Looking for ALPs with ANITA

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N3AS Seminar

Based on paper: I. Esteban, J. Lopez-Pavon, IMS, J Salvado,
Eur.Phys.J.C 80 (2020) 3, 259 • e-Print: 1905.10372

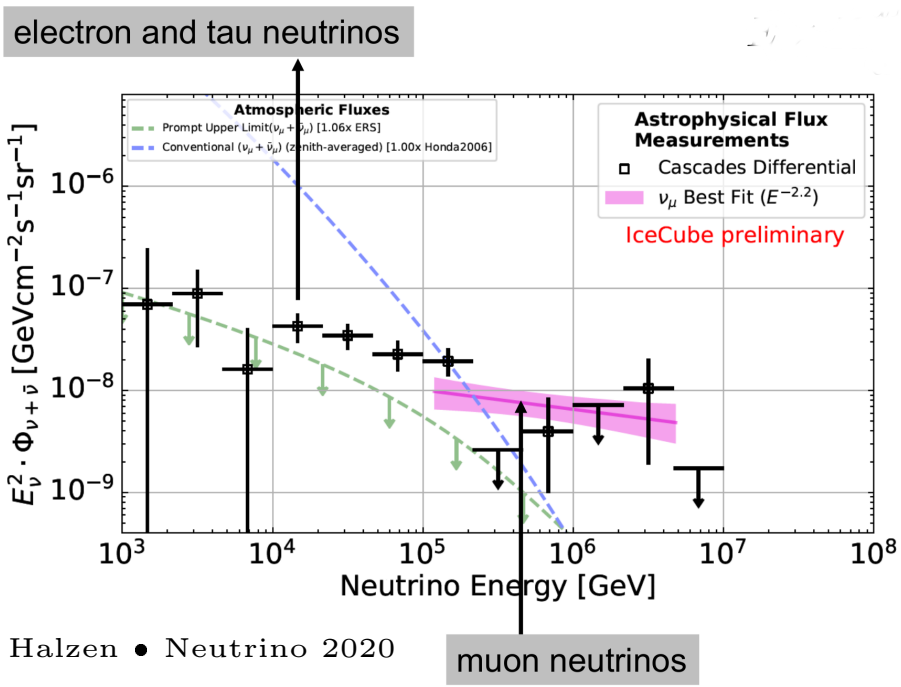
October 20, 2020

Fermilab

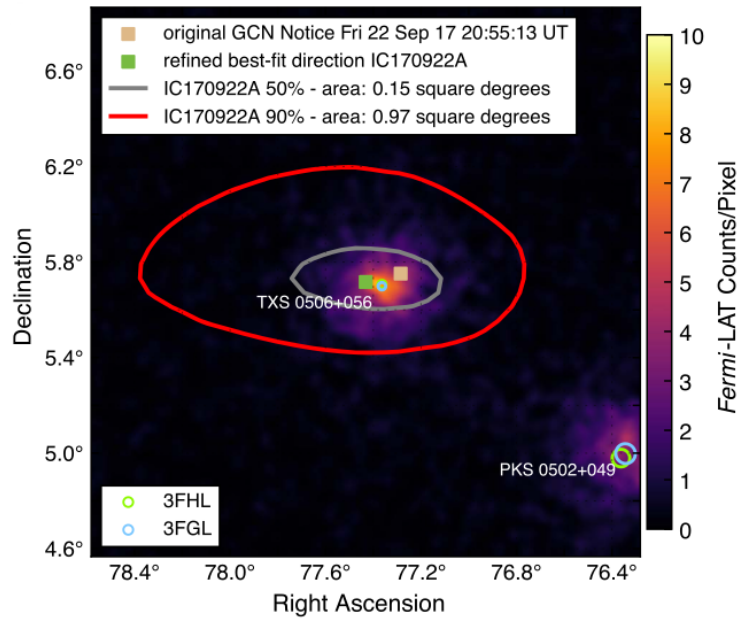
Northwestern University

High-Energy Cosmic Neutrinos

The detection of astrophysical events by IceCube has opened a new venue to probe the Universe. Neutrino astronomy.



F. Halzen • Neutrino 2020

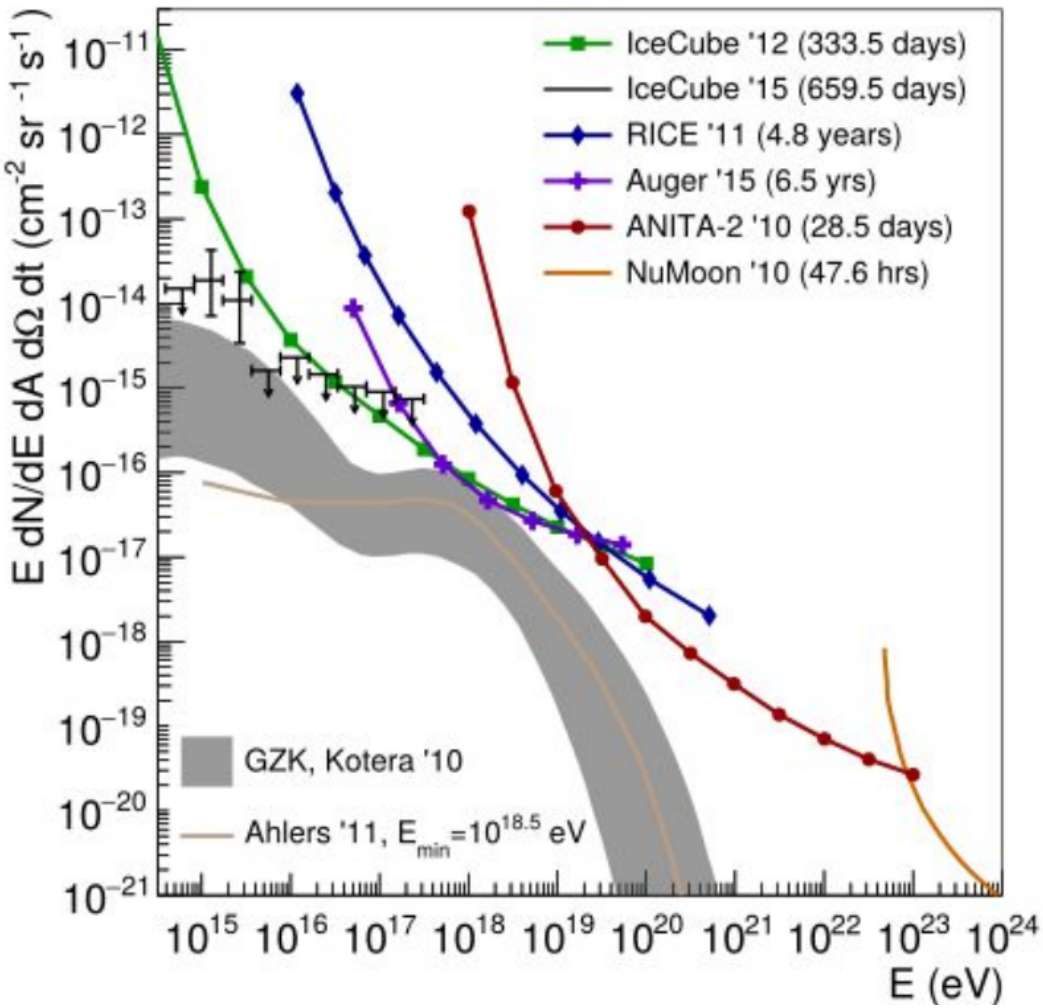


IceCube, Fermi-LAT, MAGIC, AGILE, ..., Science Vol 361 (6398)

- Neutrinos are a good candidate the study the origin of the Cosmic Rays (TXS 0506+056)
- The neutrinos measured in IceCube extend up to PeV scale.

