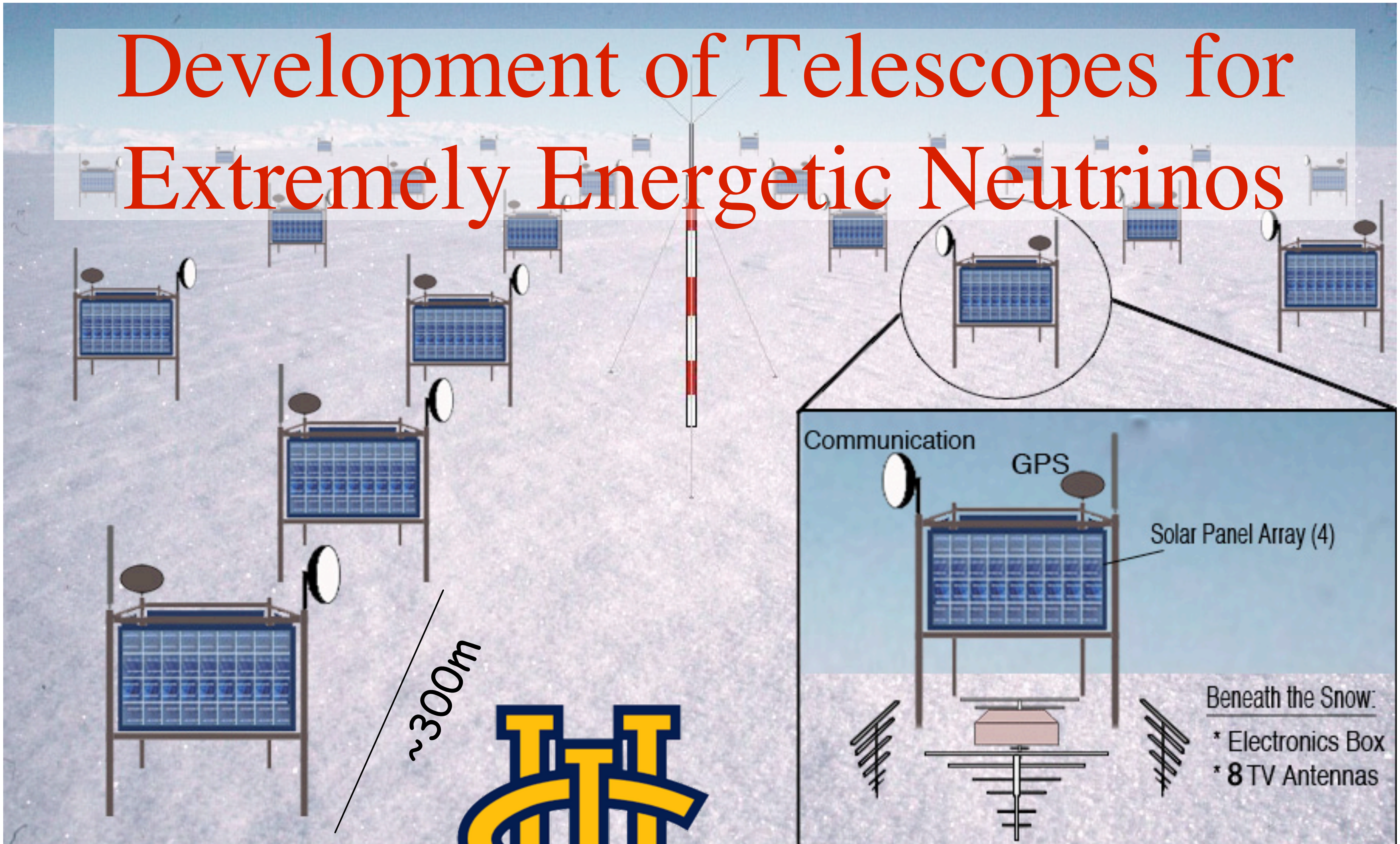
Development of Telescopes for Extremely Energetic Neutrinos



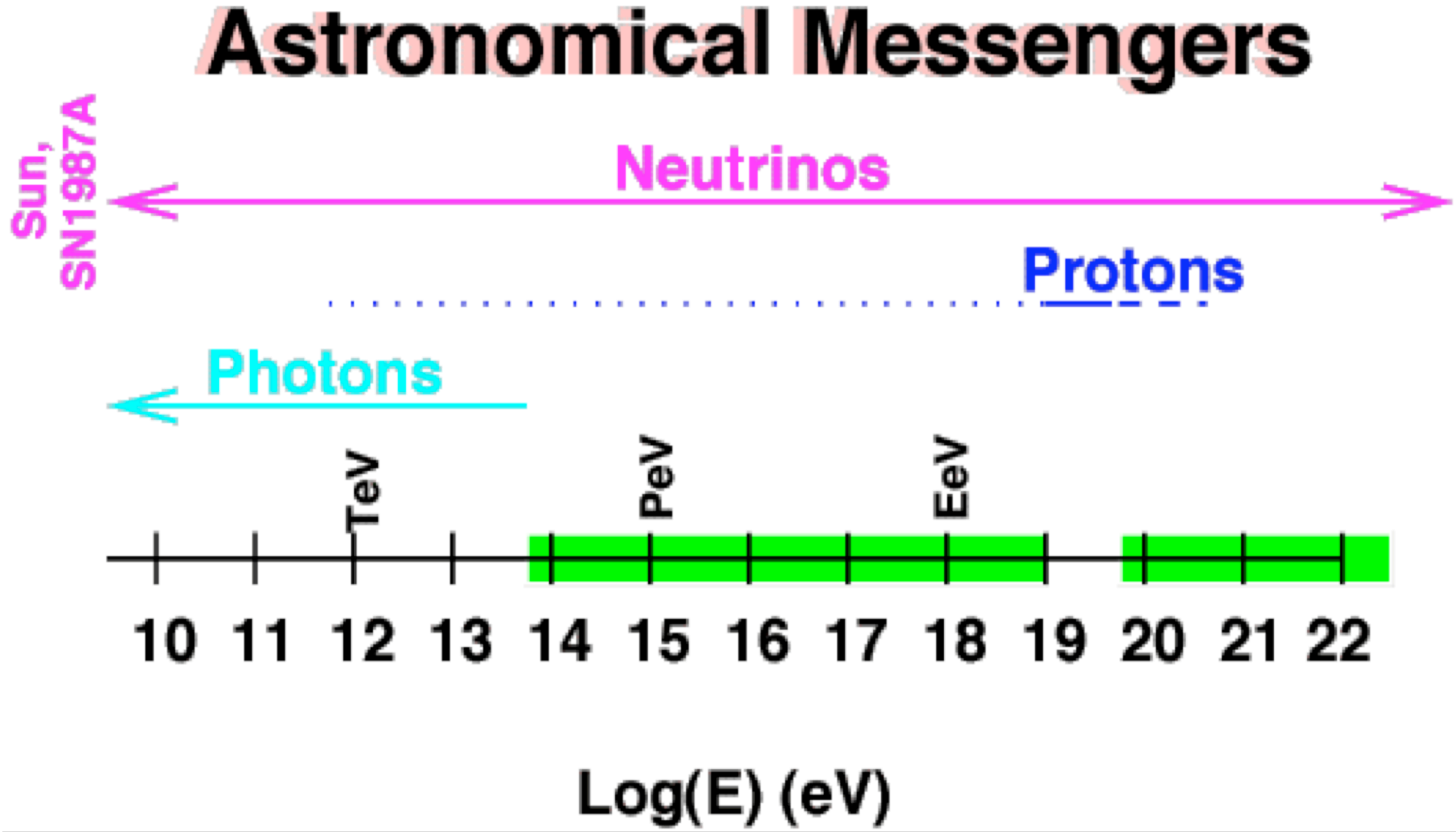
Steven W. Barwick, UC-Irvine

Neutrino Telescopes: Agenda

- 10 years of progress with optical Cherenkov Detectors
- Diffuse flux limits and EG point flux constraints
- Extremely Energetic Neutrinos - New Technologies

    Radio: ANITA and ARIANNA

Teraton -Petaton

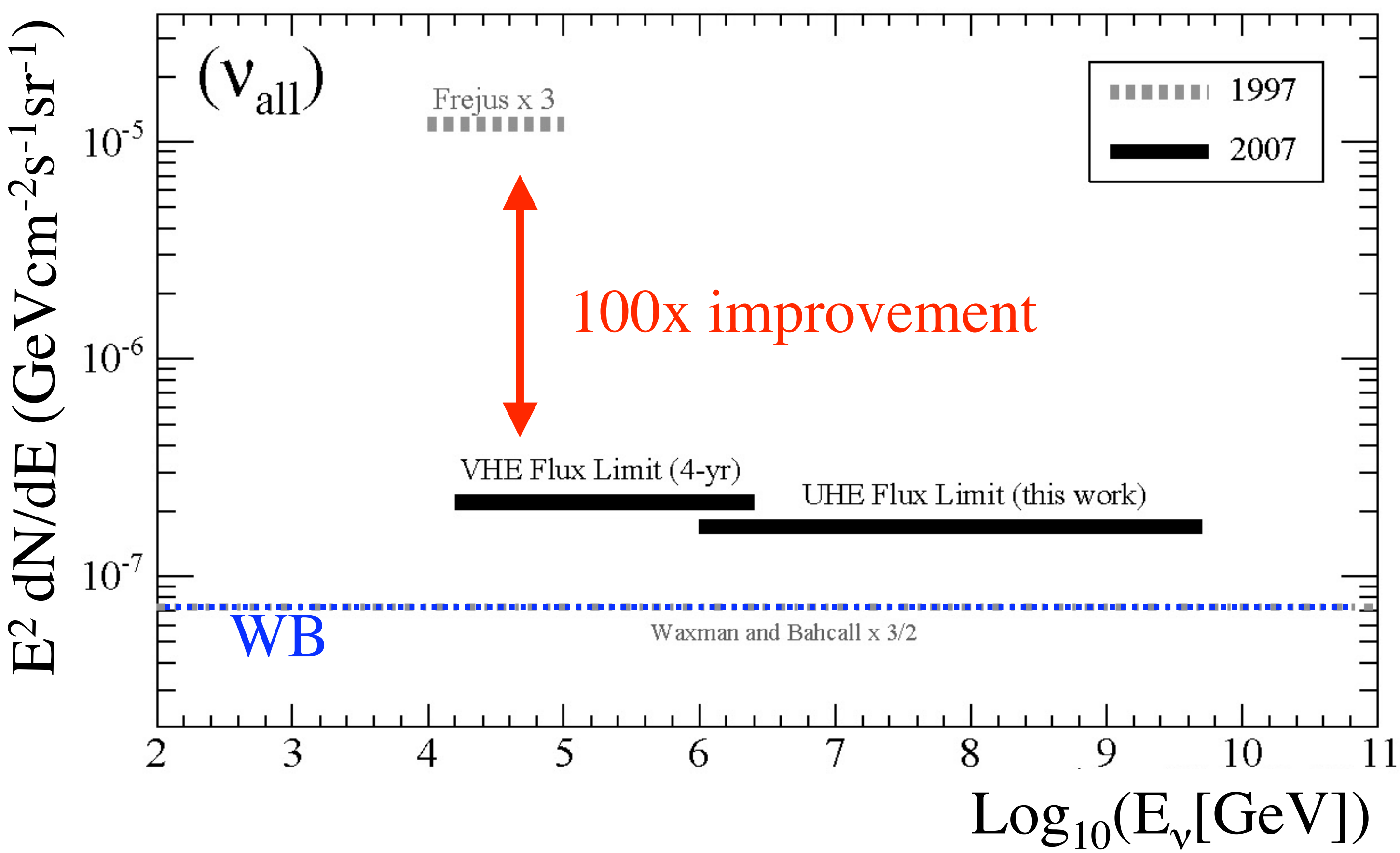


PHOTONS: not deflected, but: reprocessed in sources, absorbed in IR (100 TeV), and CBR

PROTONS: deflection in magnetic fields, GZK cutoff

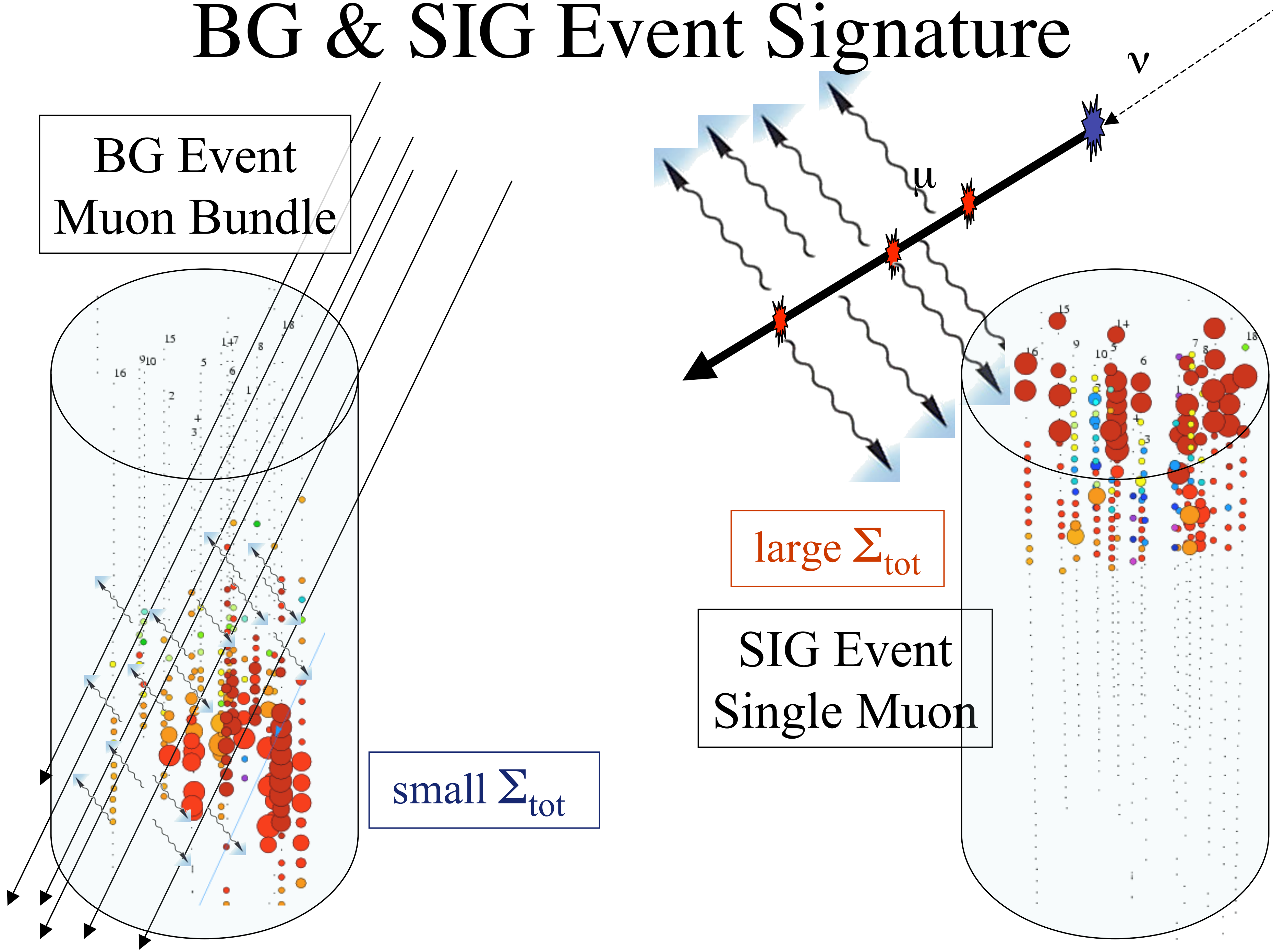
NEUTRINOS: not absorbed or deflected, hard to see

