Heavy Dark Matter Annihilation Search Towards Dwarf Galaxies with the IceCube Neutrino Observatory.

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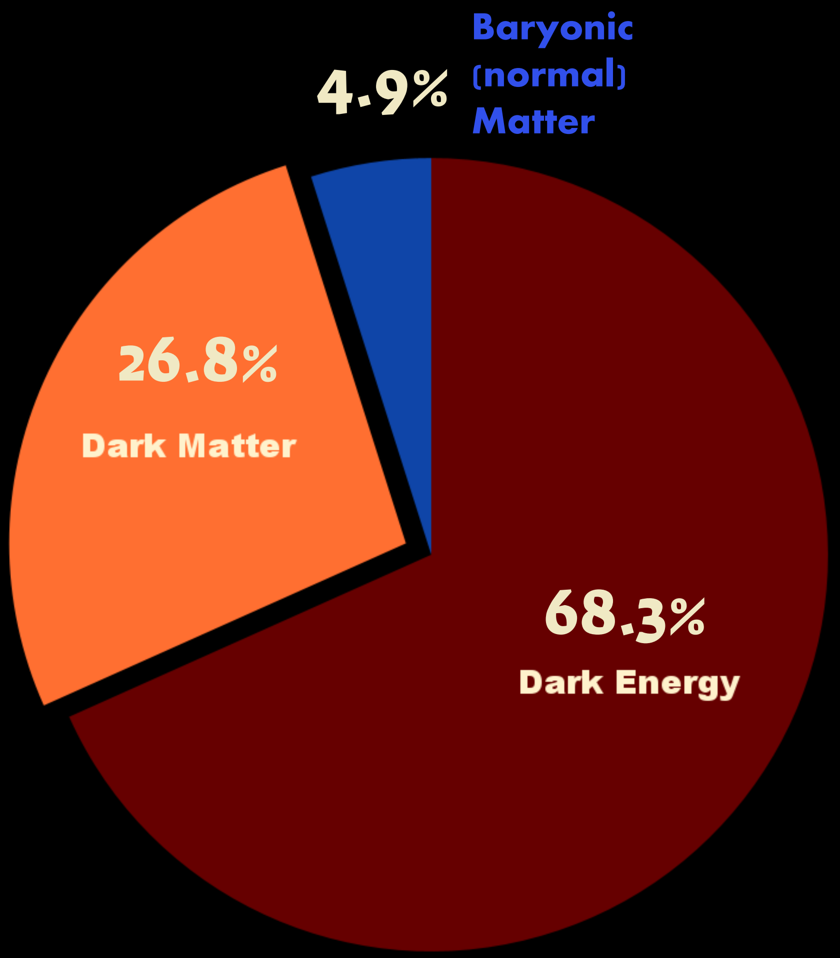
The Dark Matter Basics

What we know from astrophysical observations

ABUNDANT
- 5x more than normal (baryonic) matter
- Accounts for ~27% of the universe's energy

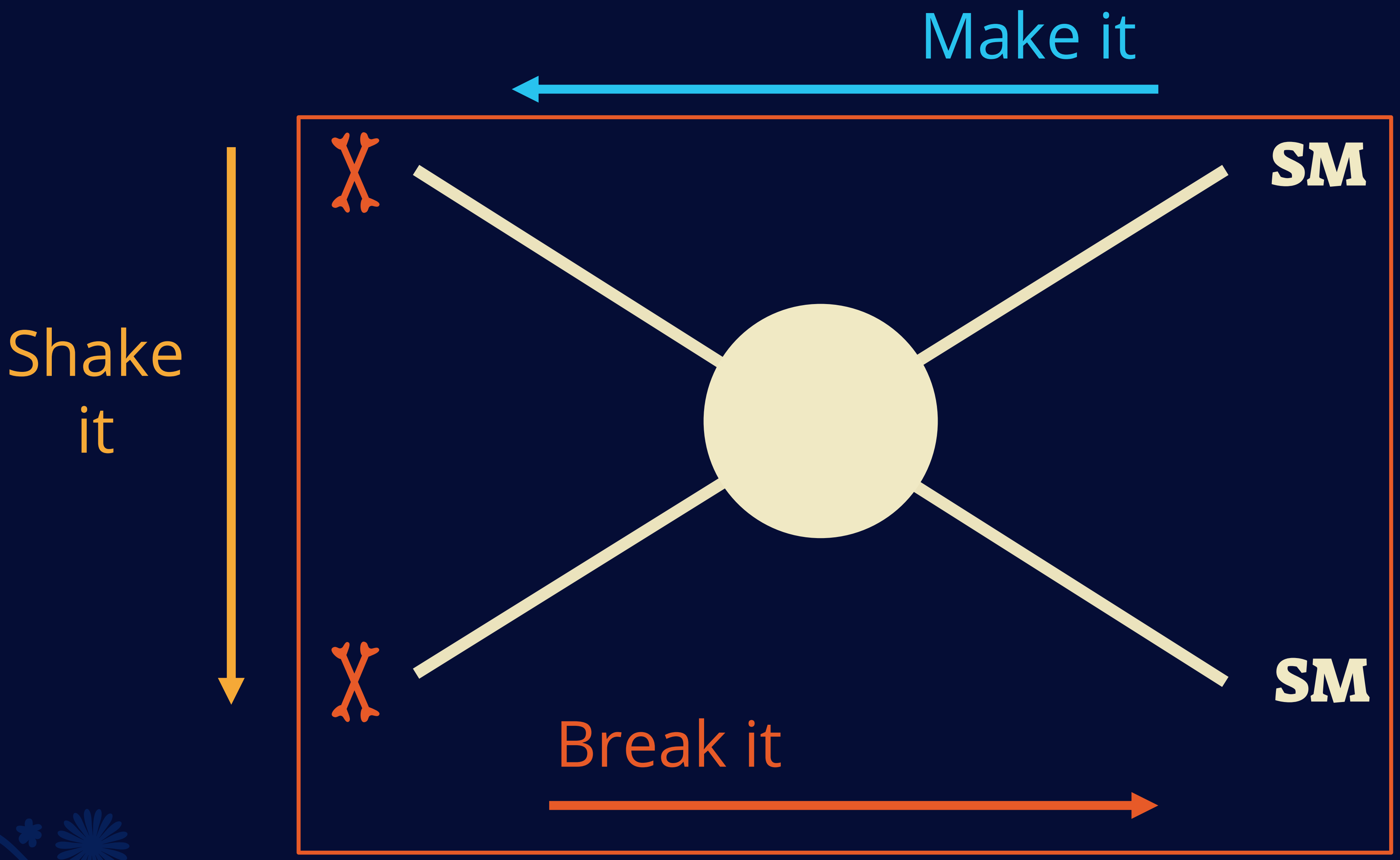
DARK
- Does not interact with the electromagnetic force (aka light)
- Tight limits on other Standard Model forces

OLD
- Plays a massive role in the shape and evolution of our universe and galaxy.



Source: NASA

How we can begin to probe DM



Indirect Detection of Annihilating Dark Matter

Physics parameter to extract

Contributes to the shape of spectra

Particle Physics Component

$$\frac{d\Phi_\nu}{dE_\nu} = \frac{1}{8\pi}\frac{\langle\sigma_{ann} v\rangle}{m_\chi^2}\frac{dN_\nu}{dE_\nu} \times \int_{src} d\Omega \int_{l.o.s.} \rho^2 dl(r,\theta')$$

Astrophysical Component (J-factor)

Priors to normalization

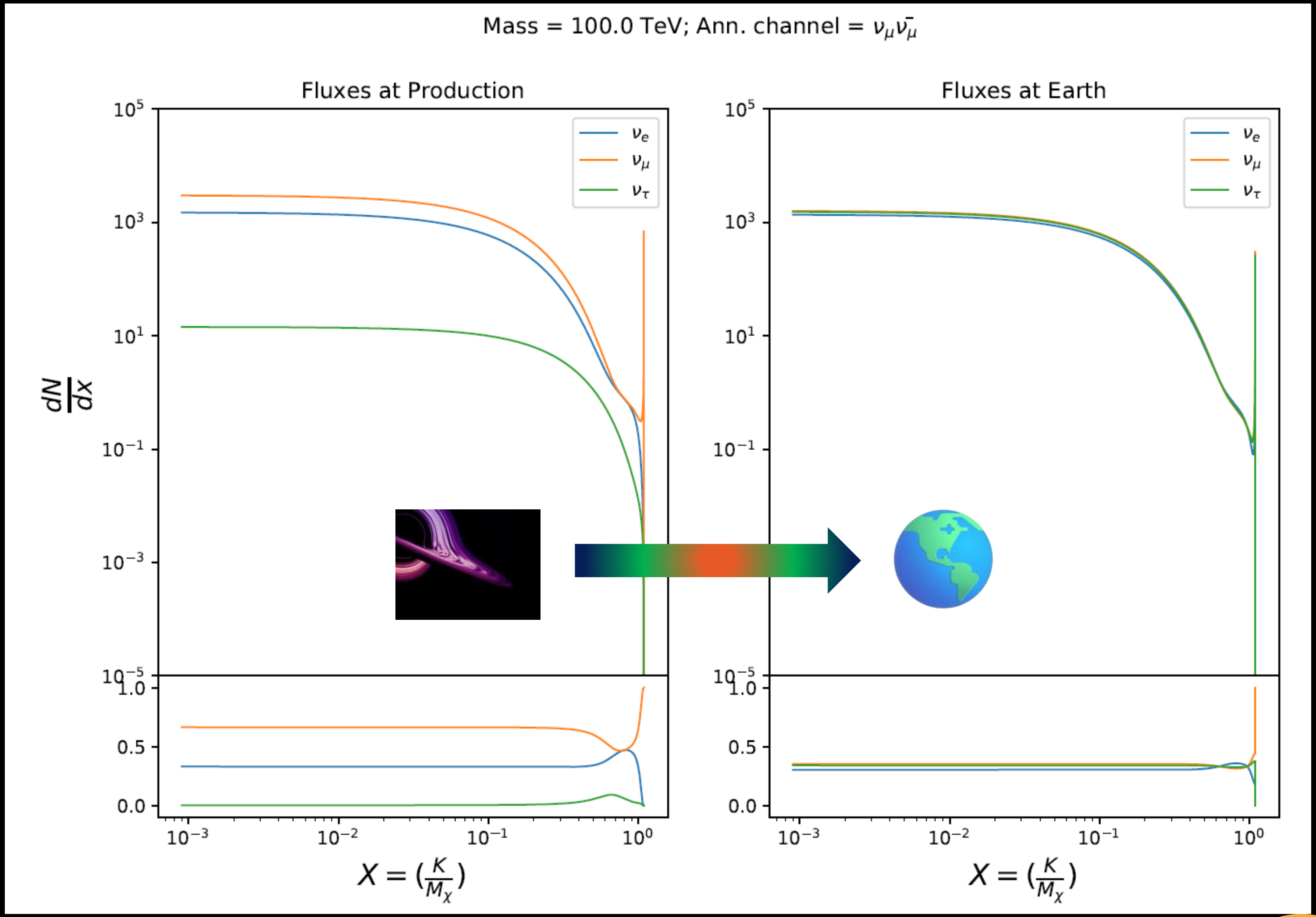
Likelihood fit over the simplified equation:

$$A \times \frac{dN_\nu}{dE_\nu}(M_\chi, E_\nu, SM_{chan})$$

Particle Physics Component Neutrinos Oscillate!

