

# Anomalous radio signals: ultra-high-energy neutrinos or new physics?

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Niels Bohr Institute, University of Copenhagen

NBIA N-Talk

Copenhagen, November 23, 2018

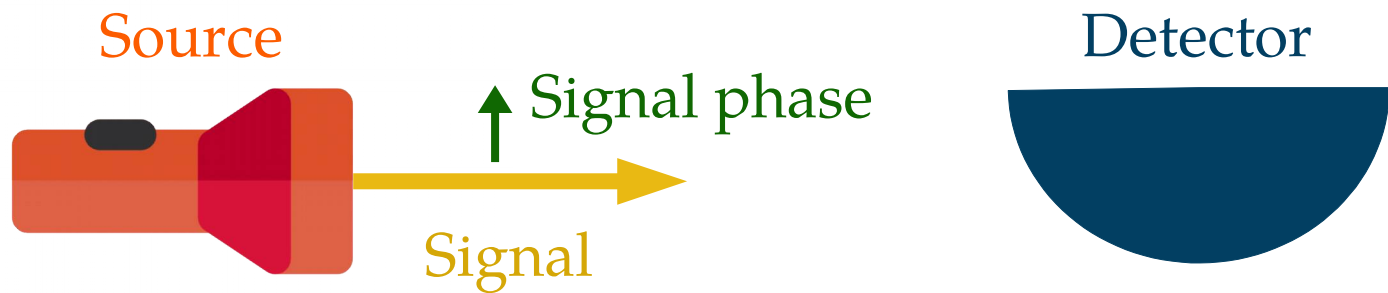
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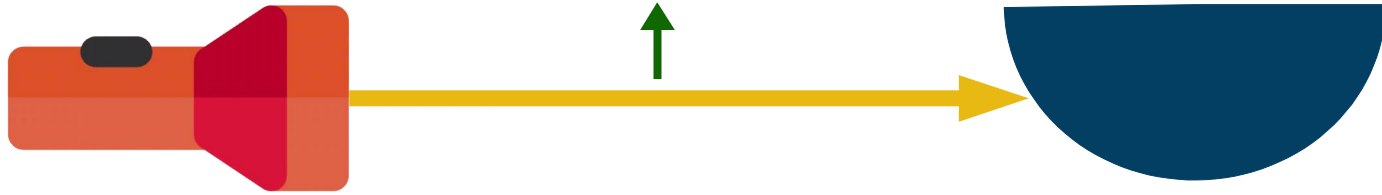
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VILLUM FONDEN

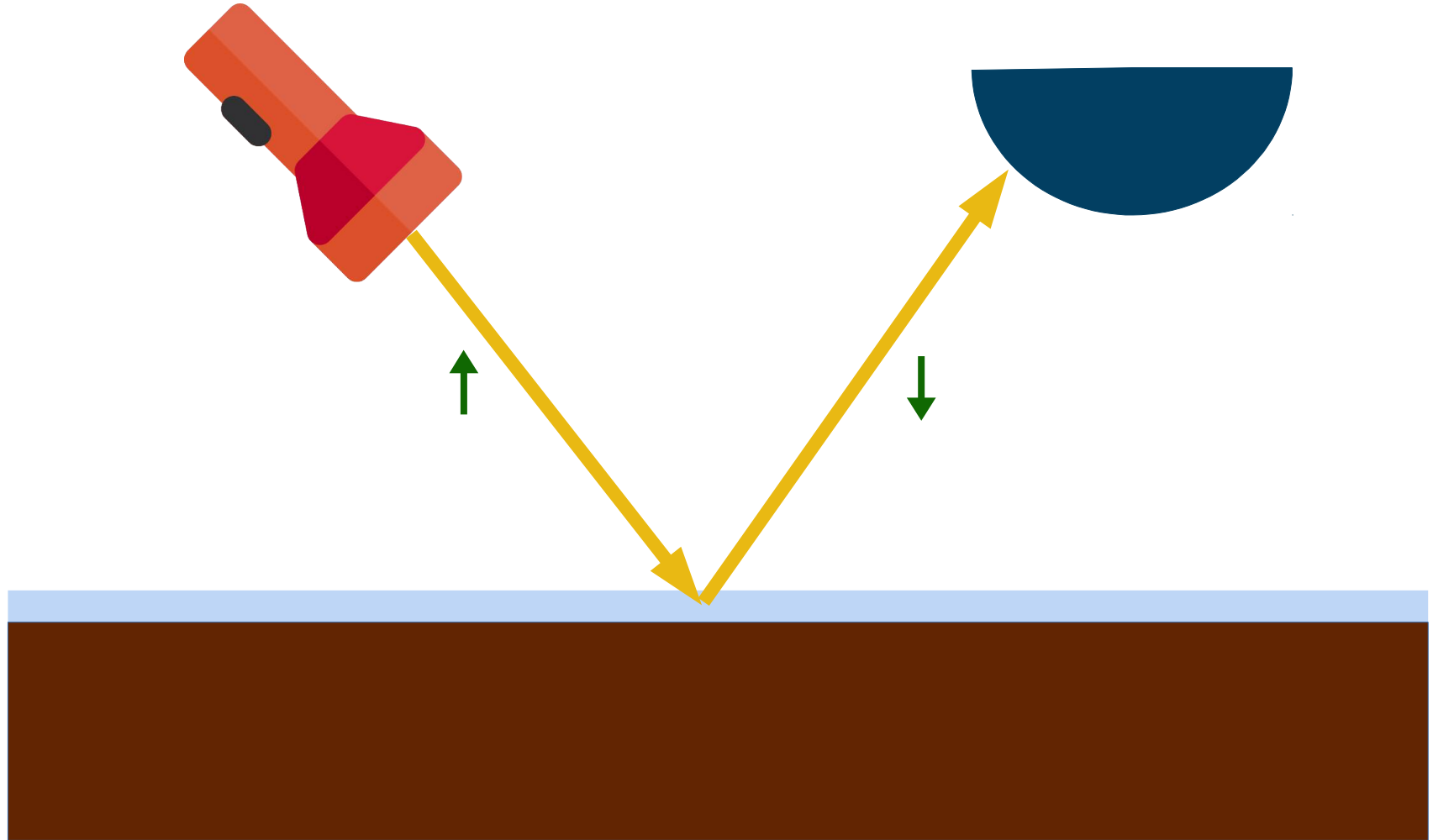




Case 1: No reflection  $\rightarrow$  no phase flip

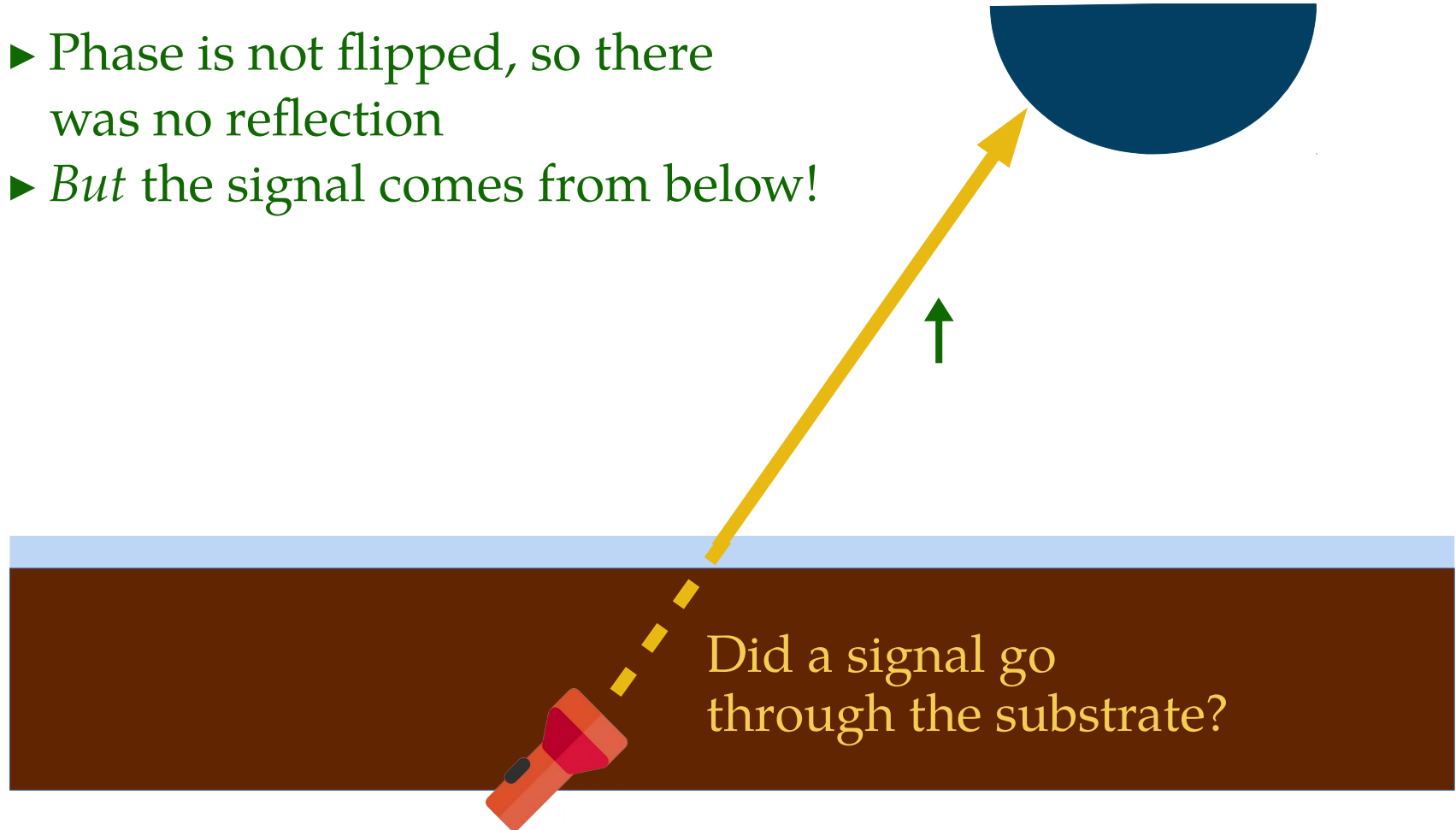


## Case 2: Reflection $\rightarrow$ phase flip



## But what if we saw this?

- ▶ Phase is not flipped, so there was no reflection
- ▶ *But* the signal comes from below!



