Hunting UHE neutrinos with ANITA

Linda Cremonesi

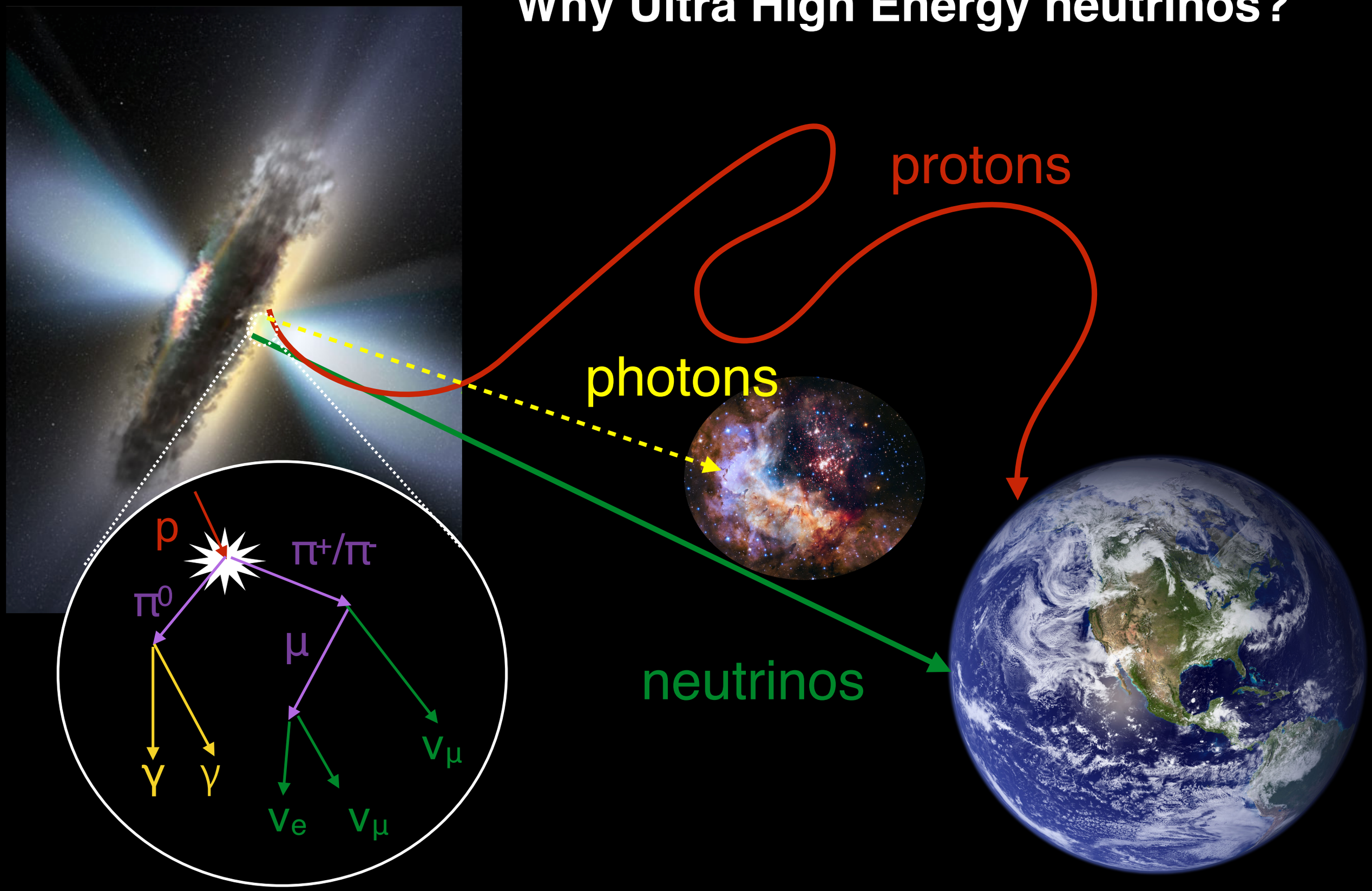
Fermilab Neutrino Seminar
October 9th 2019

Outline

- Motivations
- ANITA
- Neutrino(s) in a haystack
  Phys. Rev. D 98, 022001 (2018) & Phys. Rev. D 99,122001 (2019)
- Unusual upward-going cosmic-ray-like events
  Phys. Rev. Lett. 121, 161102 (2018)
- Future

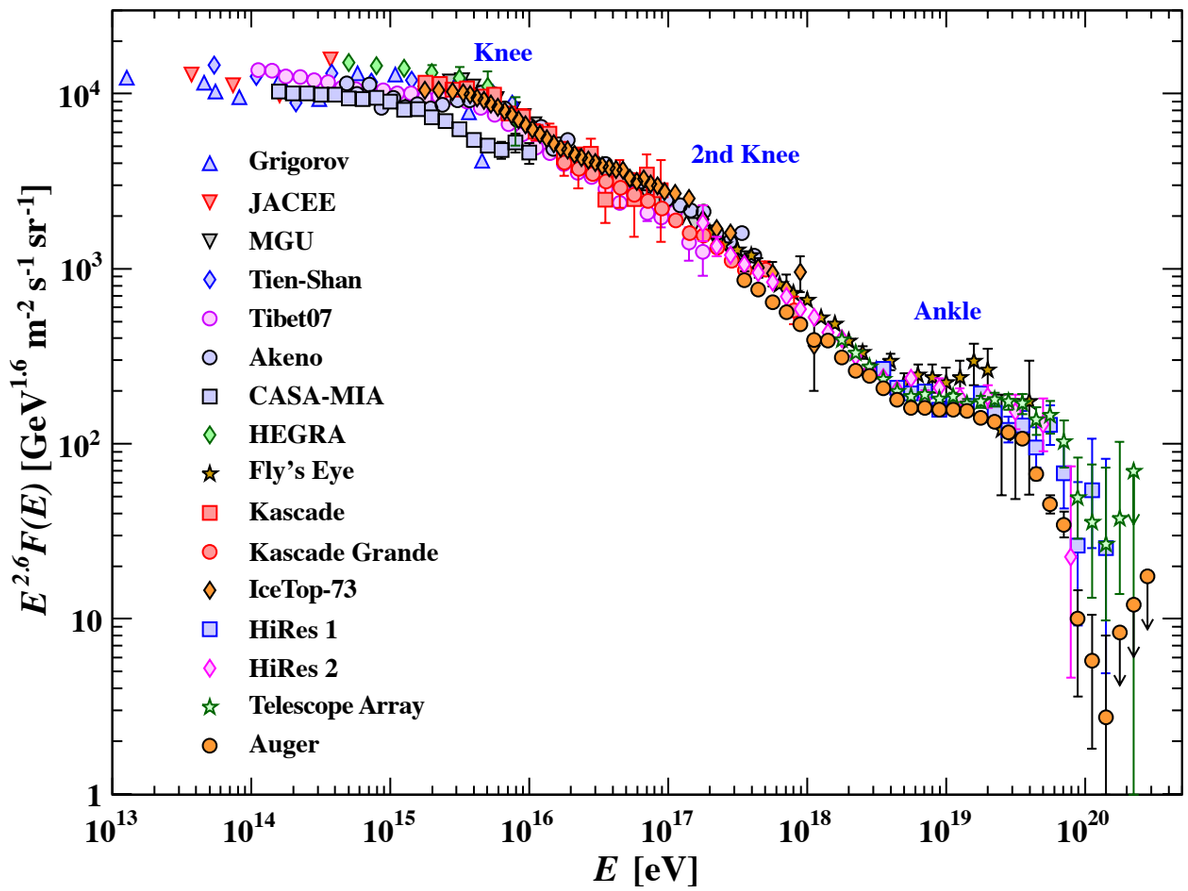
Motivations

Why Ultra High Energy neutrinos?



Cosmogenic neutrinos

C. Patrignani et al. (Particle Data Group), Chin. Phys. C, 40, 100001 (2016)



ν from GZK

$$p(E > 10^{19.5} eV) + \gamma_{CMB} \rightarrow \Delta^+$$

$$\Delta^+ \rightarrow \pi^+ + n/\pi^0$$

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

$$\mu^+ + \rightarrow e^+ + \nu_e + \overline{\nu_\mu}$$

ν from photo-disintagration

$$A + \gamma_{CMB} \rightarrow (A-1) + n$$

$$n \rightarrow p + e^- + \overline{\nu_e}$$

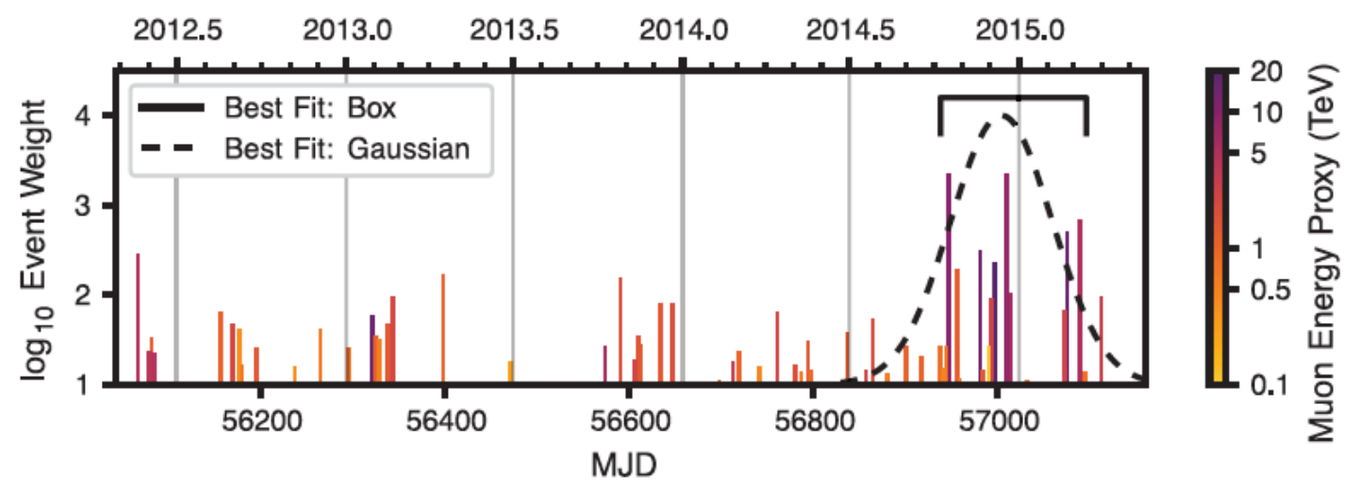
We know cosmic ray energy spectrum over 11 orders of magnitude.

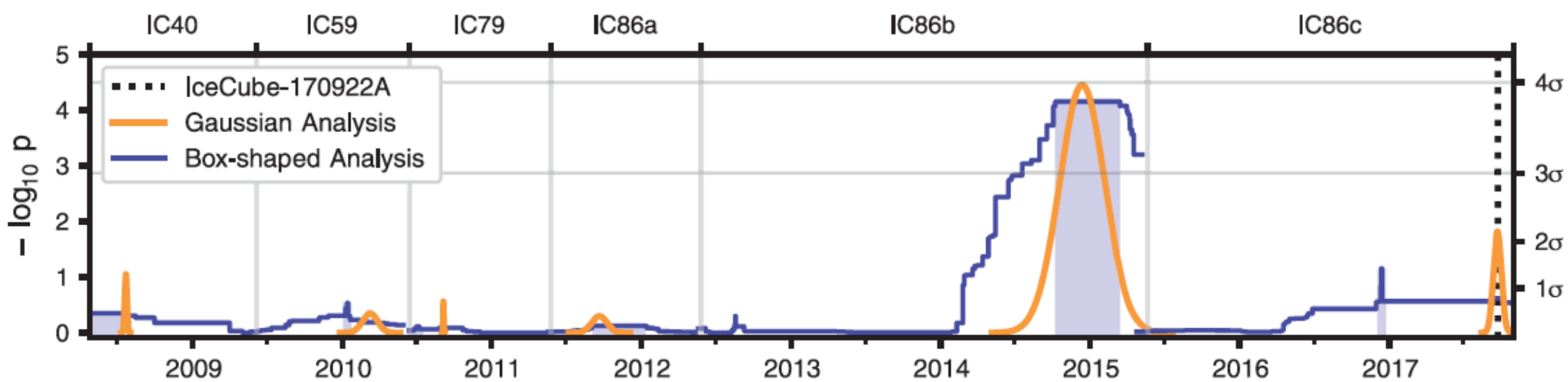
Their sources (especially at the highest energies) are still mostly unknown

TXS 0506+056

- IceCube identified 13 +/- 5 VHE astrophysical neutrinos from this direction
- Evidence of very high energy neutrino point source: at least some cosmic rays are accelerated up to few PeV in blazars

- Blazars **could** accelerate up to the highest observed cosmic rays, >1E19 eV
- IceCube-Gen2 should see loads

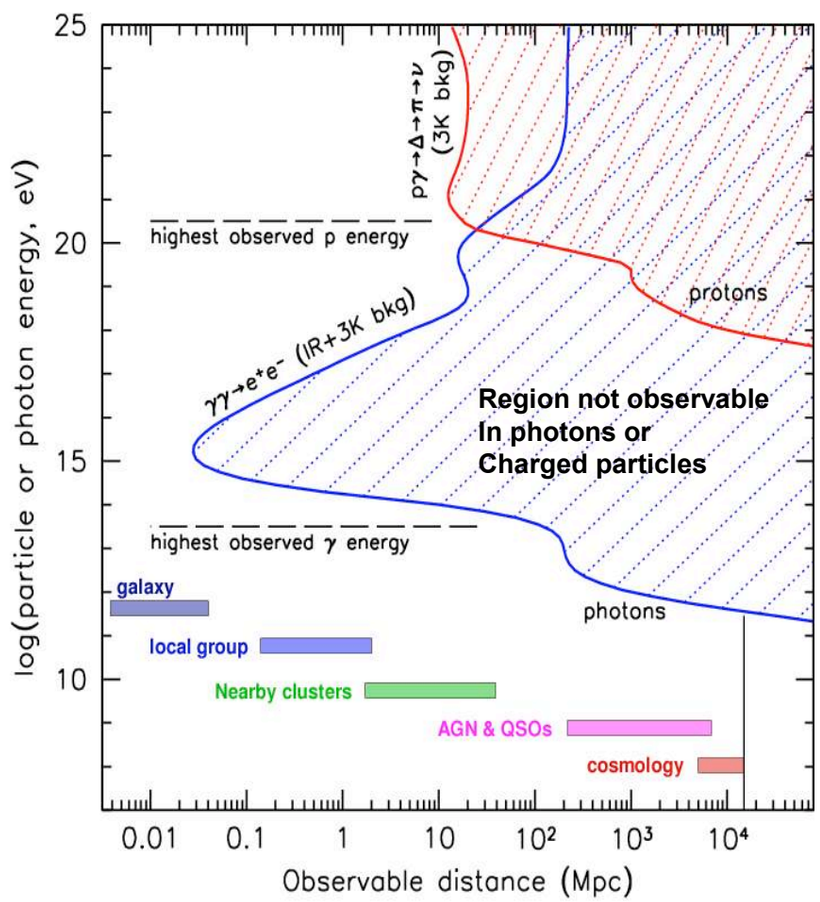


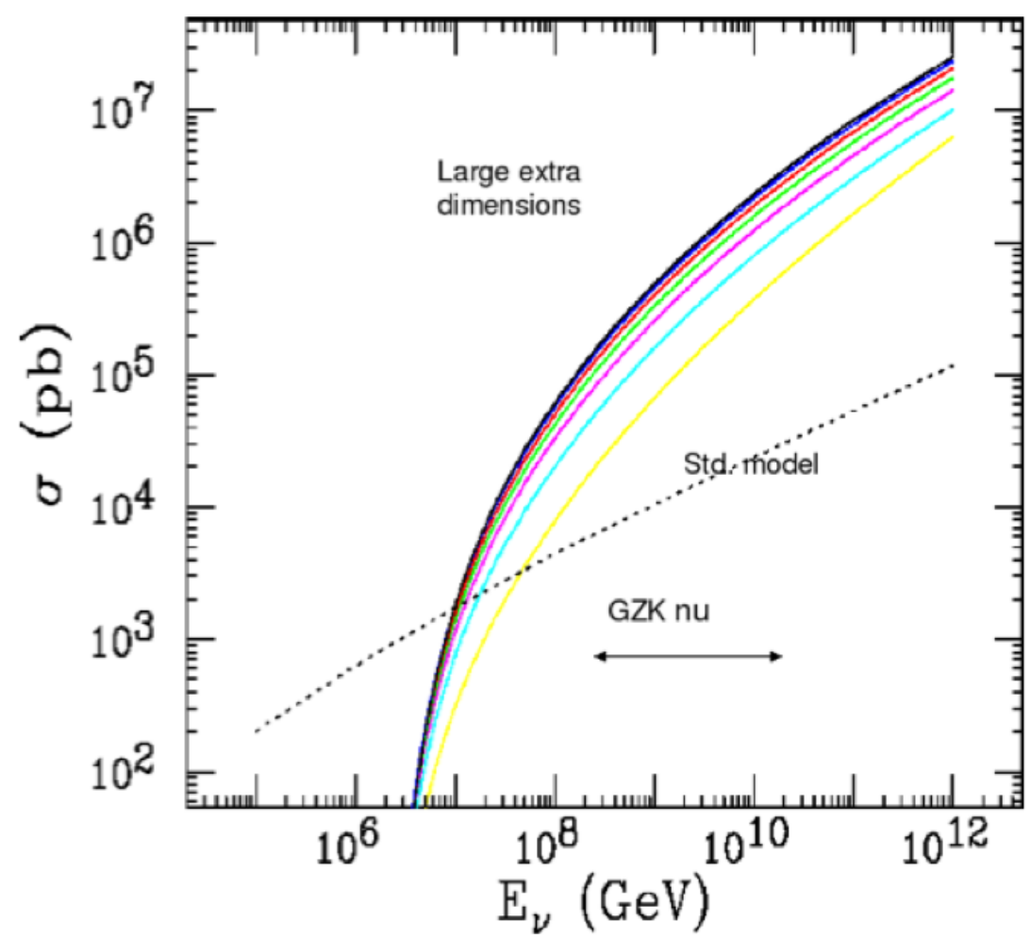


UHE (>E18 eV) neutrinos

"We can probe distances and energies that other particles can't reach!"

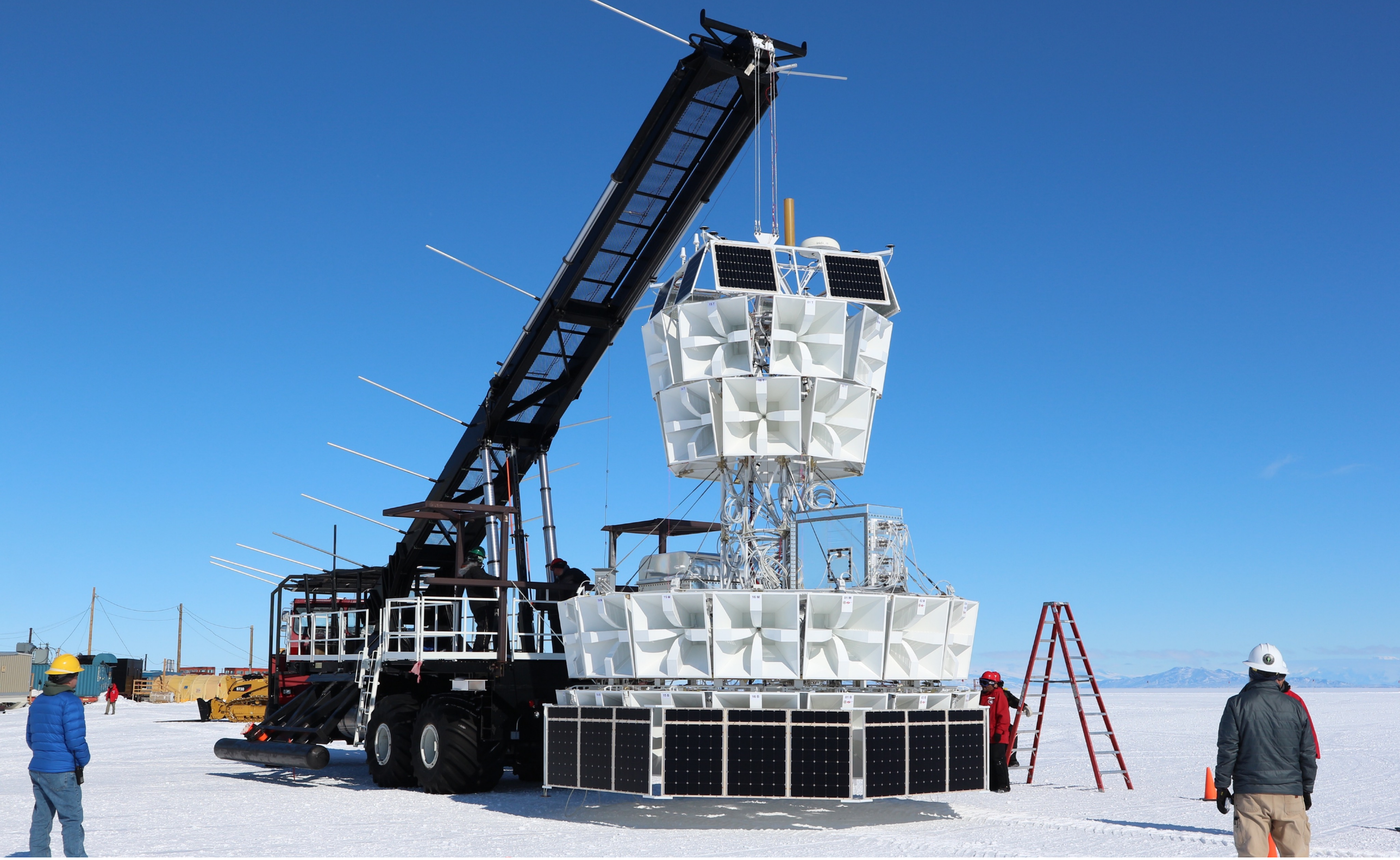
"WOW
300 TeV centre of mass energy!"





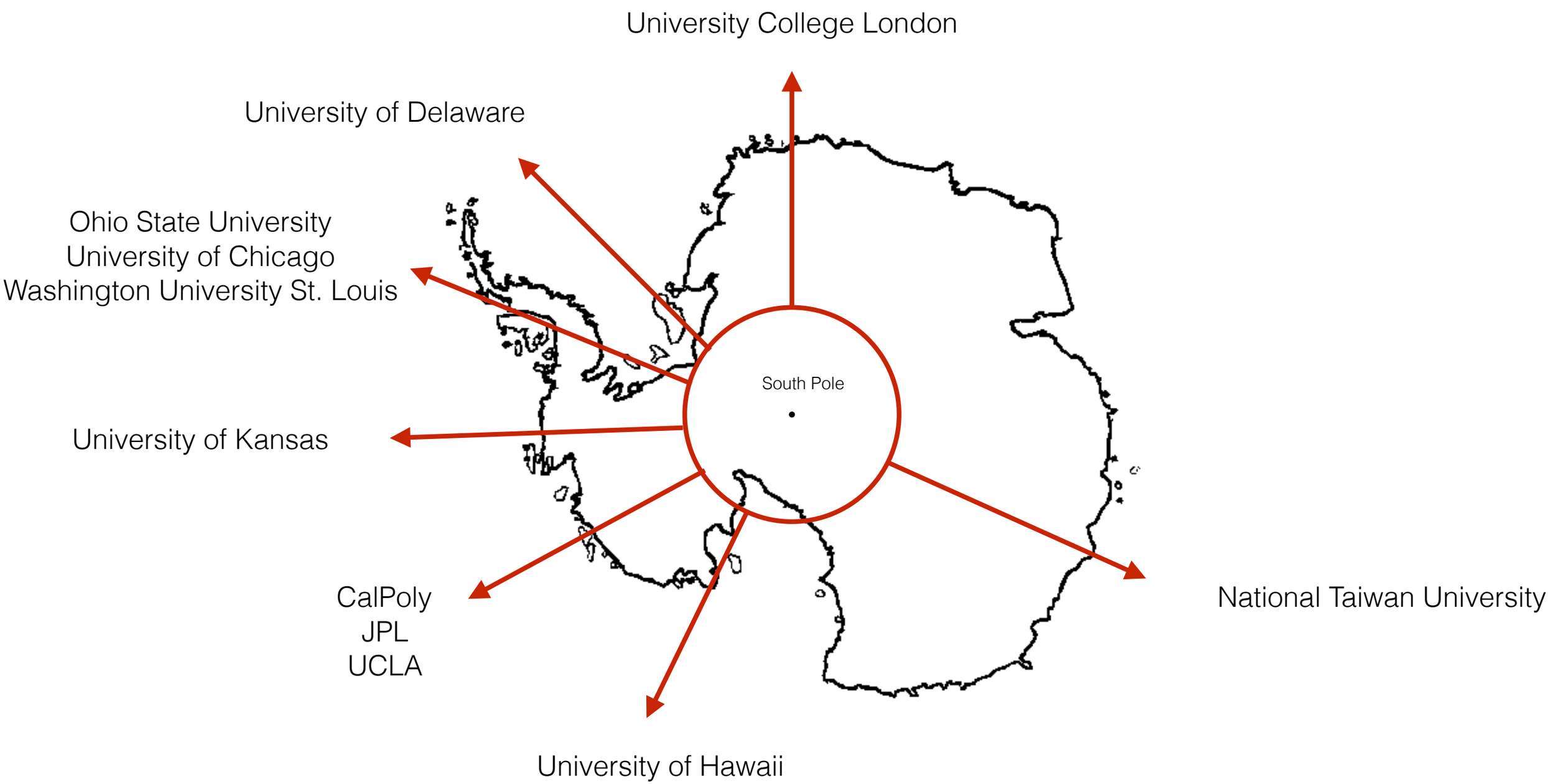
More motivations

- Implications for neutrino mixing (arXiv:1702.05238)
- Neutrino decay - JCAP 10 (2012) 020
- Ultra high energy neutrino cross-sections (Nature 551 (2017) 596-600, arXiv:1711.11043)
- Lorentz invariance - Phys. Rev. D 86, 103006
- Sterile neutrinos - arXiv:1802.01611
- Beyond Standard Model particles (staus) - arXiv:1809.09615
- Dark matter - arXiv: 1902.04584



