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.

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.

Expected polarization fraction for different models as a function of GRB EPeak
Toma et al. 2009

Compton Drag
Synchrotron - ordered B
Synchrotron - random B
Cosmology (1) 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; capability to detect highly-redshifted, non-impulsive emission (low background); on-board IR capability for distant $z$?

Fermi Symposium - GammaSIG session
Cosmology (2) Can GRBs be used like SN 1a 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. Need to characterize any selection biases in prompt or follow-up.

Relations (Liang, Amati, Ghirlanda, Yonetoku)
Physics and cosmology from (same authors, Levinson & Eichler, Guiriec, Goldstein)

Inferred jet break times
Goldstein et al. submitted

Fermi Symposium - GammaSIG session

Friday, November 13, 15
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.
Multi-messenger (1) GRB fireballs should have protons that produce a detectable neutrino flux for bright GRBs providing $\Gamma < 400 - 500$

Current: IceCube limits to neutrino fluxes from bright GRBs. This meeting: Eli Waxman says these limits not constraining - either in diffuse neutrino flux or in lack of neutrinos from individual GRBs (revised IceCube paper).

Future needs: A more sensitive IceCube! Bright GRBs - broad sky coverage. Broad energy range covering peak of SED for meaningful predictions. Very important to have GRB instrument WHEN (not if!) IceCube becomes 10x more sensitive.
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 ~40 short GRBs per year. aLIGO/Virgo coming online. Sub-threshold searches in both directions (GW and GRB) important. Handful per year within aLIGO horizon.

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.
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. Polarization can also be used.

- 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 (and other models).
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)
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 energy 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 erg/cm^2 fluence (between 50 - 300 keV)?
  - Ability to measure less impulsive events (high z in keV/MeV).
- Large collection area needed for 100s keV - MeV polarization.
What the Europeans think: GRB detector requirements from AstroMeV

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<tr>
<th>Performance parameter</th>
<th>Goal value</th>
<th>Remarks and notes</th>
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<tbody>
<tr>
<td>Field-of-view (FWHM, deg)</td>
<td>$&gt;2\pi$ (a few sr)</td>
<td>As large as possible, to monitor the sky and to provide many GRB triggers.</td>
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<tr>
<td>Angular resolution (FWHM, deg)</td>
<td>A few tens of arcmin</td>
<td>Would provide arcmin positions, but arcsecond positions are needed for follow-up observations by large optical telescopes...</td>
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<tr>
<td>Spectral resolution ($\Delta E/E @ Energy$)</td>
<td>$\leq 10% @ 300$ keV</td>
<td>Accurate $E_{\text{peak}}$ measurement. Should not be less than $\sim 10%$ at other energies (0.1-100 MeV).</td>
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<td>Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}, 3\sigma, 1$ Ms)</td>
<td>$5 \times 10^{-9}$ in 1 s (LGRBs) $2 \times 10^{-4}$ in 100 ms (SGRBs) At 1 MeV</td>
<td>For time-resolved spectroscopy in the 0.1-100 MeV range: identification of spectral components and their time evolution.</td>
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<tr>
<td>Timing performances</td>
<td>$\leq 10$ $\mu$s</td>
<td>Low deadtime needed for sensitive timing analysis, especially for SGRBs.</td>
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<td>Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)</td>
<td>$\leq 10%$</td>
<td>As a function of energy, to distinguish spectral components.</td>
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<td>Real-time data?</td>
<td>Yes</td>
<td>To promptly (within a few tens of s) disseminate GRB alerts, positions, and preliminary spectral analyses (e.g., SGRBs with high $E_{\text{peak}}$).</td>
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[https://indico.in2p3.fr/getFile.py/access?resId=1&materialId=slides&confId=8608](https://indico.in2p3.fr/getFile.py/access?resId=1&materialId=slides&confId=8608)
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?