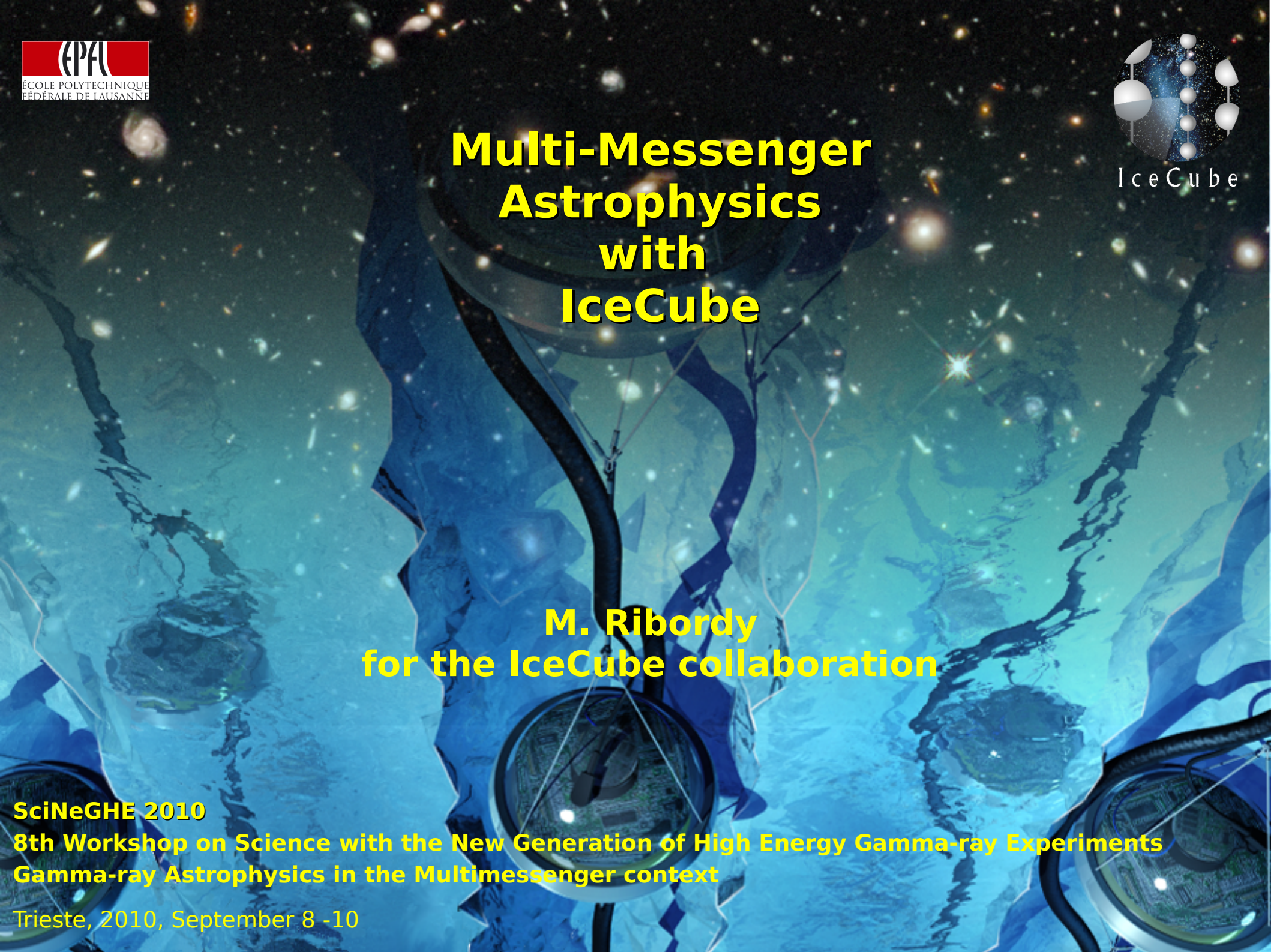


Multi-Messenger Astrophysics with IceCube

M. Ribordy
for the IceCube collaboration

SciNeGHE 2010
8th Workshop on Science with the New Generation of High Energy Gamma-ray Experiments
Gamma-ray Astrophysics in the Multimessenger context

