Gamma-Ray Bursts in ANITA-4

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What are Gamma Ray Bursts (GRBs)?

- Most luminous explosions: Luminosity **$\sim 10^{52}$ erg s^{-1}** (entire galaxy: 10^{45} erg s^{-1})
- Brief: **0.1 s to several 100s s**
- Far: most occur at **~ 1 Gpc** from us
- Isotropically distributed in the sky
- Rare: ~ 0.3 Gpc^{-3} yr^{-1} (per volume per year)

$\mathbf{1\ erg = 10^{-7}\ J}$

pc = 3.26 light years

What are Gamma Ray Bursts (GRBs)?

- Two populations:
  - **Long** (t_γ > 2 s, typically 20 s): associated with hypernovae (big supernovae, ≥ 10x more luminous)
  - **Short** (t_γ < 2 s, typically 0.2 s): neutron star – neutron star (NS-NS) or neutron star – black hole (NS-BH) mergers
- Around 1000 GRBs per year, $^2/_3$ are Long
- Two part emission: prompt, afterglow (can last several hours)

$L_{supernova} = 10^{41}\, erg\, s^{-1}$ $L_{sun} = 10^{33}\, erg\, s^{-1}$

Fireball model

Cataclysmic stellar event resulting in NS or BH

Sudden release of gravitational energy ($\sim M_{sun}$) in compact volume (10s of km)

<1% goes into fireball of $\gamma - rays, e^{\pm}, baryons$

Kinetic energy of relativistically expanding fireball

hadronic model

shock accelerated electrons

shock accelerated protons

1. synchrotron
2. inverse-Compton

$\gamma - rays$

$\mathbf{p\gamma \rightarrow \pi^{+}, ..}$

High energy neutrinos

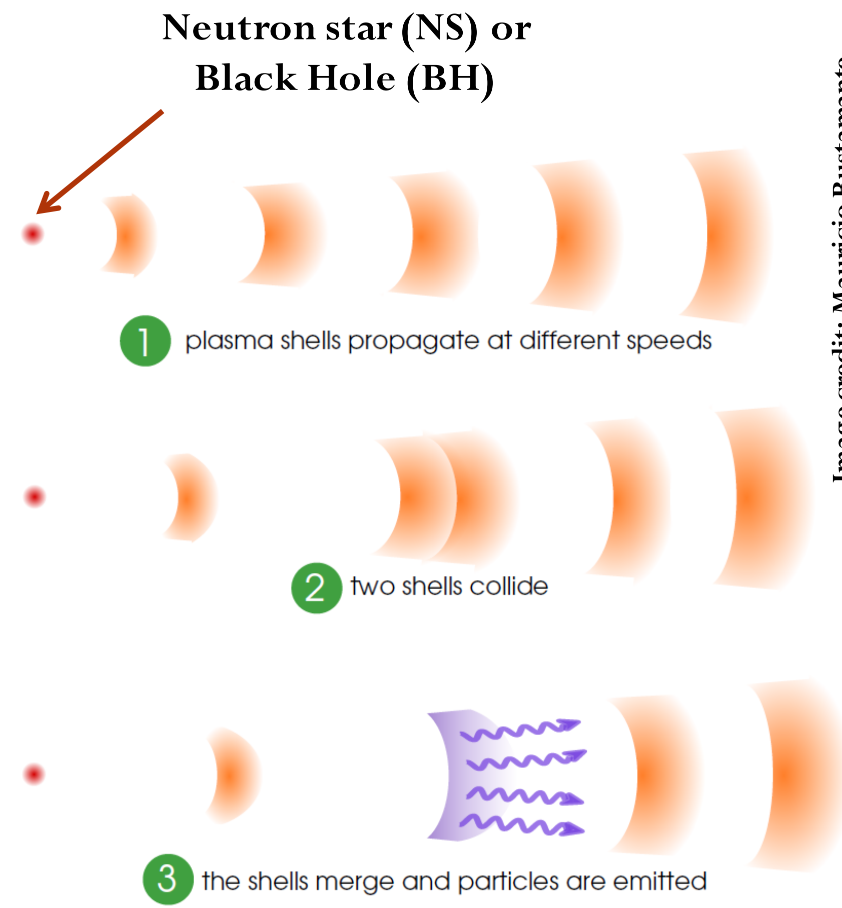


Image credit: Mauricio Bustamante

Theory: Photo-meson interaction that dominates neutrino production in GRBs

theorized cosmic rays from GRBs
n → p e^{-} $\bar{\nu}_e$

$$p + \gamma \longrightarrow \Delta^{+} \; \mathbf{(1232\ MeV/c^2)} \longrightarrow n + \pi^{+} \;\; \text{OR} \;\; p + \pi^{0}$$

