Angular power spectrum analysis on current and future high-energy neutrino data

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GRAPPA
GRavitation AstroParticle Physics Amsterdam

Dekker, Ando, JCAP 02 (2019) 002
Dekker, Chianese, Ando, arXiv: 1910.12917

Credits: IceCube/NASA

Astrophysical Sources

p-γ	p-p
Photo-hadronic interactions	**Hadro-nuclear interactions**
Active Galactic Nuclei	Starburst Galaxies
Blazars (4 — 6 %)	Galaxy clusters
Gamma-Ray Bursts	

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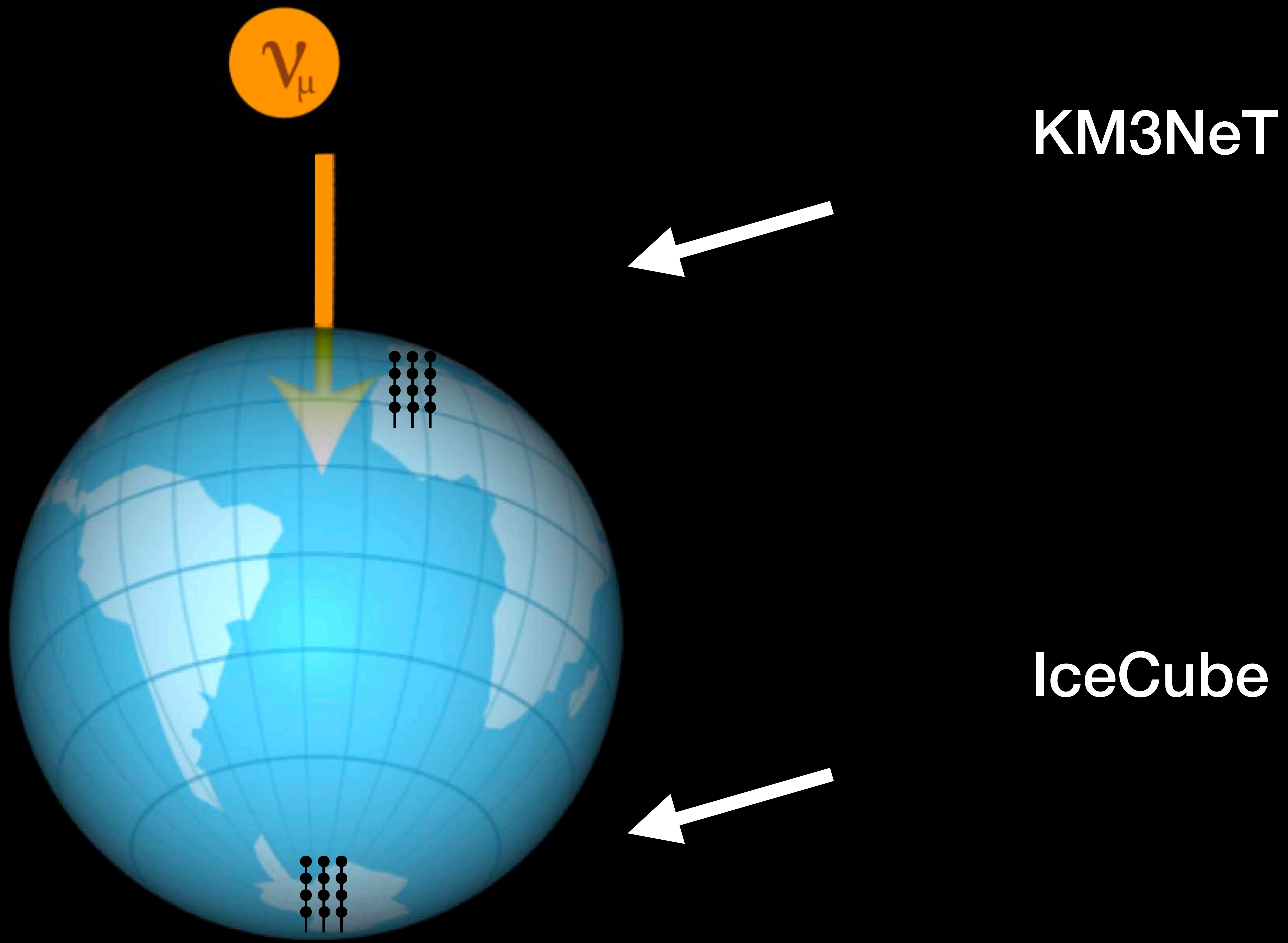
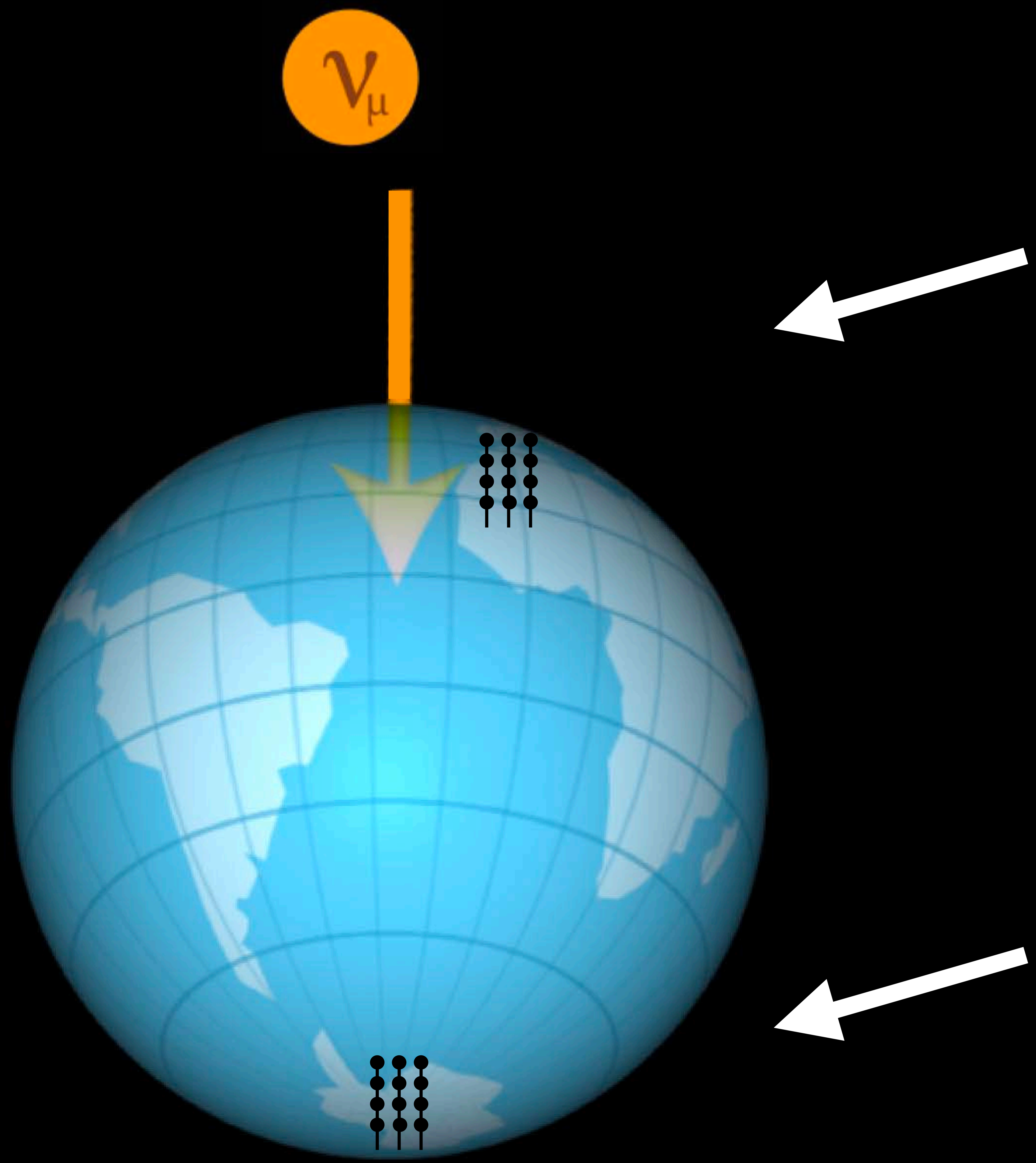
Dark Matter


ν_μ
KM3NeT
IceCube



KM3NeT

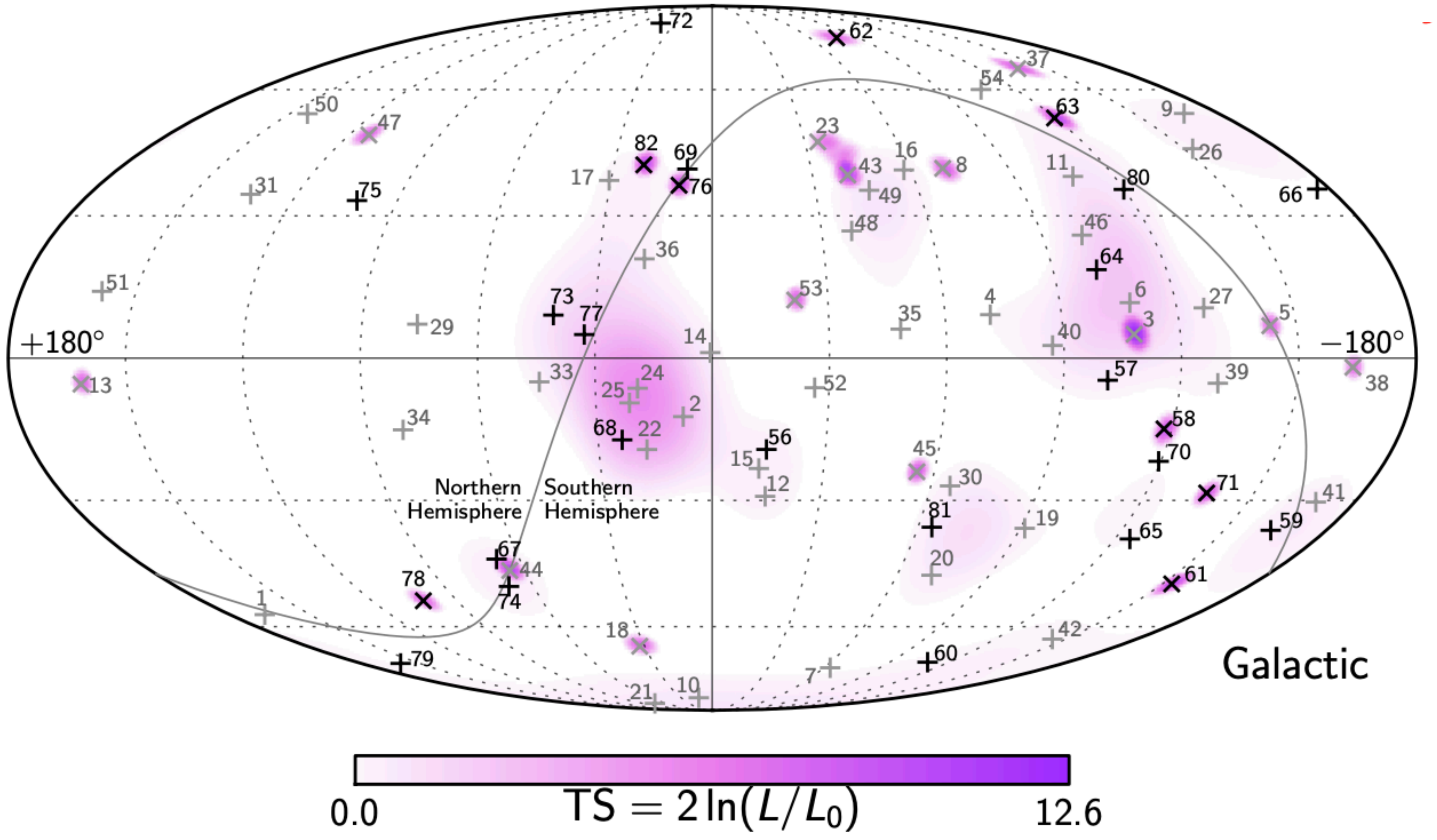
- ν Construction phase
- ν High angular resolution
- ν View on Galactic Centre with TG

IceCube

- ν 10yr observations
- ν Cubic km of Antarctic ice
- ν IceCube-Gen2

IceCube observations

- ν **HESE and Through-Going data sample**
- ν **Isotropic distribution**
- ν **Correlation with source catalogs**
- ν **Sources unknown**



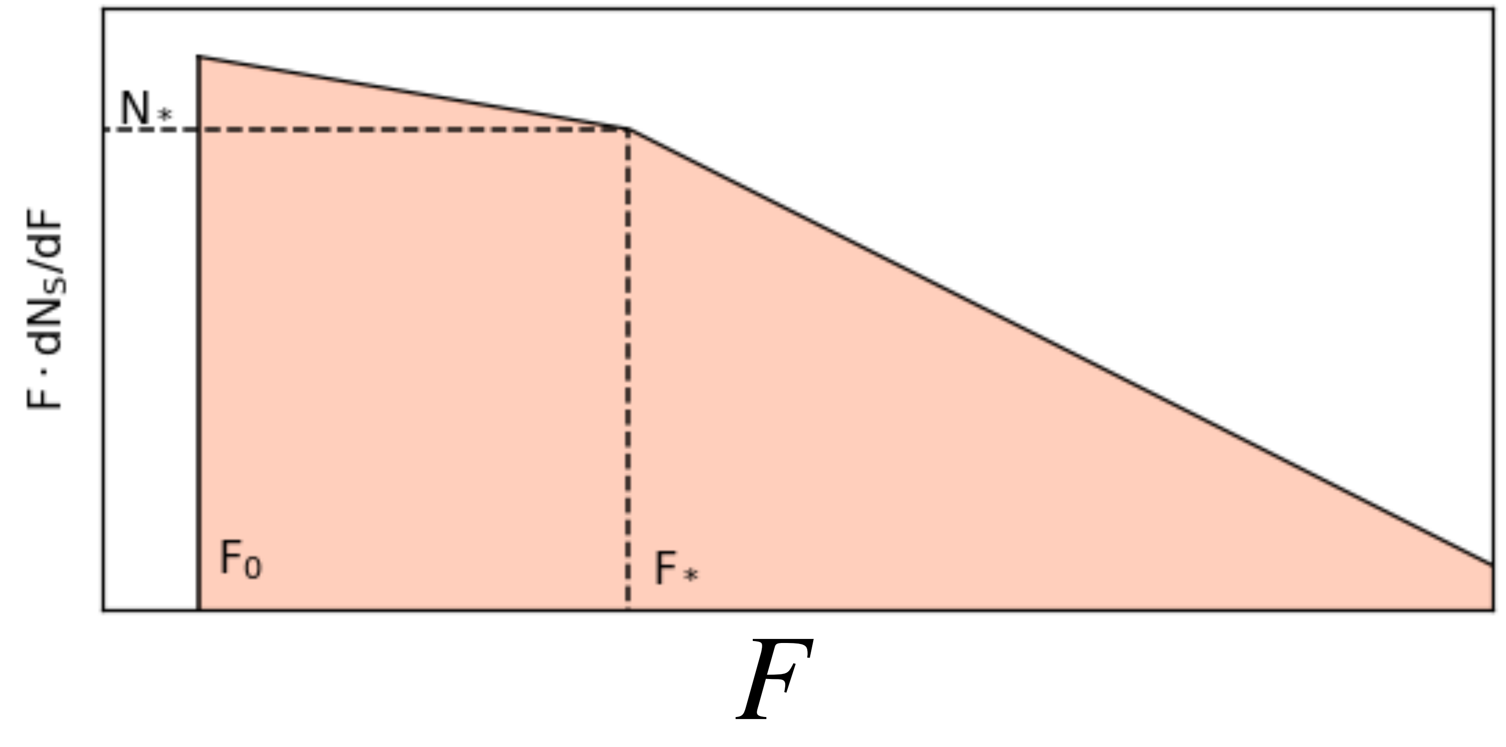
IceCube Collaboration

Method

Angular power spectrum analysis

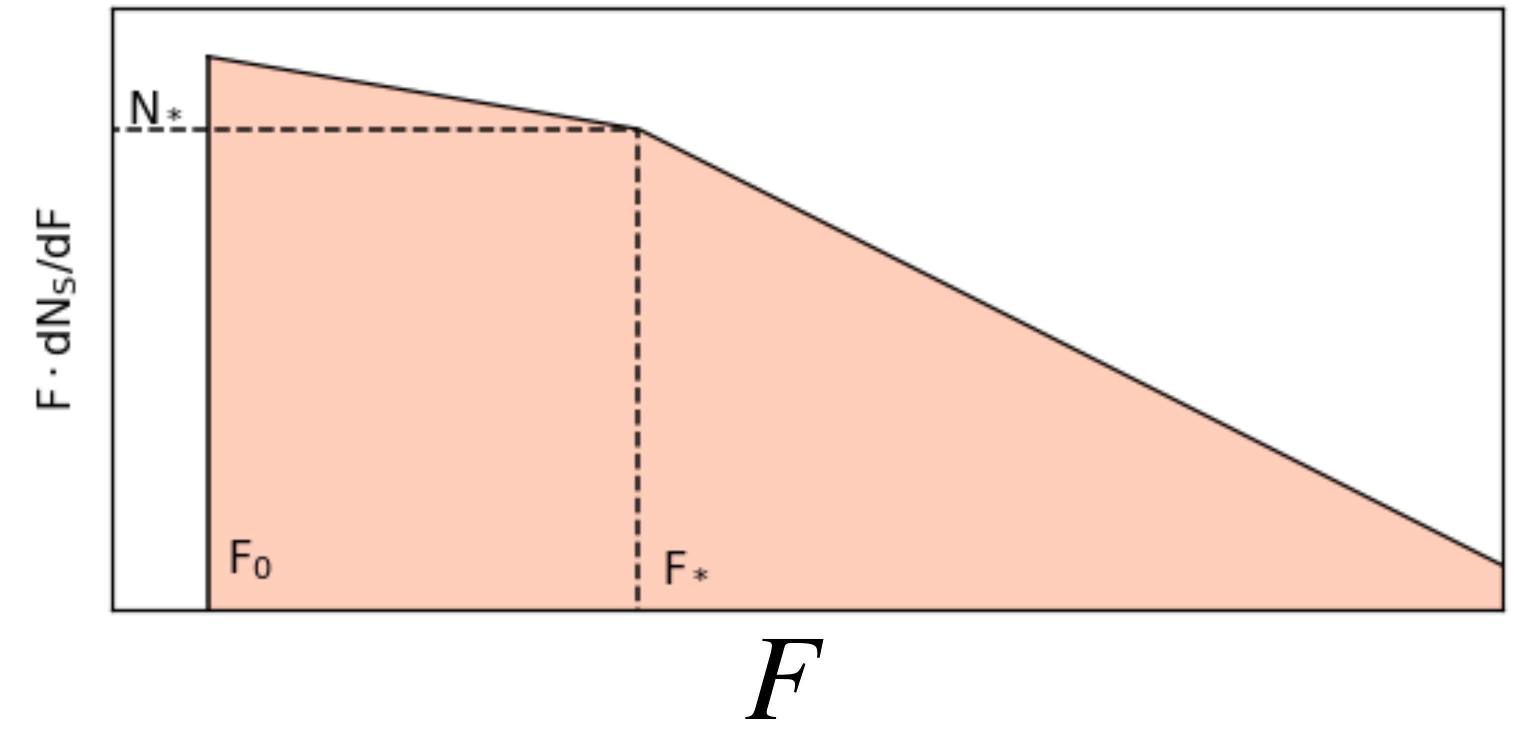
Statistical distributions

Monte Carlo method



$$\frac{dN_s}{dF} \propto \begin{cases} F^{-2.5} & F_\star < F \\ F^{-1.5} & F_0 < F < F_\star \end{cases}$$