Trieste, 2010, September 8 -10

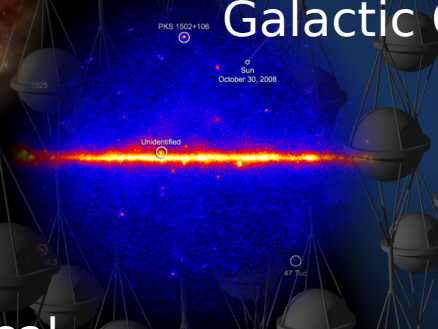
IceCube Scientific Program

Exotics

AGN

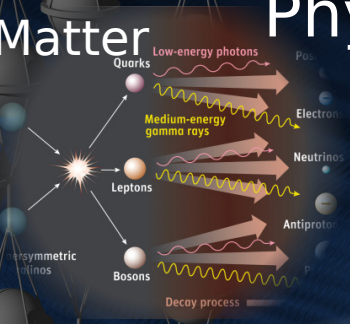
GRB

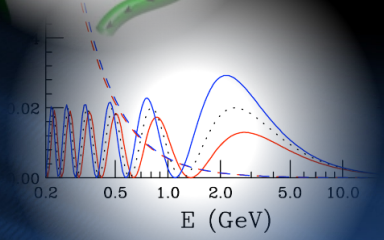
Galactic Center



Particle Physics

Dark Matter





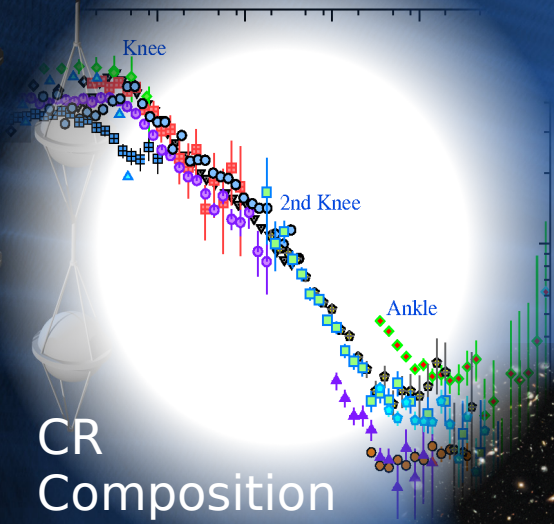
Oscillations

Astrophysical Neutrinos

Origin of Cosmic Rays

SNR

X-Ray Binaries



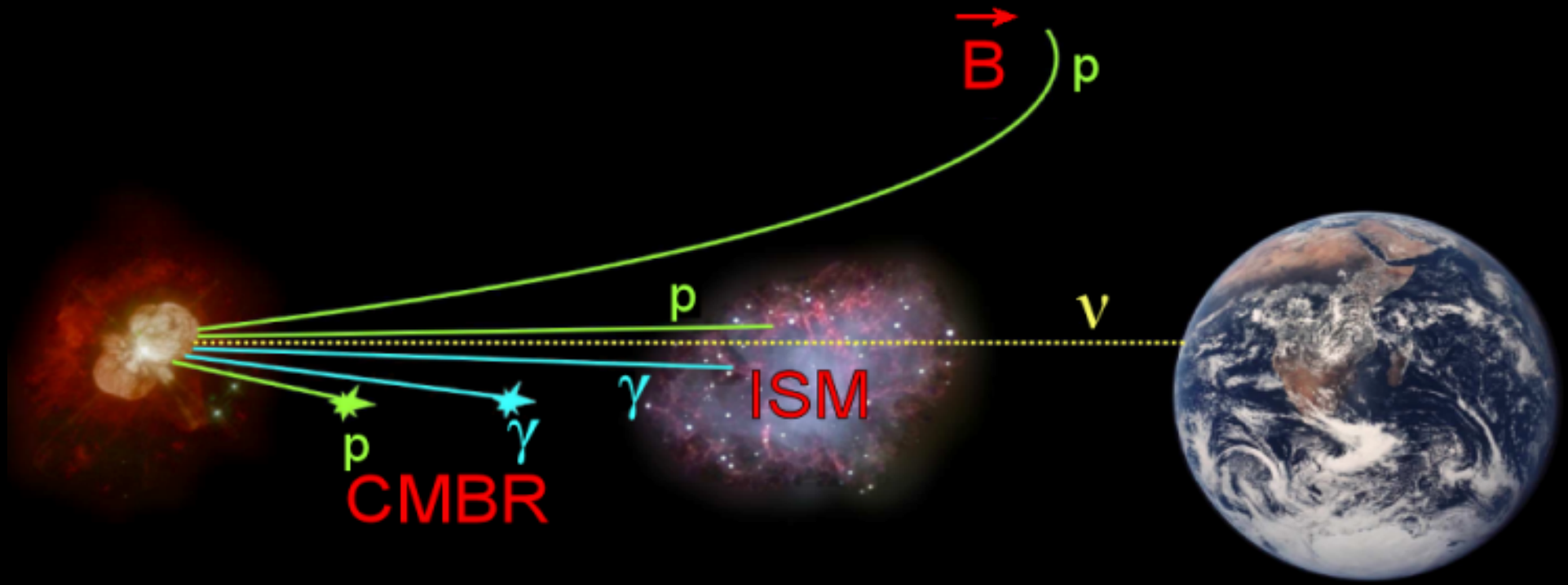
CR Composition

Cosmogenic ν

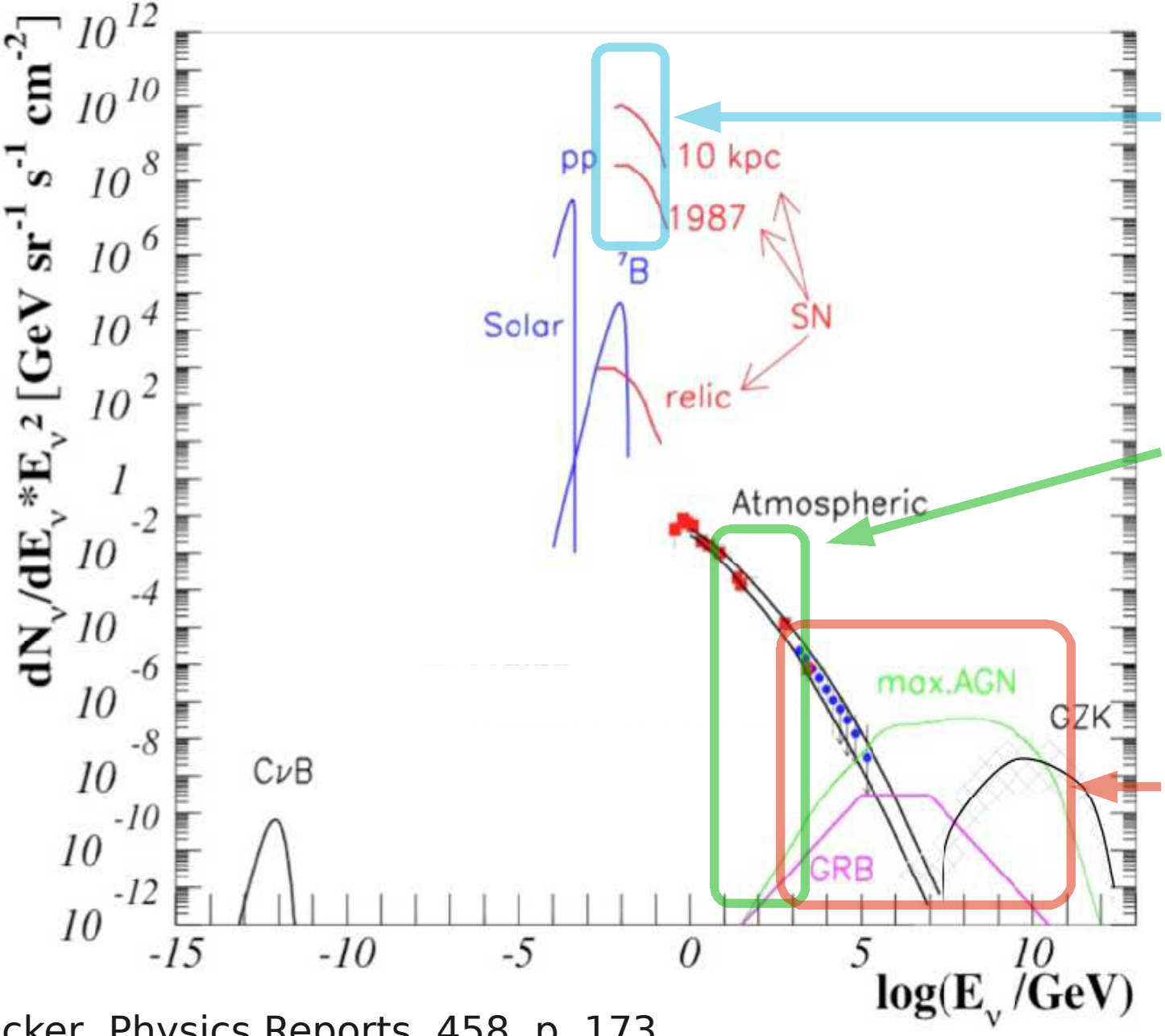
Multi-messenger approach: Contrast and combine measurements

Multi-Messenger Astrophysics

- Protons: below 1 EeV deflected by mag. fields, interact with CMB above ~10^{20} eV
- Photons: e.g. distorted nearby blazar spectra above >TeV
- Neutrinos: escape optically thick sources, difficult to detect but unambiguous signatures of acceleration of hadrons



Neutrino Energy Ranges in IceCube



MeV:
Galactic
Supernovae

GeV/TeV:
DM searches
ν oscillations

>TeV energies:
Astrophysical ν
Cosmogenic ν

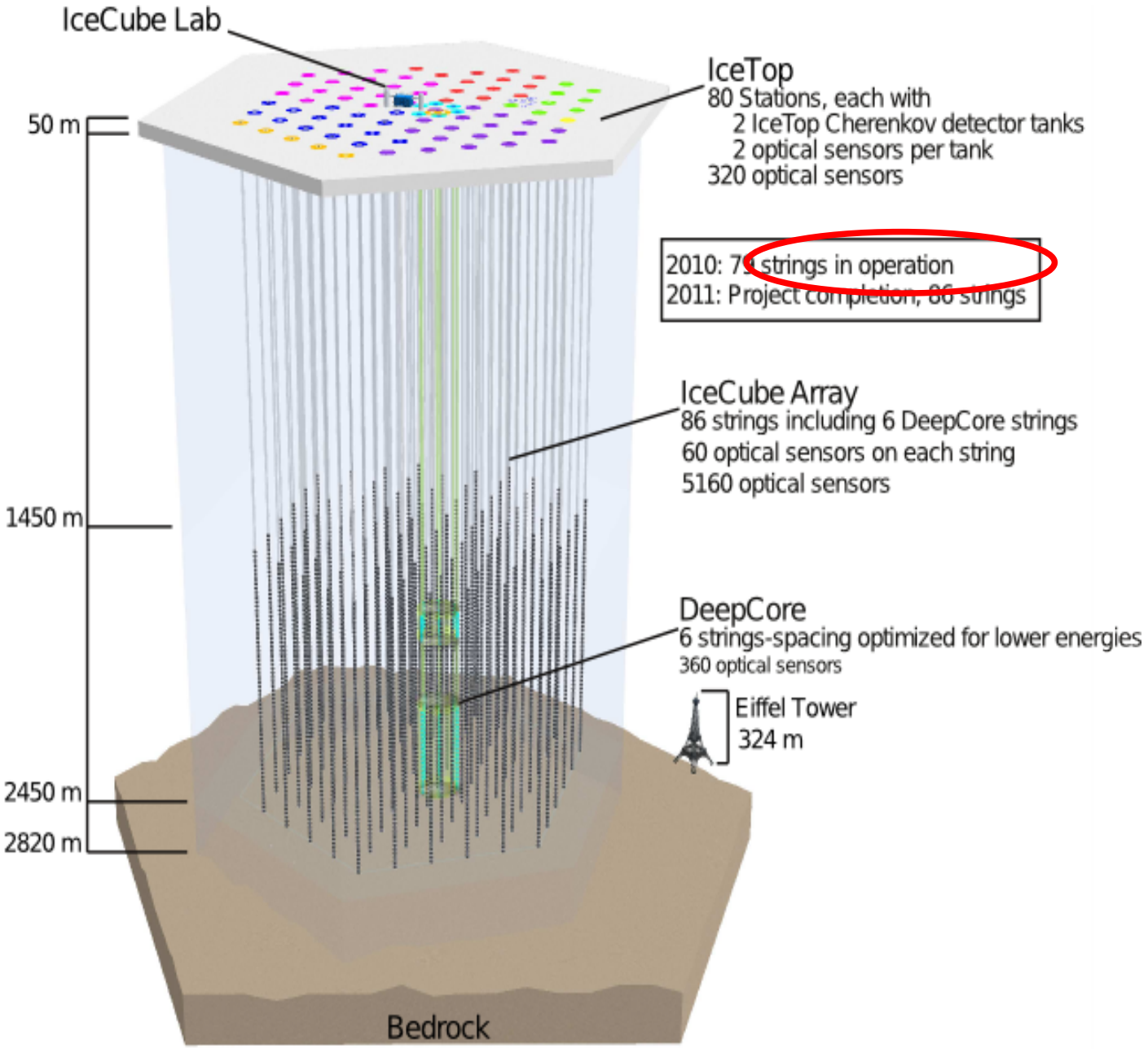
J. Becker, Physics Reports, 458, p. 173

The IceCube Observatory: Status

Since April this year:

- IC79 in operation
- IceTop: 79 stations
- includes 6 DeepCore strings

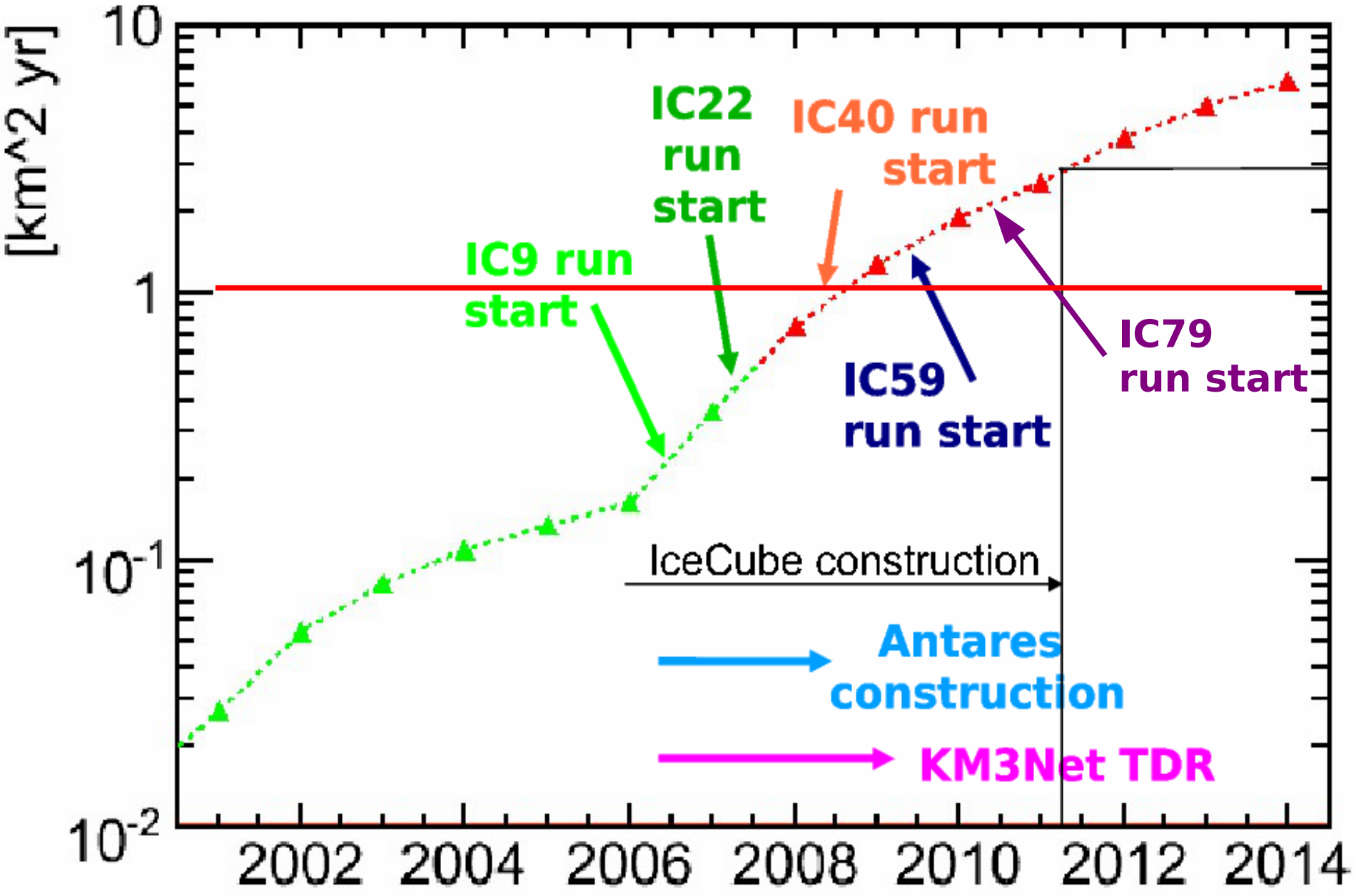
- missing 7 strings will be deployed next season
  → complete IceCube!



