Exploring the axionic dark sector with ANITA

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Ivan Esteban

Institute of Cosmos Sciences (ICCUB), University of Barcelona

In collaboration with J. Lopez-Pavon, I. Martinez-Soler and J. Salvado
Based on arXiv:1905.10372 [hep-ph]

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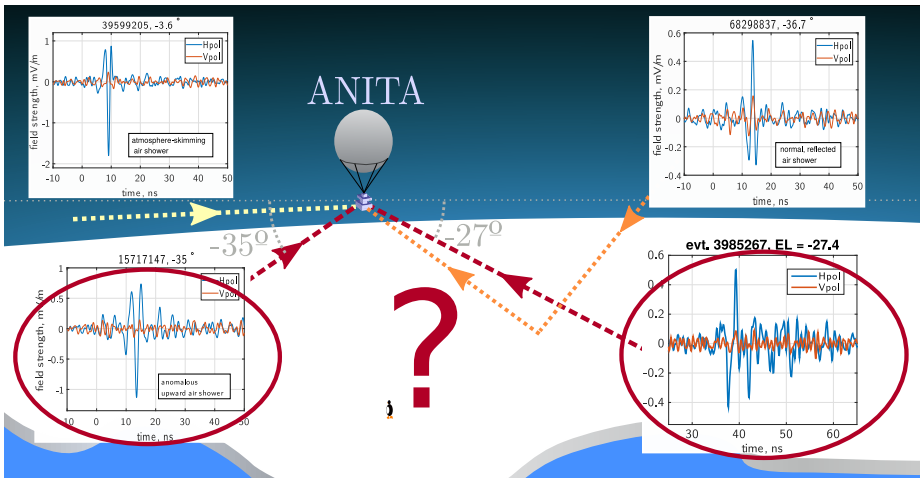
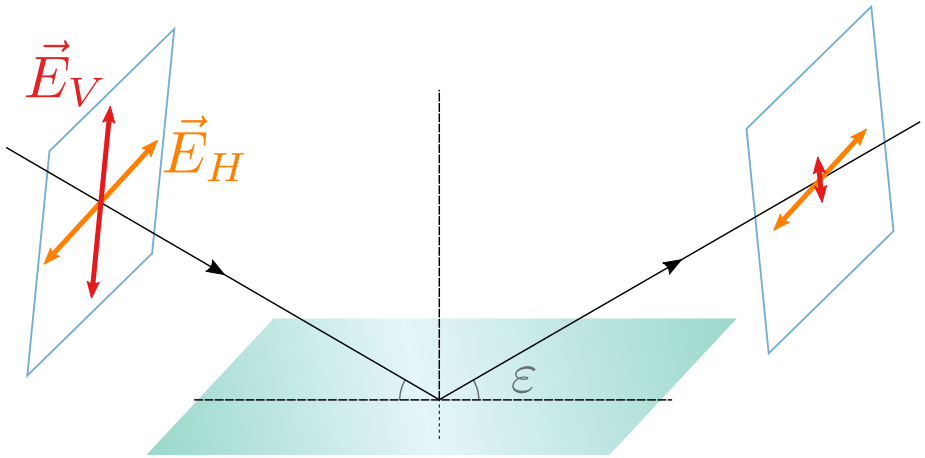
UNIVERSITAT DE BARCELONA

Introduction

- The ANITA collaboration has reported two mysterious up-going radio pulses in the Antarctica. The background is $\sim 10^{-2}$.
- SM (BSM) explanations in terms of high-energy particle showers are in tension with ANITA, IceCube and Auger (IceCube and Auger).
- The events were assigned a cosmic ray origin due to their horizontal polarization. *What if horizontal polarization comes from reflection?*



