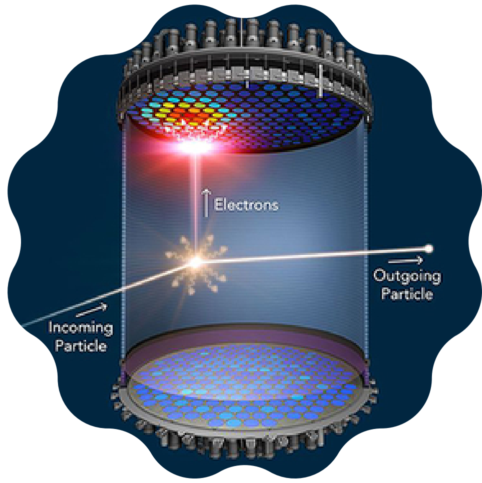
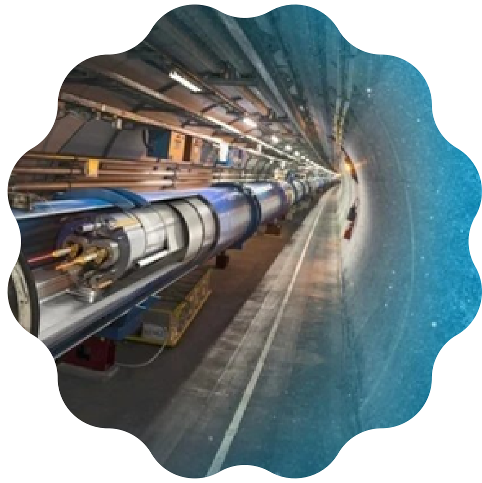
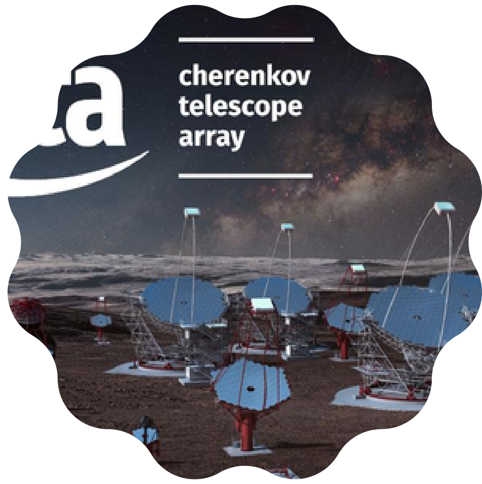
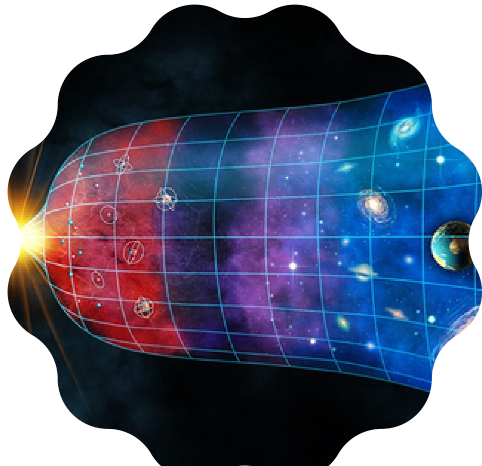
Theory and Phenomenology II: Overview of Dark Matter and AstroParticle Phenomenology









2023
SAPHIR Annual Research Meeting

Farinaldo Queiroz

SAPHIR & UFRN

MILLENNIUM INSTITUTE
FOR **SUBATOMIC PHYSICS**
AT HIGH-ENERGY FRONTIER
SAPHIR

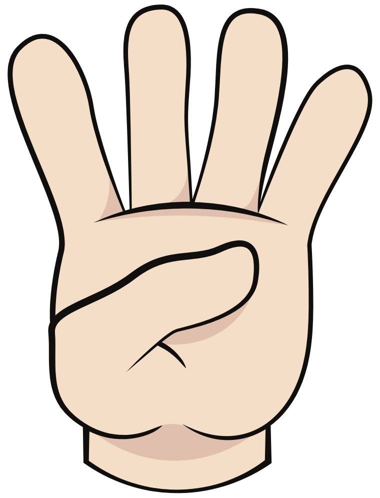
SIMONS
FOUNDATION
UNITED STATES

Take away messages

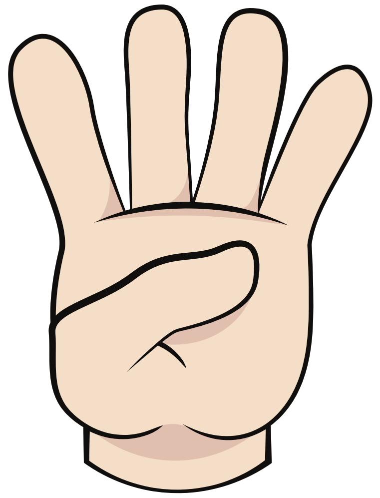
1. Without interdisciplinary searches one cannot claim the discovery of dark matter particles

2. The progress on the direct, indirect and collider experiments will move at very different paces in the near future

3. Part of the field is moving to a multifold dark matter search: Direct, indirect, collider, *neutron stars, *gravitational waves



After all, the only thing better than excellent science is creating excellent science with people you like (sometimes with beer and dinner).



After all, the only thing better than excellent science is creating excellent science with people you like (sometimes with beer and dinner).

serrapilheira

158 Million Pesos

SIMONS FOUNDATION

UNITED STATES

476 Million Pesos

CNPq

83 Million Pesos
(fellowships+per diem)

CAPES

97 Million Pesos
(PhD,Master's)

Evidence for Dark Matter

A brief history of time

Galaxy Rotation Curves

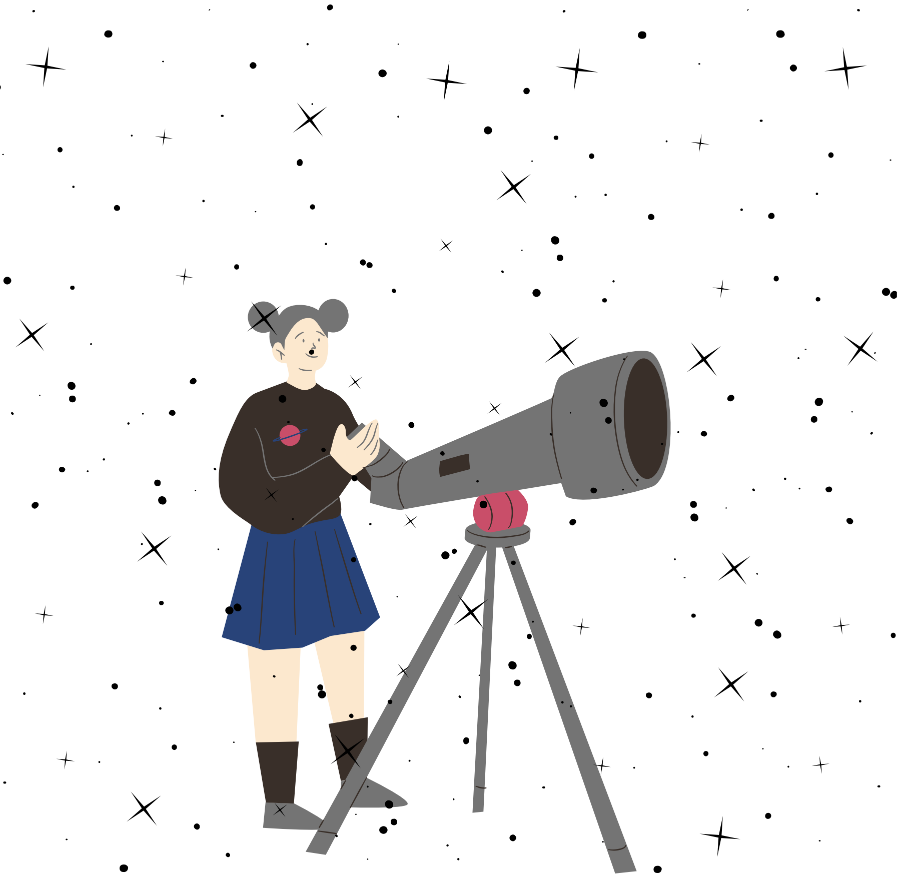
Cosmic Microwave Background

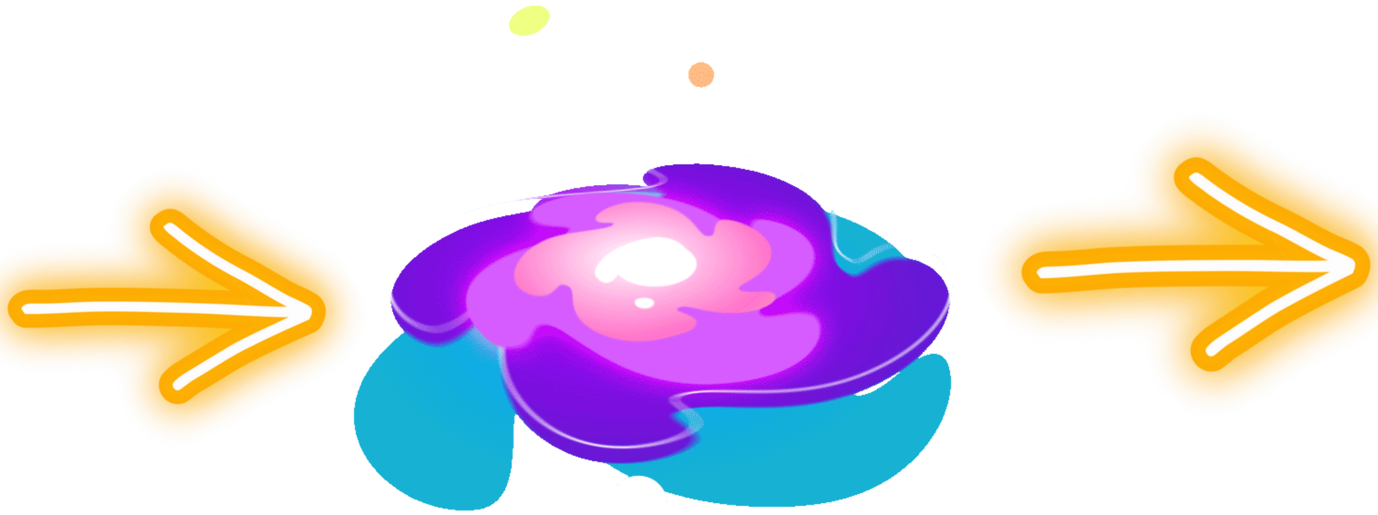
James Peebles

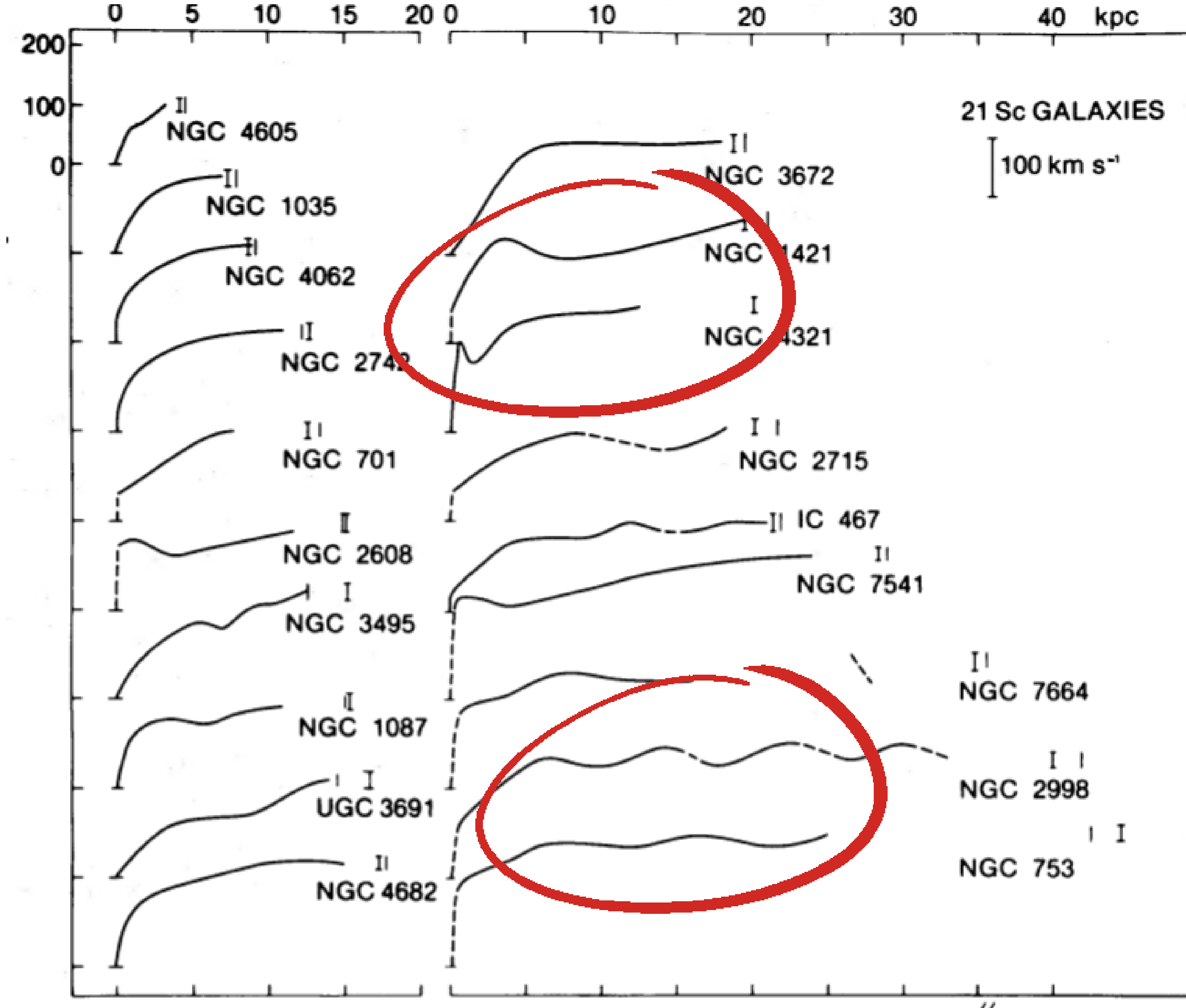
Nobel Prize 2019. I am deeply impressed with the way dark matter has explained cosmological observations.

