地上ガンマ線望遠鏡で挑む ガンマ線バーストの マルチメッセンジャー観測

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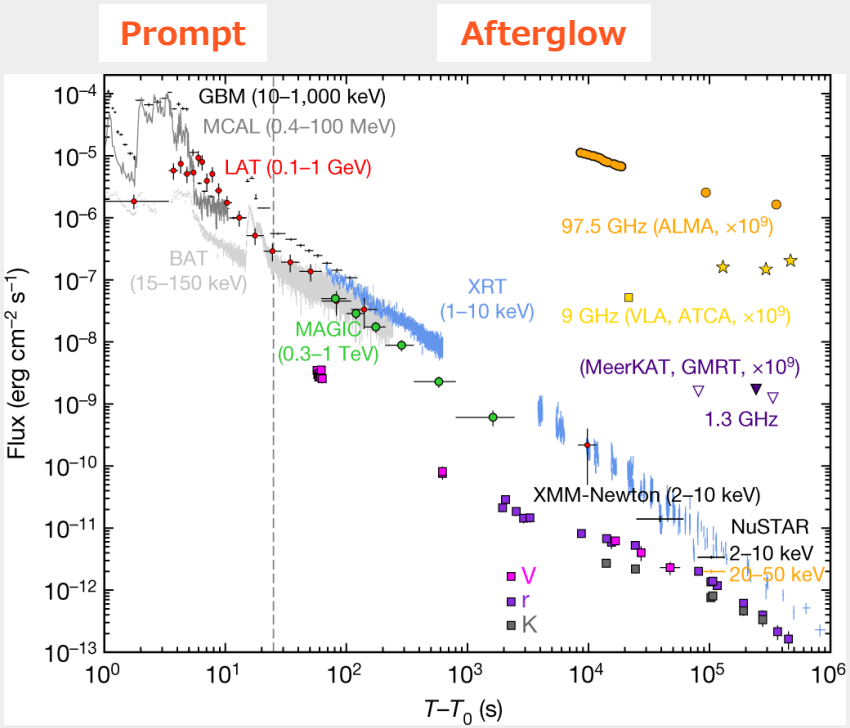
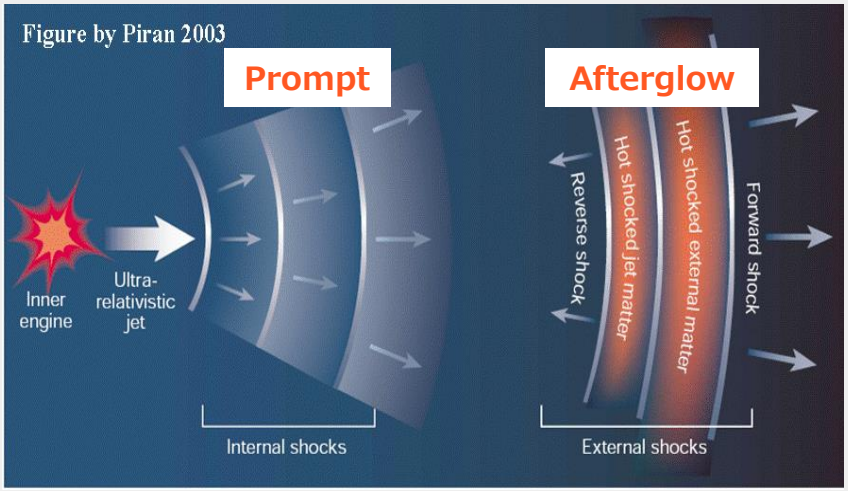
Gamma-ray Burst (GRB)

- Extremely energetic emission from relativistic jet
- Isotropic gamma-ray energy: typically, $E_{iso} > 10^{52}$ erg
- Prompt: series of short pulses
- Afterglow: power-law decay with duration of days to weeks