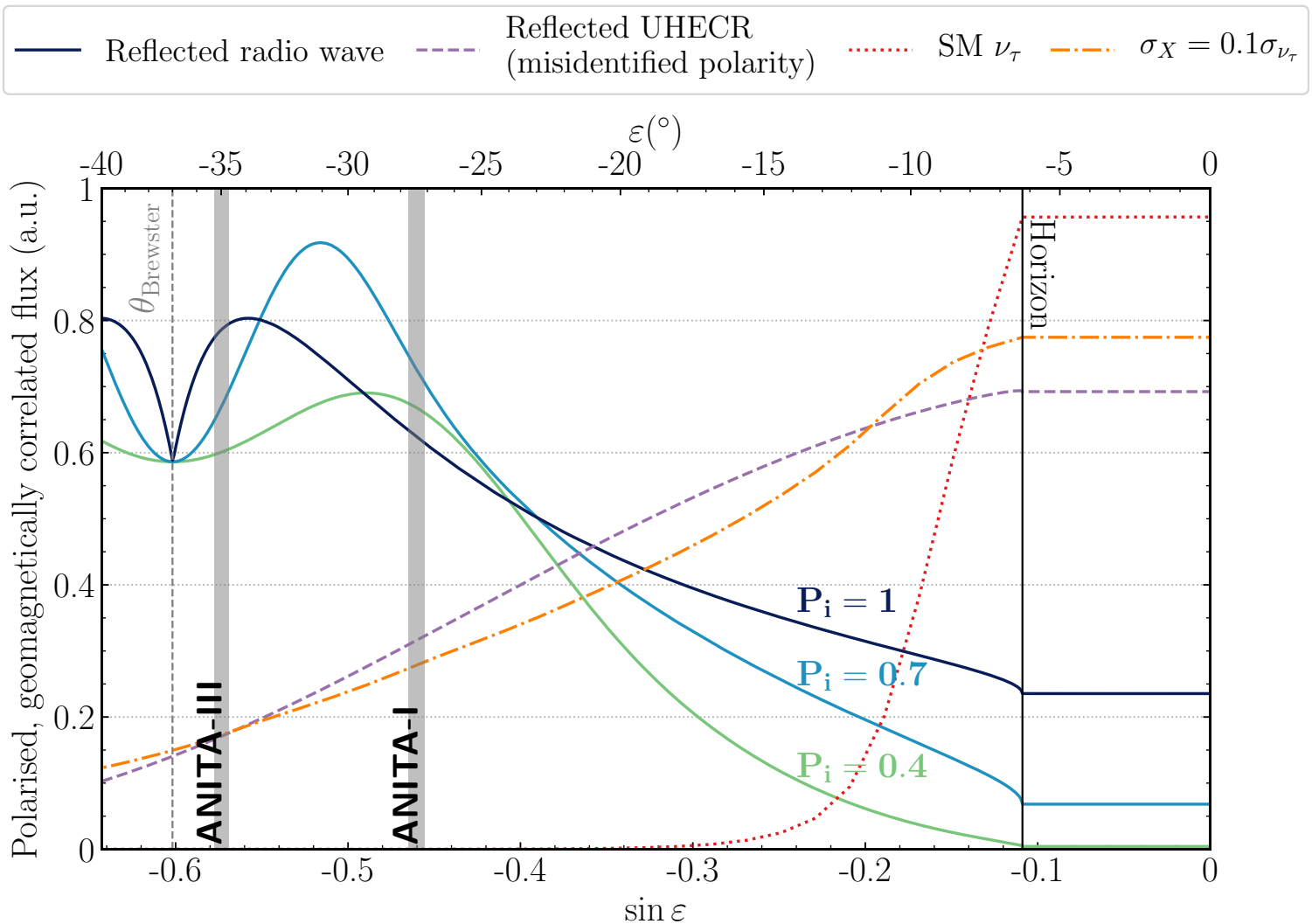


P. W. Gorham et al. [ANITA Collaboration], arXiv:1803.05088 & 1603.05218 [astro-ph.HE]
J. M. Cline, C. Gross and W. Xue, arXiv:1904.13396 [hep-ph]

What if the events are reflected?