10 Years of Diffuse ν Progress

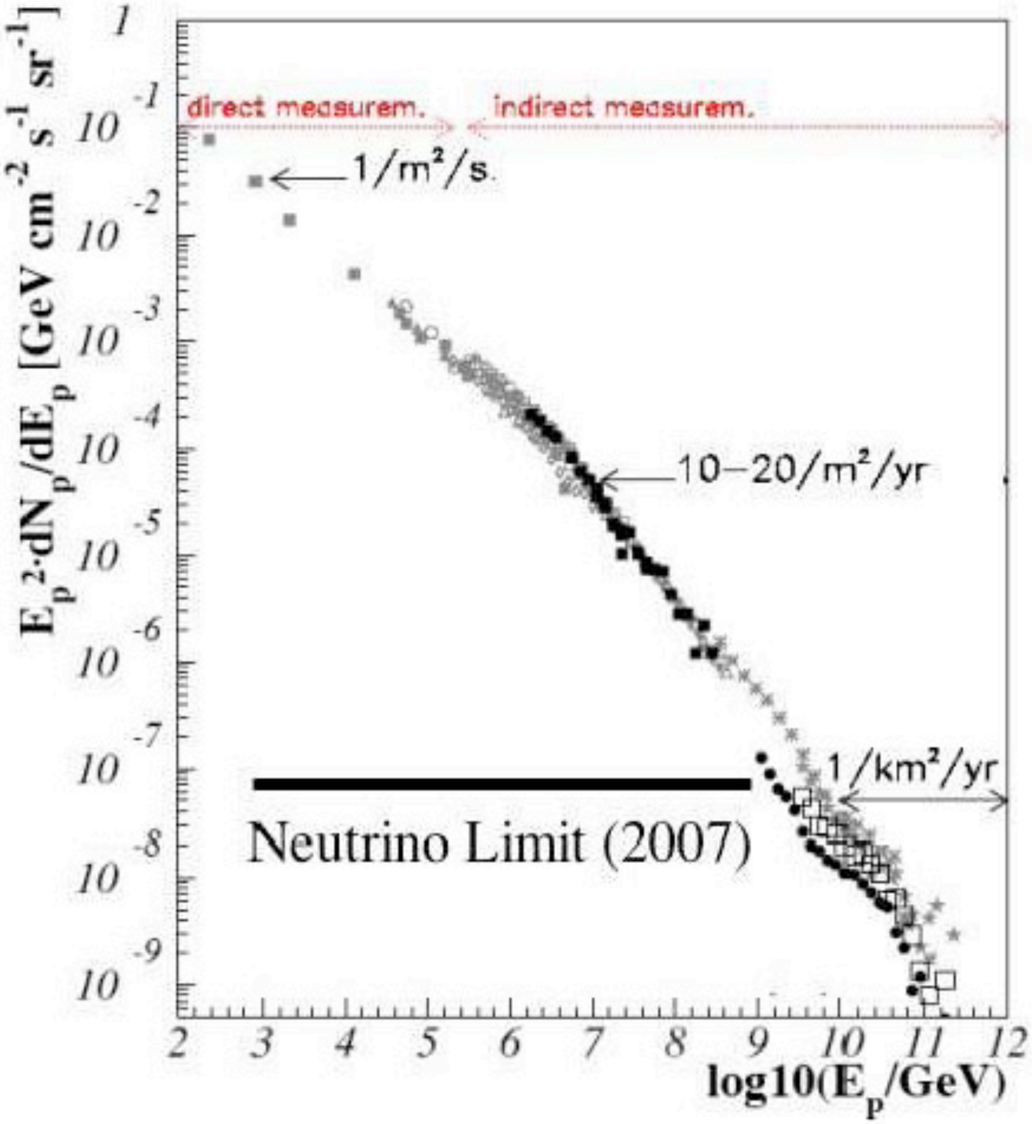


A. Silvestri, PhD Dissertation, 2008

BG & SIG Event Signature

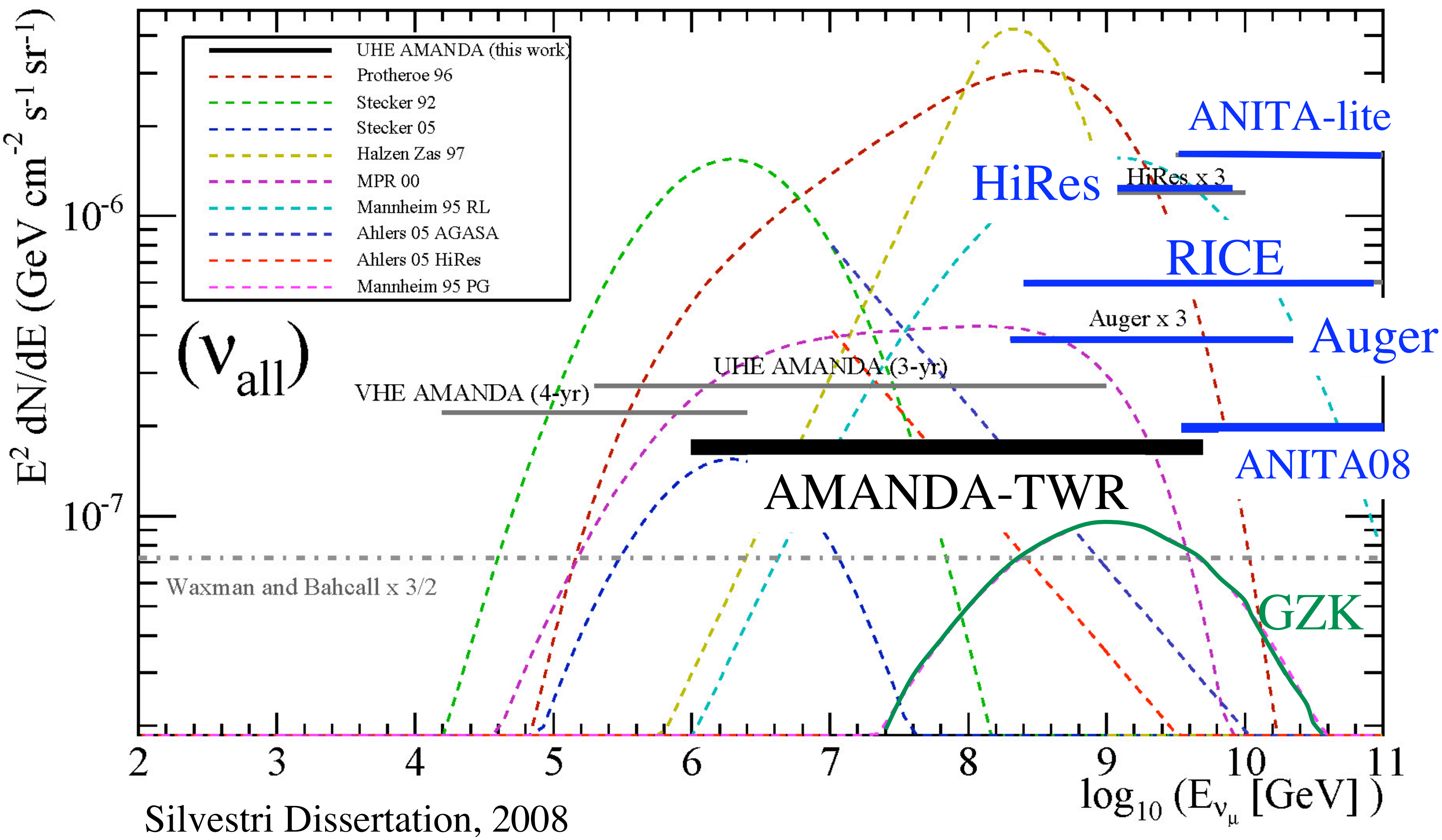


Diffuse ν-Fluxes << CR-Fluxes



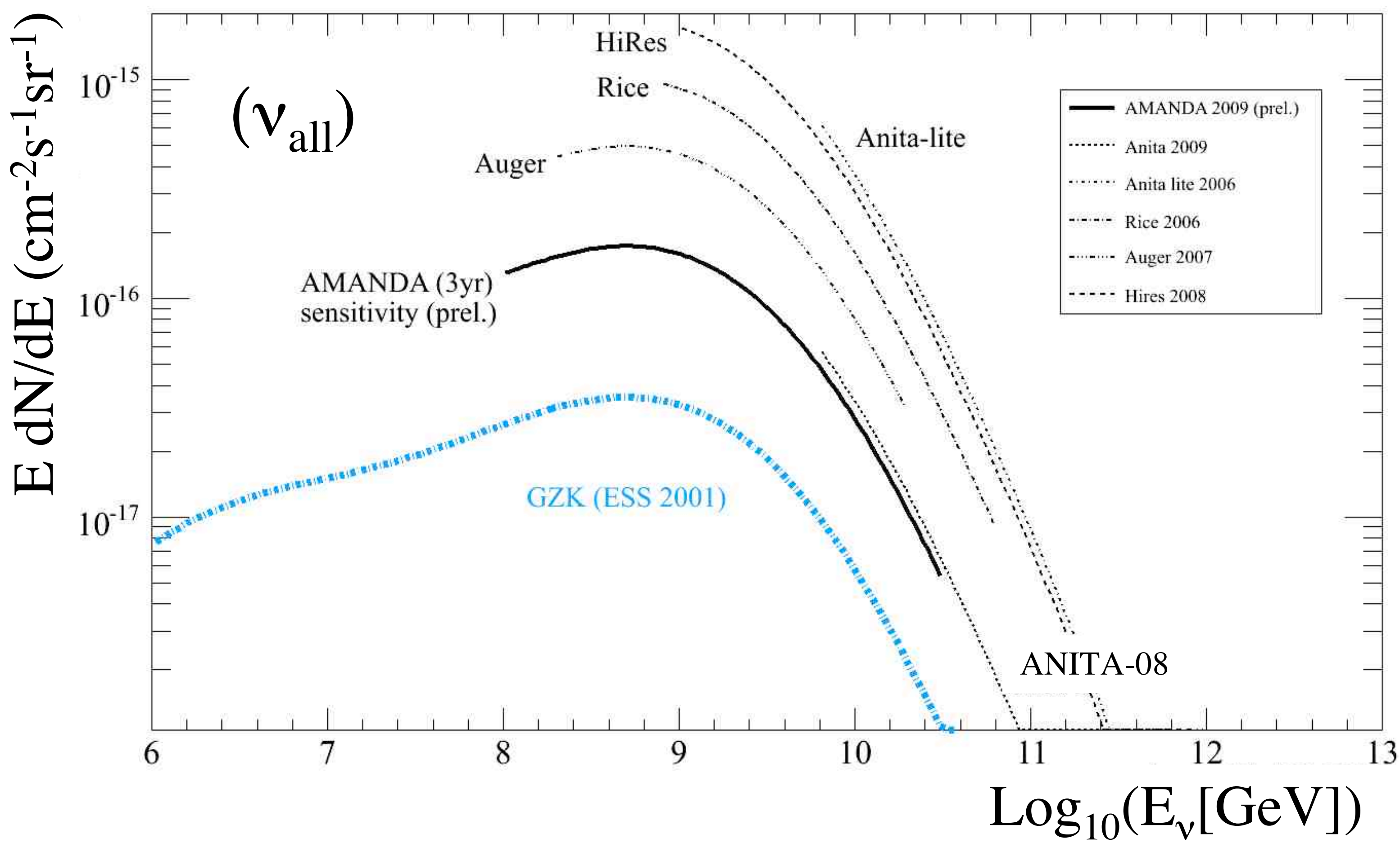
Silvestri Dissertation, 08

Diffuse Flux: Limits and Models



Silvestri Dissertation, 2008

GZK Model-Specific limits



Excluding AGN Model Predictions for Diffuse Flux

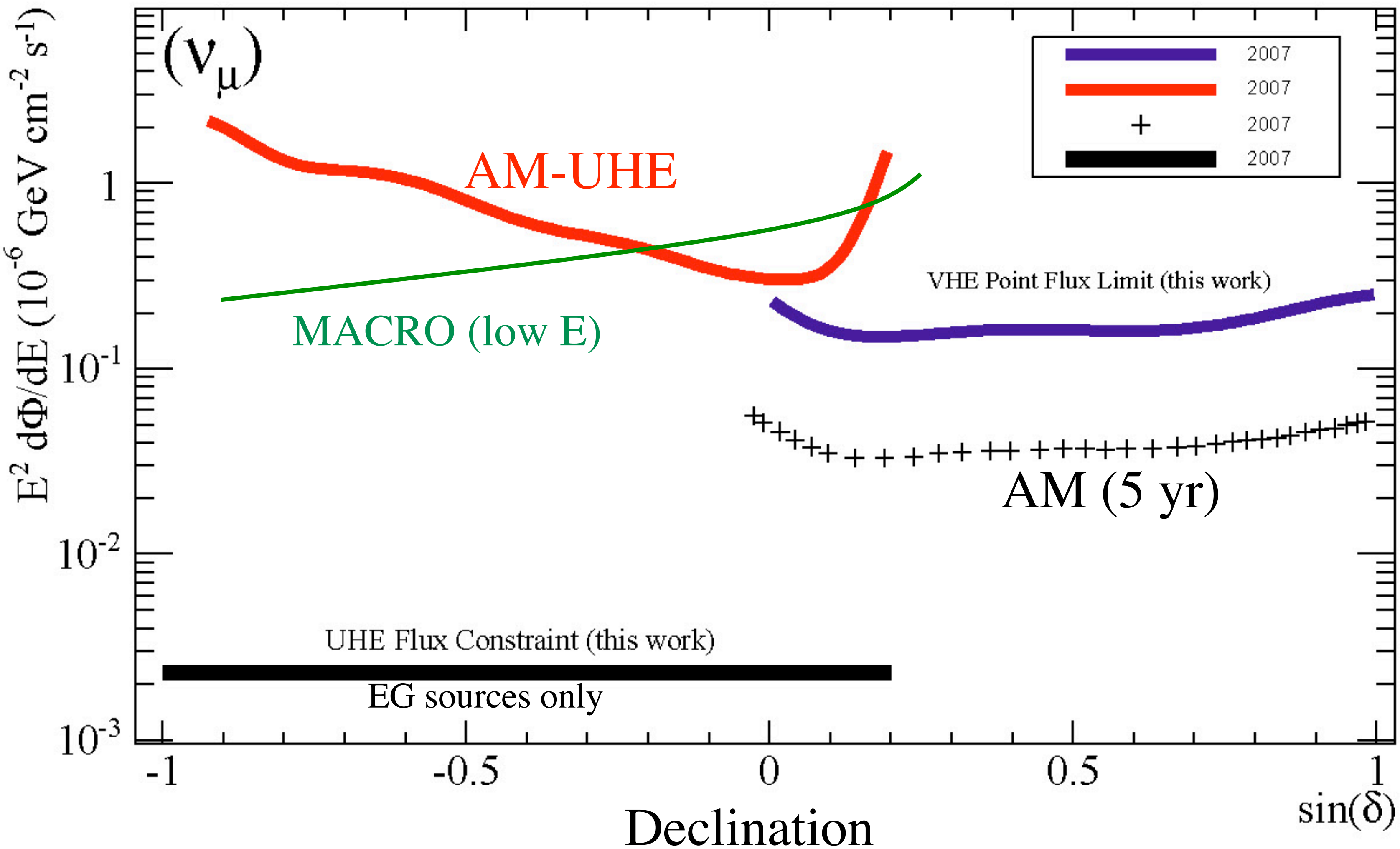
Excluded

Model	Source Type	Emission Type	Process	Normalization	Reference
radio-quiet AGN†	Seyfert/Quasar	core	pγ	x-ray diffuse	[Stecker et al., 1991]
radio-quiet AGN†	Seyfert/Quasar	core	pp	x-ray diffuse	[Nellen et al., 1993]
radio-loud AGN (B)†	Blazars	jets	pγ	1 MeV γ-ray diffuse	[Mannheim, 1995]
γ-ray loud AGN†	Blazars	jets	pγ	GeV γ-ray source	[Protheroe, 1996]
AGN †	Blazars	jets	pγ	100 MeV γ-ray source	[Stecker and Salamon, 1996]
γ-ray loud AGN†	Blazars	jets	pγ	GeV γ-ray source	[Halzen and Zas, 1997]
AGN†	Blazars	jets	pγ	100 MeV γ-ray source	[Mannheim et al., 2001]
AGN†	Blazars	jets	pγ	CR's spectrum	[Mannheim et al., 2001]
radio-loud AGN†	FSRQ	jets	pγ	radio source	[Becker et al., 2005]
radio-loud AGN (A)	Blazars	jets	pγ	100 MeV γ-ray diffuse	[Mannheim, 1995]
AGN-LBL	Blazars	jets	pγ	TeV γ-ray source	[Mücke et al., 2003]
AGN-HBL	Blazars	jets	pγ	CR's spectrum	[Mücke et al., 2003]
radio-quiet AGN	Seyfert/Quasar	core	pp and pγ	UV/x-ray source	[Alvarez-Muniz et al., 2004]
radio-loud AGN	FR-I	core	pp	TeV γ-ray source	[Anchordoqui et al., 2004]
radio-quiet AGN	Seyfert/Quasar	core	pγ	MeV γ-ray diffuse	[Stecker, 2005]
radio-loud AGN	FR-II	jets	pγ	radio source	[Becker et al., 2005]
radio-loud AGN	FR-I	core	pp	TeV γ-ray source	[Halzen and O'Murchadha, 2008]