ANITA

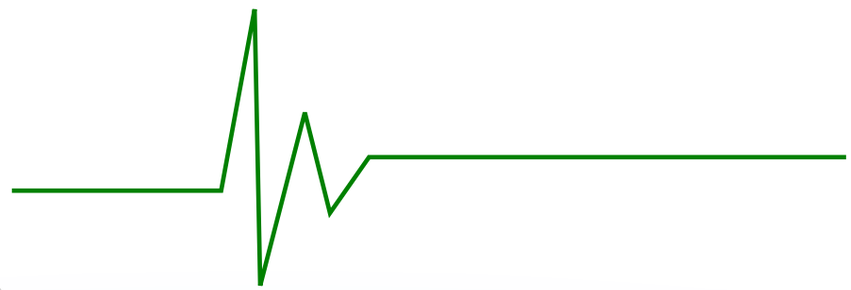
ANITA collaboration



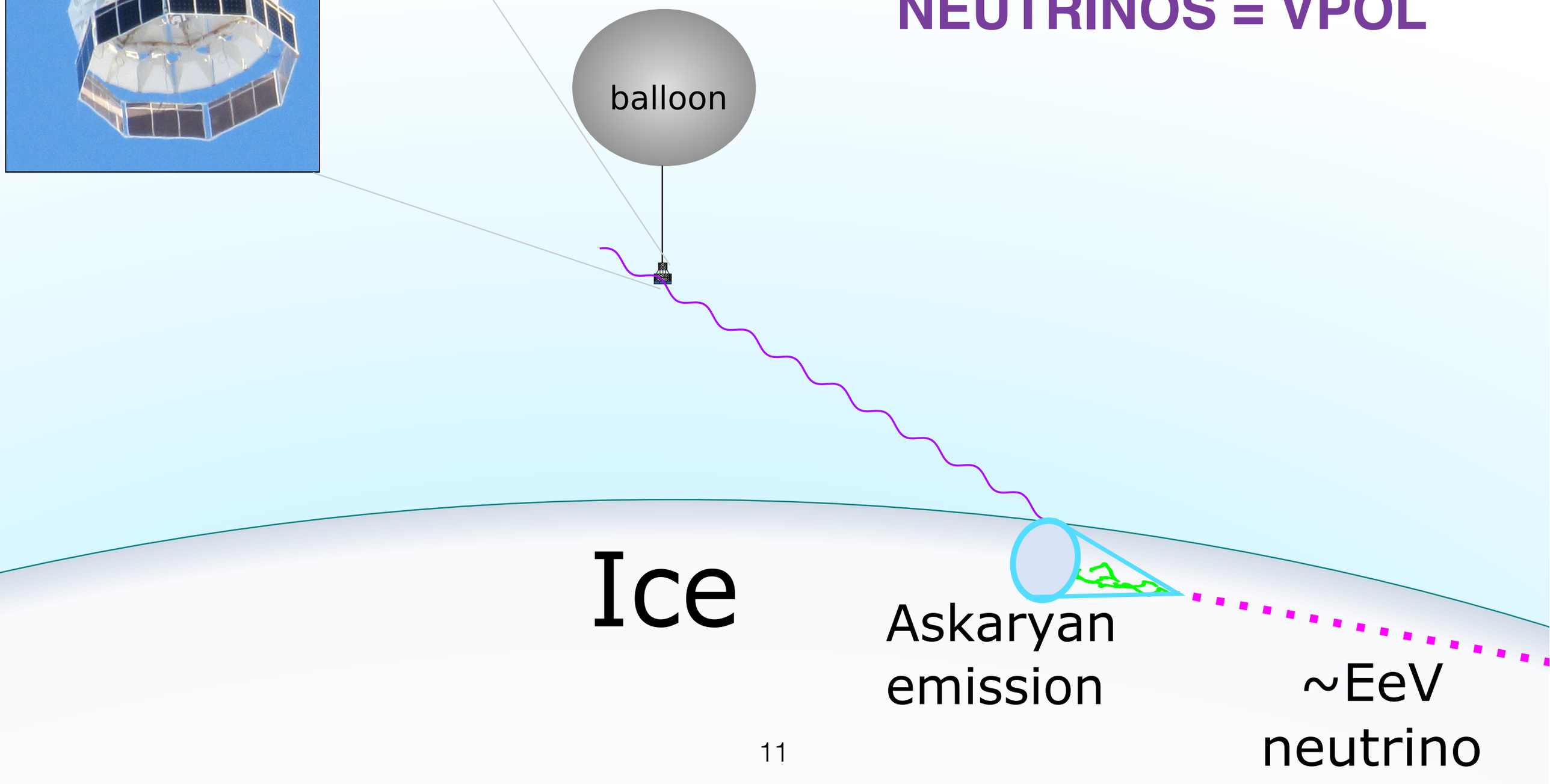
11 Institutions, ~50 collaborators in a 18 hour time zone

ANtarctic **I**mpulsive **T**ransient **A**ntenna

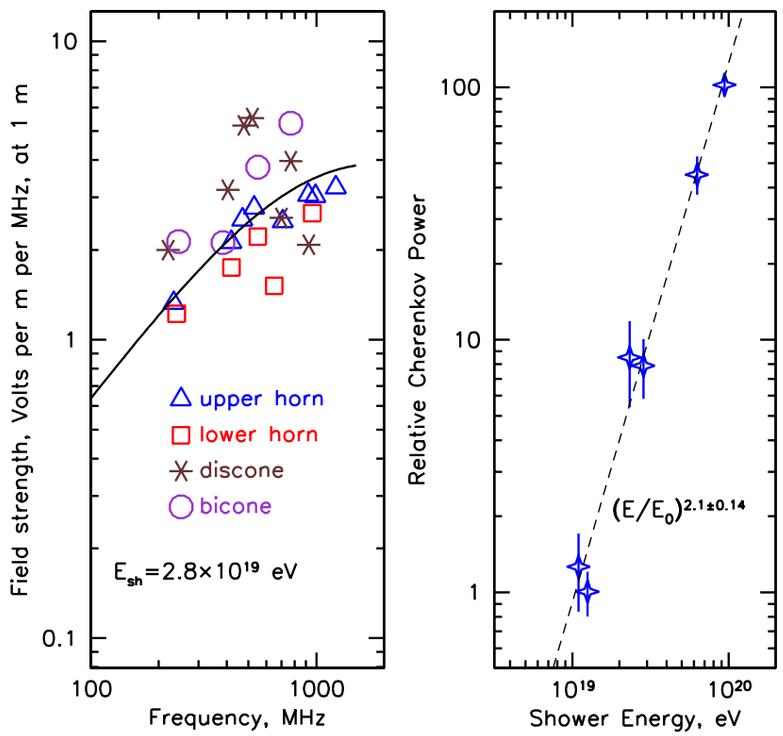
Not to scale, angles don't reflect reality



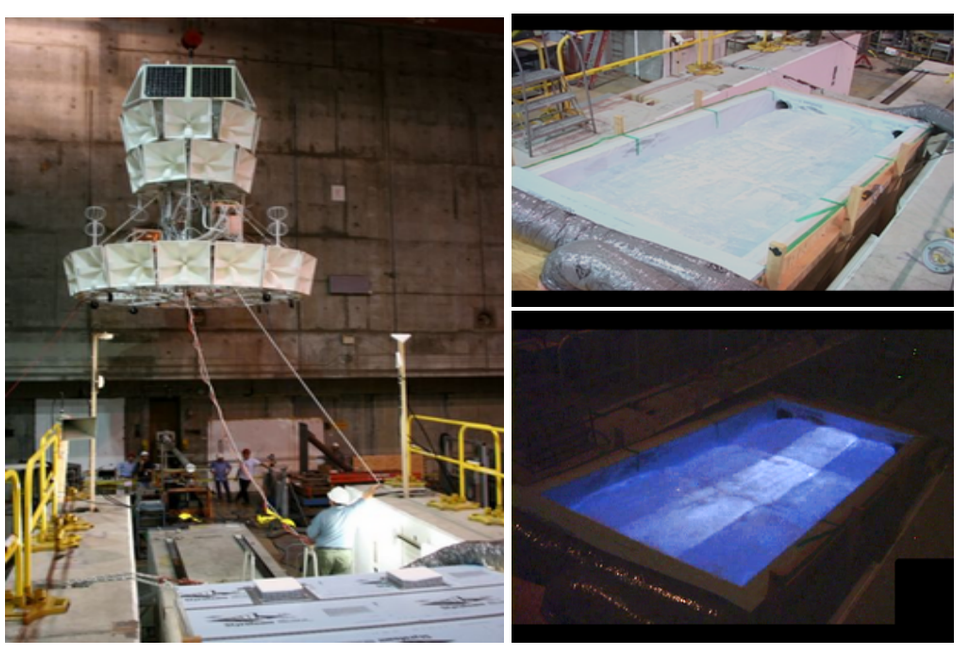
NEUTRINOS = VPOL



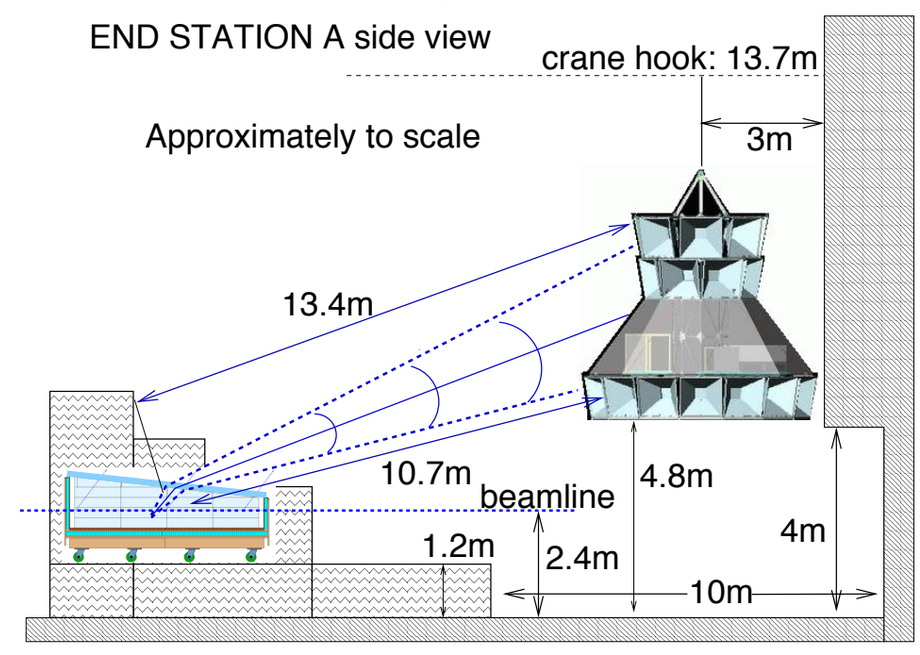
Askaryan radiation



- Coherent radio emission from EM cascades in a dielectric!
- Measured at SLAC ESA in 2006 by ANITA collaboration
- Fired bunches of 10^9 electrons at 28.5 GeV into 7000 kg of ice



Phys.Rev.Lett.99:171101,2007

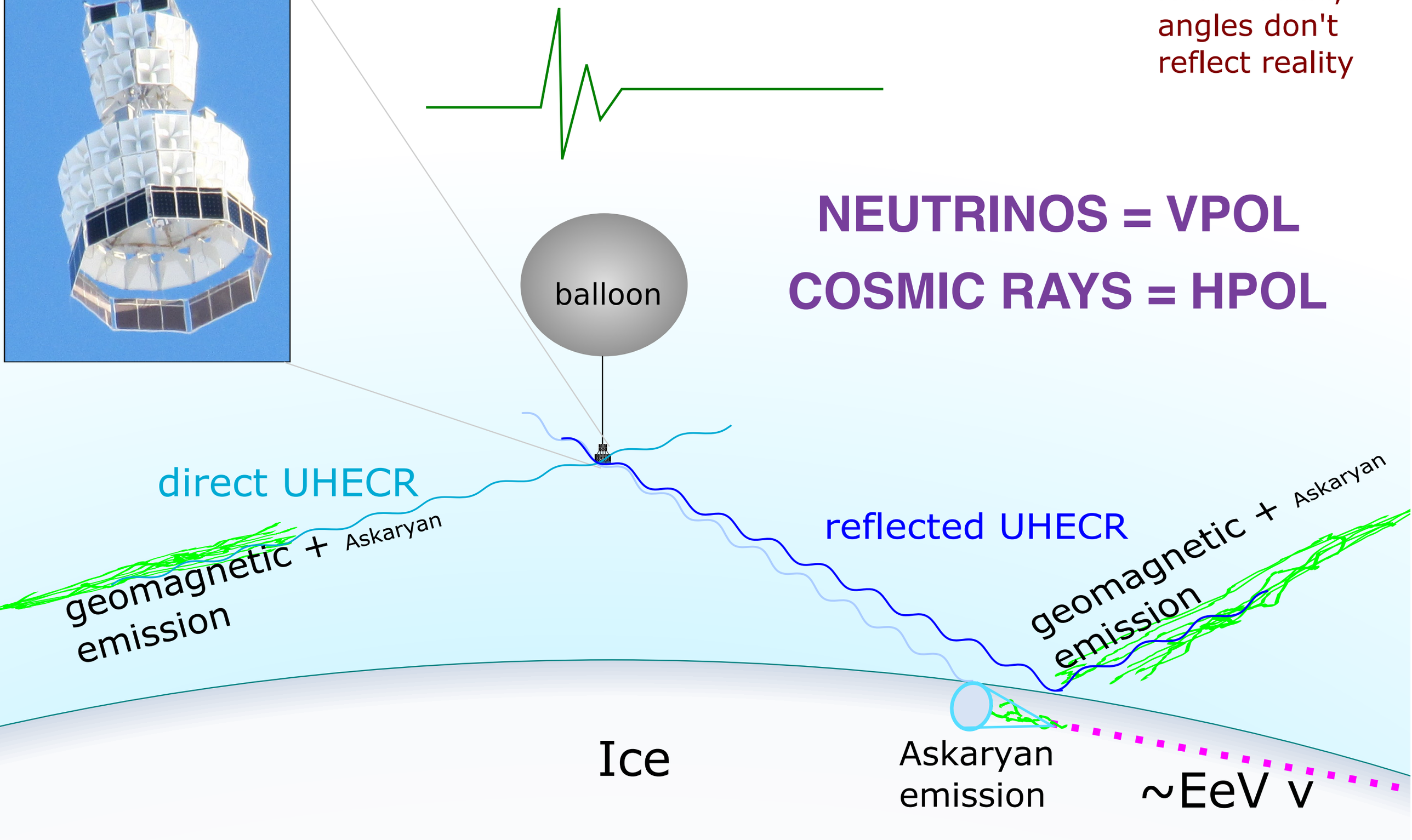


ANtarctic **I**mpulsive **T**ransient **A**ntenna

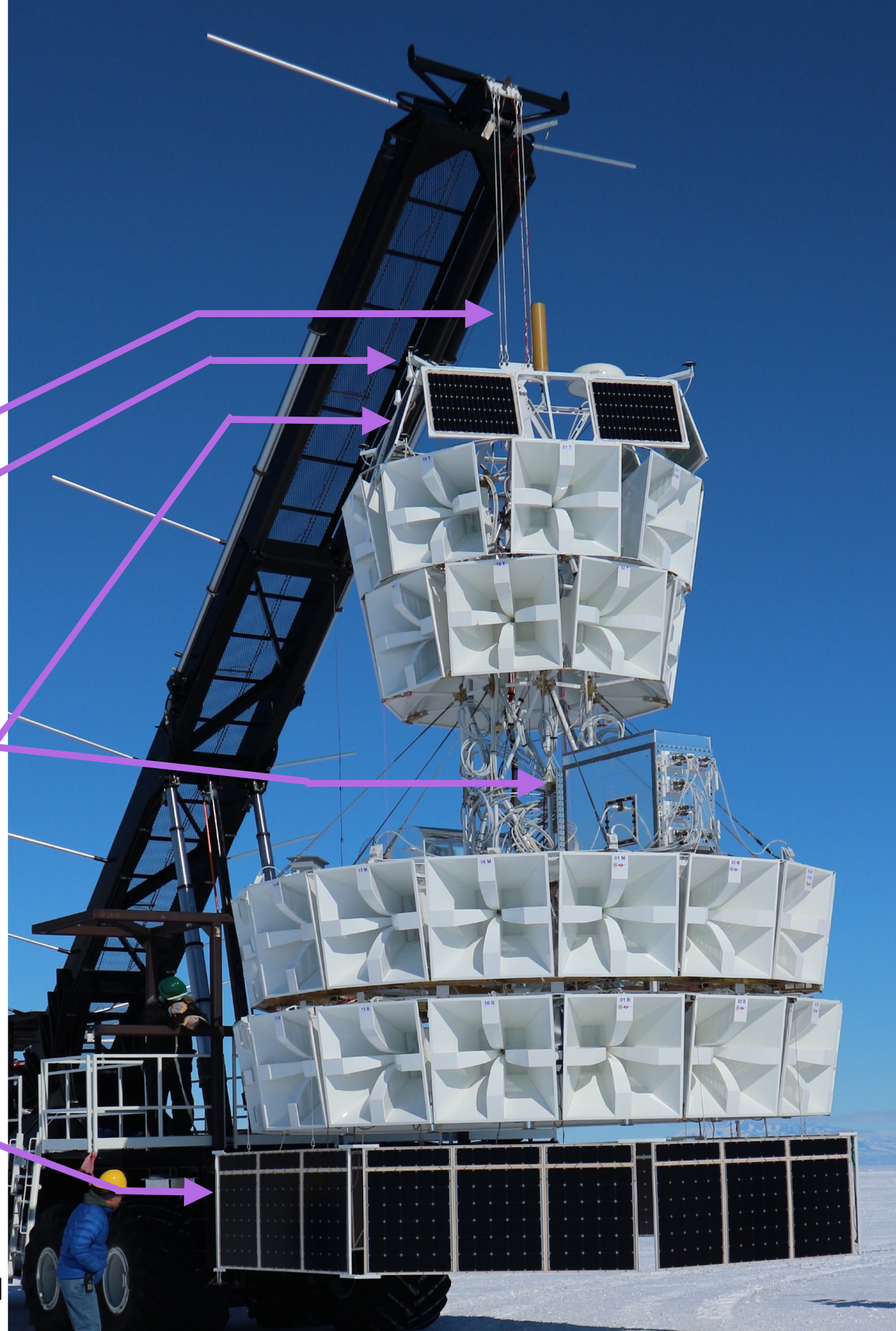
Not to scale, angles don't reflect reality

