Hunting UHE neutrinos with ANITA

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Imperial College London Seminar
January 23rd 2019

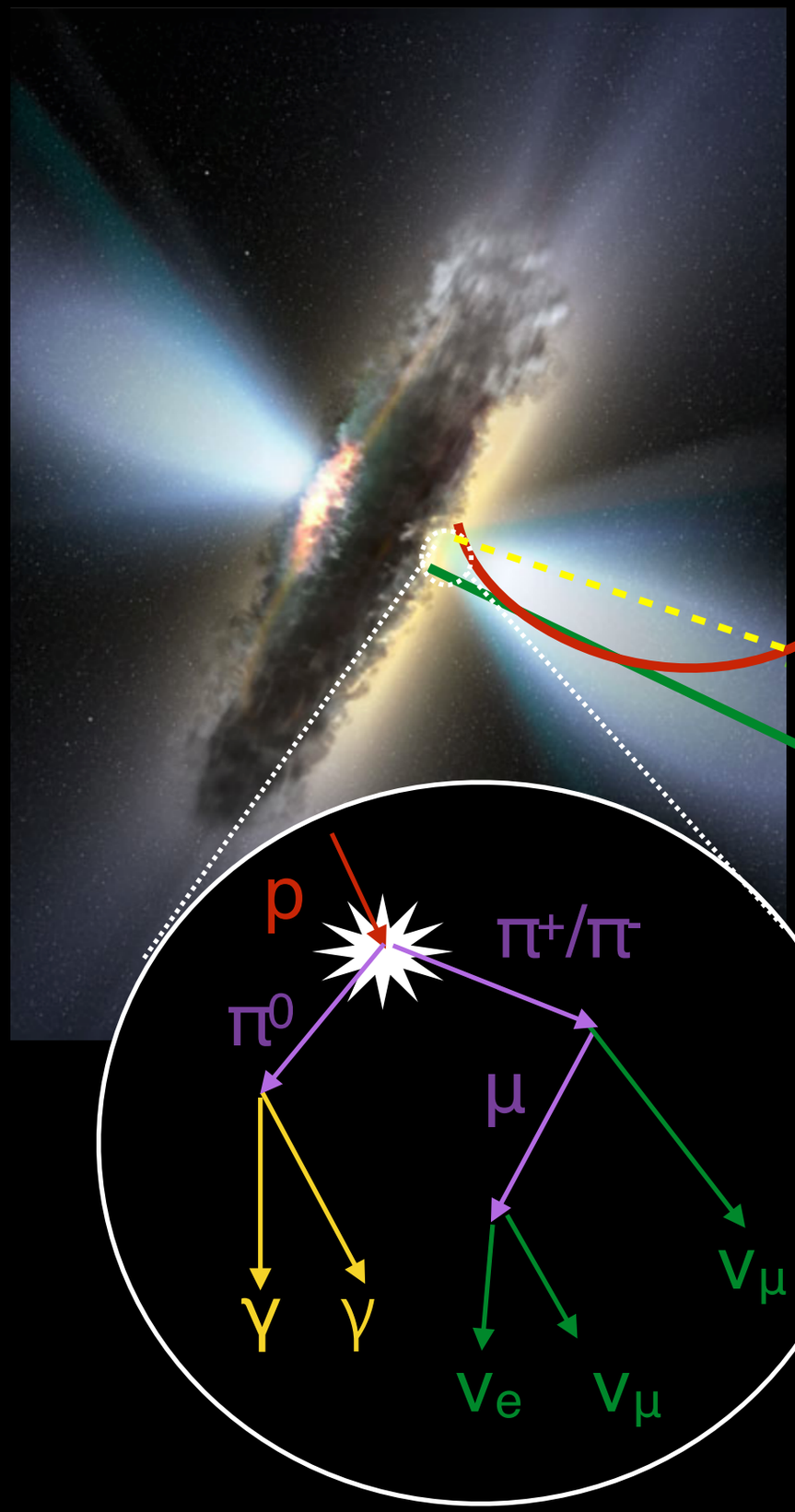
NASA

LEVERHULME TRUST

Outline

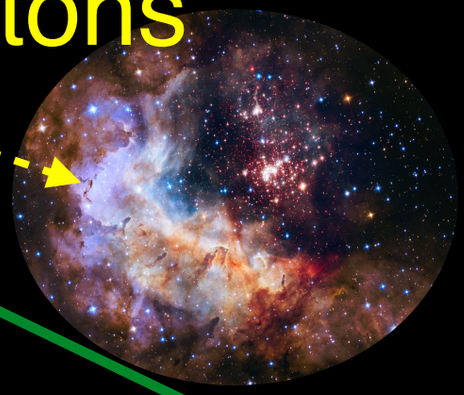
- Motivations
- ANITA
- Neutrino(s) in a haystack
  Phys. Rev. D 98, 022001 (2018)
- Unusual upward-going cosmic-ray-like events
  Phys. Rev. Lett. 121, 161102 (2018)
- Future

Motivations



protons

photons

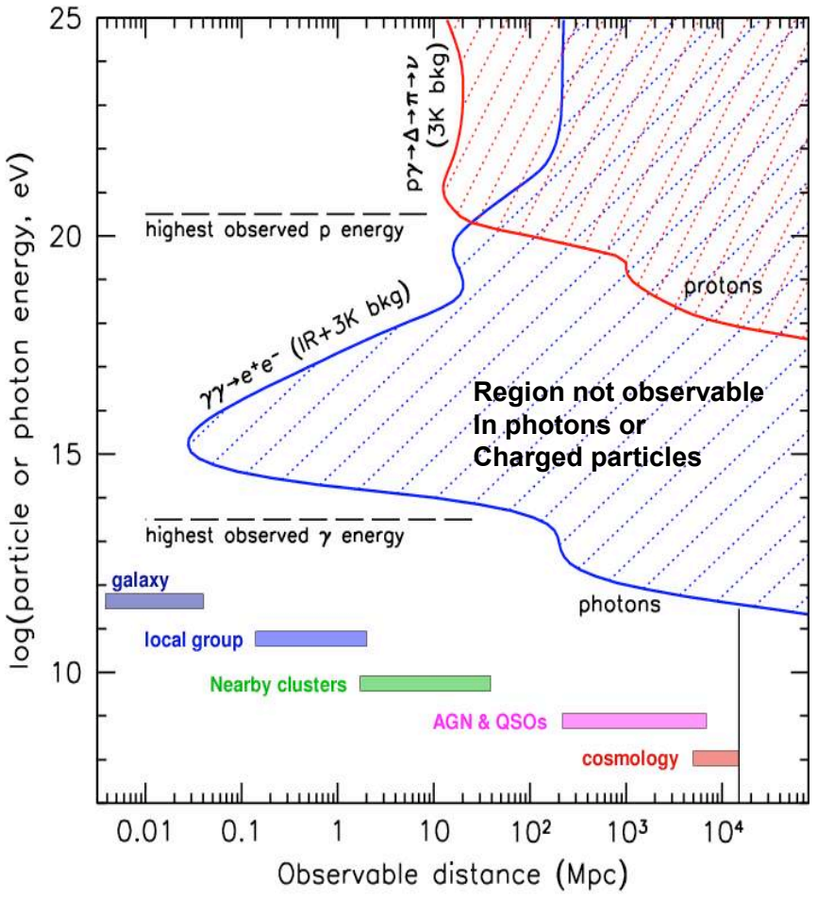


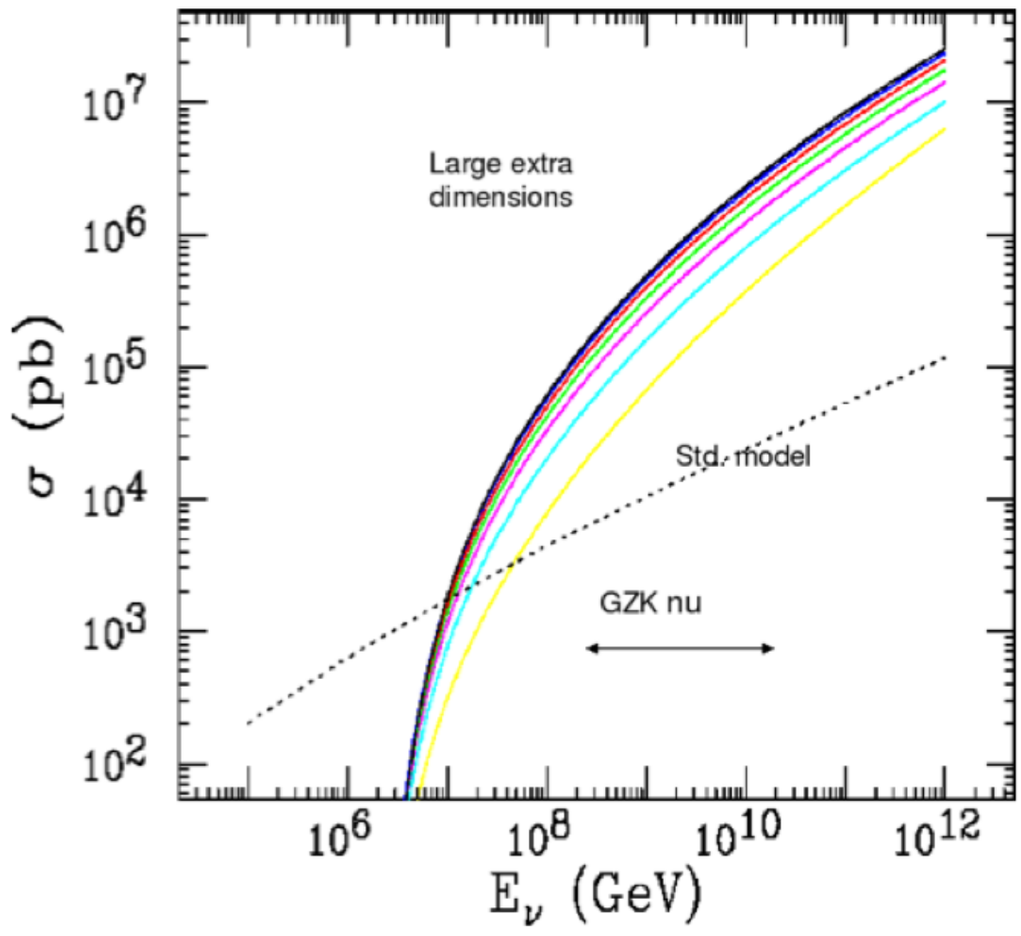
neutrinos

UHE (>E18 eV) neutrinos

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

"WOW
300 TeV centre of mass energy!"



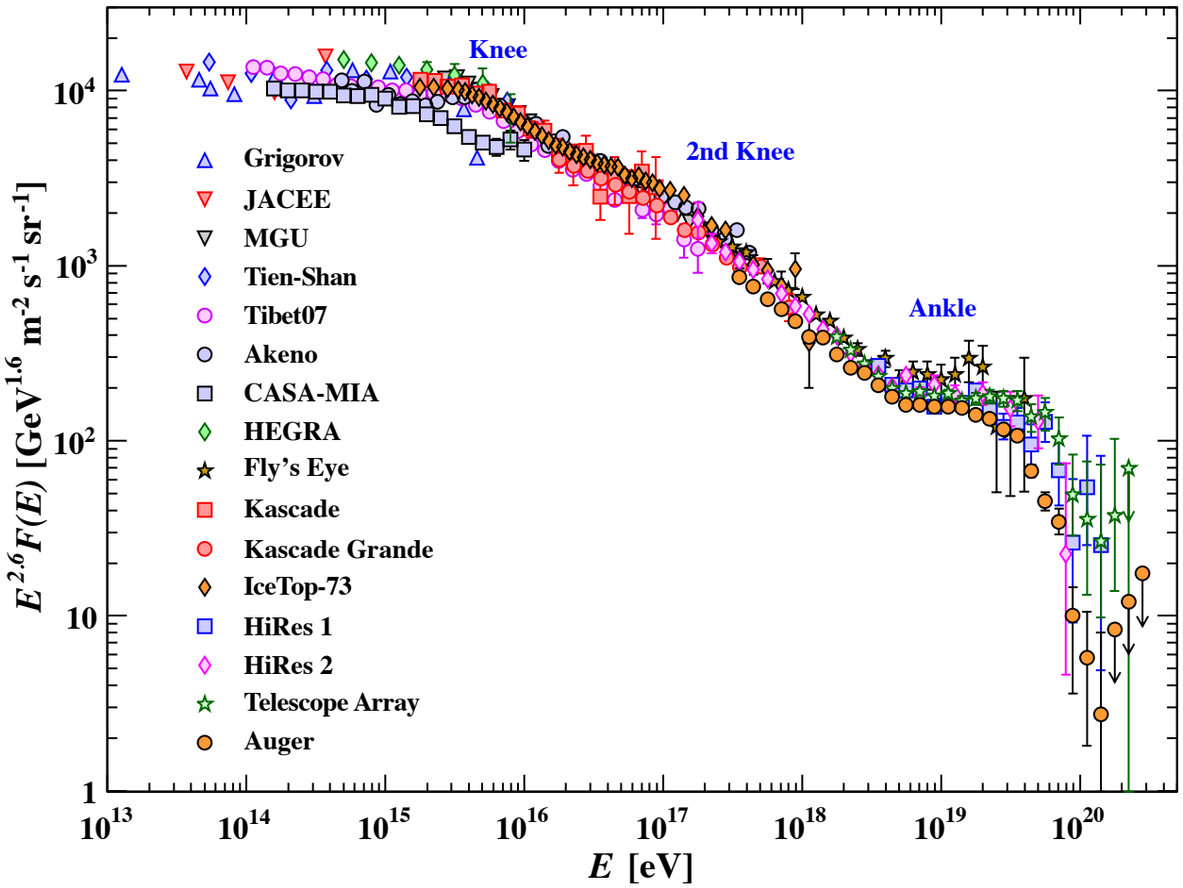


More motivations

- 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

Cosmogenic neutrinos

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



ν from GZK

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

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

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

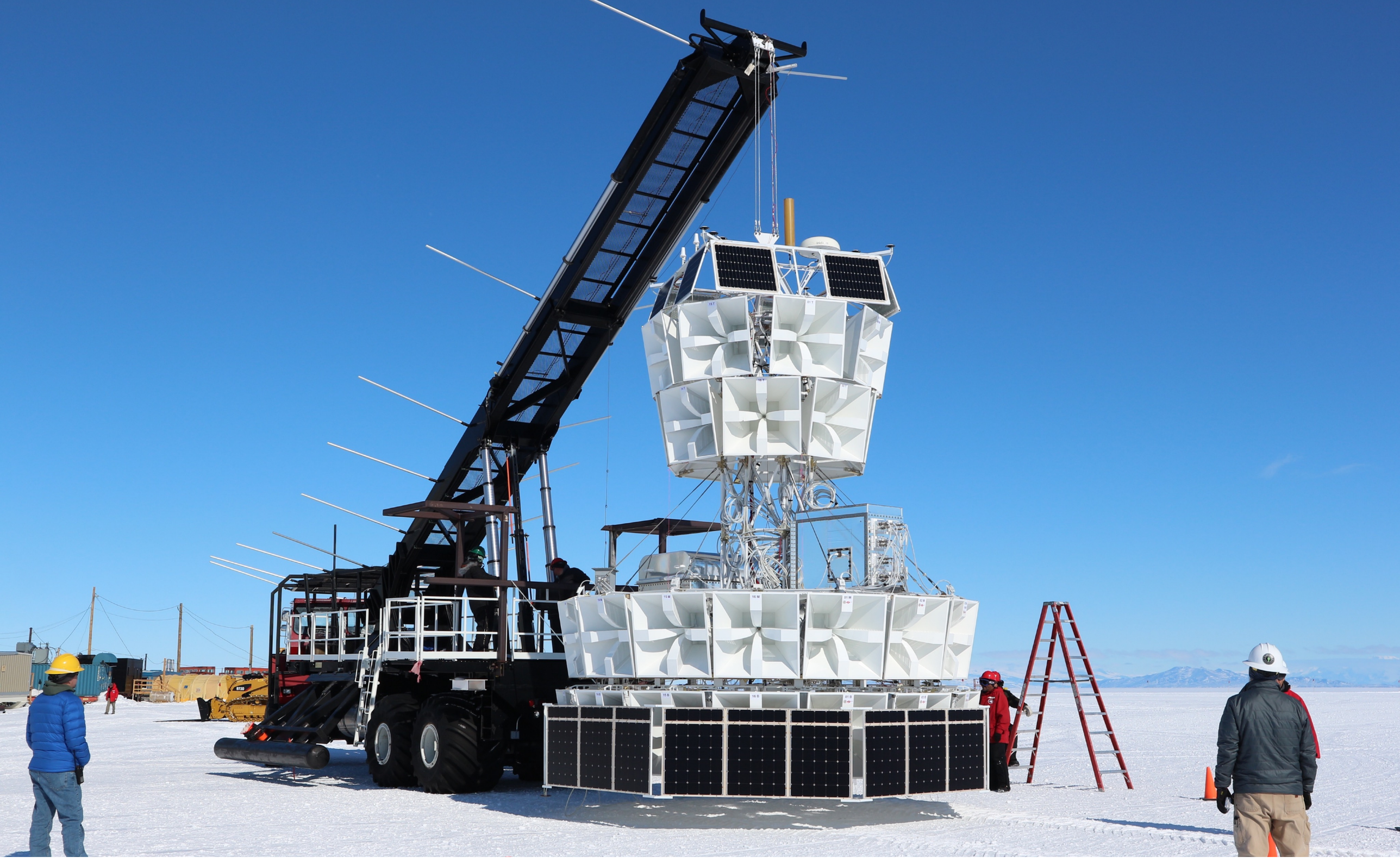
$$\mu^+ + \rightarrow e^+ + \nu_e + \overline{\nu_\mu}$$

ν from photo-disintagration

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

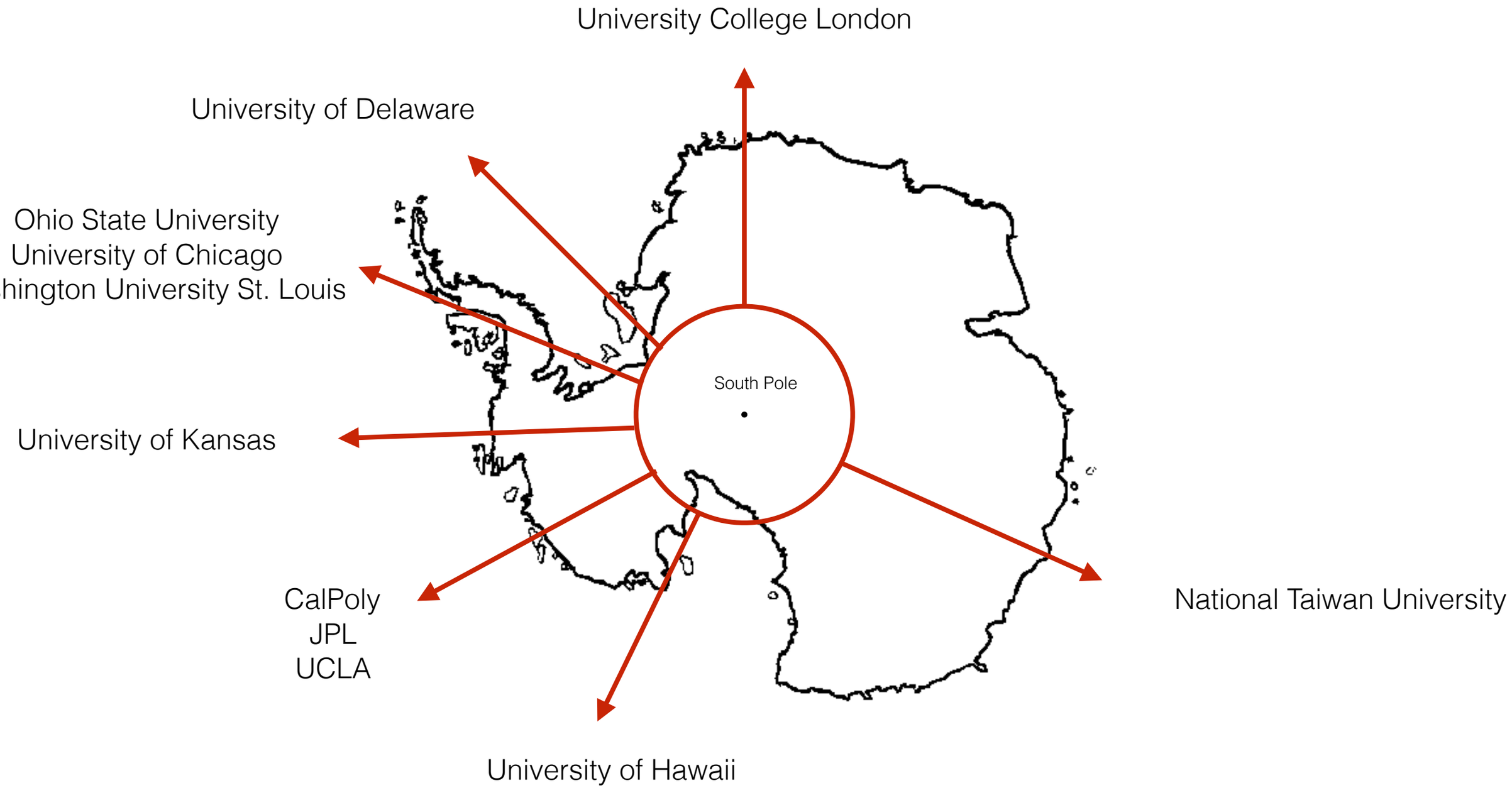
$$n \rightarrow p + e^- + \overline{\nu_e}$$

We know cosmic ray energy spectrum over 11 orders of magnitude.
Their sources (especially at the highest energies) are still mostly unknown



