Results from IceCube on high-energy neutrinos and cosmic rays

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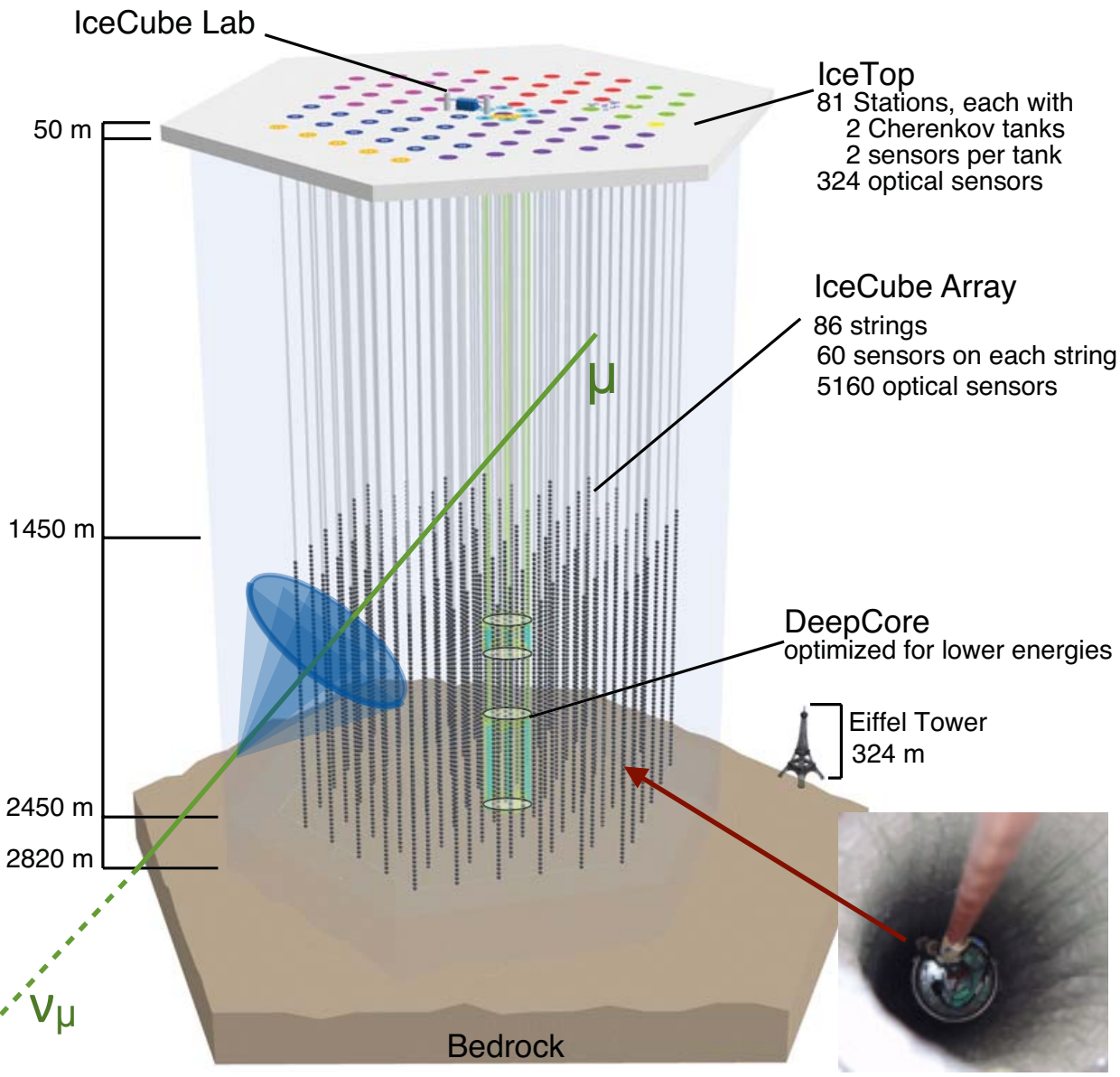
for the IceCube collaboration

Rencontres de Moriond

La Thuile

Mar, 7th 2012

The IceCube observatory



Deployment

- 04/05 1 string (IC01)
- 05/06 9 strings (IC09)
- 06/07 22 strings (IC22)
- 07/08 40 strings (IC40)
- 08/09 59 strings (IC59)
- 09/10 79 strings (IC59) (including DeepCore)
- 10/11 86 strings (IC86)

