Search for dark matter with the fermi gamma-ray space telescope

High-energy astrophysics in the multi-messenger era

Ana Vitoria de Almeida Martinheira Braga

Advisor: Prof. Dr. Aion Viana

April, 2024

UNIVERSIDADE DE SÃO PAULO
Instituto de Física de São Carlos

Introducing myself

- ★ My name is Ana Vitória and I am a Brazilian Ph.D. student at University of São Paulo (started in 2023) - APOEMA,

Academic background

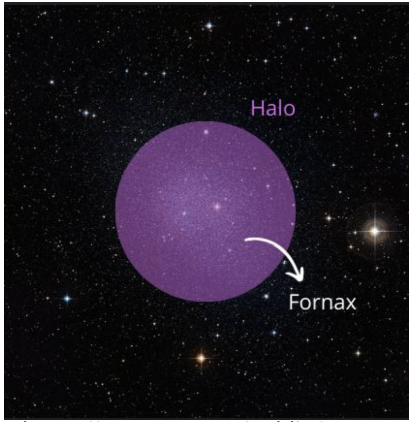
- ★ I graduated in Physics from São Paulo State University (UNESP) ,
- ★ In 2022 I completed my master's studies at UNESP.

My Ph.D project

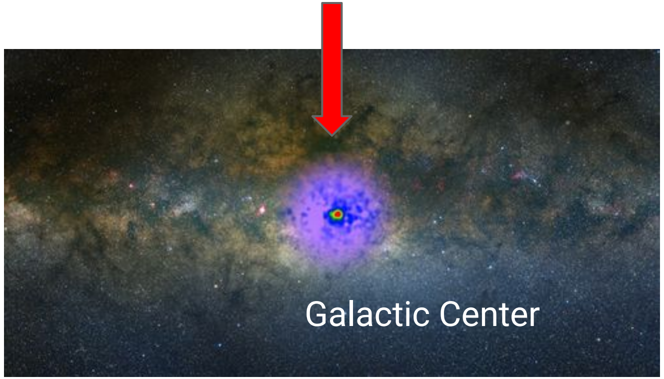
- ❑ The aim of my project is search indirect detection of dark matter using the Fermi Gamma-ray Space Telescope.

We have two main objectives:

- ❑ Analysis and constraints of Dark Matter annihilation in Dwarf Spheroidal Galaxies
- ❑ Investigation of the GeV excess detected in the Galactic Center.

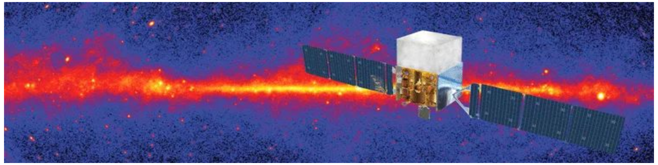


https://www.eso.org/public/portugal/images/eso1007a/?lang

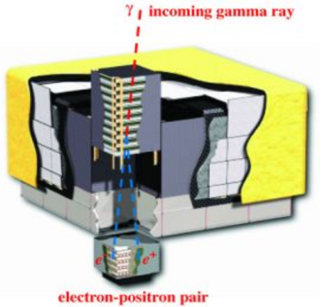


https://doi.org/10.1103/PhysRevLett.123.241101

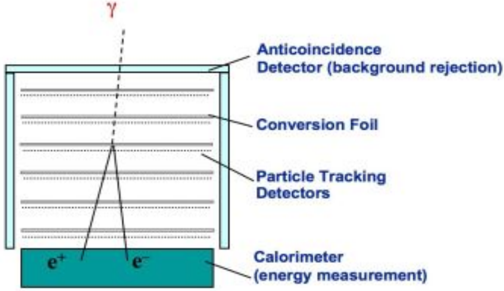
Fermi Large Area Telescope (Fermi-LAT)



