High-energy neutrino searches from GRBs with IceCube

Mathieu Labare (for the IceCube Collaboration)

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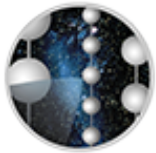
GDR Neutrino – APC, Paris

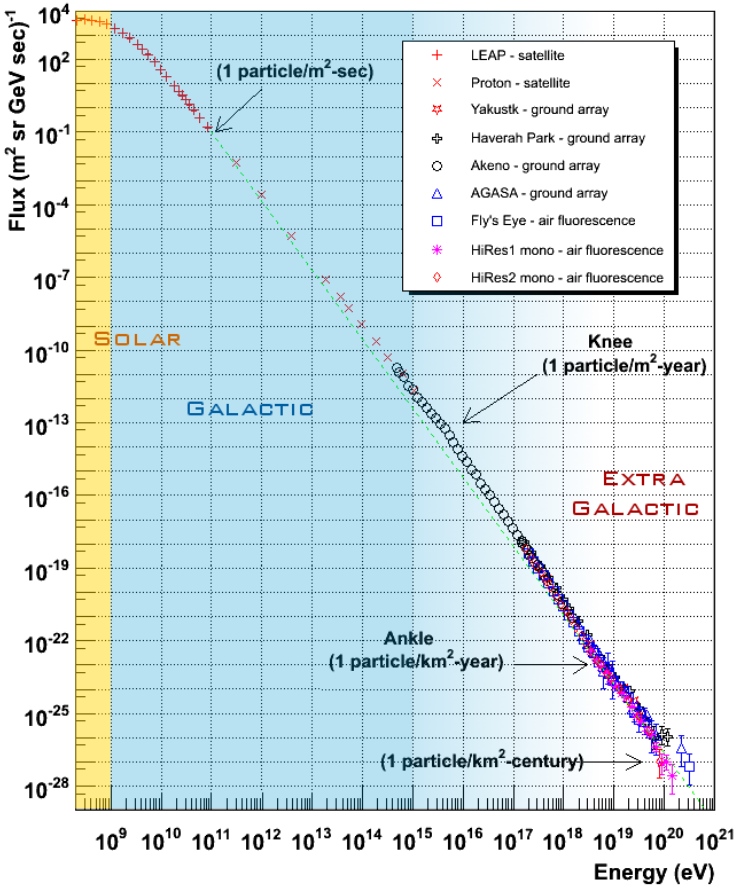
June 21, 2012



IceCube
SOUTH POLE NEUTRINO OBSERVATORY

High-energy neutrino searches from GRBs with IceCube

Cosmic Rays



- Below 1 GeV
  - Solar Energetic Particles

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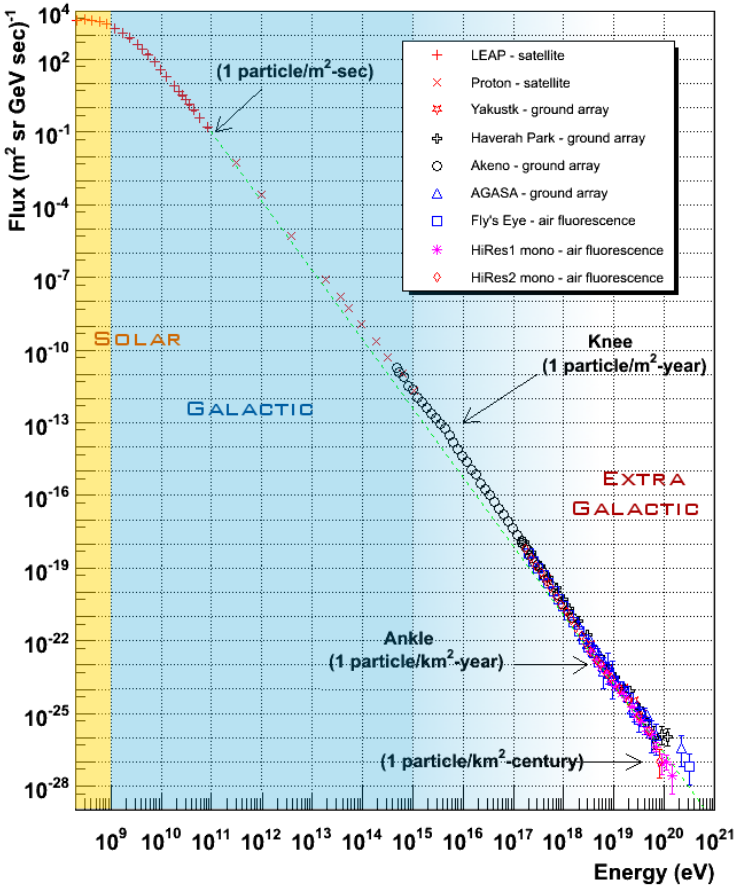

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  - Acceleration mechanisms are limited :
    $R > R_{gyr} = \frac{E}{B}$
    $\longrightarrow E_{max} \sim 10^{15}$ eV (knee)

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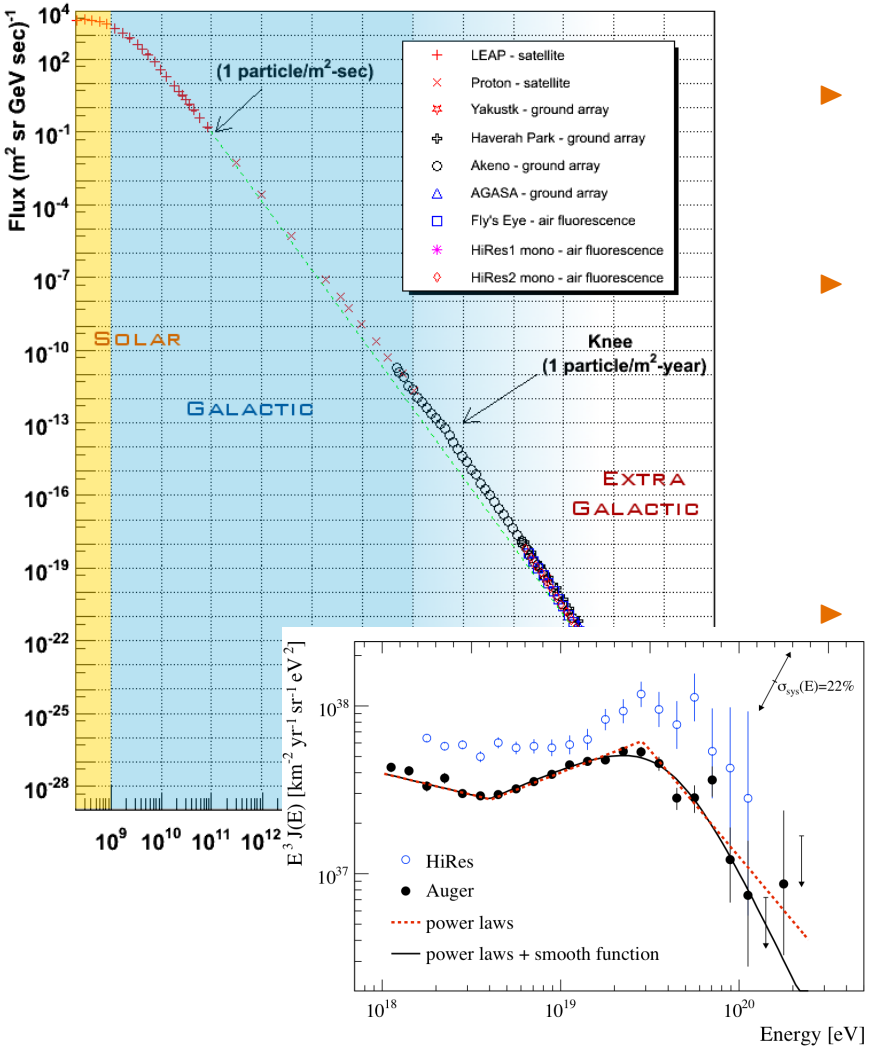

