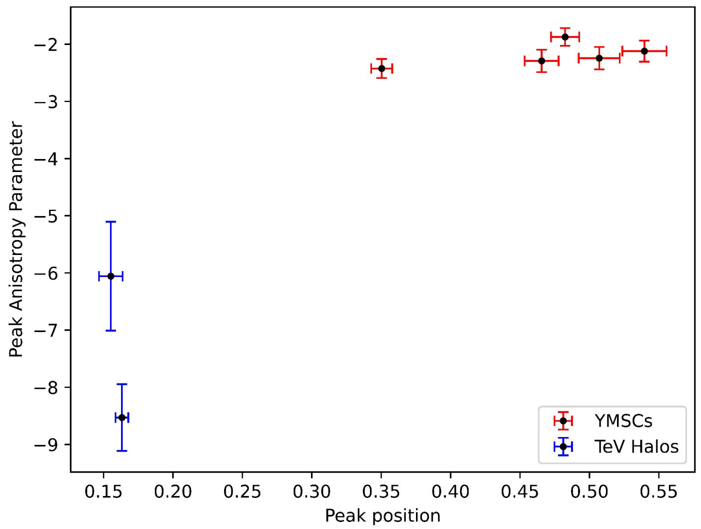
The parameters are:

- Curve height *N*.
- **Peak position x_0.**
- **Curve symmetry *s or a*.**
- Curve width *w*.

