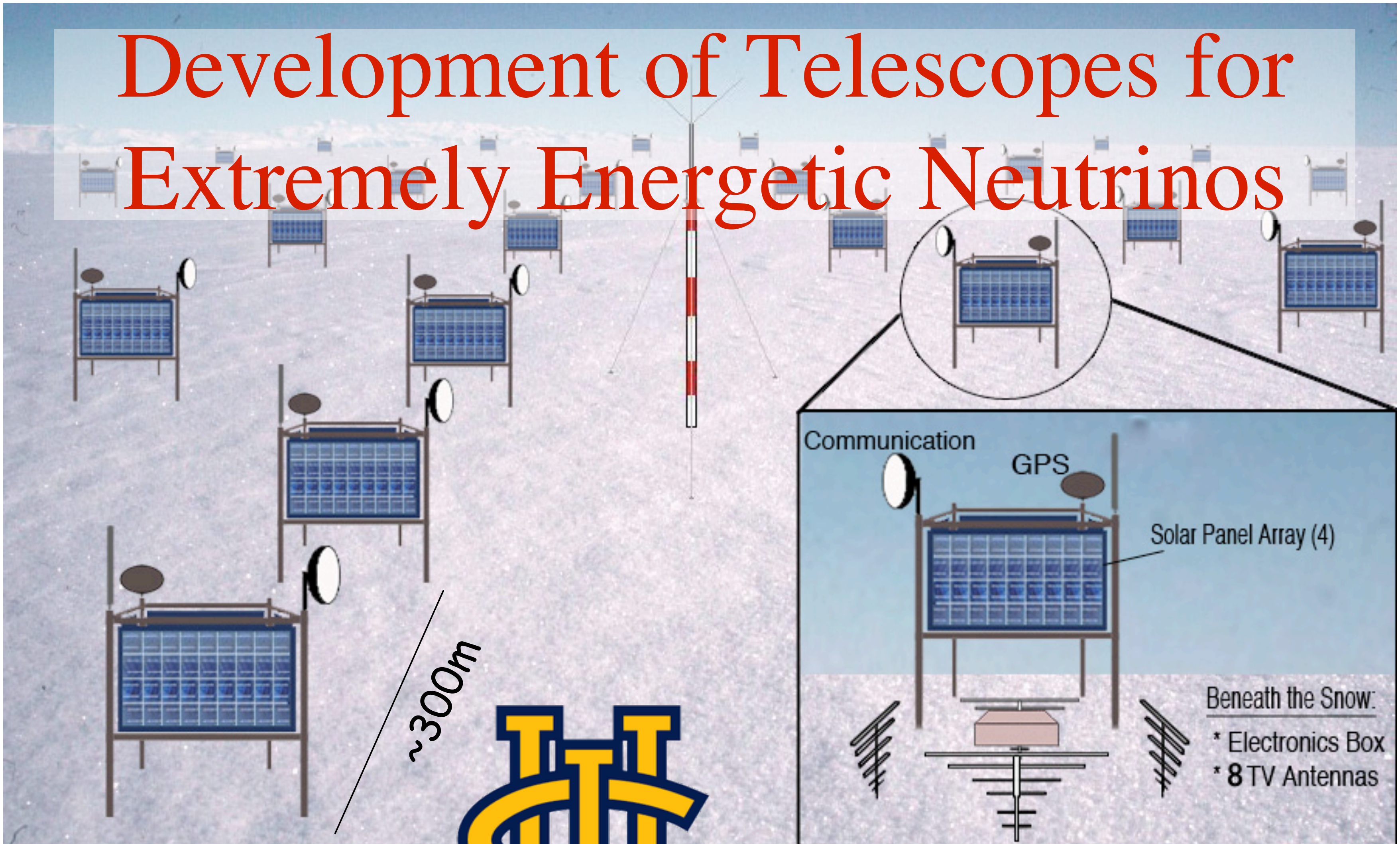
Development of Telescopes for Extremely Energetic Neutrinos



Steven W. Barwick, UC-Irvine

Neutrino Telescopes: Agenda

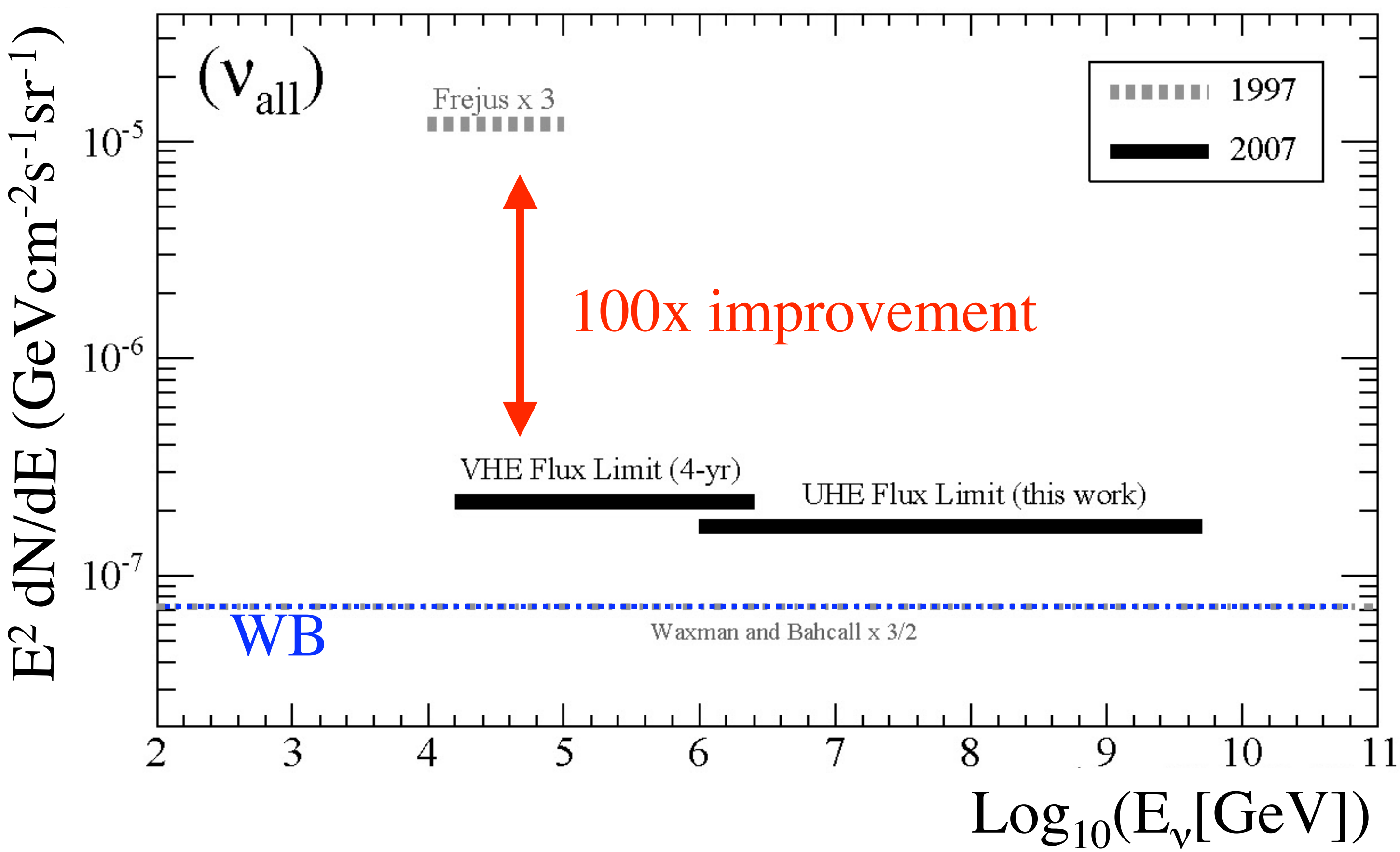
- 10 years of progress with optical Cherenkov Detectors
- Diffuse flux limits and EG point flux constraints
- Extremely Energetic Neutrinos - New Technologies

