On the origin of ANITA's intriguing events

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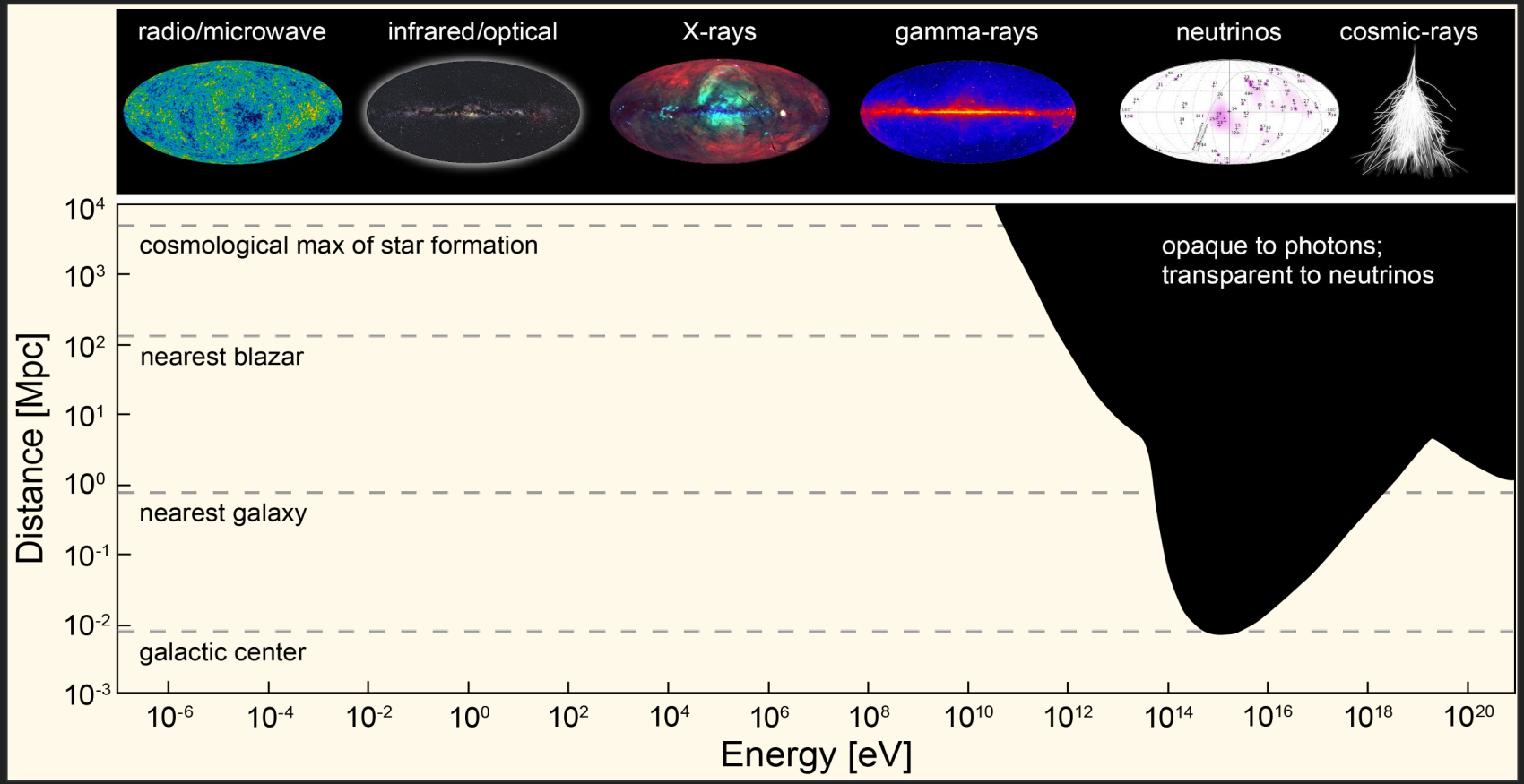
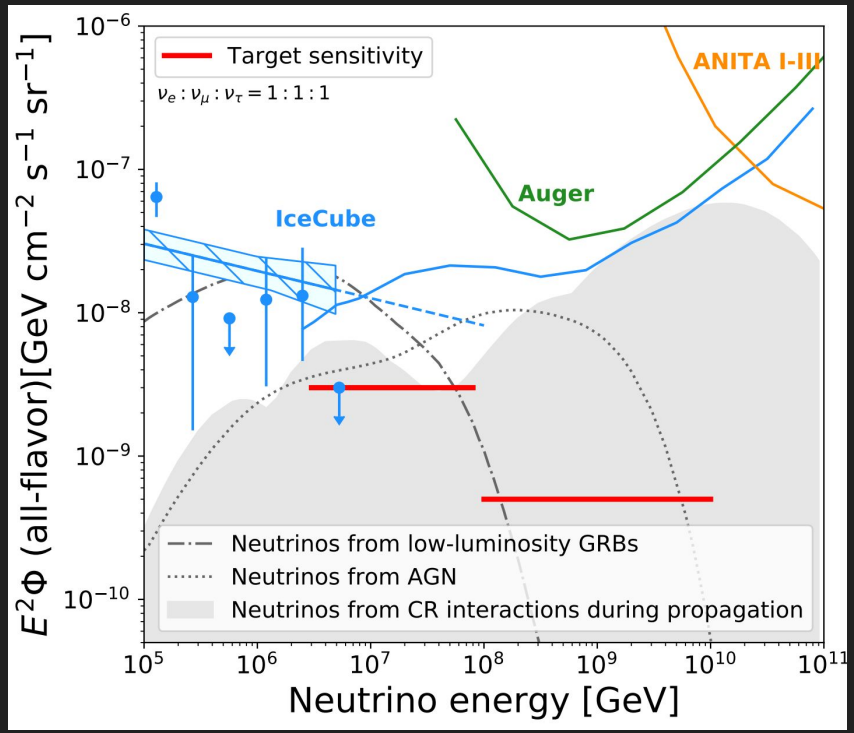
Work in collaboration with:
Carlos Arguelles, Toni Bertolez, Ivan Esteban, Jacobo Lopez-Pavon, Ivan Martinez-Soler

arXiv:1905.10372
arXiv:2305.03746

Why Neutrino Telescopes



Motivation: searching astrophysical neutrinos

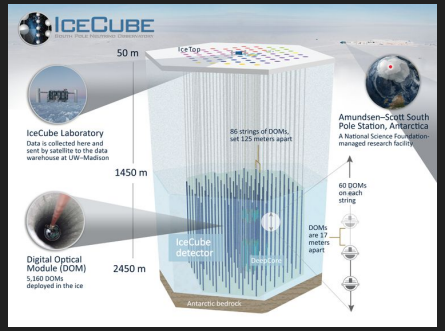


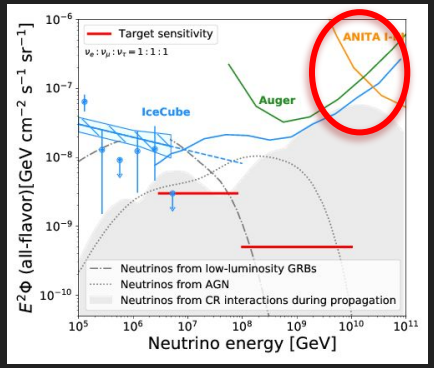
- IceCube is already seeing the universe and our galaxy with Neutrinos.
- The highest energy events are huge in energy and in size. But low in number.
- ANITA is intended to go to the highest energies expected (GZK) using even larger volumes.

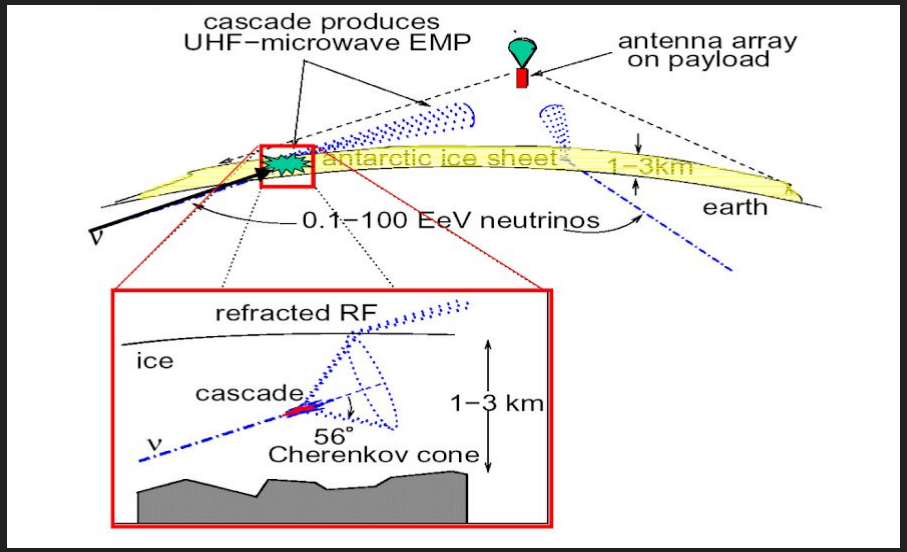
Fig. from: arXiv:1903.04334 Markus Ackermann, et.al.

