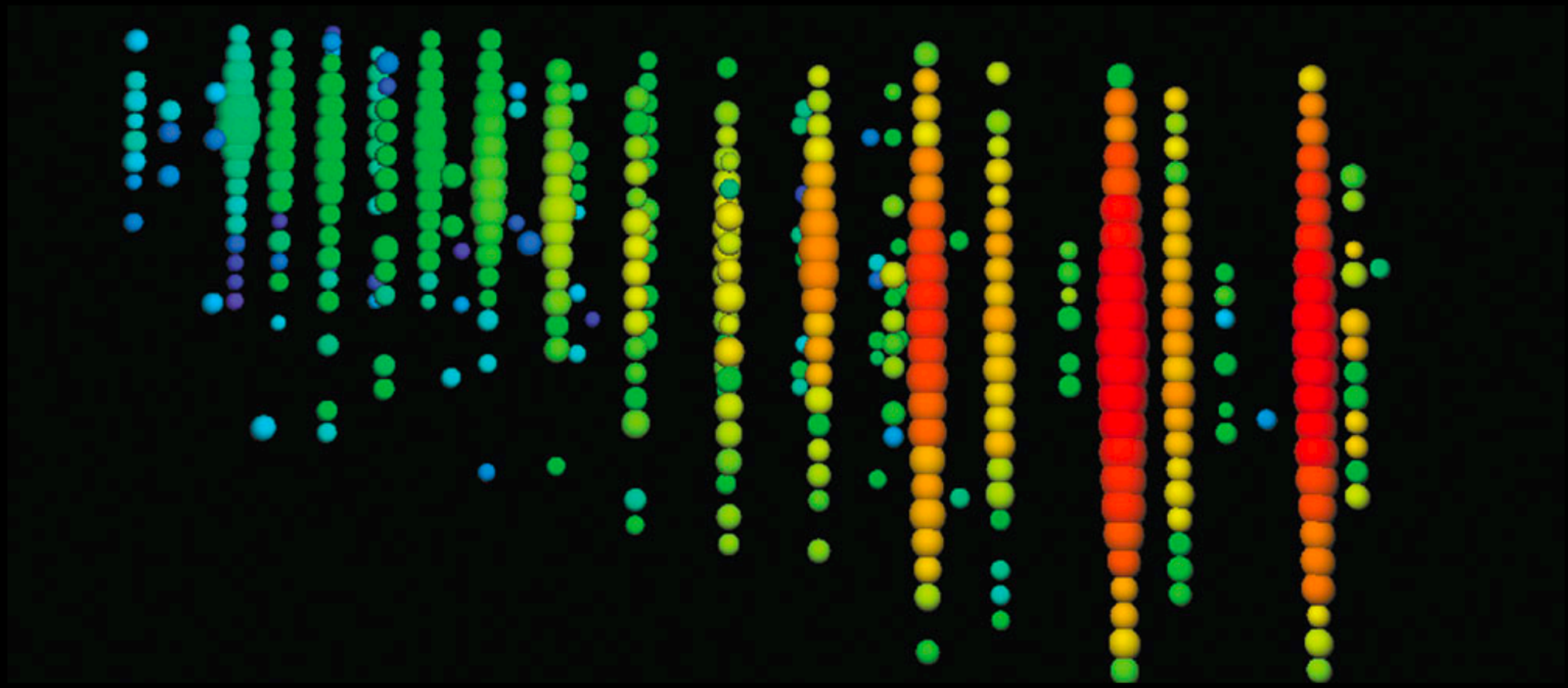
Searching for Dark Matter with High-energy neutrinos

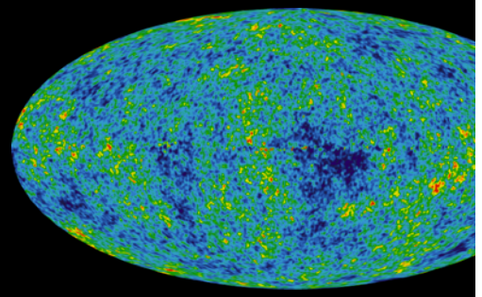


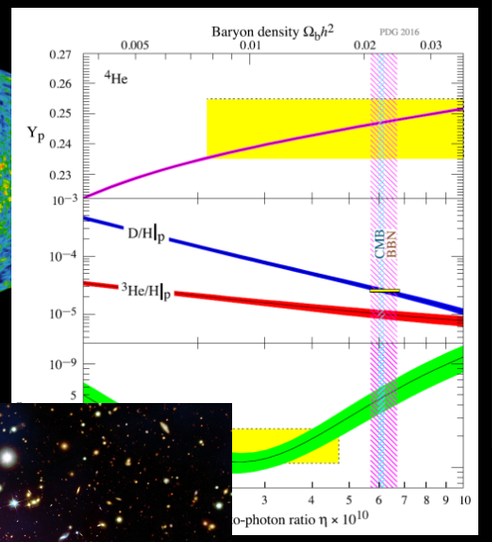
Kenny CY Ng (吳震宇)

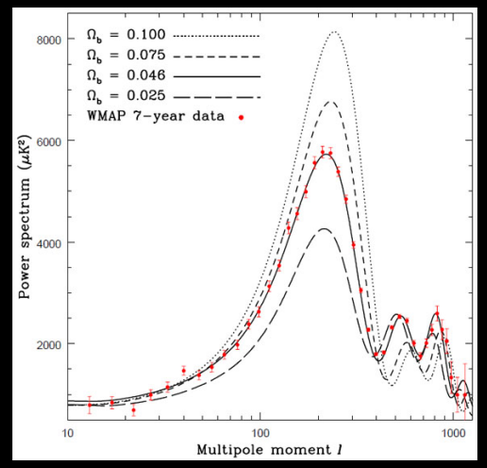
The Chinese University of Hong Kong

Dark Matter Evidence

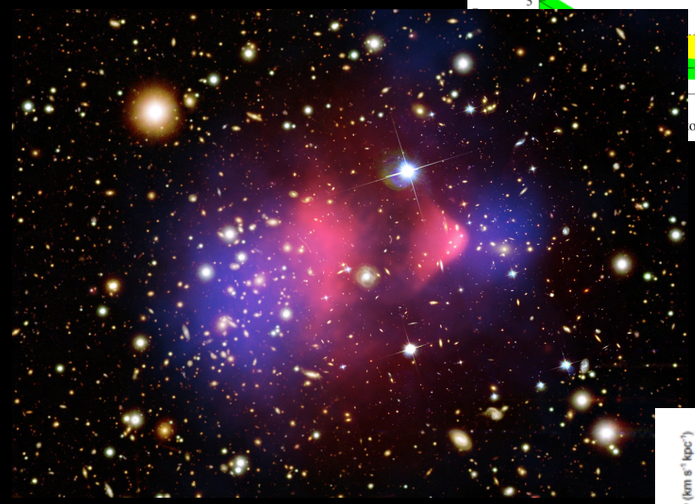
- Big Bang Nucleosynthesis/ Cosmic microwave background



