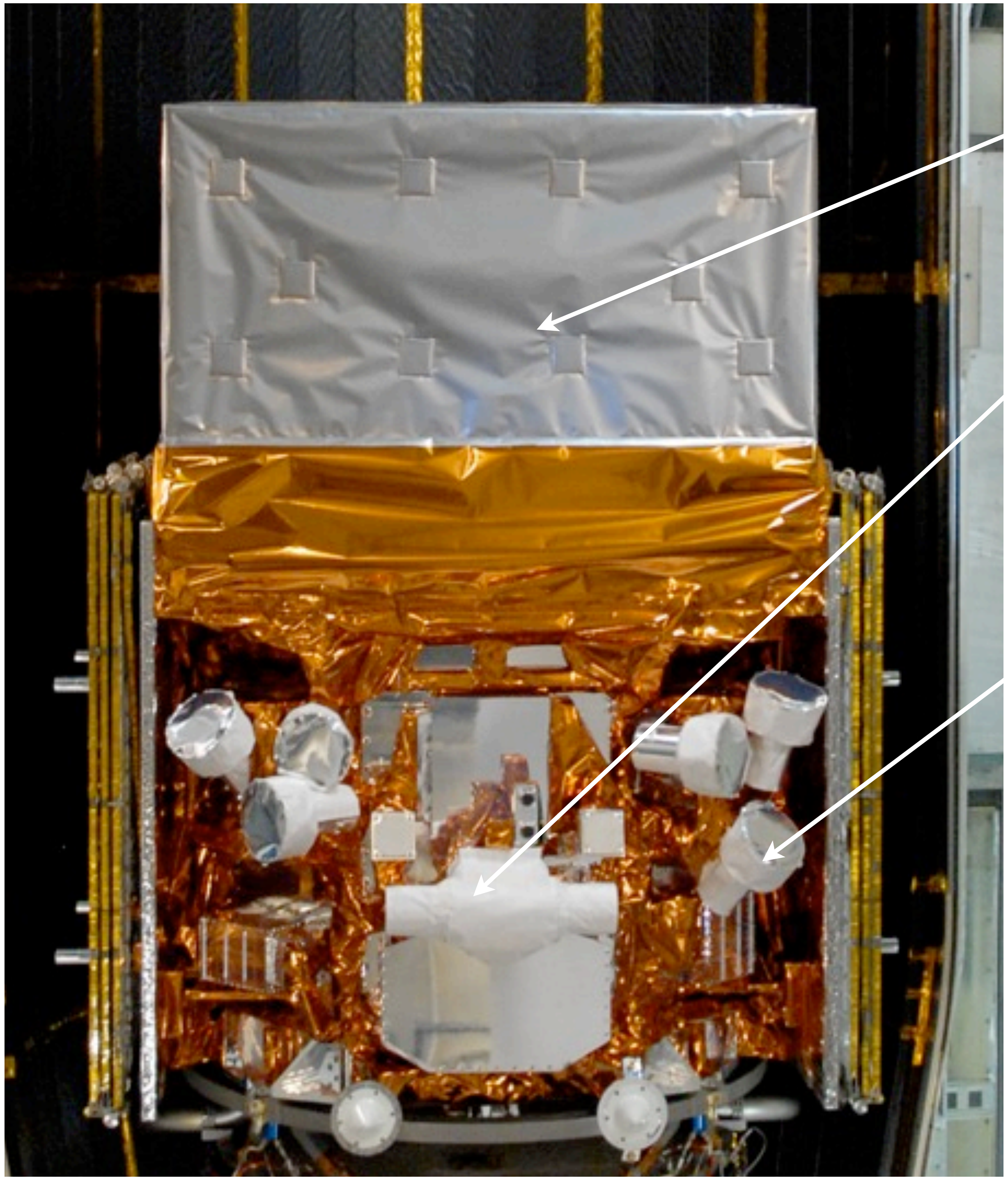
Gamma-Ray Bursts and the Fermi Gamma-Ray Burst Monitor (GBM)

Valerie Connaughton

University of Alabama in Huntsville

The Fermi gamma-ray space telescope offers an unprecedentedly broad energy range and sky coverage to study GRBs.



Fermi LAT
> 20 MeV (LLE)
> 100 MeV (Standard)

GBM BGO detector.
200 keV -- 40 MeV
126 cm^2, 12.7 cm

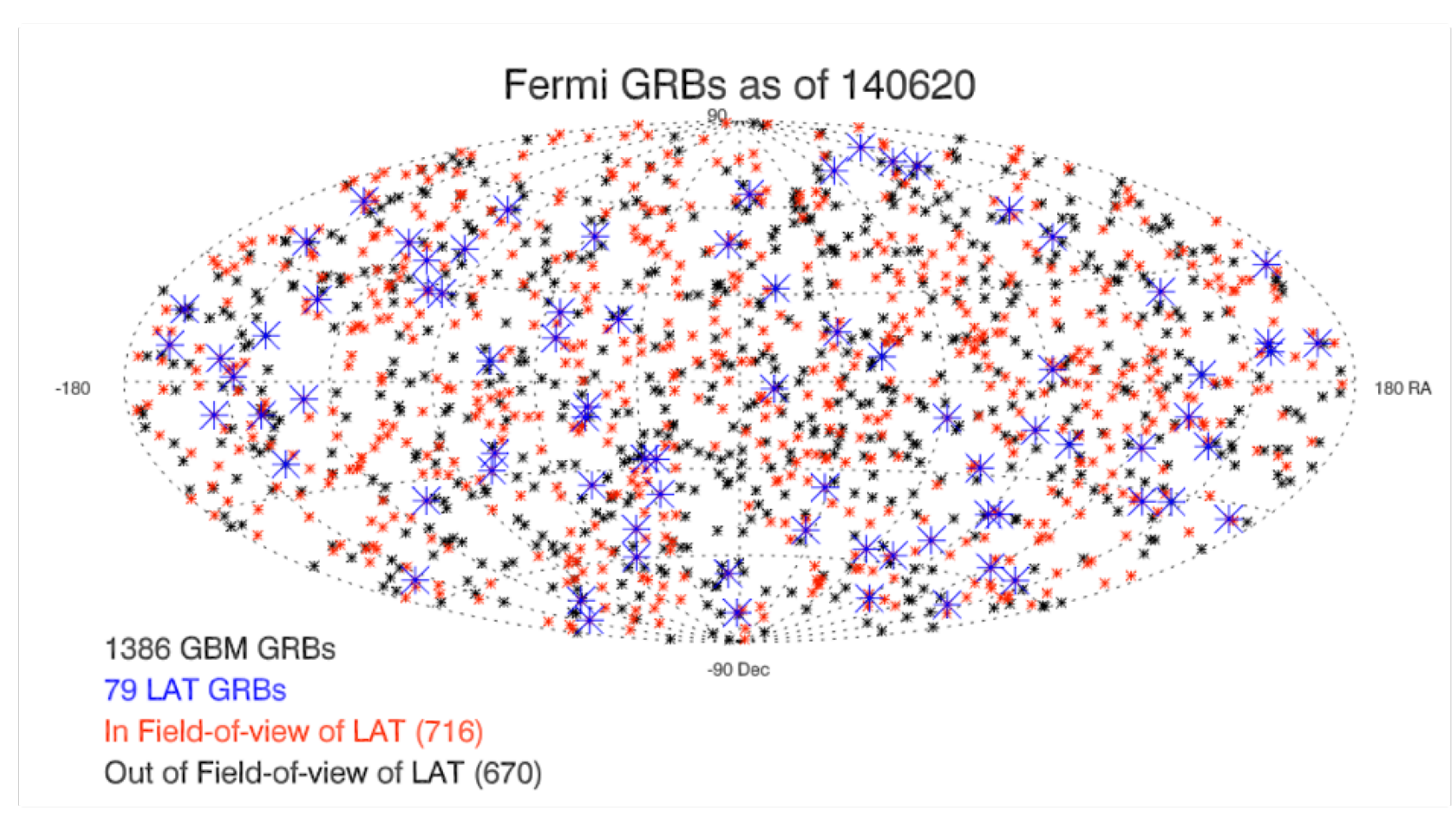
GBM NaI detector.
8 keV -- 1000 keV
126 cm^2, 1.27 cm

Instrument paper
Meegan et al. 2009

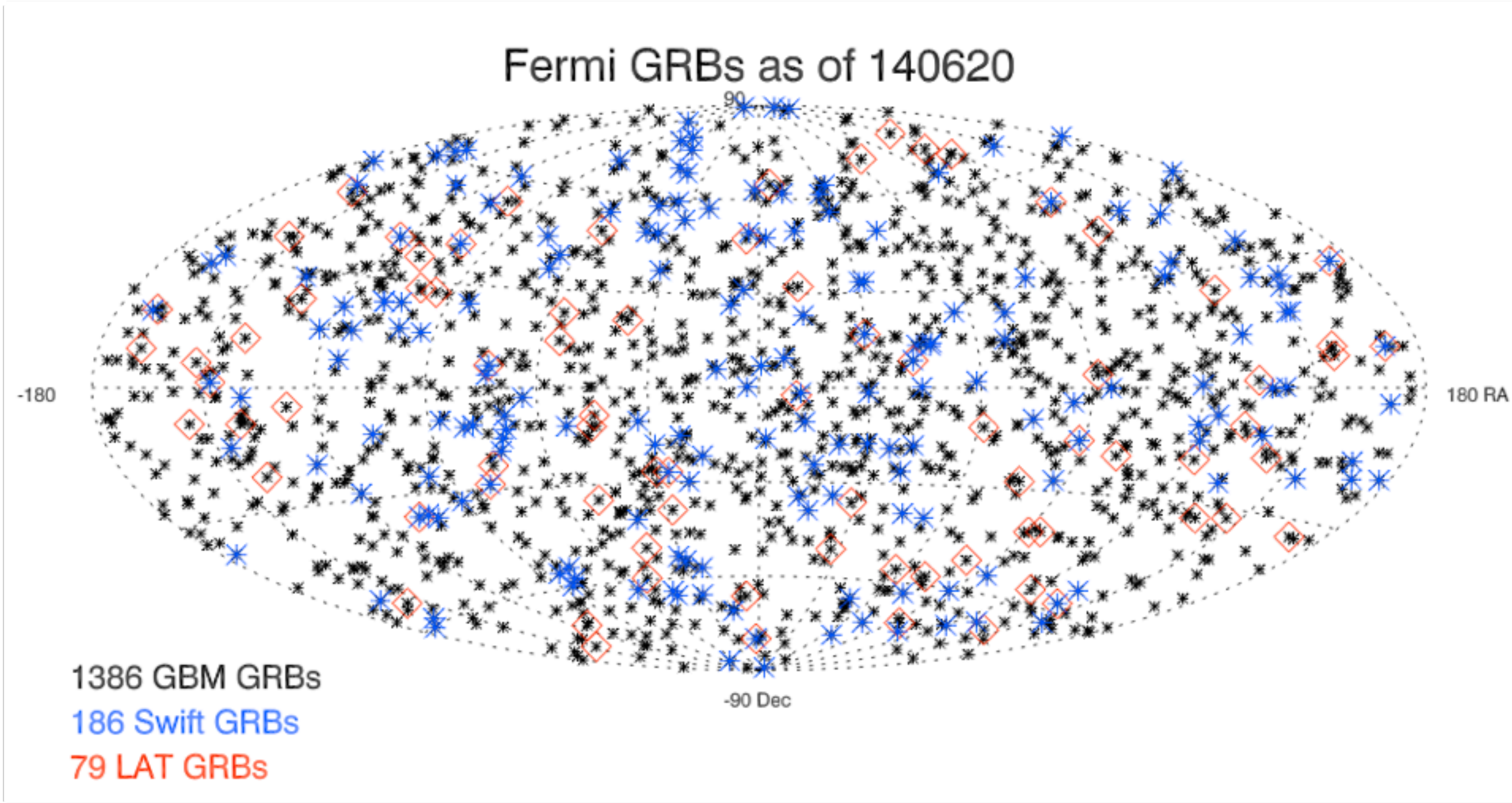
Snapshots from GBM

- Follow-up observations of GBM-detected GRBs
- Using GBM to estimate how many GRBs will be detected at VHE
- What do we learn from studying GBM GRB energy spectra?

