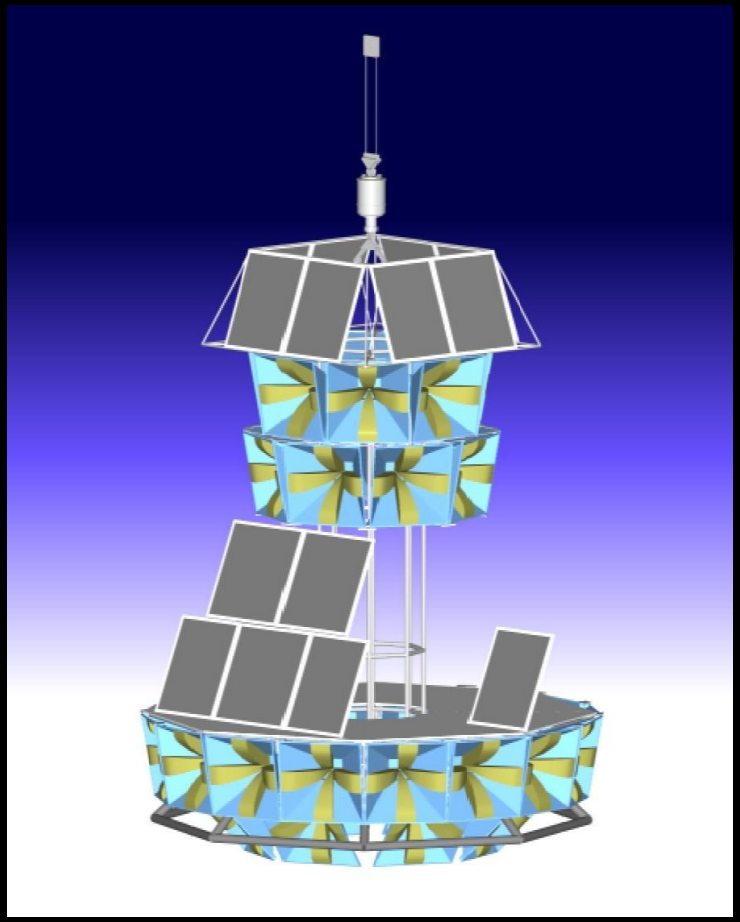
Monopole Detection with the ANITA Experiment



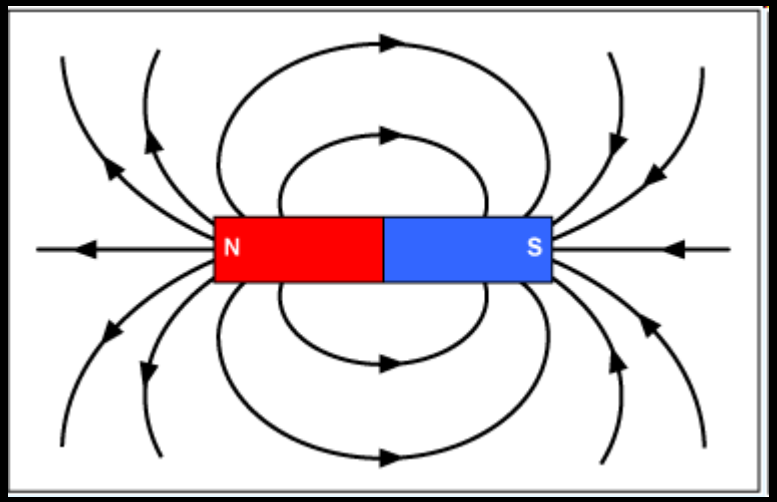
Research Goal

- Calculate an upper limit for the natural abundance of monopoles, i.e. flux
  - Particle flux depends on:
    - Number of observed particles
    - Time sensor was active
    - Sensor area
    - Portion of the sky visible to the sensor
  - Particle Flux Unit (PFU)
    - $cm^{-2}*s^{-1}*sr^{-1}$

What is a monopole?