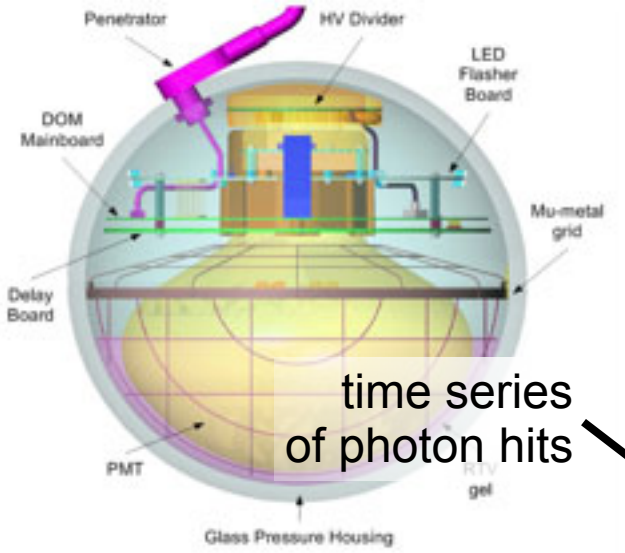
Dec, 2011

➔installation completed

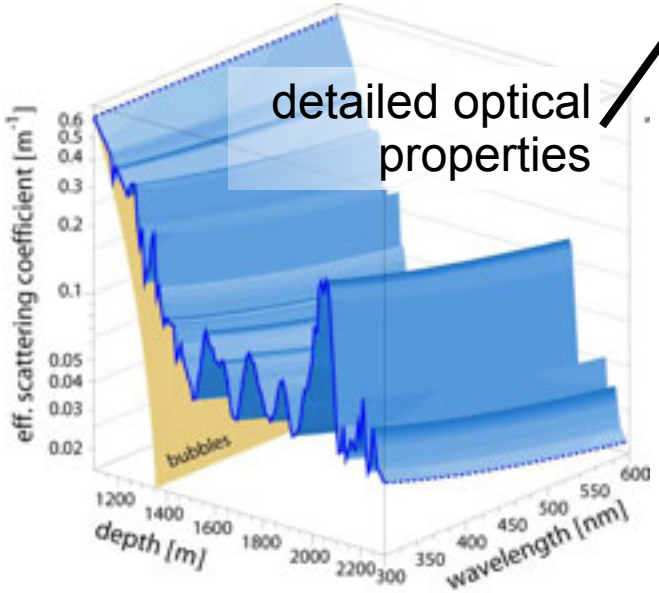
May, 2011

➔operation of IC86 array

Detection method

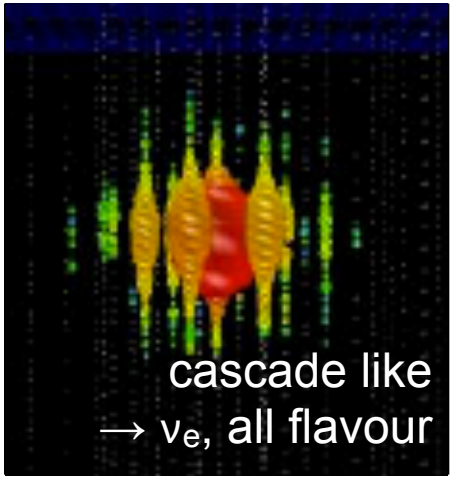


time series of photon hits

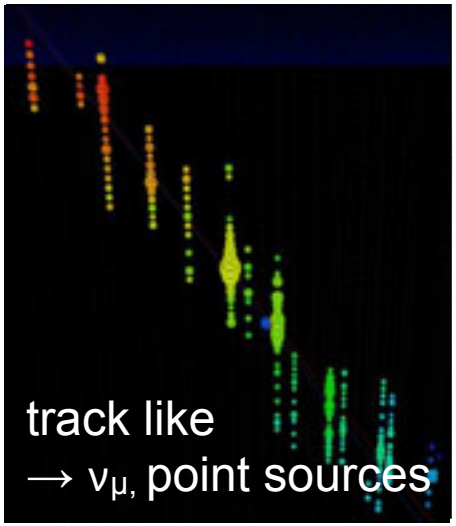


detailed optical properties

likelihood reconstruction → event selection



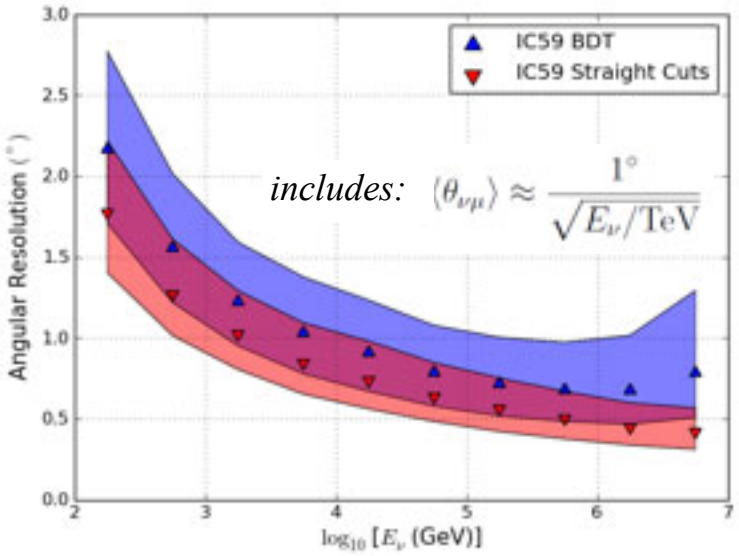
cascade like
→ ν_e, all flavour



track like
→ ν_μ, point sources

muon bundle like
→ cosmic rays

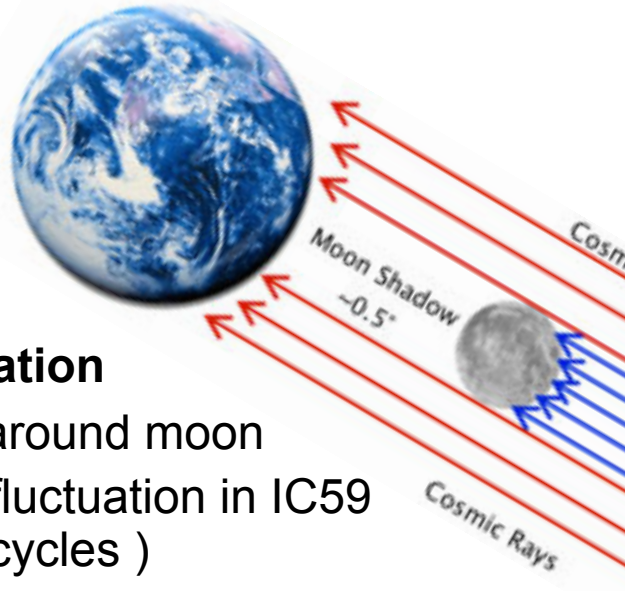
ν_μ energy and pointing resolution



Pointing resolution

- energy dependent

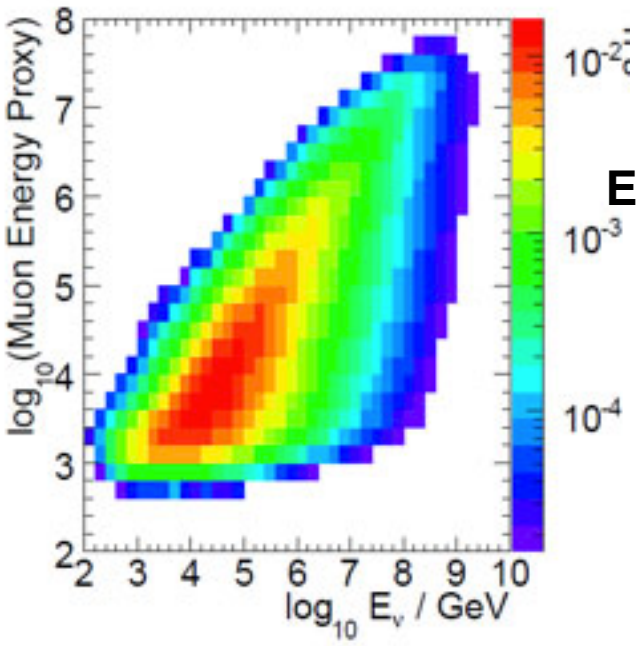
➔ $\sigma(\theta_\nu) \approx 1^\circ$ at 1TeV



Pointing verification

- $\pm 4^\circ$ window around moon

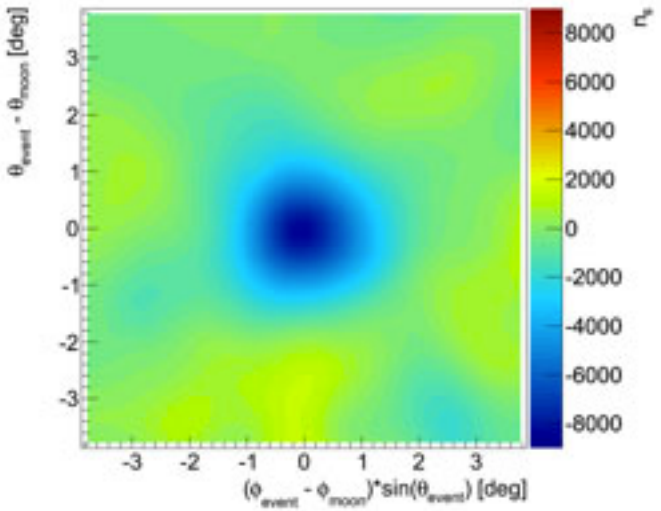
➔ 13σ underfluctuation in IC59 (14 moon cycles)

