ULDB (NASA)

The ExaVolt Antenna (EVA): Concept and Development

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GZK Process and Sources

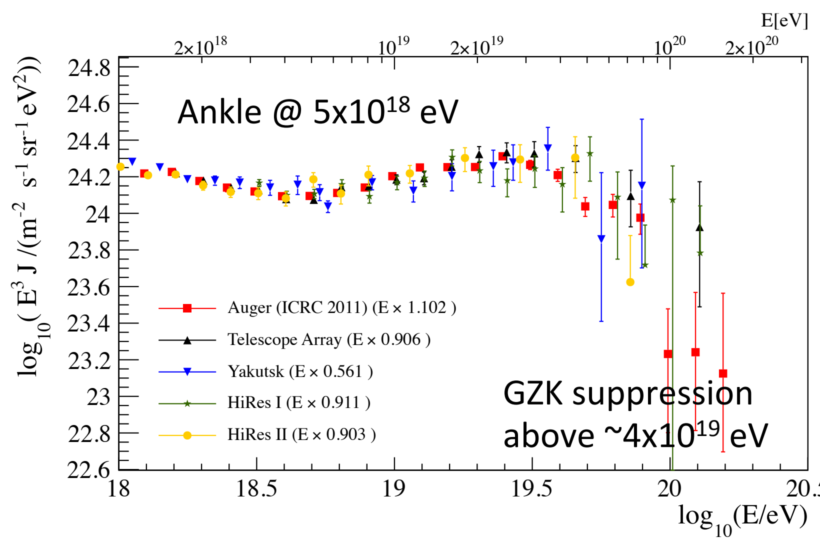
- Greisen-Zatsepin-Kuzmin (GZK): Cosmic rays with E > $10^{19.5}$ eV interact with cosmic microwave background (CMB) photons
- Process produces BZ neutrinos, some at ultrahigh energies (UHE)
- Neutrinos happily continue on
- UHE neutrinos could also be produced at a source location
  - If observed, will trace back to source
- Low x at Earth
  - Less than 1/km^3/year/energy decade
  - Need large volume detectors

$$\mathbf{p} + \gamma_{\mathrm{CMB}} \rightarrow \mathbf{\Delta}^{*} \rightarrow \mathbf{n} + \pi^{+}$$

$$\mathbf{n} \rightarrow \mathbf{p} + \mathbf{e}^{-} + \bar{\nu}_{\mathbf{e}}$$

$$\pi^{+} \rightarrow \mu^{+} \nu_{\mu}$$

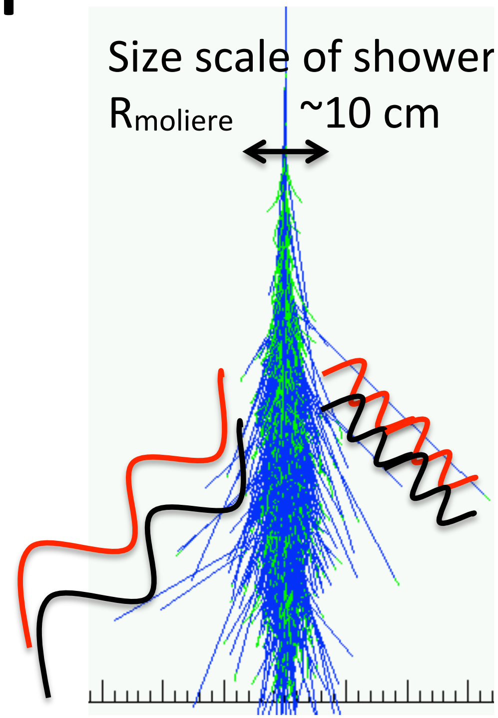
$$\mu^{+} \rightarrow \mathbf{e}^{+} \bar{\nu}_{\mu} \nu_{\mathbf{e}}$$



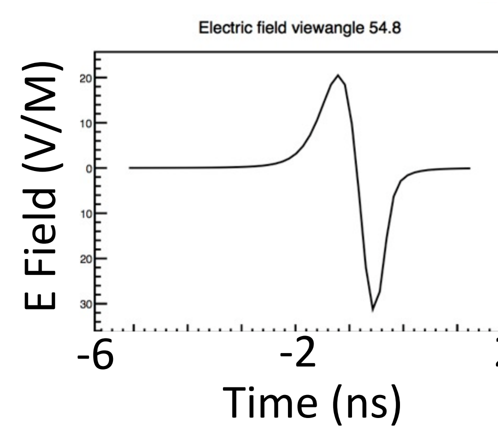
Proceedings of UHECR 2012

Detection technique

- How to get large-scale detection -
  - Brute force: make 100X IceCube
  - Use a different approach – radio Cherenkov technique
- Coherent Cherenkov signal from net "current," instead of from individual tracks
  - In dense medium, a ~20% charge asymmetry develops in the shower (positrons annihilated, electrons not)
  - If $\lambda \gg R_{Moliere}$ (radial size scale) → Coherent Emission
  - Hypothesized by Gurgen Askaryan, 1962
  - Effect observed in ice, water, salt
  - Impulsive bipolar signal
- Long (~1 km) attenuation lengths in 0.1-1 GHz → large observable volume



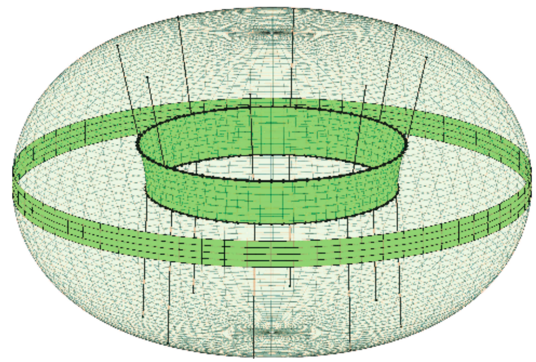
Particle shower



Synoptic Detectors

A neutrino induced cascade

ANITA-II

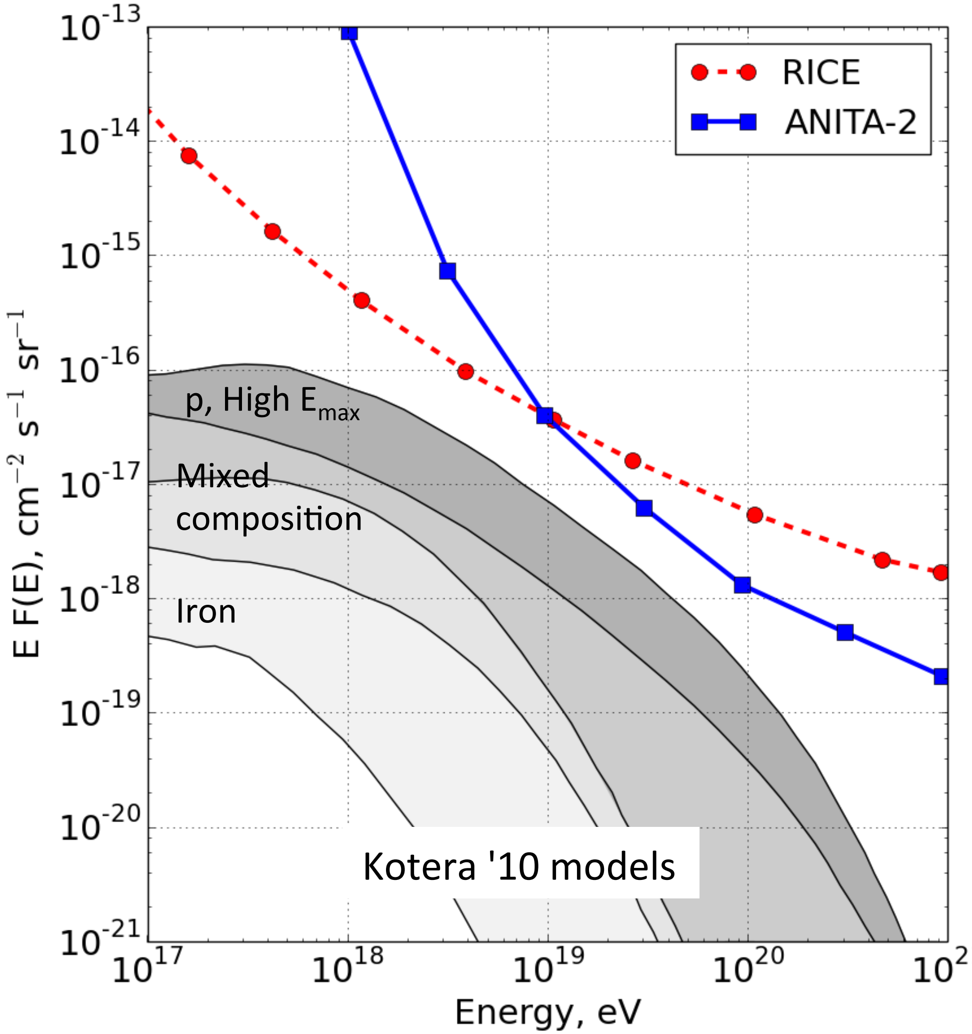


EVA

- Synoptic – balloons, satellites
  - ANITA, EVA, PRIDE
- Large target volume - O(10^6 km^3)
- Good as a "discovery" instrument for highest energies (>10^{20} eV)

