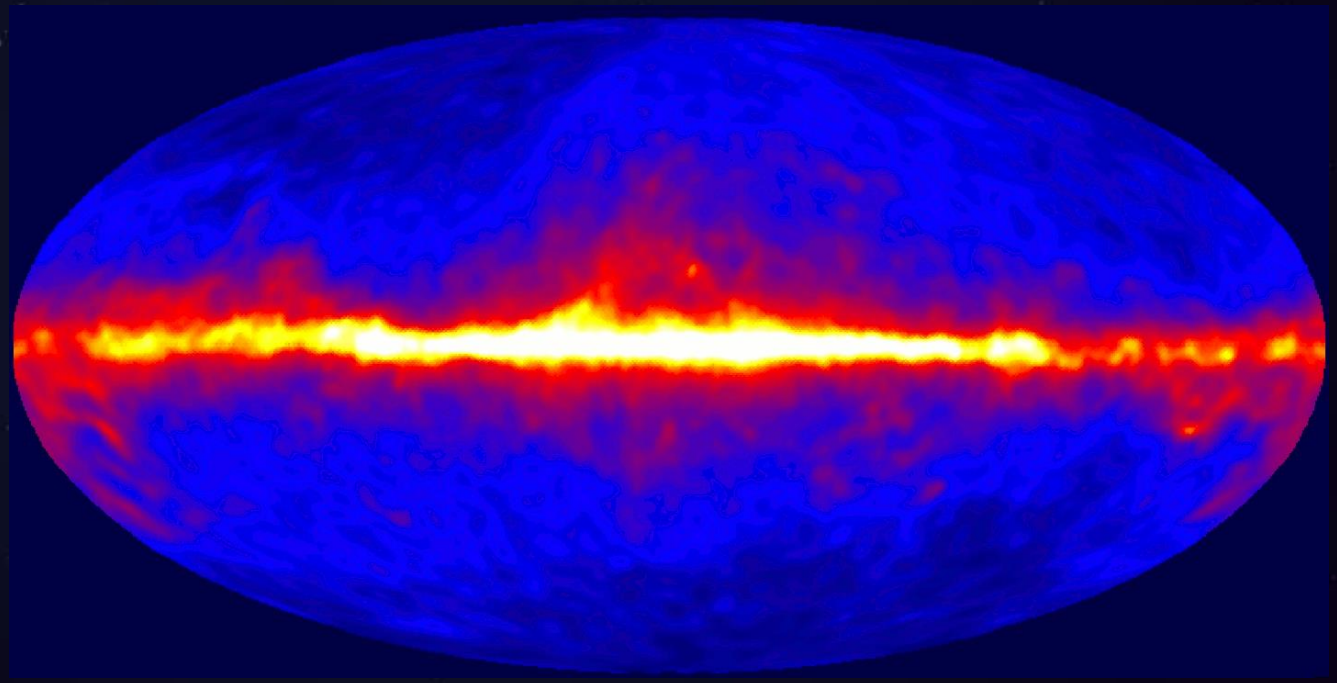
IceCube analysis on GRB precursors



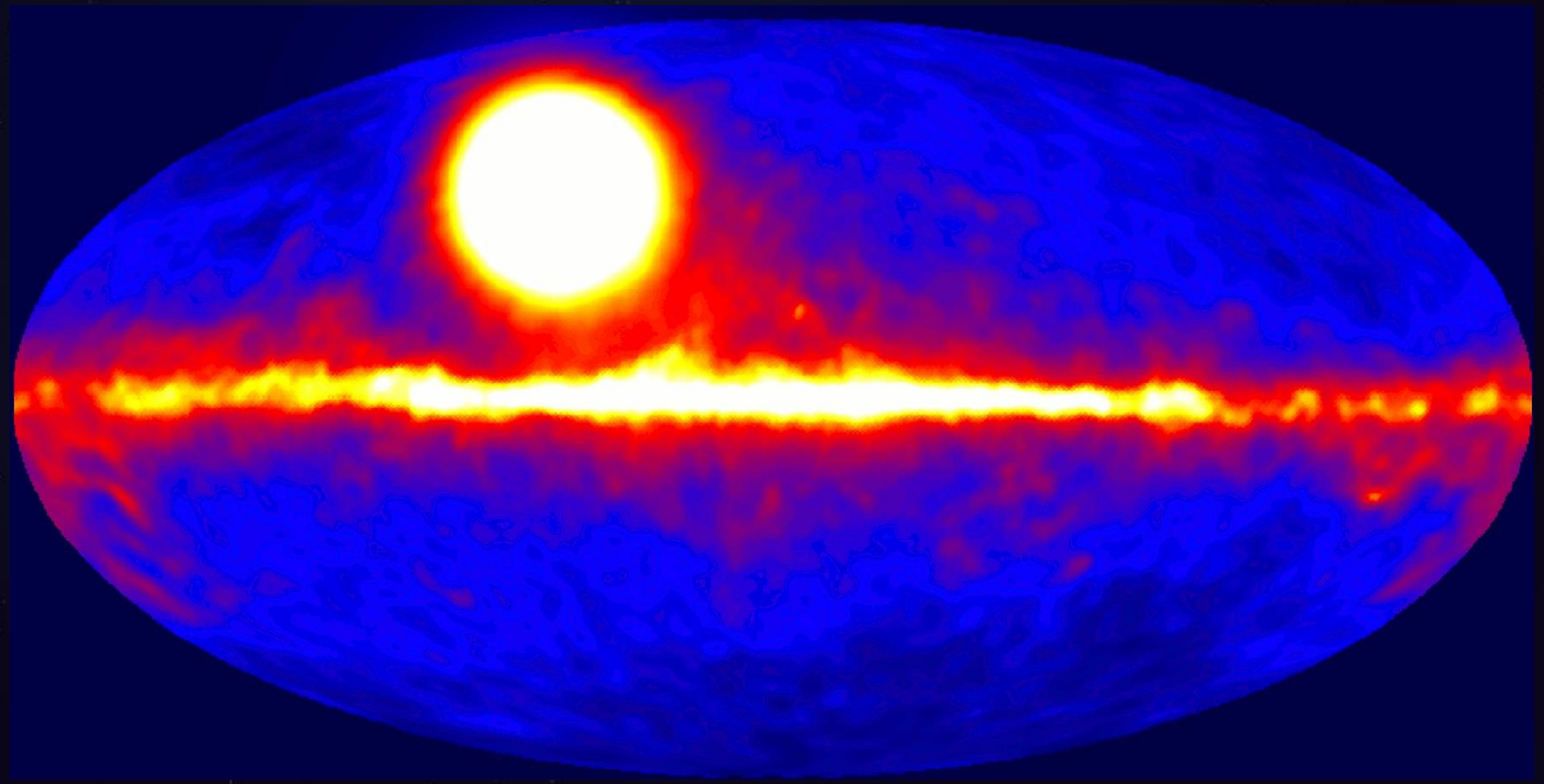
IIHE annual meeting

22-nov-2019

Paul Coppin

Promotor: Prof. Nick van Eijndhoven

Discovery of GRBs



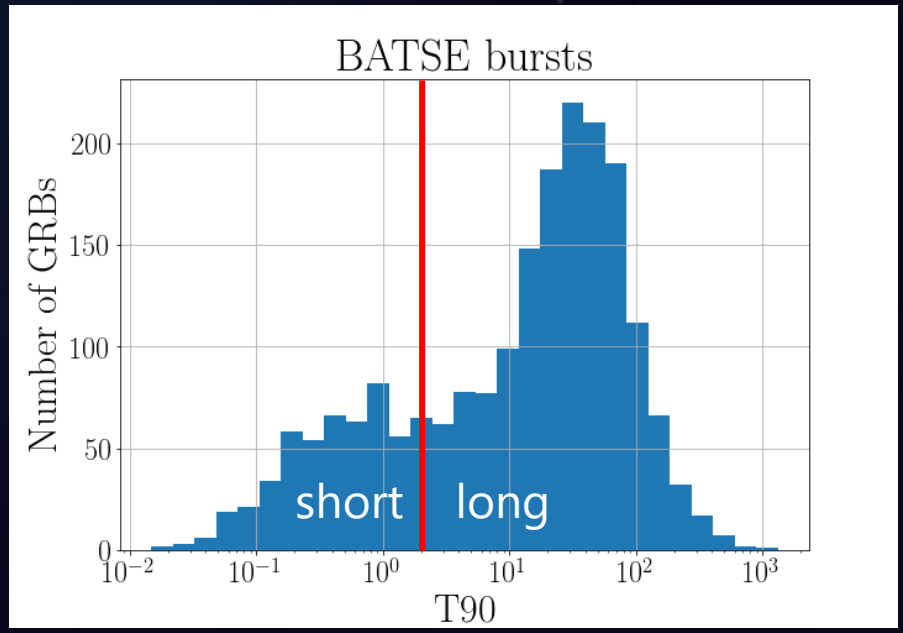
Discovery of GRBs

- Vela satellites deployed to check partial test ban treaty. Gamma-ray flashes seen, but non-consistent with nuclear bomb.