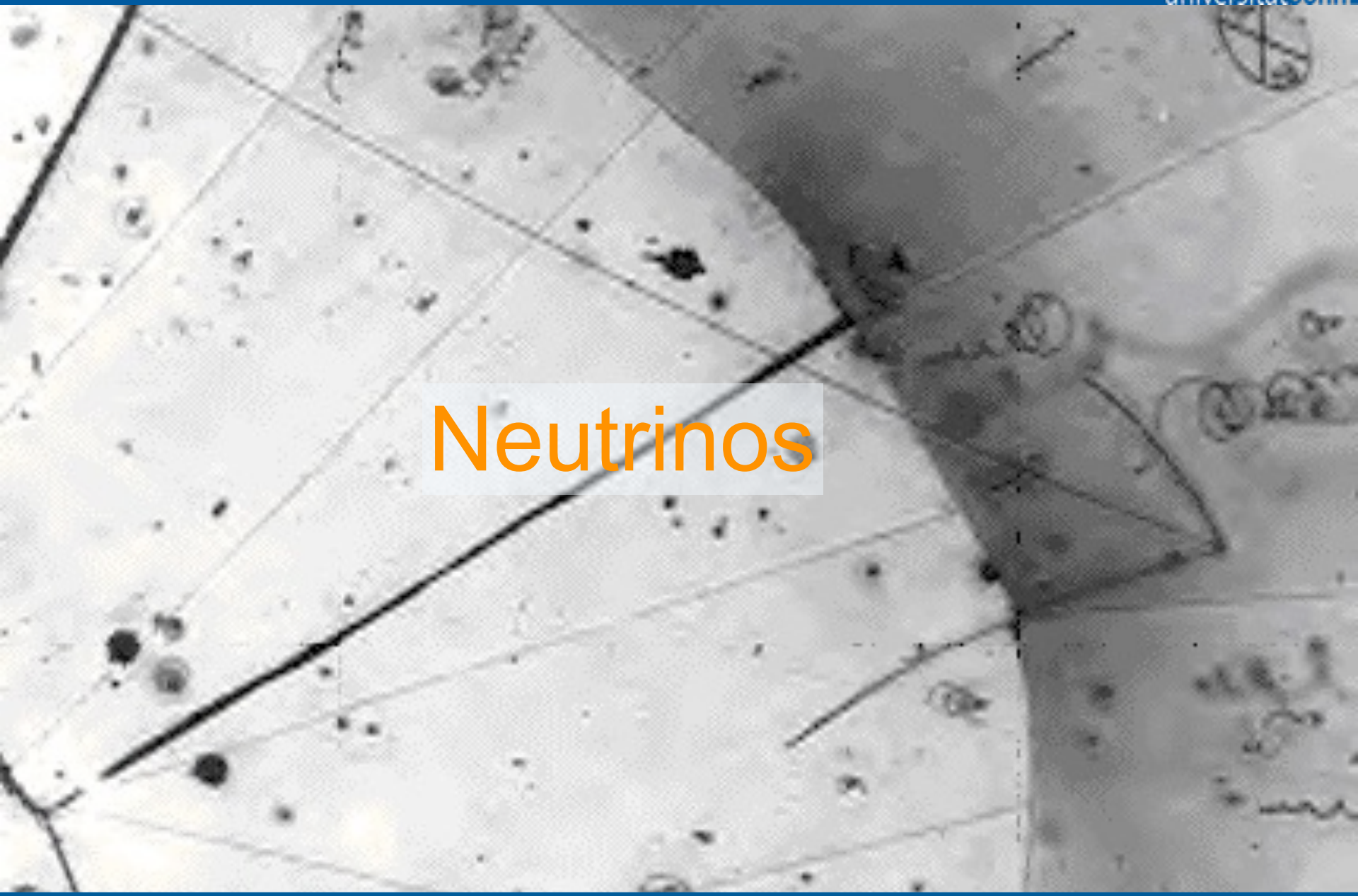


Energy resolution

- estimated from dE/dx of muons
- dominated by stochastic losses

➔ $\sigma(E_\mu) \approx 0.3 \log_{10}(E_\mu)$





Neutrinos

Point source searches

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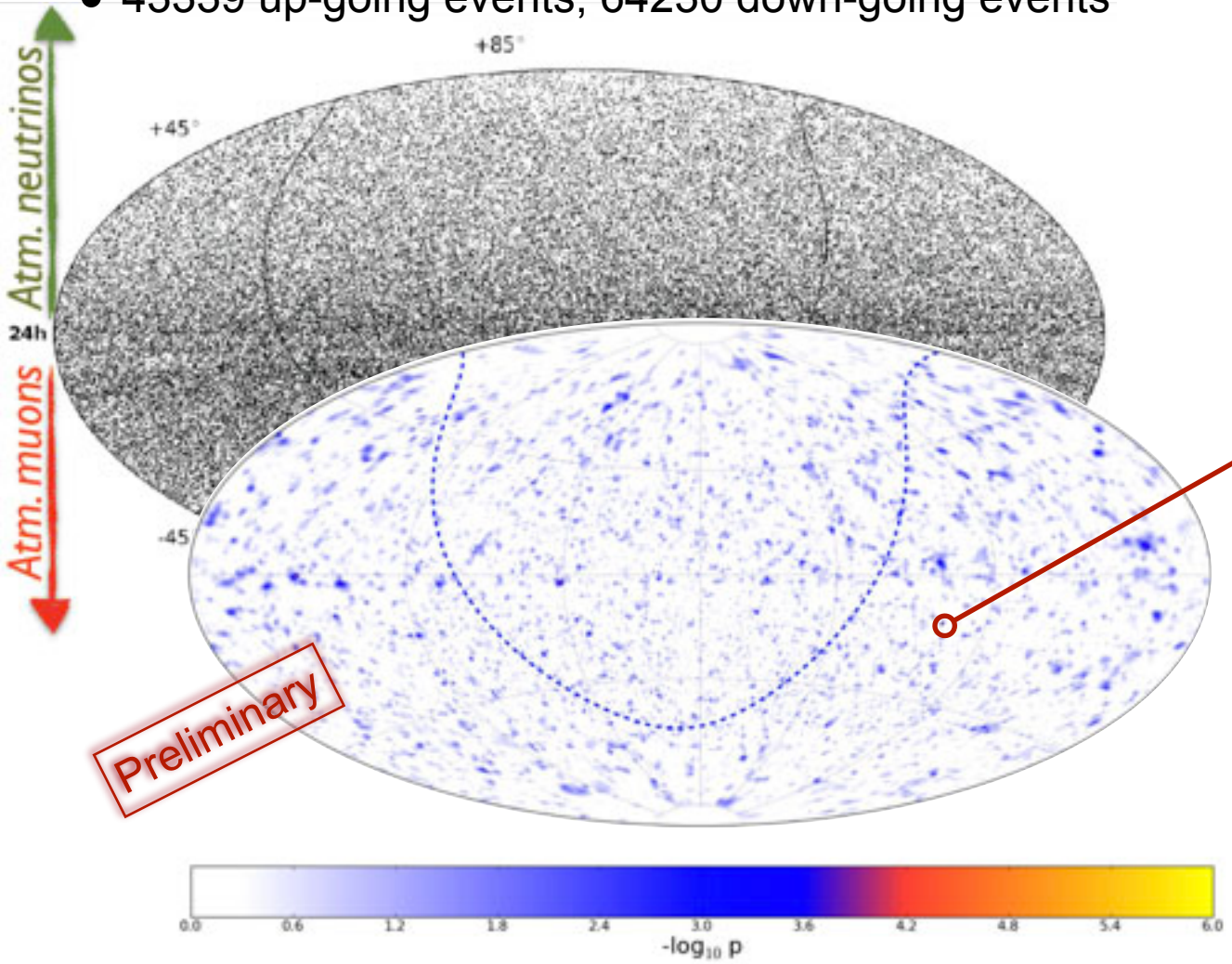
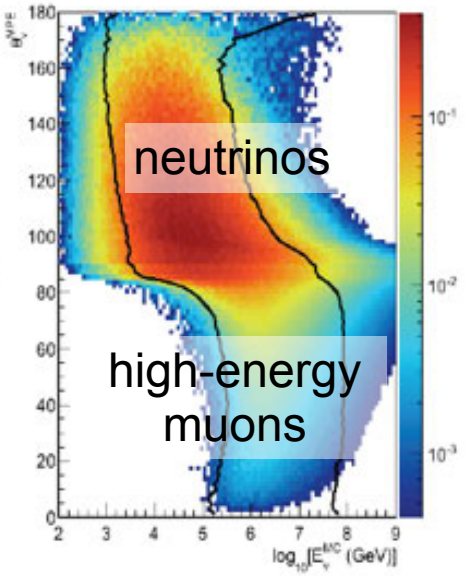
Dataset