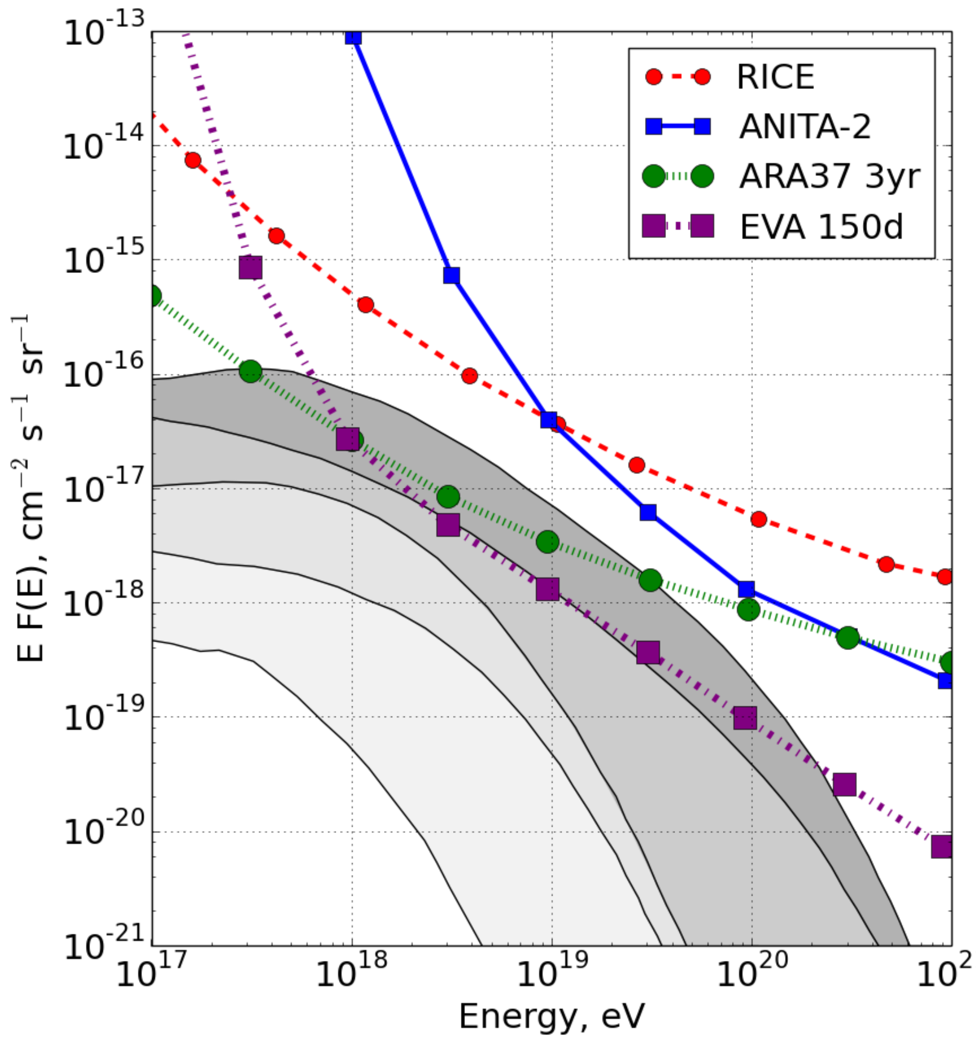
In-ice vs. Balloons

- In-ice antennas:
  - lower energy threshold.
  - Reduced visible volume.
- Balloon-borne antennas:
  - Higher energy threshold.
  - Increased visible volume.



In-ice vs. Balloons

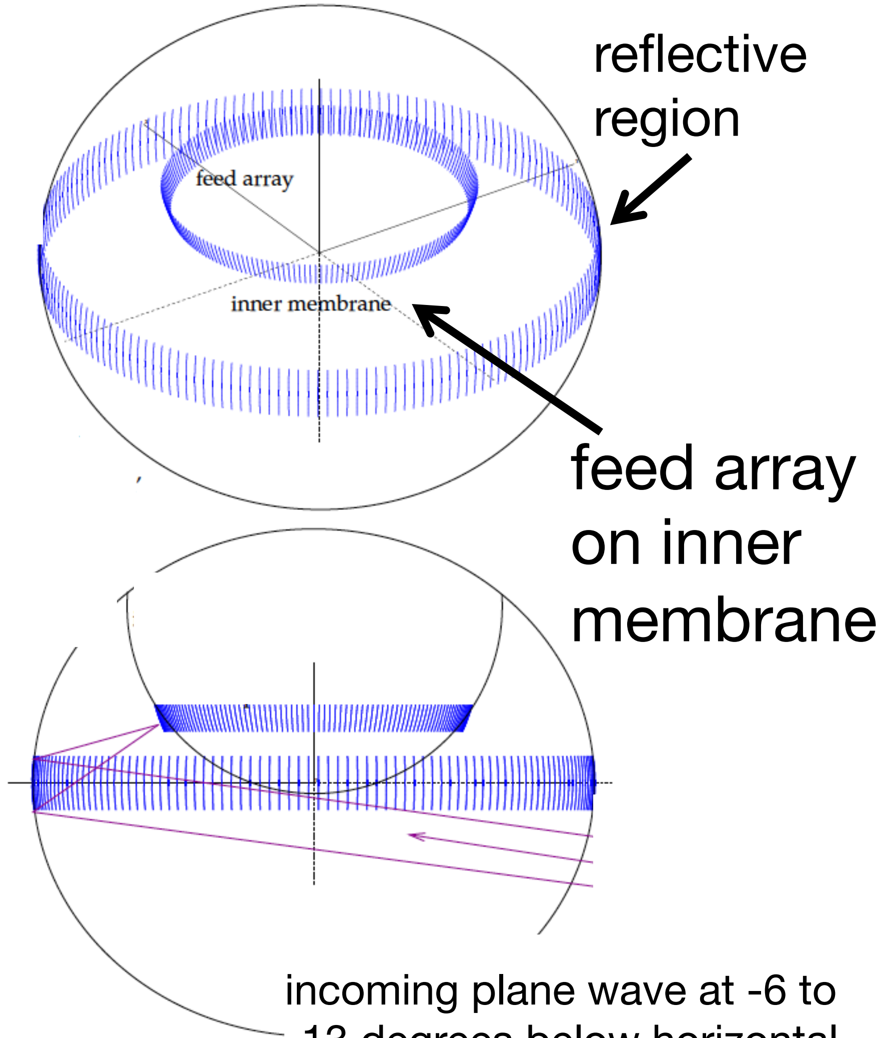
- ARA37:
  - Large number of stations increase the visible volume.
- EVA:
  - High gain antenna reduces the energy threshold while increasing visible volume.
  - EVA antenna gain is 32 dBi compared to 10 dBi for ANITA. This is a factor of 160 improvement.