Normalization to x-ray or 1-1000 MeV γ's overproduces neutrino flux

A. Silvestri 2008

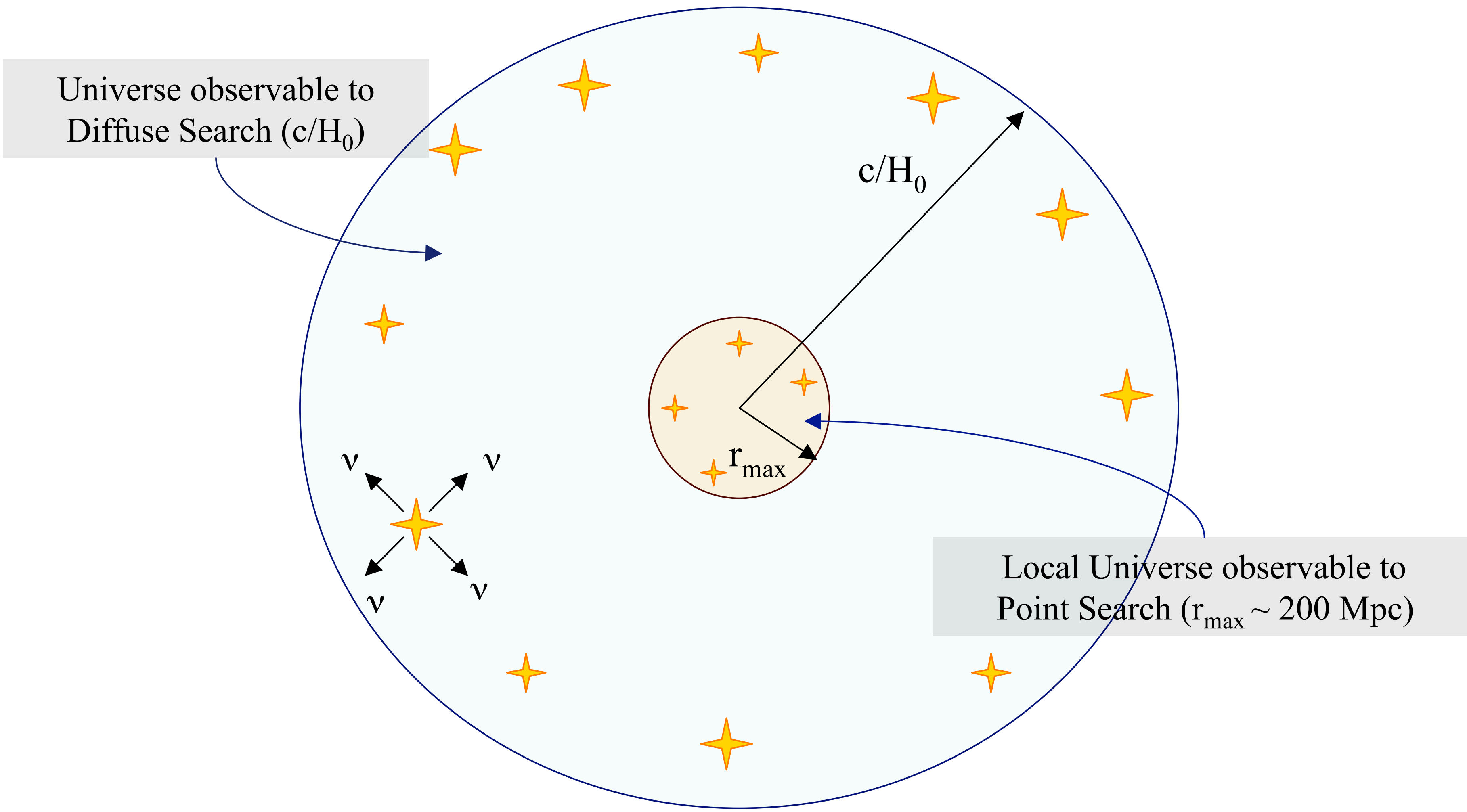
10 Years of Point ν Progress



Connecting Diffuse ν−Flux to EG Point Sources

[based on Lipari, Nucl. Instrum. Meth. A **567**, 405 (2006)]

Observable & Local Universe



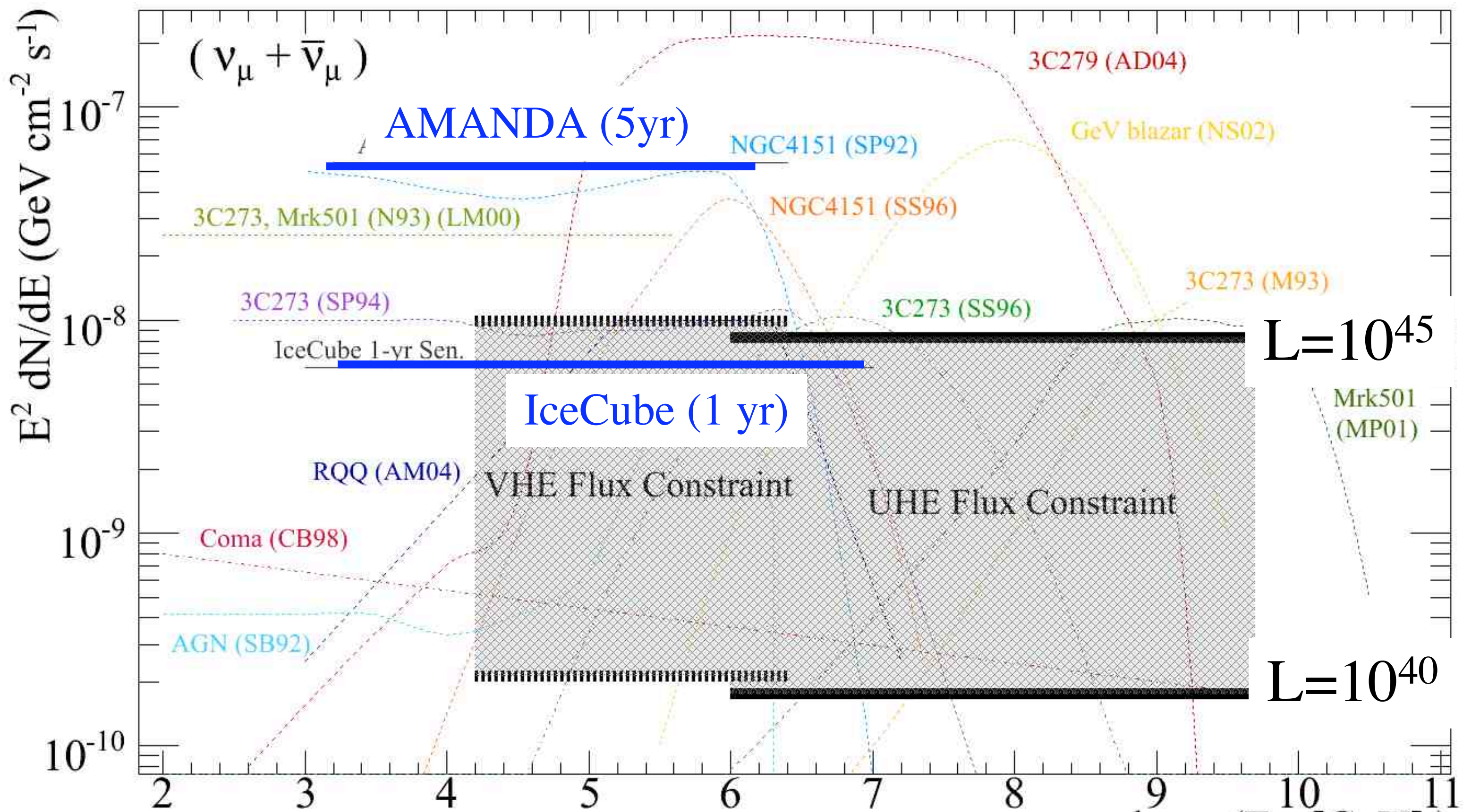
Constraining EG Point Flux

- Based on sensible collection of suppositions:
  1. EG point sources exist to redshift z=1
  2. L_ν constant, or power law luminosity distribution function
  3. Source emission described by power law energy spectrum, but details of spectrum not critical
- – Number of resolvable sources, N_s, obtained once point source sensitivity is specified.
- – In our case:
  - – K_ν^{diff}, $dN/dE = K_\nu^{diff} E^{-2}$ diffuse flux
  - – C_{point} , $dN/dE = C_{point} E^{-2}$ point source sensitivity

$$N_s \simeq \frac{\sqrt{4\pi}}{3} \frac{1}{\sqrt{\ln(10)}} \frac{H_0}{c} \frac{K_{diff}\sqrt{L_{dec}}}{(C_{point})^{3/2}} \frac{1}{\xi}$$

First derived by P. Lipari

EG Point Flux Constraint



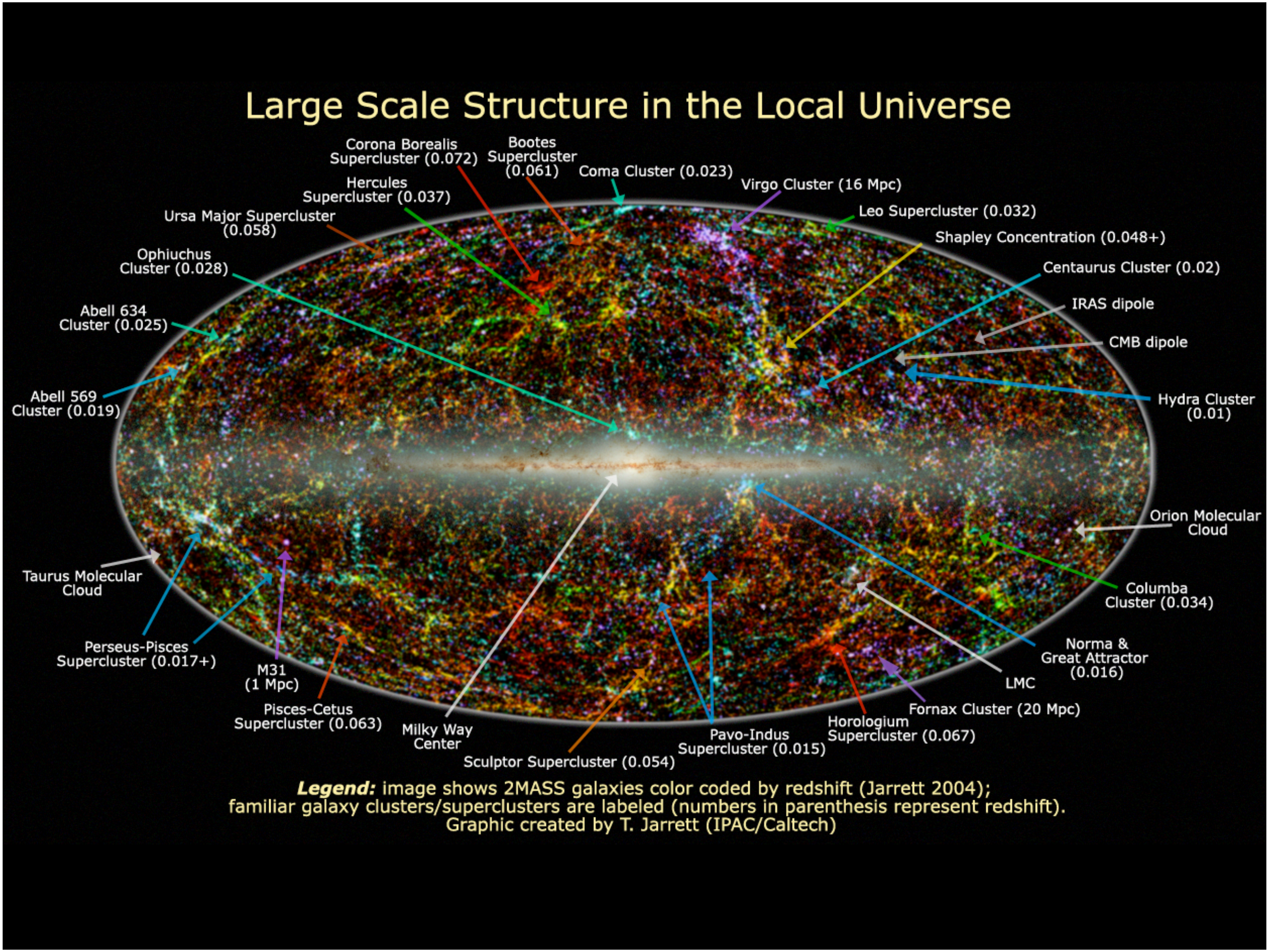
Silvestri PhD 08; Barwick, NIMA 09

Suggests EG sources may be difficult to detect

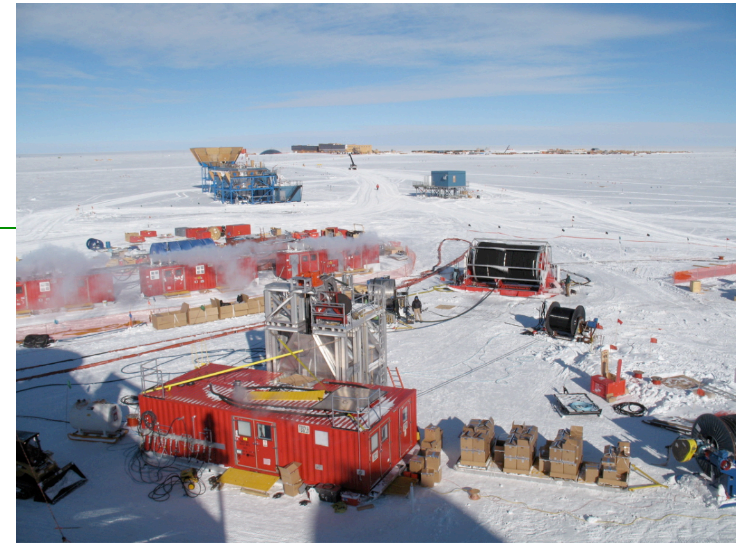
-> raises profile of Galactic sources

EG Constraint Caveats

- Only applies to Extragalactic (EG) sources
- Not competitive for GRBs
- Does not apply to “unique” source
- Local nonuniformity in matter distribution does not substantially alter conclusions (Barwick, NIMA, 2009)
  - “Nearby” (<25 Mpc) sources possess rather small photon luminosities
  - Matter distribution at “Intermediate” distances within factor 2 of universal average


Large Scale Structure in the Local Universe
Corona Borealis Supercluster (0.072)
Bootes Supercluster (0.061)
Coma Cluster (0.023)
Virgo Cluster (16 Mpc)
Hercules Supercluster (0.037)
Leo Supercluster (0.032)
Ursa Major Supercluster (0.058)
Shapley Concentration (0.048+)
Ophiuchus Cluster (0.028)
Centaurus Cluster (0.02)
IRAS dipole
Abell 634 Cluster (0.025)
CMB dipole
Abell 569 Cluster (0.019)
Hydra Cluster (0.01)
Orion Molecular Cloud
Taurus Molecular Cloud
Columba Cluster (0.034)
Perseus-Pisces Supercluster (0.017+)
M31 (1 Mpc)
Norma & Great Attractor (0.016)
LMC
Fornax Cluster (20 Mpc)
Pisces-Cetus Supercluster (0.063)
Milky Way Center
Pavo-Indus Supercluster (0.015)
Horologium Supercluster (0.067)
Sculptor Supercluster (0.054)
Legend: image shows 2MASS galaxies color coded by redshift (Jarrett 2004);
familiar galaxy clusters/superclusters are labeled (numbers in parenthesis represent redshift).
Graphic created by T. Jarrett (IPAC/Caltech)

