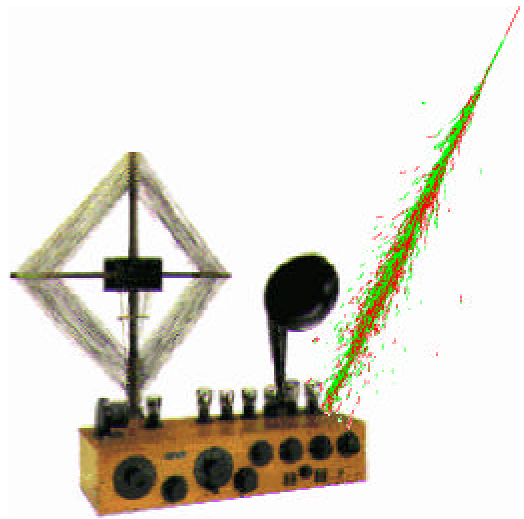
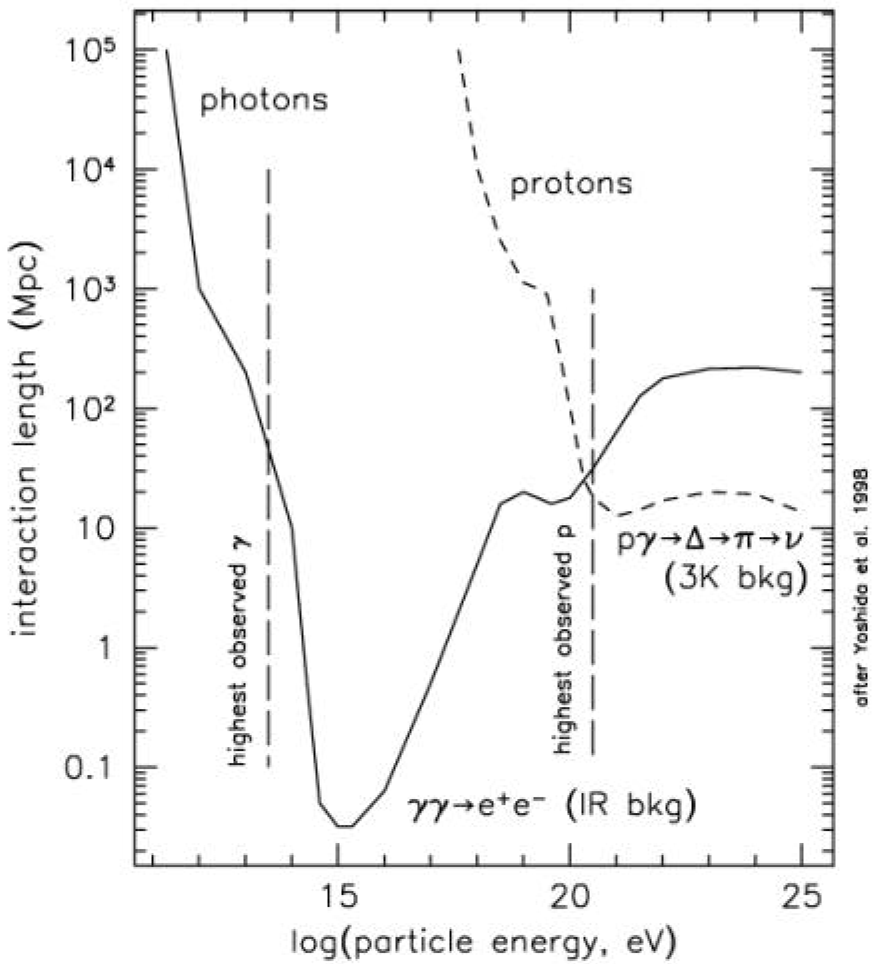
Radio Detection of GZK Neutrinos: Potential for Balloon-borne and Underground Salt-dome detectors



P. Gorham, Univ. of Hawaii & JPL/Caltech

NeSS 2002

Particle astrophysics at the highest energies



- Universe <u>optically thick</u> to photons above ~10 TeV
- Protons probably extragalactic above 10 EeV, but cannot propagate more than a few tens of Mpc ➔ GZK cutoff
- ➔ Astronomy above ~10 TeV can only be done with neutrinos
- GZK process itself is a source;
  Maybe the ONLY source
  ➔ Design for GZK flux!

What role does radio detection play?