https://glast.sites.stanford.edu/



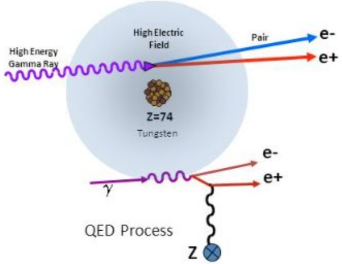
https://www-glast.stanford.edu/instrument.html



https://www-glast.stanford.edu/instrument.html

Gamma-ray observations of celestial sources

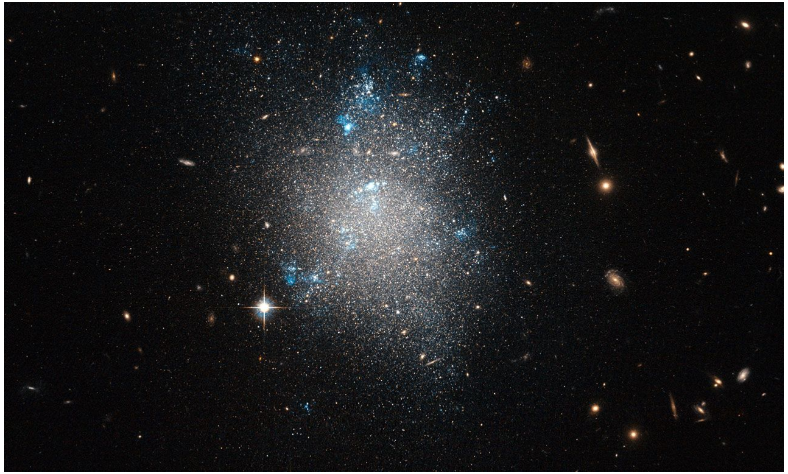
- Effective area: 8000 cm²
- Energy range: 20 MeV to 300 GeV
- 15 years of data



The tracking detector consists of several layers of a dense material that converts an incoming gamma ray into pairs of electrons and positrons

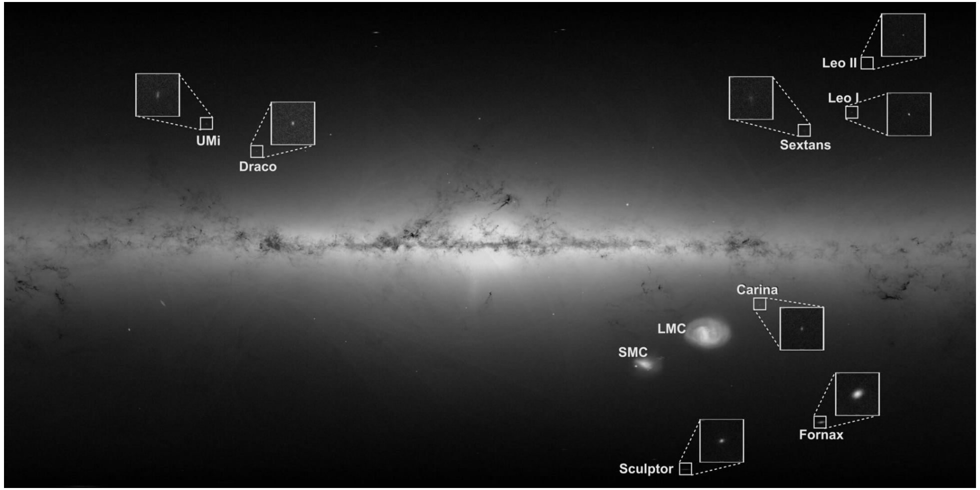
Fermi-LAT: A Retrospective on Design, Construction, and Operation

Why spheroidal dwarf galaxies?



