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Strong constraints on decaying dark matter with LHAASO

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WORK WITH

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and LHAASO data analyzed by Zhe Li[f] (on behalf of LHAASO collaboration)

AFFILIATIONS

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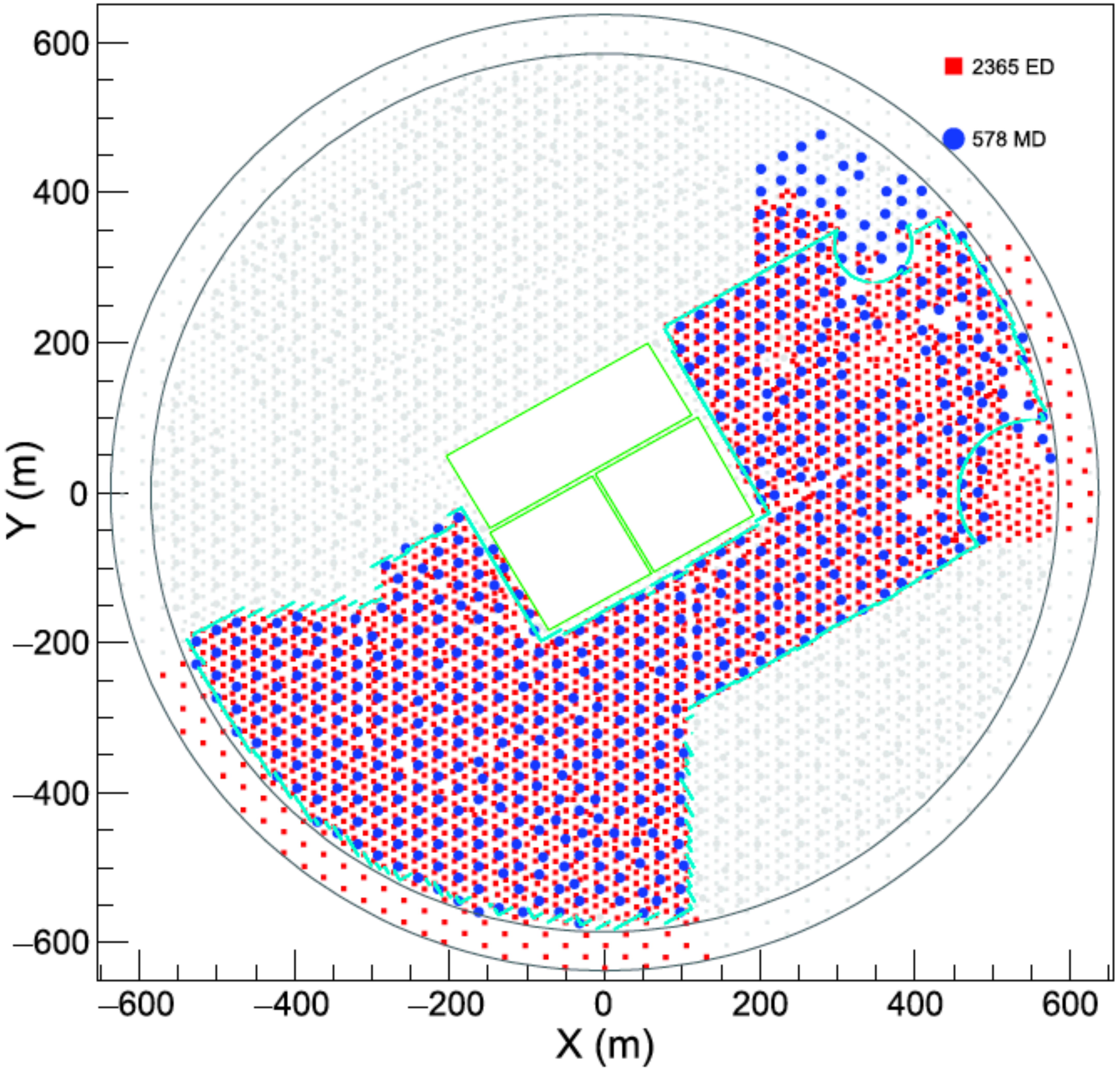
LHAASO-KM2A

KM2A is a ground-based full-duty EAS array dedicated to VHE gamma-ray astronomy above 10 TeV.



- **1/2-KM2A**: 2365 ElectroMagnetic particle detectors (EM) and 576 Muon Detectors (MD)
- Operational since December 2019 (~340 days of data)

Validation of detector performances

- Crab Nebula spectrum up to *O*(100) TeV

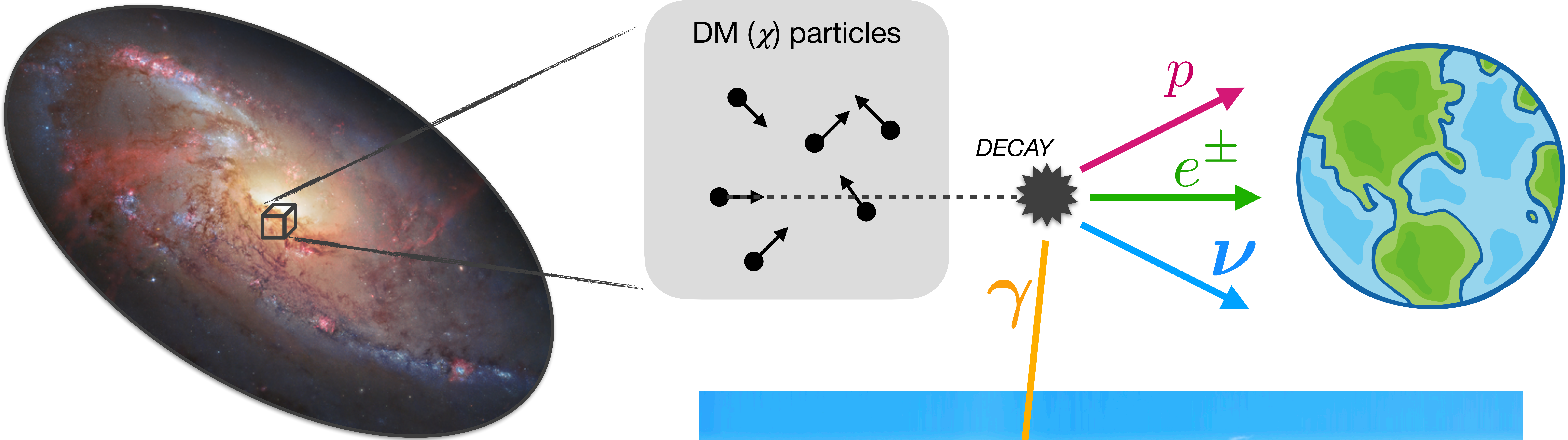
  Aharonian et al., ***Chin.Phys.C 45 (2021)***

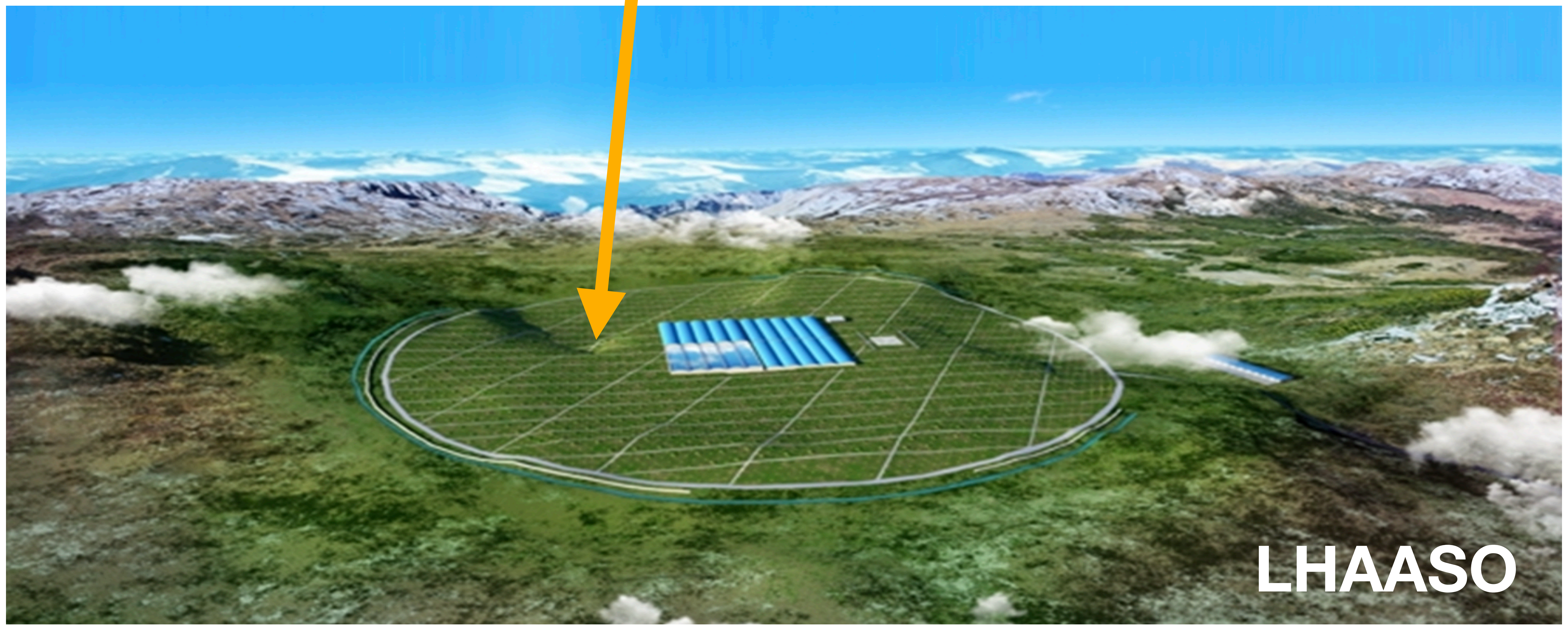
- UHE gamma-rays from 12 galactic sources up to ~PeV