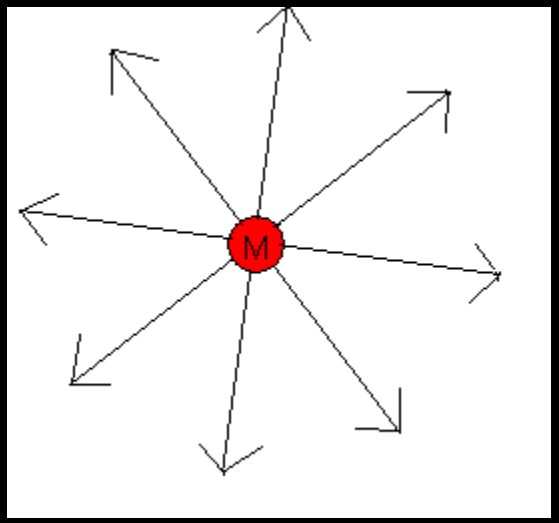
Typical Magnet

•Dipole
•Field lines form closed loops



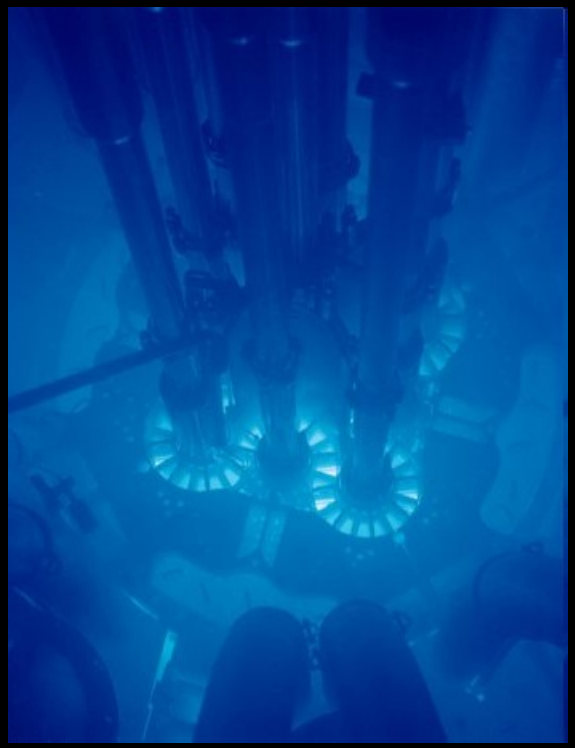
Monopole

- Field lines extend outward from particle with net “magnetic charge”
- Hypothetical particles with velocity = c



Cherenkov Radiation

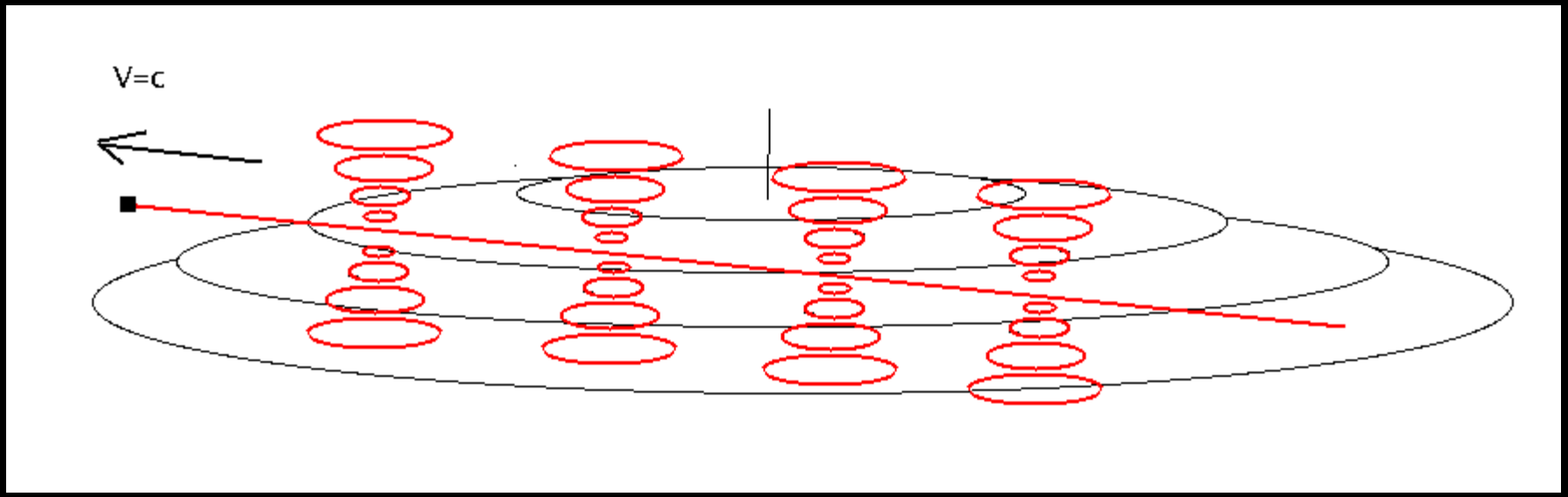
- Electromagnetic radiation
  - Charged particle with velocity > c/n
  - Energy over a wide range of the electromagnetic spectrum
  - Notably in the radio wave regime.



Example: Nuclear Reactors

Monopole-Ice Interaction

- When a monopole travels through a medium, such as ice, it emits Cherenkov radiation continuously in the form of radio waves.

