Neutrino 2002 Munich

Alternative Techniques for High Energy Neutrino Astronomy

Aside from Water/Ice Cherenkov and EAS Detection, New Techniques are Being Pursued in Radio, Acoustic and Air Cherenkov Detection

John G. Learned, ***University of Hawaii***

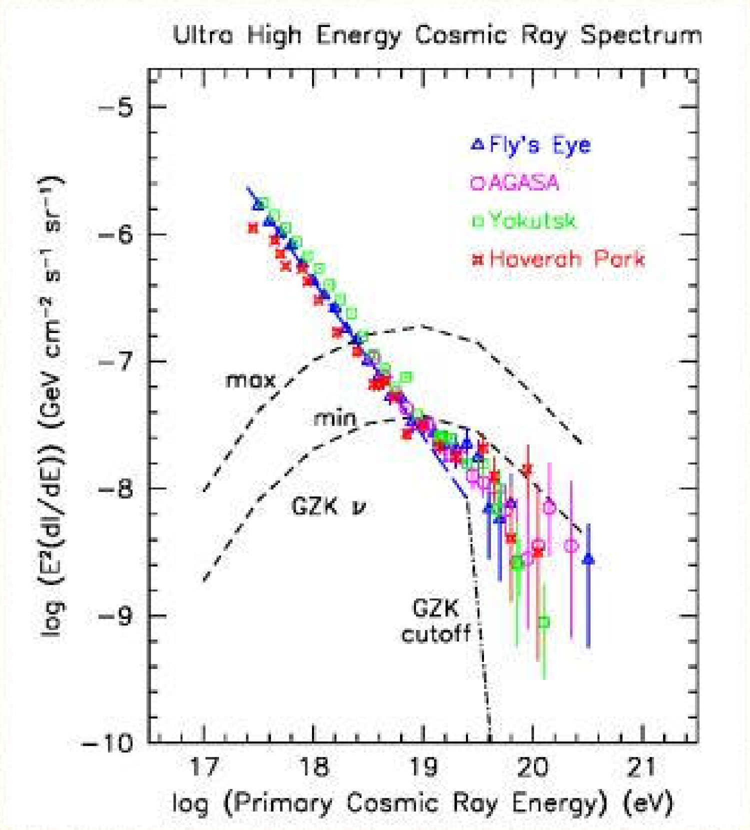
Many thanks to D. Besson, P. Gorham, G. Gratta, A. Huang, N. Lehtinen, S. Matsuno, S. Pakvasa, D. Seckel for Slides and Help

Outline of AlternativeTechniques for HE ν Astronomy

- Motivation for New Approaches
  - Focus on Energy Regime >10^{17} eV
  - Guaranteed “Cosmogenic” Neutrino Flux
  - Possibly Large Cross Sections (extra dimensions)
- Projects, Started and Proposed:
  - Radio Cherenkov from Ice, Rock, Air, and Salt
    - **RICE, GLUE, FORTE', ANITA, SALSA, … others**
  - Acoustic Detection in Water
    - **Stanford-AUTEC, SADCO and related**
  - Air Cherenkov from Emerging Tau's

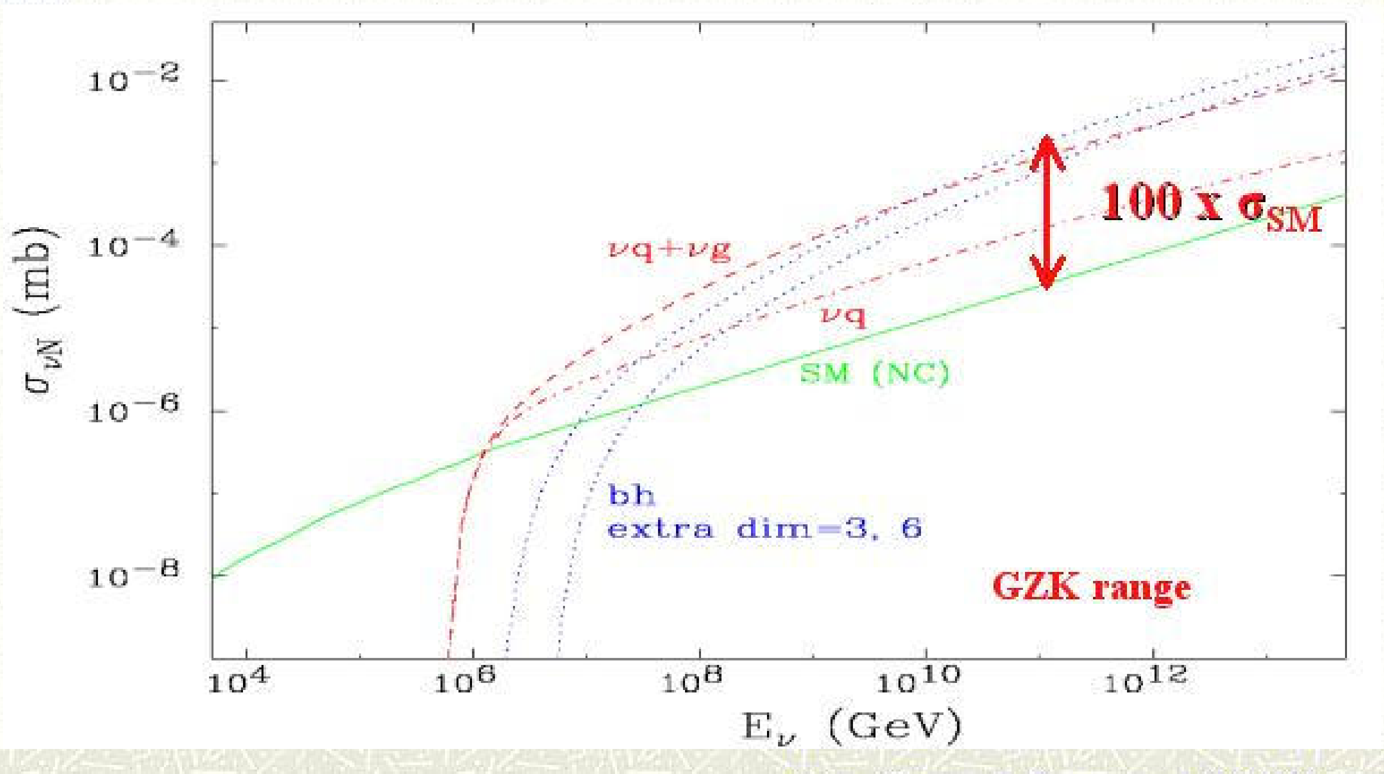
***For overview see** J. Learned and K. Mannheim, Ann. Rev. Nucl. Part. Sci. 2000, 50:679-749* ν2002

GZK Cosmic Rays ⇨ Neutrinos



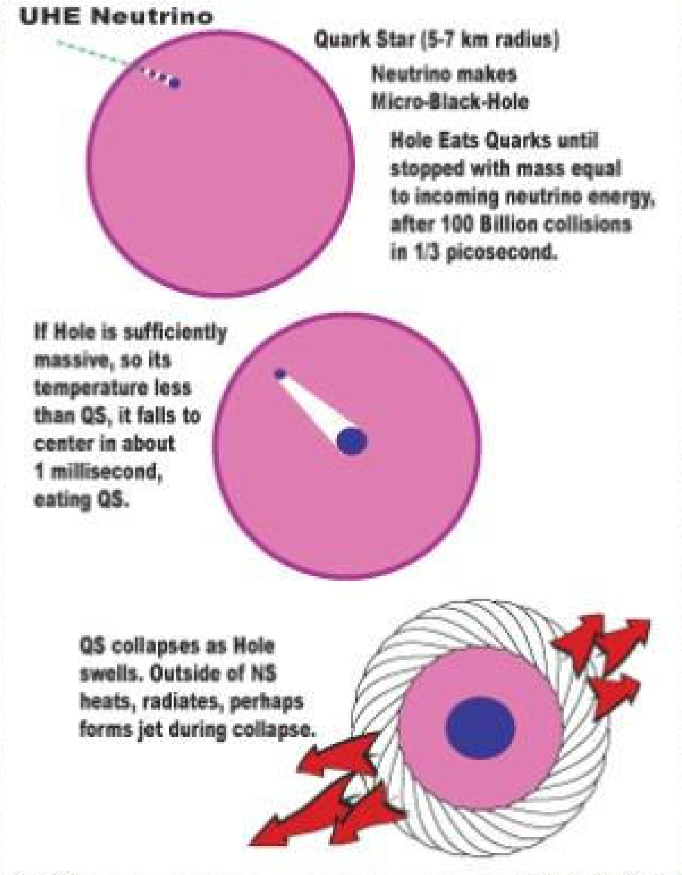
- Cosmogenic Neutrinos are Guaranteed if primaries Nucleons.
- May be much larger fluxes, for some models, such as topological defects

Neutrino Astronomy Explores Higher Dimensions



Friess, Hooper & Han astro-ph/0204112

A Very Large Super High Energy Neutrino Detector?



$>10^{20}$ eV ν +

Quark Star

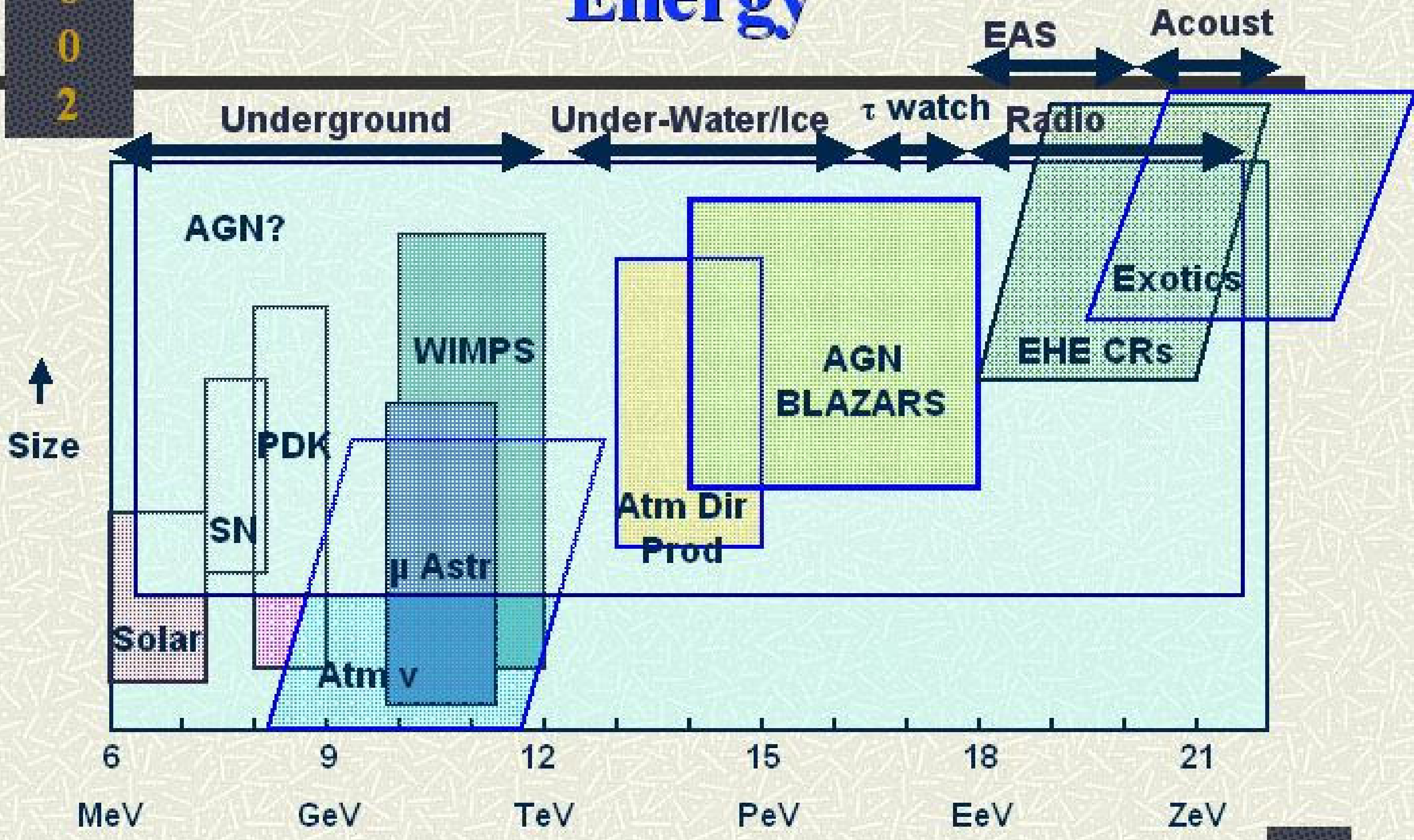
→ μBlack Hole

→ QS Collapse

→ GRB?

