Sensibilidad de CTA a aniquilación y decaimiento de materia oscura en el cúmulo de Perseo

Sergio Hernández Cadena & Rubén Alfaro Molina

División de Rayos Cósmicos, Sociedad Mexicana de Física, 2023
Instituto de Física, UNAM

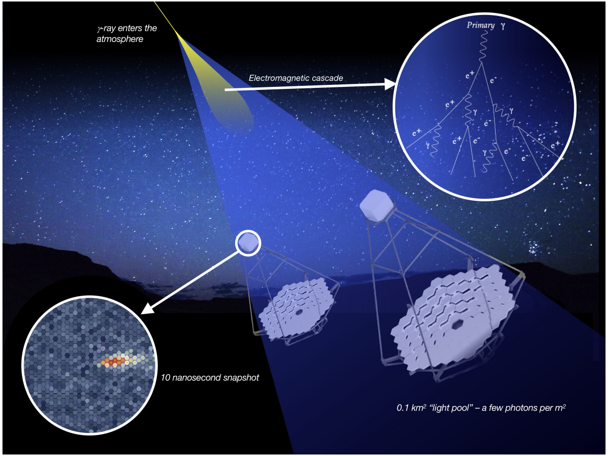
Contents

The Cherenkov Telescope Array

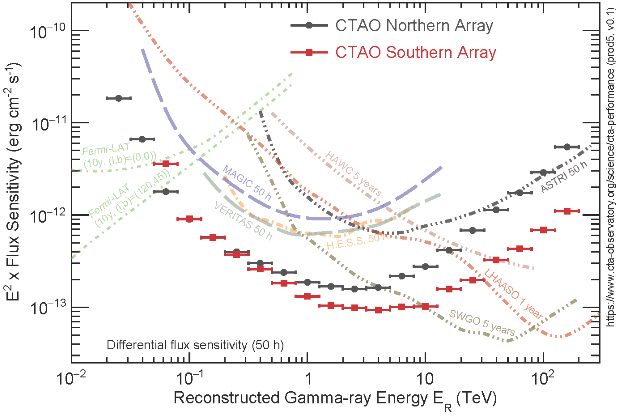
The Cherenkov Telescope Array

CTA is one of the next generation ground-based gamma-ray observatories

1. Energy range from 20GeV up to 300TeV
2. All-Sky Coverage: Two arrays of Imaging Air Cherenkov Telescopes (IACTs)
   1) CTA North [La Palma, Canary Islands, Spain]
   2) CTA South [Cerro Paranal, Chile]



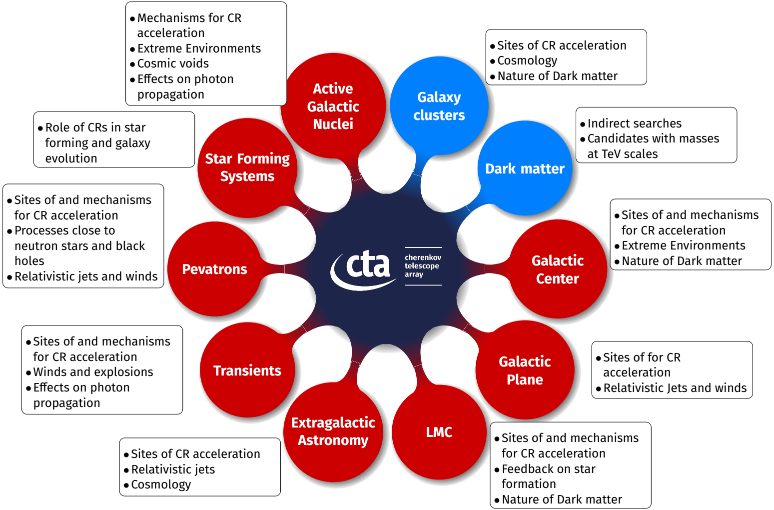
CTA Performance



With respect to current IACT's

1. Better energy resolution
2. $10\times$ improvement in Sensitivity
3. Rapid response to follow up of transients
4. Large Field of View
5. Better Angular resolution

CTA Key Science Programs



Dark matter

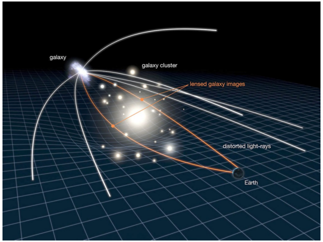
Dark Matter

There is a lot of evidence pointing to the existence of dark matter, but the nature of dark matter is still unknown

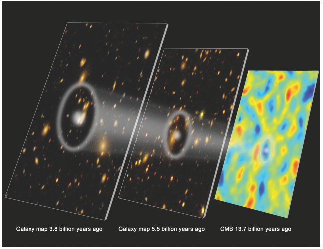
1. Rotation curve of galaxies
2. Gravitational lensing
3. Acoustic oscillations

