Status of Neutrino Astronomy
(Mini-review on neutrino telescopes)

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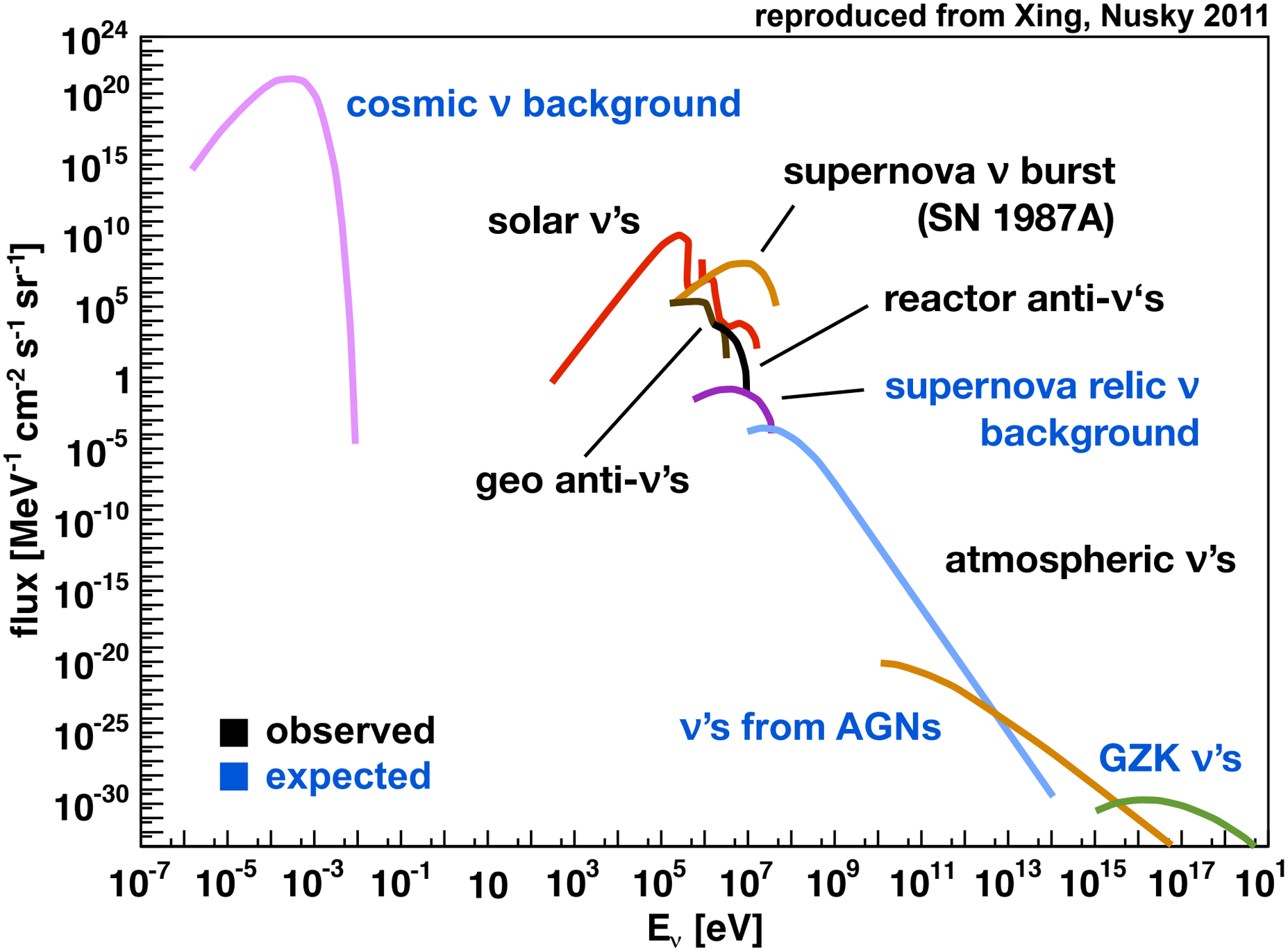
HUMBOLDT-UNIVERSITÄT ZU BERLIN

Outline

- **Introduction**
- **Neutrino telescopes**
- **Current status**
  - Sensitivities of neutrino telescopes
  - Galactic and extragalactic sources
  - Dark Matter
  - Beyond neutrino physics: cosmic-ray anisotropies

Neutrino fluxes

reproduced from Xing, Nusky 2011



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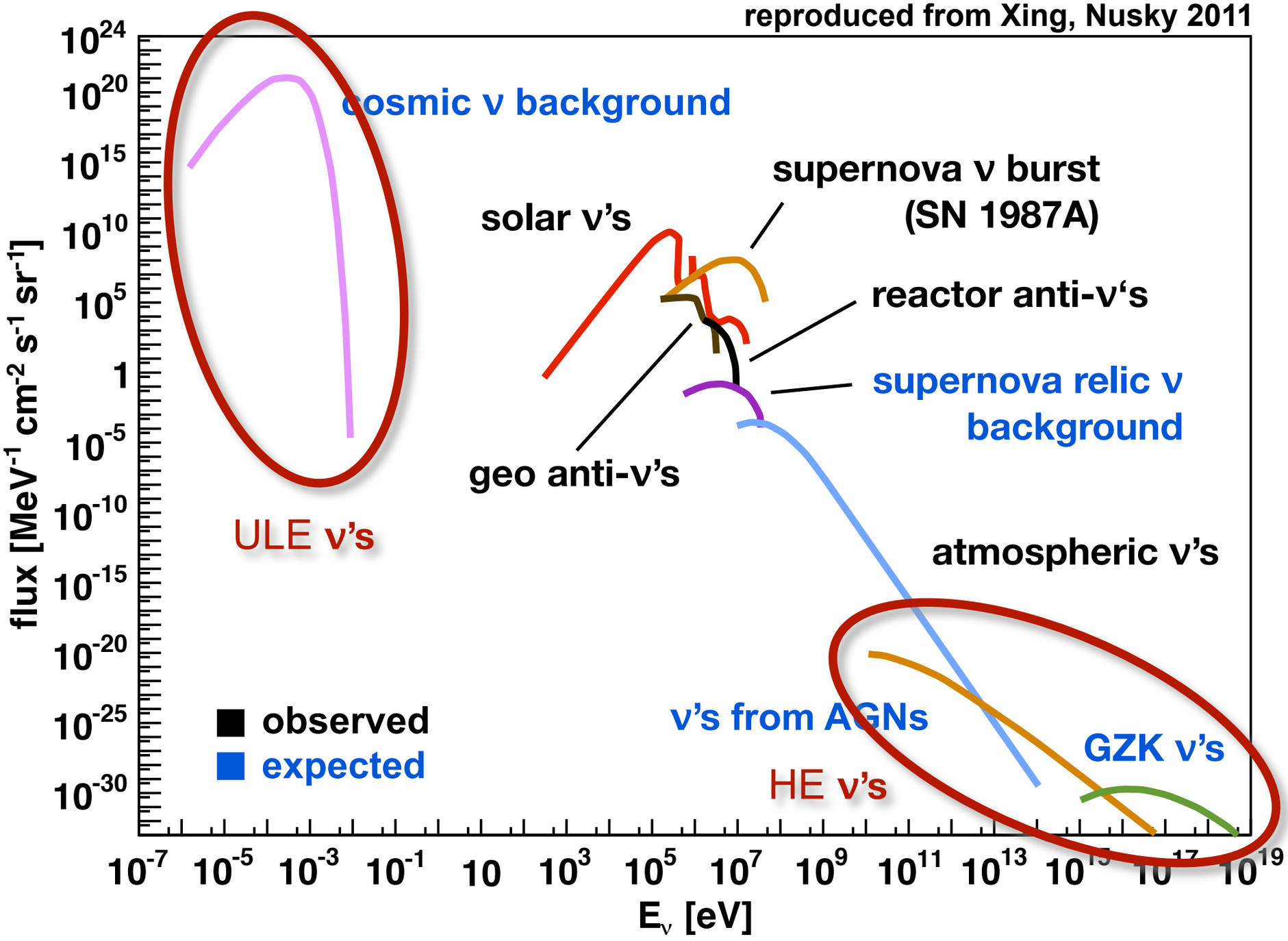


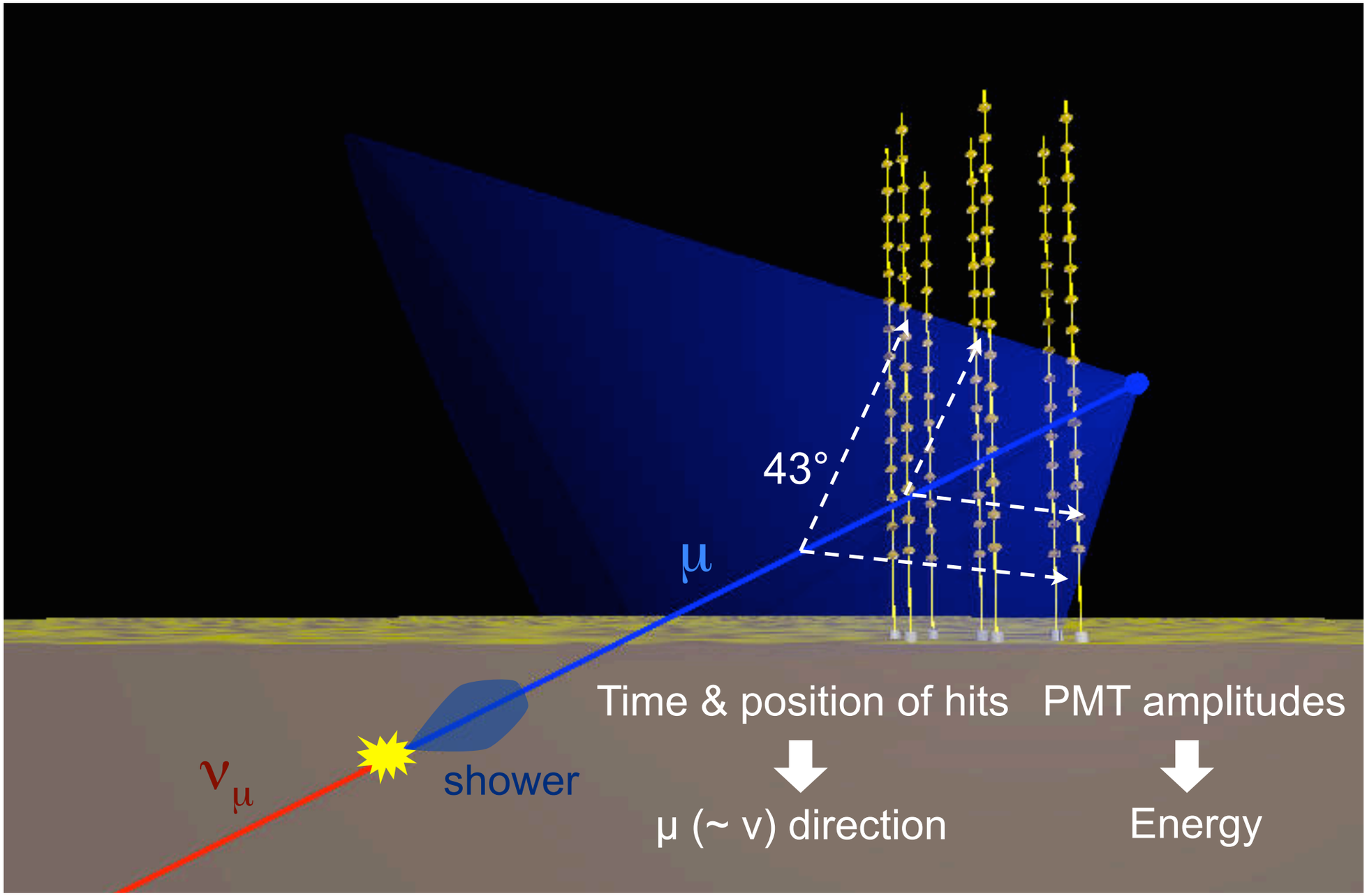
Why neutrino astronomy?