  Cao et al., ***Nature 594 (2021)***

White paper*: Bai et al.*, ***arXiv:1905.02773***

Indirect dark matter signals





Indirect-detection searches with gamma-rays!

Hints from IceCube neutrino telescope

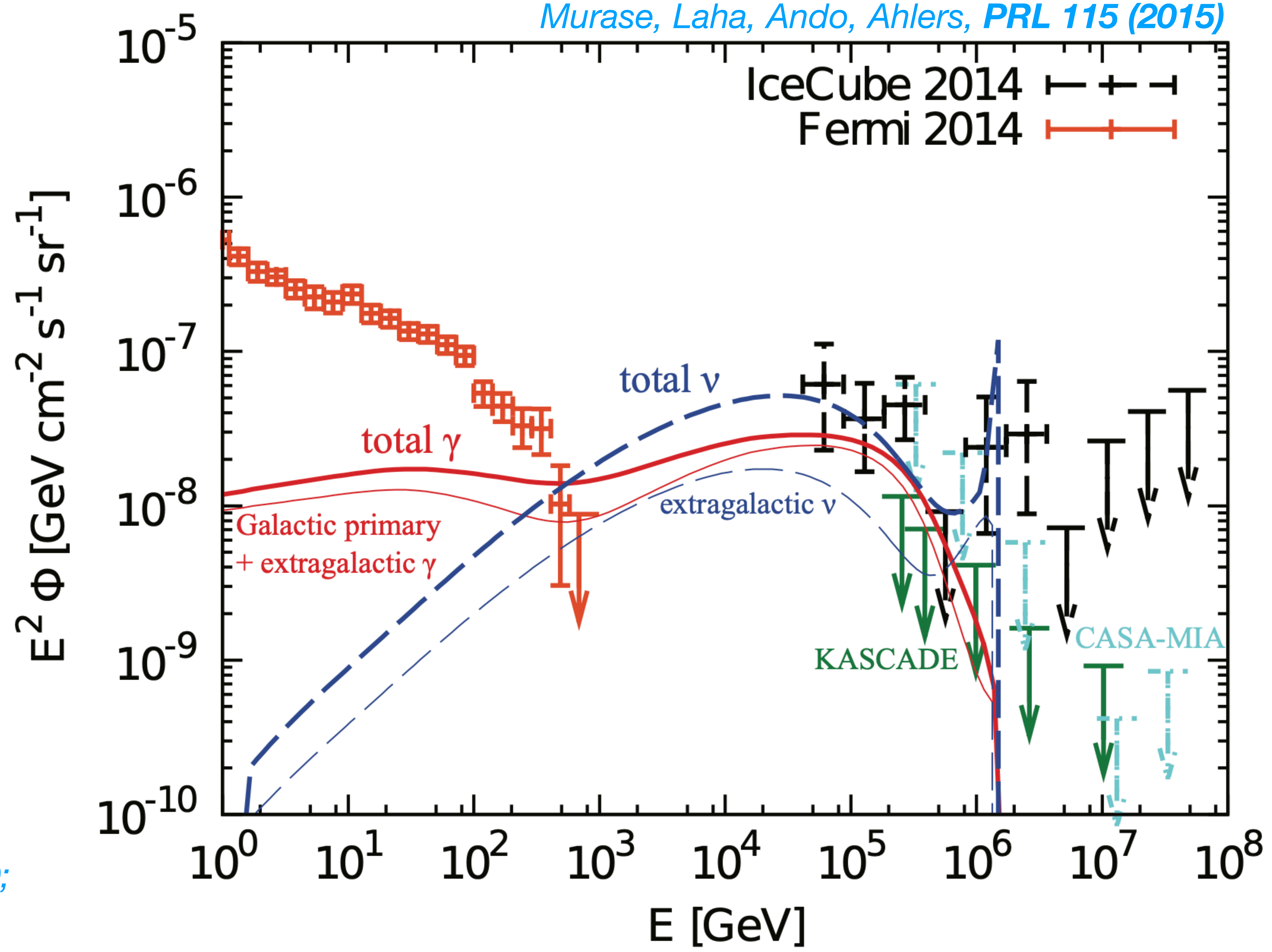
Decaying DM has been proposed as a source of the high-energy neutrinos observed by IceCube.

- Typical DM mass: $m_{\rm DM} = 10^6\ \text{GeV}$
- Typical DM lifetime: $\tau_{\rm DM} = 10^{28}\ \text{s}$
- Strong constraints from diffuse gamma-rays (Fermi-LAT, KASCADE, CASA-MIA and *recently* Tibet-ASγ)

The IceCube DM hypothesis has not been excluded yet!

Esmaili et al., ***JCAP 1311****; Cohen et al.,* ***PRL 119 (2017)****; Abeysekara et al.,* ***JCAP 1802****; Bhattacharya et al.,* ***JCAP 1905****; Chianese et al.,* ***JCAP 1911****; Argüelles et al.,* ***PoS ICRC2019 (2020) 839****; Ishiwata et al.,* ***JCAP 2001****; Dekker et al.,* ***JCAP 2009****; Esmaili et al.,* ***arXiv:2105.01826****; Maity et al.,* ***arXiv:2105.05680***

Murase, Laha, Ando, Ahlers, ***PRL 115 (2015)***



Gamma-ray intensity from dark matter

Above 10 TeV, the gamma-ray flux from DM decays has two dominant *galactic* contributions:

$$\frac{\mathrm{d}I_\gamma^{\mathrm{total}}}{\mathrm{d}E_\gamma} = \frac{\mathrm{d}I_\gamma^{\mathrm{prompt}}}{\mathrm{d}E_\gamma} + \frac{\mathrm{d}I_\gamma^{\mathrm{IC}}}{\mathrm{d}E_\gamma}$$

Prompt galactic photons

$$\mathrm{DM} \to f + \bar{f} \to \gamma$$

Attenuation via Pair Productions (PP)

$$\gamma + \gamma_{\mathrm{bkg}} \to e^+ + e^- \quad (\mathrm{PP})$$

Secondary galactic photons

$$\mathrm{DM} \to f + \bar{f} \to e^\pm$$

Inverse Compton (IC) scatterings

$$e^\pm + \gamma_{\mathrm{bkg}} \to e^\pm + \gamma \quad (\mathrm{IC})$$

Other contributions (e.g. extragalactic photons) are in general subdominant at sub-PeV energies

Buch et al., ***JCAP 1509****; Esmaili, Serpico,* ***JCAP 1510****; Chianese et al.,* ***JCAP 1911***