- lifetime 723 days (IC40+IC59)
- 43339 up-going events, 64230 down-going events





Hottest spot

- RA: 75.45º
- DEC: -15.18º
- $-\log_{10}(p) = 4.65$

➔74.2% chance probability

➔no close-by candidates

Prompt and diffuse ν_e flux

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Atmospheric neutrinos

- conventional flux
  - ν_e-flux = ~10^{-2} ν_μ-flux
- prompt flux
  - decay of charmed mesons (e.g $D^{\pm}$,D_0,Λ_c)

➔measurement allows to probe hadronic interaction models

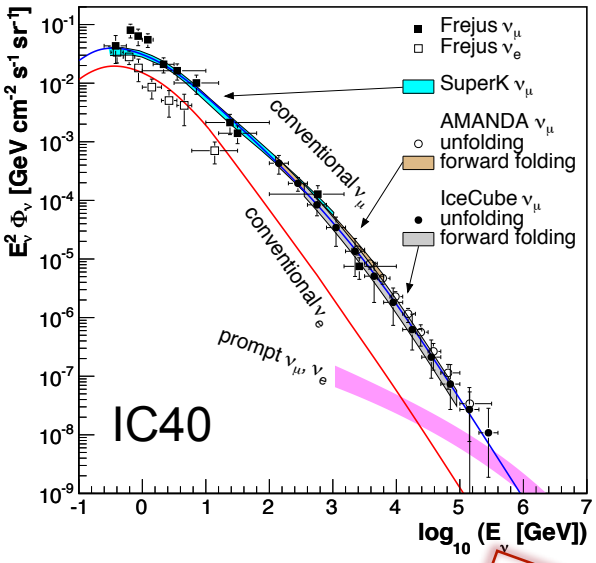
Electron neutrino flux

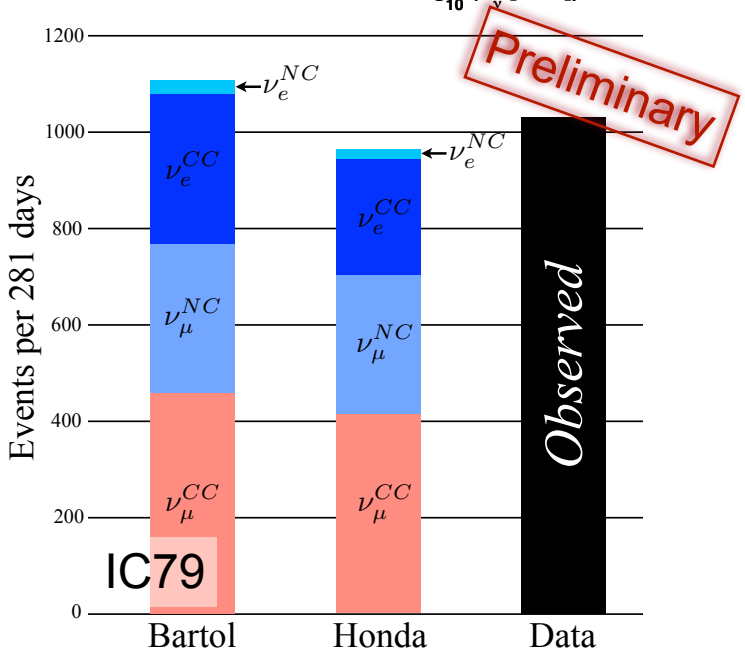
- distant neutrino sources
  - ➔ neutrino oscillations
    - flavour ratio (1:1:1)
- experimental challenges

➔limited pointing resolution

➔background from bremsstrahlung cascades

➔ approaching needed sensitivity

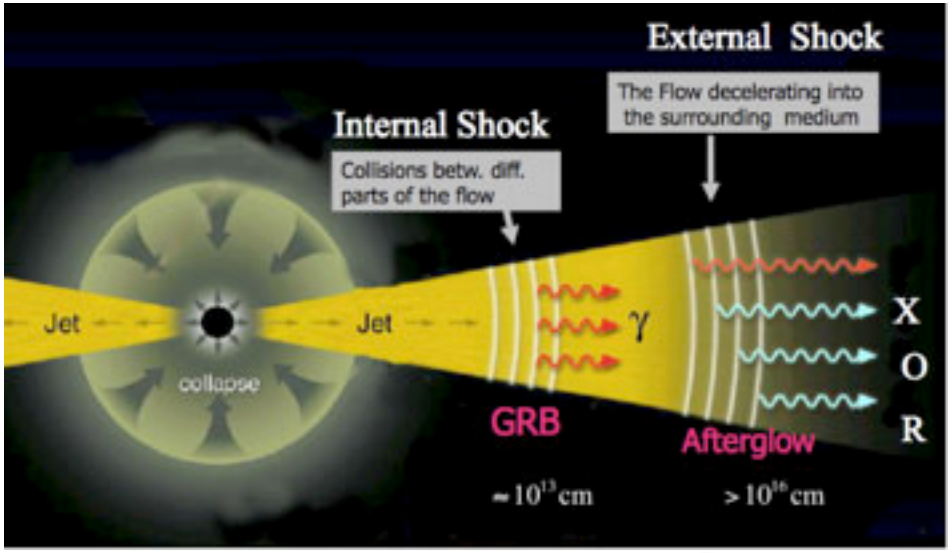




Gamma ray bursts

Fireball model (long GRBs)

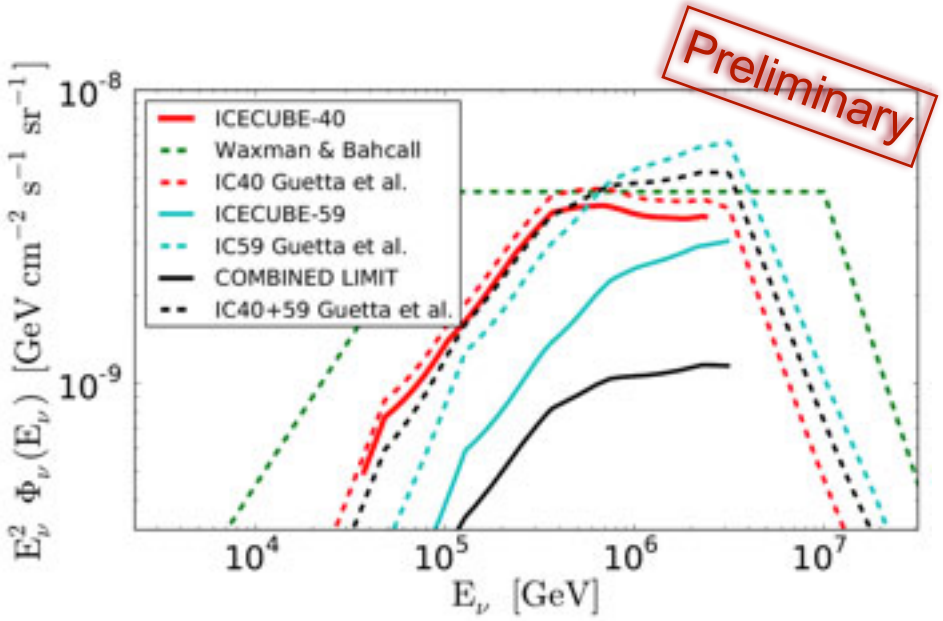
- collapse of massive star
- ultra-relativistic jets
- shock front collission
  - ➔PeV neutrino emission
- total energy release ~10^{52} ergs
  - ➔good candidate for extragalactic cosmic ray flux



