7th Roma International Conference on AstroParticle Physics

The Large Magellanic Cloud with the Cherenkov Telescope Array

CTA Consortium represented by
María Isabel Bernardos(CIEMAT, Madrid, Spain)

RICAP2018 (Roma, 05 September)

LMC group collaborators: María Benito, Elena Fedorova, Fabio Iocco, Salvatore Mangano, Olga Sergijenko.

Goals for the LMC group:

- ★ What do we want to do?
  - Characterize the **Large Magellanic Cloud** emission of Very High Energy Gamma-Rays.
  - Search for a signal of Dark Matter from the LMC.

- ★ How?
  - Using the **Cherenkov Telescope Array**, the next generation of ground-based gamma-ray observatories.

- ★ What am I going to talk about today?
  - Forecasts of CTA detections of the known gamma-ray sources within the LMC.
  - Constraints on Dark Matter indirect detection from the LMC with CTA.

NEW! The Cherenkov Telescope Array

The Ultimate Very High Energy Gamma-Ray Explorer

The CTA will explore the most energetic Cosmic-Ray accelerators, AGNs, SNR...

... And Many More!

What about **Dark Matter?**
The CTA will explore it too!!!

- *Up to* ***10 TIMES*** more sensitive than competitors.
- ***SUPER WIDE*** energy range — 0.03 to 300 TeV!!!
- ***THE LARGEST*** field of view ever seen!

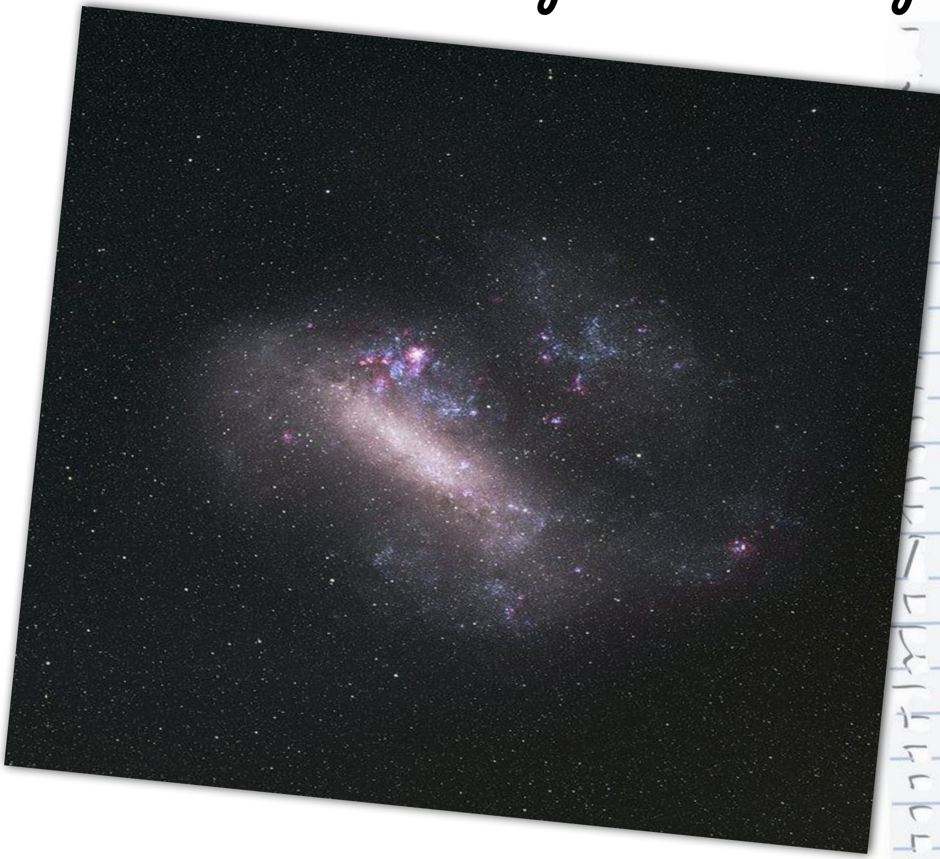
With more than **100** telescopes between **NORTH** and **SOUTH**!

...and they come in **three** sizes!

AS SEEN ON ANY OTHER ASTROPARTICLE CONFERENCE (OR WAIT FOR RENE ONG'S TALK)

"... No Gamma-Ray will escape The CTA!"

The Large Magellanic Cloud
Key Science Project of CTA



Very interesting object due to its remarkably high star formation activity for its small volume, proximity to the Milky Way (so it's very well resolved), presence of many high energy gamma-ray sources...

Magellanic Spiral Galaxy, satellite of the Milky Way..

Distance: 50kpc

Mass: 5.3 ±1.0 · 10^{10} M⊙ (Alves and Nelson, 2000)

Diameter: 4.3 kpc (~10°)

Position(RA,dec): 80.0 , -69.5

Known γ ray sources:

- ★ 30 Dor. C superbubble
- ★ PWN N157B
- ★ SNR N 132D
- ★ ...

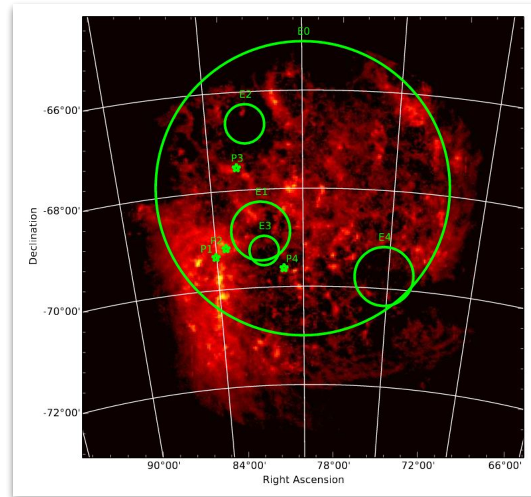
Undetected in Gamma-Rays:

SNR 1987A

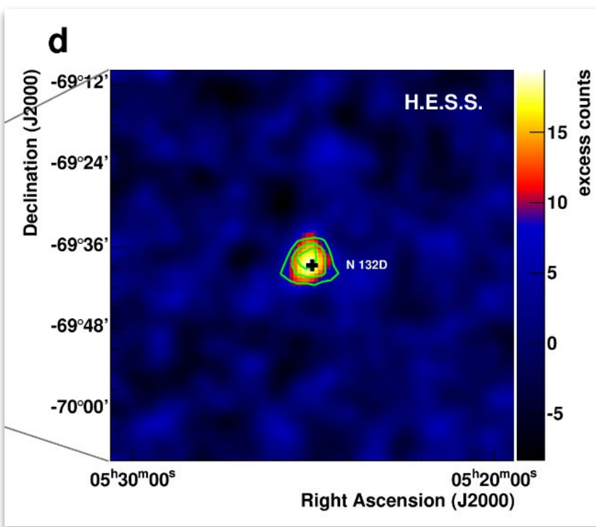
Who's there?
Previous Observations

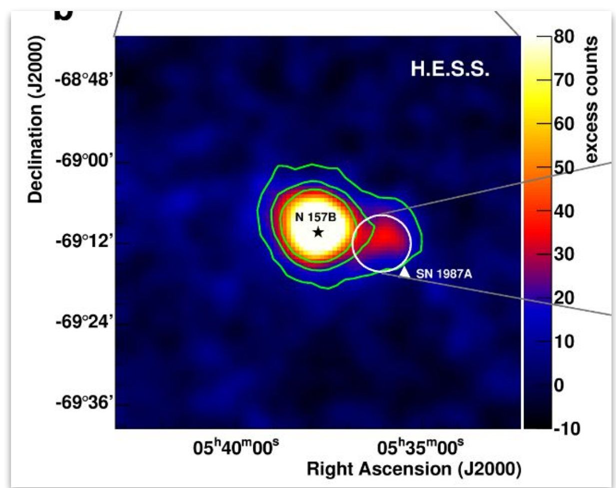
Gamma-Ray sources detected by *Fermi* LAT and H.E.S.S.:

- ★ Supernova Remnant N132D
- ★ Pulsar Wind Nebulae N157B
- ★ 30 Doradus C superbubble
- ★ Gamma-Ray Binary CXOU 053600.0-673507.
- ★ Pulsar PSR J0540−6919
- ★ 4+1 Extended sources detected by Fermi.



