Subphotospheric Neutrinos from Gamma-Ray Bursts: The Role of Neutrons

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Relativistic outflows with neutrons inevitably lead to inelastic collisions, and resulting subphotospheric γ rays may explain prompt emission of γ-ray bursts. In this model, hadronuclear, quasithermal neutrinos in the 10–100 GeV range should be generated, and they may even have a high-energy tail by neutron-proton-converter or shock acceleration mechanisms. We demonstrate the importance of dedicated searches with DeepCore + IceCube, though such analyses have not been performed. Successful detections enable us to discriminate among prompt emission mechanisms, probe the jet composition, and see roles of relativistic neutrons as well as effects of cosmic-ray acceleration.

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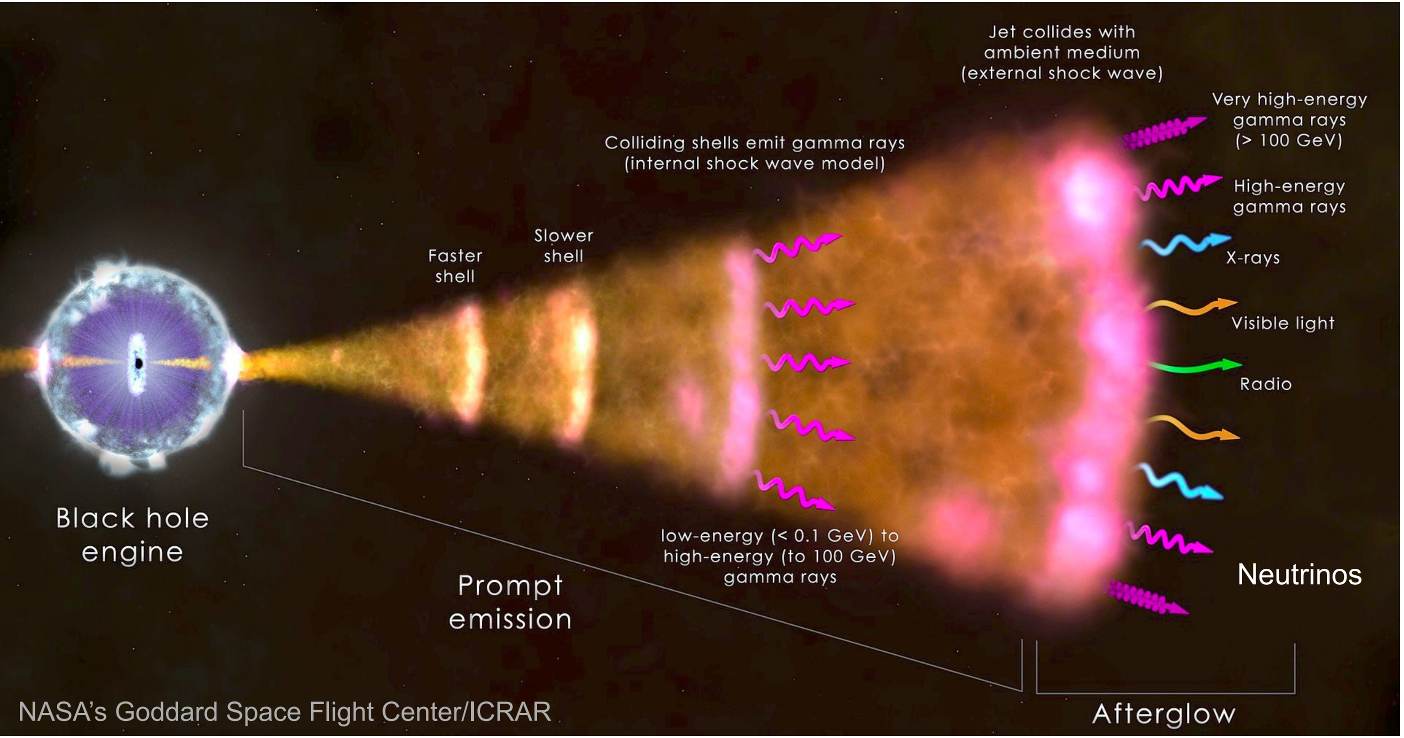
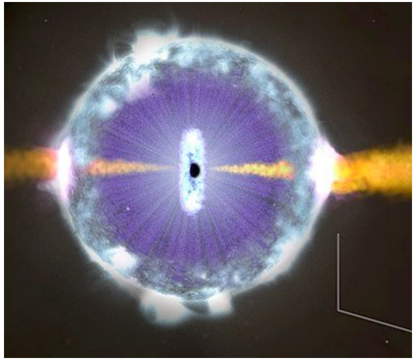
GRB Prompt emission