In 1970 they measured the velocity of 67 regions in the 2-24kpc of M31 (Andromeda).
In 1980 they measured the rotation curves of 21 galaxies.

21 galaxies





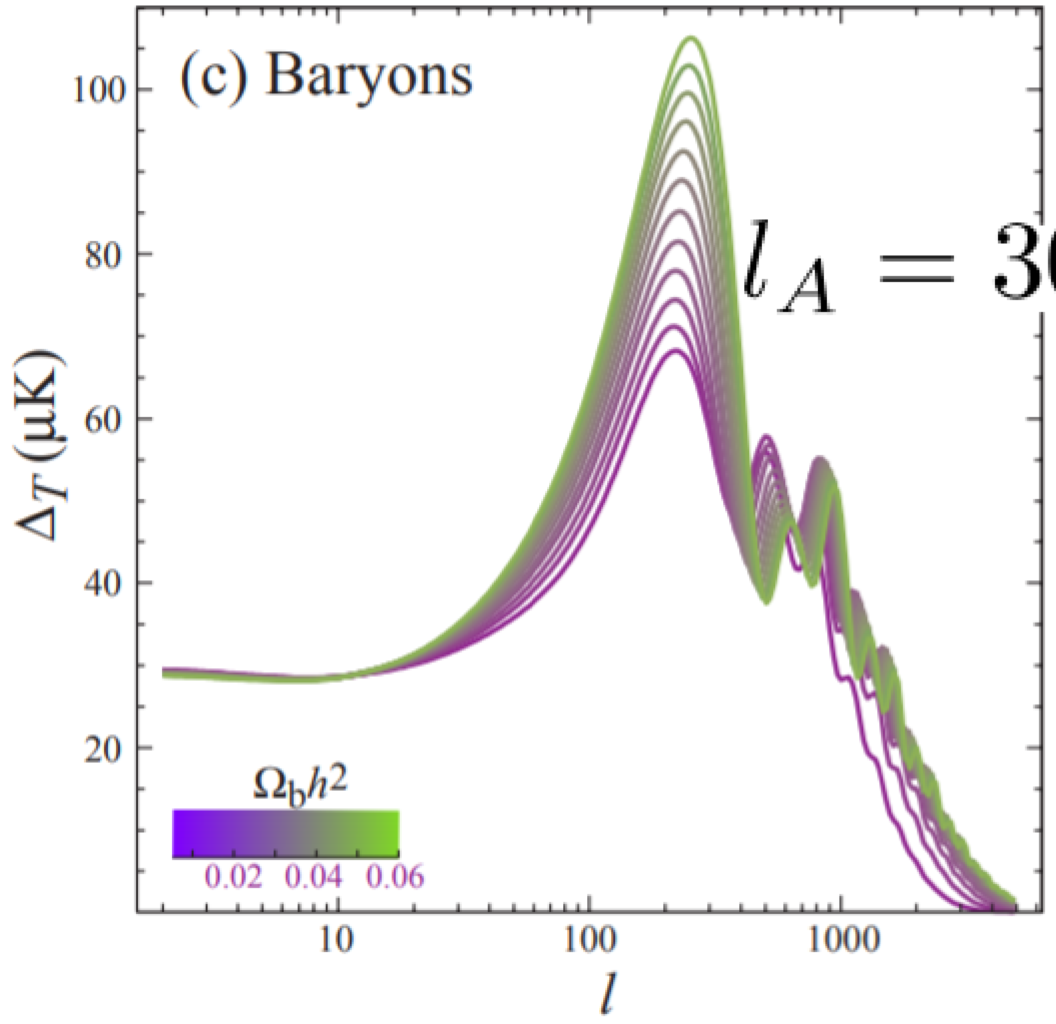


V. Rubin et al, Astrophys.J. 159 (1970) 379-403
V. Rubin et al, Astrophys.J. 238 (1980) 471

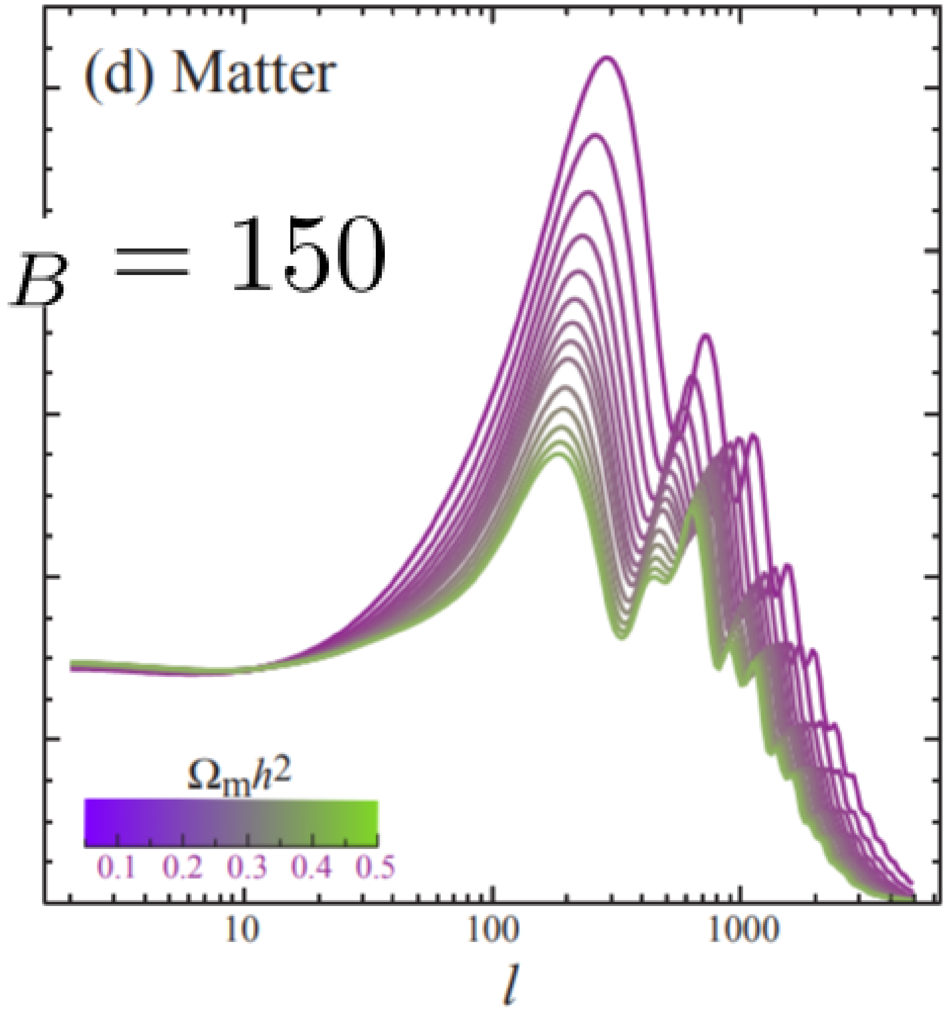
Dark Matter accounts for nearly 27% of the energy budget

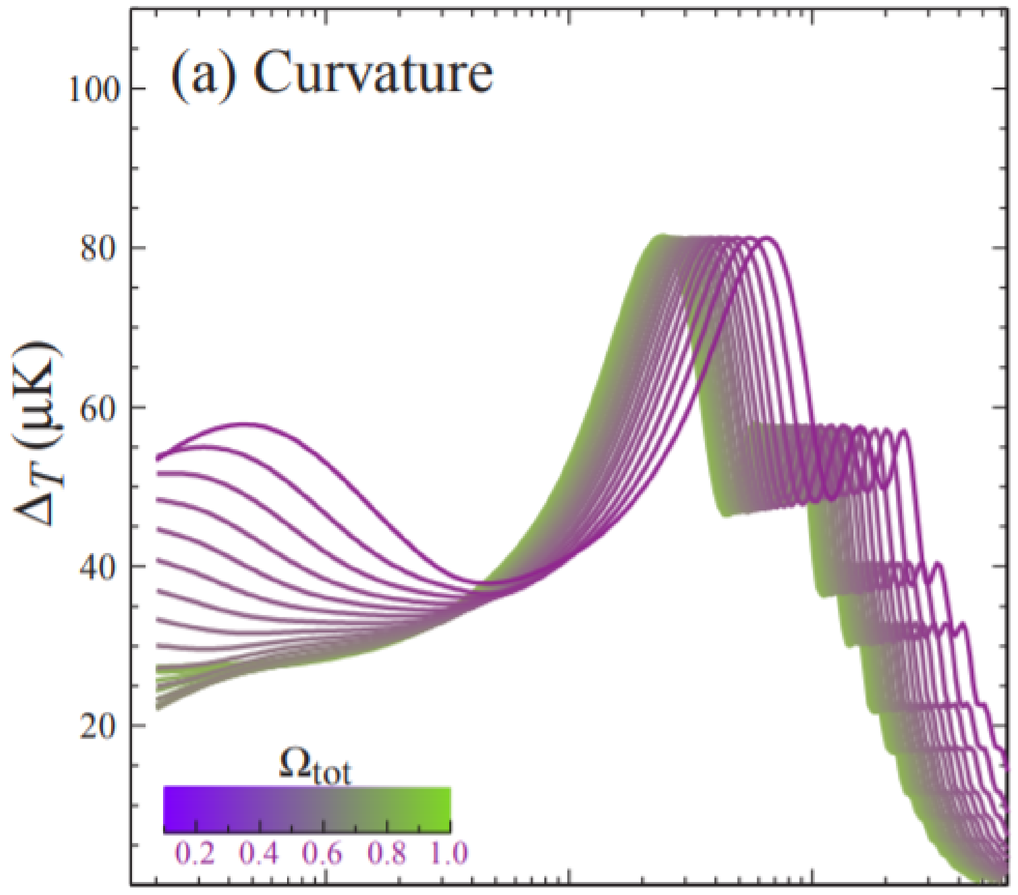
PLANCK arXiv:1807.06209

$$\frac{\Delta l_A}{l_A} \propto -0.24\frac{\Delta\Omega_m}{\Omega_m} - 1.1\frac{\Delta\Omega_{tot}}{\Omega_{tot}} \qquad \frac{\Delta l_B}{l_B} \propto 0.5\frac{\Delta\Omega_m}{\Omega_m} - 1.1\frac{\Delta\Omega_{tot}}{\Omega_{tot}}$$