Angular distribution

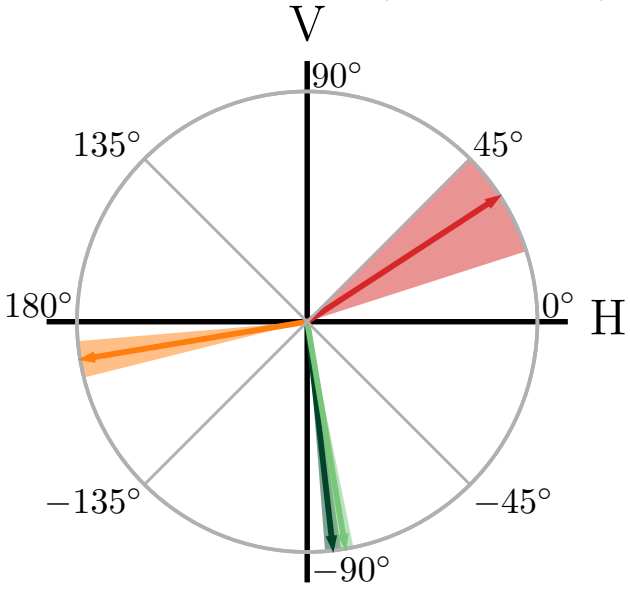
We assume an incident isotropic flux, linearly polarized with random polarization angles and a given degree of polarization $\mathrm{P_i}$ [colour].



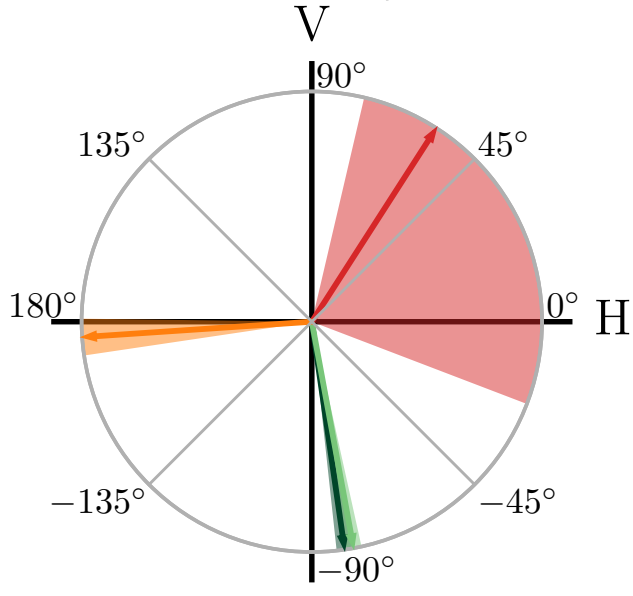
What if the events are reflected?

Polarization angle *before reflection*

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)

Where do the events come from?

1. The source must generate an isotropic flux of *impulsive*, linearly polarized radio signals.

2. To avoid tensions with IceCube and Auger, the production process must not involve high-energy particle cascades.

Where do the events come from?

A *possible* source: ALP-photon conversion

1. The source must generate an isotropic flux of *impulsive*, linearly polarized radio signals.

2. To avoid tensions with IceCube and Auger, the production process must not involve high-energy particle cascades.

What about axion-photon conversion of an ALP burst in the Earth magnetic field $B^{\oplus}$?
In the Earth ionosphere,