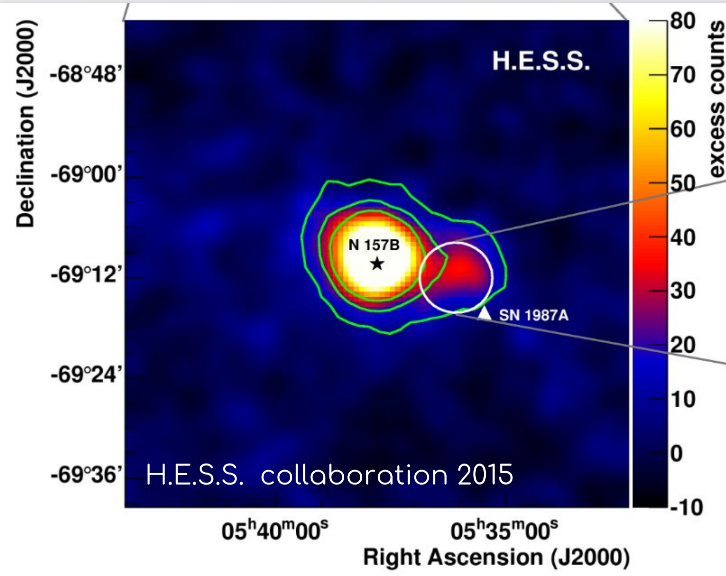
LAT collaboration, Ackermann et al. 2015

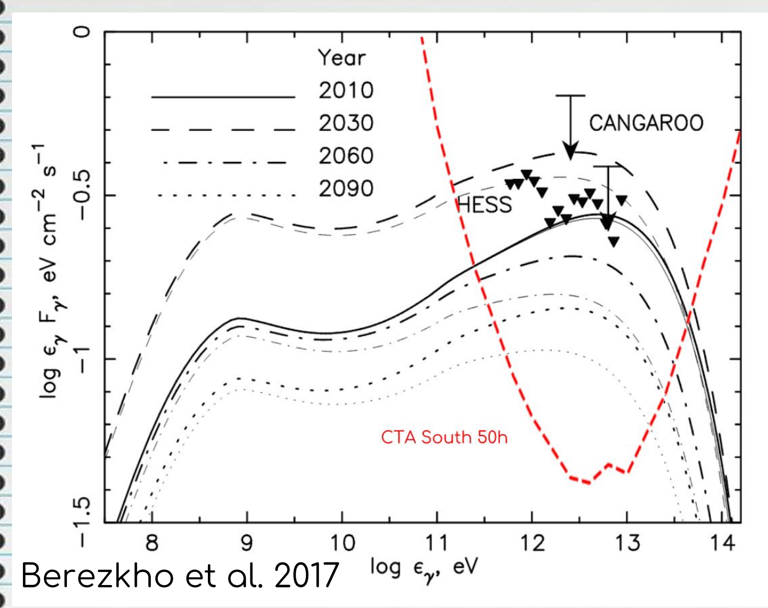




H.E.S.S. collaboration 2015

What about SN1987A?





Recent core collapse SN event visible to the naked eye.

Observed in all wavelengths.

Undetected by H.E.S.S. after ~200h of exposure.

Perfect target for CTA

Work done by the LMC Working Group

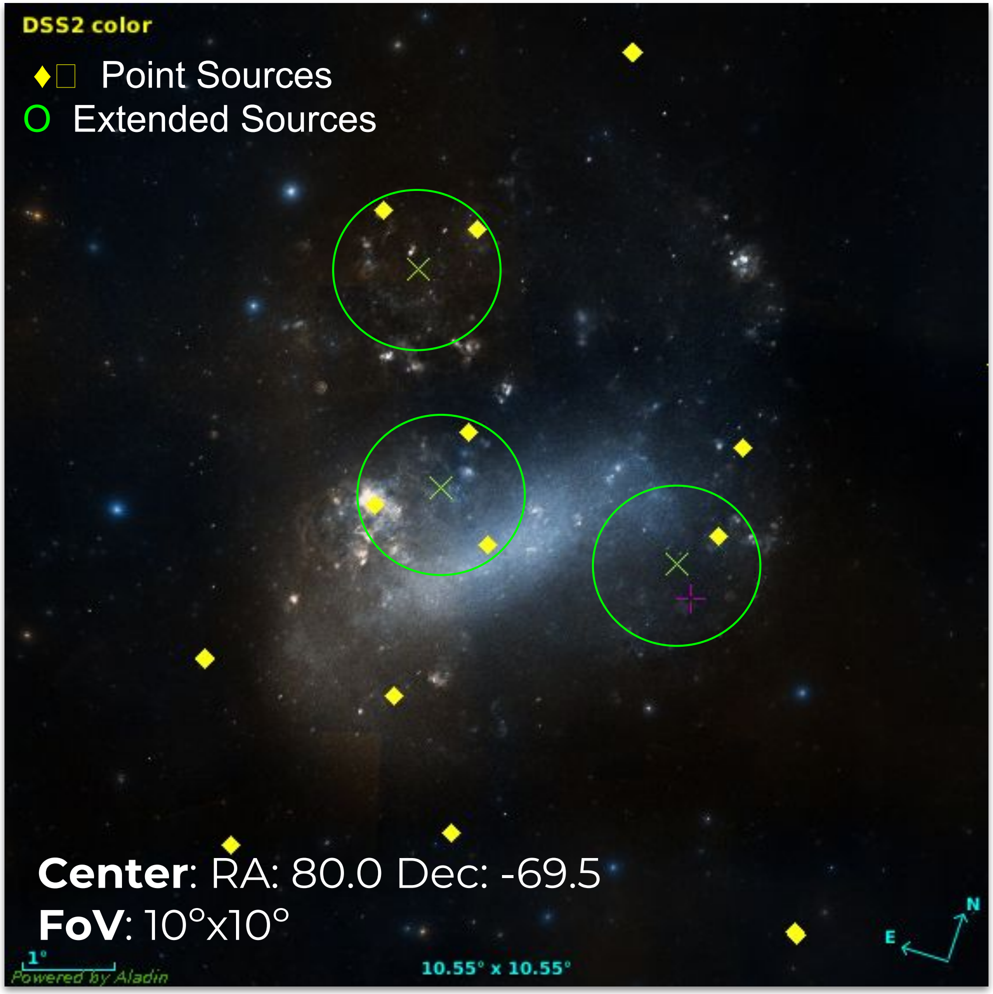
To do List

- ★ Build an emission model:
  - What are the components of LMC?
    - Point Sources
    - Extended Sources
    - Diffuse Emission

- ★ Simulate CTA observations of ROI:
  - LMC model
  - Significance of the sources
  - Correlations

- ★ Dark Matter in the LMC with CTA:
  - DM models
  - Correlations
  - Constraints on DM detection.

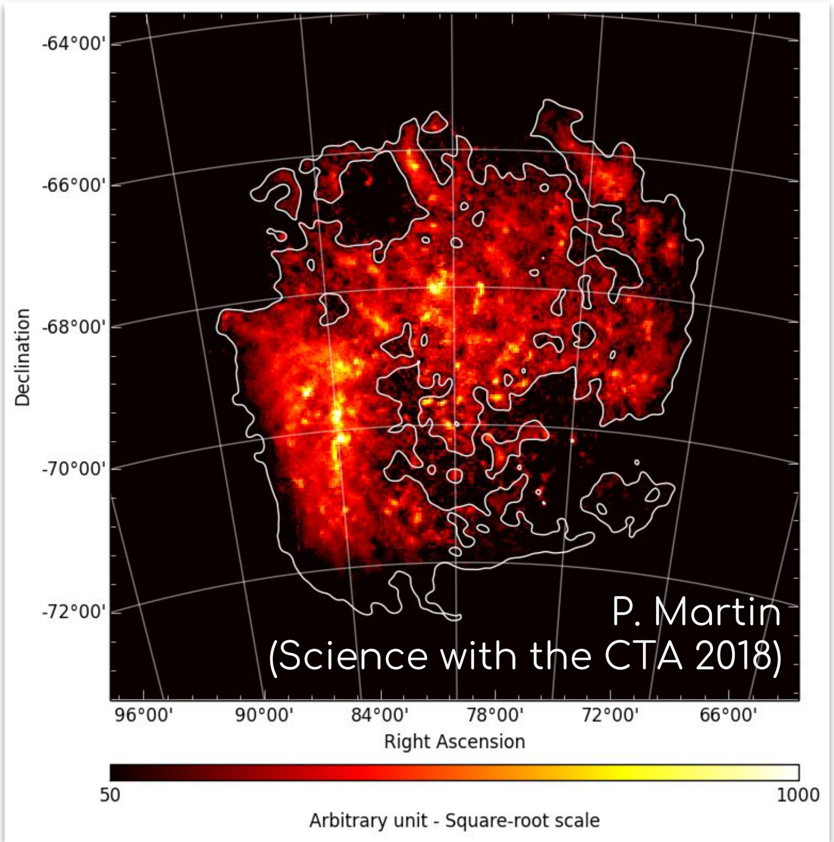
Building the Emission Model of the Region of Interest