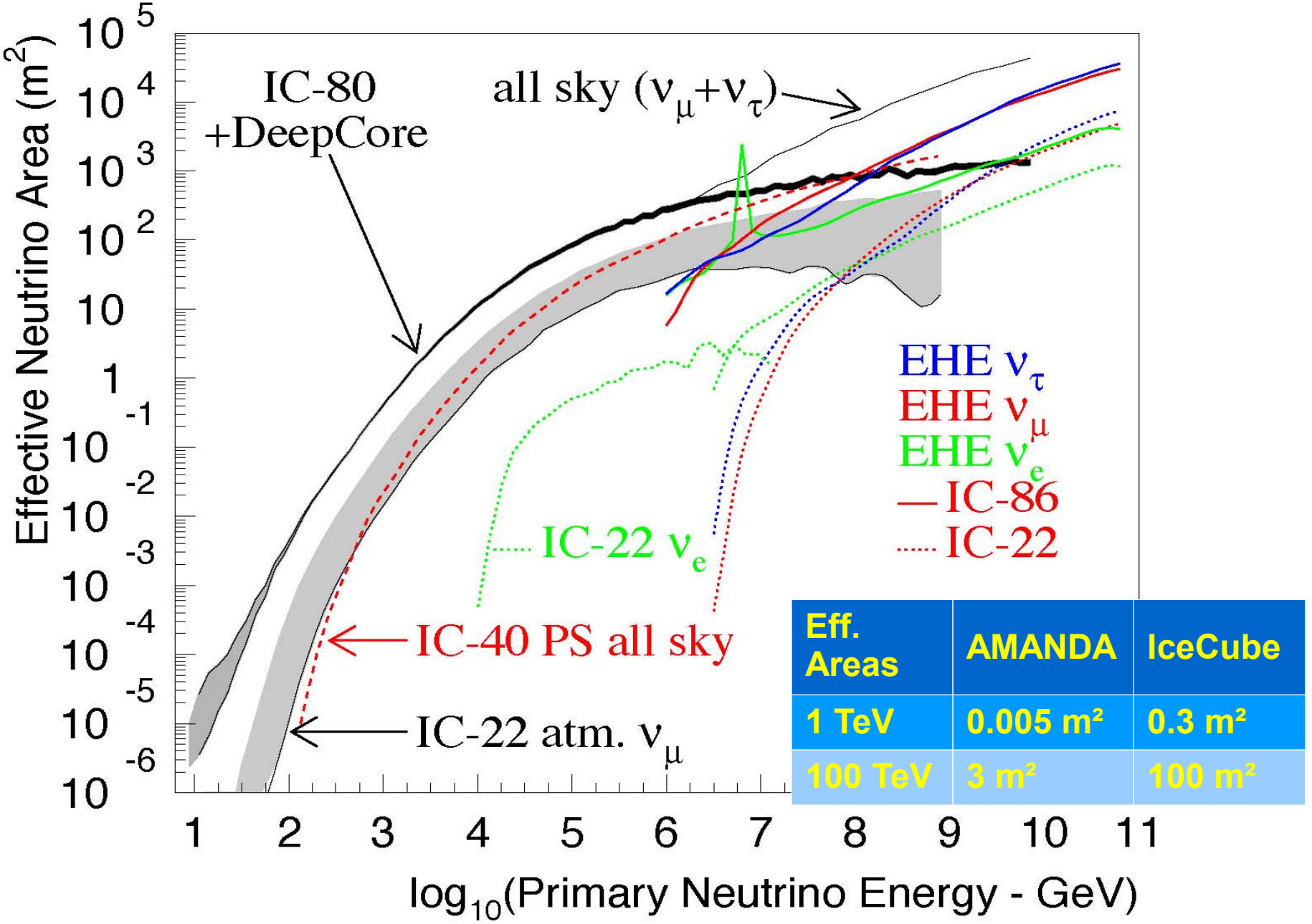
Evolution of the DAQ:

	Rate	Livetime
IC-22	800Hz	95.9%
IC-40	1400Hz	97.0%
IC-59	1800Hz	98.2%
IC-79	2200Hz	t.b.d.

IceCube Integral Exposure to Muons @ 100 TeV



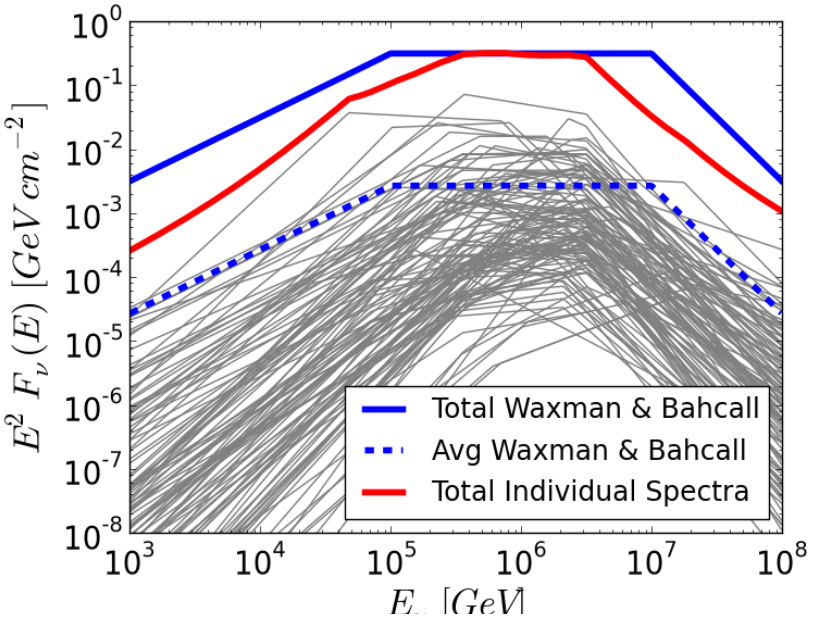
IceCube Effective Areas for Neutrinos

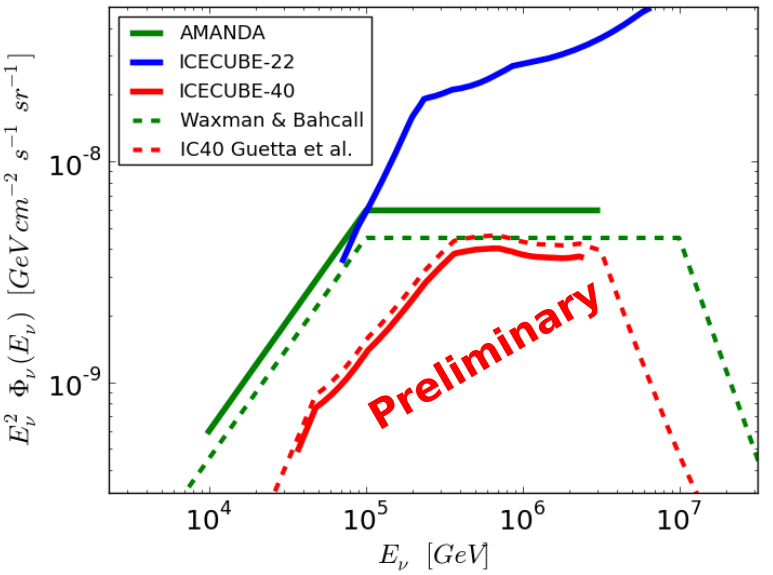


Eff. Areas	AMANDA	IceCube
1 TeV	0.005 m²	0.3 m²
100 TeV	3 m²	100 m²

IceCube-40: Search for Neutrinos from GRBs

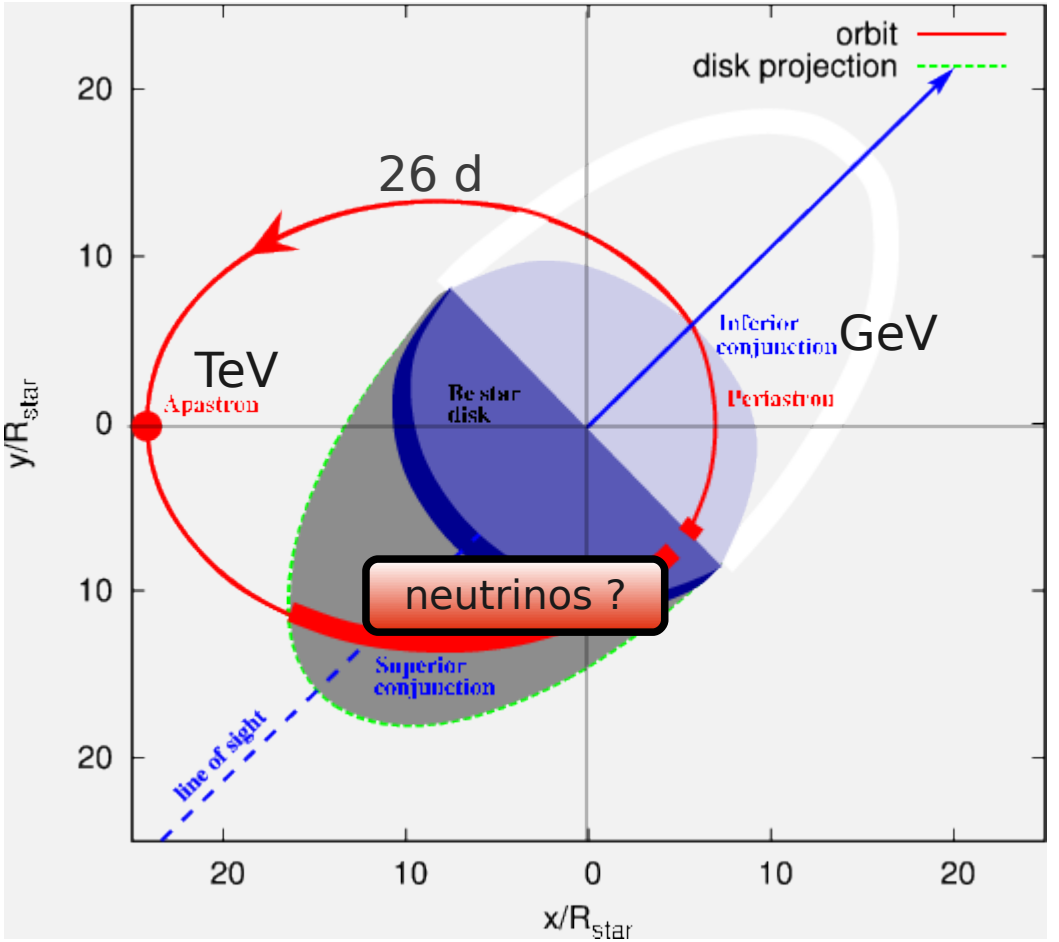
- Based on 117 satellite detected GRB in the Northern Hemisphere (mostly long bursts detected by Fermi)
- Unbinned log-likelihood model-dependent search:
  Individual burst neutrino flux predictions based on redshift, fluence and break energy ($\rightarrow\Gamma$)
  (after Guetta *et al*, Astropart. Phys., 20, 429 (2004))
- No event candidates
  → Waxman-Bahcall flux excluded at better than 90% confidence level