    Radio, Air Shower/Flourescence, Acoustic

    Noise and transparency

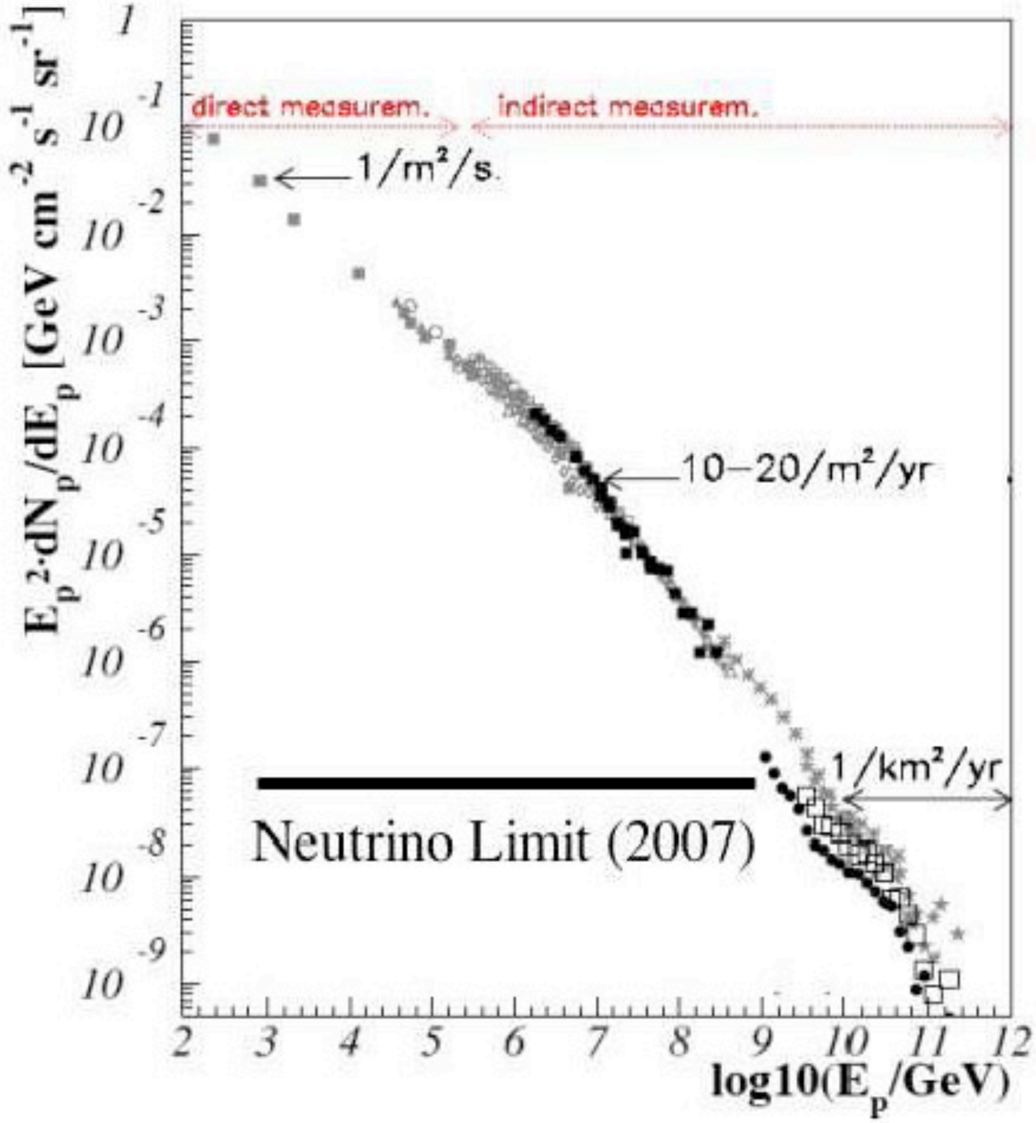
VLV = Teraton -Petaton

10 Years of Diffuse ν Progress



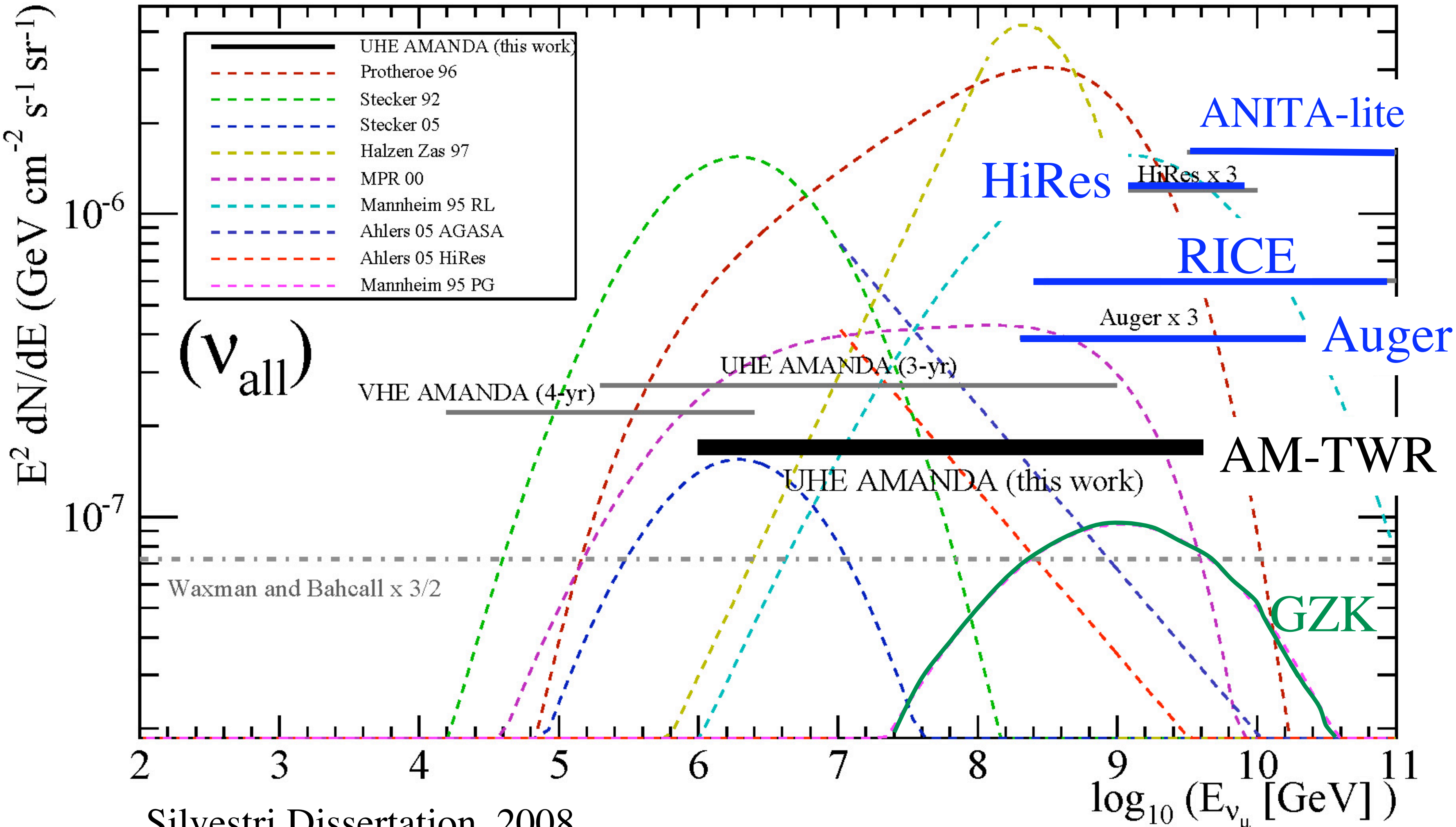
A. Silvestri, PhD Dissertation, 2008

Diffuse ν-Fluxes << CR-Fluxes



Silvestri Dissertation, 08

Diffuse Flux: Limits and Models



Silvestri Dissertation, 2008

Excluding AGN Model Predictions for Diffuse Flux

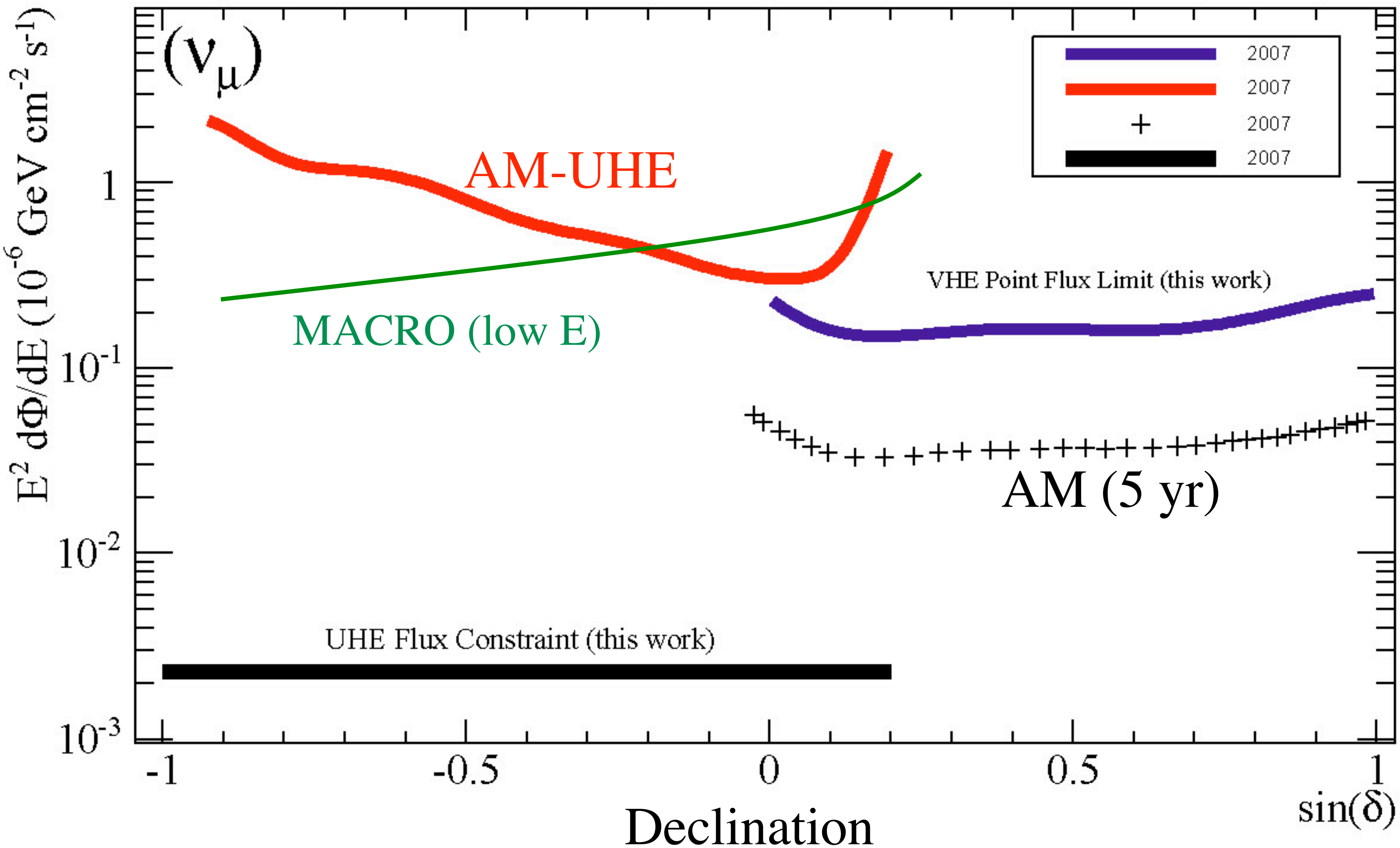
Excluded

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



Constraining EG Point Flux

- Constraint based on sensible collection of suppositions:
  1. EG point sources are uniformly distributed
  2. L_ν constant or given by luminosity distribution function
  3. Source emission described by same 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

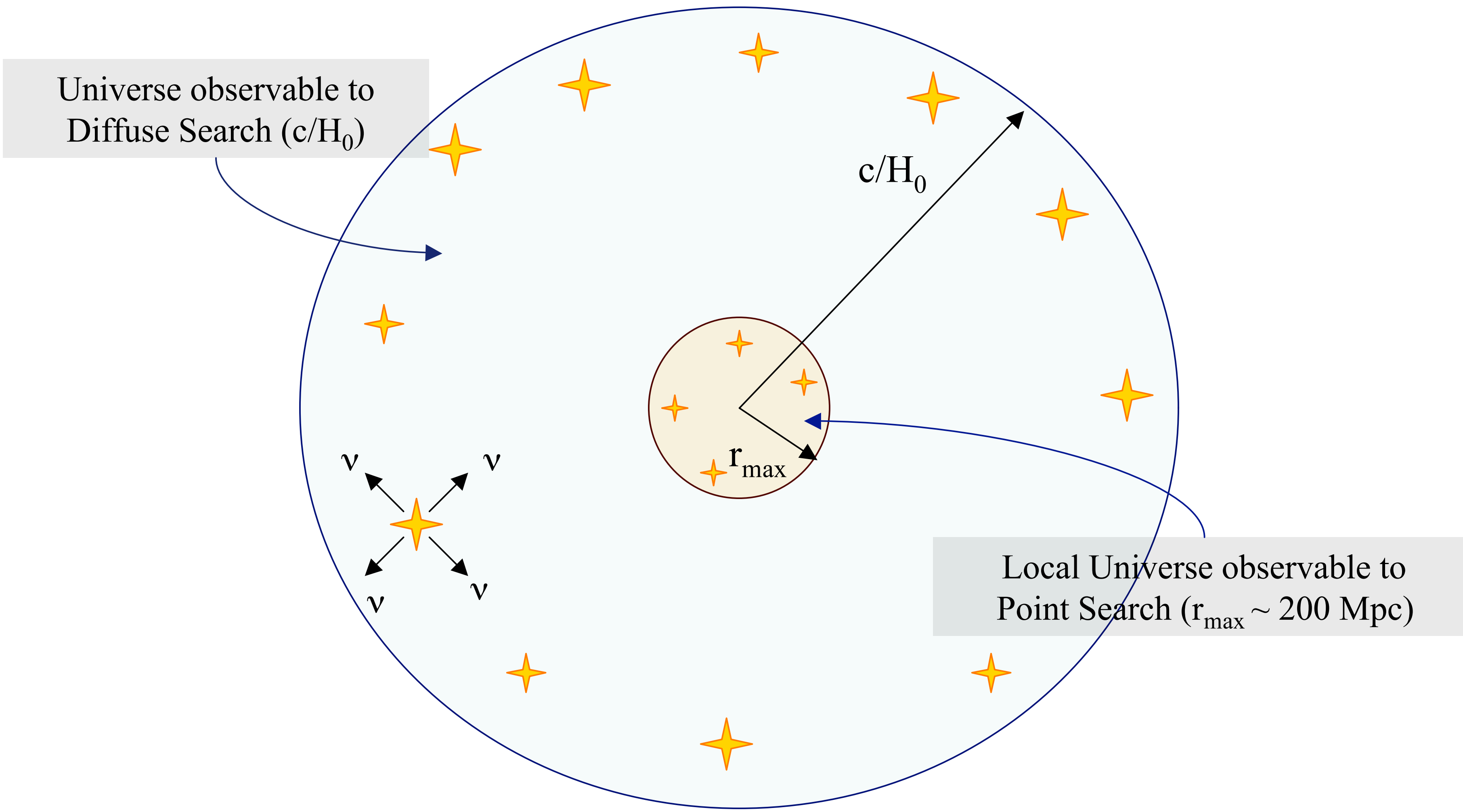
$$N_s \simeq \frac{\sqrt{4\pi}}{3} \frac{1}{\sqrt{\ln(10)}} \frac{H_0}{c} \frac{K_{diff}\sqrt{L_{dec}}}{(C_{point})^{3/2}} \frac{1}{\xi}$$

First derived by P. Lipari

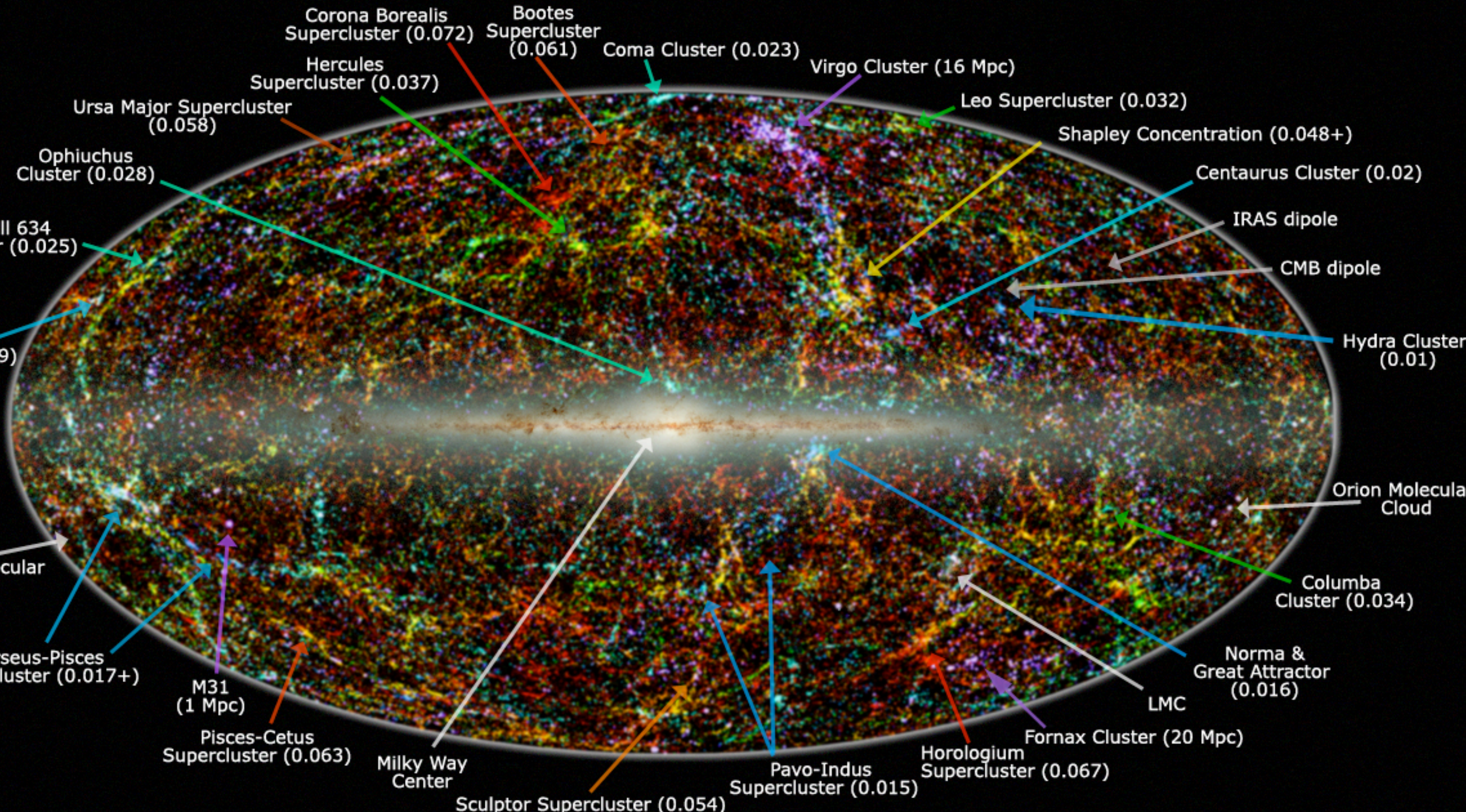
Connecting Diffuse ν−Flux to Point Sources

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

Observable & Local Universe

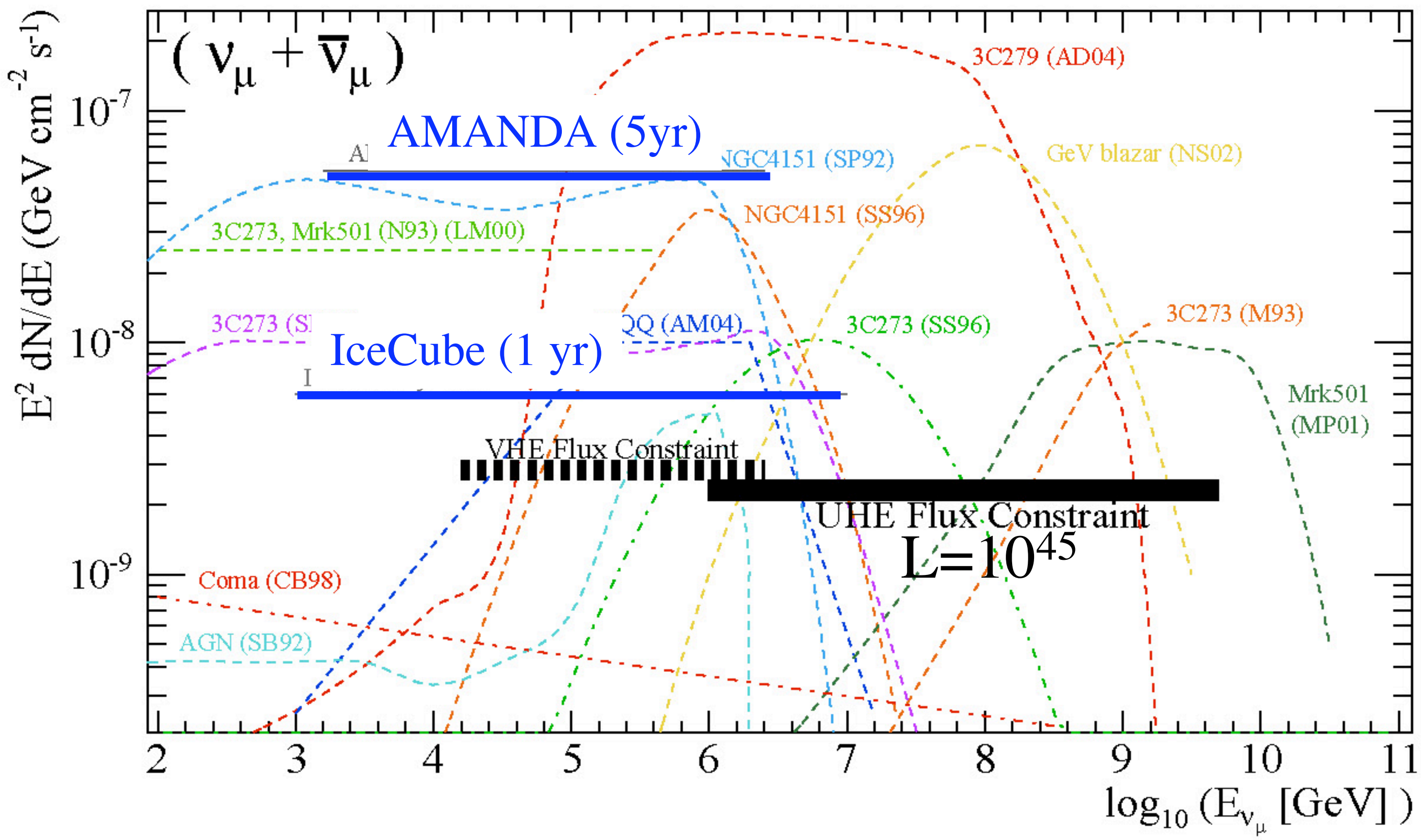


Large Scale Structure in the Local Universe



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)