- Neutrinos point back to the source
- Neutrinos travel cosmological distances
- Neutrinos escape also optical dense sources
- Neutrinos are a smoking-gun evidence for hadron acceleration

$$p + p(\gamma) \rightarrow \pi^{\pm} + X$$
$$\hookrightarrow \mu + \nu_{\mu}$$
$$\hookrightarrow e + \nu_{\mu} + \nu_{e}$$

Neutrinos provide complementary information to gamma-ray photons and protons

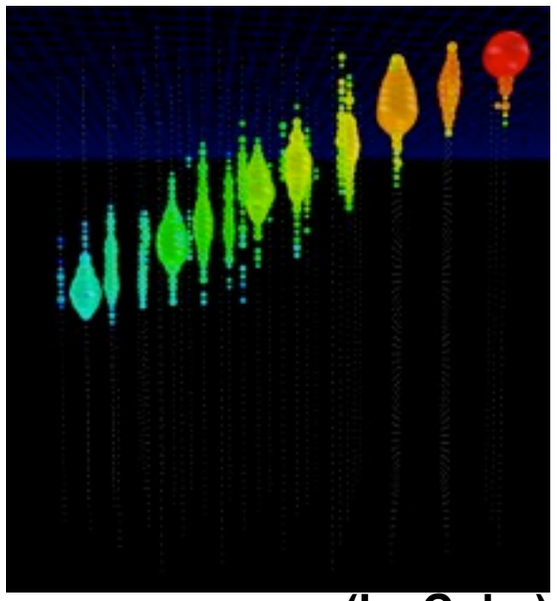
Detection principle



Neutrino signatures:

Track-like:

- Source: ν_μ CC interaction
- Good angular resolution (< 1°)
- Sensitive ≫ instrumented volume



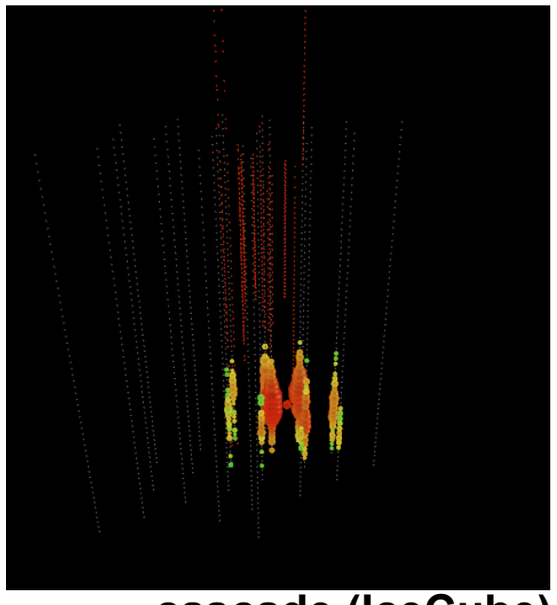
muon (IceCube)

Cascade-like:

- Source: ν_e, ν_μ, ν_τ NC + ν_e CC interaction
- Good energy resolution (few 10%)
- Bad angular resolution (> $\mathcal{O}(10°)$)
- Sensitive ≈ instrumented volume

Composites:

- Source: ν_τ CC + ν_μ CC inside instrumented volume
- Challenging to reconstruct



cascade (IceCube)

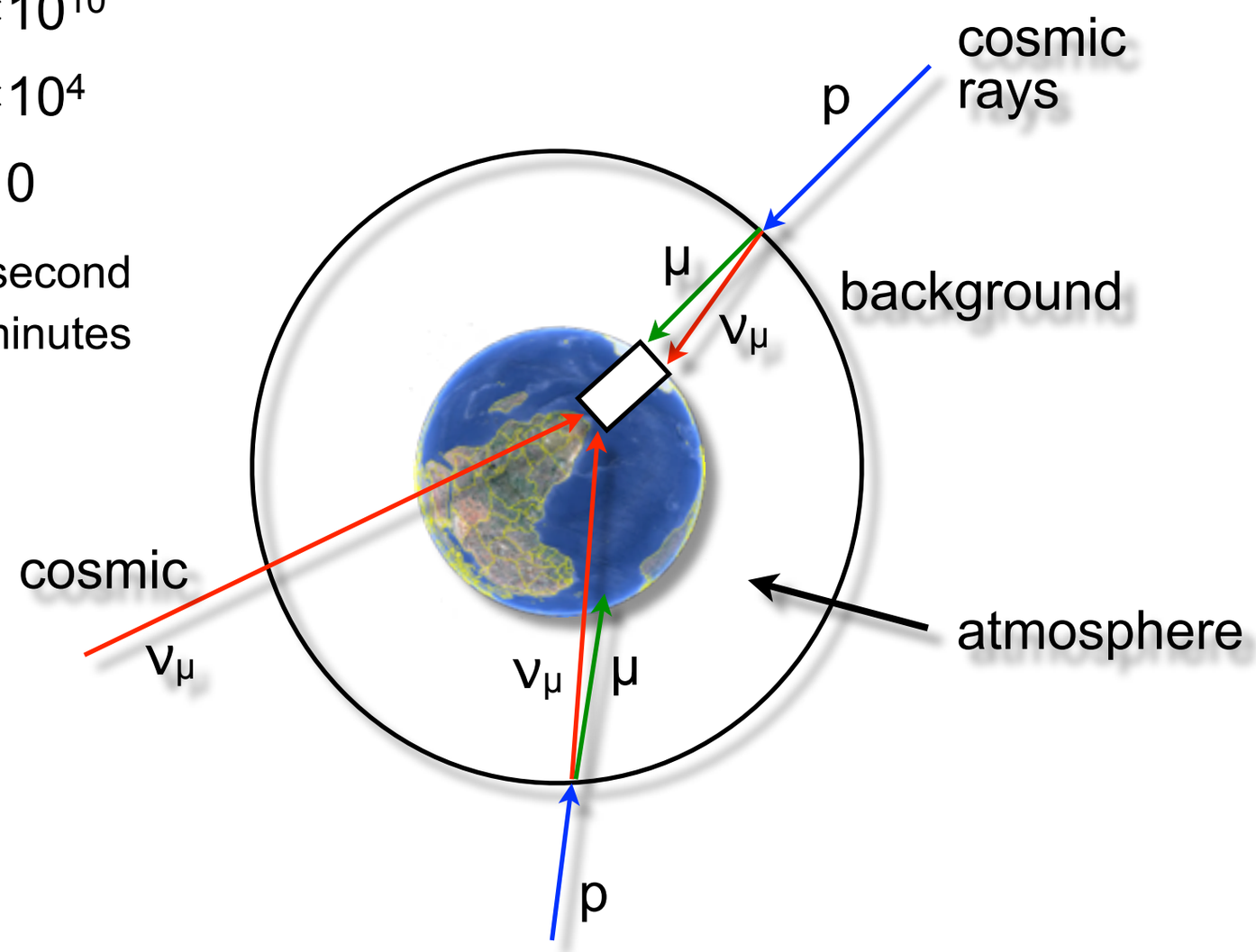
Backgrounds

Muons detected per year

- atmospheric* μ 7×10^{10}
- atmospheric** $\nu\rightarrow\mu$ 8×10^{4}
- cosmic $\nu\rightarrow\mu$ ~10