Neutrinos have been observed to oscillate between their flavor states!

A neutrino spectrum at Earth will be different than it was at the source of production



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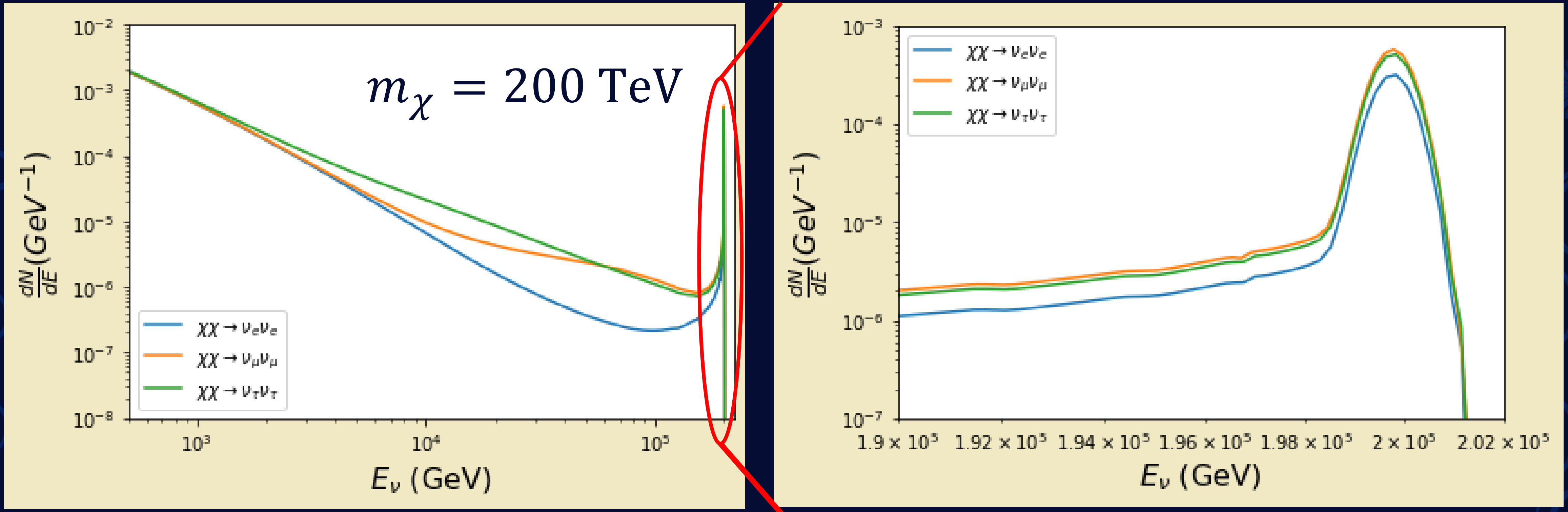
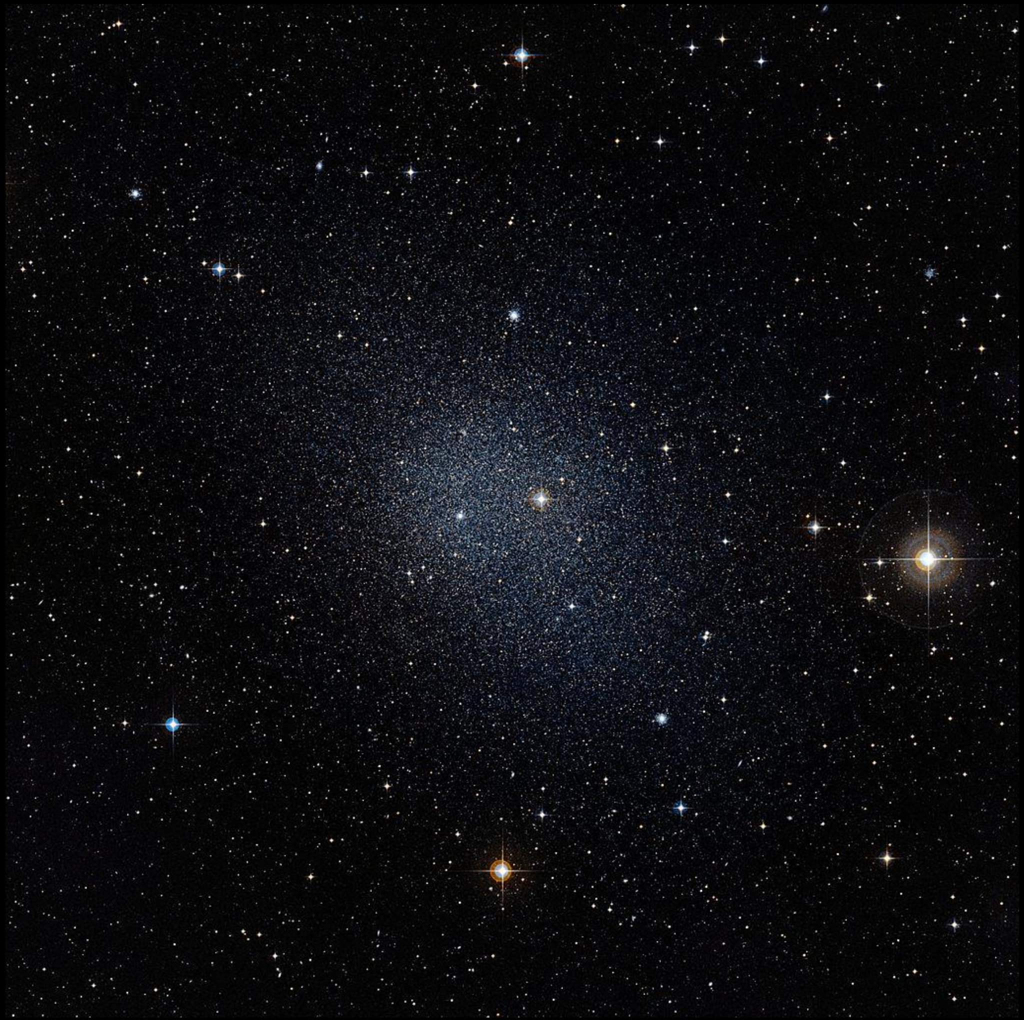
Dark Matter with Neutrino Flavors



Current DM annihilation modelling with neutrino oscillations predict unique $\nu_\mu + \nu_\tau$ fluxes from the different flavor initial states

This will be the first IceCube DM dSph analysis that can **distinguish the flavor of the primary neutrinos from DM annihilation.**

Standard DM Search; Dwarf Spheroidals



ESO/Digitized Sky Survey 2

(left) Fornax Dwarf Spheroidal Galaxy (dSph)

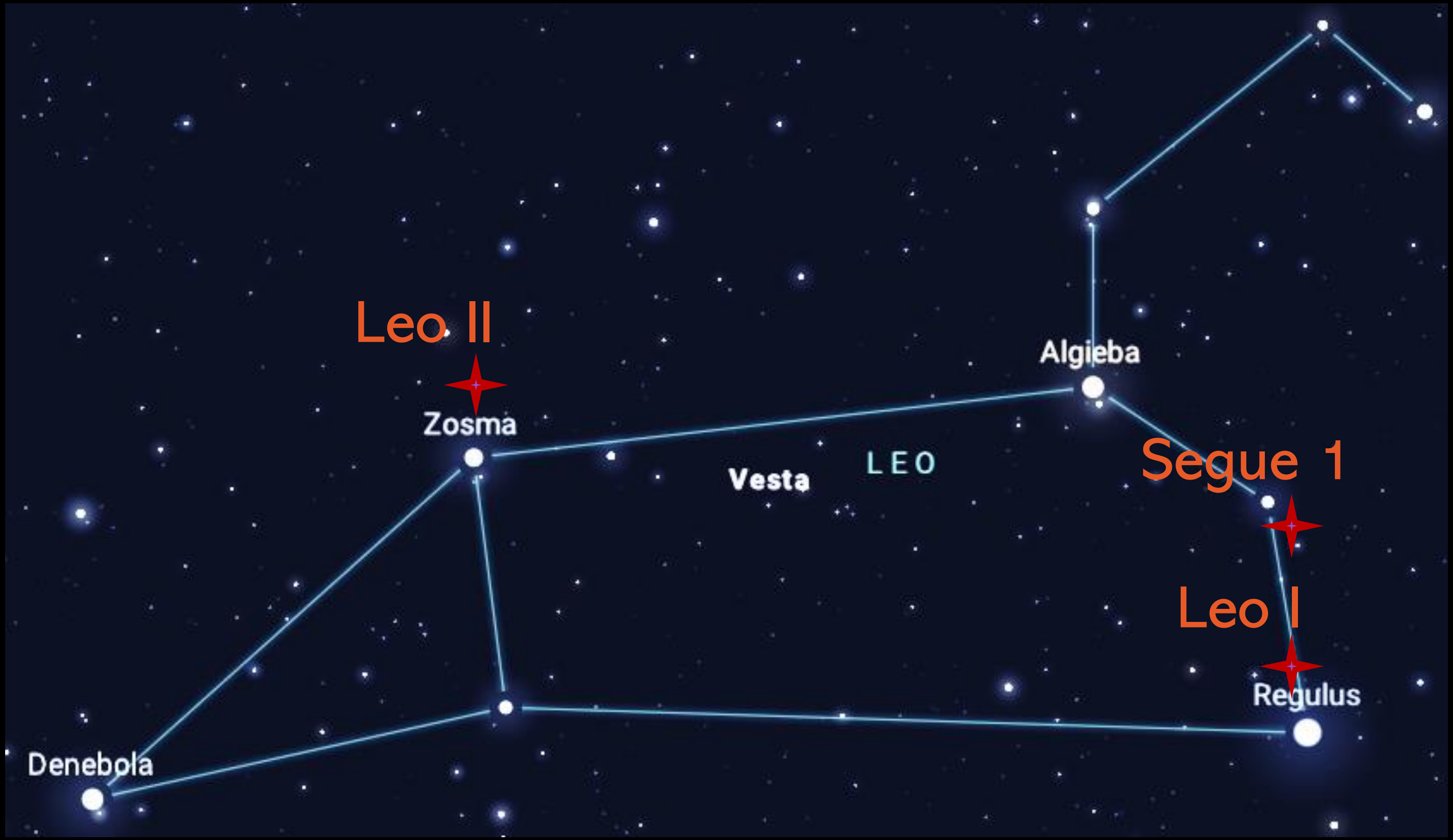
'Small' clustering of matter and stars within our galactic neighborhood

dSphs are DM dominated.