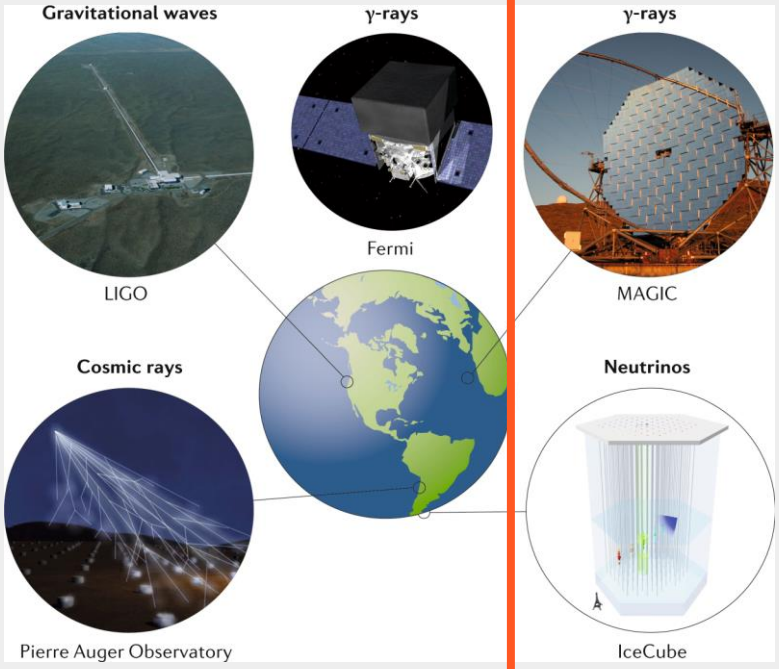
MAGIC Collaboration (2019)



Multi-messenger Observation

VHE ⋯ Very High Energy (GeV - TeV)

