

A photograph of the IceCube detector in Antarctica, showing a small building and a long line of ice-covered paths leading towards it under a clear blue sky.

# Search for Neutrino Emission from Northern Gamma-Ray Bursts with IceCube

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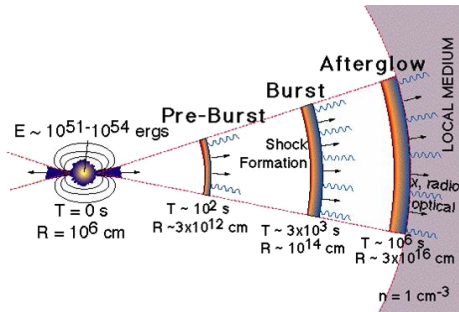
University of Maryland, College Park, MD

TeVPA, August 2013, Irvine, CA

# Background



- ▶ GRB physics remain to be fully understood
- ▶ GRBs may be a source of high energy cosmic rays
- ▶ GRBs can only be probed via  $\gamma$  and  $\nu$
- ▶ Tiny time and space window  
→ nearly background free

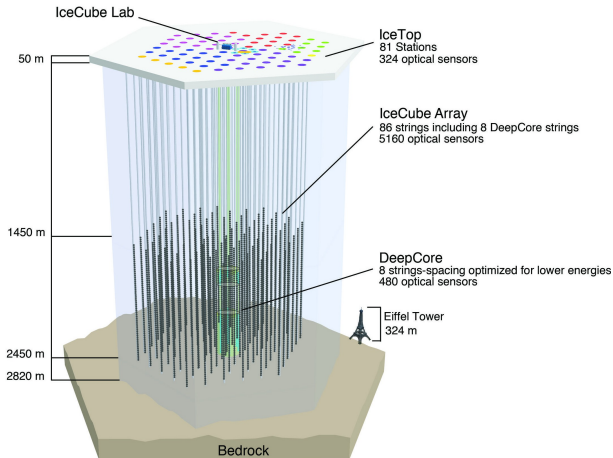


Fireball model summary.

# Detector Construction



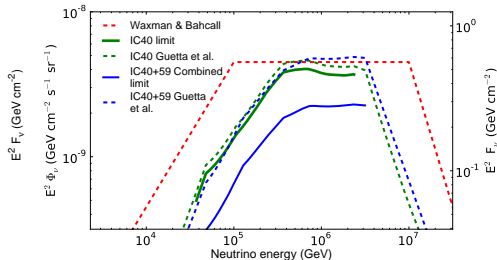
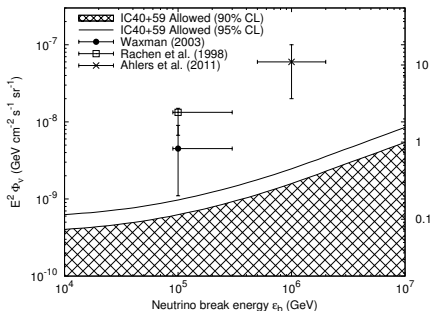
- ▶ Constructed during Austral summers
- ▶ Completed in 2010
- ▶ Search uses partial detector configurations plus first year with 86 strings



# Previous Work



- ▶ 40- and 59-string partial detector configurations: no  $\nu$  observed
- ▶ Limits rule out CR-normalized neutron escape models
- ▶ Tension with fireball physics-based models

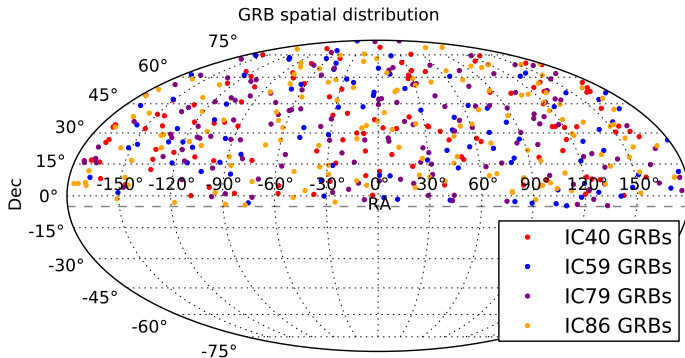


# Analysis Overview



- ▶ Burst selection from GRB-web: <http://grbweb.icecube.wisc.edu/>
- ▶ Select  $\nu_\mu$  CC events by looking at the northern hemisphere
- ▶ Test for correlation with an unbinned likelihood analysis