Source-flux distribution



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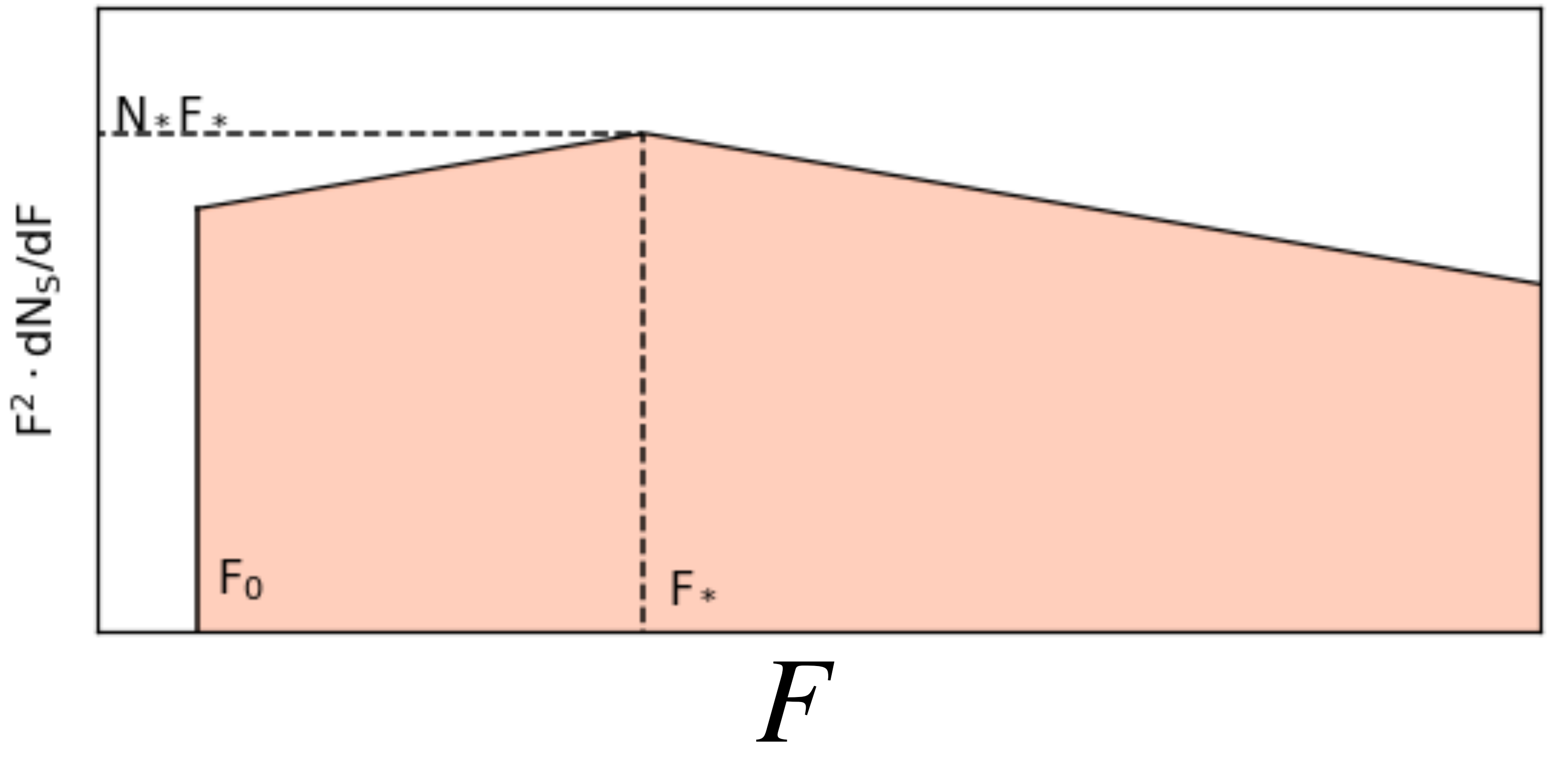
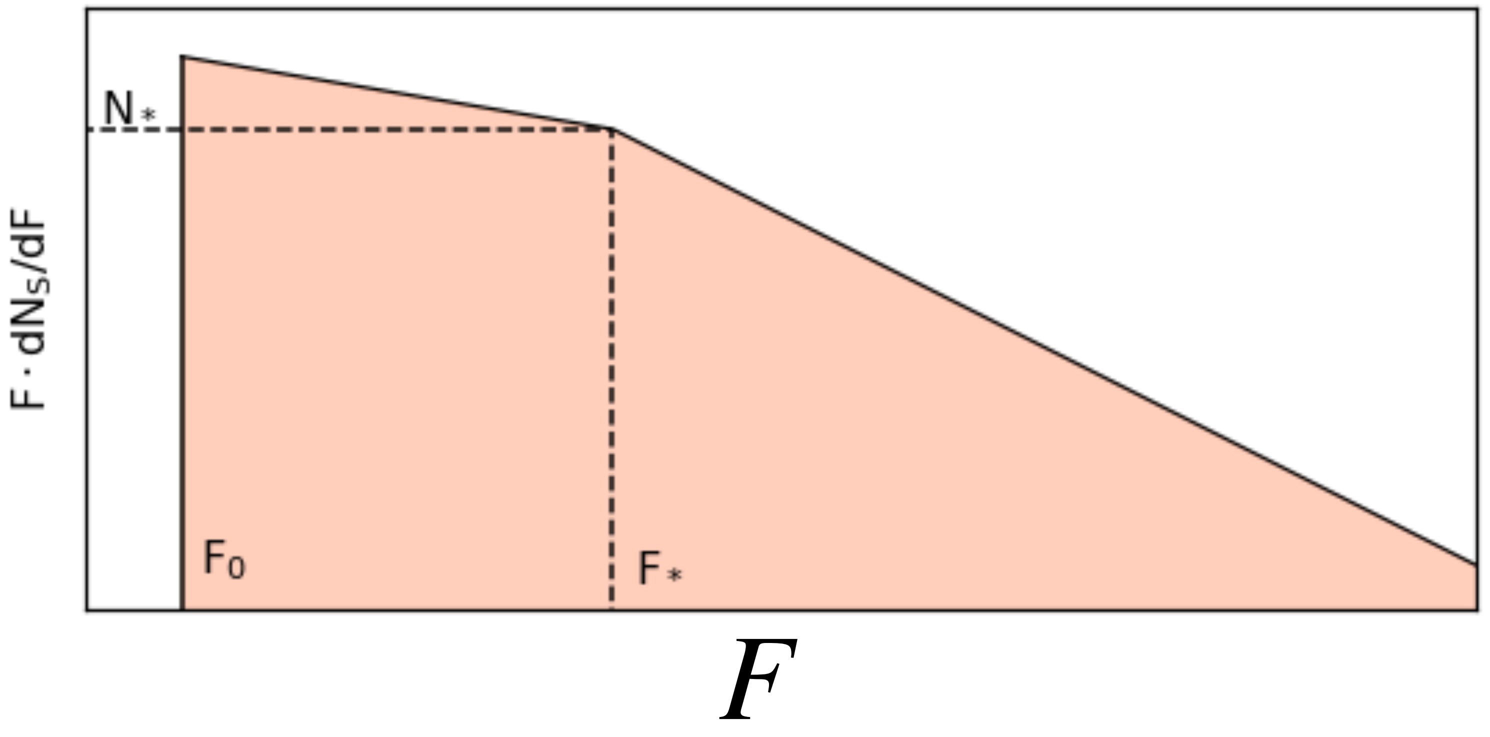


$$4\pi I_\nu = \langle F \rangle \propto N_\star F_\star$$

Mean



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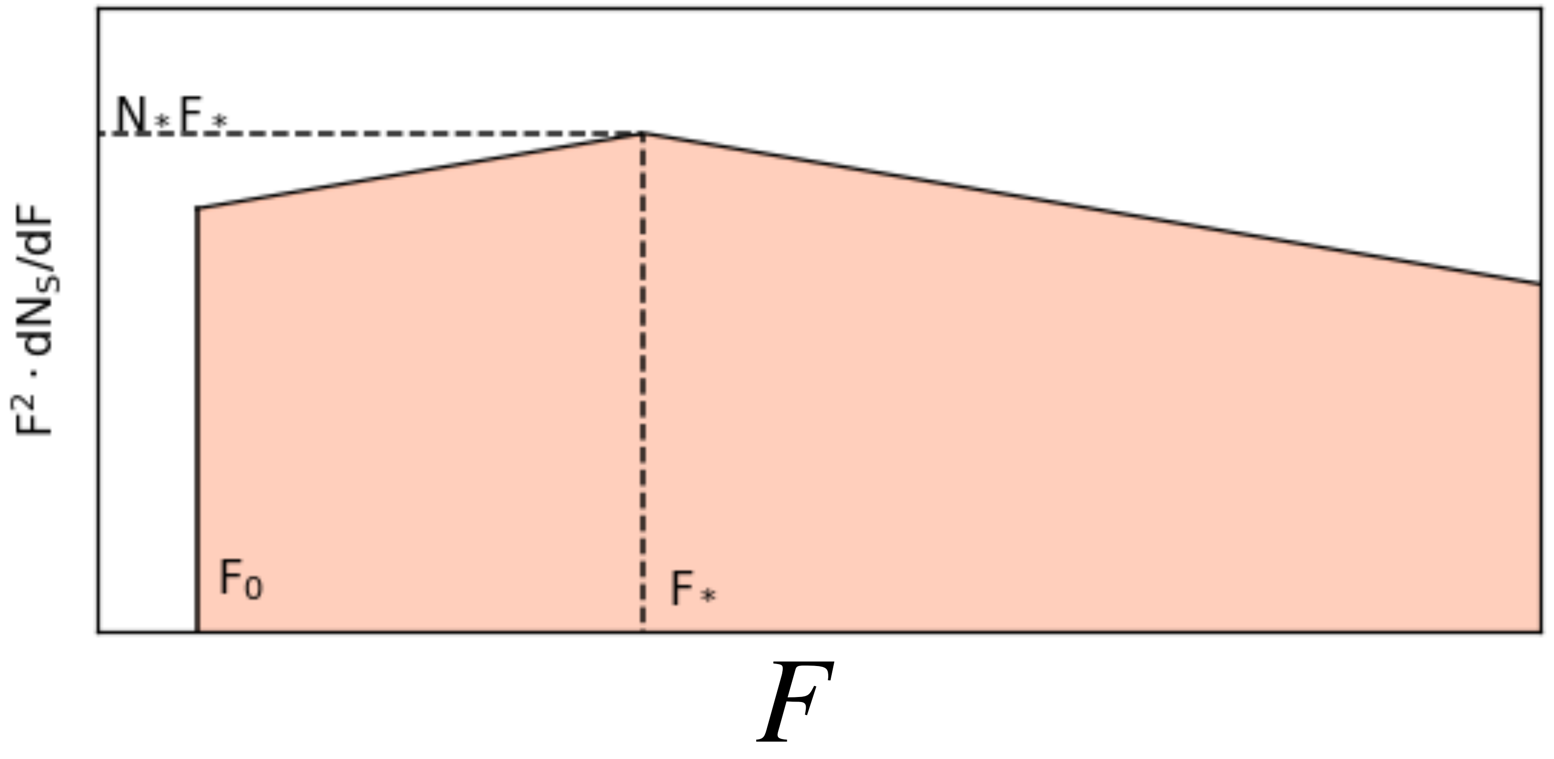

