IceCube & KM3NeT.

Towards a Global Neutrino Observatory

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Astroparticle Physics –
Workshop on German-Russian Perspectives
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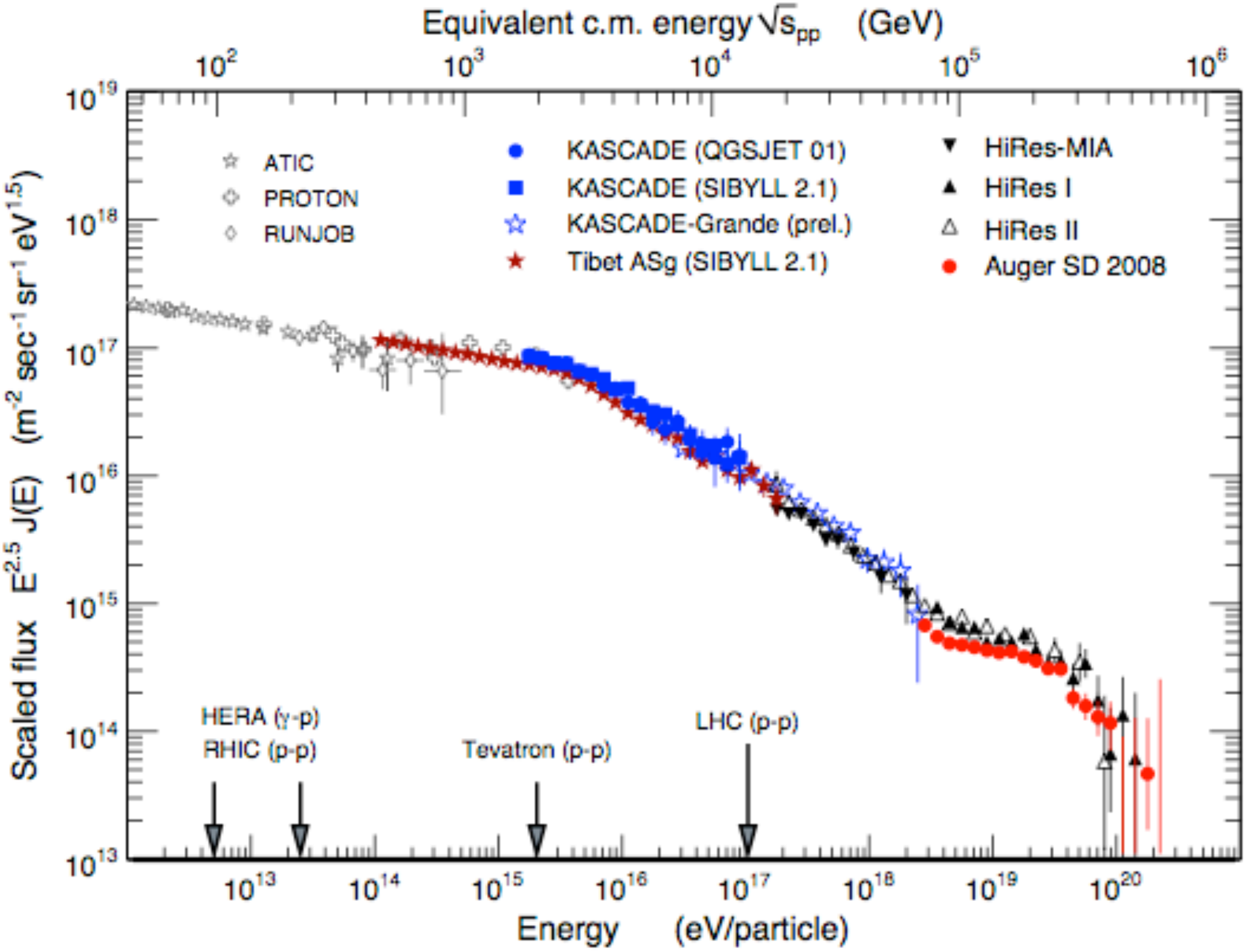
HUMBOLDT-UNIVERSITÄT ZU BERLIN

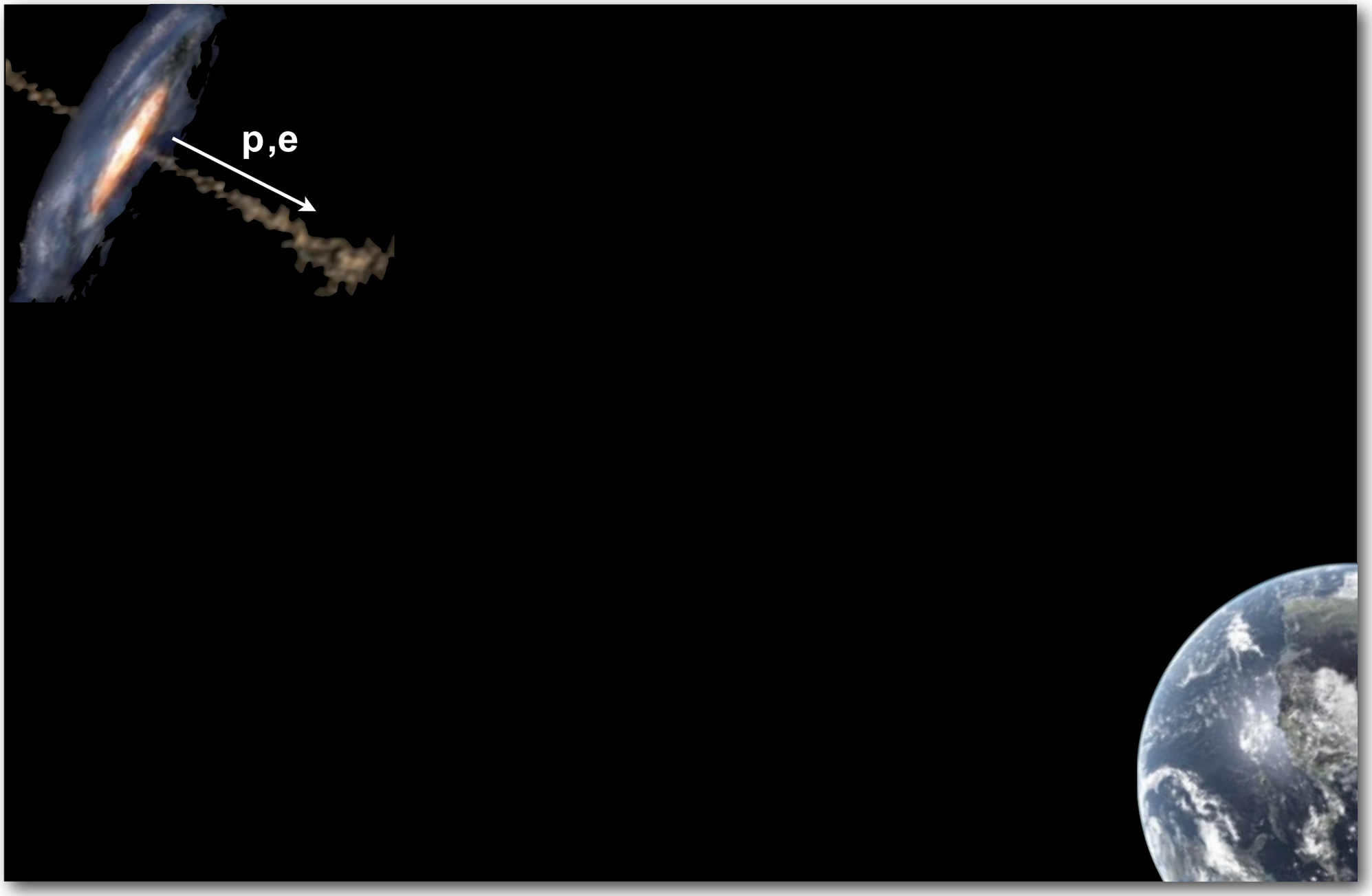
Outline

- Introduction
- Neutrino telescopes
  - IceCube
  - KM3NeT
- Future plans

Cosmic rays 99 years after their discovery



Messengers of the high-energy universe



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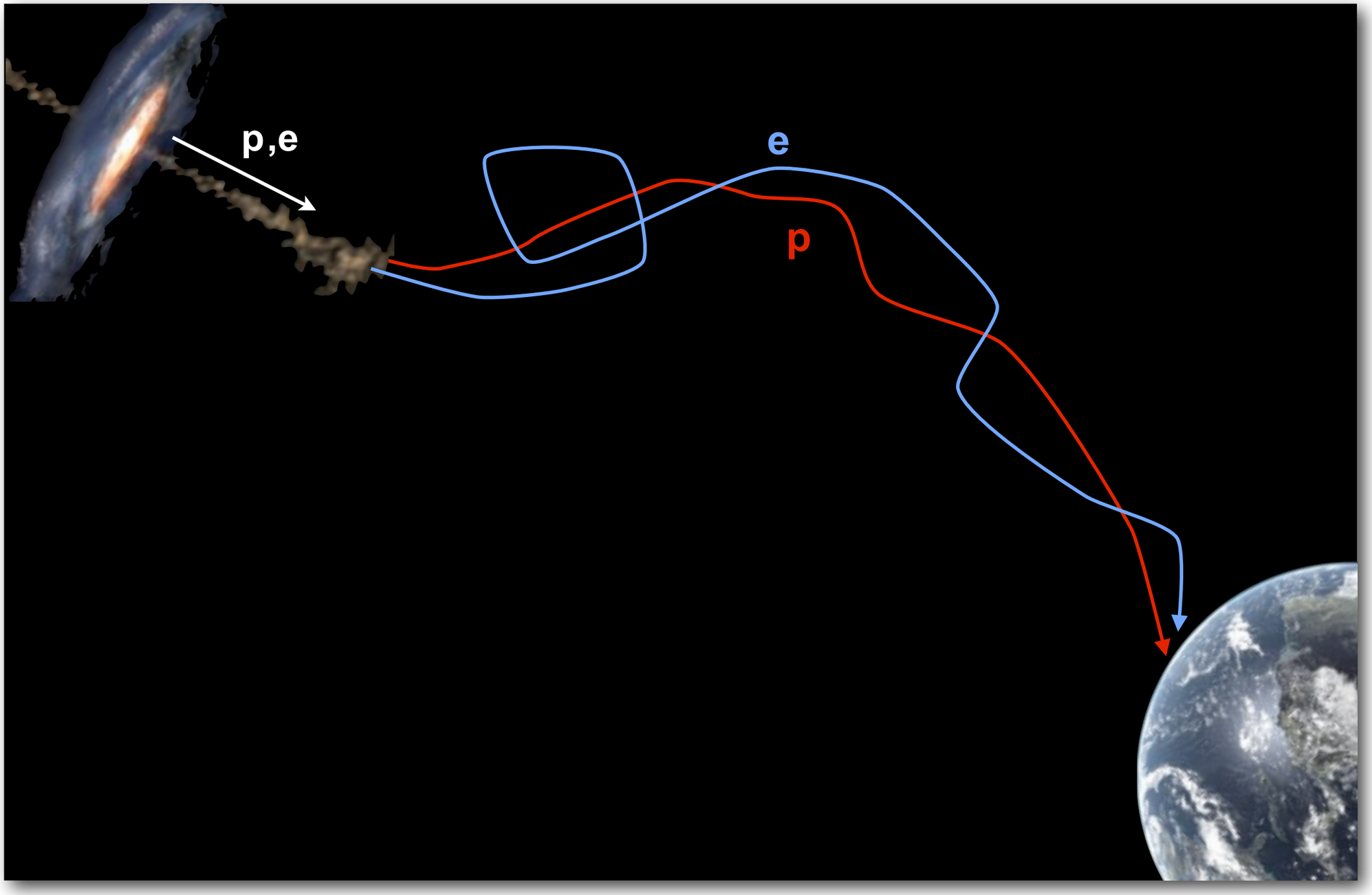

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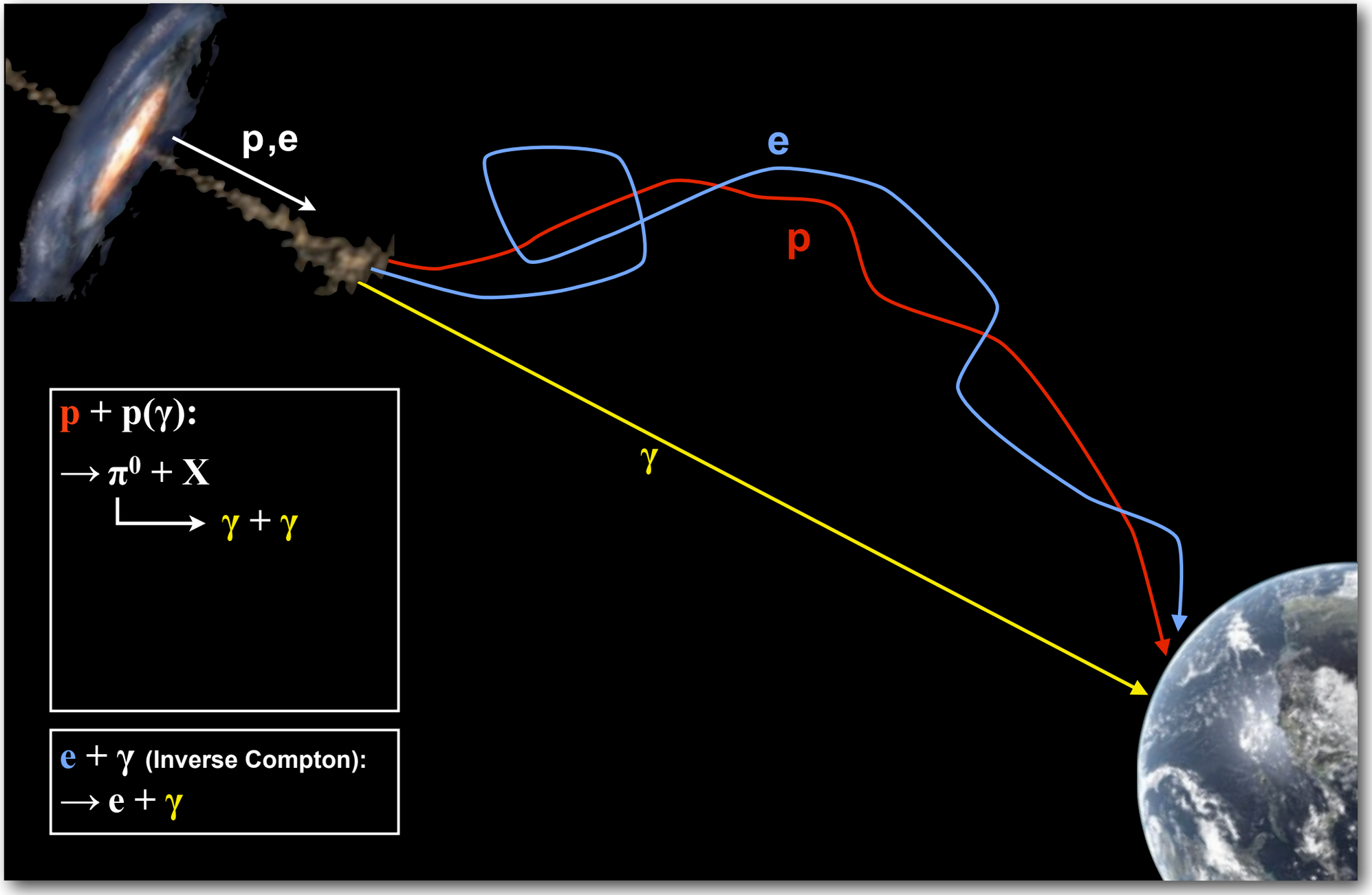