ExaVolt Antenna (EVA) concept

- Use balloon surface as a part of the detector
  - Focus signal to interior
- Would be the world's largest aperture airborne telescope
  - 1000's of square meters
  - 150-600 MHz (λ_{air}≈0.5-2 m)
- Increase in sensitivity to radio frequency neutrino impulses by factor of 100 over any previous experiment

Recently completed a 3 year feasibility study funded by NASA

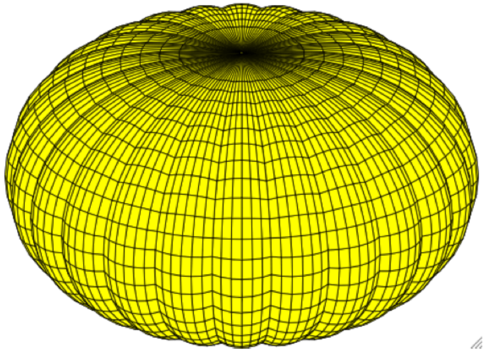


P. W. Gorham et al., arxiv:1102.3883

ZPB vs SPB - Flight Consistency

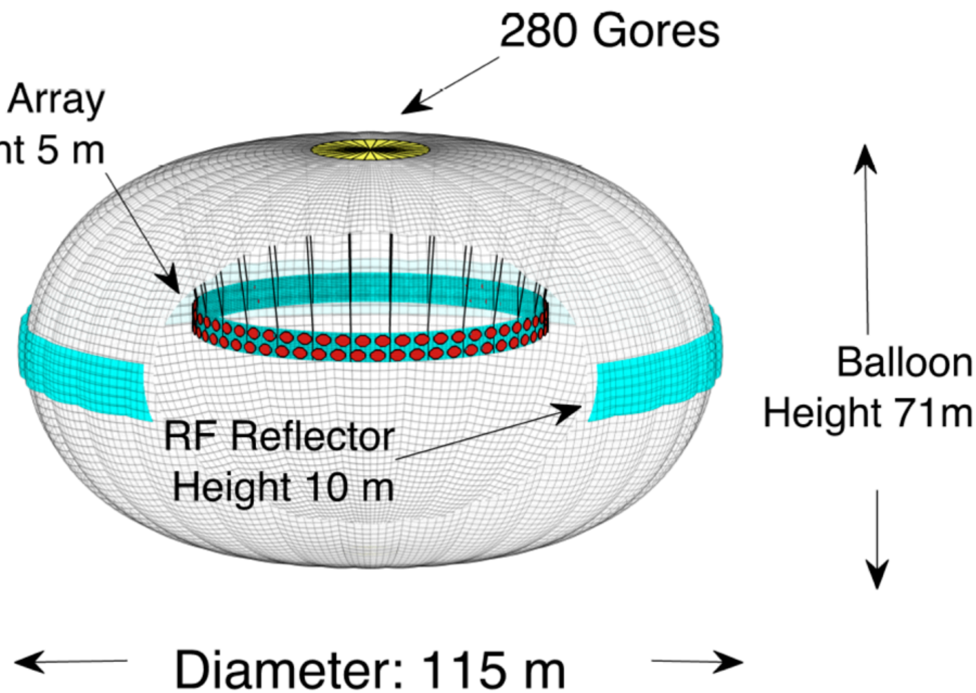
- Zero pressure balloons (ZPB) – e.g. ANITA
  - Balloon pressure at equilibrium with ambient pressure at float altitude
  - Shape can change dramatically
    - ANITA: 40% drop in volume
- Super pressure balloons (SPB)
  - Balloon pressure higher than outside pressure
  - Stability due to lobed structure
  - NASA test flights
    - 591NT – Dec. 2008, 54 days, 7 Mft^3, 1% change in height, diameter

