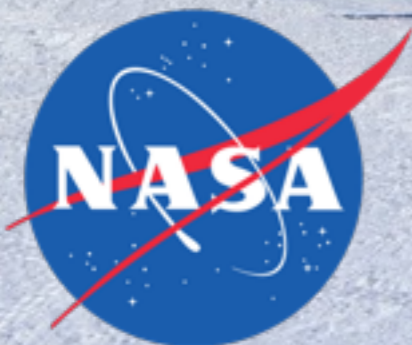


Hunting UHE neutrinos with ANITA

Linda Cremonesi

Rutherford Appleton Laboratory seminar
May 2nd 2018



LEVERHULME
TRUST

Outline

- Motivations
- ANITA
- Neutrino(s) in a haystack
arXiv:1803.02719 [astro-ph.HE]
- UHE cosmic rays and mysterious events
arXiv:1803.05088 [astro-ph.HE]
- Future

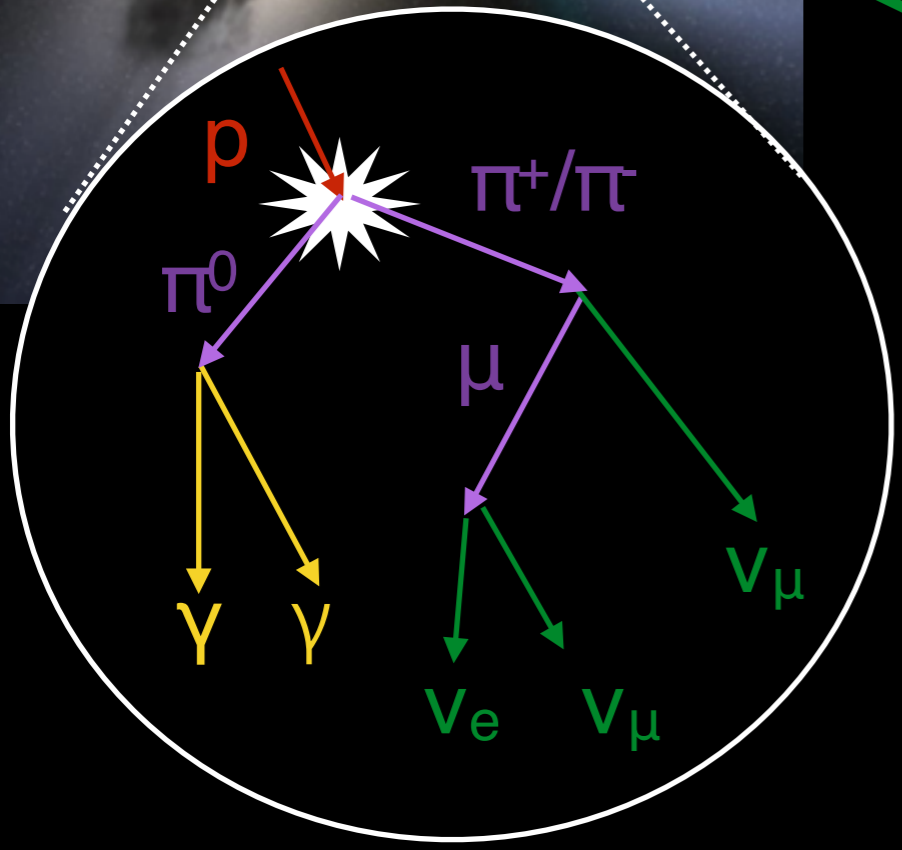
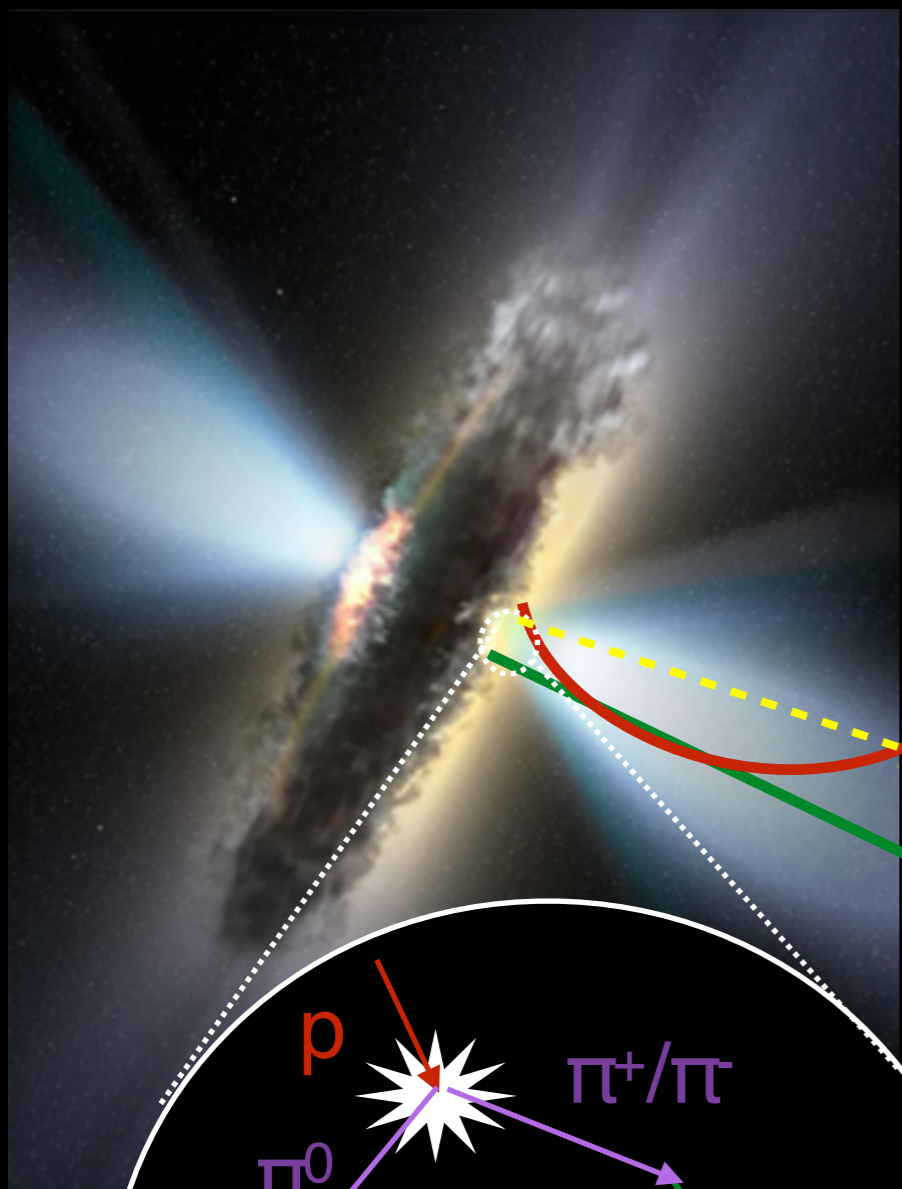


Motivations

L. Cremonesi

3

“UHE neutrinos and ANITA”



photons

protons

neutrinos

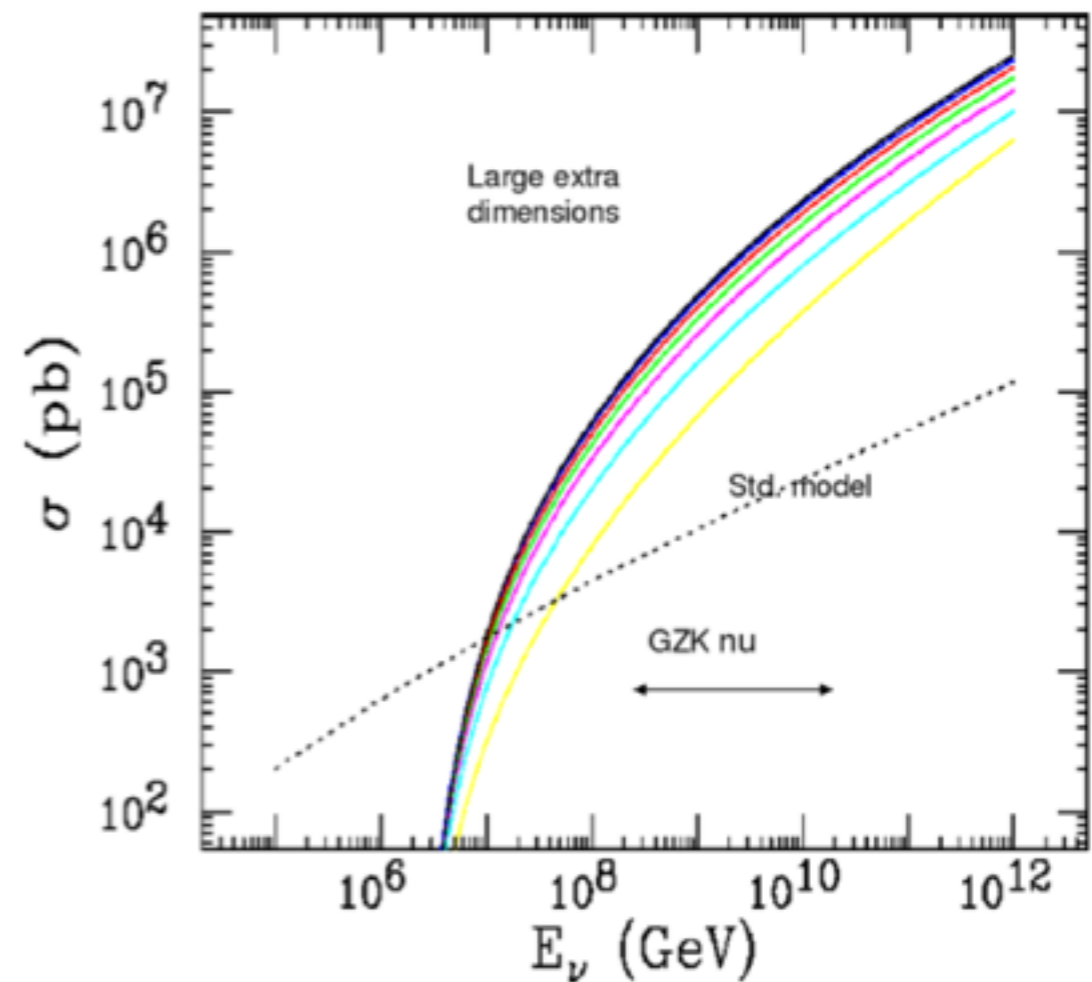
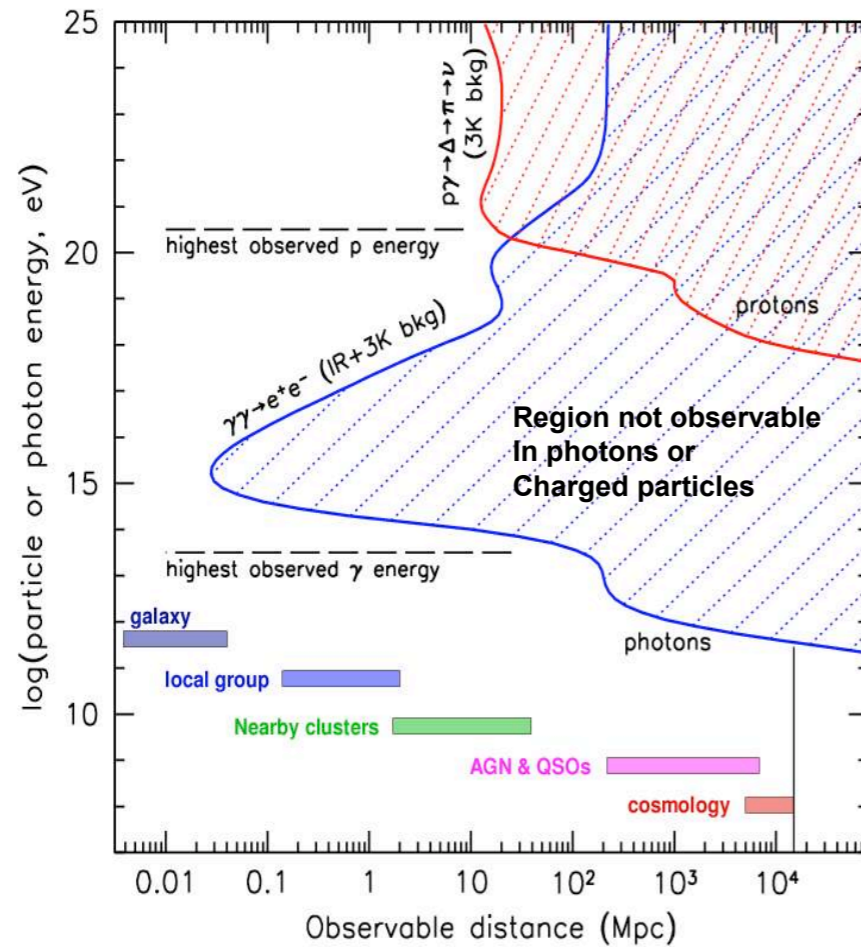


UHE ($>E18$ eV) neutrinos

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



“WOW
300 TeV centre of mass energy!”

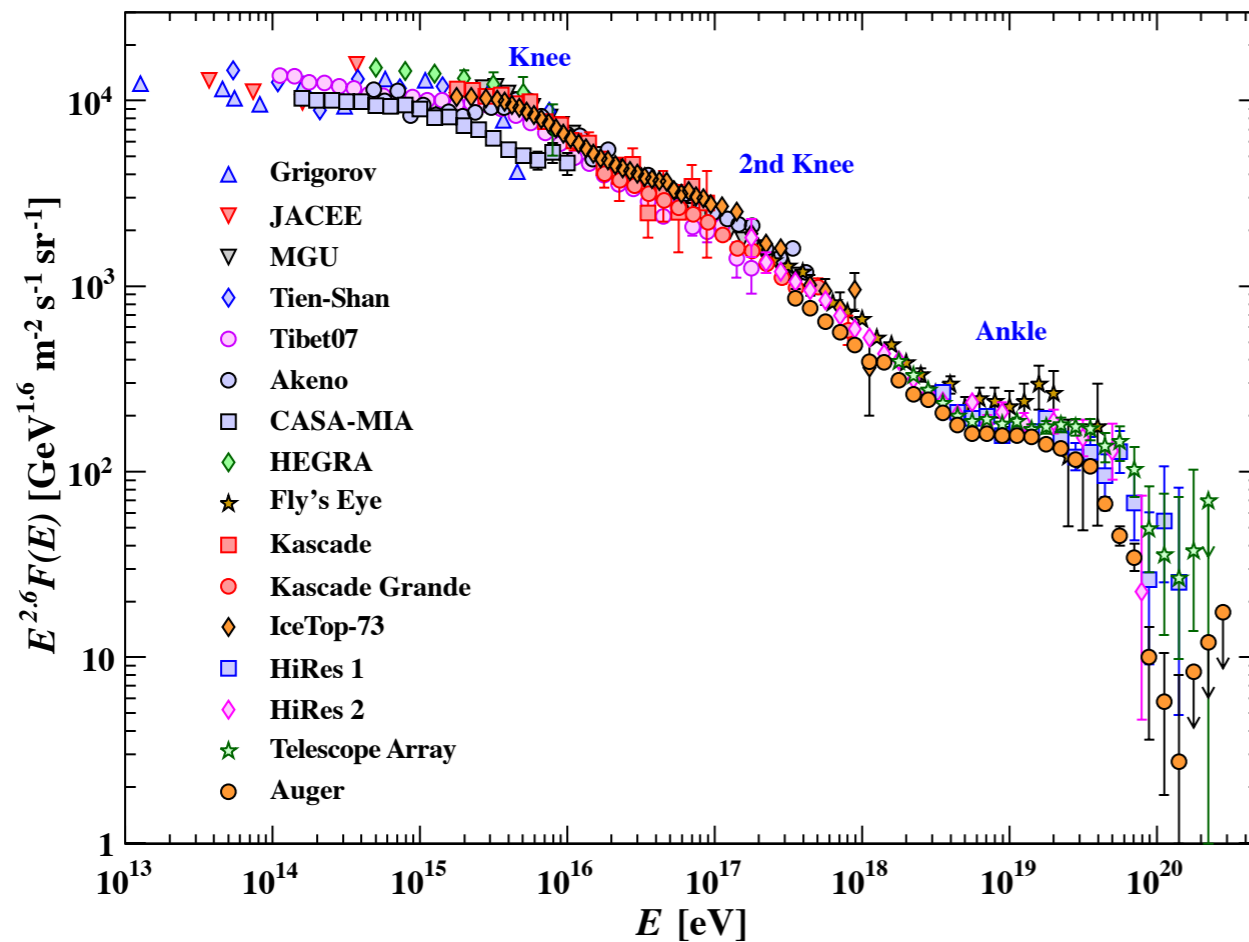


More motivations

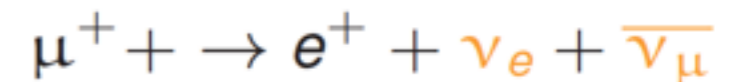
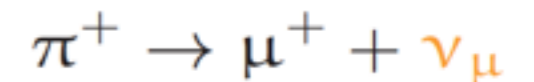
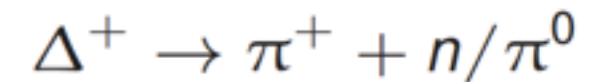
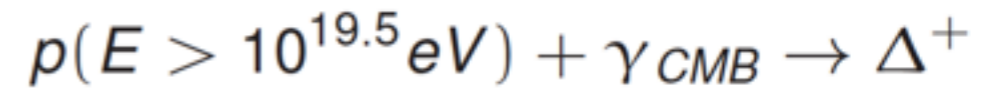
- Implications for neutrino mixing (arXiv:1702.05238)
- Neutrino decay - JCAP 10 (2012) 020
- Ultra high energy neutrino cross-sections (Nature 551 (2017) 596-600, arXiv:1711.11043)
- Lorentz invariance - Phys. Rev. D 86, 103006
- Sterile neutrinos - arXiv:1802.01611

Cosmogenic neutrinos

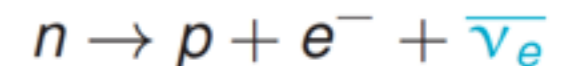
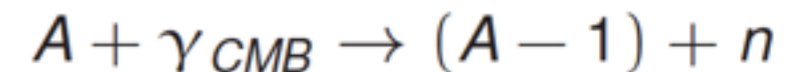
C. Patrignani et al. (Particle Data Group), Chin. Phys. C, 40, 100001 (2016)



ν from GZK



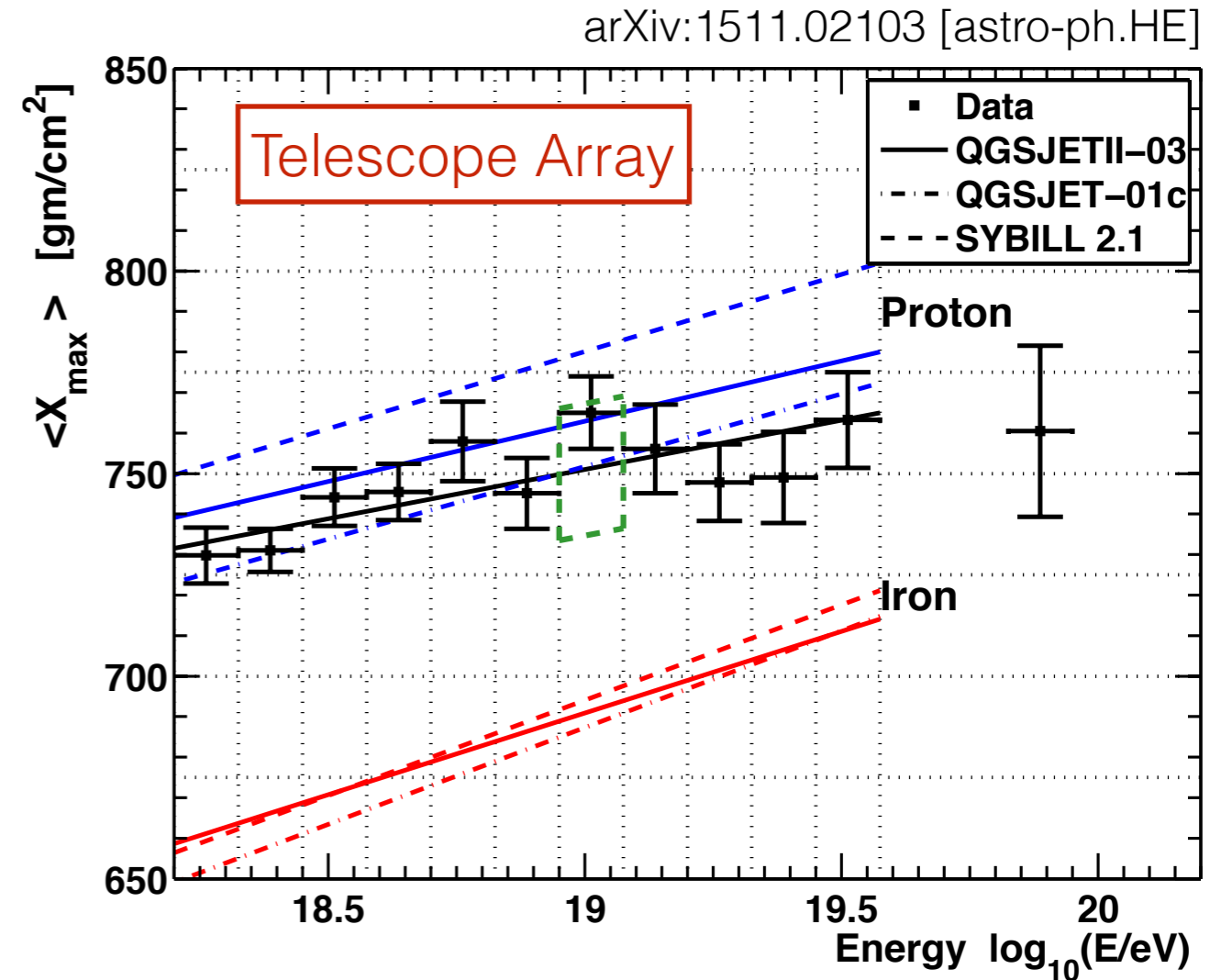
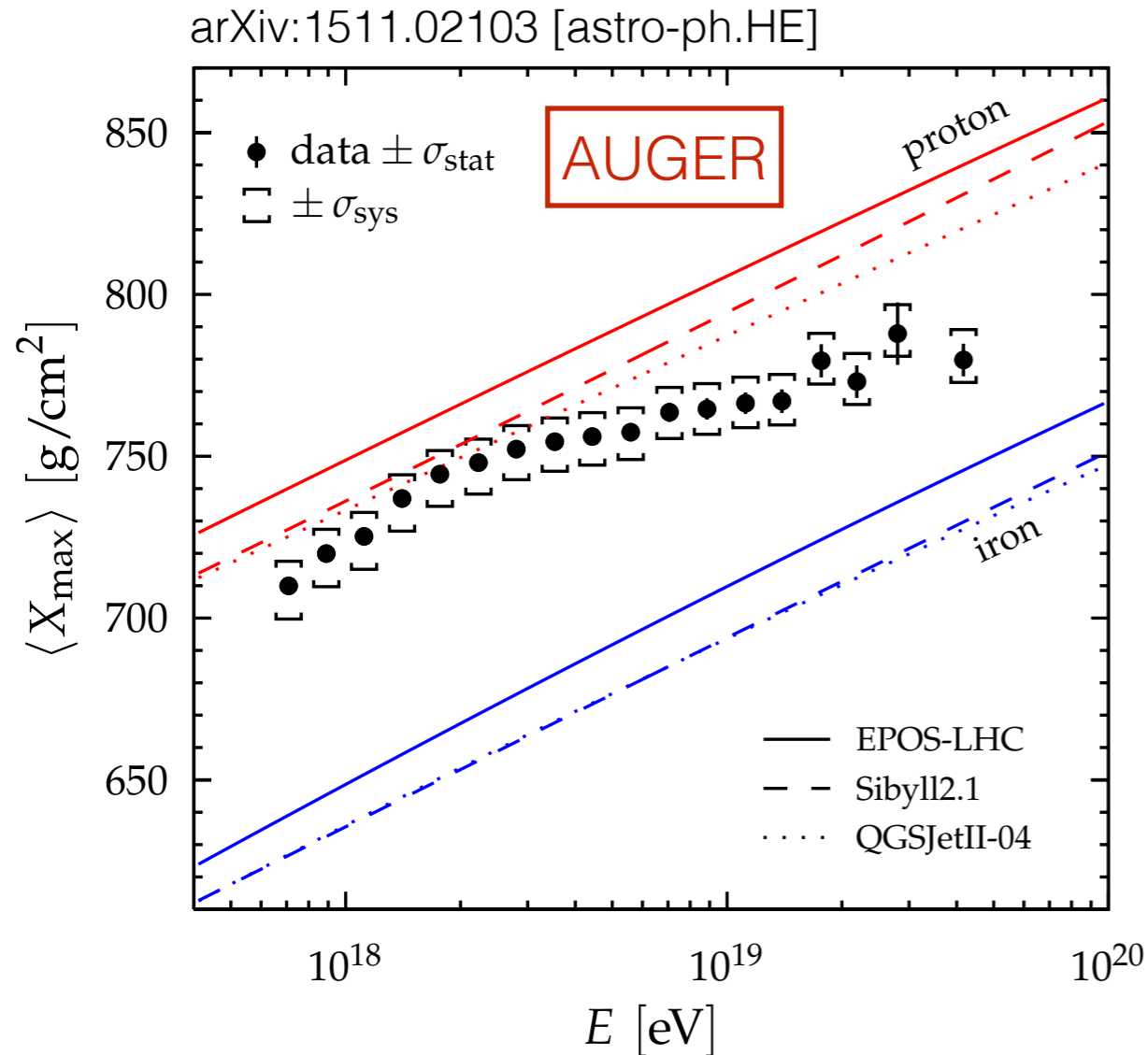
ν from photo-disintegration



