DARK MATTER SEARCHES IN IceCube

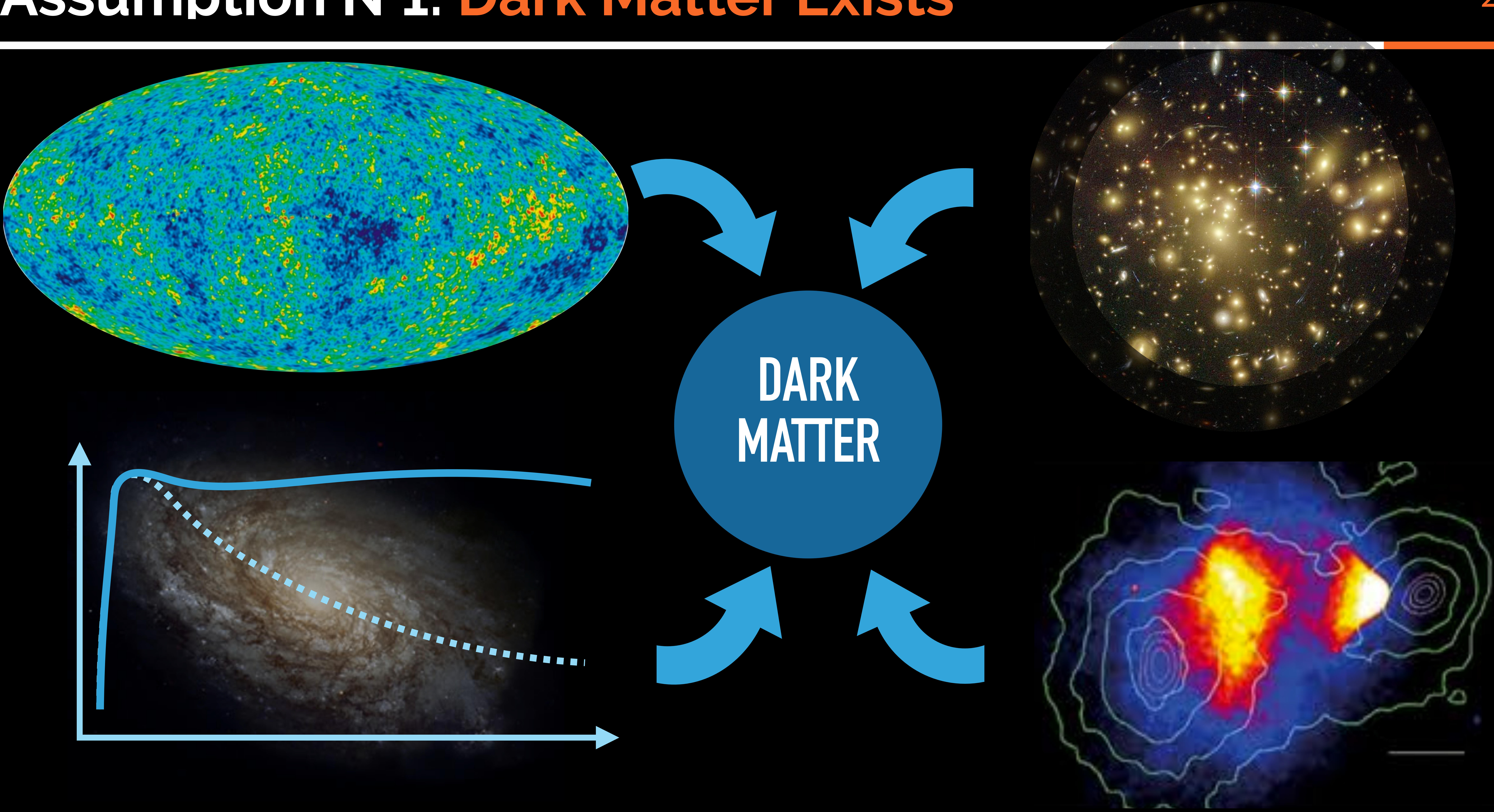
J. A. Aguilar on behalf of IceCube

Photo: Ian Reese

ULB

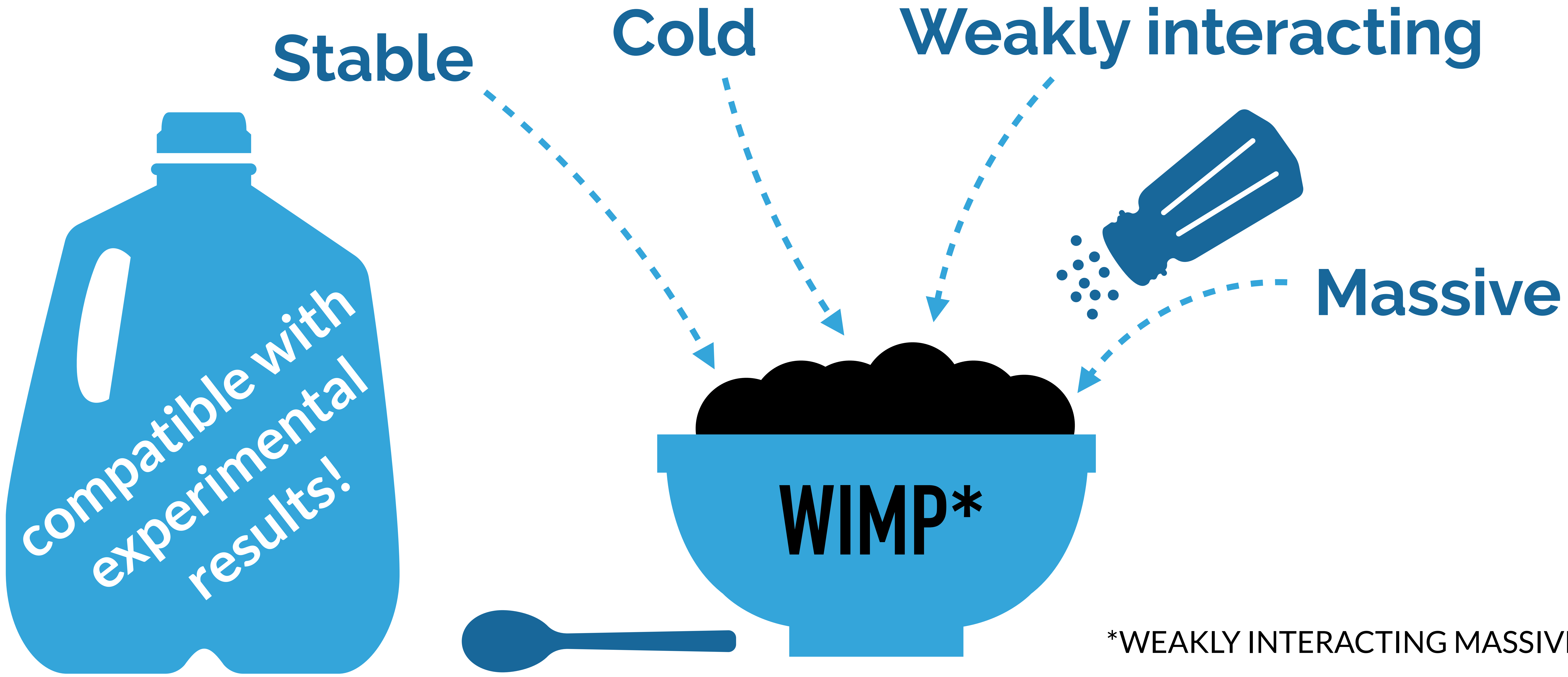
iihe

Assumption N°1: Dark Matter Exists



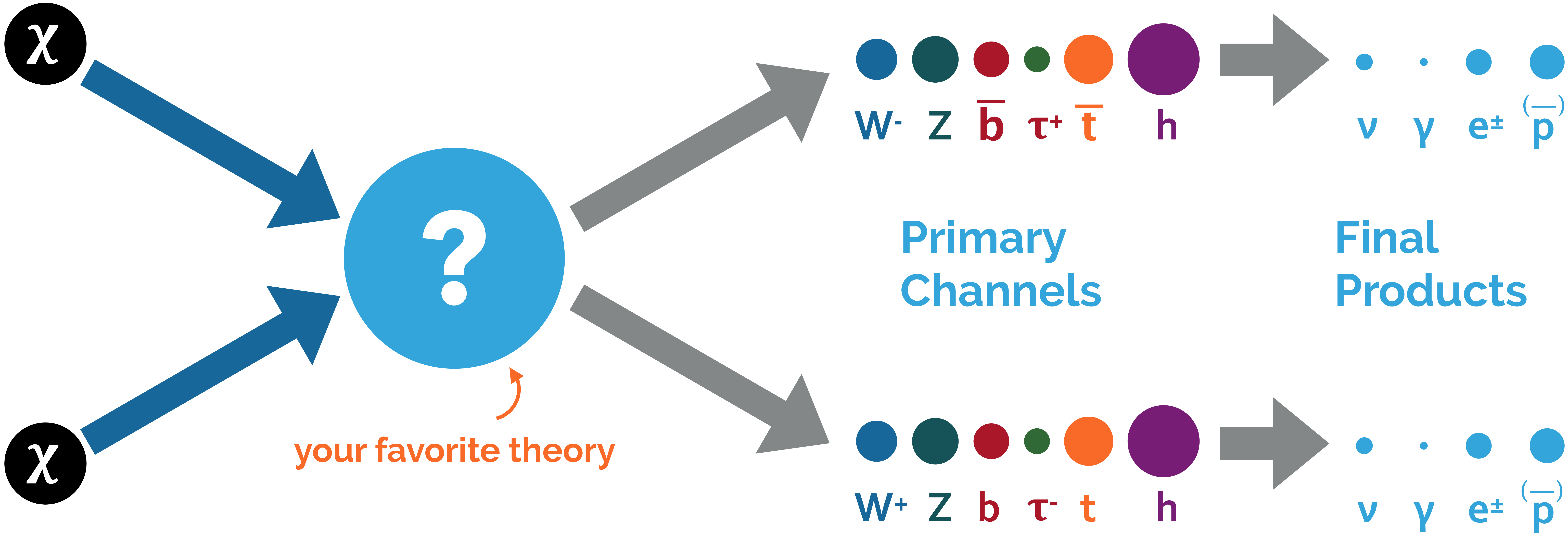
Assumption N°2: Dark Matter is a Particle…

$$\Omega_{matter} = \Omega_{Baryons} + \Omega_{\nu HDM} + \Omega_{CDM} \approx 0.05 + 0.01 + 0.24 = 0.30$$



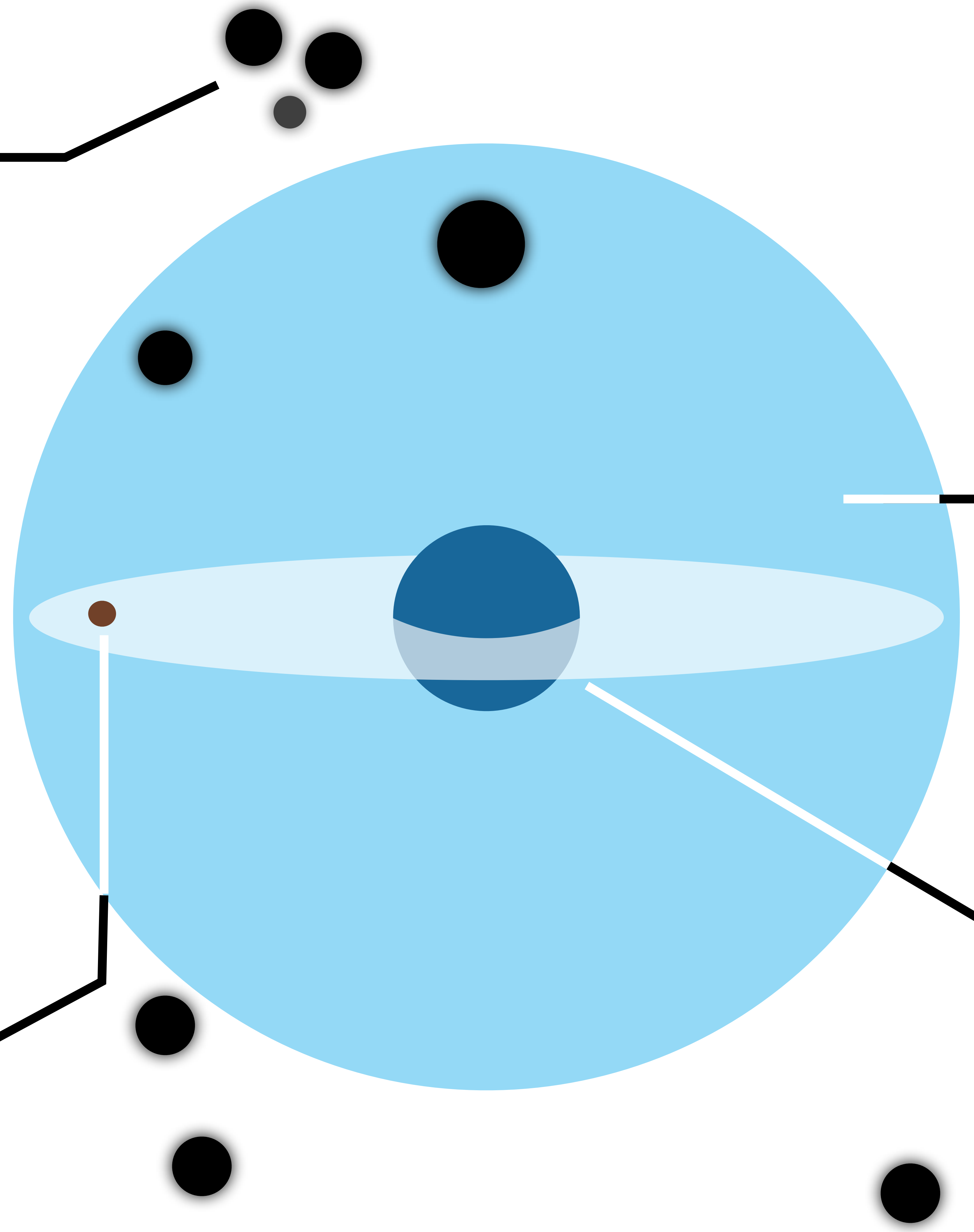
*WEAKLY INTERACTING MASSIVE PARTICLES

Indirect Detection of Dark Matter



- No need of specialized detectors: **Gamma-ray telescopes, neutrino detectors, CR-experiments**
- Search for products of dark matter annhilation processes: **Focus on large reservoirs of dark matter**

Dark Matter Searches Where to Look?