ANtarctic Impulsive Transient Antenna

ANITA concept:







APS meeting 2003 Steve Barwick, UC Irvine

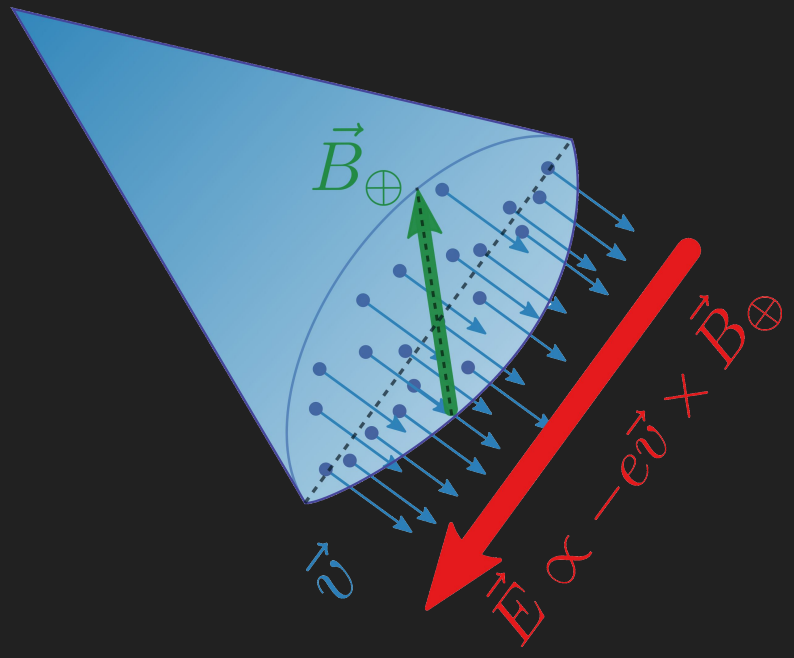
- IceCube has a kilometer cube of instrumented volume.
- ANITA has a much larger target mass but only one detection point that measures a secondary product of the EM cascade (a radio pulse).
- The events need to be HUGE!

$10^{19} eV$ to compete with IceCube

Physical properties of the expected events:

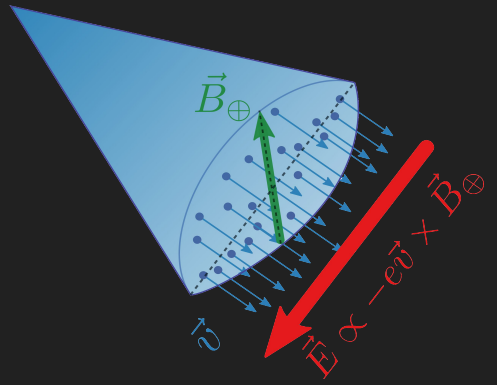
- Space and Time localization. (Isolated and Impulsive)
- Polarization. (Direction and degree of polarization).
- Phase, Polarity(name used in ANITA papers) or "*initial sign of the E field*"
- Coherence (Small relative phases of the different modes)

Radio from High E events:



- The B field in Antarctica produces H-pol(geocorr) pulses in the atm-cascades due to the Lorentz force.
- The phase is well determined.
- A cascade in the ice produces mostly V-pol pulse, Askarian radiation (not observed by ANITA).
- In the reflection process the phase changes sign.
- Coherent and isolated radio pulses are expected.

Types of expected events:



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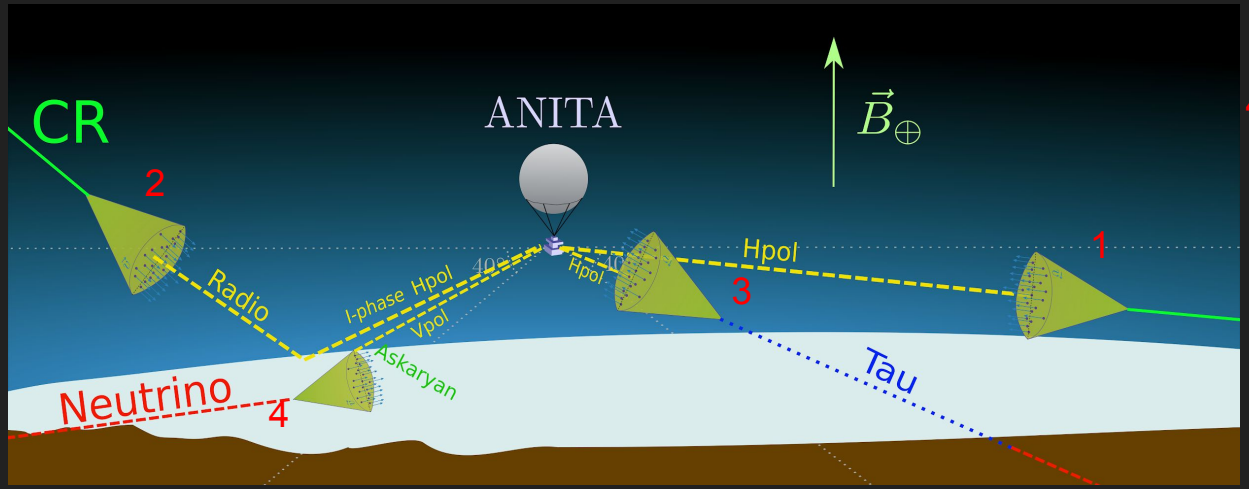
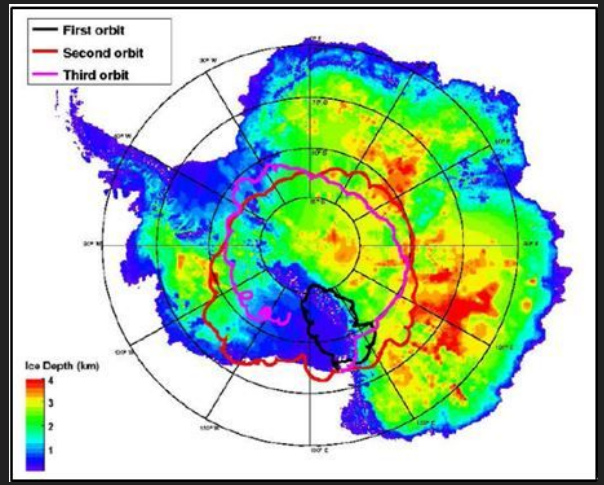


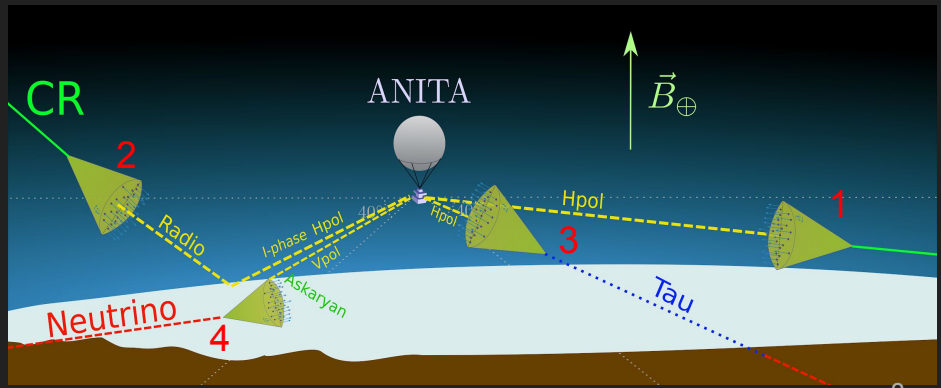
Event types:

1. Direct CR: H-pol, direct phase, above horizon.
2. Reflected CR: H-pol, inverted phase, below horizon.
3. Tau event type: Direct CR like below the horizon. (created by tau neutrino)
4. In ice high energy cascade: Askarian radiation, V-polarized.

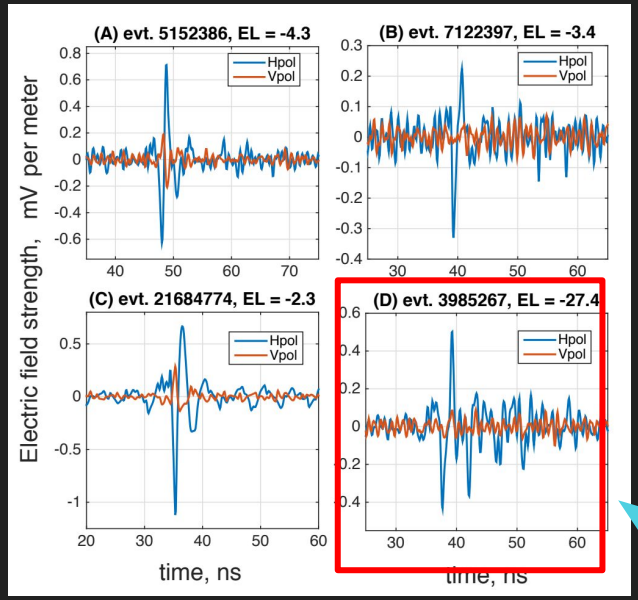
Situation before ANITA IV

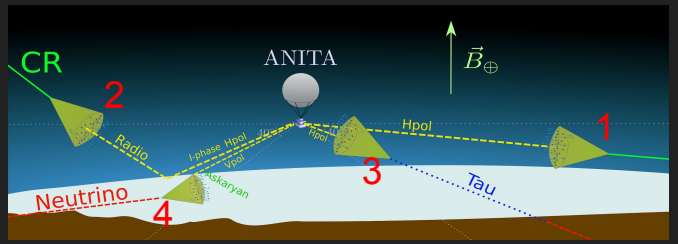
- ANITA-I:
  a. Search: Isolated, impulsive, geocorr signals.
  b. No Askarian neutrino events.
  c. 2 type (1) and 14 type (2) found.
  d. One non inverted phase upgoing CR like (3).
- ANITA-II:
  a. Search: Askarian neutrino events.
  b. Different polarization from UHECR (no CR like events expected).
  c. Some CR of high intensity detected.
- ANITA-III
  a. Search: Isolated, impulsive, signal shape selected.
  b. No Askarian neutrino events.
  c. 3 type (1) and 17 type (2) found.
  d. One non inverted phase upgoing CR like (3).