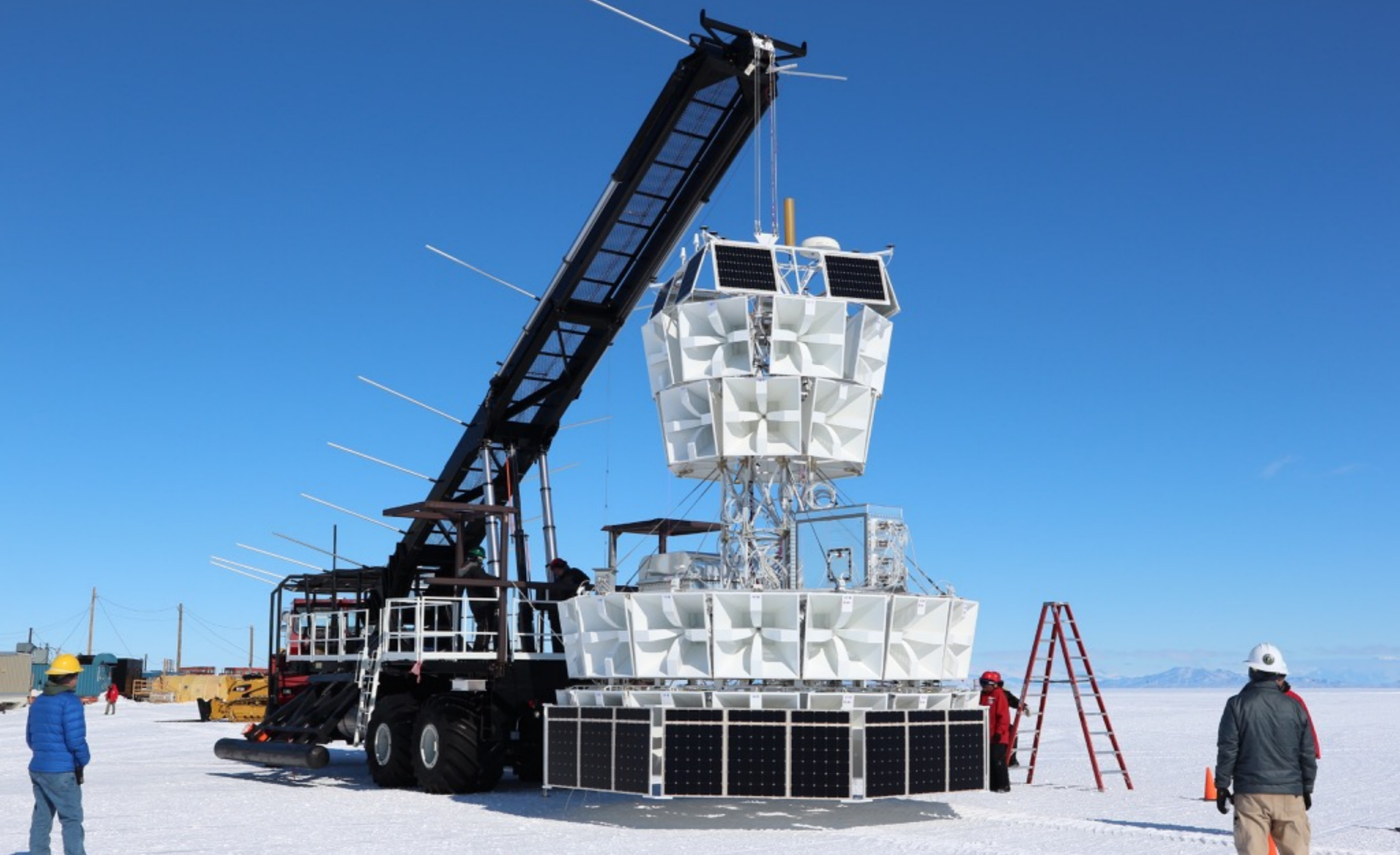
We know cosmic ray energy spectrum over 11 orders of magnitude.

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

Cosmogenic neutrinos

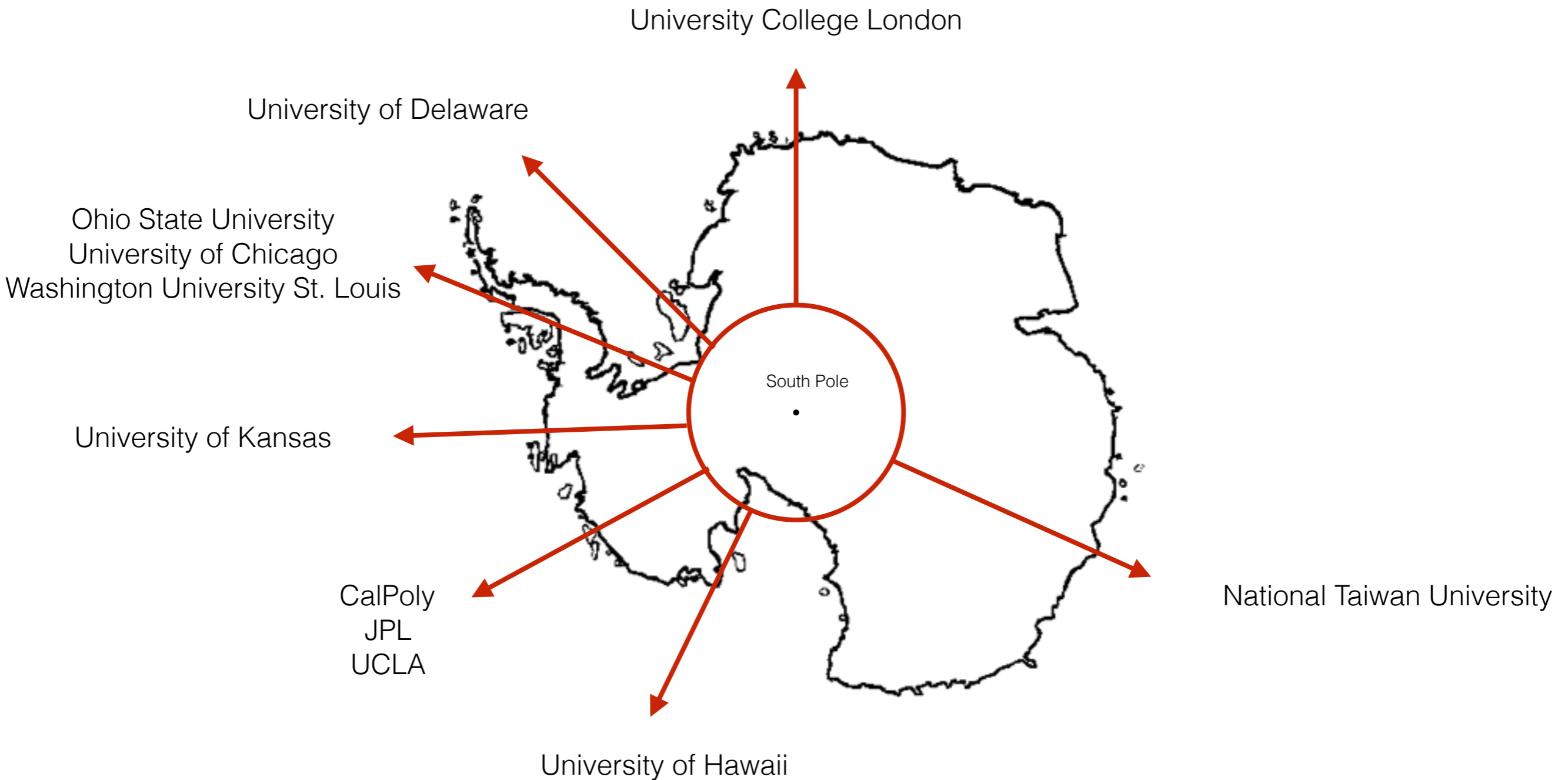


We know cosmic ray energy spectrum over 11 orders of magnitude.
 Their sources (especially at the highest energies) are still mostly unknown



ANITA

ANITA collaboration



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

ANtarctic Impulsive Transient Antenna

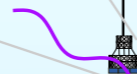
Not to scale,
angles don't
reflect reality



NEUTRINOS = VPOL



balloon

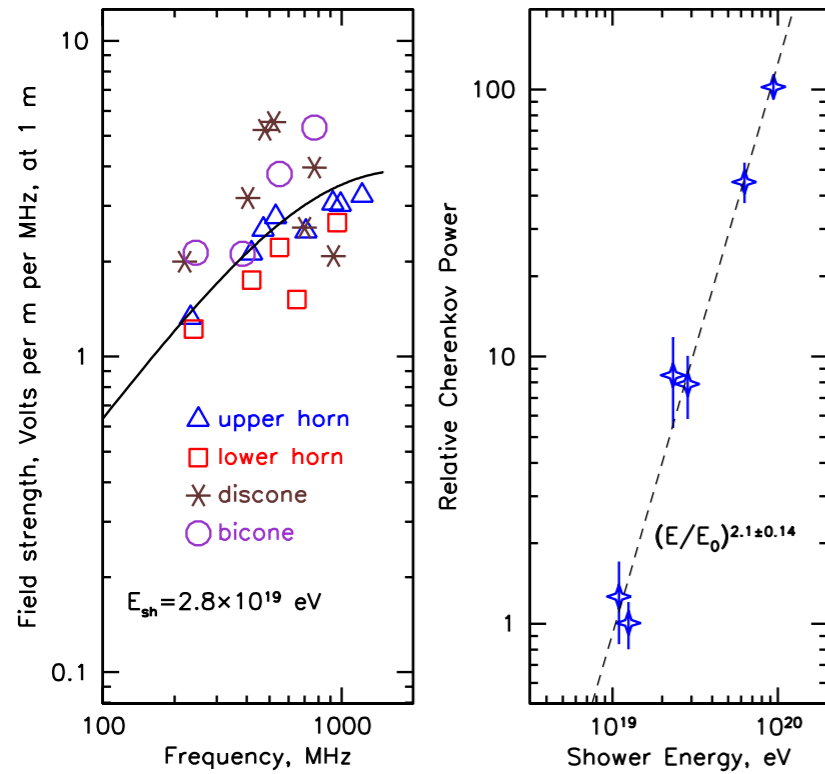


Ice

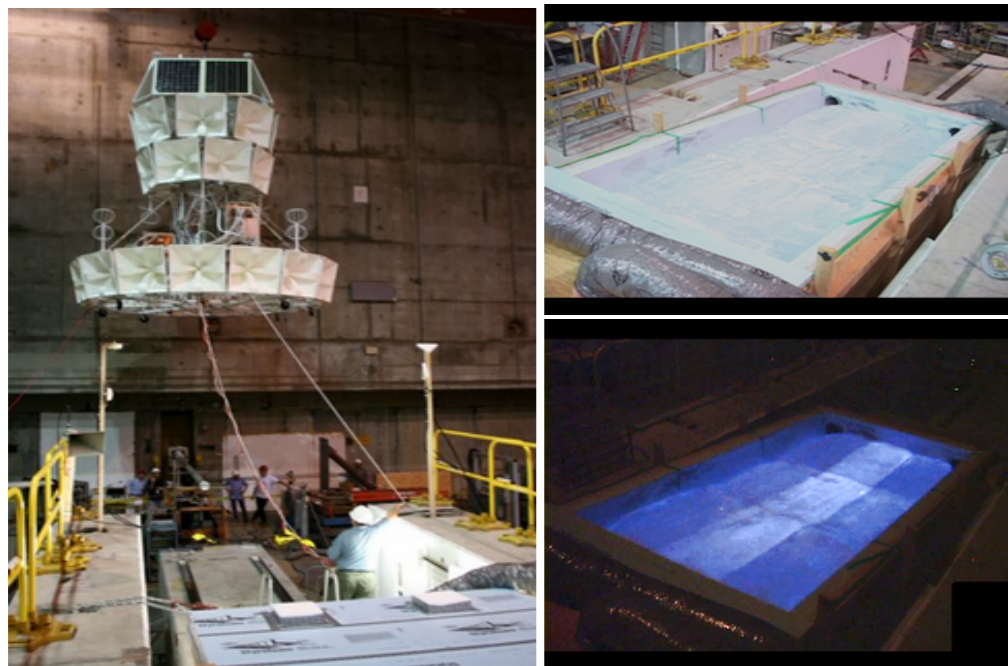
Askaryan
emission

\sim EeV
neutrino

Askaryan radiation

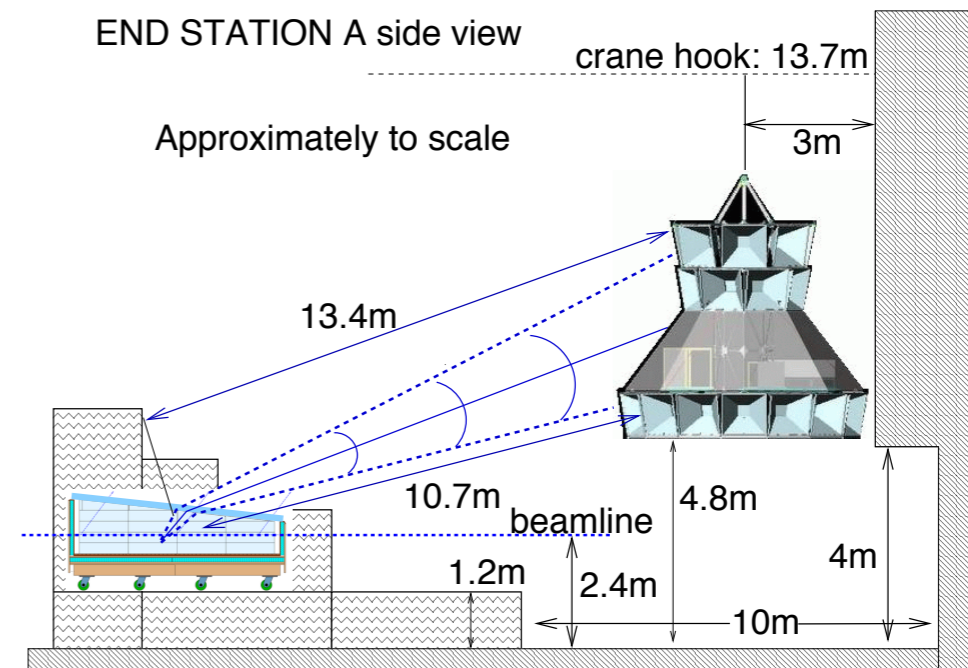


- Coherent radio emission from EM cascades in a dielectric!
- Measured at SLAC ESA in 2006 by ANITA collaboration
- Fired bunches of 10^9 electrons at 28.5 GeV into 7000 kg of ice