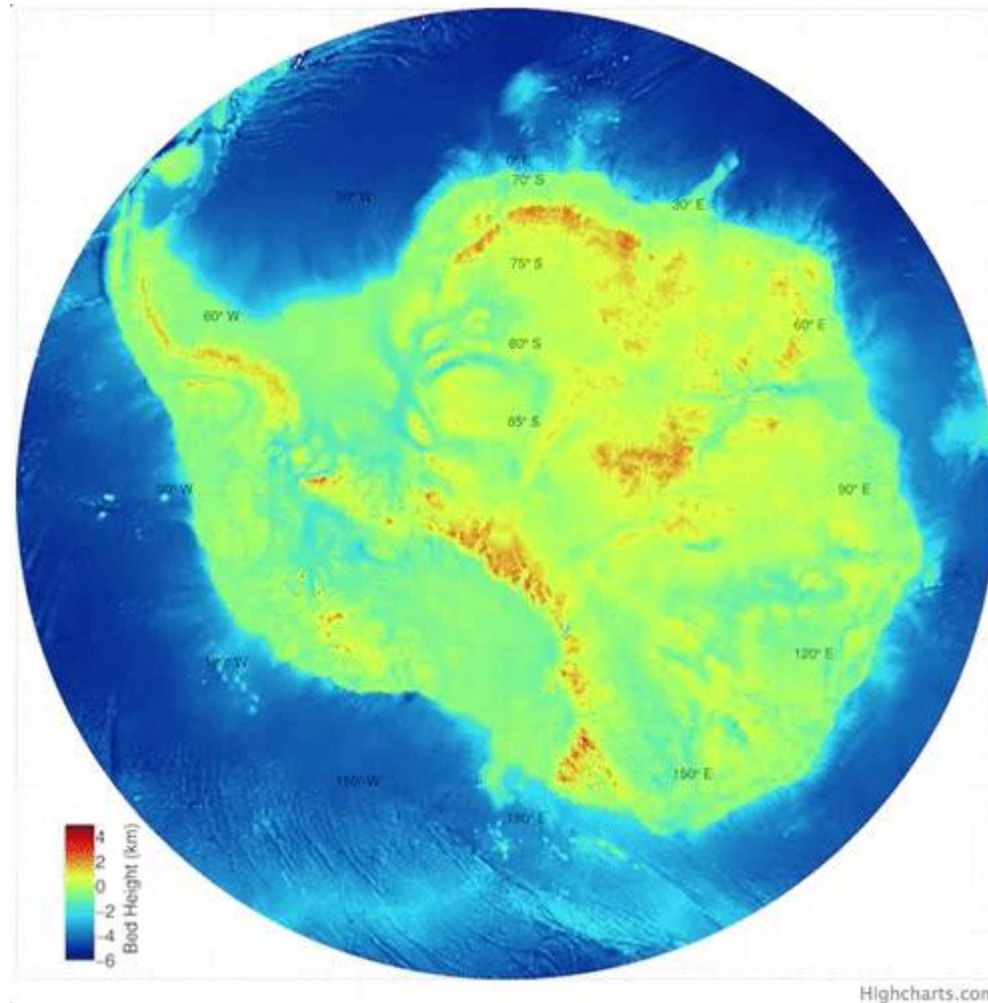
# ANITA: Antarctic Impulsive Transient Antenna



Photo by Spencer Klein



Photo by Brian Hill/U. Hawaii-Manoa



ANITA-IV flight path (Credit: UCL)

Atmosphere

Extensive  
air shower



Incoming ultra-high-energy  
cosmic ray ( $> 10^8$  GeV)