Very little astrophysical ν background or obstructive dust

Ideal sources for astrophysical Dark Matter searches

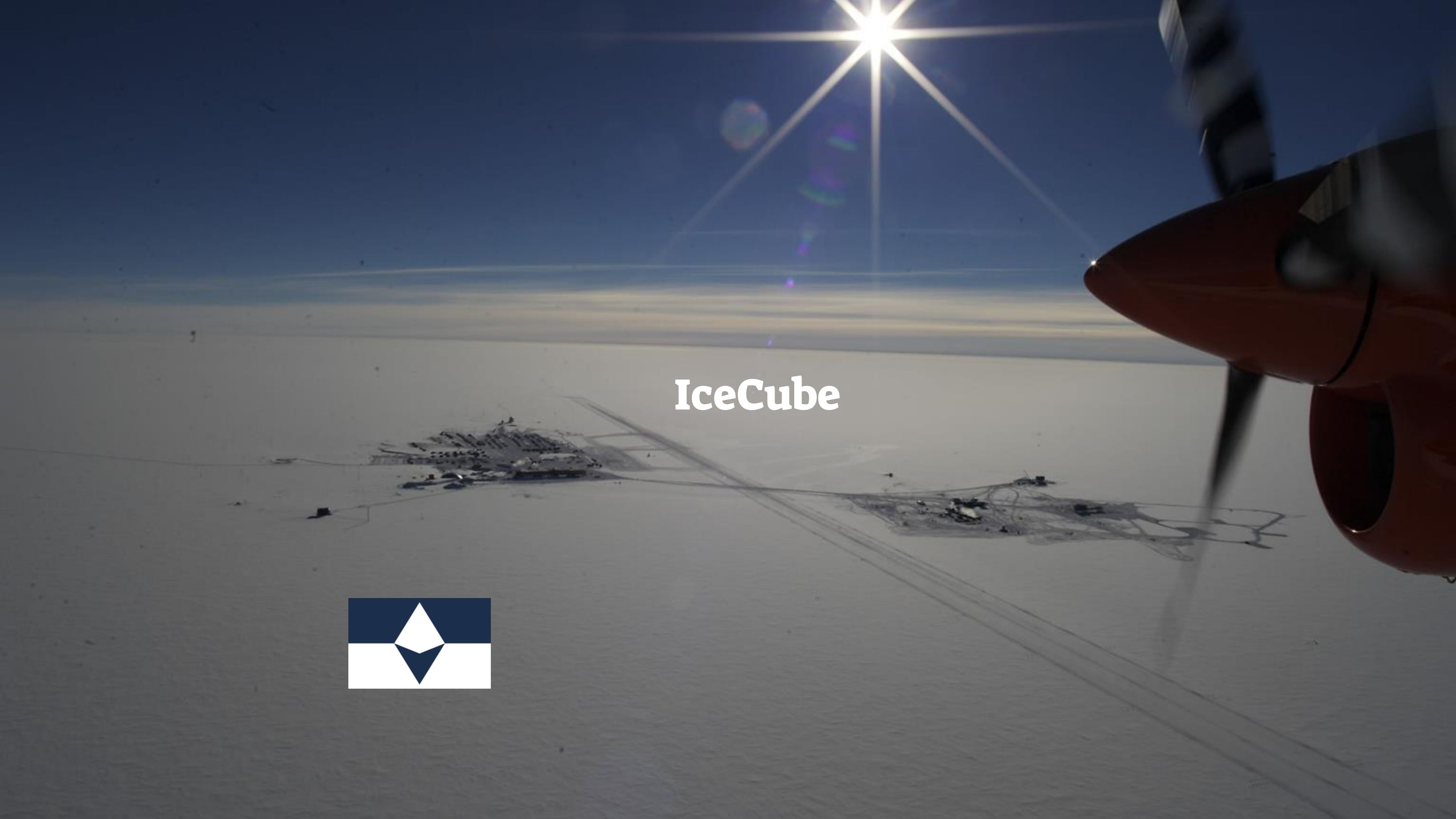
Astrophysical Component



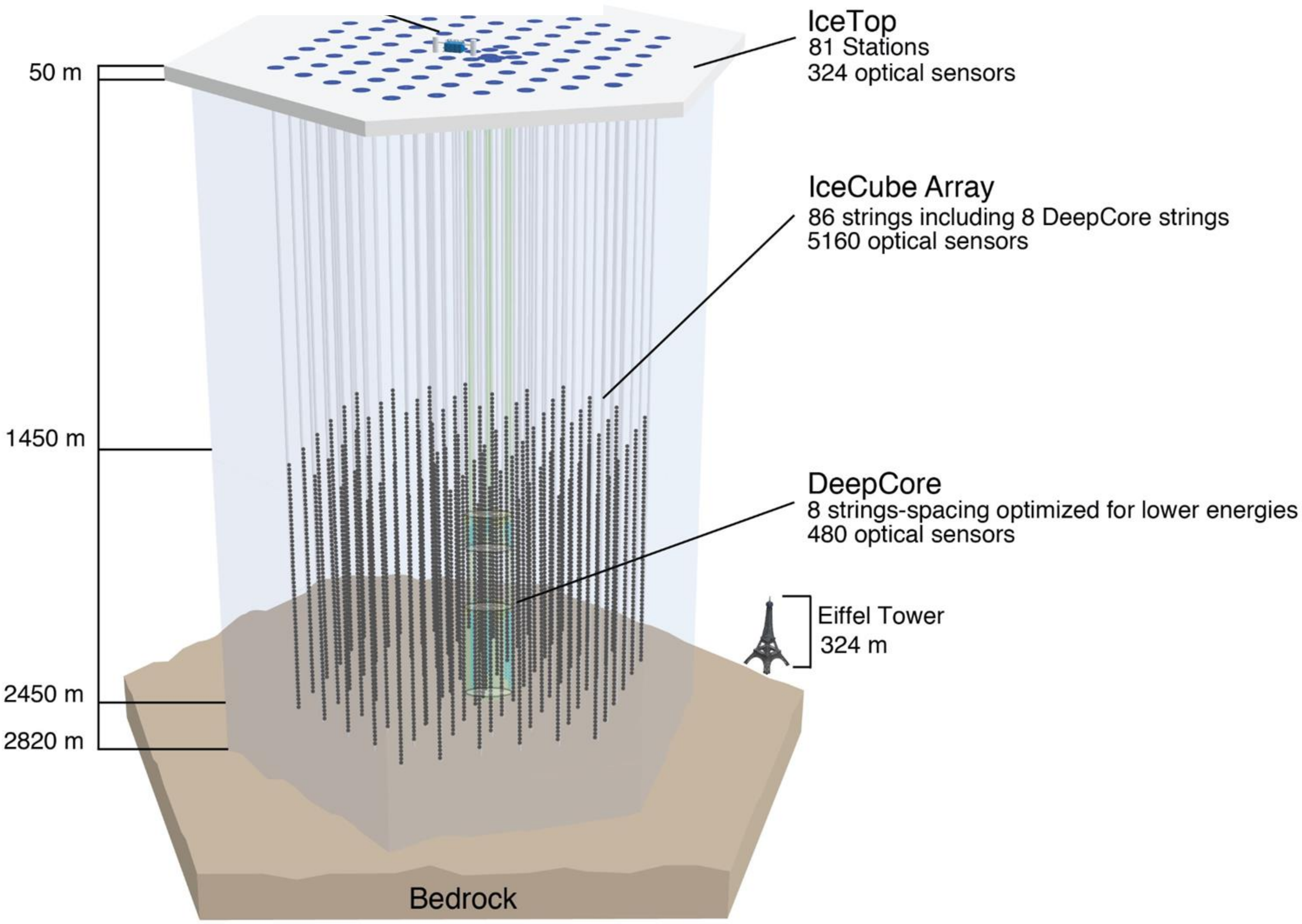
Leo constellation with location of 3 dSph's marked

Source	Jfactor	RA	Dec
UrsaMinor	8.83487E+18	227.24	67.24
UrsaMajorII	2.65522E+19	132.77	63.11
Draco	1.12772E+19	260.06	57.07
UrsaMajorI	7.45933E+17	158.72	51.94
CanesVenaticiII	4.47301E+17	194.29	34.32
CanesVenaticiI	2.73023E+17	202.01	33.56
ComaBerenices	1.05657E+19	186.74	23.9
LeoII	9.31108E+17	168.34	22.13
Segue2	1.61585E+16	34.81	20.17
LeoT	1.28825E+17	143.72	17.05
Segue1	2.26725E+19	151.75	16.06
BootesI	1.72028E+18	210.03	14.49
Hercules	7.32656E+16	247.72	12.75
LeoI	6.94225E+17	152.11	12.29
LeoV	2.34315E+16	172.79	2.22
LeoIV	2.10475E+16	173.32	-0.53
Sextans	8.32339E+17	153.28	-1.59
Sculptor	3.75405E+18	15.04	-33.7
Carina	8.26418E+17	100.41	-50.96

Catalog Used for this study. Source: Geringer-Sameth 2015


IceCube

IceCube Neutrino Observatory



IceCube has km long strings with digital optical modules (DOM)

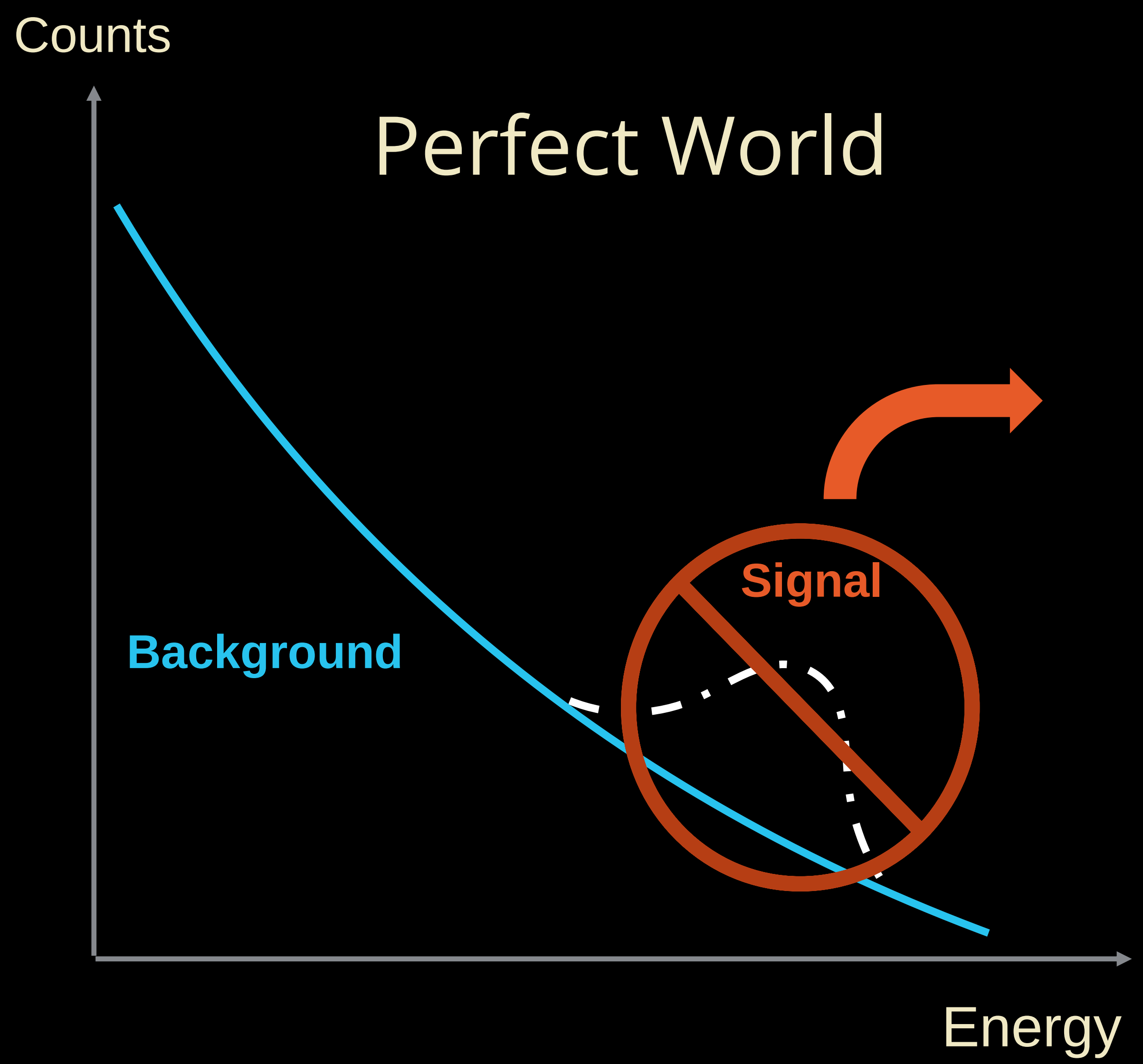
- Average vertical separation of DOM is 17m