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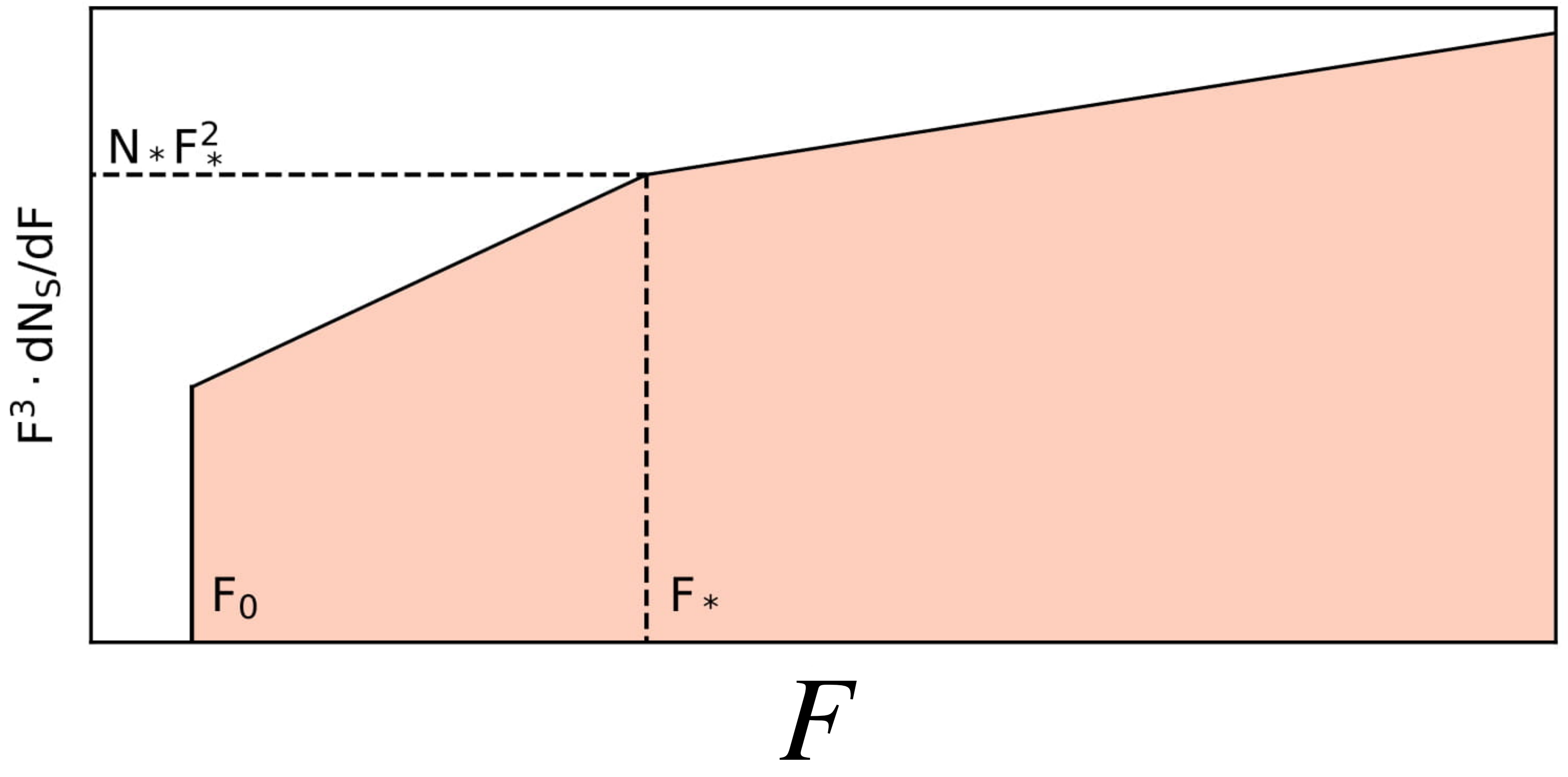
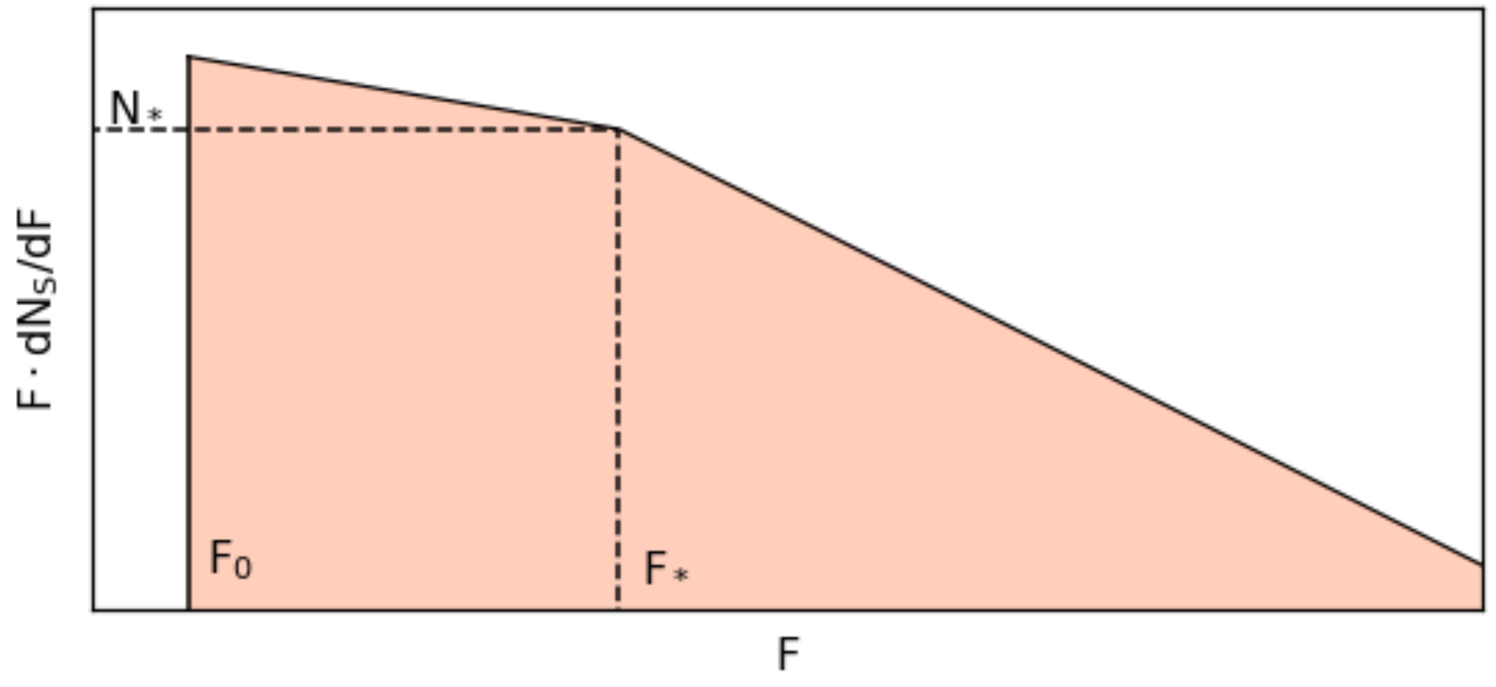
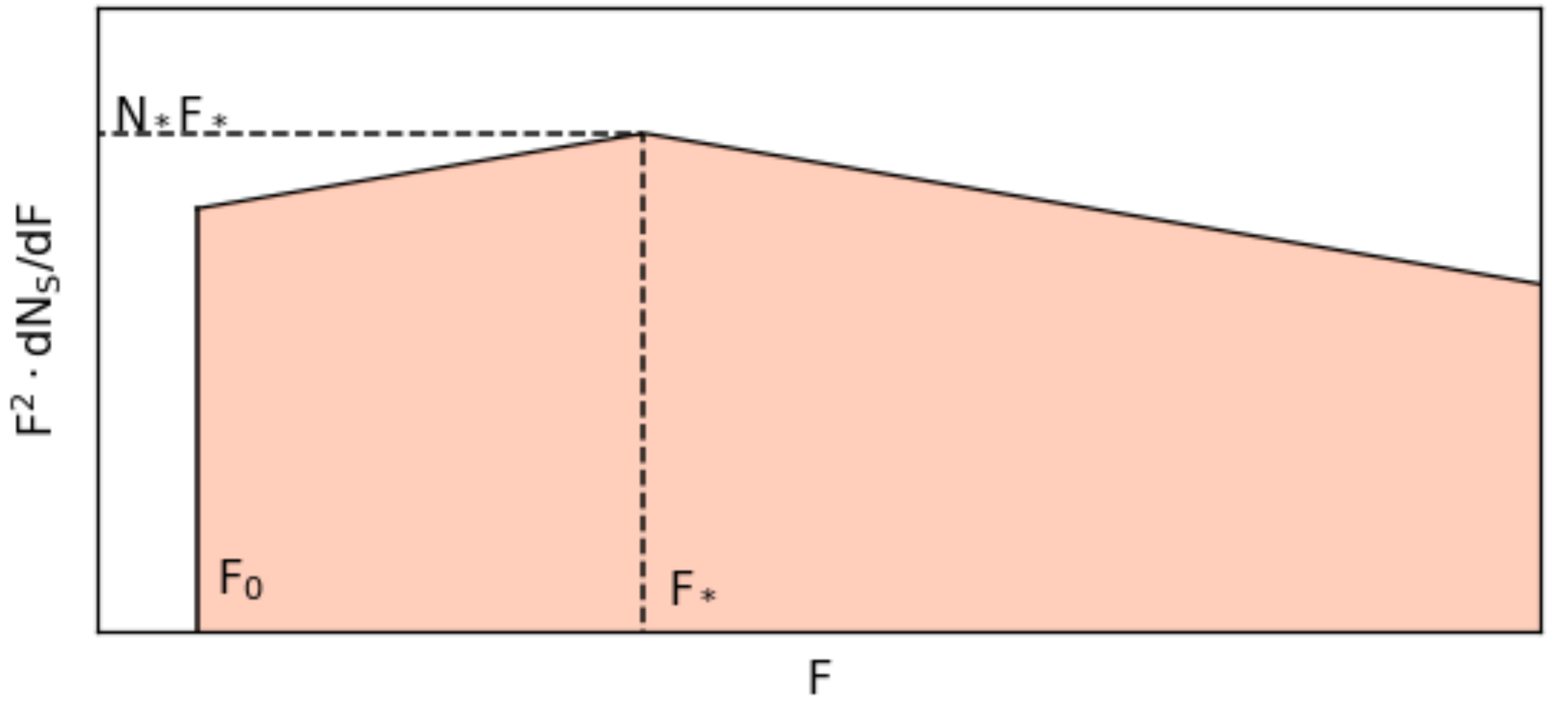
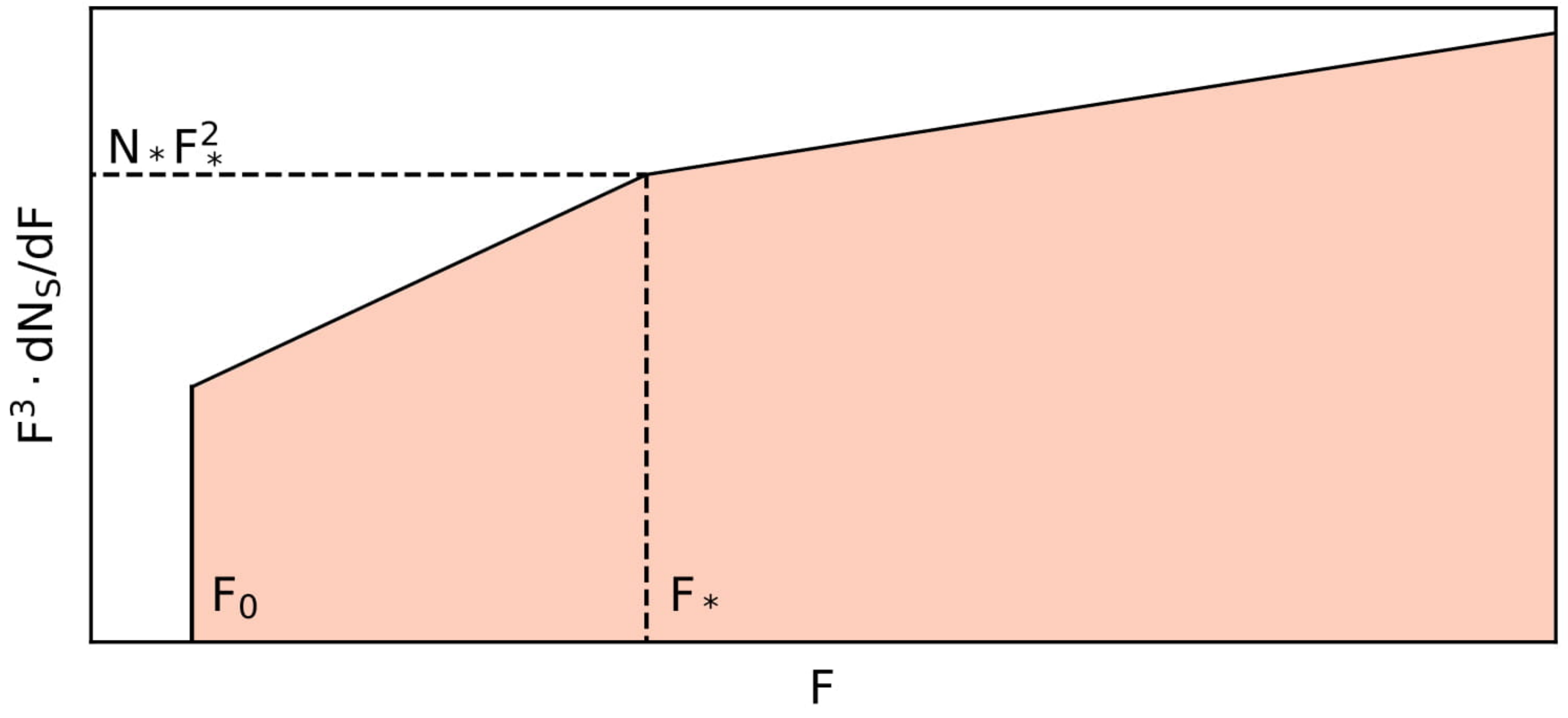