Proton in the air

Pion  $\pi^+$

Neutron  $n$

Neutrino  $\bar{\nu}_\mu$

Proton

$\bar{\nu}_e$

Muon  $\mu^+$

Positron  $e^+$

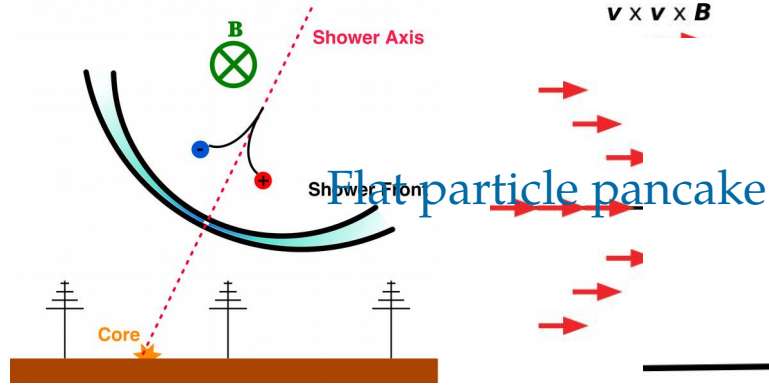
Photons





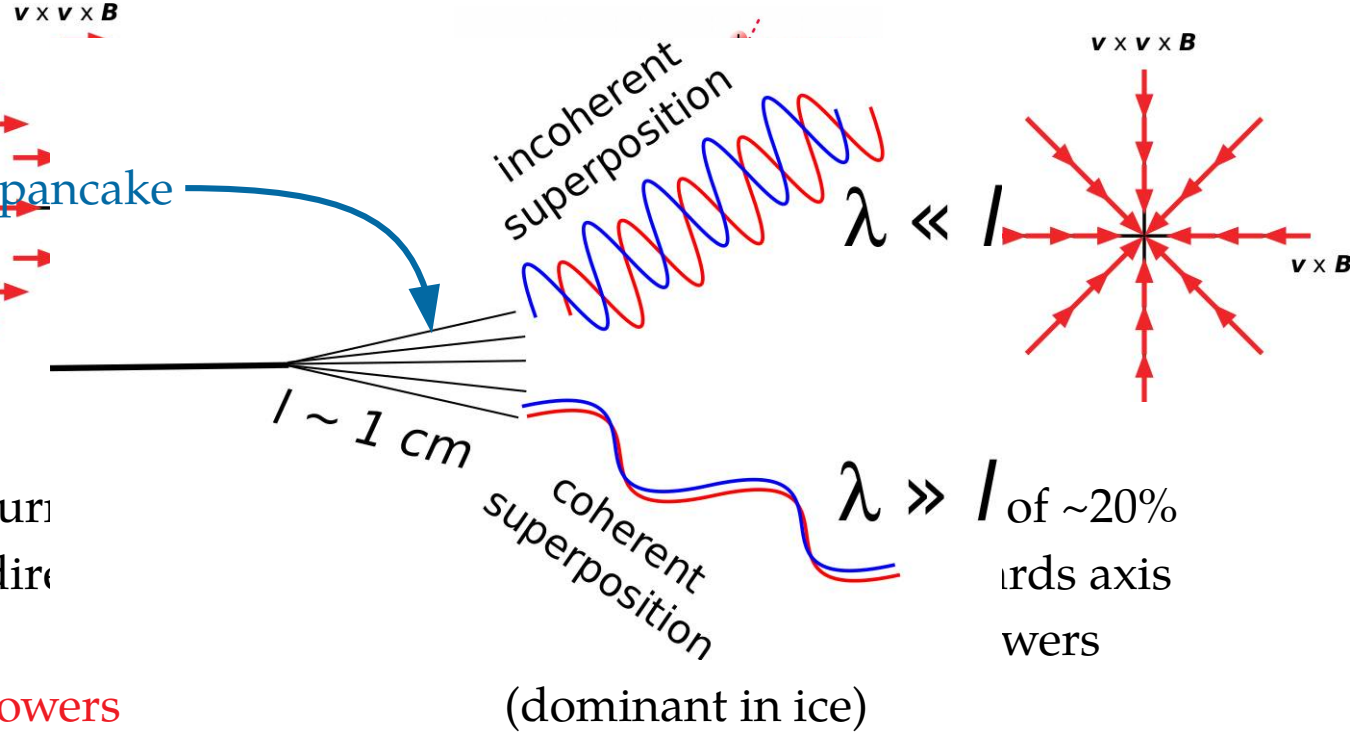
# Radio emission from air showers

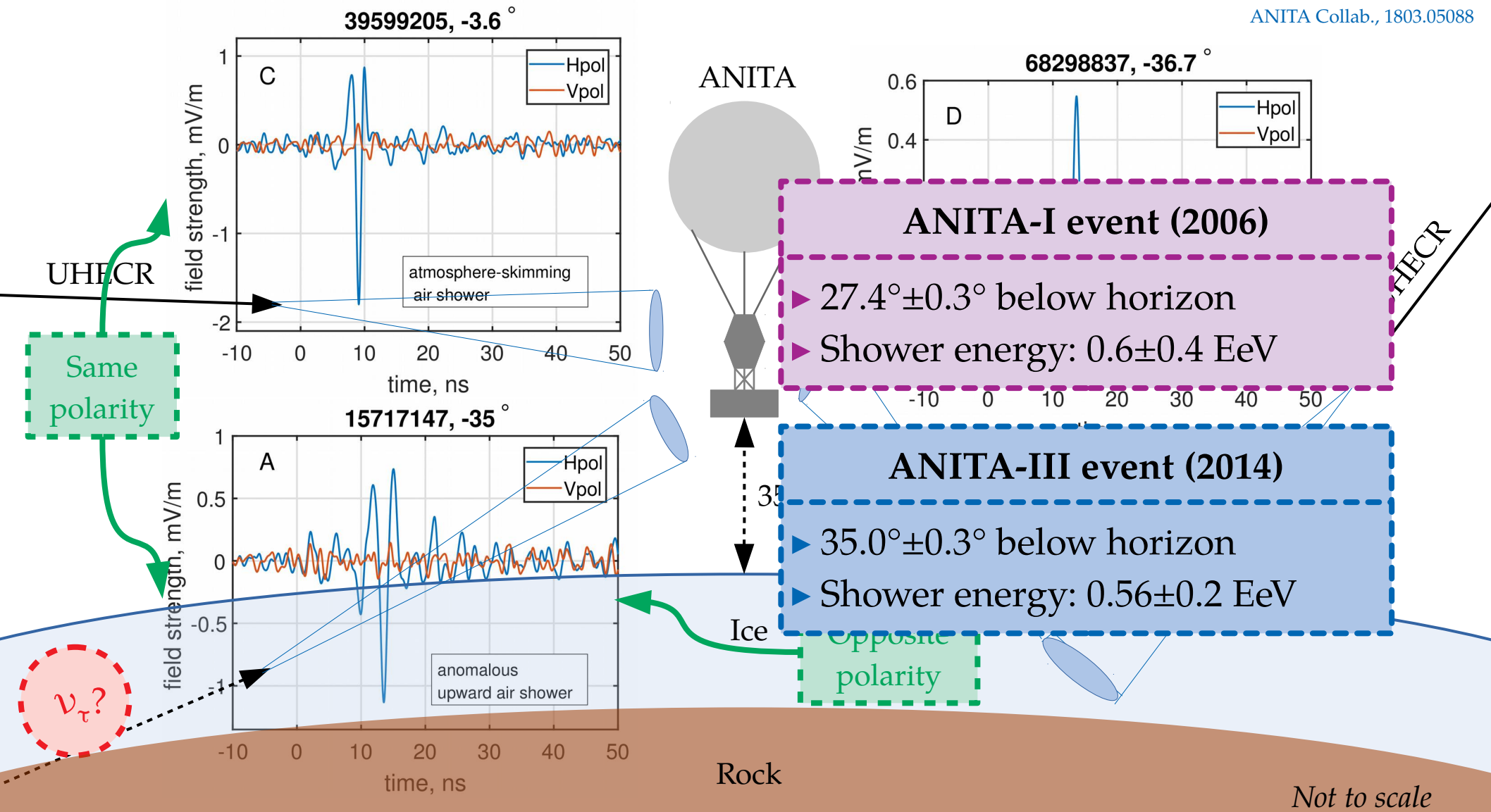
## Geomagnetic

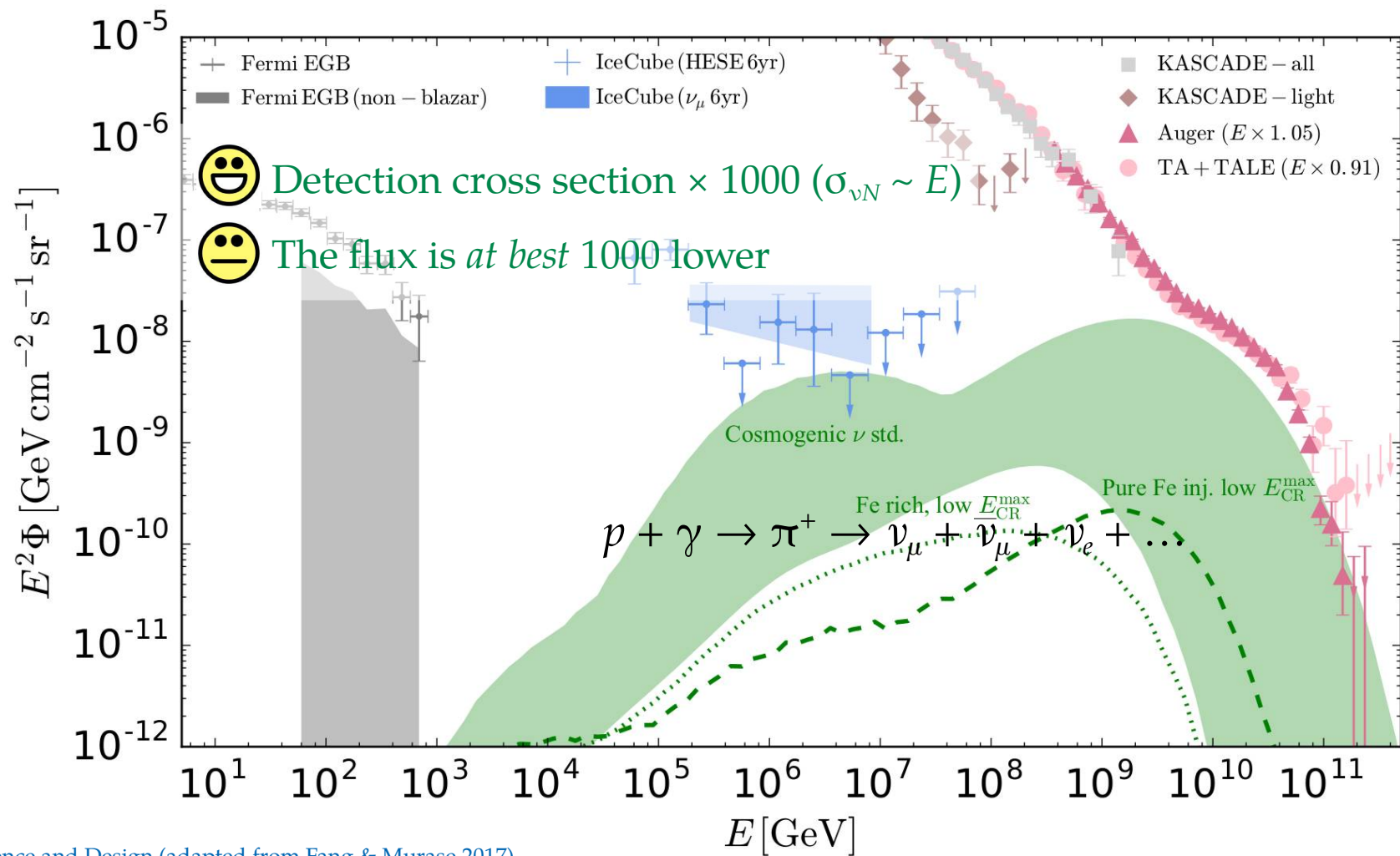


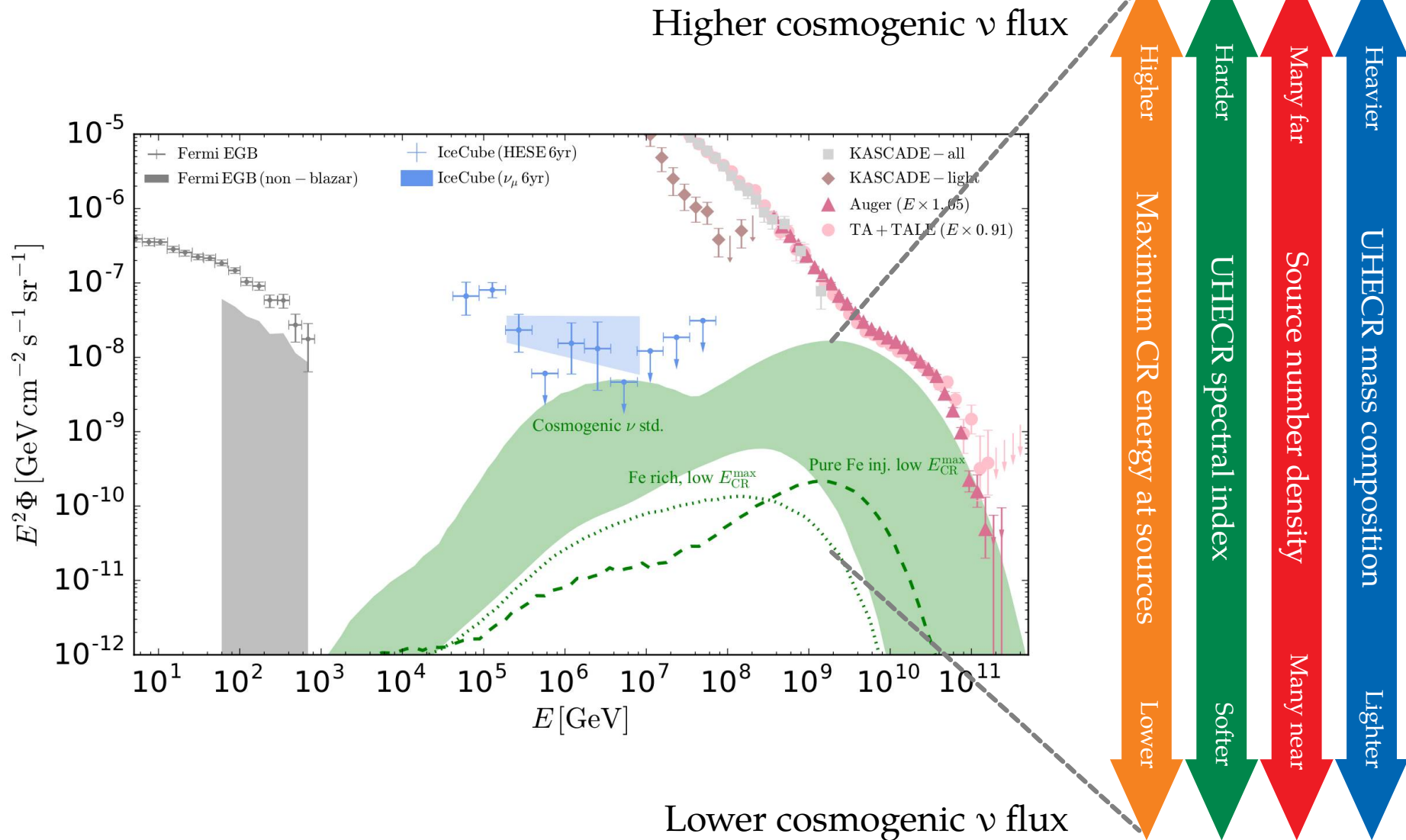
- ▶ Time-varying transverse current
- ▶ Linearly polarized in the direction of the Lorentz force
- ▶ **Main mechanism in air showers**