Source: Raven Aerostar



EVA 1:20 scale model design

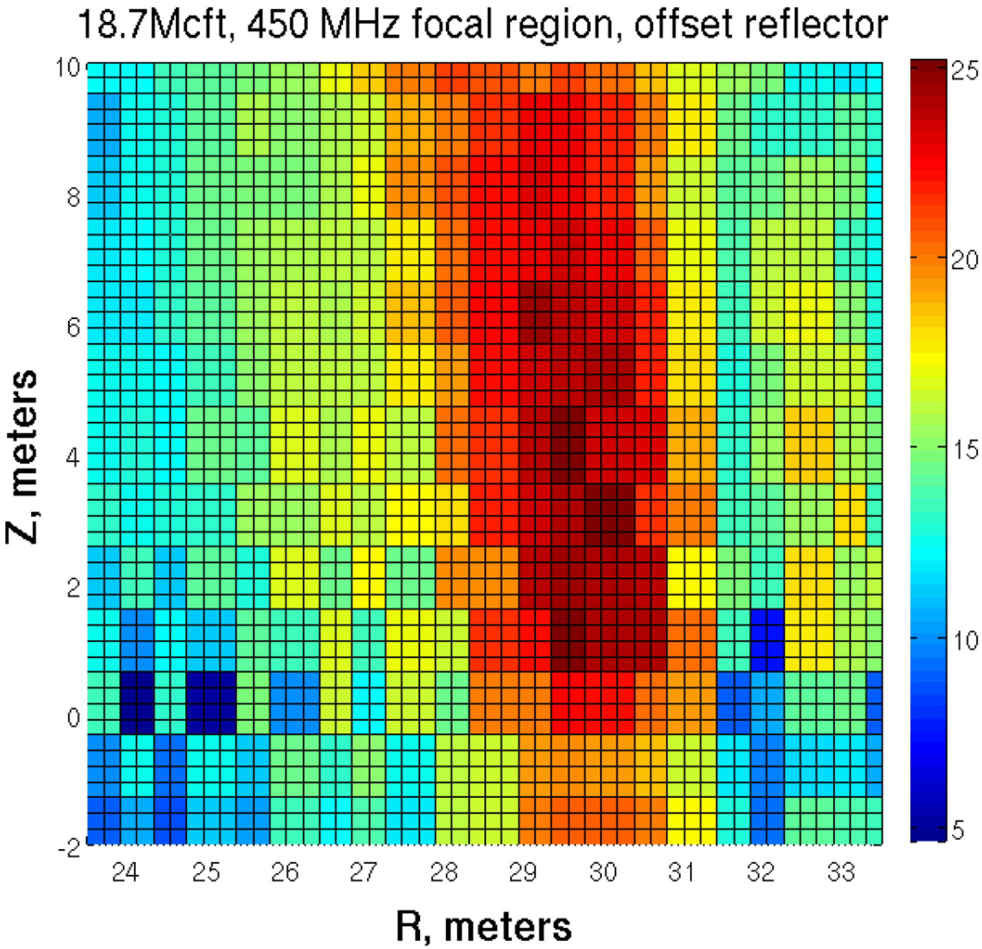
Current Design



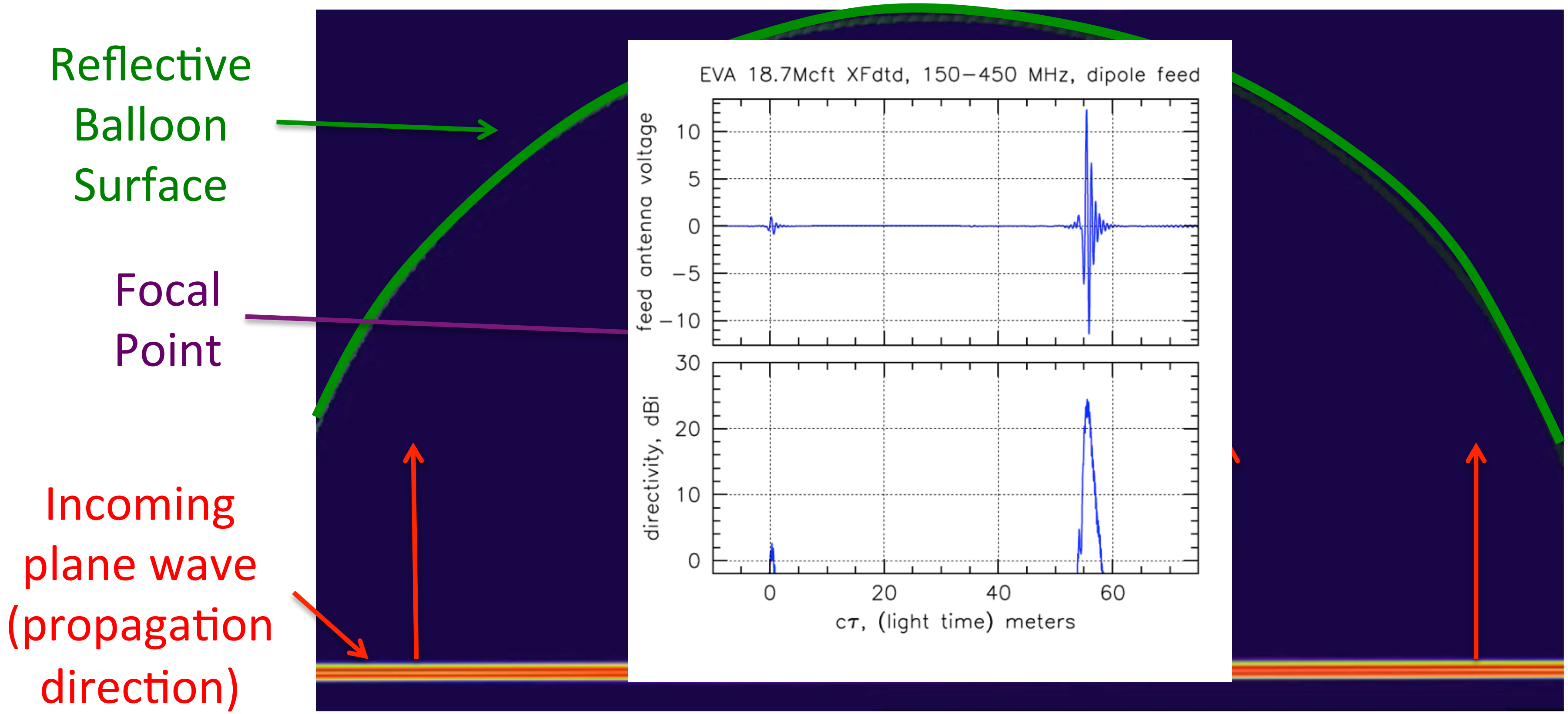
- SPB – 29 Mft^3, payload would contain DAQ, much of the electronics
- Feed array – separate Vpol and Hpol channels
  - Elevated with respect to the reflector for downward viewing
  - At least three feed antennas tall
  - ~2000 channels

Method of Moments Simulations with NEC

- Simulates the reflector using a wire mesh.
- Reflector is dipole fed.
- Optimization of feed position provides 25 dBi of gain.
- Likely an under-estimate due to sparseness of wire model reflector and it does not account for the non-dipole feed gain.



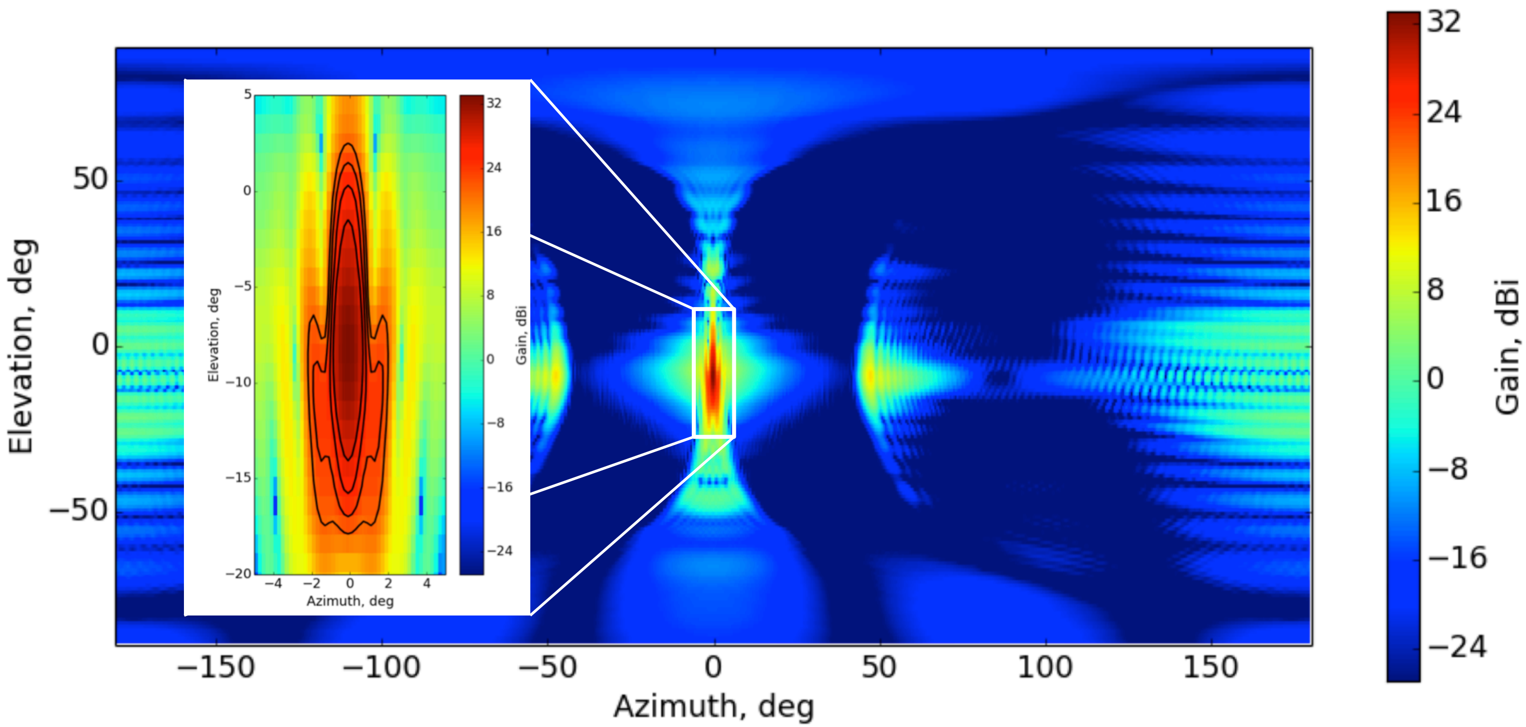
XFdtd Reflection Simulation



- FDTD discretizes a volume and applies Maxwell's equations on each cell.
- A plane wave illuminates the surface of the balloon and its reflection is propagated to find the focal point.
- A gain of 24 dBi is achieved at the focal point.

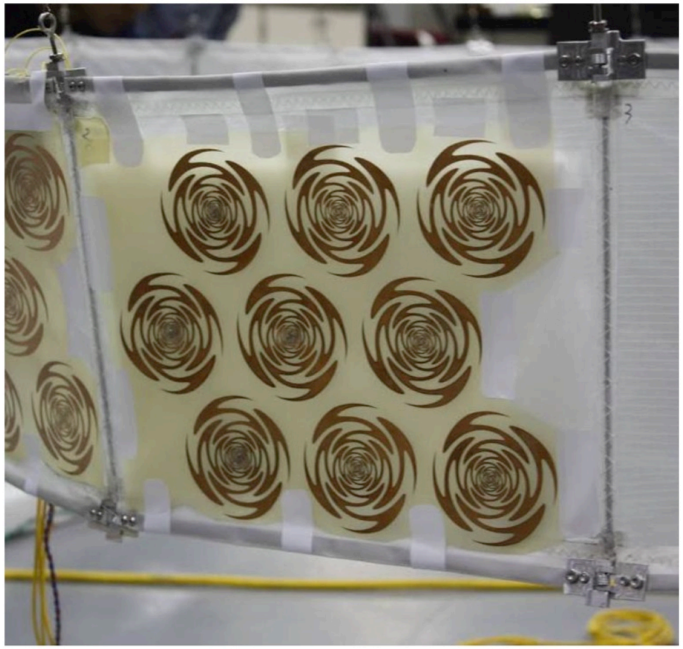
Simulations with GRASP

- GRASP is the tool of choice for reflector antenna designers.
  - Fast, flexible; not time domain
- Physical optics simulator fully accounts for the surface shape and the feed antenna gain pattern.
- Surface simulations using an optimized feed illumination pattern results in a peak of 32 dBi.



Hang Test at Wallops Flight Facility (Sept 2014)

1/20th scale model balloon.

