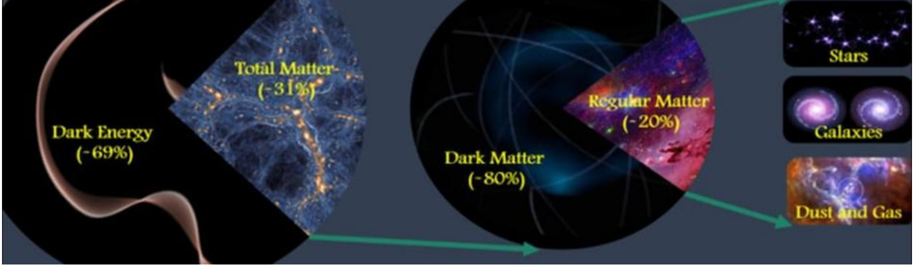


UNIVERSIDADE DE SÃO PAULO
Instituto de Física de São Carlos

Cosmo-ufes
Center for Astrophysics and Cosmology

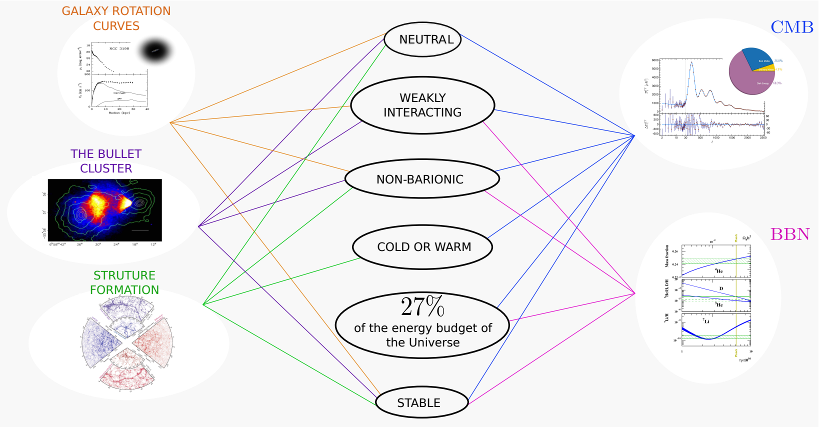
Matéria Escura tipo WIMP: status atual e cenários alternativos

Clarissa Siqueira

Abril, 2021

Contents

What are the main evidences for the Dark Matter Existence?

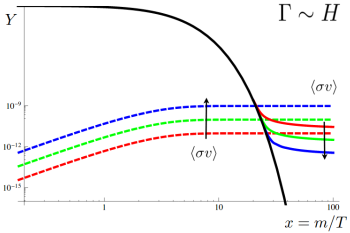


Main candidates: Weakly Interacting Massive Particles $\rightarrow$ WIMPs!

Dark Matter Relic Density

Boltzmann Equation

$$\dot{n}_i + 3Hn_i = R(T)$$



$$\Omega_{DM} h^2 = 0.1200 \pm 0.0012 \ \text{(Planck)}$$

- Freeze-out:

$$DM + DM \leftrightarrows SM + SM$$
$$DM + DM \rightarrow SM + SM$$

$$-\frac{T}{\tilde{g}} \frac{dY_\chi}{dT} = s \frac{Y^2_{\chi,eq} \langle \sigma v \rangle}{H} \left(1 - \frac{Y^2_\chi}{Y^2_{\chi,eq}} \right)$$

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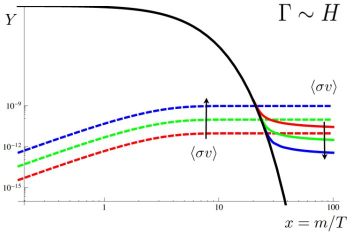

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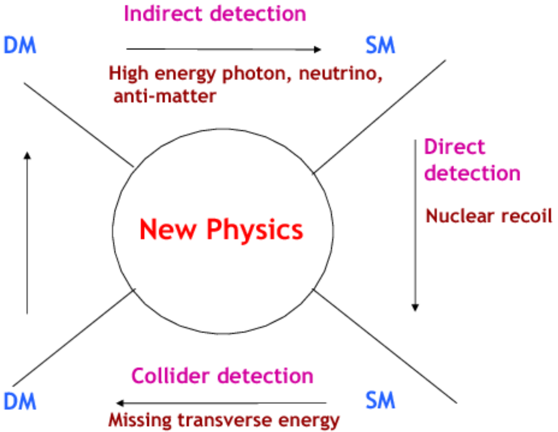
$$\Omega_{DM}h^2 = 0.1200 \pm 0.0012 \ \ (\text{Planck})$$

WIMP Miracle:

Detectable cross section by the current experiments!!

