The ExaVolt Antenna (EVA): Concept and Development

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CCAPP

NASA

THE OHIO STATE UNIVERSITY


ULDB (NASA)

Outline

1. Background
2. ExaVolt Antenna Concept
3. Simulated Response
4. Results of 1:20 Scale Hang Test
    - Comparison with Simulation
5. Projections for the Future

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

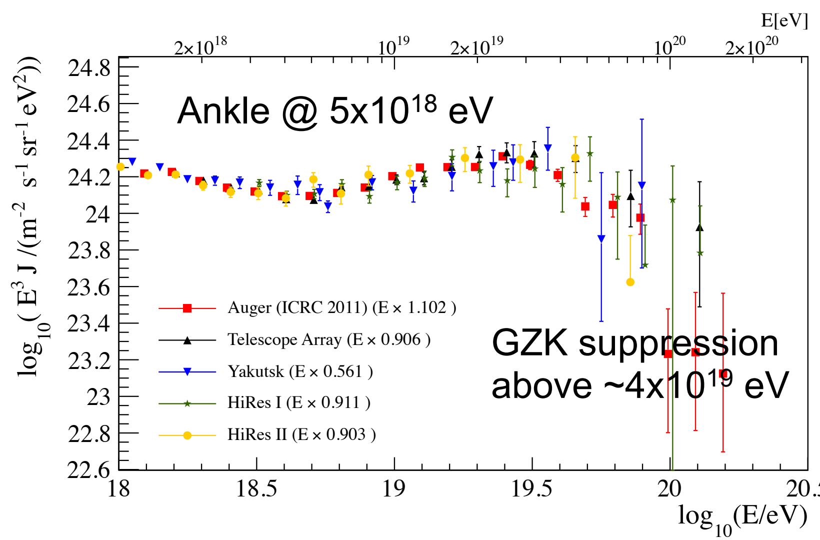
- Low flux at Earth
  - Less than 1/km^3/year/energy decade
  - Need large volume detectors

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

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

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

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



Proceedings of UHECR 2012

Detection Technique

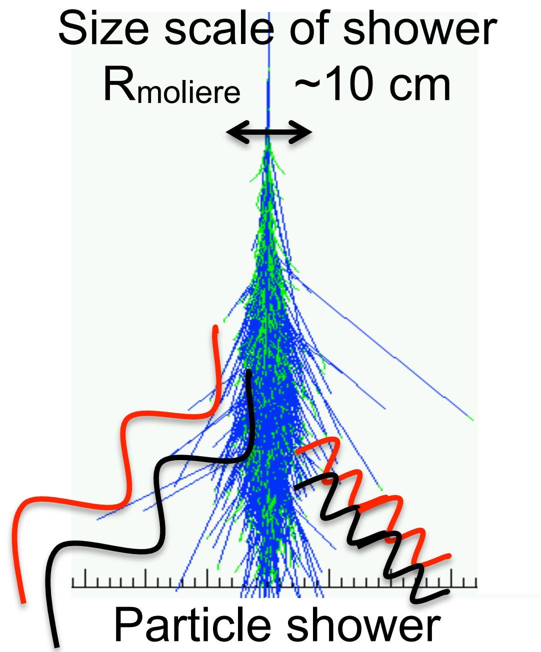
How to get large-scale detection -

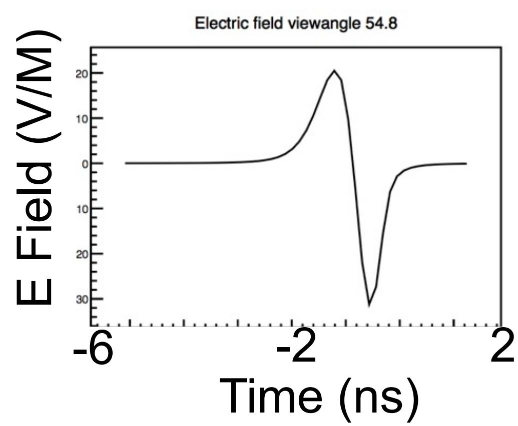
- Brute force: make 100X IceCube
- Use a different approach – radio Cherenkov technique

Coherent Cherenkov signal from net "current," instead of from individual tracks

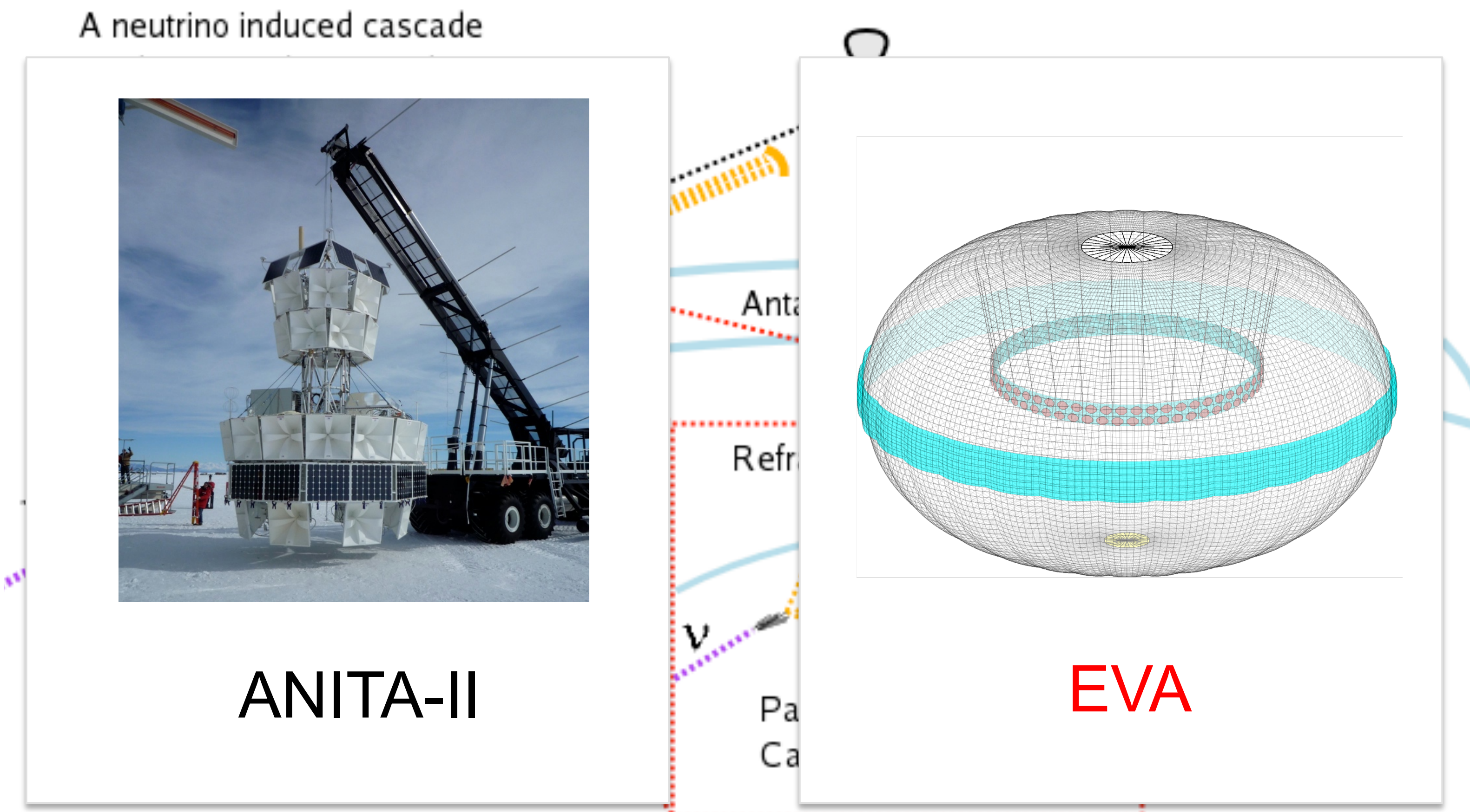
- In dense medium, a ~20% charge asymmetry develops in the shower (positrons annihilated, electrons not)
- If $\lambda \gg R_{Moliere}$ (radial size scale) → Coherent Emission
- Hypothesized by Gurgen Askaryan, 1962
- Effect observed in ice, water, salt
- Impulsive bipolar signal

