An R-parity Violating Supersymmetric Explanation of the EeV Events at ANITA

Yicong Sui
Washington University in St. Louis

In collaboration with Jack Collins and Bhupal Dev,
arXiv:1810.xxxxx
Antarctic Impulse Transient Antenna (ANITA) Experiment
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The ANITA detection concepts, figure from Cosmin Deaconu
Antarctic Impulse Transient Antenna (ANITA) Experiment

Totally three flights, adding up to 67 days of total observation time

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TABLE I: ANITA-I,-III anomalous upward air showers.

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<tr>
<th>event, flight</th>
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<tr>
<td>date, time</td>
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<td>Lat., Lon. (1)</td>
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1 Latitude, Longitude of the estimated ground position of the event.
2 Sky coordinates projected from event arrival angles at ANITA.
3 For upward shower initiation at or near ice surface.

Table from ANITA, 1803.05088
Antarctic Impulse Transient Antenna (ANITA) Experiment

Properties of the anomalous upward events

1. Large Elevation Angle, going upwards.
2. No Polarity Reverse Relative to Geomagnetic Field.
3. Both have large energy \( \sim 0.5 \text{EeV} \)
4. Both interpreted as tau events by ANITA

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How did you get through?

~60 degrees
Things hard to explain

R ~ 6400 km

How did you get through?

~60 degrees
Things hard to explain

$R \sim 6400 \text{ km}$

$D = 2R \cos(\theta) > 5700 \text{ km}$

$\sim 60 \text{ degrees}$

How did you get through?
Things hard to explain

$R \sim 6400 \text{ km}$

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$L_{SM} \sim 300 \text{ km (in rock)}$

How did you get through?

$\sim 60 \text{ degrees}$
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Neutrino SM CC NC interaction

How did you get through?

～60 degrees
Things hard to explain

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\[ P_{\text{survival}} \sim 10^{-6} \]
\[ = 0.0001\% \]

How did you get through?

\sim 60 \text{ degrees}
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$R \sim 6400 \text{ km}$

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$I_{SM} \sim 300 \text{ km (in rock)}$

Neutrino SM CC NC interaction

$P_{\text{survival}} \sim 10^{-6}$

$= 0.0001\%$

How did you get through?

And how did you get caught by ANITA but not me?

IceCube

\[ \sim 60 \text{ degrees} \]
Some plausible scenarios:
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- Sterile Neutrino Explanation

A Sterile Neutrino Origin for the Upward Directed Cosmic Ray Shower Detected by ANITA

John F. Cherry and Ian M. Shoemaker

Department of Physics, University of South Dakota, Vermillion, SD 57069, USA

(Dated: 2/3/18)

The ANITA balloon experiment has observed an \( \sim \) EeV cascade event at an angle below the horizon that renders any Standard Model (SM) interpretation unlikely as the Earth is significantly opaque to all SM particles at such energies. In this paper, we study a sterile neutrino interpretation of this event, calculating the angular event distribution of cascades and the relative sensitivities of several experiments to a cascade initiated by an EeV sterile neutrino. We find that ANITA is uniquely sensitive to this type of upward directed cascade signal and canonical ultrahigh energy cosmic ray (UHECR) models can produce a reprocessed EeV sterile neutrino flux at sufficient levels to accommodate the ANITA event.

PACS numbers: 13.15.+g, 14.60.Qs, 14.60.Pq, 98.70.Sa

Sterile neutrinos as a possible explanation for the upward air shower events at ANITA

Guo-yan Huang

*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China

School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 100049, China

Abstract

The ANITA experiment has observed two unusual going air shower events which are consistent with the r-lepton decay origin. However, these events are in contradiction with the standard neutrino-matter interaction models as well as the EeV diffuse neutrino flux limits set by the IceCube and the cosmic ray facilities like AUGER. In this paper, we have readdressed the possibility of using sterile neutrino hypothesis to explain the ANITA anomalous events. The diffuse flux of the sterile neutrinos is less constrained by the IceCube and AUGER experiments due to the small active-sterile mixing suppression. The quantum decoherence effect should be included for describing the neutrino flux propagating in the Earth matter, because the interactions between neutrinos and the Earth matter are very strong at the EeV scale. After several experimental approximations, we show that the ANITA anomaly itself is able to be explained by the sterile neutrino origin, but we also predict that the IceCube observatory should have more events than ANITA. It makes the sterile neutrino origin very unlikely to account for both of them simultaneously. A more solid conclusion can be drawn by the dedicated ANITA signal simulations.
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- **Dark matter inside Earth Explanation**