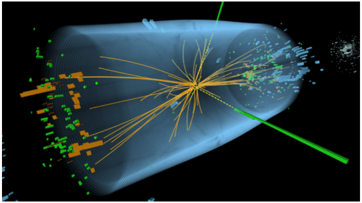
$$\langle\sigma v\rangle \simeq 3 \times 10^{-26}\text{cm}^3/\text{s}$$

Detection Methods



Searching for Dark Matter at colliders

- Large Hadron Collider (LHC) $\rightarrow$ proton-proton collision;
- Circumference of 27 km;
- Located between France and Switzerland;
- DM doesn't leave trace in the detectors $\rightarrow$ Missing Energy.



Dark Matter distribution

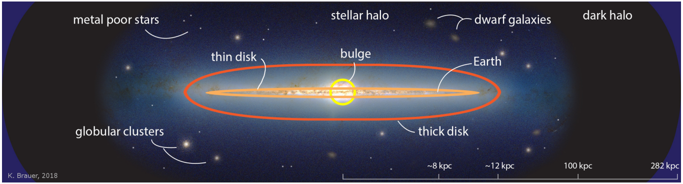


Figure: http://www.mit.edu/~kbrauer/research.html.

- Direct and Indirect detection methods need information about the velocity and density distributions in the medium;
- Milky Way: It is a complex system composed by gas and dust (intergalactic medium), stars and Dark Matter;
- Direct Detection: Information of the Milky Way at the Sun's location;
- Indirect Detection: Galactic Center / Galactic halo.

Dark Matter distribution

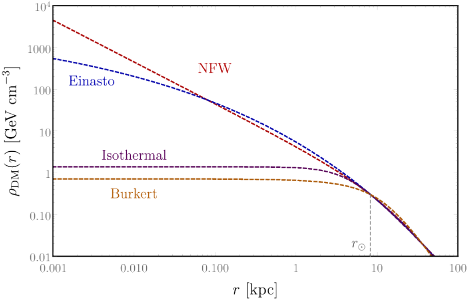


Figure: https://arxiv.org/pdf/1901.05822.pdf.

- Estimate these quantities is non-trivial;
- N-body simulations;
- Density profiles: NFW, Einasto, Burket and isothermal;
- $\rho_\odot = 0.4$ GeV/cm^3 e $v_c = 220 \pm 20$ km/s.

Targets: Dwarf Spheroidal Galaxies

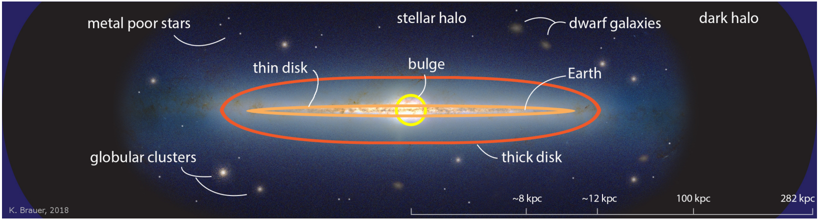


Figure: http://www.mit.edu/~kbrauer/research.html.

- Galaxies which orbits the Milky Way;
- Located between 15 and 250 kpc from the galactic Center;
- High mass-luminosity ratio, predominantly composed by DM.

Another targets

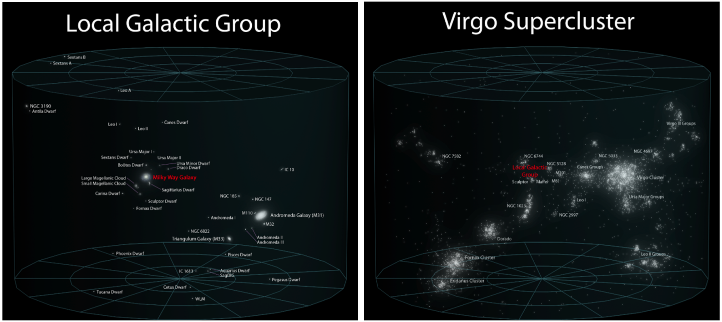
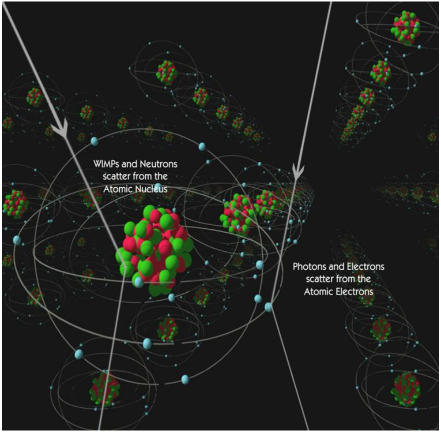


Figure: https://www.mpi-hd.mpg.de/personalhomes/marrodan/Teaching/WS2015_DM/DarkMatterSummary.pdf.

- Andromeda Galaxy (~ 780 kpc from the Milky Way);
- Virgo Cluster (~ 20 Mpc from the Milky Way);
- Coma Cluster (~ 100 Mpc from the Milky Way).