Ice: Long (~1 km) attenuation lengths in 0.1-1 GHz → large observable volume





Synoptic Detectors



Synoptic – balloons, satellites

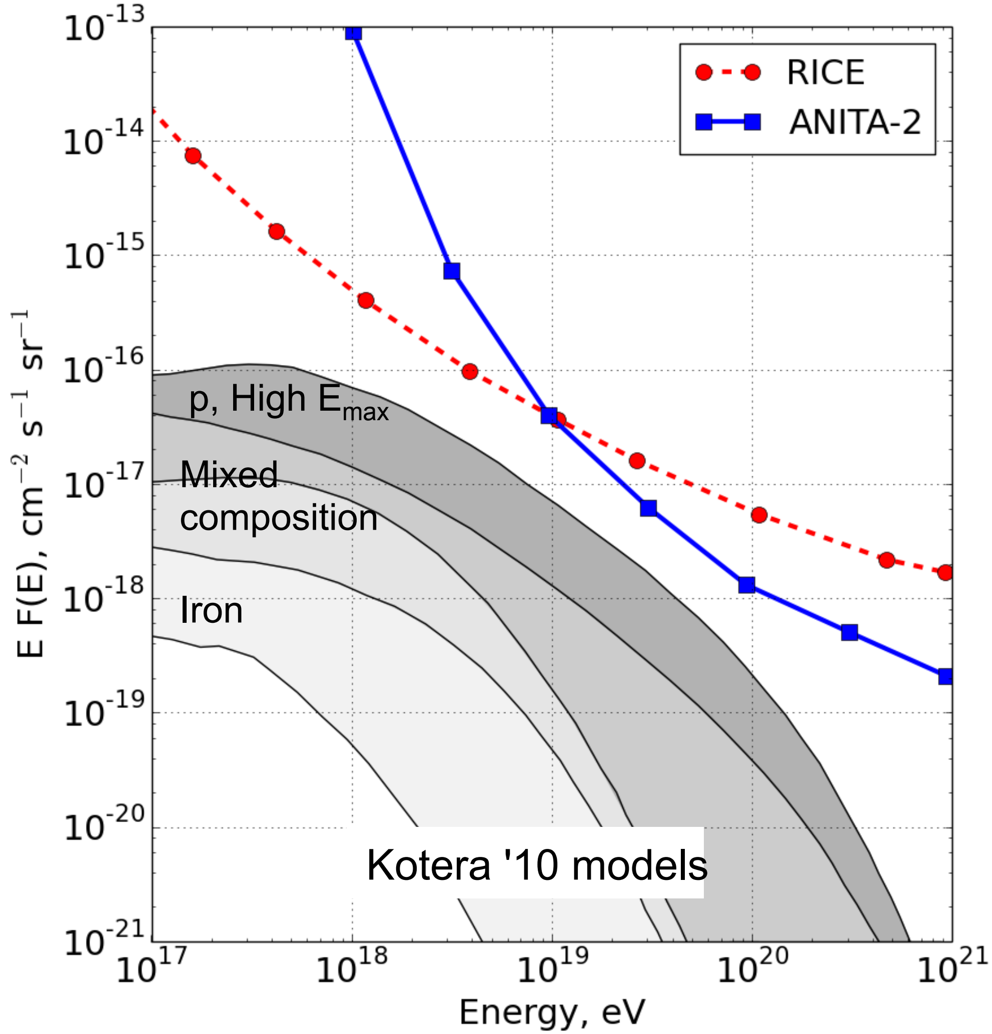
ANITA, EVA, PRIDE

Large target volume - O(10^6 km^3)

Good as a "discovery" instrument for highest energies (>10^{20} eV)

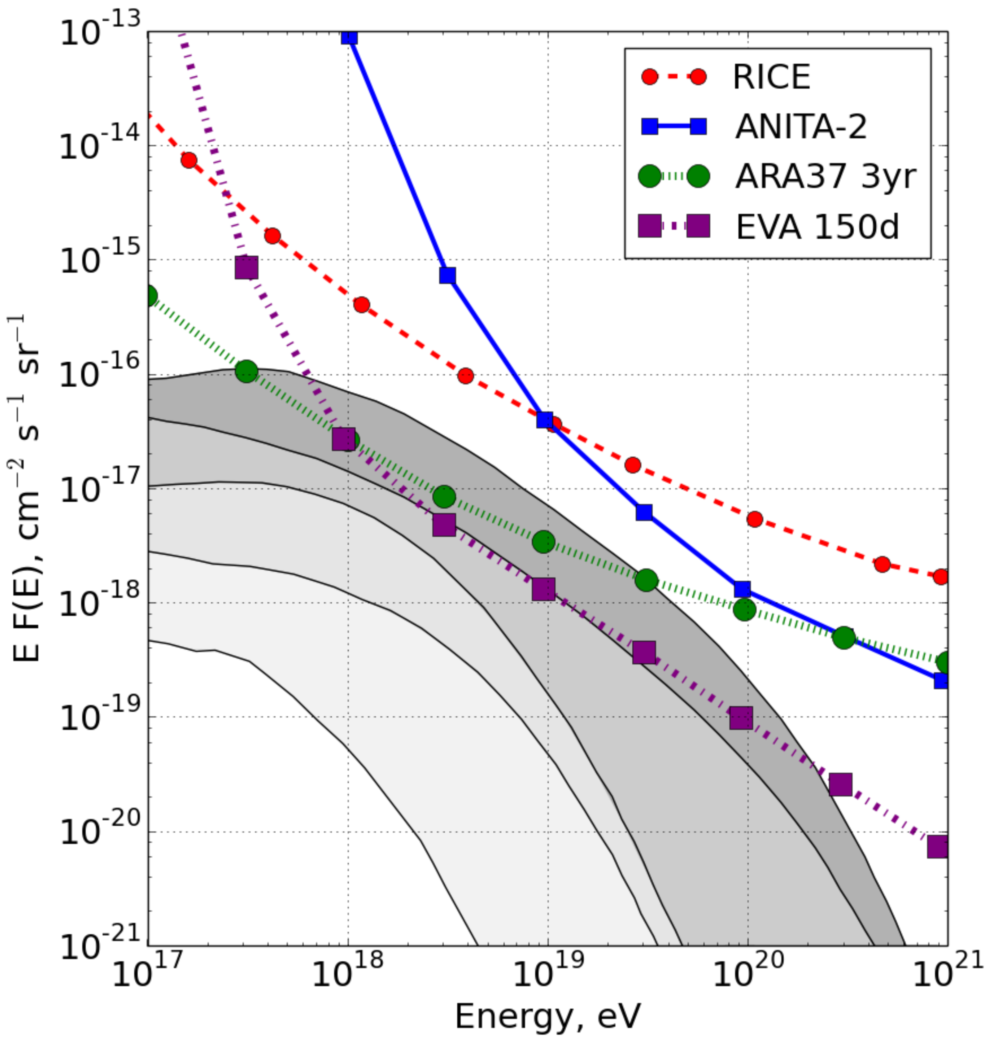
In-ice vs. Balloons

- 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.