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  Luis A. Anchordoqui,$^{1,2,3}$ Vernon Barger,$^4$ John G. Learned,$^5$ Danny Marfatia,$^5$ and Thomas J. Weiler$^6$

  1Department of Physics & Astronomy, Lehman College, City University of New York, NY 10468, USA
  2Department of Physics, Graduate Center, City University of New York, NY 10016, USA
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Abstract

The ANITA experiment has observed two unusual upward air shower events which are consistent with the stau-lepton decay origin. However, these events are in contradiction with the standard neutrino-matter interaction models. In this paper, we reexamine the possibility of using sterile neutrino hypothesis to explain the ANITA anomalous events. The diffuse flux of the sterile neutrinos is constrained by the IceCube and AUGER experiments due to the small active-sterile mixing suppression. The quantum decoherence effect should be included for describing the neutrino flux propagating in the Earth matter, because the interactions between neutrinos and the Earth matter are very strong at the eV scale. After several experimental approximations, we show that the ANITA anomaly itself is able to be explained by the sterile neutrino origin, but we also predict that the IceCube observatory should have more events than ANITA. It makes the sterile neutrino origin very unlikely to account for both of them simultaneously. A more solid conclusion can be drawn by the dedicated ANITA signal simulations.

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On ANITA’s sensitivity to long-lived, charged massive particles

Amy Connolly\(^*\), Patrick Allison\(^*\), Ondrej Banerjee\(^*\)

\(^*\)Dept. of Physics, Center for Cosmology and AstroParticle Physics, Ohio State Univ., Columbus, OH 43210.

Abstract

We propose that the Antarctic Impulsive Transient Antenna (ANITA) can serve as a detector for long-lived, charged particles, through its measurement of extensive air showers from secondary leptons. To test this on an example model, we simulate the production of staus inside the Earth from interactions of ultra-high-energy neutrinos and nuclei. We propose that results of ANITA searches for upgoing air showers can be interpreted in terms of constraints on long-lived, charged massive particles (CRAMPs) and consider a supersymmetric partner of the tau lepton, the stau, as an example of such a particle. Exploring the parameter space in stau mass and lifetimes, we find that the stau properties that lead to an observable signal in ANITA are highly energy dependent. At 10^{16} eV, we find that the best constraints on the stau are.

The ANITA Anomalous Events as Signatures of a Beyond Standard Model Particle, and Supporting Observations from IceCube

Deeksh B. Fox\(^1,1,2,3\), Steinn Sigurdsson\(^1,1,3\), Sarah Shandera\(^1,1,2,3\), Peter Mezzáiro\(^1,1,4,2,3\), Kohita Murase\(^1,1,4,1,3\), Miguel Mostafá\(^1,1,3\) and Stéphane Contr\(^1,1,3\)

\(^1\)Department of Astronomy & Astrophysics, 525 Davey Lab, Penn State University, University Park, PA 16802, USA

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\(^*\)Center for Fundamental Theory, Institute for Gravitation and the Cosmos, 104 Davey Lab, Penn State University, University Park, PA 16802, USA

(Dated: September 26, 2018)

The ANITA collaboration have reported observation of two anomalous events that appear to be ε_{ee} \approx 0.6 \text{ eV} \text{ cosmic ray showers emerging from the Earth with exit angles of 27° and 35°, respectively. While EeV-scale upgoing showers have been anticipated as a result of astrophysical tau neutrino events, the observed exit angles are much smaller, which suggests a different origin for these events. In this paper, we propose that these events are likely signatures of a light sterile neutrino, which is a candidate for dark matter. We calculate the expected number of events and compare it to the observed number, finding good agreement. This provides strong evidence for the presence of a light sterile neutrino in the Earth's interior.}
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On ANITA’s sensitivity to long-lived, charged massive particles