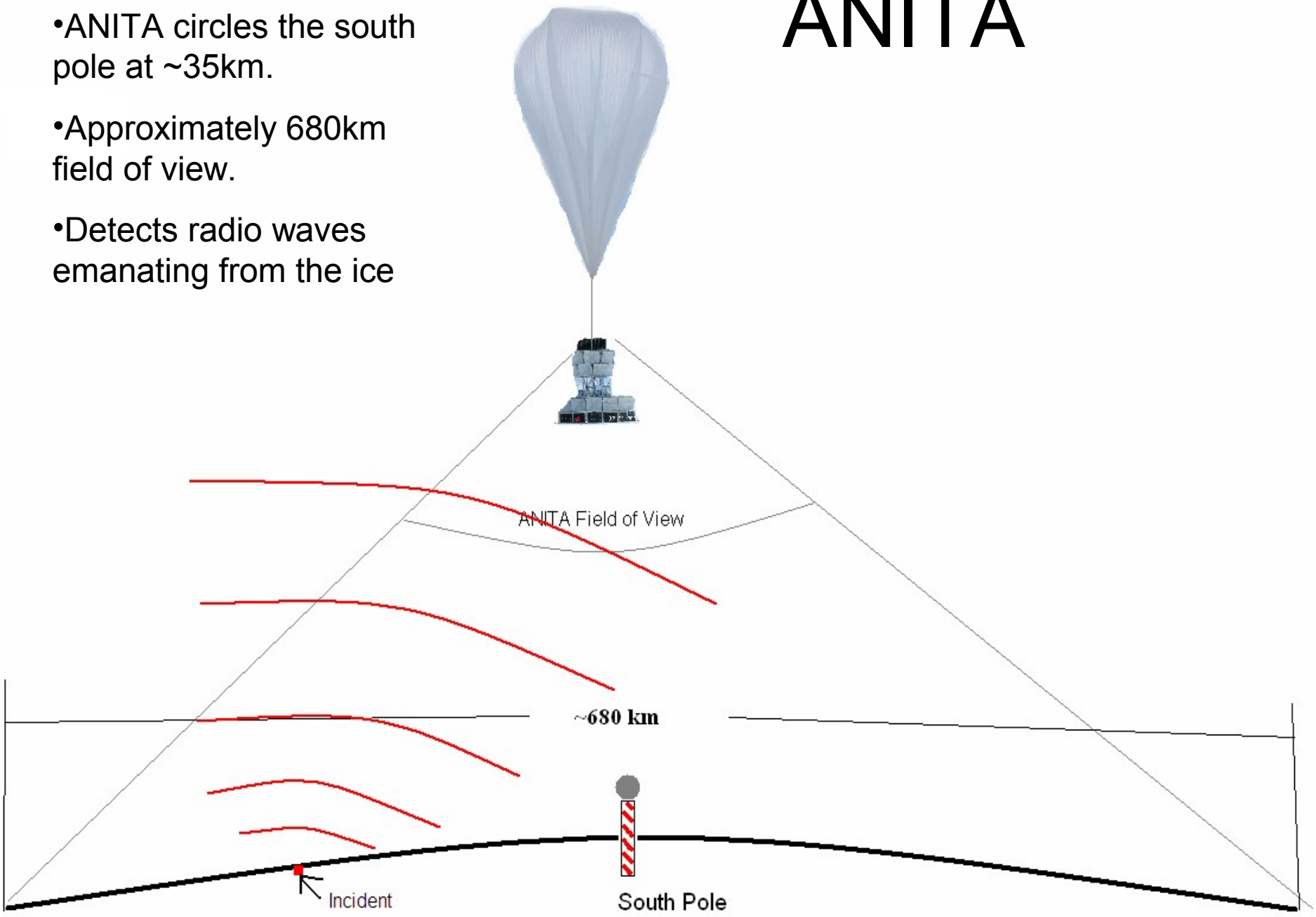


ANtarctic **I**mpulsive **T**ransient **A**ntenna

- Balloon Borne Antenna Array
- Designed to detect neutrinos by observing Cherenkov radiation in the radio regime
- 32 horn antenna array
- Operates at an altitude of ~35km

ANITA

- ANITA circles the south pole at ~35km.
- Approximately 680km field of view.
- Detects radio waves emanating from the ice