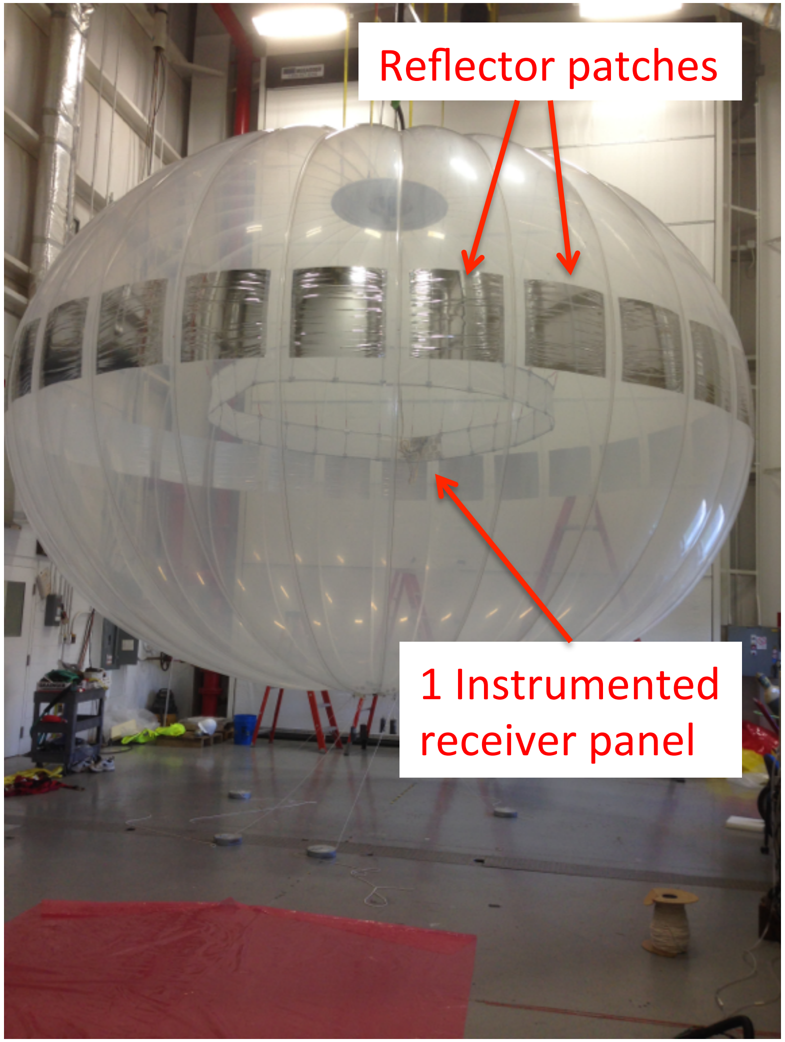


Dual-polarized sinuous antenna feeds.

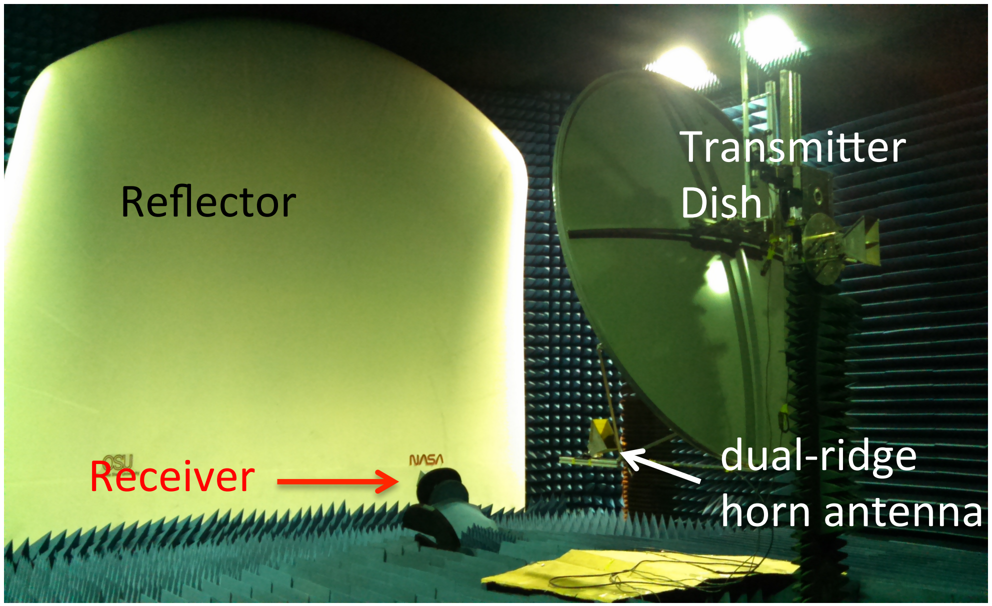
Balloon and feed system.

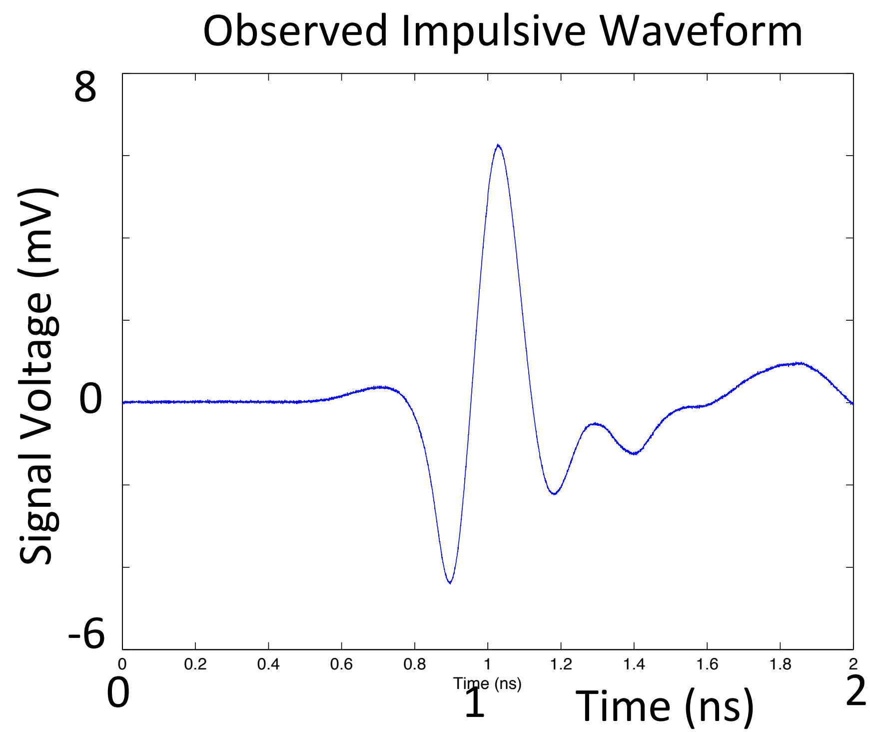
Scale Model Hang Test

- Suspended a 1:20 scale model balloon with limited instrumentation
- Notable differences from full-scale
  - Fewer lobes: 28 vs 280
  - Only 1 instrumented receiver panel
  - Reflectors = rectangular patches, not continuous strip
  - Transmitter smaller than full collecting area of reflectors



