ANITA and ASHRA New Players in EeV Neutrino Studies

John G. Learned

University of Hawaii, Manoa

XIII ISVHECRI, Pylos 2004

ASHRA: Introduction

(All-sky Survey High-Resolution Air Shower detector)

- Concept: next gen 1' all-sky monitor
- Science focus: EeV neutrinos
- Multiple products: τ appear, ν astronomy, GZK CRs, all sky TeV gammas, GRB flashes….
- Collaboration: Japan, Taiwan, and US
- Status: project in demonstration phase in HI

New Eye for Particle Universe

Ashra-1

Key Technology:

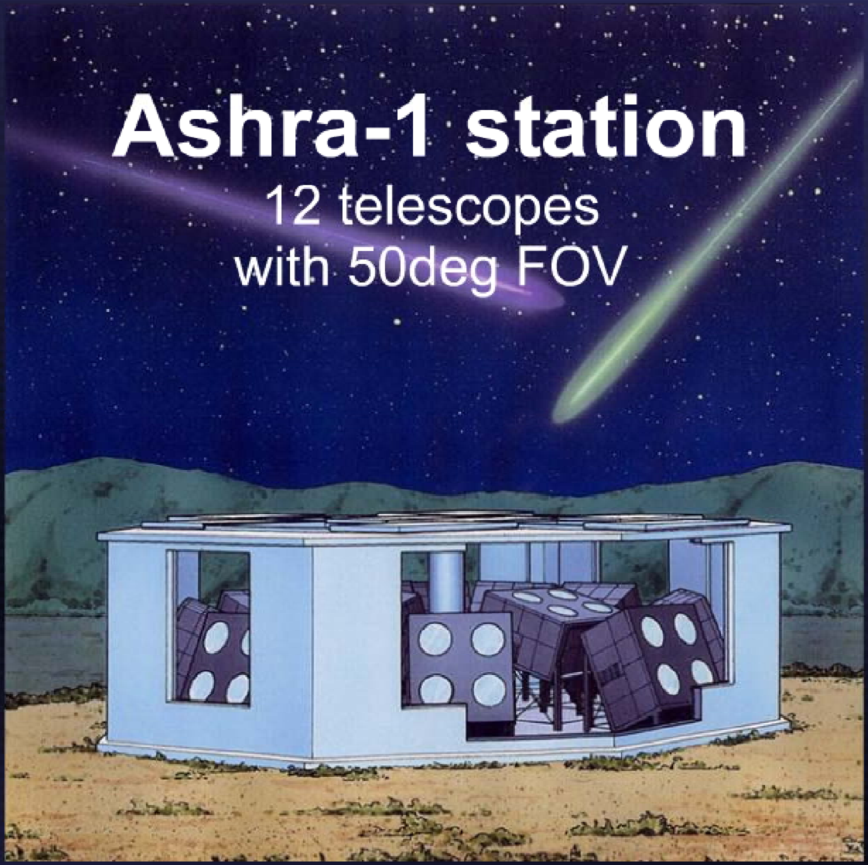
9M-pixel CMOS sensor
covering 50deg FOV

Leading Features:

All-sky Survey
=> Discovery Potential

1arcmin directional accuracy
=> Source ID

Simultaneous Detection for
Cerenkov & Fluorescence
=> Physics ID



whole hemisphere 48M-pixels

Pioneer Experiment for VHE Particle Astronomy: Ashra-1

Effect of Much Higher Resolution

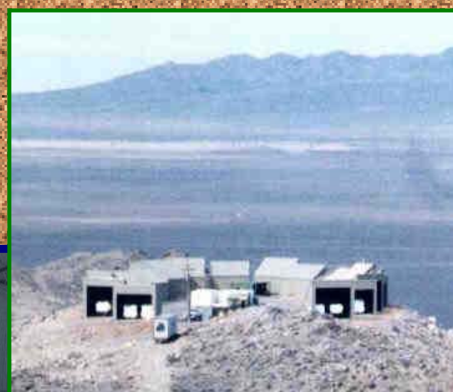
PMT array:
1 deg resolution

Usual PMT array camera resolution ~ $0.2^o - 1.0^o$

Fly's Eye

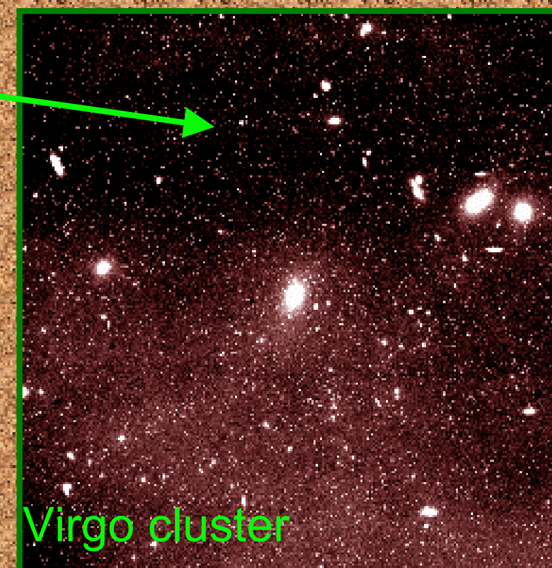
Hi-Res

Auger Fluor.



2m ϕ mirror
256ch PMT

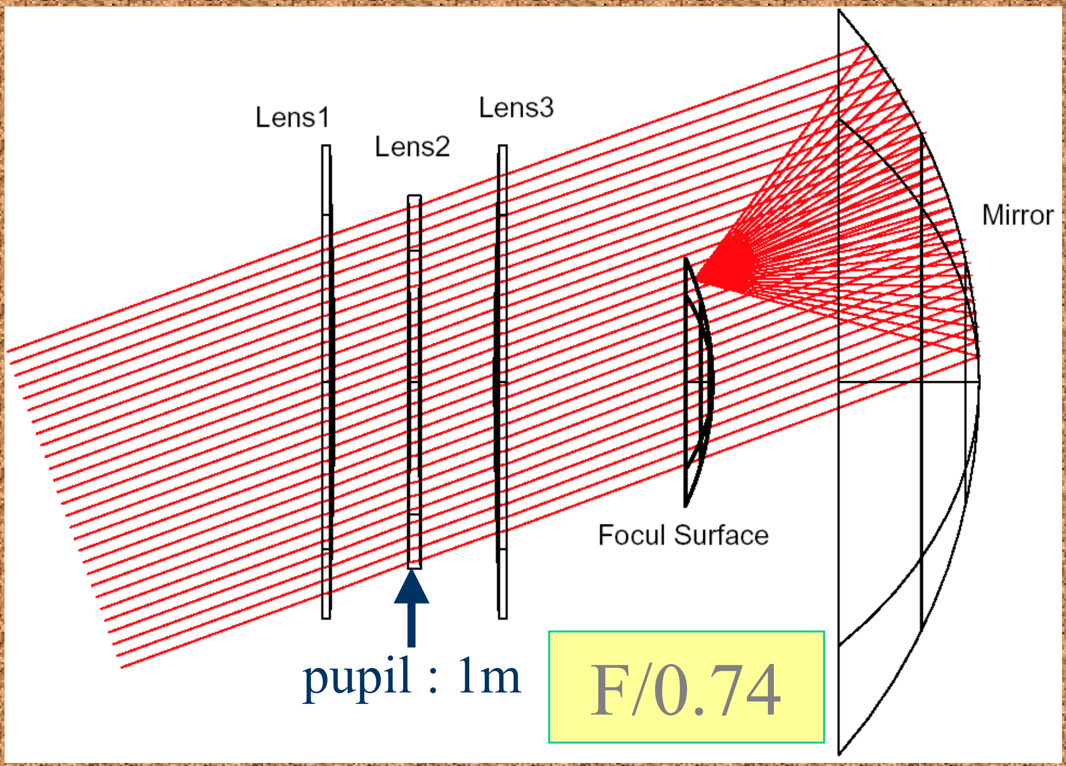
ASHRA: 1 arc minute resolution



Better resolution =>
- **Longer range**
- **Lower threshold**
- **Larger volume**
- **Better separation**

Design of Ashra Optics

Modified Baker-Nunn



- **Schmidt-type optics**
- **Spherical segment mirror**
- **Spherical focal surface**
- **3-element corrector lens**

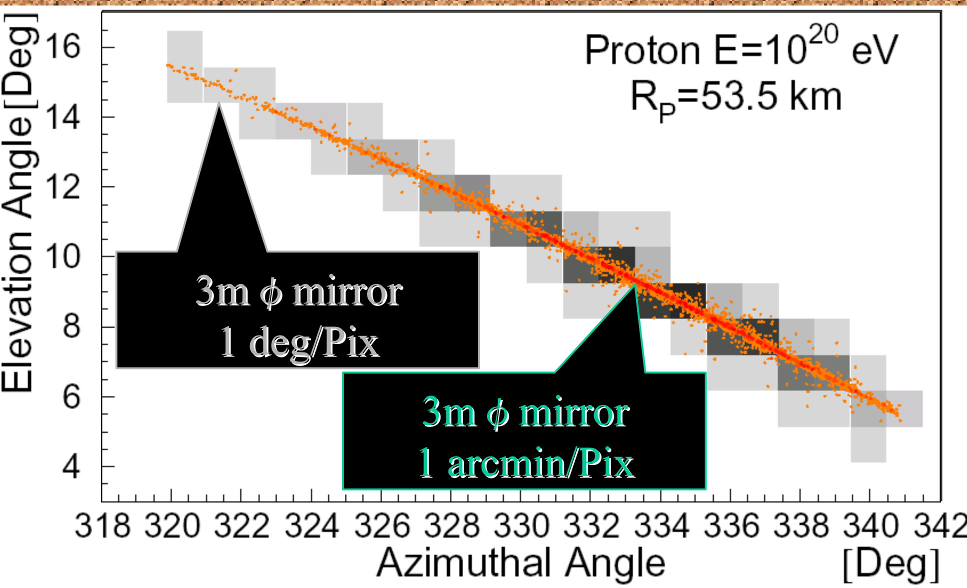
Advantage: a large degree of freedom for optimization of lens surface shape to cancel

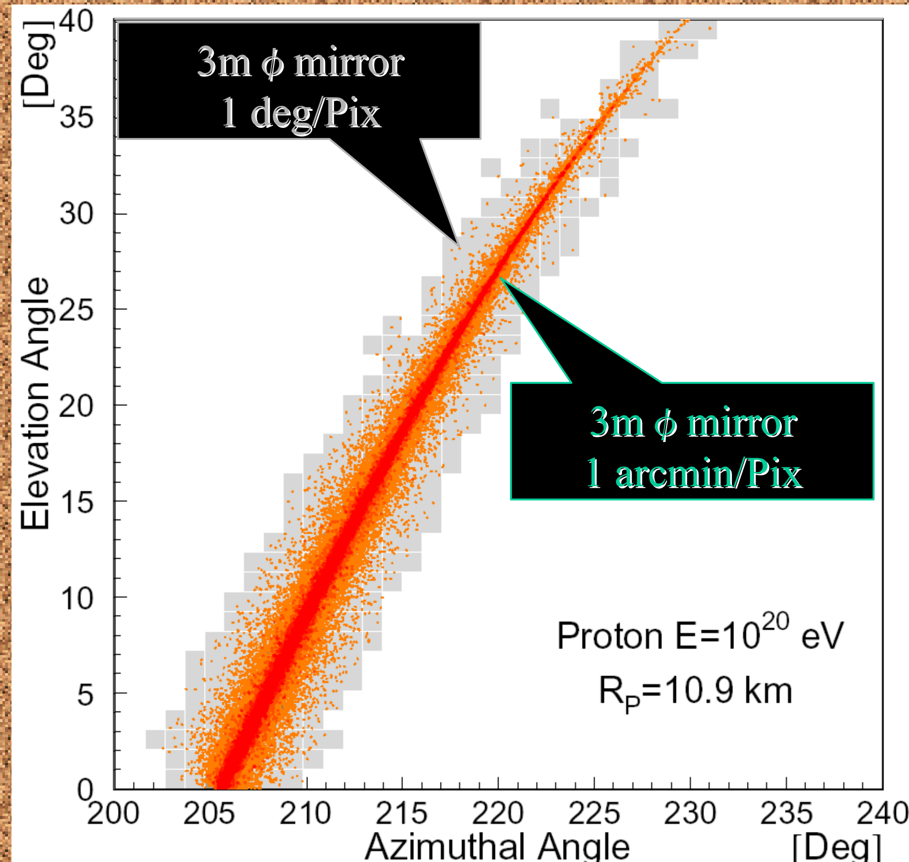
1. spherical aberration
2. chromatic aberration.