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    $R > R_{gyr} = \frac{E}{B}$
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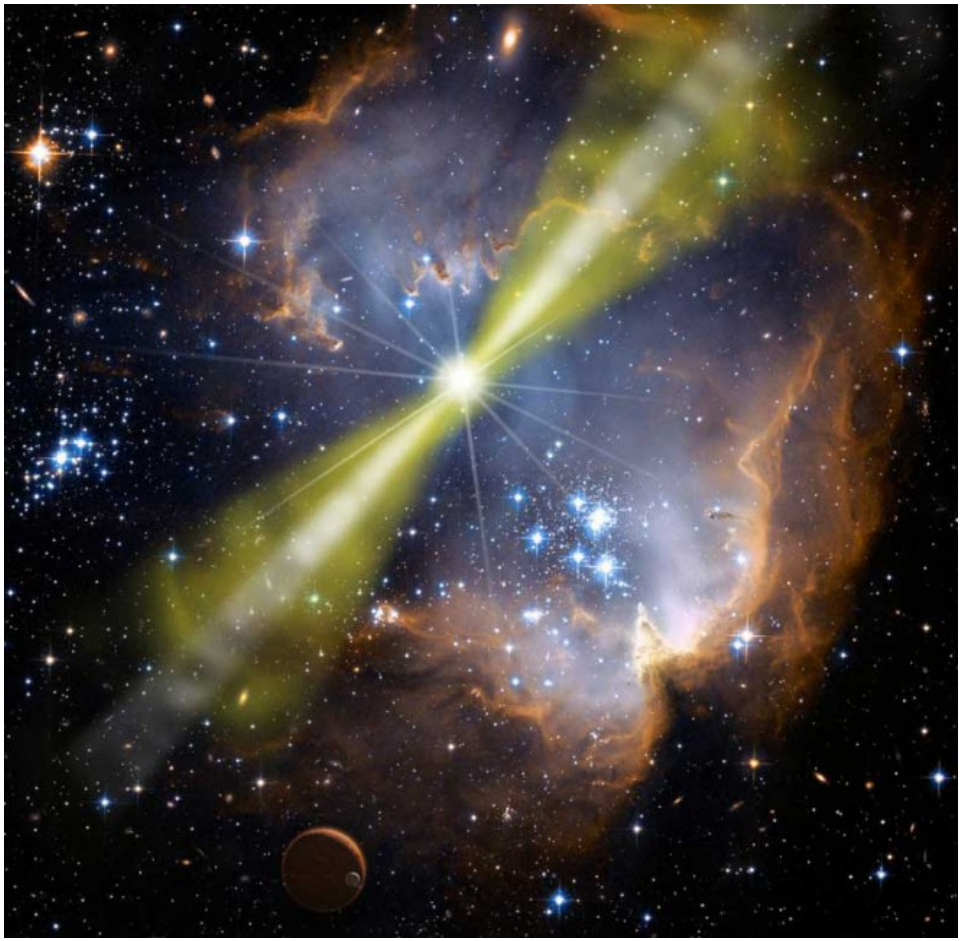
- Ultra High Energy Cosmic Ray
  - extra-galactic origin
  - change in slope $\rightarrow$ change in composition ?
  - Violent accelerators

Gamma Ray Bursts

Gamma Ray Bursts are (one of) the favorite candidates to explain cosmic rays observation above 10^{18} eV



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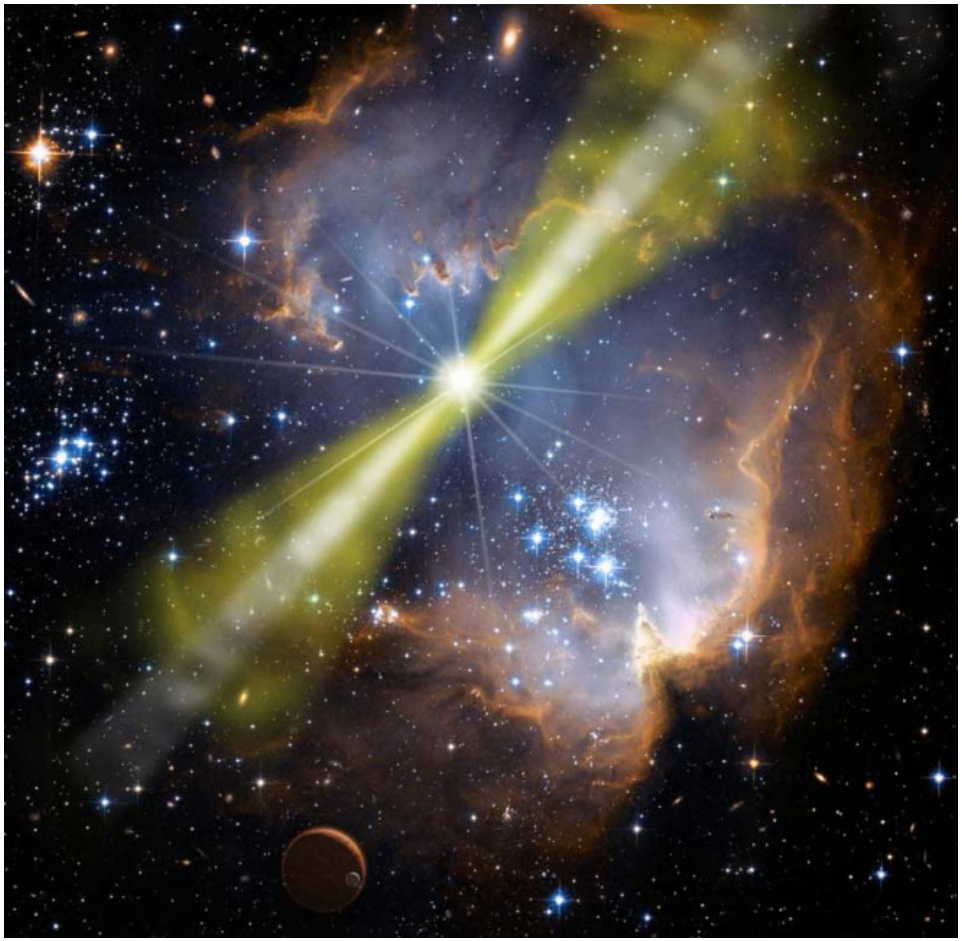

The fireball model

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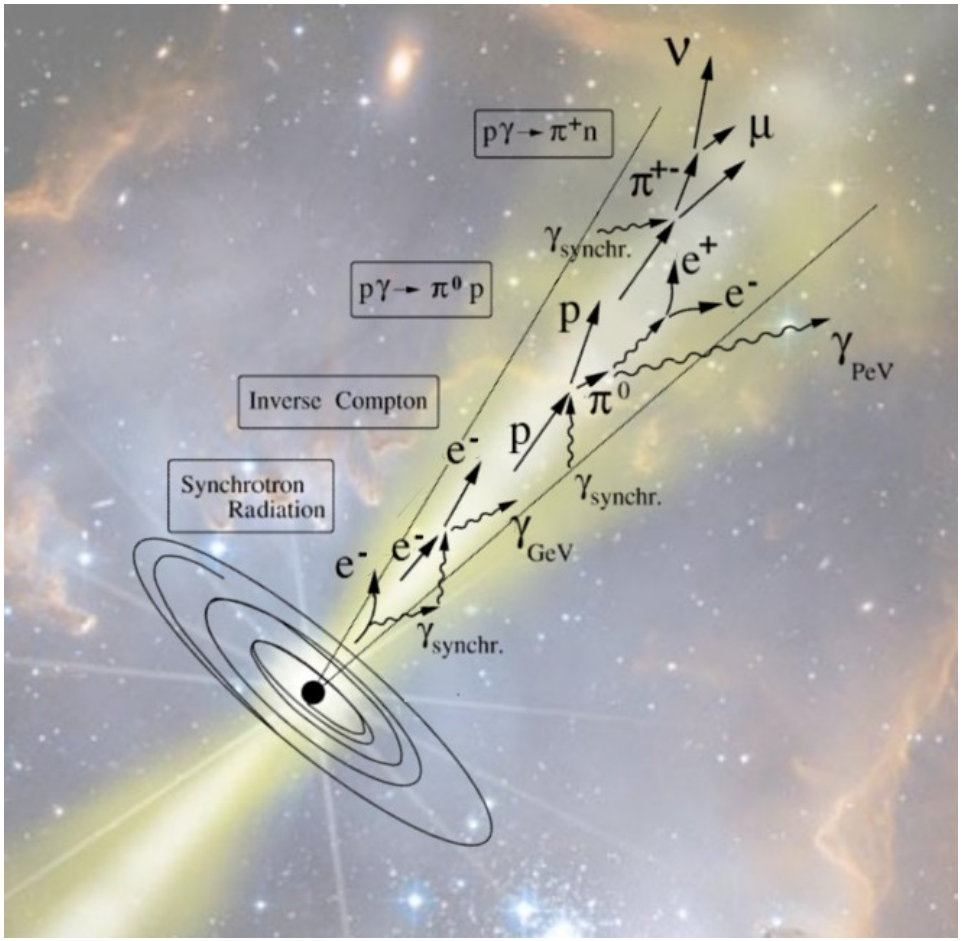

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- Collapse of massive star, compact object collision,... $\longrightarrow$ Black Hole
- Electrons acceleration in internal shocks
  - keV-MeV photons (GRB Signal)
- Protons acceleration via Fermi mechanism
- proton-γ interactions produce pions
  - Emission of high energy neutrinos
  - Emission of high energy photons (GRB Signal)