Dwarf spheroidal Galaxies
Cluster of Galaxies

Probe velocity-averaged DM annihilation cross section $\langle v\sigma_A \rangle$

Galactic Halo

Probe velocity-averaged DM annihilation cross section $\langle v\sigma_A \rangle$

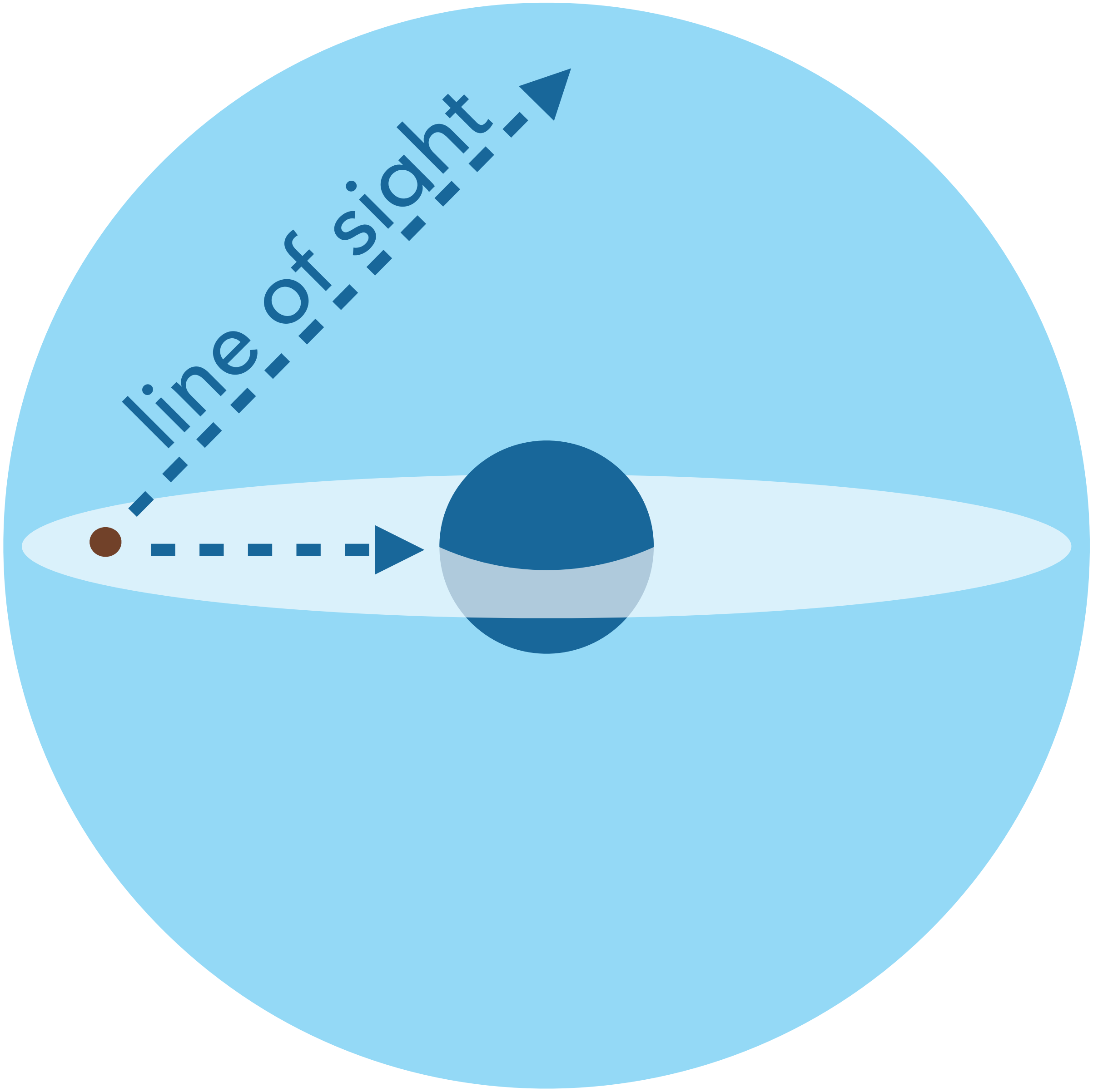
Galactic Center

Probe velocity-averaged DM annihilation cross section $\langle v\sigma_A \rangle$

Local Sources (Sun, Earth)

Only accessible with neutrinos
Under equilibrium they can probe σ_{SI} and σ_{SD}

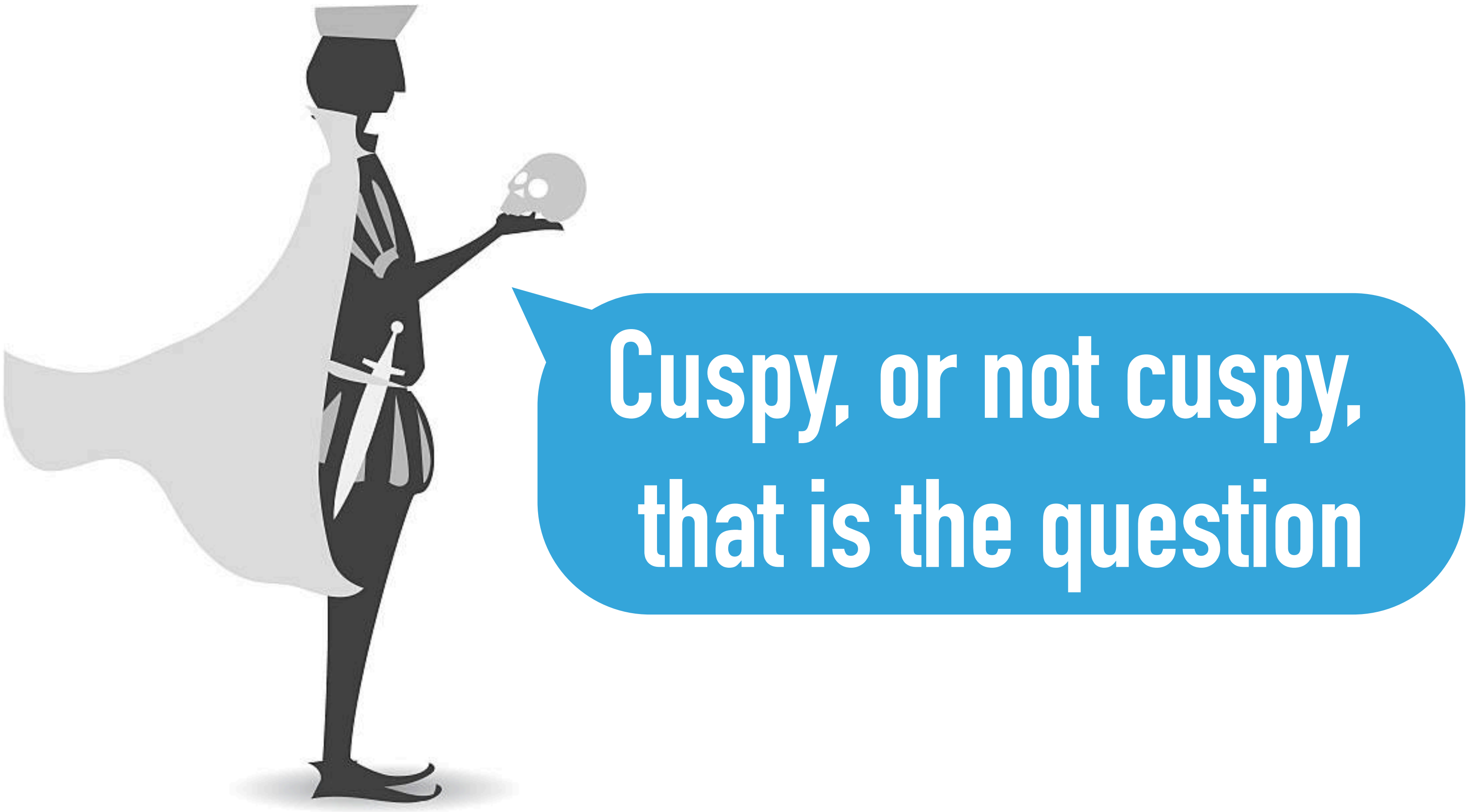
The Galactic Center The Astrophysical Input

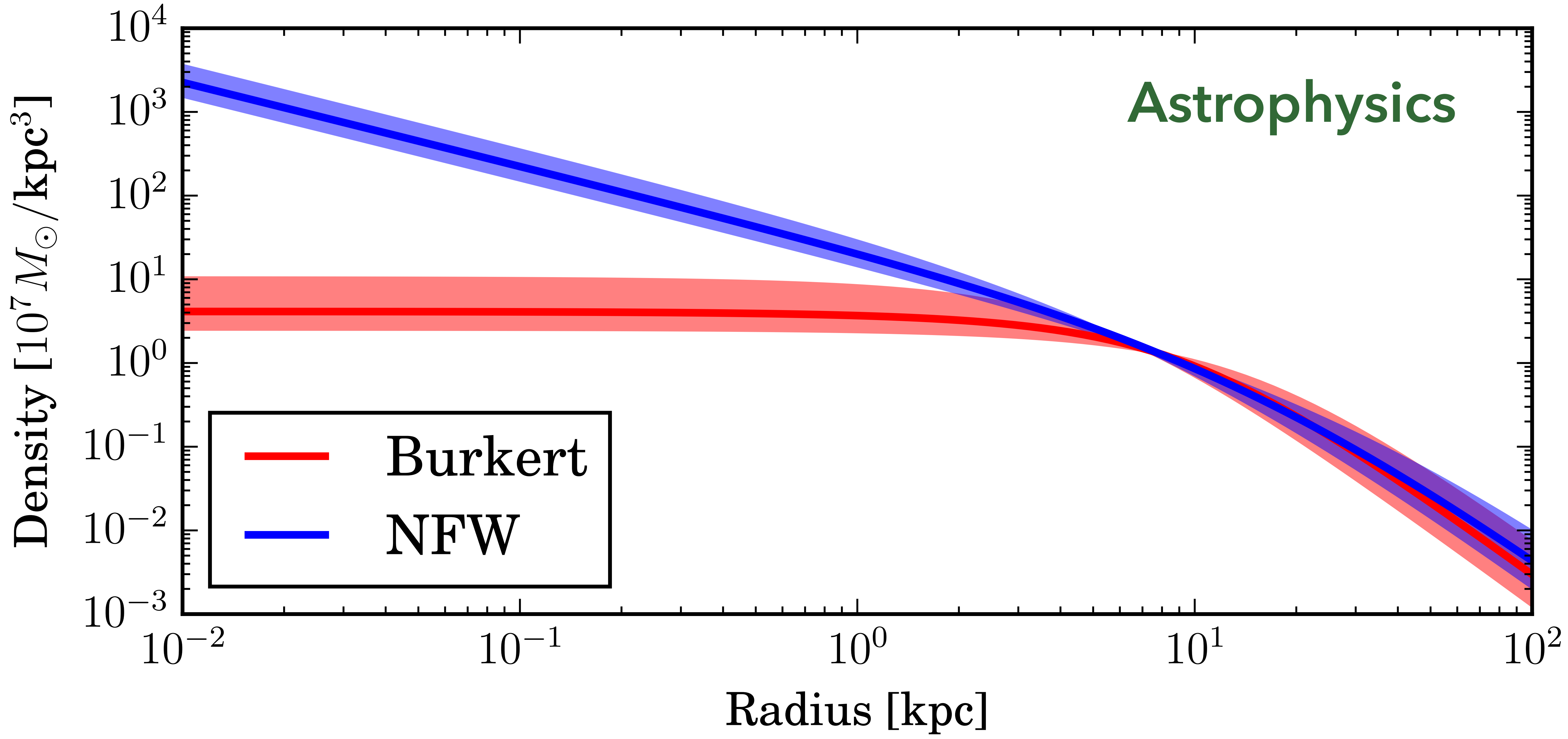


$$\frac{\mathrm{d}\Phi_\nu}{\mathrm{d}E_\nu} = \frac{1}{4\pi}\frac{\langle\sigma_A v\rangle}{2m_\chi^2}\frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu}\int_0^{\Delta\Omega}\mathrm{d}\Omega\int_{l.o.s}\rho_\chi^2(r(s,\Psi,\theta))\mathrm{d}s$$

Particle physics

Astrophysics





Dark Matter Searches In a Nutshell

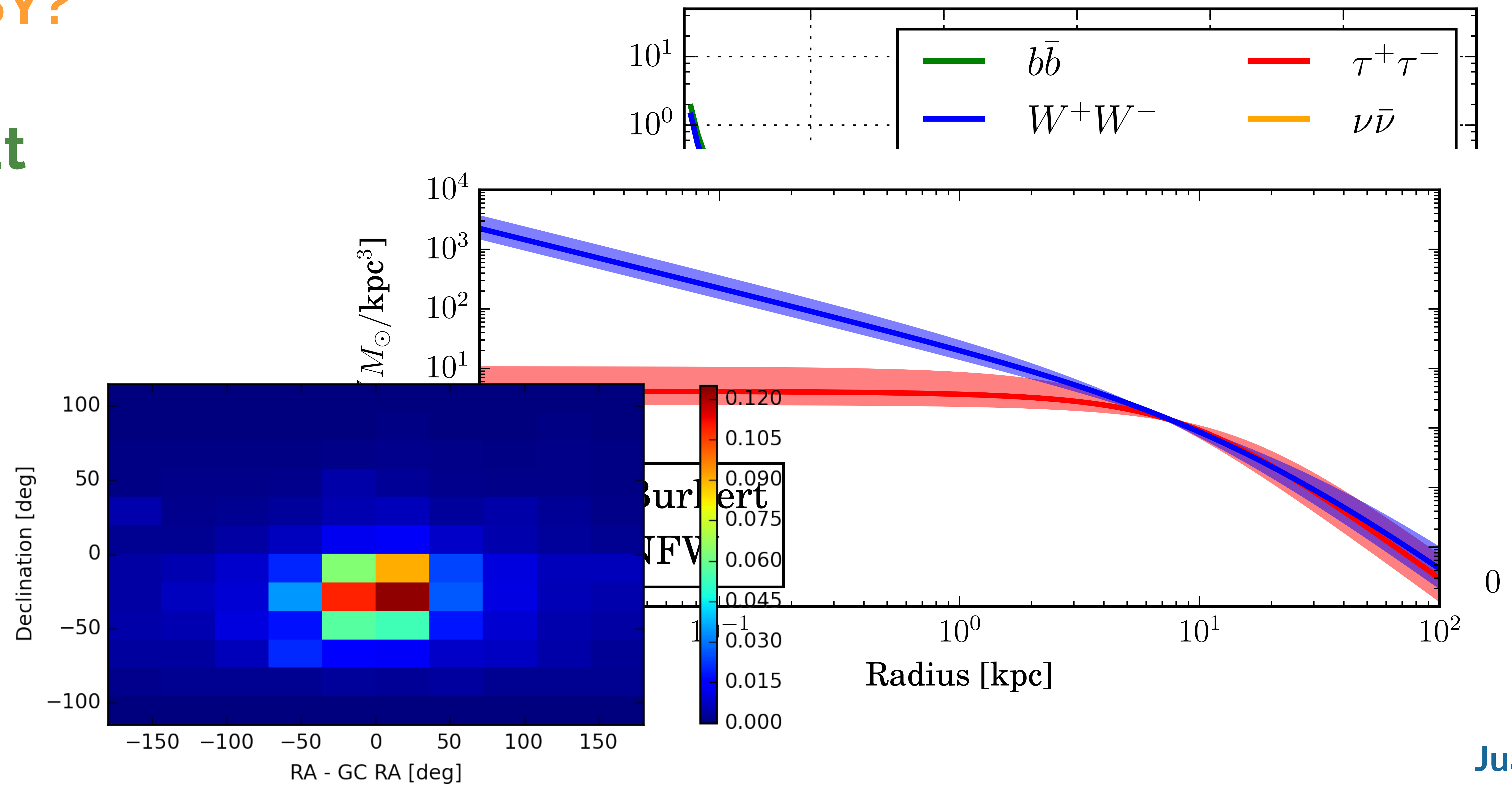
$$\frac{\mathrm{d}\Phi_\nu}{\mathrm{d}E_\nu} = \frac{1}{4\pi}\frac{\langle\sigma_A v\rangle}{2m_\chi^2}\frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu}\int_0^{\Delta\Omega}\mathrm{d}\Omega\int_{l.o.s}\rho_\chi^2(r(s,\Psi,\theta))\mathrm{d}s$$

Theory input: SUSY?

