Search for Dark Matter decay and annihilation using γ ray observation by Tibet AS$_\gamma$ and LHAASO

Based on arXiv:2105.05680 (PRD Letter) & Dubey et al (In Prep.)
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Dark Matter and Dark Matter Indirect detection

- Various astrophysical and cosmological observations indicate that the majority of matter in the universe is non-baryonic in nature, commonly referred to as dark matter (DM).
- One way to probe the non-gravitational nature of DM is indirect detection where we try to detect the annihilating or decaying signature of DM via astrophysical measurements. This is a promising way to discover various different DM candidates.

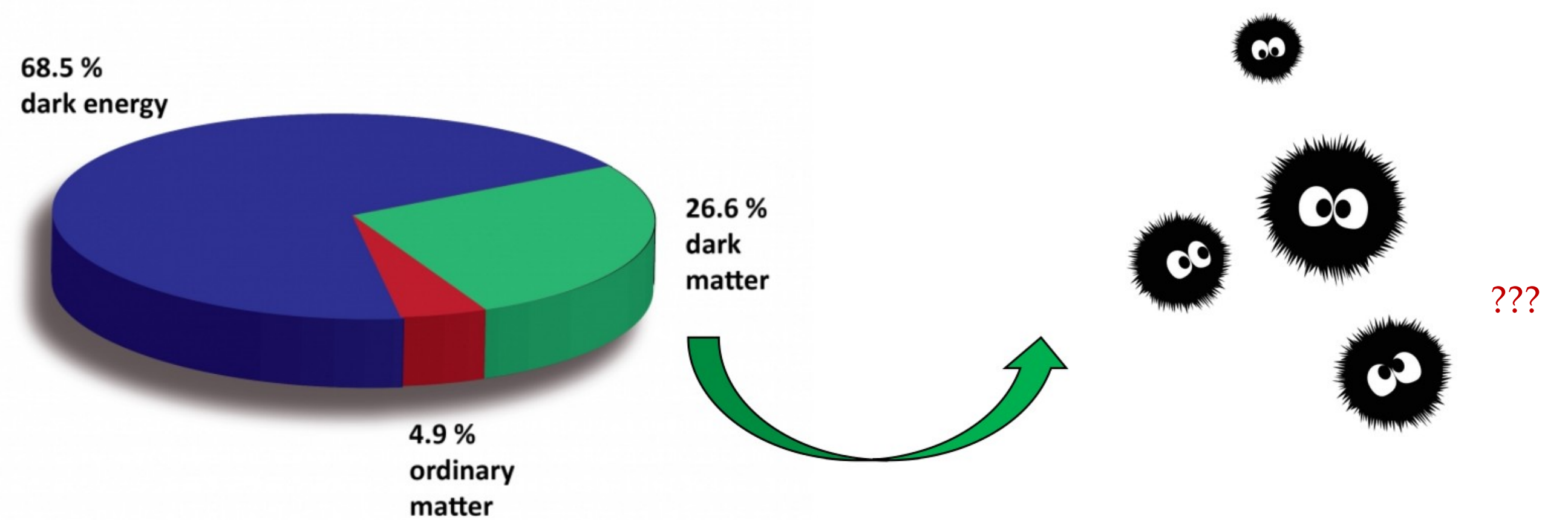

Fig:1A Dark matter (credit : AKS and NIST)

- DM can decay or annihilates into various Standard Model (SM) final states, which may further decay or hadronize, and produce high energy gamma rays.
- High-energy electrons and positrons generated in these processes can upscatter low-energy background photons (e.g., from the cosmic microwave background, starlight, and infrared) through inverse Compton scattering (ICS), producing secondary gamma rays.
- Recently, the Tibet AS$_\gamma$ and LHAASO experiments have detected diffuse gamma-ray flux in the Milky Way, offering a valuable opportunity to search for dark matter signals in this high-energy regime.