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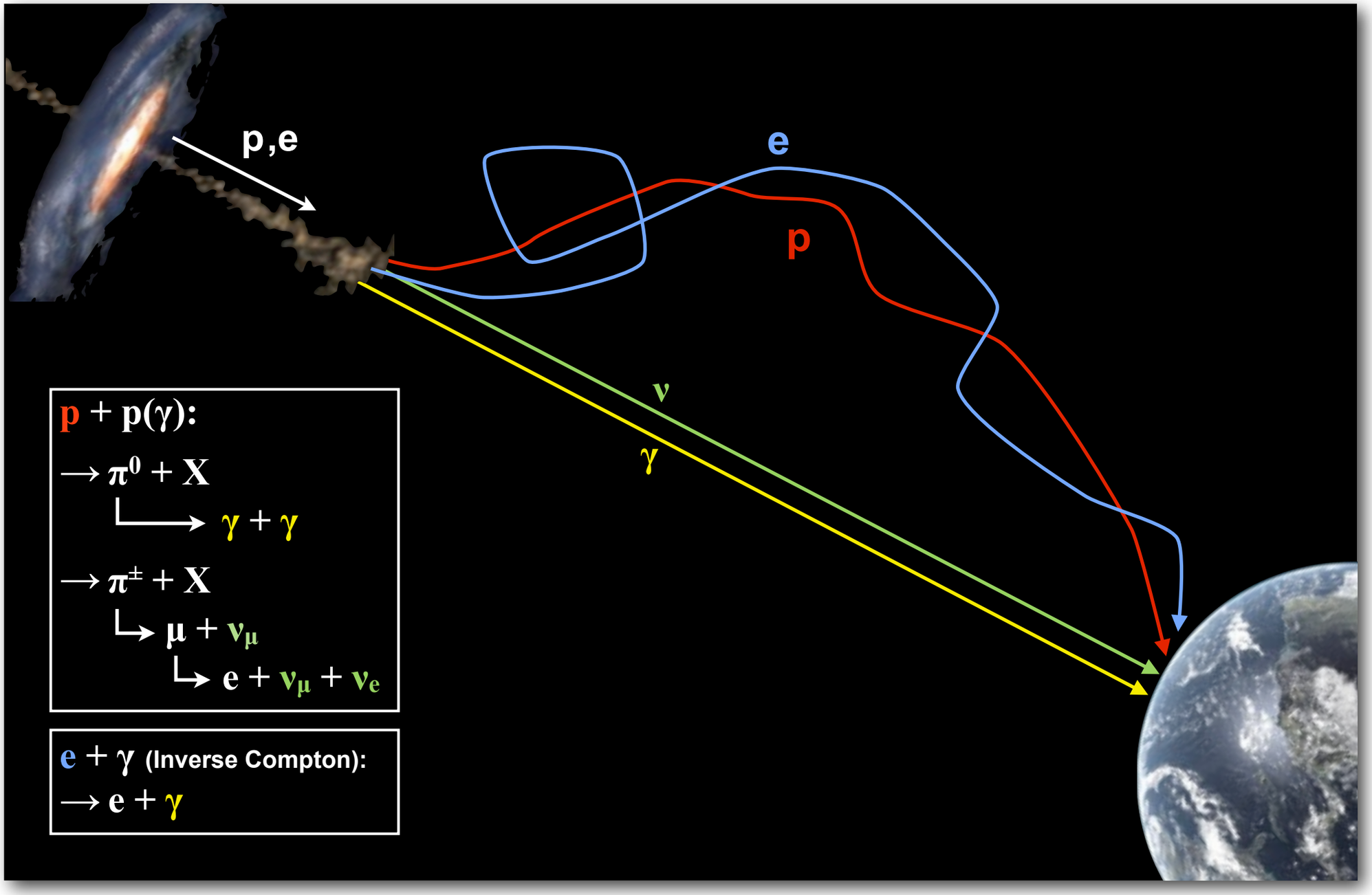


The big questions are:

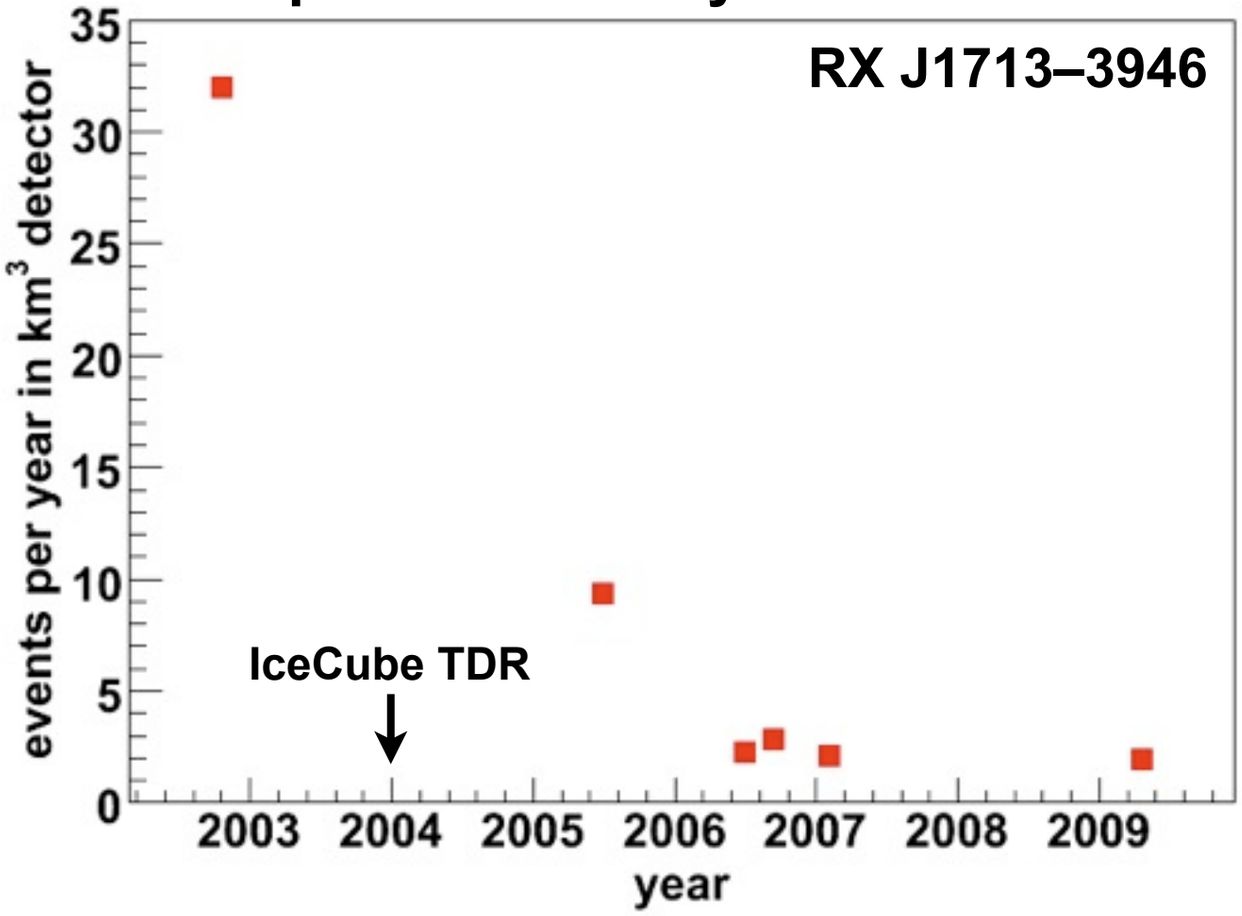
- what and where are the cosmic particle accelerators?
- what is the composition of the cosmic rays?
- what is the nature of dark matter?

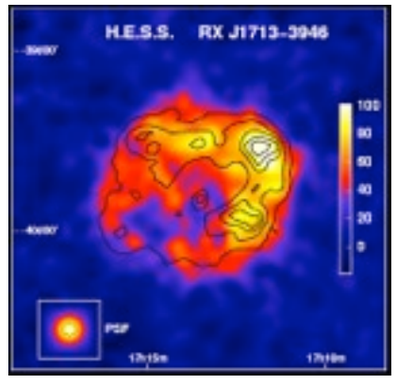
Answering them requires:

- information from all messengers
  (photons, neutrinos, cosmic rays)
- models of sources and fluxes
  (acceleration, environment, propagation)

Neutrino flux predictions

Example for a history:





Alvarez-Muniz & Halzen (2002)
Costantini & Vissani (2005)
Distefano (2006)
Kistler & Beacom (2006)
AK et al. (2007)
Morlino et al. (2009)

- Early predictions in some cases too optimistic
  (wrong γ-ray measurements, no ν oscillation, no high-energy cut-offs)
- All current observations and source models (Galactic & extragalactic) point to the need of (multi) km^3-class detectors

