Star-forming Environments as Sources of High-Energy Gamma-rays and Neutrinos

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Starburst Galaxies

https://hubblesite.org/image/3898/printshop

The Starburst Galaxy M82

Phenomenological Properties of SBGs

- ✦ Galaxies with high star-formation rate (~100 $M_\odot$/yr, to be compared with ~1 $M_\odot$/yr in the Milky Way)

- ✦ Intense Star forming activity mainly concentrated in the core (nucleus), which lasts for $\sim 10^{7-8}\mathrm{yr}$

- ✦ High dense interstellar gas ($n_{\mathrm{ISM}} \simeq 10^2\mathrm{cm}^{-3}$)

- ✦ High degree of magnetic turbulence which traps high-energy protons for a long time $\sim 10^5\mathrm{yr}$: **Cosmic Reservoirs**

Expected copious hadronic production:

Interstellar gas as the target

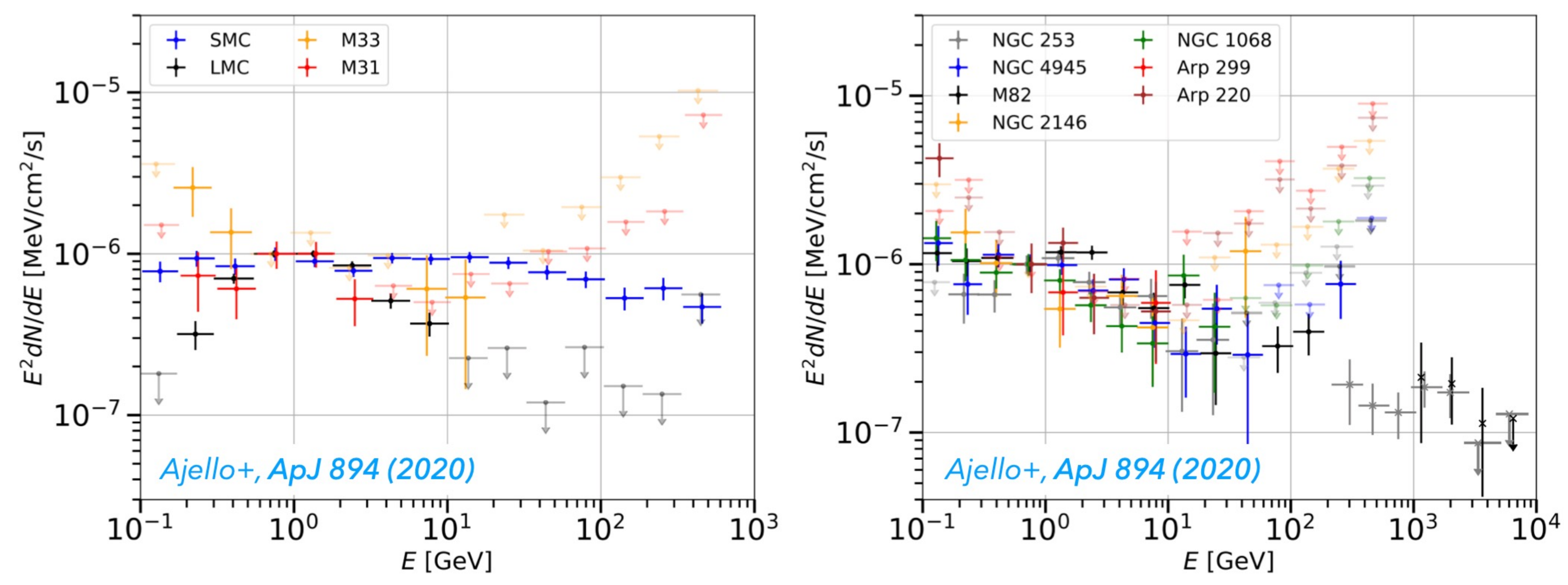
$$p + p \rightarrow \pi^+ \, \pi^- \, \pi^0 \ldots$$

✦ **Neutrinos** and **γ-rays** from pions decays:

$$\pi^\pm \rightarrow e^\pm \, \nu_e \, \nu_\mu \, \overline{\nu}_\mu$$
$$\pi^0 \rightarrow \gamma \, \gamma$$

SFGs andSBG as Gamma-Ray Emitters

✦ **Fermi-LAT data (GeV energies) + IACTs Telescope (TeV energies)**



✦Only a dozen of sources have been detected
✦Only few of them have both GeV and TeV data

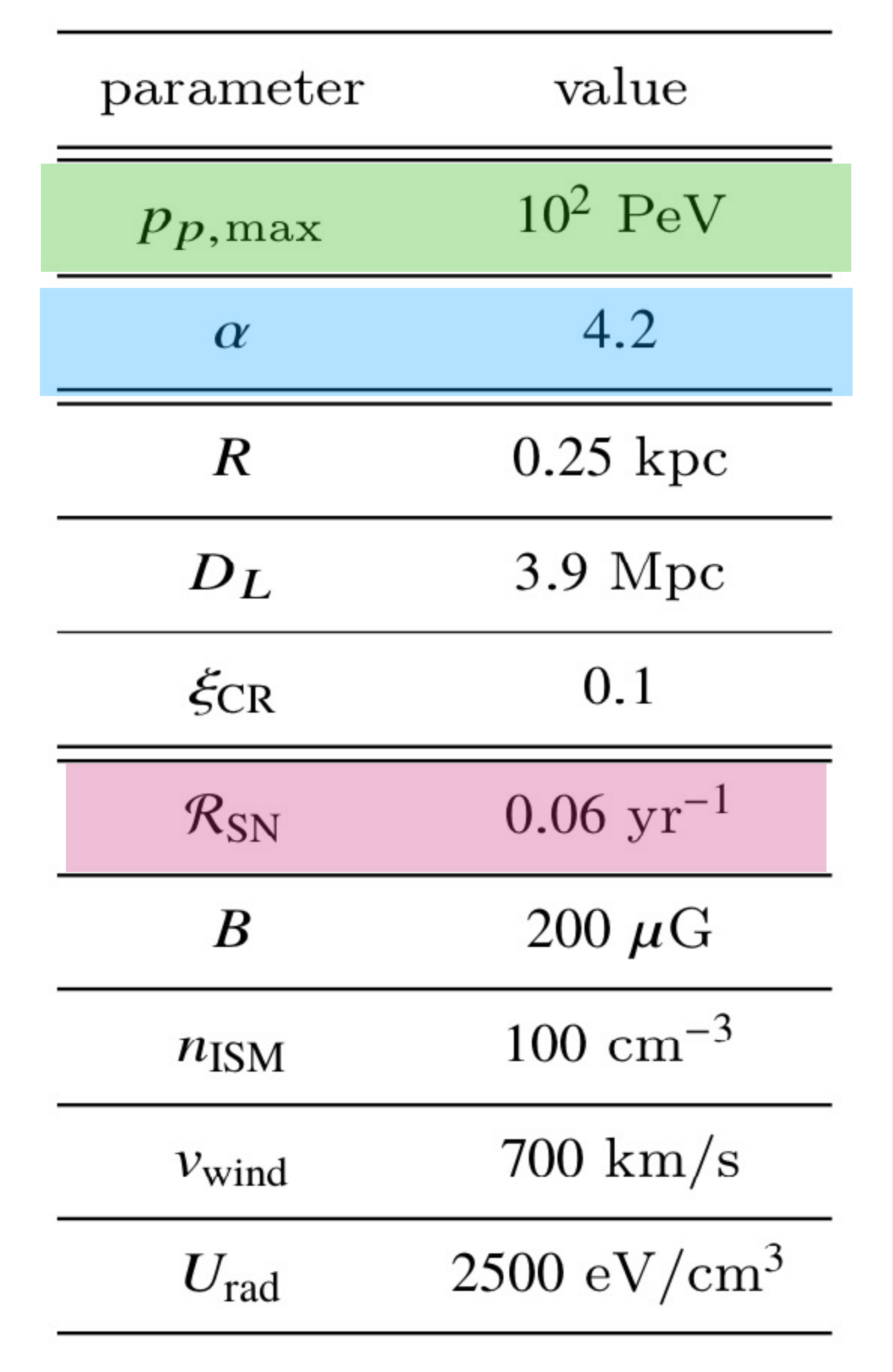
For M82 also VERITAS measurements (VERITAS Collaboration et al., 2009, Nature, 462, 770). For NGC 253 also HESS measurements (H. E. S. S. Collaboration et al., 2018, A&A, 617, A73)

CR Transport: the Leaky-Box Model

Leaky-box-like model for CR transport

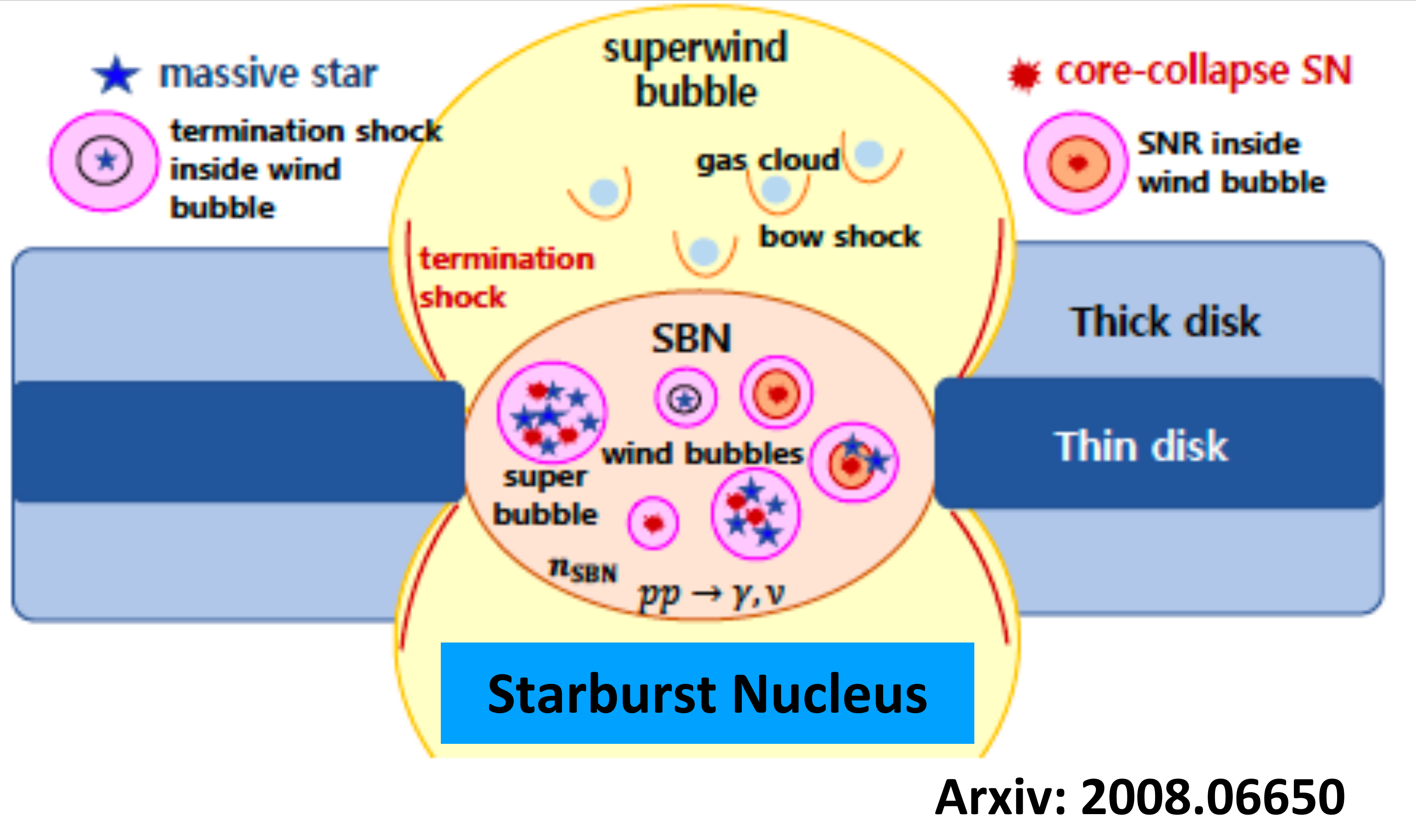
$$f(p)\left(\frac{1}{\tau_{\mathrm{loss}}(p)}+\frac{1}{\tau_{\mathrm{adv}}(p)}+\frac{1}{\tau_{\mathrm{diff}}(p)}\right)=Q(p)$$

injected CR from SN explosion $(\frac{p}{\mathrm{m_p}})^{-\alpha}\times e^{-p/\mathrm{pmax}}$



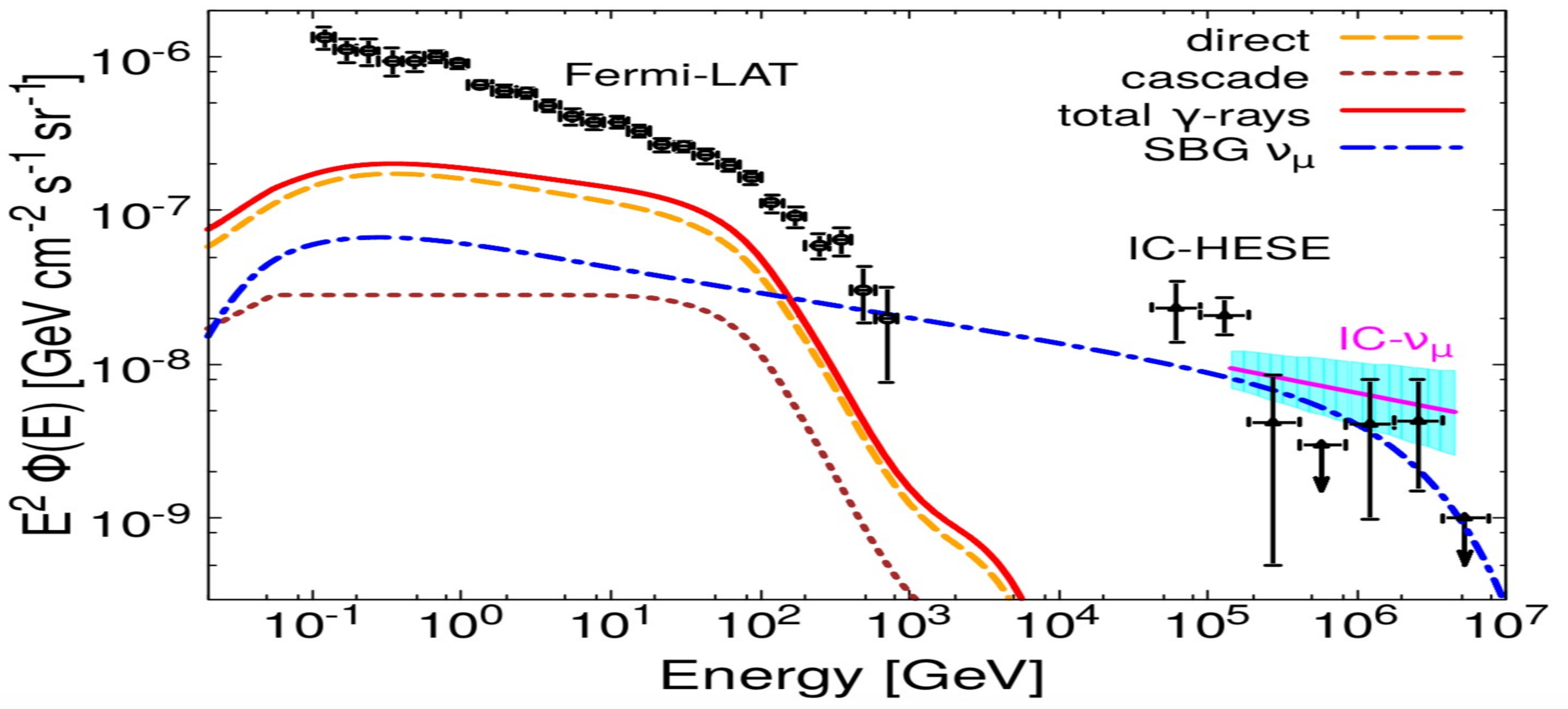
parameter	value
$p_{p,\max}$	10^2 PeV
α	4.2
R	0.25 kpc
D_L	3.9 Mpc
ξ_{CR}	0.1
$\mathcal{R}_{\mathrm{SN}}$	0.06 yr^{-1}
B	200 μG
n_{ISM}	100 cm^{-3}
v_{wind}	700 km/s
U_{rad}	2500 $\mathrm{eV/cm^3}$

- In the calorimeter scenario, three main parameters:
  - Cut-off energy
  - Spectral index
  - Rate of SuperNovae explosions



Arxiv: 2008.06650

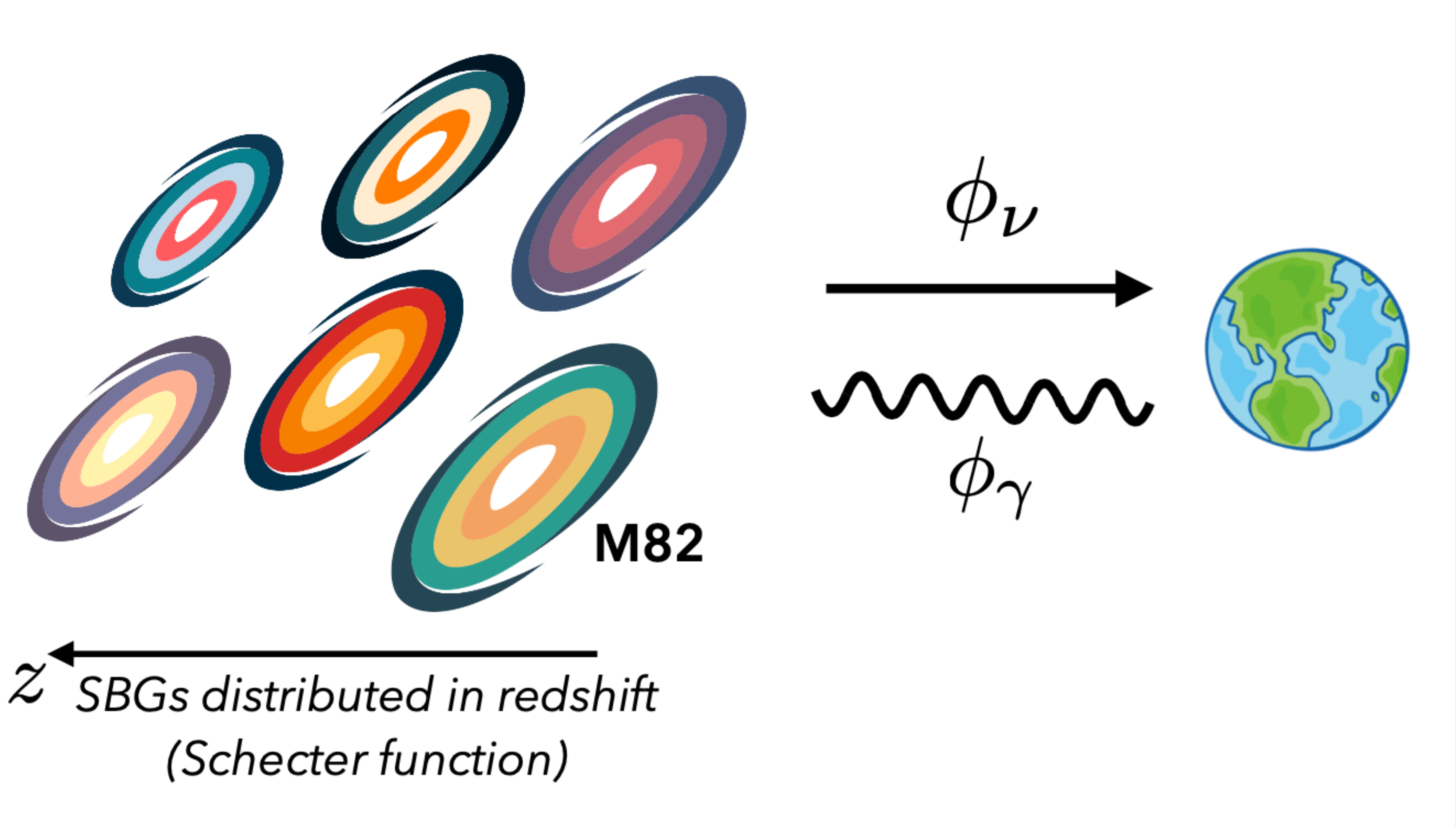
*Peretti et al., **arXiv:1812.01996**, **arXiv:1911.06163***



- ***All*** the SBGs are considered with the same properties of a ***prototype*** galaxy with “known” parameters

Diffuse Emissions: Spectral index Blending

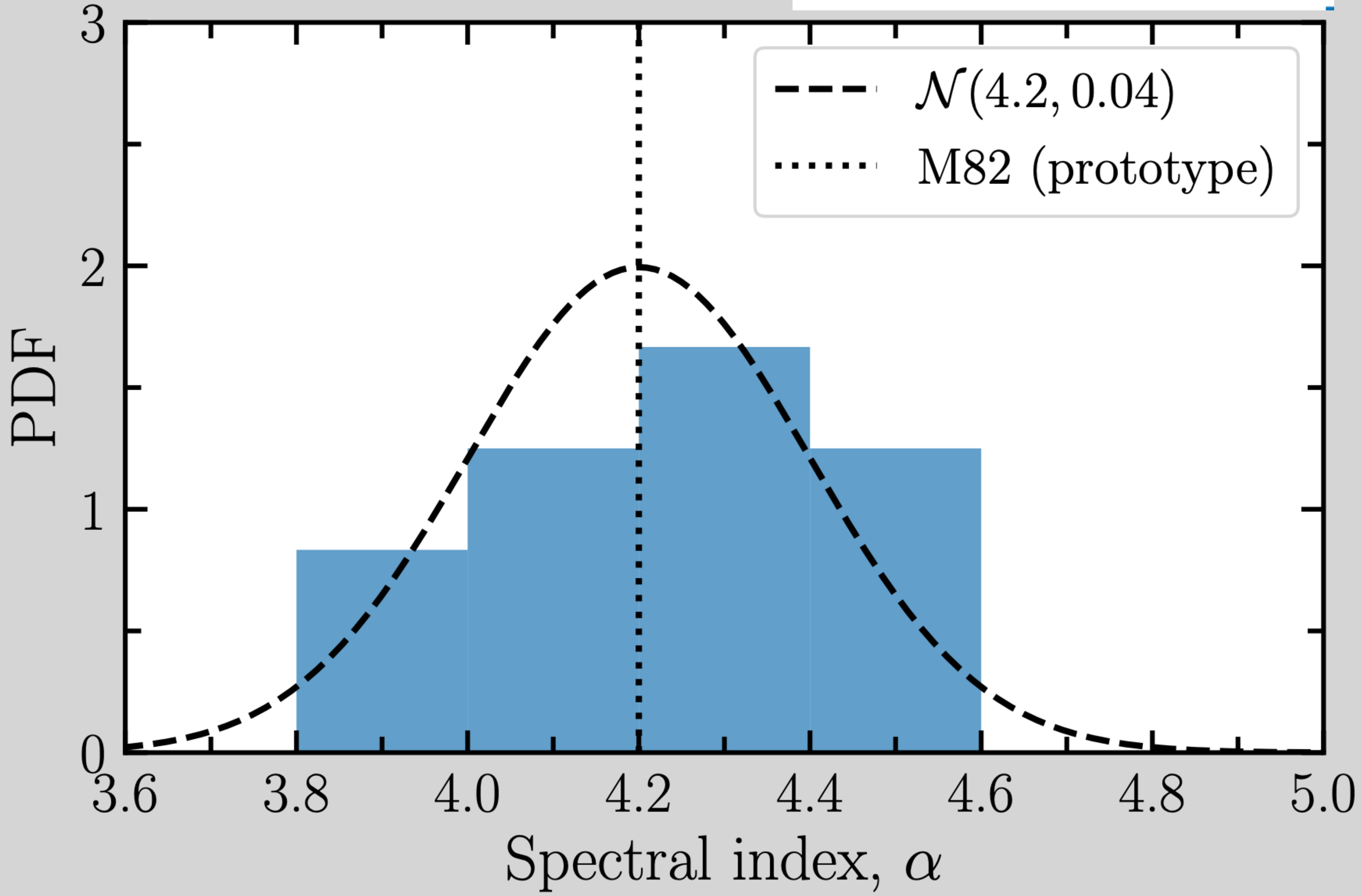
✦Each source has their own parameters (**Spectral index Blending!**)



SBGs distributed in redshift (Schecter function)

$$\left\langle \phi_{\nu,\gamma}(E|p^{\max},\alpha) \right\rangle_\alpha = \int \mathrm{d}\alpha\, \phi_{\nu,\gamma}(E|p^{\max},\alpha)\, p(\alpha)$$

*Ambrosone+, **2011.02483***



Distribution of 12 SFGs and SBGs resolved in gamma-rays

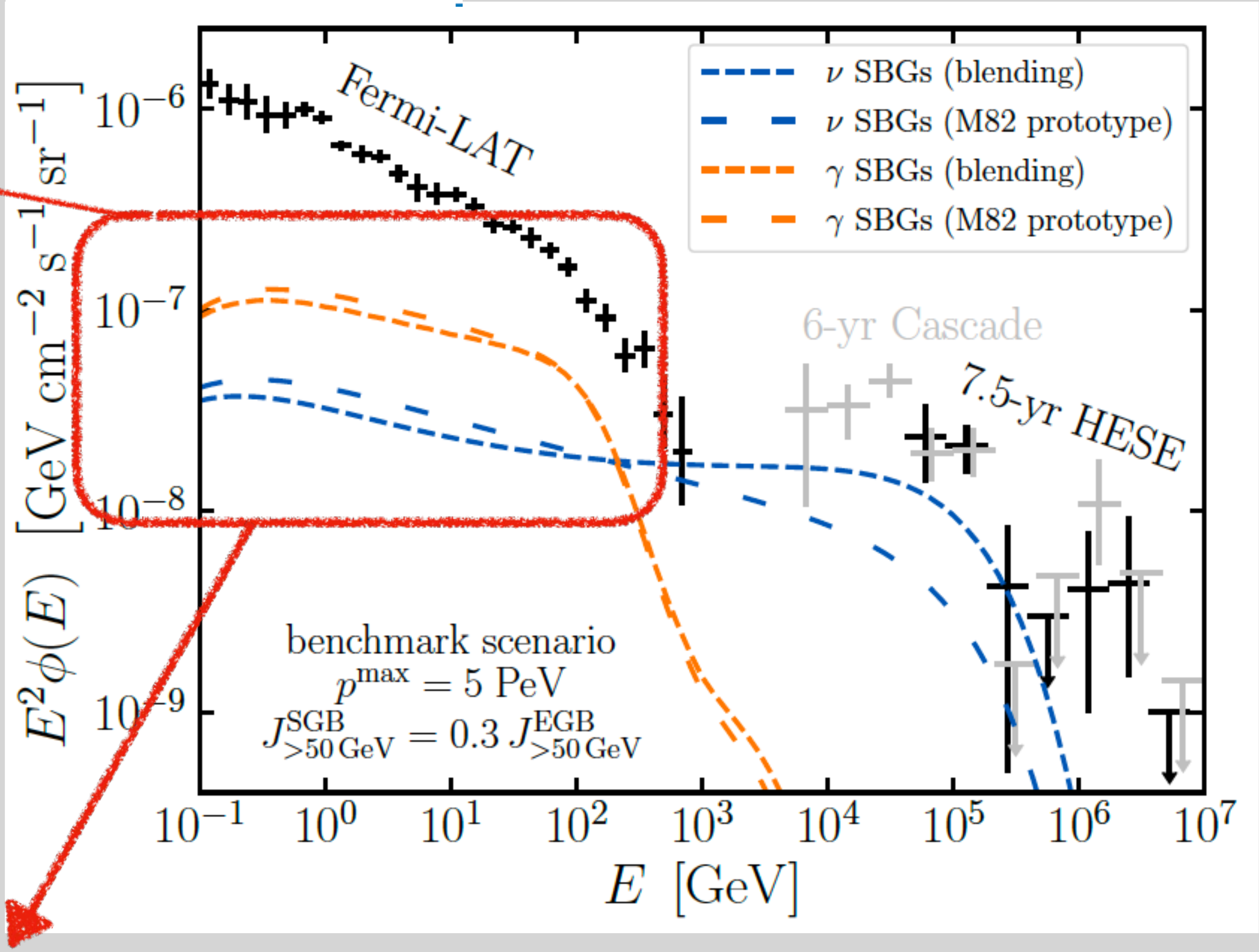
*Ajello+, ApJ 894 (2020) (**arXiv:2003.05493)***

$$p(\alpha) = \mathcal{N}(\alpha|4.2, 0.04)$$

Blending versus Prototype

Direct + electromagnetic cascades gamma-ray flux

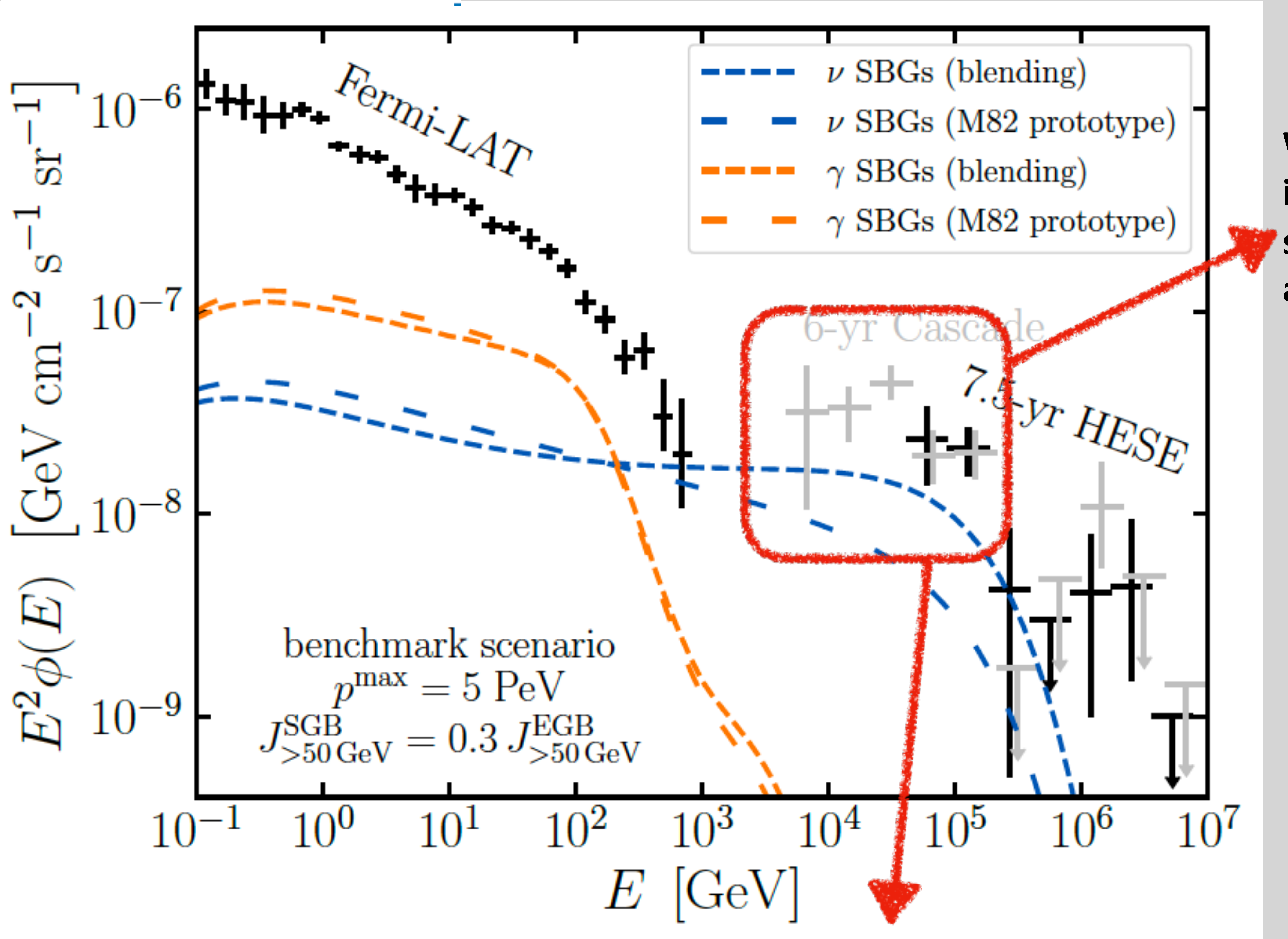
Ambrosone+, 2011.02483



The diffuse gamma contributions are almost the same!