This talk's content

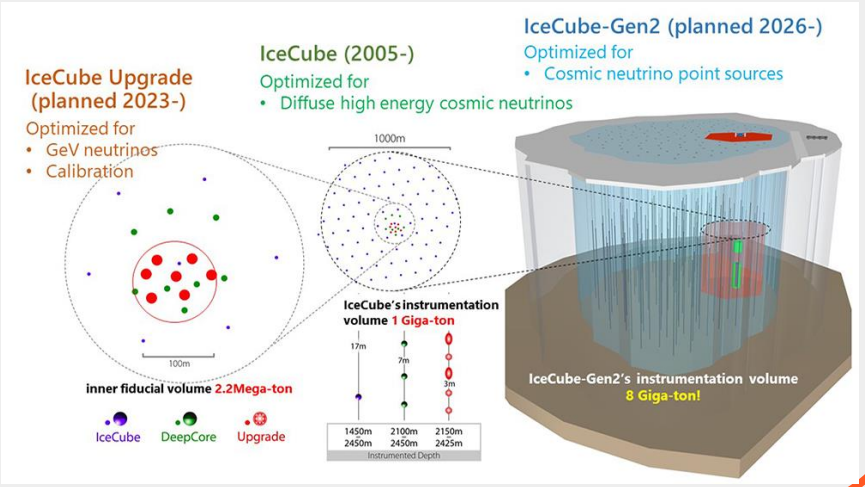


VHE gamma-ray

CTA North

Upcoming next generation instruments

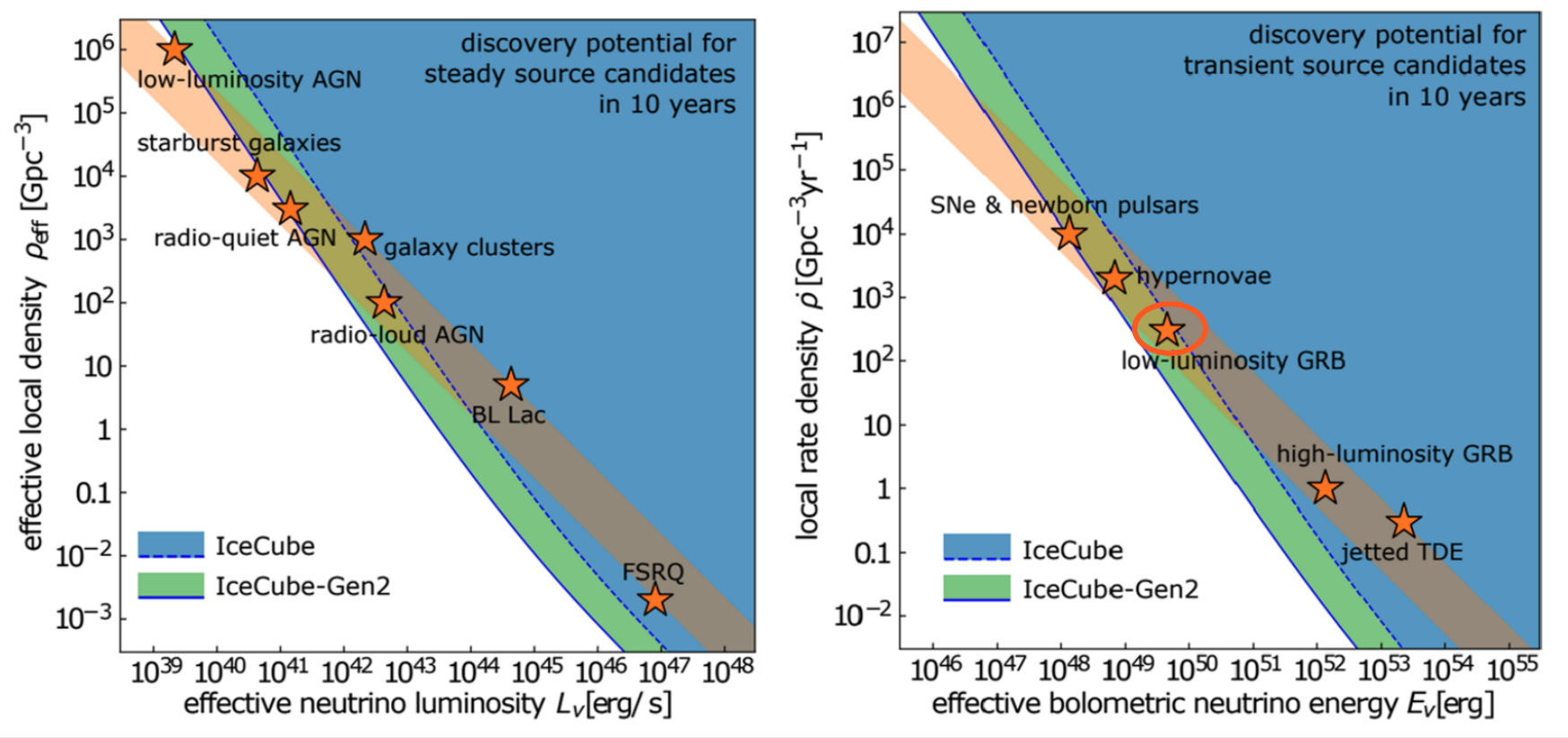
Neutrino



Origin of Neutrino Diffuse Flux

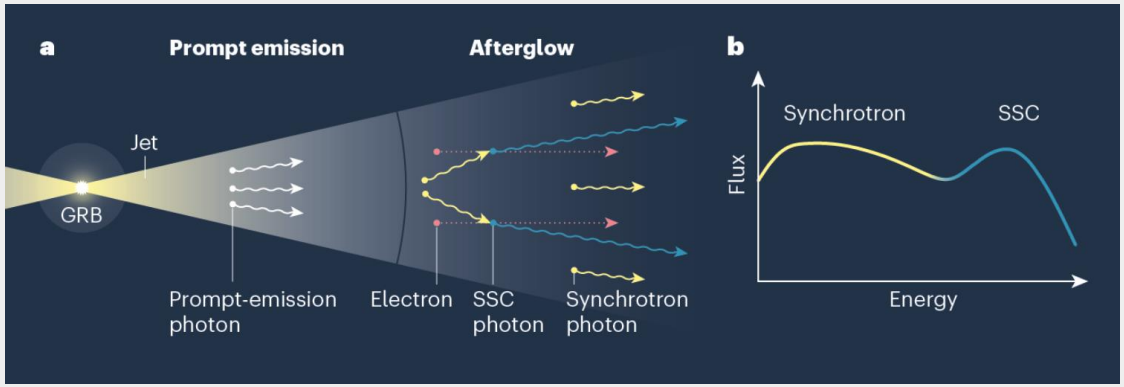
Low-Luminosity GRB (LLGRB): GRBs with isotropic energy $E_{iso} < 10^{50}$ erg

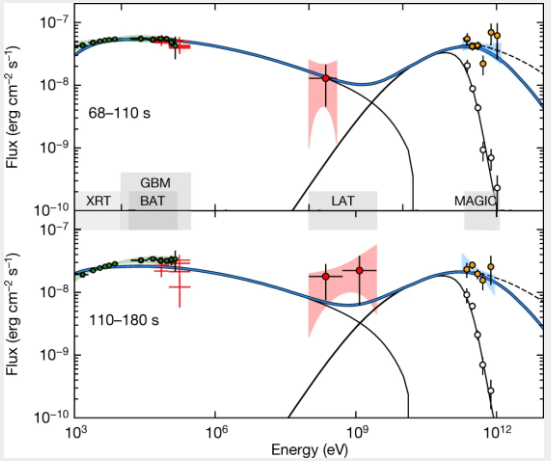
IceCube-Gen2 Collaboration (2020a)