* 2000 per second

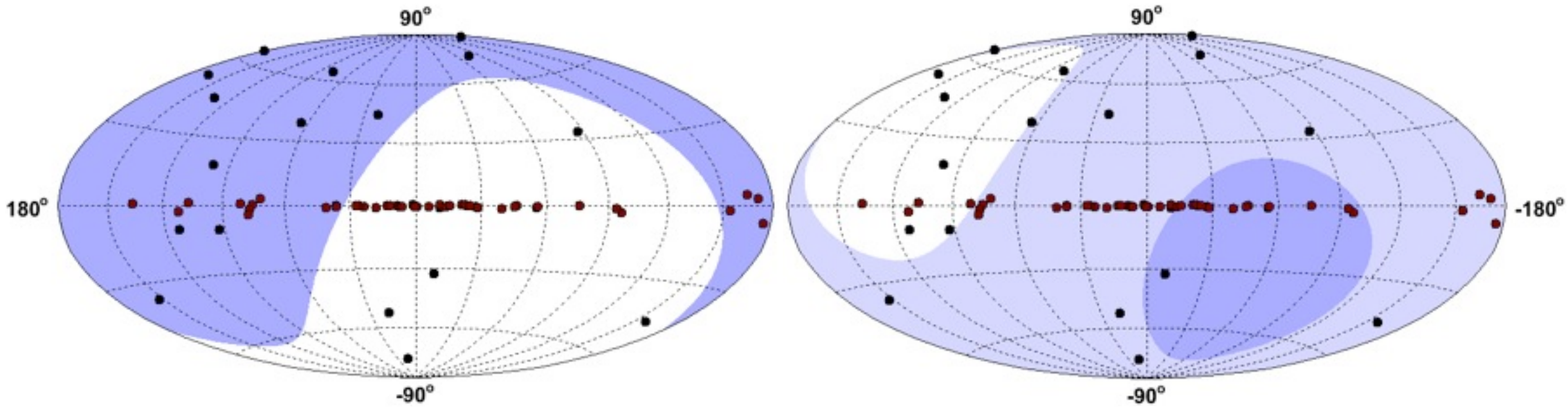
** 1 every 6 minutes



Sky coverage

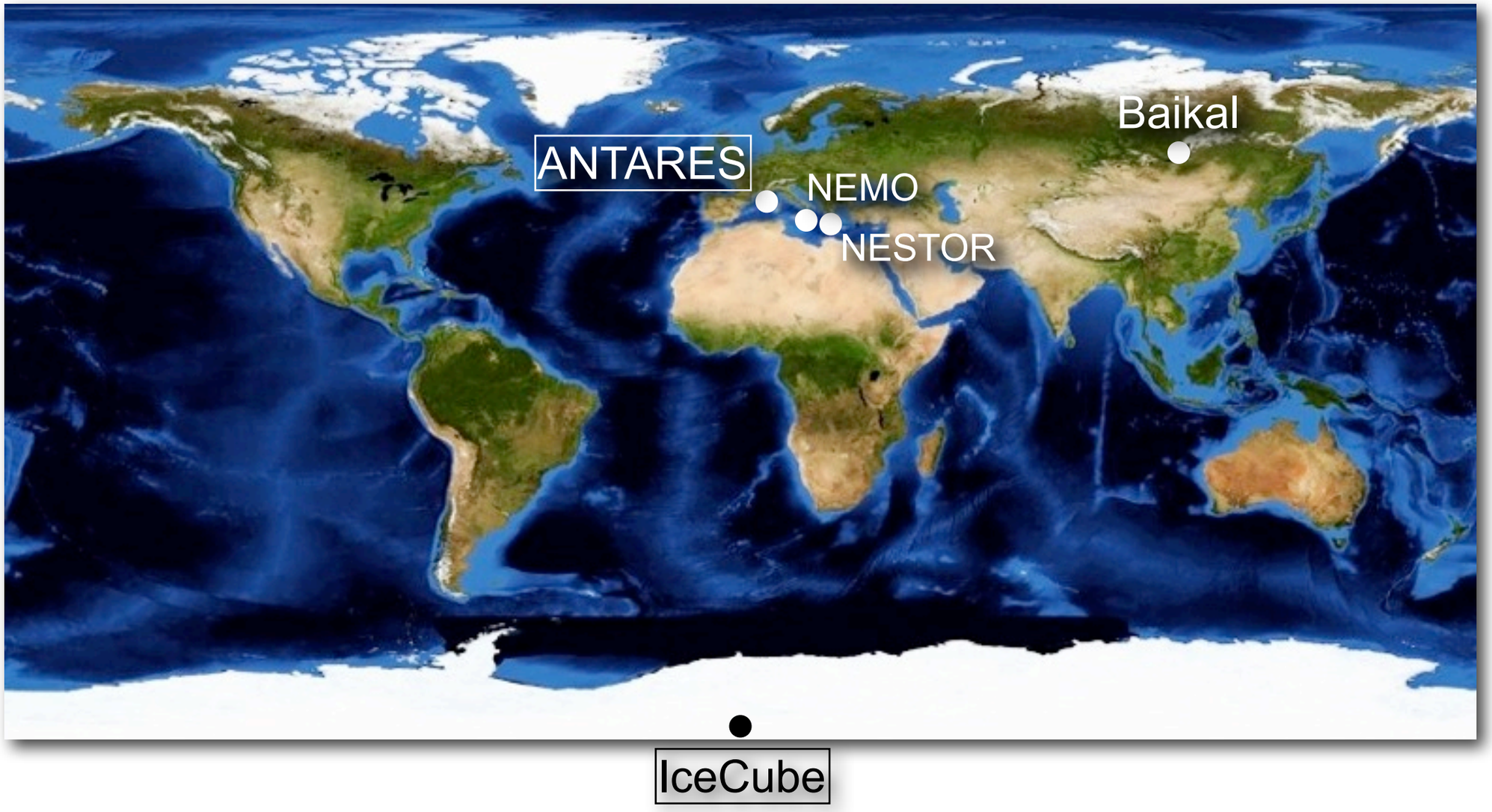
Visibility South Pole (IceCube)
- 100%
- 0%

Visibility Mediterranean (Antares)
- > 75%
- 25% – 75%
- < 25%

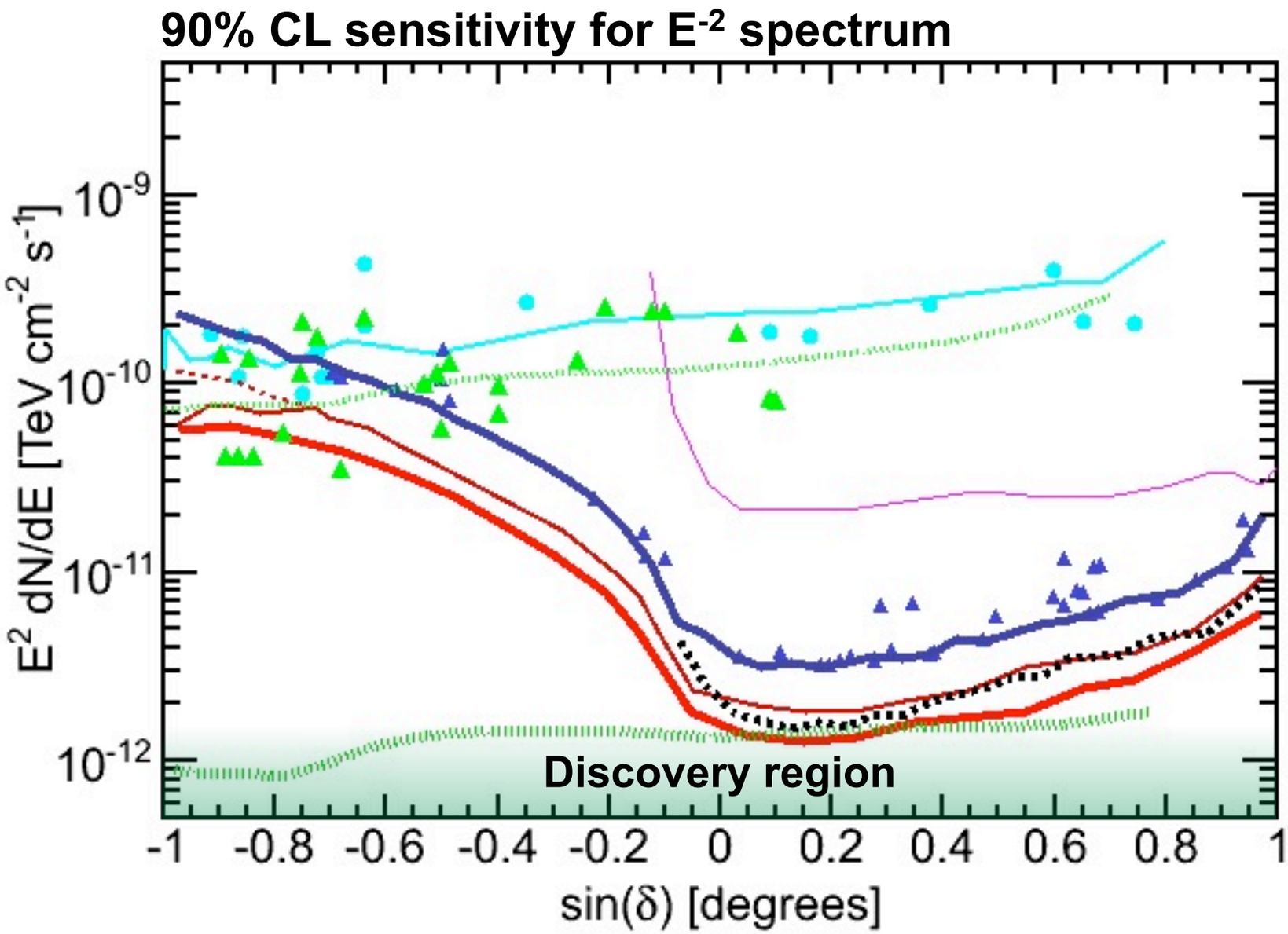


TeV gamma-ray sources
- Galactic
- extragalactic

Neutrino Telescope Projects



Sensitivities to point sources



SuperK

ANTARES

AMANDA

IceCube 40

IceCube 80
(predicted IC40)

IceCube 40+59

KM3NeT
(predicted)

