APOEMA

Search for Dark Matter with the Cherenkov Telescope Array

High-energy astrophysics in the multi-messenger era

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My PhD project

Main goal: explore different phenomena and targets related to gamma-ray astrophysics in the context of Dark Matter detection prospects.

- CTA's detection techniques
- DM models: WIMPs (CTA's energy range) and Dark Photon
- Different targets: currently, GC and Crab Nebula

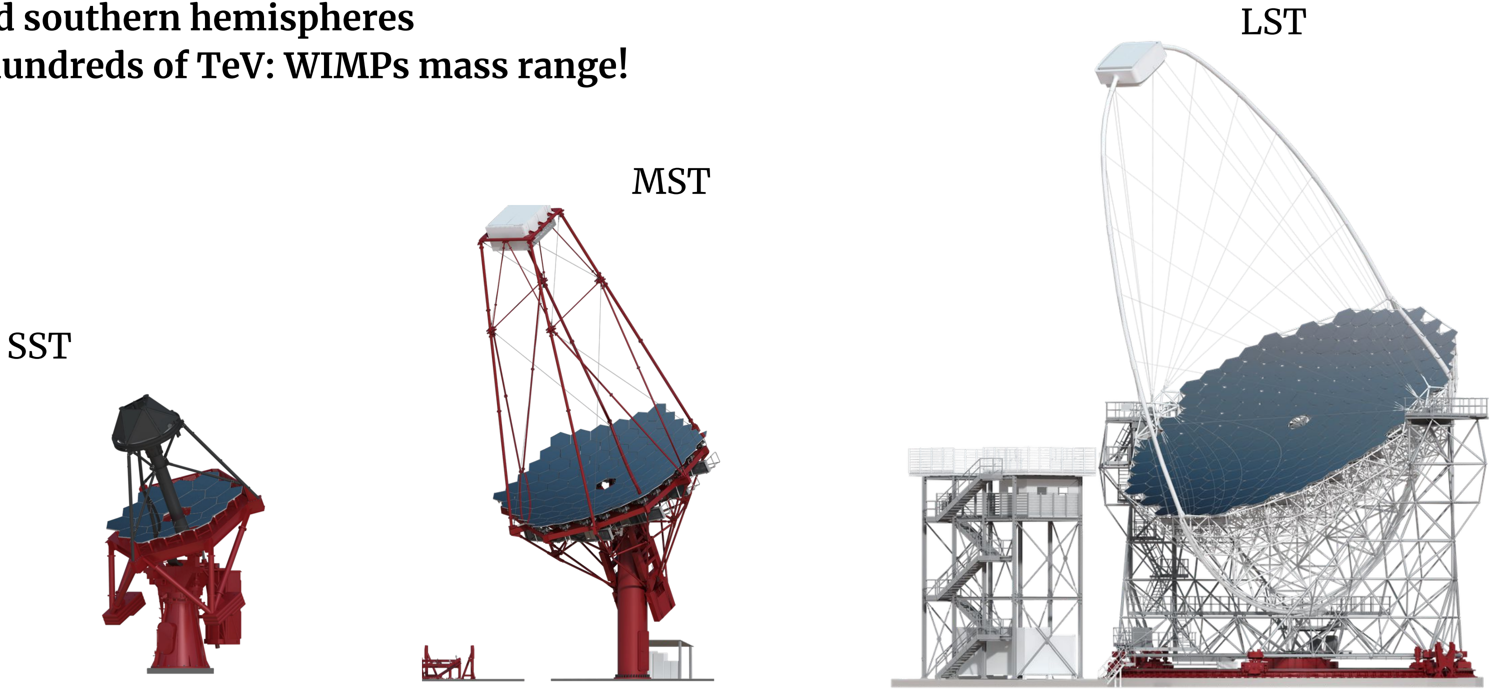
Beyond gamma-rays:

- Rotation curves (OADM model)

Credit: G. Pérez, IAC, SMM

Cherenkov Telescope Array

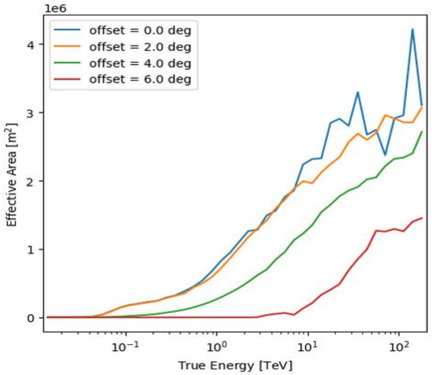
- **Imaging atmospheric cherenkov technique (IACT)**
- **High-energy gamma rays**
- **More than 60 telescopes**
- **Northern and southern hemispheres**
- **Few GeV to hundreds of TeV: WIMPs mass range!**