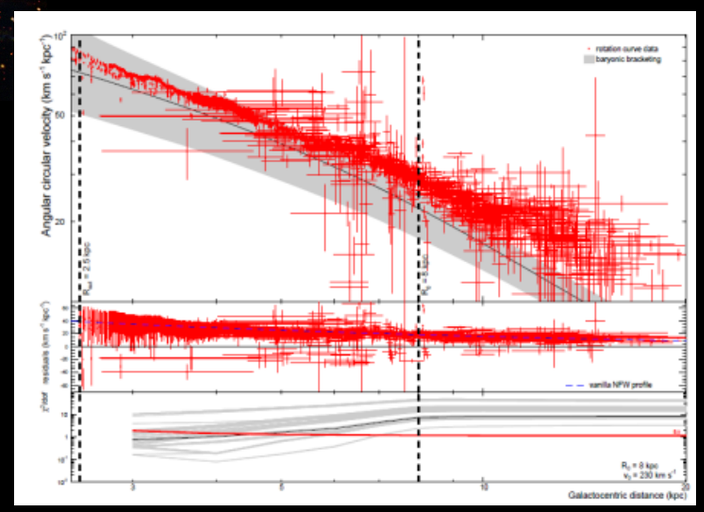




- Galaxy Clusters

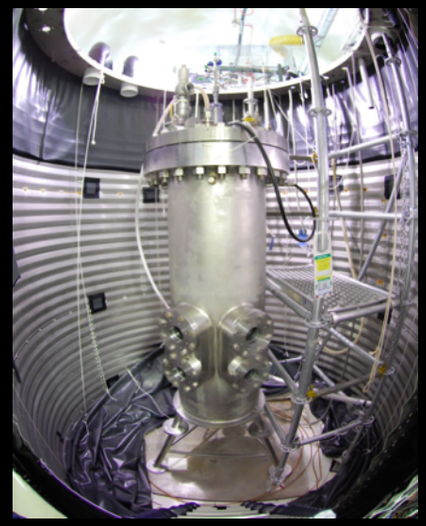


- Galaxies/ local dynamics

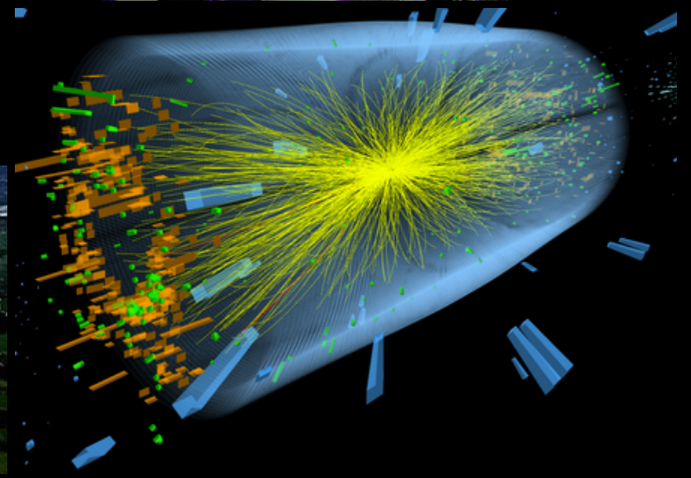


Dark Matter Identification

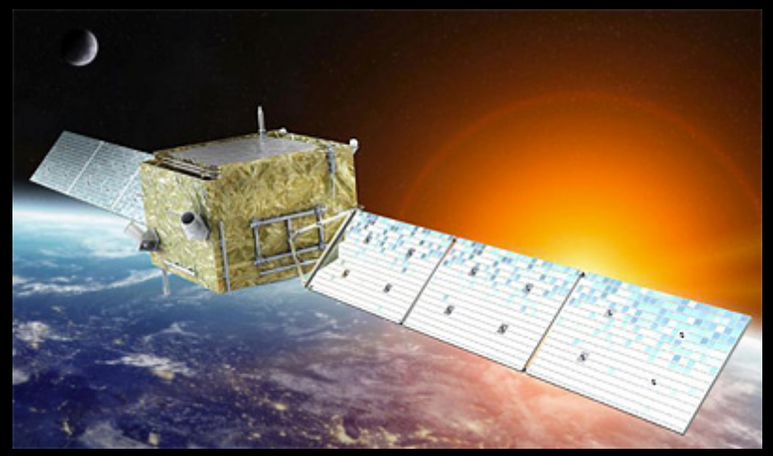
- Direct Detection

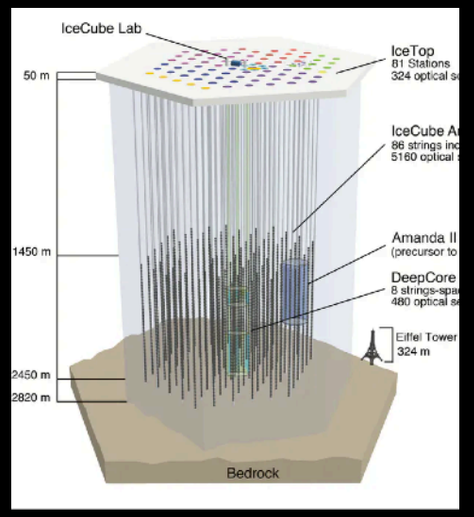


- Collider searches

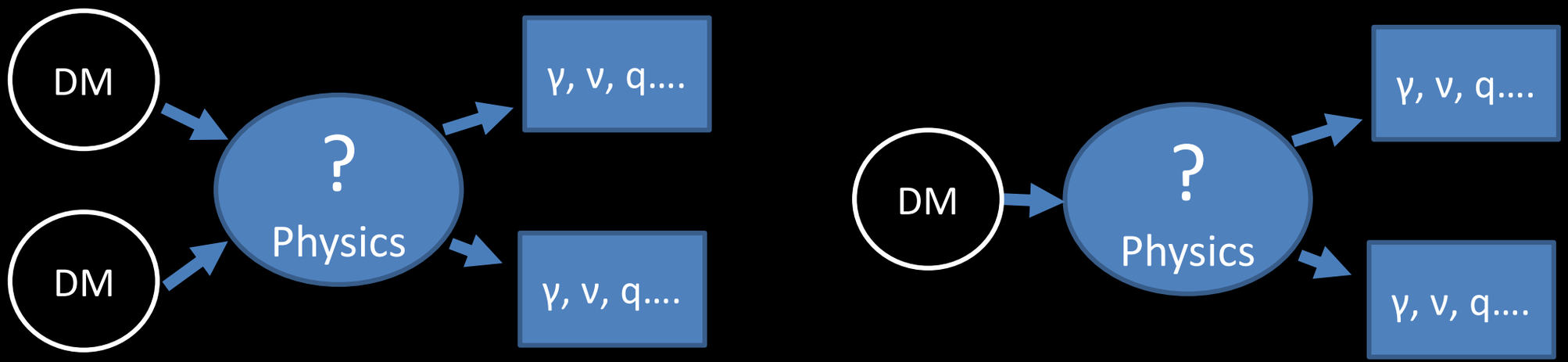


- Indirect detection





Indirect detection

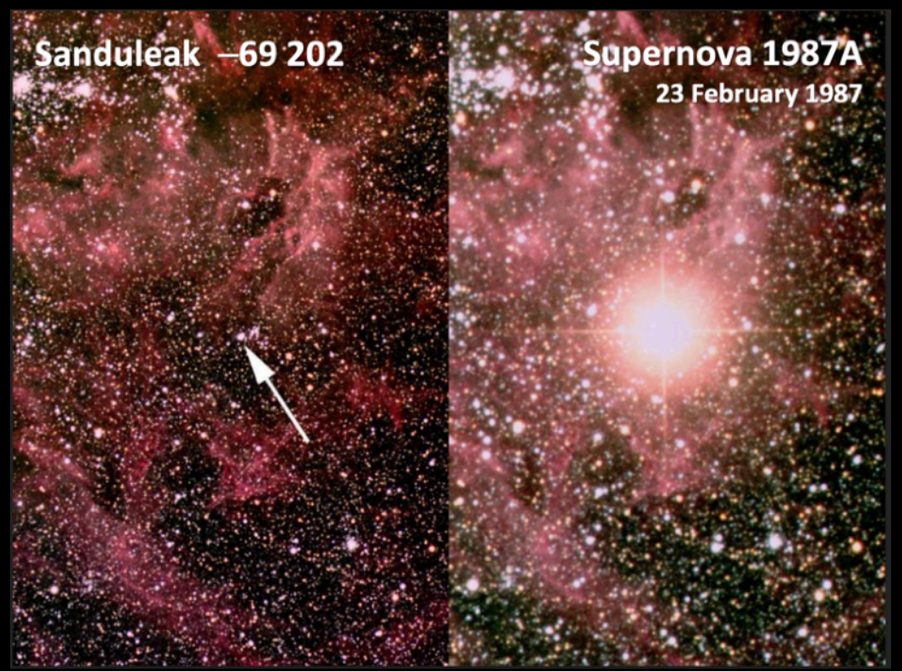


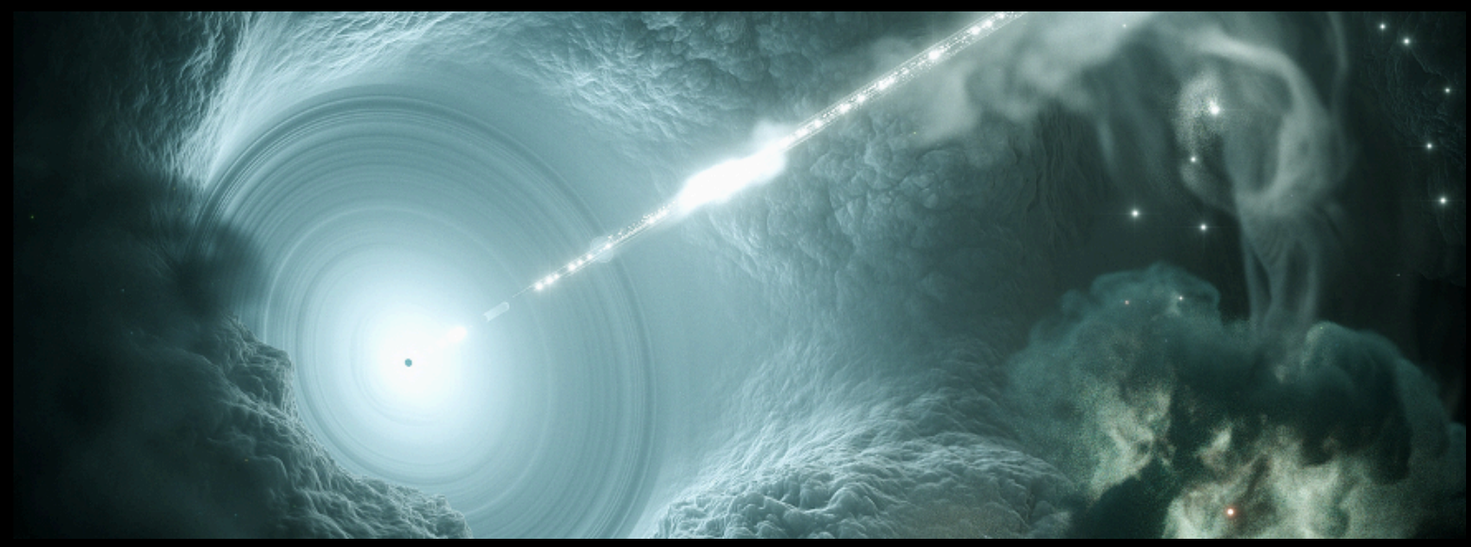
Particle Physics

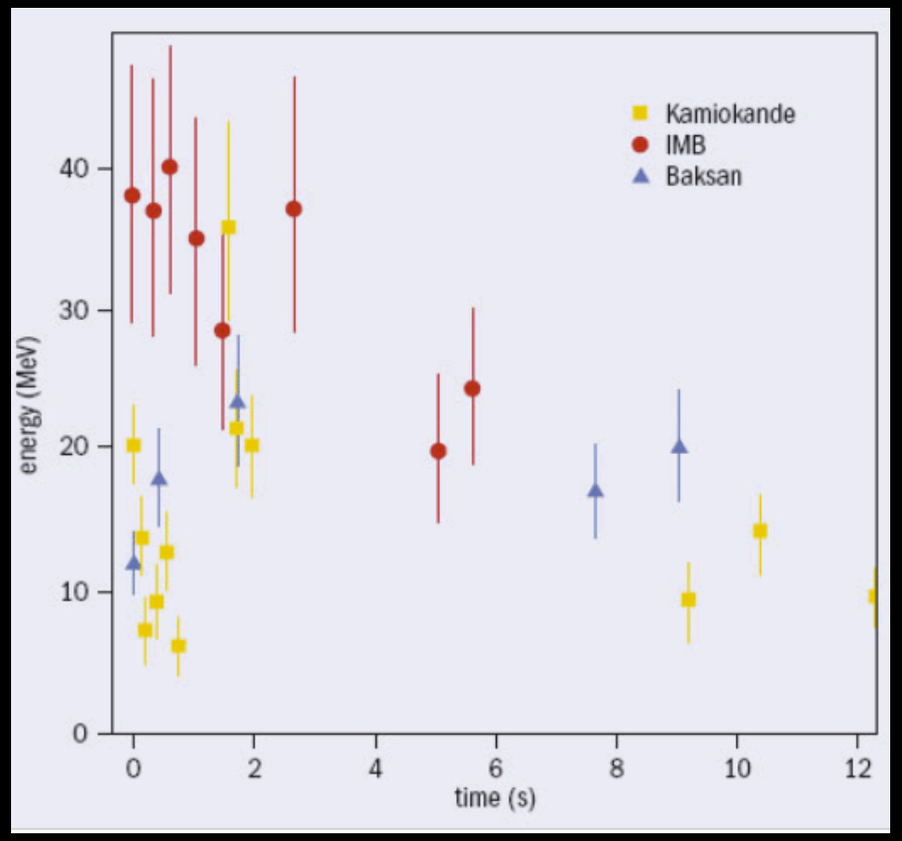
Astrophysics/detector

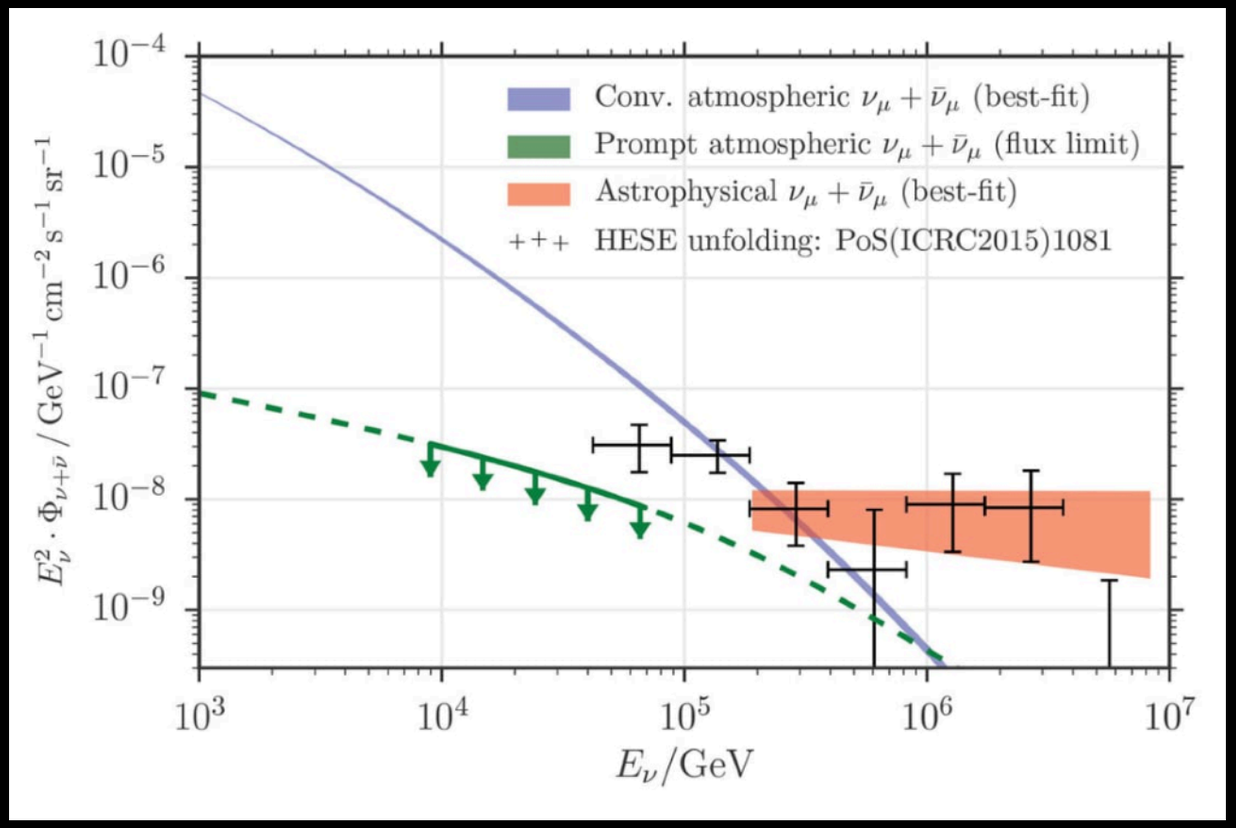
$$\frac{dF}{dE} = \frac{1}{4\pi}\frac{\Gamma}{m_\chi}\frac{dN}{dE}\int d\Omega \int d\ell \rho_\chi[r(\ell)]$$

