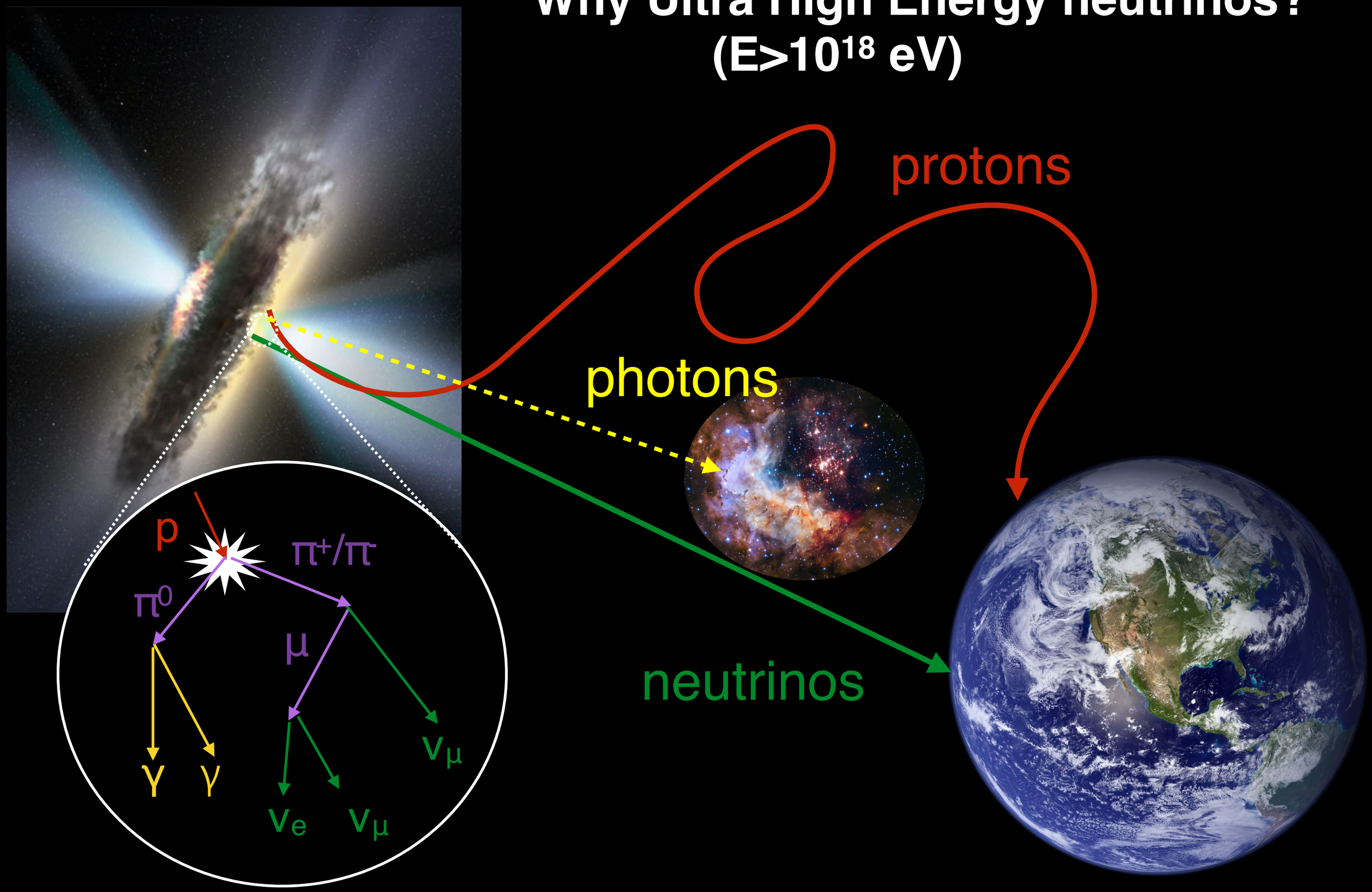
Hunting UHE neutrinos with ANITA

Linda Cremonesi

Rencontres de Blois
June 2018

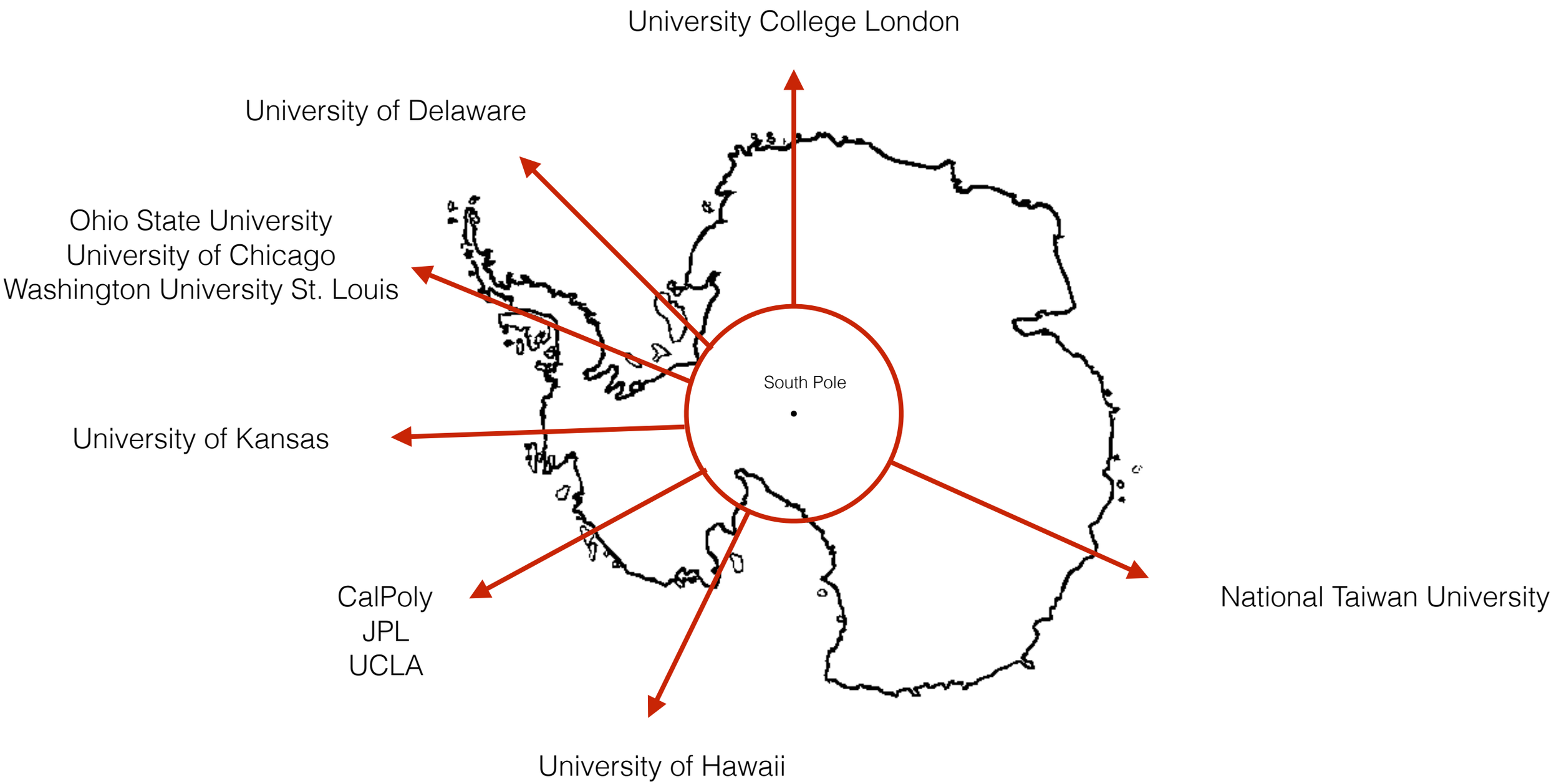
Why Ultra High Energy neutrinos? ($E>10^{18}$ eV)



More motivations

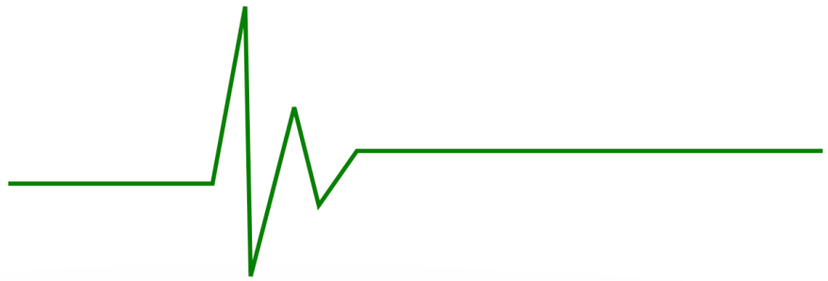
- Implications for neutrino mixing (arXiv:1702.05238)
- Neutrino decay - JCAP 10 (2012) 020
- Ultra high energy neutrino cross-sections (Nature 551 (2017) 596-600, arXiv:1711.11043)
- Lorentz invariance - Phys. Rev. D 86, 103006
- Sterile neutrinos - arXiv:1802.01611

ANITA collaboration



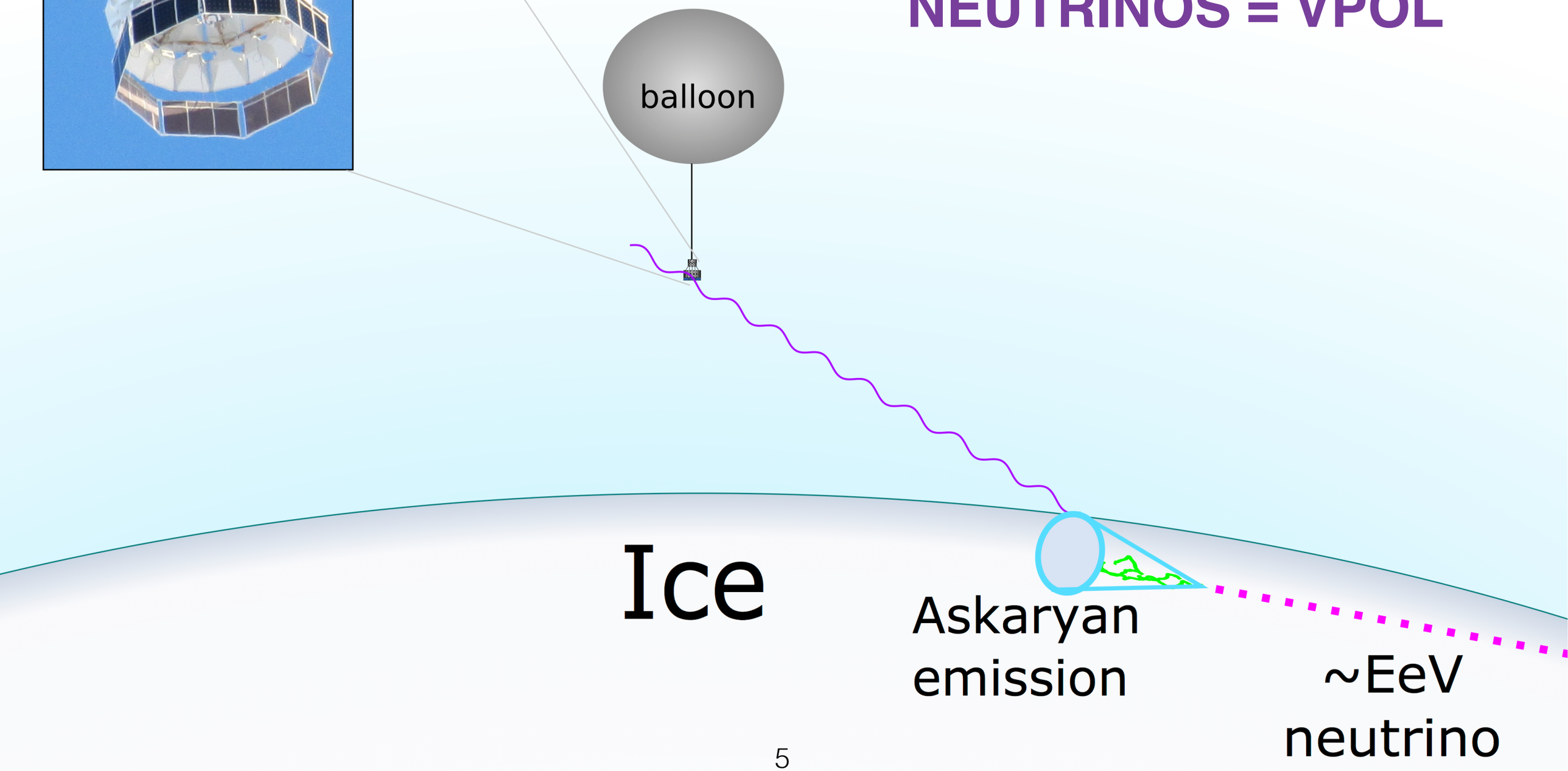
11 Institutions, ~50 collaborators in a 18 hour time zone

