A search for Dark Matter using Tibet AS_γ

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Based on

a Letter published in Physical Review D
Phys. Rev. D 105, L041301 (2022)

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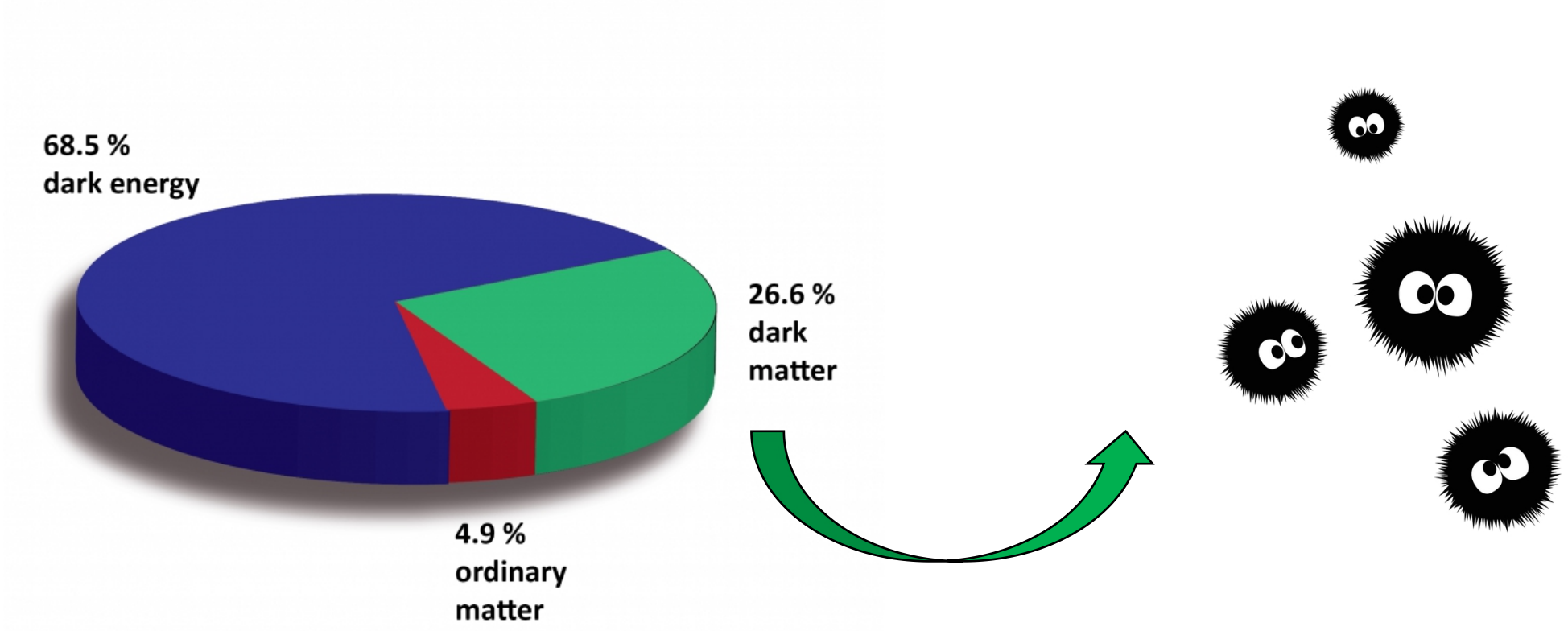
भारतीय विज्ञान संस्थान

Contents

- Introduction to Dark Matter
- Results from Tibet AS_γ experiment
- Implications for Dark Matter search
- Bounds on decaying DM
- Latest results
- Conclusion

ILLUSTRATION: TOMASZ WALENTA

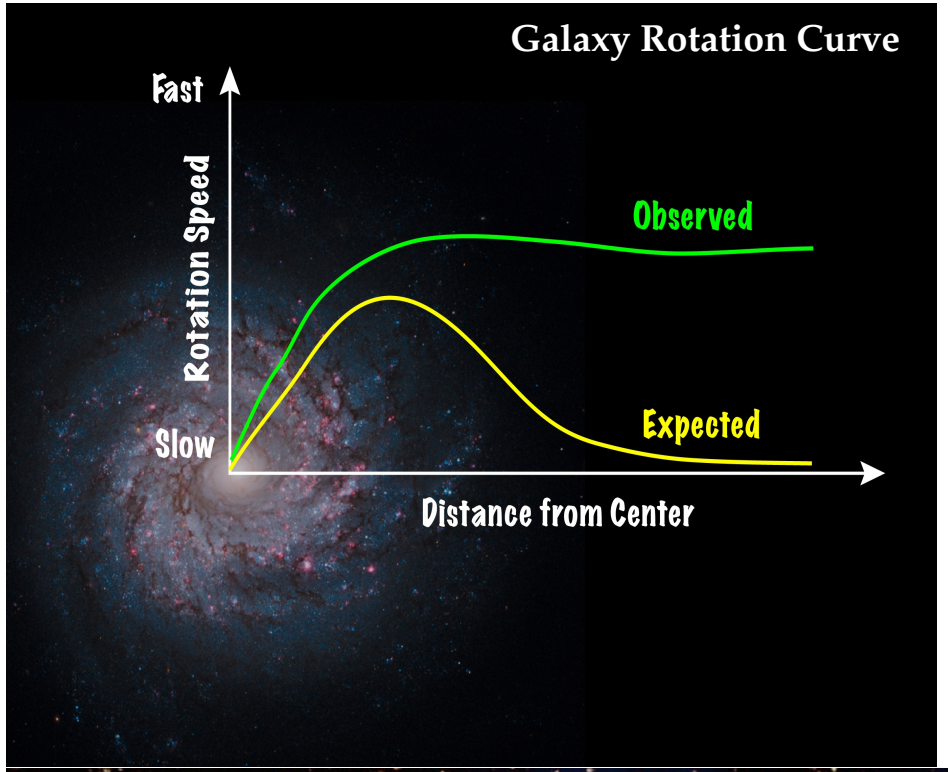
Reality Check



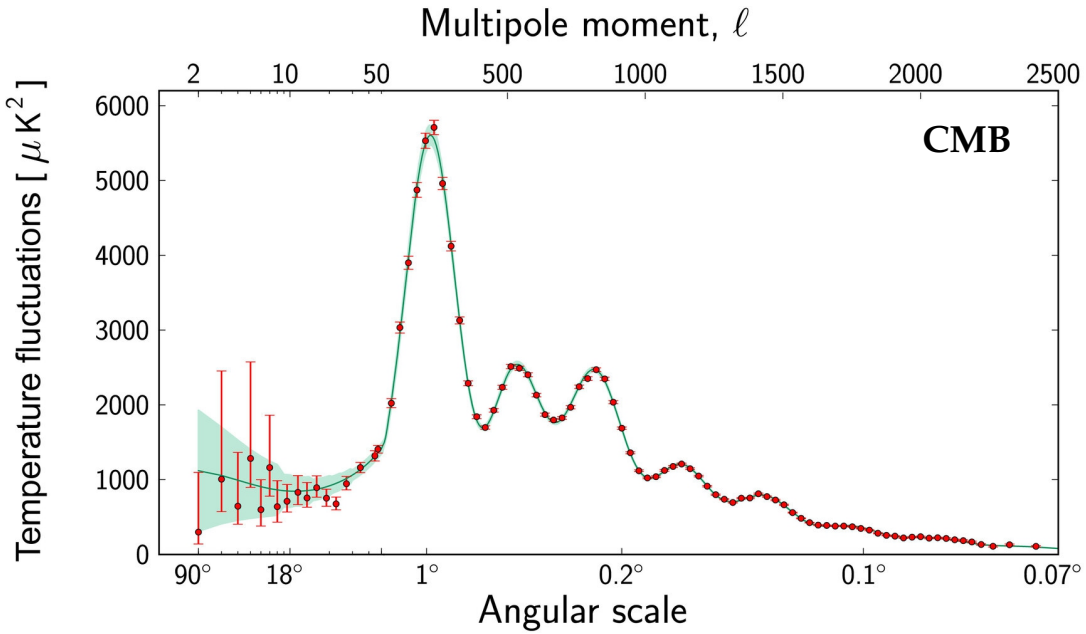
Credit: NIST

https://pngio.com/images/png-a2696042.html

What about its non-gravitational interactions?



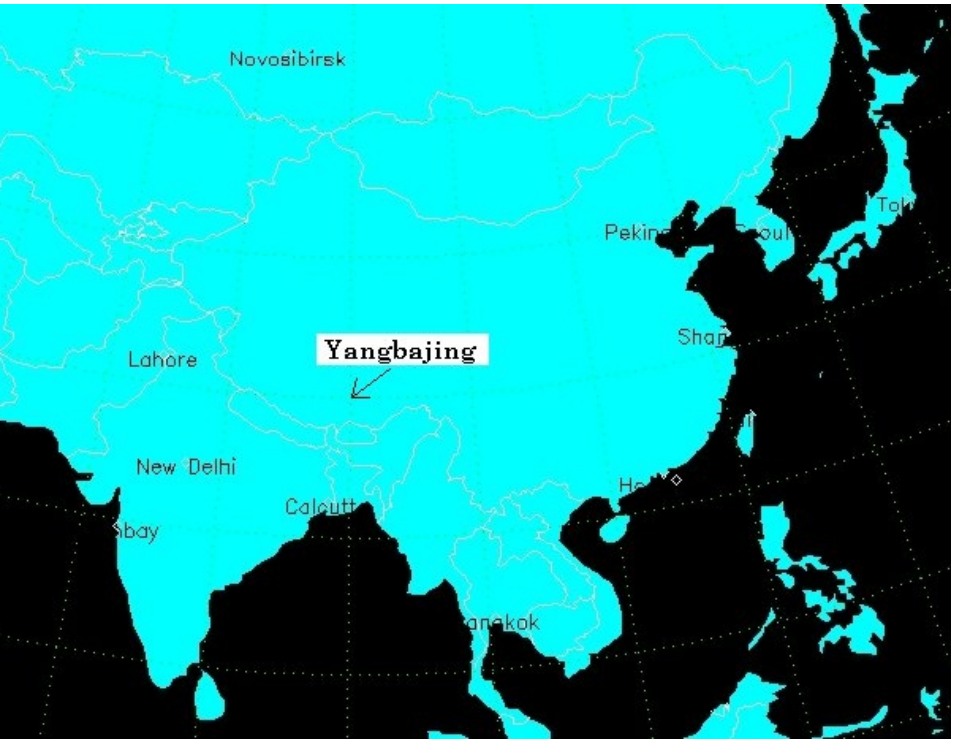
https://writesclence.files.wordpress.com/2015/05/galaxyrotationcurve.jpg



ESA and the Planck Collaboration

X-ray: NASA/CXC/CfA/M.Markevitch et al.; Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.