High-Energy Cosmic Neutrinos

- At the EeV scale are expected GZK neutrinos.
- Interaction with center-of-mass energies of 100-1000 TeV. Test the SM Beyond the TeV scale.
- The detection of such flux will require huge detectors ($\sim 1000\text{km}^3$).

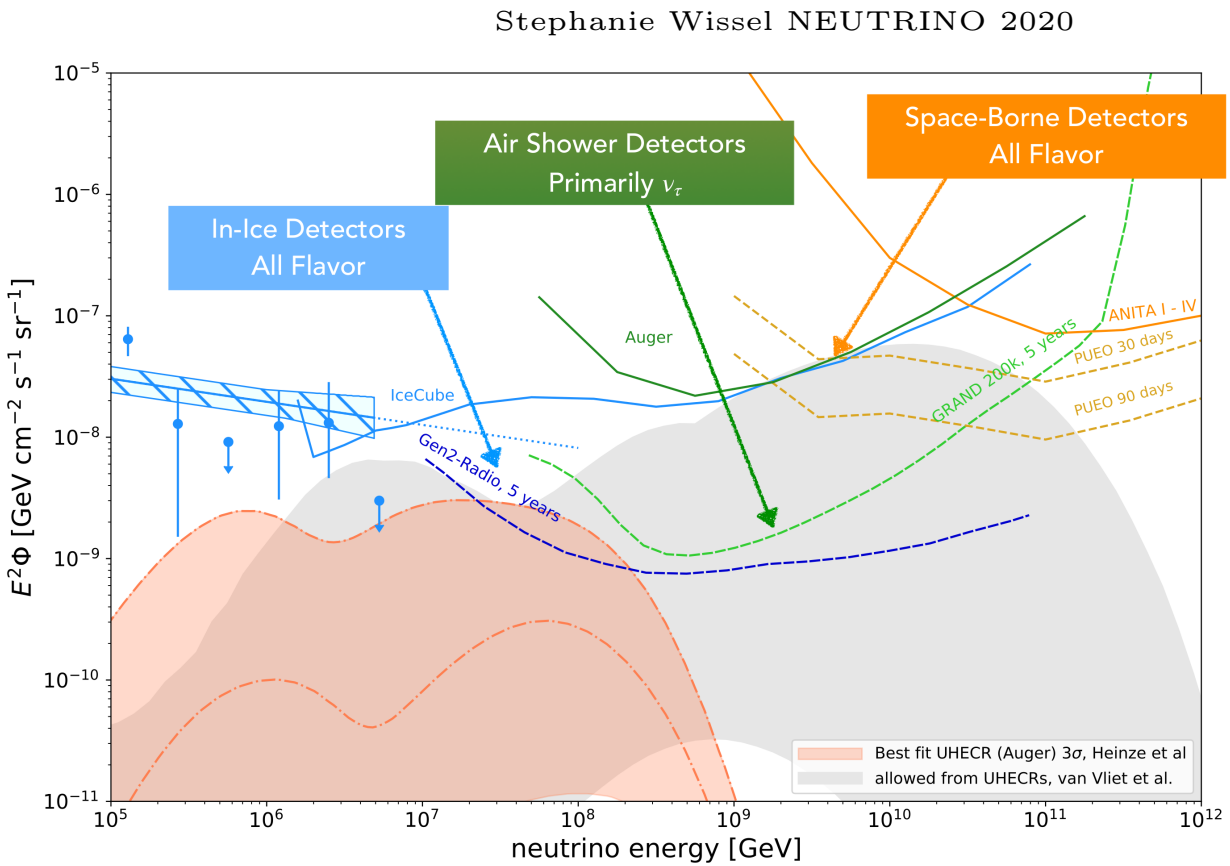


Andrew Ludwing DPF Fermilab 2017

High-Energy Cosmic Neutrinos

Several experiments are already looking for GZK neutrinos or they will do it in the near future.

- IceCube/Gen2-Radio
- Auger
- ARIANNA
- ARA
- GRAND
- **ANITA**/PUEO
- ...



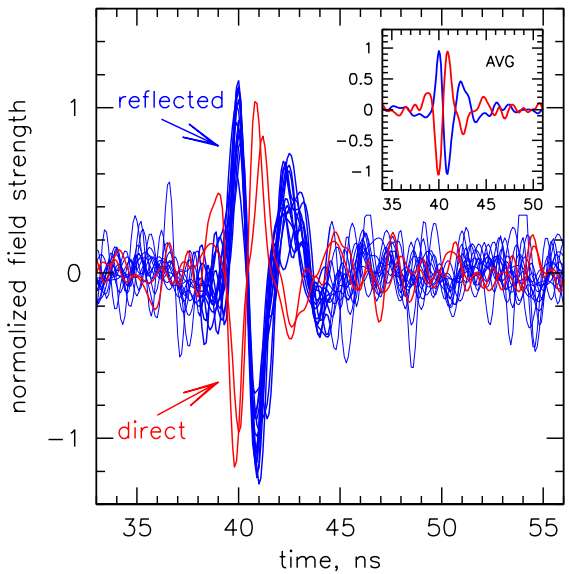
ANITA

- ANITA in a balloon experiment with an array of antennas able to detect impulsive radio emissions.
- The altitude flight is about ~ 35 km.
- The antennas observe the entire Antartica ($\sim 1.5\text{Mkm}^2$).
- The frequency band over which the measurements are done is $200 - 1200$ MHz.
- The goal is the detection of ultra-high energy neutrinos via Askaryan effect.
- ANITA search for polarized signals measuring the Hpol and Vpol of each impulse.

ANITA

Which kind of signal can be expected in ANITA?

- Cosmic Rays:
  - Create an **extensive air showers**.
  - The event can be **direct** (above the horizon) or **reflected** (below the horizon)
  - In the Antartica, $B_\oplus$ produces H-pol events due to the Lorentz force.
  - To distinguish the direction uses the **phase**.
- Neutrinos:
  - **Askaryan events**: they show up as a **vertical polarized** signal.
  - Extensive air showers: **horizontal polarized**. Created by ν_τ interactions.



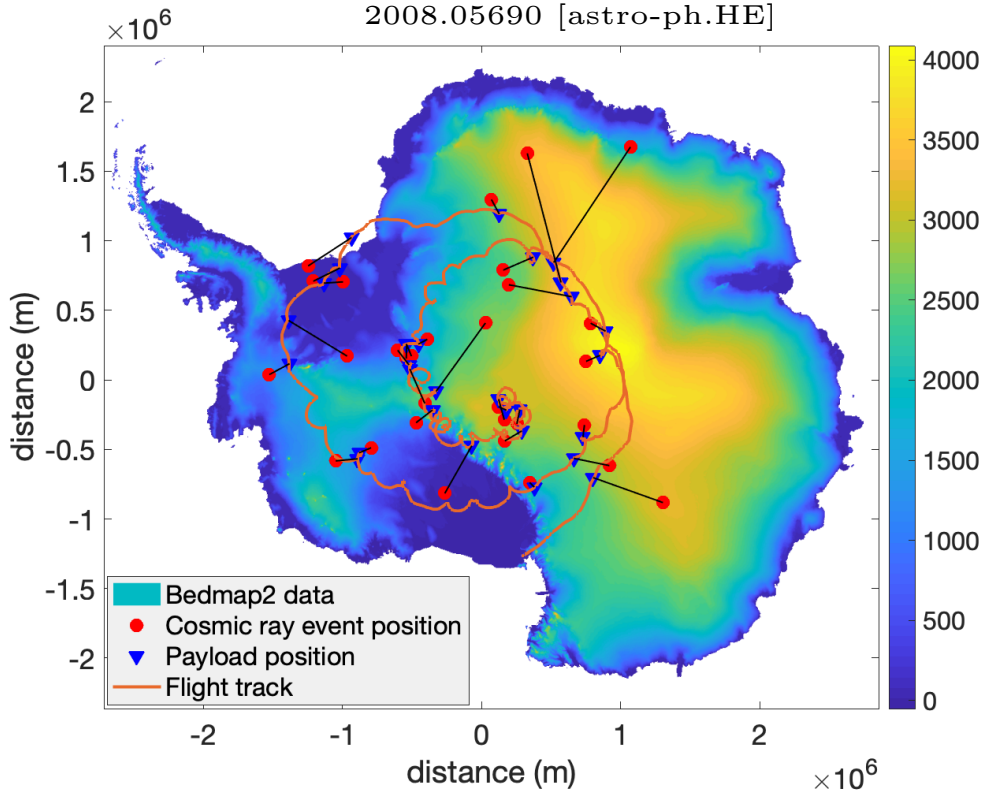
ANITA Collaboration • Phys.Rev.Lett. 105 (2010) 151101 • e-Print: 1005.0035