EVA Concept

Use balloon surface as a part of the detector

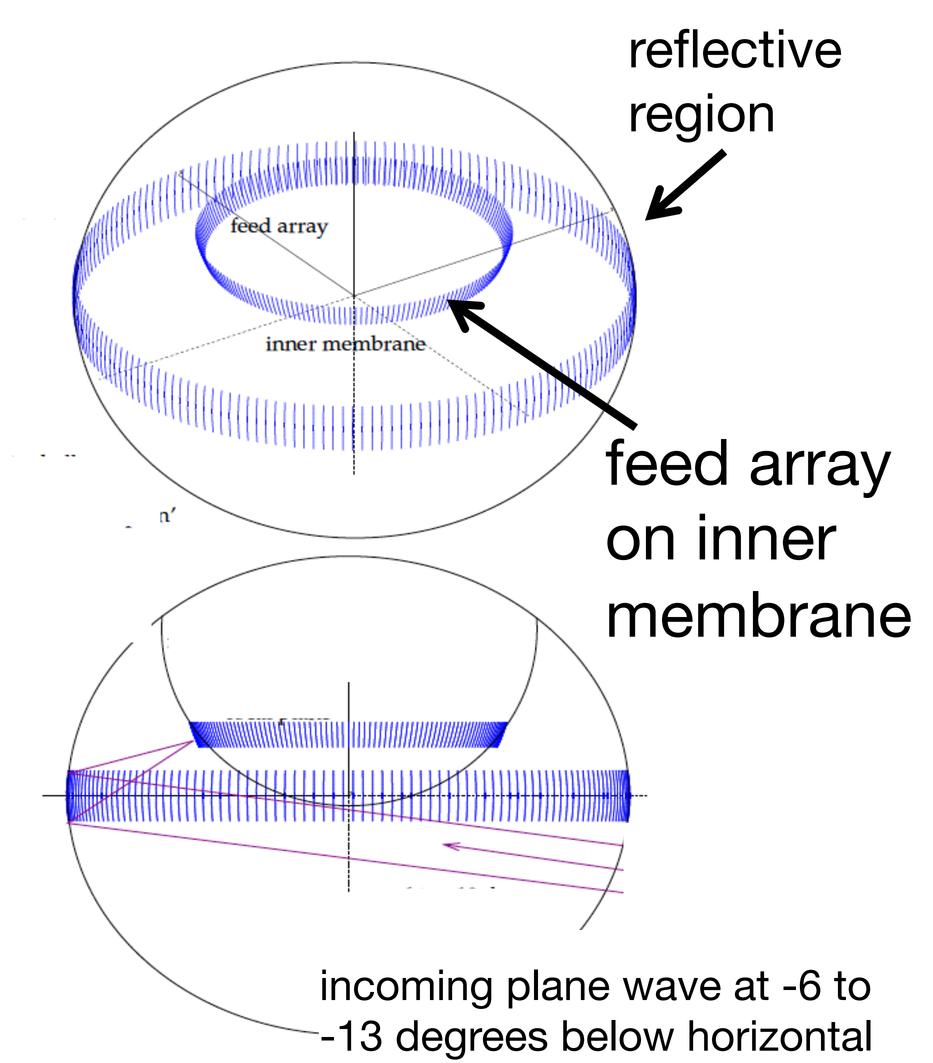
- Focus signal to interior

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

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)

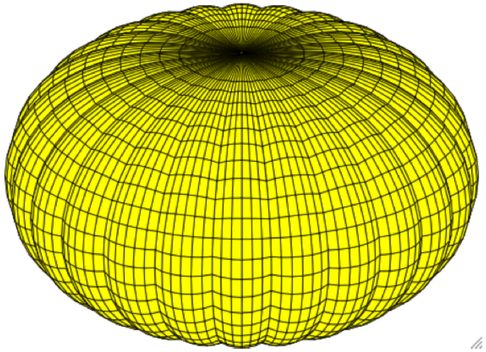
Balloon pressure higher than outside pressure

Stability due to lobed structure

NASA test flights

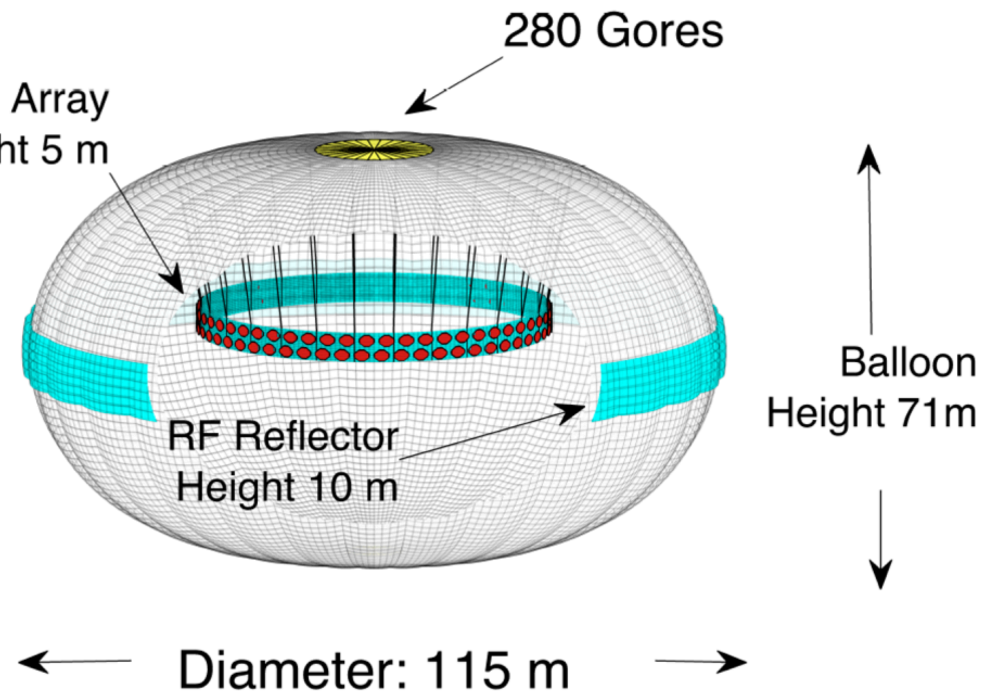
- 591NT – Dec. 2008, 54 days, 7 Mft^3, negligible shape change