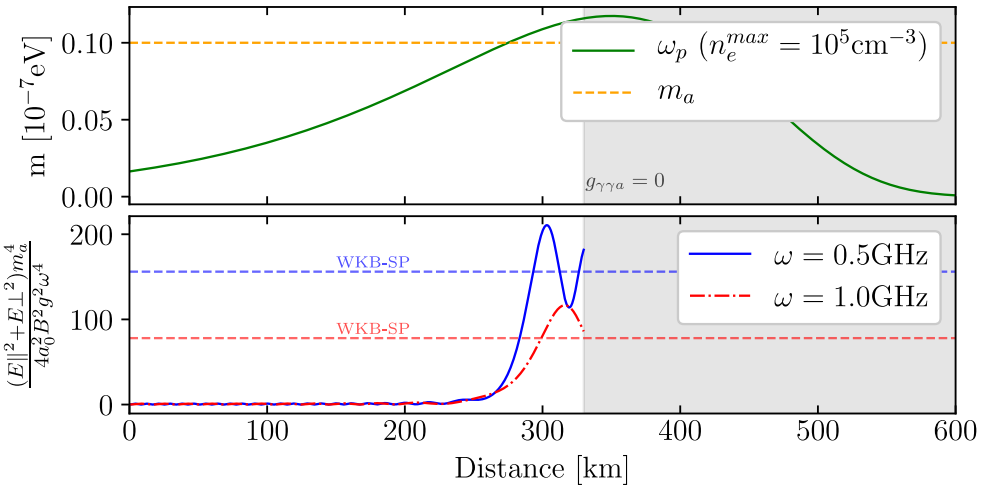
$$\left[\partial_z^2+\omega^2+\begin{pmatrix} -\omega_p^2 & -i\omega_p^2\frac{\Omega_z}{\omega} & 0 \\ i\omega_p^2\frac{\Omega_z}{\omega} & -\omega_p^2 & -g_{a\gamma\gamma}B_y^{\oplus}\omega^2 \\ 0 & -g_{a\gamma\gamma}B_y^{\oplus} & -m_a^2 \end{pmatrix}\right]\begin{pmatrix} E_x \\ E_y \\ a \end{pmatrix}=0\,,$$

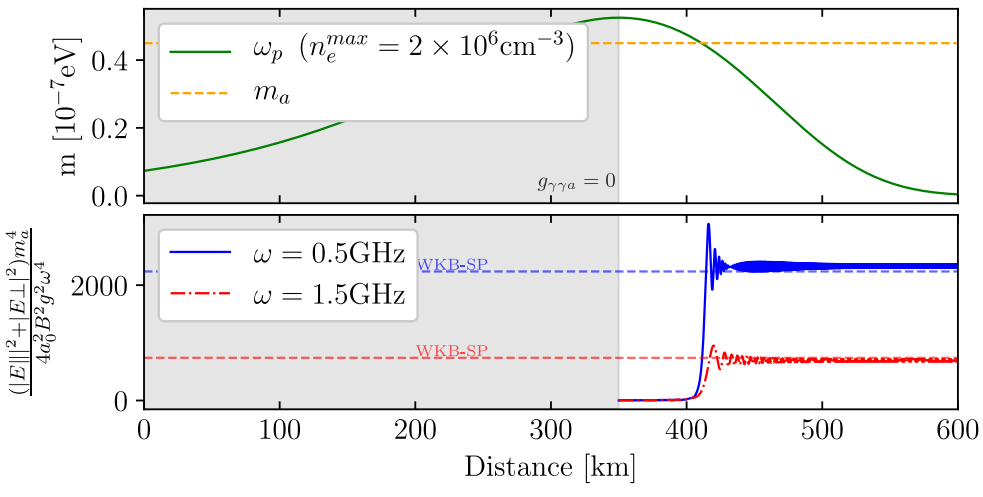
$m_a \sim \omega_p \Longrightarrow$ resonant conversion ($\sim$ solar ν MSW).
The ALP masses allowed by ANITA ($m_a \lesssim 10^{-7}\,\mathrm{eV}$) *typically resonate in the Earth ionosphere*.