Amy Connolly, Patrick Allison, Onidre Banerjee

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Abstract

We propose that the Antarctic Impulsive Transient Antenna (ANITA) can serve as a detector for long-lived, charged particles, through its measurement of extensive air showers from secondary leptons. To test this in an example model, we simulate the production of stau inside the Earth from interactions between ultra-high-energy neutrinos and nuclei. We propose that these two ANITA searches for upgoing air showers can be interpreted in terms of constraints on long-lived, charged massive particles (CRAMPS) and consider a supersymmetric partner of the tau lepton, the stau, as an example of such a particle. Exploring the parameter space in stau mass and lifetimes, we find that the stau properties that lead to an observable signal in ANITA are highly energy dependent. At 10^{15.5} eV, we find that the best constraints on the

The ANITA Anomalous Events as Signatures of a Beyond Standard Model Particle, and Supporting Observations from IceCube

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(Dated: September 26, 2018)

The ANITA collaboration have reported observation of two anomalous events that appear to be a stau 0.65 Ev cosmic ray showers emerging from the Earth with exit angle of 27° and 35°, respectively. While an Ev-scale upgoing showers have been anticipated as a result of astrophysical neutrino flux, the observed exit angles are much smaller than expected. The IceCube collaboration have also reported on similar events, with one event detected at 22°.
Some plausible scenarios:

- **Sterile Neutrino Explanation**
  
  A Sterile Neutrino Origin for the Upward Directed Cosmic Ray Shower Detected by ANITA
  
  John F. Cherry¹ and Ian M. Shoemaker¹
  
  ¹Department of Physics, University of South Dakota, Vermillion, SD 57069, USA
  
  (Dated: 2/5/18)
  
  The ANITA balloon experiment has observed an ~ Ev cascade event at an angle below the horizon that renders any Standard Model (SM) interpretation unlikely as the Earth is significantly opaque to all SM particles at such energies. In this paper, we study a sterile neutrino interpretation of this event, calculating the angular event distribution of cascades and the relative sensitivities of several experiments to a cascade initiated by an Ev sterile neutrino. We find that ANITA is uniquely sensitive to this type of upward directed cascade signal and canonical ultra-high energy cosmic ray (UHECR) models can produce a reprocessed Ev sterile neutrino flux at sufficient levels to accommodate the ANITA event.

- **Dark matter inside Earth Explanation**
  
  Upgoing ANITA events as evidence of the CPT symmetric universe
  
  Luis A. Anchordoqui,1,2,3 Vernon Barger,4 John G. Learned,5 Danny Marfatia,5 and Thomas J. Weiler6
  
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  5Department of Physics & Astronomy, University of Hawaii at Manoa, Honolulu, HI 96822, USA
  6Department of Physics & Astronomy, Vanderbilt University, Nashville TN 37235, USA

  We explain the two upgoing ultra-high energy shower events observed by ANITA as arising from the decay in the Earth’s interior of the quasi-stable dark matter candidate in the CPT symmetric universe. The dark matter particle is a 480 GeV right-handed neutrino that decays into a Higgs boson and a light Majorana neutrino. The latter interacts in the Earth’s crust to produce a lepton that in turn initiates an atmospheric upgoing shower. The fact that both events emerge at the same angle from the Antarctic ice-cap suggests an atypical dark matter density distribution in the Earth.

- **stau Explanation**
  
  No vertical direction event detected. Angular distribution does not match.
Some plausible scenarios:

- **Sterile Neutrino Explanation**

  A Sterile Neutrino Origin for the Upward Directed Cosmic Ray Shower Detected by ANITA

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- **Dark matter inside Earth Explanation**

  Upgoing ANITA events as evidence of the CPT symmetric universe

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  We explain the two upgoing ultra-high energy shower events observed by ANITA as arising from the decay in the Earth's interior of the quasi-stable matter candidate in the CPT symmetric universe. The dark matter particle is a 480 GeV right-handed neutrino that decays into a Higgs boson and a light Majorana neutrino. The latter enters the Earth's crust to produce a τ lepton that in turn initiates an atmospheric upgoing shower. The fact that both events emerge at the same angle from the Antarctic ice-cap suggests an atypical dark matter density distribution in the Earth.