- Standard model GZK ν rate:
  - ~0.2 per km^3 w.e. per year over 2π sr
    - Cf. Engel, Seckel, & Stanev 2001

Log E_{sh} (GeV)>	6	7	8	9	10
All ν, NC	0.052	0.046	0.032	0.008	0.001
ν_e, CC	0.054	0.051	0.046	0.024	0.004
$\nu_\mu + \nu_\tau$, CC	0.092	0.080	0.057	0.014	0.002
Total	0.192	0.177	0.144	0.046	0.007

- ➔ Need ~1000 km^3 sr to get 30 events per year: A Teraton detector

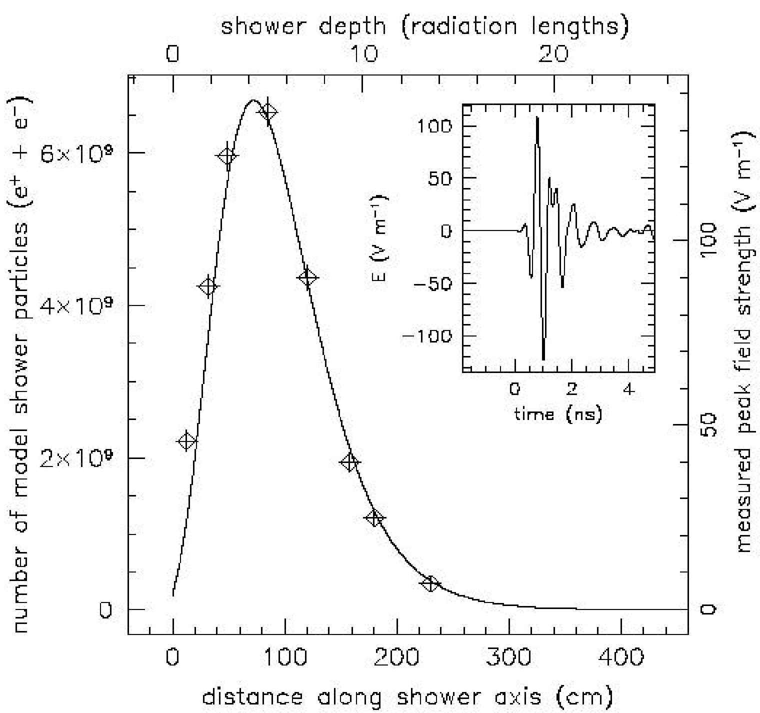
- A possible solution: Askaryan process: coherent radio Cherenkov emission

  - EM cascades ➔ net charge asymmetry ➔ radio pulse
  - Process is coherent ➔ Quadratic rise of power with cascade energy
  - Neutrinos can shower in radio-transparent media: **ice, rock salt, etc.**