Blending versus Prototype

Ambrosone+, 2011.02483

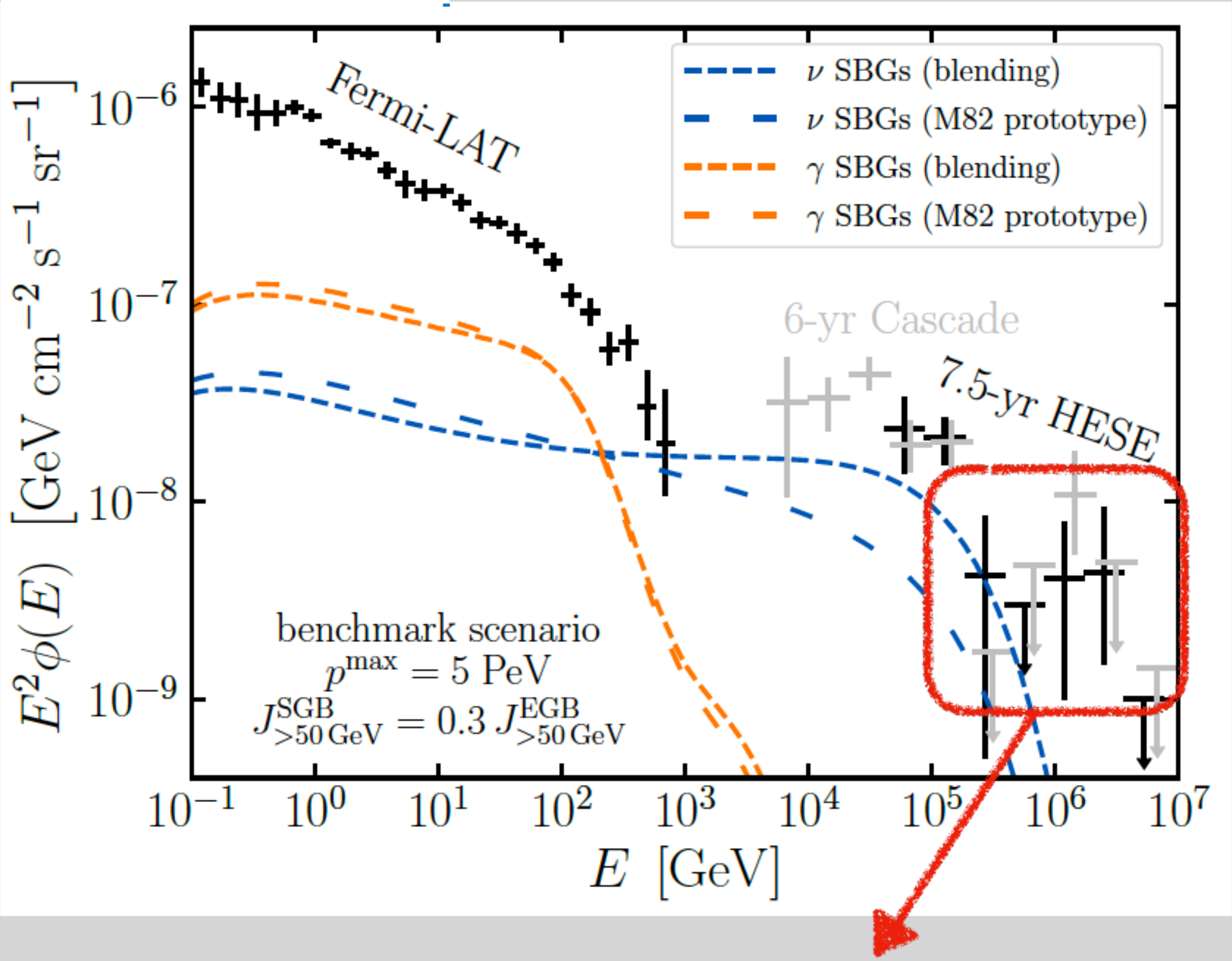


With $p^{\max} = \mathcal{O}(\mathrm{PeV})$ it is possible to give a significant contribution at around 100 TeV

Larger contribution around 100 TeV! Potentially, It could alleviate the Tension between neutrino and gamma-ray data when using a hadronic model to explain IceCube observations.

Blending versus Prototype

Ambrosone+, 2011.02483



A possible contribution from Blazar? A possible interplay between reservoirs and accelerators?

Results: Blending versus Prototype

- We performed a multi-component fit

The Gamma-Ray Contributions:
1. **SBGs**
2. **Blazar + Electromagnetic Cascades**
3. **Radio Galaxies**

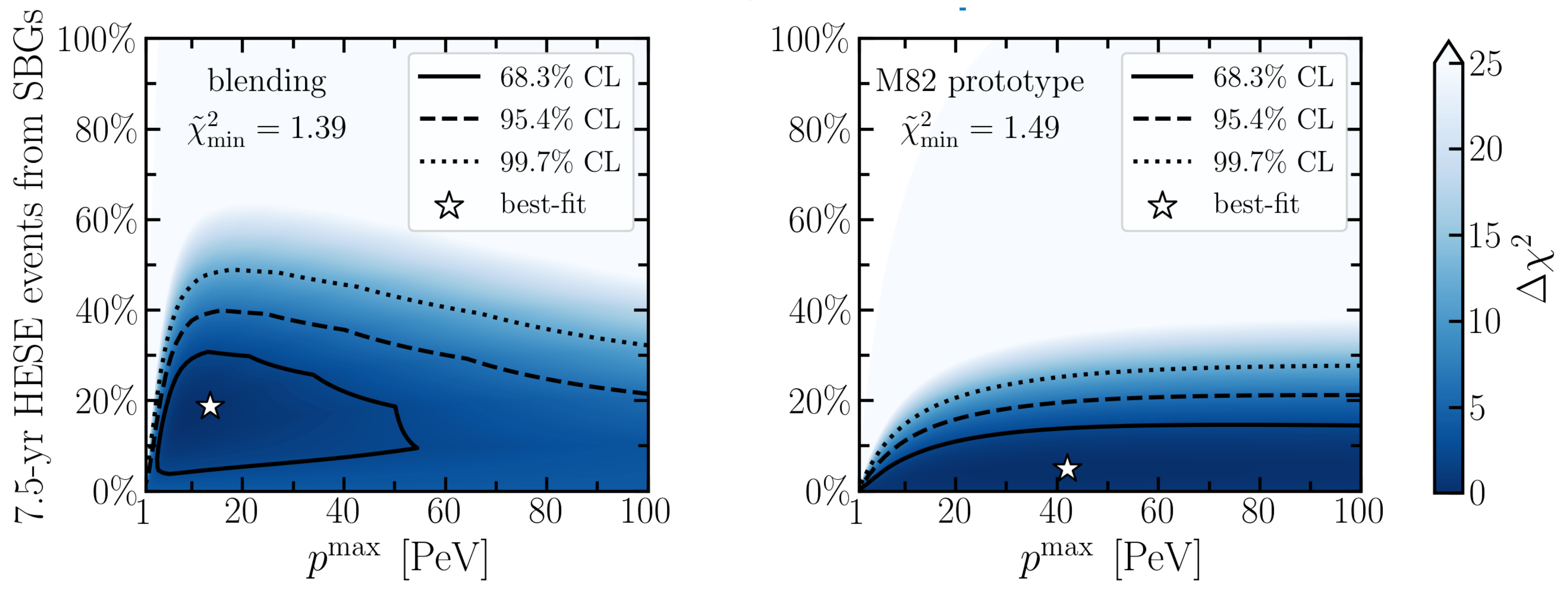
For Blazars and Radio Galaxies, we used the estimations given by Ajello et al. 2015 **(ArXiv: 1501.05301)**

The Neutrino Contributions:
1. **SBGs**
2. **Blazars**

For Blazars, we used the estimations given by Palladino et. Al 2019 **(ArXiv:1806.04769)**

Main Result

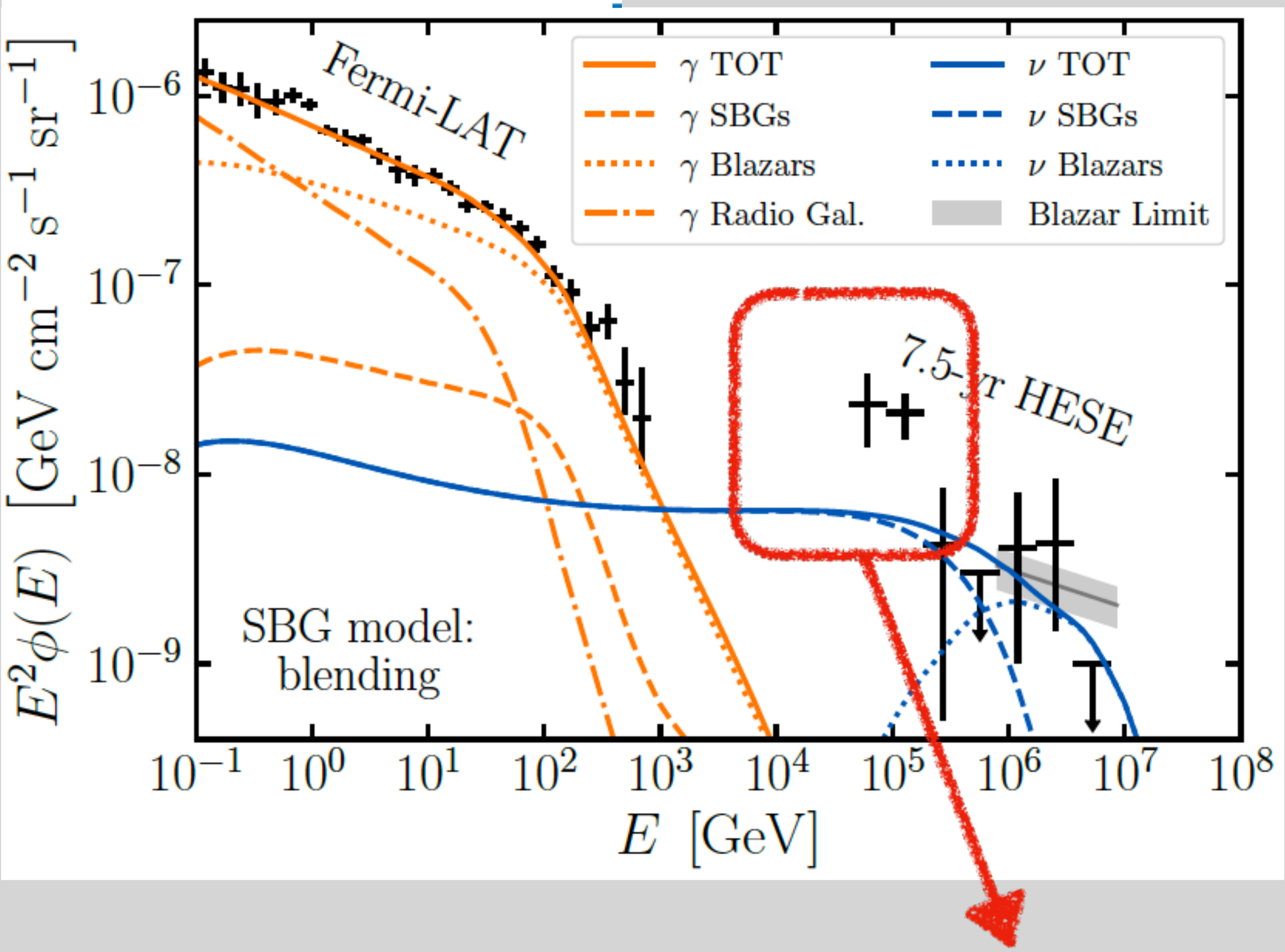
Ambrosone+, 2011.02483



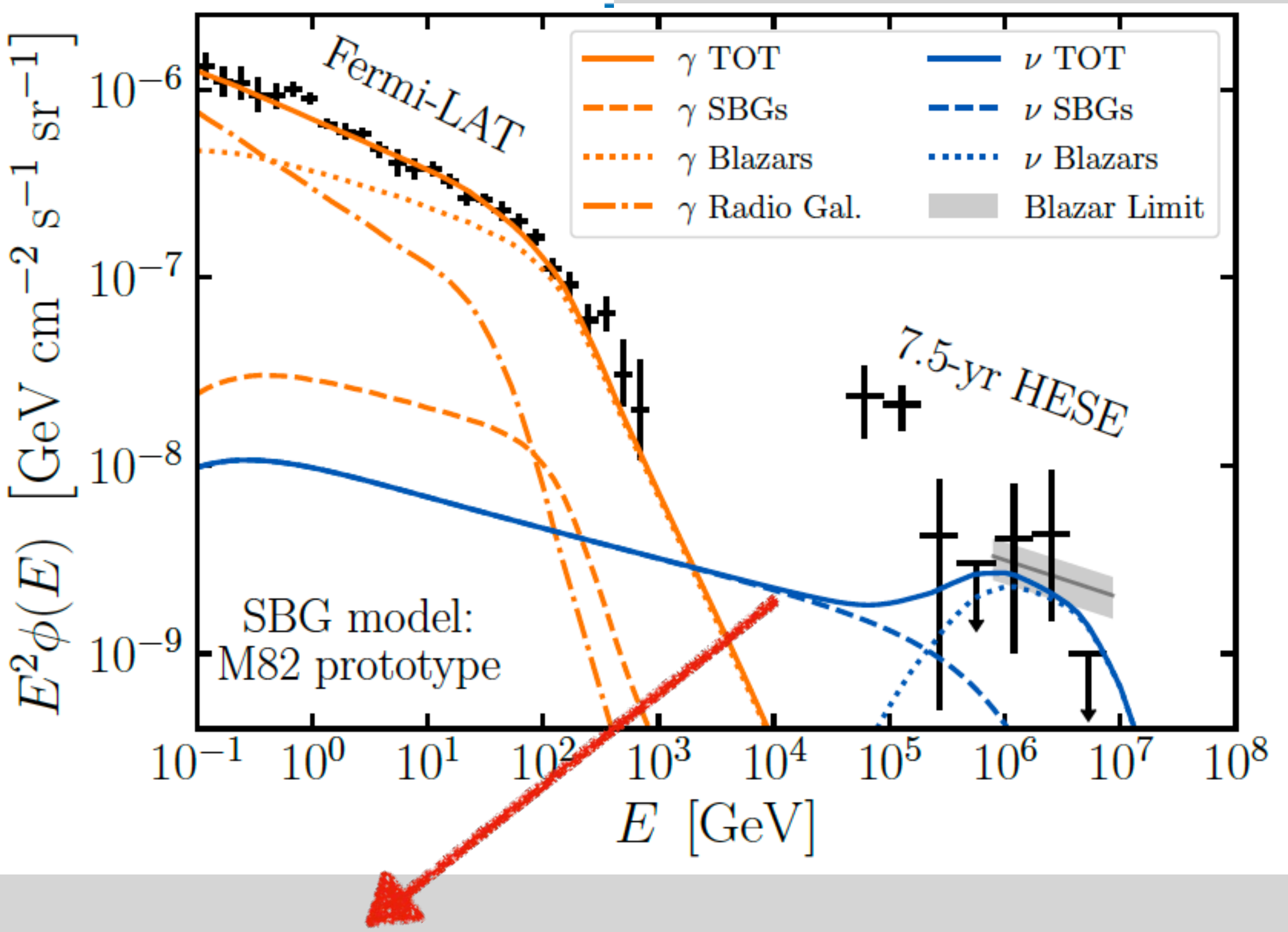
- **Non-Zero SBG component at 68% Confidence Level**
- **Preferred smaller values of the maximum energies for injected CRs: $p^{max} < 50$ PeV**

Results 2.0: Blending versus Prototype

Ambrosone+, 2011.02483



Ambrosone+, 2011.02483



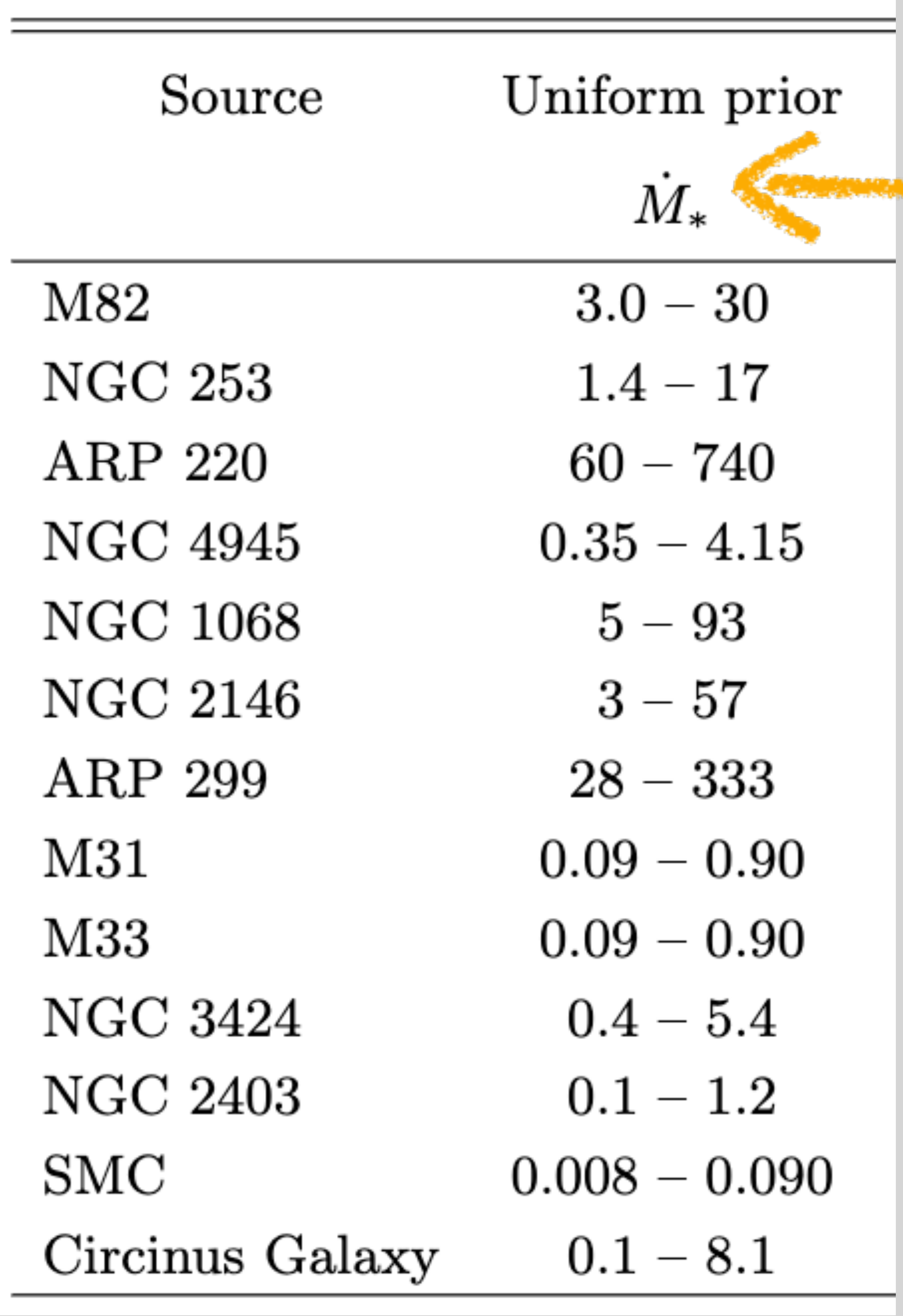
The Blending Scenario is ***allowed*** *to give a greater contribution than the prototype scenario…but it is* ***not enough****…****Other Contributions?***

Can SBGs be observed as point-like Neutrino Emitters?

Probing the SBG Calorimetric Scenario

We analyze the observed nearby SBG Gamma-ray SED: Bayesian approach

- We use both GeV and TeV gamma-ray data (Fermi-LAT + IACTs data)

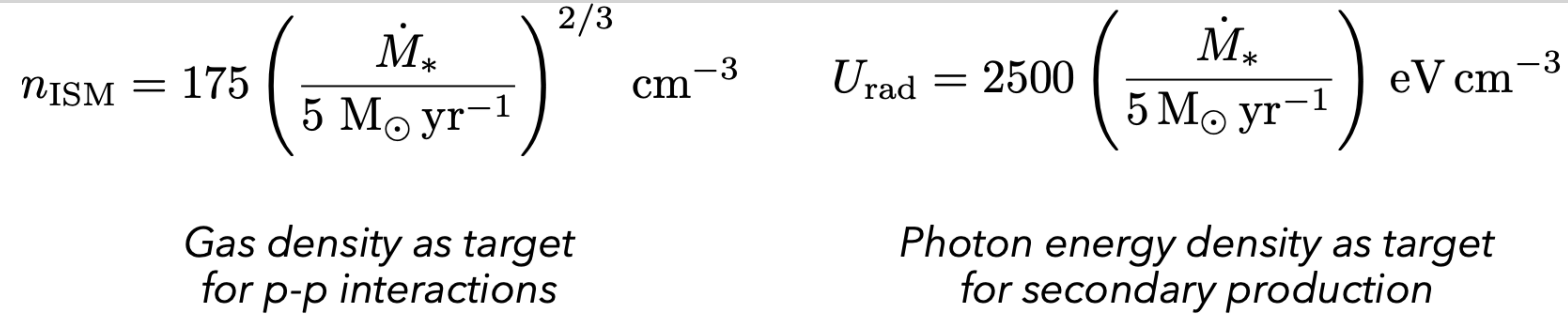


Source	Uniform prior $\dot{M}_*$
M82	3.0 – 30
NGC 253	1.4 – 17
ARP 220	60 – 740
NGC 4945	0.35 – 4.15
NGC 1068	5 – 93
NGC 2146	3 – 57
ARP 299	28 – 333
M31	0.09 – 0.90
M33	0.09 – 0.90
NGC 3424	0.4 – 5.4
NGC 2403	0.1 – 1.2
SMC	0.008 – 0.090
Circinus Galaxy	0.1 – 8.1

- IR + UV data: Prior on the star formation rate

Ambrosone+, ApJL 919 [2106.12348]

- Starburst Nucleus of the order of $10^2 \mathrm{pc}$
- Escaping phenomena dominated by advection
- Using Kennicutt's relations:



$$n_{\mathrm{ISM}} = 175 \left(\frac{\dot{M}_*}{5\ \mathrm{M}_\odot\, \mathrm{yr}^{-1}} \right)^{2/3} \mathrm{cm}^{-3} \qquad U_{\mathrm{rad}} = 2500 \left(\frac{\dot{M}_*}{5\, \mathrm{M}_\odot\, \mathrm{yr}^{-1}} \right) \mathrm{eV\, cm}^{-3}$$

Gas density as target for p-p interactions

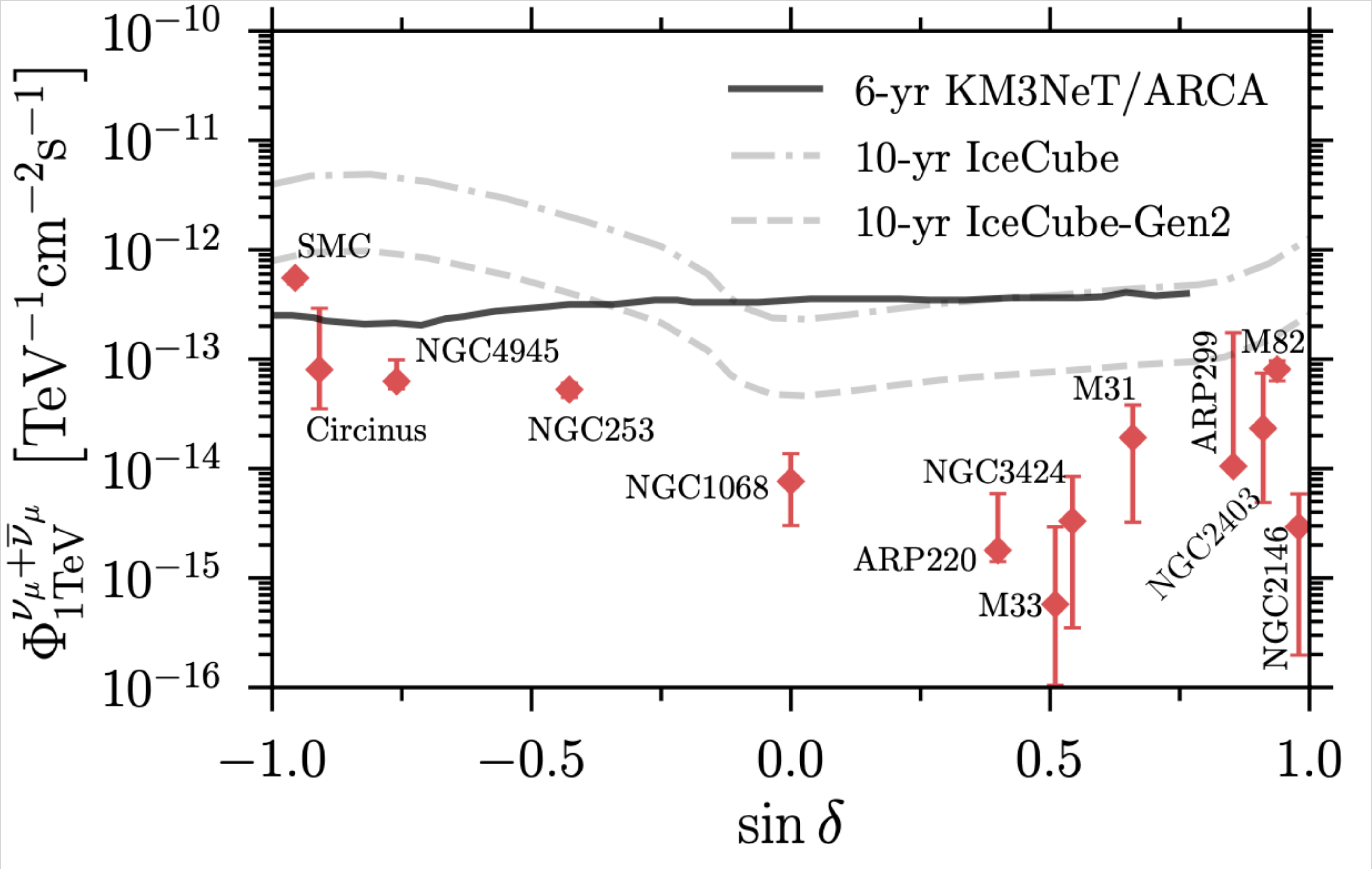
Photon energy density as target for secondary production

Kennicutt, ARA&A 36 (1998); Inoue+, PASJ 52 (2000); Hirashita+, A&A 410 (2003); Yuan+, PASJ 63 (2011); Kennicutt and Evans, ARA&A 50 (2012); Kennicutt & De Los Reyes, ApJ 908 (2021)

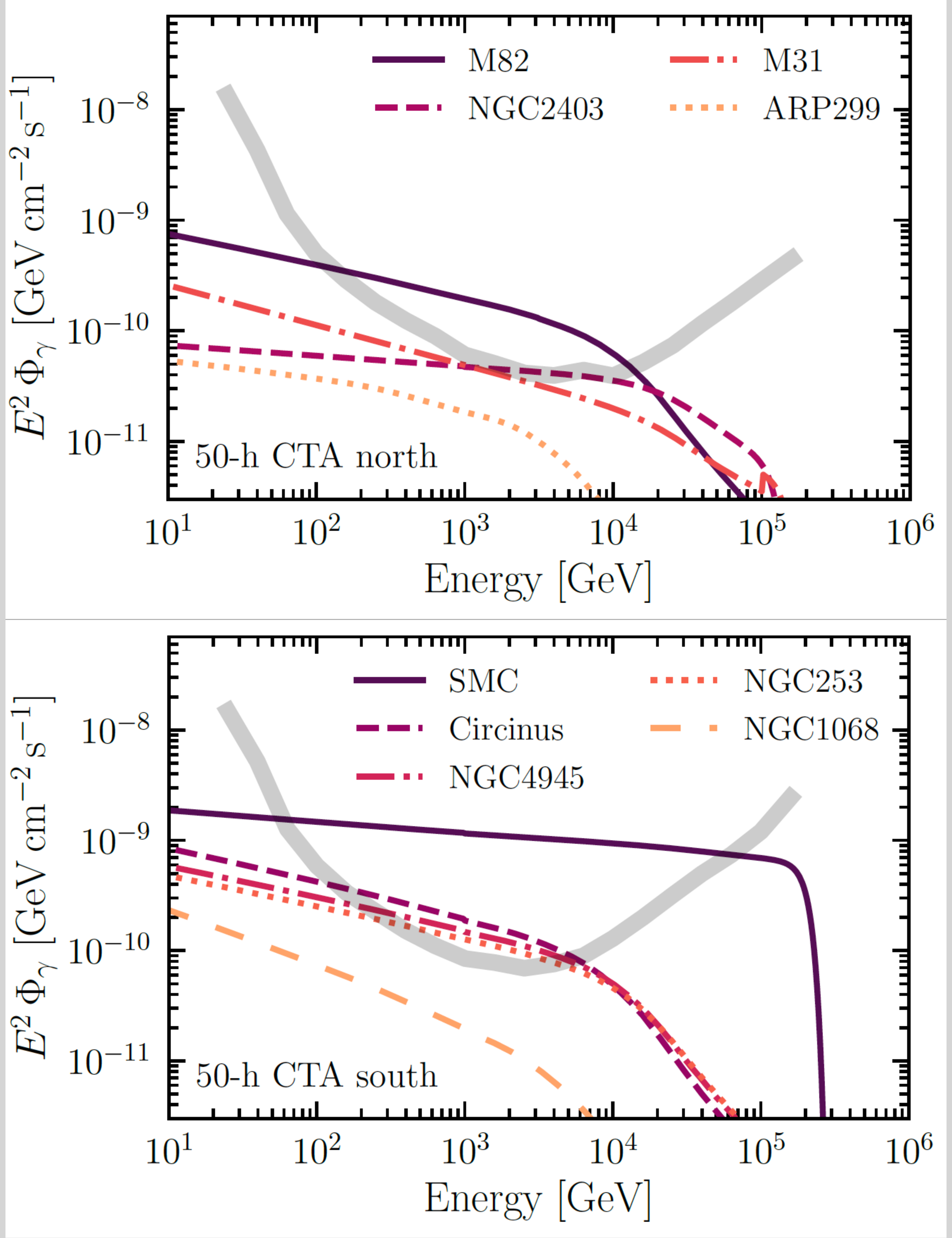
Probing the SBG Calorimetric Scenario

Ambrosone+, ApJL 919 [2106.12348]

Neutrino Expectations: KM3NeT Forecast



Gamma-Rays Expectations. CTA Forecast



Future γ/ν observations will be fundamental to:

- ✦ Discover if Neutrino Astronomy is a tracer for star-forming activity
- ✦ Probe the calorimetric fraction inside SBG: If there will be no detection, nearby SBGs are dominated by diffusion and not by either p-p collisions or advection.