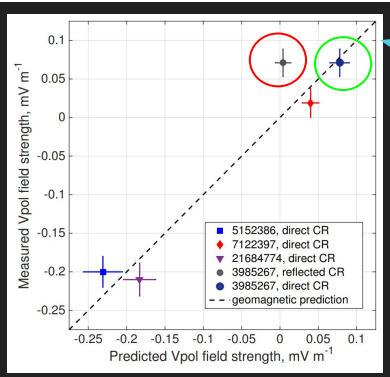


ANITA-I anomalous event



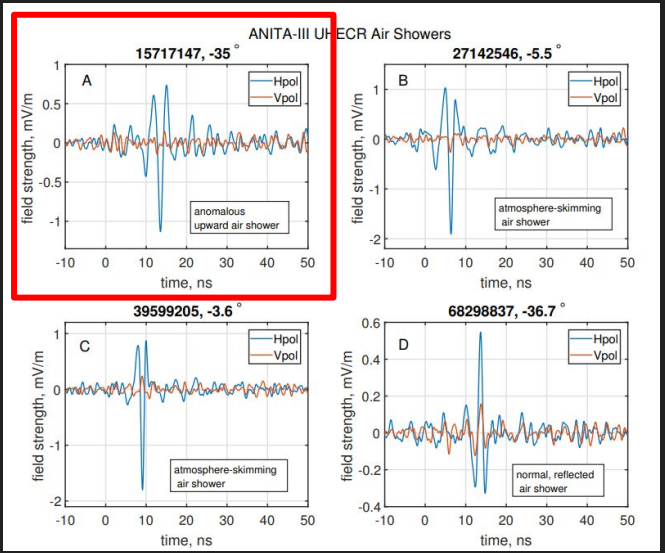


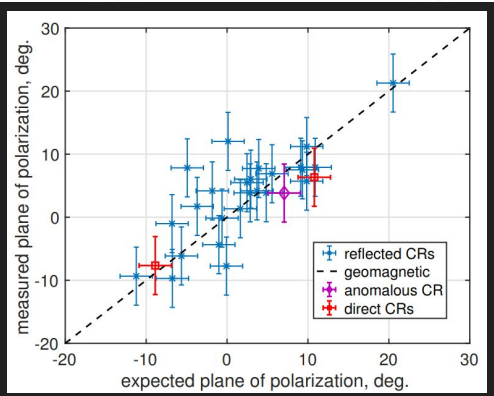
- Events A, B, C are type (1) [2 ANITA-I 1 ANITA-II].
- Event D at -27.4 degrees below the horizon can only be type (2) or (3) since is geocorrelated (~Hpol).
- The phase is consistent with a direct event.
- The small V-pol after reflection is too large before to be type (2).

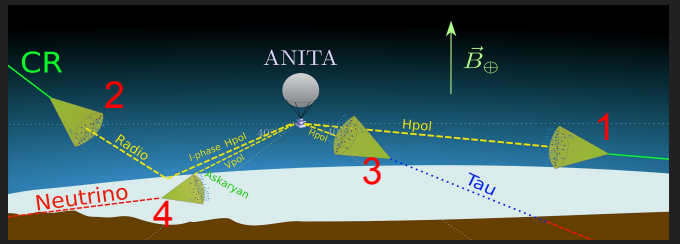


Phys.Rev.Lett. 117 (2016) no.7, 071101 ANITA collaboration

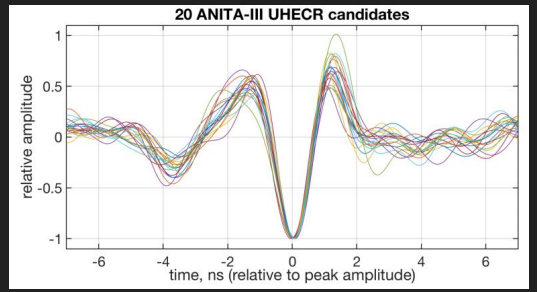
ANITA-III anomalous event







- Events B and C are type (1)
- Event D is type (2), inverted phase at a similar direction.
- Event A seems to be again type (3), direct phase and consistent polarization.
- The shape used to trigger in ANITA-III also looks consistent.



Phys.Rev.Lett. 121 (2018) no.16, 161102
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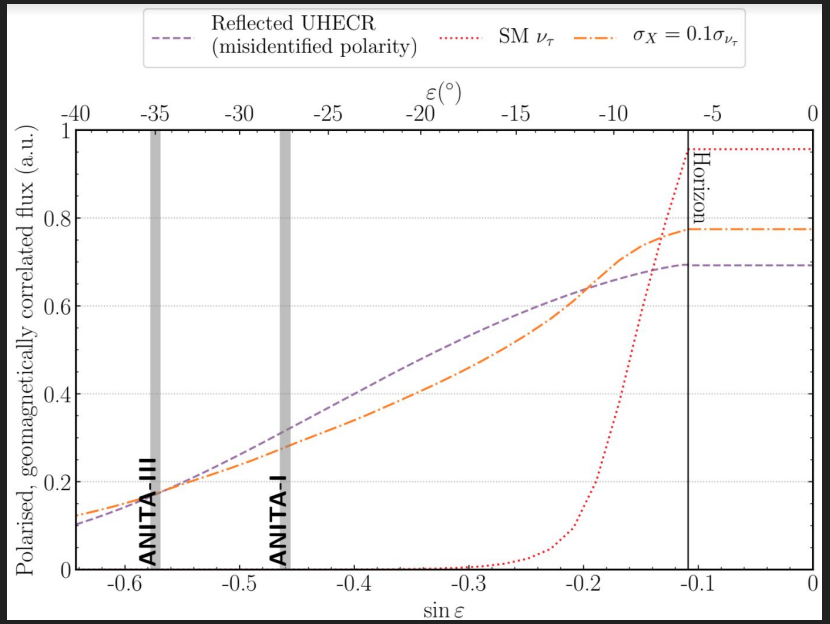
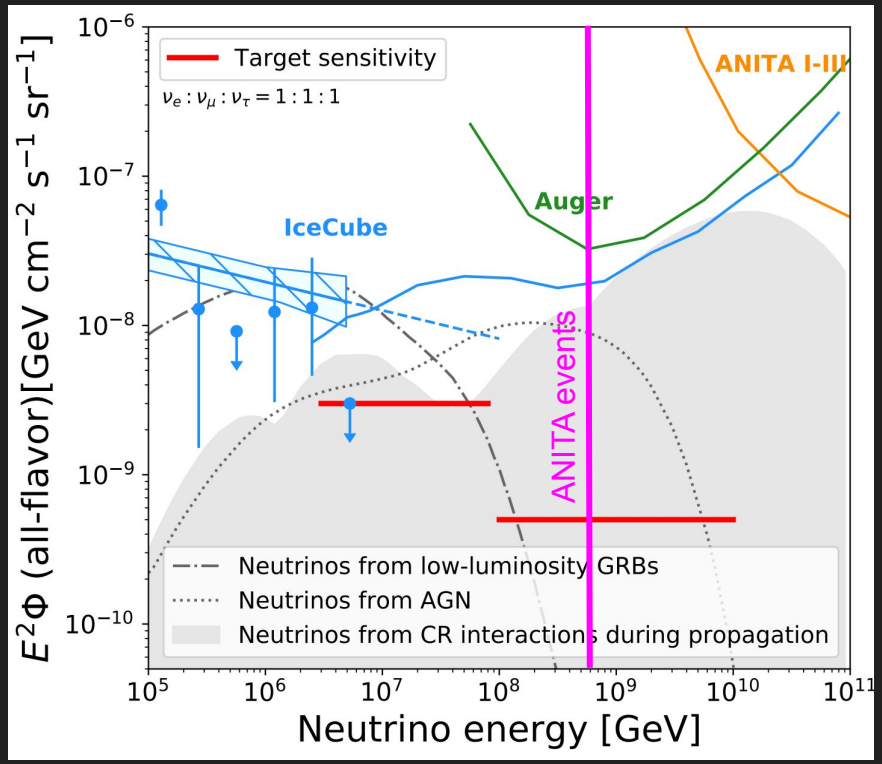
Are these Tau events?



- SM neutrino very unlikely for an isotropic flux, negligible number of events below -15 degrees.
- Smaller cross section may help, but BSM is needed.
- A reflected CR origin is only possible if ANITA misidentified the phase.

For isotropic flux

High energy origin



- Measuring these events at this energies is also in strong tension with IceCube and Auger.
- Previous BSM (steriles, CPT, HeavyDM,...) explanations involve an initial high energy vertex originating a particle cascade. Strong tension with IceCube and Auger due to the energy and larger exposure.

No isotropic flux assumed.