Source: Raven Aerostar



EVA 1:20 scale model design

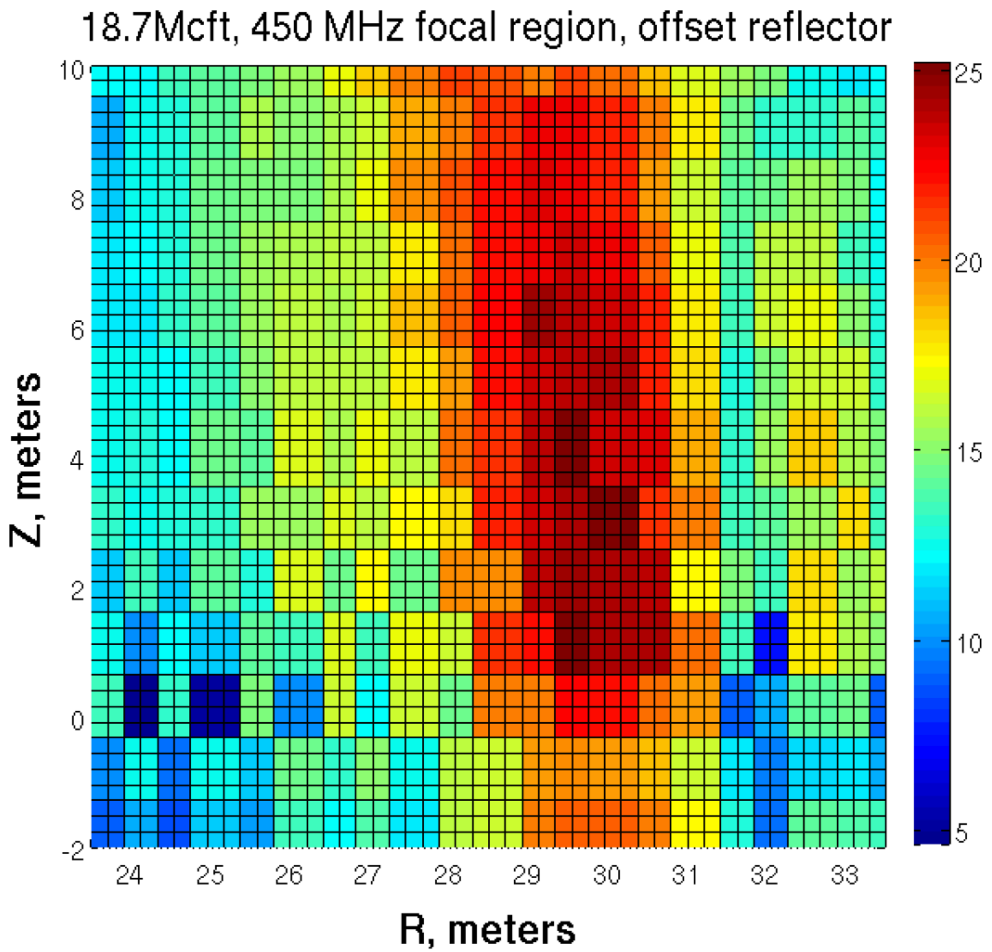
Current Design



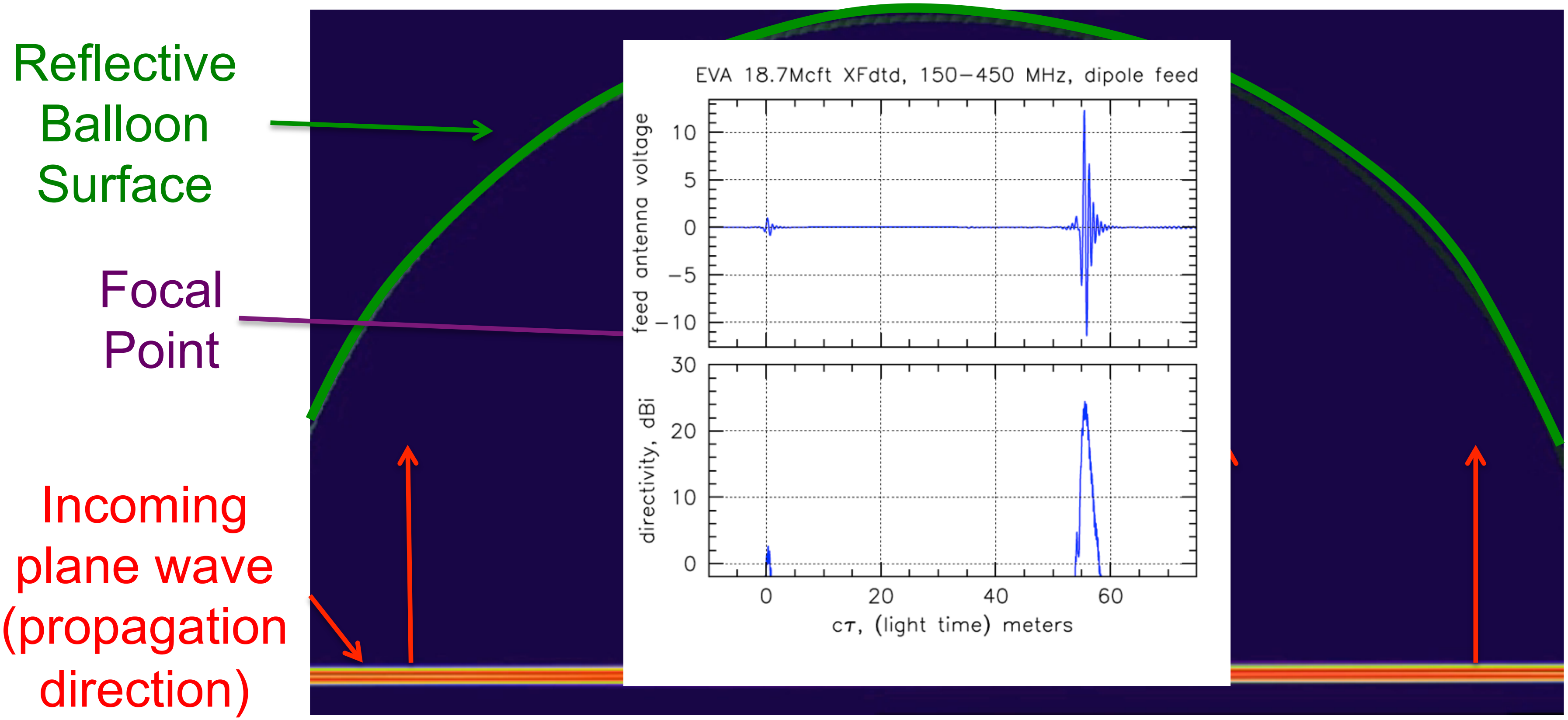
SPB – 18.8 MCF, payload would contain DAQ, much of the electronics
Feed array – separate Vpol and Hpol channels
- Elevated with respect to the reflector for downward viewing
- At least three feed antennas tall
- ~2000 channels

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.