$$\pi^{+} \longrightarrow \mu^{+} + \nu_{\mu} \longrightarrow e^{+} + \nu_{e} + \bar{\nu}_{\mu} + \nu_{\mu}$$

$$\pi^{0} \longrightarrow \gamma\gamma$$

theorized neutrinos produced by GRBs

WB Theory: Particle kinematics relation tells us expected GRB neutrino energies

$$\varepsilon_\gamma \varepsilon_p \cong 0.2\,\mathrm{GeV}^2\,\Gamma^2$$

Step 1a

Insert typical observed gamma-ray energy of 1 MeV (prompt emission) OR 100 eV (afterglow emission)

Step 2

Solve for proton energy ε_p

Step 1b

Insert Lorentz factor of 100

Step 3

$\varepsilon_\nu \sim 5\% \, \varepsilon_p$

Result

- **Prompt** emission: neutrino energy ~ **10^{14} eV**
- **Afterglow emission: neutrino energy ~ 10^{18} eV**

Past GRB search by ANITA collaboration

- Abby, Kim et al. paper is here
- Using **ANITA-2** data
- **31 day** flight, **26 GRBs** recorded by Swift or Fermi
- **Only 12 GRBs** (that had thermal-like background periods) were analyzed
- **None** had altitude angle between **−25°** **and the horizon** (considered good geometry for ANITA)
- GRB with most promising geometry had altitude of -**25.7**°

Past GRB search by ANITA collaboration

- Assumed input **E^{-4}** spectrum (theorized afterglow spectrum)
- Constrained search in **time** which reduced background, analysis threshold
  - GRB signal allowed to be in **10min** window each so total 120mins
  - Reduced background by (120mins/31days) = **0.002** (compared to diffuse search) and therefore allowed for reduction in threshold
  - But 10mins only allows for quick afterglows

Possible ANITA-4 GRB search

- Search in **constrained, longer** time windows
  - e.g. per GRB, signal allowed to be in time window: **minus 10mins to plus 6hrs = total 370mins**
  - To have improved opportunity for detection of theorized afterglow neutrinos which ANITA is sensitive to
  - Reduce background due to time windows by ((370mins x 26GRBs)/29days) = **0.230**

New neutrino direction constraint?

- Constrain search in **<u>neutrino direction</u> also**
  - This has not been done yet
  - Can try to develop techniques as part of my thesis work to constrain direction
  - e.g. per GRB, if signal is allowed to be in **$20^{\circ} \times 20^{\circ}$ = 400 degrees^2** window (if we can do that)

⇒ reduce background due to direction windows by (400 sq. degrees /(30degrees (θ range) x 360degrees (ϕ range))) = **<u>0.037</u>**

Result of time and direction constraints

- Reduce background by (**0.230 x 0.037**) = <u>**0.008**</u> (compared to diffuse search)
- Order of magnitude, ~same reduction factor as past search if we can constrain the neutrino direction to 400 degrees^2
- Plus, sensitivity to longer afterglows which are more likely to produce UHE neutrinos

NeuCosmA

- Use NeuCosmA for neutrino flux predictions (like in ARA GRB paper)
  - both prompt and afterglow models being upgraded this year to more accurate versions
  - can obtain custom spectra for each GRB
  - Mauricio Bustamante at OSU is eager to help

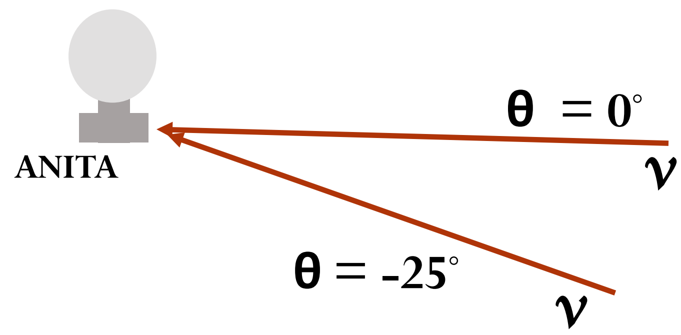
Reject fewer GRBs?