Subphotospheric scenario



Gamma rays generated under photosphere

- Inelastic nucleon-neutron collisions
    - Naturally predicts broken PL spectra via EM cascades/Coulomb heating
- Largely thermal emission
    - Explains high radiation efficiency and stabilizes peak energy
    - Observations have indicated a thermal component
- Sub-TeV neutrinos!

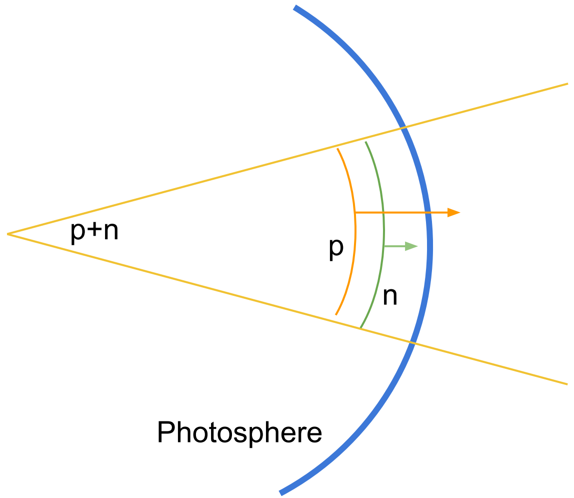
Neutrino Energies

Why search for sub-TeV neutrinos?

- Quasithermal neutrinos are inevitably produced via hadronuclear reactions, when inelastic collisions are responsible for jet dissipation
    - In classical scenario only from high energy CR - photon interactions
- Detecting sub-TeV neutrinos supports photospheric scenario
    - Revealing prompt emission mechanism
    - Probes jet composition and acceleration at subphotospheric level
- Can study the roles of relativistic neutrons on CR accelerations
    - NPC acceleration mechanism in low luminosity and failed GRBs

The inelastic collision model

- Dissipation mainly through hadronuclear reactions at subphotopheres
- Neutron loaded jets are naturally expected in GRB engines



Quasithermal nucleons: mesons and muons

- Decay into γ-rays, electrons and neutrinos

High energy γ-rays

Cannot avoid $\gamma\gamma$ process -> electromagnetic cascades

Largely thermal spectrum via modification by Compton scatterings

- Supported by observation and consistent with time evolution.

Coulomb heating or turbulence serves as slow heating

- Natural broken PL spectra with a higher energy component by pair injection via the cascades.

High radiation efficiency naturally expected: $\xi_N \approx 4\text{–}20$

Neutrinos

Quasithermal neutrinos:

- Created as consequence of the inelastic collisions
- Leave the flow easily
  - Not sensitive to details γ spectra
- GeV energies

Nonthermal neutrinos:

- Created when both flows contain protons, through internal shocks
- NPC acceleration mechanism
- Possible PL component
- TeV energies

Neutrino Energies

Neutrino Spectra

Numerically calculated with GEANT4

Quasithermal-> cold nucleons react with incoming neutrons

Cooling processes from coulomb scattering, hadronuclear reactions, Bethe-Heitler, photomeson production, sychrotron and inverse compton emission and adiabatic expansion

4 principal parameters: $\Gamma = 600$, $\Gamma_{\text{rel}} = 3$, $\tau_{pn} = 1$, and $\mathcal{E}_N^{\text{iso}} = 4\mathcal{E}_\gamma^{\text{iso}} (\approx 2\mathcal{E}_{\text{th}}^{\text{iso}})$.