[1809.09615, 1802.01611, 1803.11554, 1804.05362, 1810.08479, 1902.04584, 1904.12865, 1904.13396]

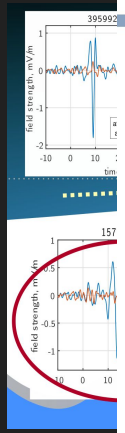
Let's summarize:

Facts:

1. ANITA saw two mysterious events.

2. Direction + IceCube and Auger bounds: strong tension with SM.

3. BSM high energy, O(EeV), explanations disfavored by IceCube and Auger. (arXiv:1909.10487, arXiv:1907.06308)



ICECUBE NEUTRINO OBSERVATORY

About Us Science Collaboration C

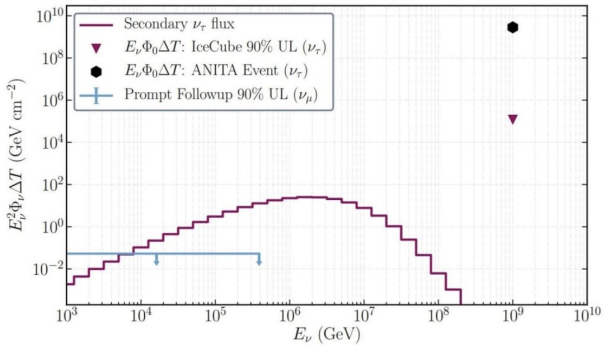
IceCube rules out last Standard Model explanation of ANITA's anomalous neutrino events

Posted on January 8, 2020 by Madeleine O'Keefe

The IceCube Neutrino Observatory is possibly the strangest telescope on Earth. From its home at the South Pole, it sits and waits for fundamental particles called neutrinos to pass through its 5,160 optical detectors buried in the ice. When a neutrino interacts with a hydrogen or oxygen atom in the ice, it produces a signal that IceCube can detect.

But IceCube isn't the only neutrino experiment in Antarctica. There is also the ANITA (the ANtarctic Impulsive Transient Antenna) experiment, which flies a balloon over the continent and points radio antennae toward the ground. ANITA searches for radio waves because *extremely* high-energy neutrinos—those hundreds of times more energetic than the ones that IceCube commonly detects—can produce intense radio signals when they smash into an atom in the ice.

From its balloon flights, ANITA claimed to have detected a few events that appear to be signals of these extremely high-energy neutrinos, so the IceCube Collaboration decided to investigate. In a paper submitted today to *The Astrophysical Journal*, they outline their search for an intense neutrino source in the direction of the events detected by ANITA. The collaboration found that these neutrinos could not have come from an intense point source. Other explanations for the anomalous signals—possibly involving exotic physics—need to be considered.



A Search for IceCube Events in the Direction of ANITA Neutrino Candidates

M. G. Aartsen[1], M. Ackermann[2], J. Adams[1], J. A. Aguilar[3], M. Ahlers[4], M. Ahrens[5], C. Alispach[6], K. Andeen[7], T. Anderson[8], I. Ansseau[3] + Show full author list

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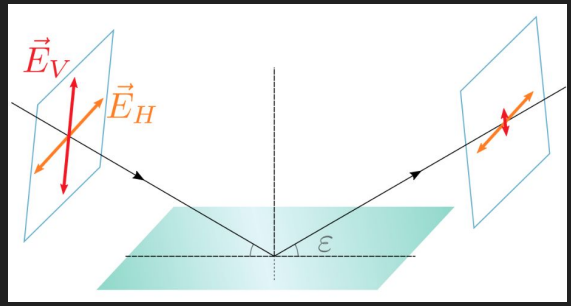
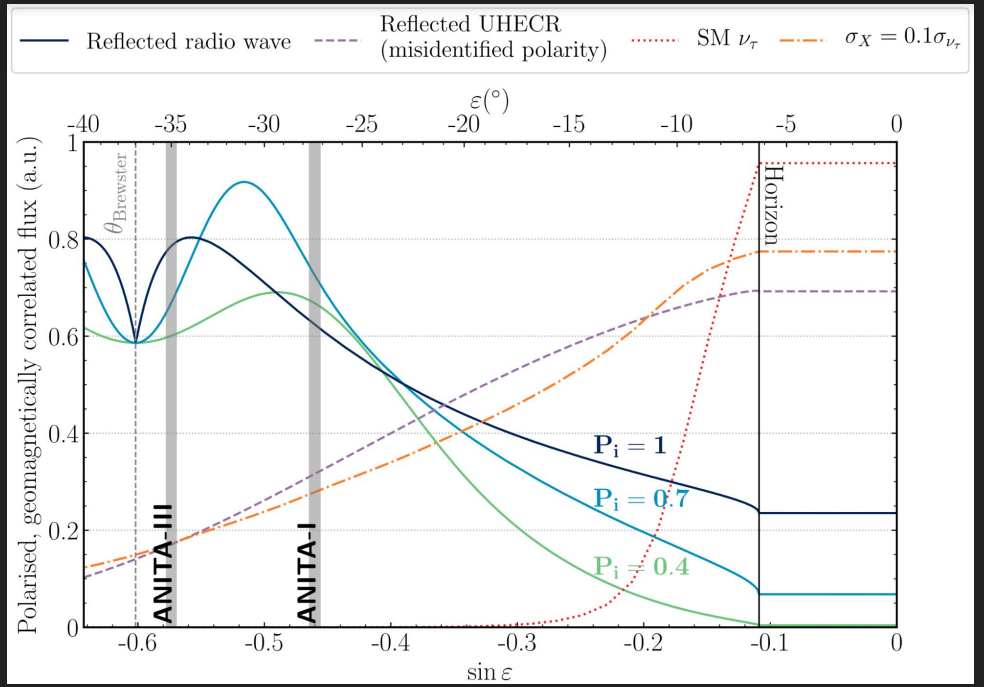
Relevant Observation:

- Any pulse with arbitrary polarization direction will look Hpol ~ geocor ~ CR-like at elevations closer to the Brewster angle (-37 degrees) (2).





Axion Hypothesis

- Can we produce a Radio Pulse with not CR like polarization and phase, but NOT involving High E physics?

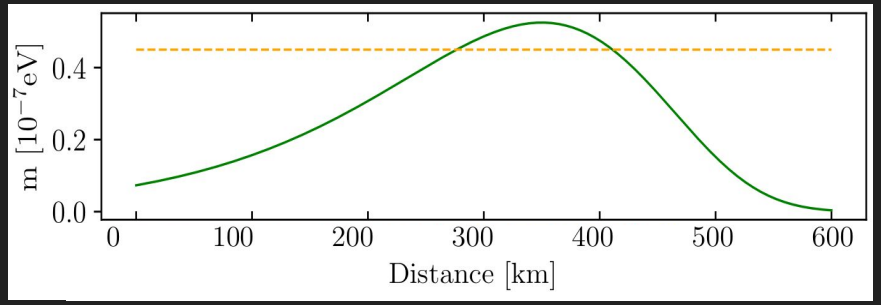
What happens if:

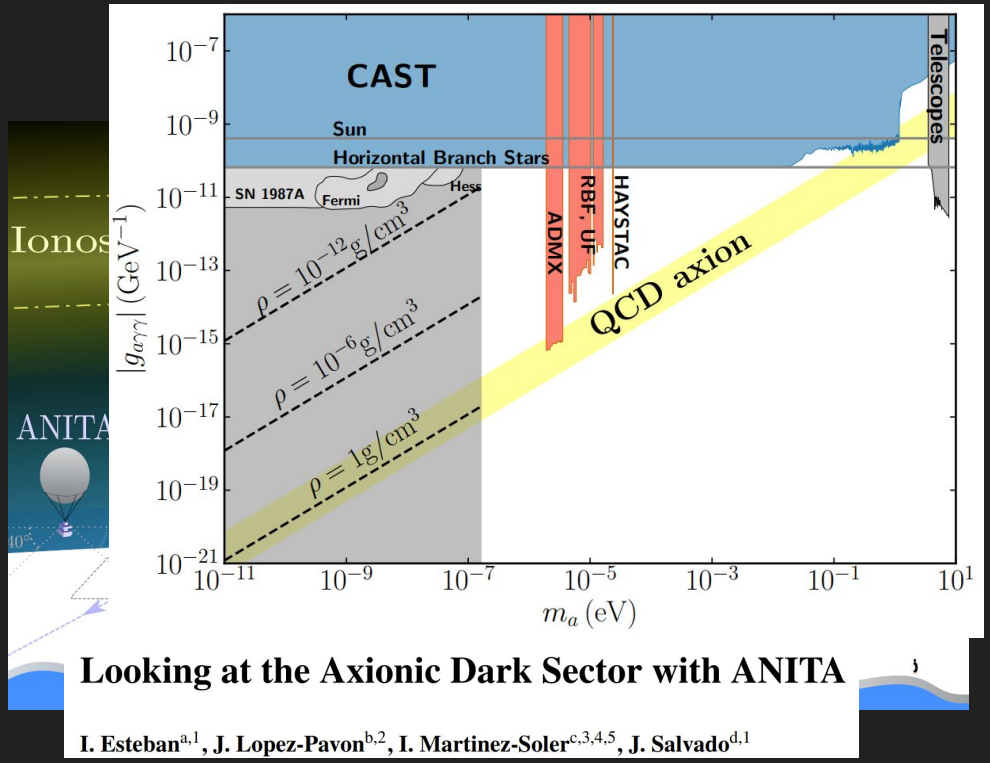
A pulse of Axion DM field with similar temporal, spatial and spectral properties of the measured events arrives to the Earth.