  - **RF economy of scale very competitive for giant detectors**

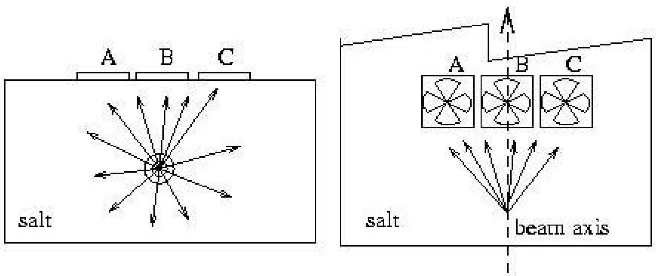
Askaryan process: Radio Cherenkov

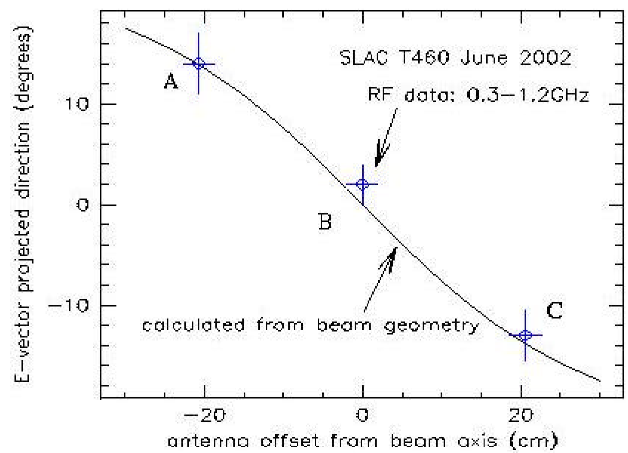
Calorimetric



SLAC T444, Saltzberg et al. PRL 2001

Vector directionality

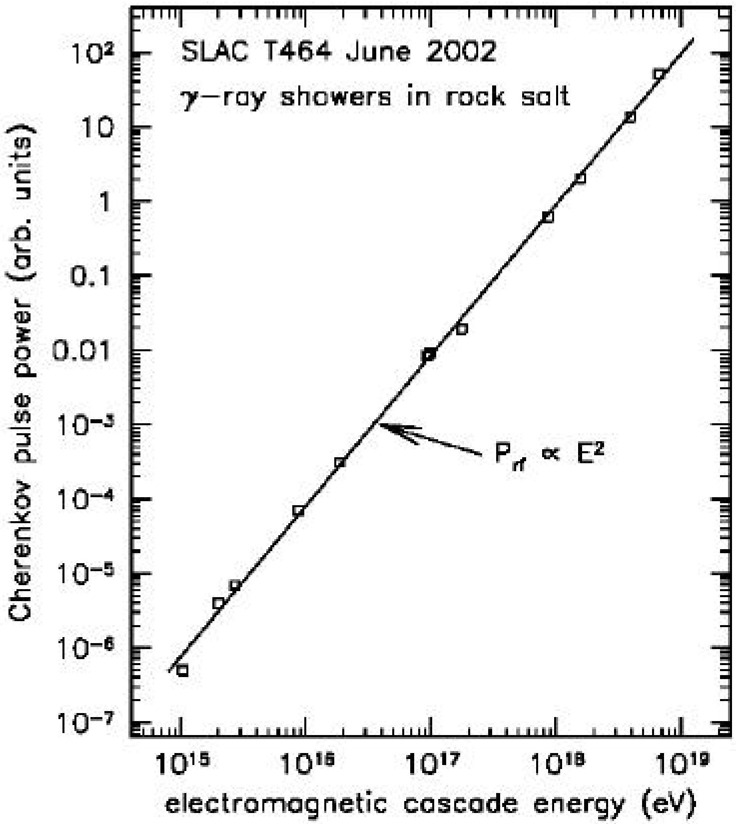




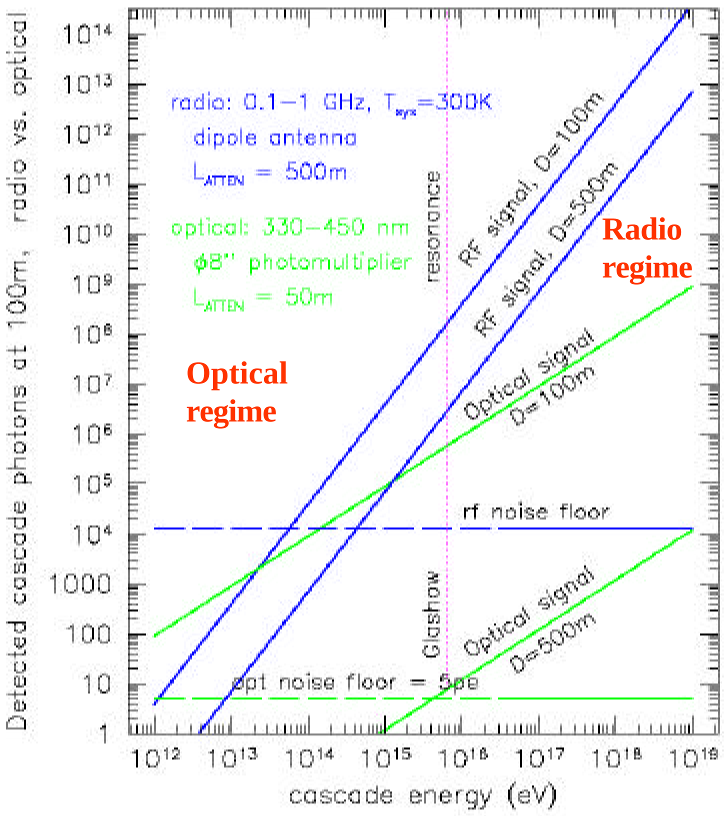
SLAC T460, Gorham et al. 2002

Askaryan process: Radio Cherenkov (II)

Huge dynamic range, linearity



SNR dominant at E >10 PeV



Exploiting the Askaryan effect

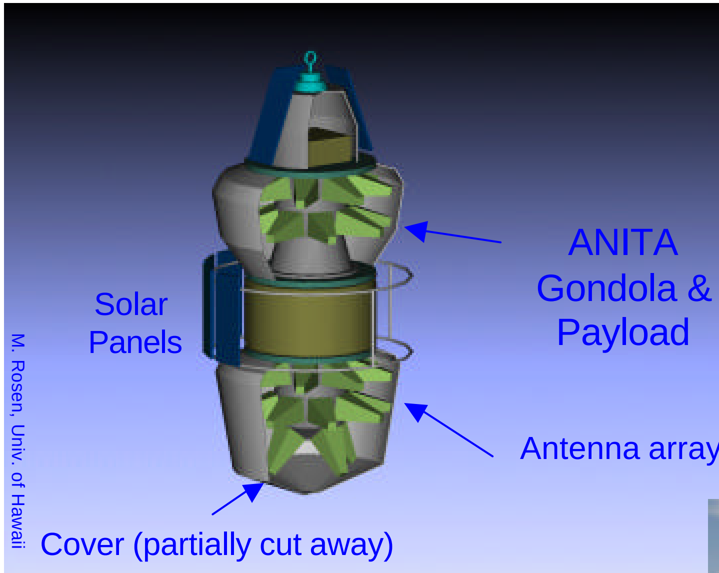
- Other experiments: Radio Ice Cherenkov Experiment (RICE) (D. Seckel talk) , Goldstone Lunar Ultra-high energy neutrino Experiment (GLUE)