EG Point Flux Constraint

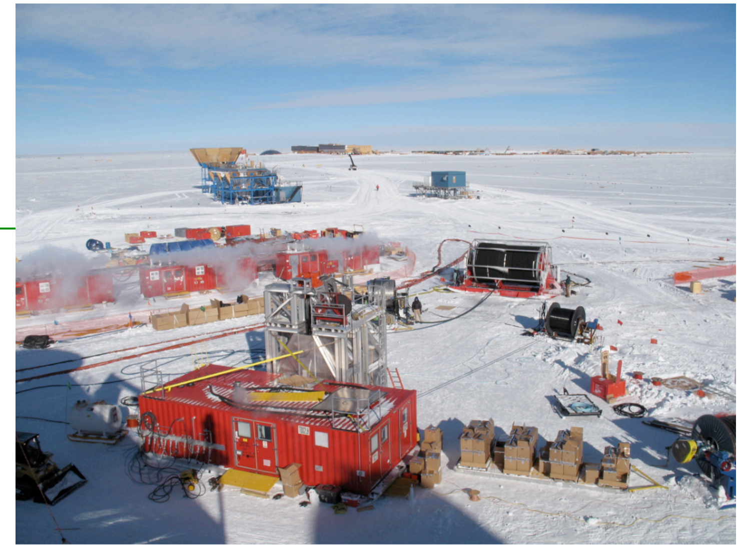


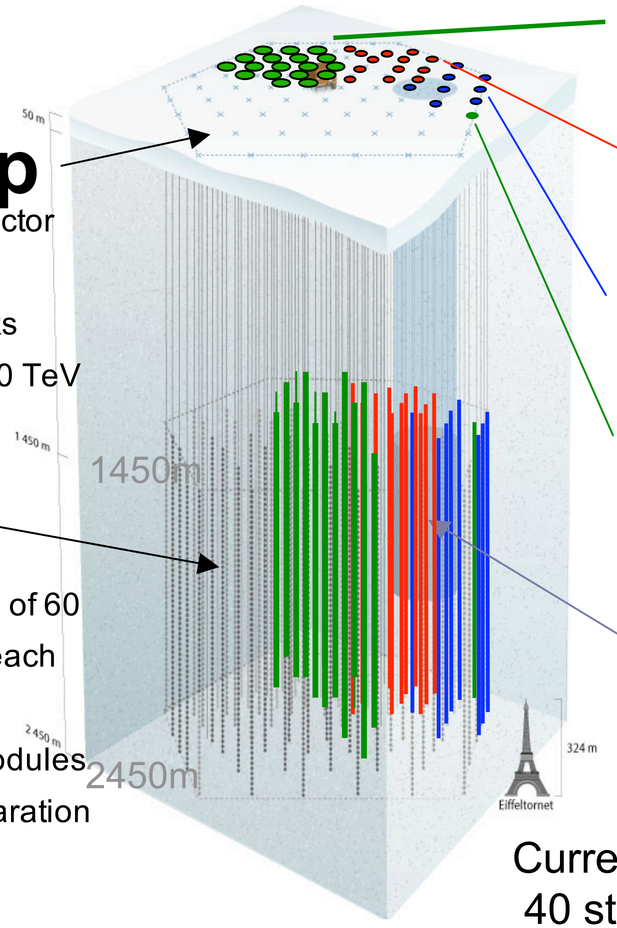
Silvestri Dissertation, 2008

Suggests EG sources may be difficult to detect

-> raises profile of Galactic sources

IceCube





2007-2008 :
18 strings

2006-2007:
13 strings

2005-2006:
8 strings

2004-2005 : 1 string

IceTop

Air shower detector
80 pairs of ice
Cherenkov tanks
Threshold ~ 300 TeV

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: add 18 strings and tank stations

Completion by 2011.

Quest for EHE neutrinos

New Technologies

Cosmogenic (or GZK) Neutrinos

Predictions are secure:

$p + \gamma_{cmb} \;\; \text{->} \;\; \Delta \text{->} n + \pi^{+}$

n -> lower energy protons

π -> $\mu+\nu$

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?

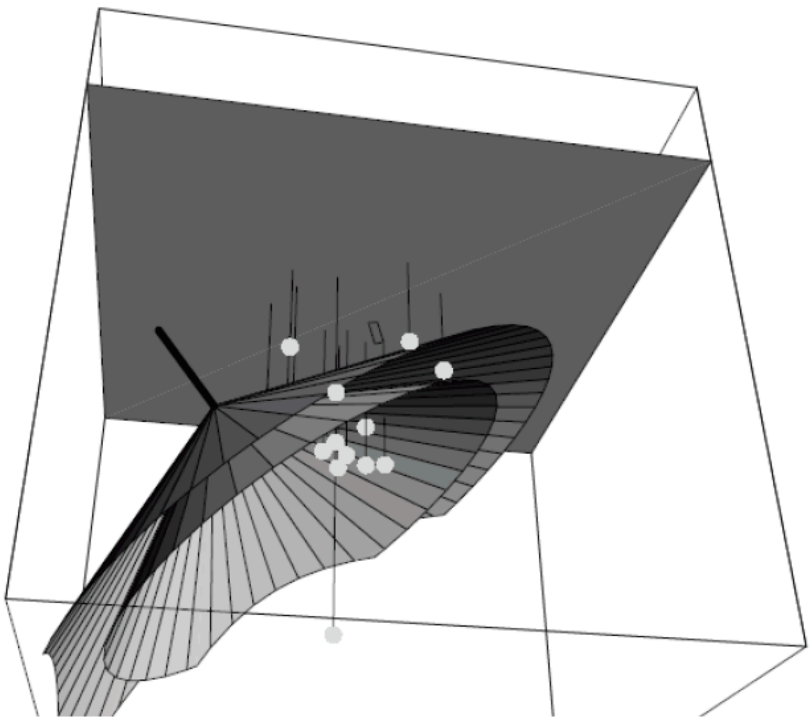
- GZK ν Flux ($E \sim 10^{18}$ eV): 10 /km^2/yr
- ν Interaction Length: 500 km
- Event Rate/km^3/yr = [10/500] ~ 0.02
- See about half the sky, 0.01/km^3/yr
- Efficiency, livetime, nice if more than one

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

Radio Ice Cerenkov Experiment

MIT, Whitman College, U. of Delaware, U. of Canterbury, University of Kansas, University of Kansas Design Laboratory

Credit: Kravchenko et al., 2003

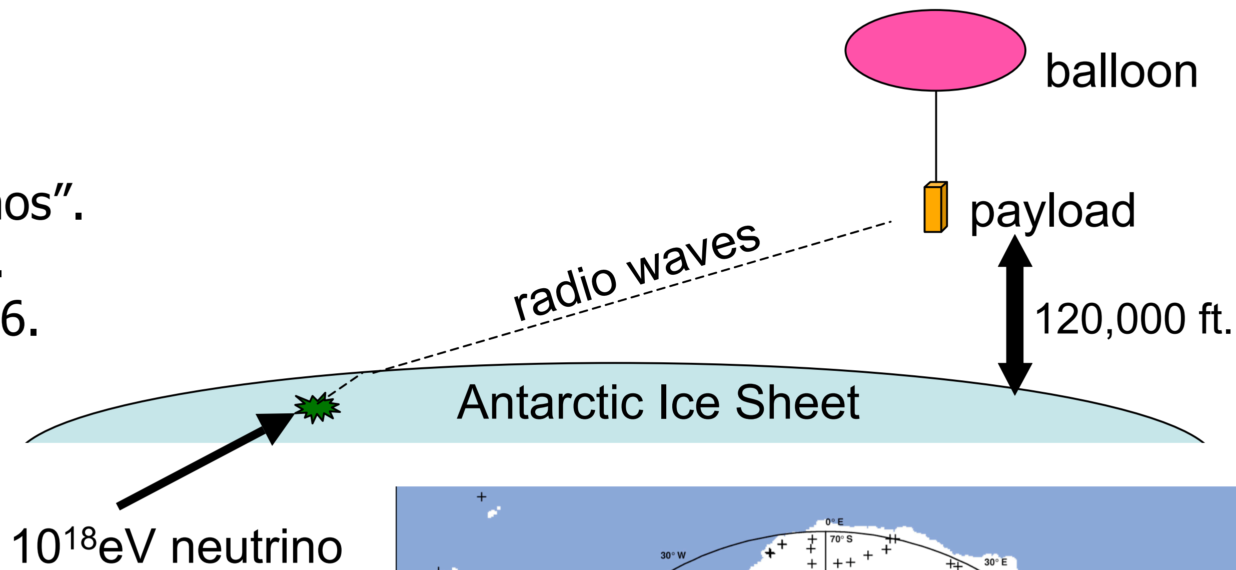


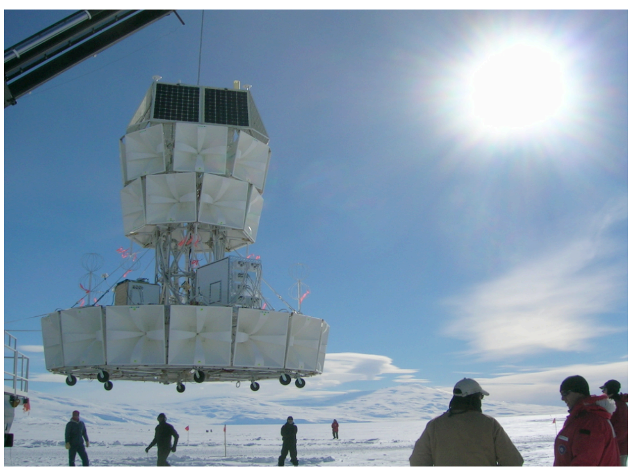
- Martin A. Pomerantz Observatory
  - 1 km from S. Pole
- 16 buried radio receivers in 200 m x 200 m x 200 m area
- Detects Cerenkov radiation in 0.2 GHz to 1 GHz frequency range

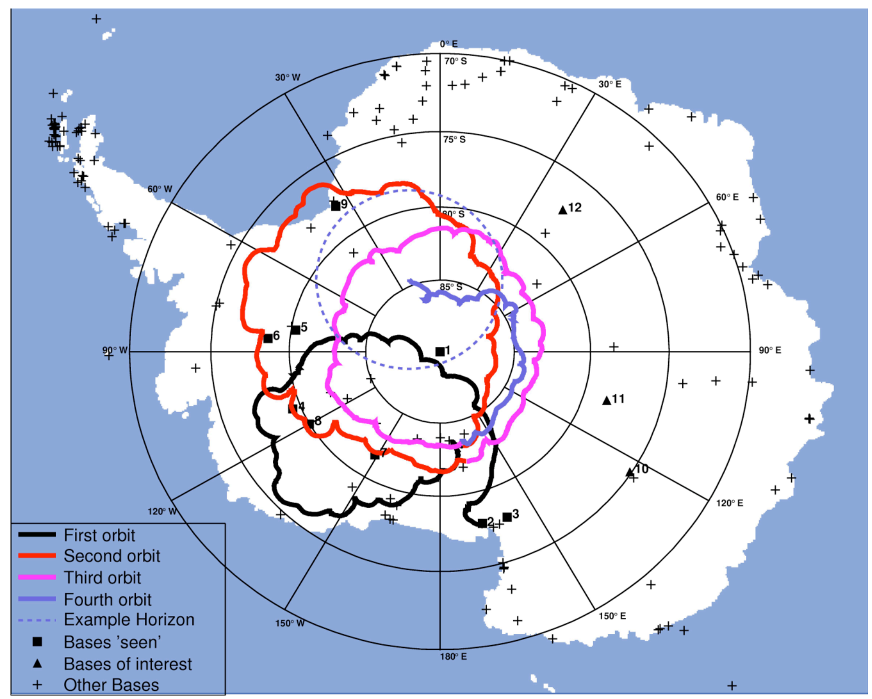
ANITA

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

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

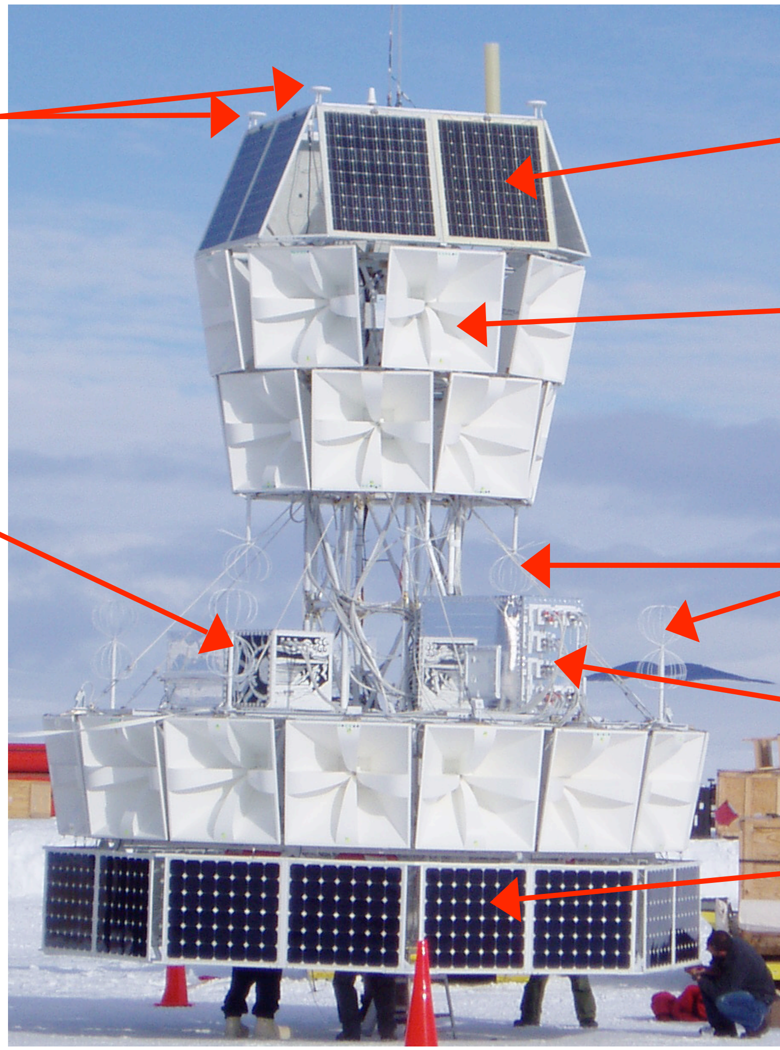
Lets get to know ANITA

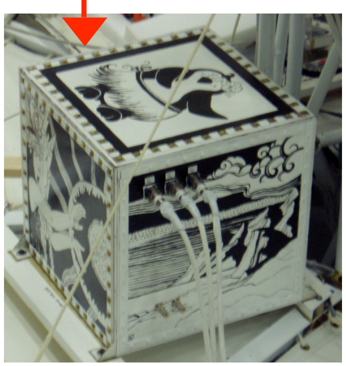
GPS Antennas

Solar cells for NASA equipment

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

Battery box
(Art by residents of McMurdo)





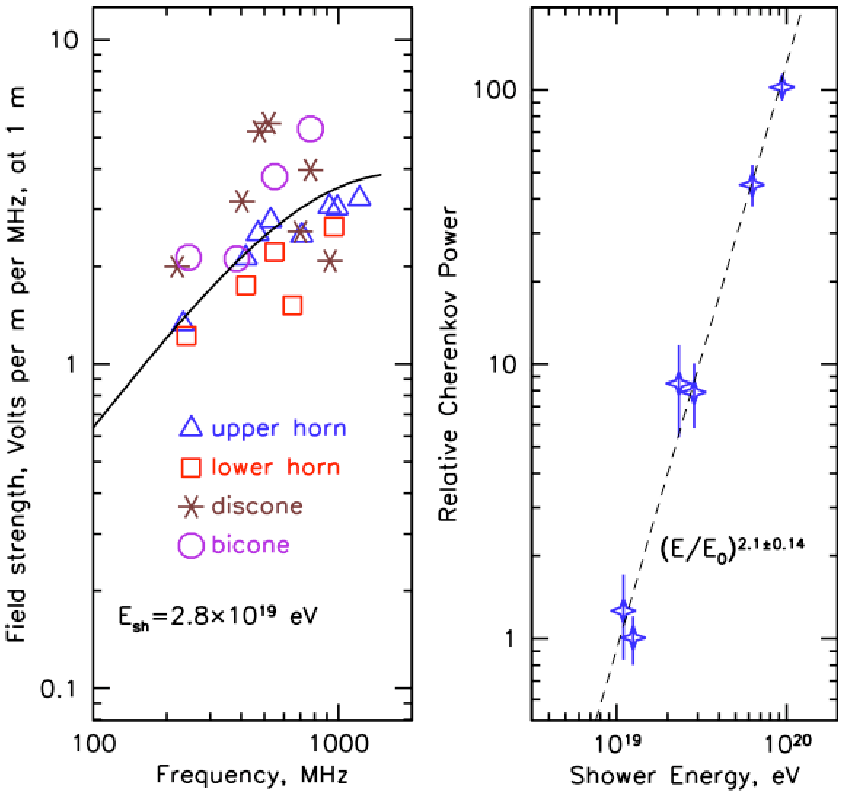
8 low gain antennas to monitor payload-generated noise