IceCube GRB analysis

- ~220 GRBs from GCN
- coincidence analysis
  - ➔time window ($\Delta T \approx 0.1$-100s)
  - ➔direction ($\Delta\Psi_{IceCube} \approx 1°$)
- per-alert emission model
  - 8.4 events expected
  - **no** events observed

➔ serious constraint on GRB models



Follow-up program

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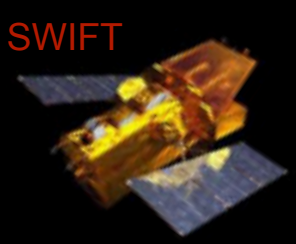
Idea

- trigger follow-up observation by neutrinos in IceCube
  ➔ online neutrino analysis

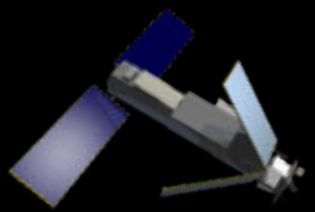


Online analysis

- neutrino selection (~75% purity)
- multiplet analysis ($\Delta T < 100s$, $\Delta\Psi < 4^{o}$)
  ➔ alert (~5 min latency)

Follow-up programs

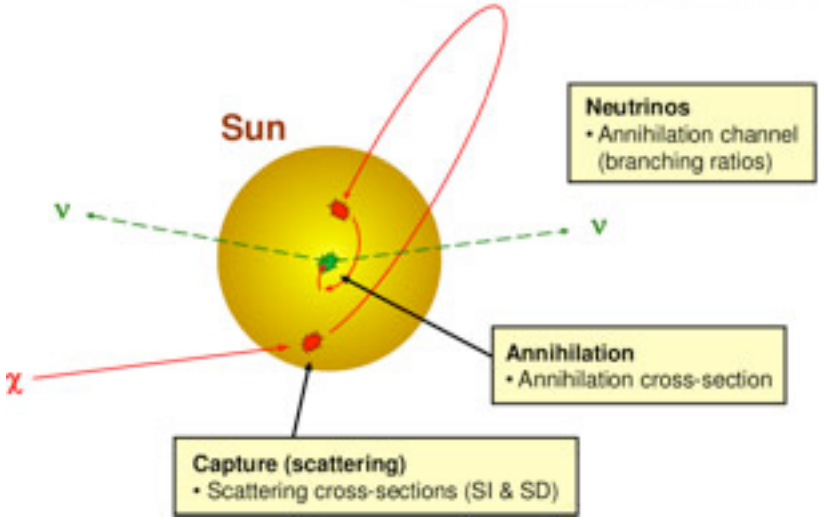
- optical: ROTSE, PTF
  ➔first limit on jet in SNe
- X-rays: SWIFT
- γ-rays: MAGIC, VERITAS

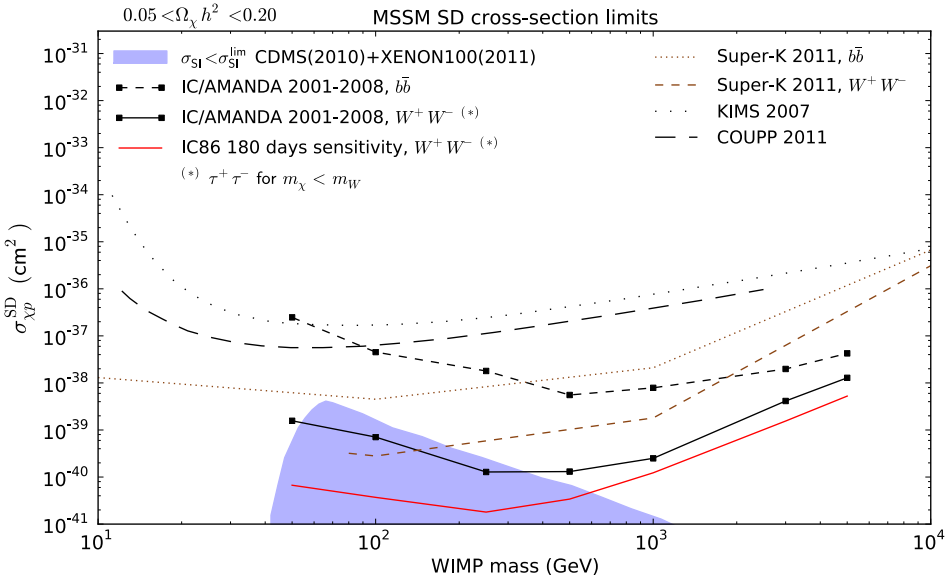


Dark Matter searches

Indirect searches

- $\chi\chi \rightarrow W^+W^-/b\bar{b} \rightarrow \nu\nu$ annihilation in
  - ➔galactic halo [Phys.Rev. D84 (2011) 022004]
    - $\langle\sigma_A \cdot v\rangle < 10^{22}\ cm^3\ s^{-1}$
  - ➔gravitational traps (sun, earth)
    - probe spin-dependent cross-section

