The ANITA anomalous event and axion quark nugget

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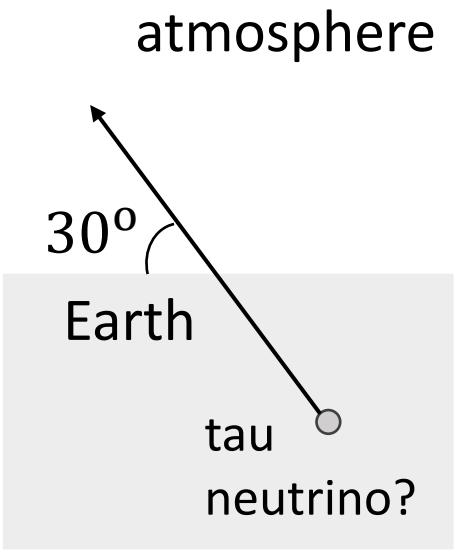
* X. Liang and A. Zhitnitsky (2021), 2105.01668, submitted to PRD

ANITA anomalous events



ANITA – Antarctic Impulse Transient Antenna

- is located in Antarctica
- is a balloon-borne array of radio antennas
- is designed to study ultrahigh energy cosmic ray via radio-wave signals

ANITA anomalous events

- are anomalously steeply upgoing, radio-detected, cosmic-ray-like events
- are compatible with a tau neutrino interpretation at energy ~EeV and exit angle $\sim -30^\circ$ relative to horizon
- BUT are exceedingly unlikely in standard model
- ANITA reported two such events in its first and third flights respectively

Axion Quark Nugget (AQN): quick facts

The AQN model

- has been developed for two decades [A. Zhitnitsky (2003), 0202161, JCAP]
- is one of the best-studied macroscopic dark matter candidates

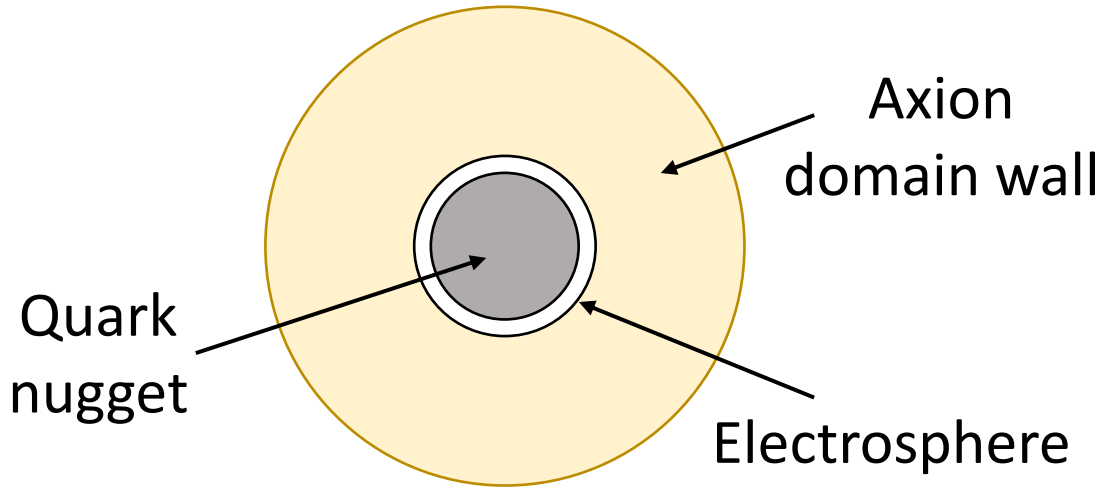
It is a good dark matter candidate because it resolves

- fine-tuning problem, $\Omega_{\mathrm{DM}} \sim \Omega_{\mathrm{vis}}$, of dark matters (unlike axion, WIMPs, etc.)
- observed asymmetry of baryon charge (i.e. baryogenesis)

An AQN:

- has mass of order grams, and size of order 0.1 μm
- is made out of either quarks or **antiquarks** in colour-superconducting phase
- is 100 times more stable than a proton in terms of binding energy
- is surrounded by an axion domain wall (NOT important here)

Substructure of AQN



	Quark nugget	**Axion domain wall**	**Electrosphere**
Mass	2/3 of an AQN	1/3 of an AQN	Almost 0% of an AQN
Size	$0.1\ \mu$m	1 cm	~1 nm to 1 cm (temperature dependent)
Stability	Colour-superconducting	Semi-topologically stable	Charge neutrality
Dominant interaction	Quark-antiquark pair annihilation	Domain wall oscillation	e^+e^- pair annihilation/production, Bremsstrahlung, etc.
Radiation	Neutrino, muon, photon	Axion	Electron, positron, radio, X-ray

ANITA signals?