A *possible* source: ALP-photon conversion

Resonant conversion in the ionosphere

If we numerically solve the equations of motion,



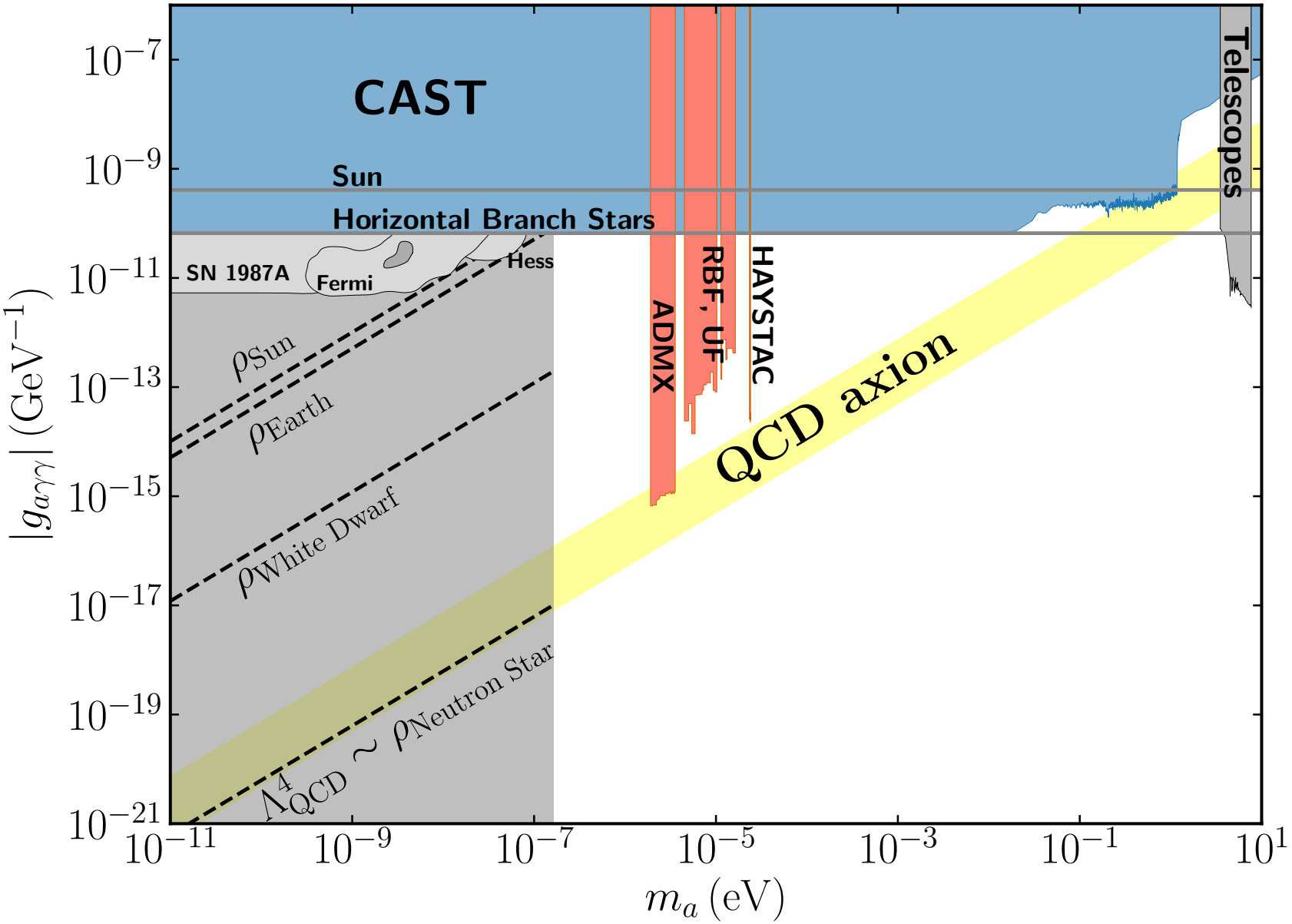


Generically, you expect two radio pulses *with different degrees of coherence*.

For more phenomenological differences among the pulses, come to my poster tomorrow!