ANITA

4 flights. No Askaryan event has found yet.

ANITA-I:

- 14 reflected CR and 2 direct CR.
- 1 **upward-pointing** CR-like consistent with the **emission from the surface**.



ANITA-II:

- 1 direct CR.
- Focused in neutrino detection via Askaryan effect.

ANITA-III:

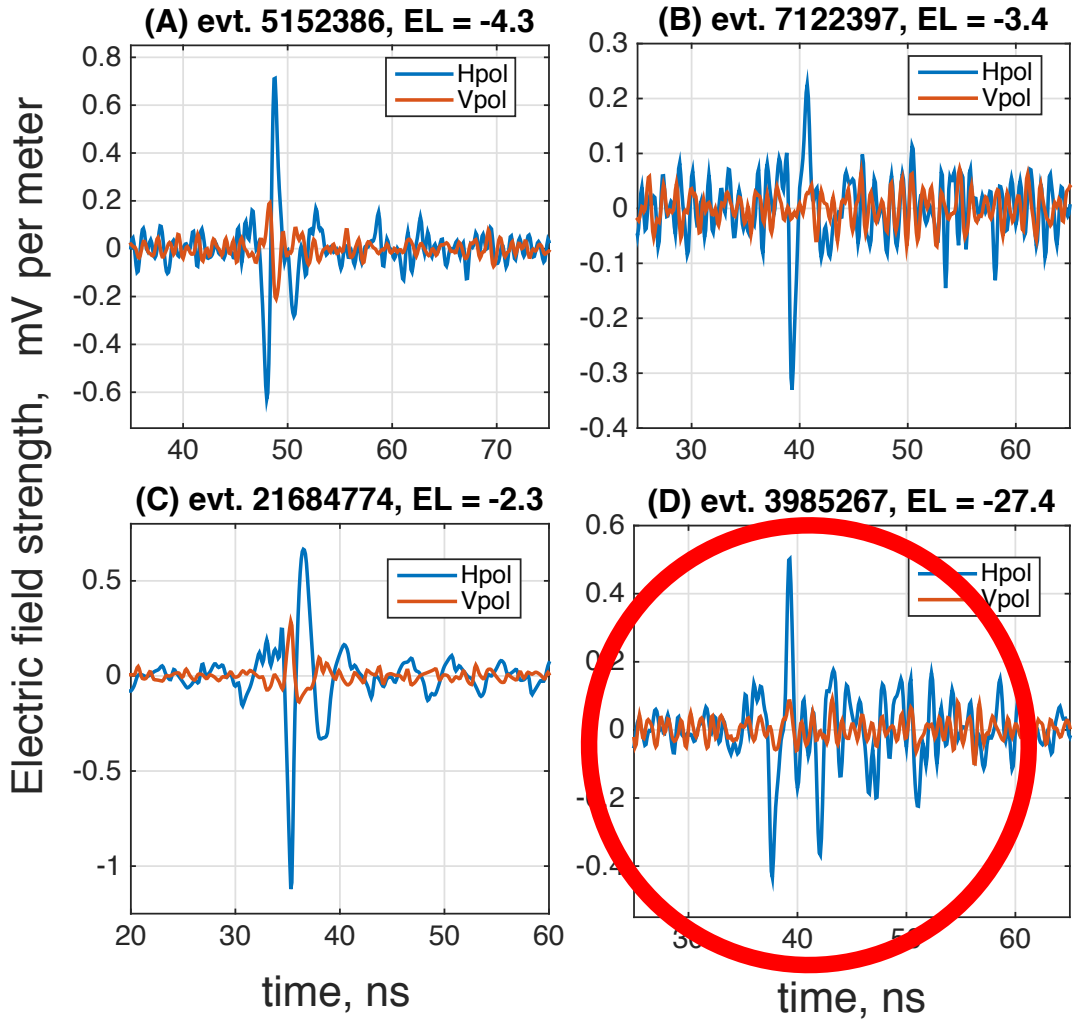
- 17 reflected CR and 3 direct CR.
- 1 **upward-pointing** CR-like consistent with the **emission from the surface**.

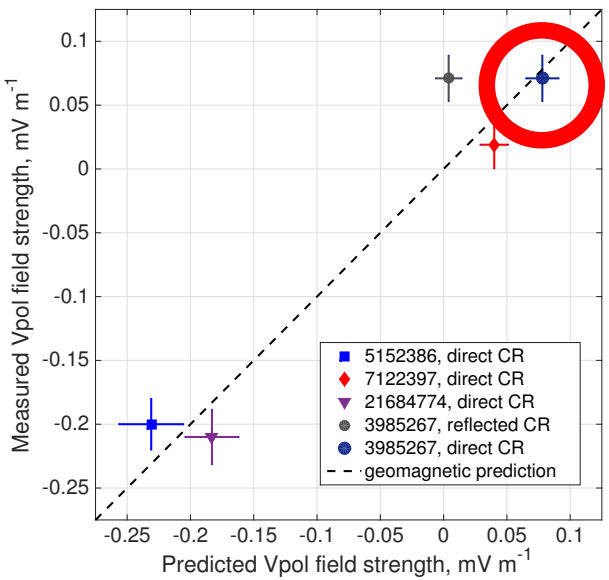
ANITA-IV:

- 23 reflected CR and 2 direct CR
- 4 near-horizon CR-like.

ANITA-I: anomalous event

- The **elevation** corresponds to -27.
- **Horizontal polarized**.
- The phase corresponds to a **direct event** (D) similar to events (A,B,C).
- Correlation with the Geomagnetic field