Technical details

- Particle energy spectrum per DM decay:
  HDMSpectra package

  *Bauer, Rodd, Webber, **JHEP 2106***

- Gamma-ray optical depth:
  CMB and galactic SL+IR from GALPROPv54

- CRs' spatial diffusion subdominant *wrt* energy losses

  *Esmaili, Serpico, **JCAP 1510***

- Energy losses: IC and synchrotron processes

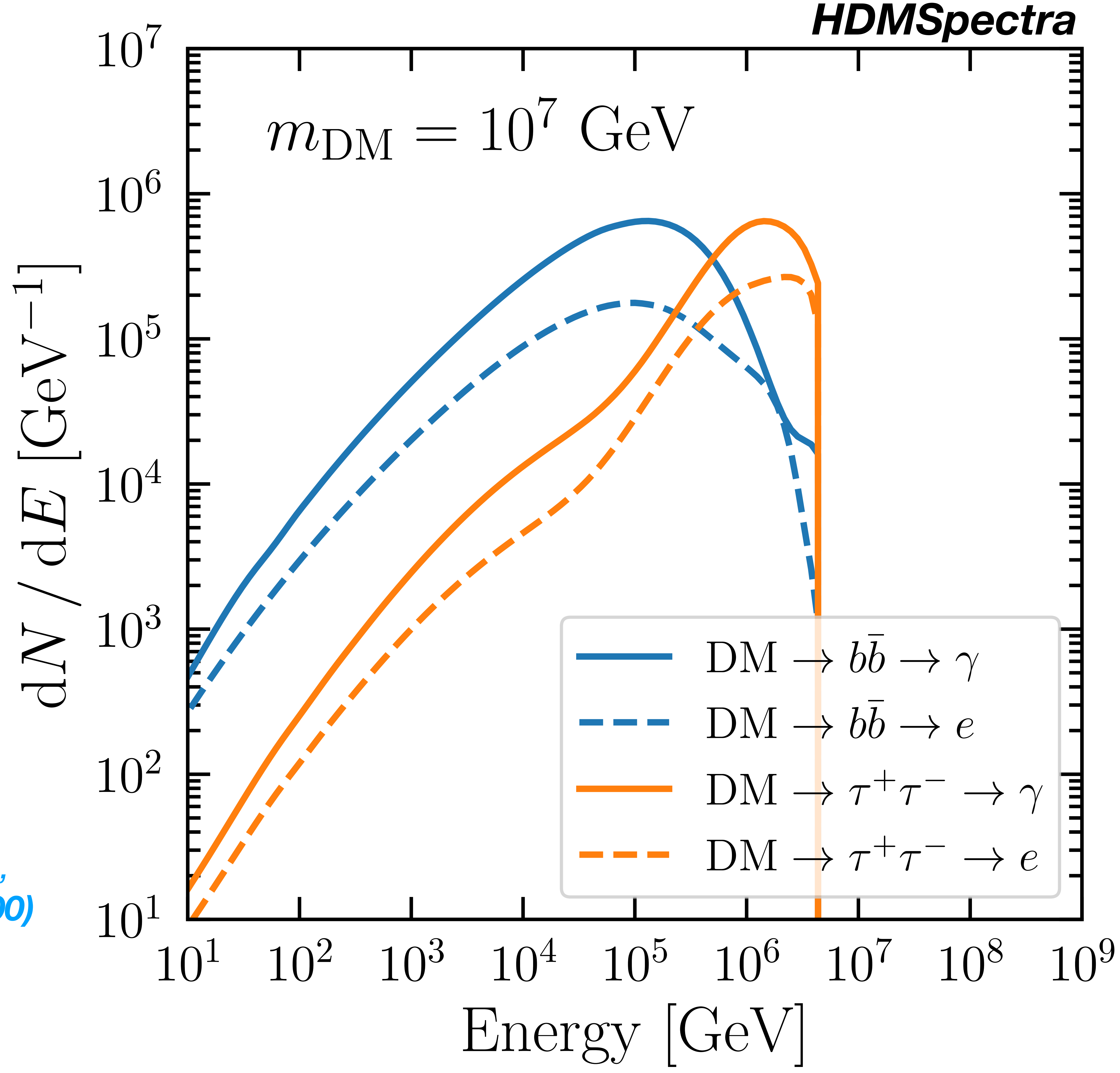
- Regular galactic magnetic field:

$$B\left(\vec{x}\right) = B_0 \exp\left[-\frac{r - R_\odot}{r_B} - \frac{|z|}{z_B}\right]$$

$B_0 = 4.78\ \mu\text{G},\ r_B = 10\ \text{kpc},\ z_B = 2\ \text{kpc}$

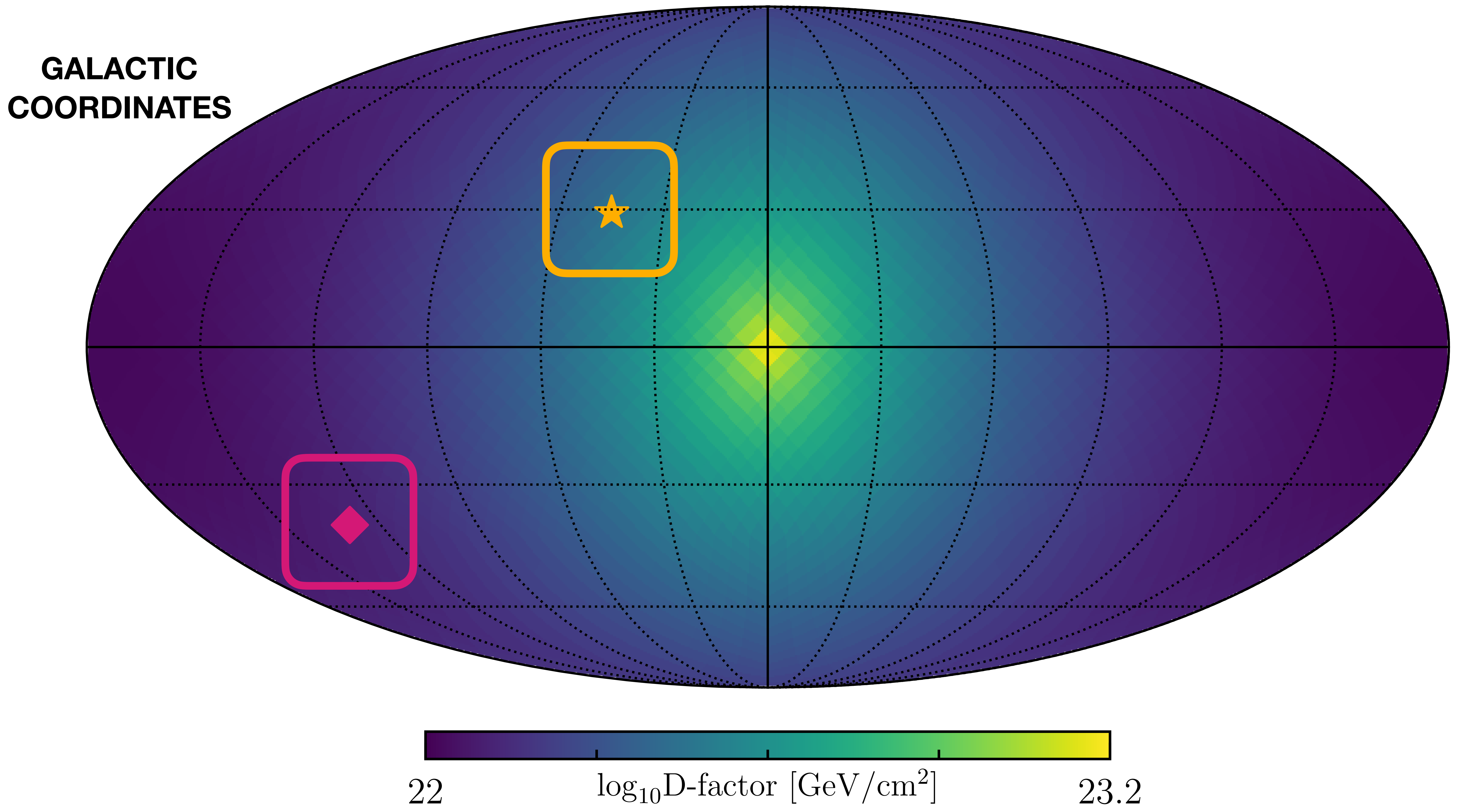
*Strong, Moskalenko, Reimer, **ApJ 541 (2000)***