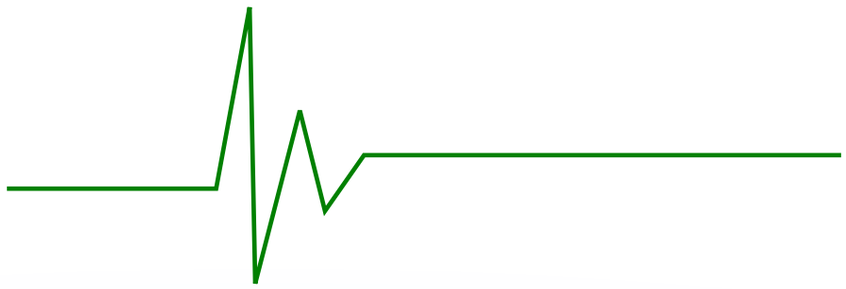
ANITA

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

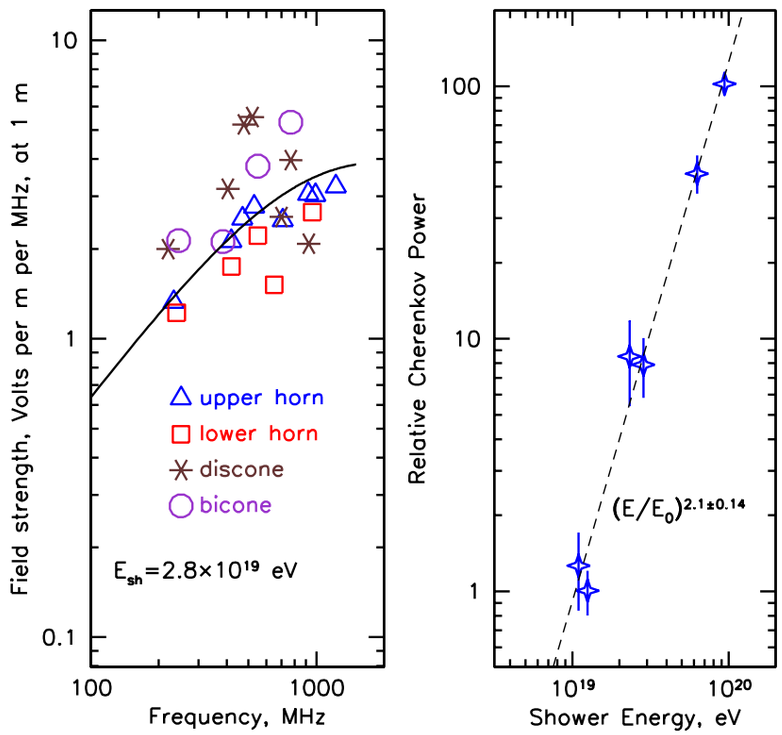
balloon

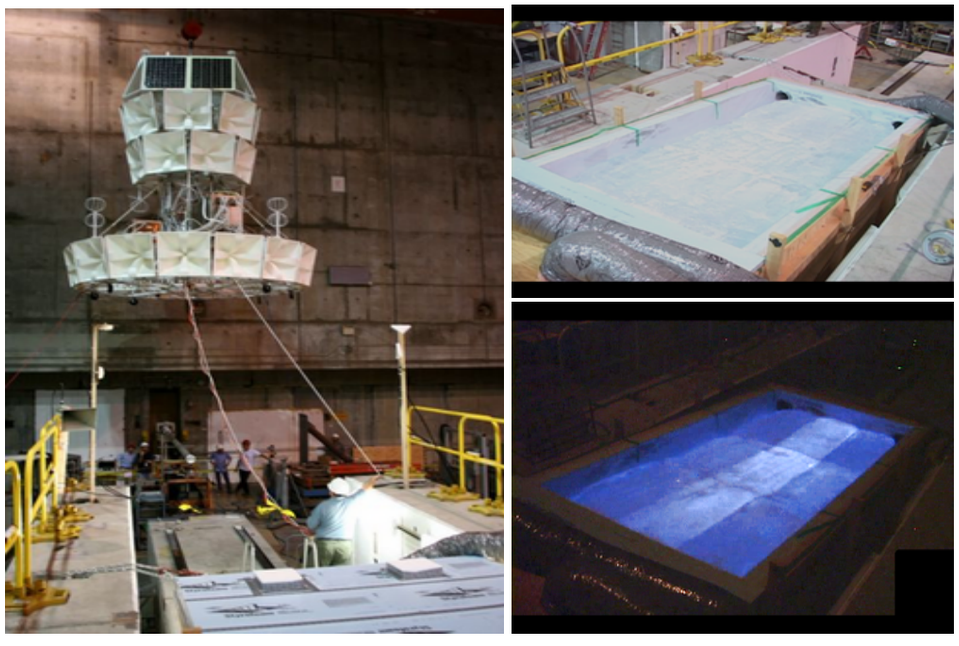
Ice

Askaryan emission

~EeV neutrino

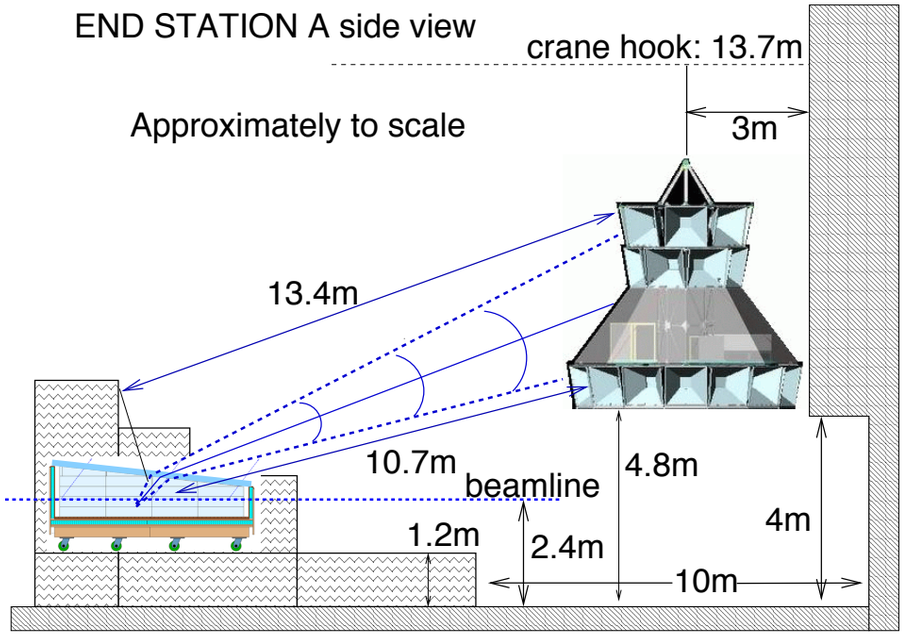
Askaryan radiation





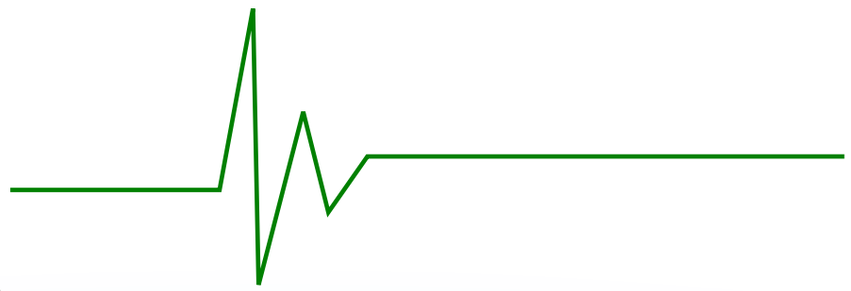
- Coherent radio emission from EM cascades in a dielectric!
- Measured at SLAC ESA in 2006 by ANITA collaboration
- Fired bunches of 10^9 electrons at 28.5 GeV into 7000 kg of ice