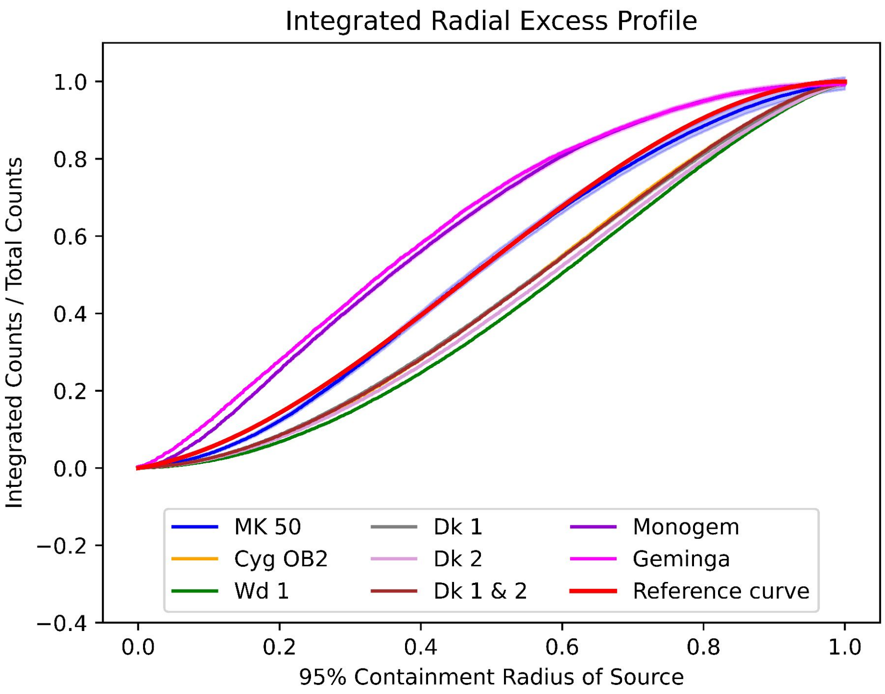
Radial Profile Models - II



Polynomial-Asymmetric Function Fit



Radial Incremental Profiles



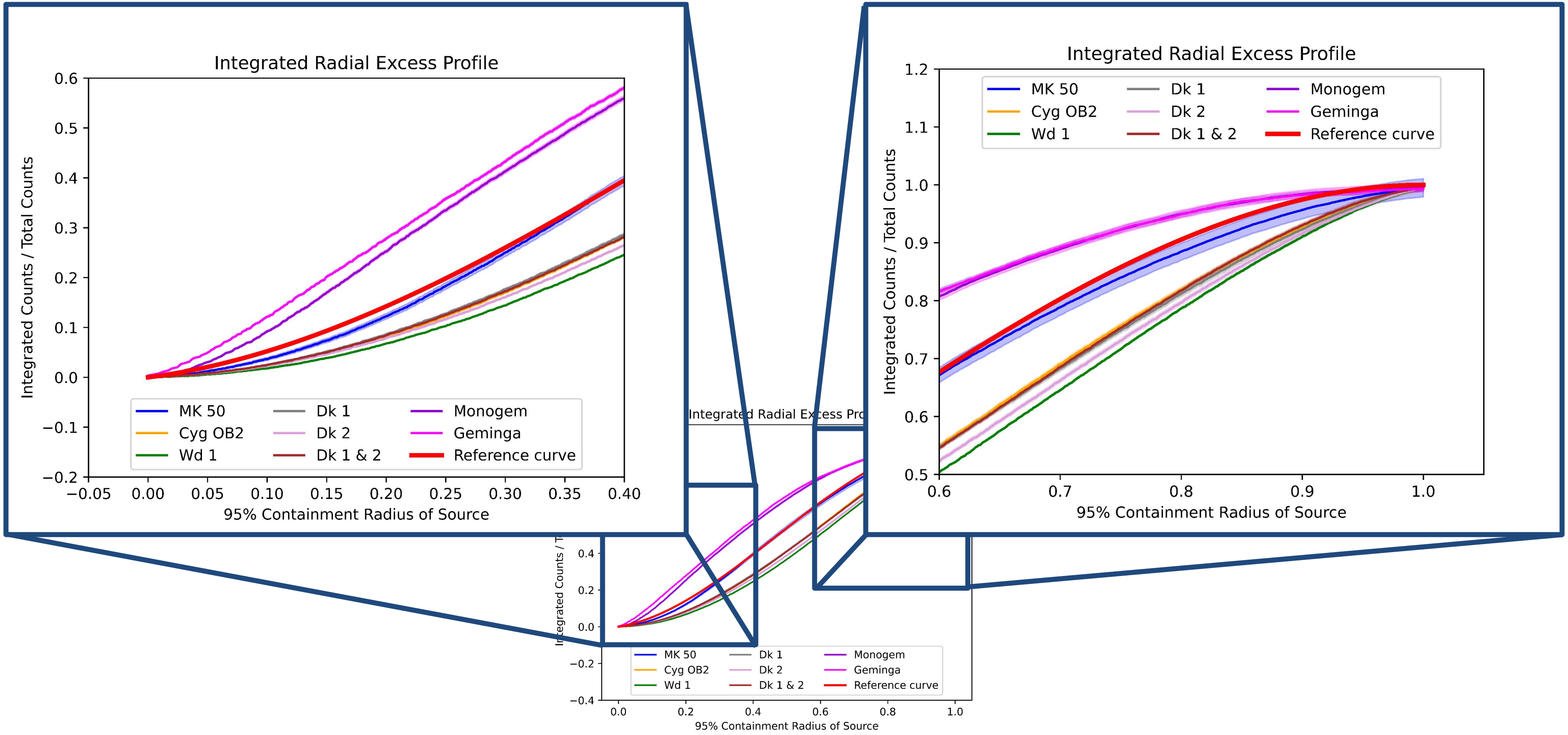
With the **incremental excess counts** we find:

- The plane is divided in two regions.
- Distance from a reference function (**area**) to evaluate the YMSCs - TeV halos classification.