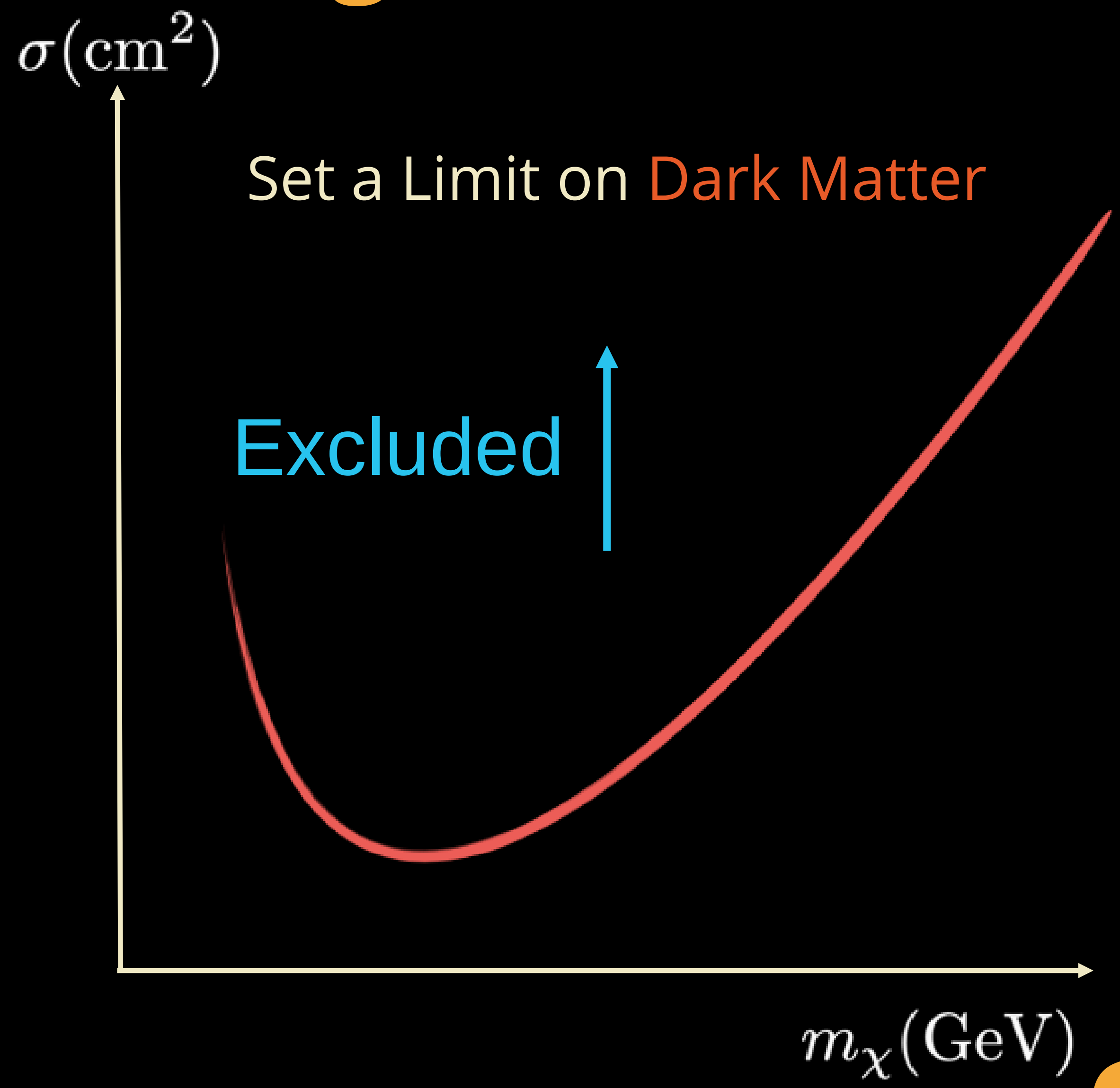
Neutrinos interacts with ice and creates charged particle tracks/cascade that we later detect from Cherenkov light.

Shown right is a muon track from ν_μ collision in ice.

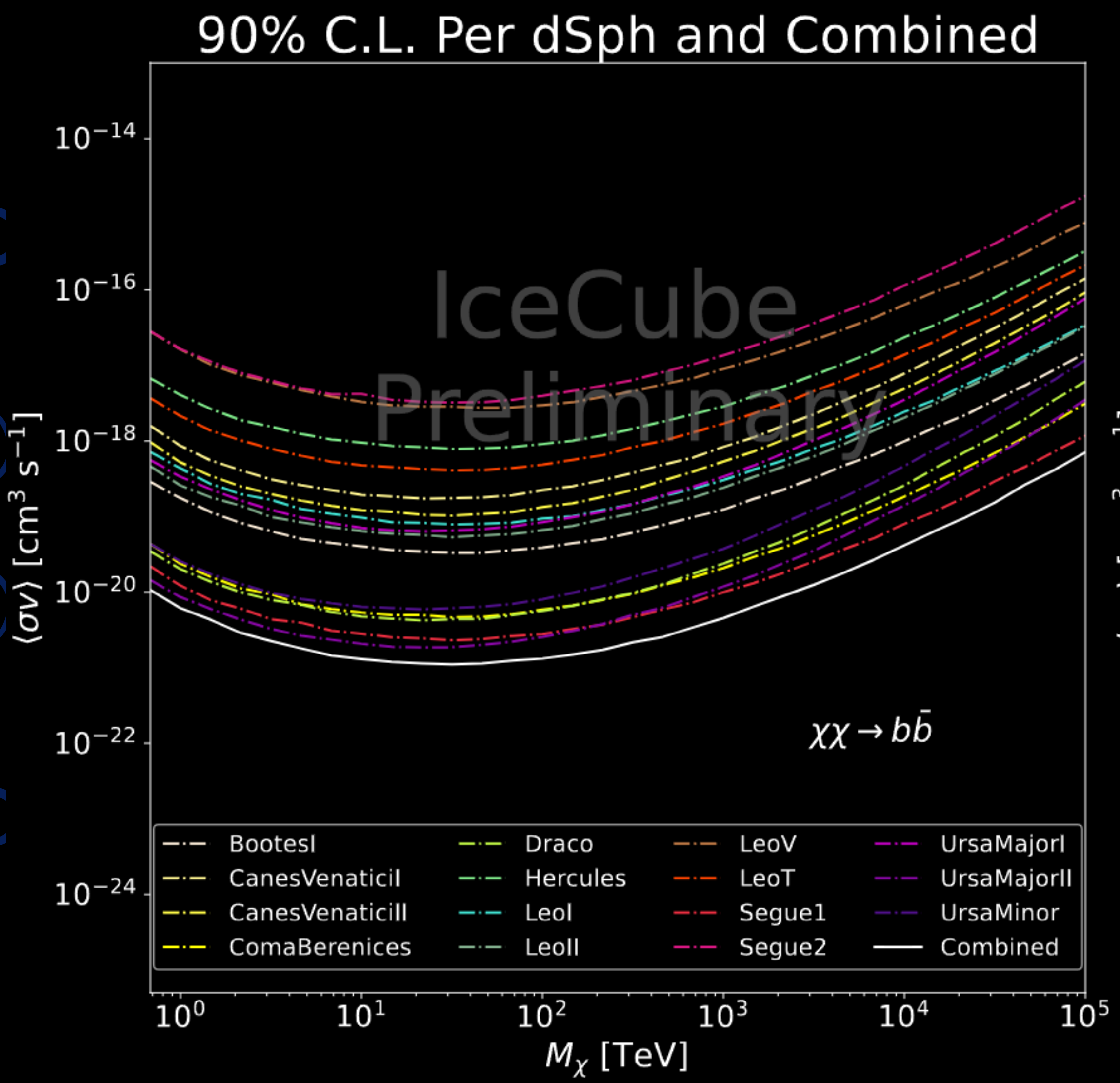
ν_e will usually produce 'cascades' instead of tracks in the detector