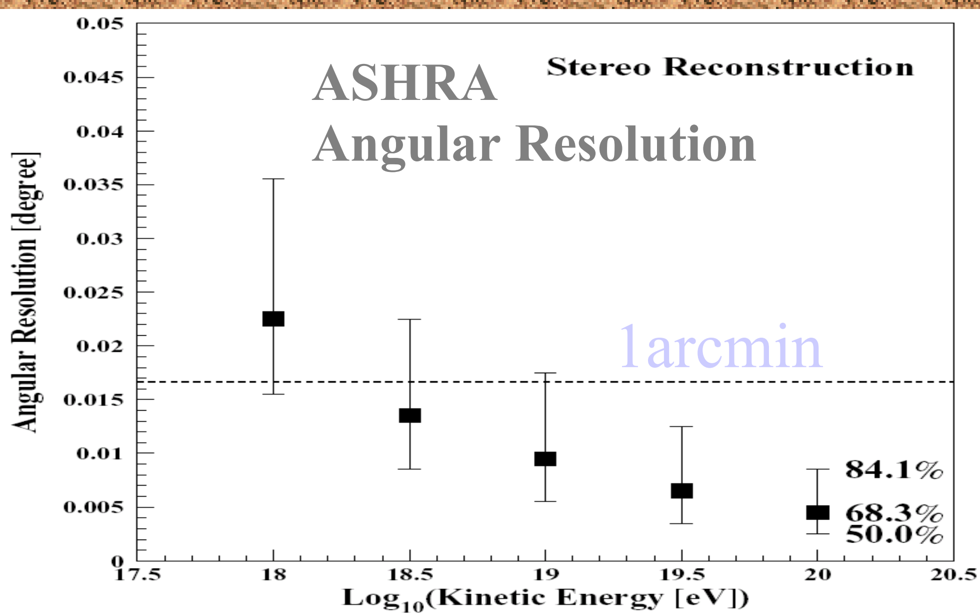
Details can be found in

M.Sasaki et al, NIM A492 (2002) 49

Pixel resolution & angular resolution



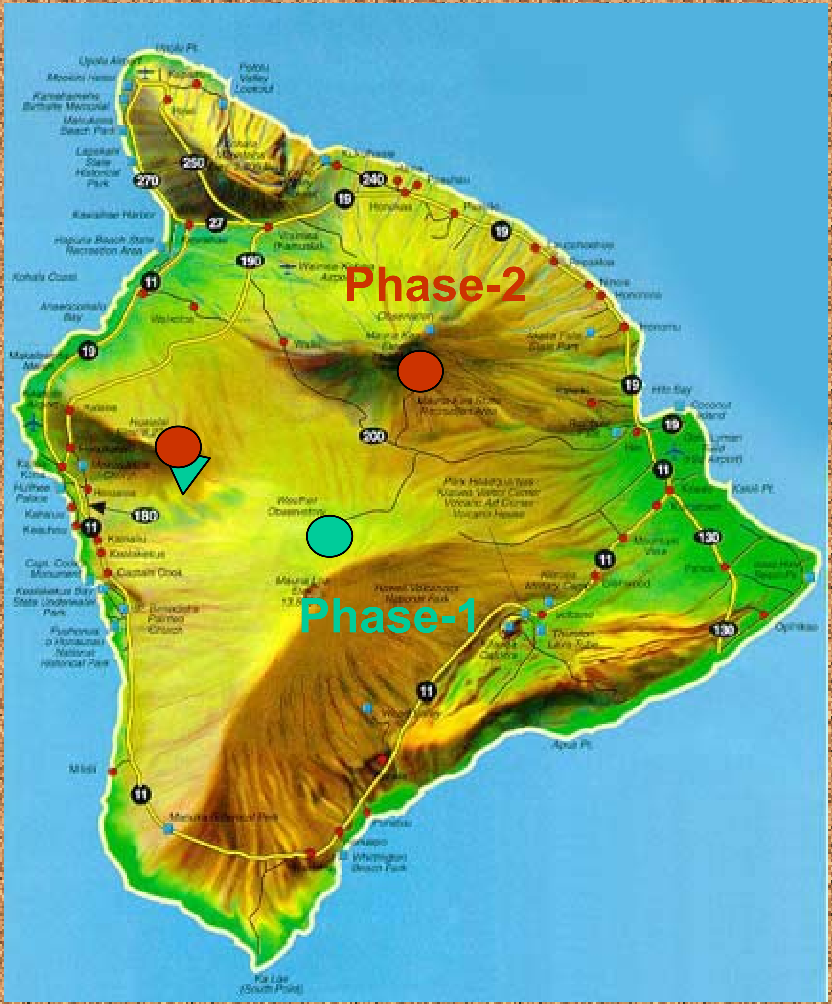




- < 1 arcmin at E > $10^{18.5}$eV
- 0.3 arcmin at E ~ 10^{20}eV

The Best Place for VHE Particle Detector!

• Environmental Requirements:
  - •Clearn air
  - •Less cloud @ >2500m
  - •Less light pollution
  - •30-40km separations
  - •Roads, electricity, …
  - •Near culture and beach
  - •And ….

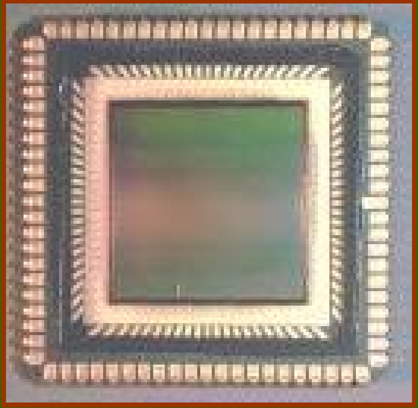


Ashra:
Imaging Particle Detector

Key Technology

9M-pix. CMOS Sensor Covering 50^o-FoV

PMT-array Camera



CMOS Sensor Chip

4,500x3,000 (14M) pix.
Commercial CMOS Camera

Pixel Cost Reduction by O(10^4)

Ashra Project Plan

2002	2003	2004	2005	2006	2007

Test Obs. @ Haleakala

phase 0

R&D

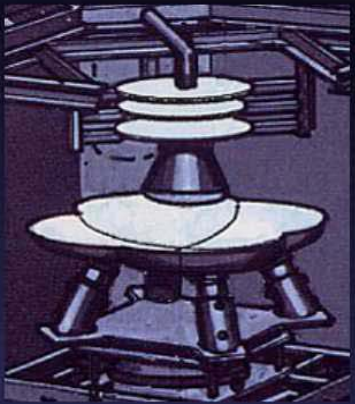
phase 1

Pioneering

phase 2

High Statistics

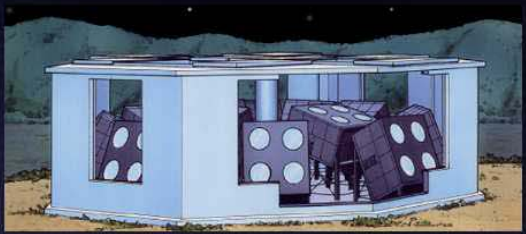
sub-telescope



prototype in labo.

1 + 1/3

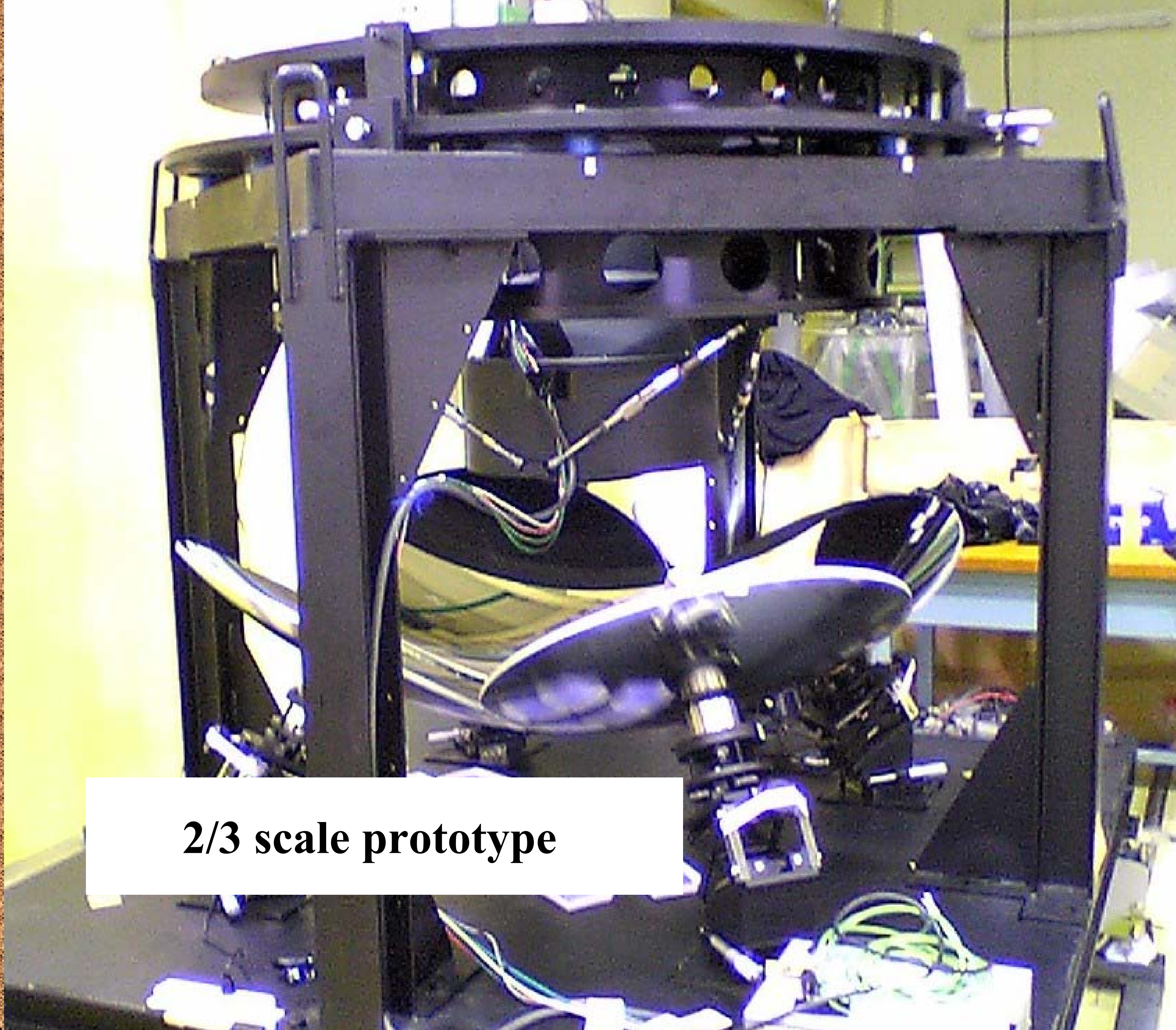
Installation @ M. Loa



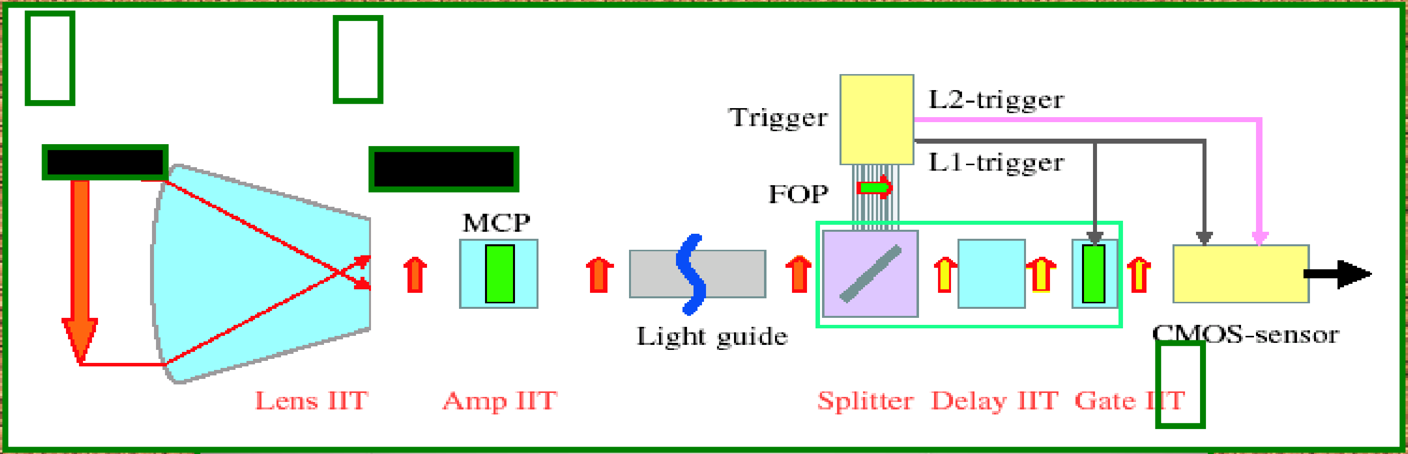
2 Mt.s on the Hawaii Is.

