Magnetic Monopole Searches in Astroparticle Physics

Oindree Banerjee
The Ohio State University
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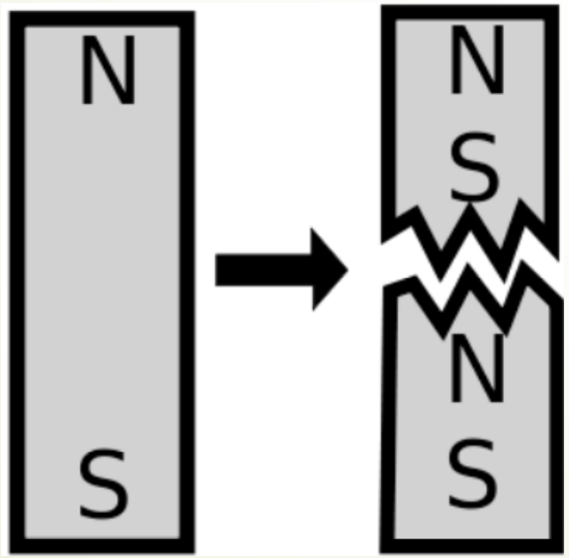
What is a magnetic monopole and why do we look for them?

- Magnetic poles always found in pairs
- Magnetic monopole would possess **one** magnetic pole
- Asymmetry in Maxwell's equations
- Motivate us to look for **magnetic charge**



$$\nabla \cdot \mathbf{D} = \rho$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

Dirac's Quantization of Magnetic Charge

- Quantization of electric charge is long-standing mystery
- Dirac showed that existence of magnetic charge ***leads to electric charge quantization***
- Calculated simple relationship between fundamental magnetic charge g and the quantum of electric charge e given by
- **$g = e / 2\alpha$**
- in Gaussian units, where α is the fine structure constant (1/137)

Suppose magnetic charge exists, rewrite Maxwell's equations with *ρ_m and J_m*

$$\nabla \cdot \mathbf{D} = \rho_e$$

$$\nabla \cdot \mathbf{B} = \rho_m$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} - J_m$$

$$\nabla \times \mathbf{H} = \mathbf{J}_e + \frac{\partial \mathbf{D}}{\partial t}$$

Perform a duality transformation of the fields and the sources

$$E = E' cosx + H' sinx$$

$$B = -D' sinx + B' cosx$$

$$H = -E' sinx + H' cosx$$

$$D = D' cosx + B' sinx$$

$$\rho_e = \rho_e' cosx + \rho_m' sinx$$

$$\rho_m = -\rho_e' sinx + \rho_m' cosx$$

$$J_e = J_e' cosx + J_m' sinx$$

$$J_m = -J_e' sinx + J_m' cosx$$

Maxwell's equations with magnetic charge remain invariant under duality transformation

Invariance under duality transformation means that

- it is matter of convention for particle to have electric charge but no magnetic charge
- maybe ALL particles have the same **ratio** of electric to magnetic charge leading to the simple equation **g = e / 2α**
- if they do, we can **choose** x so that $\rho_m = 0$, $J_m = 0$
- to get Maxwell's equations as we know them, i.e. without magnetic charge

- **point is: there is lots of motivation to look for magnetic charge**

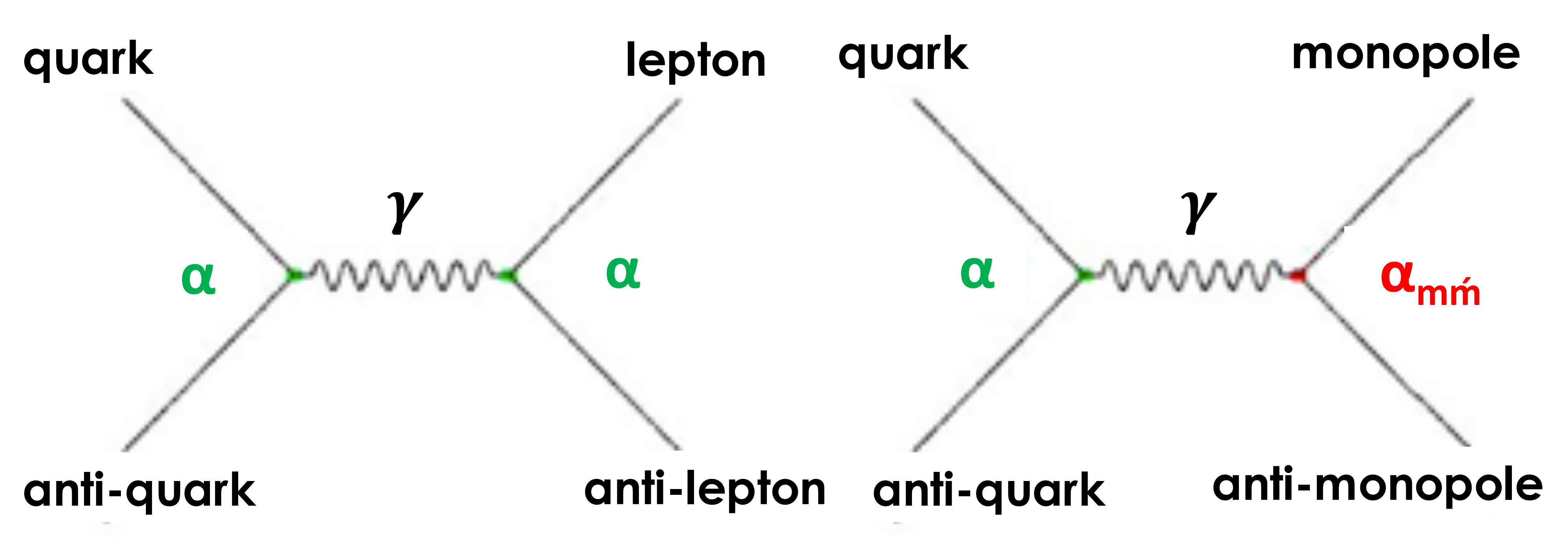
Intermediate Mass Monopole (IMM)