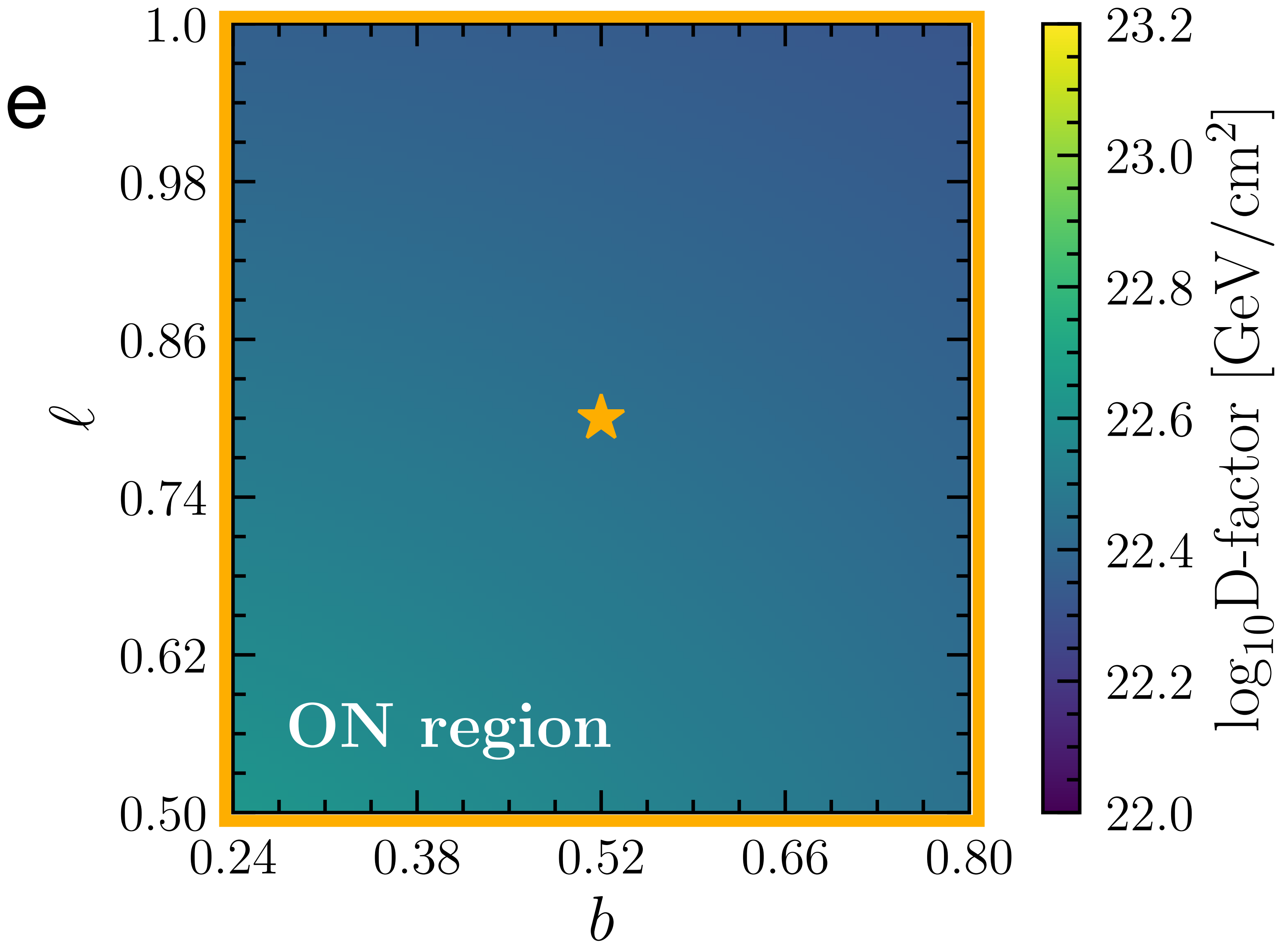
HDMSpectra

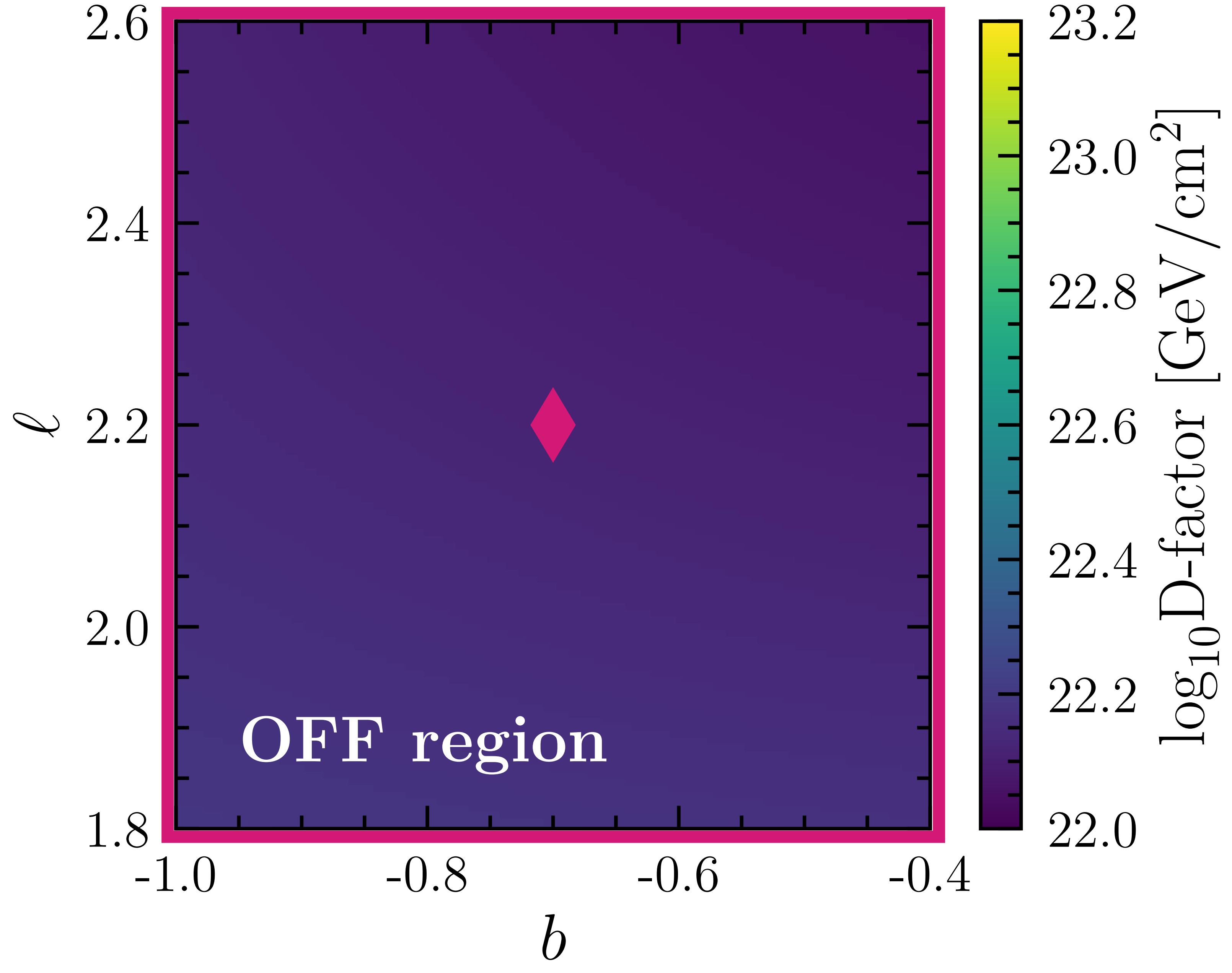


Sky map

The DM gamma-ray flux mainly traces the DM galactic halo profile





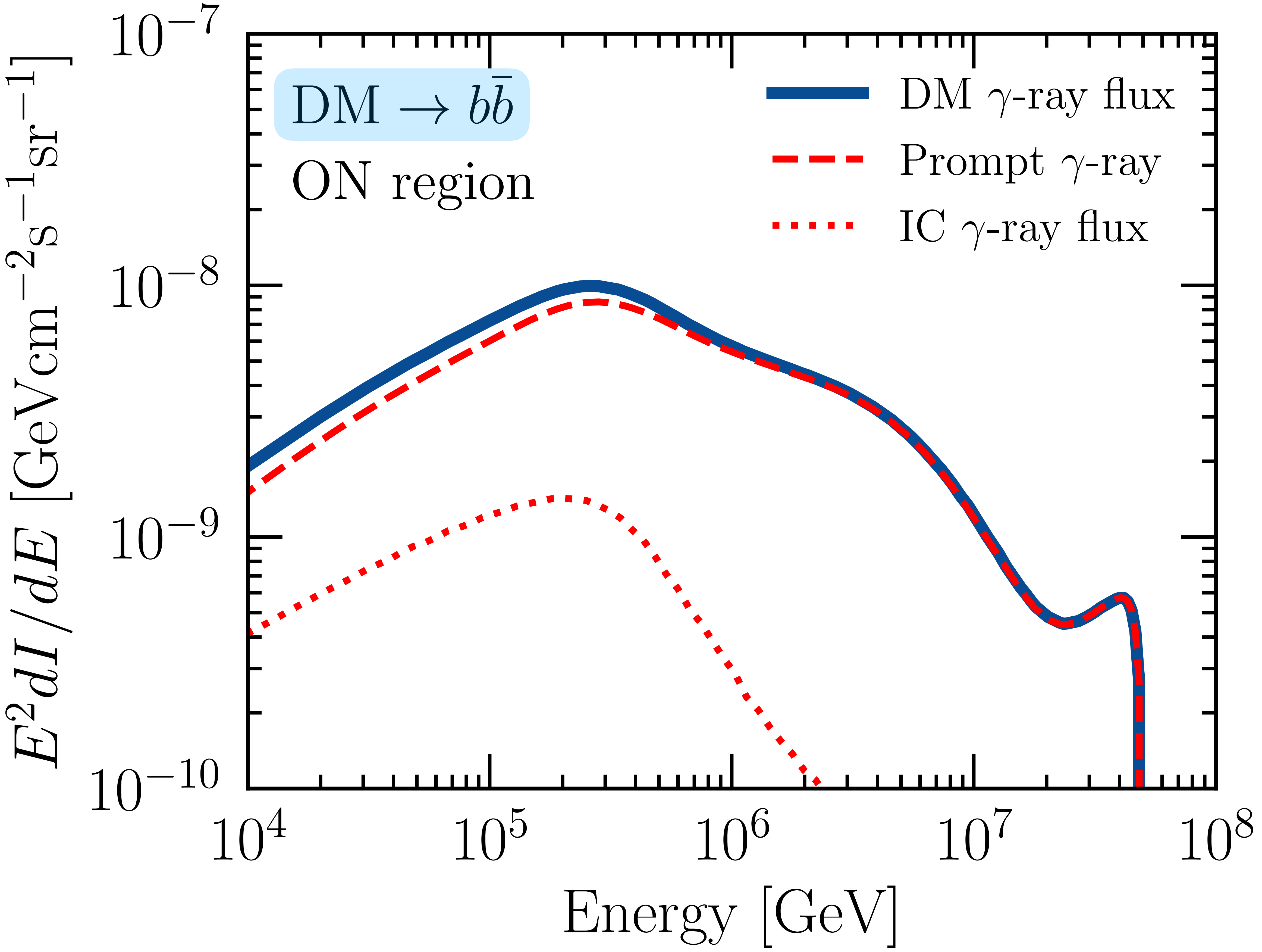


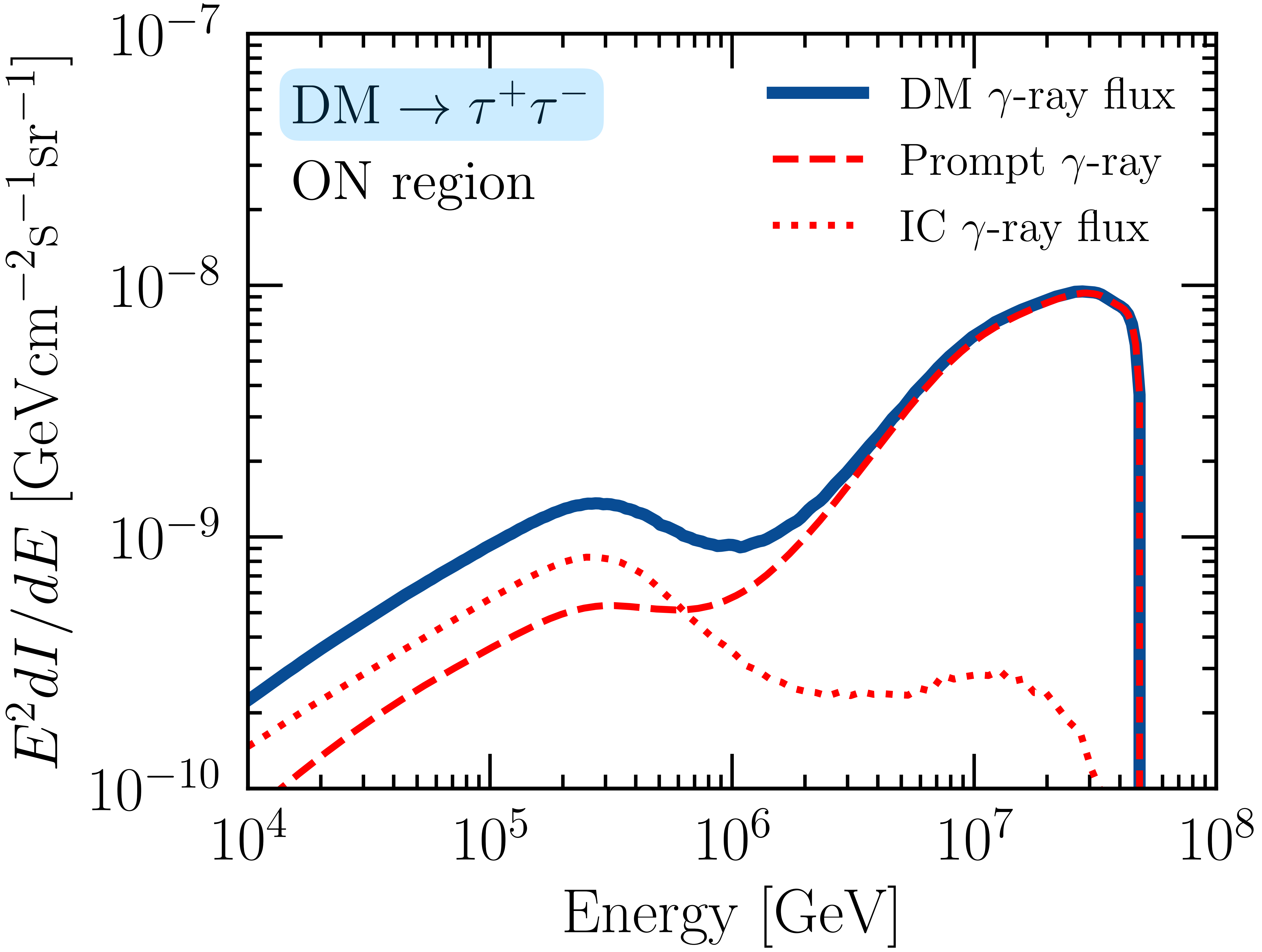
$$D(b,\ell) = \int_0^\infty \mathrm{d}s\, \rho_h[r(s,b,\ell)] \longrightarrow$$

Navarro-Frenk-White (NFW) halo profile

Benchmark cases

Lifetime : $\tau_{\rm DM} = 10^{28}\,{\rm s}$ Mass : $m_{\rm DM} = 10^{8}\,{\rm GeV}$





Likelihood analysis

The residual events are composed by:

- misidentified cosmic-rays
- electrons and positrons
- gamma-rays

We pursue a profile likelihood approach:

$$\mathcal{L}(\Gamma, b) = \sum_{a=\mathrm{ON,OFF}} \sum_i N_a^i \ln n_a^i - n_a^i$$