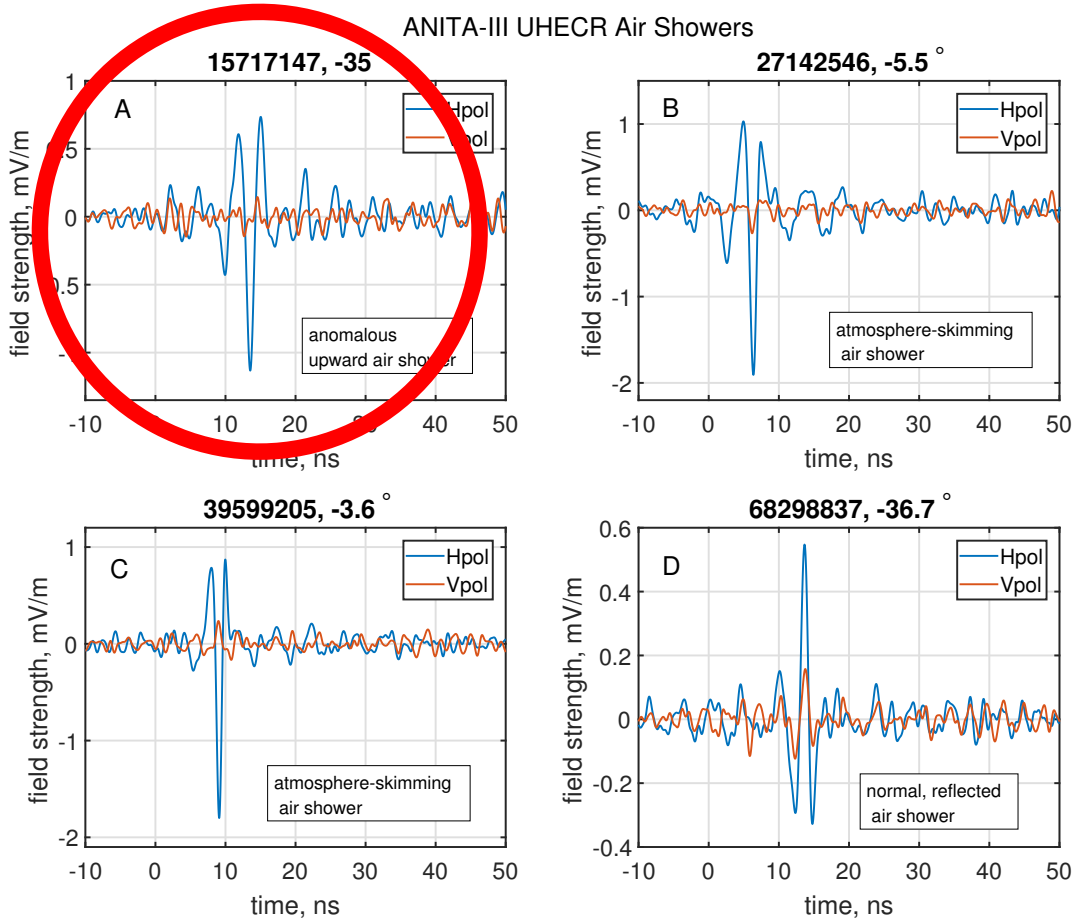


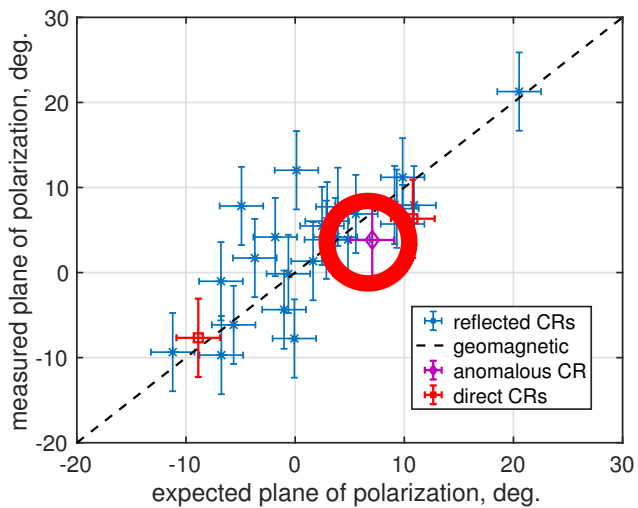


ANITA Collaboration •
Phys.Rev.Lett. 117 (2016) 7, 071101
• e-Print: 1603.05218

ANITA-III: anomalous event

- Event A:
  - **elevation** is -35 relative to the horizontal.
  - Horizontal polarized.
  - The phase corresponds to a direct event.
  - Geomagnetic-correlated
- Events B and C: direct events (same phase as A)
- Event D: reflected event.



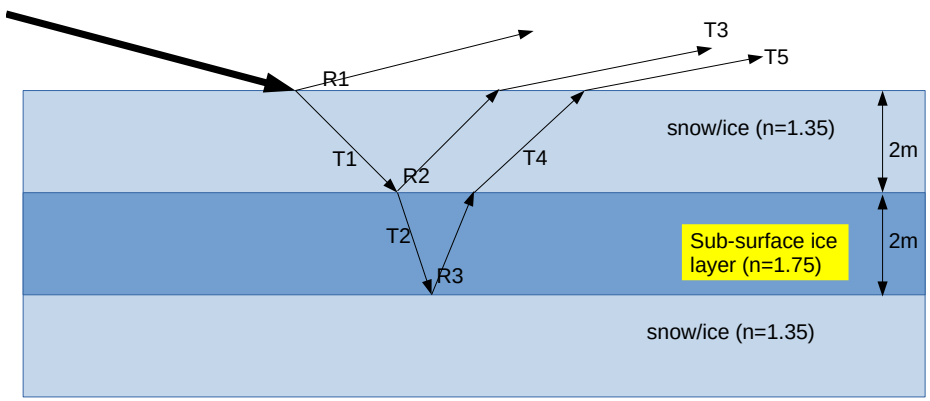


ANITA Collaboration • Phys.Rev.Lett. 121 (2018) 16, 161102 • e-Print: 1803.05088

Explaining the anomalous events: Cosmic Rays Showers

The reflection of the CR happens below the surface in a low-density layer.

- ($\geq 5\%$) of the Antartica should have sub-structures.
- The reflection in several interface layers should result in multiple observables.
- The amplitude of the observation requires higher fluxes than the actual constraints.
- HiCal disfavor the existence of the proposed sub-structure models.

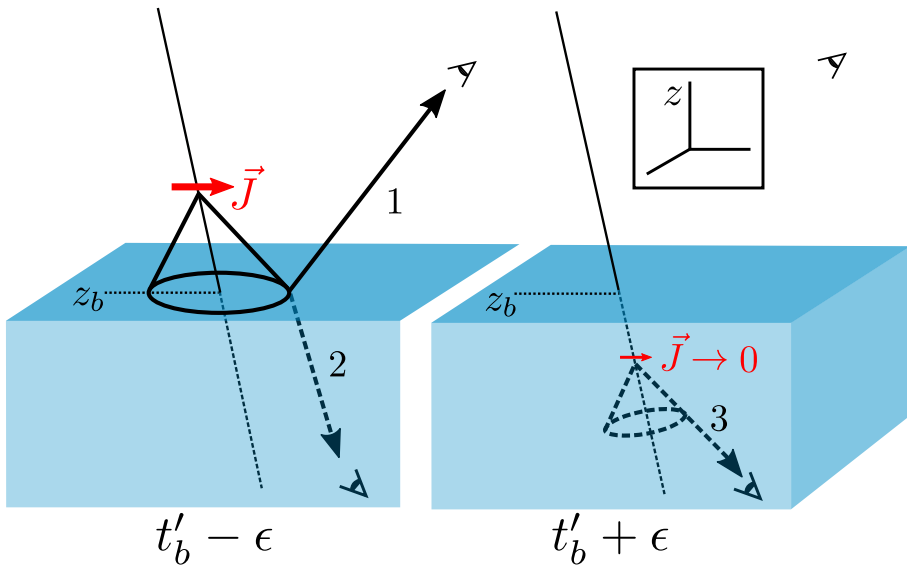


D. Smith et al. e-Print: 2009.13010 [astro-ph.HE]

Explaining the anomalous events: Cosmic Rays Showers

Coherent transition radiation

- Emitted when charged particles hit a boundary surface.
- It needs to happen in a tilted surface.
- At large elevantion angles, all the events should have a reflected phase.