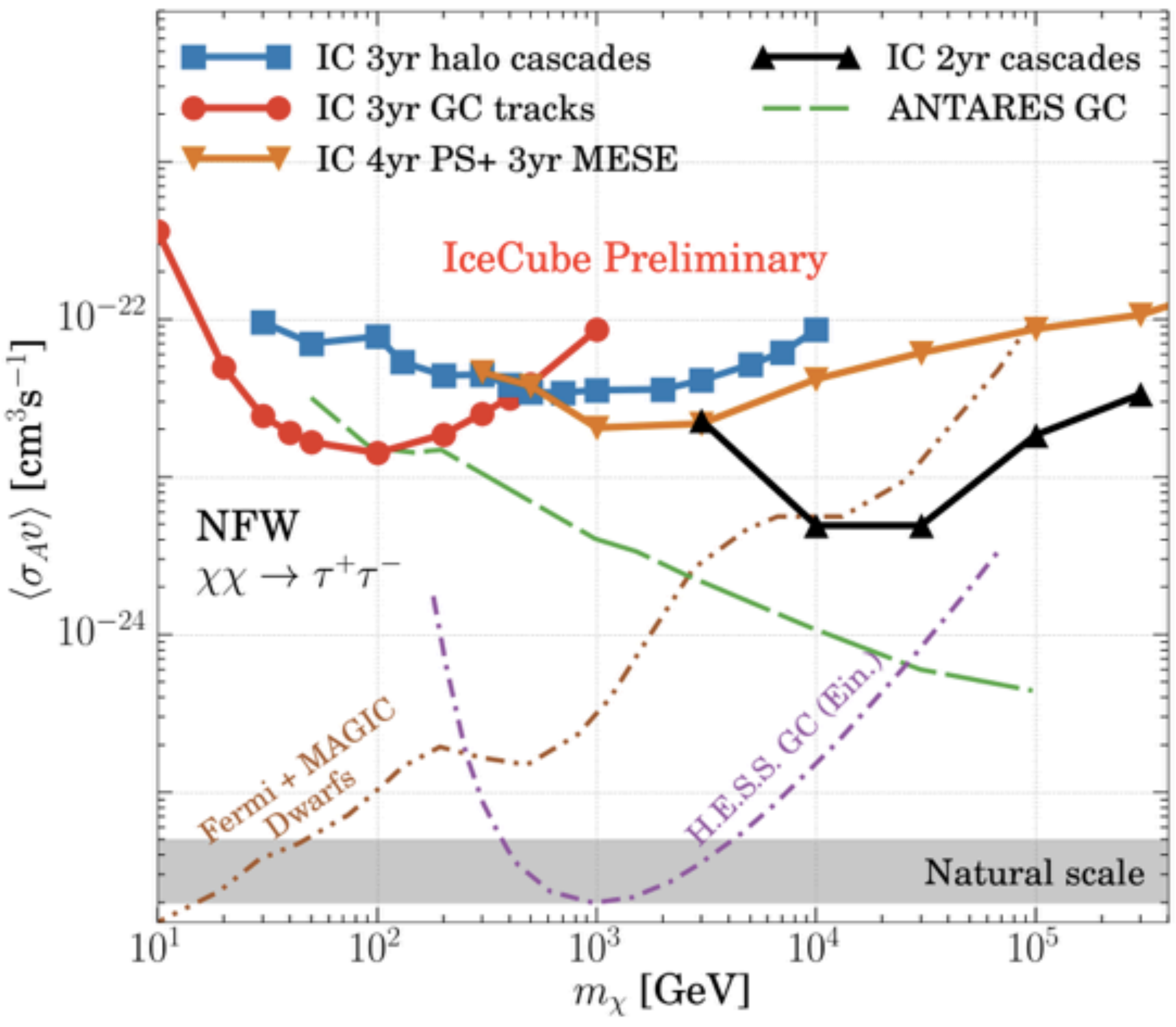
Astrophysics input

Measurement

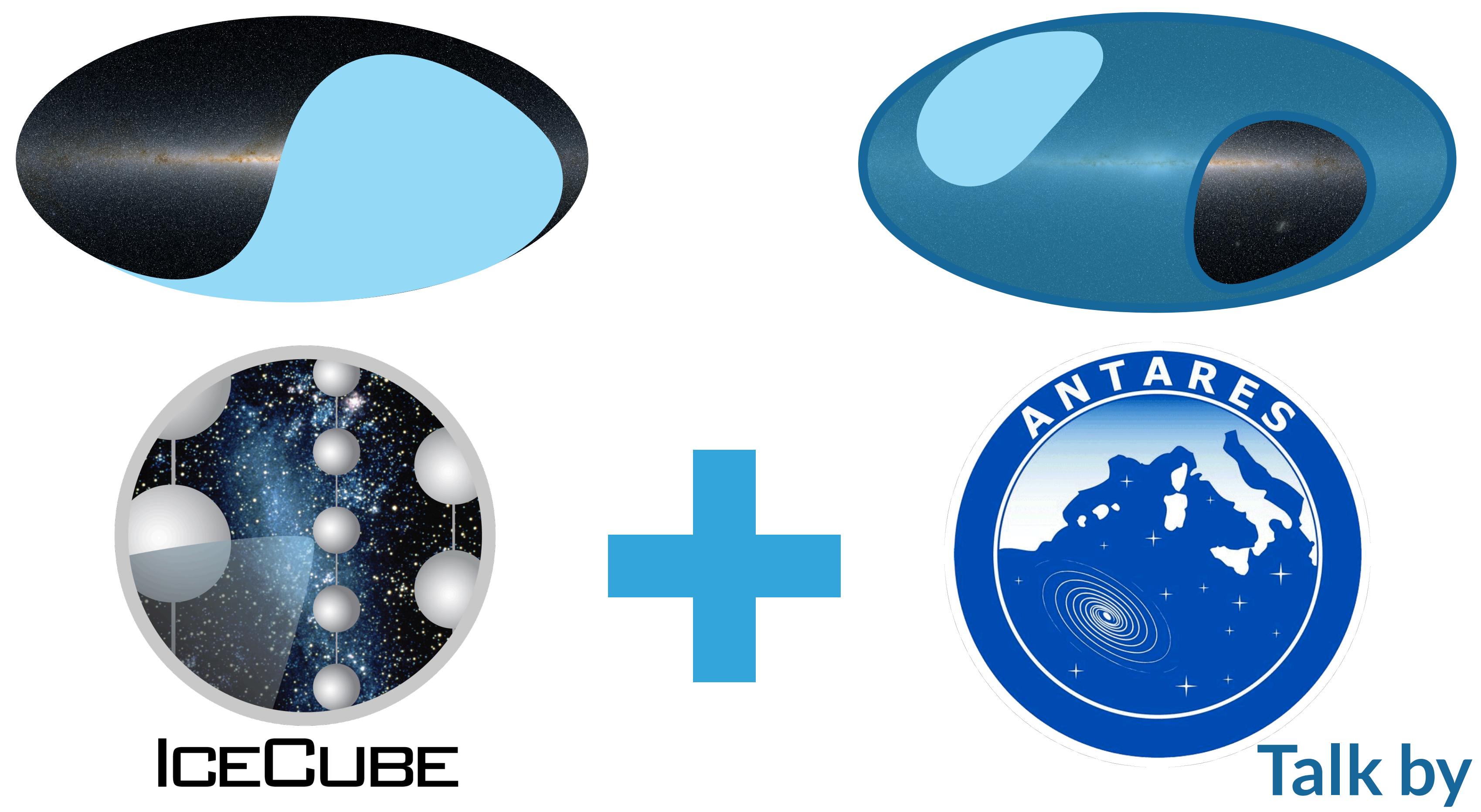
Constrain!