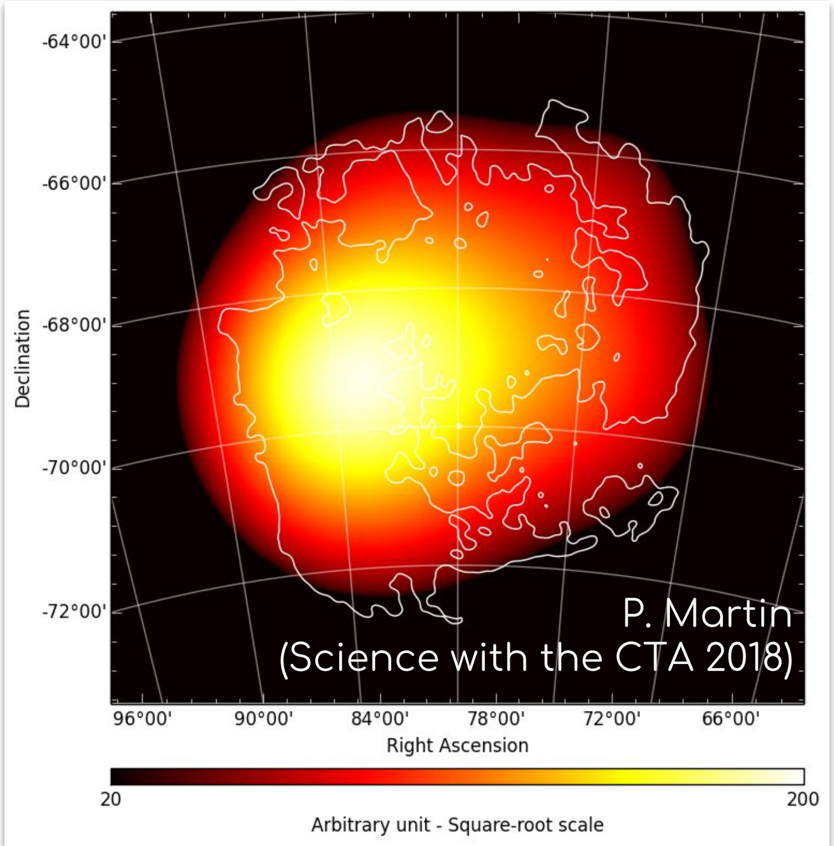
Source Catalogs:

- ★ <u>3FGL(2015)</u>: 3rd Fermi LAT source catalog (3FGL) of sources in the 100MeV–300 GeV range. Based on the first four years of science data from the Fermi Gamma-ray Space Telescope mission.
- ★ <u>3FHL(2017)</u>: 3rd catalog of Hard Fermi-LAT sources characterized in the 10 GeV–2 TeV energy range.
- ★ <u>Ackermann et al.(2015)</u> arXiv:1509.06903 [astro-ph.HE] from Fermi Collaboration.
- ★ <u>H.E.S.S. Collaboration(2015)</u> arXiv:1501.06578 [astro-ph.HE]
- ★ <u>Komin, Haupt (2017)</u> from H.E.S.S. Collaboration.

Diffuse Emission



Hadronic emission from CR protons/nuclei interacting with interstellar gas in the LMC and producing pions.



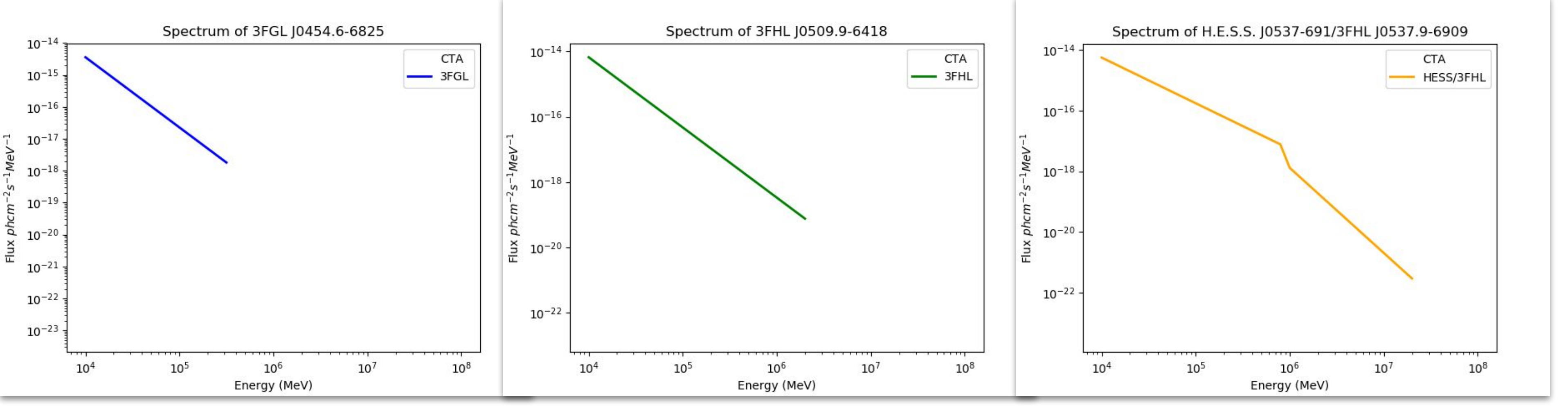
Leptonic emission from CR electrons inverse-Compton scattering off the radiation field.

Modelling the Spectra: Extrapolation of spectra

We don't have real data from CTA, so we take the observations from *Fermi* LAT/H.E.S.S. and extrapolate their results to CTA energies.

From catalogs we obtain spectral shapes (usually a power law) with parameters (spectral index and normalization):

$$M_{\text{spectral}}(E) = k_0 \left(\frac{E}{E_0} \right)^{\gamma}$$



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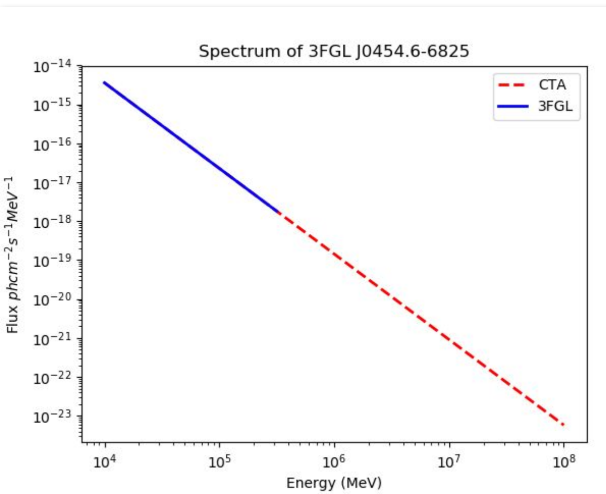
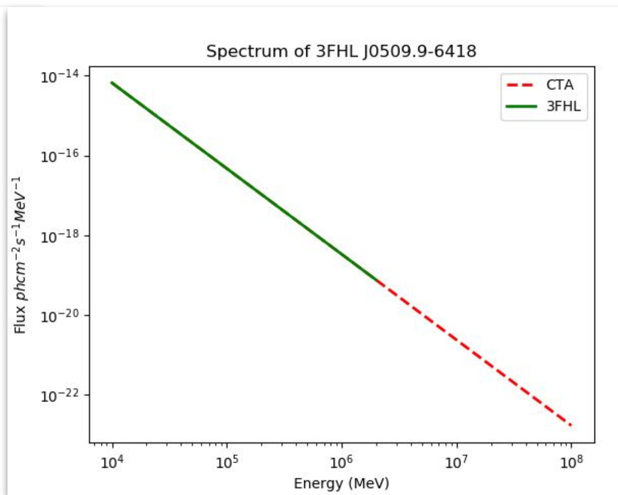
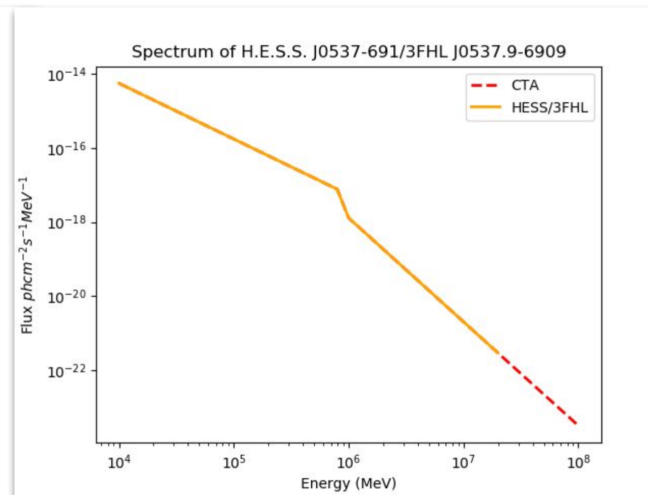