Neutrino Flux from LS I +61 303: Model I

- Together with LS 5039, the only two X-ray binaries strongly emitting in the GeV band and seen at >TeV
- However: origin of HE emission still debated
- Commonly assumed: γ-ray radiation from the interaction of the relativistic outflow from the compact object with the non relativistic wind and radiation from the companion massive Be star

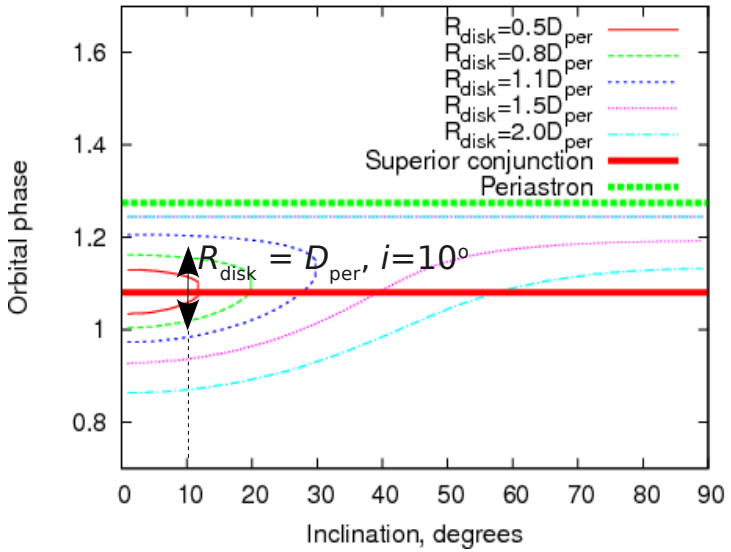


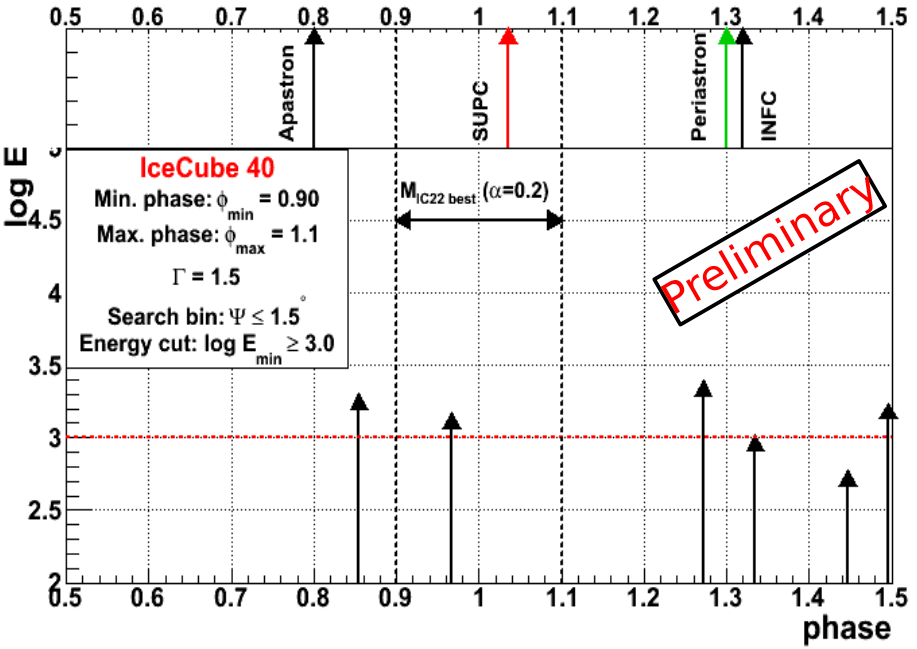
- Fermi GeV cutoff + max. at INFC (isotropic synchrotron radiation and interaction rate is greatest)
- MAGIC / VERITAS TeV radiation around apastron (do not pair-produce with UV radiation)

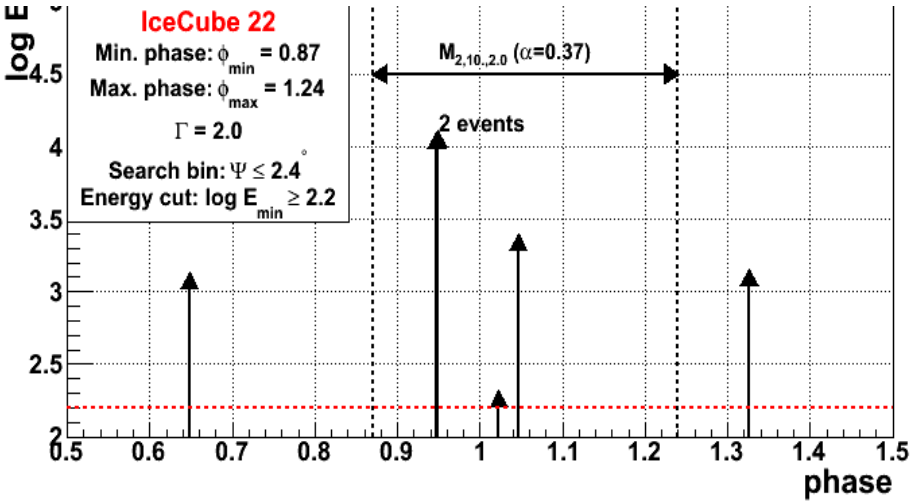
hadronic model with hard protons $\rightarrow \nu$ emission when compact object lying behind the Be star disk w.r.t. the line of sight
(PRD**79**(2009)043013; ArXiv:0912.3821)

Neutrino Flux from LS I +61 303: Results

- Search was done with IceCube 22 and 40 string data
- The stellar disk was assumed to be perpendicular w.r.t. line of sight (max. interaction rate) and with sizes in the range $D_{per}/2$ and $2D_{per}$, assuming hard and Fermi-accelerated proton spectra





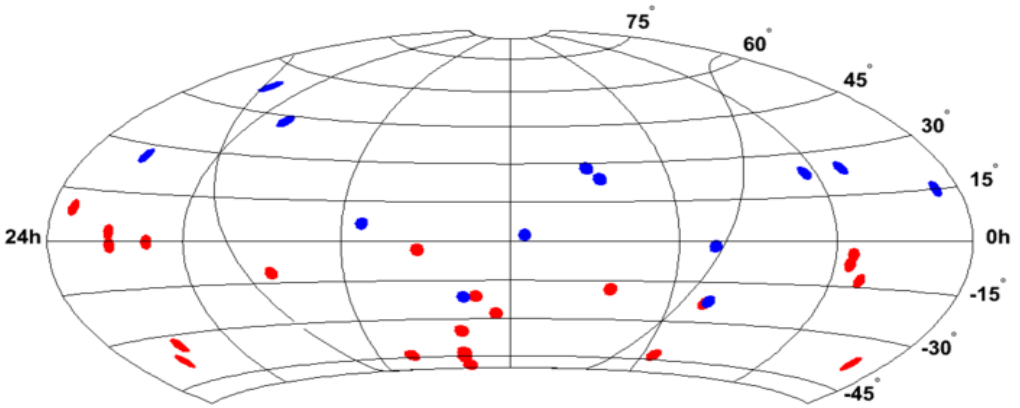


- Black: event candidates within the optimal search bin
- Search results (post-trial p-values):
  - IC22: ~6%
  - IC40: ~65%

  } → not significant!

- First search based on periodic neutrino flux predictions
  → Boost discovery potential