$$\left\langle (F - < F >)^2 \right\rangle$$

Angular Power Spectrum





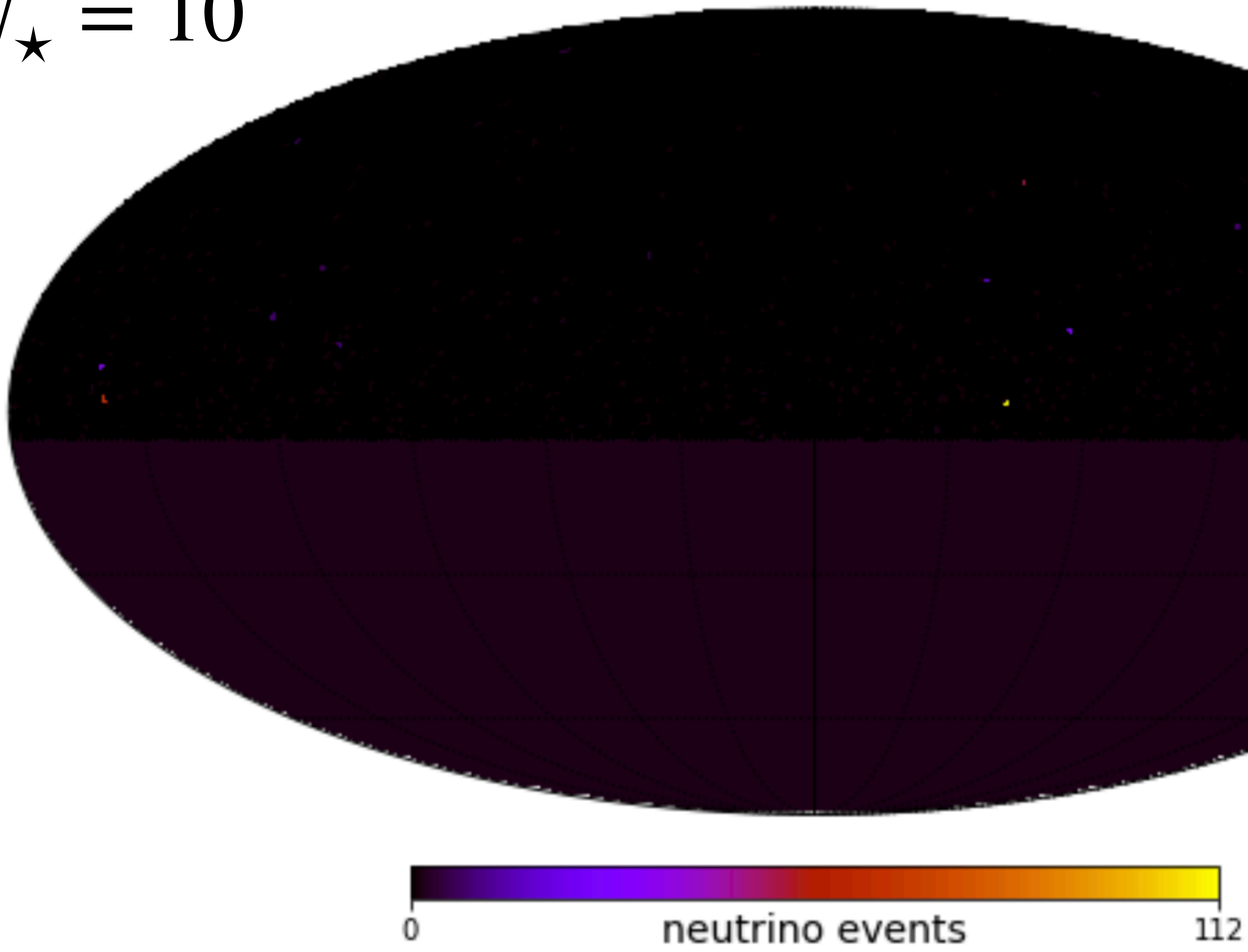


Free parameter: $N_\star \propto \dfrac{I_\nu}{F_\star}$

Blazars: $N_\star = 6 \cdot 10^2$

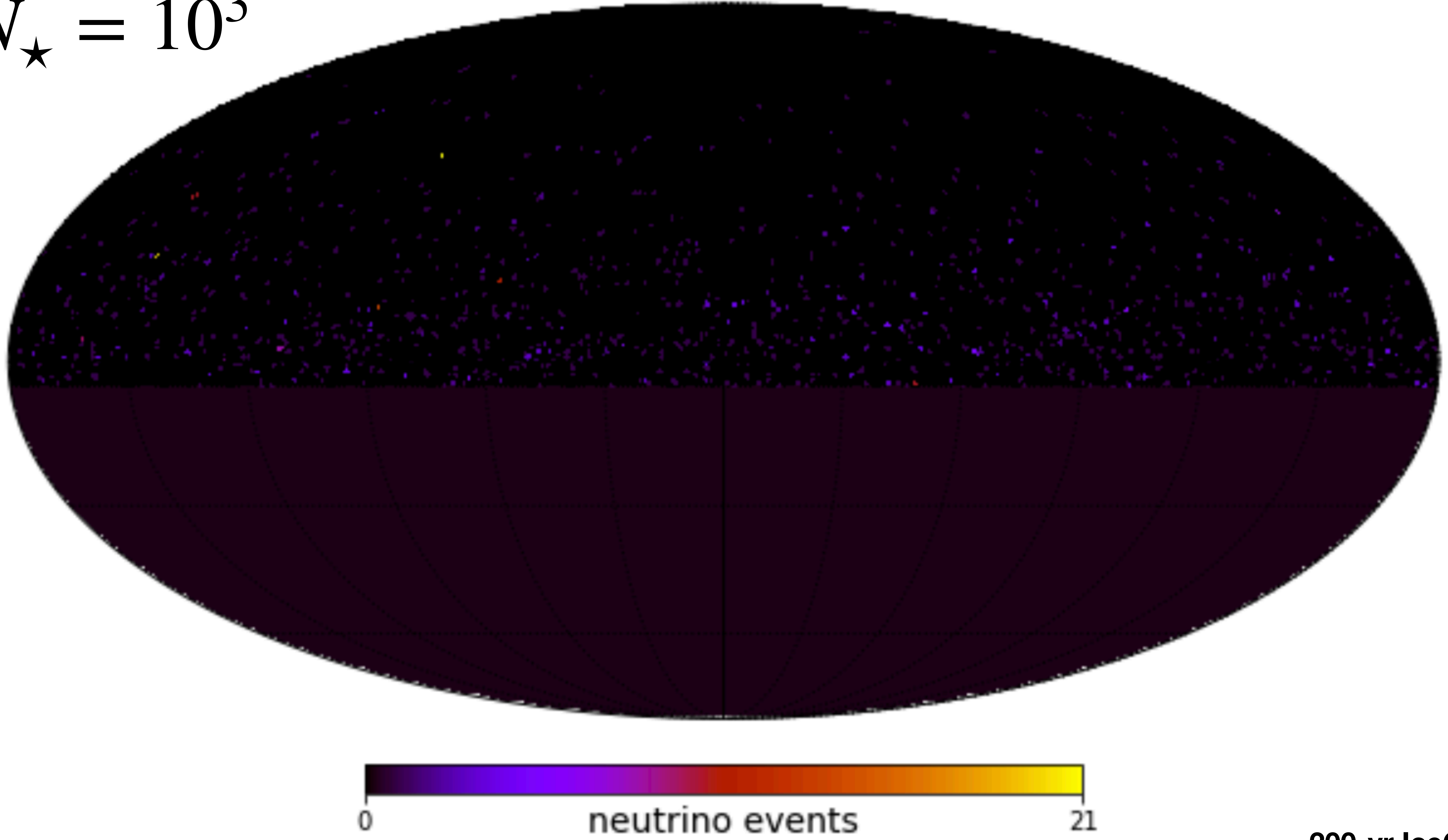
Starburst galaxies: $N_\star = 10^7$

$N_\star = 10$



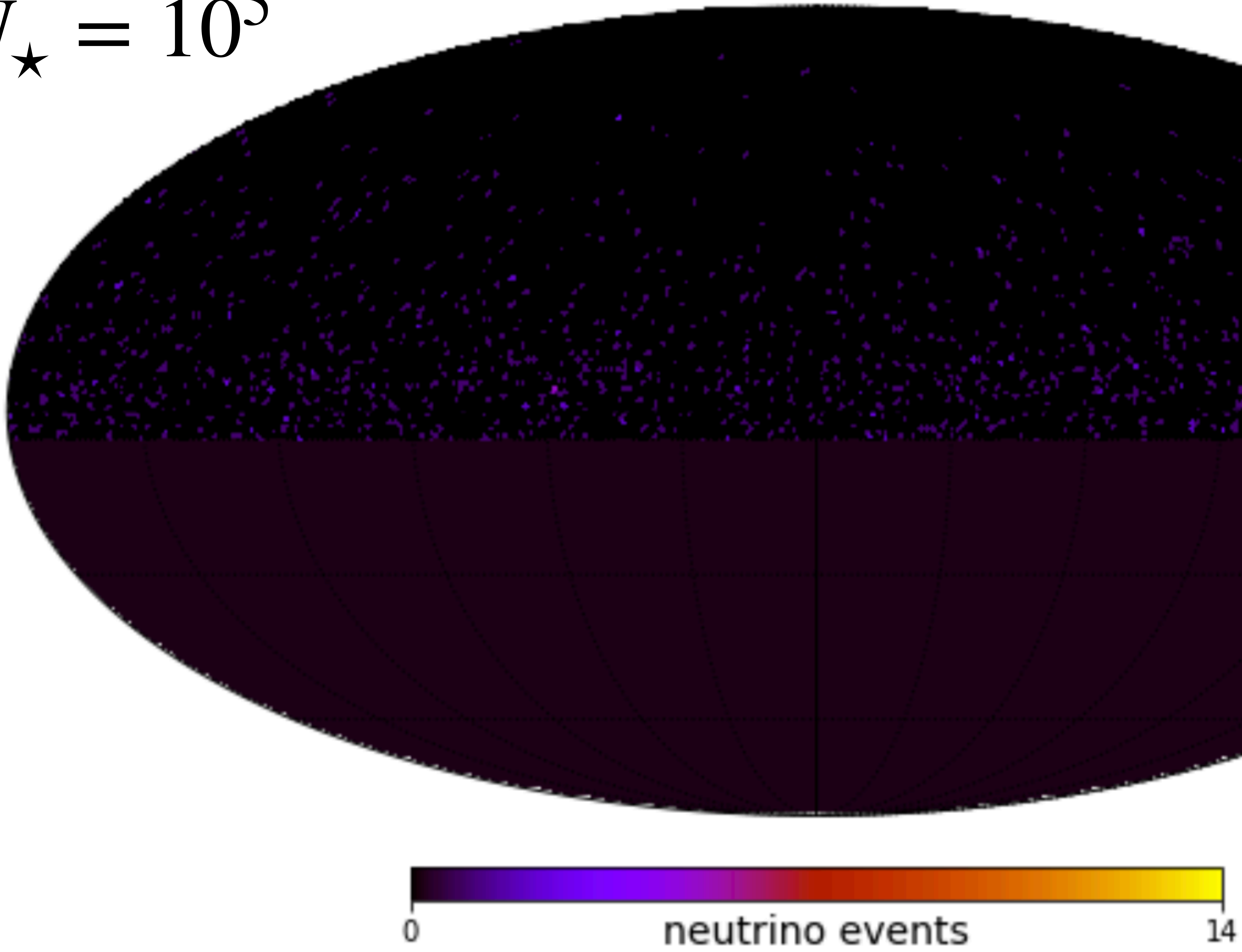
200-yr IceCube

$N_\star = 10^3$



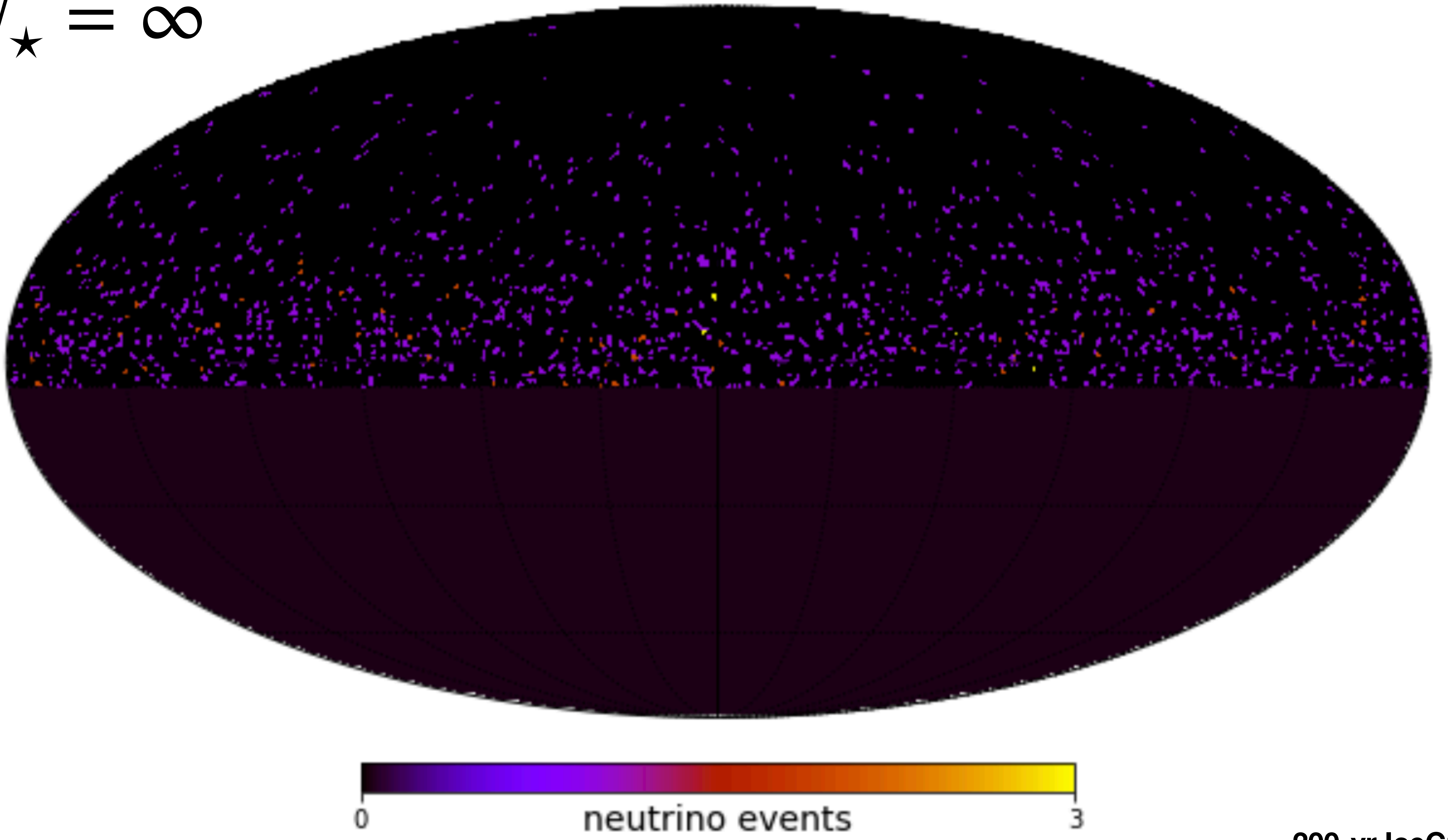
200-yr IceCube

$N_\star = 10^5$



200-yr IceCube

$N_\star = \infty$



200-yr IceCube

2-year IceCube

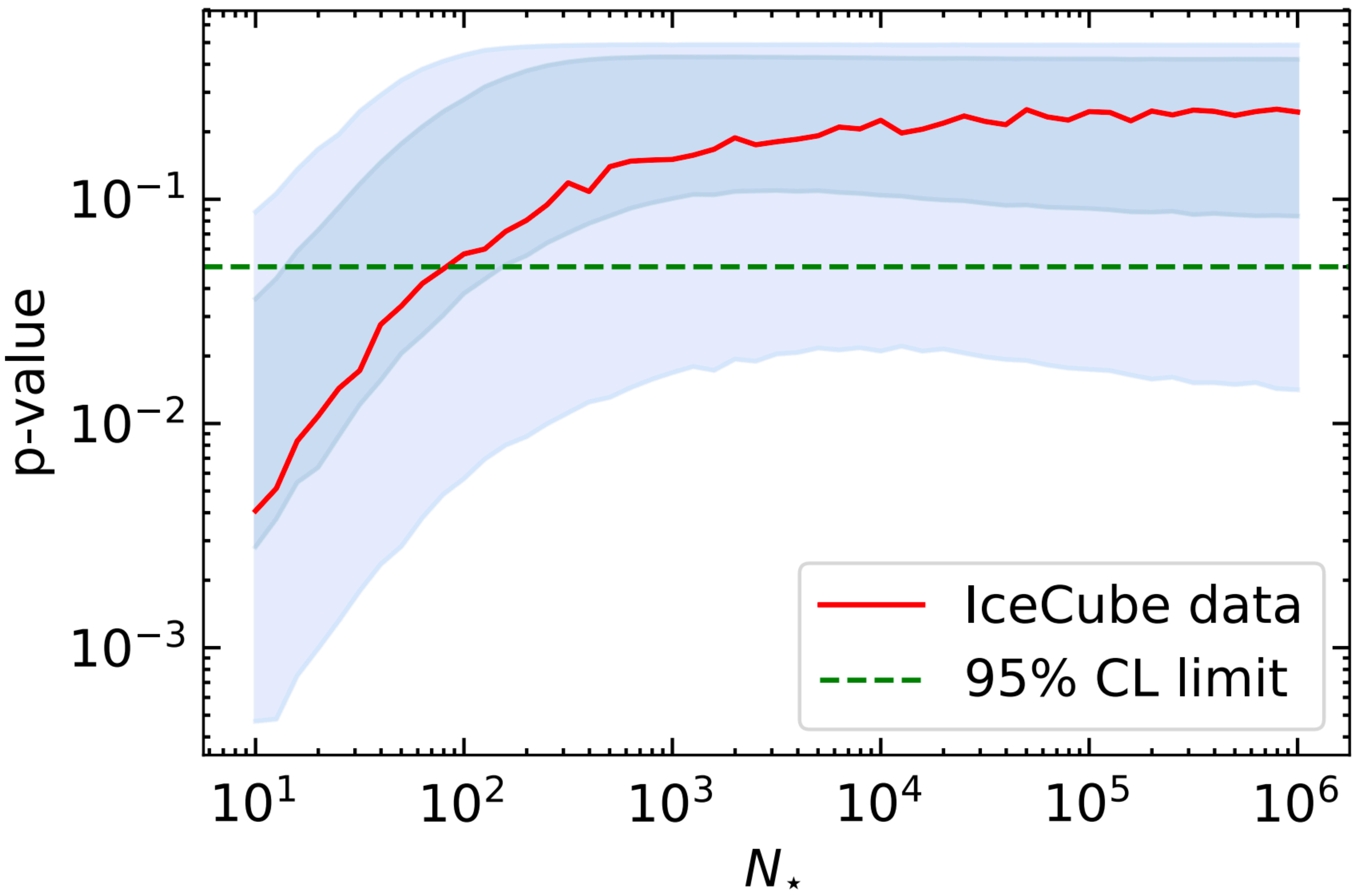
Angular Power spectrum

$$N(\theta, \phi) = \sum_{\ell m} a_{\ell m} Y_{\ell m}(\theta, \phi)$$

$$C_l = \frac{1}{2l+1} \sum_m |a_l^m|^2$$

21 observed events with $E_\nu > 50\,\mathrm{TeV}$,

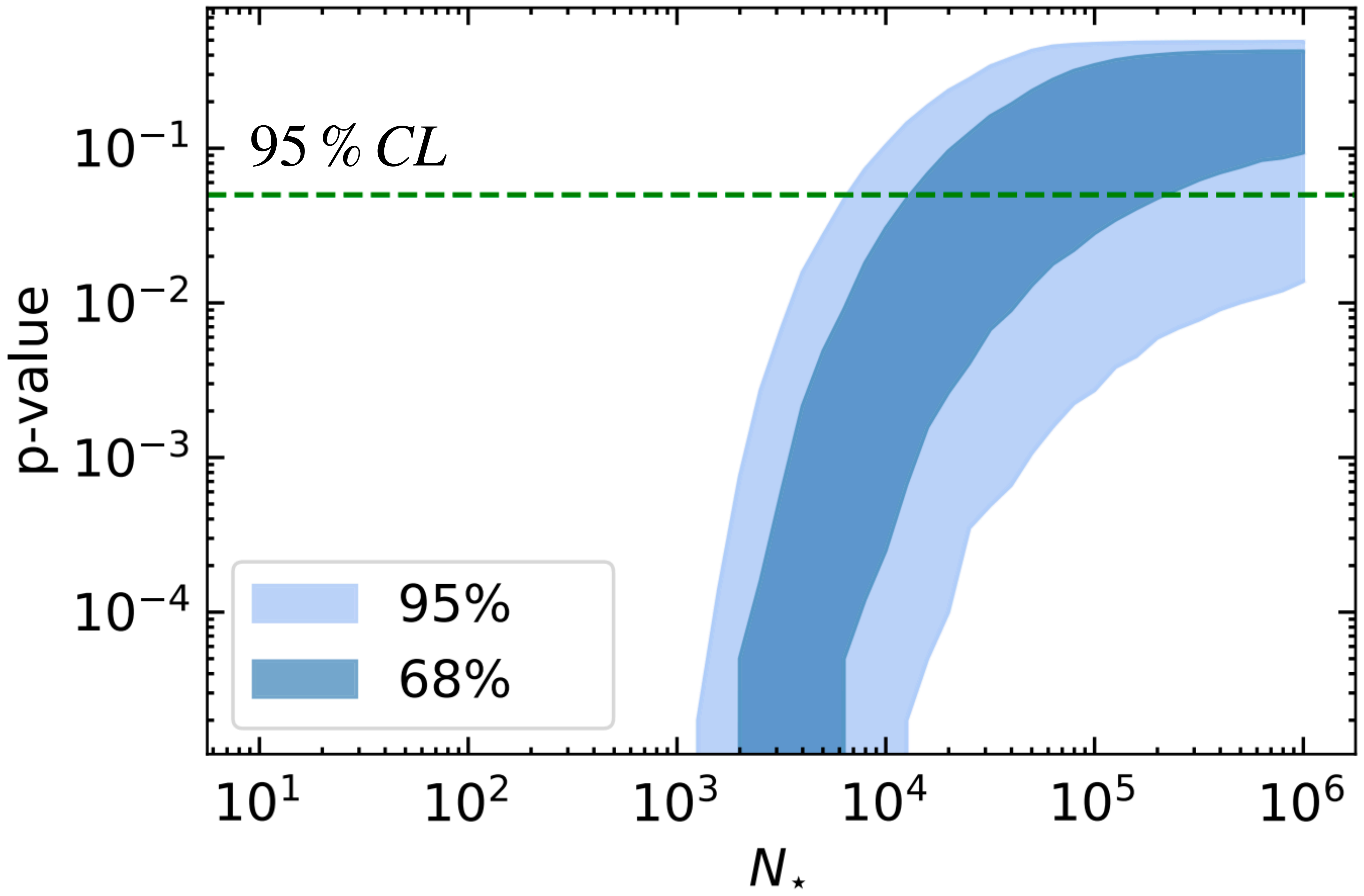
Constrain $N_\star < 82$



