Gamma-Ray Bursts: what do we need in the 2020s?

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Working group for GRB roadmap: Nicola Omodei, Bing Zhang, VC. Others?
What motivates gamma-ray observations of GRBs?

- Understanding the physics of GRBs and jetted relativistic outflows
- GRBs as a tool for cosmology
- GRBs as beacons for multi-messenger astronomy
GRB physics (1) Spectral energy distributions of GRBs probe the physics of jetted relativistic outflows

- Current: Fermi provides 8 decades of energy. Very active area of research - science moving beyond empirical functions to physical modeling of jet content, radiation mechanism.

- Future needs: Broad energy range in peak (10s - 1000s keV) and higher energies. Localization good enough for follow-ups; probe of MeV - 100 MeV region that is ill-observed.

GRB 090902B
Abdo et al. 2009

Photospheric interpretation
Ryde et al. 2009

High-energy emission is extended in time - relation to afterglow?
GRB Physics (2) Polarization of GRB prompt emission - new territory to distinguish between models based on inferences about magnetic fields

- Current: Some tantalizing results from IKAROS, INTEGRAL, RHESSI but no conclusive measurements.

- Needs: Large area for gamma-ray polarimetry of dozens -100 GRBs, broad gamma-ray energy coverage to reduce MDP. Crude localization.
Cosmology (I) can GRBs probe the time of the earliest stars and the epoch of reionization?

- Current: Swift rapid XRT response enables optical follow-up to reveal many $z$. Results imply source number or luminosity evolution.
- Future needs: Rapid location good enough for spectroscopy of distant GRBs; GRB detector sensitive enough for weak, distant GRB; on-board IR capability for distant $z$?
Cosmology (2) Can GRBs be used like SN Ia in the distant universe?

- Future needs: If relations are calibrated, gamma-ray observations suffice; rapid X-ray response and/or sensitive long-term X-ray response to uncover full range of jet breaks.

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Cosmology (3): The GRB - Core collapse supernova connection. Nearby long GRBs tend to have associated Ibc SN detections

- Current: Swift rapid XRT response enables optical follow-up to reveal z and allow optical tracking of lightcurve to uncover SN.
- Future needs: Wide field-of-view GRB detector as these local events are not common. Localization good enough for follow-up.

GRB 130702A - iPTF 13bxl
Singer et al. 2014

GRB 130702A - SN 2013dx
d'Elia et al. 2015
Multi-messenger (1) GRB fireballs should have protons that produce a detectable neutrino flux for bright GRBs providing $\Gamma < 400 - 500$

![Graph](image)

- Current: IceCube limits to neutrino fluxes from bright GRBs.
- Future needs: A more sensitive IceCube! Bright GRBs - broad sky coverage. Broad energy range covering peak of SED for meaningful predictions.

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Multi-messenger (2): if short GRBs are compact object binary mergers, they offer a clear e/m counterpart to gravitational waves detectable by LIGO/Virgo

- Current: GBM sees 45 short GRBs per year. aLIGO/Virgo coming online. Sub-threshold searches in both directions (GW and GRB) important. Handful per year within aLIGO horizon (Kalogera, this morning)

- Future needs: Capability to detect many short GRBs - broad sky coverage, energy coverage in 100s - 100s keV, sensitivity to impulsive events, location good enough for RAPID follow-up - not so important when aLIGO at full sensitivity.
Other: Fundamental Physics - Lorentz Invariance, the unknown....

- Current: Fermi offers broad energy range for LIV studies. Bright GRBs easy to locate well enough for follow-up to determine z.
- Current: High-energy emission from GRBs provides a probe of Extragalactic Background Light to more distant $z$ than blazars.
- Future needs: Unclear how to improve LIV or EBL - very high energy detections would help both. Expect the unknown.
- Role of short-lived millisecond magnetars in GRB production
Other: An all-sky monitor of transient or variable high-energy emission provides value to other space missions.

- **Current:** Fermi GBM and Swift BAT offer all/broad-sky monitoring of hard X-ray sky.
- **Future needs:** Maintain this capability to support e.g., Athena. Lower energy threshold than needed for GRB triggering is desirable for galactic transients.

*Figure credit: A. Smith, H. Campbell (IoA, Cambridge)*

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Summary of bucket list. Some of this can be done elsewhere. What is most important?

- All/Broad sky coverage
- Broad energy coverage for GRBs 10 keV - 1 GeV
  - Highest energies - on-ground with HAWC/CTA
  - Lower threshold desirable for non-GRB transients
- Localization capability for follow-up observations - how good?
  - ZTF/DES/LSST can help - ok for physics, multi-messenger
- On-board afterglow and redshift determination
  - short GRBs need rapid follow-up
  - high-z needs IR spectroscopy (on-board? JWST/TMT/GMT?)
- Sensitive instrument - weak GRBs needed for high-z universe
  \[10^{-9} \text{ erg/cm}^2\text{ fluence} \text{ (between 50 - 300 keV)?}\]
- Large collection area needed for 100s keV - MeV polarization.
The three main paths to cover GRB science needs in the 2020s


- A secondary transient-detecting instrument on-board a probe doing something else e.g. a polarization or pair telescope.

- A stand-alone transient monitor or fleet of monitors concentrating on GRB physics but enabling follow-ups on-ground or on another satellite.
Time to start our roadmap. Do we need a mailing list? A schedule? Coordination with other science groups?