L. Cremonesi

Phys.Rev.Lett.99:171101,2007

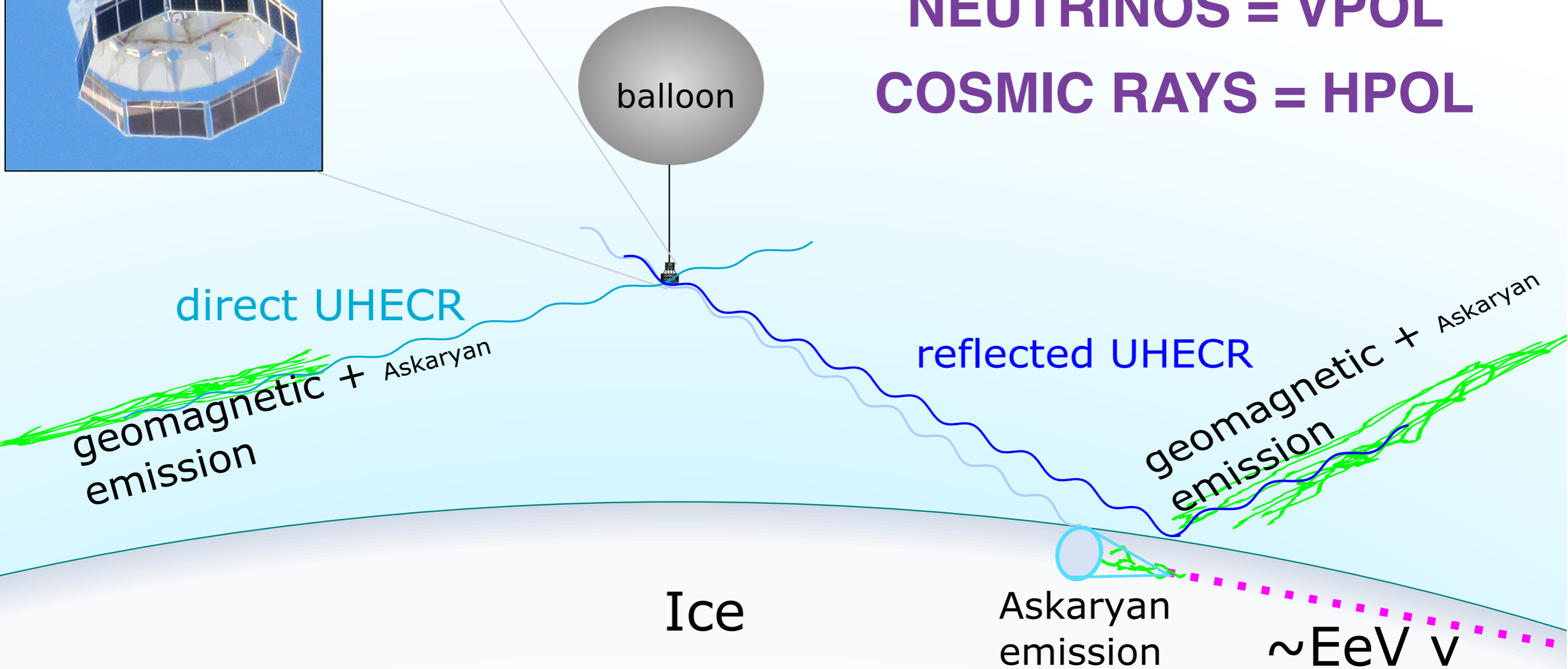


ANtarctic Impulsive Transient Antenna

Not to scale,
angles don't
reflect reality



NEUTRINOS = VPOL
COSMIC RAYS = HPOL



ANITA instrument

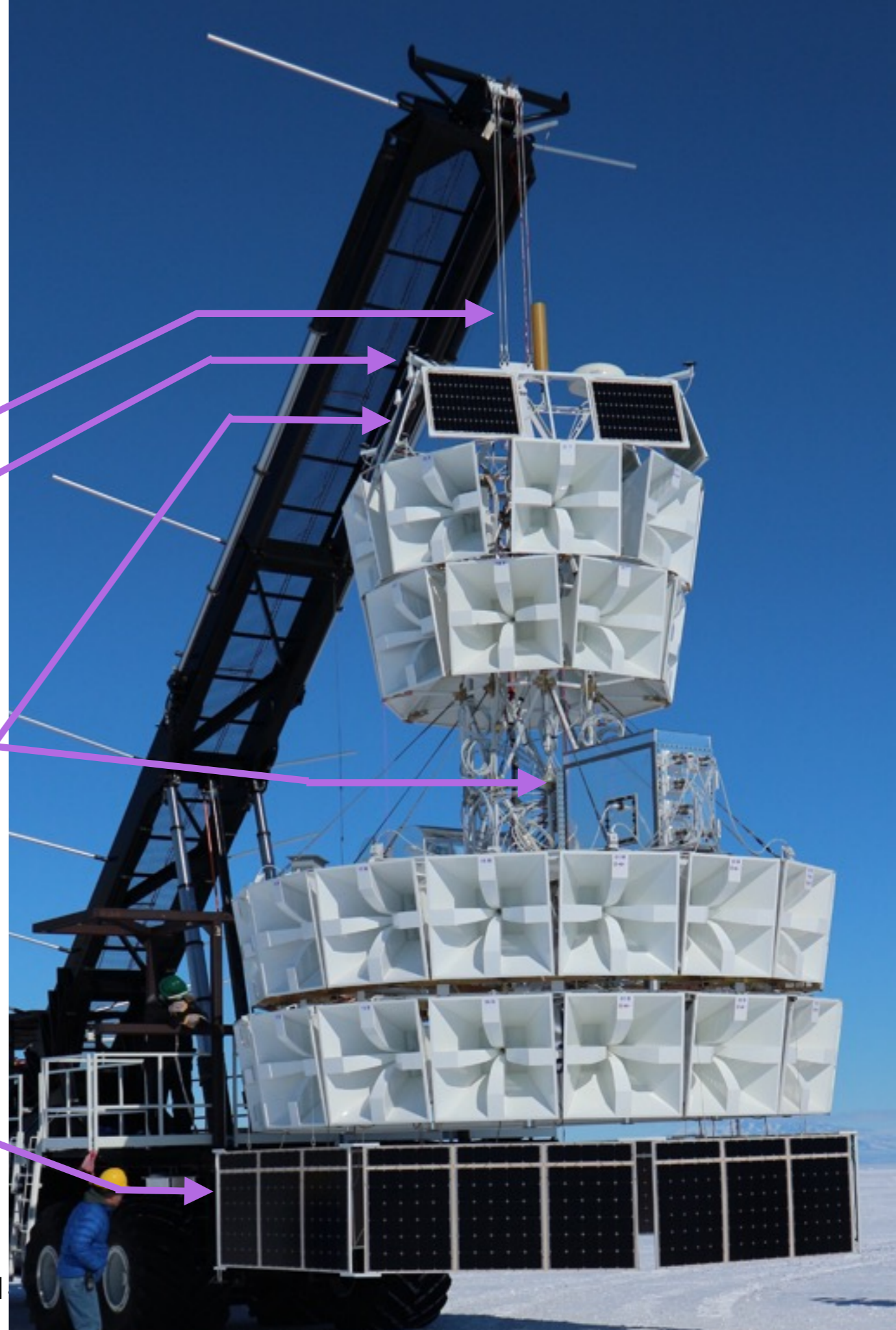
TDRSS & Iridium antennas

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

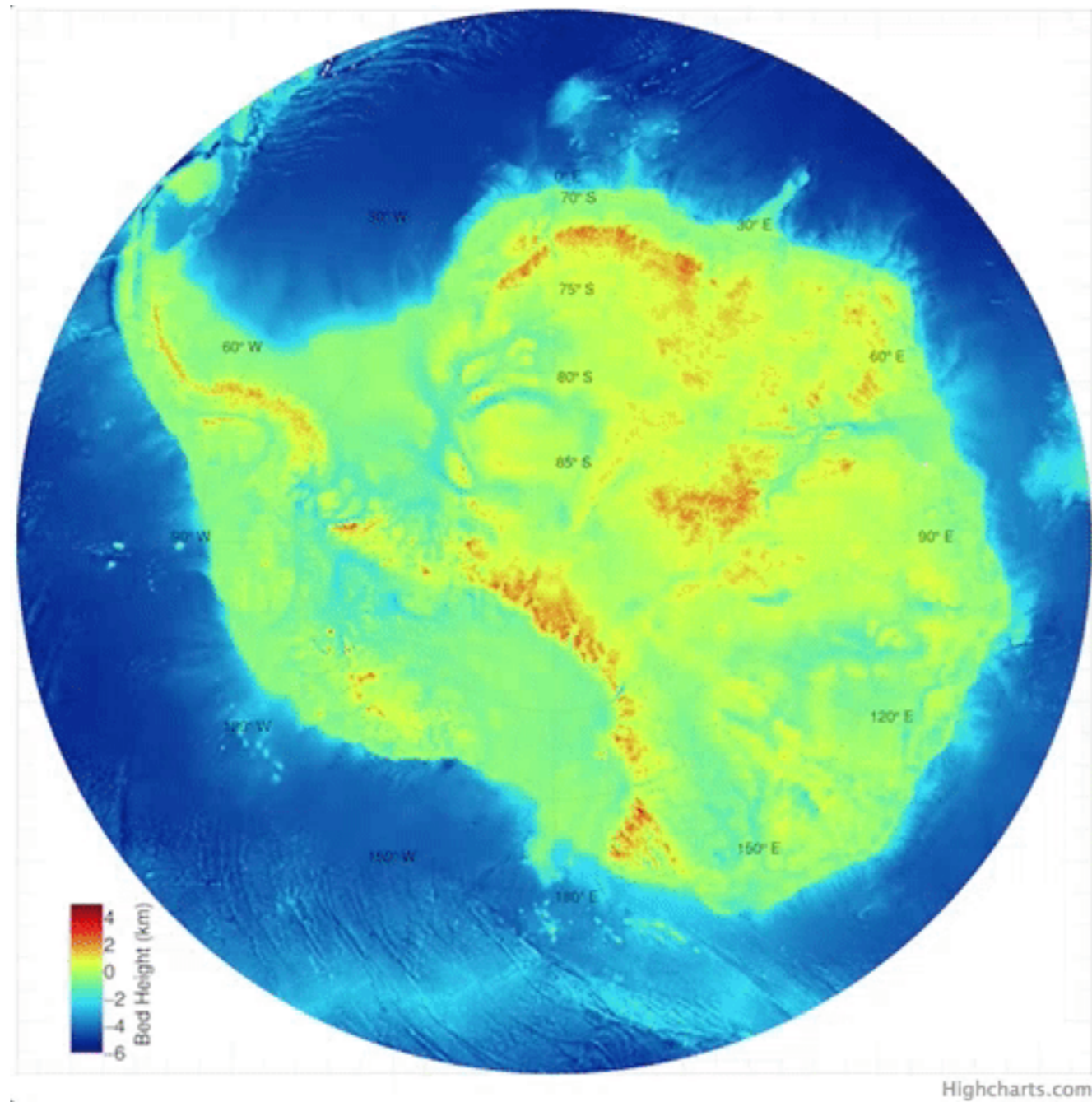
Solar panels



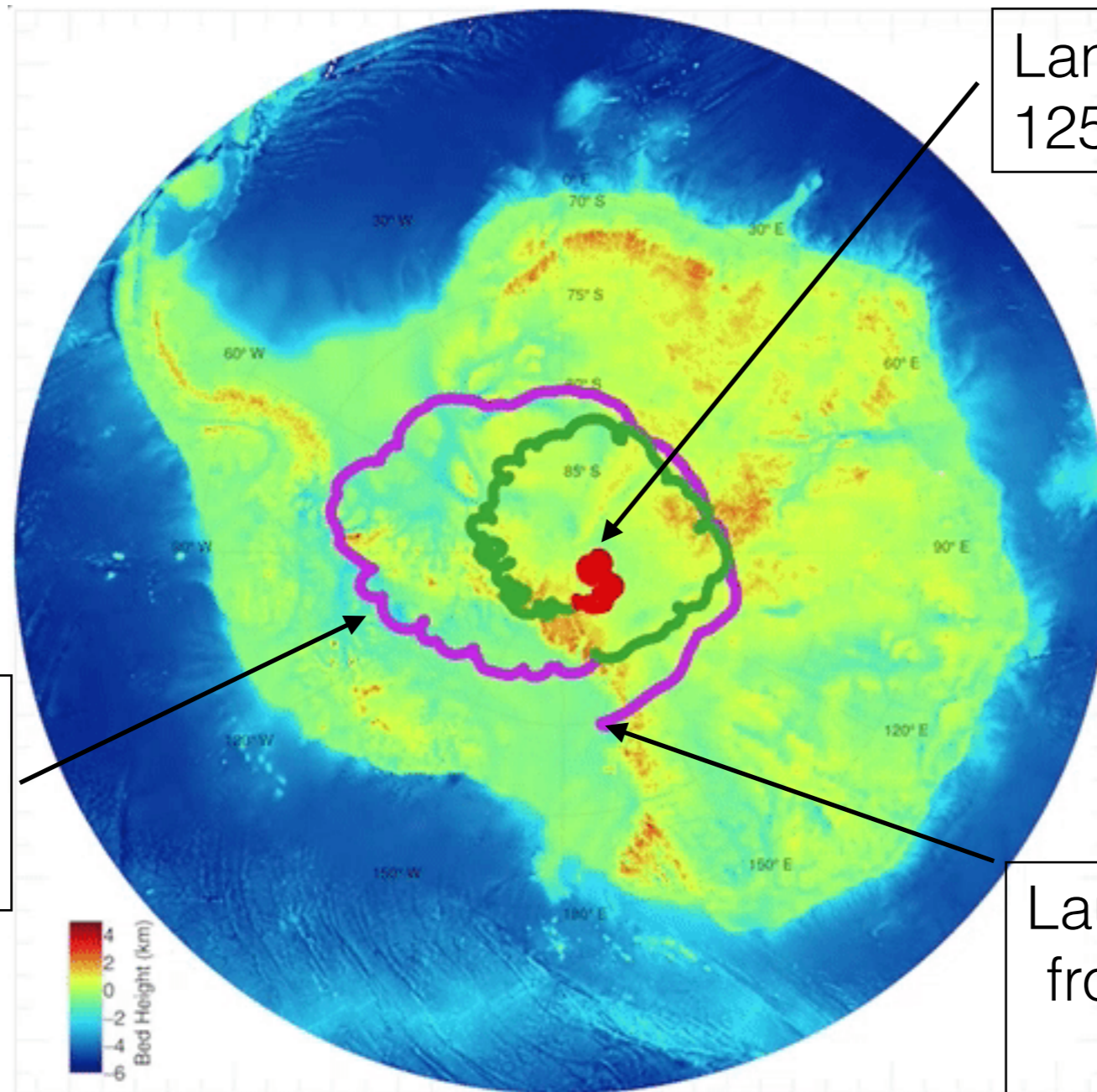
ANITA-4 taking off



ANITA-4 flight path



ANITA-4 flight path



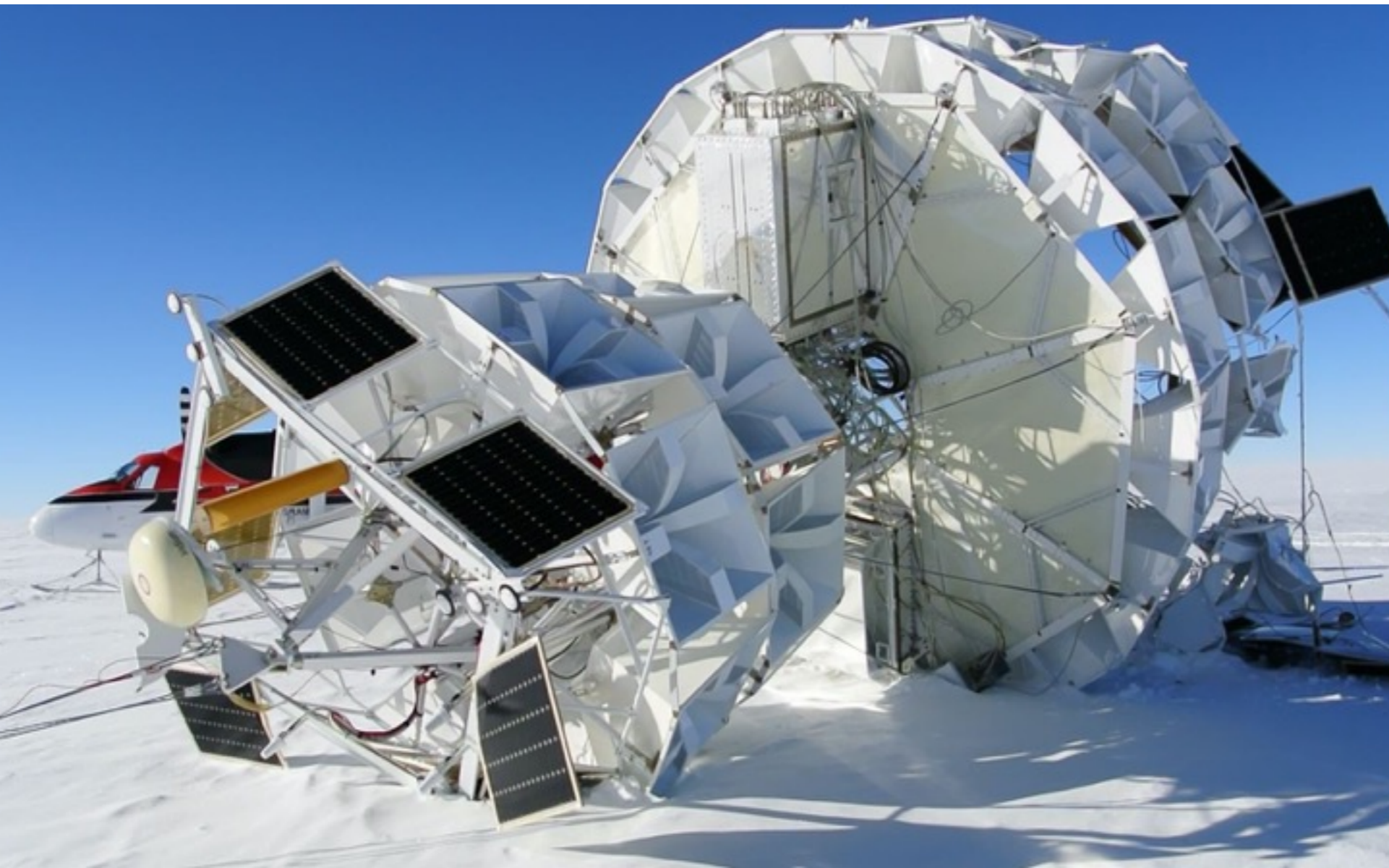
Landed Dec 30th 2016
125km from South Pole

Calibration pulser
at WAIS to optimise
pointing resolution

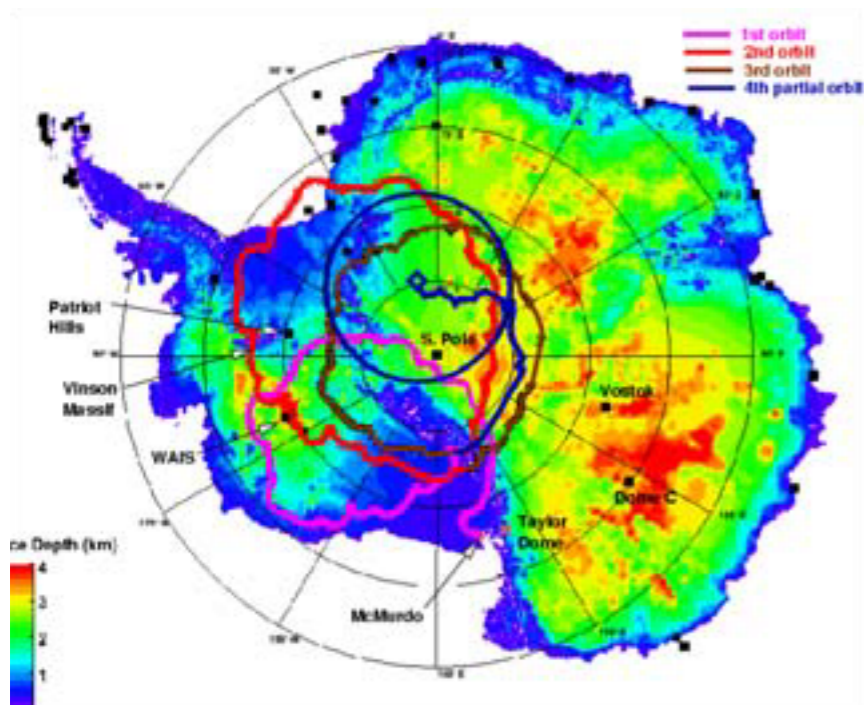
Launched Dec 2nd 2016
from NASA LDB facility,
near McMurdo

ANITA-4 Recovery

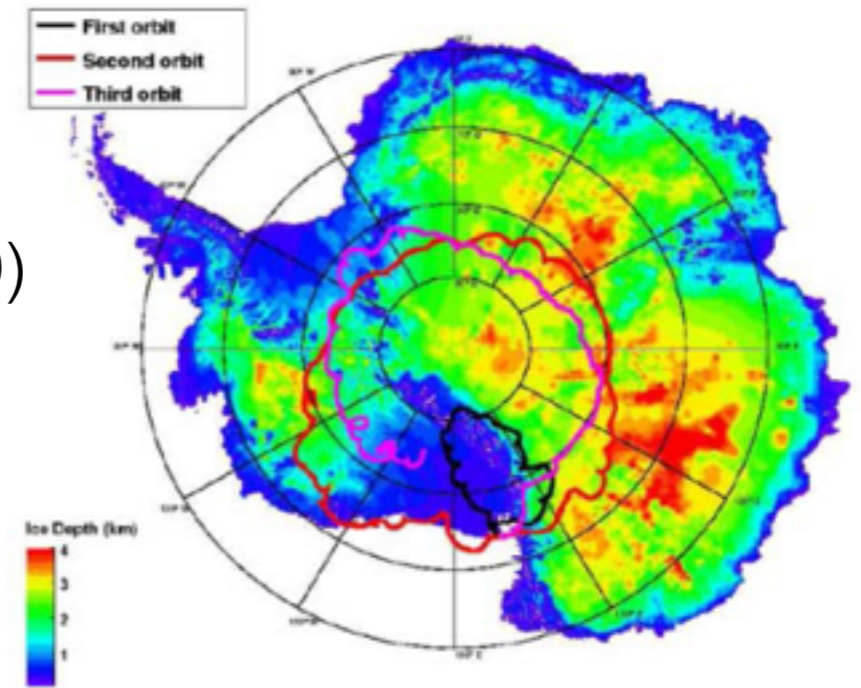
- Partial recovery done on Jan 10th 2016
- Full recovery done in December 2017



