Search for high-energy neutrino sources

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TeV—PeV neutrinos (detected by IceCube)

Evidence for High-Energy Extraterrestrial Neutrinos at the IceCube Detector #1

IceCube Collaboration • M.G. Aartsen (Adelaide U.) et al. (Nov 20, 2013)

Published in: *Science* 342 (2013) 1242856 • e-Print: 1311.5238 [astro-ph.HE]

pdf links DOI cite 1,409 citations

First observation of PeV-energy neutrinos with IceCube #1

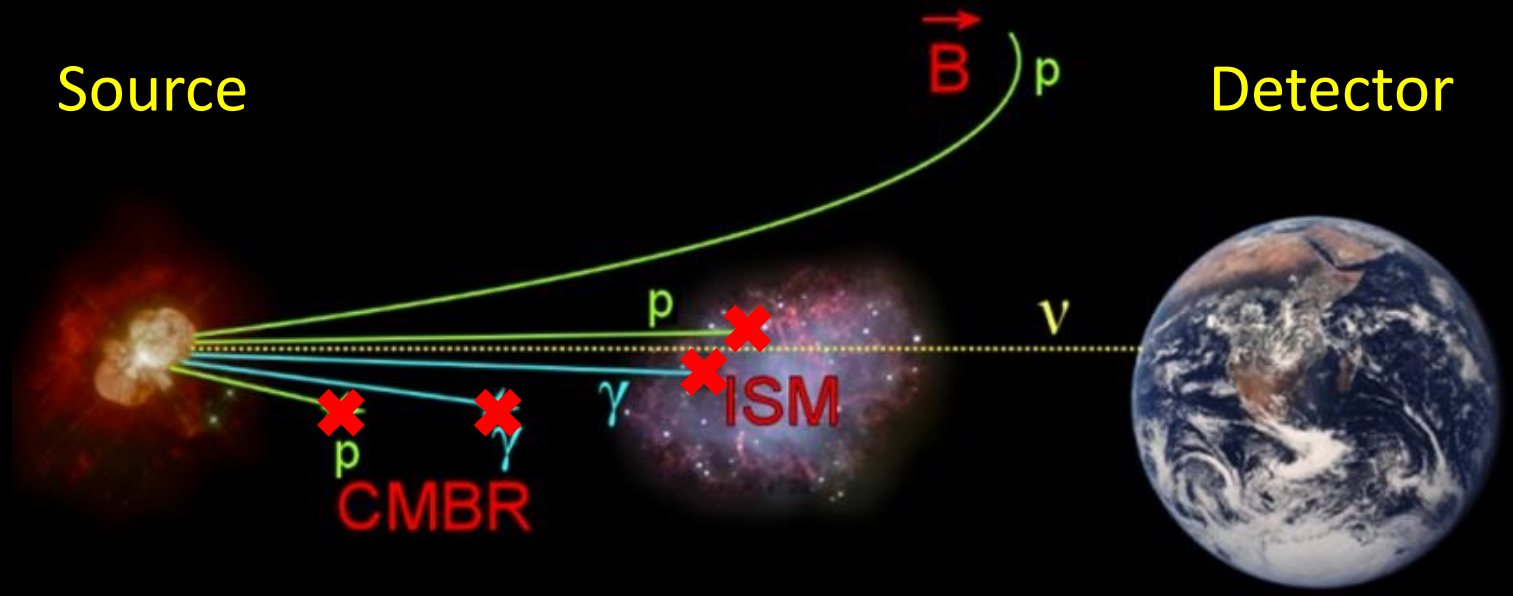
IceCube Collaboration • M.G. Aartsen (Adelaide U.) et al. (Apr 19, 2013)

Published in: *Phys.Rev.Lett.* 111 (2013) 021103 • e-Print: 1304.5356 [astro-ph.HE]