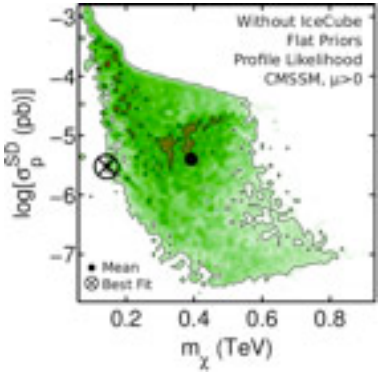


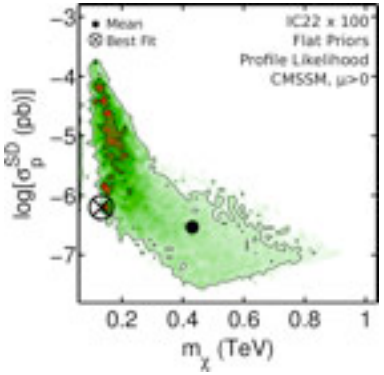


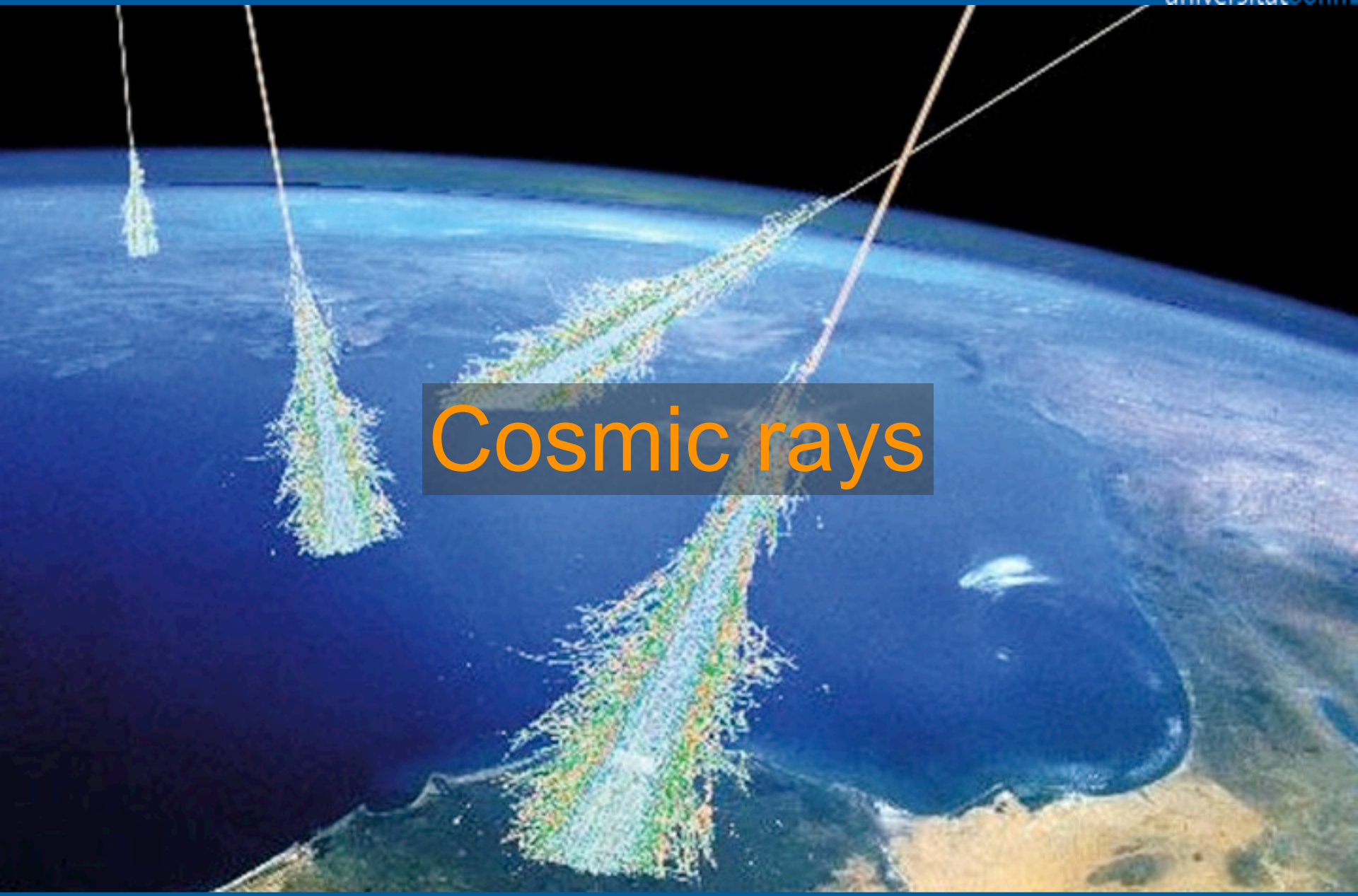
[Phys.Rev. D85 (2012) 042002]

IceCube+AMANDA results

- best limit on spin-dependent cross-sections
  - ➔IC86 will constrain global SUSY fits







Cosmic rays

Charged cosmic rays

IceTop

- sample shower on the ground
- $e^{\pm} \gtrsim 10$ MeV

IceCube

- high-energy muon core
- $\mu^{\pm} \gtrsim 300$ GeV

➔ 3D air-shower array

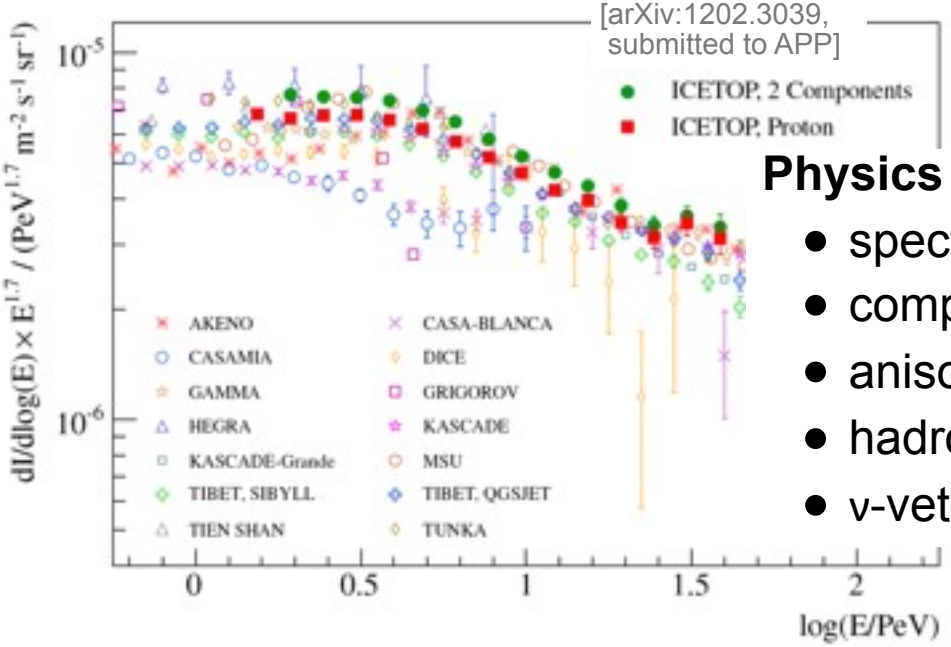
Combined

- $A_{eff} \cdot \Omega \approx 0.3$ km^2 sr
- $E_{prim} \gtrsim 300$ TeV

➔ 10^{10} showers per year

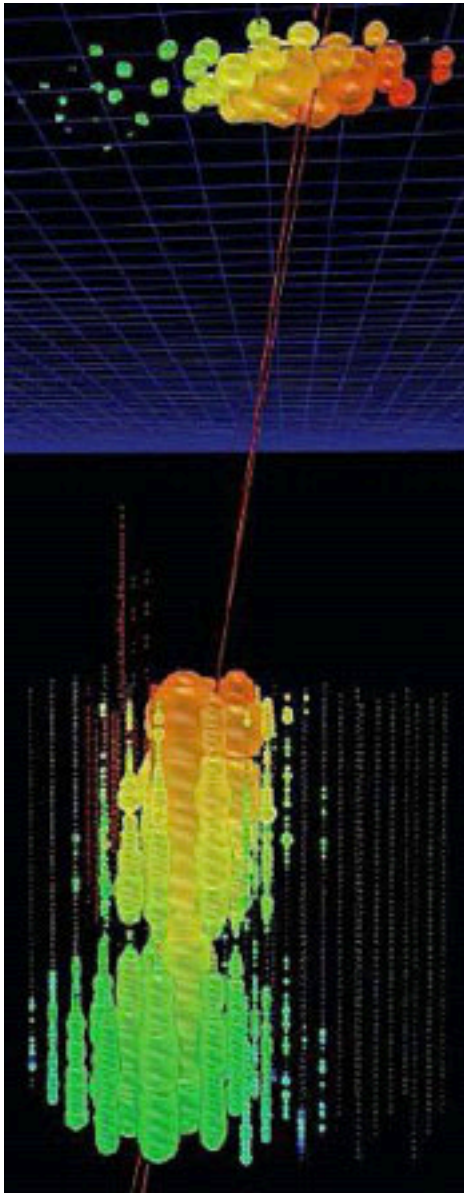
➔ 10^7 with InIce signal

[arXiv:1202.3039, submitted to APP]