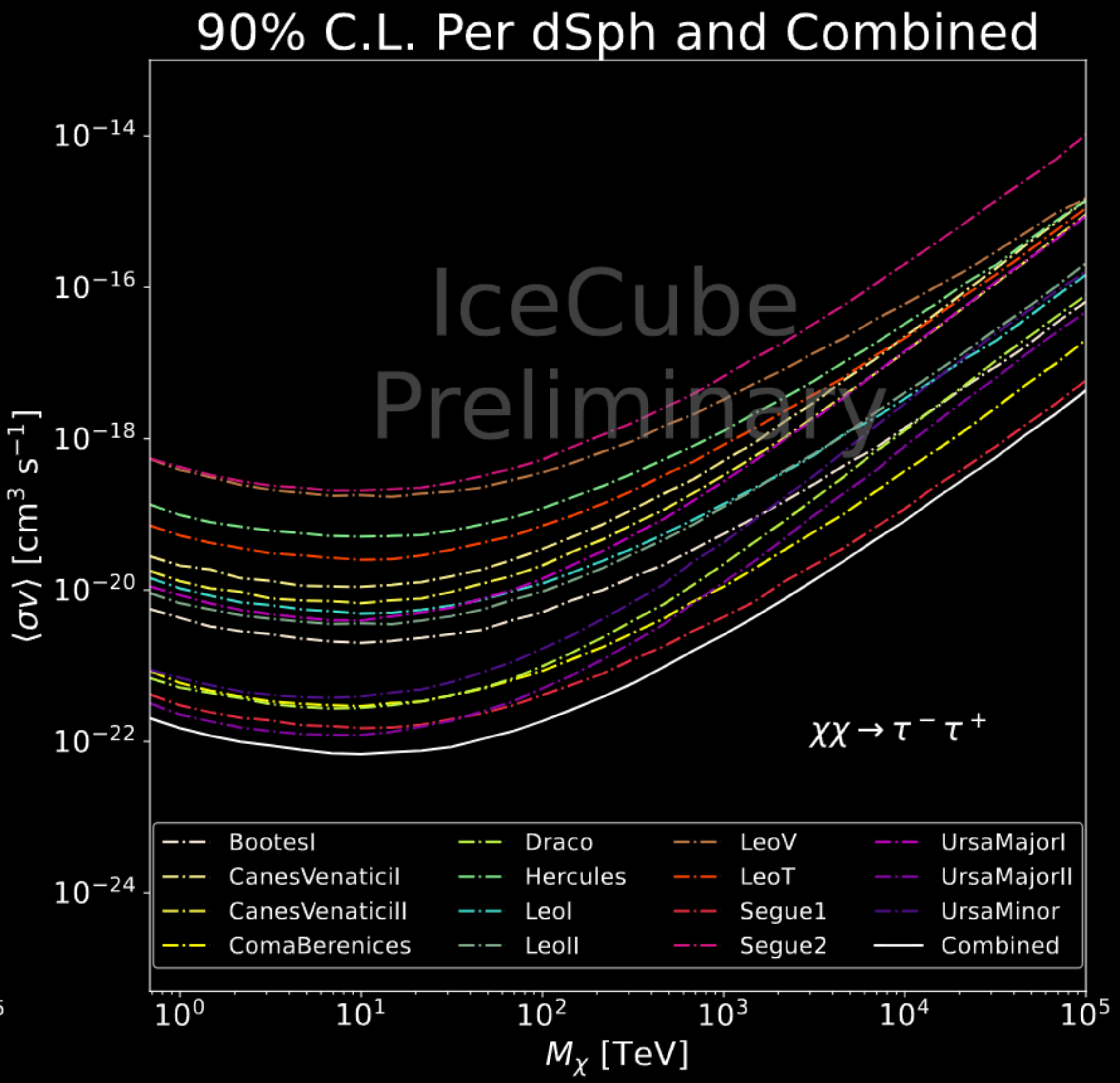
Bump Hunting





Stacked Sensitivities 1000 trials





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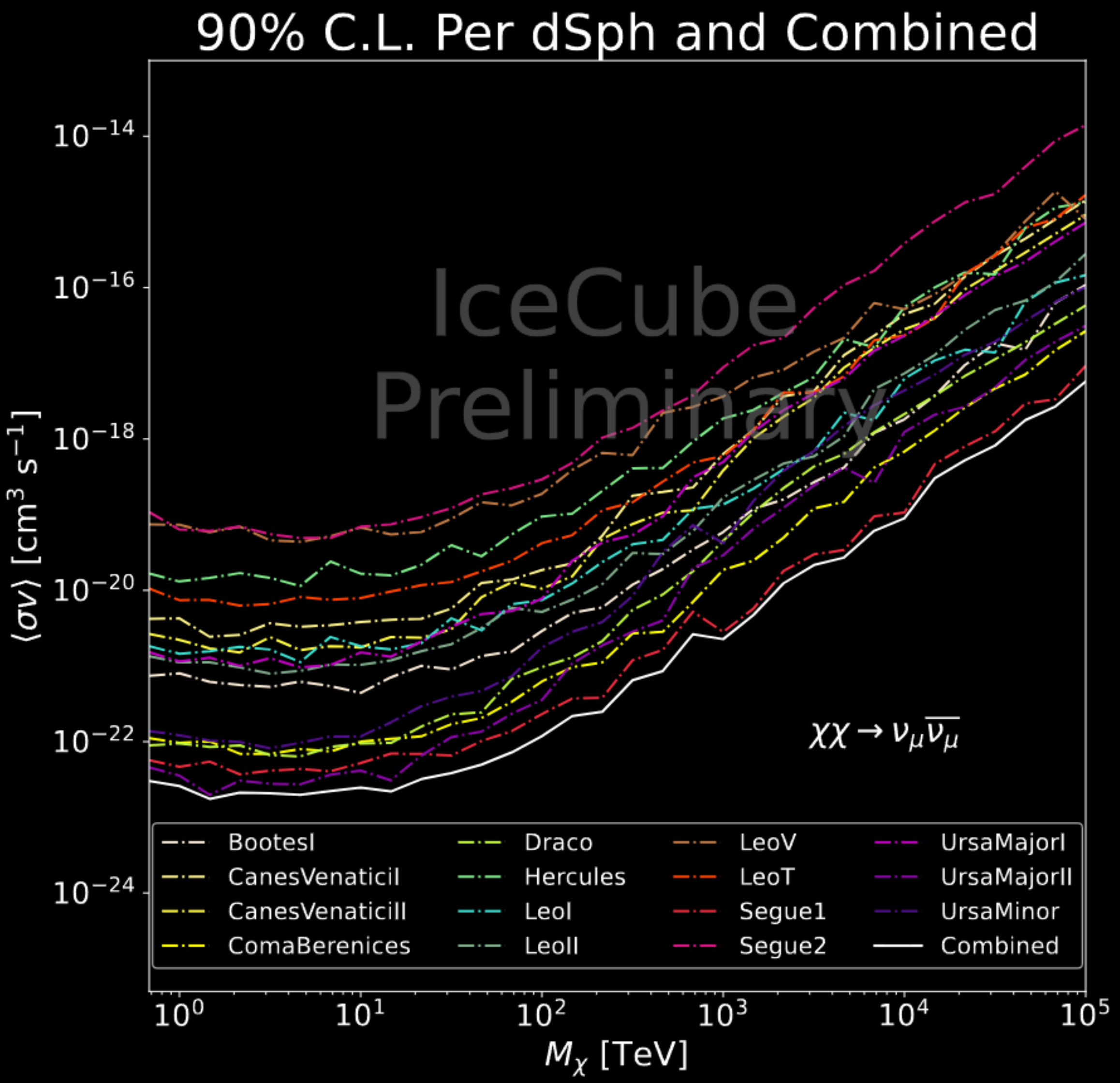

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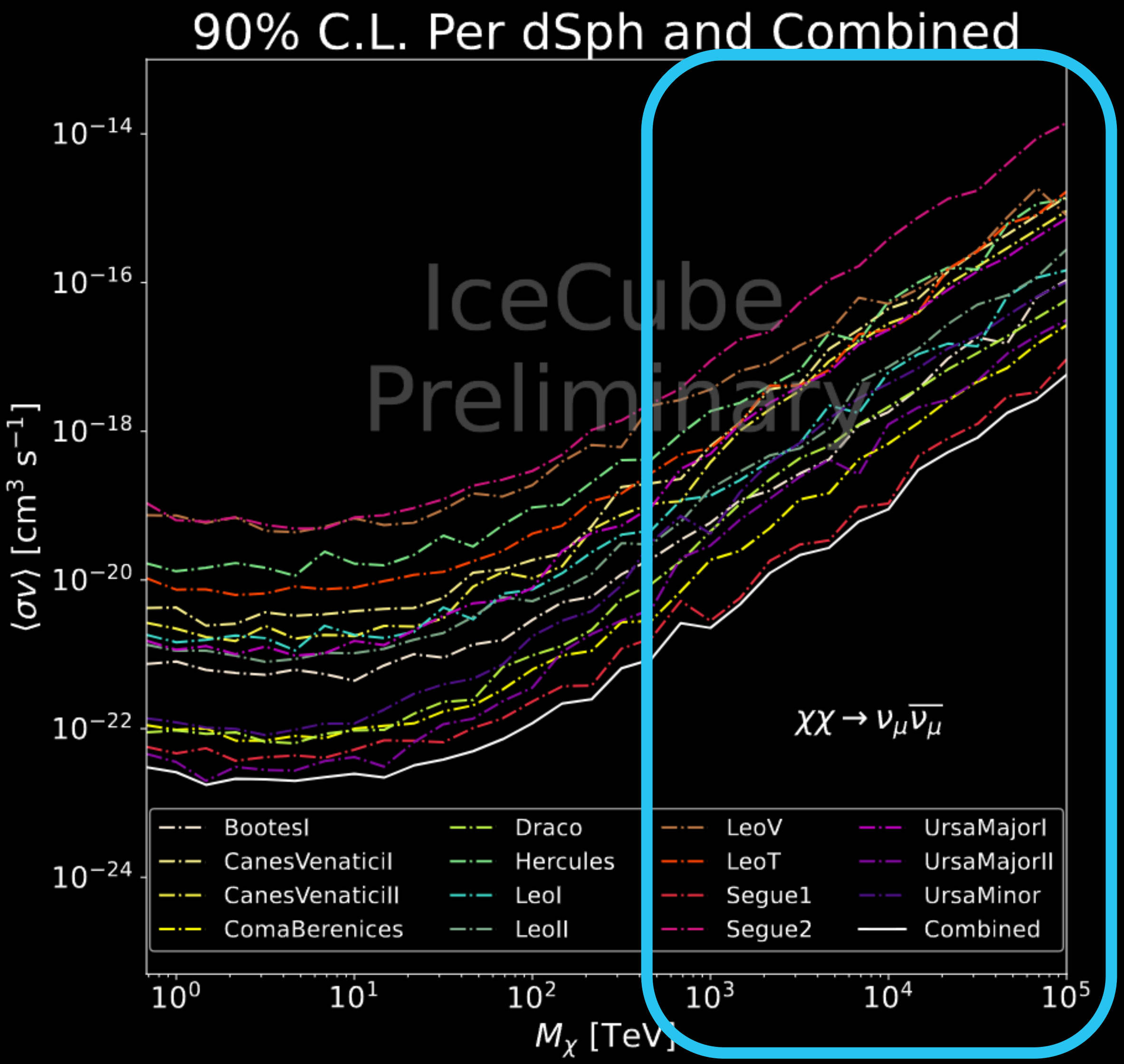
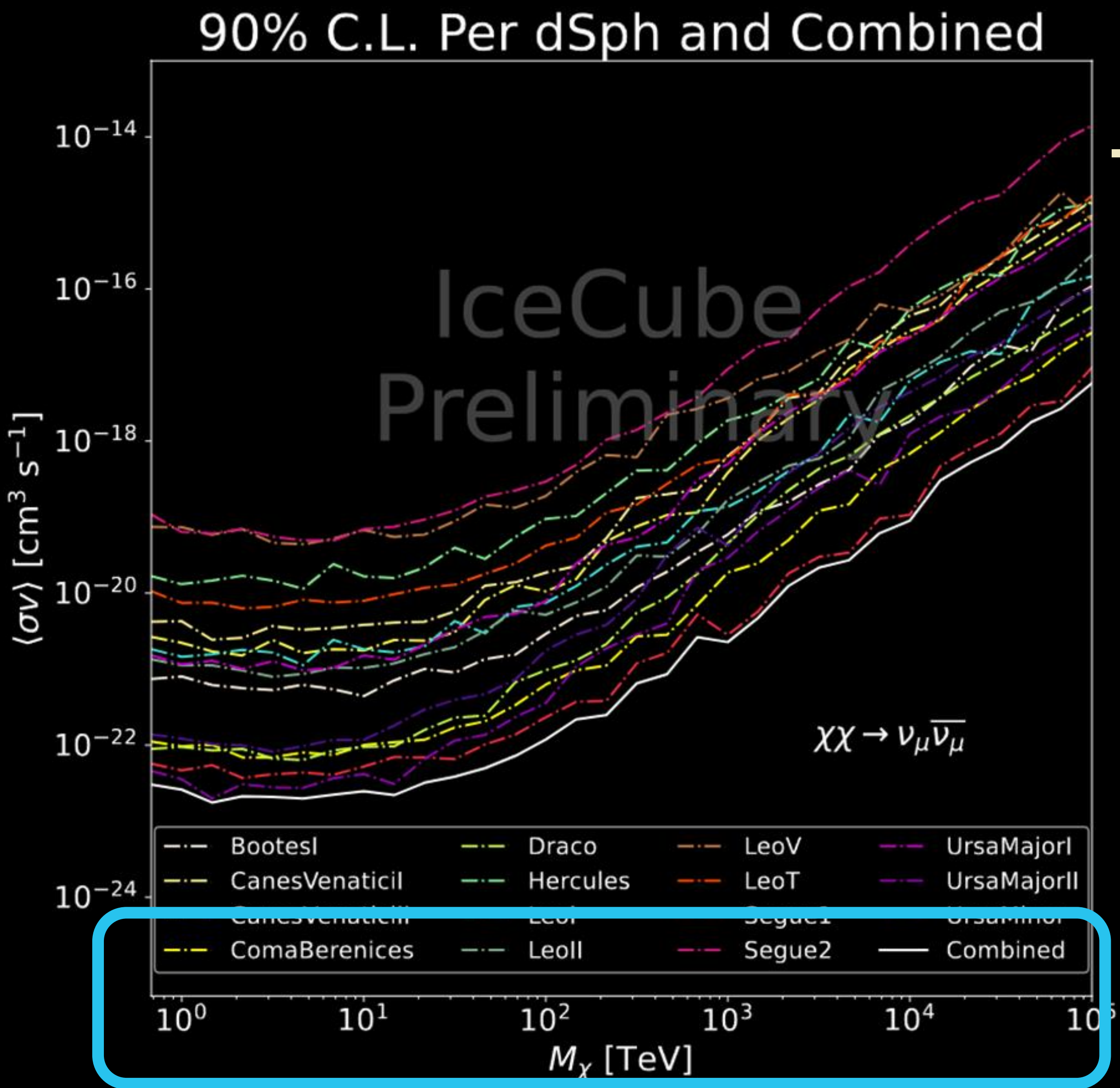