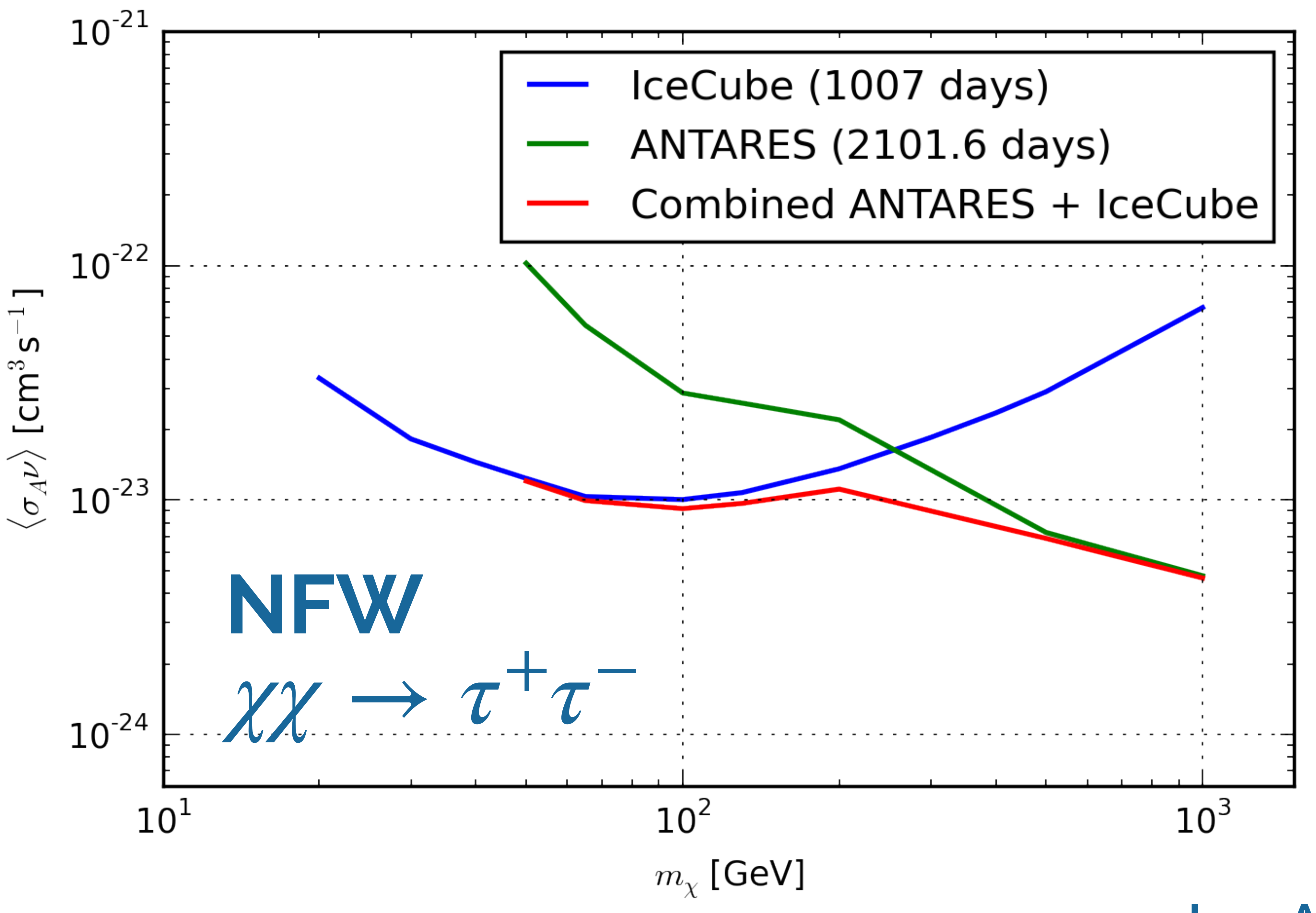
Galactic Center ANTARES & IceCube



Eur. Phys. J. C (2017) 77: 627

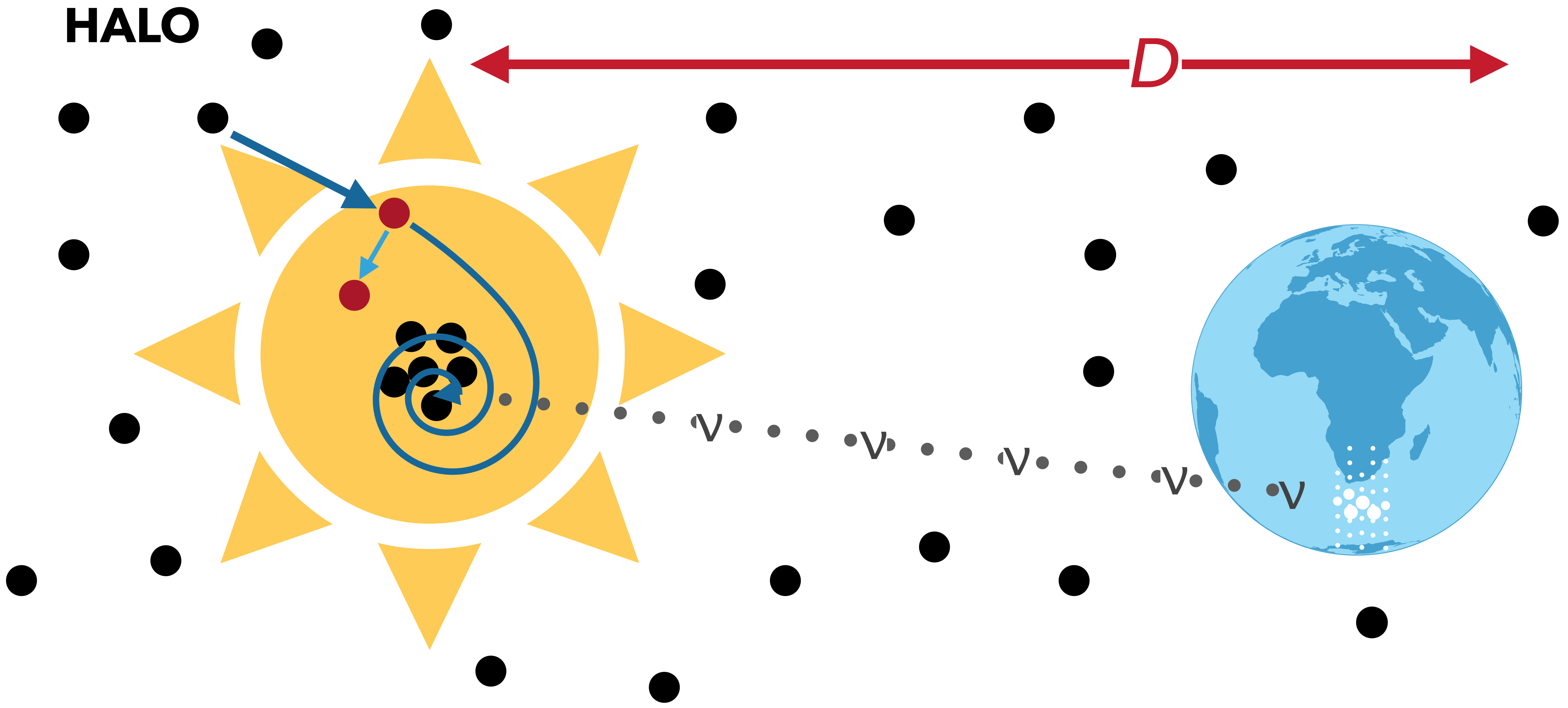


Talk by Rebecca



ICRC17 arXiv:1710.01197

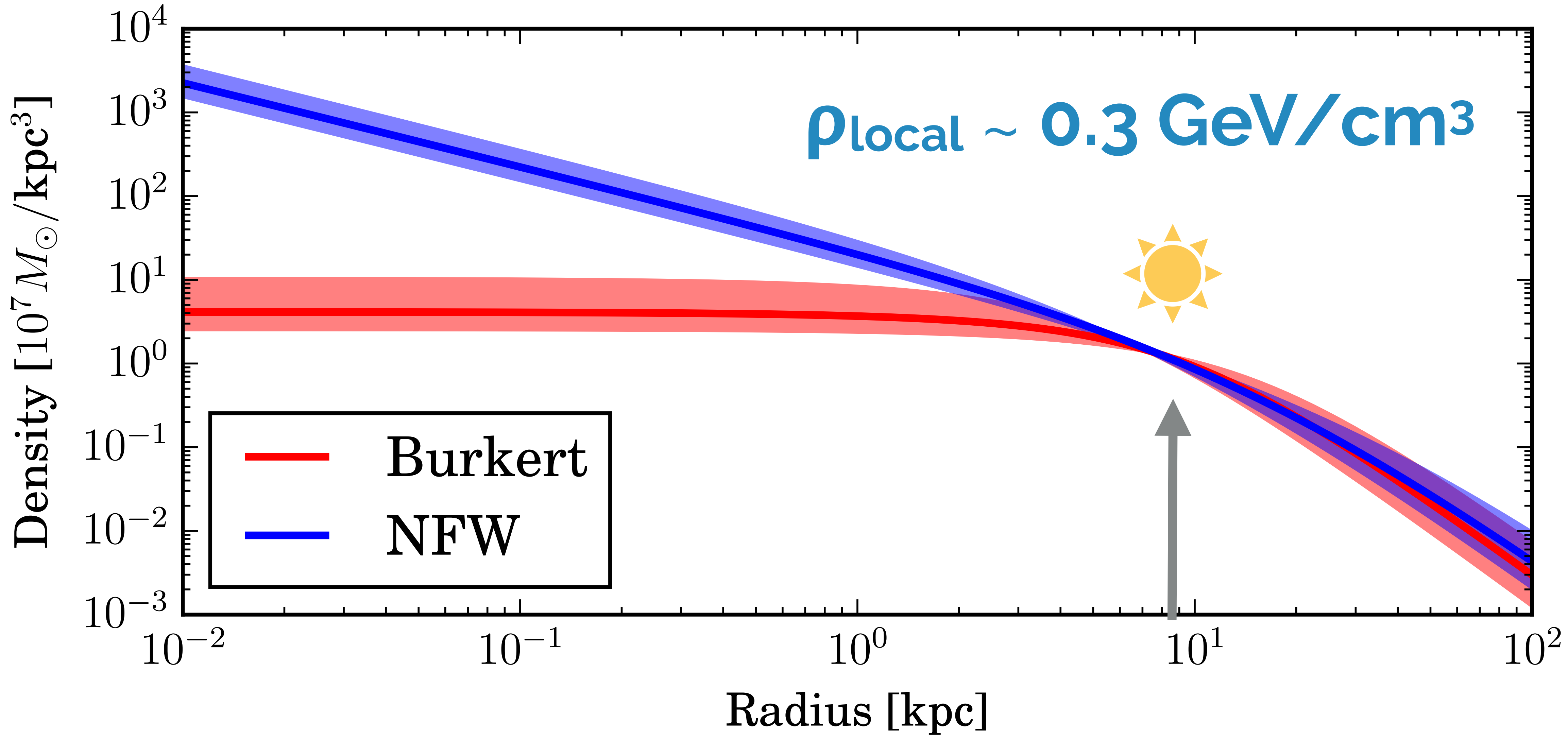
Dark Matter from Celestial Bodies



$$\frac{dN}{dt} = C_c - C_A N^2 - C_E N$$

annihilation σ_A

capture $\sigma_{\chi-N}$

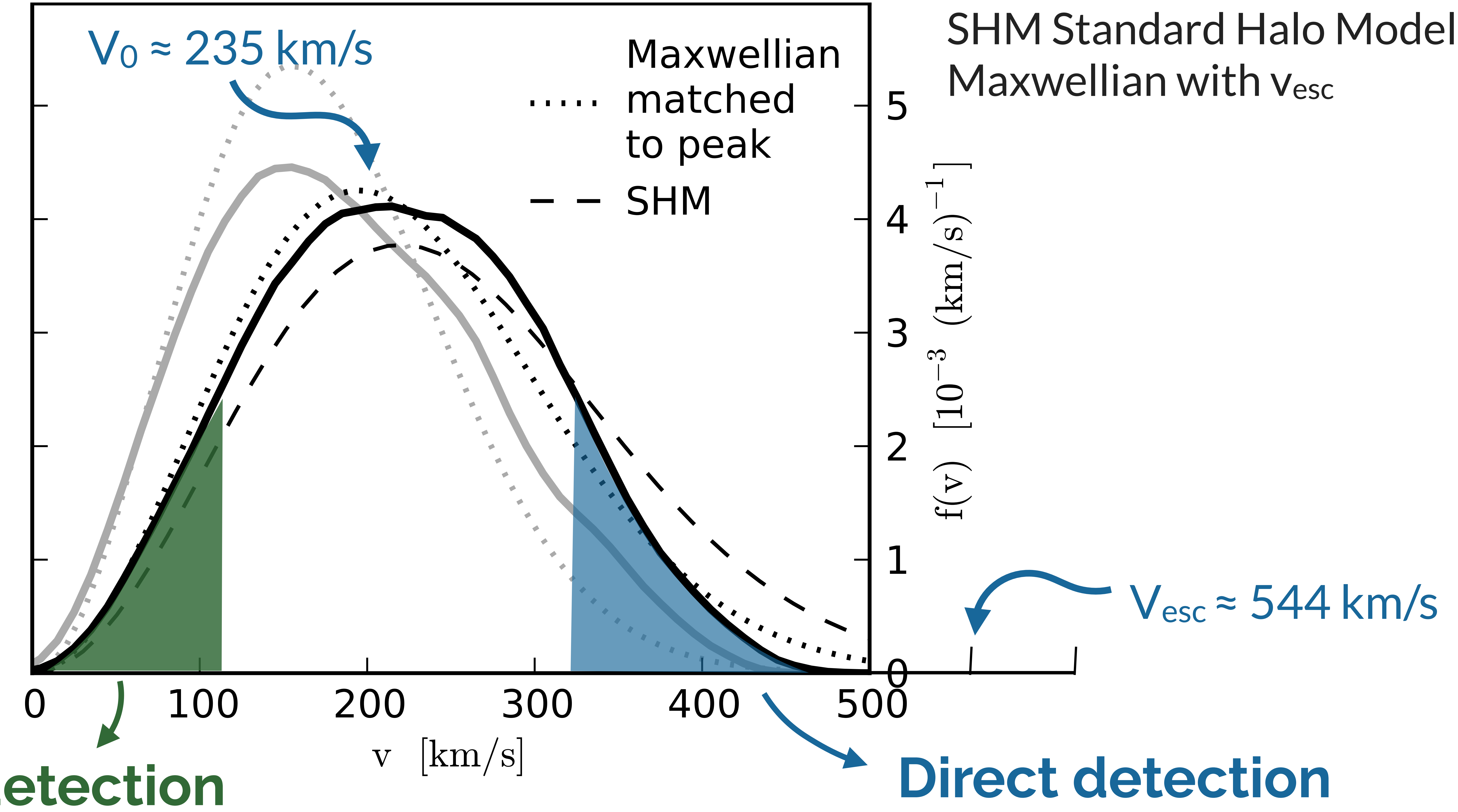


- Signal from the Sun or Earth in neutrinos cannot be mis-interpreted as an astrophysical source.
- Halo models agree in the Solar System.
- Equlibrium (dN/dt = 0) assumed for the Sun, not for Earth!

Celestial Bodies Velocity Distribution

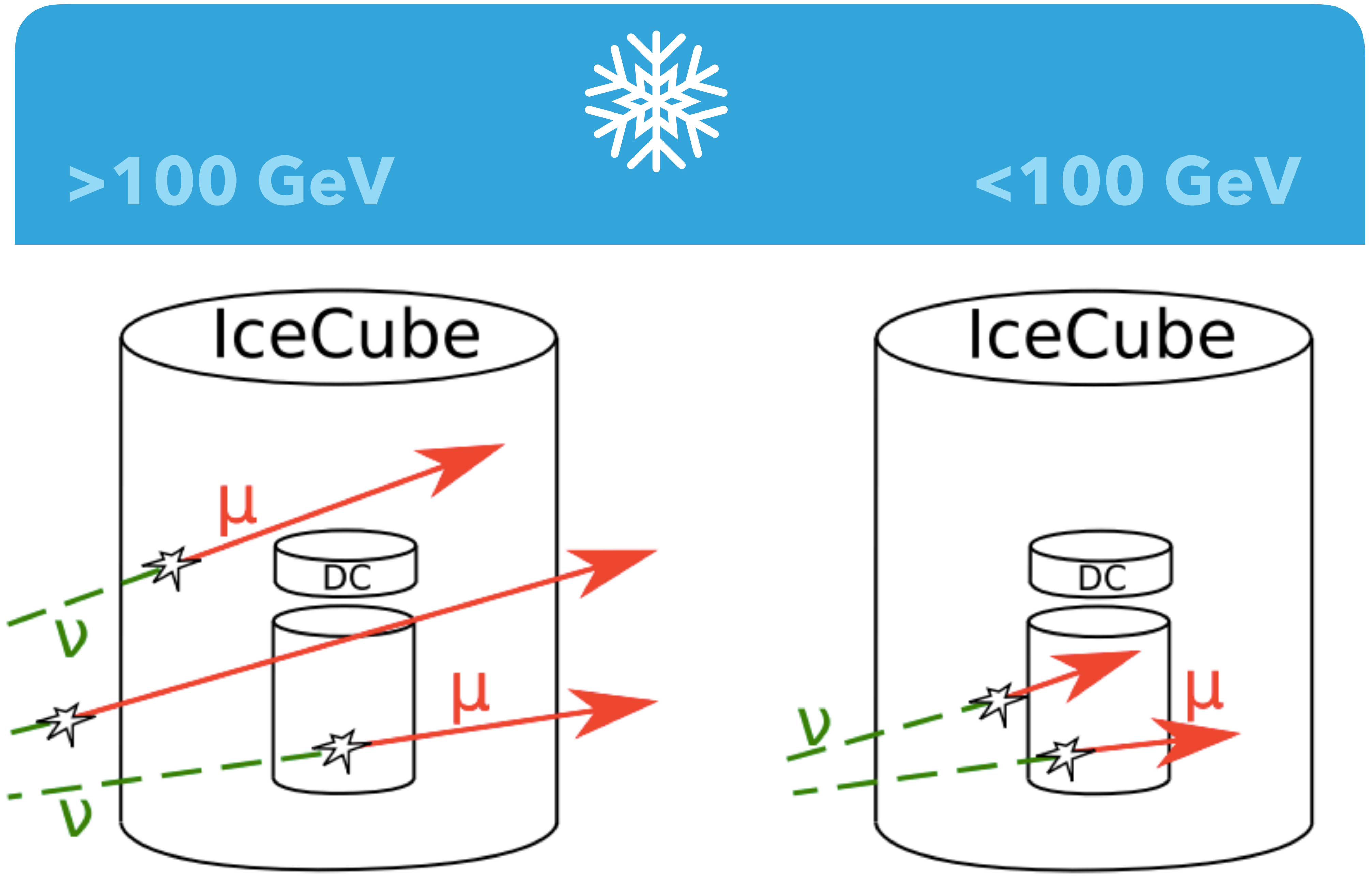
High dark matter masses are only captured in the low velocity regime

Figure from https://arxiv.org/pdf/1308.1703.pdf



SHM Standard Halo Model = Maxwellian with v_{esc}

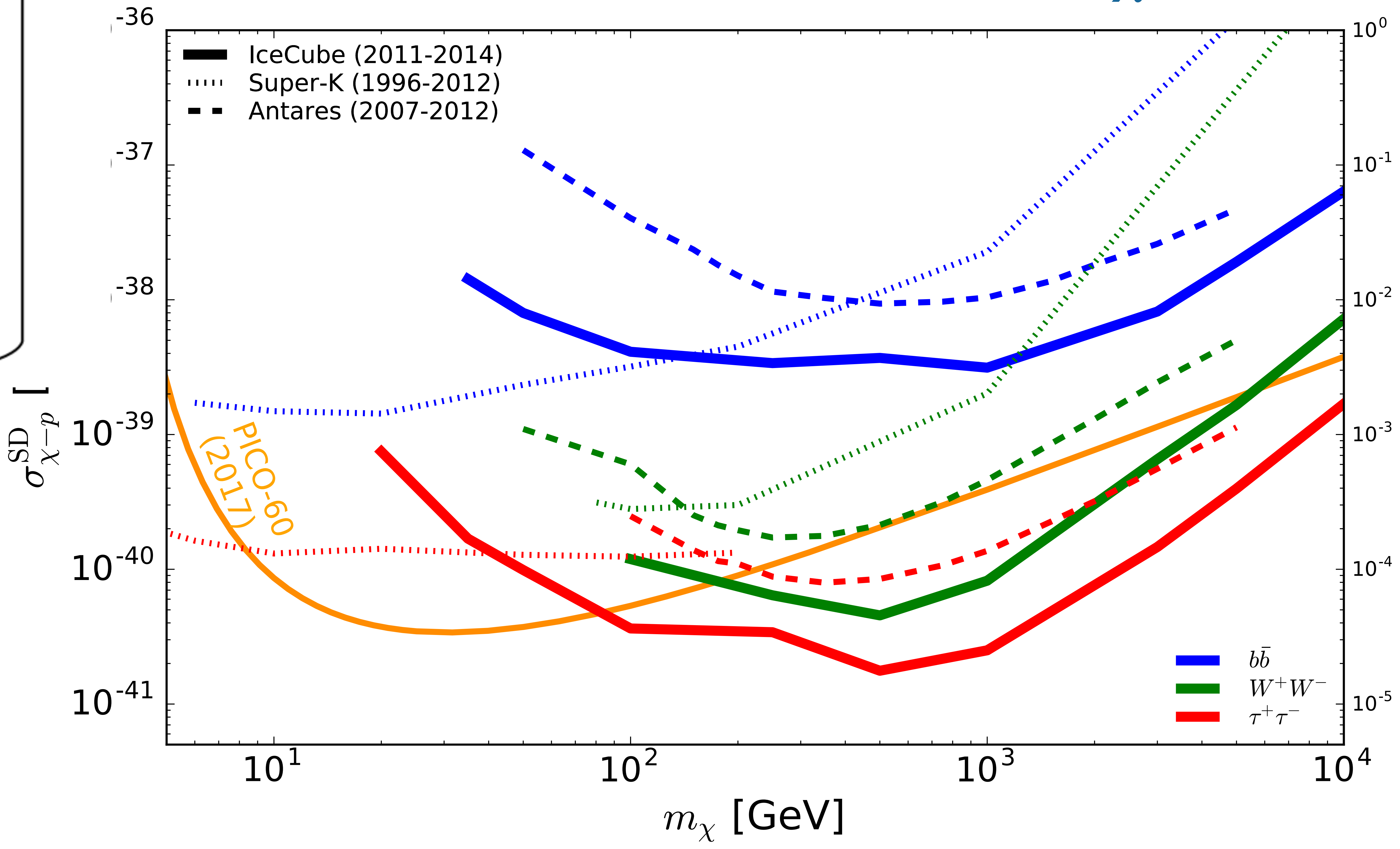
Celestial Bodies Results from the Sun



- The mean free path of TeV neutrinos smaller than the Sun radius: **Low energy analysis**
- Limit driven by capture on H: **SD cross-section**

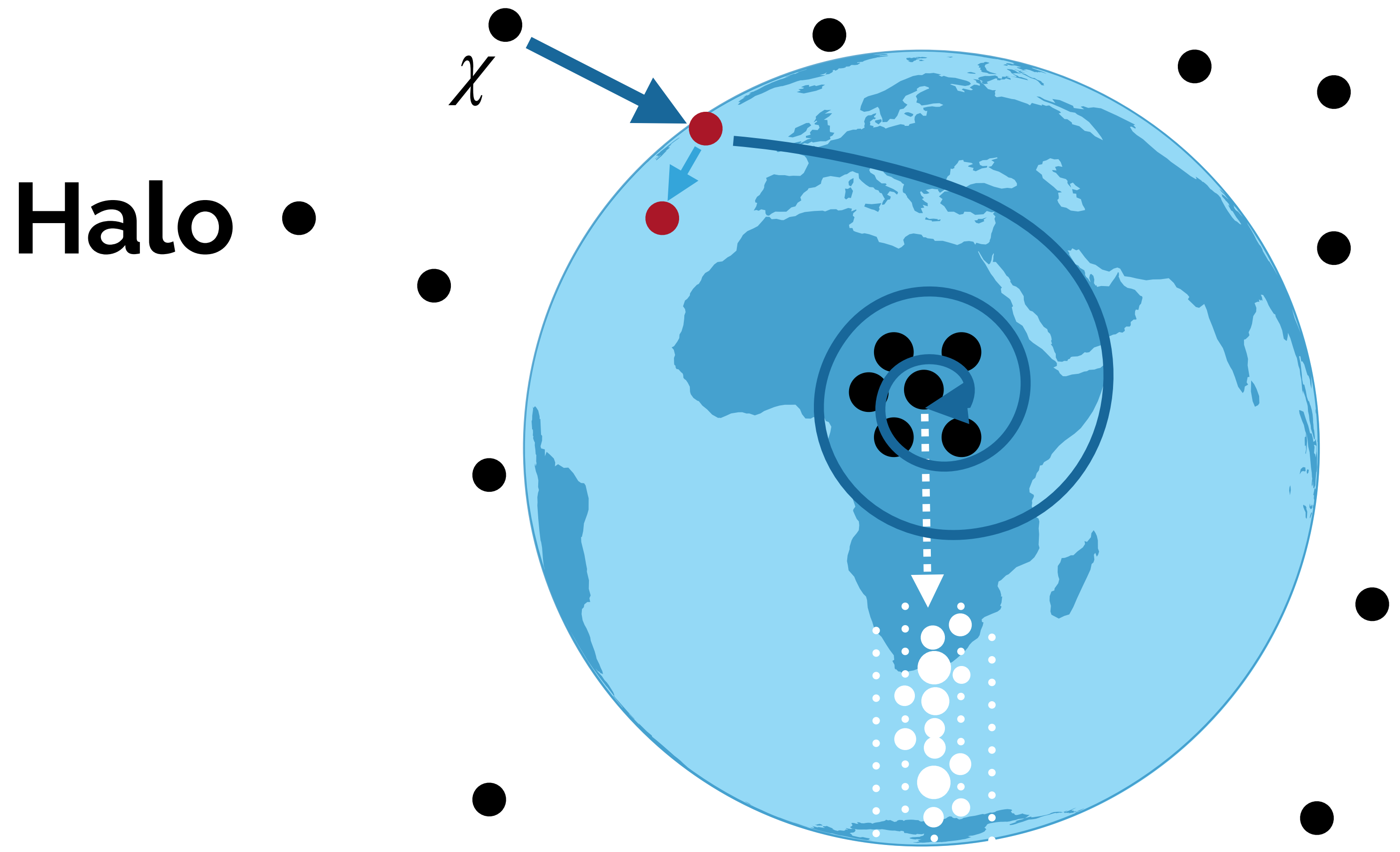
equilibrium!