Ionosphere effect: Resonance

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

Chapman-layer ionospheric profile
[Chapman 1931, Kelley:2009]



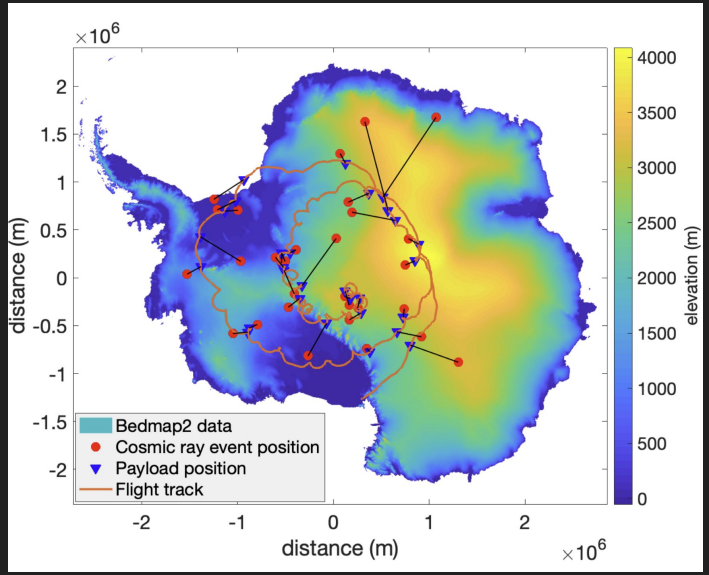


Resonance for typical free electron densities of the ionosphere:

Plasma frequency ~ Axion mass ~ ANITA frequencies !!!

Localized conversion enhancement O(100 - 1000)

ANITA-IV the last flight.
What do we expect?



Phys.Rev.Lett. 126 (2021) 7, 071103 ANITA collaboration.

Phys.Rev.D 105 (2022) 4, 042001 ANITA collaboration.

Last flight ANITA IV

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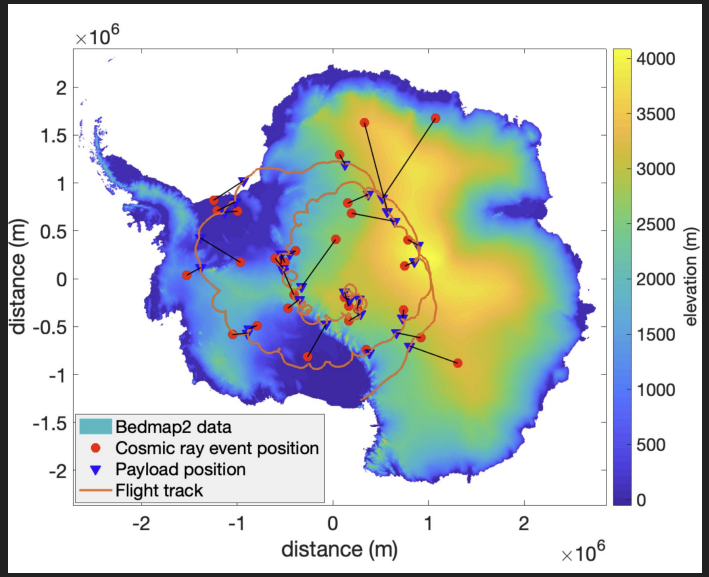

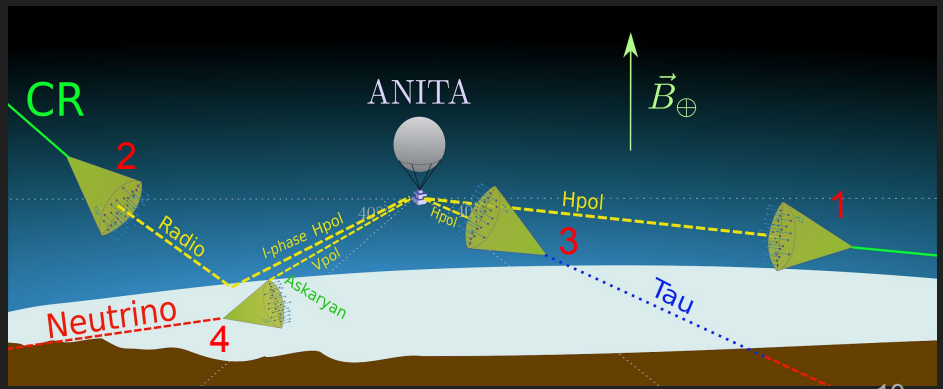

Phys.Rev.Lett. 126 (2021) 7, 071103 ANITA collaboration

Last flight ANITA IV

event #	mm dd hh mm ss UTC 2016	Apparent source location Lat.°,Lon.°, alt., m	elev. angle[a] degrees
4098827	12 03 10 03 27	-75.71, 123.99, 3184	-6.17 ± 0.21
9734523	12 05 12 55 40	-71.862, 32.61, 19000[b]	-5.64 ± 0.20
19848917	12 08 11 44 54	-80.818 , -79.87, 758	-6.71 ± 0.20
50549772	12 16 15 03 19	-83.483, 14.73, 2572	-6.73 ± 0.20
51293223	12 16 19 08 08	-74.800, 11.43, 18600[b]	-5.38 ± 0.24
72164985	12 22 06 28 14	-86.598, 0.35, 2589	-6.12 ± 0.10

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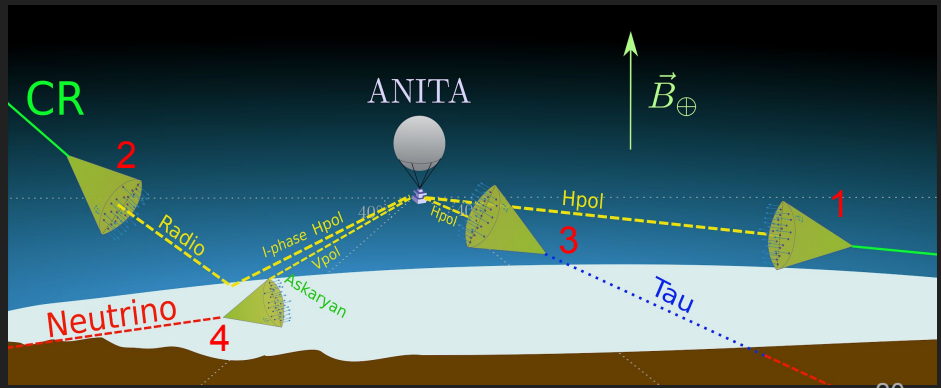
But something changed!

- Elevation is ***much closer*** to the horizon for all 4 events.



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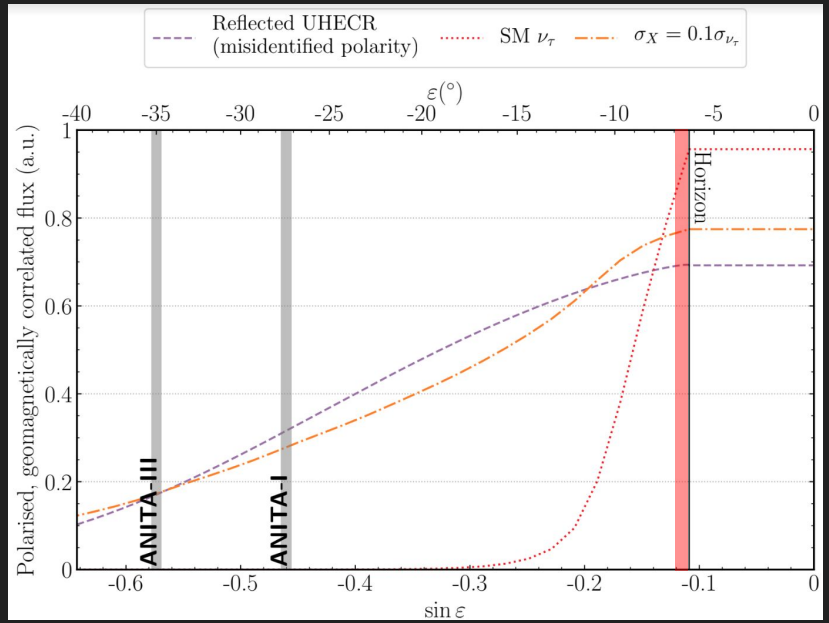
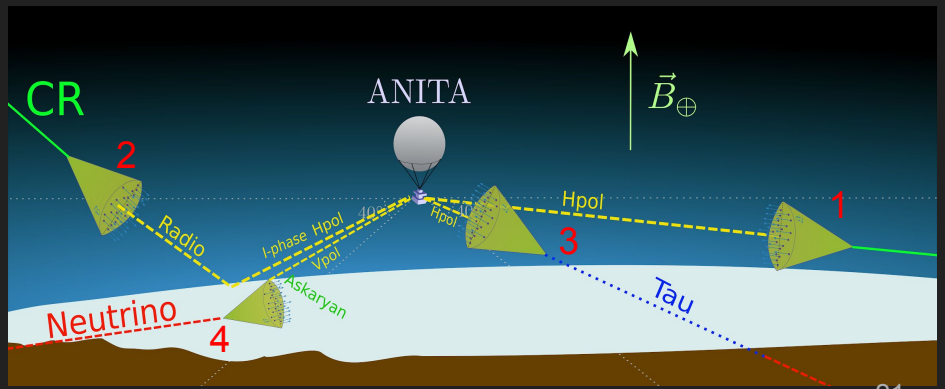
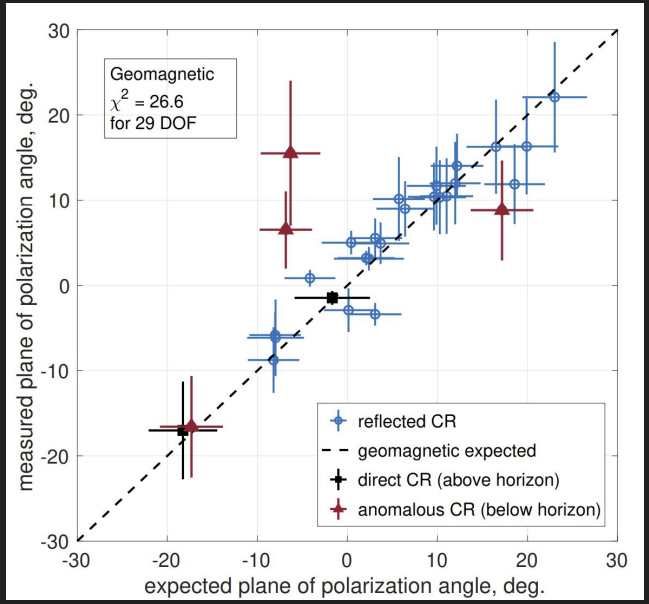
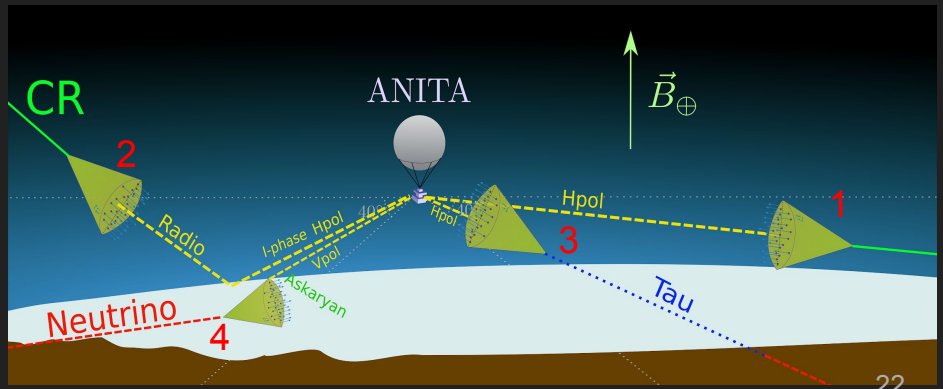