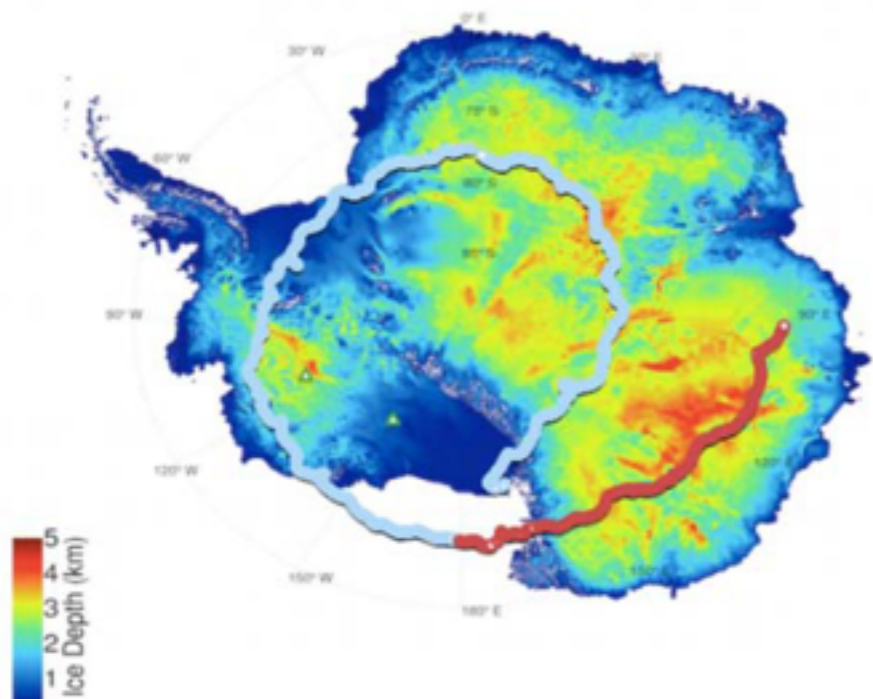
ANITA Flights



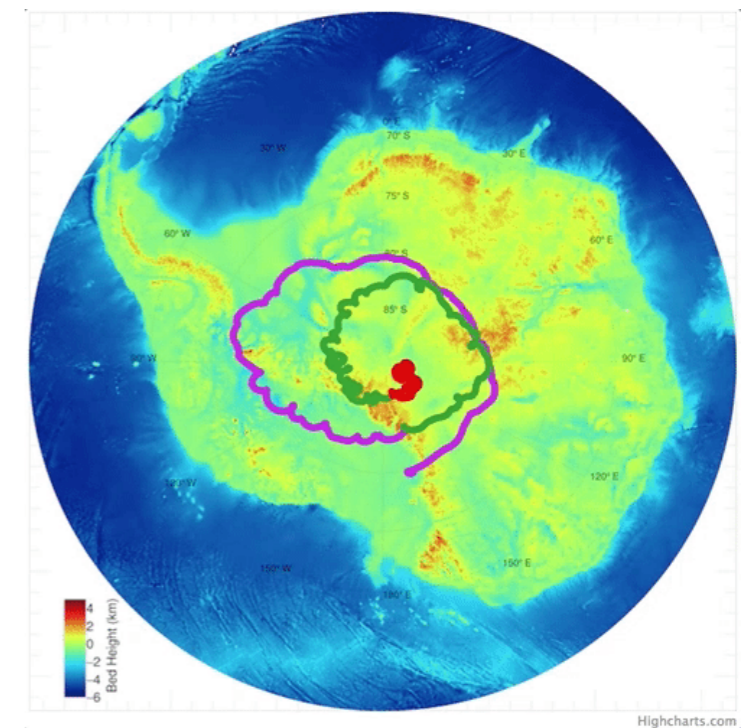
ANITA-1
(2006-2007)
35 days



ANITA-2
(2008-2009)
30 days



ANITA-3
(2014-2015)
22 days



ANITA-4
(2016)
30 days

How ANITA sees the world

V	SURF	Waveform
H	Payload	FFT
V&H	Interferometry	Hilbert
		Average FFT

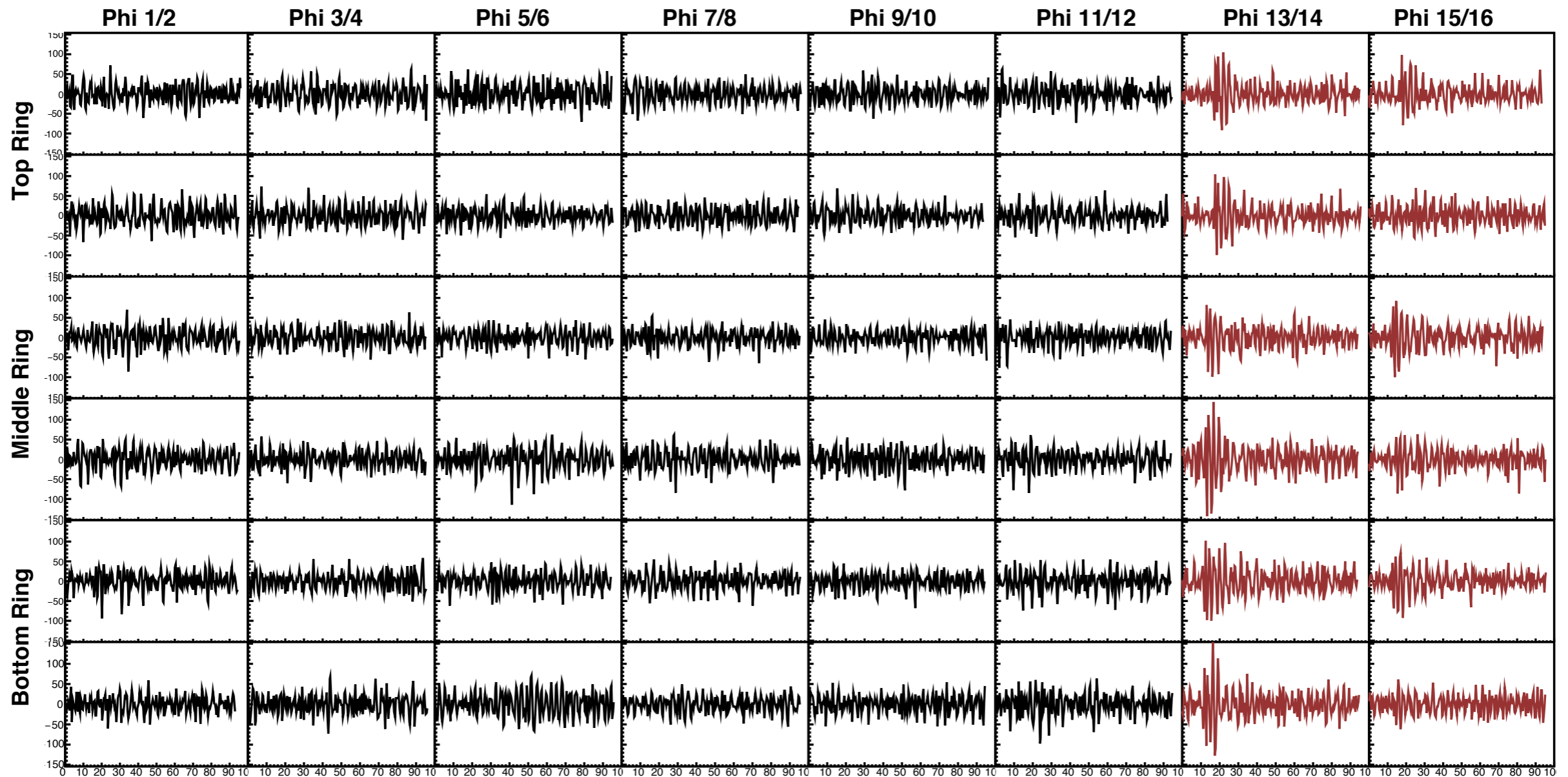
Run: 345
Event: 58851430

Time: 2015-01-01 13:39:43
Trigger: 1.214096 ms
Priority: 3 -- Queue: 3

Trig Num: 930 -- Trig Type: RF
TURF: 939

TURF This Hold: 0x9
TURF Active Holds: 0x9
Labrador CCCCCCCCCC
Phi Mask: 0

Reset Avg	Play	Next
Go to Event	Rev	Prev.
Event#	Stop	First
		Last



How ANITA sees the world

V	SURF	Waveform
H	Payload	FFT
V&H	Interferometry	Hilbert
		Average FFT

Run: 345
Event: 58851430

Time: 2015-01-01 13:39:43
Trigger: 1.214096 ms
Priority: 3 -- Queue: 3

Trig Num: 930 -- Trig Type: RF
TURF: 939

TURF This Hold: 0x9
TURF Active Holds: 0x9
Labrador CCCCCCCCCC
Phi Mask: 0

Reset Avg	Play	Next
Go to Event	Rev	Prev.
Event#	Stop	First
		Last

Phi 1/0

Phi 2/4

Phi 5/6

Phi 7/8

Phi 9/10

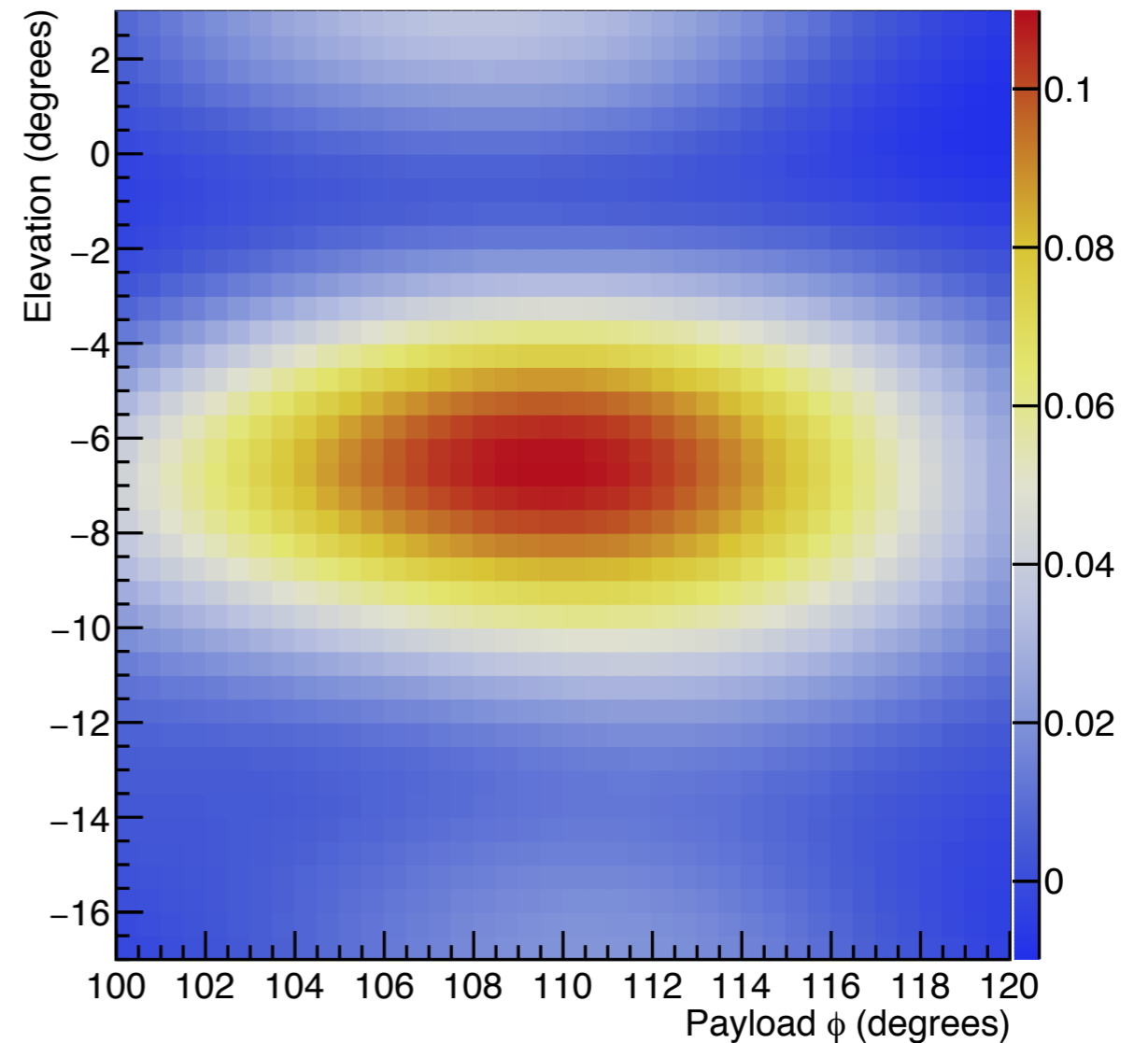
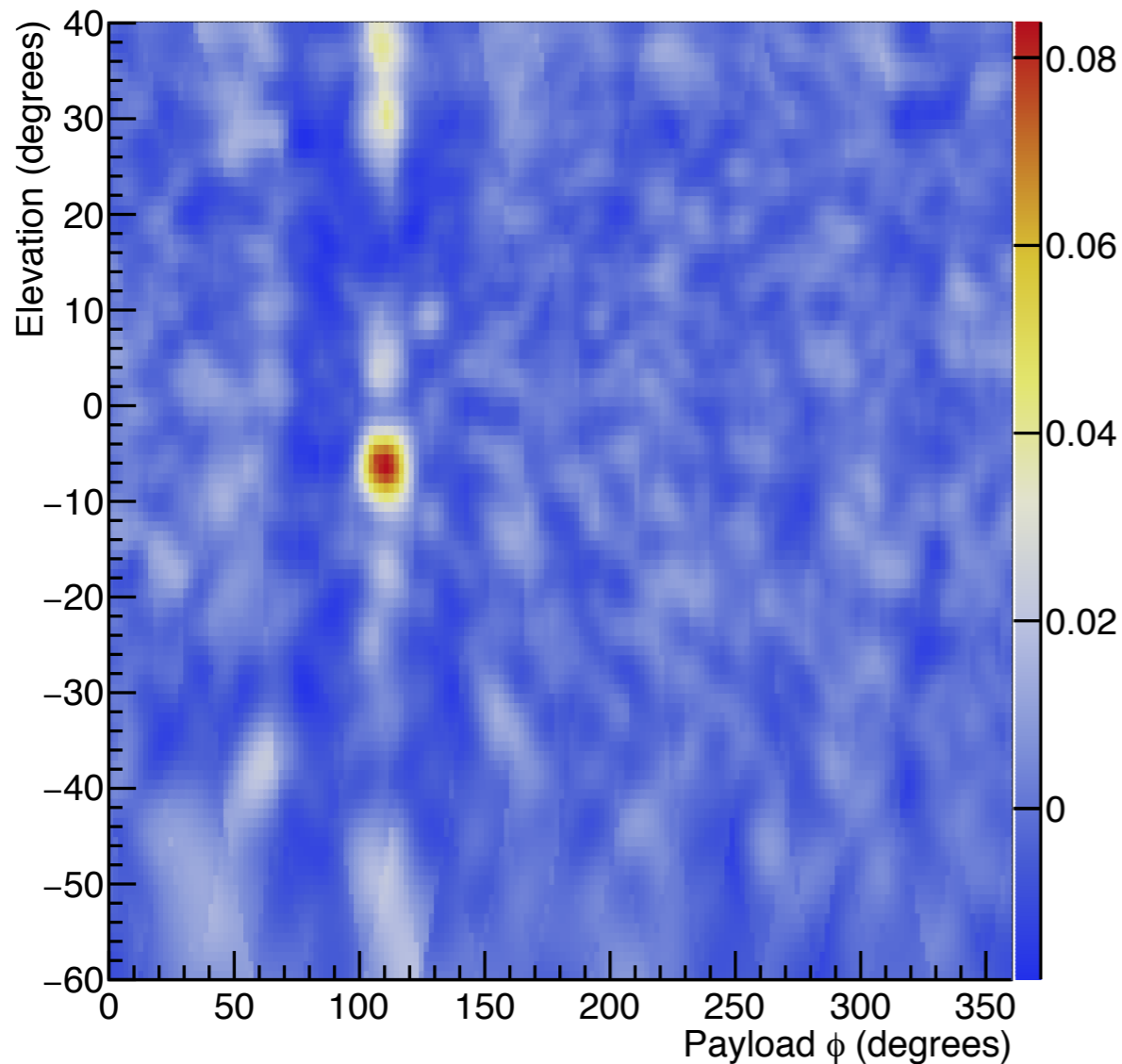
Phi 11/12

Phi 13/14

Phi 15/16

Interferometric Map

Zoomed Map





Needle(s) in a haystack

L. Cremonesi

23

“UHE neutrinos and ANITA”

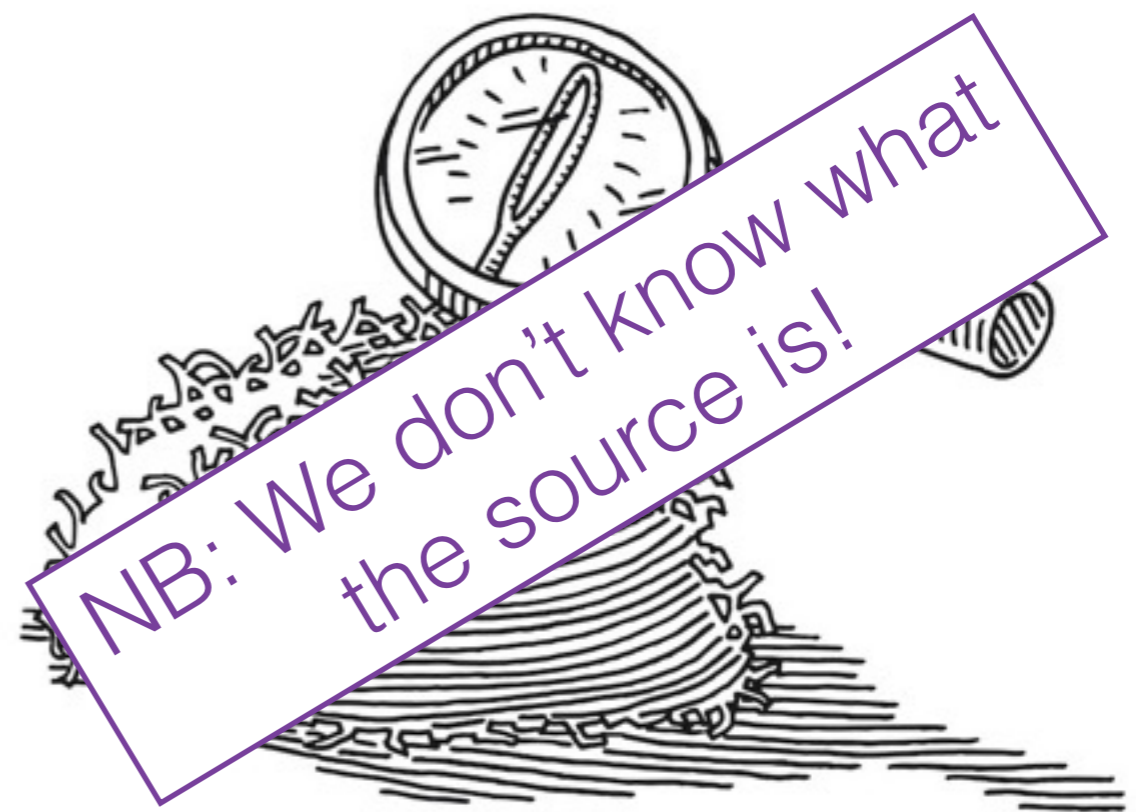
The challenge

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



The challenge

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

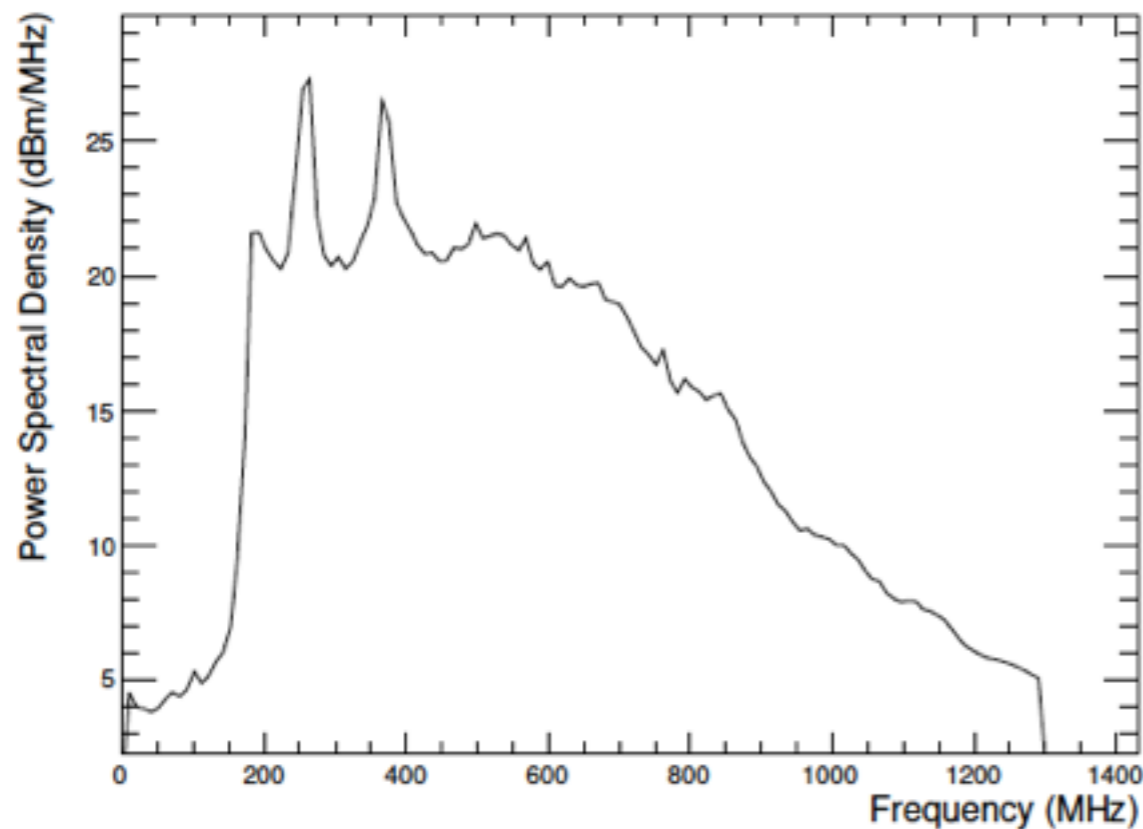


Backgrounds

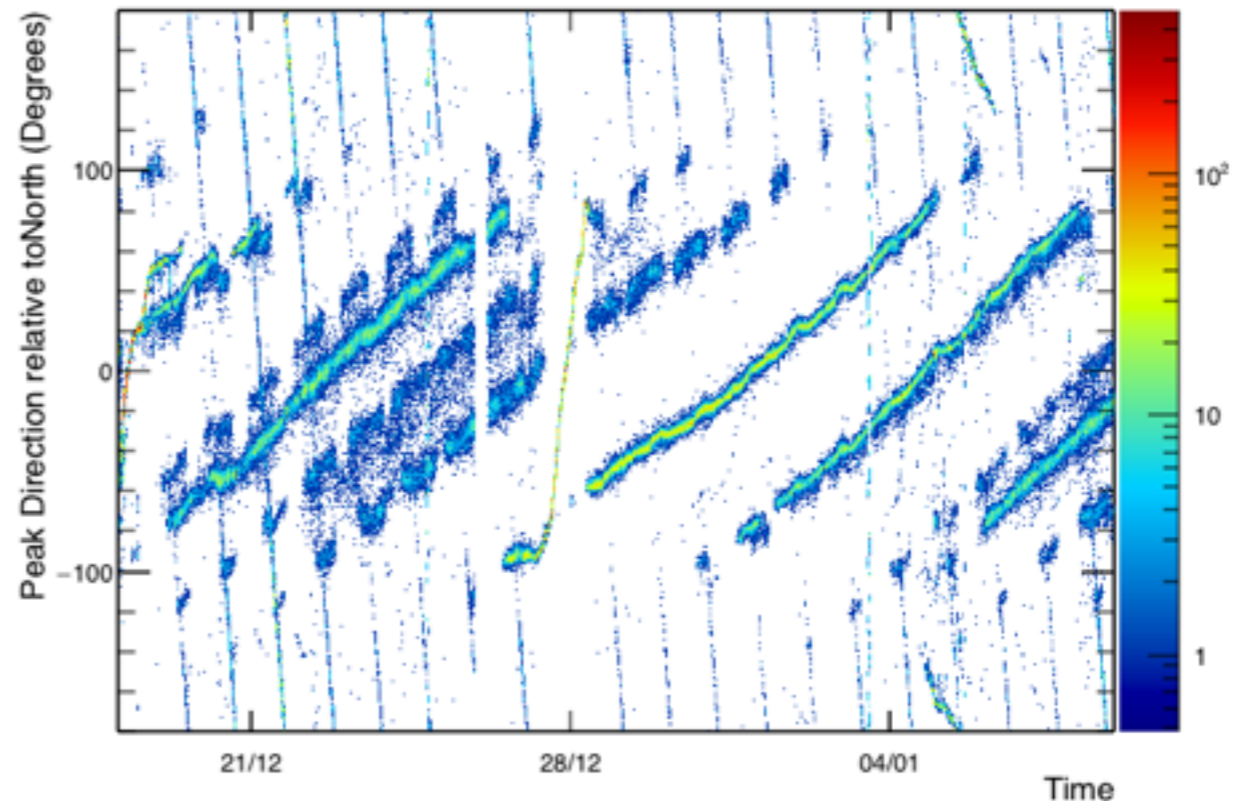
- Continuous waves
- Payload blasts
- Thermal noise
- Anthropogenic impulsive events

