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

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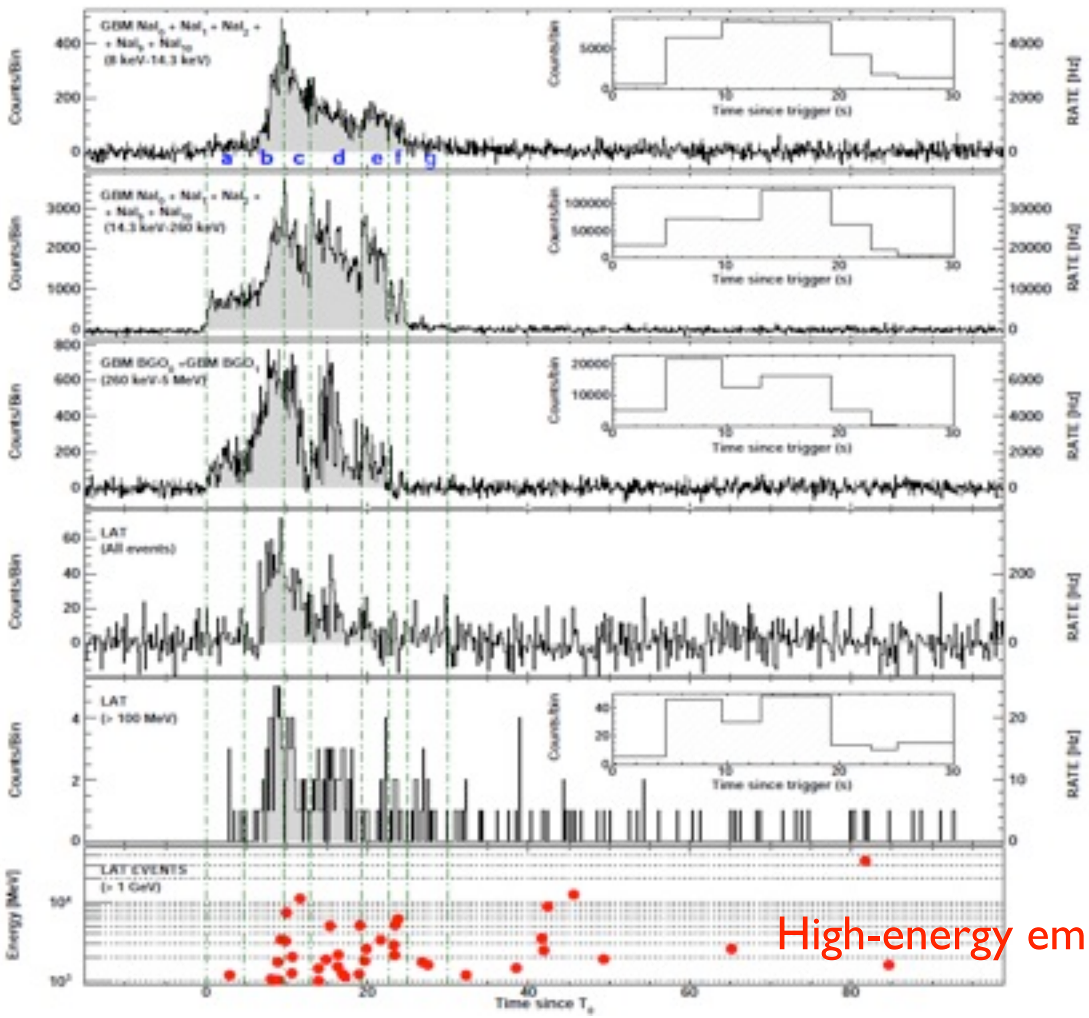
Working group for GRB roadmap: Nicola Omodei, Bing Zhang, VC. Others?

What motivates gamma-ray observations of GRBs?

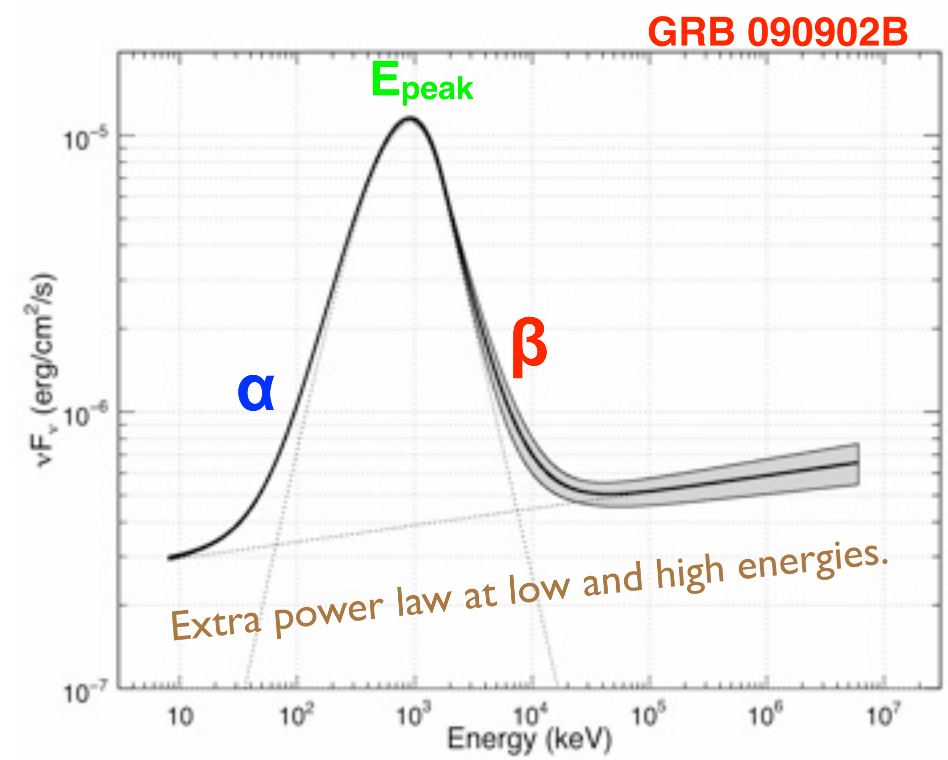
- Understanding the physics of GRBs and jetted relativistic outflows
- GRBs as a tool for cosmology
- GRBs as beacons for multi-messenger astronomy