Principle of neutrino detection

Turn a large volume of ice/water into a particle detector

Time & position of hits

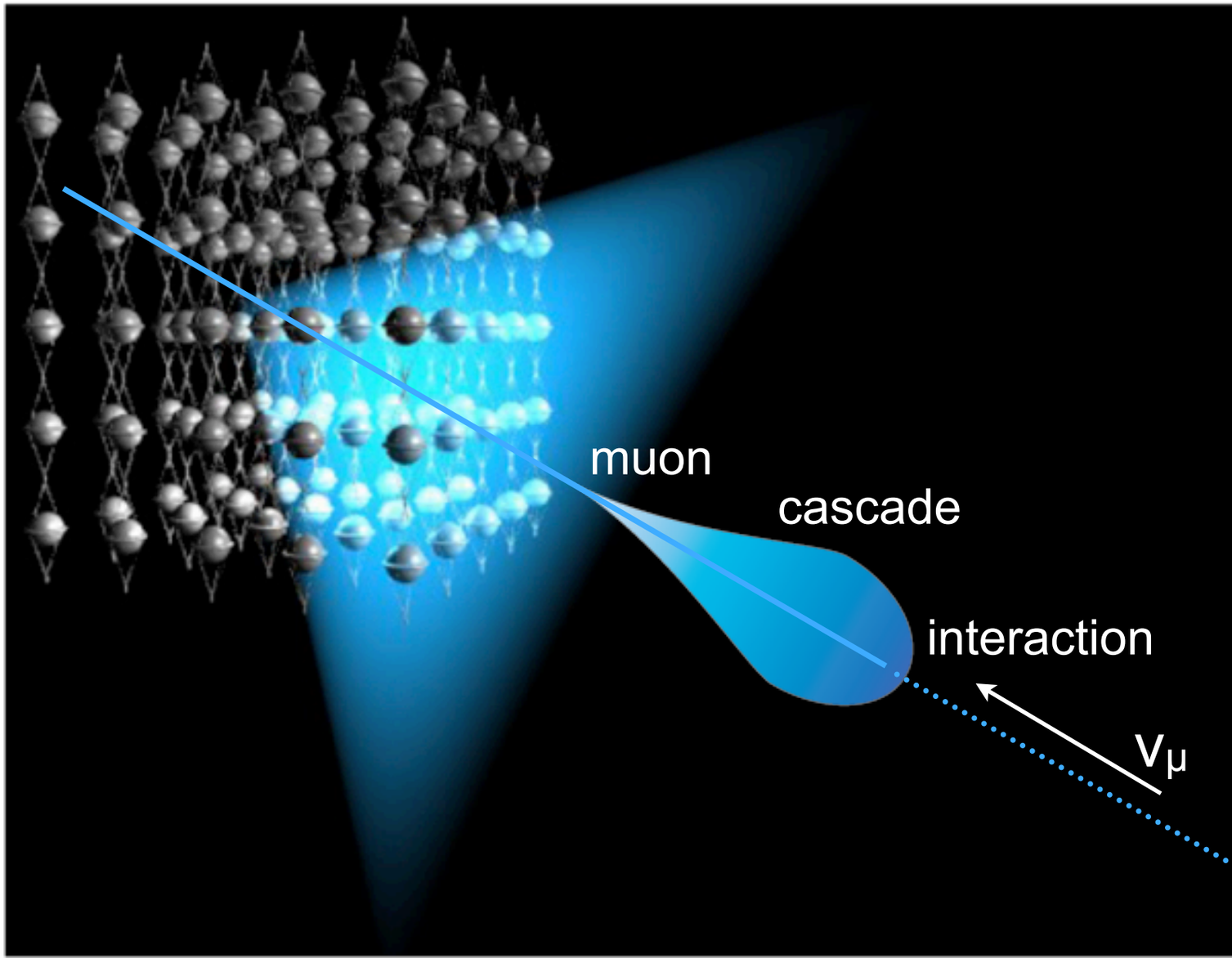
⬇

μ (~ ν) trajectory

Light intensity

⬇

Energy



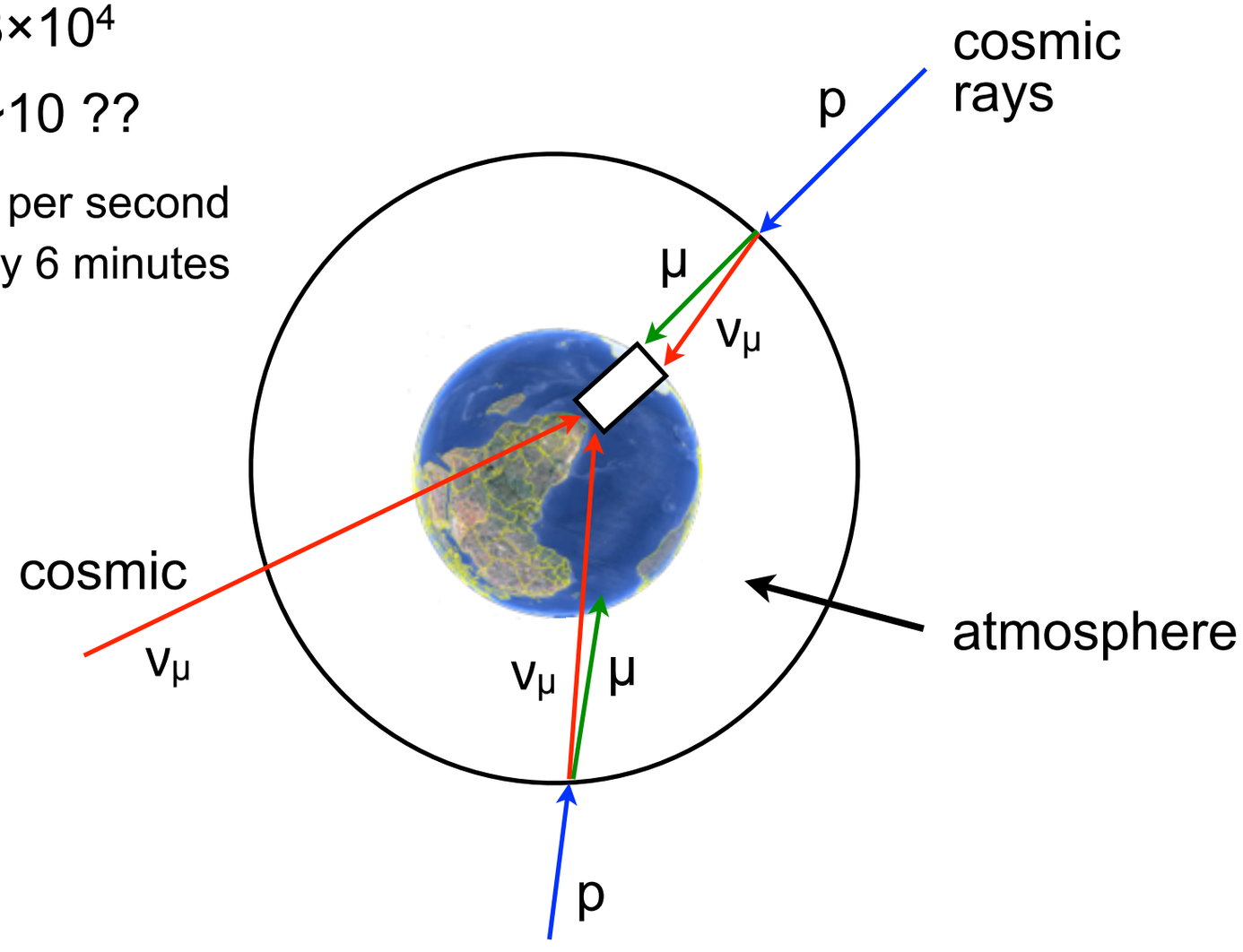
Backgrounds

Muons detected per year (IceCube)

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

* 2000 per second

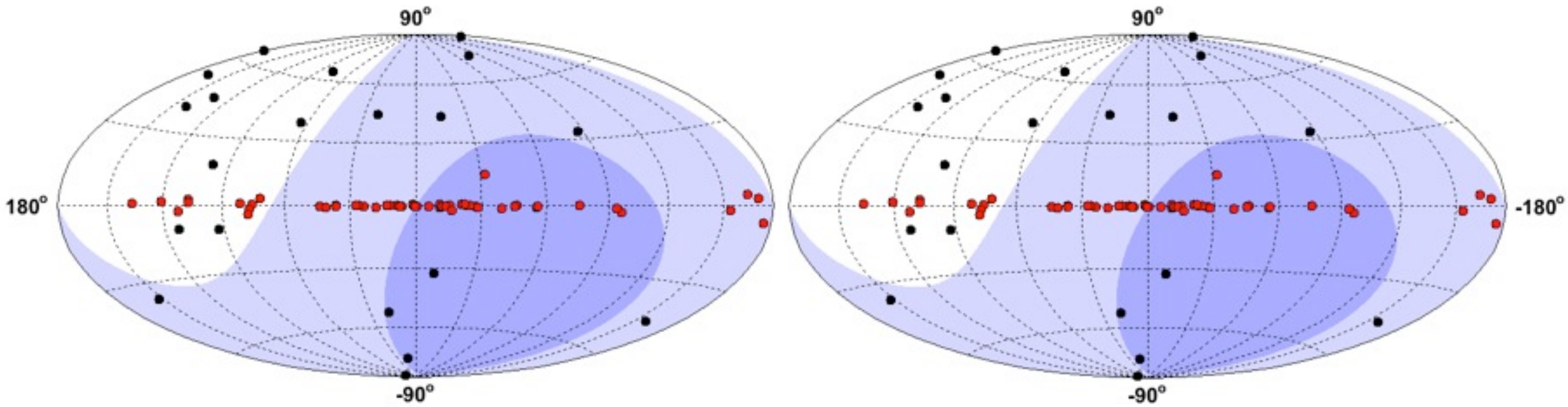
** 1 every 6 minutes



Sky coverage

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

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



TeV gamma-ray sources
- Galactic
- extragalactic

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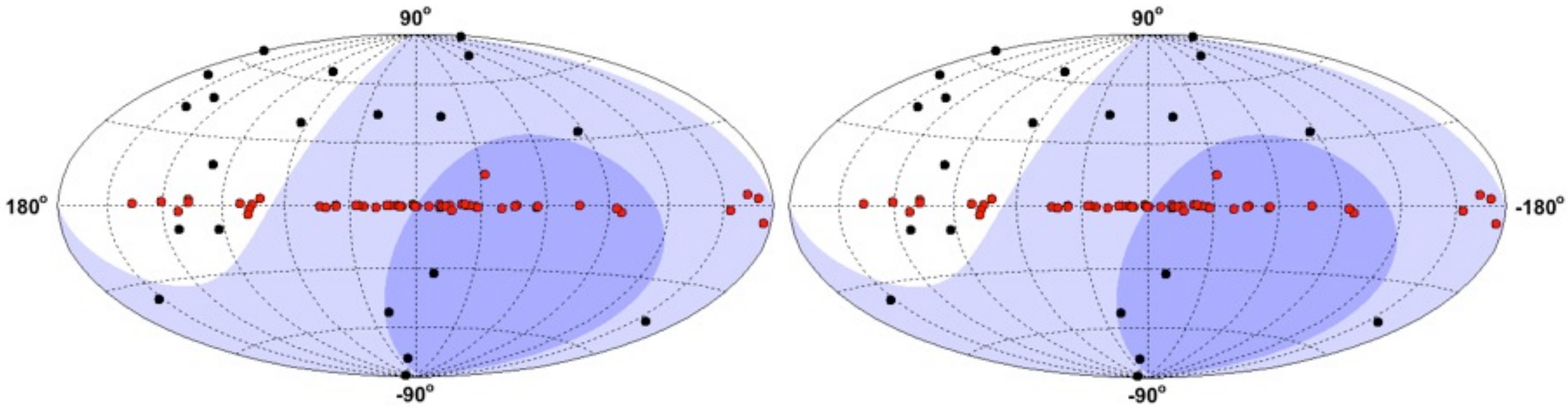

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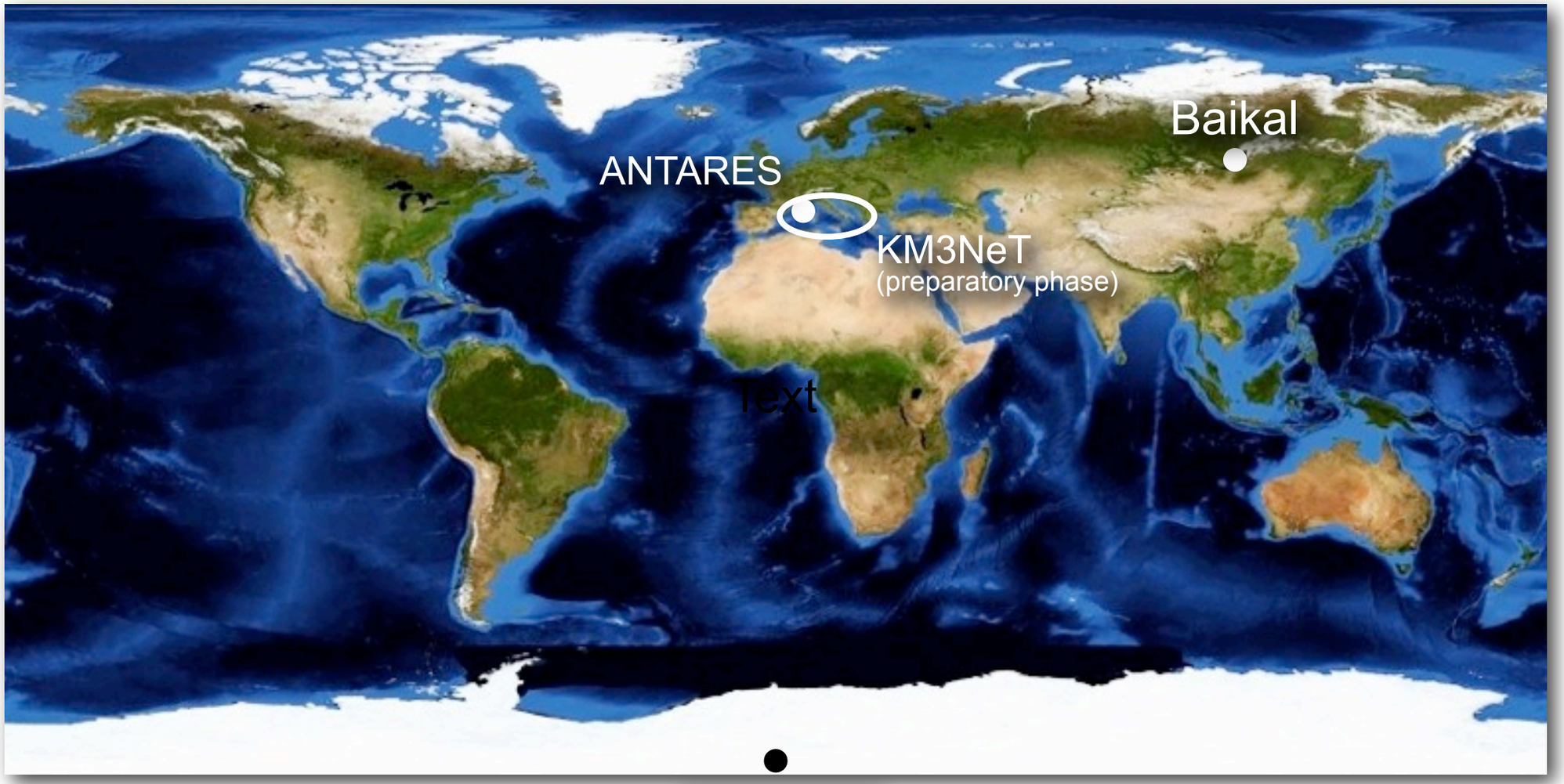
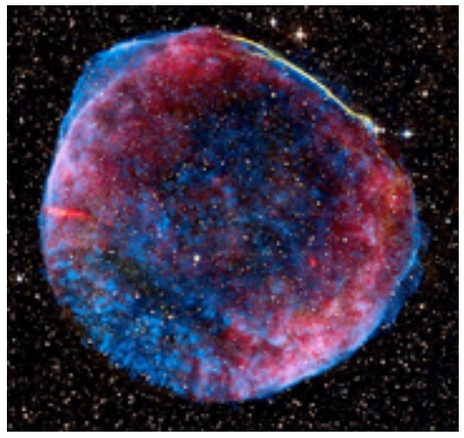
Neutrino Telescope Projects