complete 3 stations

3 Mt.s on the Hawaii Is.


2/3 scale prototype

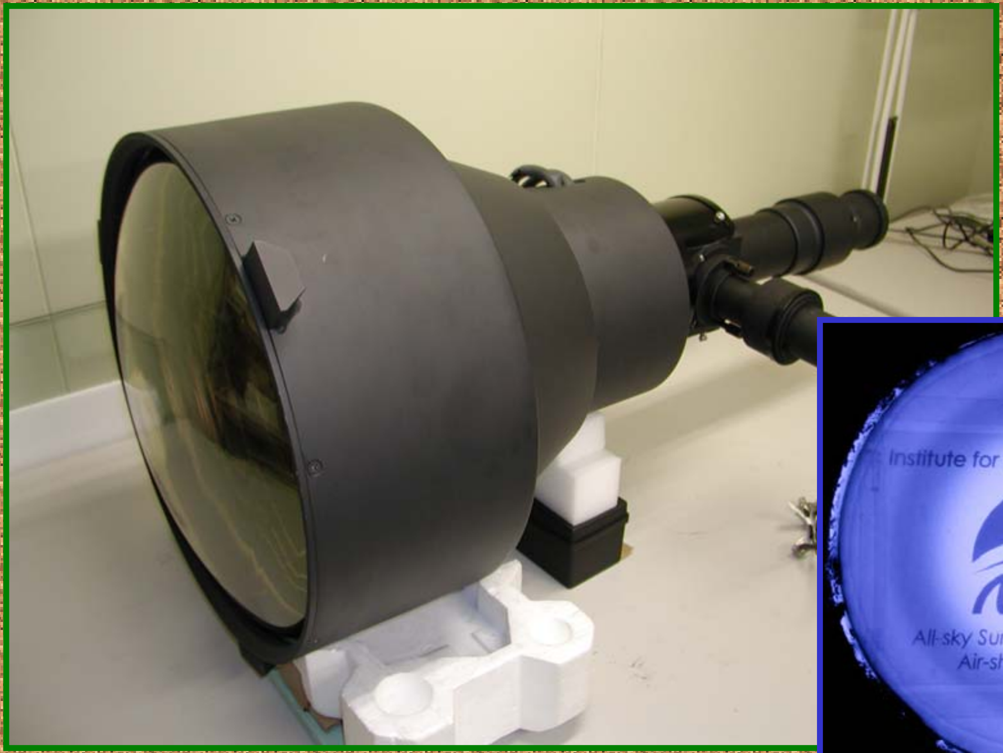
Prototype Image Pipeline



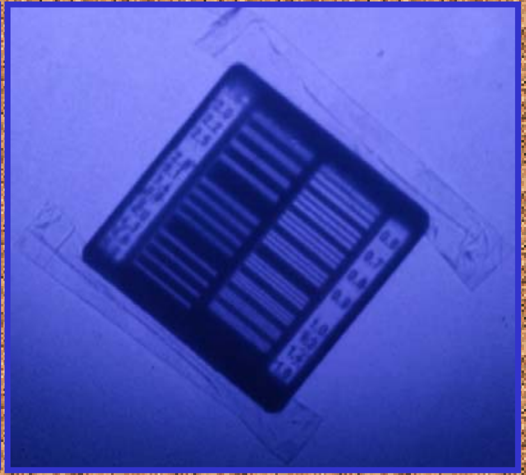
Haleakala TeV- γ Test Observation

3 m Diameter Air Cherenkov Telescope

Large Diameter Image Intensifier



16” (400mm) ϕ photocathode



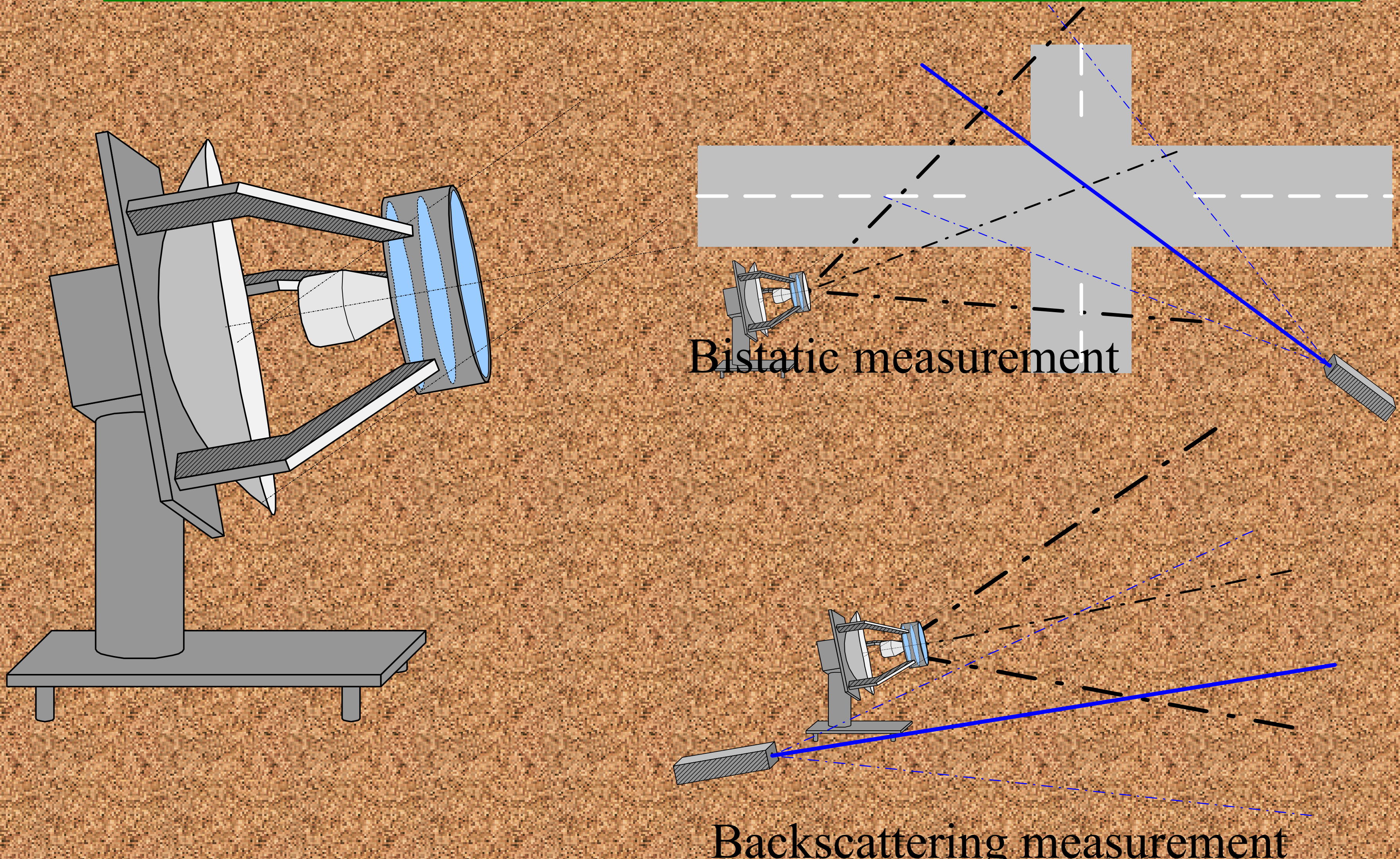
⇒ **photocathode resolution 3.4 line pair/mm**

(largest and finest resolution in world)