astro-ph/0205170

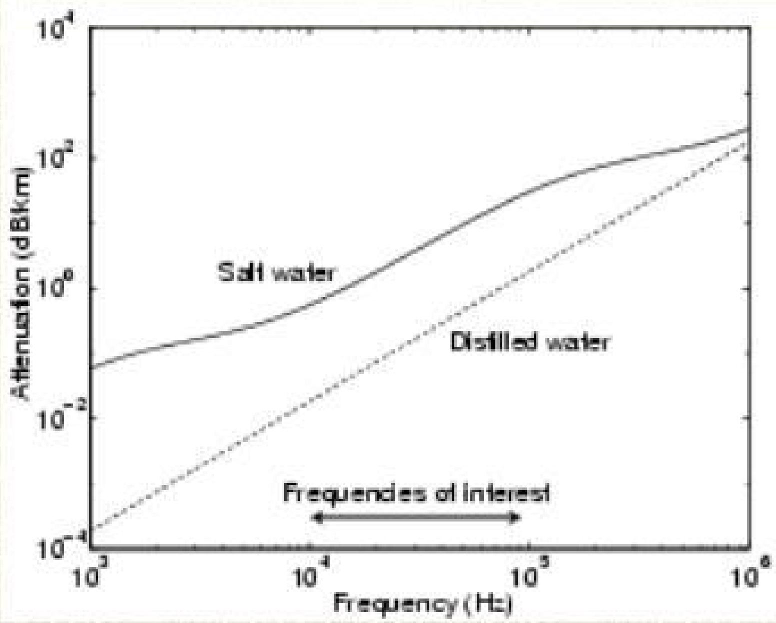
Physics and Techniques versus Energy



EAS
Acoust
Underground
Under-Water/Ice
τ watch
Radio
AGN?
WIMPS
PDK
SN
μ Astr
Solar
Atm ν
Atm Dir Prod
AGN BLAZARS
EHE CRs
Exotics
Size
6
9
12
15
18
21
MeV
GeV
TeV
PeV
EeV
ZeV

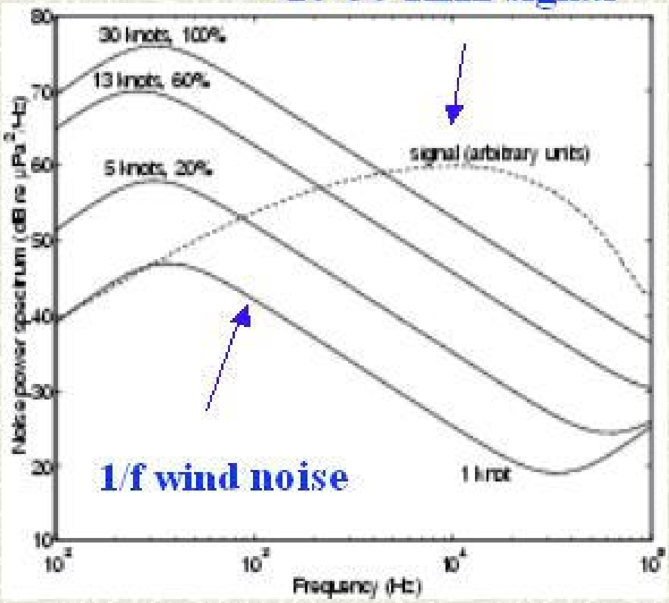
Neutrino Noises are Weak, but 10^{21} eV ν's can be Heard from Afar

Attenuation Length:
Many Km in Ocean



Noise:
Near Deep Ocean Thermal Minimum

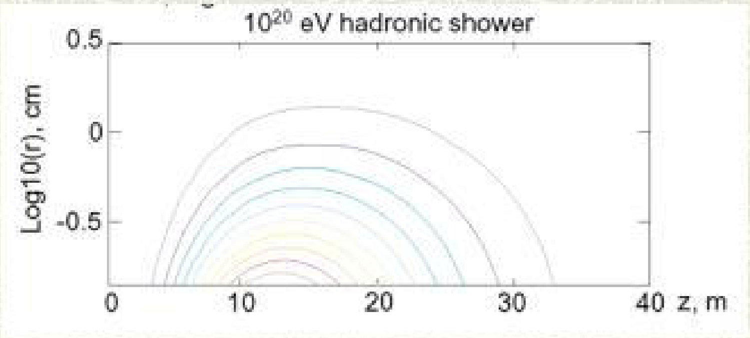
~20-30 KHz signal



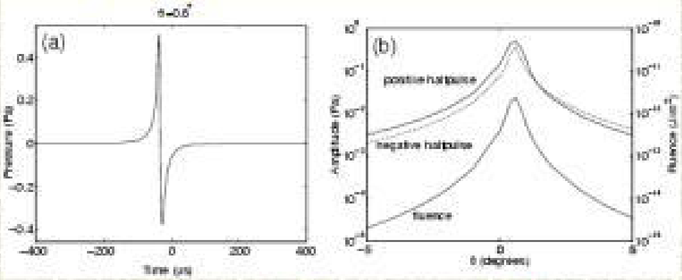
1/f wind noise

G. Gratta astro-ph/0104033

Shower Heating → Expansion → Bipolar Pressure Pulse

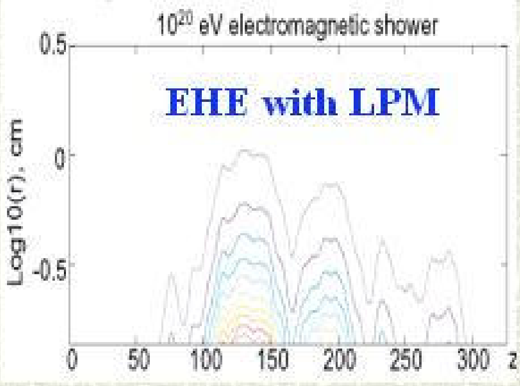


bipolar pulse **radiation disk**



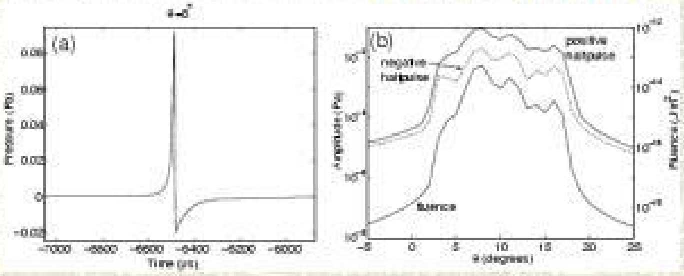
(Studied >20 yrs ago at BNL)

off-axis is asymmetric



EHE with LPM

LPM →fat disk

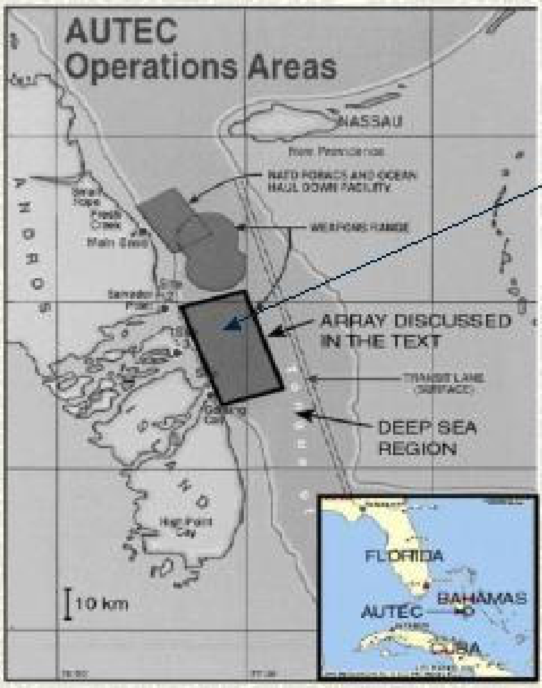


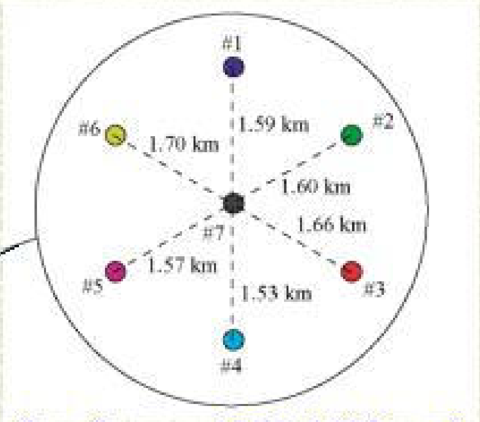
Gratta, et al.