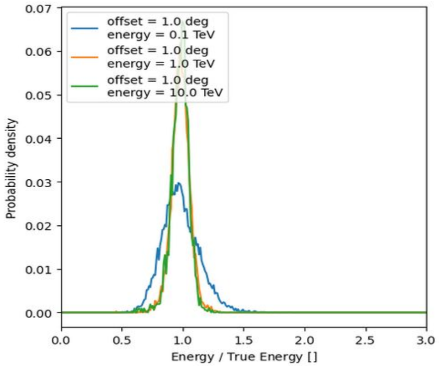


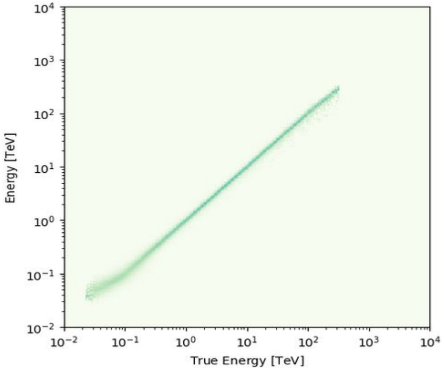
Credit: G. Pérez, IAC, SMM

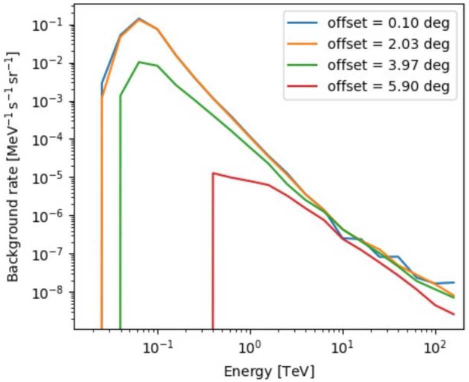
Cherenkov Telescope Array

$$N_{\rm DM} = \frac{T_{\rm obs} {\rm J} \langle \sigma v \rangle}{8 \pi m_{\rm DM}^2} \int_{E_{\rm min}}^{E_{\rm max}} \frac{dN_{\rm DM}}{dE}(E) A_{\rm eff}(E) dE.$$









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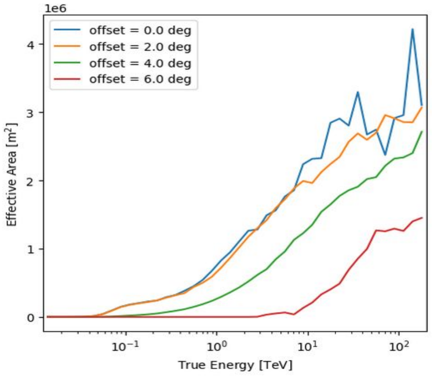
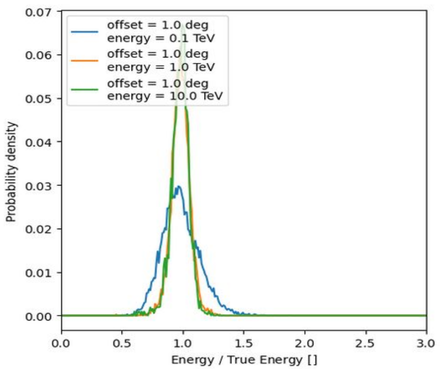
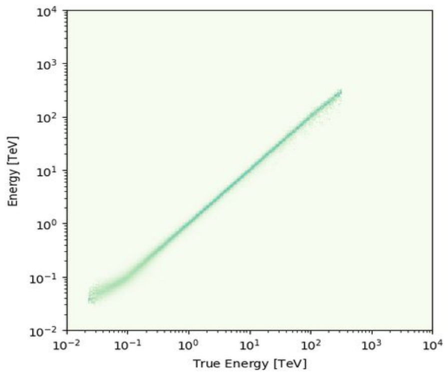
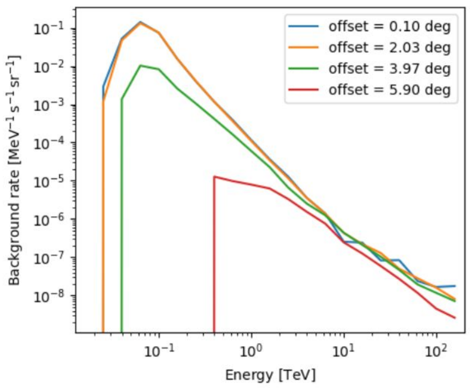
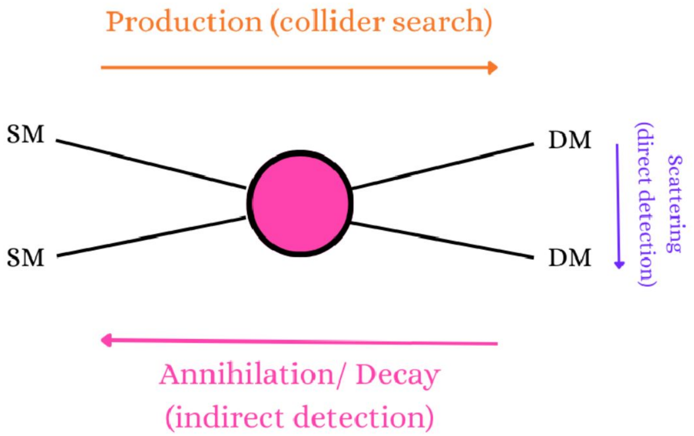