Sculptor dwarf galaxy, *ESA/Hubble*

- Low luminosity
- Simple structure
- High dark matter content
- Close to Earth



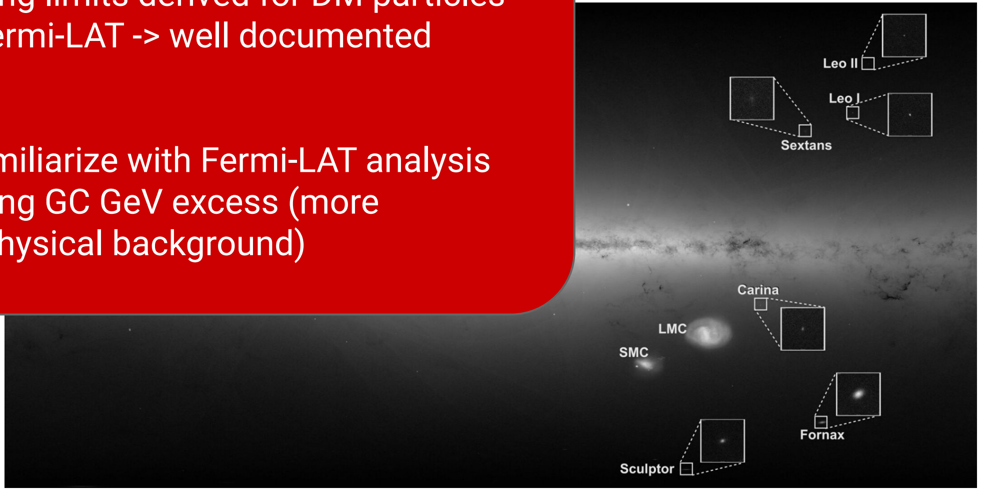
Dwarf galaxies around the Milky Way

Why start with spheroidal dwarf galaxies?

Sculptor dwarf galaxy, *ESA/Hubble*

- ❏ Low luminosity
- ❏ Simple structure
- ❏ High dark matter content
- ❏ Close to Earth

- ★ Most constraining limits derived for DM particles < 100 GeV by Fermi-LAT -> well documented analysis
- ★ Good way to familiarize with Fermi-LAT analysis before addressing GC GeV excess (more complex astrophysical background)



Dwarf galaxies around the Milky Way

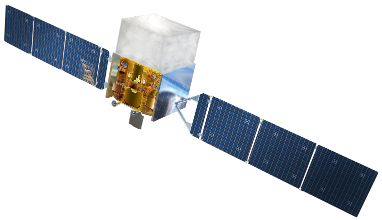
Dark Matter Indirect detection

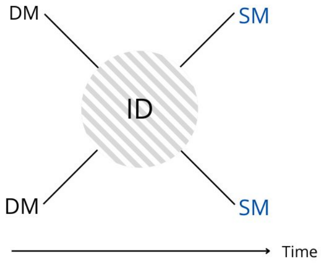
Gamma-ray flux
(signal in data)

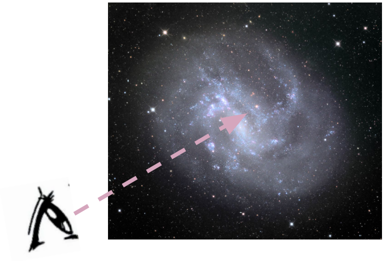
Particle Physics
(particle per annihilation)

Dark Matter Distribution
(line-of-sight integral)

$$\frac{d\Phi}{dE}(E,\phi,\theta) = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{DM}^2}\sum_f \beta_f \frac{dN_f}{dE} \times \int_{\Delta\Omega}\int_{l.o.s} \rho_{DM}^2 \, dl \, d\Omega$$