Ocean Acoustic Detection

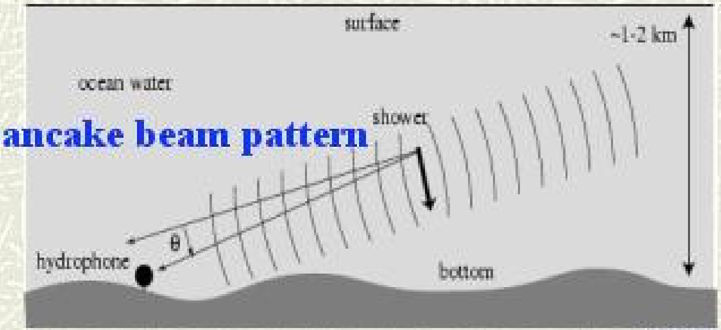
New Stanford Effort using US Navy Array

US Navy acoustic tracking range in Tongue of the Ocean, Atlantic





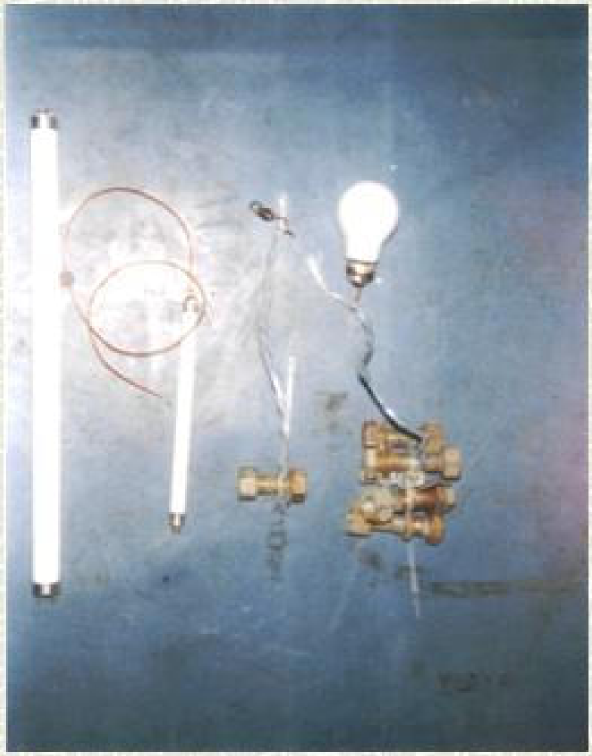
Hydrophones 1550-1600 m deep

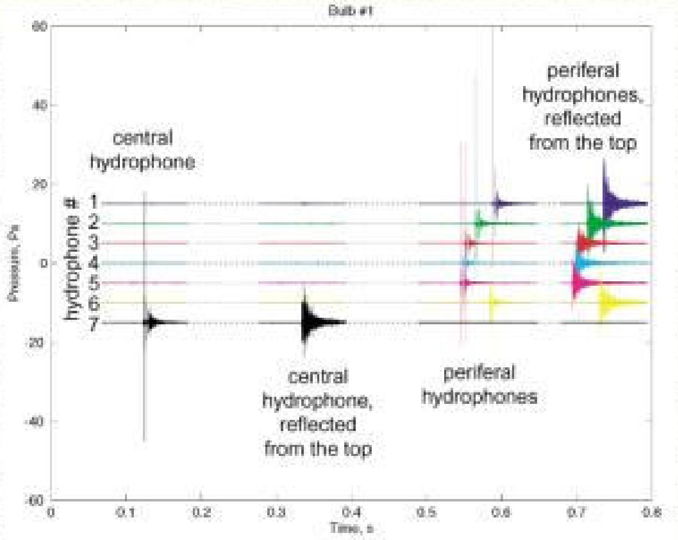


pancake beam pattern

G.Gratta, atro-ph/0104033

Acoustic Calibration: Imploding Light Bulbs

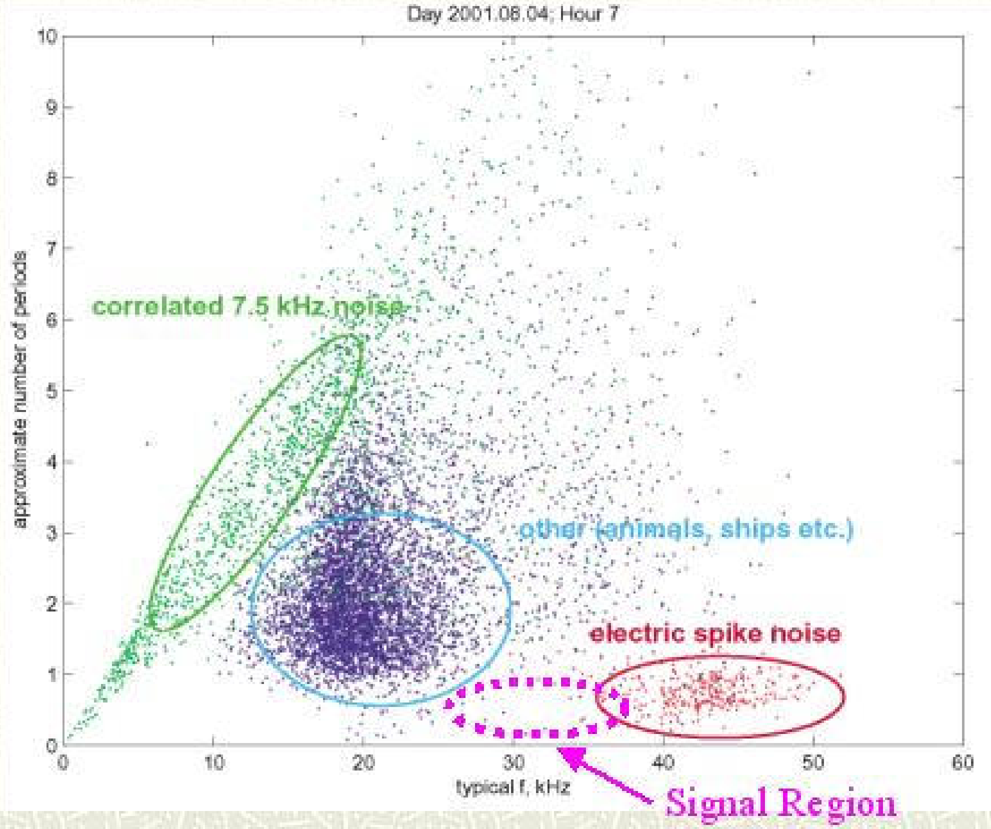




Cal Pulses ~100 J ~10^{31} eV E_ν Equiv.

Gratta/Lehtinen

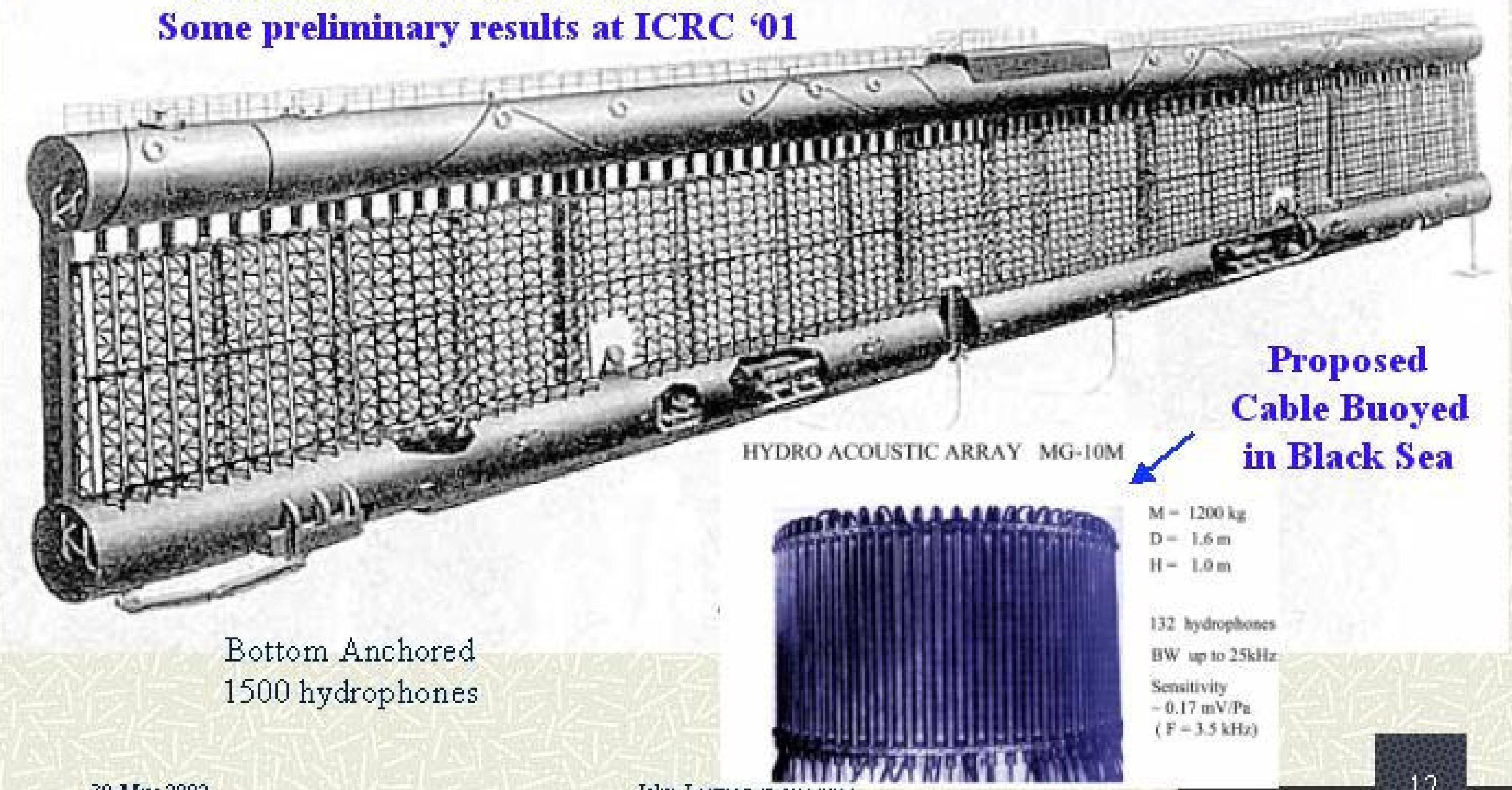
Stanford Group Has First Background Exploration Data



G. Gratta

Russian Acoustic Tests in Pacific and Black Sea

Kamchatka AGAM Acoustic Array
Some preliminary results at ICRC '01



Proposed
Cable Buoyed
in Black Sea

Bottom Anchored
1500 hydrophones

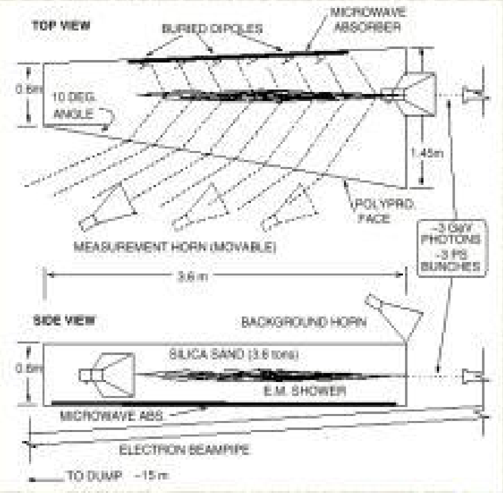
Summary of Acoustic Neutrino Detection

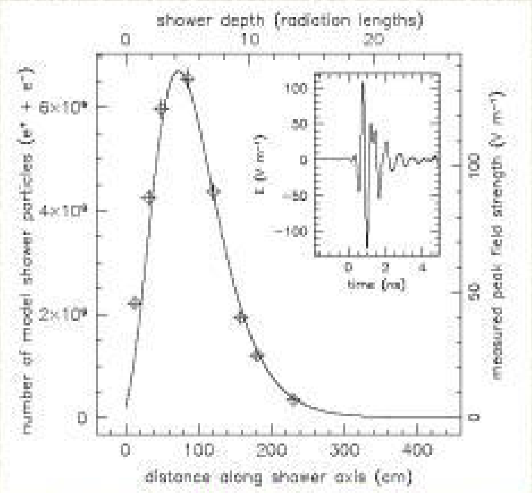
- Being revived after 20 years of little action
- Advantages:
    - Potentially >> km^3 effective volumes
    - Well developed sonar technology
    - If salt practical, could use shear waves too → range
- Disadvantages:
    - Ocean impulsive backgrounds not yet well known
    - Small Signals, Threshold >> PeV
- Prospects:
    - Modest activity underway
    - Few years from dedicated experiment