Indirect detection



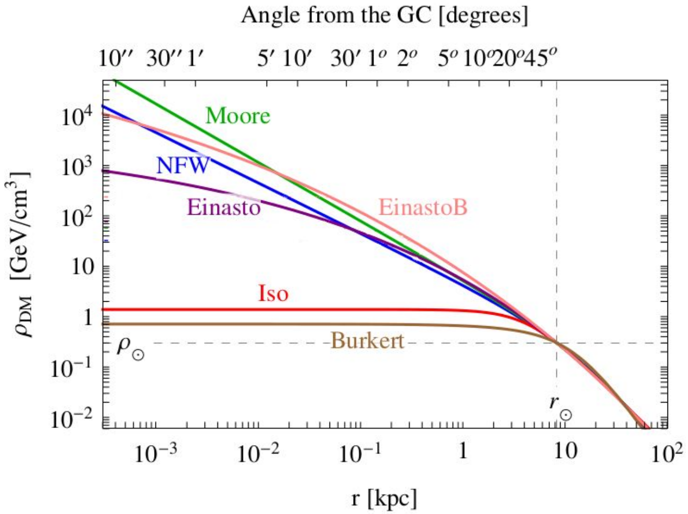
Particle physics information

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

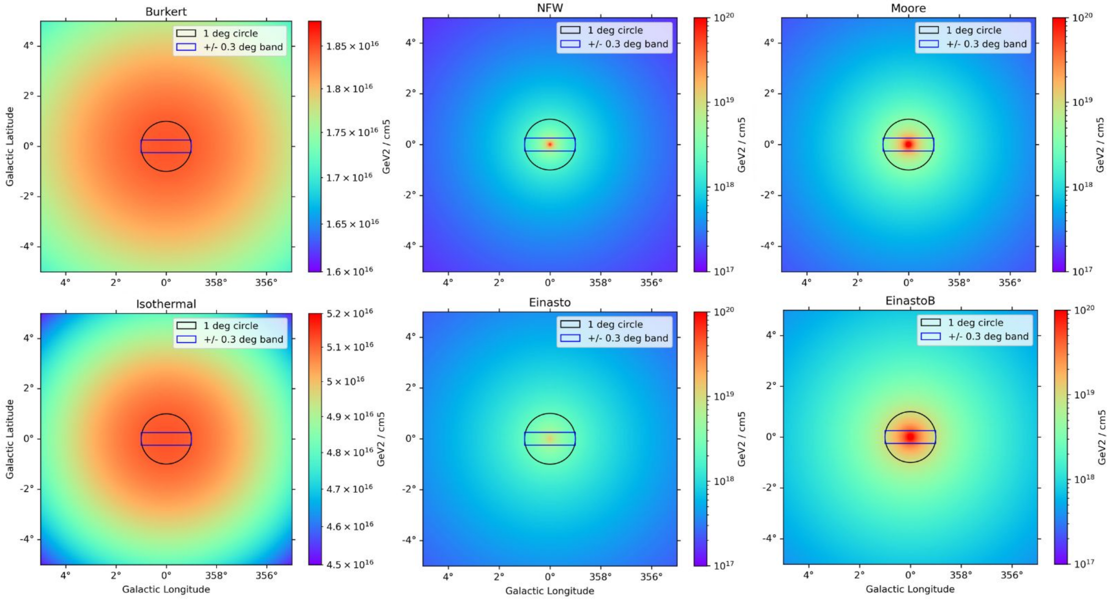
J-factor

J-factor map at the GC

Strong dependance on
density profile !