$$\Phi_\nu \rightarrow \Gamma_A \rightarrow C_c \rightarrow \sigma_{\chi N}$$

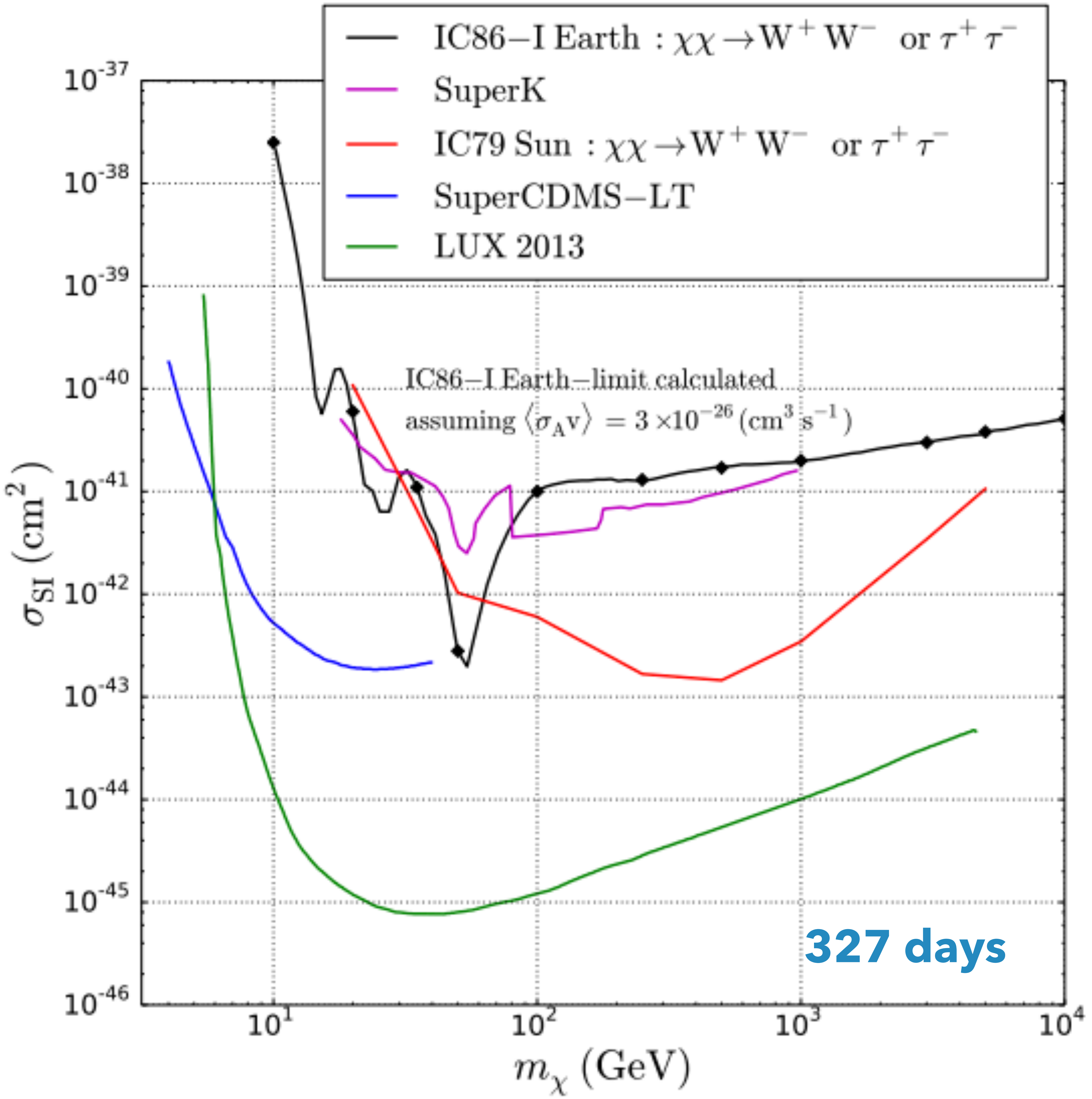


EPJC 77 146 (2017) [arXiv:1612.05949]

Celestial Bodies Results from the Earth

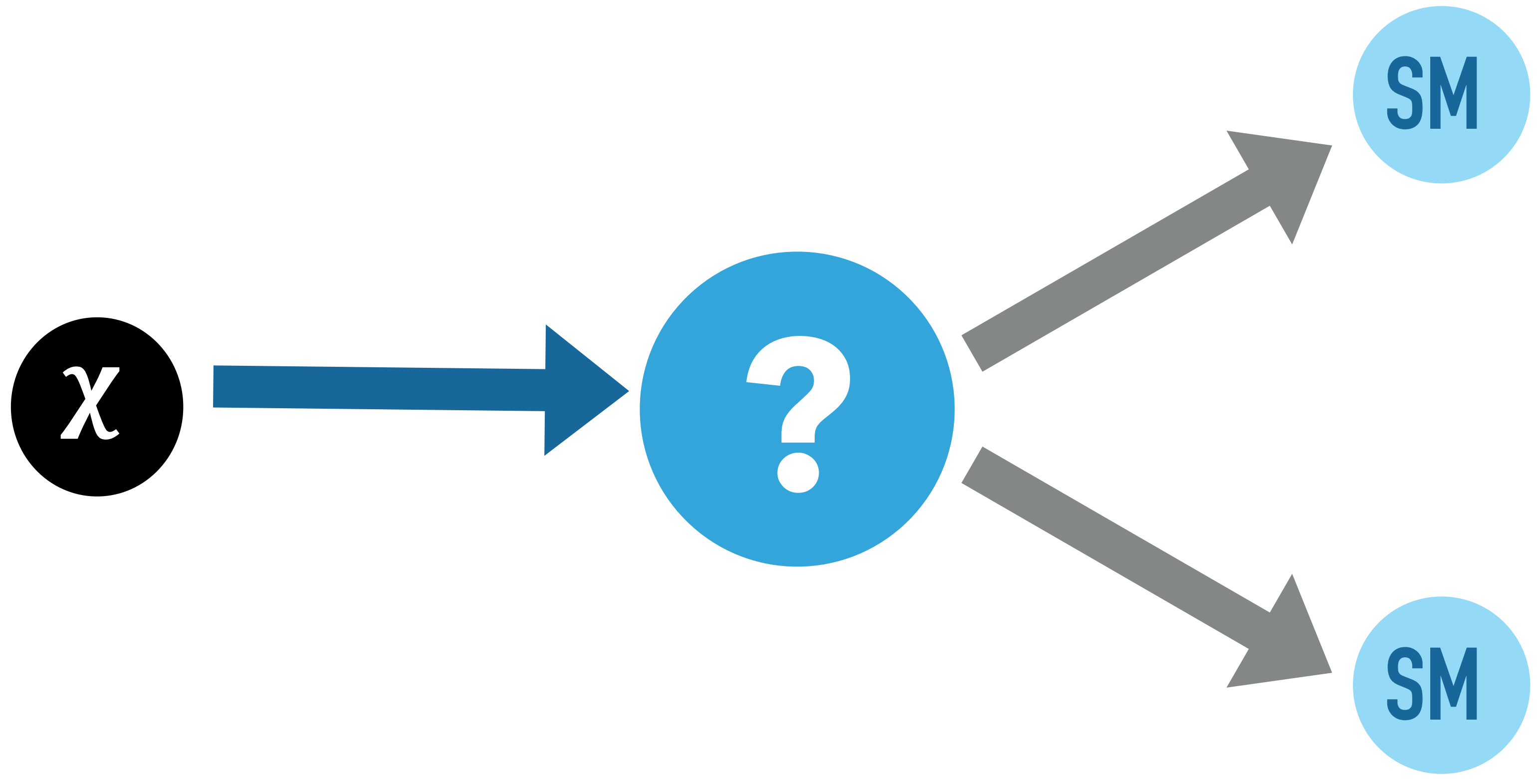


- **No thermal equilibrium**
- Background needs to be very well understood: **Earth has an unique position in the sky.**
- Analysis very senstive to astrophysical uncertainties (dark disc, velocity distribution)



Eur. Phys. J. C (2017) 77: 82

Decaying Dark Matter Lifetime



Kinematically dark matter could decay as long as the lifetime is greater than the age of the Universe.

Not factor ^{2}, no so pronounced in the direction of the GC

Galactic

$$\frac{\mathrm{d}\Phi_\nu}{\mathrm{d}E_\nu} = \frac{1}{4\pi}\frac{1}{m_\chi \tau_\chi}\frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu}\int_0^{\Delta\Omega}\mathrm{d}\Omega\int_{l.o.s}\rho_\chi(r(s,\Psi,\theta))\mathrm{d}s$$

constrain

Extra-galactic component can be ignored for Ψ < 10deg.

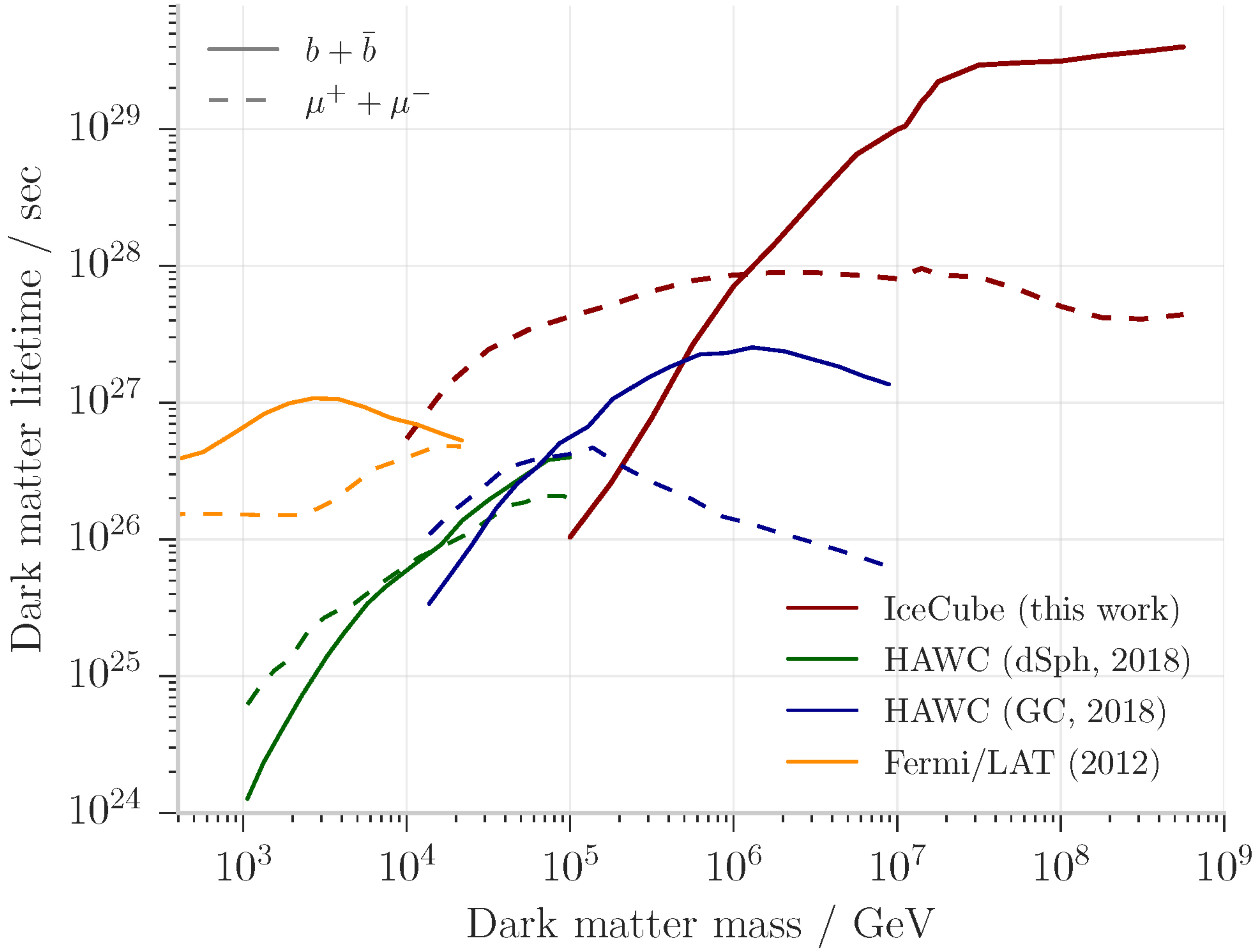
Extra-Galactic

$$\frac{\mathrm{d}\Phi_\nu}{\mathrm{d}E_\nu} = \frac{1}{4\pi}\frac{\Omega_\chi \rho_c}{m_\chi \tau_\chi}\int_0^{\infty}\mathrm{d}z\,\frac{c}{H(z)}\frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu}\bigg|_{E=E_\nu(1+z)}$$

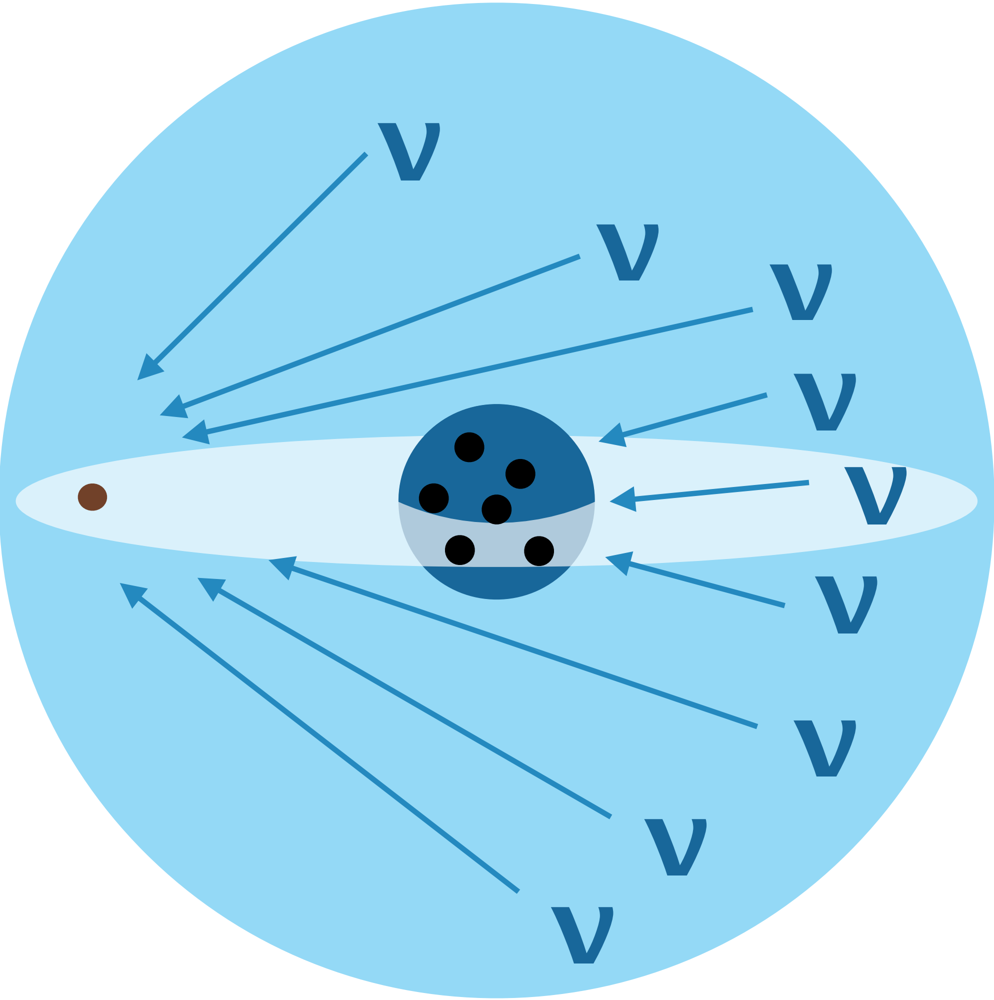
Decaying Dark Matter Lifetime

IceCube Collaboration arXiv:1804.03848

- Two IceCube independent data samples:
  - Track-like with six years of data
  - Cascade-like with two years of data
- Dark Matter alone cannot explain IceCube neutrino flux.
- Best limits > 10 TeV