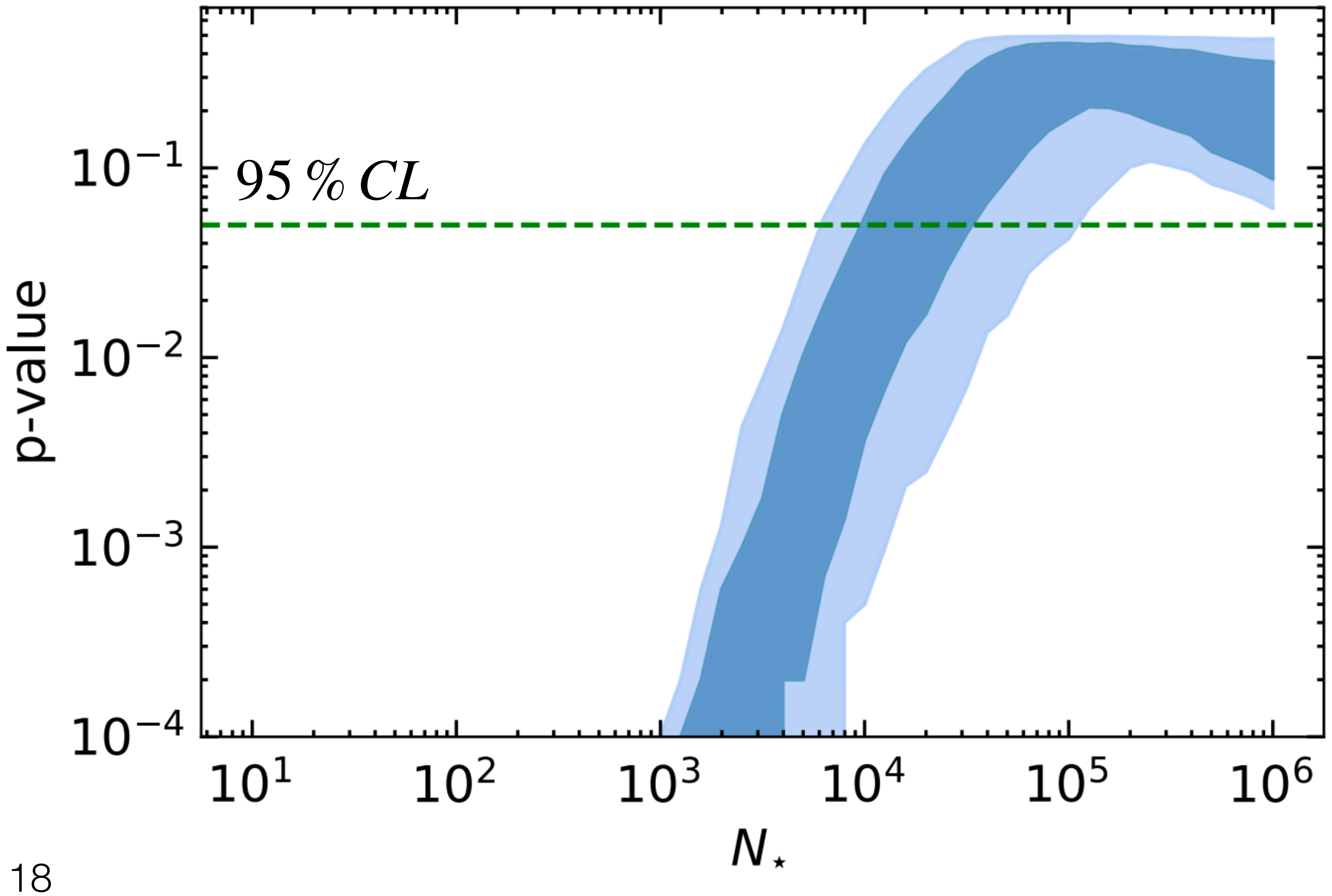
10-year exposure $N_\star = \infty$

- Blazars $N_\star = 600$
- Starburst galaxies $N_\star = 10^7$

IceCube-Gen2



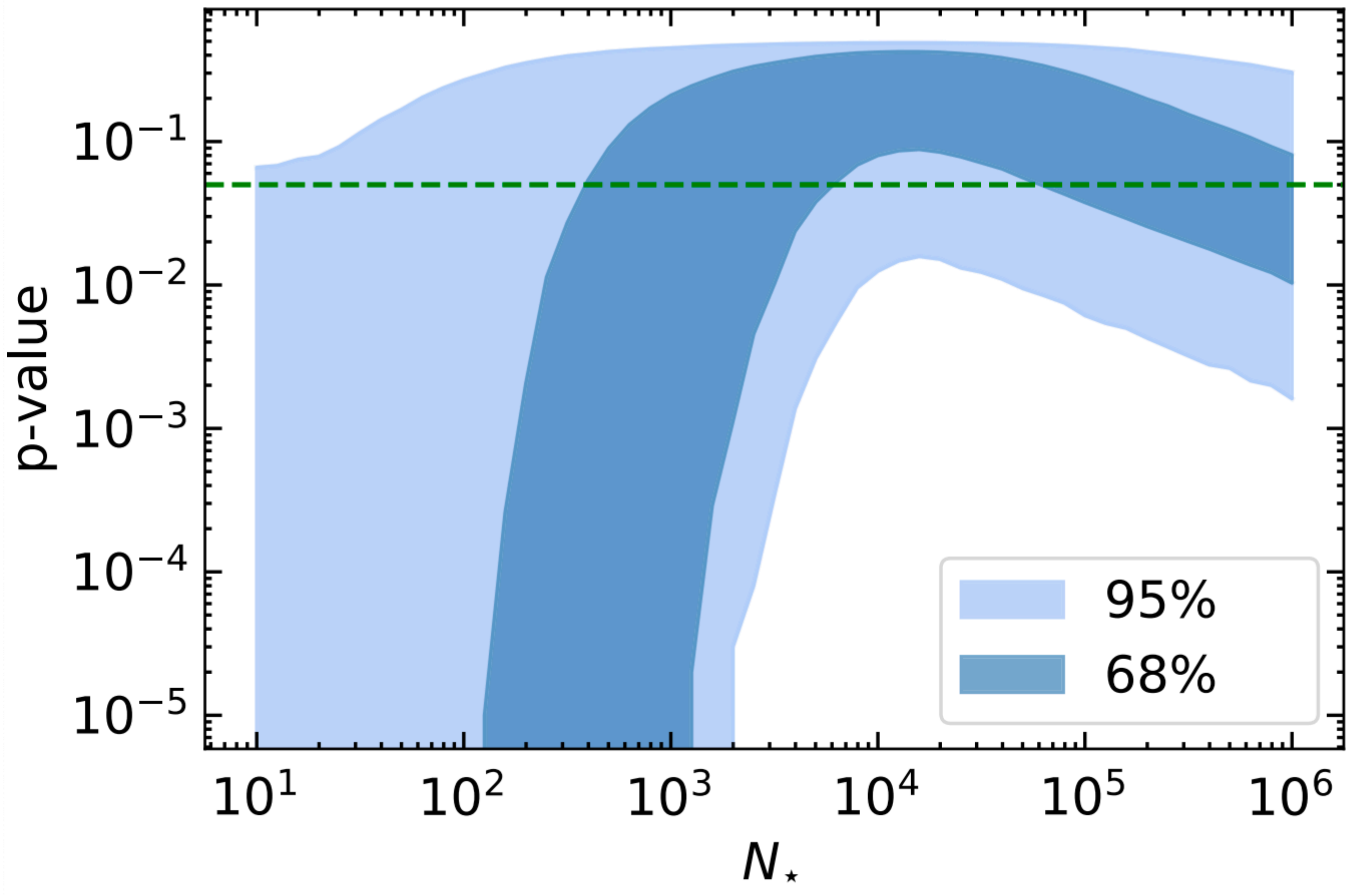
KM3NeT



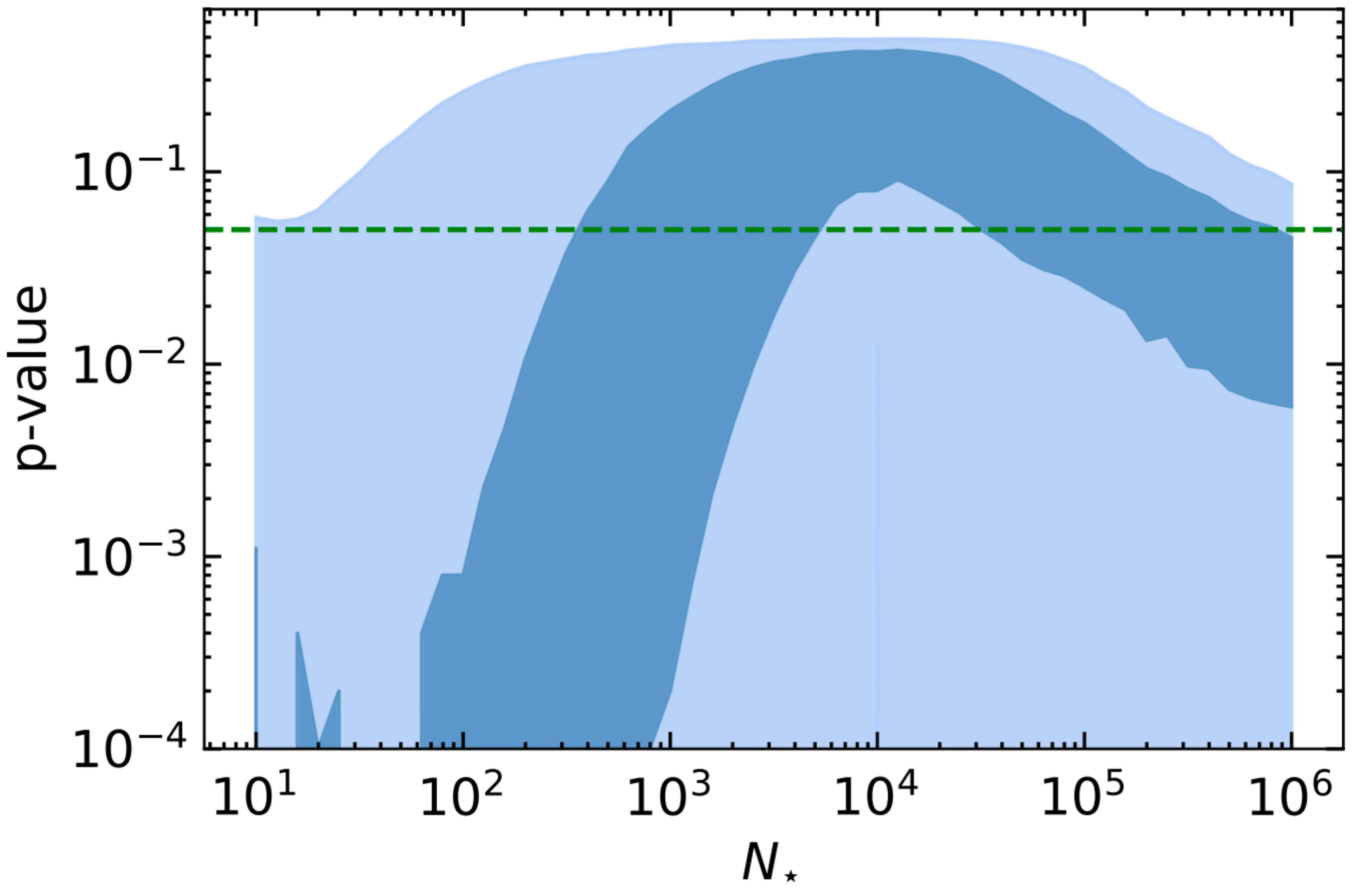
10-year exposure $N_\star = 10^4$

- Blazars $N_\star = 600$
- Starburst galaxies $N_\star = 10^7$

IceCube-Gen2



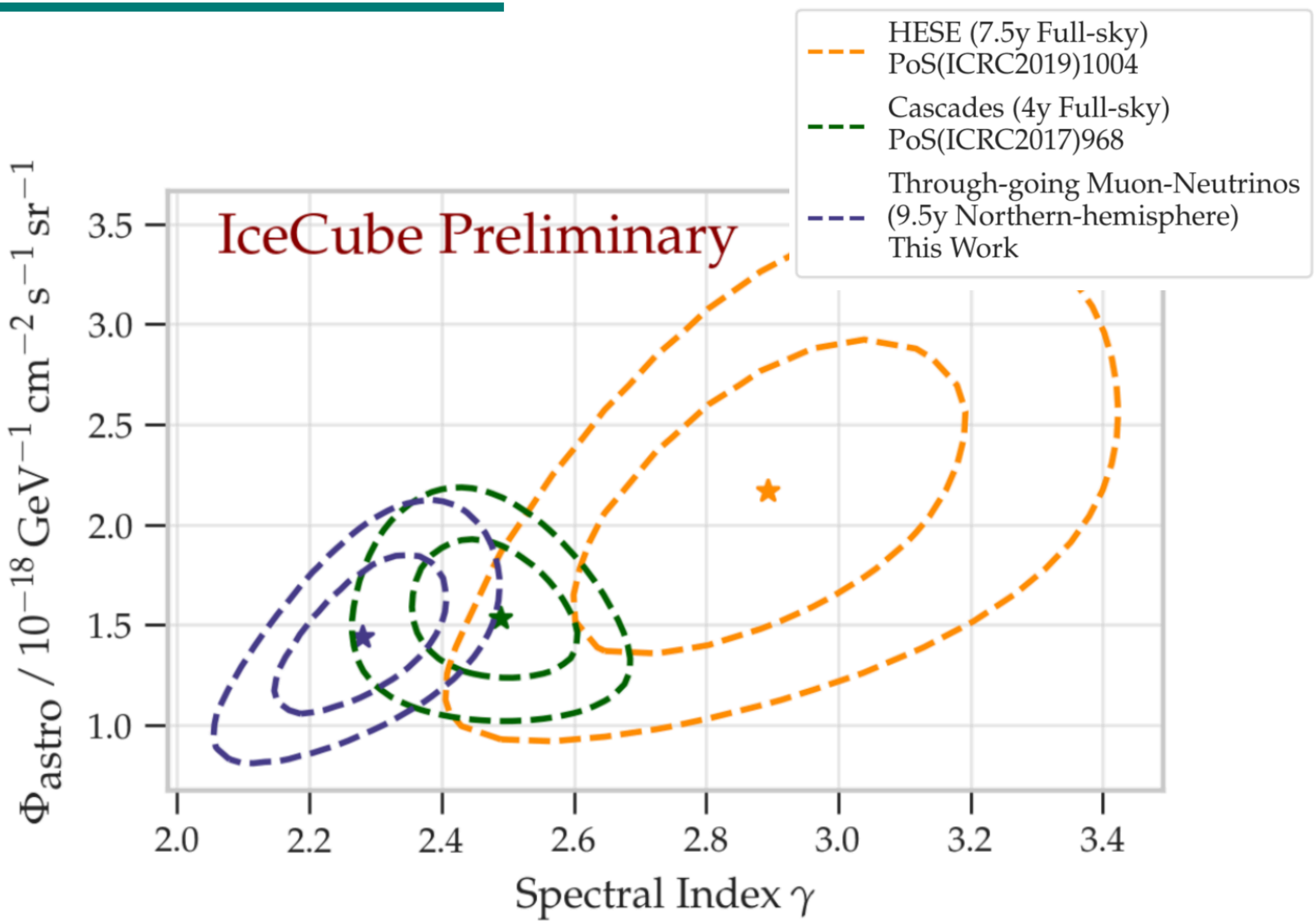
KM3NeT



Heavy Dark Matter

- **Tension between HESE (full sky) and Through-Going (Northern hemisphere)**

$$\frac{d\Phi_\nu}{dE_\nu} = \Phi_0 \left(\frac{E_\nu}{100\text{TeV}}\right)^\gamma$$

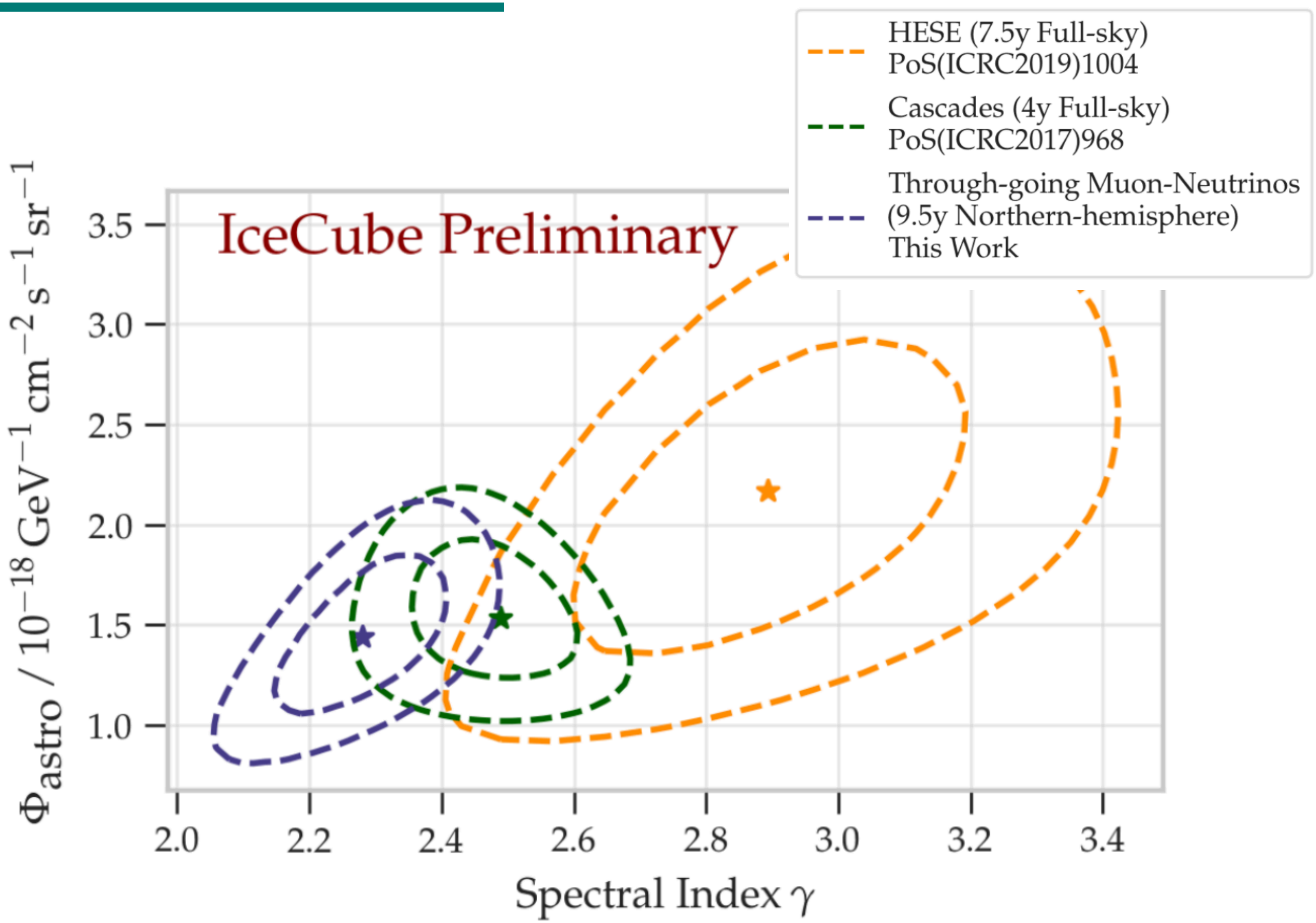


J. Stettner, 2019

Heavy Dark Matter

- **Tension between HESE (full sky) and Through-Going (Northern hemisphere)**
- **HESE best-fit** $\gamma = 2.89$
- **1st order Fermi-acceleration**