Which is the Role of KM3NeT/ARCA in Unveiling SBG Emission?

The KM3NeT Infrastructure

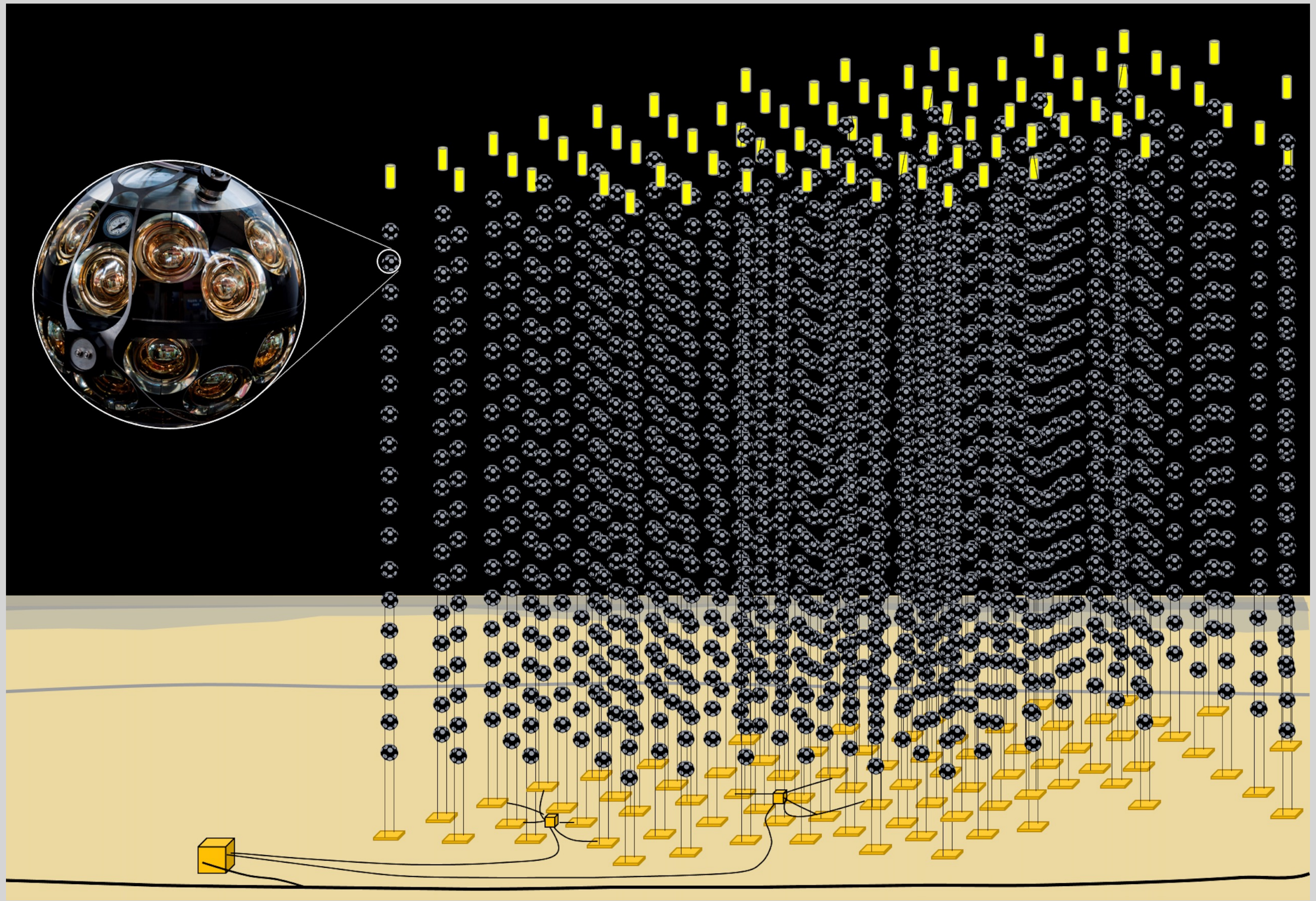
KM3NeT is a neutrino detector under construction. It is distributed in two parts. ARCA (Astroparticle Research with Cosmics in the Abyss) and Orca (Oscillation Research with Cosmics in the Abyss).

See Letter of Intent for KM3NeT 2.0, doi; 10.1088/0954-3899/43/8/084001

ARCA: Study of the high-energy astrophysical Neutrinos

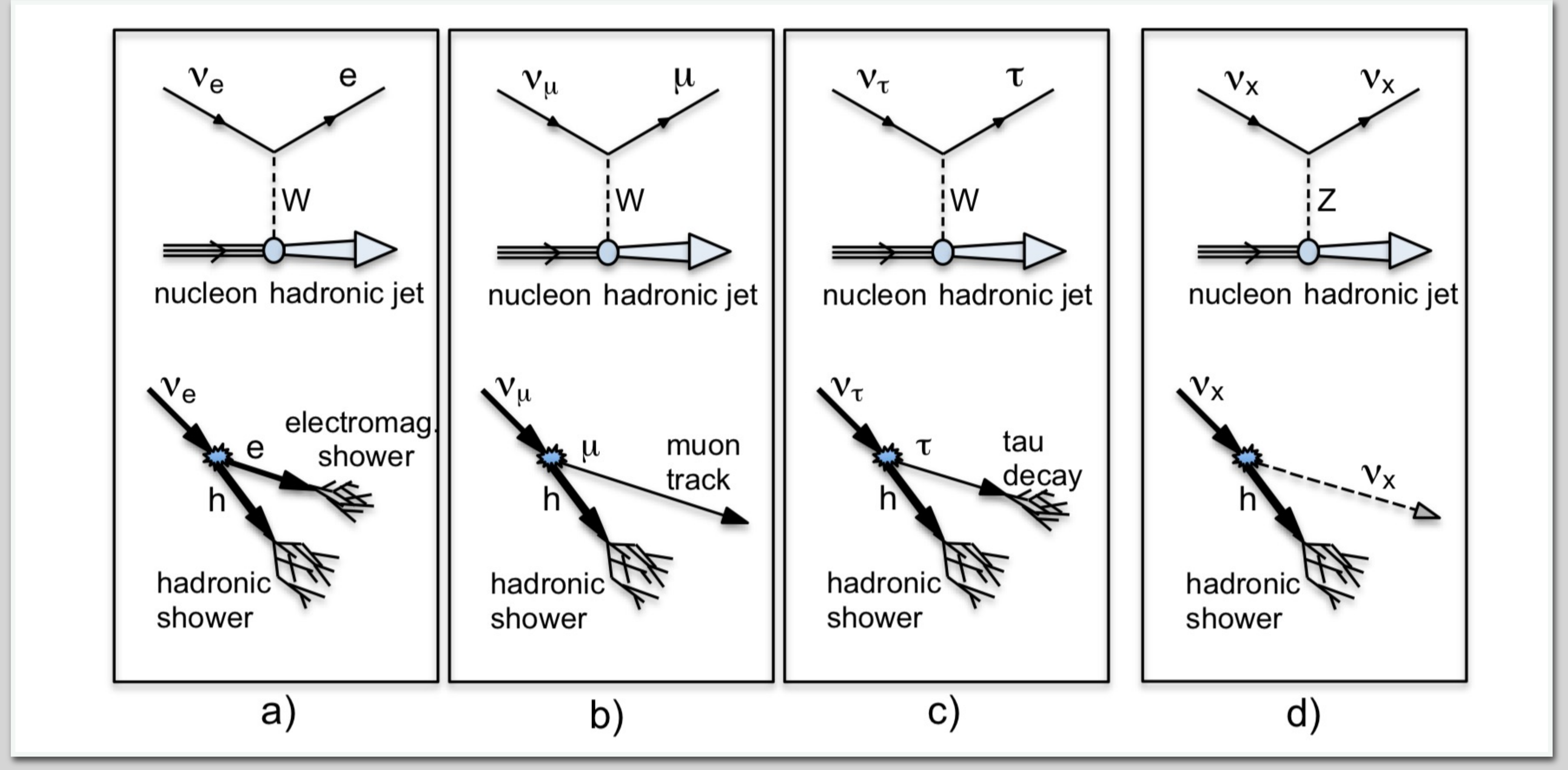
ORCA: Study of Neutrino Physics

https://www.km3net.org/

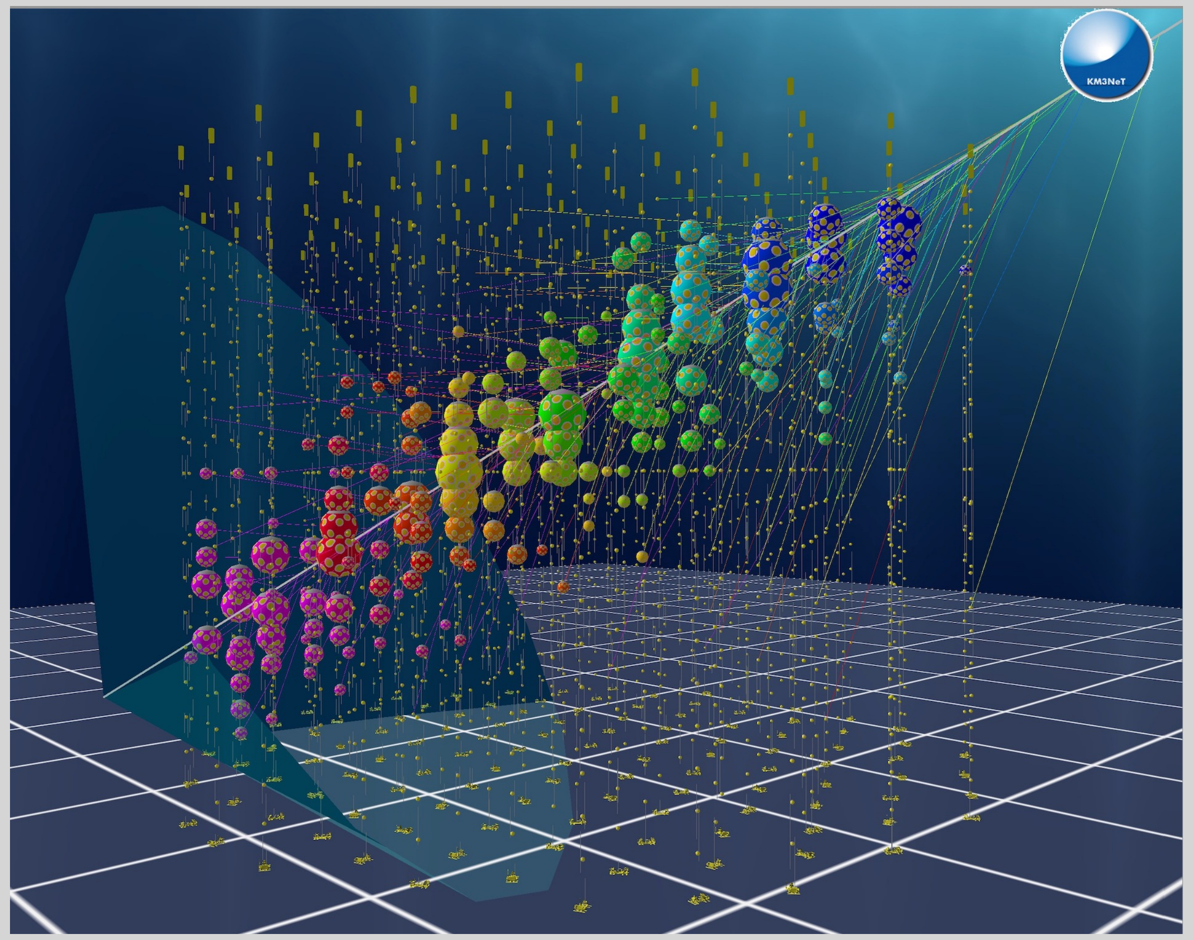


Although the detectors are under construction, KM3NeT is already operative (28 DUs for ARCA)

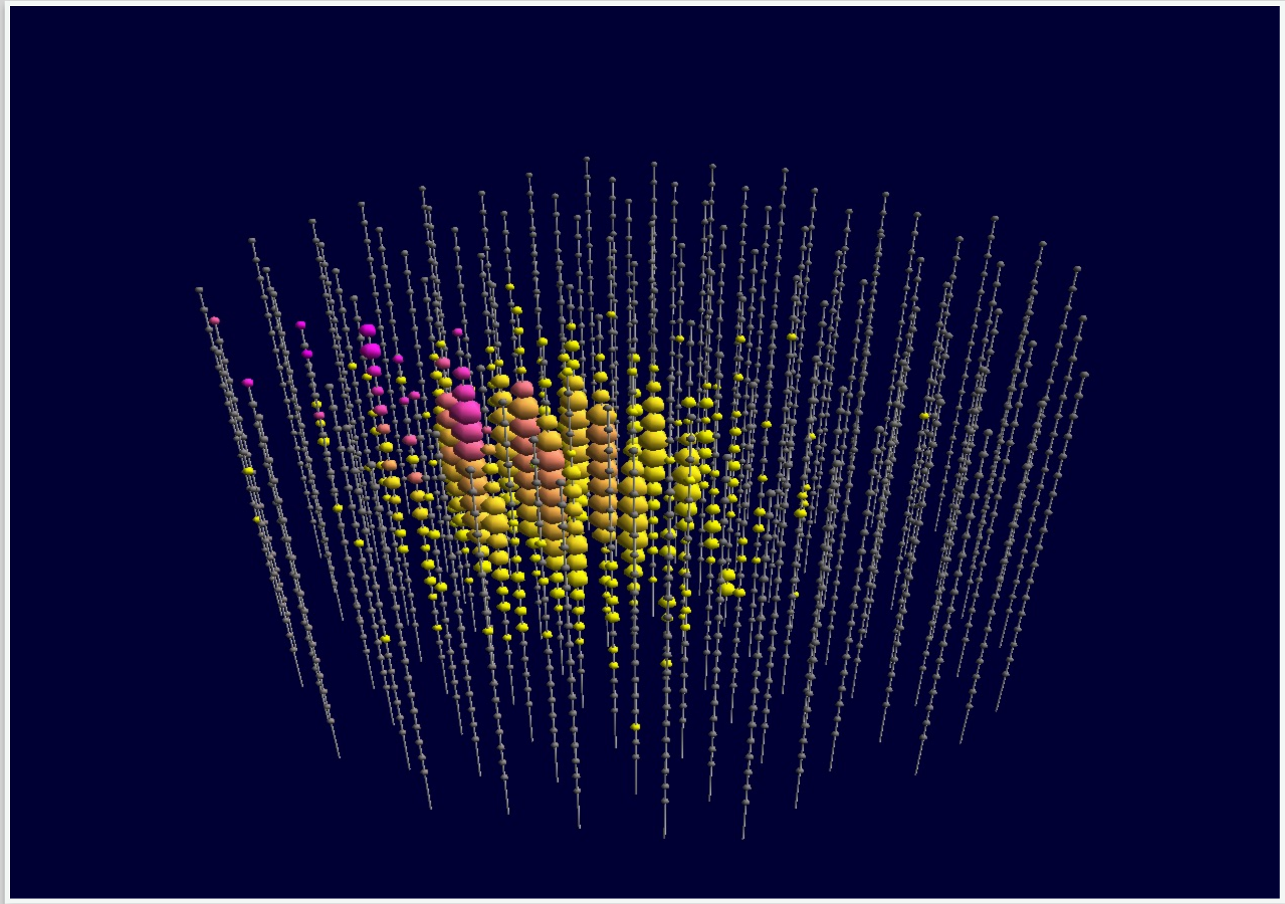
Detection Principle:



Track-like event



Shower-like Event



Analysis Framework

The Detector Response Functions are used to obtain the expected signal and background distribution

Maximum Binned Likelihood Method

$$\mathcal{L} = \prod_{i,j} P(n_{i,j} | \lambda \mu_s^{i,j} + \mu_b^{i,j})$$

We determine the Test Statistics (TS) $TS = \log \frac{\mathcal{L}(\lambda)}{\mathcal{L}(\lambda=0)}$

- Point-Like (extended) Analysis:
Binning in $\log(\mathrm{E_{reco}})$ and in cone angle (α)

- Diffuse Analysis:
Binning in $\log(\mathrm{E_{reco}})$

✦ We study the sensitivity by using the Pseudo experiment (PE) technique

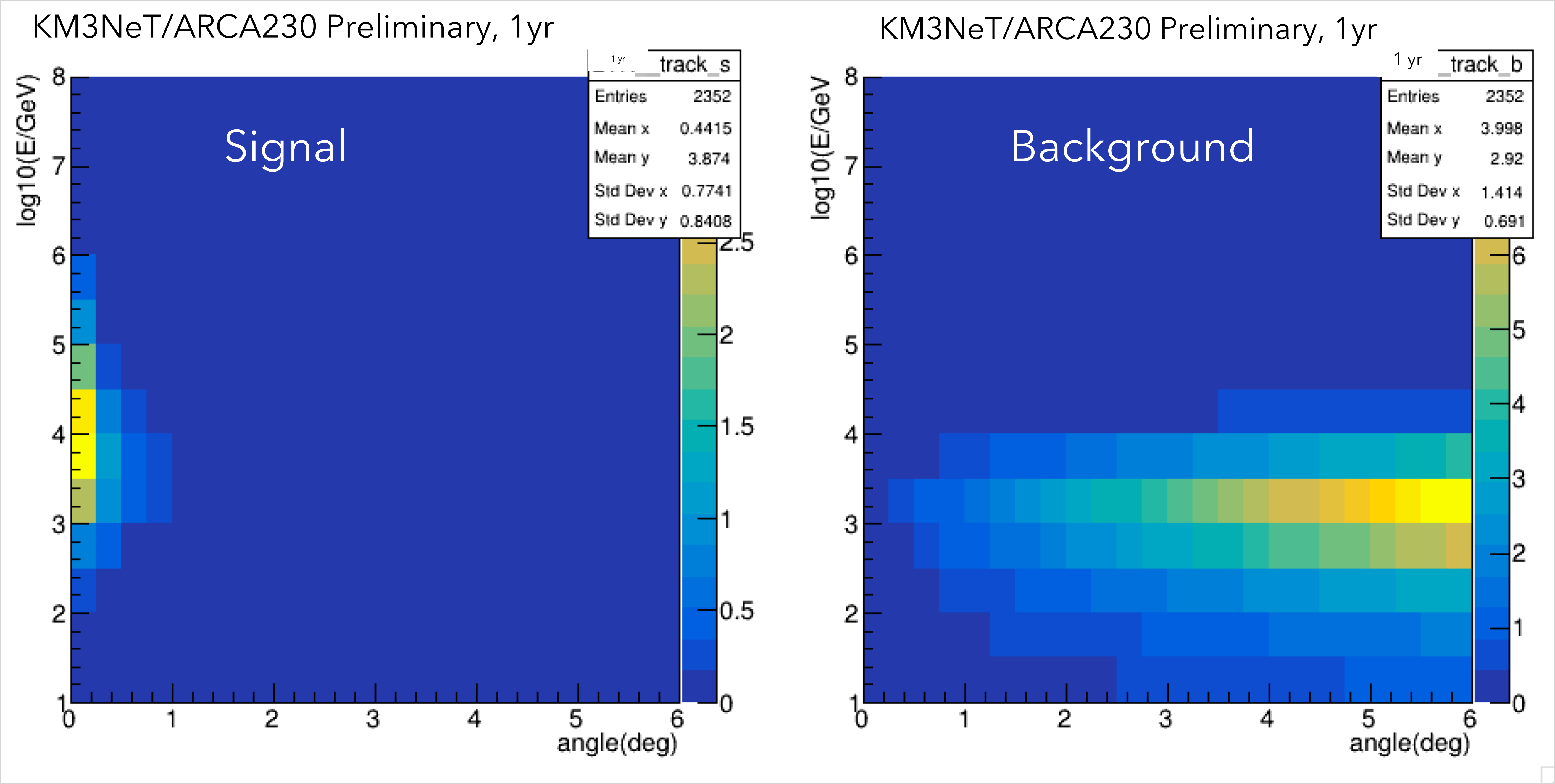
Sensitivity Definition

$\mathrm{TS_m}$ is the median TS in the background-only distribution

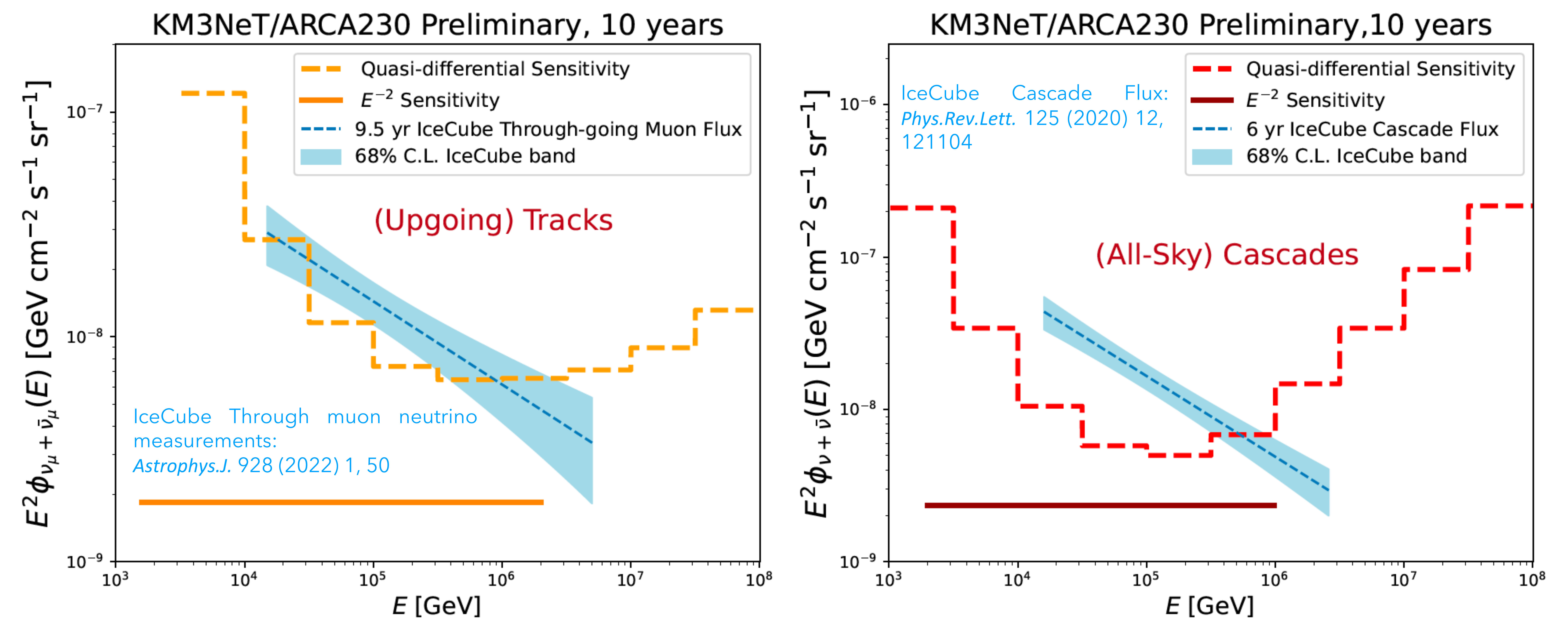
$$\int_{\mathrm{TS_m}}^{+\infty} \mathrm{d}(\mathrm{TS}|\lambda_{90})\mathrm{dTS} = 90\%$$

See *PoS* ICRC2023 (2023) 1150 for more details

Example: Signal and Background distribution



Diffuse Analysis Results



✦KM3NeT/ARCA sensitivity for tracks and cascades peak at different energies

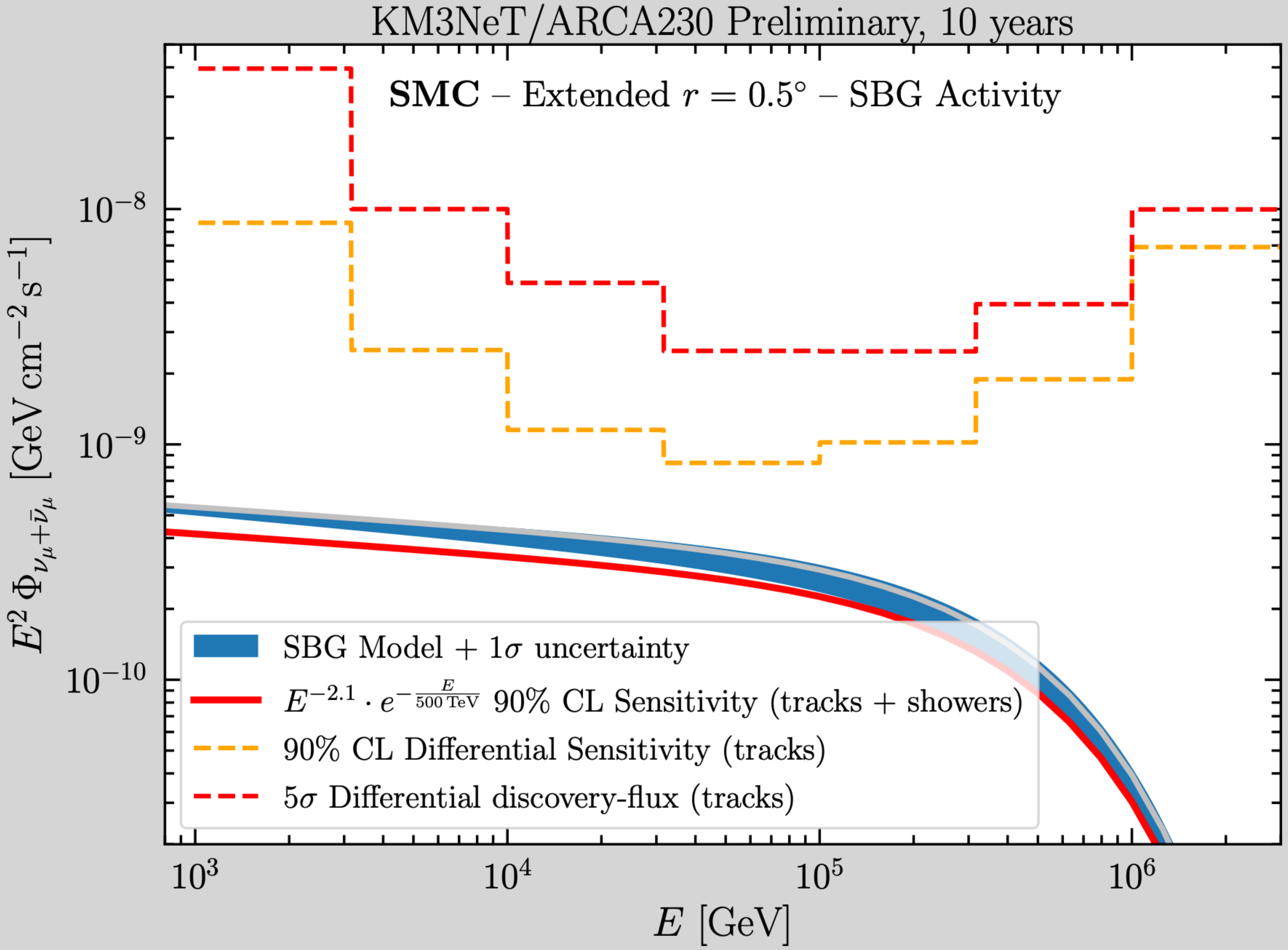
✦KM3NeT/ARCA will crucially probe the diffuse neutrino flux in few years of Data Taking