- First GRB detected in 1967
- Galactic or extra-galactic?
- >100 models proposed by 1992

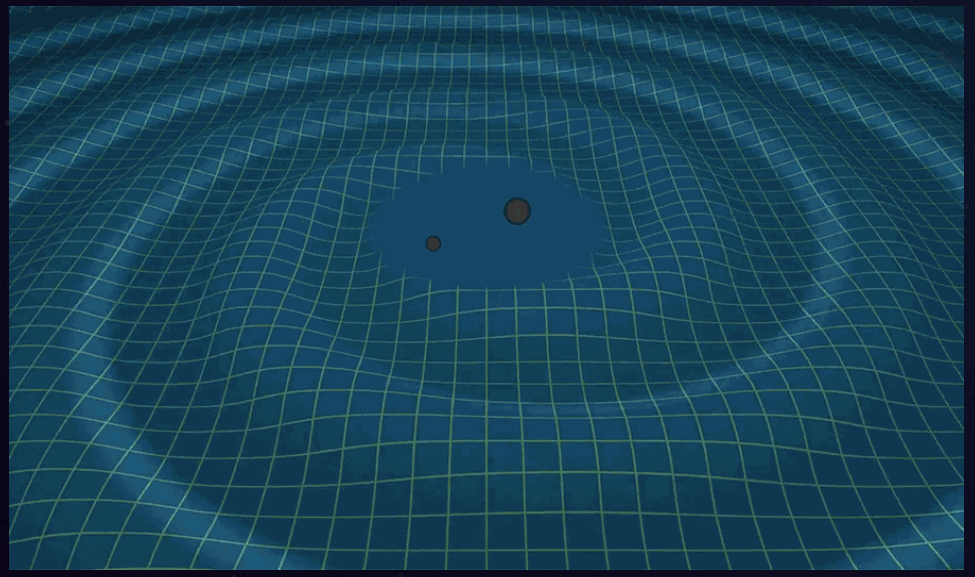
What we know by now

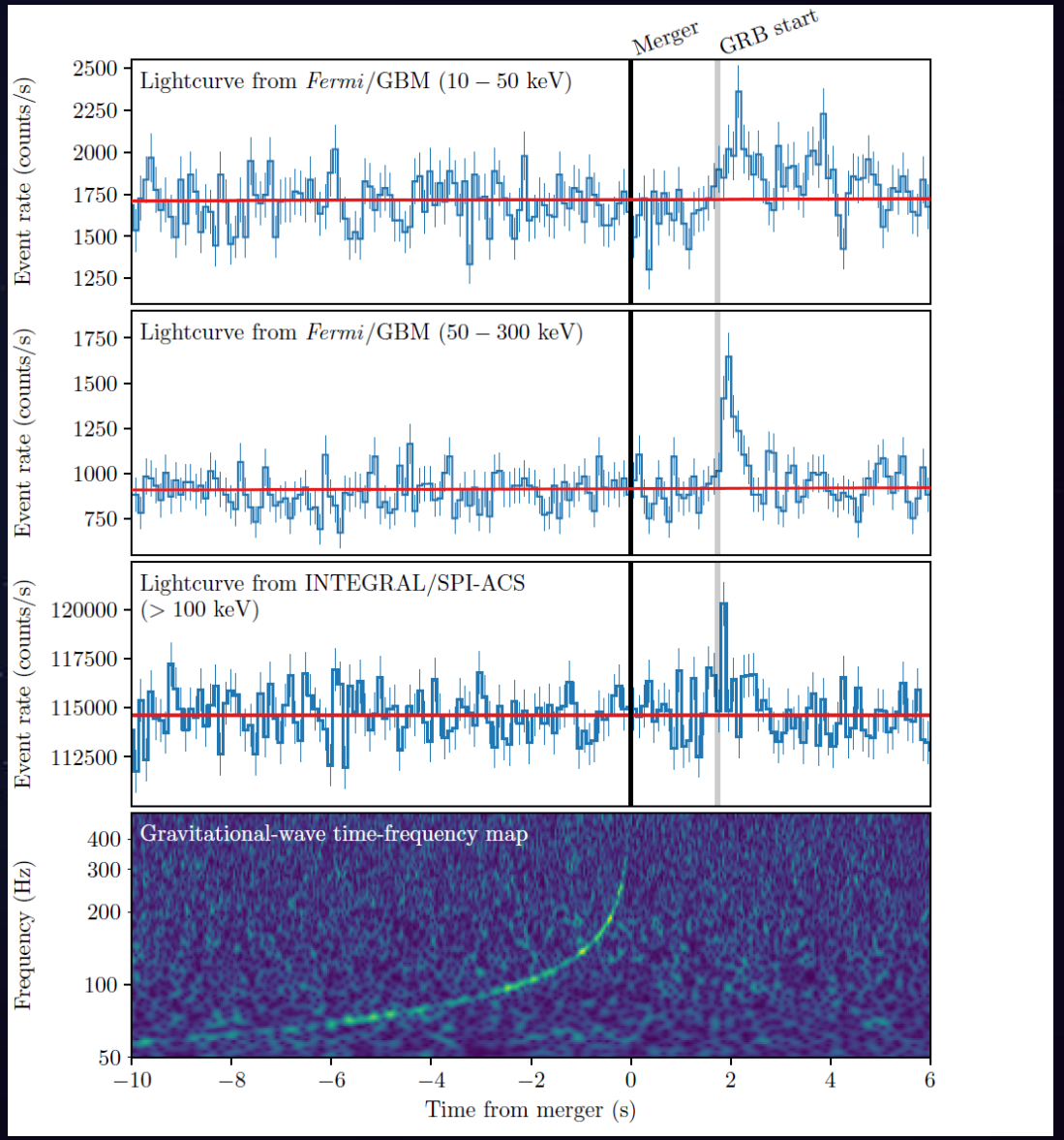
- Two progenitor types:
  - Binary neutron star mergers → short burst ($< 2s$)
  - Massive star collapse → long burst ($> 2s$)
- Satellites: Fermi, Swift, …
- ~1 GRB is observed per day
- Distance: z~2 (i. e. ~ 10 Gpc)
- Energy released: $\mathcal{O}(10^{52}$ erg)



GRB170817A

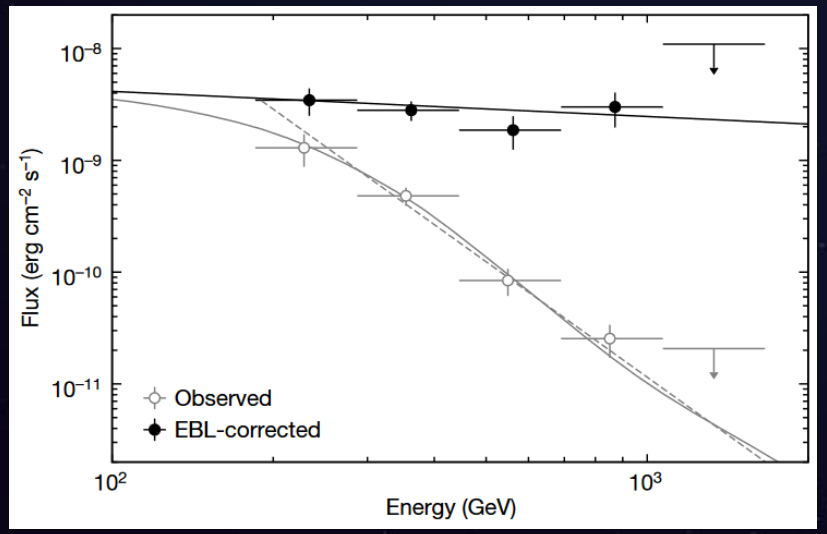
- First GW detection of a GRB!





GRB190114C

- First GRB detected with an IACT!
- Magic telescope in La Palma
- TeV γ-rays observed