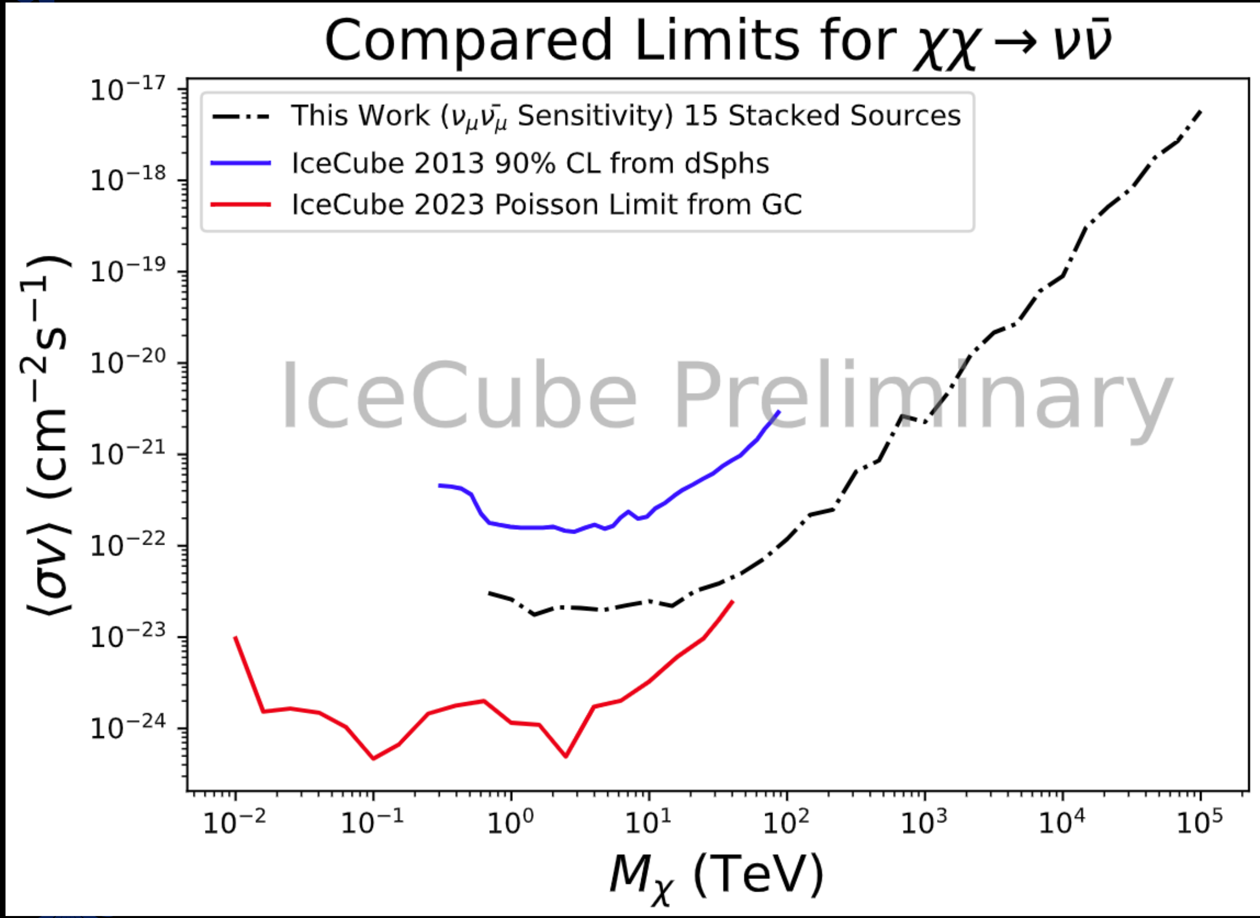
We're sensitive to PeV scale DM with IceCube

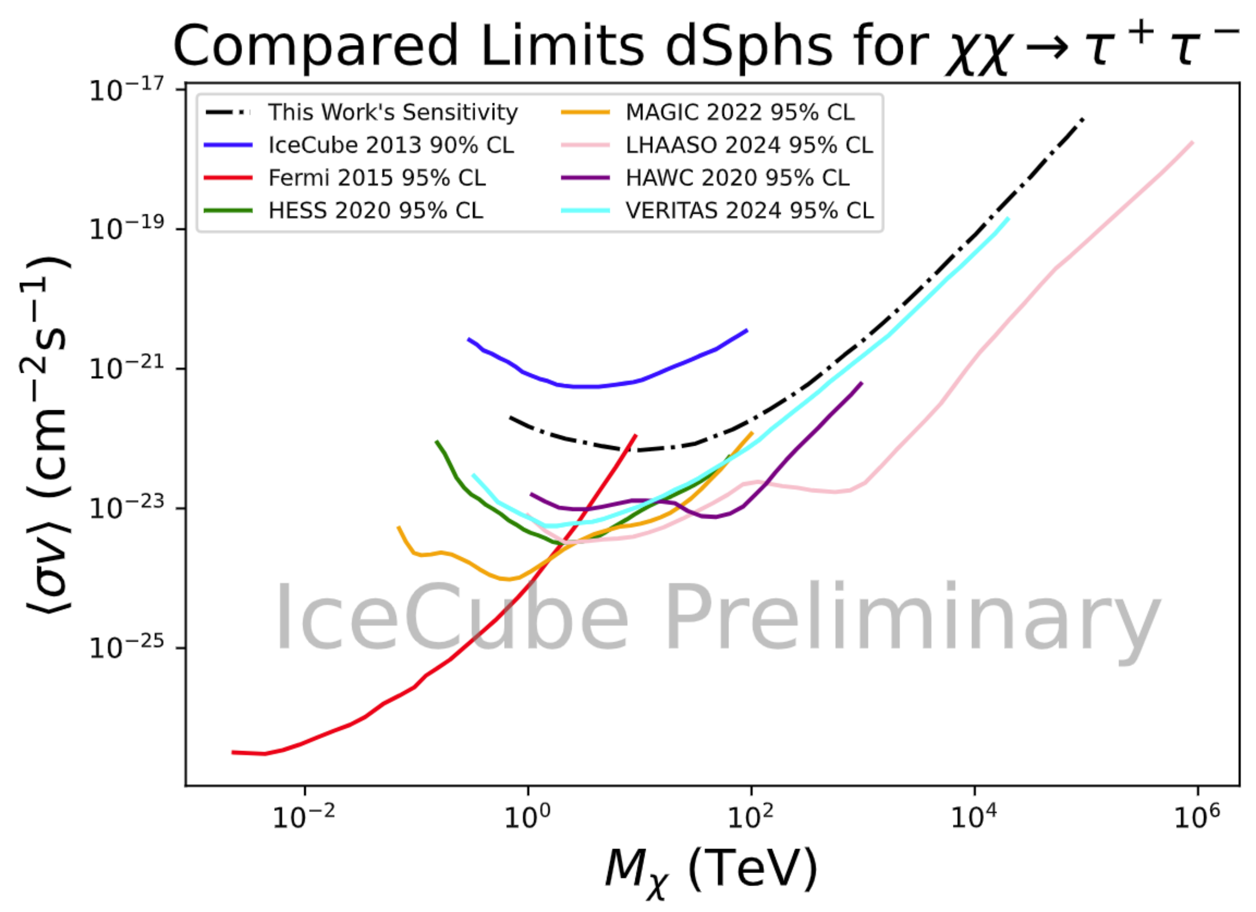
Stacked Sensitivities 1000 trials



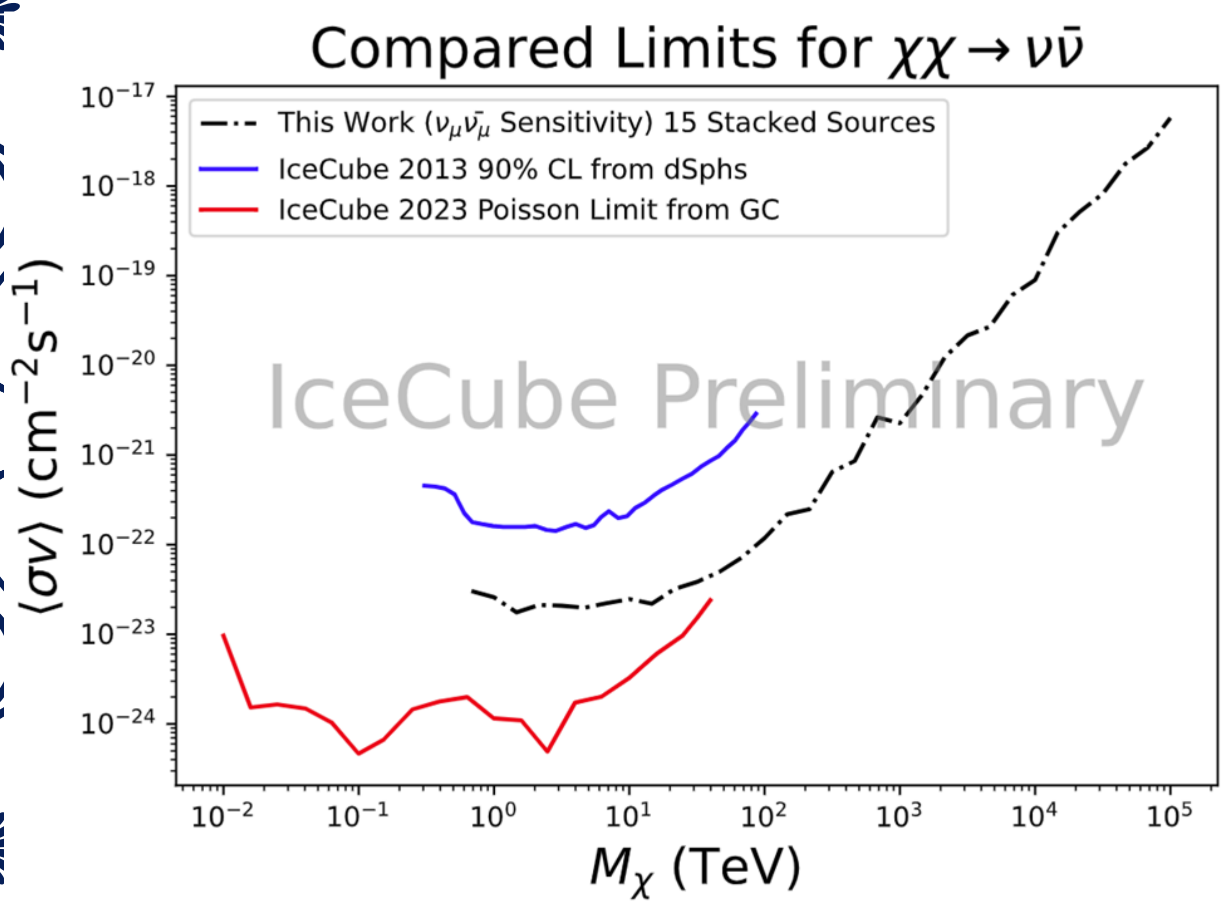
This IceCube muon track study independently sensitive to ~5 orders of magnitude in DM mass