pdf links DOI cite 830 citations

Why do we study high-energy neutrinos

1. Astrophysics: best tool for identifying sources of cosmic rays (>~ 10 TeV)

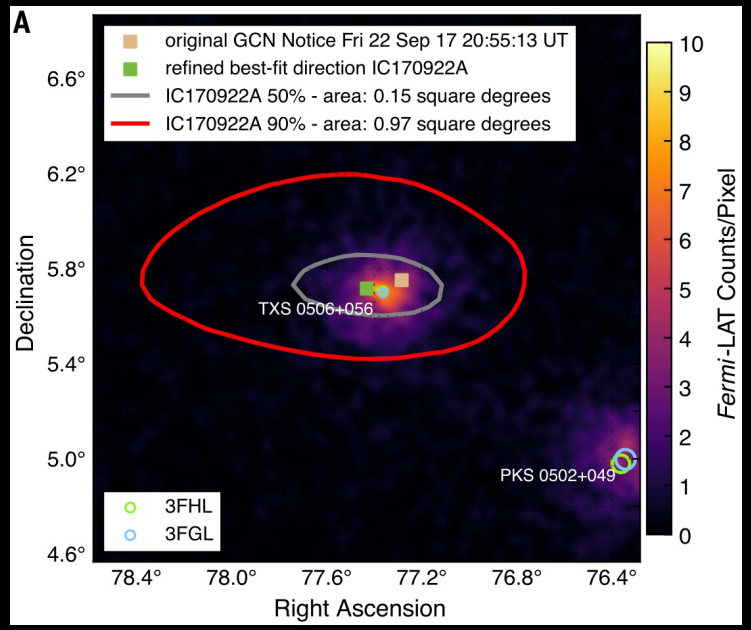


2. Astrophysics: particle acceleration mechanisms of those sources

3. Particle physics: neutrino properties, testing new physics (dark matter, etc.)

Searches for the sources of high-energy neutrinos

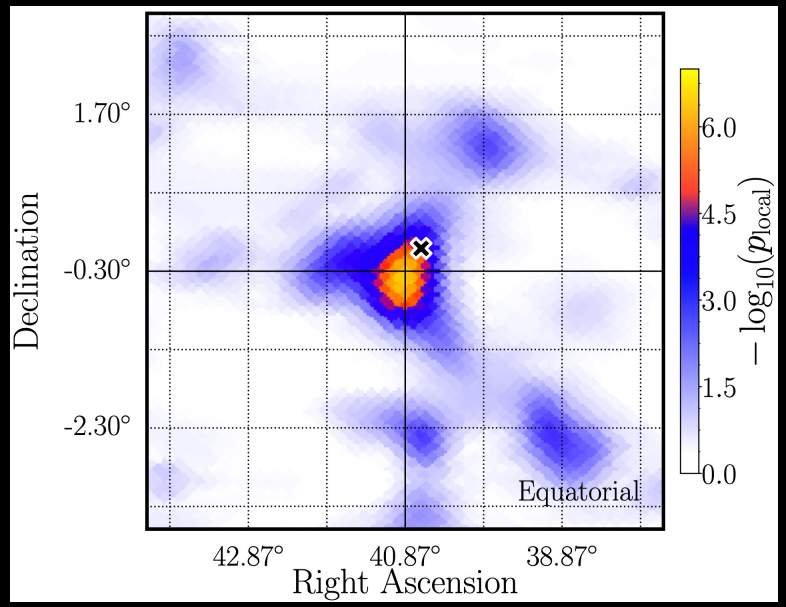
TXS 0506+056 (Blazar)



Association with ~300 TeV neutrino
3.0σ (global)
1807.08816, Science, 587 citations

Neutrino flare ~2015
3.5σ (global);
1807.08794, Science, 653 citations

NGC 1068 (Seyfert II galaxy)