## Askaryan



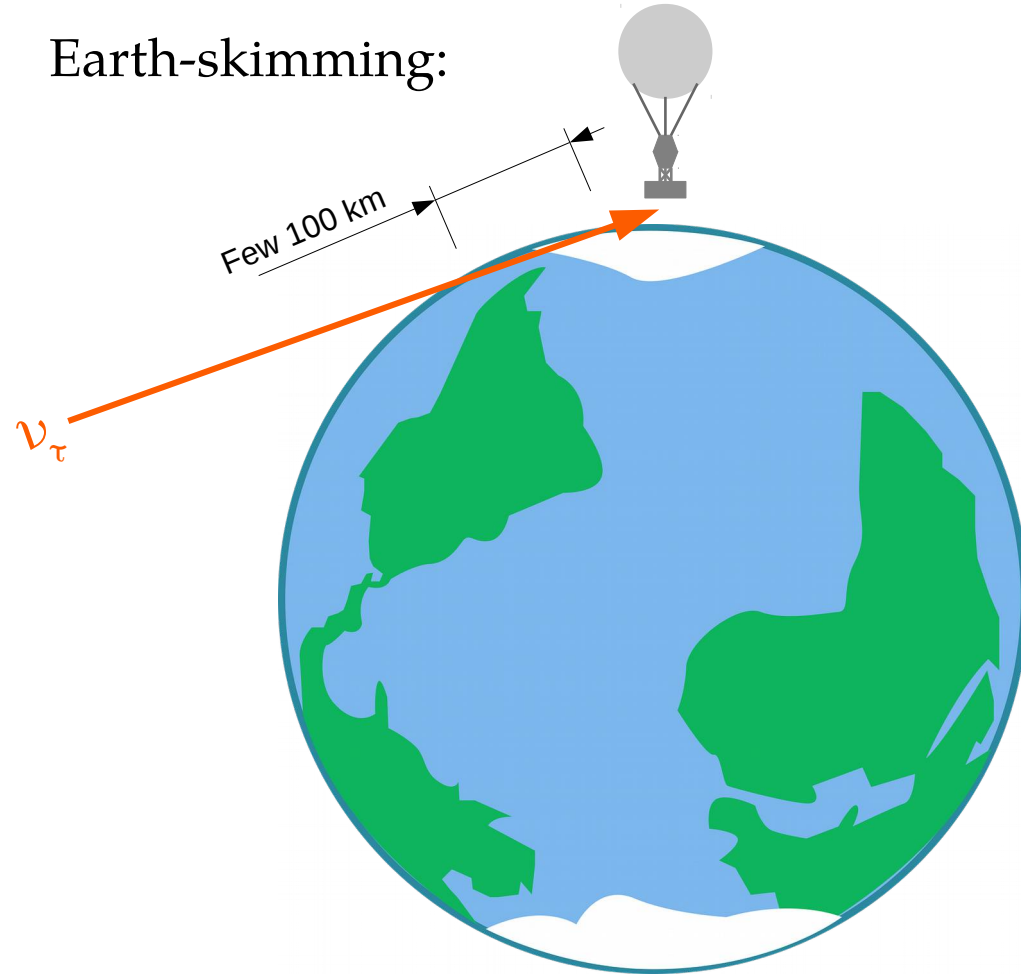




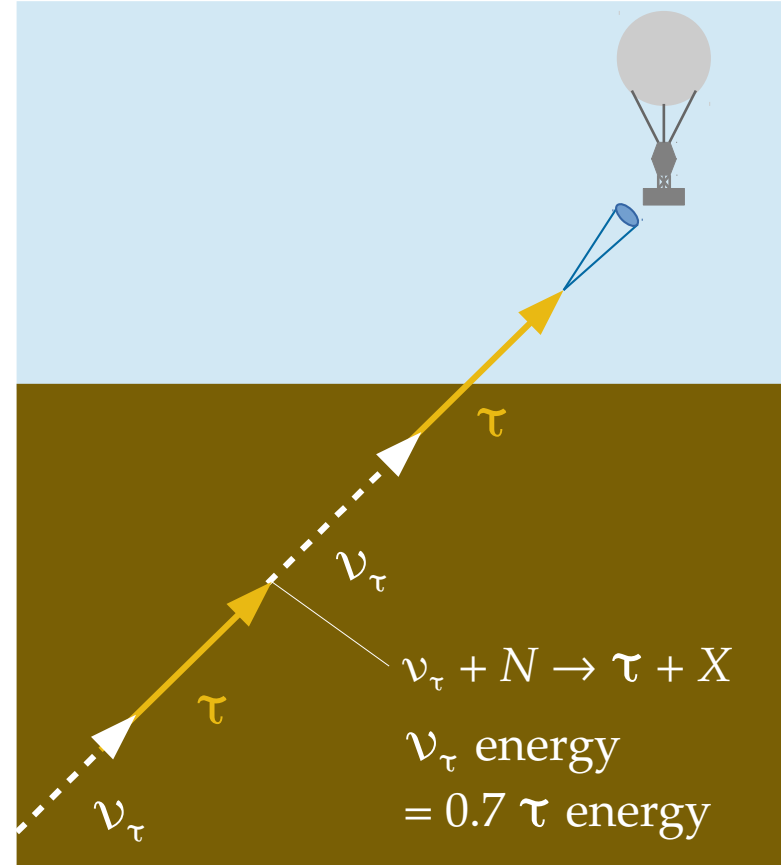


# Neutrinos: Earth-skimming *vs.* Earth-crossing

Earth-skimming:

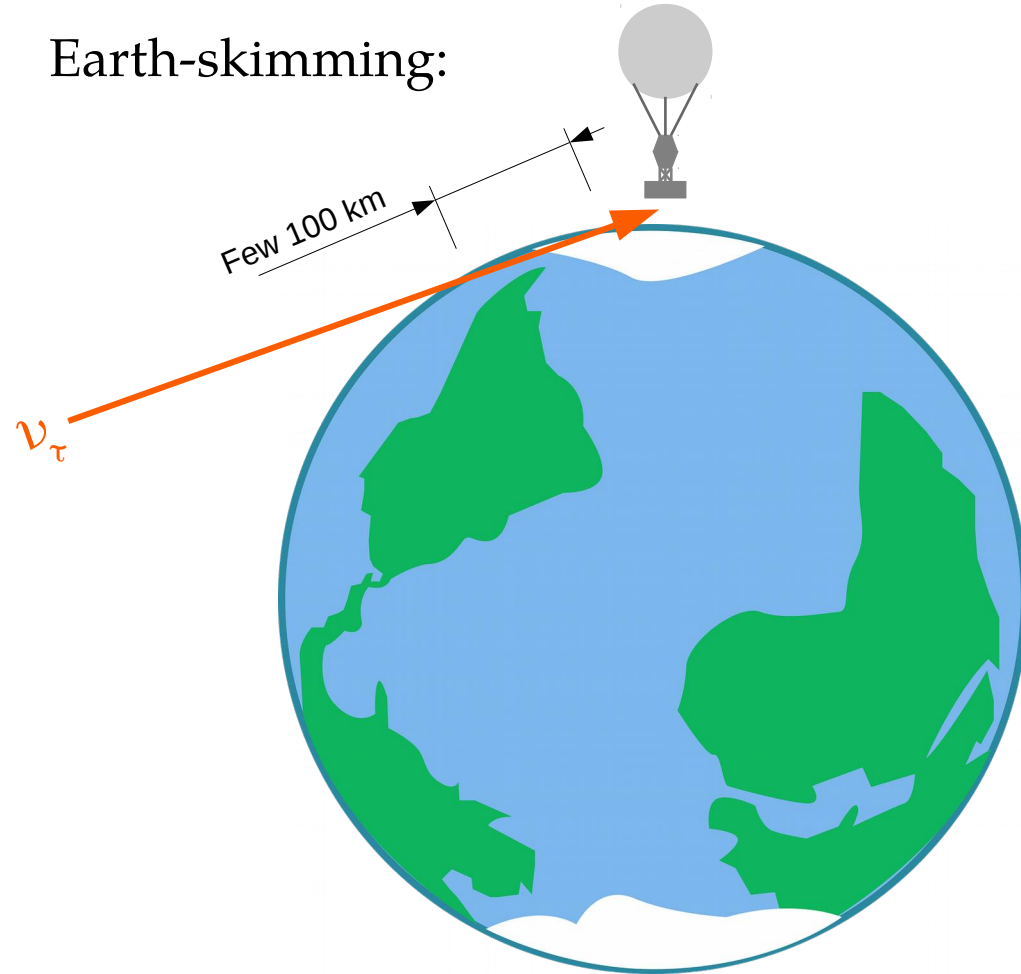


Neutrino regeneration:

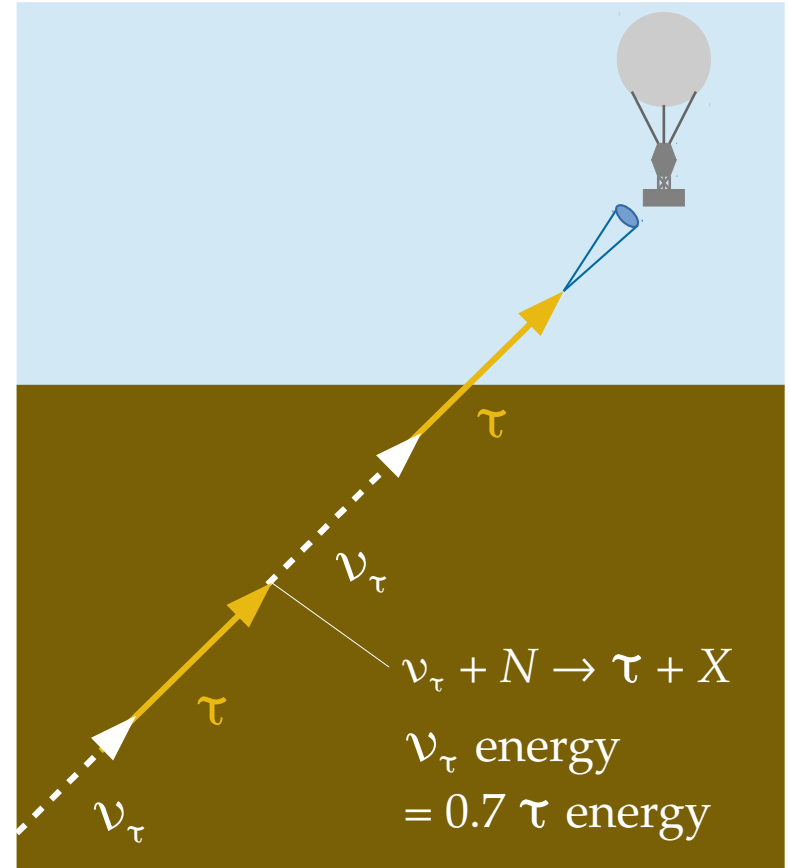


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Earth-skimming:

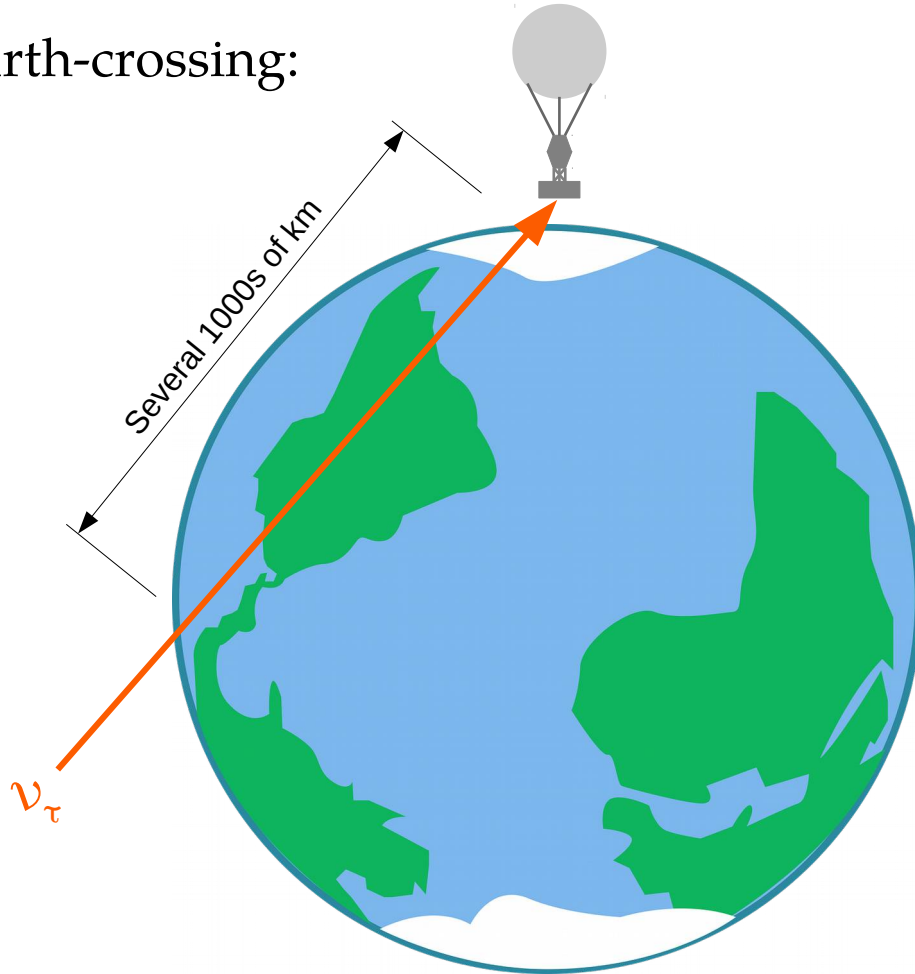


Neutrino regeneration:



# Neutrinos: Earth-skimming *vs.* Earth-crossing

Earth-crossing:



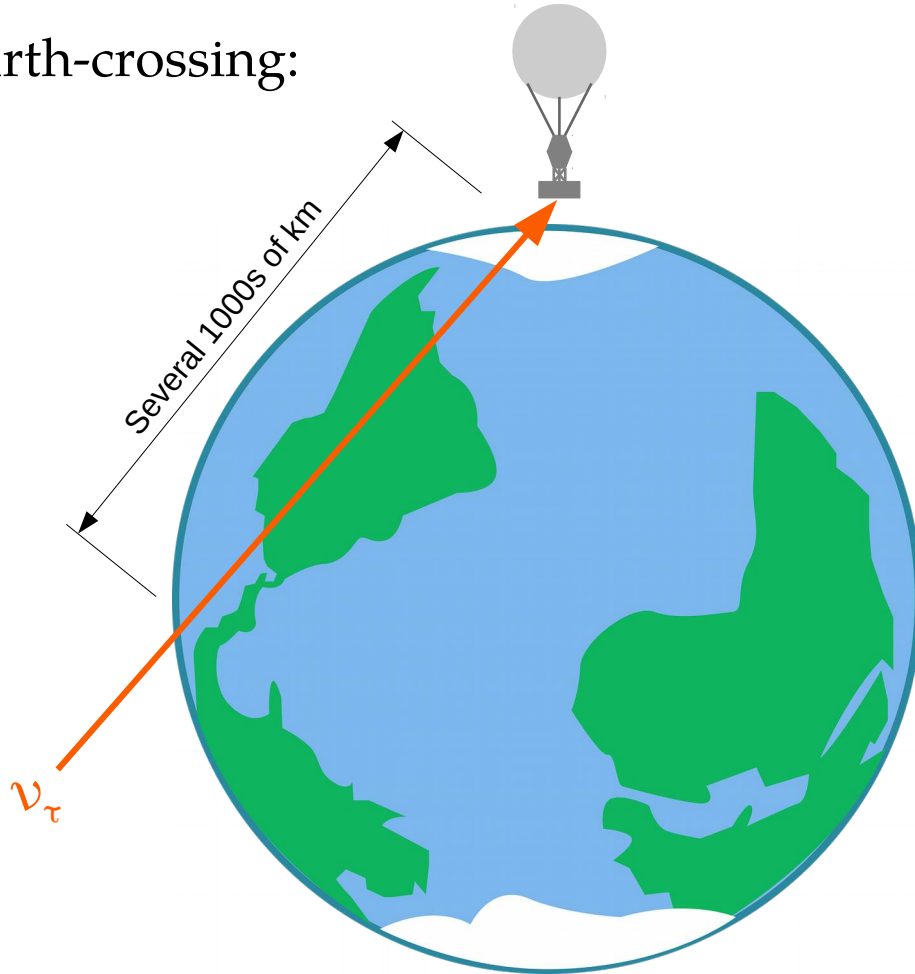
- Optical depth to  $\nu N$  interactions at EeV:

$$\frac{\text{Chord inside Earth}}{\text{Interaction length in Earth}} = \frac{7000 \text{ km}}{390 \text{ km}} = 18$$