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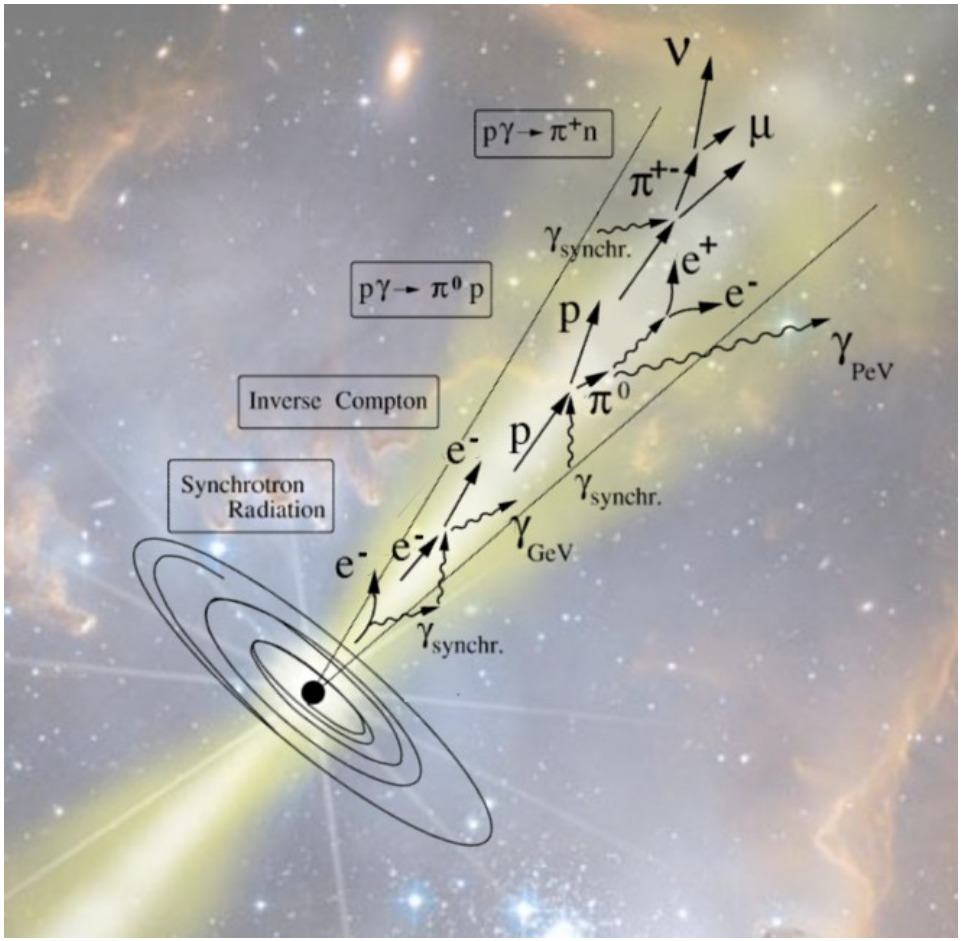

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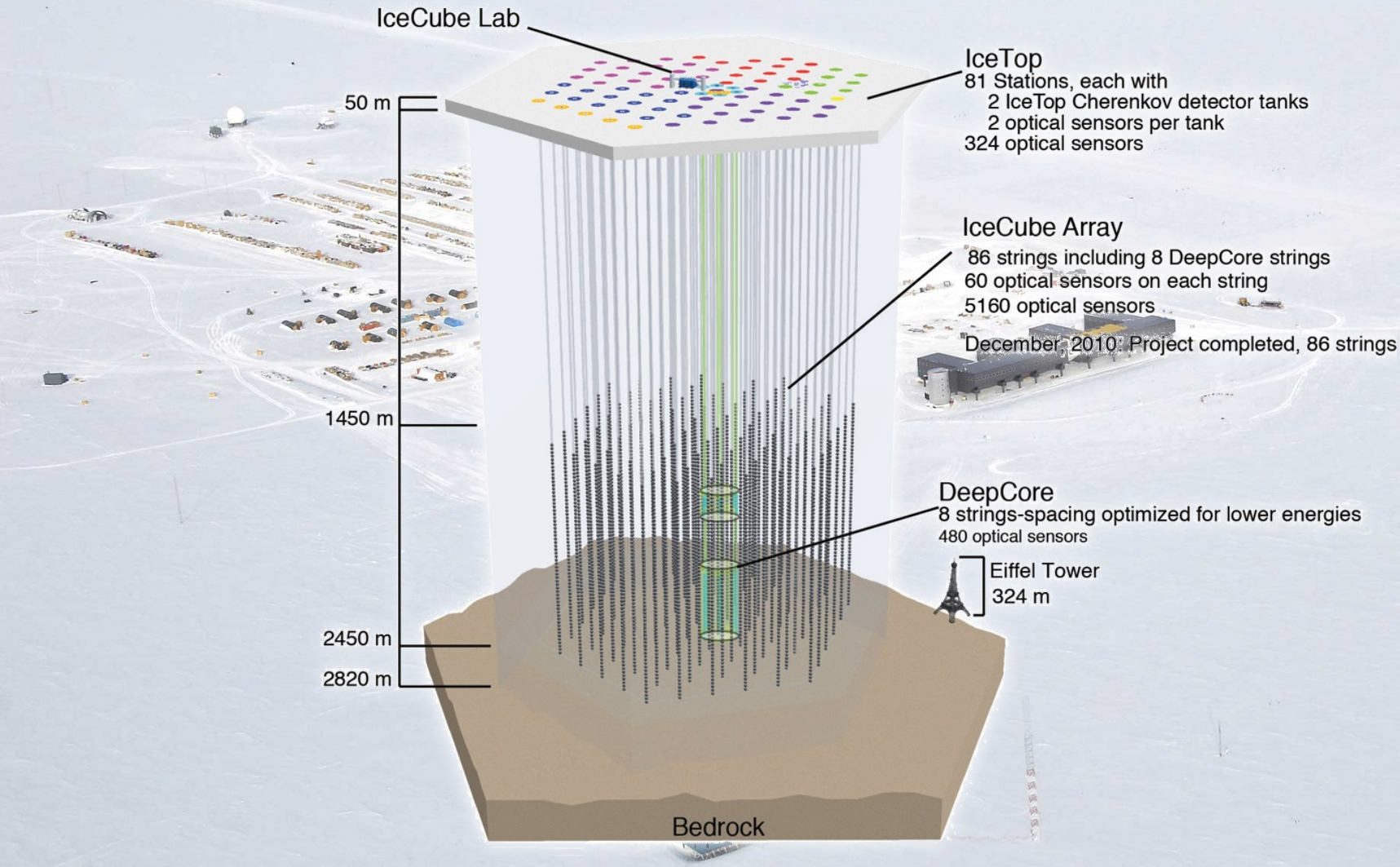
667 GRBs expected per year

The IceCube Collaboration

The IceCube Detector



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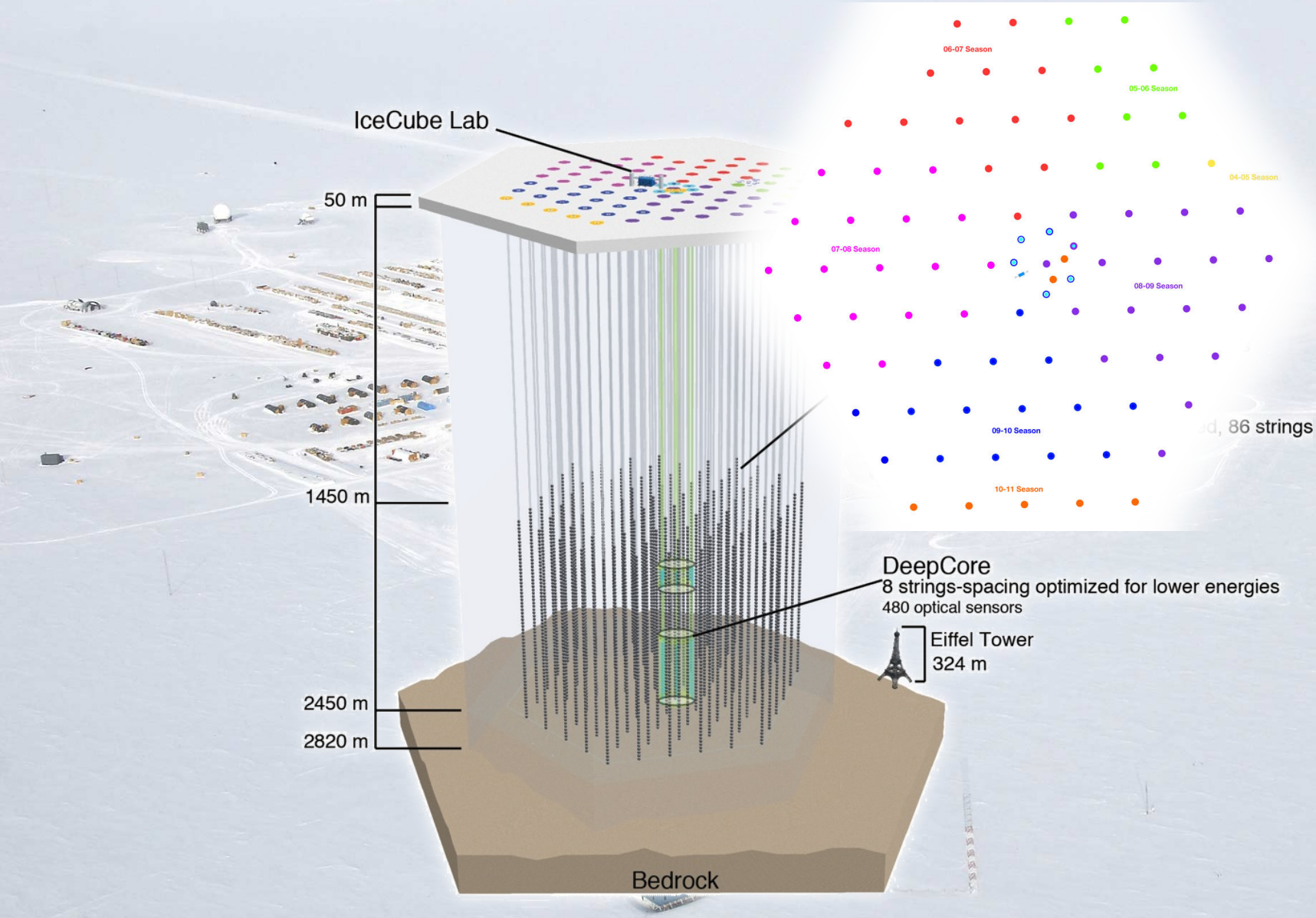