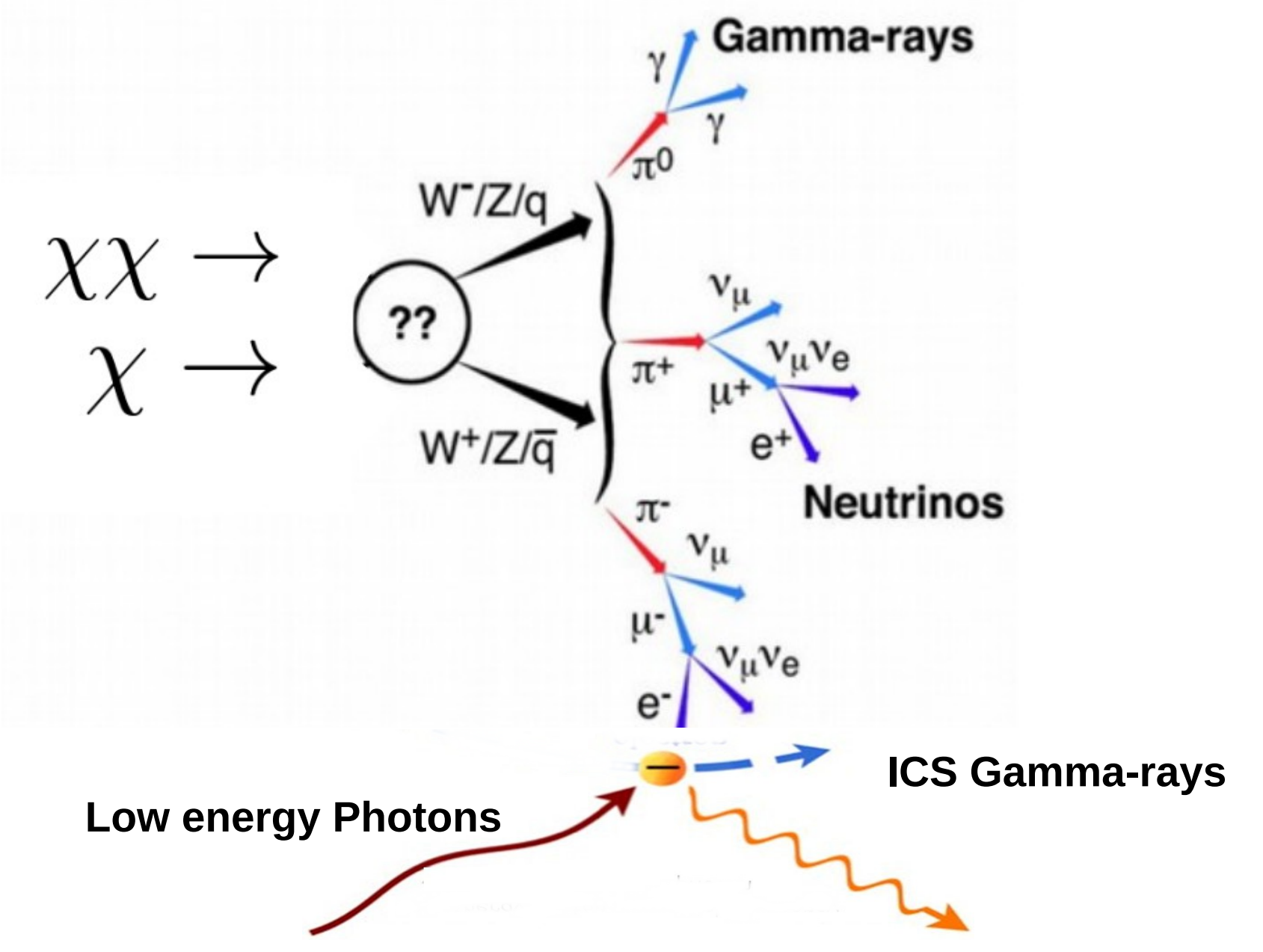

Fig:1B Primary and Secondary γ rays from DM decay and annihilation (Credit:Weniger)

γ rays flux from DM decay and annihilation

Gamma ray flux observed from DM decay to different Standard model final states will be

DM decay

$$\frac{d\Phi^G}{dE_\gamma} = \frac{1}{4\pi m_\chi \tau_\chi}\frac{dN}{dE_\gamma}\int_0^\infty ds\rho(s,b,l)e^{-\tau_{\gamma\gamma}(E_\gamma,s,b,l)}$$

Intrinsic spectrum of γ rays coming from different SM final states produced by DM decay or annihilation. We have used HDMSpectra to calculate it.

DM density profile in our galaxy, which we have taken as NFW profile

Attenuation factor, arising due to the interaction of these high energy γ rays to low energy photons and pair produce

DM annihilation

$$\frac{d\Phi^G}{dE_\gamma} = \frac{\langle\sigma v\rangle}{8\pi m_\chi^2}\frac{dN}{dE_\gamma}\int_0^\infty ds\rho^2(s,b,l)B_{sh}(s,b,l)e^{-\tau_{\gamma\gamma}(E_\gamma,s,b,l)}$$

Boost factor for DM annihilation due to DM substructures

m_χ = DM mass, τ_χ= DM lifetime, $<\sigma v>$ = DM annihilation cross section
E_γ,= energy of prompt photons.