It is estimated that dark matter represents $\approx 27\,\%$ of the content of the Universe

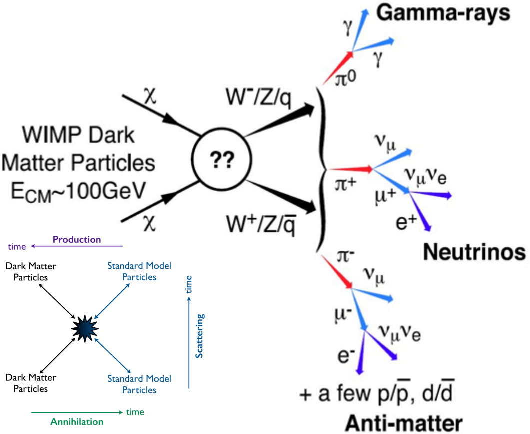
NASA; ESA



[SDSS-III; South Pole Telescope; Zosia Rostomian.]



Indirect Searches



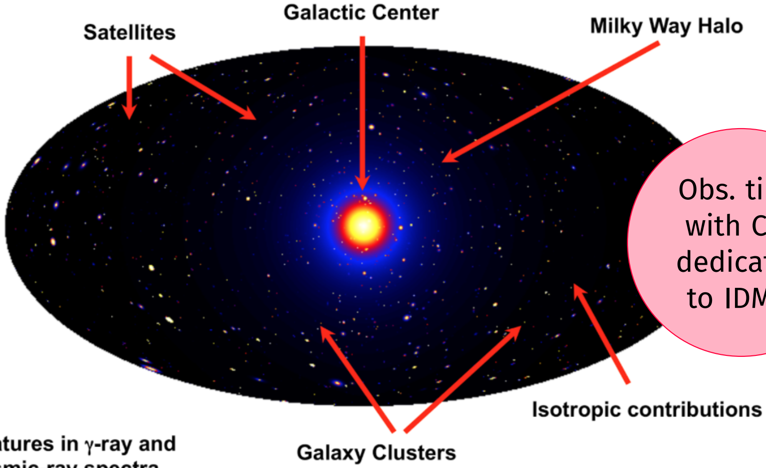
[Fermi Space Telescope; NASA]

1. Weakly Interactive Massive Particles (WIMPs)
2. Candidates with masses at TeV scales
3. Annhilation and decay of WIMPs
4. Continuum and line-emission spectra

$$\frac{d\Phi^{\text{ann}}}{dE} = \underbrace{\frac{\langle \sigma v \rangle}{8\pi m^2}\frac{dN}{dE}}_{\text{P.P. term}} \underbrace{\int\int \rho_{\text{DM}}^2 \, dl \, d\Omega}_{\text{J factor}}$$

$$\frac{d\Phi^{\text{dec}}}{dE} = \underbrace{\frac{\Gamma}{4\pi m}\frac{dN}{dE}}_{\text{P.P. term}} \underbrace{\int\int \rho_{\text{DM}} \, dl \, d\Omega}_{\text{D factor}}$$

Where to look for dark matter



Features in γ-ray and cosmic-ray spectra

Obs. time with CTA dedicated to IDMS!

Dark Matter simulation: Pieri+ 2011PhRvD..83b3518P

Perseus Cluster

Perseus Cluster

z	0.01784	d_L	75.01 Mpc
M_{200}	7.5×10^{14} $\mathrm{M}_\odot$	(l, b)	$(150.5, 13.26)$
r_s	370.8 kpc	θ_{200}	1.42 deg

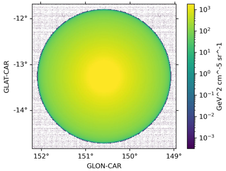
[Gendron-Marsolais et al.; NRAO/AUI/NSF; NASA; SDSS]

NGC 1275	IC 310
$l = 150.58$ deg	$l = 150.18$ deg
$b = -13.26$ deg	$b = -13.74$ deg

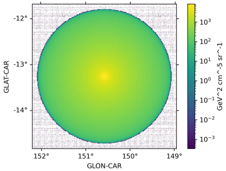
[L. Frattare; Fabian et al; NRAO/VLA/NSF; NASA; SDSS]

Dark matter Modelling

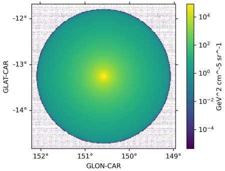
[J. Pérez-Romero & M. A. Sánchez-Conde, IFT-UAM]