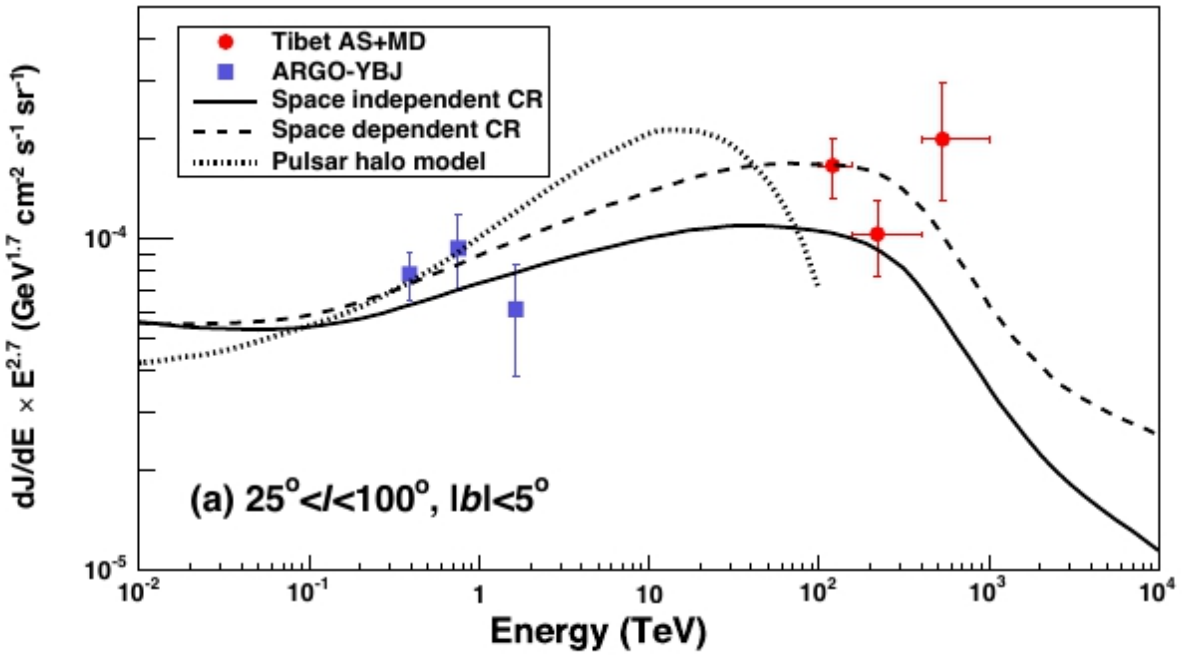
Tibet AS$_\gamma$ Experiment

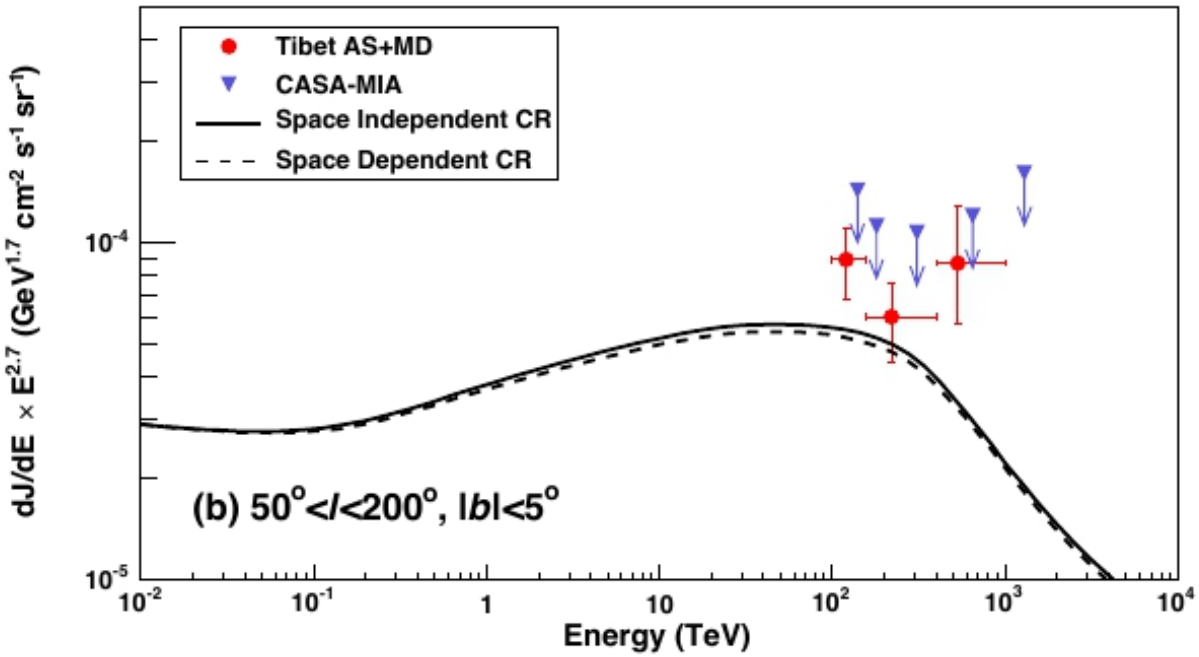


http://www.icrr.u-tokyo.ac.jp/em/index.html

Recent result

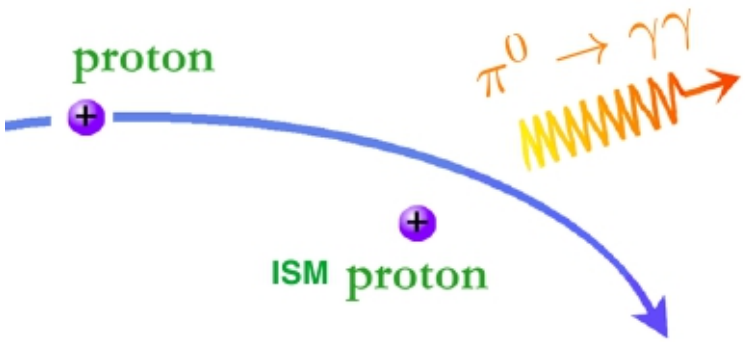
Fig : Phys. Rev. Lett. 126, 141101



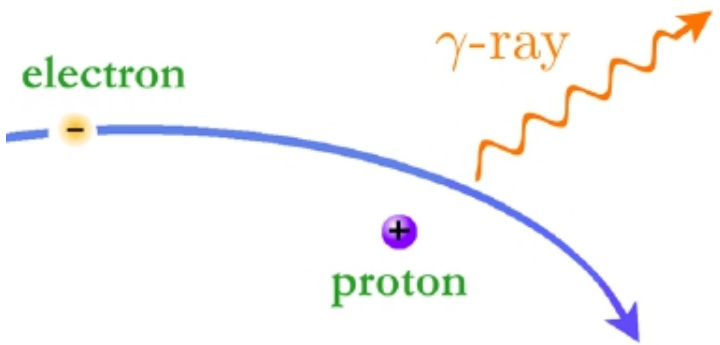


First ever detection of Galactic sub-PeV diffuse gamma rays !

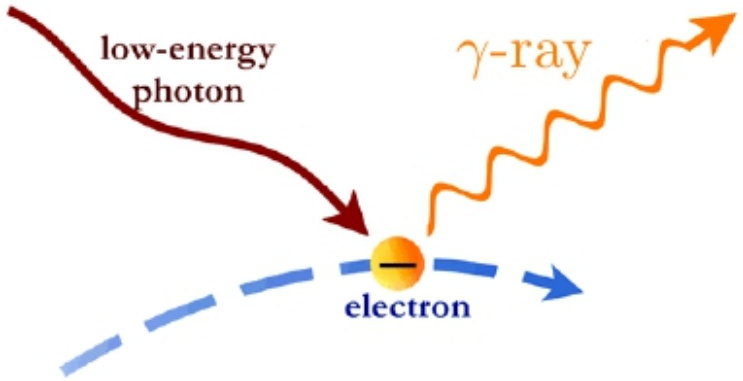
Diffuse High Energy Gamma Ray Production



Pion Decay



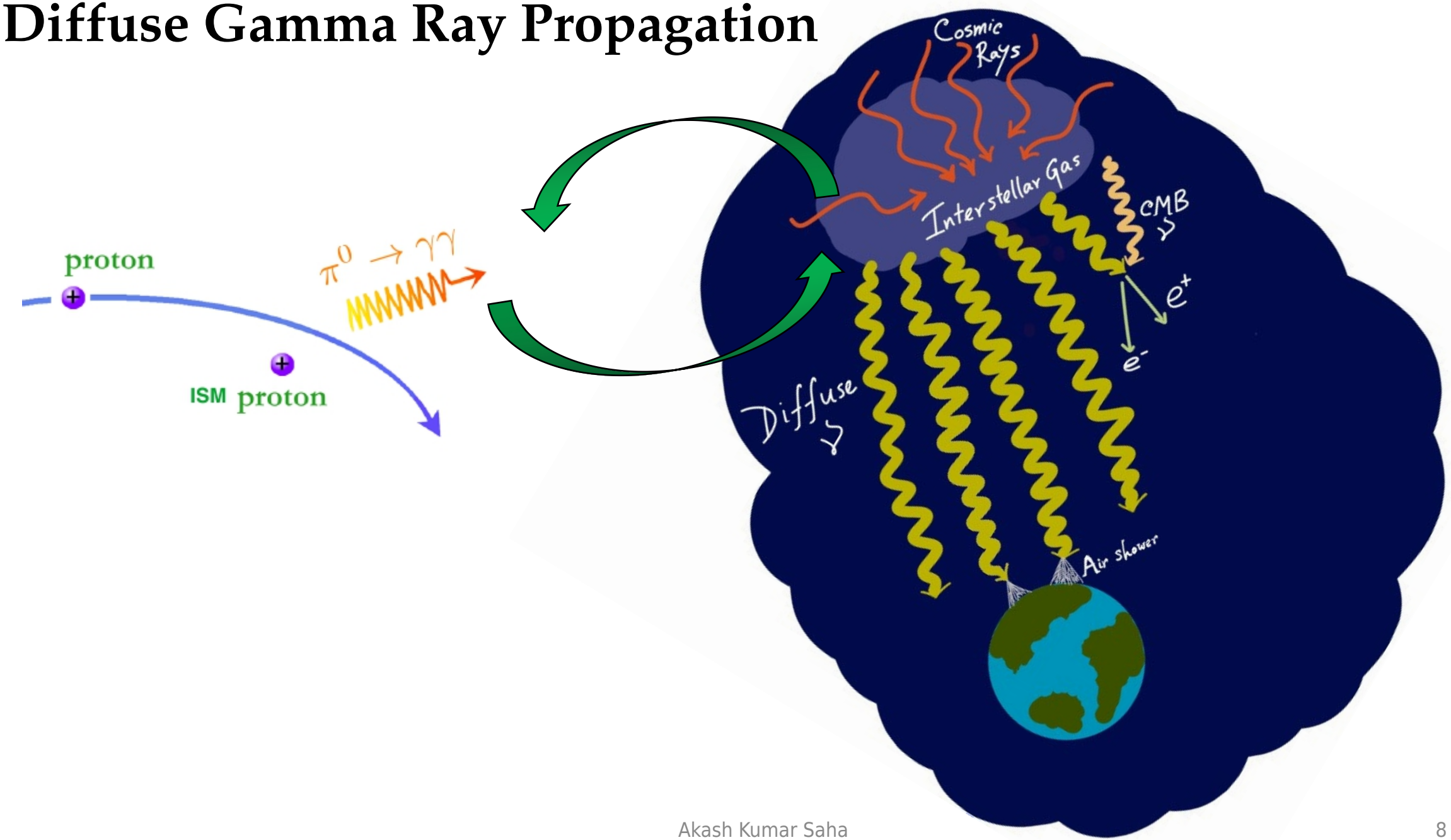
Bremsstrahlung



Inverse Compton

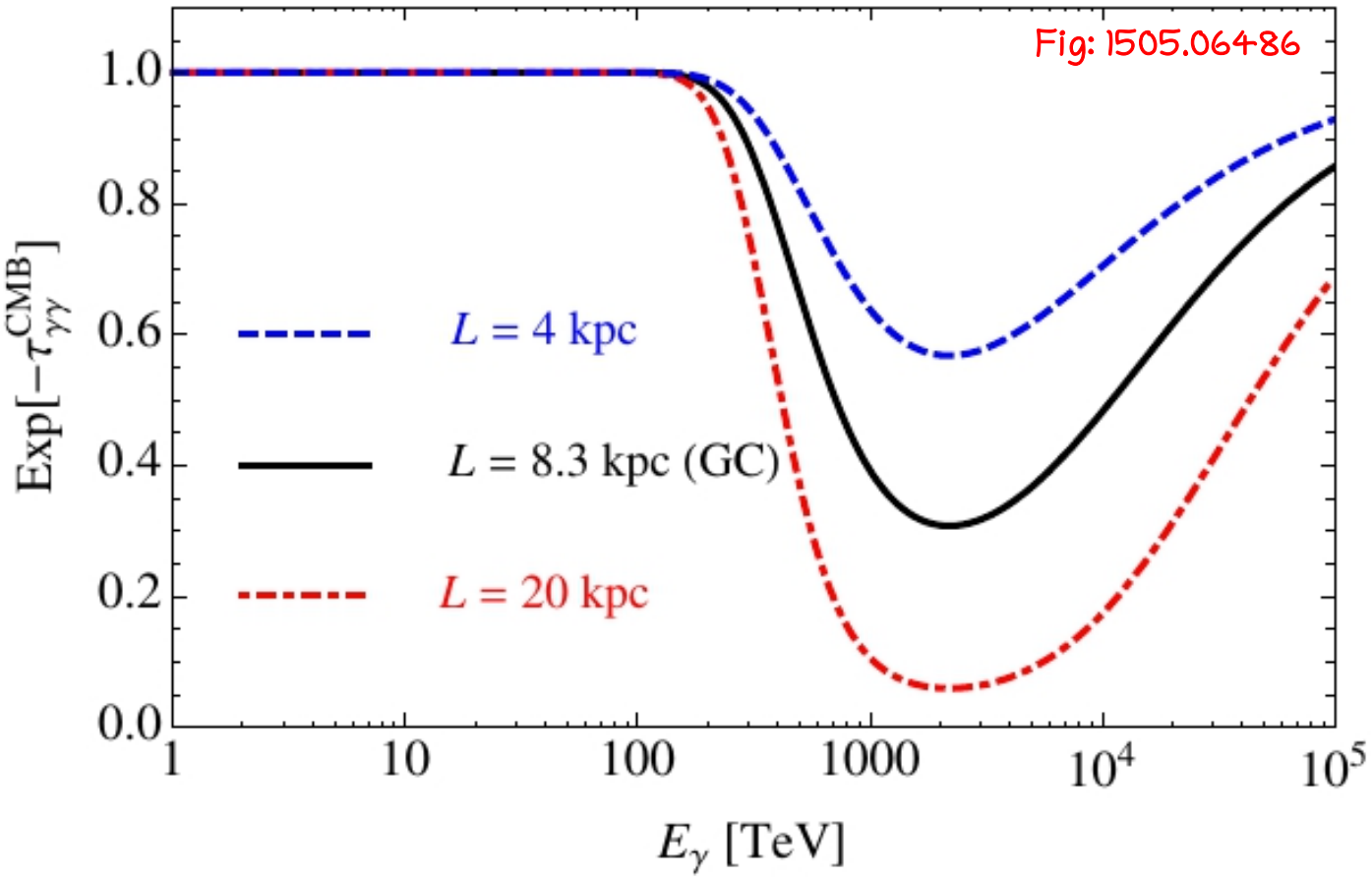
Fig: Francesca Calore (COSMO'21)

Diffuse Gamma Ray Propagation



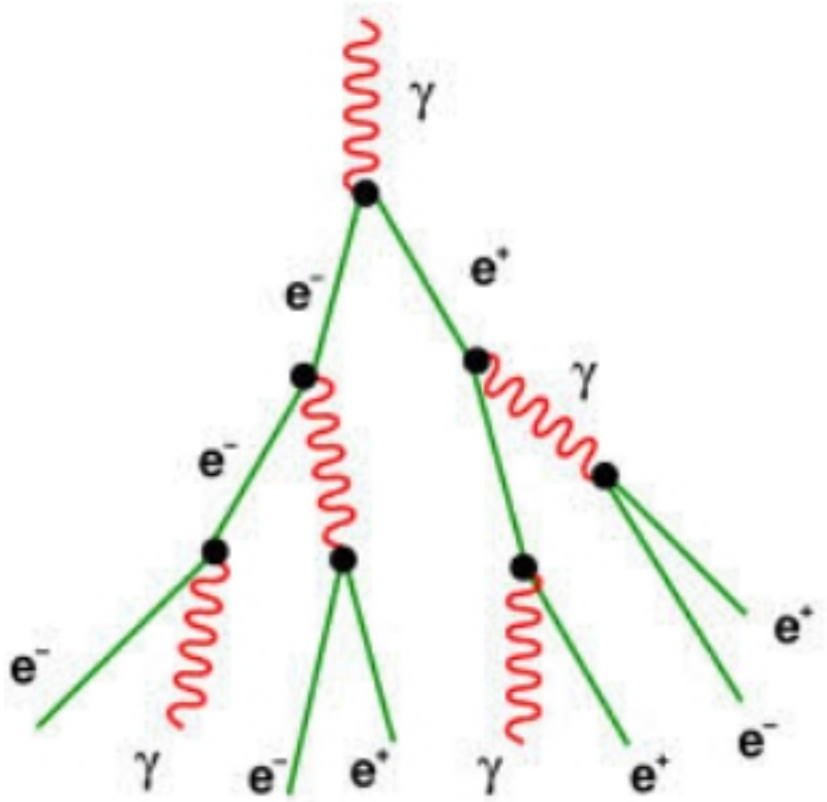
Diffuse Gamma Ray Attenuation

$$\gamma + \gamma_{\rm CMB} \rightarrow e^+ + e^-$$



Arrival of VHE diffuse gamma ray means that their origin has to be Galactic !