IceCube

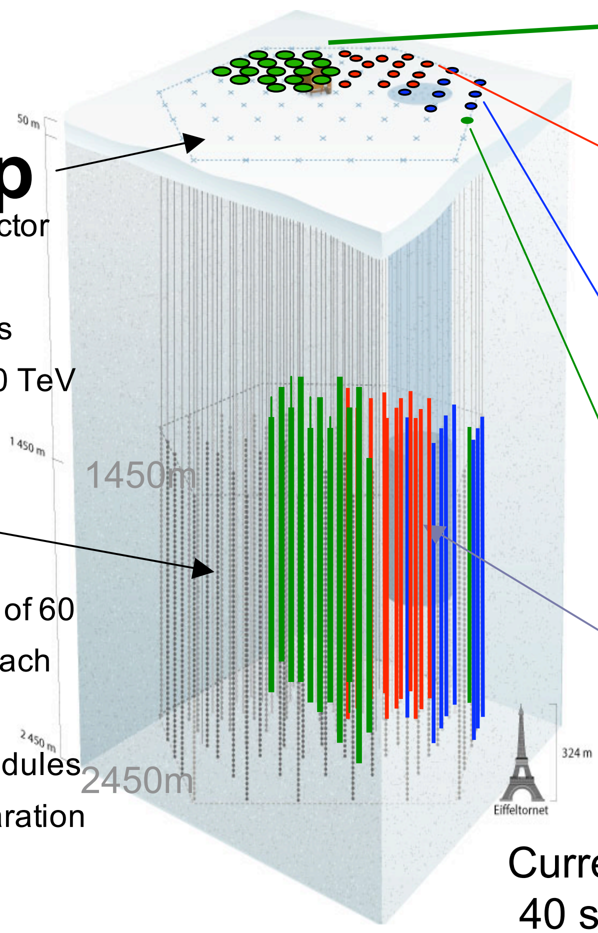


IceTop

Air shower detector

80 pairs of ice Cherenkov tanks

Threshold ~ 300 TeV



2007-2008 : 18 strings

2006-2007: 13 strings

2005-2006: 8 strings

2004-2005 : 1 string

In Ice

Goal of 80 strings of 60 optical modules each

17 m between modules

125 m string separation

AMANDA-II

19 strings

677 modules

When completed, may detect <1 cosmogenic ν per year

Current configuration:
40 strings,
40 IceTop stations
plus AMANDA

2008/09: added 19 strings

Completion by 2011.

Quest for EHE neutrinos

New Technologies

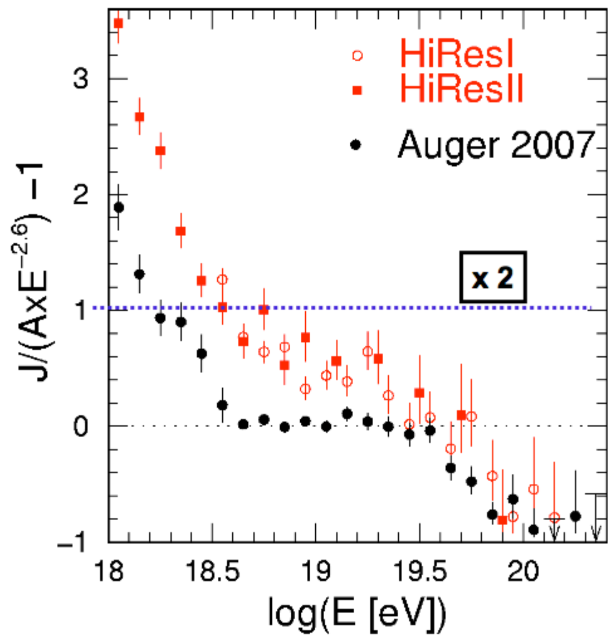
Cosmogenic (or GZK) Neutrinos

Predictions are secure:

$p + \gamma_{cmb} \rightarrow \Delta \rightarrow n + \pi^+$

n -> lower energy protons

$\pi \rightarrow \mu + \nu$



However, ν-Flux Calculations depend on:

1. Elemental composition (p, Fe, mixed)
2. Cosmology (Λ=0.7)
3. Injection Spectra, $E^{-\gamma}$ and E_{max}
4. Evolution of sources with redshift, $(1+z)^m$
   - Star formation, QSO, GRB, little or no

GZK neutrino predictions

- Two significant developments
  - Auger confirms HiRes obs. of flux suppression, both 5σ
  - Auger reports angular correlation between CR and nearby matter (AGN?) - not observed by HiRes (APS08)
    - Strengthens idea that "Ordinary" AGN responsible for UHECR
    - Relatively well known evolution of source
    - Majority of CR must be protons, else B_{gal} would scramble directions by more than observed
- If Ang. Correlation confirmed, much (but not all!) of the GZK flux uncertainty disappears.

Why Big Detectors?

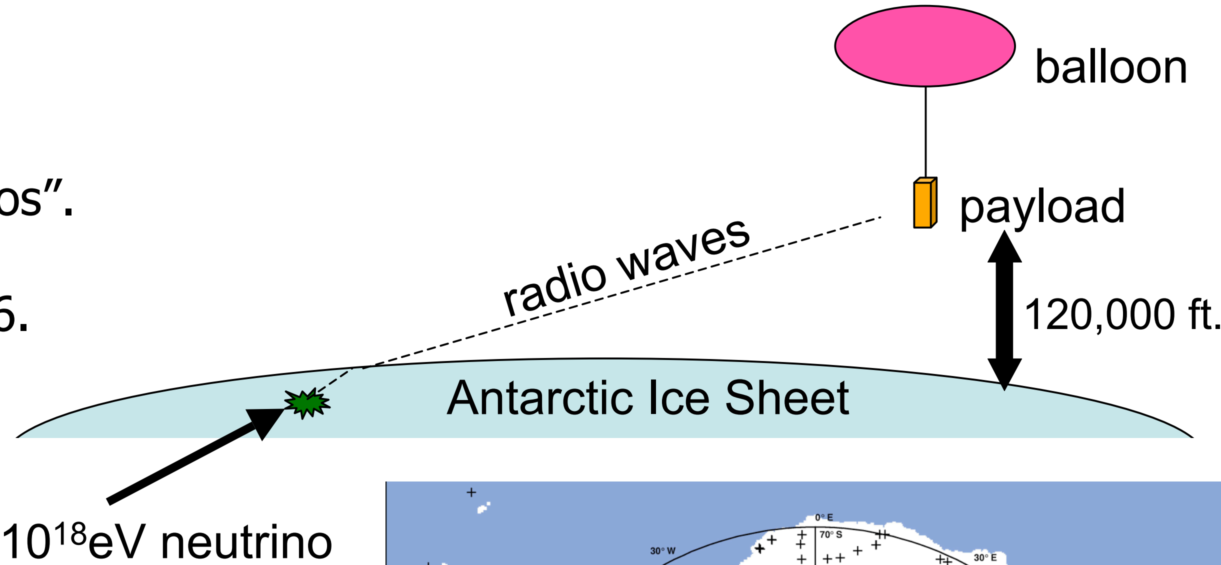
- GZK ν Flux, ϕ ($E \sim 10^{18}$ eV): 10 /km^2/yr
- ν Interaction Length, λ: 500 km
- Event Rate/km^3/yr = $[\phi/\lambda]$ ~ 0.02
- See about half the sky, 0.01/km^3/yr
- Efficiency, livetime, nice if more than one

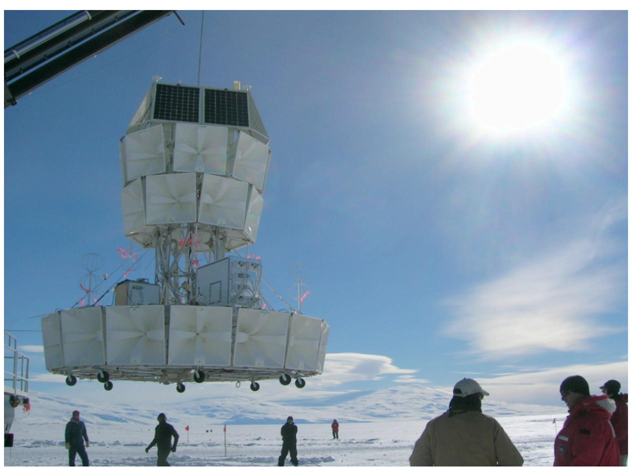
So GZK ν detection requires > 100 km^3
(aperture > 600 km^{3}sr)

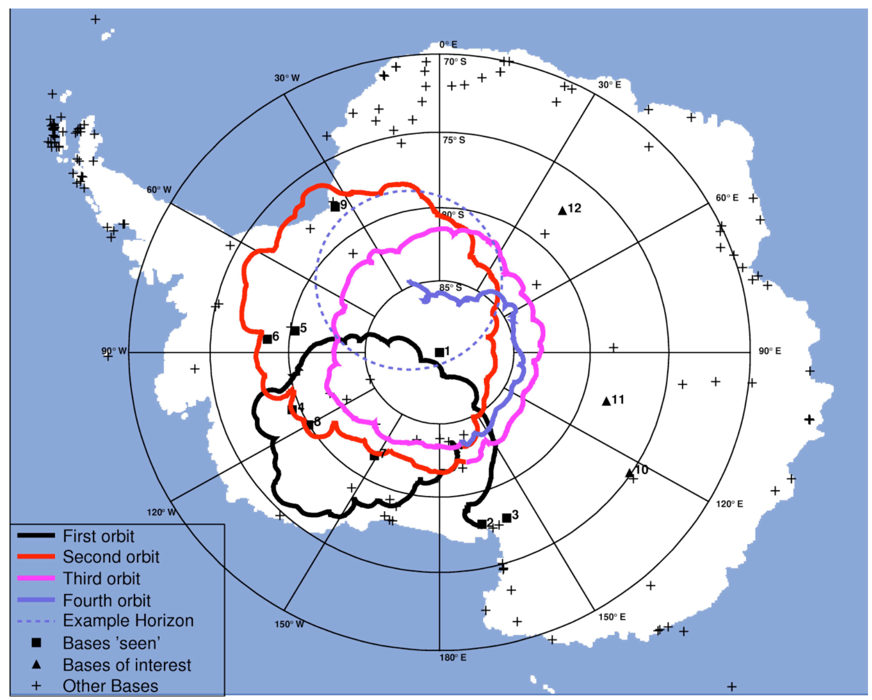
ANITA-1

ANITA:

- Looking for “GZK neutrinos”.
- View 1 Million km^3 of ice.
- 32 day flight in Dec. 2006.







The ANITA Collaboration

University of California, Irvine
Irvine, California

Ohio State University
Columbus, Ohio

University of Kansas
Lawrence, Kansas

Washington University in St. Louis
St. Louis, KMissouri

University of Delaware
Newark, Delaware

UCLA

UCL

University of California, Los Angeles
Los Angeles, California

University of Hawaii at Manoa
Honolulu, Hawaii

National Taiwan University
Taipei, Taiwan

University College London
London, England

Jet Propulsion Laboratory
Pasadena, California

Stanford Linear Accelerator Center
Menlo Park, CA

Washington University in St. Louis

SLAC

Jet Propulsion Laboratory
California Institute of Technology

UCIrvine

KU THE UNIVERSITY OF KANSAS

UNIVERSITY OF DELAWARE

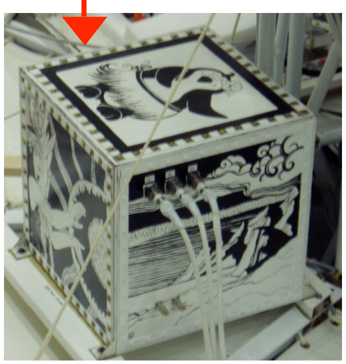
University of Hawai'i MĀNOA

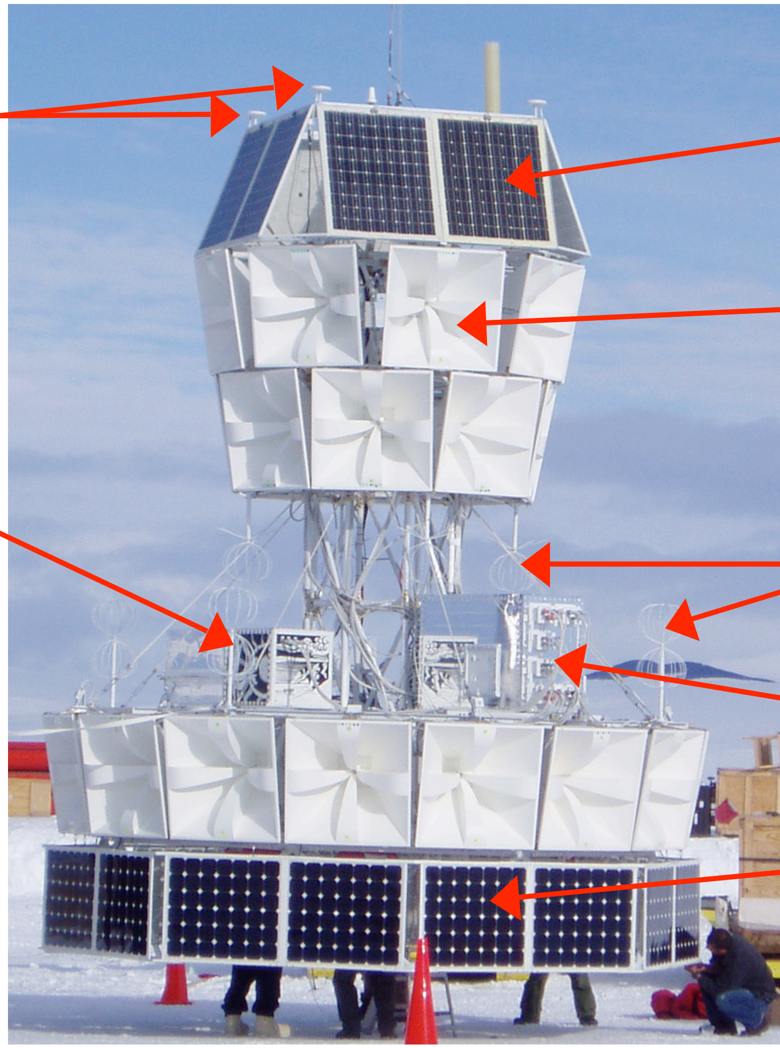
THE OHIO STATE UNIVERSITY

Lets get to know ANITA

GPS Antennas

Battery box
(Art by residents
of McMurdo)