- In our analysis, we have taken both primary and inverse Compton scattering gamma ray flux from Galactic and Extragalactic domain into consideration.

DM Substructure Boost for annihilation

Since the annihilation rate depends on the dark matter density squared (and $<\rho^2> \geqslant <\rho>^2$), the presence of the subhalos will boost the gamma-ray signatures from dark matter annihilation. It is given by B_{sh} (Boost factor) .

Total Luminosity from DM annihilation $\mathrm{L(M)}=[1+B_{\rm sh}(M)]\,L_{\rm host}(M)$

Luminosity from DM annihilation if there is no substructure.

$$B_{\rm sh}(M) = \frac{1}{L_{\rm host}(M)}\int dm\frac{dN}{dm}L_{\rm sh}(m)\left[1+B_{\rm ssh}(m)\right]$$

Shin'ichiro Ando et al. 2019

Subhalo mass function

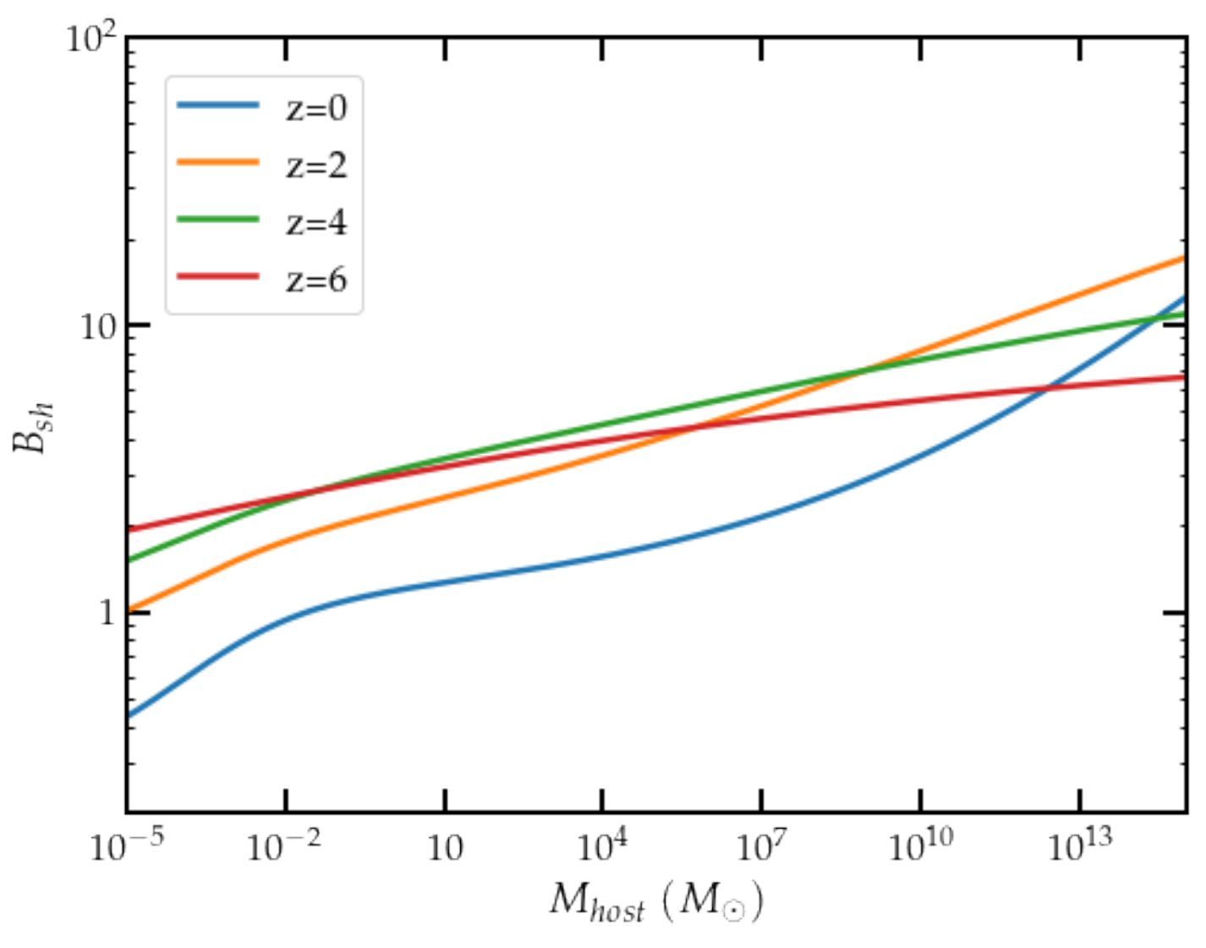

Fig:2 Boost factor for Host halo mass at differnent redshifts

Tibet AS$_\gamma$ and LHAASO experiments

Fig:3A Tibet AS$_\gamma$

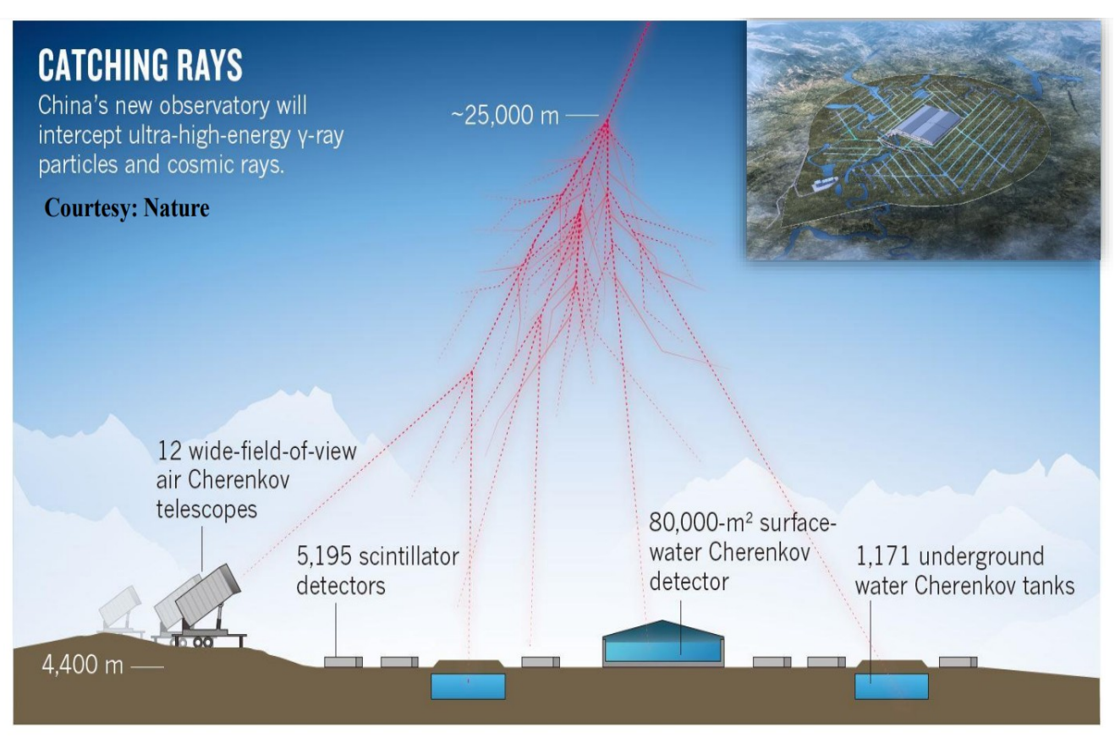

Fig:3B LHAASO

Number of detectors: 0.5 m² × 597 , Effective area: ~ 65,700 m²

Angular resolution: ~ 0.5° @ 10TeV and ~ 0.2° @ 100 TeV

Energy resolution: ~ 40% @ 10 TeV and ~ 20% @ 100 TeV

Pointing accuracy ~ 0.1°

Angular resolution ~ 0.3°

Energy resolution < 20% @ 6TeV

Observations by Tibet AS$_\gamma$ and LHAASO