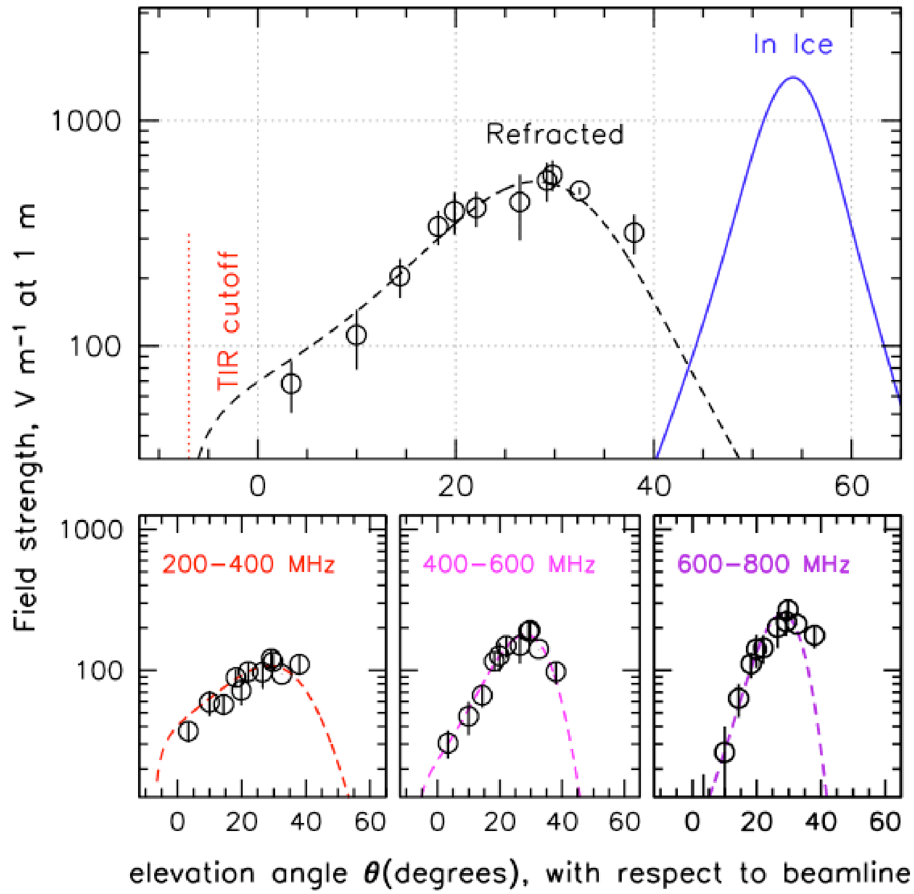
ANITA electronics box (mirrored to minimize solar heating)

Power for science mission

SLAC beam tests on Ice Target

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



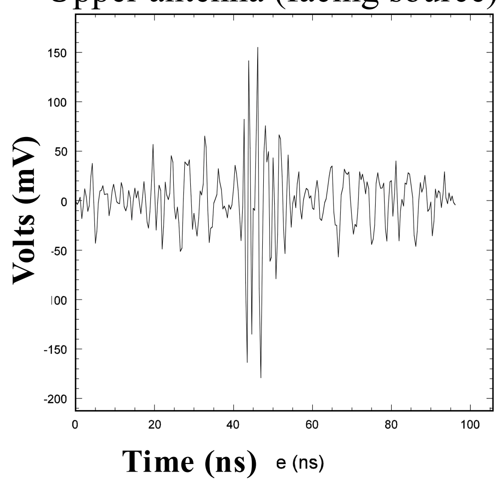


Absolute RF power and frequency dependence confirmed

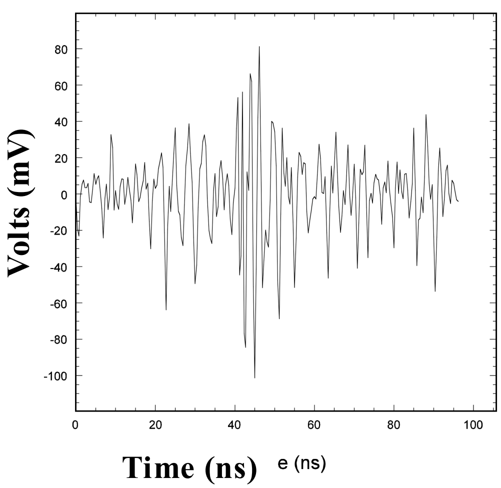
Width of cherenkov cone and frequency dependence confirmed

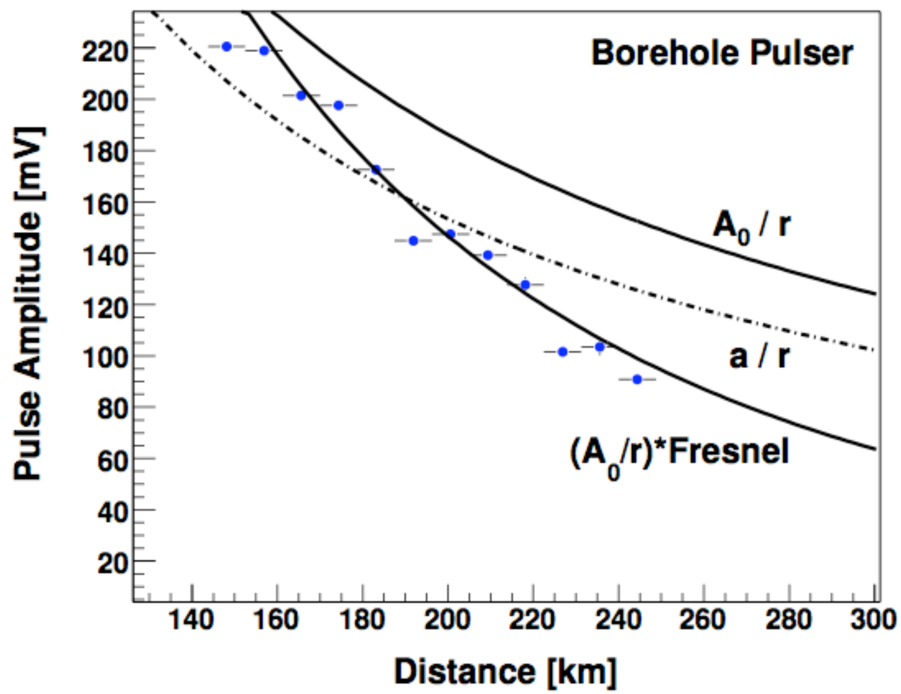
Calibration Signals

Upper antenna (facing source)



Lower antenna (facing source)



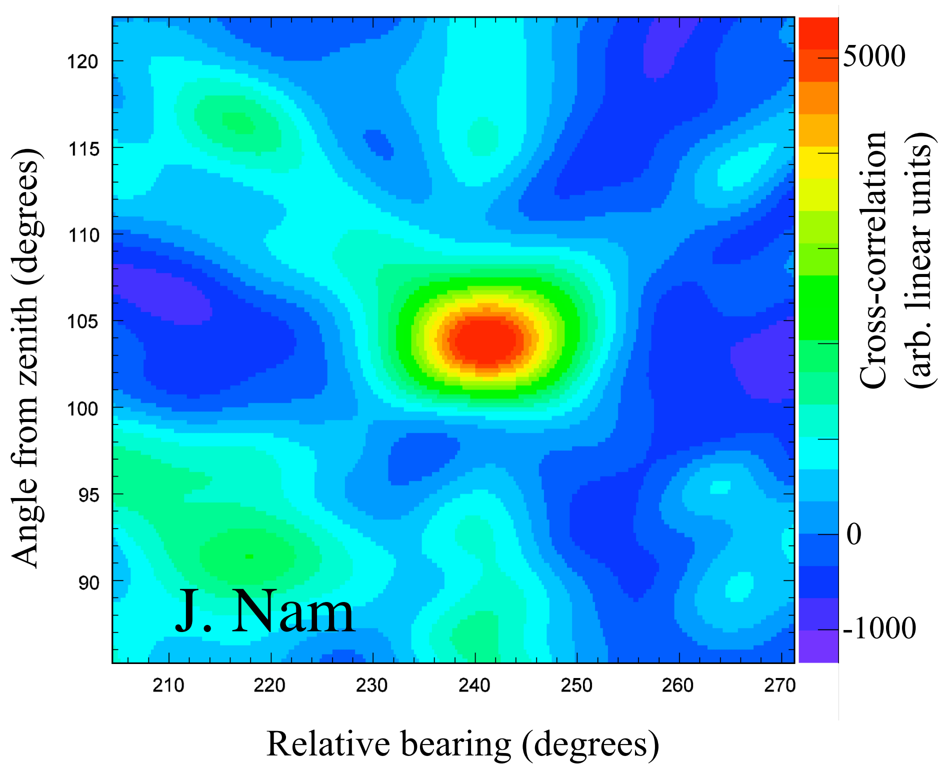


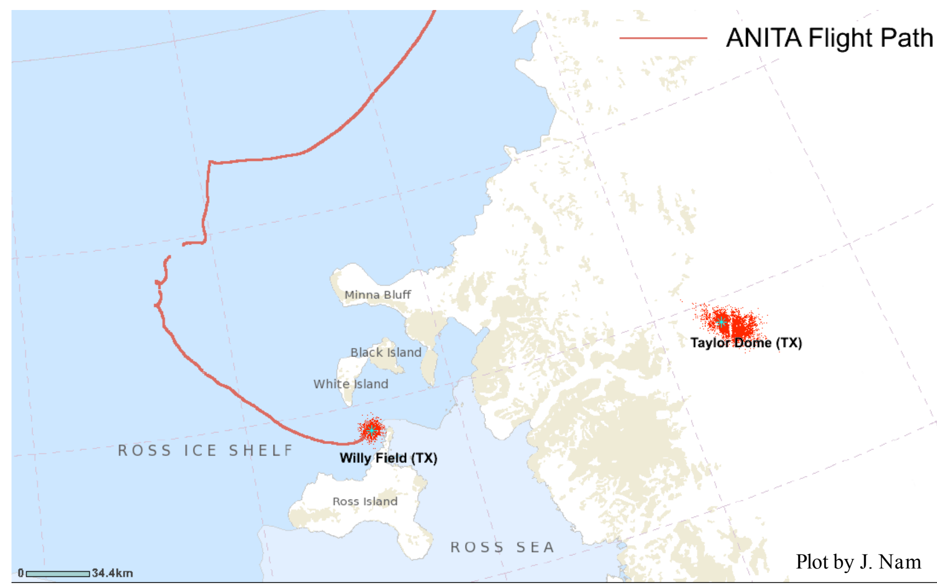
Goldstein, ICRC 2007

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

Pointing At Calibration Events

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



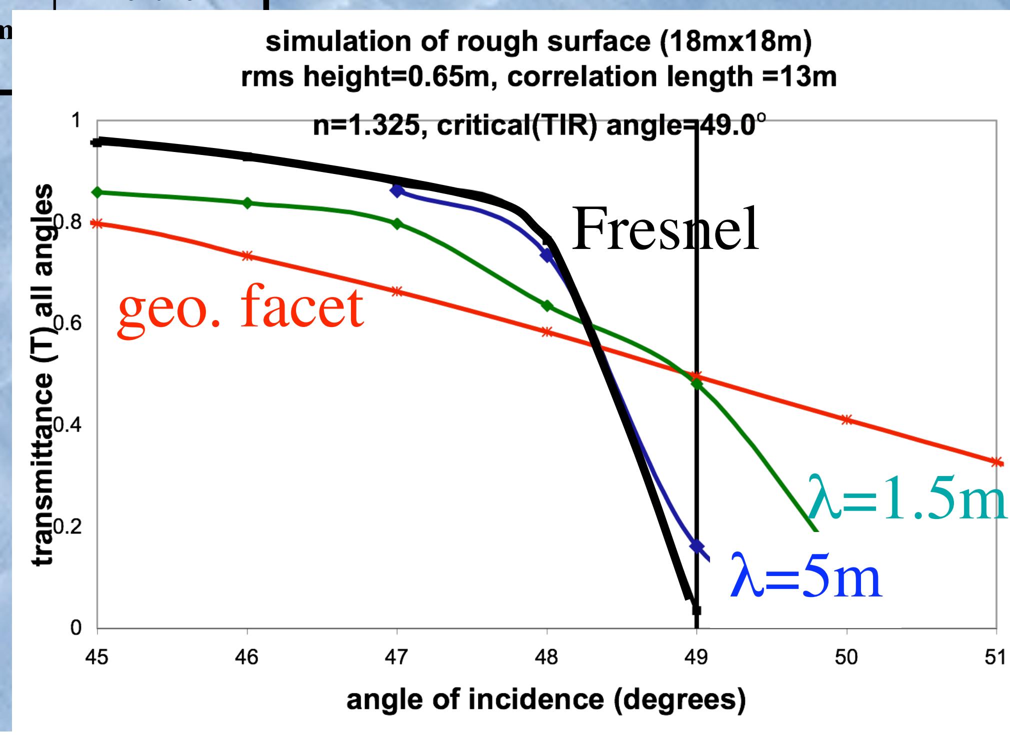


Reconstructed locations of calibration signal events

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



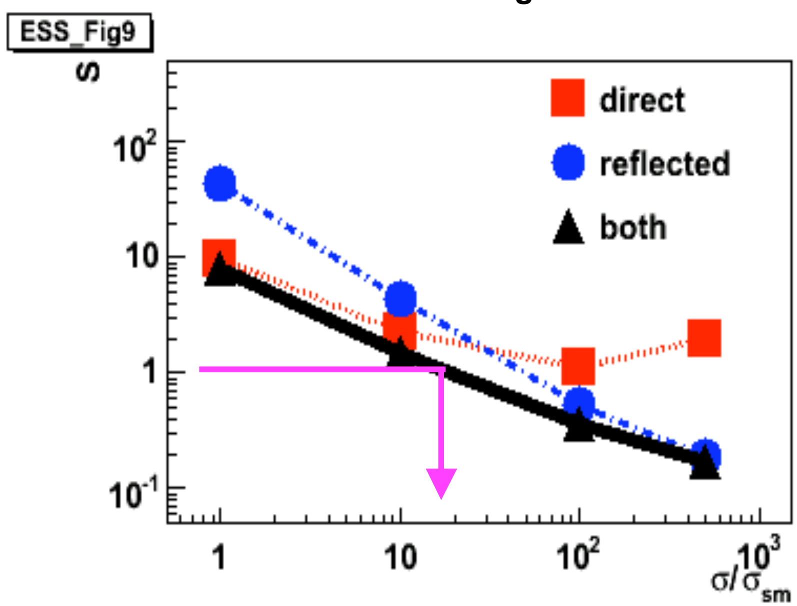
Dookayka, APS08

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

(F. Wu, ICRC 07, APS08)

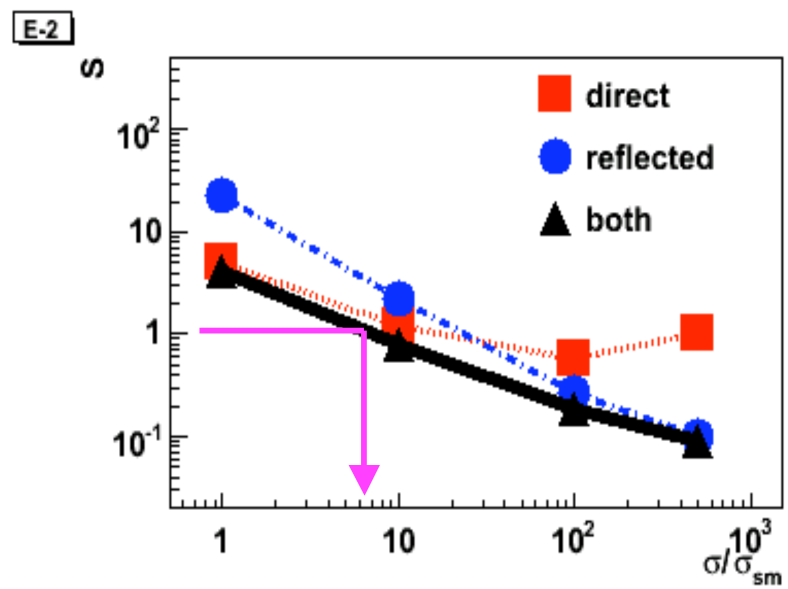
(for scenario of N_ν=0, $10^{19.5}$ eV<E_ν<10^{20} eV)