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

balloon

direct UHECR

geomagnetic + Askaryan emission

reflected UHECR

geomagnetic + Askaryan emission

Ice

Askaryan emission

~EeV ν

ANITA instrument

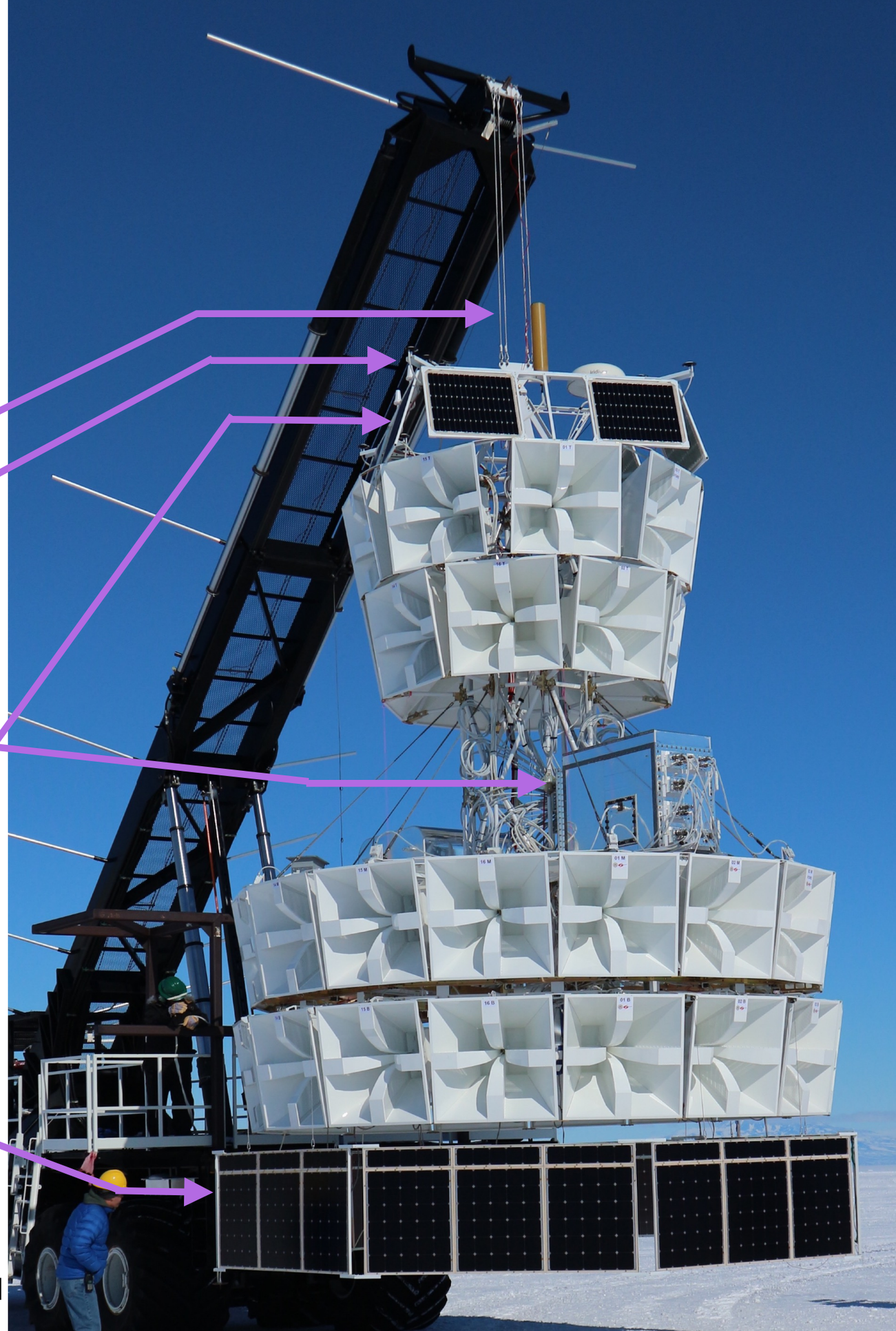
TDRSS & Iridium antennas

GPS antennas

Instrument box

48 quad-ridged horn antennas

Solar panels



ANITA instrument

TDRSS & Iridium antennas

GPS antennas

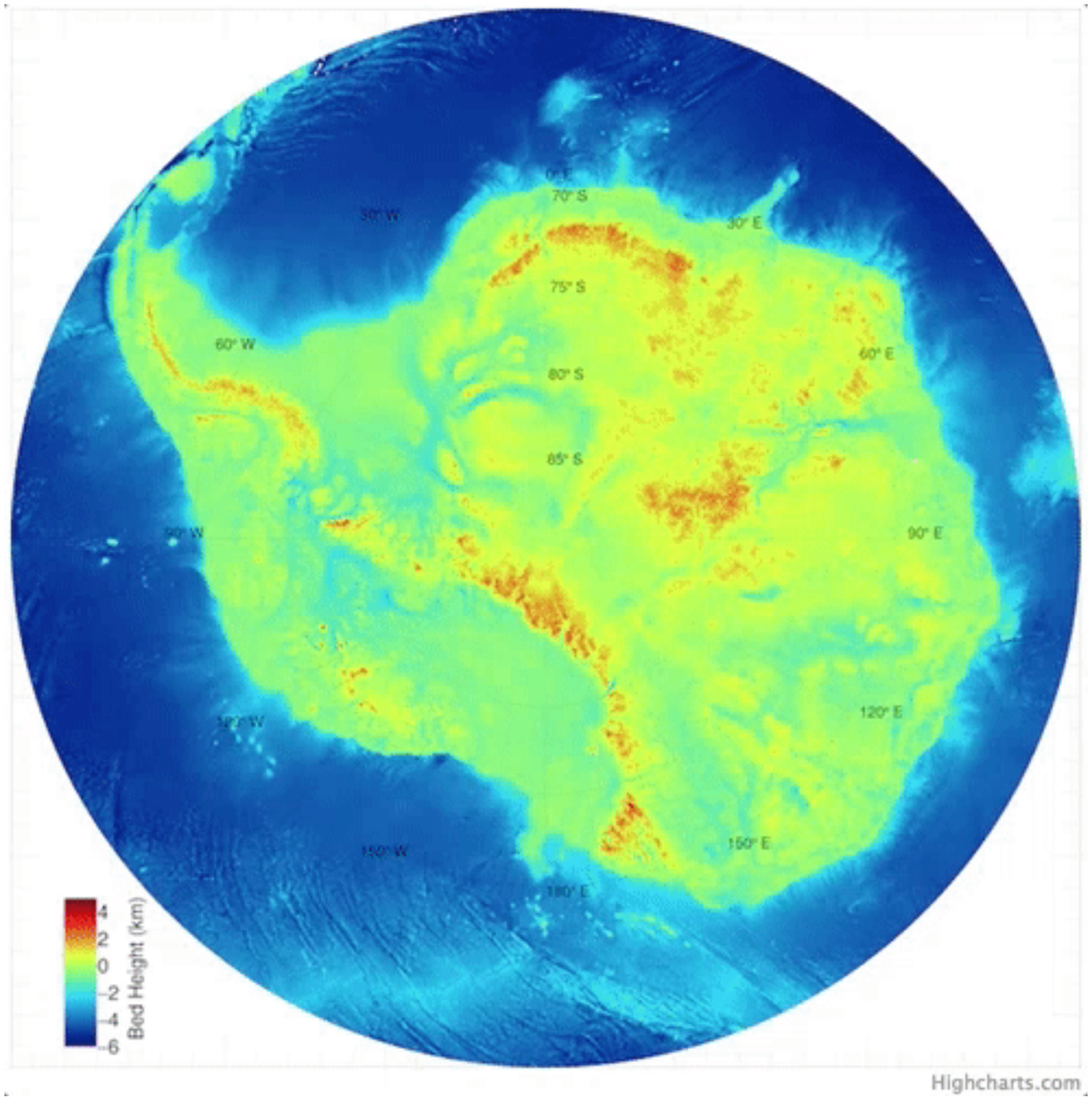
Instrument box

48 quad-ridged horn antennas

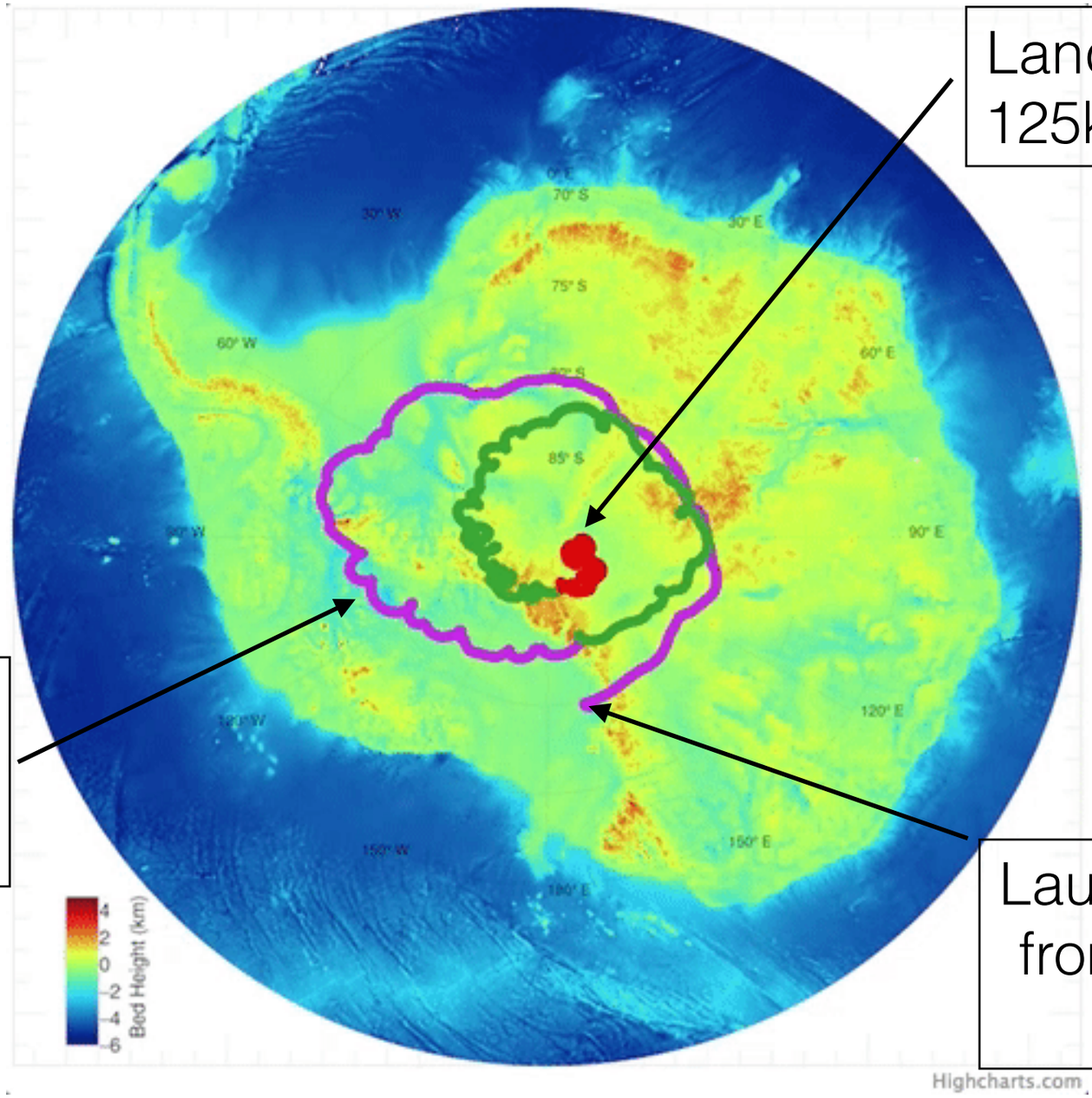
Solar panels

ANITA-4 taking off

ANITA-4 flight path

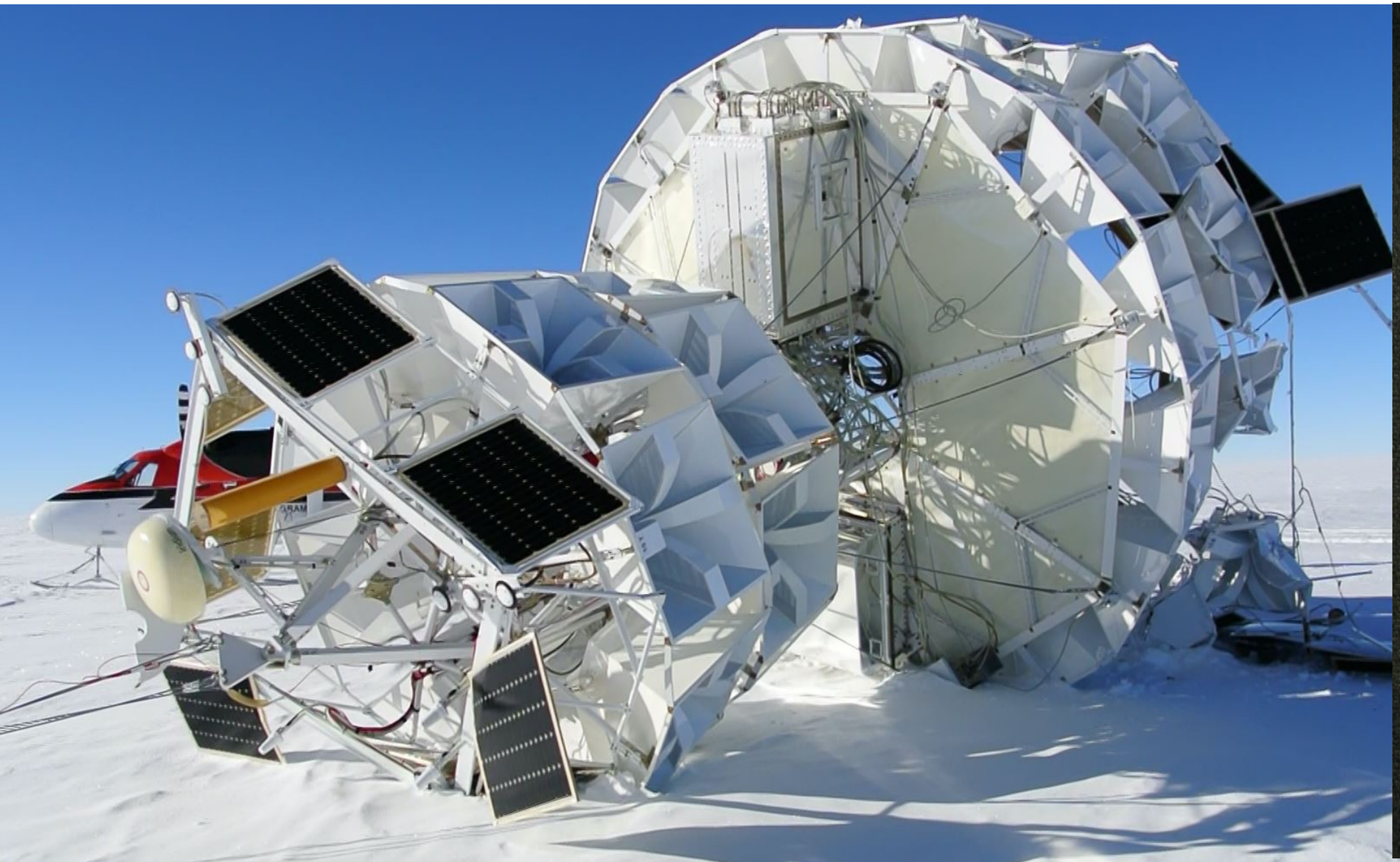


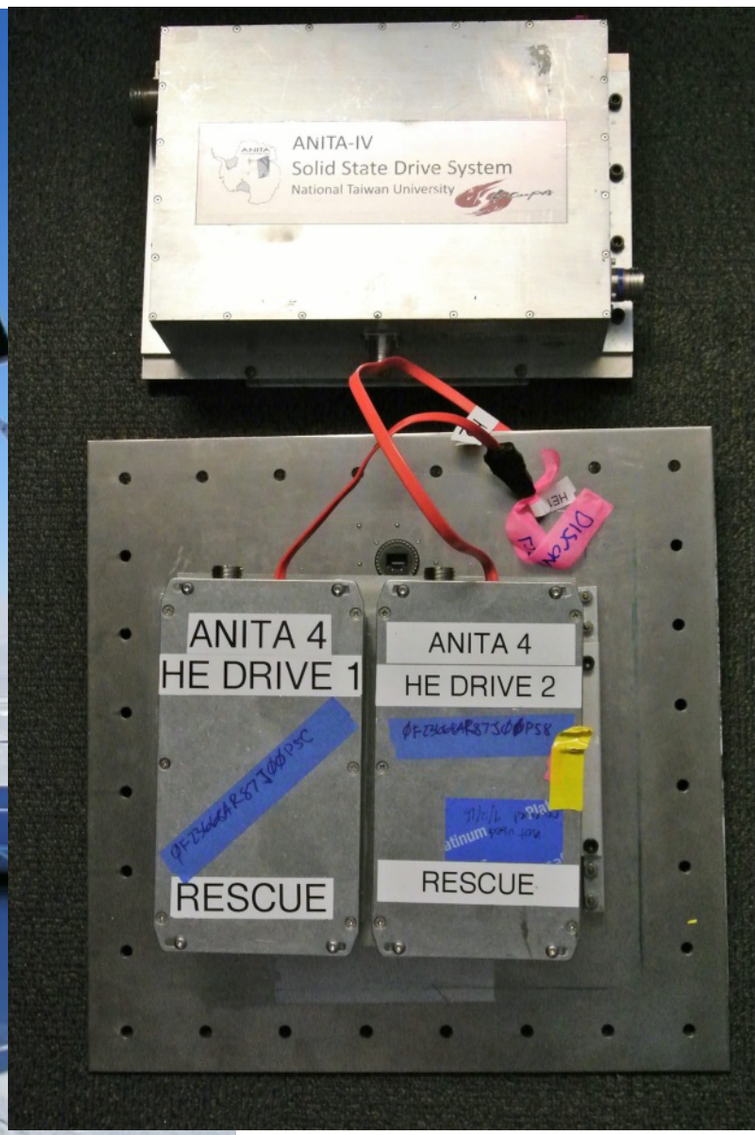
ANITA-4 flight path



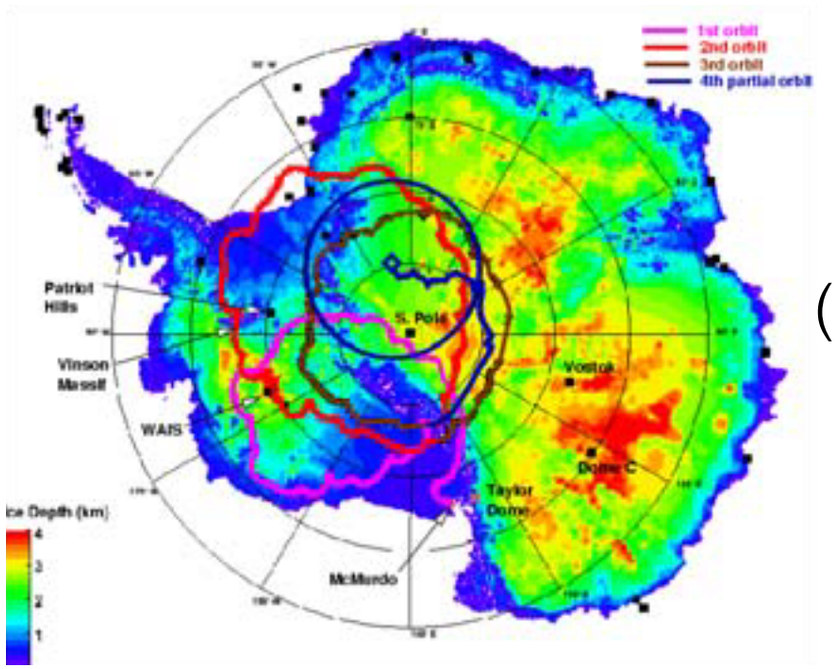
ANITA-4 Recovery

- Partial recovery done on Jan 10th 2016
- Full recovery done in December 2017



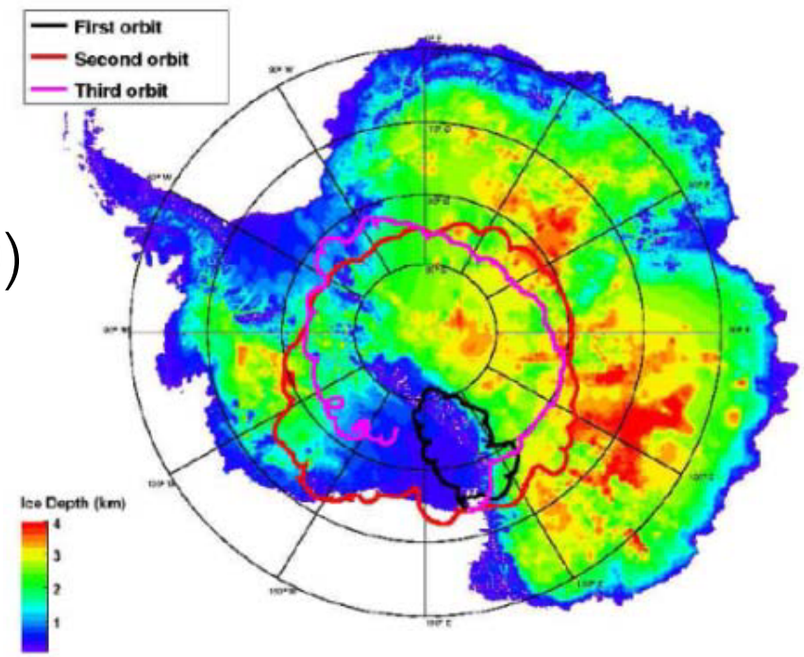


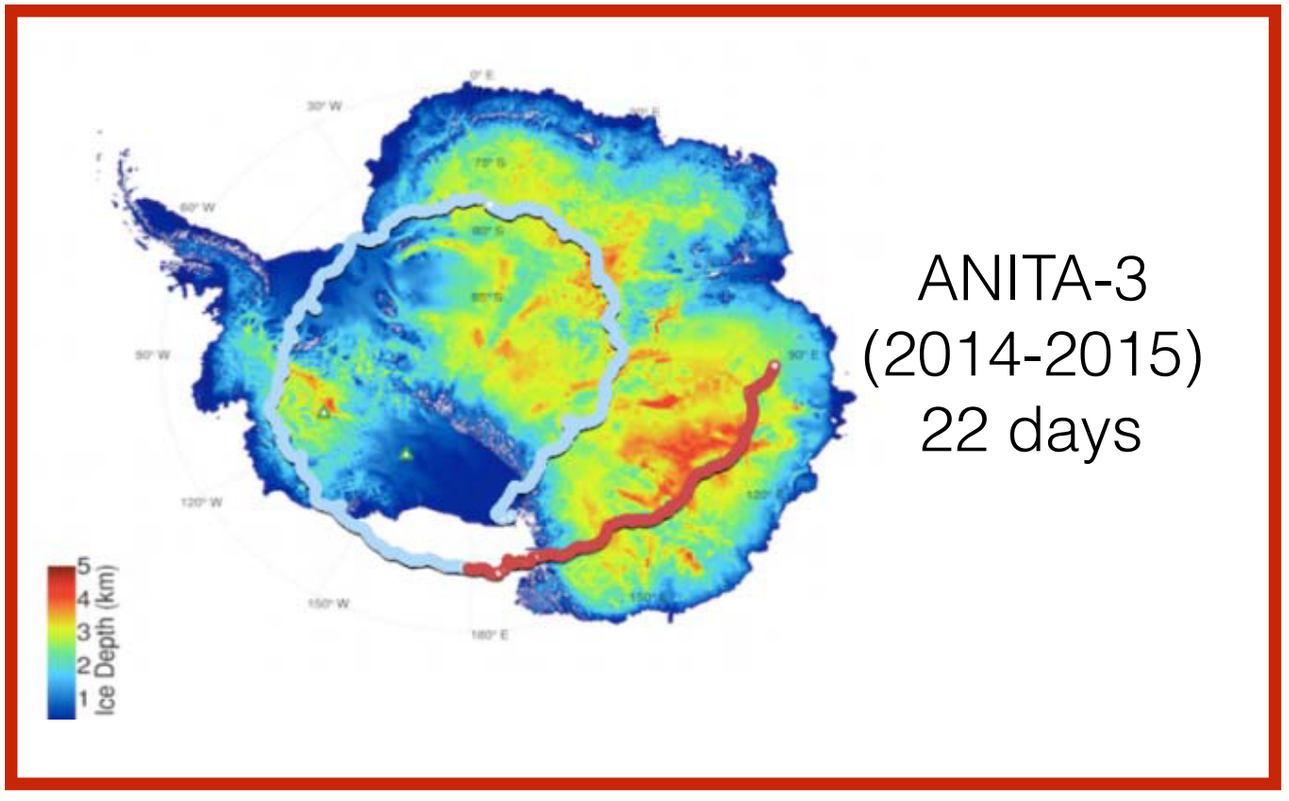
ANITA Flights



ANITA-1
(2006-2007)
35 days

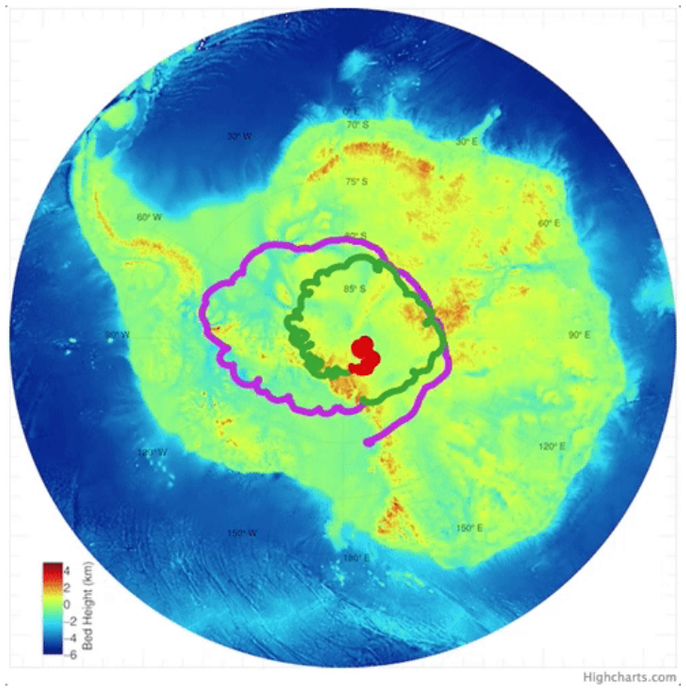
ANITA-2
(2008-2009)
30 days



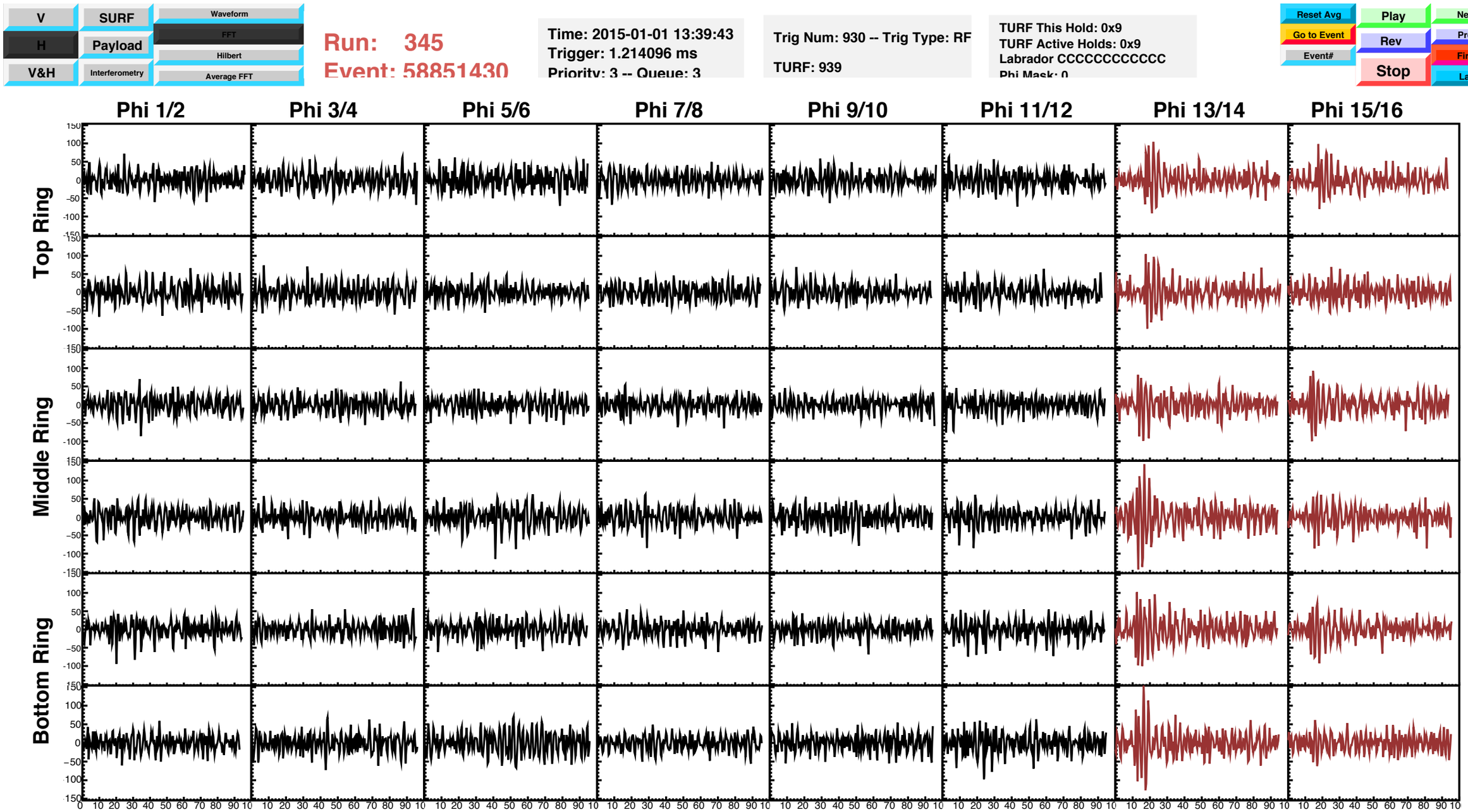


ANITA-3
(2014-2015)
22 days

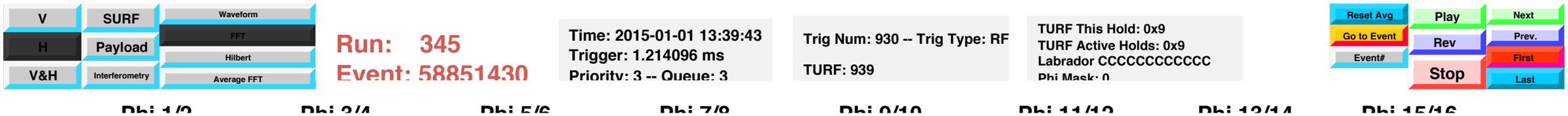
ANITA-4
(2016)
30 days