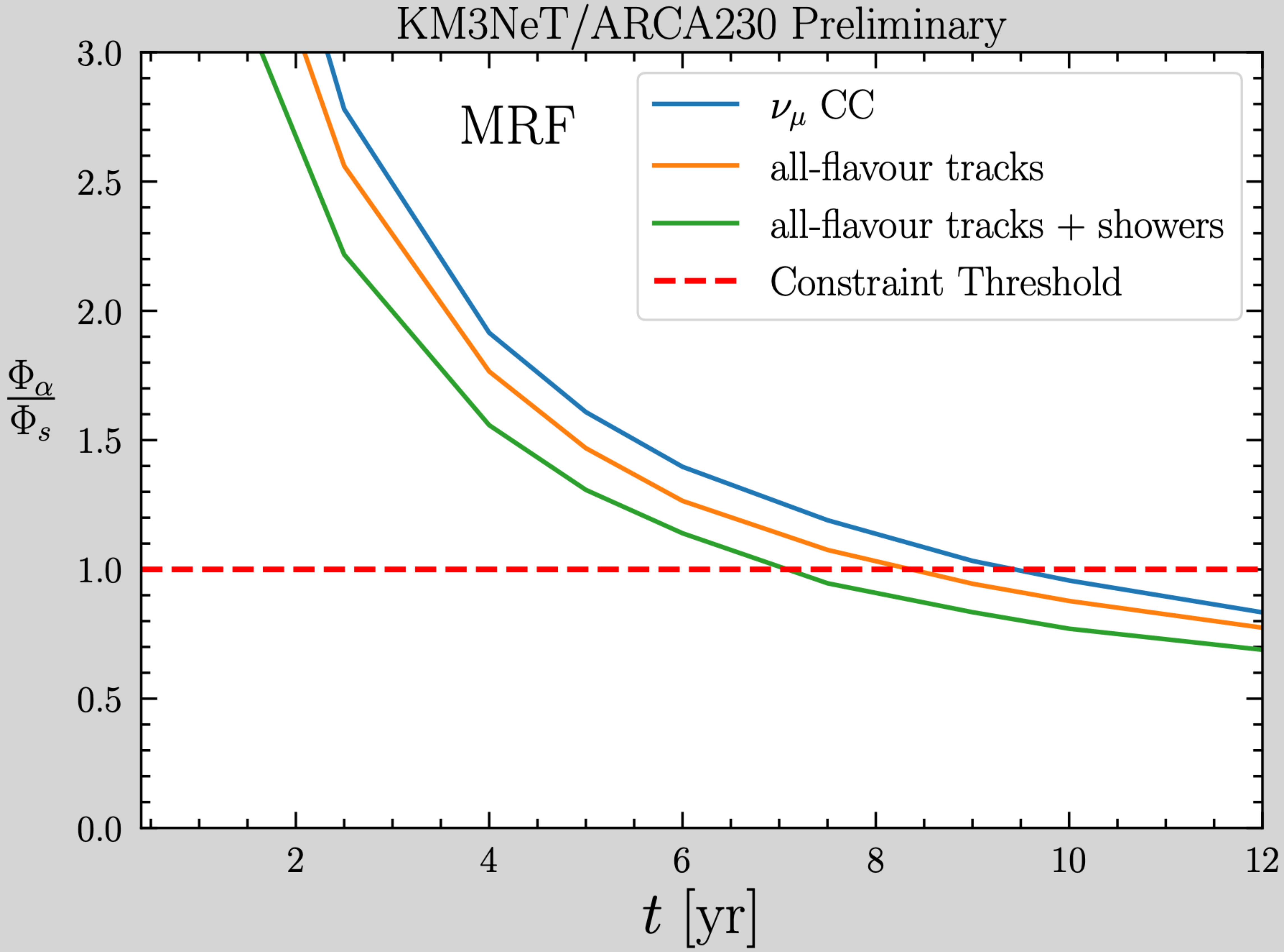
✦KM3NeT/ARCA Differential Limits set the capabilities of the detector independently on the energy spectrum

They provide the expected capabilities of KM3NeT/ARCA outside the energy of the ICeCube Flux

The Small Magellanic Cloud (SMC)

✦ The SMC is simulated as an extended source (disk with $r = 0.5°$) ~ $1°$ of extension

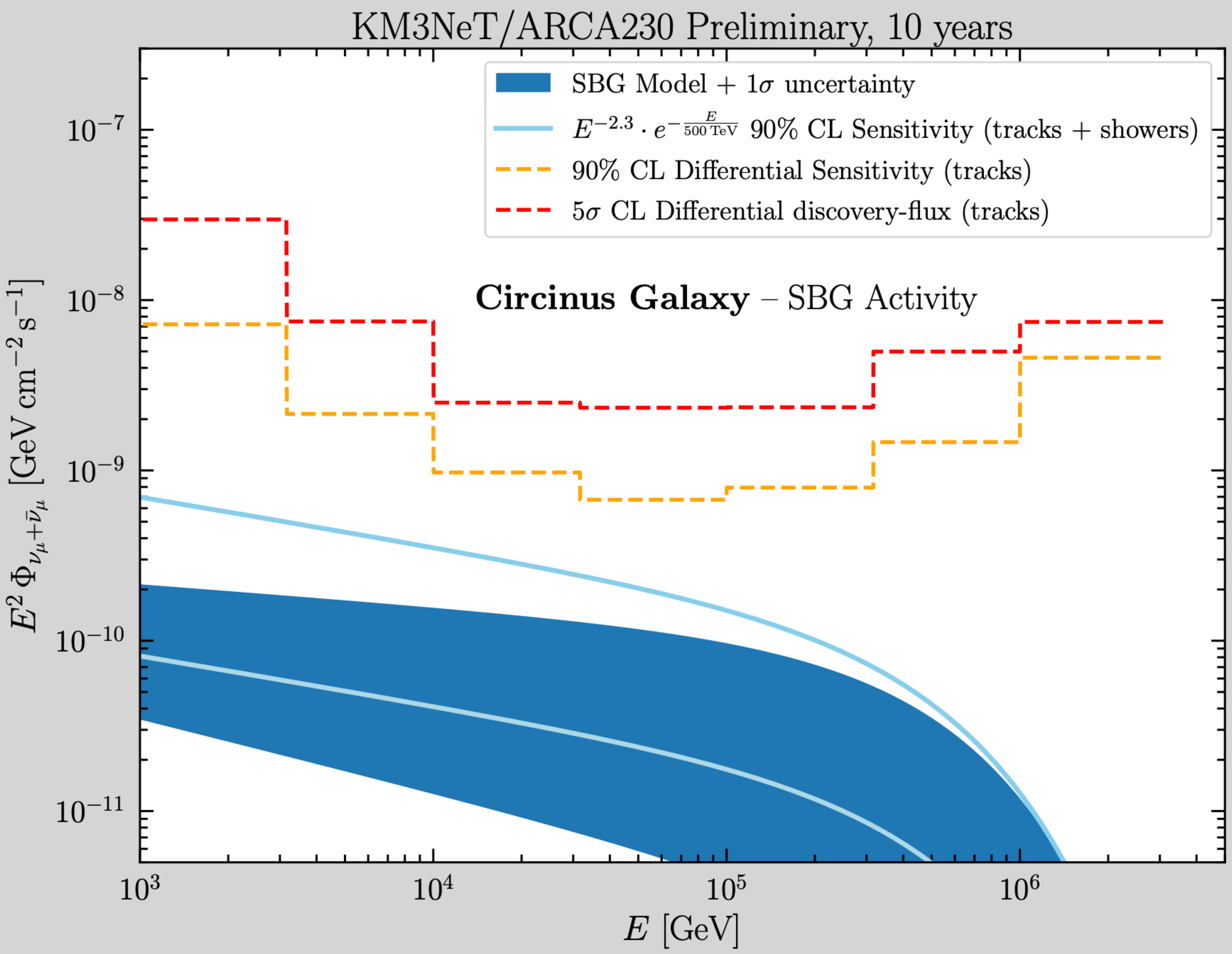


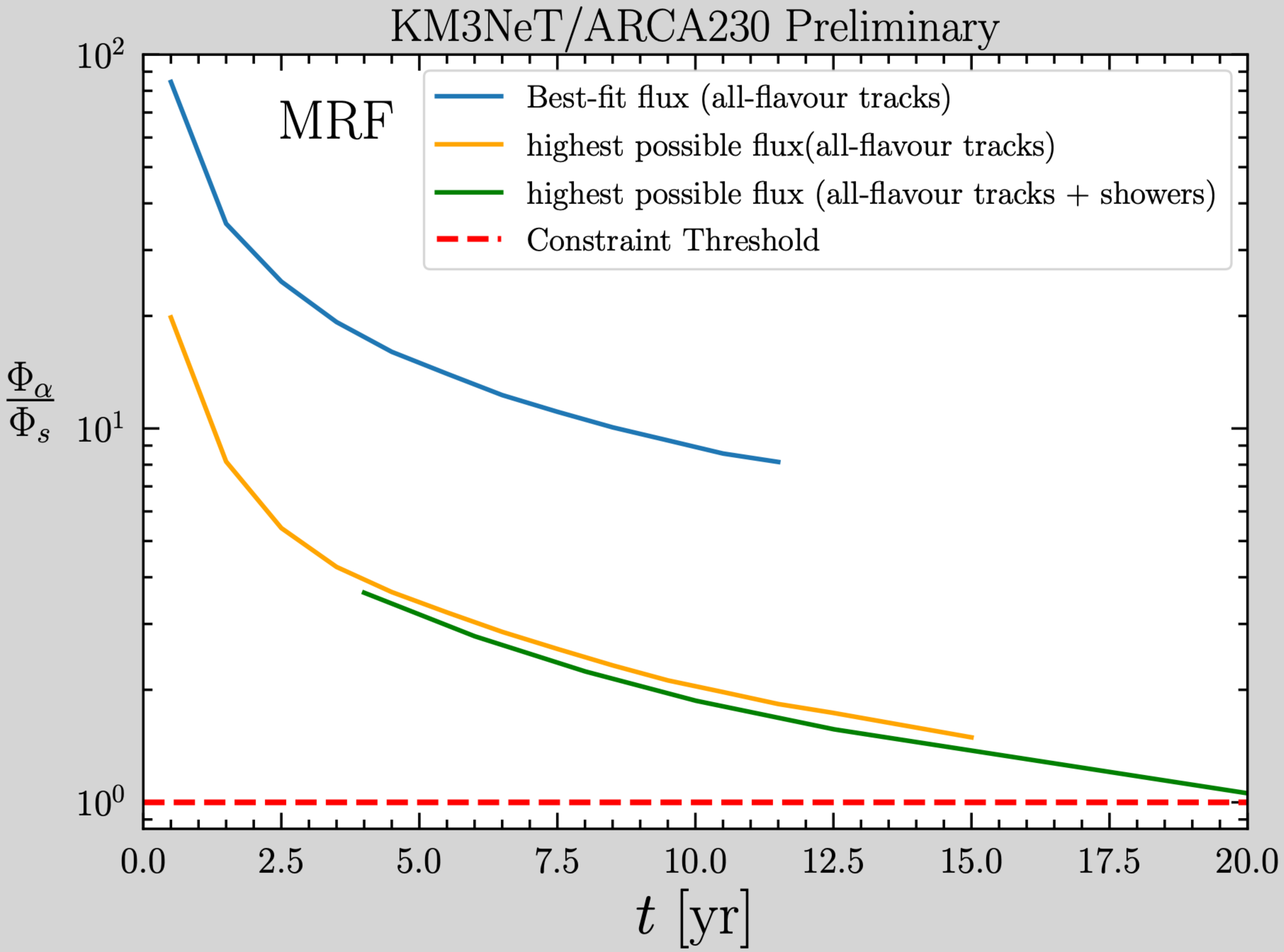


✦After ~ 8yr, the theoretical model can be constrained providing important information on the CR transport inside the source

✦The Differential Sensitivity peaks at ~ 100TeV

The Circinus Galaxy



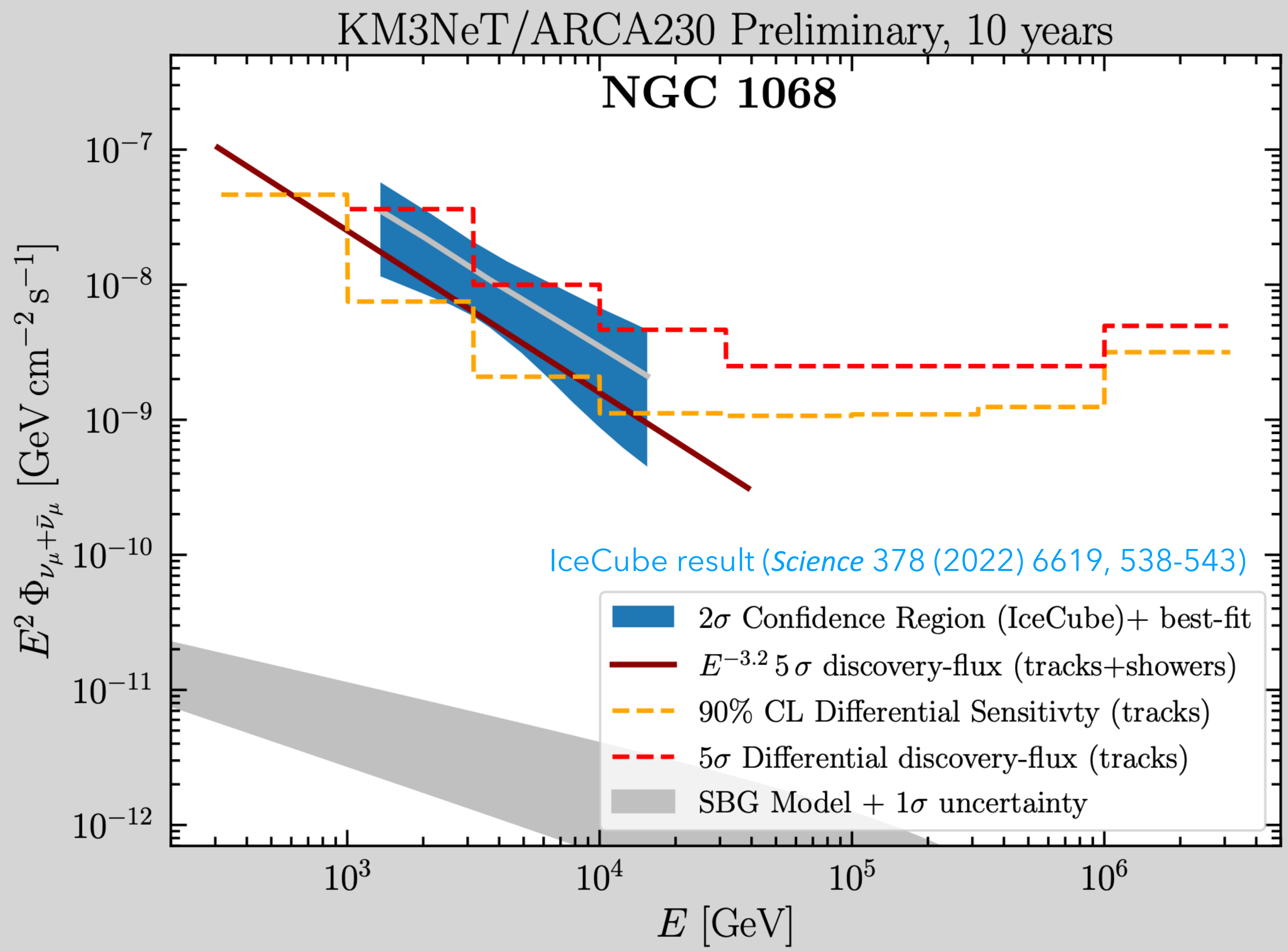


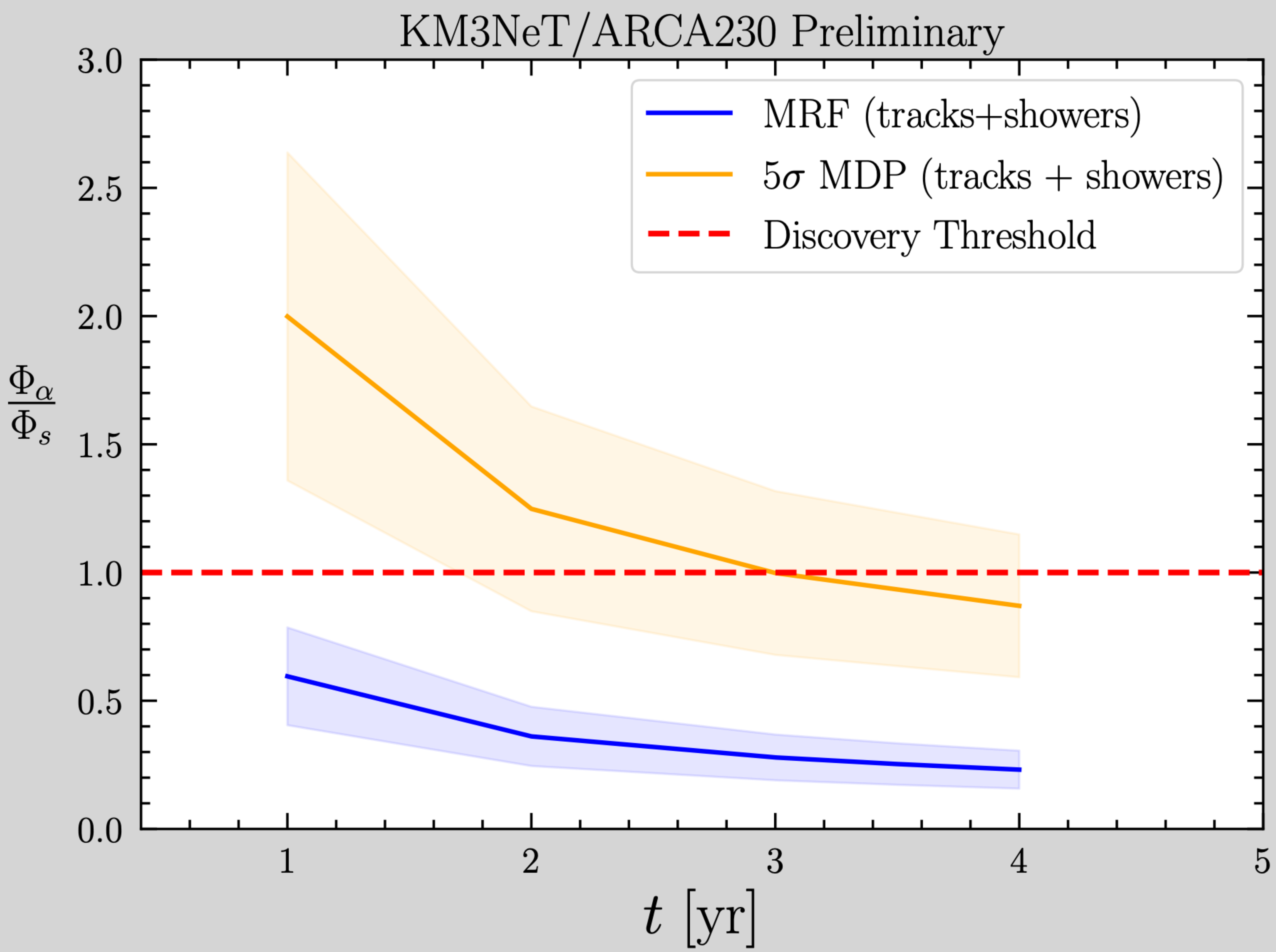
✦ Only the upper-limit of the expected neutrino flux from SBG activity can be probed after ~ 20yr of operation for the full KM3NeT/ARCA

✦The differential limits are able to constrain the AGN corona activity of this source

Important target for data analysis!

NGC 1068





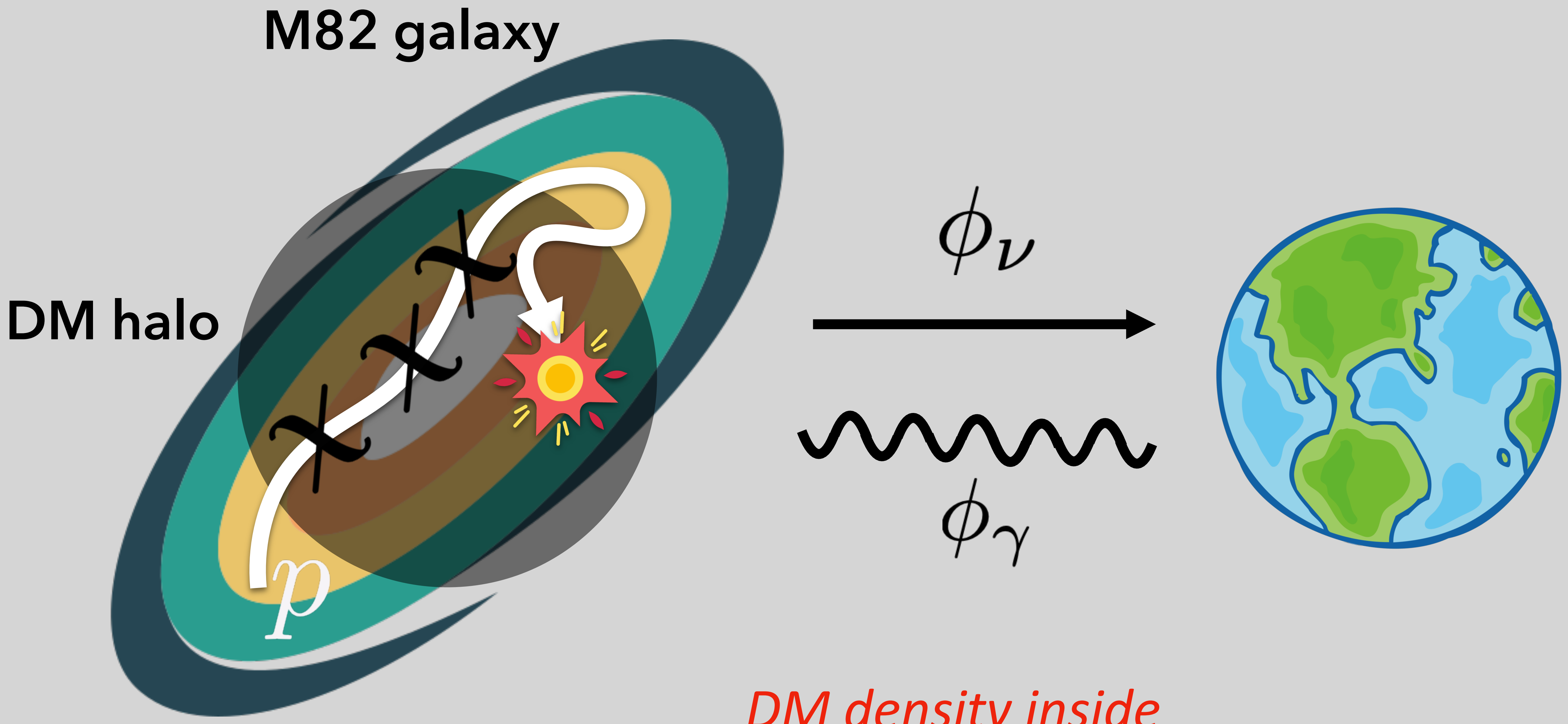
- ✦ KM3NeT/ARCA, after 3yr of data taking, will be able to discover at 5σ a $E^{-3.2}$ spectrum with the normalization IC has measured

- ✦ SBG Activity cannot explain NGC 1068 Neutrino Emission → It is difficult to probe the SBG activity of this source through neutrino observations

Can we probe Dark Matter Properties using local /nearby SBGs?

SBGs: Dark Matter Laboratories

We cannot directly probe the CR spectrum inside the SBGs…but we observe γ-rays (and possibly ν)!



Modification of CR transport

$$f_{\rm CR}(p) = \left(\frac{1}{\tau_{\rm adv}} + \frac{1}{\tau_{\rm diff}} + \frac{1}{\tau_{\rm loss}} + \frac{1}{\tau_{\rm loss}^{\chi p}}\right)^{-1} Q_{\rm CR}(p)$$

Additional energy-loss timescale

DM density inside the SBG

CR-DM energy loss

$$\left(\frac{{\rm d}E}{{\rm d}t}\right)_{\chi p} = \frac{\rho_\chi}{m_\chi} \int_0^{T_\chi^{\rm max}} {\rm d}T_\chi \, T_\chi \frac{{\rm d}\sigma}{{\rm d}T_\chi}$$

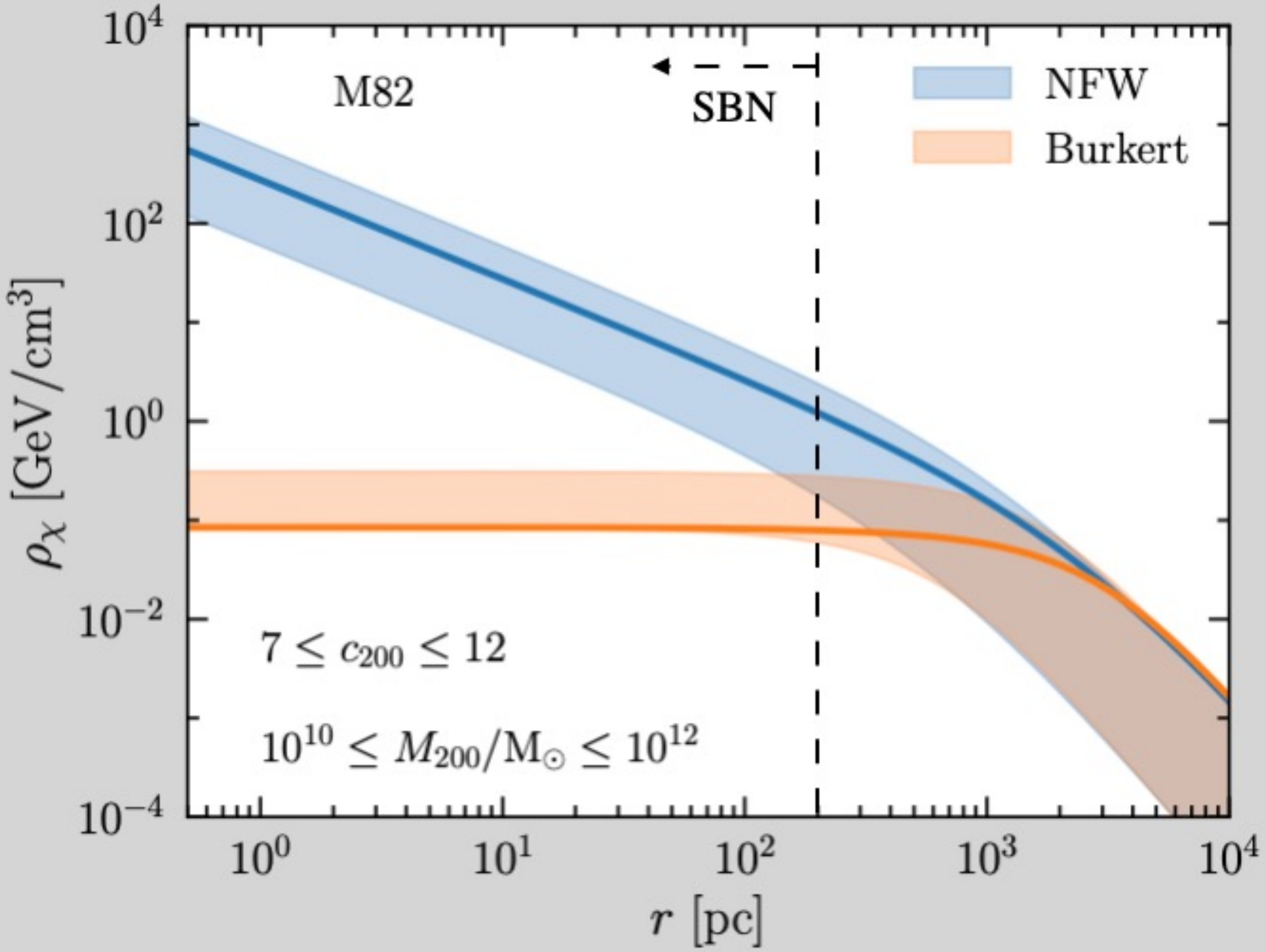
Elastic cross-section valid for transfer momenta:

$$q^2 = 2 m_\chi T_\chi \lesssim 1\,{\rm GeV}^2$$

Suppression from proton form factor

$$F_p(q^2) = \left(\frac{1}{1 + q^2/(0.77\ {\rm GeV})^2}\right)$$

Dark Matter Density



- ✦ Parameters from cosmological simulations

$$c_{200} = r_{200}/r_s \qquad M_{200} = \int_0^{r_{200}} \rho_\chi(r)\,\mathrm{d}V$$

concentration *total mass*

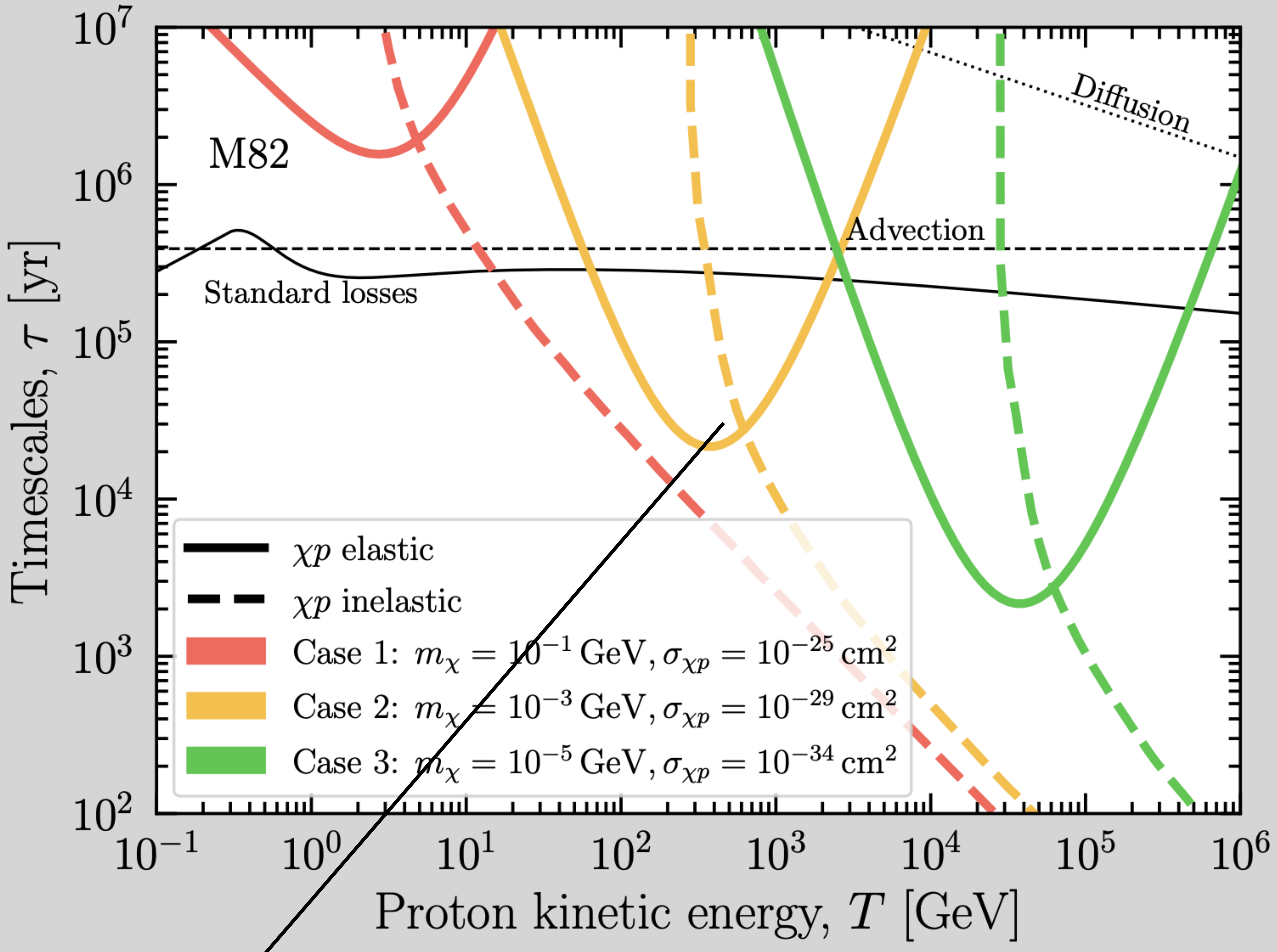
- ✦ Large uncertainty on the DM density inside the StarBurst Nucleus (SBN)