NPC and PL components

Resulting spectra

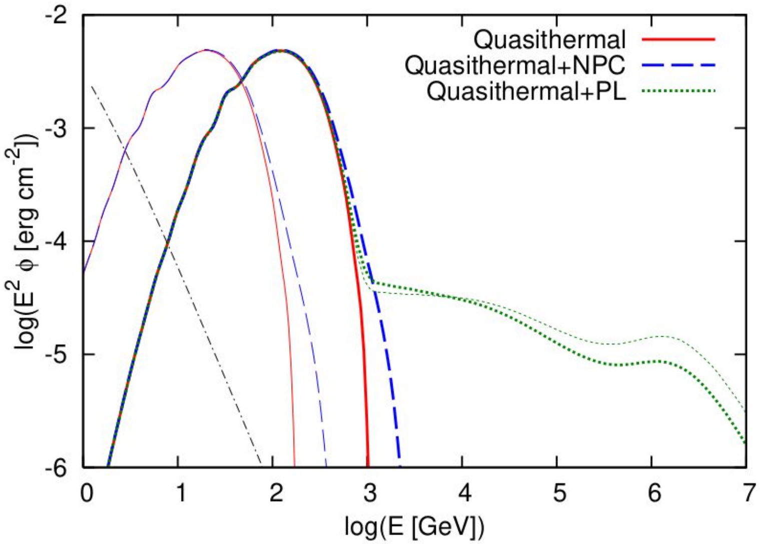


FIG. 1: The energy fluence of $\nu_\mu + \bar{\nu}_\mu$ from a high-luminosity GRB with $\mathcal{E}_\gamma^{\rm iso} = 10^{53.5}$ erg at $z = 0.1$ (corresponding to $E_\gamma^2 \phi_\gamma \sim 10^{-2}$ erg cm^{-2}). The ANB in 30 s is shown by the dot-dashed curve. For solid and dashed curves, $\Gamma = 600$ (thick) and $\Gamma = 100$ (thin) are used. For dotted curves, $s = 2.1$ (thick) and $s = 2.0$ (thin) are assumed.