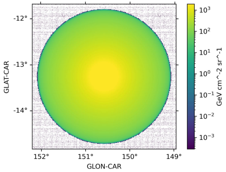
J-Max



J-Med



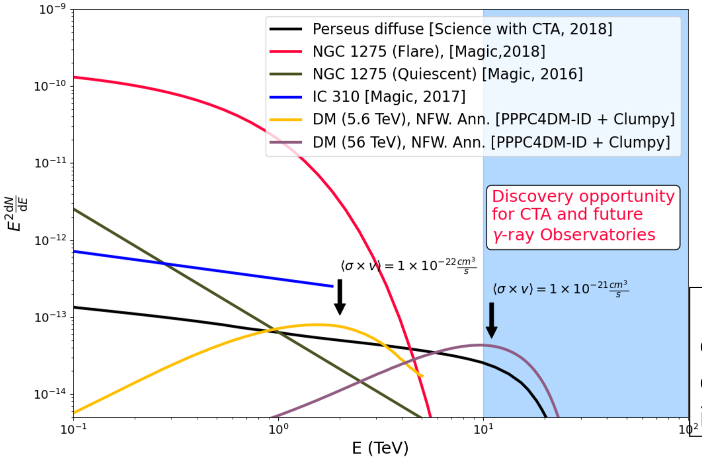
J-Min



Decay

1. J and D factors computed using Clumpy [Hütten+18]
2. DM candidates with masses in $[50 \text{ GeV}, 100 \text{ TeV}]$
3. Photon spectra for channels $b\bar{b}, \tau^+\tau^-, W^+W^-$ [Cirelli+2012,PPPC4DMID]
4. EBL attenuation: Dominguez+11

Gamma-Ray Emission



Different components of the total gamma-ray emission @ TeV energies in the Perseus cluster

Analysis

Observation setup

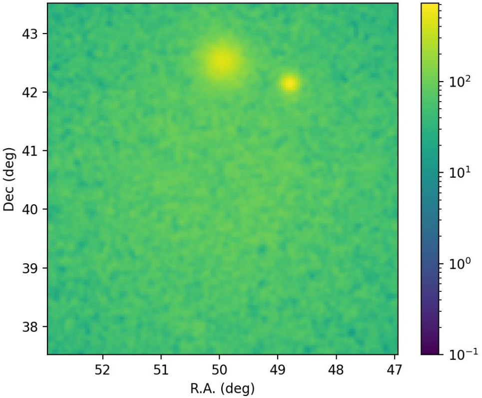
- Deep Observation: 300 h (100 reps.)
- Energy range: $[30\ \text{GeV}, 120\ \text{TeV}]$
- Software: `ctools`
- Gamma-Ray emission

1. NGC 1275 & IC 310
2. Cosmic Rays

   (`MINOT` [R. Adam 2020])
3. BKG (IRF)
4. Dark Matter

   (`PPPC4DMID` [Cirelli, 2012])

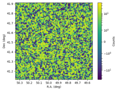
   1) Annihilation and Decay



Counts Map of one observation of Perseus, simulated with ctools

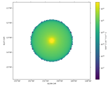
Analysis and calculation of ULs

Maps



Likelihood

DM Model



$$TS = -2\frac{\mathfrak{L}_{\text{Null}}(\hat{\alpha}, \hat{\nu}|\mathbf{D})}{\mathfrak{L}_{\text{DM}}(\widetilde{\alpha}, \widetilde{\nu}|\mathbf{D})}$$

Test Statistic

1. If $TS > 25 \rightarrow$ Detection
2. If $TS < 25 \rightarrow$ Exclusion Limits

- α: Parameters of interest $\langle\sigma v\rangle, \tau, X\angle CR\rangle$
- ν: Nuisance Parameters $J, B(r), \alpha_{pp}$

$$\mathfrak{L}(\alpha, \nu|\mathbf{D}) =$$

$$\prod_i \prod_j \frac{(S_{i,j}(\alpha)+B_{i,j})^{N_{i,j}^{\text{on}}}}{N_{i,j}^{(\text{on})}!} e^{-(S_{i,j}+B_{i,j})} \frac{(\tau_{i,j}B_{i,j})^{N_{i,j}^{\text{off}}}}{N_{i,j}^{(\text{off})}!} e^{-(\tau_{i,j}B_{i,j})} \times$$

$$\frac{1}{\ln(10) J_{\text{obs}} \sigma_J \sqrt{(2\pi)}} \exp\left(\frac{-(\log(J)-\log(J_{\text{obs}}))^2}{2\sigma_J^2}\right)$$

[Fermi, 2014]