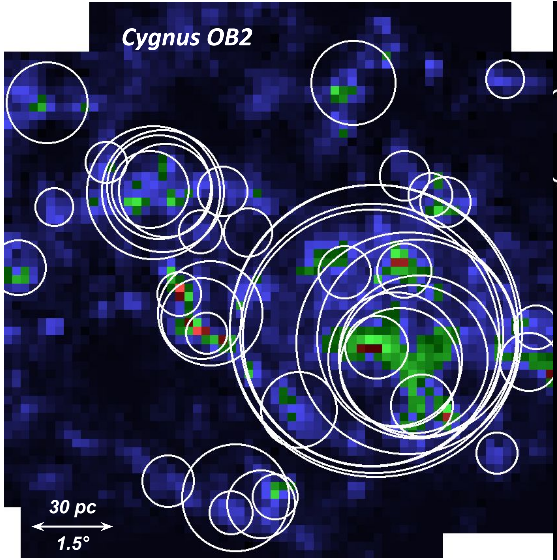
Object	Area
Mk 50	0.011
Dk 1	0.080
Dk 2	0.094
Dk 1 & 2	0.080

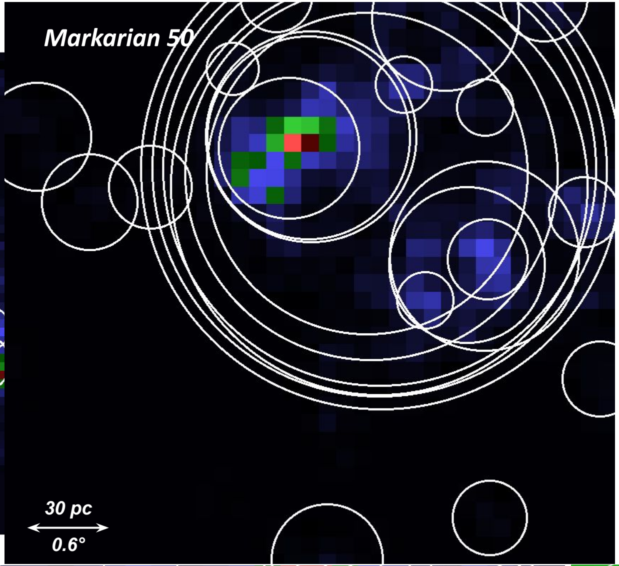
Object	Area
Cyg OB2	0.080
Wd 1	0.107
Geminga	-0.103
Monogem	-0.090

Radial Incremental Profiles



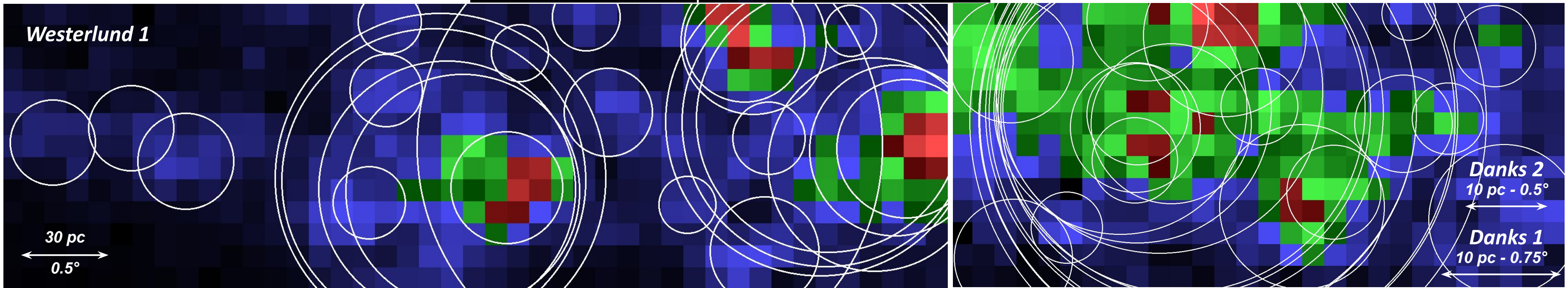
Gas Modelization - I



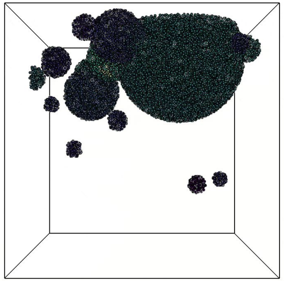


We used 3d maps from Dame et al. (2001) to compute the **density and position** of molecular clouds.