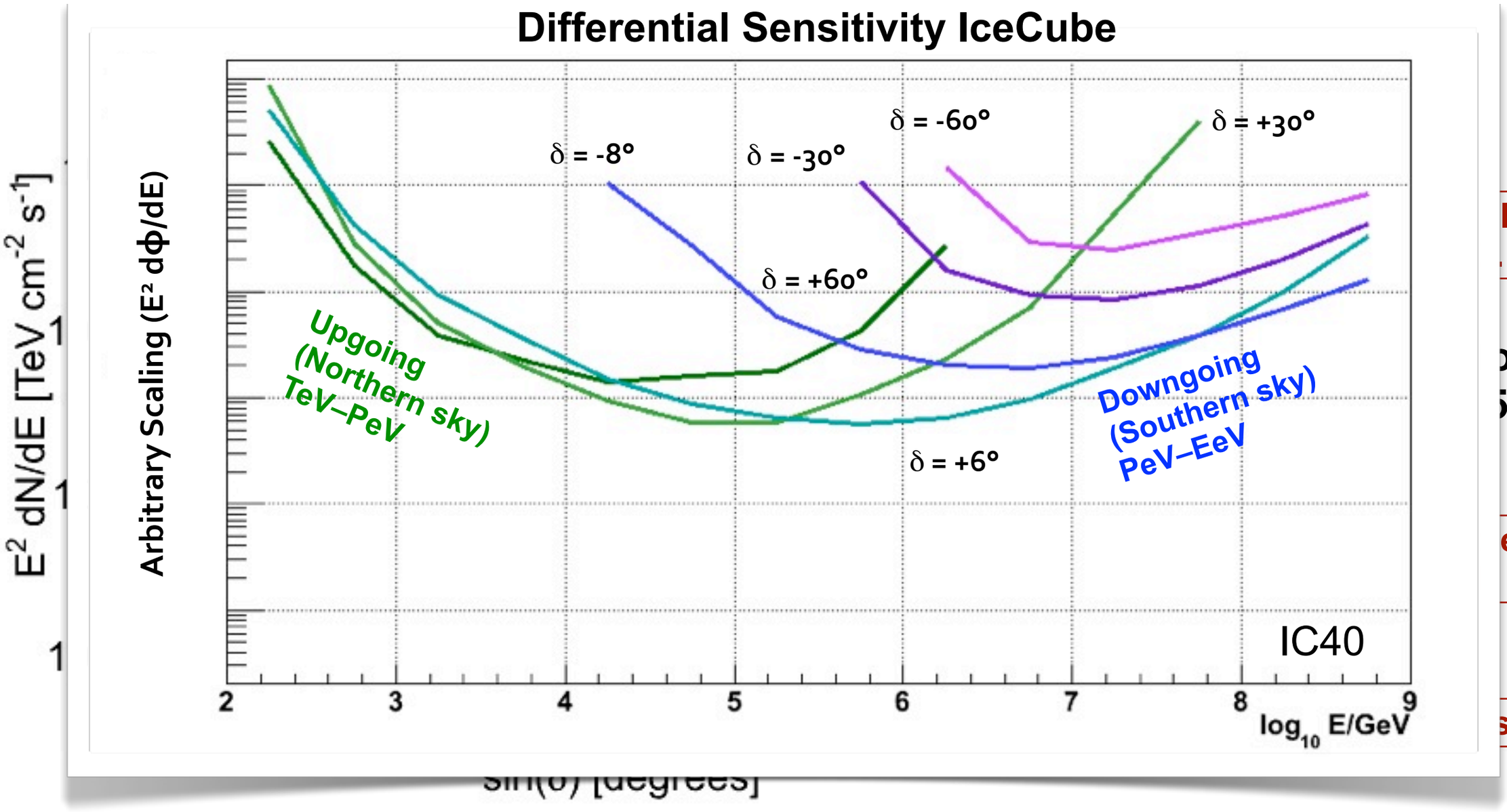
→ talk D. Dornic

factor 1000
in 15 years

→ plenary talk T. Montaruli

→ talk A. Tsirigotis

Sensitivities to point sources



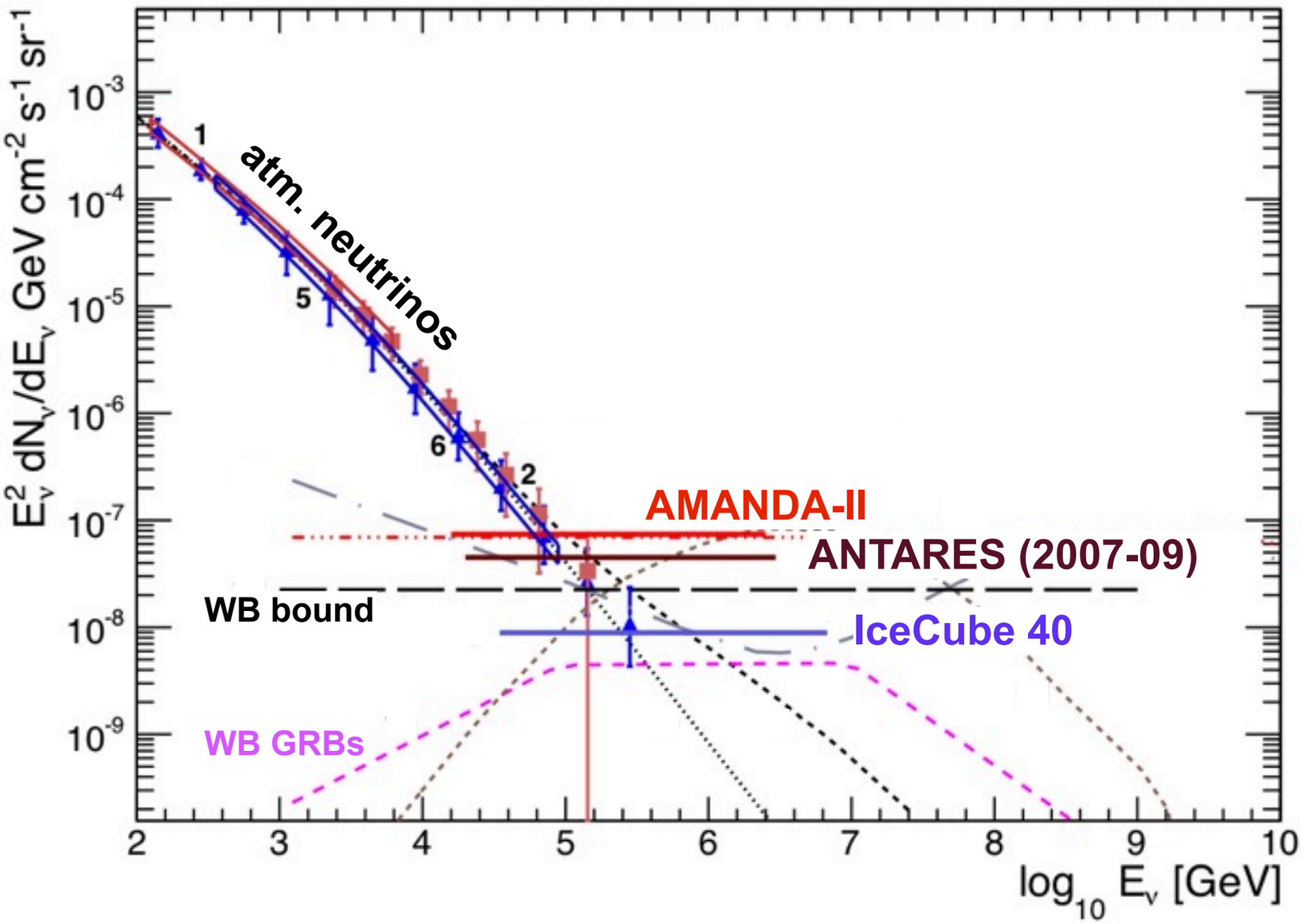
lk
. Dornic

or 1000
5 years

enary talk
Montaruli

s

Sensitivities to diffuse neutrino flux

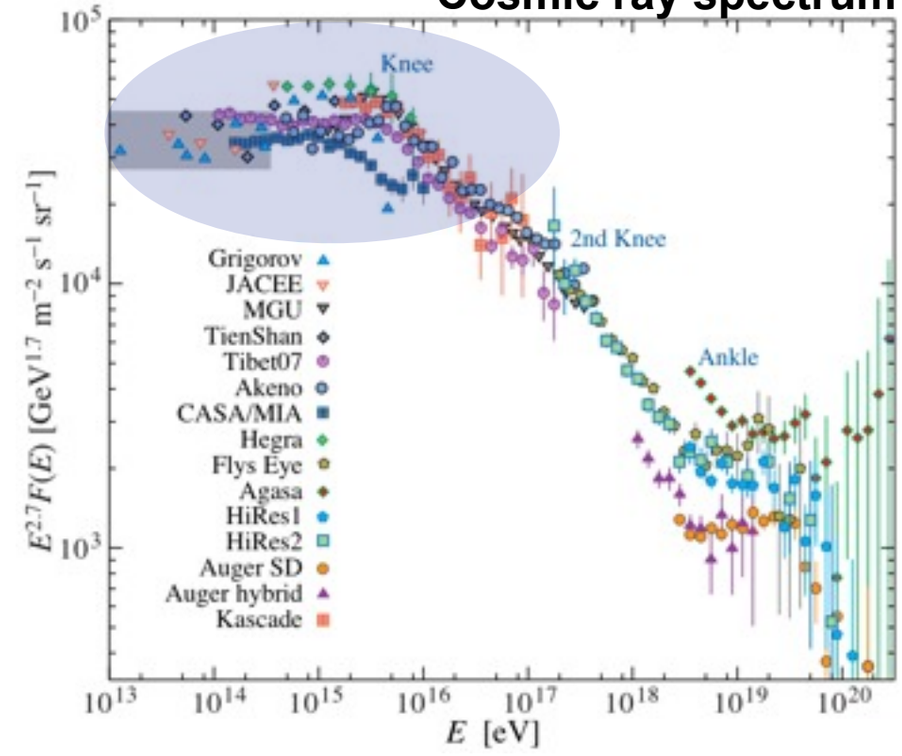


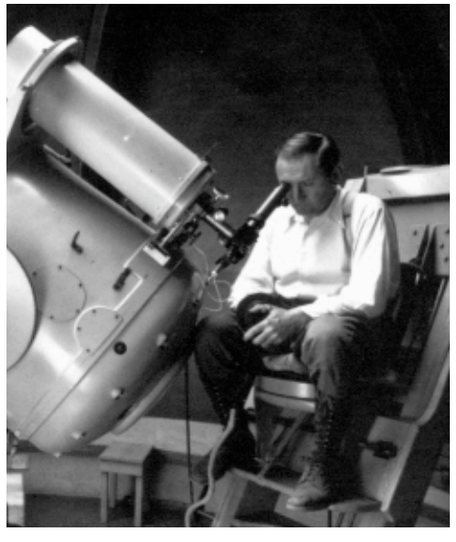
Galactic sources

- **Energy Galactic CRs:** ~10^{-12} erg/cm^3
  → injection power: ~10^{-26} erg/(cm^3 s)
  (escape time CRs ~3×10^6 yr)

- **SNe provide energy and environment**
  - 10% of 10^{51} erg/SN every 30 yr
    (Baade and Zwicky 1934)
  - shock acceleration
    (Fermi 1949)

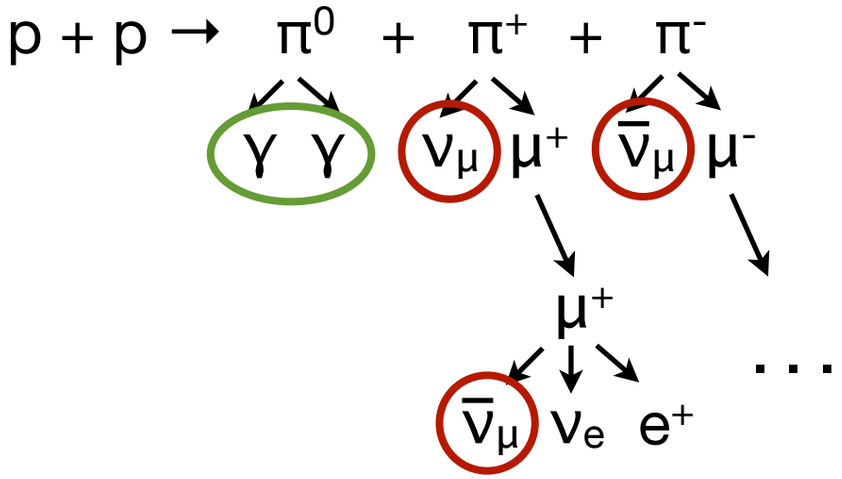
Cosmic ray spectrum





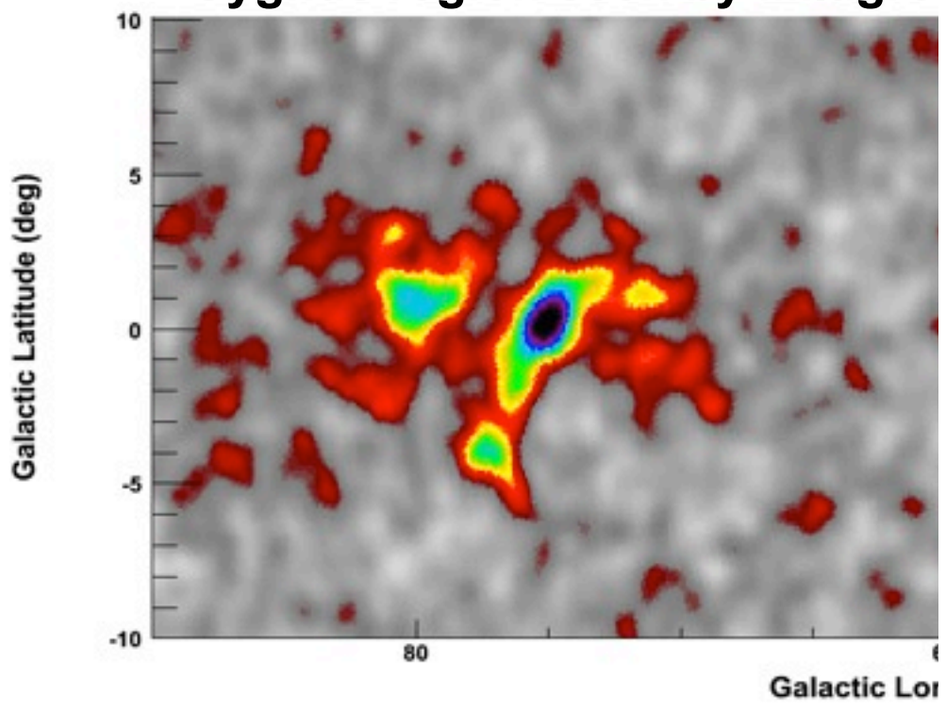
Galactic sources

- Cosmic rays must produce pionic γ-rays in interactions with hydrogen in Galactic plane