Diffuse Gamma Ray Detection



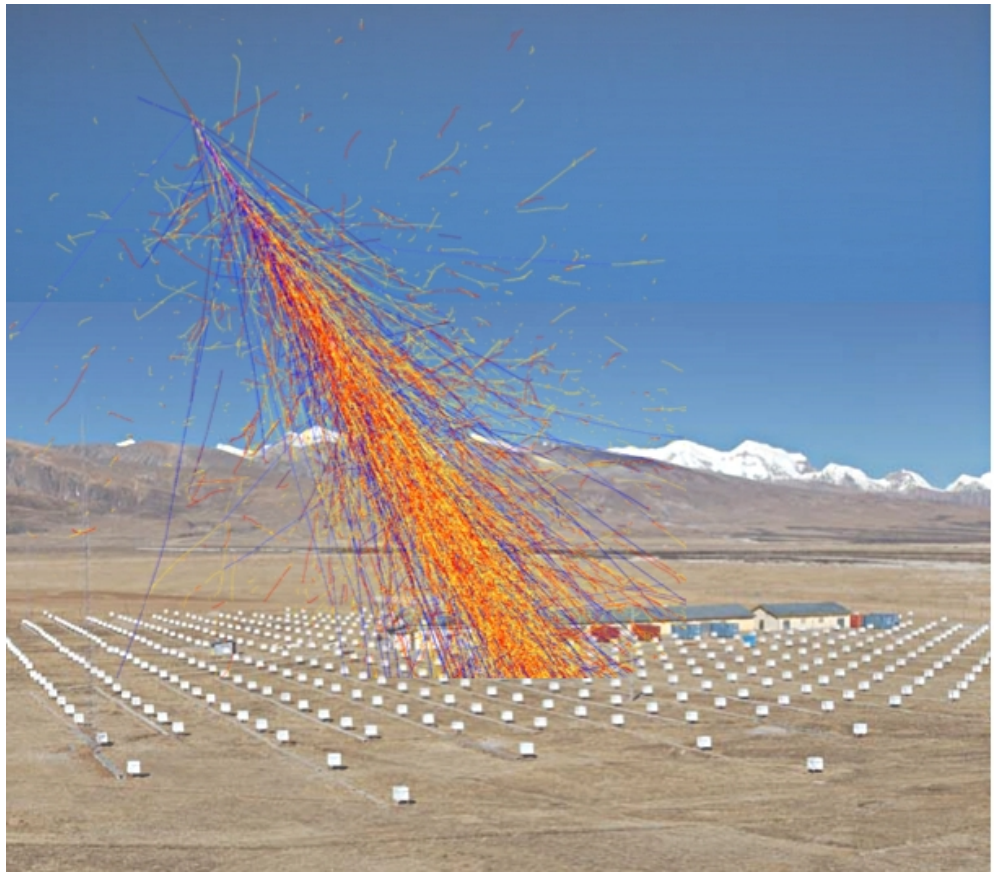
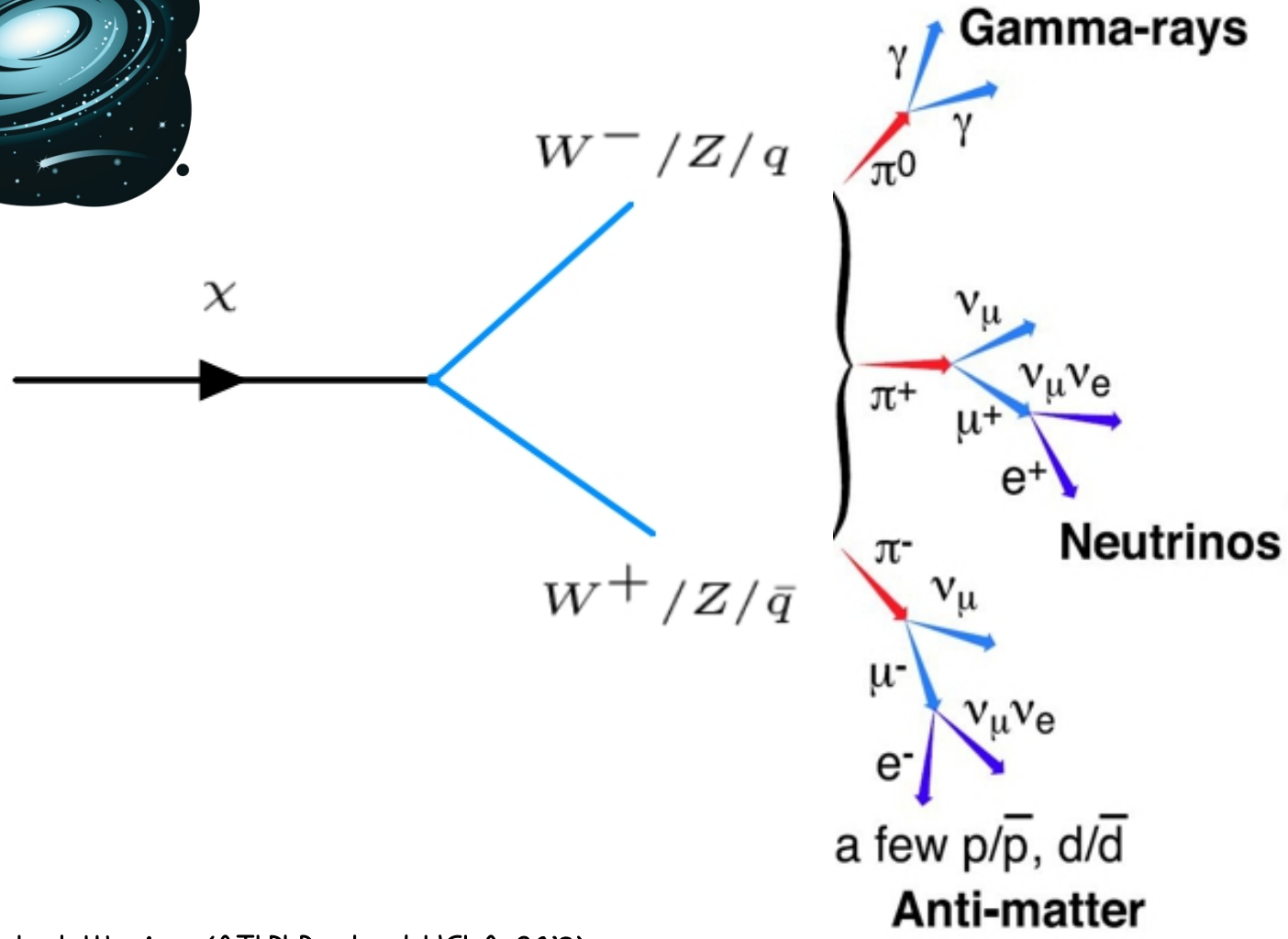
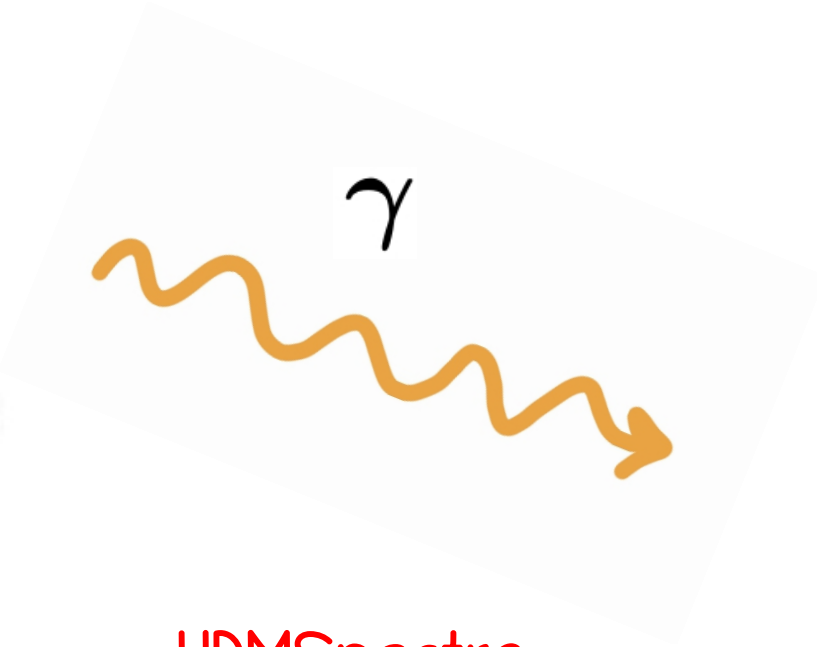


Fig: Tibet ASγ Collaboration

Fig: https://www.pngkey.com/maxpic/u2e6i1o0o0t4q8y3/

DM decay products

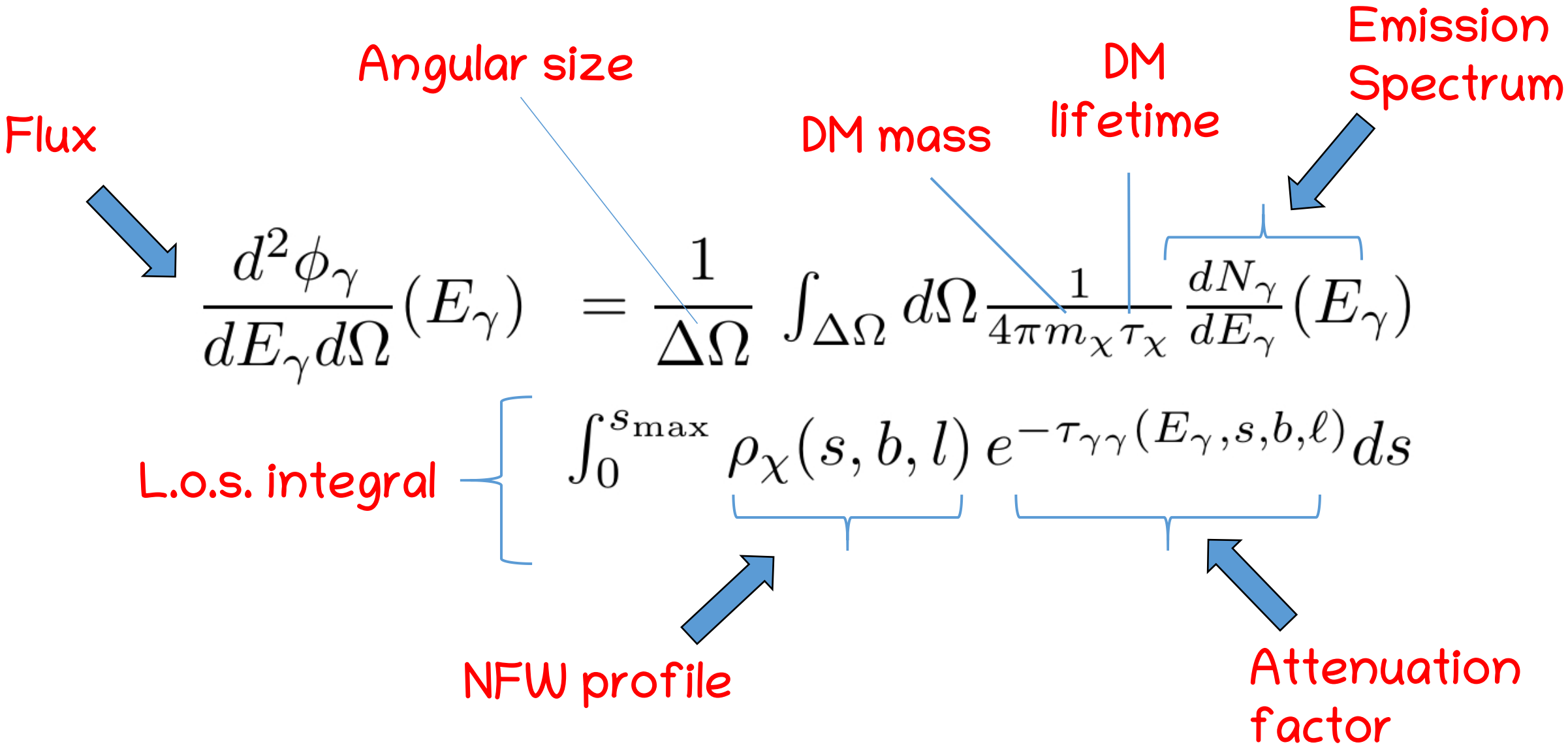




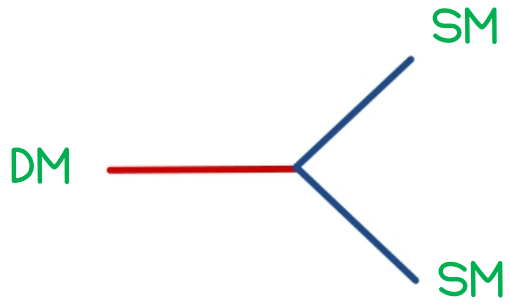
HDMSpectra
Bauer et al. (2007.15001)

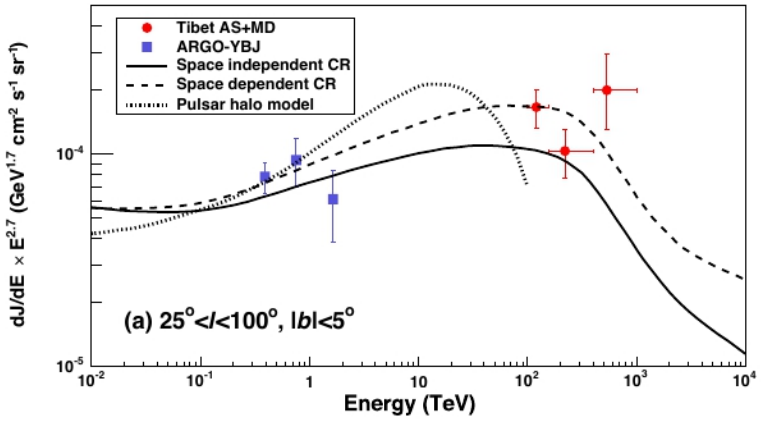
Fig: Christoph Weniger (ATI PhD school, UCLA, 2018)

Calculating Gamma Ray flux from DM



Our Proposal





Galactic CR induced Diffuse Gamma Ray

+

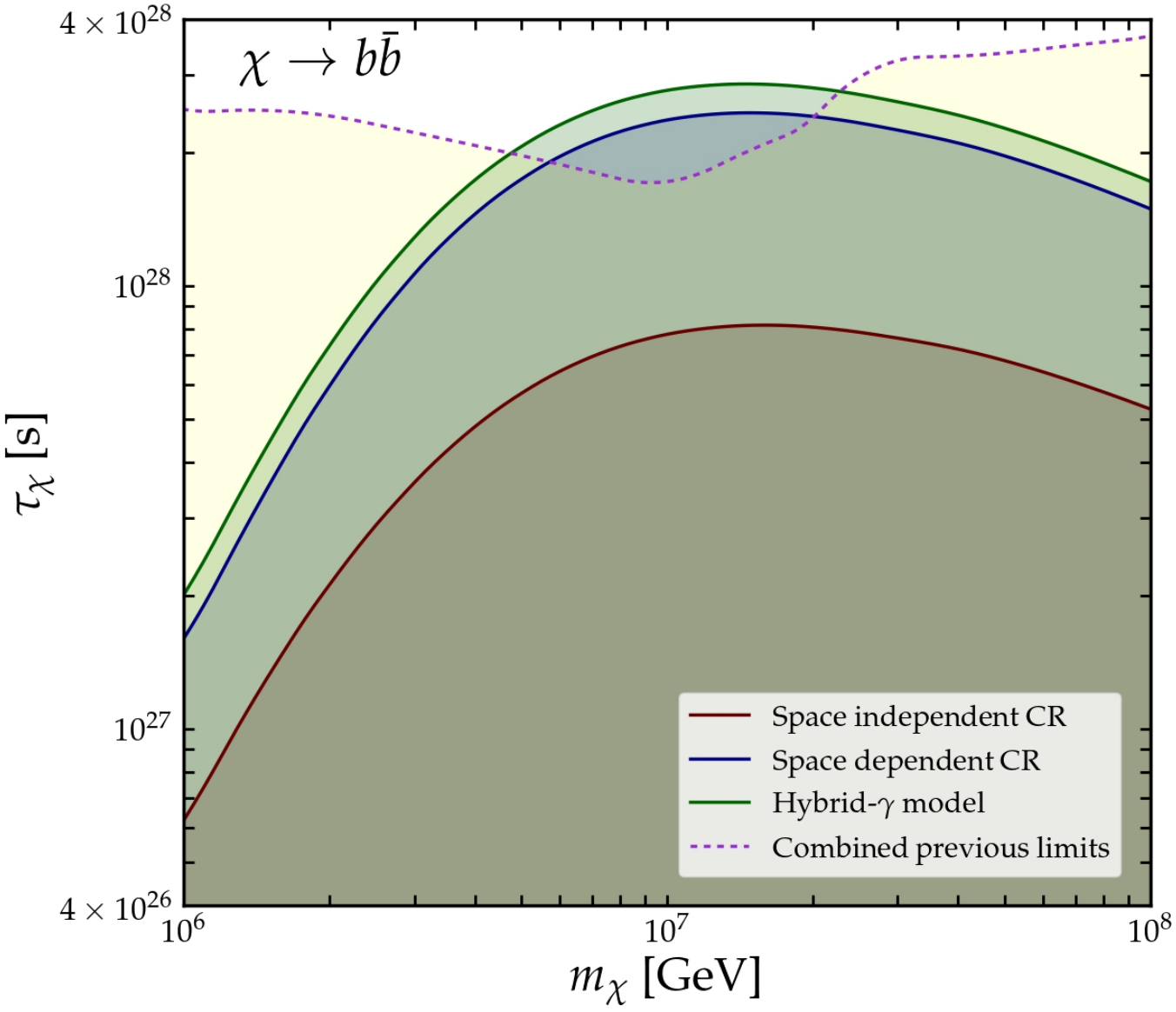
Photon from DM decay

→

Flux Observed

- Space dependent CR 1804.10116
- Space independent CR 1804.10116
- Hybrid Gamma model 2104.09491