IceCube-Gen2 measurement can distinguish whether LLGRB is one of the origin of diffuse neutrino flux

Insights from VHE Observation





- Inverse Compton radiation gives us info on:
  - Energy release in VHE range that we have overlooked
  - (Amplified) Magnetic field

- Together with multi-wavelength data, one can obtain more accurate kinetic jet energy of initial afterglow phase E_k

- Combined with prompt energy release, one can derive more accurate radiation efficiency of prompt emission
  - Essential to investigate the prompt emission mechanism
  - Relates to total proton energy after internal shock dissipation

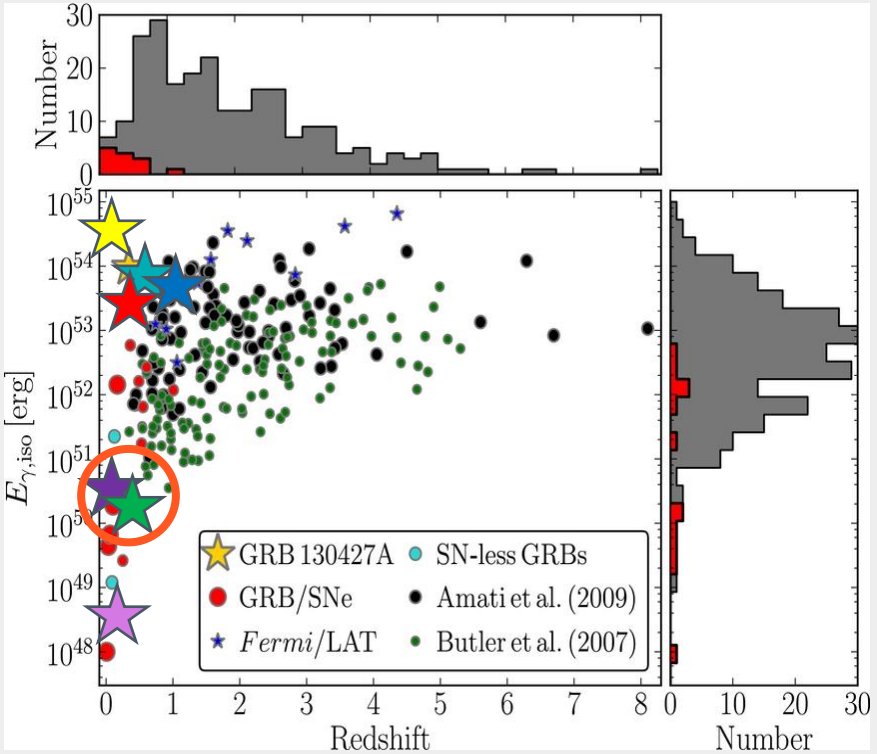
Less Luminous VHE GRBs

1 detection (GRB190829A) and 1 hint of signal (GRB201015A)
(both GRBs on the boundary between GRB and LLGRB)

★GRB190829A
- $E_{iso} = 1.8 \times 10^{50}$ erg
- Redshift z = 0.078
- H.E.S.S. detected VHE emission
- Very low radiation efficiency of prompt emission (0.12 %)
  cf.) Salafia et al. (2022)

★GRB201015A
- $E_{iso} = 1.1 \times 10^{50}$ erg
- Redshift z = 0.426
- MAGIC observed and reported ~3σ signal (GCN28659)
- MAGIC paper in prep.
  (K. Terauchi)

D. Xu et al. ApJ 776 98 (2013)



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★ GRB190114C (z = 0.42)
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★ GRB160821B (z = 0.16; short)