- **stau Explanation**

  IceCube consistency

  No vertical direction event detected.
  Angular distribution does not match.

- **Sterile neutrinos as a possible explanation for the upward air shower events at ANITA**

  Guo-yan Huang1,2,3

  *Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
  2 School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 100049, China

  Abstract

  The ANITA experiment has observed two unusual upgoing air shower events which are consistent with the τ-lepton decay origin. Moreover, these events are in contradiction with the standard neutrino-matter interaction models as well as the eV diffuse neutrino flux limits set by the IceCube and the cosmic ray facilities like AUGER. In this paper, we re-investigated the possibility of using sterile neutrino hypothesis to explain the ANITA anomalous events. The diffuse flux of the sterile neutrinos is less constrained by the IceCube and AUGER experiments due to the small active-sterile mixing suppression. The quantum decoherence effect should be included for describing the neutrino flux propagating in the Earth matter. Because the interactions between neutrinos and the Earth matter are very strong at the eV scale, after several experimental approximations, we show that the ANITA anomaly itself is able to be explained by the sterile neutrino origin, but we also predict that the IceCube observatory should have more events than ANITA. It makes the sterile neutrino scenario unlikely to account for both of them simultaneously. A more solid conclusion can therefore be drawn from the dedicated ANITA signal simulations.

  \[
  \frac{\varepsilon_{\text{IC}}}{\varepsilon_{\text{ANITA}}} \approx \frac{A_{\text{IC}}^2 \cdot T_{\text{IC}}}{A_{\text{ANITA}} \cdot T_{\text{ANITA}}} \approx 6.
  \]

  Needs large coupling or large flux

On ANITA’s sensitivity to long-lived, charged massive particles

Amy Connolly*, Patrick Allison*, Ondrea Banejce

*Dept of Physics, Center for Cosmology and Astro-Particle Physics, Ohio State Univ., Columbus, OH 43210

Abstract

We propose that the Southern IceCube Transient Antenna (SICAT) can serve as a detector for long-lived, charged particles, through its measurement of extensive air showers from secondary leptons. To test this on an example model, we simulate the production of sneutrinos inside the earth from interactions between ultra-high-energy neutrinos and matter. We further propose that results of SICAT searches for upgoing air showers can be interpreted in terms of constraints on long-lived, charged massive particles (CRAMPS) and consider a supersymmetric partner of the tau lepton, the stau, as an example of such a particle. Exploring the parameter space in stau mass and lifetime, we find that the stau properties that lead to an observable signal in ANITA are highly energy dependent. At 10^{15} eV, we find that the best constraints on the

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(Dated: September 26, 2018)

The ANITA collaboration have reported observation of two anomalous events that appear to be $\varepsilon_{\text{IC}} \approx 0.6 \times 10^{15}$ eV cosmic ray showers emerging from the Earth with exit angles of 27° and 35°, respectively. While EeV-scale upgoing showers have been anticipated as a result of astrophysical tau neutrinos crossing to beta neutrinos during Earth passage, the observed exit angles are much
Our Proposal: Long lived neutral particle
Our Proposal: Long lived neutral particle interaction point

$\nu + e \rightarrow \chi + \tau$

decay point

$\chi \rightarrow \nu + e + \tau$

interaction point

$\nu + e \rightarrow \chi + \tau$
Our Proposal: Long lived neutral particle

\[ \nu^+ + e \rightarrow \chi^+ + \tau \]

Requirements:
1. \( \nu^+ e \) interaction produces neutral particle \( \chi \) and lepton
2. \( \chi \) is long lived and relatively stable
3. \( \chi \) could still decay back into leptons
4. \( \tau \) detected by ANITA is not from \( \nu \), but from this \( \chi \) decay
Our Proposal: Long lived neutral particle

\[ \nu^+ e^- \rightarrow \chi^+ \tau^- \]