$\phi = s\phi_{ESS\text{-}fig9}$



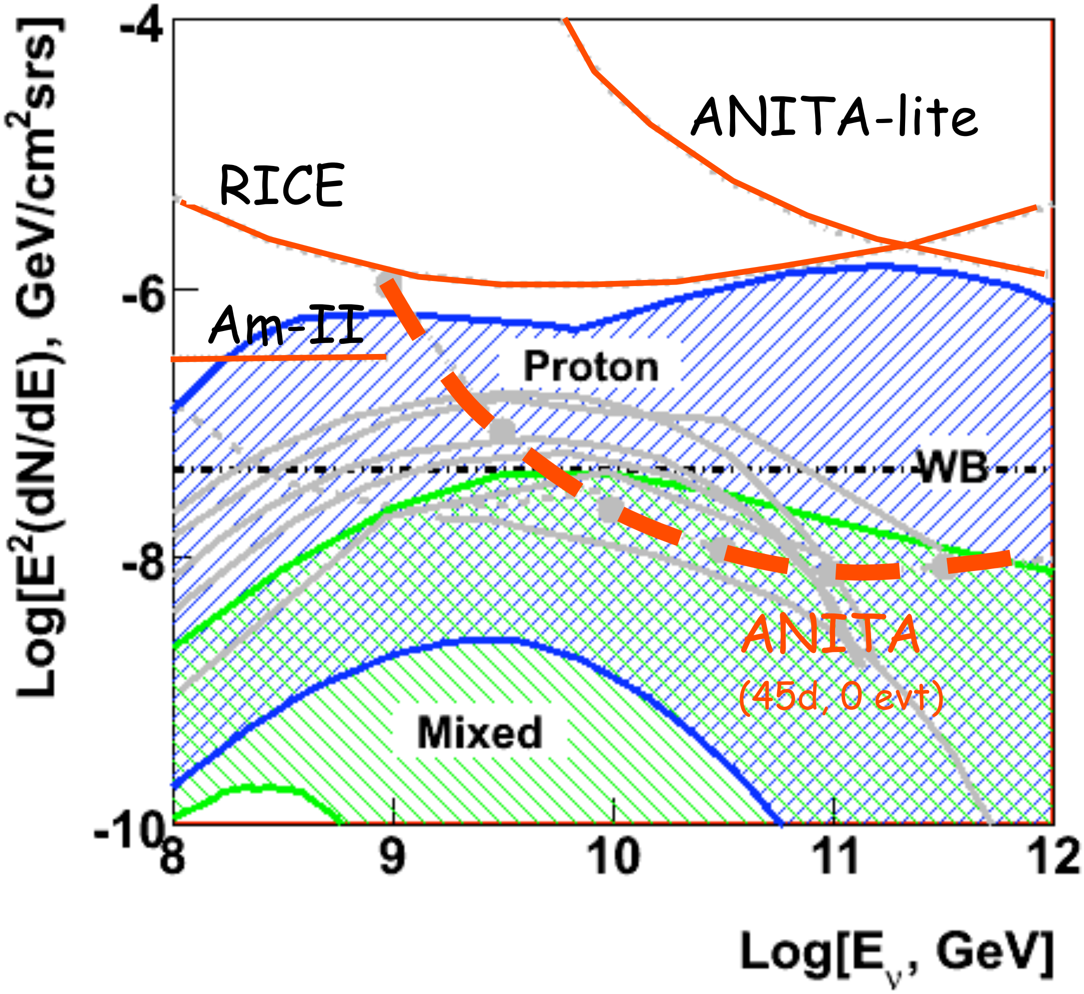
$\sigma < 17\ \sigma_{sm}$

$\phi = s\phi_{E\text{^}-2}$



$\sigma < 6.5\ \sigma_{sm}$

Projected Sensitivity (Prelim.)



Blue= proton only models
Green= mixed comp.

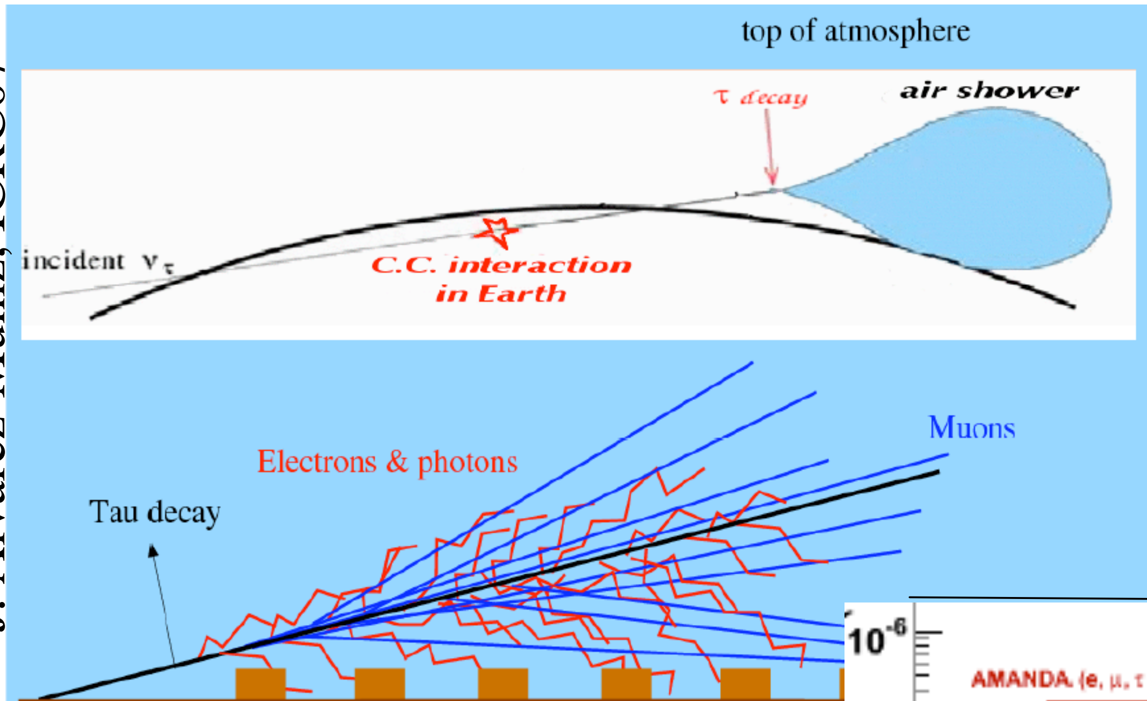
ANITA sensitivity
[Barwick et al, PRL 96(2006)]

- based on 45 days
- assume that 0 ν are found

Fluxes are for
sum of all ν flavors

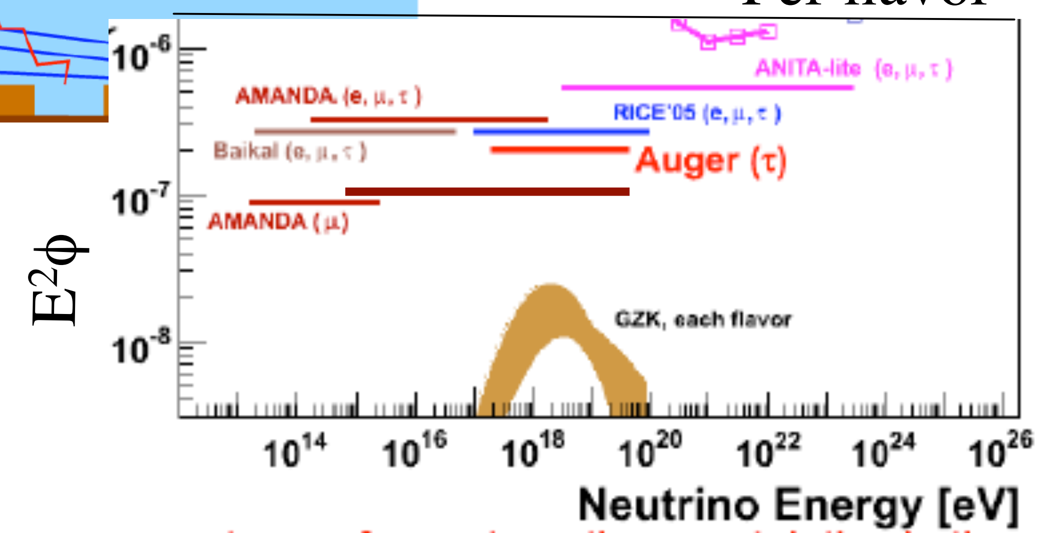
Auger ν_τ Capability

J. Alvarez-Muniz, ICRC07



Take advantage of neutrino oscillation

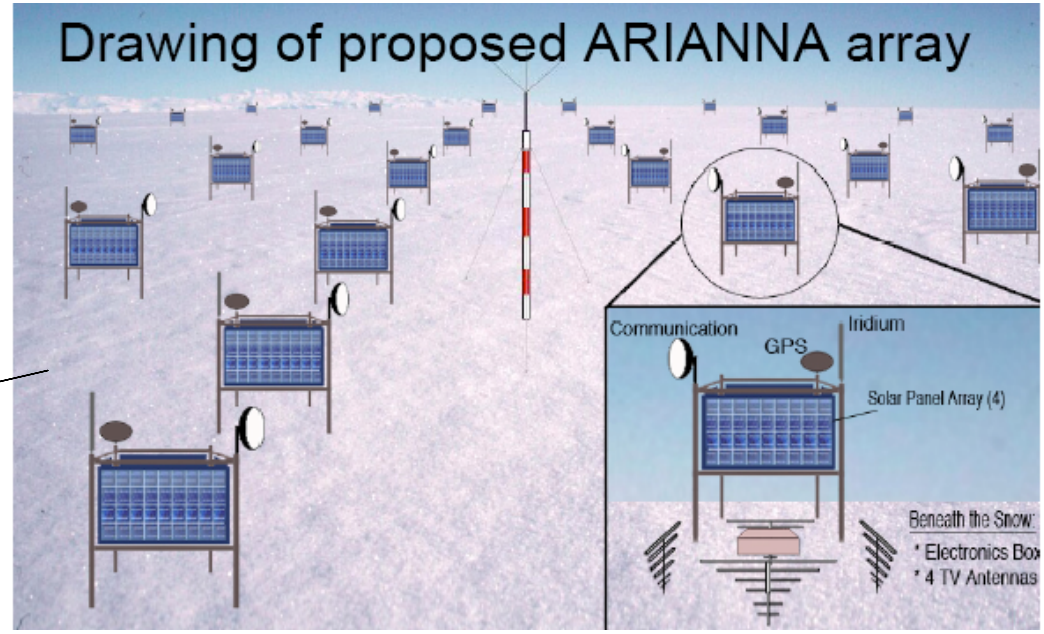
Per flavor



First results based on earth skimming ν_τ, will soon add downgoing aXiv:0712.1909v1

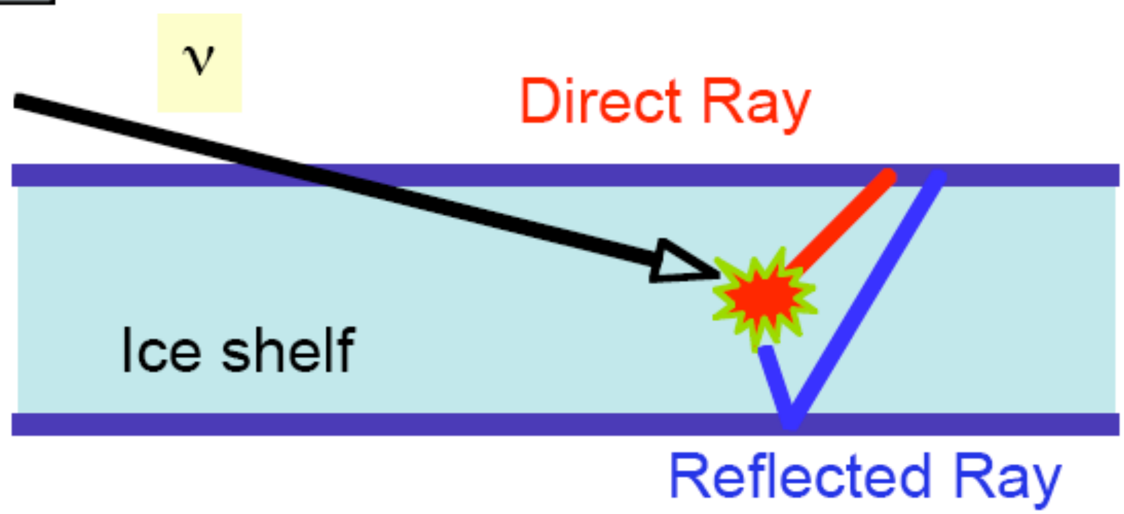
New Techniques to Observe Cosmogenic Neutrinos