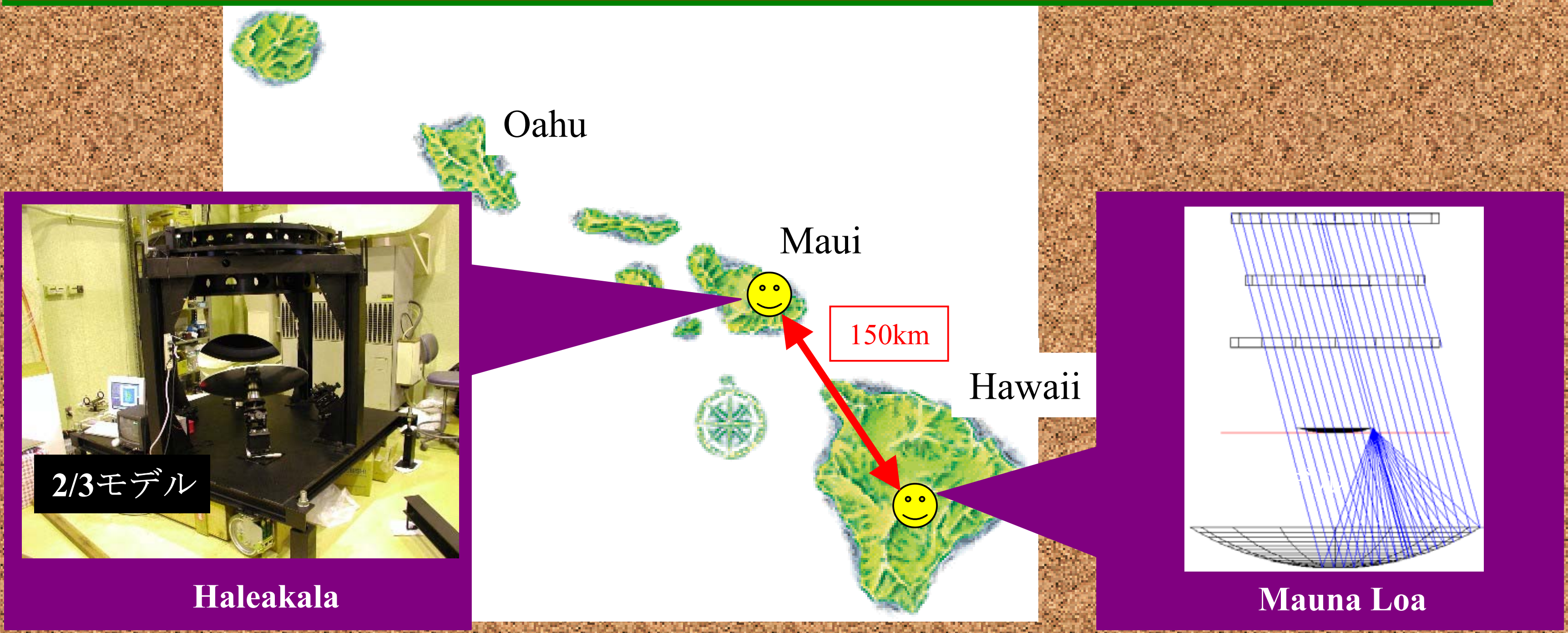
⇒ **24“ under development**

First Full Scale Element Haleakala Aug. '04

Ashra Portable Unit for Environmental Measurements



ASHRA GRB-flash Stereoscopic Observations



- **Stereo with 2 telescopes 150km apart with 1' resolution**

  → Can veto Optical Flashes closer than moon

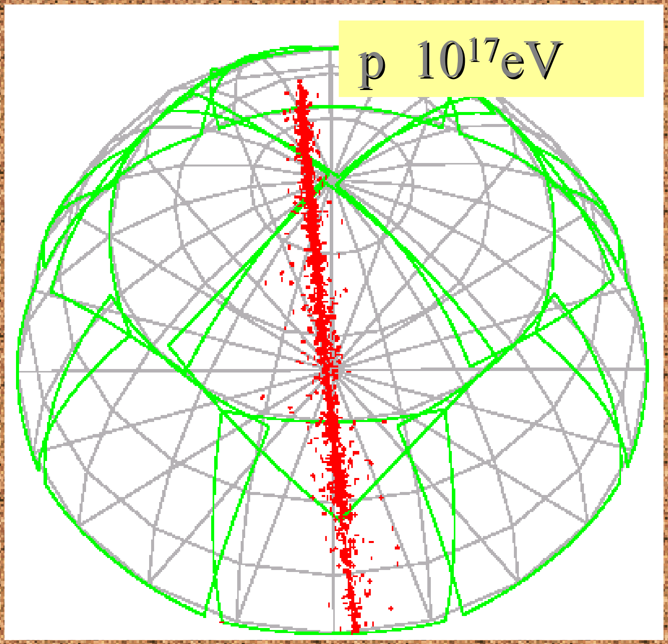
Comparison of GRB Optical Observations

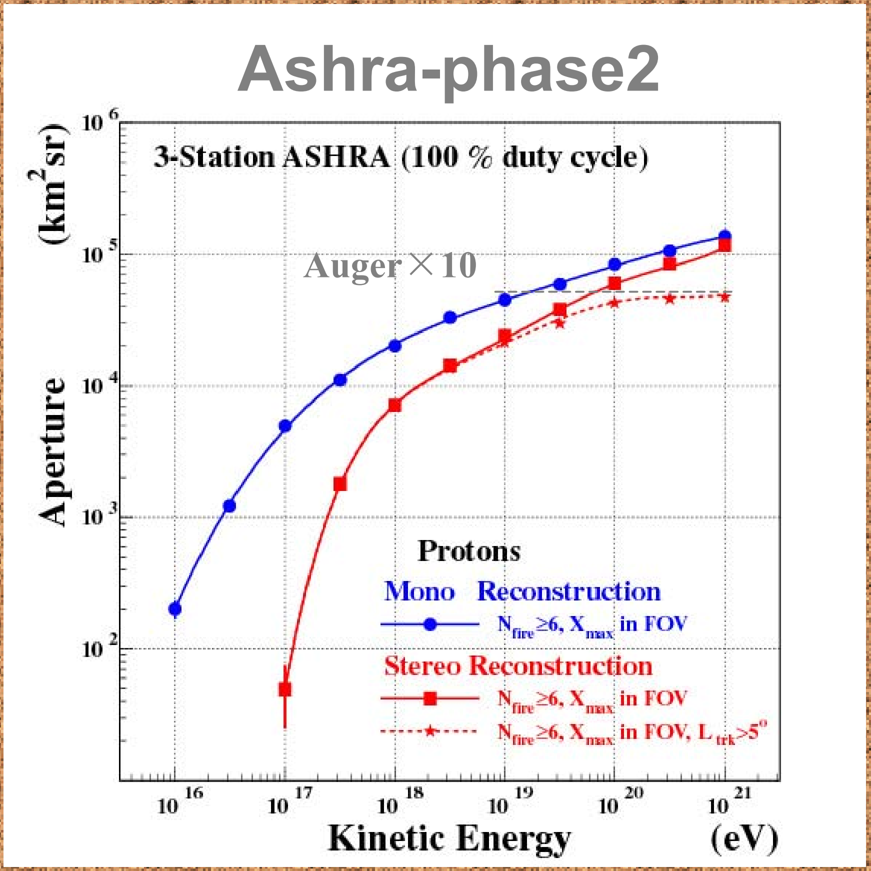
	RAPTOR -A,B (wide)	Ashra -P1/3	Ashra -P2/3
FOV (sr)	0.36	0.21	0.48
Light gathering area (cm^2)	57	318	990
Resolution (arcmin)	0.57	0.6	1.0
Wavelength band	R	U	U
Limit magnitude / exposure	12 / 30sec	14.5 / 1sec	15 / 1sec
Start	2002.10	2004.9	2004.12

Even Ashra Prototype Observation

=> Fairly Competitive

MC performance for UHECR



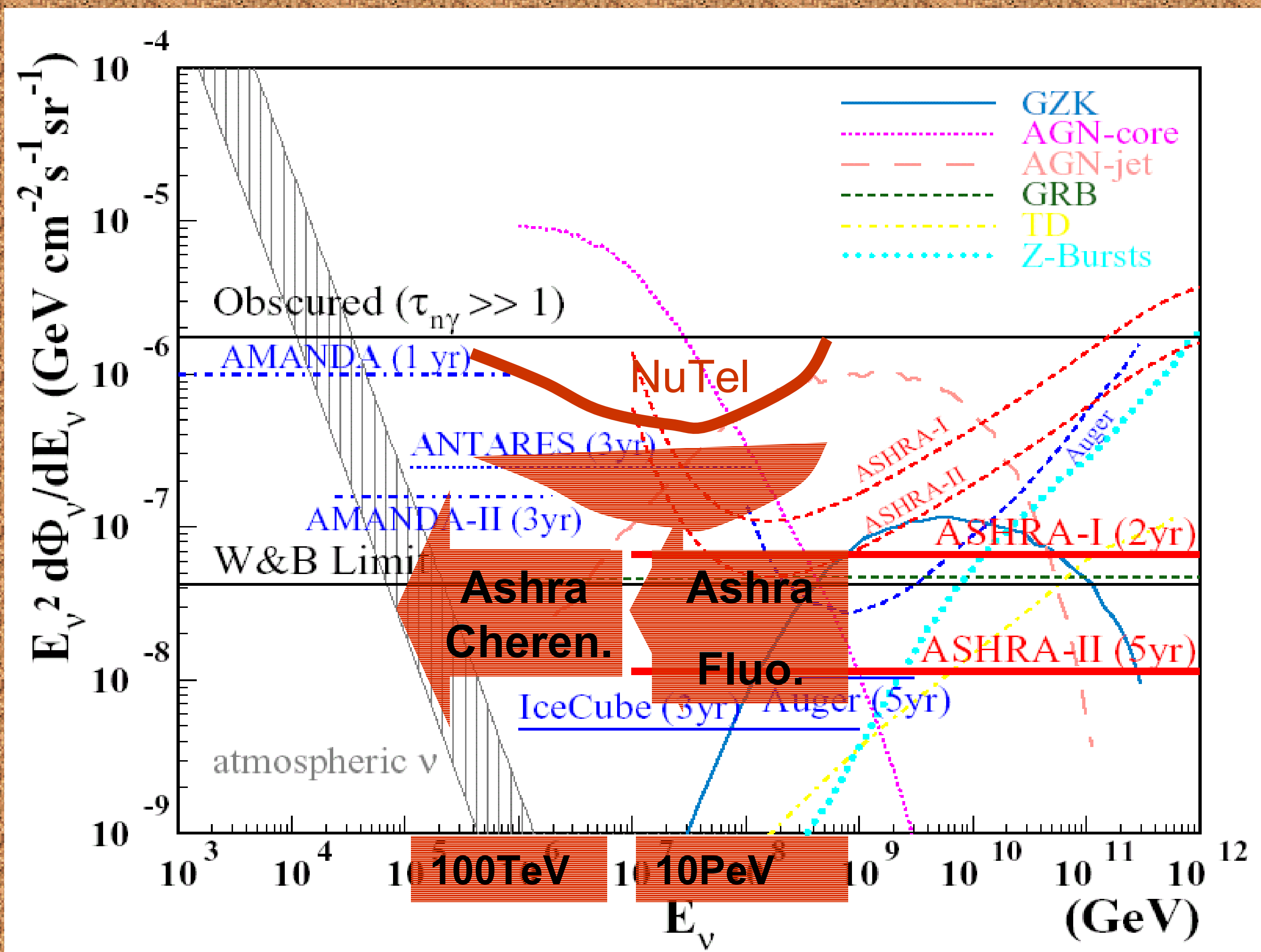


Stereo Event Rate (duty10%)

Threshold	Events/yr
10^{19}eV	1324
$10^{19.5}$eV	259
10^{20}eV	34

Neutrino Sensitivity

- 1 event/year/decade of energy (curve)
- 90% upper limit assuming E^{-2} flux (horizontal line)



Ashra

Cherenkov + Fluo.

Ashra should yield the best sensitivity in whole range E>100TeV

Great Chance of the first detection VHE Neutrinos

ASHRA Summary

Fusion of Astronomy & Particle Physics.

Wide FOV Fine Optics + Photoelectric Image Pipeline =>

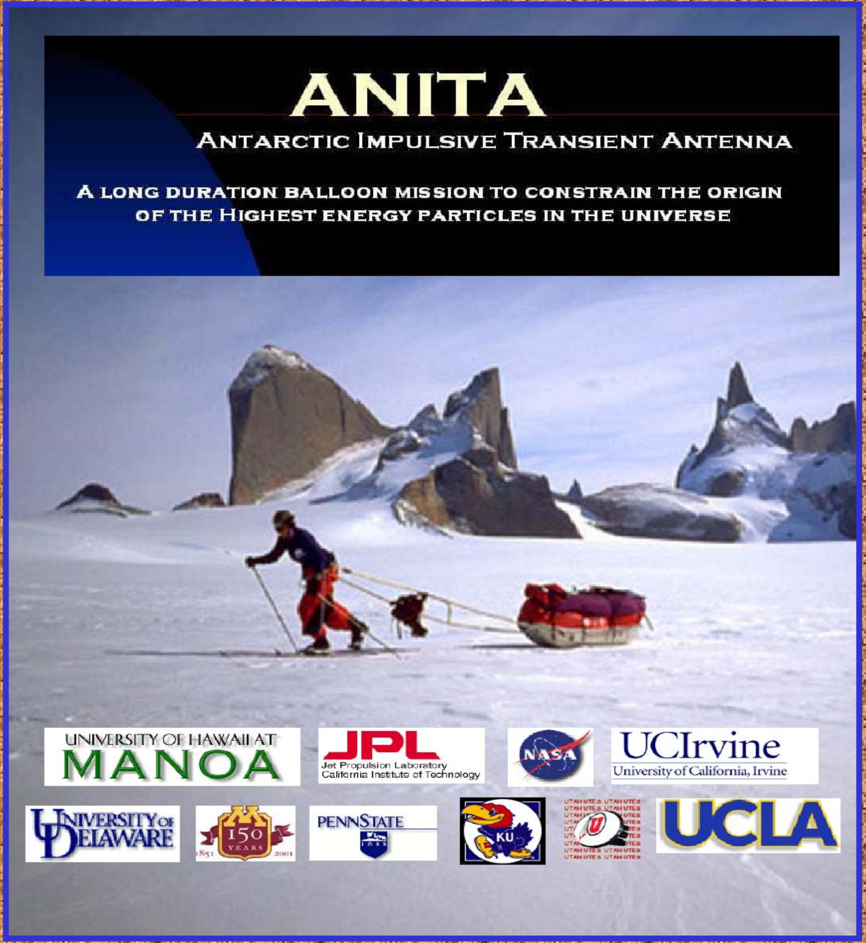
- All-sky coverage with 1arcmin resolution,
- Fluorescence detection compatible with simultaneous Cherenkov detection, and Optical GRB flash monitoring.

Steady Developments in Strong International Collab.

Superior Identification and Competitive Sensitivity.

Additional capability for Environmental Science.

ANITA:
Antarctic Impulsive Transient Antenna



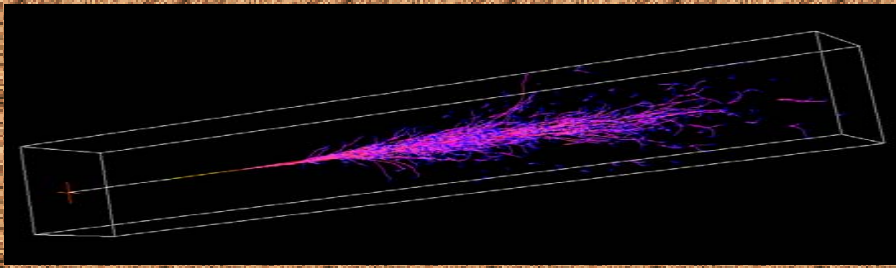
ANITA Collaboration:

S. Barwick, J. Beatty,
D. Besson, J. Clem, S. Coutu,
D. Cowen, M. DuVernois,
P. Gorham*, C. Hebert,
J. Learned, K. Liewer,
J. Link, S. Matsuno,
P. Miocinovic, J. Nam,
C. Naudet, D. Saltzberg,
D. Seckel, G. Varner