Vries and Phira, Phys.Rev.Lett. 123 (2019) 9, 091102 • e-Print:1903.08750 [astro-ph.HE]

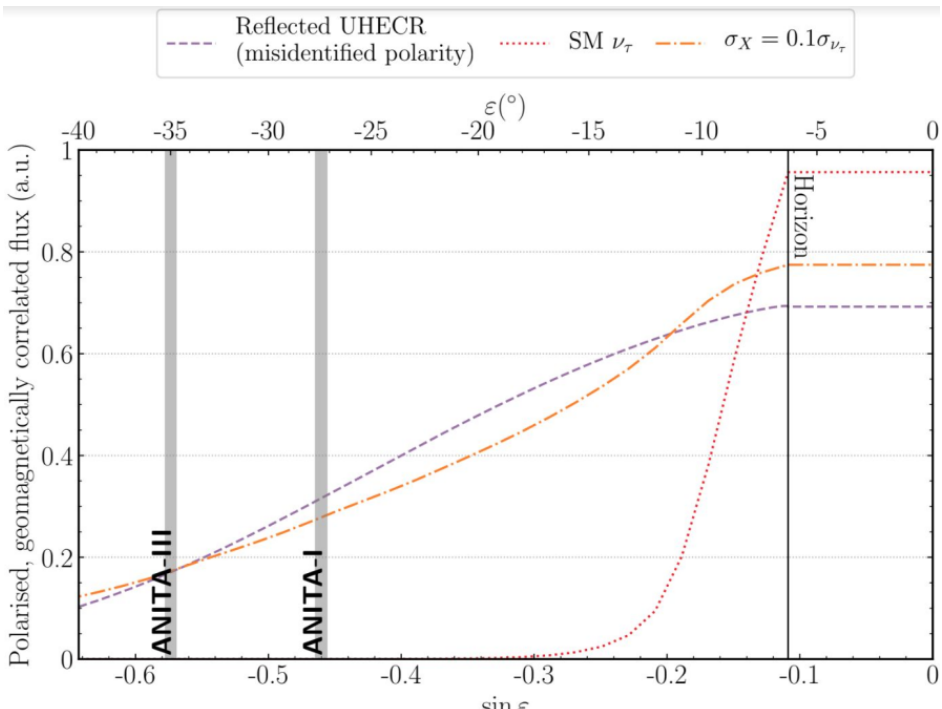
Explaining the anomalous events: High-Energy particles

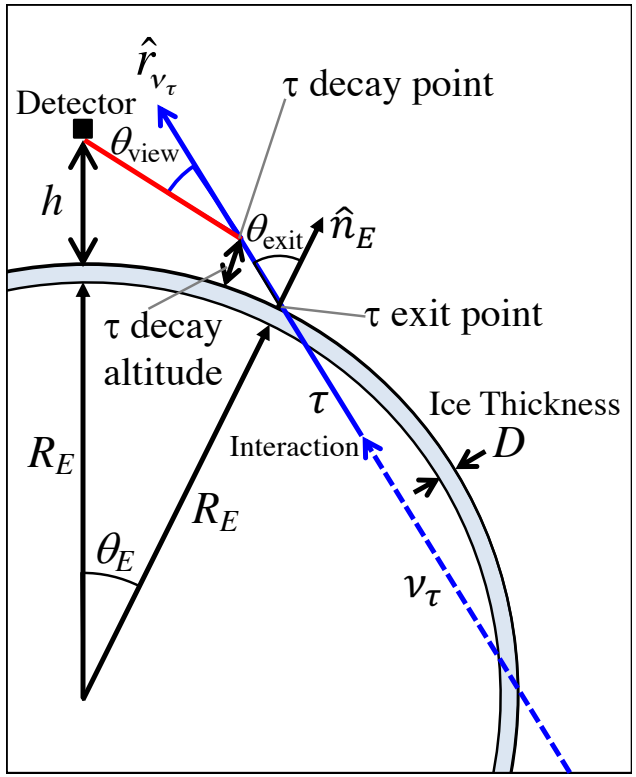
The upgoing showers could be generated by a ν_τ

- The estimated energy $\sim 0.6 \pm 0.4$ EeV.
- The distance travelled ~ 5000 km

There are some issues with this explanation:

- At the EeV scale, the interaction length is ~ 1600 km.
- We can expect more events in the horizontal direction.





A.Romero-Wolf et al. Phys.Rev.D 99 (2019) 6, 063011 • e-Print: 1811.07261 [astro-ph.HE]

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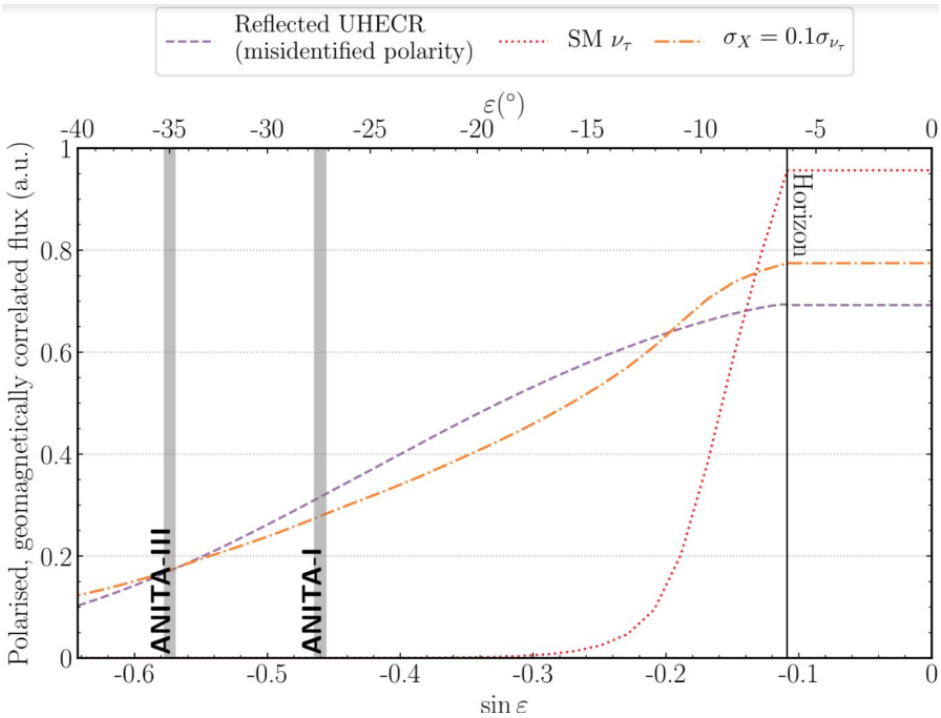
Explaining the anomalous events: High-Energy particles