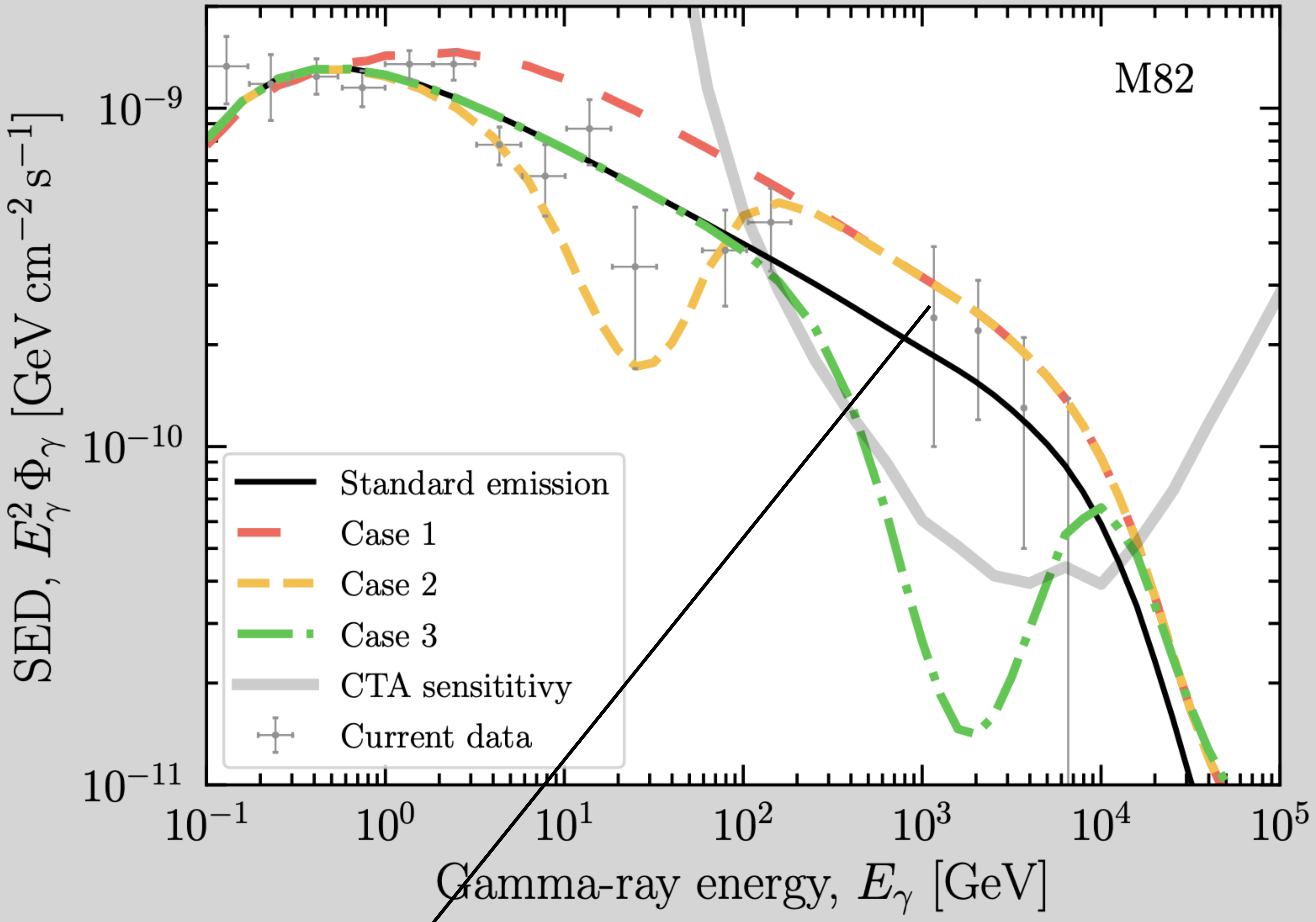
- ✦ However, it marginally affects the γ-ray emission

$$\Phi_\gamma \propto \int \frac{Q_p(p,r)\,\tau_{\rm loss}^{\chi p}(r)}{V}\,\mathrm{d}V \propto \int \frac{\rho_\chi^{-1}(r)}{V}\,\mathrm{d}V$$

Average inside the SBN

Signatures of CR-DM Interactions Scatterings





Suppression due to proton form factor

$$E^p_{\rm dip} = m_p^2/(2m_\chi) \qquad E^\gamma_{\rm dip} \simeq 0.1\, E^p_{\rm dip}$$

For DM-p inelastic collisions, we have rescaled the neutrino-nucleon cross section.

When, inelastic DM-p collisions dominate, SBGs have a higher calorimetric fraction than before!

Dip in the γ-ray SED

The smaller the DM mass, the higher the dip energy

DM Constraints from SBGs

- ✦ "Standard" constraints in shaded grey

- ✦ Distortions of Milky-Way Cosmic-Rays (5σ)

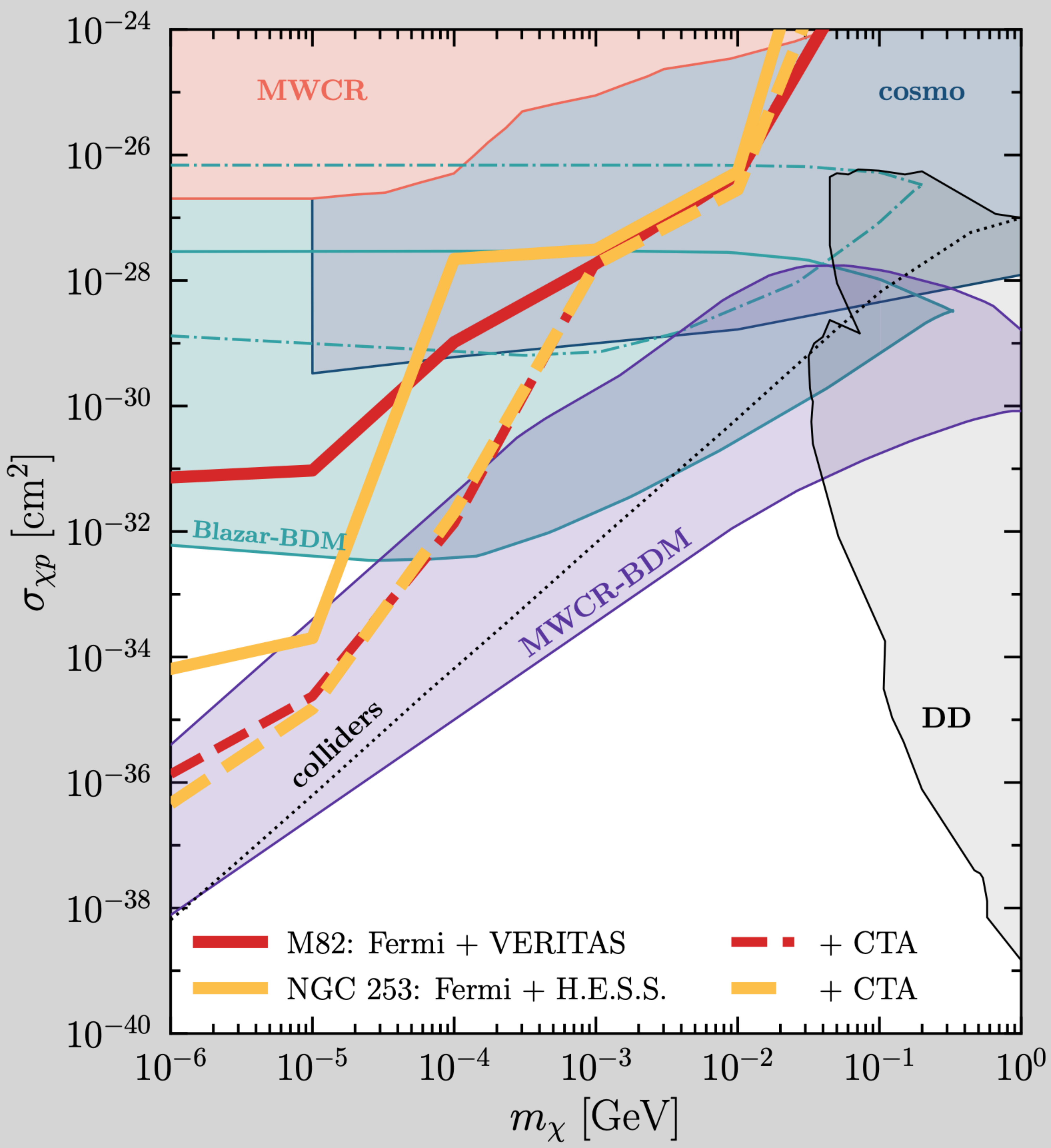
  Cappiello, Ng, Beacom, ***PRD 99 (2019)***

- ✦ Boosted DM from blazar jets (90% CL):
  - ✦ **(1) MiniBooNE** and **(2) XENON1T**
  - ✦ Requiring DM spikes (high density) around the black holes → large uncertainties!

Wang+ ***PRL 128 (2022)***, Granelli+ *J****CAP 07 (2022)***

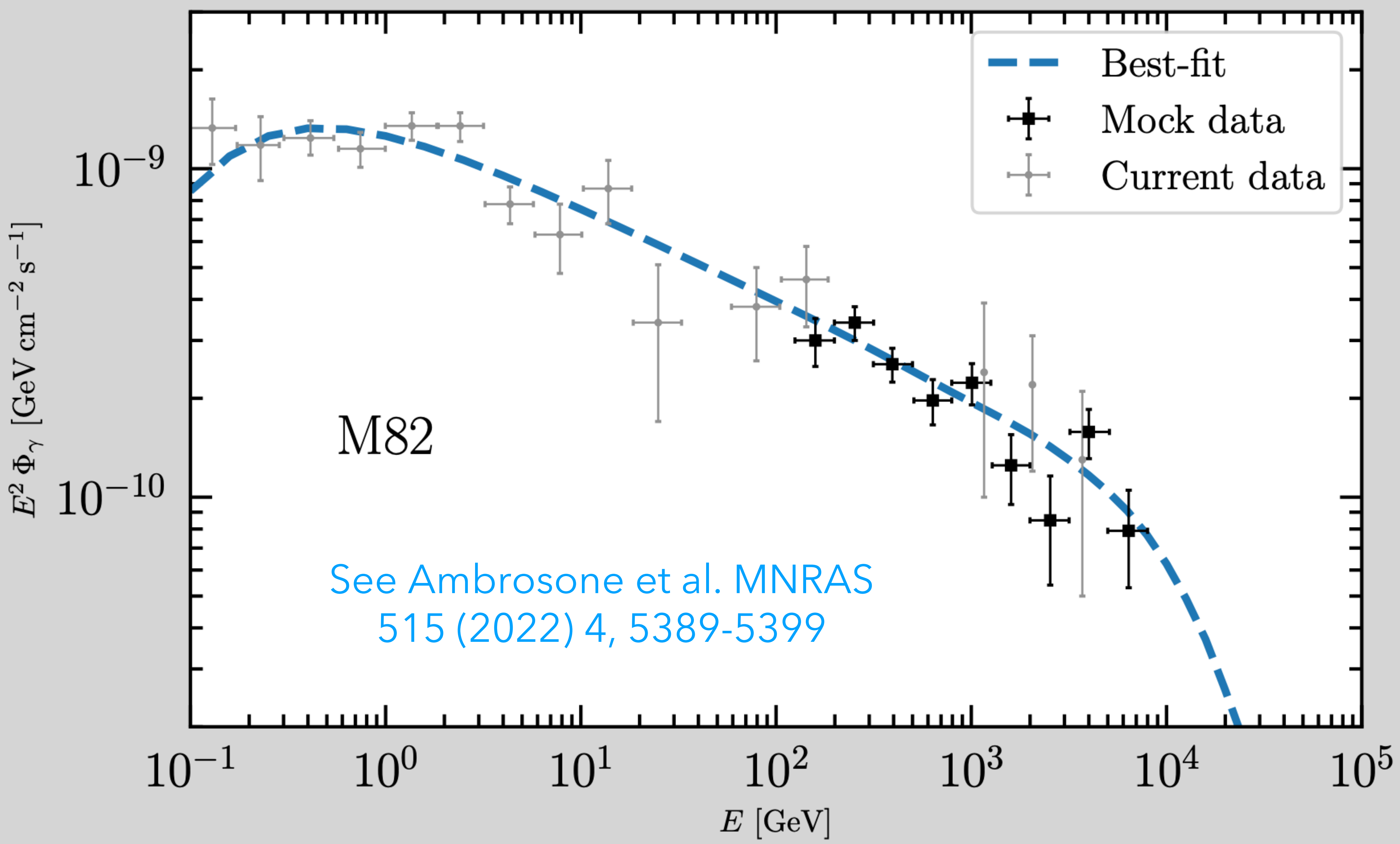
OUR CONSTRAINTS FROM SBG (5σ)

- ✦ **M82** and **NGC253**



The Importance of new Measurements

✦**The higher the energy of the data, the lower the DM masses can be probed**



See Ambrosone et al. MNRAS 515 (2022) 4, 5389-5399

- ✦ The CTA Telescope will probe SBG emission above $\gtrsim 100\mathrm{GeV}$ up to $\sim 10\mathrm{TeV}$
- ✦Public Information of the telescope can be used to simulate possible future measurements **(Mock data)**

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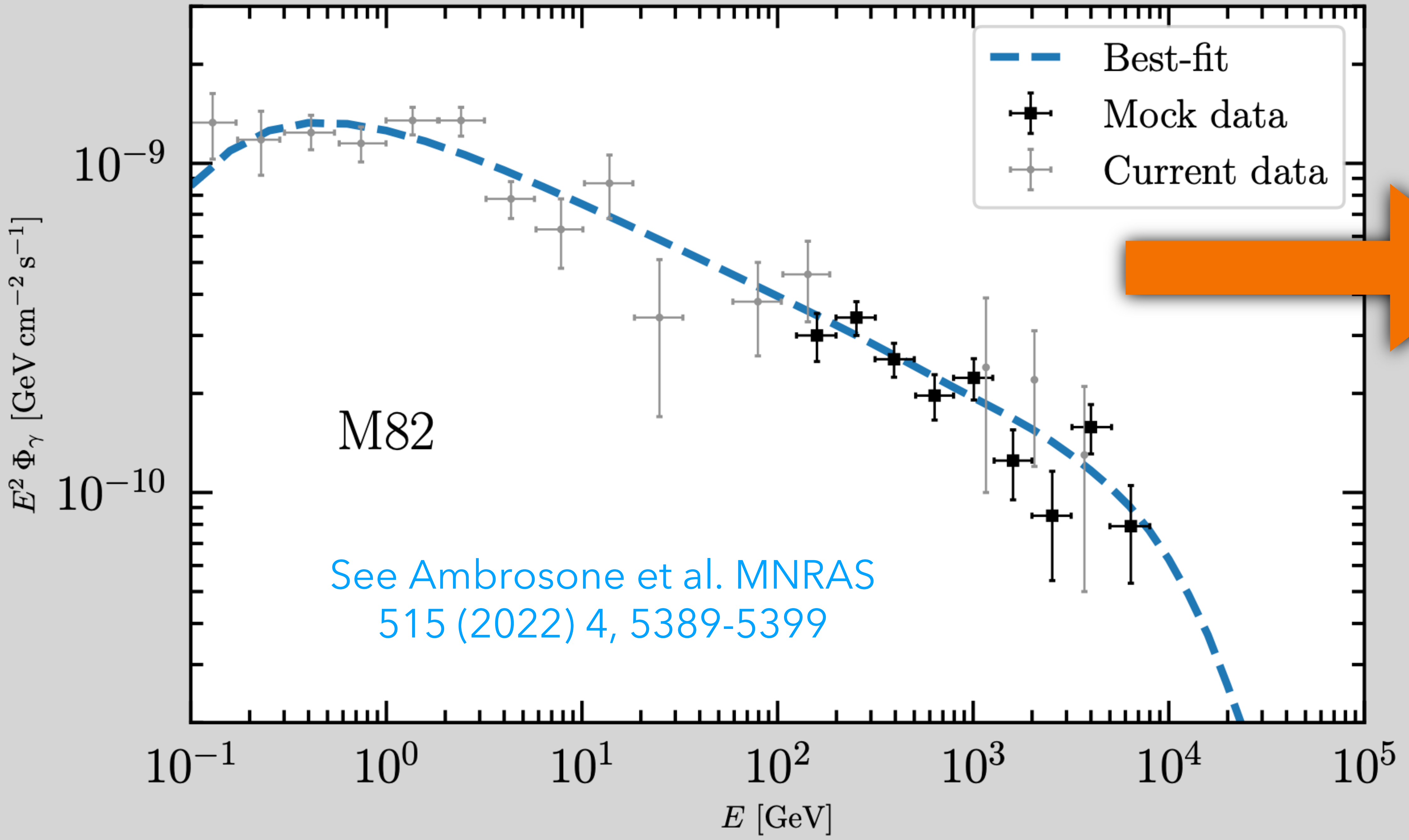

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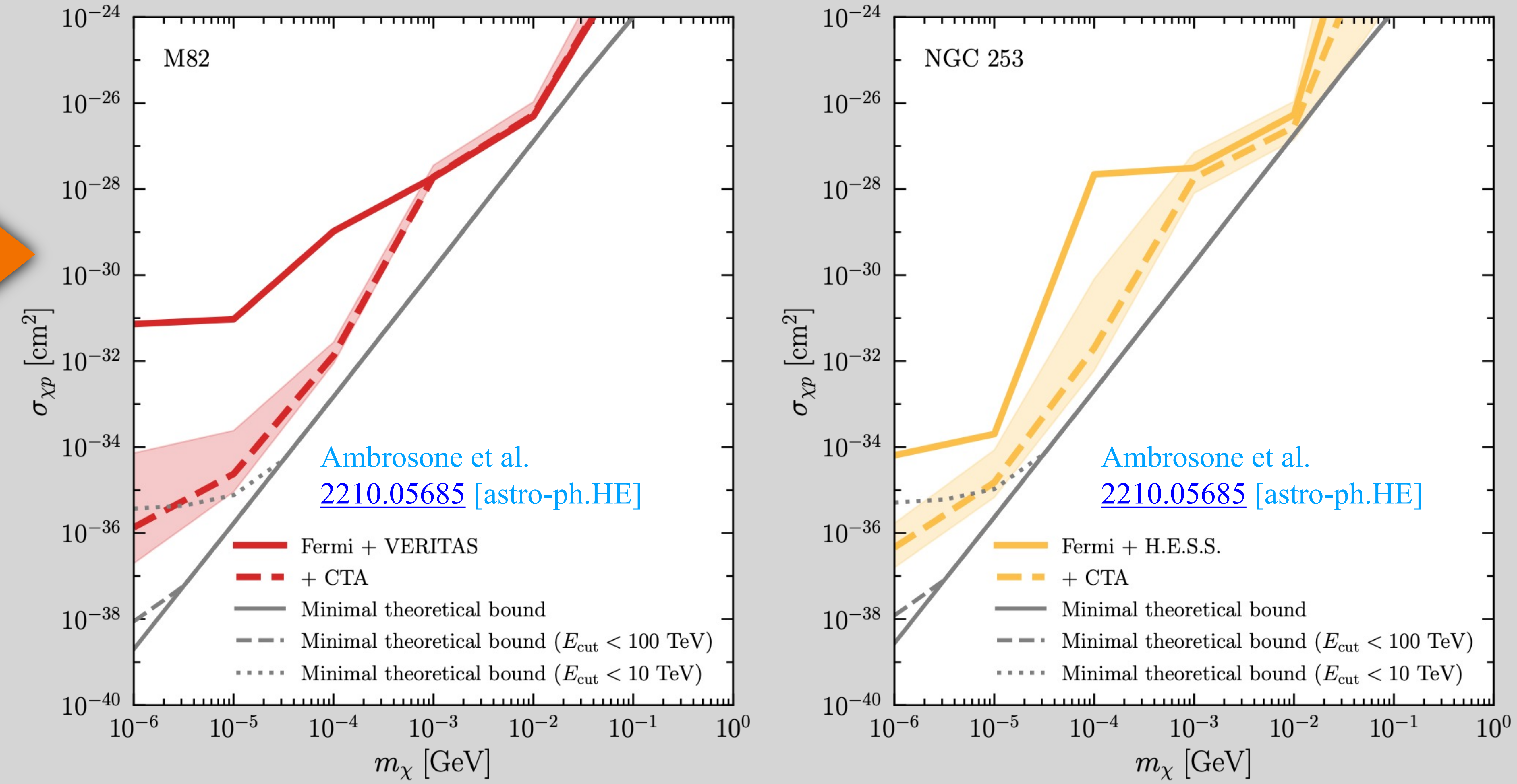

Ambrosone et al.
2210.05685 [astro-ph.HE]

Ambrosone et al.
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✦Public Information of the telescope can be used to simulate possible future measurements **(Mock data)**

✦ The same statistical Analysis with 50 mock datasets

✦The resulting band represents the expected fluctuation of the possible new datasets

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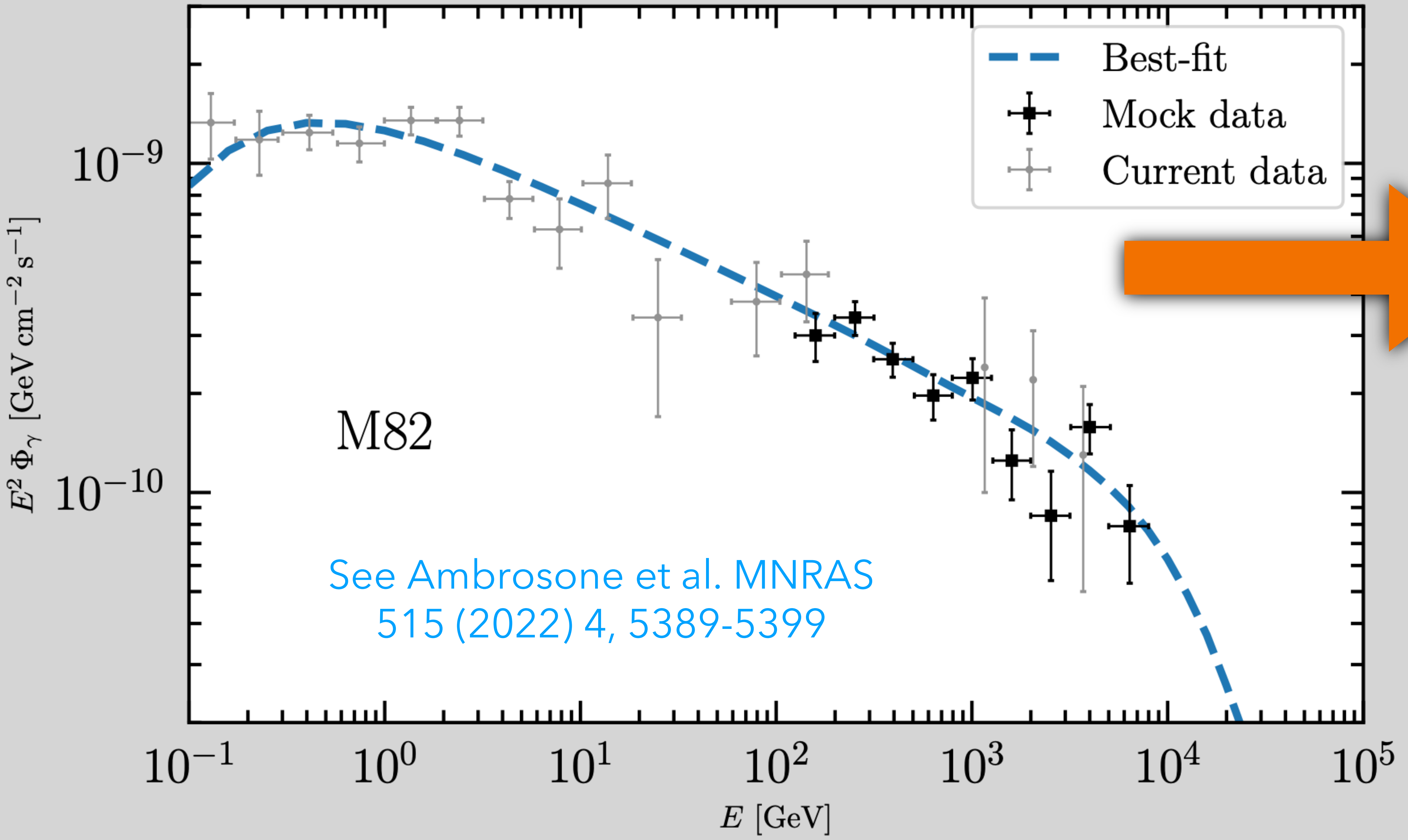