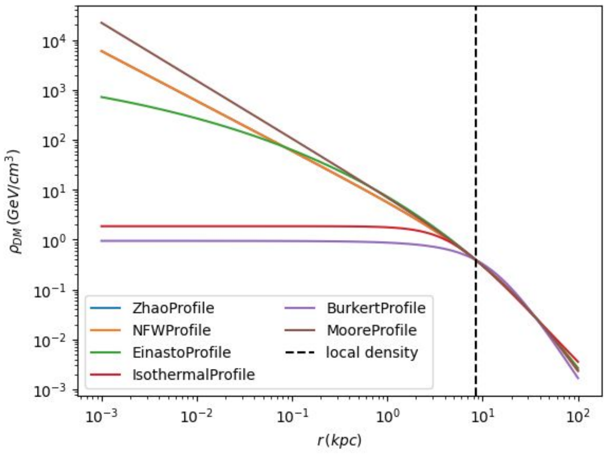




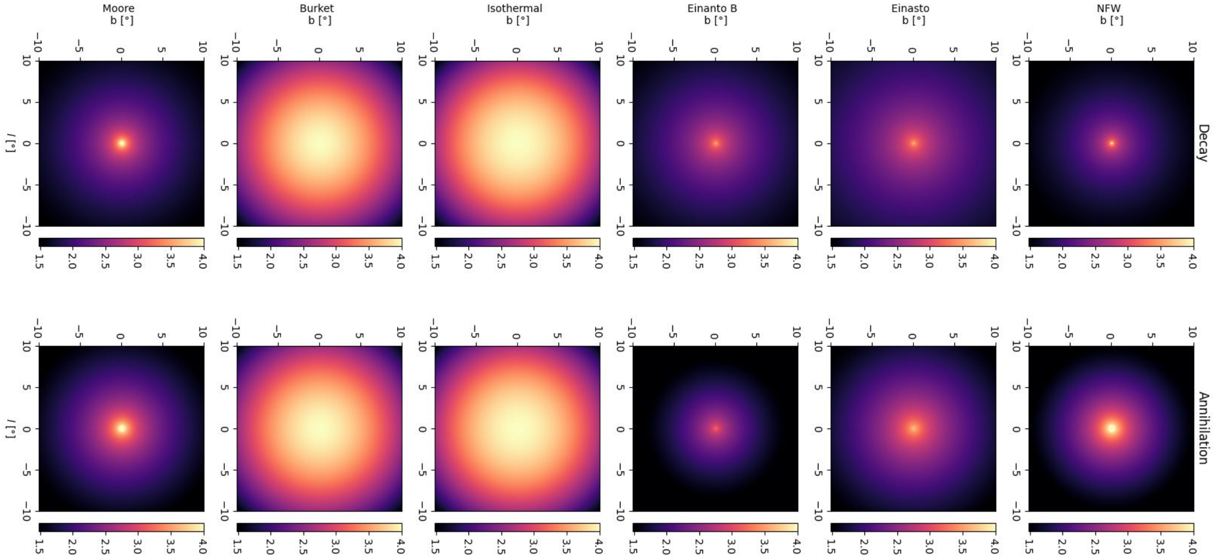


Dark Matter Indirect detection

DM Profiles (Galactic Center)