Direct Detection - WIMPs

$$E_R \sim \frac{1}{2} m_\chi v^2 = \frac{1}{2} 100\text{GeV} \times (0.75 \times 10^{-3} c)^2 \approx 30\text{keV}$$



- Ionization, excitation and/or heating;
- Observable signals at the experiments.

Direct Detection - WIMPs I

Interaction rate:

Astrophysics

$$\frac{dR}{dE}(E,t) \propto n_A \times \frac{\rho_\chi}{m_\chi} \times \sigma_{\chi N} \times \langle v \rangle$$

Experiment Interaction Model

with,

$$\sigma_{\chi N} \propto A^2,$$

where A is the mass number.

Estimate of the event rate:

$$R \sim 0.16 \ \text{events/kg/year},$$

where we took:

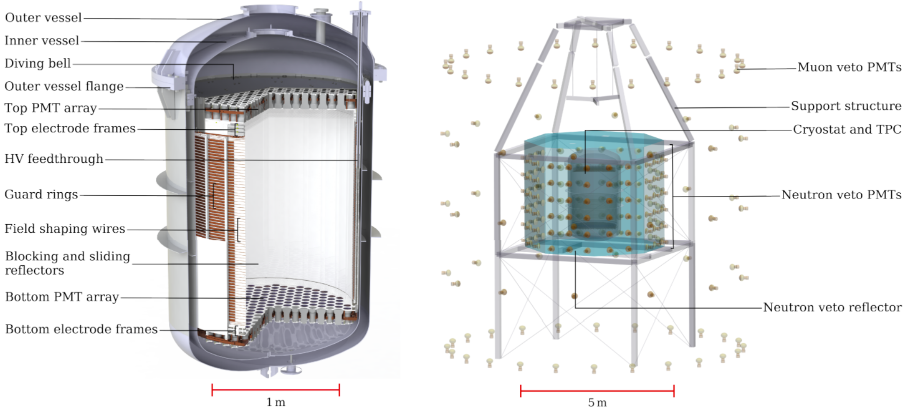
$\rho_\chi = 0.4$ GeV/cm^3,
$\langle v \rangle = 220$ km/s$= 0.75 \times 10^{-3}$c,

and for a typical WIMP,

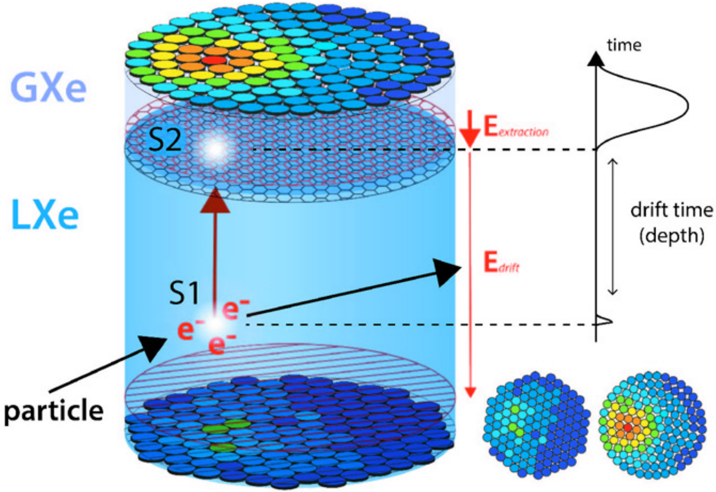
$m_\chi = 100$ GeV e
$\sigma_{\chi N} = 10^{-38}$ cm^2.

Experiments looking for WIMPs generally use heavy nuclei like Xenon!

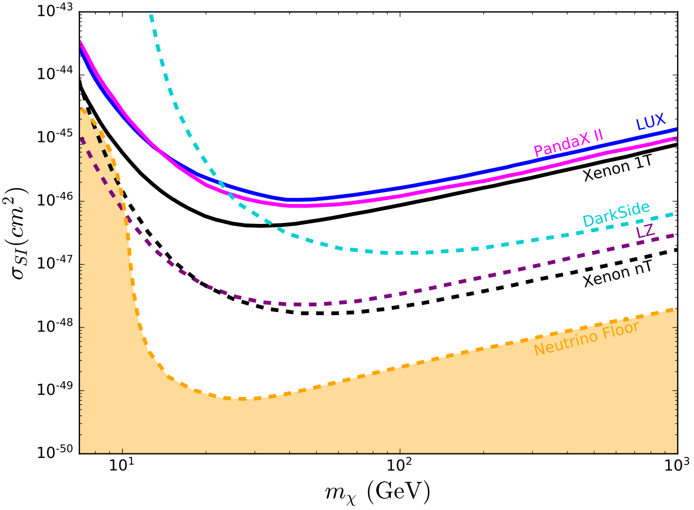
Experiments with Xenon (LUX/XENON1T)