Neutrino astronomy

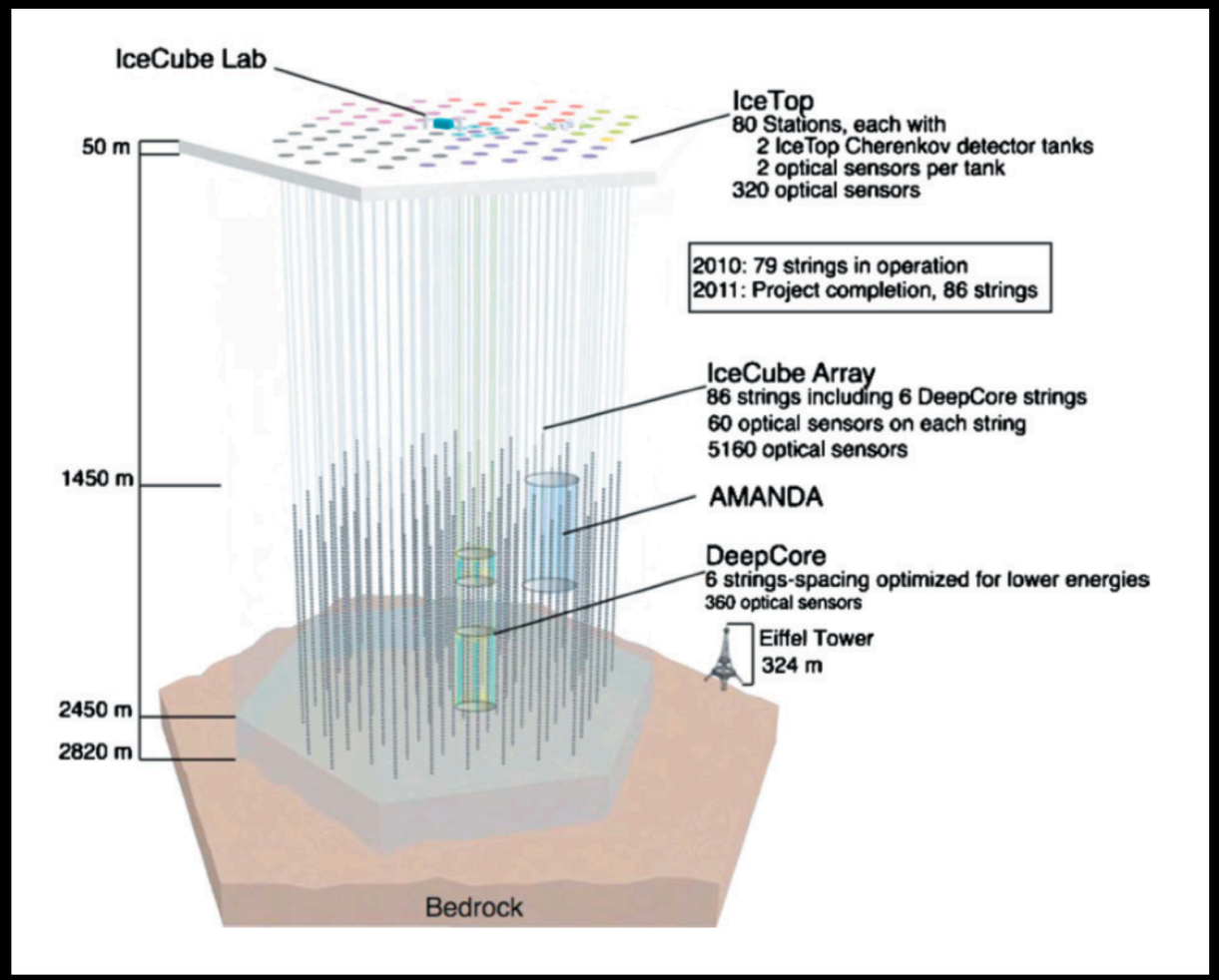


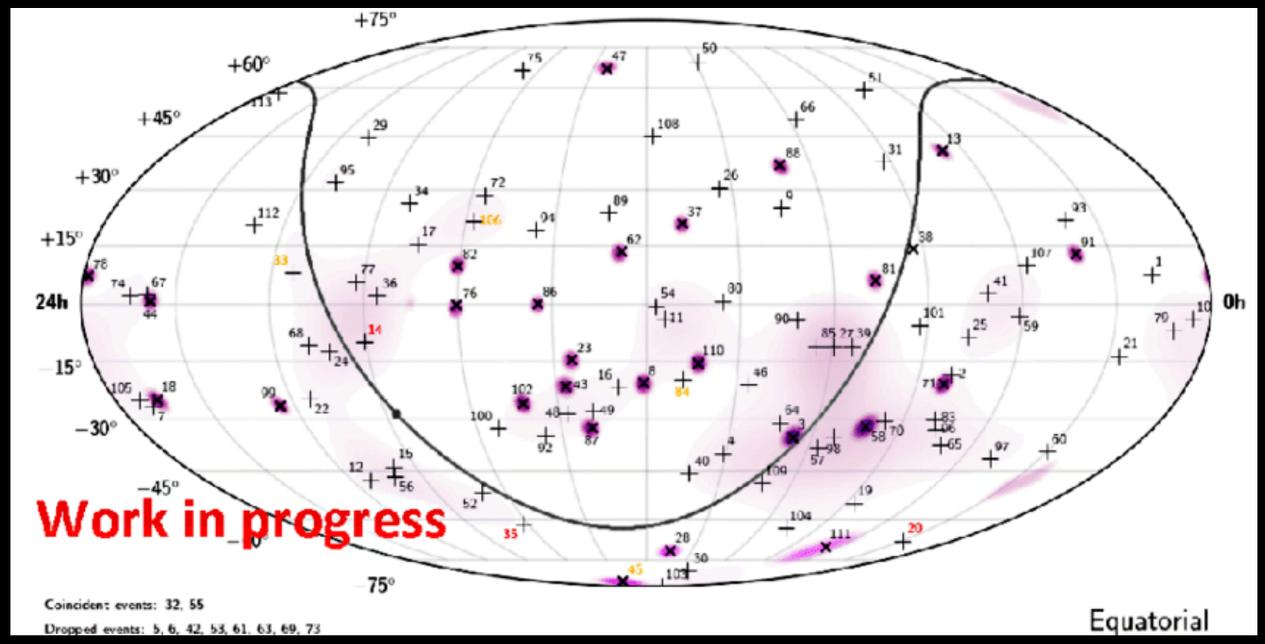






IceCube

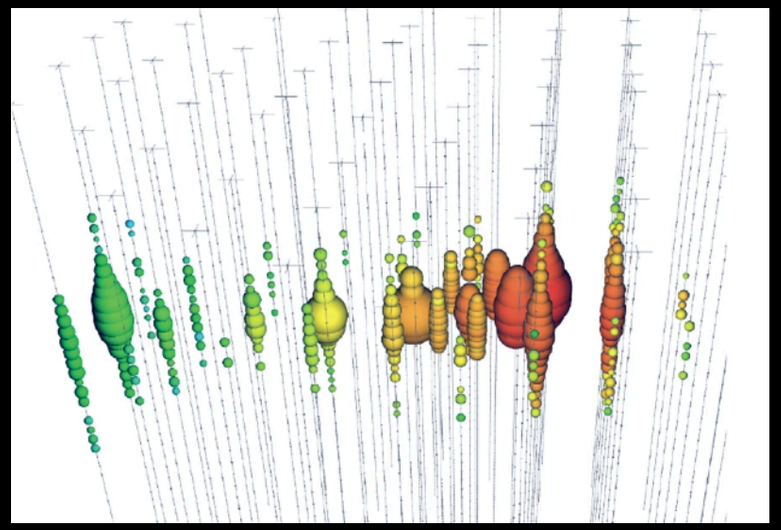




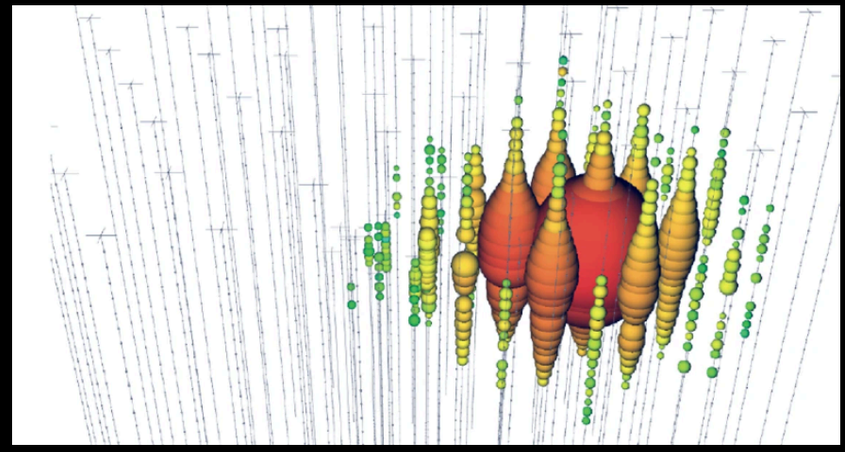
IceCube 2018

Neutrino detection in IceCube

- Tracks
  - ν_μ-CC interactions + 17% ν_τ-CC
  - Good angular resolution, bad energy resolution
  - Can also count through-going events



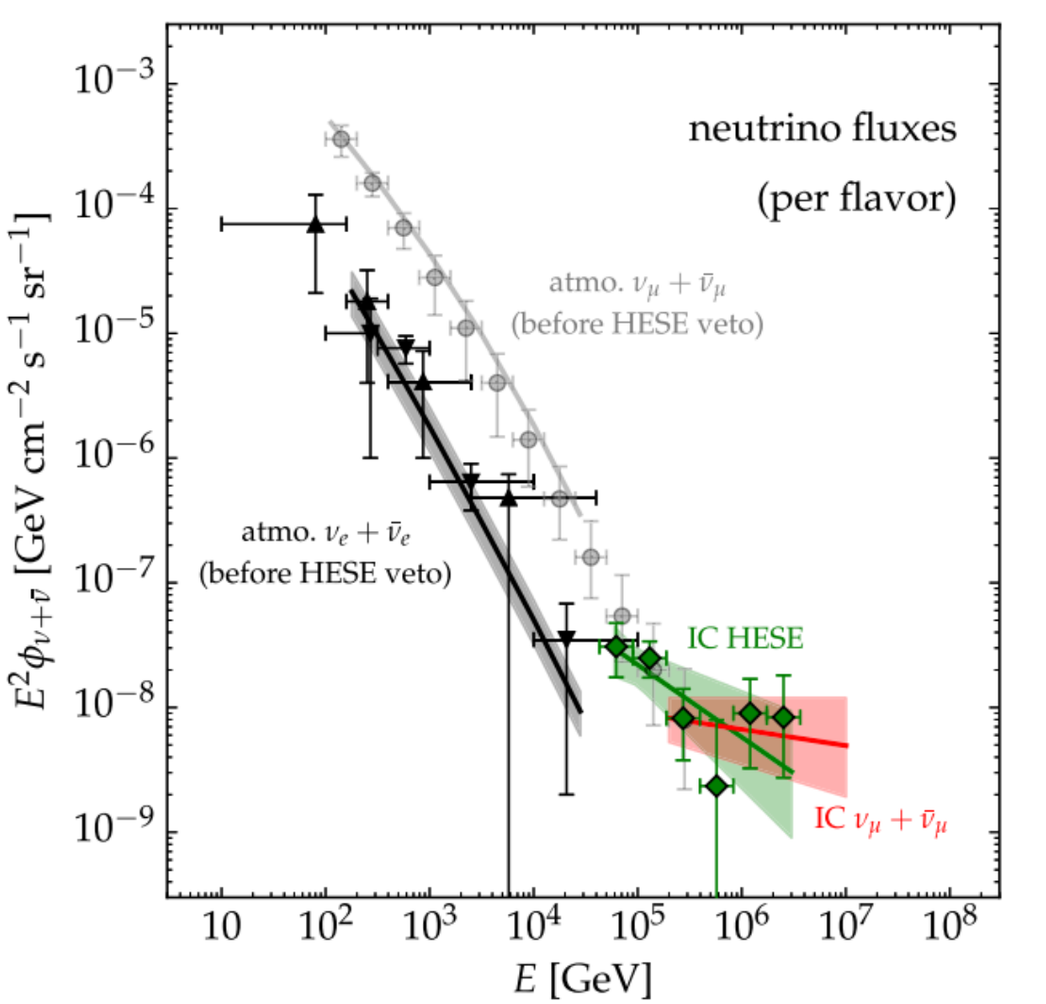
- cascades
  - electromagnetic or hadronic showers
  - All NC + ν_e-CC + 83% ν_τ-CC

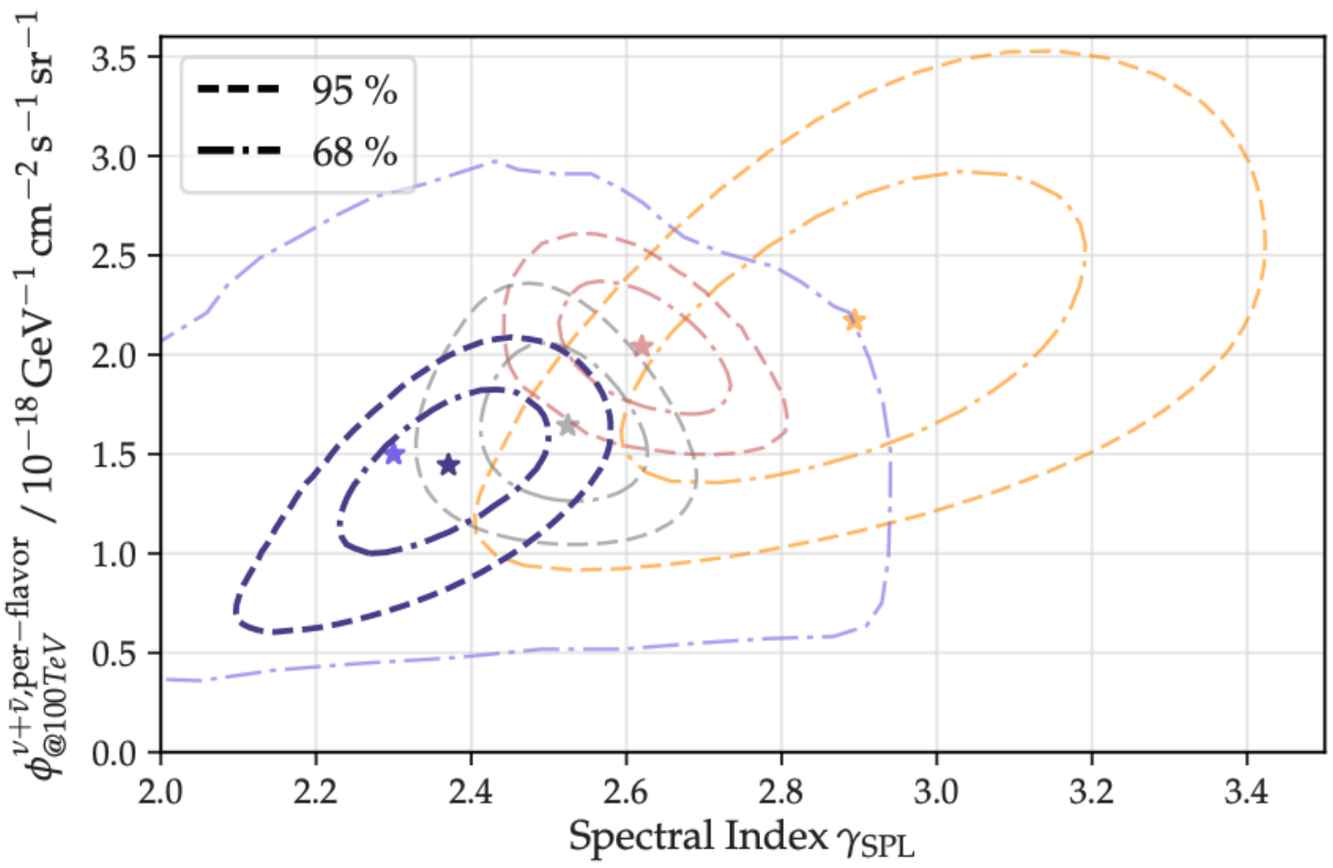


- Up going events are preferred
  - Earth Shielding

IceCube data

- Two components?
  - not significant yet
- Origin of most neutrinos are still unknown





HESE (7.5y Full-sky)
Phys. Rev. D 104, 022002 (2021)

Inelasticity Study (5y, Full-sky)
Phys. Rev. D 99, 032004

Cascades (6y, Full-sky)
Phys. Rev. Lett. 125, 121104 (2020)

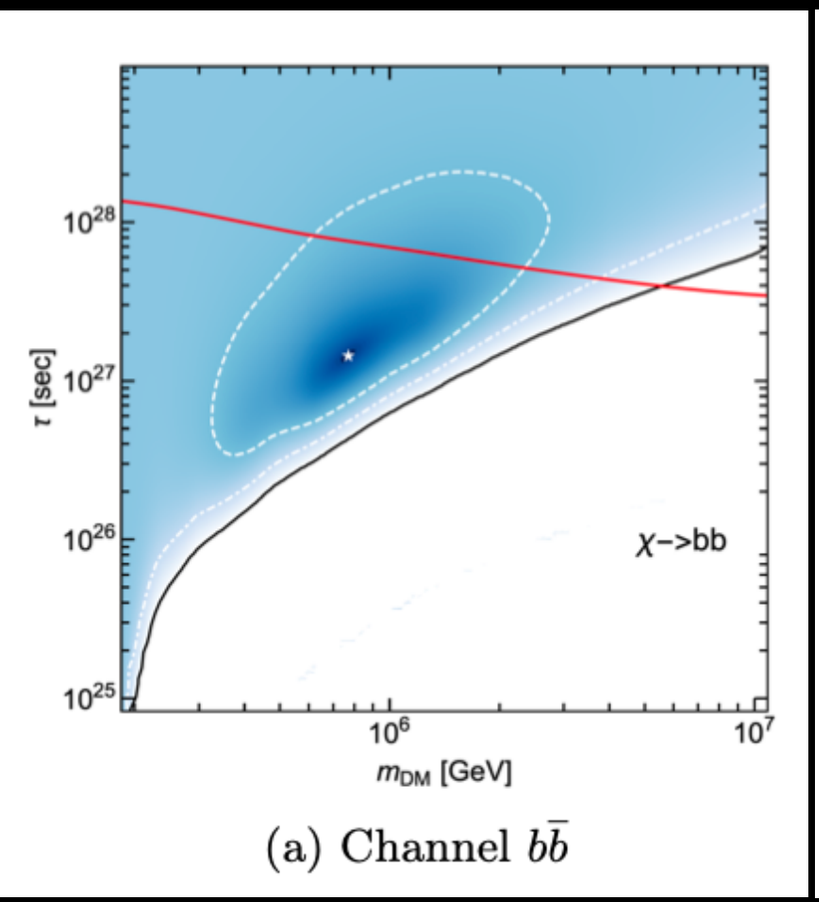
This work: Through-going Tracks
(9.5y, Northern-Hemisphere)