NEUTRINOS = VPOL

COSMIC RAYS = HPOL



ANITA instrument



ANITA instrument

TDRSS & Iridium antennas

GPS antennas

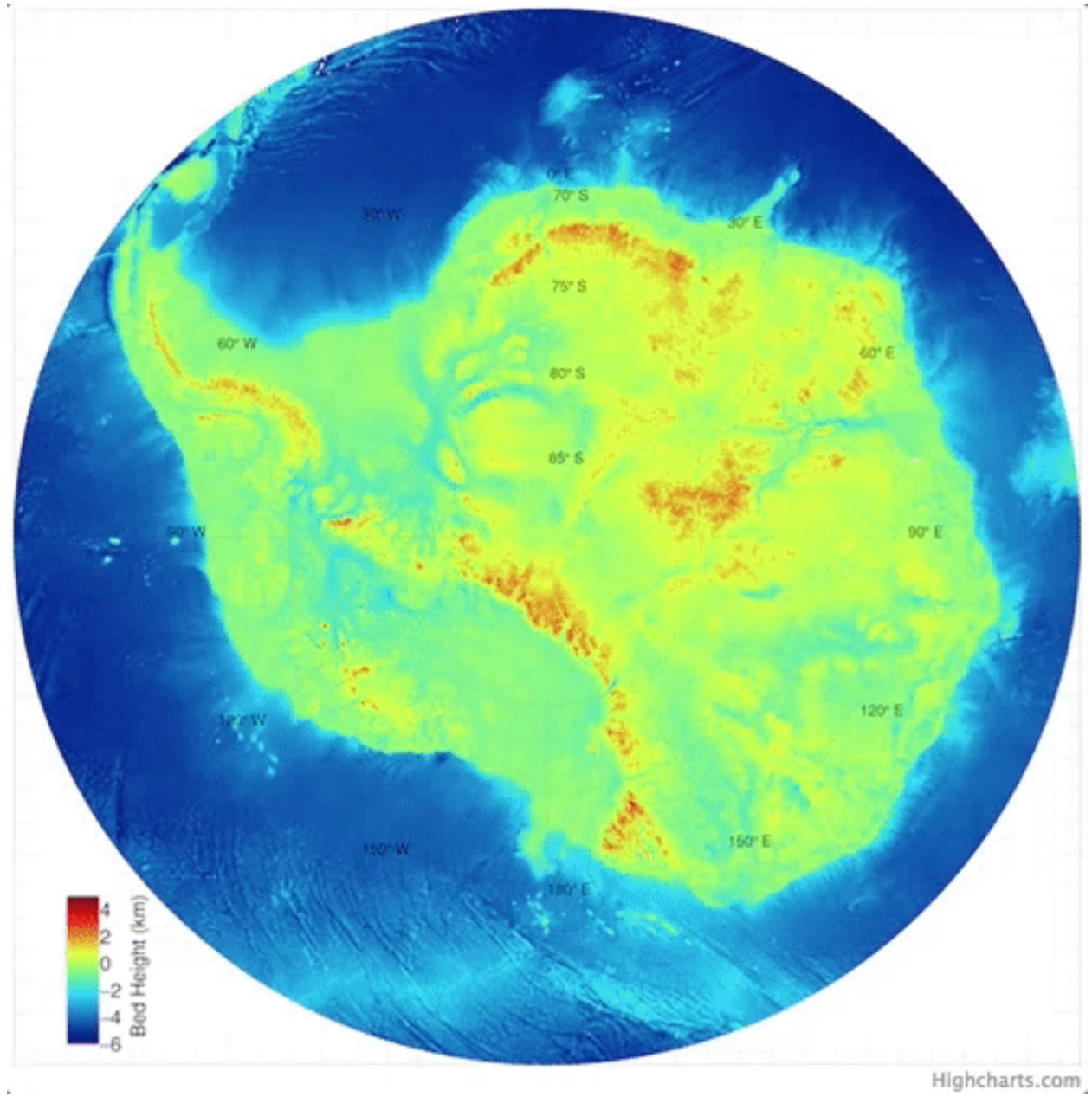
Instrument box

48 quad-ridged horn antennas

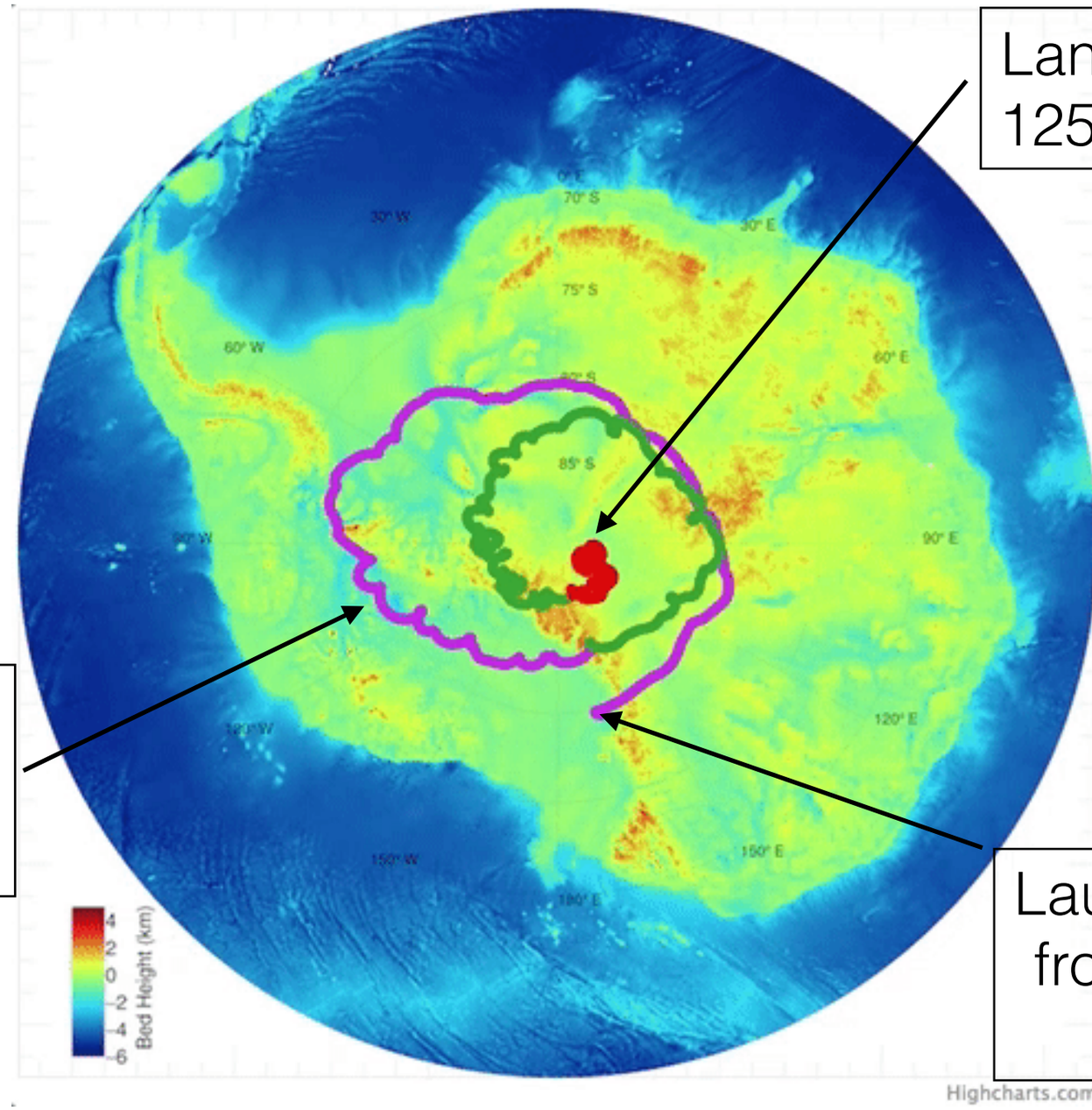
Solar panels

ANITA-4 taking off

ANITA-4 flight path



ANITA-4 flight path



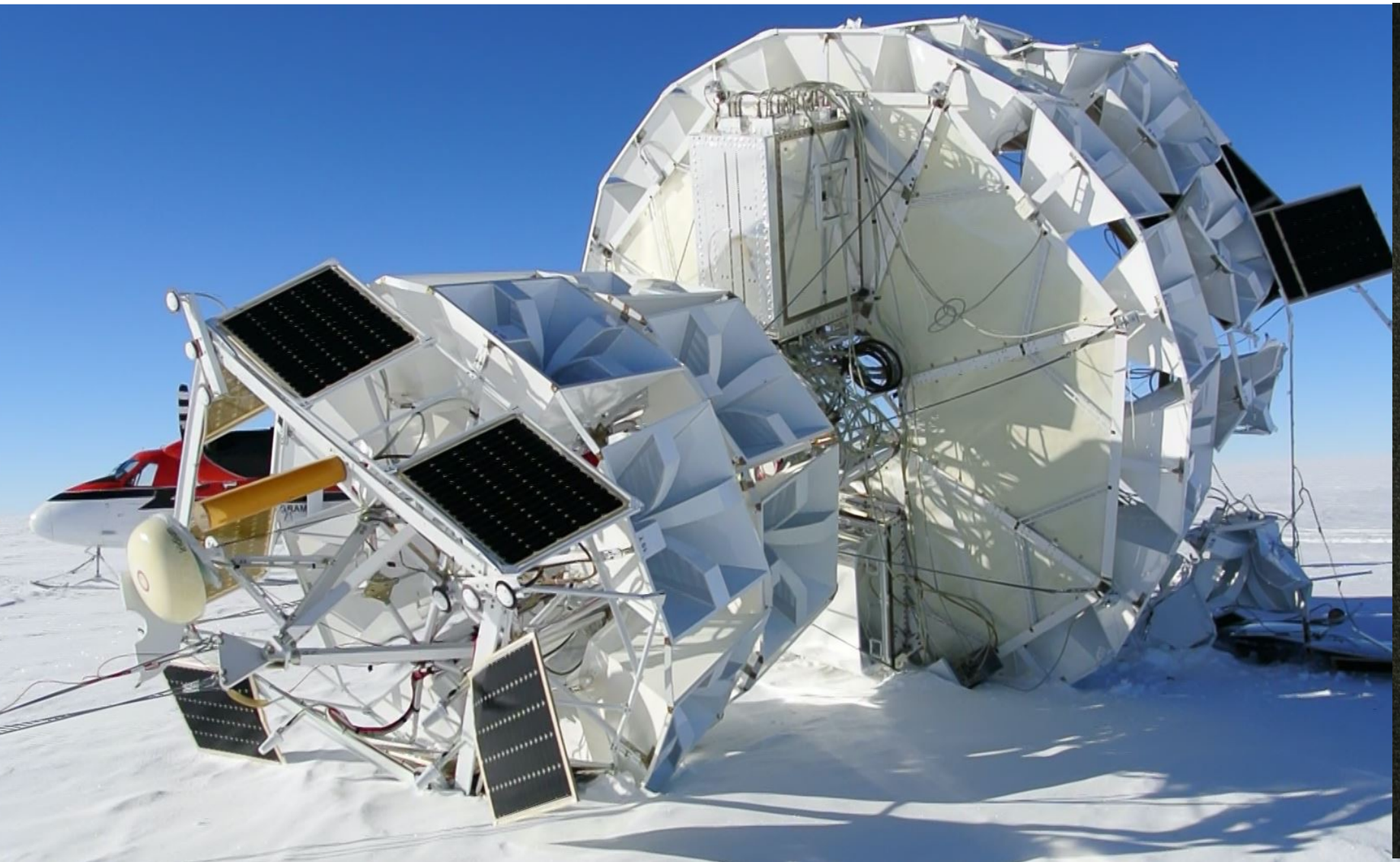
Landed Dec 30th 2016
125km from South Pole

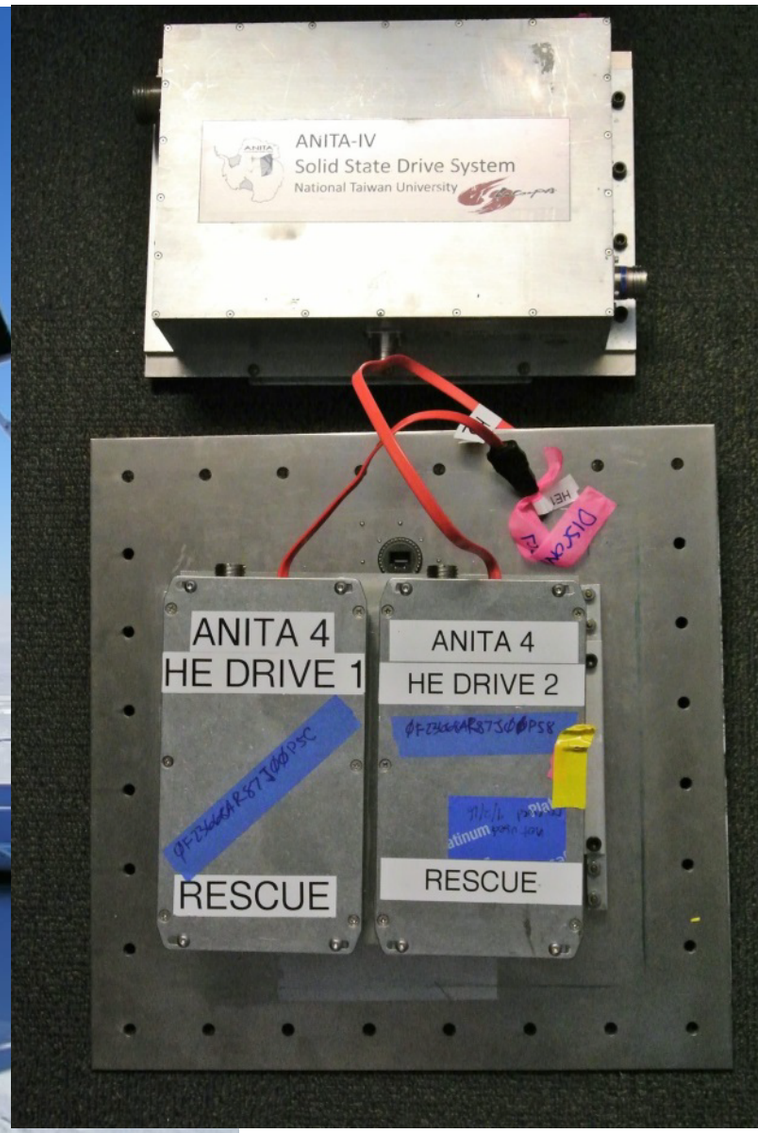
Calibration pulser at WAIS to optimise pointing resolution