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

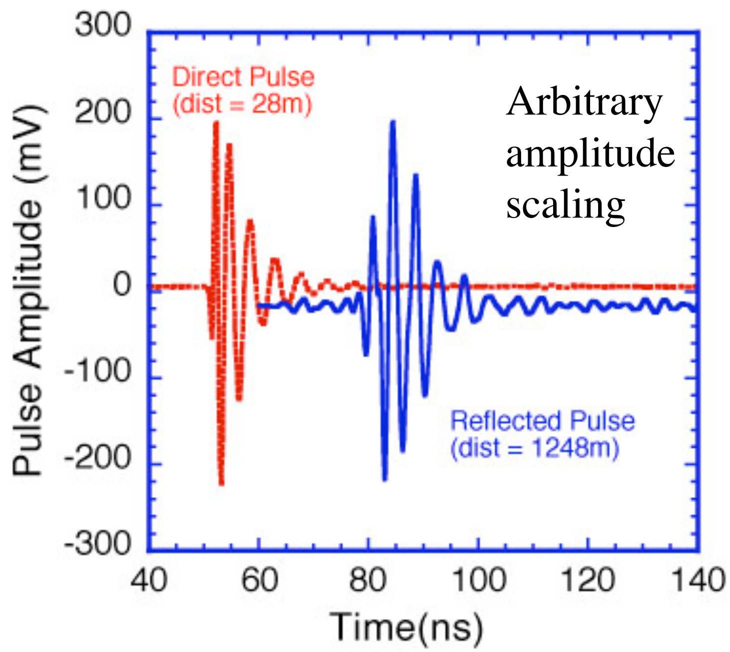


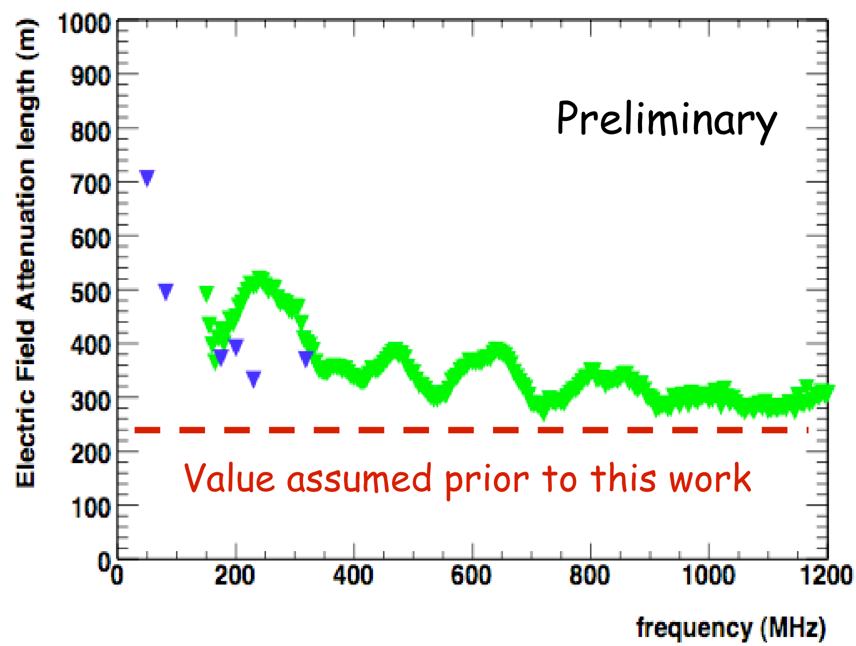
ARIANNA

1/2 Teraton Detector



ARIANNA Site Studies

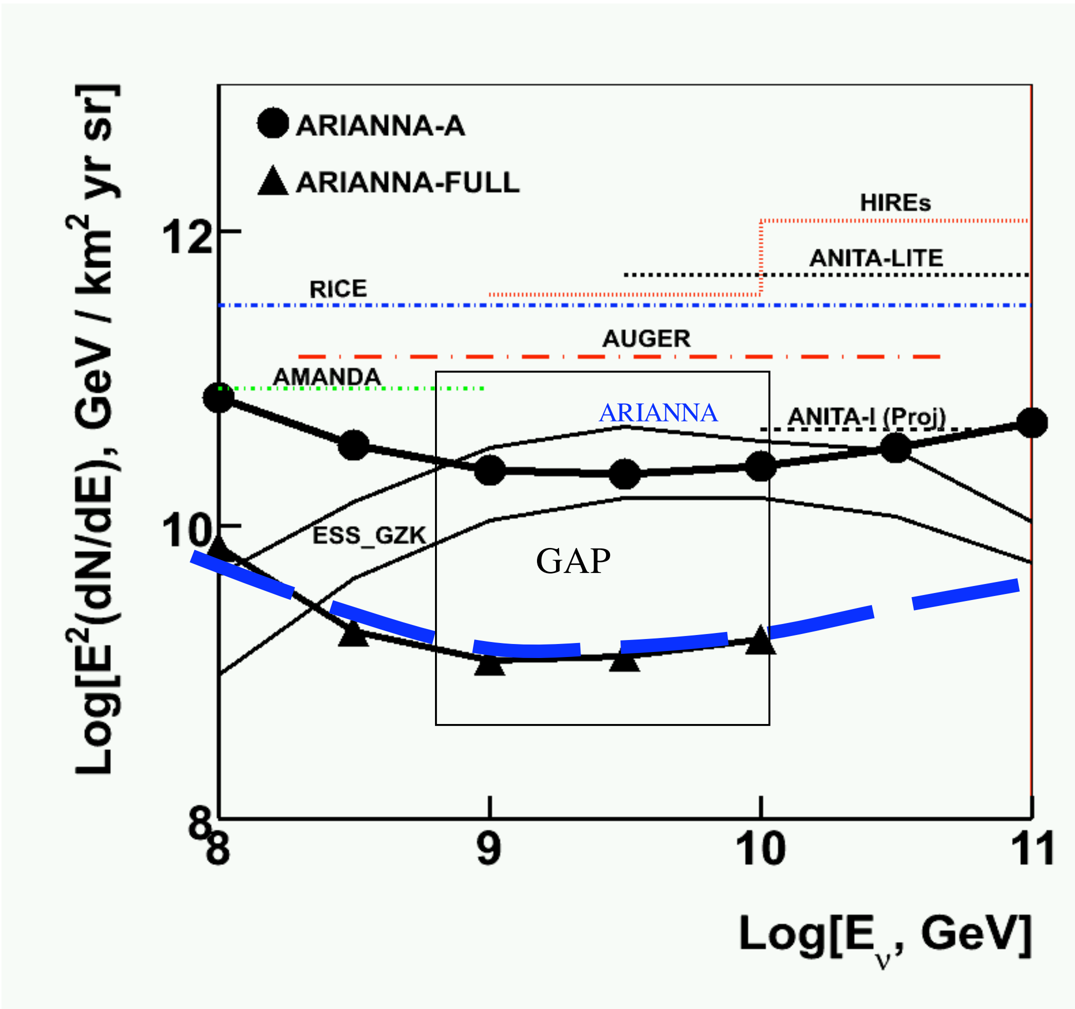




Amazing fidelity of reflected pulse from sea-water bottom -behaves as nearly flawless mirror

1-way attenuation length, averaged over depth and temperature

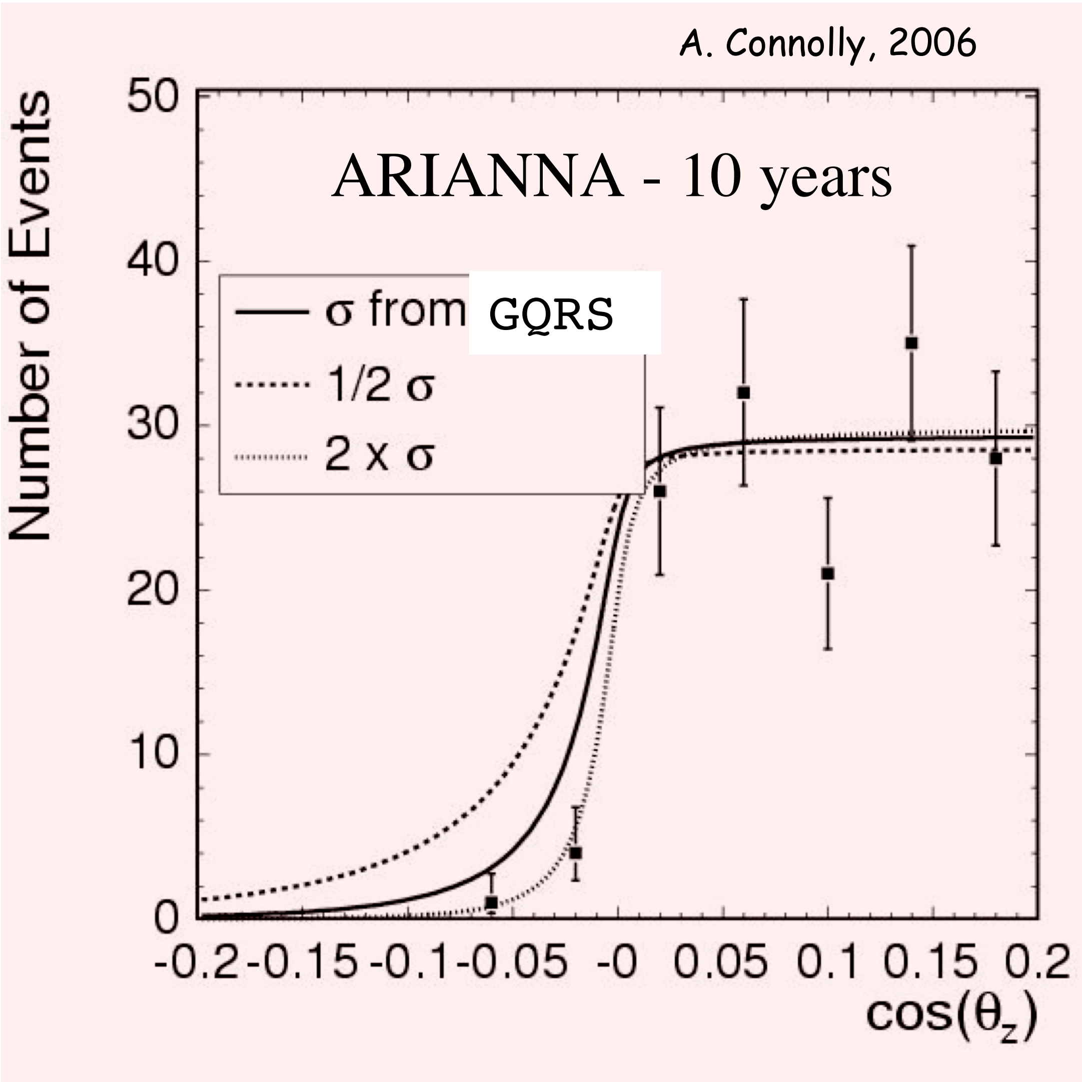
ARIANNA Sensitivity



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

ESS baseline: 40 events/yr

Neutrino Cross-Section



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

If $N_{ev} = 400$

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

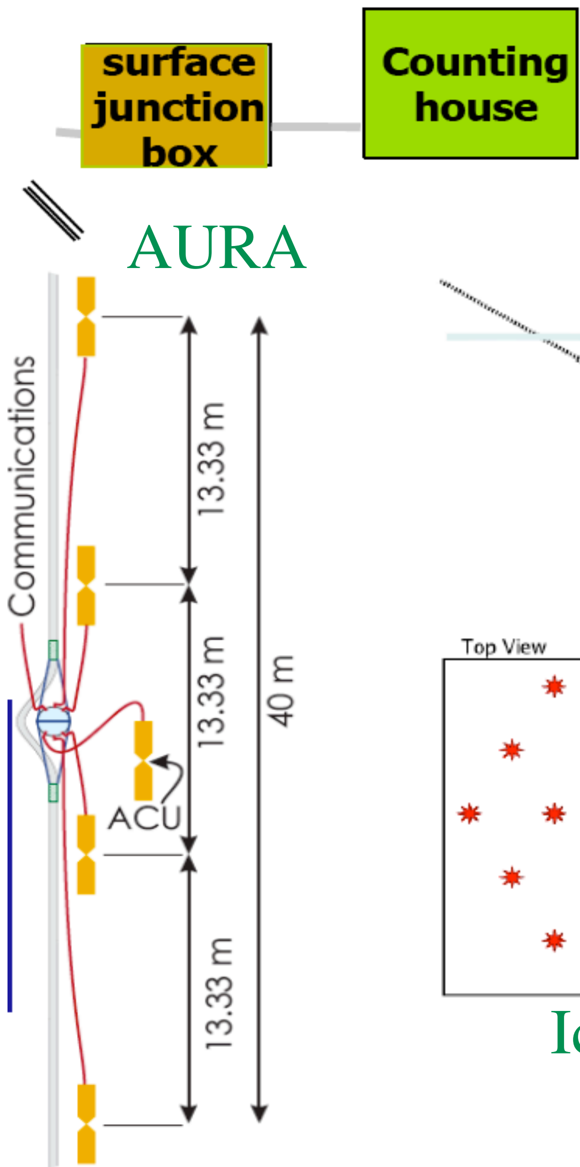
If $\sigma = 2\sigma_{GQRS}$

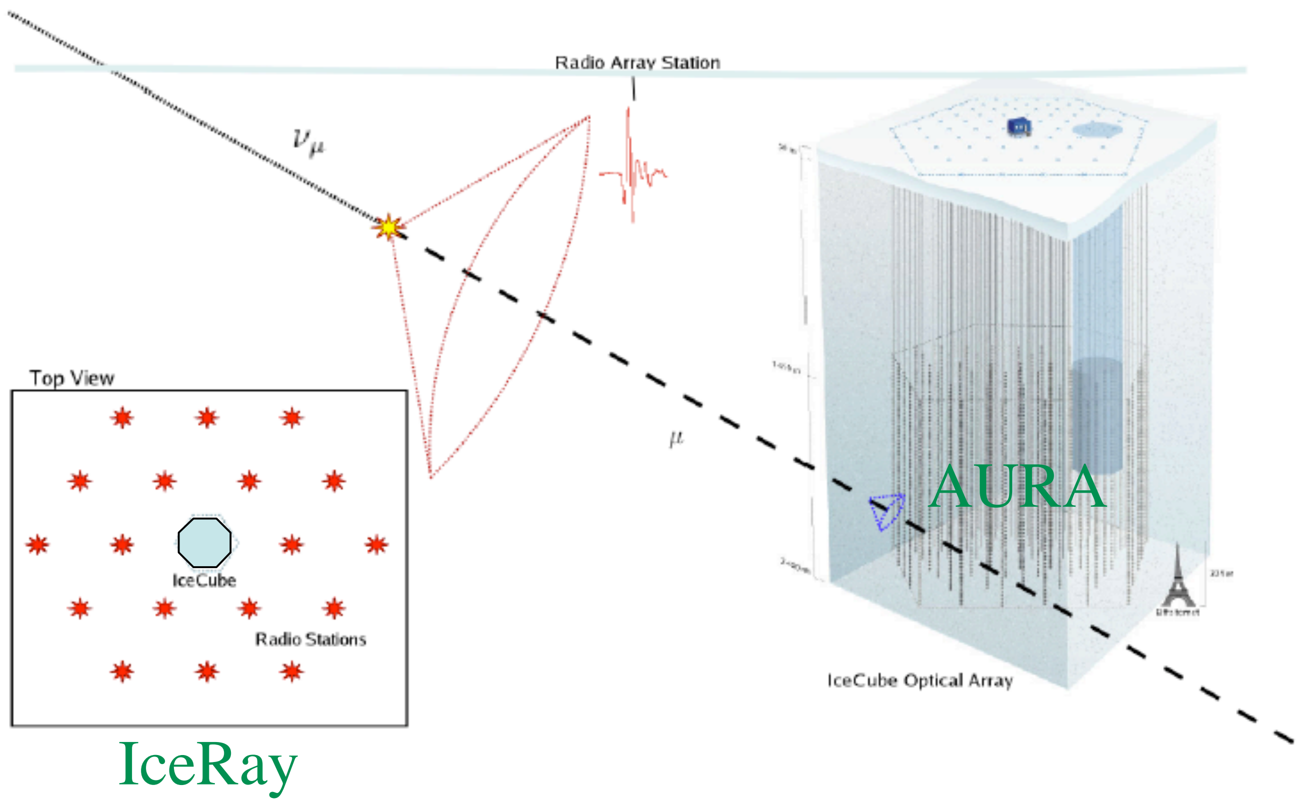
2 parameter fit:

Normalization

cross-section

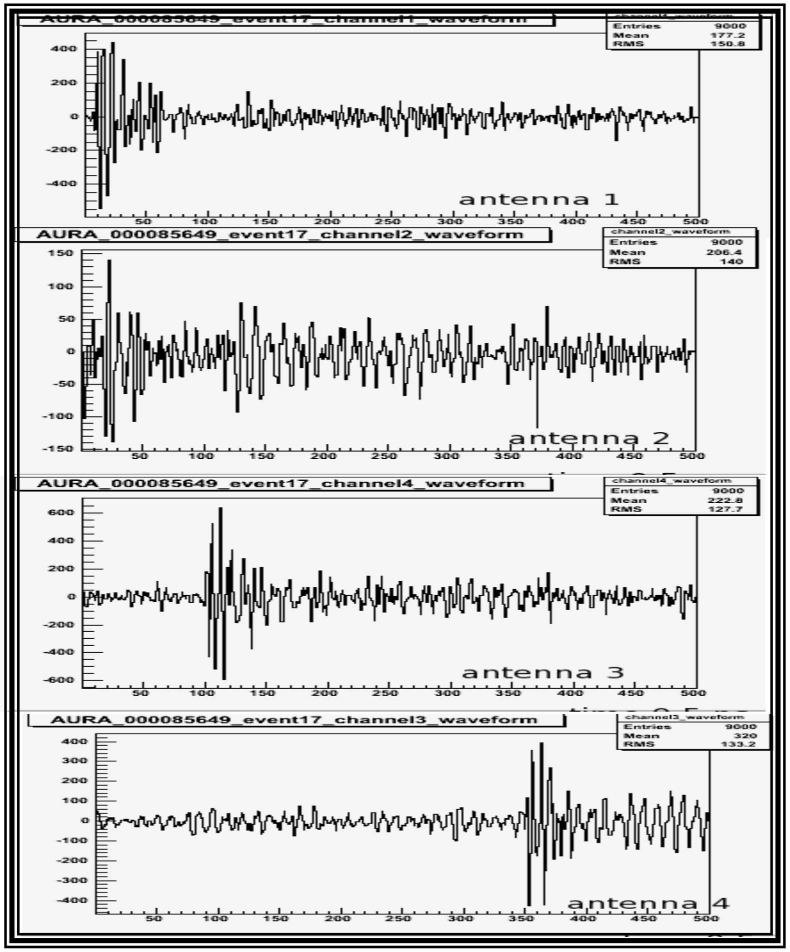
AURA/ IceRay





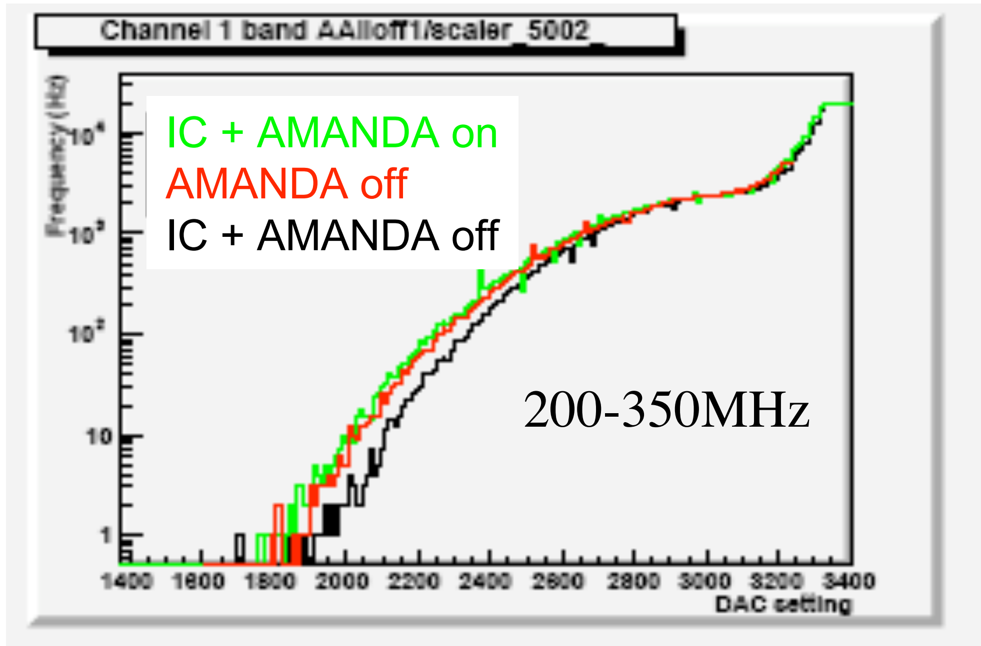
A fraction of events would be observed by IceCube and AURA