A *possible* source: ALP-photon conversion

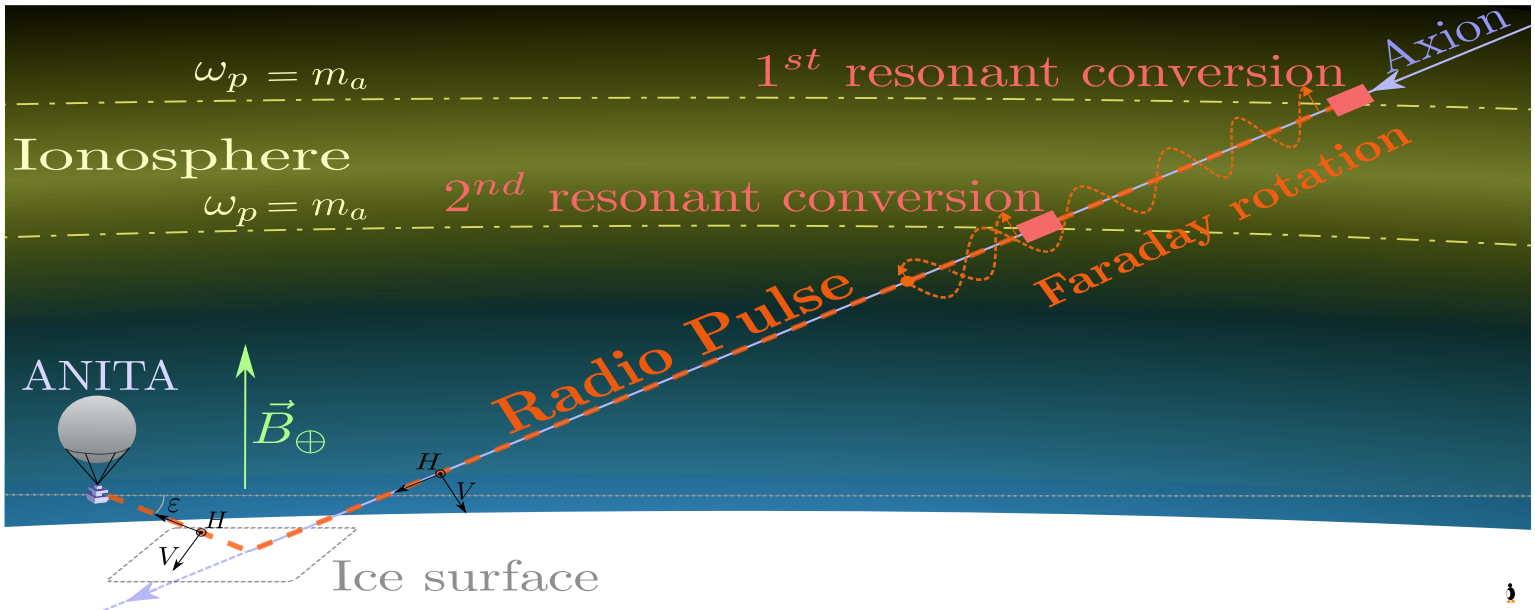
Learning about the ALP



Conclusions

For more details and discussions, come to my poster!

- An isotropic, linearly polarized flux of radio pulses can generate ANITA's anomalous events via reflection close to $\theta_{\rm Brewster}$, explaining their *directionality* and *polarization state*.
- This flux can be resonantly produced in the ionosphere via the interaction of an ALP burst with the Earth magnetic field:
  - No bounds from IceCube and Auger, since this involves very soft physics $\sim \mathcal{O}(10^{-7}\,\text{eV})$.
  - Very predictive and **readily testable scenario**: non-horizontal events far from $\theta_{\rm Brewster}$, and doubled events with lower coherence are predicted.



Backup

What about other radiotelescopes?