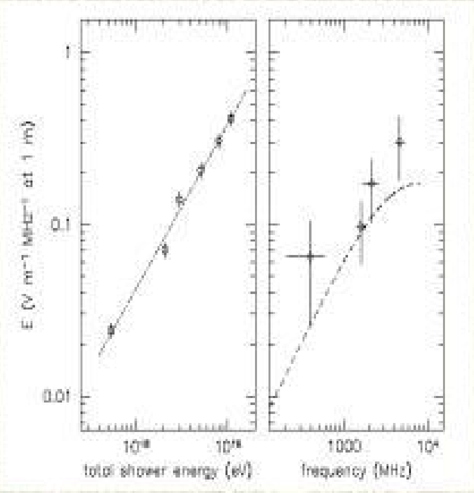
Cascade Radio Emission:

G. Askaryan 1962, pioneered by J. Jelley 1965, Renewed Activity Last Few Years

- **Electromagnetic showers γ's, e^+e^- : naïve guess is** *no net radio emission.*
- **Scattering processes & positron annihilation lead to a 15-30% e^- excess.**
- **Radiates** *coherent Cherenkov* **radiation => Power ~ $(\text{Energy})^2$**
- **Effect finally confirmed in 2000 at SLAC --** *strong effect !*

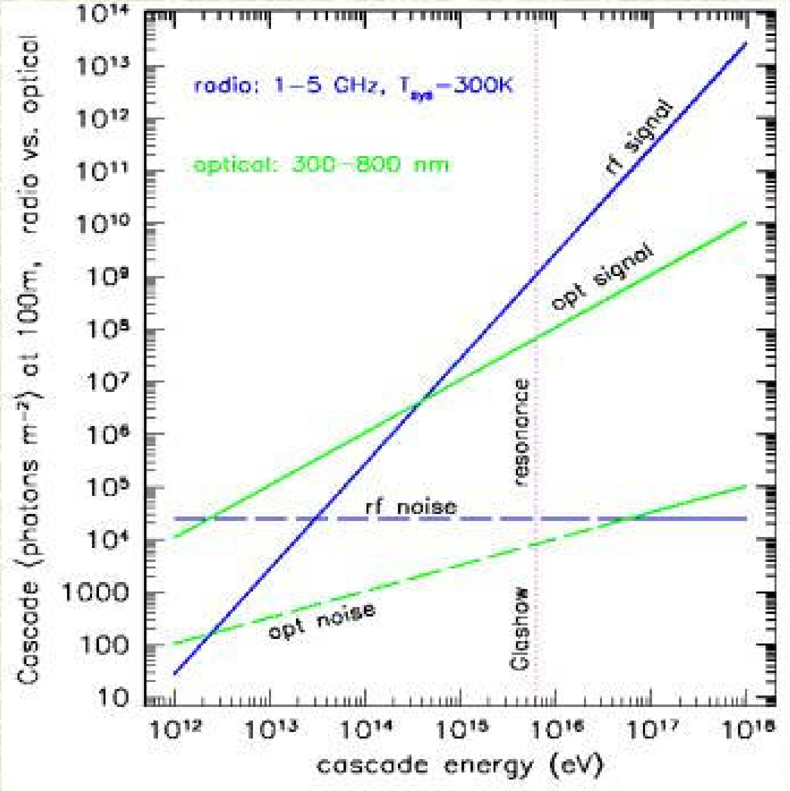






From Saltzberg, Gorham, Walz et al, PRL 86, 2802 (2001)

Detecting the TeV to EeV Cascades:
Radio *vs.* optical

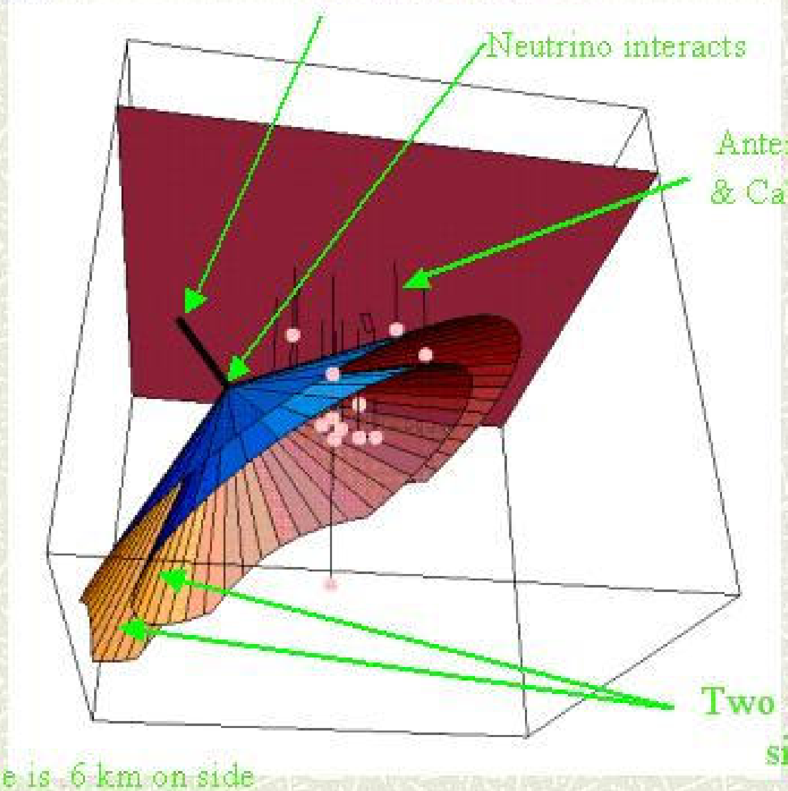


- **Radio Cherenkov**:
  - **broad spectrum, few MHz to ~10 GHz.**
  - **Intensity Power α (Energy)^2, thermal noise constant.**
  - **SNR >1 at >PeV energies for ~100 m range.**
  - **Needs Radio-Clear Medium such as cold ice or dry rock**

- ***For >>PeV cascade detection, radio favored over optical.***

P. Gorham

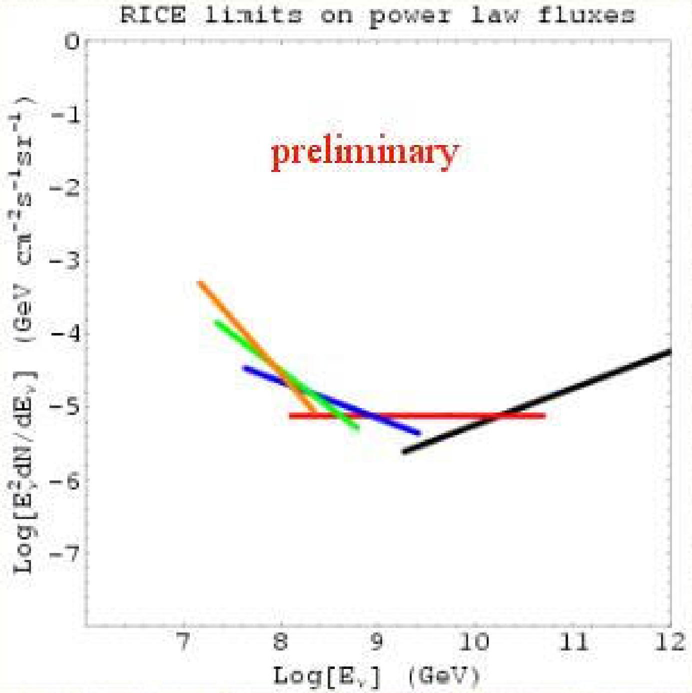
RICE
Radio Detection in South Pole Ice



Cube is .6 km on side

- Installed ~15 antennas few hundred m depth with AMANDA strings.
- Tests and data since 1996.
- Most events due to local radio noise, few candidates.
- Continuing to take data, and first limits prepared.
- Proposal to Piggyback with ICECUBE

RICE
Limits on power law fluxes

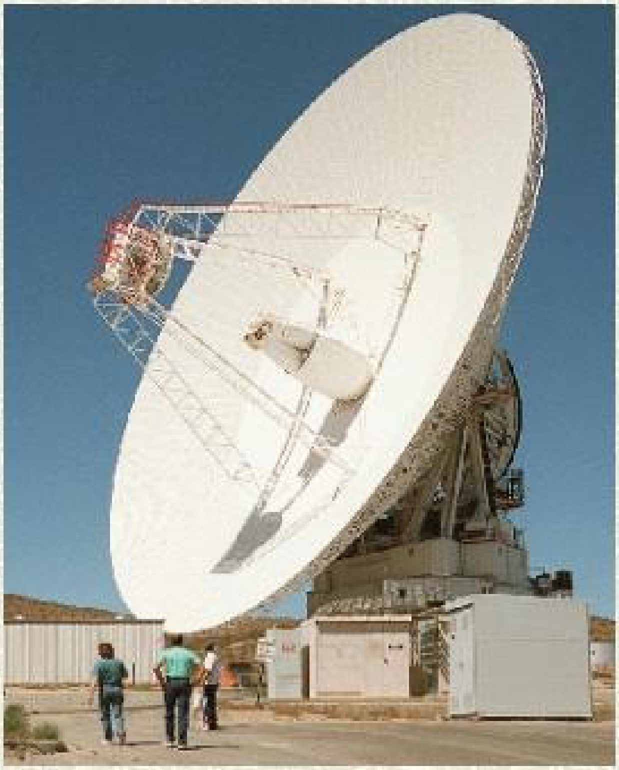


$\Phi \sim E_\nu^{-\gamma}$

Color	γ
black	1.5
red	2.0
blue	2.5
green	3.0
orange	3.5

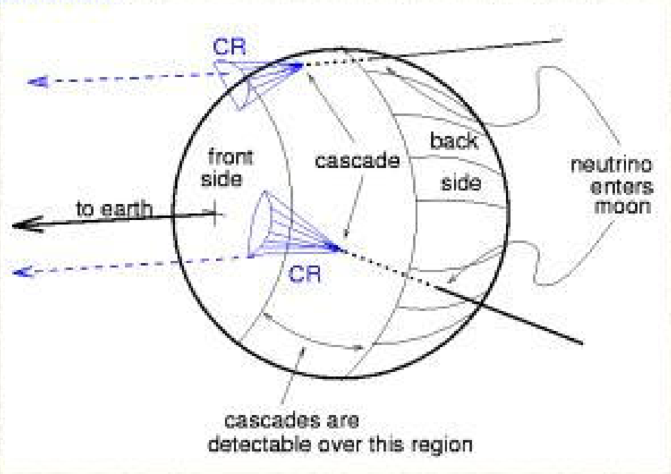
95% c.l. limits derived from absence of events consistent with neutrino induced radio pulses during Aug. 2000 (333.3 hrs). Line segments denote energy interval responsible for middle 80% of events.