- Grand Unified Theory (GUT) predicts magnetic monopoles at energy scale ~ **10^{16} GeV**

- *Theorized* magnetic charges IMM's have mass << GUT scale and are **ultra-relativistic**
  - Mass: **10^{5} - 10^{12} GeV**
  - Implies Lorentz factor: **10^{11} – 10^{4}**

  - Expect Large Cherenkov Emission
  - Should be readily detectable by Astroparticle experiments like ANITA, RICE

Feynman diagrams



The experiments and corresponding results we discuss here:

- ANITA: Antarctic Impulsive Transient Antenna
- RICE: Radio Ice Cherenkov Experiment

What is ANITA?

- Balloon-borne antenna array primarily designed to detect **radio wave pulses** caused by **neutrino interactions with matter (ice)**
- From **elevation of ~ 38 km** detector scans Antarctic continent in circumpolar trajectory
- ANITA has flown thrice so far, **ANITA-2** (40 antennas) searched for monopoles
- After launching from McMurdo Station, ANITA-2 was aloft for **31 days**

ANITA simulation for monopoles

- **Monte Carlo simulation** needed to figure out ANITA's **sensitivity** to monopoles (IMM's)
- Model of **monopole energy loss** based on the muon/tau energy loss model of **Dutta et al**
- **$-dE/dx = \alpha + \beta E$**
- α is term for ionization, β is term for bremsstrahlung, pair production, photonuclear effect
- **Photonuclear effect** is the dominant energy loss mechanism at **$\gamma > 10^4$**, while ionization energy losses dominate below this value of γ

ANITA-2 trigger

- ANITA-2 has hierarchical triggering scheme (L0 – L3) and 4 digitizing buffers
- allows relatively low neutrino detection trigger threshold while maintaining ~ **Hz** thermal noise data rate written to disk
- **Monopole signature expected to consist of first 4 threshold-crossings (~500 ns total time) once the monopole comes into view**
- **remaining signal produced by monopole ionization trail not registered due to dead-time as 4 buffers fill**