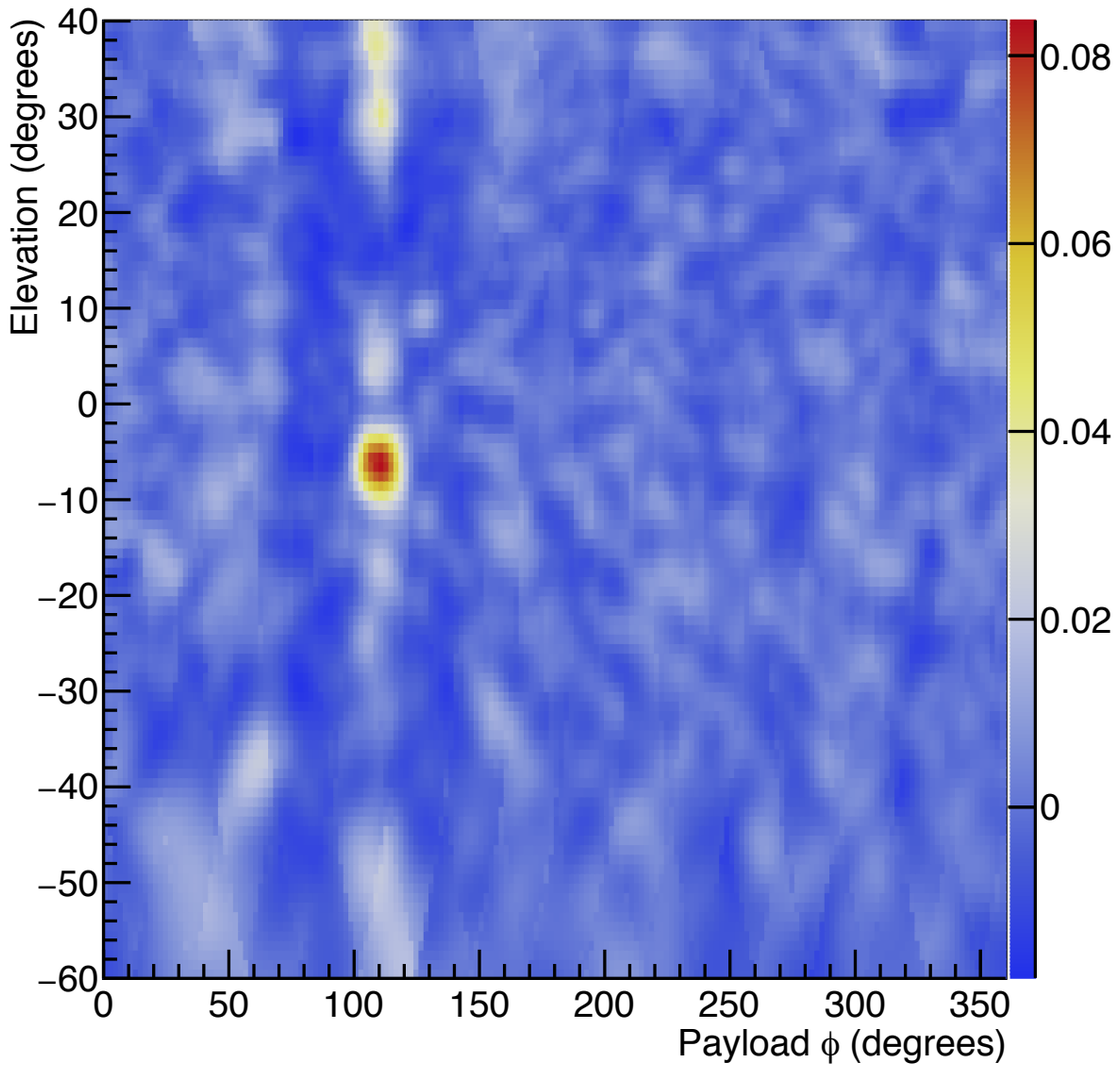
How ANITA sees the world



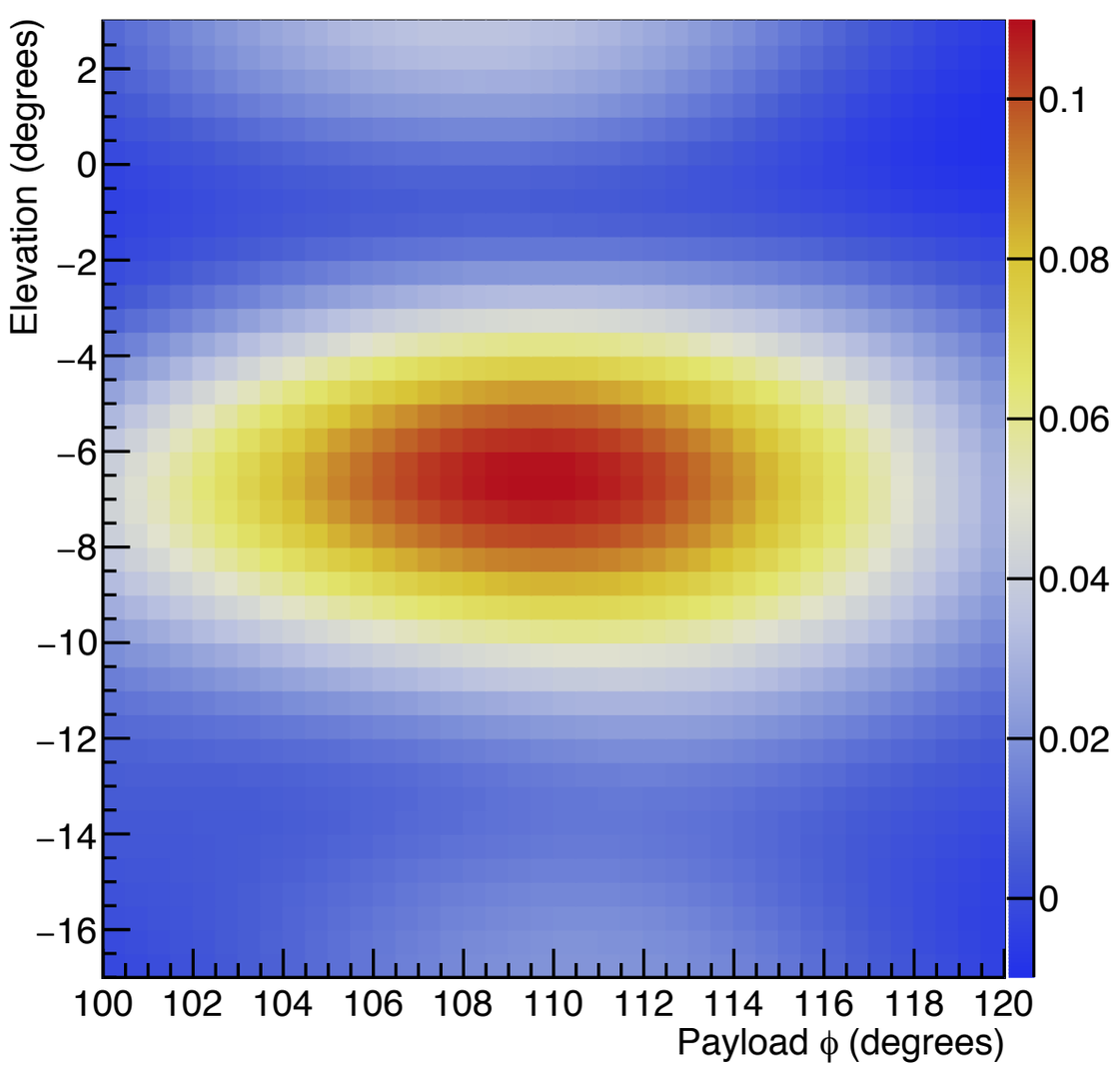
How ANITA sees the world



Interferometric Map



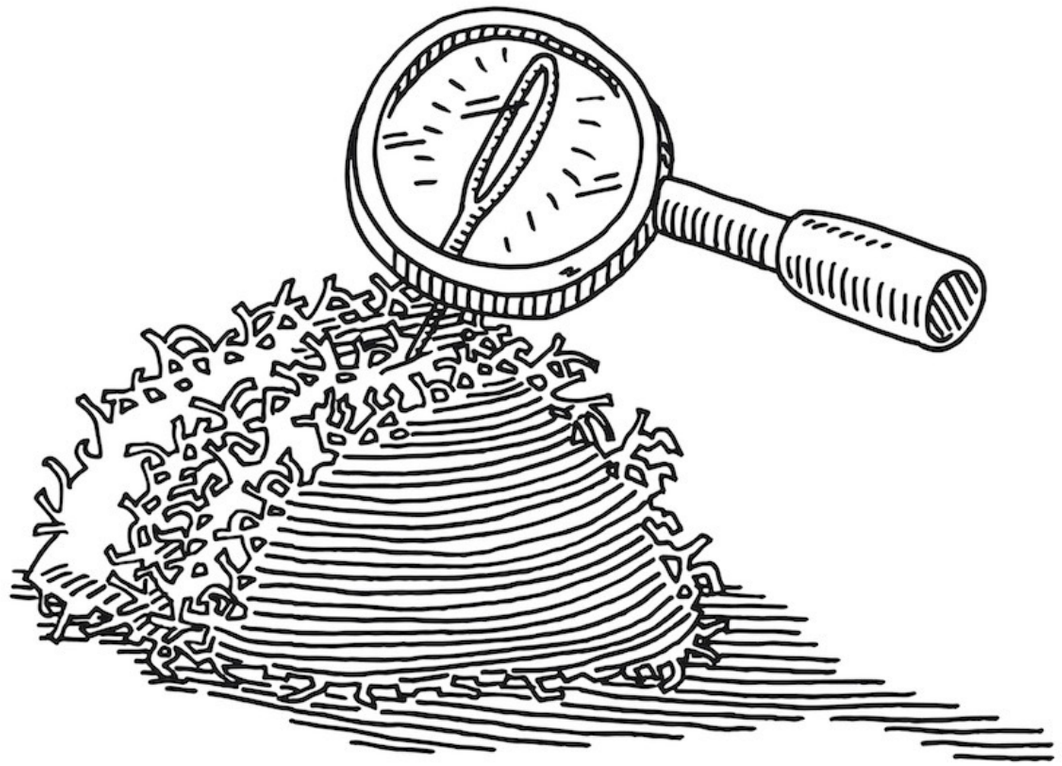
Zoomed Map



Needle(s) in a haystack

The challenge

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



The challenge

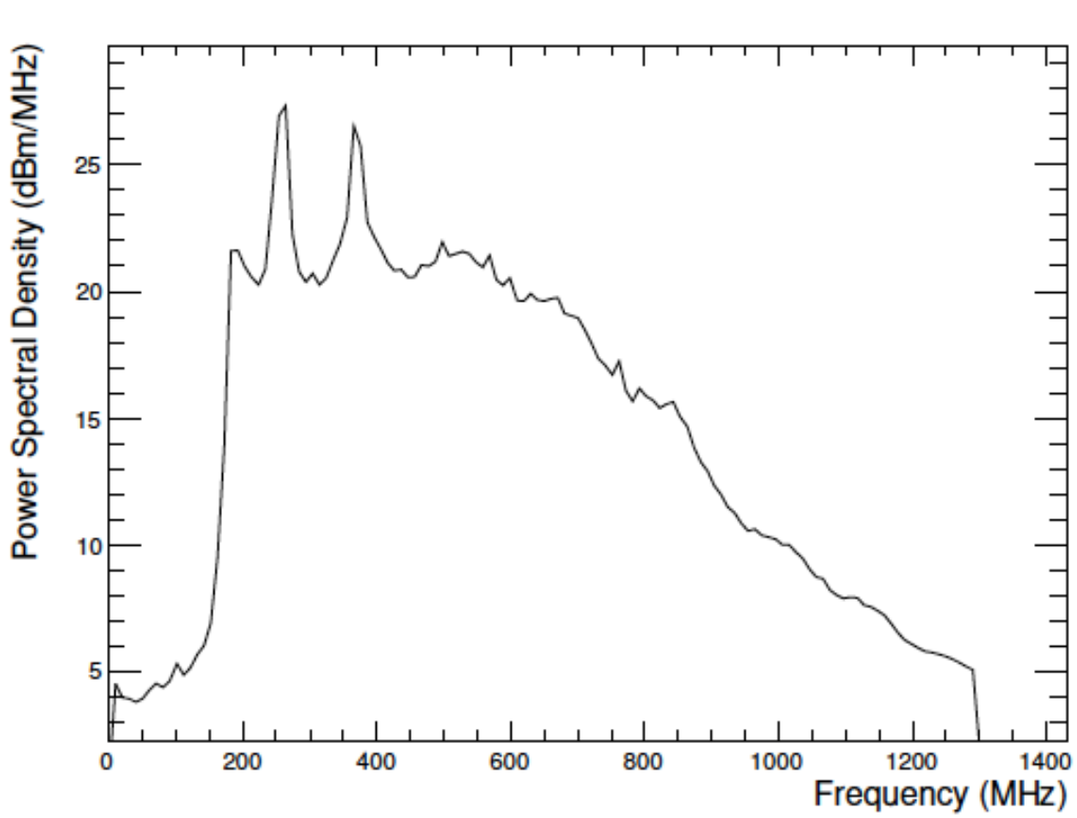
- ~100 million events
- (maybe) a few neutrinos
- Tens of cosmic rays

Backgrounds

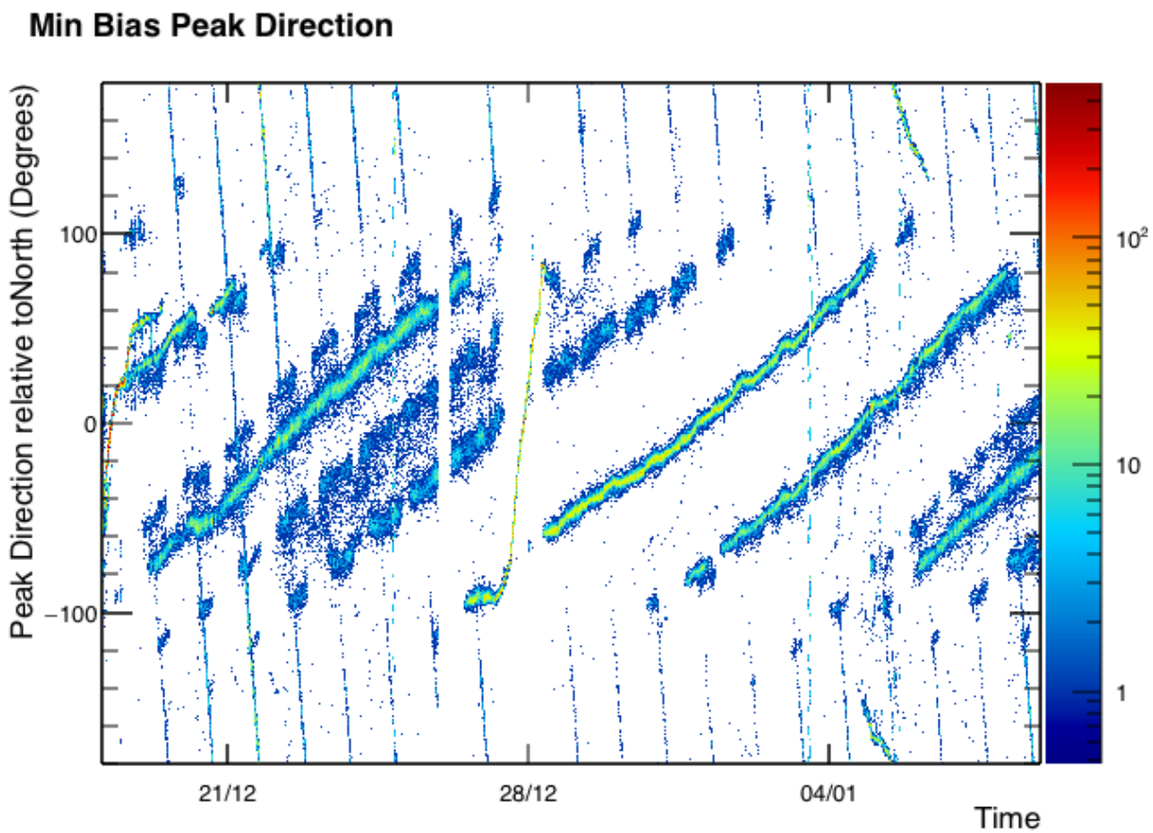
- Continuous waves
- Payload blasts
- Thermal noise
- Anthropogenic impulsive events

Continuous Waves

- Satellites and human bases using communications in the bands:
  - 260 MHz
  - 380 MHz

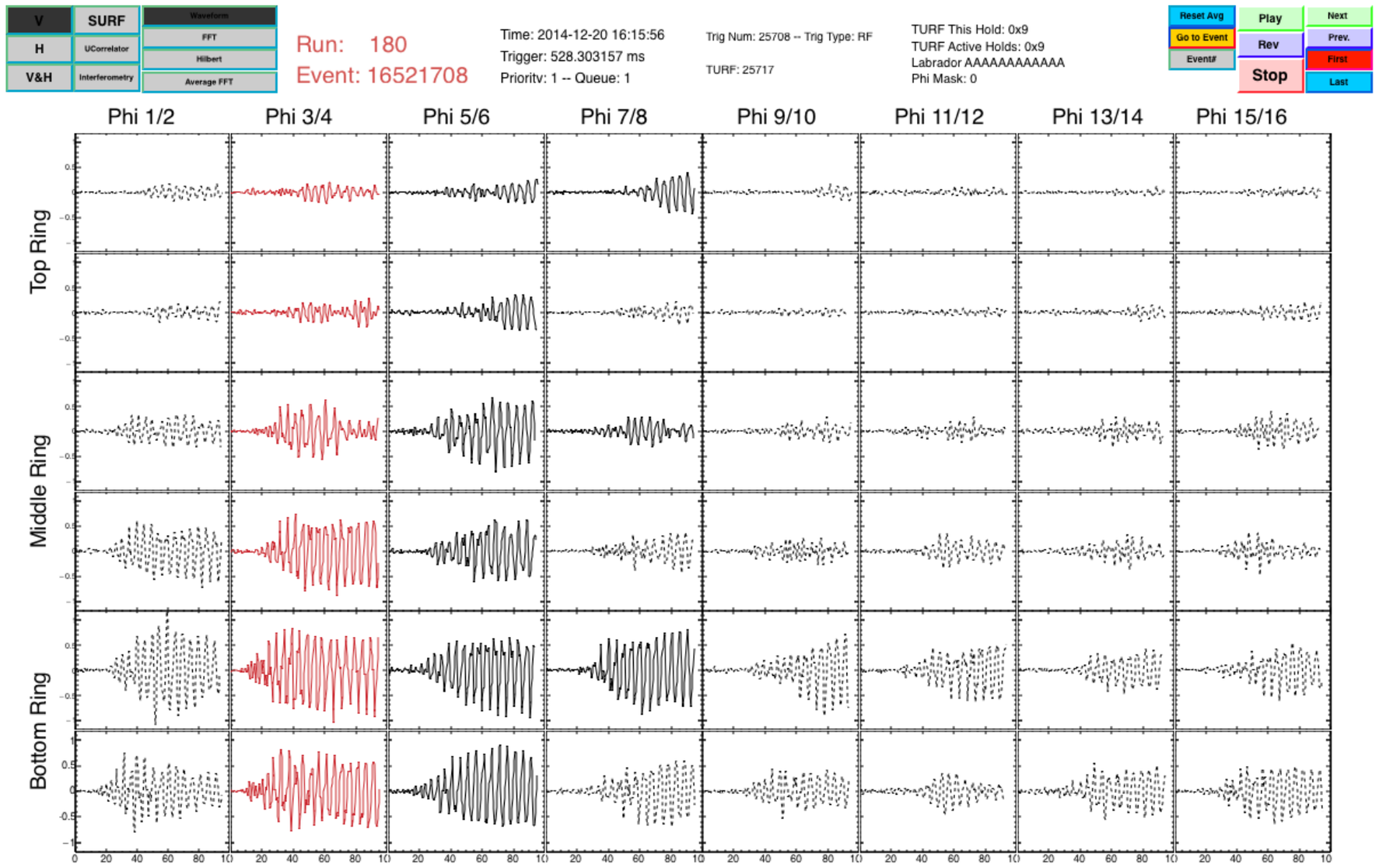


- How to get rid of this?
  - ANITA-3: software
  - ANITA-4: hardware



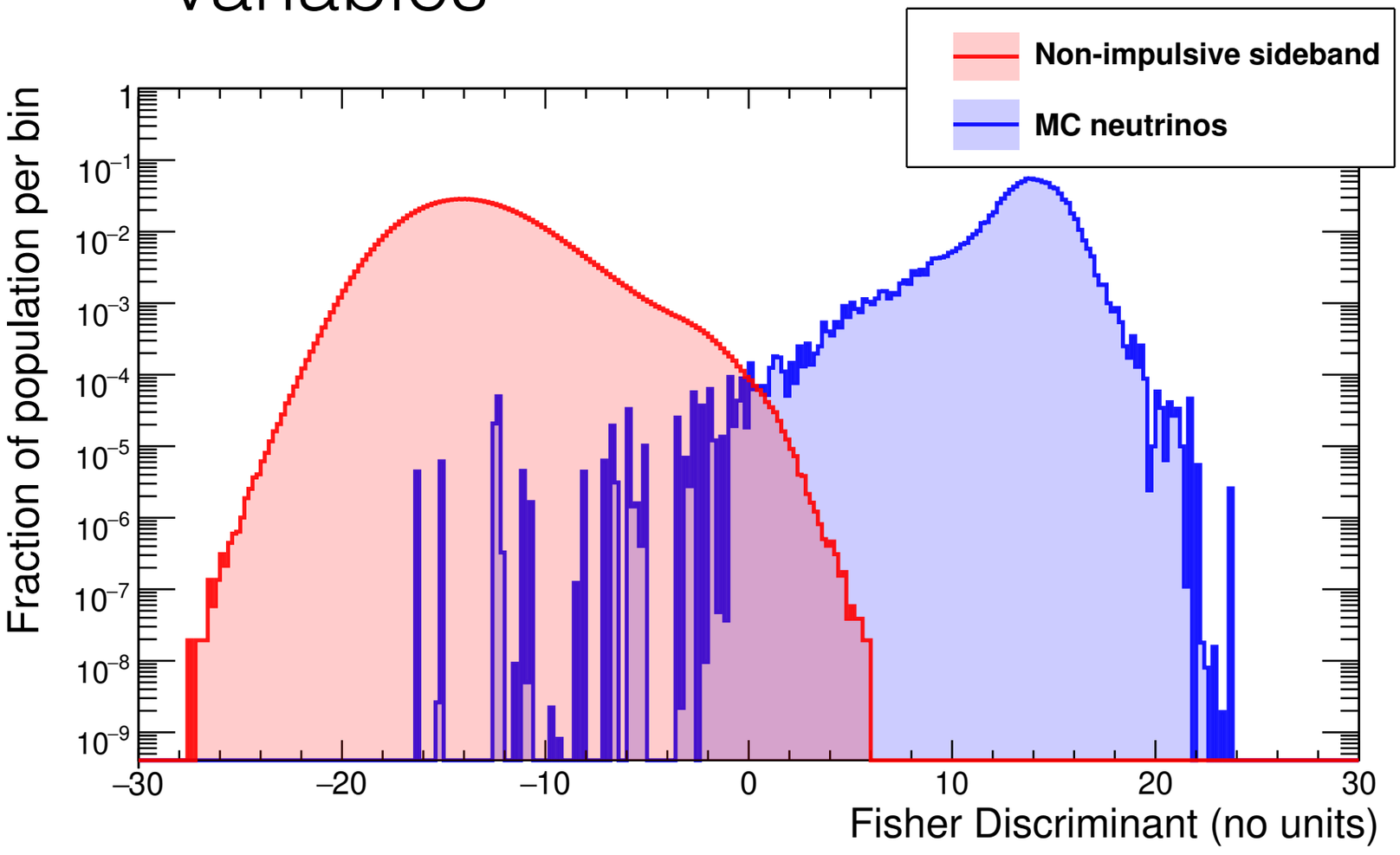
Payload blasts

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



Thermal noise

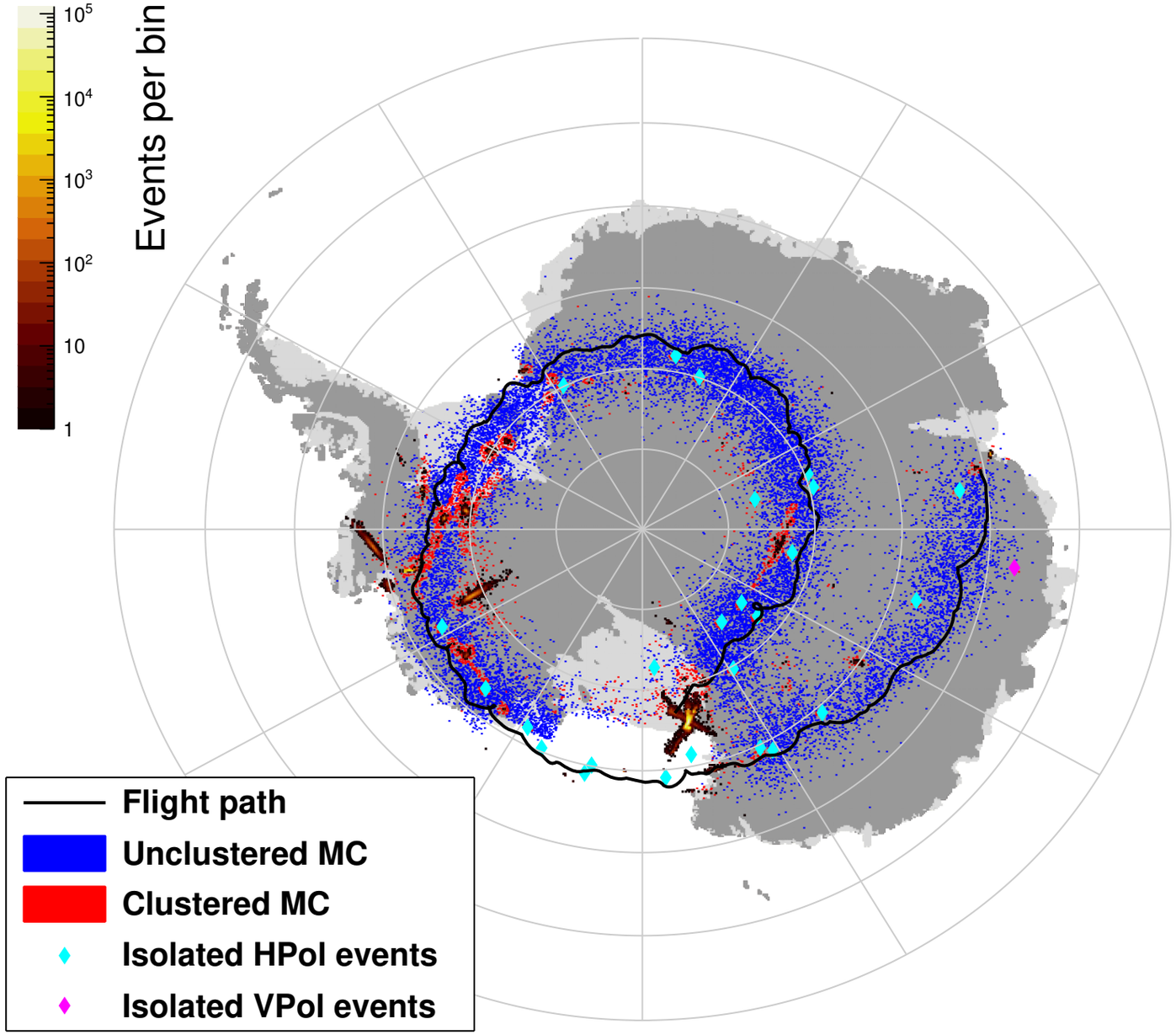
- Vast majority of ANITA events are thermal noise
- Use Fisher discriminant based on impulsivity variables



- Background sideband: above horizon triggers
- Simulation: cosmogenic neutrinos following the Kotera mix max model