2.9σ (global)
1910.08488, PRL, 176 citations

Tidal disrupt events

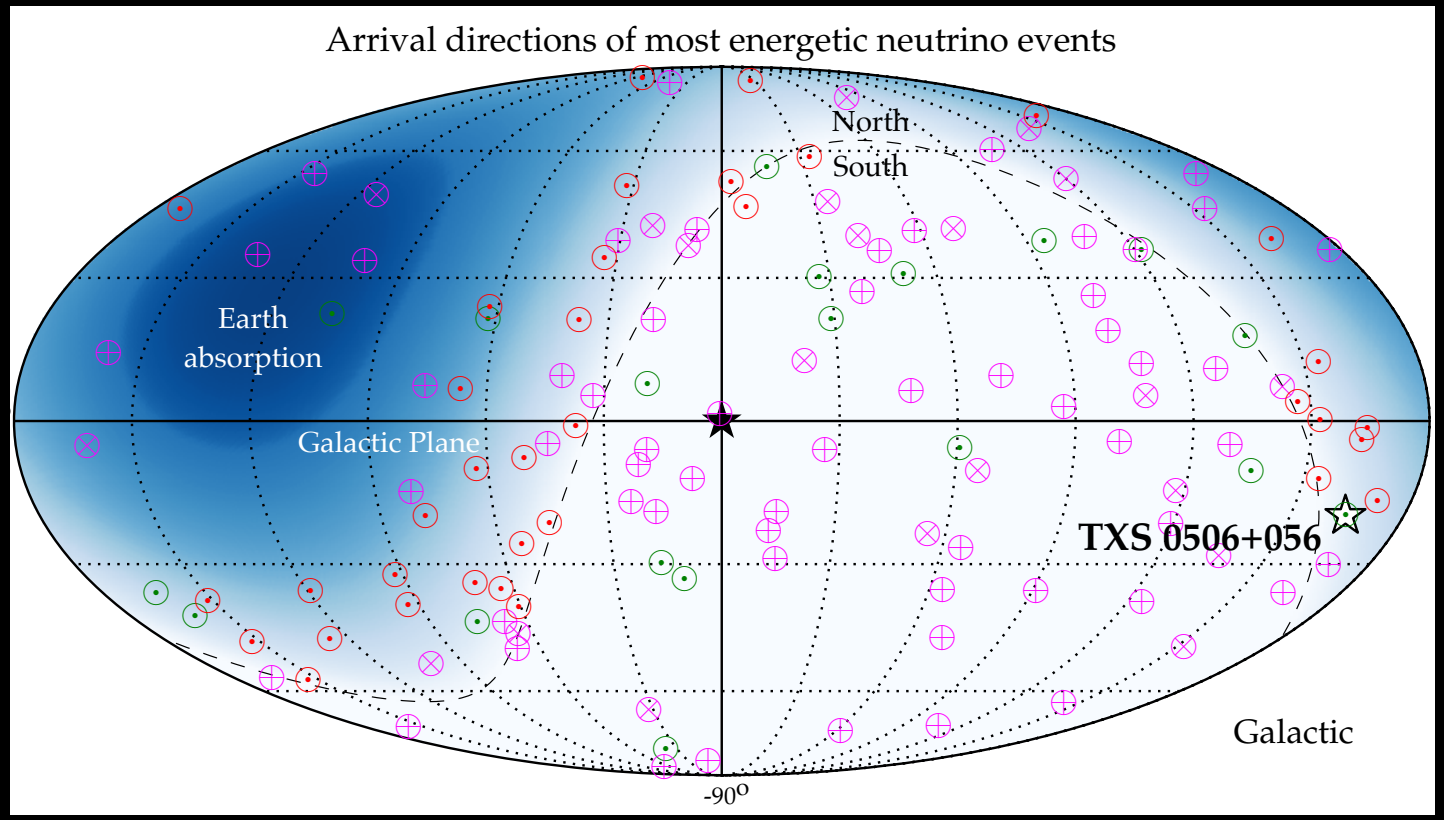
AT2019dsg (2005.05340),

AT2019fdr (2111.09390),

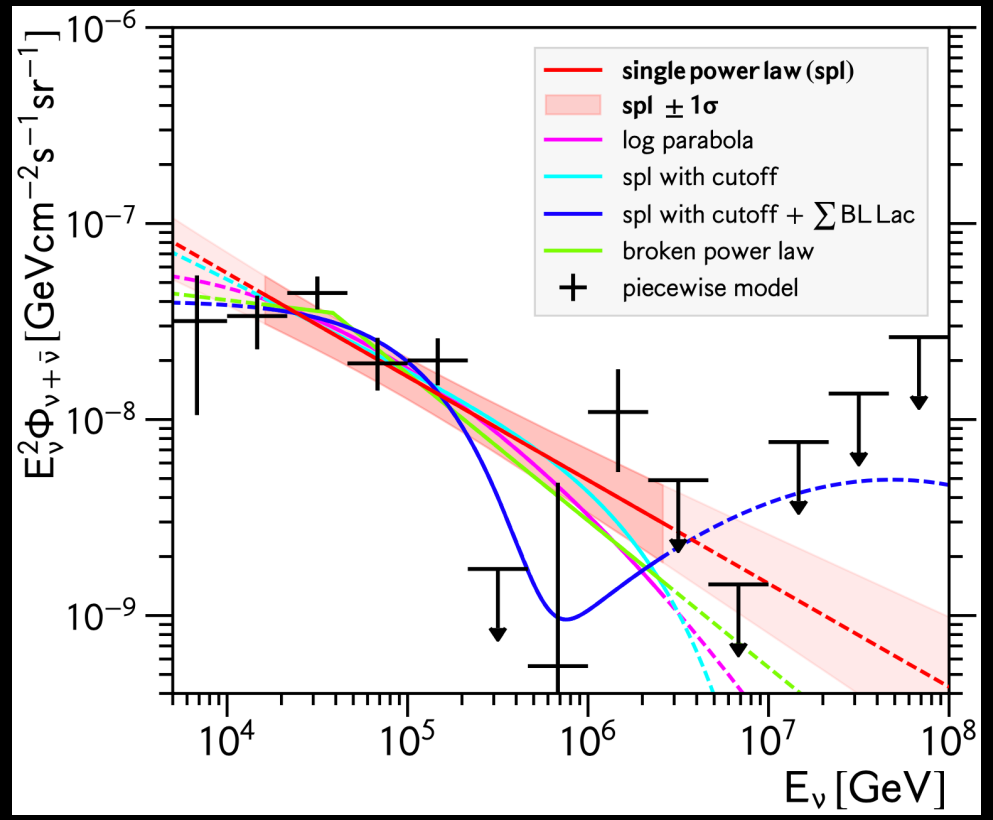
AT2019aalc (2111.09391)

possibly associated with HE neutrinos found in multi-messenger follow-ups

Vast majority of HE astroph ν remains unexplained



1903.04334



2001.09520

Many types of sources have been searched with data, but no significance was found:
gamma-ray bursts, gamma-ray blazars, pulsar-wind nebulae, galaxy clusters, etc.…

More types of sources should be considered.

Search for HE Neutrinos from Radio Bright AGN

Radio-bright active galactic nuclei (AGN), 4.1σ?

2001.00930 Plavin et al.

- ≃3400 radio-bright AGNs with 8 GHz flux density > 0.15 Jy
- 56 high-energy muon-neutrino events
- Found 3.1σ significance

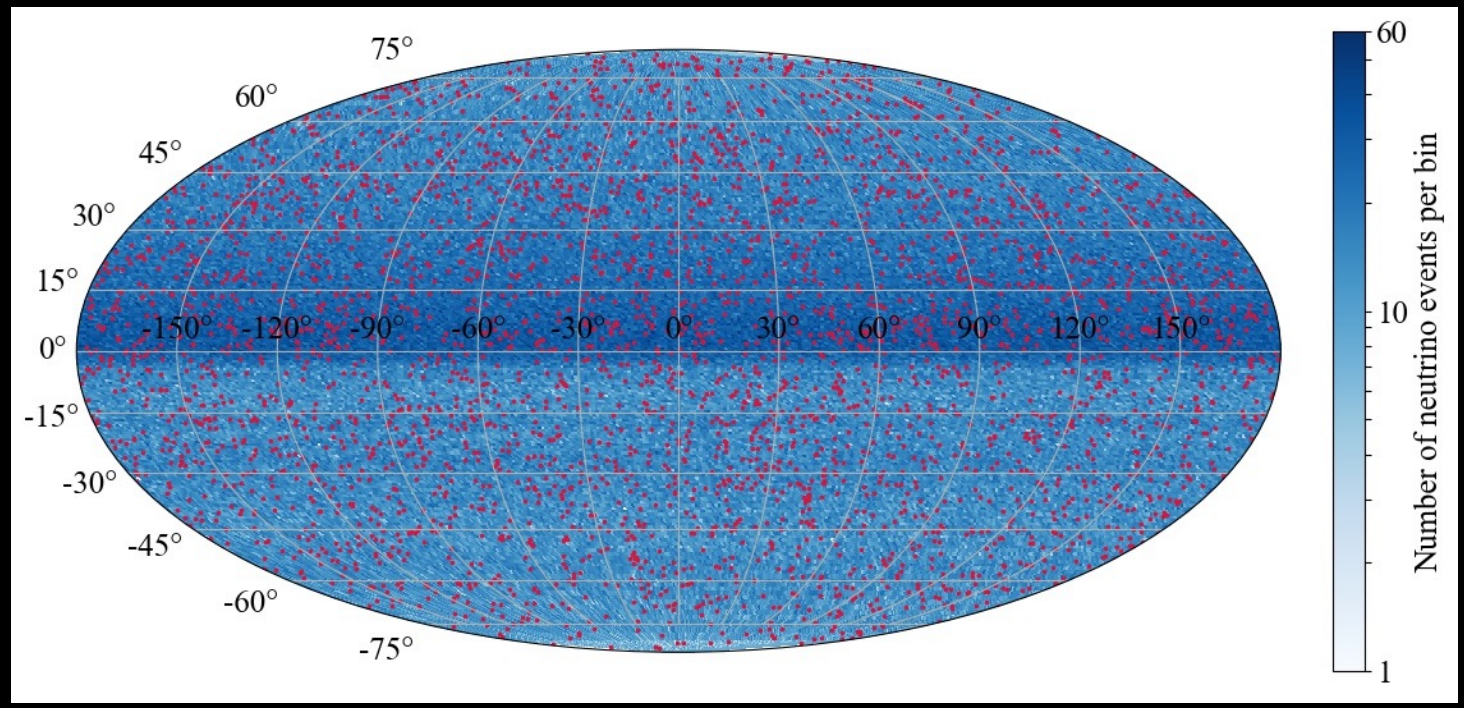
2009.08914 Plavin et al.