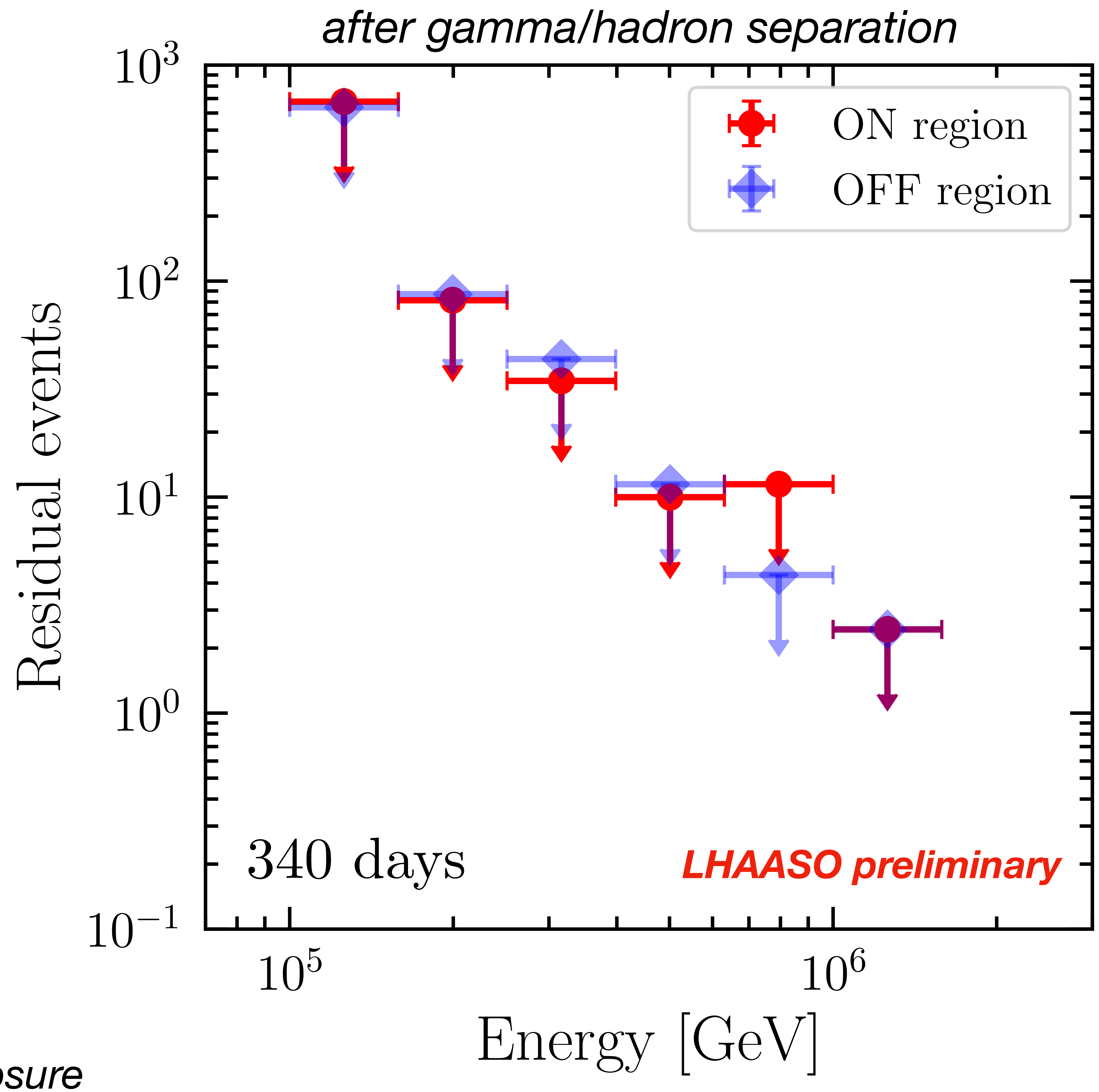
with

$$n^i_{\mathrm{ON,OFF}}(\Gamma, b) = \left(b^i + \Gamma s^i_{\mathrm{ON,OFF}}\right) \mathcal{E}^i_{\mathrm{ON,OFF}} \, \Delta\Omega$$

isotropic background (nuisance parameters)

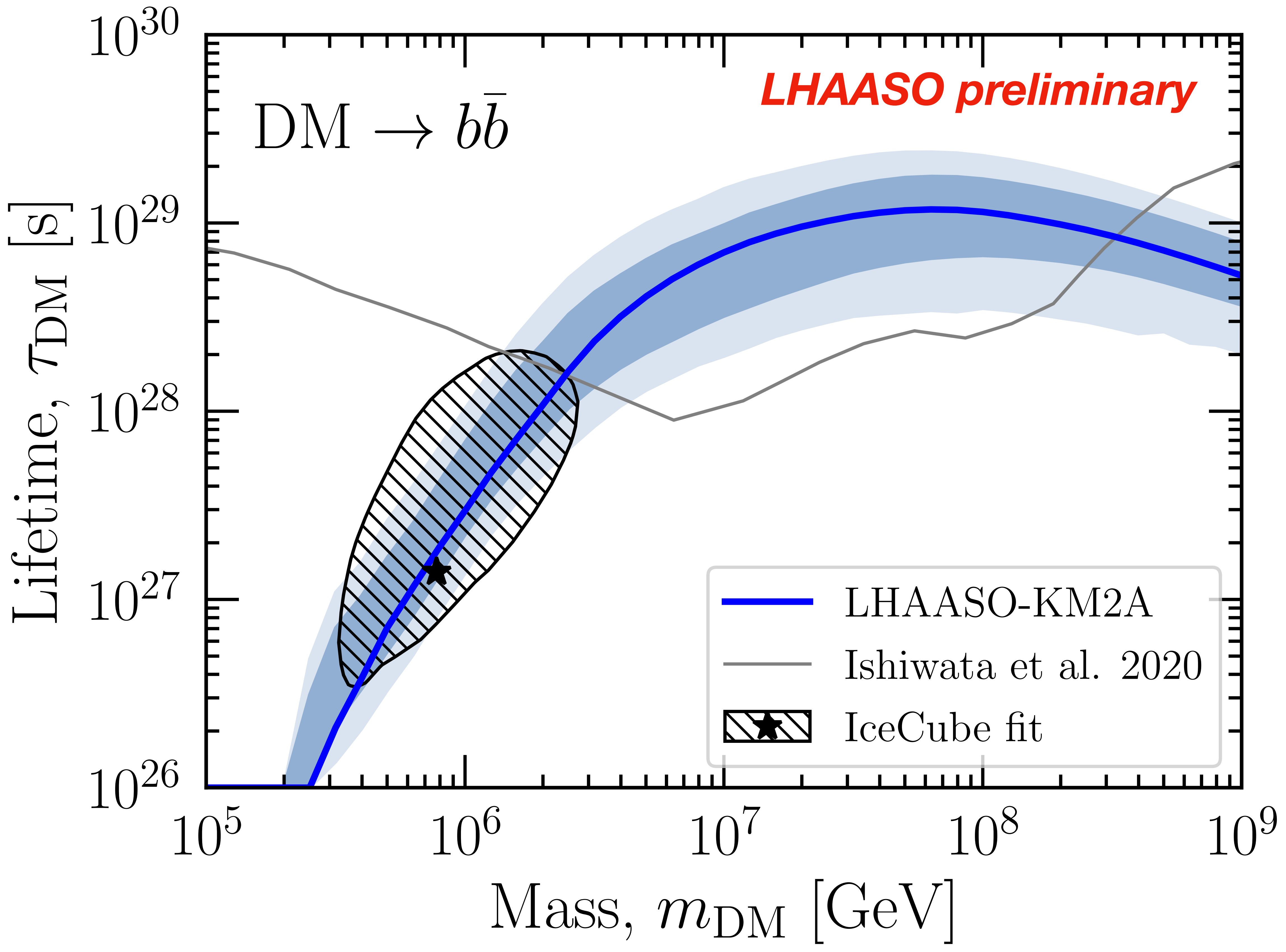
DM signal where $\Gamma = 1/\tau_{\mathrm{DM}}$