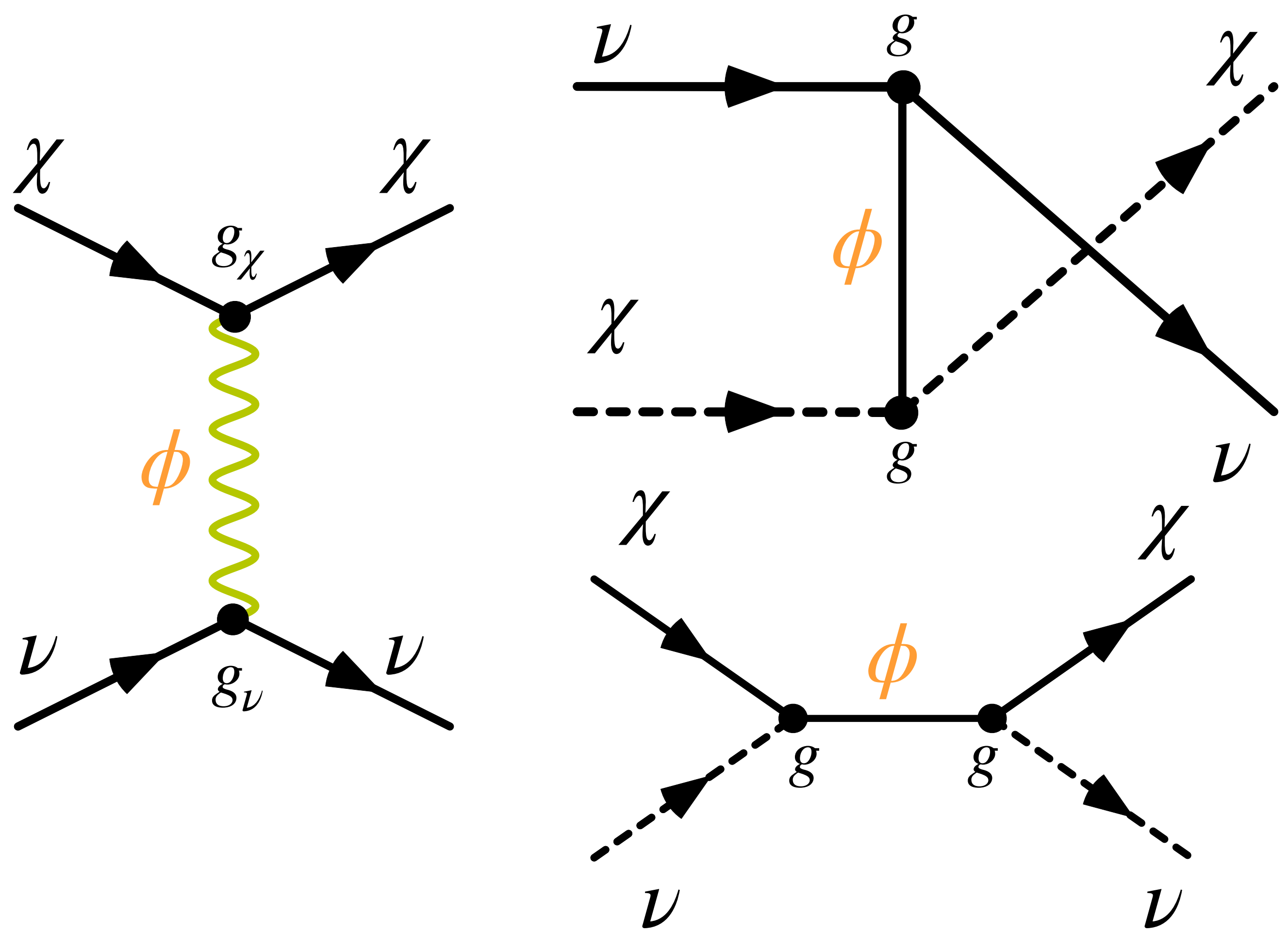


Neutrino Dark Matter Scattering

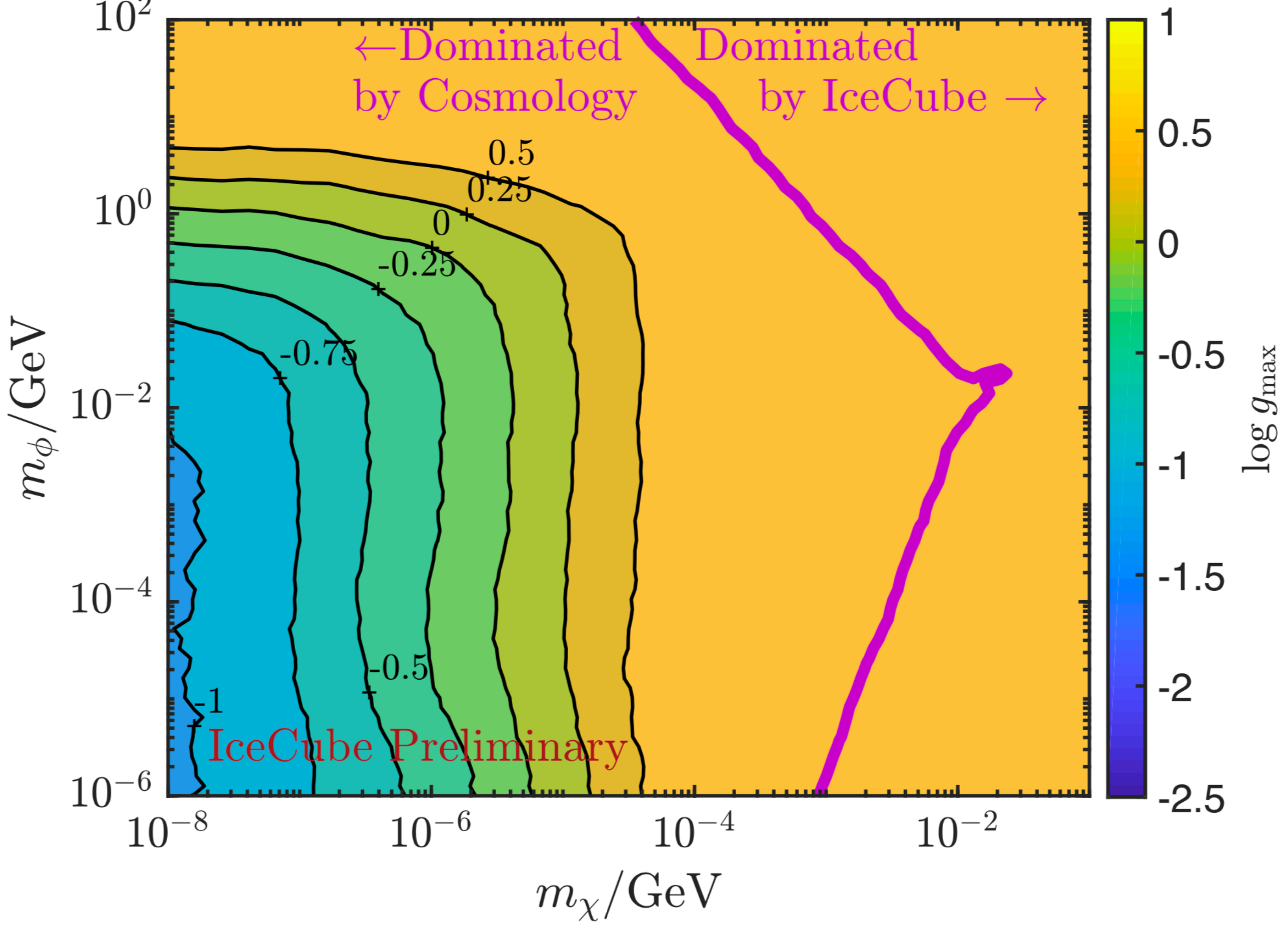


- Scattering of high energy cosmic neutrinos on DM in the halo can lead to a **deficit of high energy neutrinos** from the GC
- Focusing on HE neutrinos (cross-section increases with energy)

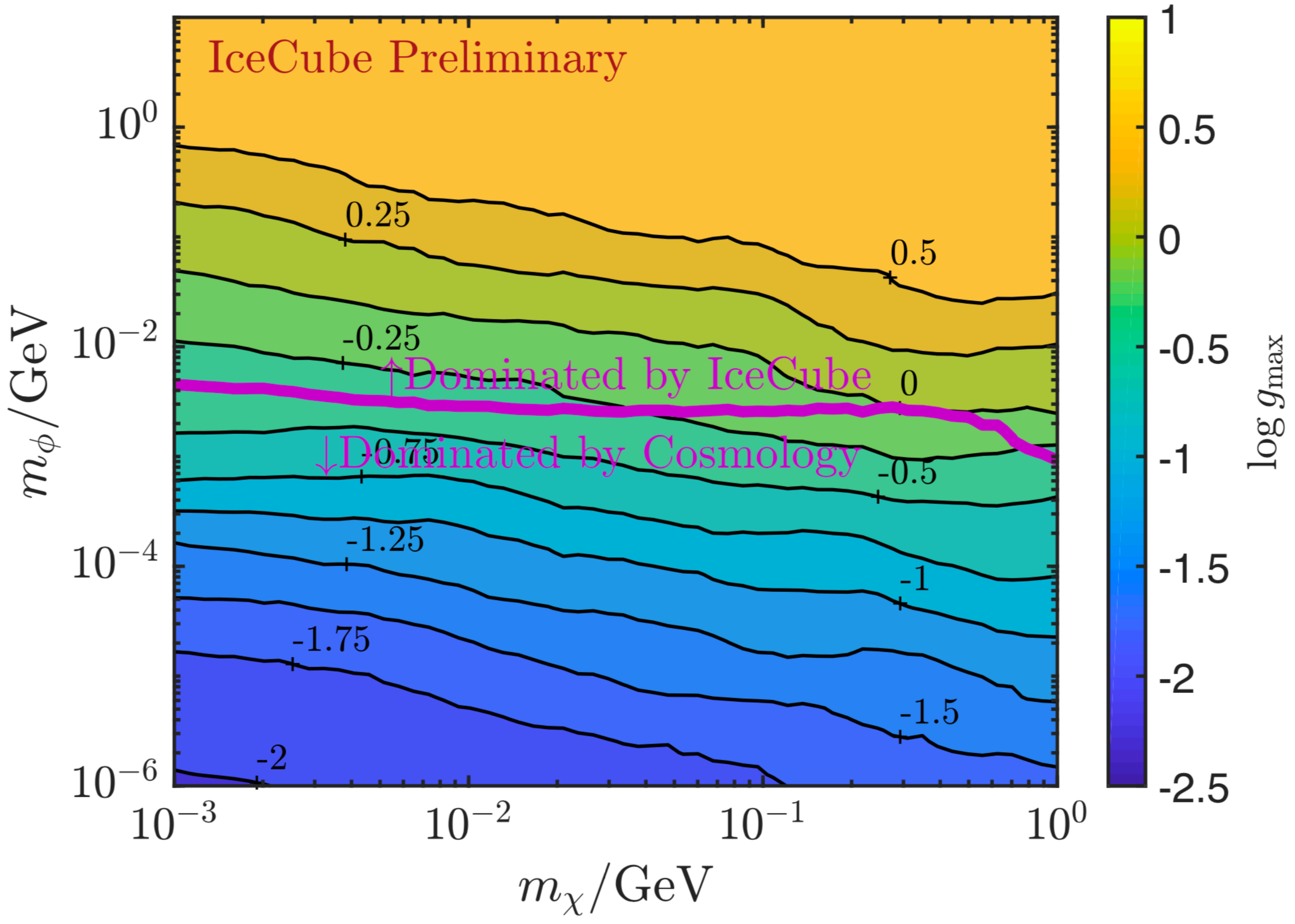
Fermion—vector **Scalar—Fermion**



Scalar—Fermion



Fermion—vector



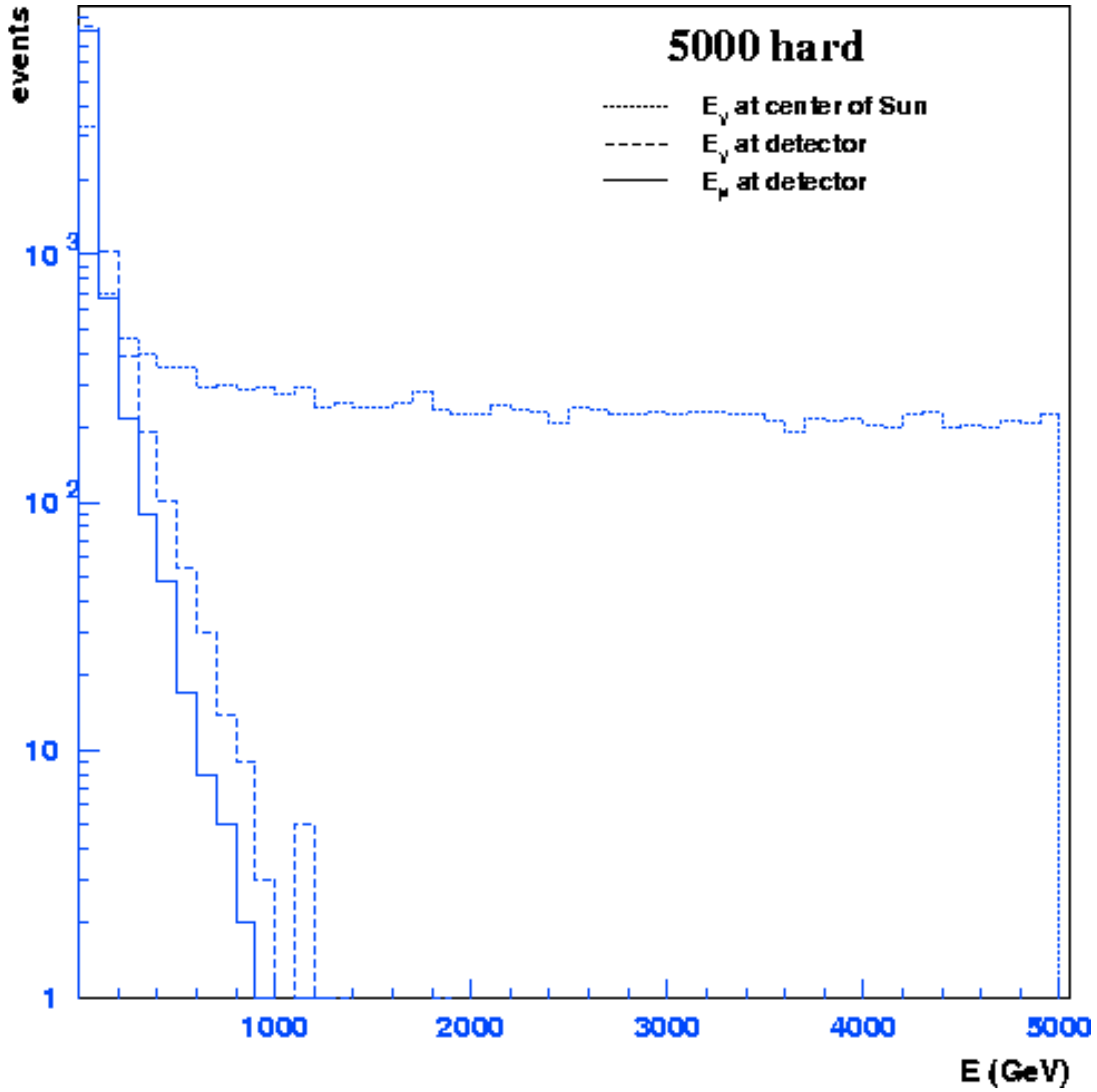
Conclusions

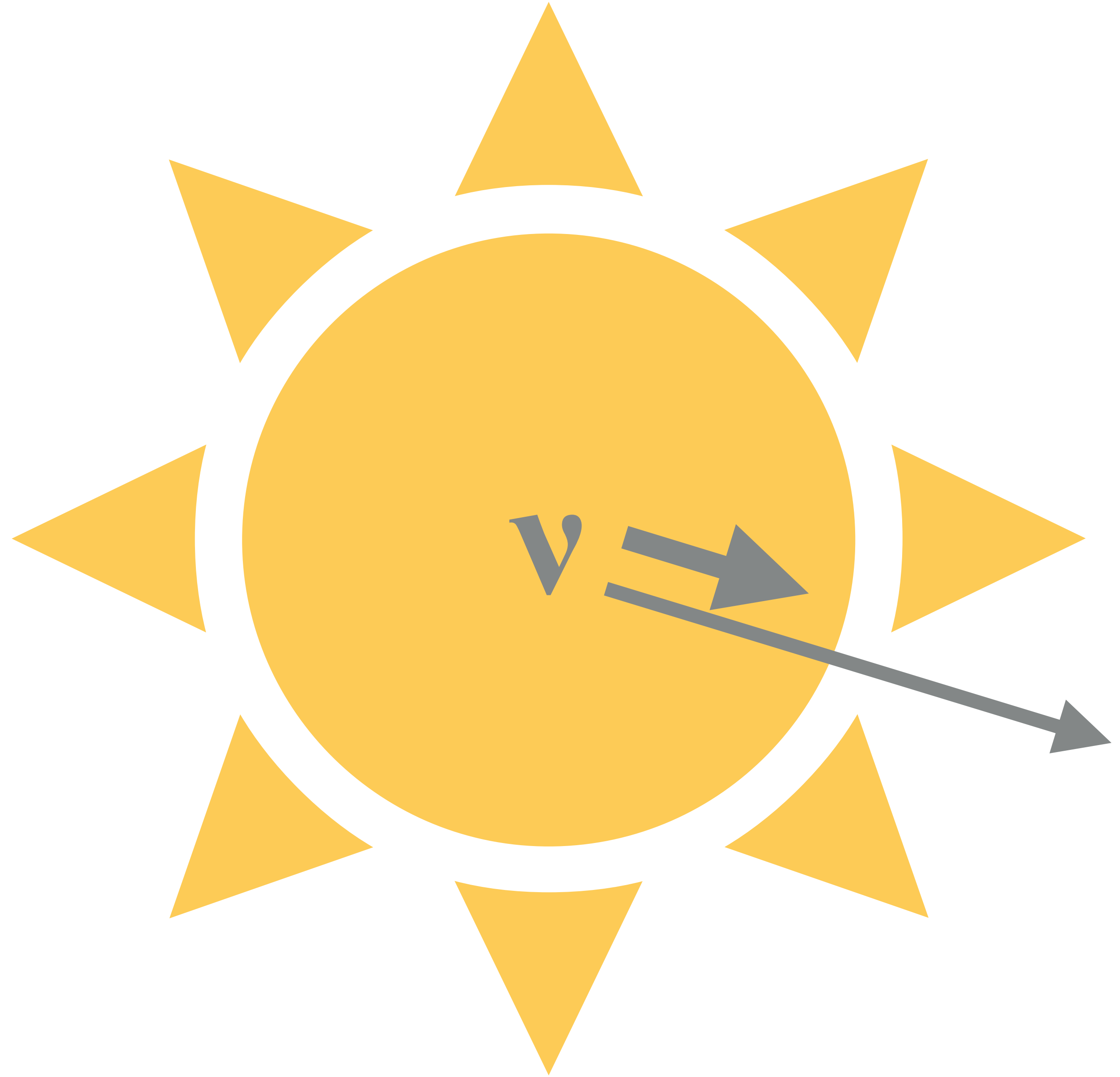
- **Indirect detection of Dark Matter** with neutrino telescopes provides complementarity to other techniques due to different backgrounds and systematics.
- Many astrophysical signals can be interpreted as Dark Matter. We need **strong corroboration** from all searching strategies.
- IceCube has a **lively program of Dark Matter searches,** with very competitive results.