Constraints on Decaying Dark Matter



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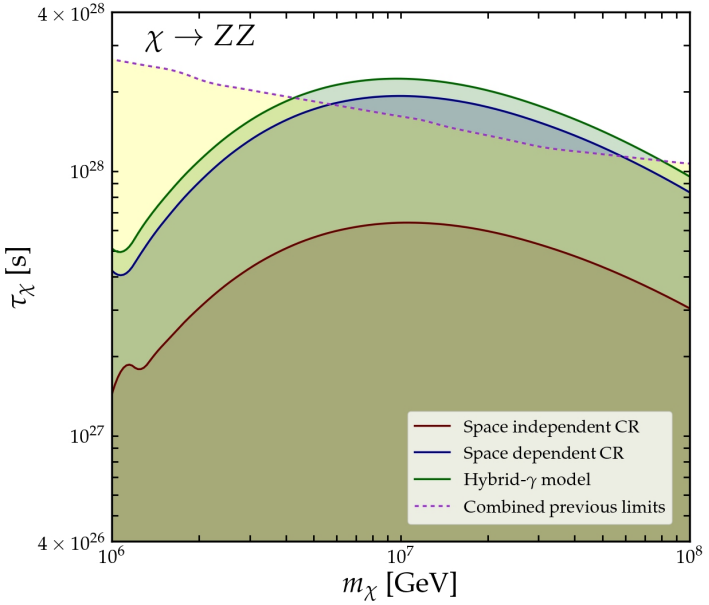
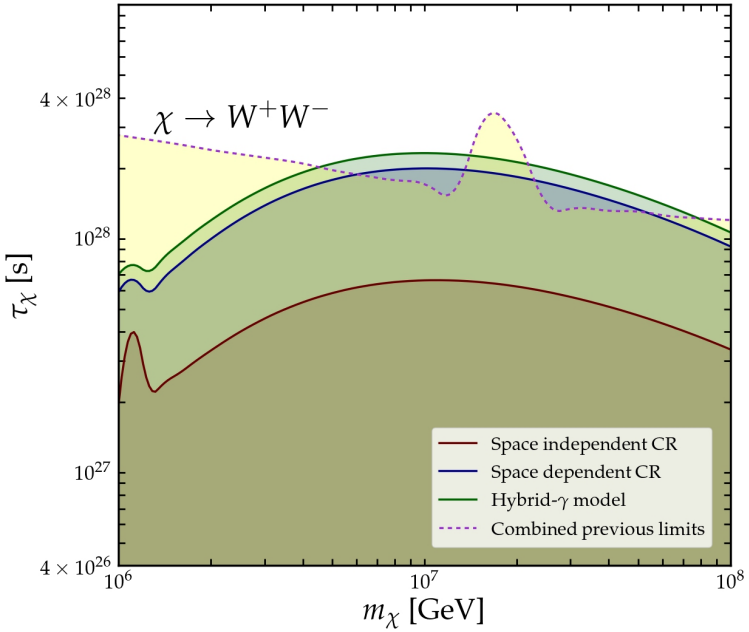
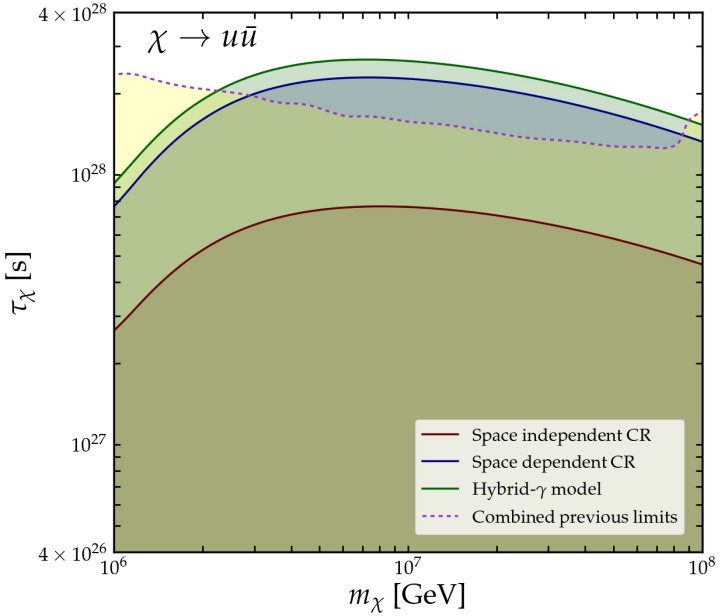
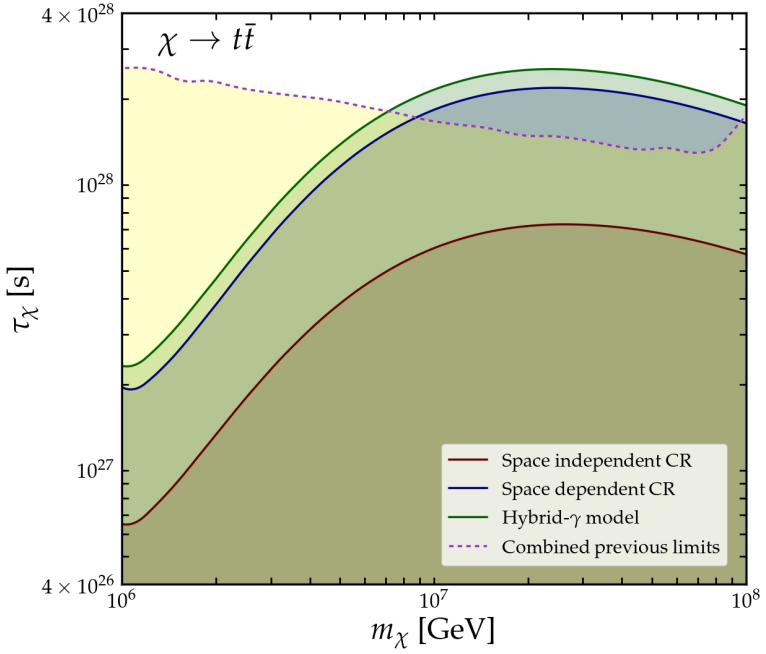
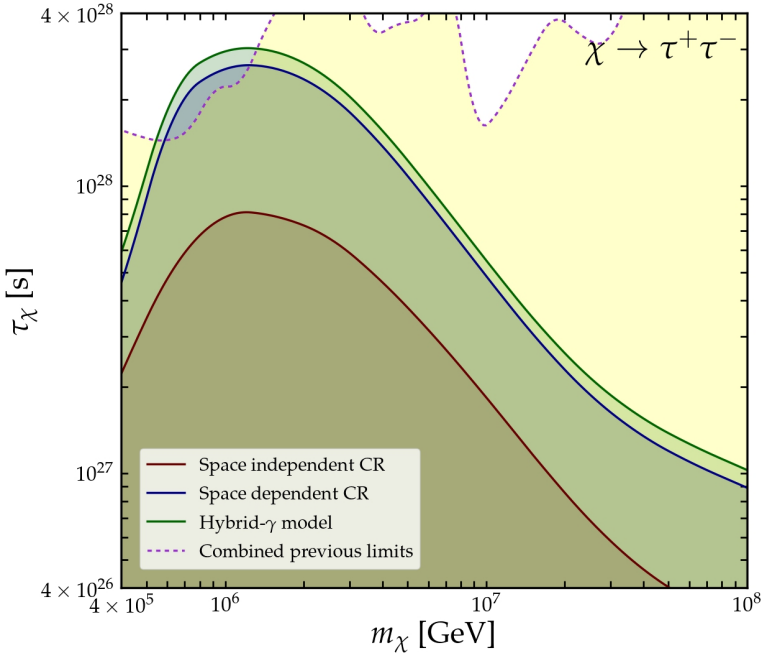
arXiv: 2105.05680

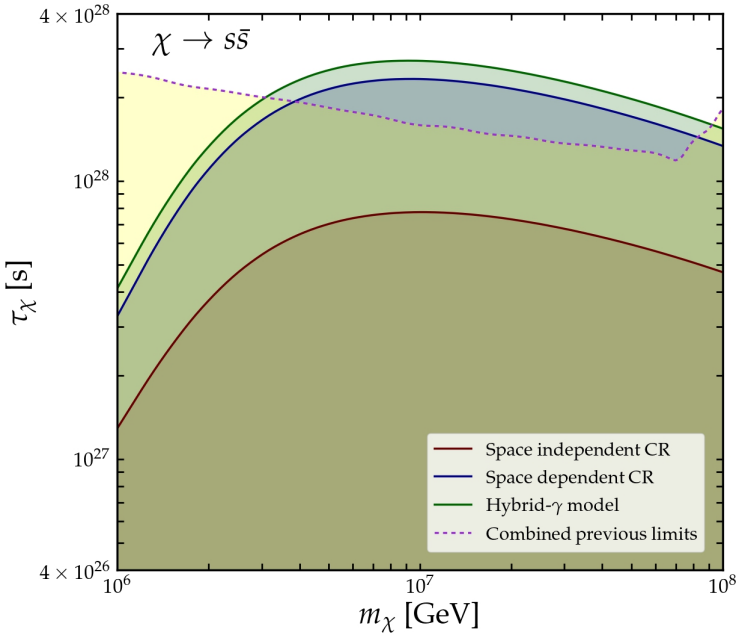

$\chi \to ZZ$
τ_χ [s]
m_χ [GeV]
Space independent CR
Space dependent CR
Hybrid-γ model
Combined previous limits

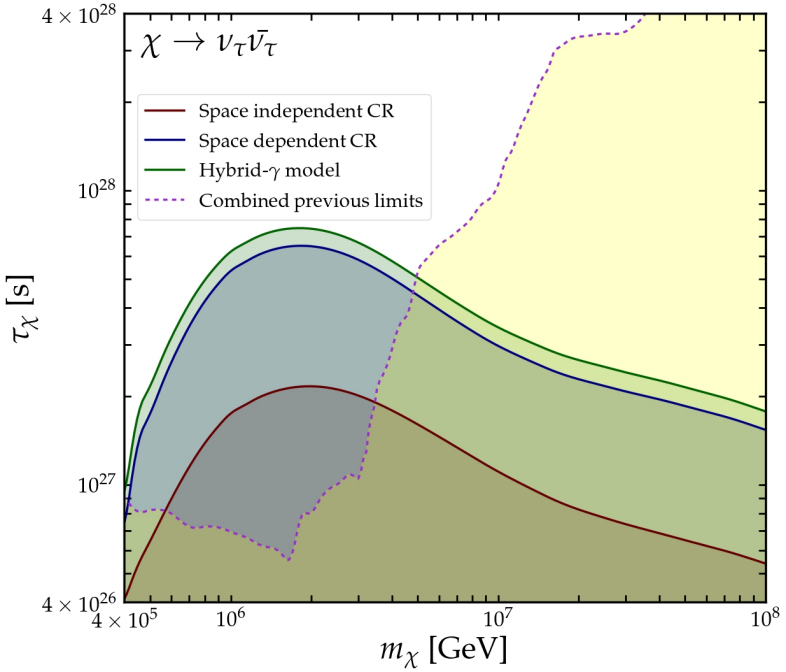

$\chi \to W^+W^-$
τ_χ [s]
m_χ [GeV]
Space independent CR
Space dependent CR
Hybrid-γ model
Combined previous limits

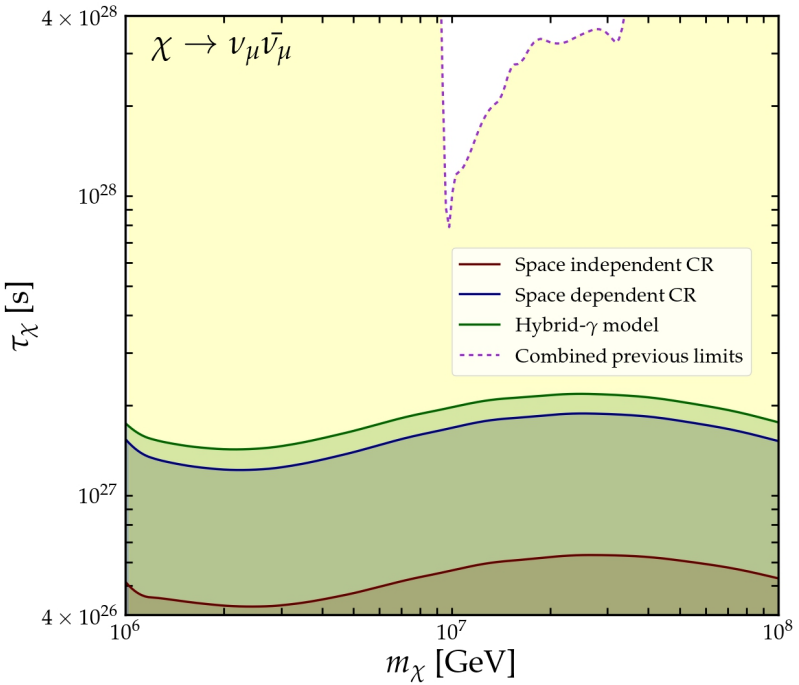

$\chi \to u\bar{u}$
τ_χ [s]
m_χ [GeV]
Space independent CR
Space dependent CR
Hybrid-γ model
Combined previous limits