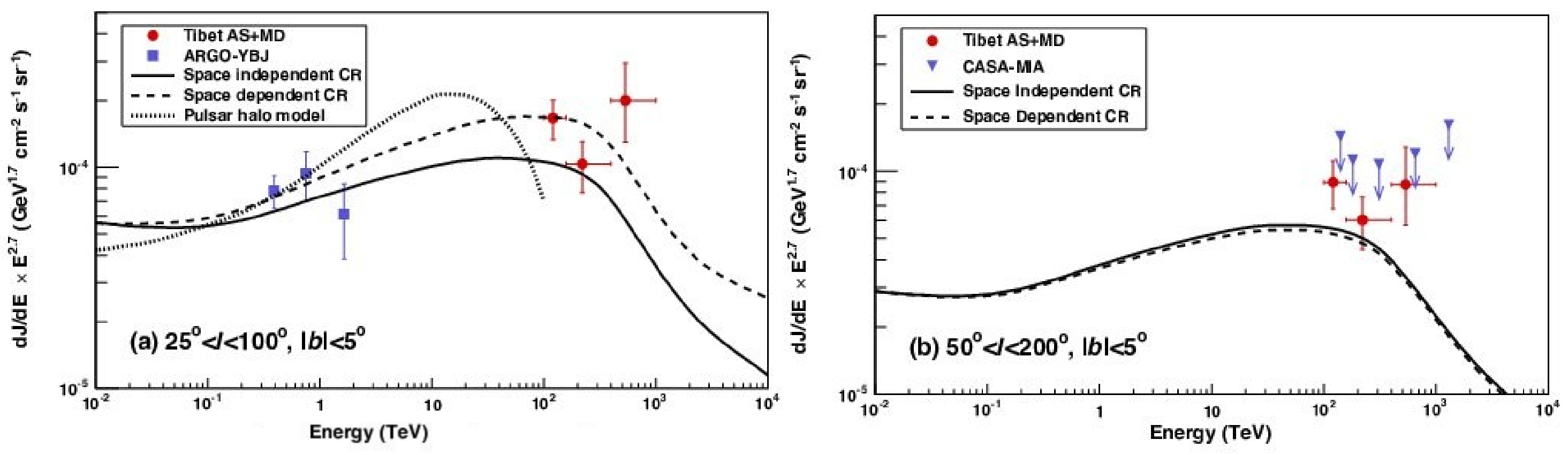

Fig:4 Diffuse gamma rays flux observaed by Tibet AS$_\gamma$ (credit: M. Amenomori et al. (Tibet AS$_\gamma$ Collaboration) 2021)

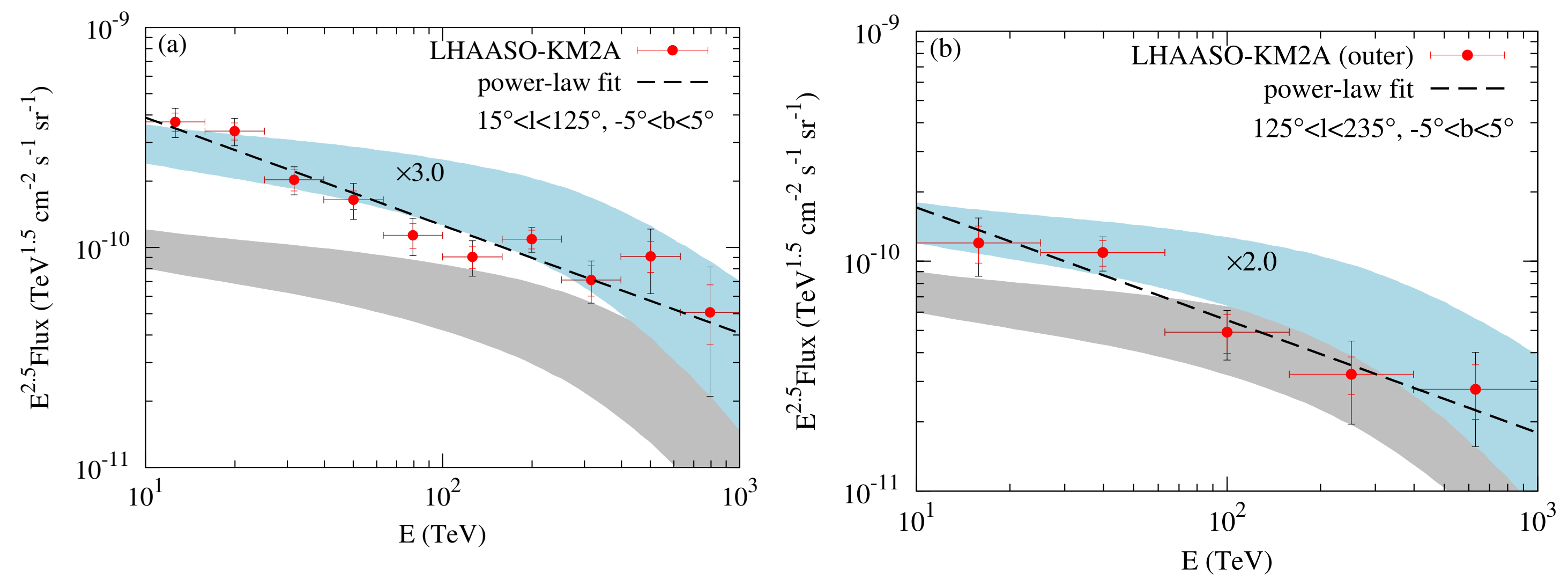

Fig:5 Diffuse gamma rays flux observaed by LHAASO (credit: LHAASO Collaboration)

- Due to the better sensitivity of Tibet-AS$_\gamma$ and higher energy reach compared to MILAGRO, HAWC, and ARGO-YBJ and also more efficient suppression of background EAS produced by protons and atomic nuclei, Tibet-AS$_\gamma$ observations can be used to constrain the γ ray flux from the sky outside the Galactic plane (|b| > 20 deg.).