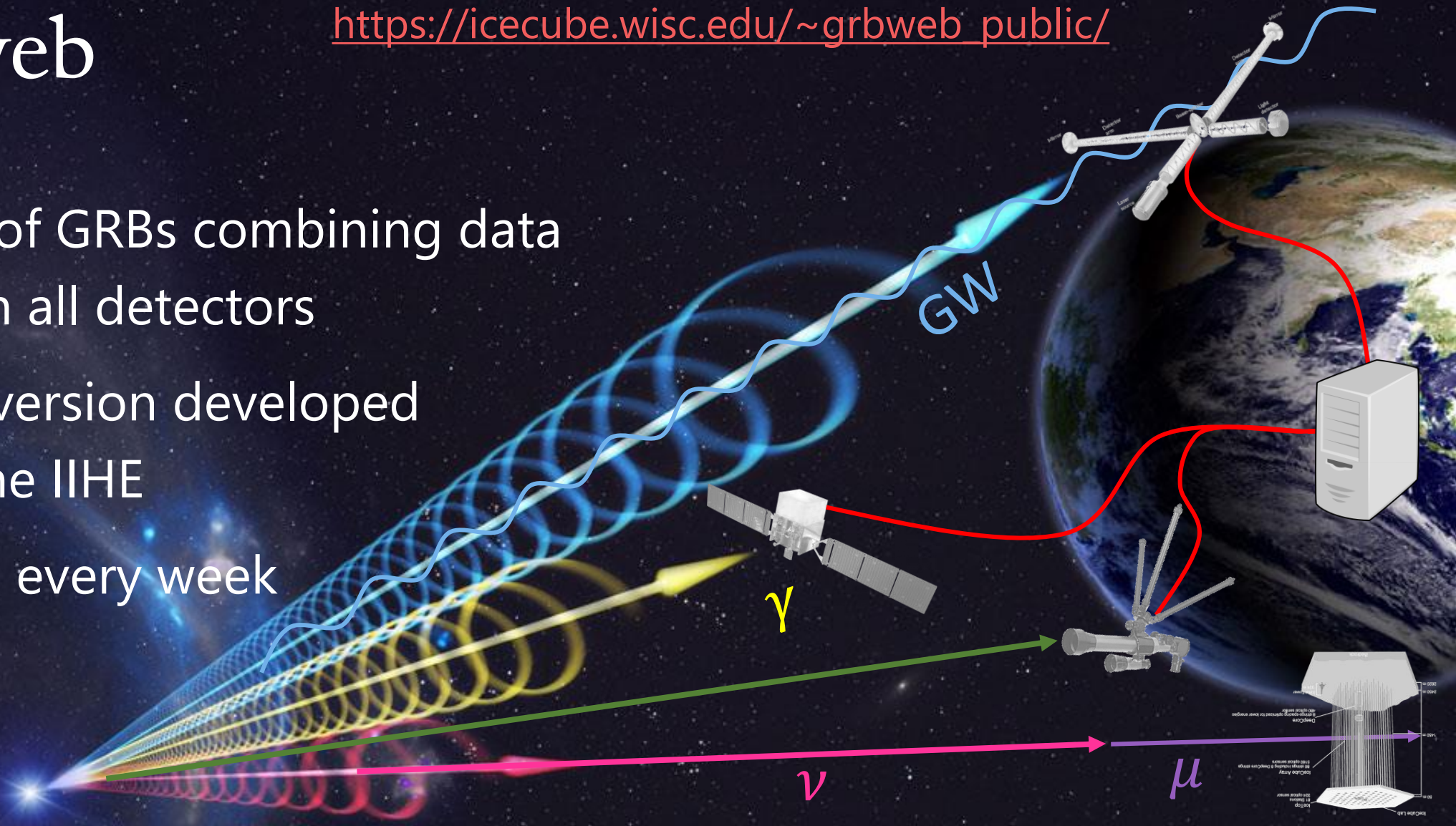


https://doi.org/10.1038/s41586-019-1750-x

GRBweb

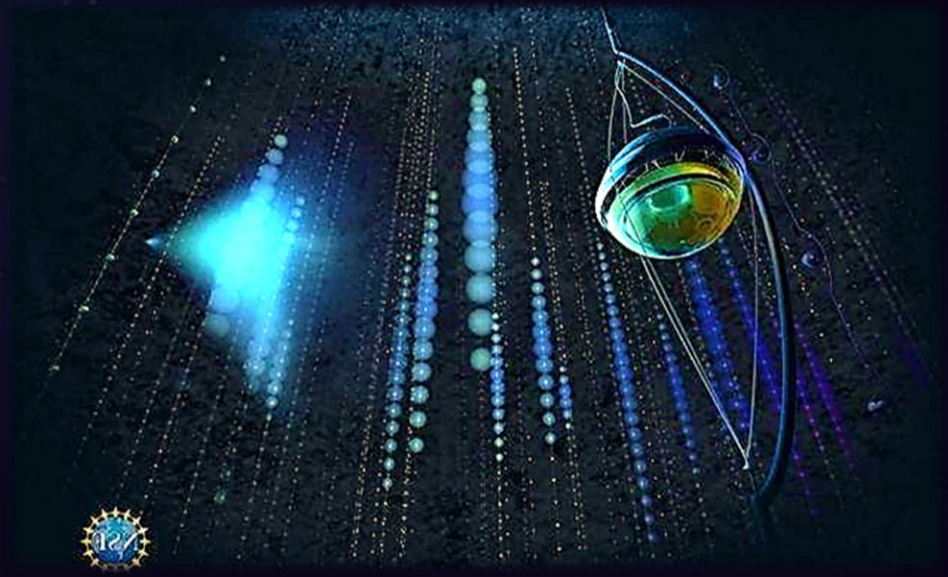
https://icecube.wisc.edu/~grbweb_public/

- Catalog of GRBs combining data from all detectors
- Current version developed at the IIHE
- Updated every week

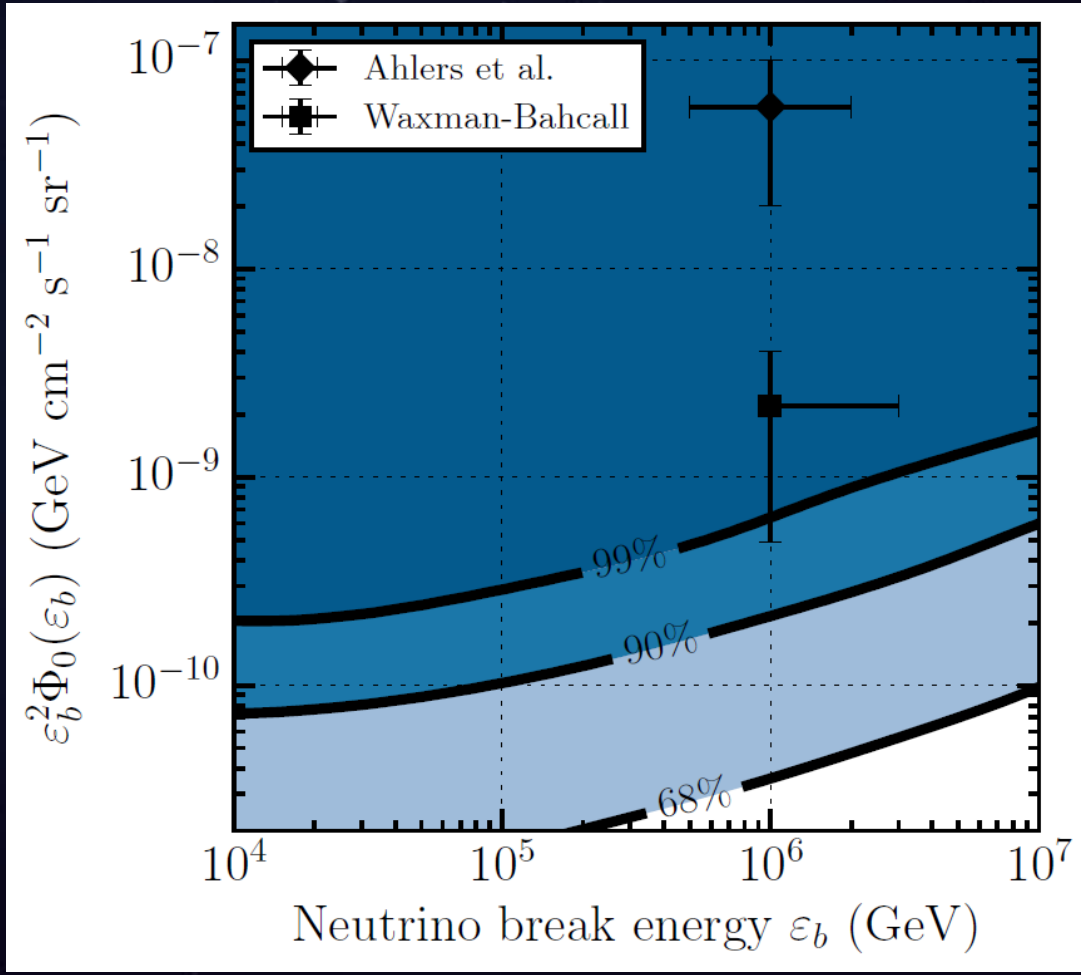


Do GRBs emit neutrinos?

- Extremely energetic
- $p + \gamma \rightarrow \Delta^{+} \rightarrow n + \pi^{+}$
  $\pi^{+} \rightarrow e^{+} + \nu_e + \nu_\mu + \bar{\nu}_\mu$
- Low background search for IceCube
  - Know **where** to look
  - Know **when** to look



IceCube prompt analysis results



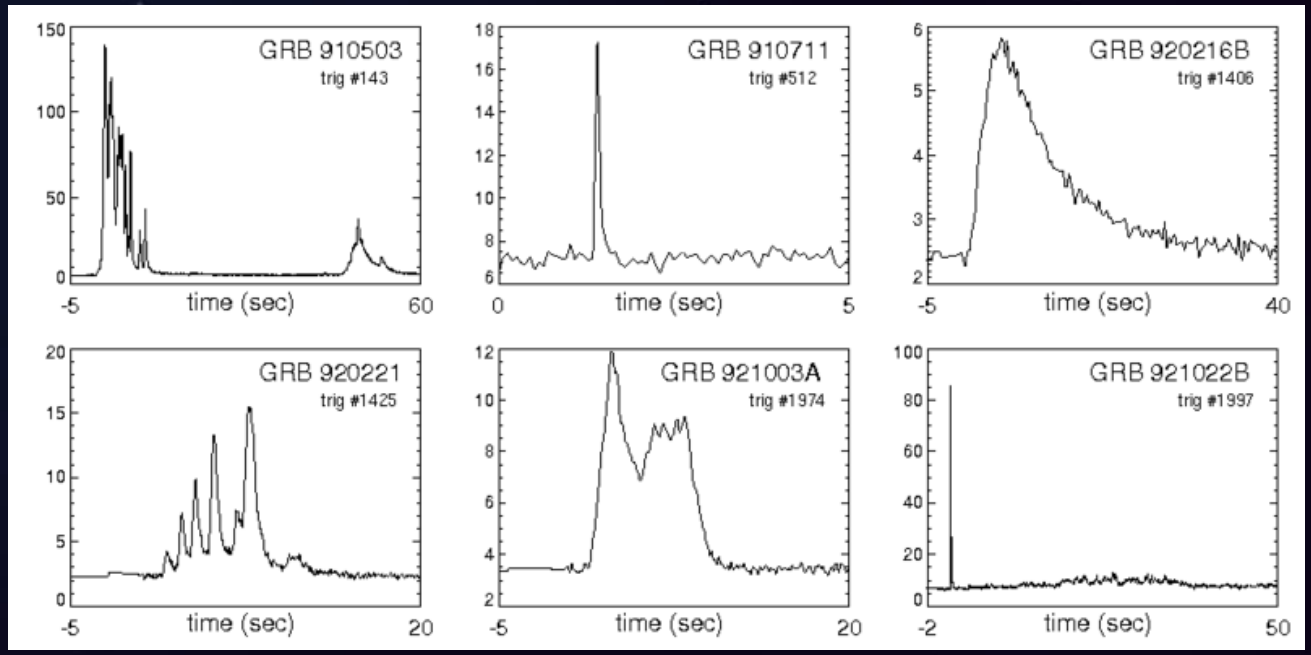
Does this mean GRBs don't emit neutrinos?

No: "Each GRB is as unique as a snowflake"

Does this mean GRBs don't emit neutrinos?