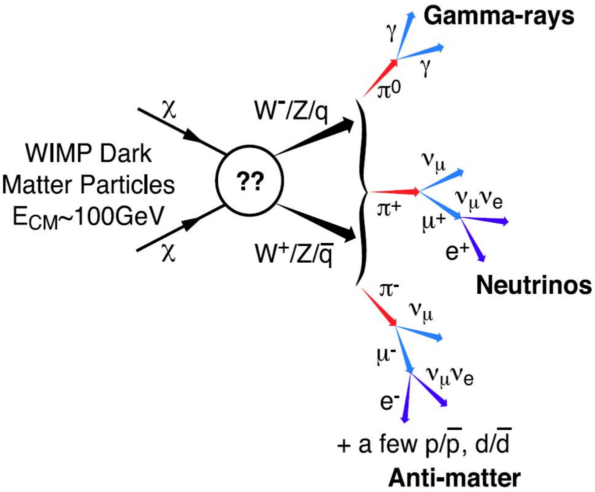
Detection in experiments with Xenon (LUX/XENON1T)



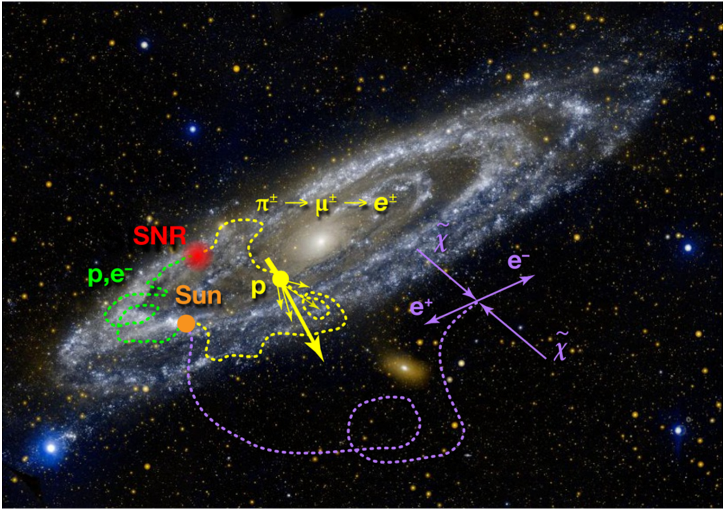
Limits - WIMPs



Indirect Detection



Indirect Detection



The electromagnetic spectrum

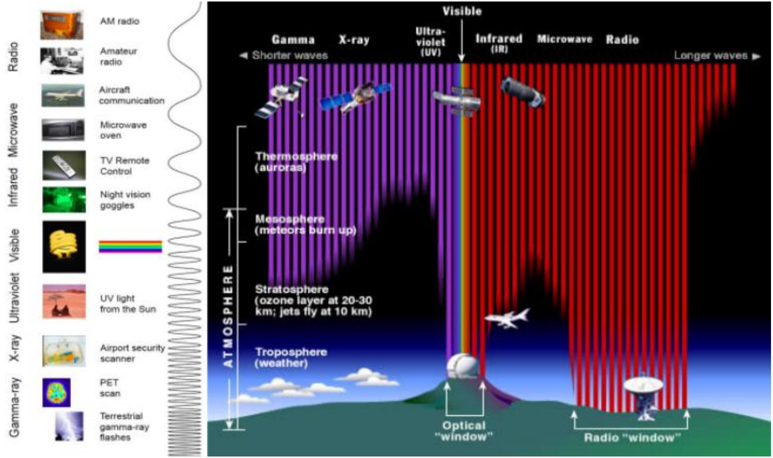


Figure: https://imagine.gsfc.nasa.gov/science/toolbox/emspectrum1.html.

Experiments - Cherenkov light

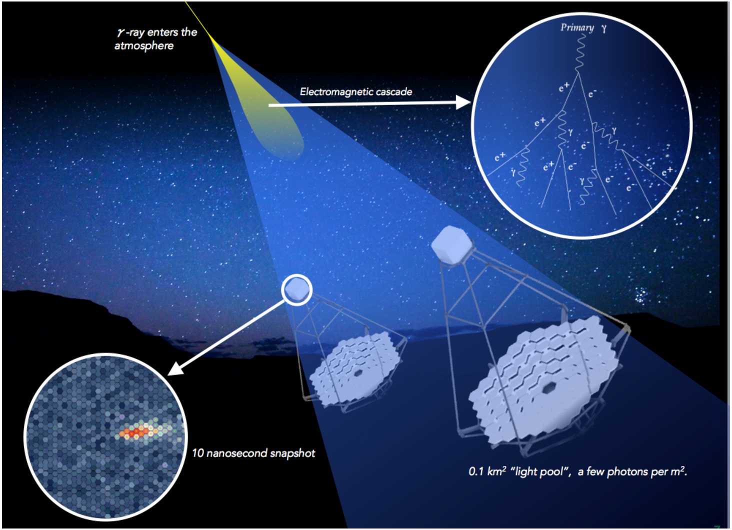
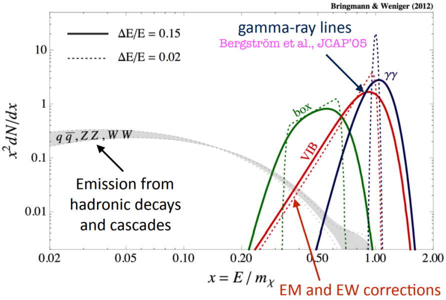


Figure: Detection of Cherenkov light through CTA.