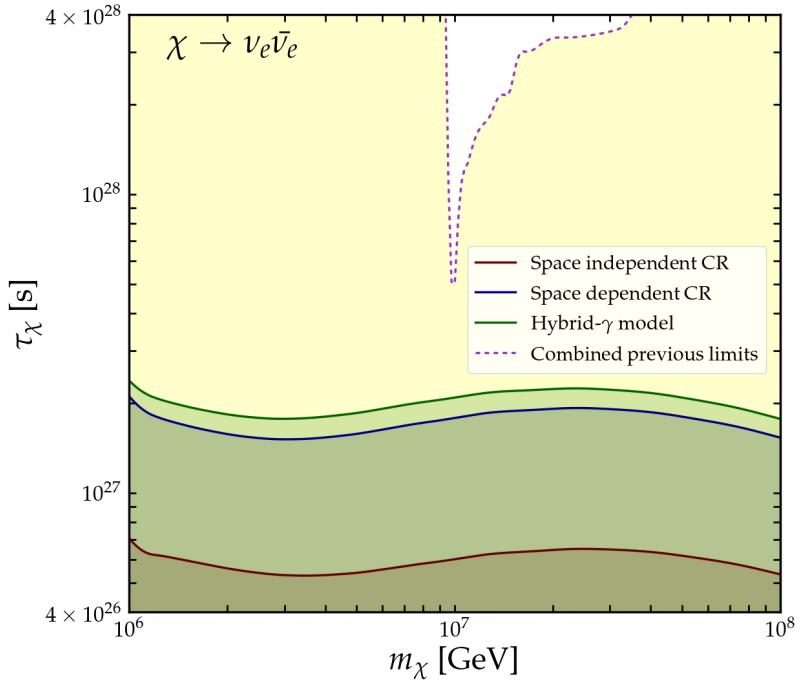

$\chi \to t\bar{t}$
τ_χ [s]
m_χ [GeV]
Space independent CR
Space dependent CR
Hybrid-γ model
Combined previous limits

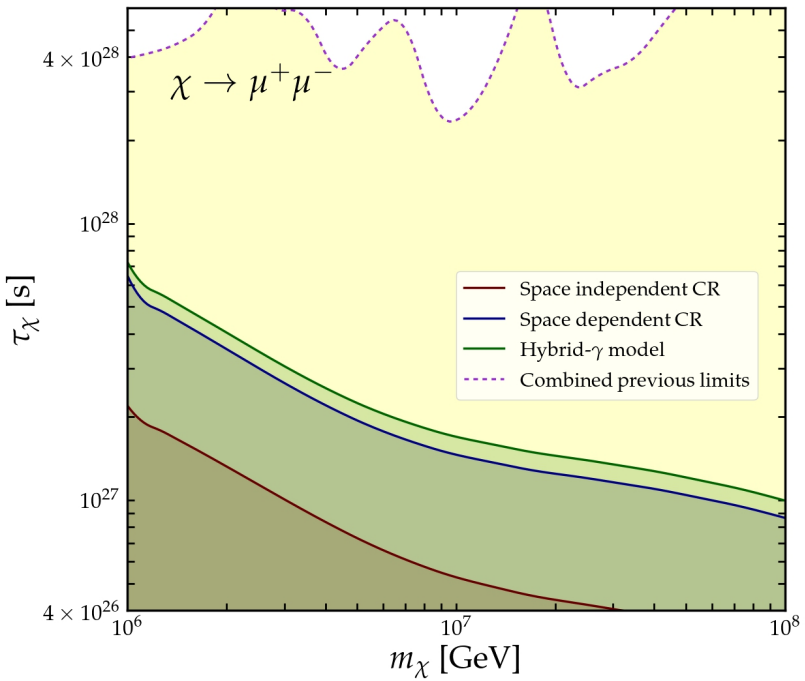

$\chi \to \tau^+\tau^-$
τ_χ [s]
m_χ [GeV]
Space independent CR
Space dependent CR
Hybrid-γ model
Combined previous limits

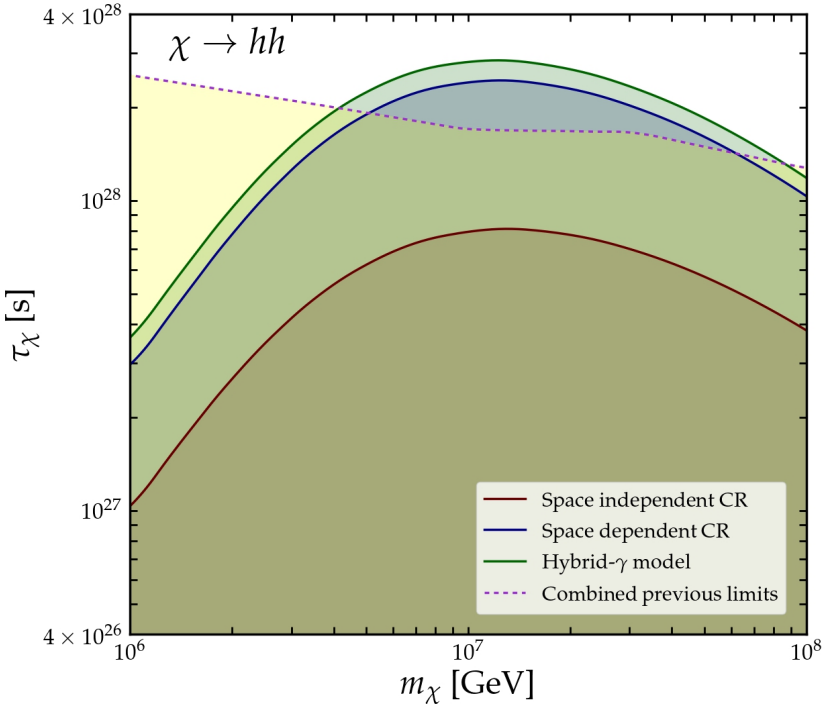

$\chi \to s\bar{s}$
τ_χ [s]
m_χ [GeV]
Space independent CR
Space dependent CR
Hybrid-γ model
Combined previous limits

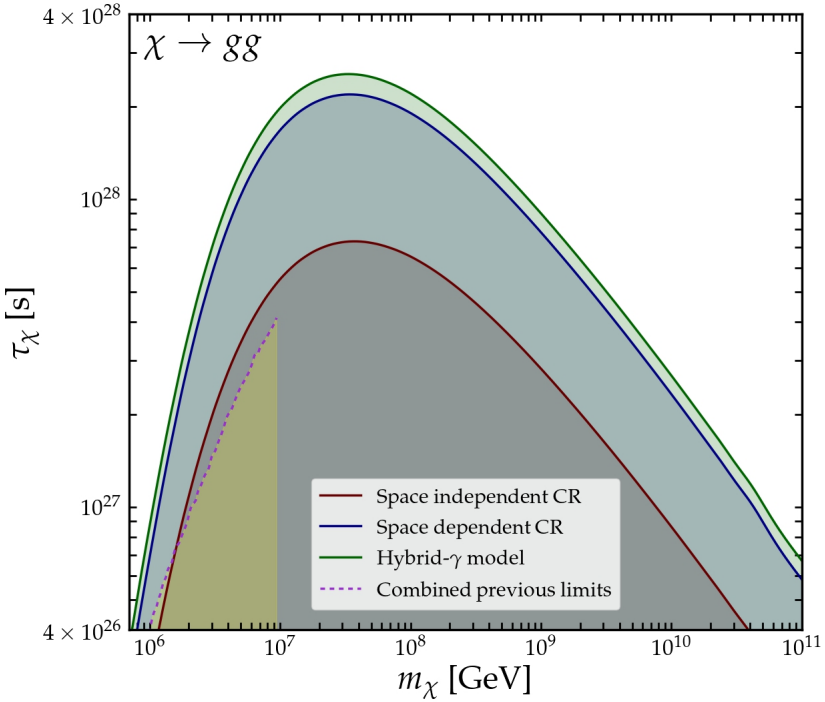

$\chi \to \nu_\tau \bar{\nu}_\tau$
Space independent CR
Space dependent CR
Hybrid-γ model
Combined previous limits
τ_χ [s]
m_χ [GeV]

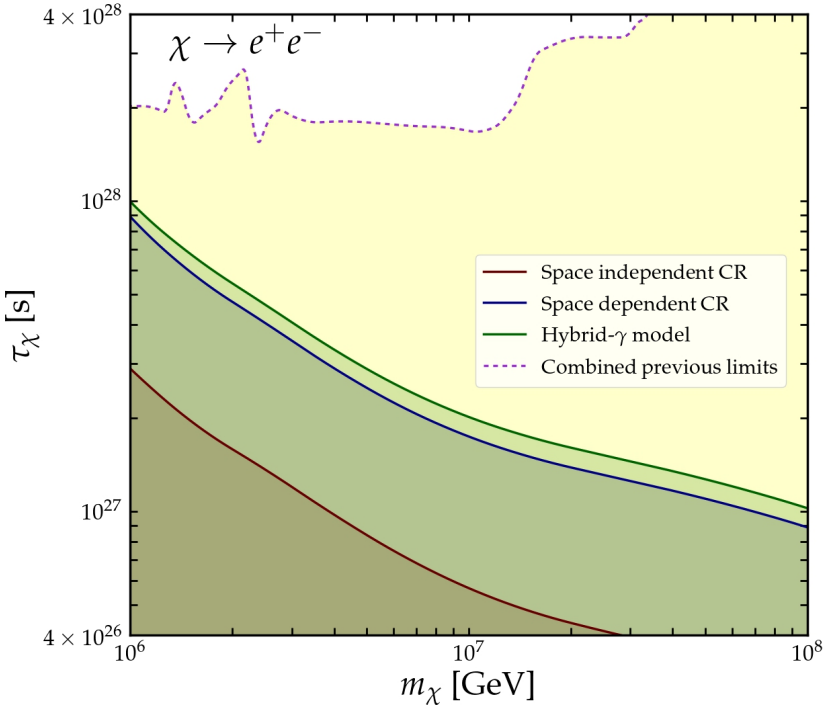

$\chi \to \nu_\mu \bar{\nu}_\mu$
Space independent CR
Space dependent CR
Hybrid-γ model
Combined previous limits
τ_χ [s]
m_χ [GeV]

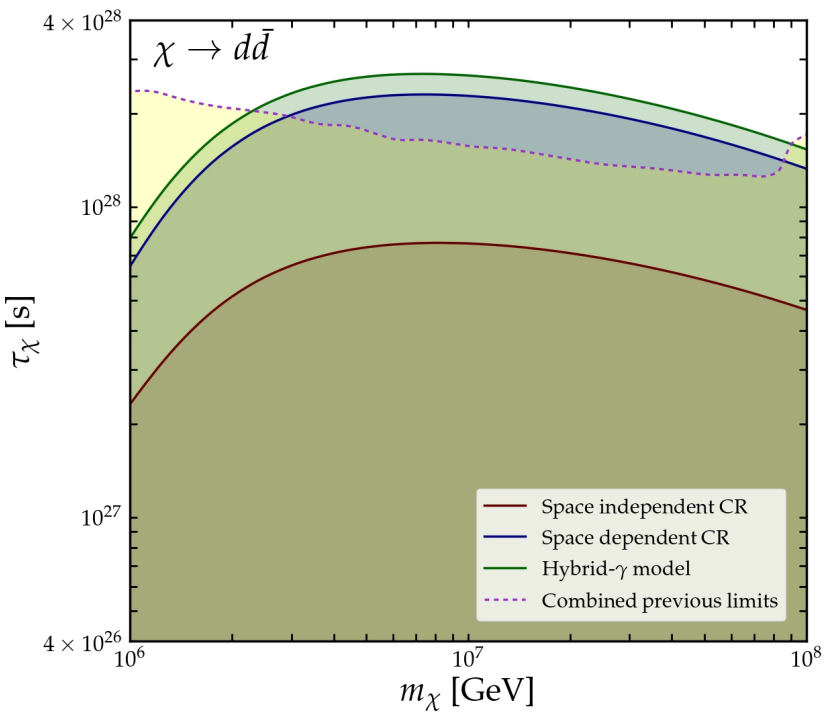

$\chi \to \nu_e \bar{\nu}_e$
Space independent CR
Space dependent CR
Hybrid-γ model
Combined previous limits
τ_χ [s]
m_χ [GeV]

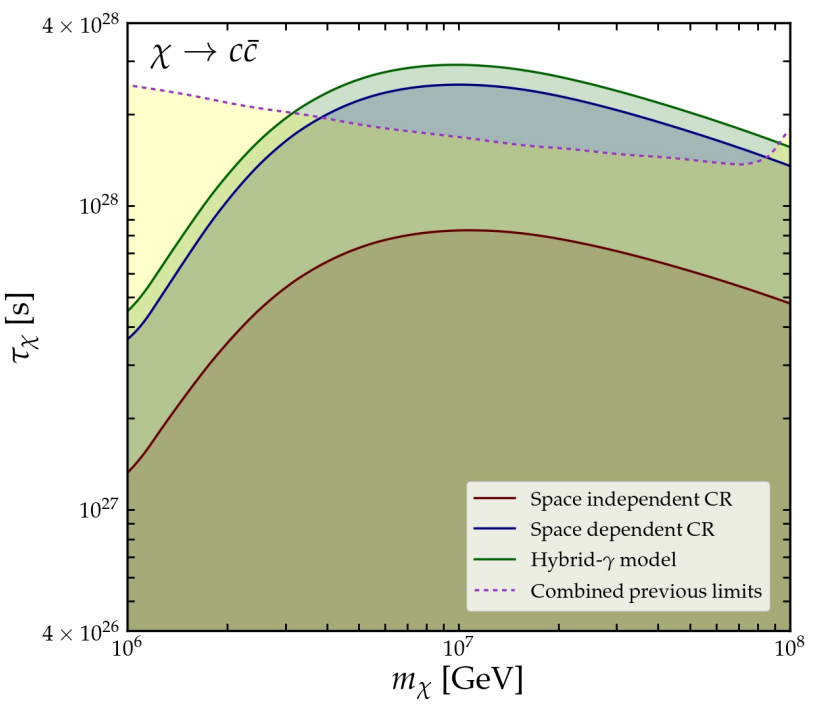

$\chi \to \mu^+ \mu^-$
Space independent CR
Space dependent CR
Hybrid-γ model
Combined previous limits
τ_χ [s]
m_χ [GeV]


$\chi \to hh$
Space independent CR
Space dependent CR
Hybrid-γ model
Combined previous limits
τ_χ [s]
m_χ [GeV]


$\chi \to gg$
Space independent CR
Space dependent CR
Hybrid-γ model
Combined previous limits
τ_χ [s]
m_χ [GeV]


$\chi \to e^+e^-$
4×10^{28}
10^{28}
10^{27}
4×10^{26}
τ_χ [s]
10^6
10^7
10^8
m_χ [GeV]
Space independent CR
Space dependent CR
Hybrid-γ model
Combined previous limits