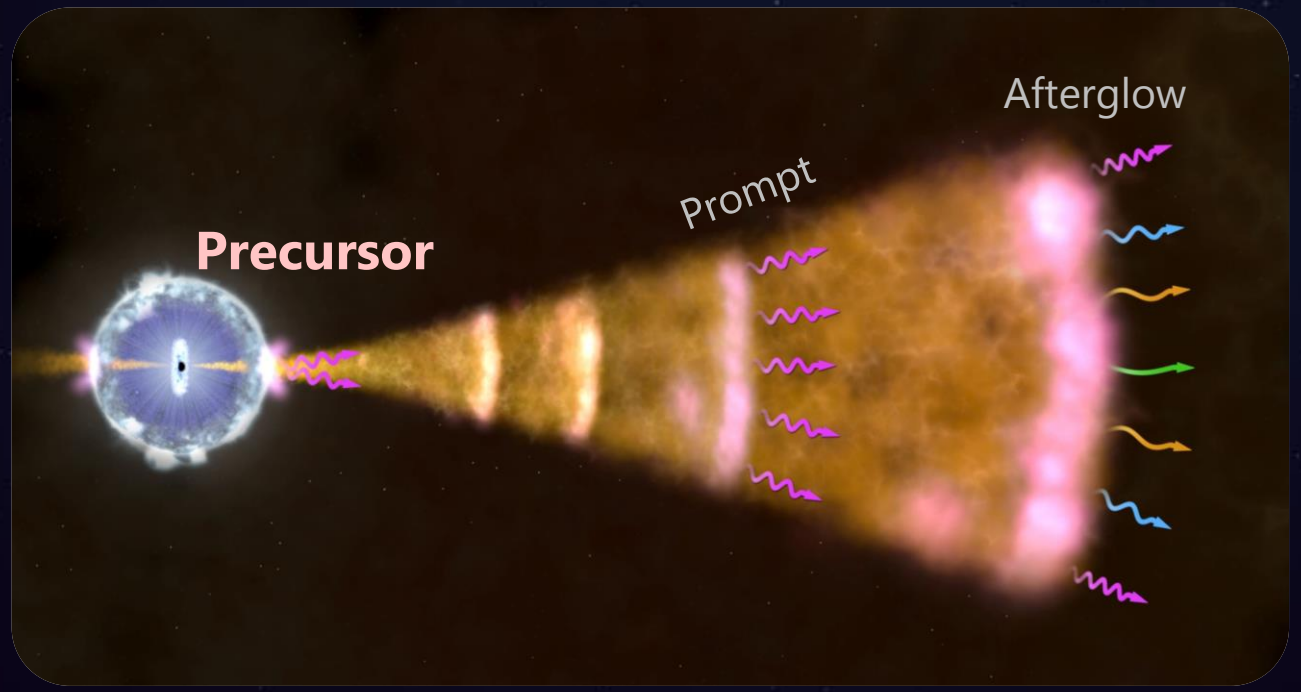
No: "Each GRB is as unique as a snowflake"

- Light curves wildly differ
- Many special cases
- Obscured/choked GRBs
- …



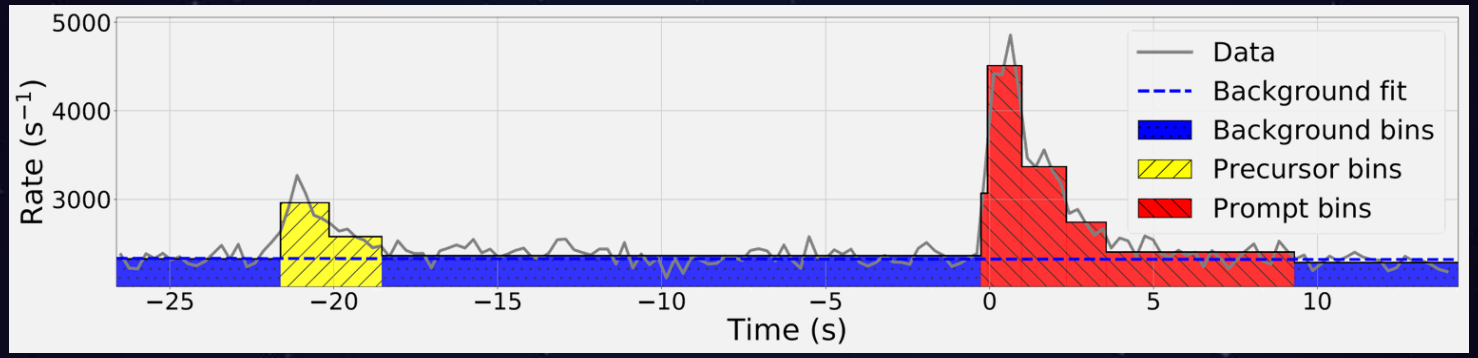
Does this mean GRBs don't emit neutrinos?

No: Limits only apply to the prompt phase!



GRB precursors

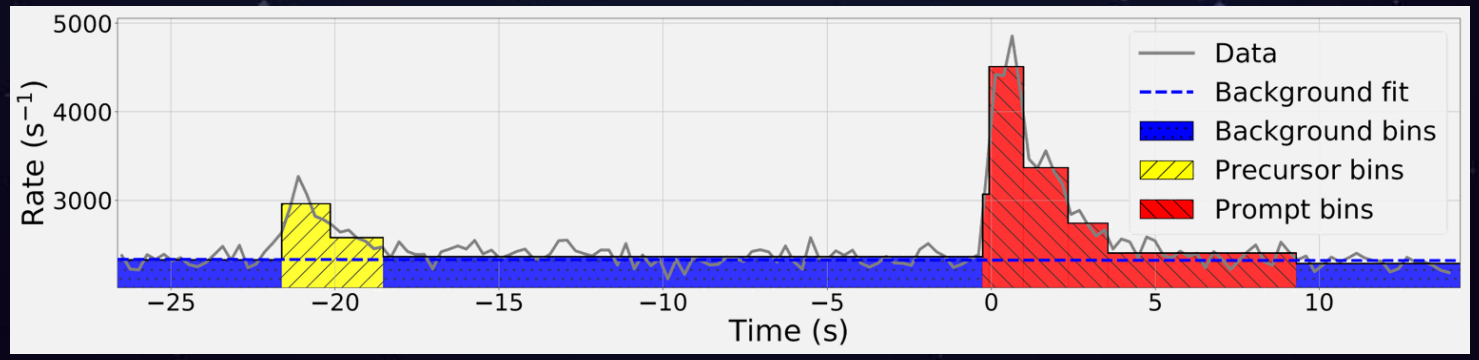
- Observed in ~15% of all bursts



- Suggests central engine activity is already ongoing
- Not fully understood, many models have been proposed
- Higher density → more hadronic interactions

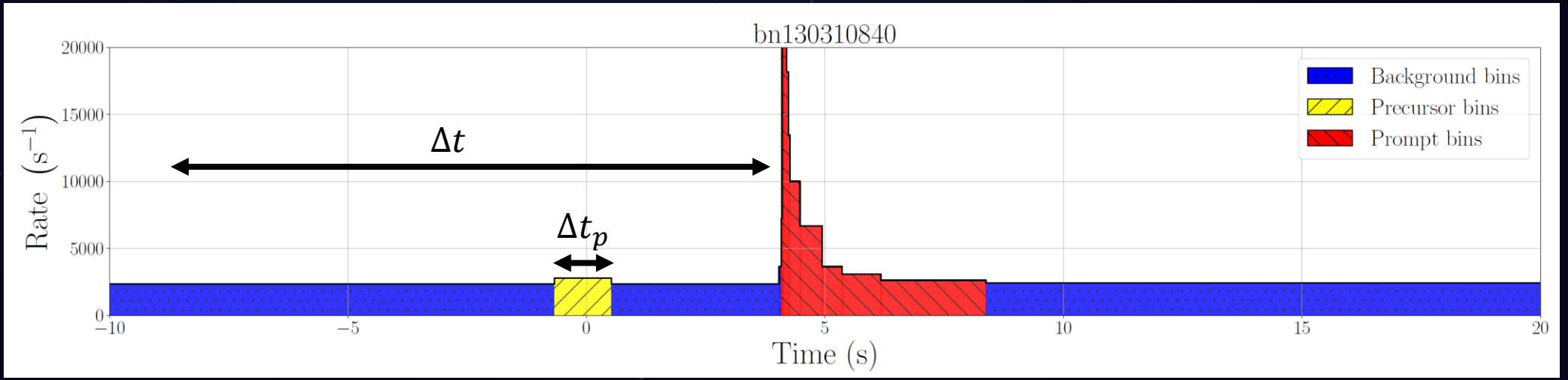
Identifying GRB precursors

- Catalogue of GRB precursors required:
  - Fermi-GBM data publicly available
  - Create background subtracted light curves
  - Identify precursors