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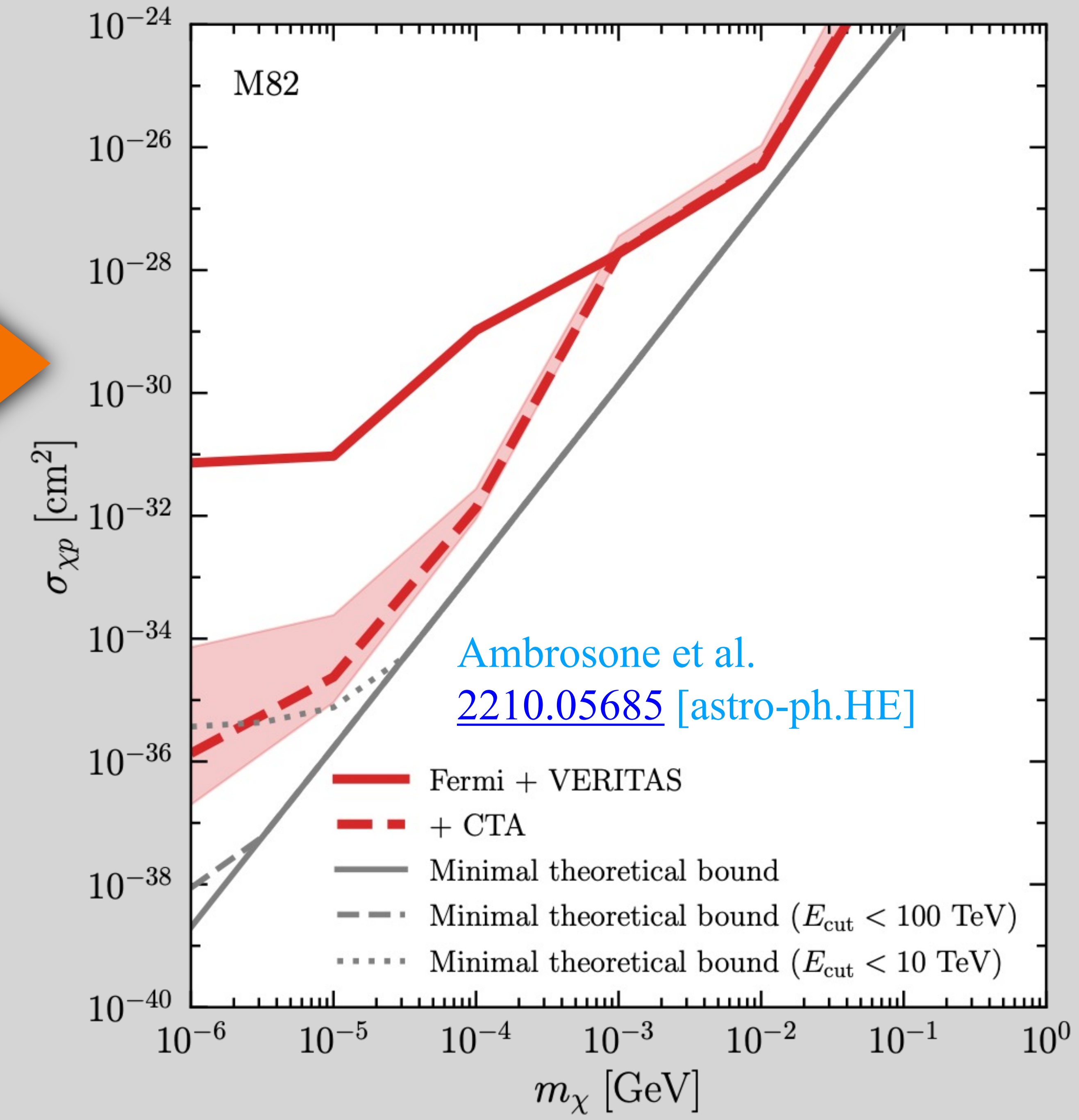
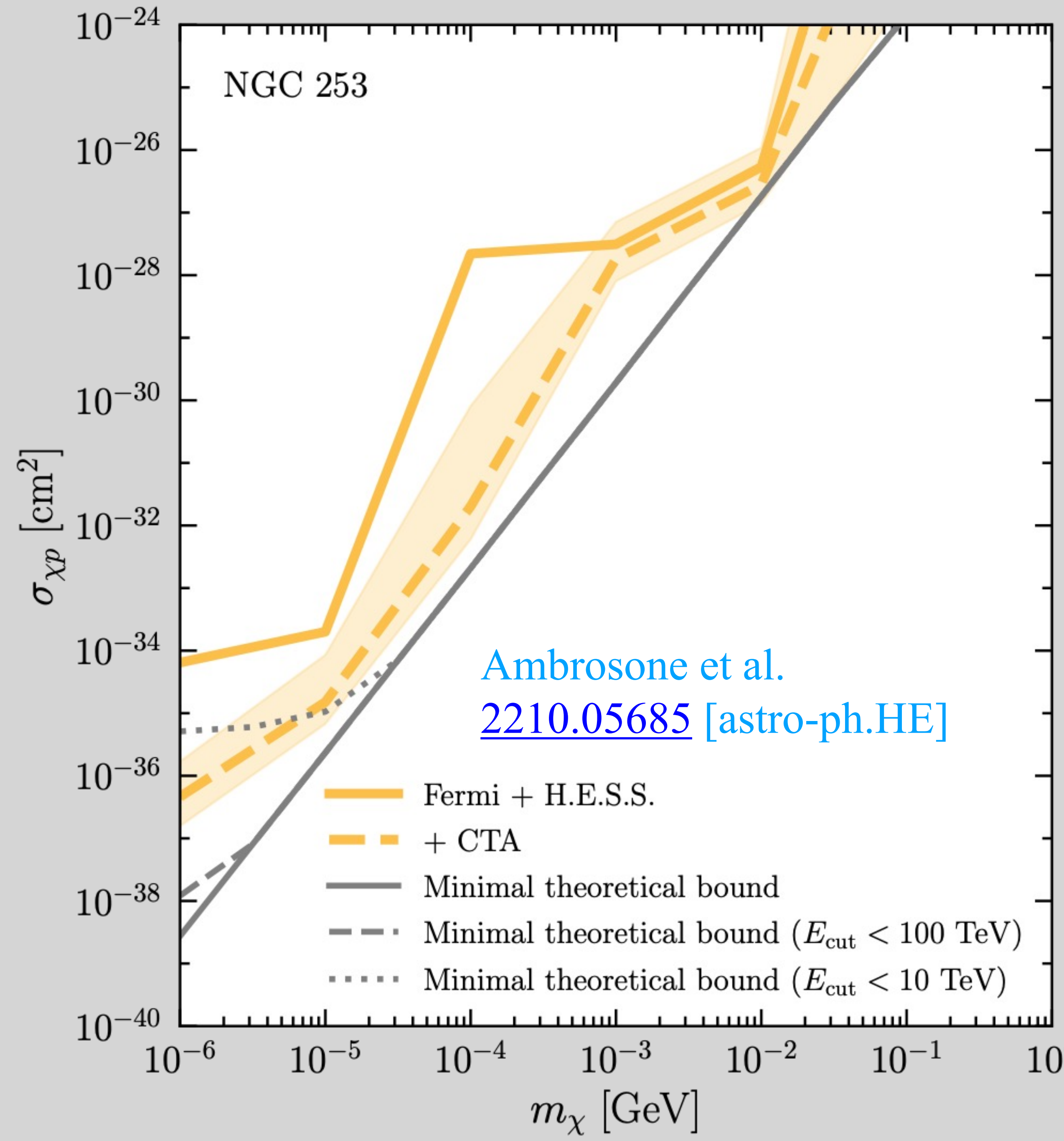


Ambrosone et al. 2210.05685 [astro-ph.HE]



Ambrosone et al. 2210.05685 [astro-ph.HE]

✦ The CTA Telescope will probe SBG emission above $\gtrsim 100\text{GeV}$ up to $\sim 10\text{TeV}$

✦Public Information of the telescope can be used to simulate possible future measurements **(Mock data)**

✦Theoretical bounds mimic the maximal energy which experiments can probe

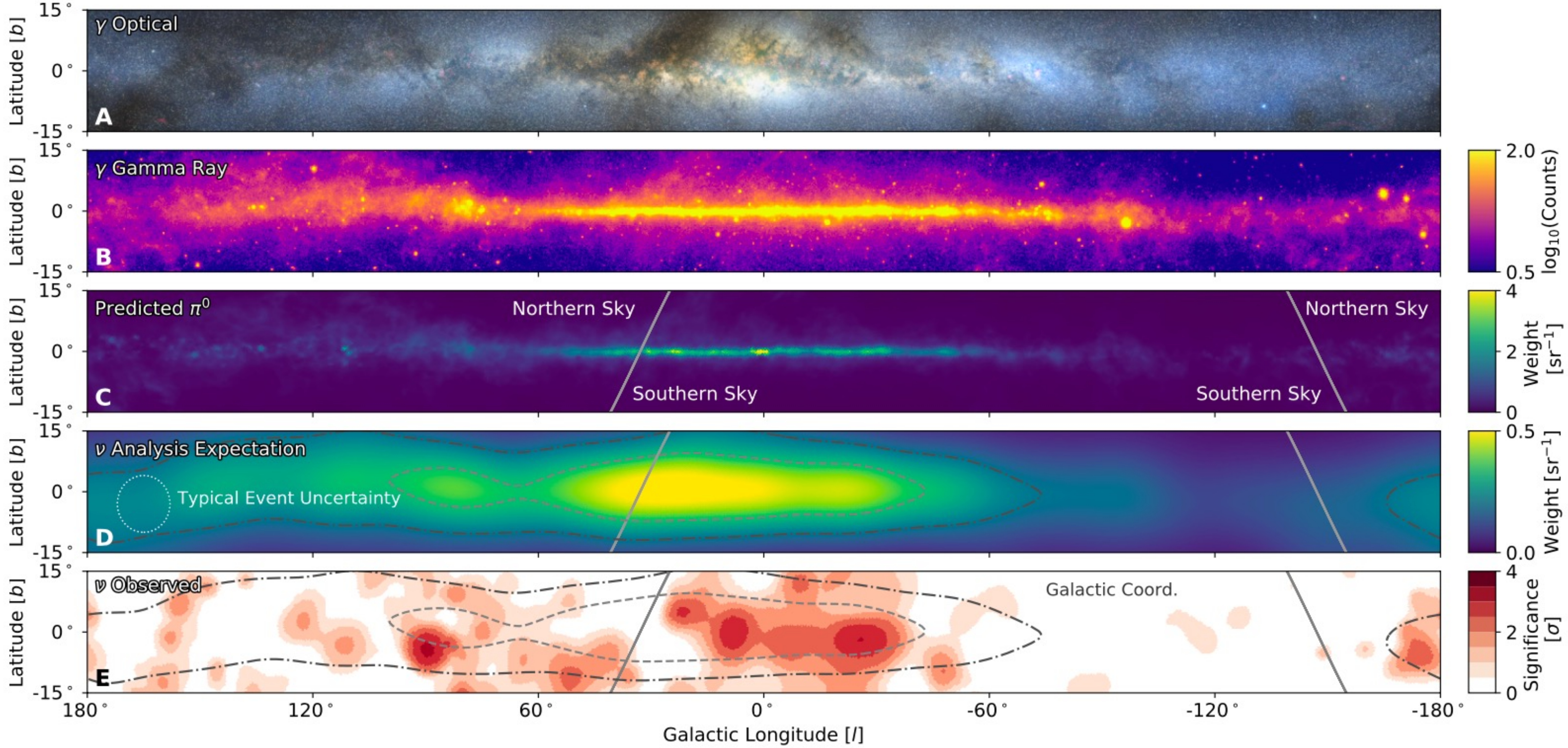
The theoretical bounds are obtained through:

$$\min_{E<E_{cut}}\left[\tau_{\chi p}^{\text{el,eff}}\left(\frac{1}{\tau_{\text{esc}}}+\frac{1}{\tau_{\text{loss}}^{\text{eff}}}\right)\right]=1$$

The Multi-Messenger Picture for the Milky Way

Which processes do account for the neutrino emissions?

Science 380 (2023) 6652, adc9818, *Science* 380 6652

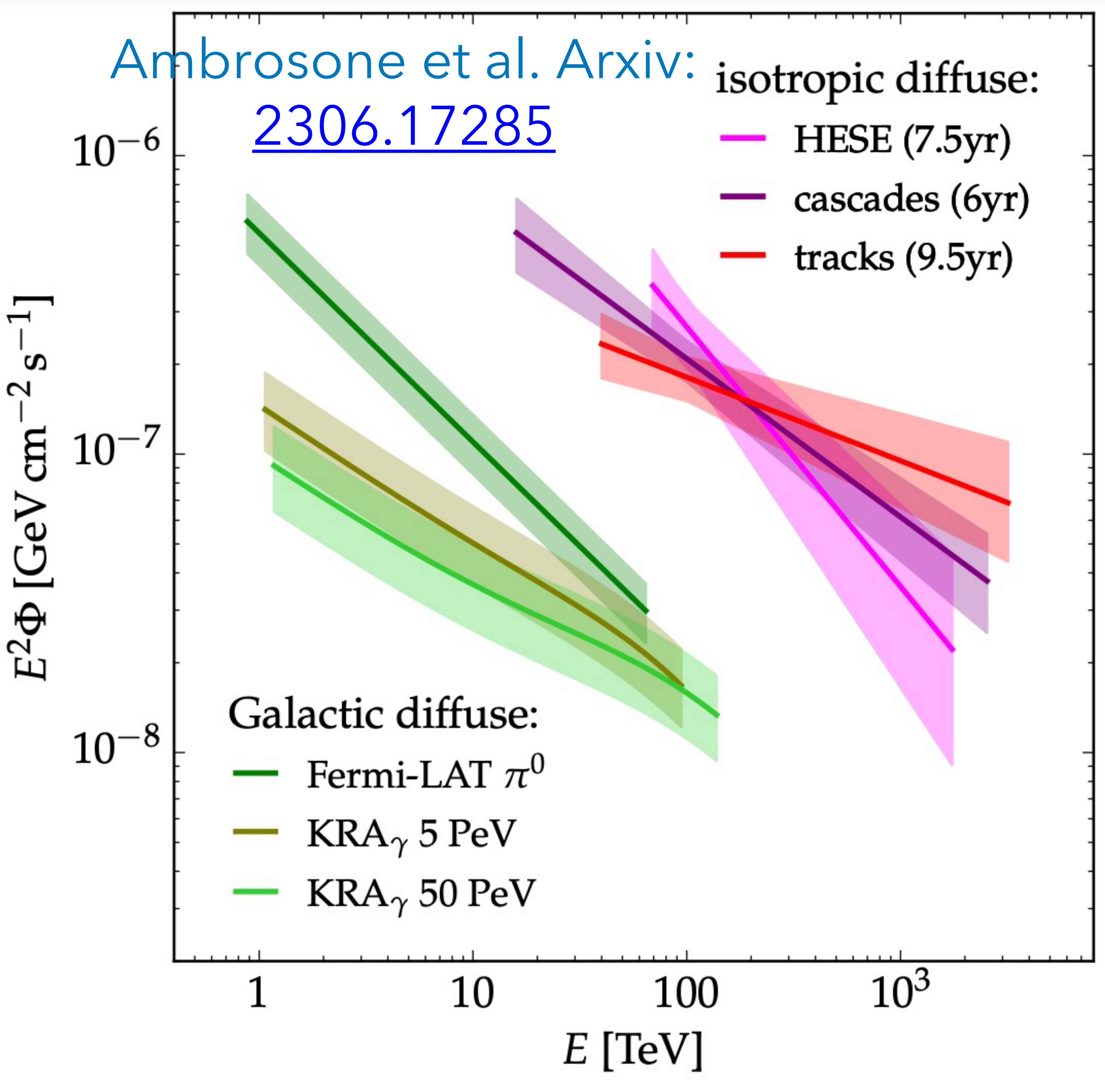


- ✦ For the first time, the multi-messenger picture of the Milky Way comprises high-energy neutrinos.

What did ICeCube really Observed?

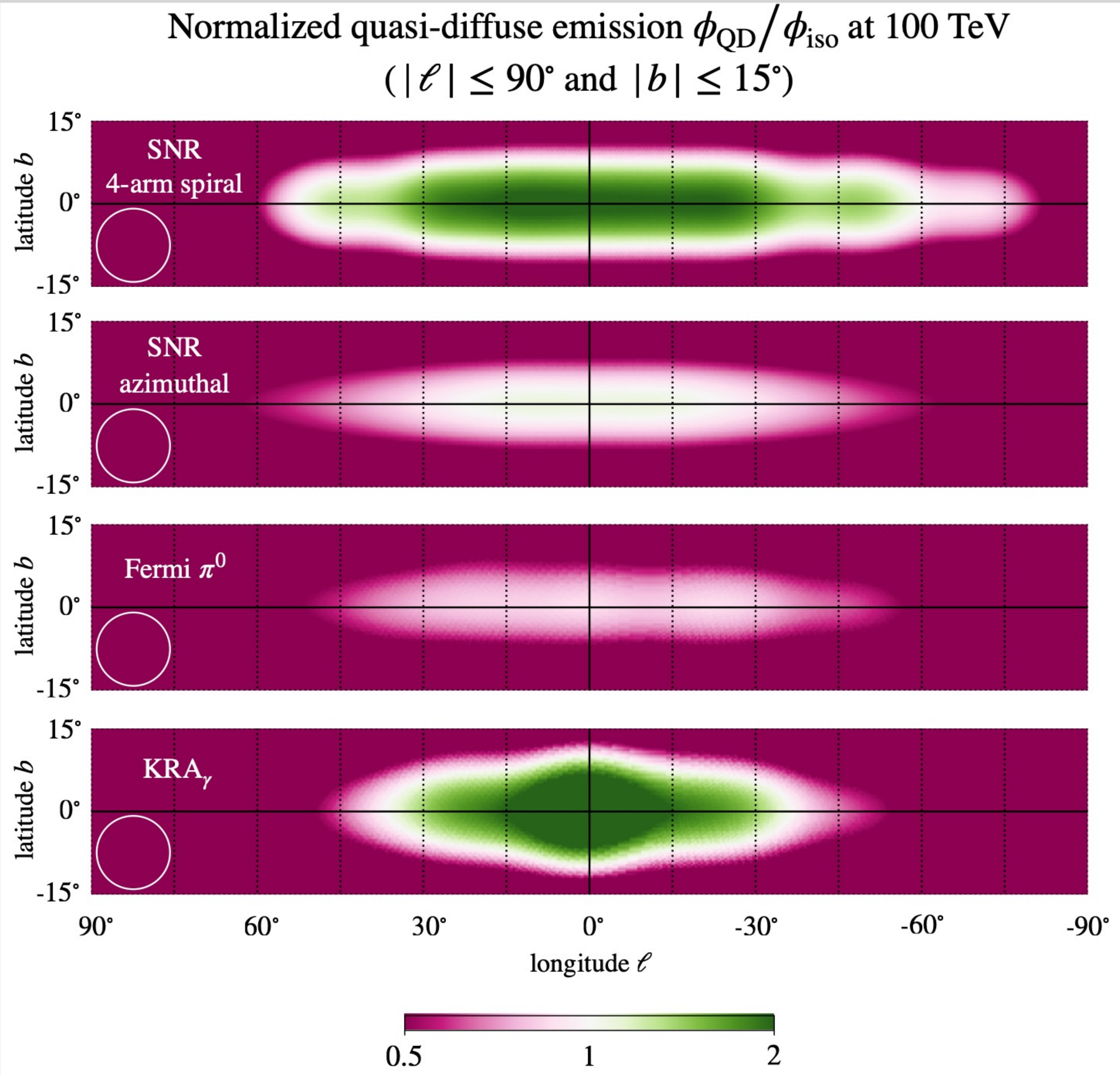
✦The IceCube Collaboration has tested different templates

Ambrosone et al. Arxiv: 2306.17285



Are galactic neutrinos totally due to diffuse emission?

Ambrosone et al. Arxiv: 2306.17285



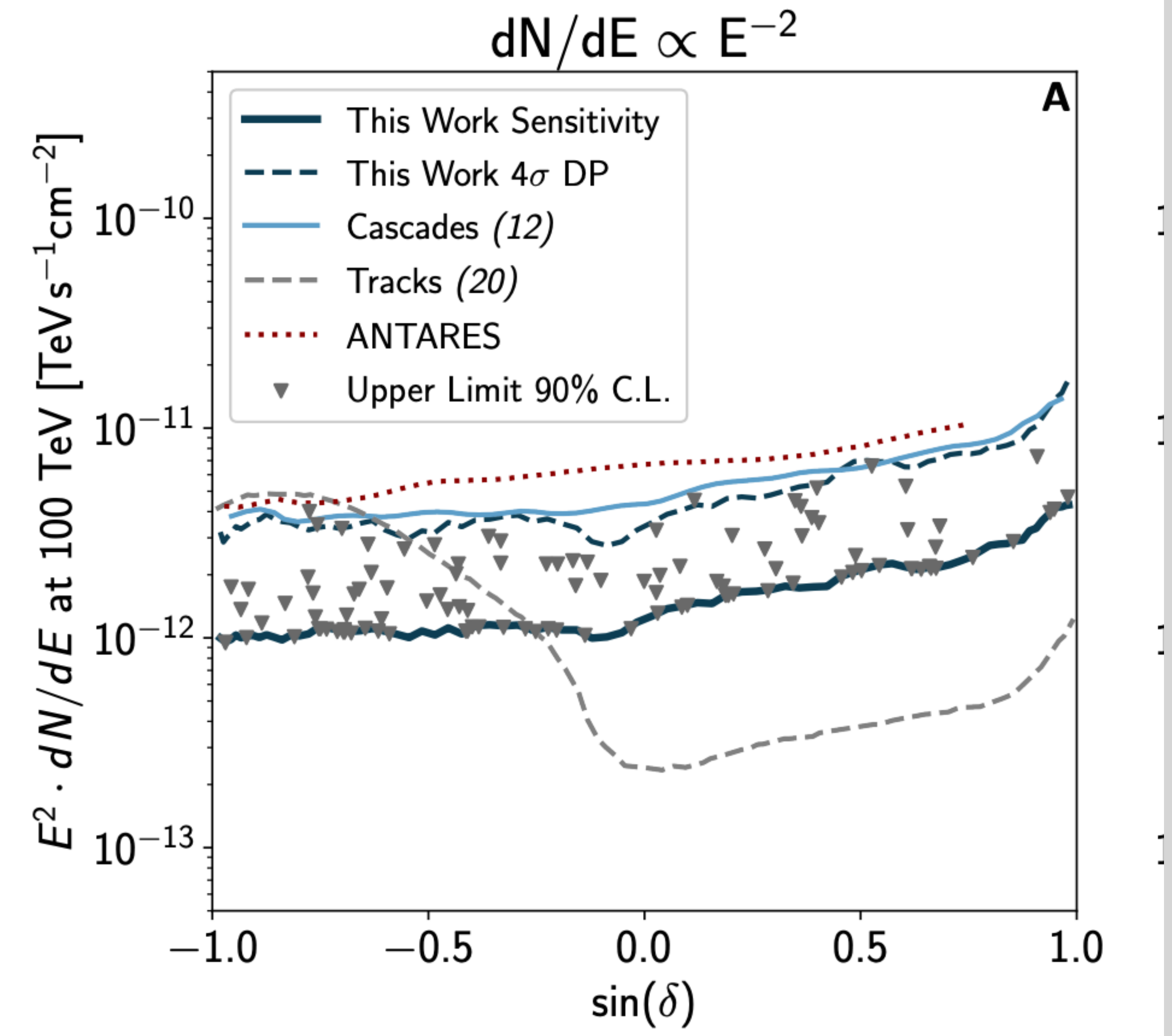
✦The result is model-dependent

✦At $\sim 100\mathrm{TeV}$, the results seem converging to $E^2\Phi_{\nu+\bar{\nu}} \simeq 2{\times}10^{-8}\mathrm{GeVcm^{-2}s^{-1}}$

IceCube's limited power to disentangle angular distribution of the signal, leave room for unresolved sources to contribute

Discovery Horizon for Galactic Sources

IceCube's Point-like Sensitivity/Discovery Potential

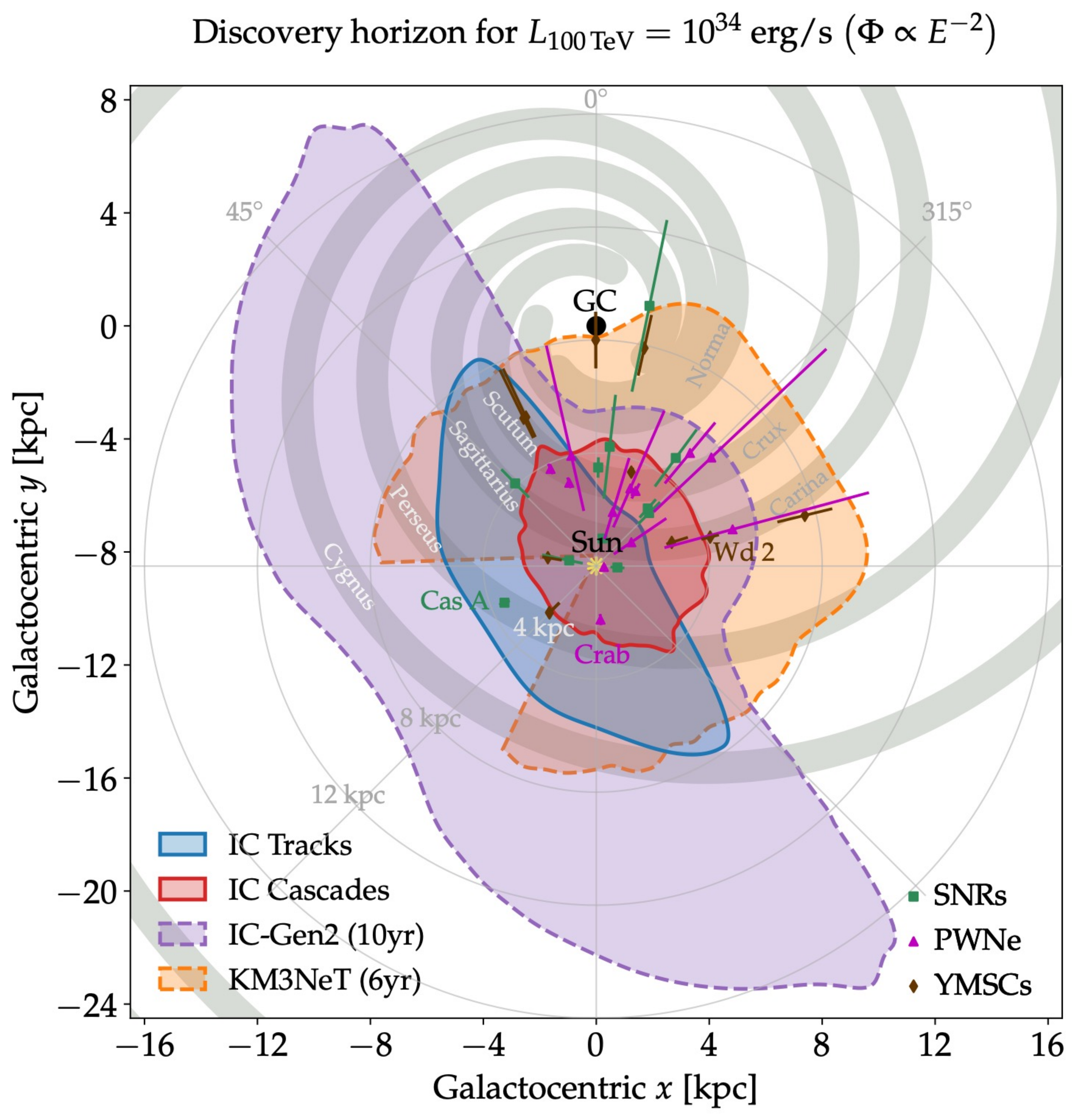


IceCube Collaboration, *Science* 380 6652 (supplementary material)

The sensitivity implies an horizon inside our Galaxy

$$D_{\max}(\delta) \equiv \sqrt{\frac{L_{100\,\mathrm{TeV}}}{4\pi[E_\nu^2\Phi_{\mathrm{DP}}(E_\nu,\delta)]_{E_\nu=100\,\mathrm{TeV}}}}$$