Thank you for your attention

backups

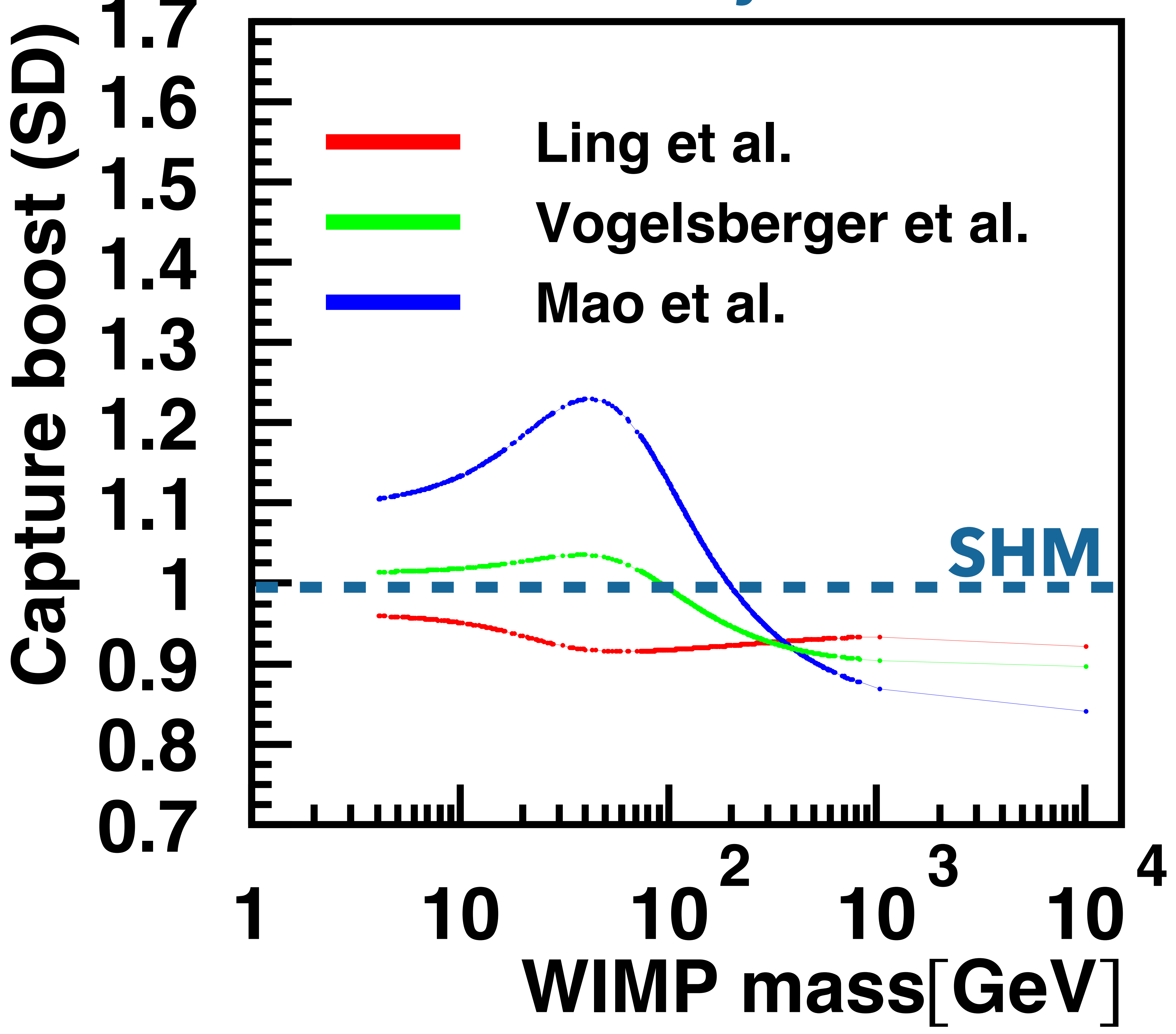
- The mean free path of neutrinos of 5000 GeV is smaller than the Sun radius
- Indirect searches from the Sun are **low-energy analysis** even for the highest dark matter masses.



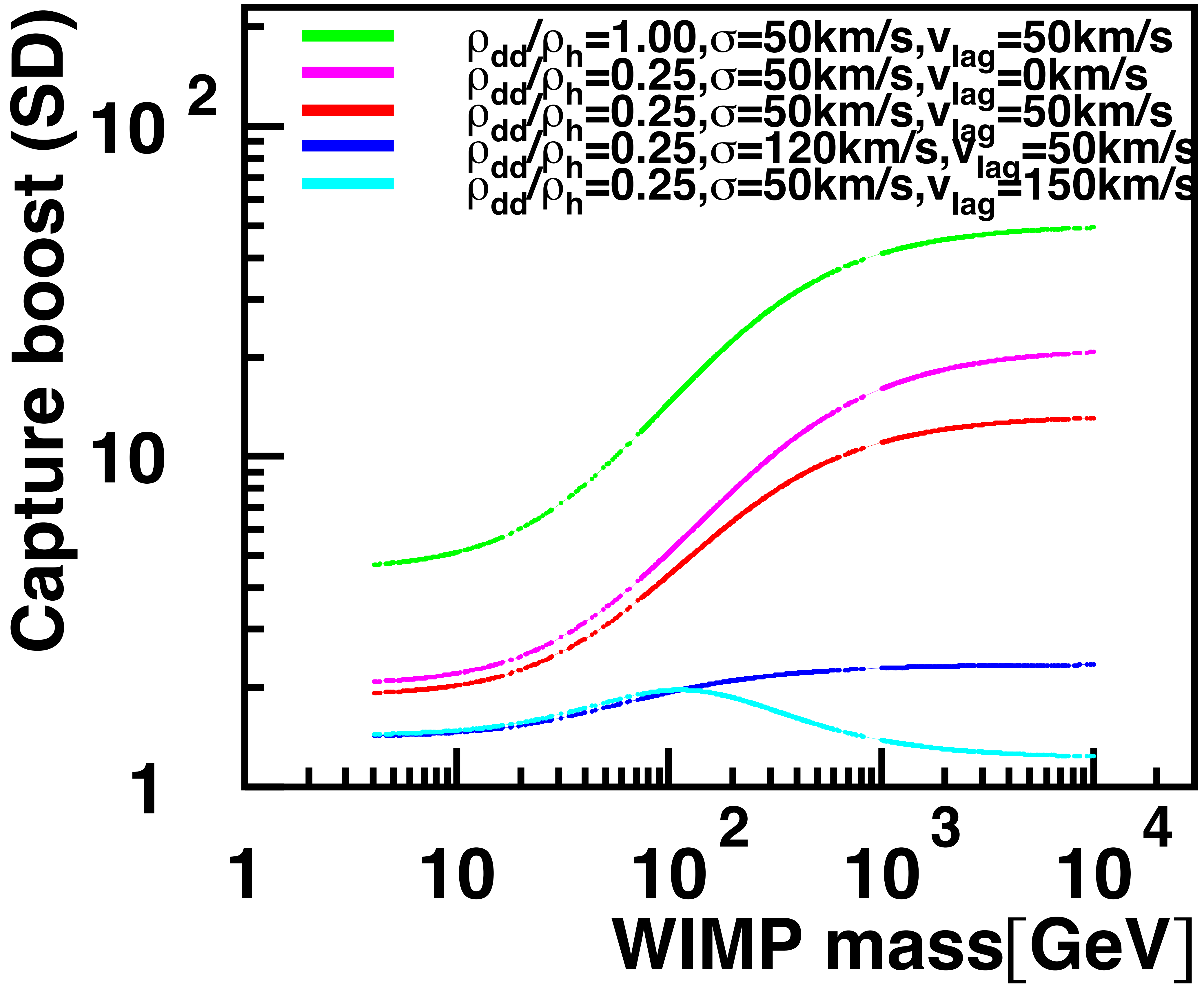


Effect of uncertainties in velocity distributions for Sun results:

Different velocity distributions



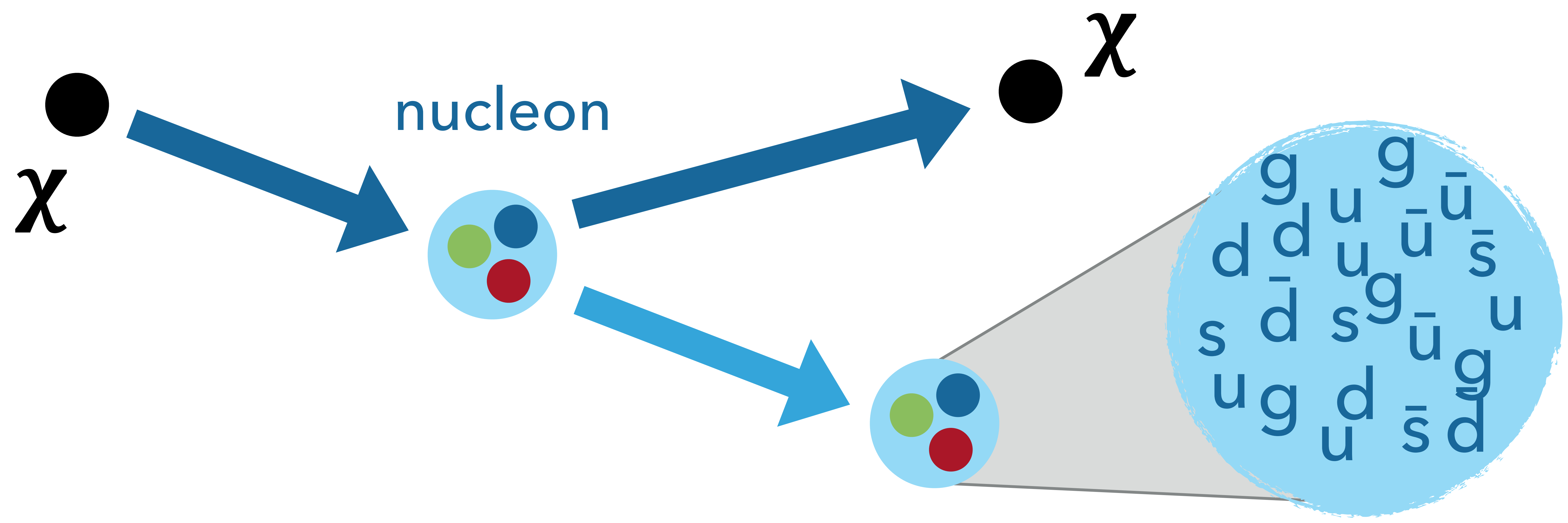
Different dark disc distributions



Choi, Rott, Itow arXiv:1312.0273

A **dark matter disc** will have a significant (good) impact on the capture rate for the Sun/Earh

CELESTIAL BODIES: PARTICLE PHYSICS INPUT



Both direct detection and indirect detection (gravitational capture) depend on the WIMP-nucleon cross-section.

$$\sigma_{SI} \propto A^2$$

Spin independent → **Use heavy nuclei as target: Direct detection**

$$\sigma_{SD} \propto (a_p\langle S_p\rangle + a_n\langle S_n\rangle)\frac{J+1}{J}\frac{S(|\vec{q}|)}{S(0)}$$

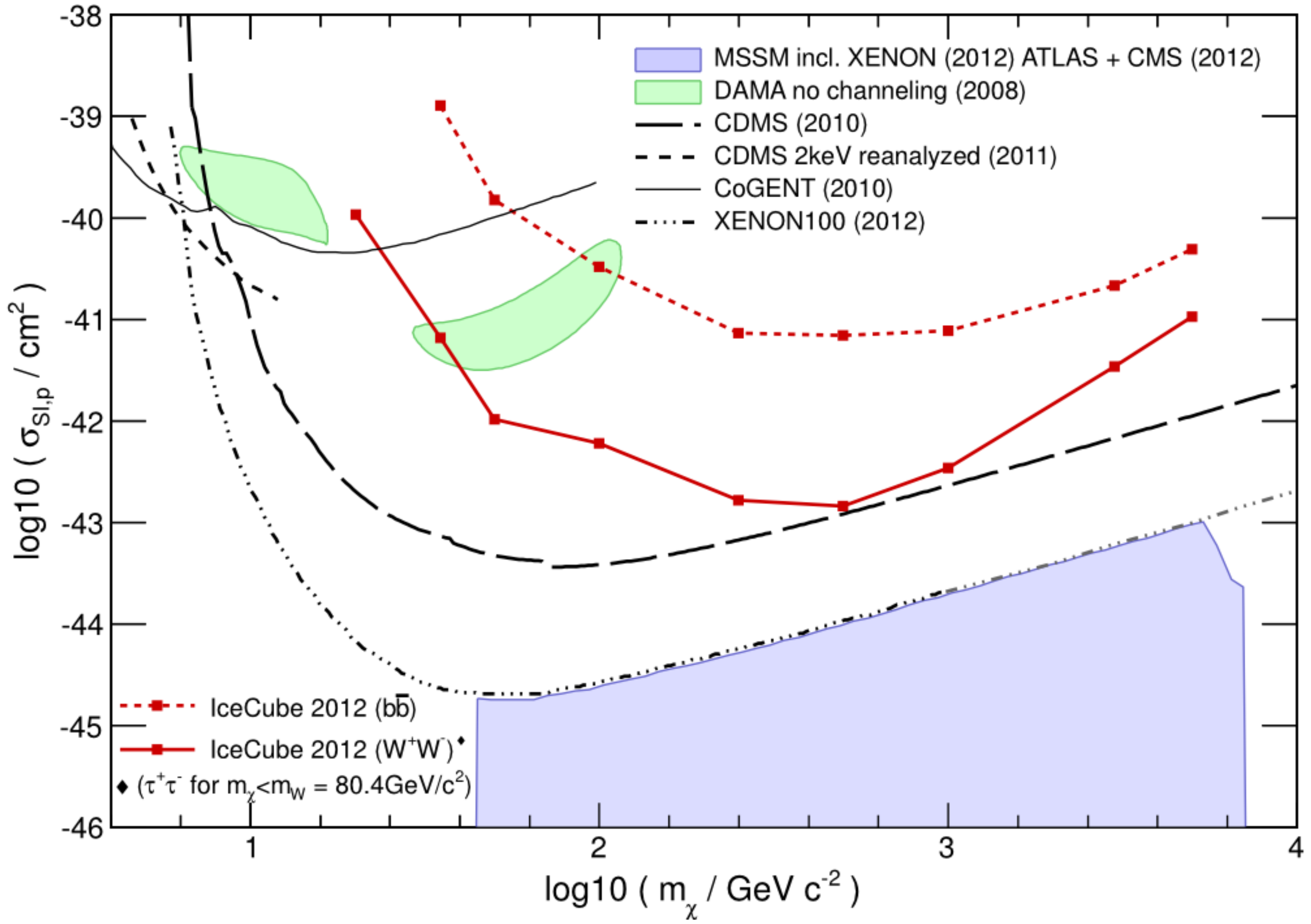
Spin dependent → **Sun is full of protons: Indirect detection**