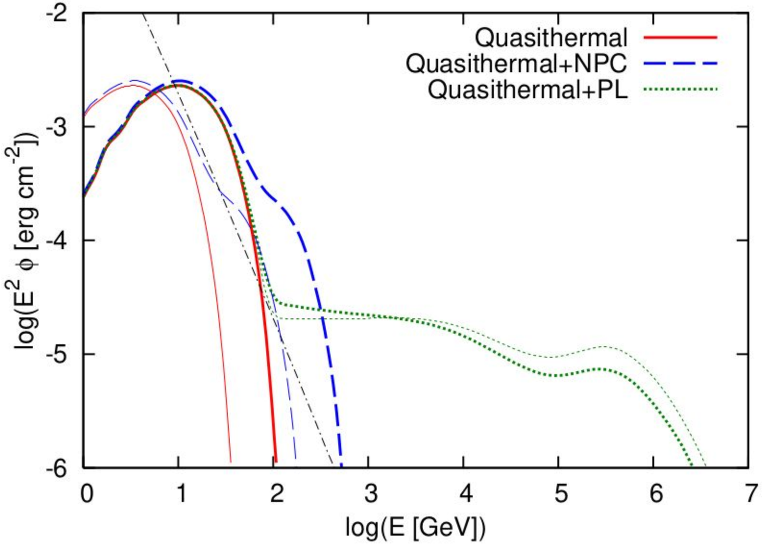
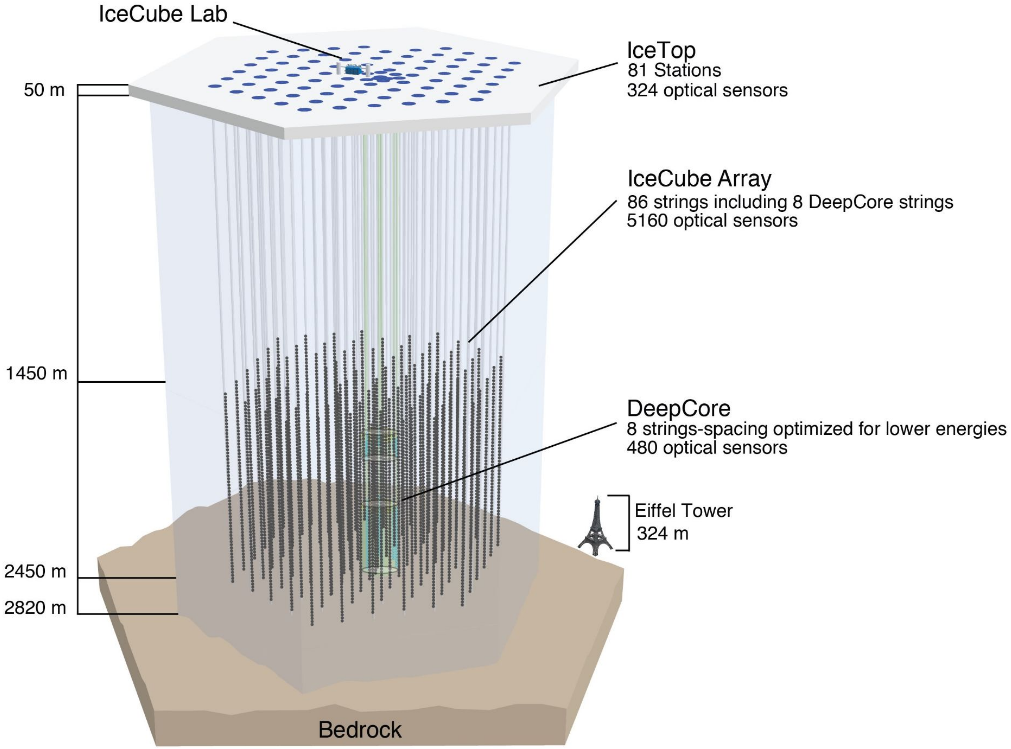
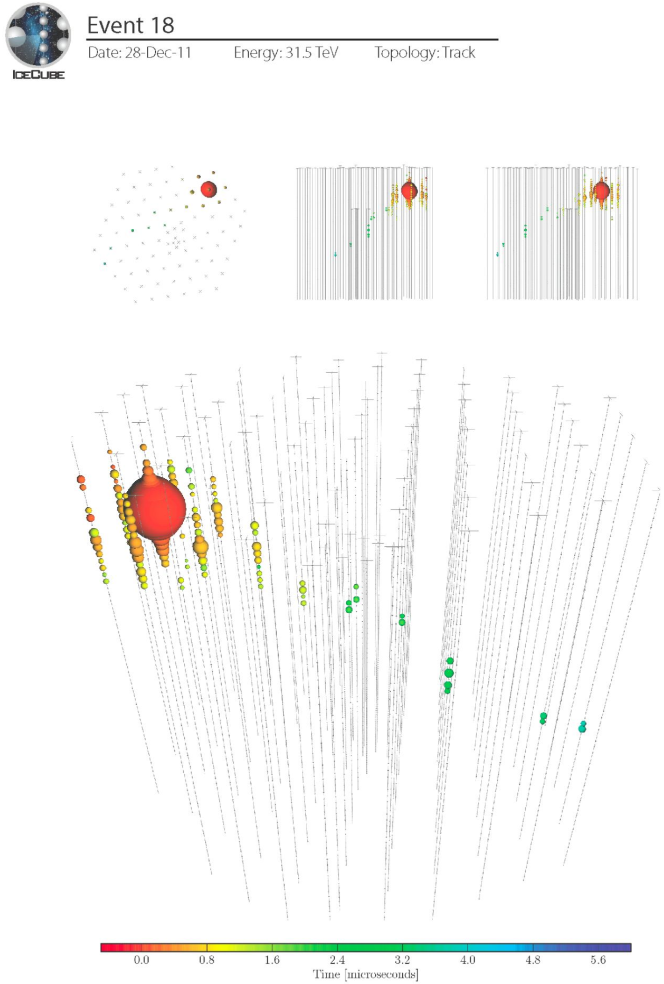