J-Factor map for the Galactic Centre region



$$J = \int_{\Delta\Omega} \int_{l.o.s} \rho_{DM}^2 dl d\Omega$$

- Line-of-sight integral
- Density profile model

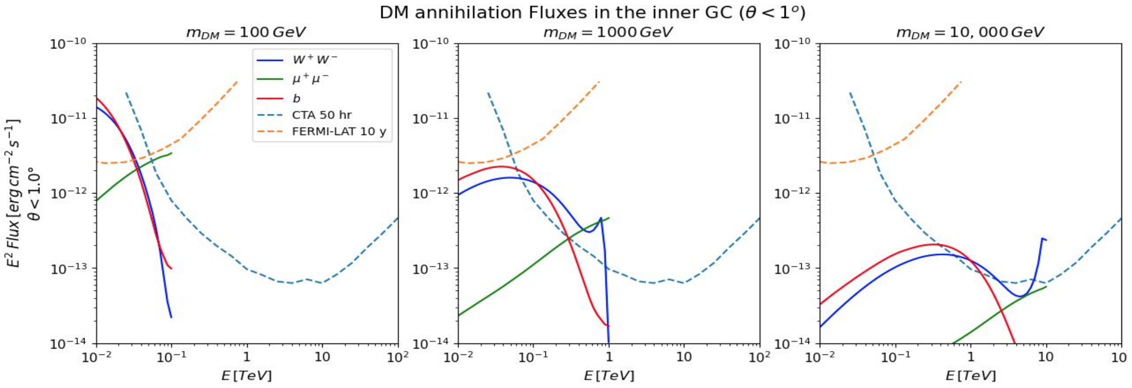
Dark Matter Indirect detection – WIMPs

Flux annihilation for differents channels and masses

$$\frac{d\Phi}{dE}(E,\phi,\theta) = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{DM}^2}\sum_f \beta_f \frac{dN_f}{dE} \times \int_{\Delta\Omega}\int_{l.o.s} \rho_{DM}^2 \, dl \, d\Omega \quad \Rightarrow \quad \rho_{NFW}(r) = \rho_s \frac{r_s}{r}\left(1+\frac{r}{r_s}\right)^{-2}$$

$$r_s = 24.42, \alpha = 0.184$$

arXiv:1012.4515v4



WIMPs

$$\langle\sigma v\rangle \simeq 3\times10^{-26}\,\mathrm{cm}^3\,\mathrm{s}^{-1}$$

Dark sector searches

Dark Matter Indirect detection

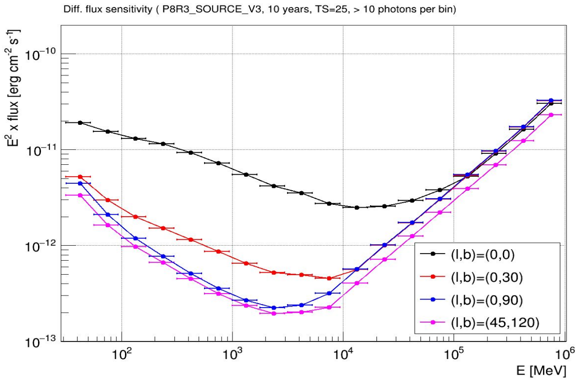
The likelihood L is the probability of obtaining the data given an input model:

2D binned Likelihood: $$L_{ij} = \frac{(B_{ij}+S_{ij})^{N_{ij}} e^{-(B_{ij}+S_{ij})}}{N_{ij}!}$$ → B_{ij} : Background signal

Differential flux sensitivity, S, is the minimum flux needed to get a standard-deviation detection from a point-like gamma-ray source

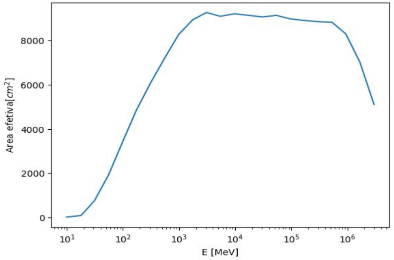
$$S(\phi_0) = 2\pi(1-\cos\theta)\ T_{obs}\ \phi_0 \int_{\Delta E} A_{eff}(E) \left(\frac{E}{MeV}\right)^{-2} dE$$