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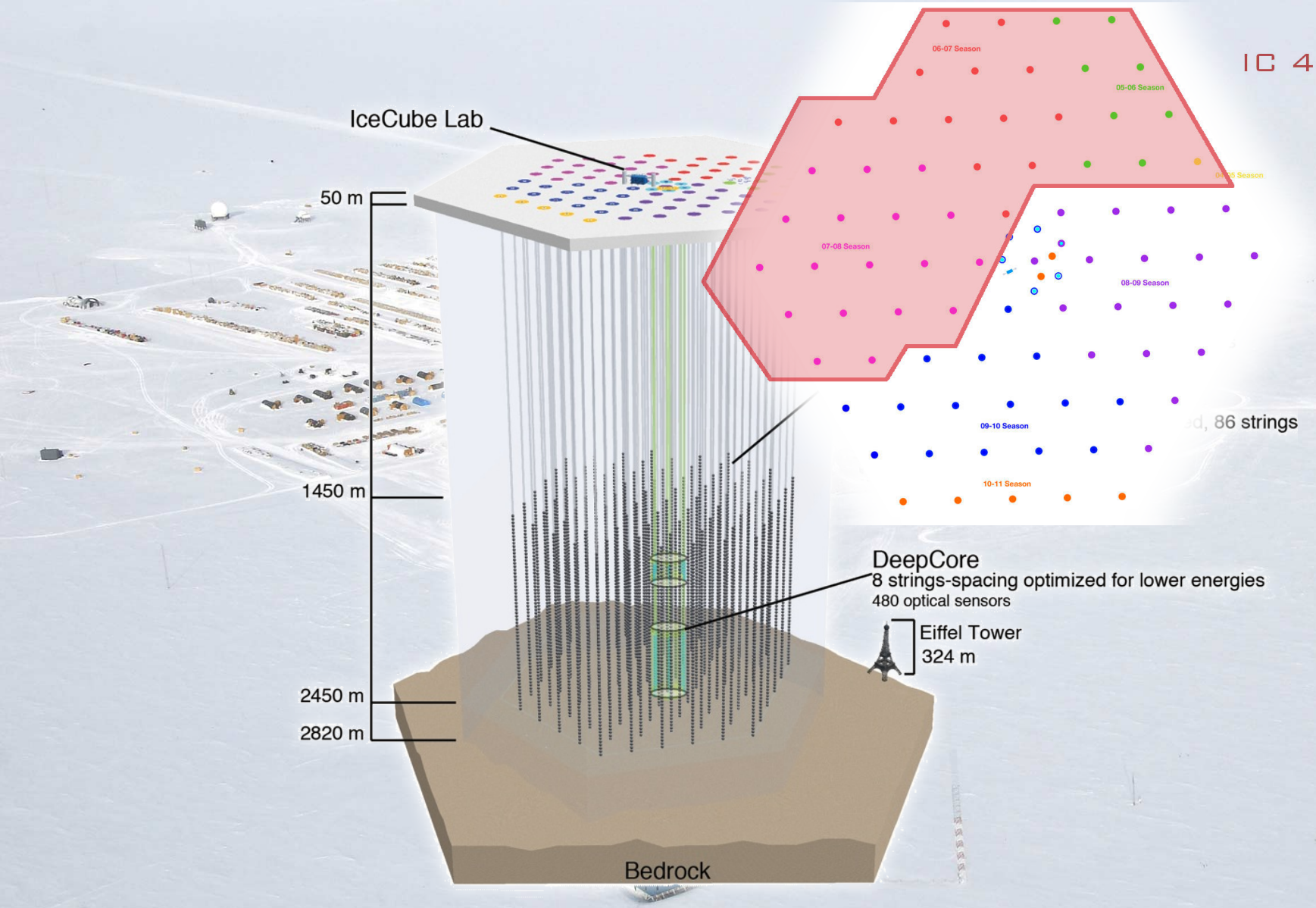

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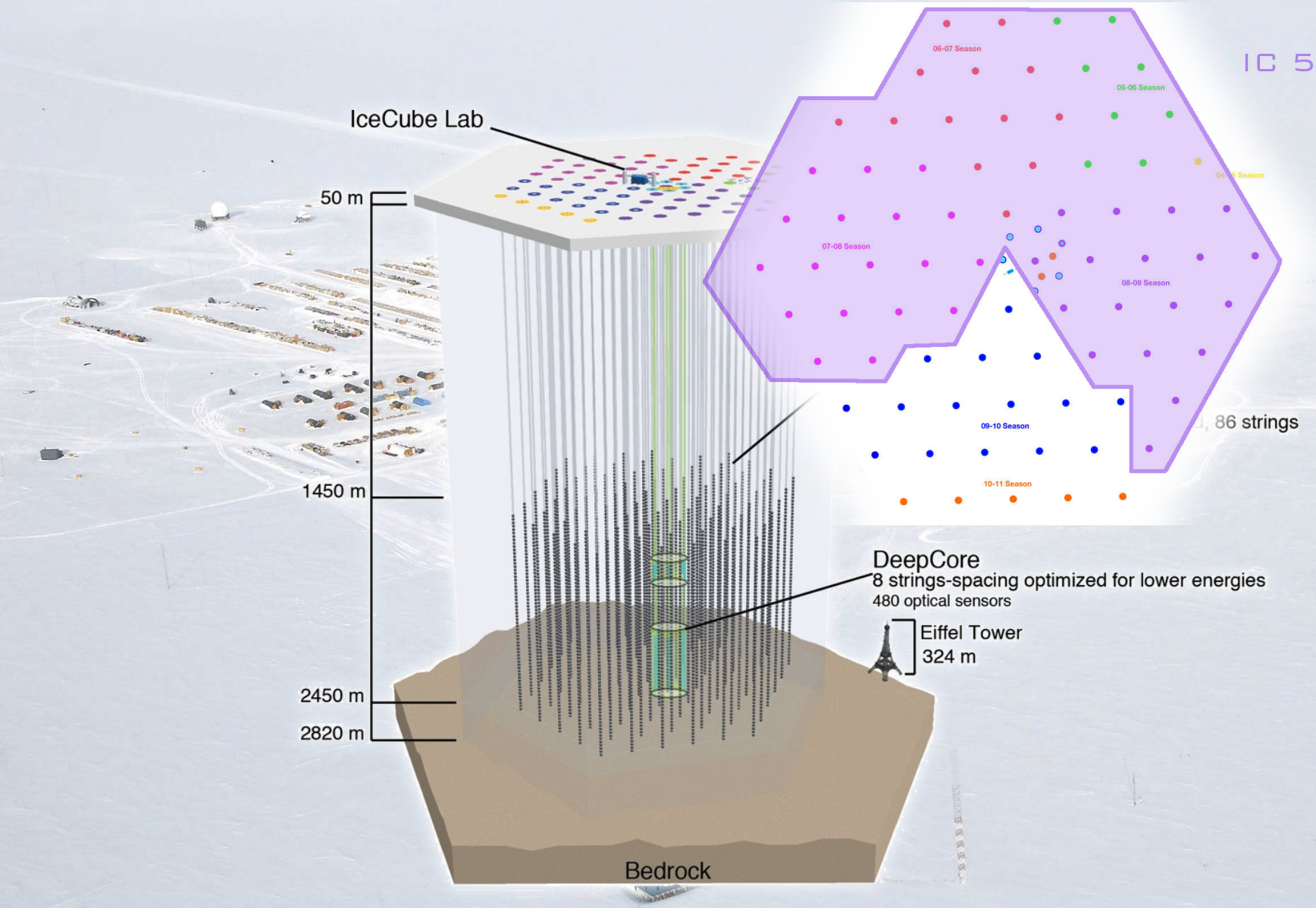
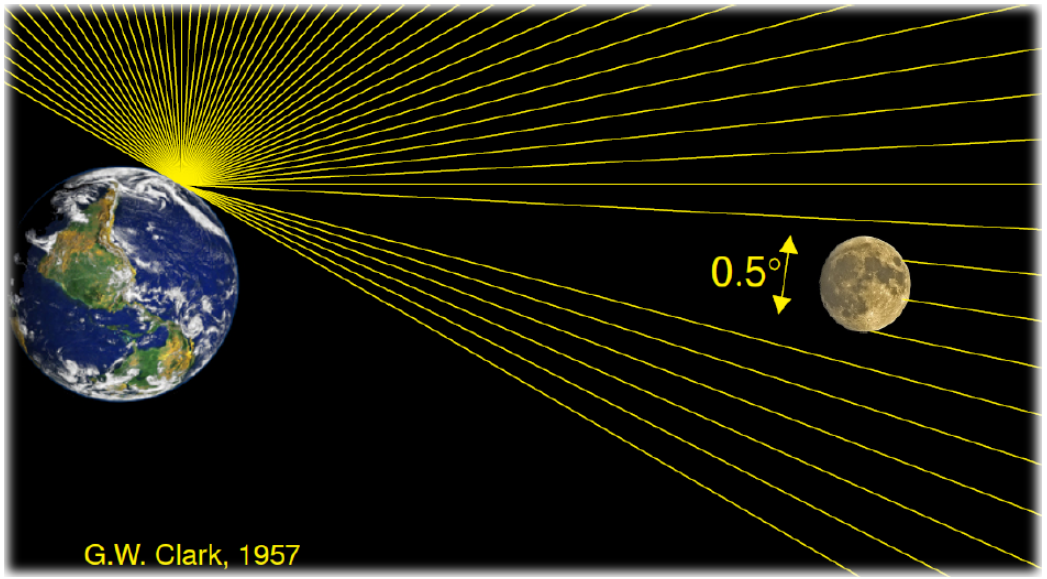
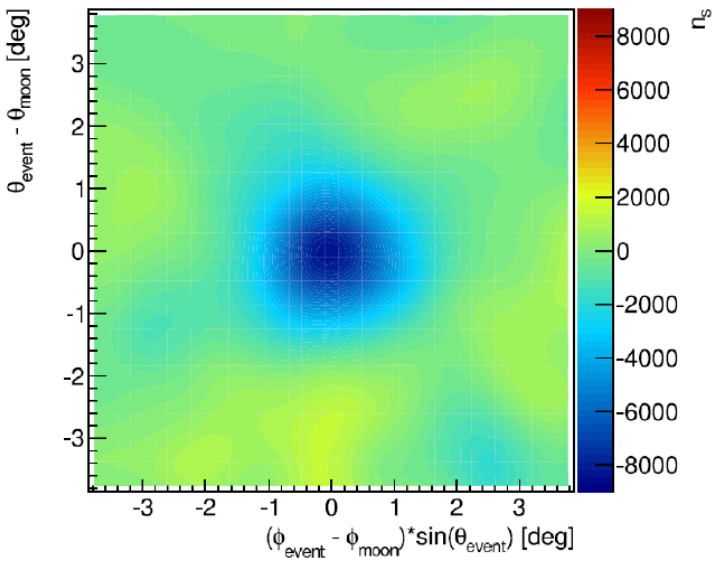