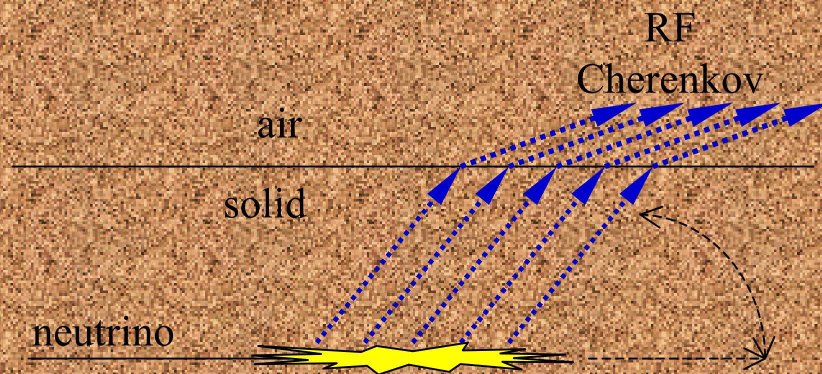
* Spokesman, U. Hawaii

Showers in solid media

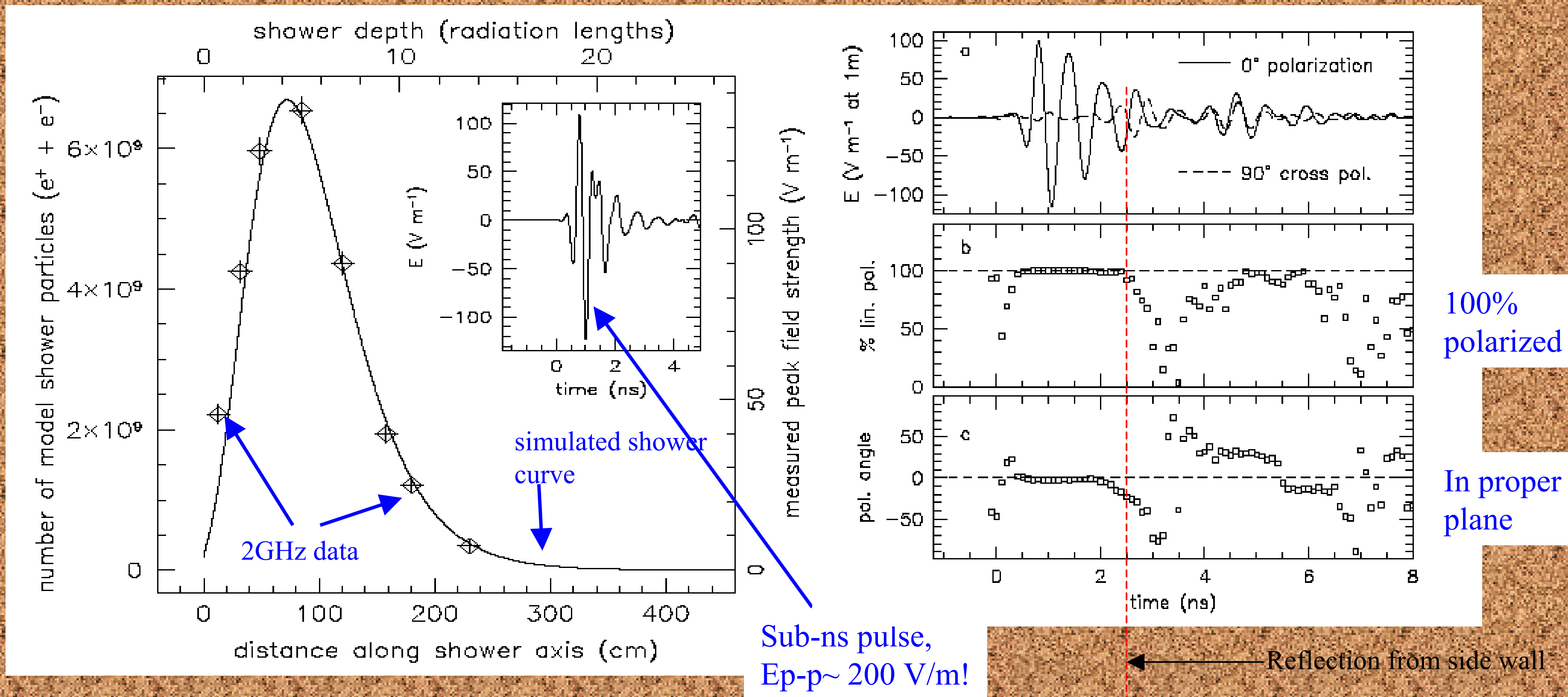
Simulation: in rock salt, 0.2-1GHz, 1EeV cascade



- Ice: n = 1.78,
  - $\cos^{-1}(1/n) = 53^{o}$
- Halite (rock salt): n=2.45,
  - $\cos^{-1}(1/n) = 66^{o}$
- RF Cherenkov cone: propagates through solid, refracts at interfaces



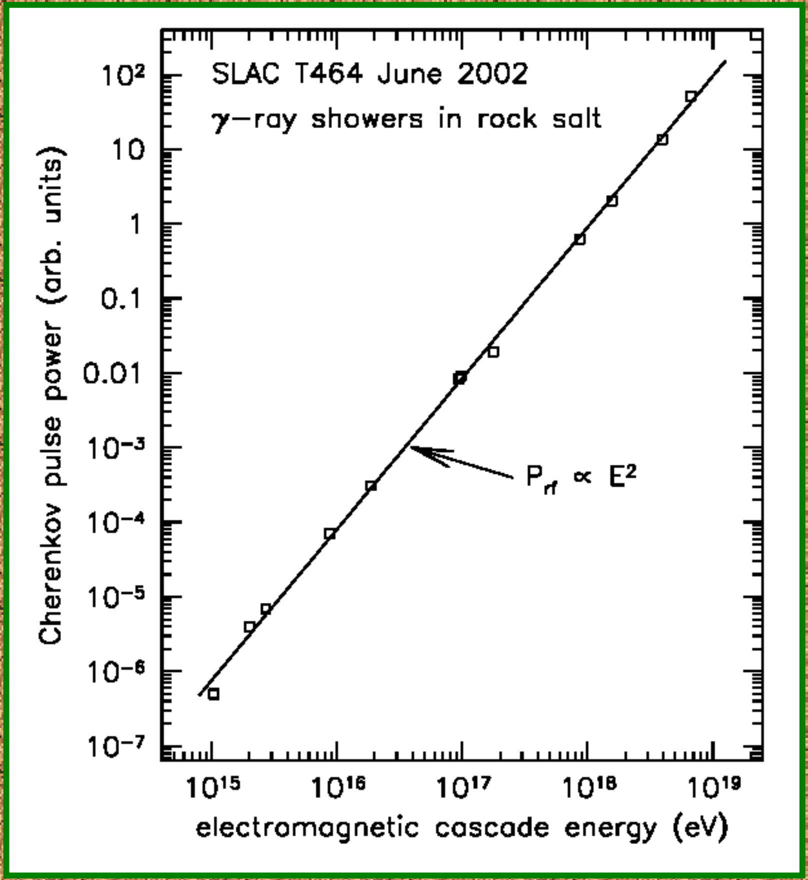
Shower profile observed by radio (~2GHz)



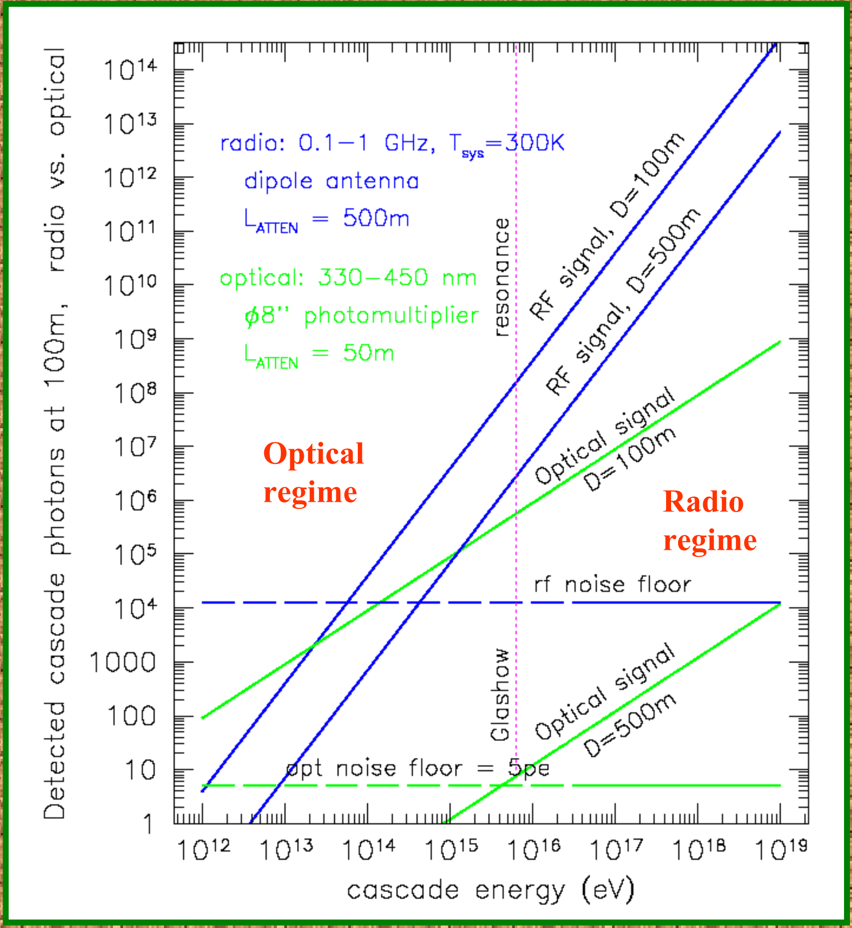
- Measured pulse field strengths follow shower profile very closely
- Charge excess also closely correlated to shower profile (EGS simulation)
- Polarization completely consistent with Cherenkov—can track particle source

Askaryan process: where does it win?