Simulated Observations of the LMC

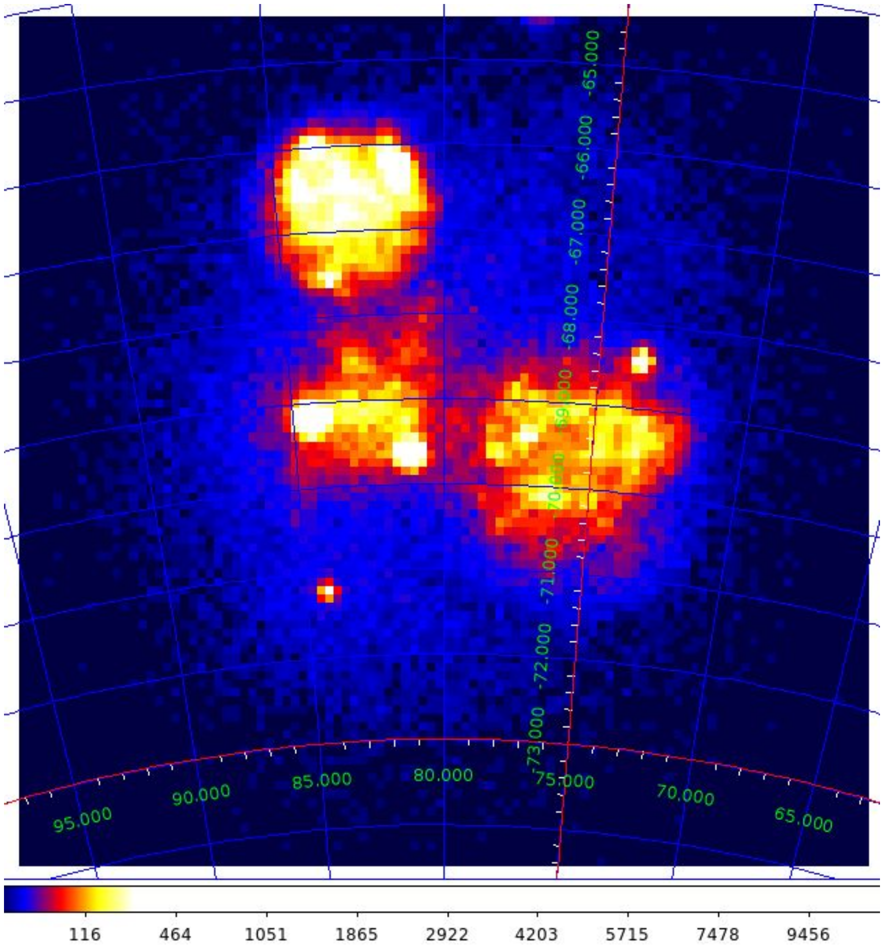
We use software ctools to simulate LMC observations.

<u>Observation settings:</u>

- ★ **Pointing**: 6 Pointings around LMC center.
- ★ **Exposure time**: 50h per pointing, 300h.

<u>Analysis settings:</u>

- ★ 3D binned maximum-likelihood analysis.
- ★ **Energy:** 0.03 TeV to 100 TeV.



Counts number, sqrt scale (CR Background substracted).

Sources Significances and detection at TeV energies

Likelihood Analysis:

$$L = \prod_{i}^{N} \frac{m_i^{n_i}}{n_i!} e^{-m_i}$$

n_i = number of observed counts in the bin i (simulated data)

m_i = number of predicted number of counts in the bin i (model):

$$m_i = K_0 Srcmodel_{0,i} + K_1 Srcmodel_{1,i} + .. + K_N Srcmodel_{N,i}$$

Parameters “K” (Normalization) maximize the likelihood.

Significance:

$$TS = 2log \frac{L}{L_{null}}$$

Source Significances and detection at TeV energies

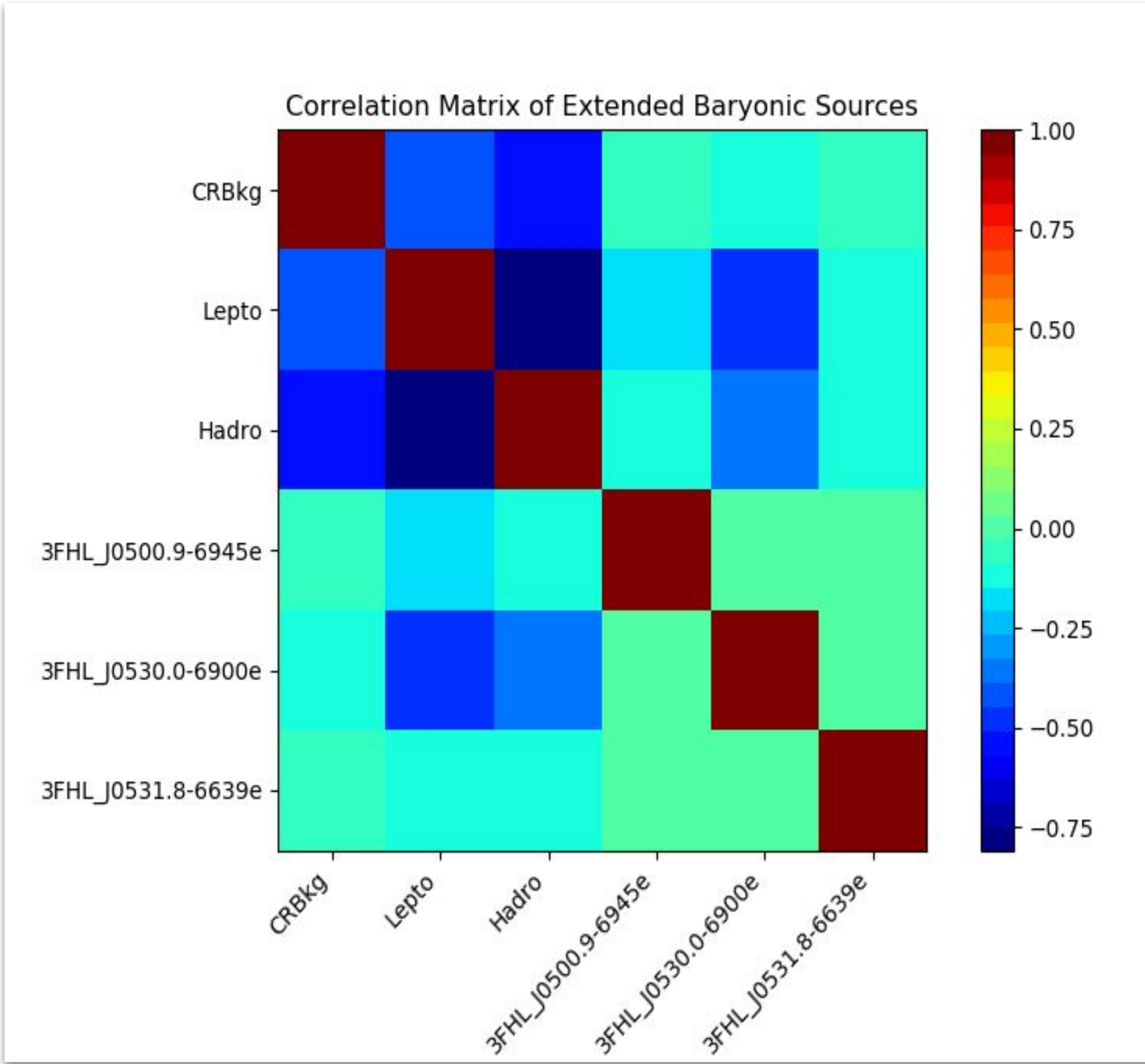
Source name	Significance(σ)
J0500.9-6945e	88.41
J0530.0-6900e	19.98
J0531.8-6639e	111.97
J0537-691	264.43
J0524.5-6937	116.62
J0534.1-6732	44.58
J0525.2-6614	83.40
J0535.3-6559	64.72
J0454.6-6825	47.81
J0537.0-7113	10.66
J0535-691	21.05
J0525-696	40.58
J0509.9-6418	0.50

Usually a detection is considered for TS > 25, which is a significance of 5σ

Observation and analysis settings such as pointing and binning were optimized to improve the significance of the point sources.