FIG. 2: The same as Fig. 1, but for a low-luminosity GRB with $\mathcal{E}_\gamma^{\rm iso} = 10^{50}$ erg at $D = 10$ Mpc. The ANB in 1000 s is shown by the dot-dashed curve. For solid and dashed curves, $\Gamma = 30$ (thick) and $\Gamma = 10$ (thin) are used.

Neutrino Detection



IceCube



Example TeV neutrino event

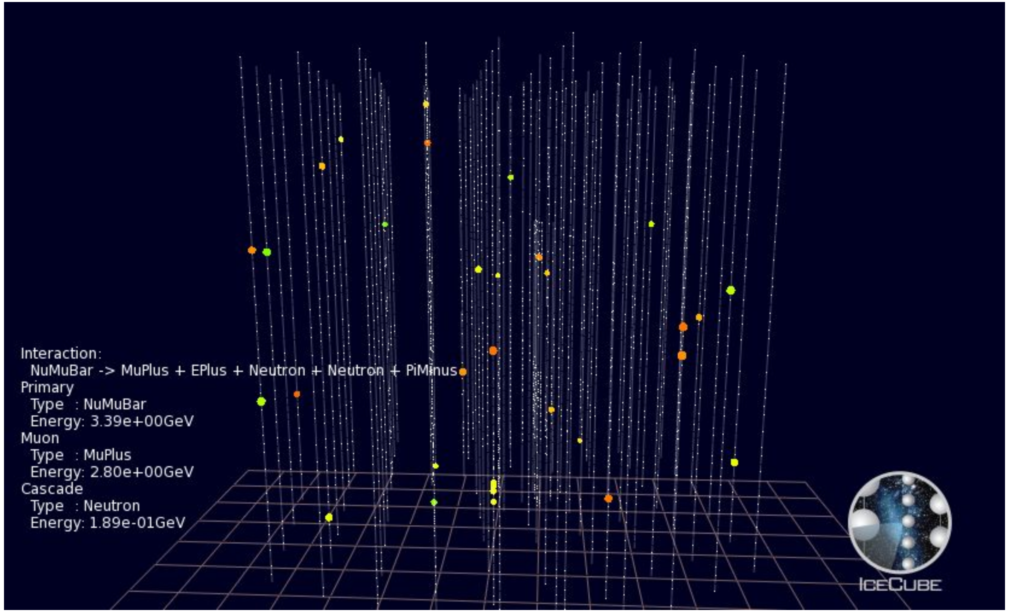
Neutrino events

IceCube and DeepCore

Only nearby and energetic GRBs are visible

Use stacking analyses, which have been done before, but not at <TeV

Focus on northern hemisphere and muon neutrinos for better tracking



Expected number of neutrinos detected

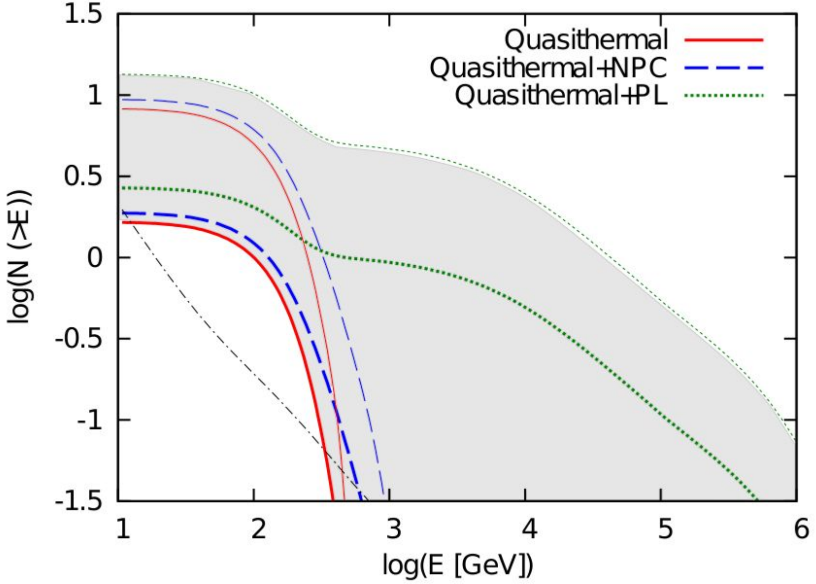


FIG. 3: The expected number of $\nu_\mu + \bar{\nu}_\mu$ events, which can be detected by coincident 20 yr observations with DeepCore+IceCube. The dot-dashed curve is the ANB.

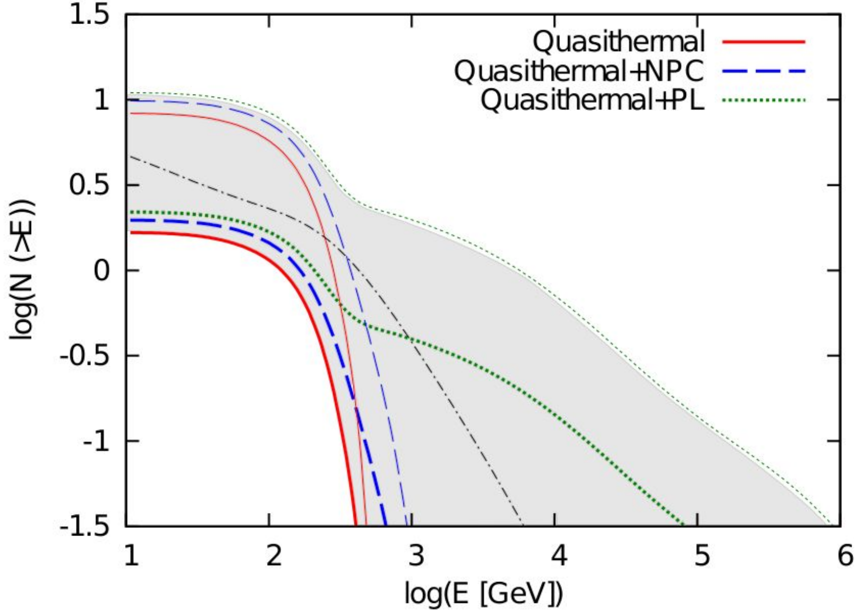


FIG. 4: The same as Fig. 3 but for $\nu_e + \bar{\nu}_e$ that can be observed via shower detections. The angular resolution for the ANB is assumed to be 20 deg.

Conclusion

- Hadronuclear quasi-thermal 10-100 GeV neutrinos inevitable if neutrons generate the prompt gamma ray emission
  - More robust than conventional reliance on CR acceleration
  - Gives information about prompt emission mechanism and probes jet composition/acceleration
- Neutrons have many consequences for processes inside the photosphere
  - Quasithermal particles can become seeds for CR
  - NPC acceleration mechanism
  - Magnetic fields-> plasma anisotropies
- Encouragement for IceCube and KM3Net to work together

At this point in time

- >10yrs of IceCube data
- <TeV stacking research
- Increased sensitivity
- Using both Northern and Southern Hemisphere
- My research
    - Improve detection and reconstruction at lowest tail
    - Classification of GRBs to decrease background

Thank you