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

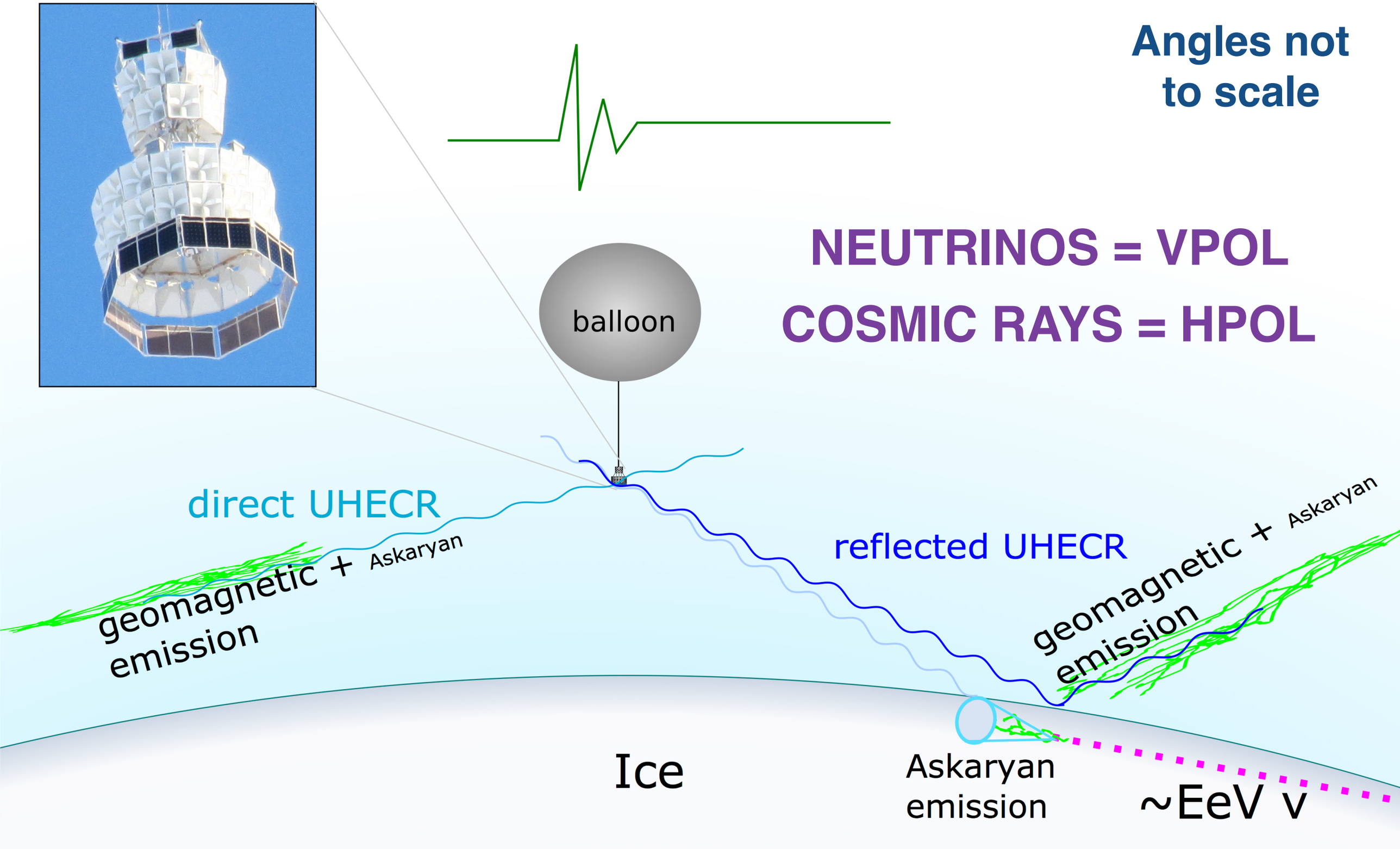


Angles not to scale

NEUTRINOS = VPOL



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



ANITA instrument

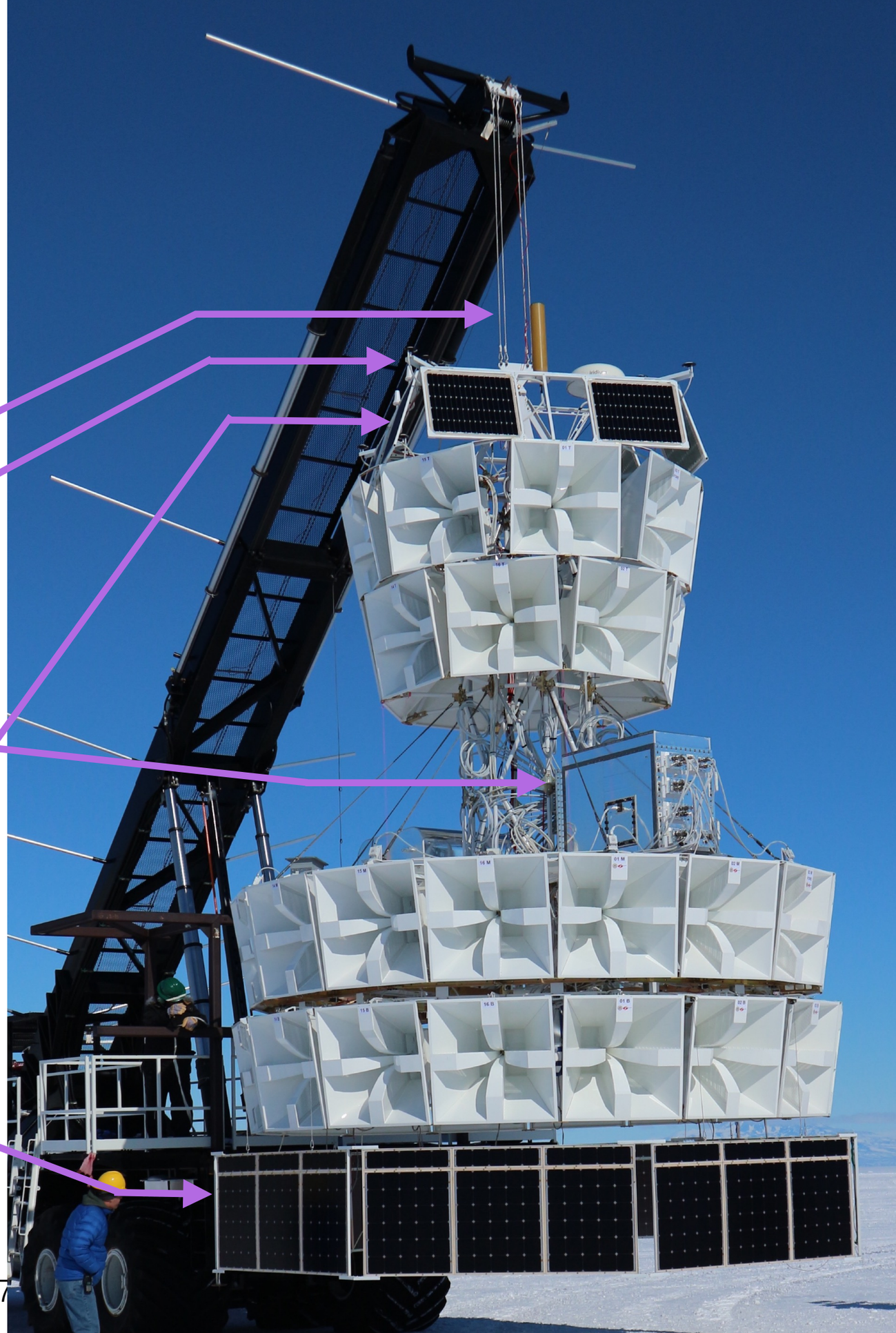
Telemetry:
TDRSS & Iridium antennas

GPS antennas

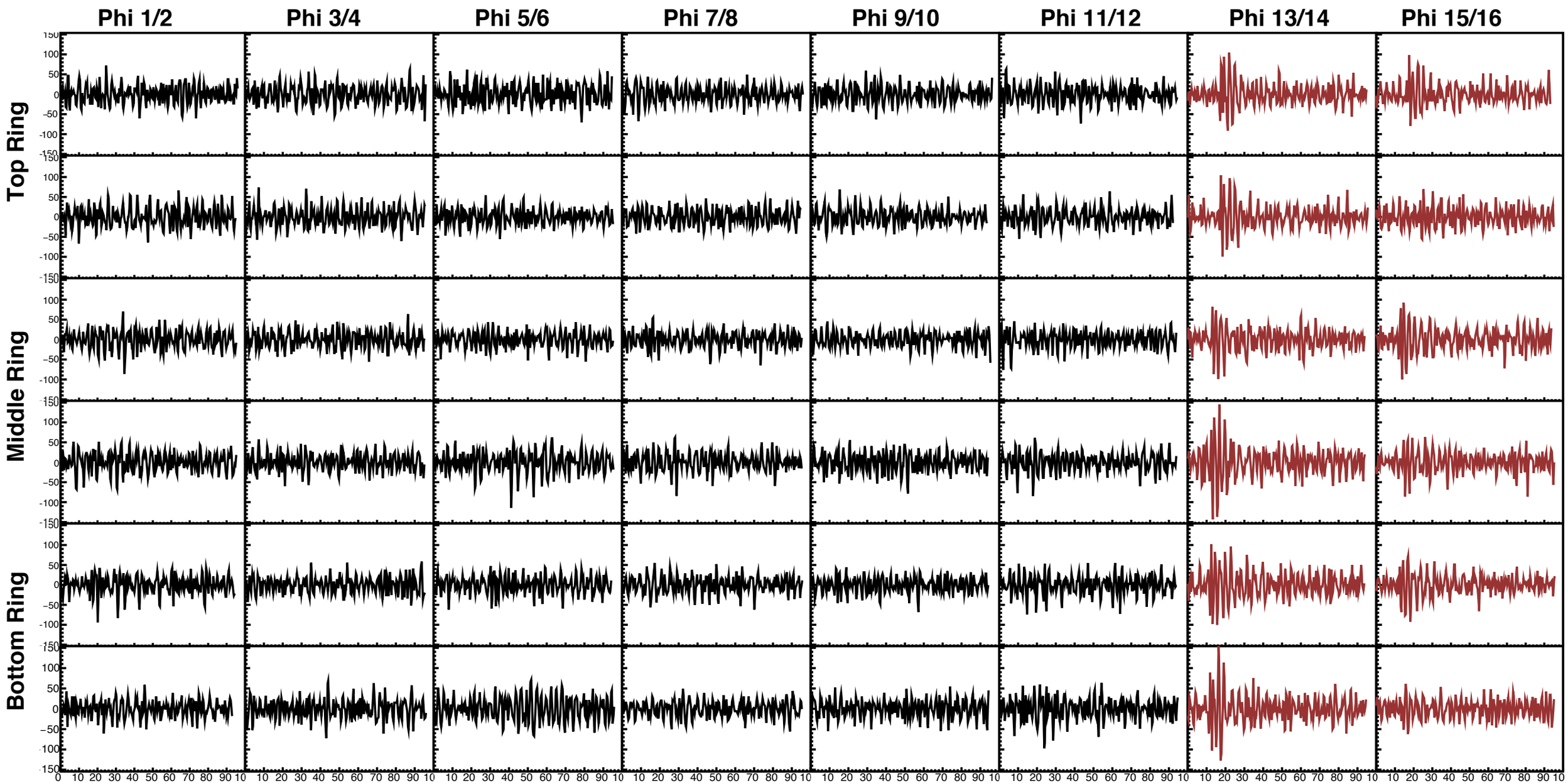
Instrument box

48 quad-ridged horn antennas

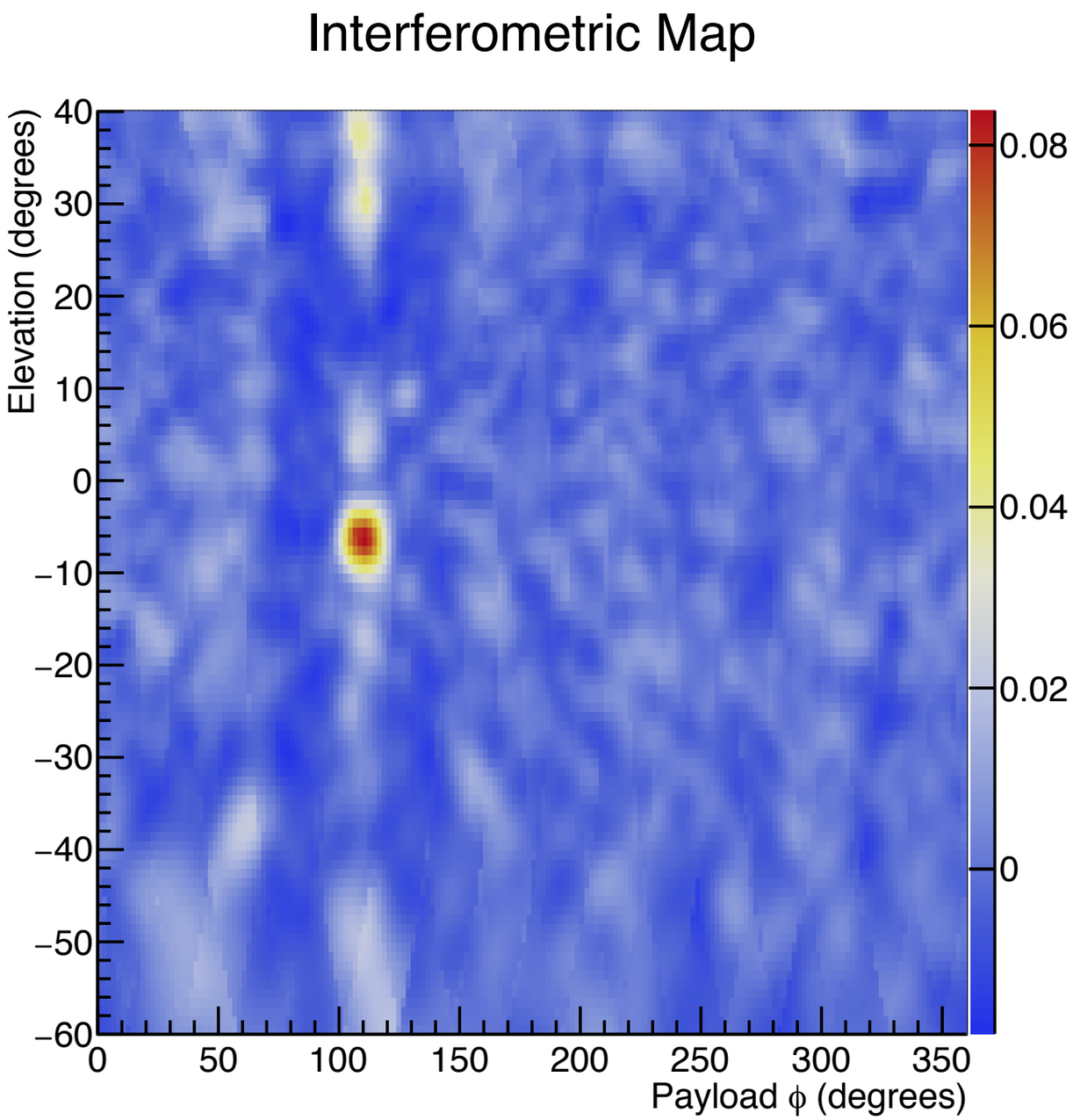
Solar panels

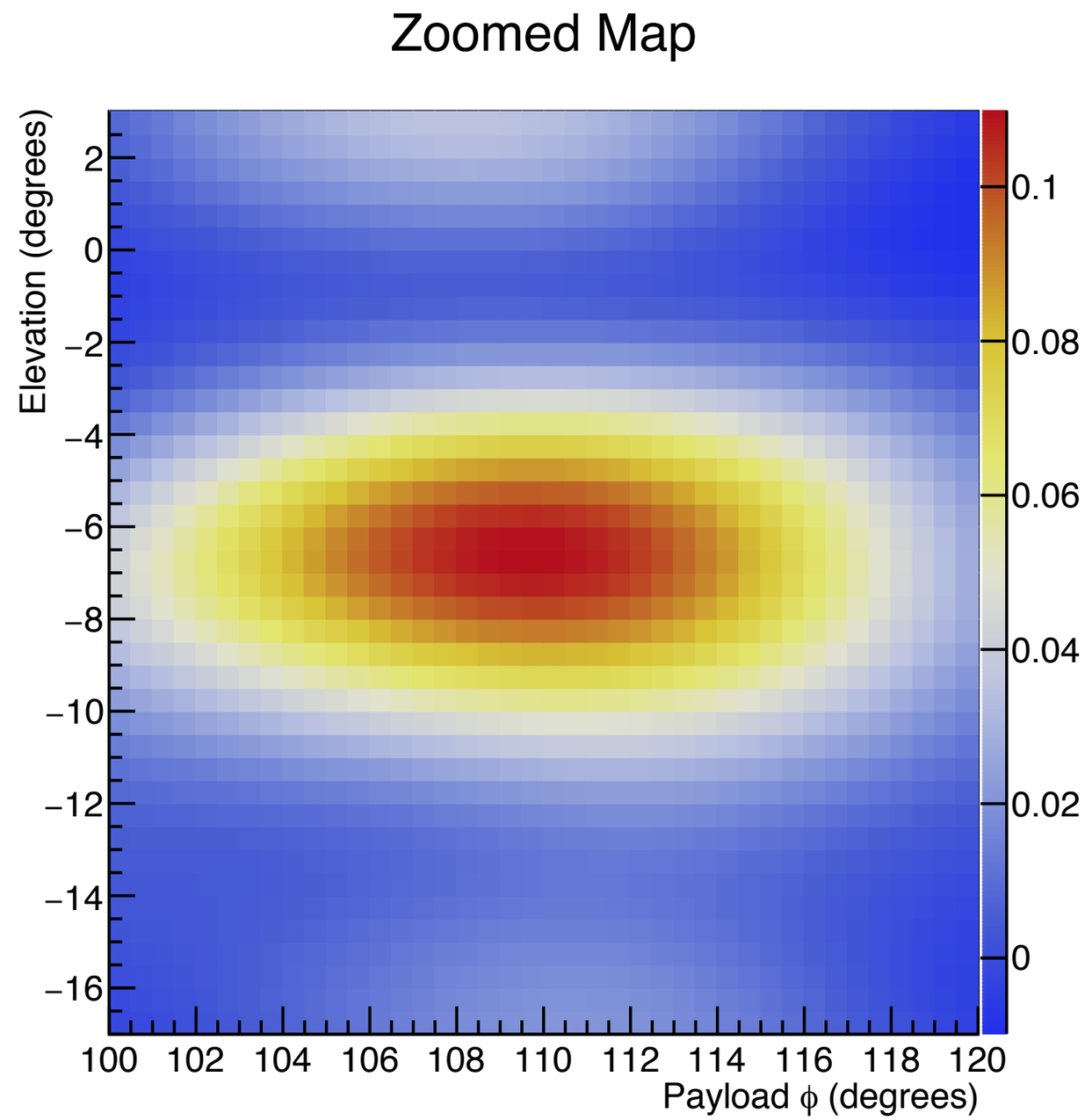


How ANITA sees the world

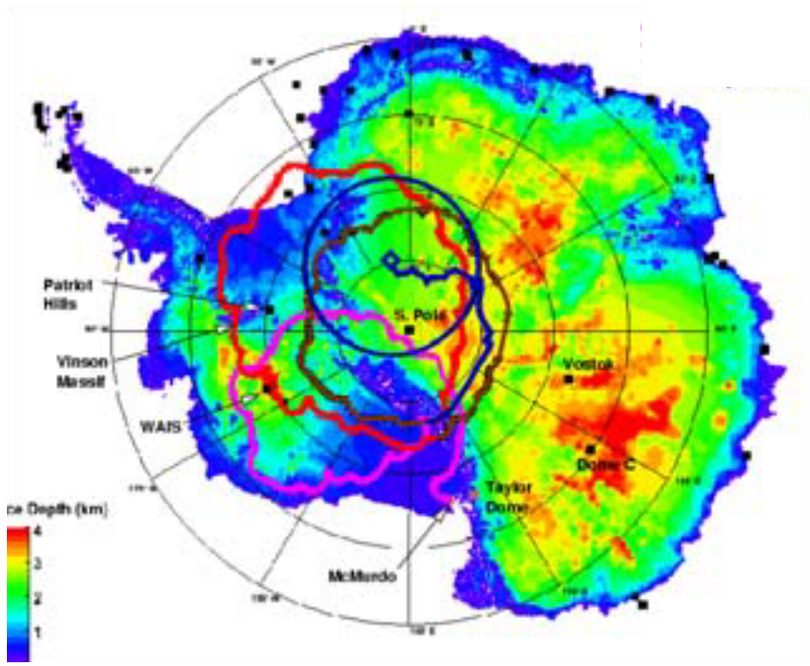


How ANITA sees the world



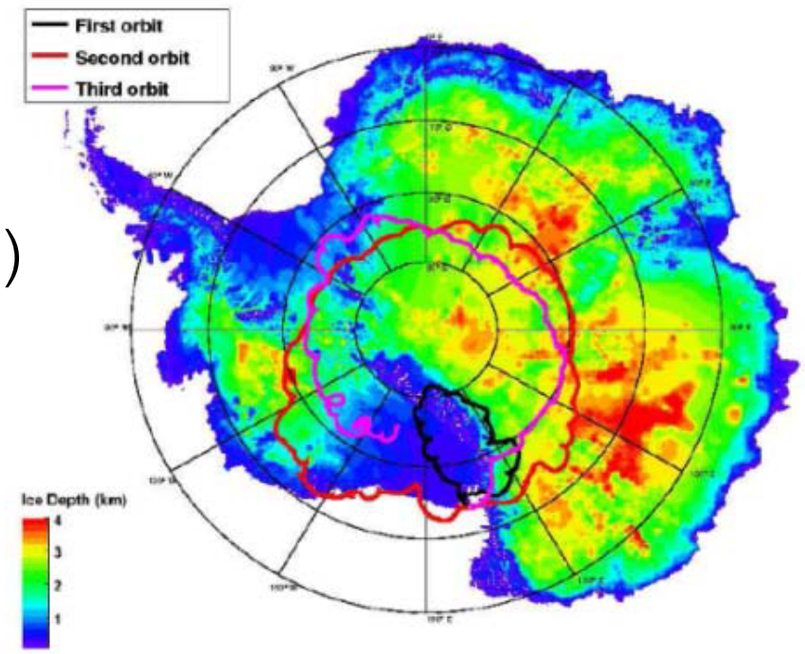