→ **translation of γ into ν fluxes**

Cygnus region seen by Milagro



- **Best environments:** star forming regions

Stacking of 6 Milagro SNRs (Abbasi et al. 2011):

model	sensitivity	p-value	upper limit
3 events	2.9 × model	2% (posteriori)	7.2 × model

model Halzen, AK, O'Murchadha (2008)

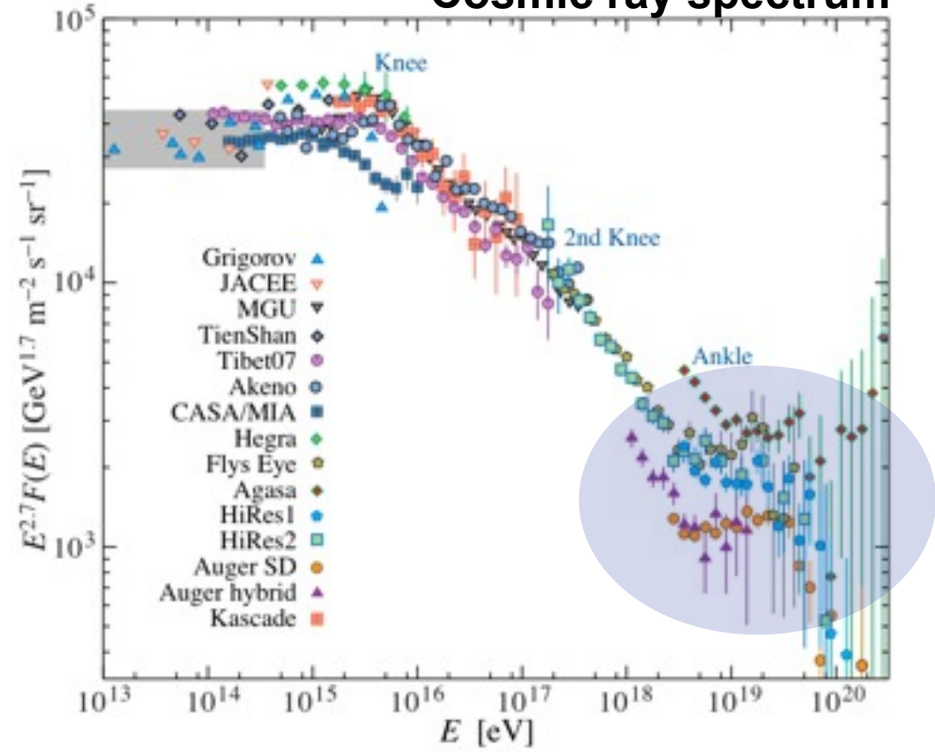
Extragalactic sources

- **Source requirements:**
  - acceleration up to 10^{20} eV
  - produce energy in cosmic rays
    (~3×10^{-19} erg/cm^3 ⇒ ~8×10^{44} erg Mpc^{-3} yr^{-1})

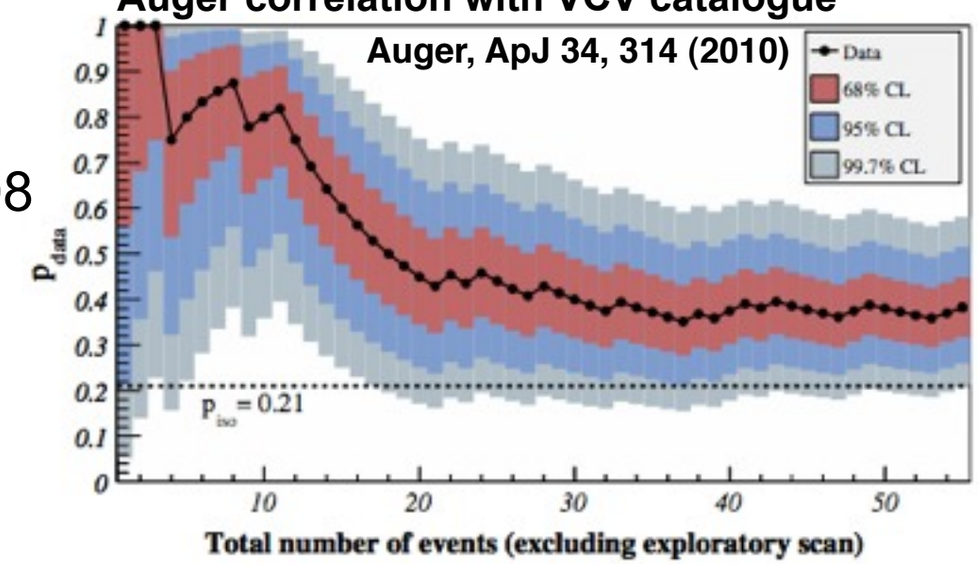
- **Best (only?) candidates:** AGNs and GRBs

- **Active Galactic Nuclei (AGNs):**
  - Auger: sources revealed?
    → weak AGN correlation decreased since 2008
    → in conflict with composition measurements
  - neutrino-flux predictions difficult

Cosmic ray spectrum



Auger correlation with VCV catalogue



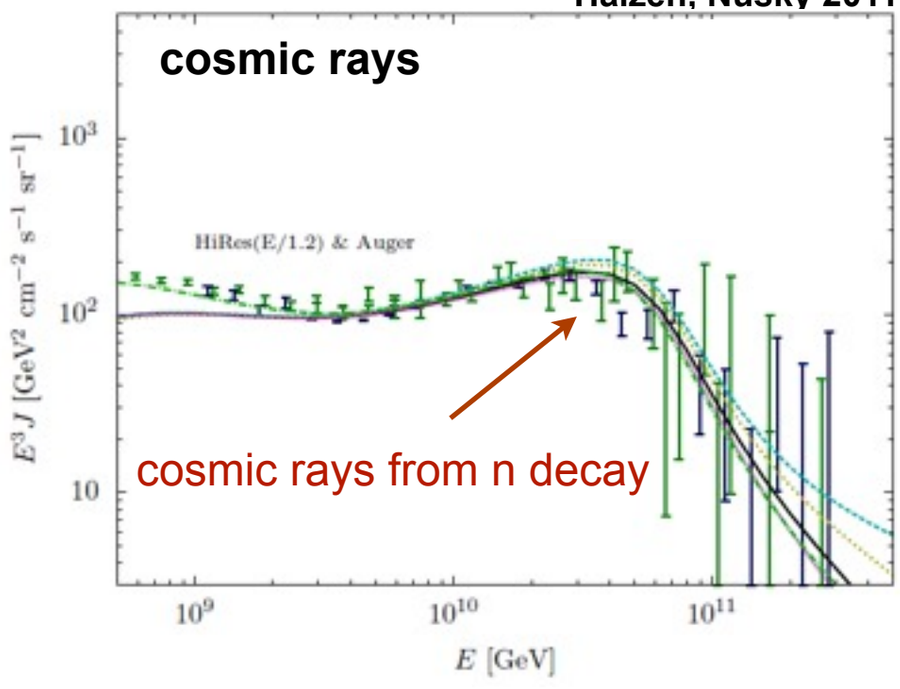
Extragalactic sources: GRBs

- **Gamma-Ray Bursts (GRBs):**
  - provide energy and environment to explain extragalactic cosmic rays (~10^{52} erg × 100/Gpc^3)

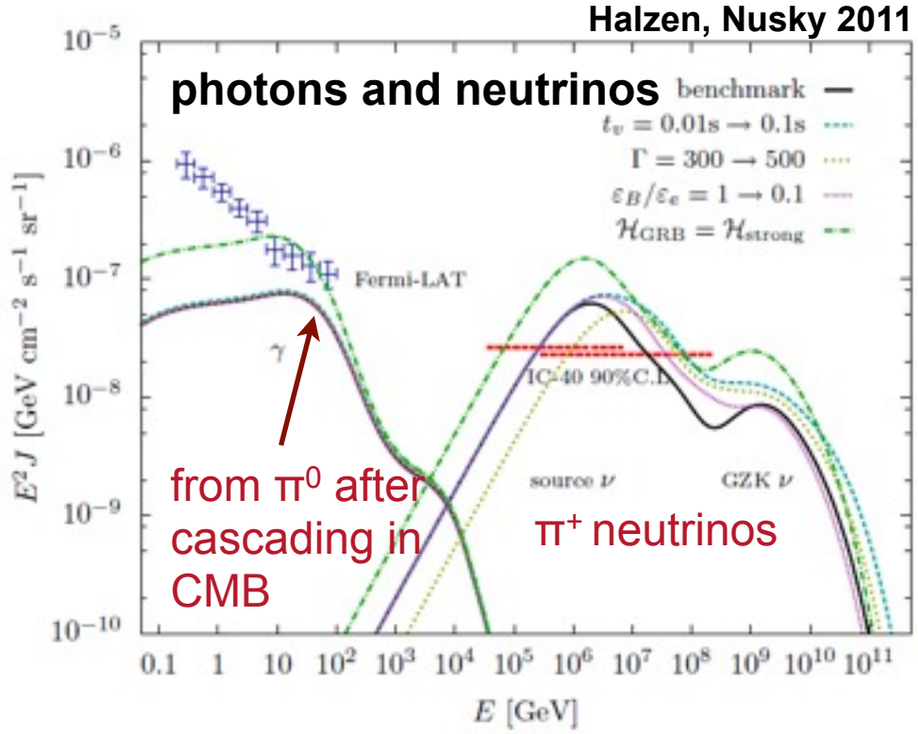
- **Source model** (Ahlers et al. 2011):
  - acceleration in internal shocks (fireball model)
  - collide accelerated protons with photons: $p + \gamma \rightarrow n + \pi^+$ and $p + \pi^0$
  - observed cosmic rays from *n* decay
  - Neutrino and photon flux from pion decay