ANTARES Cascades+Tracks
(best-fit: 9y, Full-sky) PoS(ICRC2019)891

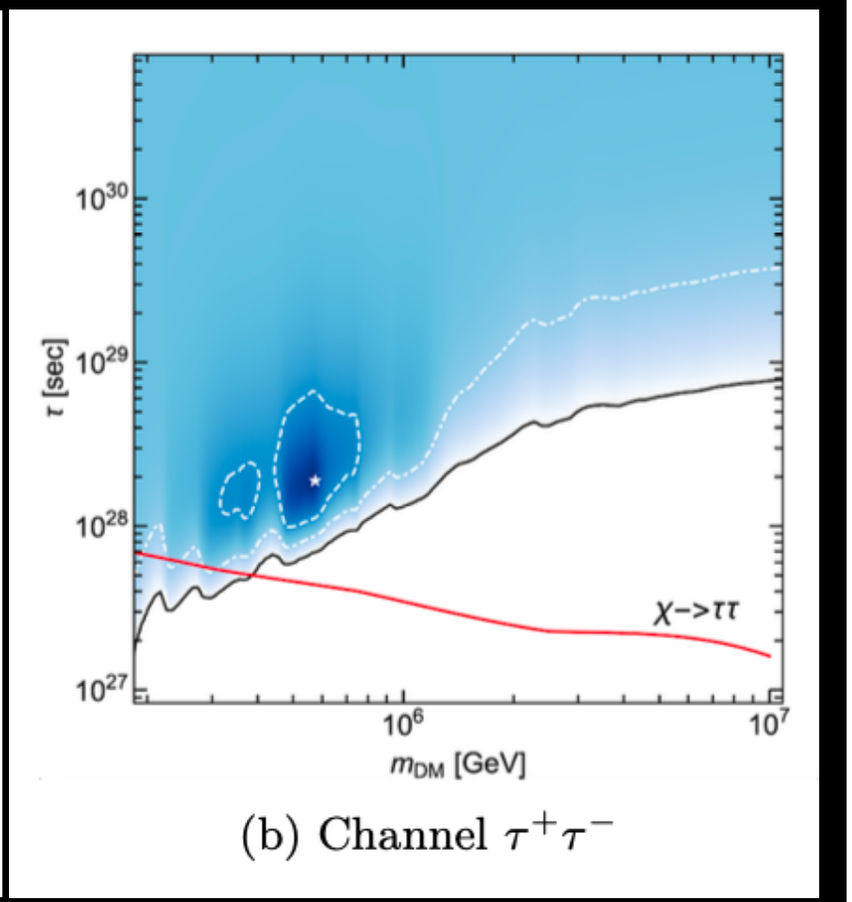
icecube: 2111.10299

Dark Matter interpretation

- Decaying dark matter can contribute to the neutrino events

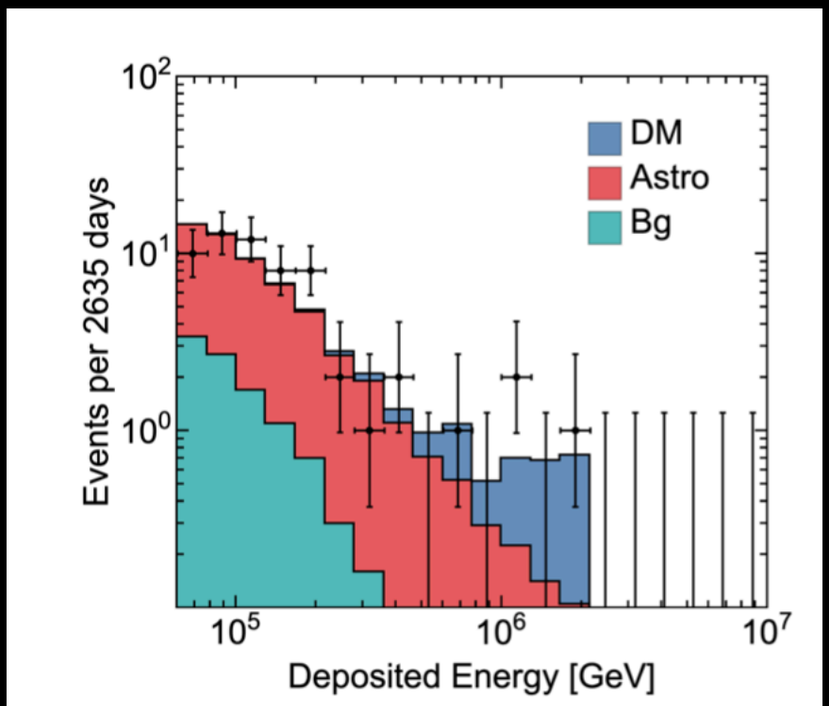


(a) Channel $b\bar{b}$

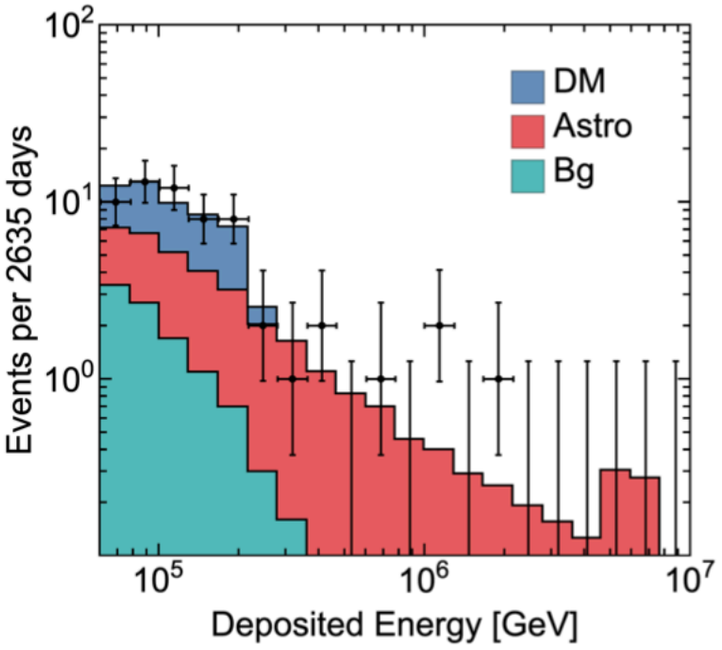


(b) Channel $\tau^+\tau^-$

Chianese et al 1907.11222



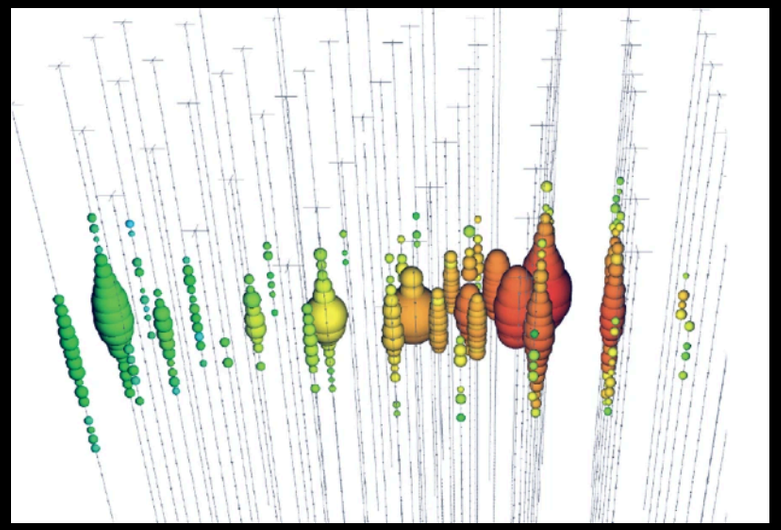
(a) Channel ν_e, no prior distribution



(c) Channel W, no prior distribution

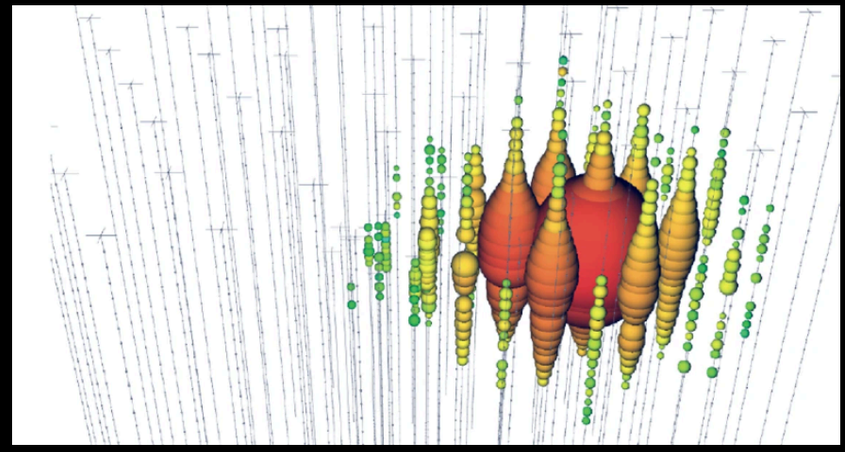
Neutrino detection in IceCube

- Tracks
  - ν_μ-CC interactions + 17% ν_τ-CC
  - Good angular resolution, bad energy resolution
  - Can also count through-going events



- cascades
  - electromagnetic or hadronic showers
  - All NC + ν_e-CC + 83% ν_τ-CC

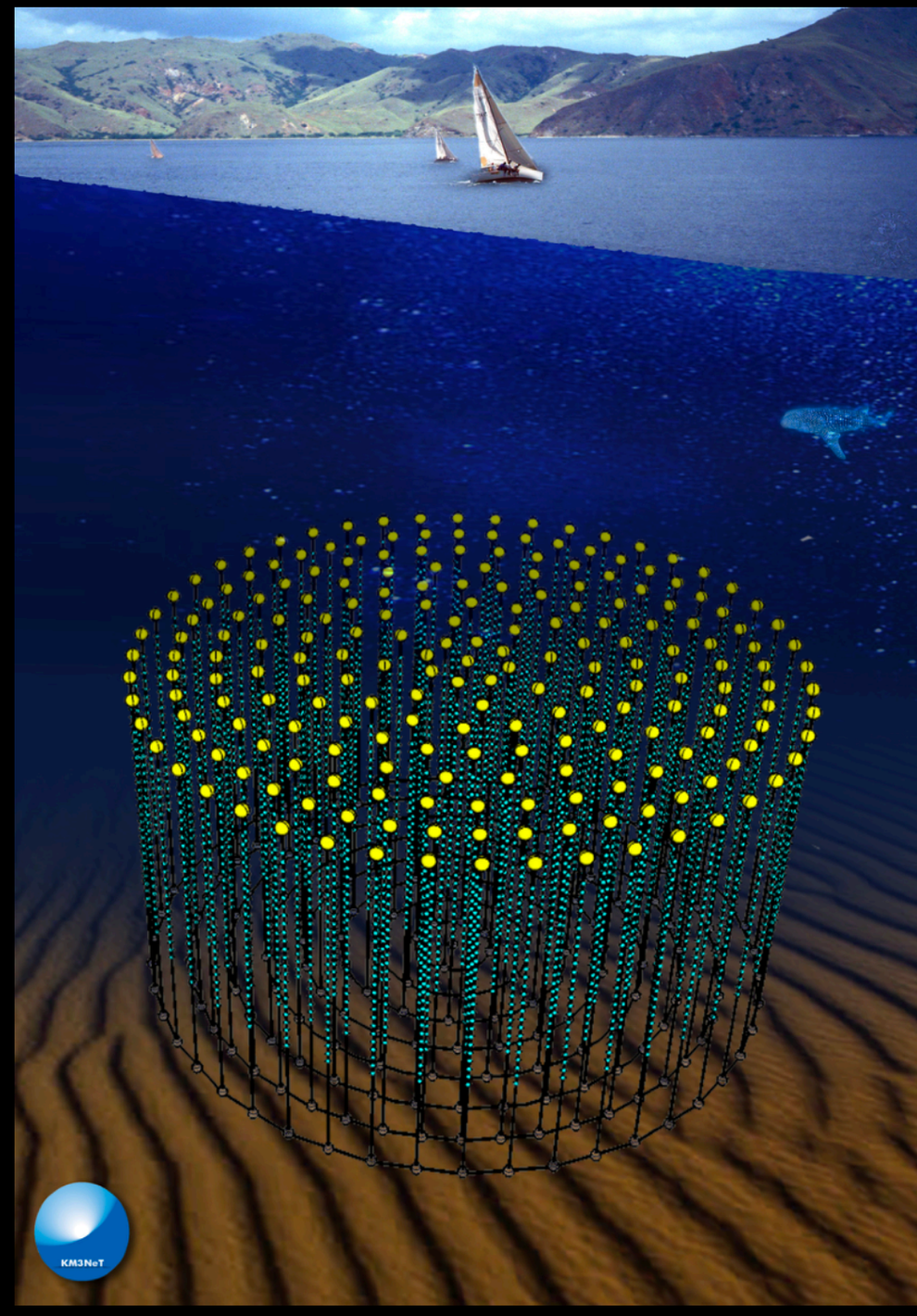
  - Cherenkov light scattering in ice => bad angular resolution



- Up going events are preferred
  - Earth Shielding
  - IceCube cannot see the galactic centre!

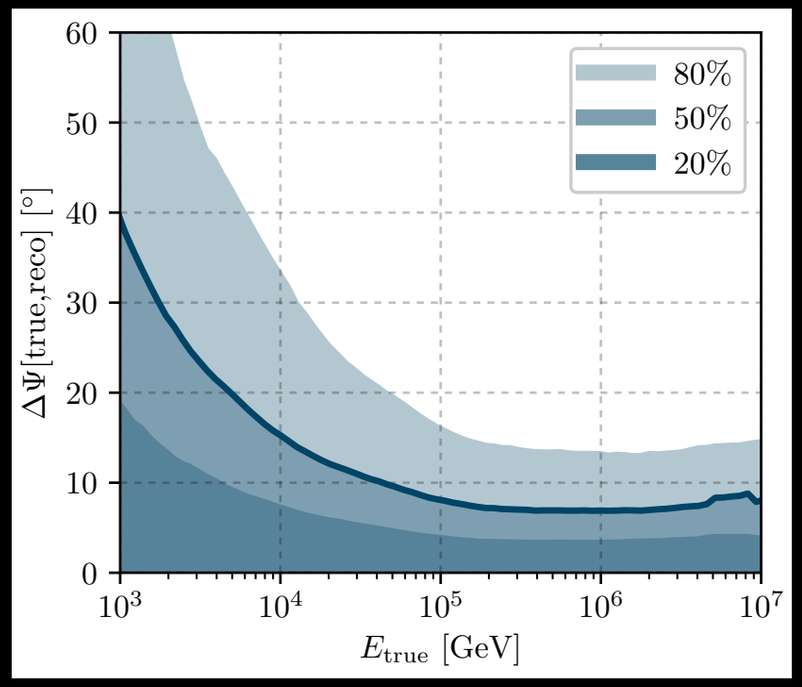
KM3NeT

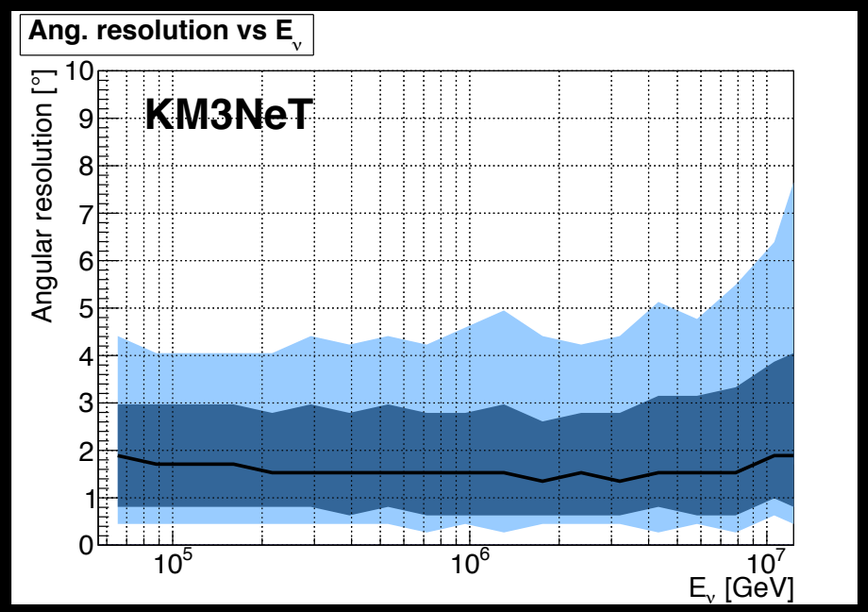
- Next-generation 1-gigaton neutrino detector in the Mediterranean