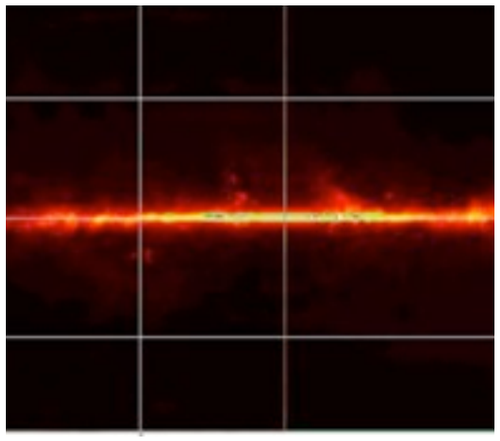


Physics with neutrino telescopes

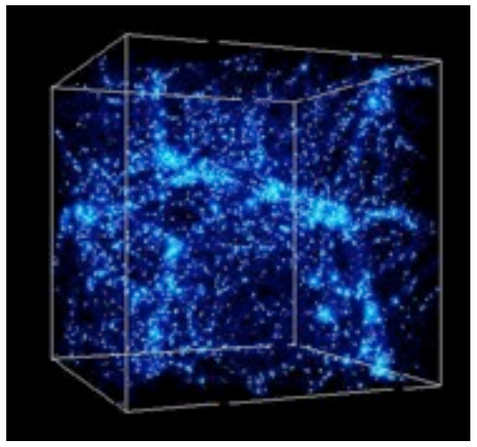
Cosmic accelerators



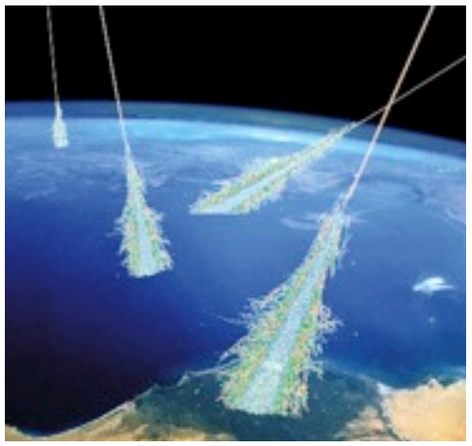
Diffuse fluxes



Dark Matter & Exotic Physics

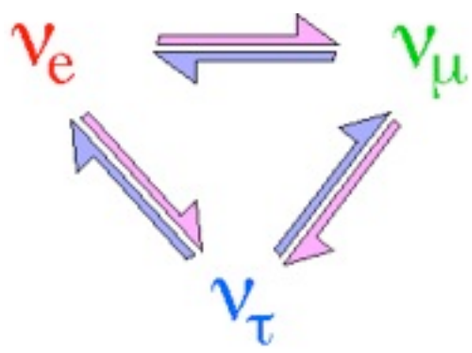


Cosmic rays



Supernova explosions

Neutrino Properties & Particle Physics



Physics with neutrino telescopes

Cosmic accelerators

- ☆ Point-like sources (SNRs, binaries ...)
- ☆ Extended sources (SNRs, molecular clouds ...)
- ☆ Transients (GRBs, AGN flares ...)

Diffuse fluxes

- ☆ All-sky fluxes (e.g. cosmogenic)
- ☆ Galactic plane
- ☆ Extended structures

Dark Matter & Exotic Physics

- ☆ Indirect DM search (Sun, Galactic halo)
- ☆ Magnetic monopoles, Q-balls, . . .
- ☆ Lorentz invariance violation

Cosmic rays

- ☆ Anisotropy
- ☆ High-energy shower cores

Supernova explosions

- ☆ Galactic/LMC SNe
- ☆ Phases
- ☆ Neutrino hierarchy

Neutrino Properties & Particle Physics

- ☆ Neutrino oscillations
- ☆ Heavy flavors in showers
- ☆ K/π ratio in showers
- ☆ Cross sections at very high energies

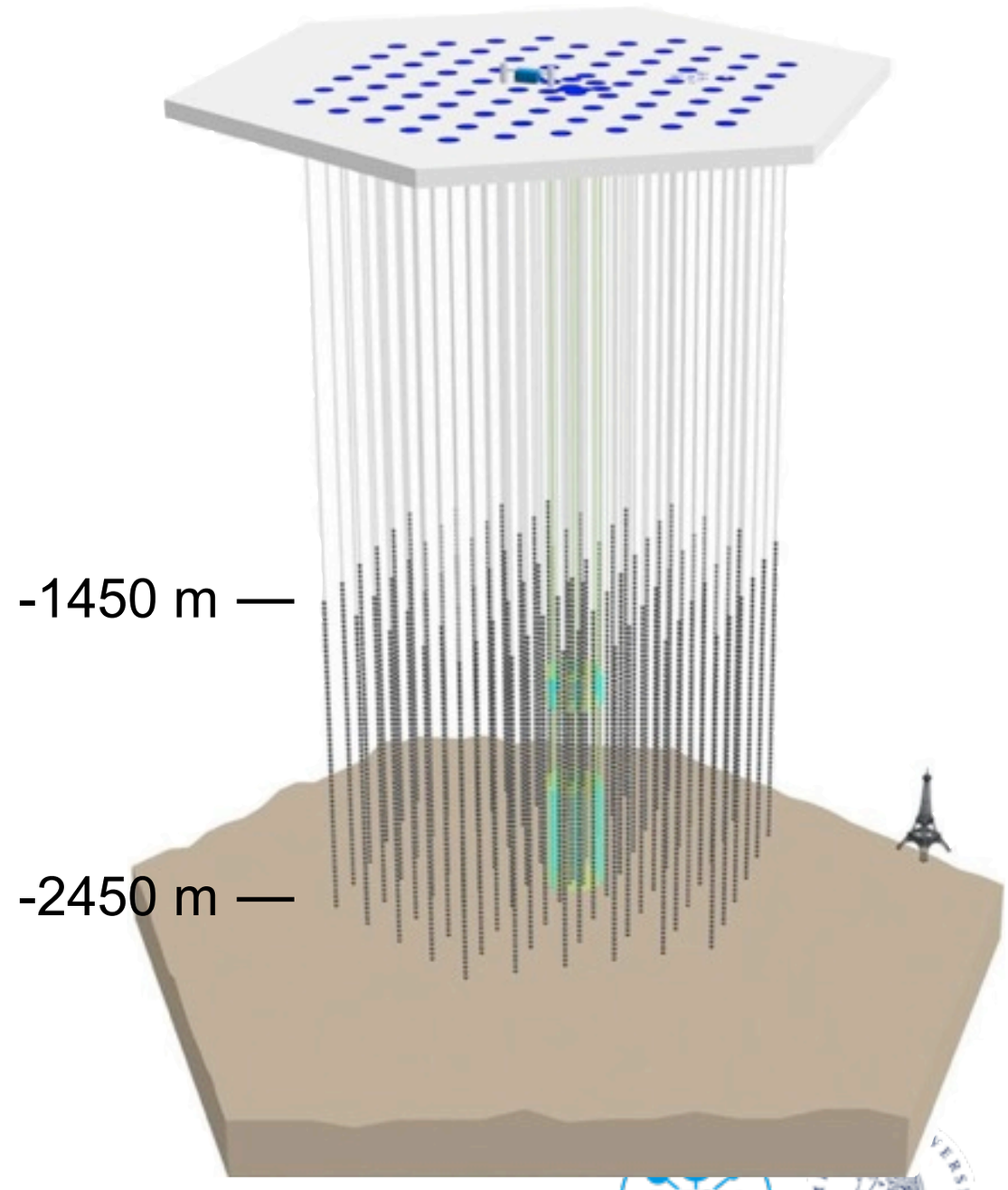
The IceCube observatory

Completed since Dec. 2010

- **IceTop**
  Air shower detector

- **IceCube**
  86 strings (5160 PMTs)
  Instrumented volume: 1 km^3

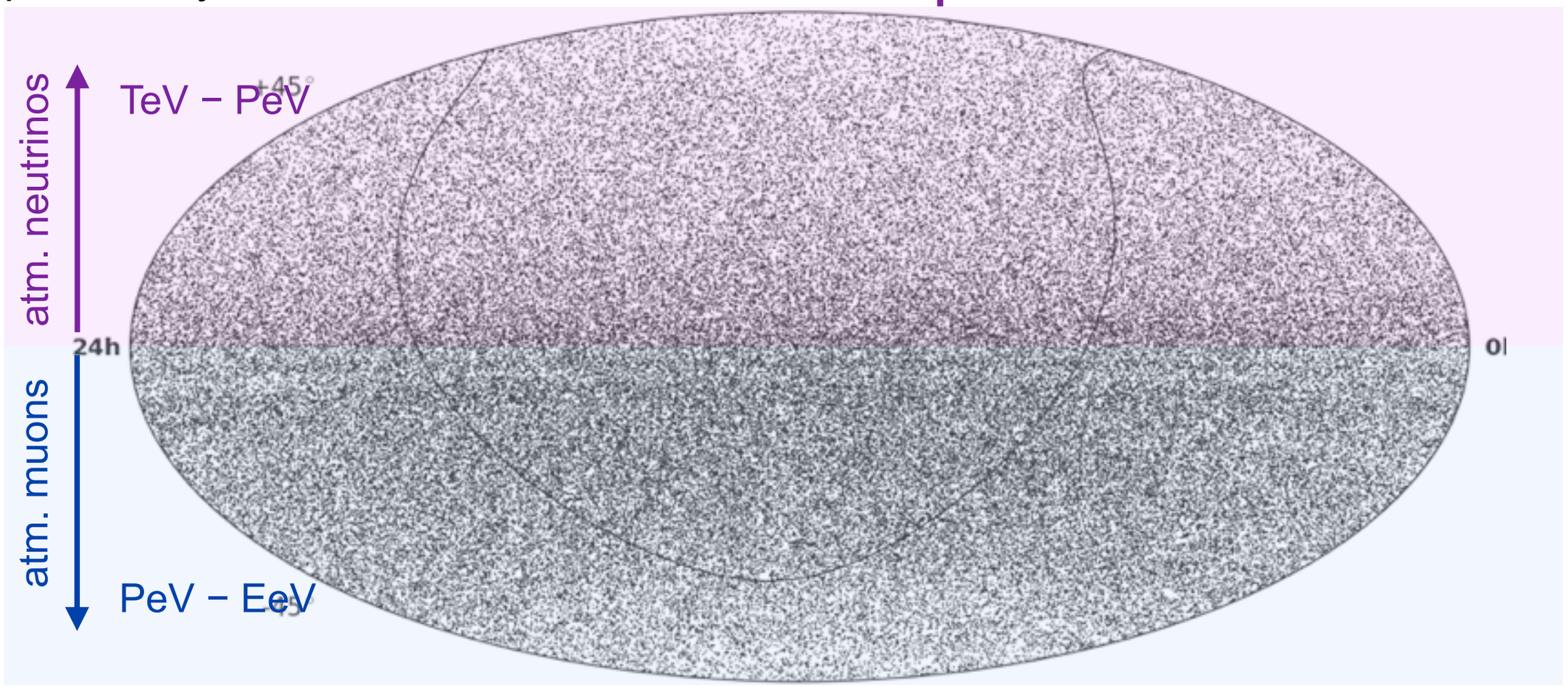
- **Deep Core**
  densely instrumented
  central region (8 strings)



Run 113641 Event 33553254 [6000ns, 9952ns]

Skymap IceCube (IC40+59)

preliminary



- **107,569 events** (30% upgoing, livetime 723 d)

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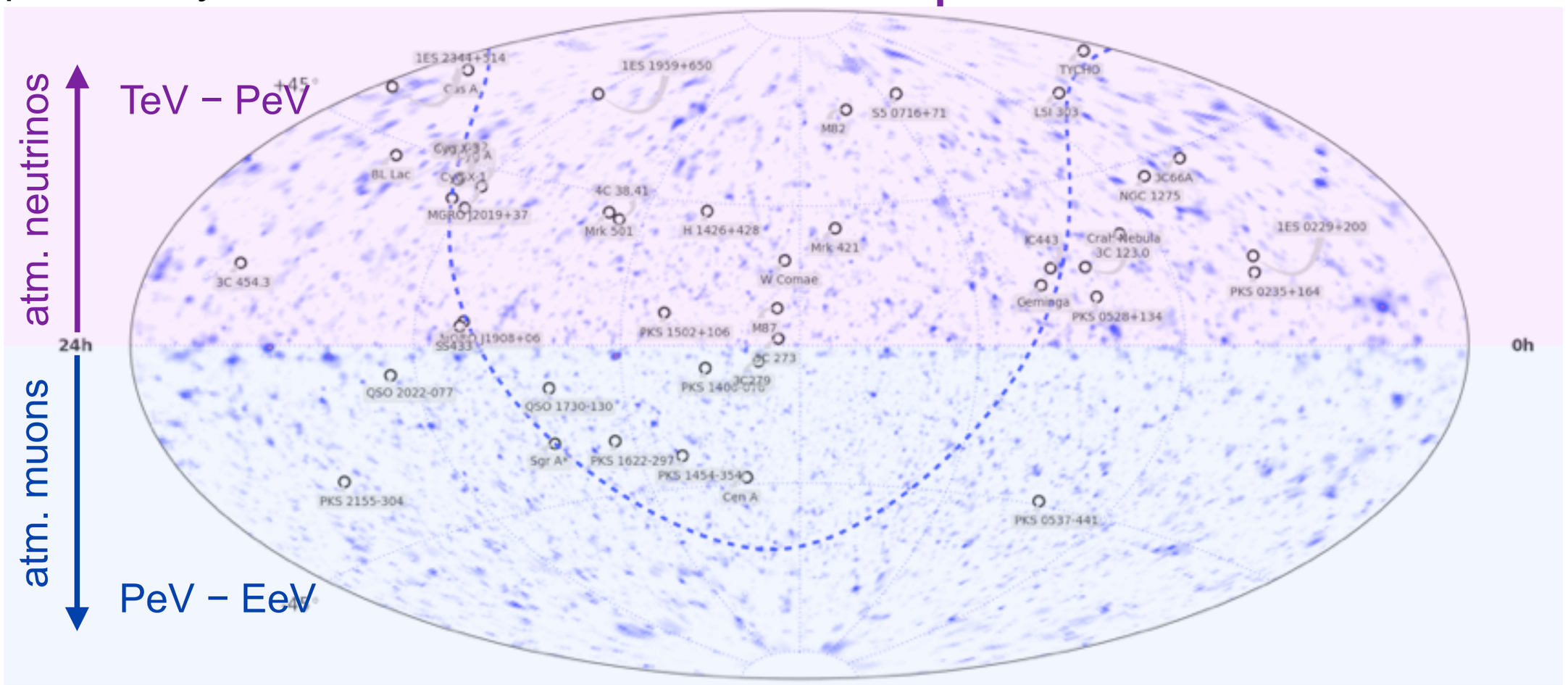