S. Hoover *et al.* [ANITA Collaboration], "Observation of Ultra-high-energy Cosmic Rays with the ANITA Balloon-borne Radio Interferometer," Phys. Rev. Lett. **105**, 151101 (2010) doi:10.1103/PhysRevLett.105.151101 [arXiv:1005.0035 [astro-ph.HE]].

The origin of ultra-high energy cosmic rays (UHECR) remains a mystery decades after their discovery [1, 2]. Key to the solution will be increased statistics on events of high enough energy ($\geq 3 \times 10^{19}$ eV) to elucidate the endpoint of the UHECR energy spectrum as seen at Earth. The primary difficulty is the extreme rarity of events at these energies. Despite steady progress with experiments such as the Pierre Auger Observatory, there remains room for new methodologies. Cosmic rays have been detected for decades via impulsive radio geosynchrotron emission [3, 5–16] but until now not in this crucial energy range, which offers the possibility of pointing the UHECRs back to their sources. We present data from the Antarctic Impulsive Transient Antenna (ANITA) [21] which represents the first entry of radio techniques into this energy range. We find 16 UHECR events, at least 40% of which are above 10^{19} eV, and we show compelling evidence of their origin as geosynchrotron emission from cosmic-ray showers. Our results indicate degree-scale precision for reconstruction of the UHECR arrival direction, lending strong credence to efforts to develop radio geosynchrotron detection as a competitive method of UHECR particle astronomy.

particle cascade initiated by a primary cosmic ray encounters the Lorentz force in the geomagnetic field. The resulting acceleration deflects the electrons and positrons and they begin to spiral in opposite directions around the field lines [17, 18]. In air, the particles' radiation length is of order 40 g cm^{-2}, a kilometer or less at the altitudes of air shower maximum development. Particle trajectories form partial arcs around the field lines before they lose enough energy to drop out of the shower. The meter-scale longitudinal thickness of the shower particle 'pancake' is comparable to radio wavelengths below several hundred MHz; thus the ensemble behavior of all of the cascade particles yields forward-beamed synchrotron emission which is partially or fully coherent in the radio regime. Therefore, the resulting radio impulse power grows quadratically with primary particle energy, and at the highest energies, yields radio pulses that are detectable at large distances. Current systems under development for detection of these radio impulses are co-located with cosmic-ray particle detectors on the ground to aid in cross-calibration [14–16]. They detect showers with primary energies in the 10^{17-18} eV range because of their limited acceptance. No such system has reported a sample of $> 10^{19}$ eV UHECR events.

Backup

Where does the ALP burst come from?

D. G. Levkov, A. G. Panin and I. I. Tkachev, "Relativistic axions from collapsing Bose stars," Phys. Rev. Lett. **118**, no. 1, 011301 (2017) doi:10.1103/PhysRevLett.118.011301 [arXiv:1609.03611 [astro-ph.CO]].

INR-TH-2016-034

Relativistic axions from collapsing Bose stars

D.G. Levkov,[1,*] A.G. Panin,[1,2] and I.I. Tkachev[1]

[1] *Institute for Nuclear Research of the Russian Academy of Sciences, 60th October Anniversary prospect 7a, Moscow 117312, Russia*