GRB physics (1) Spectral energy distributions of GRBs probe the physics of jetted relativistic outflows



GRB 090902B
Abdo et al. 2009

Photospheric interpretation
Ryde et al. 2009

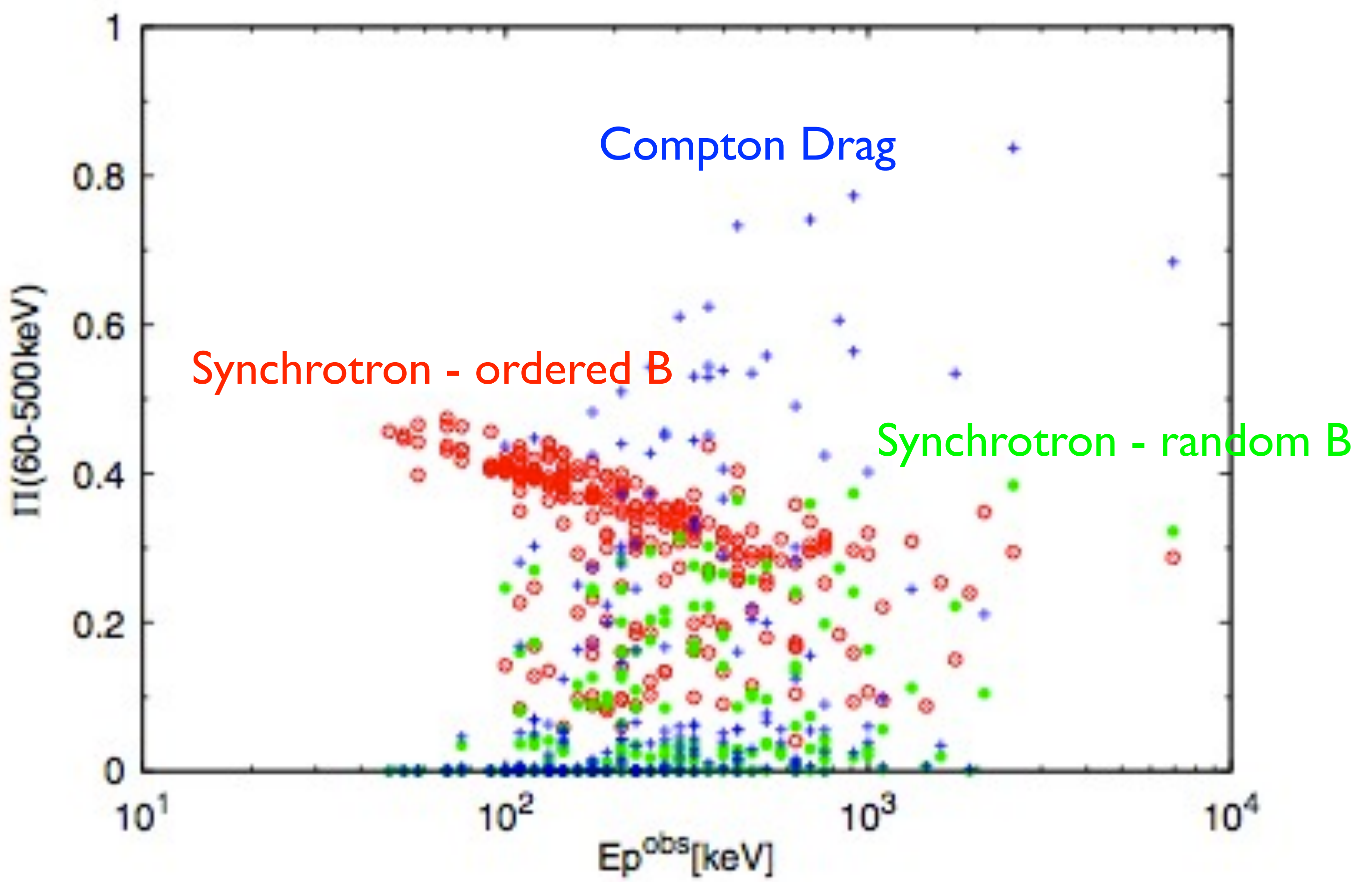


High-energy emission is extended in time - relation to afterglow?

- 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.