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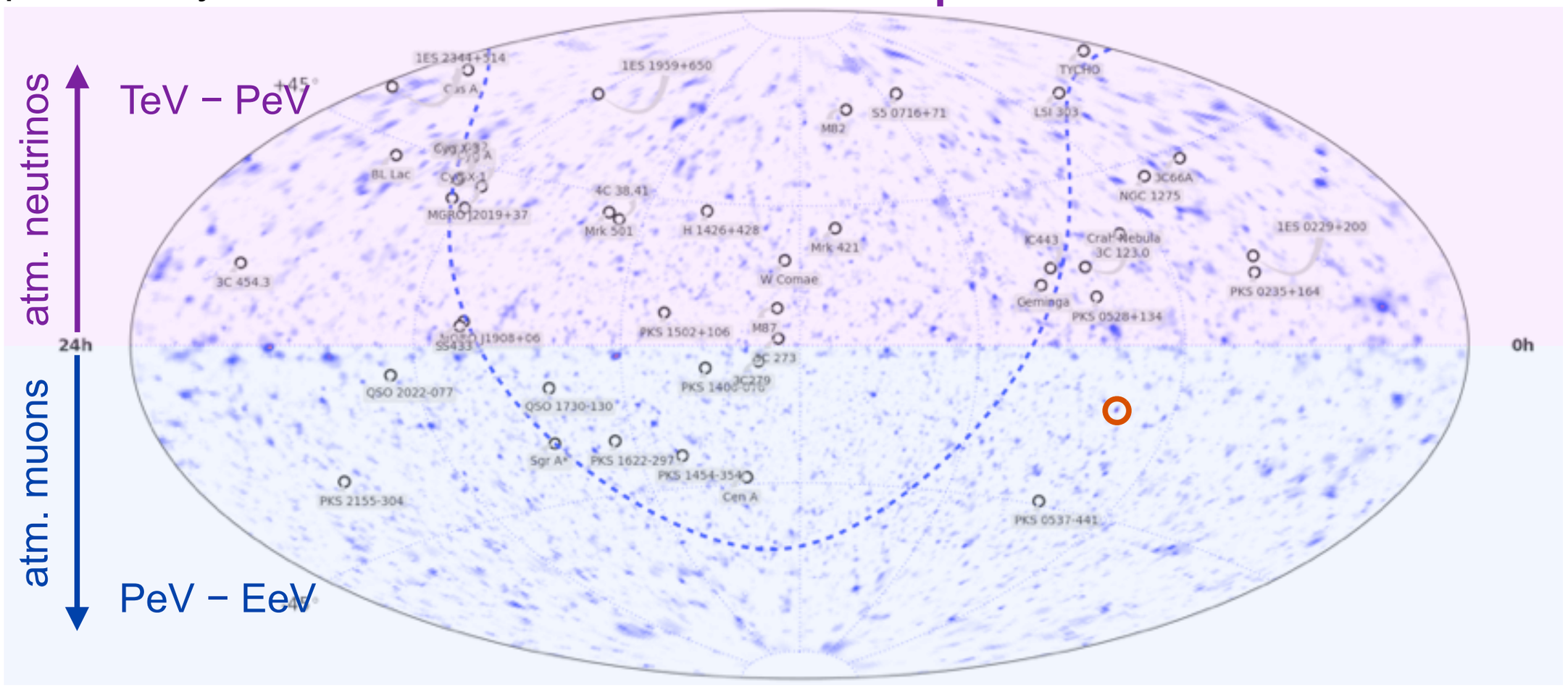

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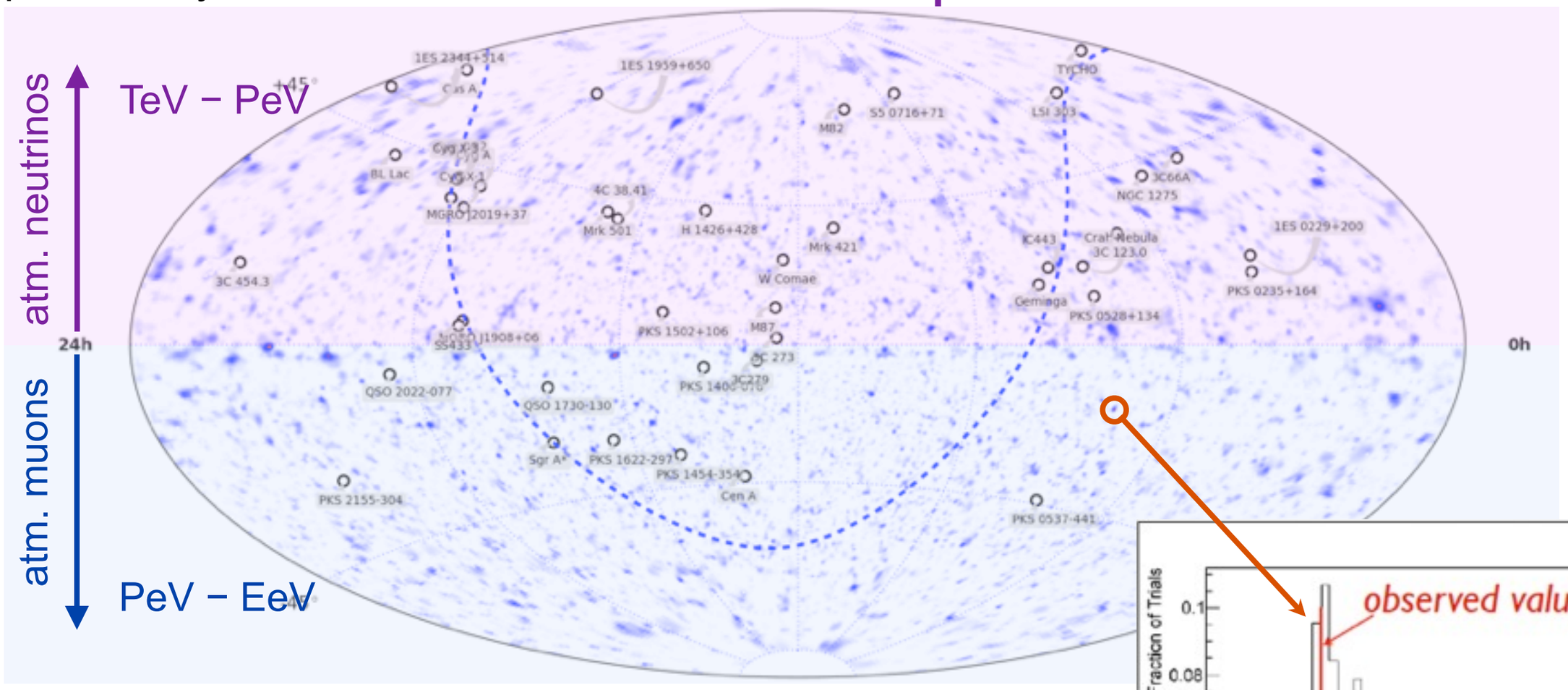
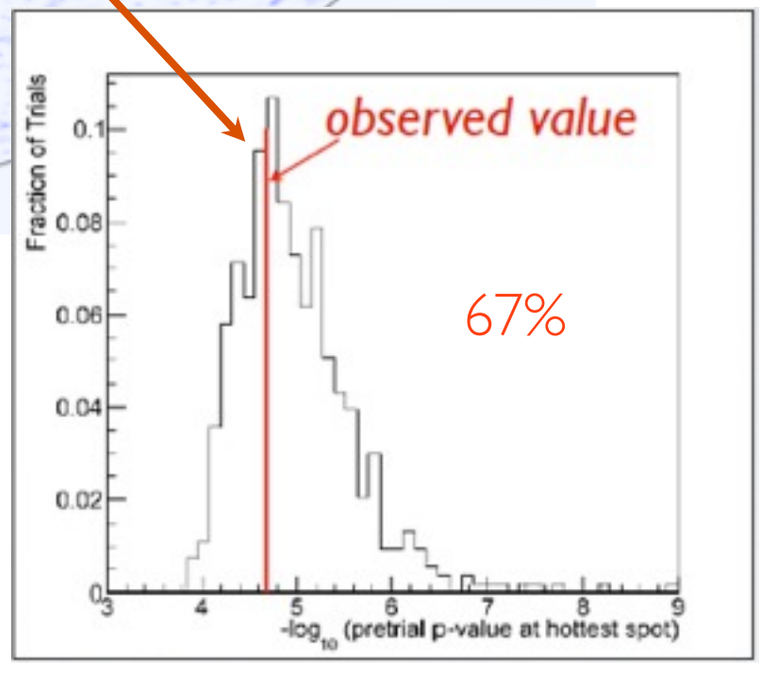
Northern hemisphere

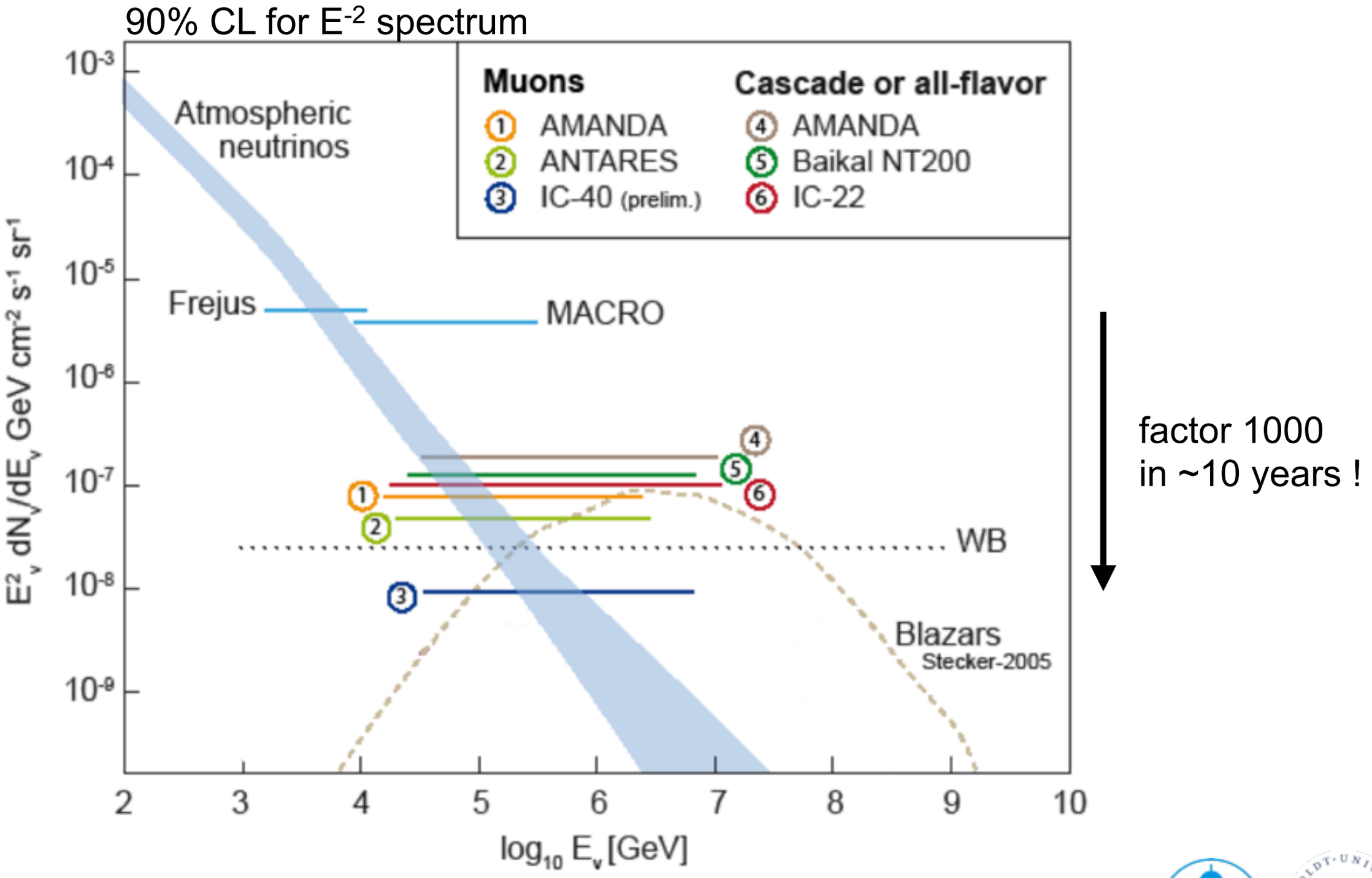


Southern hemisphere



- **107,569 events** (30% upgoing, livetime 723 d)
- **Source list:** 13 Galactic, 20 extragalactic
- **No significant excess**