- Flux is suppressed by  $e^{-18} = 10^{-8}$

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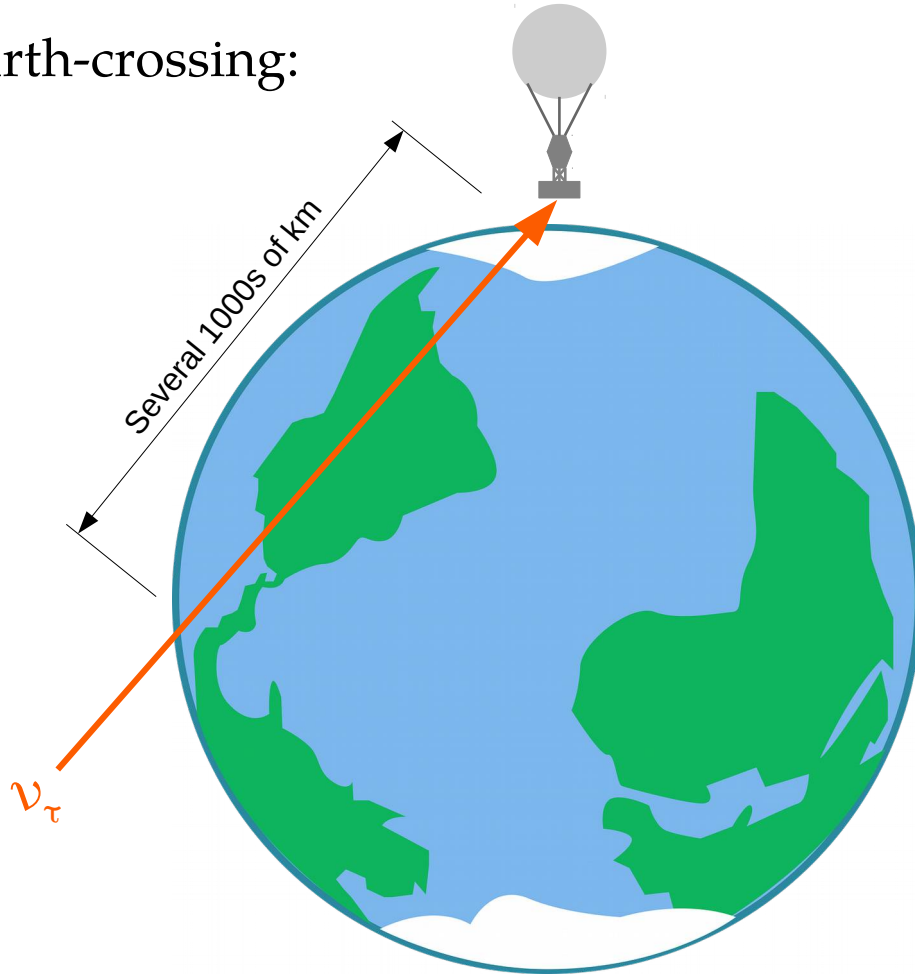
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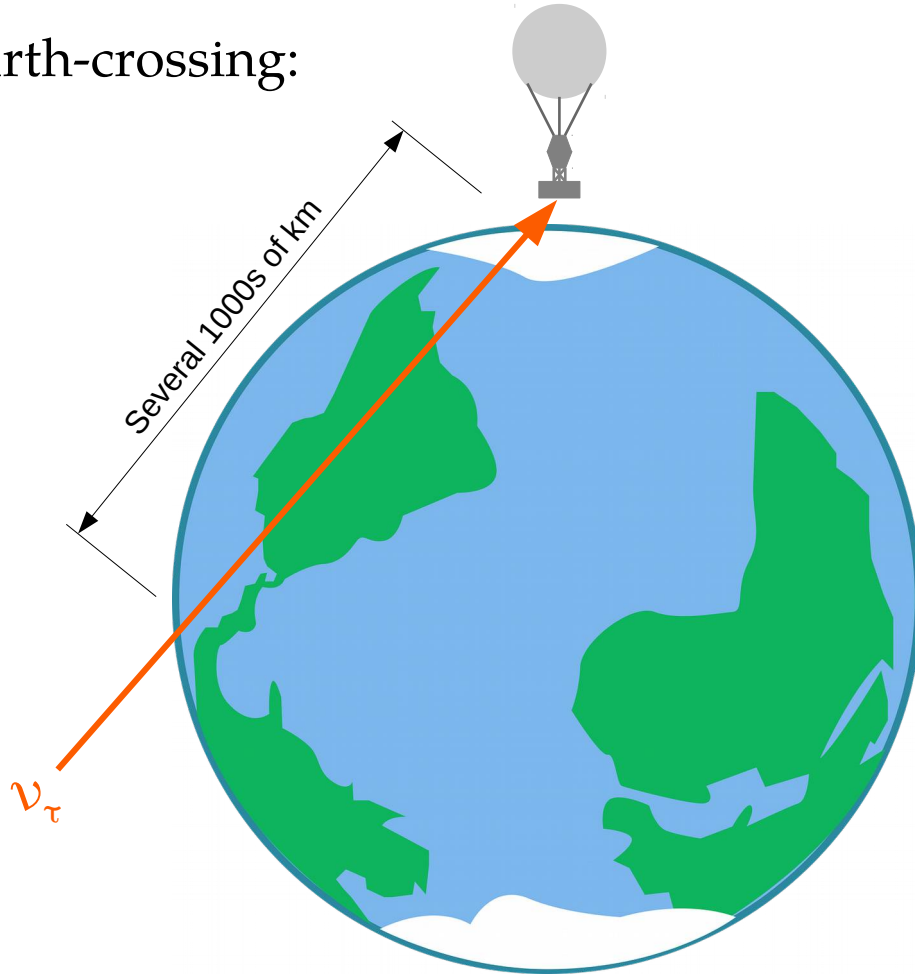
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**Solution:** Make EeV cross section 10 times smaller

**Problem:** Within the SM, only factor-of-few suppression is possible

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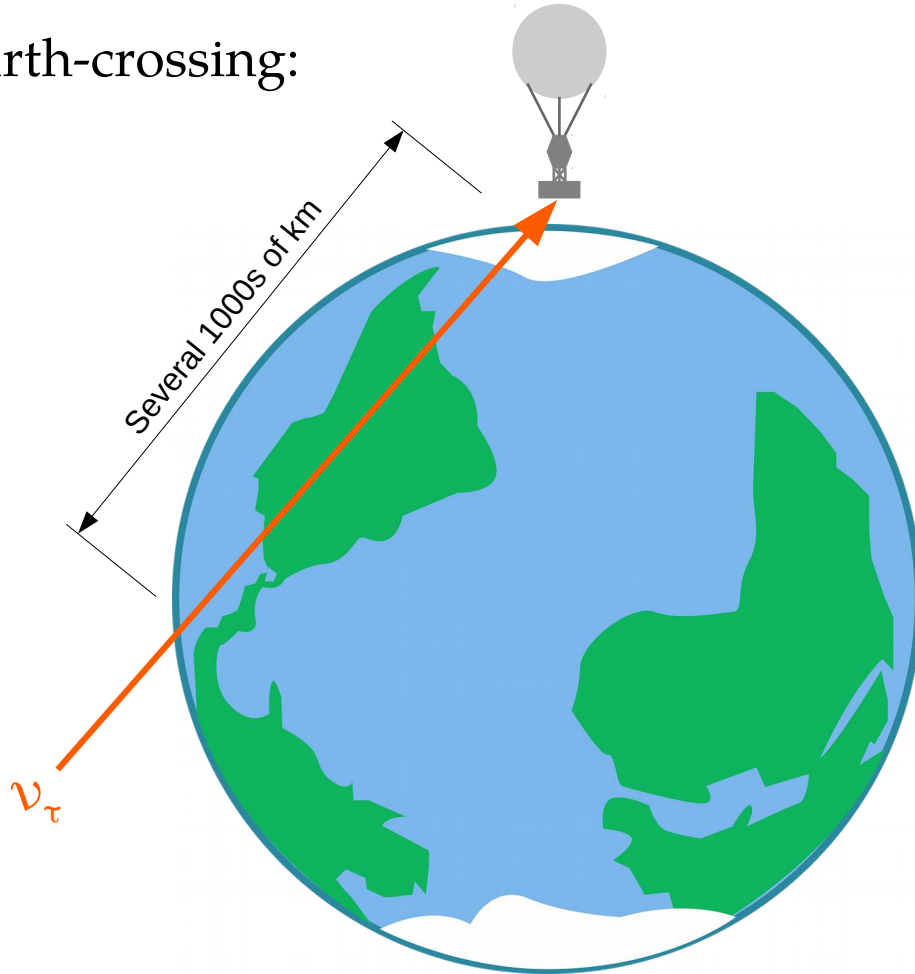
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## Problems with diffuse-flux interp.

- Flux needs to be  $10^8$  times larger
- No events seen closer to horizon

# Neutrinos: Earth-skimming *vs.* Earth-crossing

Earth-crossing:



## Transient astrophysical event?

- ▶ **ANITA-1 event:** none associated
- ▶ **ANITA-3 event:**
  - ▶ Type-Ia SN2014dz ( $z = 0.017$ )
  - ▶ Within  $1.9^\circ$ , 5 hours before event
  - ▶ Probability of chance SN:  $3 \times 10^{-3}$
  - ▶  $\nu$  luminosity must exceed bolometric luminosity of  $4 \times 10^{42} \text{ erg s}^{-1}$

# Quantifying the incompatibility

## By diffuse flux limits

- ▶ Propagate EeV  $\nu_\tau$  in Earth
- ▶ Same directions as AAEs\*
- ▶  $\nu_\tau$  interact and regenerate
- ▶ Probability of  $\tau$  exiting:  $10^{-8}$ – $10^{-7}$
- ▶ Diffuse flux needed is  $\sim 10^6$  higher than Auger/IceCube upper limits
- ▶ p-value for a Standard-Model  $\nu$ :  
 $p = 2.8 \times 10^{-12} (7\sigma)$

D. Fox *et al.*, 1809.09615

(\*) AAE: ANITA anomalous event

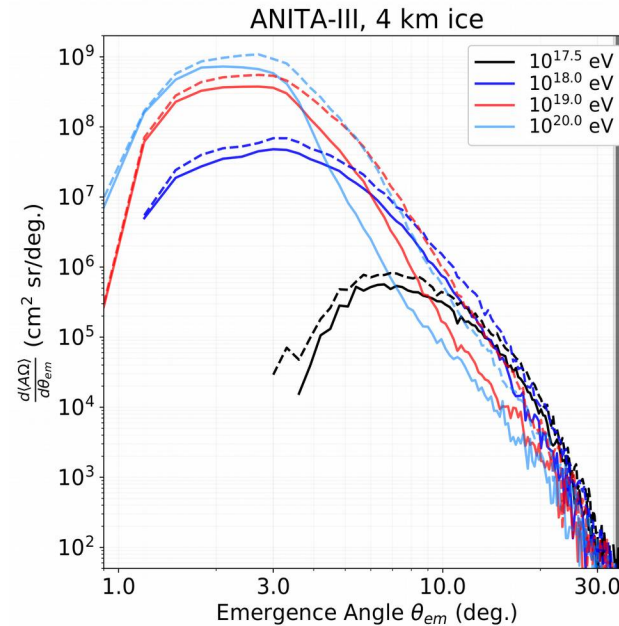
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## By direction arguments