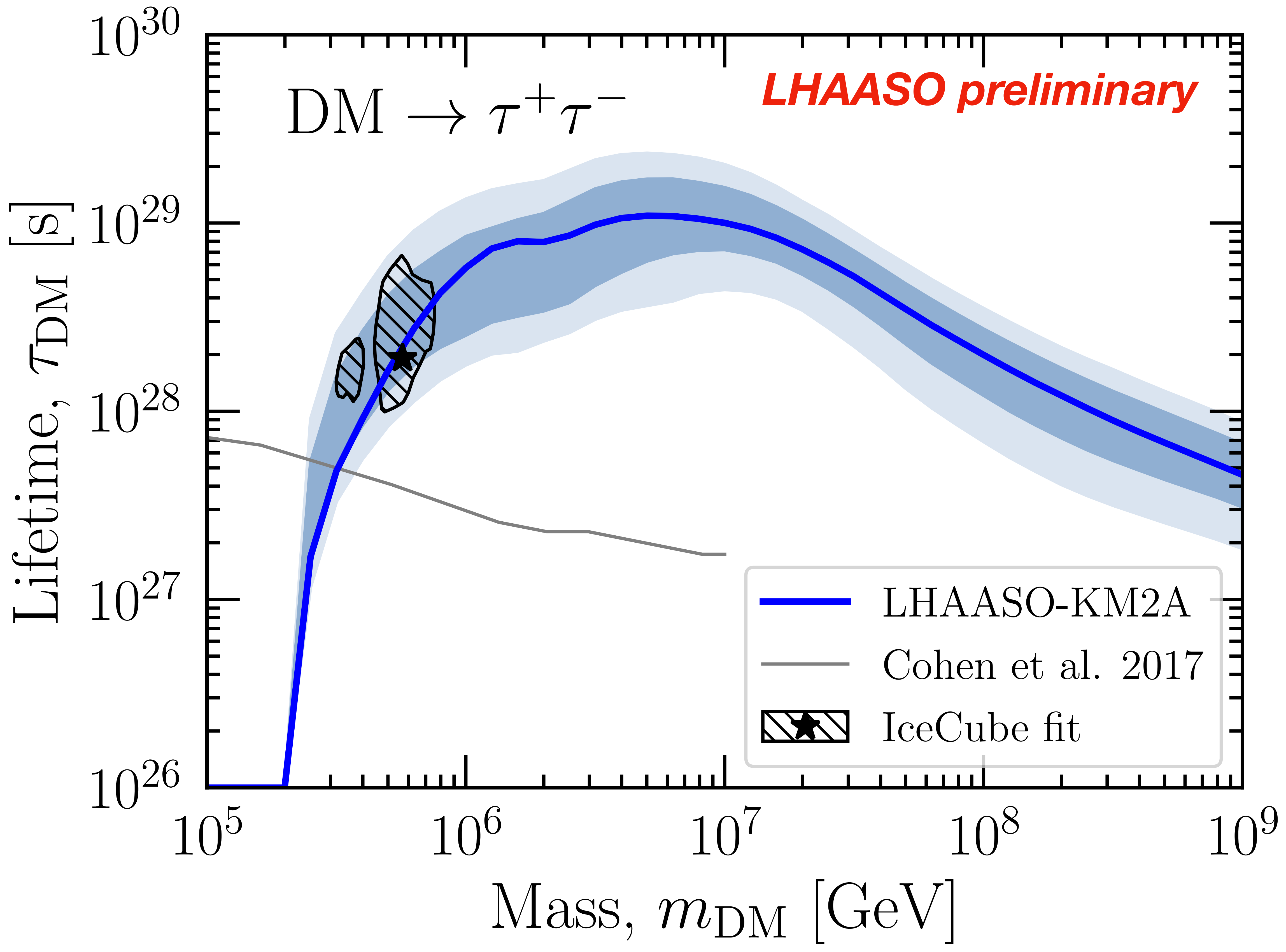
Detector exposure



Results

Constraints at 95% CL and exclusion bands from Monte Carlo simulations





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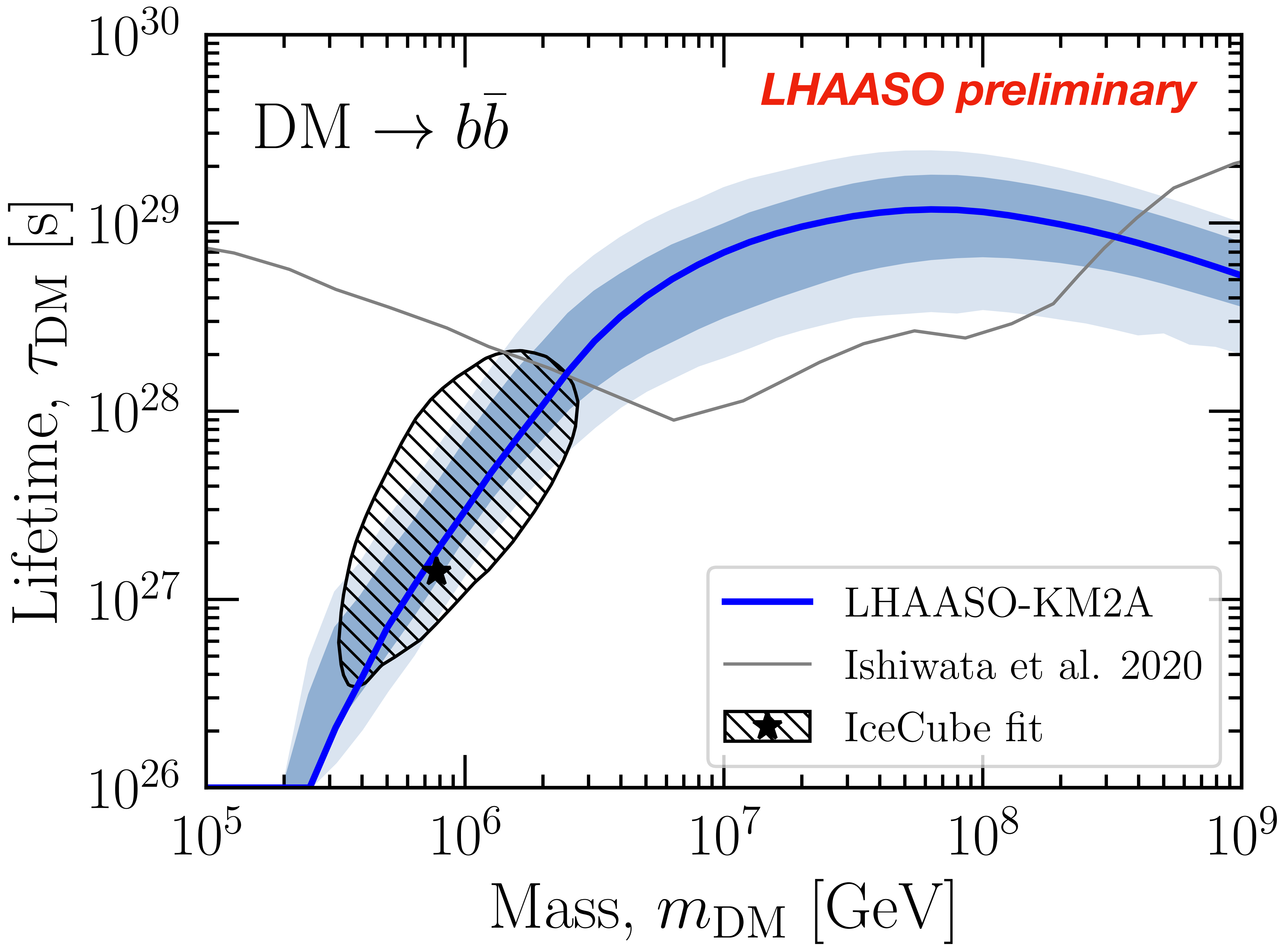
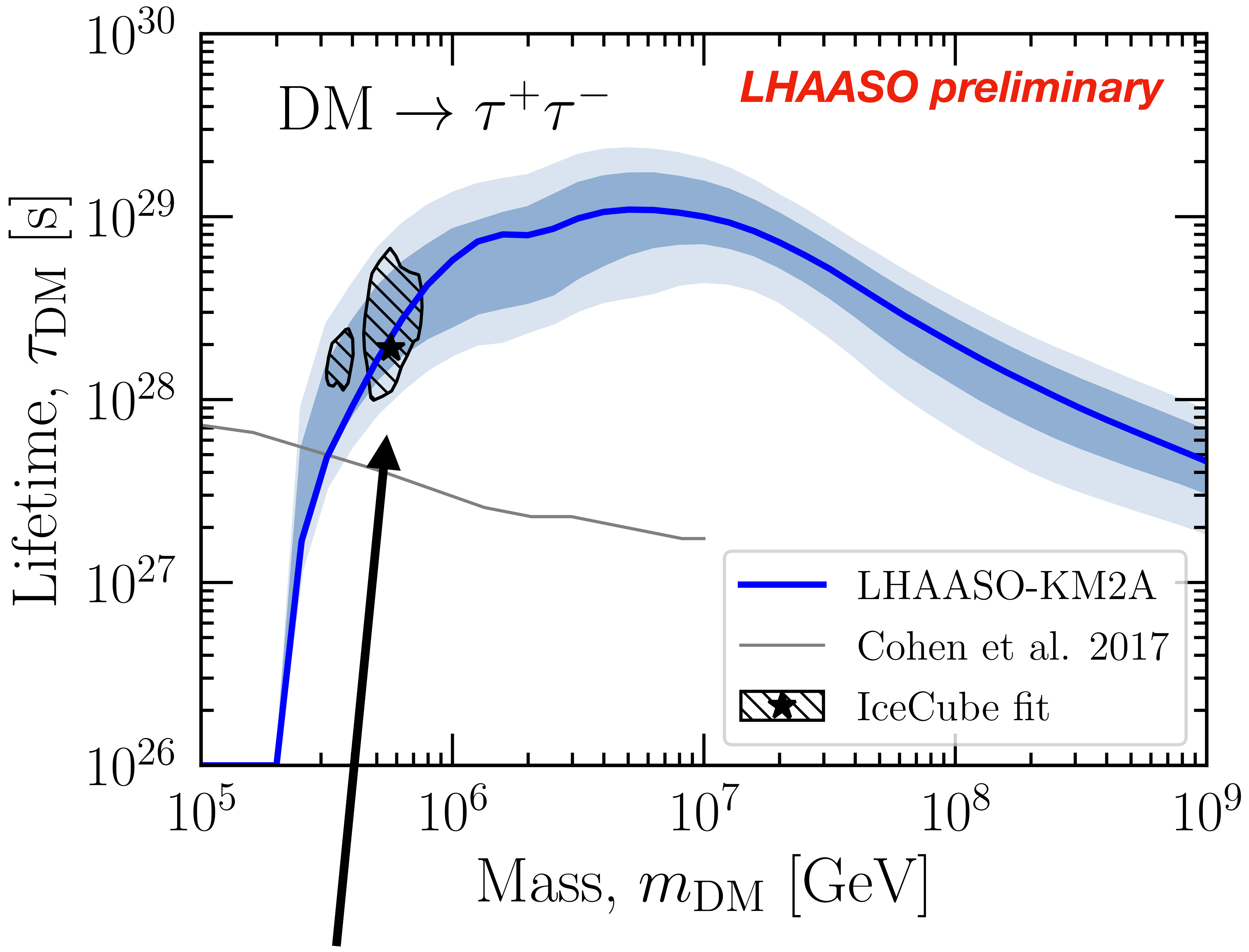