GBM detects ~240 GRBs per year, ~45 of them short GRBs
The LAT sees 10% of GBM GRBs in its field-of-view above 100 MeV



Common GBM-Swift GRB sample and Swift follow-up of LAT-detected GRBs have been the best-studied GBM-detected GRBs because of difficulties of observing GBM-only detected GRBs with sensitive follow-up instruments

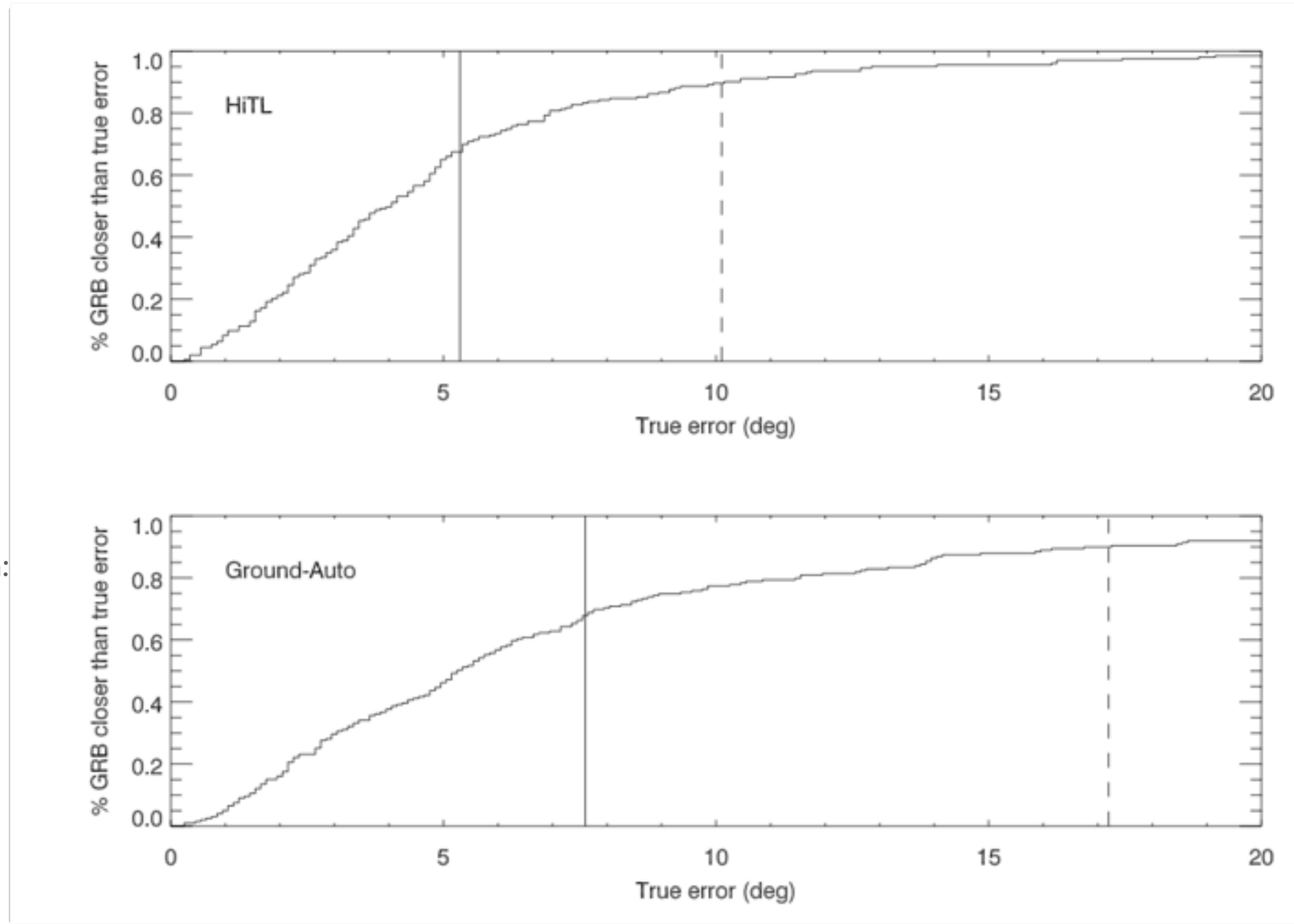


- Follow-up observations of GRBs that trigger GBM

Following up GBM GRBs with most telescopes is difficult:
Using ~200 reference locations we find 68% GBM localizations are within 5 [8] degrees of true location

Best localization:
20 min - hr after trigger

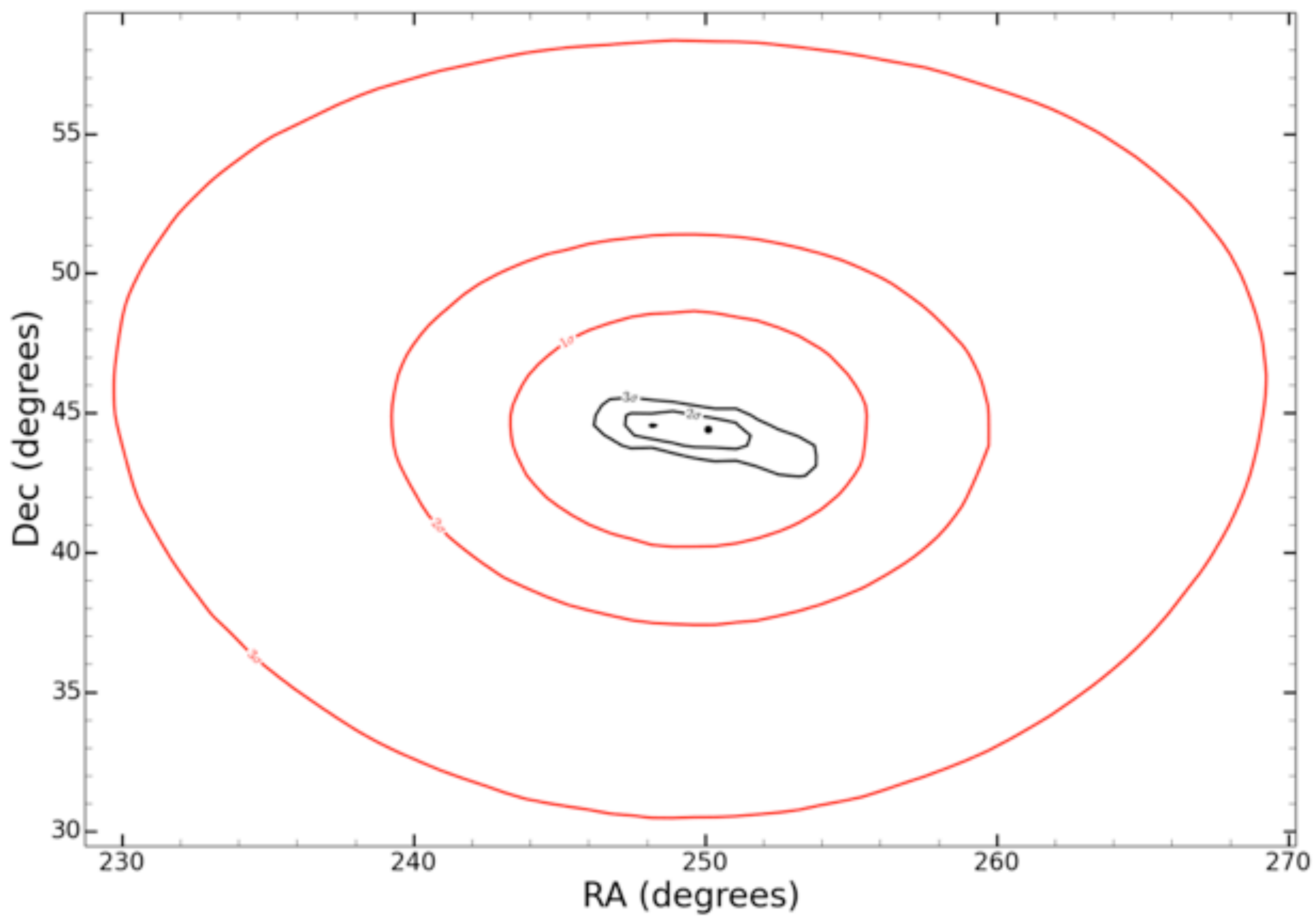
Automated location:
15 - 45 s after trigger



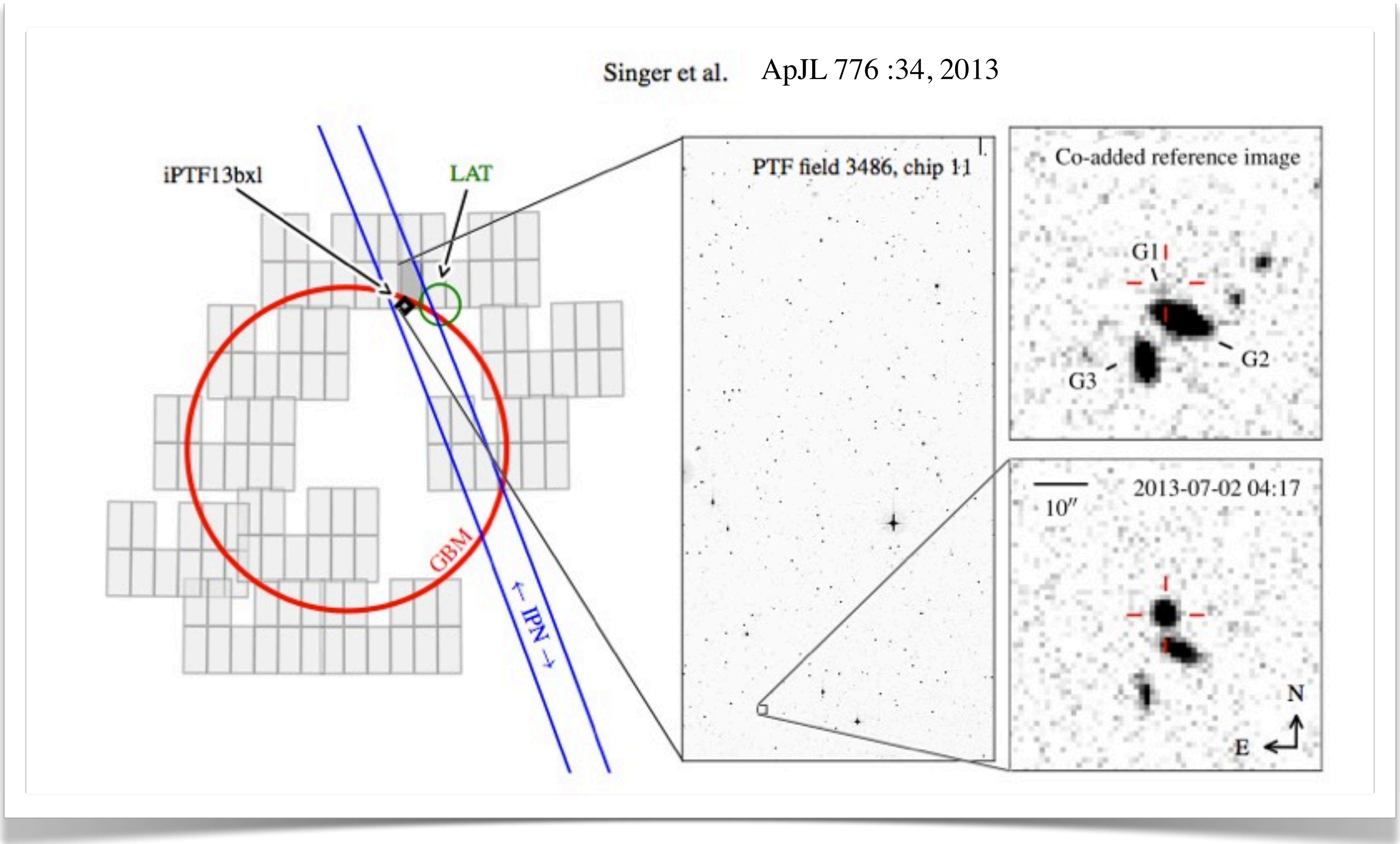
Localization paper
VC et al. 2014

Monday, August 4, 14

Localization contains both statistical and systematic uncertainties: since January 2014 contours reflecting total uncertainty have been distributed and used by follow-up observers to tile uncertainty regions.

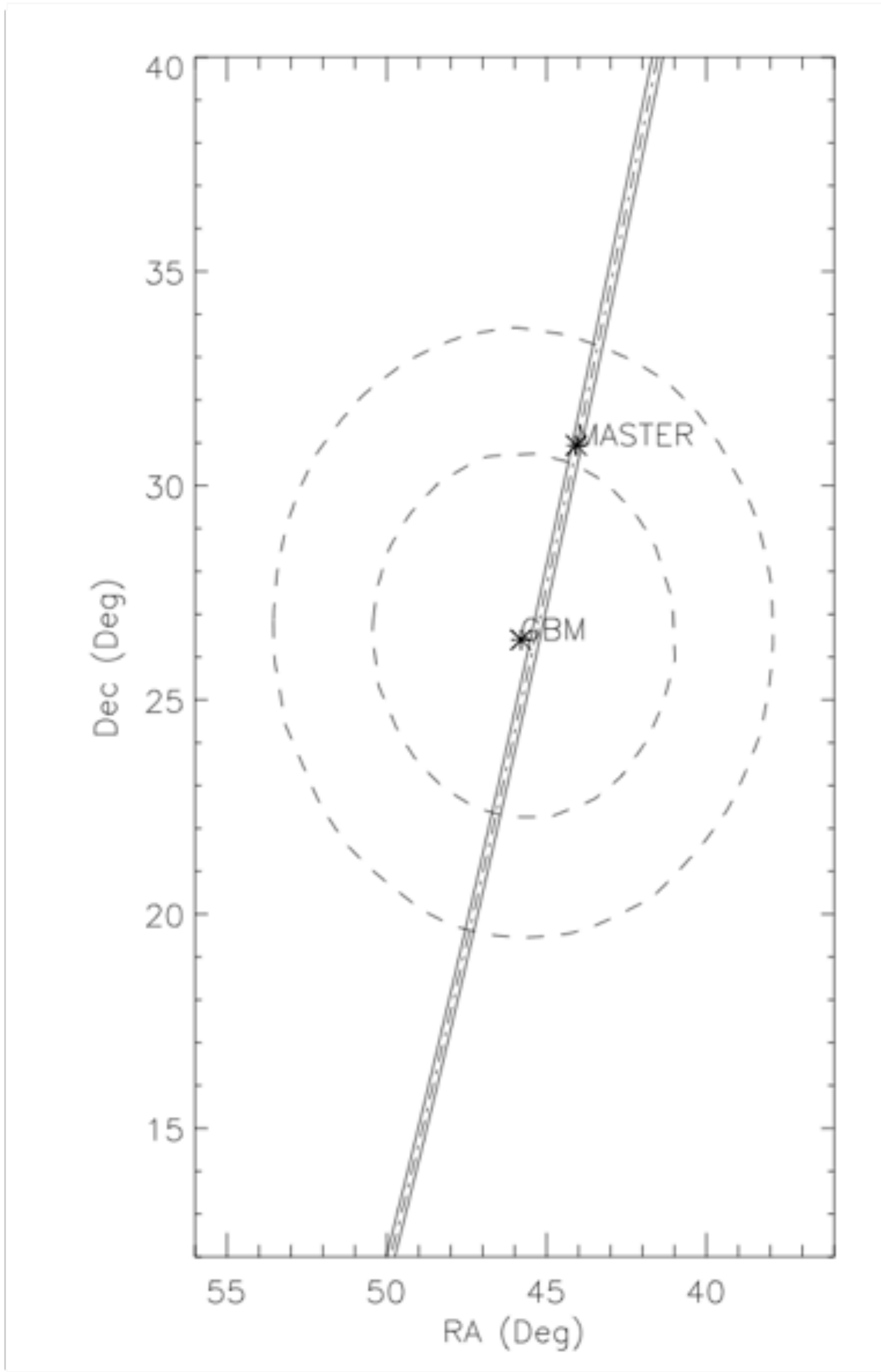


The intermediate Palomar Transient Factory (iPTF) has been scanning our localization error boxes. The first iPTF detection (130702a) was based on GBM position and later confirmed by both LAT and IPN.