Launched Dec 2nd 2016 from NASA LDB facility, near McMurdo

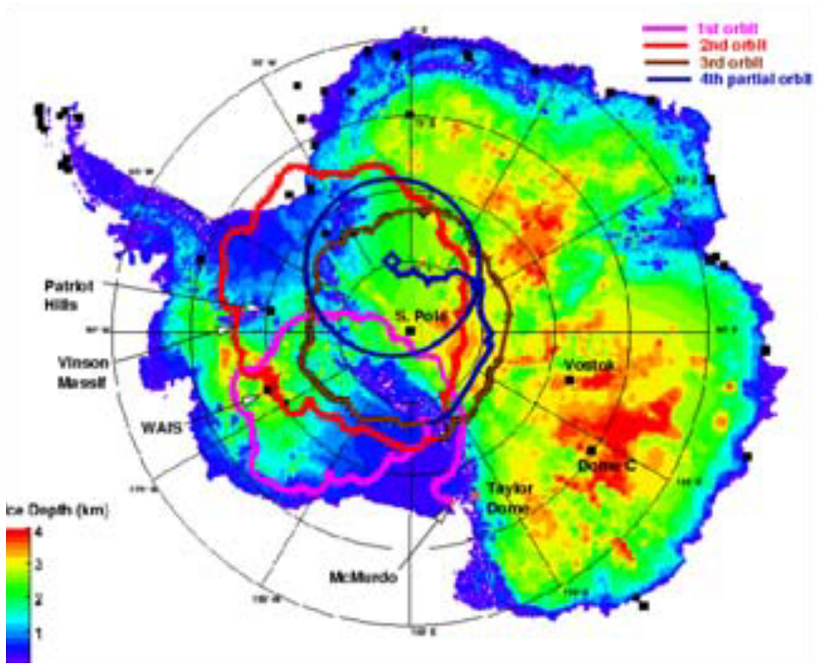
ANITA-4 Recovery

- Partial recovery done on Jan 10th 2017
- Full recovery done in December 2017



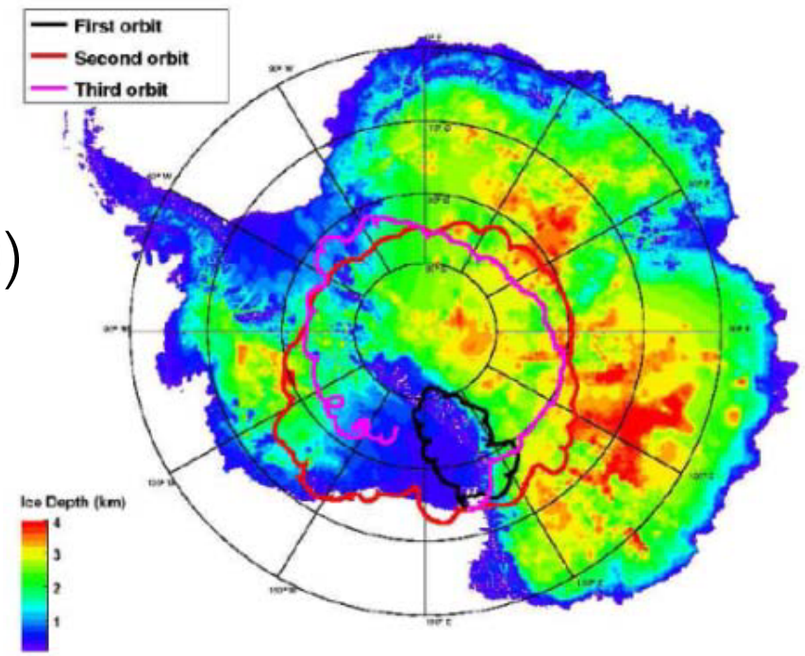


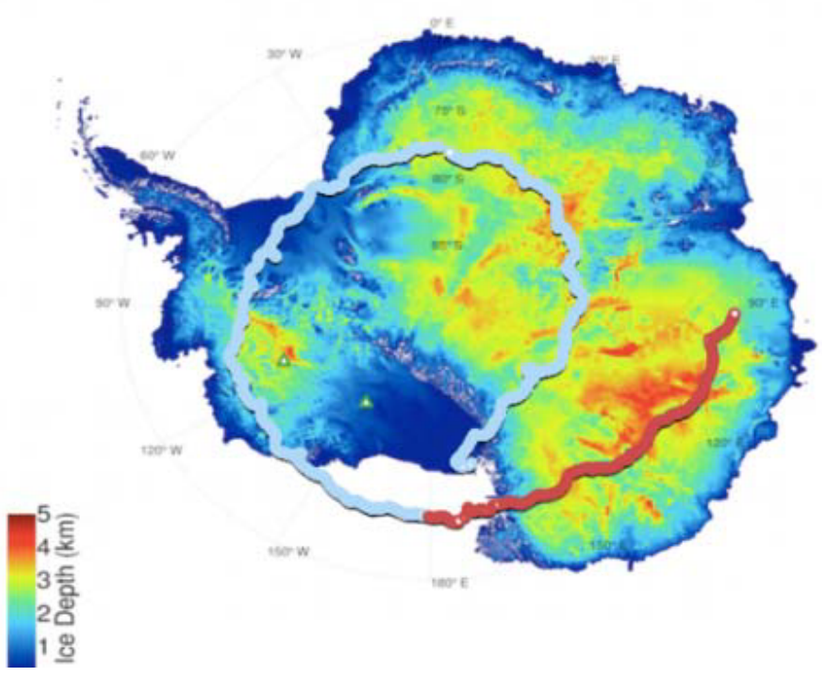
ANITA Flights



ANITA-1
(2006-2007)
35 days

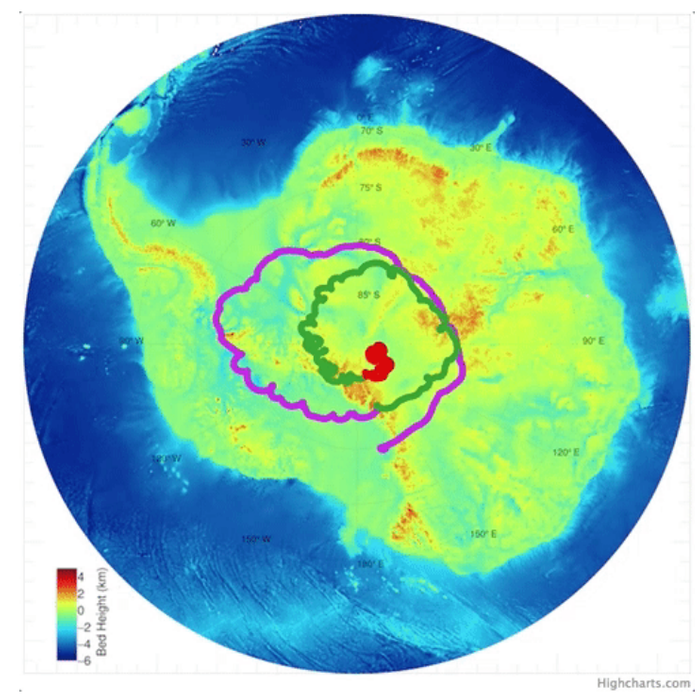
ANITA-2
(2008-2009)
30 days



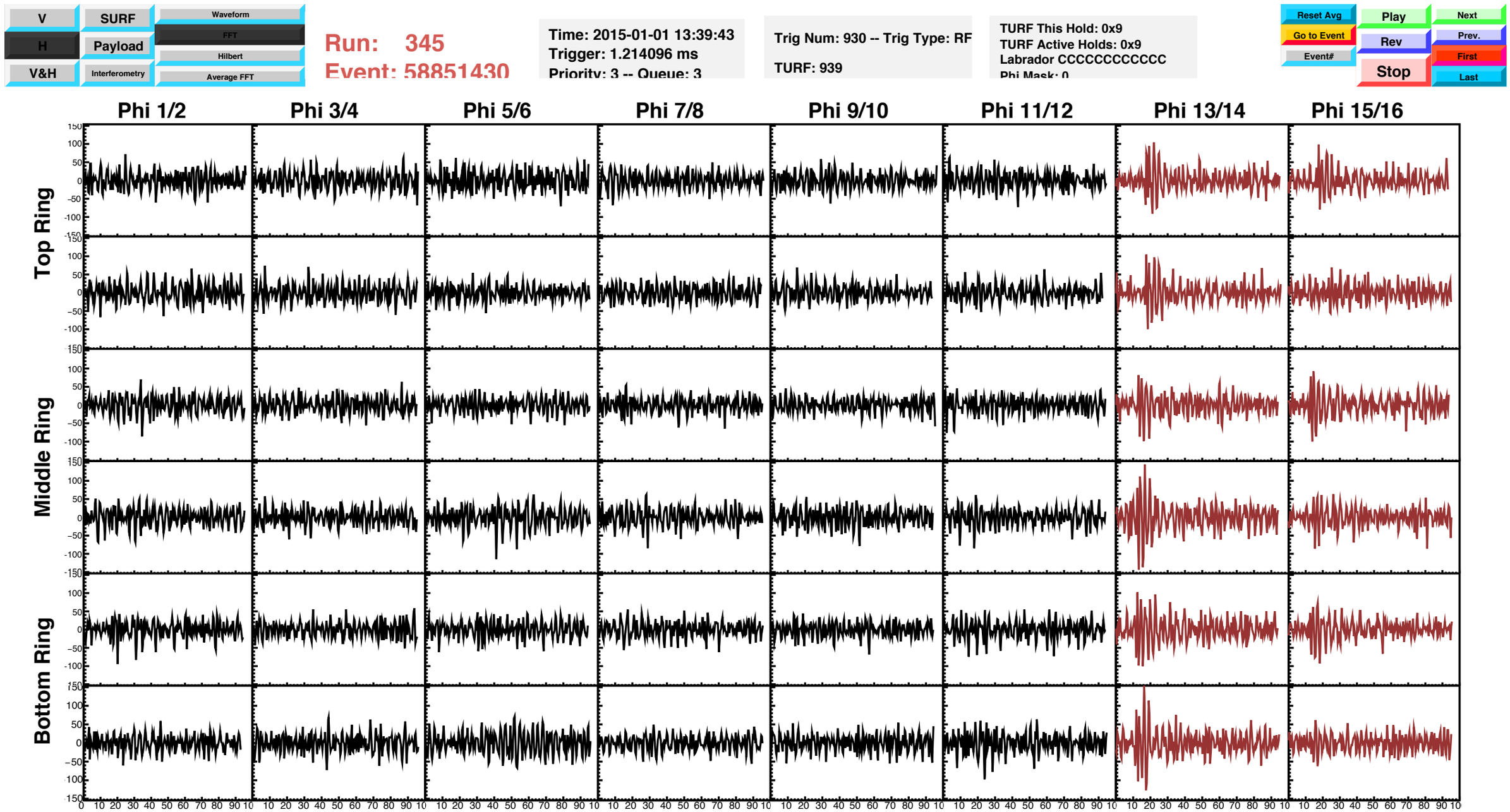


ANITA-3
(2014-2015)
22 days

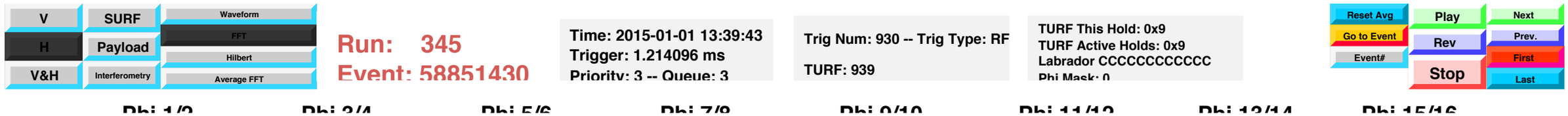
ANITA-4
(2016)
30 days



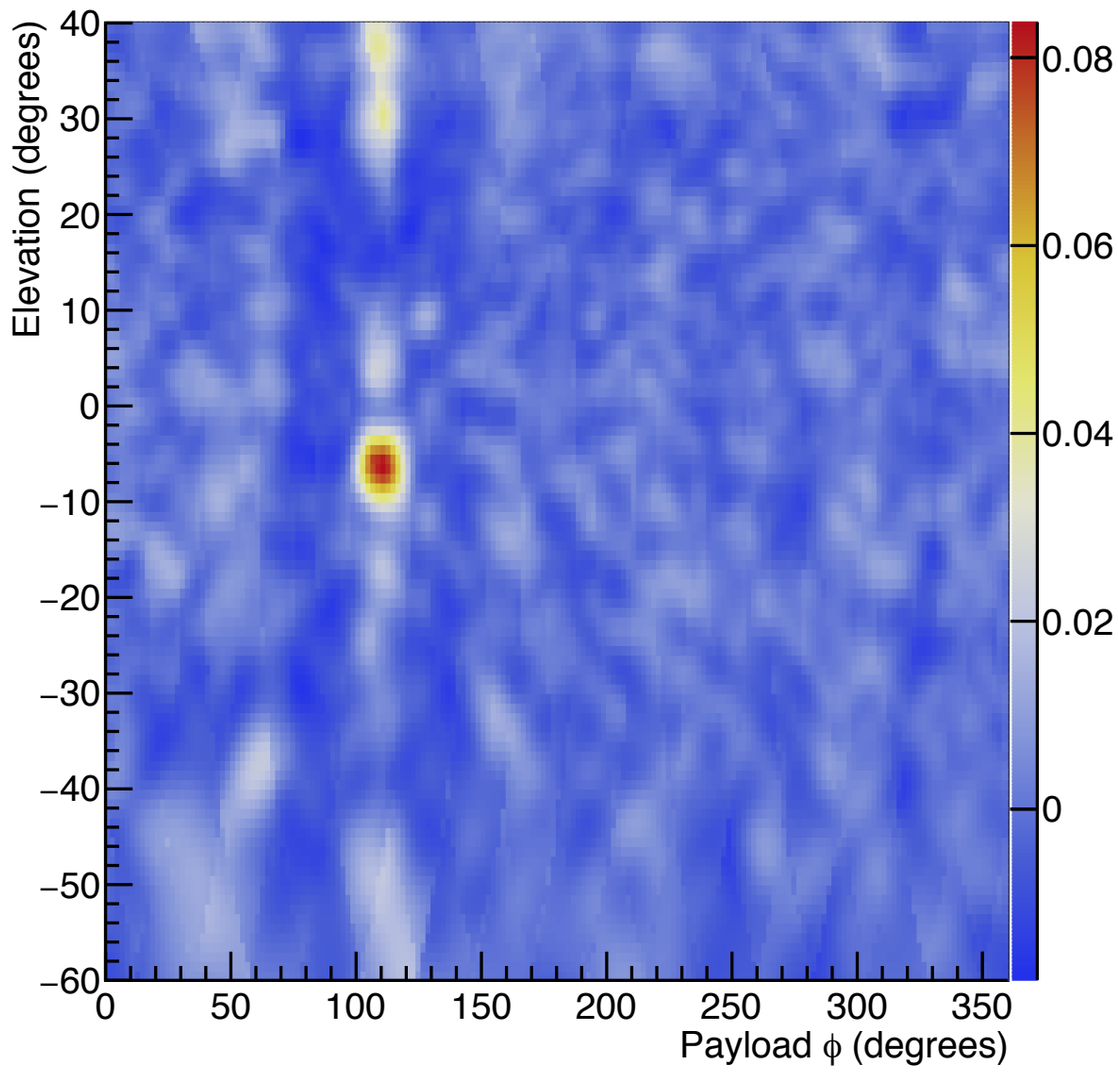
How ANITA sees the world



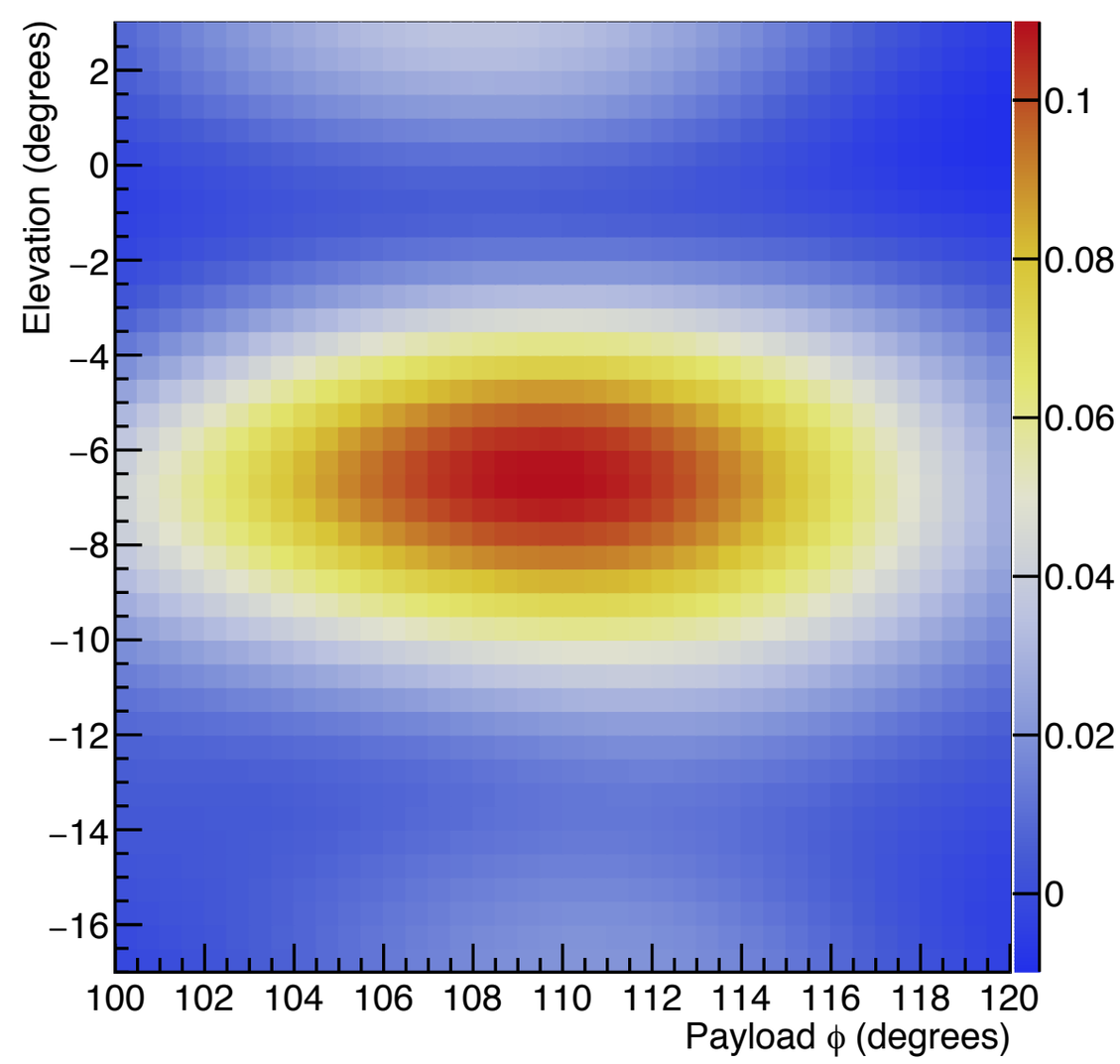
How ANITA sees the world



Interferometric Map



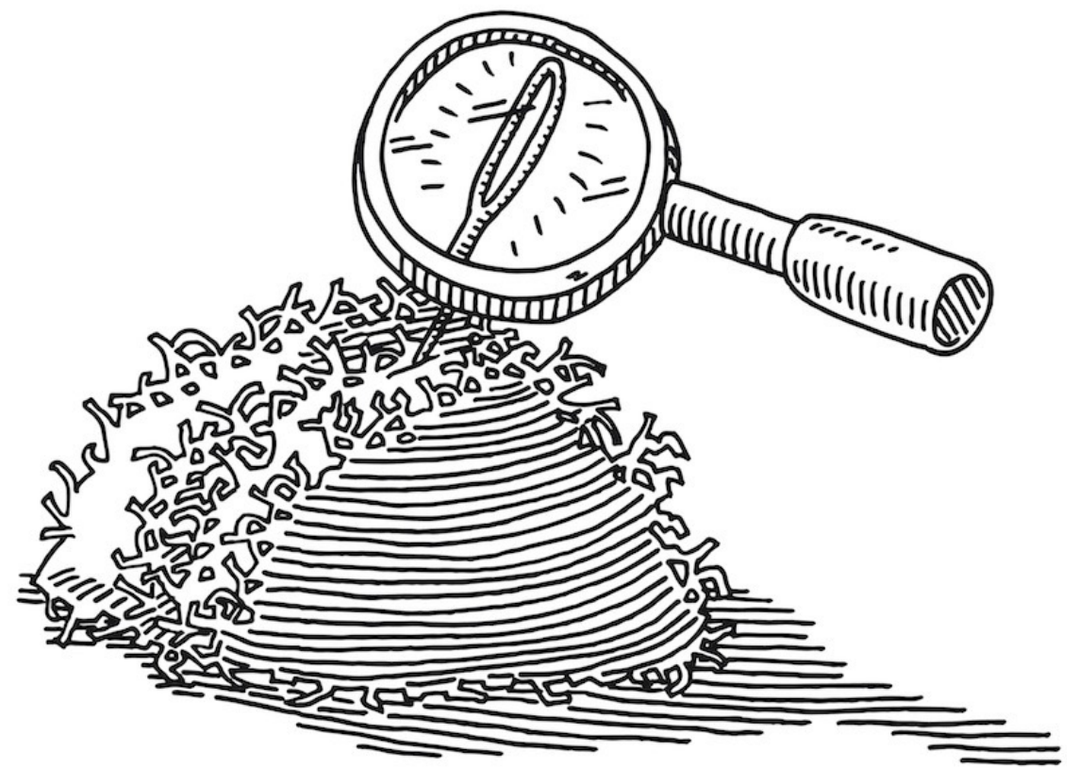
Zoomed Map



Needle(s) in a haystack

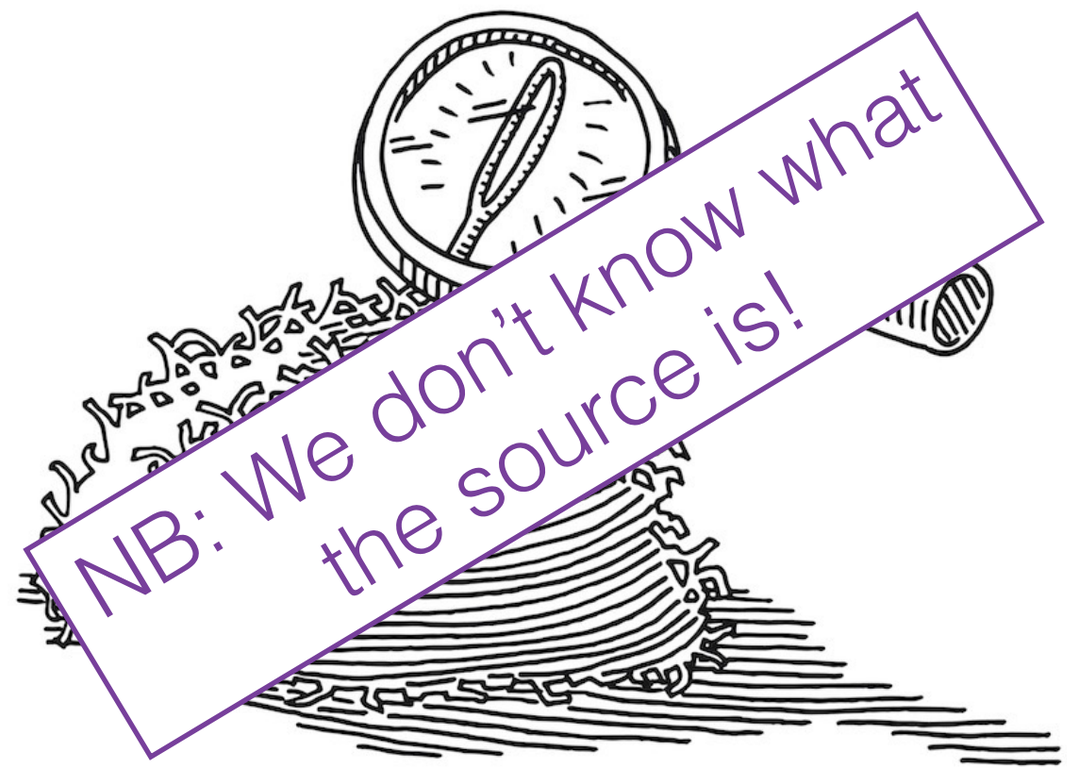
The challenge

- ~100 million events
- (maybe) a few neutrinos
- Tens of cosmic rays



The challenge

- ~100 million events
- (maybe) a few neutrinos
- Tens of cosmic rays

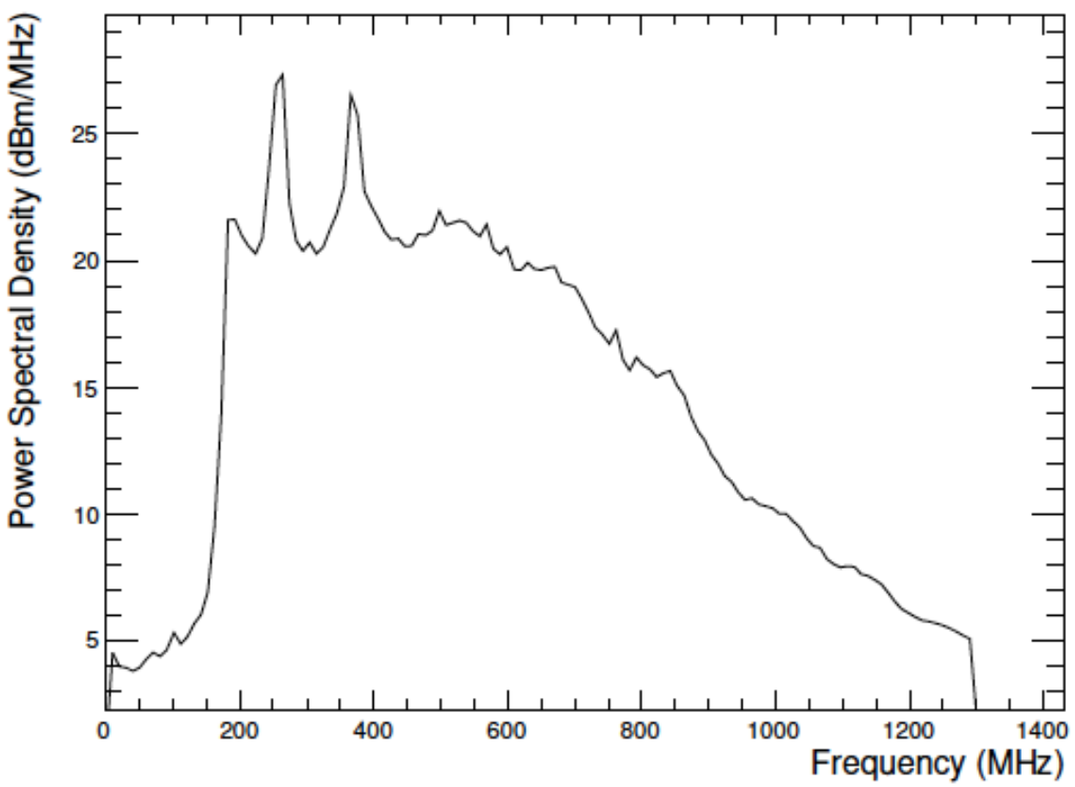


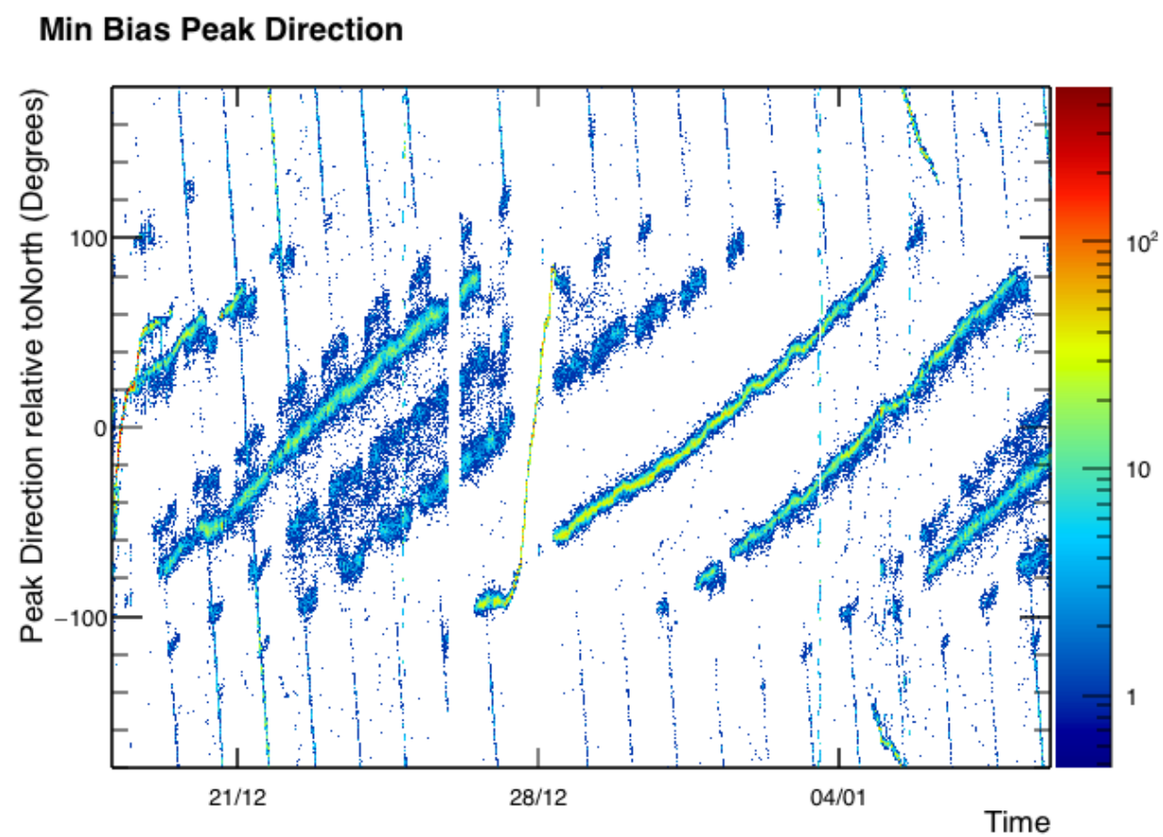
Backgrounds

- Continuous waves
- Payload blasts
- Thermal noise
- Anthropogenic impulsive events

Continuous Waves

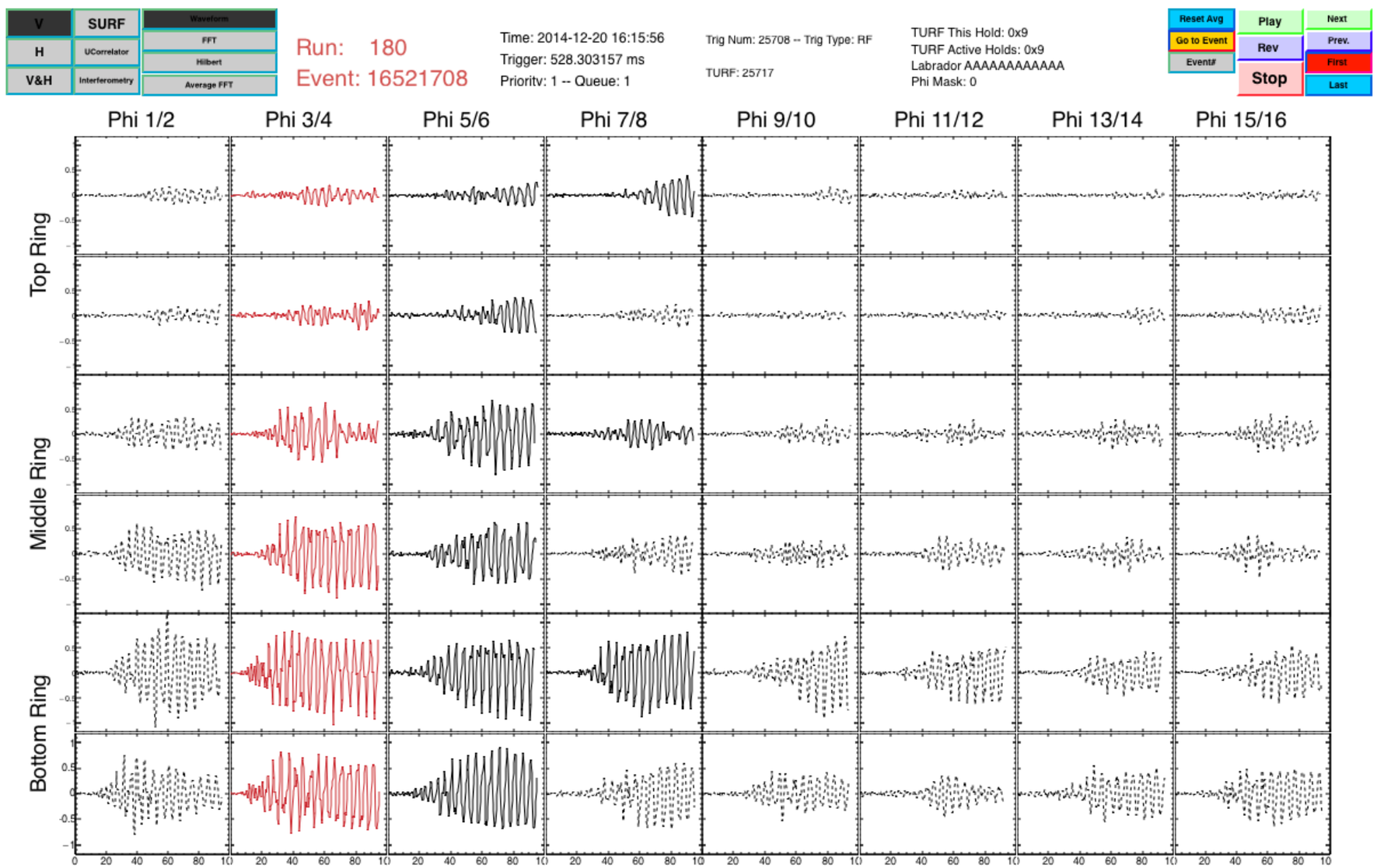
- Satellites and human bases using communications in the bands:
  - 260 MHz
  - 380 MHz
- How to get rid of this?
  - ANITA-3: software
  - ANITA-4: hardware





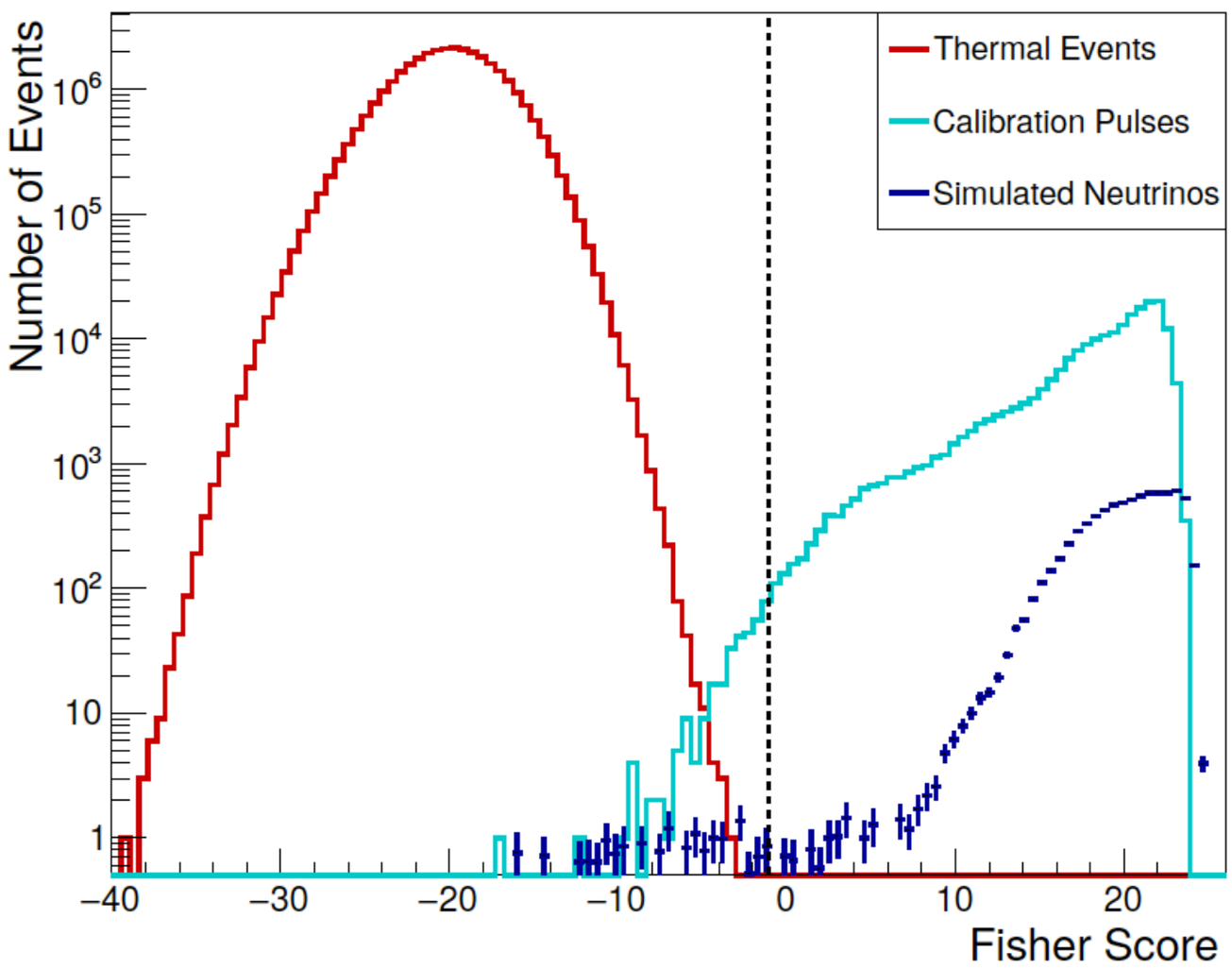
Payload blasts

- Impulsive radio frequency emissions generated by electronics on board
- Exact origin is unknown
- Removed by simple cuts



Thermal noise

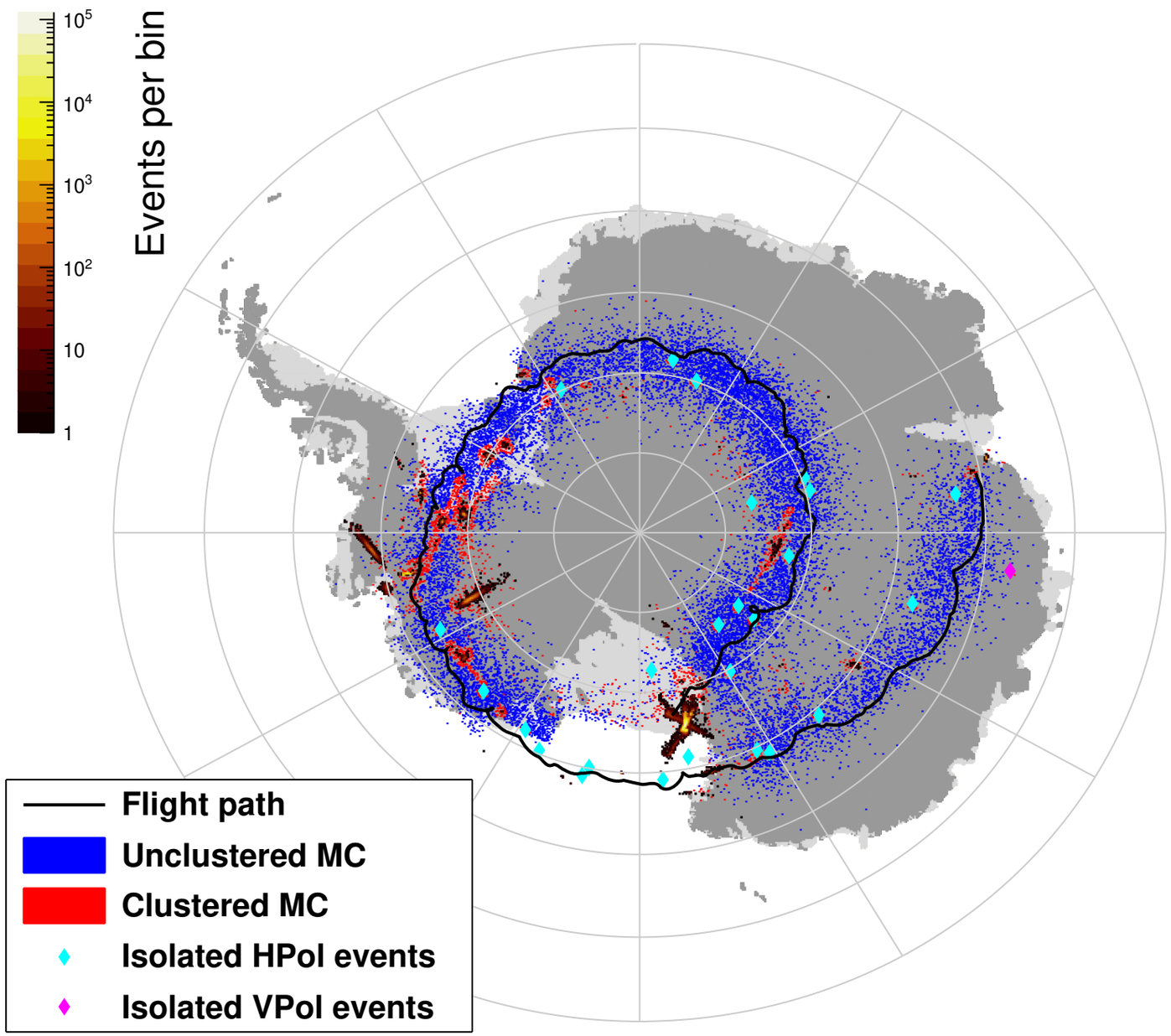
- Vast majority of ANITA events are thermal noise
- Use Fisher discriminant based on impulsivity variables



- Background sideband: above horizon triggers
- Simulation: cosmogenic neutrinos following the Kotera mix max model **(arxiv:1903.11043)**