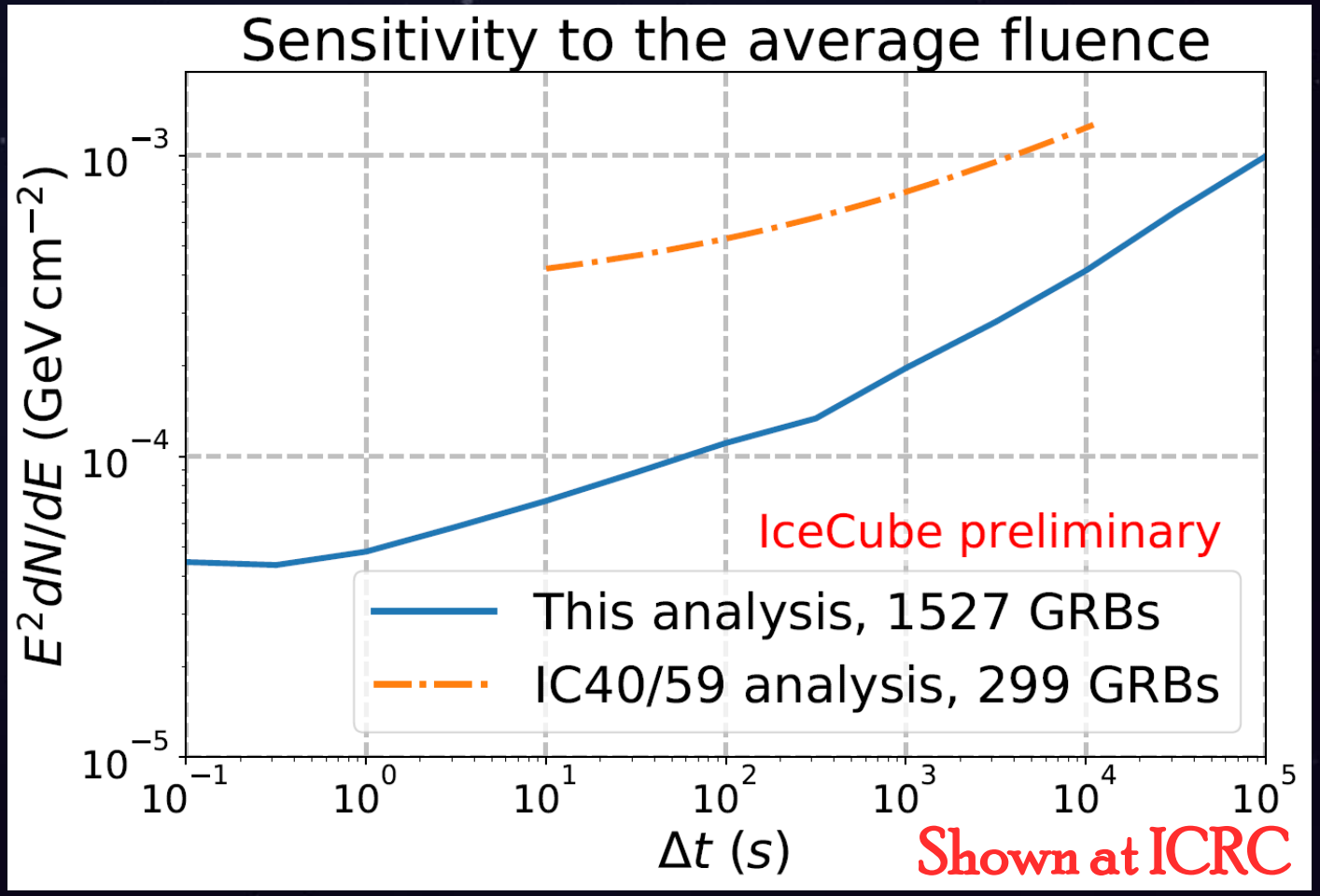


Stacking analysis overview

- Two approaches:
  1. Search for ν during the precursors: Δt_p
  2. Search for ν before the prompt emission: Δt

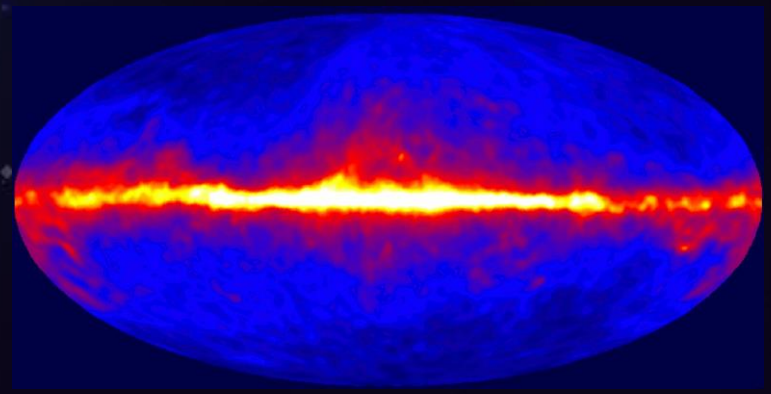


Stacking analysis sensitivity

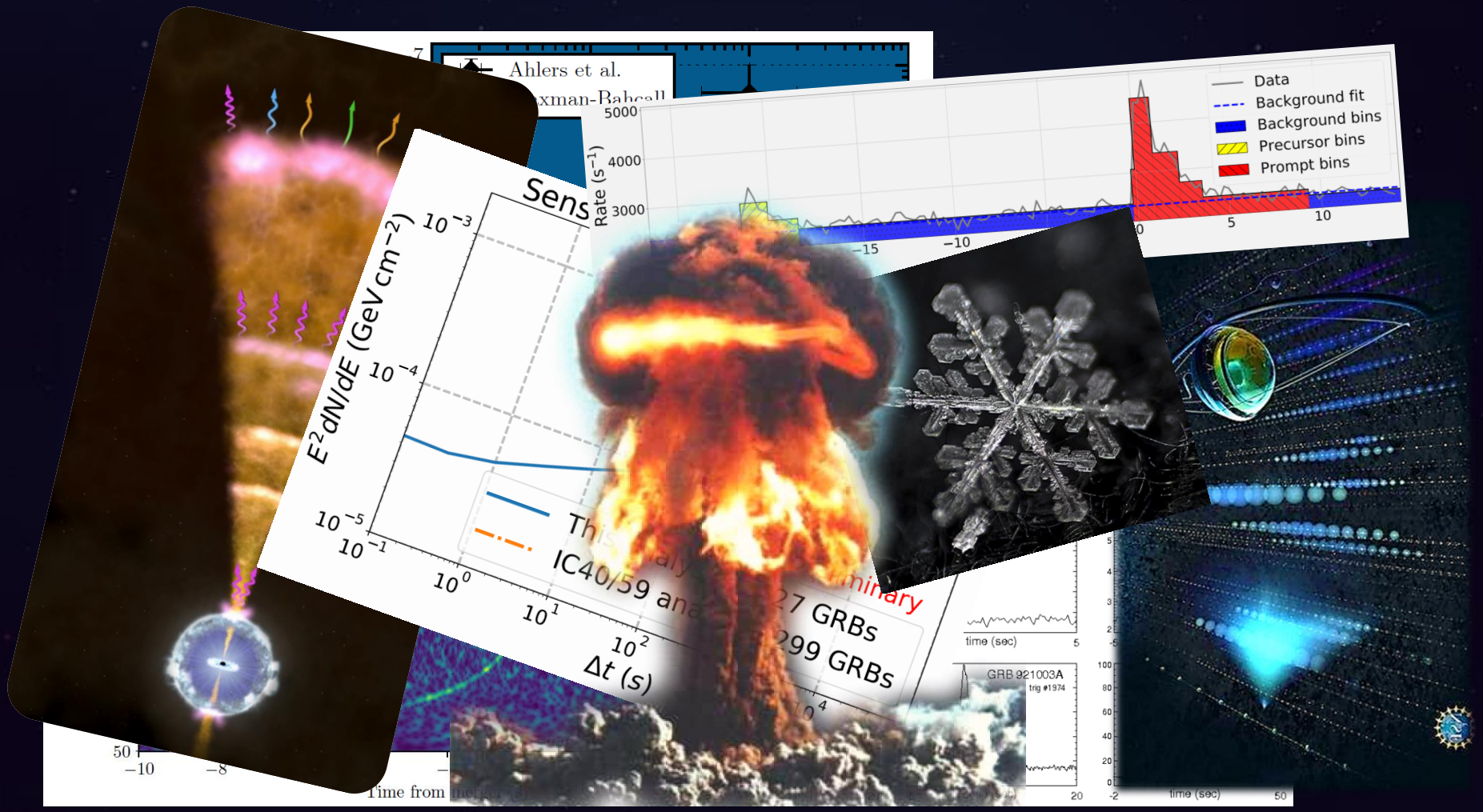


Conclusion

- Recent discoveries: First GW & IACT detection of a GRB
- IceCube has not seen a significant excess from GRBs yet
- My analysis: Look for neutrinos from the precursor phase
  - Identify precursors using Fermi-GBM data
  - Look for coincidences in IceCube