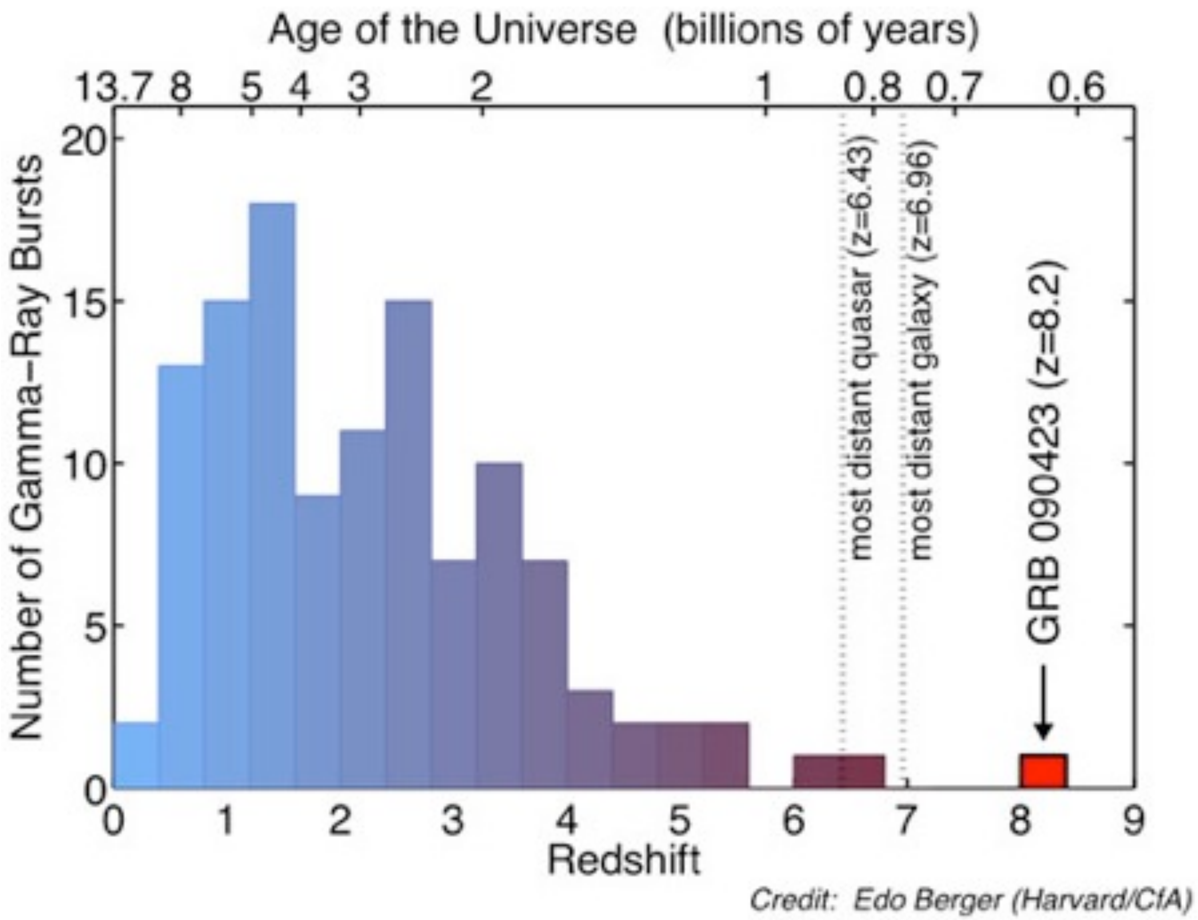
GRB Physics (2) Polarization of GRB prompt emission - new territory to distinguish between models based on inferences about magnetic fields

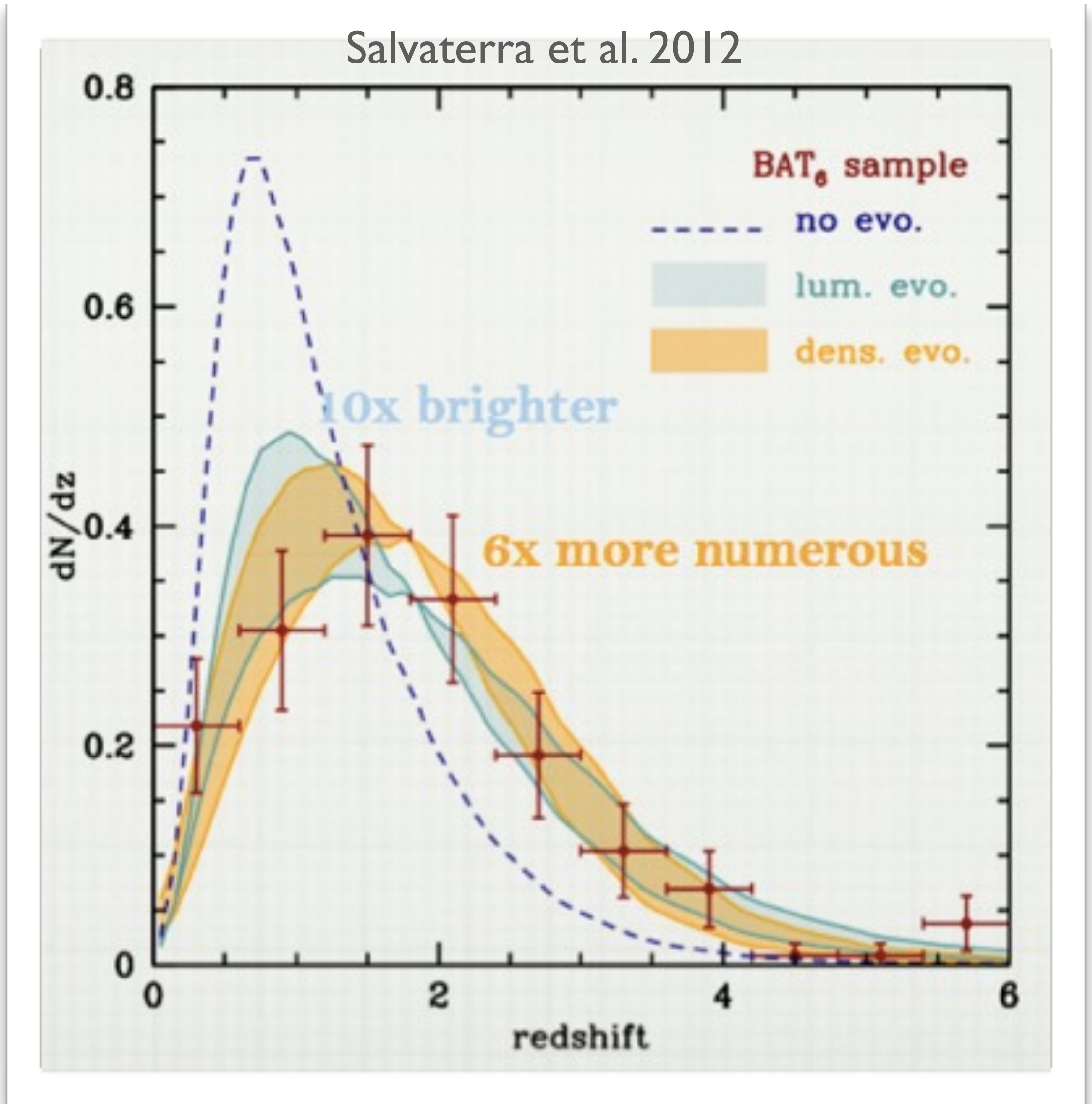
Expected polarization fraction for different models
as a function of GRB EPeak
Toma et al. 2009



- 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 (1) can GRBs probe the time of the earliest stars and the epoch of reionization?