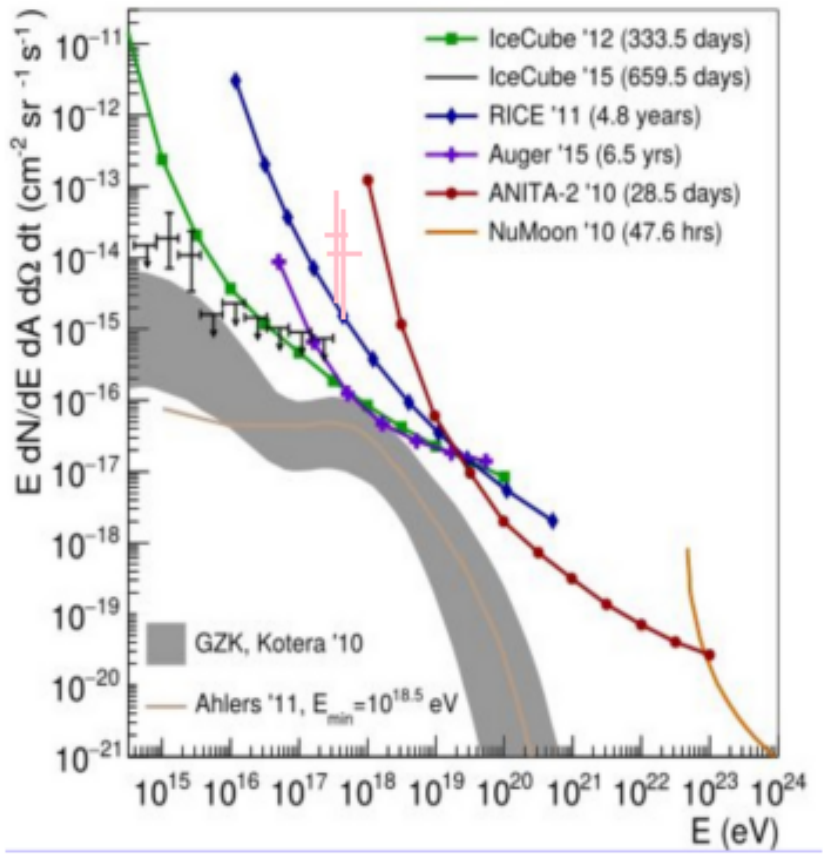
Some other solution considers BSM physics: Sterile neutrinos, Heavy Dark-Matter...

- Tension with neutrino telescopes (IceCube) and Cosmic Rays Observatories

Andrew Ludwing DPF Fermilab 2017



J. Salvado, Invisibles 19



Ivan Martinez-Soler (Fermilab and Northwestern U.)

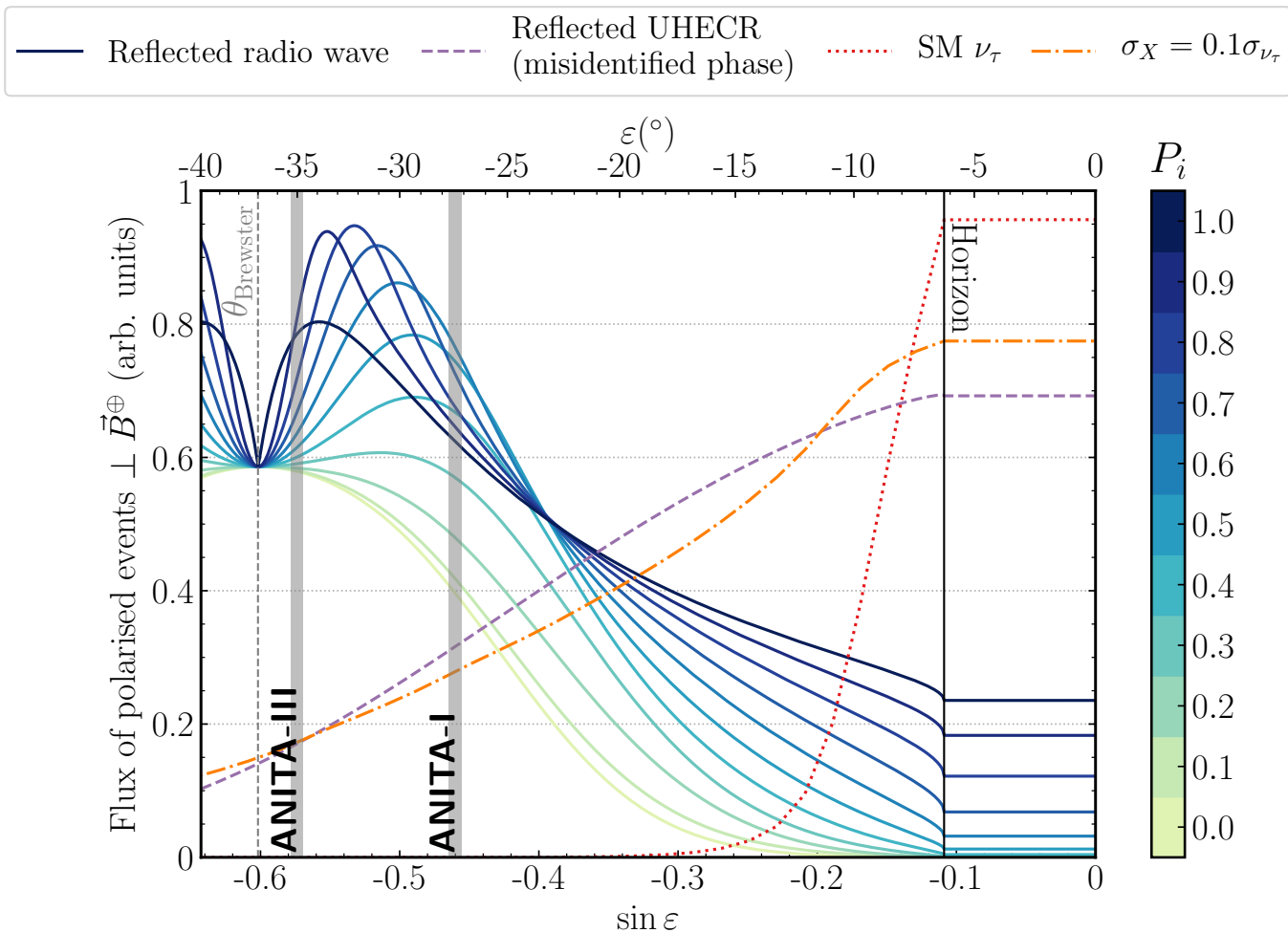
How can be explained the anomalous events?

To explain the anomalous events, we require:

- A source of impulsive **radio signals linearly polarized** and with a phase consistent with the observed events.
- The production of the signal should **not involve high-energy particles**.

How can be explained the anomalous events?

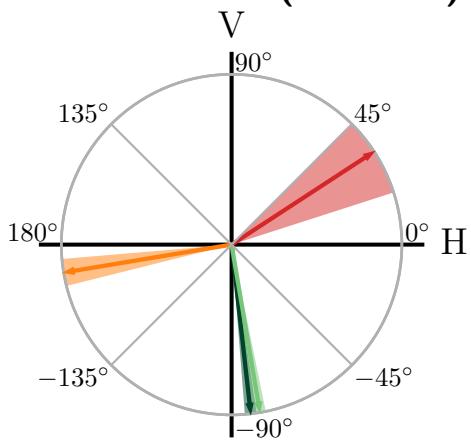
Assuming an incident isotropic flux, linearly polarized with random polarization angles and a given degree of polarization.



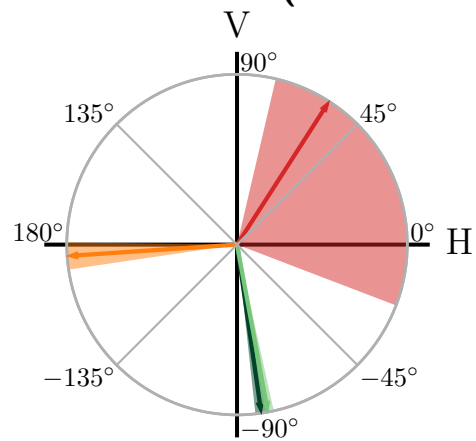
How can be explained the anomalous events?

Assuming an incident isotropic flux, linearly polarized with random polarization angles and a given degree of polarization.

Event 3985267 (ANITA-I)



Event 15717147 (ANITA-III)



$\vec{B}^{\oplus}$ (after reflection) $\vec{B}^{\oplus}$ (before reflection) $\vec{E}$ (after reflection) $\vec{E}$ (before reflection)

How can be explained the anomalous events?

Assuming an incident isotropic flux, linearly polarized with random polarization angles and a given degree of polarization.