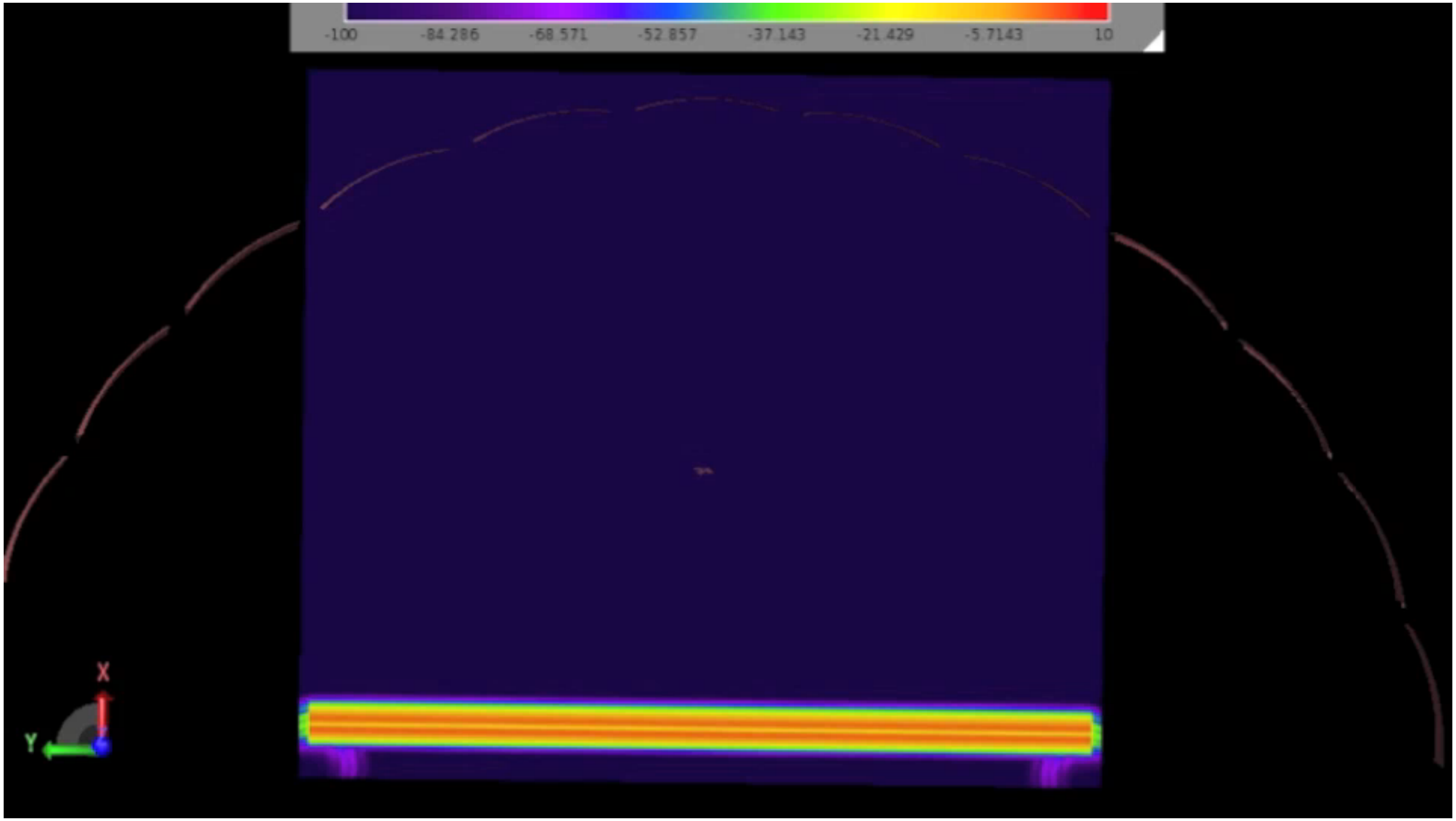
Transmitter/Pulser





- Assembled an impulsive signal transmitter with dish
  - Fast (1-5 GHz) pulser, dual-ridge horn antenna, 1.8m satellite dish
  - Tested and characterized using facilities at the OSU ElectroSciences Lab (ESL)

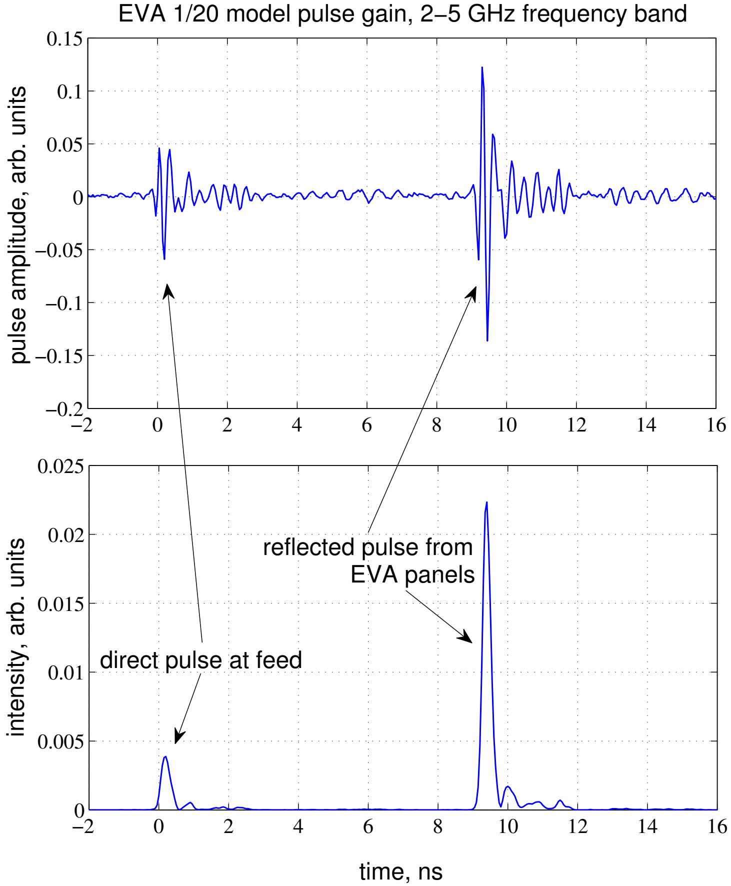
Hang Test Simulation



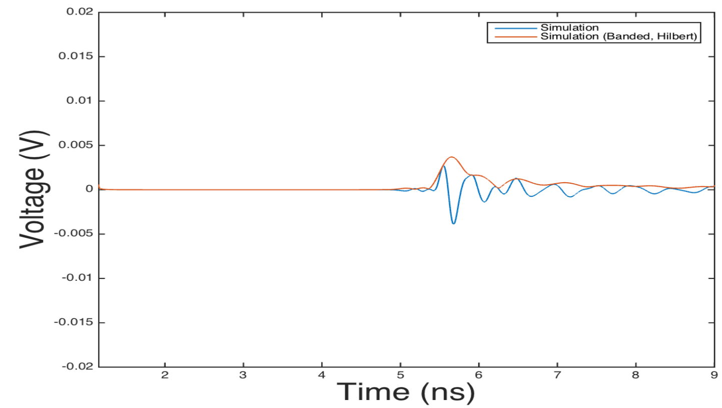
- Limited signal region, less focused reflections

Hang Test Results

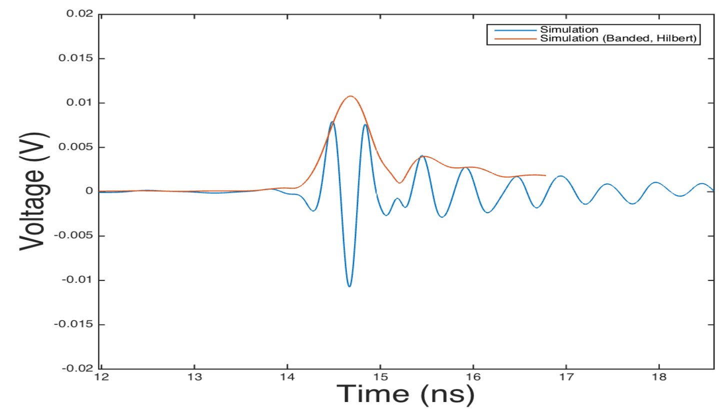
Hang Test Data



XFdtd Simulation Results



Direct pulse



Reflected pulse

- Data from scaled model test shows increased gain is achieved with pulse coherence is maintained upon reflection.
- The gain estimated from this measurements is ~11.4 dBi.
- GRASP simulations of the scaled model antenna predict 11.5 dBi while XF7 predicts 10.0 dBi.
- Results are consistent within ~2 dBi lending credibility to the EVA concept.