Physics program

- spectrum
- composition
- anisotropies
- hadronic interactions
- ν-veto



Multi-scale cosmic ray anisotropies

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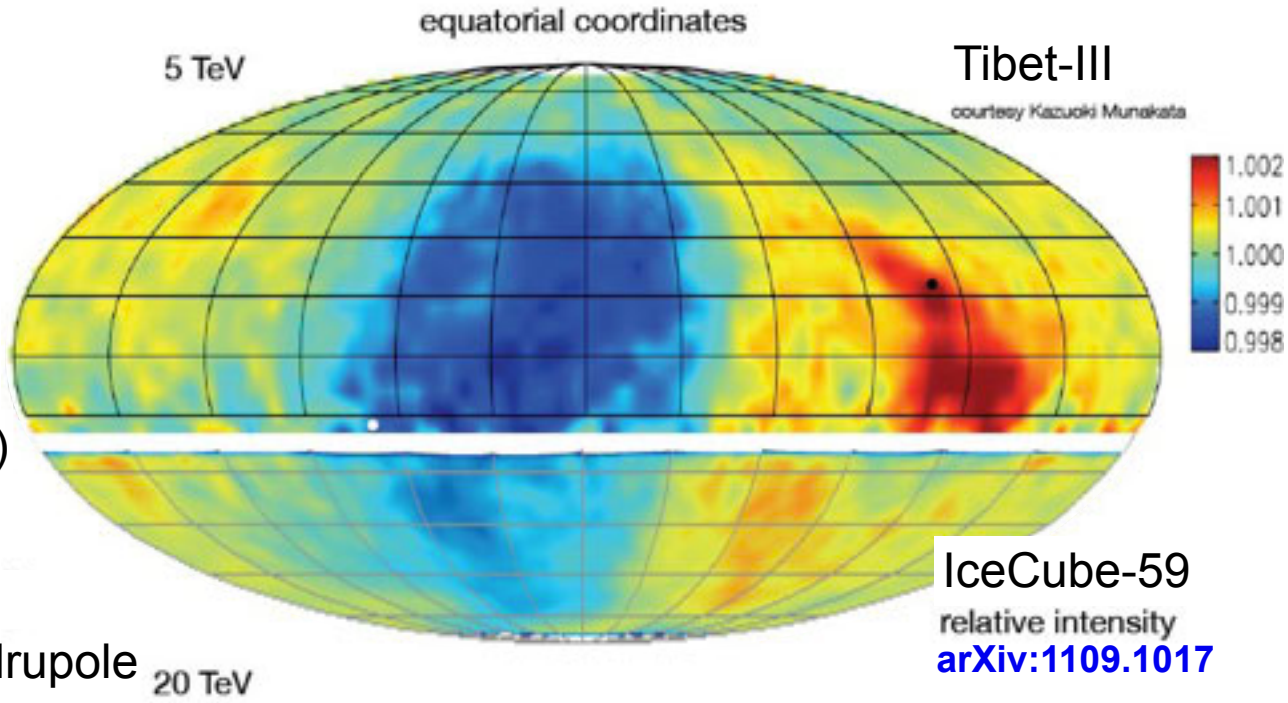
Anisotropy analysis

- 10^{-3} intensity variation
- energy dependent

Dipole moment

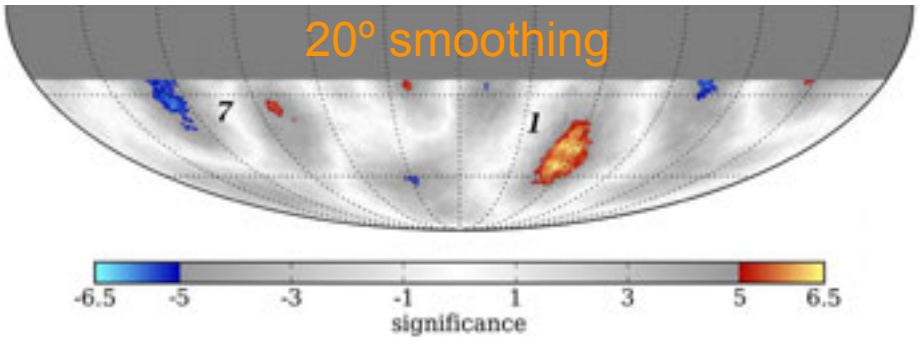
- does **not** correspond to the relative motion in the Galaxy (Compton-Getting effect)

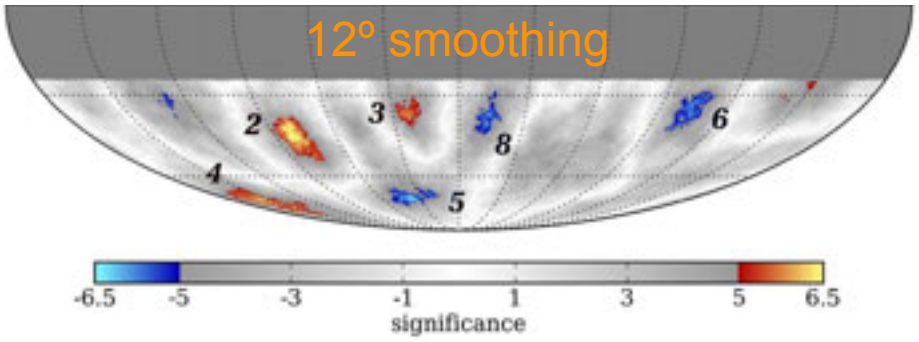


Hot-spot analysis

- subtract dipole and quadrupole
- smooth map on different scales

➔multiple hot-spots observable





Enhancing the cosmic-ray laboratory

Radio emission from air-showers

- geosynchrotron mechanism
  - $e^{\pm}$ deflected in earth B-field

  ➔10ns radio pulse (10-150MHz)

Physics gain

✚ increased $A_{eff} \cdot \Omega$ (veto!)