- ≃3400 radio-bright AGNs with 8 GHz flux density > 0.15 Jy
- Pre-trial p-value map from IceCube
- Found 3.0σ significance

- 4.1σ combining the two analysis (2009.08941)
- These sources could explain all the HE astroph. nu of IceCube (2009.08941)
- 8-GHz flux of AGN may be an indicator of HE nu emission (Both papers)
- But…

Our work

- Unbinned maximum-likelihood-ratio method
  - Routinely used by IceCube and others (Fermi-LAT, Super-K, etc.)
  - Extensively used by theorists.
  - Info of every single event
- Same sources (≃3400 radio bright AGN)
- Ten years of IceCube ν_μ data (1,134,450 events)



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Unbinned maximum-likelihood-ratio method

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Data samples

# of signal events, to be fit

Each ν event

Background PDF

$$\mathcal{L}(n_s) = \prod_k \prod_{i \in k} \left[\frac{n_s^k}{N_k} S_i^k + \left(1 - \frac{n_s^k}{N_k}\right) B_i^k \right]$$

Tot # of neutrinos in the sample

Signal PDF

$$S_{ij}^k \equiv S_k(\vec{x}_i, \sigma_i, \vec{x}_j) = \frac{1}{2\pi\sigma_i^2} \exp\left(-\frac{D(\vec{x}_i, \vec{x}_j)^2}{2\sigma_i^2}\right)$$

$$\mathrm{TS}(n_s) = 2 \ln \frac{\mathcal{L}(n_s)}{\mathcal{L}(n_s = 0)}$$

← Events from sources & background

← Events from background only

Sqrt(TS_max) ≃ significance

Search for neutrino emission from each source

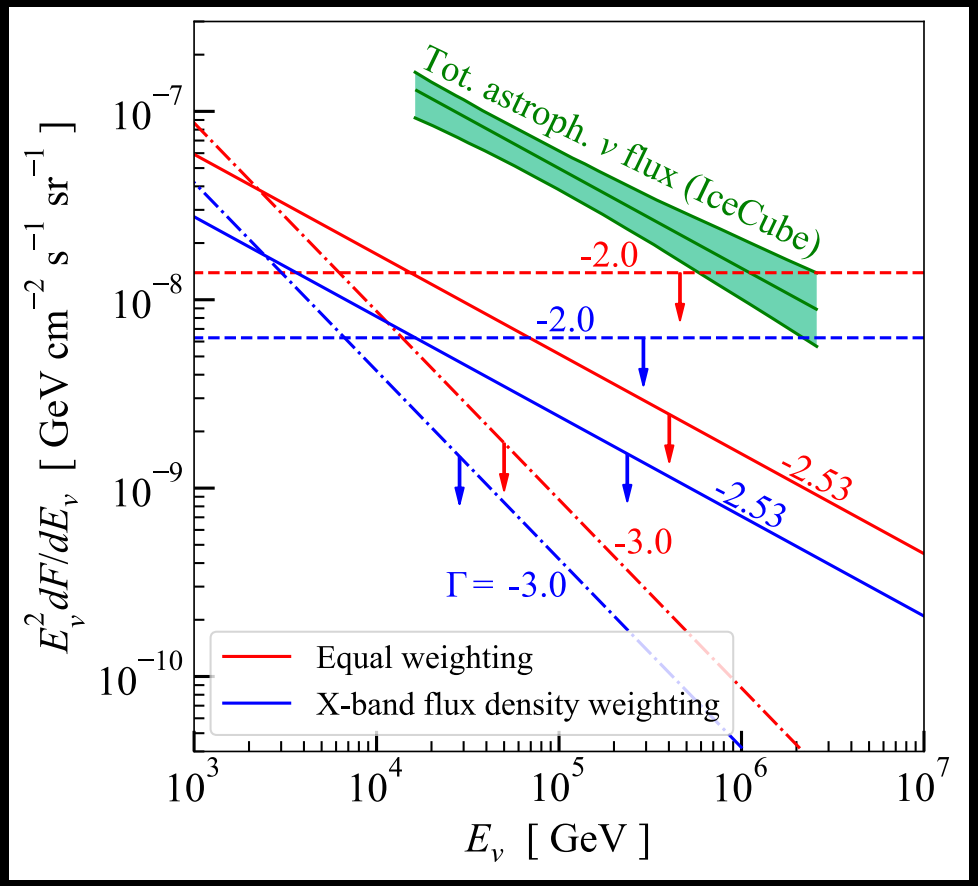
TABLE I. List of the five sources with highest significance.

IVS name	J2000 name	X-band flux density (Jy)	$\hat{n}_s$	$\mathrm{TS}_{\mathrm{max}}$	Pretrial p value, significance	Post-trial p value, significance
1303-170	J1306-1718	0.208	21.6	16.6	2.28×10^{-5}, 4.1σ	0.074, 1.5σ
2245+029	J2247+0310	0.434	50.8	14.5	7.14×10^{-5}, 3.8σ	0.21, 0.8σ
0228-163	J0231-1606	0.162	15.9	9.8	8.90×10^{-4}, 3.1σ	0.95, 0
1424+240	J1427+2348	0.187	38.1	8.9	1.42×10^{-3}, 3.0σ	0.99, 0
0958+559	J1001+5540	0.180	27.2	8.3	2.02×10^{-3}, 2.9σ	1.0, 0

We don’t find any sources that have significant neutrino emission

Correlation between all srcs & events (Stacking analysis)