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

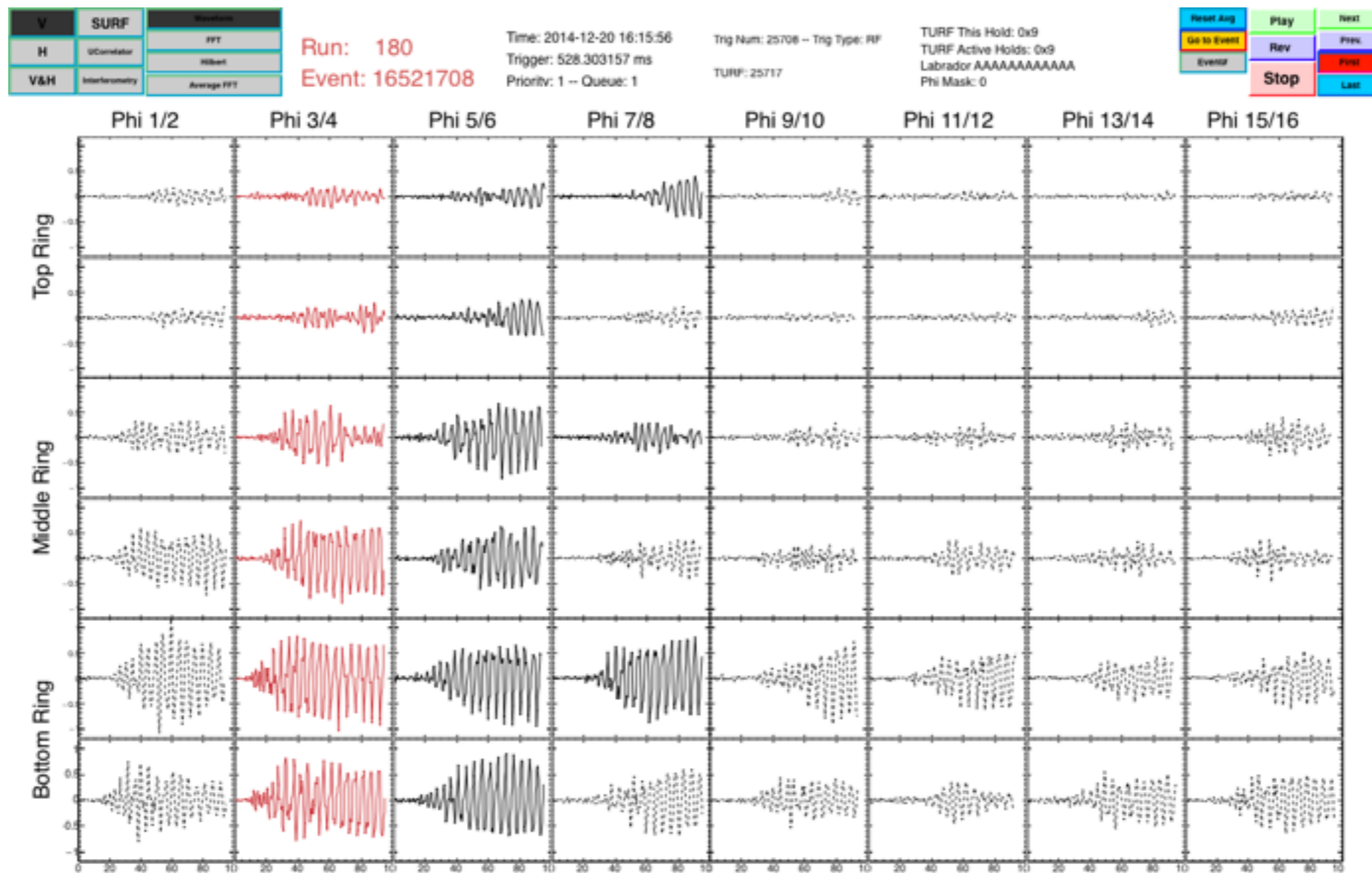


Min Bias Peak Direction



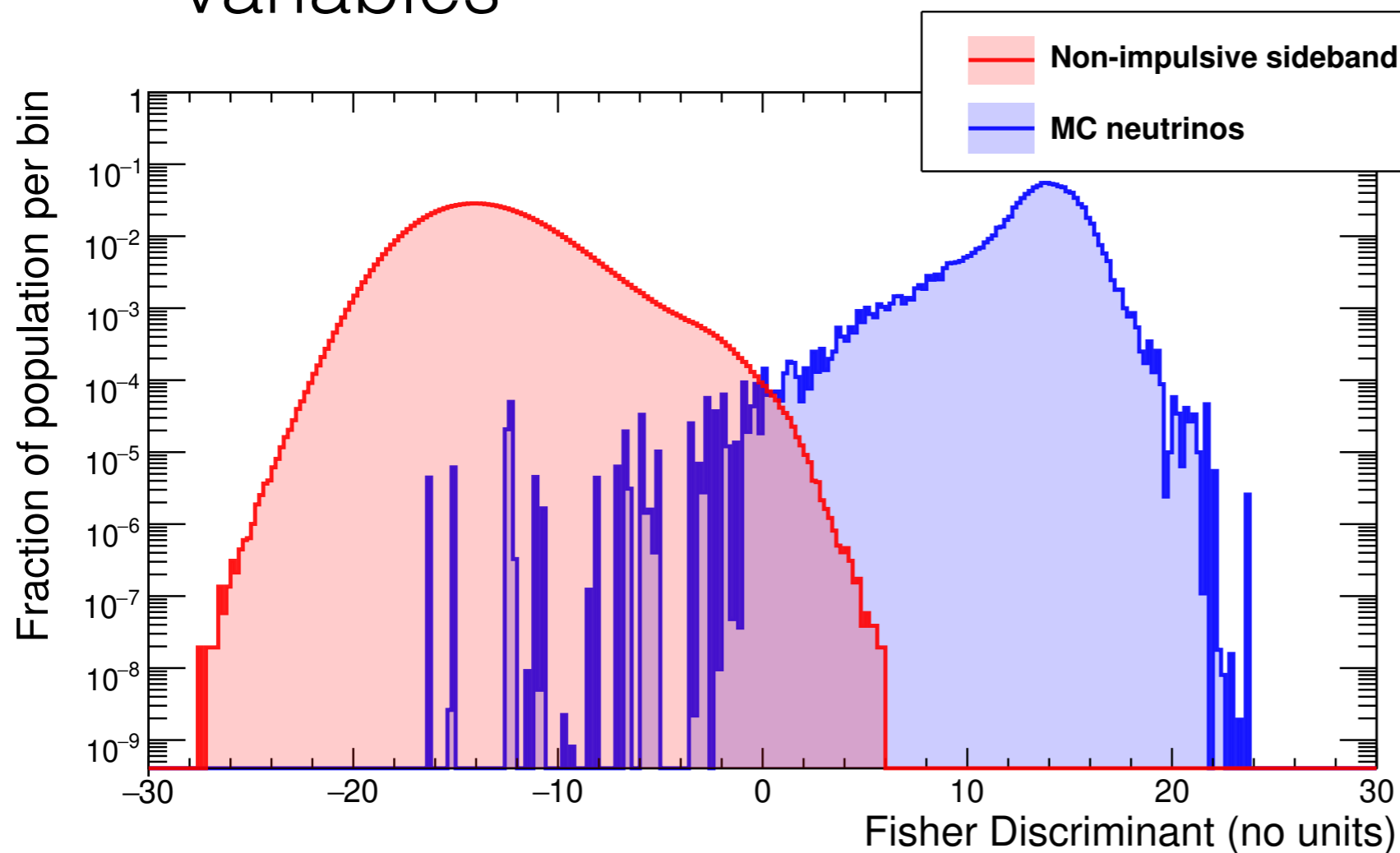
Payload blasts

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



Thermal noise

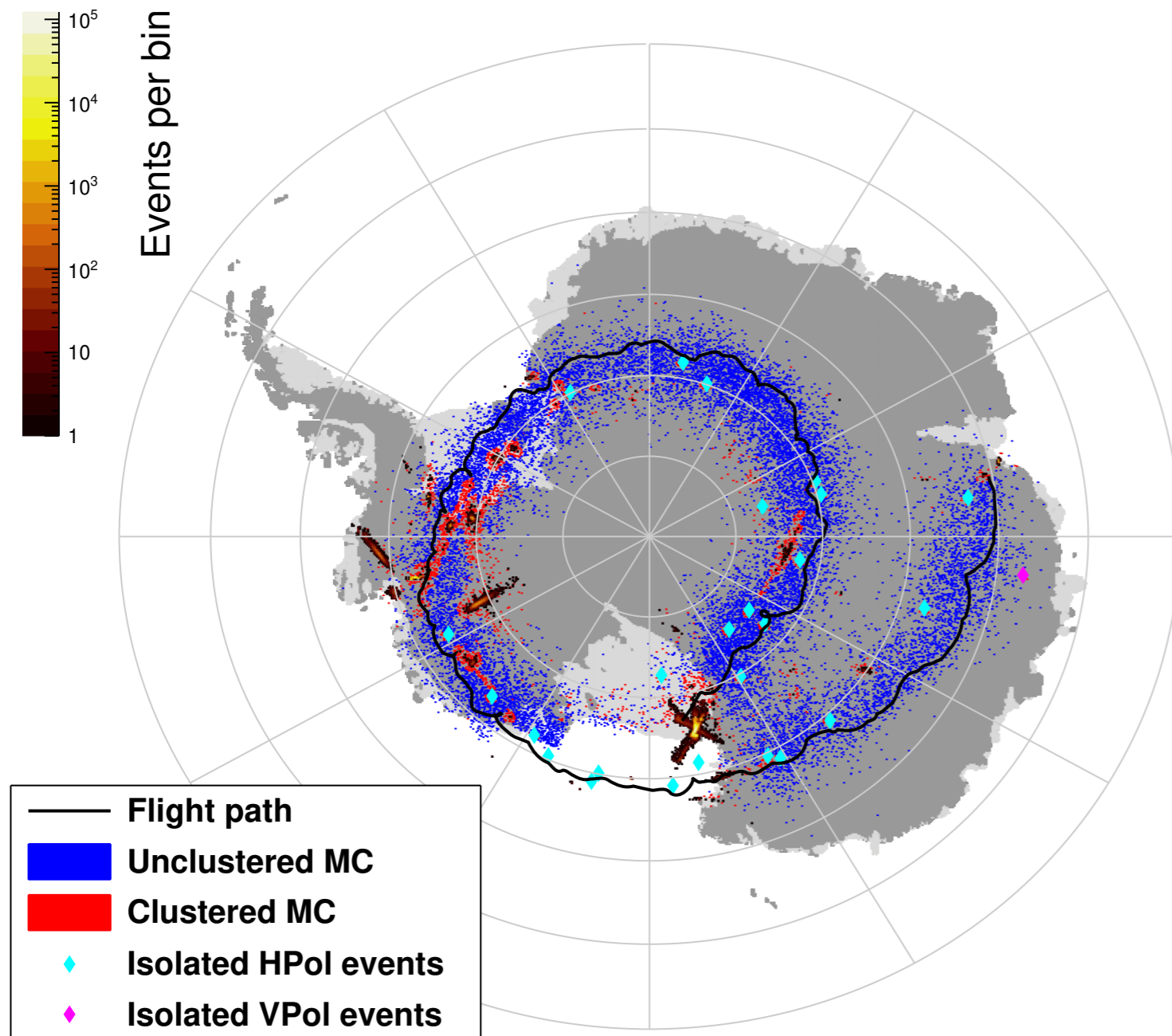
- Vast majority of ANITA events are thermal noise
- Use Fisher discriminant based on impulsivity variables



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

Clustering

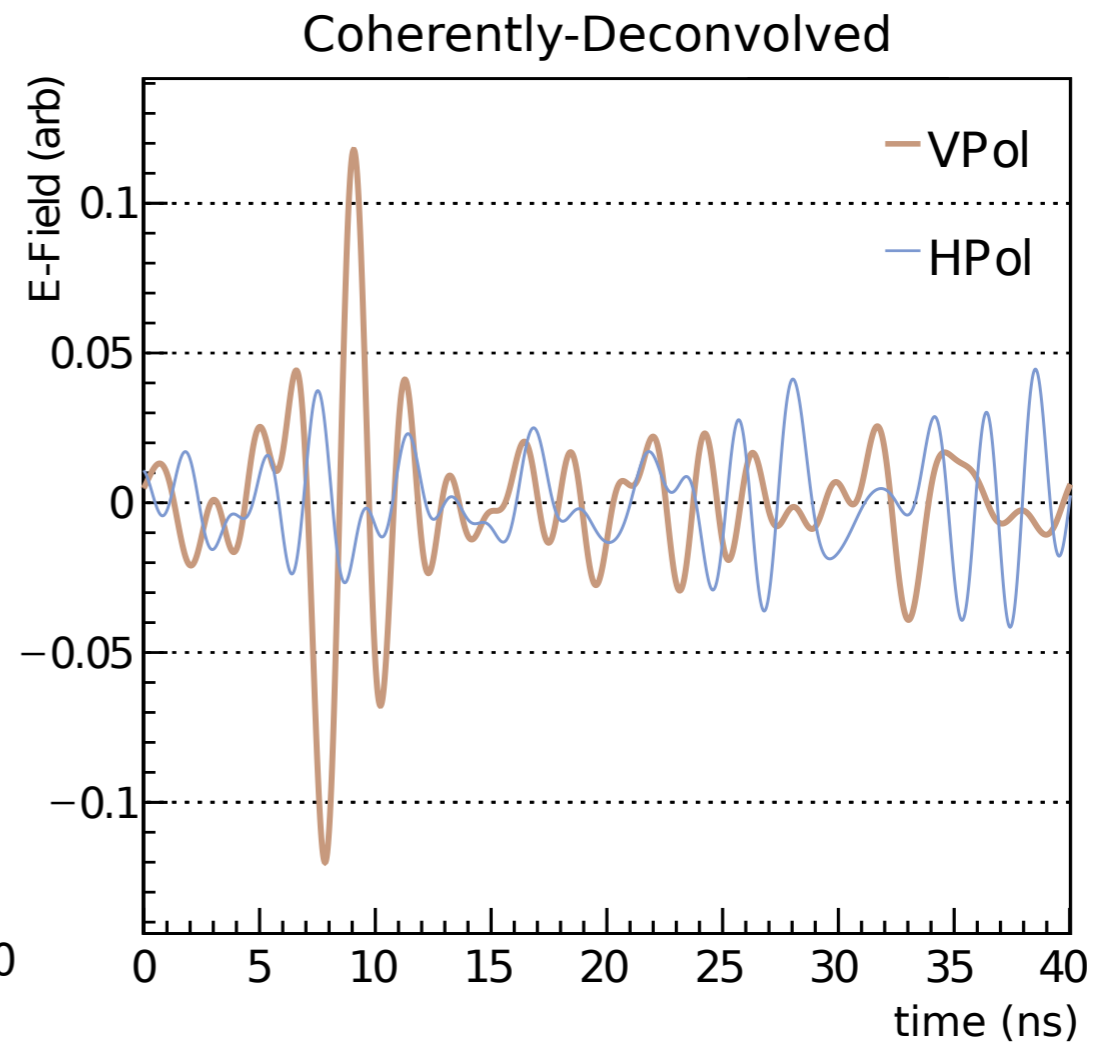
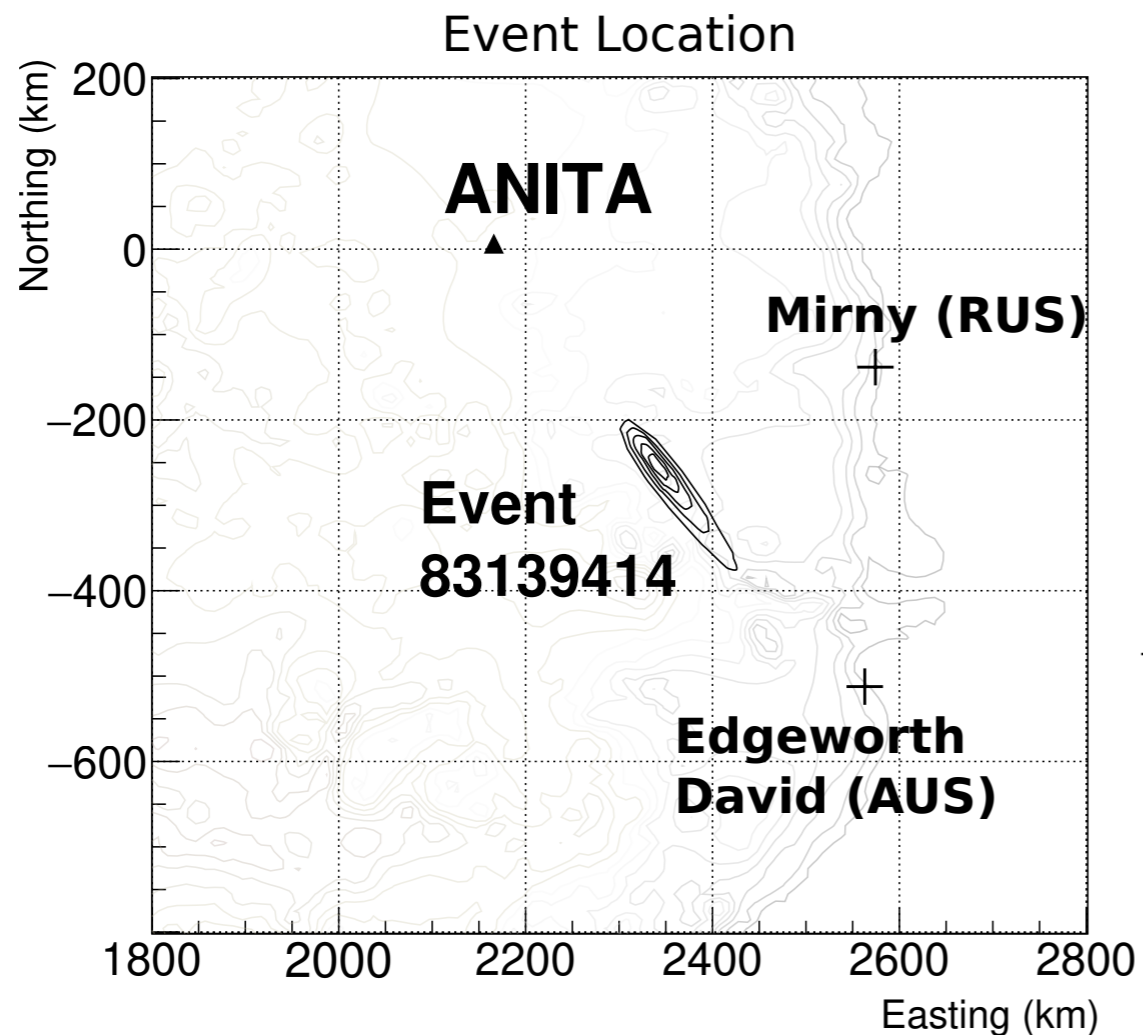
- From previous cuts, $\sim 500\text{k}$ events



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

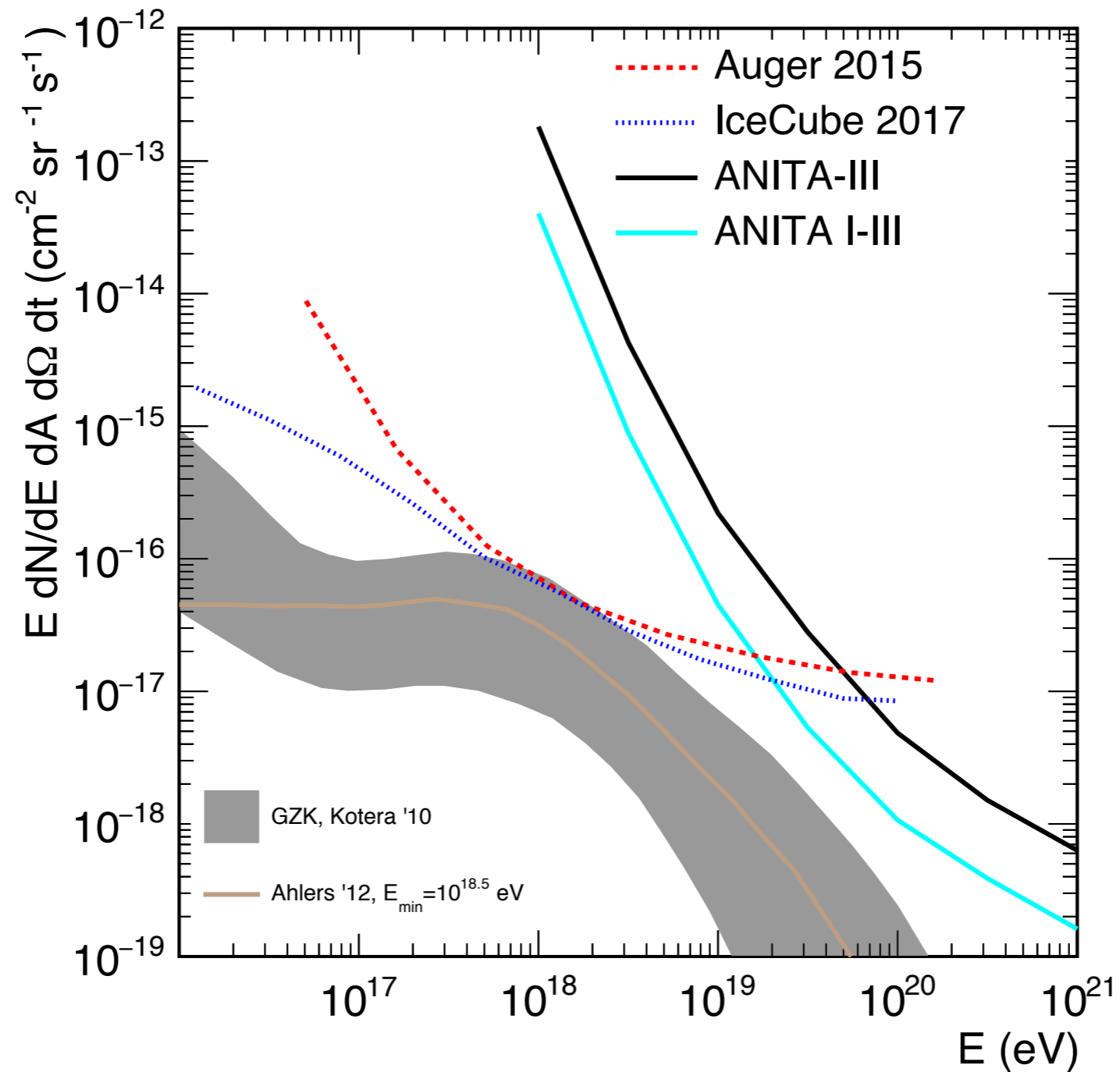
What's left?