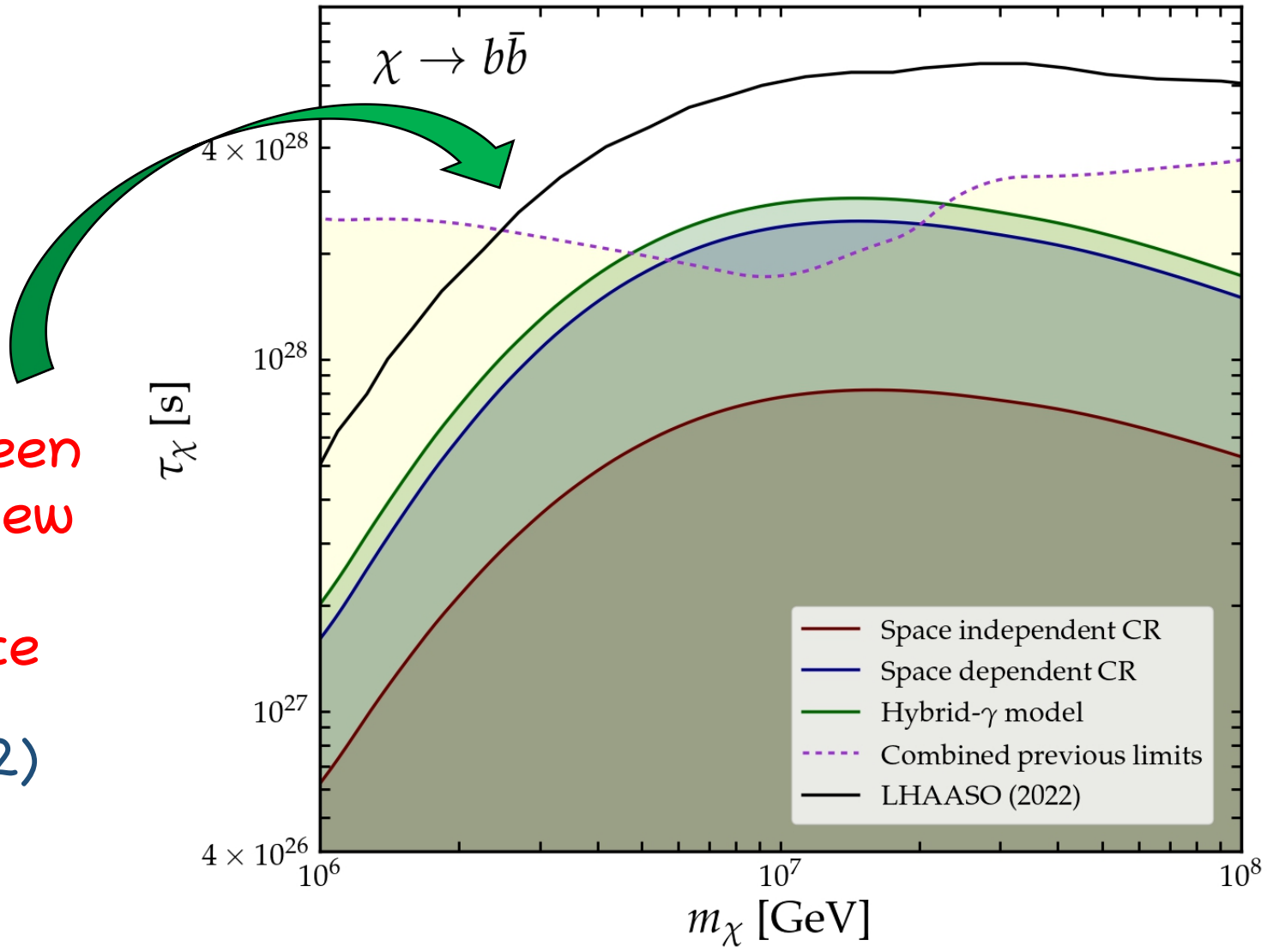

$\chi \to d\bar{d}$
4×10^{28}
10^{28}
10^{27}
4×10^{26}
τ_χ [s]
10^6
10^7
10^8
m_χ [GeV]
Space independent CR
Space dependent CR
Hybrid-γ model
Combined previous limits


$\chi \to c\bar{c}$
4×10^{28}
10^{28}
10^{27}
4×10^{26}
τ_χ [s]
10^6
10^7
10^8
m_χ [GeV]
Space independent CR
Space dependent CR
Hybrid-γ model
Combined previous limits

Large High Altitude Air Shower Observatory (LHAASO)

Credit: Liu Kun/Xinhua/Alamy

Constraints on Decaying Dark Matter



LHAASO has been able to probe new regions of parameter space

Cao et al. (2022) 2210.15989

Summary

- Dark Matter makes up majority of the total matter content in the Universe
- Looking at the high energy diffuse gamma ray can be a very important discovery probe for DM
- In future with improvements in both theoretical and experimental aspects, we may either discover DM or put stringent constraints on its properties.

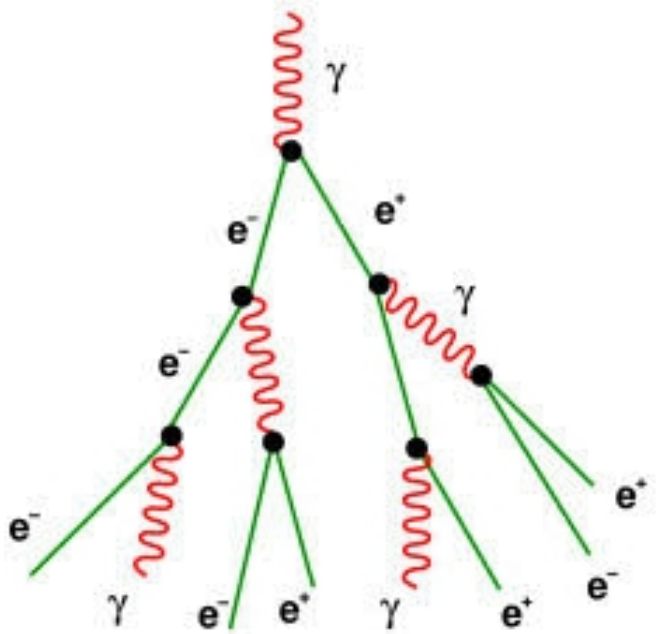
Questions & comments:
akashks@iisc.ac.in

Thank You !

Backup Slides

Diffuse Gamma Ray Detection

Primary γ



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Cosmic Ray

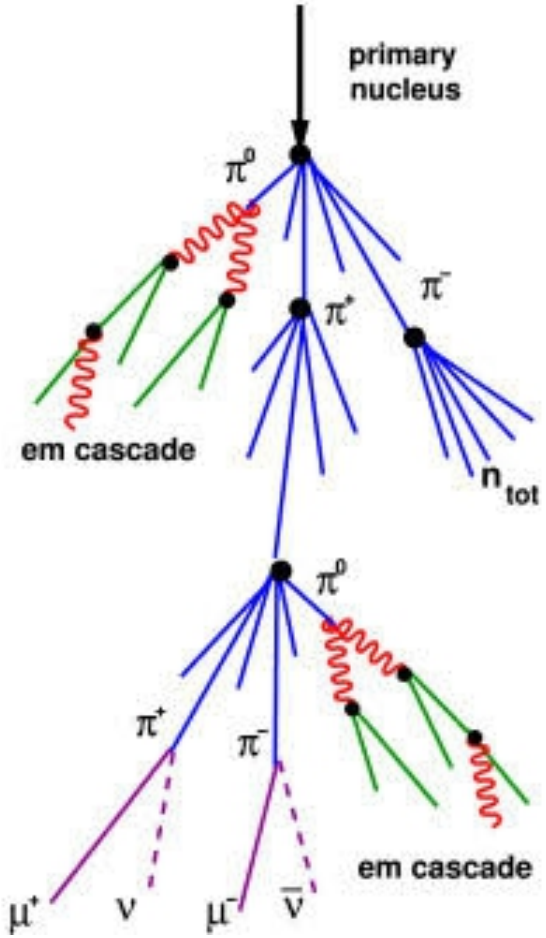
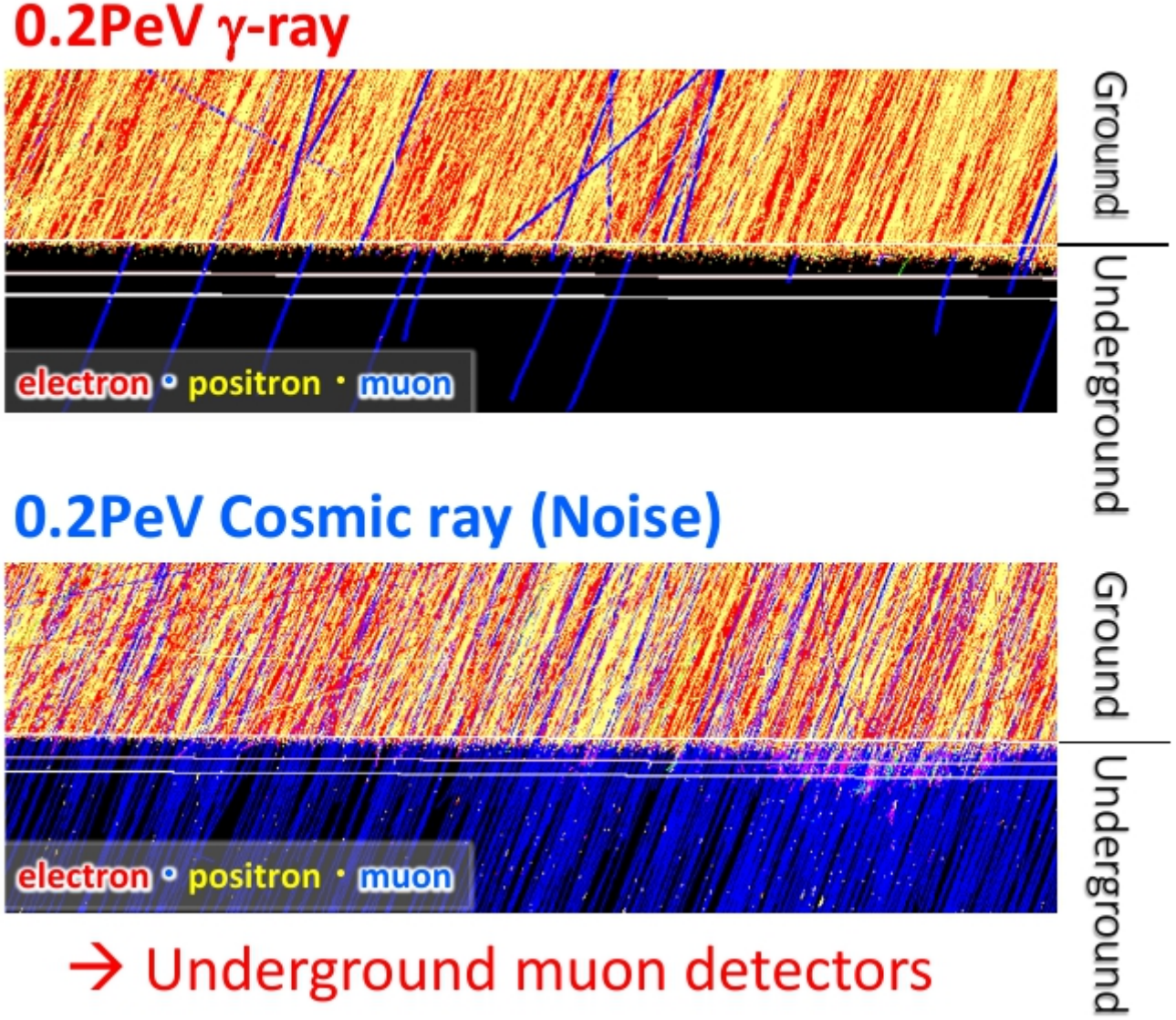


Fig: https://www.pngkey.com/maxpic/u2e6i1o0o0t4-q8y3/

Discriminating Gamma Ray induced Air-shower

Fig: Masato Takita, CRA2019



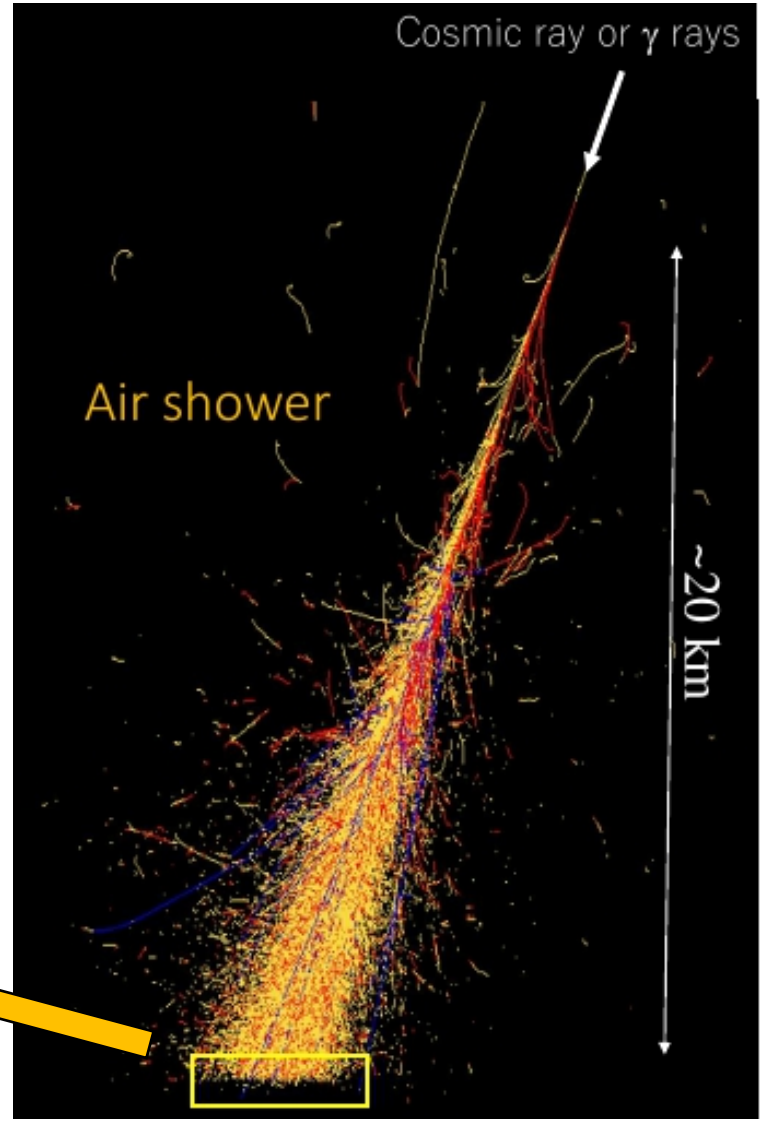
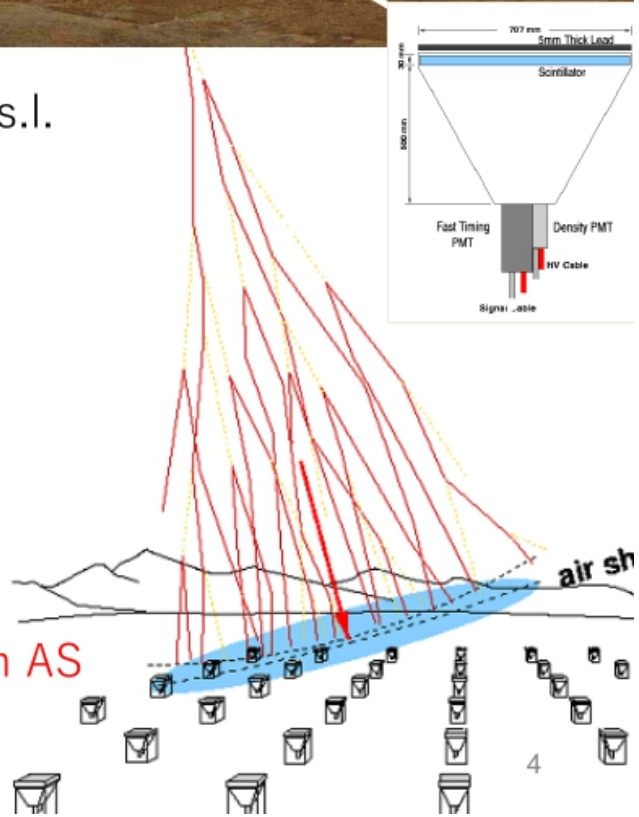


Fig: Masato Takita, CRA2019

- Site: Tibet (90.522°E, 30.102°N) 4,300 m a.s.l.