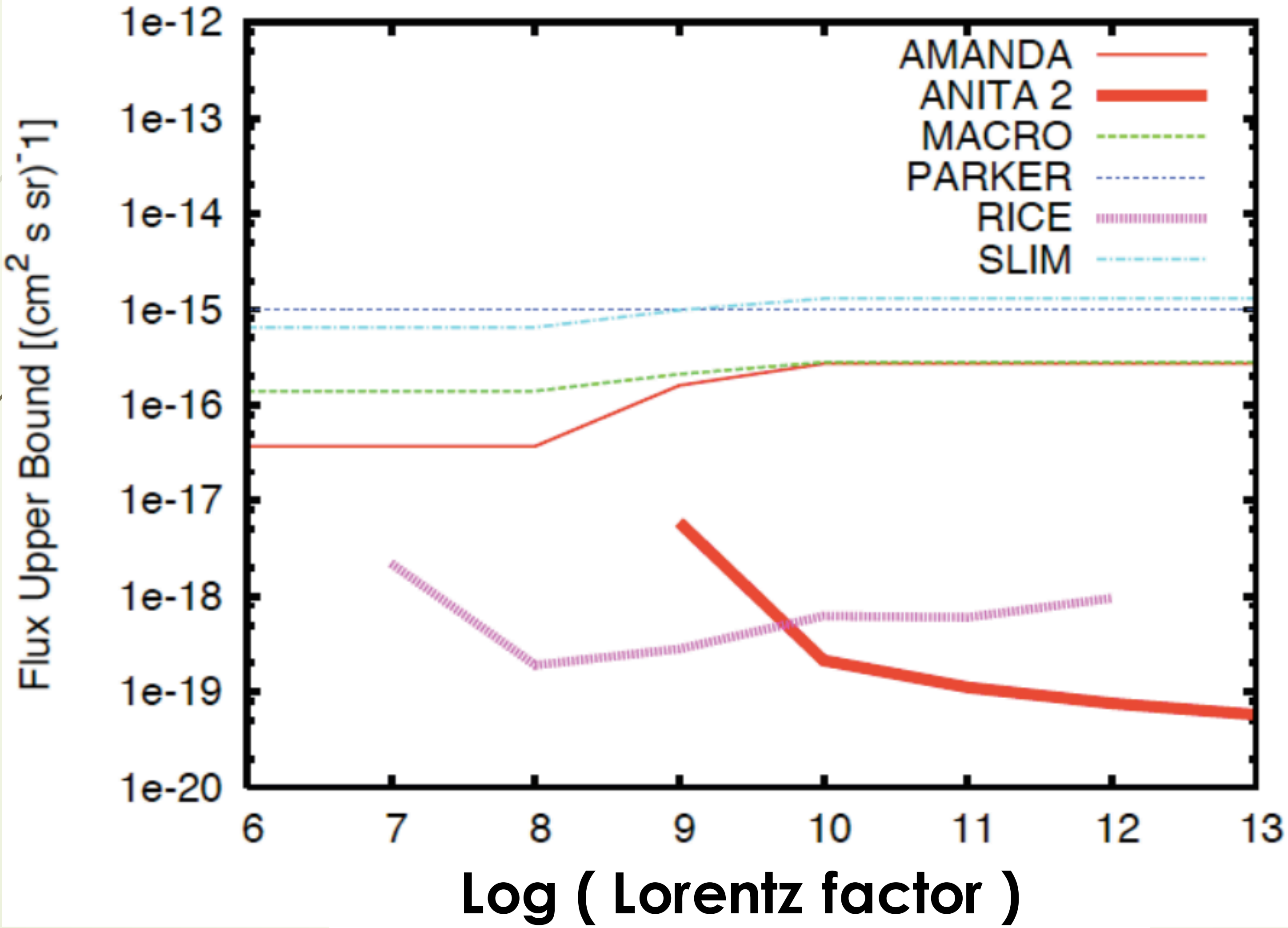
ANITA analysis

- In entire data sample, only 4 events contained 4 rapid triggers satisfying the 500 ns maximum total trigger time criterion
- all 4 were background dominated by CW lines
- whereas monopole signals should exhibit broadband characteristics of temporally-sharp, coherent radio wavelength signals
- so no monopoles were found

RICE

- RICE consists of **16 data-taking antennas** buried in the Antarctic ice ~ 1 km from geographic South Pole
- Antennas roughly within a **cube of ice ~ 200 m on a side** with its **center ~ 150 m below the surface**
- have peak sensitivity in the **200–500 MHz regime**
- Used same model of **monopole energy loss (Dutta et al)** as ANITA
- Trigger occurs if **4 or more antennas register high-amplitude voltages** within a **time coincidence of 1.25 microseconds**
- Triggers initiate an **8.192 μs waveform capture**, sampled at a rate of **10^9 samples / second**, for all under-ice antennas
- did not find any monopoles

Best Limits on Monopole Flux so far



Detrixhe *et al.* [ANITA Collaboration], Phys.Rev. D83 (2011) 023513

D.P. Hogan *et al*.[RICE Collaboration] Phys.Rev. D78 (2008) 075031

Thank you
Questions?

Backup slides

ANITA-2 trigger details

- **Hierarchical ANITA-II trigger (L0 – L3)** allows relatively low neutrino detection trigger threshold, while maintaining ~**Hz** thermal noise data rate written to disk
- In contrast to ANITA-I, **only signals from the VPol channel** of the dual-polarization horn antennas contribute to ANITA-II trigger
- Following antenna, signals routed through trigger path are tested for their spectral power in 4 frequency bands **200→350, 330→600, 630→1100 and 150→1240 MHz**
- Frequency-banded signals are then passed through a **tunnel-diode**, which integrates roughly **7-ns units of data** and provides a unipolar (negative) output pulse.
- **L0** required signal in 1 of 4 frequency bands > $2.3\sigma_V$ where σ_V is the RMS of the typical tunnel-diode output voltage at this point
- **L1** required 2 of 3 frequency bands + full-band trigger within 10 ns window
- **L2** issued in 1 of 16 phi sectors when 2 of 3 antennas on or adjacent to that phi sector triggered within 10 ns of each other
- **L3** required 2 of 3 antenna rings (upper, lower, and nadir) to have an L2 trigger within 10 ns