Clustering

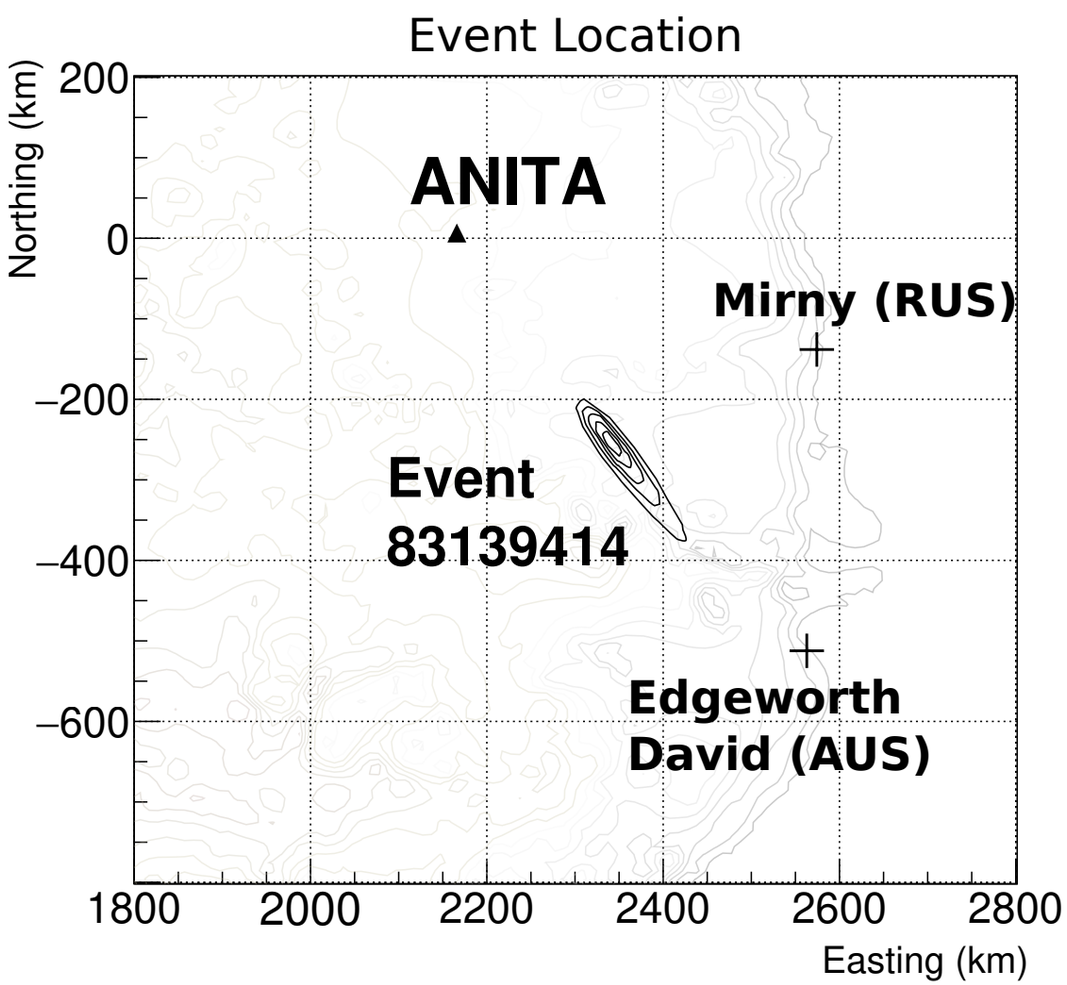
- From previous cuts, ~500k events

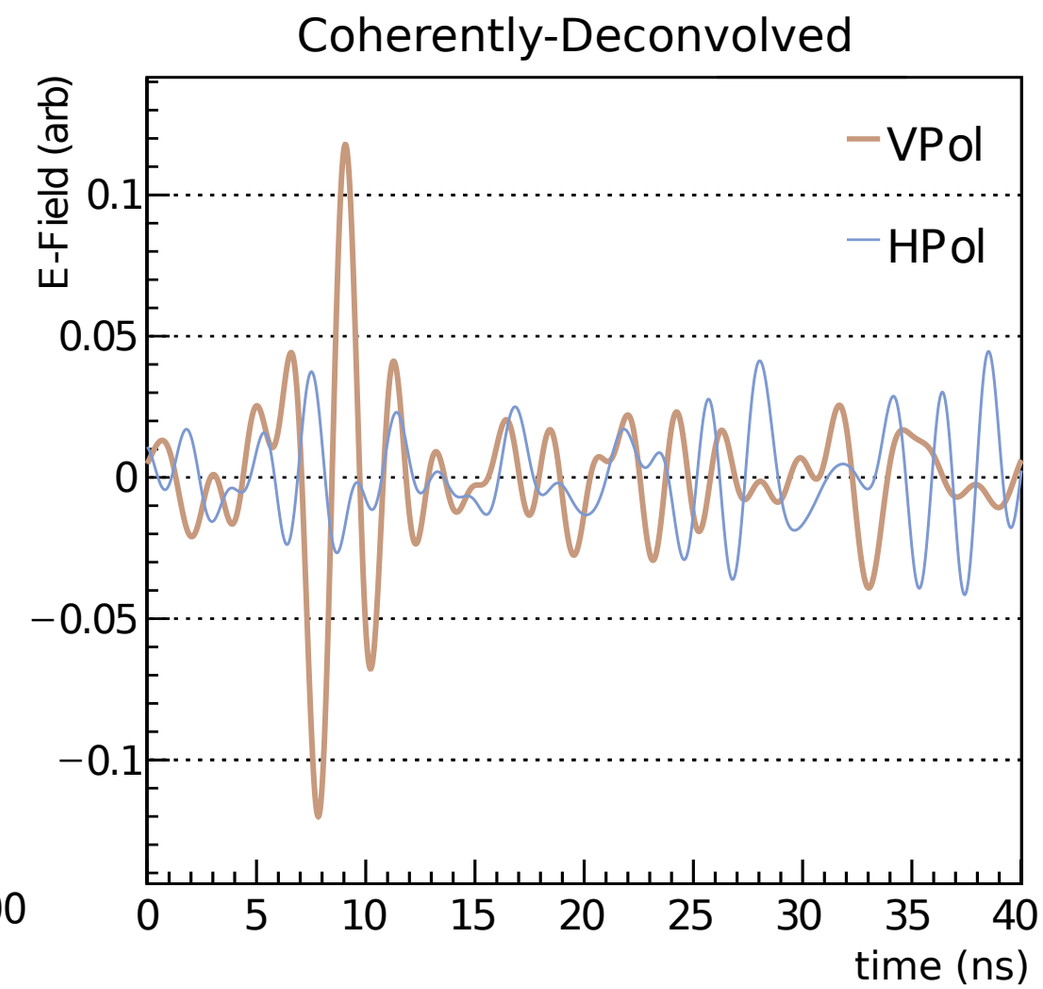


- Look for isolated singlets and doublets
- Remove anything that clusters with human bases
- Remove anything which forms a cluster of 3 or more

ANITA-3: What's left?

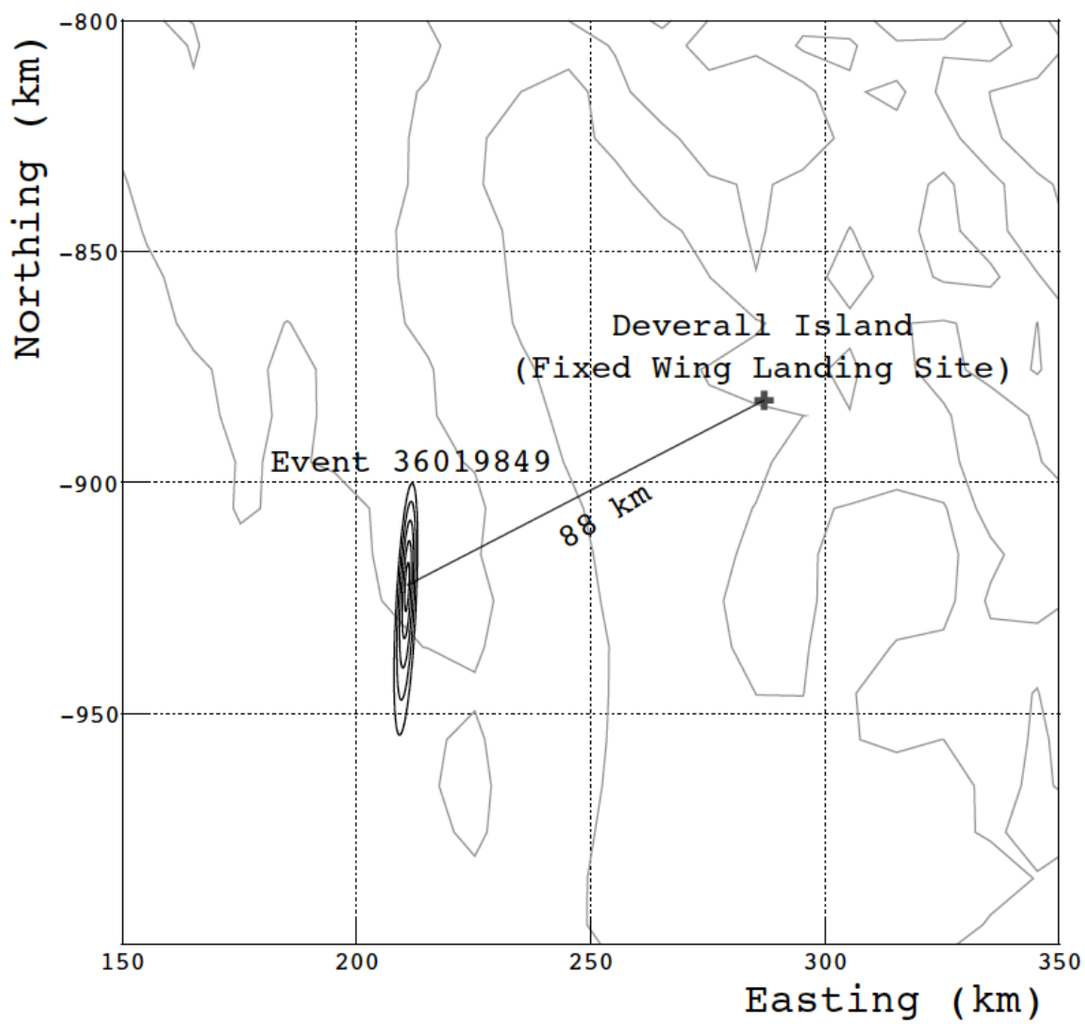
- One V-POL candidate
- Background estimate: $0.7^{+0.5}_{-0.3}$ per polarisation
- No known human activity within 260km

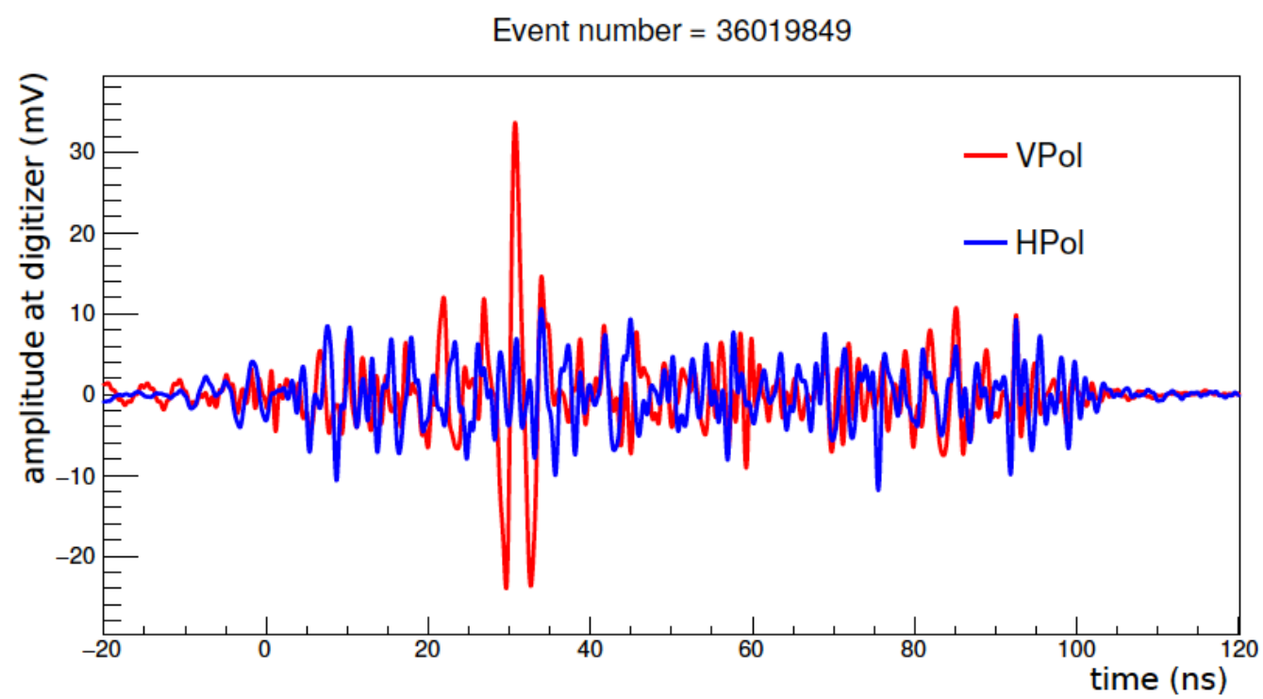




ANITA-4: What's left?

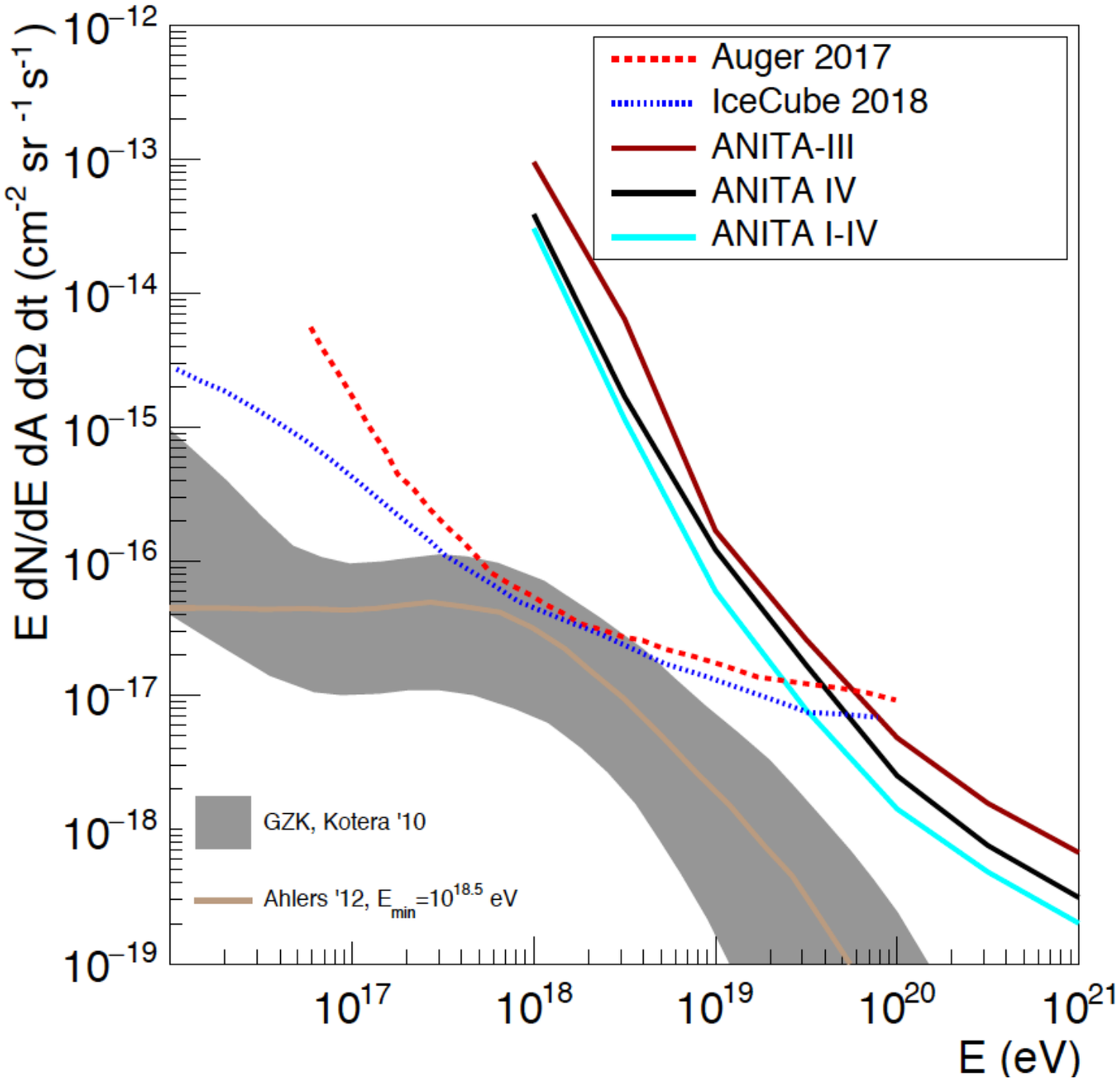
- One V-POL candidate
- Background estimate: $0.64^{+0.69}_{-0.45}$ per polarisation
- On Ross Ice Shelf (~300m ice thickness)





Neutrino limit

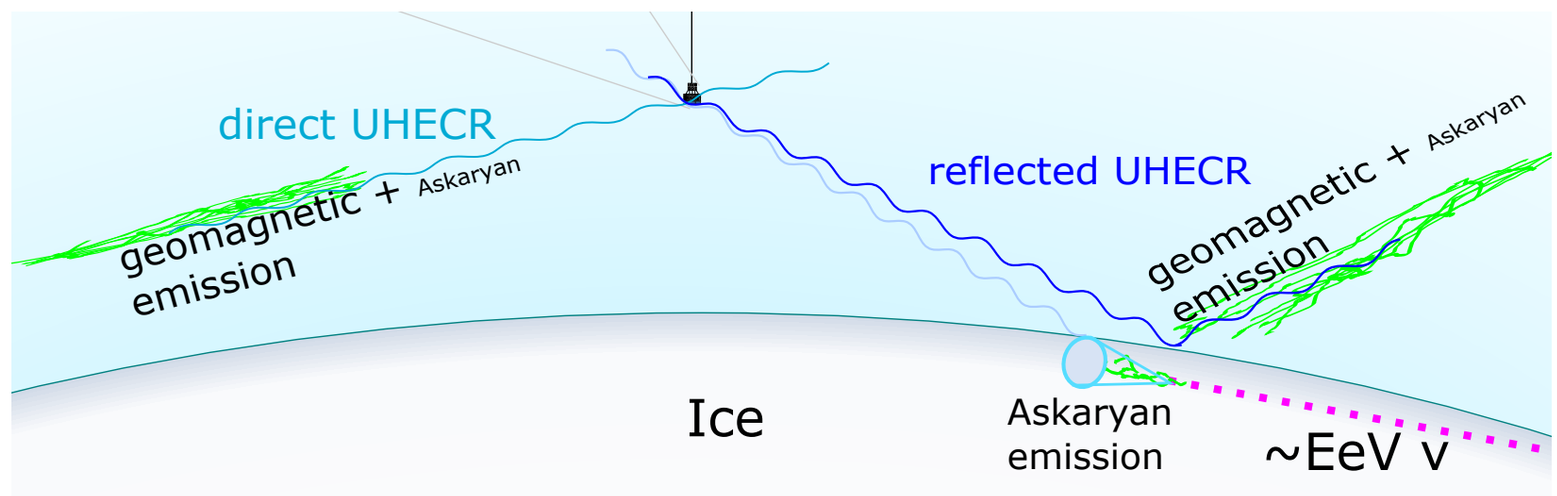
Limit on all-flavour-sum diffuse UHE neutrino flux

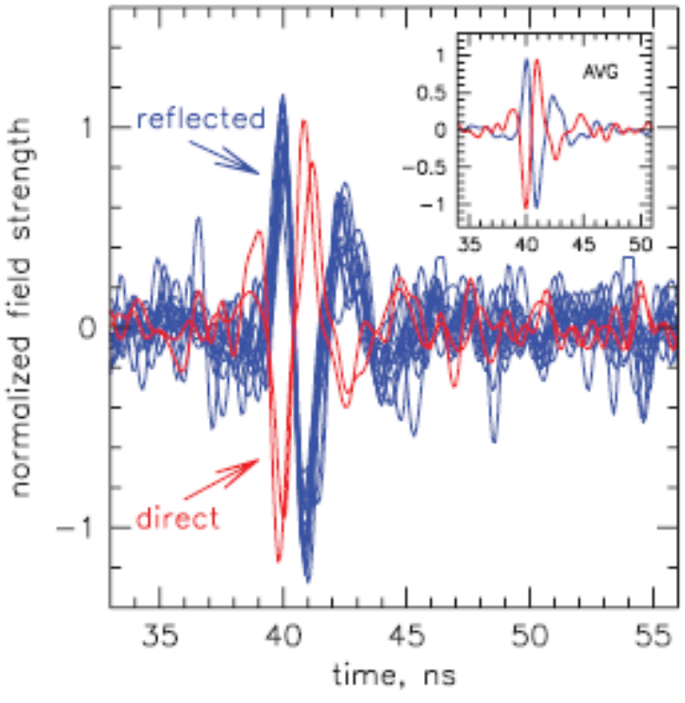


UHE cosmic rays

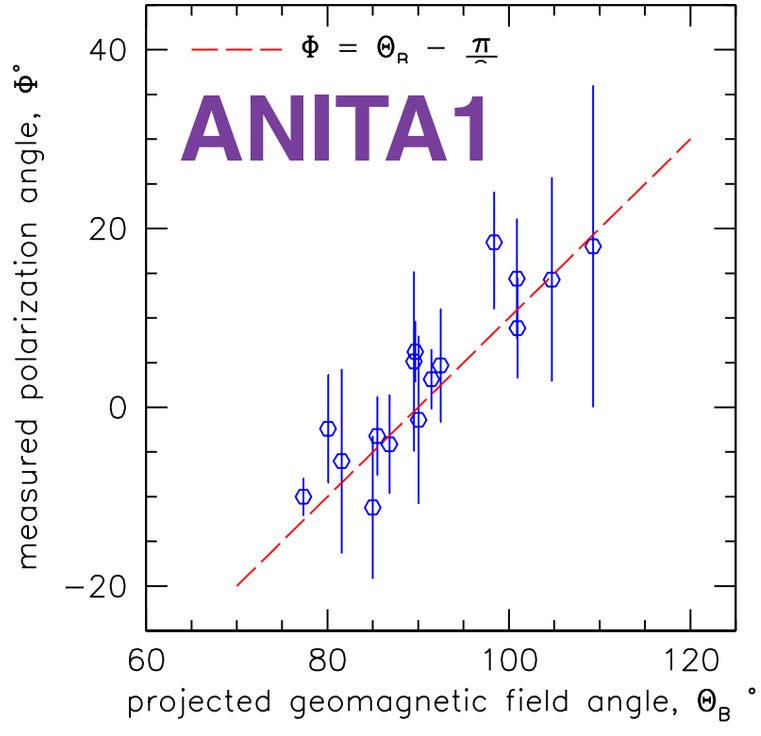
UHECR

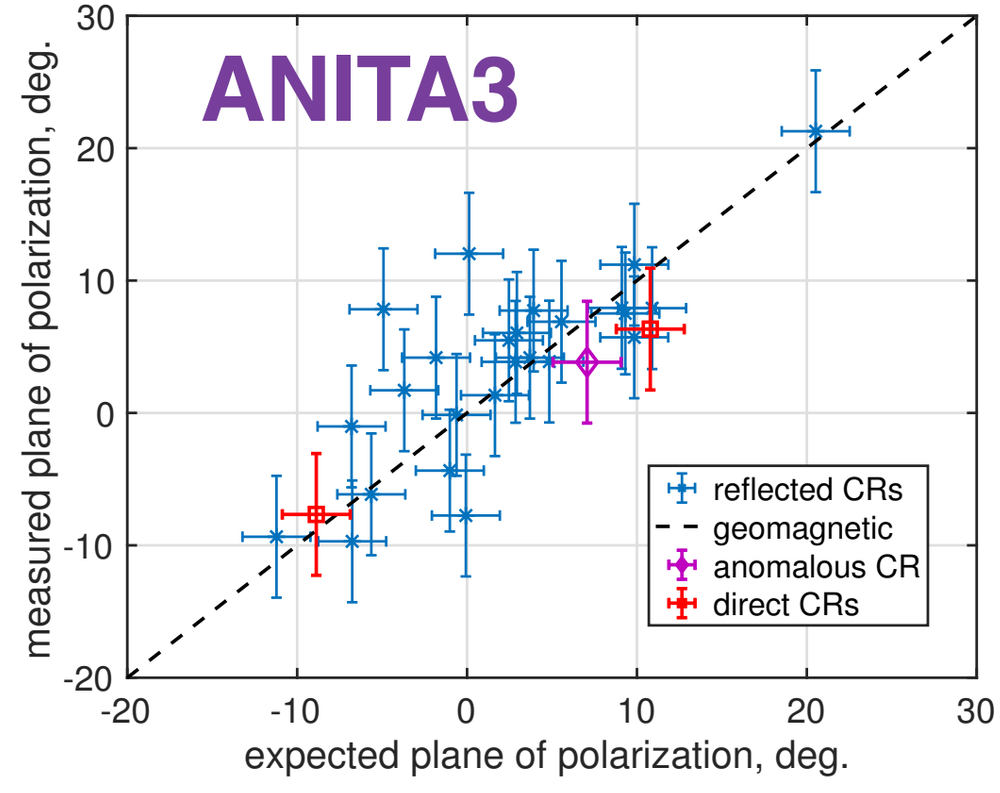
ANITA1: 16 UHECR
 14 reflected + 2 direct
ANITA-2: 2 UHECR
 H-pol trigger was off
ANITA-3: 25 UHECR
ANITA-4: analysis in progress





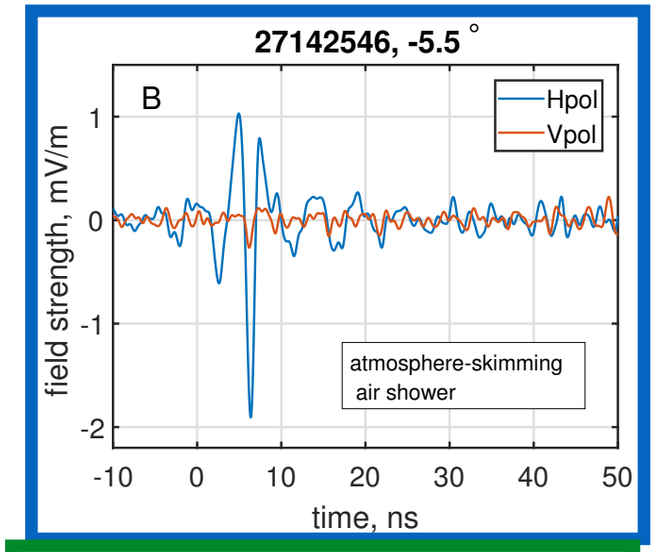
PRL 105, 151101 (2010)