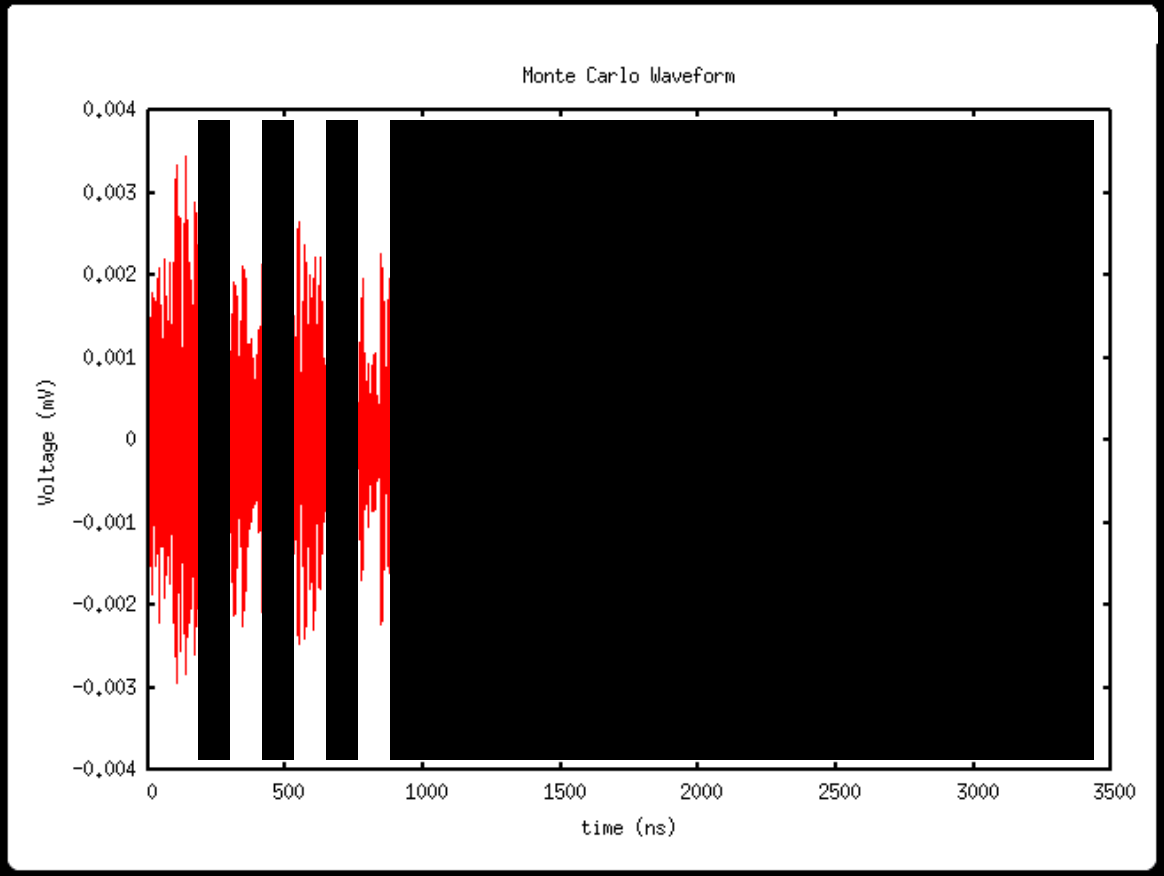
ANITA Limitations

- For each “trigger” ANITA records 100ns of waveform.
- After each trigger, ANITA goes “dead” for approximately 150ns
- Can hold up to four events before reading to disk and becoming effectively “dead”.

Data Reduction

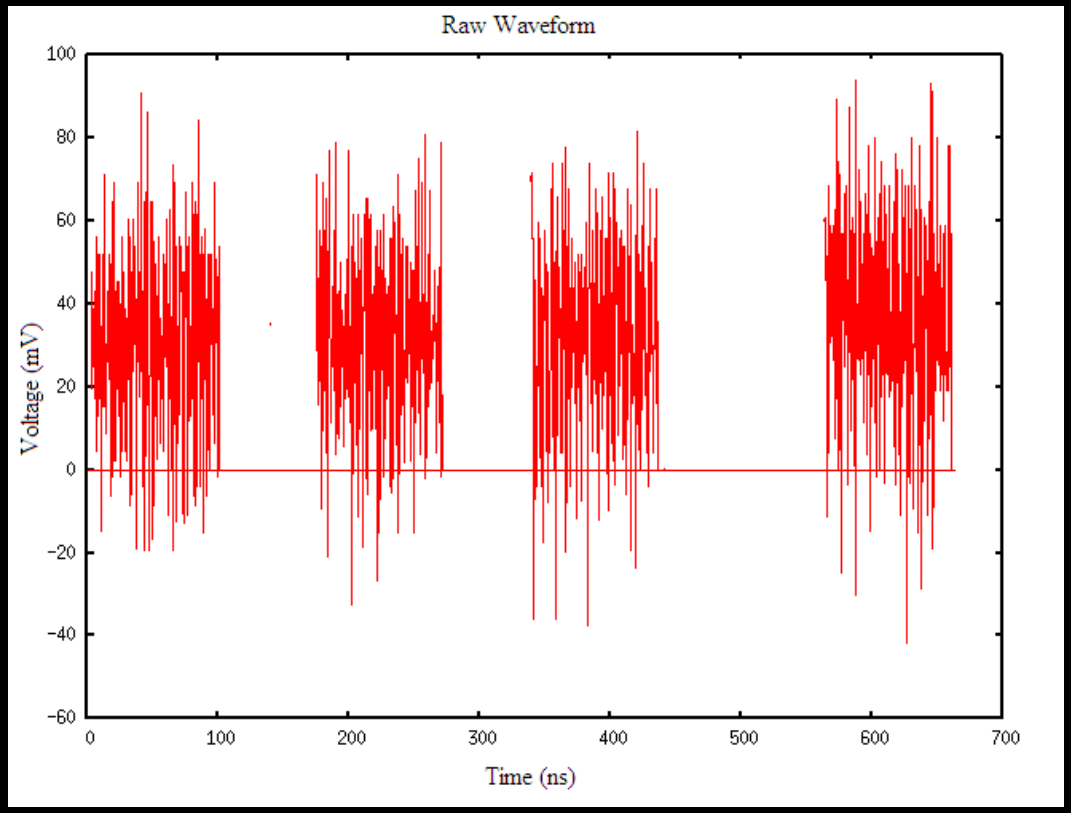
- ANITA flew ~35 days in 2006-2007
- Observed ~8.1 million events
- To begin the monopole analysis a subset of events was selected
  - Require four consecutive events “quickly” triggered
    - Total elapsed time <1 microsecond
- This requirement created a subset of 20 groups of four events
- To eliminate these events as monopole candidates, their waveforms would be analyzed

Monte Carlo Simulation



MC code simulates monopole-ice interactions and produces hypothetical waveforms as would be observed by ANITA