γ-ray Flux

$$\gamma\text{-ray Flux: } \frac{\varphi_\gamma}{dE} = \overbrace{\frac{\langle\sigma v\rangle}{8\pi m_{DM}^2}\frac{dN_\gamma}{dE}}^{\text{Particle Physics}} \overbrace{\int ds \int d\Omega\, \rho_{DM}^2}^{\text{J-Factor}}$$

Spectral Energy Distribution



γ-ray Flux

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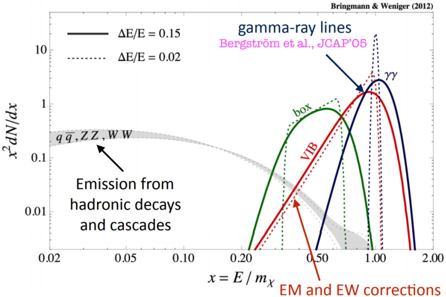
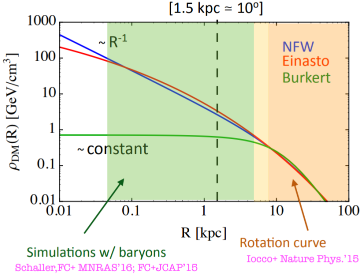
Spectral Energy Distribution

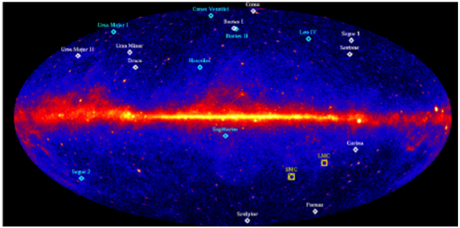


Spacial Distribution



Pictures from Calore, 2018.

Local targets: Dwarf Galaxies $\times$ Galactic Center



dSph

- Predominantly composed by DM;
- Very clean targets for DM searches;
- Exclude the std cross section for $M_{DM} < 100$ GeV;
- Strongest limits by Fermi-LAT.

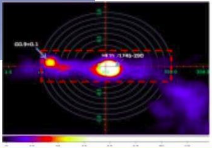
GC

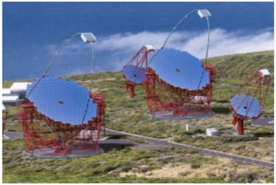
- Central region of the Galaxy;
- Excludes $|b| < 0.3^\circ$;
- Region with high DM density;
- Limits from HESS and CTA.

γ-ray Experiments

Fermi-LAT
Energy: 500 MeV - 500 GeV

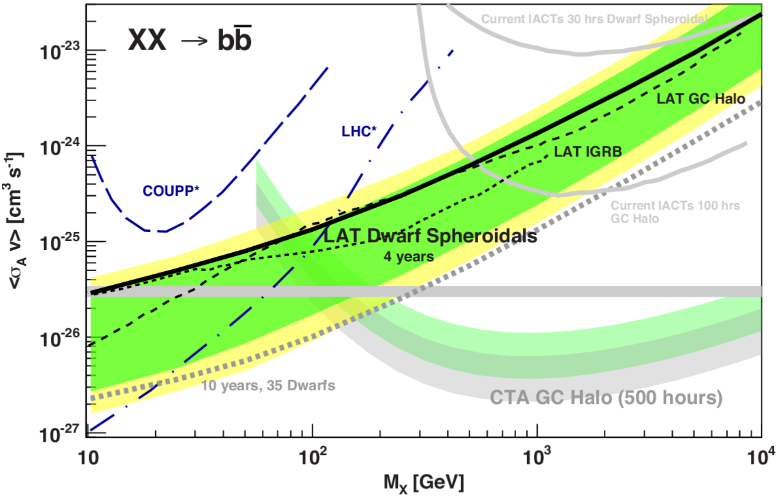
HESS
Energy: 230 GeV - 30TeV





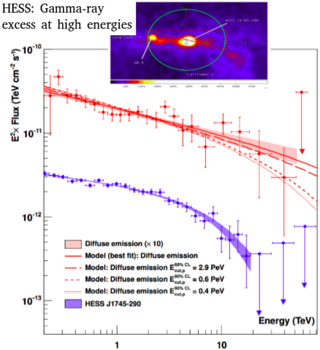
CTA
Energy: 20 GeV - 300 TeV

Limits from Indirect Detection Searches

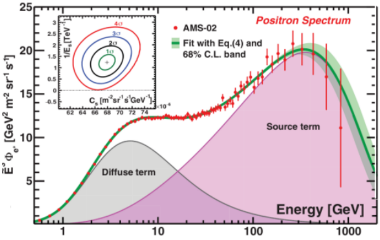


Possible DM signals?