KM3NeT dark matter advantage

IceCube vs KM3NeT, angular resolution





KM3NeT letter of intent: 1601.07459

"Downward sensitivity"

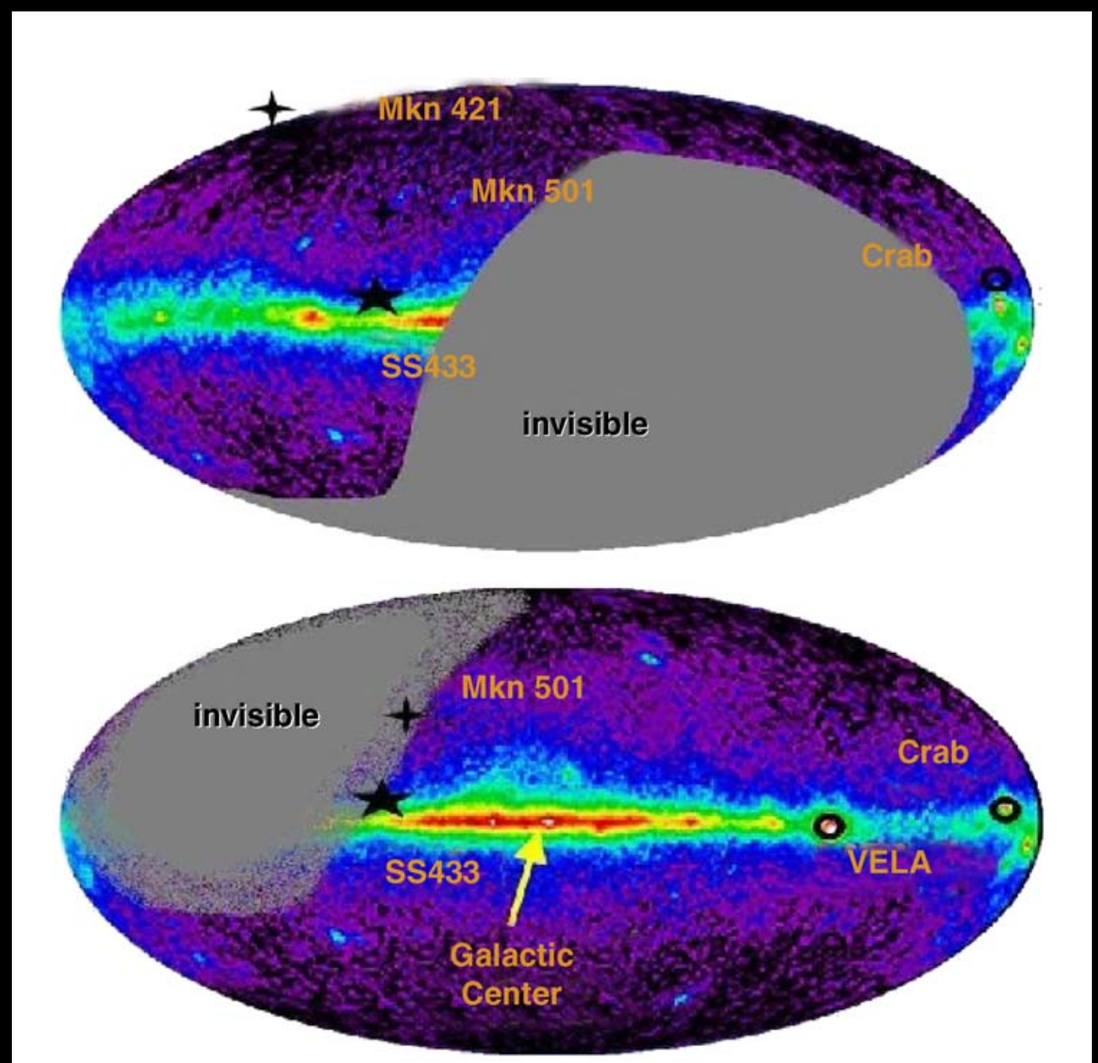
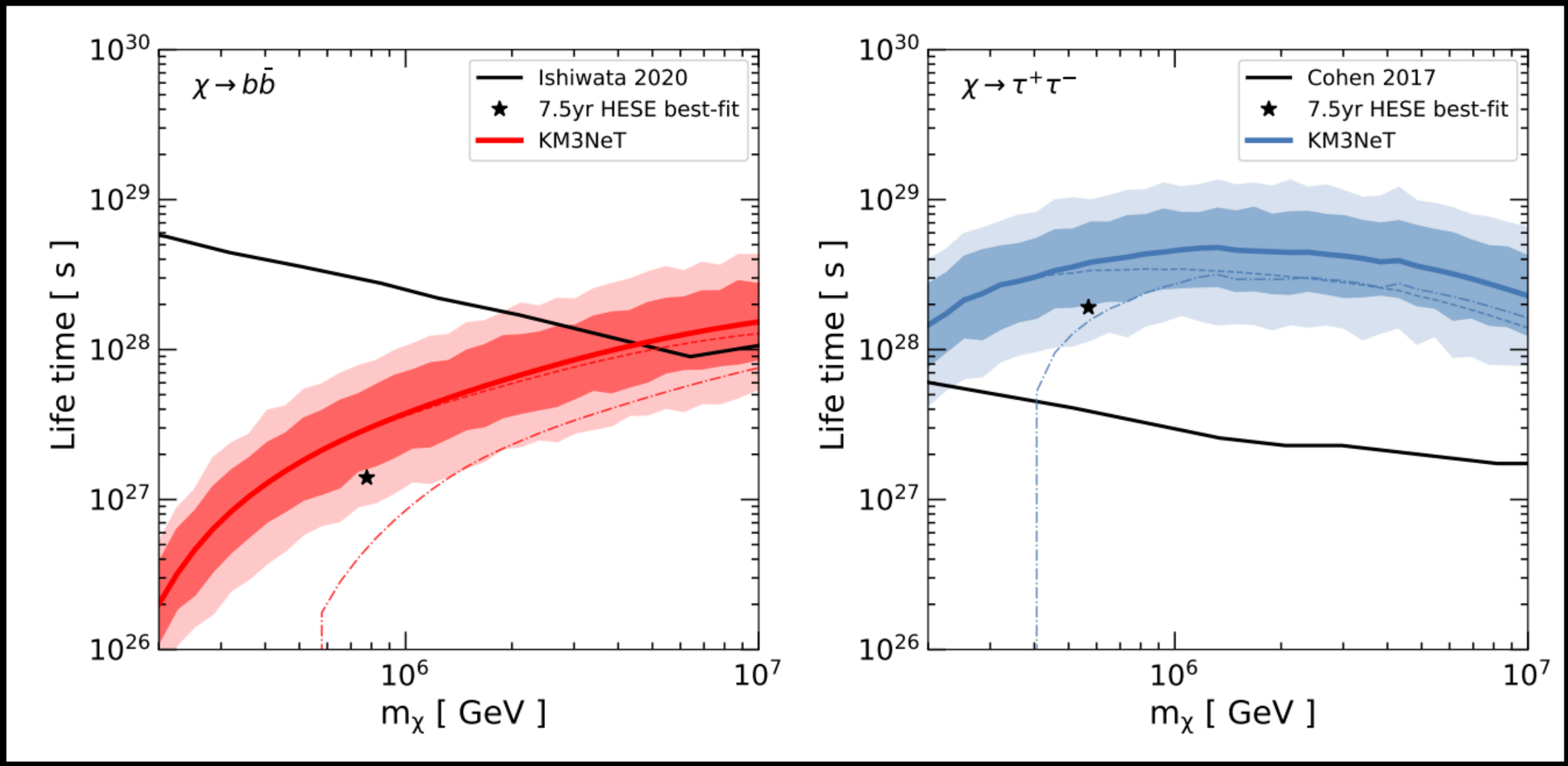


Fig. 1. Field of view of a neutrino telescope at the South Pole (top) and in the Mediterranean (bottom), given in galactic coordinates. A 2π-downward sensitivity is assumed; the grey regions are then invisible. Indicated are the positions of some candidate neutrino sources.

KM3NeT dark matter sensitivity

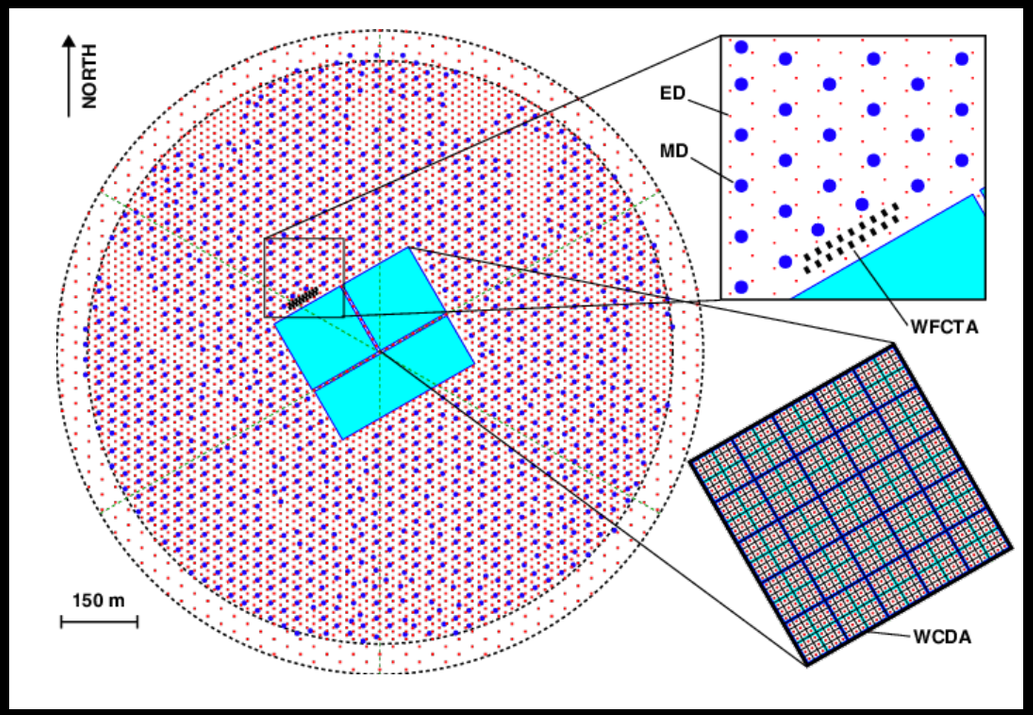
- Cascade contributes significantly the sensitivity!
- Fully test the IceCube dark matter interpretation



KCYN et al
2007.03692

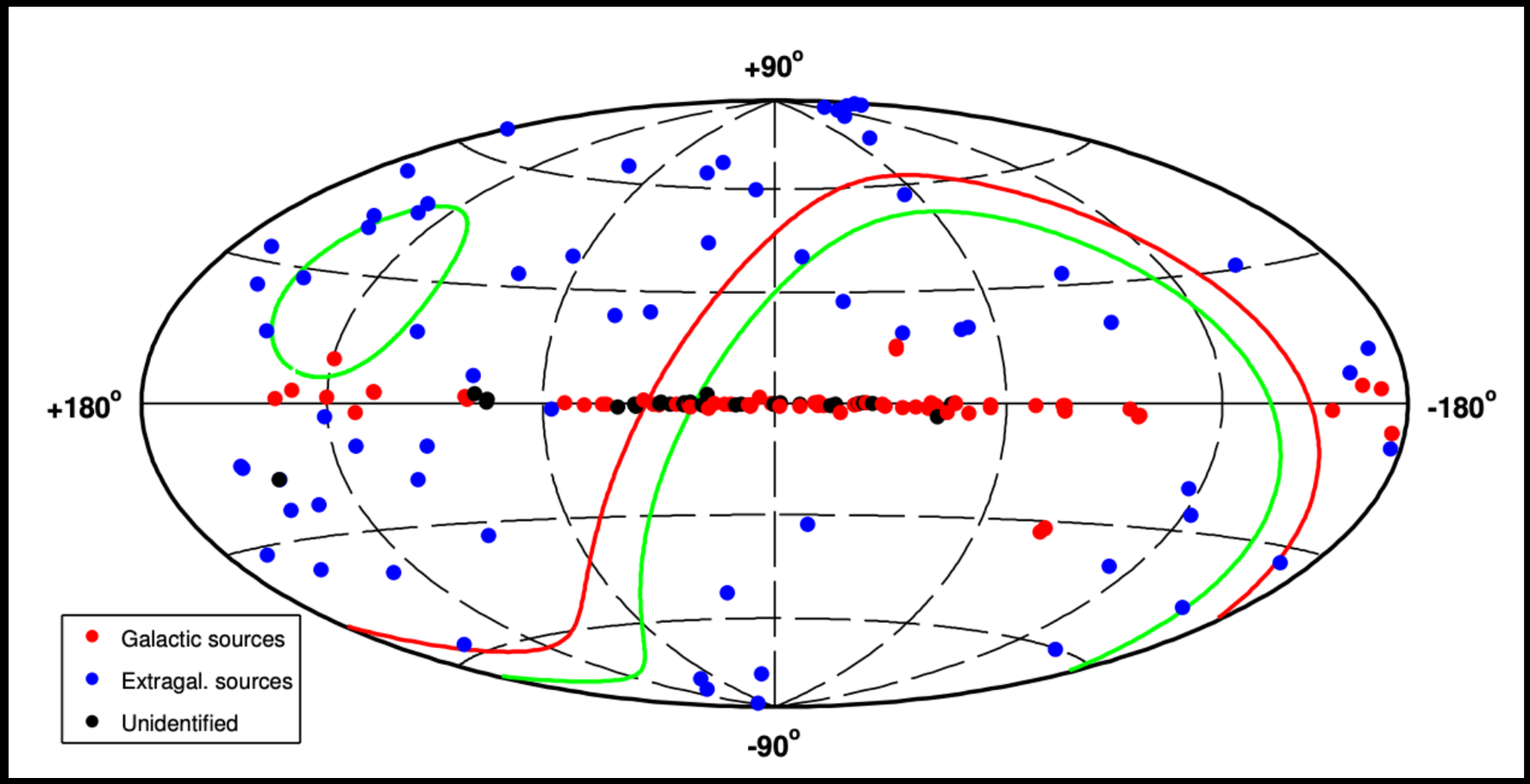
The Large High Altitude Air Shower Observatory (LHAASO)

- WCDA
  - 4x HAWC
- KM2A (electron + muon detectors)
  - Unprecedented PeV gamma-ray sensitivity
- WFCTA
  - Air Cherenkov telescope for cosmic ray study



The Large High Altitude Air Shower Observatory (LHAASO)

- LHAASO field of view (Galactic coordinate)