Singer et al. 2013

GRB 140801A: First success with MASTER: 100 s after trigger!



GRB 140801A

GBM
Pelassa et al. 2014
(GCN 16658)

MASTER
Gorbovskoy et al. 2014
(GCN 16653)

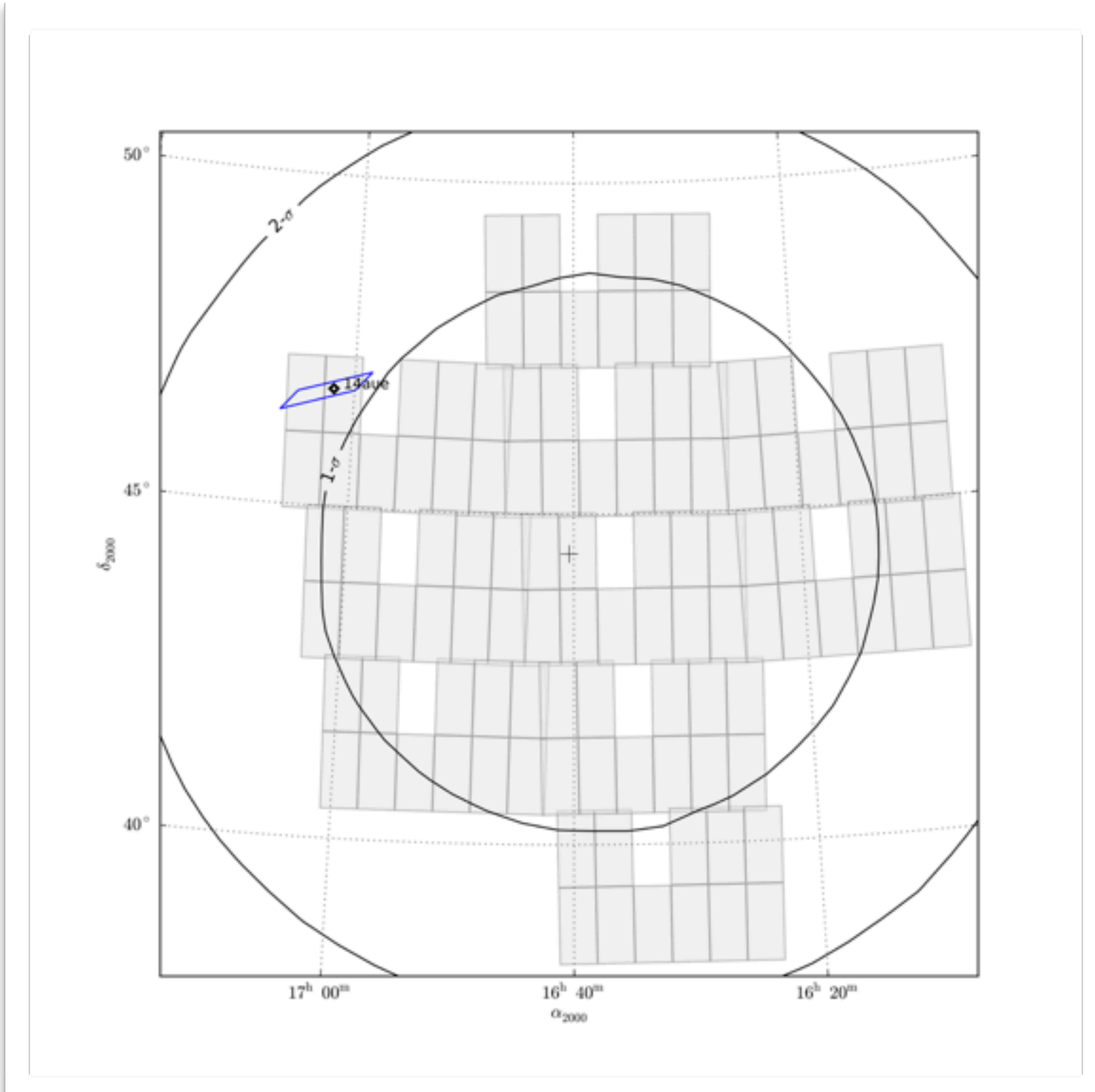
IPN
Hurley et al. 2014
(GCN 16655)

GTC Redshift = 1.32
de Ugarte Postido et al. 2014
(GCN 16657)

iPTF looks at Ground-Auto or Final localizations (depending on timing) and tiles as much of the error box with 48" as it can, using our probability maps, then observes candidates with 60". Promising candidates are then followed up with e.g., Gemini

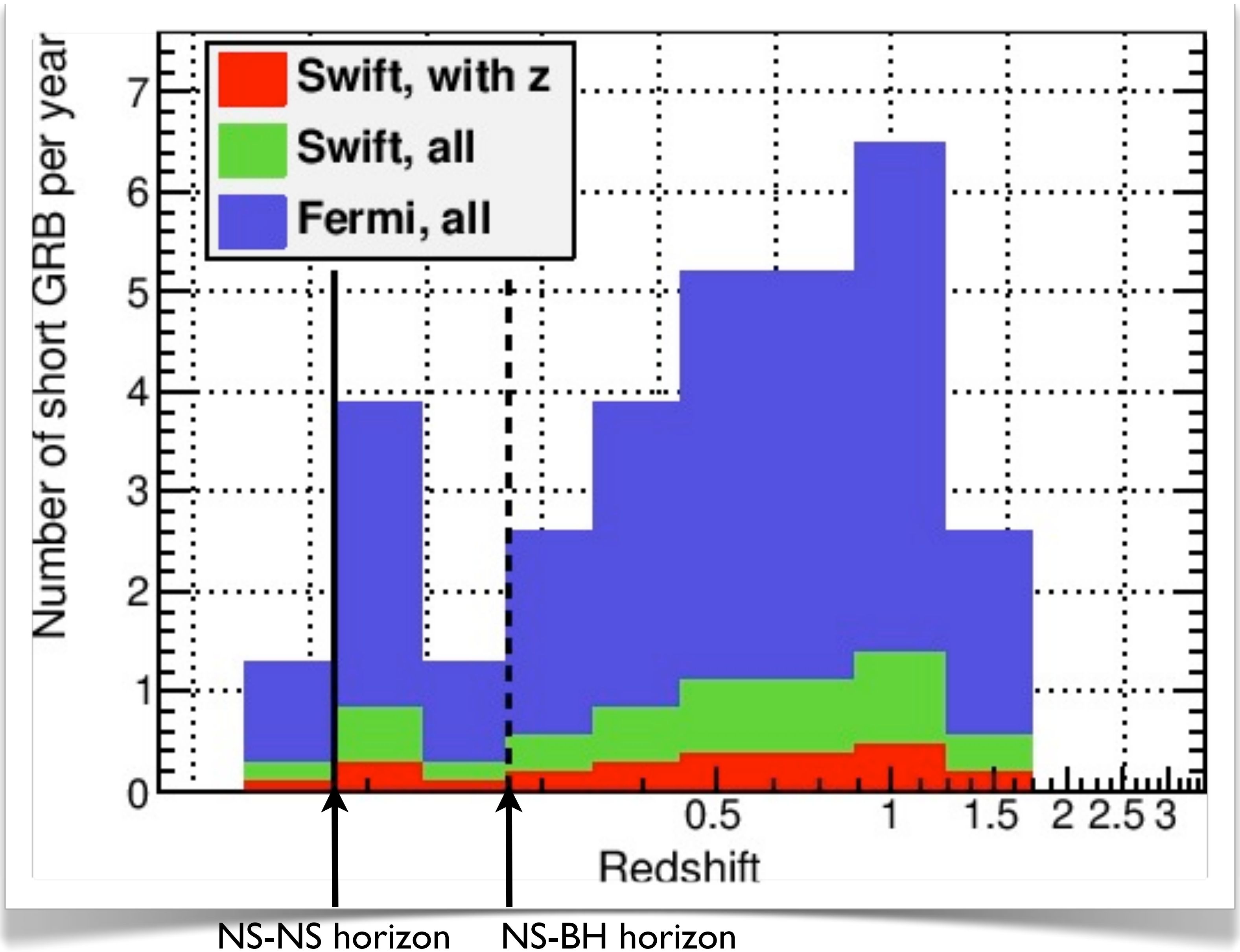
- ~30 attempts, 7 definite successes, a couple more with unconfirmed candidates
  - GRB 130702A (Singer et al, ApJL 776 :34, 2013) → z=0.145, supernova, radio AG
  - GRB 131011A (Kasliwal et al, GCN 15324)→ z=1.874 (Rau et al, GCN 15325)
  - GRB 131231A (Singer et al, GCN 15643) → z=0.642 (Xu et al, GCN 15645)
  - GRB 140508A (Singer et al, GCN 16225) → radio AG (Horesh et al., GCN 16266), 1.03<z<2.1 (Moskvitin et al, GCN 16228, Malesani et al GCN 16229)
  - GRB 140606B (Singer et al, GCN 16225) → z=0.384 (Perley et al, GCN 16365)
  - GRB 140620A (Kasliwal et al. GCN 16425) → z=2.04
  - GRB 140623A (Bhalerao et al. GCN 16442) → z=1.92

Sometimes IPN will confirm iPTF optical transient - other candidates have no confirmation. This will become trickier with short GRBs - larger statistical uncertainty and lower chance of IPN confirmation (except GBM-Konus annuli)



The number of short GRBs in the aLIGO/Virgo horizon is small but GBM offers the best chance for serendipitously overlapping with a gravitational wave candidate

Assuming redshift distribution of short GRBs with unknown z is same as known...