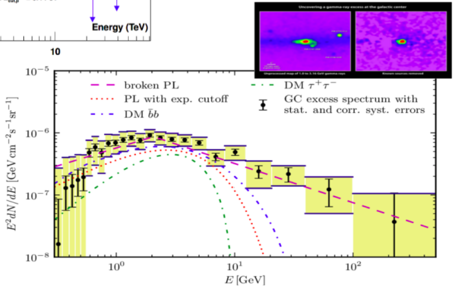
HESS: Gamma-ray excess at high energies



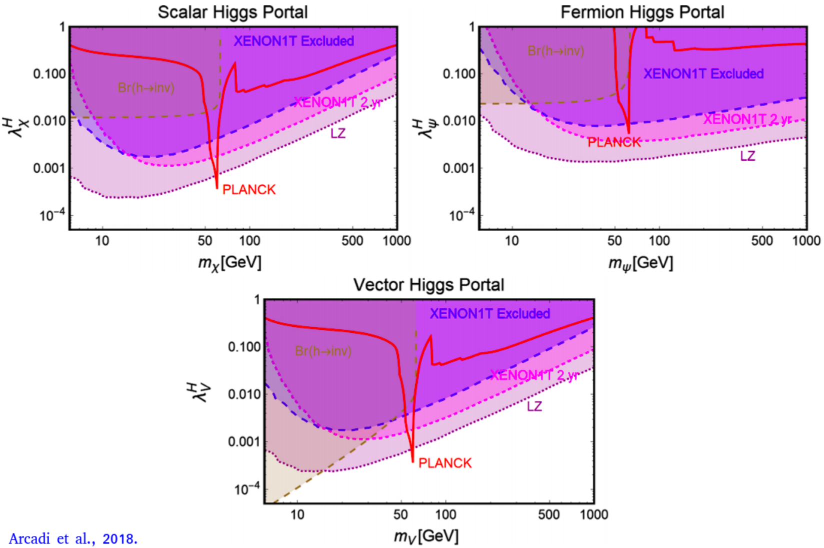
AMS-02: Positron excess



Fermi-LAT: Gamma-ray excess at lower energies

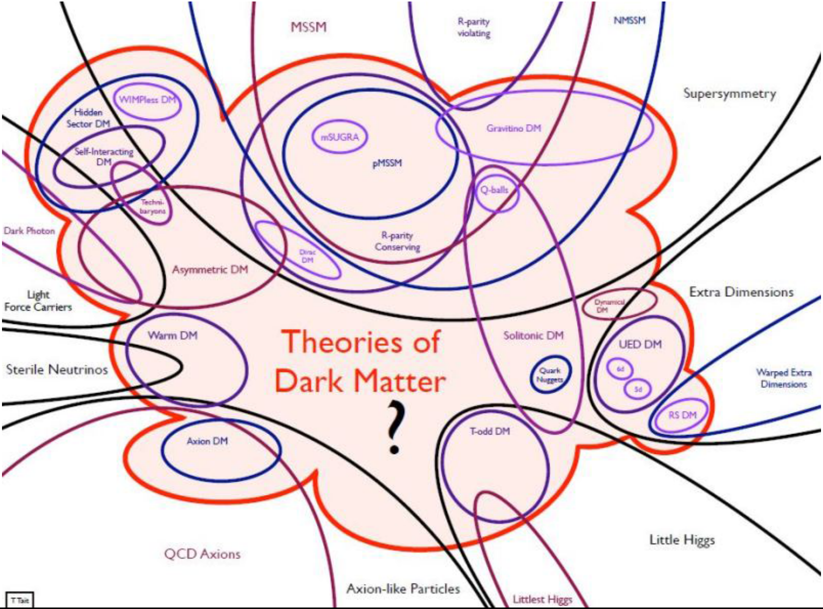


Stringent limits on WIMPs

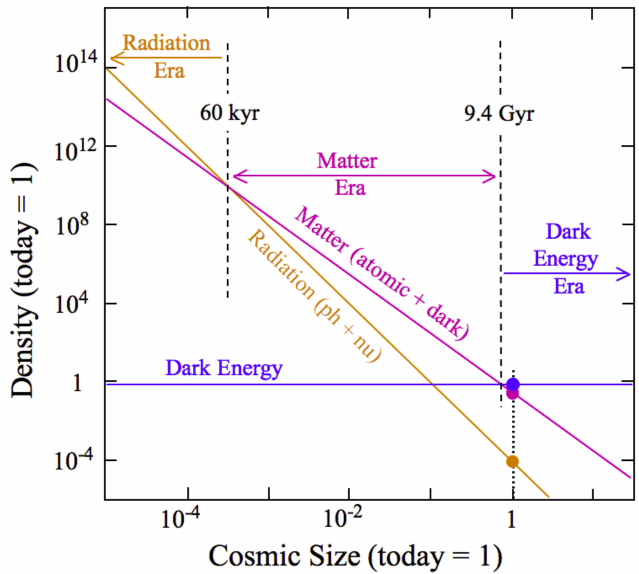


Arcadi et al., 2018.