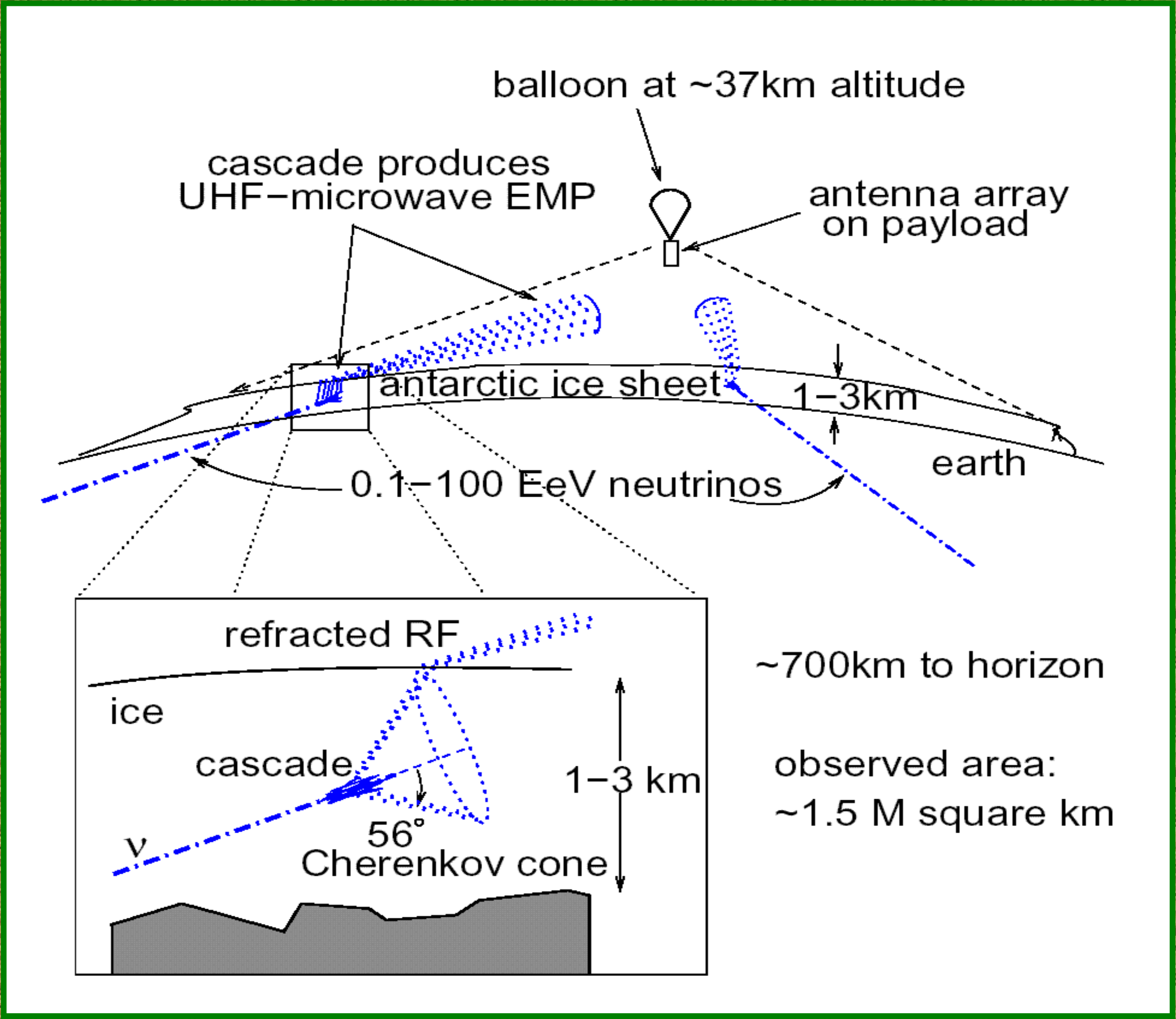
Huge dynamic range, linearity



SNR dominant at E >10 PeV



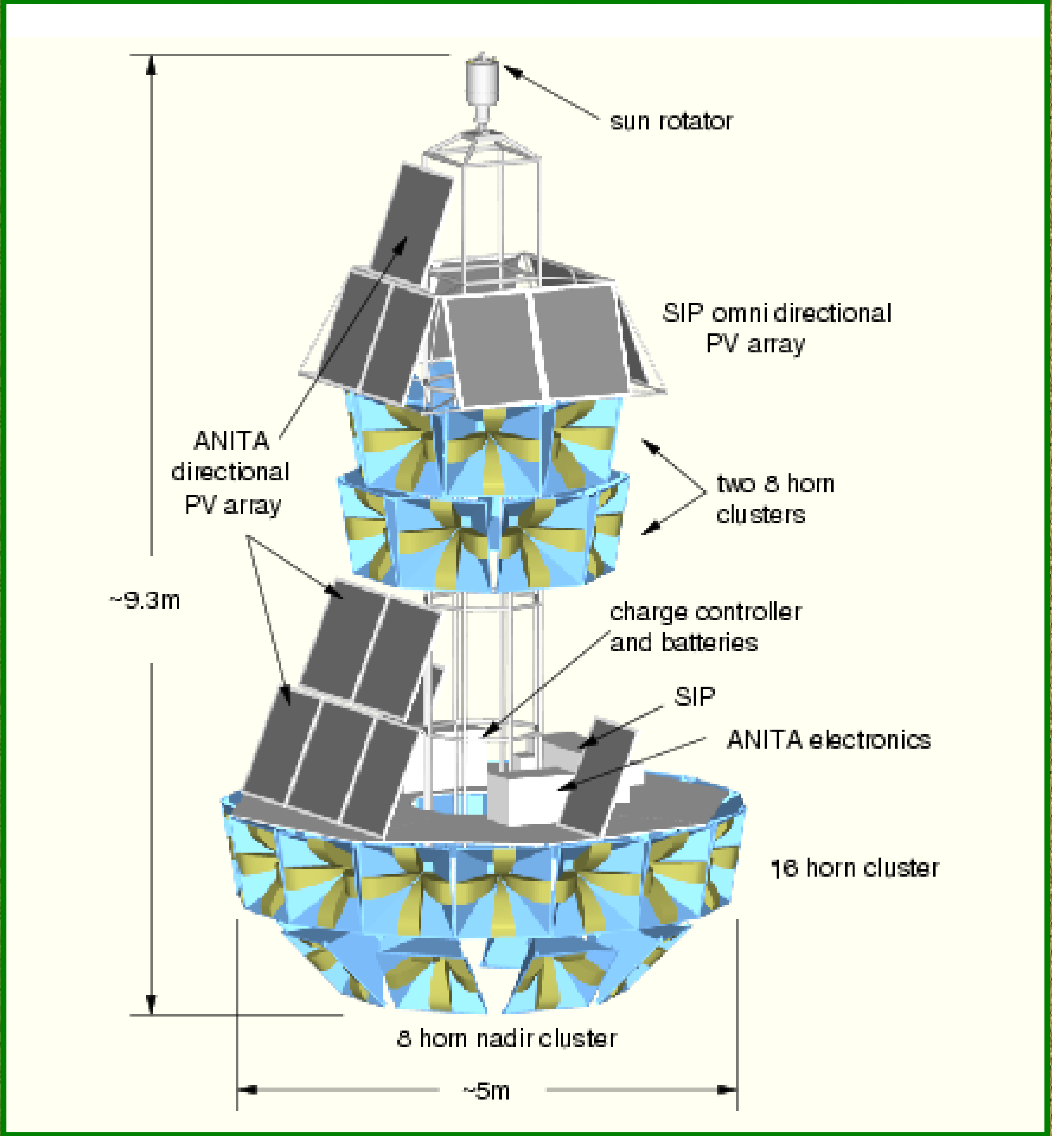
ANITA concept



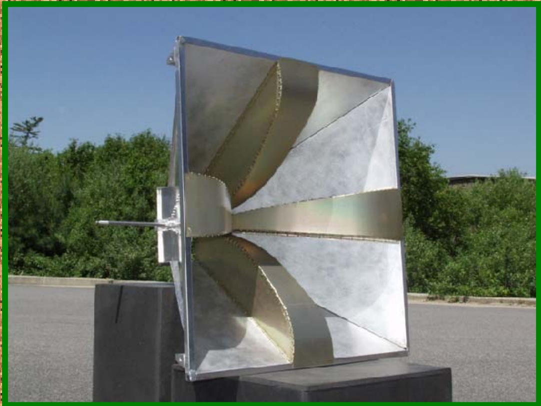
Antarctic Ice at f<1GHz, T<-30C :

- **Nearly Lossless RF transmission**
- **Negligible scattering**
- **largest homogenous, RF-transmissive solid mass in the world**

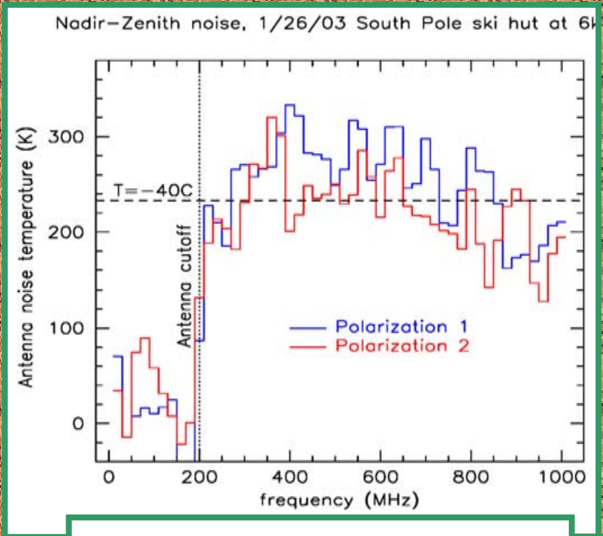
ANITA Payload



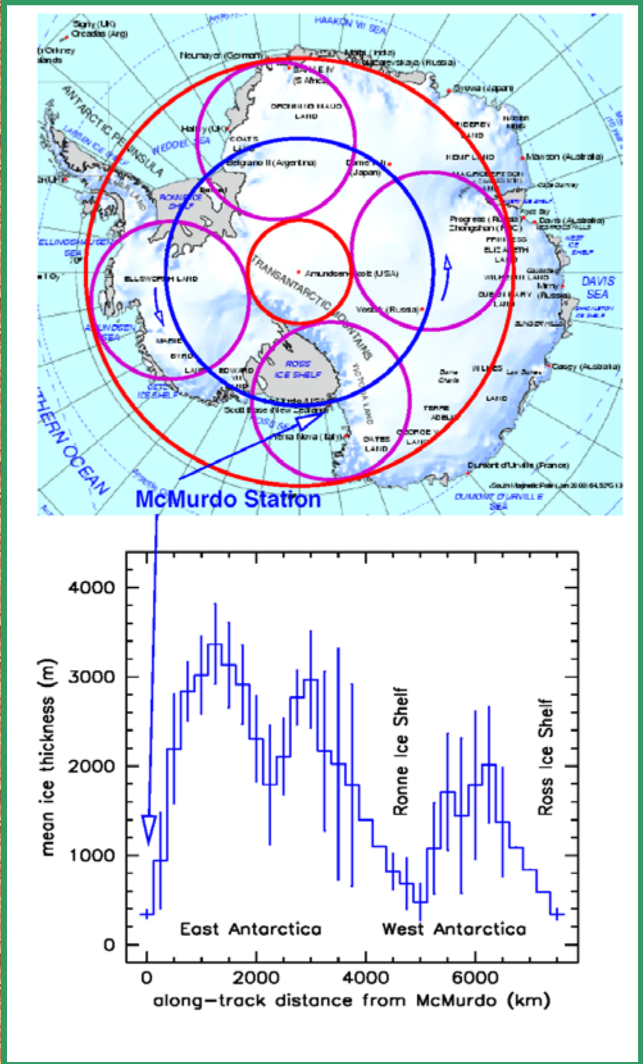
- ANITA antennas view ~2pi sr with ~60 deg overlapping beams
- Beam intensity gradiometry, interferometry, polarimetry used to determine pulse direction & thus original neutrino track orientation

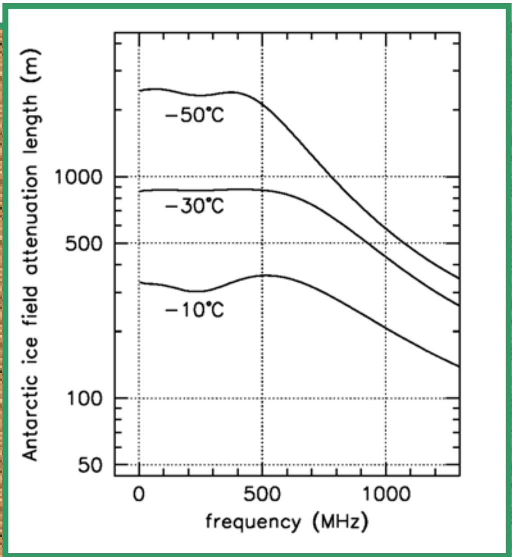


Antarctic ice temperature, transparency, topography



Radarsat SAR image

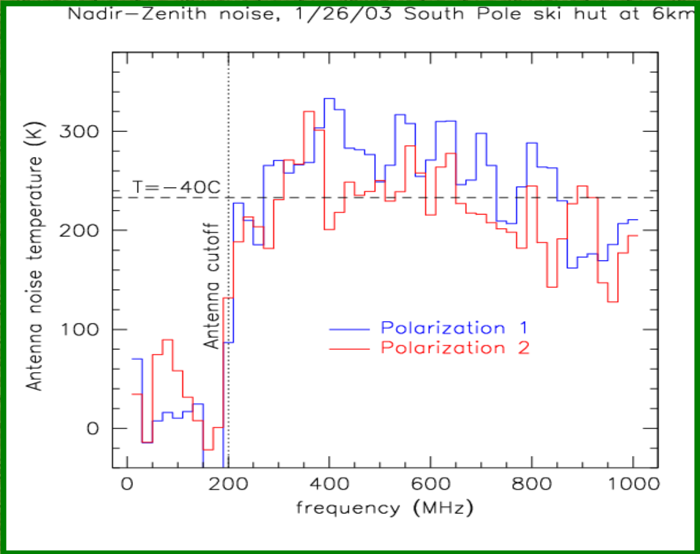


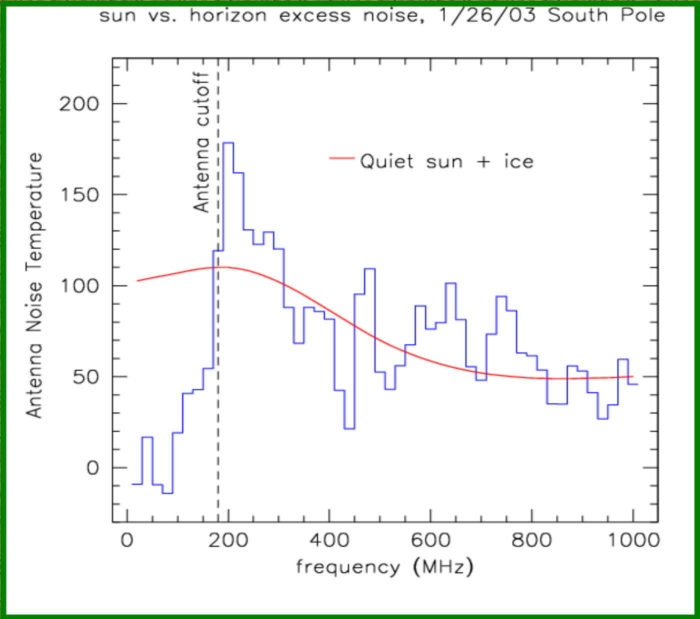


- RF background spectrum: Ice at -40C
- RF Transparency at this T: 1000m or more E-field attenuation length