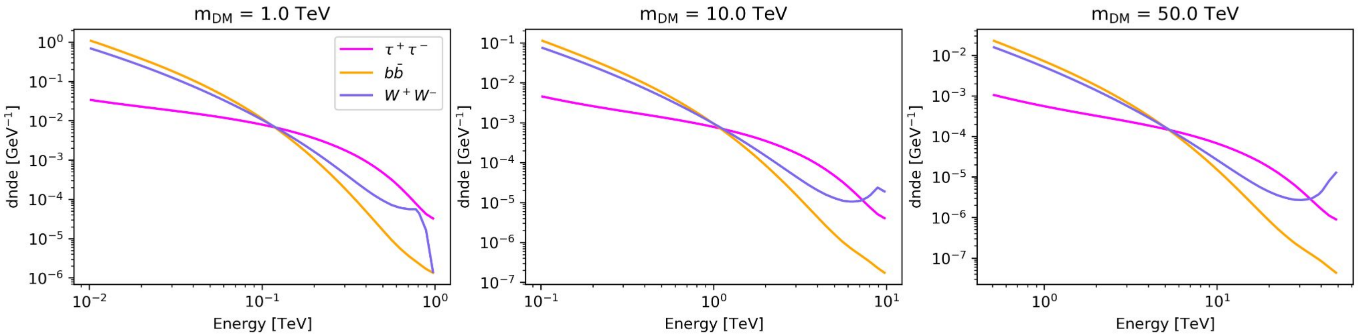


arXiv:1012.4515v4

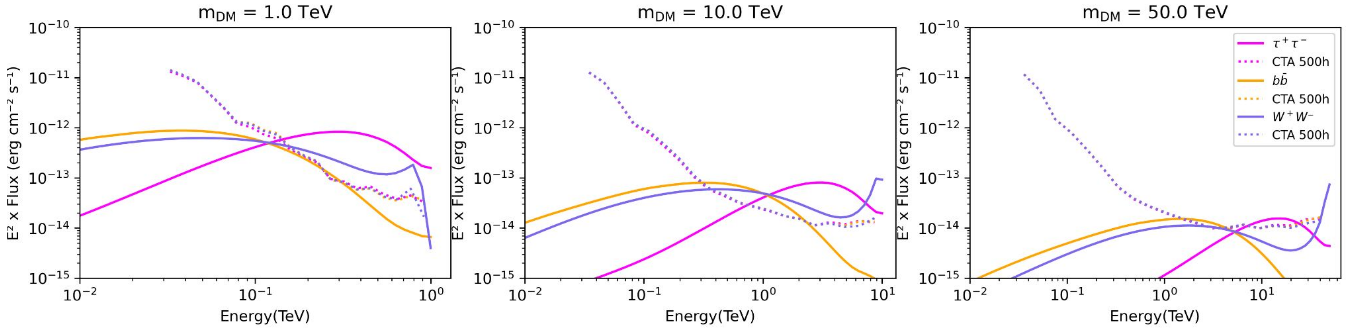


WIMP DM annihilation

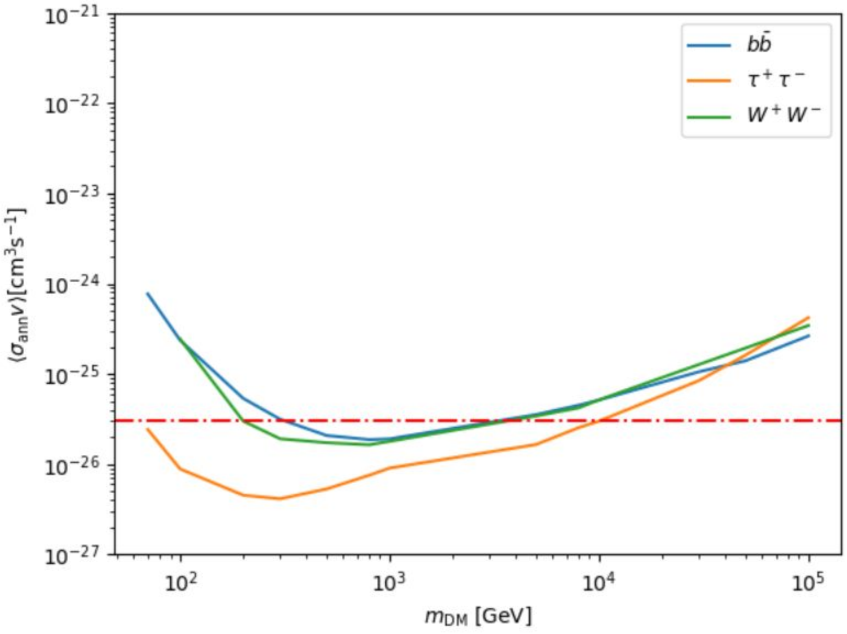
Gamma ray spectra at production:

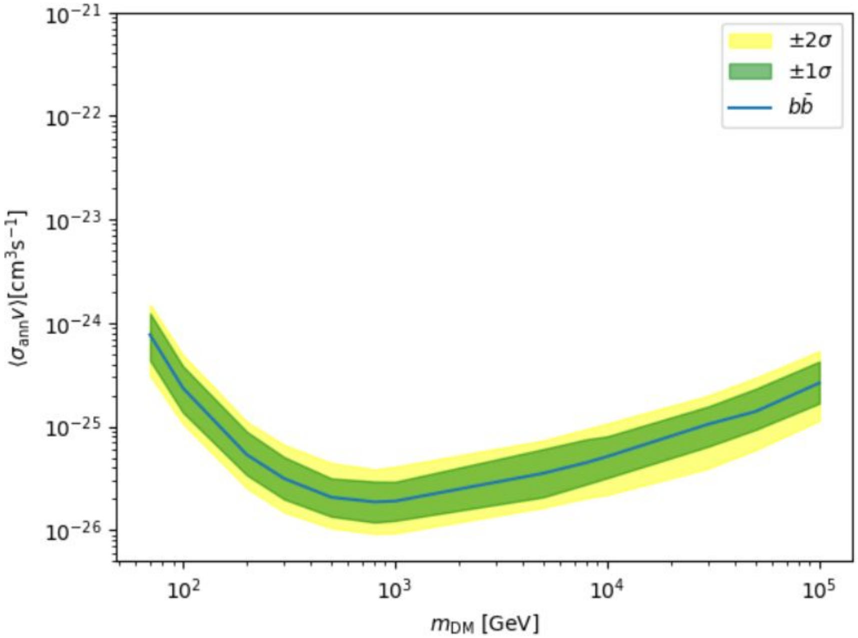


Gamma ray flux for the GC region (Einasto profile):



