Multi-messenger observations of Gamma Ray Bursts

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Astronomical messengers

Photons

Cosmic Rays

Neutrinos

Gravitational Waves

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Big questions for neutrino astrophysics

• What are the sources of (galactic + extra galactic) cosmic rays?
  – GRBs are a plausible candidate source for extra galactic cosmic rays
    (but also AGNs, Galaxy clusters, etc …)

• Are there dark sources of neutrinos?
  – Choked GRBs?

(not a complete list)
Neutrinos from GRBs

Also possible: $p-p$ neutrino production

Precursor neutrinos and choked GRBs
Burst neutrinos
Afterglow neutrinos

GRBs: Candidate sources for the highest energy cosmic-rays
IceCube: a one gigaton detector

IceCube Lab

IceTop
- 80 Stations, each with
  - 2 IceTop Cherenkov detector tanks
  - 2 optical sensors per tank
  - 320 optical sensors

2010: 79 strings in operation
2011: Project completion, 86 strings

IceCube Array
- 86 strings including 6 DeepCore strings
- 60 optical sensors on each string
- 5160 optical sensors

DeepCore
- 6 strings-spacing optimized for lower energies
- 360 optical sensors

Eiffel Tower
324 m

Bedrock
Antares & KM3Net

French coast on the Mediterranean (2.5 km depth)
12 lines – 1000 PMTs – 15 Mtons
In full operation since 2008
KM3Net proposed – Mediterranean
At least as big as IceCube
(with better view of the Galactic Center)

By shear size, IceCube is more currently interesting for GRBs

See Poster 11.04
E. Presani et al

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IceCube search for neutrinos from GRBs

For average BATSE parameters of 109 bursts

Modeling following: Guetta et al, Astropart Phys, 2004

109 Northern GRBs
IceCube 59-string
May 2009 – May 2010

Delta Resonance: Neutrino spectrum traces photon spectrum
Neutrino fluence proportional to photon fluence


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IceCube search for neutrinos from GRBs

See Poster 11.02
E. Blaufuss et al.
for details on IceCube searches

IceCube 59-string limit 2.2 below (default) prediction.
Combined IceCube 40- and 59-string limit not available yet
In 2-3 years, full IceCube sensitivity is one order of magnitude below model

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DeepCore and Choked GRBs

Ando & Beacom reference SN @ 10 Mpc:
4 neutrinos (all flavors) in DeepCore
Similar event rate in Antares

Taboada PRD 2010

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Optical Follow-Up with ROTSE & PTF

Select neutrino-like multiplets in 100 s and 3.5° coincidence

Iridium satellites

Fast reaction to GRB alerts

IceCube

Northern Hemisphere IceCube CPU

ROTSE III
Joint LIGO - IceCube search

See Poster 11.01
I. Bartos et al.
for details on
LIGO + IceCube

Spatial PDF for LIGO (a) and IceCube (b)

Search will proceed on archival data for LIGO science run 5
in coincidence with IceCube

Aso Y et al. Class & Quant Grav, 2008

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Conclusions

• Neutrinos can test whether GRBs are the sources of extragalactic cosmic rays
• IceCube is already below the default model prediction
• In 2-3 years IceCube’s sensitivity will be an order of magnitude below default model prediction
• Choked GRBs can be searched by IceCube / DeepCore / Antares
• Multi-messenger programs in place with LIGO, ROTSE and PTF
• Upcoming program with Swift (XRT) follow up.
Detecting neutrinos at cosmological distances

\[ \sigma \propto \sqrt{E} \]

For MeV scale the cross section is 14 orders of magnitude below that of PeV scale

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Neutrino detection

Tracks

- O(km) muon tracks
- Good angular resolution
  - IceCube: 1°
  - Antares: 0.1°
- $\nu_\mu$ sensitivity

Cascades

- Light point sources
- Good energy resolution
- No directionality
- $4\pi$ sensitivity
- All flavor sensitivity
Neutrinos from SN 2008D

✓ X-ray flash provides (more) precise SN time

✓ Slow Jet model
  Razzaque et al. PRD, 2003
  Ando and Beacom, PRL 2005

✓ Proof of principle
✓ 0.1 evts in IceCube 22-strings if jet points to Earth
✓ $\Gamma_b = 3$, $E_j = 3 \times 10^{51}$ erg
✓ No signal found

Abbasi R. et al. Submitted to A&A
Choked GRBs and precursor neutrinos

• Jets with low $\Gamma$ still inside progenitor star
  $\rightarrow$ TeV neutrinos

• Possibly large fraction of “choked” bursts
  $\rightarrow$ only detectable with “rolling window”

Choked bursts rate
x100 GRB rate