Upper limits



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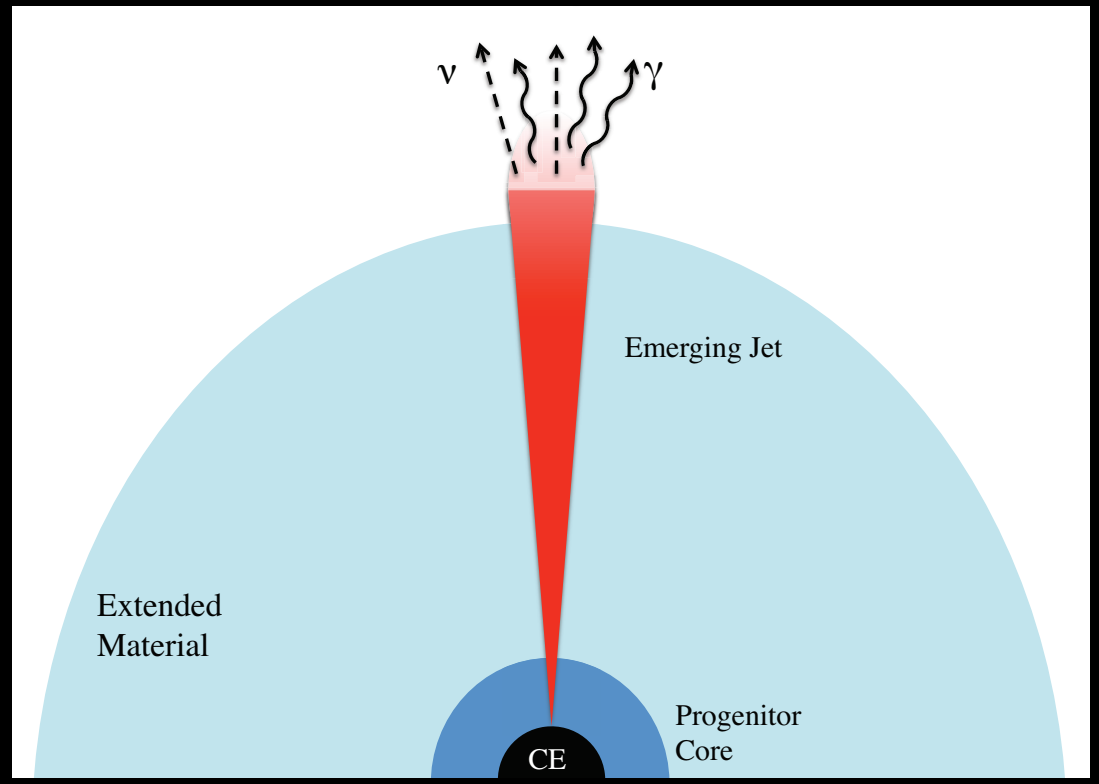
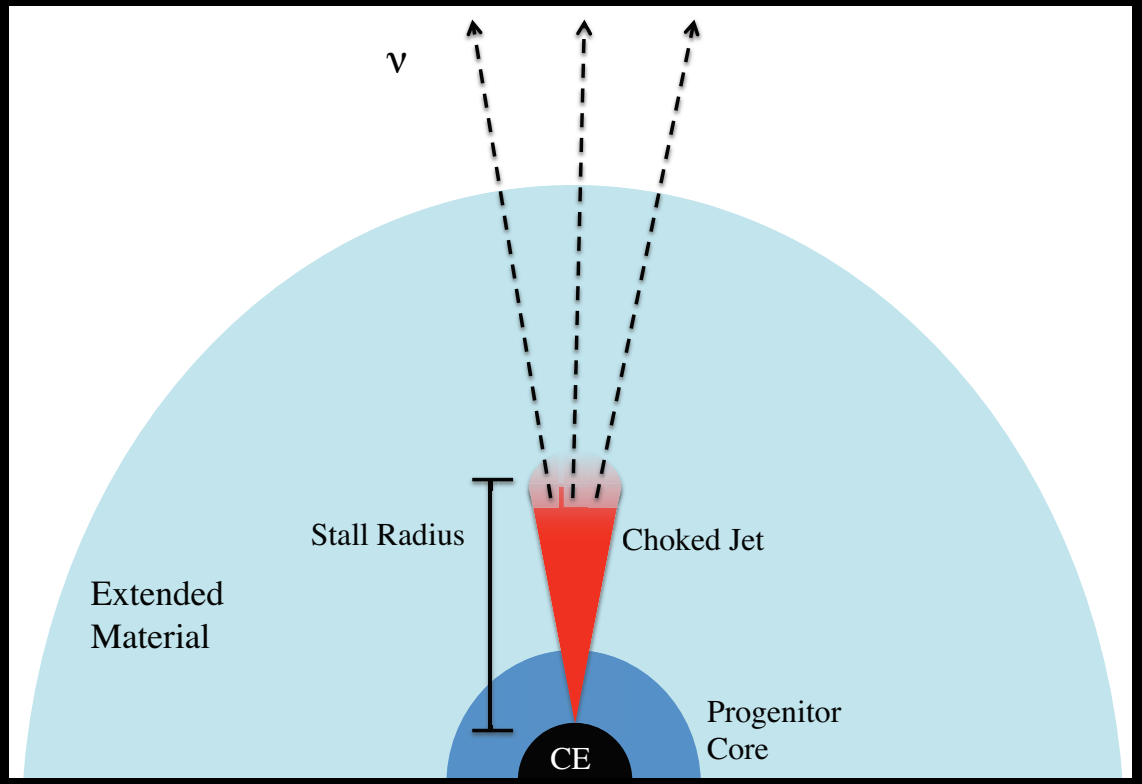
1. No significance.
2. Contribute < 30% of HE astro nu flux.
3. 8-GHz radio emission might not be an indicator of HE nu emission.