IceCube-22 UHECR Correlation Study



13 HiRes and 22 Auger events
> 57 EeV
in IceCube-22 UHE field of view

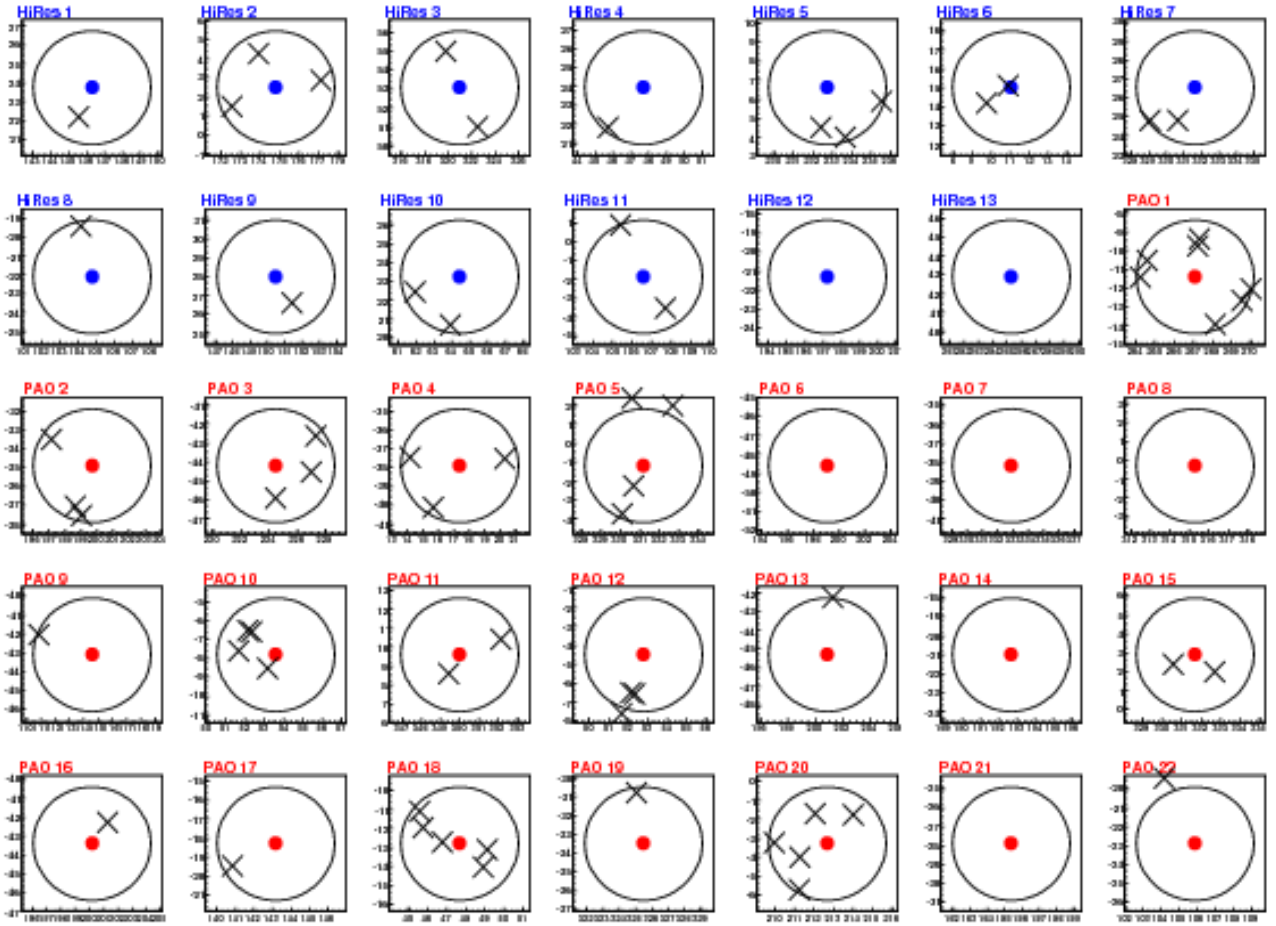
3° search bin selected a priori
(allow mag. deflection offset
between UHECR and source)

Result:
- 60 events observed
- 43.7 events bkg. expectation

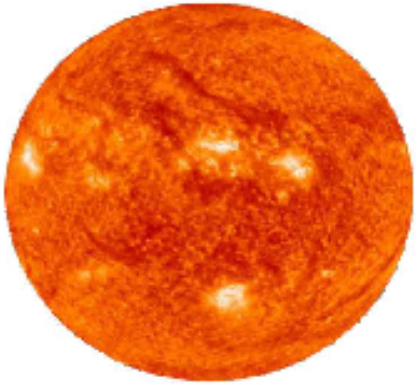
At 2.3 sigma significance (1% p-value), no evidence claimed for association.

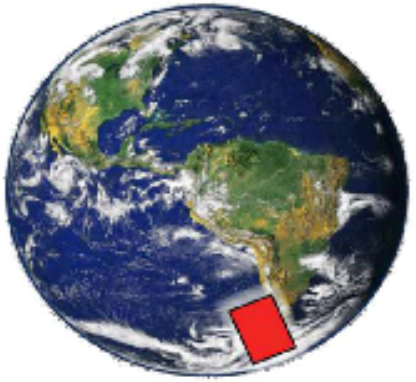
Follow-up:
- updated Auger data set
- IceCube-40 data set

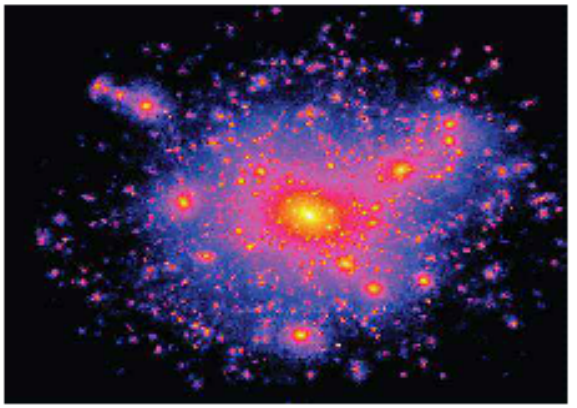
Each set has ~ 2x more events



IceCube Dark Matter Searches

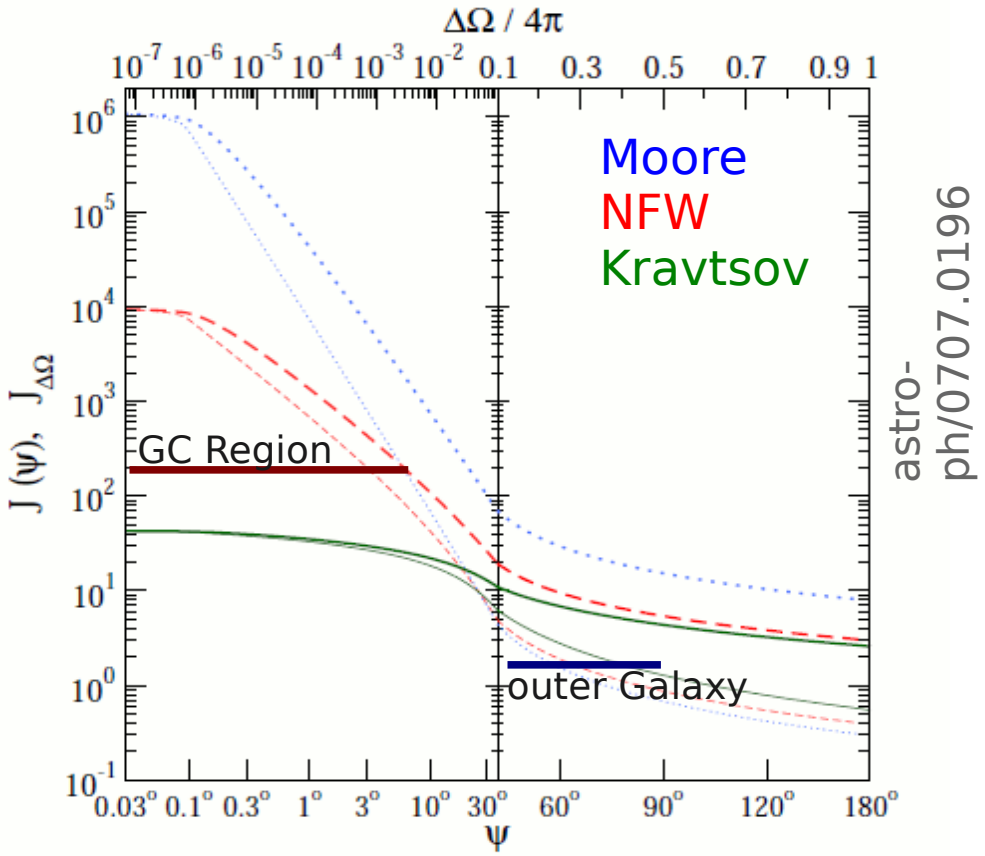




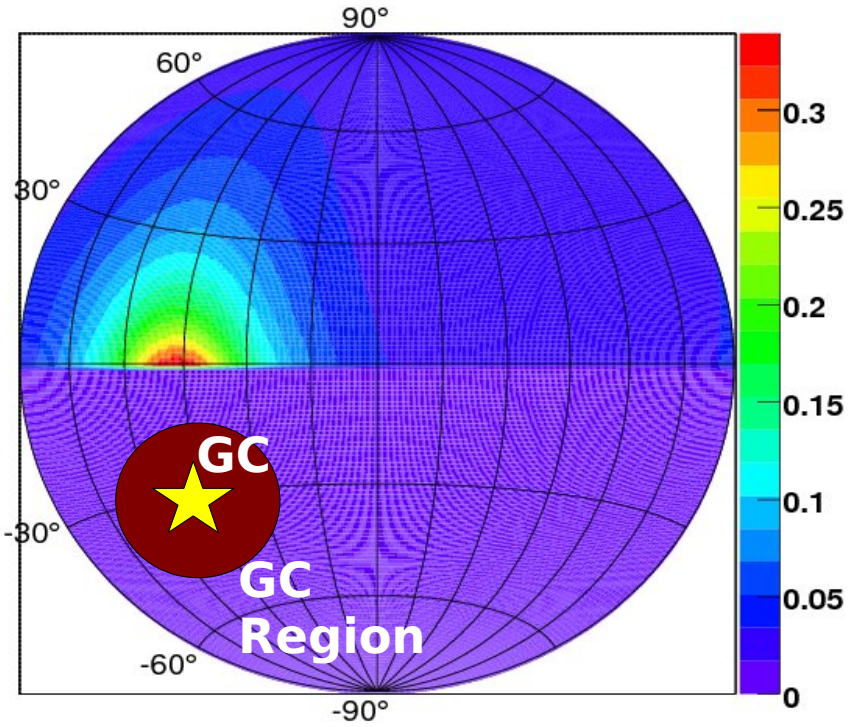


Solar	Earth	Halo
Neutrino Flux, Scattering cross section	Neutrino Flux, ?	Neutrino Flux, Self annihilation cross section
Muon neutrinos	Muon neutrinos	Muon neutrinos, Cascades
Background off source on source	Background simulations	Background off source on source
Excess	Excess	Anisotropy, Spectrum
IceCube (+Deep Core)	IceCube (+Deep Core)	DeepCore (+IceCube)

IceCube Galactic DM Halo limit



astro-ph/0707.0196



Two search regions for DM from the Galactic Halo:

Outer Galactic region:

- DM density less model dependent
- weak neutrino flux, less atm. background
  → Icecube 22 Search

Galactic Center:

- DM density depends on halo model
- stronger neutrino flux, huge atm. background
  → Icecube 40 Search

see ArXiv:0912.5183

IceCube Galactic Halo WIMPS limit

- No excess of events in the on source region in both analyses

- limit WIMP self annihilation x-section

  from Icecube 40:

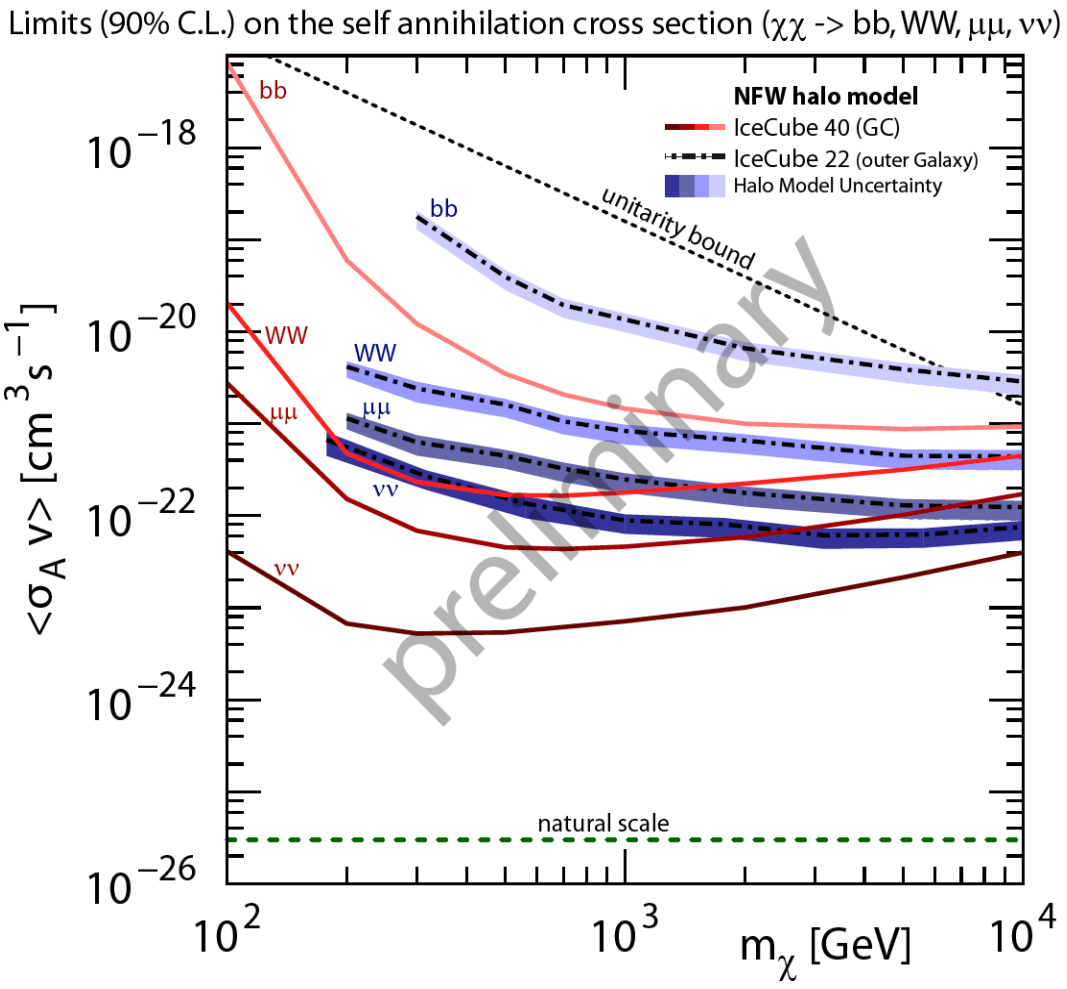
  - Limits by GC analysis more restrictive, but

    halo model dependent

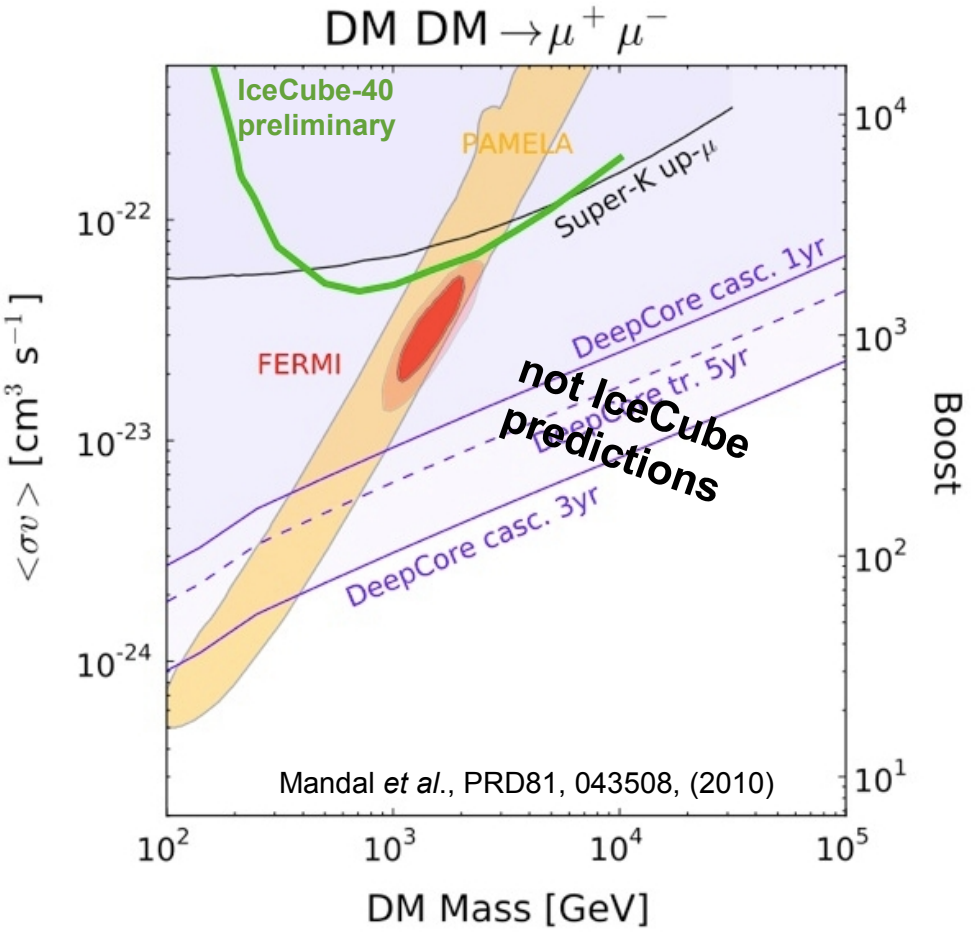
- from Icecube 22:

  - Outer Galaxy analysis more sensitive for large WIMP masses, and

    is mostly halo model independent



Multi-Messenger search for dark matter
In the light of HESS, PAMELA and Fermi

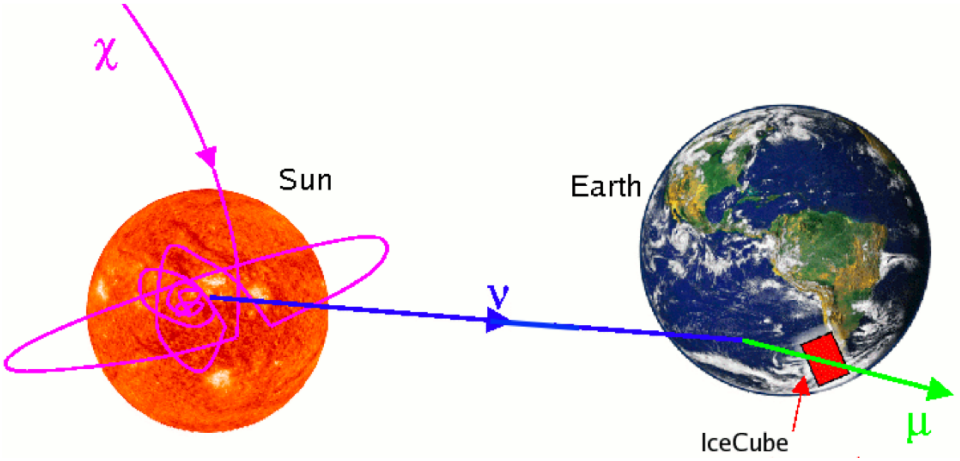


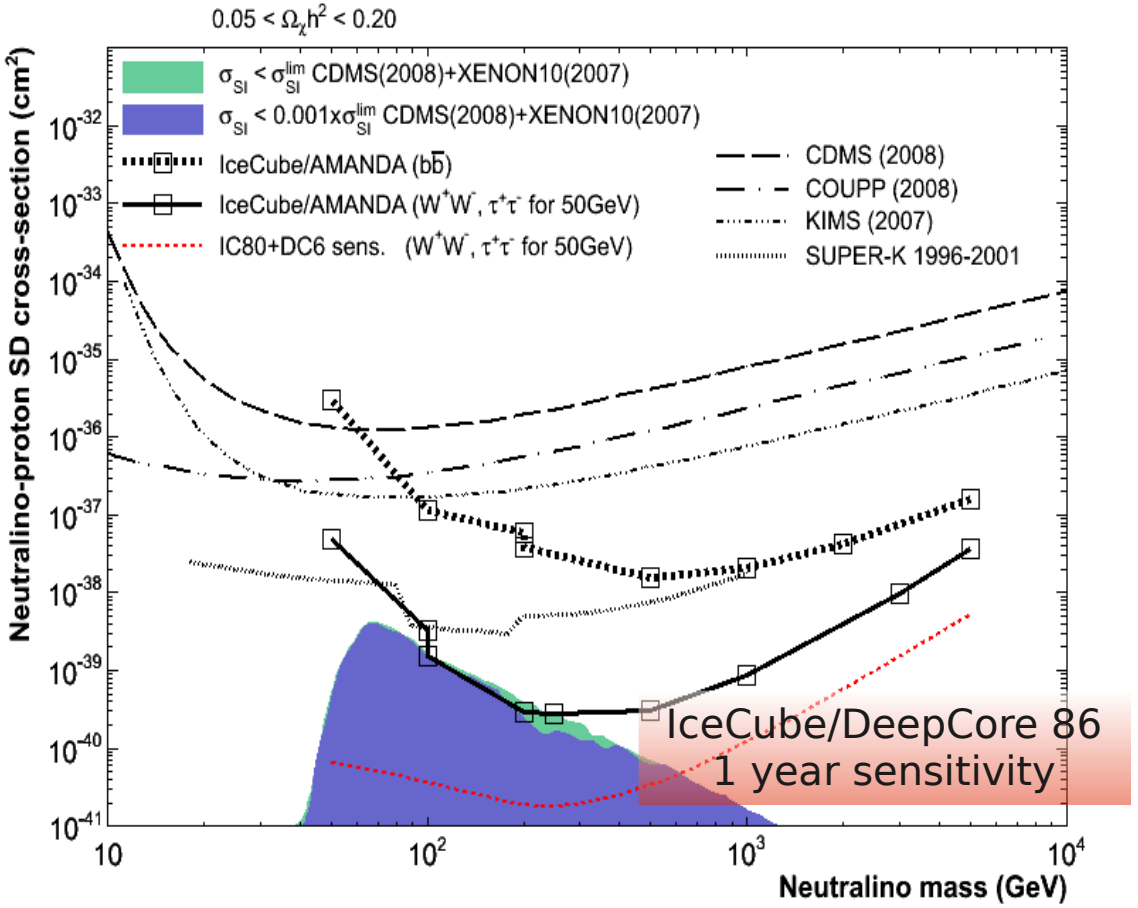
- Positron fraction above few GeV (PAMELA) and electronic component excess above few 10's of GeV (HESS/Fermi) → leptophilic DM
- Favored region may be soon excluded by IceCube.
- Current generation astroparticle physics experiments exploiting various messengers are complementary and competitive