$$l_A = 300, l_B = 150$$





W. Hu et al, Astrophys.J. 549 (2001) 669

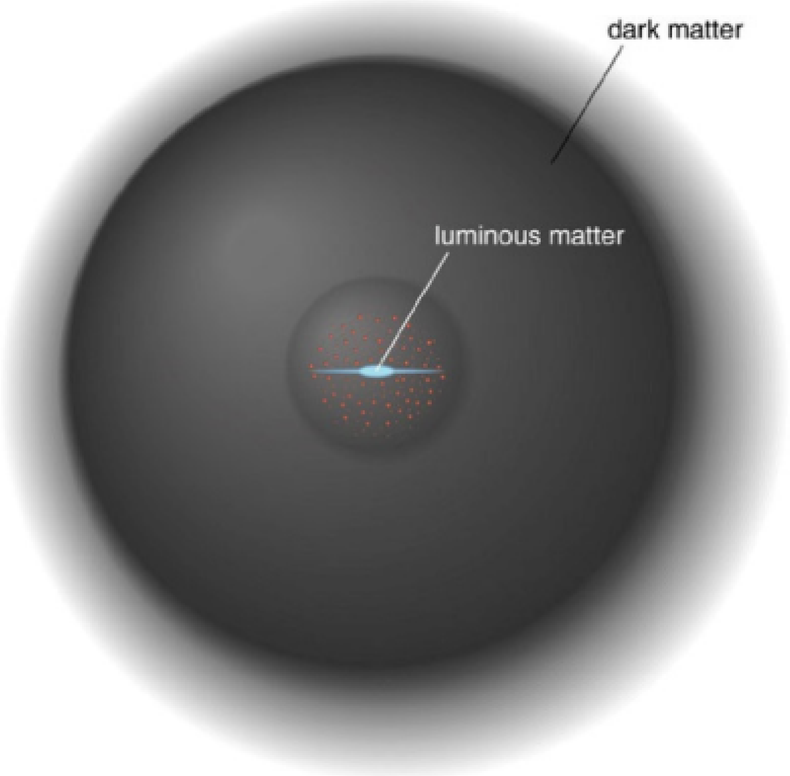
W. Hu, Annals Phys. 303 (2003) 203-225

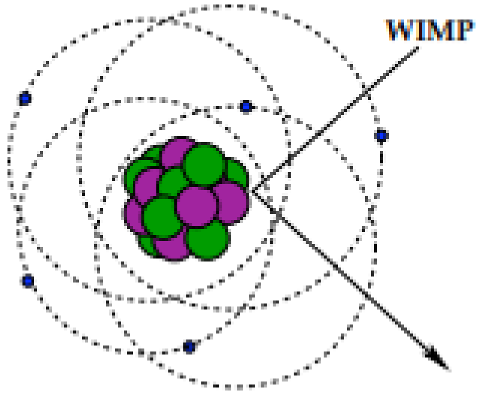
There is no alternative to dark matter

Black Holes

Particles

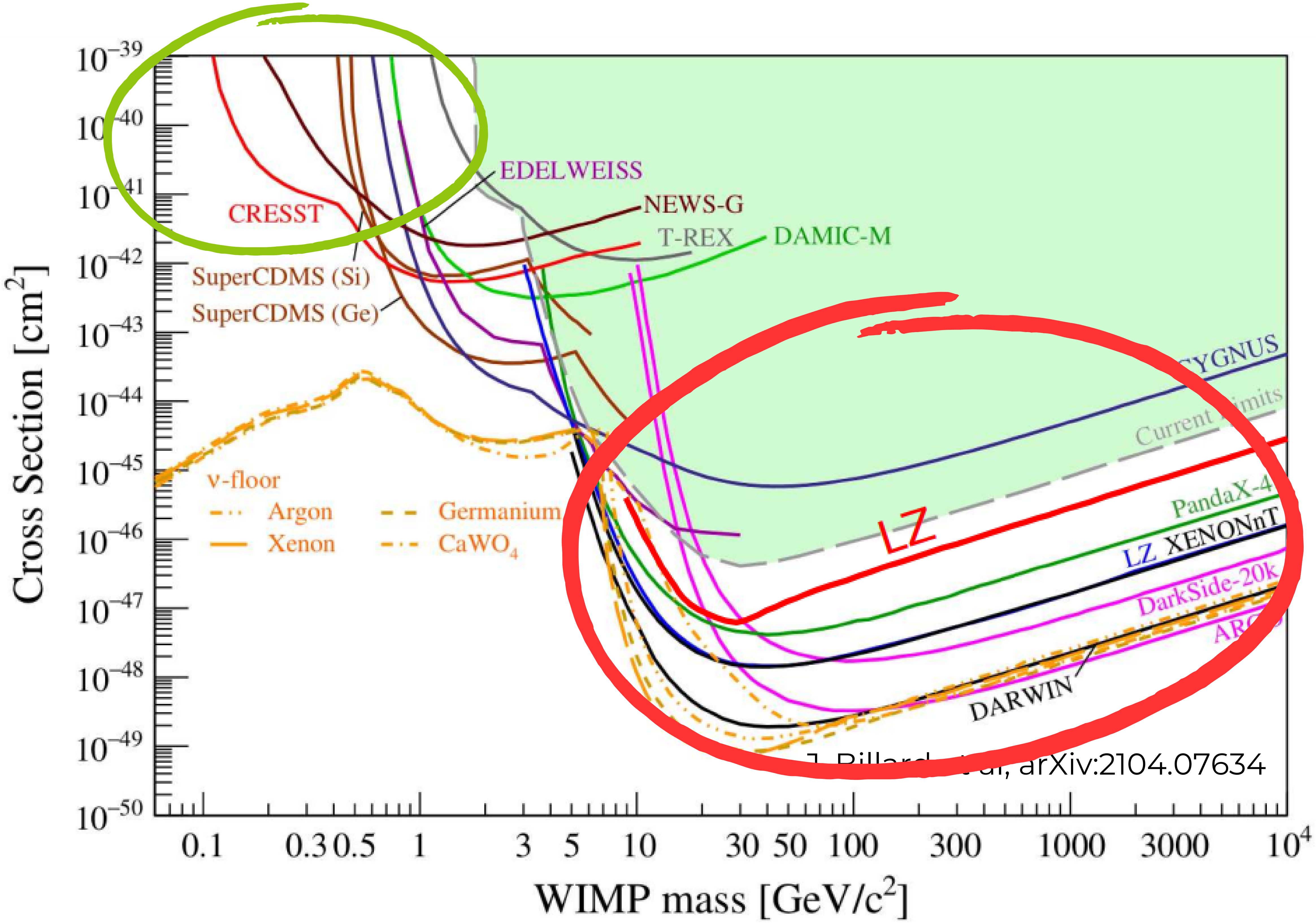
Let's Go!





$E_R \sim \mathcal{O}(10\,\text{keV})$

$$\frac{dR}{dE}(E,t) = \frac{\rho_0}{m_\chi \cdot m_A} \cdot \int v \cdot f(\mathbf{v},t) \cdot \frac{d\sigma}{dE}(E,v)\, d^3v$$



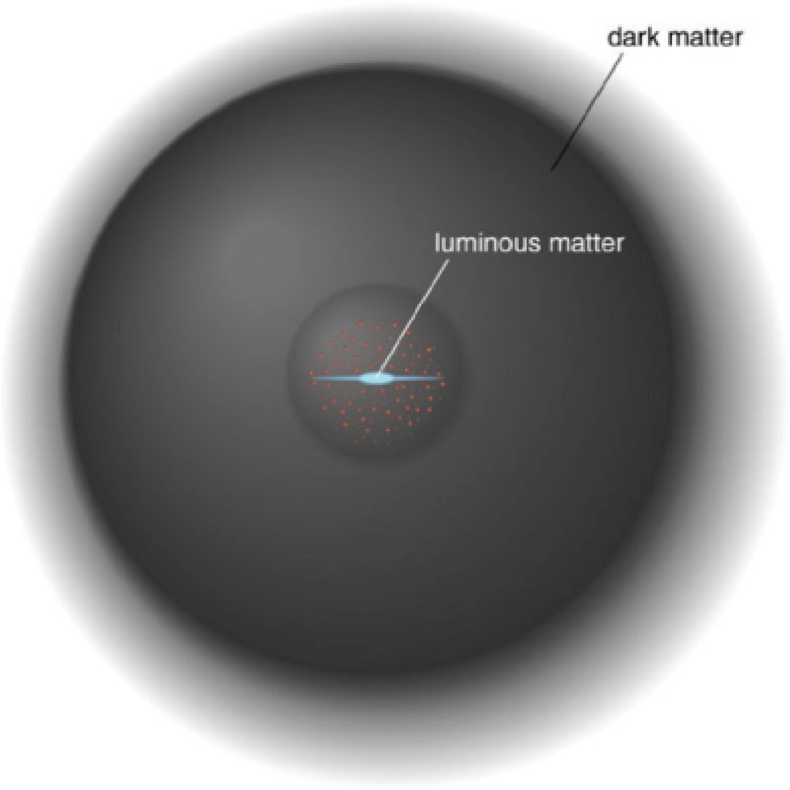
J. Billard et al, arXiv:2104.07634

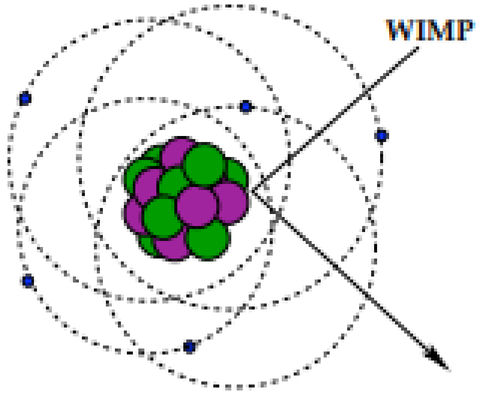
Sub-GeV dark matter?

pseudoscalar mediators

Non-standard Cosmologies

Lindner, Profumo, Mambrini, FSQ, 1703.07364
Marrodan Undagoitia, Rauch, arxiv:1509.08767





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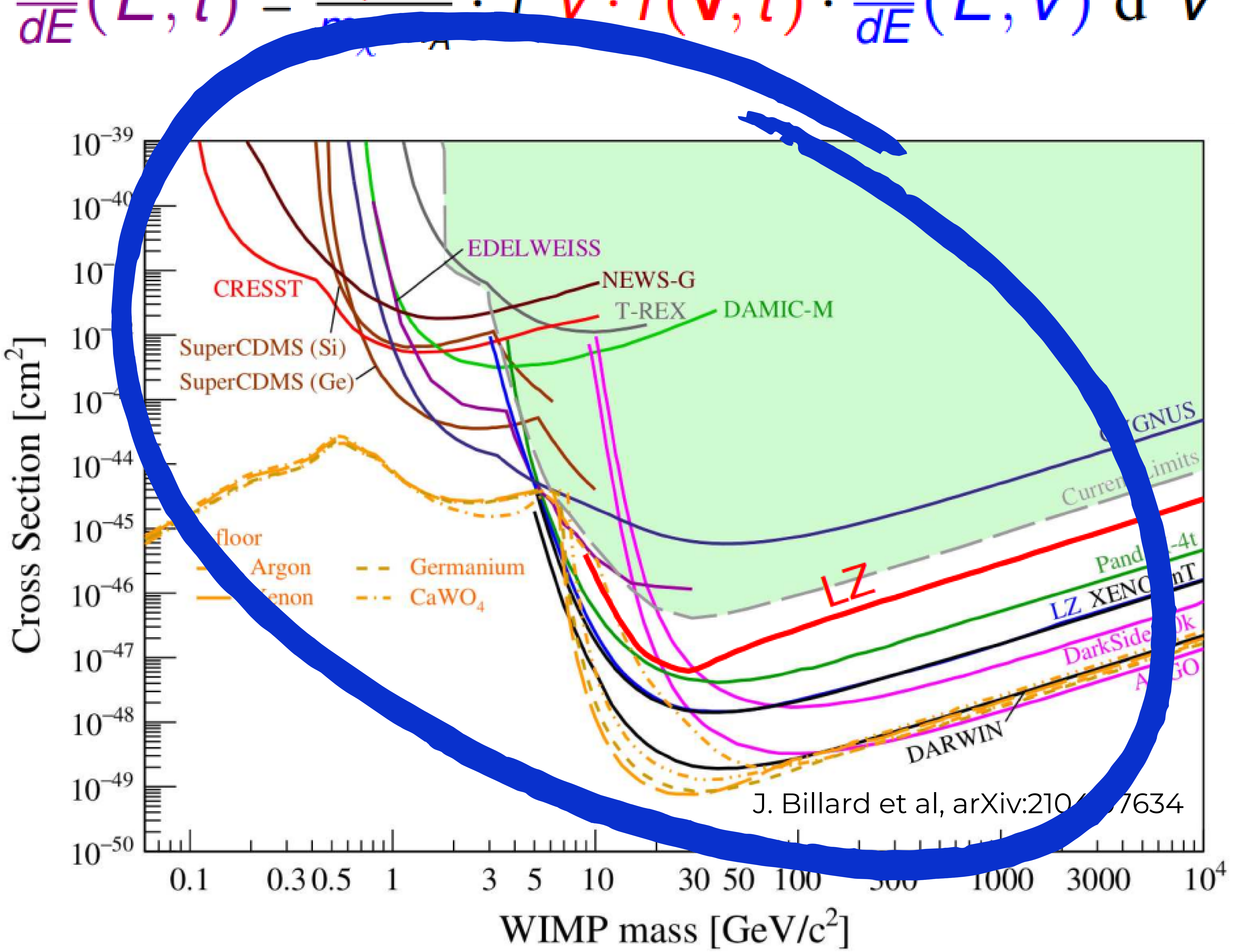

Sub-GeV dark matter?

pseudoscalar mediators

Non-standard Cosmologies

Lindner, Profumo, Mambrini, FSQ, 1703.07364
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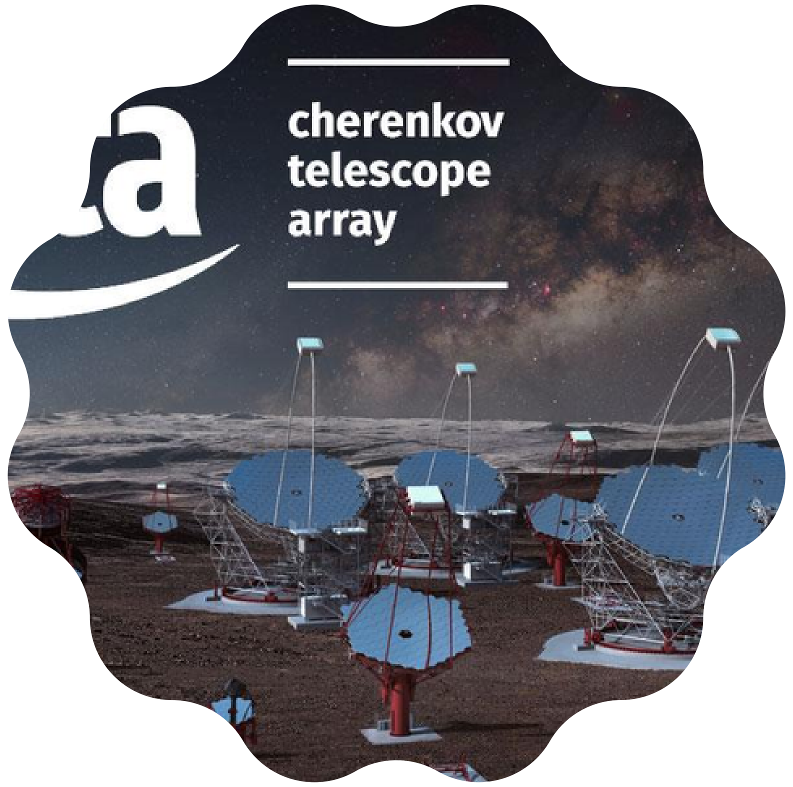
Indirect Detection