But ANITA is not the first to try this…

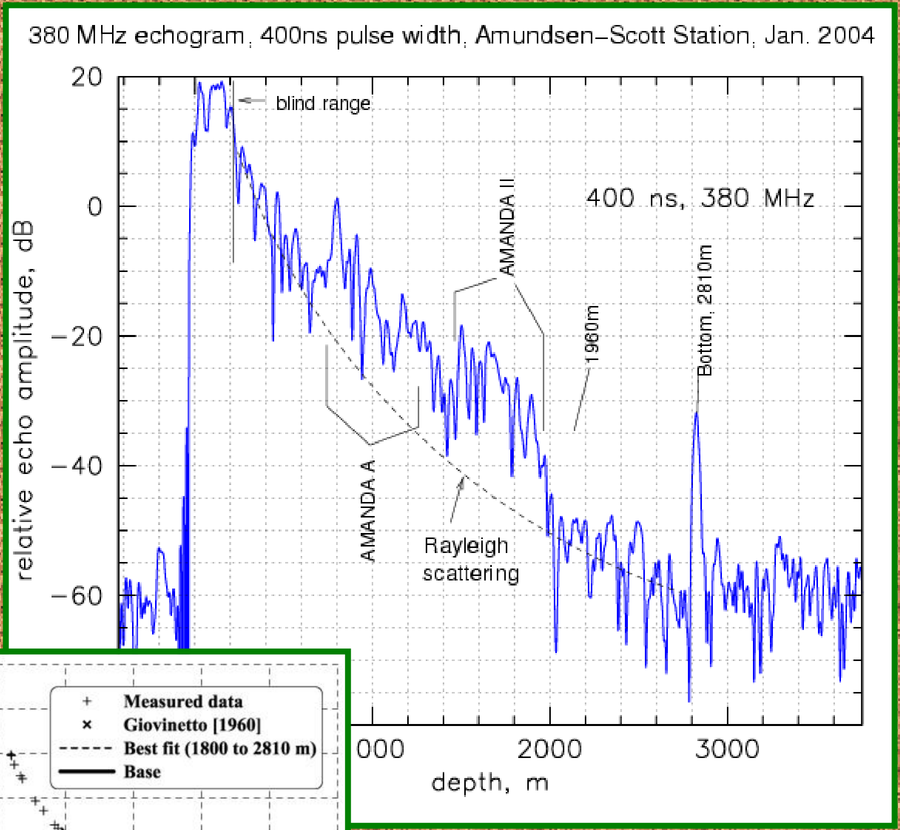
2003 Ground –Based measurements at South Pole

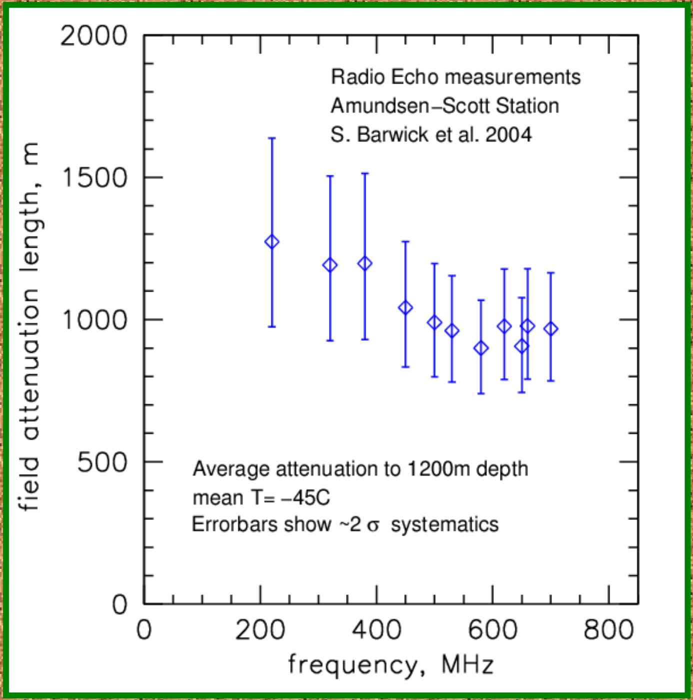


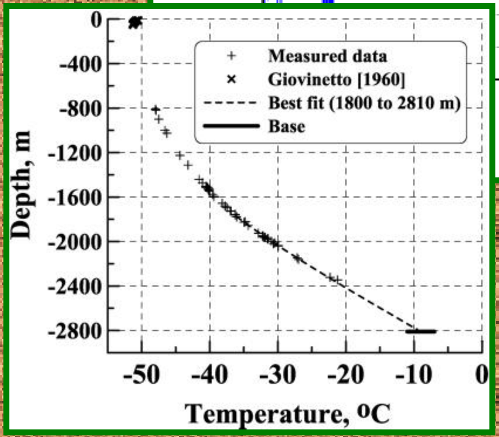


- Made at ~6 km distance from pole at "ski hut" location.
- <u>Thermal noise dominant</u> =lowest possible noise floor
- Station noise not an issue, no significant background seen at 6km.
- <u>So far so good—now we need a survey at altitude.</u>

ANITA Ice transparency measurements



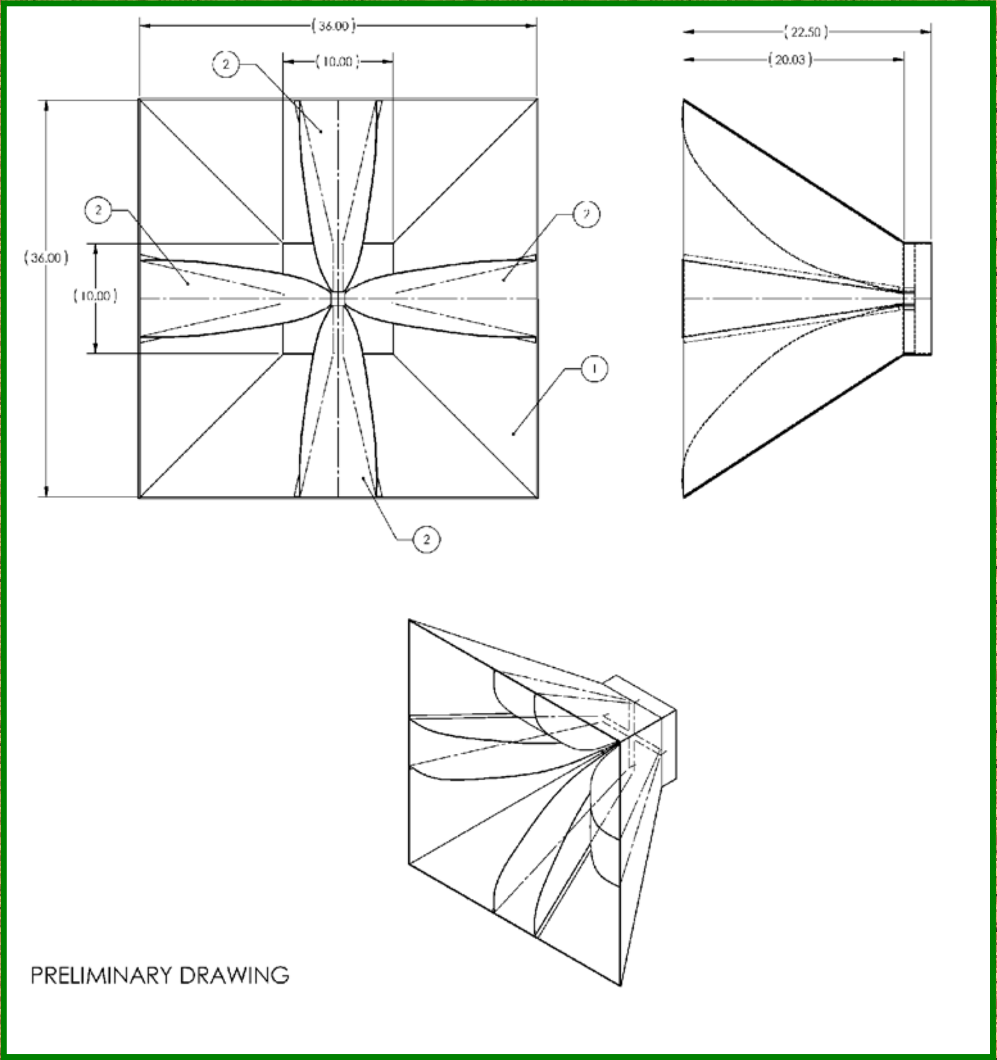




Conservative estimates for ANITA's frequency range:

> 1km field attenuation length!

ANITA-lite antennas & RF system

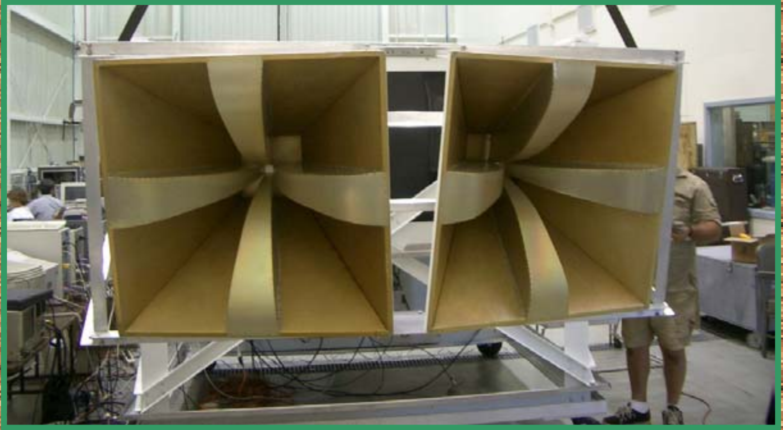


Quad-ridged horn:

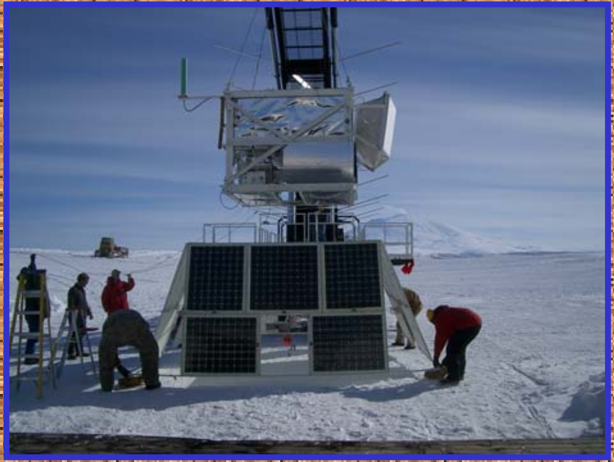
- Custom design by Seavey antenna
- 36" mouth, 22" deep

- covers range from 0.23 to >1.2 GHz with excellent phase & gain

- thinwall Al 6061-T6 construction



Preparing to Launch ANITA-Lite (piggyback with TIGER)