Sensitivities Compared





IceCube Conlusions



$\chi\chi \rightarrow \nu_\mu\overline{\nu_\mu}$ shows the most competitive sensitivity for $\langle\sigma v\rangle$ with O(10^{-23}) after stacking 15 source.

We've gained a substantial amount of sensitivity to DM annihilation from dwarf galaxies!

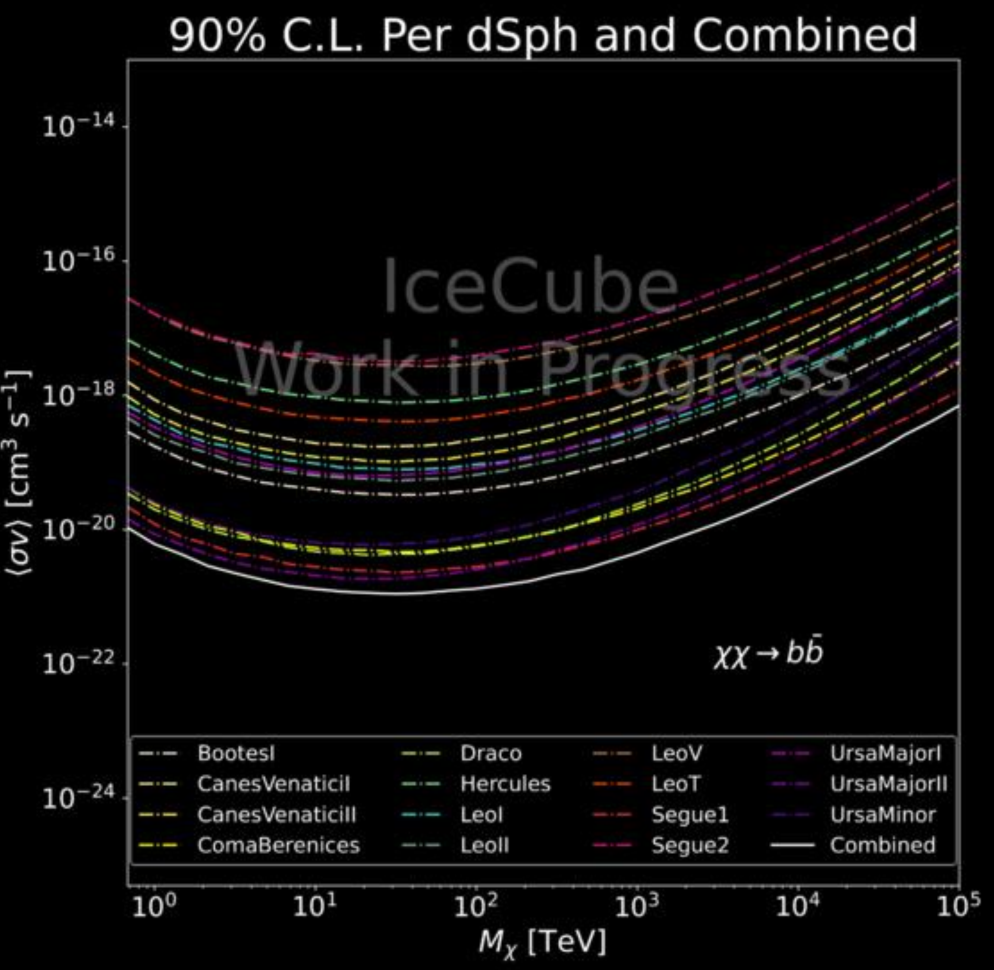
IceCube is competitive at the highest DM mass ranges.

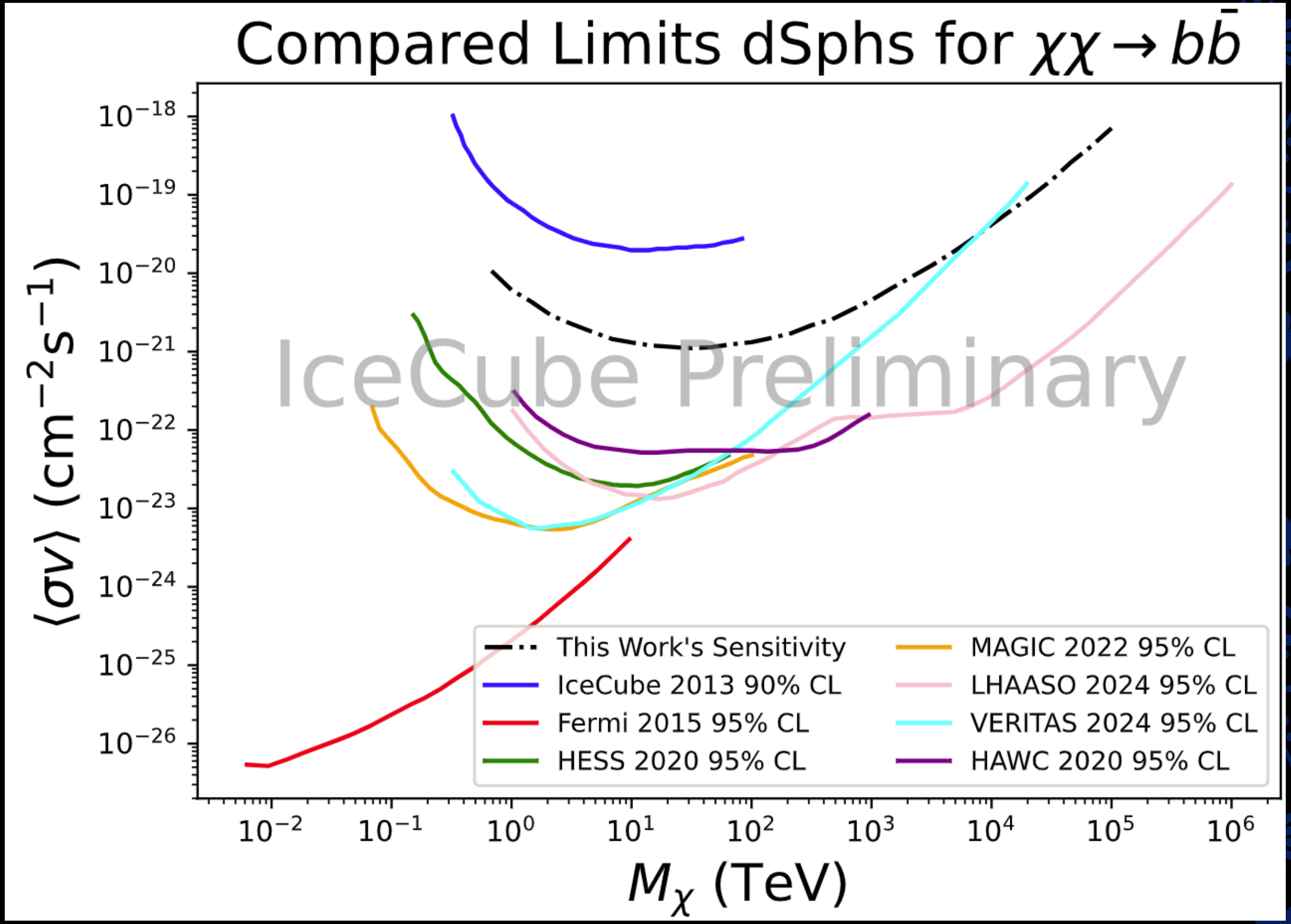
IceCube has comparable sensitivity to past gamma-ray studies for charged lepton channels in the heavy DM regions