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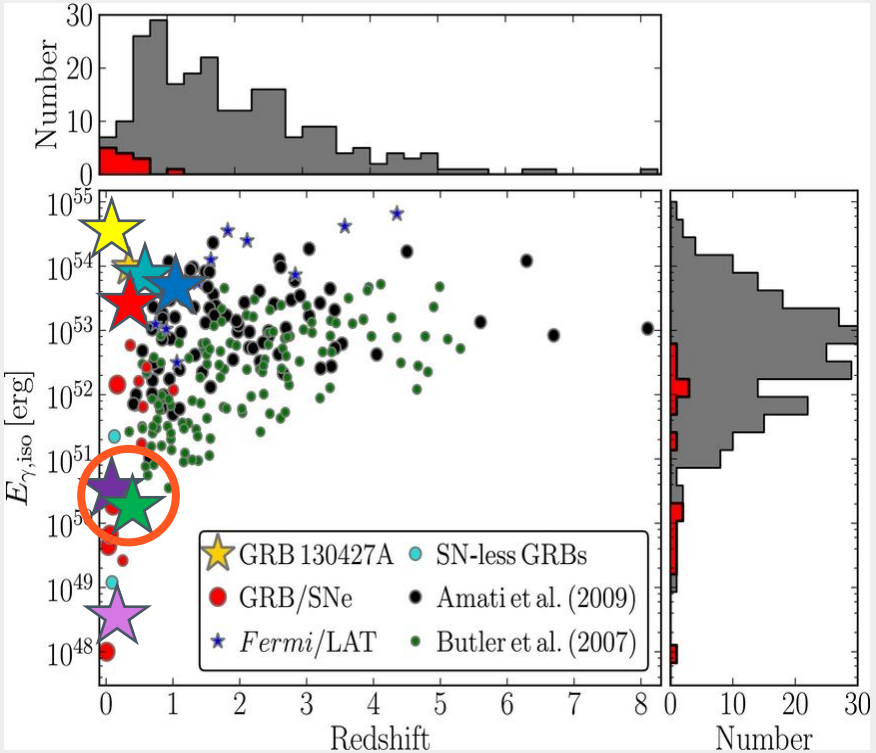
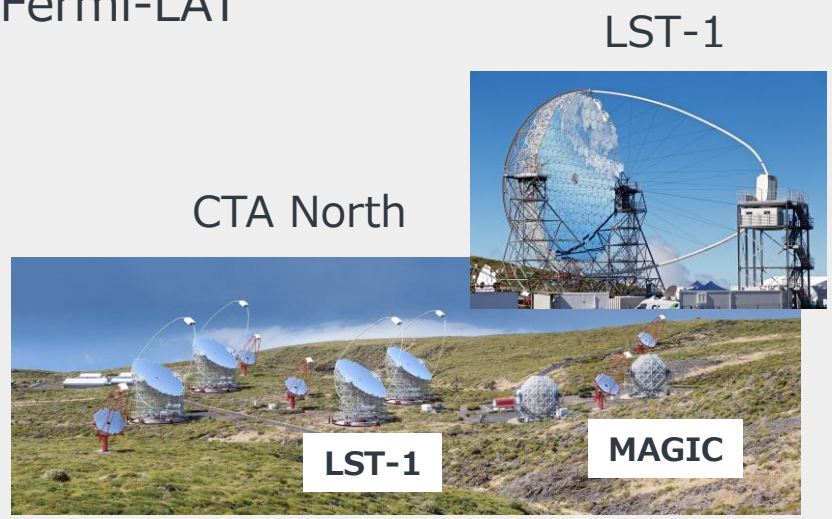
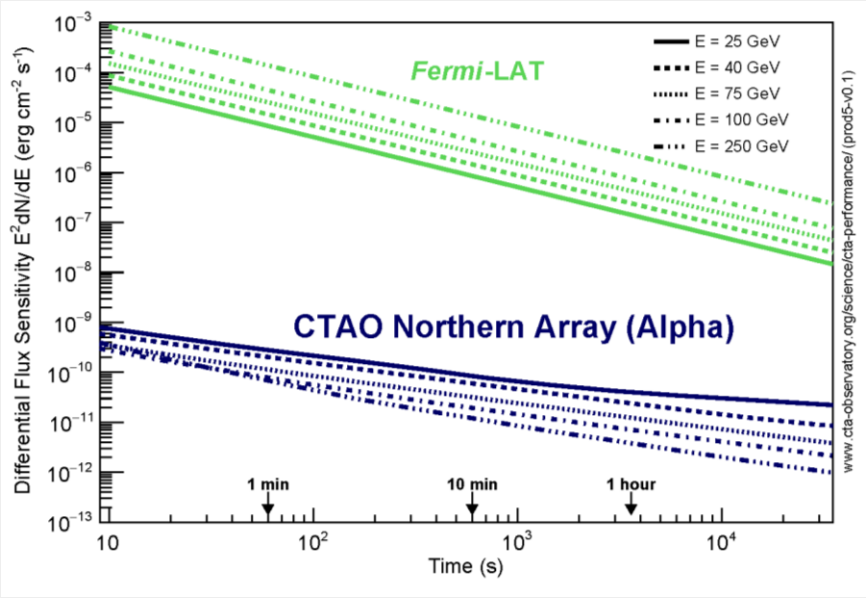