Constraining the cross-section

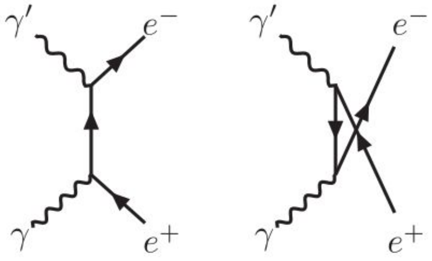




The dark photon

Dark Photon attenuation

- New gauge boson that arises from a symmetry of a hypothetical Dark Sector.
- Kinetic mixing with the ordinary photon.
- Massive or massless.



Photon attenuation diagrams for $\gamma - \gamma'$ scattering.

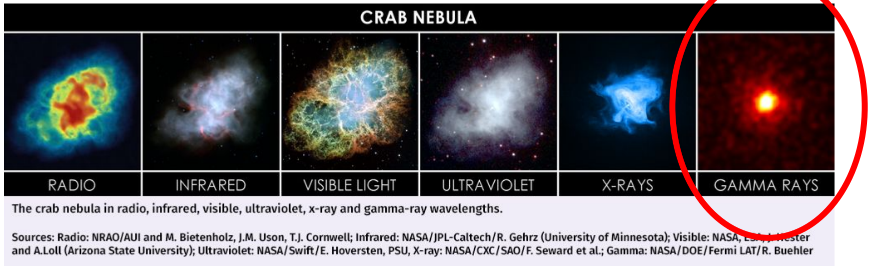
If the dark photon is massive, the scattering process kinematically opens up for gamma rays above the energy threshold

$$E > \frac{2m_e^2}{m_{\gamma'}}$$

$$\frac{\mathrm{d}\phi}{\mathrm{d}E} = (1 - P_{\mathrm{abs}}) \cdot \left.\frac{\mathrm{d}\phi}{\mathrm{d}E}\right|_{\mathrm{source}}$$

Crab observations with CTA

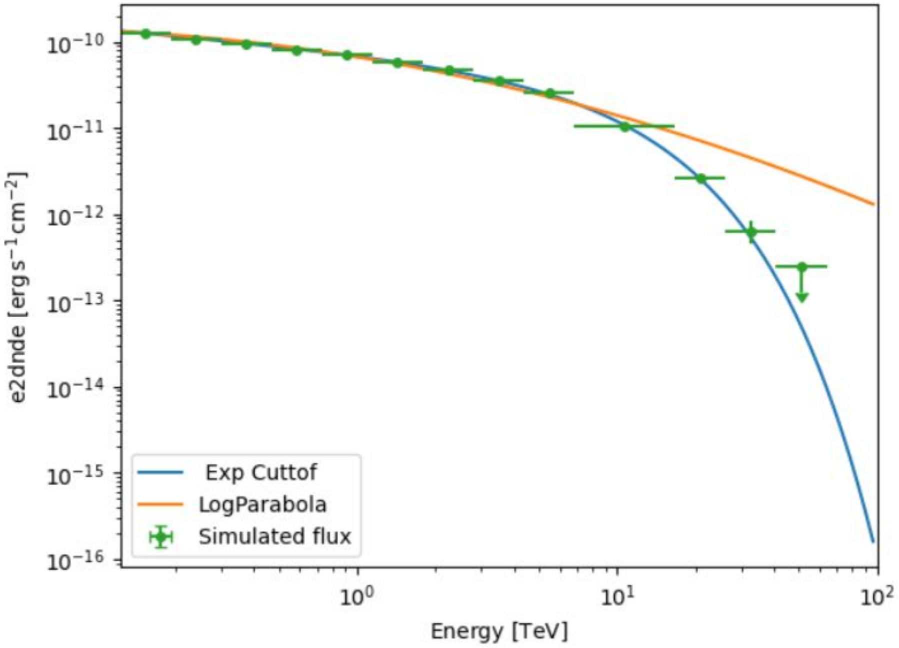
First step: simulating CTA Crab Nebula observations with gammapy.