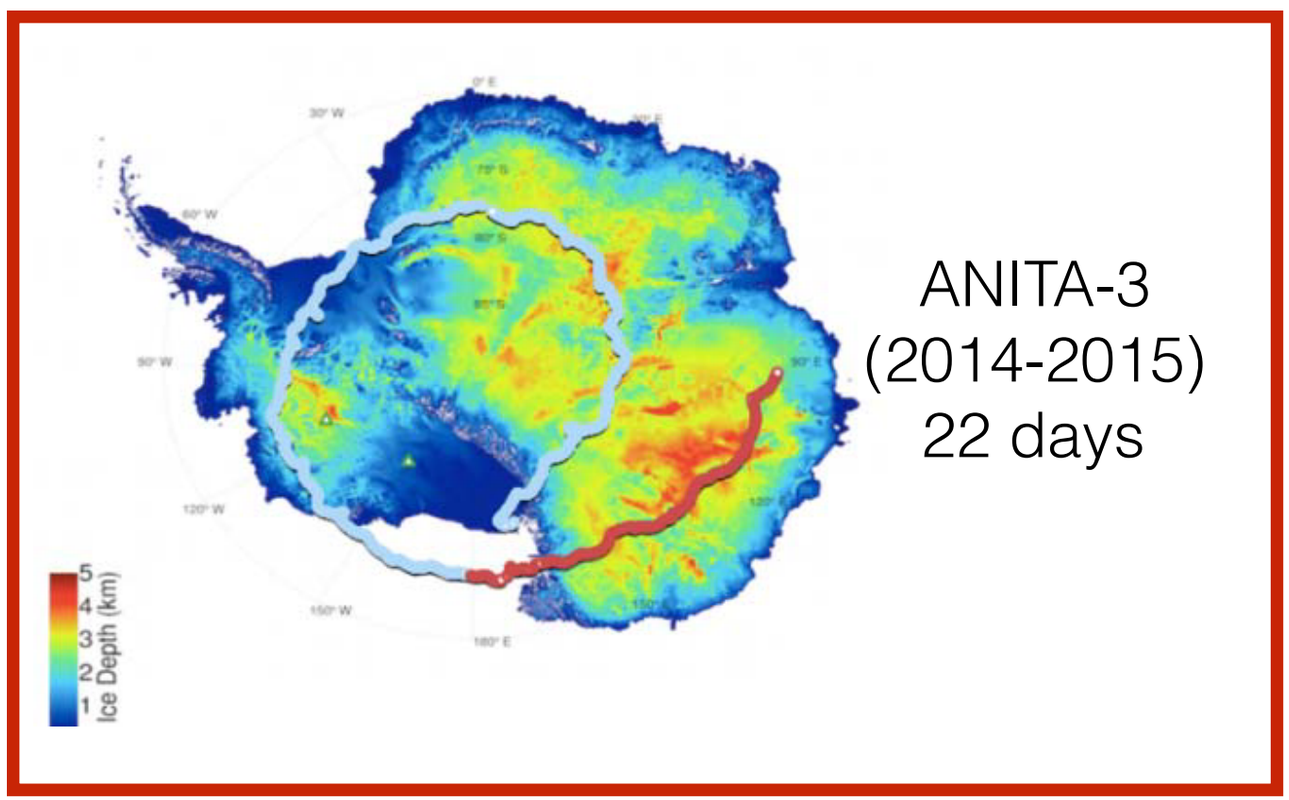
ANITA Flights



ANITA-1
(2006-2007)
35 days

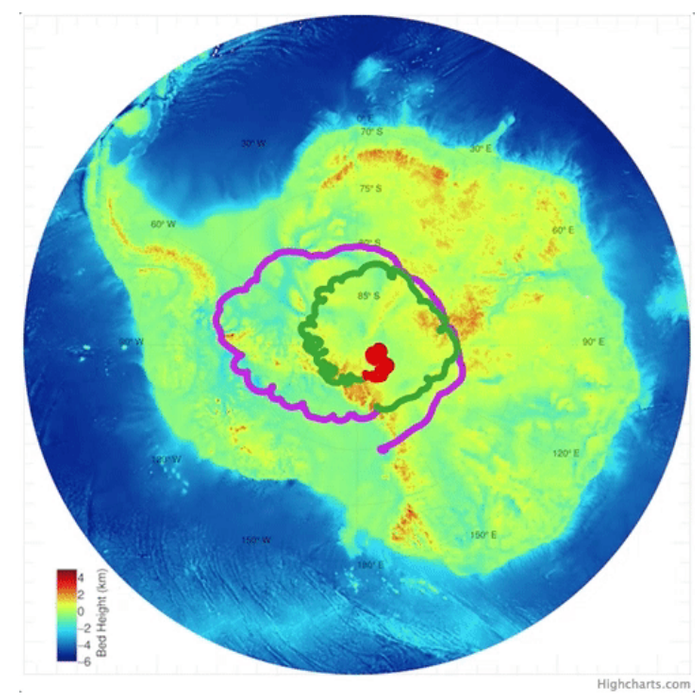
ANITA-2
(2008-2009)
30 days





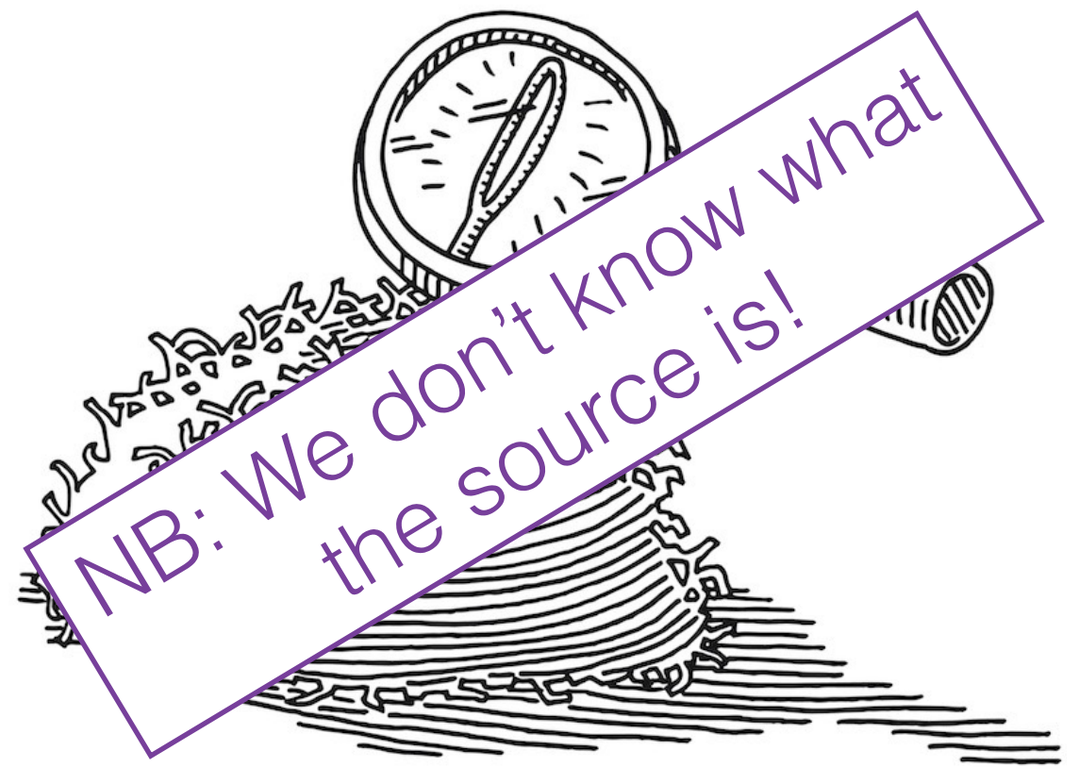
ANITA-3
(2014-2015)
22 days

ANITA-4
(2016)
30 days



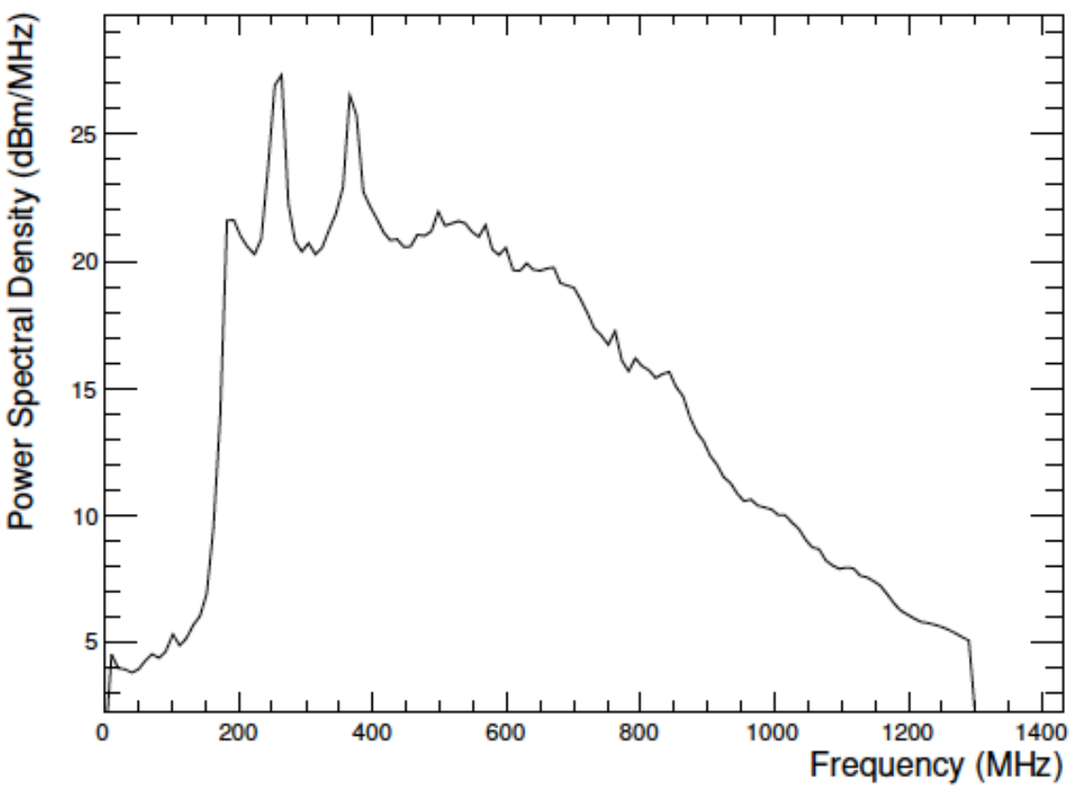
The challenge

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

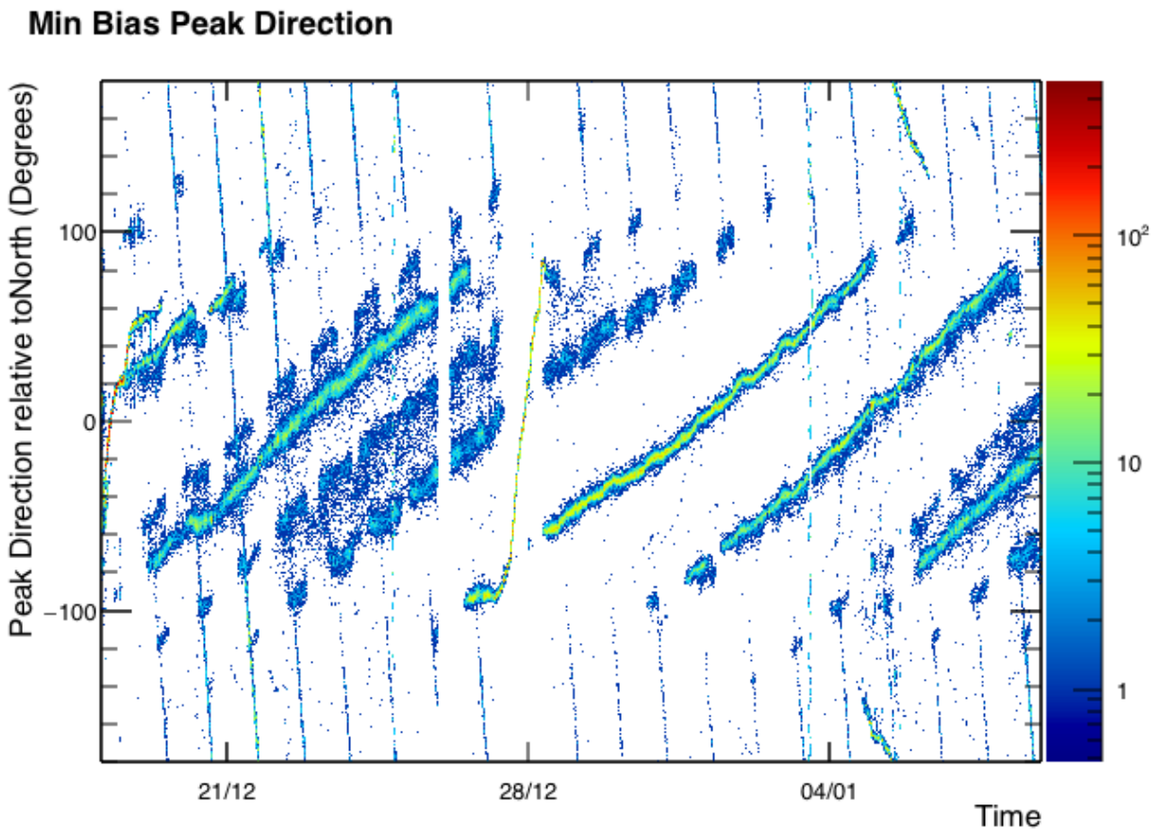


Continuous Waves

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

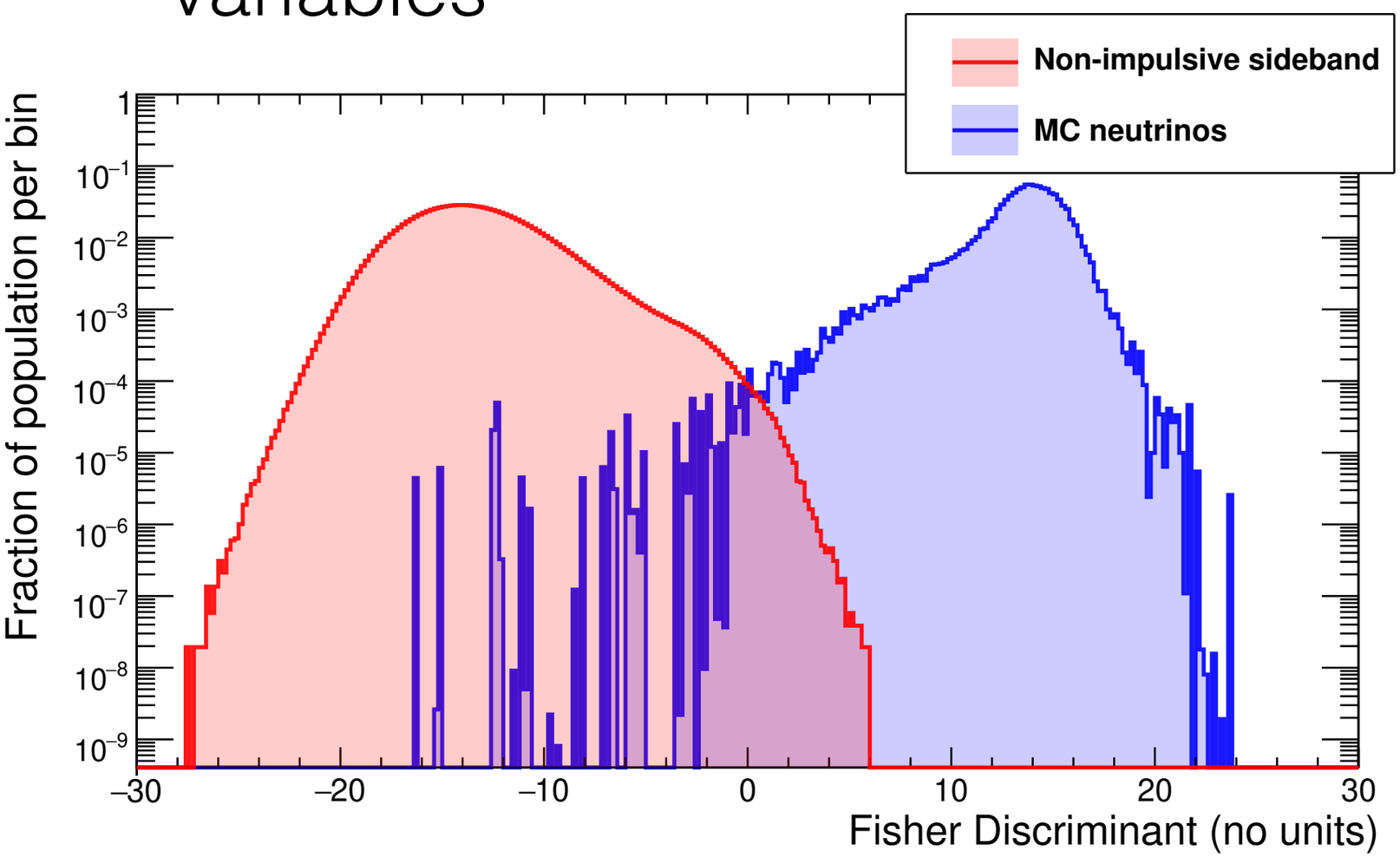


- How to get rid of this?
  - ANITA-3: software
  - ANITA-4: hardware



Thermal noise

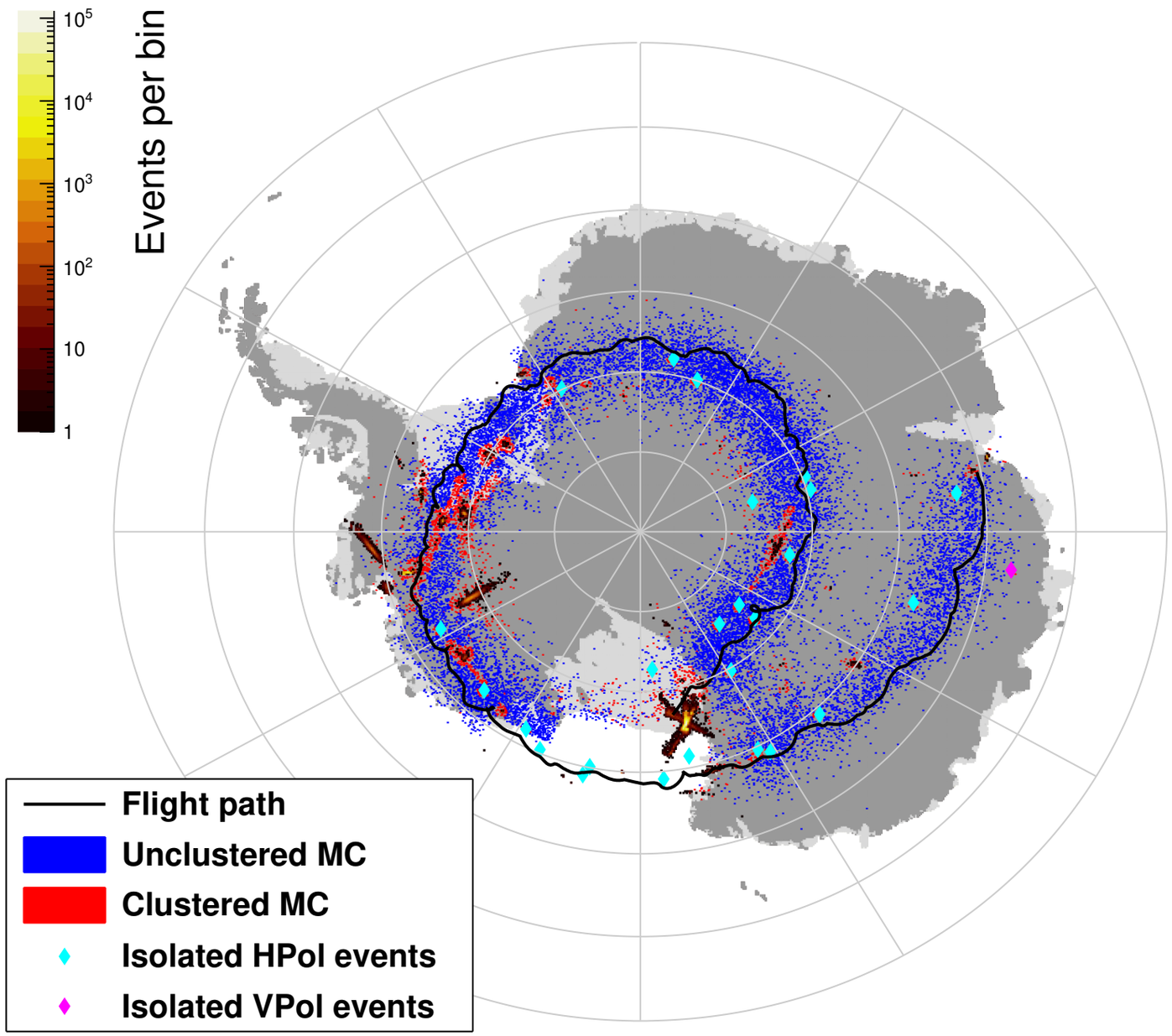