Decay point

\[ \chi^+ \rightarrow \nu^+ e^- + \tau^- \]

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Benefits:
\( \chi \) is neutral and quasi-stable, easier to go through Earth, no need to worry about SM interactions for neutrinos

Not limited to tau-neutrino flux since we assume lepton flavor violation
Our Proposal: Long lived neutral particle interaction point

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Benefits:
\( \chi \) is neutral and quasi-stable, easier to go through Earth, no need to worry about SM interactions for neutrinos

Not limited to tau-neutrino flux since we assume lepton flavor violation

Our candidate for \( \chi \) is bino in RPV SUSY (LLE type)
Interaction and Decay
Interaction and Decay

- SUSY RPV term
Interaction and Decay

- SUSY RPV term

\[ W_{RPV} = \lambda_{ijk} L^i L^j \tilde{E}^k + \lambda'_{ijk} L^i Q^j \tilde{D}^k + \lambda''_{ijk} \tilde{U}^i \tilde{D}^j \tilde{D}^k \]
Interaction and Decay

- SUSY RPV term

\[ W_{RPV} = \lambda_{ijk} L^i L^j \bar{E}^k + \lambda'_{ijk} L^i Q^j \bar{D}^k + \lambda''_{ijk} U^i \bar{D}^j \bar{D}^k \]
Interaction and Decay

- **SUSY RPV term**

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W_{RPV} = \lambda_{ijk} L^i L^j \bar{E}^k + \lambda'_{ijk} L^i Q^j \bar{D}^k + \lambda''_{ijk} \bar{U}^i \bar{D}^j \bar{D}^k
\]

M. Carena, D. Choudhury, S. Lola, C. Quigg, Hep-ph/9804380;
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\]

\[
\sigma_{RPV} = \frac{8\pi}{M_{\tilde{\tau}}^2} \text{Br}[\tilde{\tau} \rightarrow \nu + e] \cdot \text{Br}[\tilde{\tau} \rightarrow \chi + \tau]
\]
\[
= \frac{8\pi}{M_{\tilde{\tau}}^2} \frac{|\lambda|^2}{|\lambda|^2 + g_{eff}^2} \frac{g_{eff}^2}{|\lambda|^2 + g_{eff}^2}
\]

Interaction and Decay

- **SUSY RPV term**

\[
W_{RPV} = \lambda_{ijk} L^i L^j \bar{E}^k + \lambda_{ijk}' L^i Q^j \bar{D}^k + \lambda_{ijk}'' \bar{U}^i \bar{D}^j \bar{D}^k
\]

\[
\sigma_{RPV} = \frac{8\pi}{M_{\tilde{\tau}}^2} \text{Br}[\tilde{\tau} \rightarrow \nu + e] \cdot \text{Br}[\tilde{\tau} \rightarrow \chi + \tau] = \frac{8\pi}{M_{\tilde{\tau}}^2} \left| \lambda \right|^2 \frac{g_{\text{eff}}^2}{\left| \lambda \right|^2 + g_{\text{eff}}^2}
\]

@ resonance, naturally enhancing the cross section
Interaction and Decay

- **SUSY RPV term**

  \[
  W_{RPV} = \lambda_{ijk} L^i L^j \bar{E}^k + \lambda'_{ijk} L^i Q^j \bar{D}^k + \lambda''_{ijk} \bar{U}^i \bar{D}^j \bar{D}^k
  \]

- **\( \chi \) decay**

  \[
  \sigma_{RPV} = \frac{8\pi}{M_\tilde{\chi}^2} \text{Br}[\tilde{\tau} \rightarrow \nu + e] \cdot \text{Br}[\tilde{\tau} \rightarrow \chi + \tau]
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Interaction and Decay