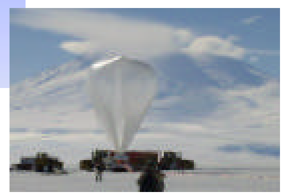
Potential GZK ν Detectors:

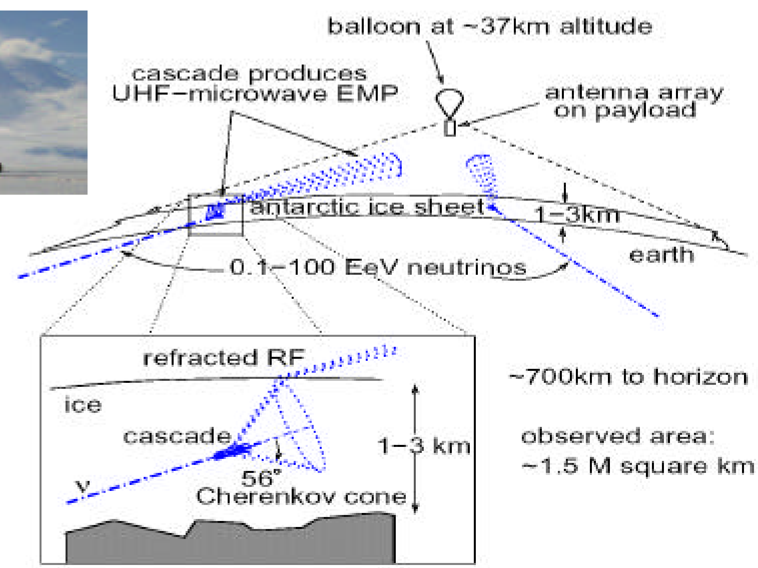
- Antarctic Impulsive Transient Antenna (ANITA) (cf. Gorham or K. Liewer, Kona SPIE 2002)
  - Balloon-borne VHF-UHF antenna array: view ~1M km^3 of ice sheet
  - NASA Space research & technology (SR&T) mission, 2005-2006 launch
  - Coarse angular & energy precision but very high potential sensitivity
  - Expect **~2000 km^3 sr aperture at ~1 EeV**
  - Long duration balloon=30 days/yr, Ultra-long duration balloon=100days/yr

- Saltdome Shower Array (SALSA) (cf. D. Saltzberg Kona SPIE 2002)
  - Antenna array(s) embedded in saltdome(s)
  - Concept: 10 by 10 strings, 10 antenna nodes per string, ~250 m spacing
  - 2π sr (no muons!) available, density 2.2 ➔ **~400 km^3 sr at 1 EeV**

Antarctic Impulsive Transient Antenna (ANITA)