Solar cells for NASA equipment

32 Quad-ridge horn antennas in 3 layers
- 200 MHz to 1200 MHz
- 10 degree down angle

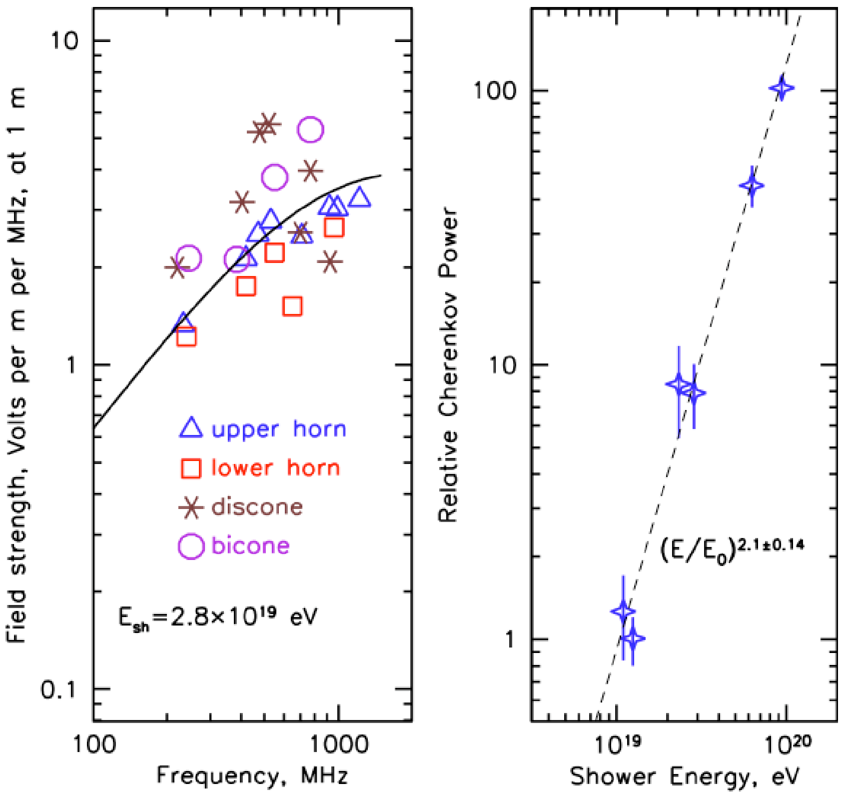
8 low gain antennas to monitor
payload-generated noise

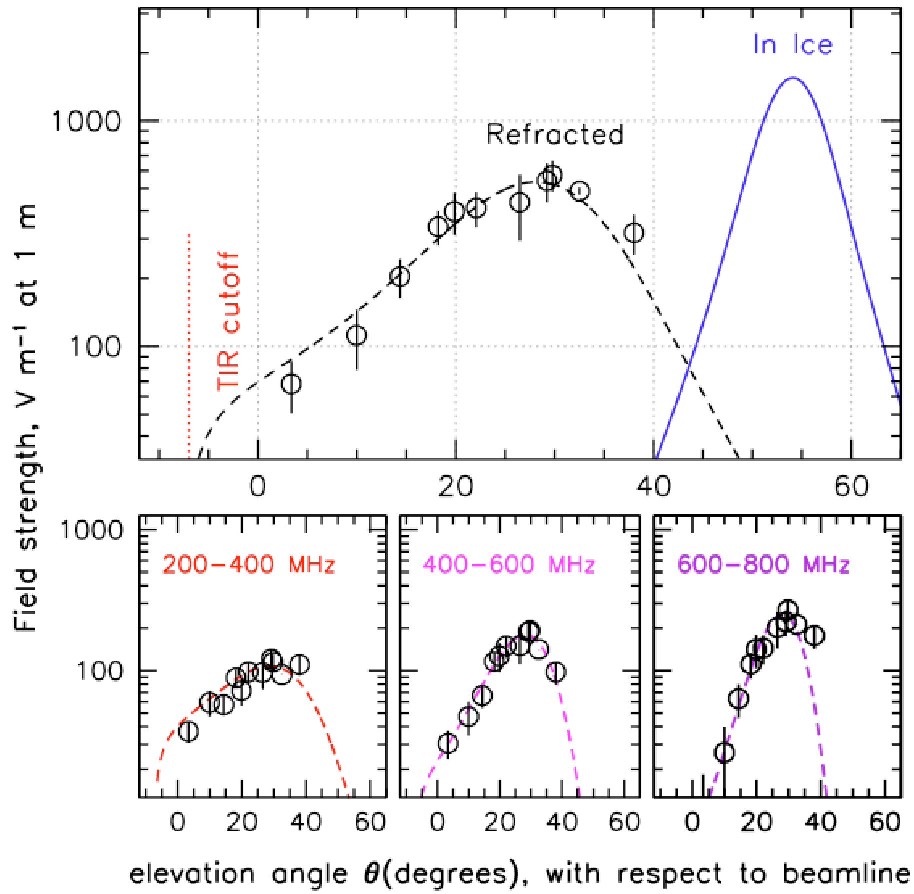
ANITA electronics box (mirrored to
minimize solar heating)

Power for science mission

SLAC beam tests on Ice Target

Gorham, Barwick, et al., astro-ph/0611008



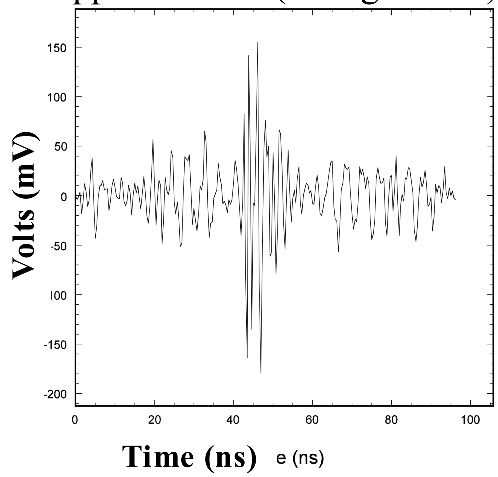


Absolute RF power and frequency dependence confirmed

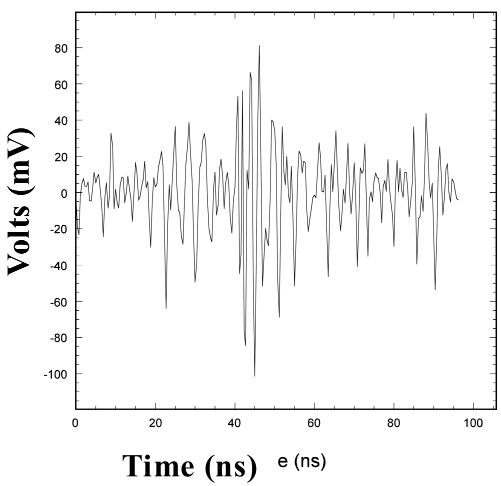
Width of cherenkov cone and frequency dependence confirmed

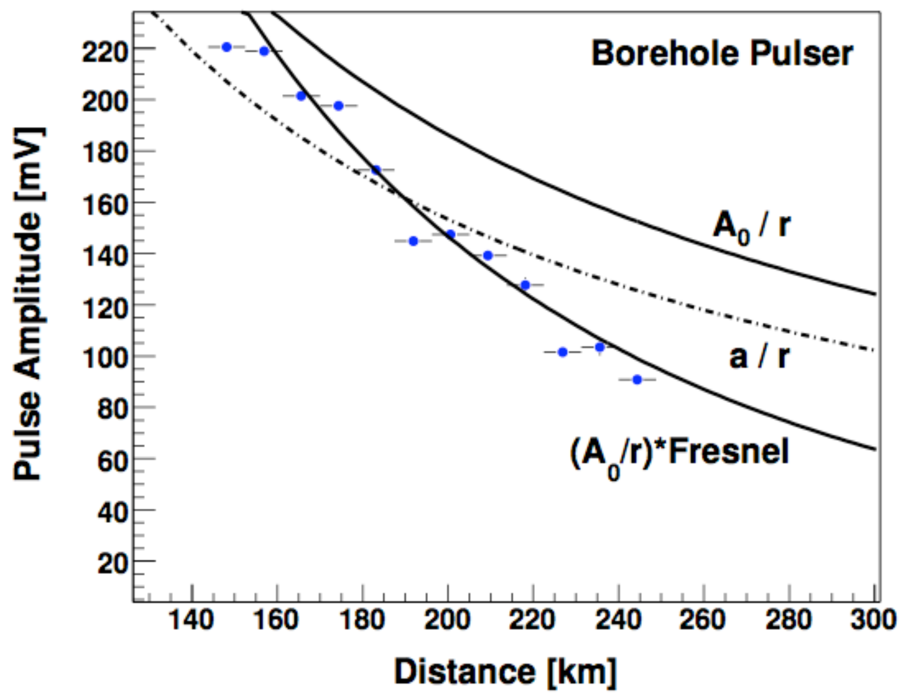
Calibration Signals

Upper antenna (facing source)



Lower antenna (facing source)



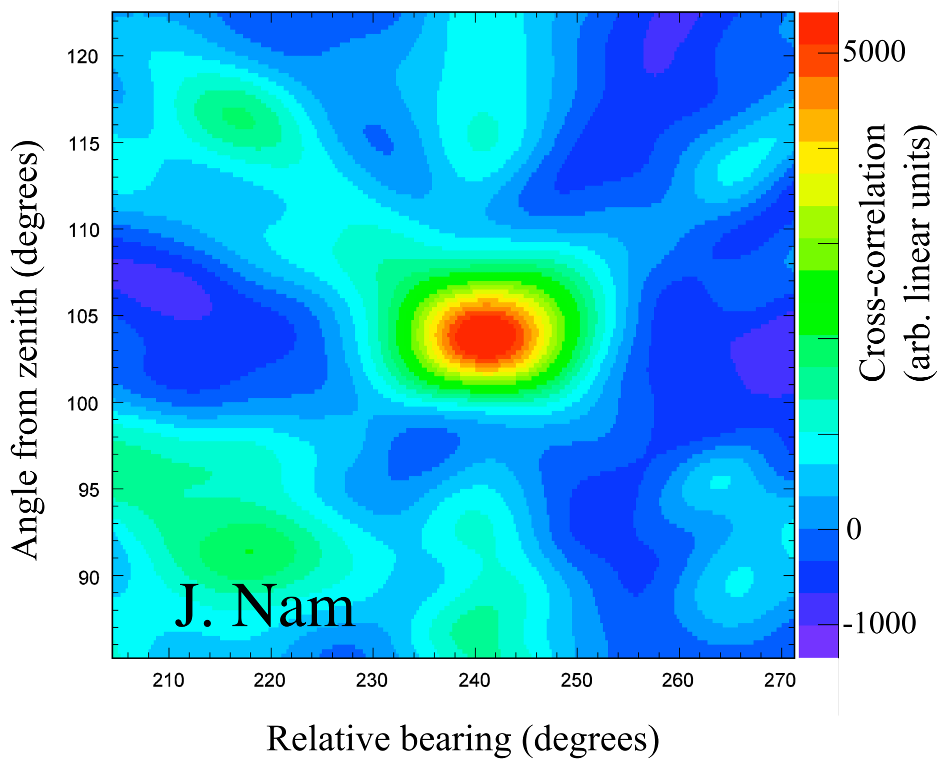


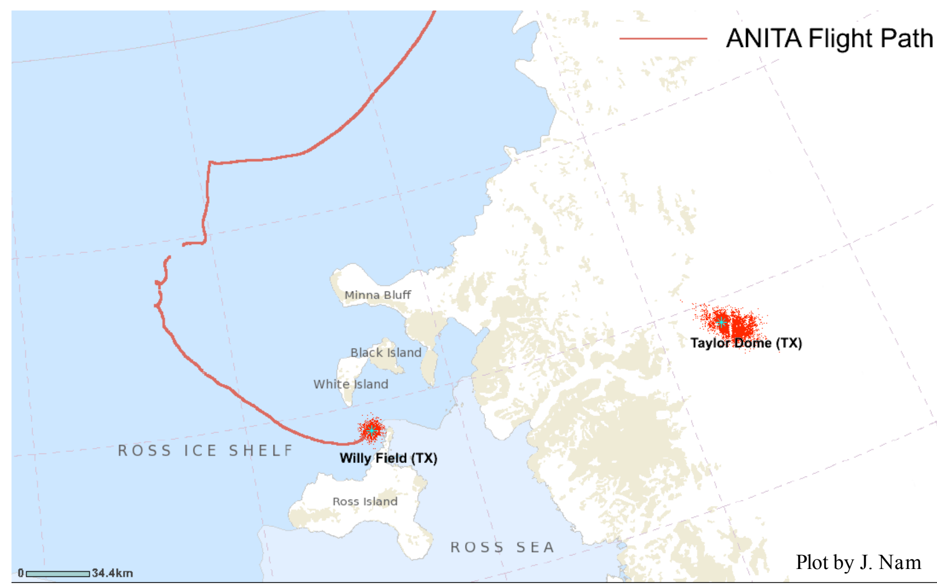
Goldstein, ICRC 2007

- Confirmed 1/r and Fresnel effects
- Established absolute amplitude

Pointing At Calibration Events

- Anthropogenic background → Need good pointing!
- Pointing resolution ($\Delta\theta$, $\Delta\phi$) ≈ (0.25°, 0.75°)



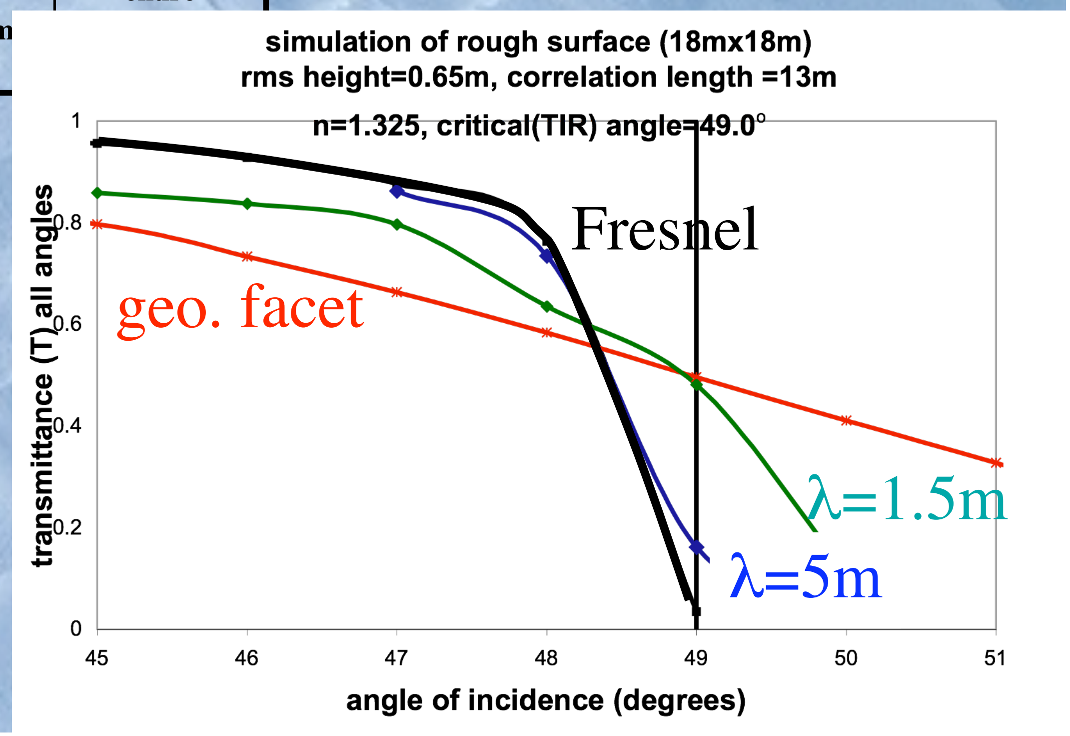


Reconstructed locations of calibration signal events

Modeling Surface Roughness

scales	categories	amplitude/ rms height	correlation length	coverage
LARGE (meter)	sastrugi	~30cm (average)	8m	about half of the continent
	snow dunes	~70cm (average)	13m	
SMALL (centimeter)	micro-roughness	~few cm	30-60cm	entire

www.physics.ucla.edu/~moonemp/roughness

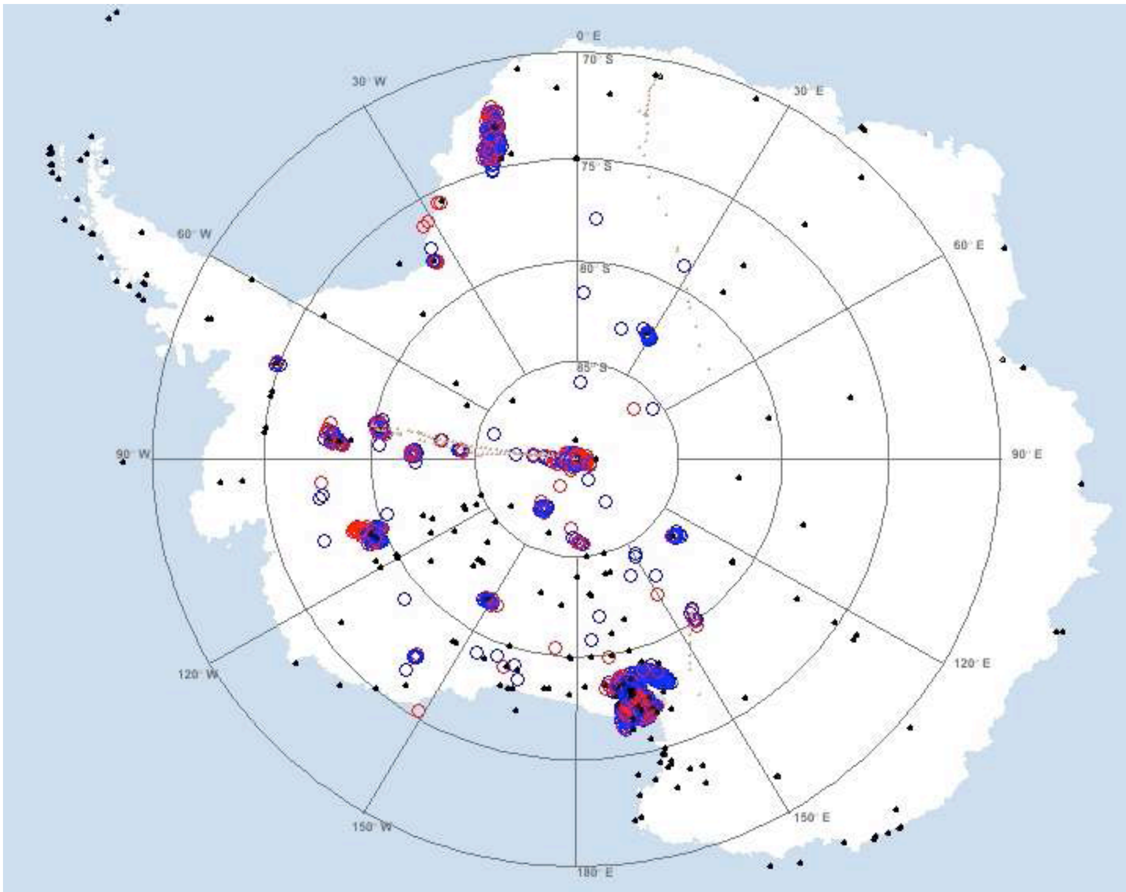


Dookayka, APS08

Important Caveat on Surface Studies

Distortion of time dependence, and consequently angular reconstruction and analysis efficiency are still unknown