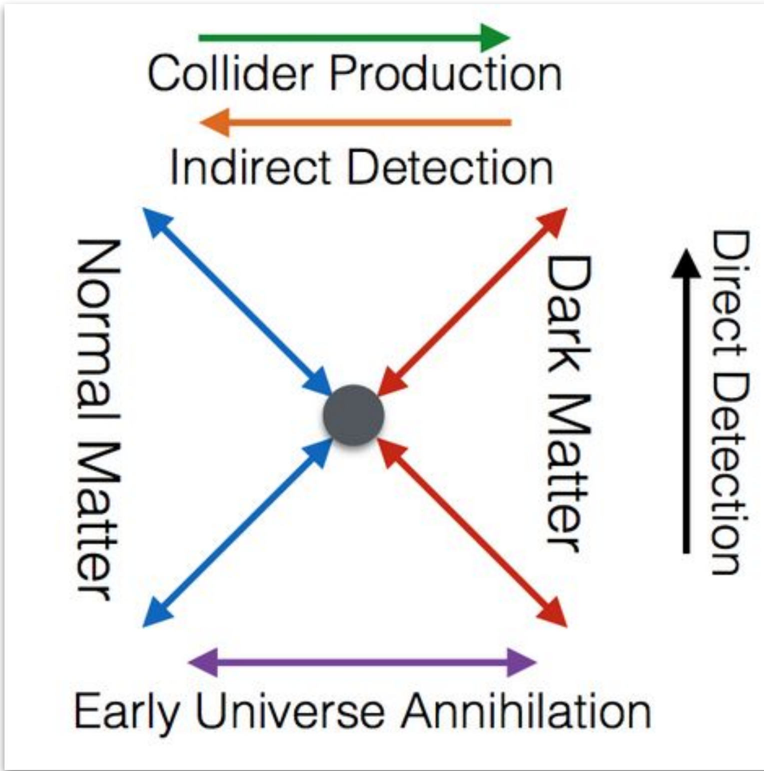
Most individual sources within the ROI will be detected.

Correlation between sources



- ★ Detection of extended sources is complicated due to correlations.
- ★ High correlation factors mixed with low statistics results in similar sources to being mixed during the likelihood fitting.
- ★ CTA finest spatial resolution will help to reduce correlations.

Indirect Detection of Dark Matter in the LMC



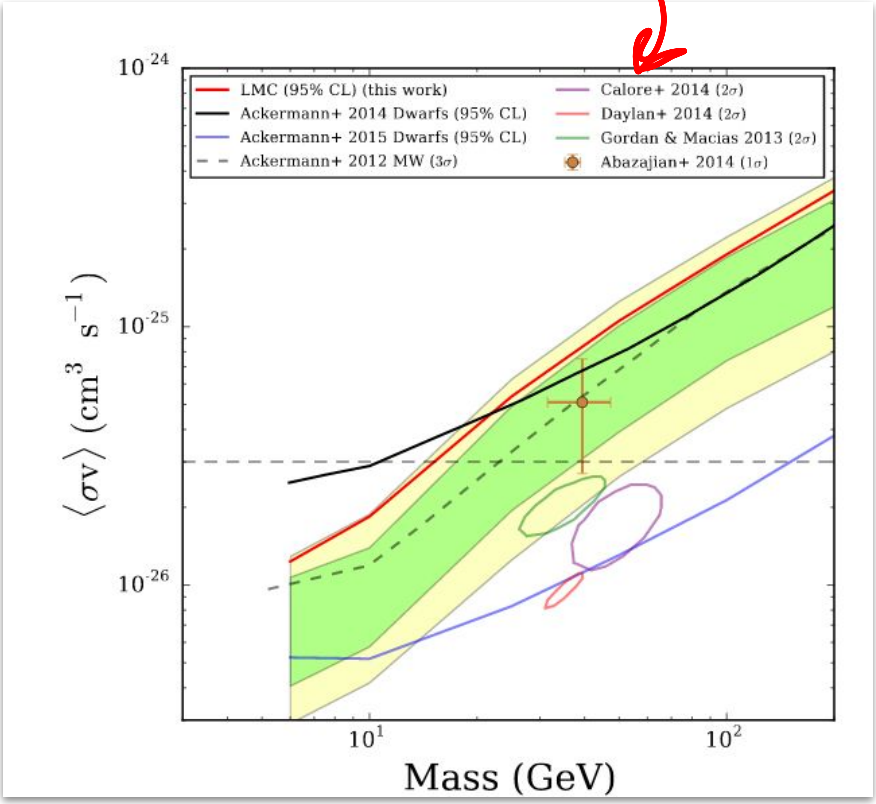
- ★ We have a Gamma-ray detector.
- ★ We can look for gamma-ray signal resulting from dark matter particles interaction (many channels!).
- ★ A model exist (WIMPs)! with an annihilation cross section compatible with the relic density of Dark Matter:

$$\Omega_X h^2 \sim \frac{3 \cdot 10^{-27} cm^3/s}{<\sigma v>} \sim \mathcal{O}(0.1)$$

$$<\sigma v> = 3 \cdot 10^{-26} cm^3/s$$

Finding Dark Matter in the LMC

Previous Fermi LAT work(Buckley et al. 2015)



★ LMC is a star forming galaxy with significant gamma ray background.

★ However, its J-factor is as large as the best dwarf spheroidal galaxies.

★ As it's spatially extended, we can use the morphology of dark matter signal to separate it from background.

★ Therefore, LMC is an interesting source where to search for Dark Matter annihilation signals.

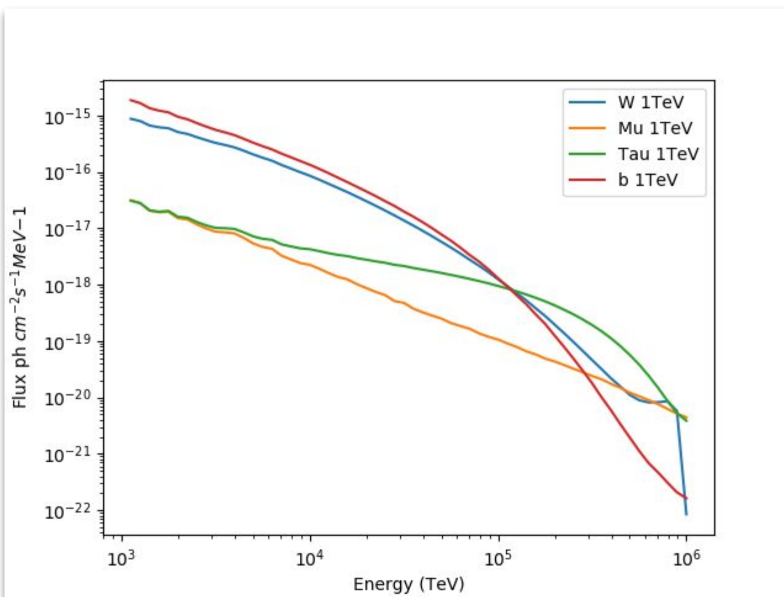
We want to discover the region of the parameter space <σv> vs. Mass that CTA will be able to explore.