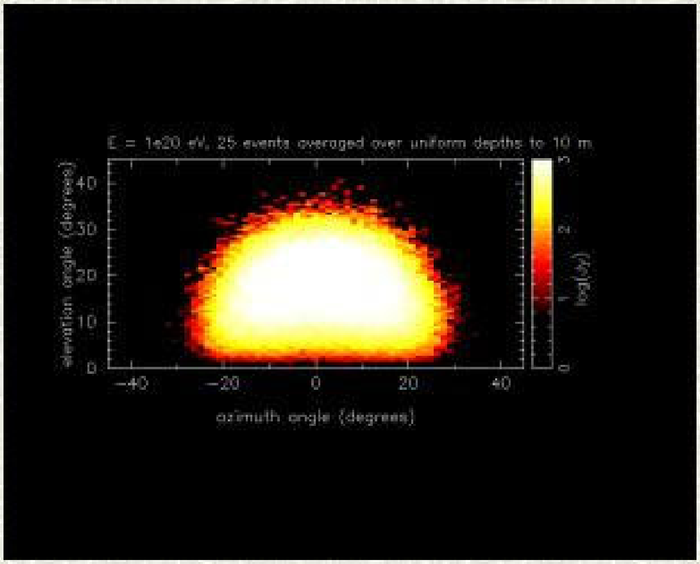
Goldstone Lunar Ultra-high energy neutrino Experiment (GLUE)



- **Utilize NASA Deep Space telecom 70m antenna DSS14 for lunar RF pulse search— GLUE fill gaps in SC sched.**
- **First observations late 1998:**
  - approach based on Hankins et al. 1996 results from Parkes 64 m telescope (10hrs live)
  - idea due to I. Zheleznykh, Neutrino `88
  - utilize active RFI veto
- **Preliminary data taken 1999 through present, with continuing improvements in configuration and sensitivity.**
- **First results and limits available.**

Lunar Regolith Interactions & RF Cherenkov radiation





- At ~100 EeV energies, neutrino MFP in lunar material is ~60km.
- R_{moon} ~ 1760 km, so most detectable interactions are grazing rays, but detection not limited to just limb.
- Refraction of Cherenkov cone at regolith surface "fills in" the pattern, so acceptance solid angle is ~50 times larger than apparent solid angle of moon.

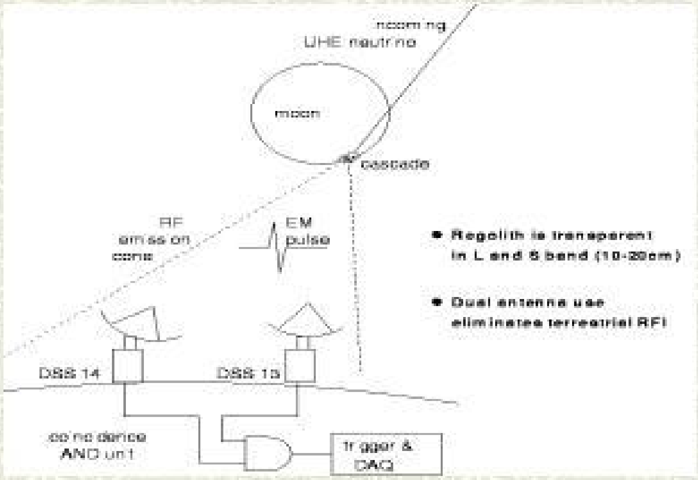
Gorham

Goldstone DSN Radio

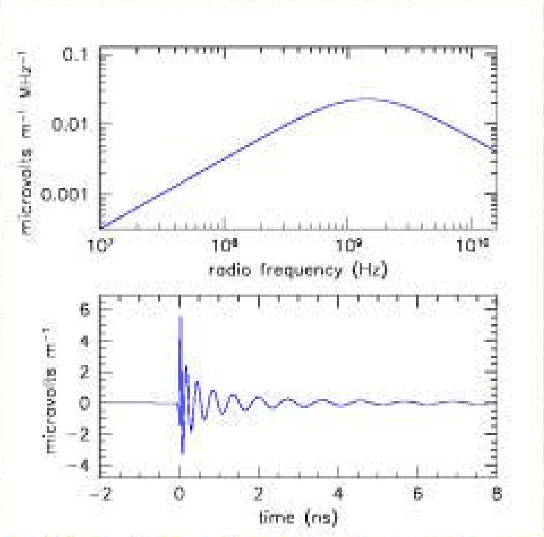
Detection Approach

RF pulse spectrum & shape

P. Gorham



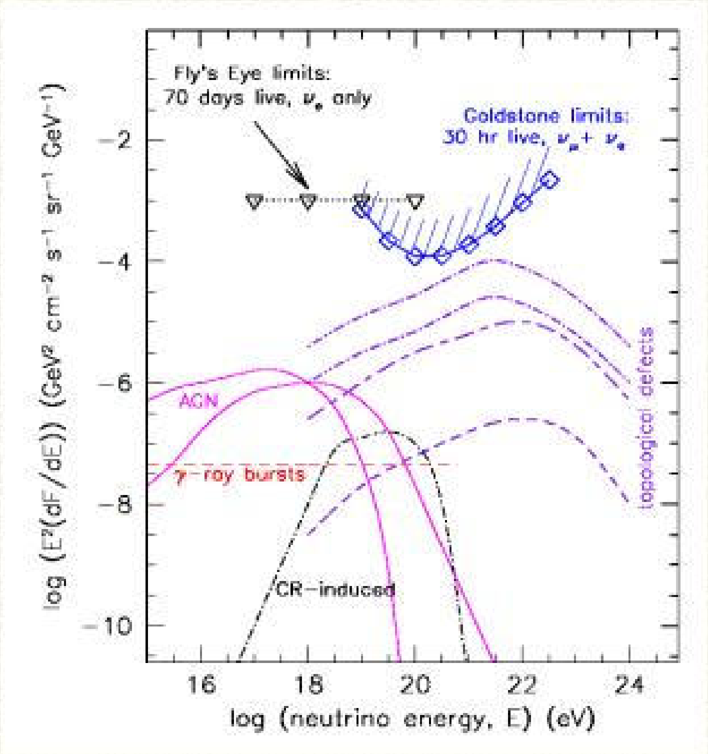
- Regolith is transparent in L and S band (10-20cm)
- Dual antenna use eliminates terrestrial RFI



- **Effective target volume: antenna beam (~0.3 deg) times ~10 m layer**
  => ~100,000 cubic km !
- **Limited primarily by livetime - only a small portion of antenna time can typically be devoted to 1 project.**

Goldstone GLUE

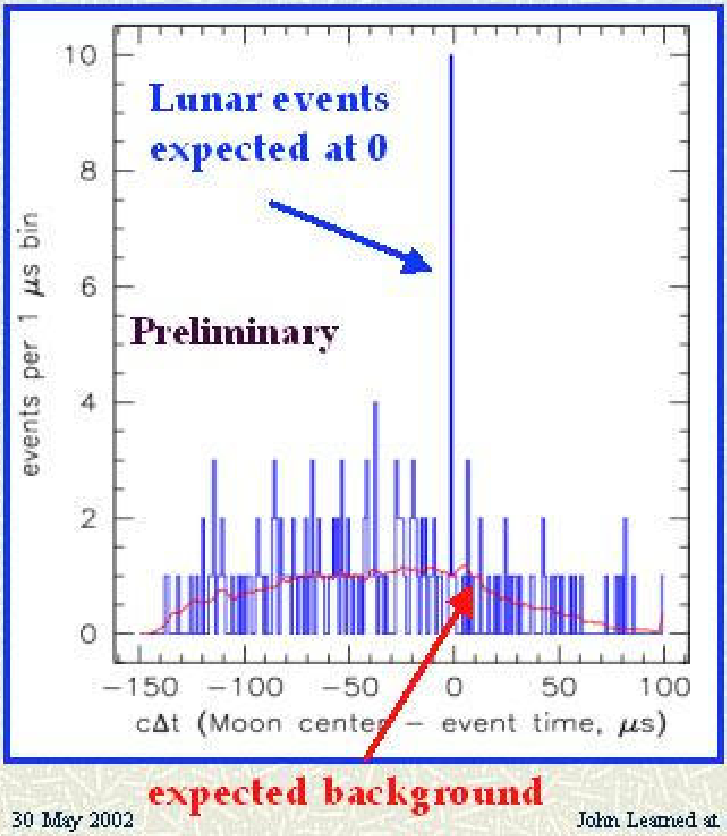
diffuse EHE neutrino flux limits



- **~30 hrs livetime (includes previous data)**
  - No events above net 5 sigma
- **New Monte Carlo estimates:**
  - cross-sections 'down' by 30-40%
    - moving target effect!
  - Full refraction raytrace, including surface roughness, regolith absorption
  - Y-distribution, LPM included
- **Limb observations:**
  - lower threshold, but much less effective volume (factor of ~1/10)
  - 'Weaker' limit but with more confidence
- **Fly's Eye limit needs update:**
  - Corrected (PG) by using published CR aperture, new neutrino cross sections.

P. Gorham

Small Event analysis of GLUE data



- **Cuts applied**:
  - tighter timing
  - pulse width close to band-limited
  - not obvious RFI
- **BKG weight determined by randomizing event UT within run period**
- **Some concentration of events near correct delay**:
  - not significant yet
  - ~1 microsec offset hard to explain ??
- *Seeing EHE cosmic rays?*

P. Gorham

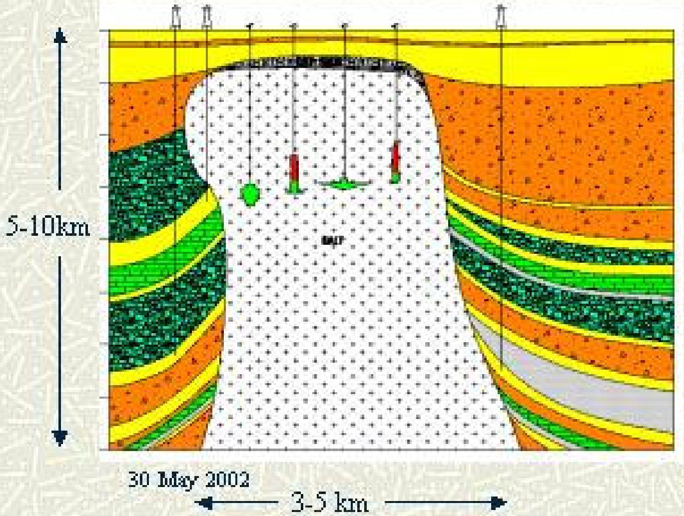
Other Radio Telescope Initiatives: Russia, Australia?