- Past ANITA GRB search rejected 14 out of 26 GRBs due to the presence of anthropogenic noise in the time window

- With ANITA-4, we might be able to keep more GRBs due to reduction of anthropogenic noise in triggered events due to TUFFs and LCP/RCP

26 GRBs during ANITA-4 flight and their altitudes (θ)

GRB list	Altitude (degrees)
GRB161202A	-10.953
GRB161203A	no data yet
GRB161205A	-20.477
GRB161206A	-62.117
GRB161207B	-25.799
GRB161207A	-58.076
GRB161210A	11.660
GRB161211-072730	-2.723
GRB161212A	19.278
GRB161213A	60.664
GRB161214A	-23.943
GRB161214B	38.802
GRB161217A	76.067
GRB161217B	7.424
GRB161217C	no data yet
GRB161218A	-36.671
GRB161218B	-74.304
GRB161219A	0.242
GRB161219B	-26.686
GRB161220A	-44.670
GRB161223A	0.981
GRB161224A	69.031
GRB161228A	40.615
GRB161228B	-21.161
GRB161228C	76.201
GRB161229A	24.798



- **Good geometry: -25° to 0°**
- **Close to good range**
- **Below horizon, steep**
- **Above horizontal**

Past search: GRB with most promising geometry had altitude of -**25.7**°

**GRB databases still updating, numbers can change, errors next time

Next Steps

- Obtain GRB time durations and photon energy spectra as GRB databases get updated
- Contribute to completion of ongoing diffuse search efforts
- Learn to generate GRB spectra with NeuCosmA by end of Summer (Mauricio leaves OSU)
- Check out noise levels in background regions surrounding each GRB
- Start to look at techniques for constraining neutrino direction

Thank you!

Back up slides

Early (1997-2000) theoretical predictions by Waxman-Bahcall (WB)

- From **cosmic ray observation** WB set model-independent upper bound on high energy neutrino intensity:
  - $E_\nu^2 \Phi_\nu < 2 \times 10^{-8}\ GeV\ cm^{-2} s^{-1} sr^{-1}$

- ~ 20 GRB muon neutrinos of energy **~ 10^{14} eV** per year over 4π steradian predicted for detection by km^2 neutrino detector

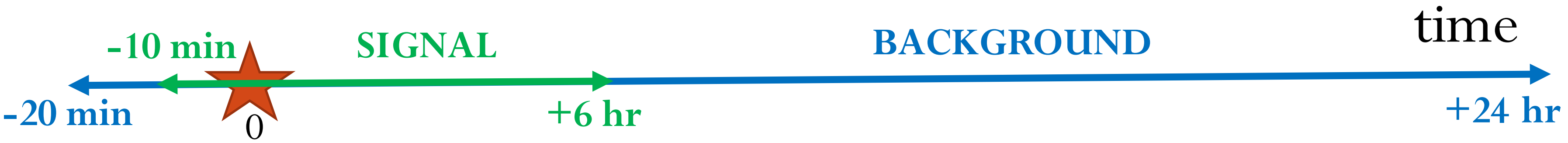
- ~ **0.06** GRB muon neutrinos of energy **$10^{17} – 10^{19}$ eV** per year over 2π steradian predicted for detection by km^2 neutrino detector

Fireball FAQs

- Expands – why?
  - Observed photon luminosity ≫ Eddington luminosity = **1.3 x 10^{38} (M/M_{sun}) erg s^{-1}**
  - Above which radiation pressure exceeds self-gravity, so the fireball will expand
- Highly relativistic – why?
  - Mean free path of $\gamma\gamma \rightarrow e^{\pm}$ in isotropic plasma (if sub-relativistically expanding fireball) would be very short
  - But many bursts show spectra extending above 1 GeV so flow must be able to avoid degrading these via $\gamma\gamma$ interactions
  - Flow must be expanding with Lorentz factor $\Gamma \geq 100$

Break energy

- Theory → GRB neutrino flux follows broken power law given by ϵ_{ν}^{-b} where b = 2 for prompt emission and b = 4 for afterglow. Break energy is the energy at which b changes.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-10 min
SIGNAL
BACKGROUND
-20 min
0
+6 hr
+24 hr