Upper limits on diffuse neutrino fluxes



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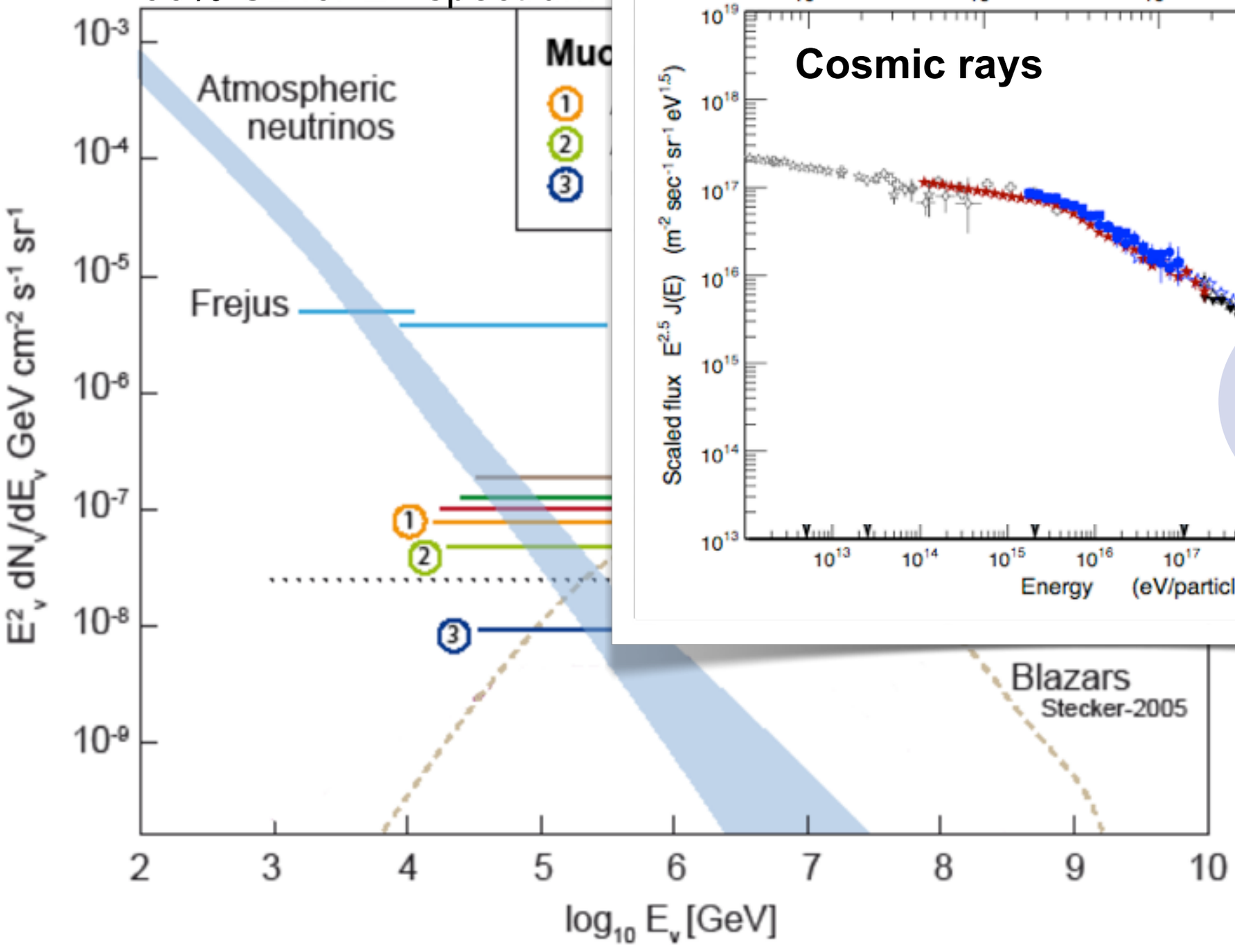
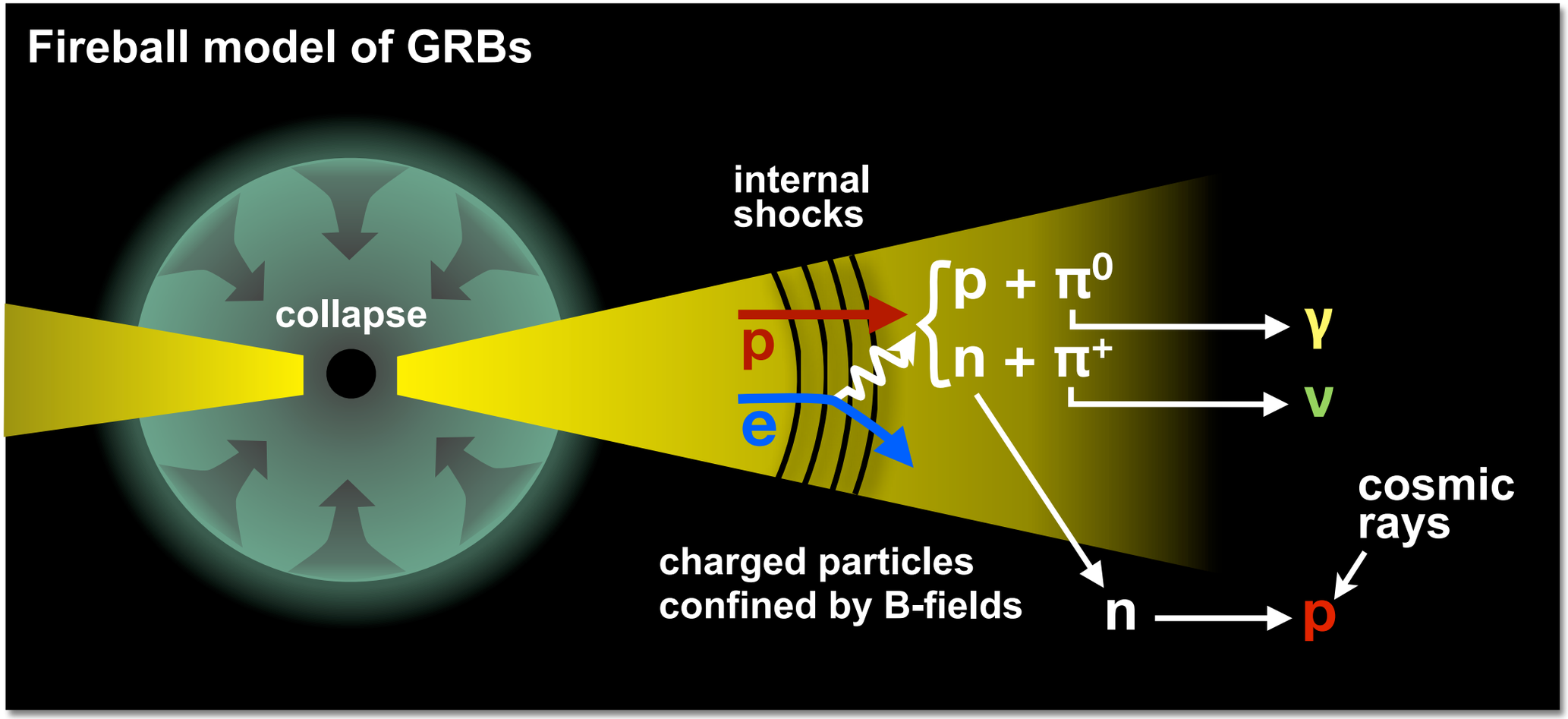


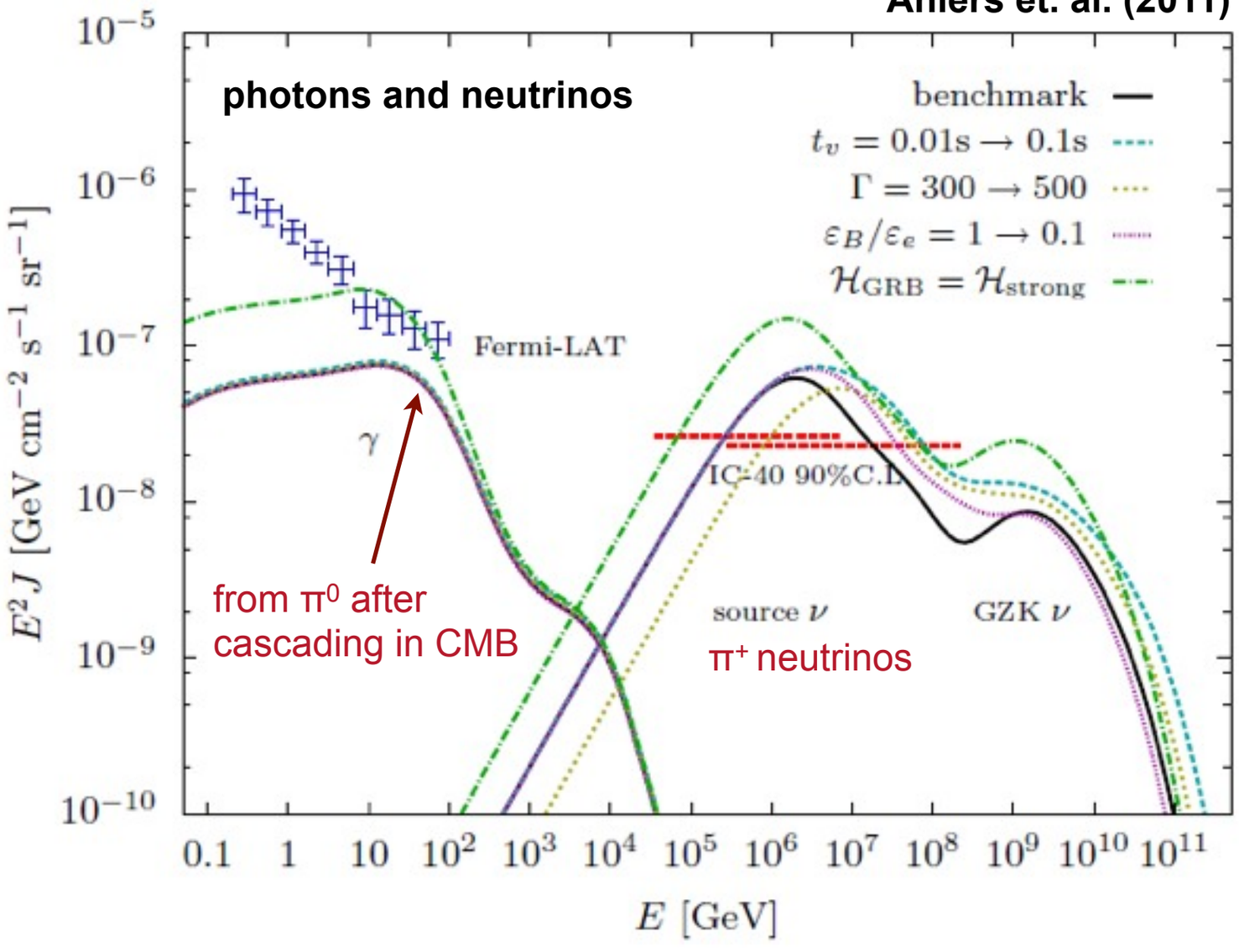
Fireball model of GRBs



Fireball model of GRBs

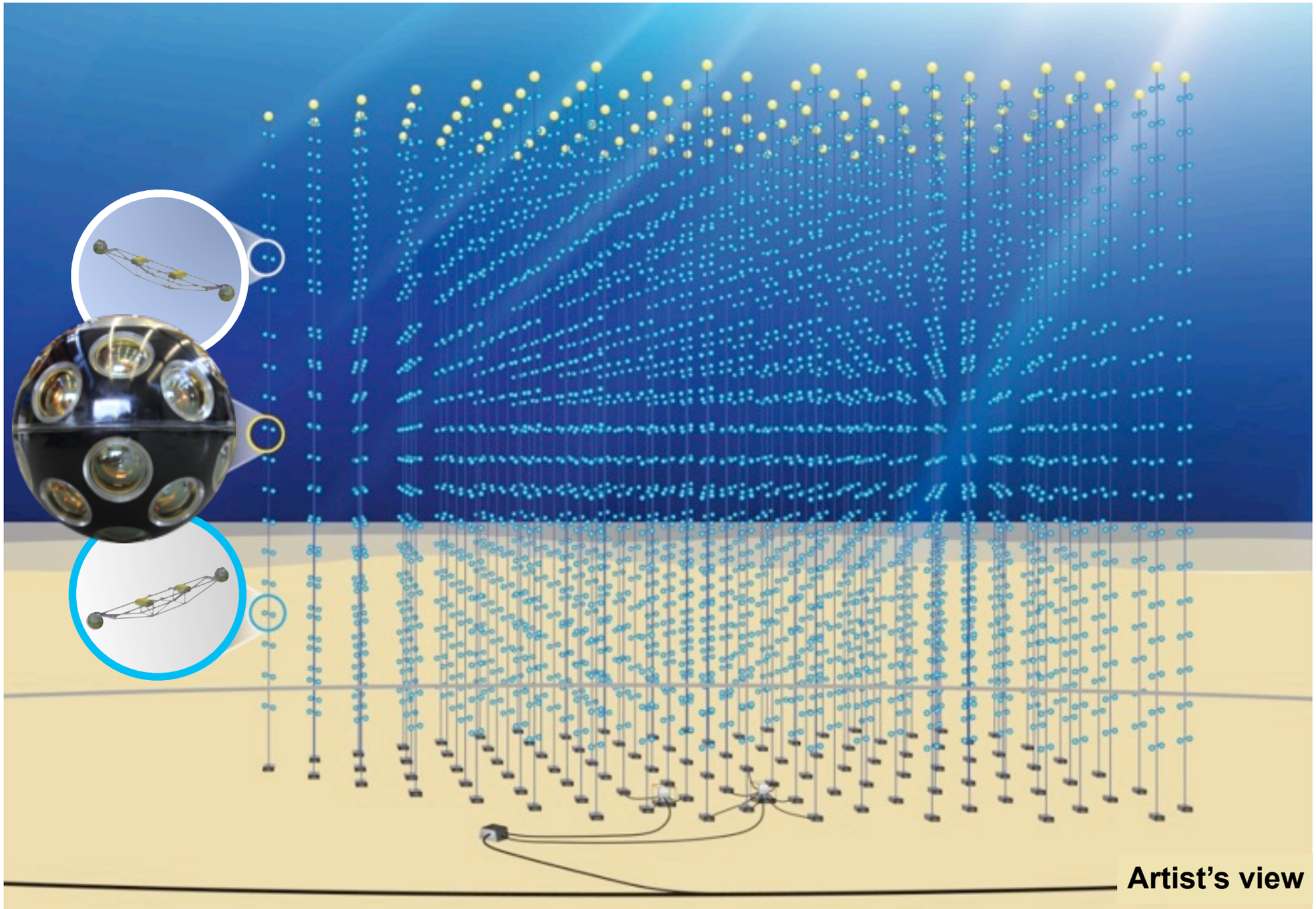
- Protons from *n*-decay fitted to cosmic-ray spectrum
- Photons from π^0-decay cascade down in CMB