The nucleon structure plays an essential role in calculating observables

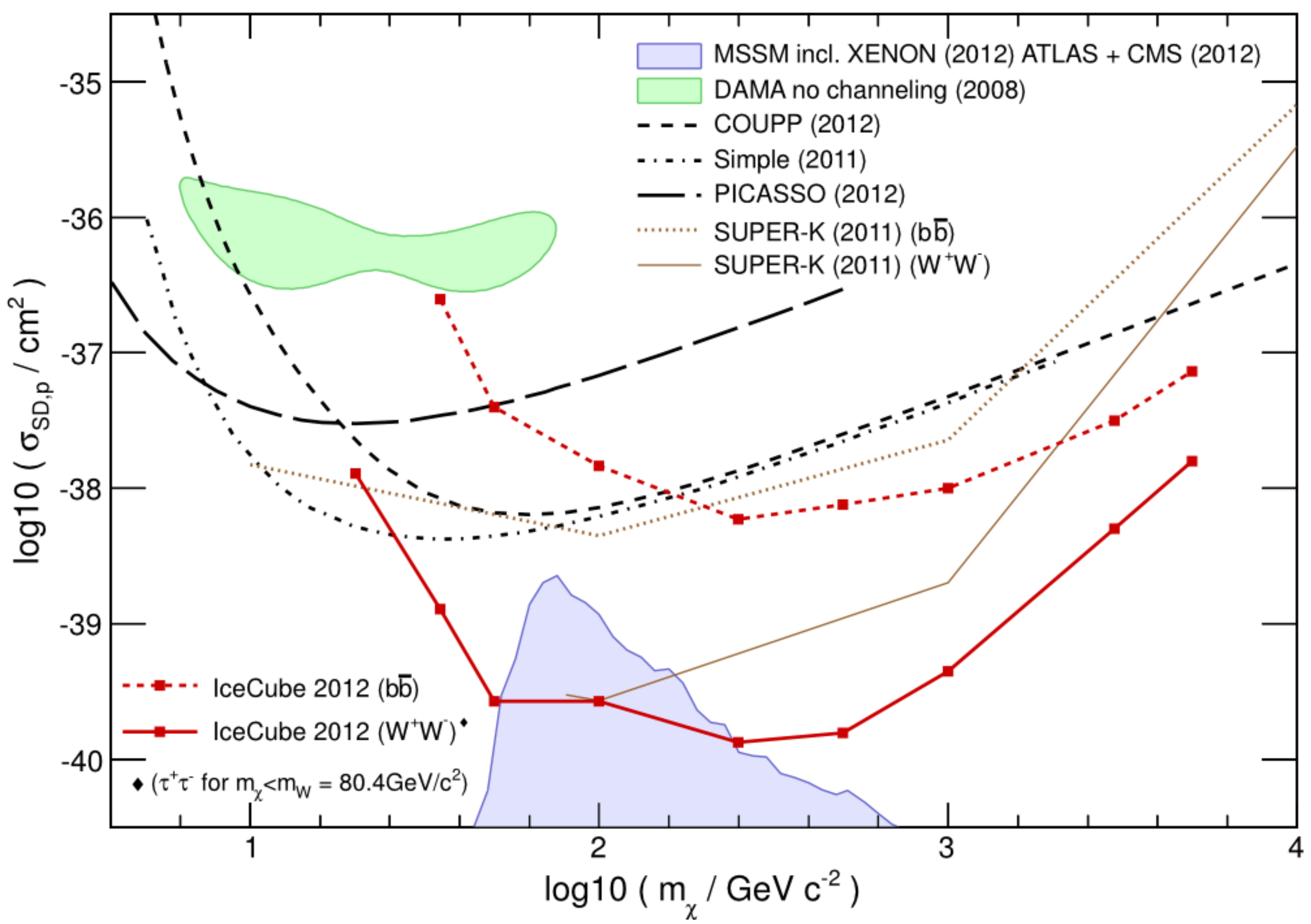
But it seems to affect more σ^{SI} than σ^{SD}

R. Ruiz, C. de los Heros arXiv:1307.6668

WIMP Searches From the Sun



90% CL χ-p cross-section (spin-independent)



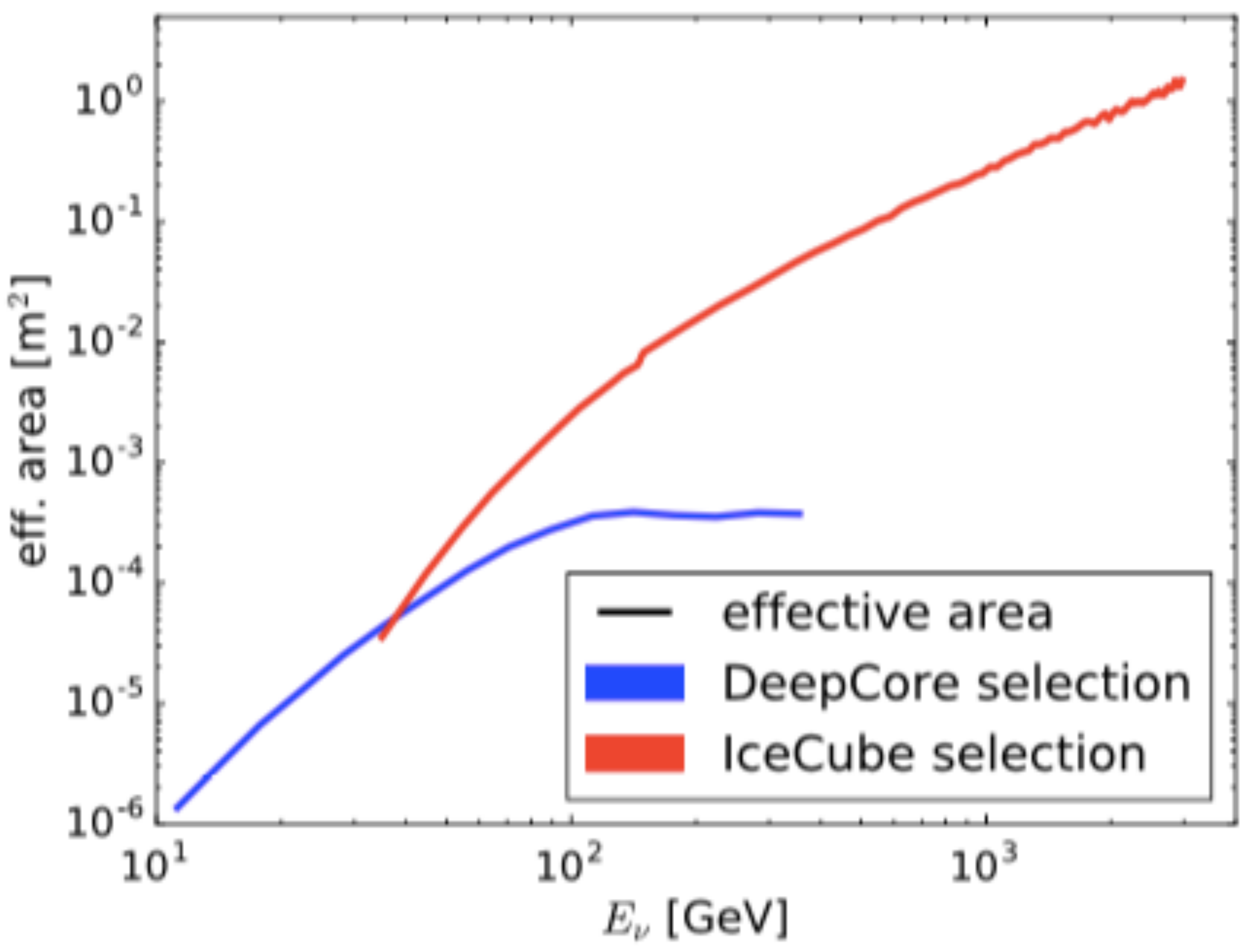
90% CL χ-p cross-section (spin-dependent)

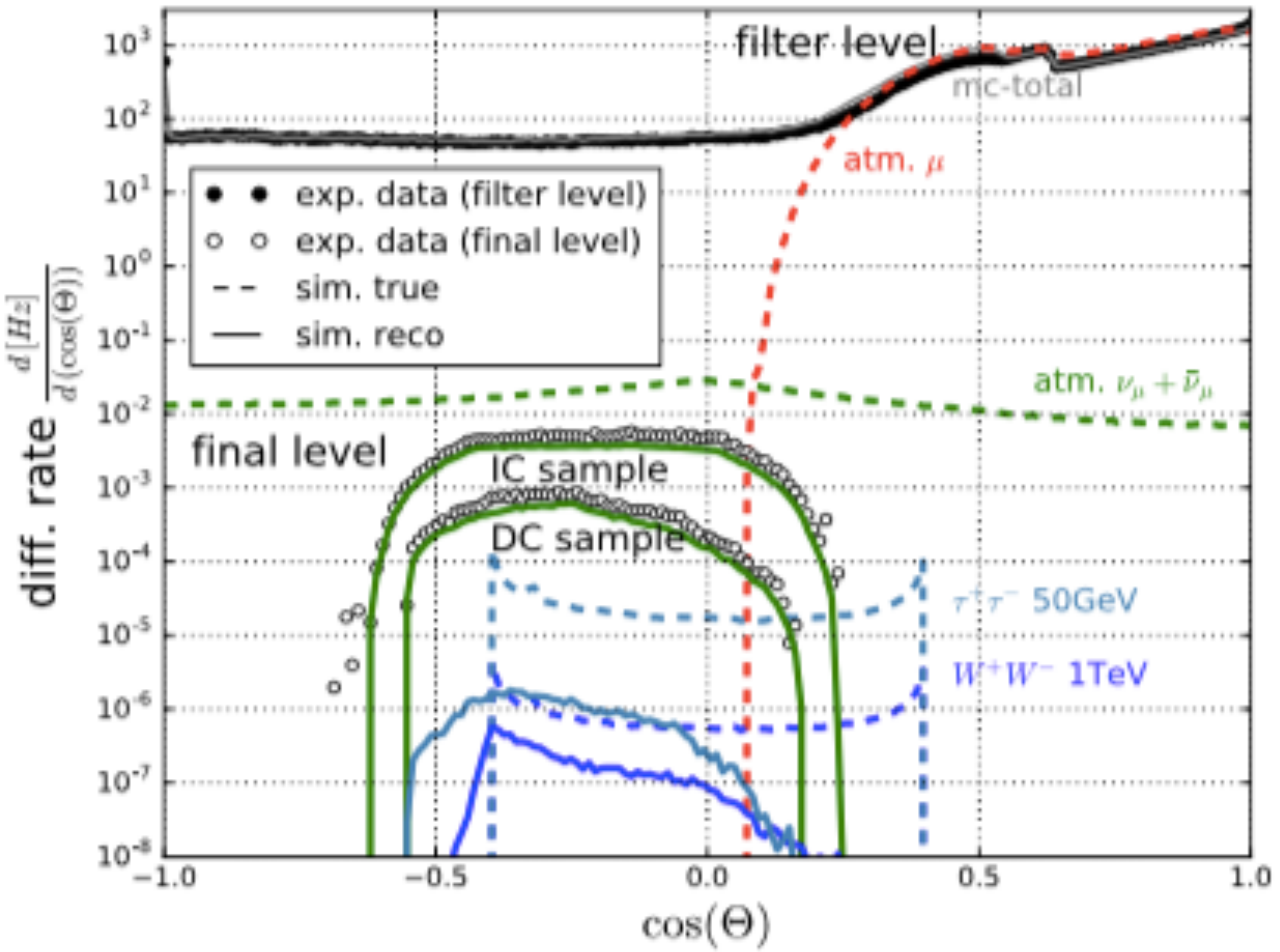
Complementary to direct detection search efforts

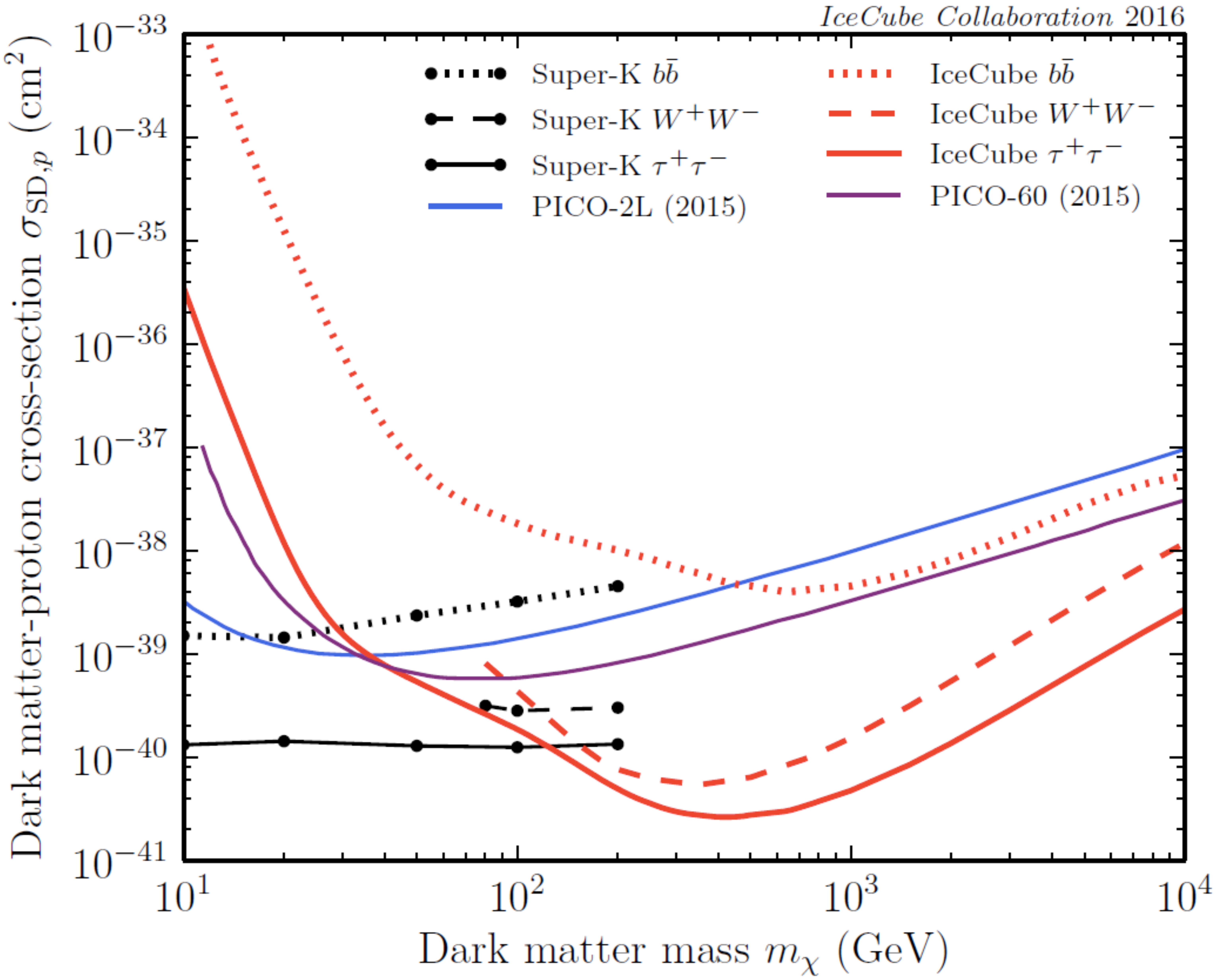
fills out WIMP picture by testing other properties

Most stringent SD cross-section limit for most models

Effective Areas Sun






IceCube Collaboration 2016
Super-K $b\bar{b}$
Super-K W^+W^-
Super-K $\tau^+\tau^-$
PICO-2L (2015)
IceCube $b\bar{b}$
IceCube W^+W^-
IceCube $\tau^+\tau^-$
PICO-60 (2015)
Dark matter-proton cross-section $\sigma_{SD,p}$ (cm^2)
10^{-33}
10^{-34}
10^{-35}
10^{-36}
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^1
10^2
10^3
10^4
Dark matter mass m_χ (GeV)

EARTH WIMP Spin independent