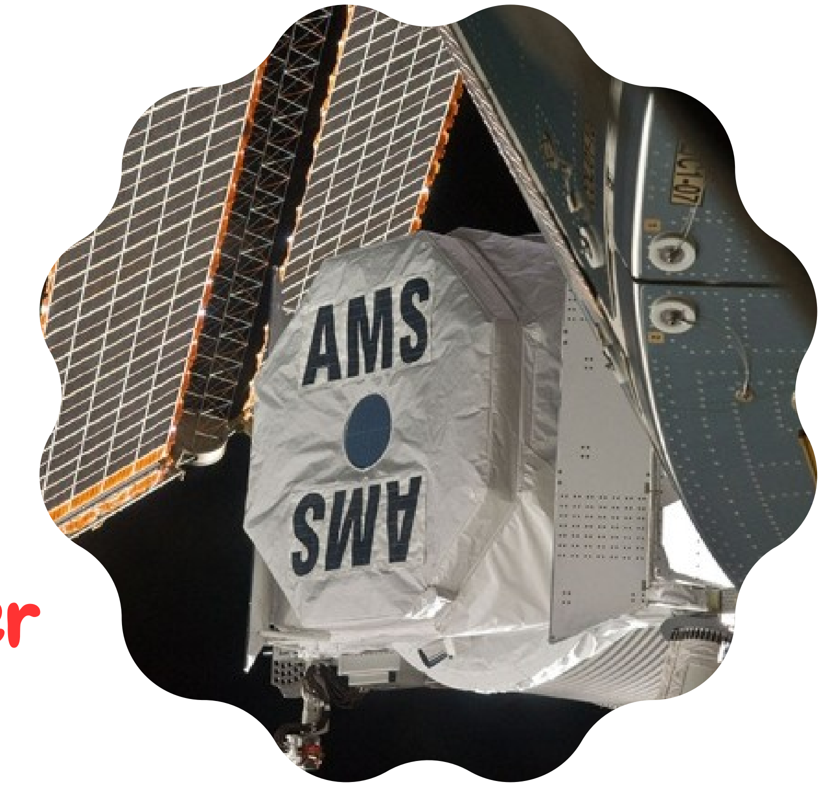
*Fermi-LAT



CTA

It is related to the dark matter local density.

I don't want to run from it



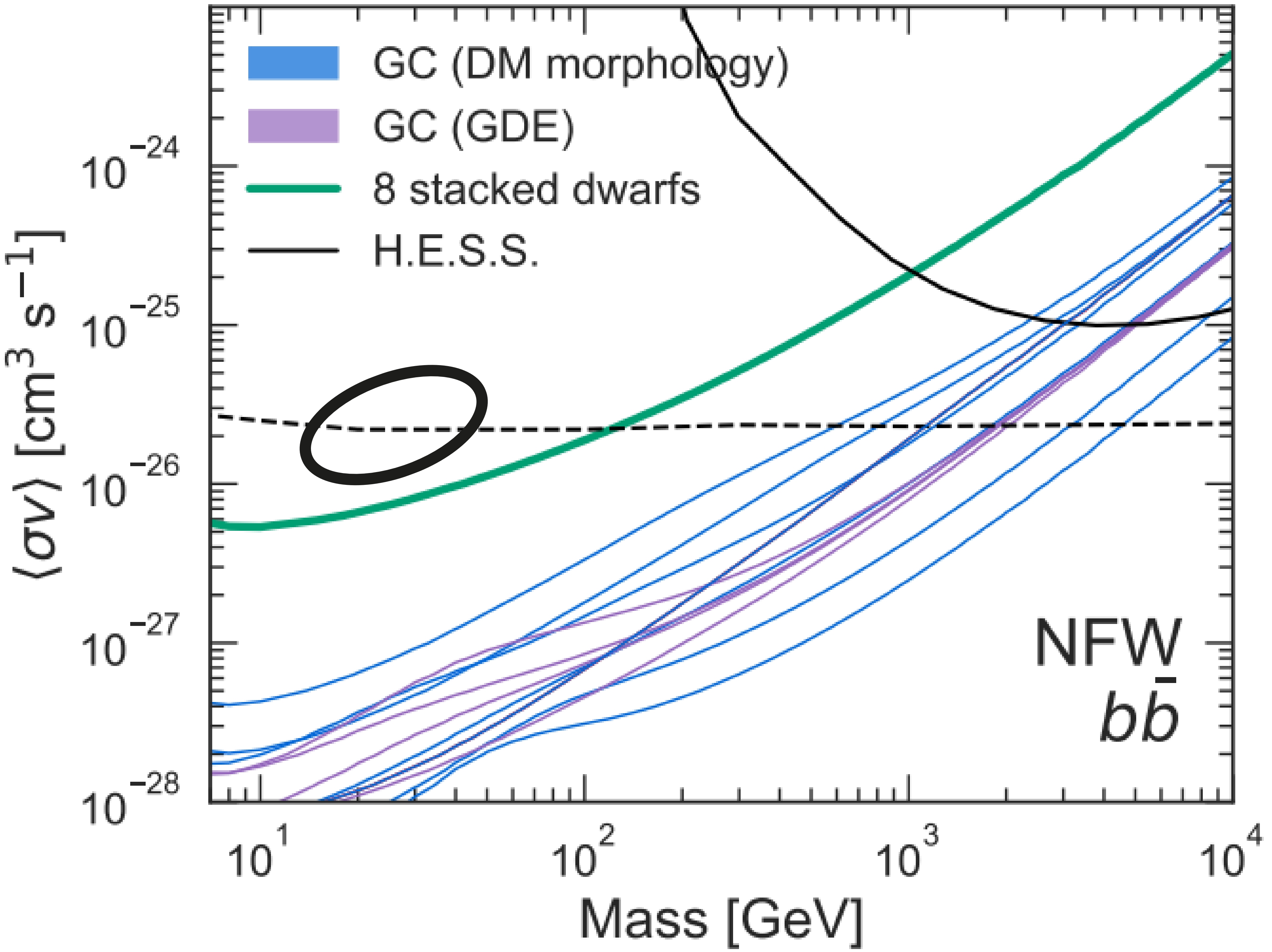
AMS

*Neutrino telescopes

$$\overbrace{\frac{d\Phi}{d\Omega dE}}^{Diff.Flux} = \frac{\overbrace{\sigma v}^{Anni.\,Cross\,Section}}{8\pi m_\chi^2} \times \underbrace{\frac{dN}{dE}}_{Energy\,Spectrum} \times \int_{l.o.s} ds \underbrace{\rho^2(\vec{r}(s,\Omega))}_{Dark\,Matter\,Distribution}$$

Where are we?

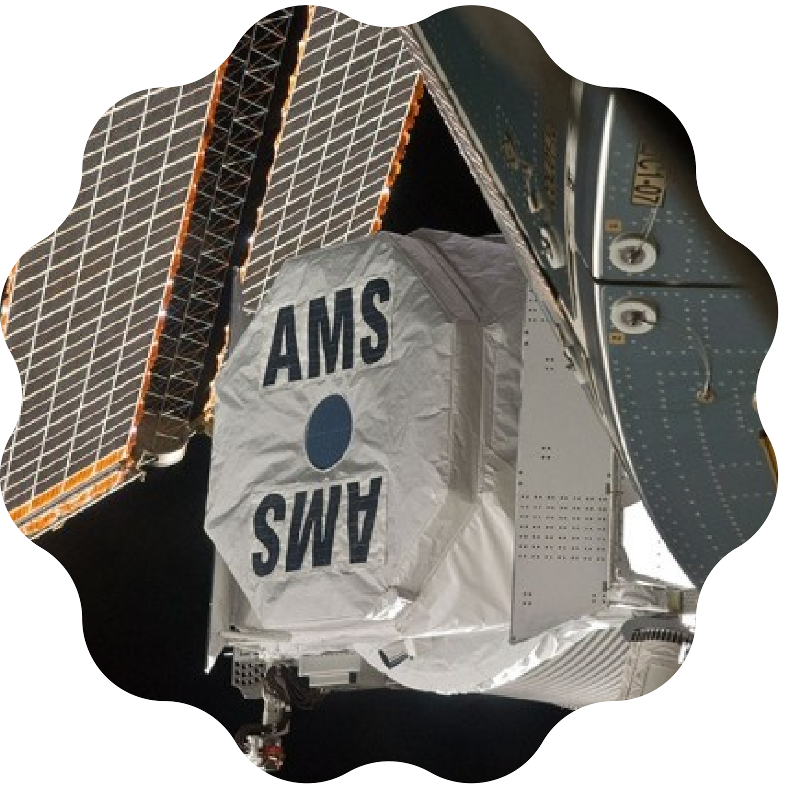
***Fermi-LAT**
through 2023, possibly will cotinue



$$\overbrace{\frac{d\Phi}{d\Omega dE}}^{Diff.Flux} = \frac{\overbrace{\sigma v}^{Anni.\,Cross\,Section}}{8\pi m_\chi^2} \times \underbrace{\frac{dN}{dE}}_{Energy\,Spectrum} \times \int_{l.o.s} ds \underbrace{\rho^2(\vec{r}(s,\Omega))}_{Dark\,Matter\,Distribution}$$

Abazajian, Horiuchi, Kaplinghat,Keeley, Macias 2003.10416

Where are we?

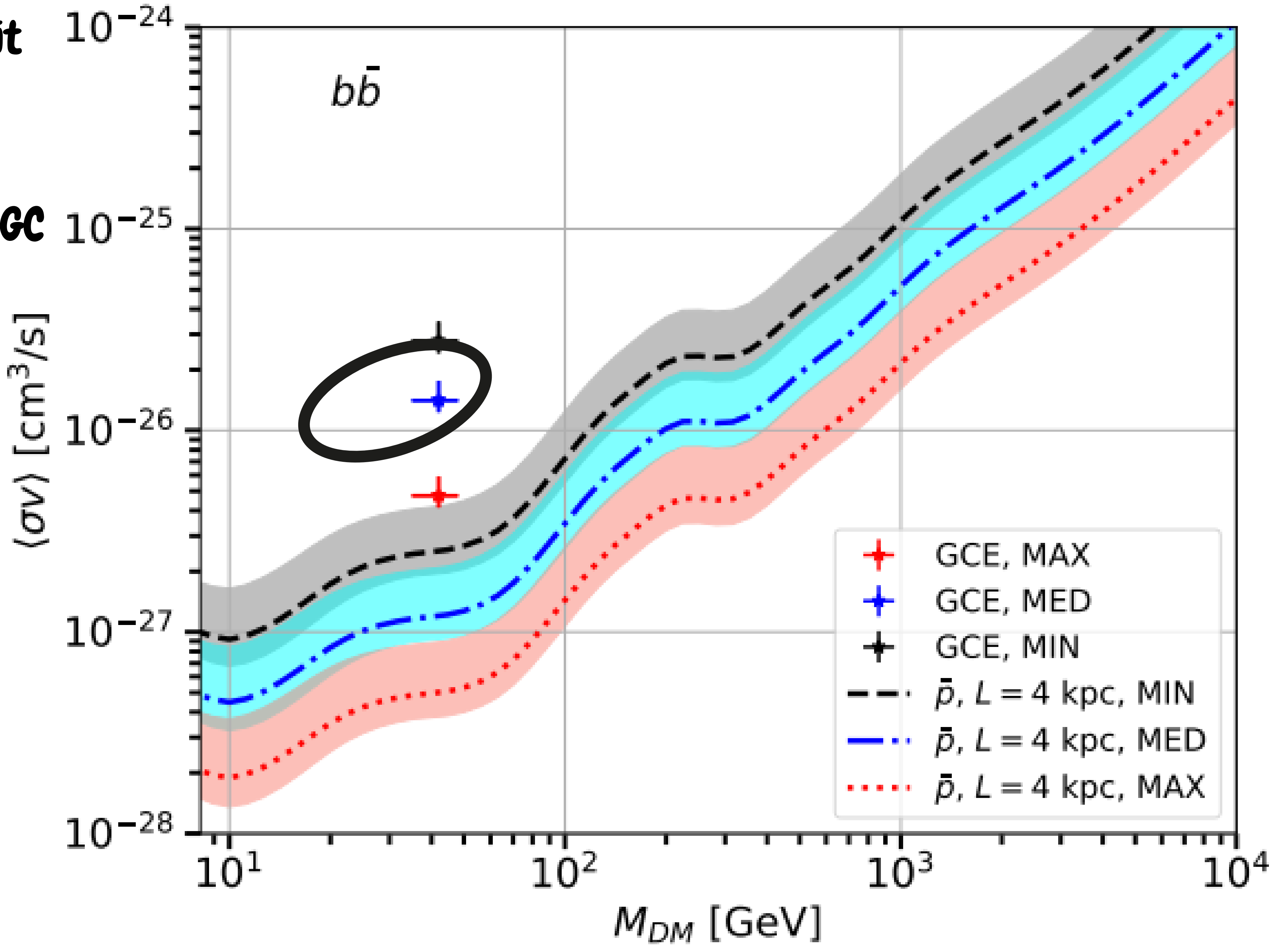


AMS

Our plans are to keep AMS operating on the International Space Station as long as there is a space station.