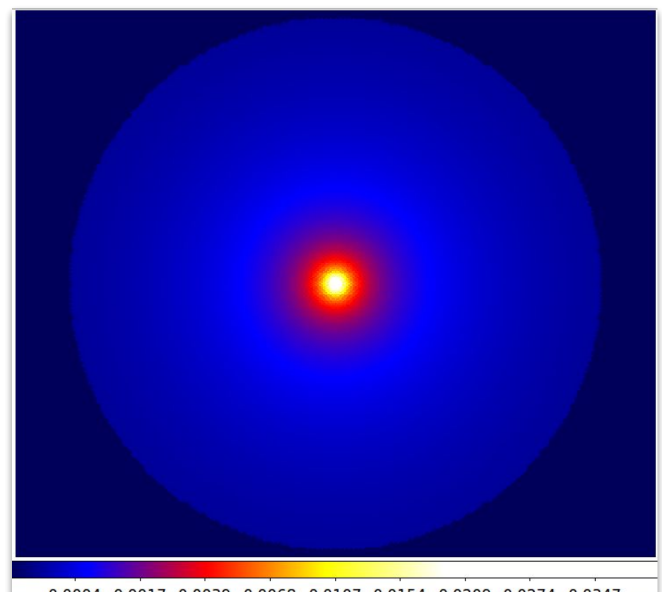
Dark Matter Model in the LMC

$$\frac{d\Phi}{dEd\Omega} = \frac{1}{4\pi}\frac{<\sigma v>}{km_{DM}^2}\frac{dN_\gamma}{dE}\int_{l.o.s} dl\rho^2(l,P)$$

Particle Physics term
Spectra from Cirelli et al. 2011

Astrophysics term
J-Factor computed with Clumpy software





Counts (sqrt scale)

Search for Constraints: Likelihood Fitting

$$L = \prod_{i}^{N} \frac{m_i^{n_i}}{n_i!} e^{-m_i}$$

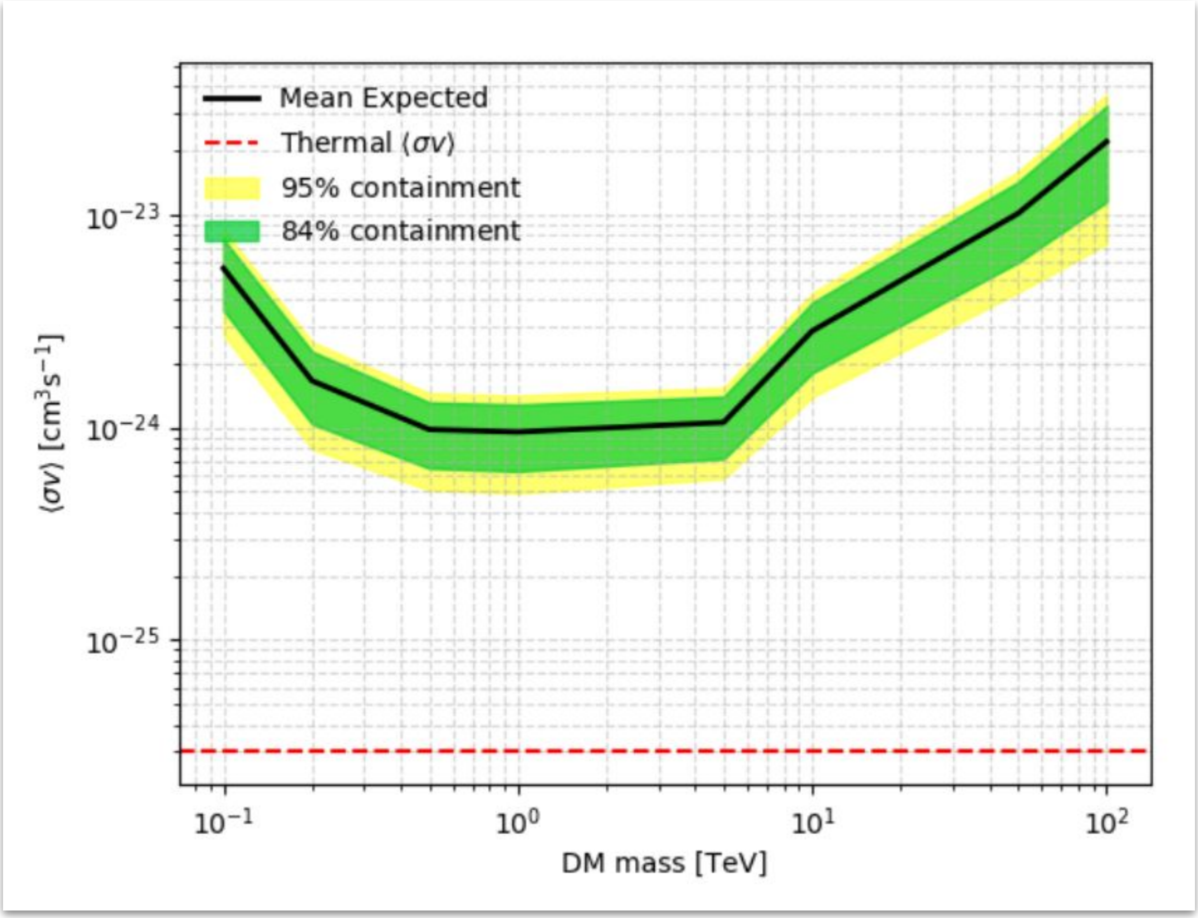
$$m_i = K_0 * DMmodel_i + \sum_{j=background} K_j BSrcmodel_i$$

This is the DM spectra
Normalization ↔ <σv>

$$TS = 2log \frac{L(<\sigma v>, \theta)}{L_{max}} = 2.71$$

We assume the null hypothesis (no dark matter in the data) and calculate limits on the annihilation cross section at 95% Confidence Level.

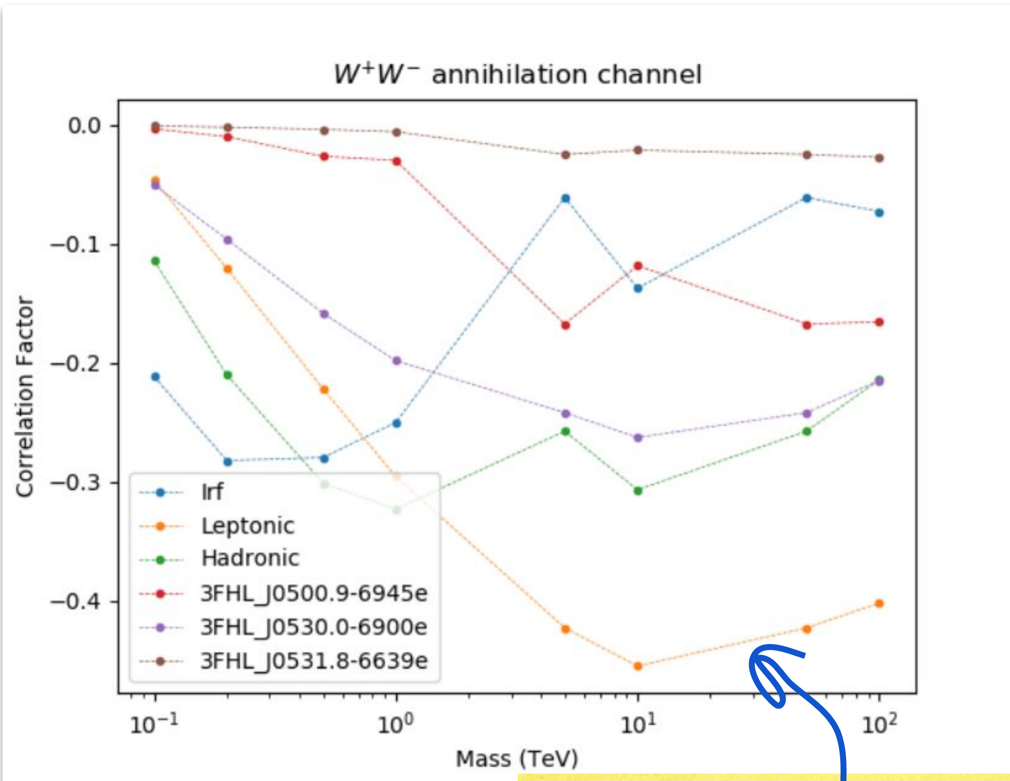
Constraints on dark matter annihilation <σv>



W^+W^- annihilation channel, 100 realizations of LMC data.