- signal proportional to integral $e^{\pm}$ component

  ➔additional energy estimator

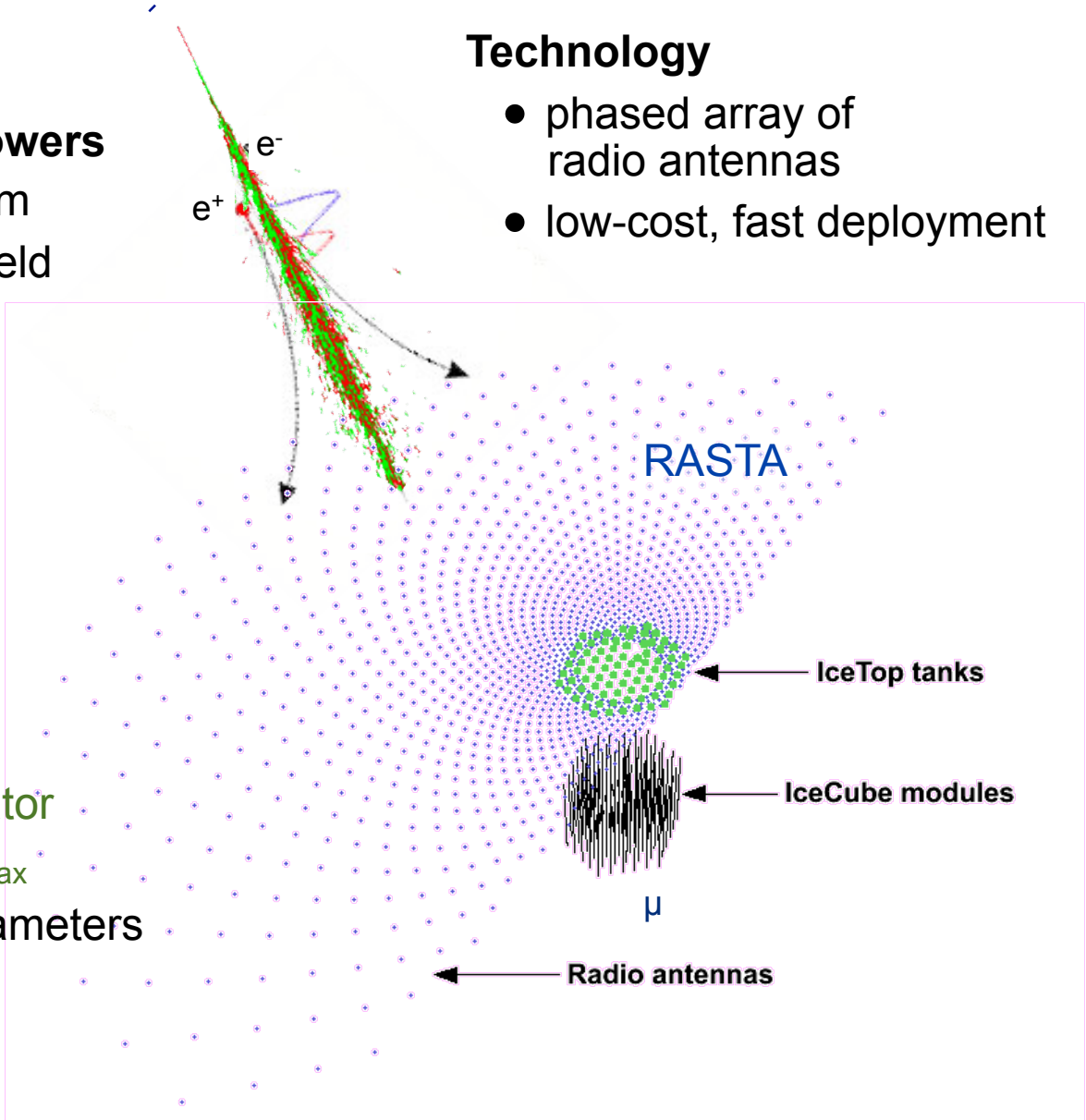
✚ additional sensitivity to X_{max}

- overconstrain shower parameters

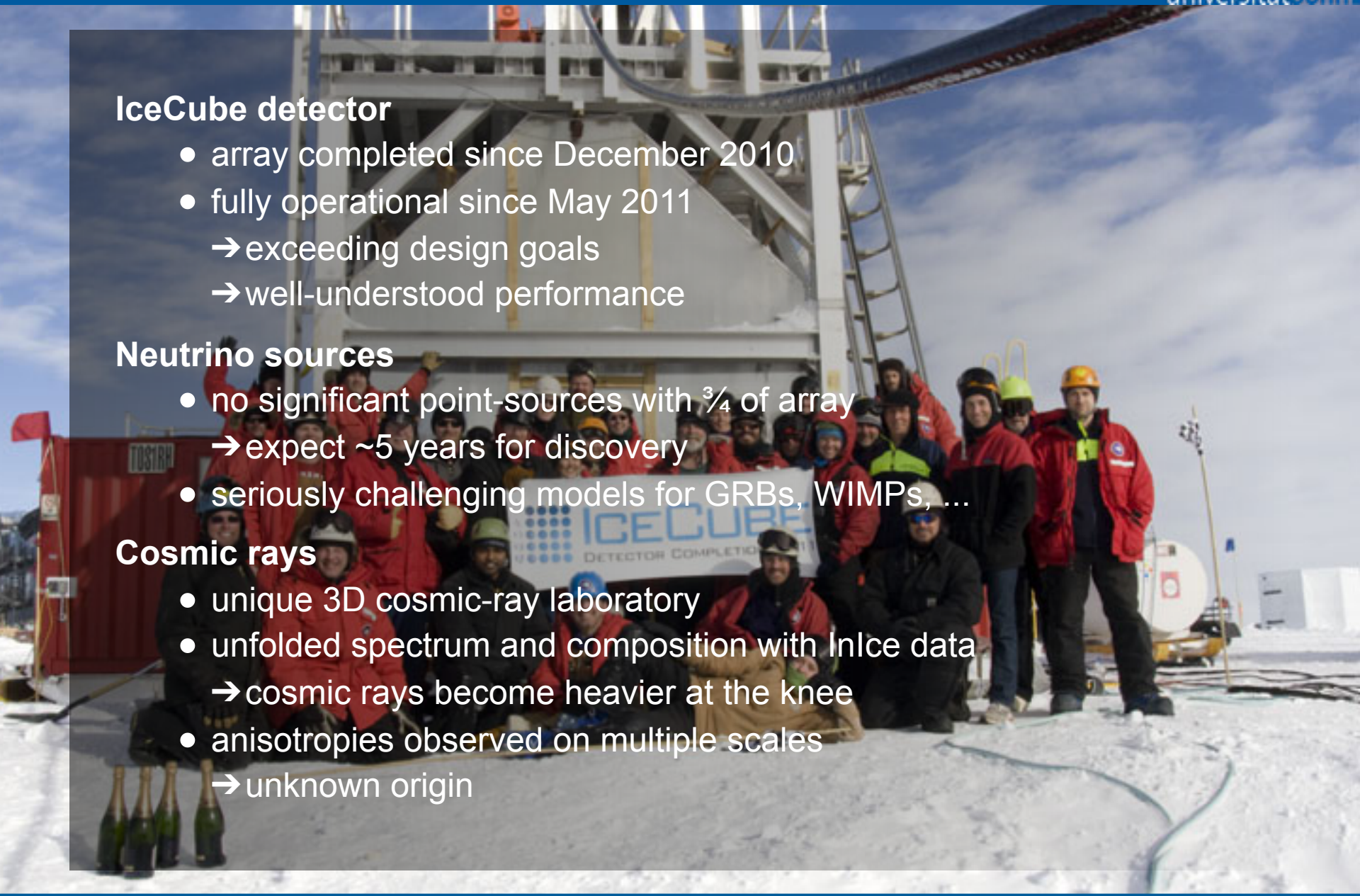
  ➔improve systematics

Technology

- phased array of radio antennas
- low-cost, fast deployment



Summary



IceCube detector

- array completed since December 2010
- fully operational since May 2011
  ➔exceeding design goals
  ➔well-understood performance

Neutrino sources

- no significant point-sources with ¾ of array
  ➔expect ~5 years for discovery
- seriously challenging models for GRBs, WIMPs, …

Cosmic rays

- unique 3D cosmic-ray laboratory
- unfolded spectrum and composition with InIce data
  ➔cosmic rays become heavier at the knee
- anisotropies observed on multiple scales
  ➔unknown origin