The IceCube Detector

The Moon shadow (with IC-59)

- Verification of the IceCube pointing accuracy
- Using downgoing muons from air showers





- Angular resolution ~ 0.8 deg
- Deficit observed at 12.7 σ

Neutrino Searches from GRBs

Two types of analyses

- Model dependent
  - unbinned maximum likelihood
  - direction, arrival time, energy
- Model independent
  - wider time search window
  - looser event selection criteria

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IC-40 Analysis

Ph.Rev.Let 106(2011) 141101

- April 5, 2008 until May 20, 2009
- 129 GRBs in northern hemisphere : 117 GRBs kept
- MD :Upper Limit (90%CL) : 82% of the expected flux in the 37 – 2400 TeV
- MI : No events observed (4.2 expected) in ± 2248 sec window.

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Combined IC-40 + IC-59 Analysis — Nature 484 (2012) 351-353

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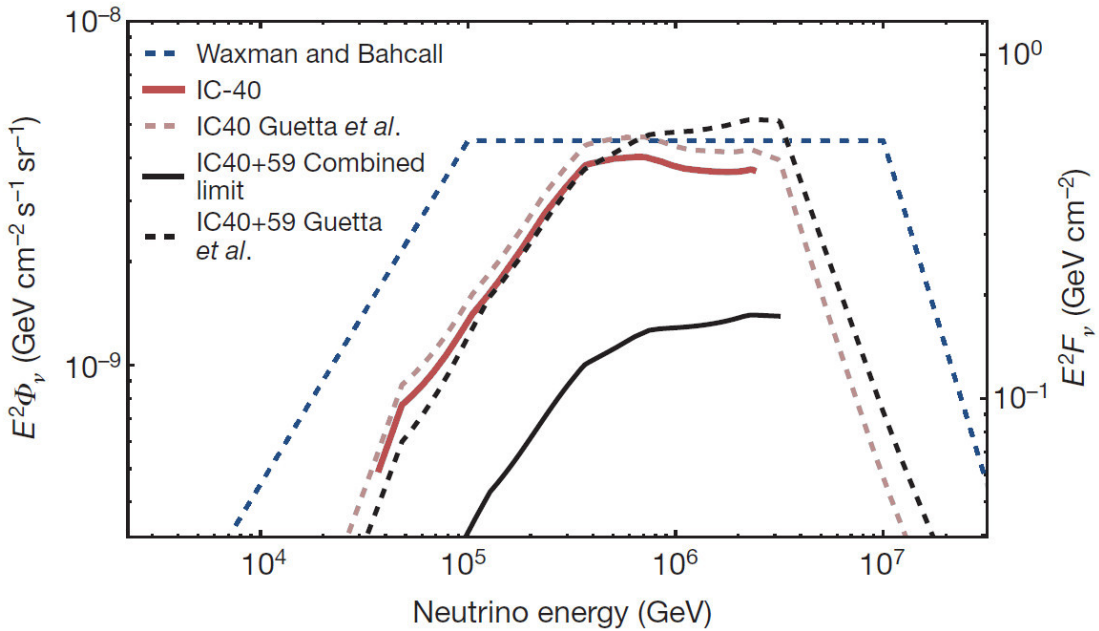
Neutrino Searches from GRBs

Model-dependent analysis

- Background : 24 ev. expected – 21 ev. observed
- Signal : 8.8 ev. expected – No event found ''on-source/on-time''
  - Upper Limit (90%CL) : 0.24 × predicted flux
  - Burst model parameter constraint $\frac{\epsilon_p}{\epsilon_e} = 10 \longrightarrow 2.4$ (90%CL)



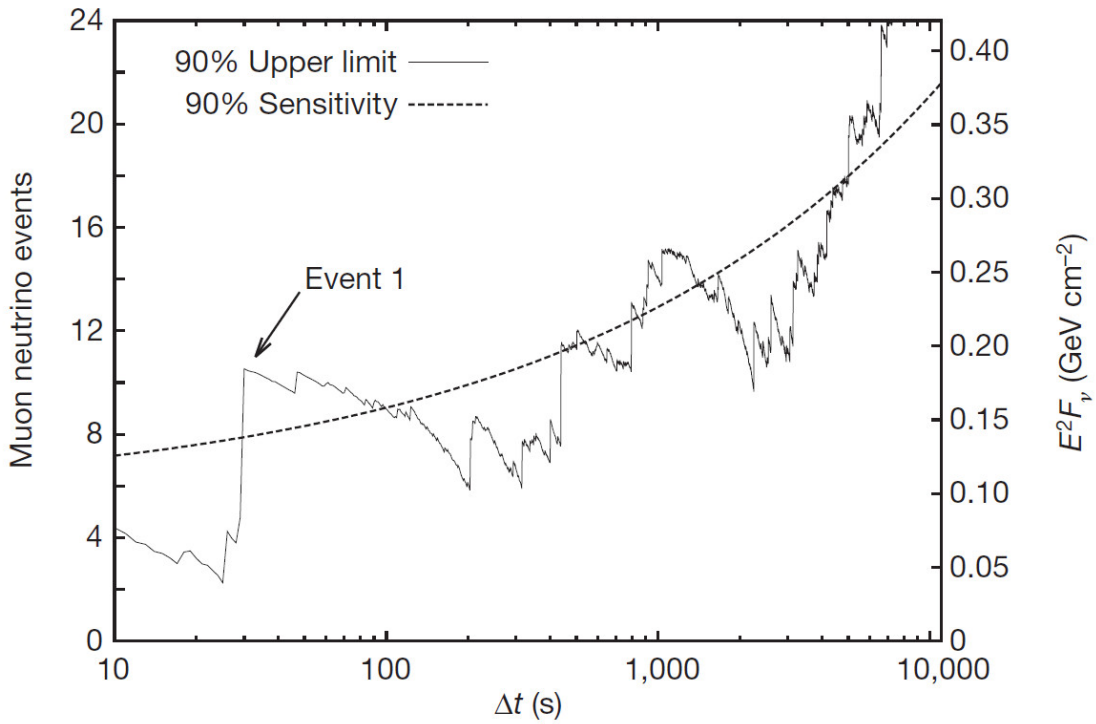
Neutrino Searches from GRBs

Model-independent analysis

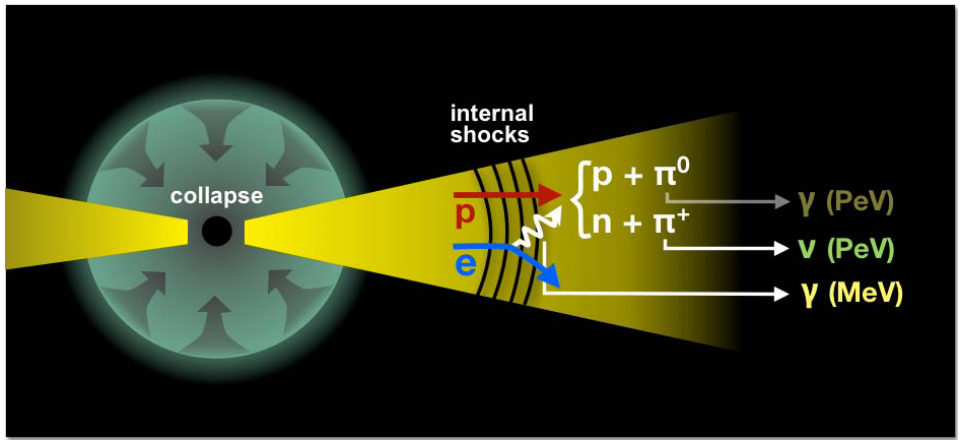
Two candidate events :