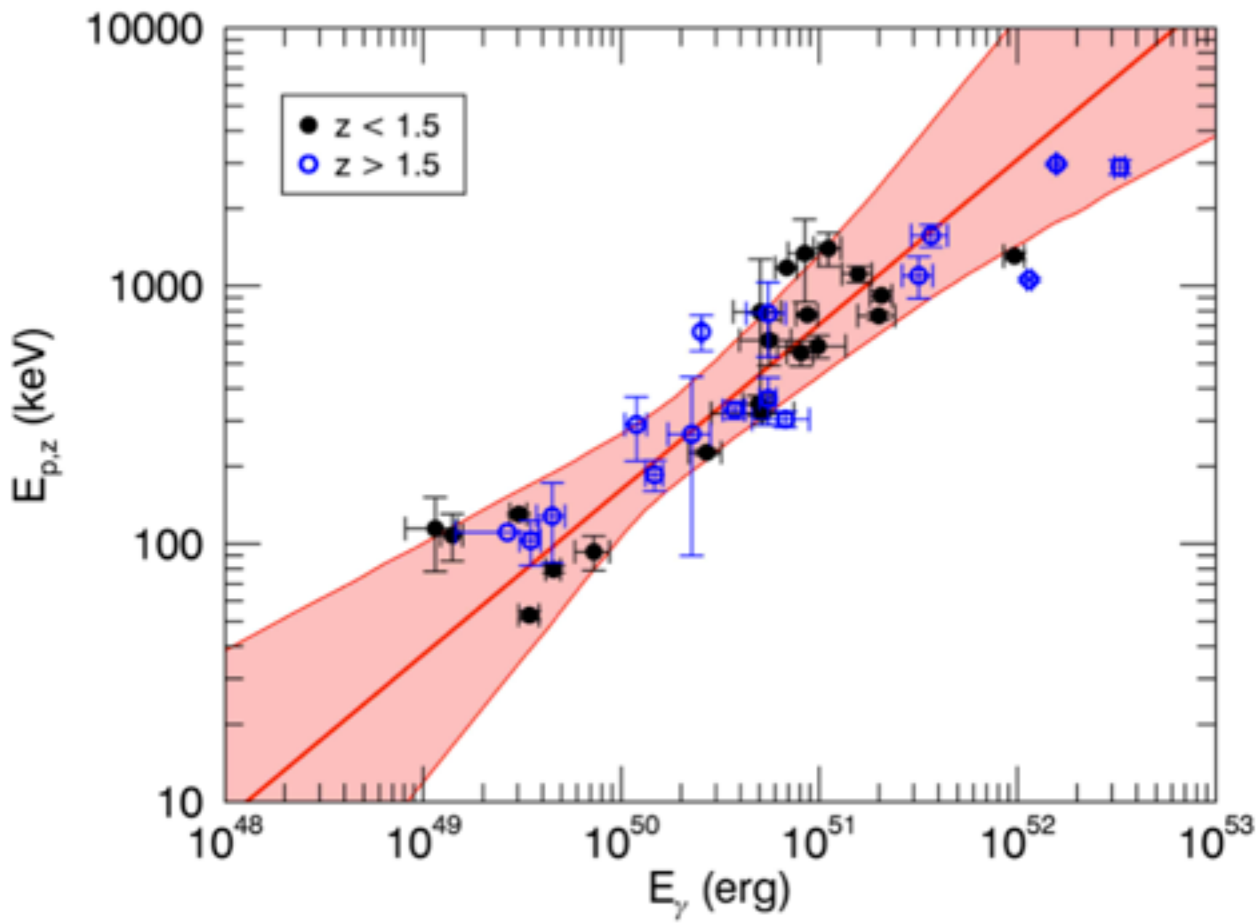




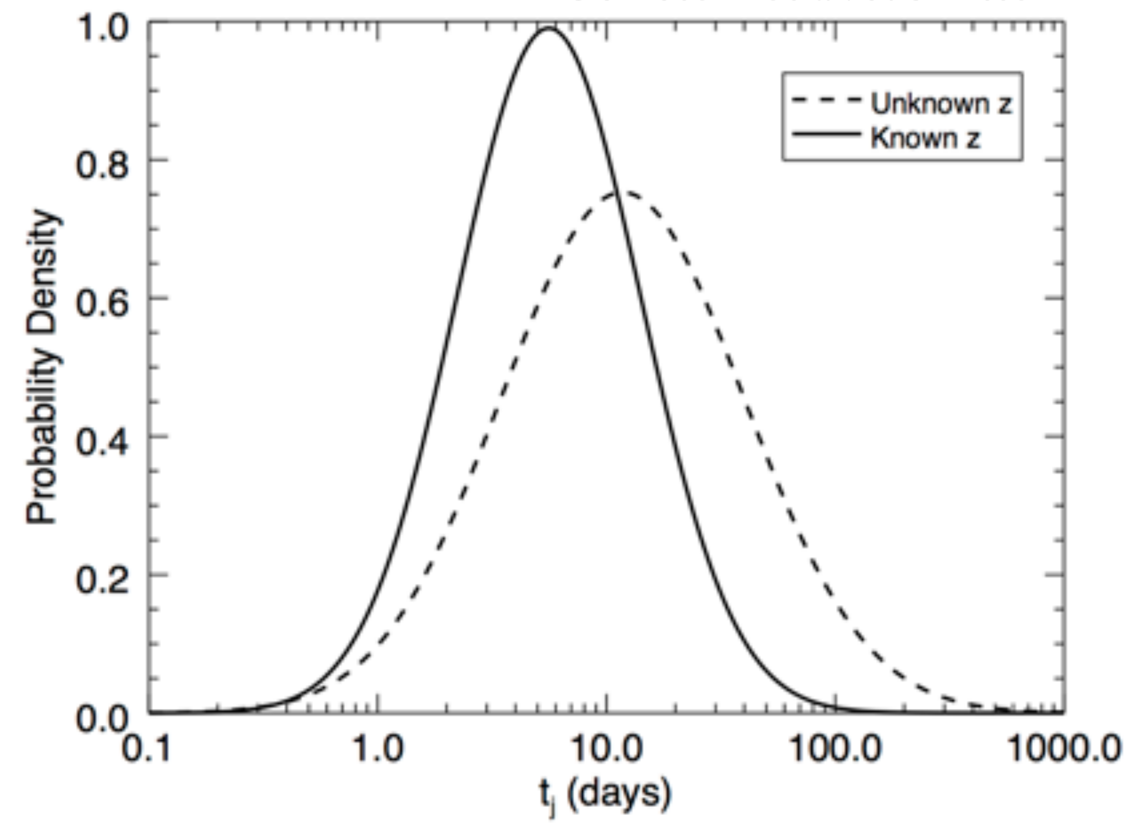
- Current: Swift rapid XRT response enables optical follow-up to reveal many z. Results imply source number or luminosity evolution.
- Future needs: Rapid location good enough for spectroscopy of distant GRBs; GRB detector sensitive enough for weak, distant GRB; capability to detect highly-redshifted, non-impulsive emission (low background); on-board IR capability for distant z?