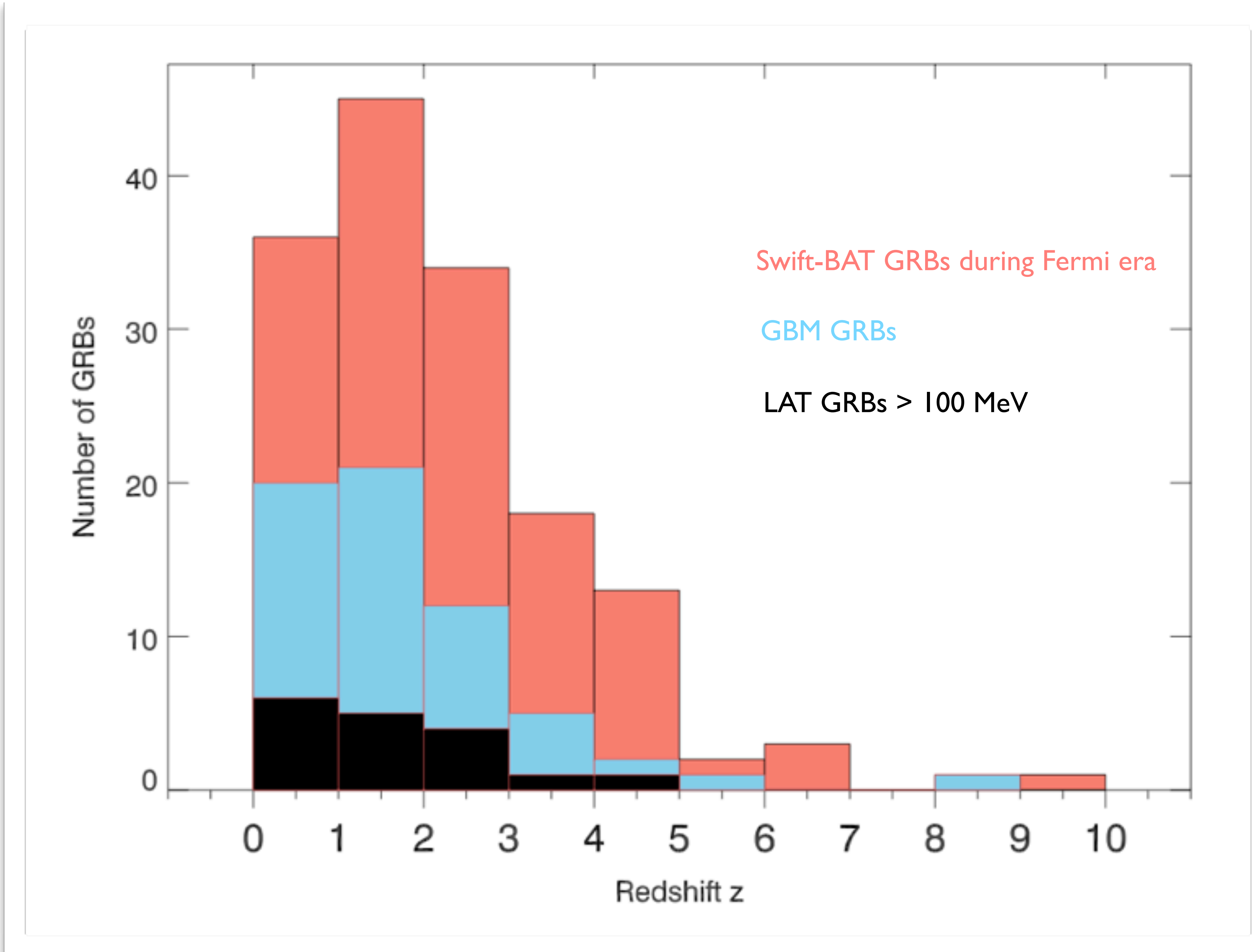


Courtesy of
V. Pelassa

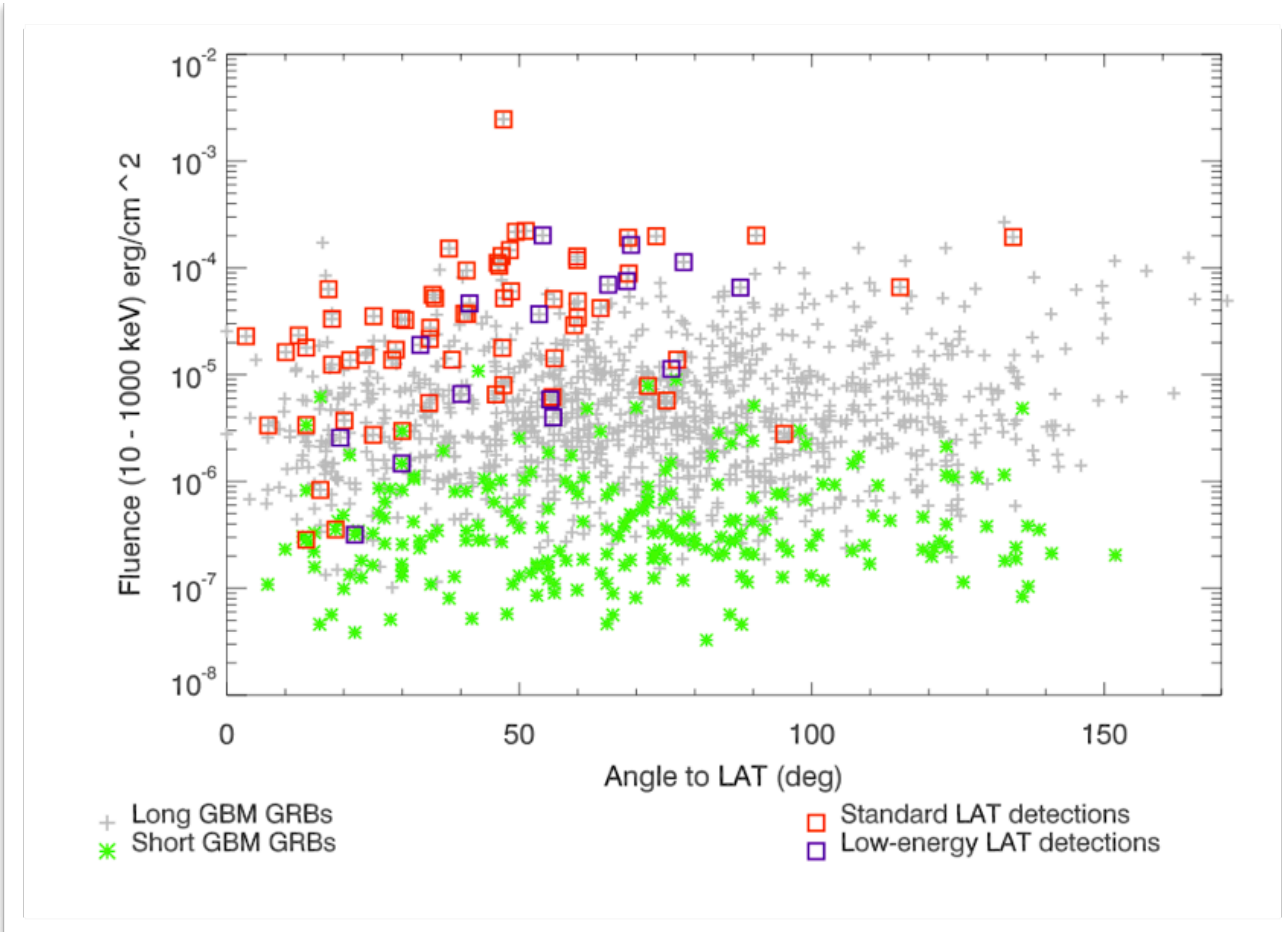
Based on observations and non-detections by both instruments, GBM and Swift BAT detect ~same populations of short GRBs (Burns et al. in prep)

- How many GRBs can we be expected to see at VHE?

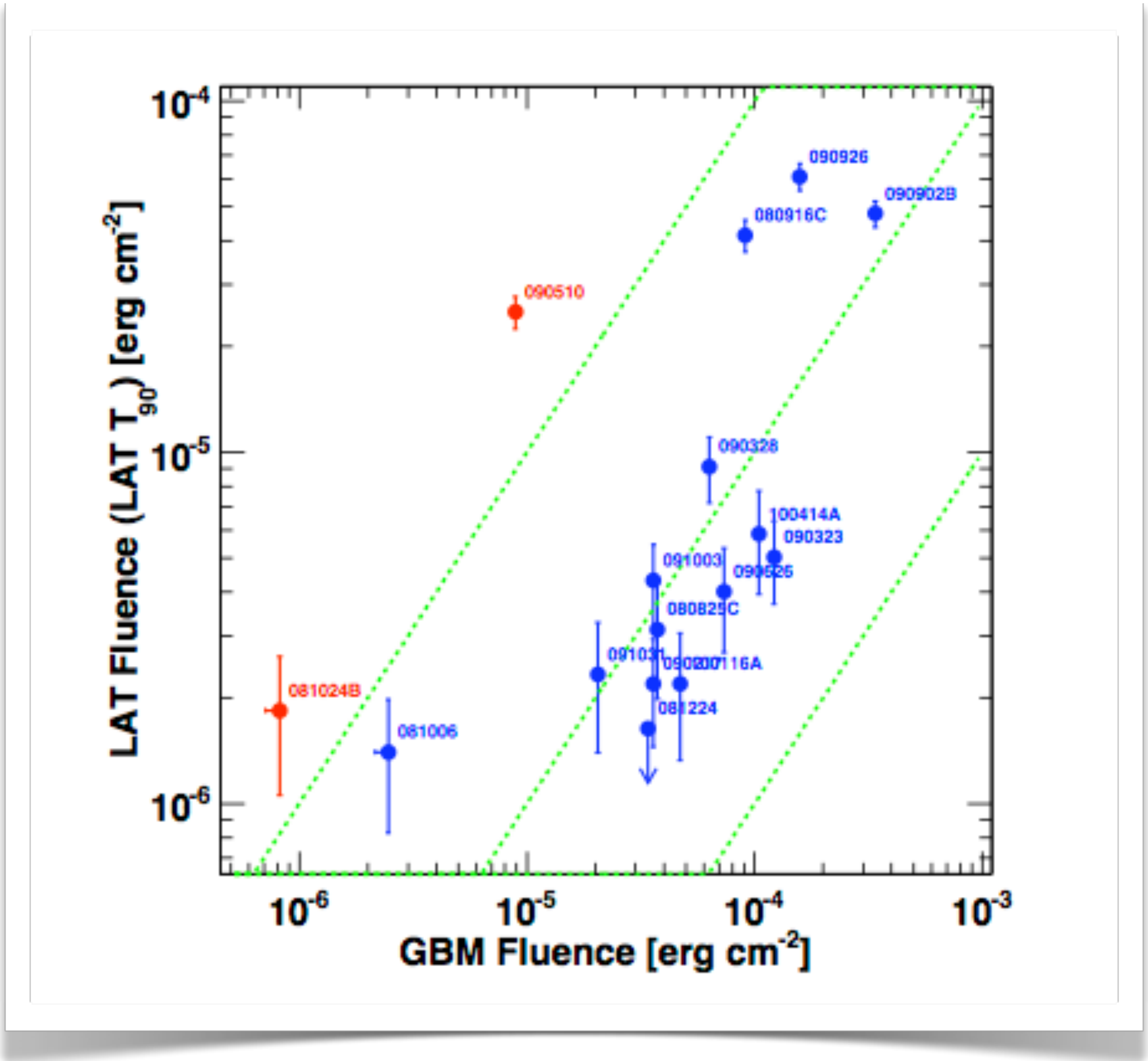
Using joint GBM-Swift GRB sample, LAT-detected GRBs, and GBM GRBs followed up independently we find GRBs detected above 100 MeV span a wide range of redshifts



Detectability by the LAT at high energies depends on fluence at GBM energies. Weaker GRBs are seen on-axis - low detection rate is likely due to LAT sensitivity



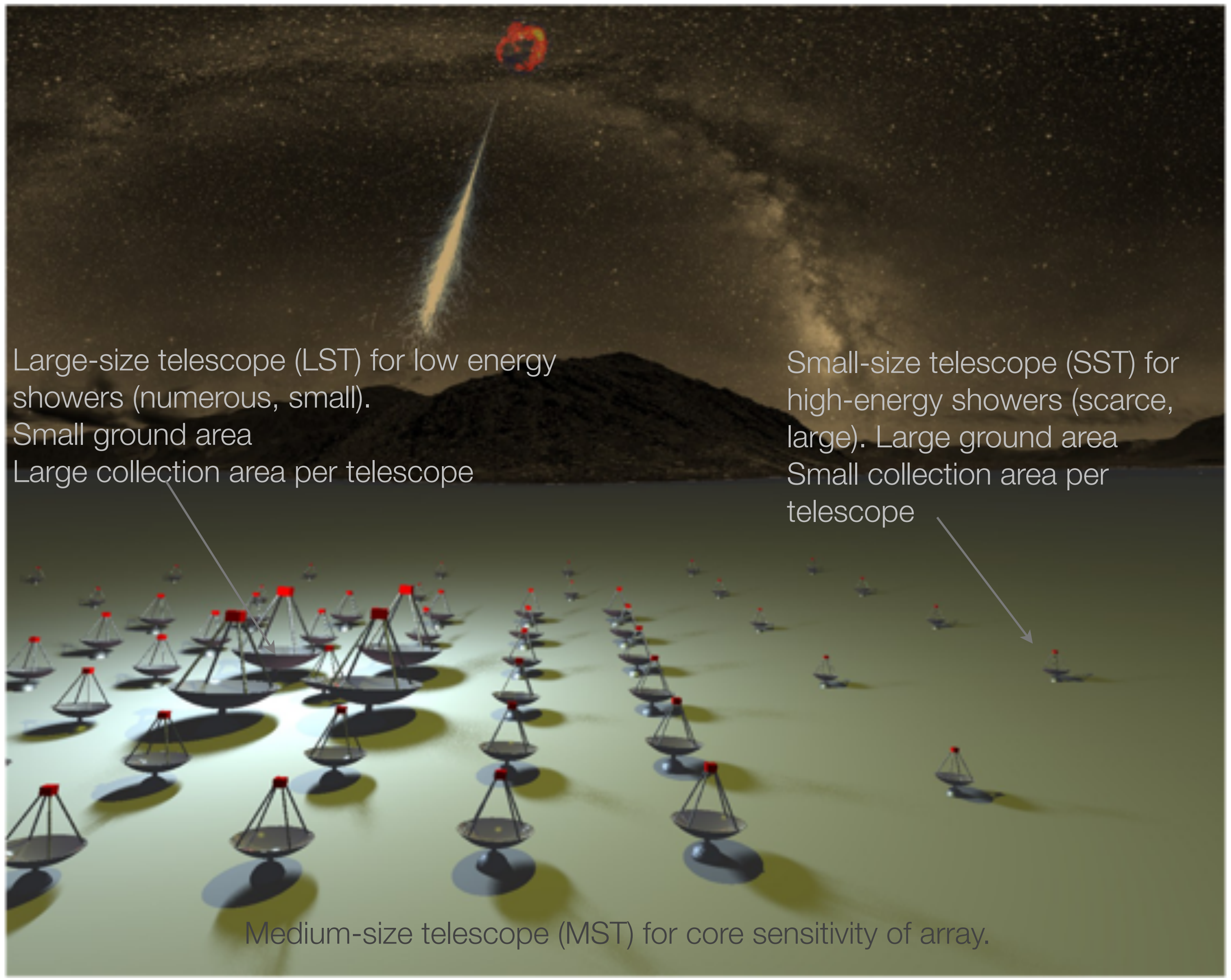
Fluence > 100 MeV is ~10% of fluence 10 keV - 1 MeV for long GRBs
but can be >100% for short GRBs



LAT GRB Catalog
Ackermann et al. 2013

On average 50% of emission > 100 MeV is in prompt emission - but this is very observation-dependent (angle to GRB, repoint by spacecraft...)