  $2.0 \lesssim \gamma \lesssim 2.2$
- **Excess of events for single component (IC & ANTARES)**
- **2-component**



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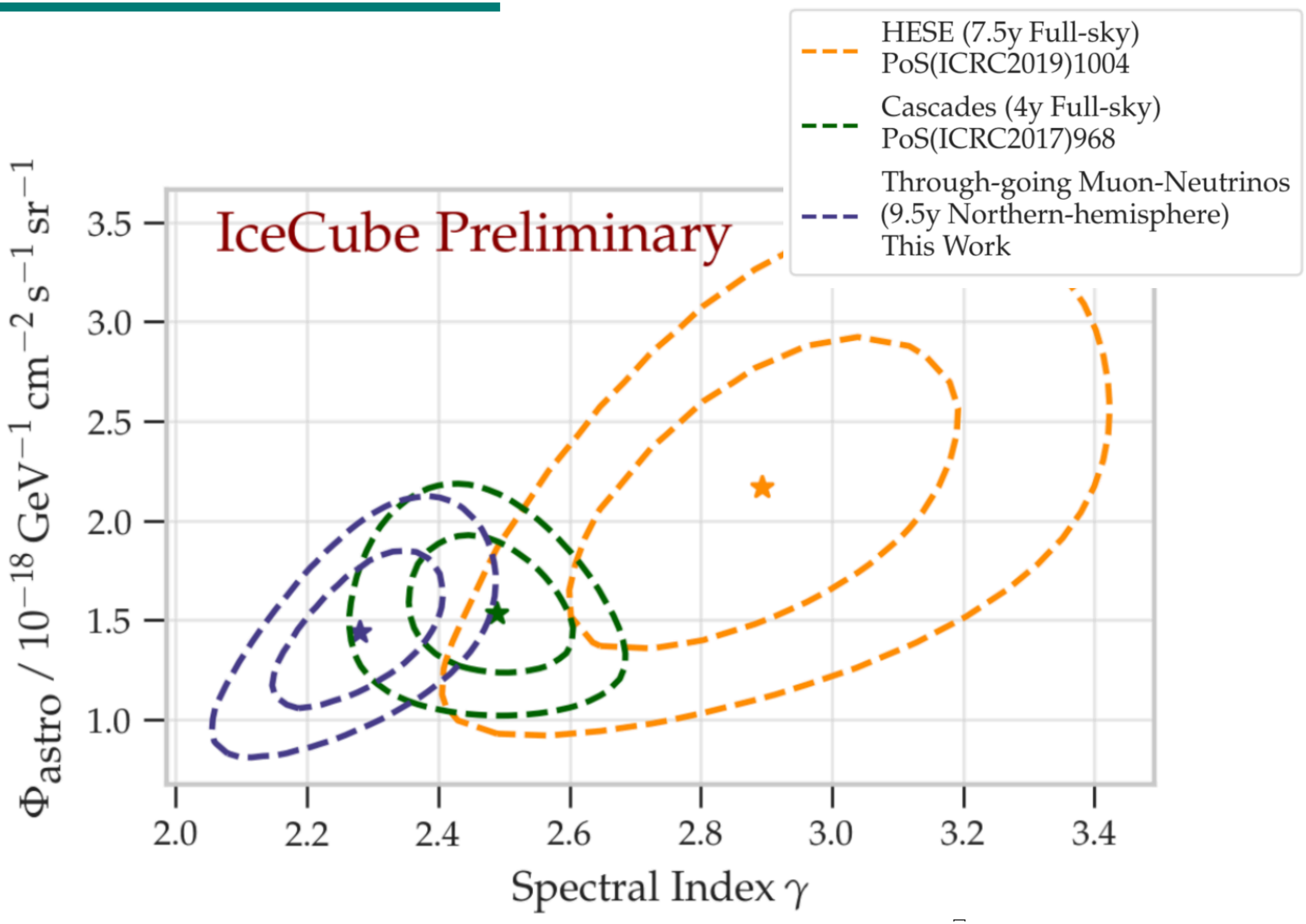
Heavy Dark Matter

- **Tension between HESE (full sky) and Through-Going (Northern hemisphere)**
- **DM contributes to Extra-Galactic and Galactic emission**
- **Cannot produce too much anisotropy -> constrain DM parameters**



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Null hypothesis

- **Isotropic astrophysical flux:** 7.5-yr HESE

$$\frac{d\Phi_{\nu+\bar{\nu}}}{dE} = \frac{6.45}{3} \cdot \left(\frac{E}{100\mathrm{TeV}}\right)^{-2.89} \cdot 10^{-18}\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$$

Model

- **Isotropic astrophysical flux:** 10-yr Through-going

$$\frac{d\Phi_{\nu+\bar{\nu}}}{dE} = 1.44 \cdot \left(\frac{E}{100\mathrm{TeV}}\right)^{-2.28} \cdot 10^{-18}\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$$

- **Dark matter flux**

Null hypothesis

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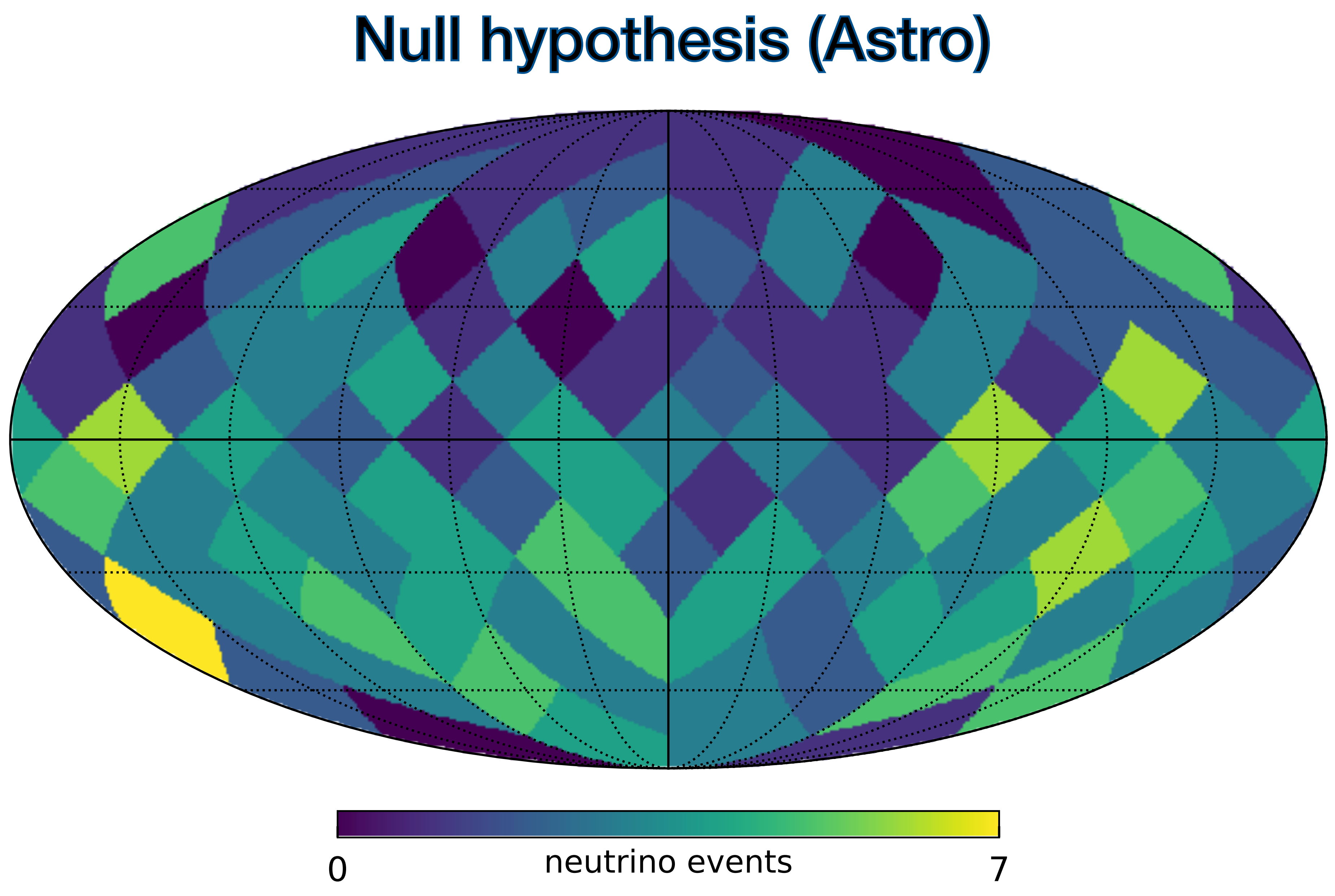
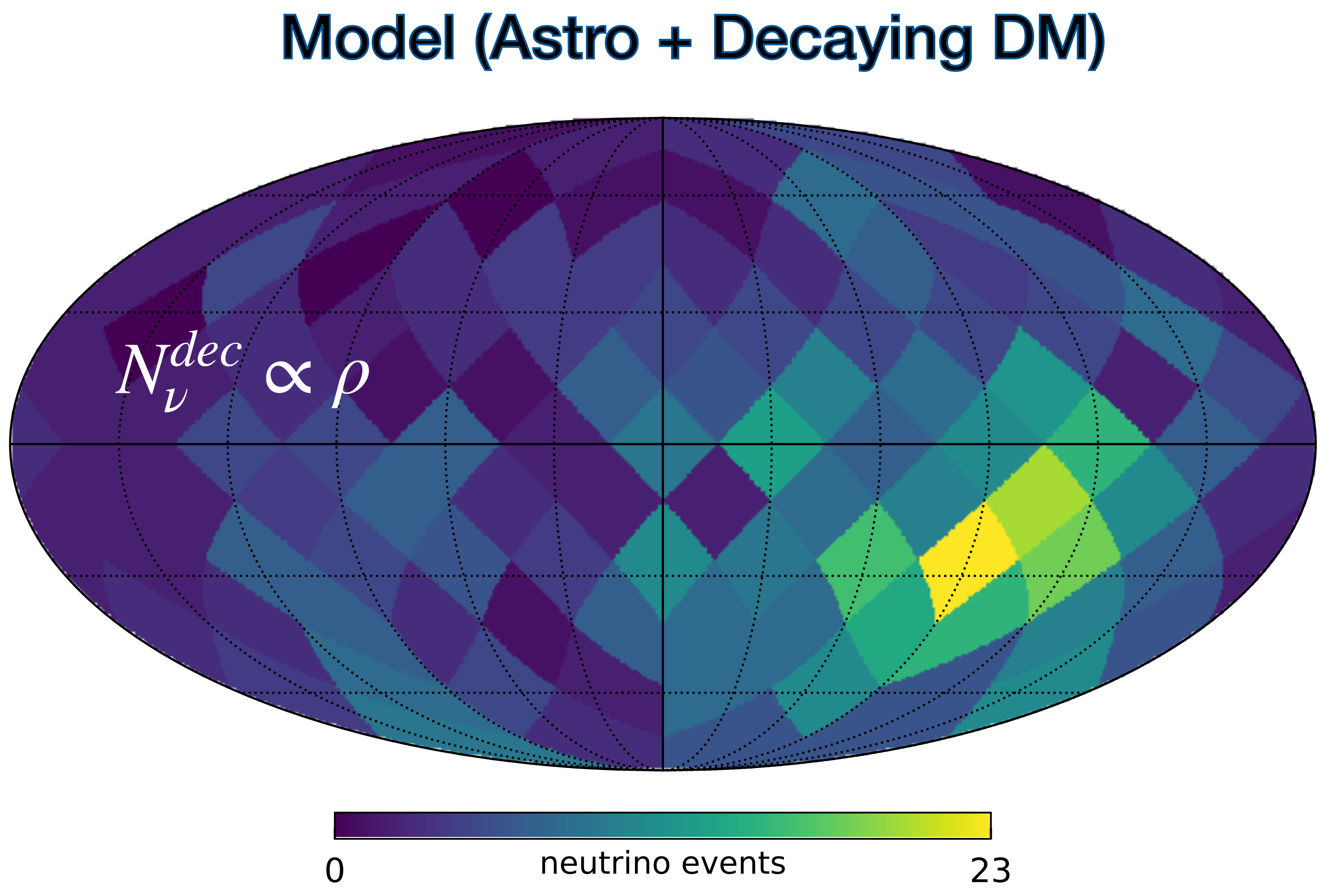
- **Dark matter flux**

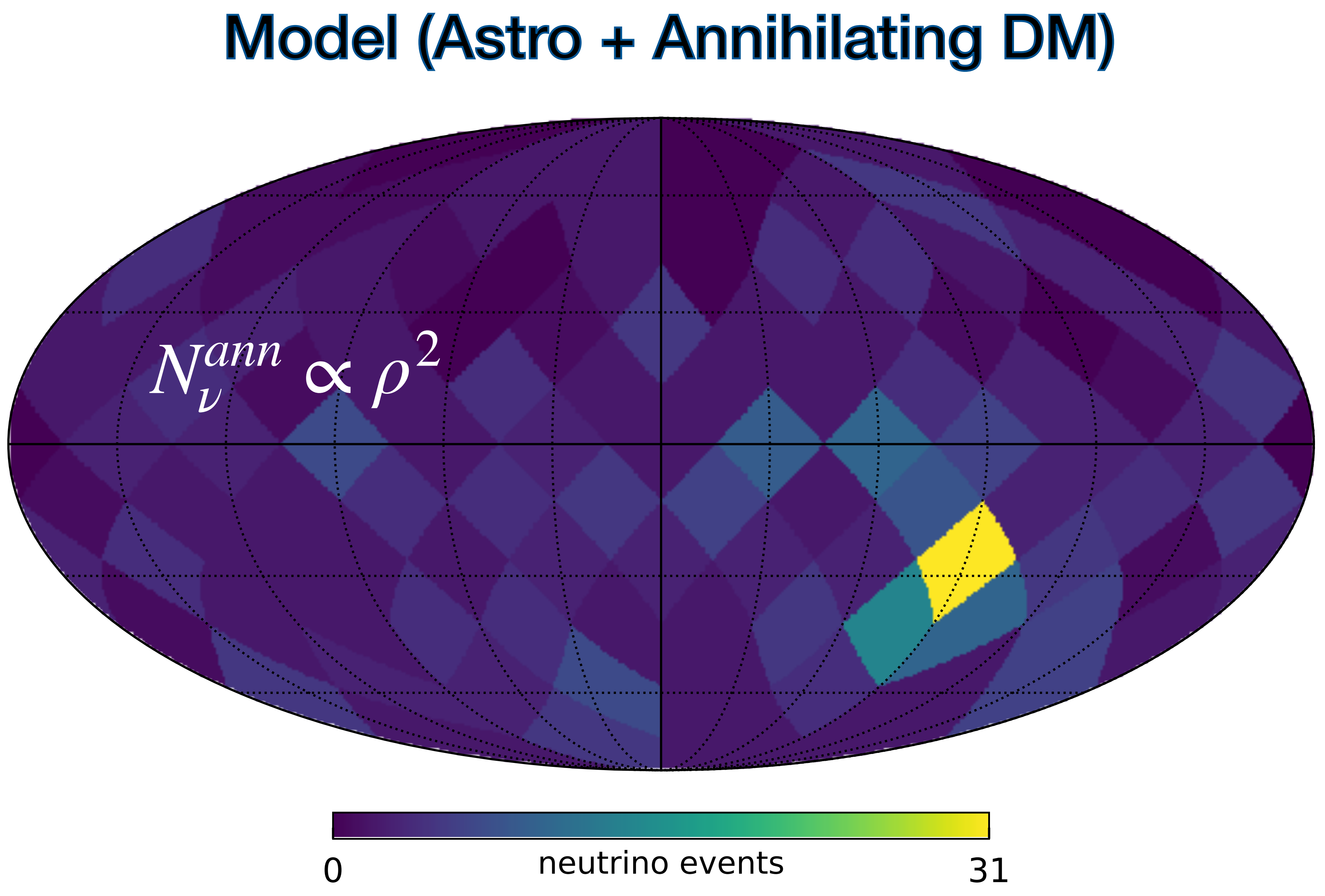
$$N_\nu^{tot} = \underbrace{N_\nu^{Astr} + N_\nu^{Atm} + N_\nu^{DM,EG}}_{\text{Isotropic}} + \underbrace{N_\nu^{DM,Gal}}_{\text{Anisotropic}}$$

MC Simulations

10-yr IceCube-Gen2 HESE events







6-year HESE data

33 observed events (60-200 TeV)

Free parameter:

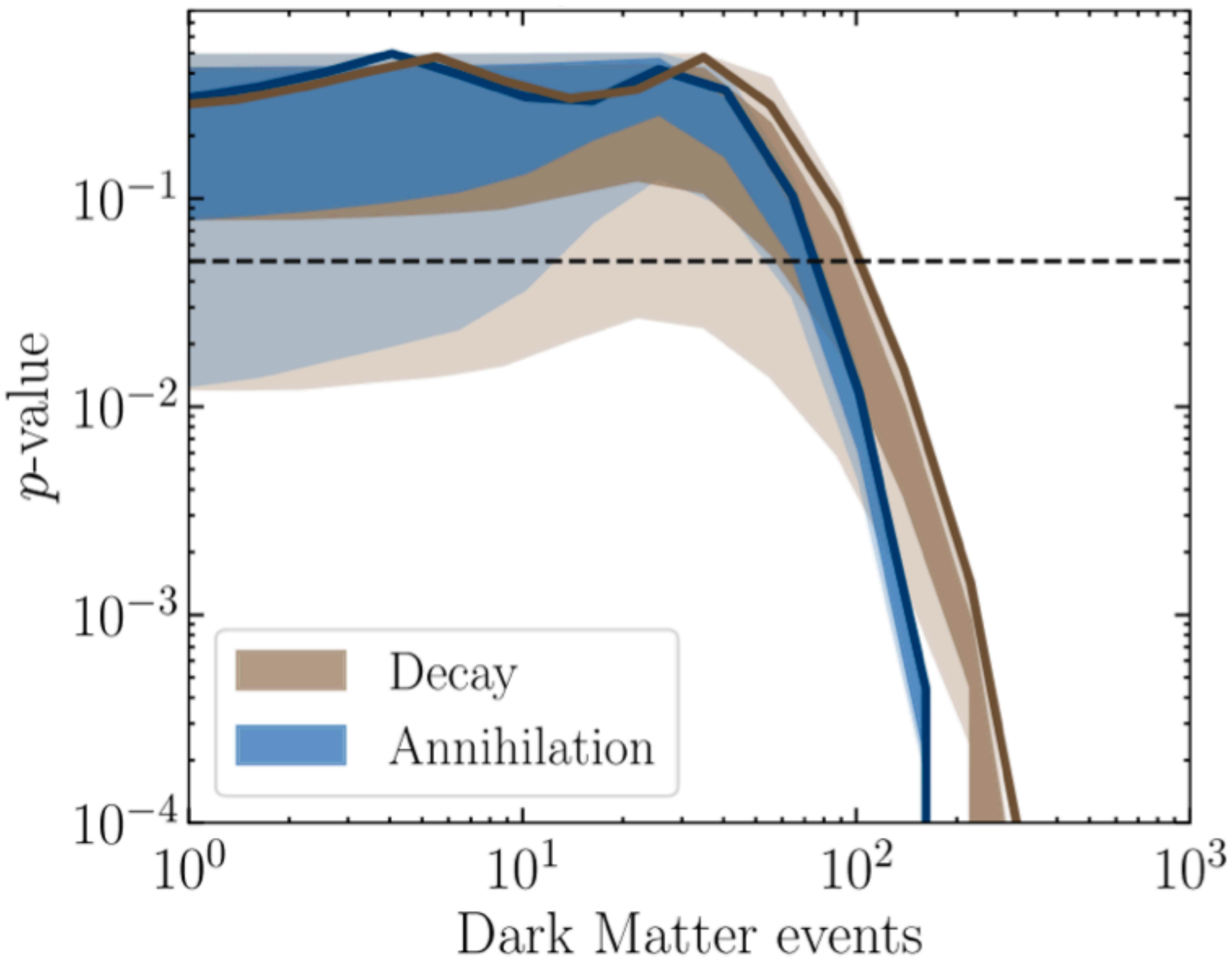
Cross section & Lifetime

Model

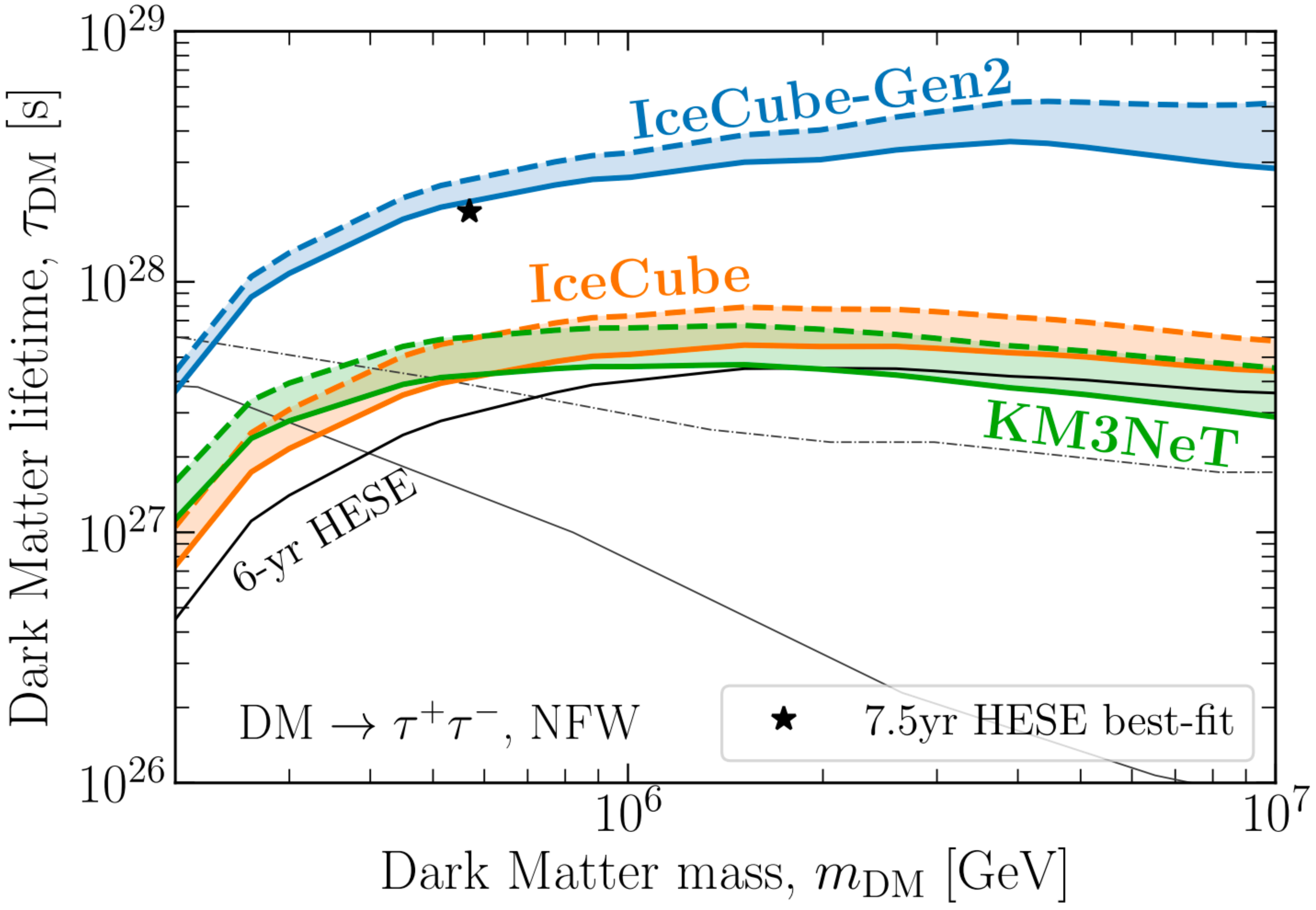
$$\mathrm{DM} \rightarrow \tau^+\tau^-,\ \ \mathrm{m_{DM}} = 400\,\mathrm{TeV}$$

$$\mathrm{DM\,DM} \rightarrow \tau^+\tau^-,\ \ \mathrm{m_{DM}} = 200\,\mathrm{TeV}$$

NFW density profile

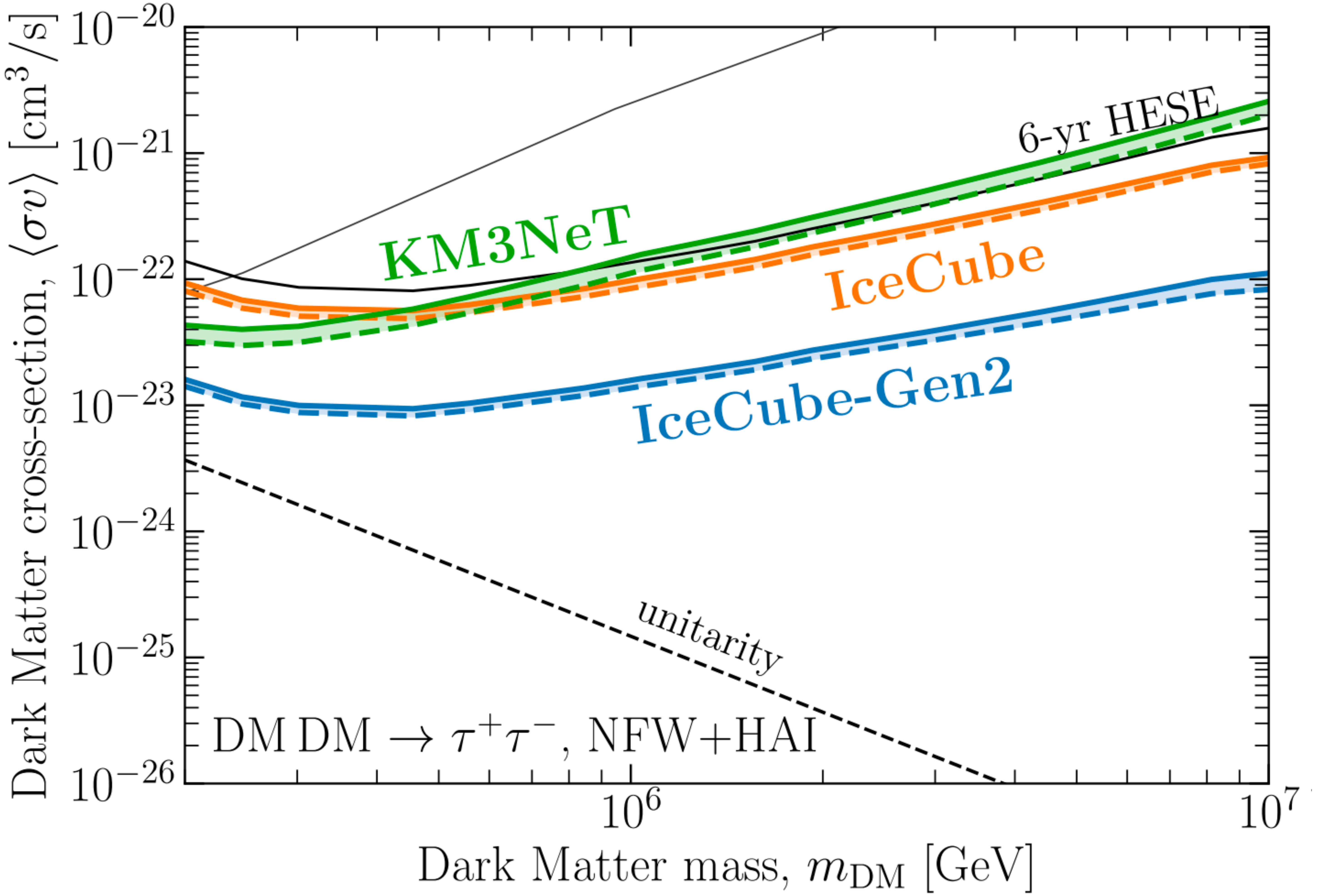


Future sensitivity Decay



- 10-yr exposure
- ★ Best-fit DM component
- Gamma-ray constraints

Future sensitivity Annihilation



- 10-yr exposure
- Gamma-ray constraints
- Constraint by unitary

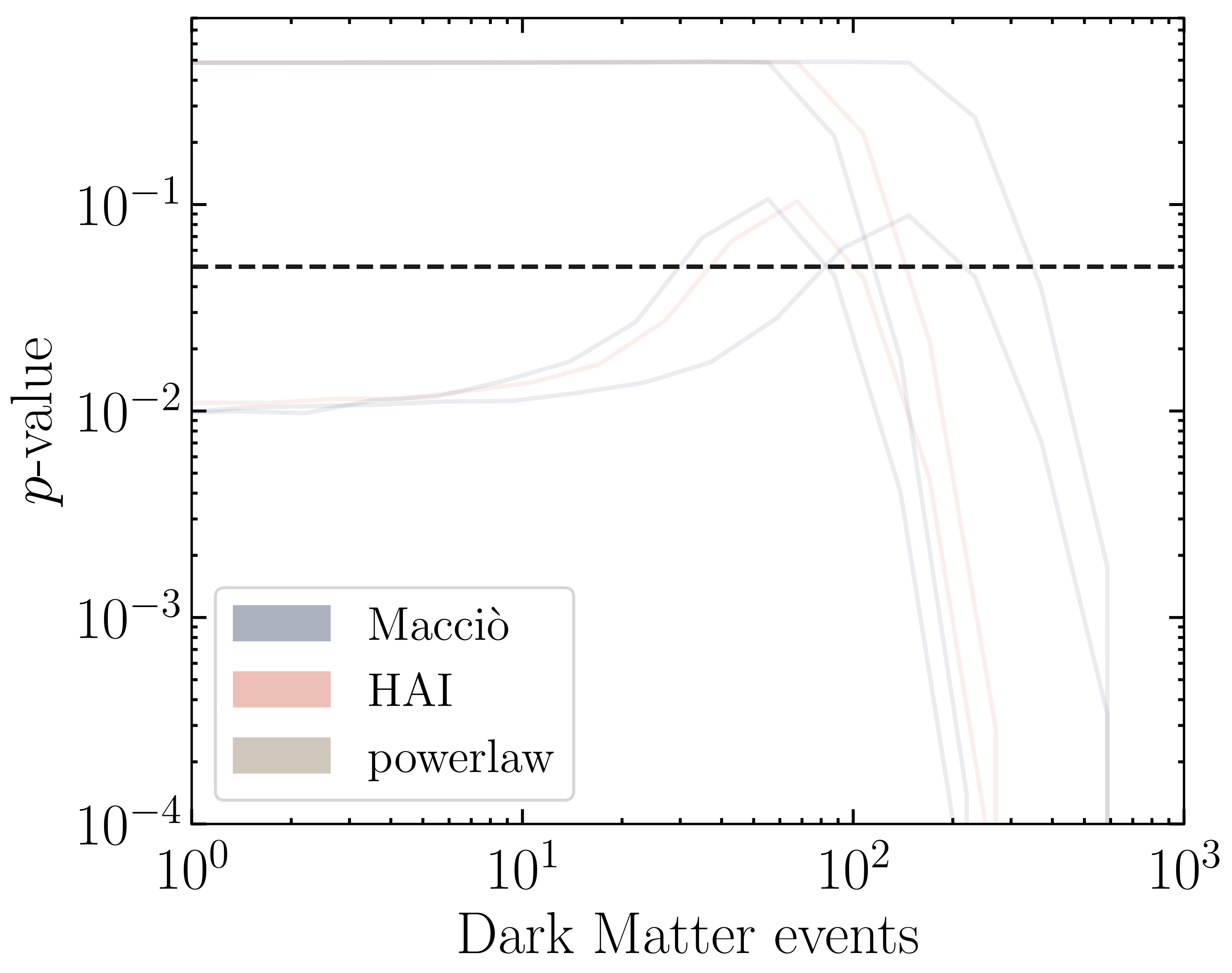
Summary

- ν **Angular Power Spectrum powerful probe**
- ν **2-year of IceCube data with 21 events already constrains $\mathbf{N_\star > 82}$**
- ν **With 10-yr IceCube-Gen2 & KM3NeT exposure we can constrain bright sources**
- ν **Constrain DM parameters with IceCube HESE and TG KM3NeT exposure**
- ν **Using only isotropic/anisotropic features**
- ν **Poster Marco Chianese on DM constraints with neutrino detectors**