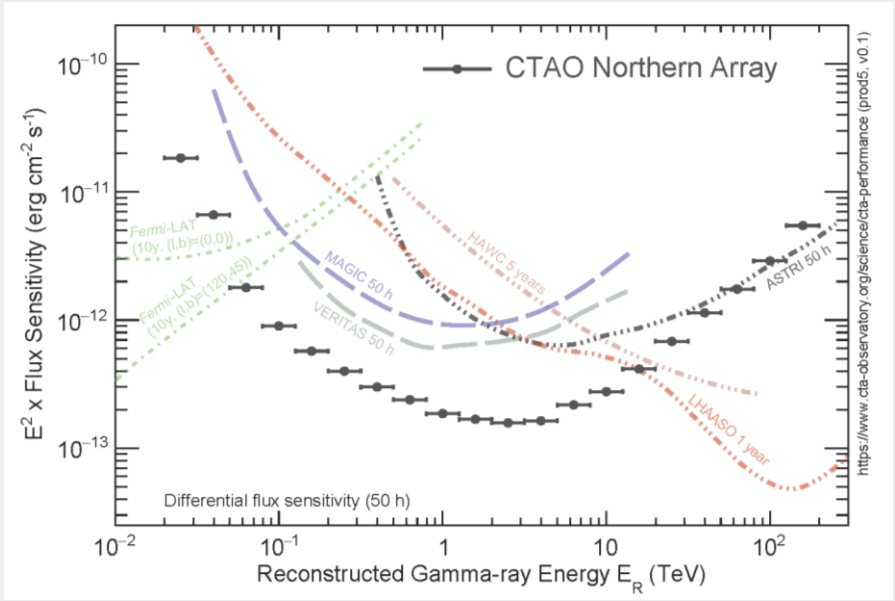
Further VHE observation will reveal the properties of LLGRB which are still largely unknown

Future Prospect: CTA North/LST

- $>10^4$ times better integral sensitivity than Fermi-LAT in few tens of GeV
  - Suitable for GRB follow-up
- Best sensitivity in VHE range
  - Suitable for observing LLGRB which faint signal is typically expected
  - Low energy (tens of GeV) sensitivity is essential to avoid EBL absorption
  - Approvement with LST-1+MAGIC



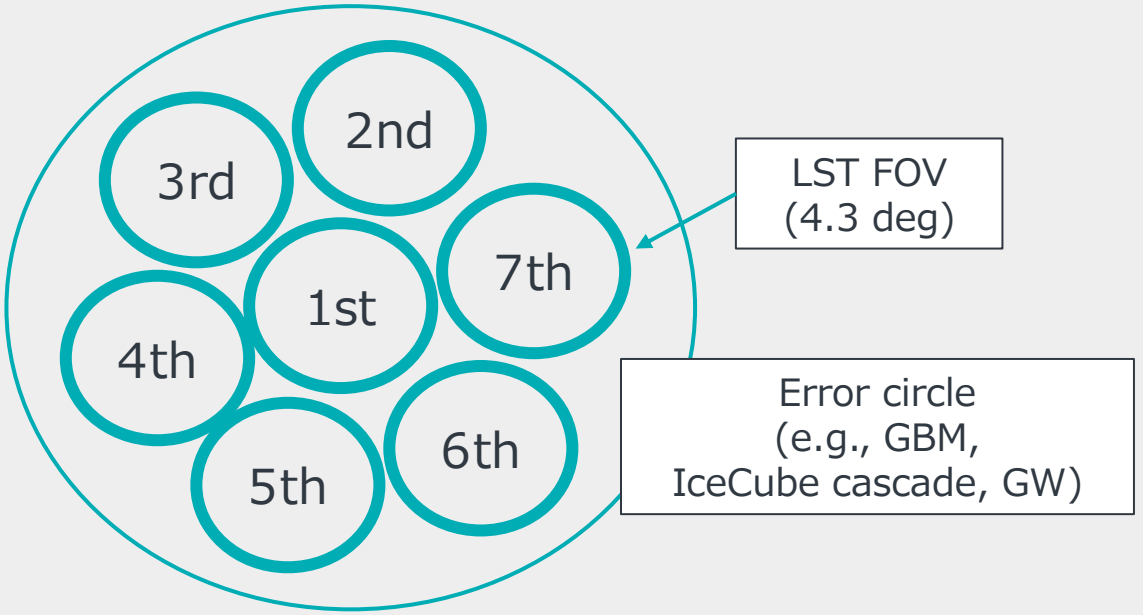




Alert Follow-up Strategy: Tiling Observation

- Some approach is necessary to increase the number of GRB follow-up (and detection)
  - Bad duty cycle of ground-based VHE telescopes (~10%)
  - "Tiling" observation is one of the ways to tackle this problem
- Position error of alerts from Fermi-GBM, IceCube cascade, and gravitational wave (GW) are often large
  - 5 - 15 deg (GBM position notice), 3 – 30 deg (IC-cascade; 90%)
- Real time analysis is essential for the alert follow-up
  - Currently under development