It is fair to say that the DM interpretation does provide a good fit to the Fermi-LAT data but is disfavored by other probes. The neutron stars interpretation for the GC excess is debatable

Leane and Slatyer, arXiv:1904.08430



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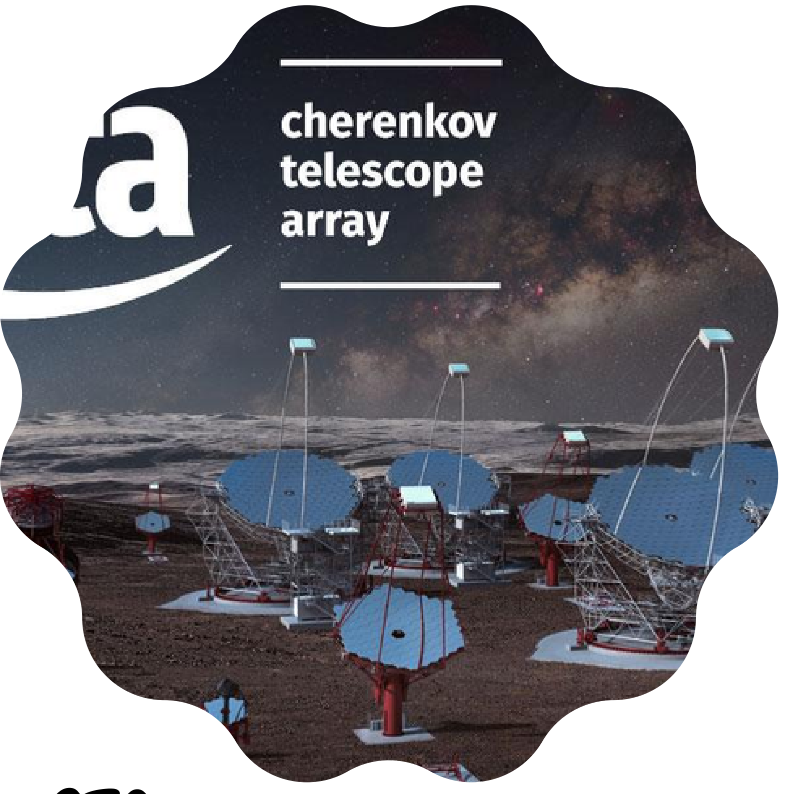
Mauro, Winkler arxiv: 2101.11027

Where are we?



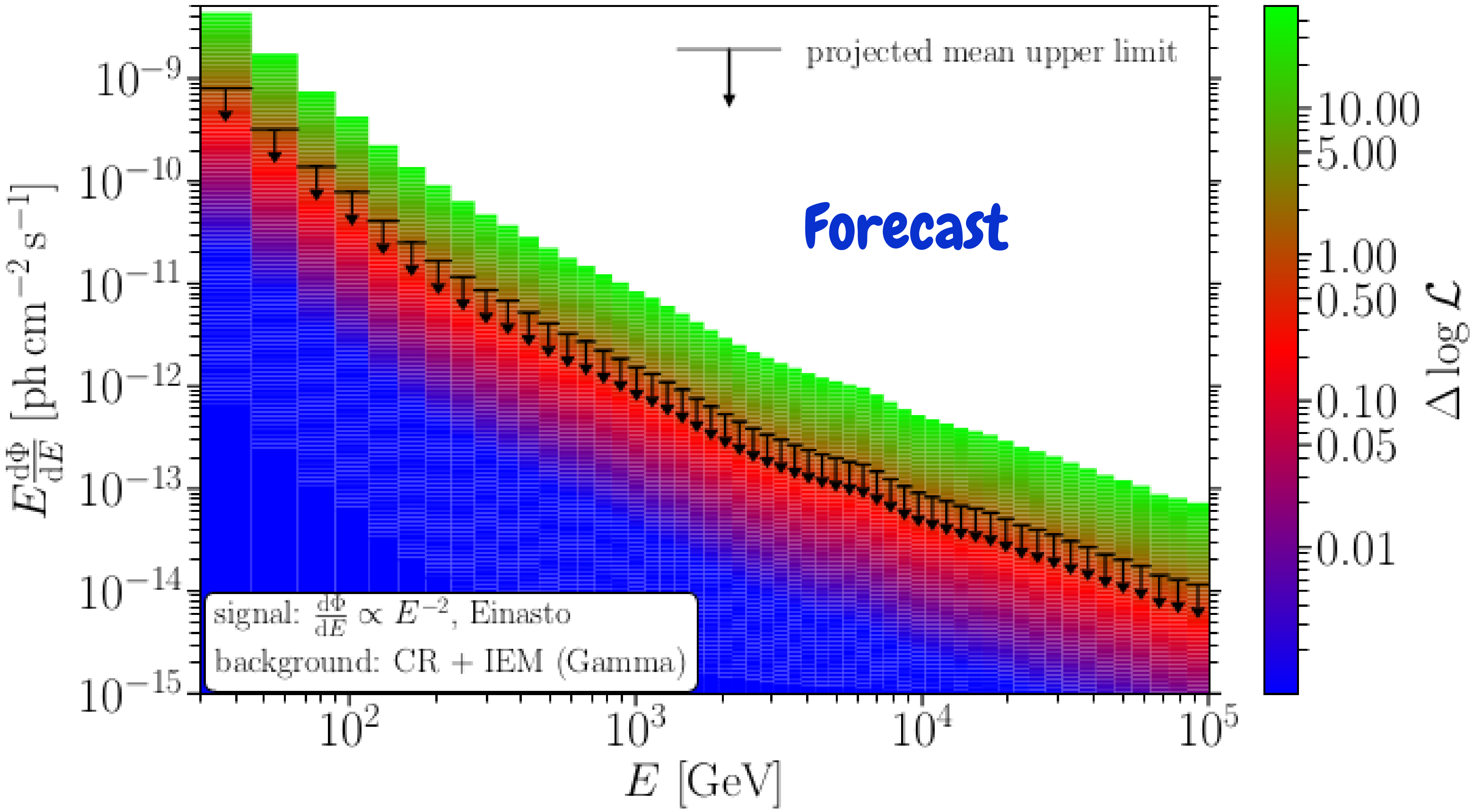
CTA

CTA might shed light on the GeV excess

arxiv:2212.08080

The CTA design concept :
i) LSTs (Large-Sized Telescopes, 23 m in diameter) E= 20 – 150 GeV,
ii) MSTs (Medium-Sized Telescopes, 11.5 m) E=150 GeV-5 TeV
iii) a large number of SSTs (Small-Sized Telescope, 4 m) E> 5TeV

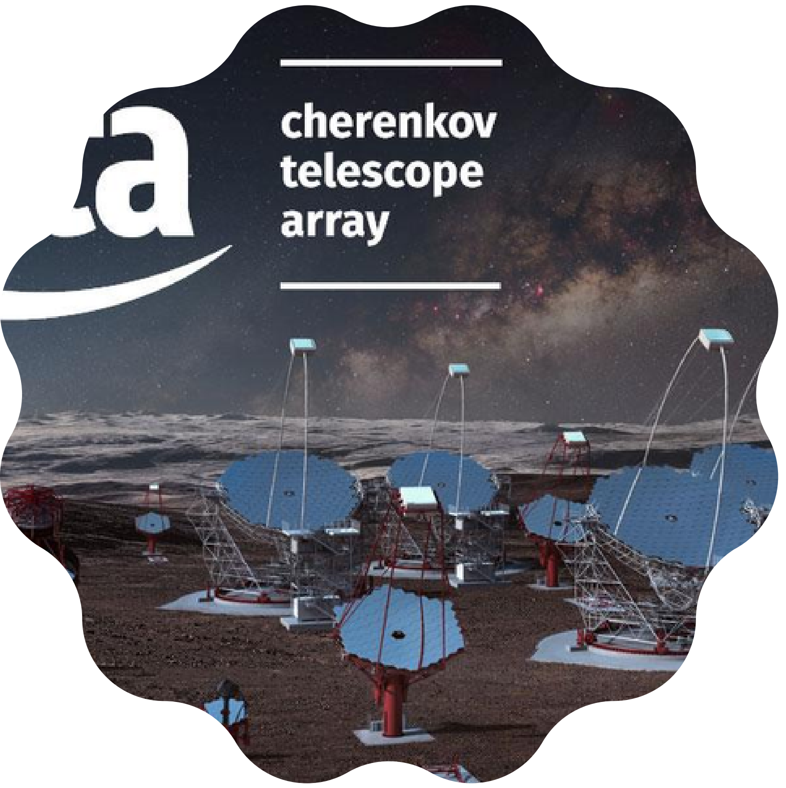
CTA consortium,arxiv: 2007.16129



Some early studies
FSQ, Yaguna, Weniger 1702.06145
FSQ, Yaguna 1511.05967

CTA is expected to improve by 1-2 orders of magnitude the limits (masses > 300GeV)

Where are we?



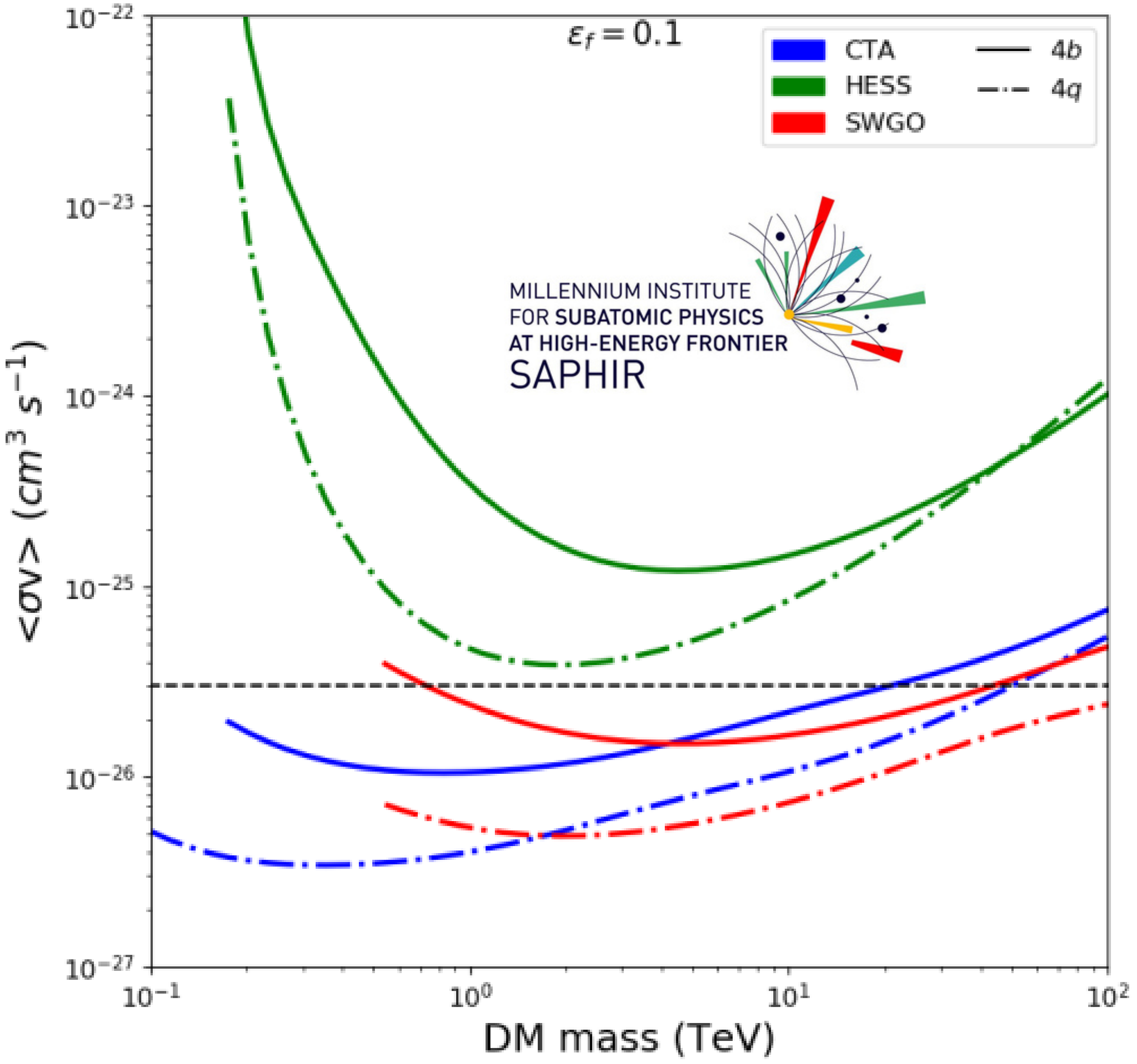
CTA

Hopefully in the coming years

LATEST NEWS

CTA/SWGO

PROJECTIONS FOR HIDDEN SECTORS



Fortes, FSQ, Siqueira, Viana 2212.05075

$$\overbrace{\frac{d\Phi}{d\Omega dE}}^{Diff.Flux} = \frac{\overbrace{\sigma v}^{Anni.Cross\,Section}}{8\pi m_\chi^2} \times \underbrace{\frac{dN}{dE}}_{Energy\,Spectrum} \times \int_{l.o.s} ds \underbrace{\rho^2(\vec{r}(s,\Omega))}_{Dark\,Matter\,Distribution}$$