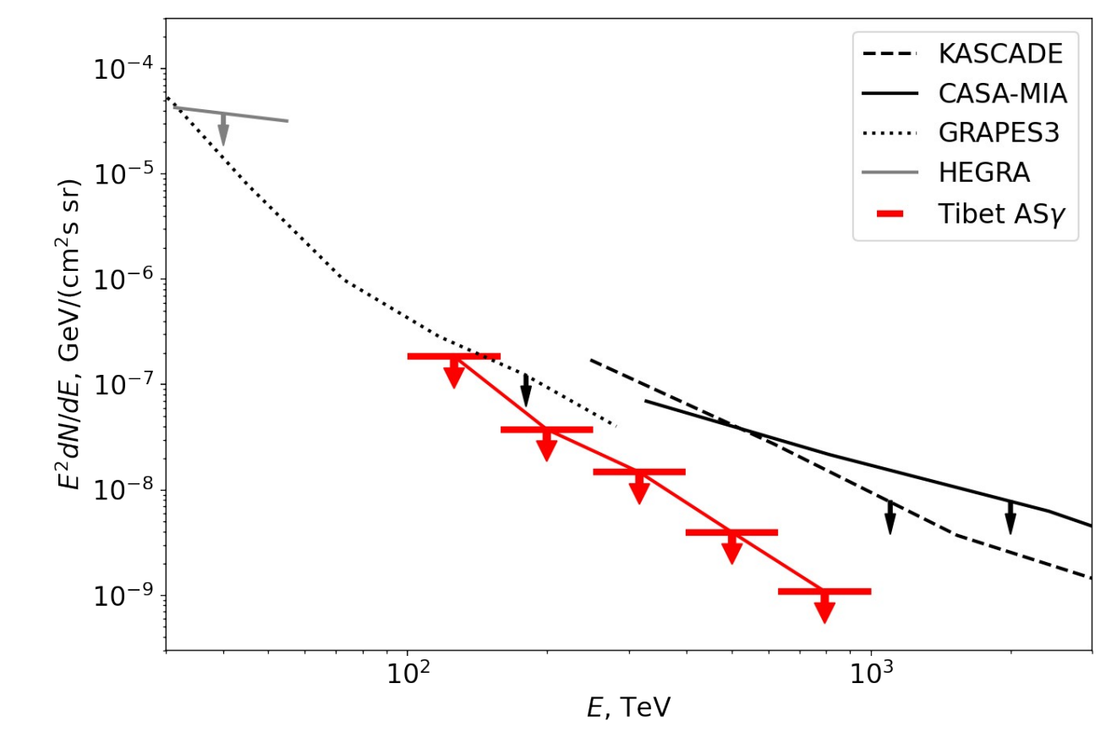

Fig: 6A Upper limit on γ rays flux coming from outside the Galactic plane (|b| > 20 deg.) (credit: Neronov et al. 2021)