Significant improvement with respect to previous constraints



Tension with the parameter regions favored by IceCube neutrino data

Chianese et al., ***JCAP 1911***

Results

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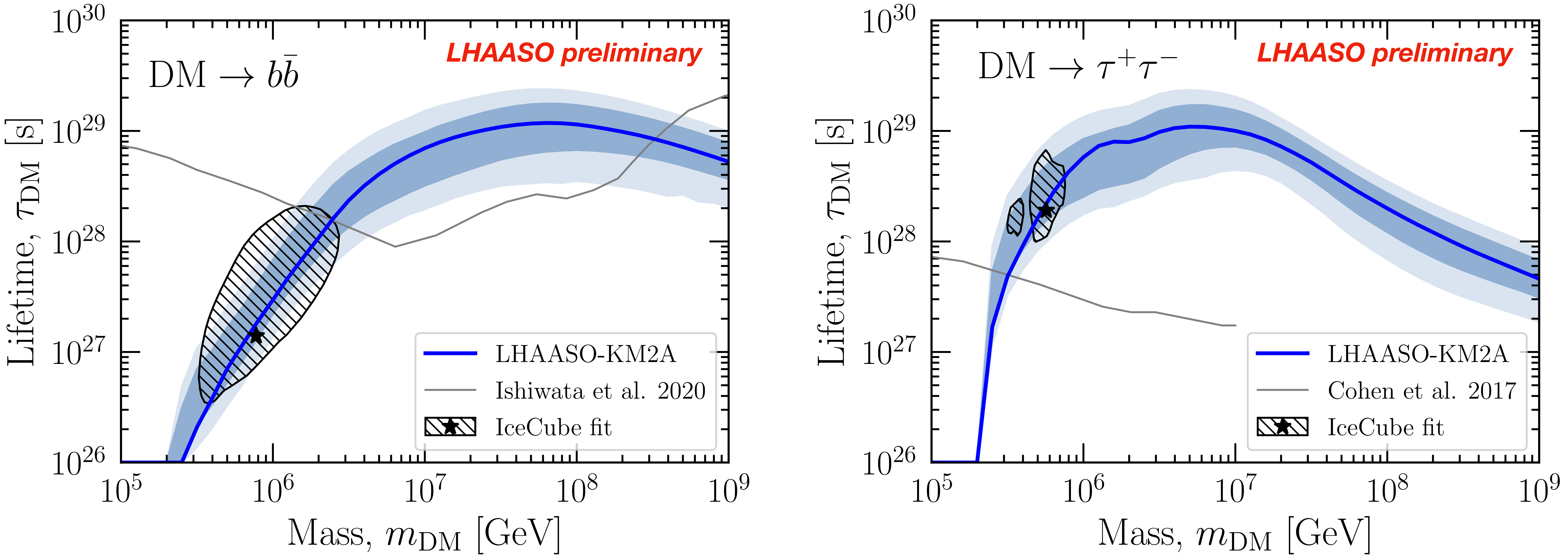

Recent constraints from Tibet-ASγ data:

- Esmaili et al., arXiv:2105.01826
- Maity et al., arXiv:2105.05680

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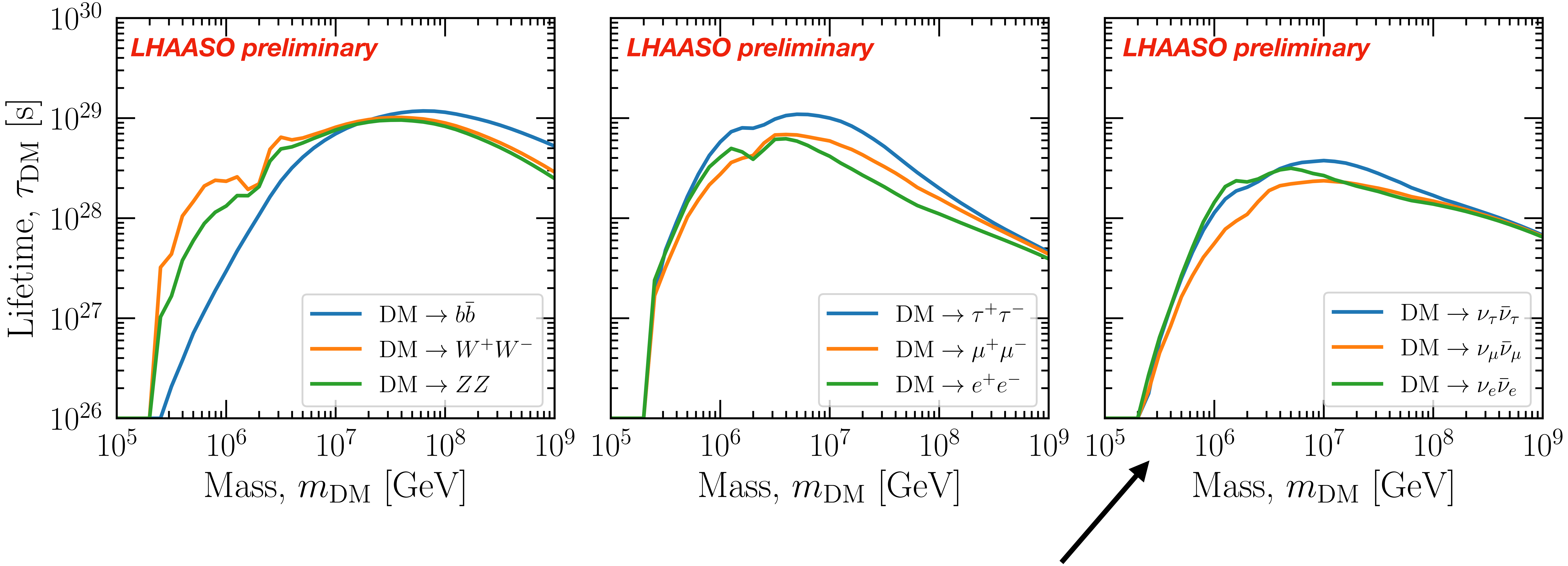
Our results are generally stronger and more robust being based on model-independent background assumptions!

Different DM decay channels

Constraints on DM lifetime at 95% CL for different DM decay channels

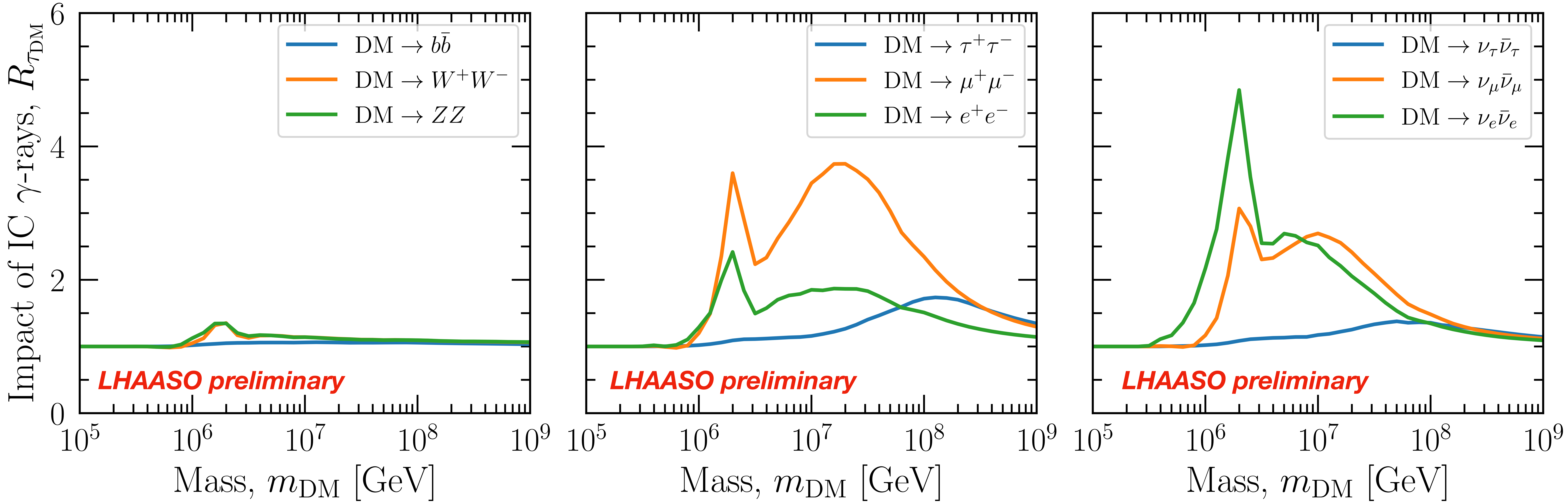


Prompt gamma-rays mainly produced through EW radiative corrections

Impact of secondary photons

Secondary IC gamma-rays are relevant!

$$R_{\tau_{\rm DM}} = \frac{\tau_{\rm DM,95\%}[\text{prompt + IC}]}{\tau_{\rm DM,95\%}[\text{prompt}]}$$



Conclusions

- We have presented **the first dark matter analysis in LHAASO-KM2A**.
- We have placed some of the strongest gamma-ray limits on decaying dark matter particles with 340 days of 1/2-KM2A data.
- We have accounted for prompt photons as well as secondaries from Inverse Compton.
- Our results are in tension with dark matter scenarios proposed to explain the IceCube high-energy neutrino data.
- **Stay tuned: there is plenty to look forward in the future!**

Thanks for listening