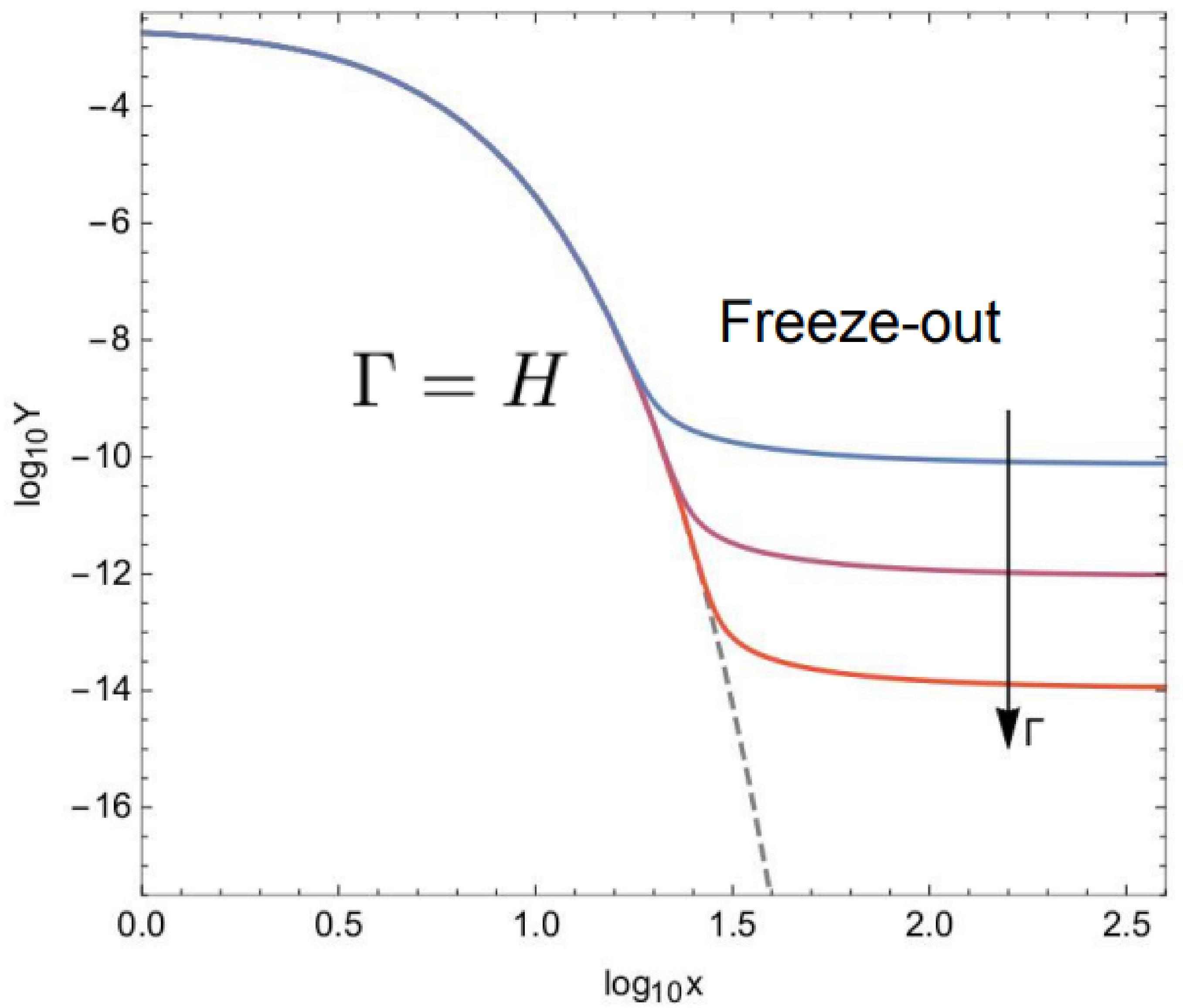
Standard Darkness

We often use as evidence for dark matter

Galaxy rotation curves
Cosmic Microwave Background
Collision of Clusters
Baryon Acoustic Oscillations
Gravitational Lensing
Cosmic Shear
Structure Formation
*Fermi GeV excess
*AMS-02 results
Neutrino Masses
Lepton Flavor Violation
Hierarchy Problem
Grand Unification

Extra

Thermal relic



$$\frac{dn_\chi}{dt} + 3Hn_\chi = -\langle \sigma v \rangle \left(n_\chi^2 - n_\chi^{\mathrm{eq}\,2}\right)$$

Non-Standard Cosmology

Flavor

ATLAS

Model Building

Gamma-rays

Cosmology

Neutrino physics

NEW

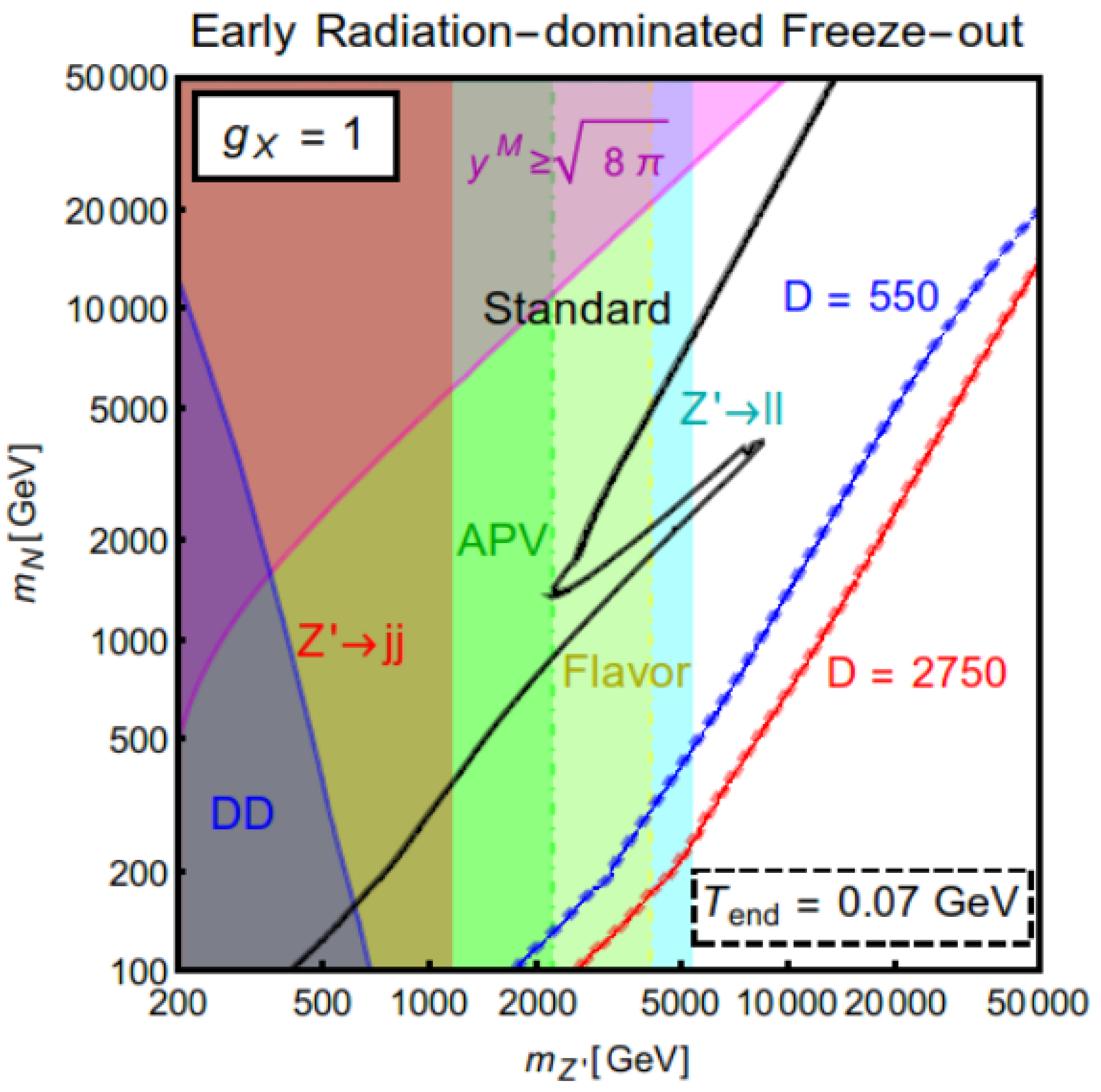
Dark Matter and Early Universe

Taking a very constrained scenario: Z'

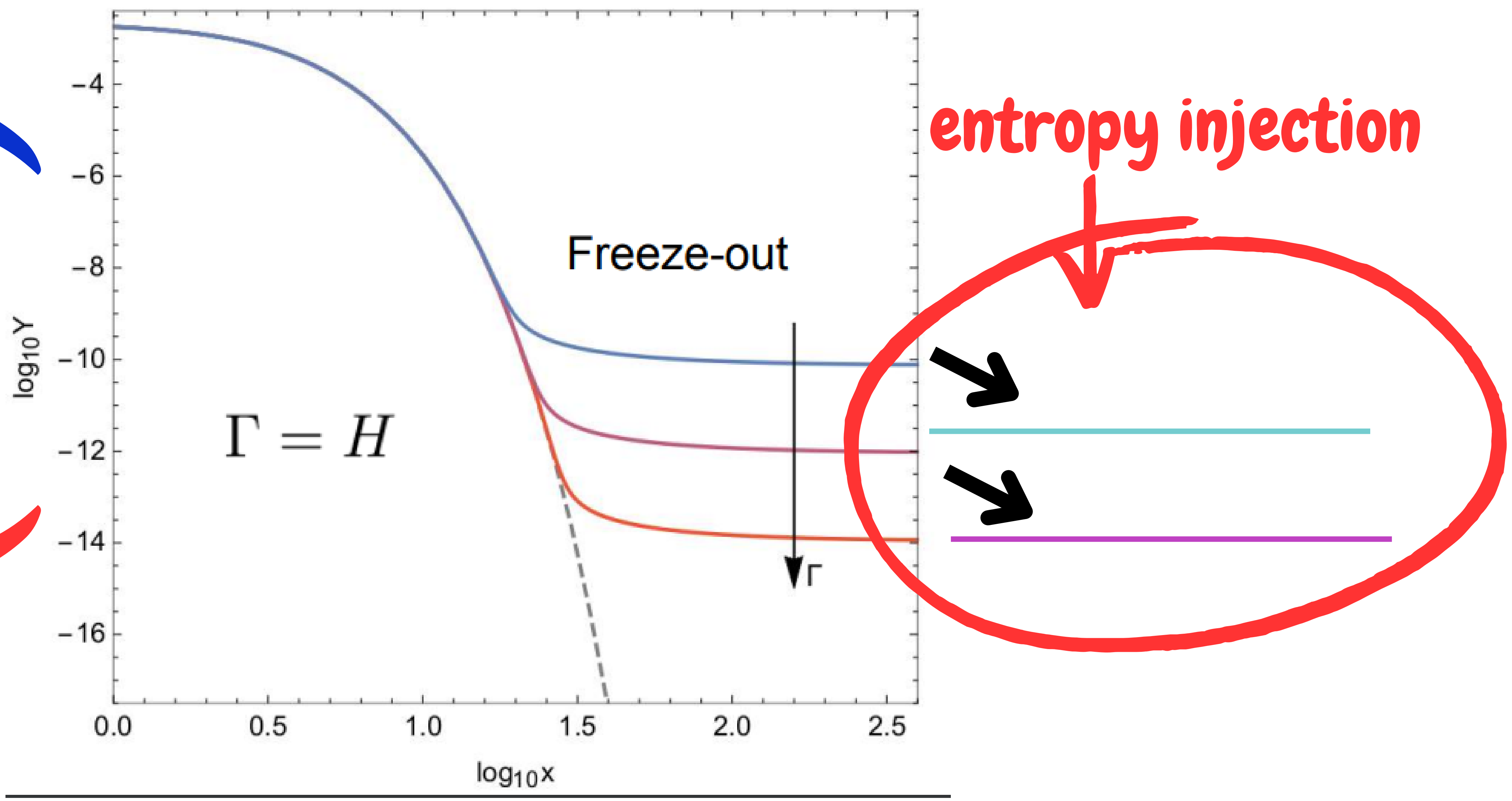
$$+\frac{1}{4}g_X\left(N_{1R}\gamma^\mu\gamma_5 N_{1R}\right)Z'_\mu \quad -\frac{g_X}{2}Q_{X_f}\left(\bar\psi_f\gamma^\mu\psi_f\right)Z'_\mu$$

PROGRESS IS NEEDED HERE:

Scalar dominates the energy density and decays into radiation



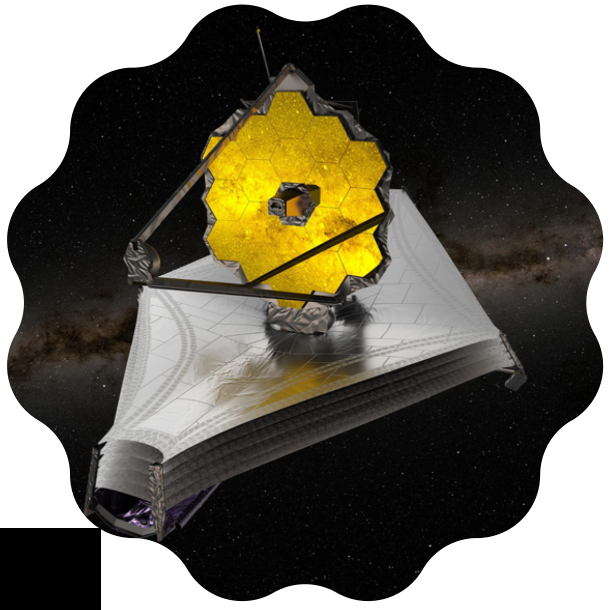
Dilution factors

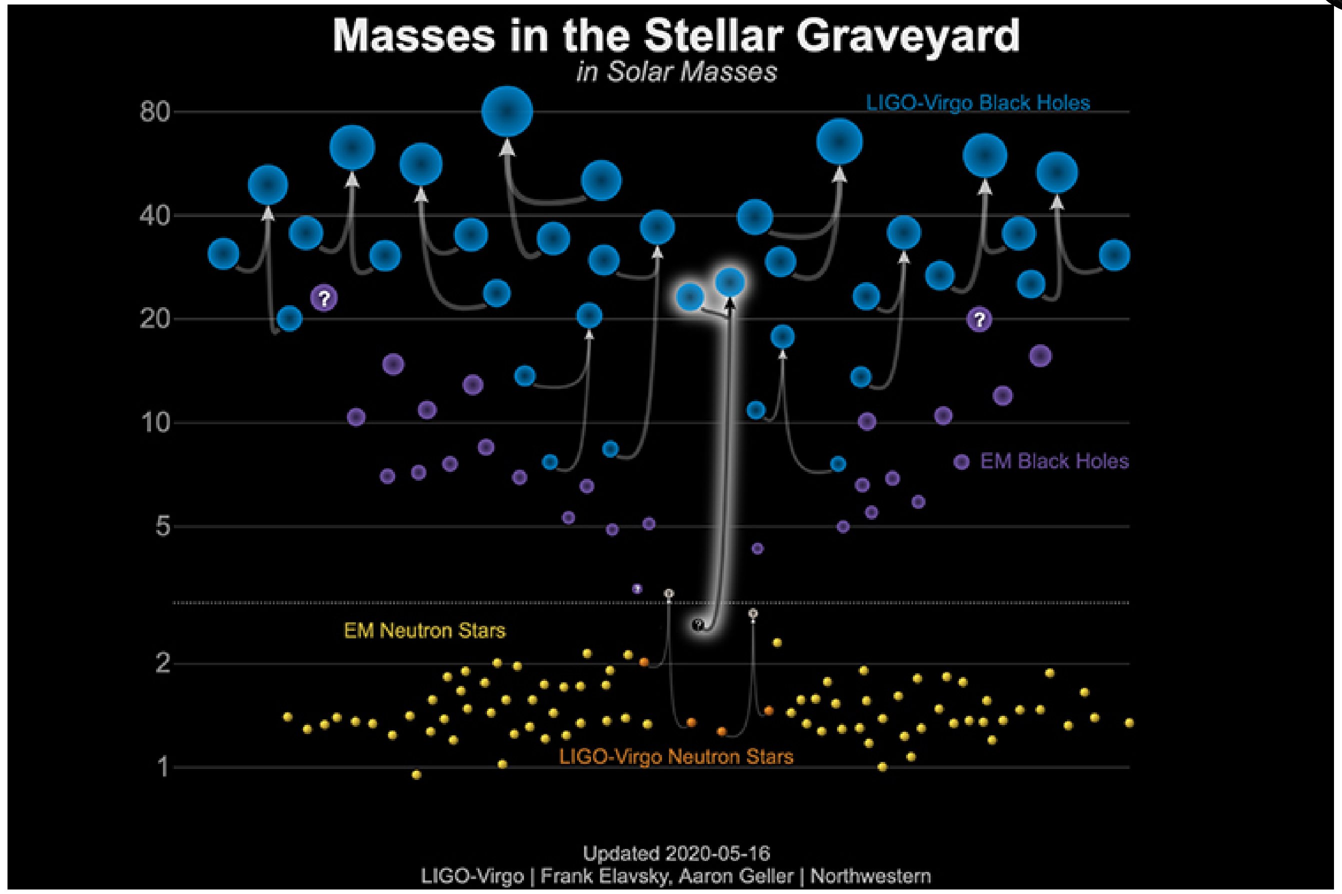


Arcadi, Neto, Siqueira, FSQ 2108.11398

Dark Matter and Neutron Stars

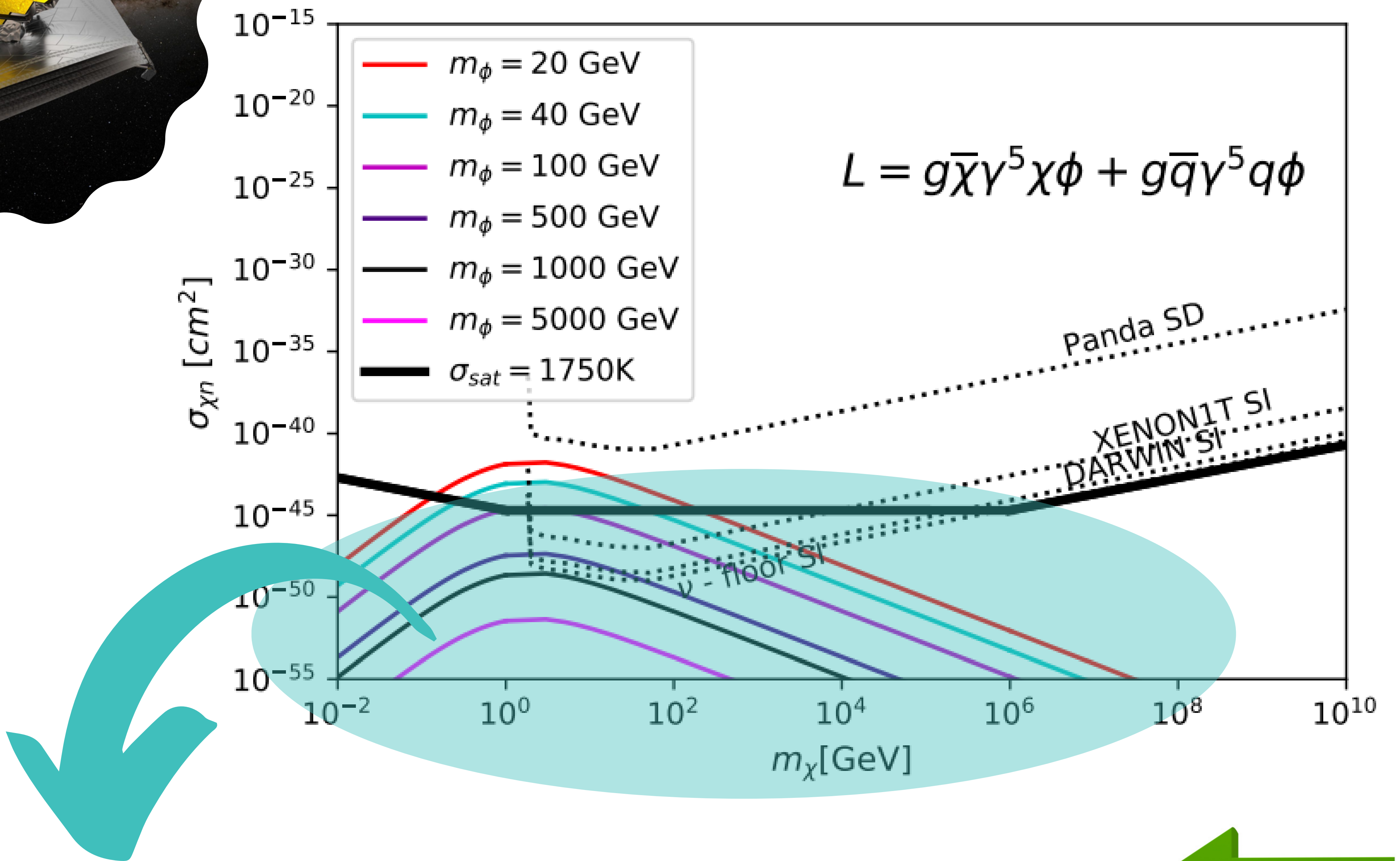
Collective effect is needed



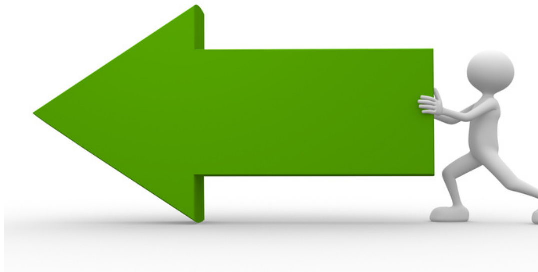


Maity, FSQ 2104.02700

Fermion DM + pseudoscalar Mediator



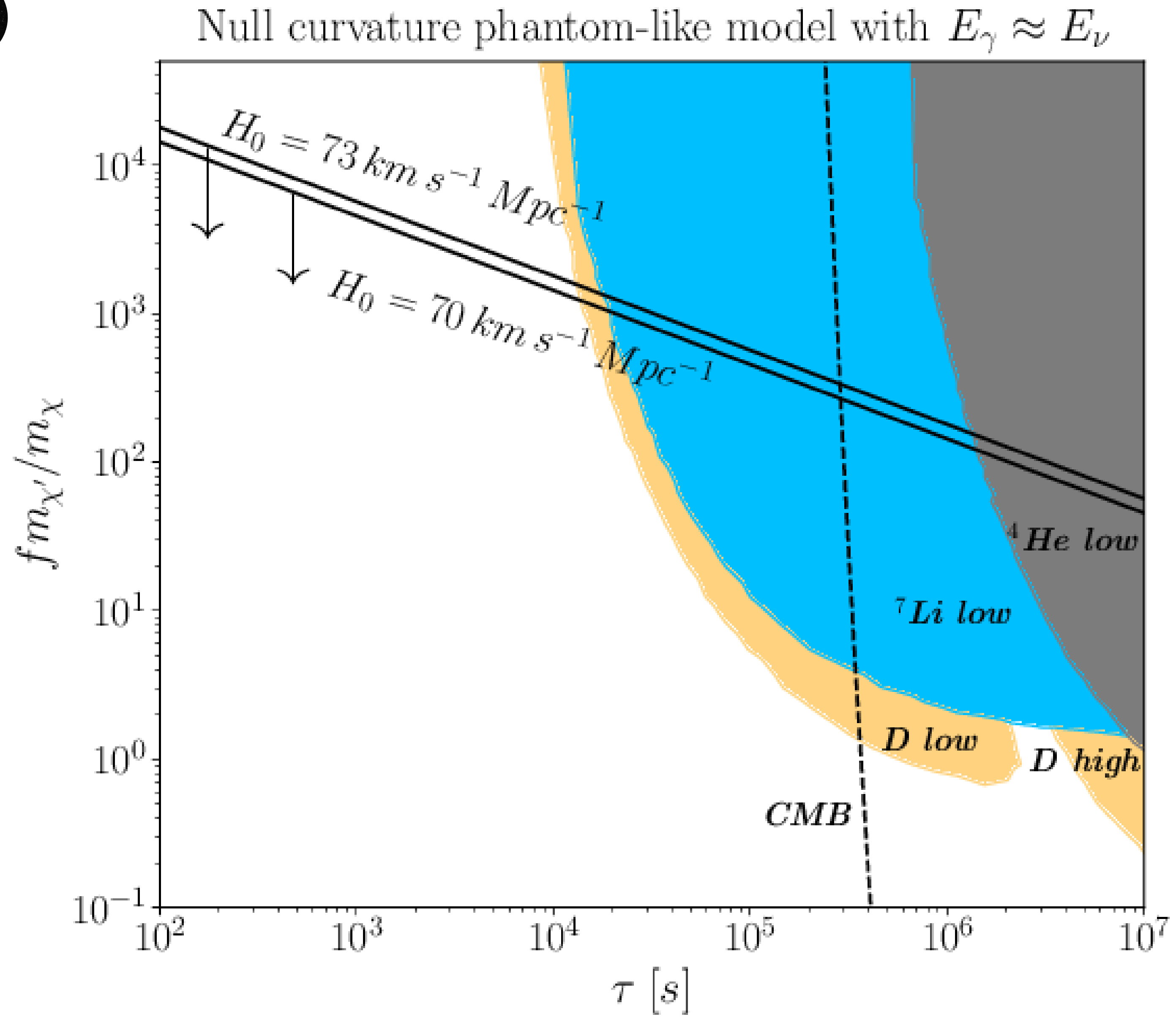
Neutron stars will constitute an important probe!



Dark Matter and the Hubble Rate

Alcaniz, Neto, Silva, FSQ 2211.14345

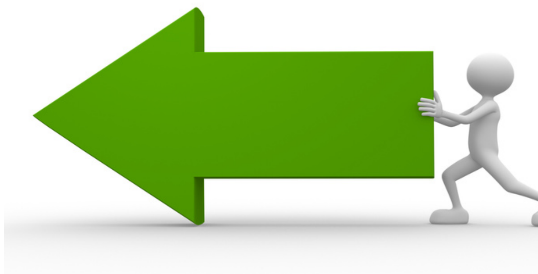
Non-thermal production of dark matter



Collective effect is seen

EARLY UNIVERSE	Dataset
$H_0 = 70.0 \pm 2.2 kms^{-1}Mpc^{-1}$	WMAP9 [12]
$H_0 = 67.36 \pm 0.54 kms^{-1}Mpc^{-1}$	CMB 2018 [4]
$H_0 == 67.36 \pm 0.54 kms^{-1}Mpc^{-1}$	SPT 2021 [13]
$H_0 = 69.72 \pm 1.63 kms^{-1}Mpc^{-1}$	ACT 2019 [14]
$H_0 = 67.9 \pm 1.1 kms^{-1}Mpc^{-1}$	BOSS data [15]
$H_0 = 69.6 \pm 1.8 kms^{-1}Mpc^{-1}$	eBOSS Collab. [16]
LATE UNIVERSE	**Dataset**
$H_0 = 73.8 \pm 2.1 kms^{-1}Mpc^{-1}$	SN1a 2021 [17]
$H_0 = 75.4 \pm 1.7 kms^{-1}Mpc^{-1}$	Pantheon 2019 [18]
$H_0 == 72.8 \pm 1.9 kms^{-1}Mpc^{-1}$	Gaia 2020 [19]
$H_0 = 73.2 \pm 1.3 kms^{-1}Mpc^{-1}$	Gaia and HST 2020 [20]