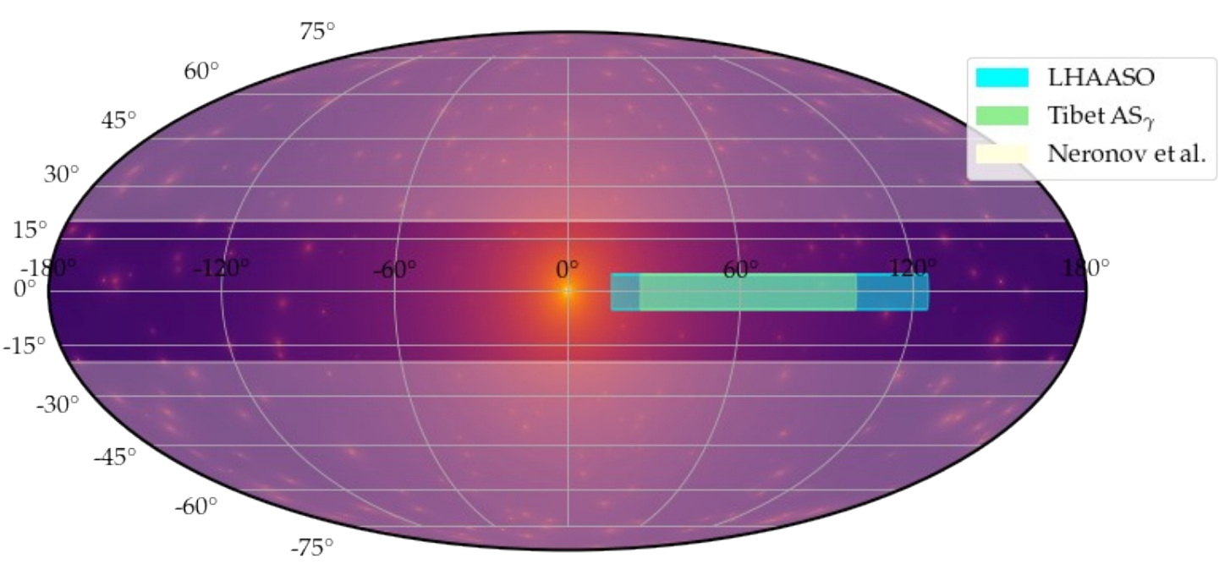

Fig: 6B Galactic regions of obsevation by Tibet AS$_\gamma$ and LHAASO

Our Results

arXiv:2105.05680 **(PRD Letter)** + Dubey et al. (In Prep.)