Correlations with baryonic sources

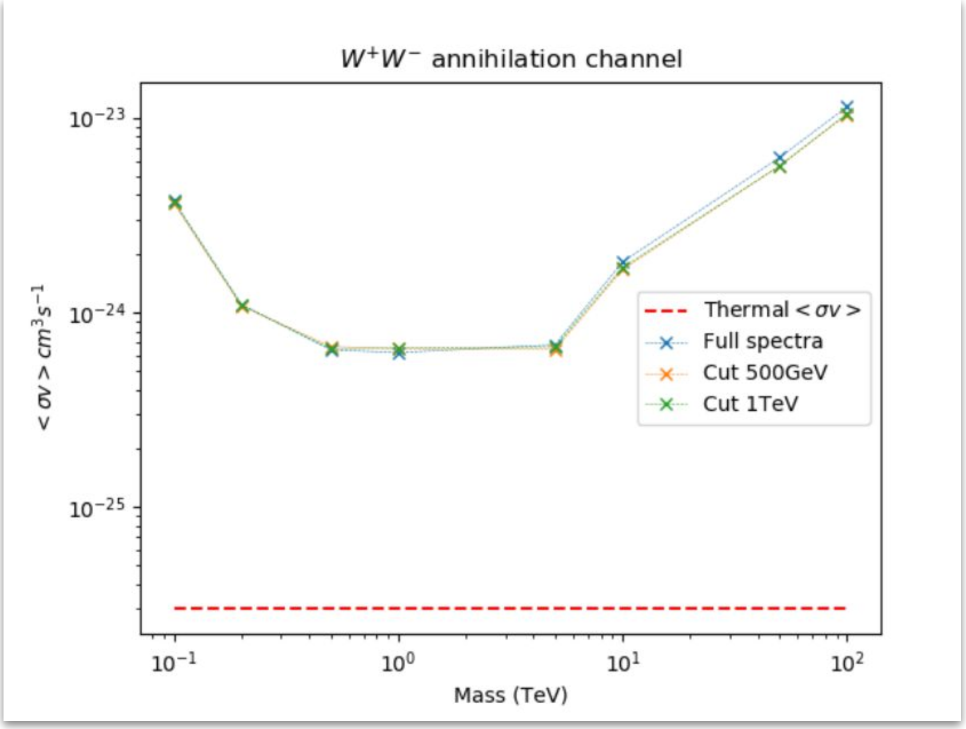
Correlation of the dark matter model with the baryonic sources affect the constraints.



High correlations difficult the dark matter signal to be separated from extended baryonic sources

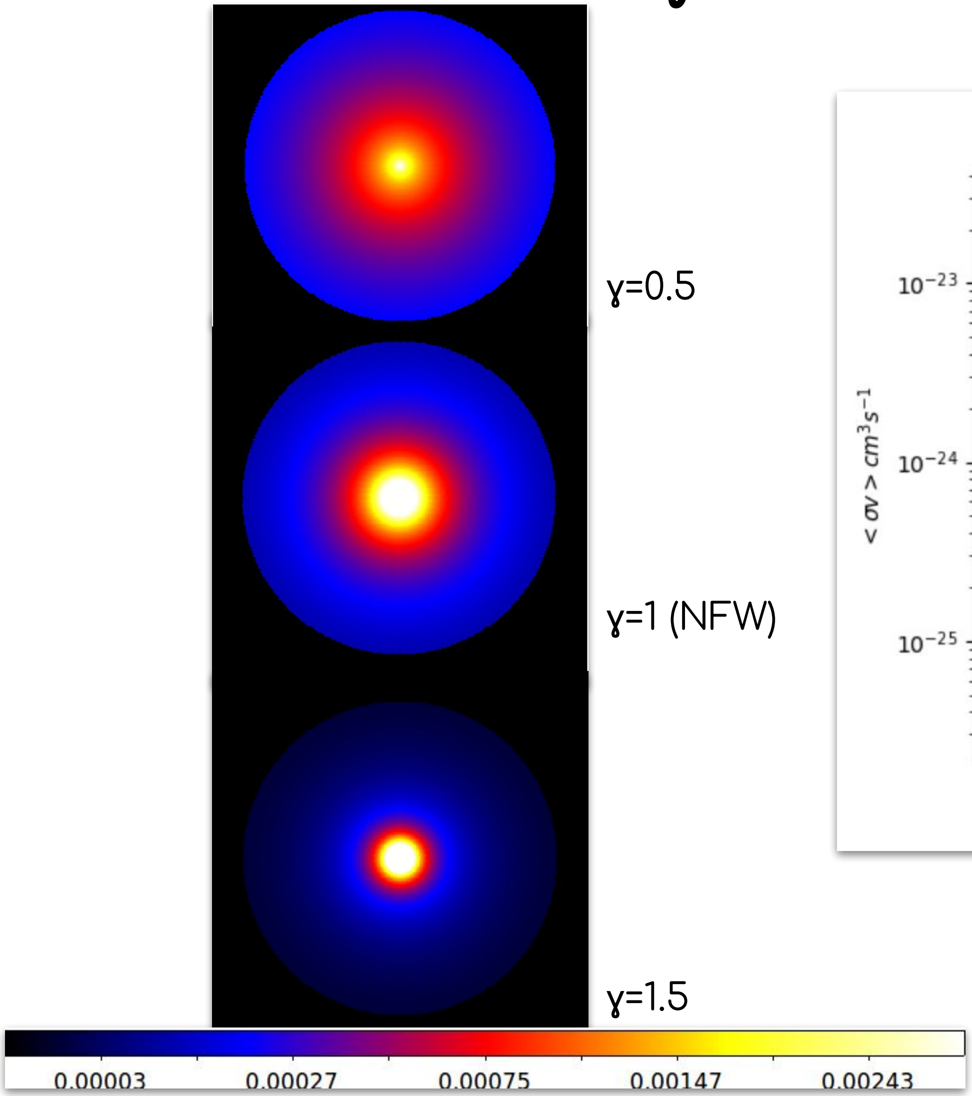
Some high correlations of DM with mass > 1 TeV with diffuse emission!

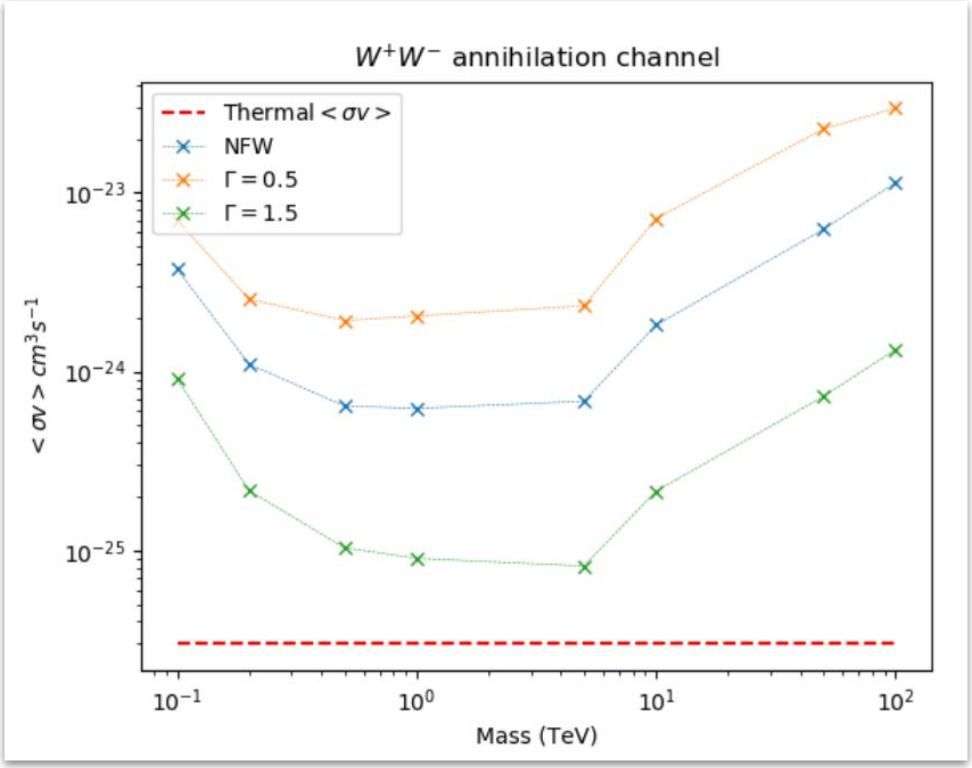
Tests on diffuse emission spectra
How does it affect the correlations and constraints?