Actual ANITA Data



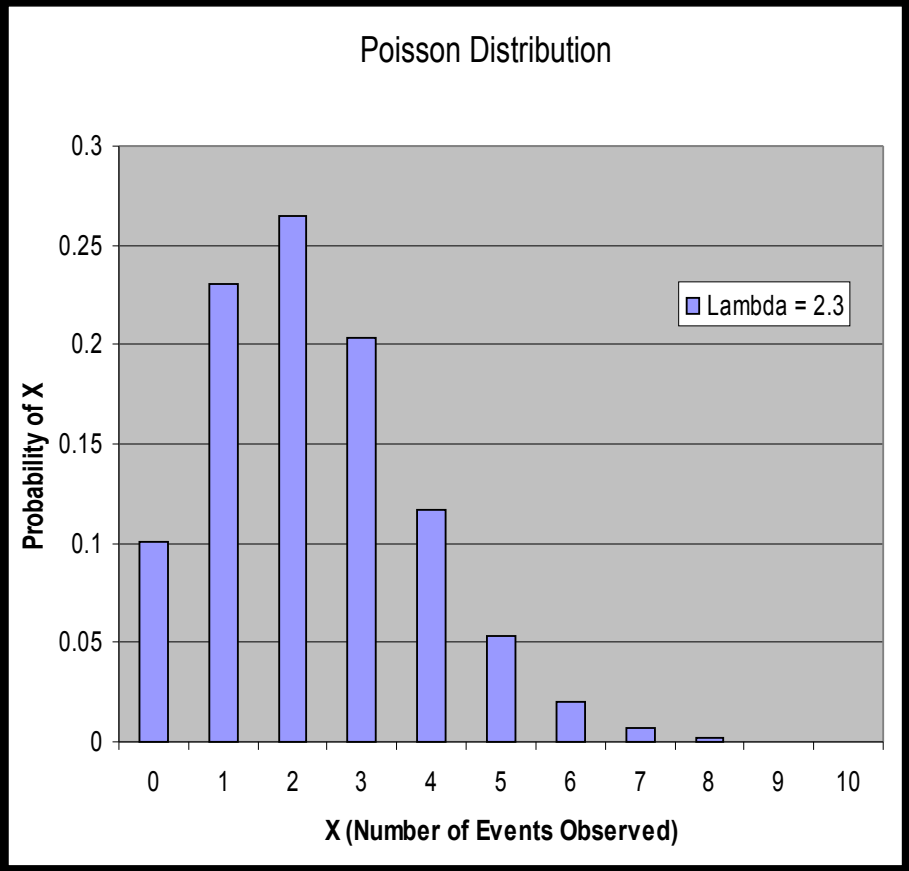
Because ANITA can only hold up to four events, the best case scenario would be four separate segments of the actual signal.

The Method of Moments

- First Moment
  - $\mu_1 = \Sigma(V_i)/N = V_{av}$
- Second Moment
  - $\mu_2 = 1/N*\Sigma(V_i - V_{av})^2$
- Require that the second moment decrease from event 1 to event 4
  - E.g. $\mu^1_2 > \mu^4_2$
- Also require that the percent decrease in the second moment doesn't deviate for each antenna
  - E.g. The waveform seen by each antenna lies in the range: μ^4_2 / μ^1_2 +-10%

No Candidates Left

- The method of moments effectively eliminated all possible candidate events
- Number of monopoles observed = 0
  - By assuming poisson distribution
  - At 90% confidence, the mean number of events < 2.3
    - i.e. upper limit for the mean = 2.3