IceCube challenges GRBs as major sources of extragalactic cosmic rays

Halzen, Nusky 2011



Halzen, Nusky 2011



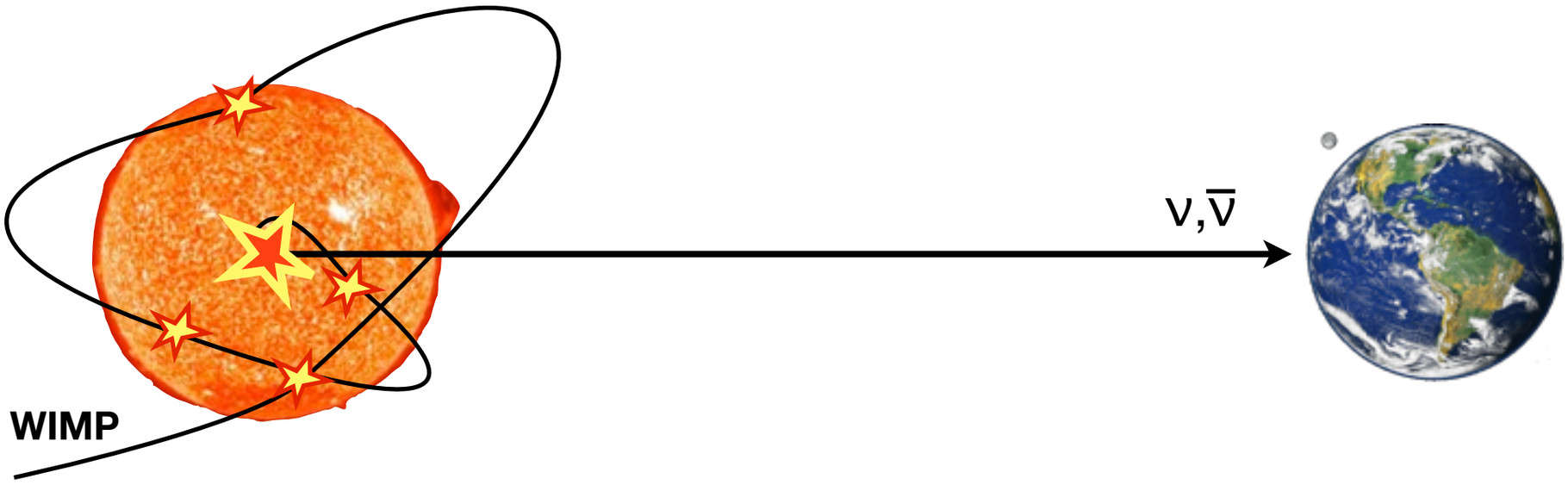
Dark Matter (WIMPs)

- Gravitational capture of WIMPs in the Sun
  followed by self annihilation

- Neutrino rate only depends on scattering cross section
  (equilibrium between capture and annihilation)

  → Sensitive to spin-dependent cross section

- Expected ν energies < 1 TeV

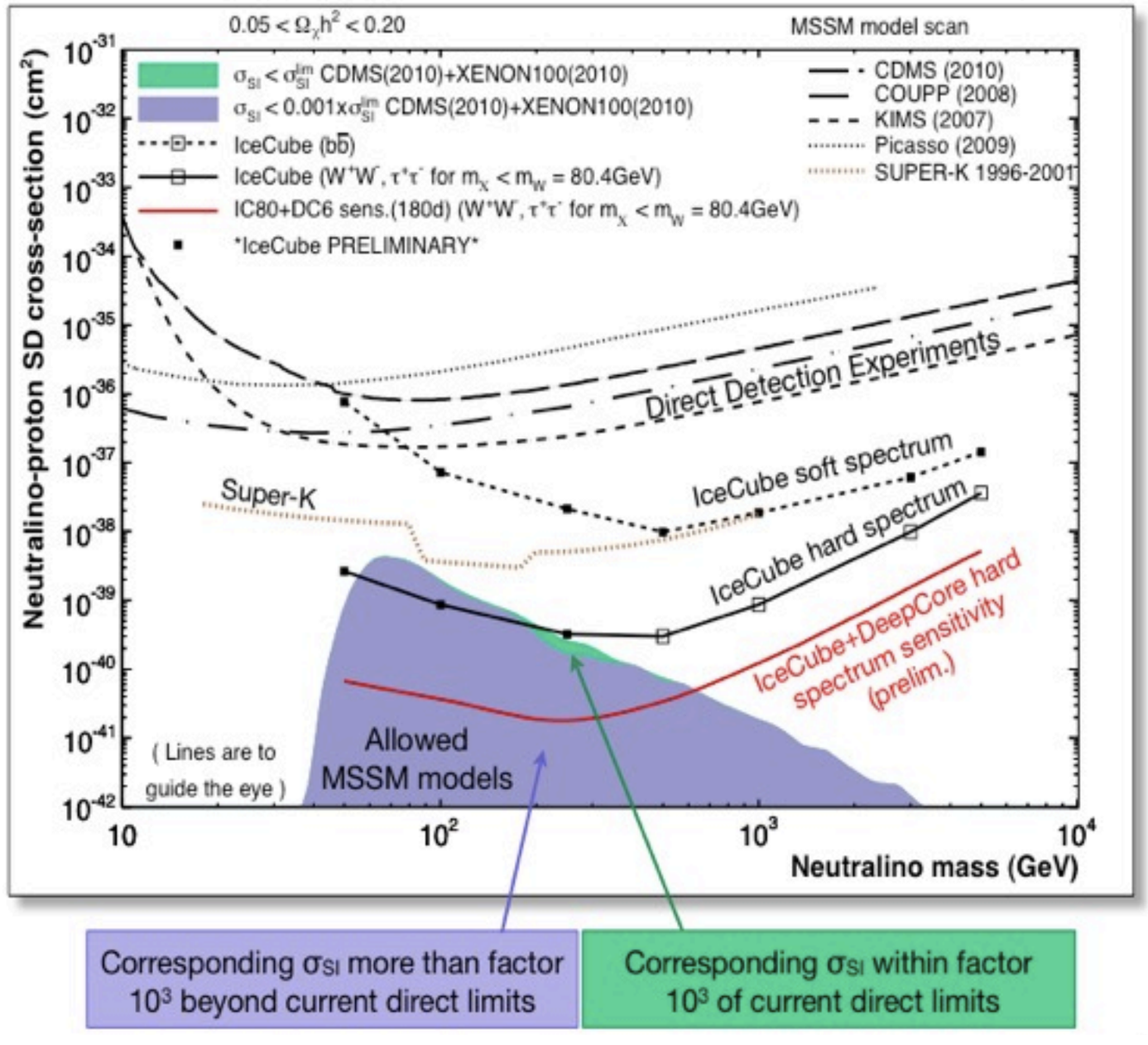


WIMP sensitivities

- *Spin-independent* σ_{scat} well constrained by direct searches
- Solar dark matter searches probe *spin-dependent* σ_{scat}
- DeepCore will probe large region of allowed phase space

talks
F. Lee (low energy),
H. Melbeus (Kaluza-Klein),
G. Lambard (Antares)

Neutralino WIMP **D. Cowen, Nusky 2011**



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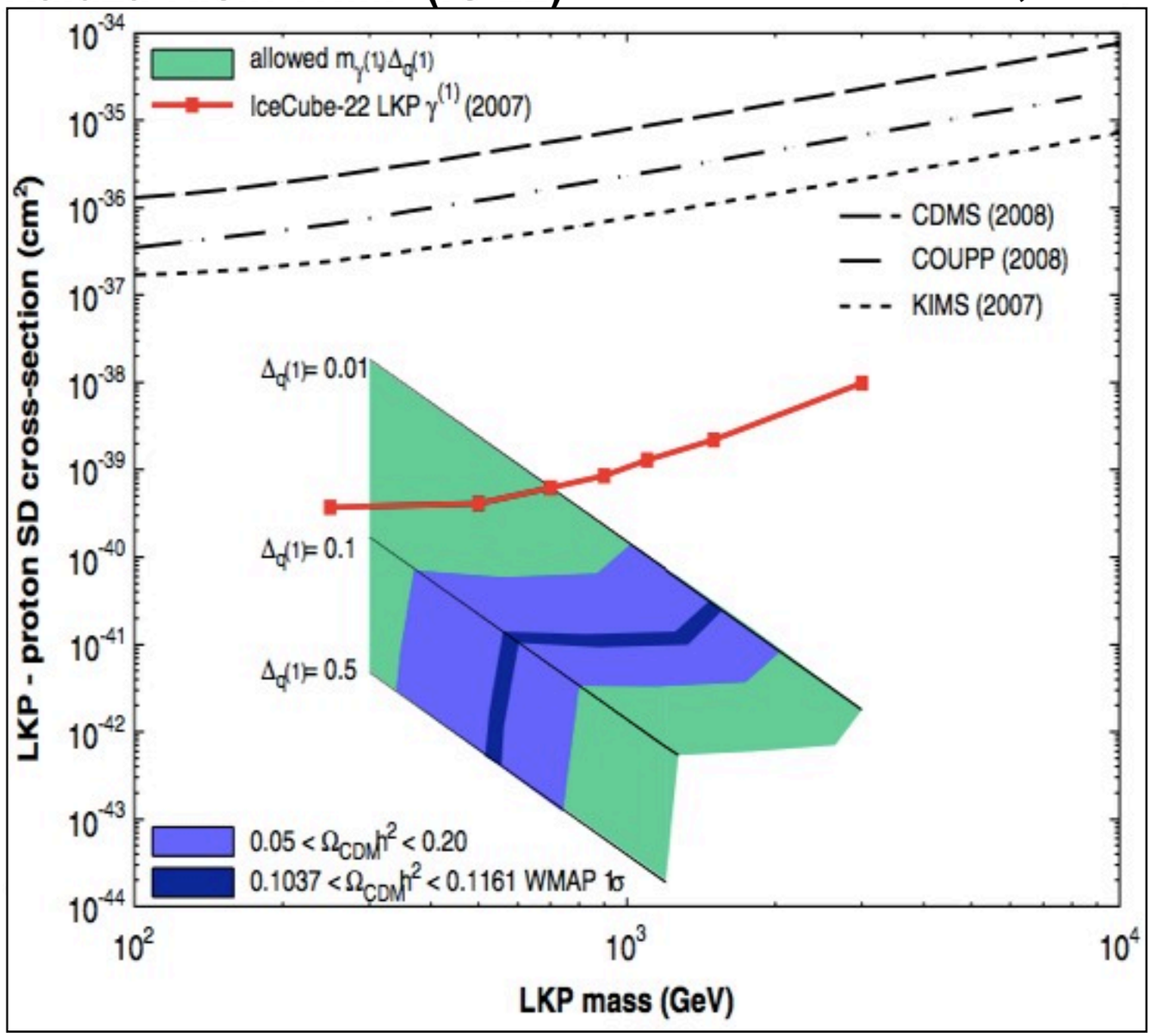
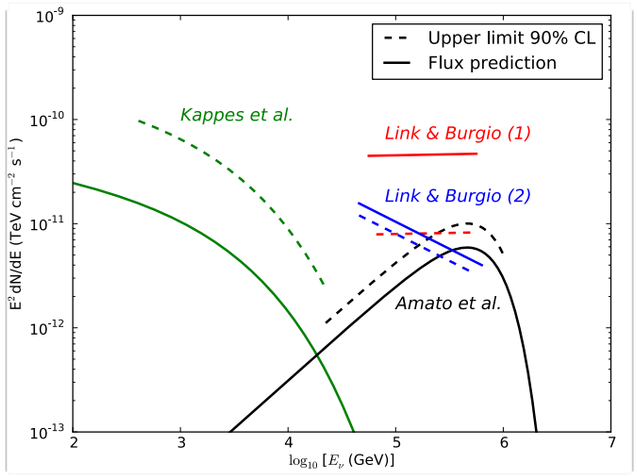
Kaluza-Klein WIMP (IC 22) **Abbasi et al., 2010**