Expected EVA Results

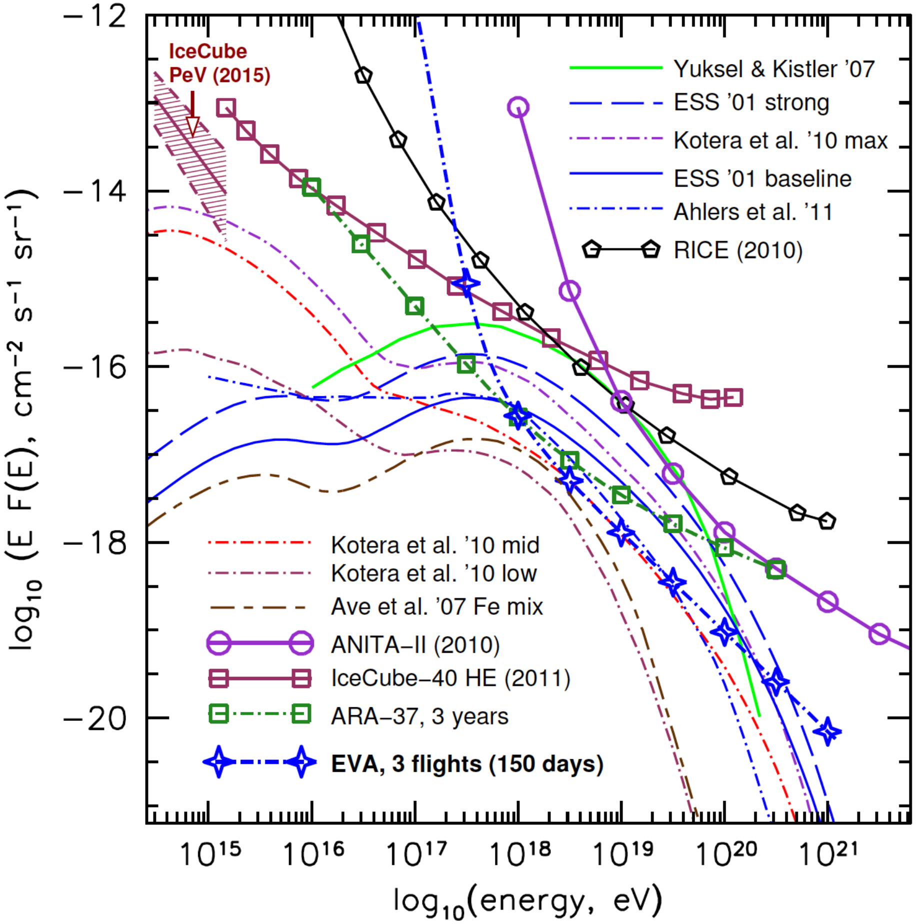


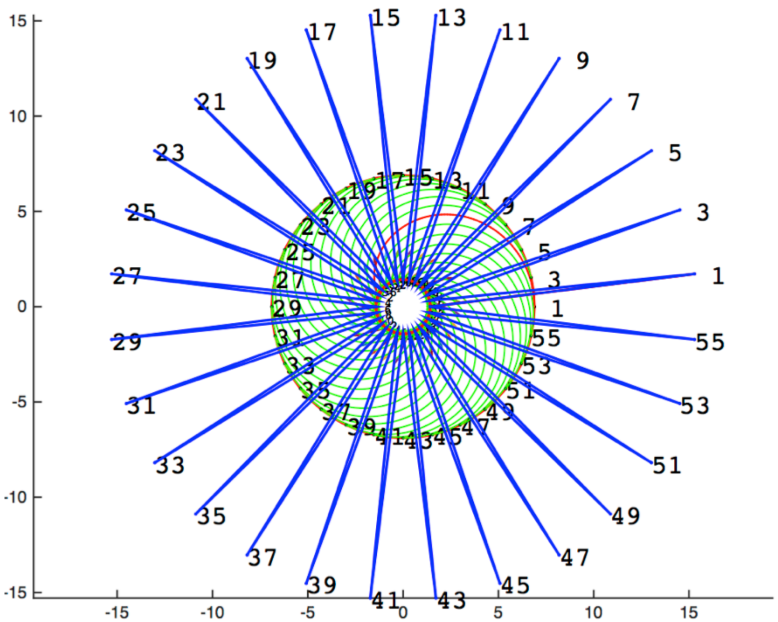
Table 1: *Expected numbers of events N_ν for published values of ANITA-II, 3 years of ARA-37, and 150 days of EVA with 80% analysis efficiency.*

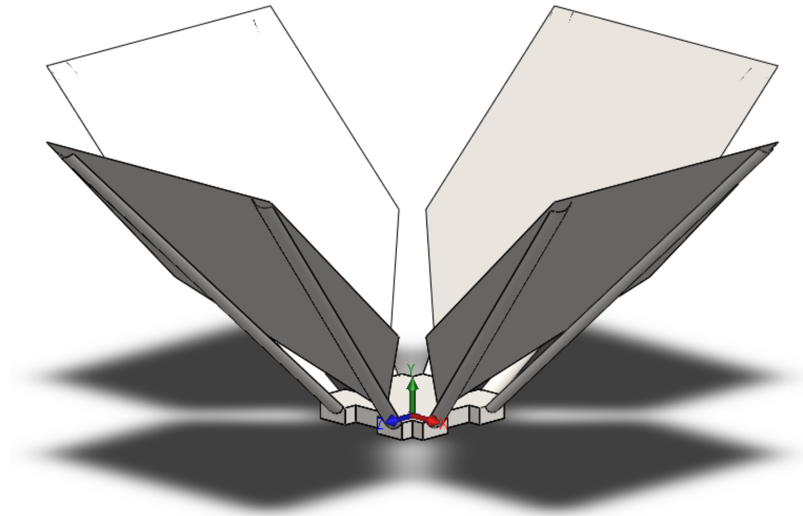
Model & references N_ν:	ANITA-II (2008)	ARA 3yr	EVA 150d
Baseline cosmogenic models:			
Protheroe *et al.* 1996[11]	0.6	13	44
Engel *et al.* 2001[3]	0.33	11	38
Kotera *et al.* 2010[12]	0.5	13	38
Strong evolution models:			
Engel *et al.* 2001[3]	1.0	34	120
Kalashev *et al.* 2002[13]	5.8	41	312
Barger *et al.* 2006[14]	3.5	32	91
Yuksel *et al.* 2007[15]	1.7	50	156
Mixed-Iron-Composition:			
Ave *et al.* 2005[16]	0.01	1.3	2.5
Stanev 2008[17]	0.0002	0.23	0.3
Kotera *et al.* 2010[12] high	0.08	2.4	6.4
Kotera *et al.* 2010[12] low	0.005	0.76	1.4
Waxman-Bahcall (WB) fluxes:			
WB 1999, evolved[18]	1.5	17	98
WB 1999, standard[18]	0.5	5.9	35
IceCube PeV E^{-2} power-law			
IceCube 2015 [19]	...	2.9	6.10

- Also expect ~300 cosmic ray events from geomagnetic effects

Design Improvements

Top-down view of compacted feed array





- Compact folding design permits larger feed array through the top
- Preliminary bowtie antenna design improves gain over sinuous antenna
  - Unidirectional, meets gain requirements of optimal feed antenna (GRASP simulations give ~31 dBi)
  - Not flat but could be deployed in situ

Summary

- EVA is a novel design that uses the balloon itself as part of the antenna
- Would increase gain by a factor of ~100 over previous radio neutrino experiments
- Hang test 1:20 scale model was tested (2014) and results are consistent (within 2 dB) with simulation
- Proposal and development in progress for full scale detector

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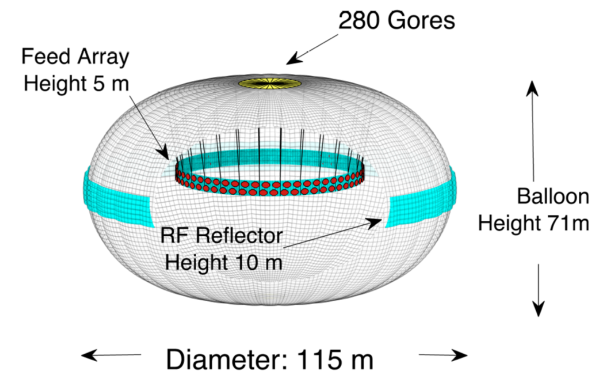