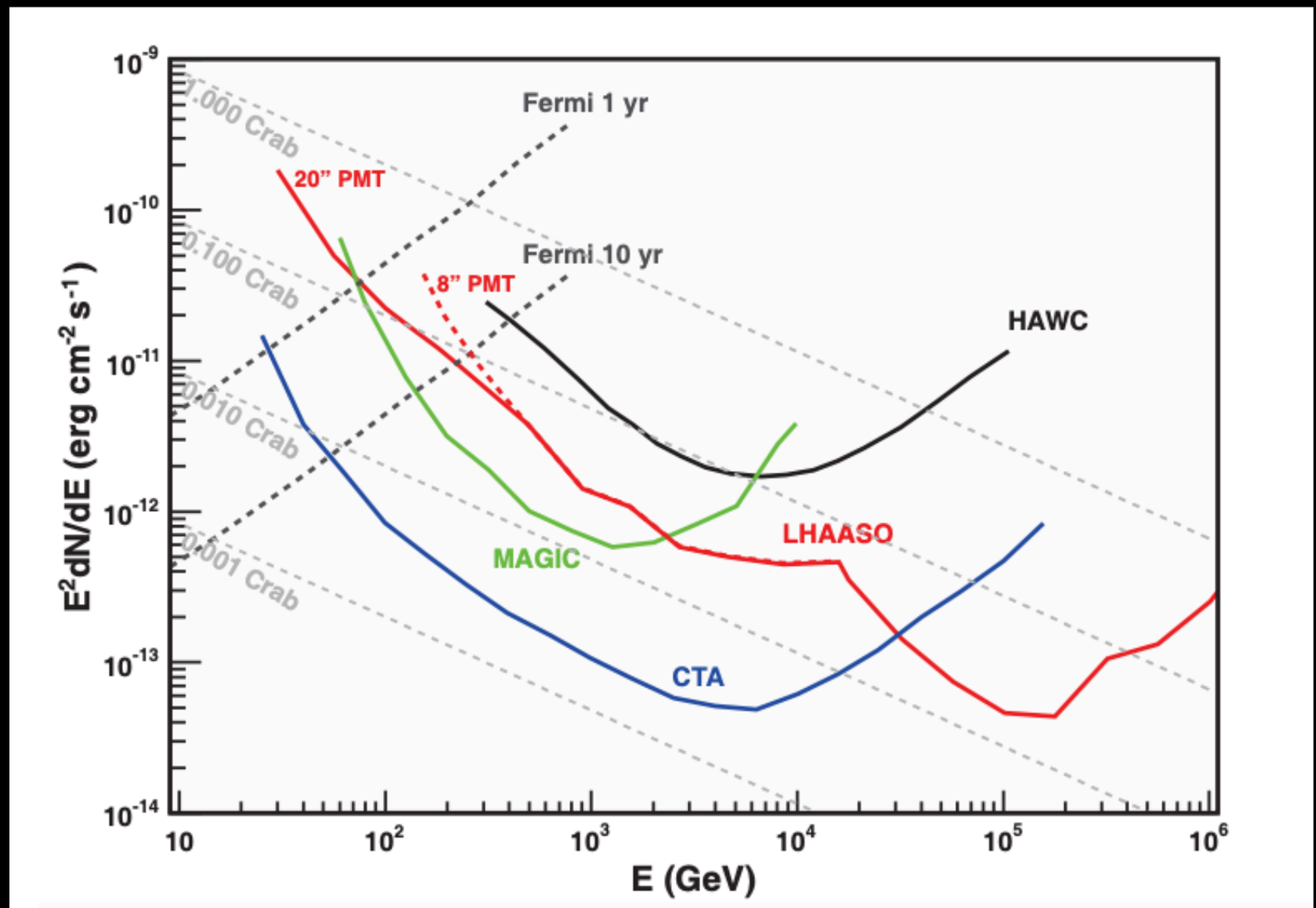
LHAASO white paper 1905.02773

The Large High Altitude Air Shower Observatory (LHAASO)

LHAASO DM searches

+ Large field of view
+ 100% duty factor
+ Good enough energy and angular resolution

point source sensitivity

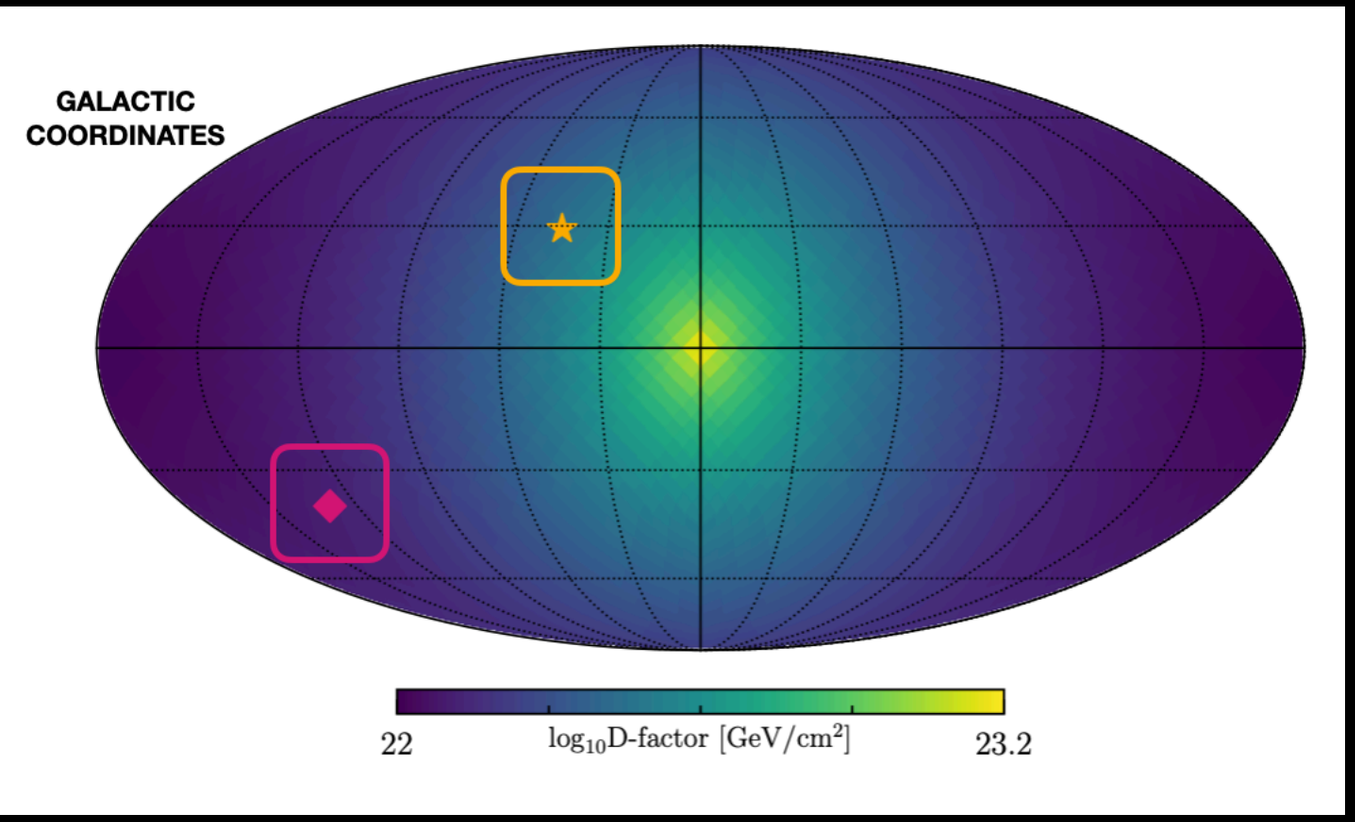


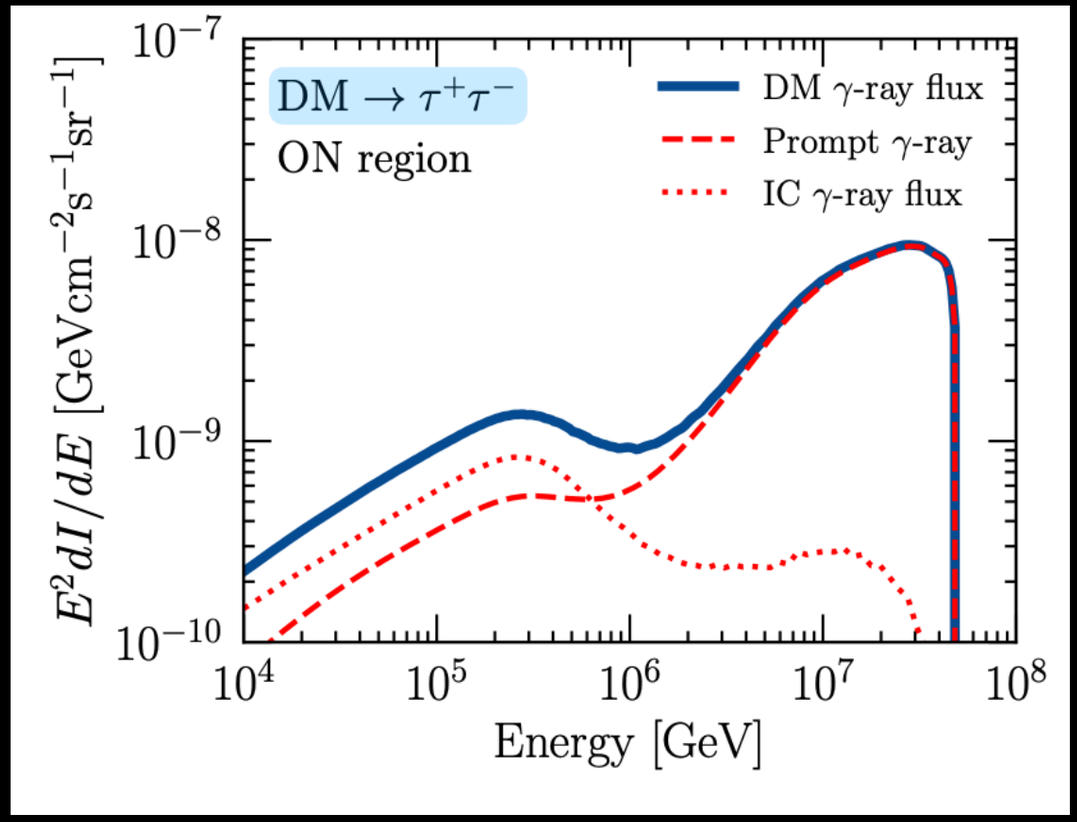
LHAASO white paper 1905.02773

Dark Matter searches with LHAASO

- Ando, *Chianese*, Fiorillo, Miele + *KCYN* + LHAASO Collab. (*Zhe Li*)
  - soon