- 30 sec after GRB091026A (Event 1)
- 14 hrs before GRB091230A

Most probably muons from cosmic ray air showers



GRB Fireball Flux Models



Three different models

- Guetta et al. — Astrop.Phys.20 (2004) 429
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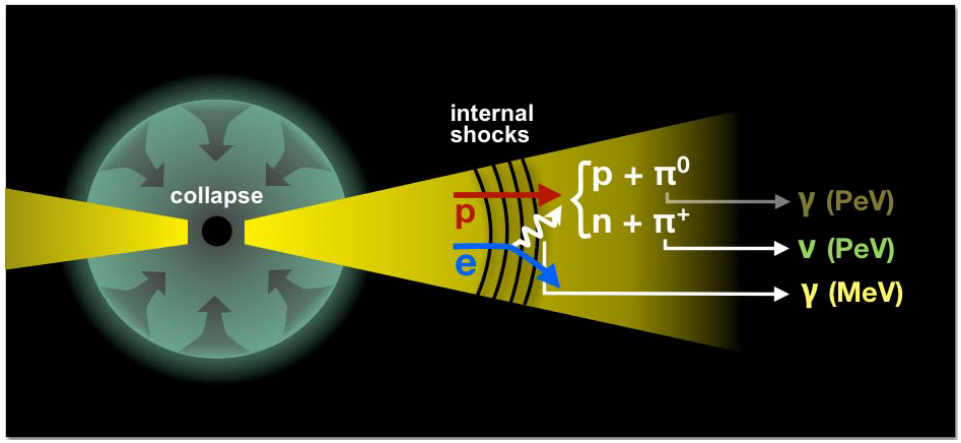

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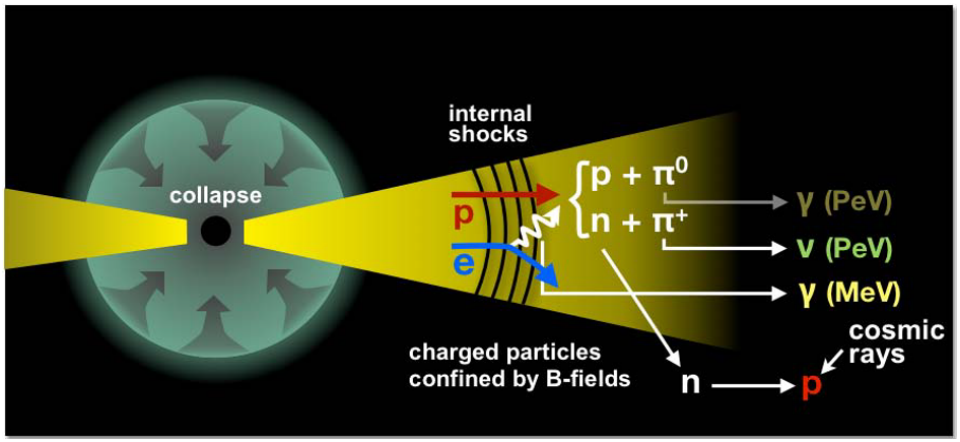

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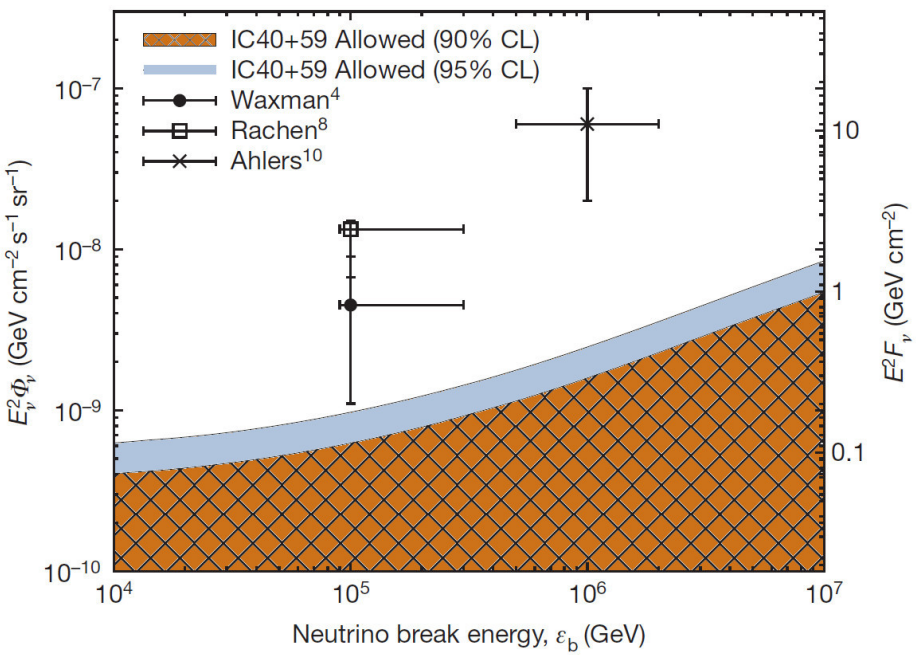
- Alhers et al. — Astrop.Phys.35 (2011) 87
  - ''Neutron-escape'' model, protons stay confined inside the fireball
  - UHECR flux directly translate into charge pion, and therefore neutrino flux
  - Using the shape of observed UHECR spectrum instead of integrated energy

Discussion : Parameters

Model compatibility with observations

90(95)%CL of the ν flux vs. neutrino break energy ε_b from the model-independent analysis with time window $|\Delta t| = 28$ sec.



- ε_b : Δ-resonance for pγ in the shock frame
- Flux : Broken law spectra
  - $\phi_\nu\ E^{-1}/\varepsilon_b \qquad E < \varepsilon_b$
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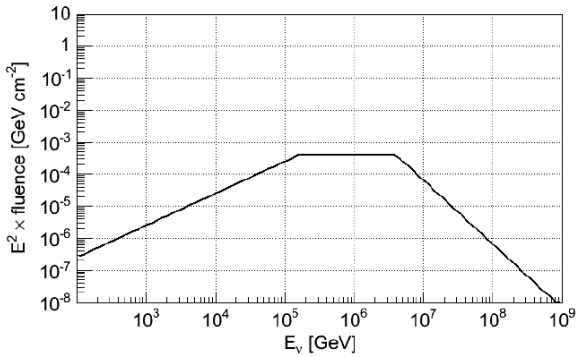

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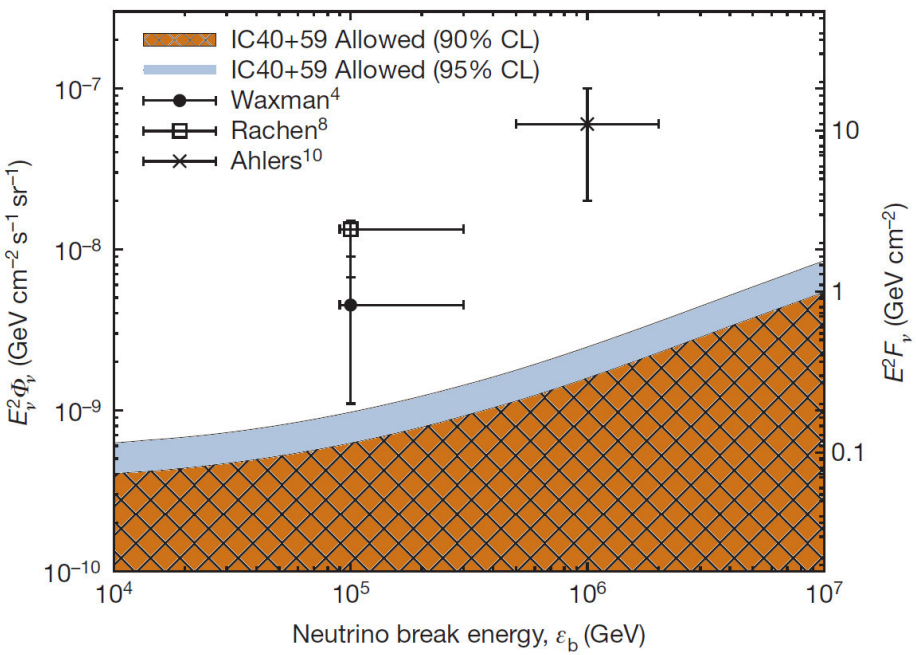