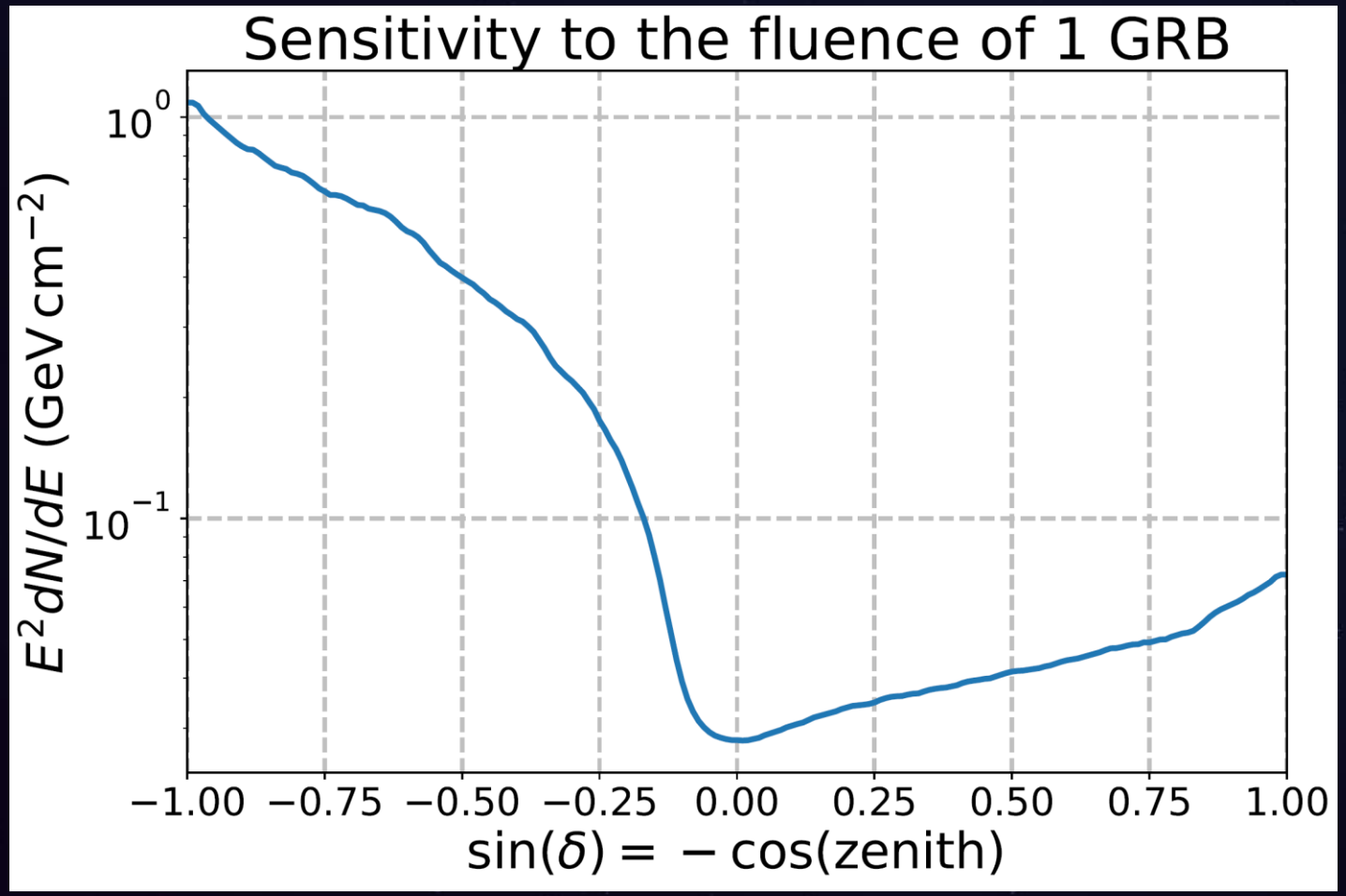


Questions?


Ahlers et al.
Data
Background fit
Background bins
Precursor bins
Prompt bins
Rate (s^{-1})
E^2dN/dE (GeV cm^{-2})
Δt (s)
IC40/59 ana
27 GRBs
299 GRBs
GRB 221003A
time (sec)
Time from

Back-up slides

Sensitivities – Single GRB



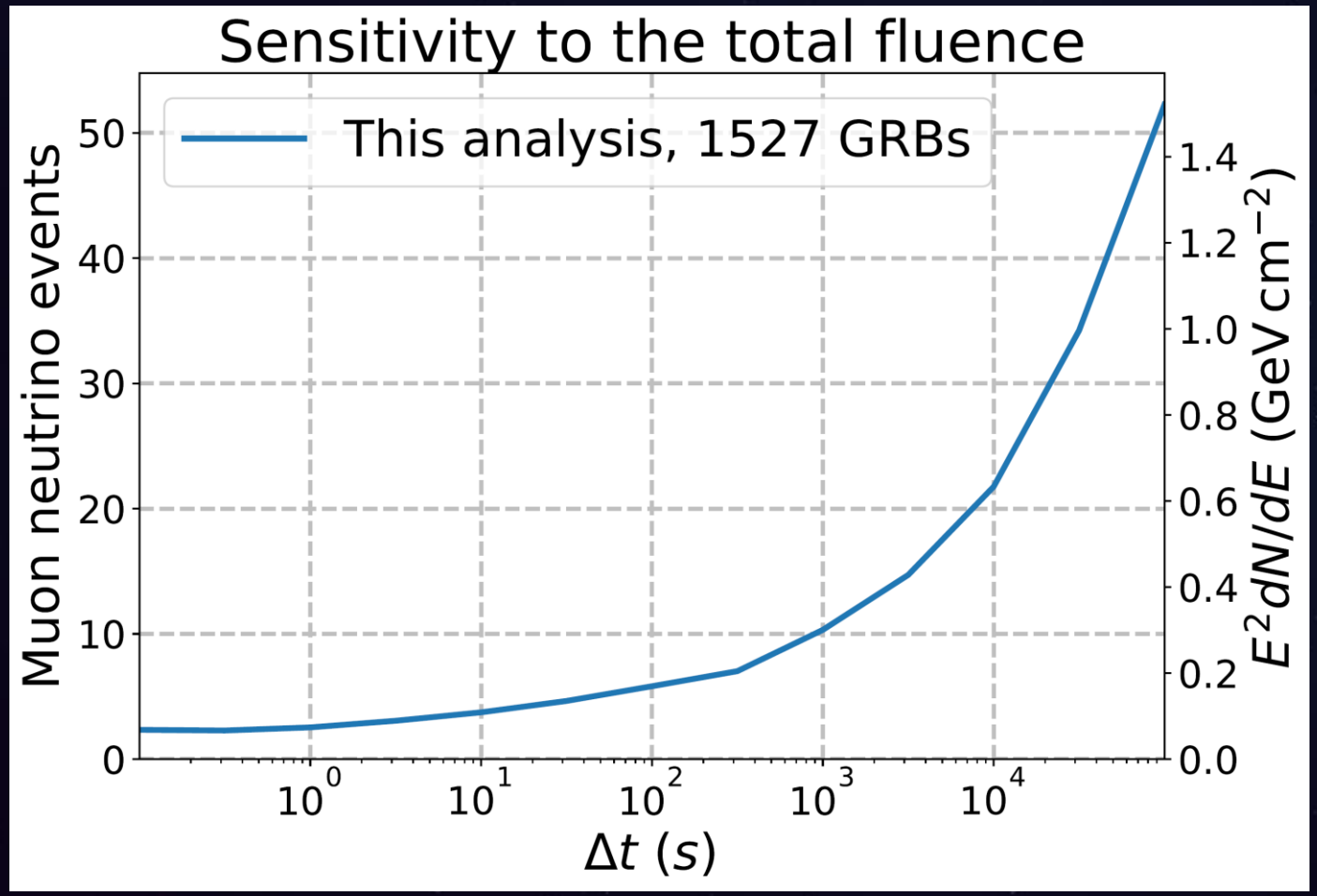
Search is ´background free´

if $\Delta t < 1000$s

⇒ Sensitivity requires 2.3 signal events to be observed

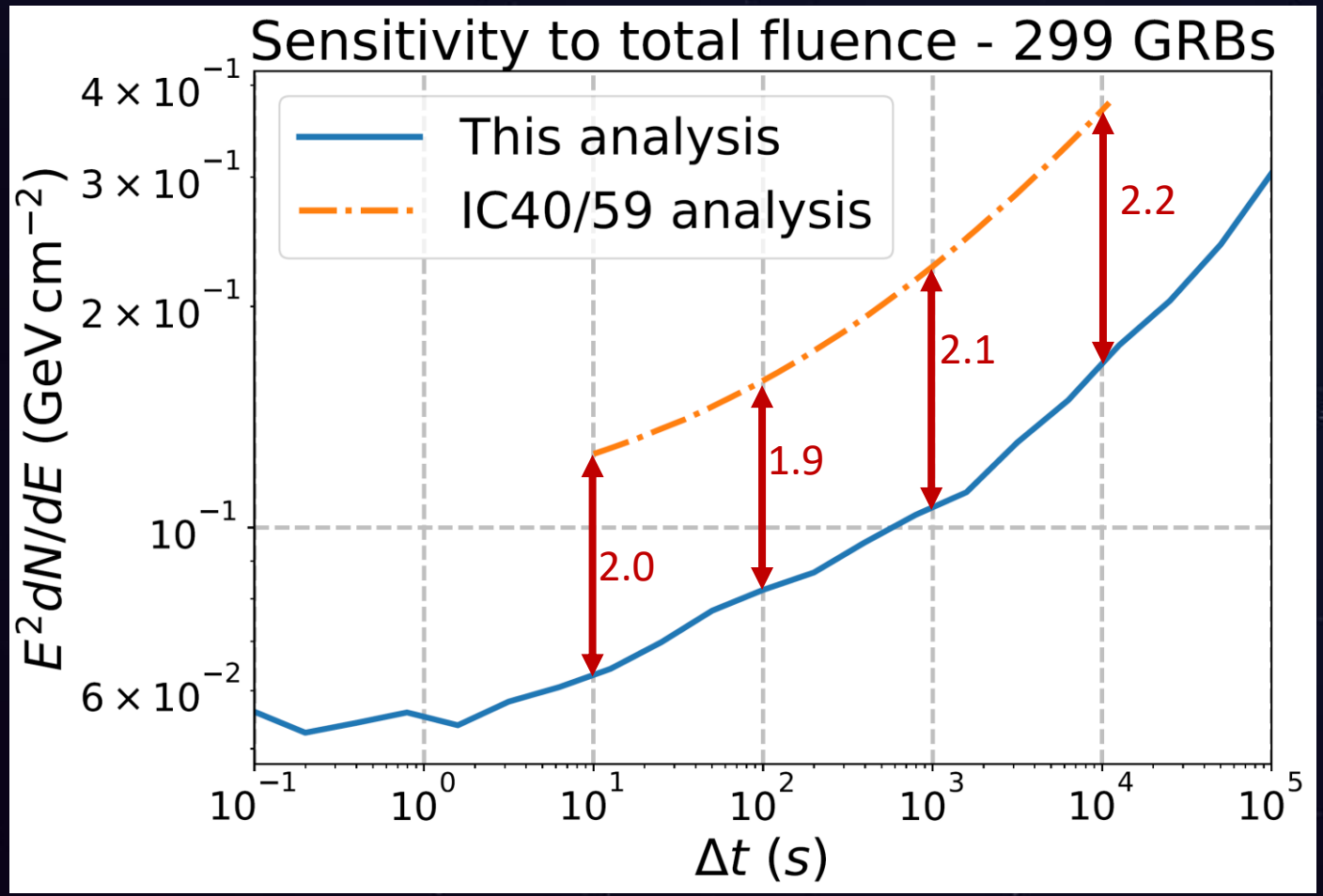
$$0{,}9 = \sum_{k=1}^{\infty} \frac{\lambda^k}{k!} e^{-\lambda} = 1 - e^{-\lambda} \Rightarrow \lambda = \ln(10) \approx 2{,}3$$