A. Romero-Wolf *et al.*, 1811.07261

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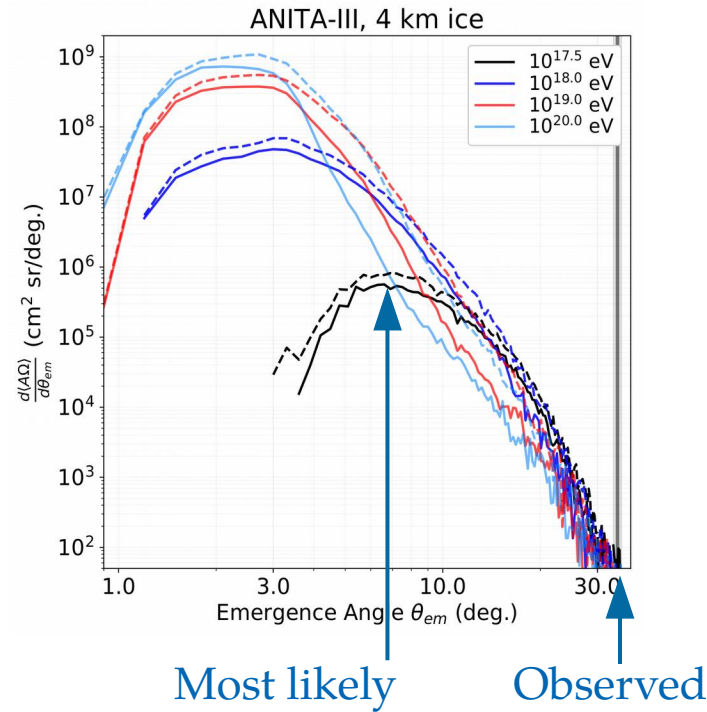
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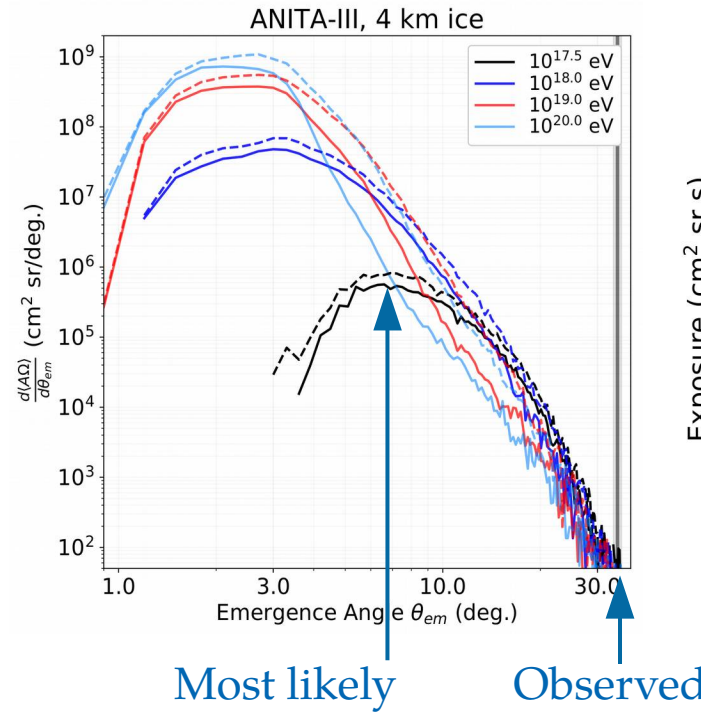
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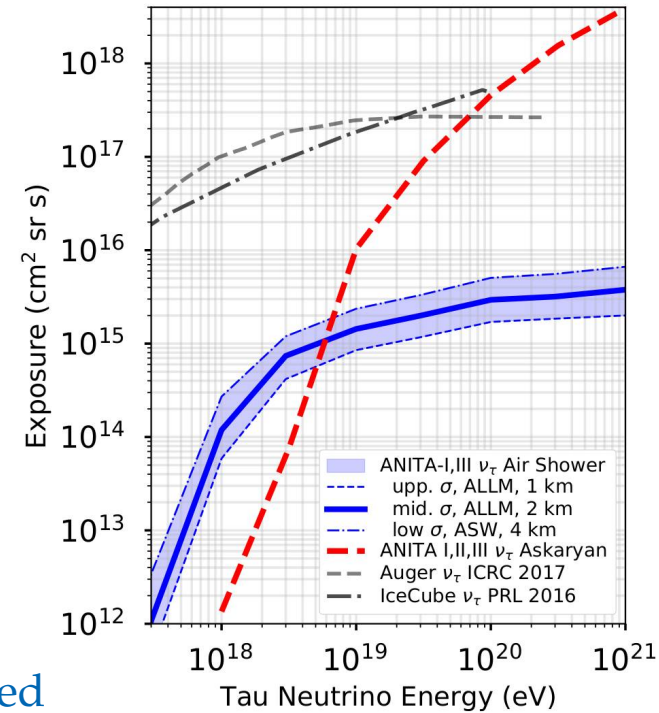
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## By direction arguments



## By comparison to others



A. Romero-Wolf *et al.*, 1811.07261

(\*) AAE: ANITA anomalous event

So, is ANITA seeing the first  
ultra-high-energy neutrinos?

*Most likely not*



Home » Physics » General Physics » October 1, 2018

# New evidence suggests particles detected in Antarctica don't fit Standard Model

October 1, 2018 by Bob Yirka, Phys.org [report](#)

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ANITA-IV after returning from the edge of space.

COSMIC MYSTERIES | By Daniel Oberhaus | Sep 28 2018, 7:40pm

## Mysterious Cosmic Rays Shooting from the Ground in Antarctica Could Break Physics

# So what is ANITA seeing?

## ► Transition radiation [Motloch *et al.*, PRD 2017]:

- Wide-angle emission of radio waves at ice-air interface could make horizontal  $\nu_\tau$  look upgoing
- **Assessment:** Needs too large a diffuse flux of  $\nu_\tau$ , because transition radiation is a small effect

## ► Sterile neutrinos [Cherry & Shoemaker, 1802.01611; Huang, 1804.05362]:

- Sterile neutrinos propagate in Earth, then convert  $\nu_s \rightarrow \nu_\tau$
- **Assessment:** Model predicts more (unseen) events at shallower angles

## ► Dark matter decay in Earth core [Anchordoqui *et al.*, 1803.11554]:

- Decay of 480-PeV sterile right-handed  $\nu_r$  (relic DM) trapped “puffy” Earth core:  $\nu_r \rightarrow \text{Higgs} + \nu_\tau$
- **Assessment:** Viable, but exotic explanation

## ► Staus (NLSP) [Fox *et al.*, 1809.09615]:

- Made by UHECRs, decays to  $\tau$  prior to exiting; can satisfy:  $\sigma \sim \sigma_{\nu N}/1000$ ,  $\tau \sim 10 \text{ ns}$  ( $m/500 \text{ GeV}$ )
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Mean free path  $\sim$  Earth radius      Decay length  $\sim$  Earth radius

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Decay length  $\sim$  Earth radius

# What are you taking home?

- ▶ ANITA has seen (so far) 2 upgoing anomalous events
- ▶ A Standard-Model explanation is incompatible at  $7\sigma$
- ▶ Transient sources unlikely
- ▶ There are a few viable BSM models that could explain the events
- ▶ We need more data! ANITA-IV analysis is underway

Backup slides

# Constraining UHECRs with UHE Neutrinos

UHECR sources are hard to find:

- ▶ **Magnetic deflection:**  $\text{few} \times 10^\circ$ , composition-dependent
- ▶ **GZK horizon:**  $p\gamma_{\text{CMB}}$  scattering kills CRs with  $> 40$  EeV after 100 Mpc

How to find them?

- ▶ Look for UHECR ( $> \text{few EeV}$ ) arrival-direction anisotropies
- ▶ Look for UHE ( $> 10$  EeV) gamma rays and neutrinos from  $p\gamma$

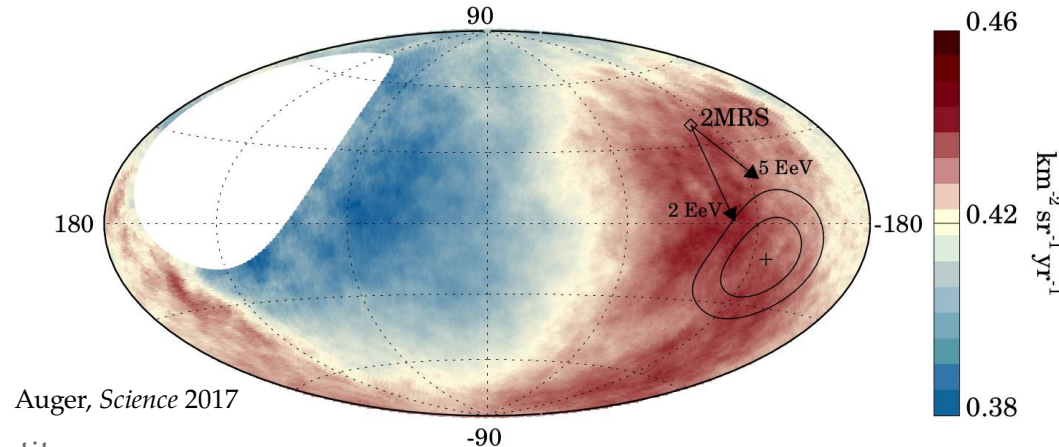
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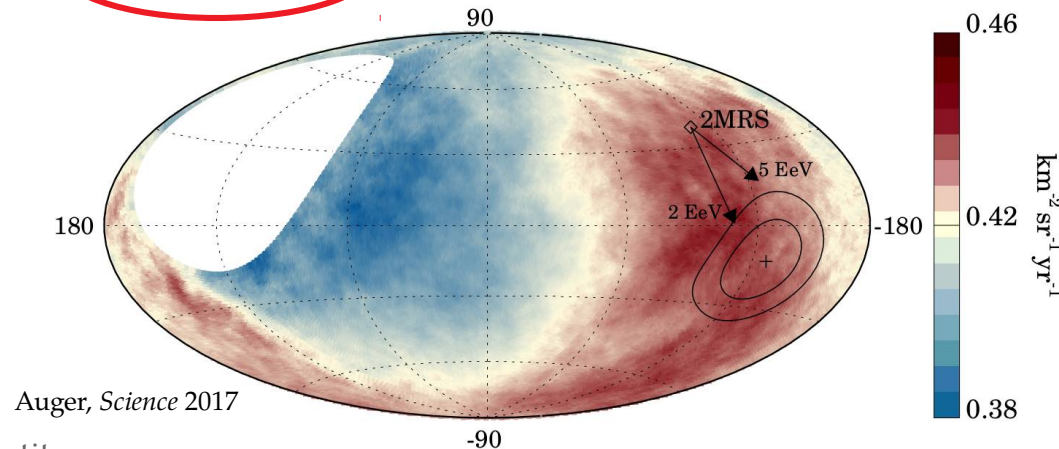
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Can only find nearby sources because of gamma-ray opacity of Universe