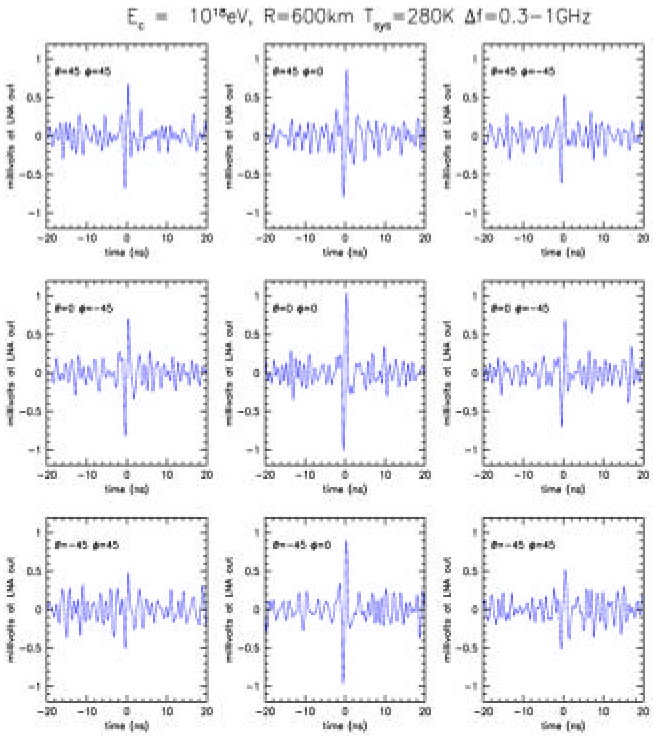




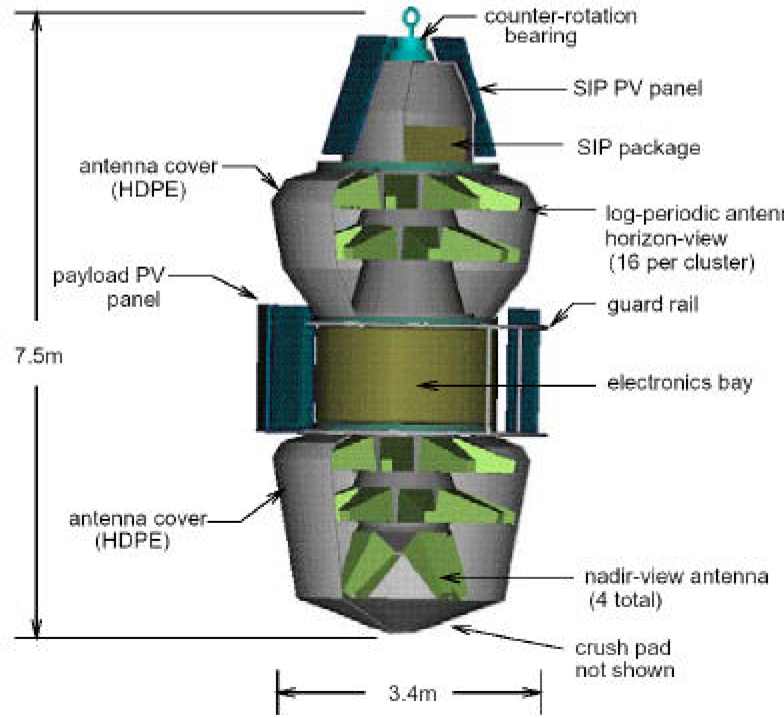


- **ANITA Goal: Pathfinding mission for GZK n**
- NASA SR&T start October, launch in `05-`06
- UH (Gorham, Learned, Varner), UCI (Barwick), JPL (Liewer, Naudet), Penn State (Beatty, Coutu, Cowen), U.Del. (Seckel, Evenson, Clem), UCLA (Saltzberg), U.Minn. (DuVernois), UW (Halzen), Utah (Kieda), Kansas (Besson)

ANITA Payload




antenna cluster detail



Simulated pulse—multiple antennas

- ANITA antennas view ~2pi sr with 60 deg overlapping beams
- Beam intensity gradiometry, interferometry, polarimetry used to determine pulse direction & thus original neutrino track orientation

Antarctic ice topography

~few m feature relief

~5 mile long “highway”

- RadarSat completed comprehensive SAR map of Antarctica in late 1990s—feature resolutions of ~10-50m, available public domain
- Can calibrate surface roughness—SAR λ = 5.6 cm

ANITA questions & issues

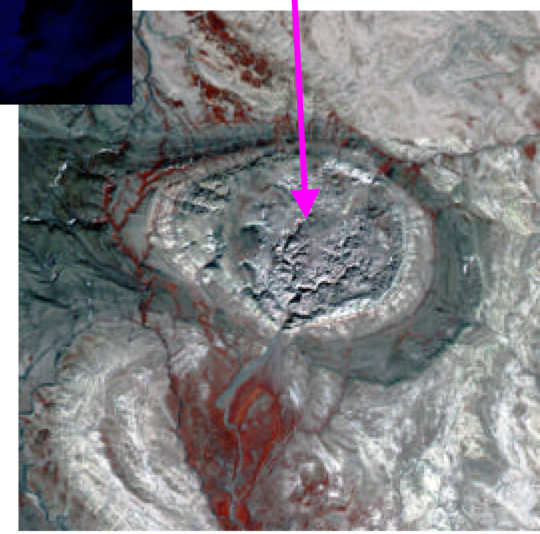
- RF interference?
  - Studies suggest Antarctica is extremely quiet
- How will cascade pulses be distinguished?
  - Askaryan pulse spectrum: unique bandwidth, coherence, polarization
- Energy & Angular resolution?
    - Pulse interferometry & beam gradiometry ➔ ~5-10^0
    - Depth of cascade from spectral rolloff & known ice properties
    - Track angle from plane of polarization
    - $\Delta E/E \sim 1$ from combination of all of the above