Last flight ANITA IV

- **What about the polarization?**
  a. Axion Hypothesis (forced low energy to avoid IceCube) — They may not be necessary geocorr.
  b. Is this moving towards the high energy hypothesis? Maybe not SM, but BSM?





High E BMS with ANITA IV

IceCube and the origin of ANITA-IV events

Toni Bertólez-Martínez,[a] Carlos A. Argüelles,[b] Ivan Esteban,[c,d] Jacobo Lopez-Pavon,[e] Ivan Martinez-Soler,[b] Jordi Salvado[a]

- We will not take very seriously the hypothesis of a population of transient astrophysical sources located in very different parts of the universe that flash ultra high energy neutrinos every few days **BUT only when the ANITA balloon is in the air**.

Despite this, it can still be tested for example in IceCube: ANITA IV results will imply naivelly O(1) events in IceCube for O(10yrs). For SM with the production of secondaries may be excluded for some of the events.

Last flight ANITA IV

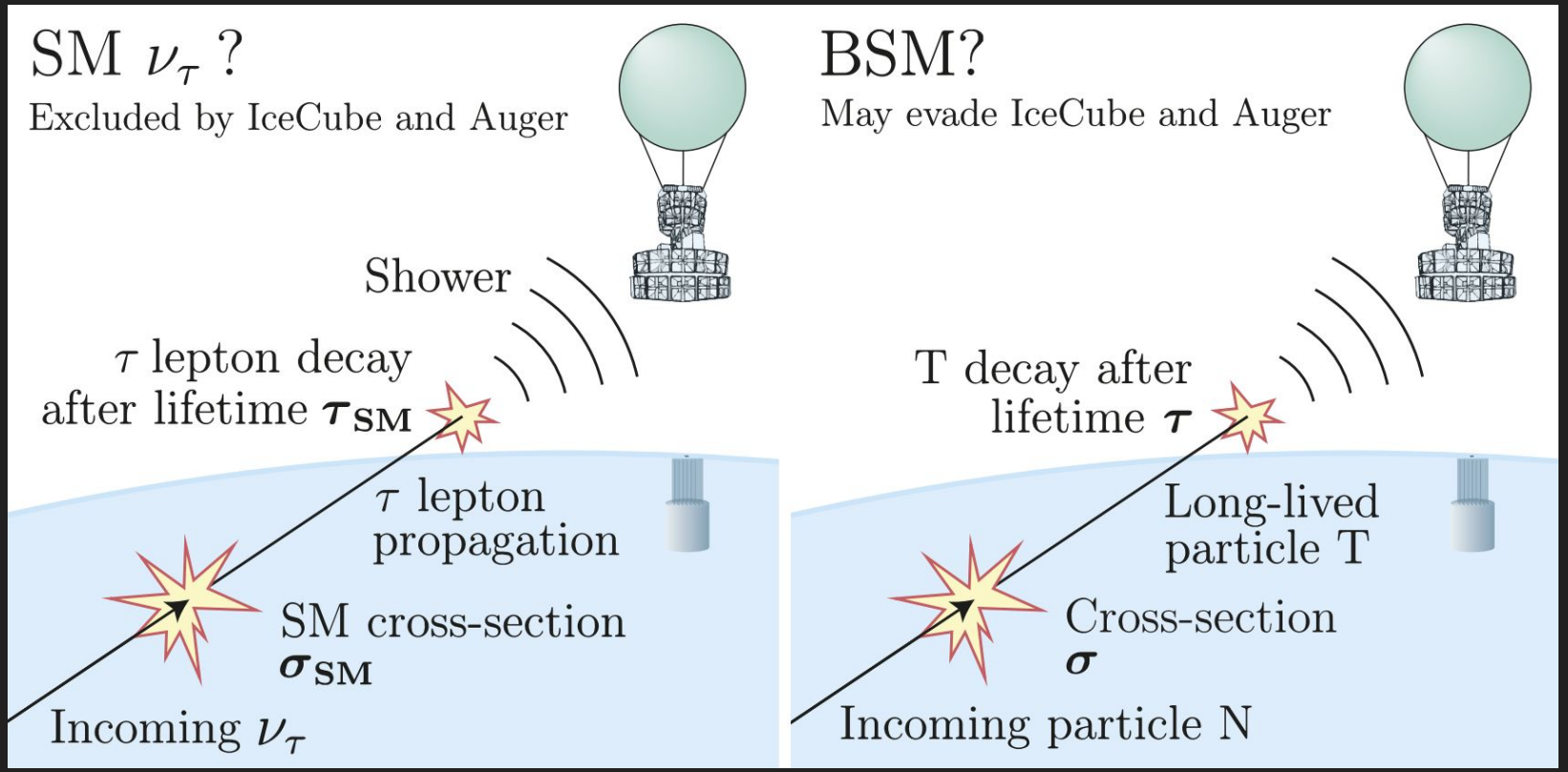
Assumptions:

- Isotropic flux.
  - A population of transients with the average observed rate should be equivalent.

- The source only emits in ultra high energy range of the ANITA observed events.
  - Any astrophysical source should produce a low energy contribution but we will focus on BSM, ex. DM decay, …

Last flight ANITA IV

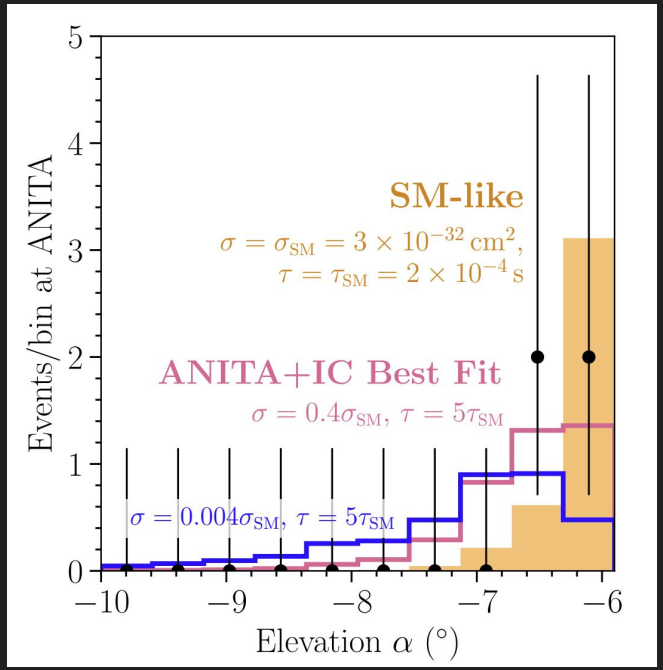
Generic BMS scenario:

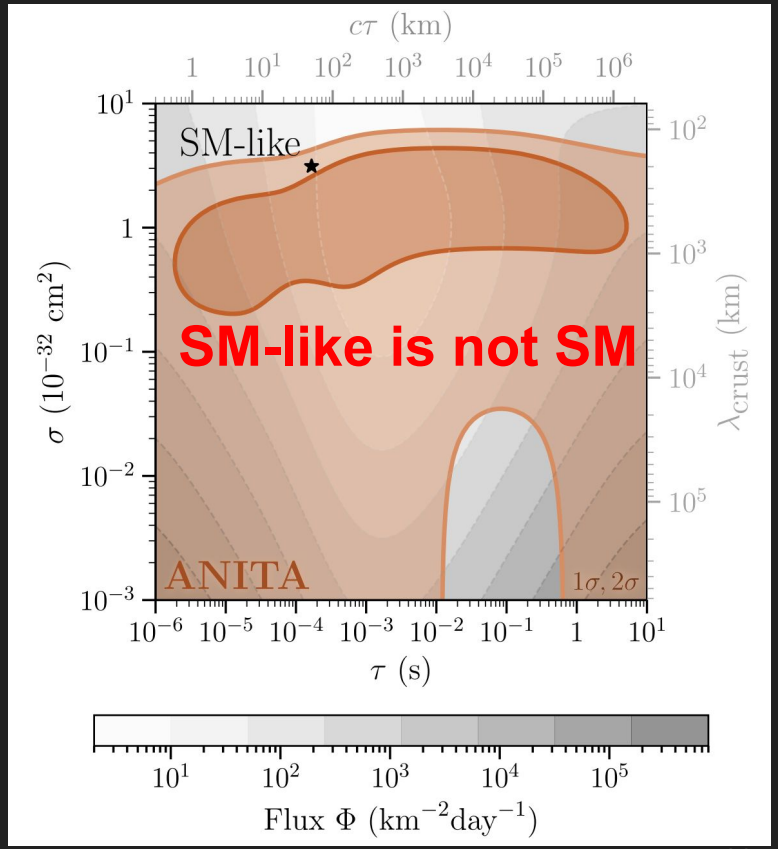


Last flight ANITA IV

ANITA self consistency (Example: I and III events)

The relevant information is in the angular distribution.