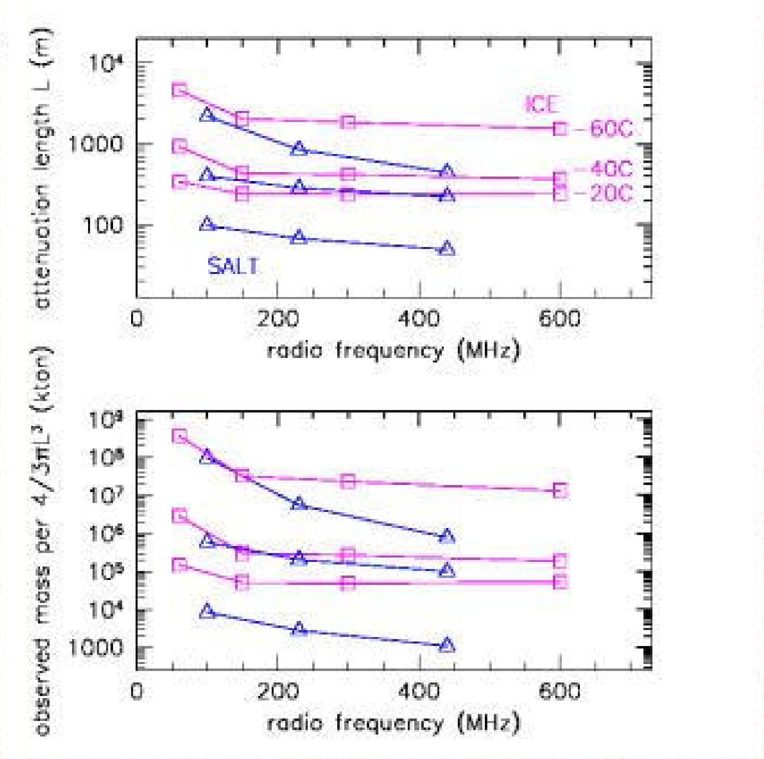
- Possible follow up to GLUE in ATNF Narrabri.
- Kalyasin 64m Radio Telescope in Russia (Dagkesamansky, et al of Lebedev and INR) begun obs 6/01, 1.4, 2.3, 4.8 GHz, 3ns res, 35 hrs, no pulses >3500 Jy, continuing with more chnls.

Potential PeV Neutrino Detectors:

Natural Salt Domes

- **Natural salt can have low RF loss**
- **2.5 times as dense as ice.**
- **Typical salt dome halite comparable to ice at -40C for RF clarity.**

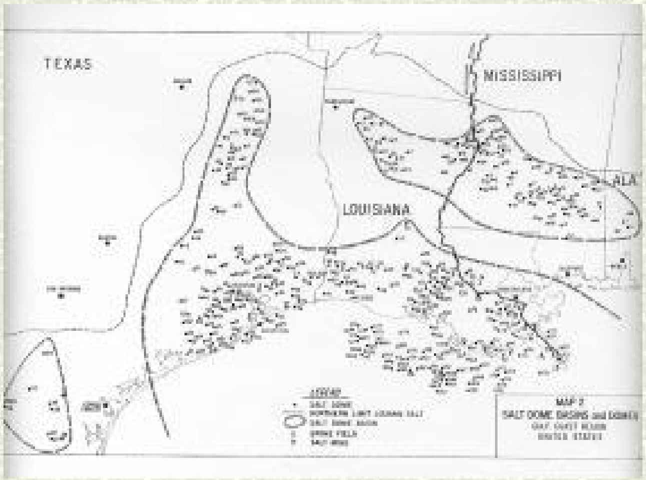




SALT curves are for (top): purest natural salt; (middle): typical good salt dome; (bottom) best salt bed halite. New measurements 2001.

P. Gorham

Hockley mine prototype

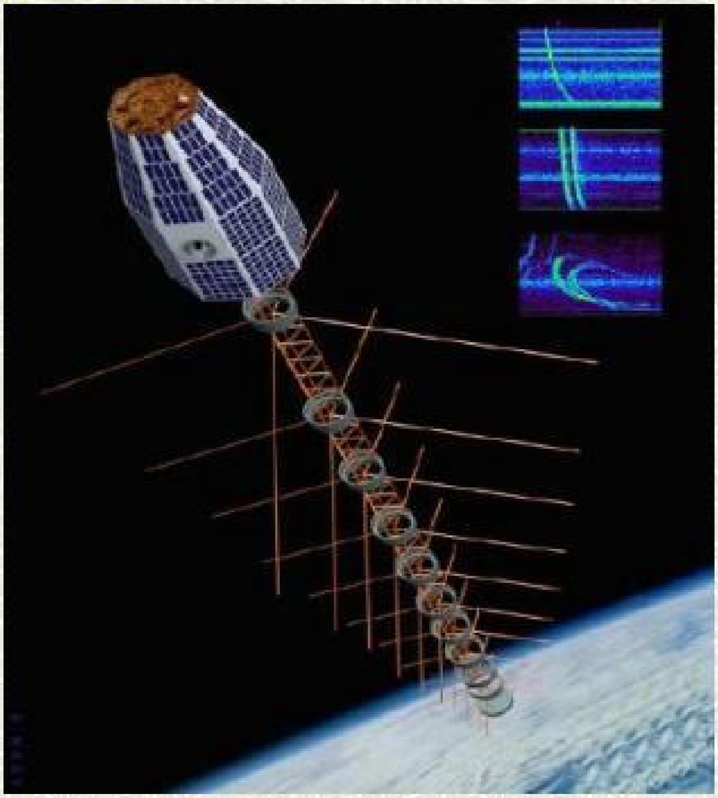


**Many available salt domes
In Southwest USA**

- Cluster of 4-6 antennas, with trigger & DAQ
    - Insert into shallow boreholes within mine, ~40 m separation
    - Measure background noise levels, HE muons?
    - Effective volume ~1 cubic km water equivalent at 1 EeV
- Deploy in mine for 6-12 months, target date late 2003-2004
    - Existing seismic system (UT Austin) could provide fiber link to surface
- Testbed for a GZK neutrino detector!
- *Emphasis on simplicity, scalability, low cost*

FORTE:

An Existing Space-based EHE Neutrino & Cosmic Ray Radio Detector?

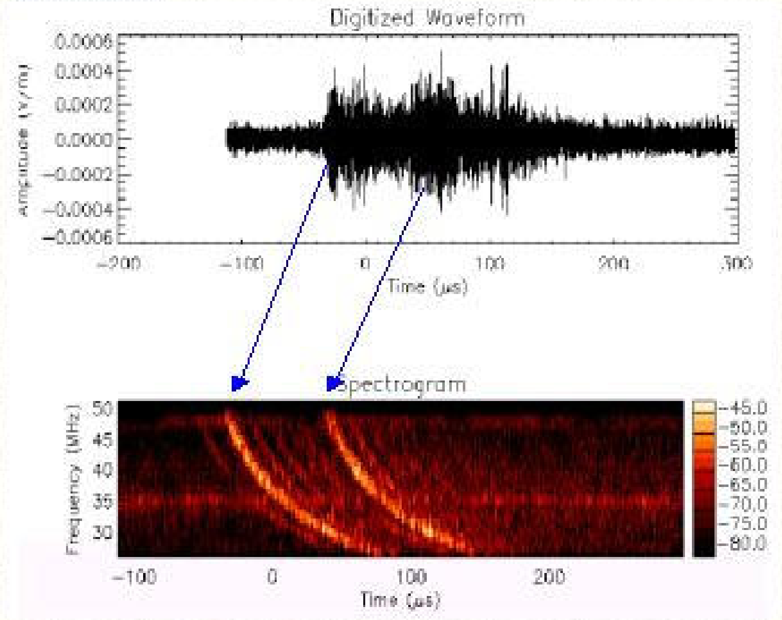


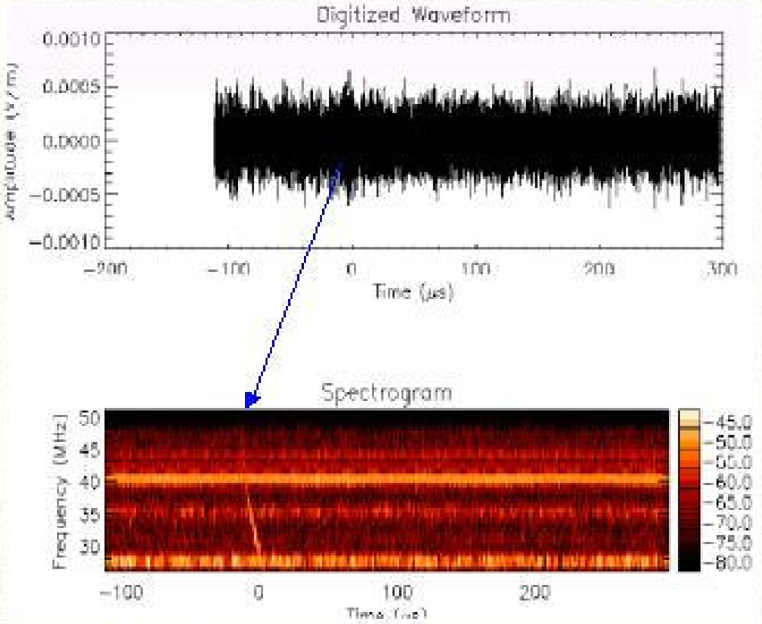
Fast On-orbit Radio Transient Expt.

- **Pegasus launch in 1997**
  - 800 km orbit, 3 year planned life
  - Testbed for non-proliferation & verification sensing
  - Dept. of Energy funded, LANL & Sandia construction & operation
  - Scientific program in lightning & related atmospheric discharges
- **30-300MHz range, dual 20 MHz bands, 16 - 1MHz trigger channels**
- **~2 M triggers recorded**
- **Can trigger on EAS ~100 EeV**
- **~50-100 cosmic ray events in sample?**
- **Analysis in progress (UH, JPL, LANL)**

FORTE

Data Examples





- **Typical lightning trigger**
  - dispersion (curvature) due to ionosphere
  - multiple strikes
- **Correlated to ground-based networks**

- **Isolated trigger**
  - Band-limited, very short duration
  - No pre- or -post-trigger pulses close
  - No related pulses within several sec

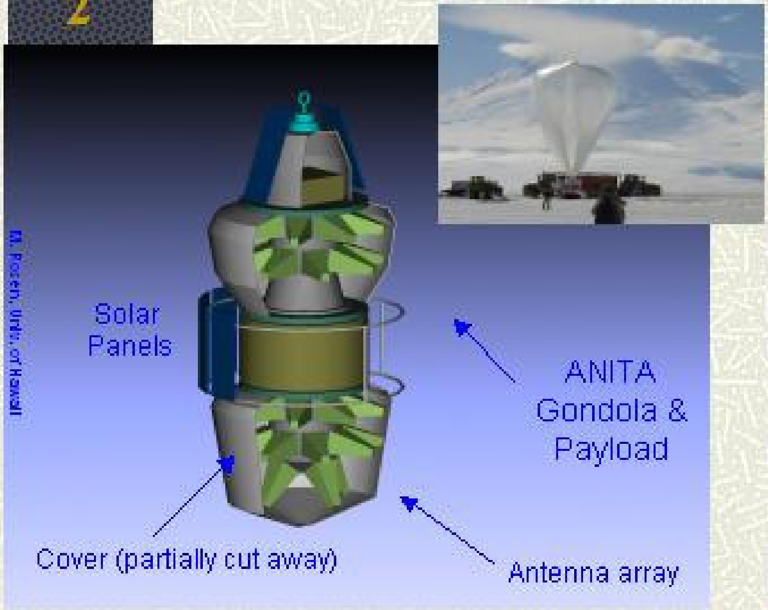
RITA: Radio Impulsive Transient Array

a possible mission of opportunity for the Space Station

- Geosynchrotron & radio Cherenkov from extensive air showers, down & upgoing
- Backward TR from EAS that impact the ocean
- Threshold ~ 10^{20} eV
- Area~ 4M km^2, V~40,000km^3, water equiv.
- Requires 3 or more elements
  - ~ 80m separation possible
  - < 5° resolution @ 50MHz
  - Dual circular polarization
  - Use FORTE approach to deal with anthropic bkgd: moving sub-bands for (RFI-quiet) trigger