$S(\phi_0)$ → 25



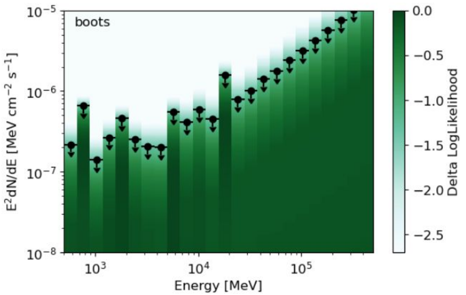
Fermi LAT Performance

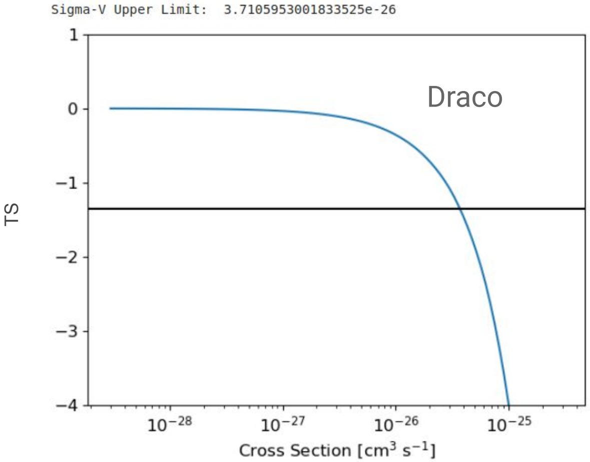
$A_{eff}(E)$ →



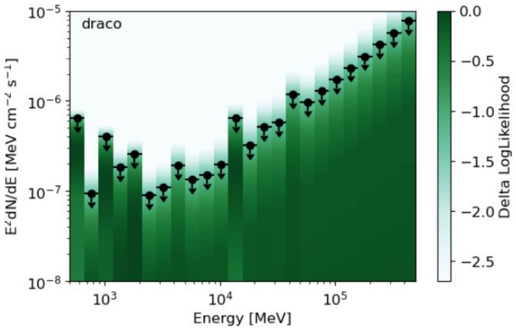
Dwarf galaxies analyses

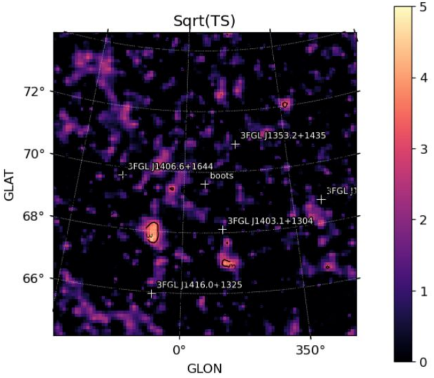
Dwarf galaxy: Bootes

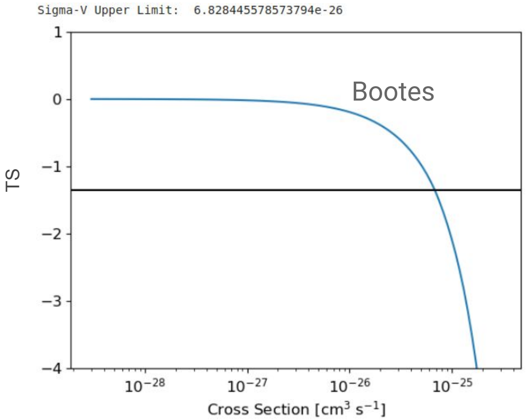


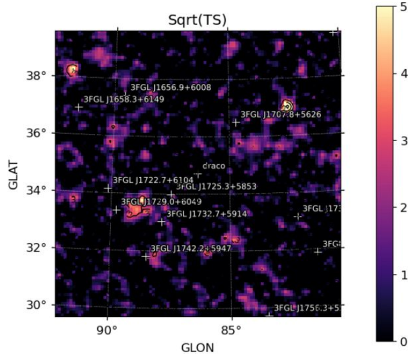


Dwarf galaxy: Draco









Next steps

Legacy Analysis of Dark Matter Annihilation from the Milky Way Dwarf Spheroidal Galaxies with 14 Years of *Fermi*-LAT Data

Alex McDaniel* and Marco Ajello
Department of Physics and Astronomy, Clemson University, Clemson, SC, 29631, USA

Christopher M. Karwin
NASA Postdoctoral Program Fellow, NASA Goddard Space Flight Center, Greenbelt, MD, 20771, USA