Exponential Cutoff Power Law spectral model :

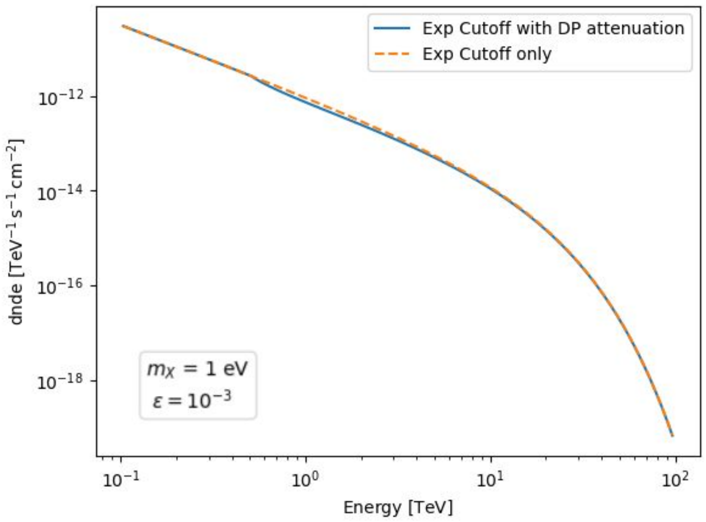
$$\phi(E) = \phi_0 \cdot \left(\frac{E}{E_0}\right)^{-\Gamma} \exp(-(\lambda E)^{\alpha})$$

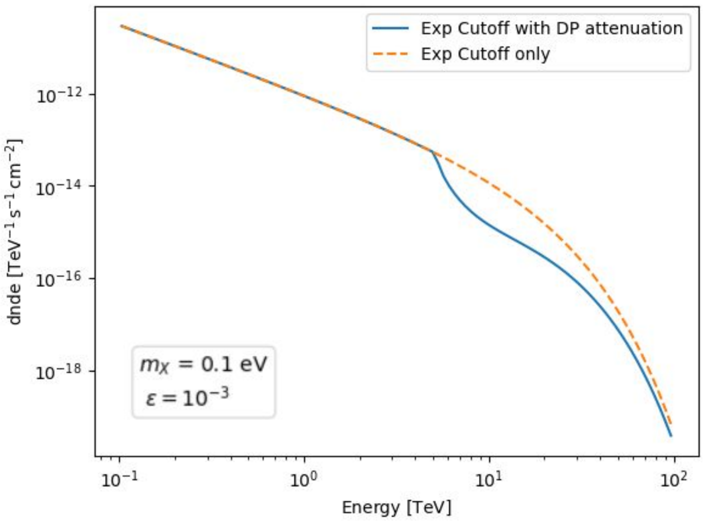
Parameters as fitted in arXiv:astro-ph/0607333



Crab nebula spectral models

Second step: create a custom spectral model that accounts for the photon–dark photon scattering attenuation and compare it to the simulated data.

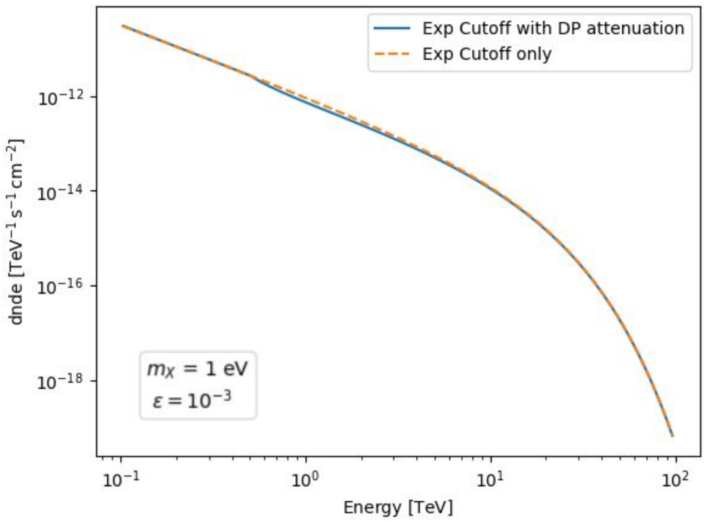


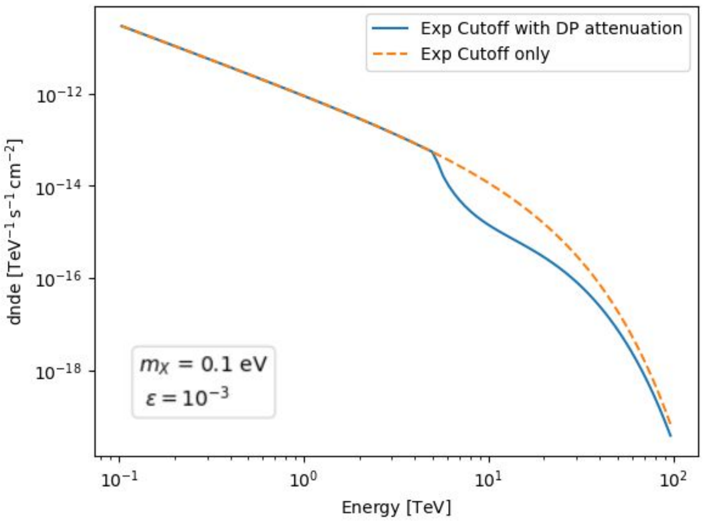


Crab nebula spectral models

Second step: create a custom spectral model that accounts for the photon–dark photon scattering attenuation and compare it to the simulated data.