Alternative scenarios

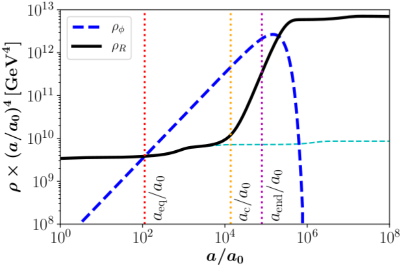


Scenario 1: Non-standard Cosmology

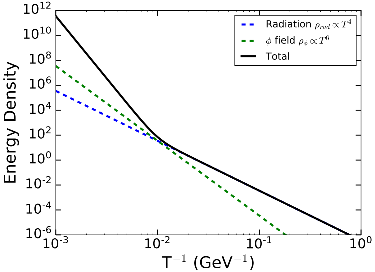


Scenario 1: Non-standard Cosmology

Matter Domination



Fast Expanding



The new relic density:

$$Y_{obs} = \frac{Y_0}{D}$$

with,

$$D = \frac{S(T_{end})}{S(T_{eq})}$$

Relic density altered:

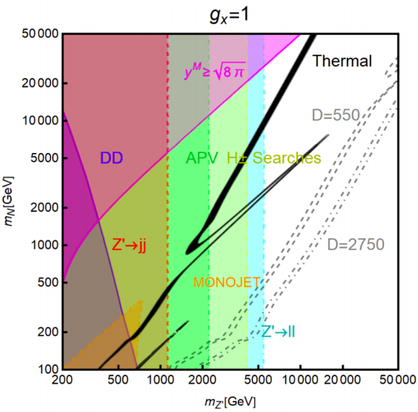
$$\uparrow H \rightarrow \uparrow \Gamma \rightarrow \uparrow \langle \sigma v \rangle$$

and,

$$Y_\chi(x) \simeq \frac{x_r}{m_\chi M_{Pl} \langle \sigma v \rangle} \left[\frac{2}{x_f} + \log(x/x_f) \right]^{-1}$$

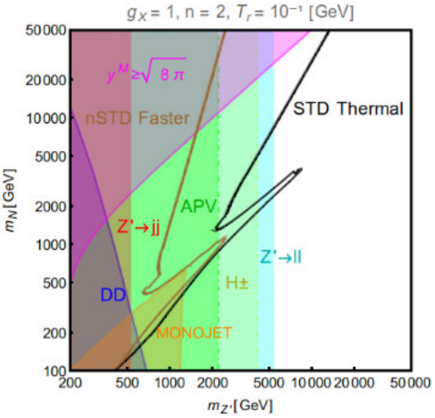
Scenario 1: Non-standard Cosmology

Matter Domination



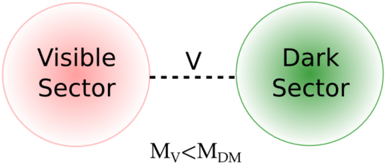
Arcadi, Queiroz, C.S.

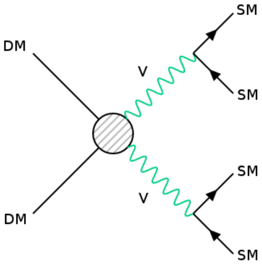
Fast Expanding



In preparation. Arcadi, Queiroz, Silva, CS

Scenario 2: Secluded Models





Motivation

- Escape from the stringent limits from direct and collider searches;
- It can be probed by indirect detection experiments;
- We will focus on TeV secluded models;
- Channels: $V \to 4e$, $V \to 4\mu$, $V \to 4\tau$, $V \to 4q$, and $V \to 4b$.

Gamma-ray spectrum for Secluded TeV I

$$\frac{dN^{\gamma}}{dx_1} = 2\int_{t_{1,min}}^{t_{1,max}} \frac{dx_0}{x_0\sqrt{1-\epsilon_1^2}}\frac{dN^{\gamma}}{dx_0} \quad (1)$$

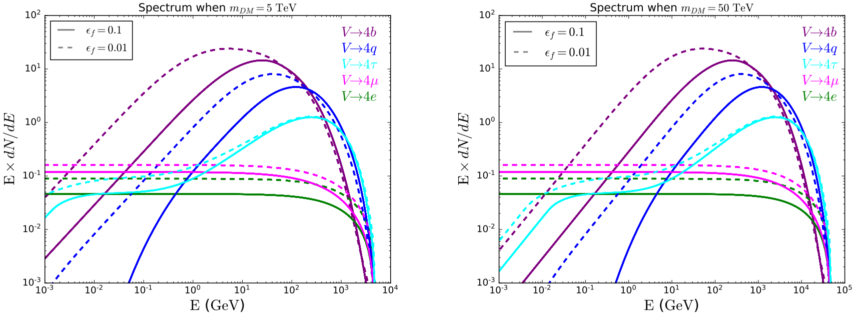
with $\epsilon_1 = m_V/m_{DM}$, and

$$\begin{aligned} t_{1,min} &= \frac{2x_1}{E_1^2}\left(1-\sqrt{1-\epsilon_1^2}\right) && (2)\\ t_{1,max} &= Min\left[1, \frac{2x_1}{E_1^2}\left(1+\sqrt{1-\epsilon_1^2}\right)\right] && (3)\end{aligned}$$