Clustering

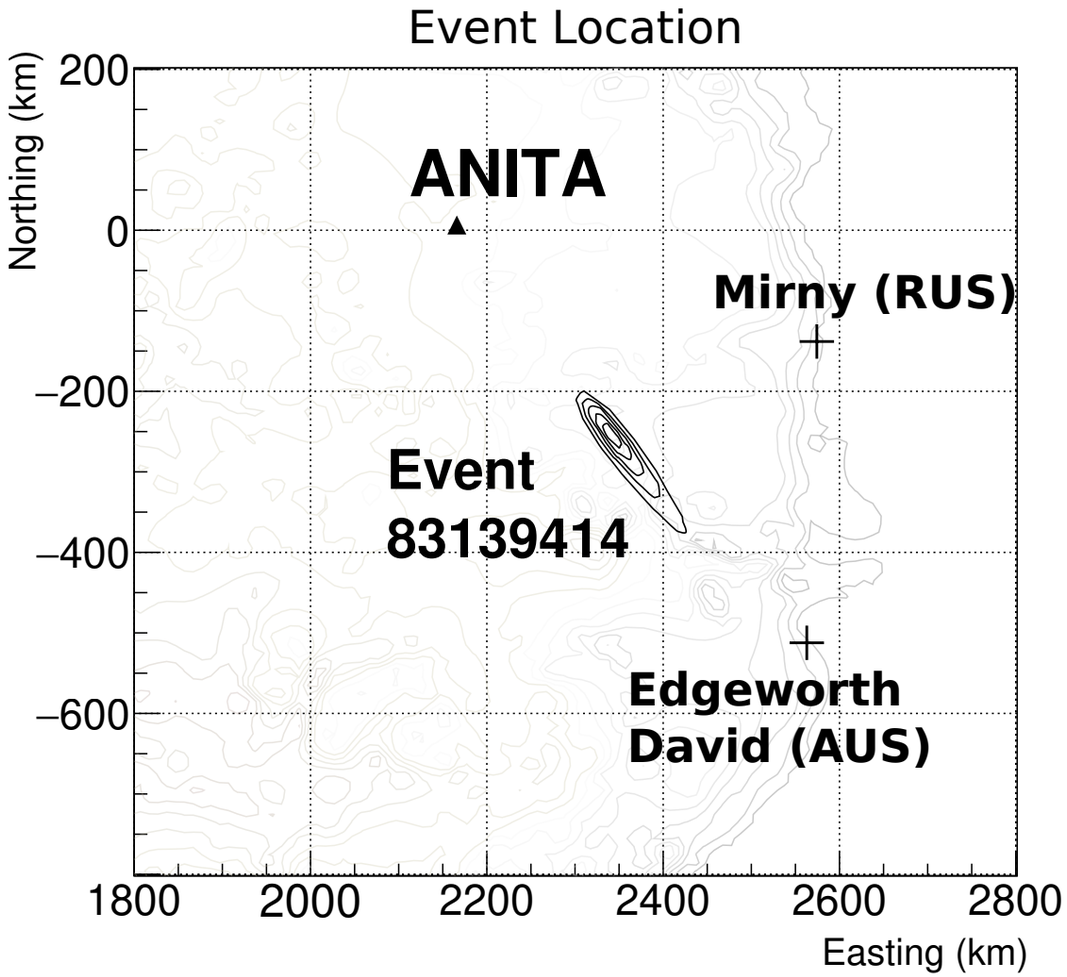
- From previous cuts, ~500k events

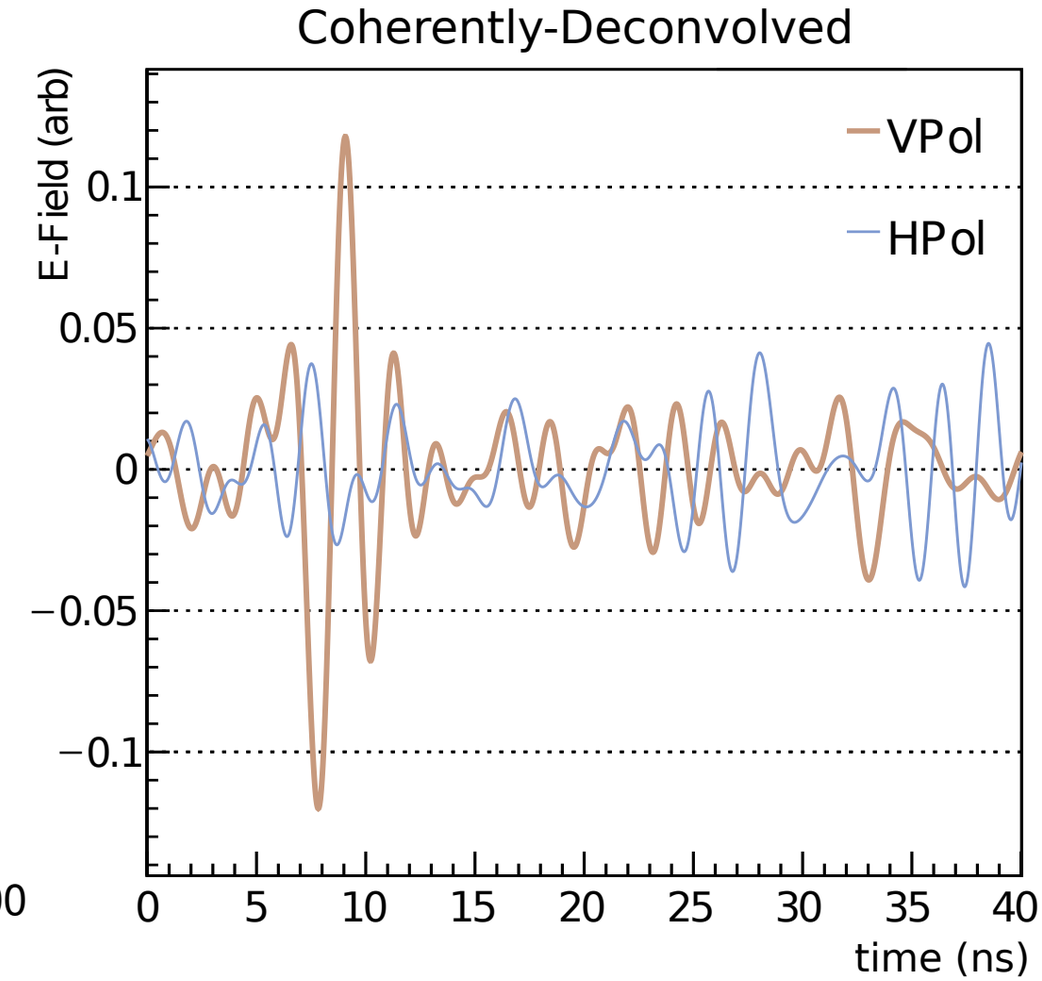


- Look for isolated singlets and doublets
- Remove anything that clusters with human bases
- Remove anything which forms a cluster of 3 or more

What's left?

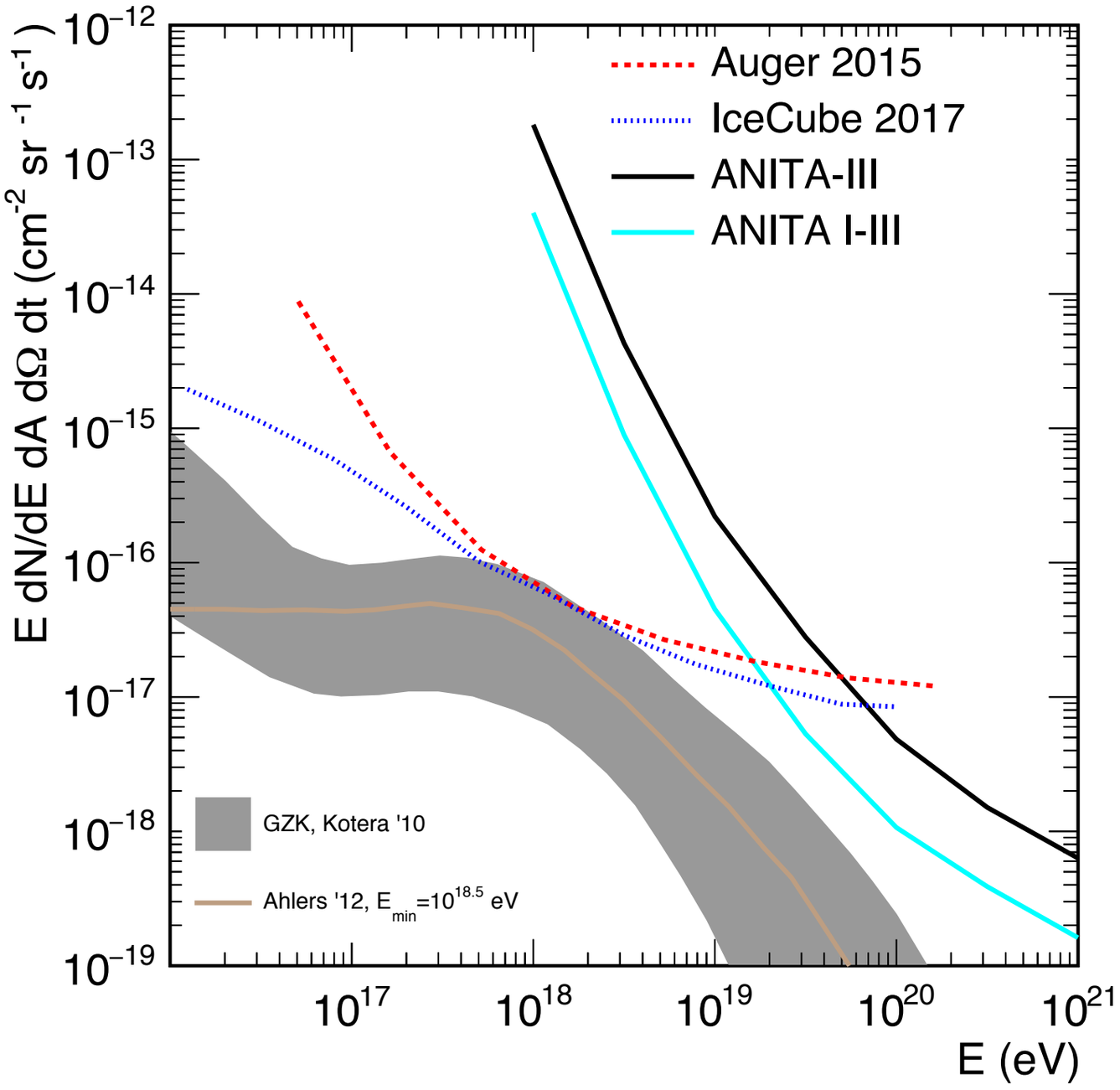
- One V-POL candidate
- Background estimate: $0.7^{+0.5}_{-0.3}$ per polarisation
- No known human activity within 260km





Neutrino limit

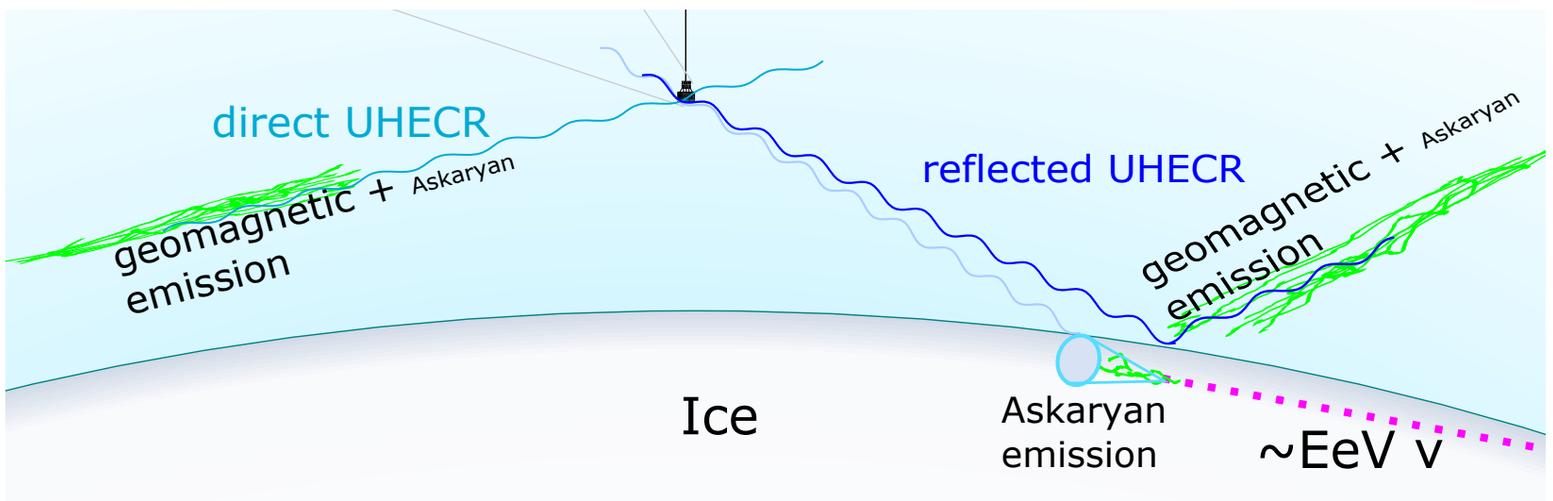
Limit on all-flavour-sum diffuse UHE neutrino flux

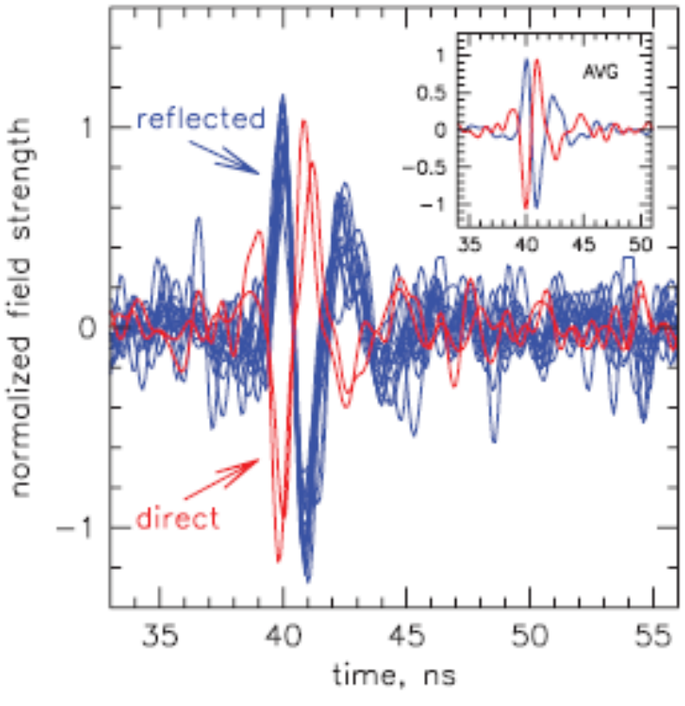


UHE cosmic rays

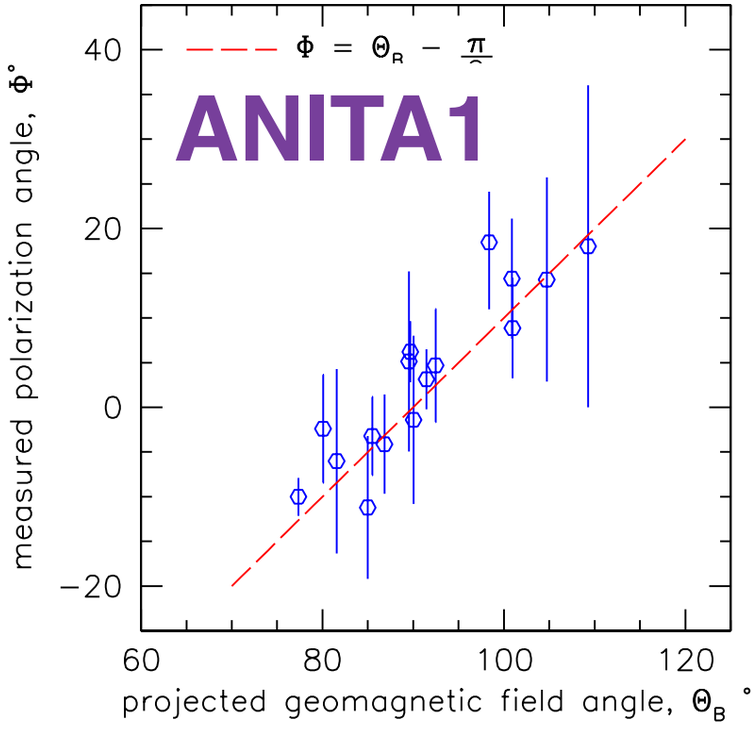
UHECR

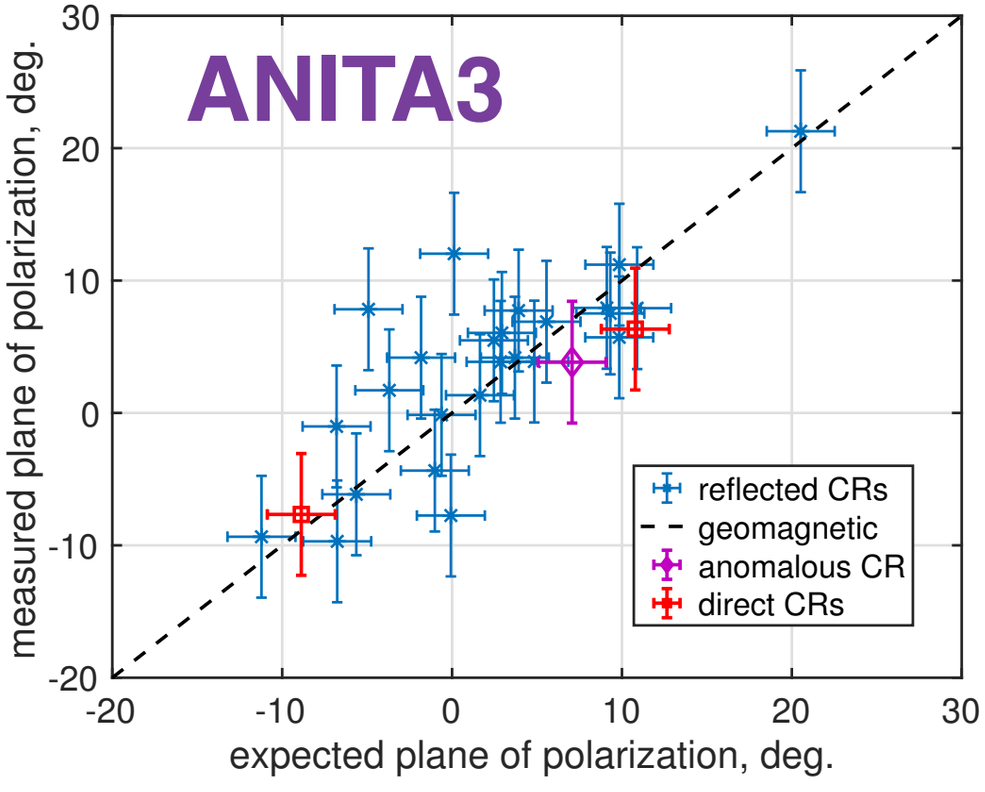
ANITA1: 16 UHECR
 14 reflected + 2 direct
ANITA-2: 2 UHECR
 H-pol trigger was off
ANITA-3: 25 UHECR
ANITA-4: analysis in progress





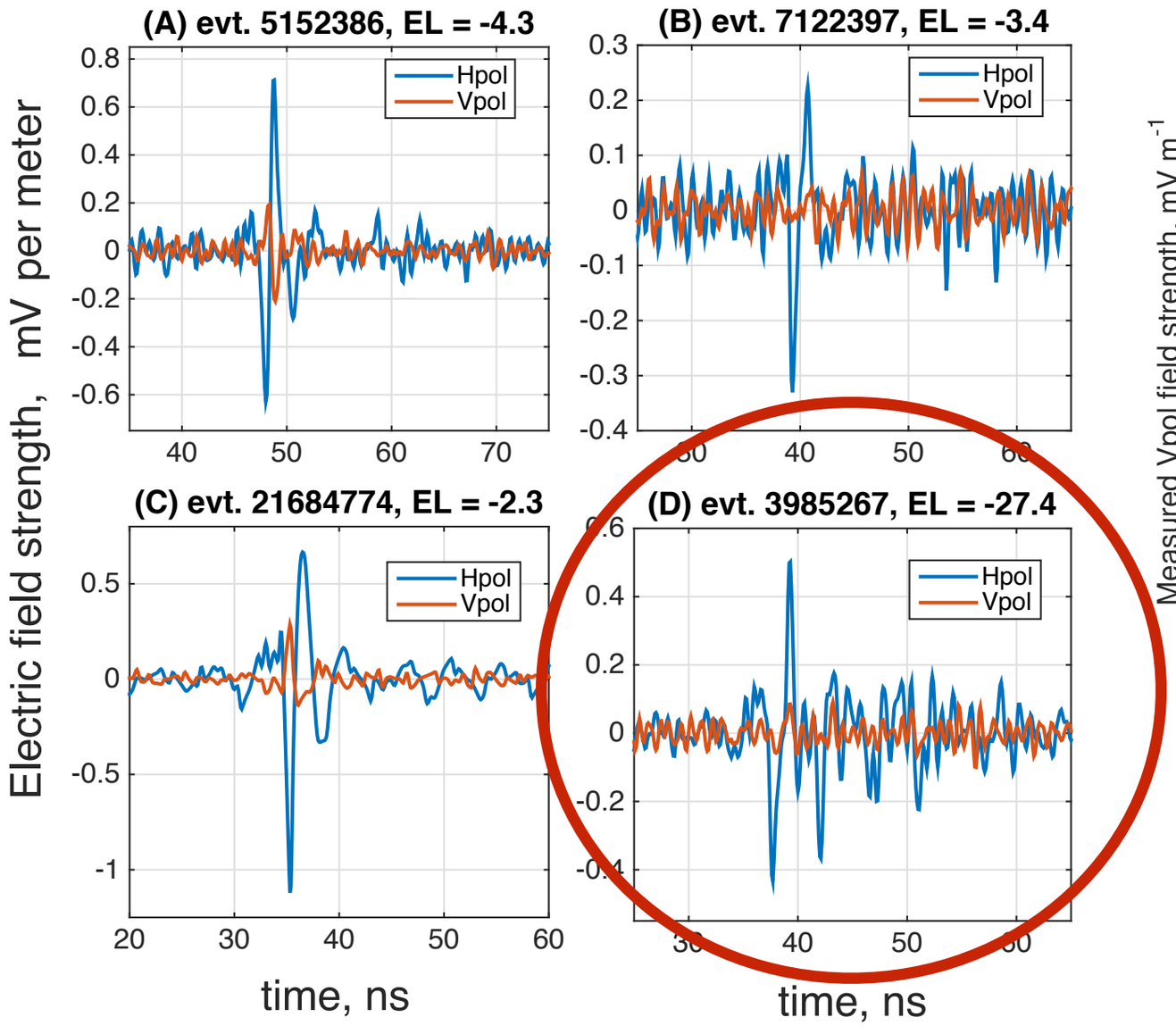
PRL 105, 151101 (2010)