RF Noise at South Pole



Downgoing neutrino-like RF events used for timing calibration

Scalar rates vs threshold

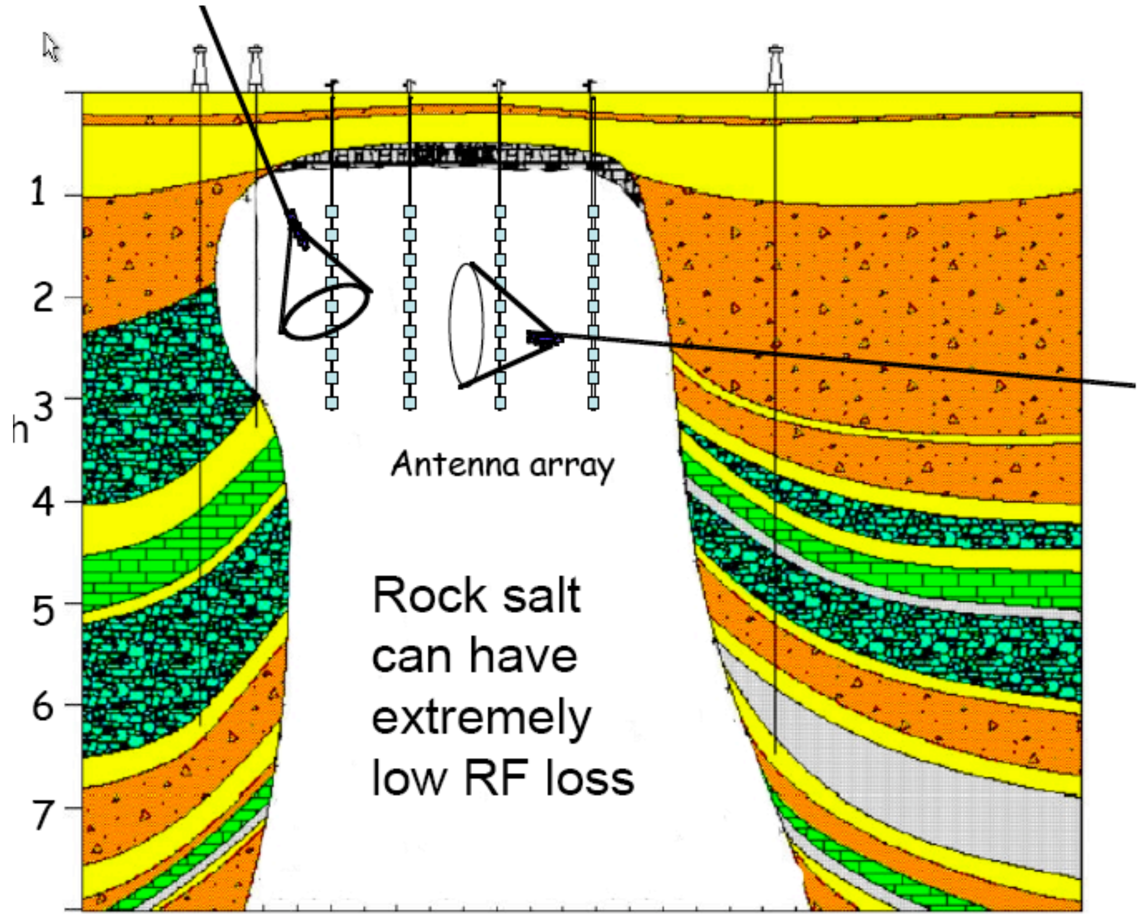


Multi-band trigger rejects RF noise from AMANDA/Ice3

SALSA

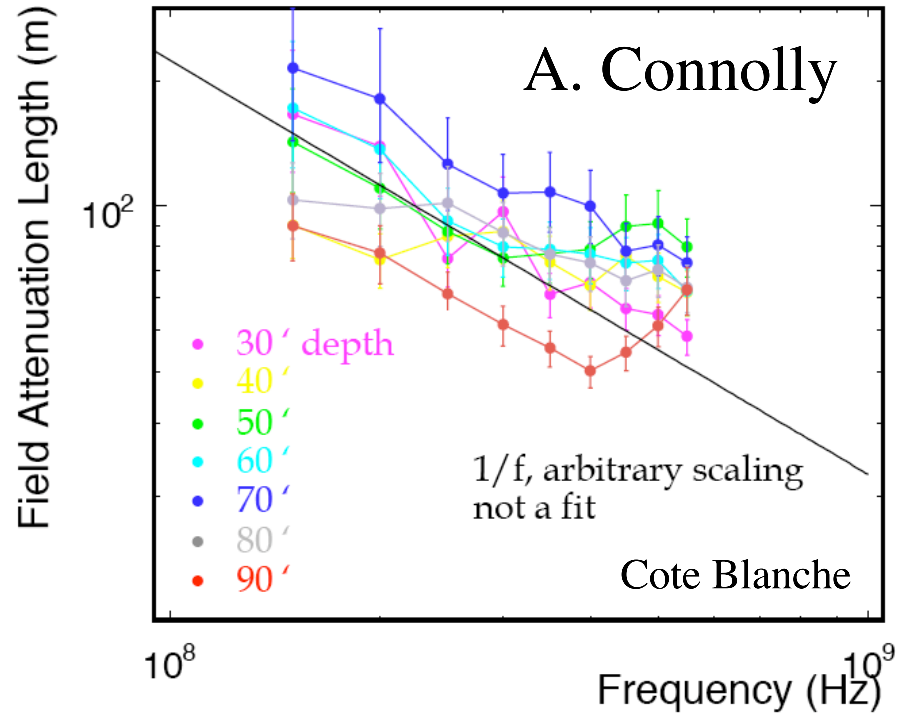
Bury radio sensors in salt dome by drilling holes or utilizing existing floors in mine

Main question: what is attenuation length at relevant radio wavelengths?

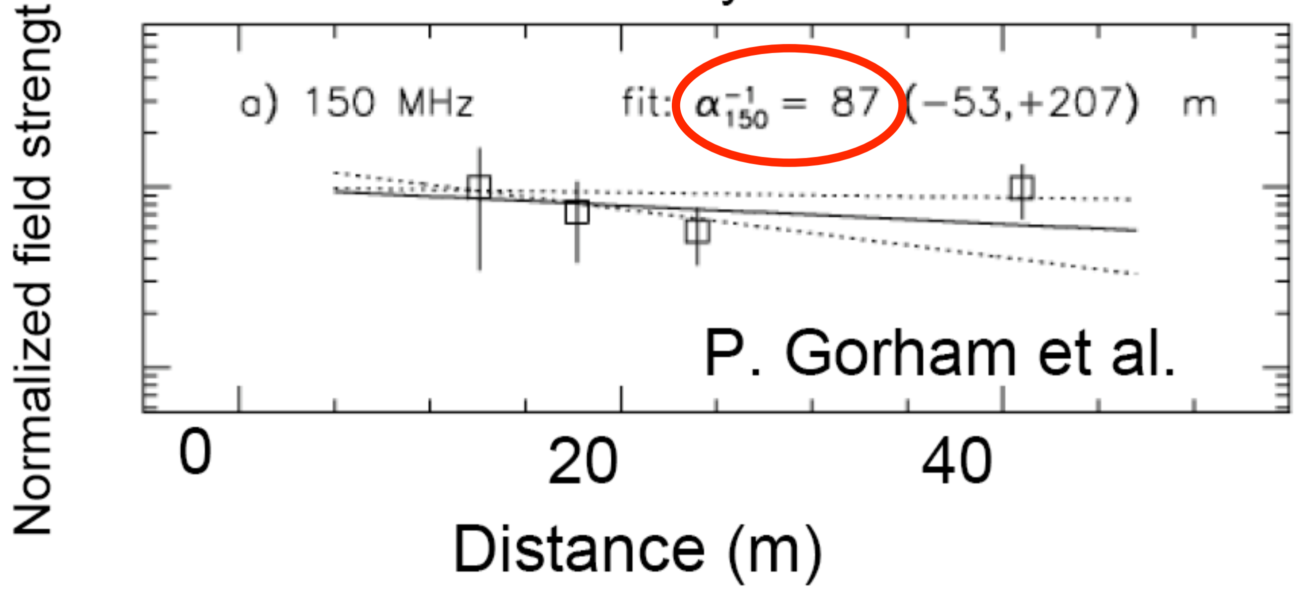


Attenuation Length in salt domes
~100m at low frequencies

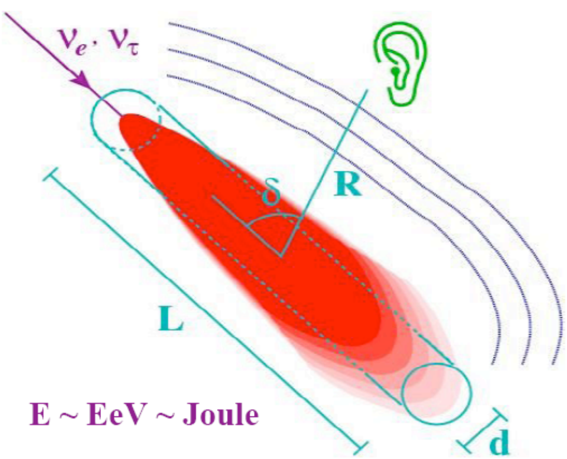
Hockley (Tx) , Cote Blanche (La) similar

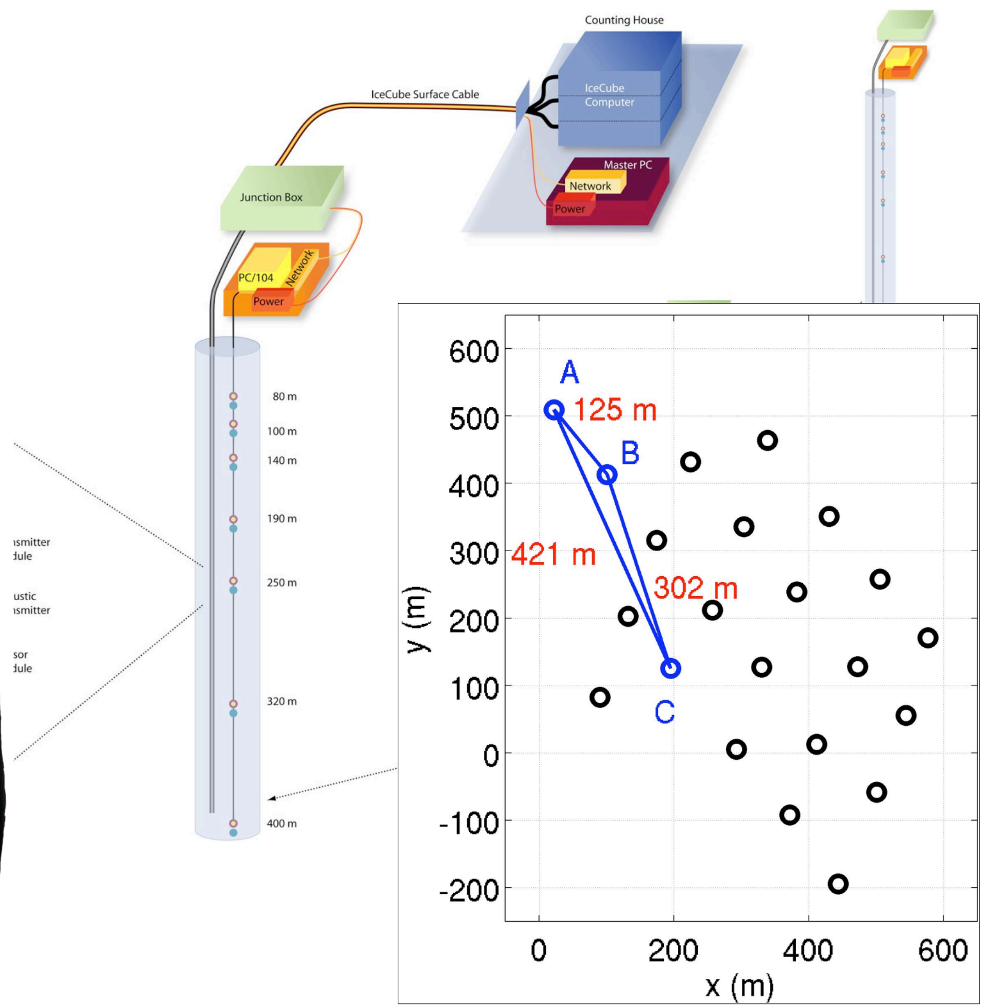


Measurement at Hockley Salt Mine in Texas:

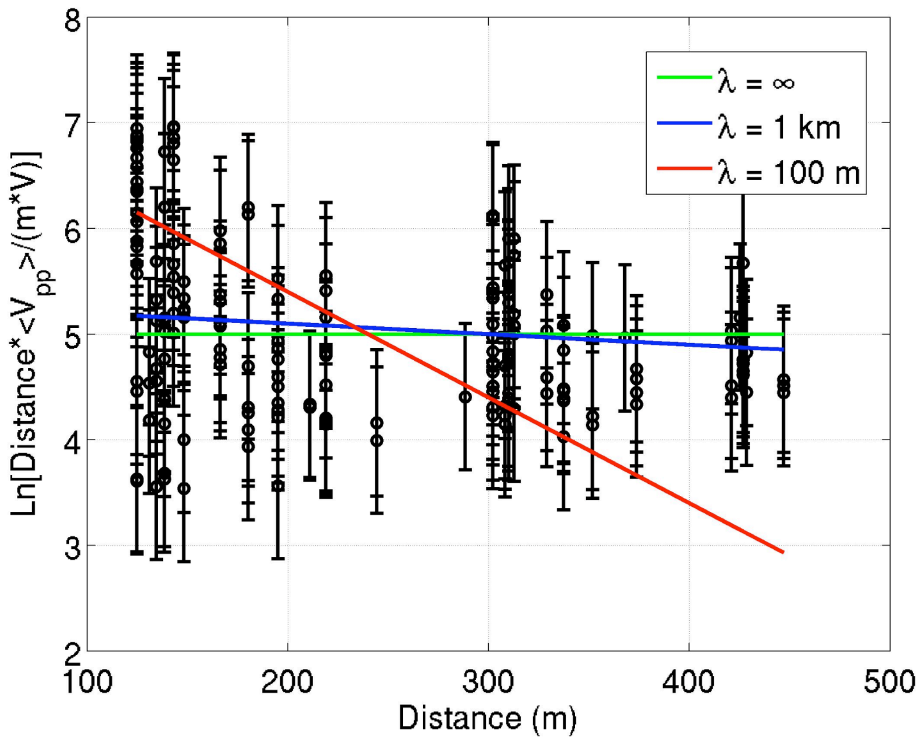


SPATS - Acoustic Detection in Ice





Attenuation Length of Acoustic Waves



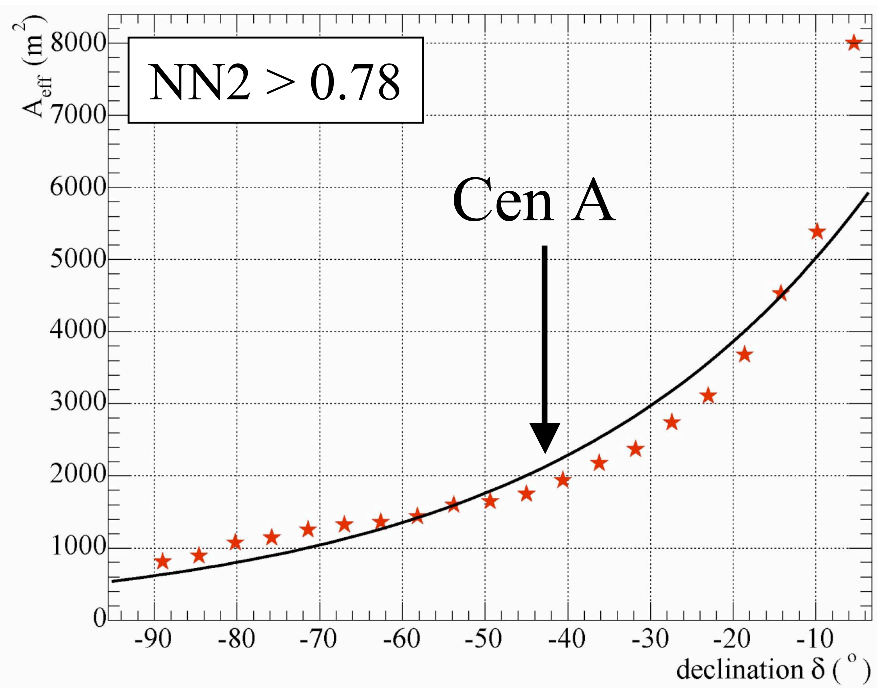
Additional work required to determine attenuation length in presence of significant noise

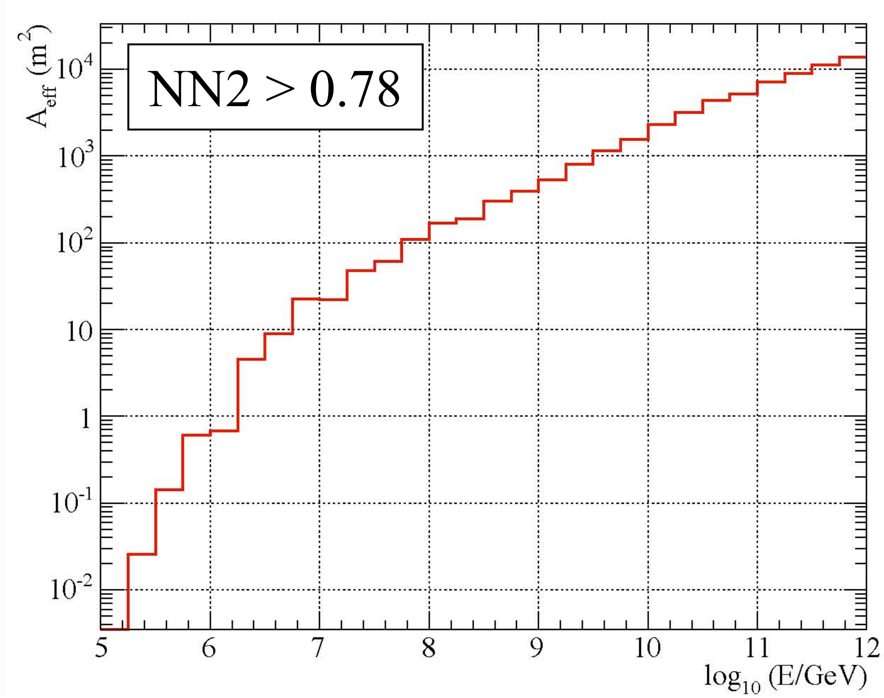
Outlook

- 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 imminent (maybe this summer)
- 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]

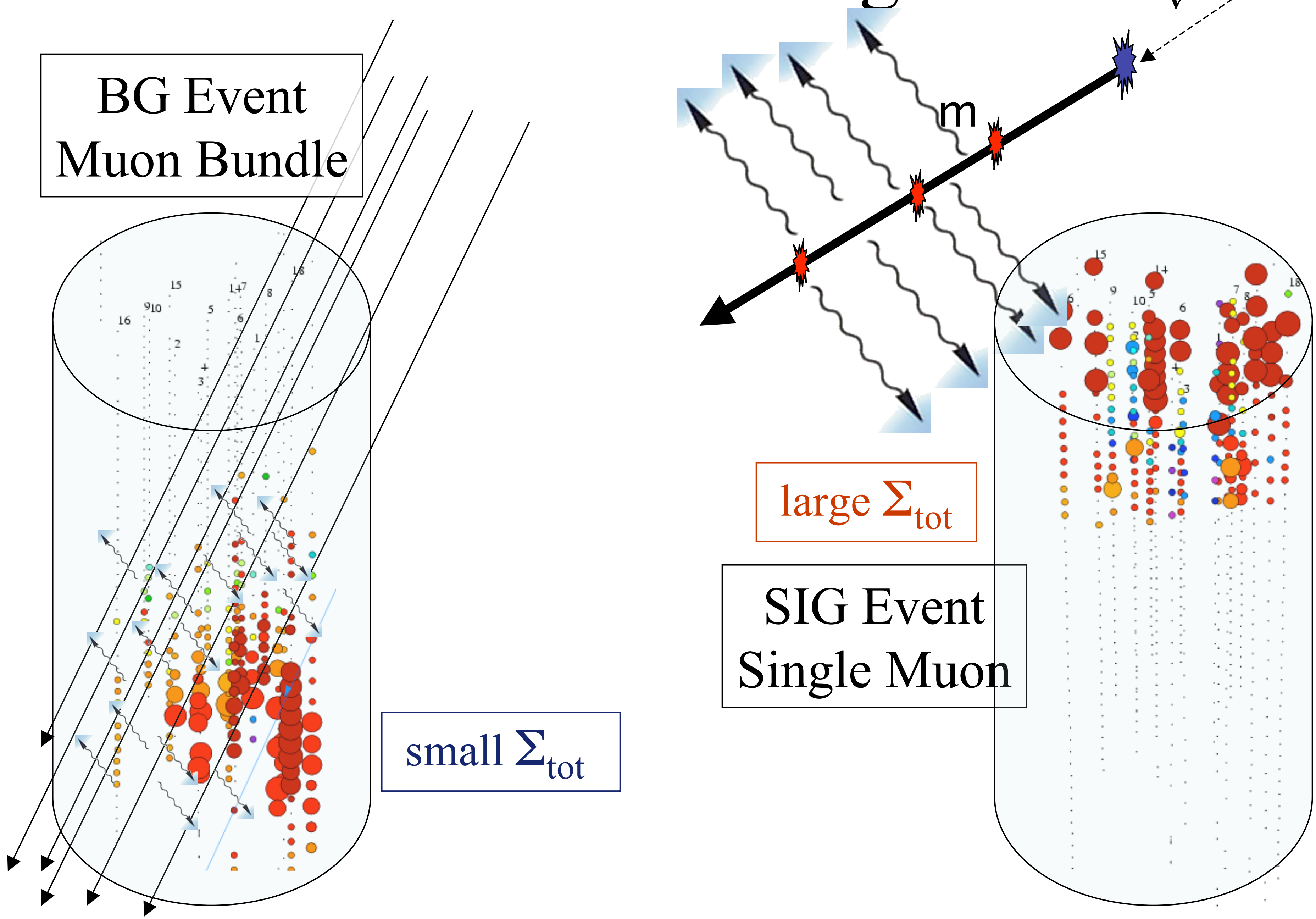
UHE analysis sensitive over the southern sky $\phi_\nu \sim E^{-2}$



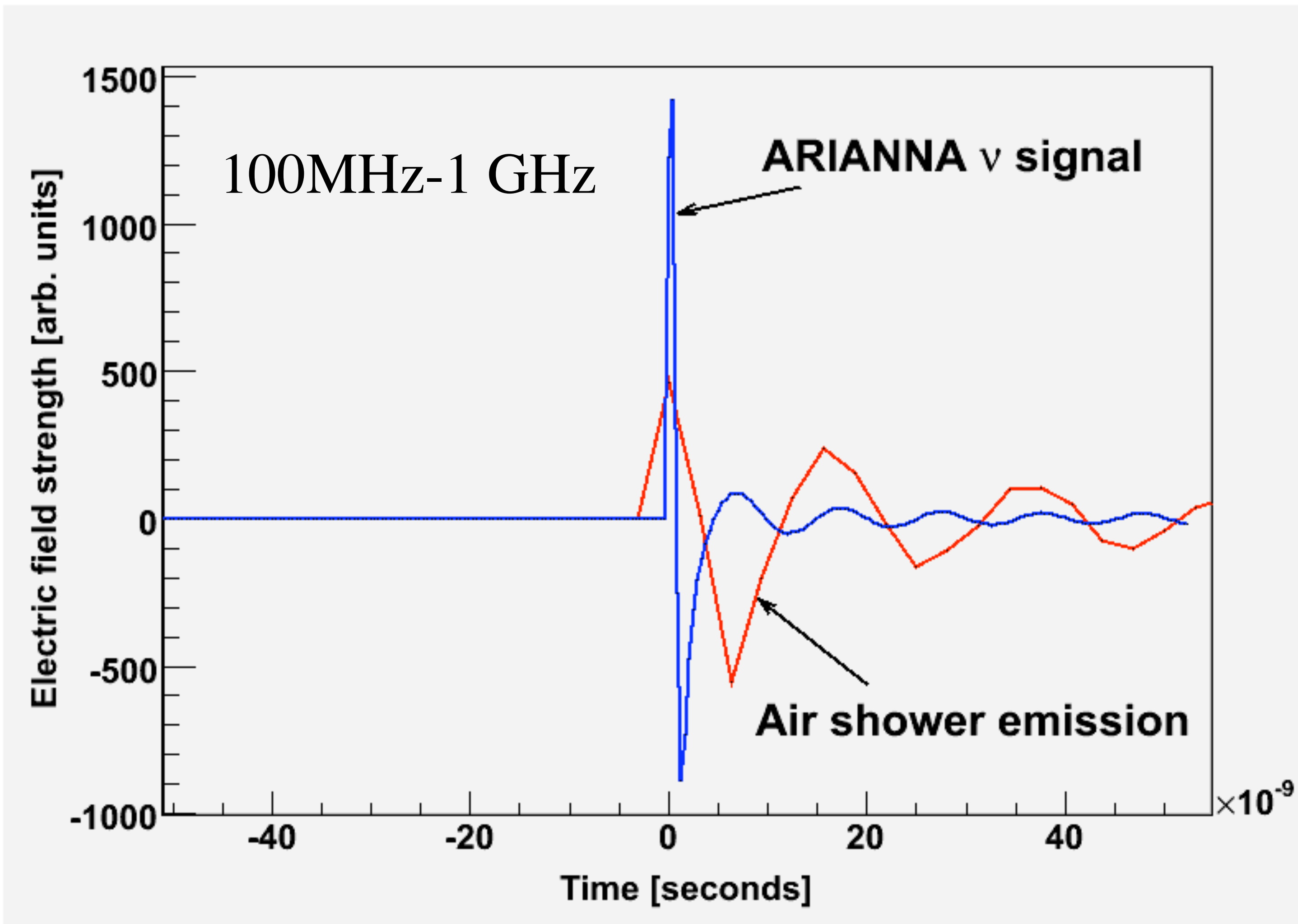


- A_{eff} as a function of declination δ and neutrino energy E_ν

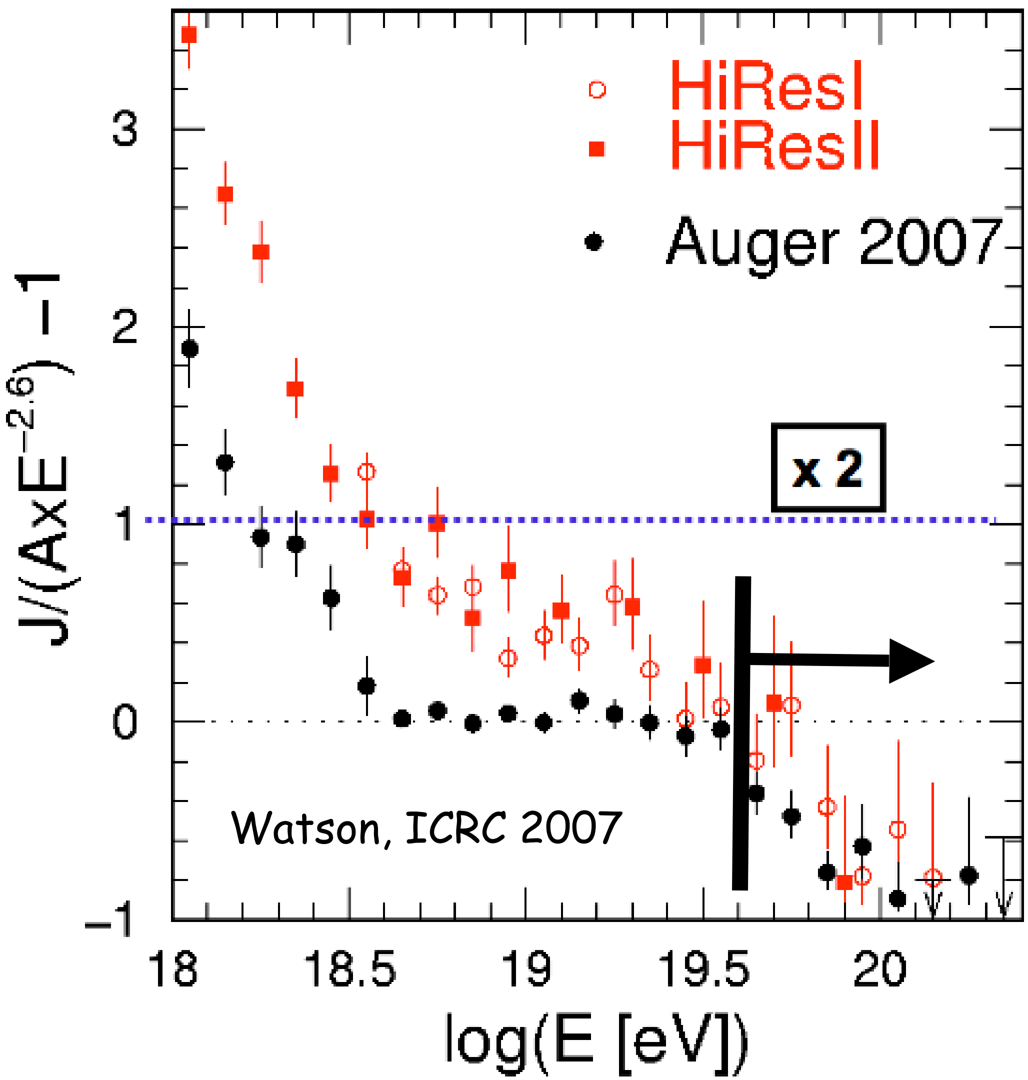
BG & SIG Event Signature



Air Shower vs Ice Shower
(time profiles quite different!)



“GZK” suppression exists!



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