Ohio Supercomputer Center
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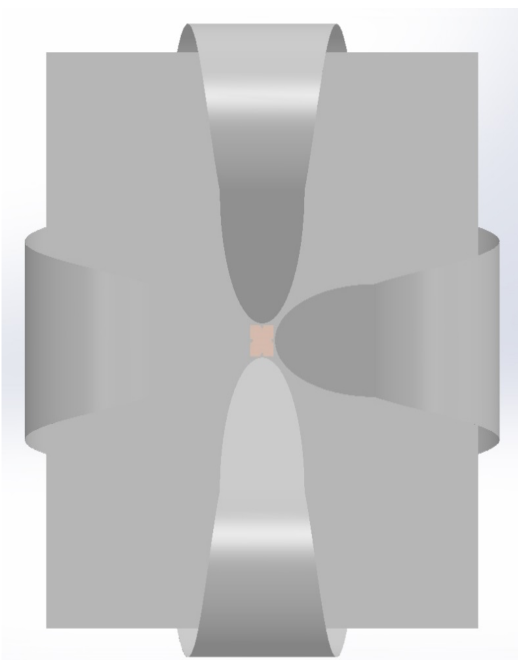
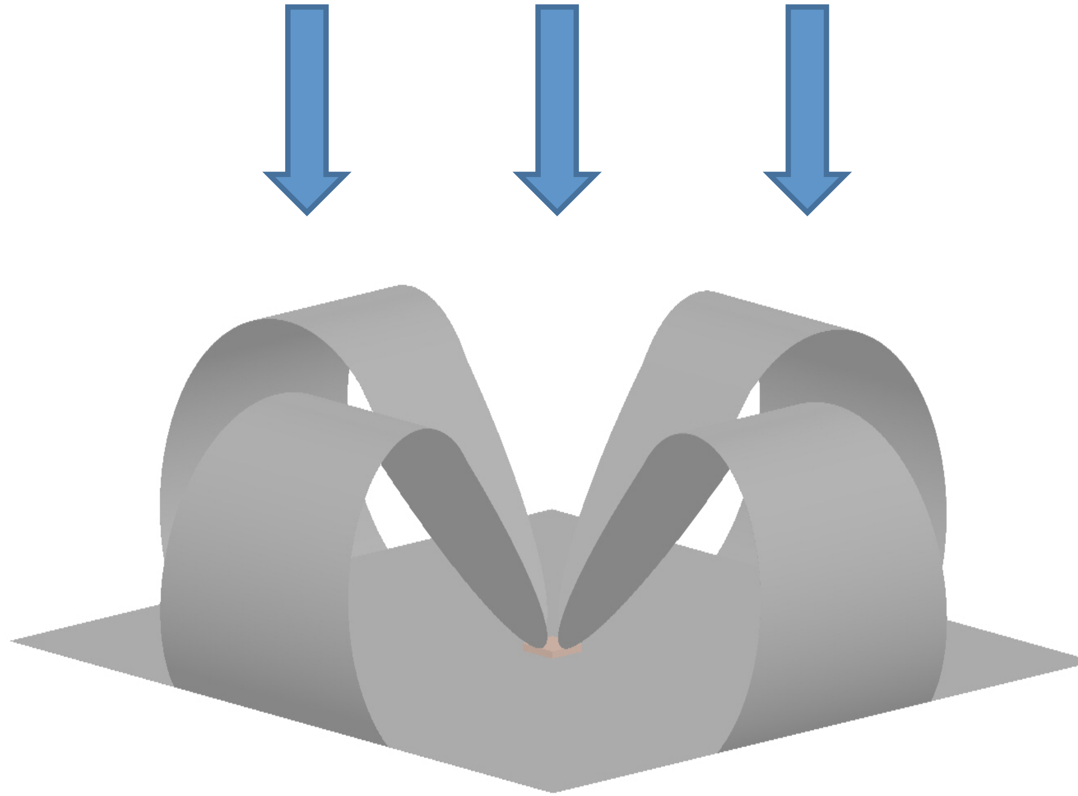
Backup

Challenge

- Bow-tie shape
- Collapsible
- Self-deployable





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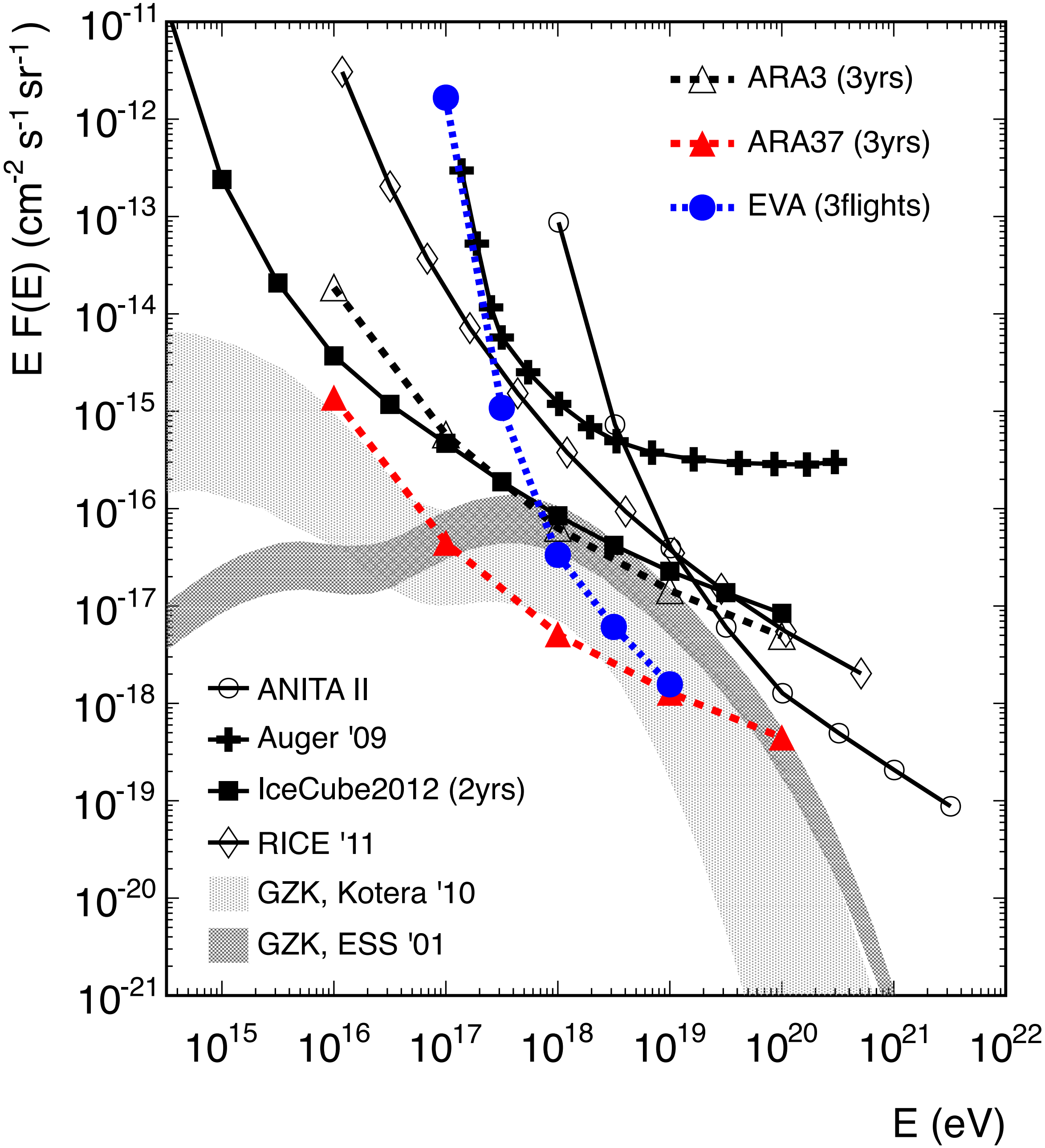

E F(E) (cm^{-2} s^{-1} sr^{-1})
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
ARA3 (3yrs)
ARA37 (3yrs)
EVA (3flights)
ANITA II
Auger '09
IceCube2012 (2yrs)
RICE '11
GZK, Kotera '10
GZK, ESS '01
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
10^{22}
E (eV)