Put constraints on the $m_{\gamma'} \times \varepsilon$ parameter space

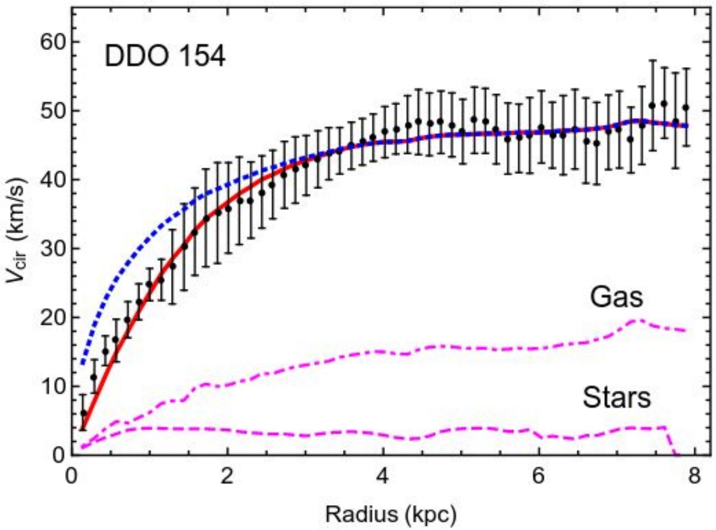


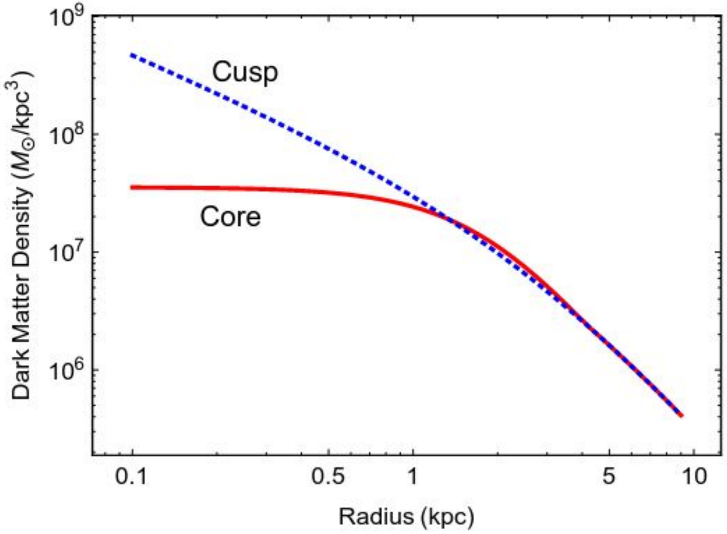


Oscillating Asymmetric Dark Matter

Galaxy rotation curves

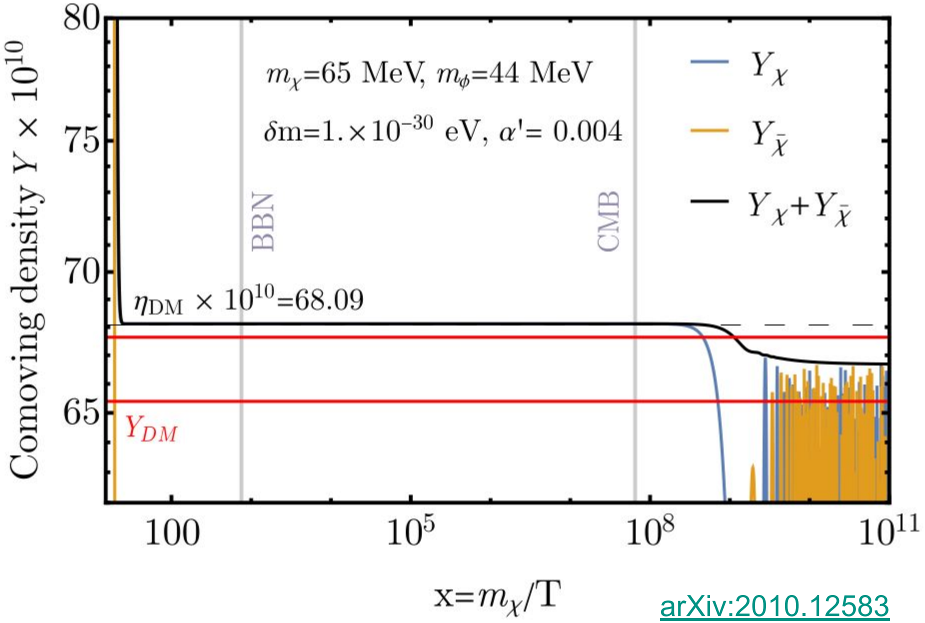
- N-body simulations: *cusp* profiles
- Dwarf spheroidal galaxies: *core* profiles





Probing OADM model

- Light fermionic Dark Matter particle, $m_\chi \sim 0.1 - 1\text{GeV}$
- Oscillates between DM and anti-DM
- Conversion of *cusps* into *cores* through reactivation of DM annihilation in galaxies at structure formation times.