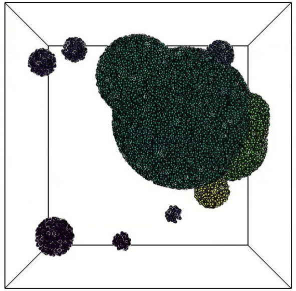
We modelled the molecular clouds as **spheres of homogeneous density**.



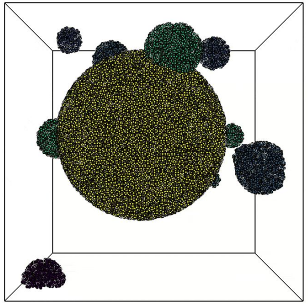
Gas Modelization - II



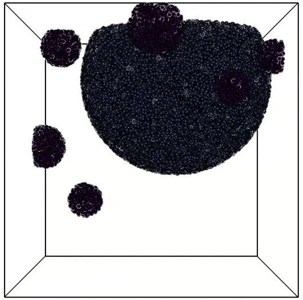
Cygnus OB2



Westerlund 1



Danks 1 & 2



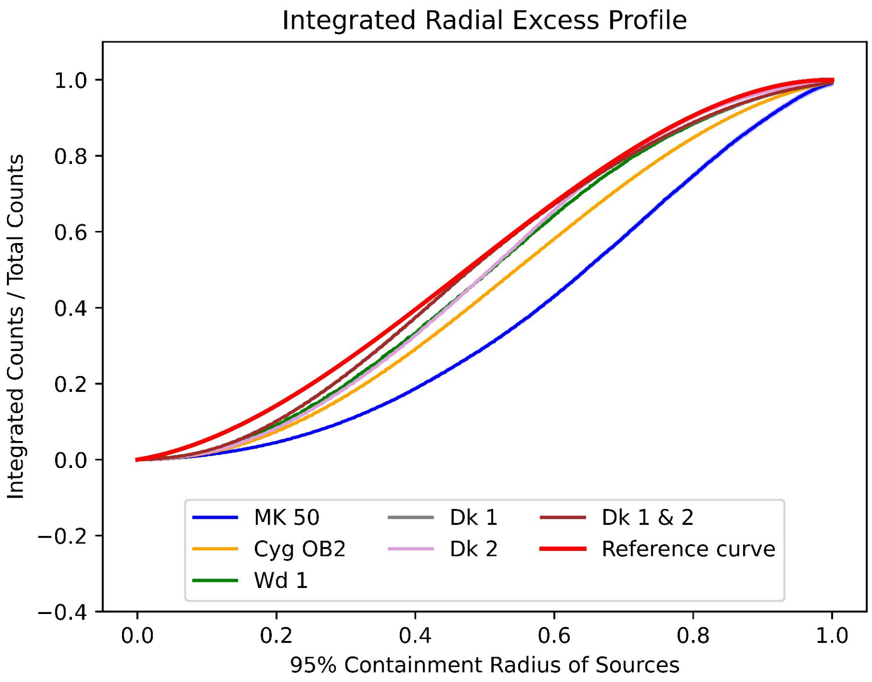
Markarian 50

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

We created 3d **temperature** and hydrogen **density** maps.

We used the 3d maps to generate new source models for the YMSC simulations.

Radial Incremental Profiles



We compare the case with the molecular clouds model with the spherically symmetrical case:

- The sources show the same **behaviour** of the reference curve (correct function).
- The sources occupy the same **plane region** (correct source identification).