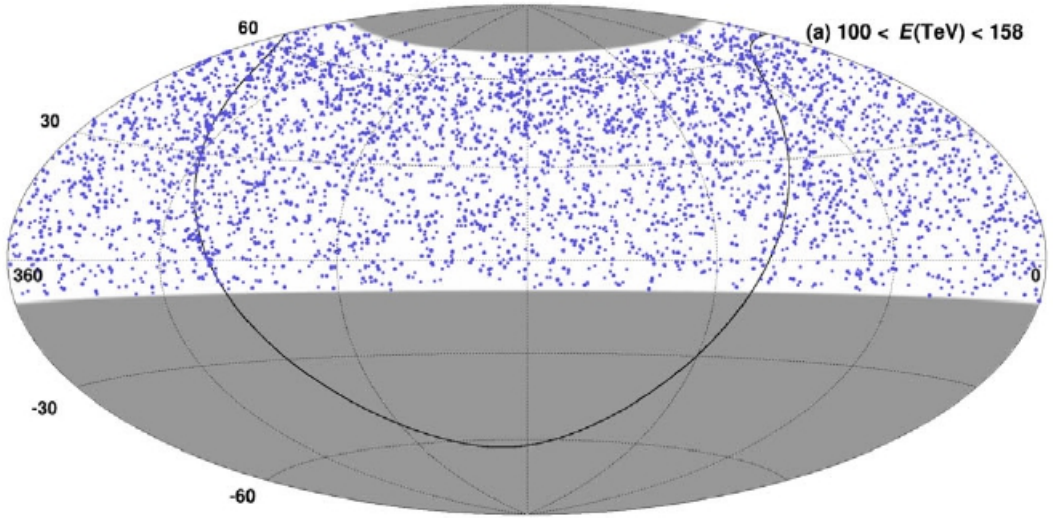
Present Performance

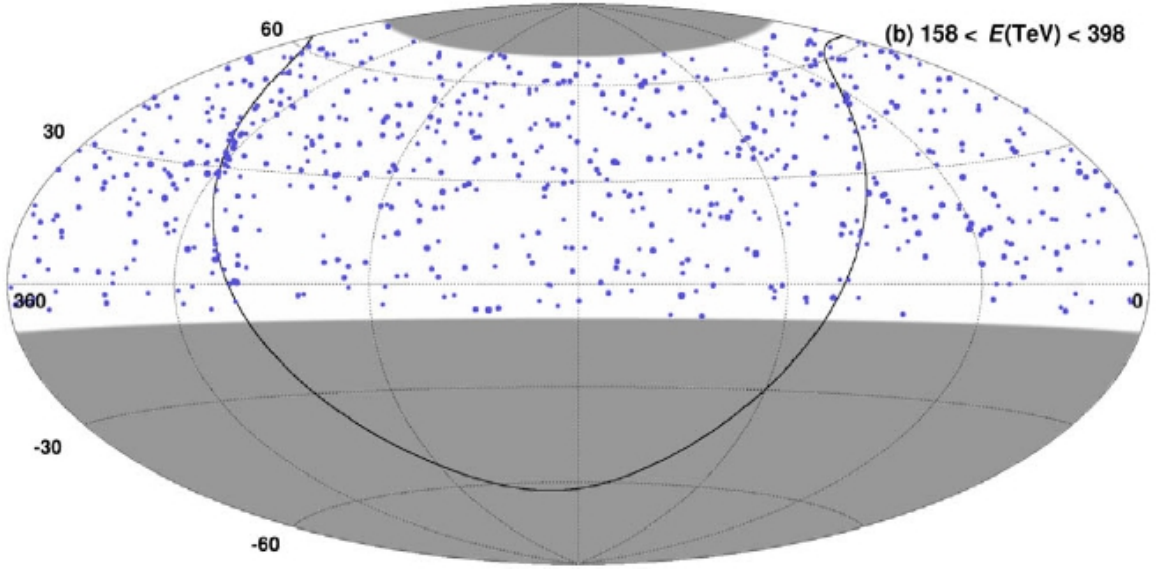
# of detectors	0.5 m^2 x 597
Effective area	~65,700 m^2
Angular resolution	~0.5° @10TeV
	~0.2° @100TeV
Energy resolution	~40%@10TeV γ
	~20%@100TeV γ

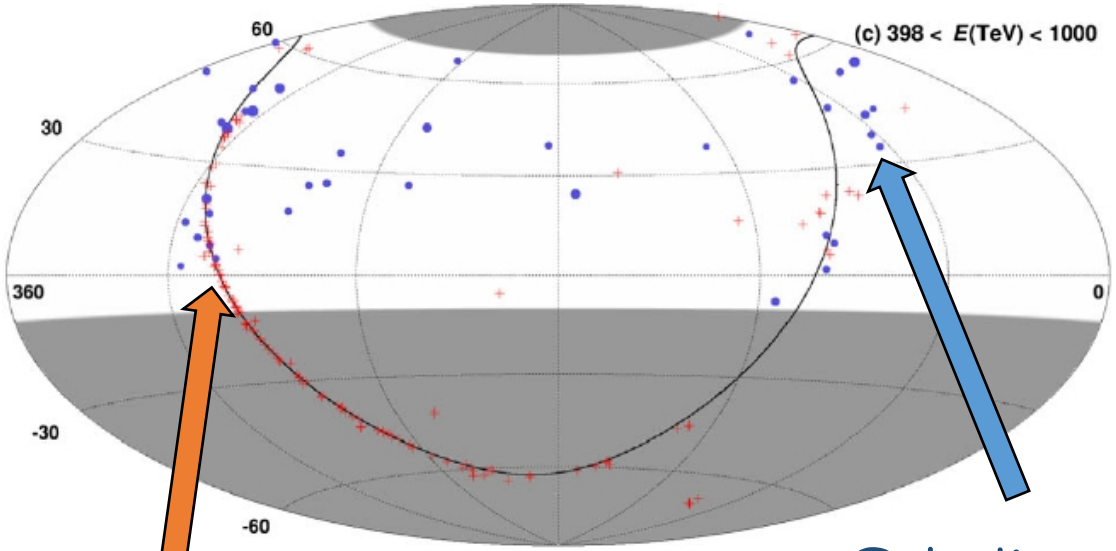


→Observation of secondary (mainly $e^{+/-}$, γ) in AS
Primary energy : 2nd particle densities
Primary direction : 2nd relative timings

Diffuse gamma ray events seen by Tibet AS$_\gamma$ Experiment







Gamma Ray from known sources

Galactic Diffuse Gamma Ray

Fig : Phys. Rev. Lett. 126, 141101

Tibet AS$_\gamma$ Experiment

TABLE S2. Galactic diffuse gamma-ray fluxes measured by the Tibet AS+MD array.

Energy bin (TeV)	Representative E (TeV)	Flux ($25^\circ < l < 100^\circ, \lvert b\rvert < 5^\circ$) ($\mathrm{TeV^{-1}\ cm^{-2}\ s^{-1}\ sr^{-1}}$)	Flux ($50^\circ < l < 200^\circ, \lvert b\rvert < 5^\circ$) ($\mathrm{TeV^{-1}\ cm^{-2}\ s^{-1}\ sr^{-1}}$)
$100 - 158$	121	$(3.16 \pm 0.64) \times 10^{-15}$	$(1.69 \pm 0.41) \times 10^{-15}$
$158 - 398$	220	$(3.88 \pm 1.00) \times 10^{-16}$	$(2.27 \pm 0.60) \times 10^{-16}$
$398 - 1000$	534	$(6.86\ ^{+3.30}_{-2.40}) \times 10^{-17}$	$(2.99\ ^{+1.40}_{-1.02}) \times 10^{-17}$

Effect of SL + IR

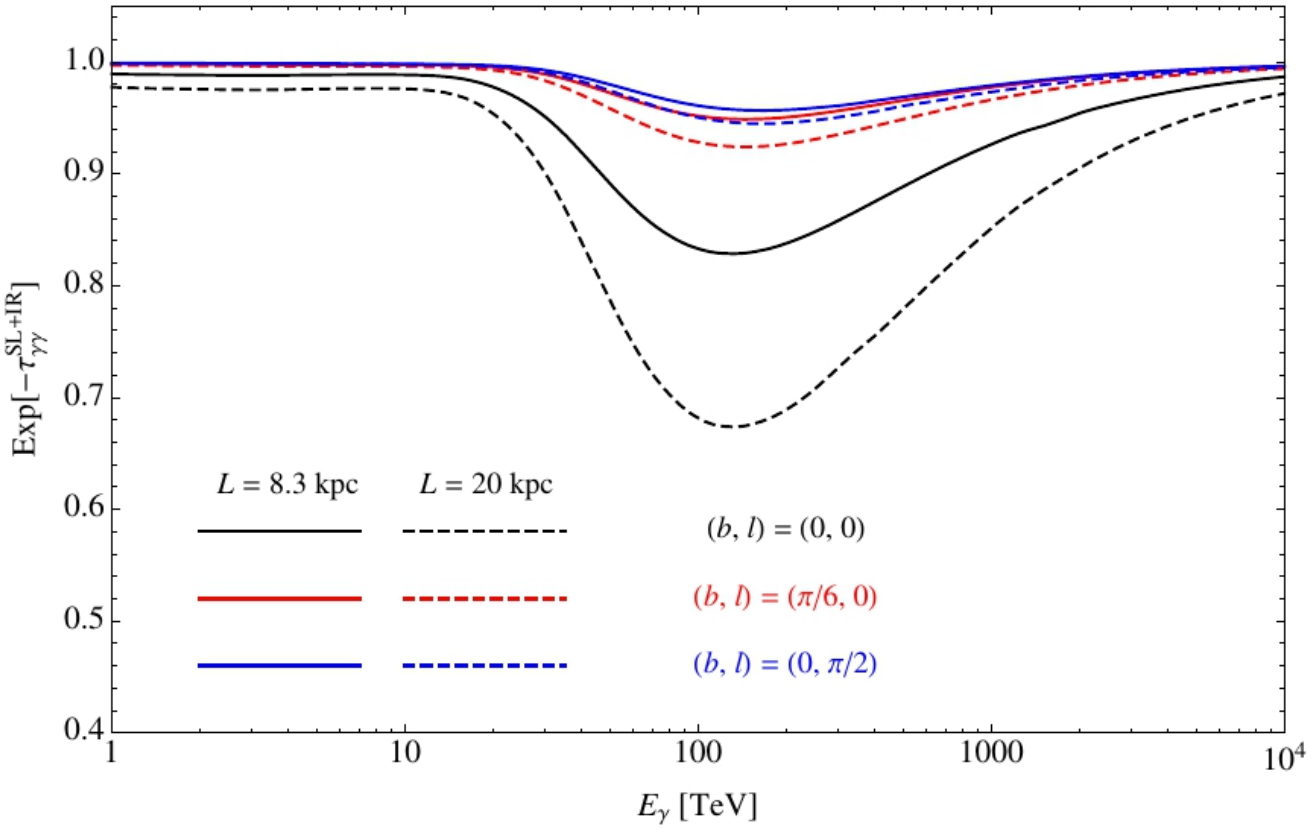
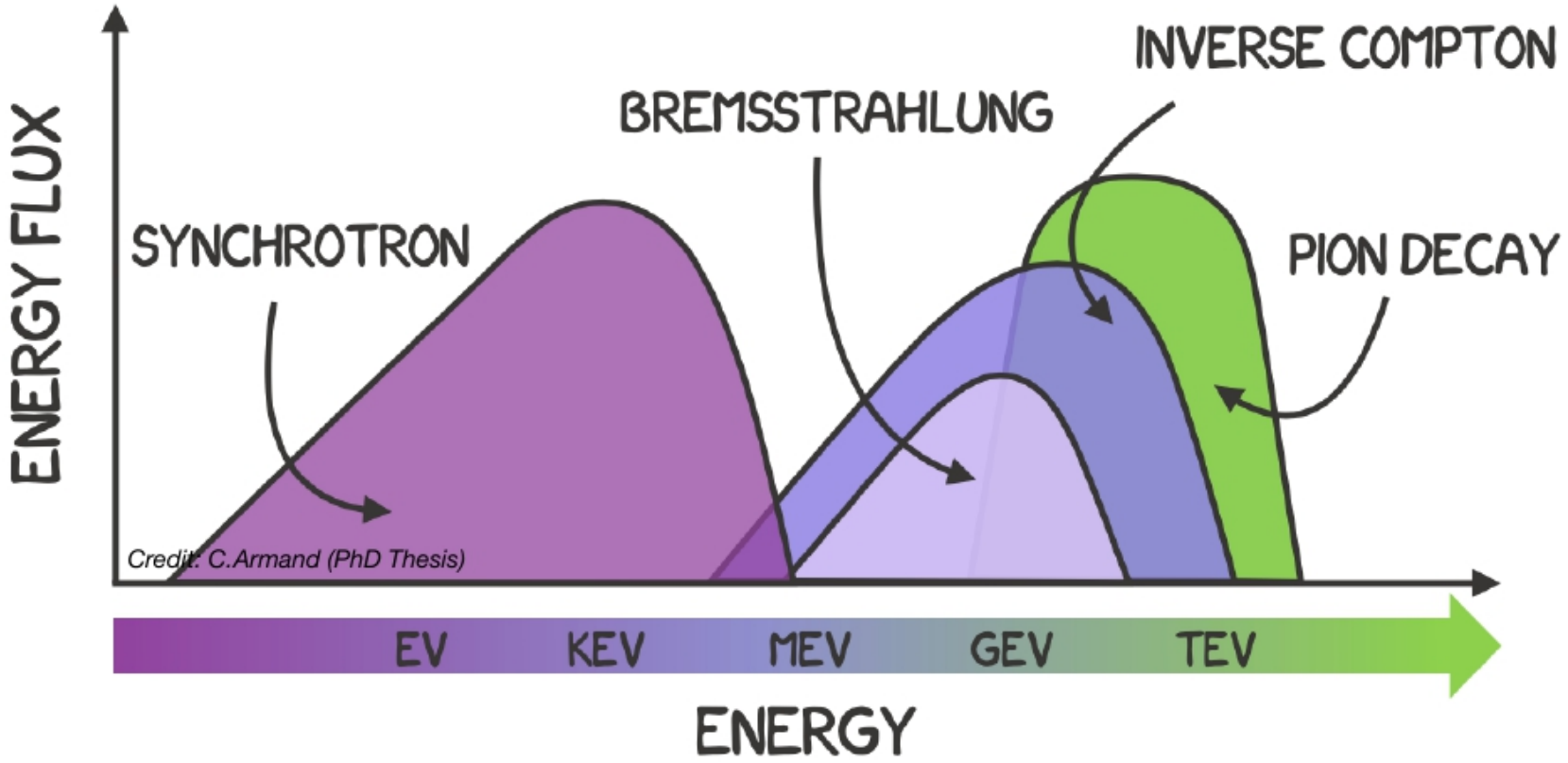
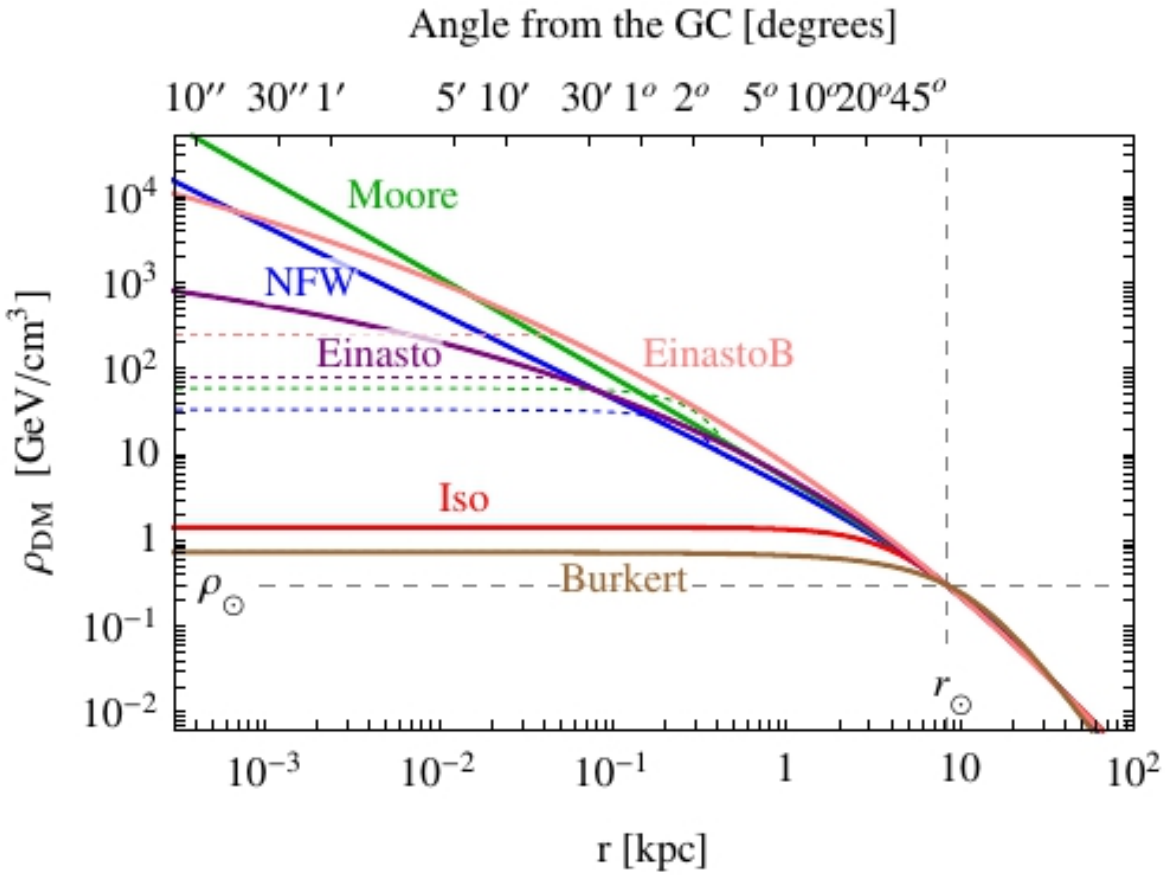