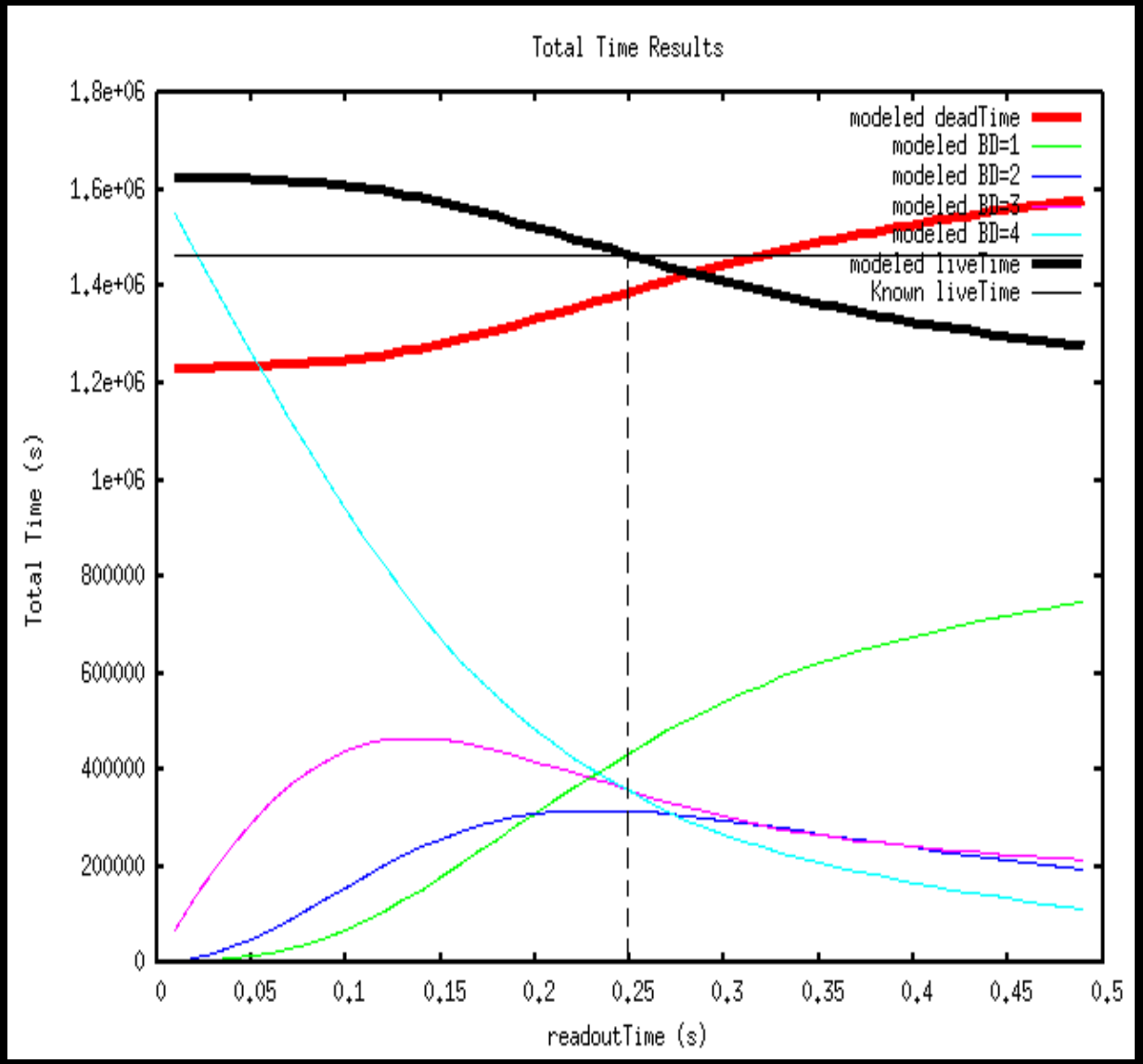


Live Time

- Recall: Particle Flux
  - Flux (F)=$N*cm^{-2}*s^{-1}*sr^{-1}$
- Must know the time the detector was active
  - Four consecutive events were required
    - Buffer Depth (BD) = 4
    - ANITA recorded BD for events, but somehow the data became corrupted and unreliable
    - Some other method of obtaining liveTime was required

Live Time Simulation

- Take known info on ANITA triggering
- Create a simulation of BD based on assumption of readout time
- Run simulation for large range of assumed values
- Match to known data
- Make inference



Monopole Efficiency

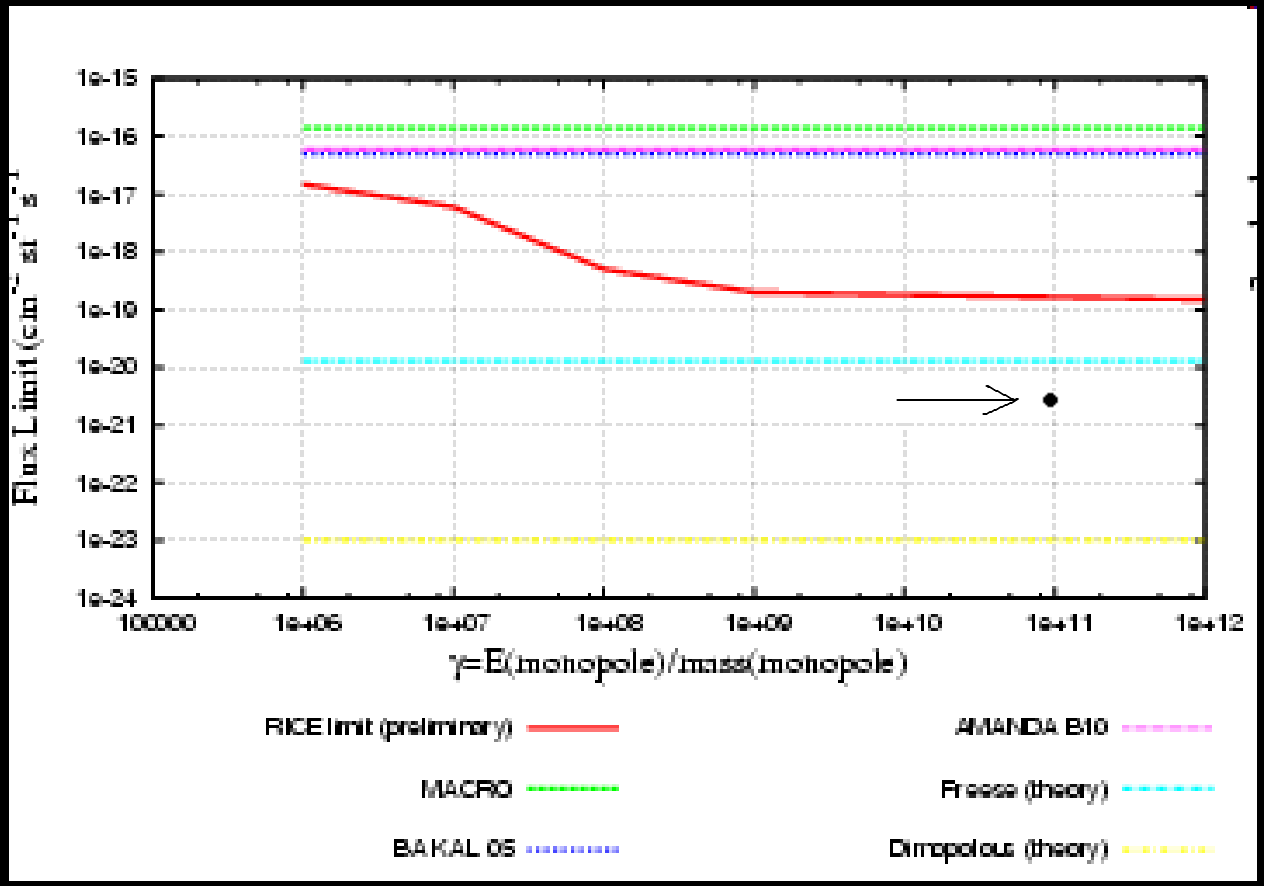
- The efficiency (ε) at which monopoles would be detected must also be considered
  - The total efficiency (ε) is the fraction of simulated monopoles that would produce an ANITA trigger and satisfy the criteria (moments) out of the total number of monopoles generated.
    - Total monopoles generated = 5000
    - Total remaining after cuts = 36
    - ε = 36/5000 = .72%