Ahlers et. al. (2011)



IceCube starts to challenge GRBs as major sources of UHECR cosmic rays

KM3NeT: A multi km^3-scale ν telescope in the Mediterranien Sea



Artist's view

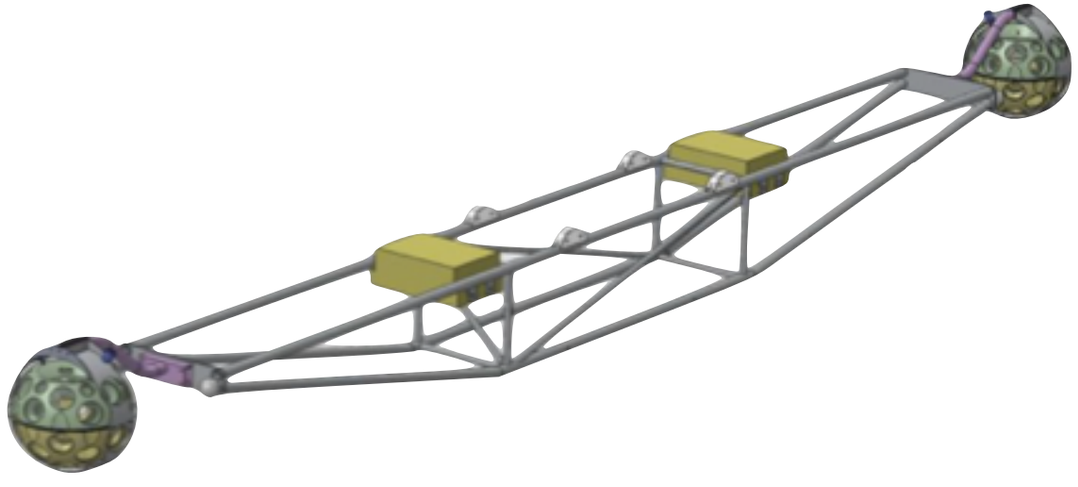
Design aspects

- Investigation of technical solutions during Design Study (2006−2009)
  - optical sensors
  - vertical structure
  - seafloor layout
  - data network
  - electrical network
  - deployment
- Agreement on a single design in 2010
  (backup solutions for critical components)
- Multi-site installation possible
  (no significant performance decrease)
- Seafloor layout still subject to optimization
- Possibly first data in 2014

Design aspects: Optical sensors

Multi-PMT DOM

- 31 small PMTs
  (~3 times that of a 10” PMT)
- Almost uniform coverage
- Photon counting
- Minimize # pressure transitions
- All electronics inside
- All identical units



Scientific focus

- **Geographical location**
  → field of view includes inner Galactic plane & center

- **Optical properties of sea water**
  → excellent angular resolution

- **Envisaged budget of 220−250 MEuro**
  (up to now: France 20M, Italy 22M, NL 8M, Romania 2M, Greece(?) 50M)
  → large effective neutrino area

⇩

Observation of Galactic sources
(SNRs, microquasars, binary systems ...)

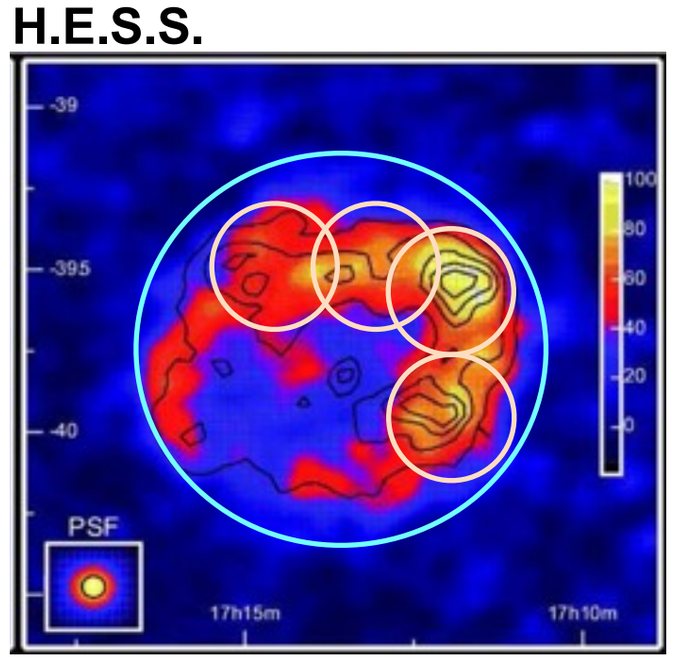
Performance: Case study RXJ1713

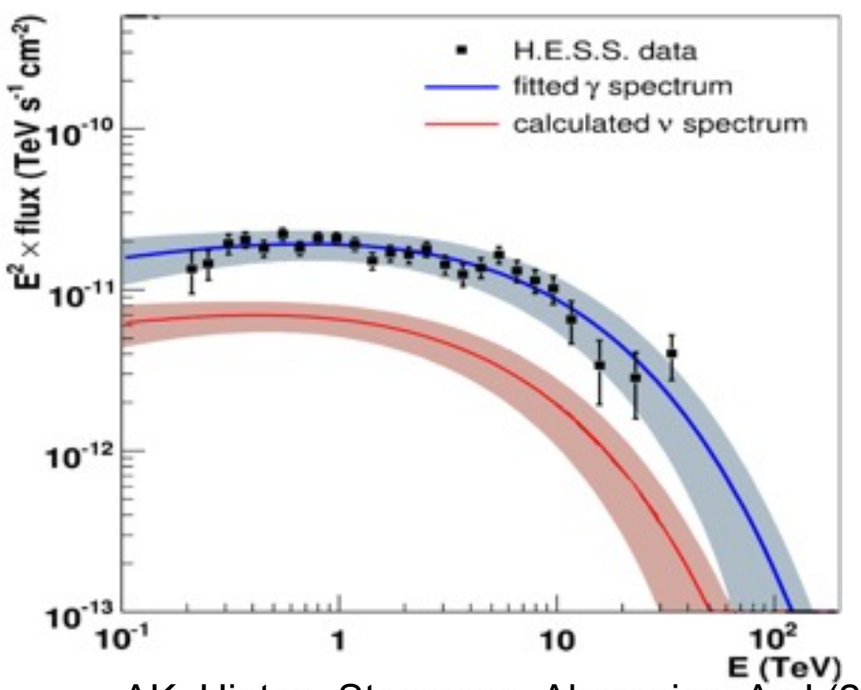
- Strongest Galactic γ-ray source
- Hadron or electron origin?
- Sensitivity (308 towers):

dist.	sign.	years	signal	bkg
180m	5σ	12.1	41	51
130m	5σ	8.0	22	13
130m	3σ	2.9	7.9	4.8

Potential for improvements
(trigger, reconstruction, unbinned analysis, energy estimator, source morphology)

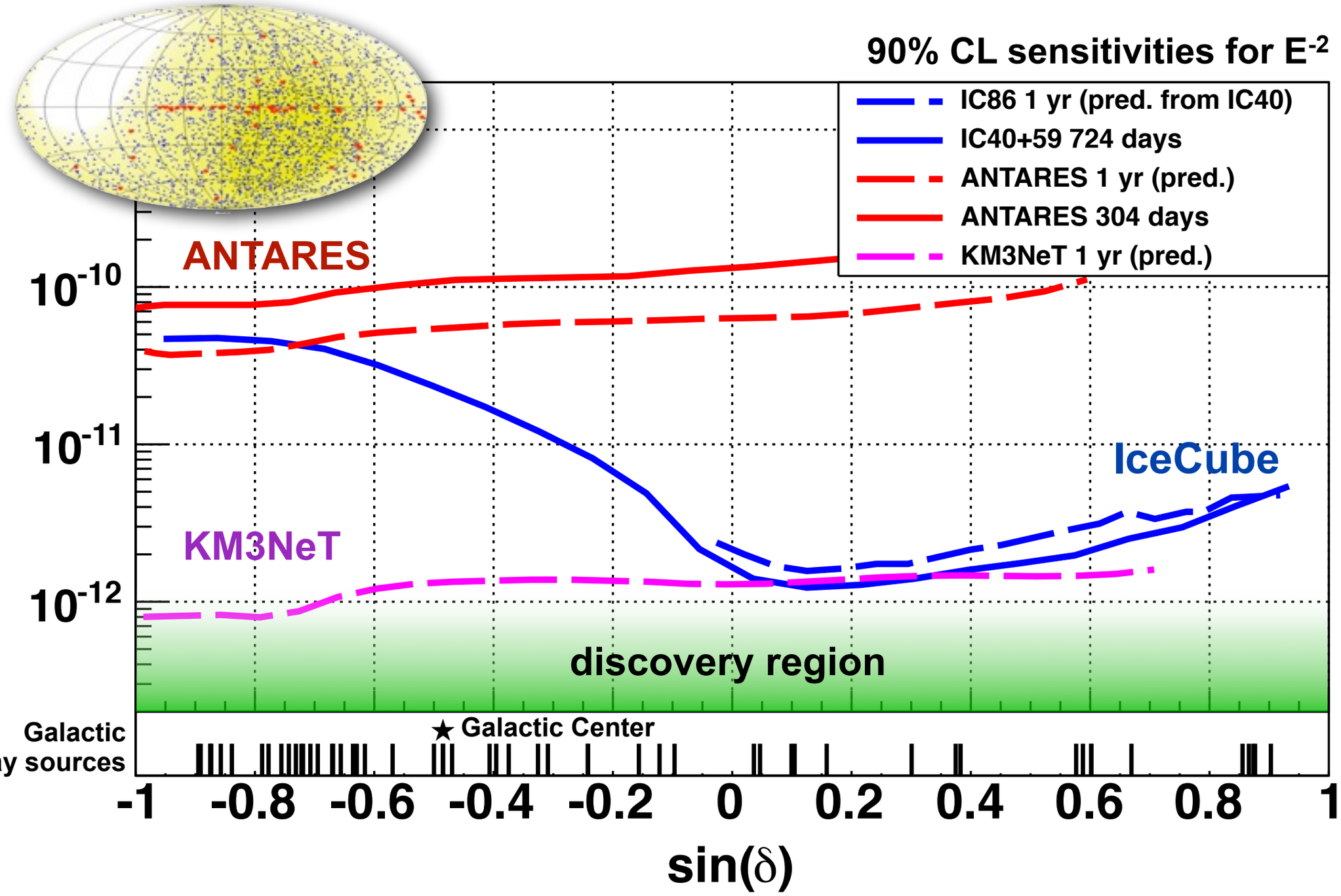
→ 5σ in 5 years appears to be feasible





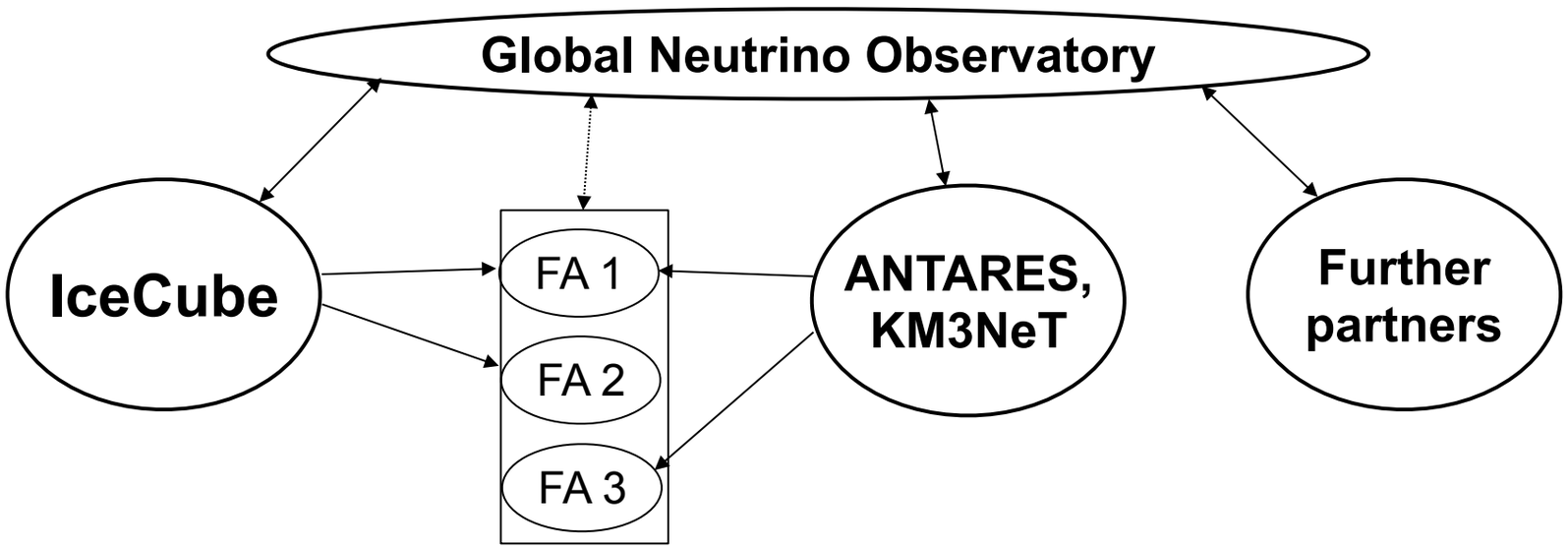
AK, Hinton, Stegmann, Aharonian, ApJ (2006)

Sensitivities to point-like sources



Towards a Global Neutrino Observatory

- **Critical situation for neutrino astronomy (no signal, large funds required)**
  → need to coordinate and strengthen our efforts
- **Recommendation in ASPERA roadmap:**
  "The IceCube and KM3NeT collaborations are encouraged to strengthen cooperation, with the goal to form a future Global Neutrino Observatory."
- **How GNO could fit into the picture:**