- Vast majority of ANITA events are thermal noise
- Use Fisher discriminant based on impulsivity variables



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

Clustering

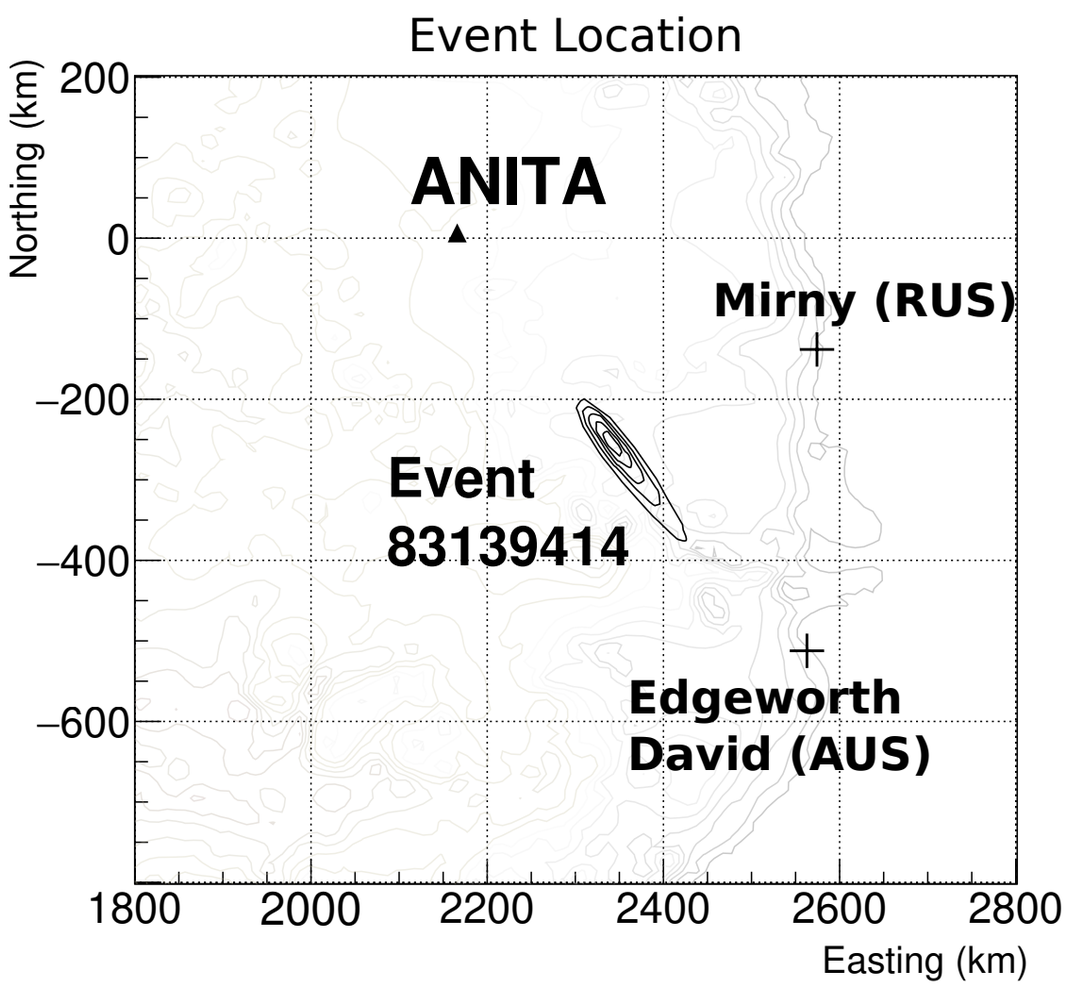
- From previous cuts, ~500k events

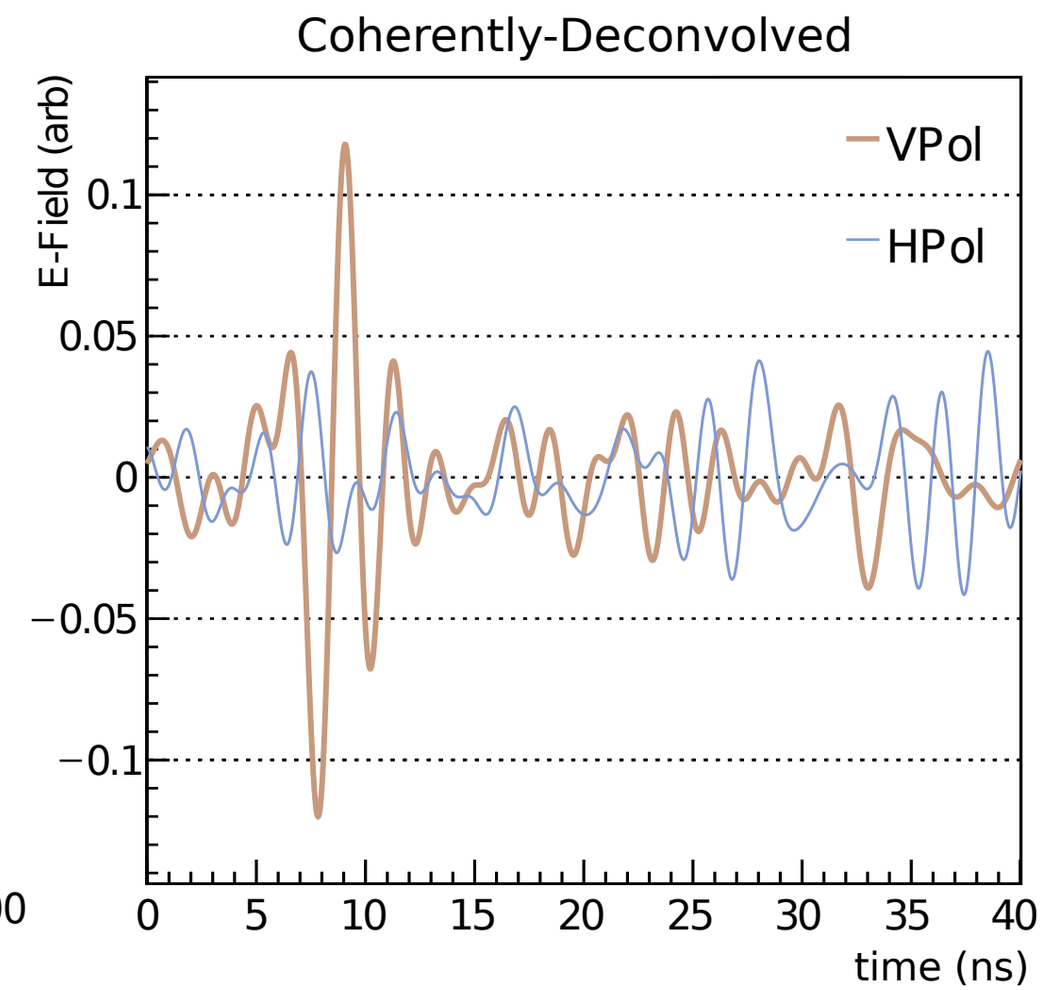


- Look for isolated singlets and doublets
- Remove anything that clusters with human bases
- Remove anything which forms a cluster of 3 or more

What's left?

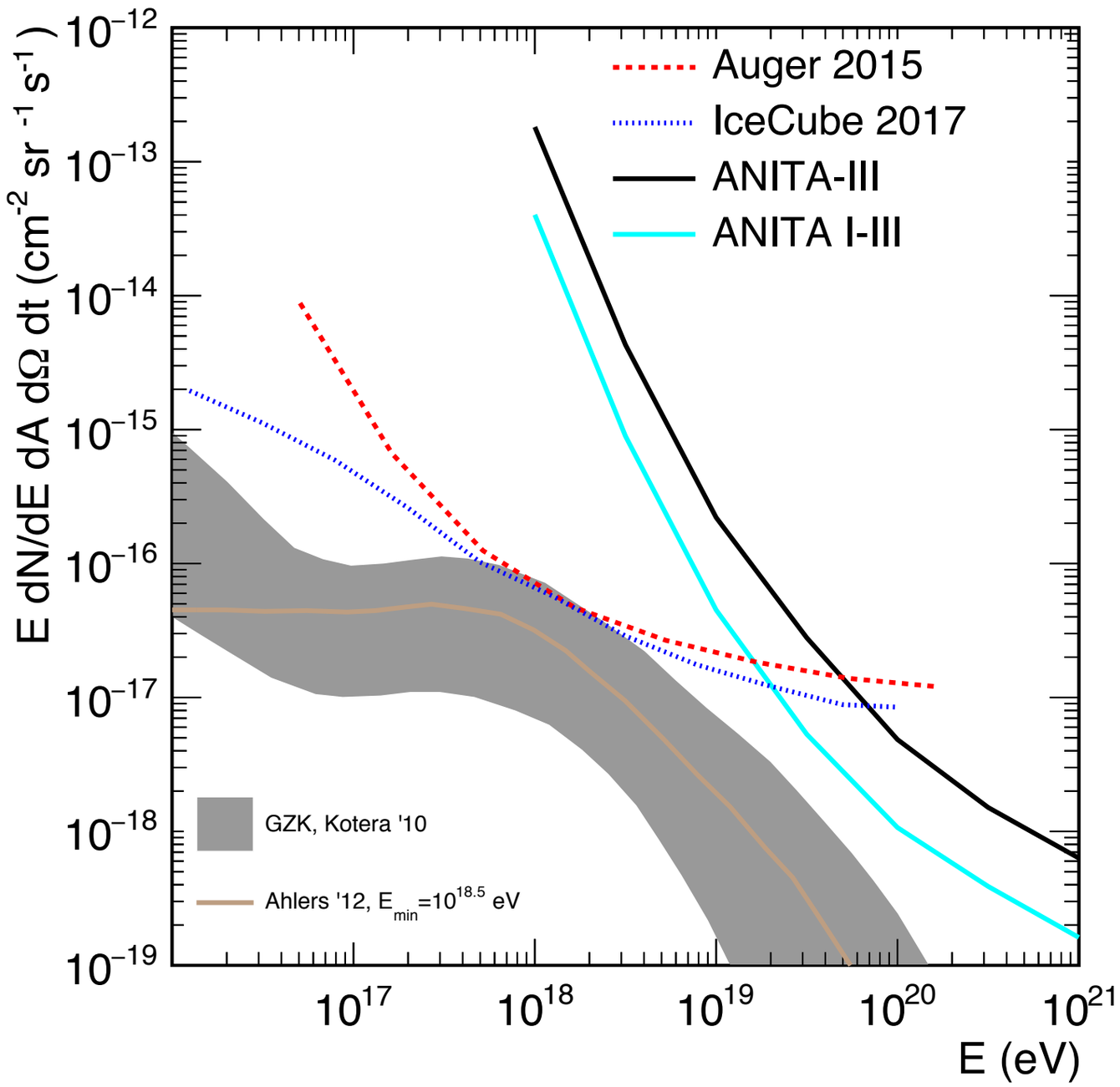
- One V-POL candidate
- Background estimate: $0.7^{+0.5}_{-0.3}$ per polarisation
- No known human activity within 260km