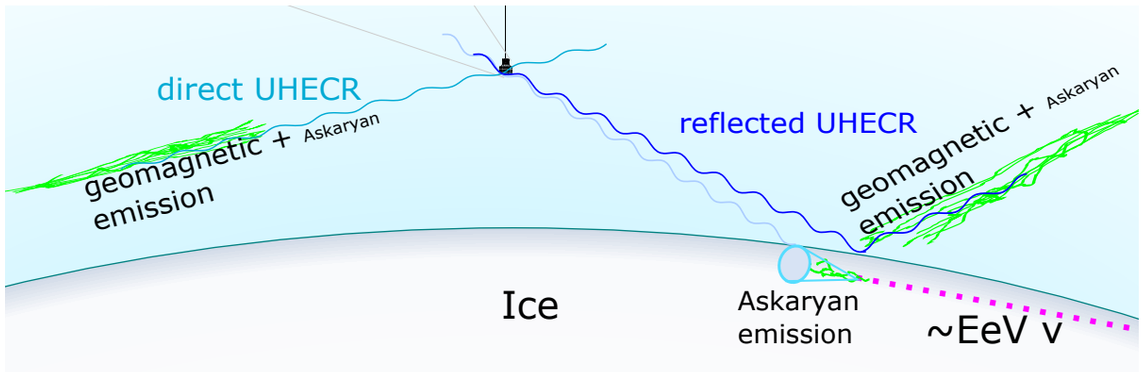


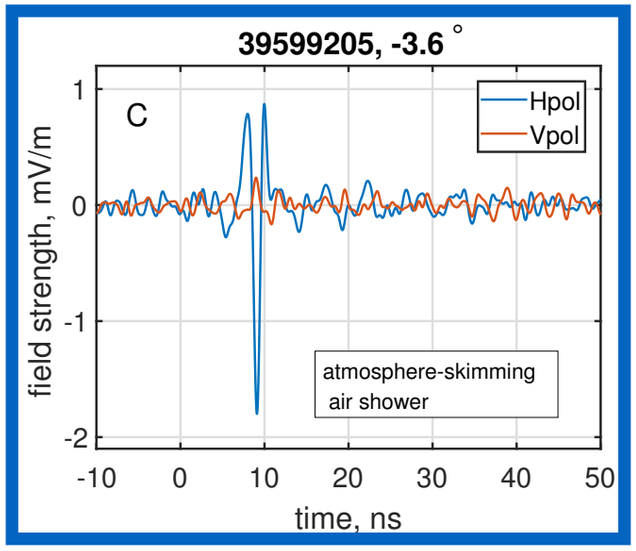


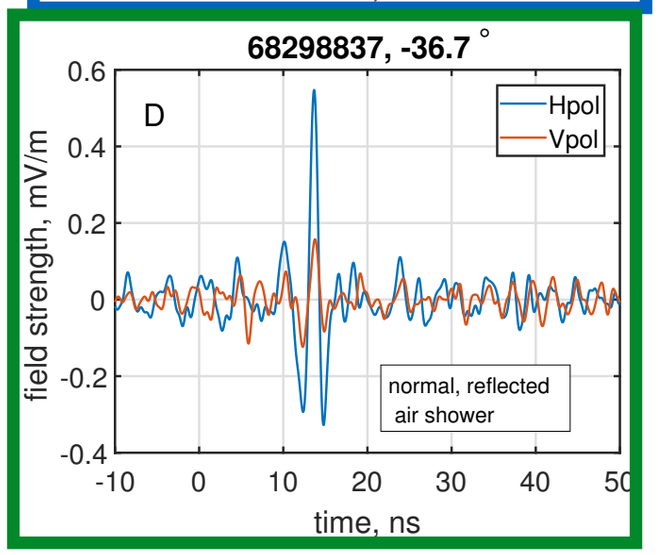
arXiv:1803.05088 [astro-ph.HE]

2 mystery events





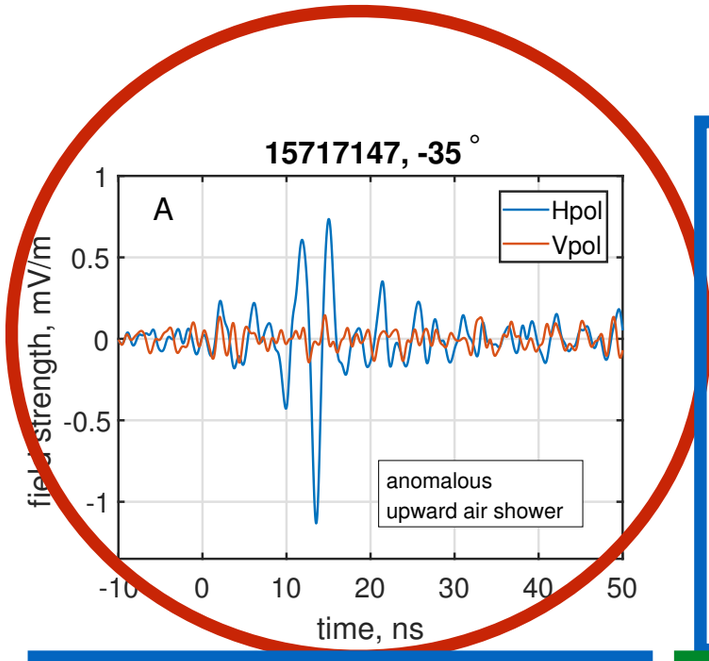


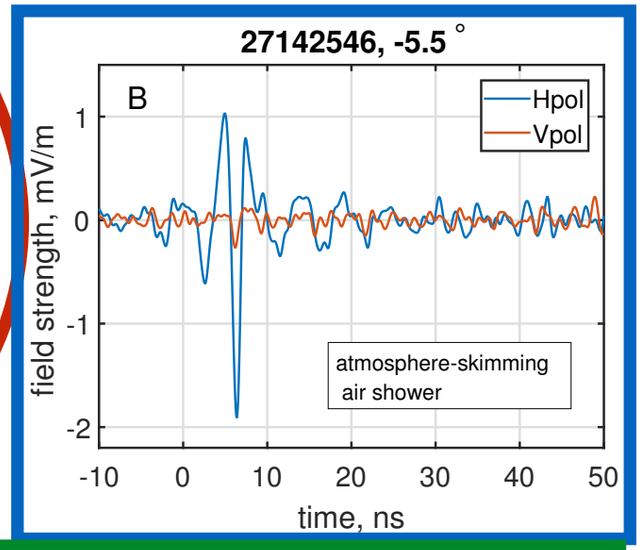


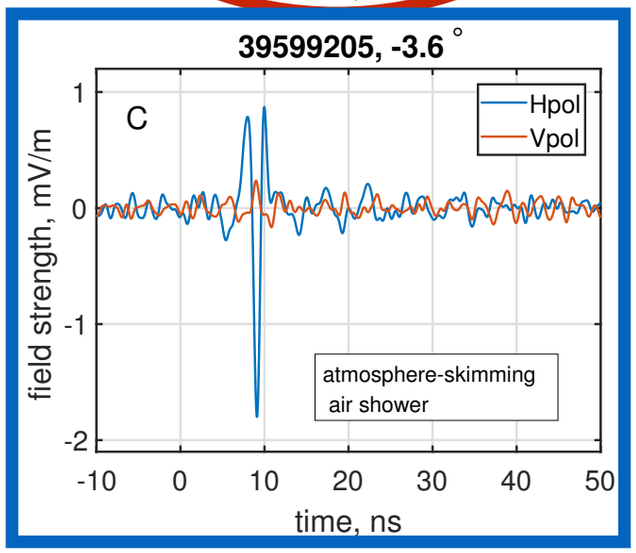
Direct Cosmic Rays

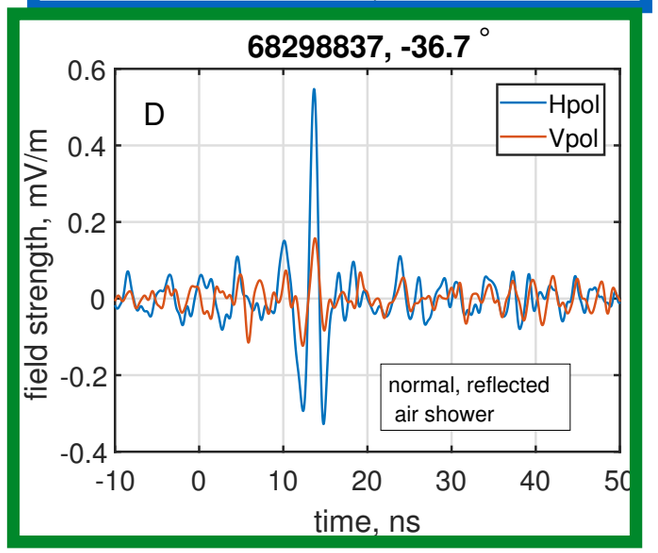
Reflected Cosmic Rays

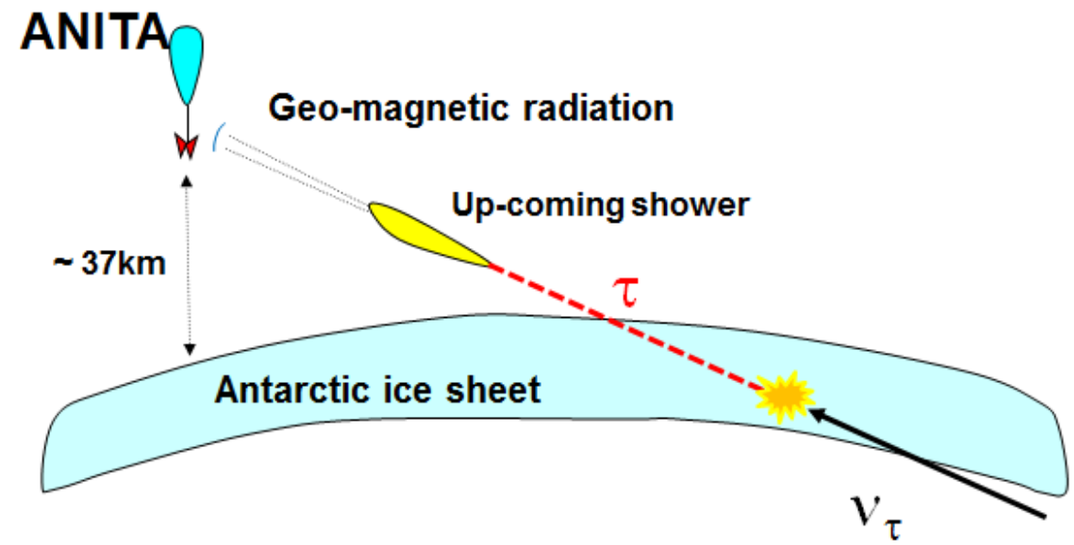
2 mystery events











Direct Cosmic Rays

Reflected Cosmic Rays

NEW PHYSICS ?

Chord length: 5500-7000 km (20-30,000km water equivalent)
1600km SM interaction length @ 1 EeV

Background estimate < 10^{-2}

All news is good news?

LIVESCIENCE

NEWS TECH HEALTH PLANET EAR

Live Science > Space

Bizarre Particles Keep Flying Out of Antarctica's Ice, and They Might Shatter Modern Physics

By Rafi Letzter, Staff Writer | September 26, 2018 08:16pm ET

0

0

IFLSCIENCE!

PHYSICS
Scientists Confirm The Electron Is Truly Round, And It's A Big Deal.

PHYSICS
Dandelion Seeds Reveal A New Form Of Aerodynamics

PHYSICS
These Are Stephen Hawking's Last Messages To Humanity

PHYSICS
Stephen Hawking's Final Paper Tackles A Crucial Black Hole Mystery

An Astonishing Discovery Might Have Just Broken Particle Physics

THE DAILY NEWSLETTER
Sign up to our daily email newsletter

NewScientist

News Technology Space Physics Health Environment Mind Video | Travel Live Jobs

Home | News | Physics

22

Moveable Hacking Environment Space Gaming Health Tech Science

COSMIC MYSTERIES | By Daniel Oberhaus | Sep 28 2018, 6:40pm

Mysterious Cosmic Rays Shooting from the Ground in Antarctica Could Break Physics

NASA went searching for micro black holes in Antarctica. Instead, it detected cosmic rays shooting from the ground and some physicists think it could be evidence of a supersymmetric particle.

DAILY NEWS 28 September 2018

Weird signals in Antarctica could be hints of a new realm of physics

ScienceNews
MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC

SUPPORT SCIENCE NEWS
Science News is a nonprofit.
Help us keep you informed.
SUBSCRIBE

Search Science News...

MENU TOPICS BLOGS EDITOR'S PICKS MAGAZINE

LATEST | MOST VIEWED

NEWS IN BRIEF
T. rex pulverized bones with an incredible amount of force
BY CAROLYN GRAMLING OCTOBER 22, 2018

RETHINK
An eye disorder may have given Leonardo da Vinci an artistic edge
BY AMANDA B. KEENER OCTOBER 22, 2018

NEWS PARTICLE PHYSICS

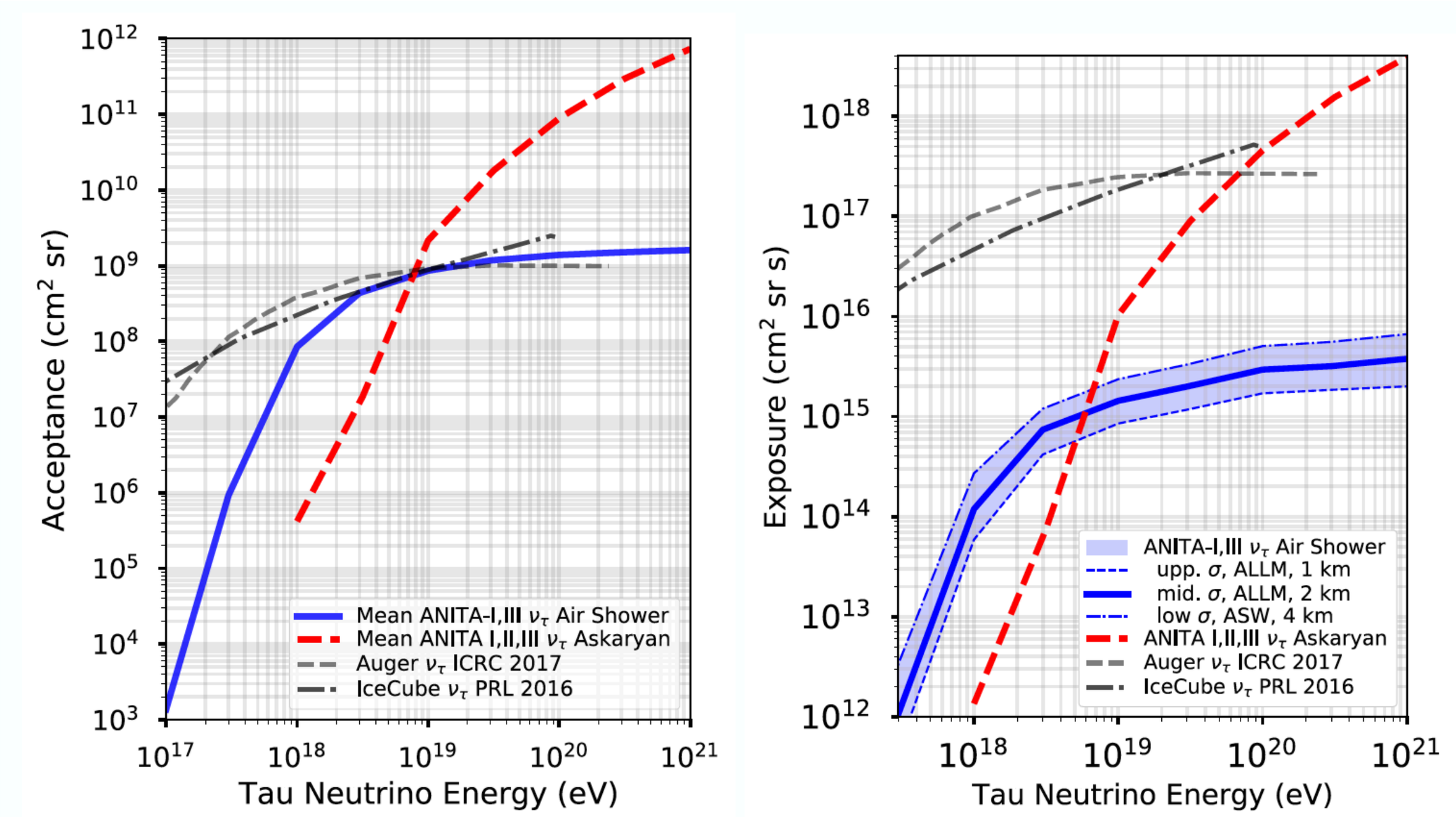
Hints of weird particles from space may defy physicists' standard model

L. Cremonesi

"UHE neutrinos and ANITA"

Diffuse neutrinos: problem 1

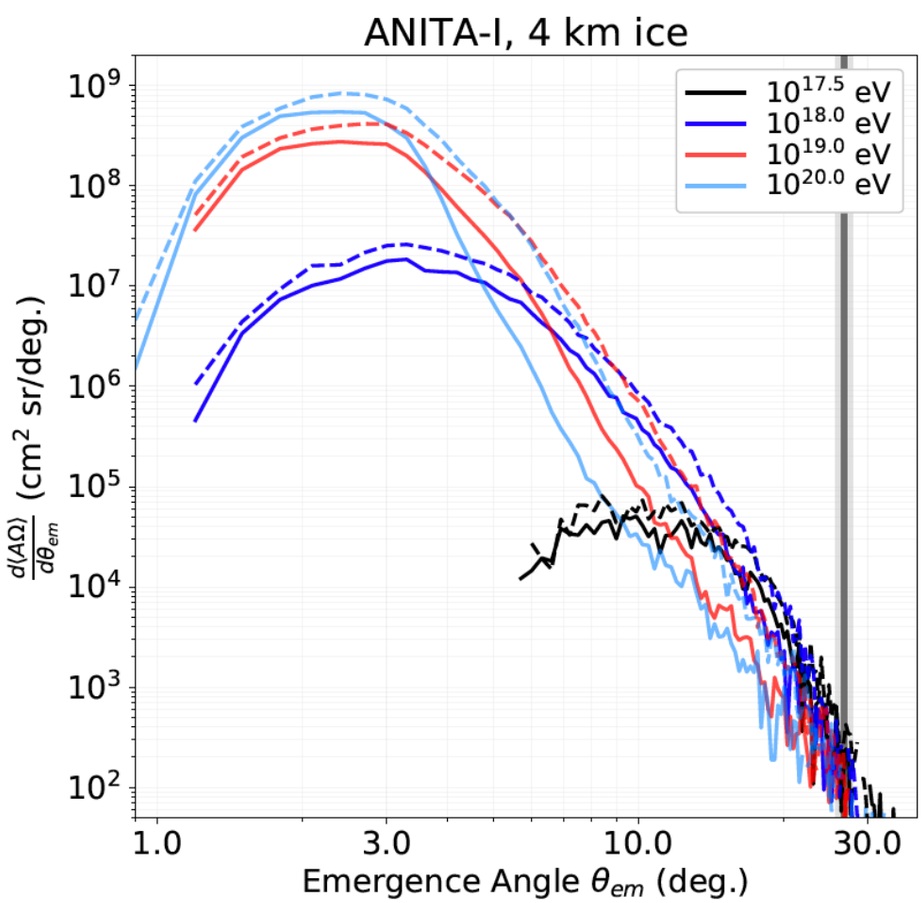
- If these are tau neutrinos why hasn't IceCube seen them?

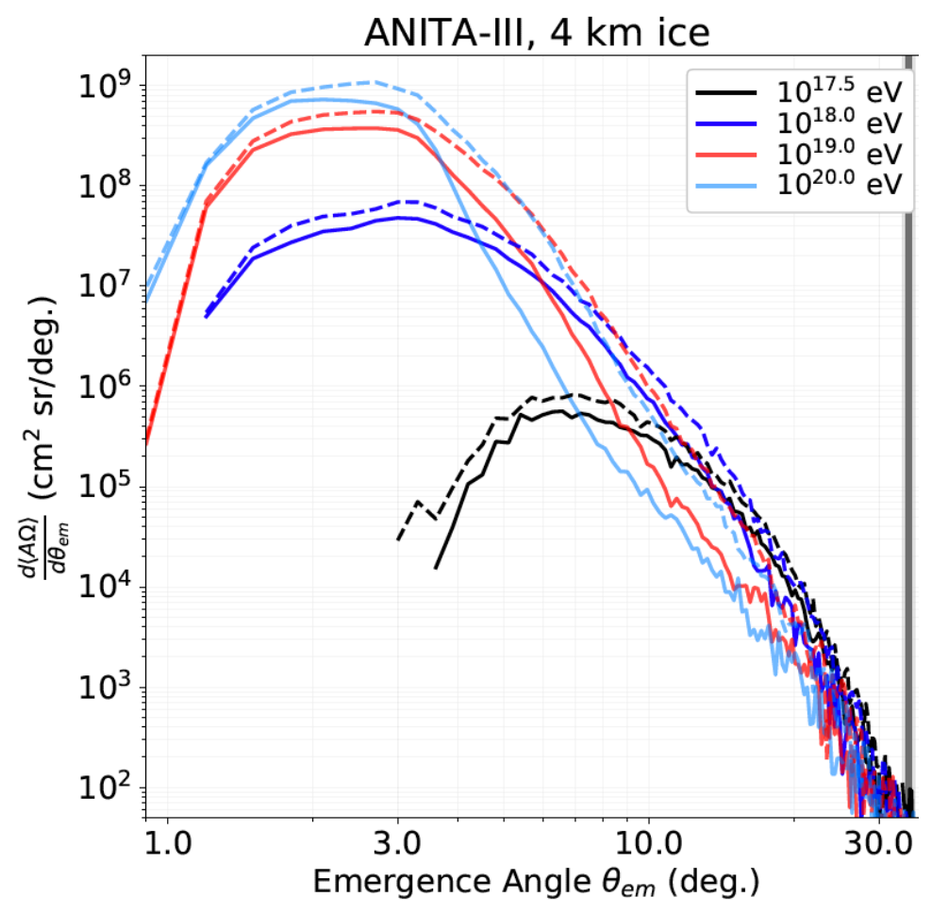


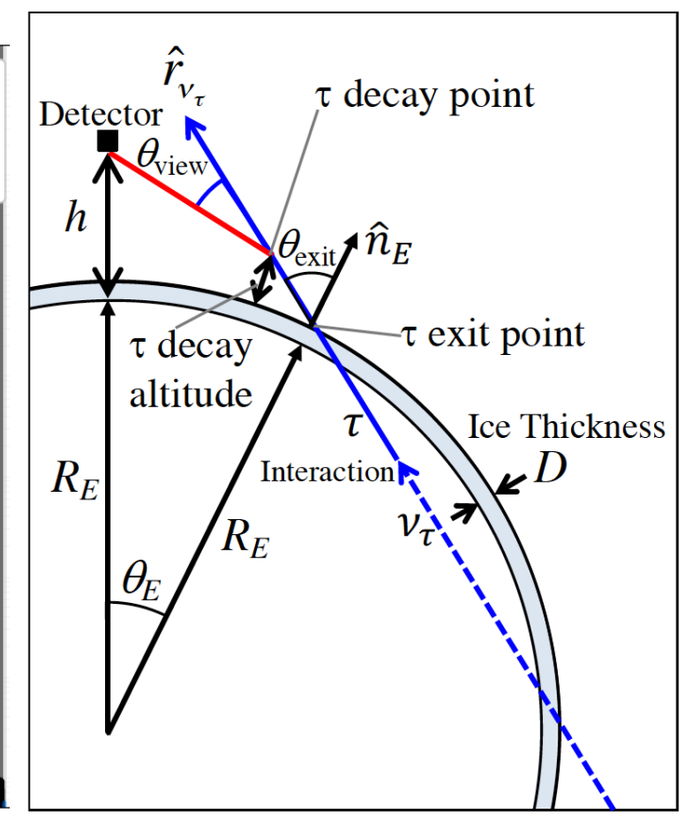
arXiv: 1811.07261

Diffuse neutrinos: problem 2

- Both ANITA-1 and ANITA-3 events were relatively close to the balloon
- There is much more acceptance close to the horizon
- Where are those tau candidate events?







arXiv: 1811.07261

Some other interpretations..