The Cherenkov Telescope Array (CTA) will be 10x more sensitive than current-generation IACTs with 5 - 15x detection efficiency for GRBs compared to VERITAS



- Extrapolation to TeV assumes fixed fraction (10%) of GBM fluence in LAT energy range and -2 power law.
- Absorption by Extragalactic Background Light (EBL)
- Look at prompt (t90) - slew time. Efficiency for extended emission is higher
- Assume nominal array layout and observation strategy

5 attempts per year with Swift = 0.6 - 1.6 prompt detections
10 attempts with GBM = 0.4 - 1.6 prompt detections

Gilmore et al. 2012
Kakuwa et al. 2012

High Altitude Water Cherenkov (HAWC)

Less sensitive than CTA but...
95% duty cycle
16% sky coverage

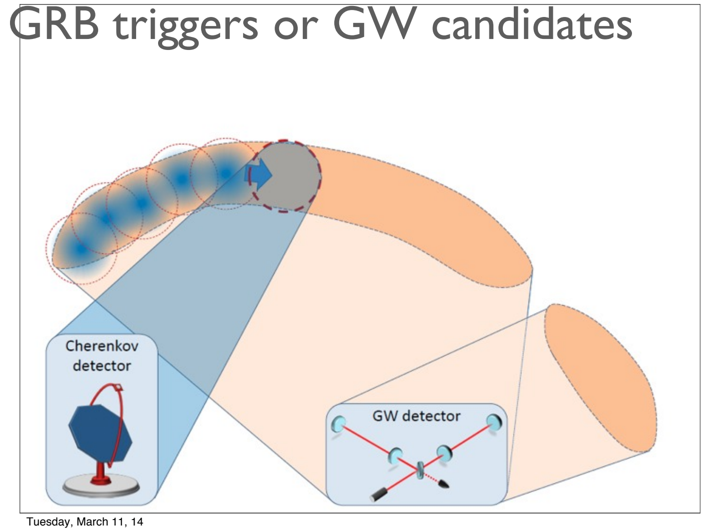
Taboada and Gilmore 2014

Assuming fluence of short GRBs > 100 Mev is 100% GBM fluence
HAWC will see 1.4 short GRBs per year

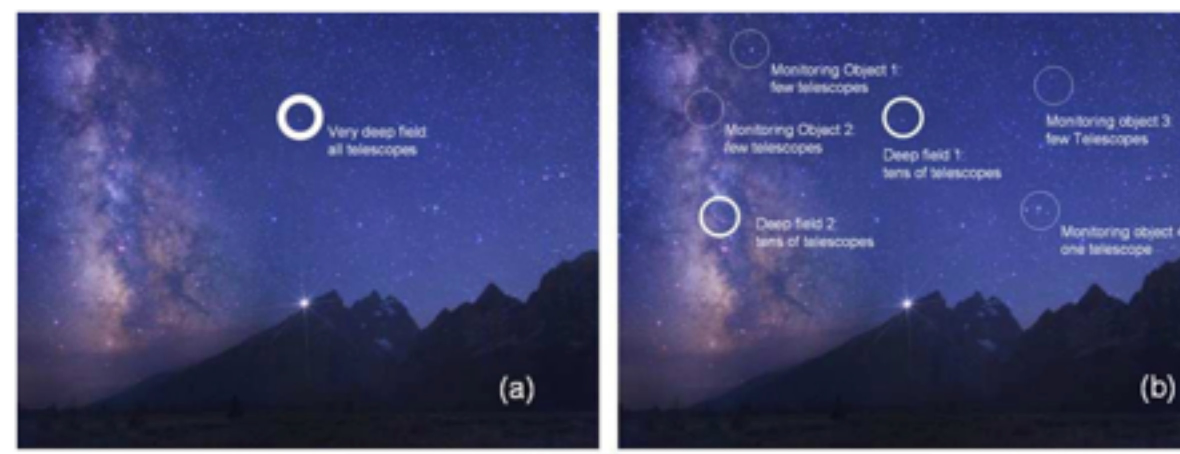
In the absence of well-localized sub-MeV triggers and the dimness and short lives of short GRB afterglows, late-time VHE emission may offer the most likely electromagnetic counterparts of gravitational wave candidates

Bartos et al. (arXiv:1403.6119) to appear in MNRAS

CTA in survey mode following up e.g., GBM or HAWC short GRB triggers or GW candidates



- CTA may provide best way to find e-m counterpart to GW candidates from ALIGO-VIRGO
  - Swift may not be operational or may not see GW SGRB
  - SVOM will be later than ALIGO-VIRGO
  - X-ray counterparts to SGRB fade rapidly (50% within a day)
  - optical counterparts to SGRB very faint & fade rapidly
  - merger GRBs can lie outside their host
- 2-3 GRBs in FoV per year assuming telescopes with minimal overlap
  - Fewer than 1 per year will be short
  - Extended emission offers 2nd chance even in non-survey



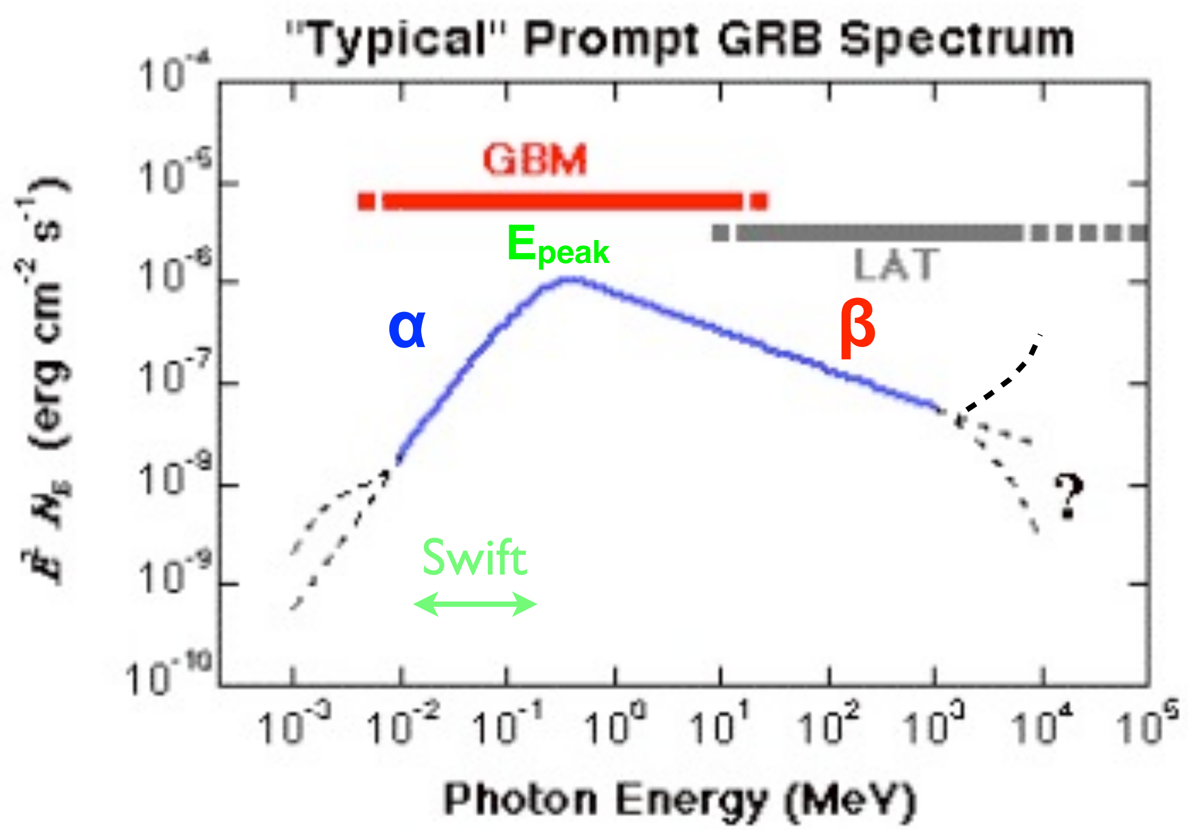
CTA in survey mode scanning large sky region for short GRB serendipitous discovery

- GRB prompt emission spectral analysis: the bread-and-butter of GBM. Two sets of catalogs:

Catalog papers

Paciesas et al. 2011
Goldstein et al. 2011
von Kienlin et al. 2014
Gruber et al. 2014

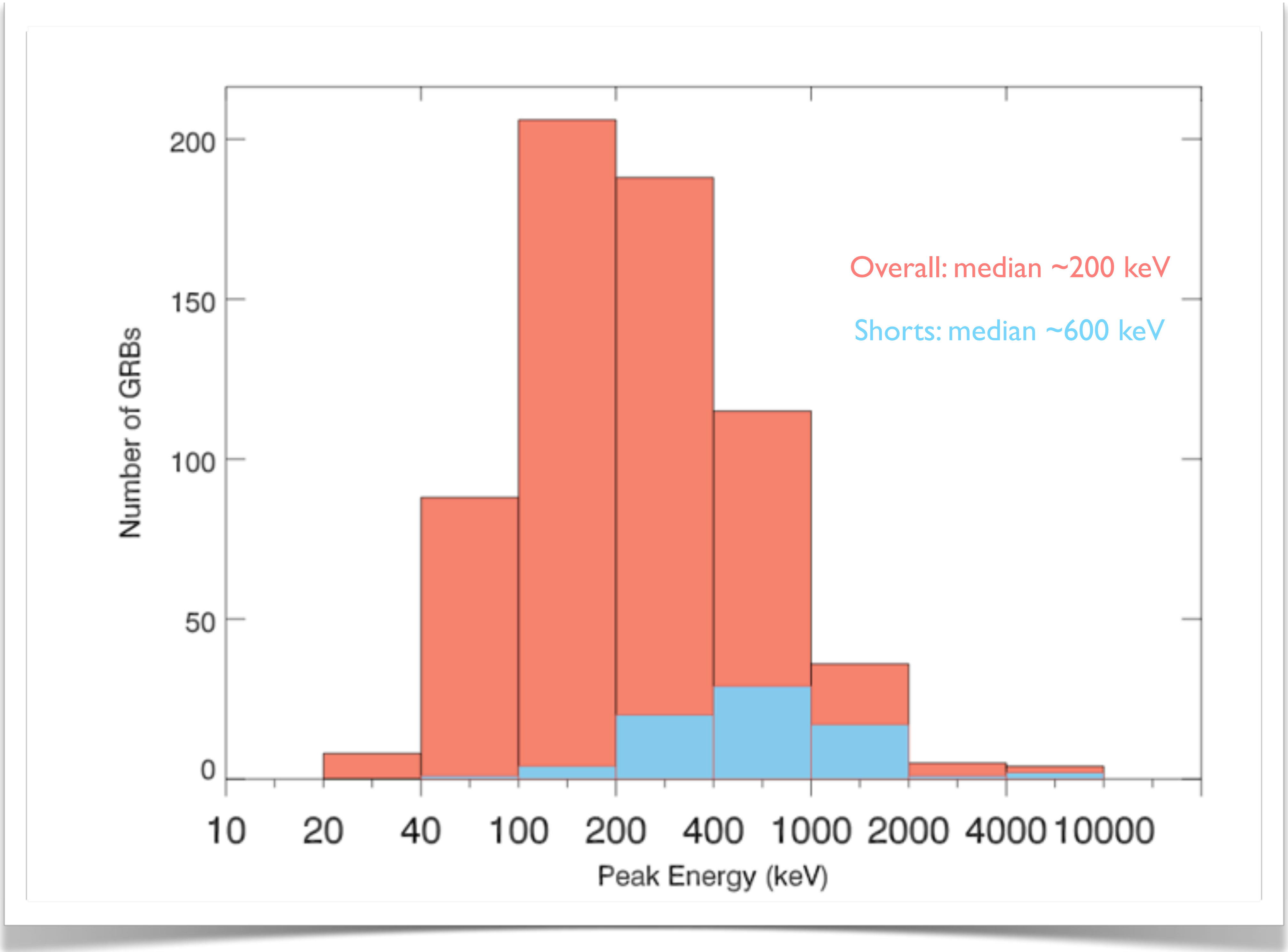
The Band function is a good enough fit to most GRB spectra and can be seen to evolve over the GRB prompt emission time-scale.
GRB spectra peak energies soften over time.
Fermi offers a wider window for spectral studies than its predecessors



$$N(E) = \begin{cases} E^{\alpha} \exp\left(-\frac{E}{E_0}\right), & \text{if } E \leq (\alpha - \beta) E_0 \\ [(\alpha - \beta) E_0]^{(\alpha-\beta)} E^{\beta} \exp(\beta - \alpha), & \text{if } E > (\alpha - \beta) E_0 \end{cases}$$