Natural Salt Domes: Potential PeV-EeV Neutrino Detectors

Salt domes: found throughout the world…

Qeshm Island, Hormuz strait, Iran, 7km diameter salt dome

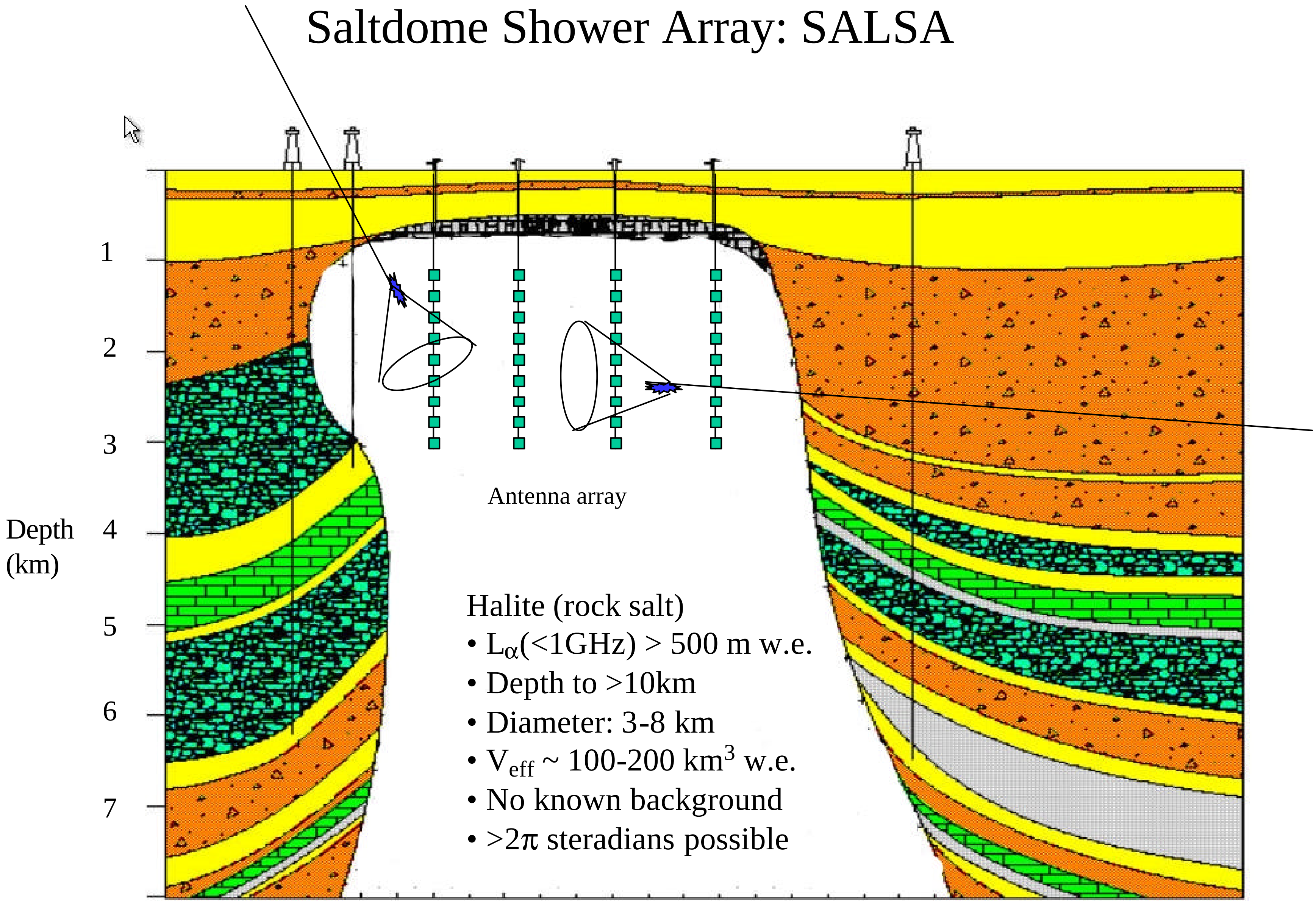
Caprock visible from space



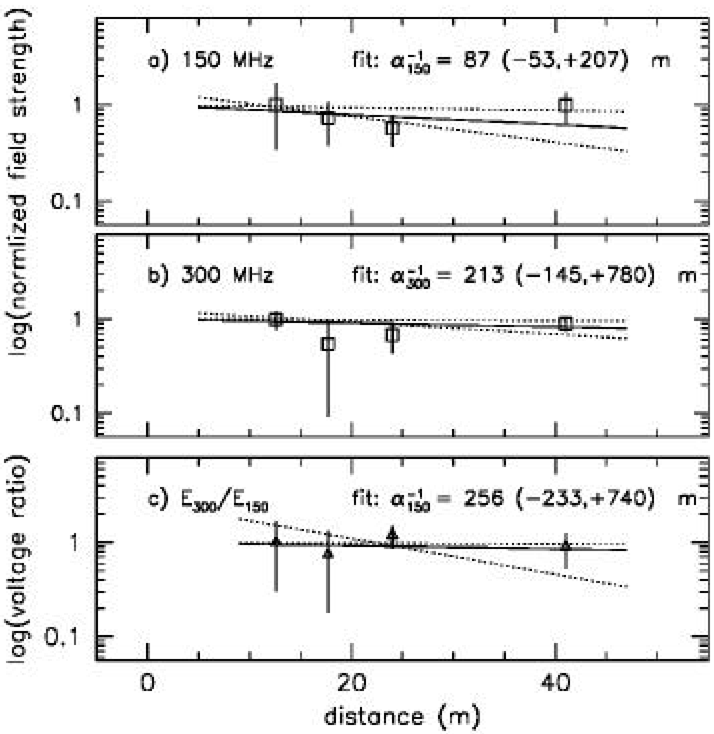
Isacksen salt dome, Elf Ringnes Island, Canada 8 by 5km