P. Gorham

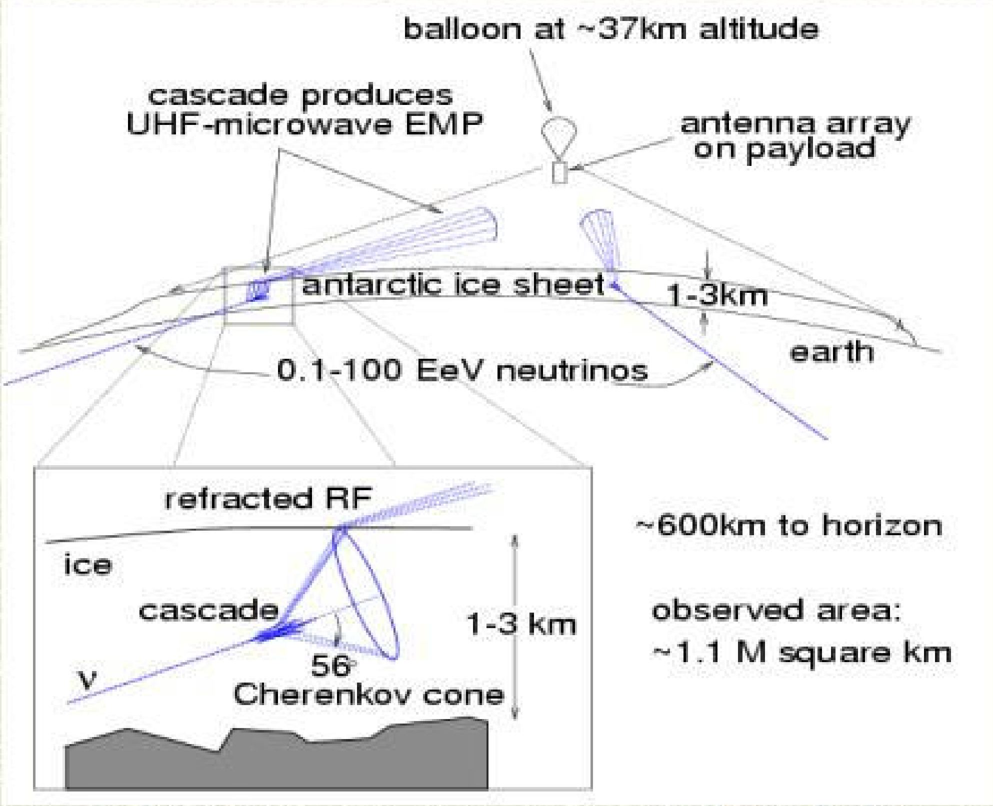
Antarctic Impulsive Transient Antenna (ANITA)



- ANITA Goal: Pathfinding mission for ultra-high energy cosmic neutrinos
- Science team: P. Gorham (PI), S. Barwick (UCI), J. Beatty, S. Coutu (Penn State), P. Evenson, J. Clem, D. Seckel (U.Del./Bartol), F. Halzen (Wisconsin), D. Kieda (Utah), J. Learned (UH), D. Saltzberg (UCLA), K. Liewer, S. Lowe, C. Naudet (JPL), A. Jacobson (LANL)

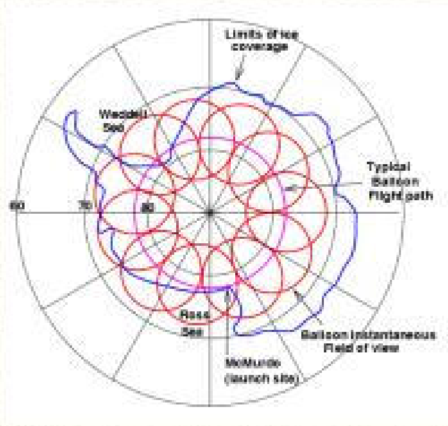
ANITA

Radio from EeV ν's in Polar Ice



~600km to horizon

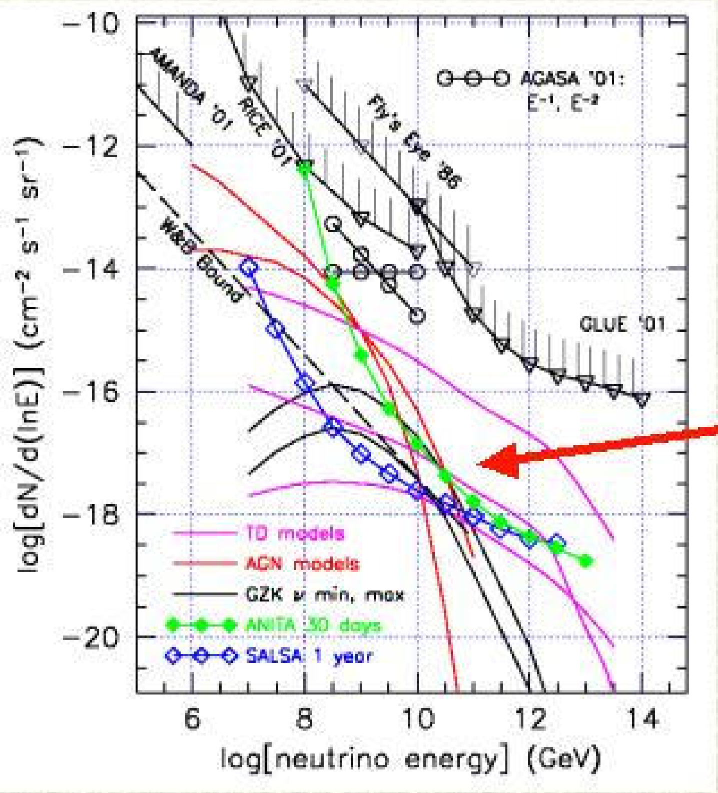
observed area:
~1.1 M square km



- **NASA proposal now**
- **Data in 2005 if successful**

Peter Gorham, UH

Existing UHE Neutrino Limits and Potential Future Sensitivity



- RICE, AGASA, Fly's Eye limits for ν_e only
- GLUE limits ν_μ & ν_e
  - ~50 hours livetime
  - Goal: 300 hrs over next 3 years
- **SALSA & ANITA sensitivity**:
  - Based on 2 independent Monte Carlo simulations

Models:

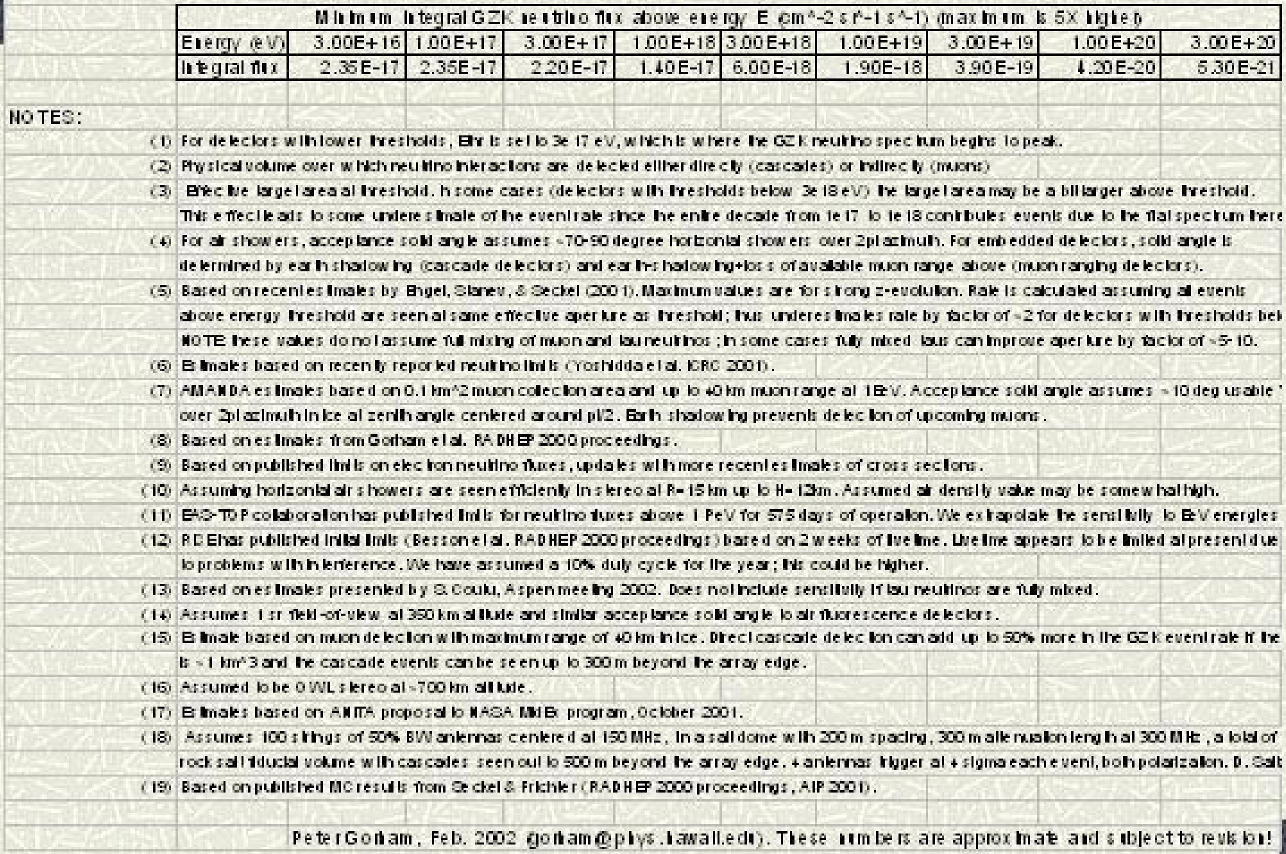
- *Topological Defects: Sigl; Protheroe et al.; Yoshida et al.*
- *AGN: Protheroe et al.; Mannheim*
- *GZK neutrinos: Engel et al. '01*