Ambrosone et al. Arxiv: 2306.17285

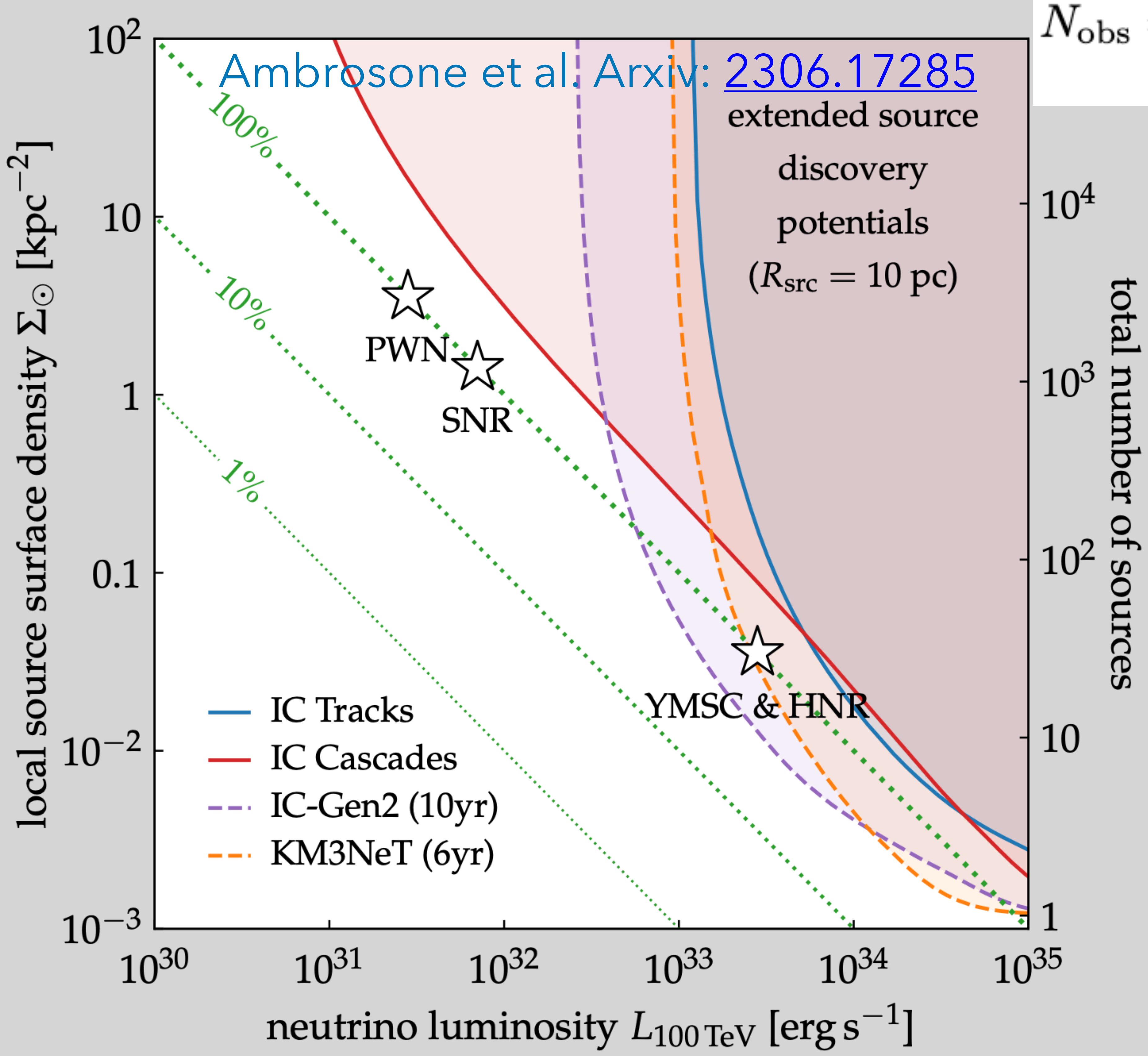


- ✦ Different Neutrino telescopes provide complementary view of the sky

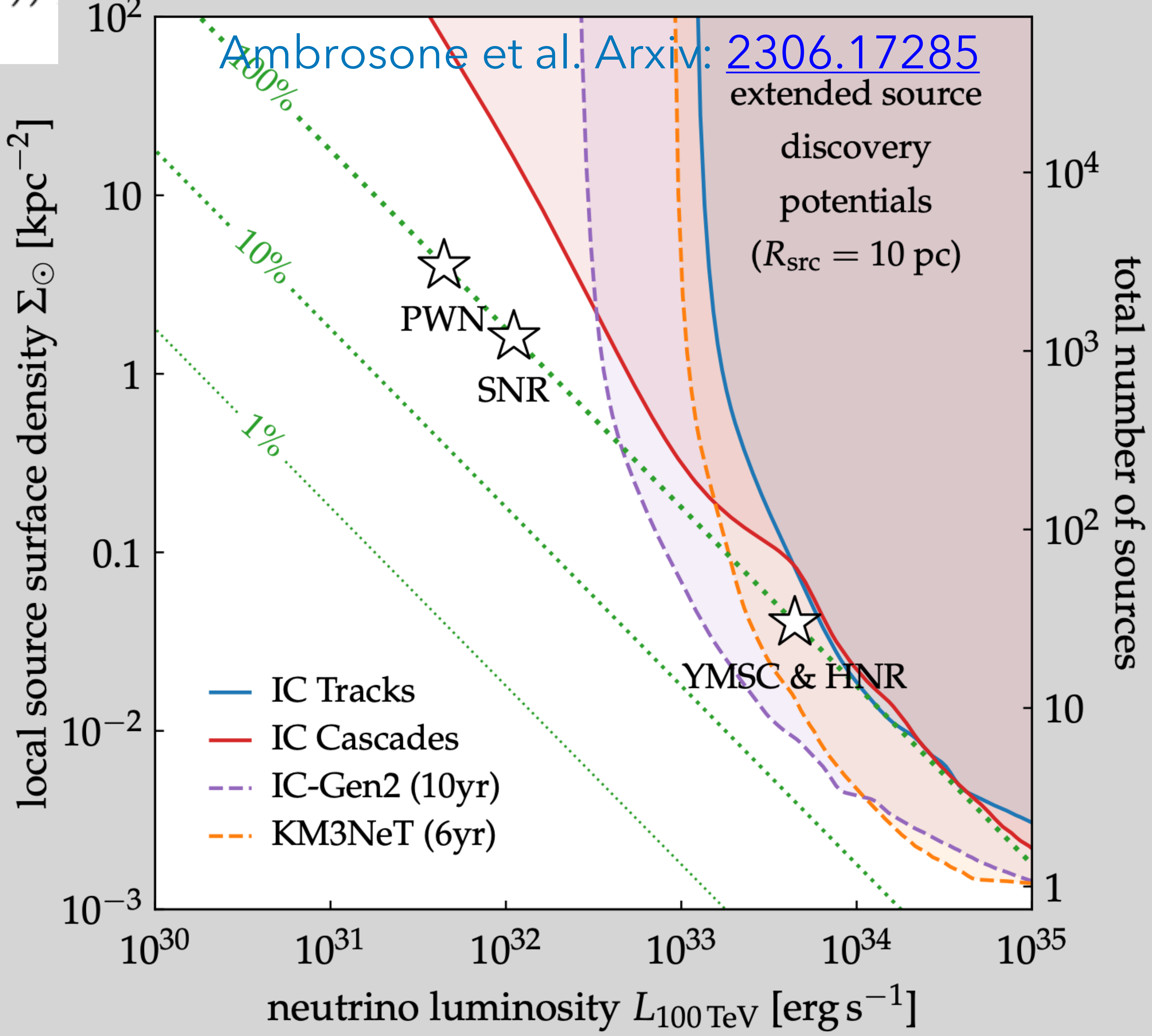
Limits on Galactic Source Population

No galactic source has been detected, so this implies limits on a population of galactic sources

$$N_{\rm obs} = \int d\Omega \int_{R_{\rm src}}^{D_{\rm max}(\delta)} dD D^2 \rho(\mathbf{r}_\odot + D\mathbf{n}(\Omega))$$



$$N_{\rm obs} \lesssim 1$$



- ✦At the moment, IceCube is not sensitivity enough to exclude a 100% contribution from point-source and extended sources
- ✦Future telescopes such as KM3NeT and ICeCube Gen 2 can probe powerful bevatrons such as Hypernovae

Conclusions

SBGs Non-thermal Emissions

- ✦ We have introduced a new evidence-based spectral index blending to quantify the diffuse SBG gamma-ray and neutrino emissions
- ✦ Some Nearby SBGs can produce a point-like excess within few years of data taking of the upcoming KM3NeT Telescope
- ✦Upcoming gamma-ray telescopes will give us a better understanding of the cosmic-ray transport inside SBGs.

KM3NeT

- ✦We have calculated, for the first time, the differential sensitivity for the KM3NeT/ARCA detector
- ✦ KM3NeT/ARCA full detector will strongly constrain the properties of the diffuse neutrino spectrum in few years of data taking
- ✦In a few years of data taking, ARCA will be able to test the potential hadronic emission coming from SMC

Galactic Neutrino Emission

- ✦At the moment, the galactic neutrinos might be powered by point sources at $\mathrm{E}_\nu \simeq 100\mathrm{TeV}$
- ✦Future neutrino telescopes are going to probe powerful bevatrons such as YMSCs and HNR

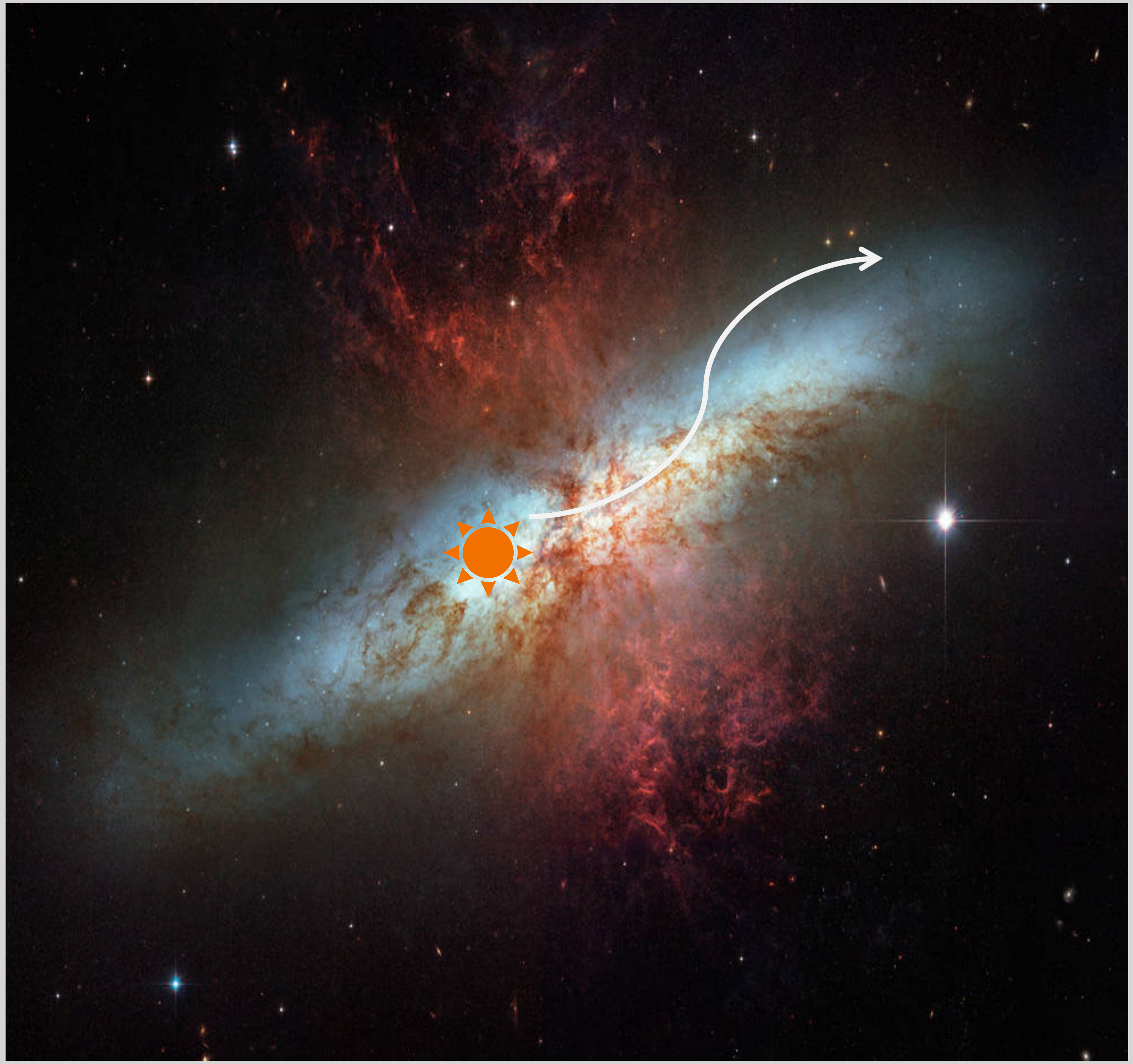
SBGs as a probe for DM

- ✦ Strong and robust **constraints on sub-GeV Dark Matter** from M82 and NGC253!
- ✦ The neutrino and γ-ray emission from SBGs can be used to probe new physics!
- ✦ Current γ-ray data put strong constraints on DM-P cross section up to $\sigma_{\chi\mathrm{p}} \simeq 10^{-34}\mathrm{cm}^2$

Back-Up Slides

Cosmic-Rays Transport inside SBGs

https://hubblesite.org/image/3898/printshop



The Starburst Galaxy M82

Leaky-box-like model for CR transport

$$f(p)\left(\frac{1}{\tau_{\rm loss}(p)}+\frac{1}{\tau_{\rm adv}(p)}+\frac{1}{\tau_{\rm diff}(p)}\right)=Q(p)$$

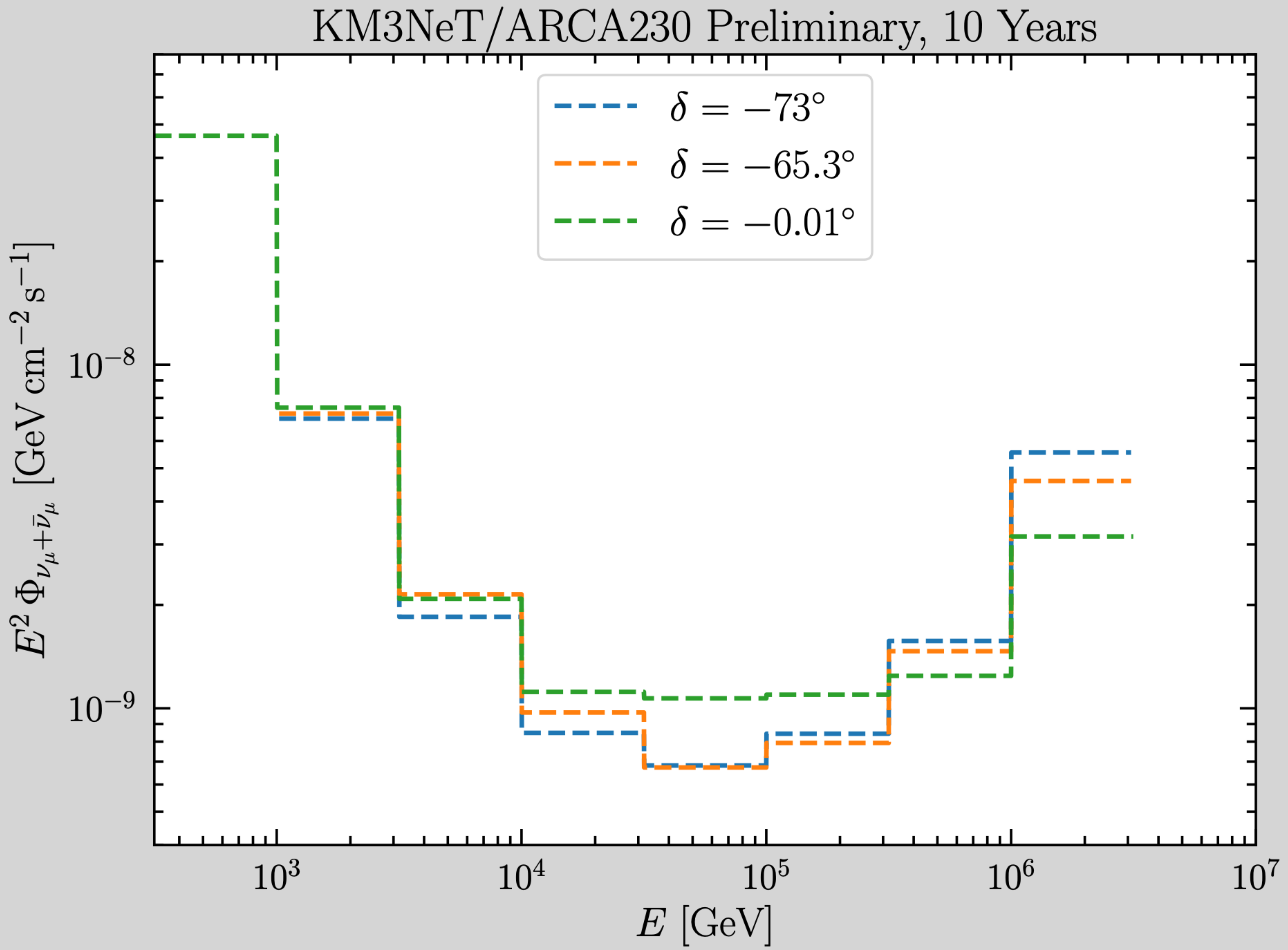
injected CR from SN explosion

CR acceleration up to the knee in Supernovae Remnants

$$Q(p) \propto \left(\frac{p}{m_p}\right)^{-\alpha} \cdot e^{-p/p_{\rm max}}$$

- $\tau_{\rm loss} \simeq \tau_{pp} \propto \frac{1}{n_{\rm ISM}}$ The denser the SBN, the more the energy losses affects the CR transport
- $\tau_{\rm adv} = R/v_{\rm wind}$
- $\tau_{\rm diff} = R^2/D$

Sensitivity Dependence on Declination

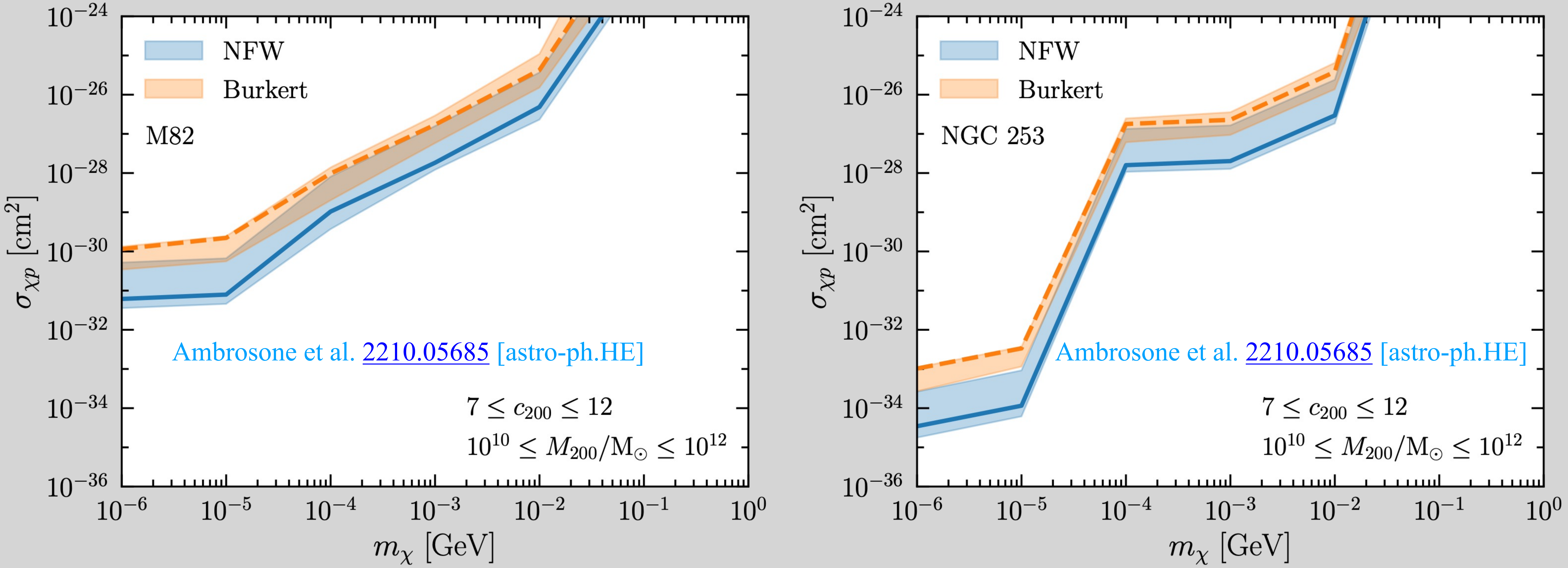


✦The sensitivities are calculated considering point-like neutrino source emissions (No extension)

✦For very low declination bands, the sensitivity at high energy gets worse

DM Constraints Dependence on the Profile

The constraints are robust against the uncertainty on the DM profile!



✦DM-p cross section can be probed to be $\lesssim 10^{-34}\mathrm{cm}^2$ for $\mathrm{m}_\chi \lesssim 10^{-6}\mathrm{GeV}$

✦The uncertainty on the bounds is of the order of $\sim 1-2$ orders of magnitudes

Neutrino Selection

- **Background:** μ **atmospheric,** ν **atmospheric** $(\nu_\mu, \nu_e, \nu_\tau)$

- **Signal:** $\nu\ E^{-2}$ **Spectrum** $(\nu_e, \nu_\mu, \nu_\tau)$

Tracks

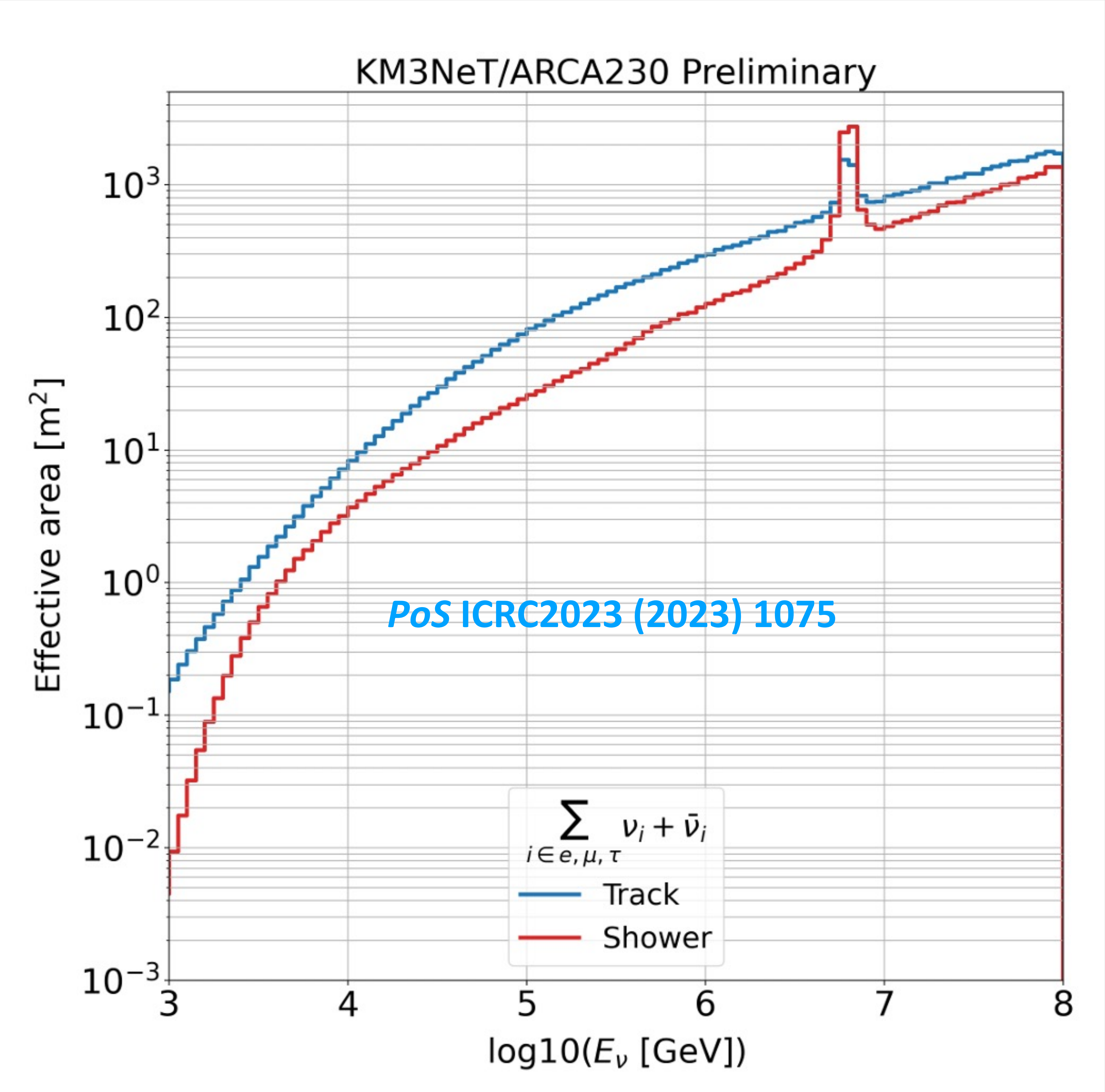
- **Up-going cut** $(\theta < 100°)$
- **Long-track events (Len > 300 m)**

Cascades

- **All sky**
- **Contained events (fiducial volume)** $(R_{det}$ **<600,** Z_{det}**<650)**

For both channels, we finalize the selection by using a Boosted decision tree (BDT) (Machine learning techinque)

See (*PoS* ICRC2023 (2023) 1074) for more details and (*EPJ Web Conf.* 280 (2023) 03001, *J.Phys.Conf.Ser.* 2429 (2023) 1, 012028)



PoS ICRC2023 (2023) 1075

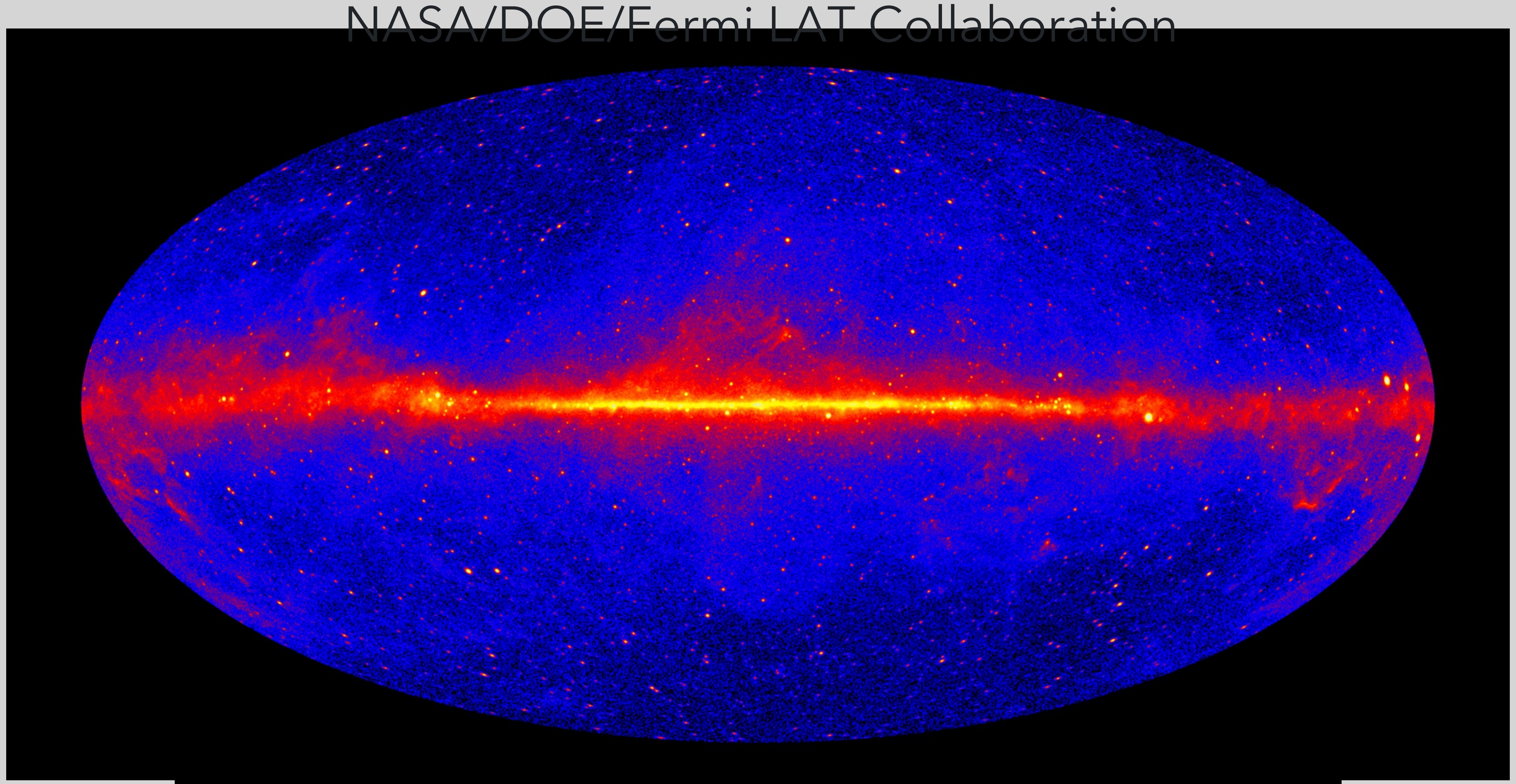
$$n_s = T \int_{\Delta E} A_{eff}(E) \phi_s(E) dE$$

On the Origin of the Galactic Neutrino Emissions

✦There are different models to describe the neutrino emission of the galactic plane

How do we model the galactic neutrino emissions? Exploiting CR and γ-rays observations

NASA/DOE/Fermi LAT Collaboration

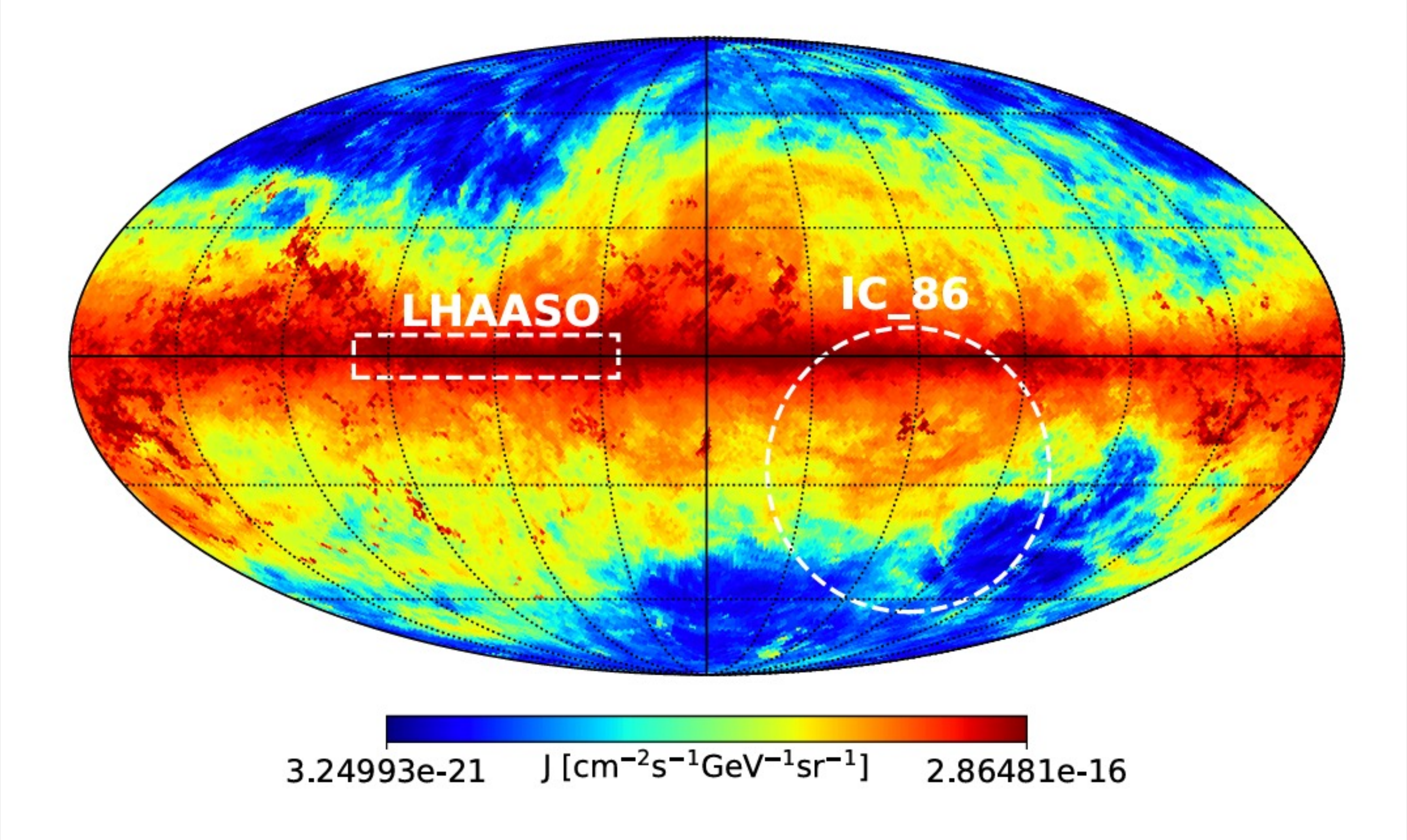


Credit: NASA's Goddard Space Flight Center

✦Π^0 Model from Fermi-LAT Observations (It assumes homogeneous CR diffusion along the galactic plane)