# Burst Catalog



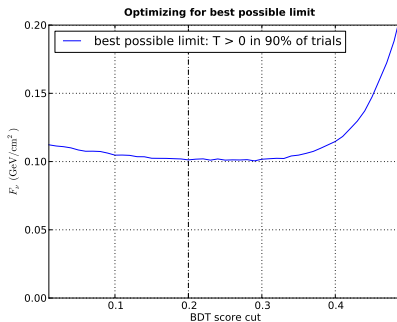
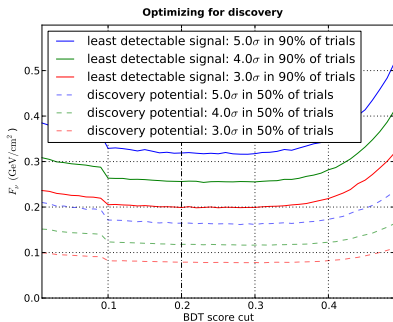
- ▶ Select bursts during clean IceCube operation with  $\delta > -5^\circ$
- ▶ 492 bursts included in 4-year analysis

# Neutrino Selection



- ▶ Simple cuts remove most of 2 kHz cosmic ray muon background
- ▶ Misreconstructed events rejected by Boosted Decision Tree forests using fit quality, fit stability, and event topology parameters.
- ▶ Remaining events must be  $\nu_\mu$  (or difficult backgrounds)
- ▶ Atmospheric  $\nu_\mu$  are an irreducible background

# Cut Optimization



- ▶ Nearly equivalent performance for background rates 5 to 2 mHz
- ▶ Final cut optimizes discovery potential and sensitivity



- ▶ Signal strength of data given by the test statistic:

$$\hat{\mathcal{T}} = -\hat{n}_s + \sum_{i=0}^N \ln \left( \frac{\hat{n}_s \mathcal{S}_i}{\langle n_b \rangle \mathcal{B}_i} + 1 \right),$$

where  $\hat{n}_s$  maximizes  $\mathcal{T}$ .

- ▶ The PDFs  $\mathcal{S}$  and  $\mathcal{B}$  reward:
  - ▶ Events during the gamma emission
  - ▶ Events spatially near the burst
  - ▶ Events with high reconstructed energy
- ▶ Significance determined by comparing with  $\mathcal{T}$  distribution in randomized background pseudo-experiments



- ▶ One low-significance event during IC79 run:

$\mathcal{T}$	0.0537
$p$	11%

- ▶ GRB and  $\nu$  properties:

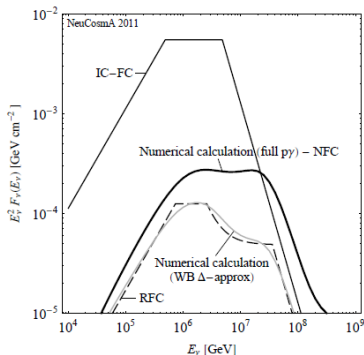
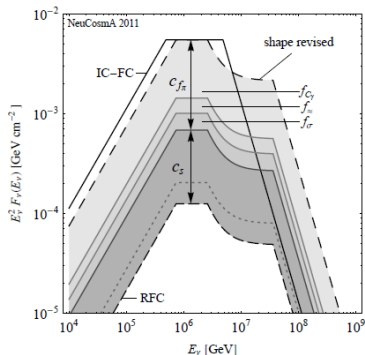
	GRB100718B	IceCube $\nu$
time	T100 = 39 s	15 s into burst
RA, Dec	298°, 41.4°	32°, 57°
$\Delta$ angle		16°
$\sigma_{\text{stat}}$	10.2°	1.3°
$\sigma_{\text{sys}}$	2.6° 72% & 10.4° 28%	$\sim 1^\circ$
energy	$2.535 \times 10^{-6} \text{ erg cm}^{-2}$	10 TeV