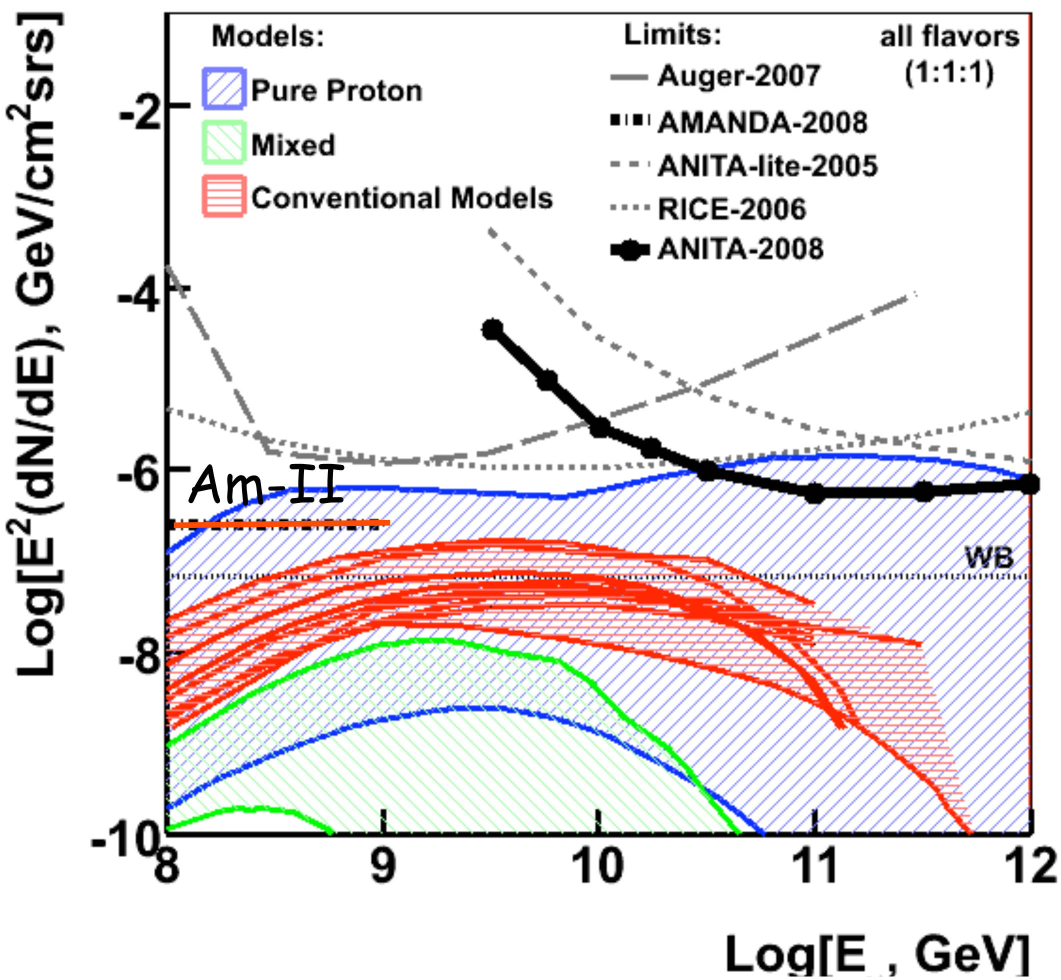
Well Reconstruction Event Distribution



No neutrino candidates!

All events associated with known bases, camps, traverses or dominated by wrong (horizontal) polarization

EHE ν limits

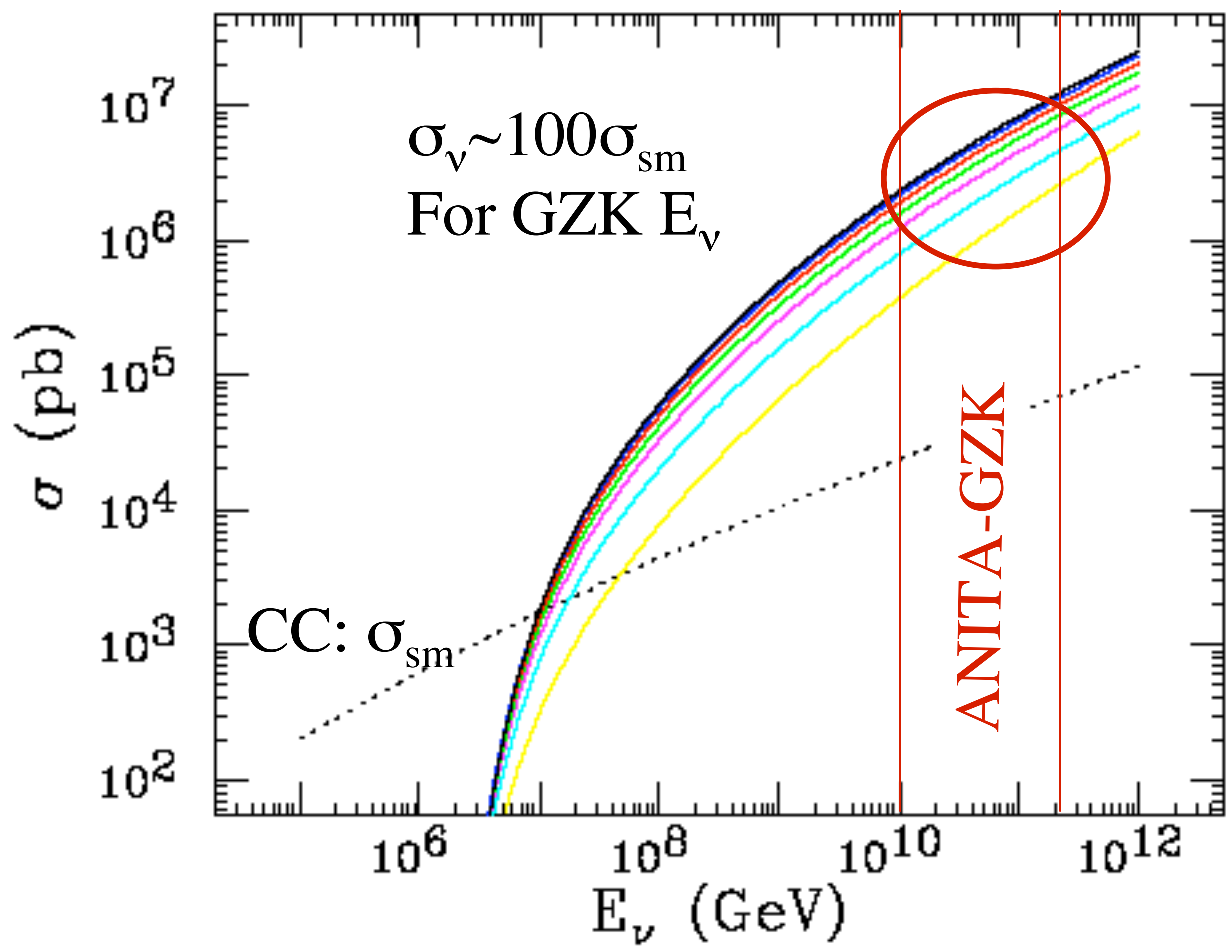


Blue= proton only models
Green= mixed comp.

ANITA-2008
[arXiv:0812.2715v1]
ANITA-2 sensitivity
improves by ~2-3

Fluxes are for
sum of all ν flavors

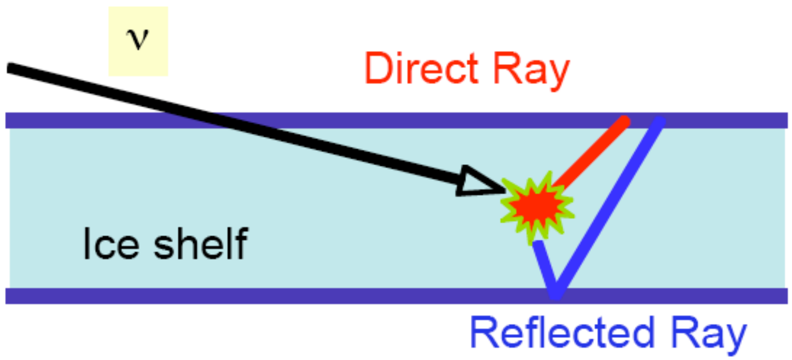
EHE Neutrinos Explore Higher Dimensions



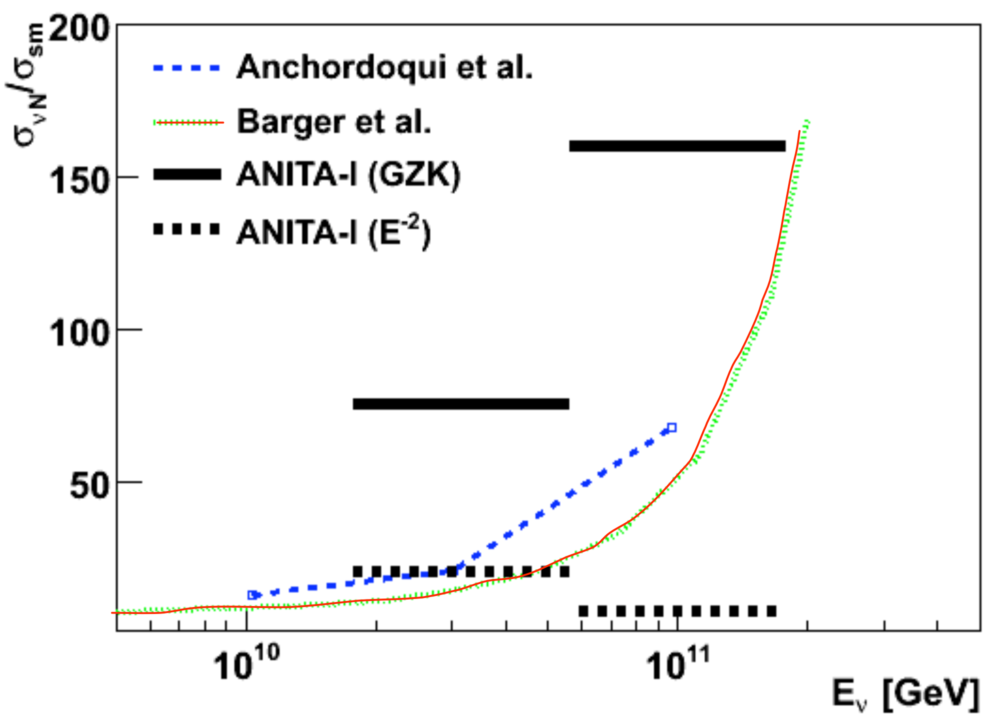
(Anchordoqui, et al, hep-ph/0307228)

ANITA Can Constrain $\sigma_{\nu N}$!

(F. Wu, ICRC 07, APS08)



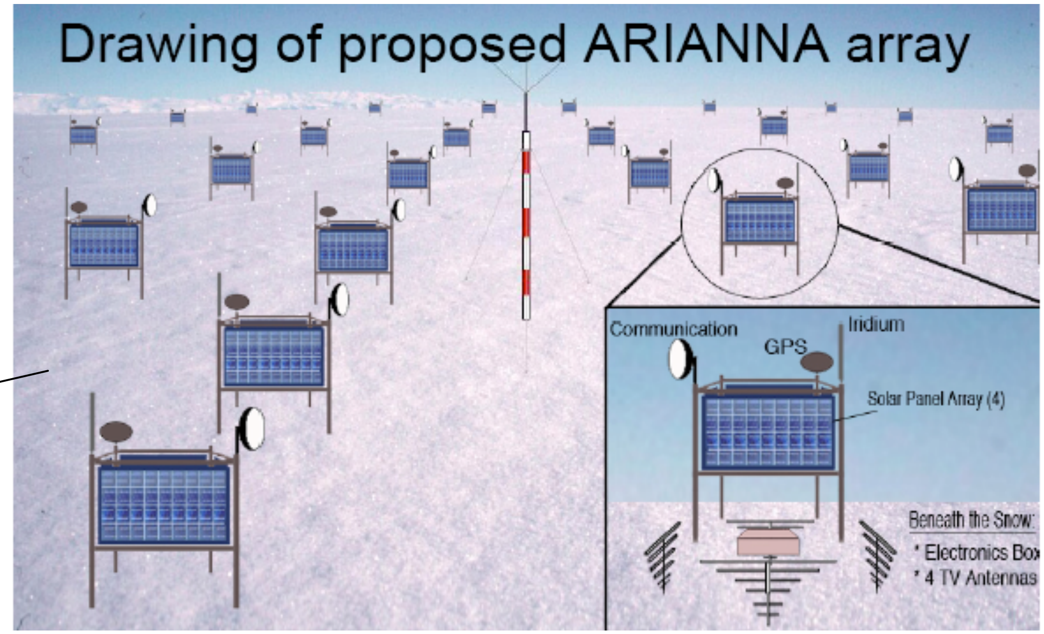
Rate of events from ice *shelf* to ice sheet is related to neutrino σ



New Techniques to Observe Cosmogenic Neutrinos

	Current	Under Development
Radio	RICE, ANITA	ARIANNA, AURA, IceRay, SALSA
Air Shower	HiRes, Auger	TA, Auger N, OWL
Acoustic		SPATS, AMADEUS