- 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

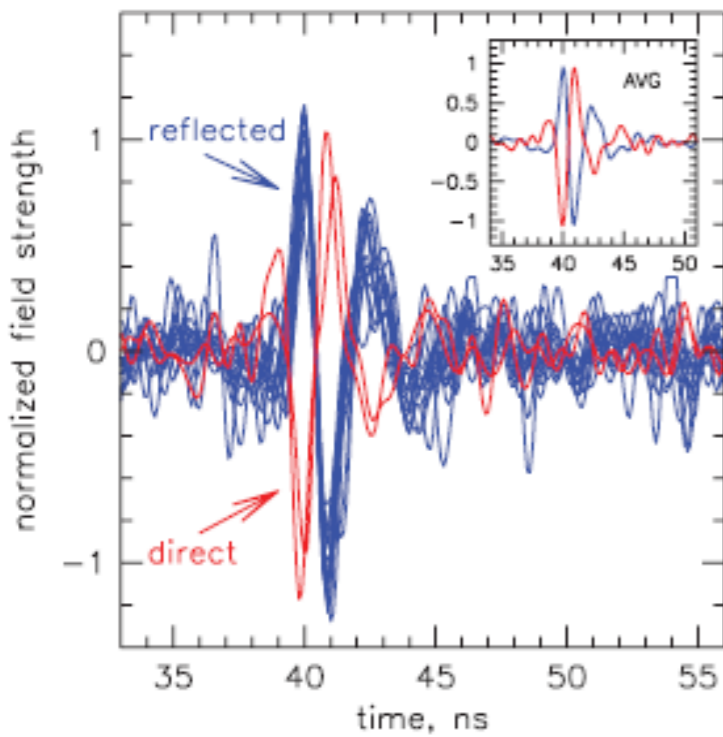
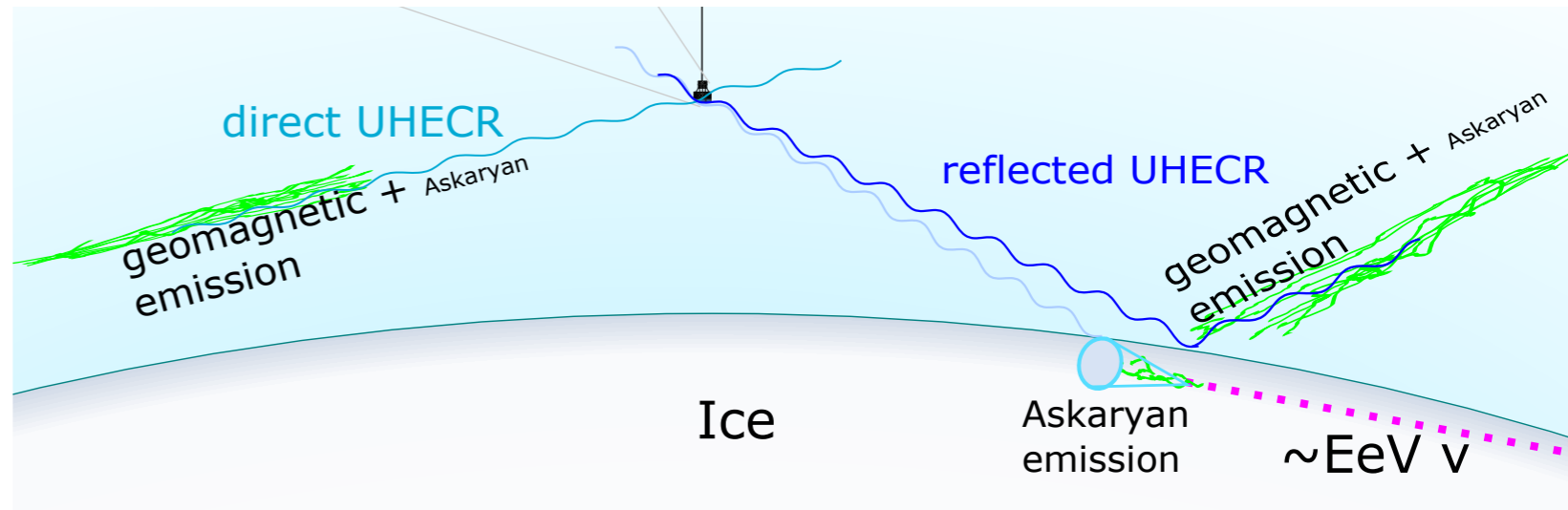
L. Cremonesi

33

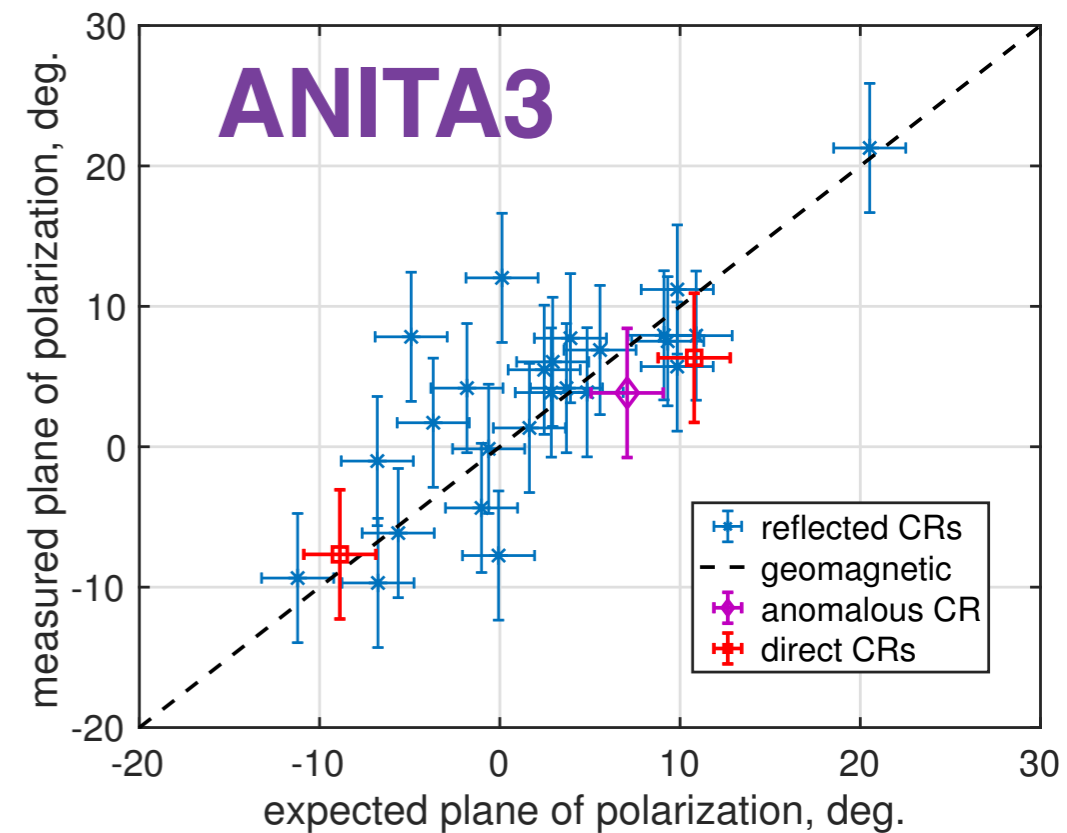
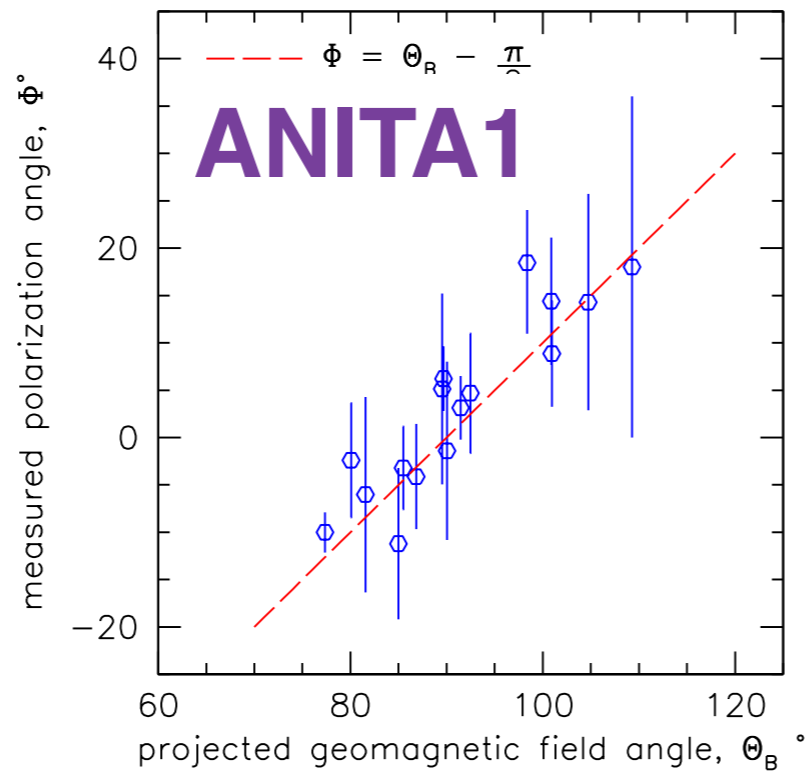
“UHE neutrinos and ANITA”

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

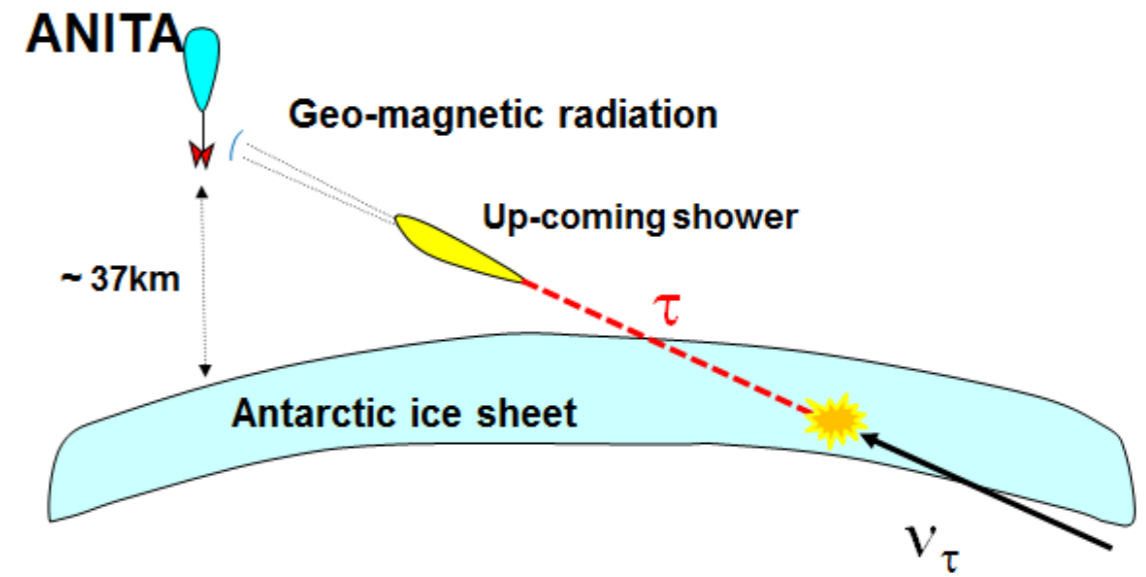
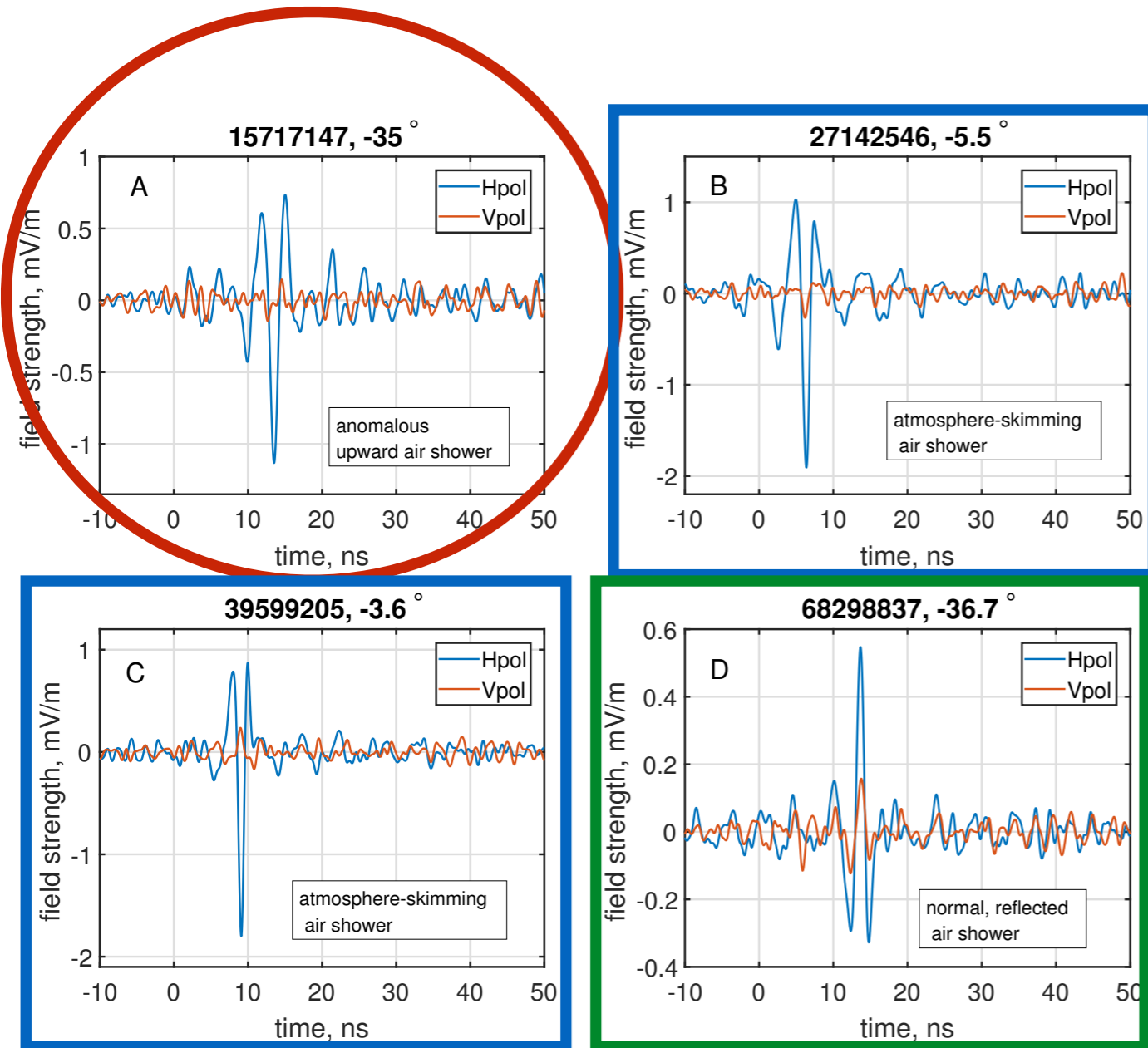


PRL 105, 151101 (2010)



arXiv:1803.05088 [astro-ph.HE]

And ANITA-3 mystery event



Direct Cosmic Rays

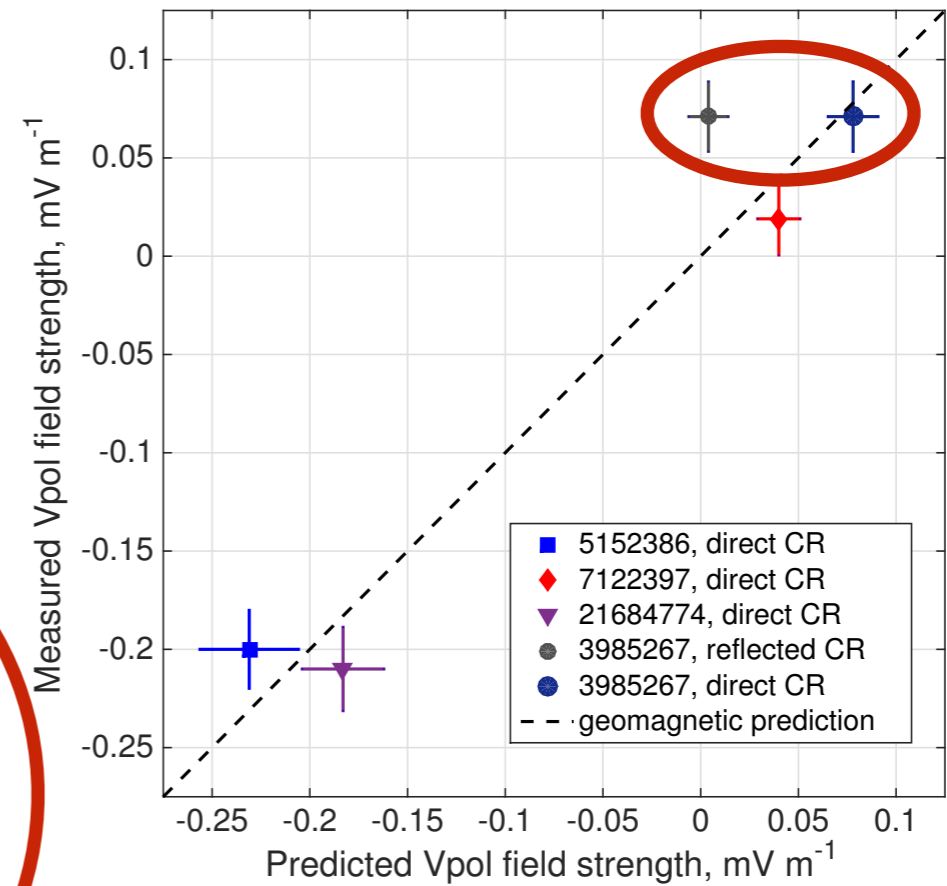
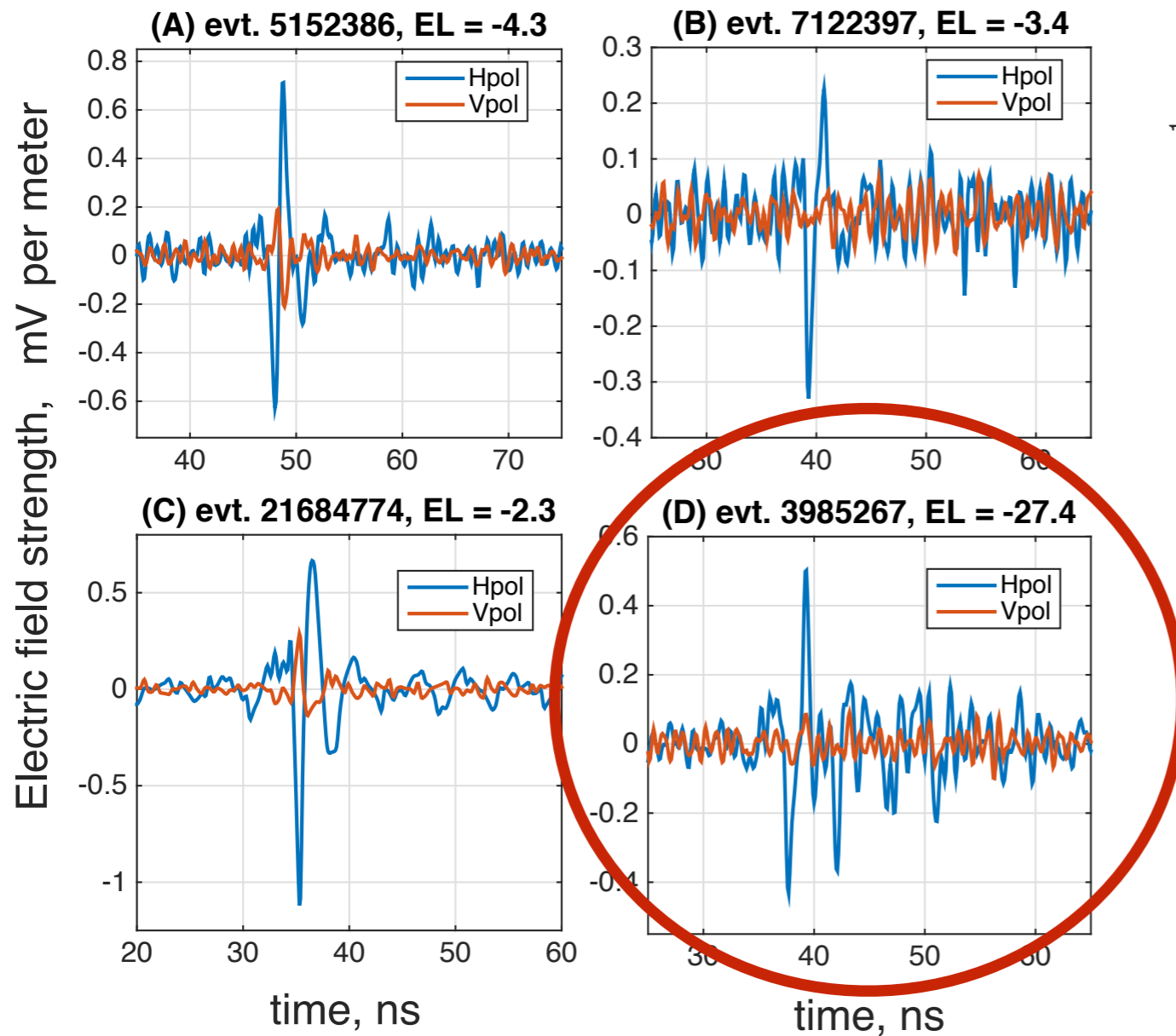
Reflected Cosmic Rays

NEW PHYSICS ?

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

Background estimate $< 10^{-2}$

ANITA-1 mystery event



A strong H-pol non-inverted signal seen!

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

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

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 ($\sigma_{vs} \sim \theta^2 \sigma_v$) : 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)



Future

L. Cremonesi

38

“UHE neutrinos and ANITA”

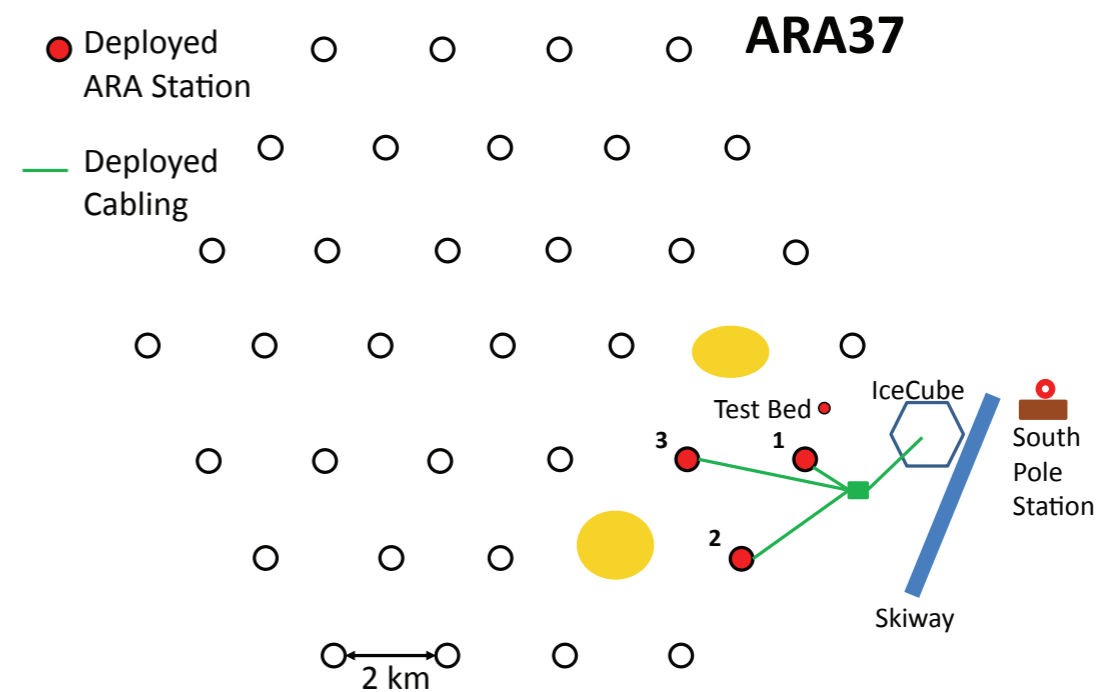
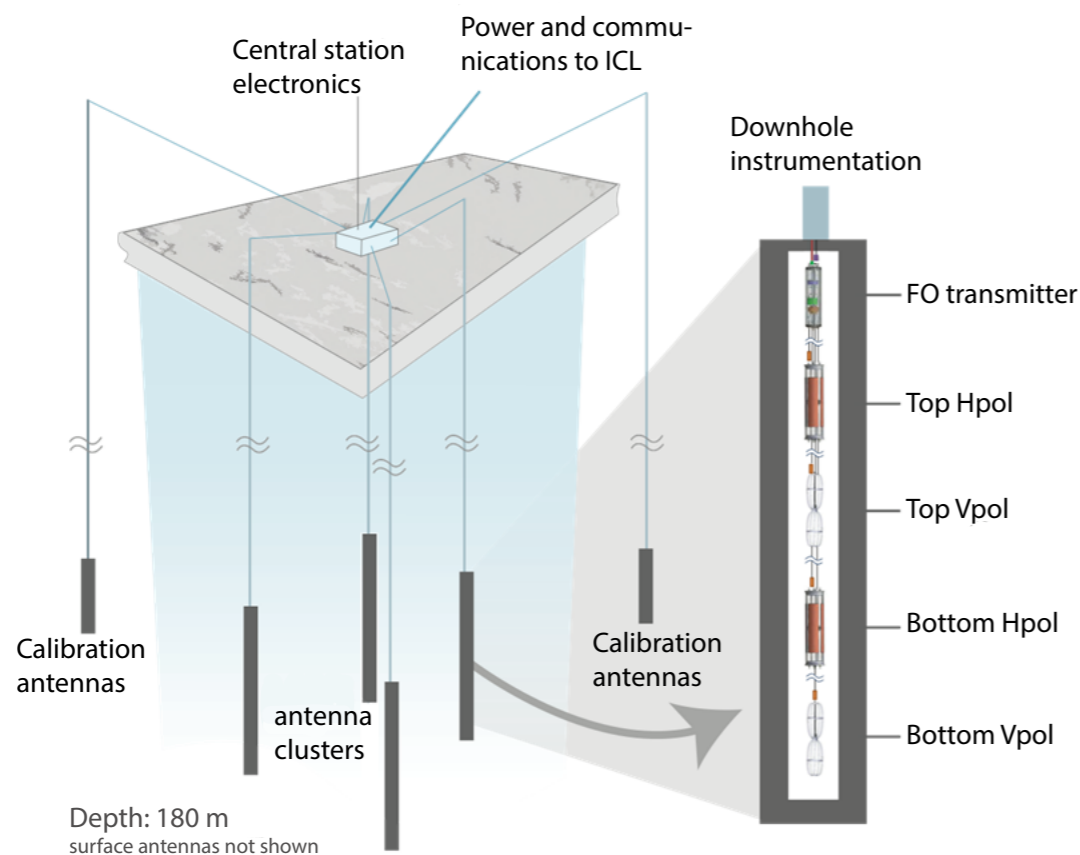
What about the future?