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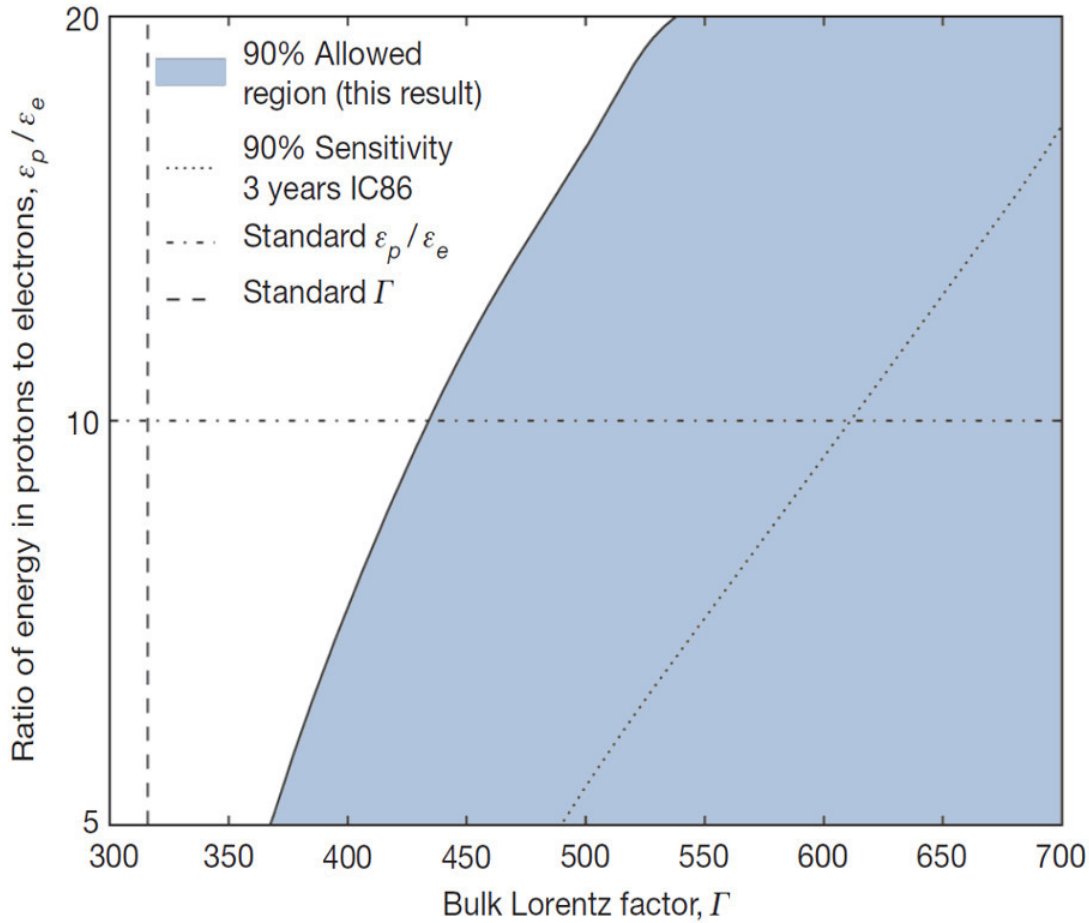
- Flux : Broken law spectra
  - $\phi_\nu \; E^{-1}/\varepsilon_b \qquad E < \varepsilon_b$
  - $\phi_\nu \; E^{-2} \qquad E > \varepsilon_b$
- All models assume $\Gamma \approx 300$
- Vertical axes related to accelerated proton flux by f_π
  - Waxman : $f_\pi \sim \Gamma^{-4}$
  - Rachen & Ahlers : independent

Discussion : Parameters

Constaints on fireball parameters

90% allowed region of the proton to electron energy ratio vs. bulk Lorentz factor Γ from the model-dependent analysis.



Summary and conclusions

The facts

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- For the first time, the upper limit on the expected flux of neutrinos is well below the predictions.

The fallouts

- The models must be revisited !
- The proton density in GRB fireball is below what is needed to explain UHECR
- The GRB mechanismes are significantly different from the current theories

Other topics with IceCube

Cosmic Rays

- Measurement of C.R. Anisotropy — Astrophys.J. 746 (2012) 33 — Phys.Rev.D83 (2011) 012001

Point Sources searches

- Time-Dependent Search with IC-40 and IC-22 — Astroph. Journal 744 (2012) 1

Supernovae

- Crab Nebula Flare analysis — Astrophys. J. 745 (2012) 45
- Constraints on HE neutrino emission from SN2008D — Astron.Astroph. 527 (2011) A28

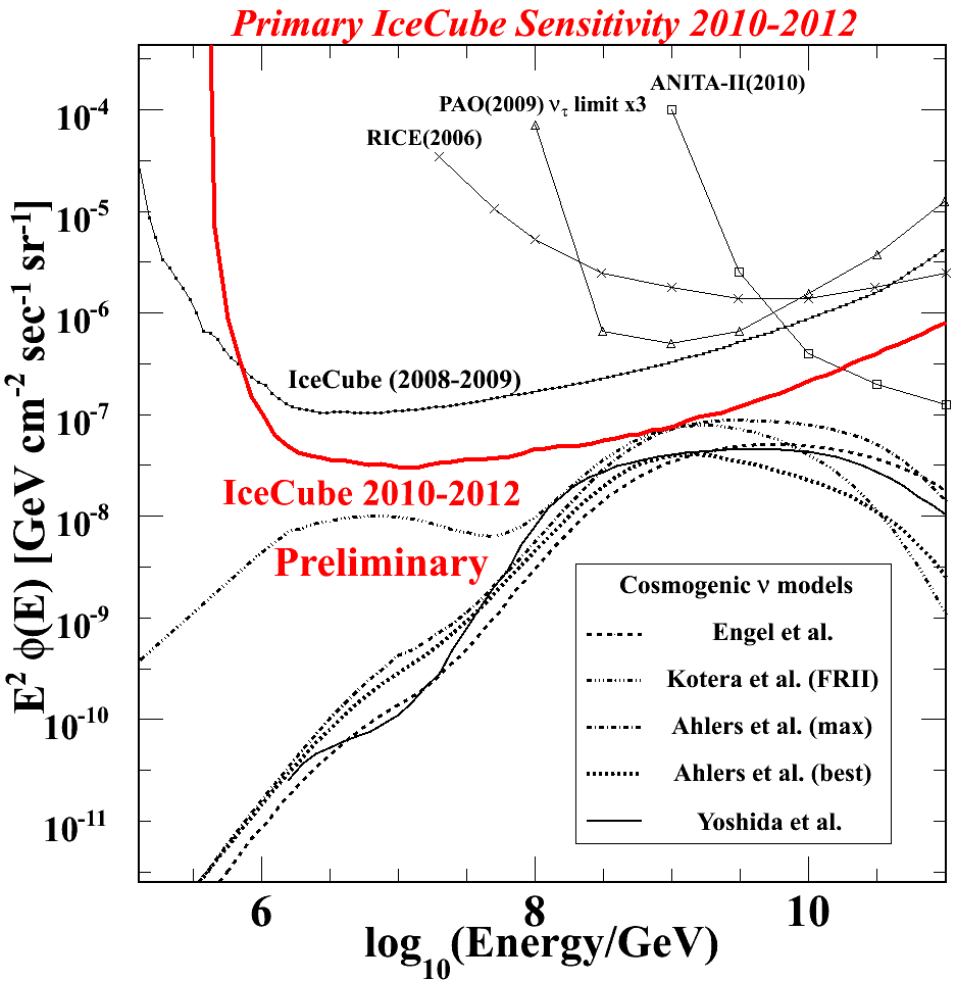
Dark Matter

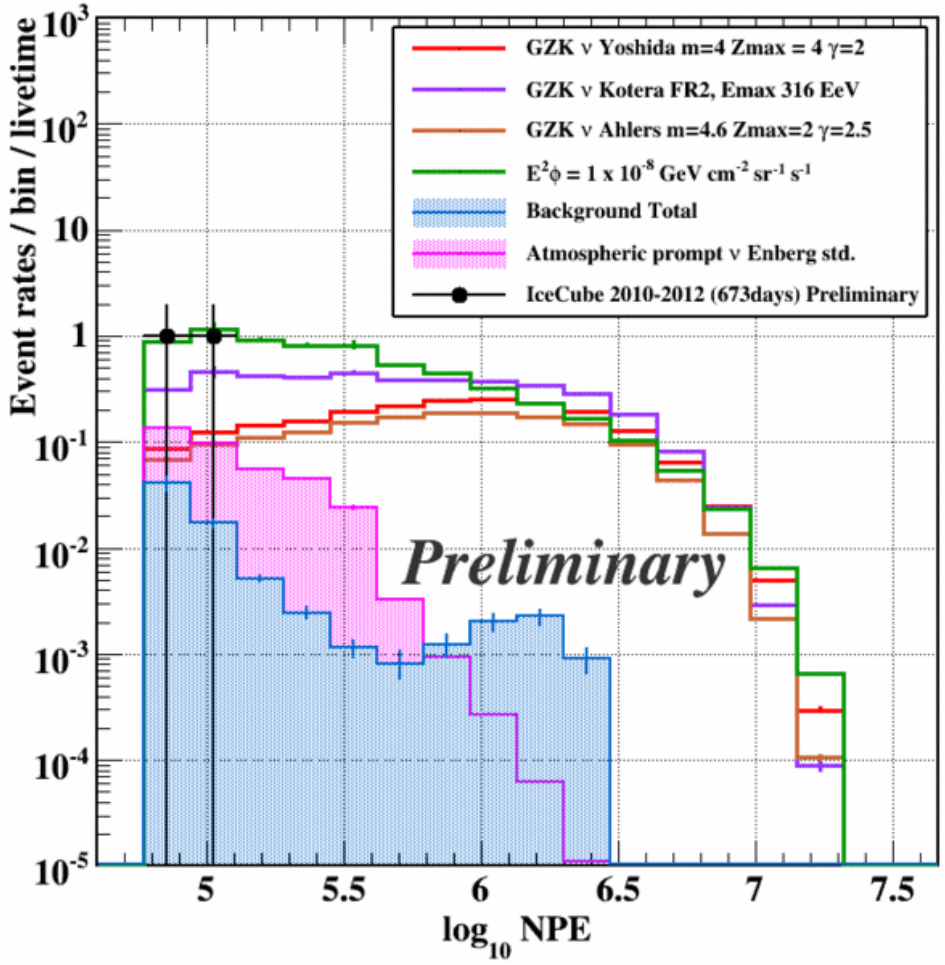
- Multi-year search for dark matter annhilations in the Sun with AMANDA-II/IceCube — Phys.Rev. D85(2012) 042002
- Search for Dark Matter from the Galactic Halo — Phys.Rev. D84(2011) 022004