Connection between early universe and particle physics

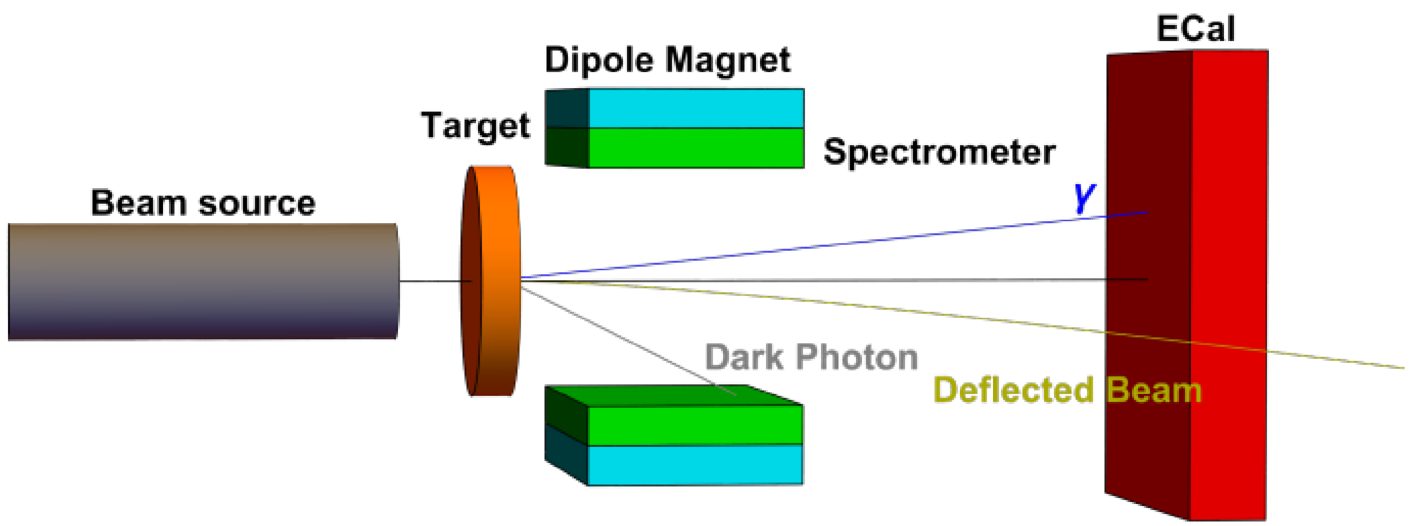


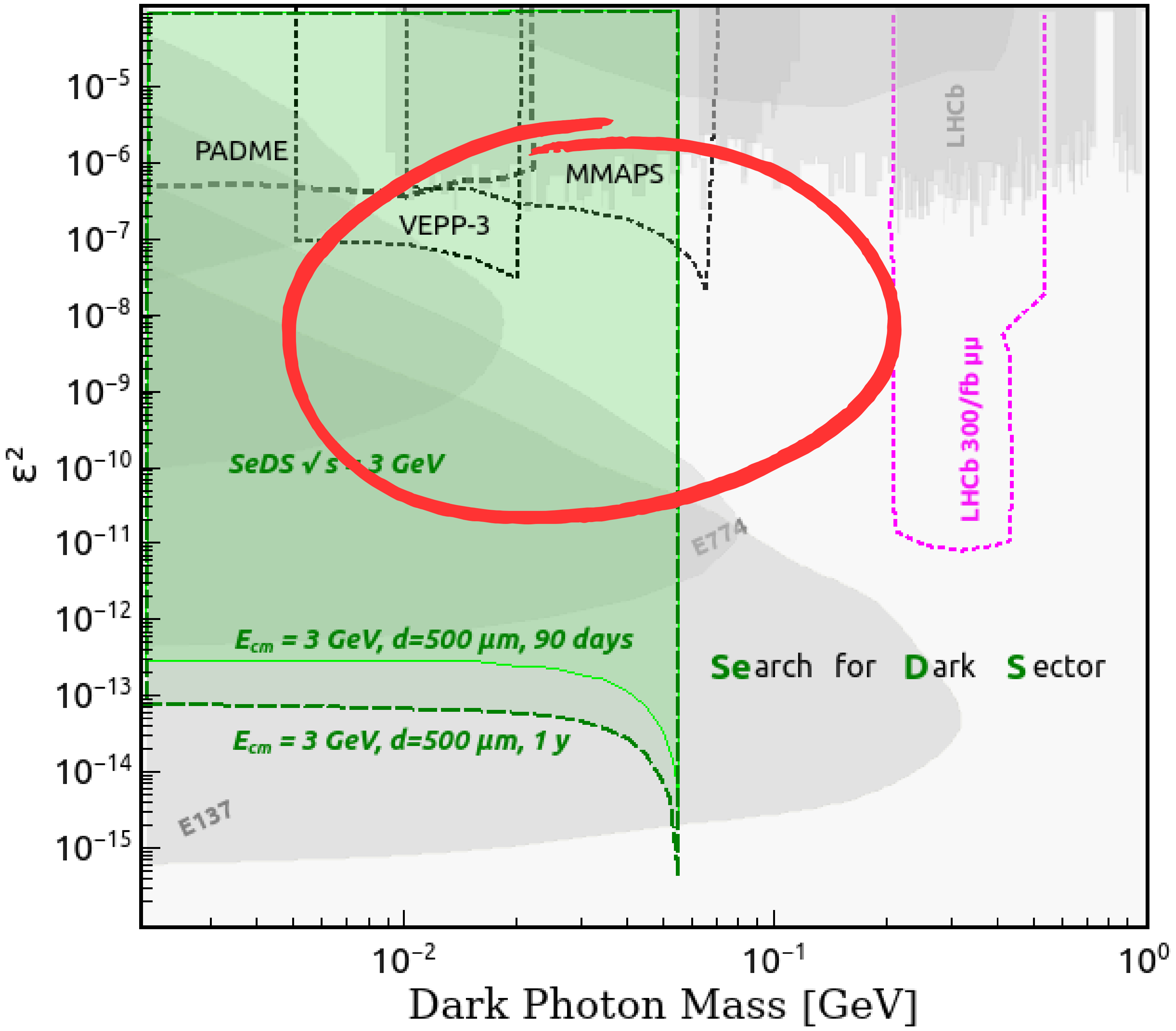
Dark Sectors and Accelerators

Search for Dark Sector by Repurposing the UVX Brazilian Synchrotron

L. Duarte (IIP, Brazil), L. Lin (LNLS, Campinas), M. Lindner (Heidelberg, Max Planck Inst.), V. Kozhuharov (Sofiya U. and INFN, Italy), S.V. Kuleshov (Andres Bello Natl. U. and Unlisted, CL) et al. (Jun 10, 2022)

e-Print: 2206.05305 [hep-ph]

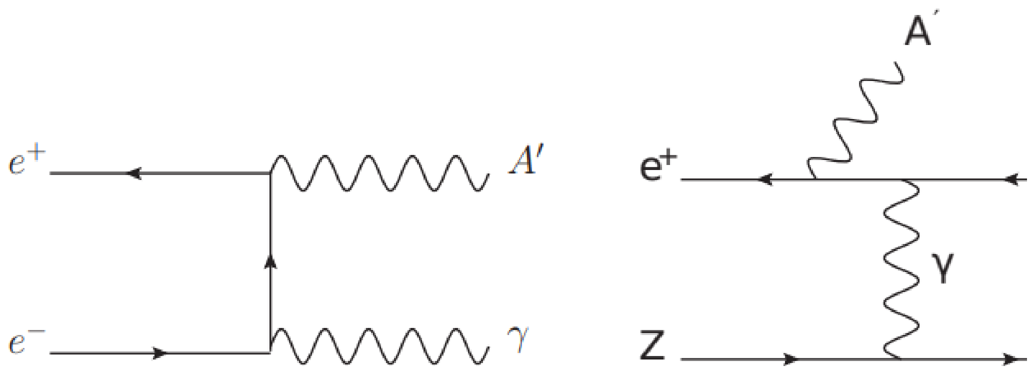




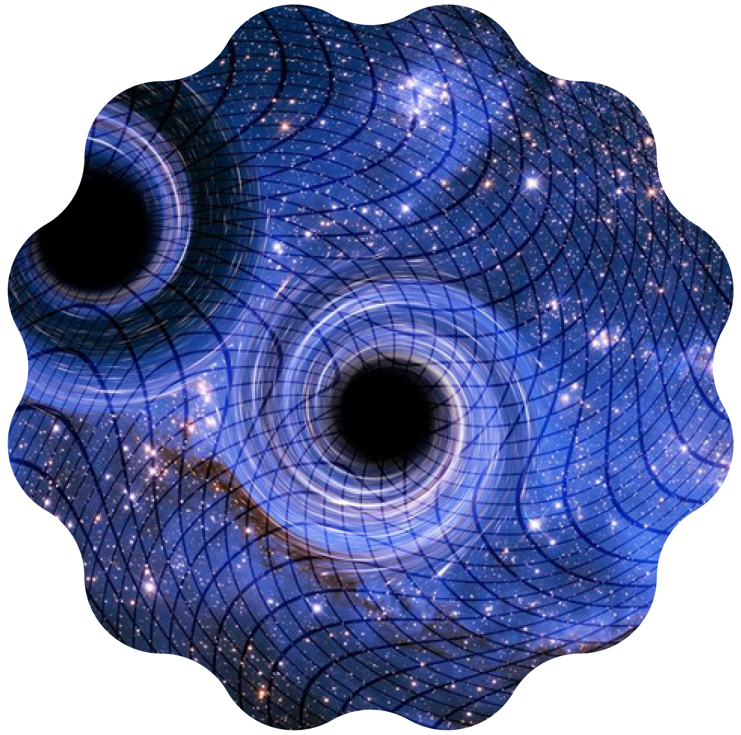
e+e- collisions

competitive probe

In Latin-America



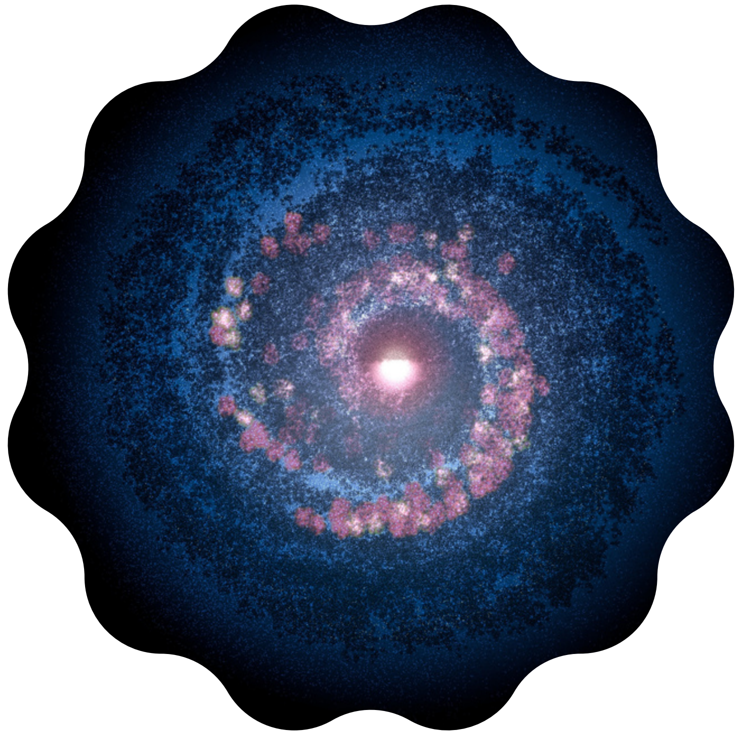
Vision for the future



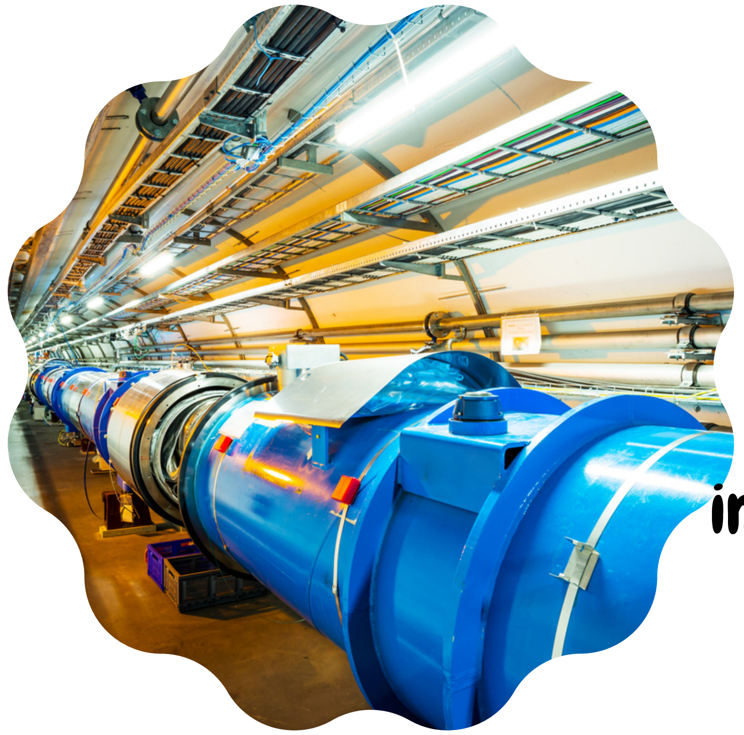
Dark Matter

Accelerators/
Colliders

Gravitational
Waves



Early Universe



New Ideas
(quantum
information/superconductors/
new materials)

Neutron Stars

Flavor

ATLAS

Gravitational Waves

Model Building

Lasers

Cosmology

Gamma-rays

Quantum Information

Neutrino physics

Superconductors

THANK YOU SO MUCH!

More than Chile, I like the Chilean Physicists