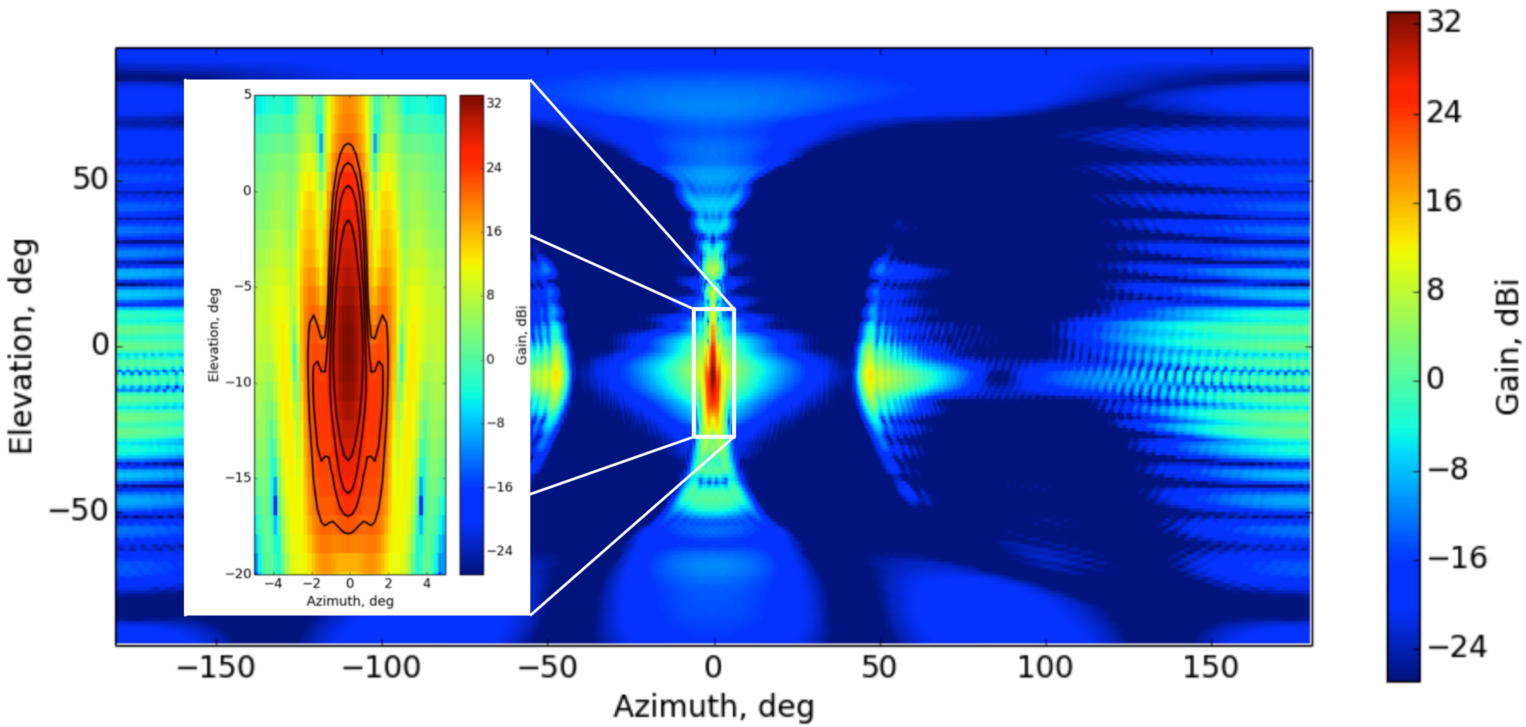
XFdtd Simulation



- 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.

GRASP Simulations

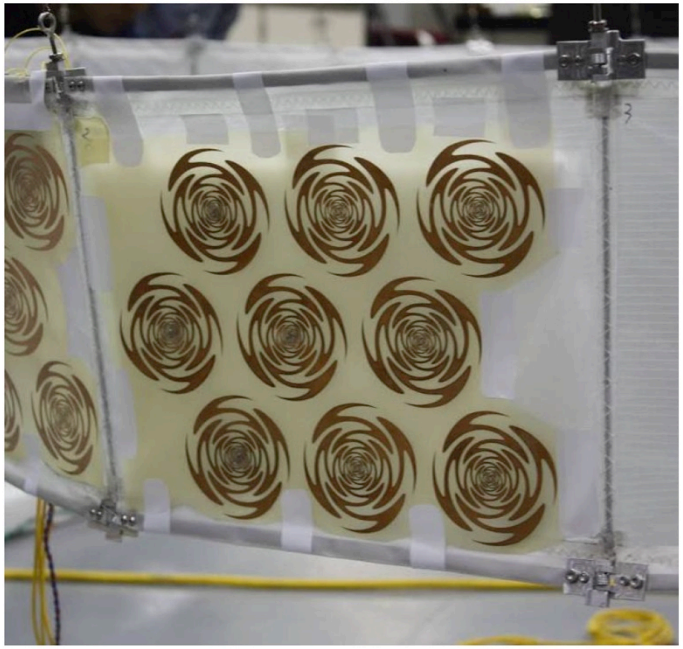
- GRASP is the tool of choice for reflector antenna designers.
  - Fast, flexible; not time domain
- Physical optics simulator fully accounts for surface shape and feed antenna gain pattern.
- Surface simulations using an optimized feed illumination pattern → peak of 32 dBi.



Hang Test

Wallops Flight Facility, September 2014

1/20th scale model balloon.

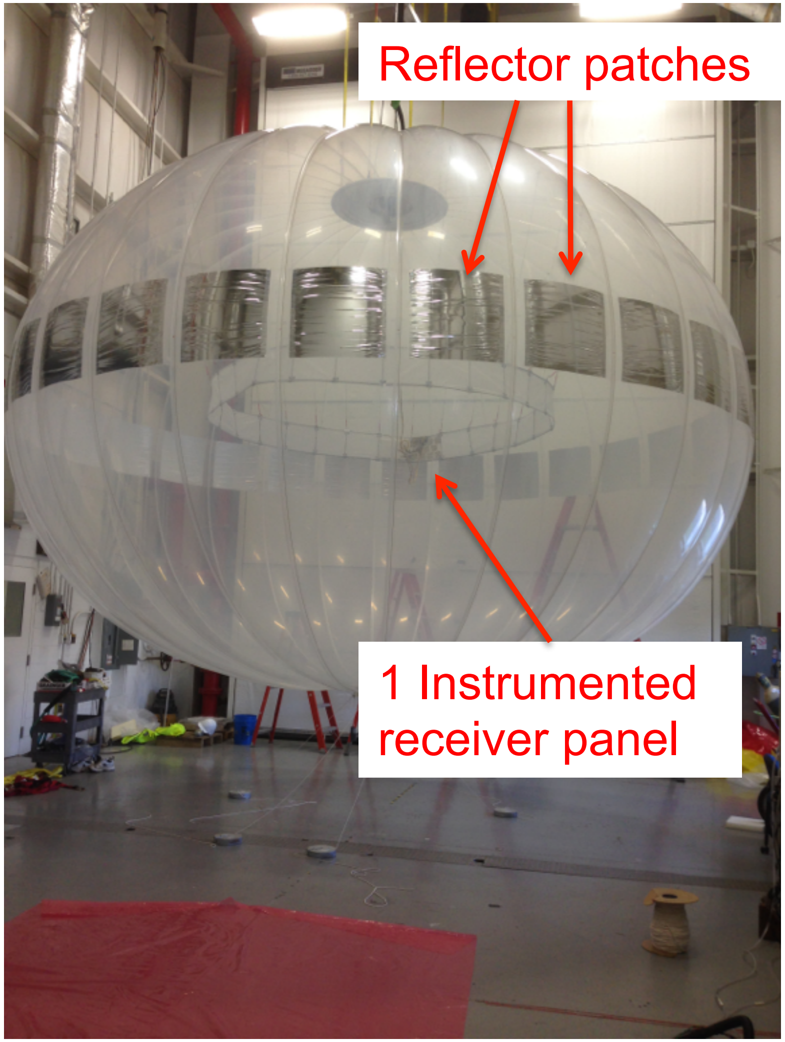


Dual-polarized sinuous antenna feeds.