- ANITA-5 proposal: new hardware to try out! (J. Nam ICRC2017)



What about the future?

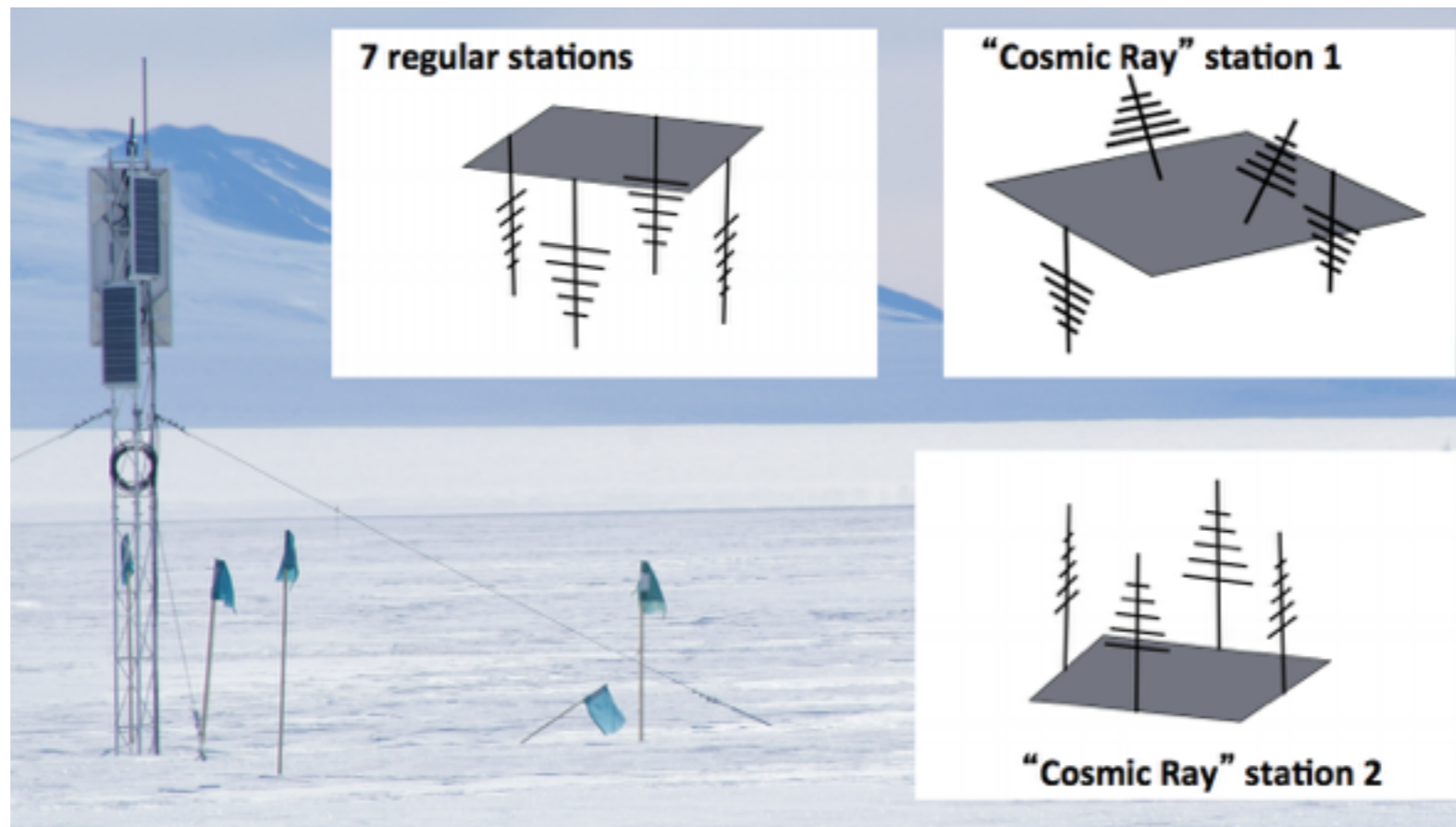
- ANITA-5 proposal, new hardware to try out! (J. Nam ICRC2017)
- ARA: 5 deployed stations (M.Y. Lu ICRC2017)



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. Vieregge ICRC2017)

What about the future?

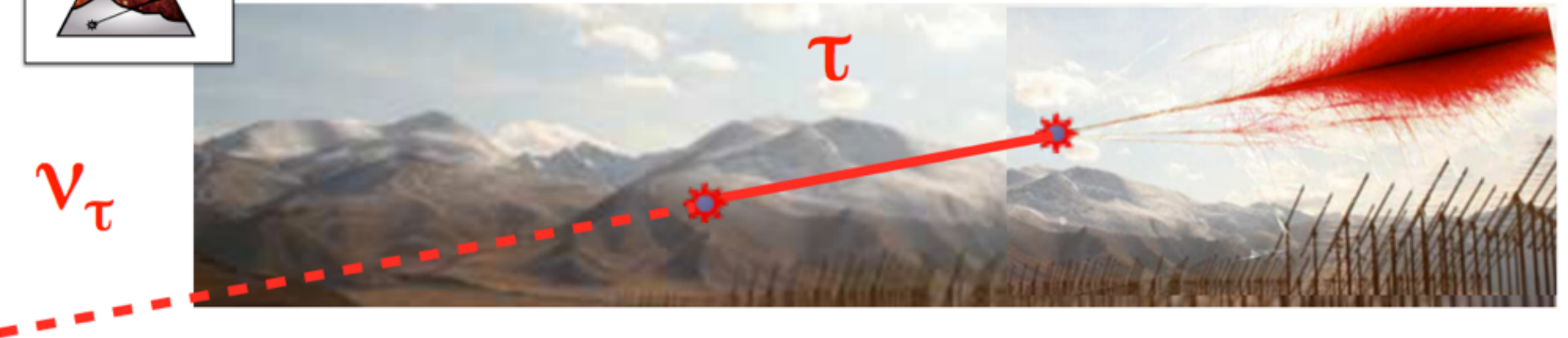


- ARIANNA: 7 regular + 2 CR stations deployed (S. Barwick ICRC2017)

What about the future?



From Neutrino to Lepton



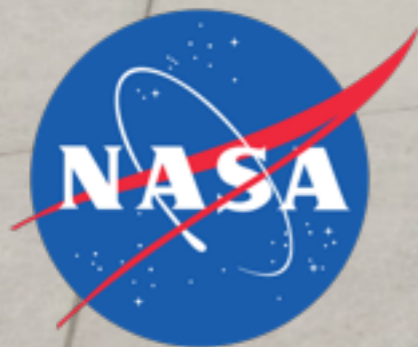
- ARIANNA: 7 regular + 2 CR stations deployed (S. Barwick ICRC2017)
- GRAND: proto35 operational (K. Fang ICRC2017)

Summary and future

- The ANITA experiment has a rich physics program:
 - ANITA-3 diffuse neutrino analysis:
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



LEVERHULME
TRUST _____

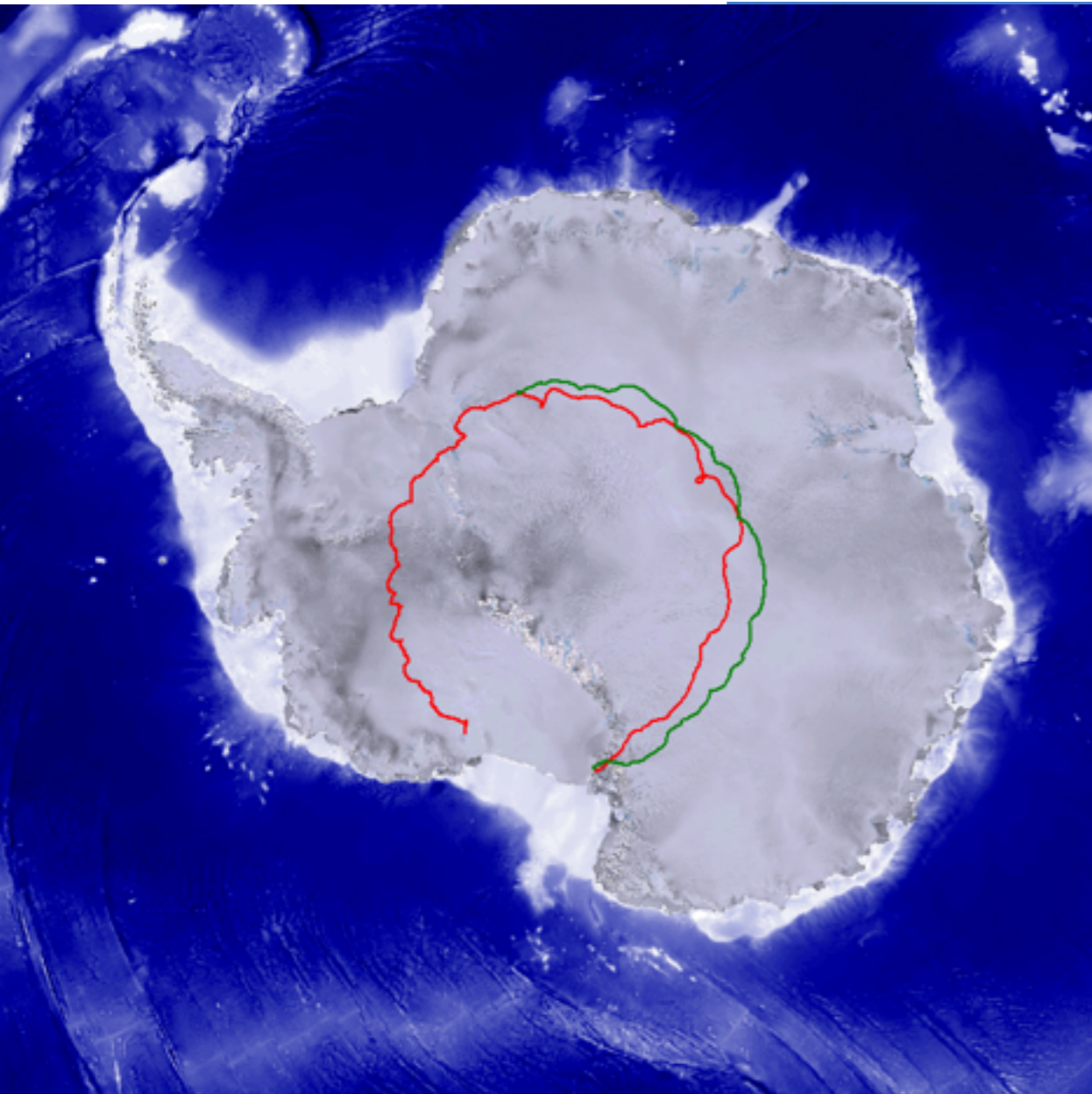


Back up

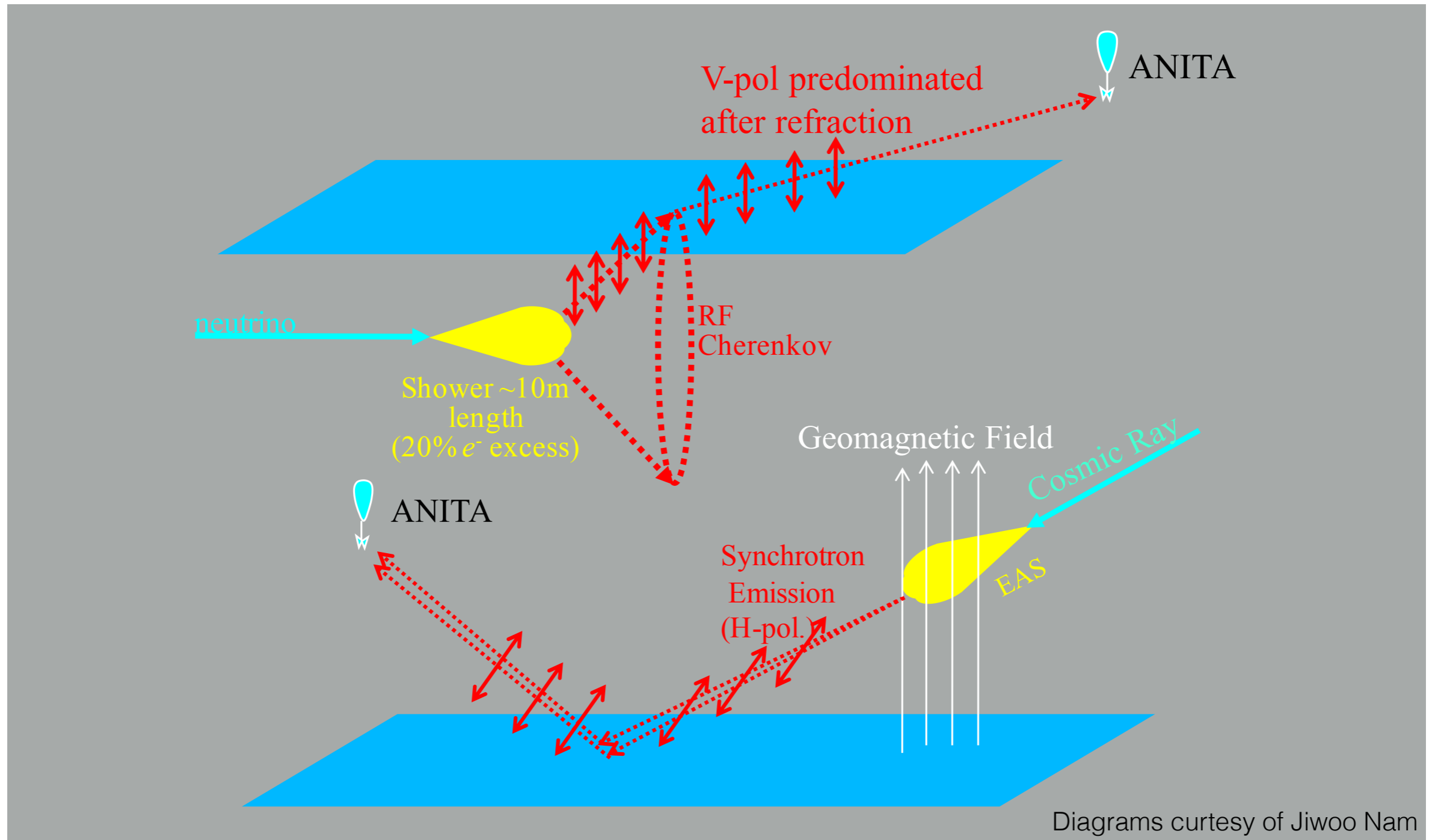
HiCal

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](https://arxiv.org/abs/1703.00415) [astro-ph.IM]



Neutrinos and Cosmic Rays



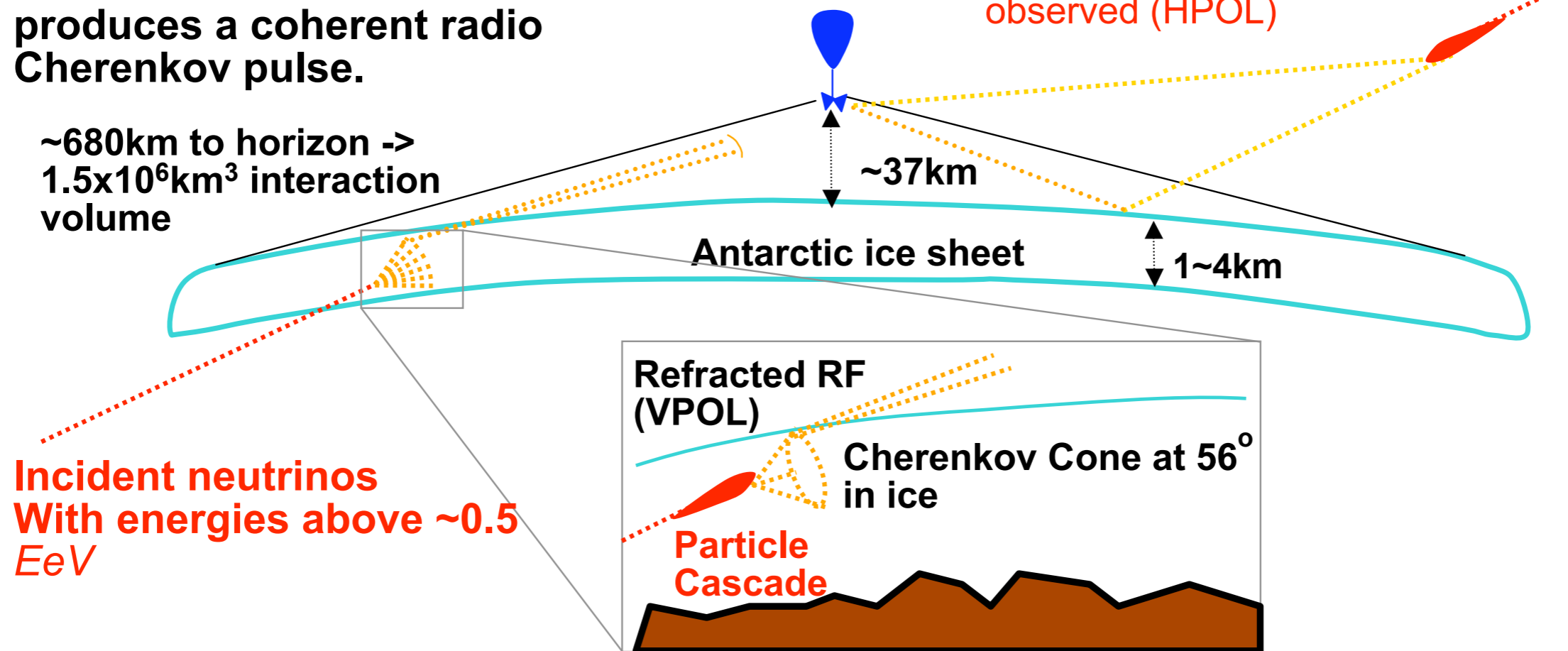
ANITA

ANtarctic Impulsive Transient Antenna

A neutrino induced cascade produces a coherent radio Cherenkov pulse.