Expect to unblind and analyze data this year

Backup

Sensitivities Compared





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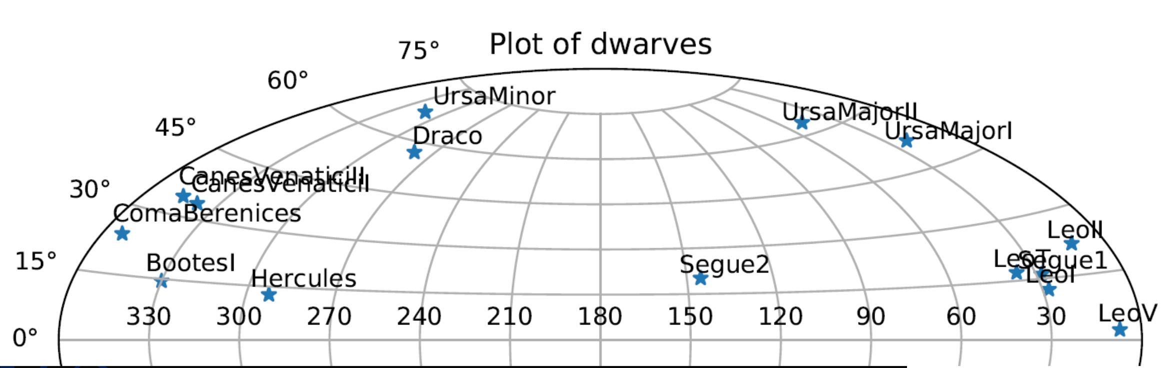
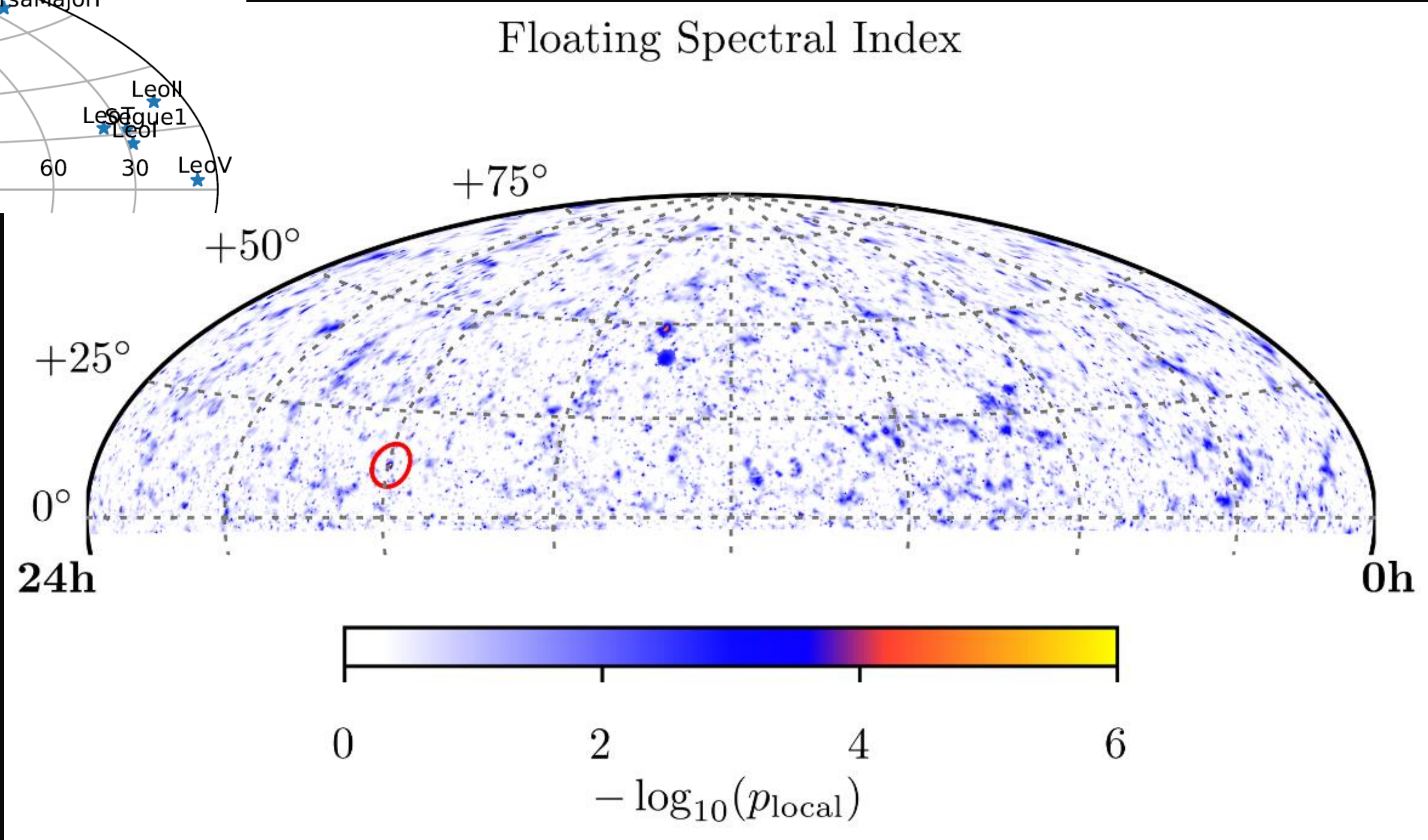
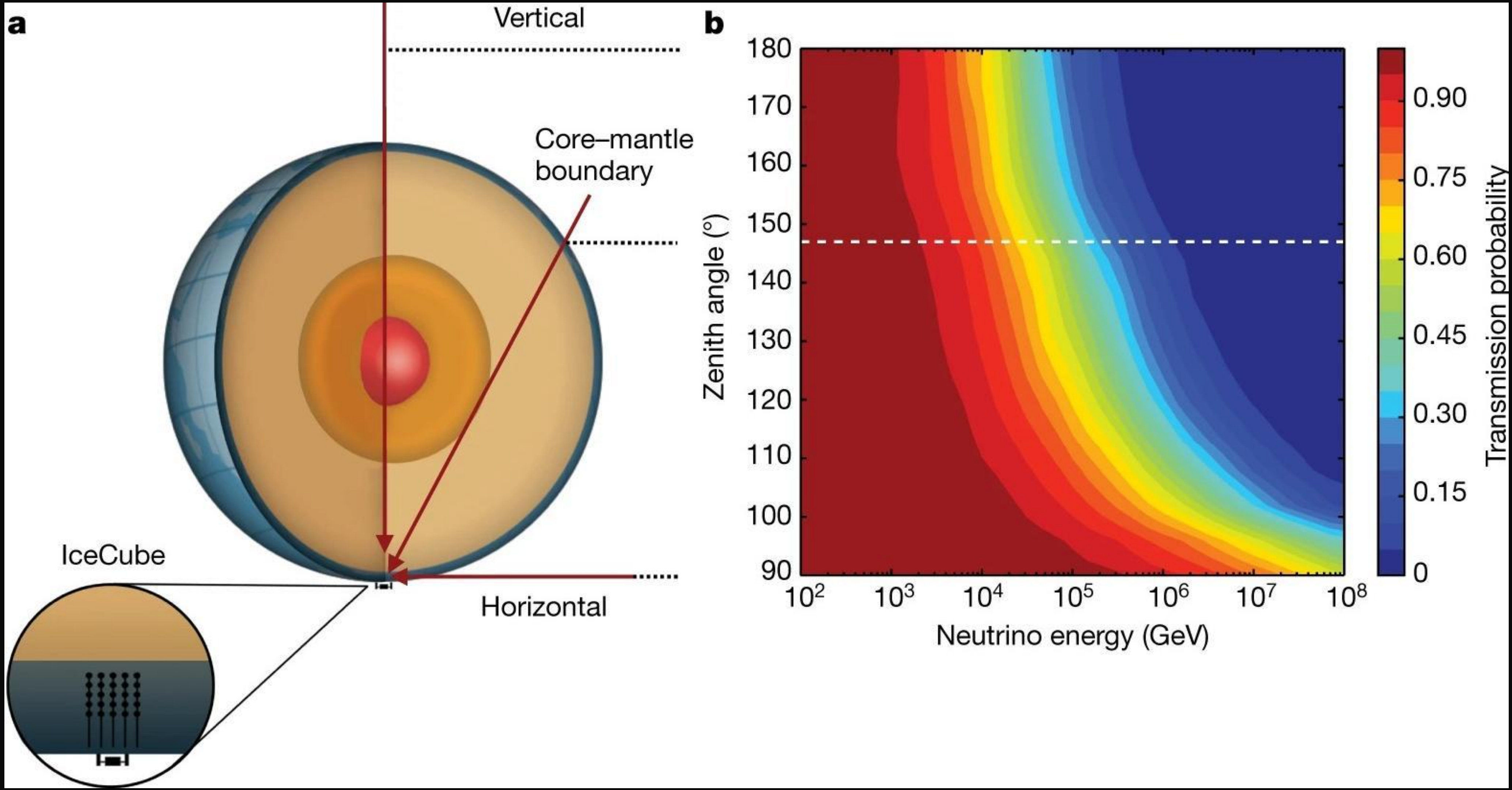
Sources w.r.t Data

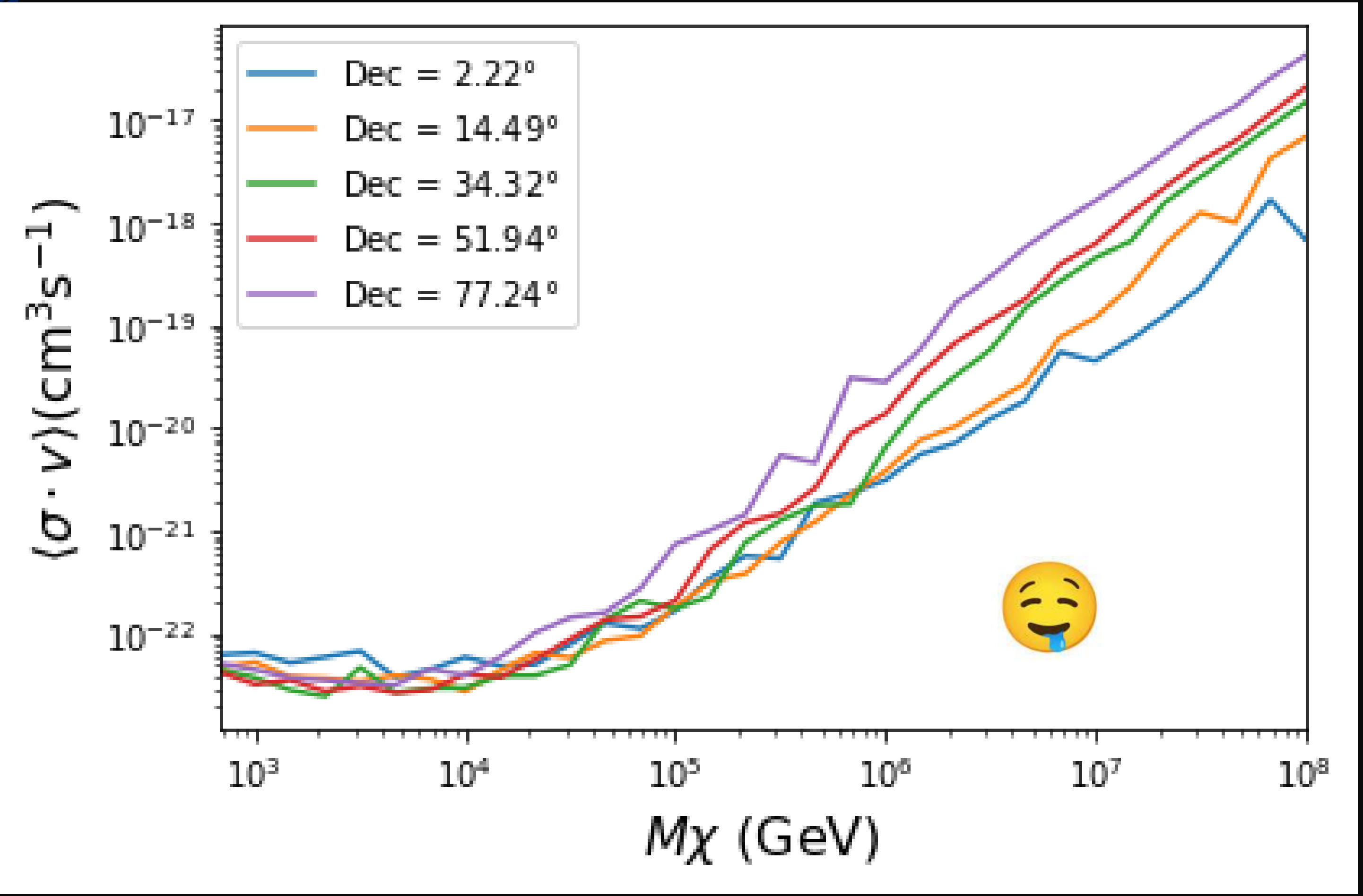




Declination Sensitivity Studies 1/2



Declination Sensitivity Studies 2/2



You can really see the impact of the earth on this one.

Have not included tau contamination in these sensitivities yet.

However, that would add counts which would push these sensitivities down

IceCube PtSrc LLH

$$L(n_s) = \prod_{i=1}^{N} \left[\frac{n_s}{N} S_i + \left(1 - \frac{n_s}{N}\right) B_i \right]$$

$$L(n_s) = \prod_{i=1}^{N_{\text{sources}}} L_i(n_s)$$