Band et al. 1993

Fermi GBM shows us how short GRB spectra are different from long: higher peak energies, and steeper Band beta

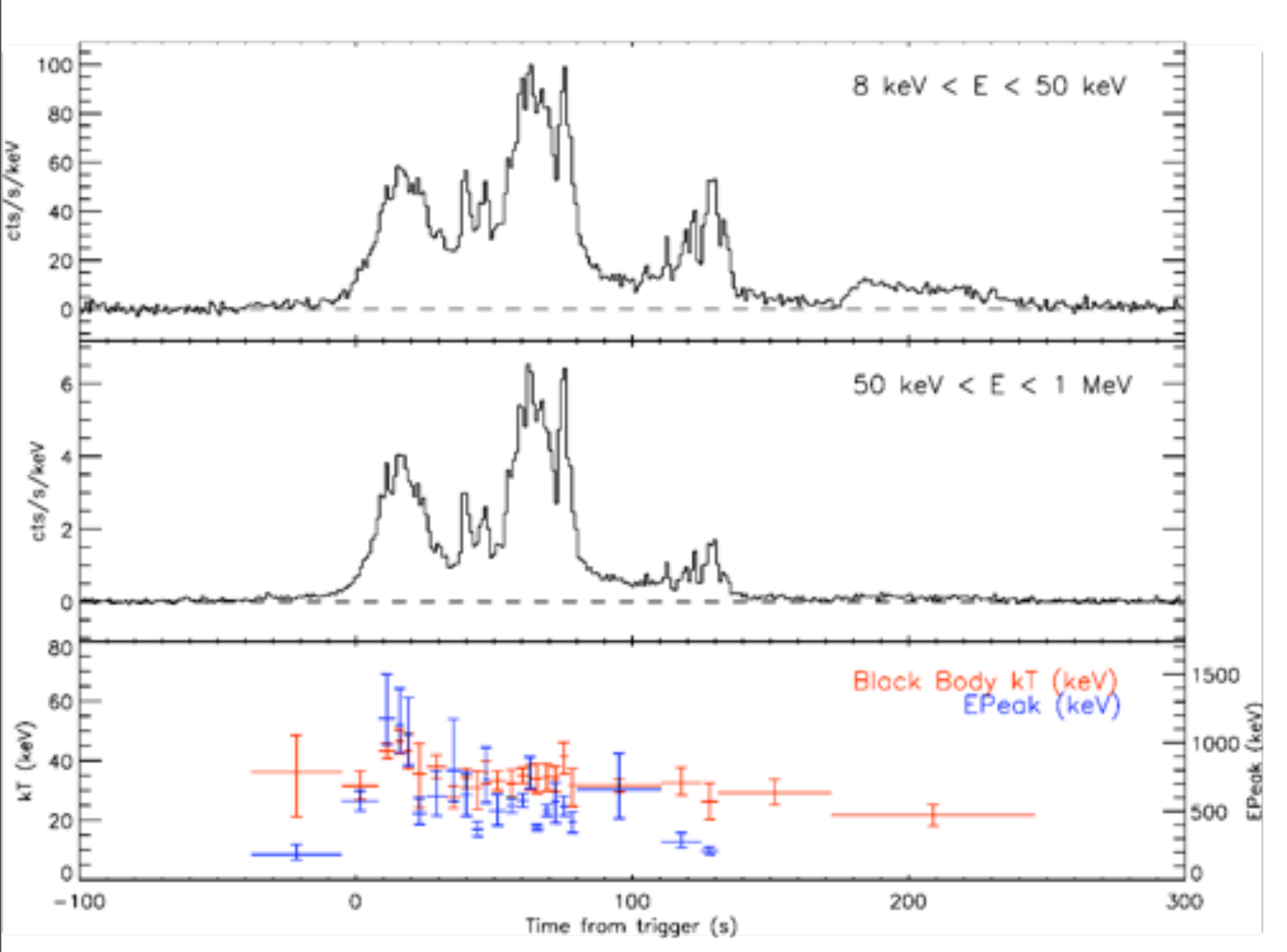


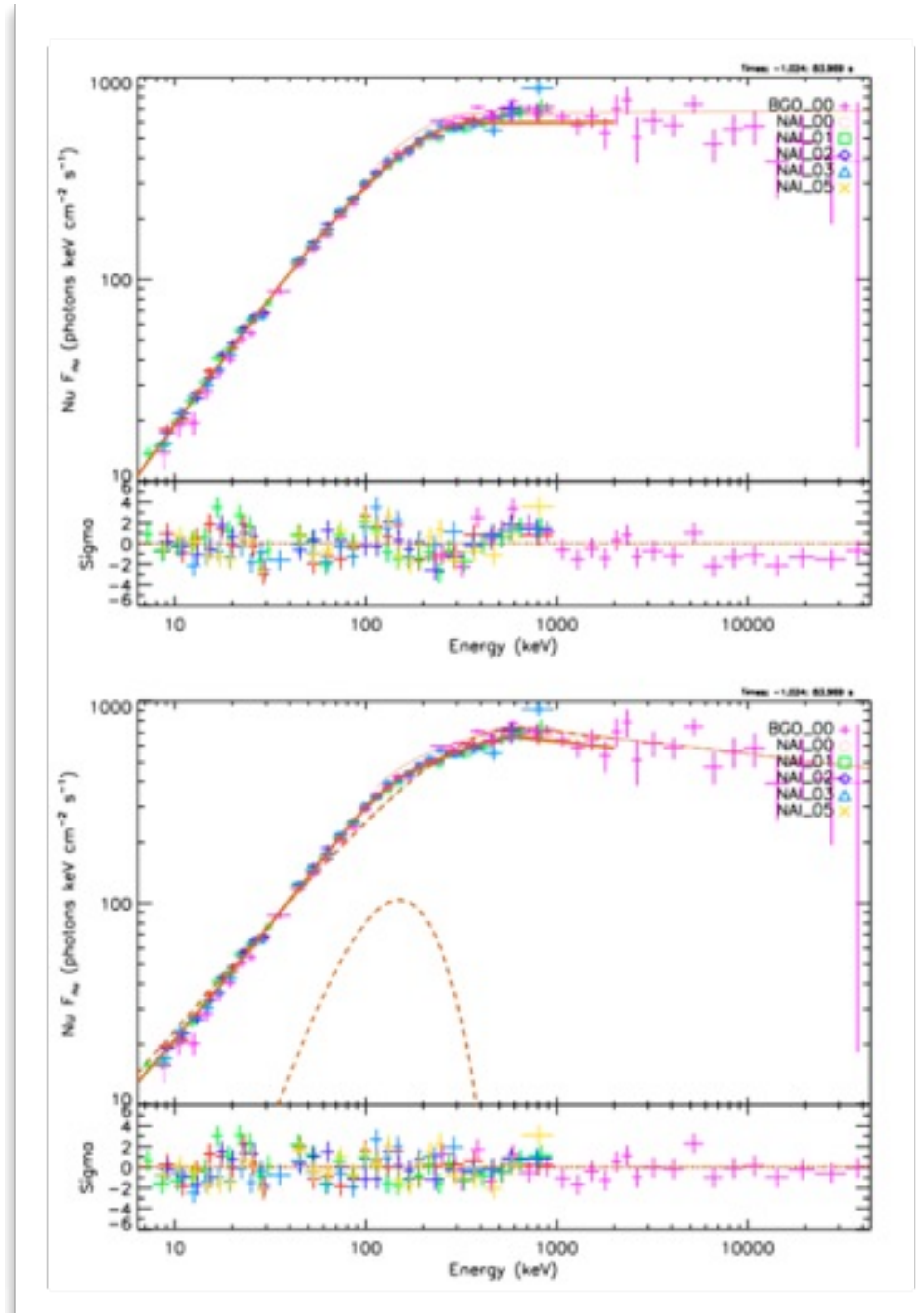
Data from
2nd GBM GRB Catalog
Gruber et al. 2014

GBM sees extra component above Band function that is consistent with blackbody emission from the photosphere