Flux Calculation

- $F=N/(A*L*S*\varepsilon)$
  - N= Number of monopoles observed
    - At 90% confidence N=2.3
  - A = Area detector is sensitive to monopoles
    - $A=\pi*(680km)^2$
  - L = Live Time
    - L= 390,000 seconds
  - S = Visible Sky (steradians)
    - S = 4 π steradians
  - ε = efficiency
    - ε ~ .0248

Preliminary Result

- Substituting values into the equation yields an upper bound for the flux of magnetic monopoles:
- $F = 4.09 * 10^{-21}$ $(cm^{-2}*s^{-1}*sr^{-1})$
  - This was done for one γ value, hence only one point
  - $\gamma = 10^{11}$



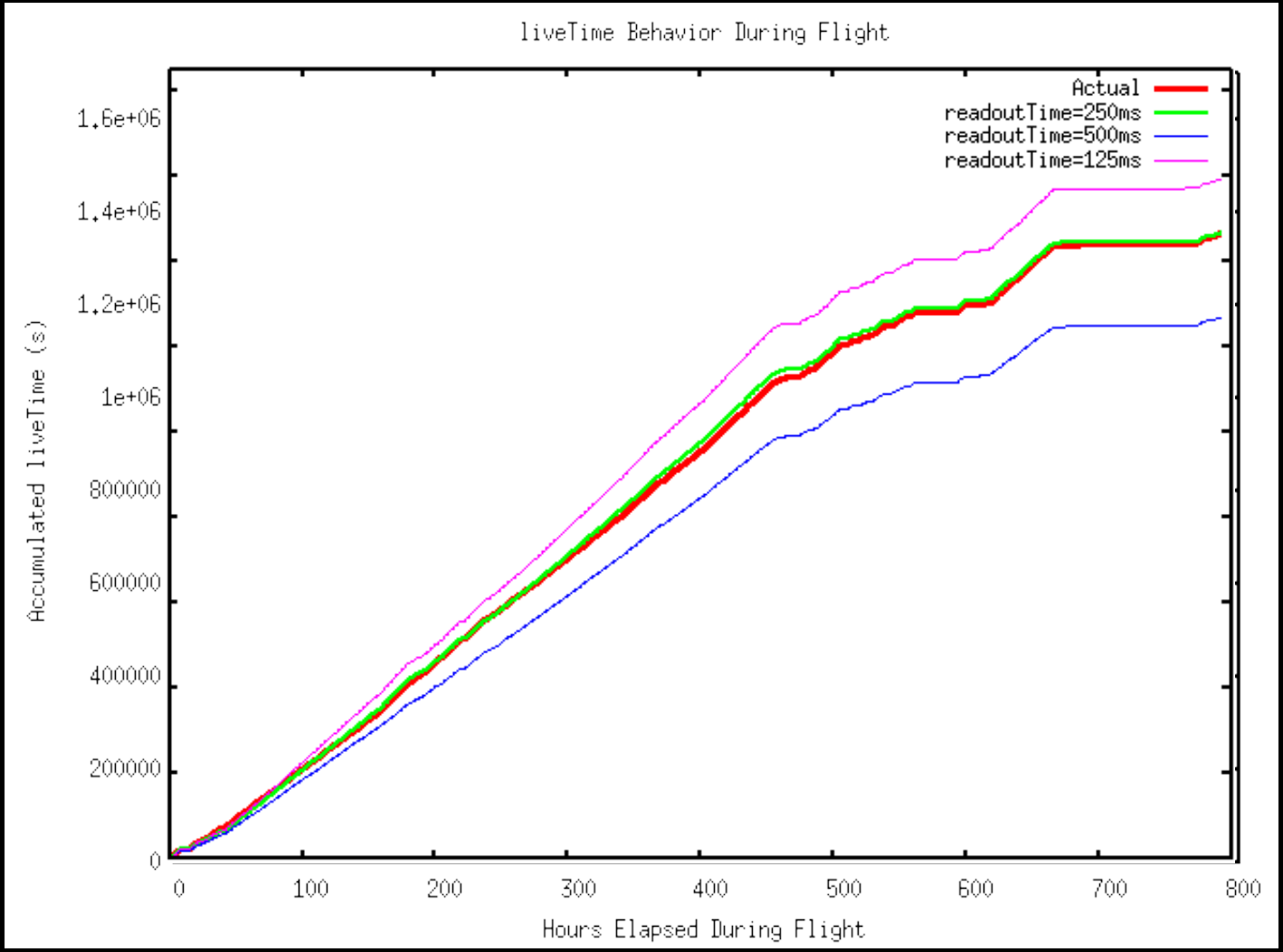
We have the capability to generate monopoles at γ values from 10^6 to 10^{12}