- Sterile neutrinos explanation ($\sigma_{\nu s} \sim \theta^2 \sigma_\nu$), would need powerful transient source to avoid IceCube's constraints arXiv:1802.01611

- Decay of massive dark matter candidate (>E18 eV) into two right handed neutrinos arXiv: 1902.04584

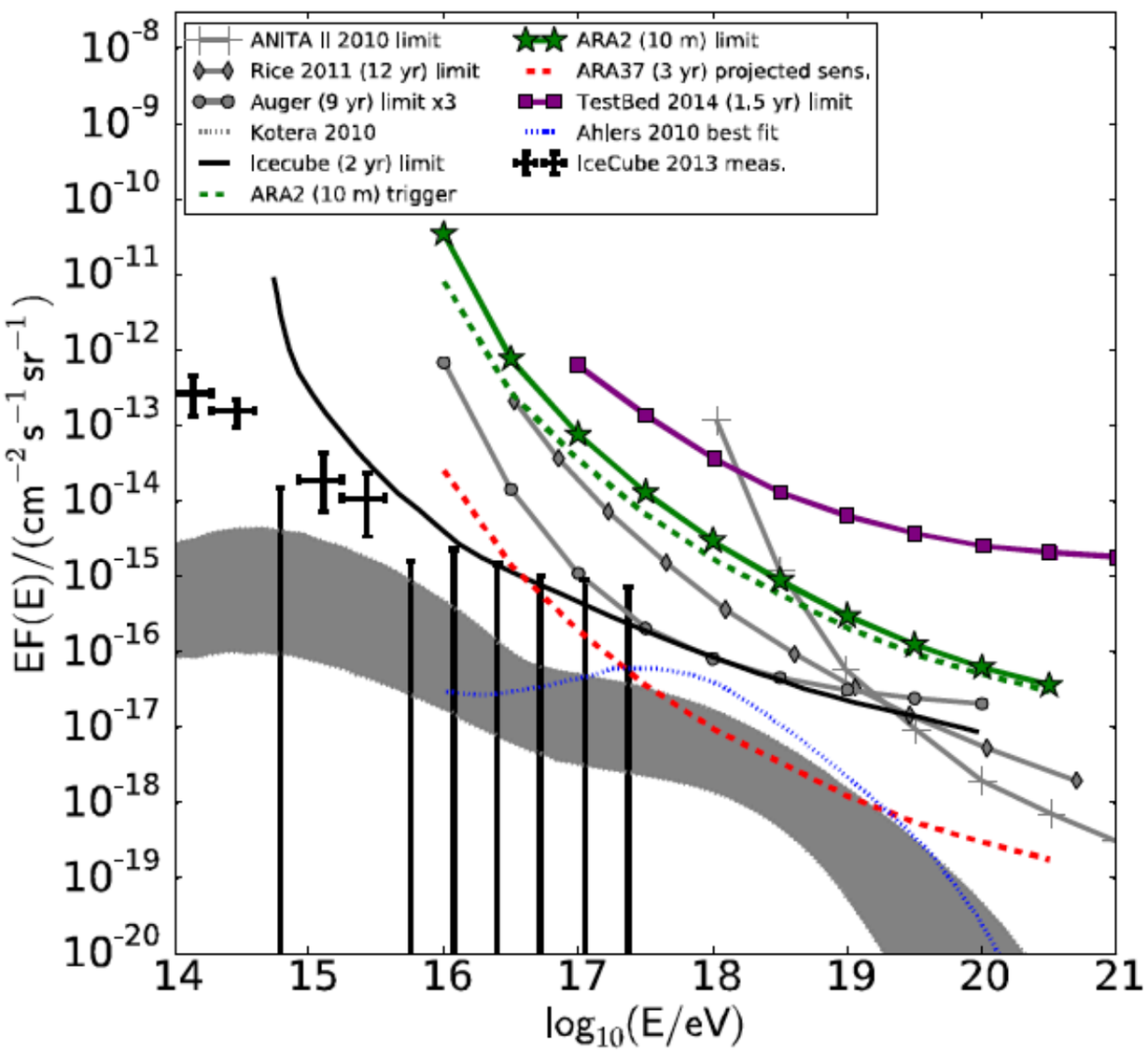
- Intermediary BSM particle produced in UHECR interactions with low cross-section and and low EM energy losses (stau) arXiv:1809.09615

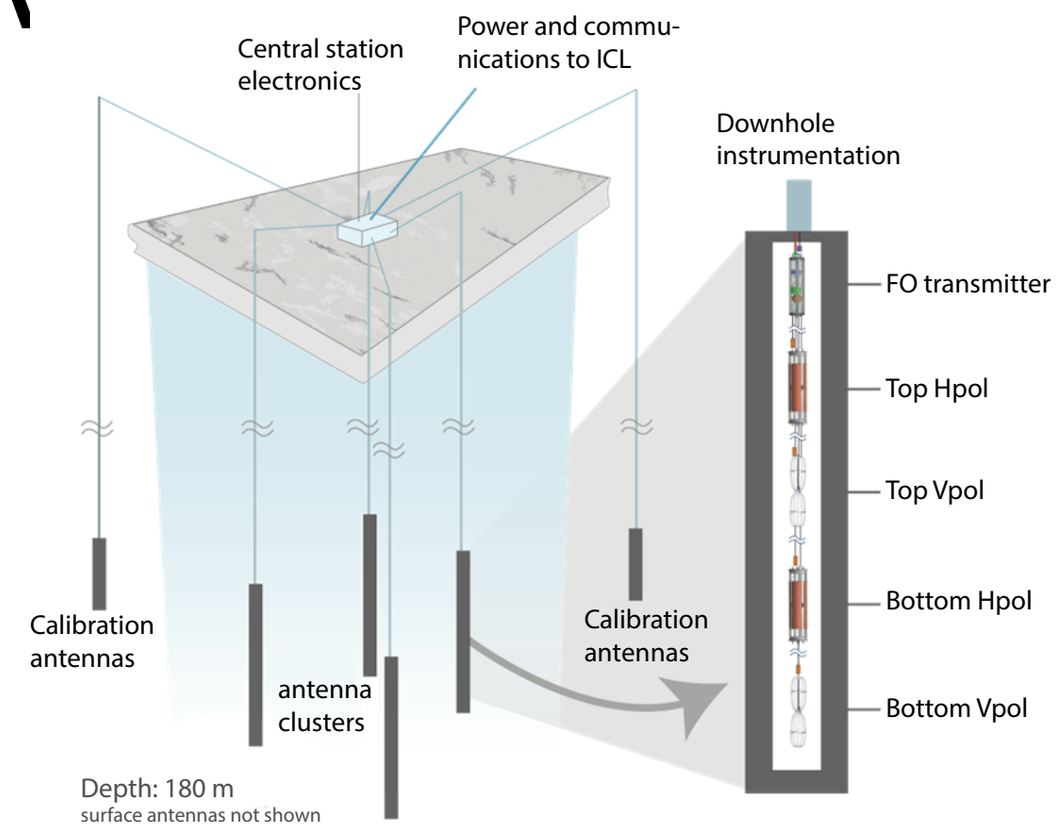
- Powerful transient source search with 1.5 degree error:
  - No concurrent GRBs
  - SN2014dz, type Ia SN at z=0.017, 5 hours after initial discovery (a posteriori chance association 2.7σ)

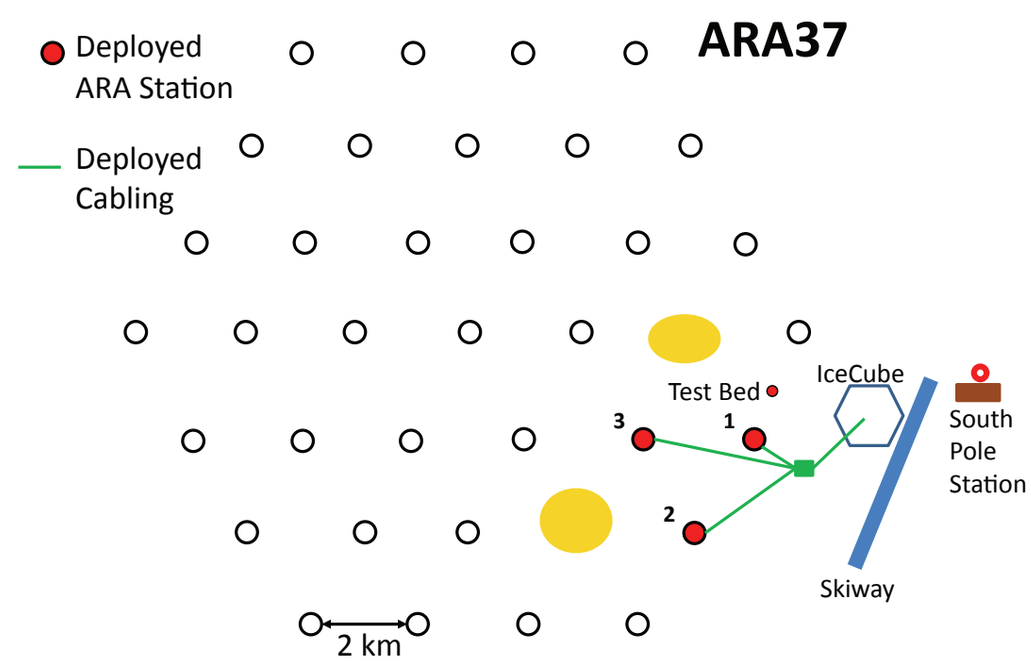
Future

ARA

Askaryan Radio Array:
5 deployed station and 1 phased array
(A. G. Vieregg, et al., JCAP 1602 (2016) no.02, 005)

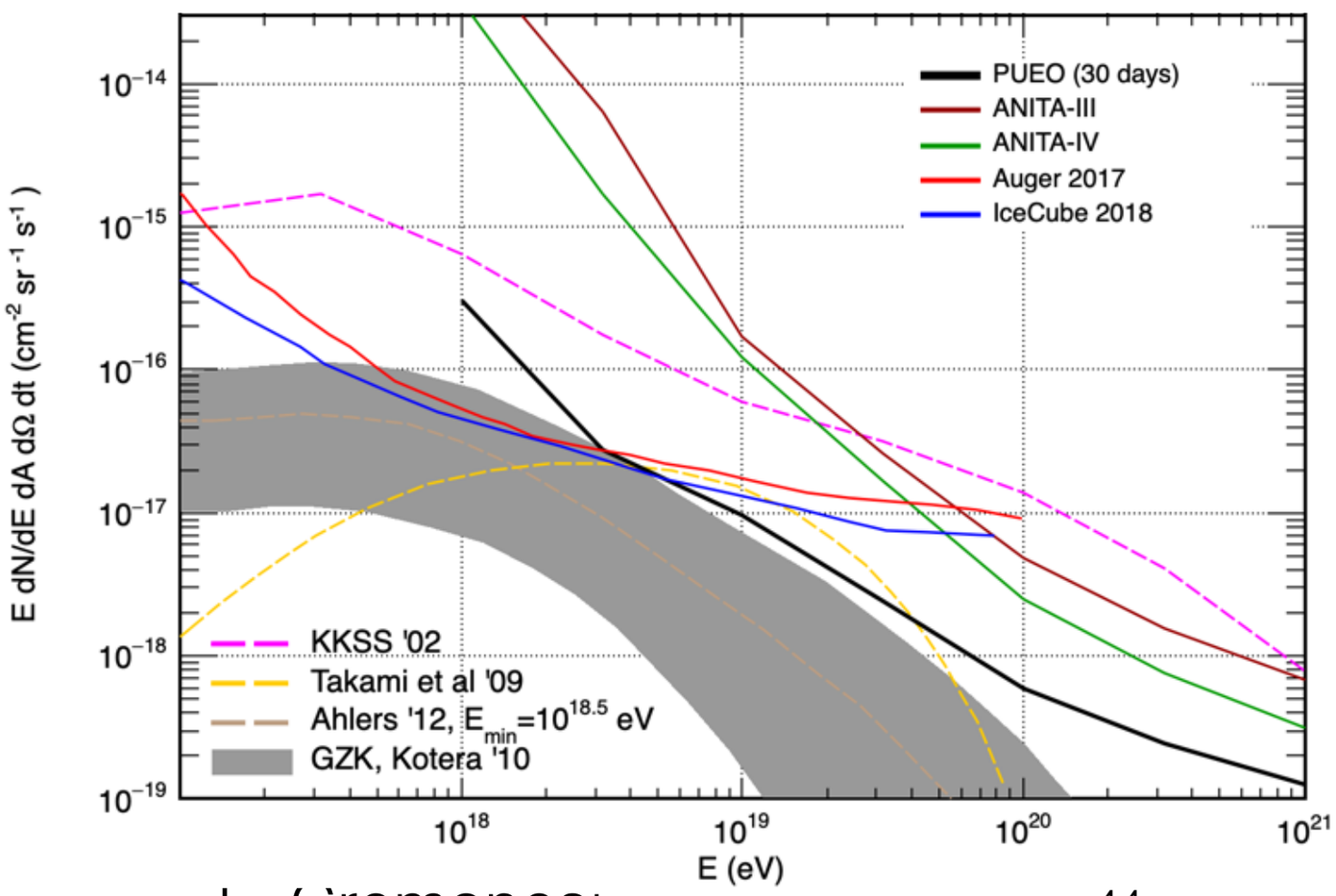






PUEO

- Payload for Ultrahigh Energy Observations
- 2.5x lower threshold than ANITA-IV
  - More antennas (120 vs. 48) , but higher-frequency (300 MHz vs. 200 MHz cutoff)
  - 16-antennas phased together at a time using a low-bit streaming digitiser as trigger
- 24 antennas in inclined array for steep “mystery events”



Summary and future

- The ANITA experiment has a rich physics program:
  - ANITA-3 and ANITA-4 diffuse neutrino analyses:
    Phys. Rev. D 98, 022001 (2018) & Phys. Rev. D 99,122001 (2019)
  - ANITA-3 cosmic ray-like analysis: Phys. Rev. Lett. 121, 161102 (2018)
  - Things I didn't cover: iceman simulation (arXiv: 1903.11043), ANITA-3 HiCal (Journal of Astronomical Instrumentation 6.02 (2017): 1740002), GRB searches (ApJ 736 (2011) 50) , Lorentz violation (PhysRevD.86.103006), and other analyses
- ANITA-4 cosmic ray like analysis coming out soon!
- ANITA-3 and ANITA-4 source coincidence analyses also coming out soon!

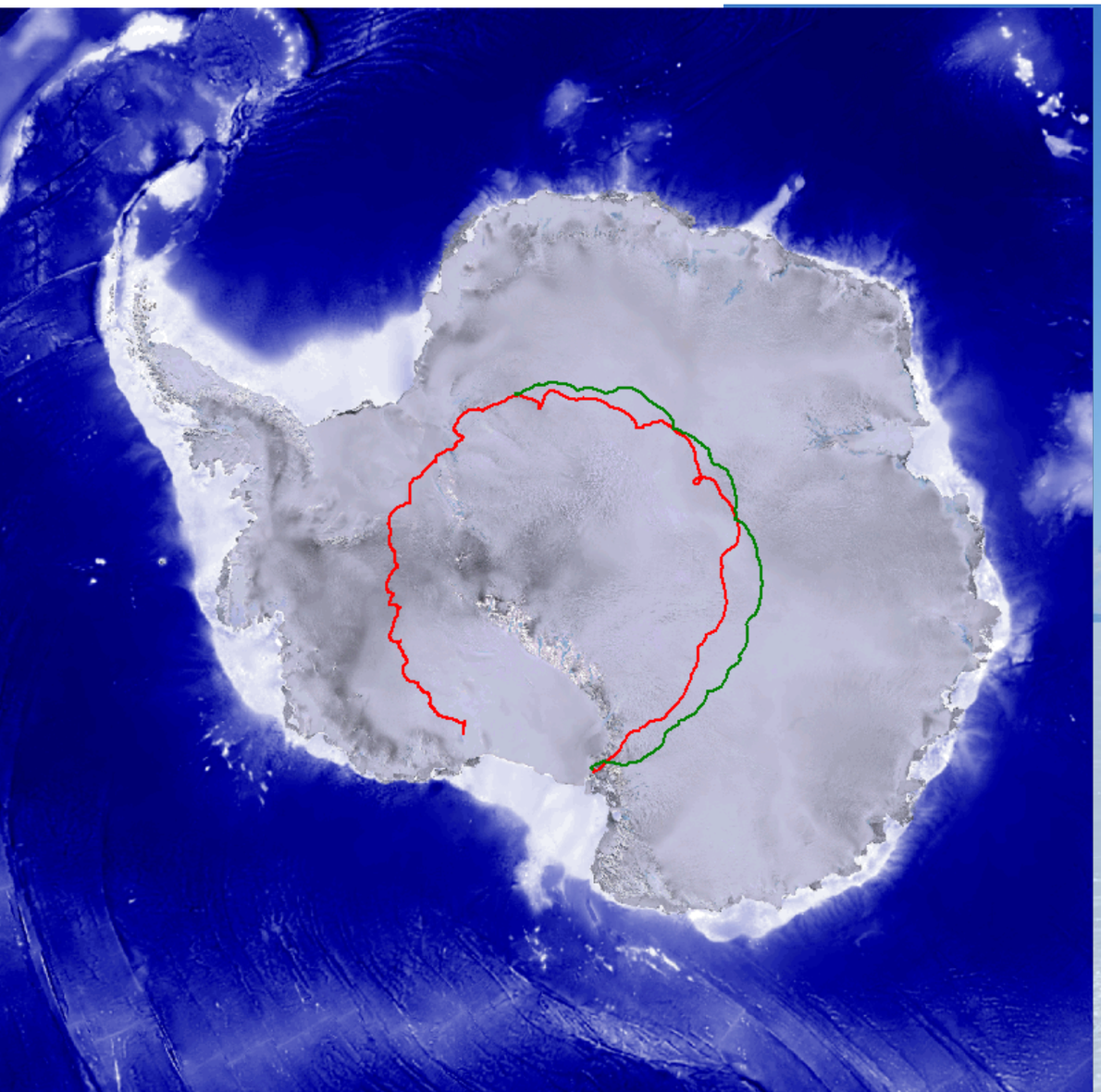
THANK YOU
NASA
LEVERHULME
TRUST

Back up

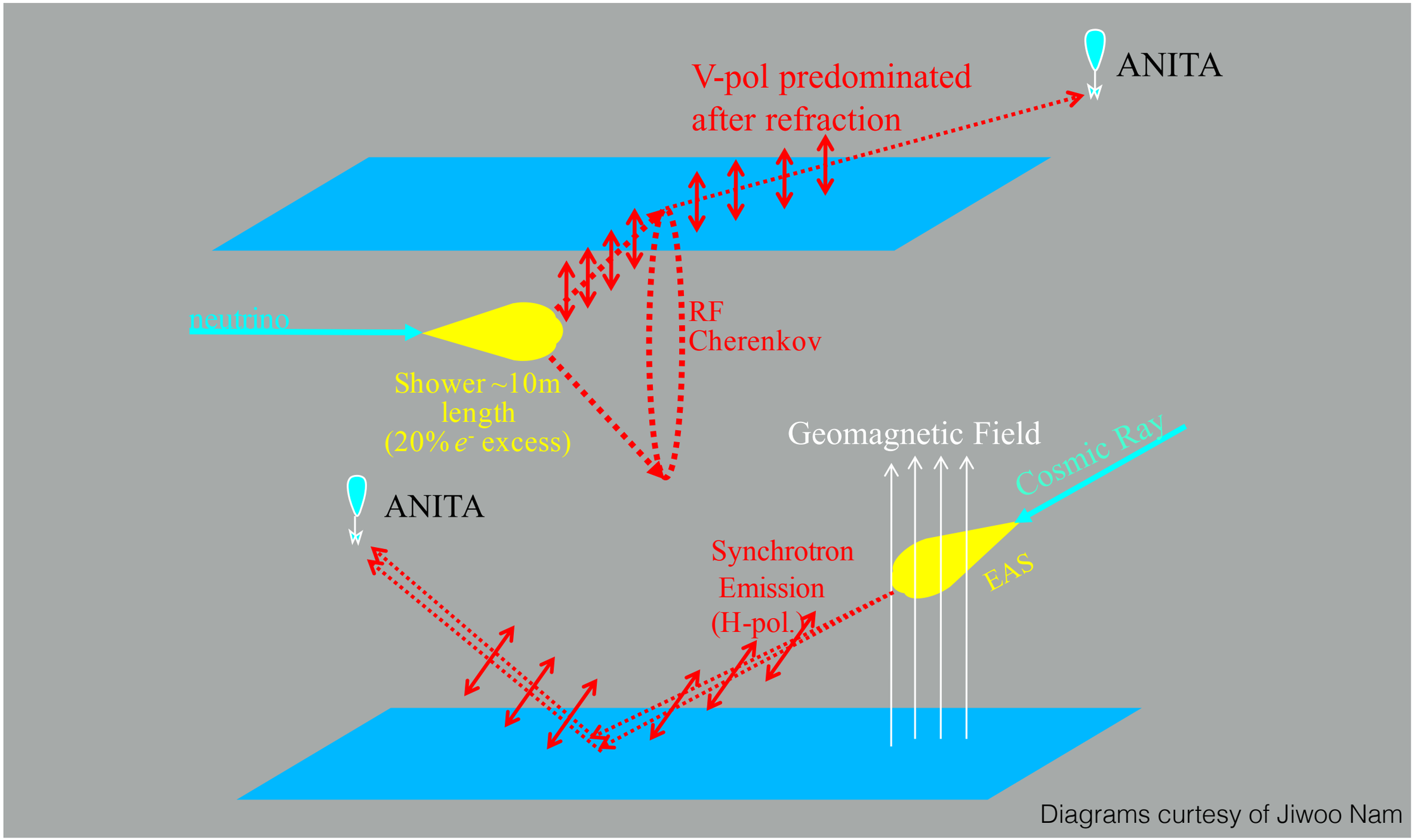
HiCal

Two calibration payloads (HiCals) launched on ANITA's second pass:

- Periodic calibration pulse
- Use direct and reflected pulse to characterise ice surface and roughness
- HiCal 1 (ANITA-3) results: arXiv:1703.00415 [astro-ph.IM]



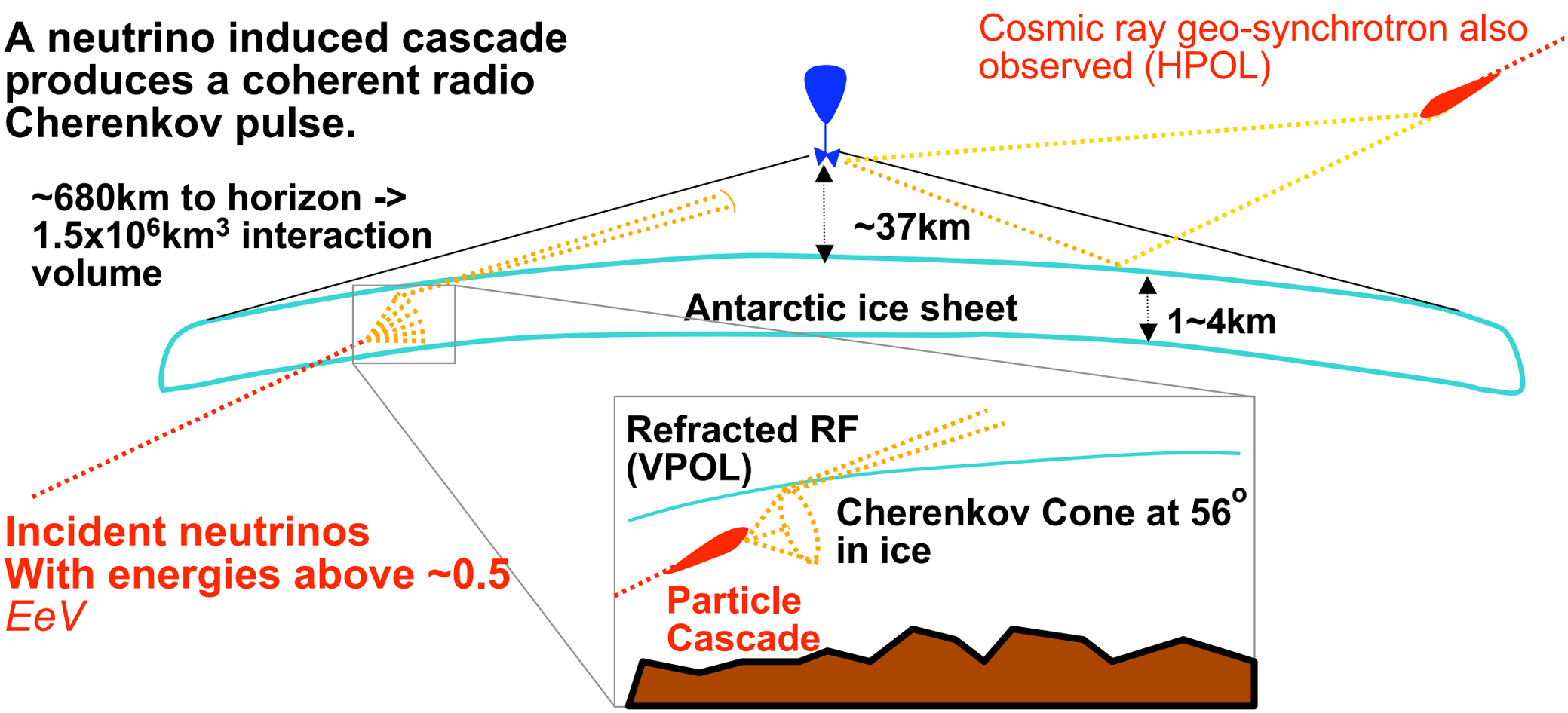
Neutrinos and Cosmic Rays



ANITA

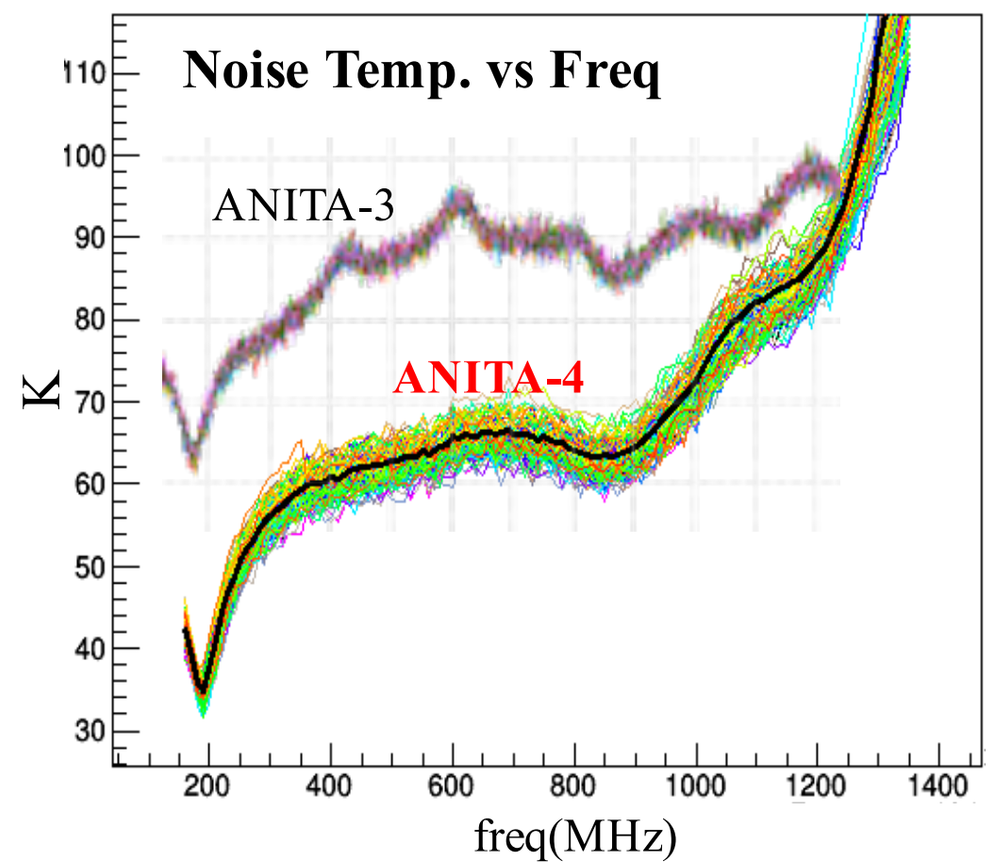
ANtarctic **I**mpulsive **T**ransient **A**ntenna

A neutrino induced cascade produces a coherent radio Cherenkov pulse.