GRB 100724B

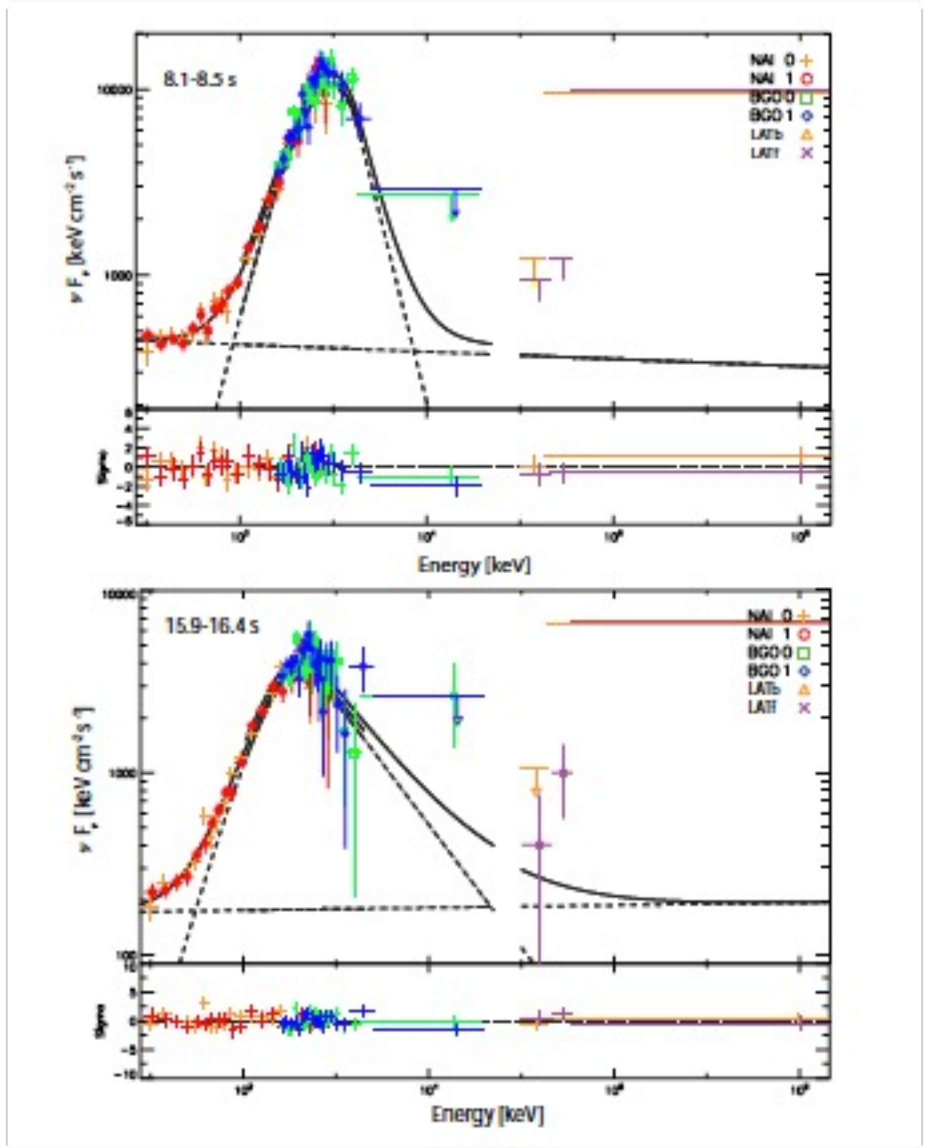
Guiriec et al. 2011





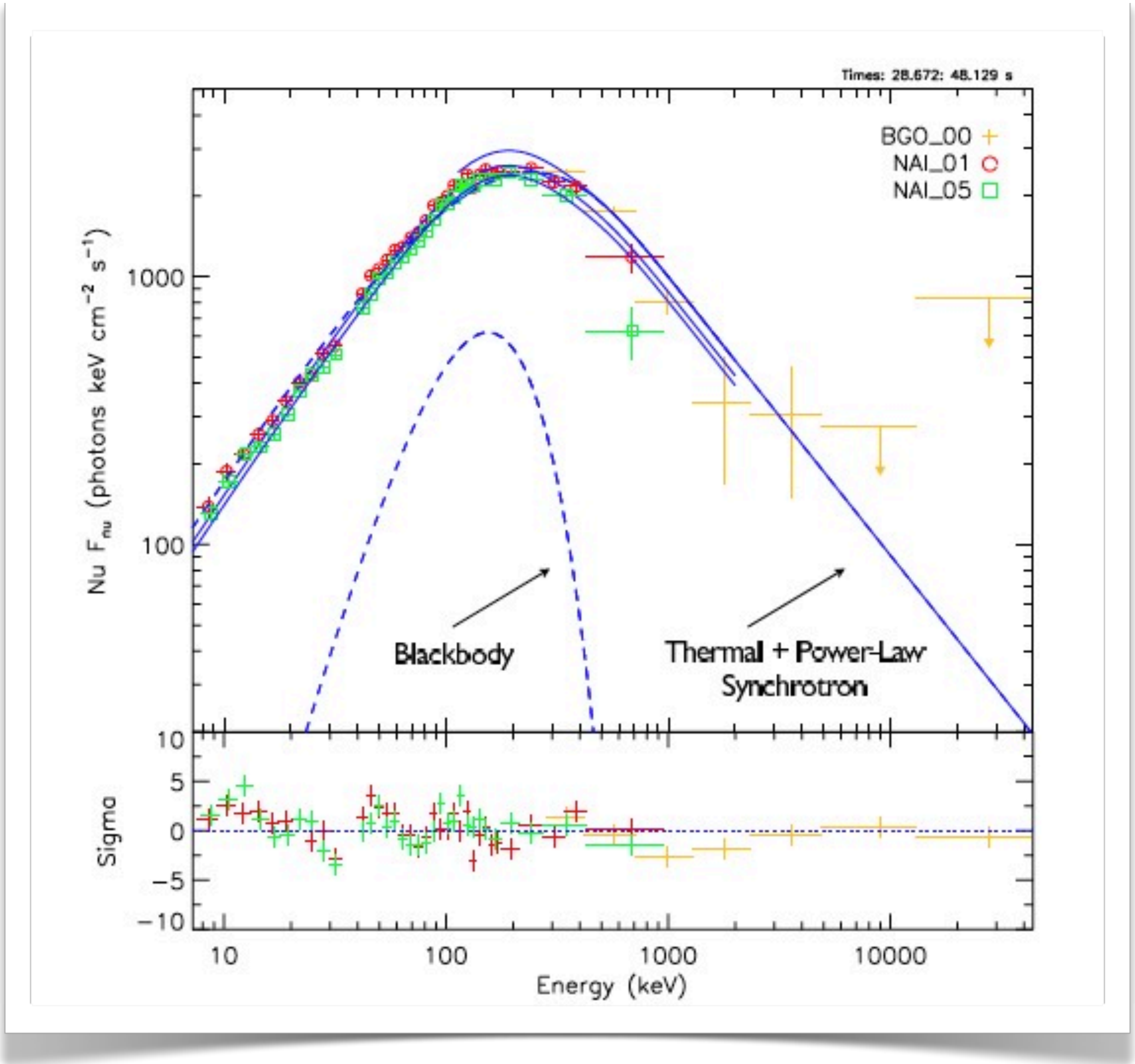
Photospheric component raises EPeak, steepens alpha and beta

Sometimes photospheric emission can dominate spectrum with a power-law added to represent non-thermal emission.



GRB 0900902B
Ryde et al. 2011

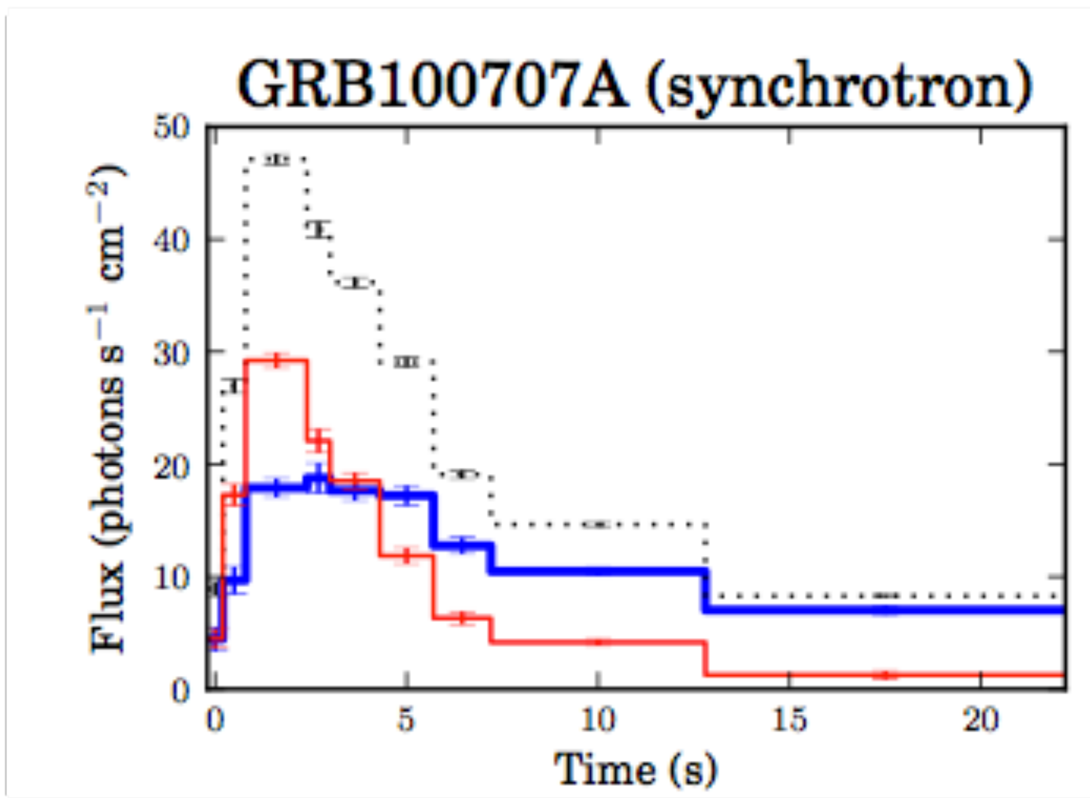
With the addition of the photospheric component, we can fit physical slow-cooling synchrotron models to bright, single-pulse GRBs

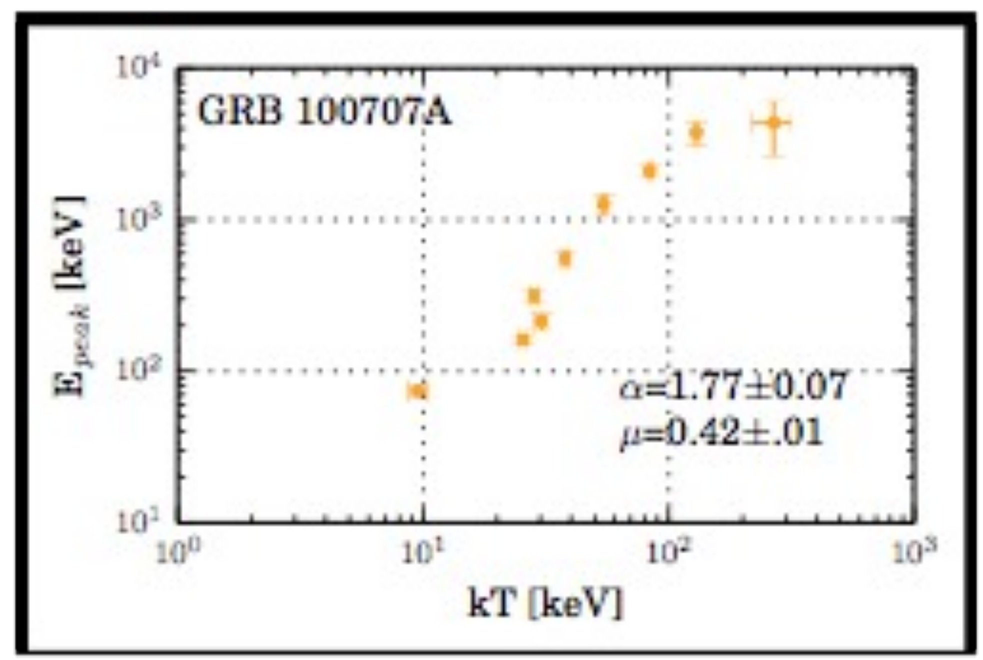


GRB 090820

Burgess et al. 2011

The evolution and relationship between peak energy and temperature gives an indication of the baryonic vs magnetic dominance of the relativistic outflow.
It is found that examples of both types of jet exist in this GRB population.



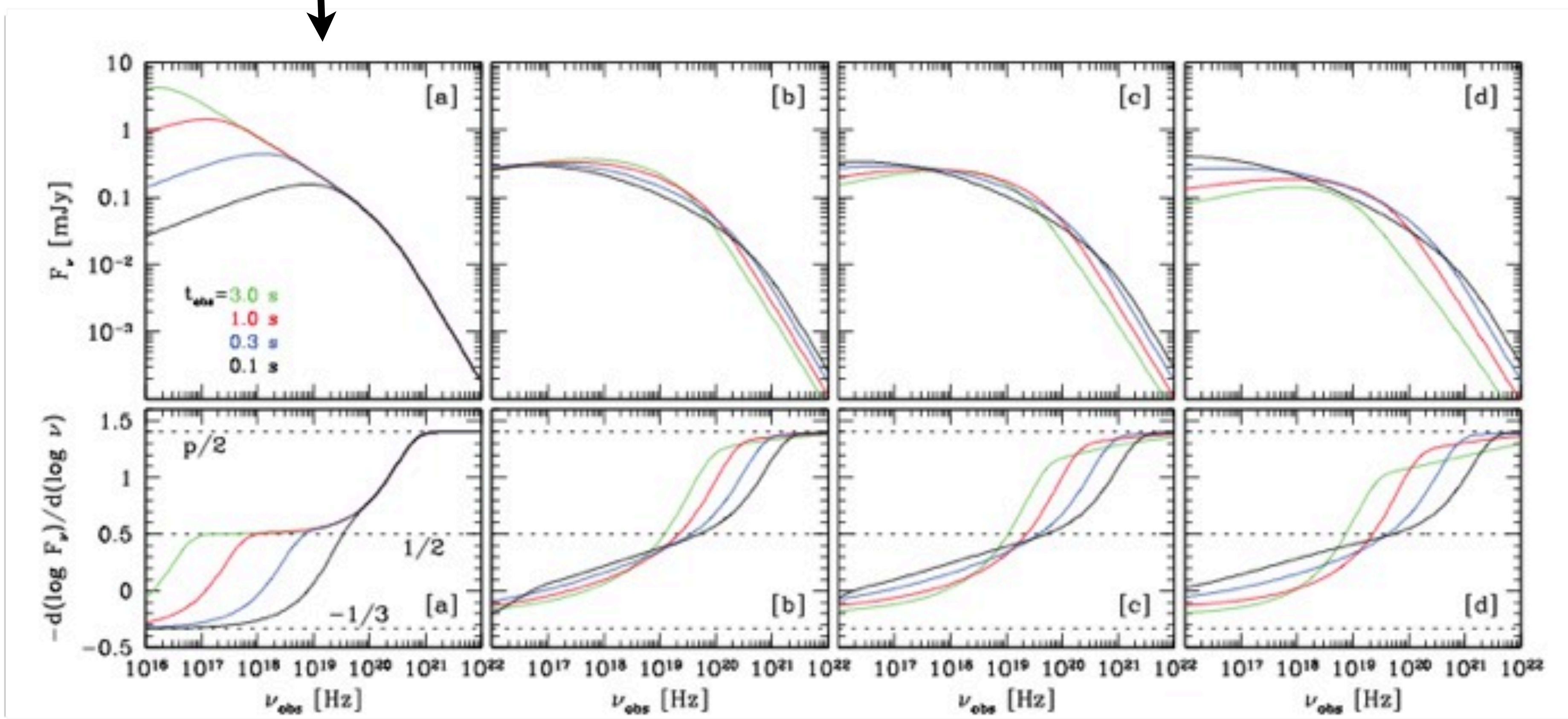


GRB 100707A
(one of 8)
Burgess et al. 2014

Fast-cooling synchrotron may fit the observed spectra if the magnetic field is allowed to vary.

no B evolution - fast-cooling e's produce steep spectrum below EPeak

B evolution flattens spectrum below EPeak



No consideration of photospheric component.
Magnetic fields very large in calculations.