Mattia Di Mauro
Dipartimento di Fisica, Universitá di Torino, Via P. Giuria 1, 10125 Torino, Italy and
Istituto Nazionale di Fisica Nucleare, Sezione di Torino, Via P. Giuria 1, 10125 Torino, Italy

Alex Drlica-Wagner
Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, IL 60510, USA
Kavli Institute for Cosmological Physics, University of Chicago, Chicago, IL 60637, USA and
Department of Astronomy and Astrophysics, University of Chicago, Chicago IL 60637, USA

Miguel Sànchez-Conde
Instituto de Física Teórica, IFT UAM-CSIC, Departamento de Física Teórica,
Universidad Autónoma de Madrid, ES-28049 Madrid, Spain

(Dated: November 10, 2023)

More than 50 dwarf spheroidal satellite galaxies (dSphs)

$$500 MeV - 1 TeV$$

DATA: Fermi-LAT

Using the most recent models:

P8R3 SOURCE V3 (sources)
gll_iem_v07.fits (emission model)
gll_psc_v29.fits (catalogs)

Next steps

The likelihood L is the probability of obtaining the data given an input model:

2D binned Likelihood: $L_{ij} = \frac{(B_{ij}+S_{ij})^{N_{ij}} e^{-(B_{ij}+S_{ij})}}{N_{ij}!}$

Nuisance parameter: $\mathcal{J}_j = \frac{1}{\sqrt{2\pi}\sigma_j log(10)\bar{J}} e^{-(log_{10}J - log_{10}\bar{J})^2/2\sigma_J^2}$

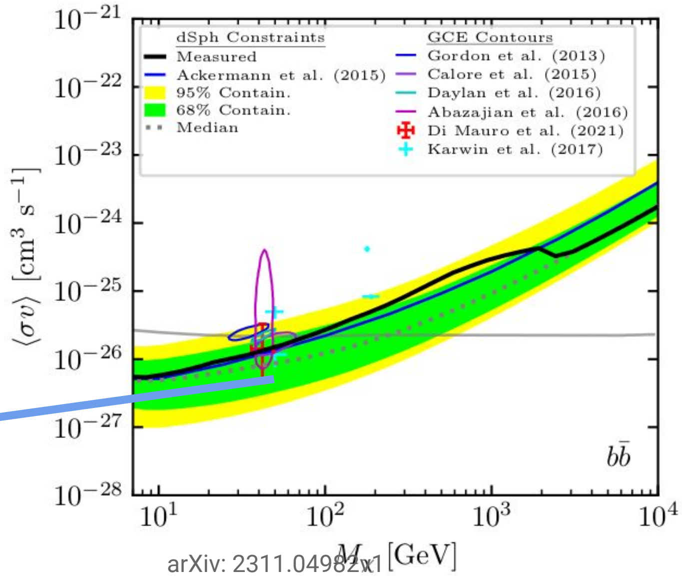
Combined Likelihood: $\mathcal{L} = \prod_i \prod_j \mathcal{L}_{ij} = \prod_i \prod_j L_{ij} \times \mathcal{J}_j$

Combined likelihood analysis of the dSphs

Improve the constraints to study different DM models (astro and particle physics)

Test statistic: $TS = -2ln(\mathcal{L}/\mathcal{L}_0)$

95% confidence level



arXiv: 2311.04982v1

Conclusions and prospects

- Utilizing data from gamma-ray observations conducted by the Fermi-LAT telescope to investigate indirect searches for dark matter:
  - Dwarf spheroidal galaxies
  - Galactic Center

- We can use the data obtained from dwarf spheroidal galaxies to estimate and refine limits and parameters such as cross-section, apply limits to different DM models, etc…;

- **Prospects**: With the Vera Rubin Observatory, we expect to accelerate the discovery of new dwarf galaxies and thus refine the data;

- Once dSph analysis done -> attack Galactic Center GeV excess problem.

Thank you!

Acknowledgements

FAPESP

CNPq

CAPES

IFSC USP