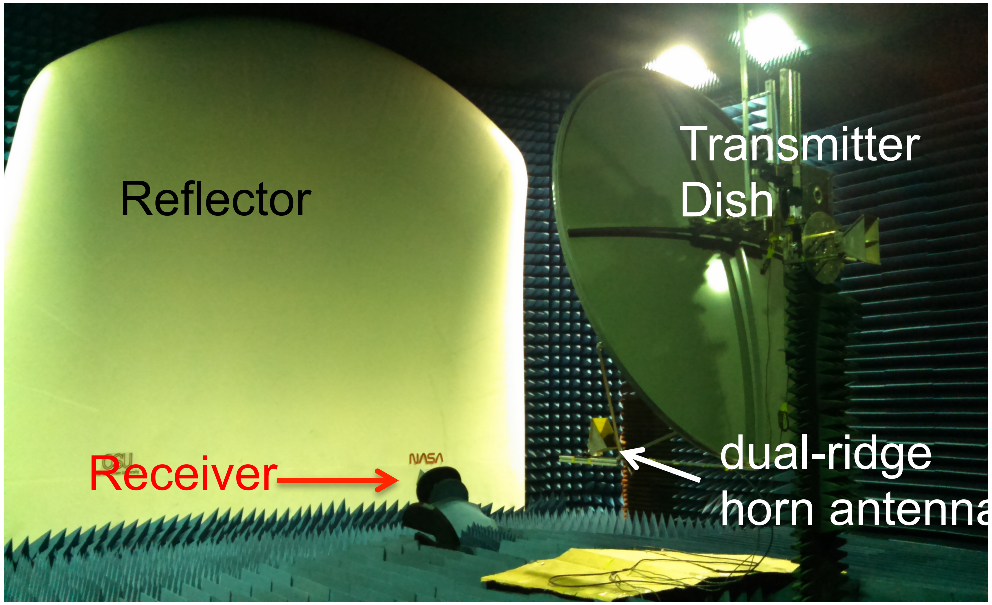
Balloon and feed system.

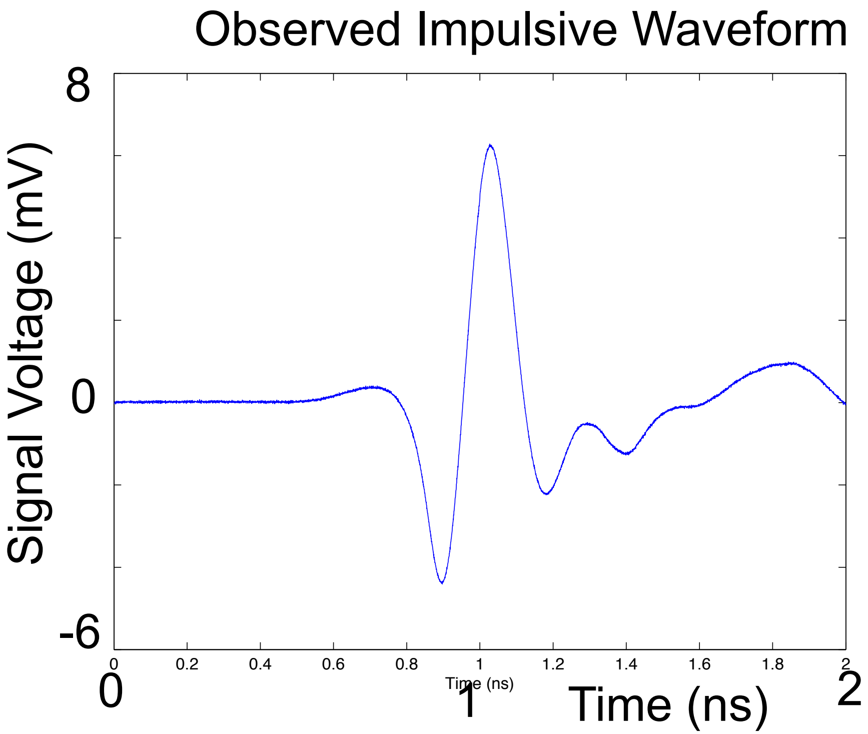
1:20 Scale Model

- 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 have large gaps
  - Transmitter smaller than full collecting area of reflectors