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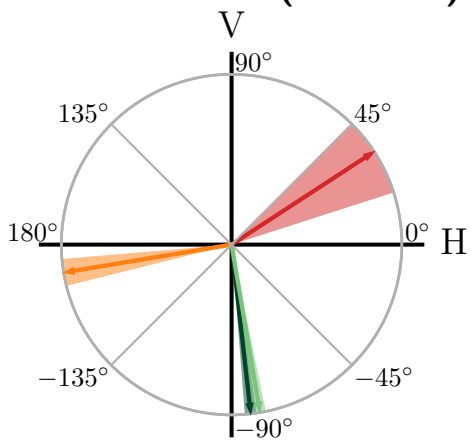
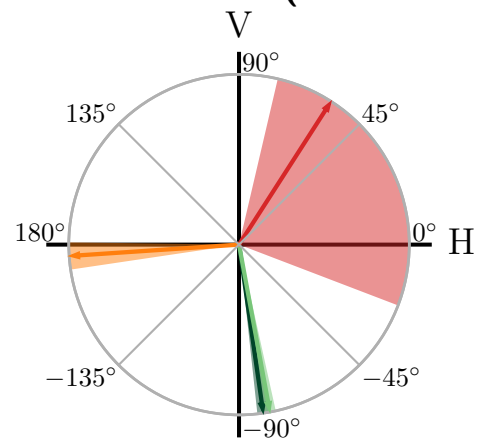


Event 15717147 (ANITA-III)



$\vec{B}^{\oplus}$ (after reflection) $\vec{B}^{\oplus}$ (before reflection) $\vec{E}$ (after reflection) $\vec{E}$ (before reflection)

We will consider **Axions like Particles (ALPs)** as a possible explanation of the events.

Axions

Axions are proposed to solve the strong CP problem, but also can contribute to solve other questions in physics

$$\mathcal{L} \supset \frac{1}{2}\left(\partial_\mu a \partial^\mu a - m_a^2 a^2\right) - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \frac{1}{4} g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu}$$

- Dark Matter
- Anomalous energy loss in stellar systems like White Dwarfs, Red Giants, ...
- Observation of high energy photons

Can the ALP generate a detectable signal in ANITA?

In the presence of a magnetic field ($B_\oplus$), the equation of motion for the axion and the electric field (E)

$$\left[\partial_z^2+\omega^2+\begin{pmatrix} -\omega_p^2 & -i\omega_p^2\frac{\Omega_z}{\omega} & 0 \\ iw_p^2\frac{\Omega_z}{\omega} & -\omega_p^2 & -g_{a\gamma\gamma}B_y^\oplus\omega^2 \\ 0 & -g_{a\gamma\gamma}B_y^\oplus & -m_a^2 \end{pmatrix}\right]\begin{pmatrix} E_x \\ E_y \\ a \end{pmatrix}=0$$

There are two characteristic frequencies:

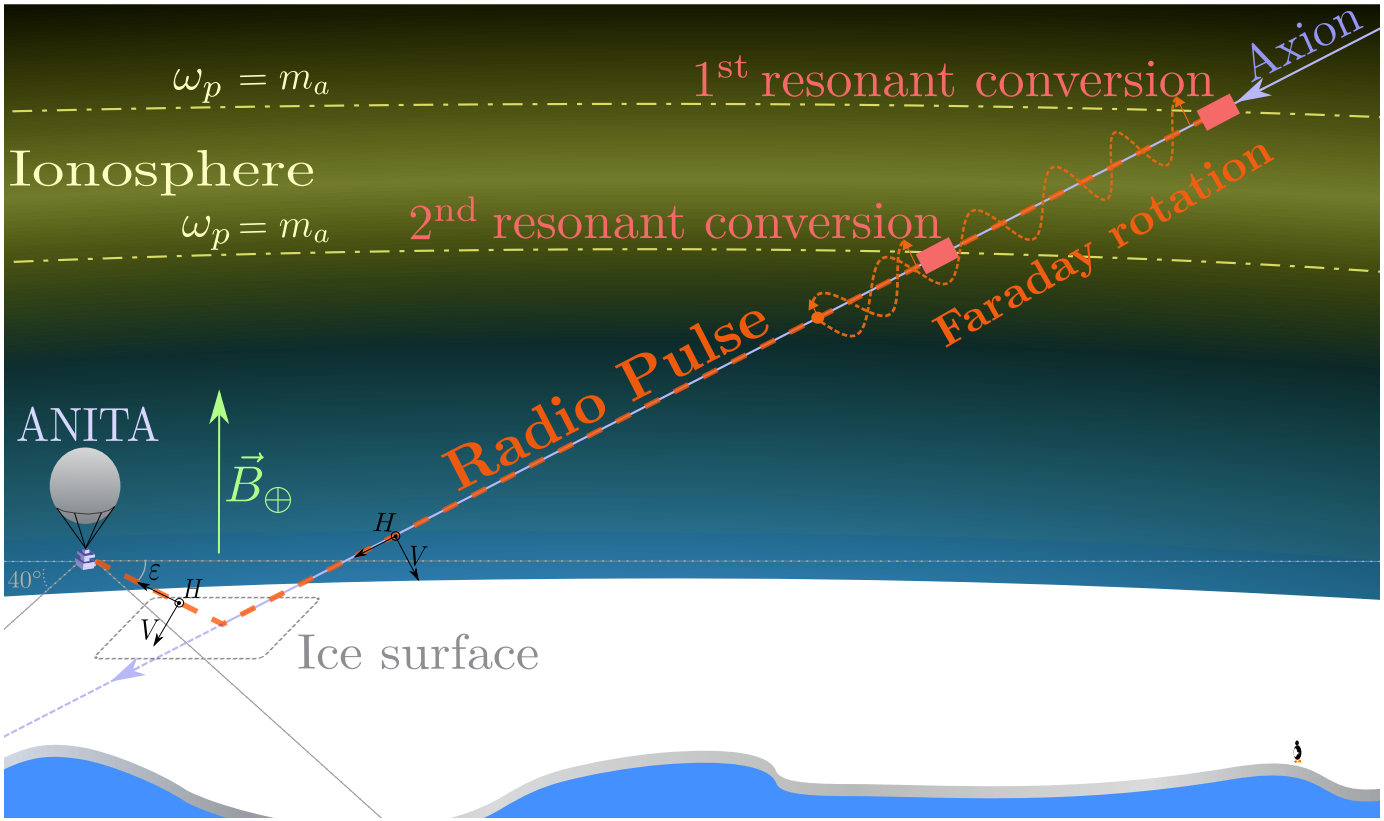
- the plasma frequency ($\omega_p = \sqrt{e^2 n_e/m_e}$)
- the axion mass (m_a)

$w_p = m_a$
Resonant production of photons

$\Omega_z = eB_\oplus/m_e$

For $\Omega_z \neq 0$ there is a rotation of the electromagnetic wave XY plane (**Faraday rotation**)

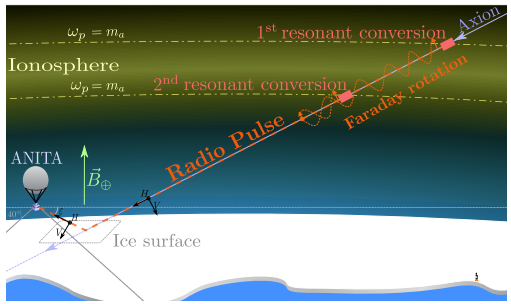
Can the ALP generate a detectable signal in ANITA?