Sensitivities – Stacking all GRBs



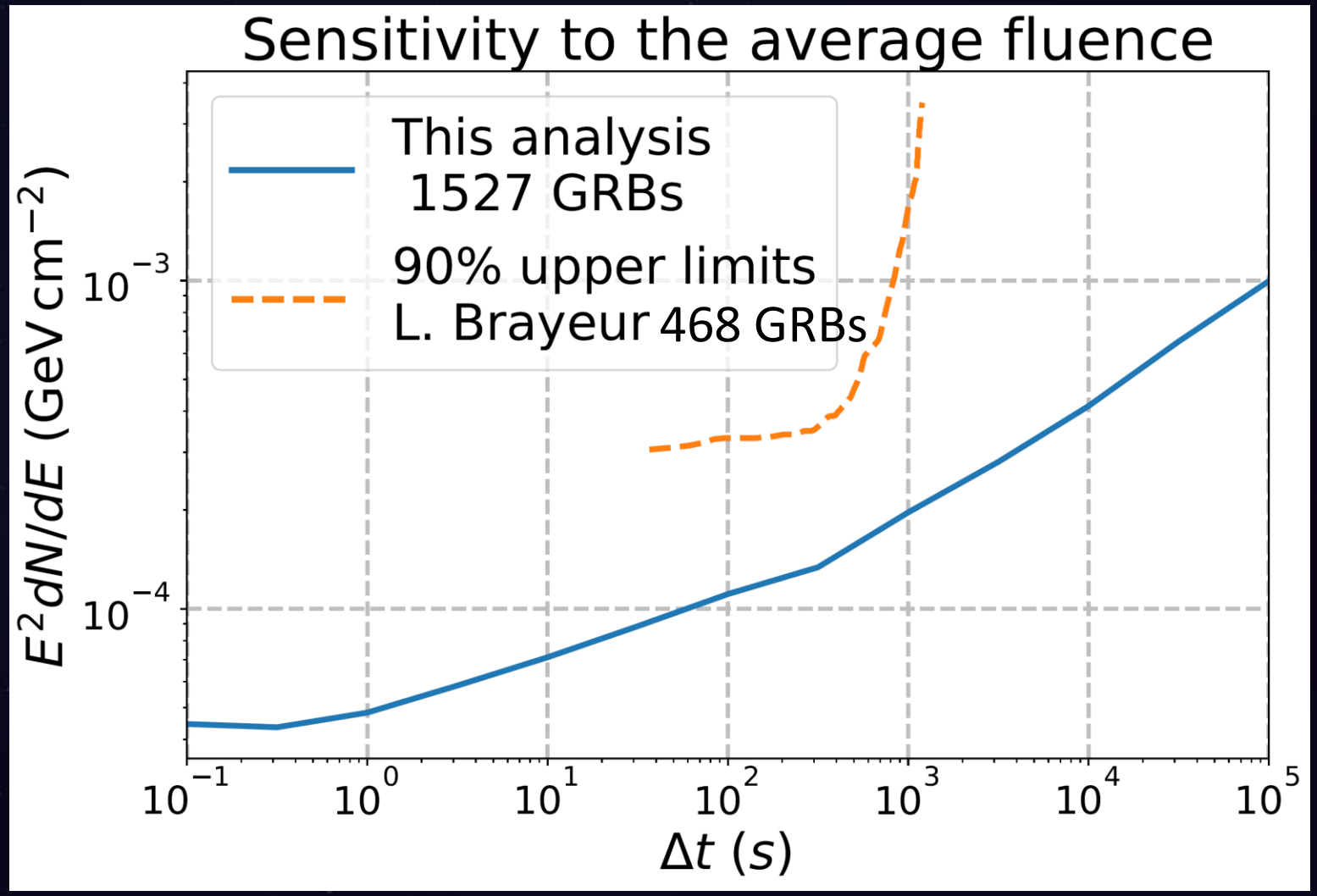
- Declination dependence averaged out over all GRBs
- Sensitivity mainly dependent on the time window size Δt

Sensitivities – Stacking 299 GRBs



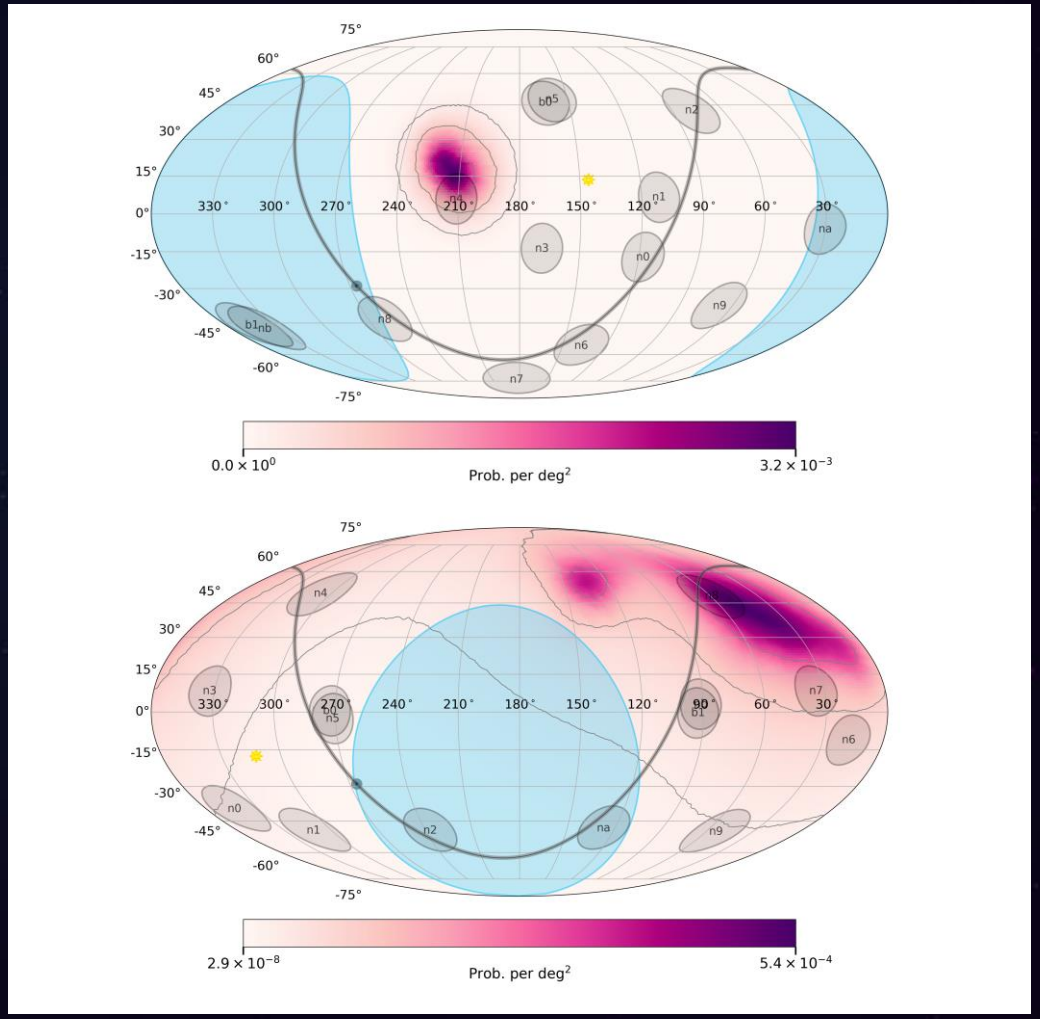
- Previous published limits date back to IC40/59
- Differences:
  - ~~Number of GRBs~~
  - (Analysis software)
  - Event selection
  - Detector geometry

Precursor limits placed by L. Brayeur



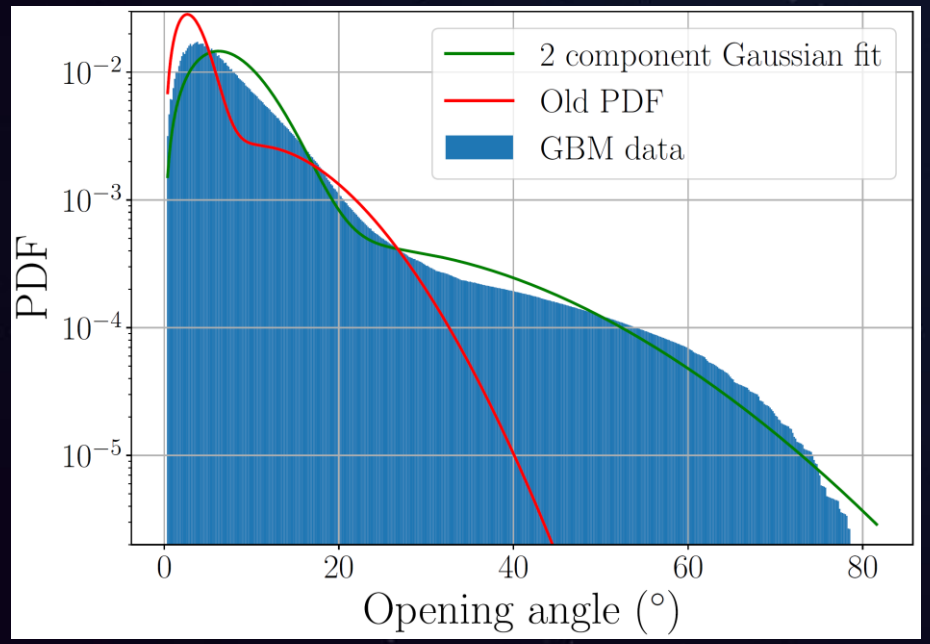
Spatial priors for GBM bursts

- Fermi-GBM localizations ill described by a 2d Gaussian
- Healpix prior recently became available for all GBM bursts
- Proper treatment in csky in progress for (time-dependent) stacking analyses