Transmitter/Pulser

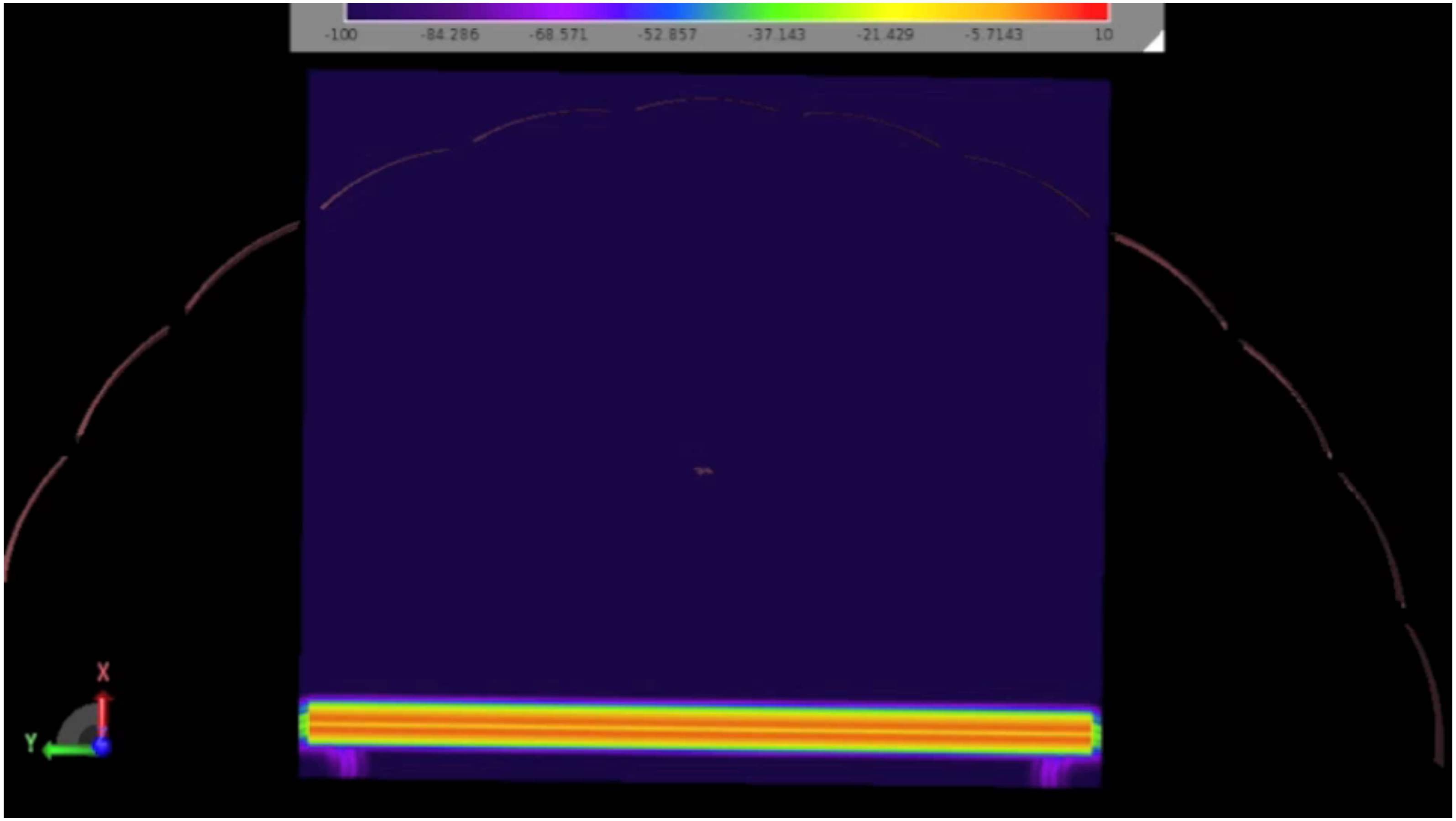




Assembled an impulsive signal transmitter with dish

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

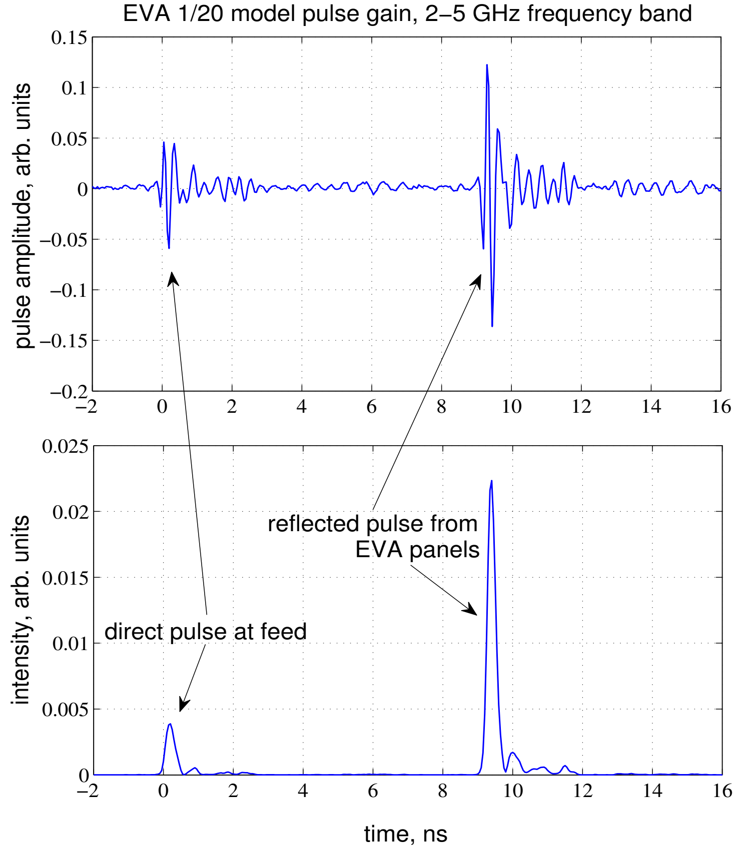
Hang Test Simulation



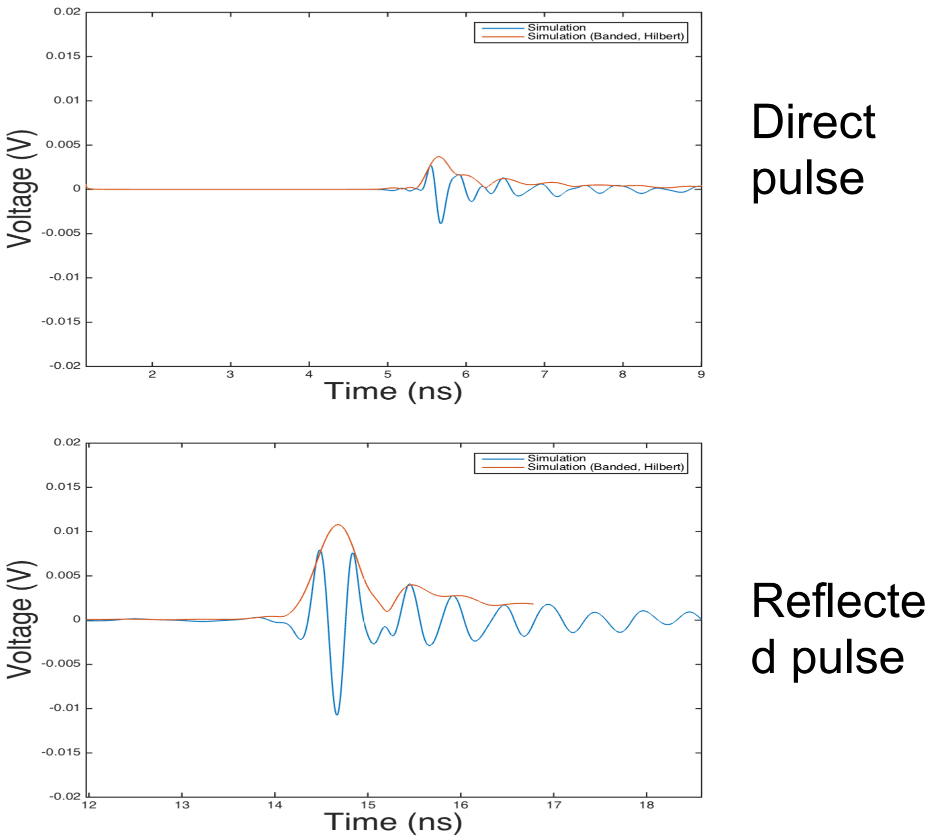
Limited signal region, less focused reflections