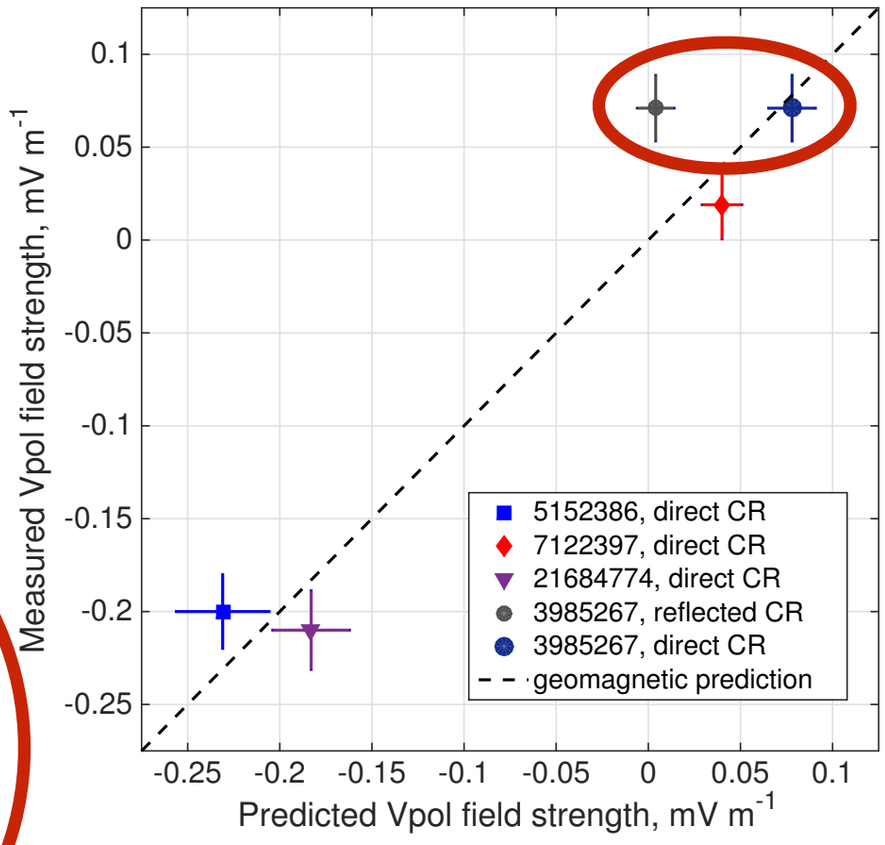




arXiv:1803.05088 [astro-ph.HE]

ANITA-1 mystery event



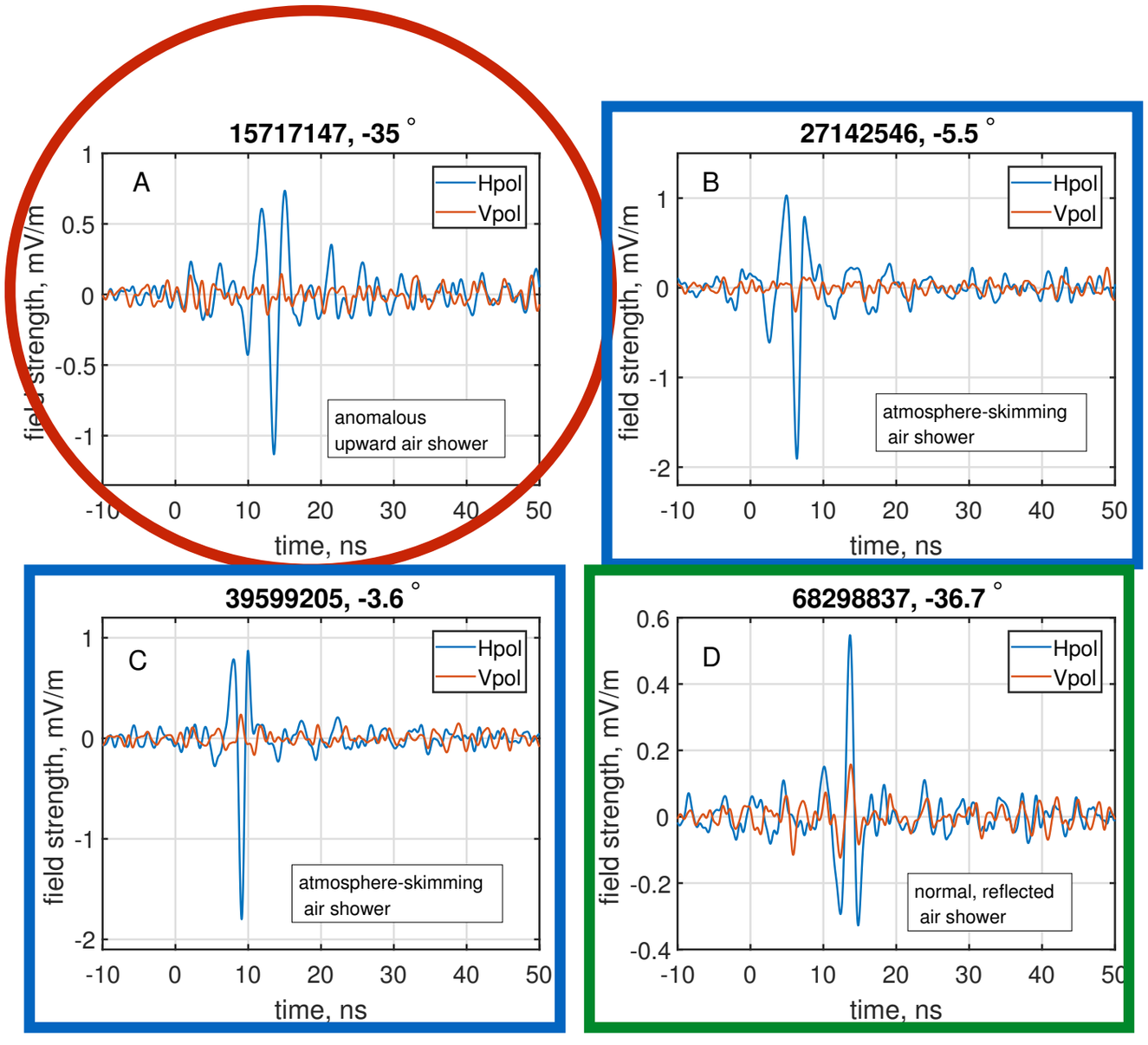


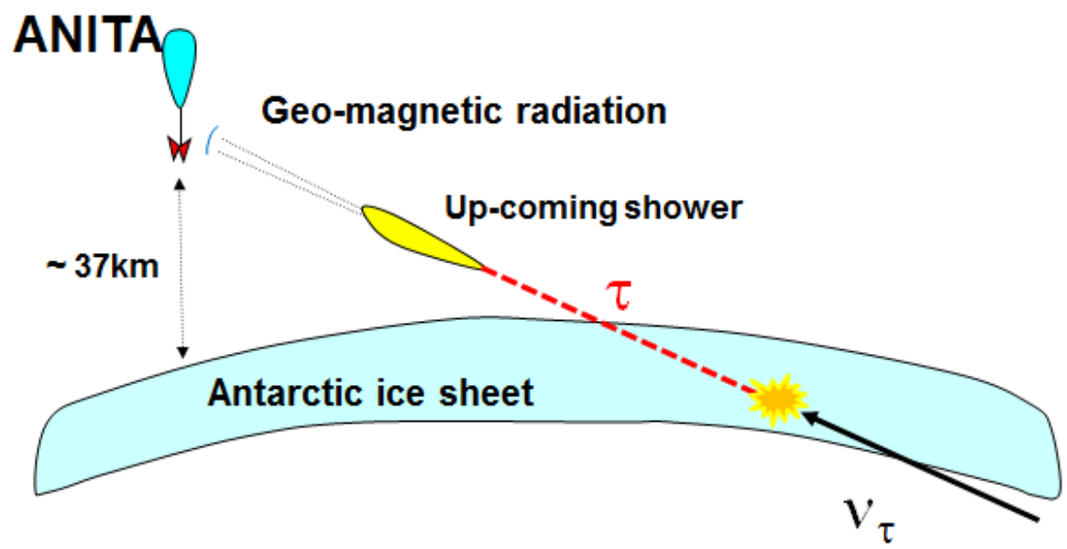
A strong H-pol non-inverted signal seen!

- 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





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

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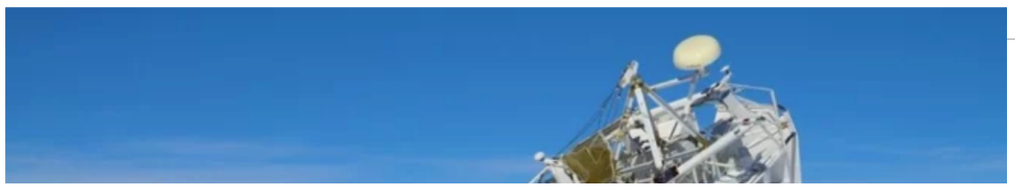

IFLSCIENCE!

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An Astonishing Discovery Might Have Just Broken Particle Physics

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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

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NEWS PARTICLE PHYSICS

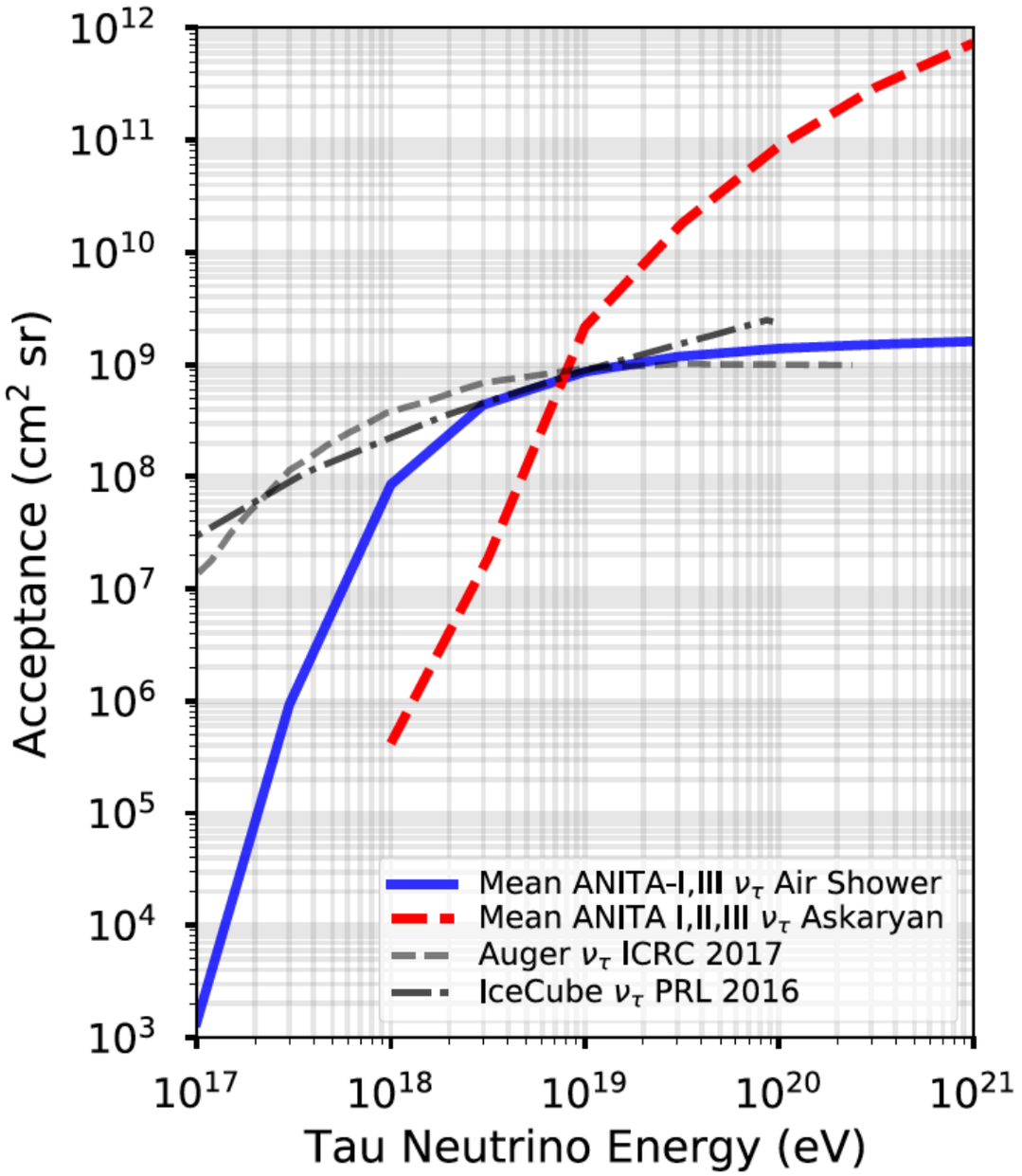
Hints of weird particles from space may defy physicists' standard model

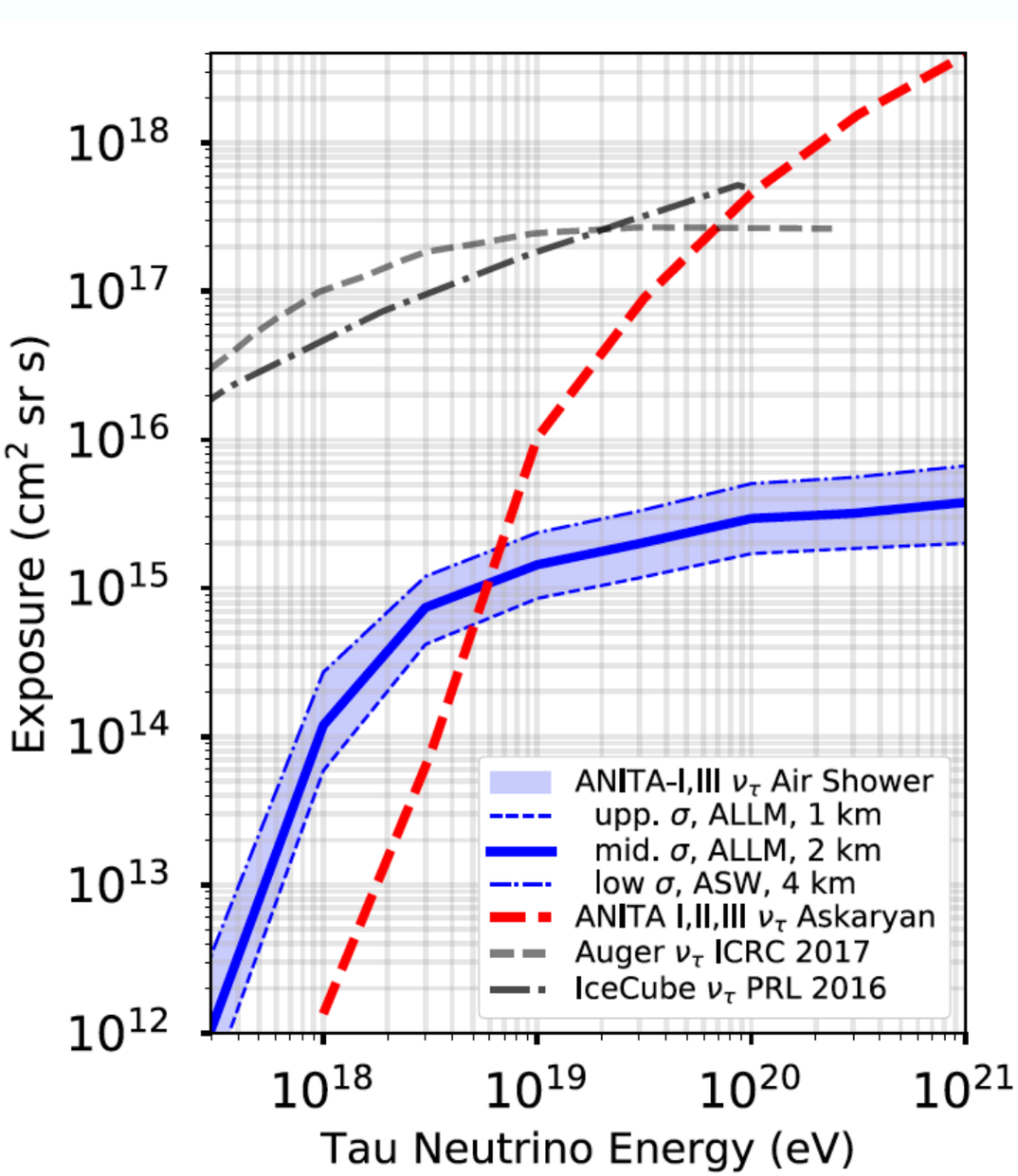
L. Cremonesi

"UHE neutrinos and ANITA"