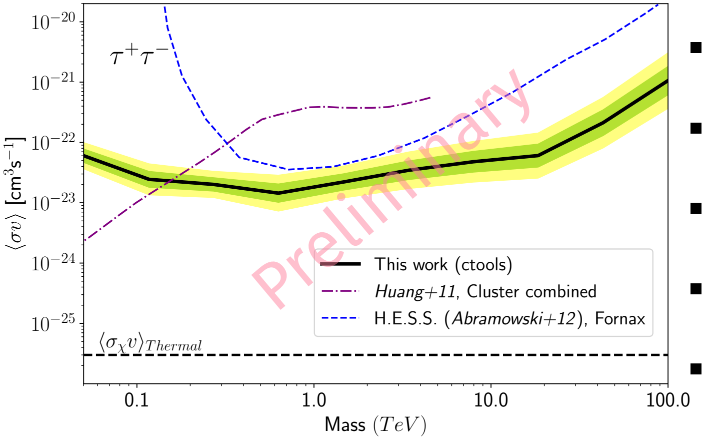
ctadmtool

cherenkov telescope array

1. Based on `ctools`
2. Calculation of gamma-ray flux induced by annihilatio or decay of DM
3. Calculation of best fit parameters
4. (If not detection) Calculation of ULs for a range of masses
5. Results saved to a fits file
6. Public repository (Github): `https://github.com/sergiohcdna/ctadmtool`

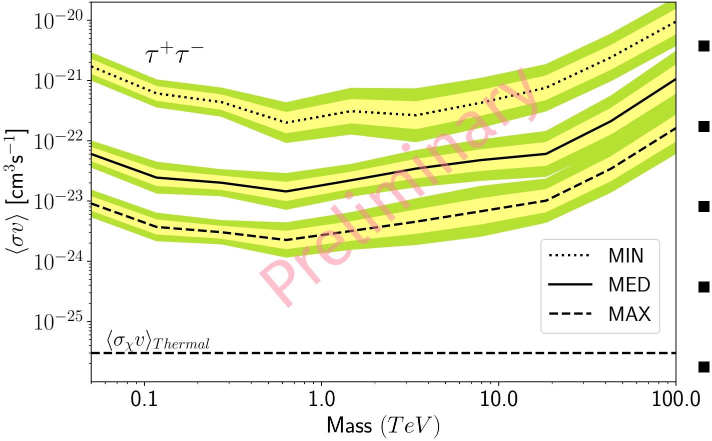
Results

Annihilation



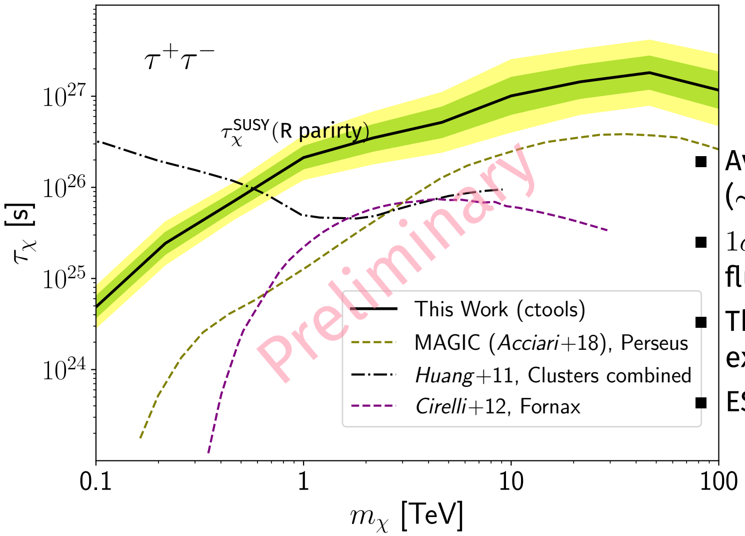
- Average value for $\langle\sigma_\chi v\rangle$ (~ 100 realizations)
- 1σ band. Effect of Bkg fluctuations.
- The region above the curves is excluded
- Effect of the different emission escenarios
- ES: Extended search

Annihilation



- Average value for $\langle \sigma_\chi v \rangle$ (~ 100 realizations)
- 1σ band. Effect of Bkg fluctuations.
- The region above the curves is excluded
- Effect of the different emission escenarios
- ES: Extended search

Decay



- Average value for τ_χ (~ 100 realizations)
- 1σ band. Effect of Bkg fluctuations.
- The region below the curves is excluded
- ES: Extended search

Summary

1. CTA has a unique chance of discovery for DM candidates with masses @TeV scales and close to the unitarity-limit
2. Results by CTA, even in the case of null detection, will complement direct and collider searches
3. CTA will be able to put restrictive constraints to annihilation $\langle \sigma_\chi v \rangle$ and decay τ_χ using deep observations of the Perseus Cluster

Thanks!