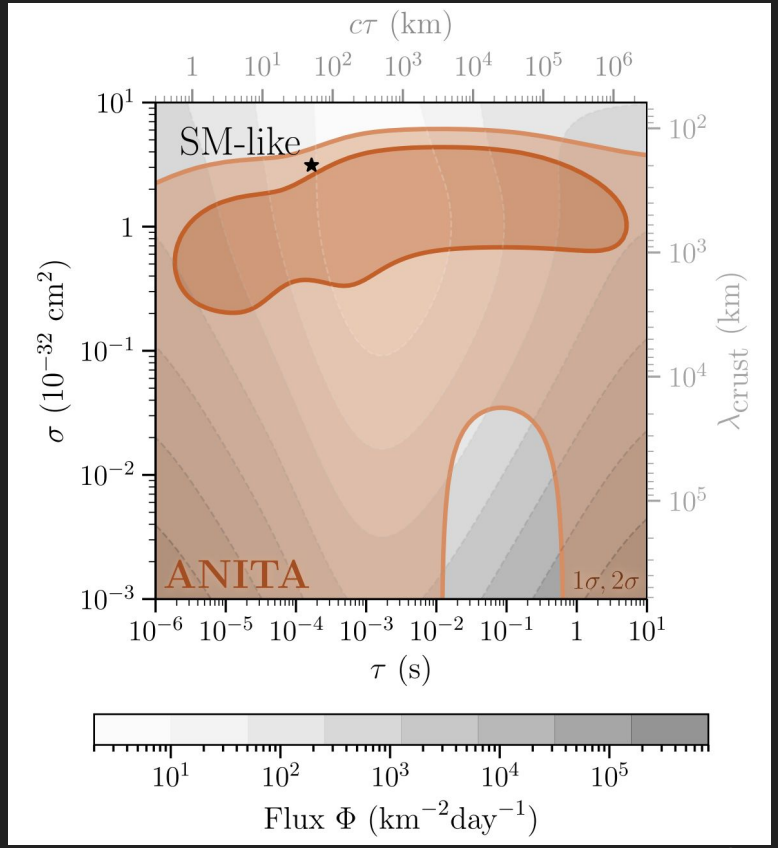


Last flight ANITA IV

ANITA self consistency *(This is enough to force BMS in ANITA I and III)*

The relevant information is the angular distribution.

- **ANITA itself can put a bound to high cross section values (keep in mind for the future).**



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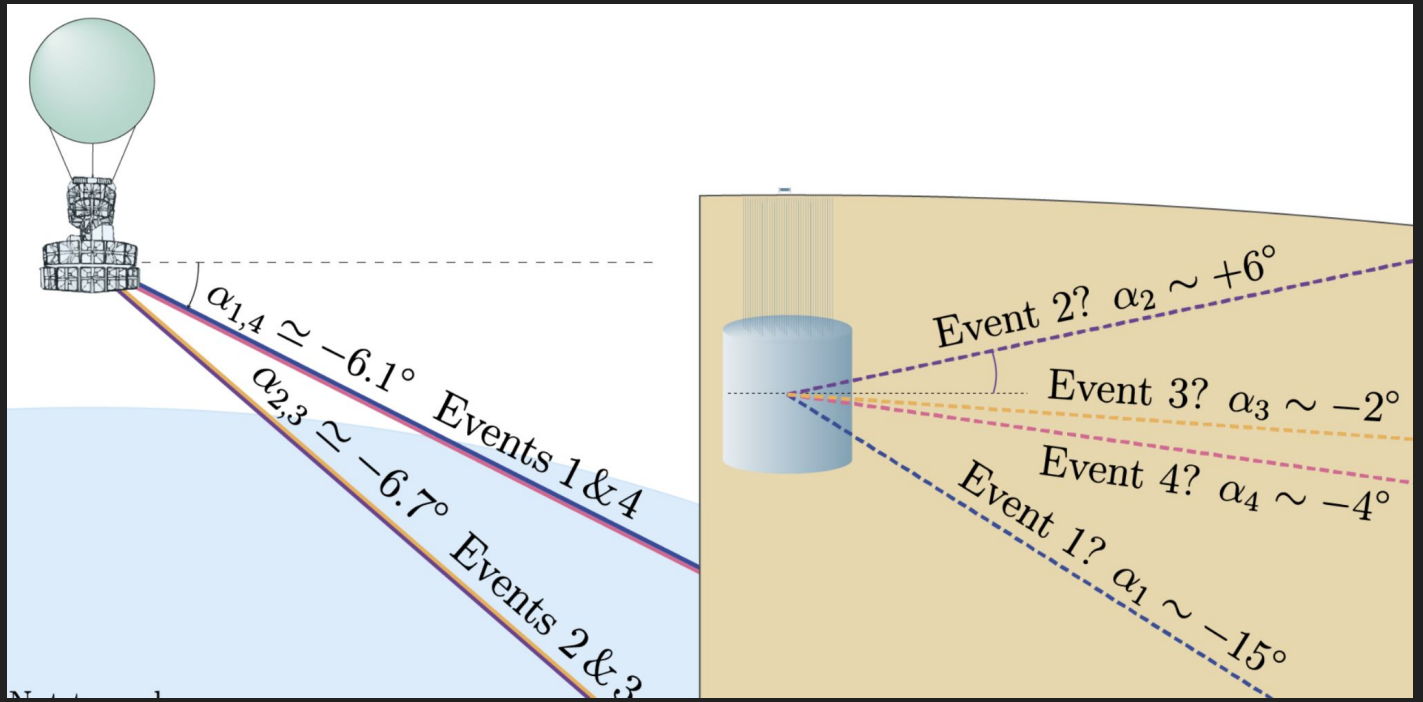
ANITA and IceCube

Where do they come from?



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ANITA and IceCube

The no observation by

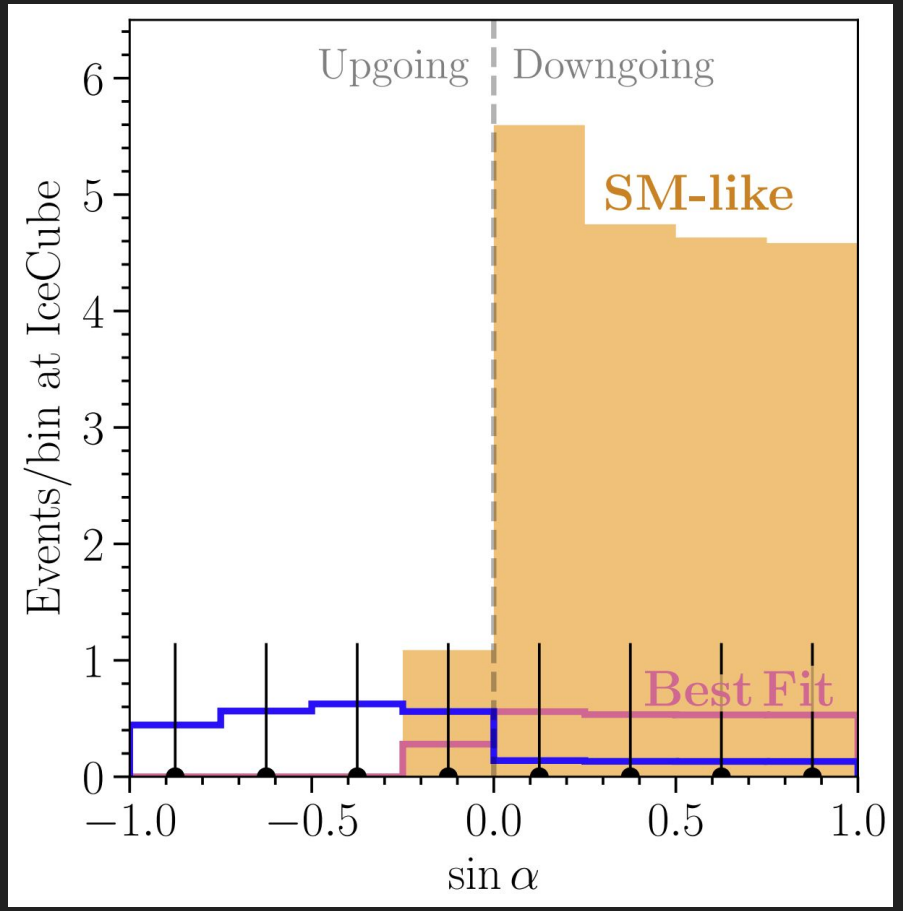
IceCube

SM-like

$\sigma = \sigma_{\rm SM} = 3 \times 10^{-32}\,{\rm cm}^2$,
$\tau = \tau_{\rm SM} = 2 \times 10^{-4}\,{\rm s}$