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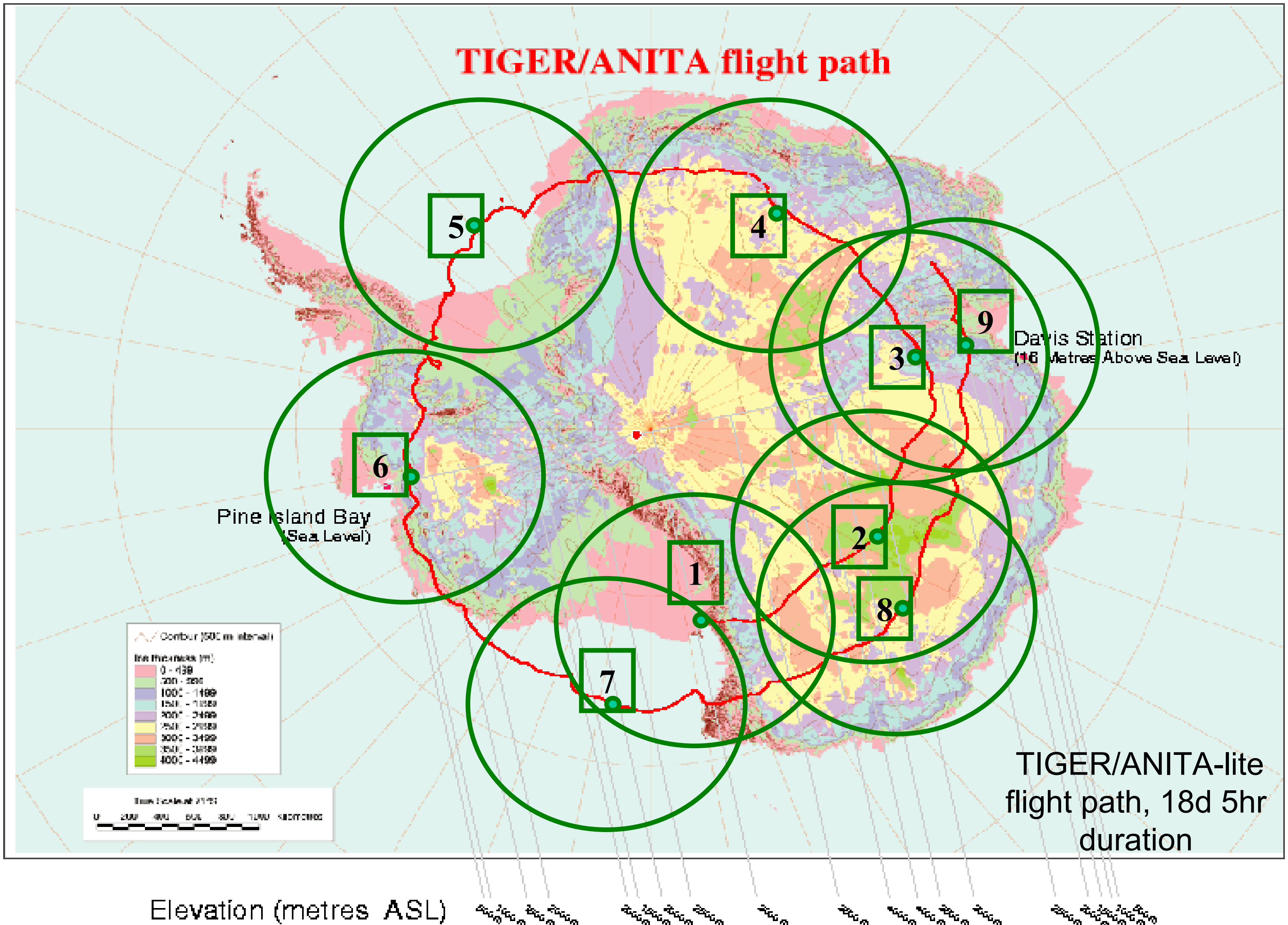
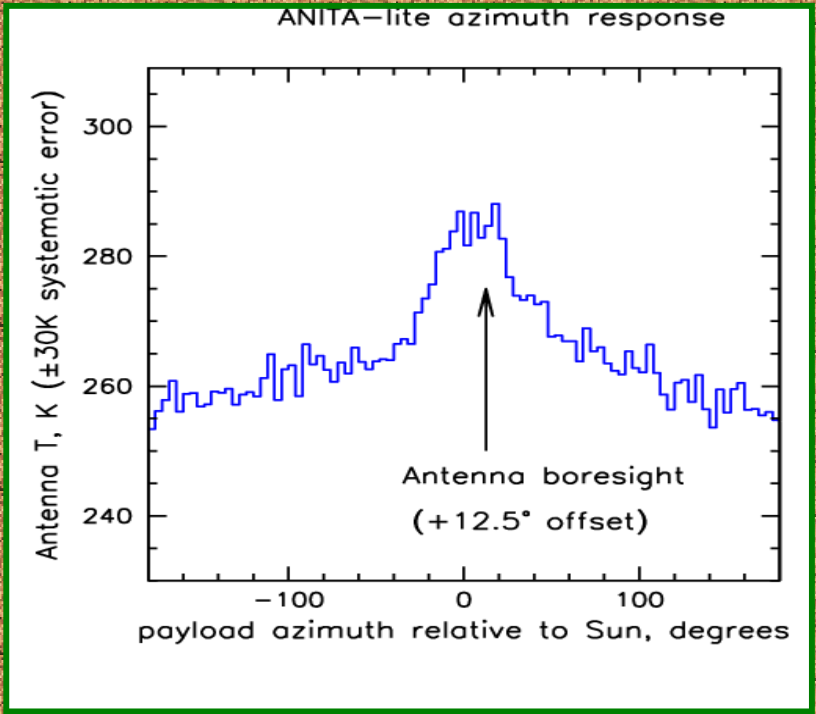
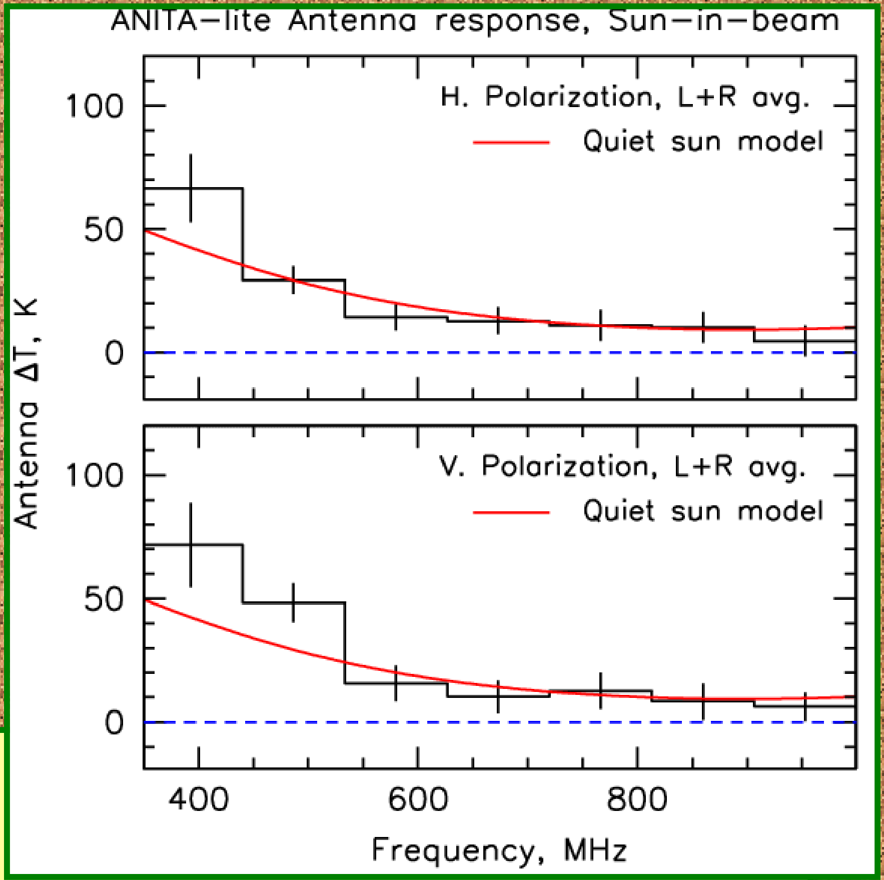
ANITA-lite fields of view



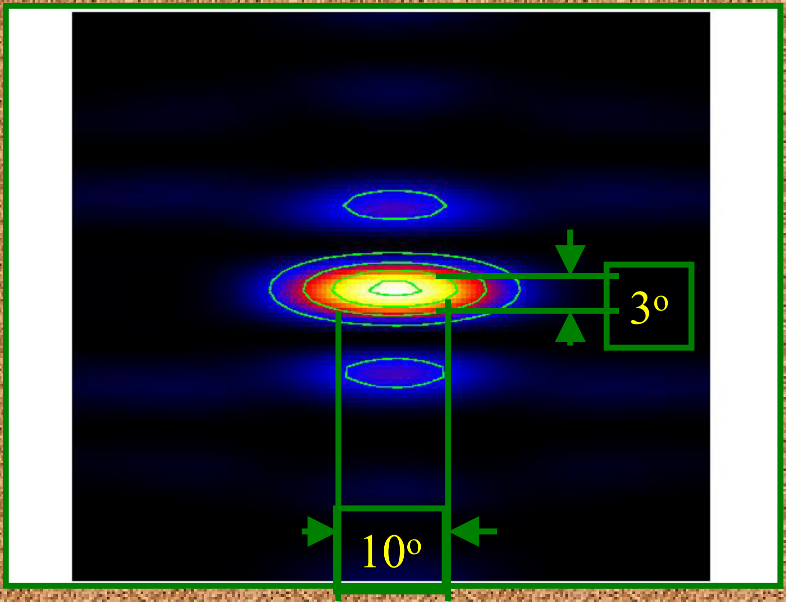
Initial results from ANITA-lite

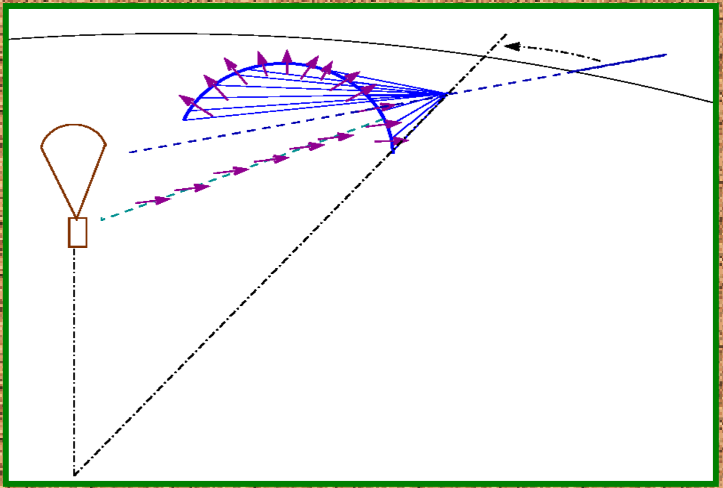




- Antarctic Thermal noise measurements
  - ANITA-lite antenna beams: ~π sr each
  - measured broadband UHF noise
- Data consistent with galactic+solar+kT_{ice}
  - Solar contribution clearly seen (above)
  - Antarctica still among the quietest places on earth in radio frequencies
  - Results crucial to ANITA progress!

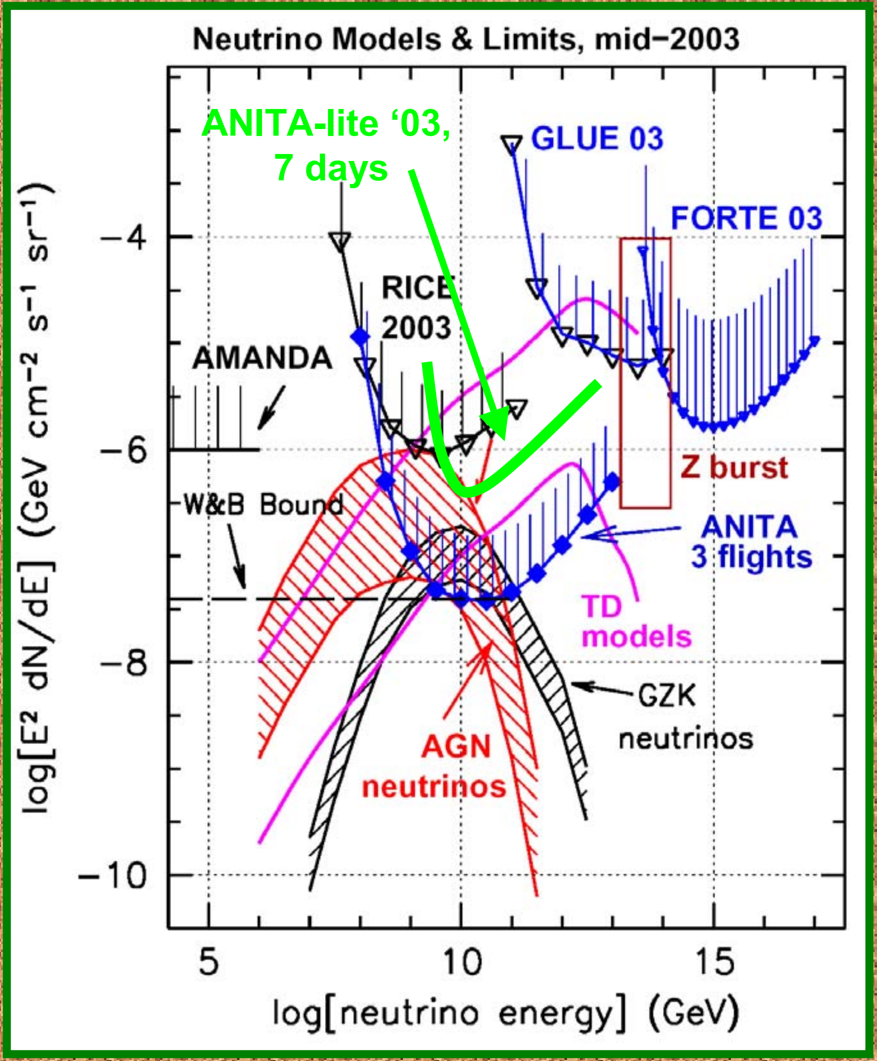
ANITA as a neutrino telescope





- Pulse-phase interferometer (6 antennas assumed) gives intrinsic beamsize of ~3° elevation by ~10° azimuth for arrival direction of radio pulse
- Improves by ~factor of 2 with better pulse timing, beam calibration
- Neutrino direction constrained to ~1-2° in elevation by earth absorption, and by 3-5° in azimuth by polarization angle

Existing Neutrino Limits and Potential Future Sensitivity



- RICE limits for 3500 hours livetime
- GLUE limits ~120 hours livetime
- FORTE (N Lehtinen, UH) limits on ~3 days of satellite observations of Greenland ice sheet
- **ANITA sensitivity:**
  - ν_μ & ν_e included, full-mixing parameterized
  - 1.5-2 orders of magnitude gain
- These are all limits based on radio detection!

ANITA Summary

Radio detection: The most cost-effective way to do PeV (10^{15} eV) to ZeV (10^{21} eV) astronomy.

UHE neutrino models already constrained by existing detectors.

ANITA-lite 2003: most sensitive EeV to date!?

ANITA 2006: the GZK factory!!

Grand Summary

- New Techniques for detecting the highest energy neutrinos are being developed and actively tested.
- ANITA, ASHRA, and other new methods not discussed (acoustic, radio, particularly in salt domes) hold much promise within this decade to see the first cosmic neutrinos.