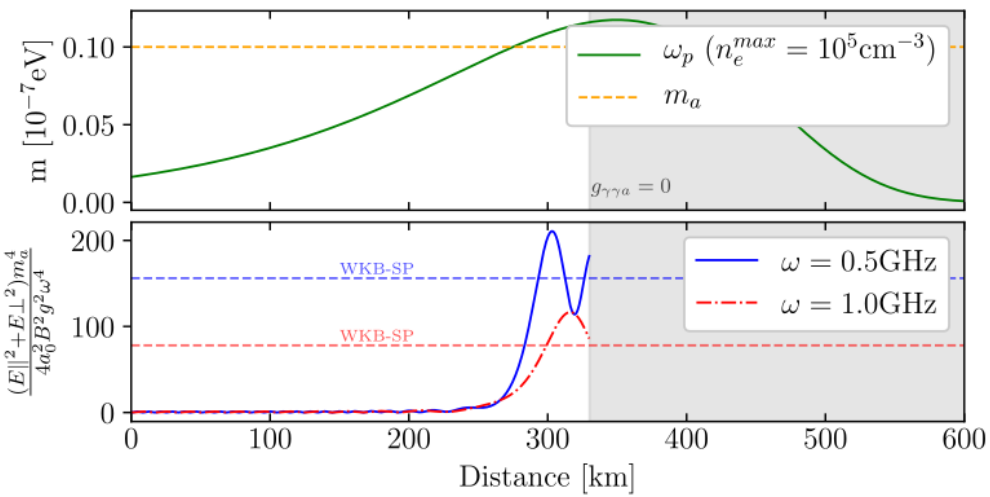


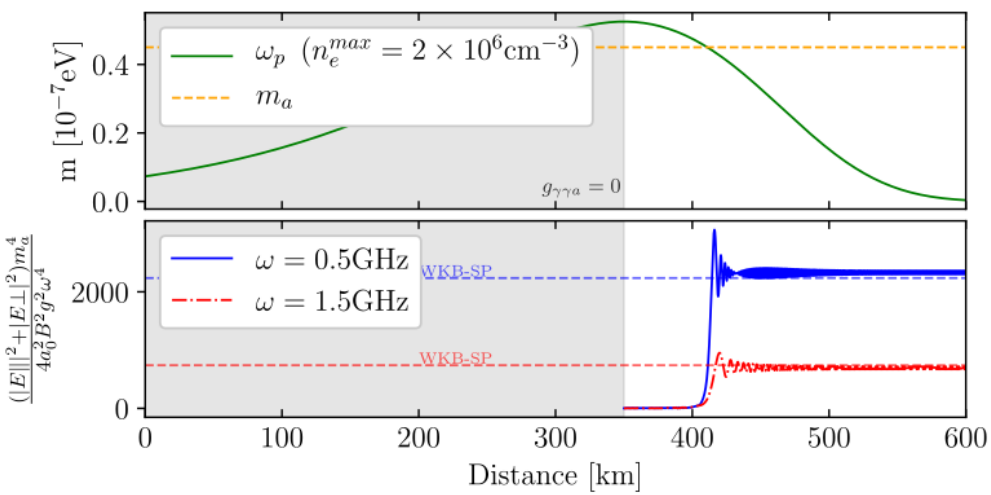
- $\epsilon(\text{ANITA-I}) = 27^\circ$
- $\epsilon(\text{ANITA-III}) = 35^\circ$

The elevation for both events is close to **Brewster angle** ($\epsilon \sim 37^\circ$), so the **vertical component** of the electric field is **very suppressed**.

Can the ALP generate a detectable signal in ANITA?







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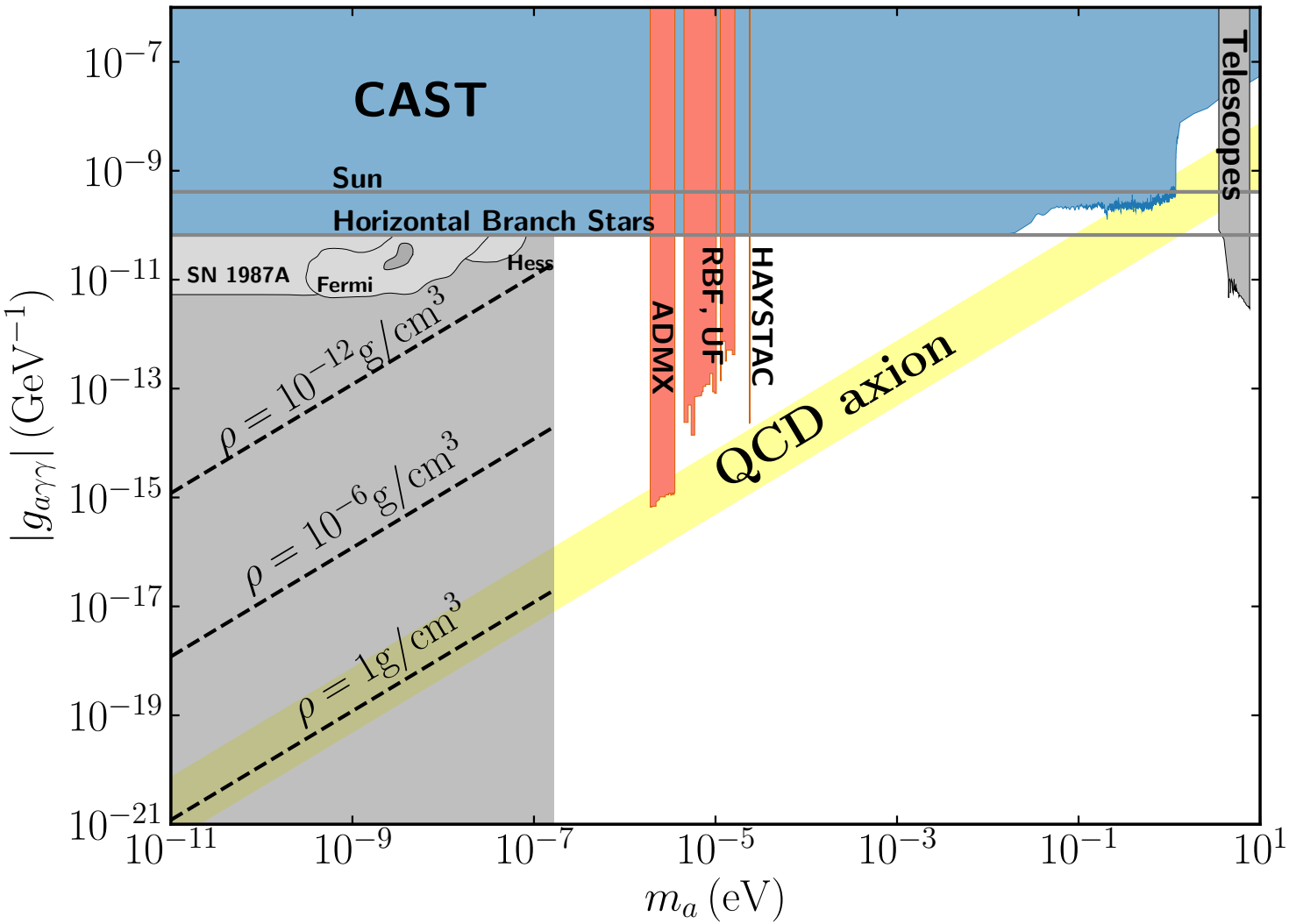
What can be inferred from those events?

- ALPs can lead condensation and instabilities that will develope a burst
- The event rate $\sim$ month^{-1}



Conclusions

- ANITA has observed **two upward-pointing CR-like** consistent with the emission from the Antartica surface.
- Proposed explanations: Cosmic Rays (challenging explanation of the event directionality), high energy (disfavor by IceCube and Auger)
- The directional and polarization properties of both events can be explained by the reflexion of an **isotropic flux, linear polarized in a radom direction**.
- We propose a generation mechanism based on the **axion-photon conversion**.

Thank you!