Compare Potential GZK Neutrino Detectors

Table by P. Gorham, 2/02

Detector or Experiment	GZK threshold energy(1)	GZK Geometric volume(2)	target density	Effective interaction mass	Effective neutrino target area(3)	Accept-ance solid angle(4)	Aperture	actual or projected livetime/yr	GZK neutrino rate (minimum) (5)	GZK neutrino rate (maximum)
	EeV	km^3	gm/cm^3	km^3 w.e.	km^2	ster	km^2 ster	sec/yr	events per calendar yr	events per calendar yr
Active or completed:										
AGASA(6)	0.3	1000	1.00E-03	1	7.44E-04	2	1.49E-03	3.00E+07	9.8E-03	4.9E-02
AMANDA(7)	0.3	4	0.9	4	2.68E-03	1	2.68E-03	3.00E+07	1.8E-02	8.8E-02
GLUE(8)	300	100,000	2	200,000	1789	0.01	17.89	2.00E+05	1.9E-04	9.5E-04
Fly's Eye(9)	1	500	6.00E-04	0	3.44E-04	2	6.88E-04	3.00E+06	2.9E-04	1.4E-03
HiRes(10)	1	8500	6.00E-04	5	5.85E-03	2	1.17E-02	2.00E+06	3.3E-03	1.6E-02
EAS-TOP(11)	0.3	30	6.00E-04	0	1.34E-05	2	2.68E-05	1.00E+07	3.7E-05	1.9E-04
RICE(12)	0.3	1	0.9	1	6.69E-04	6	4.02E-03	3.00E+06	2.7E-03	1.3E-02
In construction or advanced planning:										
Auger(13)	1	1.50E+04	8.00E-04	12	1.38E-02	2	2.75E-02	3.00E+07	0.12	0.58
EUSO(14)	100	1.00E+06	1.00E-03	1,000	6.0	2	12.04	3.00E+06	1.5E-02	7.6E-02
Ice Cube(15)	0.3	40	0.9	36	2.68E-02	1	2.68E-02	3.00E+07	0.19	0.94
Telescope Array	1	3.00E+04	1.00E-03	30	3.44E-02	2	6.88E-02	2.00E+06	1.9E-02	9.6E-02
Proposed, pre-proposal, or conceptual										
OWL(16)	100	3.00E+06	1.00E-03	3,000	18.1	2	36.13	3.00E+06	4.6E-02	0.23
ANITA(17)	0.3	1.00E+06	0.9	900,000	669	0.01	6.69	2.50E+06	3.7	18.4
SALSA(18)	0.3	30	2.2	66	4.91E-02	6	0.29	3.00E+07	2.1	10.4
Super RICE(19)	10	100	0.9	90	2.37E-01	6	1.42	3.00E+07	0.81	4.0

notes to previous table



Minimum integral GZK neutrino flux above energy E (cm^-2 sr^-1 s^-1) (maximum is 5X higher)									
Energy (eV)	3.00E+16	1.00E+17	3.00E+17	1.00E+18	3.00E+18	1.00E+19	3.00E+19	1.00E+20	3.00E+20
Integral flux	2.35E-17	2.35E-17	2.20E-17	1.40E-17	6.00E-18	1.90E-18	3.90E-19	4.20E-20	5.30E-21

NOTES:

(1) For detectors with lower thresholds, Ethr is set to 3e17 eV, which is where the GZK neutrino spectrum begins to peak.

(2) Physical volume over which neutrino interactions are detected either directly (cascades) or indirectly (muons)

(3) Effective target area at threshold. In some cases (detectors with thresholds below 3e18 eV) the target area may be a bit larger above threshold.
This effect leads to some underestimate of the event rate since the entire decade from 1e17 to 1e18 contributes events due to the flat spectrum there

(4) For air showers, acceptance solid angle assumes ~70-90 degree horizontal showers over 2pi azimuth. For embedded detectors, solid angle is
determined by earth shadowing (cascade detectors) and earth-shadowing+loss of available muon range above (muon ranging detectors).

(5) Based on recent estimates by Engel, Stanev, & Seckel (2001). Maximum values are for strong z-evolution. Rate is calculated assuming all events
above energy threshold are seen at same effective aperture as threshold; thus underestimates rate by factor of ~2 for detectors with thresholds bel
NOTE: these values do not assume full mixing of muon and tau neutrinos; in some cases fully mixed taus can improve aperture by factor of ~5-10.

(6) Estimates based on recently reported neutrino limits (Yoshidda et al. ICRC 2001).

(7) AMANDA estimates based on 0.1 km^2 muon collection area and up to 40 km muon range at 1 EeV. Acceptance solid angle assumes ~10 deg usable
over 2pi azimuth in ice at zenith angle centered around pi/2. Earth shadowing prevents detection of upcoming muons.

(8) Based on estimates from Gorham et al. RADHEP 2000 proceedings.

(9) Based on published limits on electron neutrino fluxes, updates with more recent estimates of cross sections.

(10) Assuming horizontal air showers are seen efficiently in stereo at R=15 km up to H=12km. Assumed air density value may be somewhat high.

(11) EAS-TOP collaboration has published limits for neutrino fluxes above 1 PeV for 575 days of operation. We extrapolate the sensitivity to EeV energies

(12) RICE has published initial limits (Besson et al. RADHEP 2000 proceedings) based on 2 weeks of livetime. Livetime appears to be limited at present due
to problems with interference. We have assumed a 10% duty cycle for the year; this could be higher.

(13) Based on estimates presented by S. Coutu, Aspen meeting 2002. Does not include sensitivity if tau neutrinos are fully mixed.

(14) Assumes 1 sr field-of-view at 350 km altitude and similar acceptance solid angle to air fluorescence detectors.

(15) Estimate based on muon detection with maximum range of 40 km in ice. Direct cascade detection can add up to 50% more in the GZK event rate if the
is ~1 km^3 and the cascade events can be seen up to 300 m beyond the array edge.

(16) Assumed to be OWL stereo at ~700 km altitude.

(17) Estimates based on ANITA proposal to NASA MidEx program, October 2001.

(18) Assumes 100 strings of 50% BW antennas centered at 150 MHz, in a salt dome with 200 m spacing, 300 m attenuation length at 300 MHz, a total of
rock salt fiducial volume with cascades seen out to 500 m beyond the array edge. 4 antennas trigger at 4 sigma each event, both polarization. D. Sal

(19) Based on published MC results from Seckel & Frichter (RADHEP 2000 proceedings, AIP 2001).

Peter Gorham, Feb. 2002 (gorham@phys.hawaii.edu). These numbers are approximate and subject to revision!

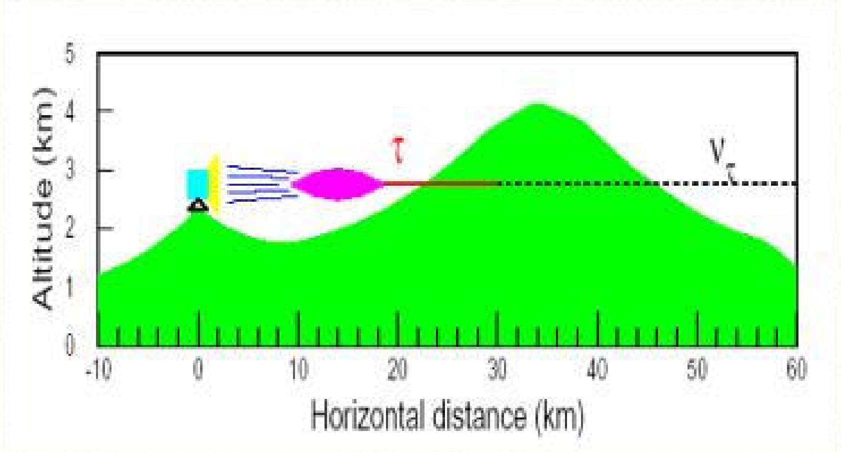
Tau Watch in Hawaii
Neutrinos Converted in Mountain

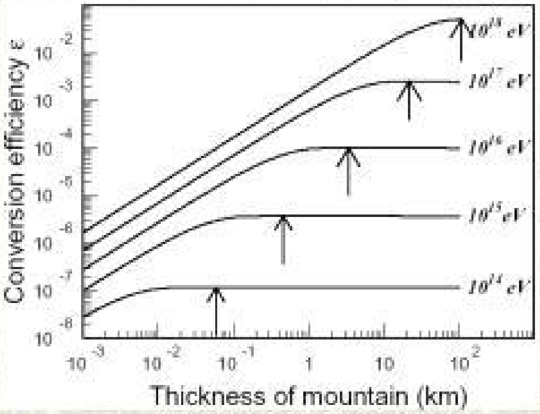
- Astronomer's dream site
  - Excellent weather
  - Little artificial light
- 3km Mt. Hualalai provides good view of Mauna Loa.
- Mauna Loa provide long base line, ~ 90 km wide and 4 km high.

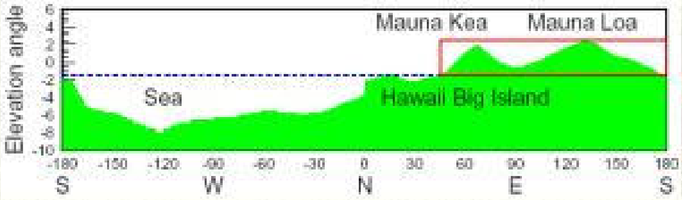
TauWatch

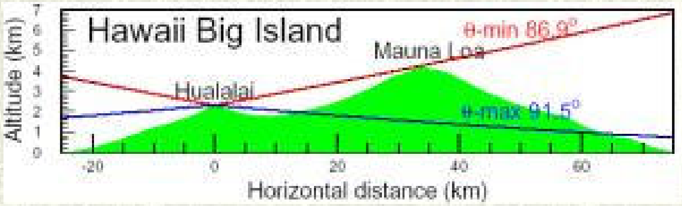
Using Mountains to Convert ν_τ

3/02 Workshop in Taiwan, see http://hep1.phys.ntu.edu.tw/vhetnw





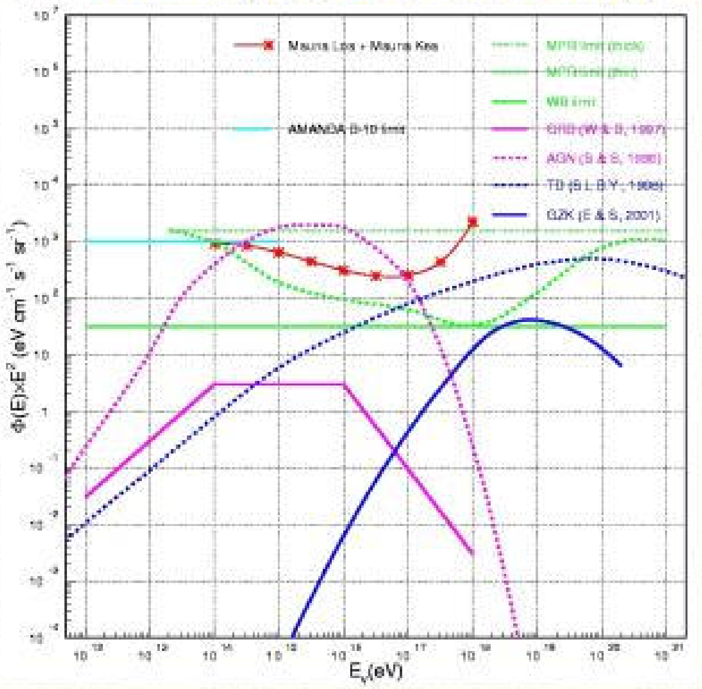




Tau Watch Sensitivity

- Chance to explore MPR limits and set upper limit ~AMANDA-B10, but at higher energy.
- Nearby point source could be detected.
- Technology exists, can be mounted in several years.
- Collaboration formation meeting at SPIE Telescope Conf. in Hawaii, Aug 2002. Participation invited.

- **Sensitivity** = that flux which produces **0.3 events/year per half decade of energy**.



Alfred Huang

Summary: New Techniques in HE ν Astronomy

- **It is an exciting time in the neutrino business! Progress on all fronts from low energy to high.**

- Much new activity aimed at EeV regime and upwards, and old ideas (and new applications) at last being realized.

- Next few years will see significant limits and possible discovery of **E.H.E. ν's** in some of these… radio could be first.

- **As for last 25 years: Stay Tuned for the Cosmic ν's!**