U. Katz
MANTS 2011

- "Umbrella" over (all) parties of neutrino astronomy
- Partners autonomous, independent entities participating in GNO
- Forum for exchanges and consultations which can represent neutrino astronomy vs. science and science policy communities

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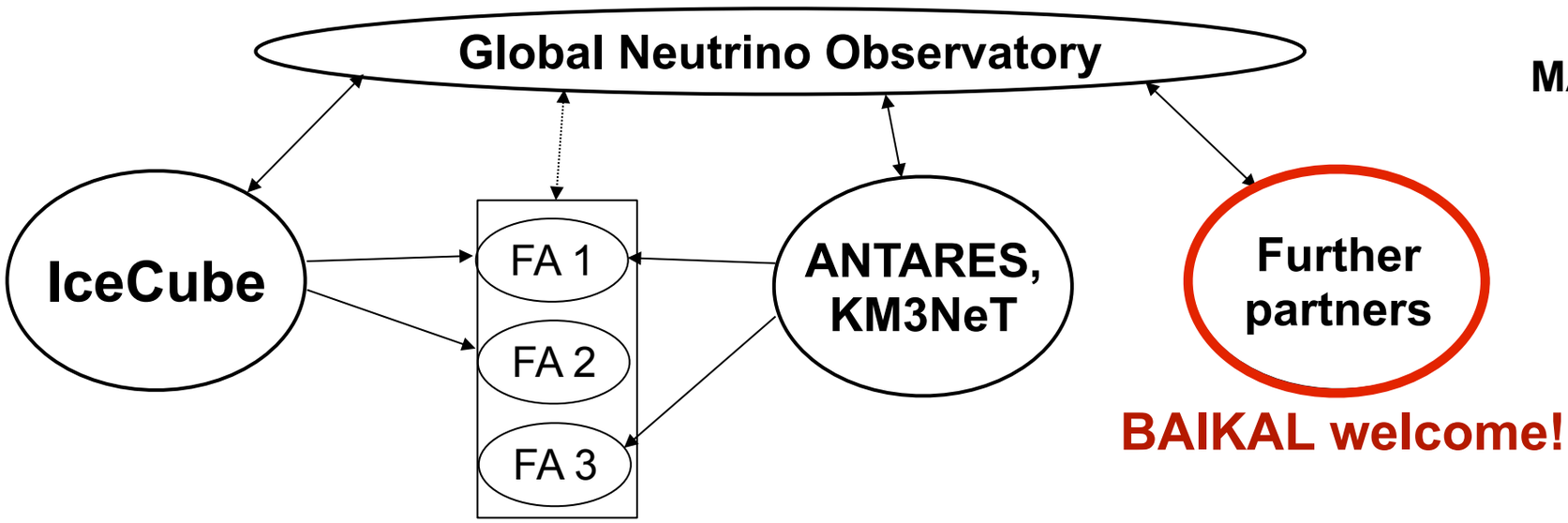

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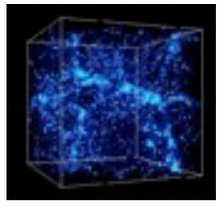
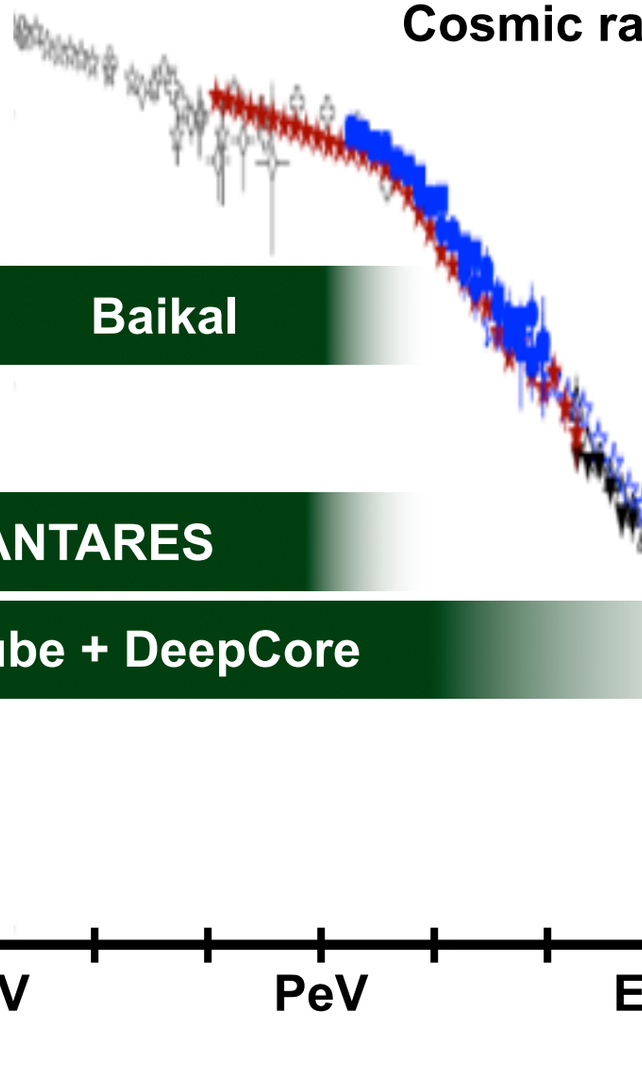
Going to lower and higher energies

Supernovae

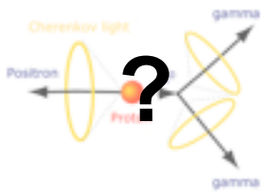
Dark Matter



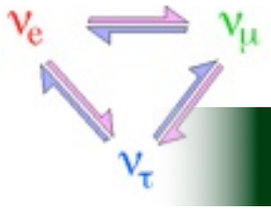
Cosmic rays



Proton decay



Neutrino oscillation



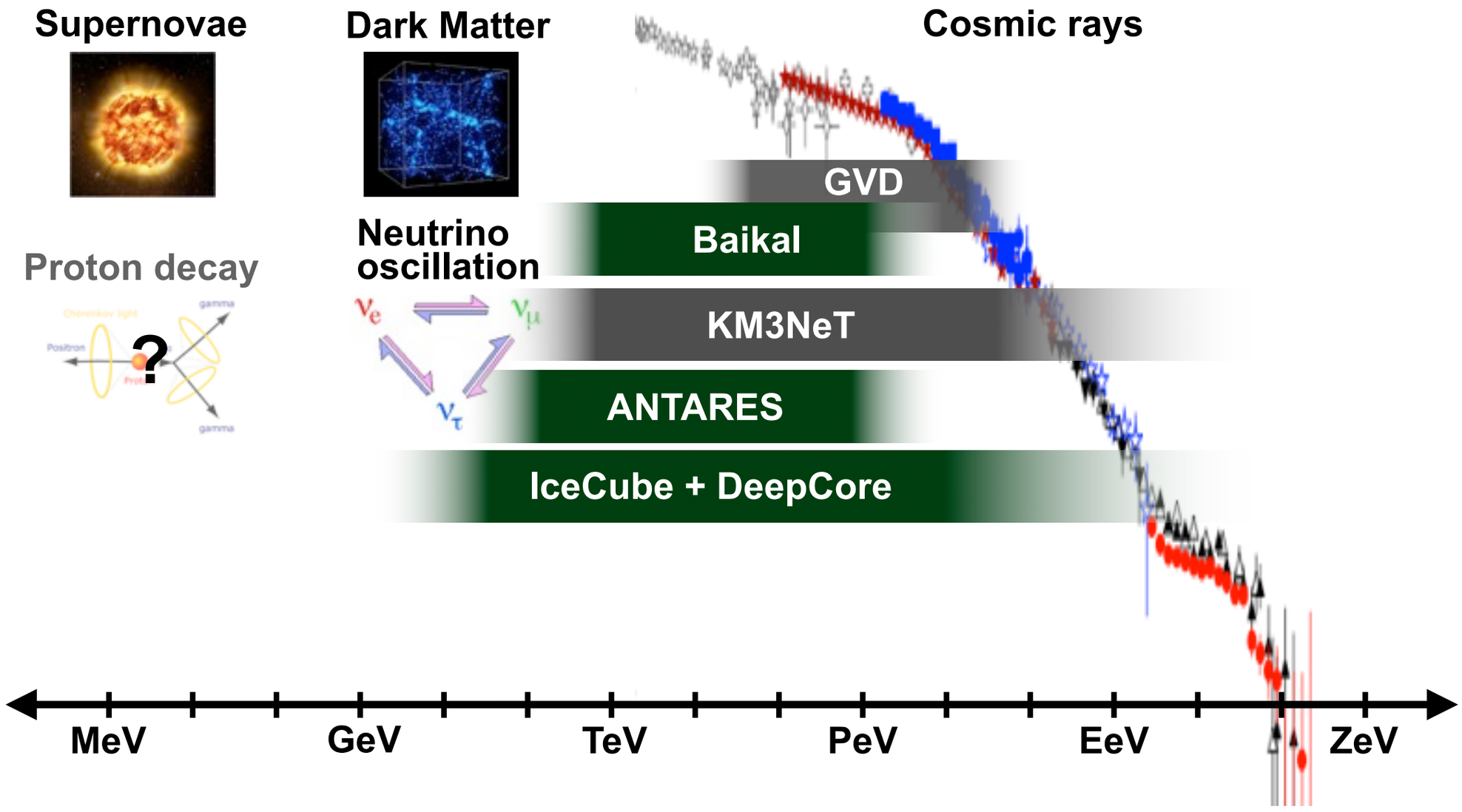
Baikal

ANTARES

IceCube + DeepCore

MeV **GeV** **TeV** **PeV** **EeV** **ZeV**

Going to lower and higher energies



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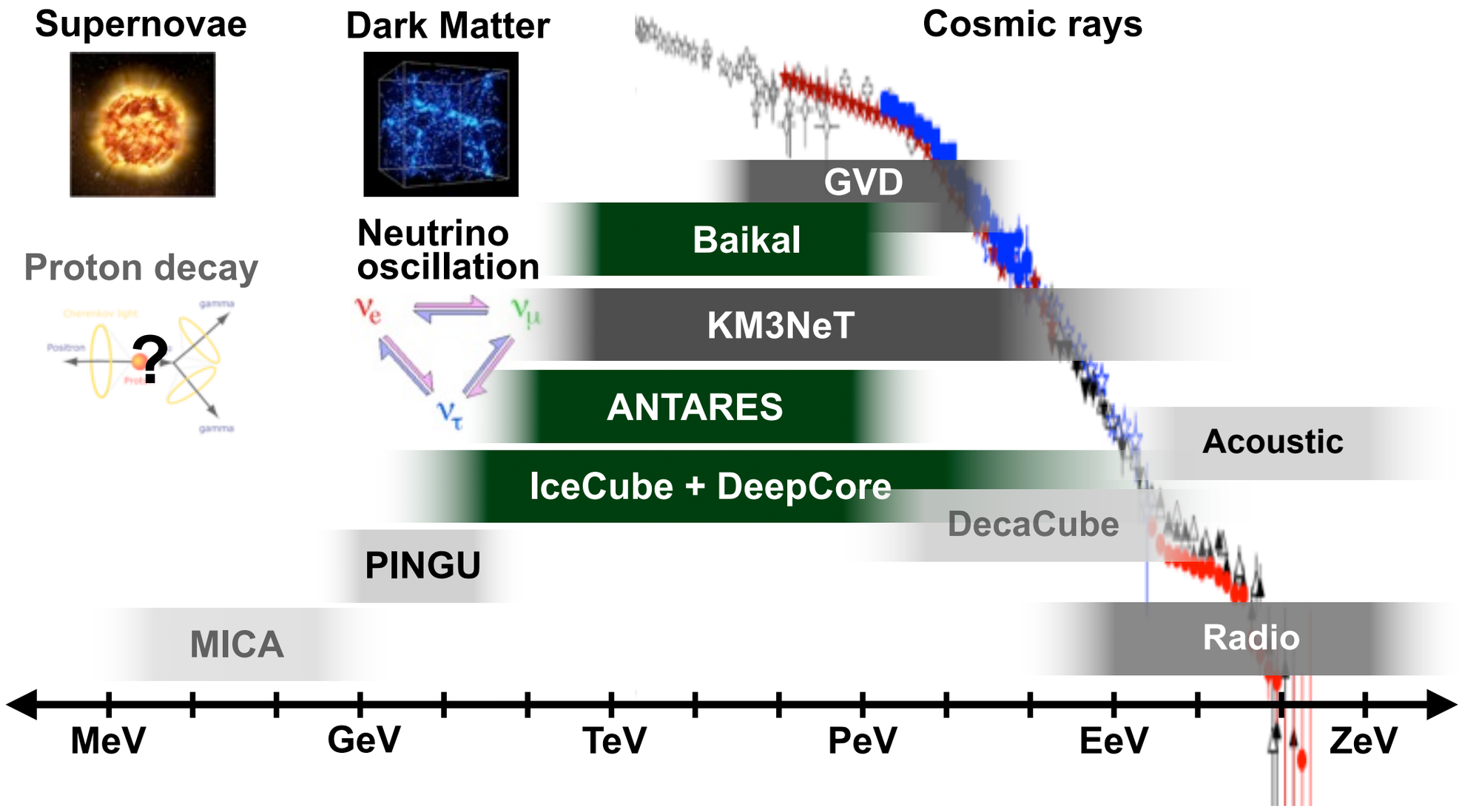

Conclusions

- Rich astro (and particle) physics program for neutrino telescopes
- Source models and measurements show that **(multi) km^3-scale** telescopes are needed to detect Galactic and extragalactic sources
- IceCube starts to reach into discovery region
  → fair chance for discoveries but by no means guaranteed
  → starts to close in on GRBs
- Need for a multi-km^3 scale detector in the Northern hemisphere
- Strengthen community and exploit synergies through a Global Neutrino Observatory initiative

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