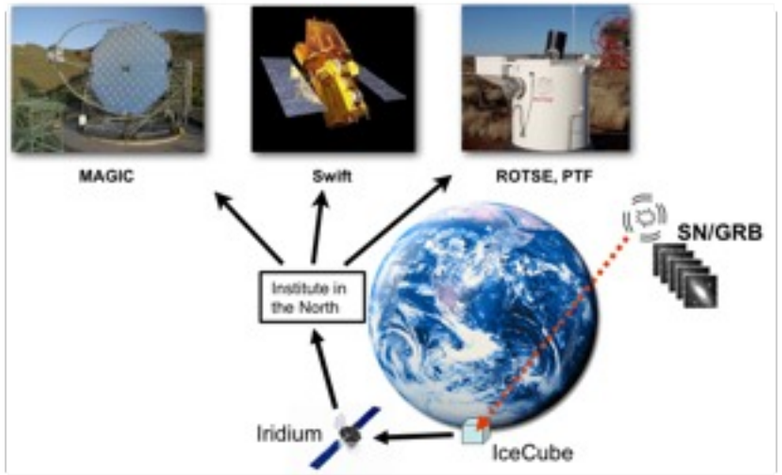


Neutrino telescope physics

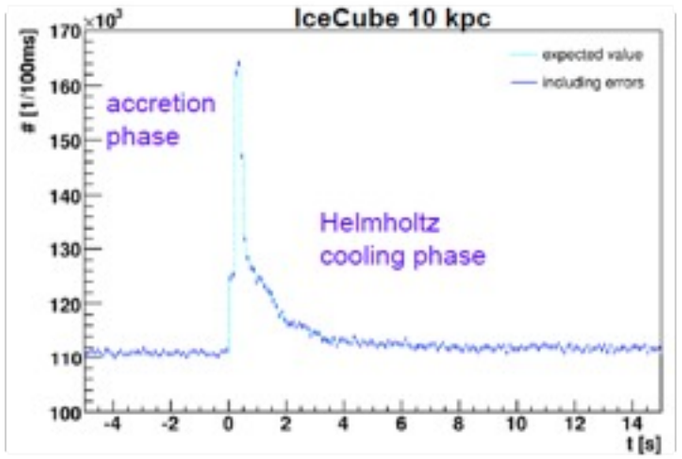
flaring/periodic sources



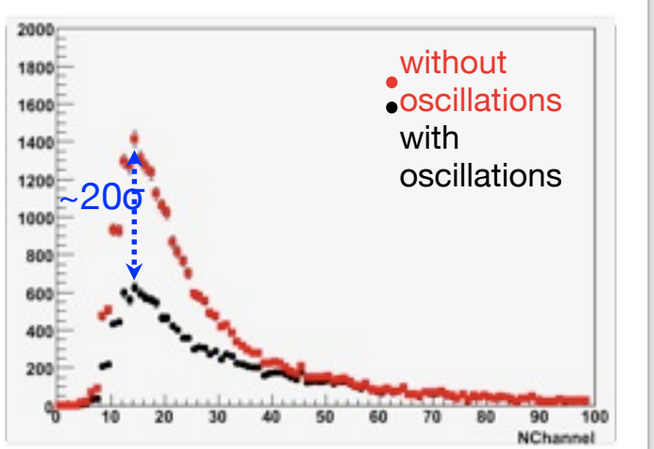
follow-up programs



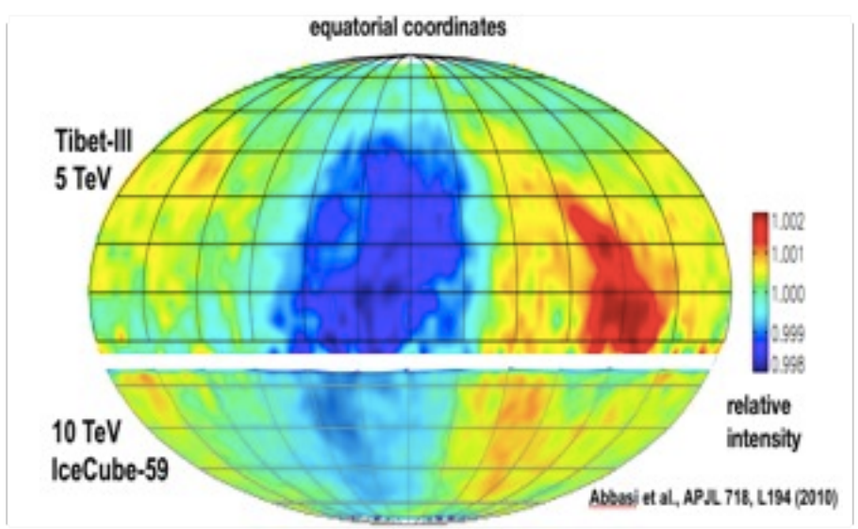
supernovae (MeV ν's)