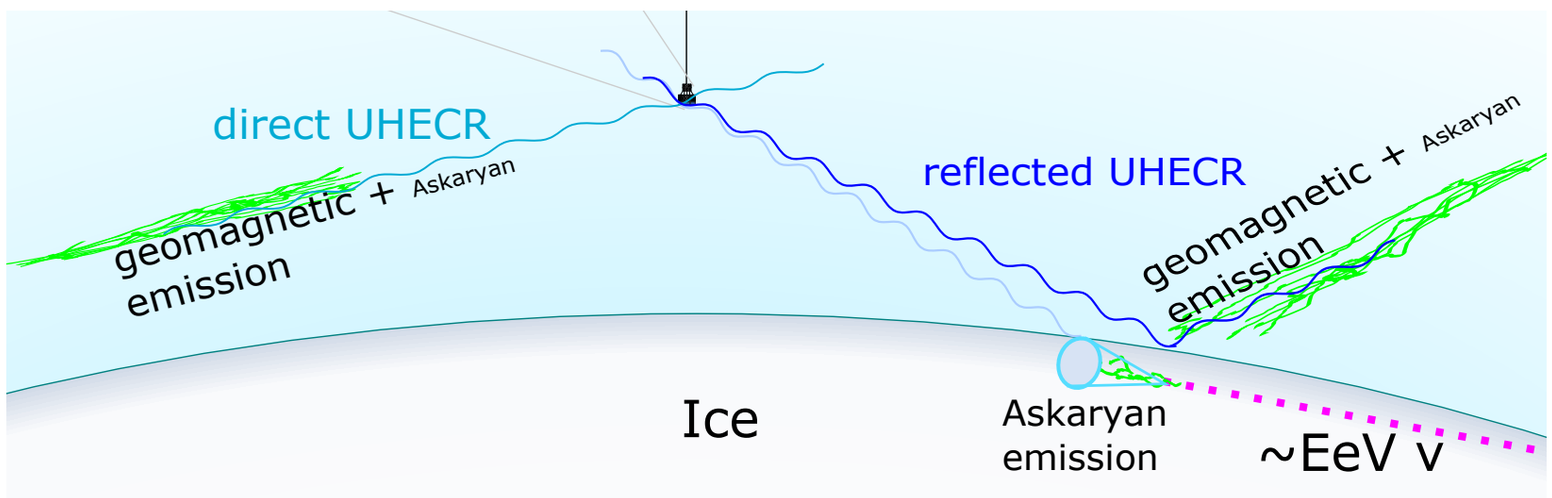
Neutrino limit

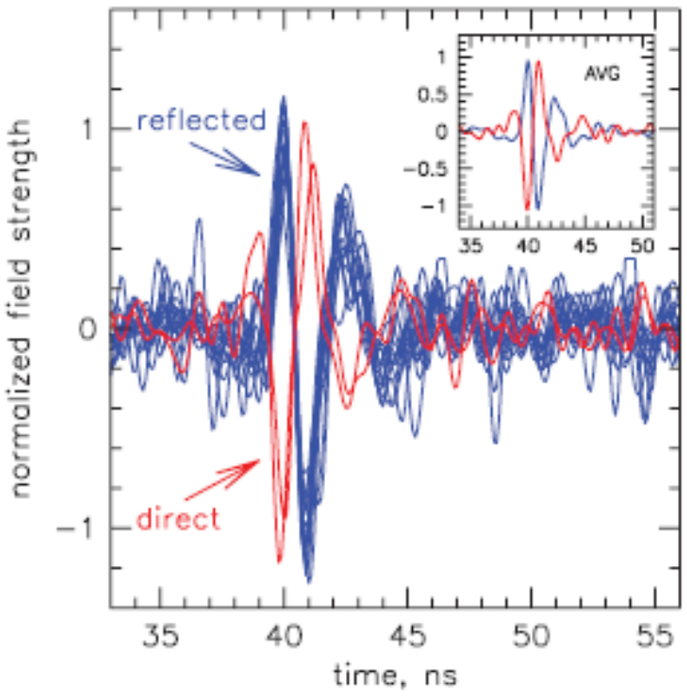
Limit on all-flavour-sum diffuse UHE neutrino flux



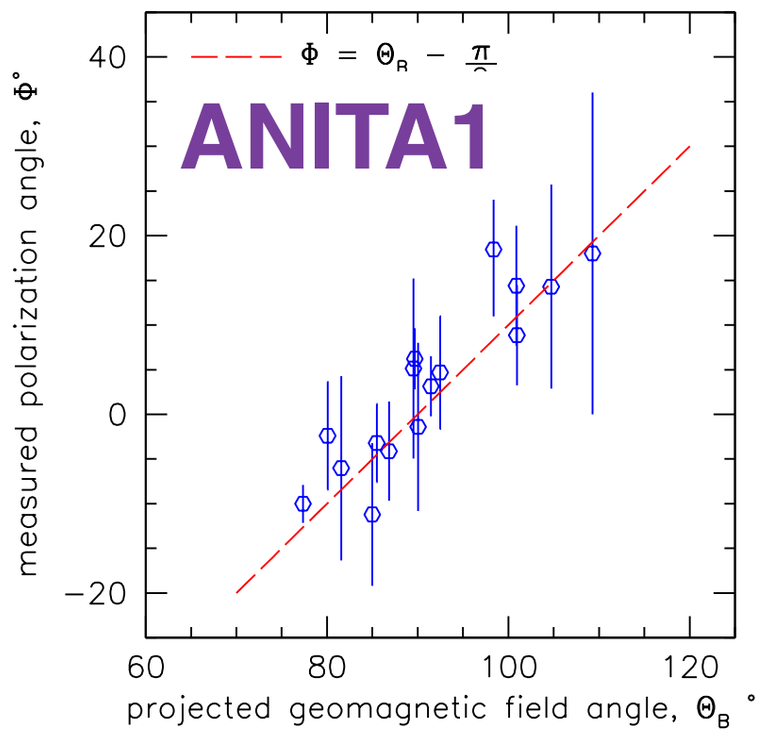
UHECR

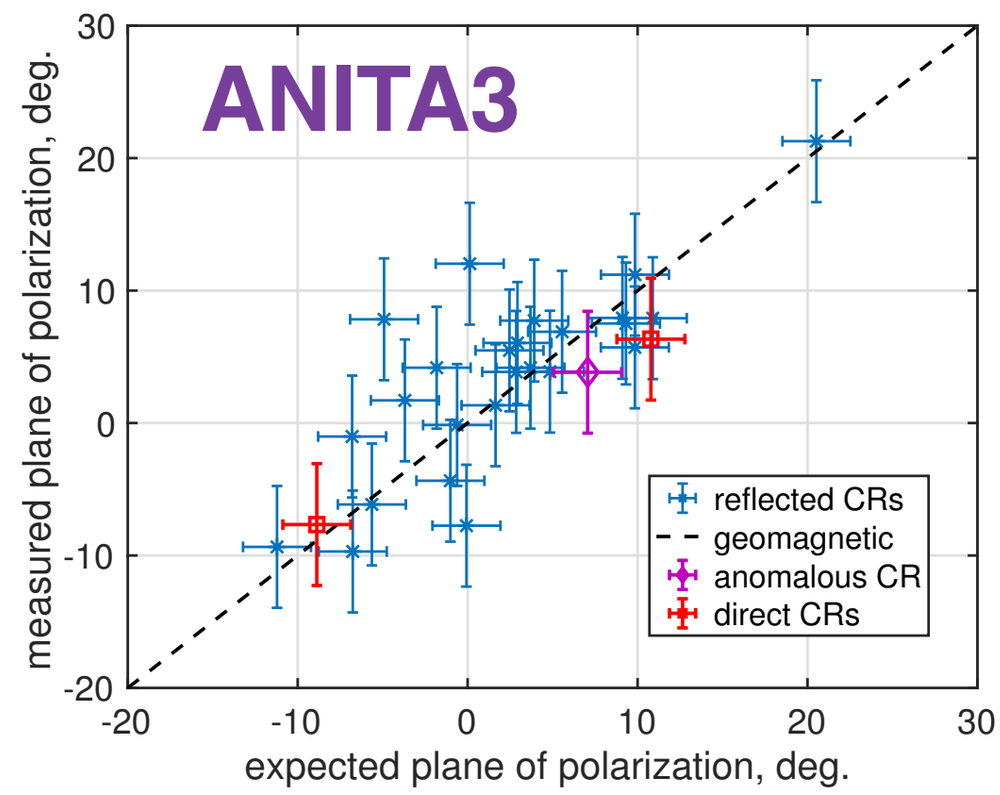
ANITA1: 16 UHECR
 14 reflected + 2 direct
ANITA-2: 2 UHECR
 (No H-pol trigger)
ANITA-3: 25 UHECR
ANITA-4: analysis in progress





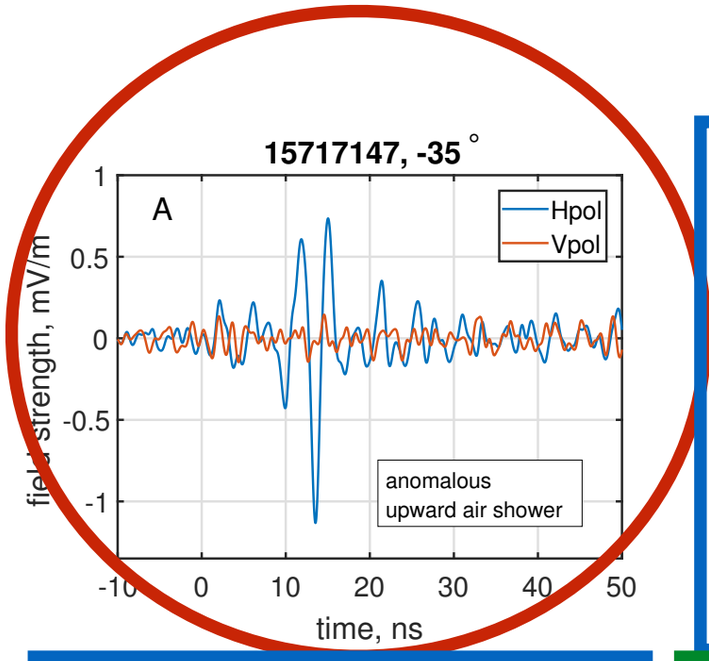
PRL 105, 151101 (2010)

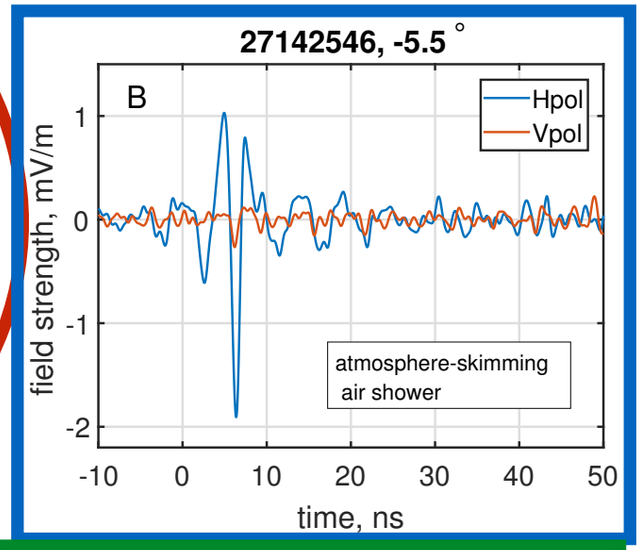


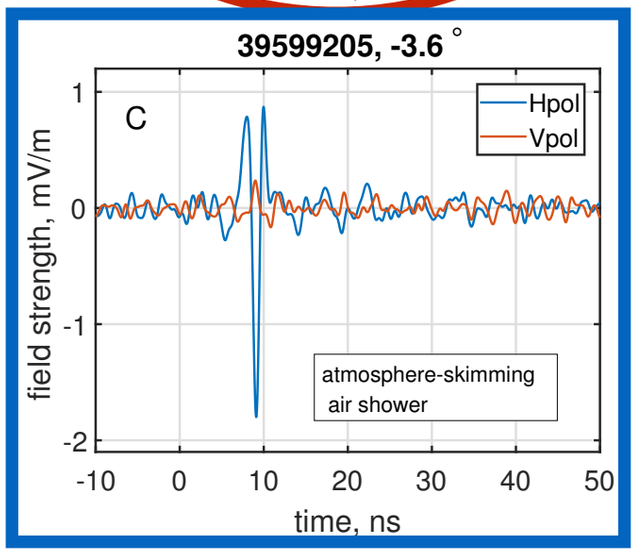


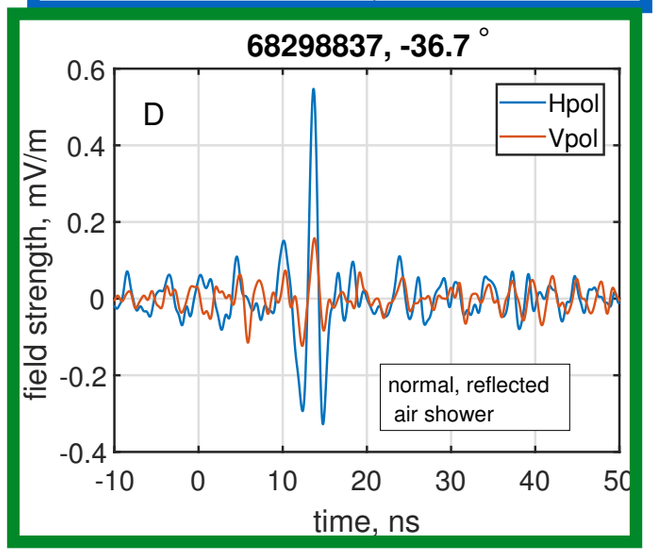
arXiv:1803.05088 [astro-ph.HE]

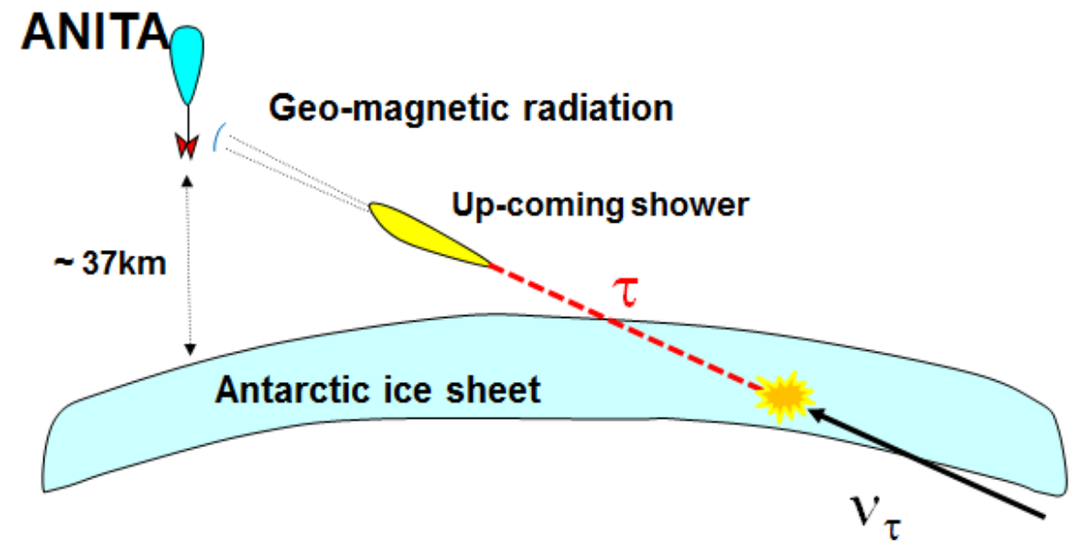
And ANITA-3 mystery event











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}

Mysterious neutrinos

- Diffuse neutrinos:
  - SM cross-section needs to be suppressed by a one order of magnitude to explain these events
  - SM cross-section greatly suppressed for extremely low values of Bjorken-x
  - Possible sterile neutrinos explanation ($\sigma_{\nu s} \sim \theta^2 \sigma_\nu$) : arXiv:1802.01611
- 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)