Diffuse neutrinos: problem 1

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

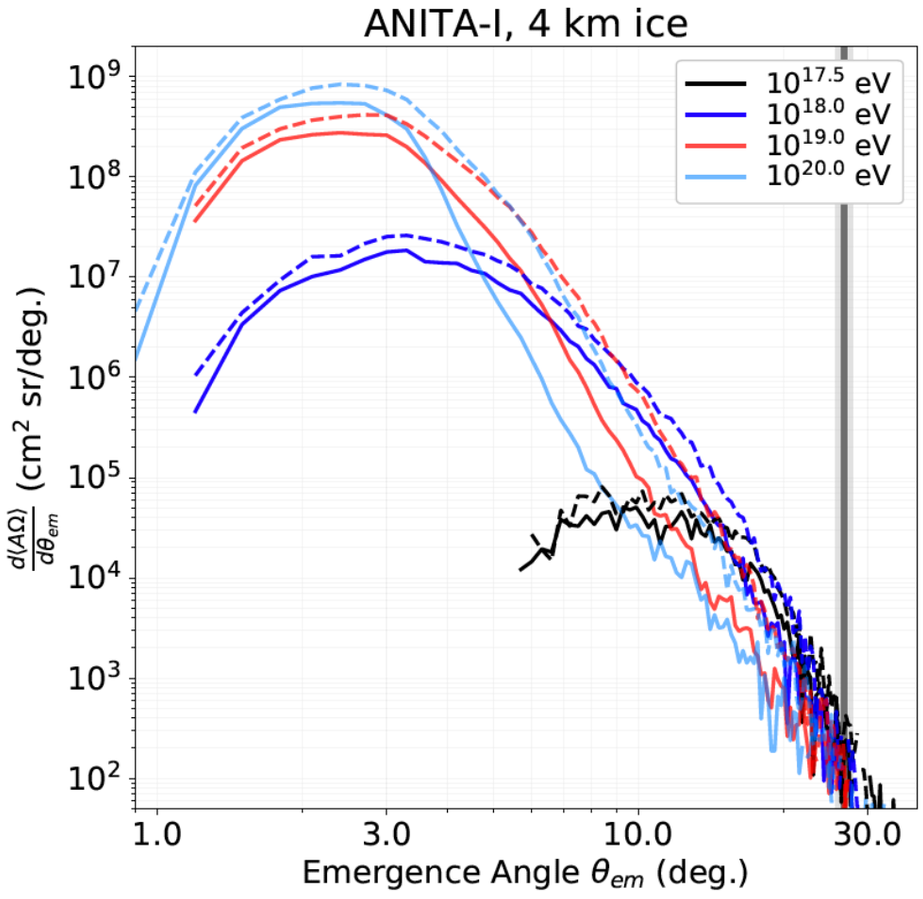


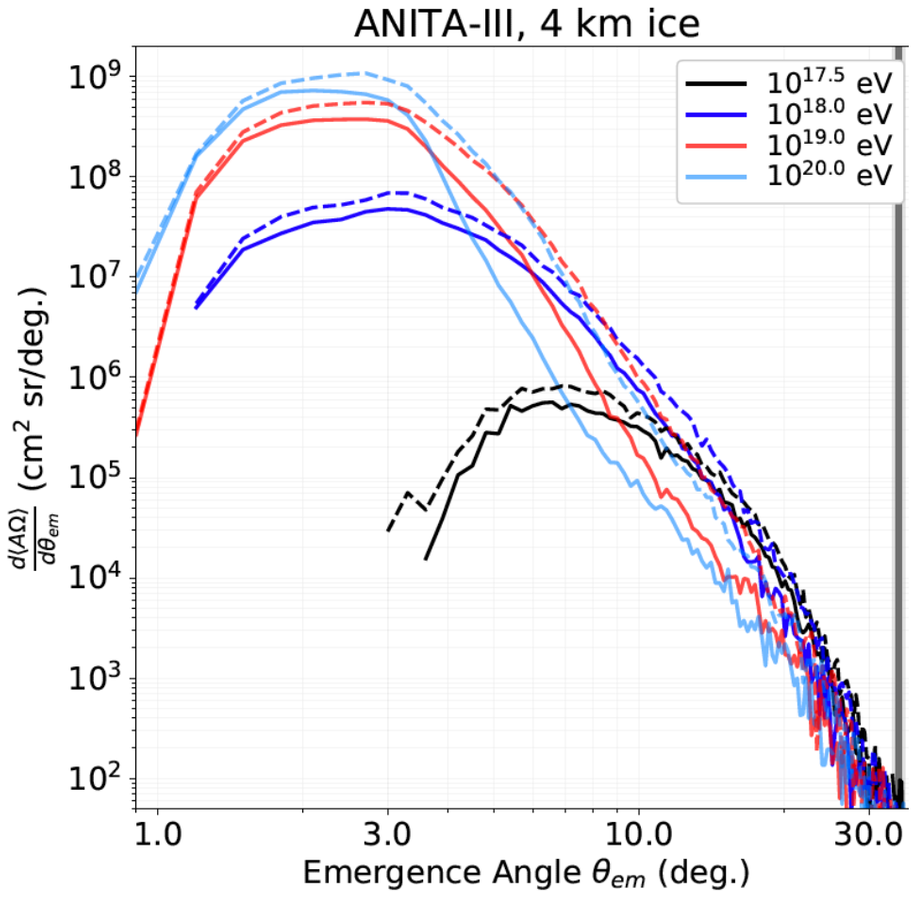


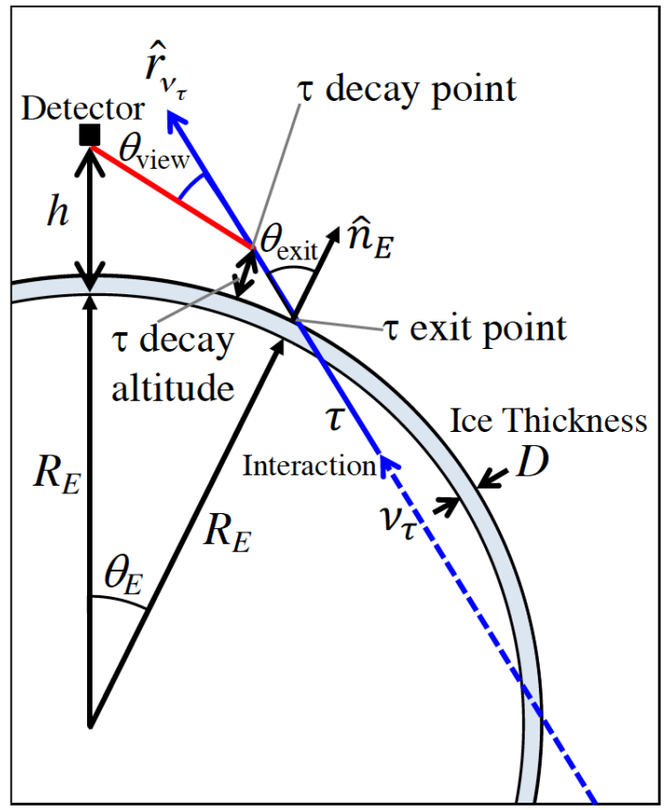
arXiv: 1811.07261

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

Possible solutions

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

- 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

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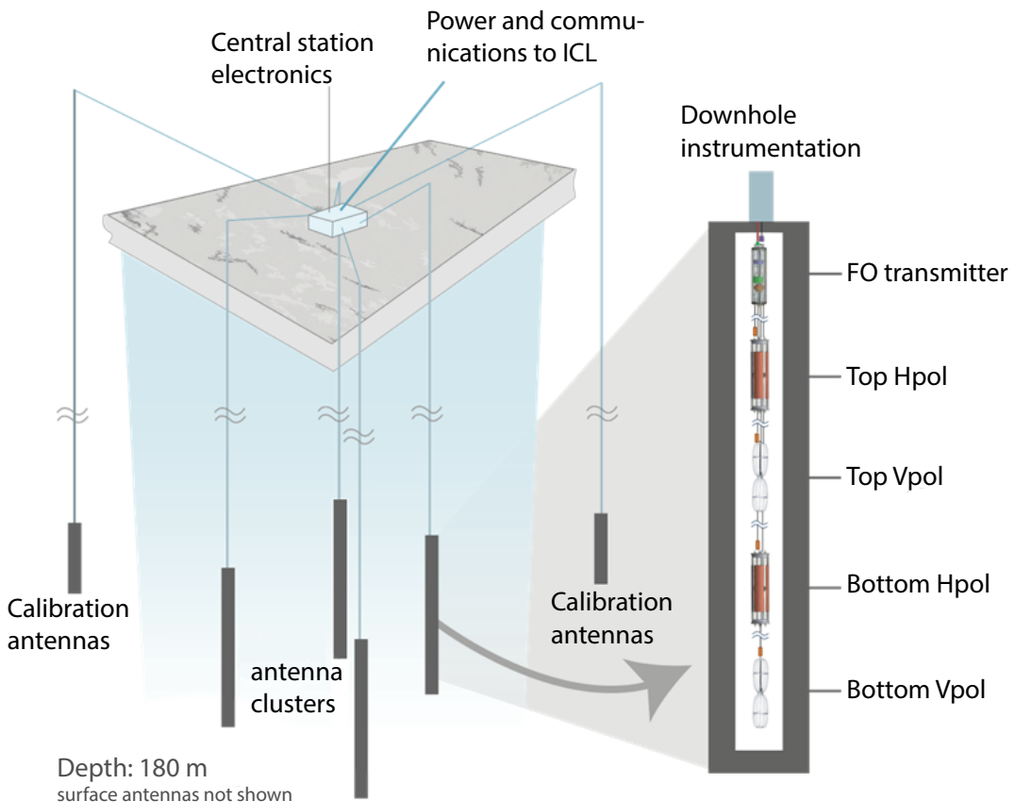
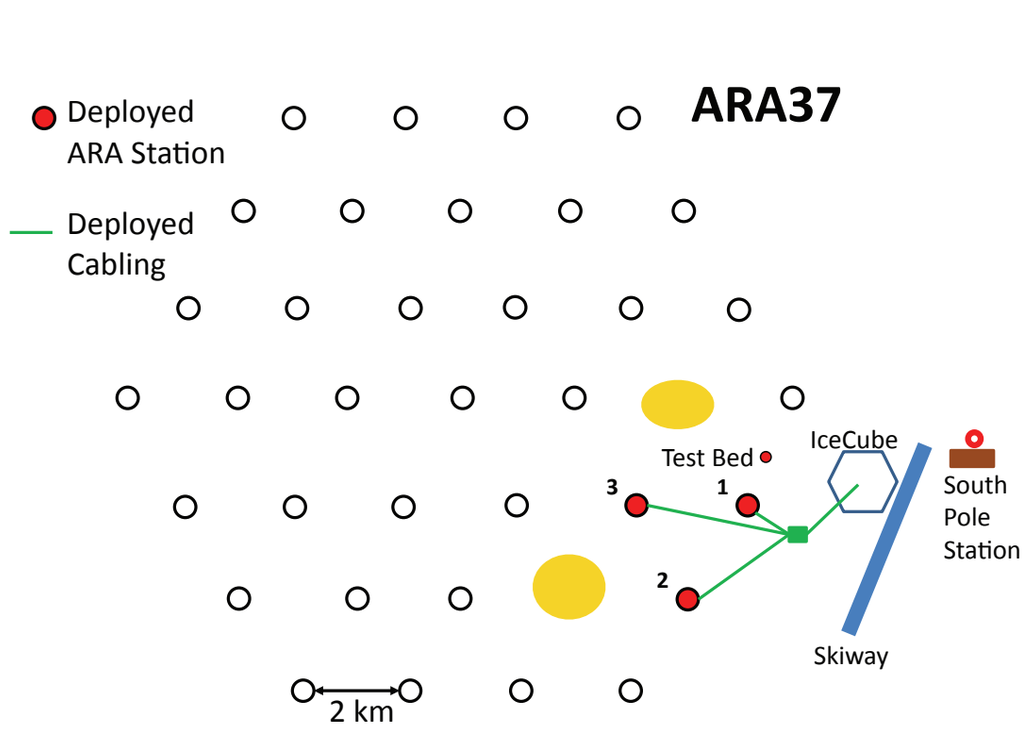
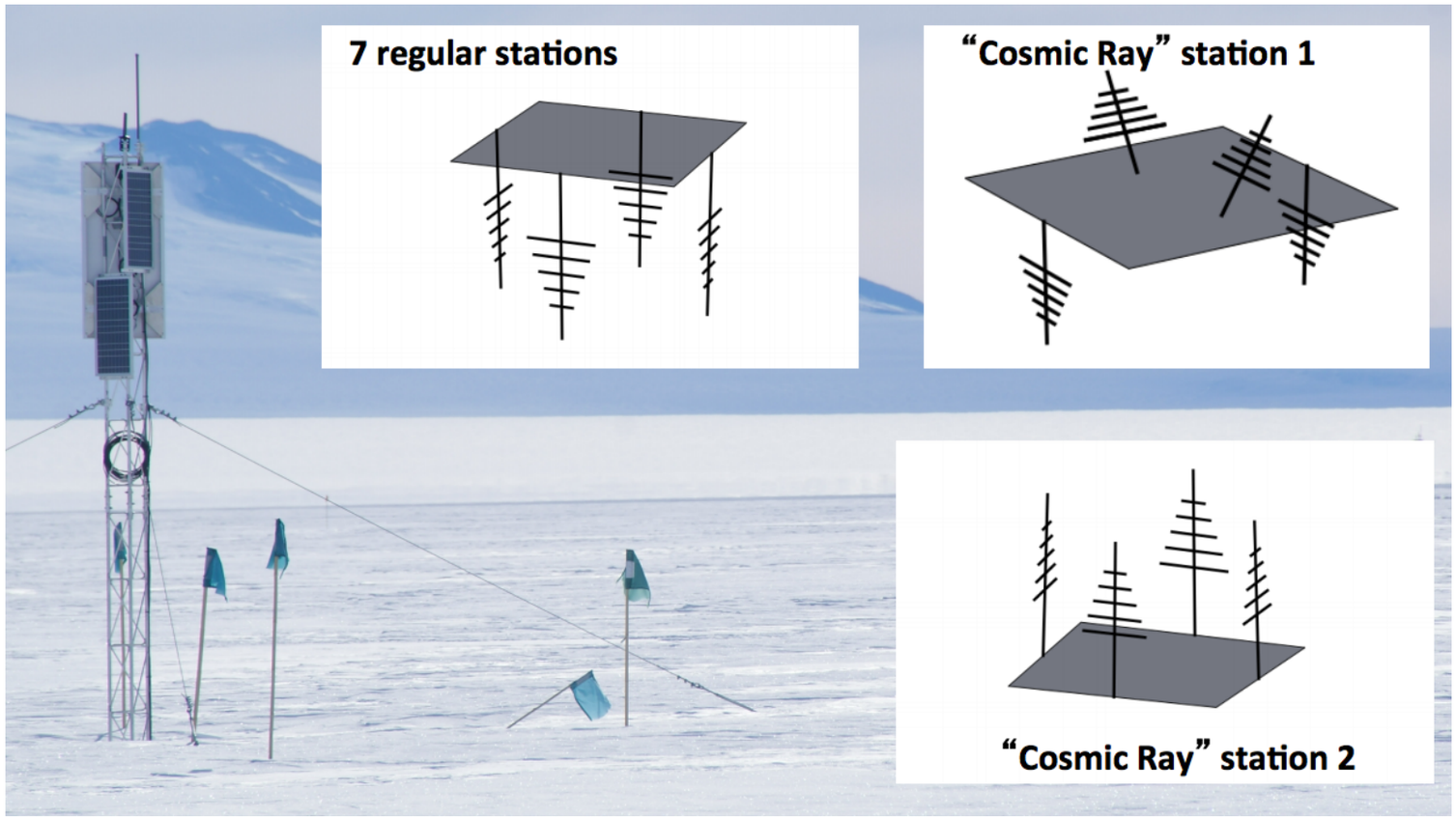




What about the future?

- ANITA-5 proposal, new hardware to try out! (J. Nam ICRC2017)
- ARA: 5 deployed stations (M.Y. Lu ICRC2017)
- Phased array deployed this summer (A. Vieregg ICRC2017)

What about the future?



- ARIANNA: 7 regular + 2 CR stations deployed (S. Barwick ICRC2017)

What about the future?

- ARIANNA: 7 regular + 2 CR stations deployed (S. Barwick ICRC2017)
- GRAND: proto35 operational (K. Fang ICRC2017)

Summary and future

- The ANITA experiment has a rich physics program:
  - ANITA-3 diffuse neutrino analysis:
    Phys. Rev. D 98, 022001 (2018)
  - ANITA-3 cosmic ray-like analysis: Phys. Rev. Lett. 121, 161102 (2018)
  - Things I didn't cover: 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 is expected to have 4 times better sensitivity than ANITA-3: analysis coming out soon!
- ANITA-5 proposal: new hardware to try out! (J. Nam ICRC2017)

THANK YOU

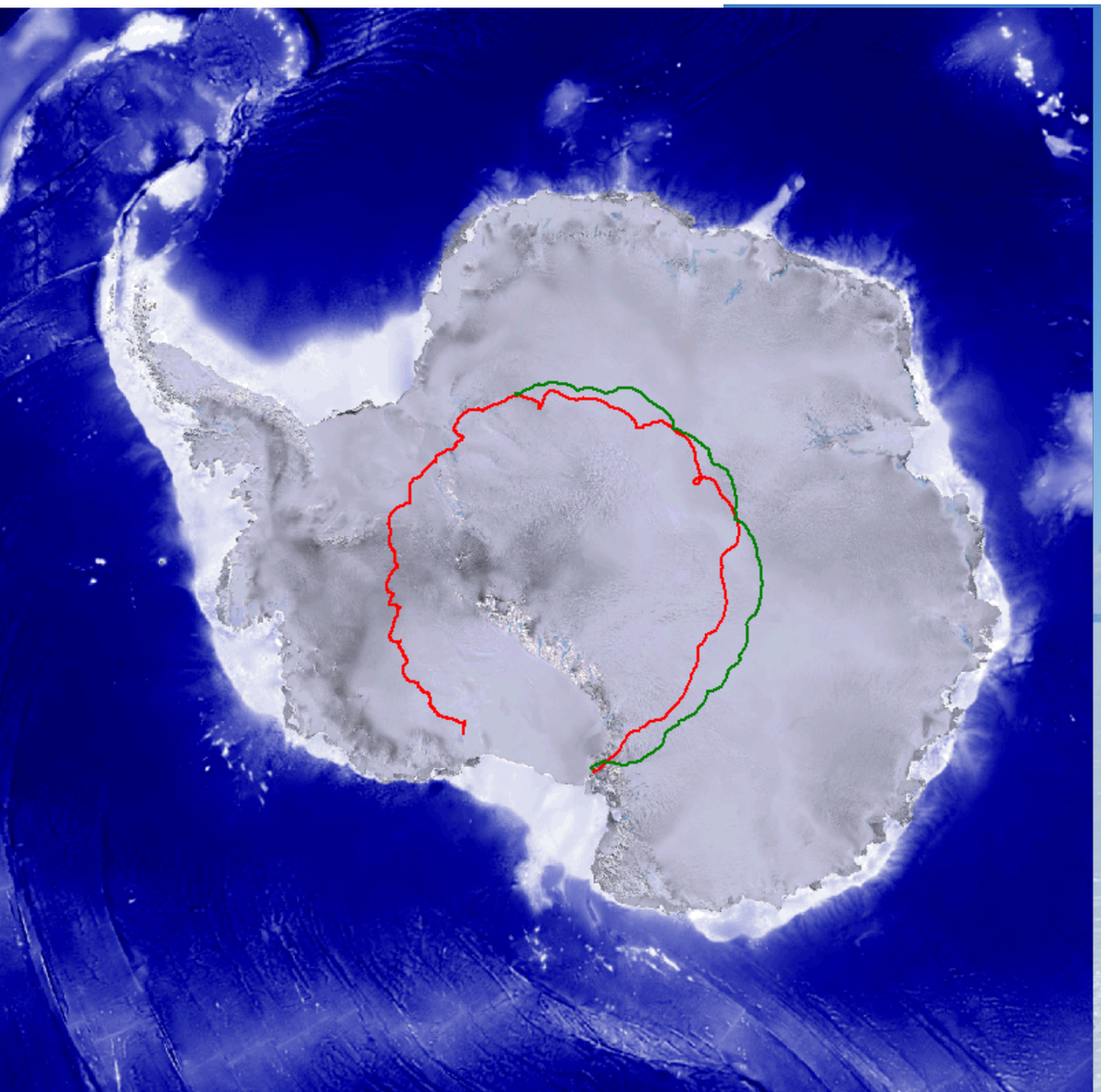
NASA

LEVERHULME TRUST

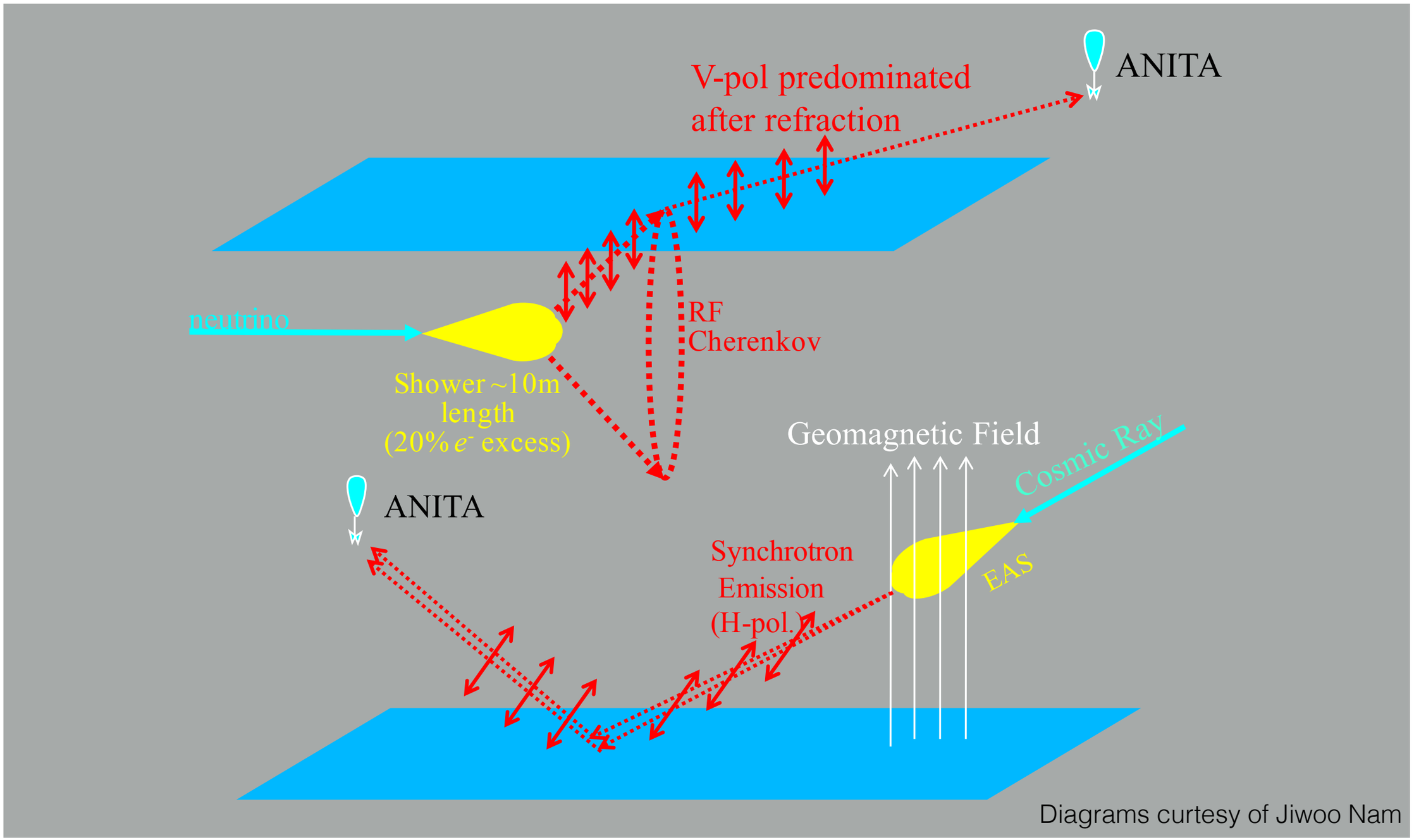
Back up

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

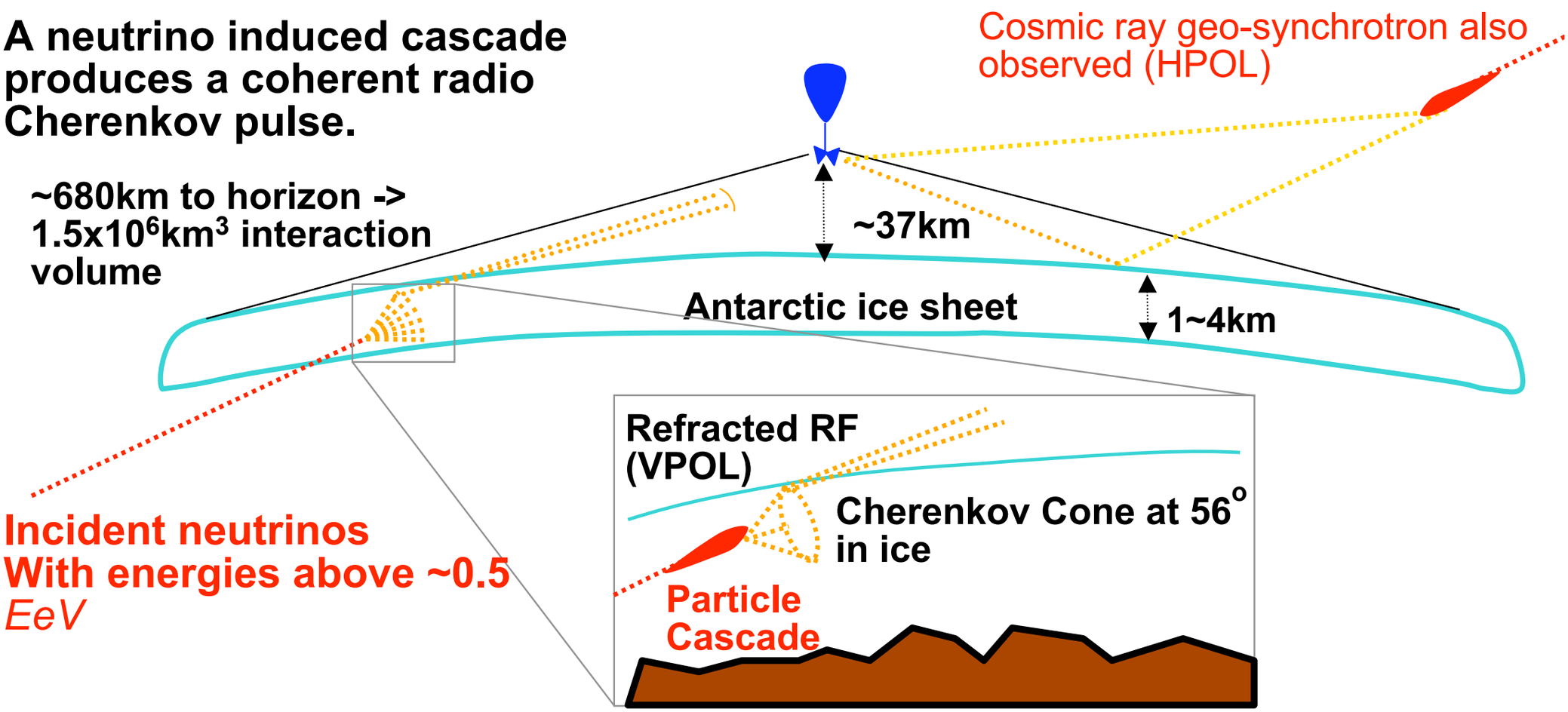


ANITA

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

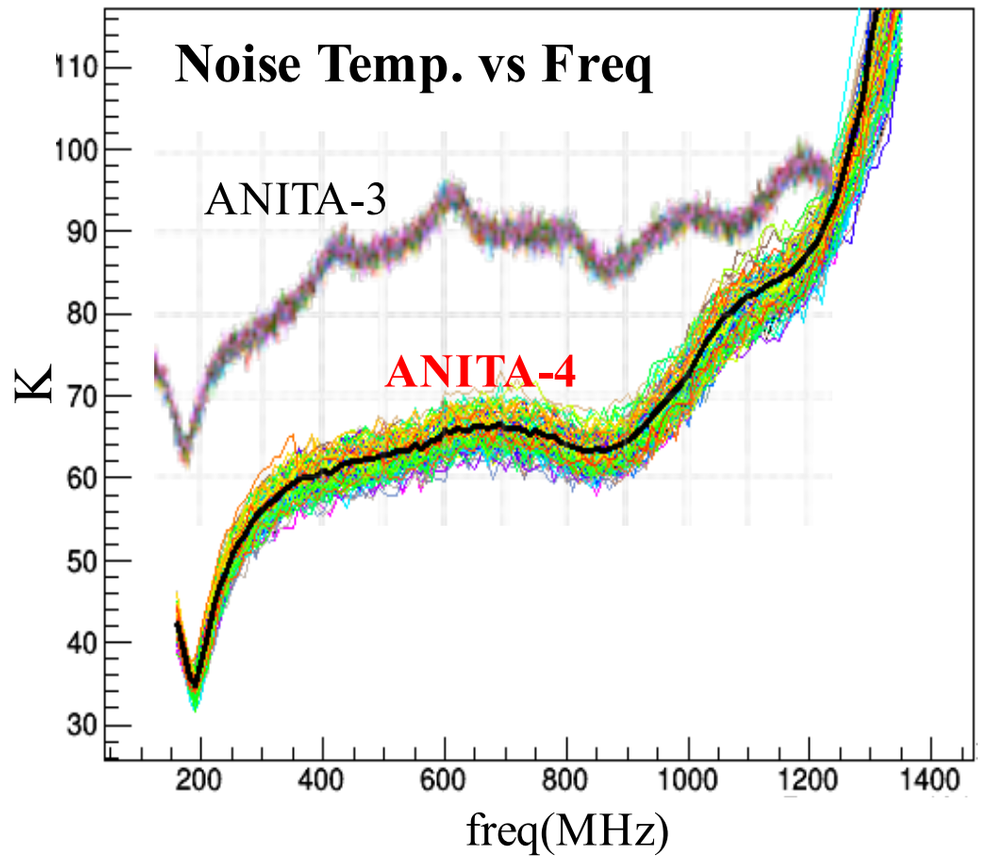
A neutrino induced cascade produces a coherent radio Cherenkov pulse.