We can also define,

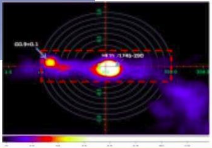
$$\epsilon_f = \frac{2m_f}{m_V}. \quad (4)$$

Gamma-ray spectrum for Secluded TeV II

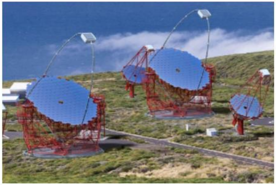


γ-ray Experiments

Fermi-LAT
Energy: 500 MeV - 500 GeV

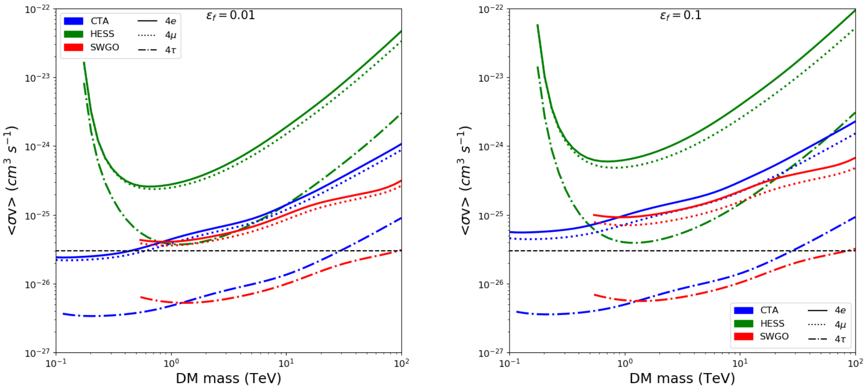


HESS
Energy: 230 GeV - 30TeV



CTA
Energy: 20 GeV - 300 TeV

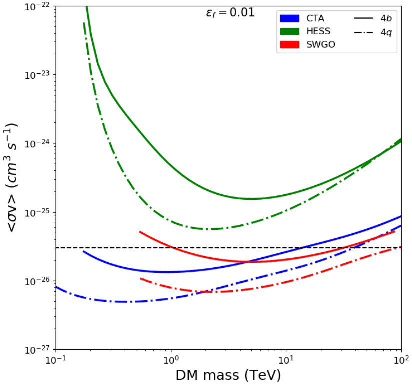
Preliminary Results - Leptons

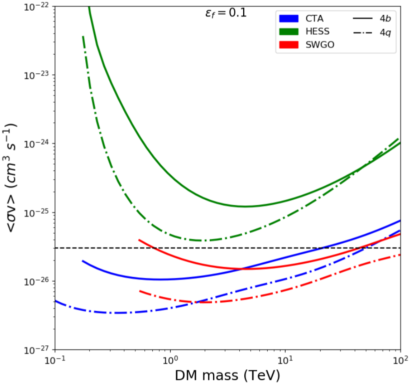


In preparation. Fortes, Queiroz, C.S., Viana

- Limits from H.E.S.S. (current, 254h) and SWGO and CTA (prospects, 10 years and 500h, respectively);
- ON-OFF 2D (energy and space) joint-likelihood method.

Preliminary Results - Quarks



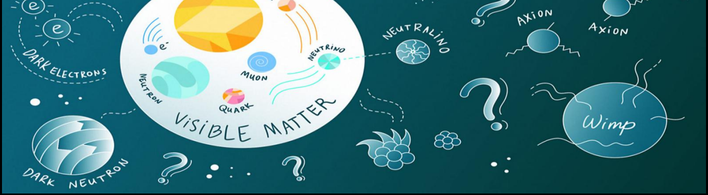


In preparation. Fortes, Queiroz, C.S., Viana

- Limits from H.E.S.S. (current, 254h) and SWGO and CTA (prospects, 10 years and 500h, respectively);
- ON-OFF 2D (energy and space) joint-likelihood method.

Conclusions

- The Dark Matter problem remains one of the big mysteries nowadays;
- WIMPs are excellent candidates to solve the DM problem, however, no signals were observed until now;
- Several alternative scenarios have been studied in the literature;
- We presented here two possibilities: Modify the cosmology or work with hidden sector particles, like secluded models.



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- **Thank you!!**
- **WIMP DM: current status and alternative scenarios**

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