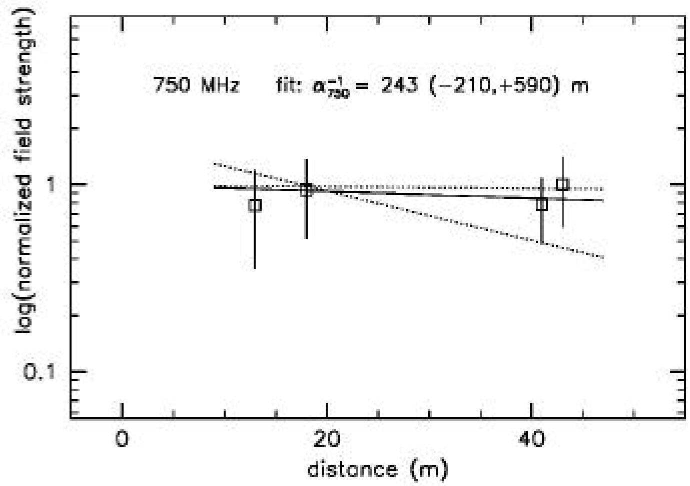
- Rock salt can have extremely low RF loss: ➔ as radio clear as Antarctic ice
- ~2.4 times as dense as ice
- typical salt dome: **50-100 km^3** water equivalent in top ~3km

Saltdome Shower Array: SALSA



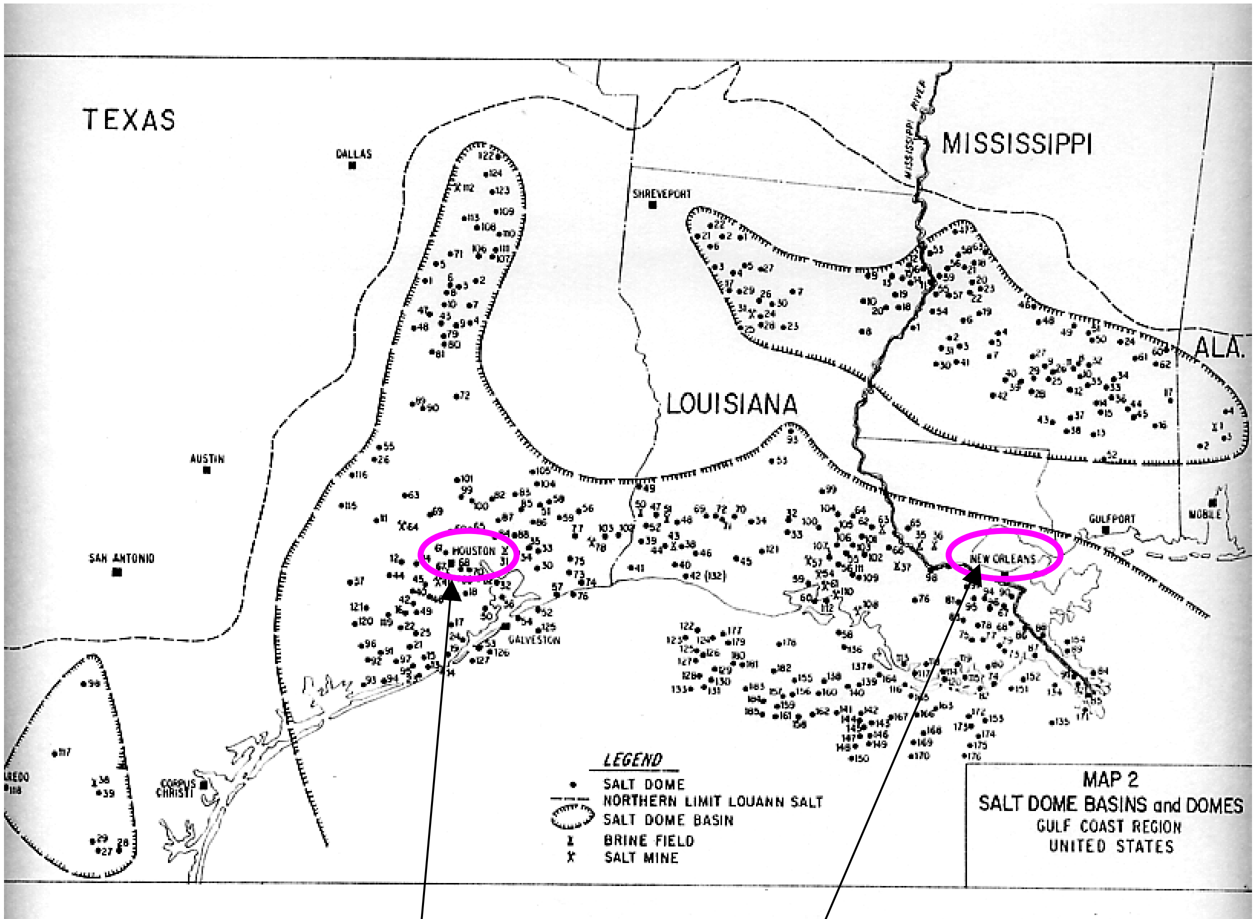
Results from Hockley Mine rock salt tests