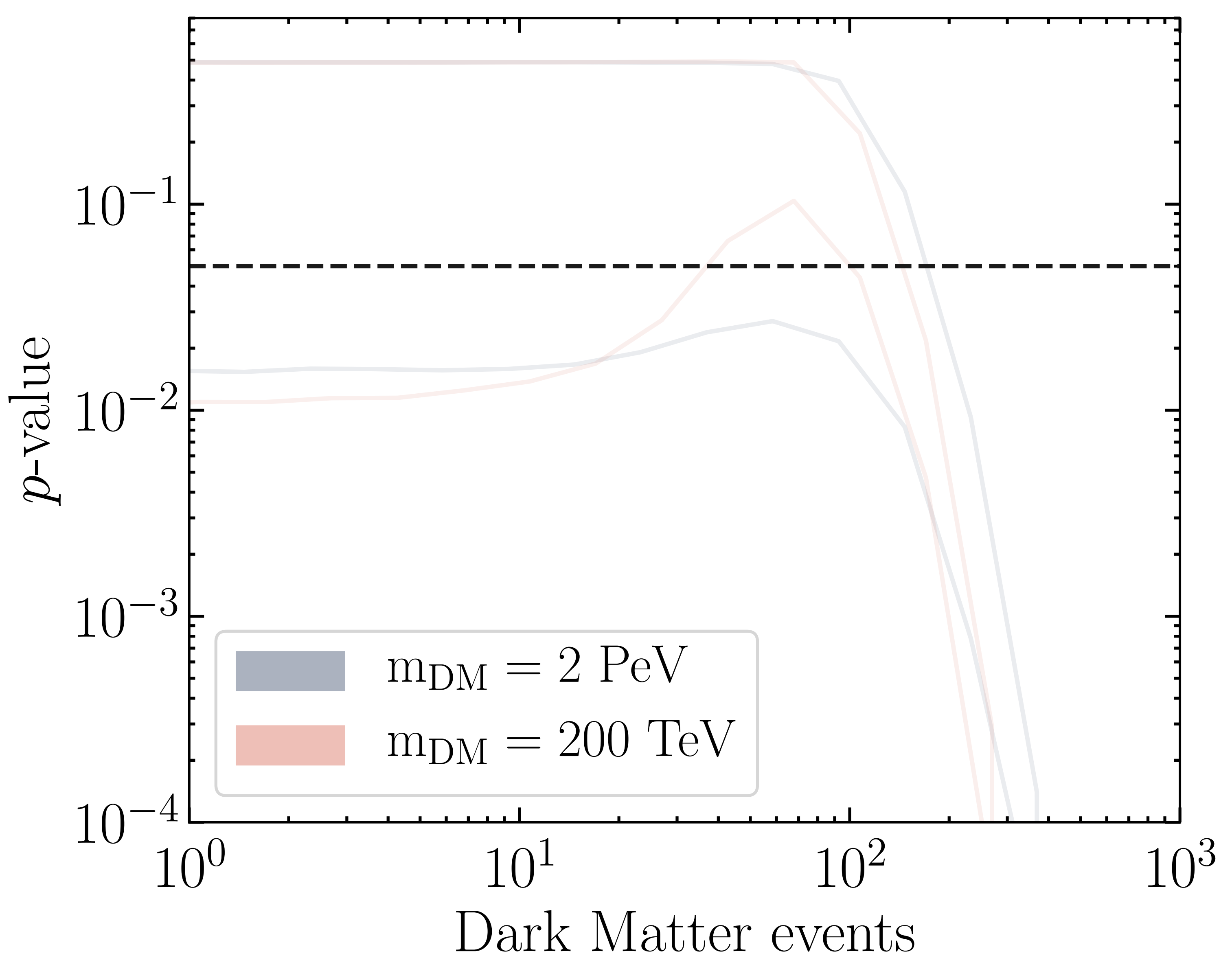
Backup slides

P-value 10-year IceCube-Gen2 Annihilation

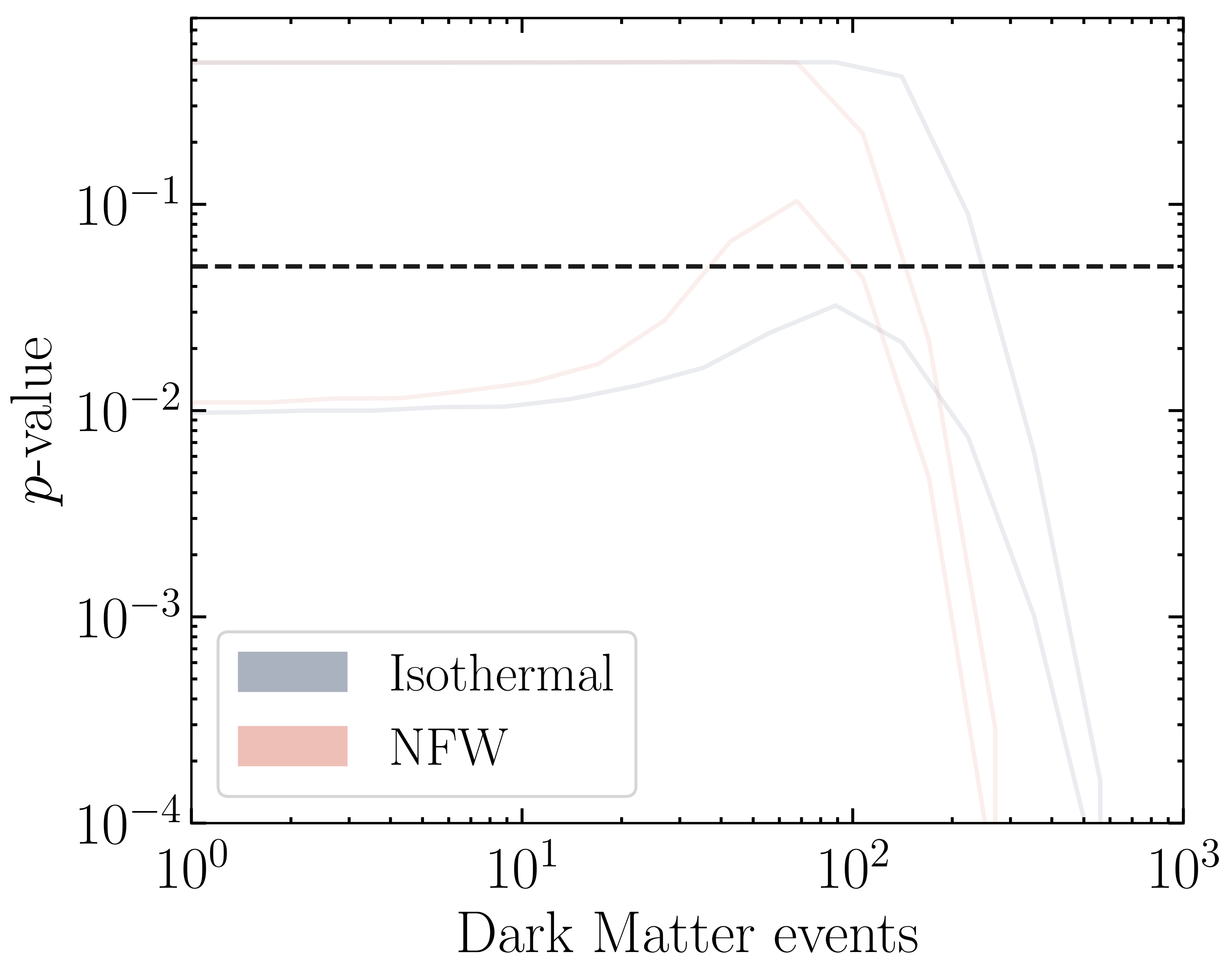
Boost factor



DM Mass

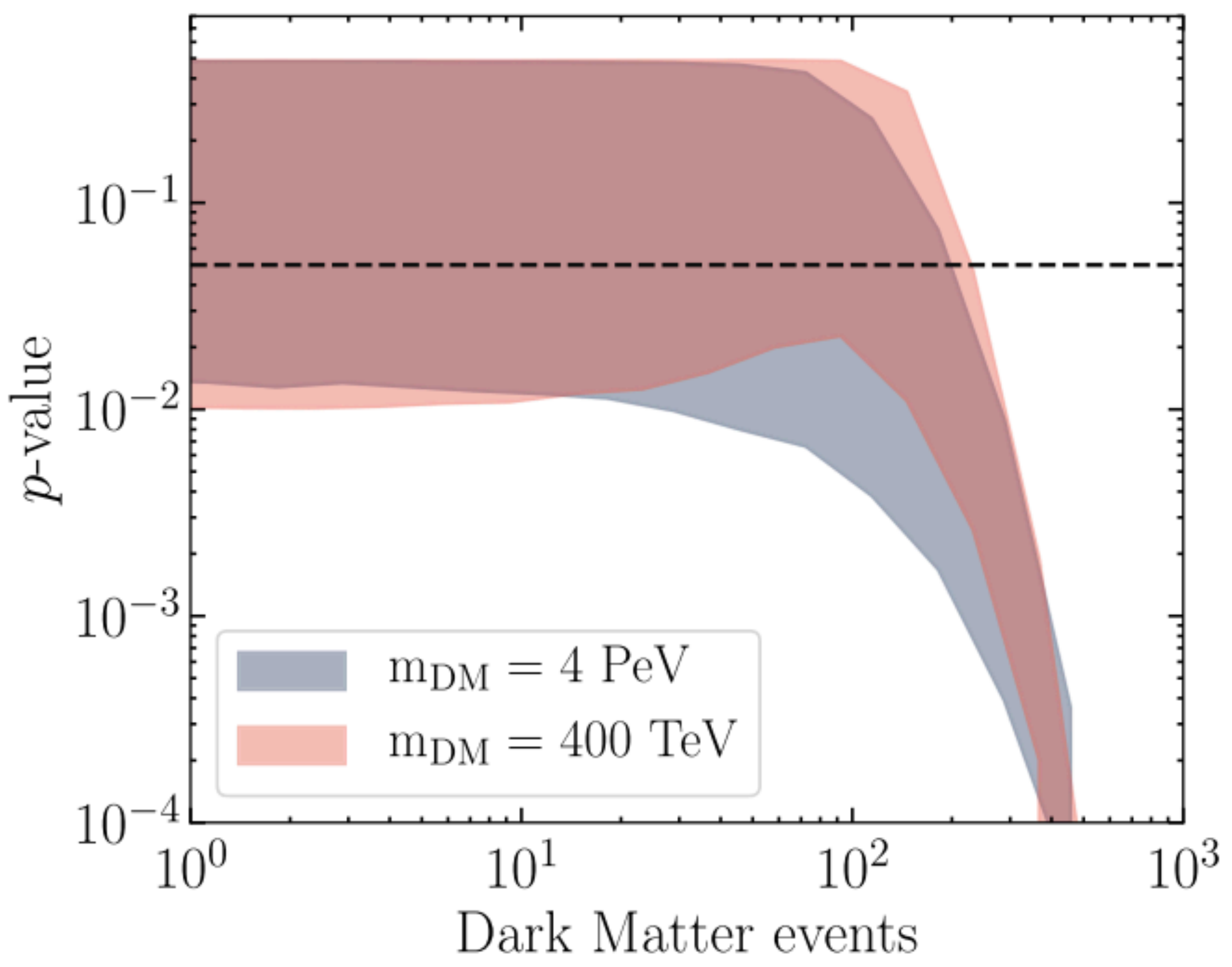


Density profile

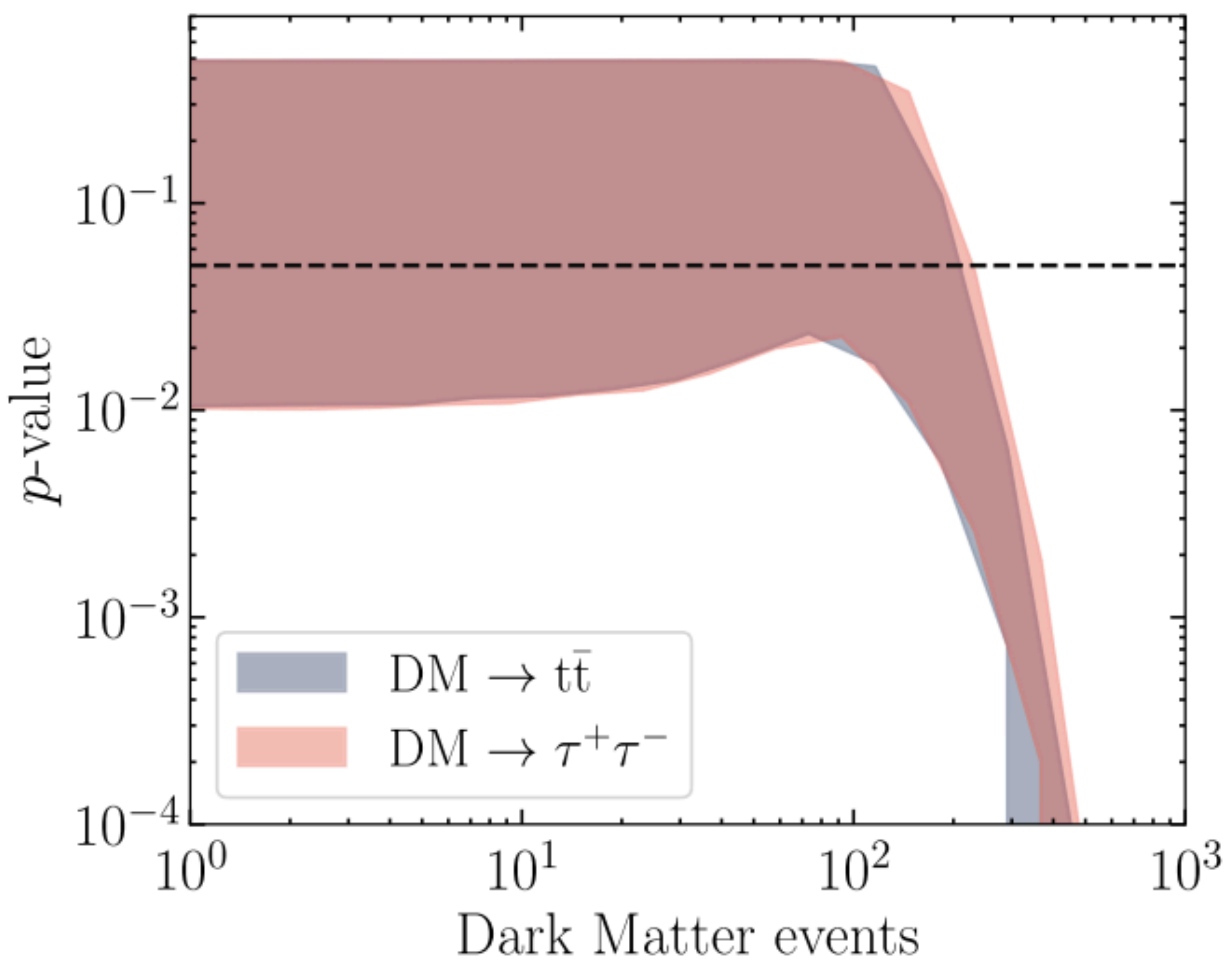


P-value 10-year IceCube-Gen2 Decay

DM Mass



Channel



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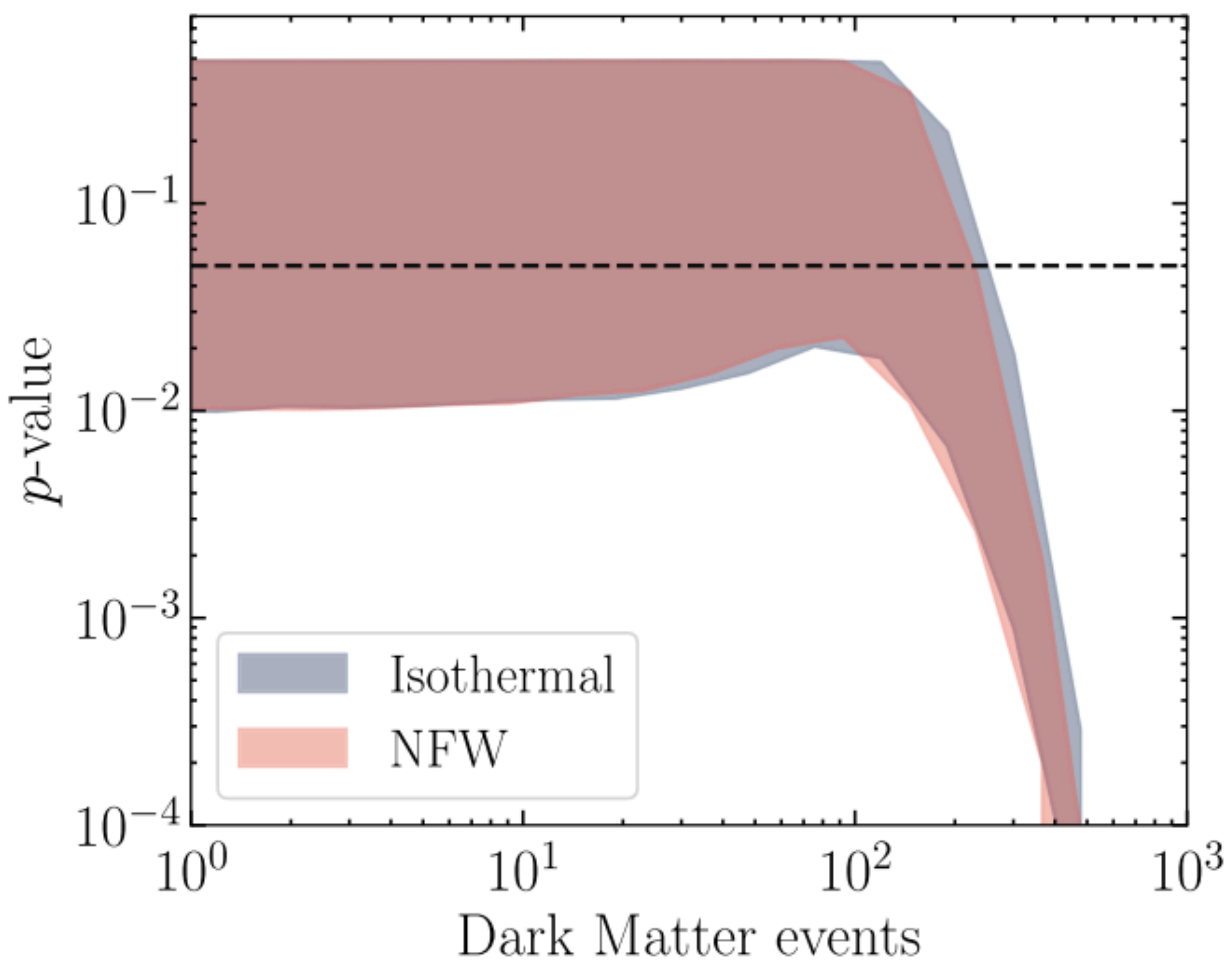

Source-flux distribution

Homogeneous Univers, Euclidean space

$$F = \frac{L}{4\pi r^2},\ \rho = \frac{N}{V}$$

$$\frac{d\mathrm{N}}{d\mathrm{F}} = \frac{d\mathrm{N}}{d\mathrm{r}}\frac{d\mathrm{r}}{d\mathrm{F}} = F^{-5/2}$$

$$\alpha = 2.5$$

Olber's paradox

$$\beta = 1.5$$

$$\frac{d\mathrm{N_s}}{d\mathrm{F}} \propto \begin{cases} F^{-\alpha} & F_\star < F \\ F^{-\beta} & F_0 < F < F_\star \end{cases}$$