Fig: 1505.06486

Multi-wavelength Emission Spectrum



Different DM profiles



Away from Galactic Centre all the profiles follow similar r dependence.

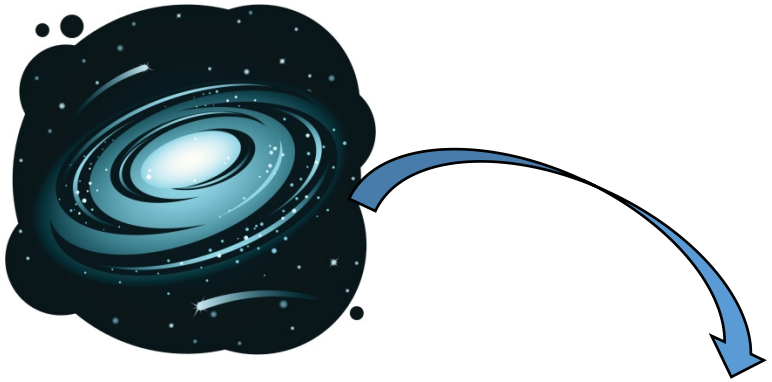
DM halo	α	r_s [kpc]	ρ_s [GeV/cm^3]
NFW	–	24.42	0.184
Einasto	0.17	28.44	0.033
EinastoB	0.11	35.24	0.021
Isothermal	–	4.38	1.387
Burkert	–	12.67	0.712
Moore	–	30.28	0.105

For NFW profile,

$$\rho_{\rm NFW}(r) = \rho_s \frac{r_s}{r}\left(1+\frac{r}{r_s}\right)^{-2}$$

PPPC 4 DM ID: a poor particle physicist cookbook for dark matter indirect detection, arXiv: 1012.4515

Calculating Gamma Ray flux from DM



Flux of photons received at a detector of area A

DM density

$$\frac{A}{4\pi s^2} \times \frac{dN_\gamma}{dE_\gamma}(E_\gamma) \times \frac{1}{\tau_\gamma} \times \frac{\rho_\chi}{m_\chi} \times dV$$

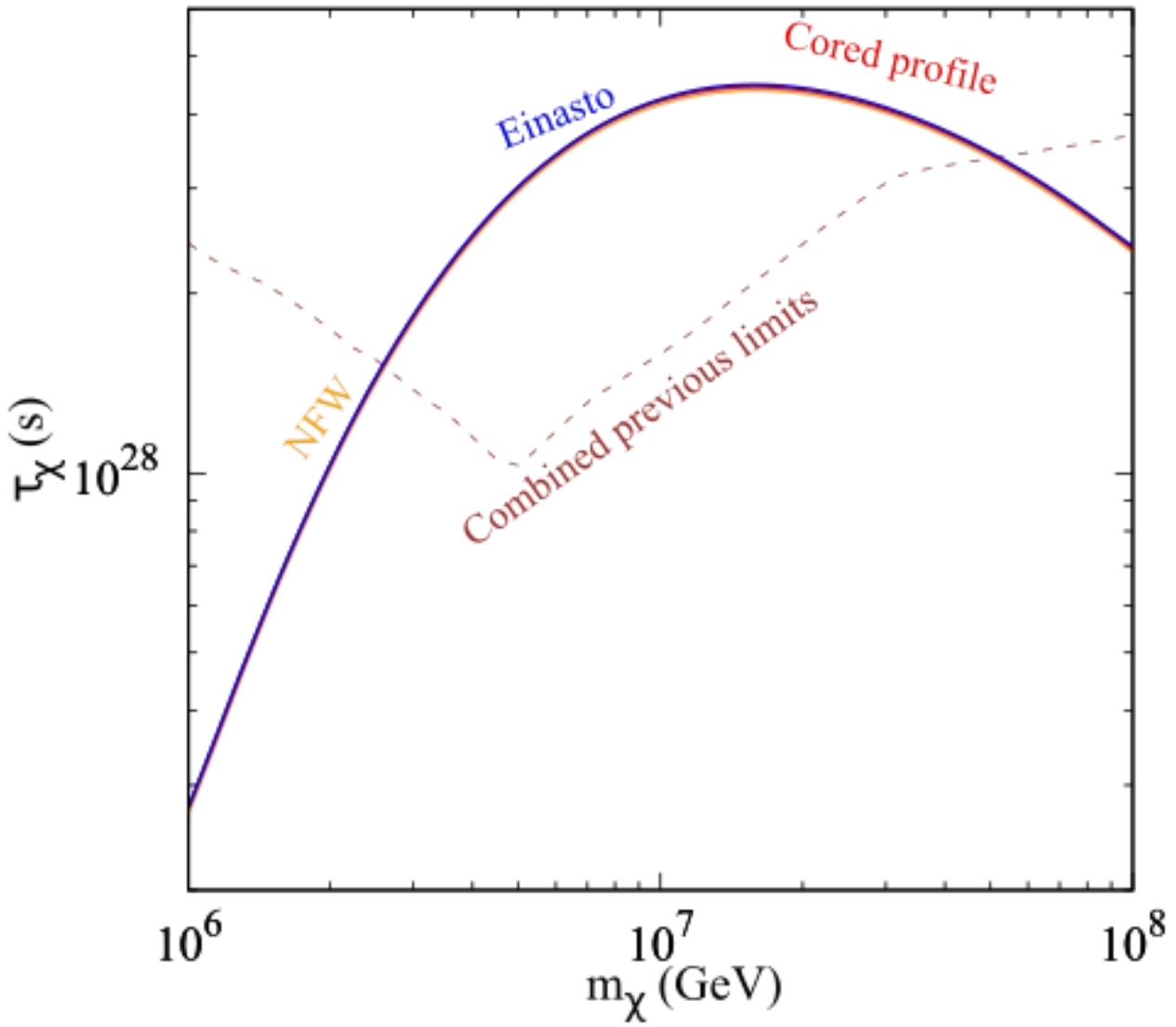
Spectra of photons per DM decay

Total decay rate of all DM particles in volume dV

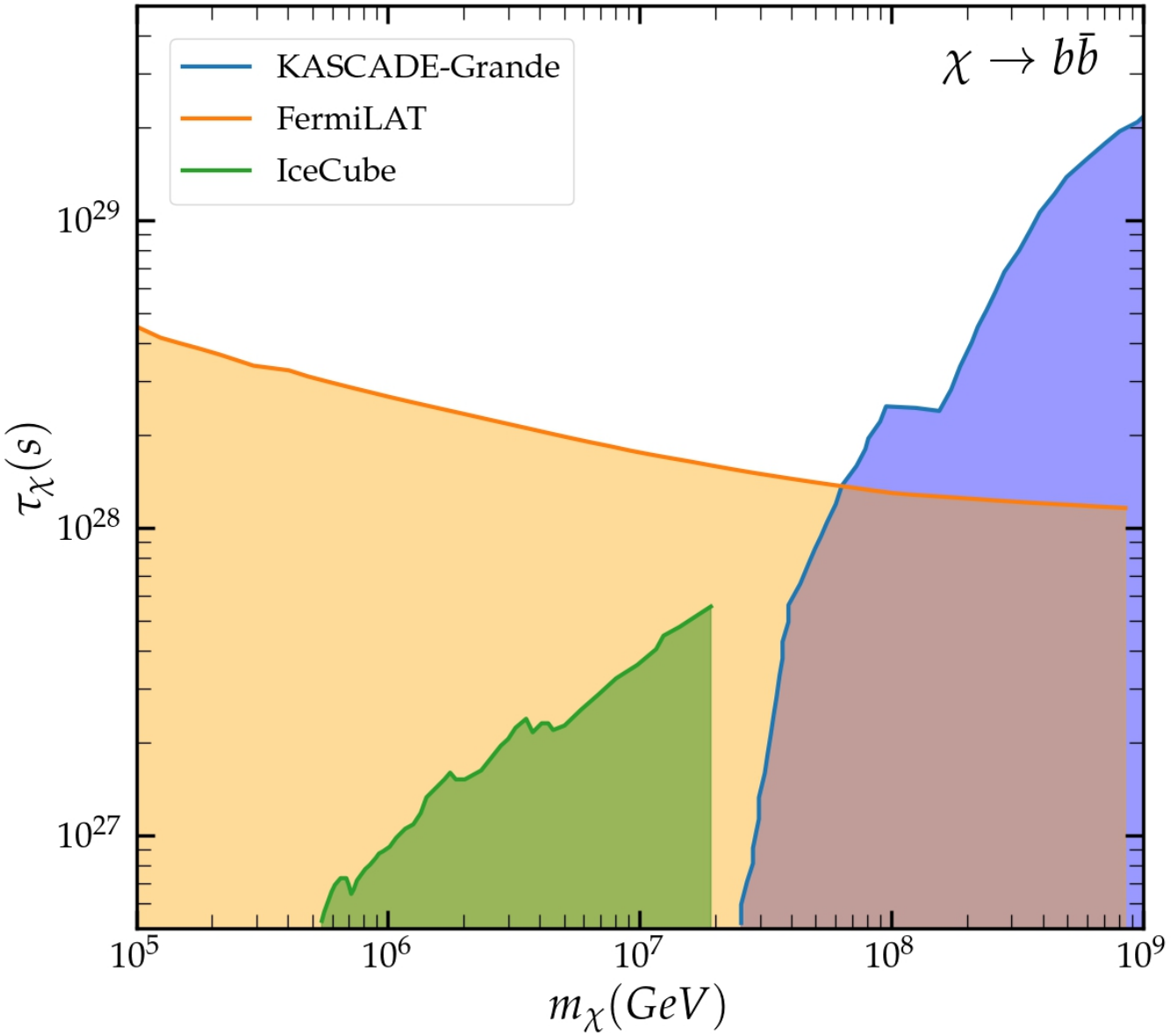
DM mass

DM lifetime

Dependence of our constraints on DM profiles



Constraints on Decaying Dark Matter



Ishiwata et al., 1907.11671
Hooper et al., 1811.05988
Abbasi et al., 2205.12950

Effective area comparison

Credit: G. Di Sciascio (2020)

Muon detectors

Experiment	m asl	μ Sensitive Area (m^2)	Instrumented Area (m^2)	Coverage
LHAASO (✦)	4410	4.2×10^4	10^6	4.4×10^{-2}
TIBET ASγ	4300	4.5×10^3	3.7×10^4	1.2×10^{-1}
KASCADE	110	6×10^2	4×10^4	1.5×10^{-2}
CASA-MIA	1450	2.5×10^3	2.3×10^5	1.1×10^{-2}

Heavy Dark Matter

Giudice et al hep-ph/0005123
Chung et al hep-ph/9805473
Berlin et al 1602.08490
Heurtier et al 1905.05191
Davoudiasl et al 1912.05572
Baldes et al 2110.13926

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