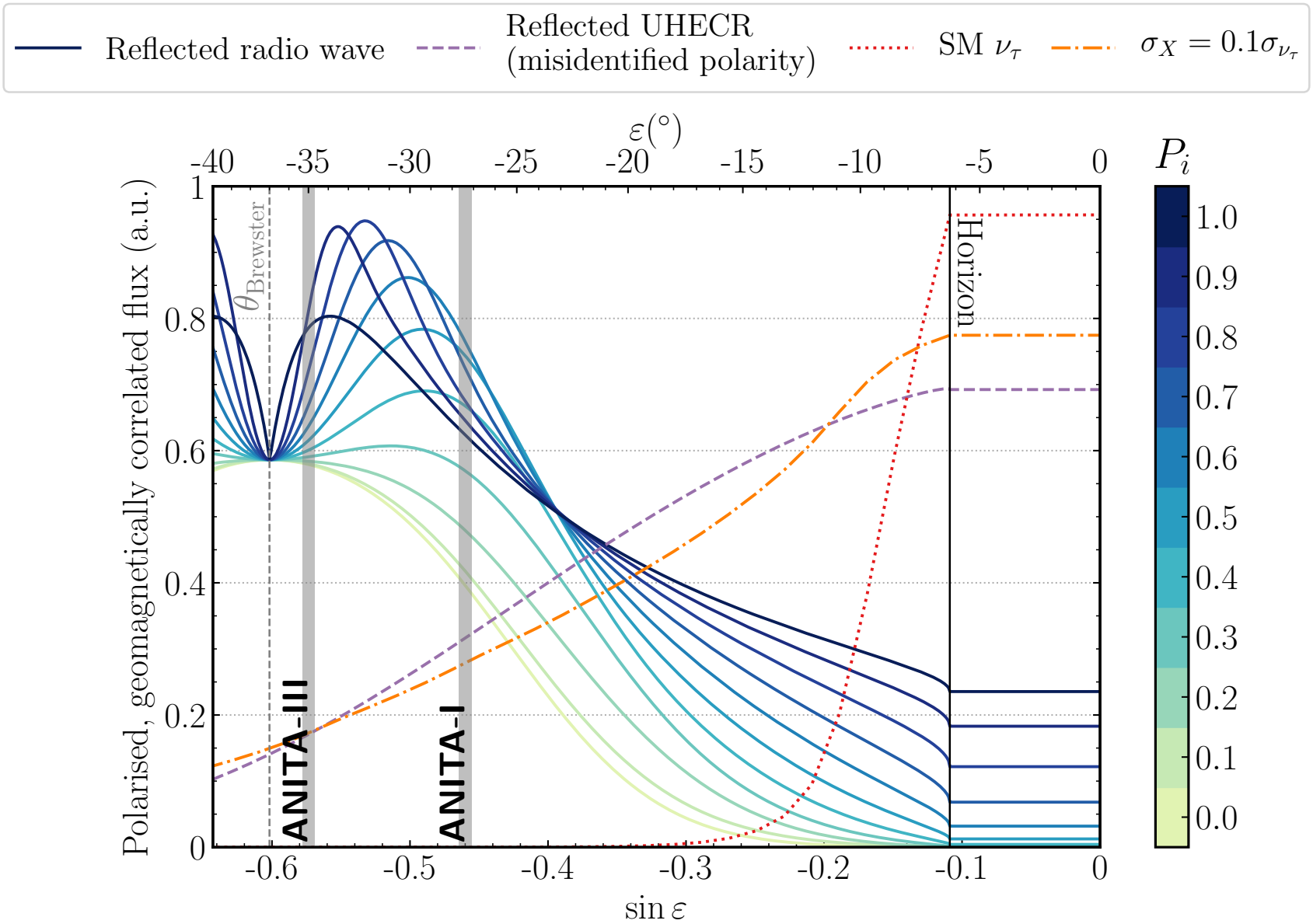
[2] *Moscow Institute of Physics and Technology, 141700, Dolgoprudny, Russia*

The substructures of light bosonic (axion-like) dark matter may condense into compact Bose stars. We study collapses of the critical-mass stars caused by attractive self-interaction of the axion-like particles and find that these processes proceed in an unexpected universal way. First, nonlinear self-similar evolution (called "wave collapse" in condensed matter physics) forces the particles to fall into the star center. Second, interactions in the dense center create an outgoing stream of mildly relativistic particles which carries away an essential part of the star mass. The collapse stops when the star remnant is no longer able to support the self-similar infall feeding the collisions. We shortly discuss possible astrophysical and cosmological implications of these phenomena.

2016

Backup

Directionality: non-polarized initial pulse



Backup

Polarization state: non-polarized initial pulse