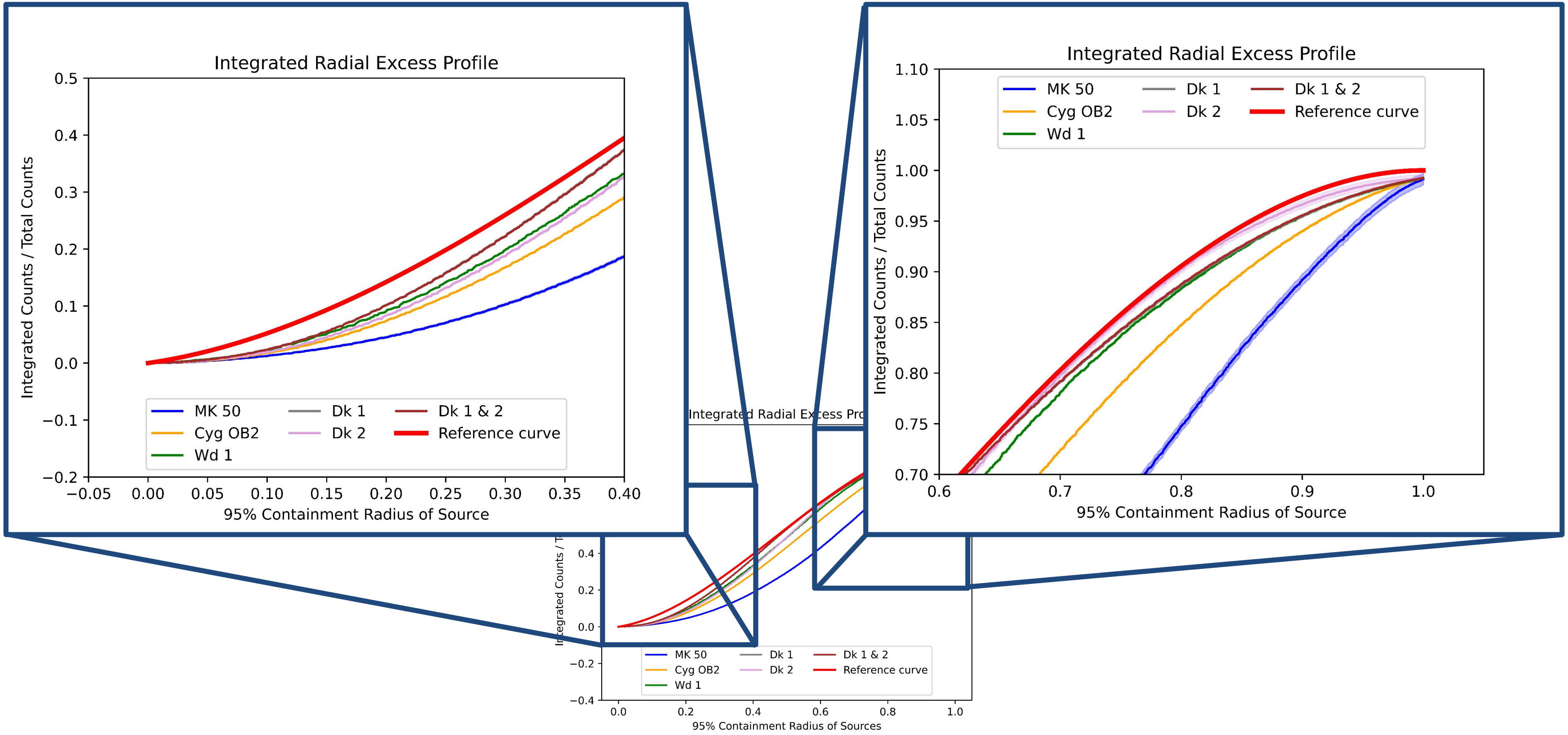
The emission intensity strongly depends on the *<u>positions of the clouds.</u>*