but also

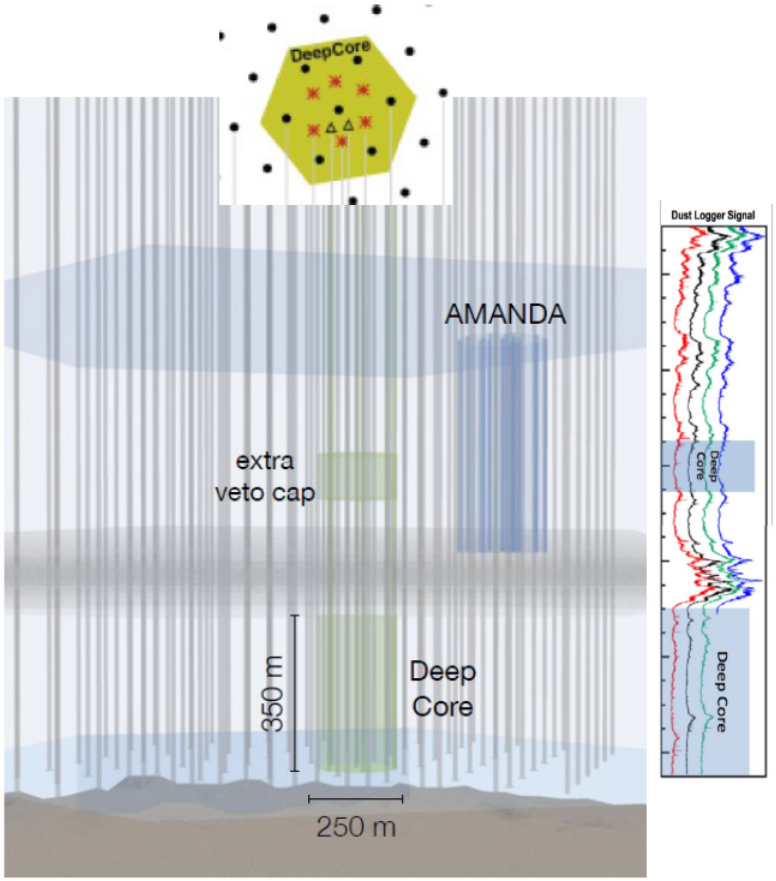
- Atmospheric muons, Diffuse fluxes , Exotic particles, Tau neutrinos, Cascades ,...

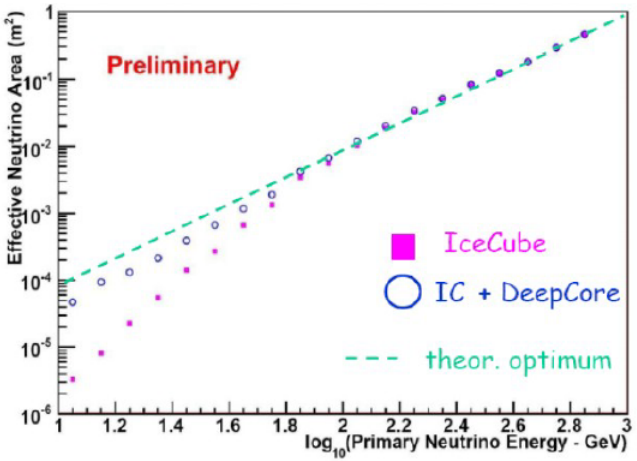
Back-up: IC86 EHE





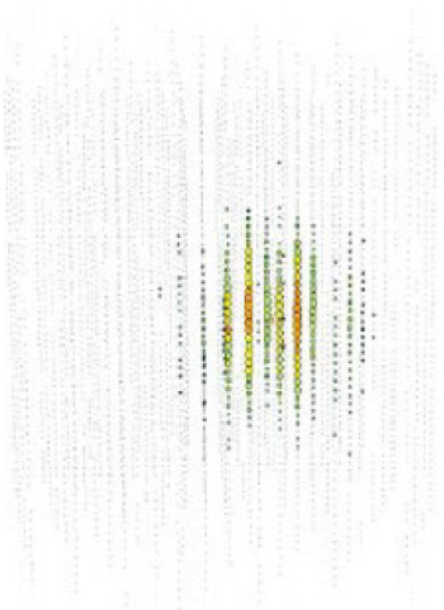
Back-up: DeepCore



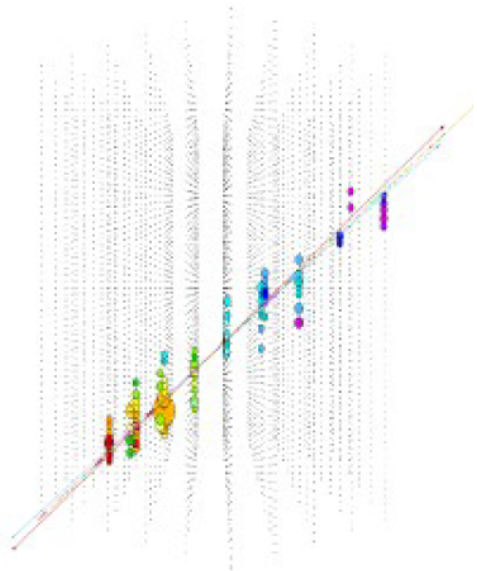


Back-up: Signal in IceCube

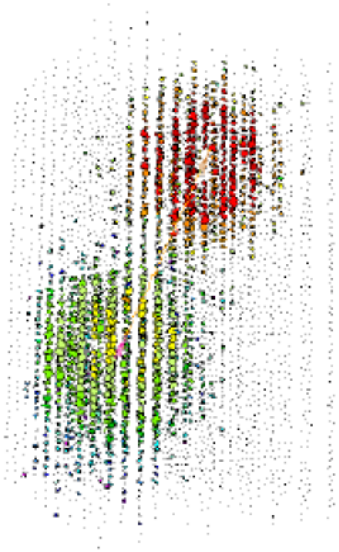
ν_e with E = 375 TeV



ν_μ with E = 6 TeV

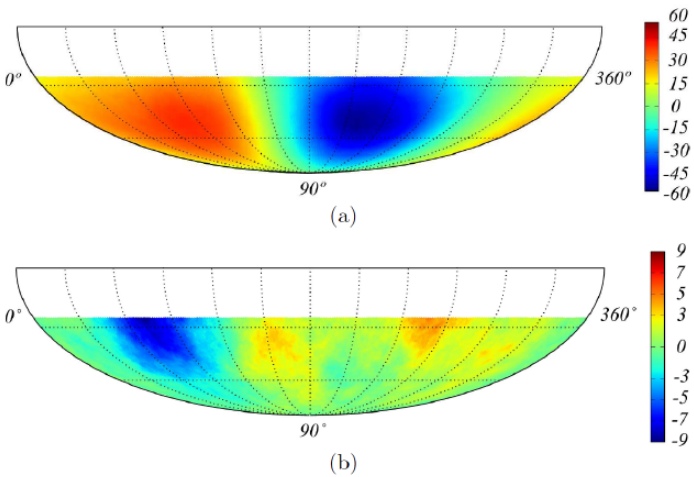


ν_τ with E ~ PeV



Back-up: Other IC-59 results

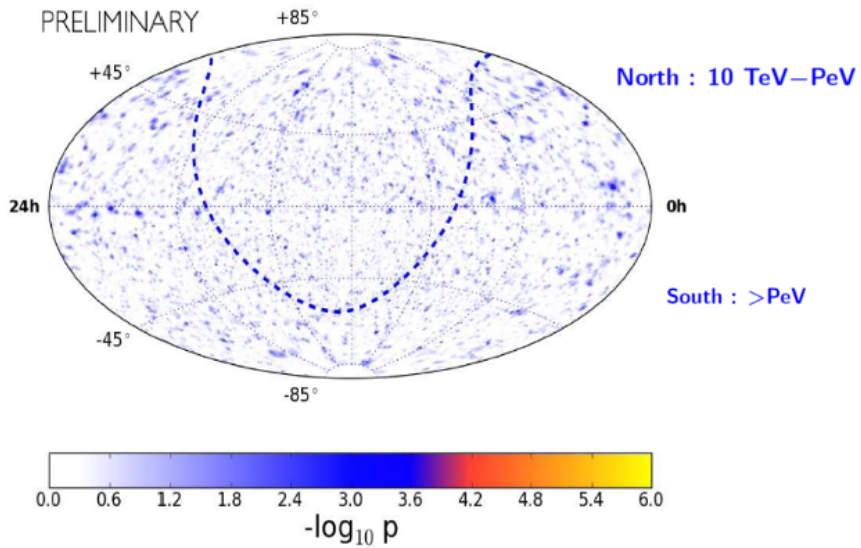
Large scale Cosmic Ray anisotropy (59-string detector)



Top : 20 TeV **Bottom : 400 TeV**

Astrophysical Journal 746 (2012) 33

Neutrino equatorial skymap 2008-2010 (40&59-strings)



Most significant excess : $\alpha = 5\text{h } 1\text{m } 48\text{s}$ $\delta = -18.15°$ P-value $= 2.23 \cdot 10^{-5}$
Randomised α data sets → post-trial : P-value=0.67

Back-up : Point Sources IC-40