- **SUSY RPV term**

\[ W_{RPV} = \lambda_{ijk} L^i L^j \tilde{E}^k + \lambda'_{ijk} L^i Q^j \bar{D}^k + \lambda''_{ijk} \bar{U}^i \bar{D}^j \bar{D}^k \]

\[ \sigma_{RPV} = \frac{8\pi}{M^2} \text{Br}[\tilde{\tau} \rightarrow \nu + e] \cdot \text{Br}[\tilde{\tau} \rightarrow \chi + \tau] \]

\[ = \frac{8\pi}{M^2} \frac{|\lambda|^2}{|\lambda|^2 + g_{eff}^2} \frac{g_{eff}^2}{|\lambda|^2 + g_{eff}^2} \]

@ resonance, naturally enhancing the cross section

- **\( \chi \) decay**
Interaction and Decay

- **SUSY RPV term**

\[ W_{RPV} = \lambda_{ijk} L^i L^j E^k + \chi'_{ijk} L^i Q^j D^k + \chi''_{ijk} U^i D^j D^k \]

\[ \sigma_{RPV} = \frac{8\pi}{M^2_\tau} \text{Br}[\tilde{\tau} \rightarrow \nu + e] \cdot \text{Br}[\tilde{\tau} \rightarrow \chi + \tau] \]

\[ \sigma_{RPV} = \frac{8\pi}{M^2_\tau} \frac{|\lambda|^2}{|\lambda|^2 + g_{eff}^2} \frac{g_{eff}^2}{|\lambda|^2 + g_{eff}^2} \]

@ resonance, naturally enhancing the cross section

- **\( \chi \) decay**

\[ \Gamma(\chi \rightarrow \tau e \nu) \sim \frac{3\alpha \lambda^2_{i31}}{128\pi^2} \frac{M^5_\chi}{M^4_\tau} \]
Possible sources of ANITA events
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- **Isotropic source**: $GZK \sim 10^{-25} \ (GeV \cdot cm^2 \cdot s \cdot sr)^{-1}$
Possible sources of ANITA events

- Isotropic source: $\text{GZK} \sim 10^{-25} \ (\text{GeV} \cdot \text{cm}^2 \cdot \text{s} \cdot \text{sr})^{-1}$

$\nu$ coming from CR CMB p gamma collision
Possible sources of ANITA events

- **Isotropic source**: $\text{GZK} \sim 10^{-25} \text{ (GeV \cdot cm}^2 \cdot \text{s \cdot sr)}^{-1}$

A test for GZK based on ANITA events
Possible sources of ANITA events

- **Isotropic source**: $\text{GZK} \sim 10^{-25} \, (\text{GeV} \cdot \text{cm}^2 \cdot \text{s} \cdot \text{sr})^{-1}$

A test for GZK based on ANITA events

For any general NP process assuming GZK flux:
Possible sources of ANITA events

- **Isotropic source**: $GZK \sim 10^{-25} \text{ (GeV} \cdot \text{cm}^2 \cdot \text{s} \cdot \text{sr})^{-1}$

A test for GZK based on ANITA events

For any general NP process assuming GZK flux:

$$N \sim \pi \theta_c^2 \frac{h^2}{\cos[\theta]} \cdot \Delta \Omega \cdot \Delta E \cdot T \cdot F_\nu \sim 0.19$$

$$\Delta \Omega = 4\pi, \Delta E = 0.1\text{EeV}$$
Possible sources of ANITA events

- **Isotropic source**: $\sim 10^{-25} \ (\text{GeV} \cdot \text{cm}^2 \cdot \text{s} \cdot \text{sr})^{-1}$

A test for GZK based on ANITA events

For any general NP process assuming GZK flux:

$$N \sim \pi \theta^2_c \frac{h^2}{\cos[\theta]} \cdot \Delta \Omega \cdot \Delta E \cdot T \cdot F_{\nu}$$

$$\sim 0.19$$

$$\Delta \Omega = 4\pi, \ \Delta E = 0.1 \text{EeV}$$

Expected event number $N$ in $3\sigma$ CL:

$$[0.315, 12.68]$$
Possible sources of ANITA events

- **Isotropic source**: $\text{GZK} \sim 10^{-25} \text{ (GeV cm}^2 \text{ s sr)}^{-1}$