Summary and future

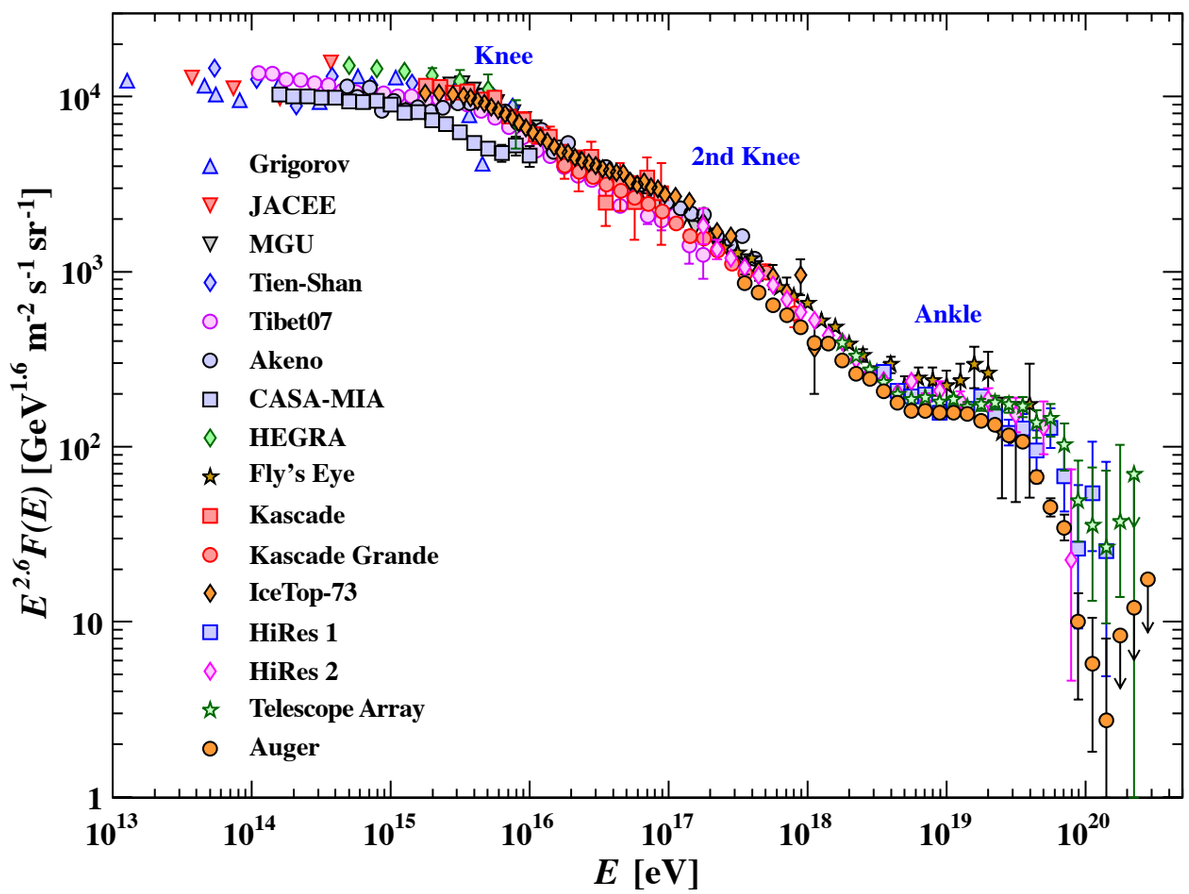
- The ANITA experiment has a rich physics program:
  - ANITA-3 diffuse neutrino analysis: arXiv:1803.02719 [astro-ph.HE]
  - ANITA-3 cosmic ray and tau neutrino analysis: arXiv:1803.05088 [astro-ph.HE]
  - Things I didn't cover: ANITA-3 HiCal (arXiv:1703.00415 [astro-ph.IM]), GRB searches (ApJ 736 (2011) 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

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

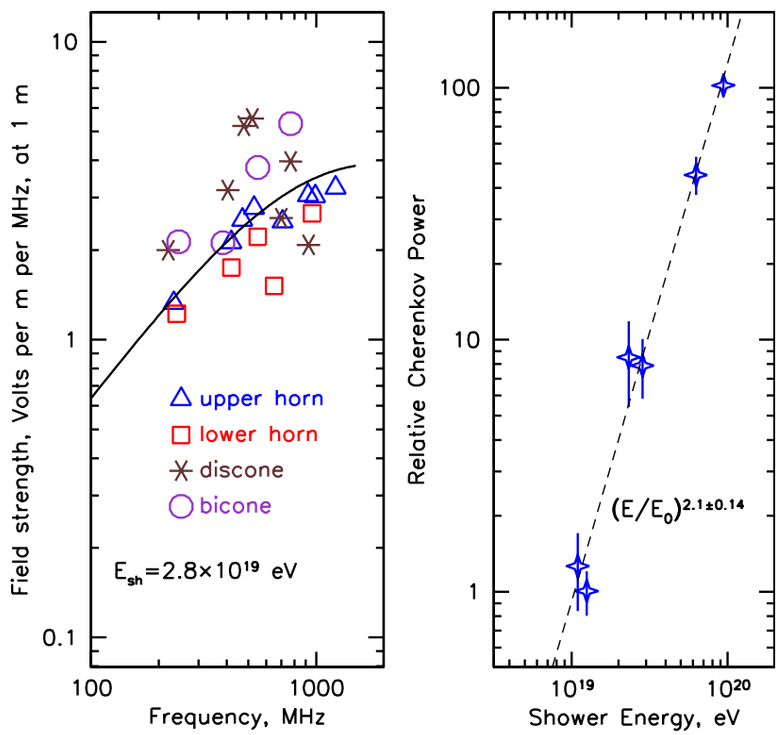
$$A + \gamma_{CMB} \rightarrow (A-1) + n$$

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

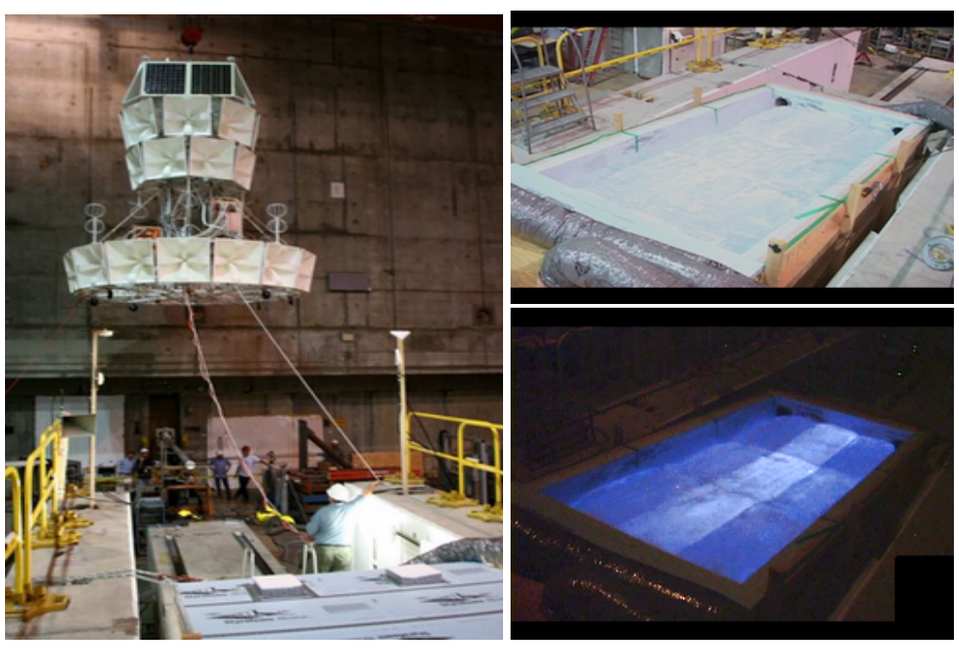
We know cosmic ray energy spectrum over 11 orders of magnitude.

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

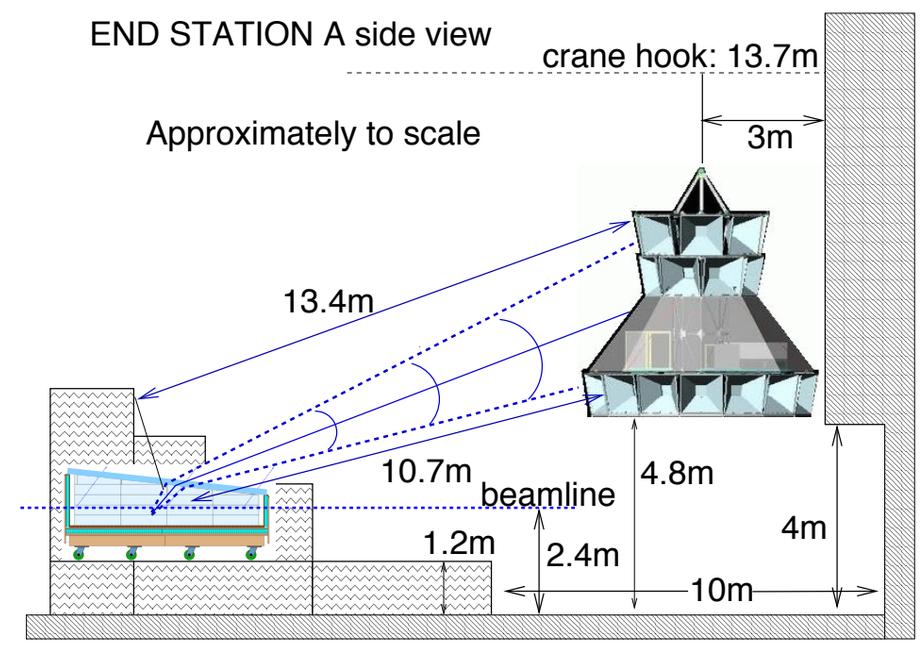
Askaryan radiation



- 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



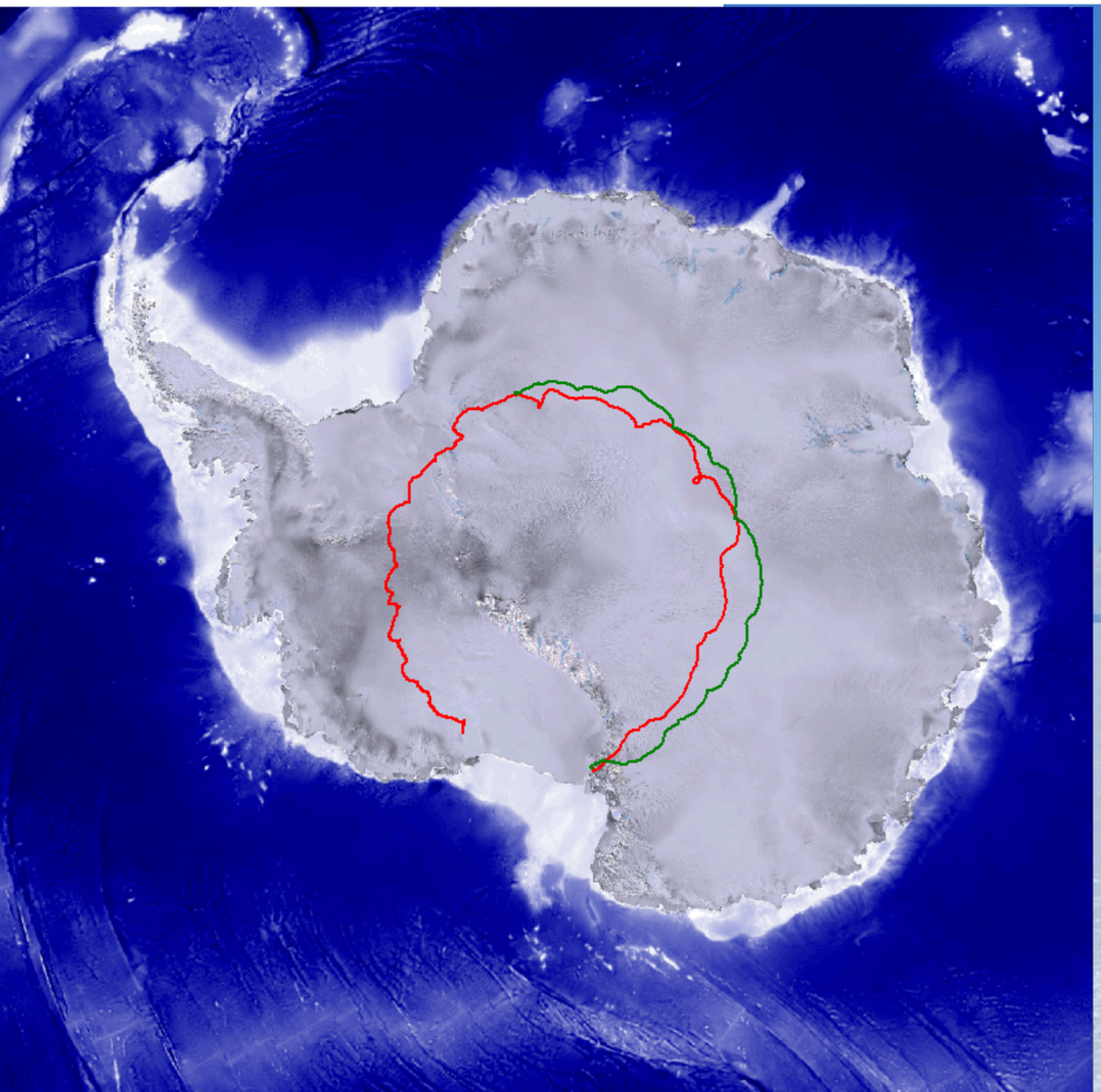
Phys.Rev.Lett.99:171101,2007



HiCal

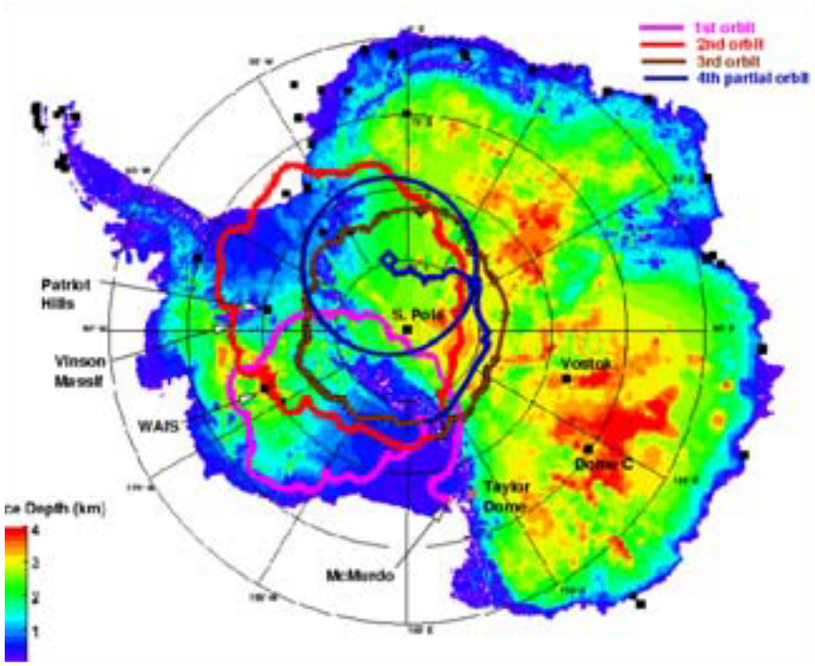
Two calibration payloads (HiCals) launched on ANITA's second pass:

- 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]



Past ANITA Flights

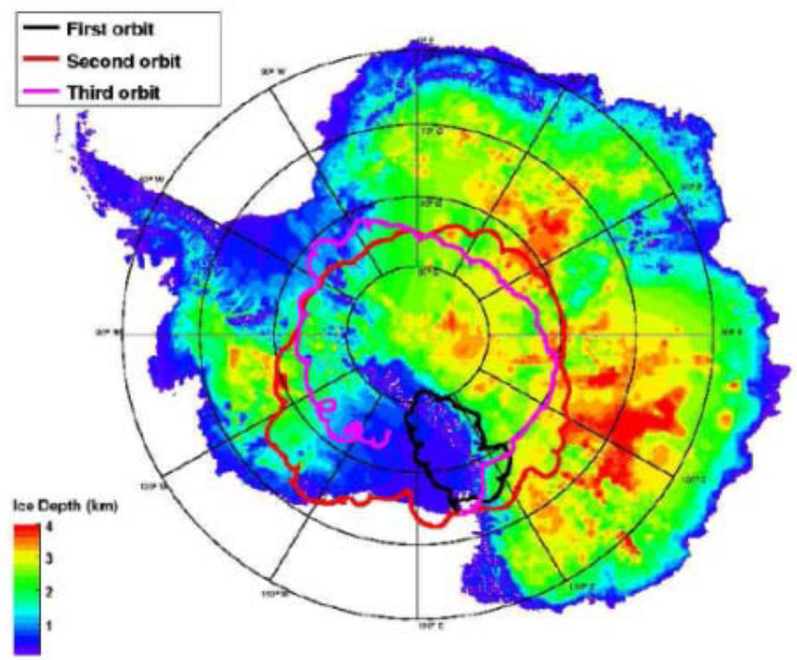
ANITA-1
(2006-2007)
35 days



32 Antennas

No neutrino candidate seen
Discovery of 16 CR events
Discovery of 1 up-coming event