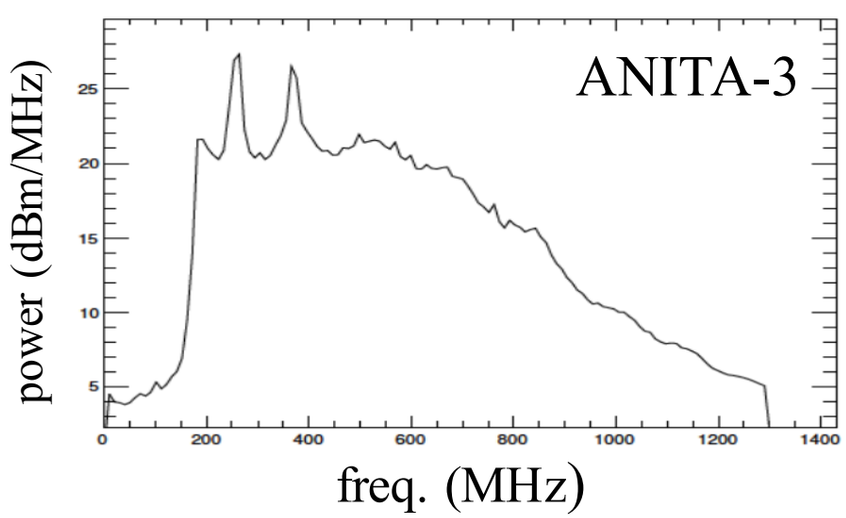
ANITA-4 improvements

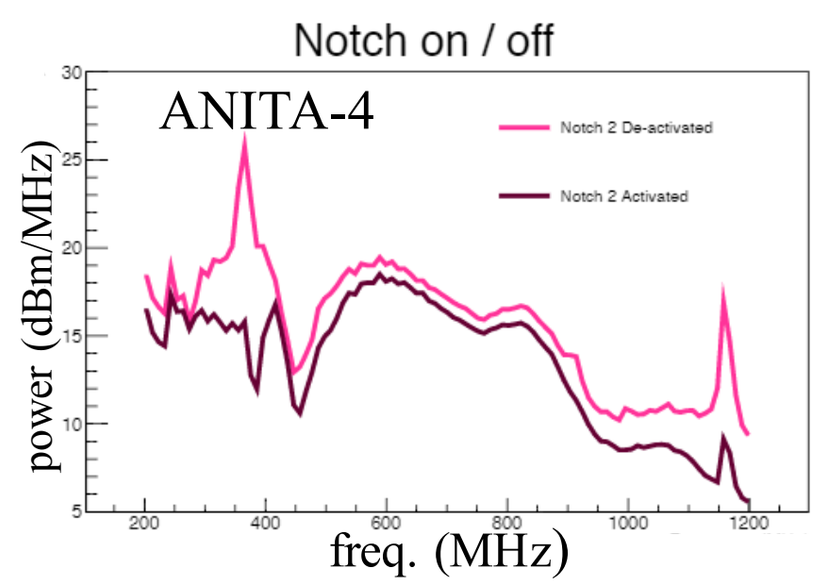
- Using Low Noise Amplifiers for all channels
  - Improvement in noise figure (30-40K)
  - 20% improvement in energy threshold



ANITA-4 improvements

- Using Low Noise Amplifiers for all channels
  - Improvement in noise figure (30-40K)
  - 20% improvement in energy threshold
- Tunable Universal Filter Frontend
  - Reduce Carrier Waves noise coming from Satellites





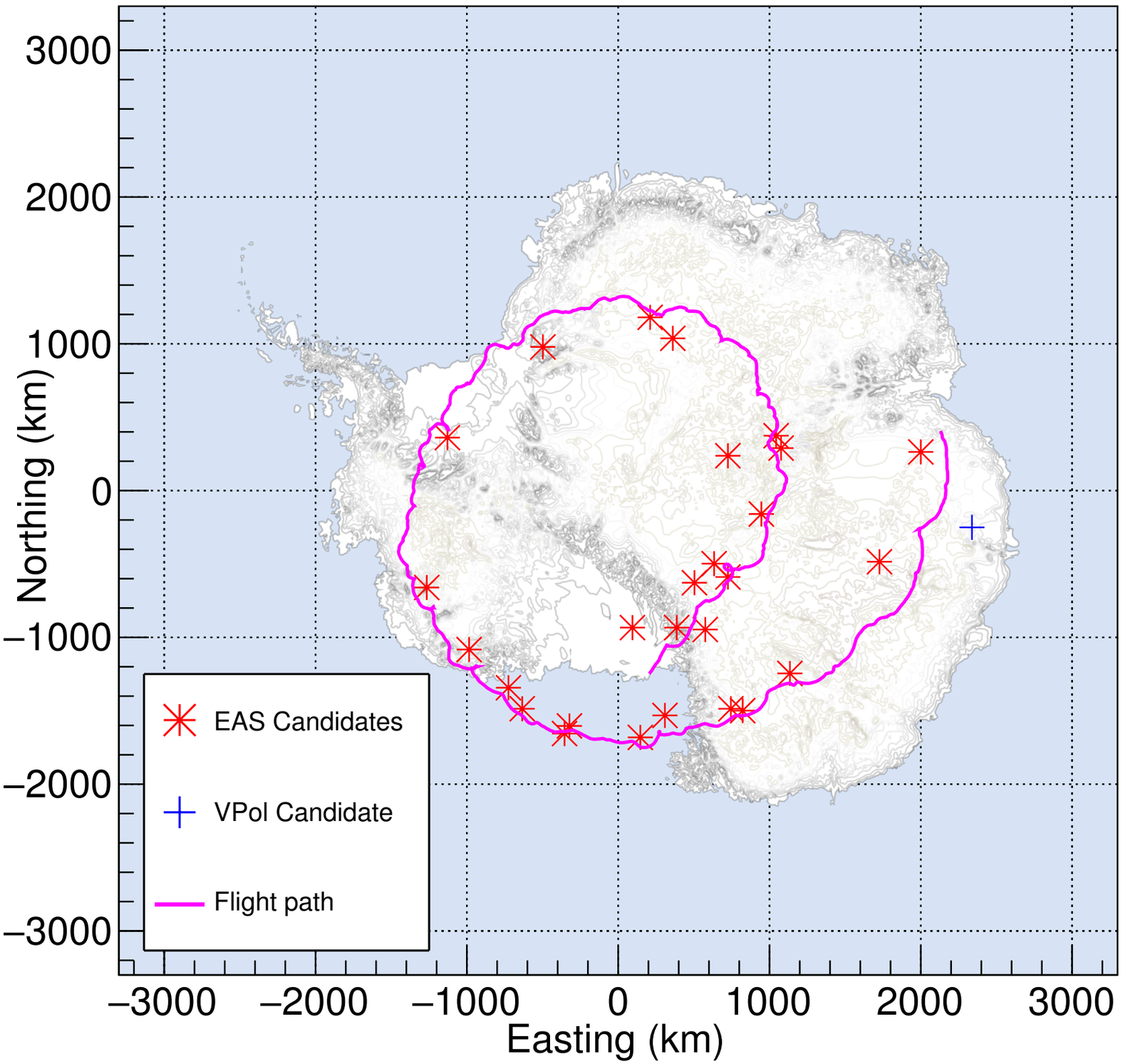
ANITA-4 improvements

- Using Low Noise Amplifiers for all channels
  - Improvement in noise figure (30-40K)
  - 20% improvement in energy threshold
- Tunable Universal Filter Frontend
  - Reduce Carrier Waves noise coming from Satellites
- Trigger on Left and Right Circular Polarisation coincidences
  - Satellite noise predominantly circularly polarised (either LCP or RCP) —> 2.5 improvement in acceptance

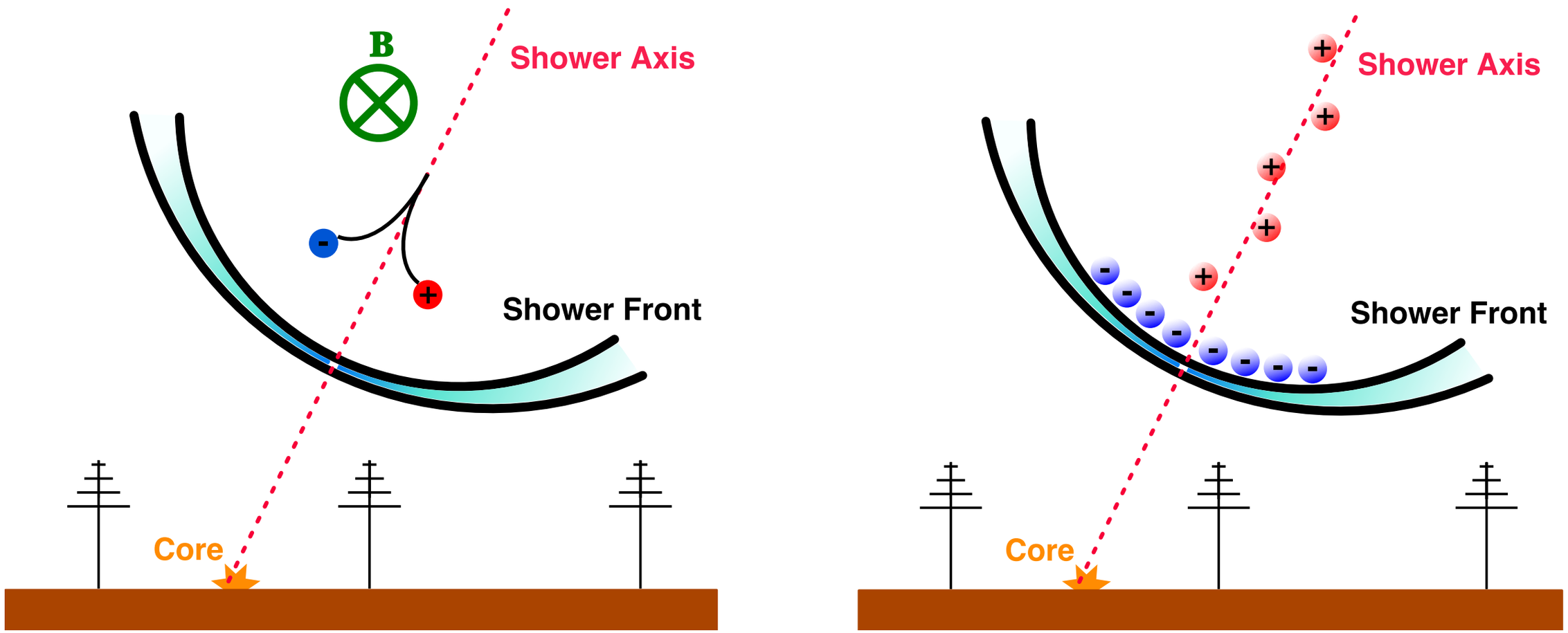
ANITA-3 efficiencies

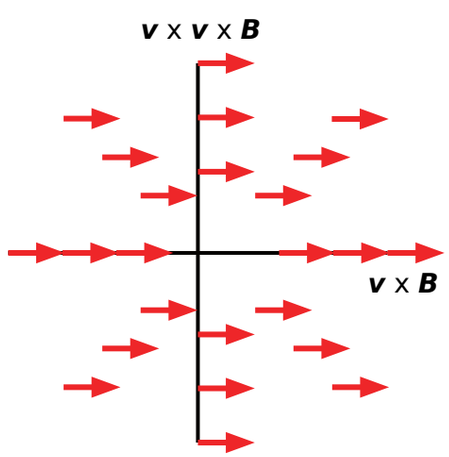
Cut	HPOL data	VPOL data	MC efficiency
None	36,700,502	38,274,132	1
Data quality	18,811,772	20,565,939	0.96
Blast	15,655,493	16,474,185	0.95
Thermal	311,795	169,824	0.88
Clustering	25	1	0.72

Better map

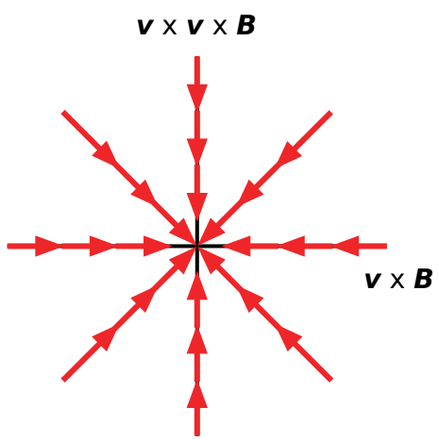

3000
2000
1000
0
−1000
−2000
−3000
Northing (km)
−3000
−2000
−1000
0
1000
2000
3000
Easting (km)
EAS Candidates
VPol Candidate
Flight path

Air showers are complicated…

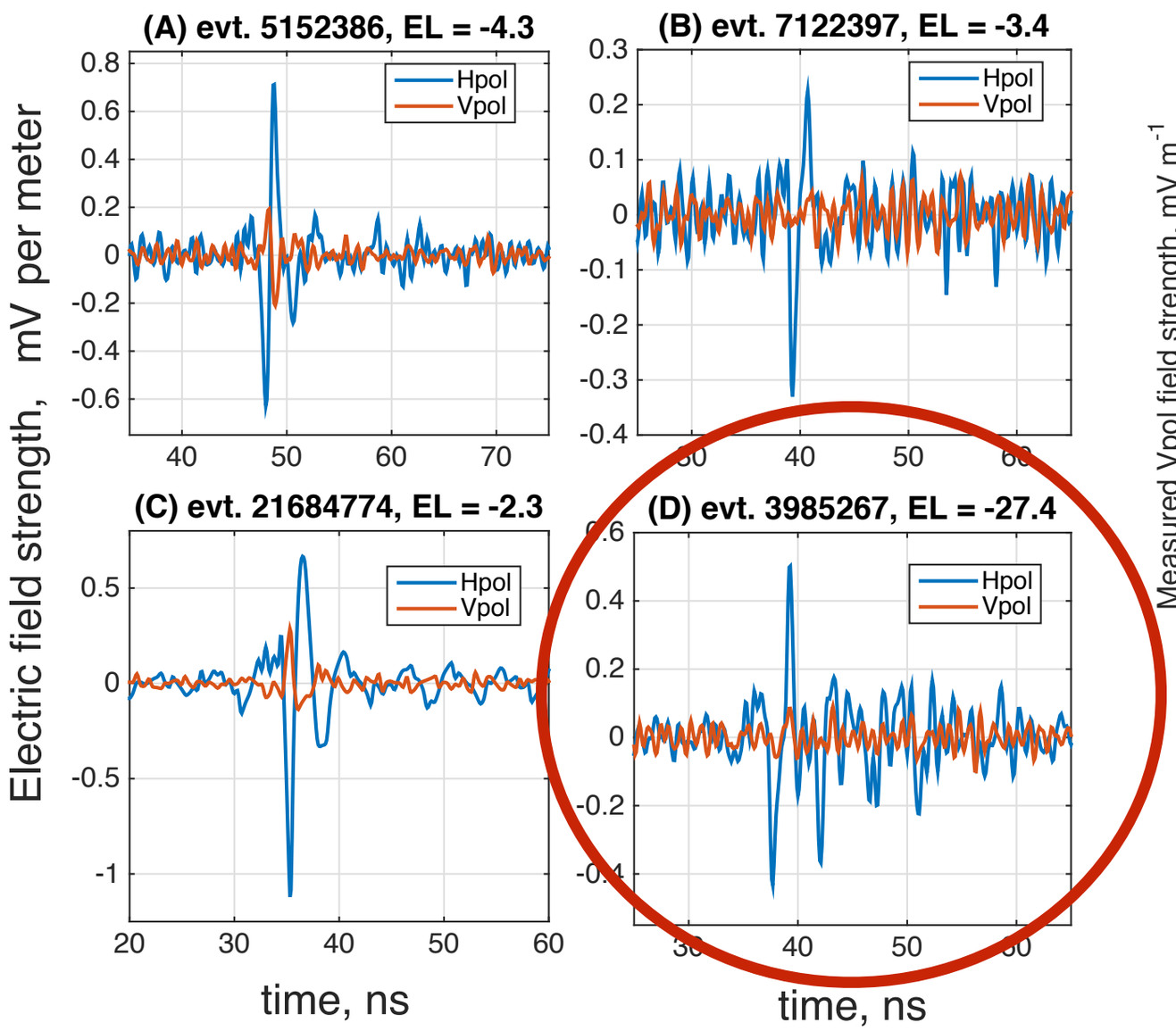


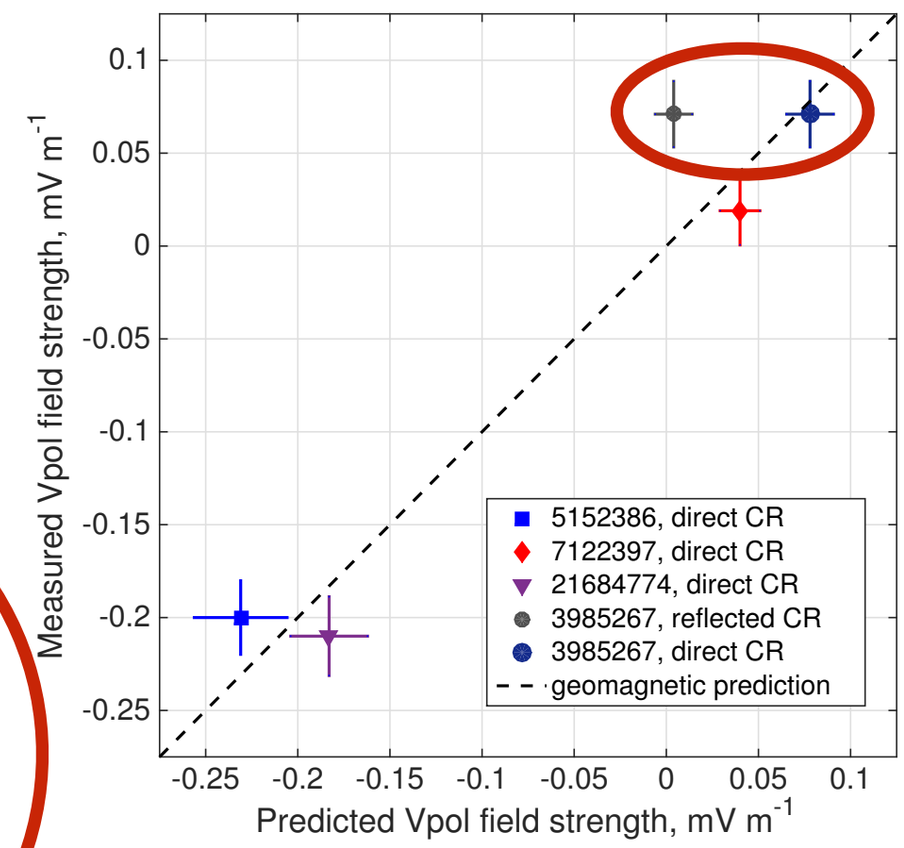


–Geomagnetic component from positron-electron separation
–Askaryan component
–Cherenkov effects from the varying refractive index of air, compresses pulse giving high frequency component



ANITA-1 mystery event



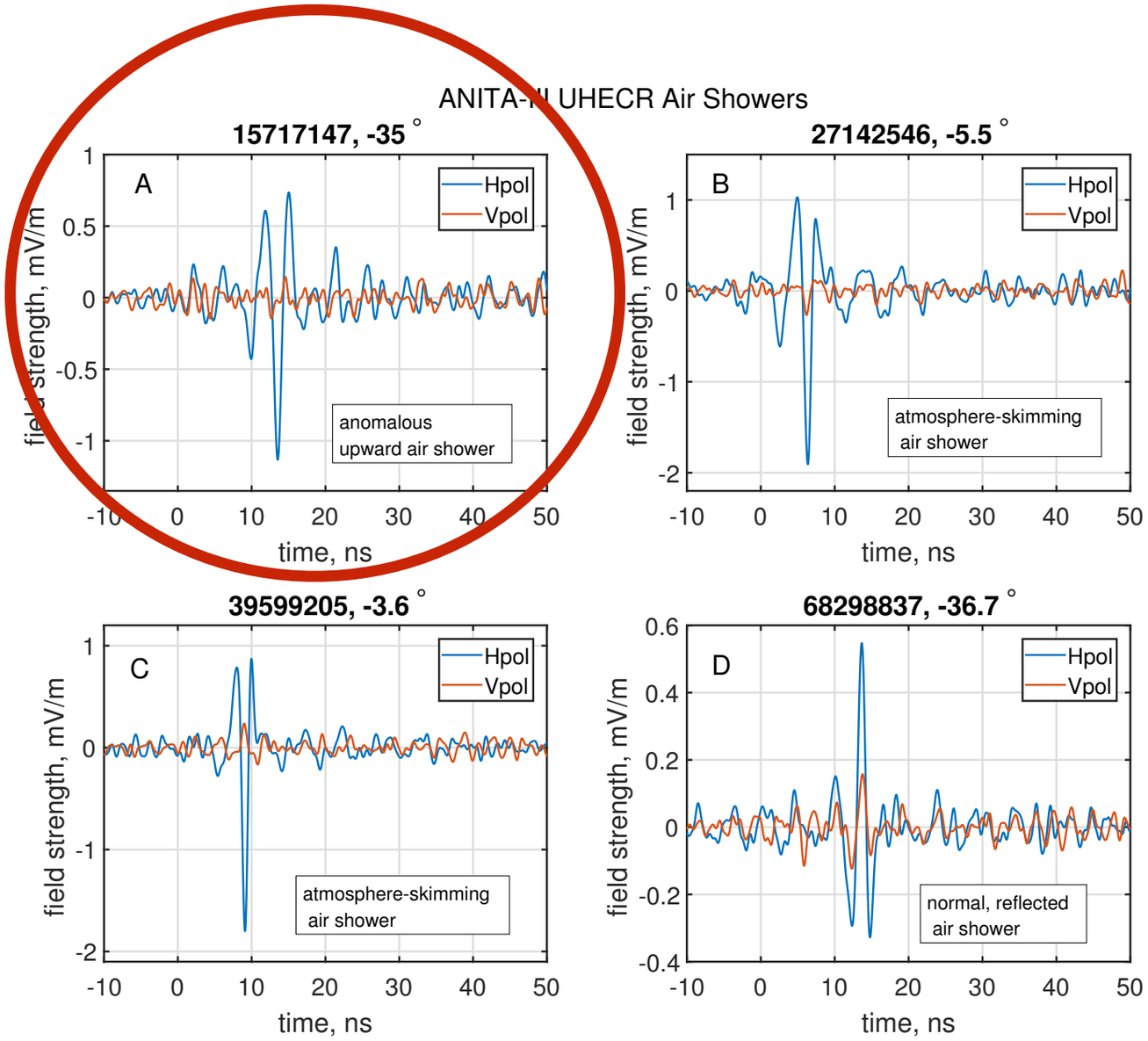


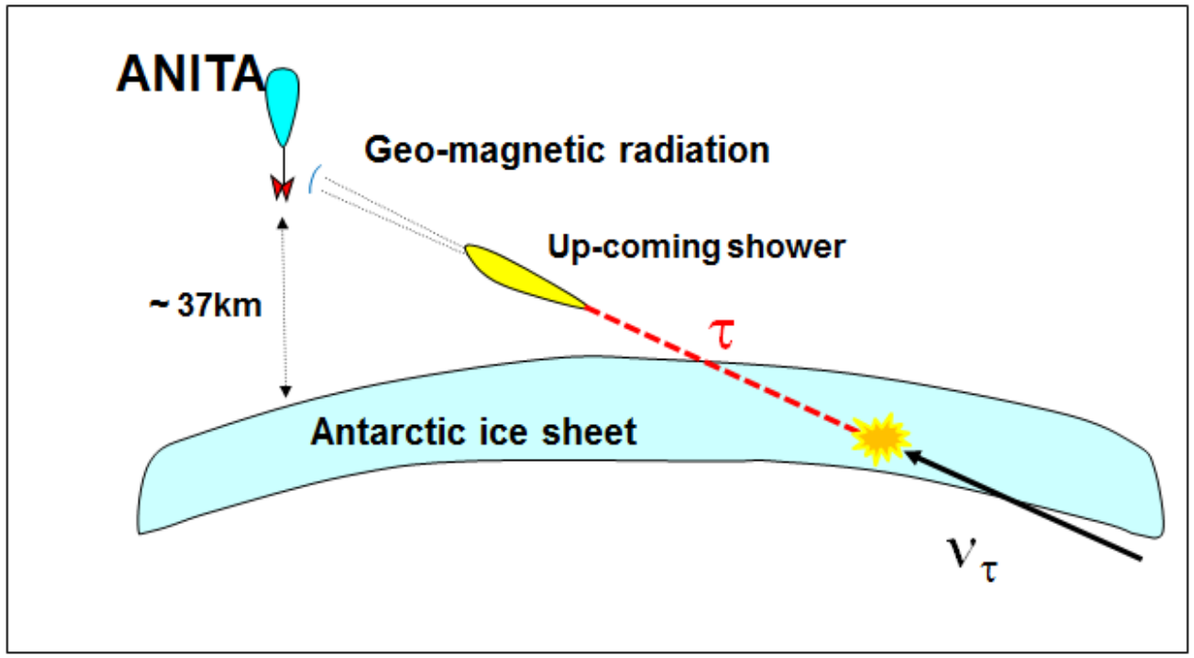
A strong H-pol non-inverted signal seen!

- Expected background events: 4×10^{-4}
- 27.4 deg below horizon, E = 0.6 ± 0.4 EeV

Phys. Rev. Lett. 117, 071101 (2016)

And ANITA-3 mystery event





event, flight	3985267, ANITA-I	15717147, ANITA-III
date, time	2006-12-28,00:33:20UTC	2014-12-20,08:33:22.5UTC
Lat., Lon.(1)	-82.6559, 17.2842	-81.39856, 129.01626
Altitude	2.56 km	2.75 km
Ice depth	3.53 km	3.22 km
El., Az.	$-27.4 \pm 0.3°, 159.62 \pm 0.7°$	$-35.0 \pm 0.3°, 61.41 \pm 0.7°$
RA, Dec(2)	282.14064, +20.33043	50.78203, +38.65498
$E_{shower}^{(3)}$	0.6 ± 0.4 EeV	$0.56^{+0.3}_{-0.2}$ EeV

Chord length: 5500-7000 km (20-30,000km water equivalent)
1600km SM interaction length @ 1 EeV

Background estimate < 10^{-2}