Object	Area
Cyg OB2	0.072
Wd 1	0.041

Object	Area
Dk 1	0.025
Dk 2	0.044

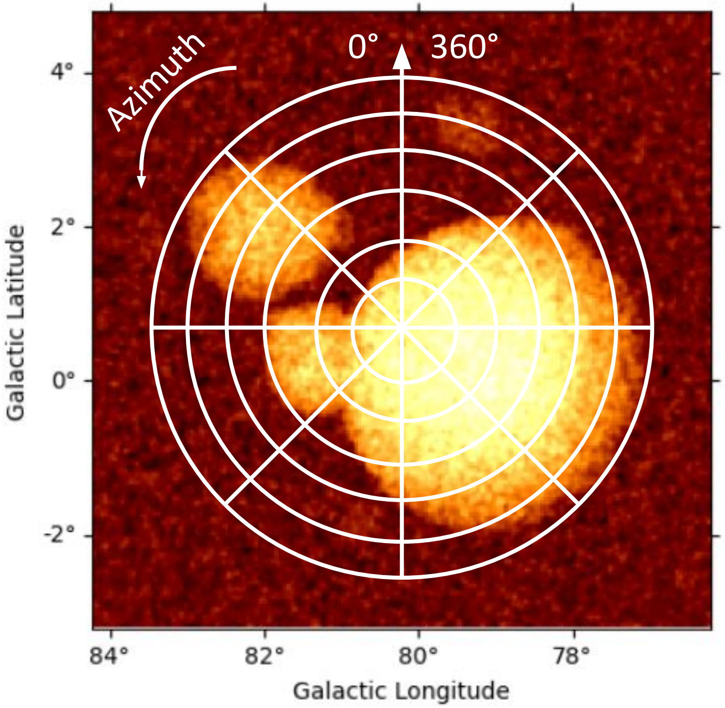
Object	Area
Dk 1 & 2	0.025
Mk 50	0.148

Radial Incremental Profiles

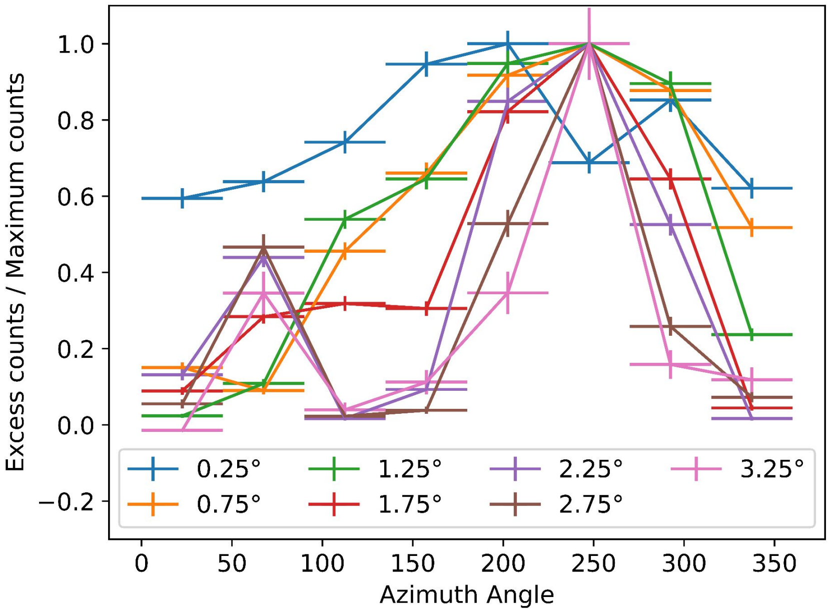


Azimuth Profiles I

The Azimuth profiles show the areas of intense gamma-ray emission and the distribution of the gas around each YMSC.



We measure how the emission changes with the **azimuth** in shells at **radial angle** from the centre.