arXiv:2010.12583

Probing OADM model

- Evolution of an NFW profile
- Combined fit for 18 DM-dominated galaxies
- Compare the results with the model’s constraints

$$\langle \sigma v \rangle_a = \frac{\pi\, \alpha'^2}{m_\chi^2}$$

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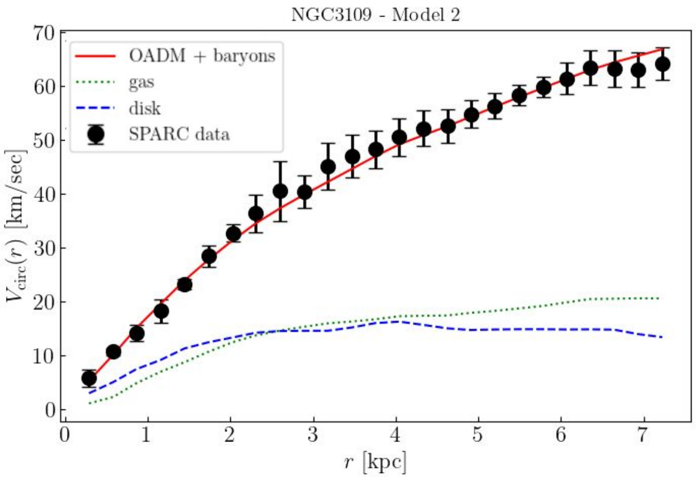
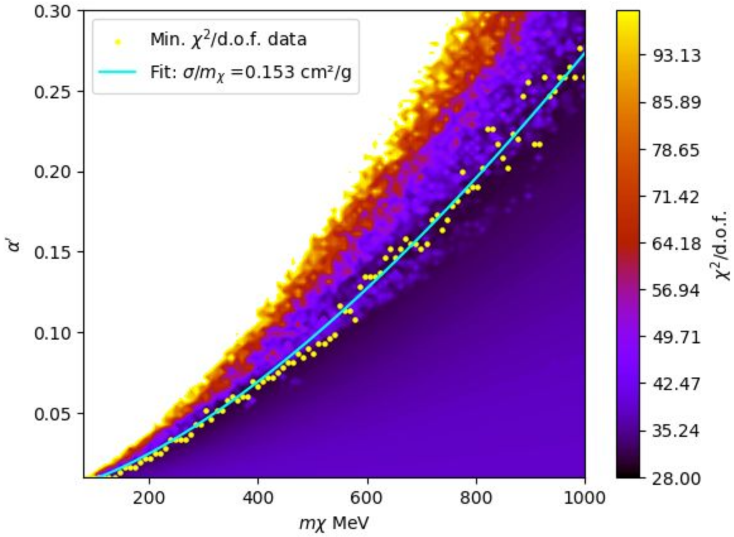


m_χ =478.7049440361467 MeV
α' =0.18803015465431974
ρ_s =0.00146±4e-05 $M_\odot/pc^3$
r_s =29.03±1.03 kpc
χ^2_{red} =0.26



Conclusions and prospects

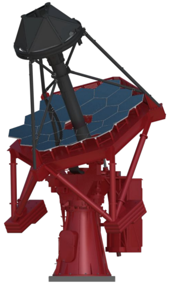
- Refine limits and parameter constraints such as cross-section for different DM models and sources, utilizing the CTA IRF’s and simulated data.

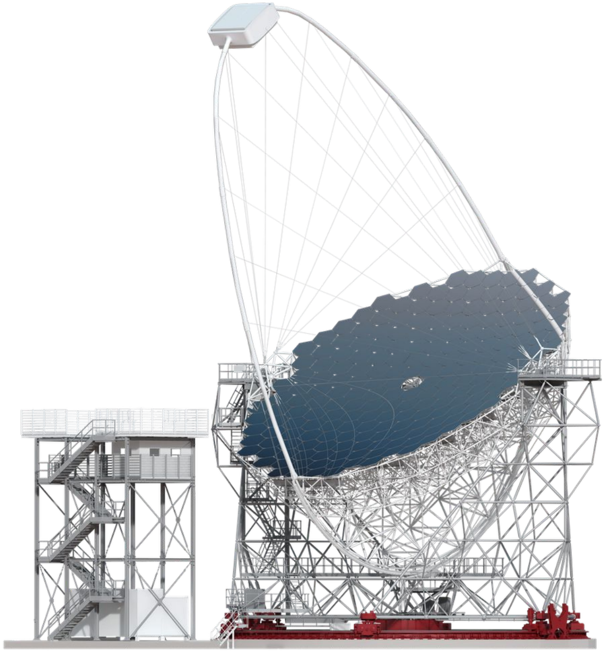
- Delve deeper into the Dark Photon model, looking for interesting effects and phenomenology (especially in the gamma ray energy range).

- Investigate the effects of the DP on UHE cosmic rays (I hope to start this soon).

- Improve the OADM analysis with new rotation curves data and exploring different density profiles.

Thanks!





Acknowledgements

FAPESP

2021/01089-1 2022/16842-0

CNPq

CAPES

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