$\Phi_\nu \propto E^{-2.7}$(Soft Spectrum inherited by the CR distribution)

Astron.Astrophys. 672 (2023) A58

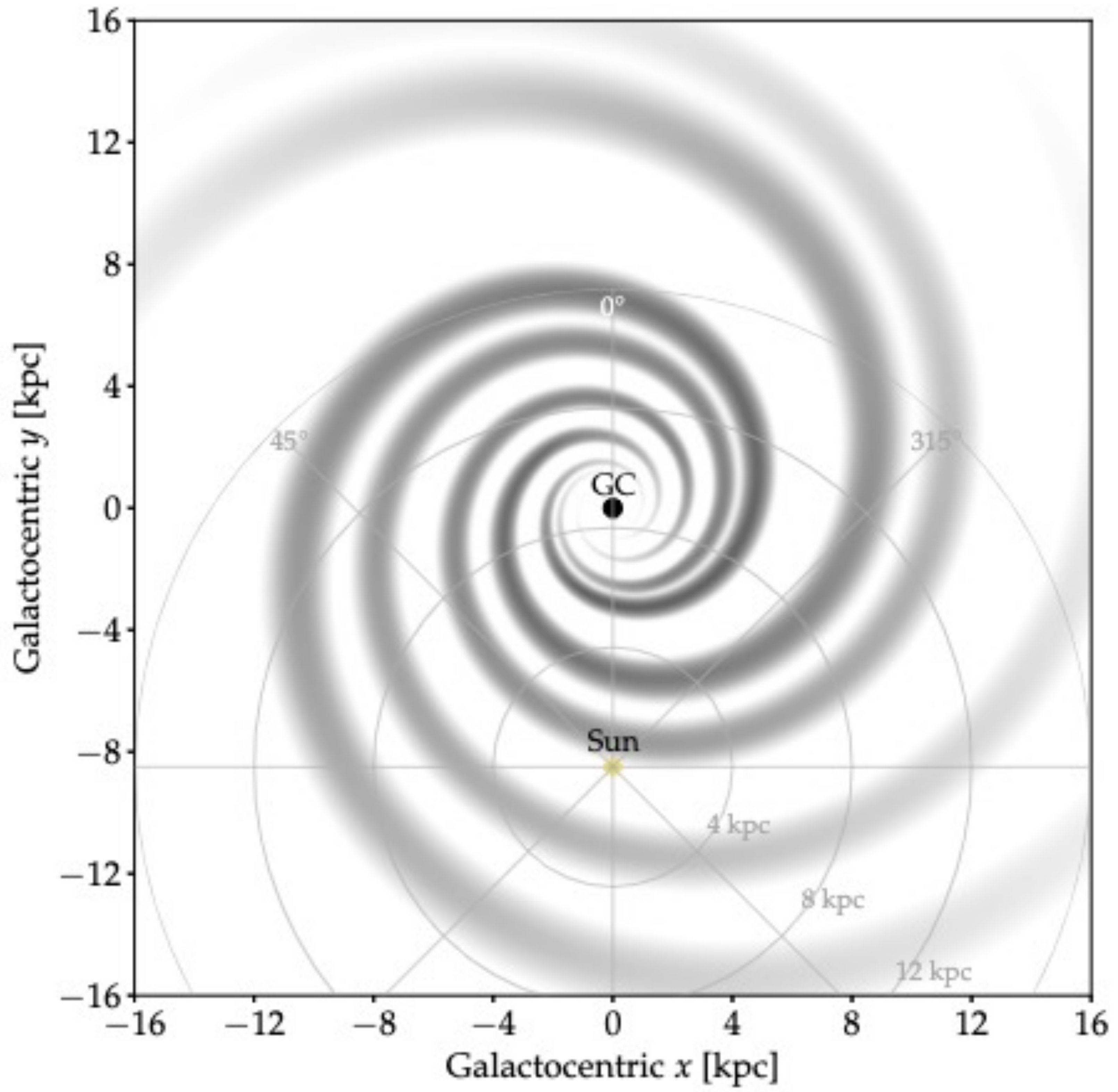


✦KRA gamma Model

$\Phi_\nu \propto E^{-2.5}$(Hard spectrum due to radial-dependent diffusion)

Neutrino Emission from Galactic Point-Sources

Ambrosone et al. Arxiv: [2306.17285](https://arxiv.org/abs/2306.17285)



Azimuthally-independent (SNR) distribution

$$\bar{\rho}(r) = \rho_\odot \left(\frac{r}{r_\odot}\right)^{\alpha} e^{-\beta(r/r_\odot - 1)}$$

4-arm Distribution

$$\rho(r, \phi, z) \equiv \bar{\rho}(r) \sum_i w_i \frac{e^{\kappa \cos(\phi - \phi_i(r))}}{I_0(\kappa)} e^{-\frac{z^2}{2\sigma_z^2}}$$

Assuming the same power-law for each source, the flux is

$$\phi_{\mathrm{QD}}(\mathrm{E}_\nu, \Omega) = \frac{\mathrm{Q}_\nu(\mathrm{E}_\nu)}{4\pi} \int_0^{+\infty} \mathrm{dD}\, \rho(\mathbf{r}_\odot + \mathrm{D}\mathbf{n}(\Omega))$$

Can we probe the Cosmic-Rays transport using local /nearby SBGs?

Probing the Cosmic-Ray Transport inside SBGs

Ambrosone+, MNRAS [2203.03642]

Cosmic- Ray Transport Mechanism inside SBGs are, **however**, model-dependent.

Model A (adopted in the previous results): *Peretti+, MNRAS 487 (2019)*

$$f(p) = Q(p)\left(\frac{1}{\tau_{\mathrm{loss}}} + \frac{1}{\tau_{\mathrm{adv}}} + \frac{1}{\tau^{A}_{\mathrm{diff}}}\right)^{-1}$$

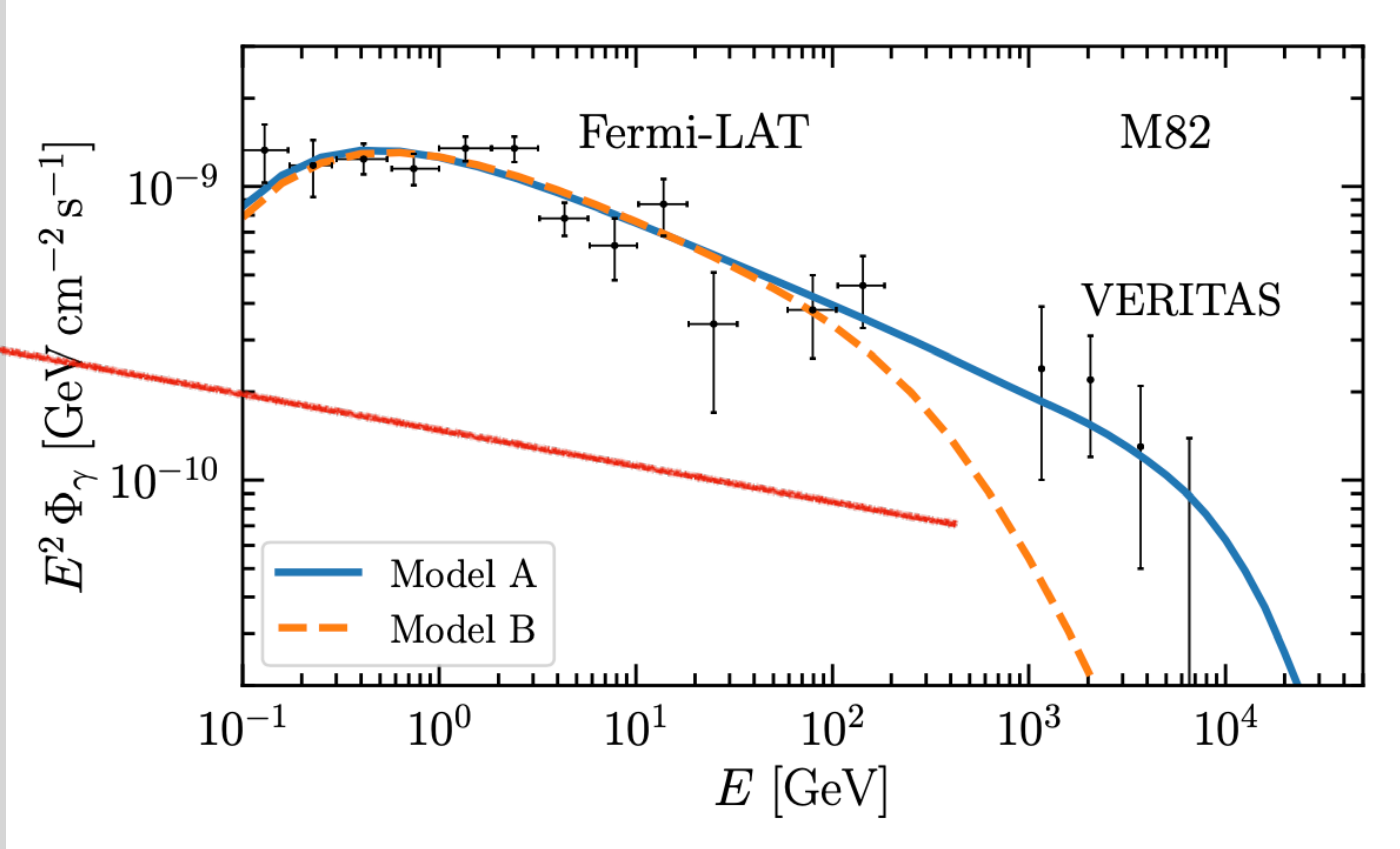
- ✦Winds are global phenomena in SBGs
- ✦The diffusion of CRs occurs along pre-existing (strong) magnetic turbulence. This leads to a small diffusion coefficient

Model B *Krumholz+, MNRAS 493 (2020)*

$$f(p) = Q(p)\left(\frac{1}{\tau_{\mathrm{loss}}} + \frac{1}{\tau^{B}_{\mathrm{diff}}}\right)^{-1}$$

- ✦ Advection is negligible process
- ✦Diffusion of CRs occurs by self-generated streaming instability. This leads to a high diffusion coefficient

TeV Gamma-rays from Model B are suppressed due to major role of diffusion. SBGs stop being calorimetric!

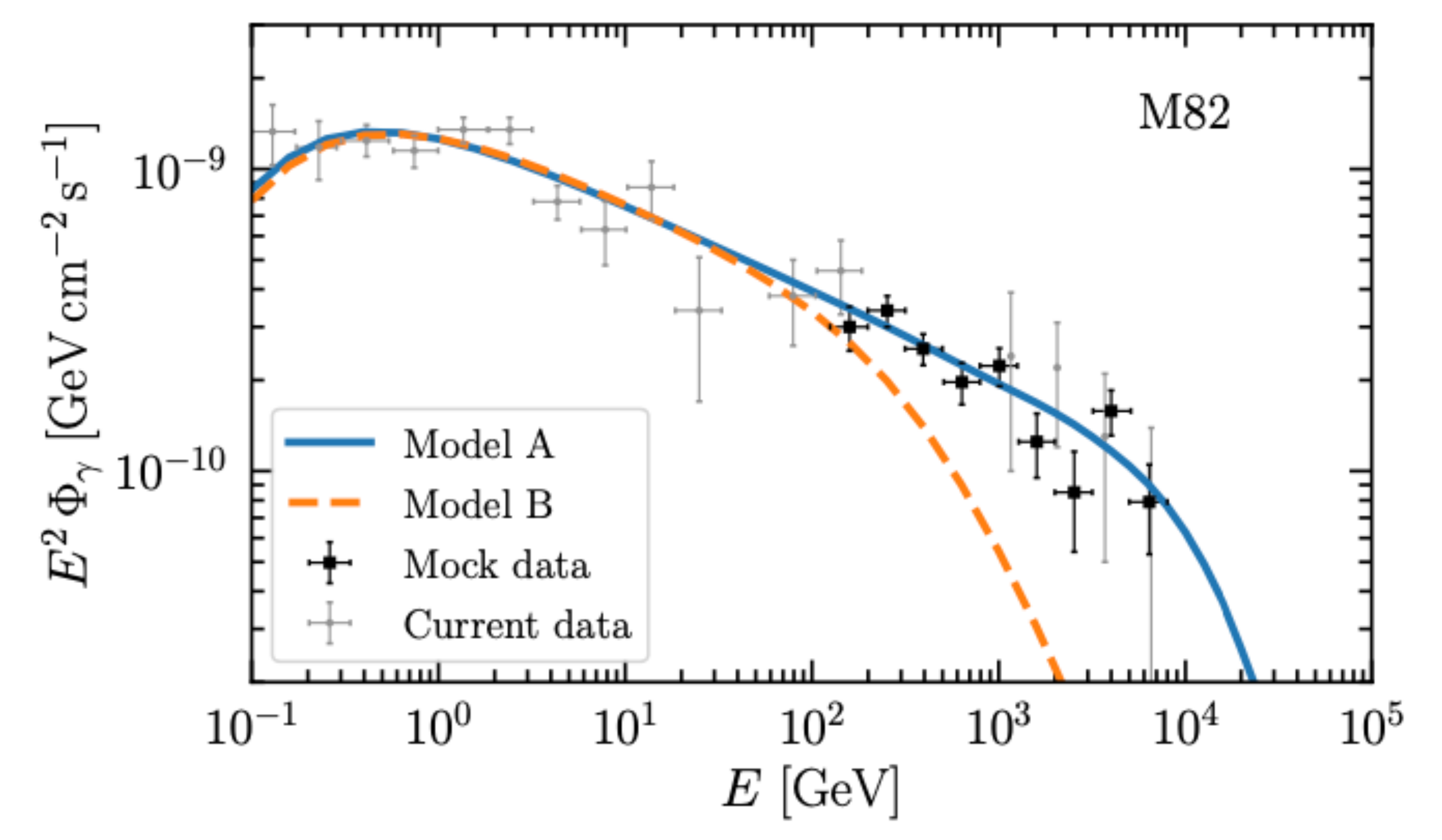


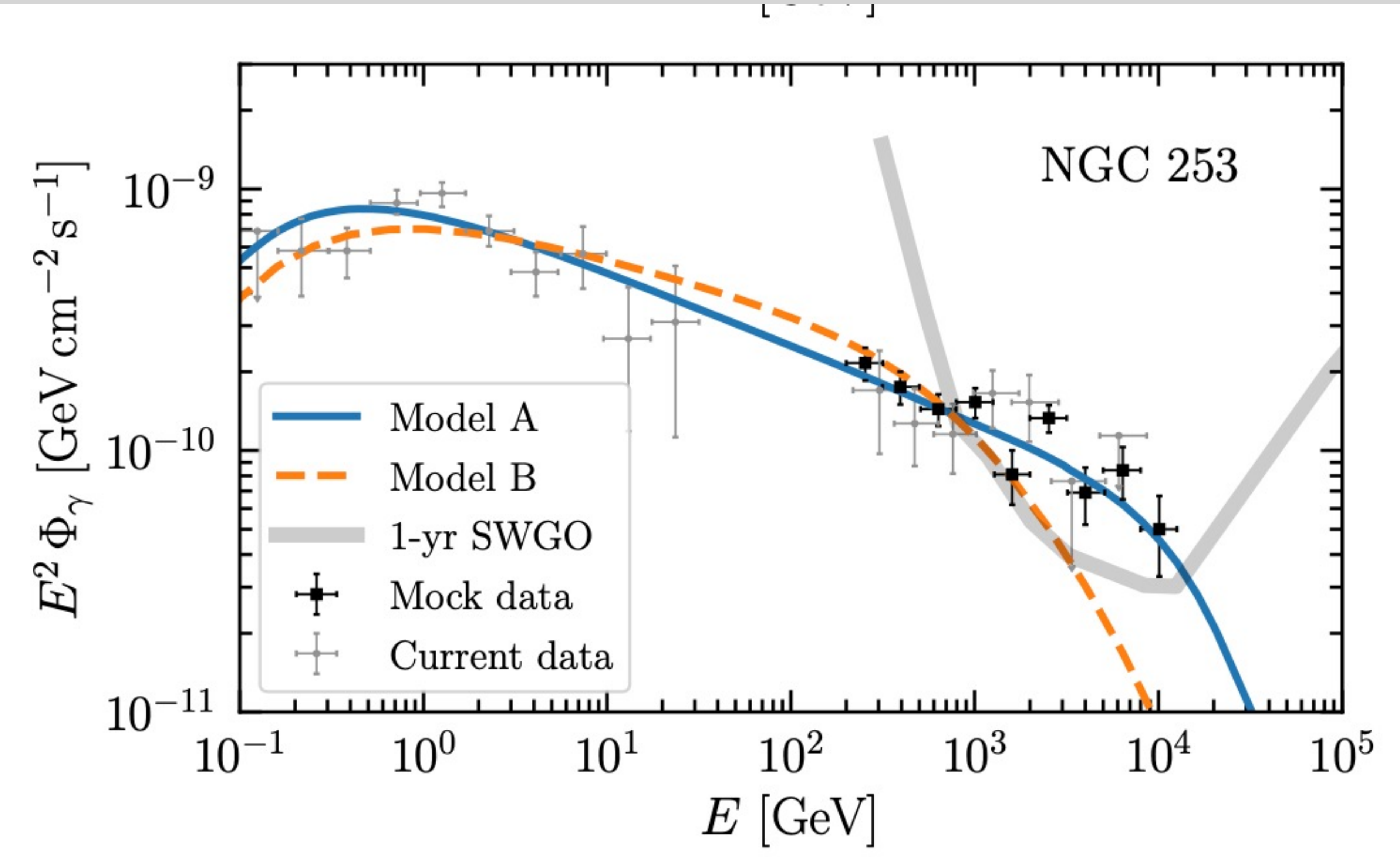
TeV Measurements are fundamental: CTA Forecast

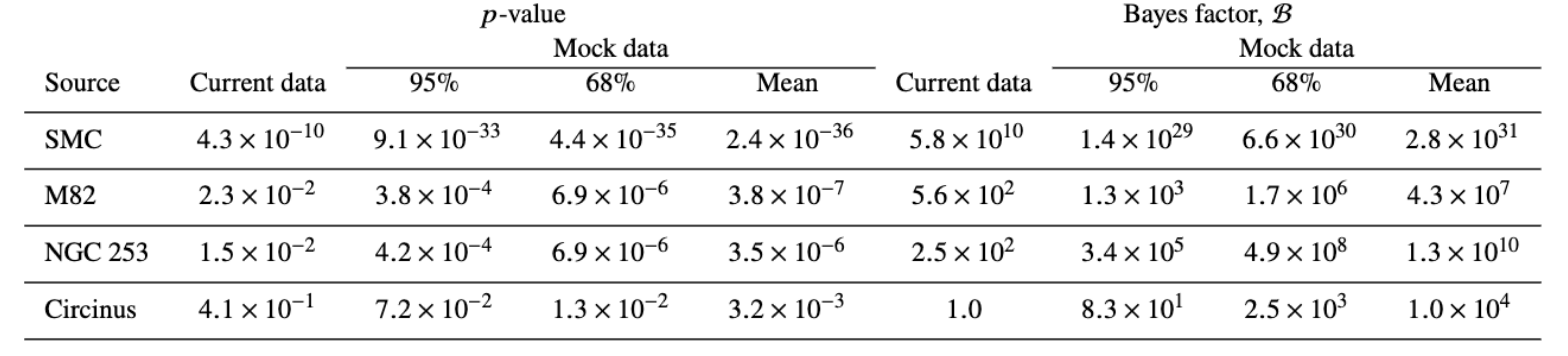
Ambrosone+, MNRAS [2203.03642]

We test Krumohlz + (model B) by means of CTA mock data simulations assuming Peretti + (Model A)

- ✦**Generation of 10^4 sets of mock SED data**
- ✦ **CTA Info from: Acharya+, 1709.07997**
- ✦ **SWGO Info from: Albert+, 1902.08429 Hinton, PoS ICRC2021 023**







	p-value				Bayes factor, $\mathcal{B}$			
		Mock data				Mock data		
Source	Current data	95%	68%	Mean	Current data	95%	68%	Mean
SMC	4.3×10^{-10}	9.1×10^{-33}	4.4×10^{-35}	2.4×10^{-36}	5.8×10^{10}	1.4×10^{29}	6.6×10^{30}	2.8×10^{31}
M82	2.3×10^{-2}	3.8×10^{-4}	6.9×10^{-6}	3.8×10^{-7}	5.6×10^{2}	1.3×10^{3}	1.7×10^{6}	4.3×10^{7}
NGC 253	1.5×10^{-2}	4.2×10^{-4}	6.9×10^{-6}	3.5×10^{-6}	2.5×10^{2}	3.4×10^{5}	4.9×10^{8}	1.3×10^{10}
Circinus	4.1×10^{-1}	7.2×10^{-2}	1.3×10^{-2}	3.2×10^{-3}	1.0	8.3×10^{1}	2.5×10^{3}	1.0×10^{4}

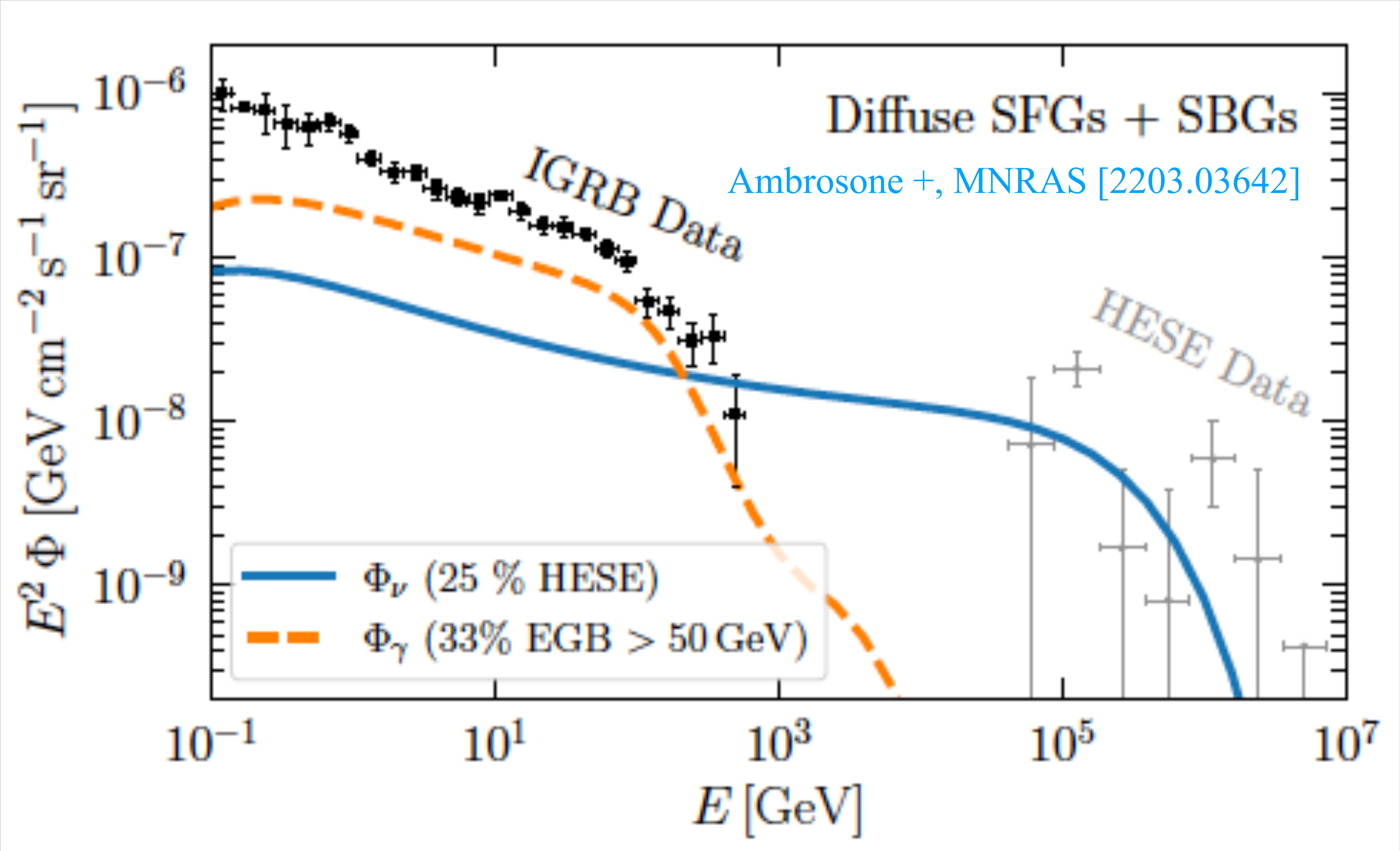
Future Measurements should be able, despite astrophysical uncertainties, to distinguish between the two scenario at more than 2σ level!

Implications For Neutrino Astronomy

Different CR mechanism scenarios might well give a different contribution to the diffuse emissions

Model A (Peretti+, MNRAS 487 (2019))

Model B (Krumholz+, MNRAS 493 (2020))

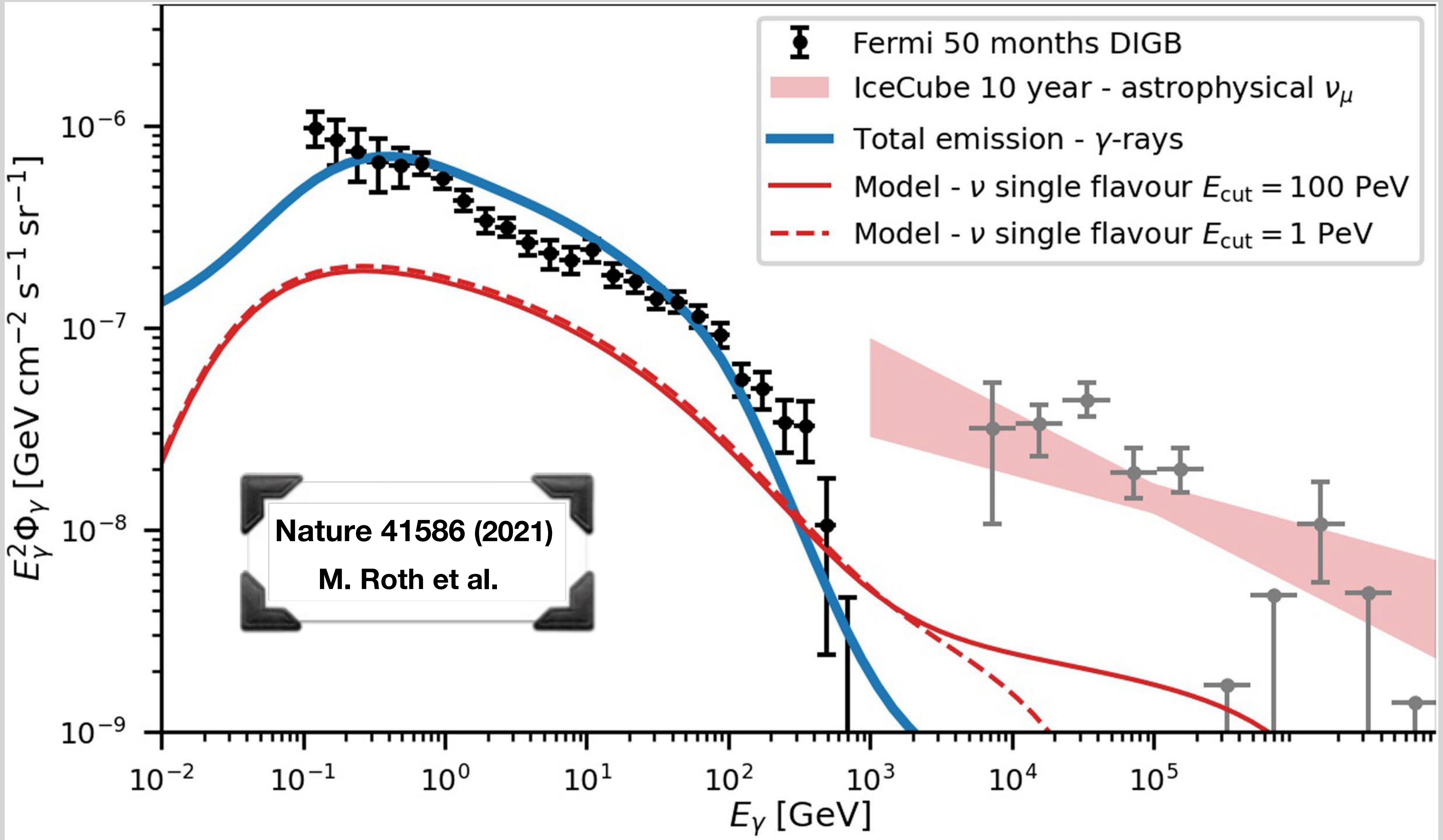


Ambrosone +, MNRAS [2203.03642]

Fcal is independent on energy. The calorimetric approach is justified

✦ Important contribution to Neutrinos (25% of the HESE)

✦ Important Contribution to gamma-rays (33% of the EGB)



Nature 41586 (2021)
M. Roth et al.

Fcal is depedent on the energy above $\sim 100\mathrm{GeV} - 1\mathrm{TeV}$

✦ Negligible contributions to Neutrinos

✦ Important Contributions to gamma-rays (which can saturate the DIGB)

Attention: Due to uncertain origin of the diffuse emissions data, we cannot use them to discrminate between the two CR transport models