Cosmology (2) Can GRBs be used like SN 1a in the distant universe?

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



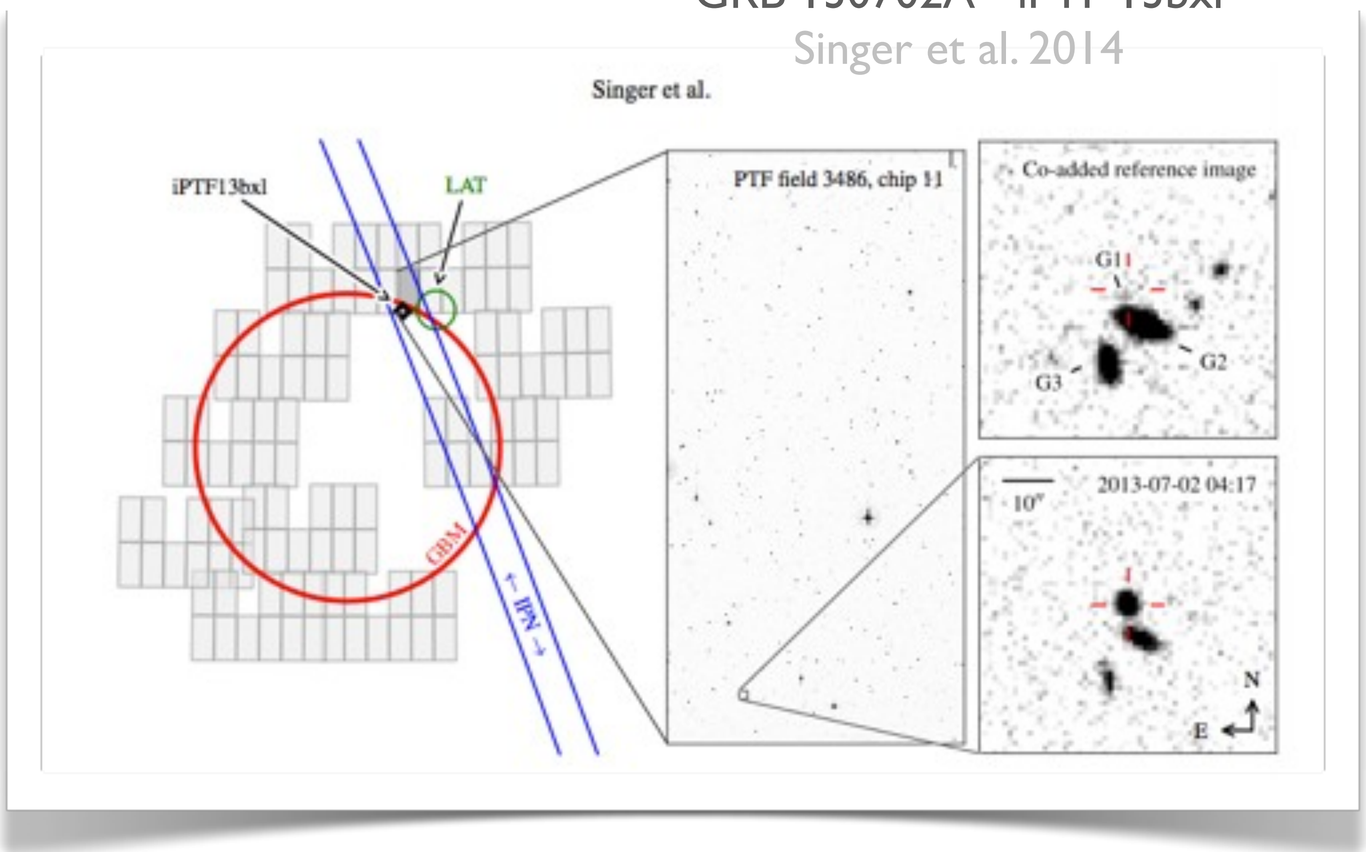
Inferred jet break times
Goldstein et al. submitted