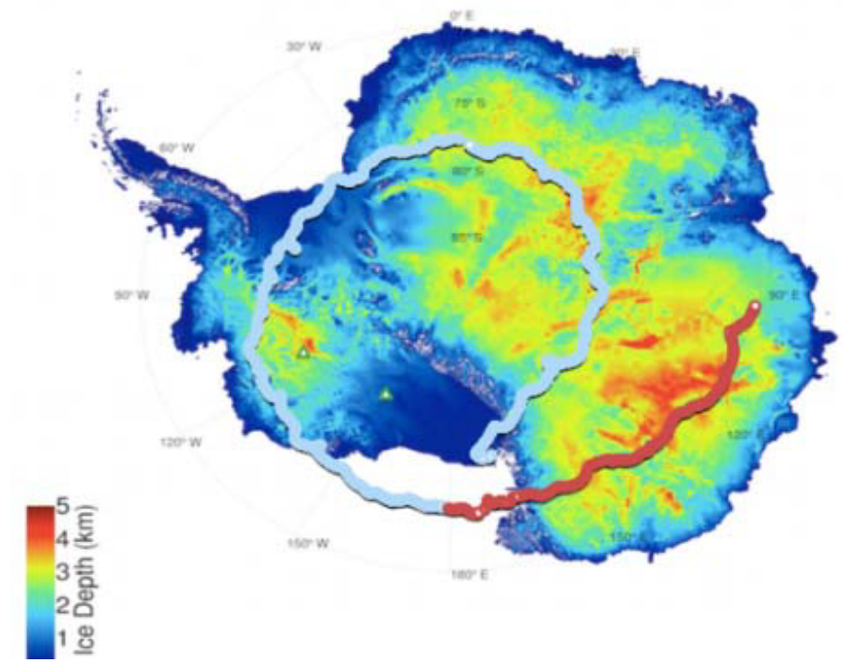
ANITA-2
(2008-2009)
30 days



40 Antennas

1 neutrino candidate observed
Additional 2 CR events

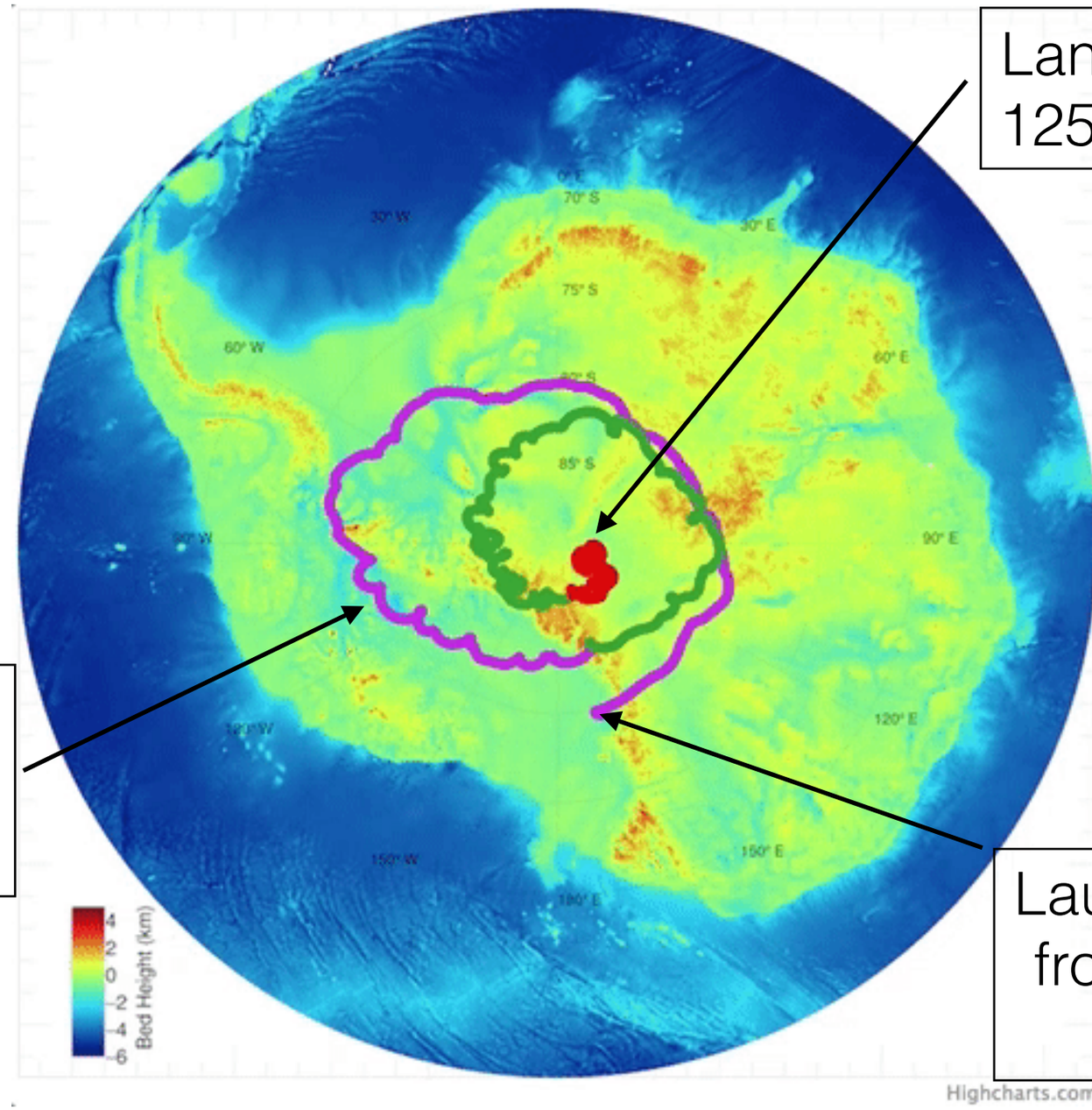
ANITA-3
(2014-2015)
22 days



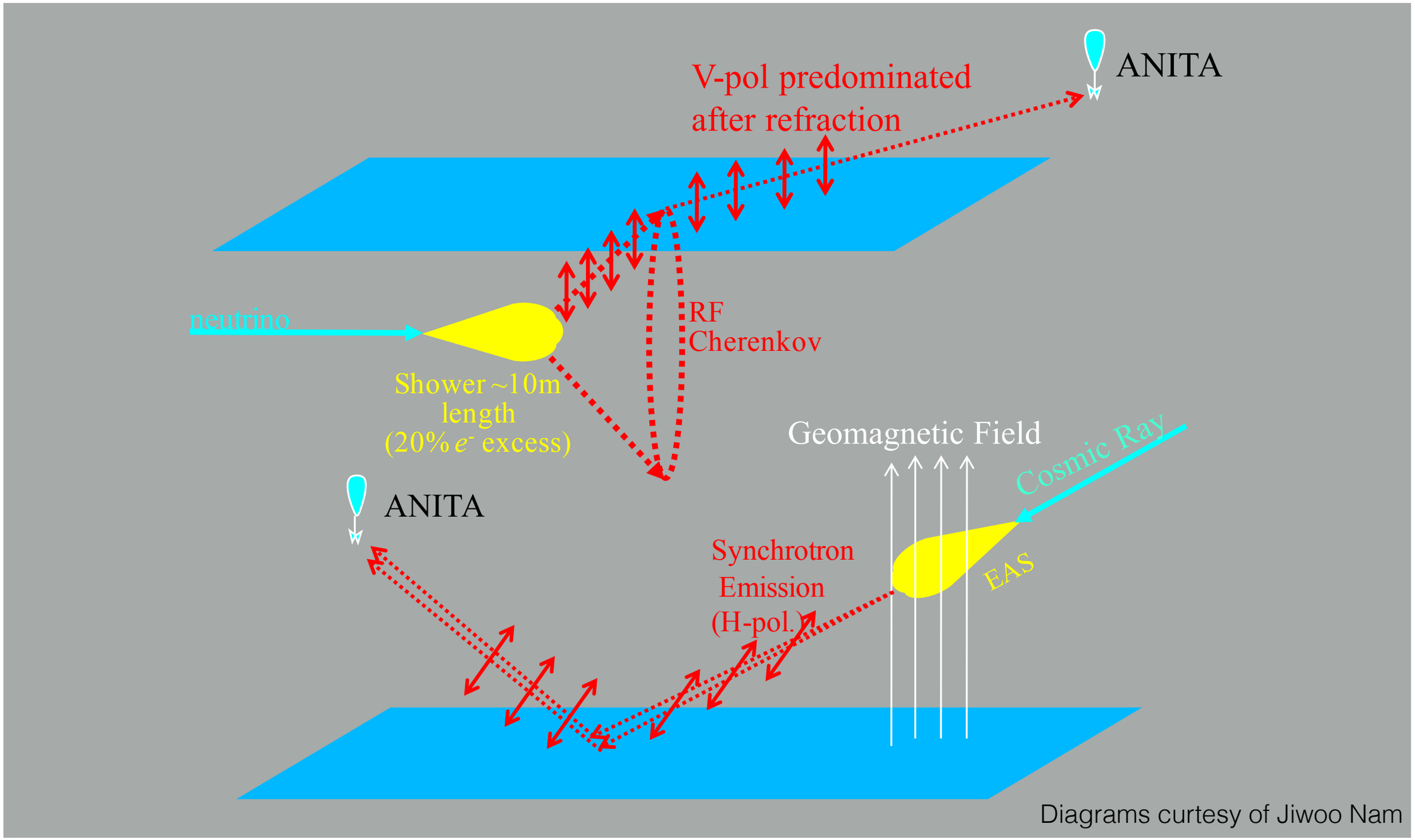
48 Antennas

1 neutrino candidate observed
20 CR events
1 up-coming event

ANITA-4 flight path



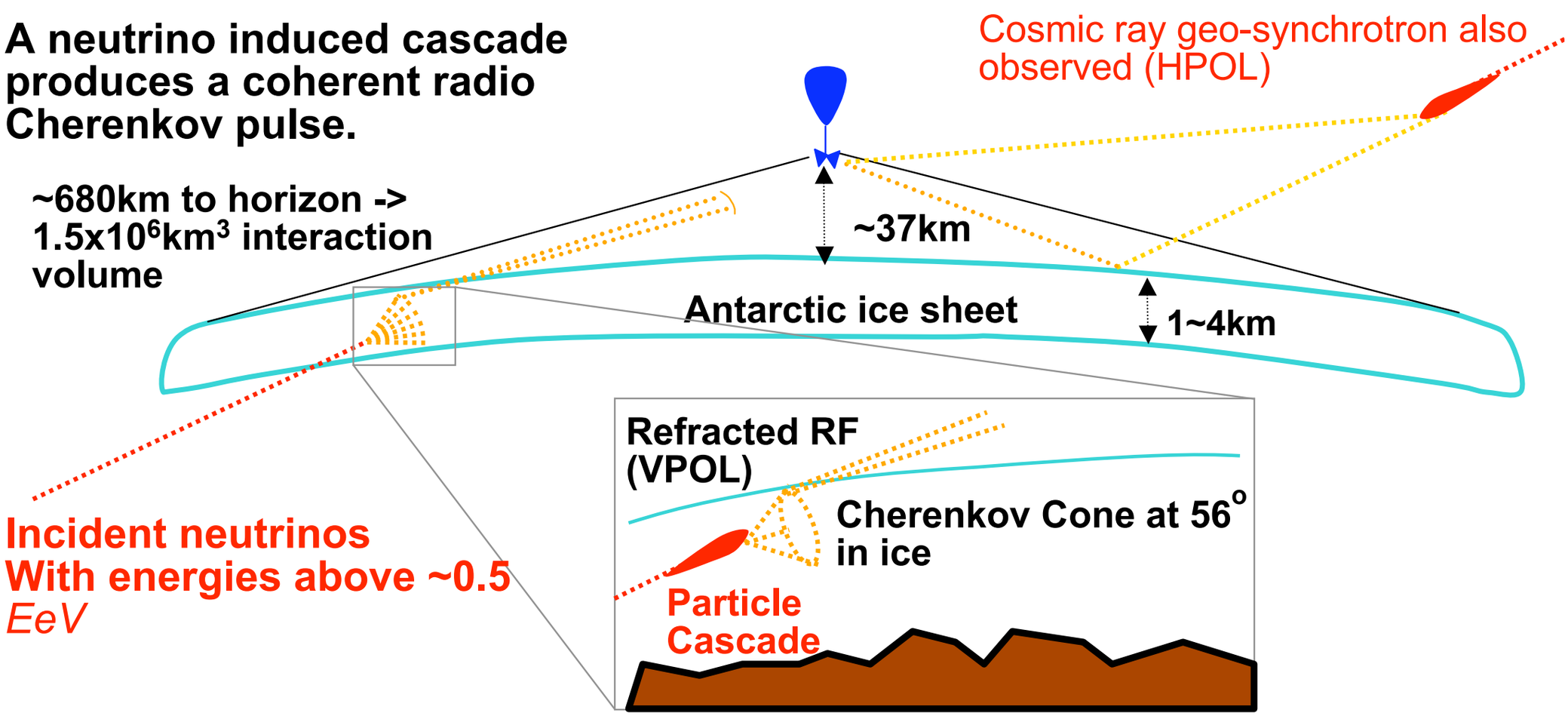
Neutrinos and Cosmic Rays



ANITA

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

A neutrino induced cascade produces a coherent radio Cherenkov pulse.



Continuous Waves

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

- How to get rid of them?