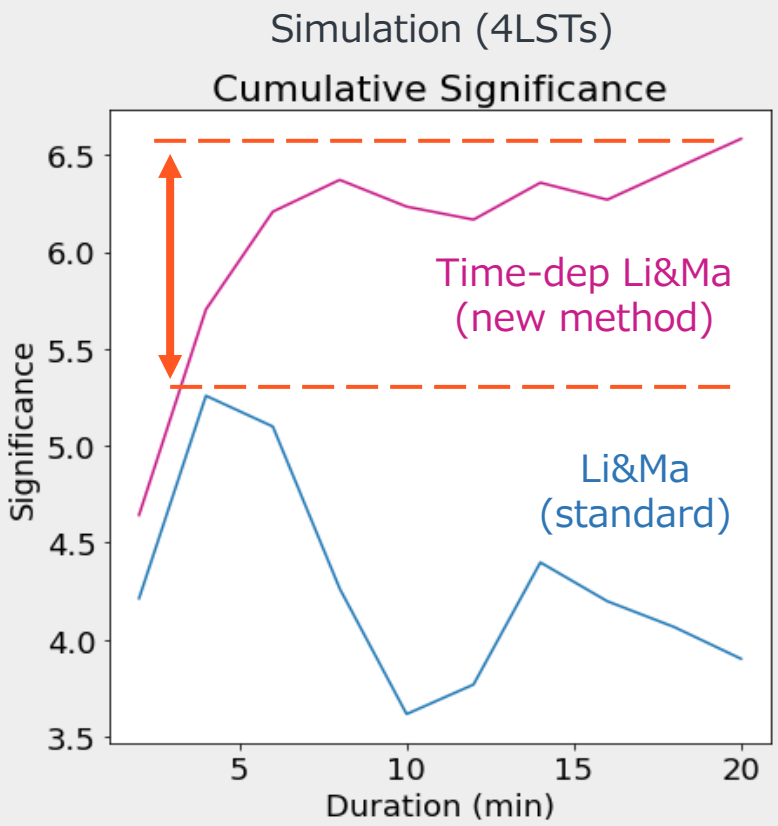
Tiling observation:
Observe in a tiled way



*No fast follow-up of IceCube alert for now

New Detection Method

- New method for calculating detection significances
  - Use likelihood ratio test
- Take into account the temporal information of gamma-ray events
  - Assume signal from a source is decaying in power-law
  - Use a priori info of GRBs (especially the ones detected in VHE)
- Will be implemented in real time analysis in the future



5.25 σ → 6.58 σ
(Sensitivity improvement of about 25 %)

Summary

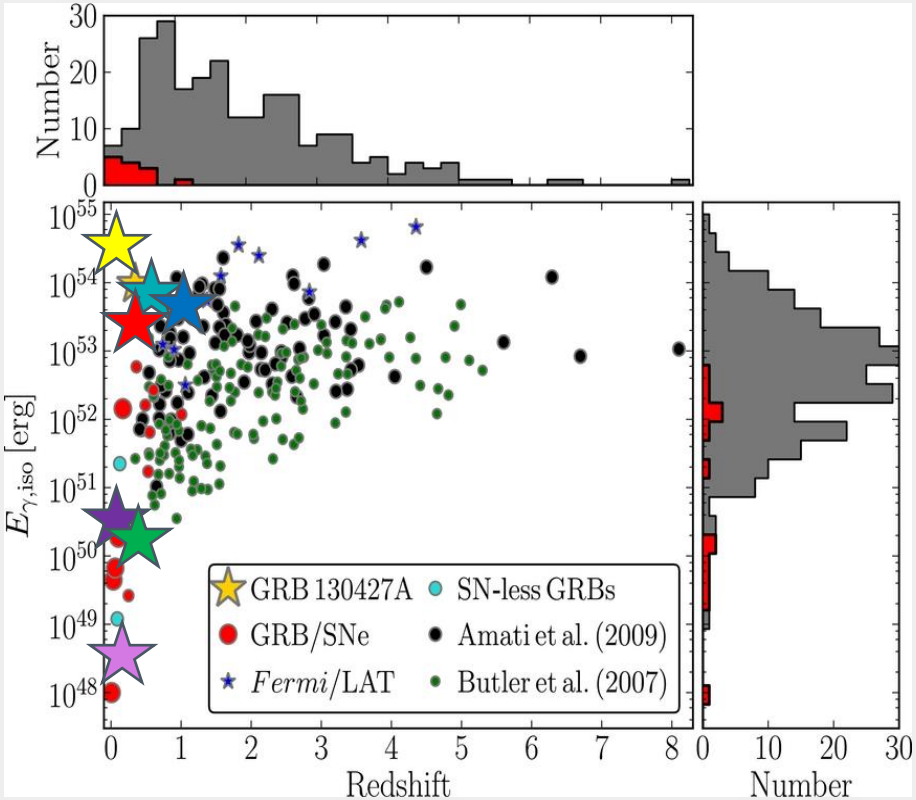
- Low Luminosity GRB (LLGRB) is a subclass of GRB with small isotropic energy ($E_{iso} < 10^{50}$ erg)