Search for HE neutrinos from Choked-Jet Supernova

Choked-Jet Supernova as sources of HE neutrinos





Choked-jet scenario

1512.08513 Senno, Murase, Meszaros

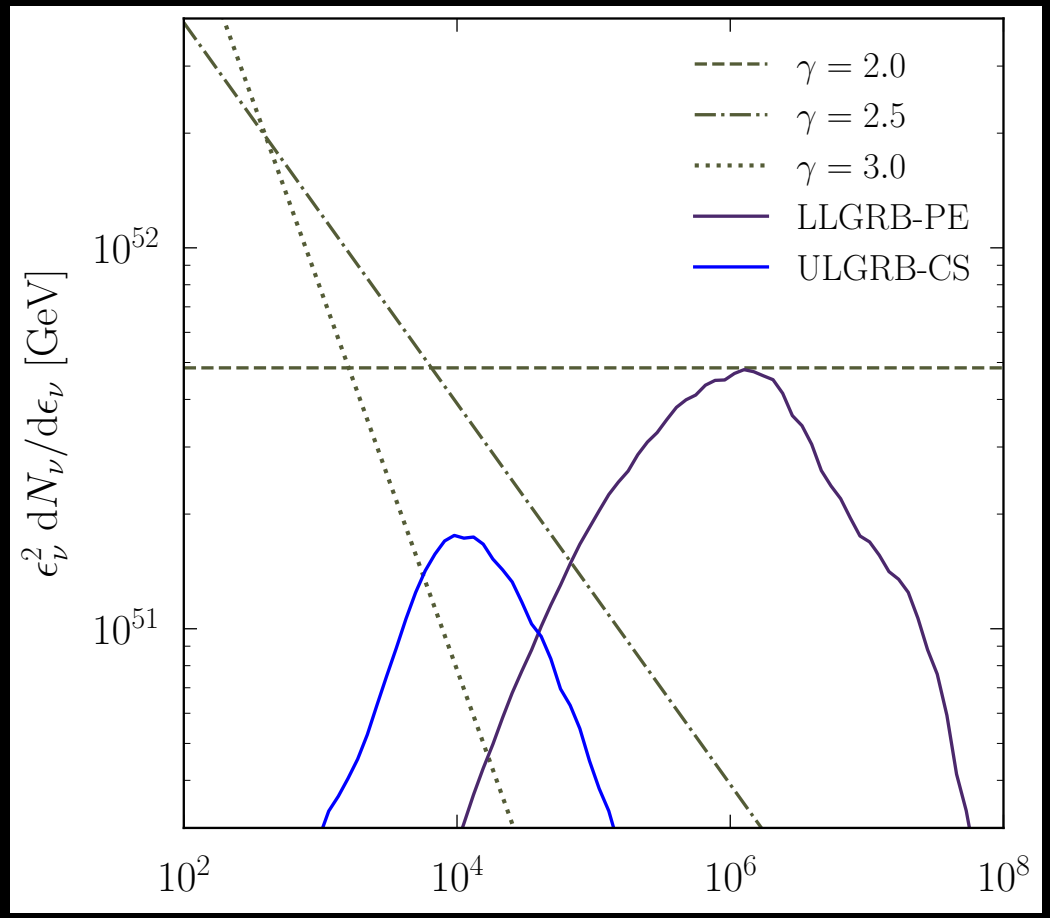
Choked-jet SN models

Two classes of models

1. Power-law
   1706.02175 Senno, Murase, Mészáros

1. More realistic model
   astro-ph/0607104 Murase et al.
   1306.2274 Murase & Ioka

Universal parameters
Ep: isotropic equivalent cosmic ray energy
f_jet: fraction of type Ib/c SNe that have je



New analysis considerations

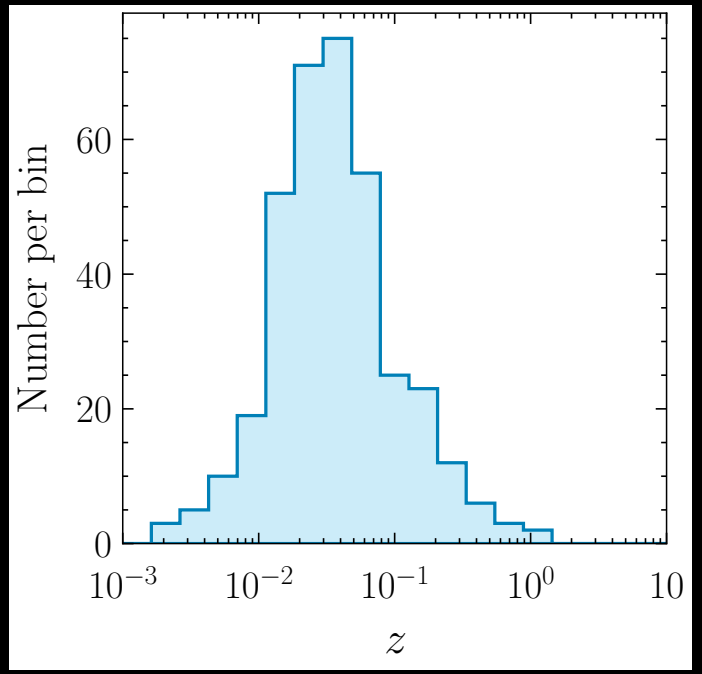
Data

Same ten-yrs of IceCube data

Remove the 19 double-counted events due to a misreconstruction error
(*found by 2110.02974 BZ, Beacom*).

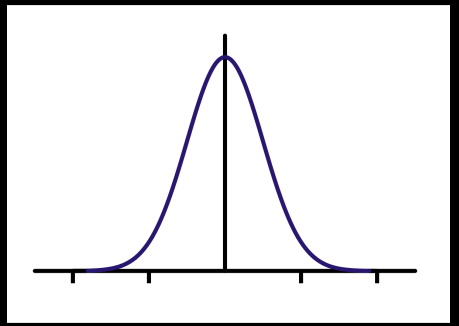
SN sample

Collected 386 type Ib/c SN between 2008—2018, from several public SN catalogs



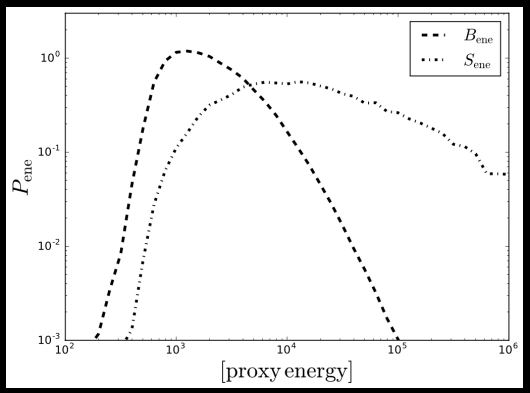
Analysis formalism

Temporal PDF



σ_T = 4 days
Center: 13 days before SN max

Energy pdf



Summary

Radio bright AGN

- No significance neutrino emission from radio-bright AGN.
- At most contribute to ~30% (95% C.L.)
- 8 GHz flux density might not be the indicator of HE nu emission from these sources

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Choked-jet supernova

- Choked-jet SN, a very natural scenario, could be HE nu emitters
- If find nothing, constrain the theory parameters
- Stay tuned for our results

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Thanks for your attention!