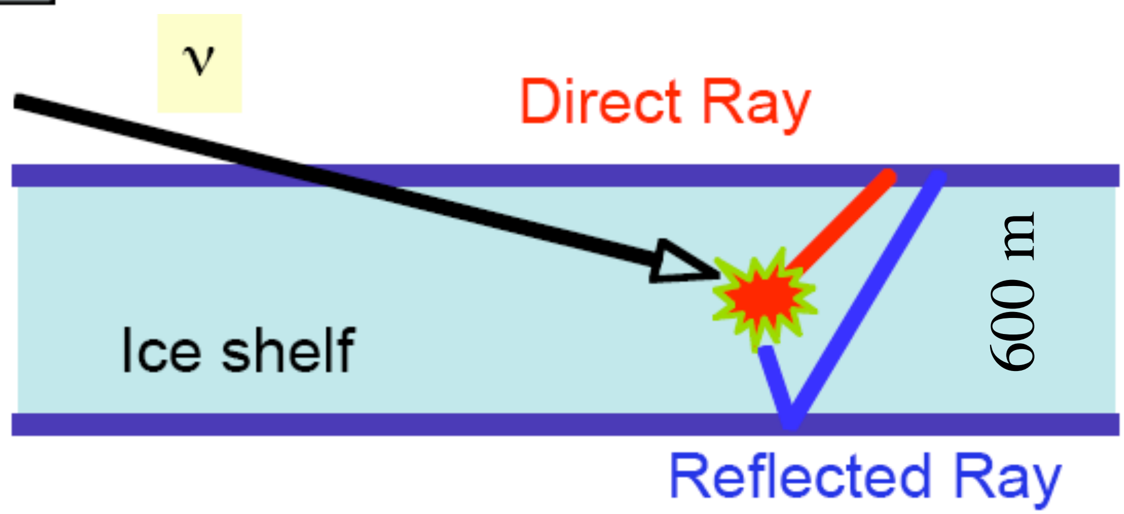
100 x 100 array [30 km x 30 km]



ARIANNA

UCI, LBL, OSU, WashU, UCLA, UCLondon

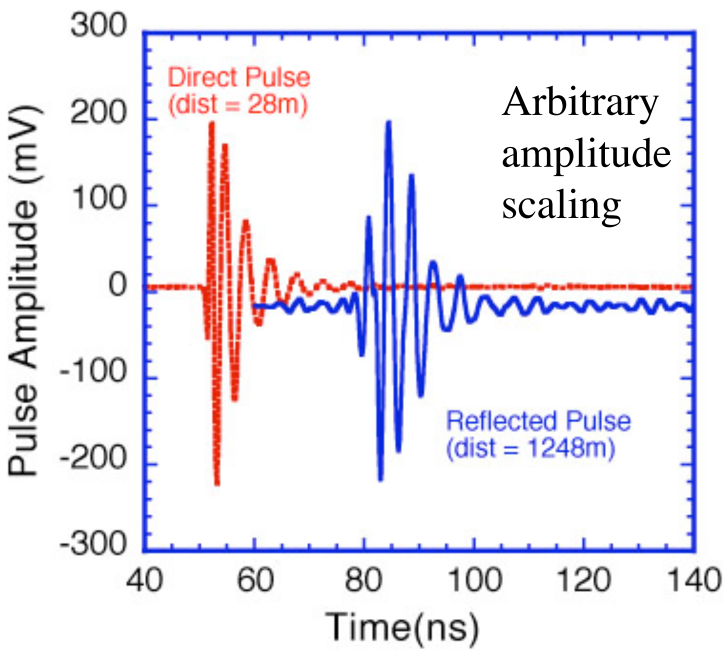
Barwick, astro-ph/0610631

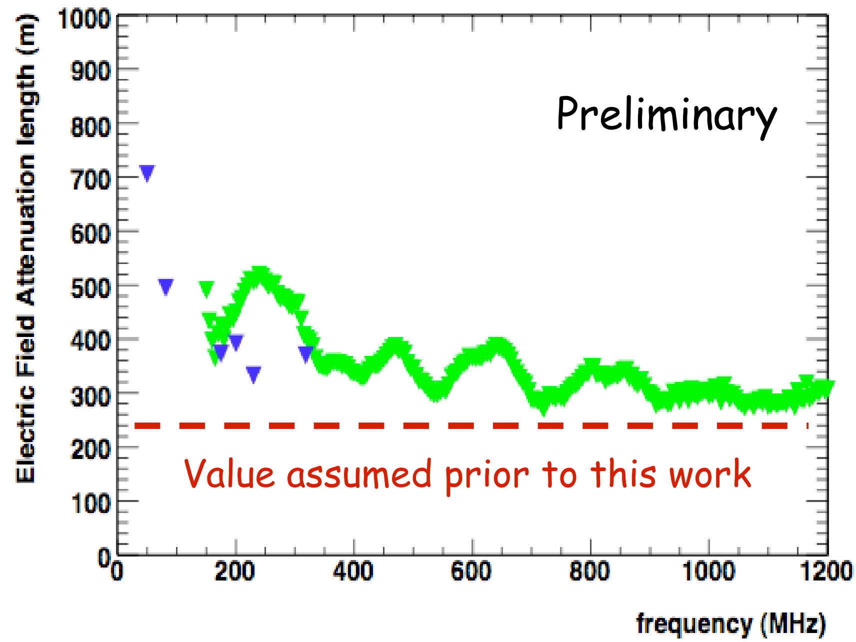


Camping at Moore's Bay Site

ARIANNA Site Studies

Barwick, ICRC 07



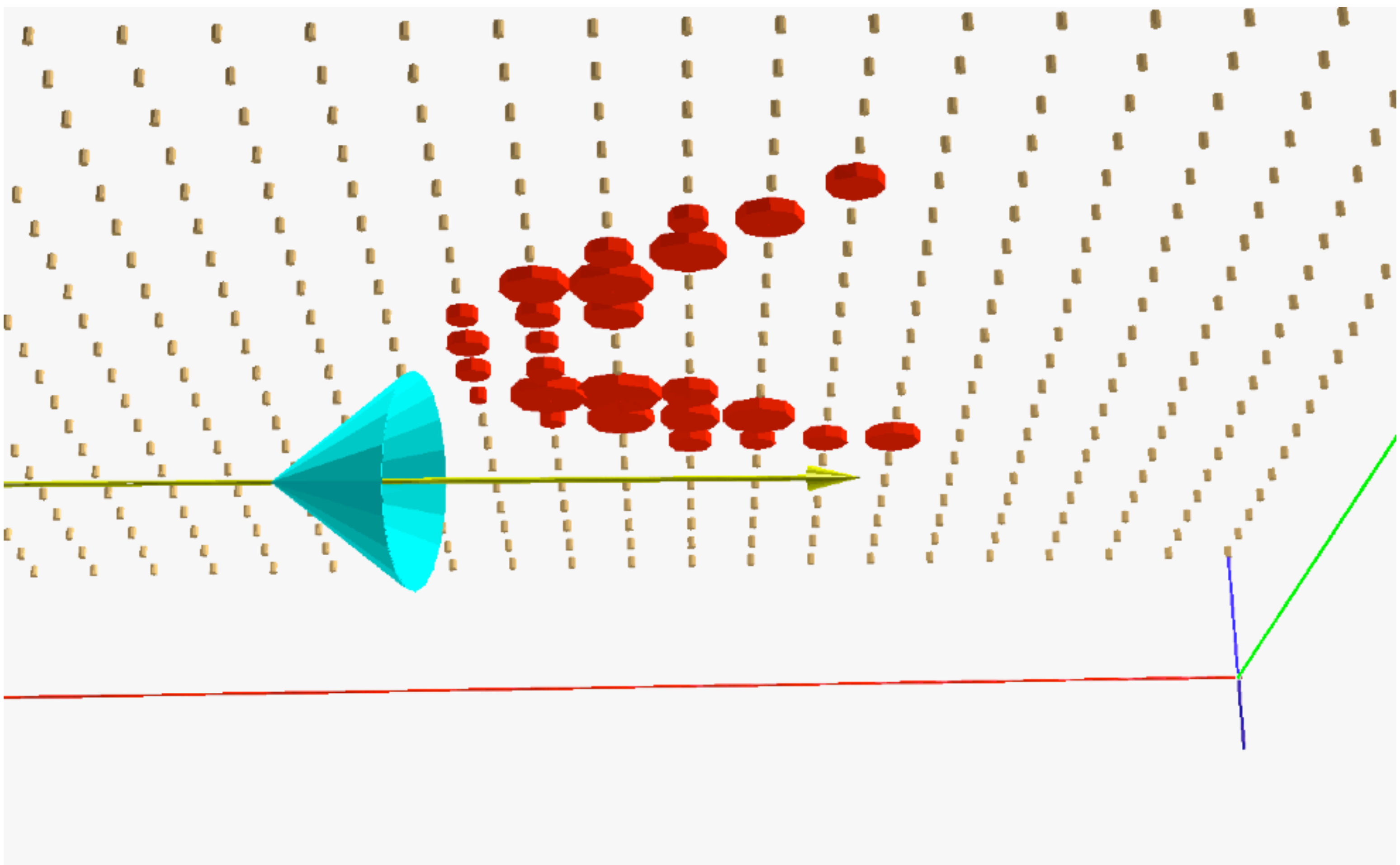


Amazing fidelity of reflected pulse from sea-water bottom -behaves as nearly flawless mirror

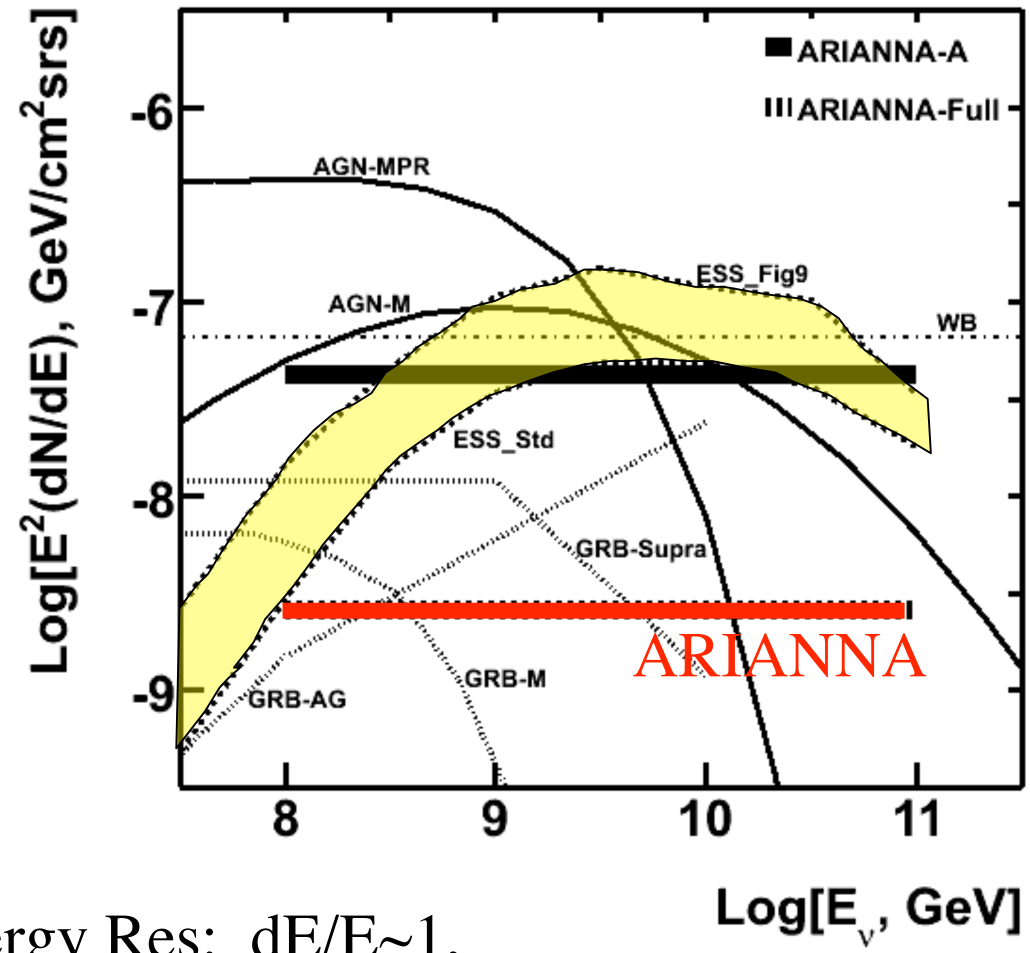
1-way attenuation length, averaged over depth and temperature

And Radio Quiet!