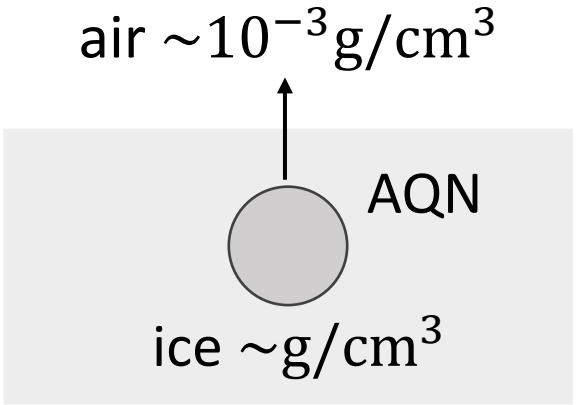
AQN explains ANITA anomalous events

Proposal:

- AQNs are heated and become less stable when propagating underground
- Electrosphere will emit 10^9 positrons/electrons instantly when subjects to an abrupt and critical change of environment [e.g. X. Liang and A. Zhitnitsky (2021), 2101.01722 & 2105.01668]
- The emitted positrons/electrons look like a cosmic-ray event

ANITA anomalous events:

- An upward-going AQN crosses the surface of ice and enters atmosphere
- It induces emission of 10^9 electrons



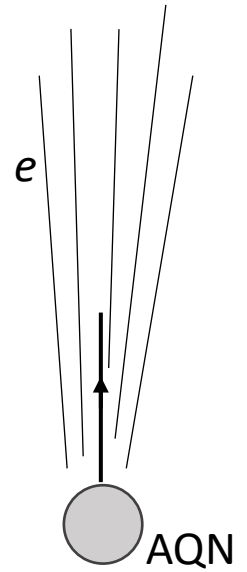
Consistent with observation

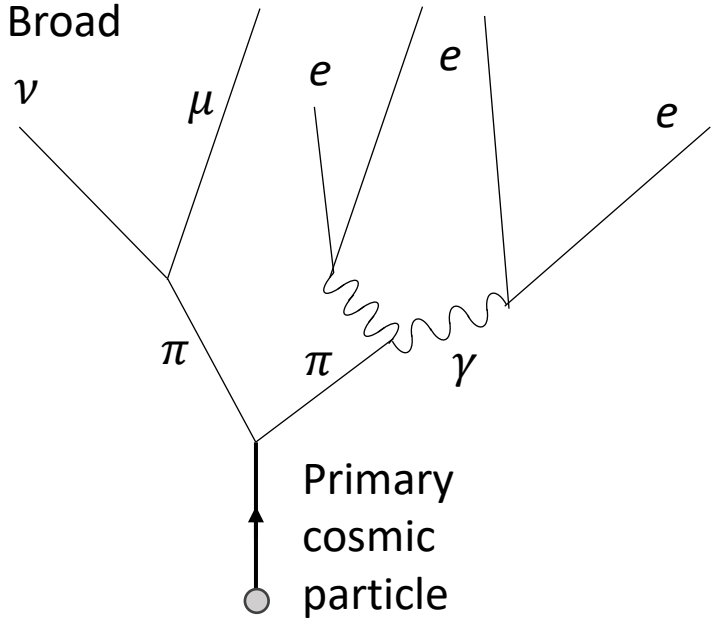
	AQN interpretation	**ANITA observation**
Radio frequency	$\sim(0.1-1)$ GHz	$\sim(0.04-0.8)$ GHz
Radio pulse duration	$\sim(2-4)$ ns	$\sim(1-10)$ ns
Electric filed strength	~ 1 mV/m	$\sim(0.1-1)$mV/m
Power spectrum	$\sim(0.05-0.5)$ pW $\mathrm{m}^{-2}\mathrm{MHz}^{-1}$	$\sim(0.1-1)$ pW $\mathrm{m}^{-2}\mathrm{MHz}^{-1}$
Exit angle relative to horizon	$\sim 30^\circ - 60^\circ$	27° and 35°
Expected number of events	~ 0.3 (exposure dependent)	2

- Estimation based on a simplified model
- Results may vary within order of magnitude range
- Future direction: AQN-induced signal can be distinguished from cosmic ray with more qualitative data

Air showers induced by different mechanisms

	AQN-induced air shower	**Conventional cosmic ray**
Types of dominant particles	Electrons	Electrons and positrons
Electron number	Fixed	Time-dependent
Emission	Instantaneous	Continuous
Shower profile	Shallow	Broad



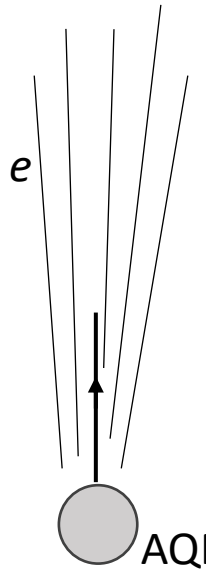


Suggestion for future tests

- AQN-induced signal can be distinguished from cosmic ray
- More detailed observation on characteristics of air shower is required
- E.g. use a synchronized network of ANITA-like experiments
  [X. Liang et al. (2021), 2012.00765, PRD]

Shower profile

Shallow



Broad