~680km to horizon -> 1.5x10^{6}km^3 interaction volume



ANITA-4 improvements

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



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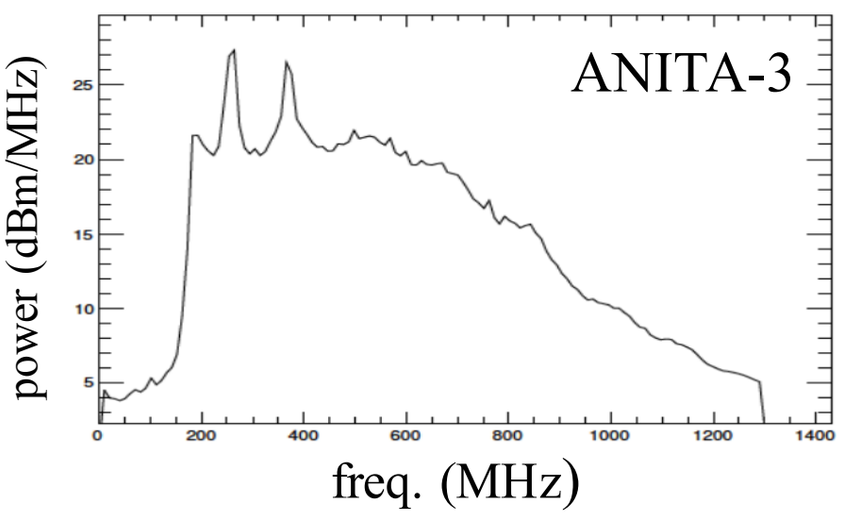

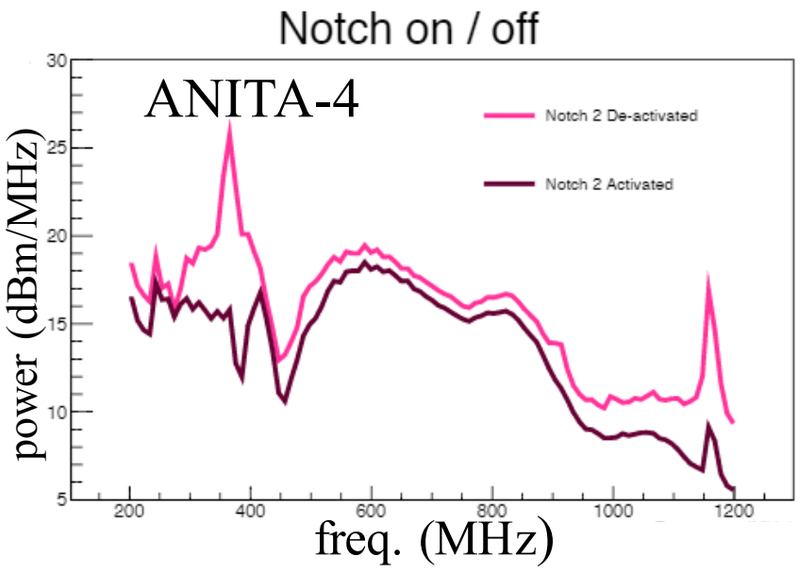

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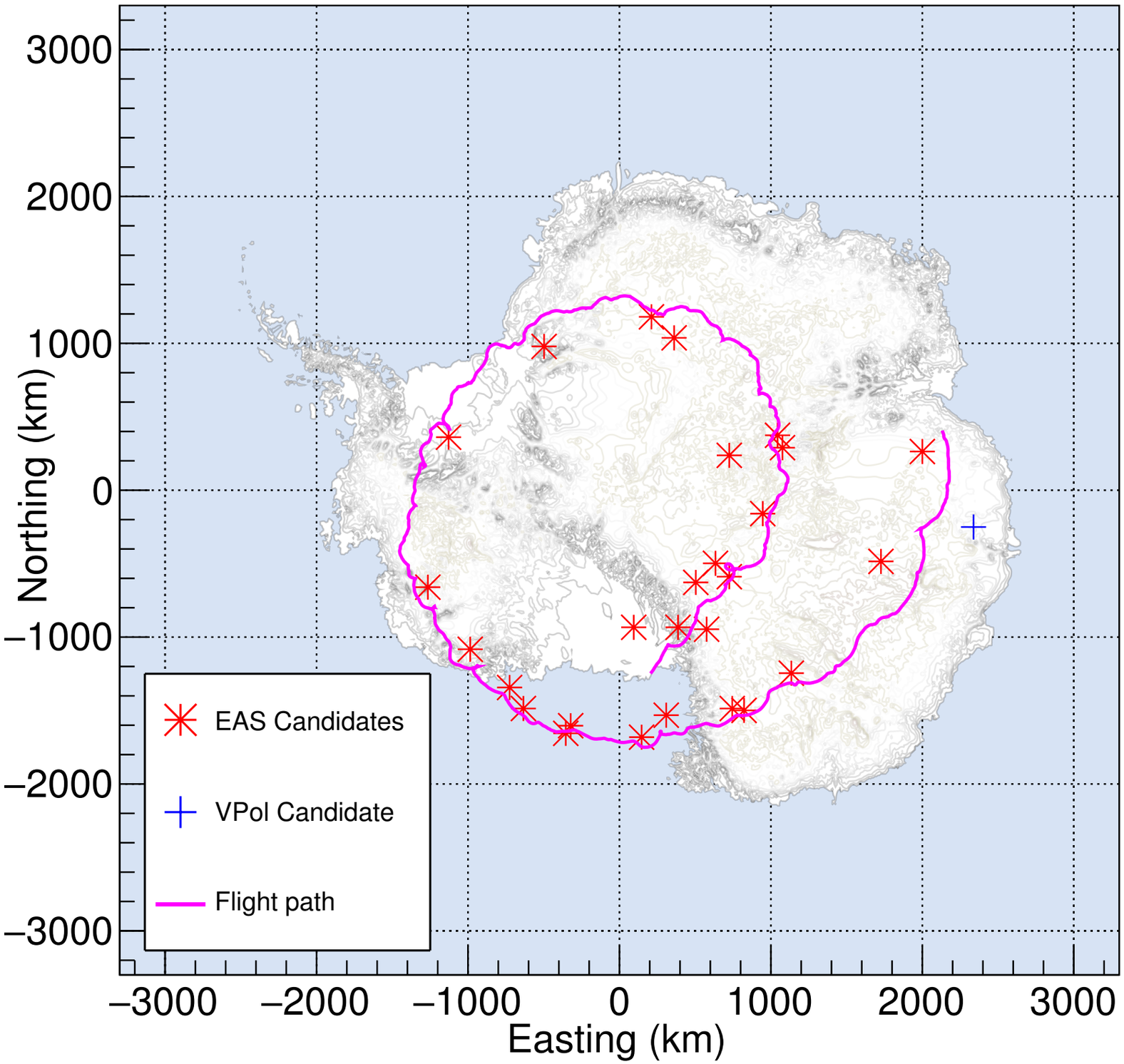
  - Improvement in noise figure (30-40K)
  - 20% improvement in energy threshold
- Tunable Universal Filter Frontend
  - Reduce Carrier Waves noise coming from Satellites
- Trigger on Left and Right Circular Polarisation coincidences
  - Satellite noise predominantly circularly polarised (either LCP or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

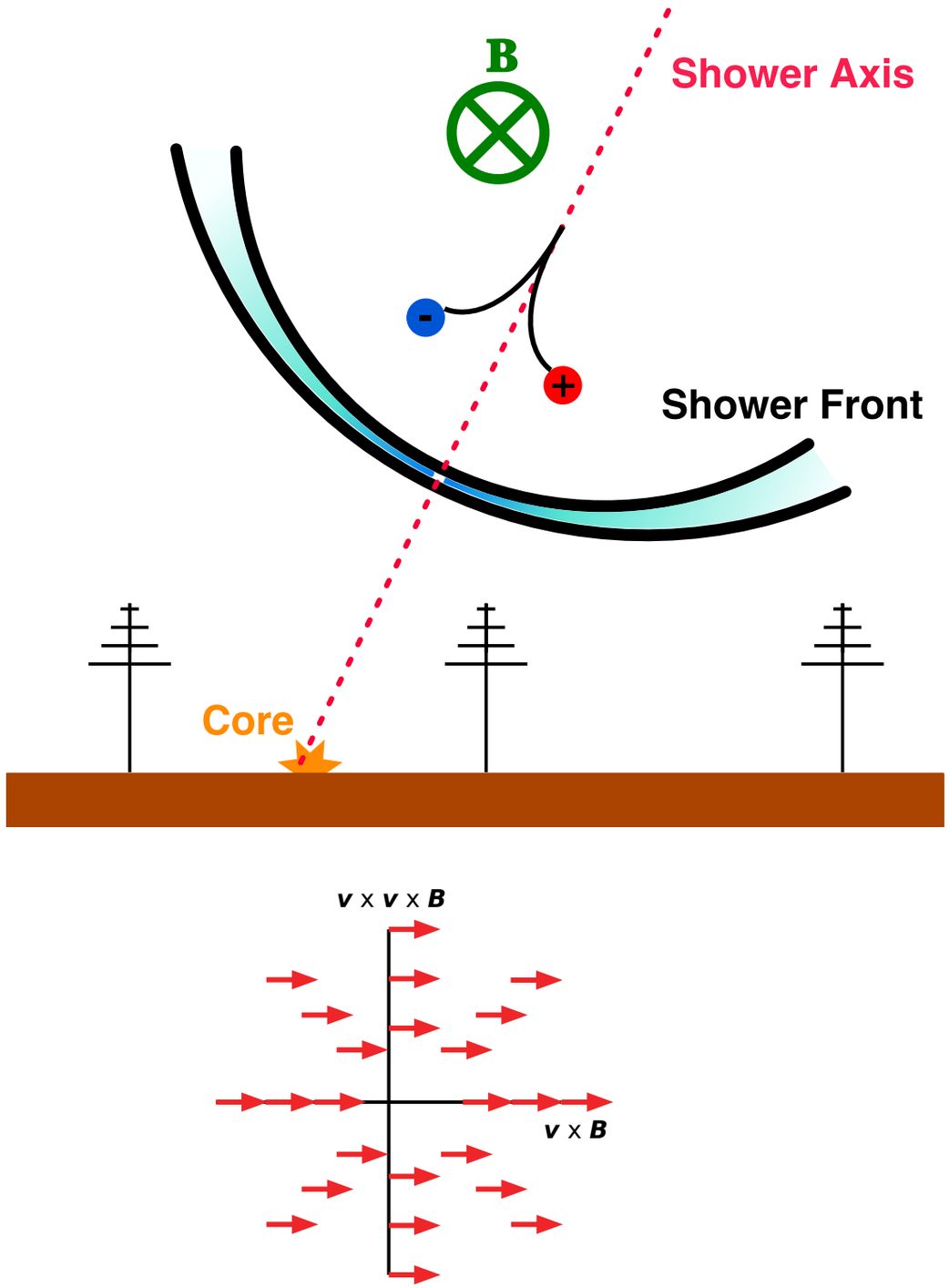
ANITA-3 efficiencies

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

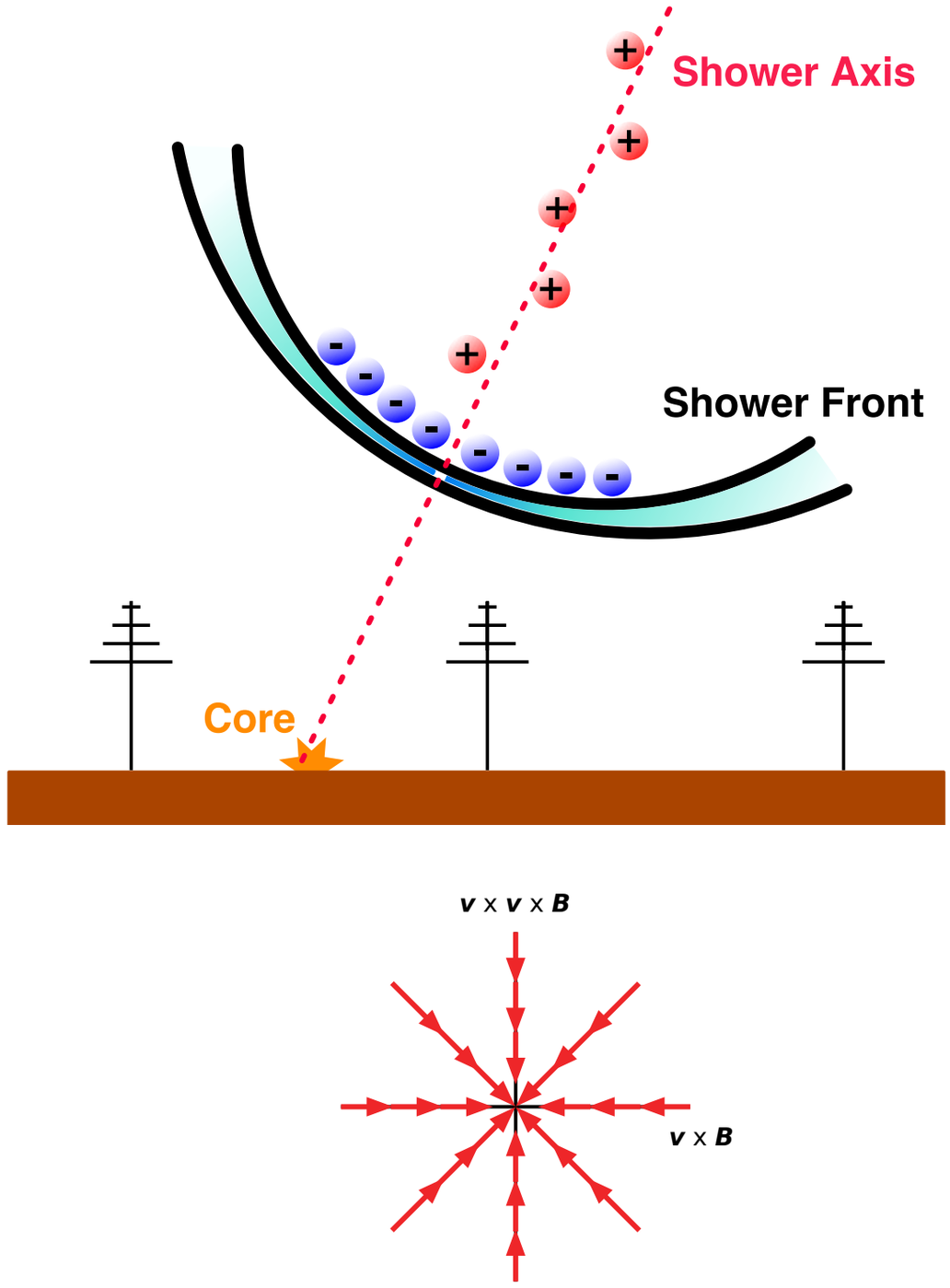
Better map


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

UHECR

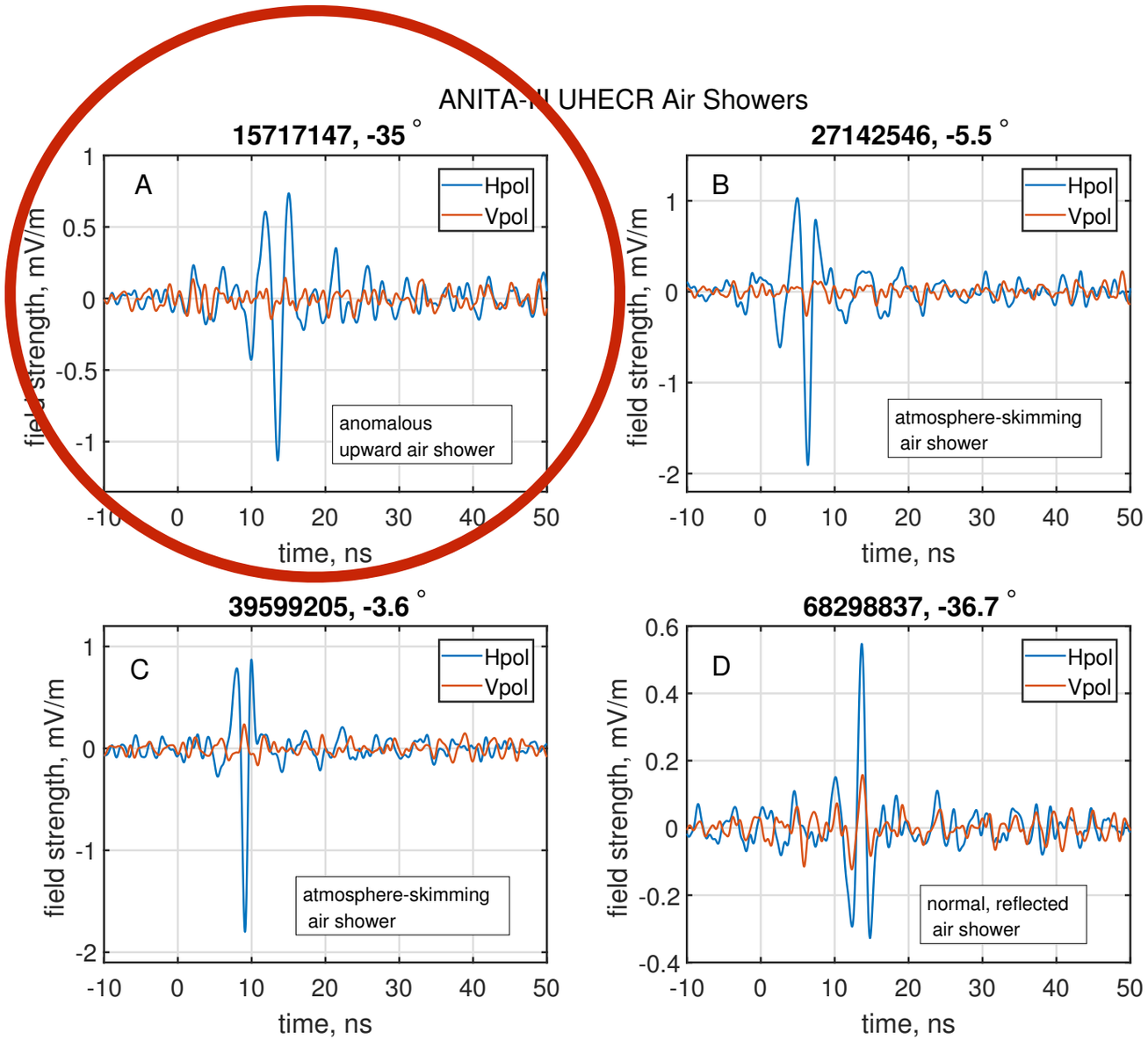


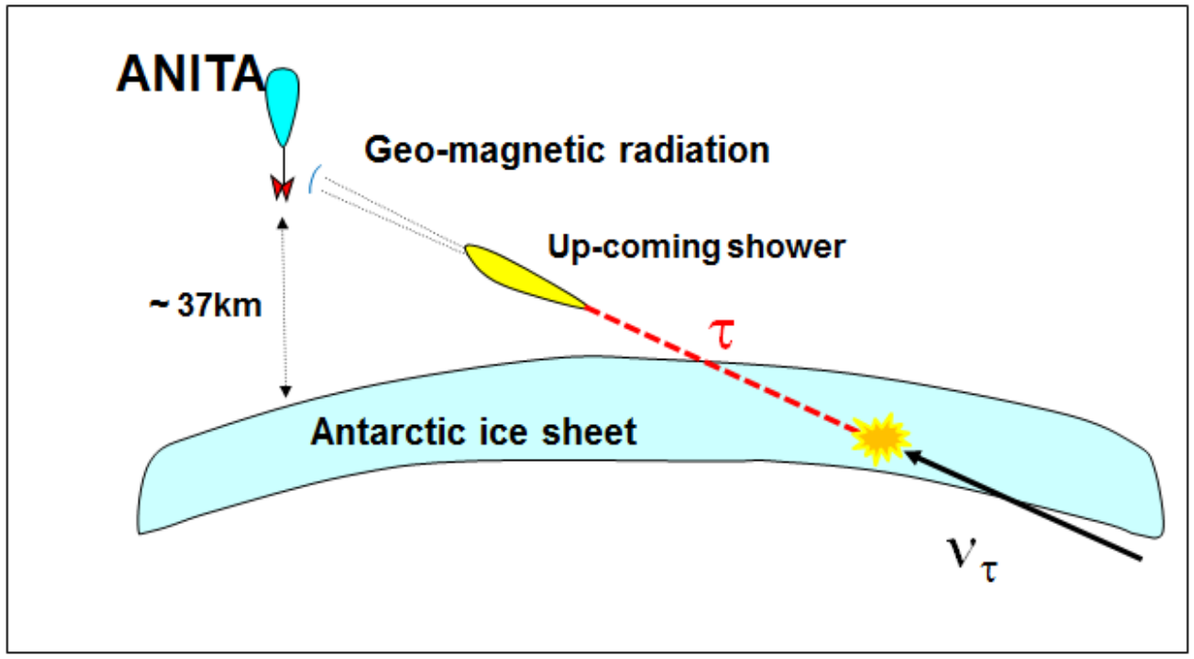
L. Cremonesi



“UHE neutrinos and ANITA”

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}