Search for neutrino emission from each source

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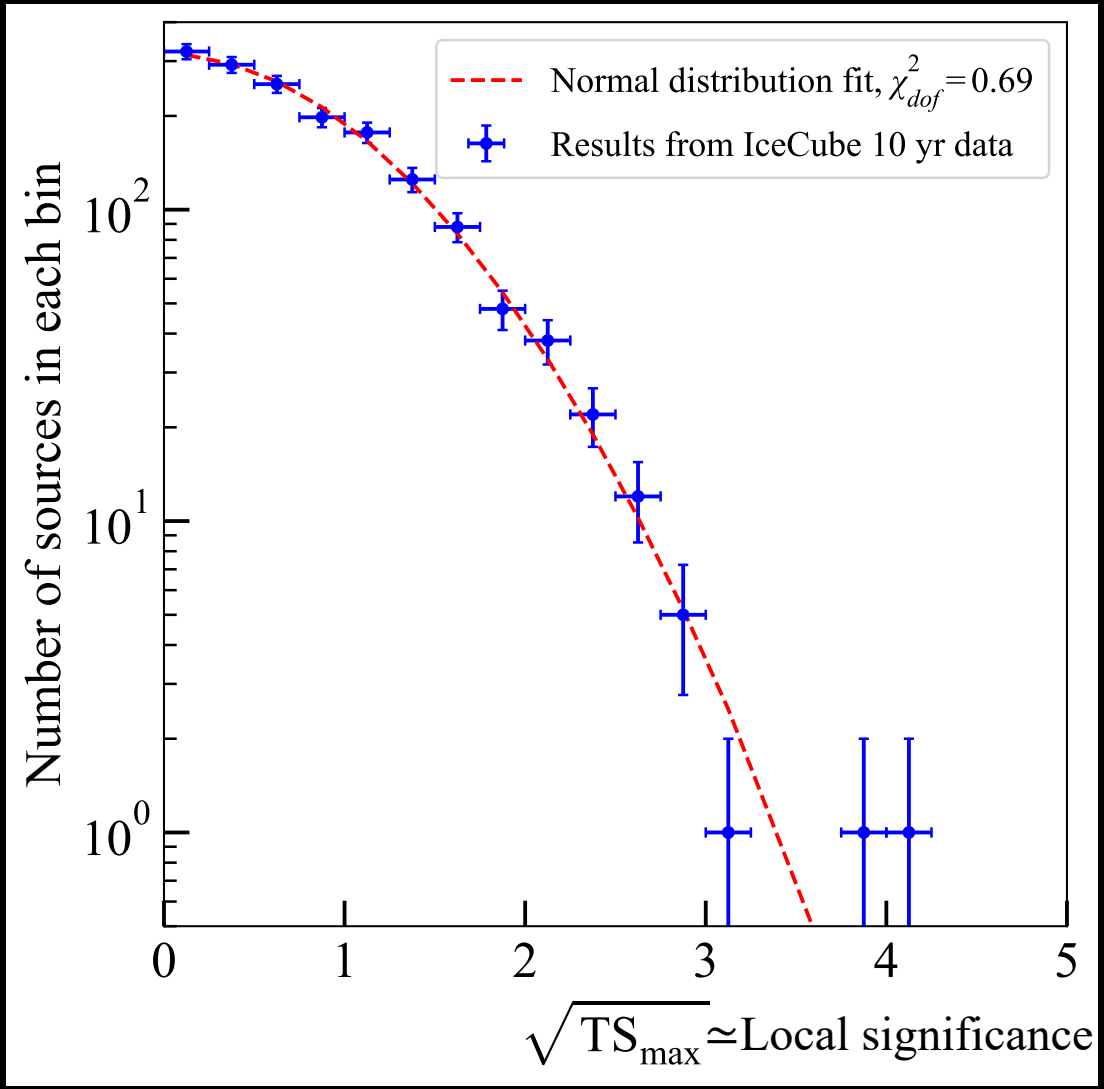


1. None of the sources show a large global significance

   The two highest-significant sources

   I. 1.5σ (global), 4.1σ (local)

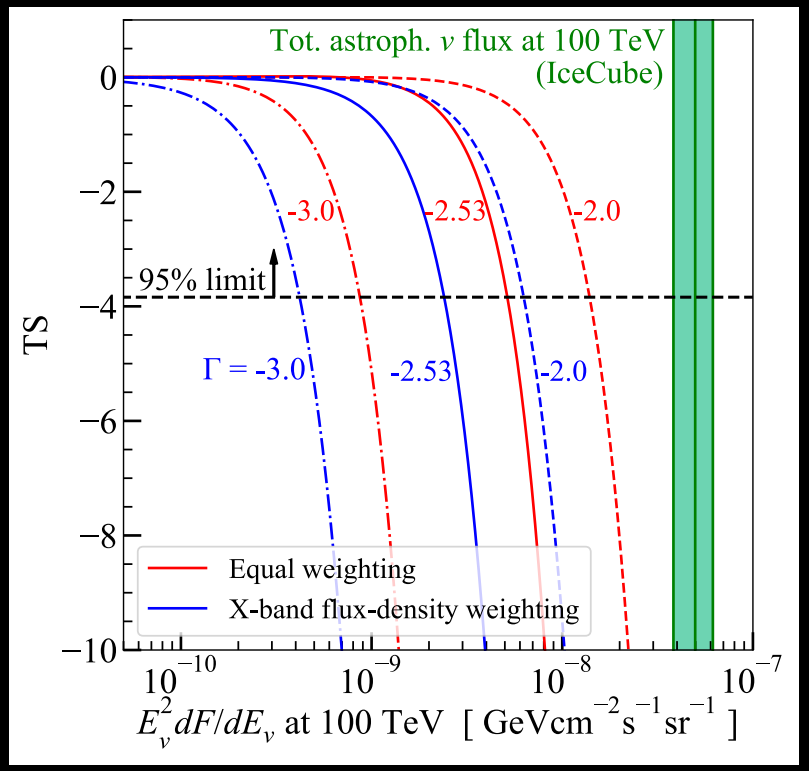
   II. 0.8σ (global), 3.8σ (local)