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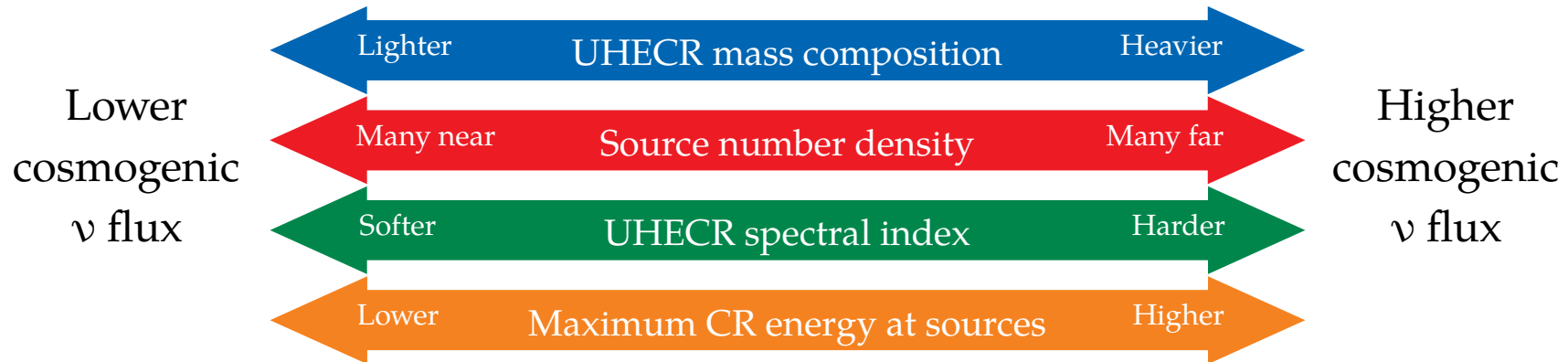
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# Constraining

## UHECR sources

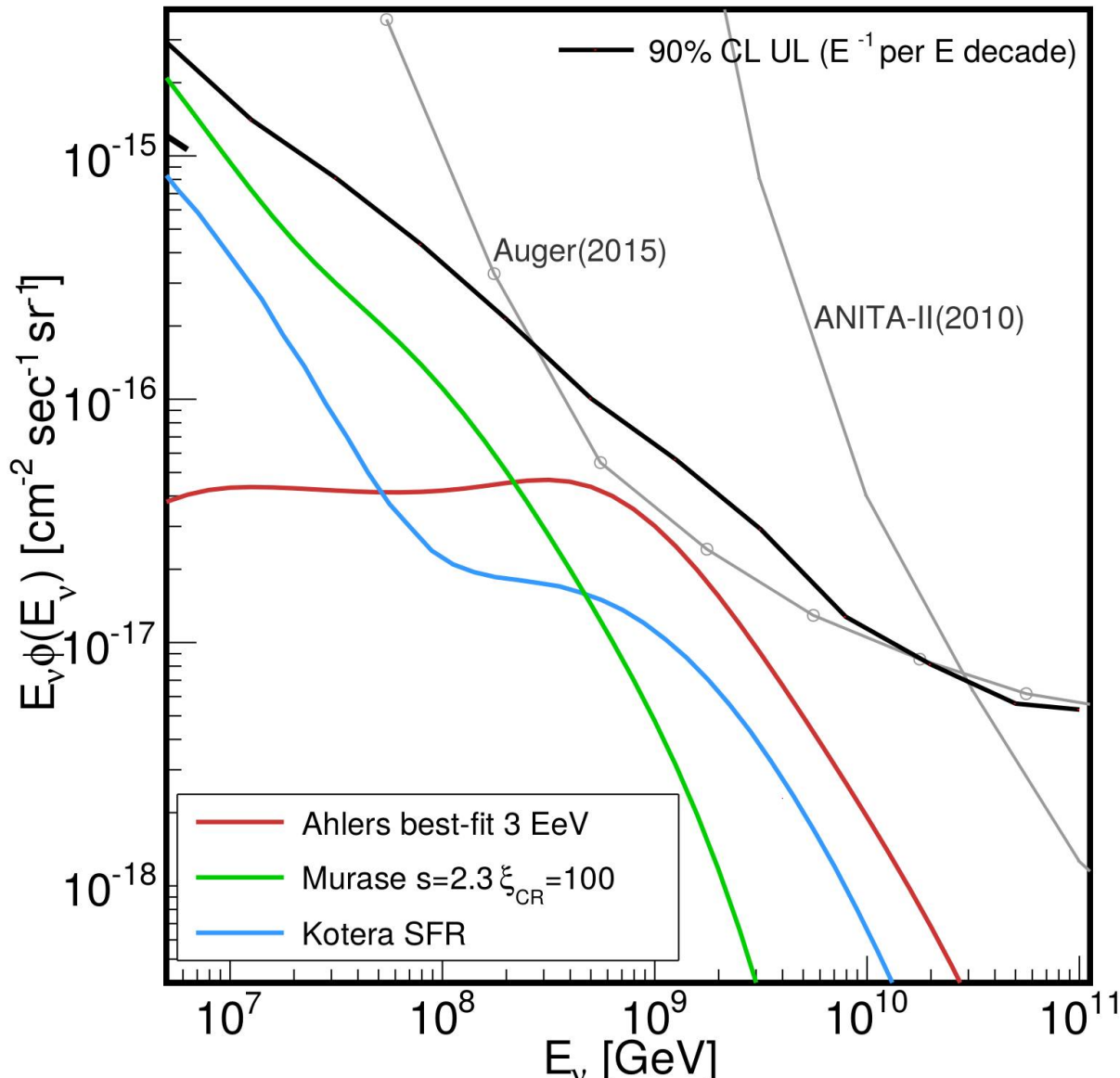
- ▶ Magnetic deflection
- ▶ GZK horizon:  $p\gamma_c$

## How to find the

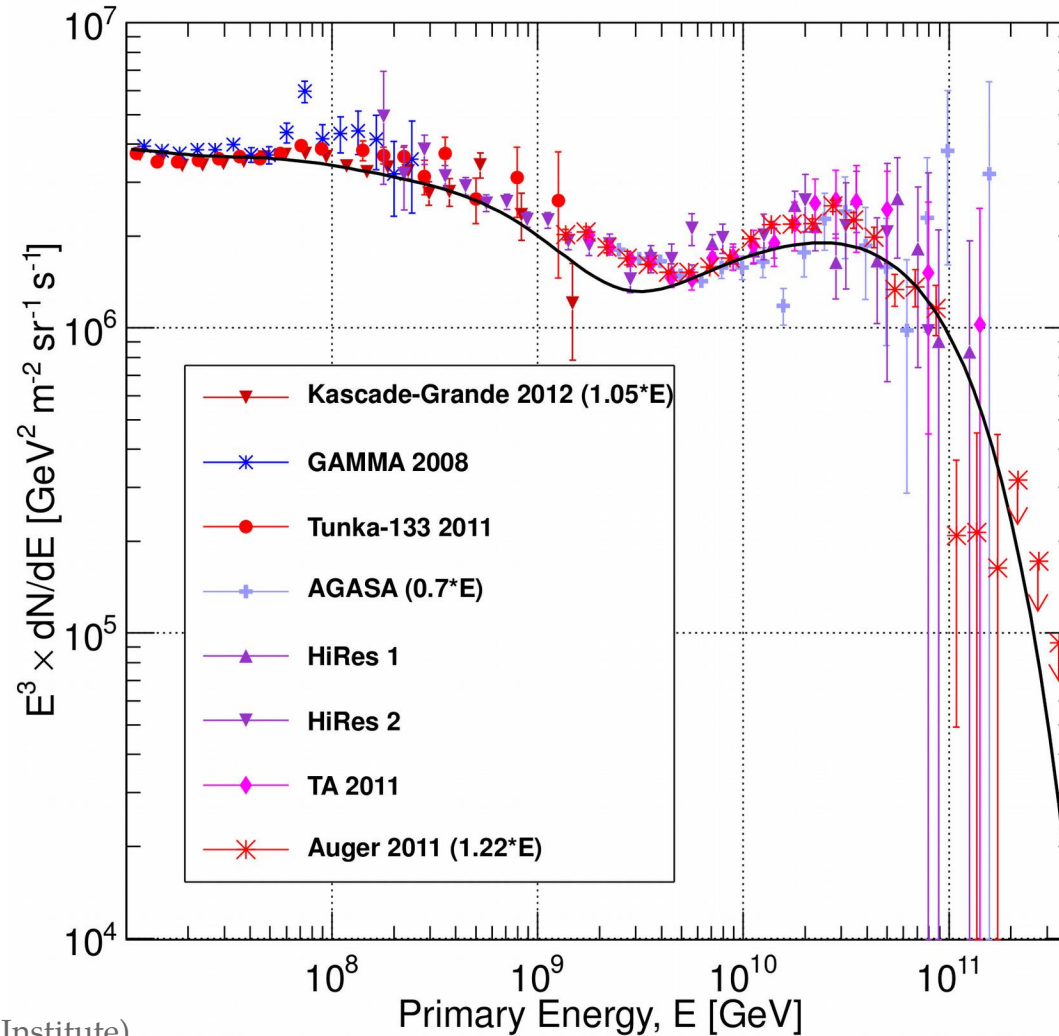
- ▶ Look for UHECR
- ▶ Look for UHE (>

Lower  
cosmogenic  
 $\nu$  flux

Higher  
cosmogenic  
 $\nu$  flux



# 50+ years of UHECR observations –



Abundant, but hardly interacting ▼