- Both prompt and secondary gamma-ray included

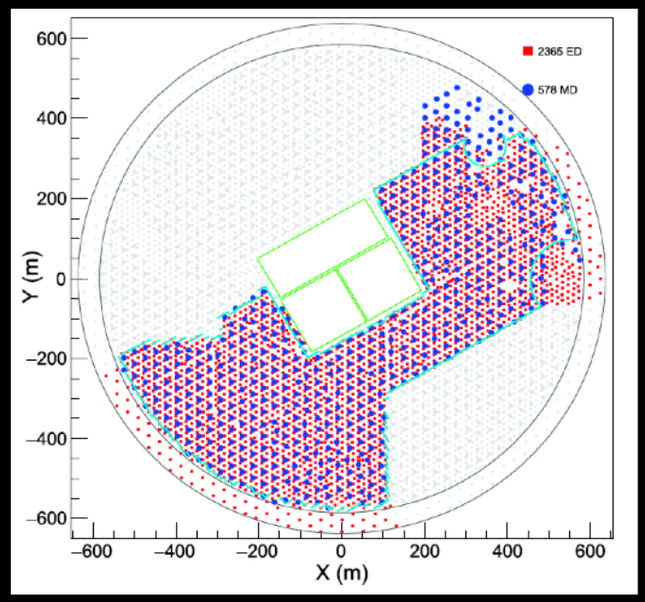


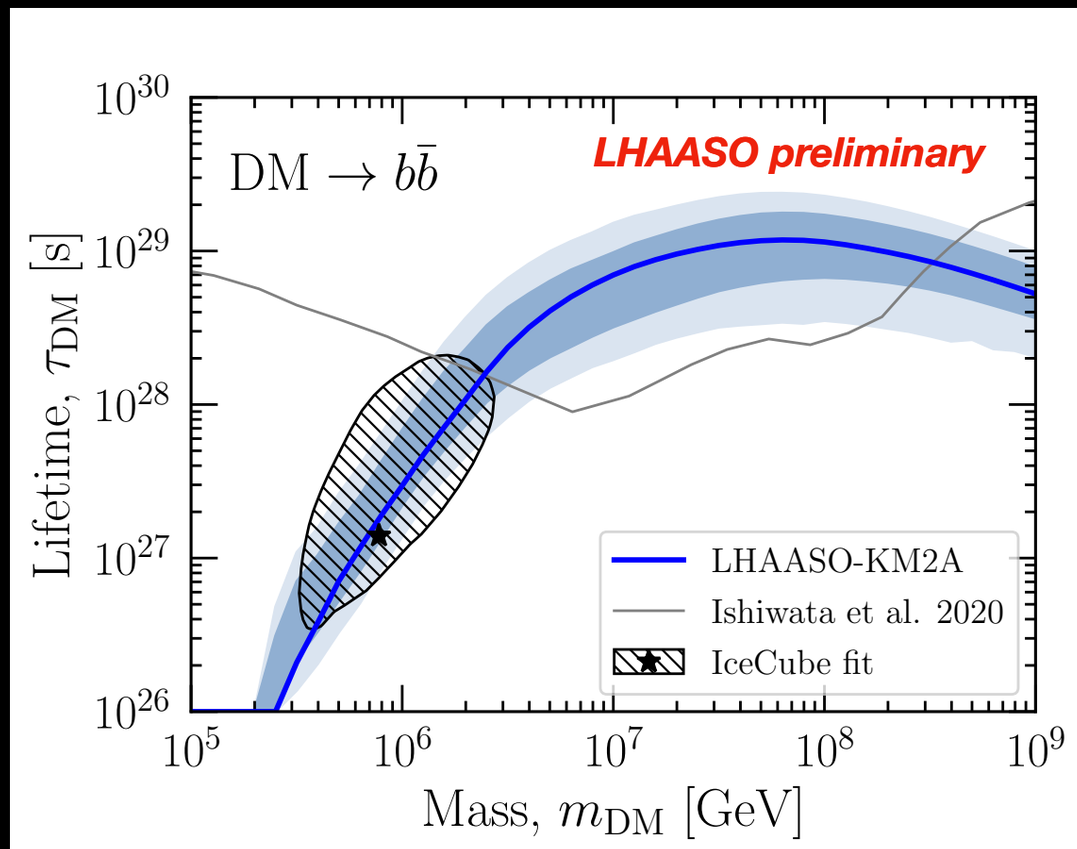


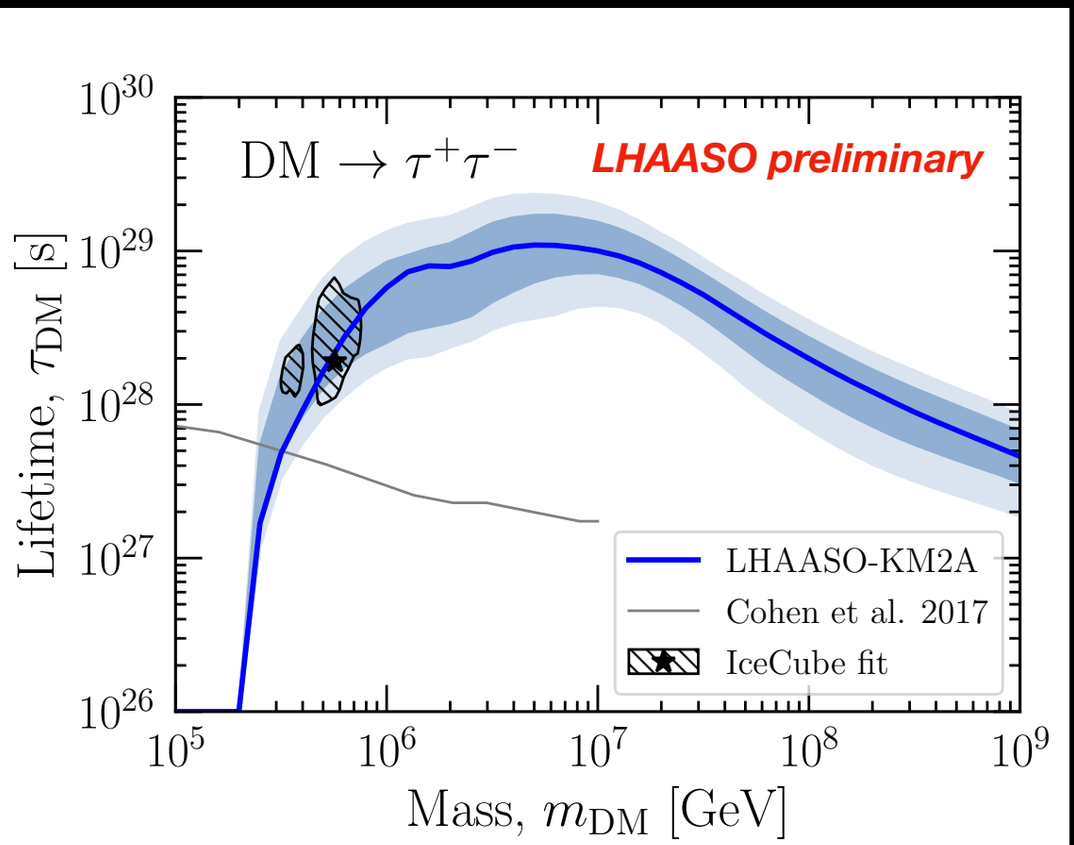
Chianese ICRC 2021

Dark Matter decay searches with 1/2- KM2A

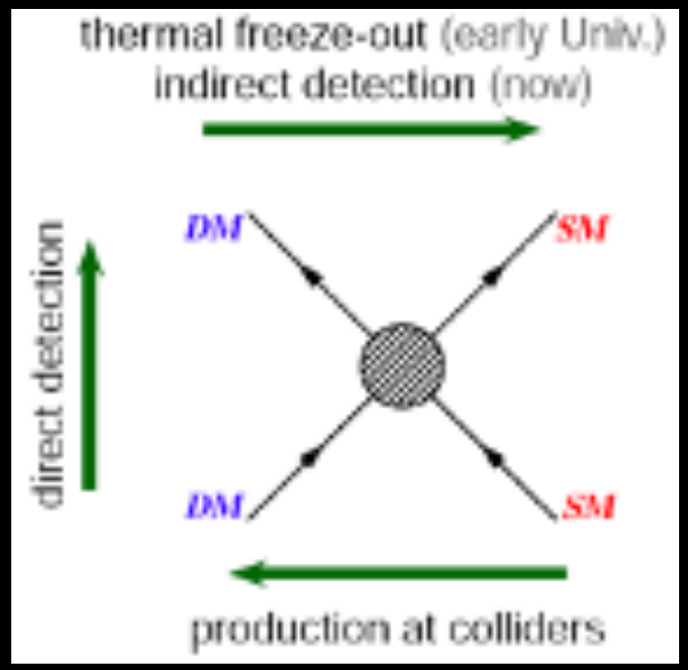
- Significant improvements in limits
- In tension with DM interpretation of IceCube data







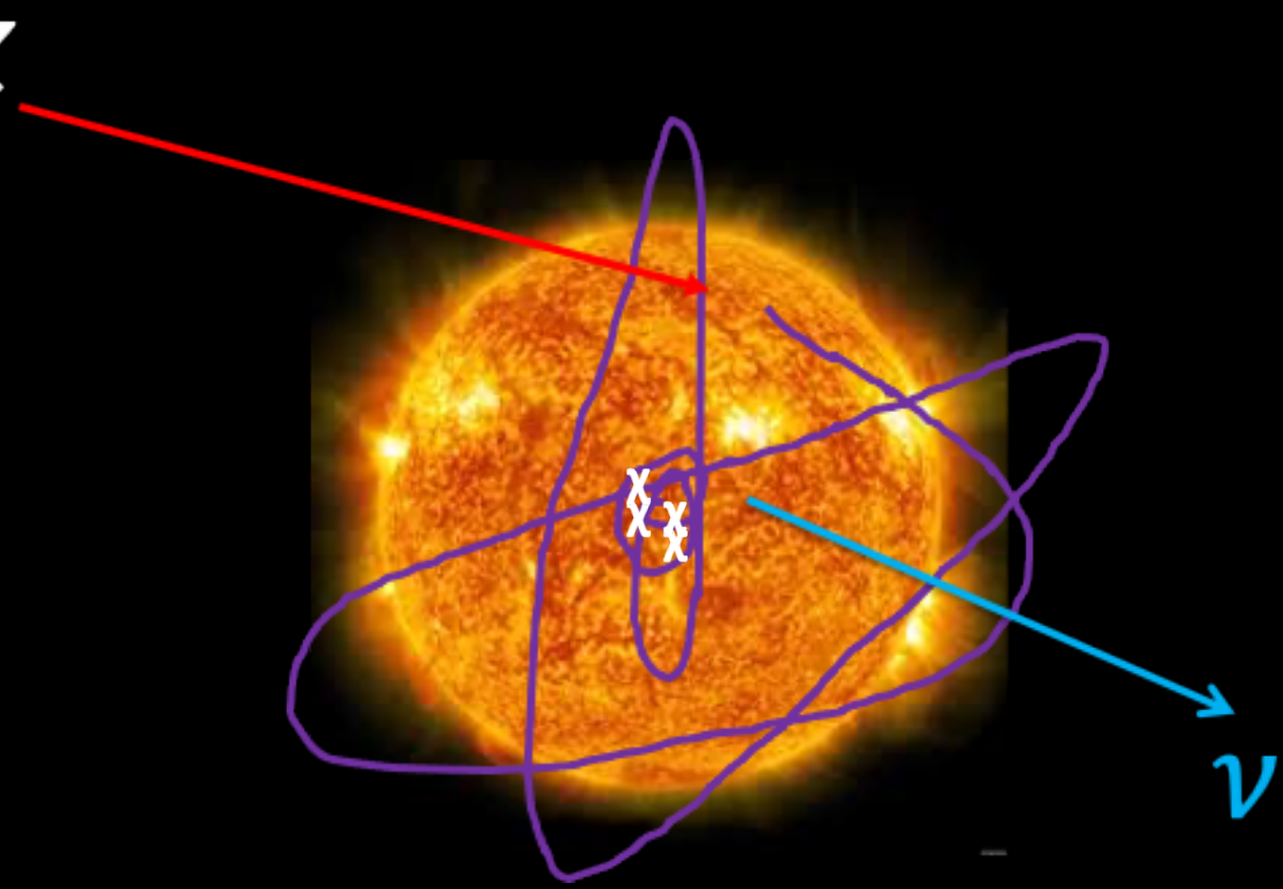
Sun as a dark matter detector



- DM-nucleon scattering
  - Dark matter capture in the Sun

- -> Dark matter annihilation in the centre of the Sun

- -> High-energy neutrinos leaving the Sun

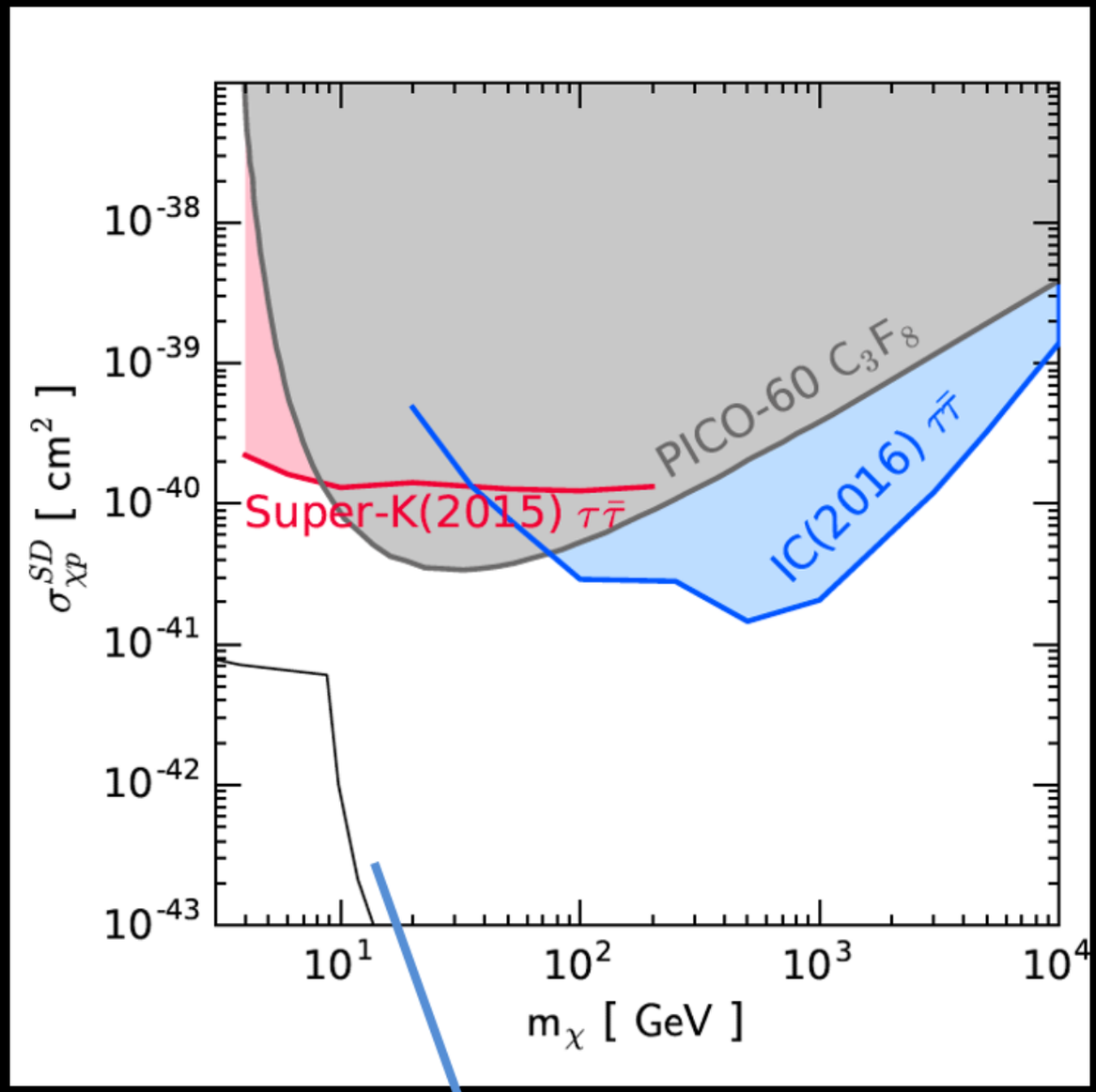


Solar WIMP search

- Best limit on SD cross sections
  - Hard Channels

- Both scattering and Annihilation!

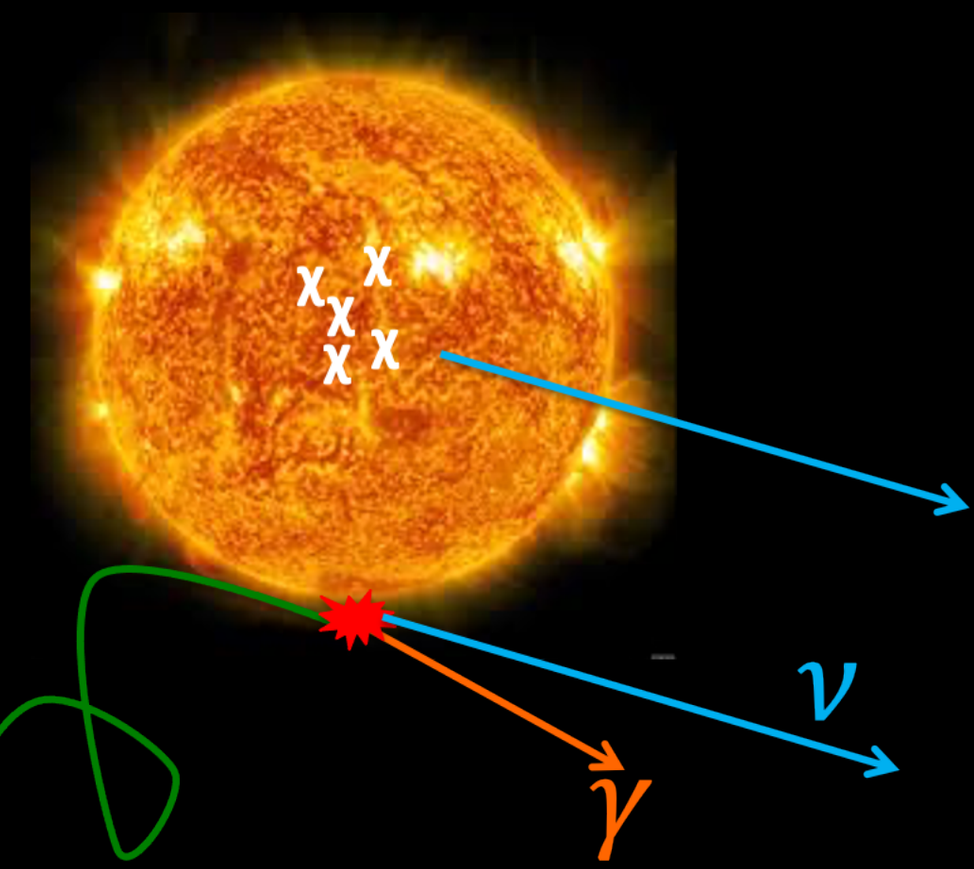
- How far can neutrino telescopes reach?