2. So, the ≃3400 radio-bright AGN might not have a strong correlation with HE nu

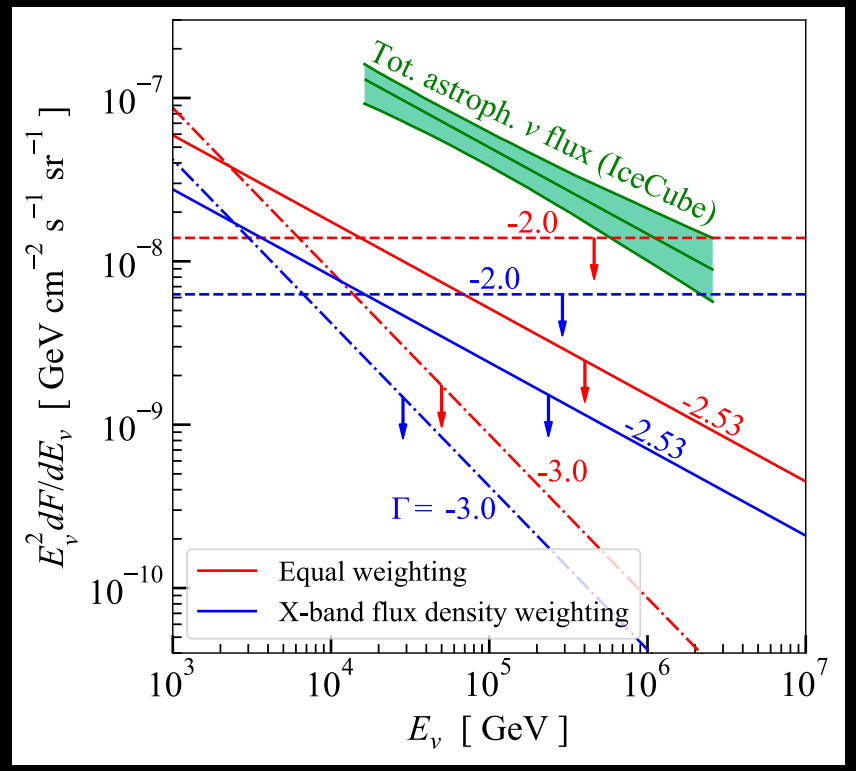
3. 8-GHz flux density might not be an indicator of HE nu emission.

Correlation between all srcs & events (Stacking analysis)

Significance



Upper limits



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Results 1: search for HE nu emission from the SNe

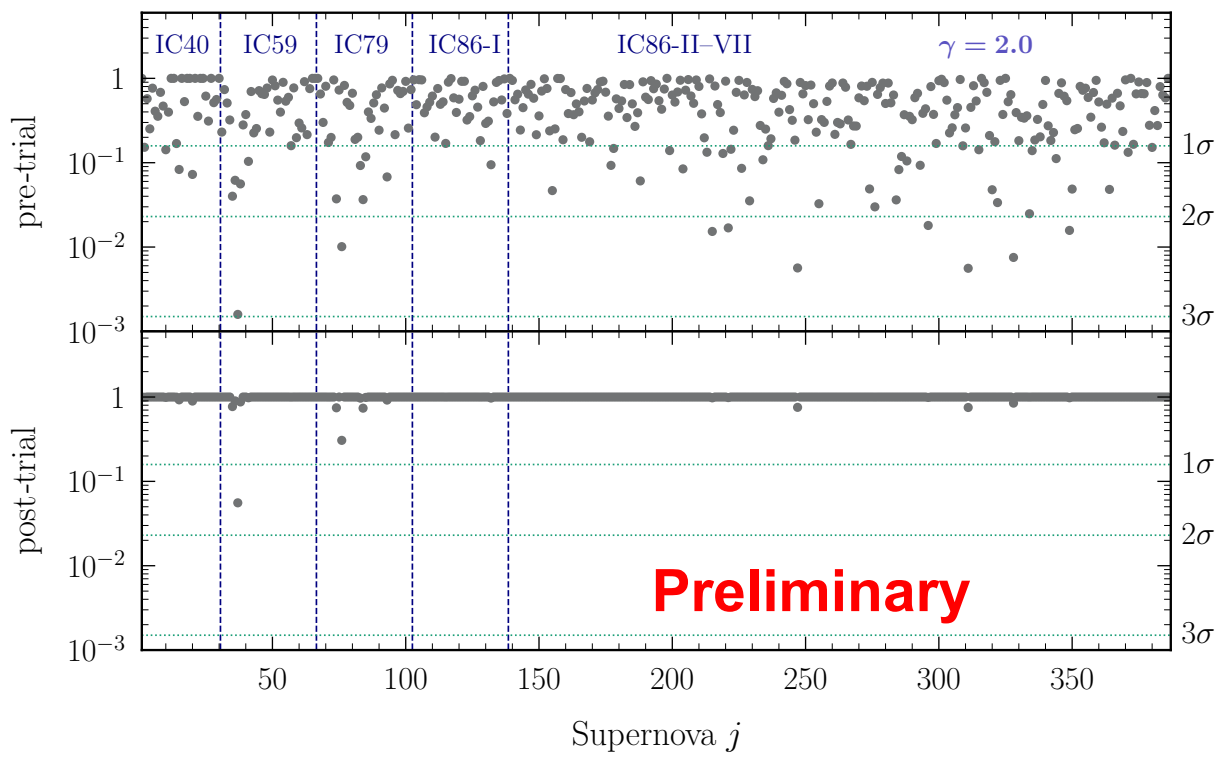

TABLE I. Pre-trial and post-trial p-values and significance from our stacking analysis for different cjSN models we consider.

Preliminary

Model	p_{pre} (significance)	p_{post} (significance)
$\gamma = 2.0$	0.566 (0)	0.985 (0)
$\gamma = 2.5$	0.498 (0)	0.968 (0)
$\gamma = 3.0$	0.429 (0.2 σ)	0.939 (0)
LLGRB-PE [31]	0.620 (0)	0.992 (0)
ULGRB-CS [32]	0.590 (0)	0.988 (0)

Results 2: Constraints