Also not equivalent:

- Electronic component measured with HESS PAMELA Fermi: locally probing DM annihilation
- IceCube: Integrated DM annihilation along the line of sight

IceCube-22/AMANDA Solar Wimp limits





Abbasi *et al.*, PRL **102** (2009) 201302

- Neutralinos gravitationally trapped
- Neutralinos concentrate in the core where they pairwise annihilate
- Equilibrium between annihilation and capture rates is assumed
- The SD cross section limit is extracted from the muon flux limit, for a given annihilation channel
- In contrast to nuclear recoil experiment (setting σ_{SI} limits) and excluding astrophysical uncertainties, the class of model which can be excluded are with $\sigma_{SI} \ll \sigma_{SD}$

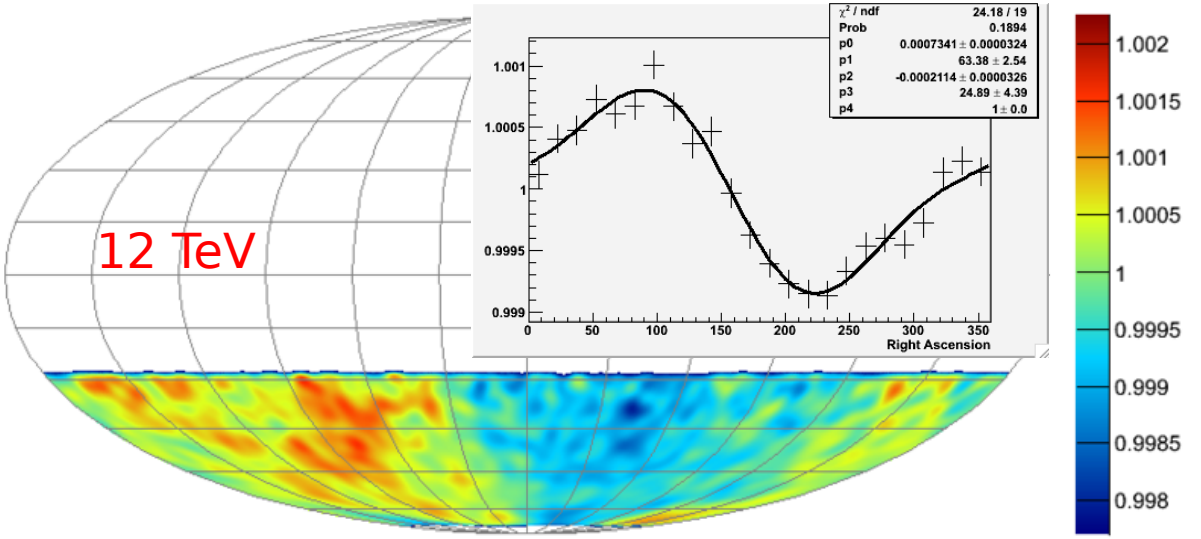
IceCube-22 Large Scale Anisotropy of Cosmic Rays

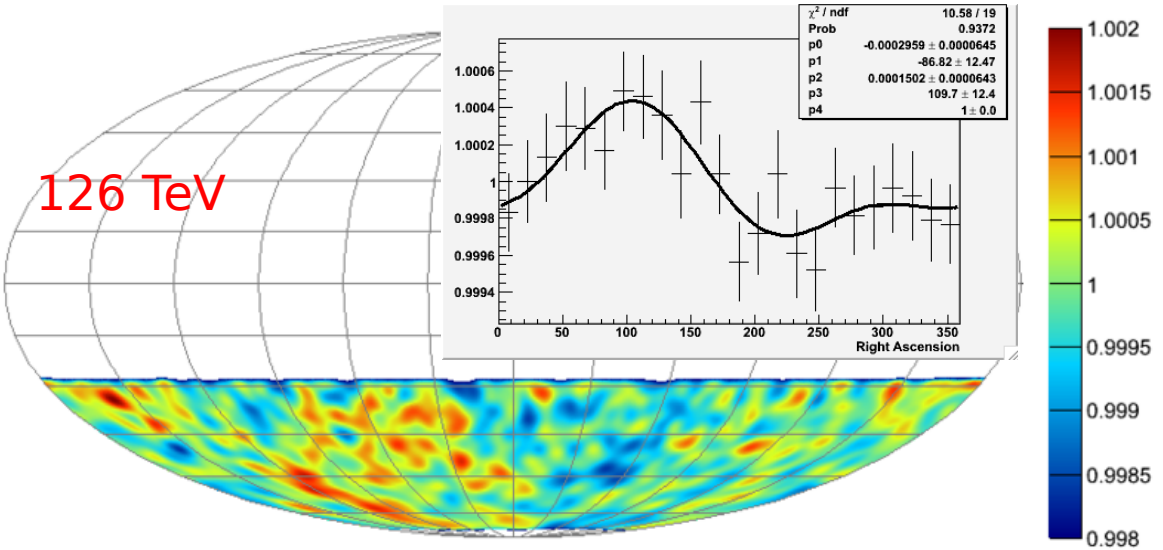
- Data: IceCube-22
  4.3×10^9 atm. muons
- Median angular resolution:
  3 deg
- Median energy per cosmic ray particle:
  ~20 TeV

- Observe large scale anisotropy incompatible with CG effect

- Amplitude decreases with increasing CR energy

- Local magnetic field features over pc scales or streaming of CR from nearby sources, e.g. VELA

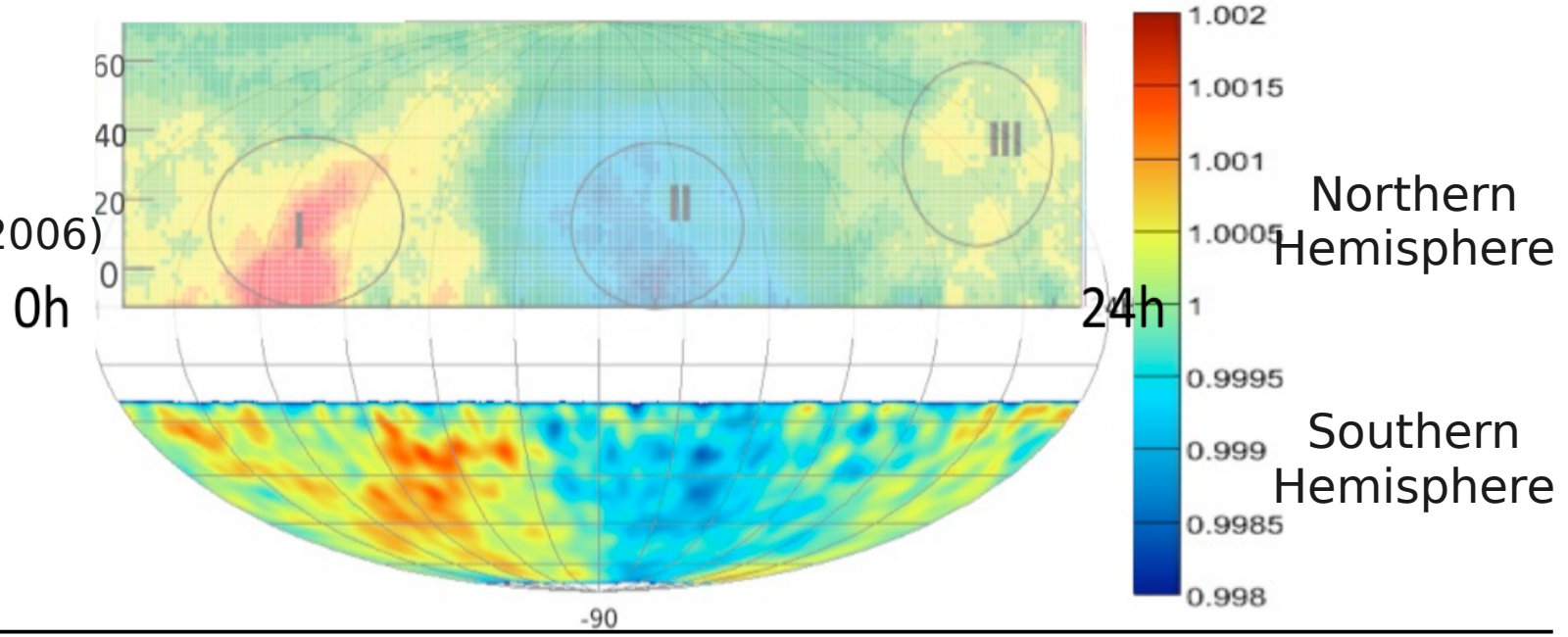




R. Abbasi et al. 2010 ApJ 718 L194

IceCube-22 Large Scale Anisotropy of Cosmic Rays

Tibet Array
M. Amenomori *et al*,
Science, 314, 439 (2006)