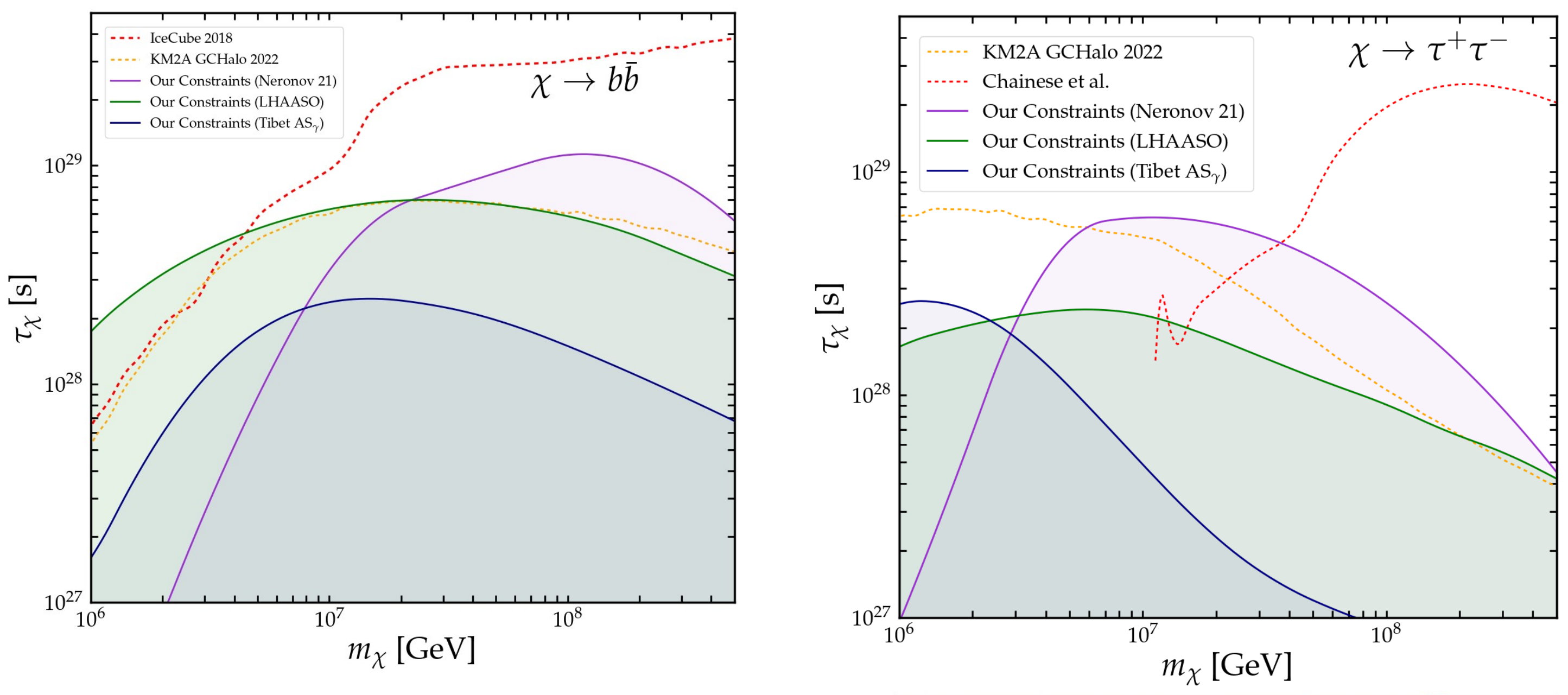

Fig: 7A Constraints on DM decay lifetime

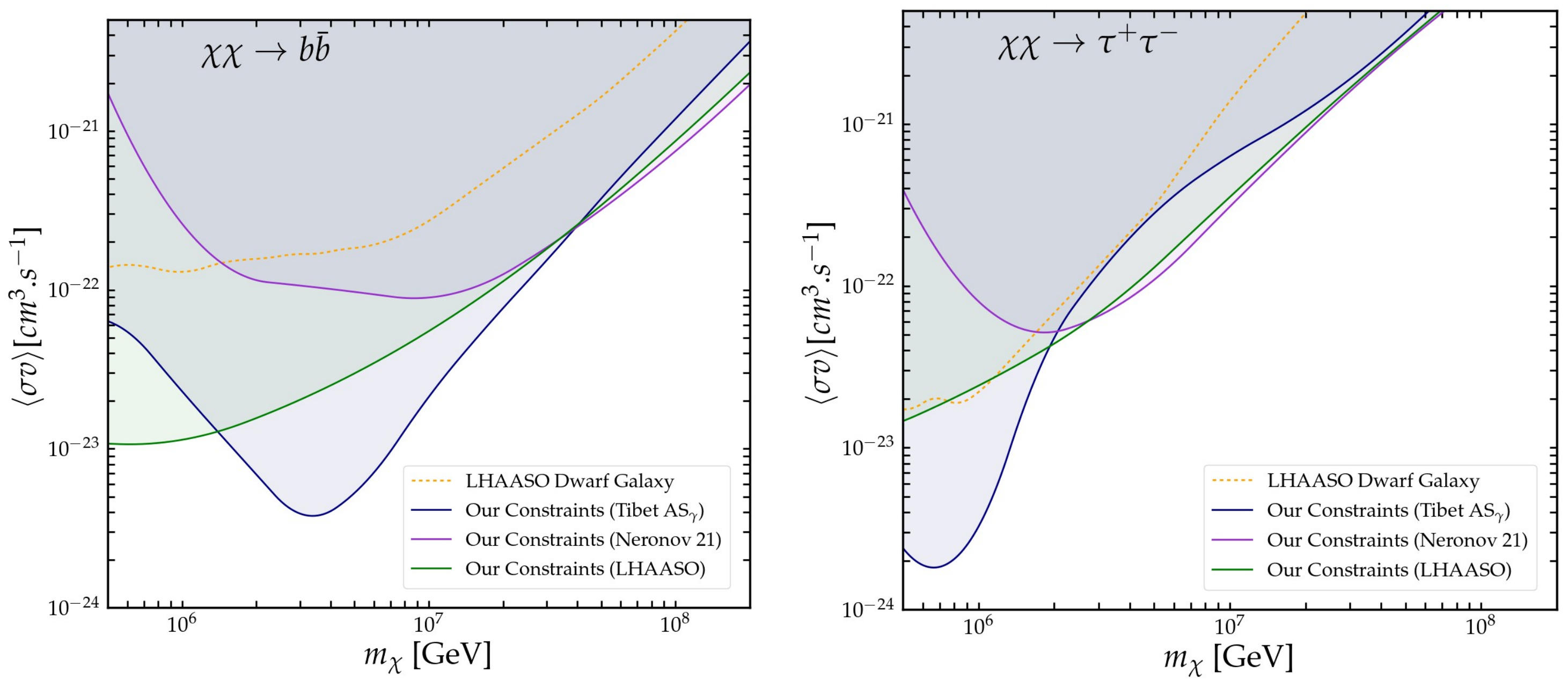

Fig: 7B Constraints on DM annihilation cross section

Conclusion

- We have obtained constraints on dark matter lifetime and annihilation cross section for different final states using Tibet AS$_\gamma$ and LHAASO observation.
- We have studied the effect of inverse Compton scattering and dark matter substructures which helps put better constrain dark matter parameters.
- We get the most stringent constraints in large region of parameter space for both dark matter decay and annihilation.