Questions?

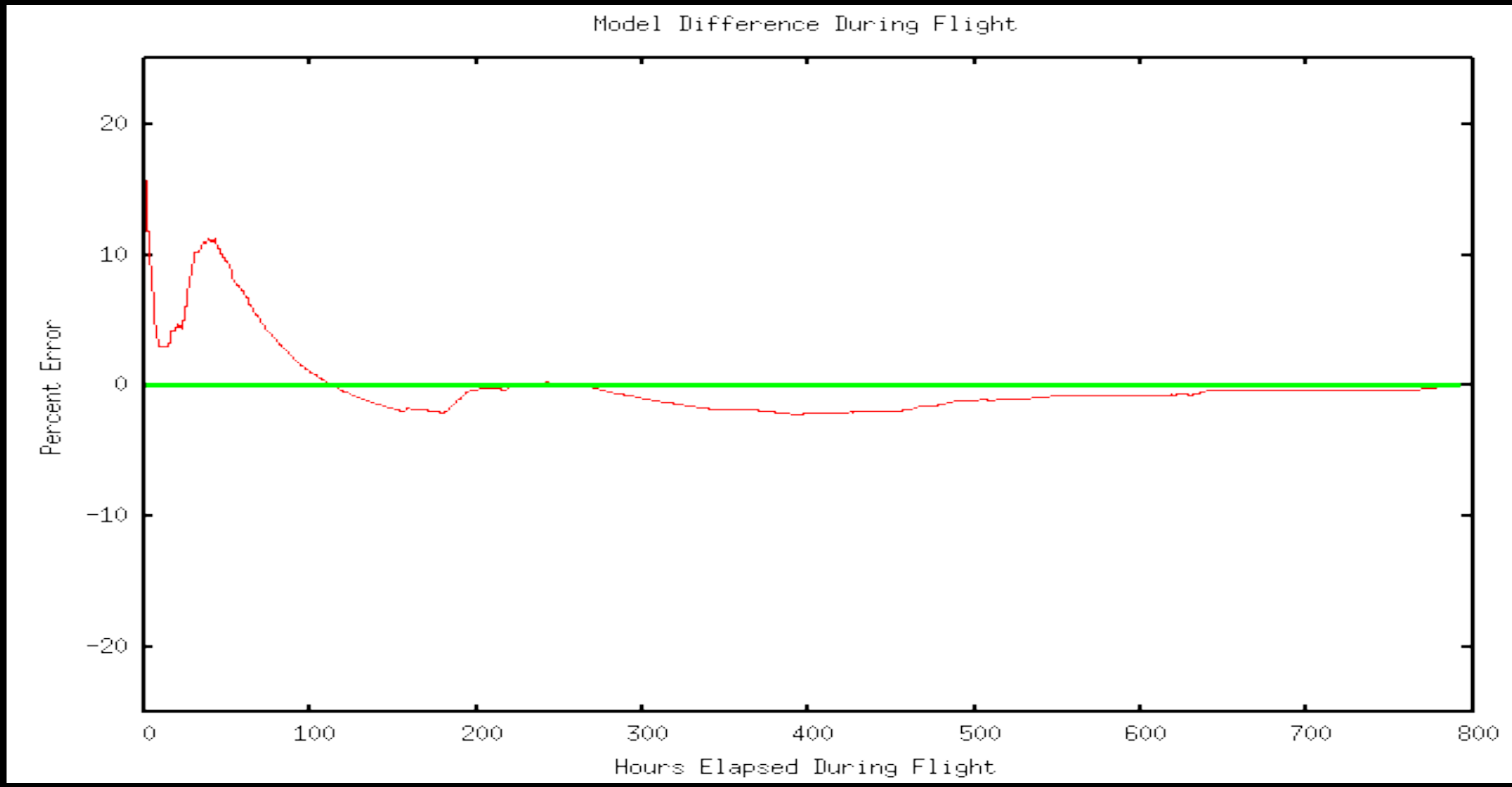
Bonus Slides

Accumulated Live Time

To test the validity of this model, we looked at the live time as it accumulated during the flight.



Deviation from Actual



After the first few days of the flight, the difference never exceeds ~4%.