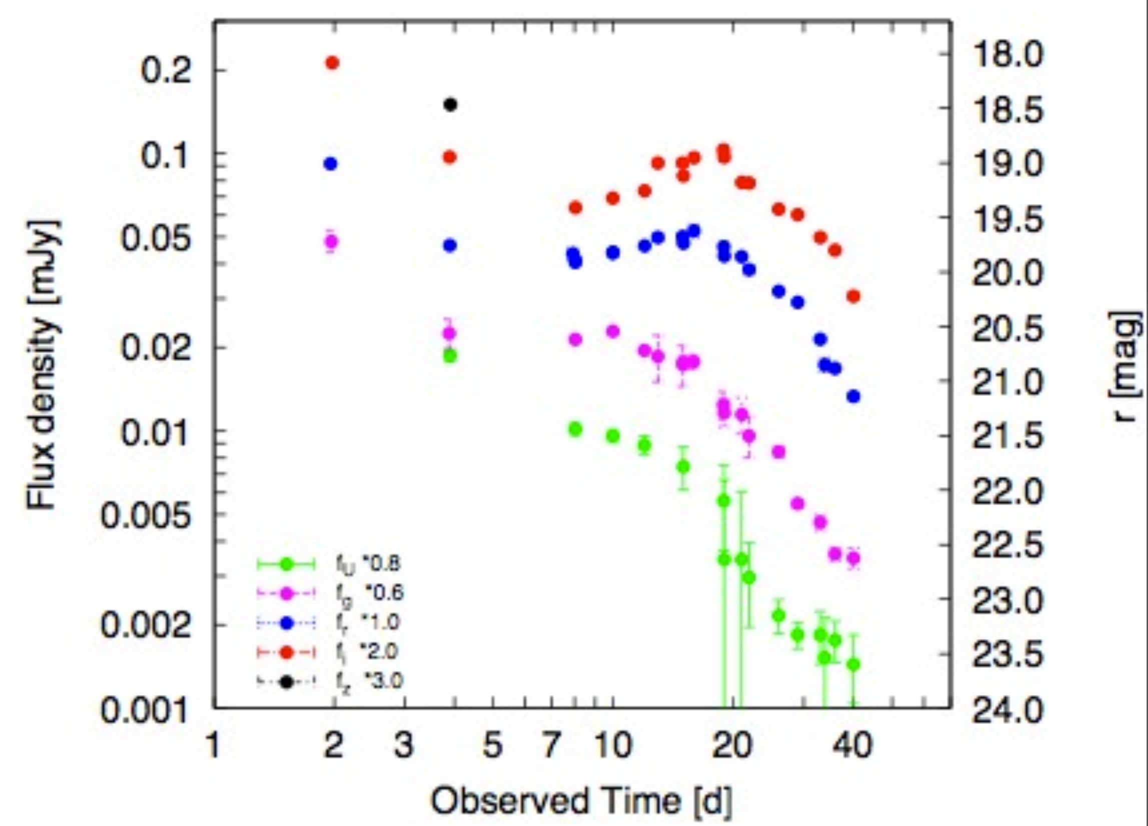
- Current: Golden age. Fermi reveals observer-frame energetics. Follow-up to Swift reveals z.
- Future needs: If relations are calibrated, gamma-ray observations suffice; rapid X-ray response and/or sensitive long-term X-ray response to uncover full range of jet breaks. Need to characterize any selection biases in prompt or follow-up.

Cosmology (3): The GRB - Core collapse supernova connection. Nearby long GRBs tend to have associated 1bc SN detections

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



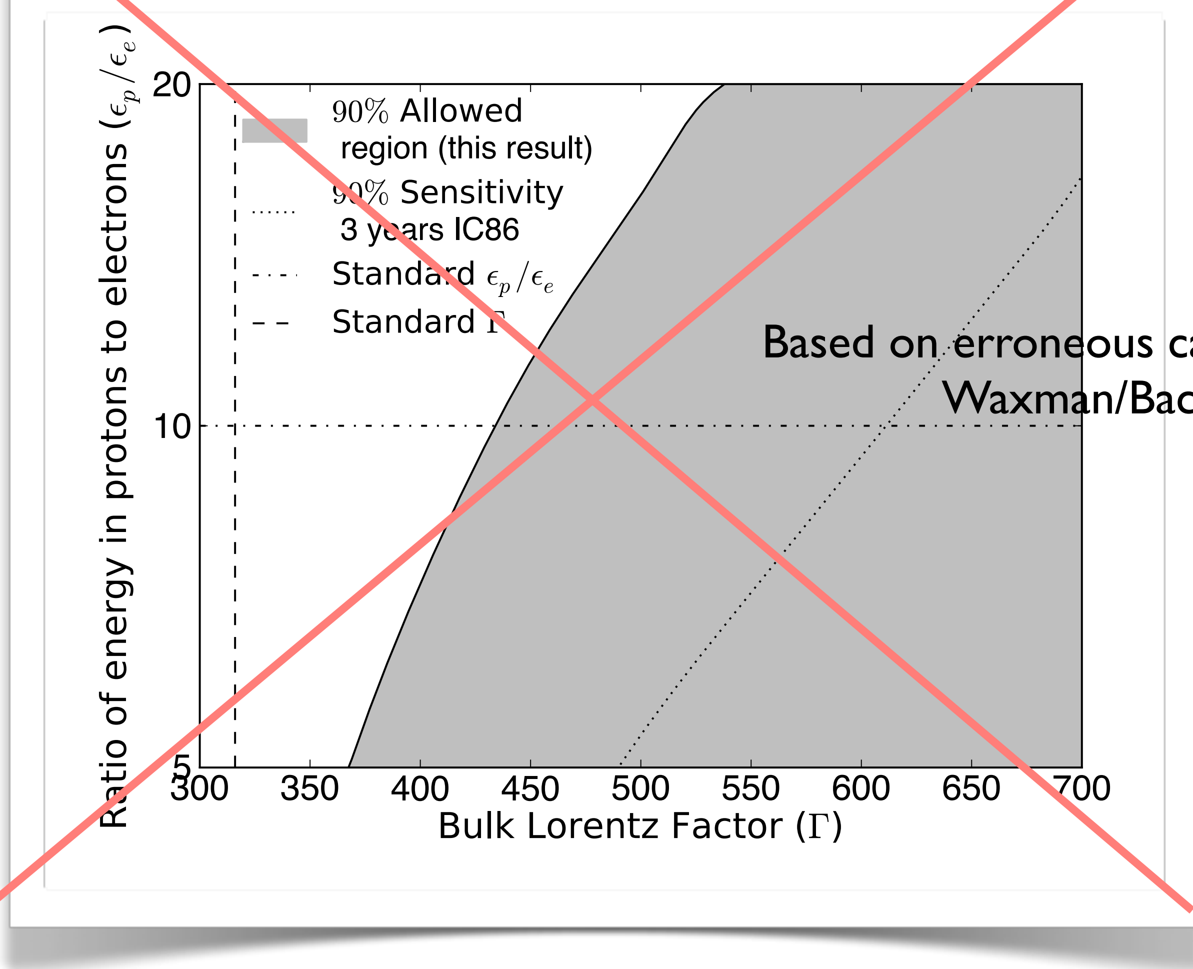
GRB 130702A - SN 2013dx
d'Elia et al. 2015