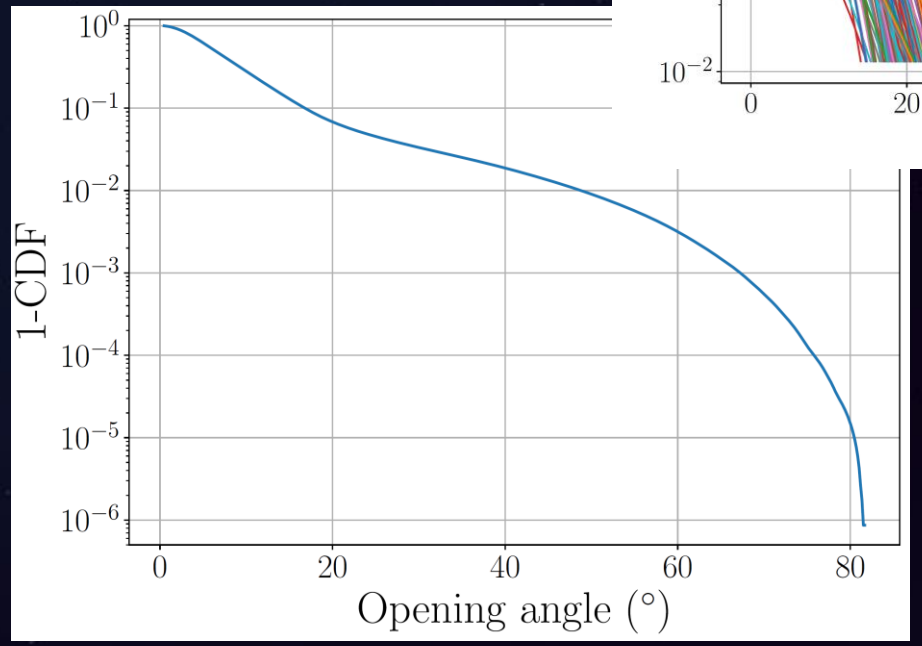


Localization of GRBs by Fermi-GBM

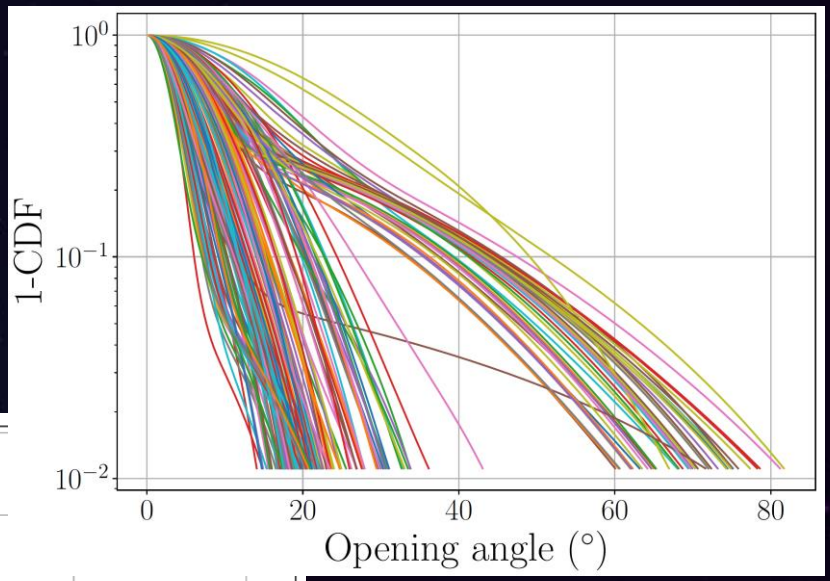
- 20% of all bursts have ‘bad’ contours
- PDF in previous IceCube analyses too optimistic



Combined PDF of 100 bursts

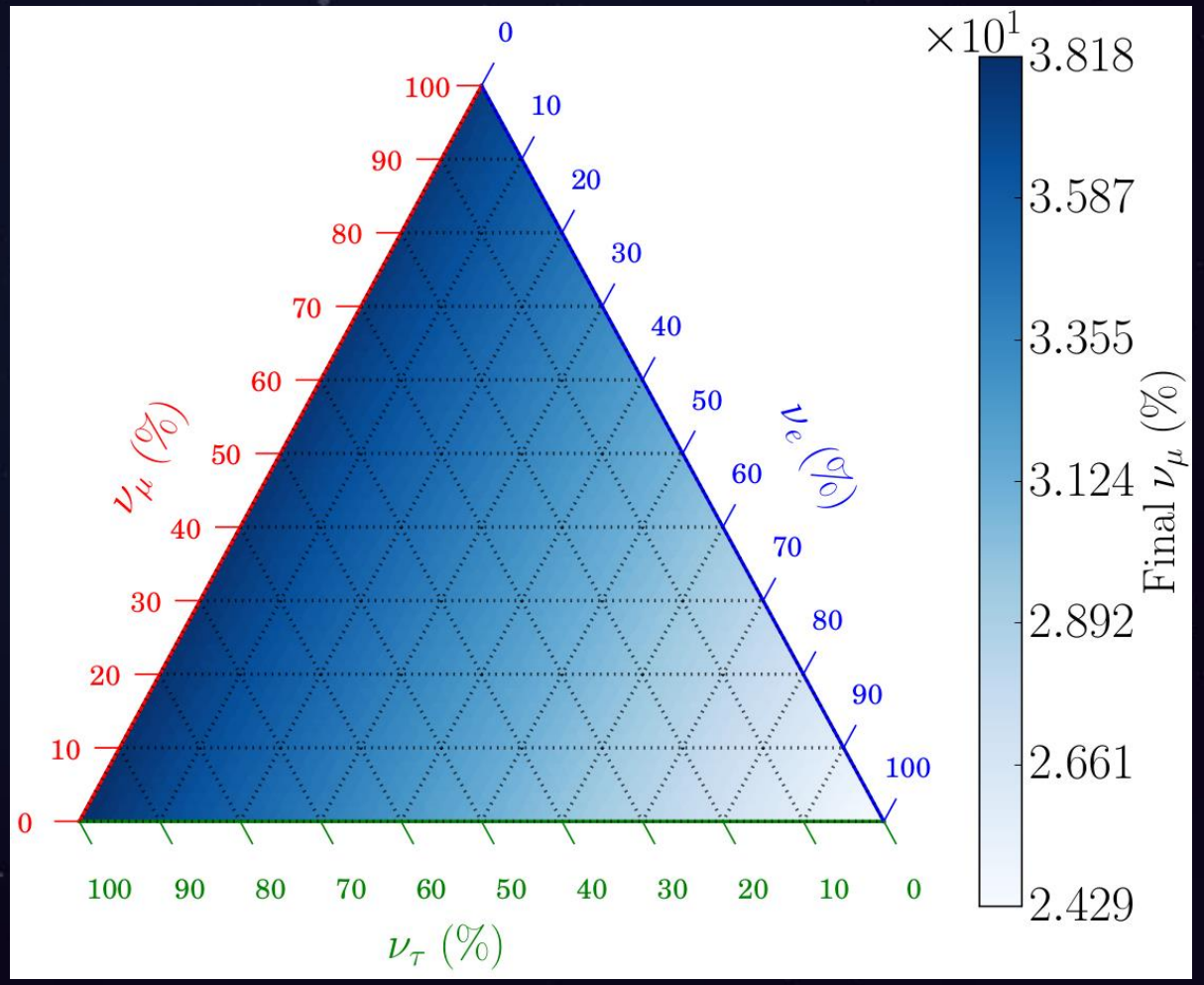


Combined CDF of 100 bursts



Per burst CDF (one line corresponds to one GRB)

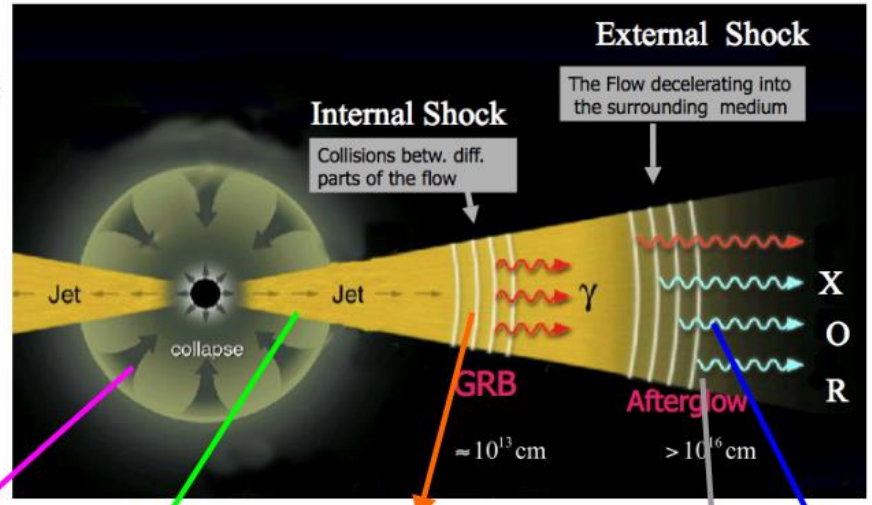
ν_μ fraction after oscillations



GRBs as sources of high-energy neutrinos

Fireball model for long GRBs:

Credit:
Meszaros & Murase



MeV neutrinos at collapse

PeV neutrinos from internal shock
[Waxman & Bahcall 1997]
[Gupta & Zhang, 2006]
[Murase & Nagataki 2006]

EeV neutrinos from external shocks [Dermer 2001]
[Waxman & Bahcall 2000]

TeV neutrinos from inside the star
[Meszaros & Waxman, 2001]
[Razzaque et al. 2003]

PeV-EeV neutrinos from flares
[Murase & Nagataki 2006]

Photon horizon