Hang Test Results

Hang Test Data



XFdtd Simulation Results



Data shows increased gain, coherent pulse

Estimated gain = ~11.4 dBi

GRASP simulations predict 11.5 dBi

XF7 predicts 10.0 dBi

Credible concept: consistent within ~2 dBi

Expected EVA Results

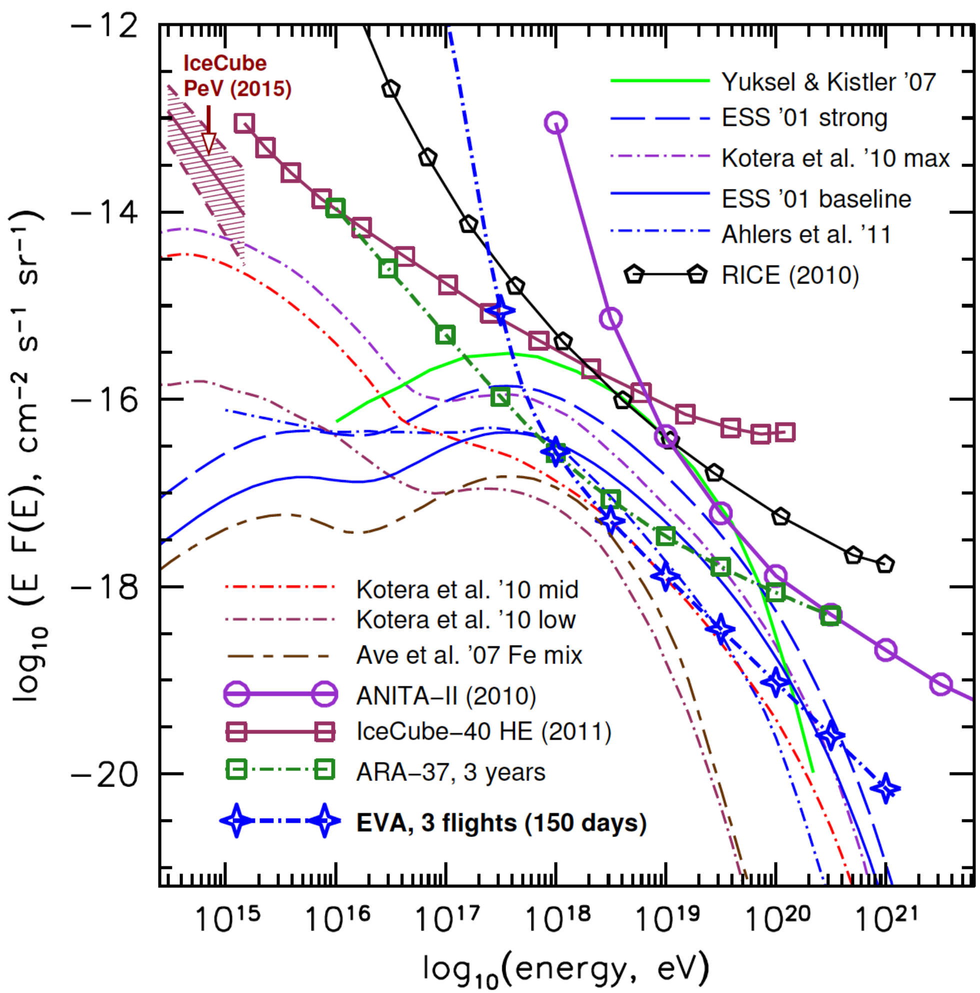


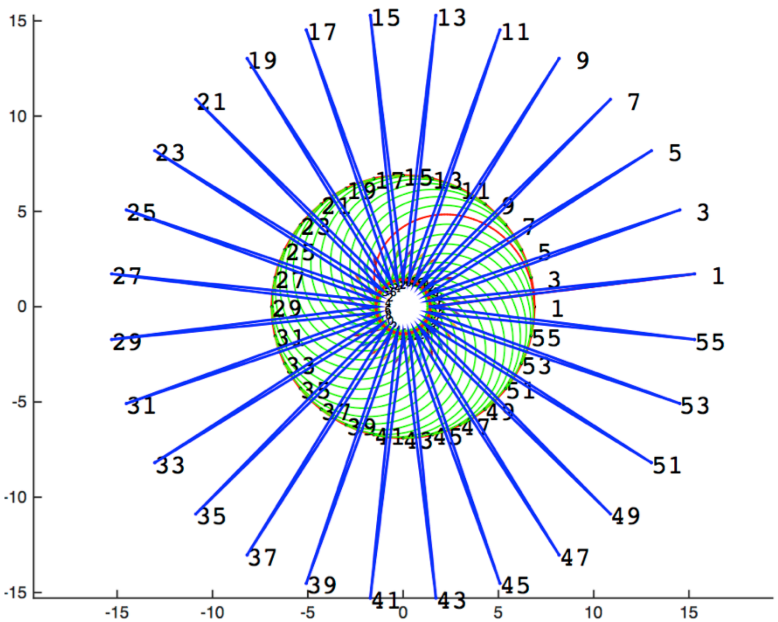
Table 1: *Expected numbers of events N_ν for published values of ANITA-II, 3 years of ARA-37, and 150 days of EVA with 80% analysis efficiency.*

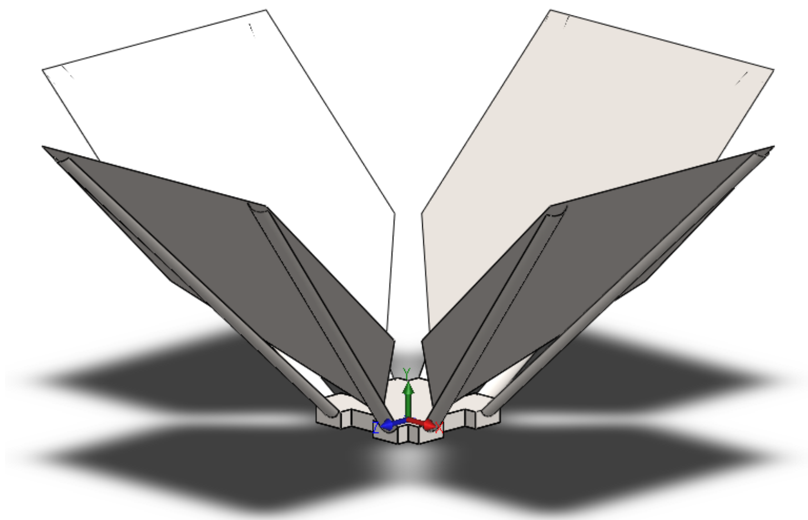
Model & references N_ν:	ANITA-II (2008)	ARA 3yr	EVA 150d
Baseline cosmogenic models:			
Protheroe *et al.* 1996[11]	0.6	13	44
Engel *et al.* 2001[3]	0.33	11	38
Kotera *et al.* 2010[12]	0.5	13	38
Strong evolution models:			
Engel *et al.* 2001[3]	1.0	34	120
Kalashev *et al.* 2002[13]	5.8	41	312
Barger *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 balloon top plate
- 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 simply 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
- Technology development proposal in progress
    - Looking towards a full-scale detector in a few years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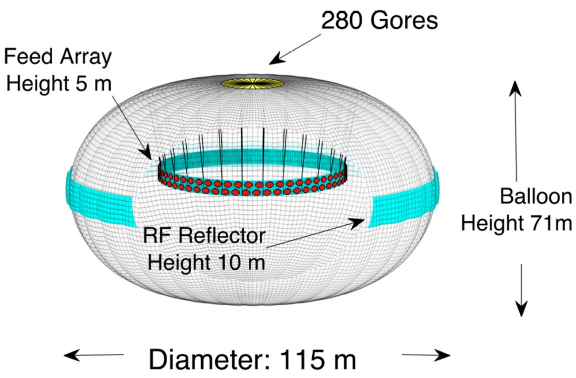

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CHEAPR Workshop

Computing in High-Energy Astro-Particle Research

Topics: Genetic programming, analytics, data analysis, feature selection, high-performance computing

Activities: tutorials, lectures, example code packages

Who: Members of ANITA, ARA, LIGO, SKA, others
Experts in genetic programming from industry and academia

When: August 24th – 26th, 2016

Where: Center for Cosmology and AstroParticle Physics (CCAPP), The Ohio State University

Contact: Carl Pfendner pfendner.1@osu.edu or
Jordan Hanson hanson.369@osu.edu

Questions?