- ▶ When IC40 thru IC86 year one are analyzed together, best fit  $\mathcal{T} = 0$

# Updated Fireball Model



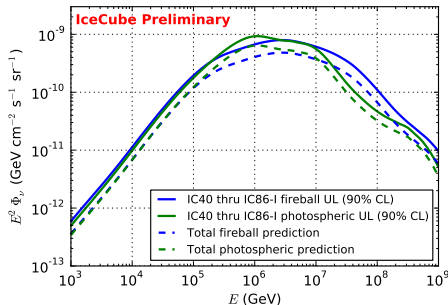
- ▶ IC40 + IC59 limits have encouraged continued modeling work
- ▶ Winter, et al. use full energy distributions of particles and model the fireball numerically
- ▶ The resulting prediction may shift as much as an order of magnitude



# Fireball Model Limits



- ▶ Feldman-Cousins method
- ▶ Predictions evaluated with custom SOPHIA-based package
- ▶ “Photospheric” model moves  $\nu$  production to the photosphere
- ▶ Fireball and photospheric model limits are 1.72 and 1.47 times the predictions
- ▶ Systematics not yet calculated; for now, assuming 6% as was found in past searches



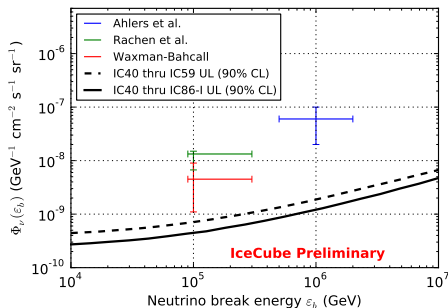
# Generic Model Limits



- ▶ May assume bursts have identical doubly broken power law spectra
- ▶ Such models can be normalized so GRBs would dominate high energy cosmic ray production
- ▶ Second break has negligible effect, so limit flux of the form

$$\Phi_\nu \cdot \begin{cases} E^{-1}/\varepsilon_b, & E < \varepsilon_b; \\ E^{-2}, & E \geq \varepsilon_b. \end{cases}$$

- ▶ IceCube excludes some popular models of this type

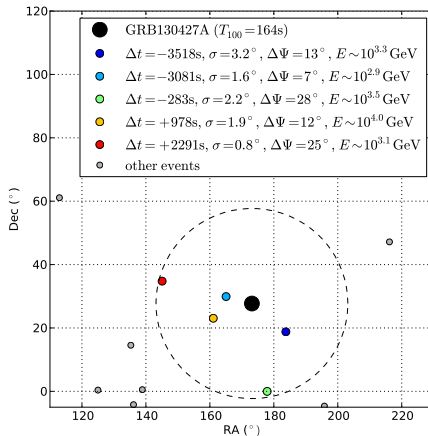


# GRB130427A



- ▶ One of the brightest bursts ever observed!
- ▶ An exceptional case — special analysis approved within 3 days
- ▶ Used rolling and expanding time window within  $\pm 1$  hr
- ▶ Also:
  - ▶ No HESE within  $\pm 1$  day
  - ▶ No multiplets in online search
- ▶ Null result ( $\mathcal{T} = 0$ , all time windows) released in GCN circular 14520

Events within  $\pm 1$  hour and  $30^\circ$  of GRB130427A (3.3 expected)



## Additional data sets:

- ▶ Southern hemisphere (have not searched since IC59)
- ▶ All-flavor cascade search
- ▶ Newer data sets – full IceCube is in 3rd year of operation

## Towards near-realtime:

- ▶ Can check for  $\nu$  within  $\sim 1$  day of gamma detection
- ▶ A coincidence would result in a circular to encourage follow-up
- ▶ GRB100718B shows we need this; GRB130427A shows we can do it

# Summary



- ▶ IceCube excludes popular models of GRB-neutron dominated CR flux
- ▶ Increasing tension with GRB-proton based models
- ▶ New event channels and near-realtime search are coming soon