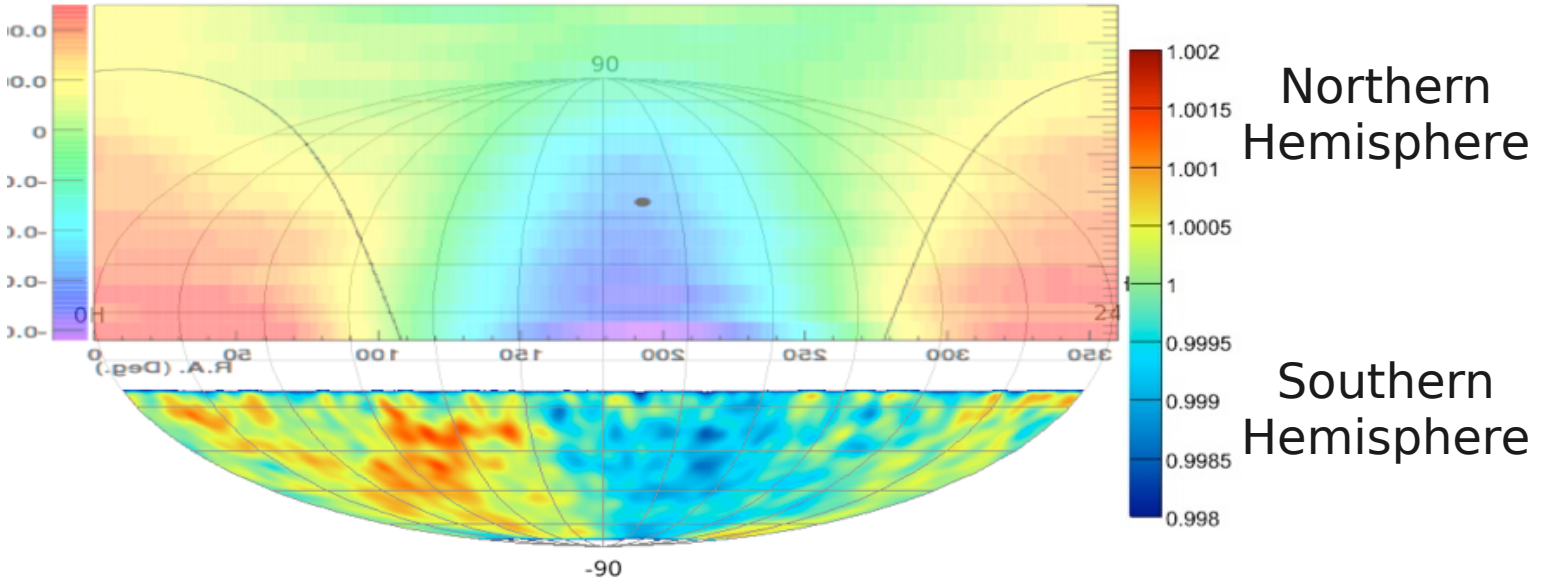


Northern Hemisphere

Southern Hemisphere

IceCube-22

Milagro
A. A. Abdo *et al*,
ApJ 698, 2121 (2009)



Northern Hemisphere

Southern Hemisphere

IceCube-22

R&D Projects for GZK neutrino detection
Radio and Acoustic

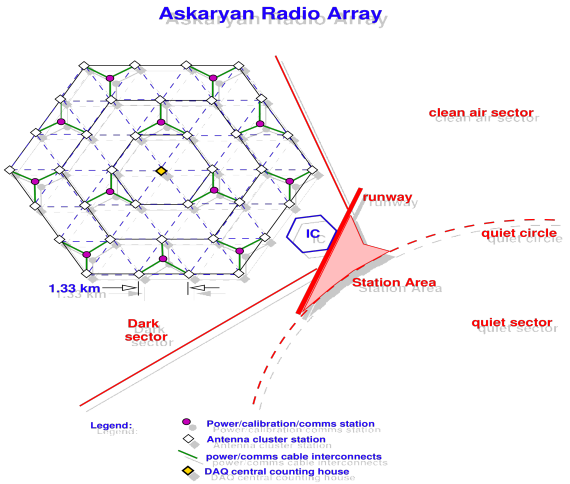
Above $E_p \sim 10^{20}$ eV: $p\gamma_{CMB} \rightarrow \nu_{GZK}$

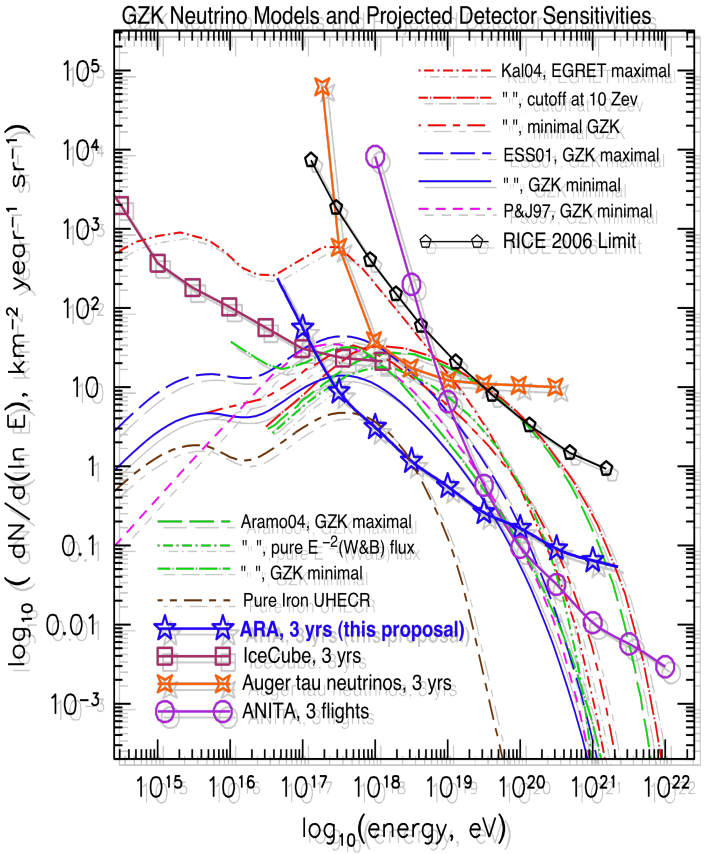
Demultiplication of the neutrinos + large interaction cross section
→ measure the GZK neutrino flux and partly recover the degraded information carried by UHE CR

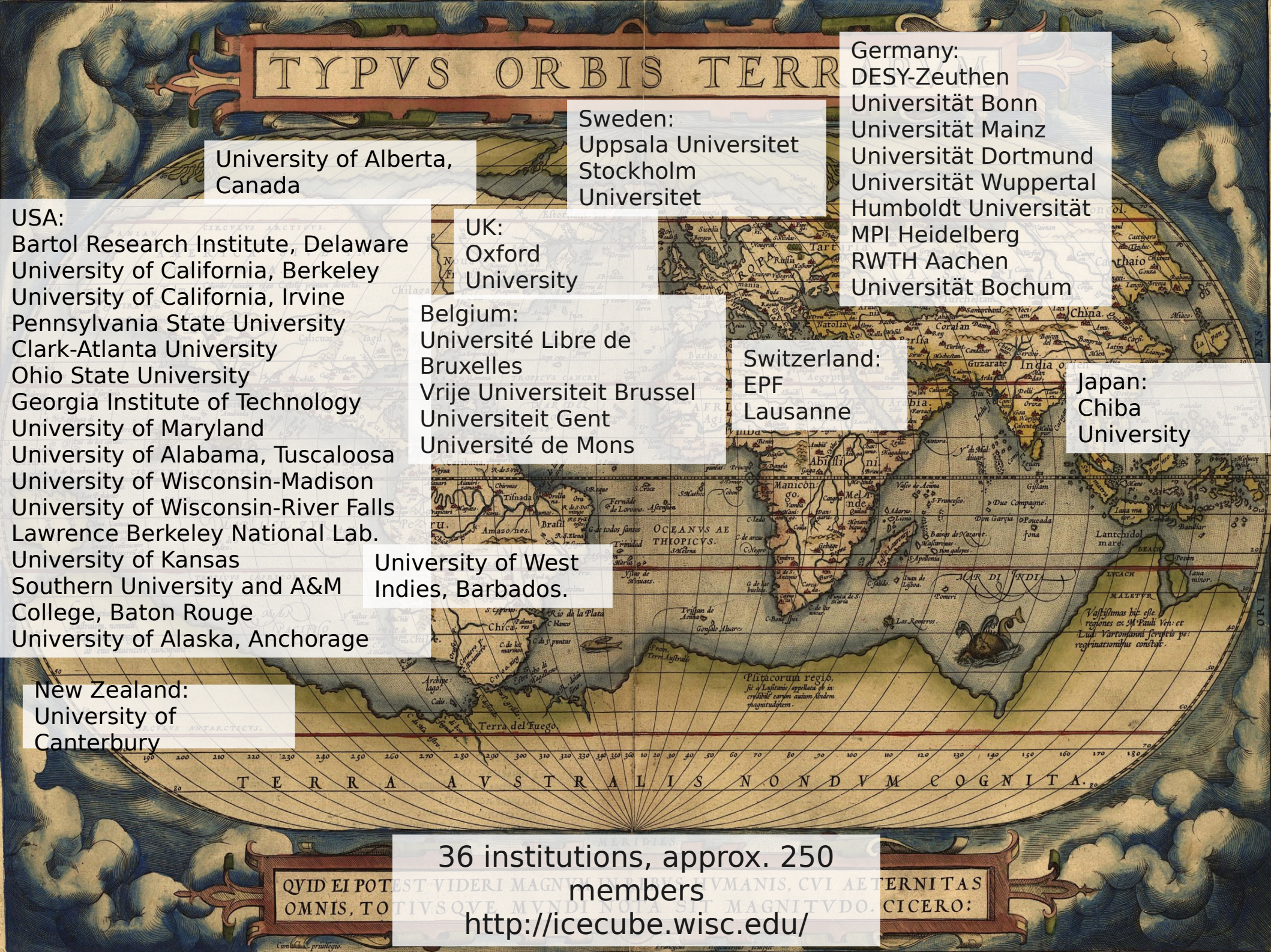
Signatures: coherent radio Cherenkov and acoustic pancake signals

Acoustic neutrino detection feasibility:
To be demonstrated with the measurement of missing ice properties this Winter (absolute noise level and spectral characteristics) which may impede the applicability of the technique if inadequate

Askaryan Radio Array:
GZK neutrino flux sensitivity at the most pessimistic level (pure iron)






TYPVS ORBIS TERR
University of Alberta, Canada
Sweden:
Uppsala Universitet
Stockholm Universitet
Germany:
DESY-Zeuthen
Universität Bonn
Universität Mainz
Universität Dortmund
Universität Wuppertal
Humboldt Universität
MPI Heidelberg
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University of California, Irvine
Pennsylvania State University
Clark-Atlanta University
Ohio State University
Georgia Institute of Technology
University of Maryland
University of Alabama, Tuscaloosa
University of Wisconsin-Madison
University of Wisconsin-River Falls
Lawrence Berkeley National Lab.
University of Kansas
Southern University and A&M College, Baton Rouge
University of Alaska, Anchorage
UK:
Oxford University
Belgium:
Université Libre de Bruxelles
Vrije Universiteit Brussel
Universiteit Gent
Université de Mons
Switzerland:
EPF Lausanne
Japan:
Chiba University
University of West Indies, Barbados.
New Zealand:
University of Canterbury
OCEANVS AETHIOPICVS.
MAR DI INDI
TERRA AVSTRALIS NONDVM COGNITA.
36 institutions, approx. 250 members
http://icecube.wisc.edu/