Drastically cutting the diffuse emission spectra does not affect very much the limits on DM <σv>, meaning the main contribution to the constraints is the CR background and data fluctuations.

Tests on dark matter J-Factor
How different shapes of DM affect the constraints?





Conclusions

DATE 5 / 9 / 2018

★ CTA will provide observations of the VHE emission of the LMC in a wider range and with a higher resolution and sensitivity than ever.

★ All the sources with emission above TeV energies already discovered will be observable with CTA.

★ Good prospects on detecting gamma-ray signal from SN1987A, among many new sources.

DATE / /

★ Constraints on dark matter annihilation cross section, for the tested channels, are not competitive with other sources, in agreement with previous studies, being the lower limits far above the thermal relic cross section.

Back Up

LMC Region of Interest
Point Sources after selection

Sources in the LMC

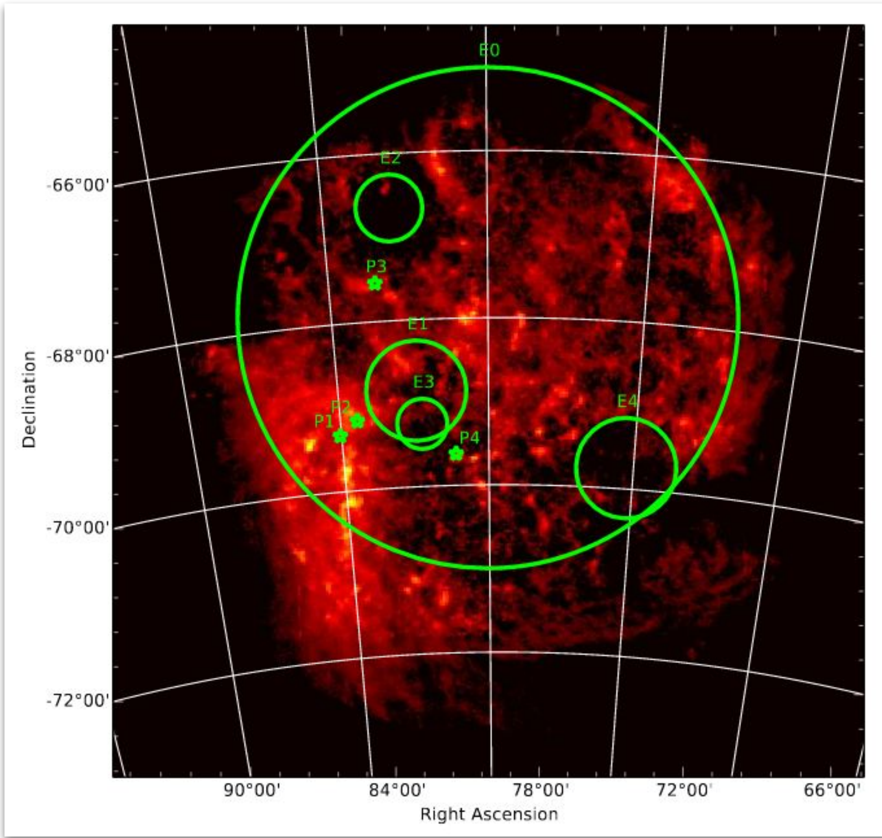
Catalog	Name	Object
HESS	J0537−691	N157B
HESS	J0535−691	30 Dor C
HESS	J0525−696	N132D
HESS	J0536-675	CXOU053600.0-673507
3FGL	J0524.5-6937	N132D?

Background Sources in the ROI

Catalog	Name	Object
3FGL	J0525.2-6614	-
3FGL	J0454.6-6825	PWN
3FGL	J0535.3-6559	-
3FGL	J0537.0-7113	-
3FHL	J0509.9-6418	Blazar candidate.

Up to 14 background sources were tested in the region of the LMC but most of them where either outside the final ROI or too faint at TeV energies, so they were discarded for the final analysis.

LMC Region of Interest
Extended Sources



Catalog	Name	Alt. name
3FHL	J0500.9-6945e	LMC-FarWest (E4)
3FHL	J0530.0-6900e	LMC-30DorWest (E1+E3)
3FHL	J0531.8-6639e	LMC-North(E2)

Fermi detected a 4th extended source (E0) as the large scale disk of LMC but its emission is too faint at TeV energies, so it's not included in the LMC model for this work.

Modelling the ROI: EBL

EBL: Extragalactic Background Light is the radiation in the universe due to star formation processes and Active Galactic Nuclei(AGN).

Very High Energy photon flux coming from cosmological distances is attenuated by pair production with EBL photons.

We must take into account EBL for sources in the background.

We can only apply EBL absorption accurately if we know the redshift

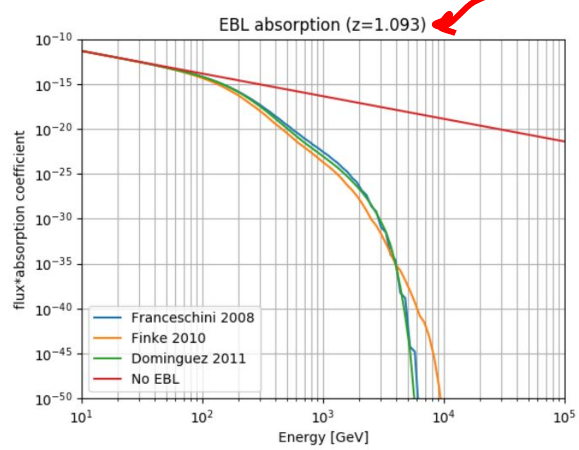


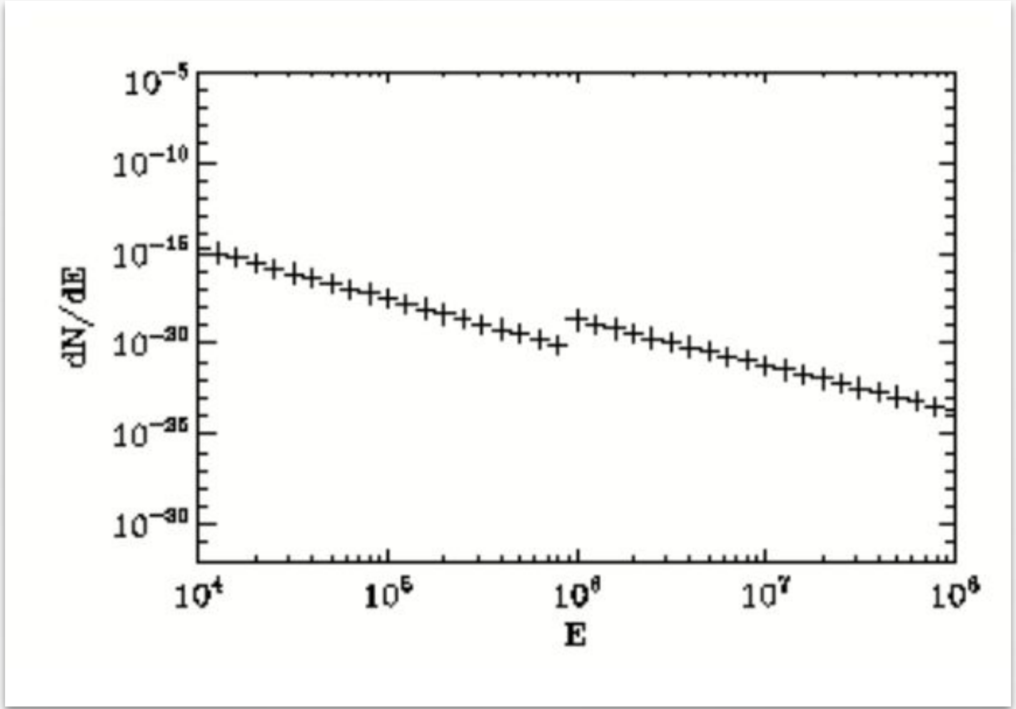
Figure 5: Spectrum of J0507.1-6102 with and without the EBL absorption.

Modelling the ROI: Extrapolation of spectra

We don't have real data, so we take observations from other experiments and extrapolate their results to CTA energies.

Combinations of different catalogs can lead to discrepancies...

Example: Inconsistency in J0534.1-6732/HESS J0536-675 spectrum



- Source observed by Fermi and H.E.S.S.. The spectrum normalization shows a discrepancy at 1TeV.