- 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 Γ < 400 - 500

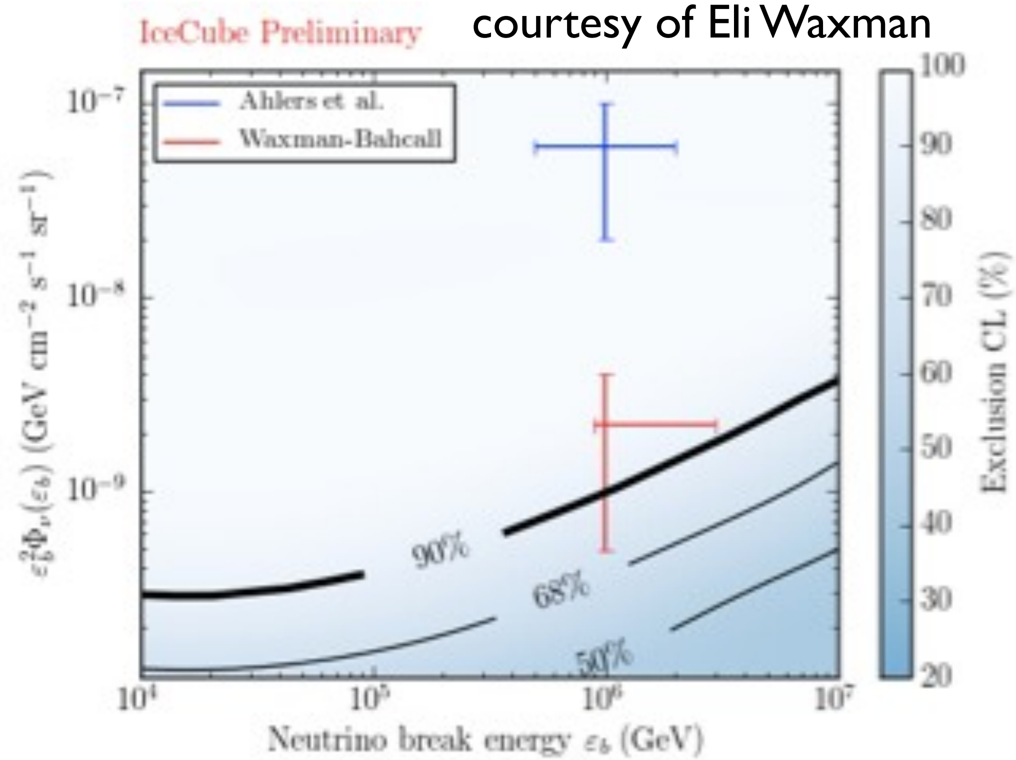
Abbasi et al. 2012
Constraints from 196 GRBs



Based on erroneous calculation from Waxman/Bacall 97

Prediction for diffuse neutrino flux from GRBs revised with correct calculation from WB97:

courtesy of Eli Waxman



- 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

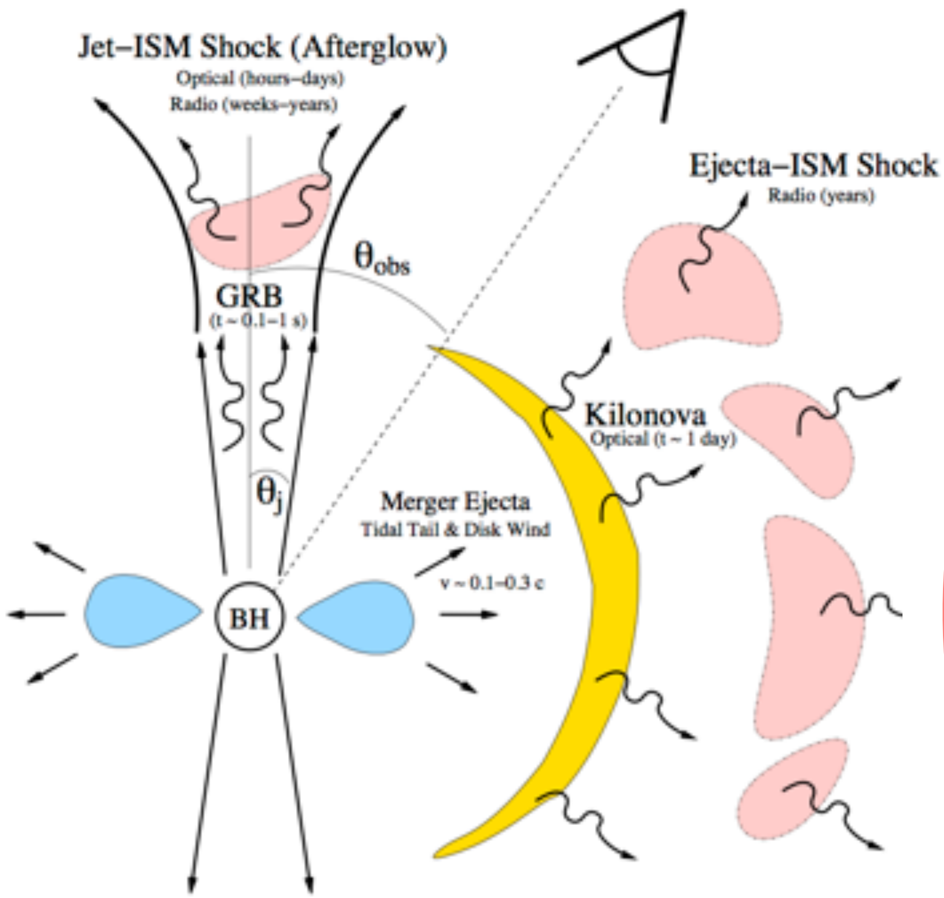


Figure 1 of Meztger & Berger 2012

Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_{\odot} c^2$ Burst Range (Mpc) LIGO	Virgo	BNS Range (Mpc) LIGO	Virgo	Number of BNS Detections	% BNS Localize within 5 deg^2	20 deg
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	9 months	75 – 90	40 – 50	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 1
2019+	(per year)	105	40 – 80	200	65 – 130	0.2 – 200	3 – 8	8 – 28
2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