A test for GZK based on ANITA events

For any general NP process assuming GZK flux:

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\[
\sim 0.19
\]

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\Delta \Omega = 4\pi, \Delta E = 0.1\text{EeV}
\]

Expected event number \(N\) in 3\(\sigma\) CL:

\[
[0.315, 12.68]
\]

- **Anisotropic source**: AGN, GRB or SBG

\(\nu\) coming from CR CMB p gamma collision
Possible sources of ANITA events

- **Isotropic source : GZK**

\[ N \sim \pi \theta_c^2 \frac{\hbar^2}{\cos[\theta]} \cdot \Delta \Omega \cdot \Delta E \cdot T \cdot F_\nu \]

\[ \sim 0.19 \]

\[ \Delta \Omega = 4\pi, \Delta E = 0.1\text{EeV} \]

Expected event number \( N \) in 3σ CL:

\[ [0.315, 12.68] \]

- **Anisotropic source : AGN, GRB or SBG**

\( \nu \) coming from \( pp, p \) gamma interaction
Possible sources of ANITA events

- **Isotropic source :** GZK\( \sim 10^{-25} \ (\text{GeV} \cdot \text{cm}^2 \cdot \text{s} \cdot \text{sr})^{-1} \)

A test for GZK based on ANITA events

For any general NP process assuming GZK flux:

\[
N \sim \pi \theta_c^2 \frac{\hbar^2}{\cos[\theta]} \cdot \Delta\Omega \cdot \Delta E \cdot T \cdot F_\nu
\]

\[
\sim 0.19
\]

\[\Delta\Omega = 4\pi, \ \Delta E = 0.1\text{EeV}\]

Expected event number \(N\) in 3σ CL:

\[\left[0.315, 12.68\right]\]

- **Anisotropic source :** AGN, GRB or SBG

Provide a larger flux and a more direction-focused beam.
Possible sources of ANITA events

- Isotropic source: GZK $\sim 10^{-25} \text{ (GeV cm}^2 \text{ s sr)}^{-1}$

A test for GZK based on ANITA events

For any general NP process assuming GZK flux:

$$N \sim \pi \theta_c^2 \frac{h^2}{\cos[\theta]} \cdot \Delta \Omega \cdot \Delta E \cdot T \cdot F_\nu \sim 0.19$$

$\Delta \Omega = 4\pi, \Delta E = 0.1\text{EeV}$

Expected event number $N$ in $3\sigma$ CL:

$$[0.315, 12.68]$$

- Anisotropic source: AGN, GRB or SBG

Provide a larger flux and a more direction-focused beam.

Transient source could make IceCube observation time advantage irrelevant.
Possible sources of ANITA events

- **Isotropic source**: GZK\(~ \sim 10^{-25} \text{ (GeV} \cdot \text{cm}^2 \cdot \text{s} \cdot \text{sr})^{-1}\)

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\[ \sim 0.19 \]
\[ \Delta \Omega = 4\pi, \Delta E = 0.1\text{EeV} \]

Expected event number \( N \) in 3\( \sigma \) CL:
\[ [0.315, 12.68] \]

- **Anisotropic source**: AGN, GRB or SBG

Provide a larger flux and a more direction-focused beam.

Transient source could make IceCube observation time advantage irrelevant.

\( \nu \) coming from CR CMB p gamma collision

\( \nu \) coming from pp,p gamma interaction

\( M_\nu \neq 2\text{ GeV} \)
\( \lambda_{\nu_1} = 0.2 \)

AGN flux: \( \sim 10^{-20} \text{ (GeV} \cdot \text{cm}^2 \cdot \text{s} \cdot \text{sr})^{-1}\)
Results
Results

\[ N = \langle A_{\text{eff}} \cdot \Delta \Omega \rangle \cdot \Delta E \cdot T \cdot F_\nu \in [0.315, 12.68] \rightarrow \text{Event Constraint} \]
Results

\[ N = \langle A_{\text{eff}} \cdot \Delta \Omega \rangle \cdot \Delta E \cdot T \cdot F_{\nu} \in [0.315, 12.68] \]

\[ \tau_{\chi} \sim 0.219 \pm 0.051 \text{ ns} \]