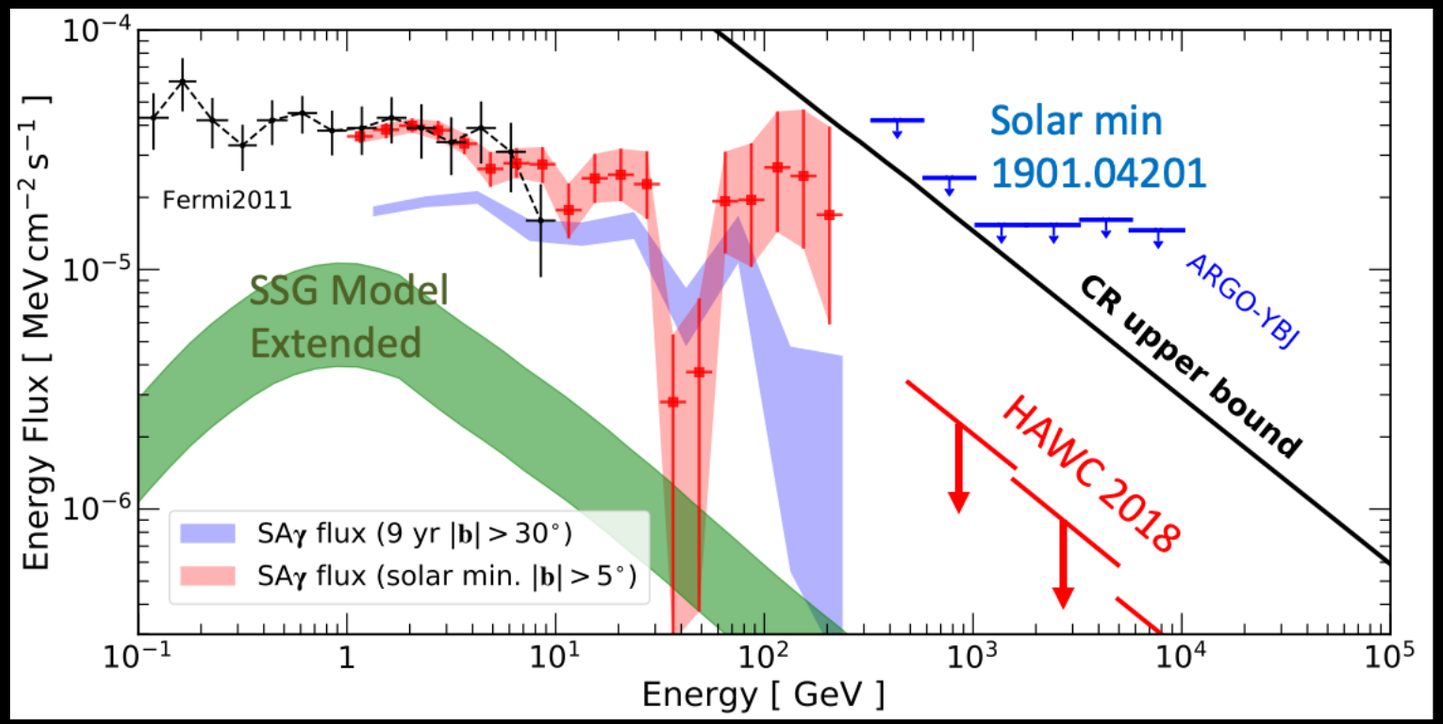
The Sun as a cosmic-ray beam dump

- Solar atmospheric neutrinos
  - background to dark matter search
  - difficult to eliminate

- Solar atmospheric gamma rays
  - Detected
  - can help understand solar atm. neutrinos



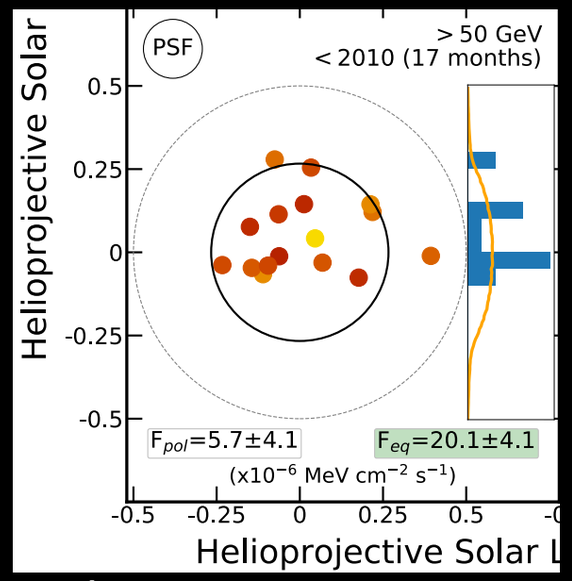
Solar gamma rays are not understood



KCYN+ 1508.06276
Tang + 1804.06846
Linden+ 1803.05436
HAWC+ 1808.05620
Linden+ 2012.04654

- Observation higher than Model (Green: Seckel et al 1991)
  - only partially remedied in Mazziotta et al (2001.09933) and Li et al (2009.03888)
- Hard spectral index (close to $E^{-2.2}$, harder than CR index)
- Large time variations with solar activity
- non-trivial solar surface morphology

=> Magnetic Fields strongly affect CR interactions in the surface!



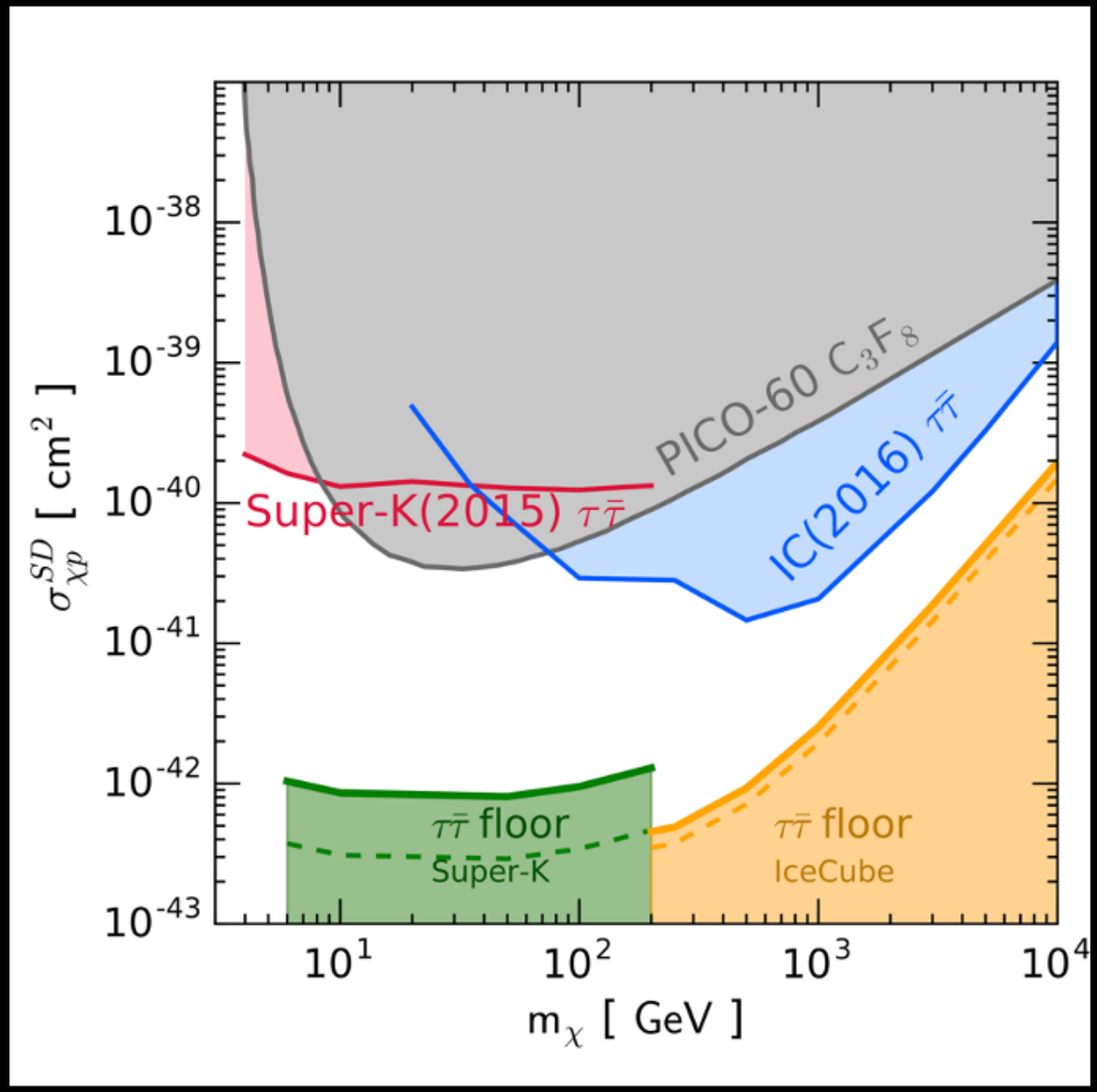
Linden+ 1803.05436

Solar atmospheric neutrino ‘Floor’

- KCYN+ 1703.10280, also Arguelles+ 1703.07798 and Edsjo+ 1704.02892

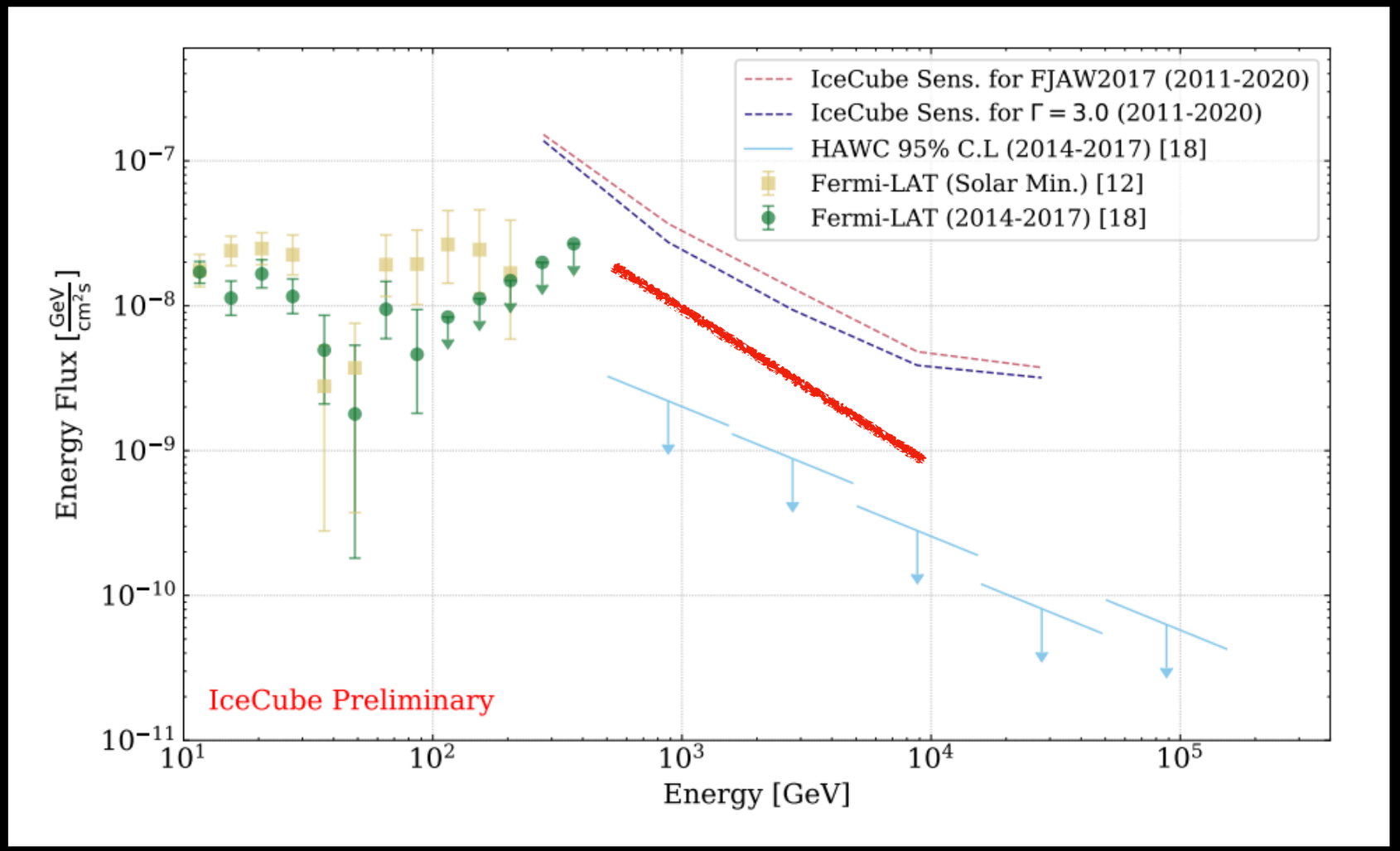
- Once suspected Solar atm. neutrino is detected. => hard to find weaker DM signals

- No reliable predictions
  - Magnetic field effects are complicated
  - Understand gamma rays first



Solar atmospheric neutrino search with IceCube

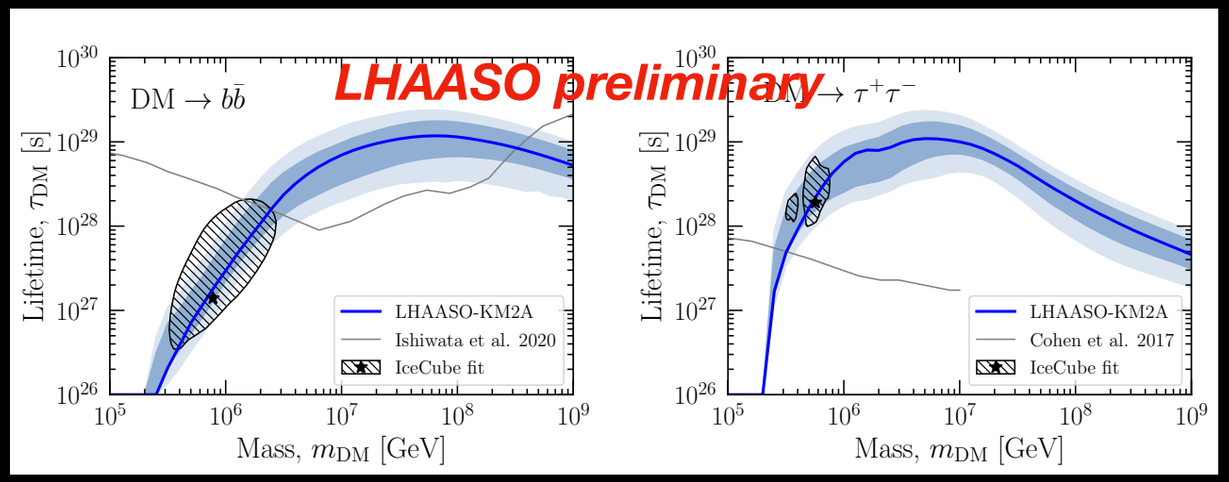
- Box not yet opened.
- Updated sensitivity presented in ICRC2021
- Based on non-magnetic models
- Detection could be soon



Summary

- Active scene in search for dark matter with neutrinos

- Dark matter decay search with high-energy neutrinos
  - Strong tests from LHAASO soon



- Dark matter annihilation searches from the Sun
  - Event detection could be soon
  - Need better understandings of the Sun to quantify background.