~680km to horizon ->
 $1.5 \times 10^6 \text{ km}^3$ interaction volume

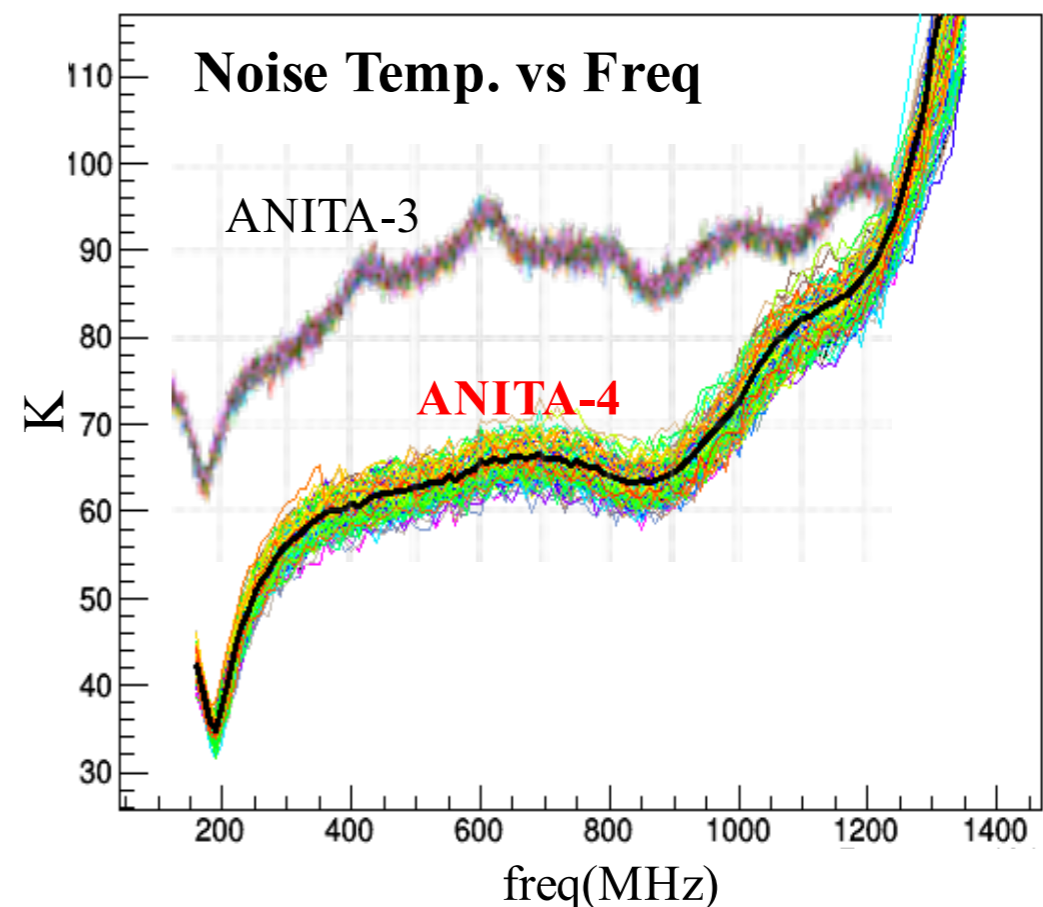
Cosmic ray geo-synchrotron also observed (HPOL)



Incident neutrinos
With energies above ~0.5
 E_{eV}

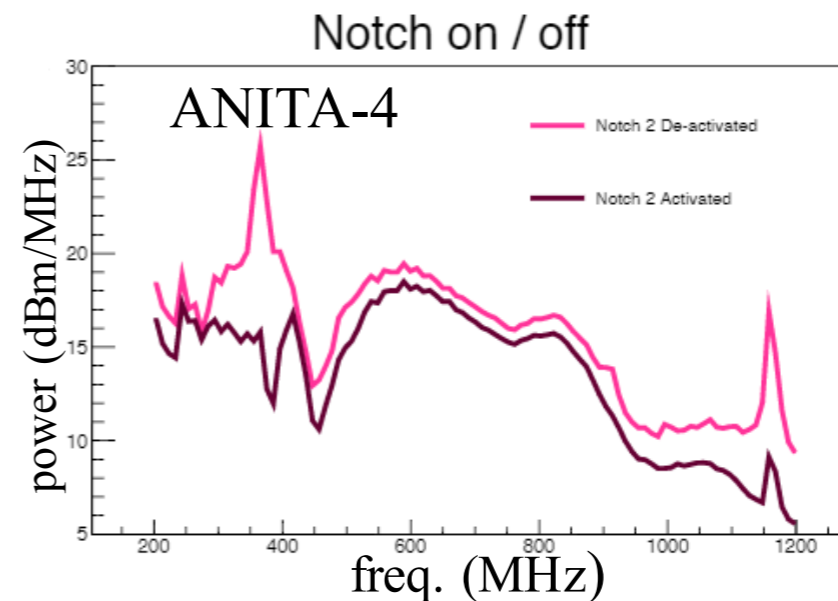
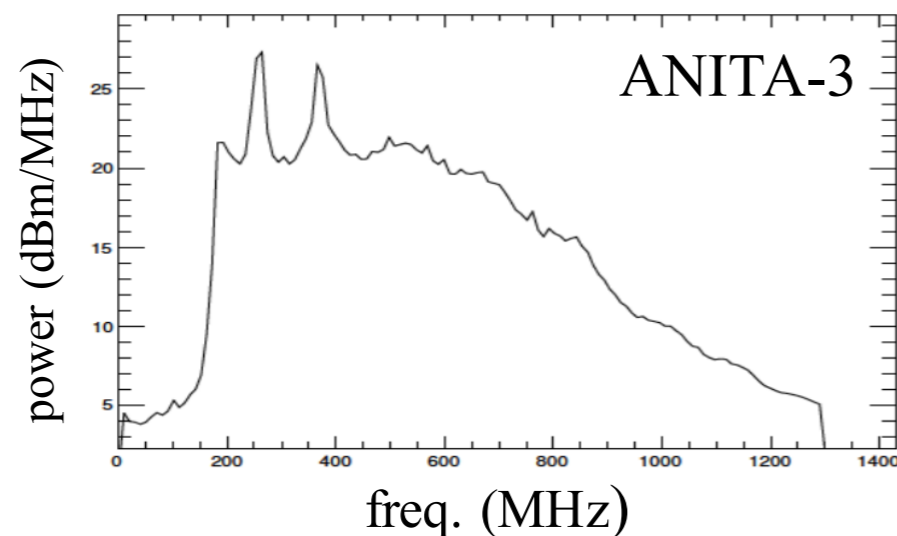
ANITA-4 improvements

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



ANITA-4 improvements

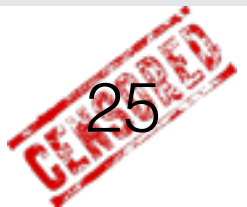
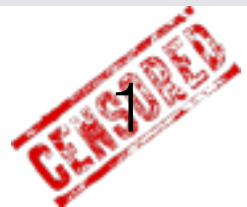
- Using Low Noise Amplifiers for all channels
 - Improvement in noise figure (30-40K)
 - 20% improvement in energy threshold
- Tunable Universal Filter Frontend
 - Reduce Carrier Waves noise coming from Satellites



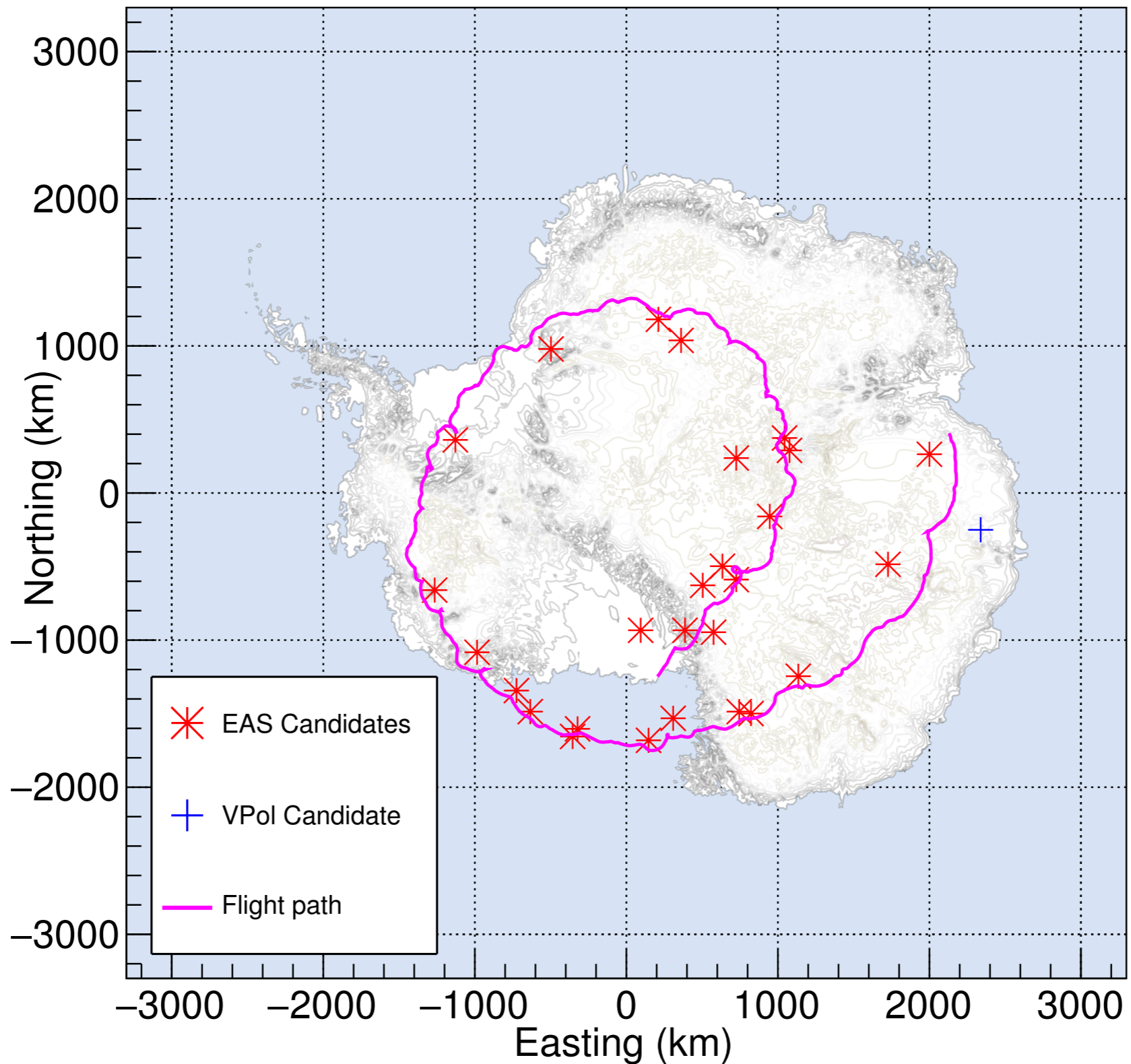
ANITA-4 improvements

- 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

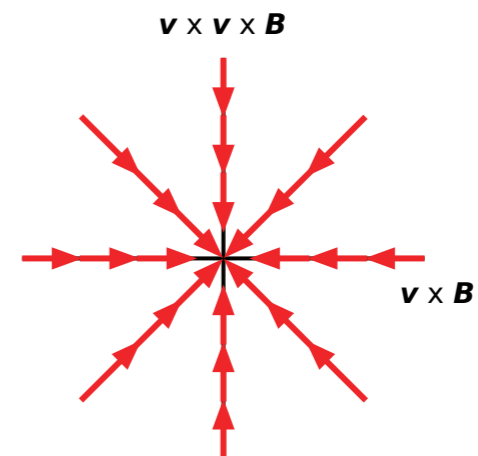
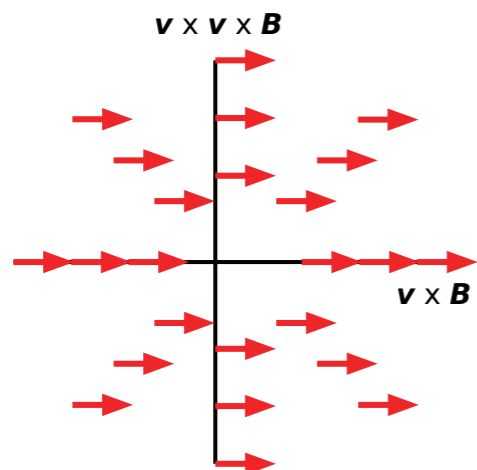
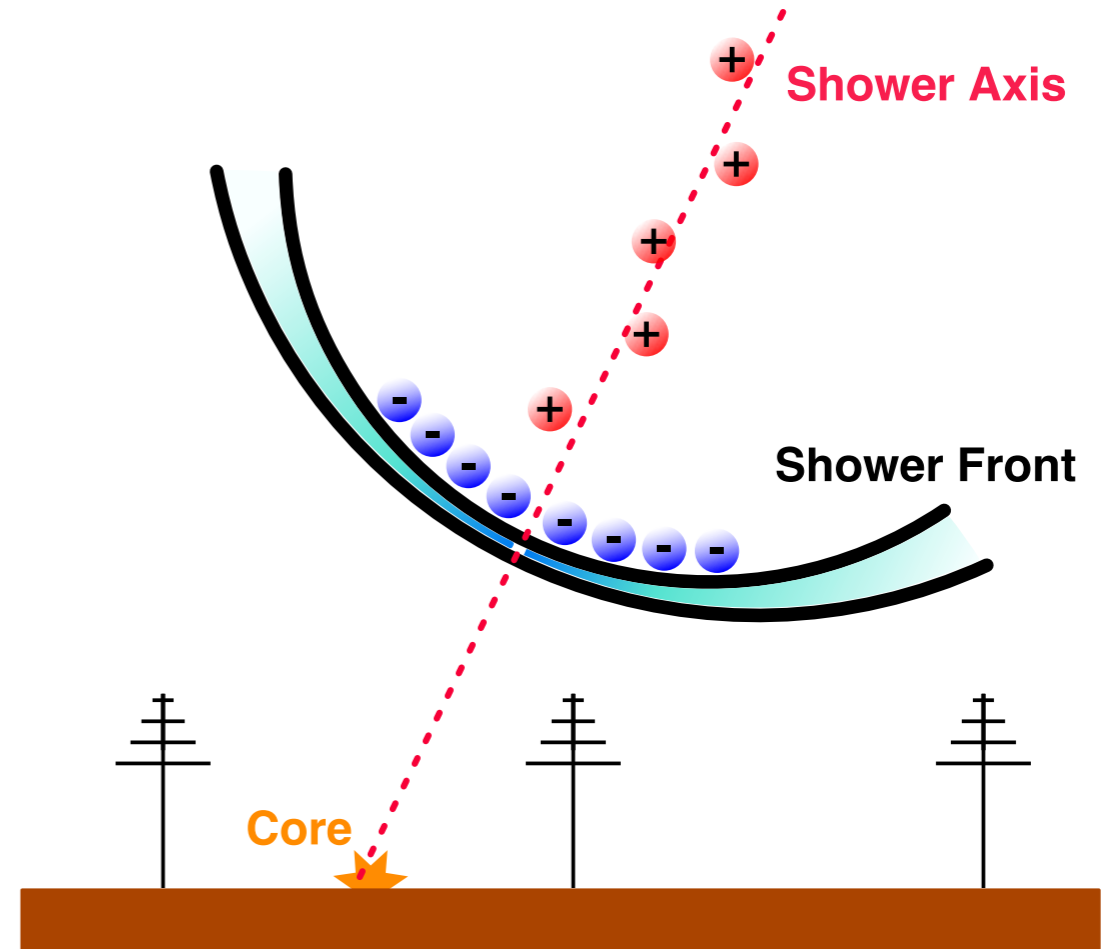
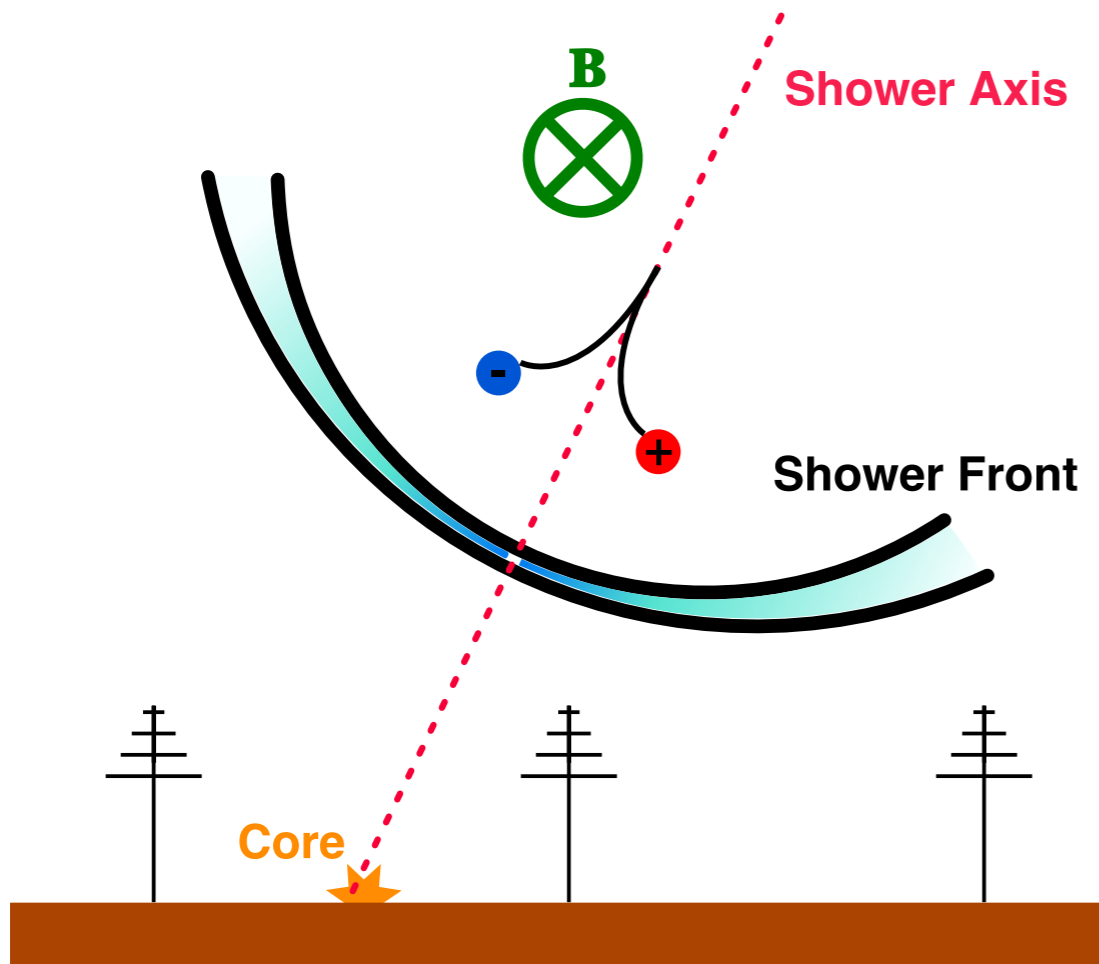
ANITA-3 efficiencies

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



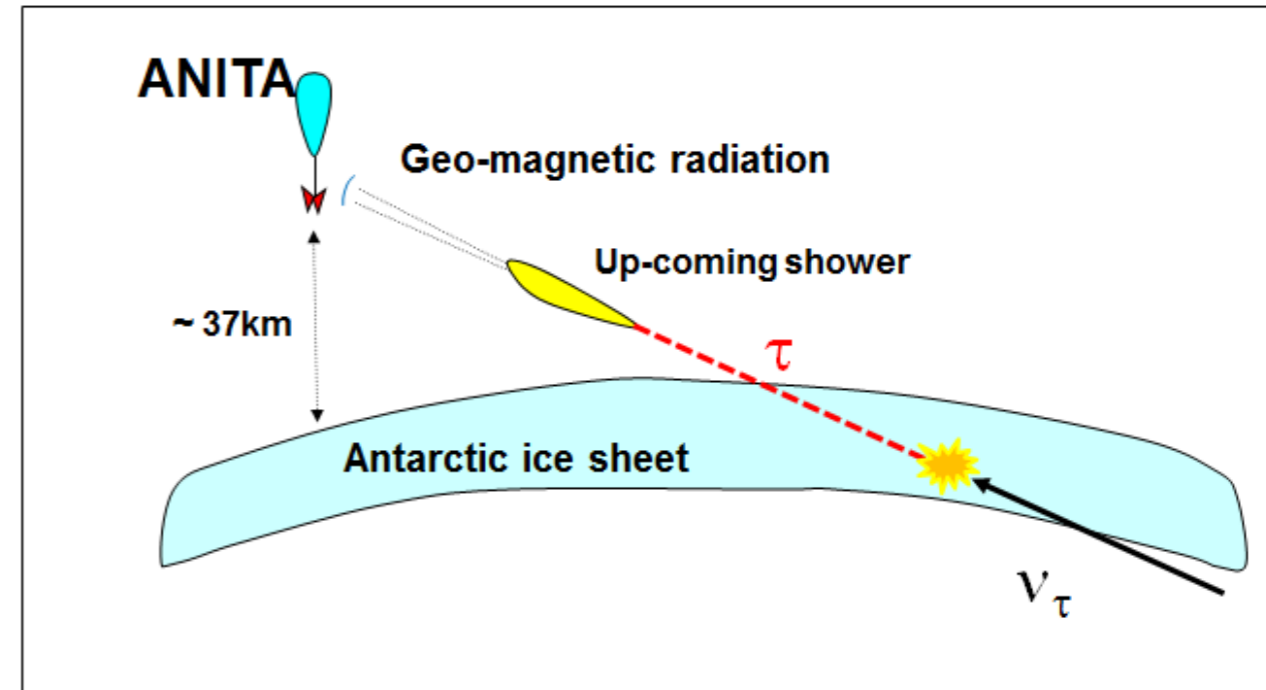
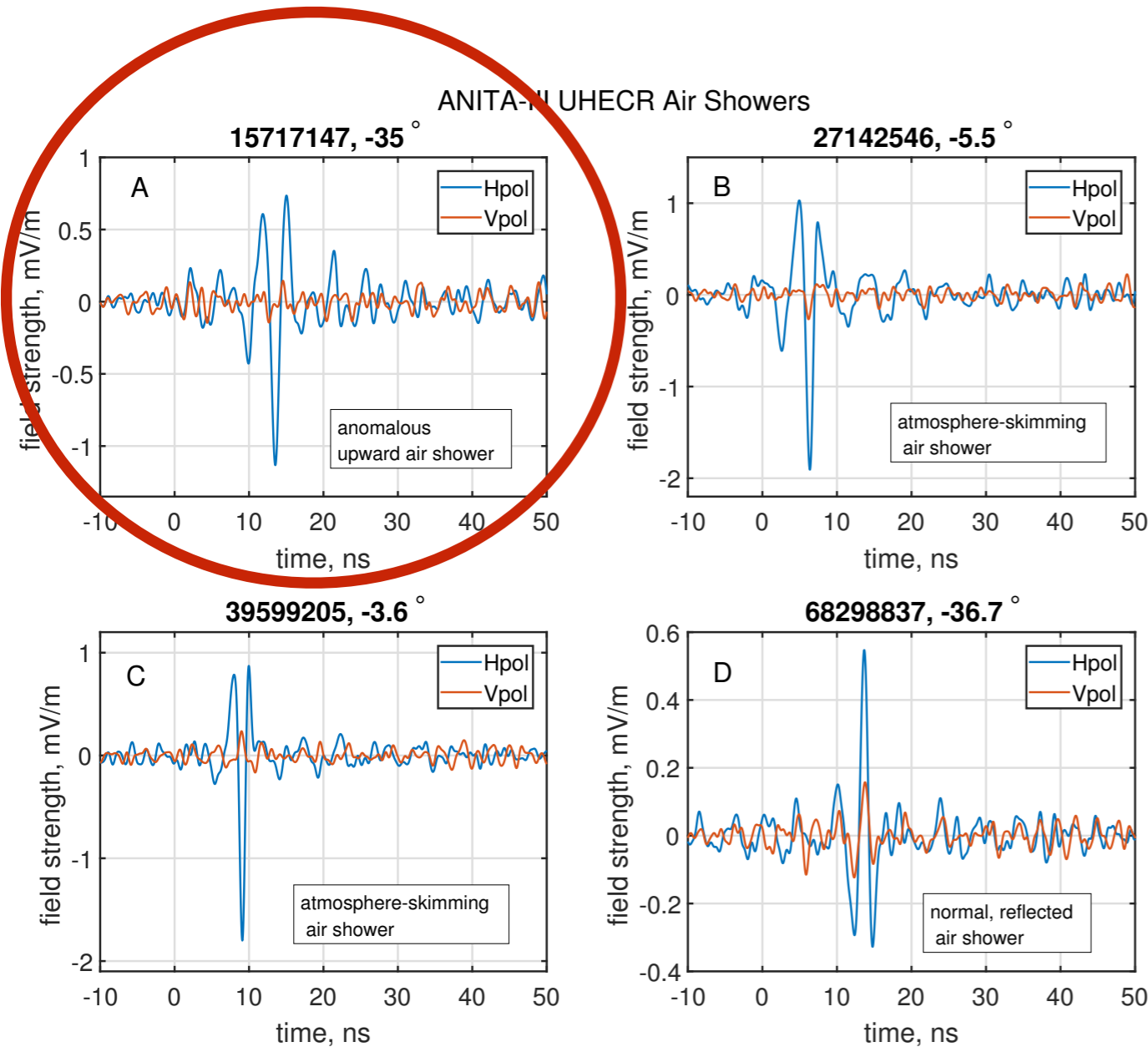
UHECR



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.	$-27.4 \pm 0.3^\circ, 159.62 \pm 0.7^\circ$	$-35.0 \pm 0.3^\circ, 61.41 \pm 0.7^\circ$
RA, Dec ⁽²⁾	282.14064, +20.33043	50.78203, +38.65498
$E_{shower}^{(3)}$	$0.6 \pm 0.4 \text{ EeV}$	$0.56^{+0.3}_{-0.2} \text{ EeV}$

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

Background estimate $< 10^{-2}$