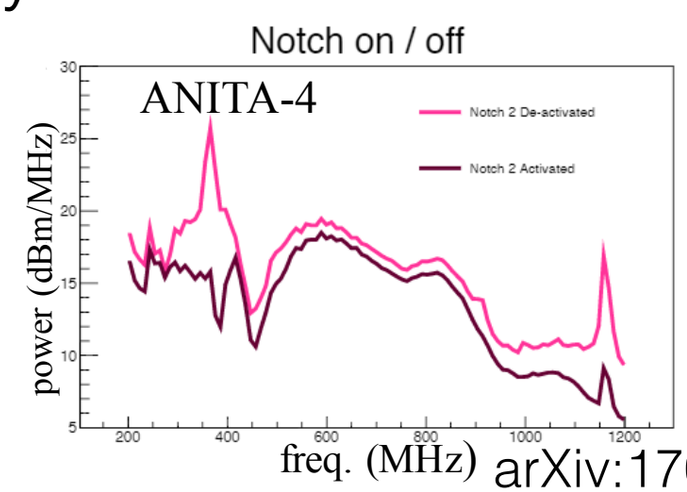
ANITA-3: Software

Sine subtraction algorithm

- Find peaks in power spectra
- Remove peaks with best fit sinusoid
- Iterate

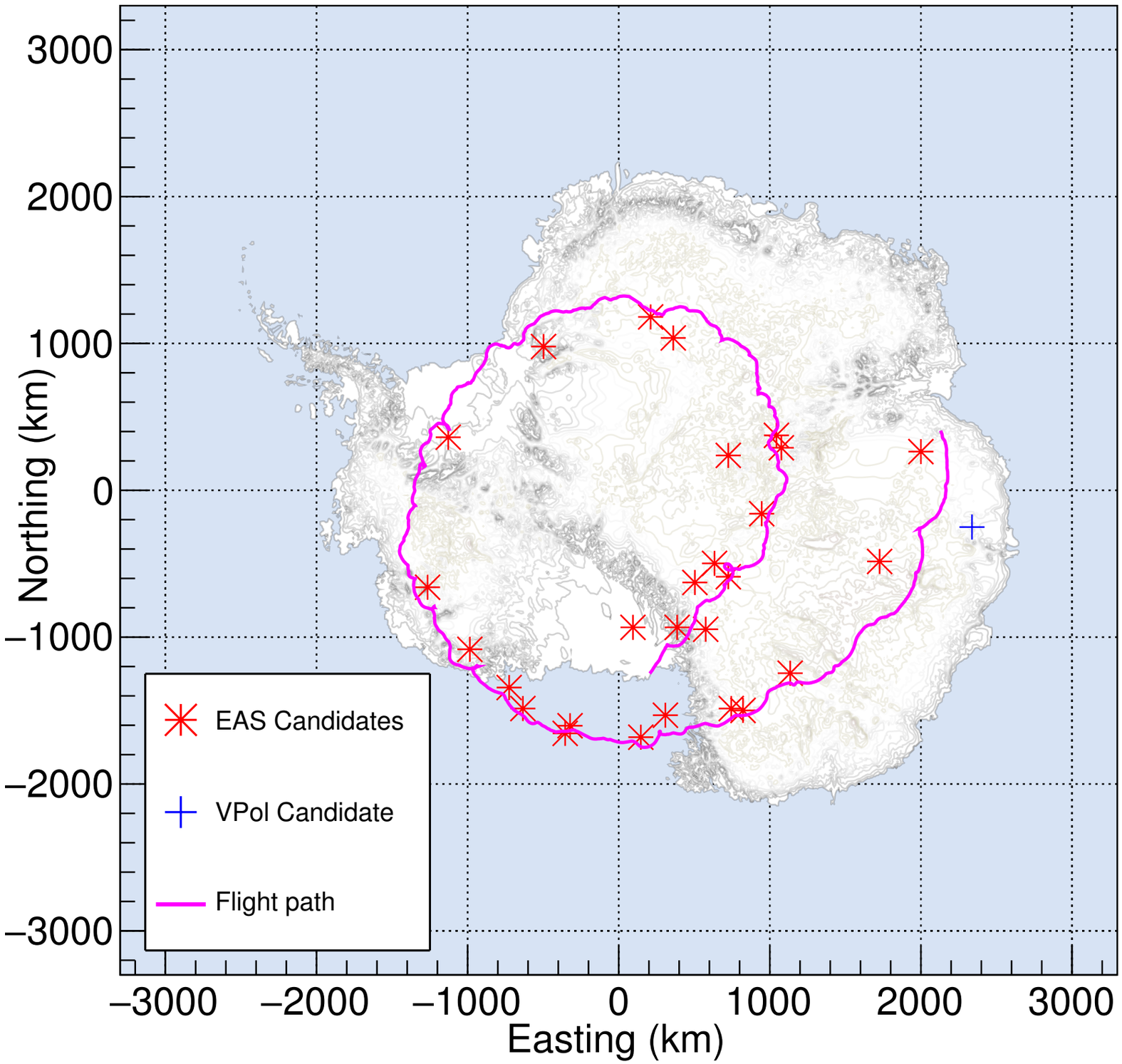
ANITA-4: Hardware

- Circular polarisation Trigger
- Dynamic tunable notch filters

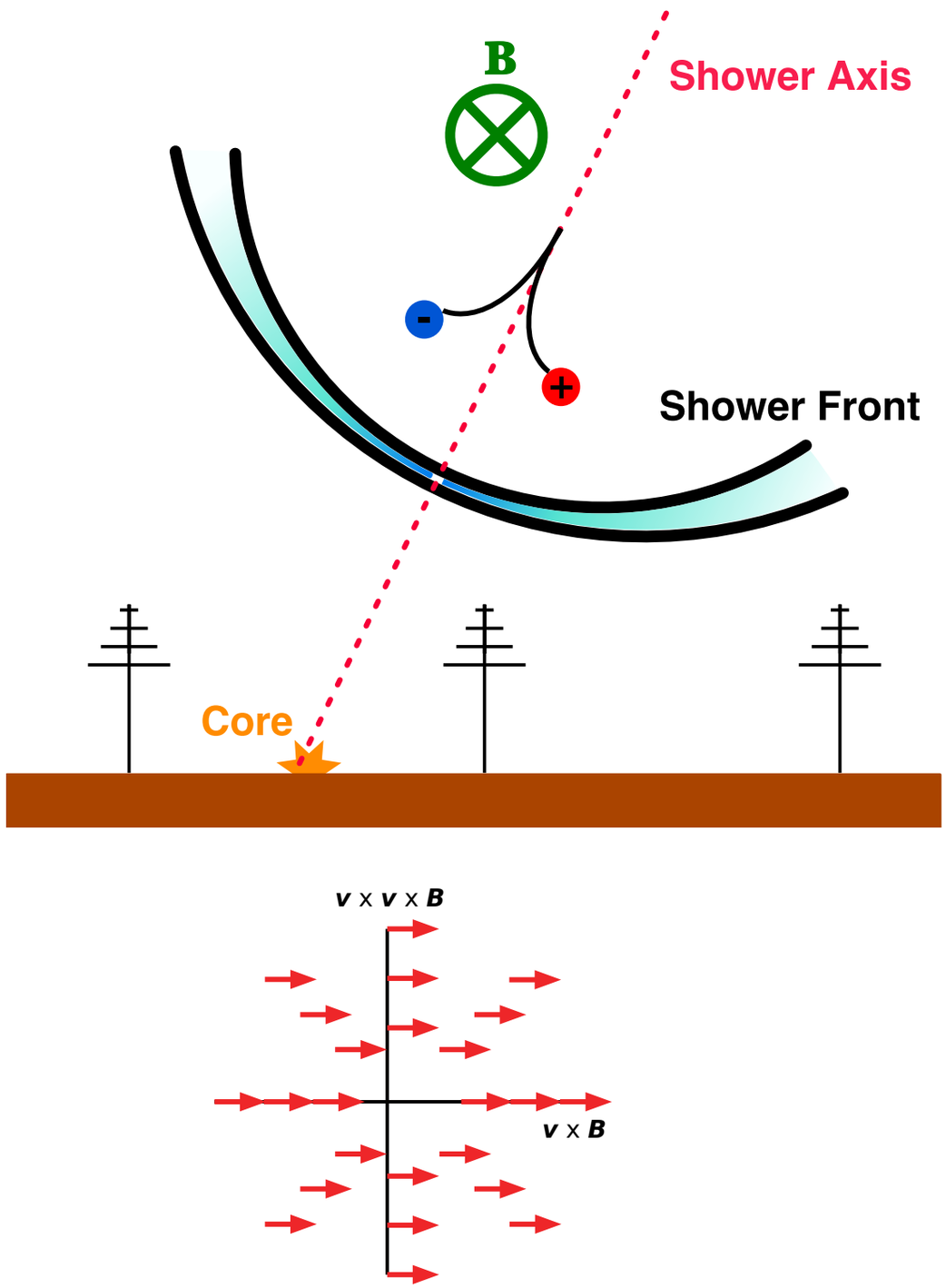


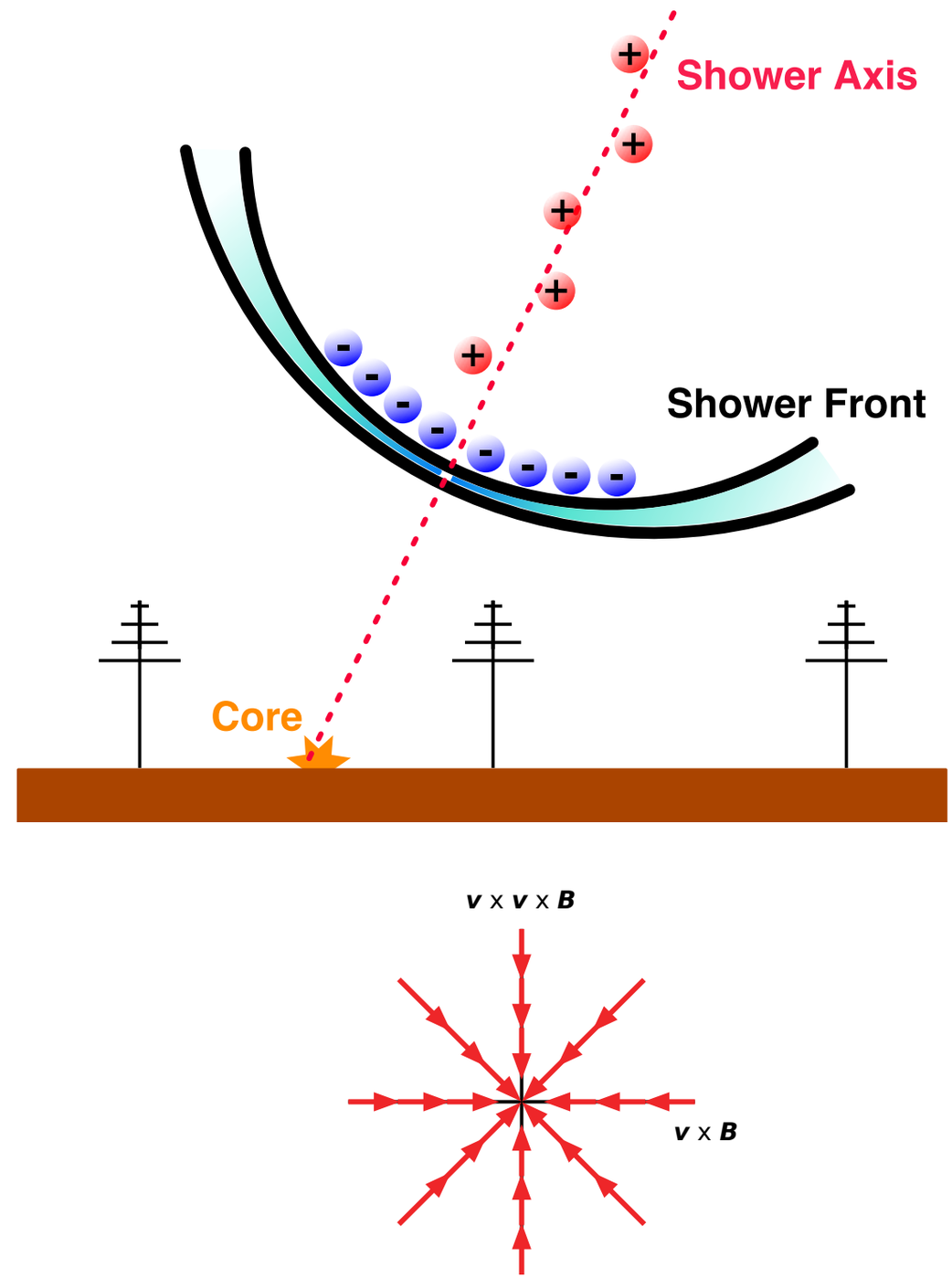
arXiv:1709.04536

Better map

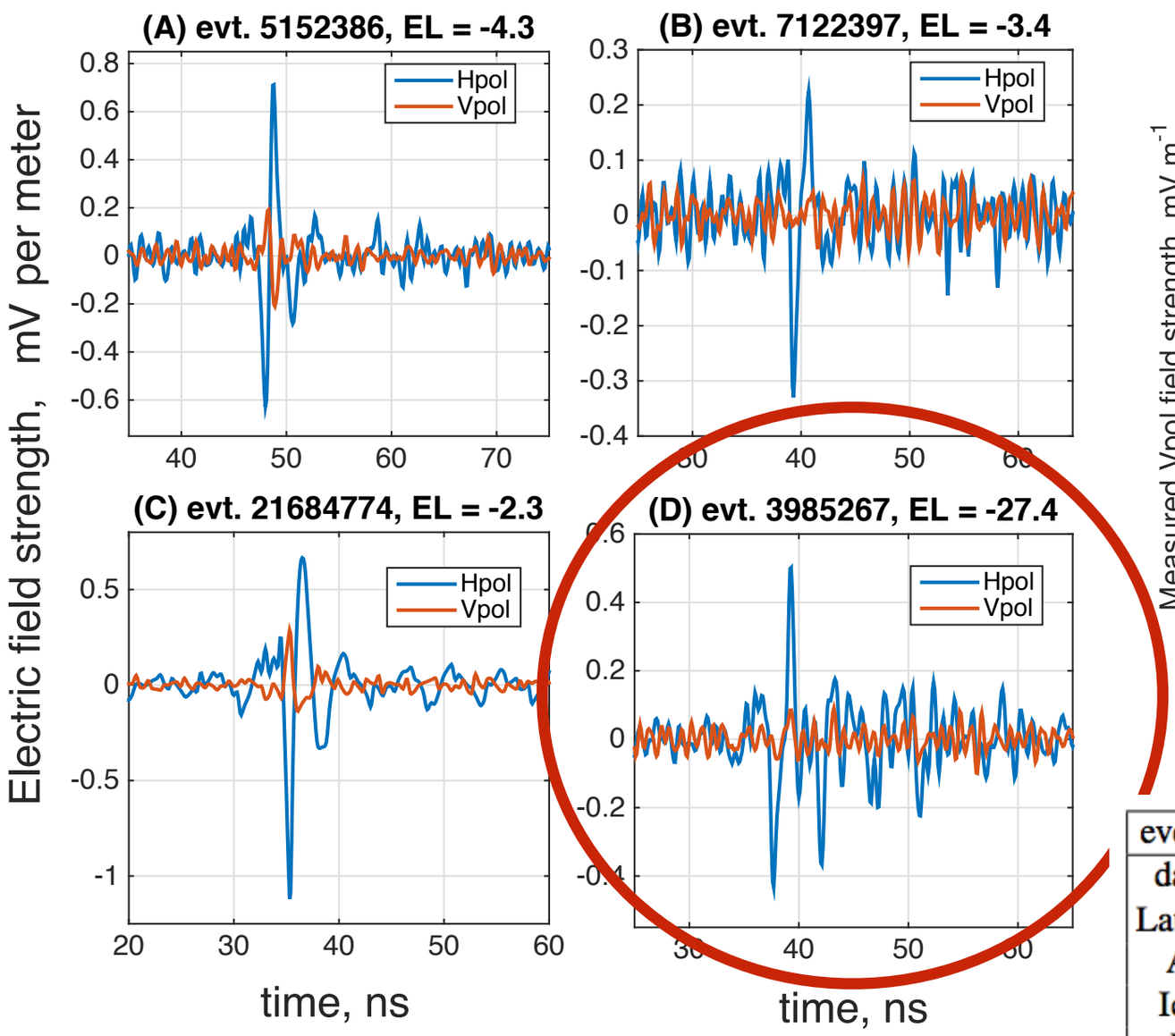

3000
2000
1000
0
−1000
−2000
−3000
Northing (km)
−3000
−2000
−1000
0
1000
2000
3000
Easting (km)
EAS Candidates
VPol Candidate
Flight path

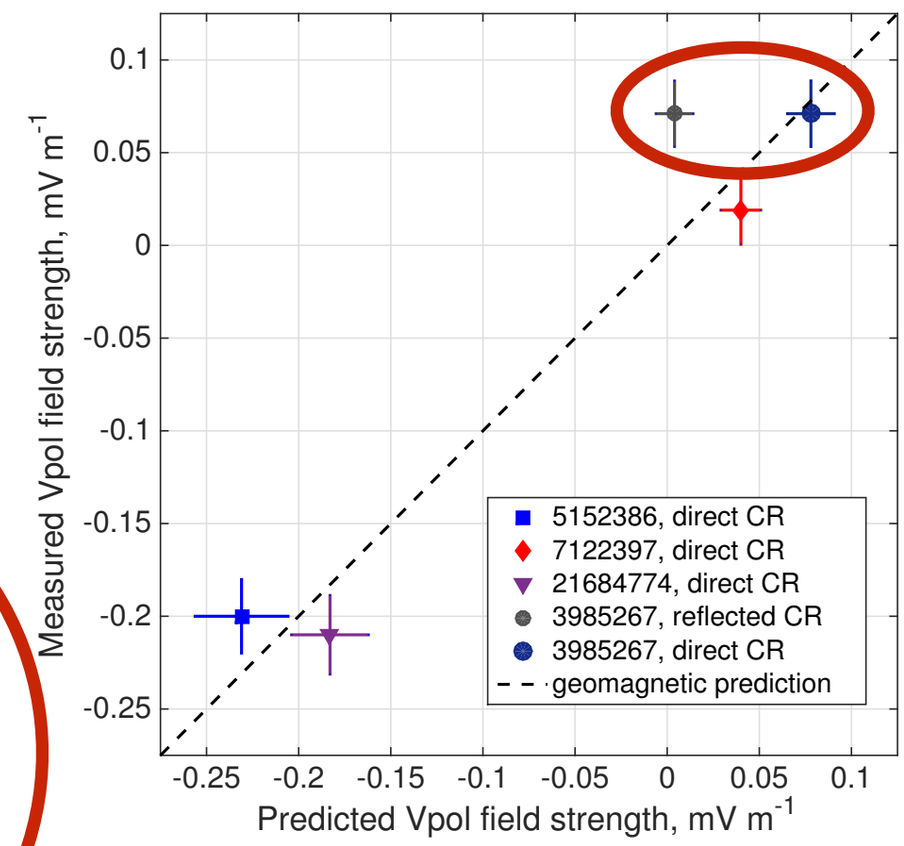
UHECR


B
Shower Axis
Shower Front
Core
v x v x B
v x B


Shower Axis
Shower Front
Core
v x v x B
v x B

ANITA-1 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

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