- LLGRB is a good target for multi-messenger astronomy
  - Future observation by IceCube (Gen2) will help us determine whether LLGRB is the origin of neutrino diffuse flux
  - Future VHE gamma-ray observation by CTA (especially LST) will provide us info (e.g. radiation efficiency) on LLGRB

- Several strategies for future VHE observation of (LL)GRBs
  - Tiling observation for the alerts with large position uncertainty
  - New technique for calculating detection significance of gamma-ray signal

Yonetoku Relation

D. Xu et al. ApJ 776 98 (2013)



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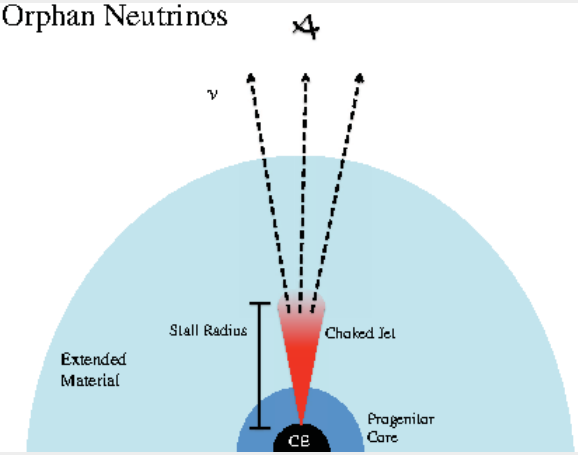
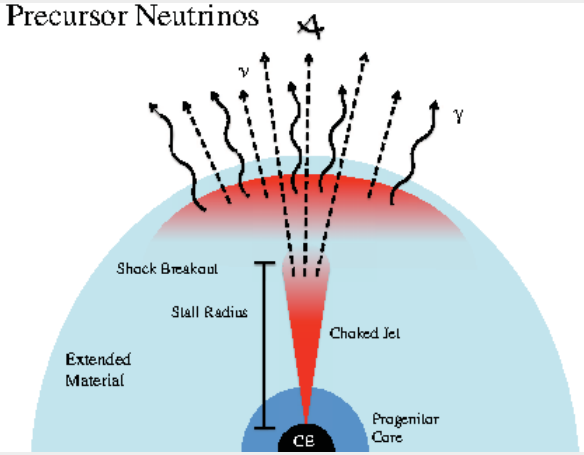
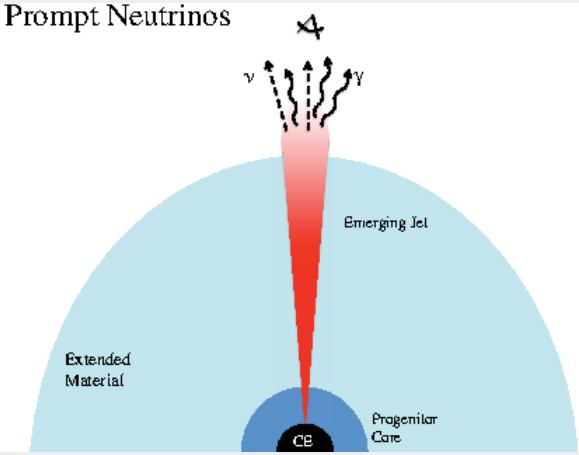
Connection Between Gamma-ray and Neutrino

This talk focuses on a connection between gamma-ray and neutrino from GRBs

S. Nicholas et al. (2015)







GRB fails

GRB succeed