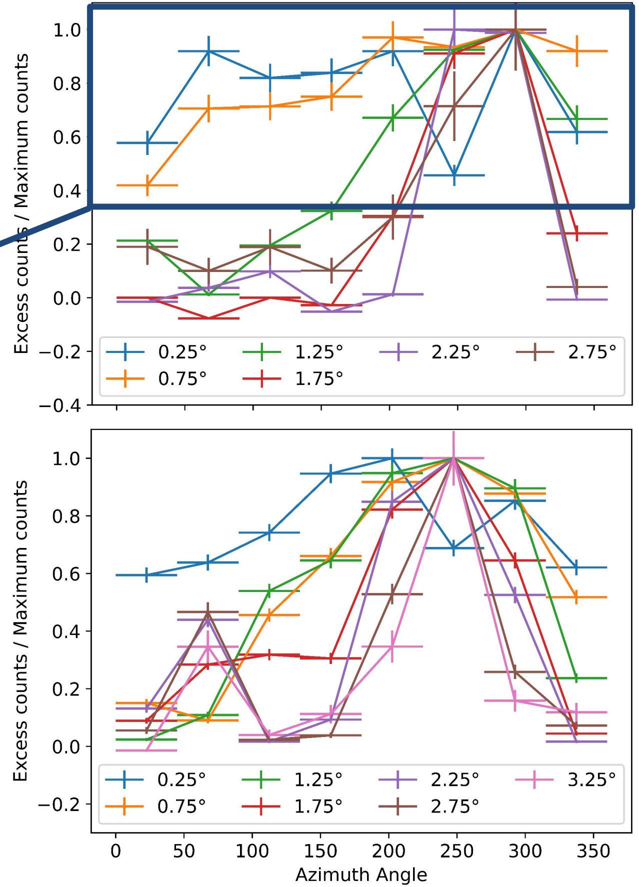


Azimuth Profiles II

The curves can be very different for different radial angles.

- Curves are **constant** when the shell is within one of the gas clouds.
- Curves with many peaks are given by **clumpy gas** distribution.

CTAO and ASTRI Mini-Array observation can be used to reconstruct the gas distribution in large regions.



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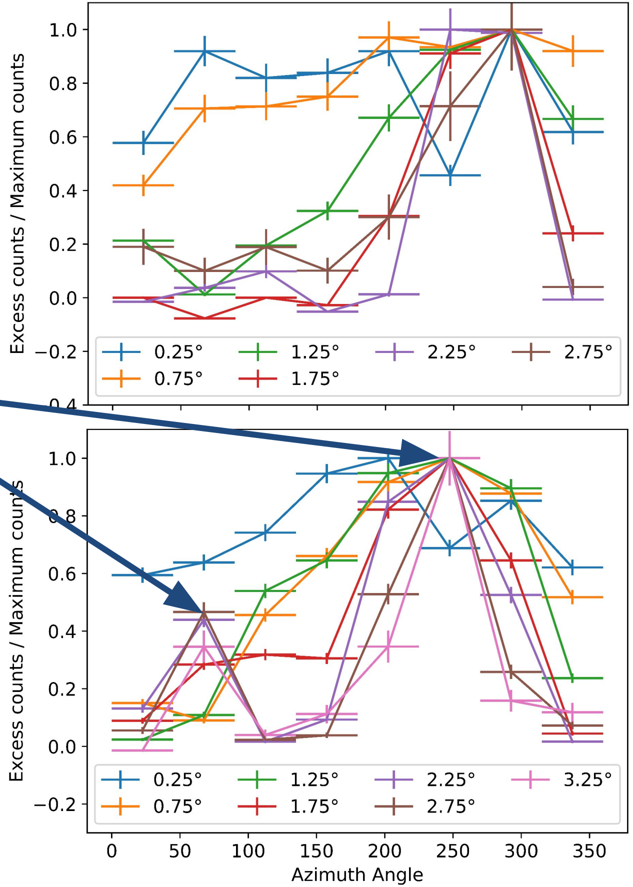

Final Remarks

- More advanced morphology studies with **next-generation SSTs**.

- Radial emission profile fits can characterize the morphology.
- YMSC models predict peculiar morphological features that can help **source classification** (YMSCs - TeV halos).

- More realistic simulations of YMSC systems require **gas distribution modelizations**.
- Incremental radial profiles are still valid features to **classify** sources.
- **Azimuth radiation profiles** further characterize the morphology and can help in reconstructing the gas distribution around YMSCs.

Thank you