ANITA+IC Best Fit

$\sigma = 0.4\sigma_{\rm SM},\ \tau = 5\tau_{\rm SM}$
$\sigma = 0.004\sigma_{\rm SM},\ \tau = 5\tau_{\rm SM}$



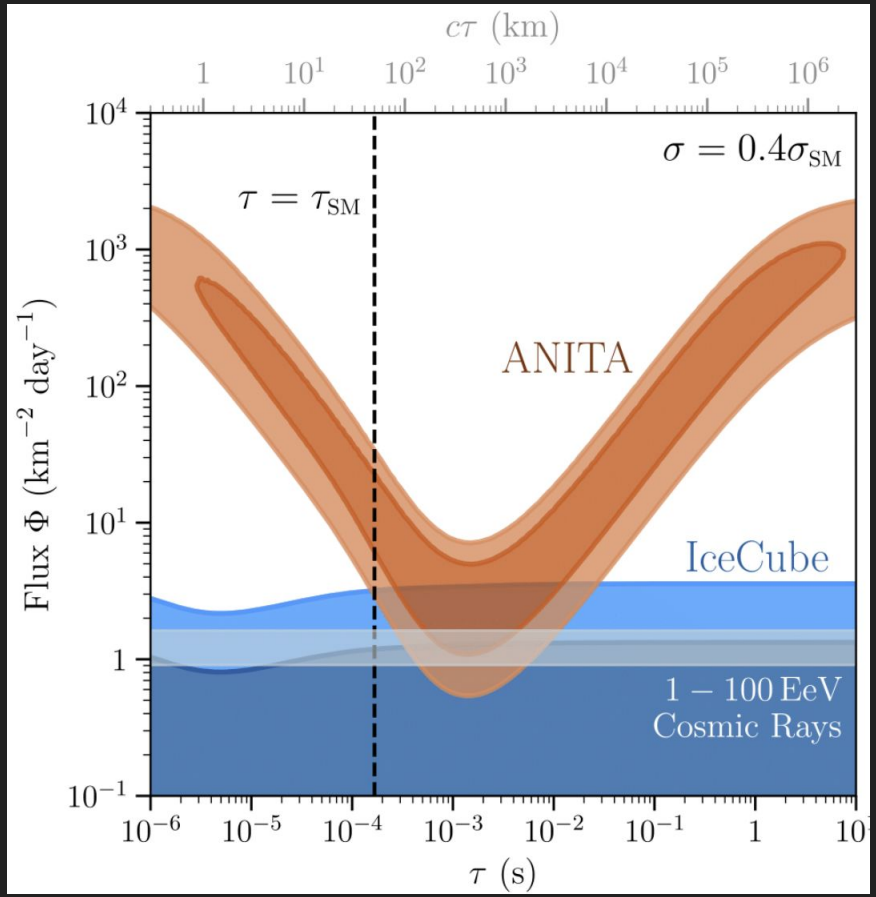
Last flight ANITA IV

ANITA and IceCube

The no observation by IceCube can be accommodated with the ANITA result in BSM with relatively large fluxes.

O(10) the expected for neutrinos at this energies, similar to the UHECR in 1-100EeV

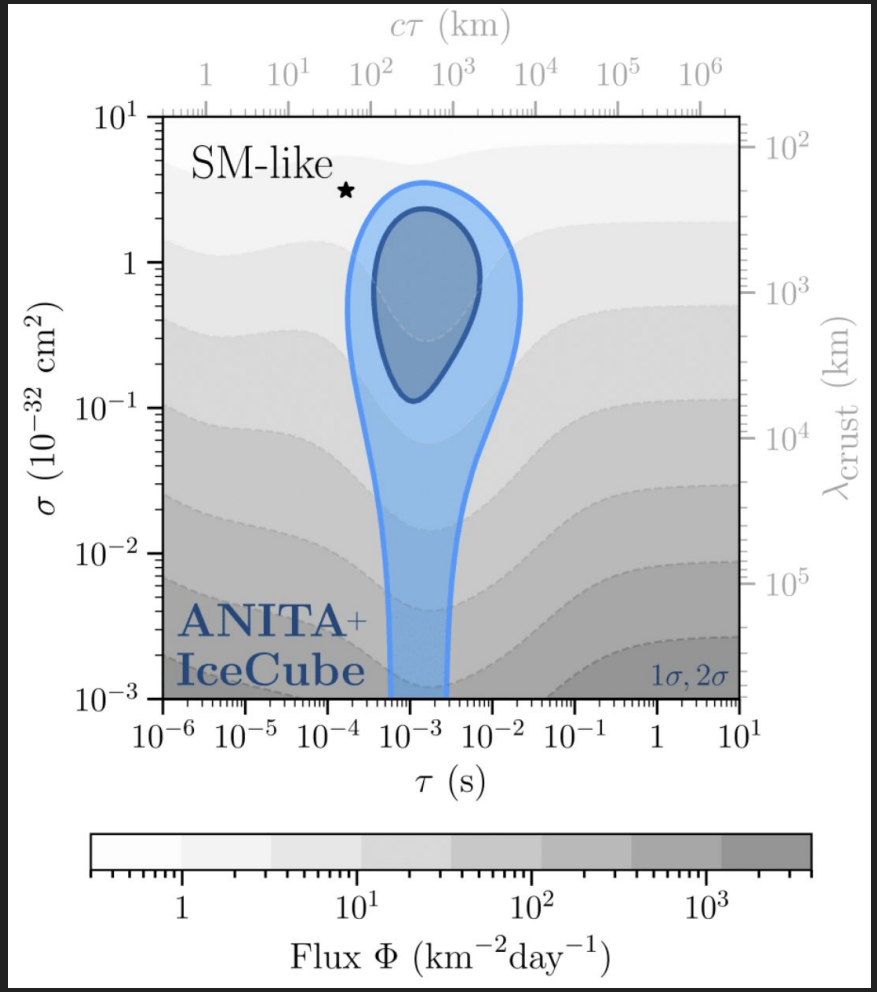
In BSM scenario this can be achieved by heavy DM-decay.



ANITA IV + IC

The combined result strongly constrains the parameter space for BMS physics.

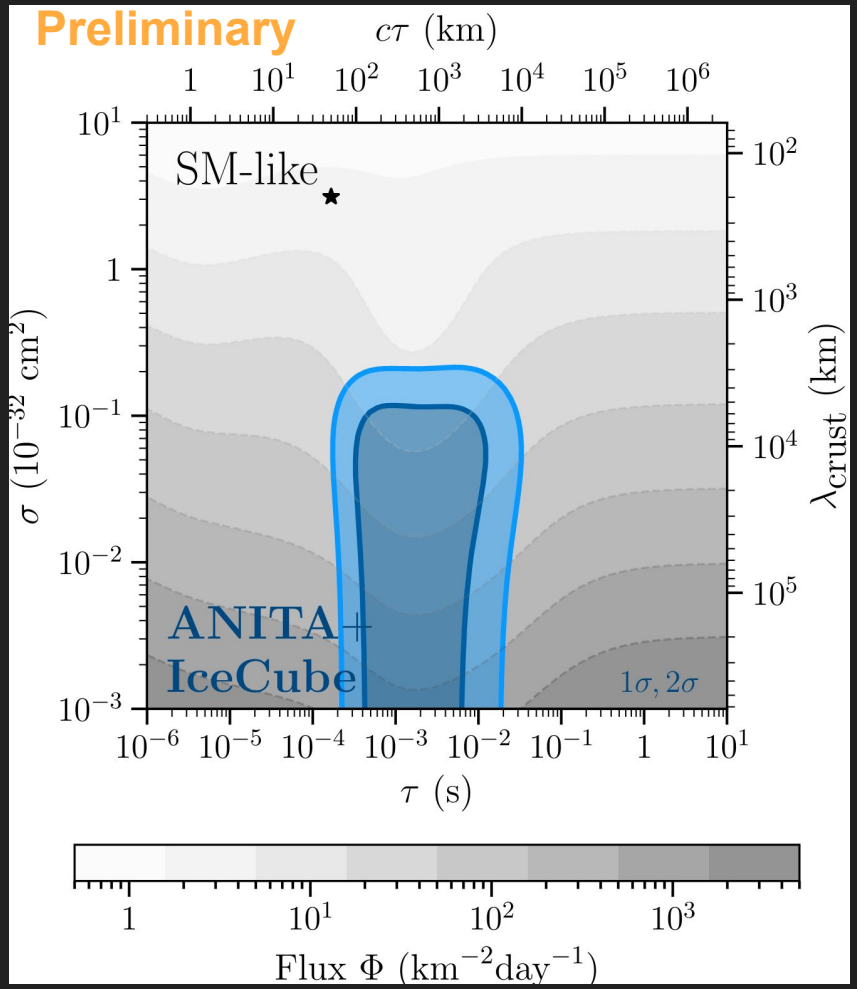
The best fit predicts O(1) event in IceCube. Consistent with not observing.



ANITA I+III+IV+IC

But may be we should not discard the last ANITA events in the scenario?

The tension by ANITA itself and with IC is much higher. They seem hard to accommodate.



Conclusions

Today:

- ANITA has measured 2+4 intriguing CR like upgoing events.
- A high energy SM explanation for all the events is already unlikely by ANITA itself.
- For the 4 ANITA IV event SM can be accommodated but in tension with IceCube.

In the near future with more experiments:
(PUEO, IceCube Gen2, KM3NeT, …)

- We may confirm the “existence” of this type of events.
- (high E vs low E) IceCube, KM3NeT, Auger,... should see this if it involves high energies (SM or beyond).
- If they don’t, only low energy explanations will survives and a proper analysis for every hypothesis will be necessary (ex. Axion hypothesis).

Thanks!