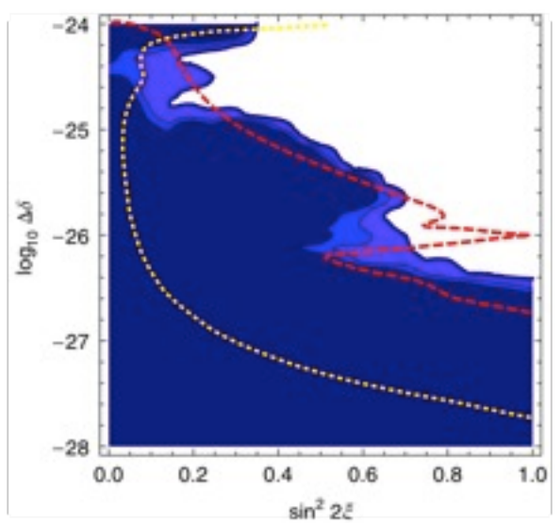
neutrino oscillation



cosmic ray anisotropy

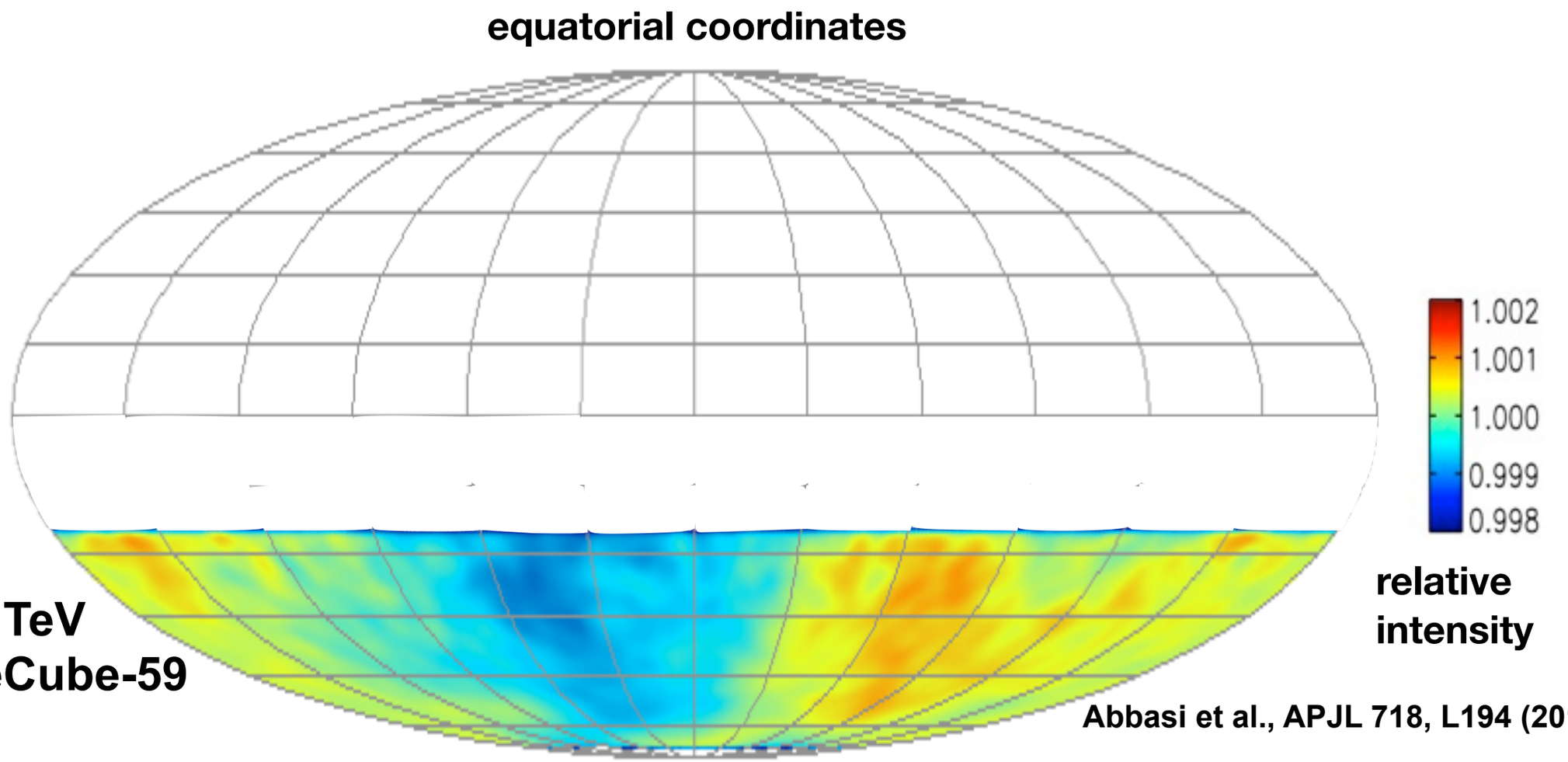


Lorentz violation



Cosmic-ray anisotropy

Desiati, Nusky 2011

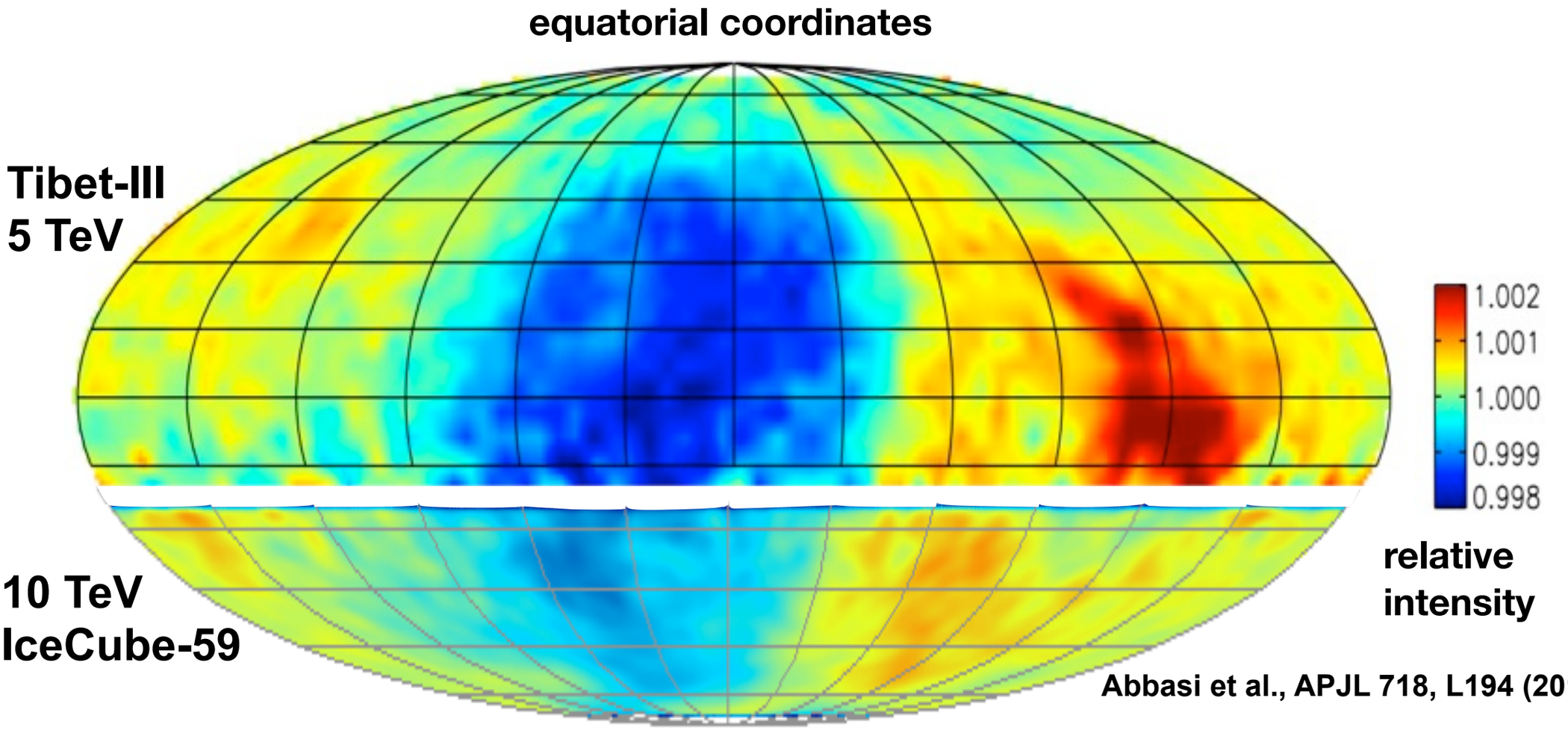


Abbasi et al., APJL 718, L194 (2010)

- Gyroradius < 1 pc in μG Galactic B-field
- Closest sources ~100 pc
  → cosmic rays should not point !

Cosmic-ray anisotropy

Desiati, Nusky 2011



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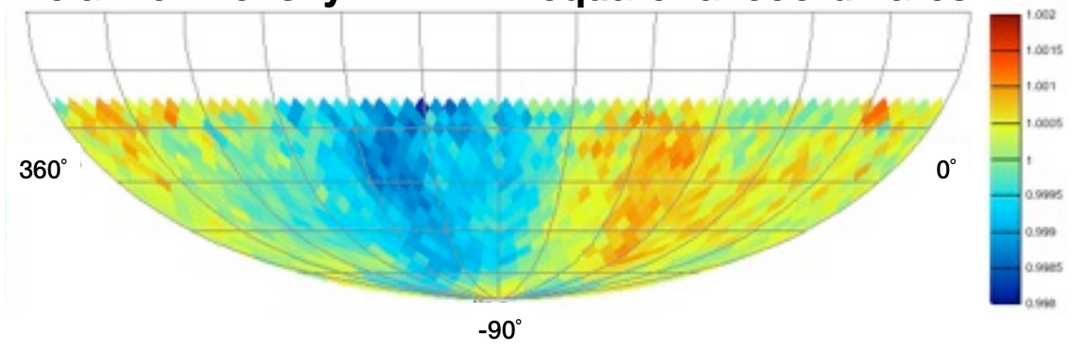
Cosmic-ray anisotropy

Desiati, Nusky 2011

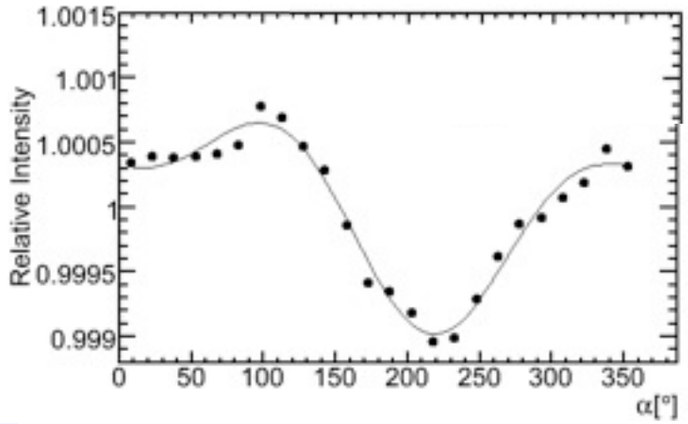
preliminary

relative intensity

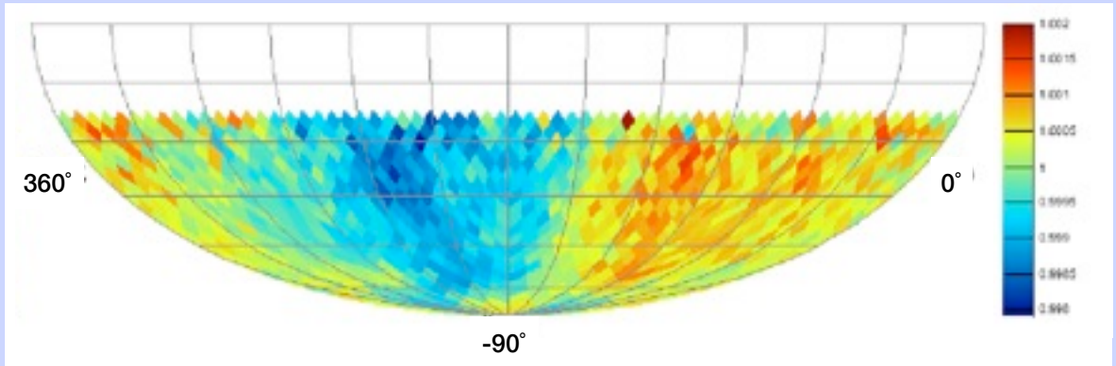
equatorial coordinates



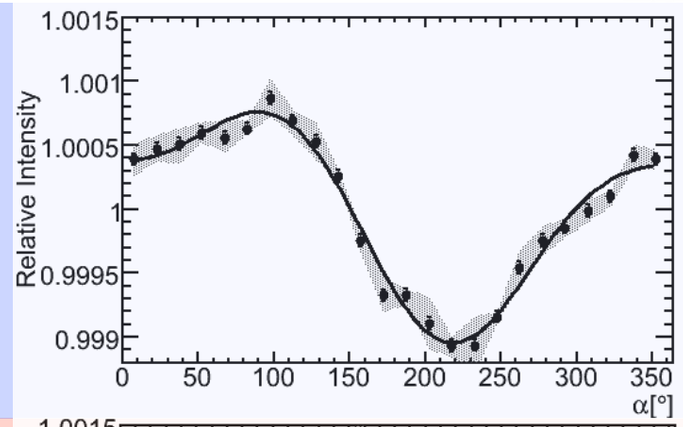
no energy selection



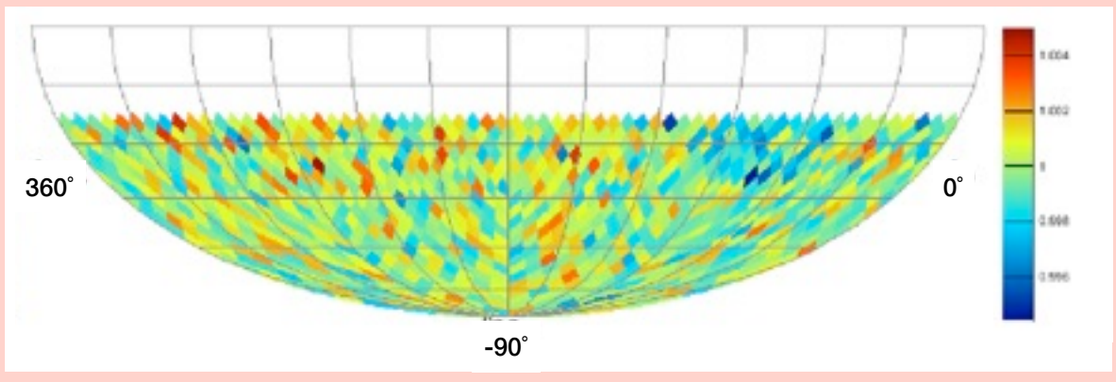
energy

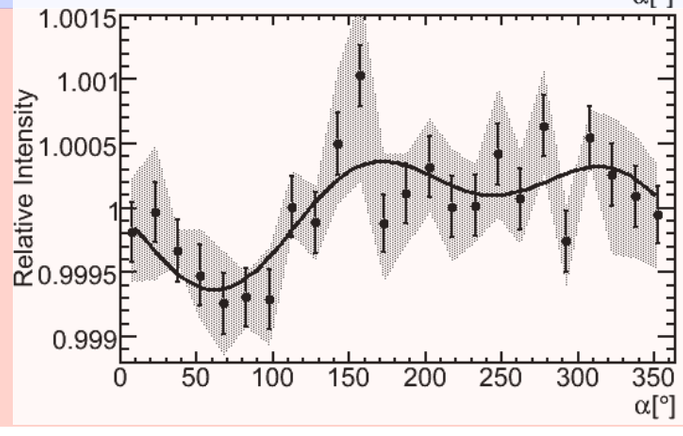


20 TeV



400 TeV





Summary

- **Full-sky coverage with completed neutrino telescopes**
  - IceCube scans northern sky with unsurpassed sensitivity
  - Antares observes interesting Galactic center region . . .
    . . . but KM3NeT in Northern hemisphere badly needed

- **Analysis results so far:**
  - Searches for cosmic neutrinos with negative results
  - IceCube limits challenge GRBs as major sources of extragalactic cosmic rays
  - Exciting physics beyond neutrino astronomy

- **Outlook:**
  - IceCube enters discovery region for Galactic sources
  - Upcoming years will be critical for neutrino astronomy