ARIANNA Visualization



ARIANNA Sensitivity

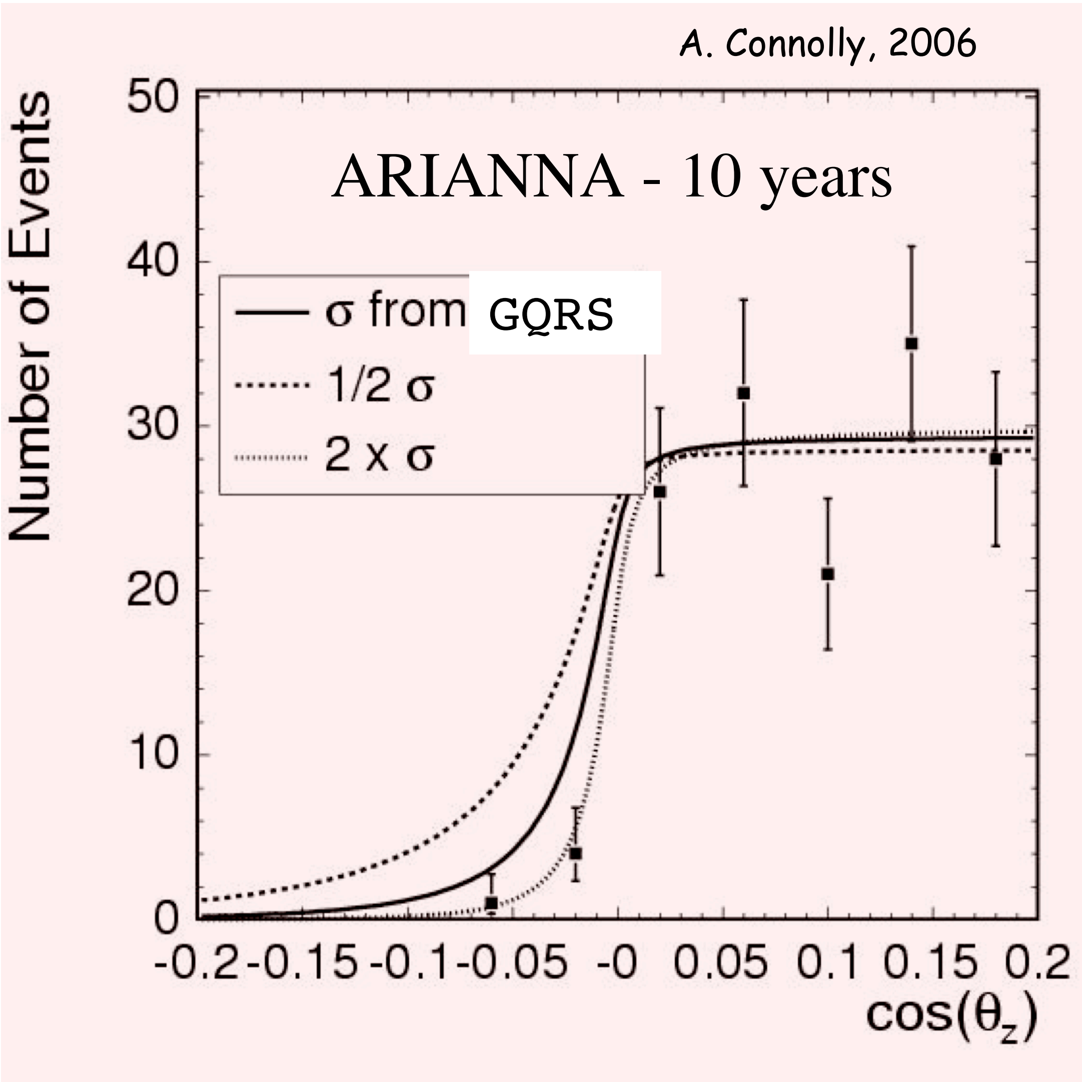


Greatly increases sensitivity to GZK ν in $E=10^{18}$-10^{19} eV

ARIANNA + ESS Flux: 40 events/yr

Energy Res: dE/E~1,
Angular Res: σ_θ~1 deg

Neutrino Cross-Section



$[\Delta\sigma/\sigma\ ] = 0.24$

If $N_{ev} = 400$

If $\delta\theta\ = 0.5^{o}$

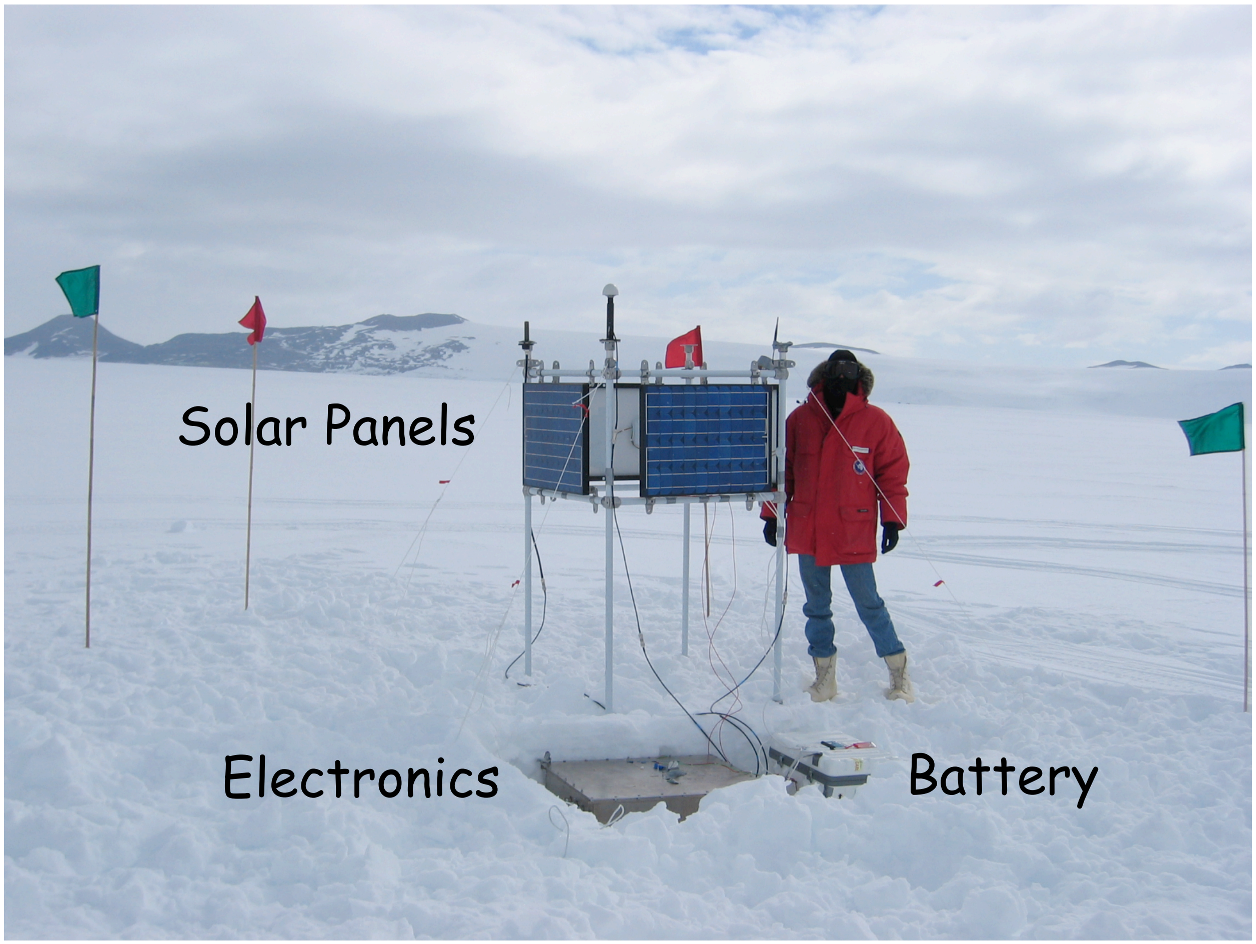
If $\sigma = 2\sigma_{GQRS}$

2 parameter fit:

Normalization

cross-section

Protostation Deployed 12/26/06

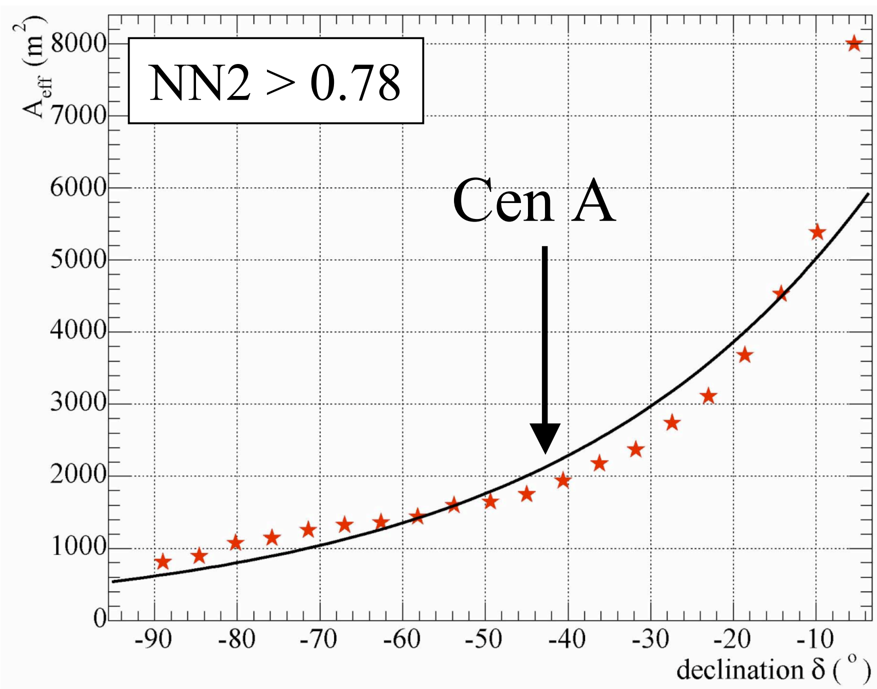


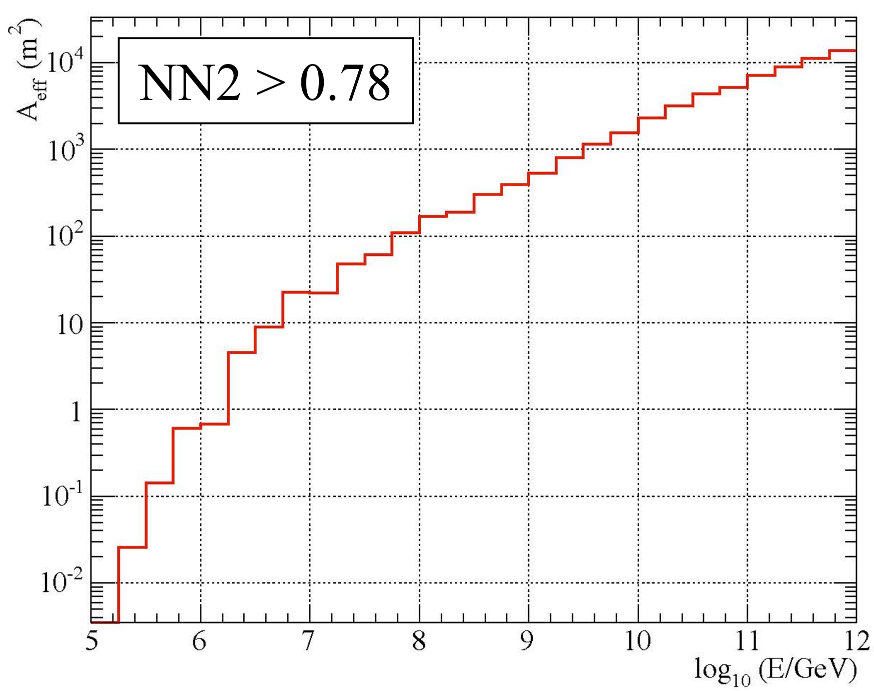
Outlook

- Requisite tools to inaugurate multi-messenger astronomy are available -> IceCube, Mediterranean efforts continue to improve this technique.
  - Flux from EG sources may be low -> galactic sources very important
- To probe the neutrino fluxes and physics at highest energies, new techniques are being developed based on radio cherenkov , air shower and acoustic detection.
- ANITA extends search volume to 10^6 km^3
  - Launched from McMurdo Dec 15, 2006, and remained aloft 35 day
  - Results recently released, 2nd flight completed in Jan 09
- ARIANNA spans the impending energy gap
  - Ice studies in Nov’ 06 astonishingly good, but not the only contender (SALSA, AURA/IceRay, Auger, acoustic detection)

[redacted]

UHE analysis sensitive over the southern sky $\phi_\nu \sim E^{-2}$

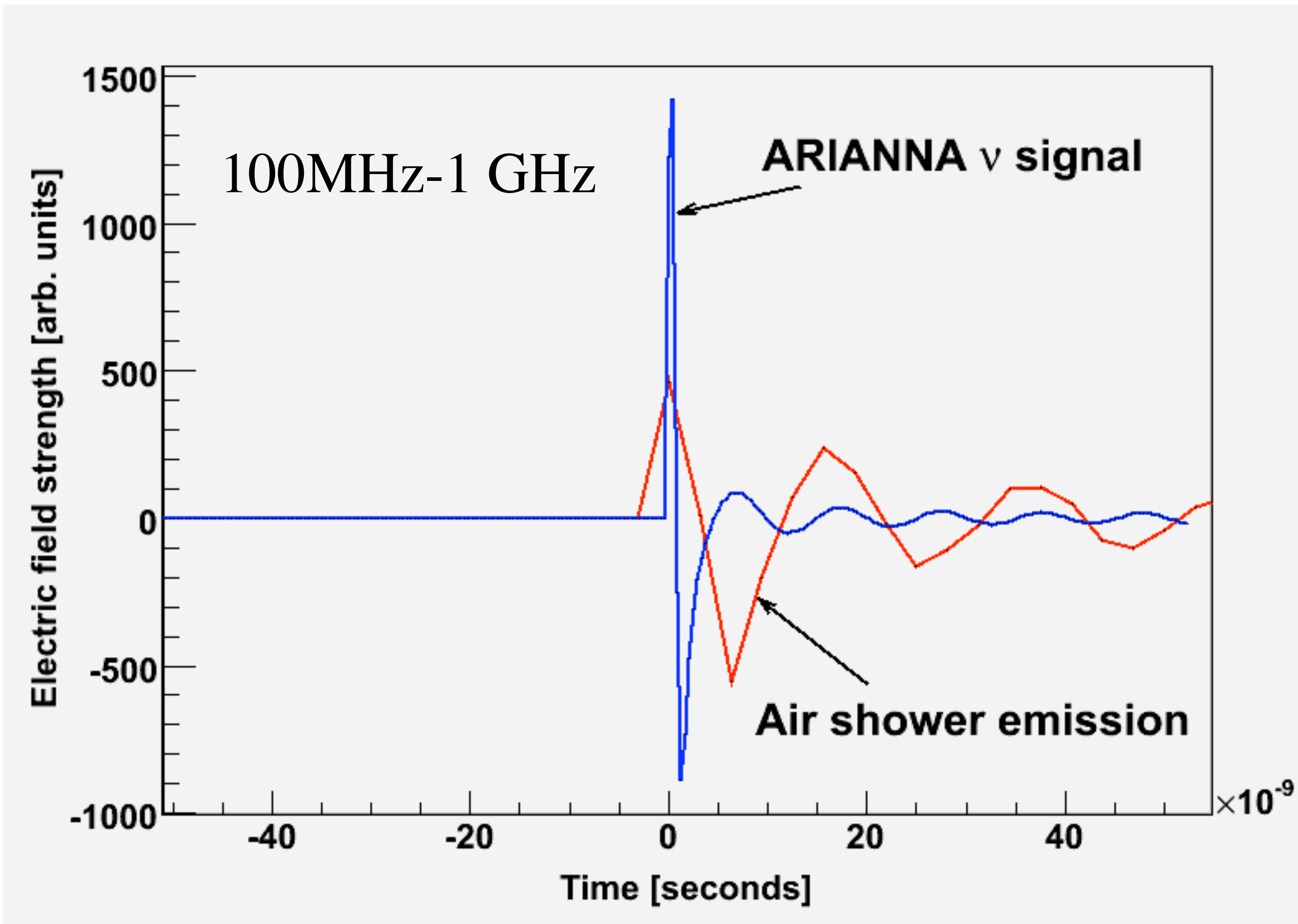




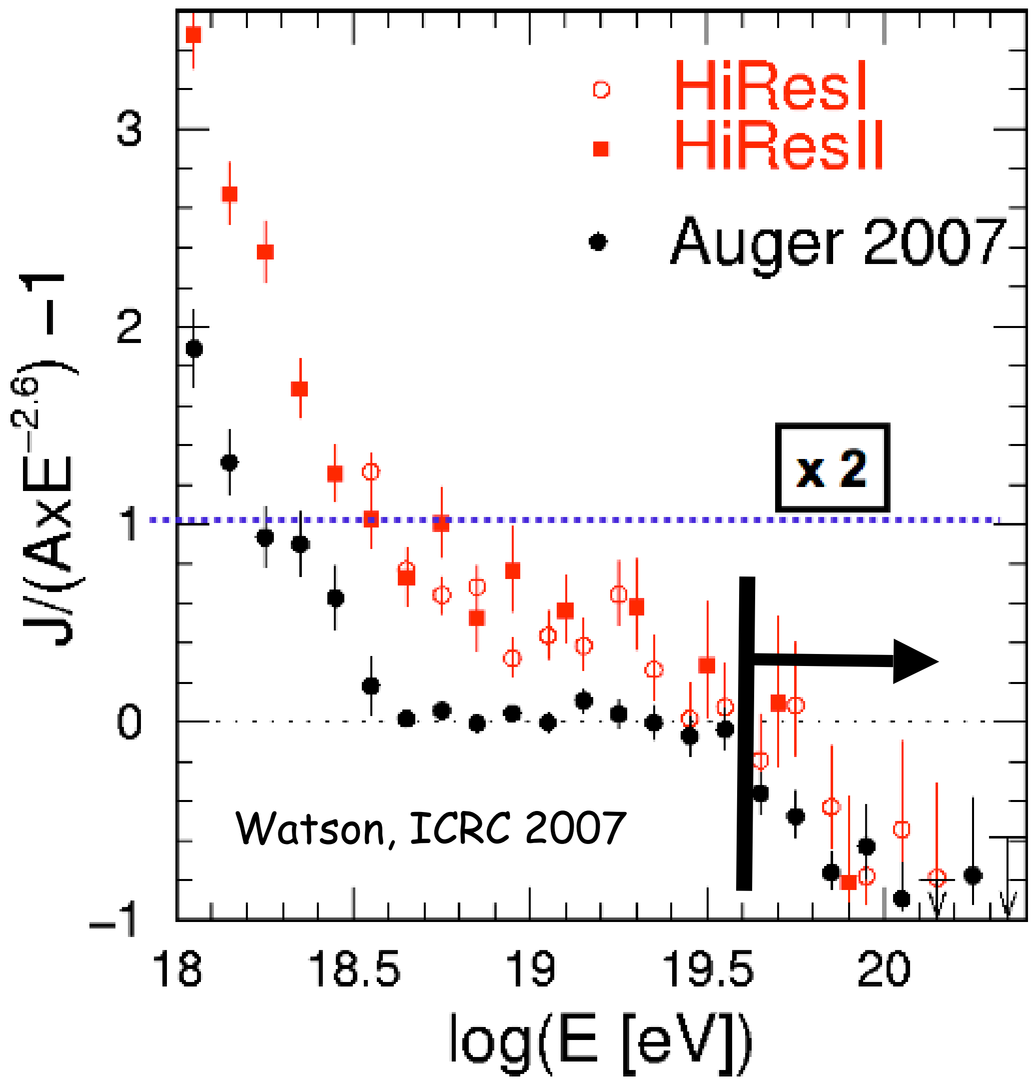
- A_{eff} as a function of declination δ and neutrino energy E_ν

Air Shower vs Ice Shower

(time profiles quite different!)



“GZK” suppression exists!



Both HiRes and AUGER see suppression @ E ~$10^{19.5}$ eV