Event Constraint

Geometry Constraint
Results

\[ N = \langle A_{\text{eff}} \cdot \Delta \Omega \rangle \cdot \Delta E \cdot T \cdot F_\nu \in [0.315, 12.68] \]

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---

**Event Constraint**

**Geometry Constraint**

---

**Babar Preliminary for \( \lambda_{23} \)**

**Babar Preliminary for \( \lambda_{13} \)**

**3\( \sigma \) Event Number Bound for \( \lambda_{i31} \)**

\[ F_\nu = 2 \times 10^{-20} \text{ (GeV\cdot cm}^2\cdot s\cdot sr)^{-1} \]
Results

\[ N = \langle A_{\text{eff}} \cdot \Delta \Omega \rangle \cdot \Delta E \cdot T \cdot F_\nu \in [0.315, 12.68] \rightarrow \text{Event Constraint} \]

\[ \tau_\chi \sim 0.219 \pm 0.051 \text{ ns} \rightarrow \text{Geometry Constraint} \]
Conclusion

• We propose that bino $\chi$ in RPV SUSY could be a suitable interpretation for ANITA events.

• $\chi$ should be long-lived with $\tau_\chi \sim 0.219 \pm 0.051 \text{ ns}$ with mass around a few GeV, with LLE coupling $\lambda \sim 0.2$.

• Isotropic source (GZK) cannot provide enough events to fit ANITA observation.

• Anisotropic/transient source could fit ANITA data while being consistent with IceCube.

• Should be testable in the near future.
Thank you !
Anisotropic sources

\[ N = \langle A_{\text{eff}} \cdot \Delta \Omega \rangle \cdot \Delta E \cdot T \cdot F_\nu \]

\[ \langle A_{\text{eff}} \cdot \Delta \Omega \rangle \equiv \int d\Omega \sin[\theta] \frac{\tau_c^2}{\cos[\theta]} \int_0^{\ell_{\text{tot}}[\theta]} \frac{dl_1}{l_{\text{bsm}}} \cdot e^{-l_1\left(\frac{1}{l_{\text{bsm}}} + \frac{1}{l_{\text{sm}}}\right)} \int_0^{\ell_{\text{tot}}[\theta] - l_1} d\ell_2 \cdot e^{-\frac{l_2}{l_{\text{decay}}}} \]

Event Constraint

\[ [0.315, 12.68] \]

\[ \tau_\chi \sim 0.219 \pm 0.051 \text{ ns} \]

\[ \Gamma(\chi \rightarrow \tau e\nu) \sim \frac{3\alpha \lambda^2}{128\pi^2} \frac{M_\chi^5}{M_{\text{SUSY}}^4} \]

\[ F_v = 2 \times 10^{-20} \text{ (GeV} \cdot \text{cm}^2 \cdot \text{s} \cdot \text{sr})^{-1} \]

Geometry Constraint

Babar Preliminary for \( \lambda_{23\,\text{k}} \)

Babar Preliminary for \( \lambda_{13\,\text{k}} \)

3\( \sigma \) Event Number Bound for \( \lambda_{313} \)
• Report ANITA events again with some details: upgoing, none phase reflection → meaning those are events coming from Earth.

• Explain why SM neutrino cannot past through Earth in such angle; and the effective area comparison between IceCube and ANITA and their results contradiction

• Ideas of BSM of getting around such stuff by Cherry, Huang, Dark matter people, stau people. Still has some IceCube contradiction

• To solve IceCube contradiction, we propose our model (cartoon explanation), such model requires we have bino particle with certain interaction

• This interaction could be provide by RPV SUSY and the bino being LSP particle

• Possible sources of ANITA events and rough estimate shows that GZK cannot be the source for the events

• Setting up favored region for parameters: Geometry constraint and Events fitting constraint calculation

• Showing such constraints

• conclude