Aasi et al. 2013
(submitted and
arXiv:1304.0670)

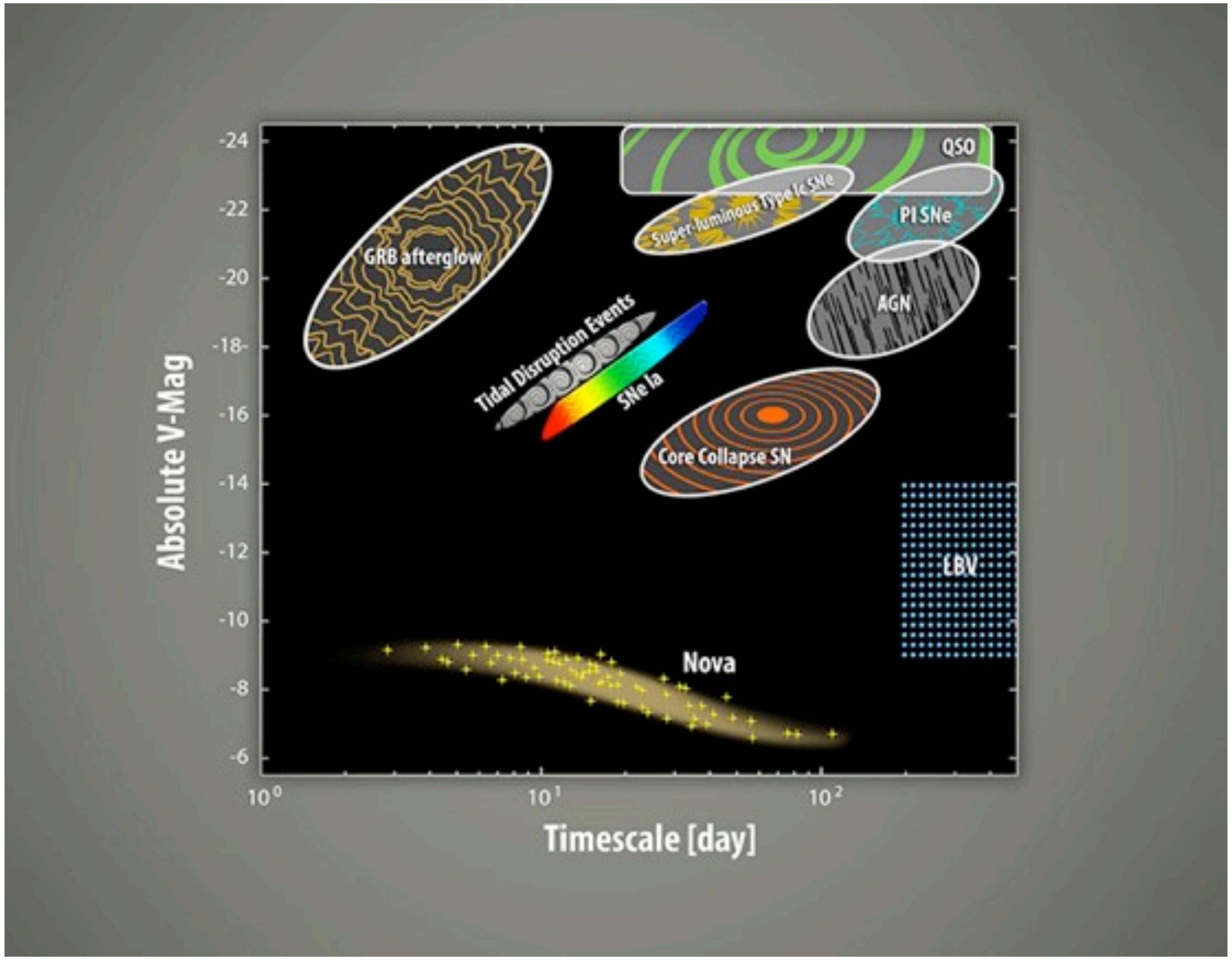
- Current: GBM sees ~40 short GRBs per year. aLIGO/Virgo coming online. Sub-threshold searches in both directions (GW and GRB) important. Handful per year within aLIGO horizon .

- 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



The transient sky to GAIA

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

- 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.

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

Performance parameter	Goal value	Remarks and notes
Field-of-view (FWHM, deg)	$>2\pi$ (a few sr)	As large as possible, to monitor the sky and to provide many GRB triggers.
Angular resolution (FWHM, deg)	A few tens of arcmin	Would provide arcmin positions, but arcsecond positions are needed for follow-up observations by large optical telescopes...
Spectral resolution ($\Delta E/E$ @ Energy)	$\leq 10\%$ @ 300 keV	Accurate E_{peak} measurement. Should not be less than ~10% at other energies (0.1-100 MeV).
Line sensitivity (@ Energy) ($cm^{-2}.s^{-1}$, 3σ, 1 Ms)		
Continuum sensitivity (in which energy band?) (cm-2 s^{-1} keV^{-1}, $\Delta E=E$, 3σ, 1 Ms)	5.10^{-5} in 1 s (LGRBs) 2.10^{-4} in 100 ms (SGRBs) At 1 MeV	For time-resolved spectroscopy in the 0.1-100 MeV range: identification of spectral components and their time evolution.
Timing performances	$\leq 10\ \mu s$	Low deadtime needed for sensitive timing analysis, especially for SGRBs.
Polarimetric capability (Minimum Polarization Fraction for a Crab source in 1 Ms)	$\leq 10\%$	As a function of energy, to distinguish spectral components.
Real-time data ?	Yes	To promptly (within a few tens of s) disseminate GRB alerts, positions, and preliminary spectral analyses (e.g., SGRBs with high E_{peak}).

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 probe-class mission that does it all: sky monitor, spectral coverage, localization, afterglow and redshift determination. Can polarization be accommodated too? More of a flagship.
- 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?