- **All results consistent with >200 meter attenuation lengths**
- Supported by ground-penetrating radar results since early 1970’s
  - Radar pulses sent through ~3 km of salt in some Gulf-coast salt domes

US Gulf Coast Saltdomes



Houston New Orleans

Salt dome demographics:

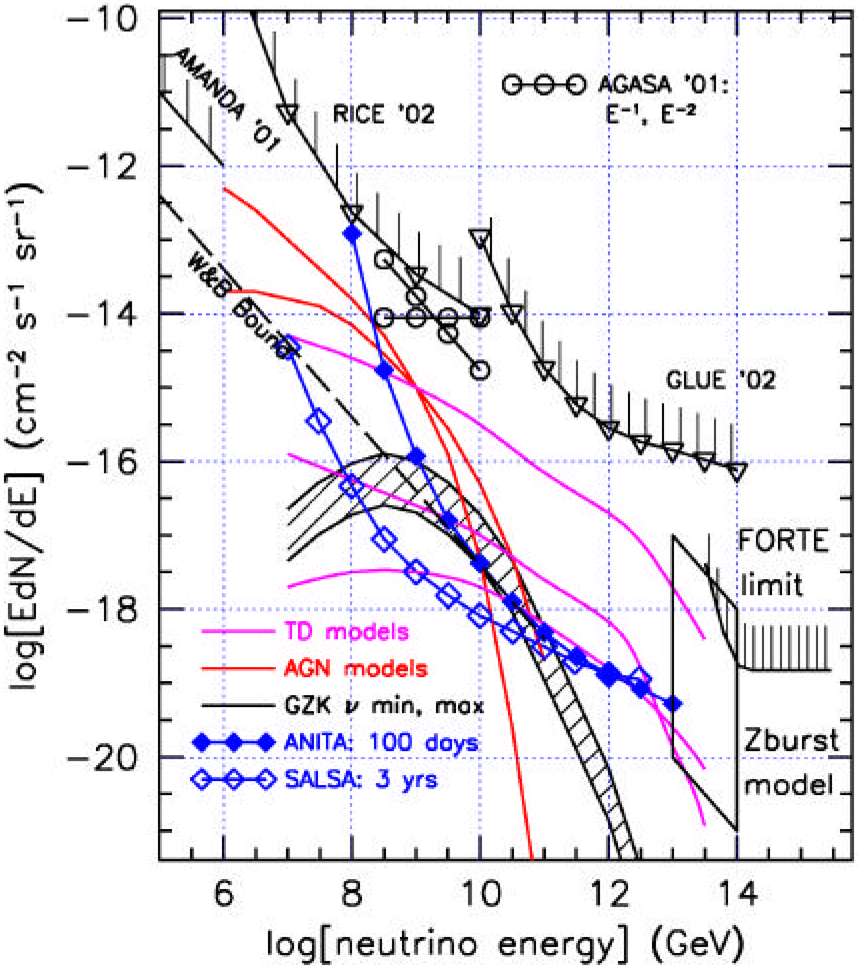
- Several hundred known in Gulf coast area alone—some are good source of oil
- Mapped for oil (on flanks, not in salt) but most are undeveloped

Roadmap to a large-scale salt detector

1. Verify Askaryan process: silica sand, SLAC T444, 2000
2. Identify radio-transparent natural salt structures 2001
   - GPR tests from 1970's give strong indications
   - Hockley salt dome tests (Gorham et al. 2002) confirm La>250m
3. Extend accelerator results to rock salt: 2002
   - SLAC T460: salt behaves as predicted!
4. Cosmic-ray testbed for antenna development/signal characterization 2002
   - In progress at Univ. of Hawaii progress since early August

5. Deploy an on site testbed in a salt mine 2003-2004
   - Small antenna array—study backgrounds
6. Site studies and selection 2005-2006
7. Detector construction & deployment 2007-2010

Existing Neutrino Limits and Potential Future Sensitivity



- RICE, AGASA, Fly's Eye limits for ν_e only
- GLUE limits ν_μ & ν_e
  - ~80 hours livetime
- FORTE limits ν_μ & ν_e
  - 3.8 days live, Greenland ice
- SALSA & ANITA sensitivity:
  - Based on 2 independent Monte Carlo simulations: D. Saltzberg (SPIE02), Gorham (GLUE adaptation); ν_μ & ν_e included, full-mixing not yet

Models:

• Topological Defects: Sigl; Protheroe et al.; Yoshida et al.

• AGN: Protheroe et al.; Mannheim

• GZK neutrinos: Engel et al. '01

Summary

Radio Detection:
The Dark horse in the GZK neutrino race…

- ANITA appears to have the earliest shot at constraints (or detection) of the GZK flux (2005-2006 austral summer)

- SALSA: probably the most cost-effective GZK neutrino telescope