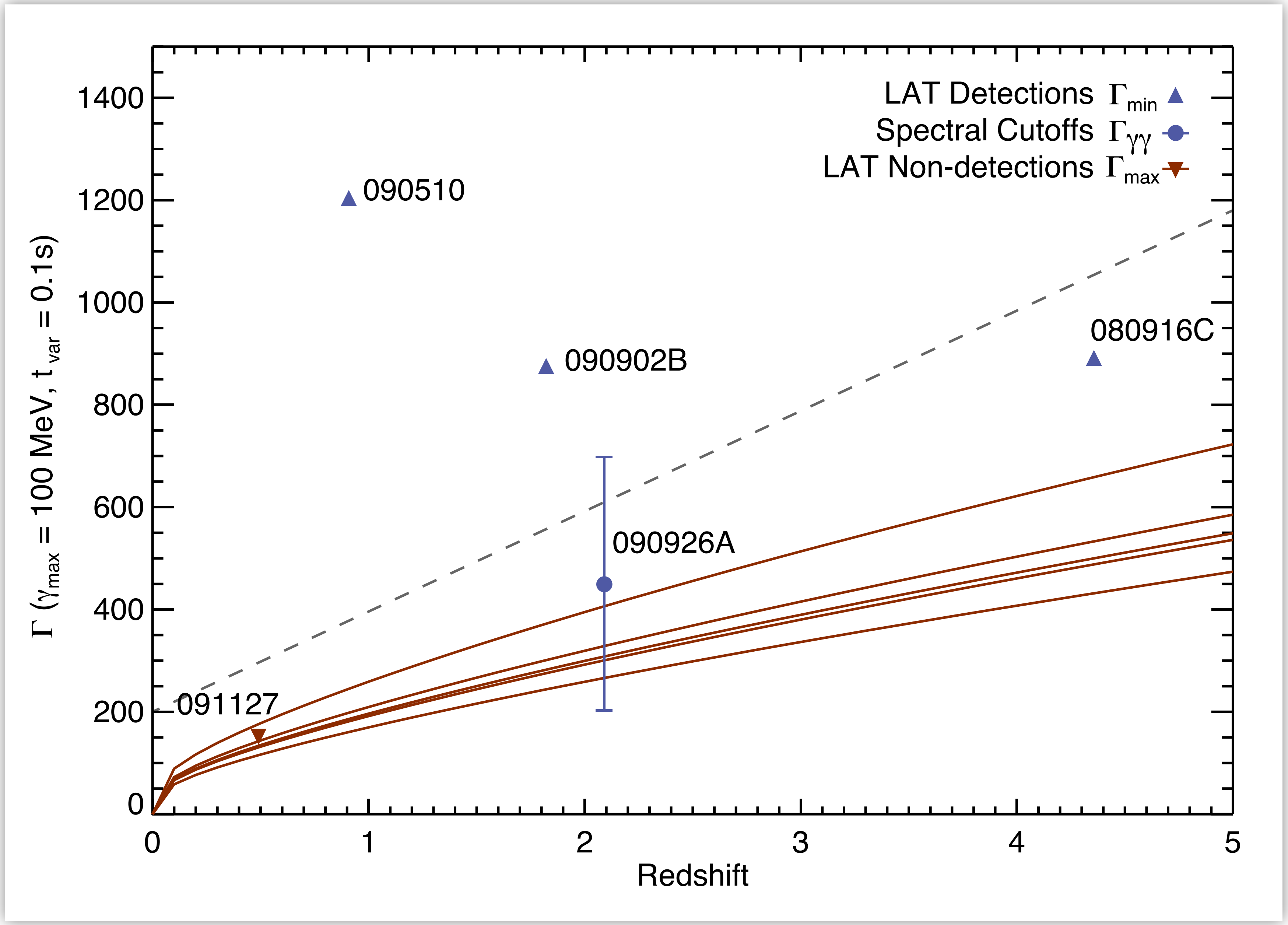
Uhm and Zhang 2014

Snapshots from GBM

- Follow-up observations of GBM-detected GRBs are occurring
  - Will we be able to detect short GRB afterglows in aLIGO/Virgo era?
- Using GBM to estimate how many GRBs will be detected at VHE
  - 1-3 long GRBs (prompt) with CTA, 1-2 short GRBs with HAWC
  - Possibility of VHE counterparts to GW candidates?
- What do we learn from studying GBM GRB energy spectra?
  - Physical modeling of emission processes indicates multiple components, mixture of baryon/magnetic jet, varying magnetic field?
  - Are short GRB processes the same despite harder spectra?

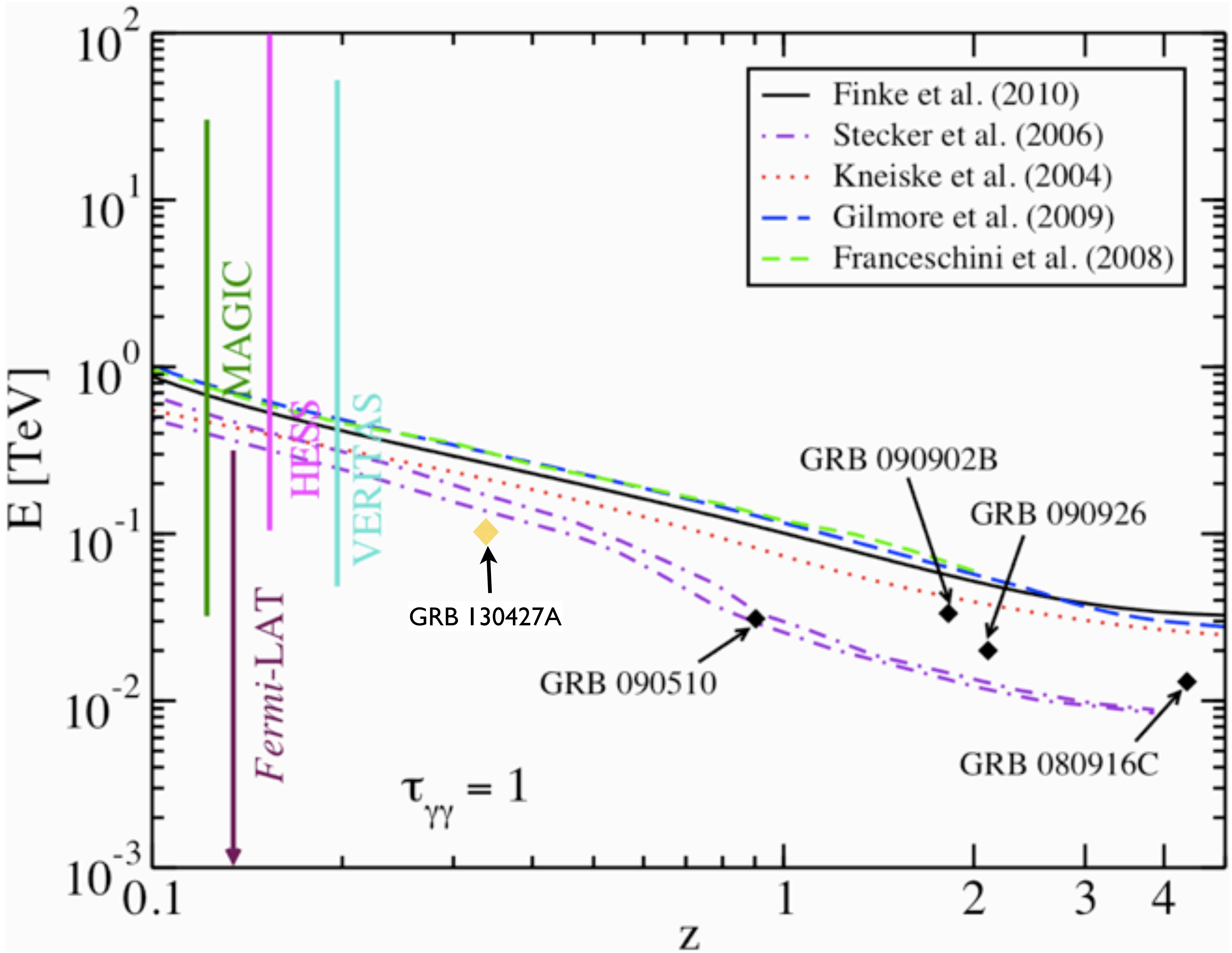
- Thank you for your attention!

LAT detects only 10% of GBM GRBs in its FoV above 100 MeV.
Are GRBs with HE emission special?



LAT Upper Limits paper
Ackermann et al. 2012 arXiv:1201.3948

GRBs are probes of Extragalactic Background Light

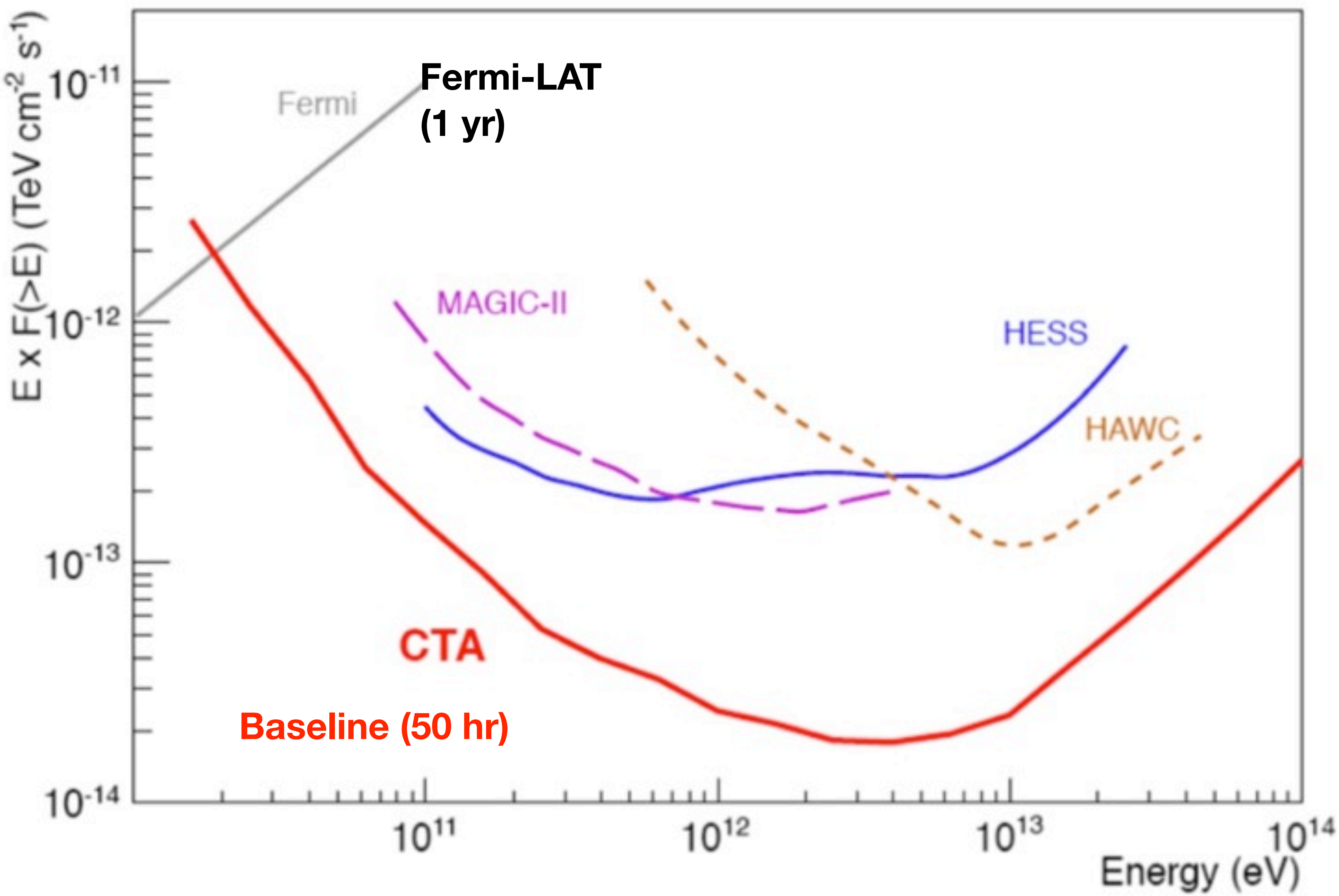


Adapted from Finke et al. 2010

Prospects for VHE GRB detections

- From CTA: 1 - 3 long GRB prompt emission per year
  - perhaps 3 - 4x more afterglows?
  - Observing strategies (survey mode, faster slews) can help
- From HAWC: 1-2 short GRB prompt emission per year
- Can we see turnover in HE spectrum?
  - synchrotron vs inverse Compton, leptonic vs hadronic
- Can we disentangle prompt from afterglow HE emission?
- VHE emission implies huge bulk Lorentz factors

Relative differential sensitivities of CTA - Fermi LAT
(doesn't include US contribution of telescopes) show crossover energy of 40 GeV



GRB Detection efficiency of CTA
Prompt emission of long GRBs: Swift-like trigger and GBM-like trigger

Extrapolation of Band function to TeV

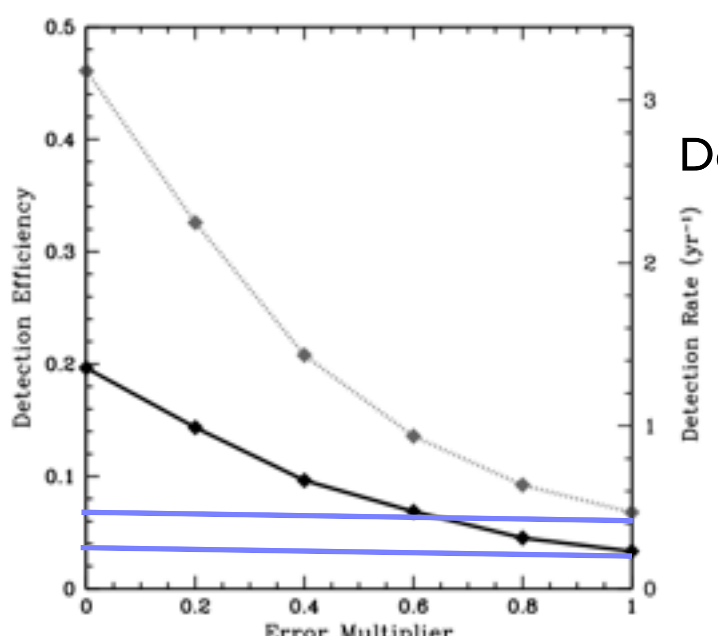
Fixed 0.1 fluence of MeV as per LAT

Swift-like instrument

Gilmore+ 2012. arXiv:1201.0010

Instrument	DE (bandex)	DE (fixed)
CTA (baseline)	0.0744	0.115
CTA (optimistic)	0.163	0.328
CTA (baseline; LST only)	0.0732	0.110
CTA (baseline; MST only)	0.0231	0.0310
VERITAS ($E_{th} = 65$ GeV)	0.0241	0.0281
VERITAS ($E_{th} = 100$ GeV)	0.0216	0.0235

Lower threshold for LST (triggering), full complement of MSTs



Detection efficiency for GBM (DE fixed)

Kakuwa+ 2012 arXiv:1112.5490:

Lower numbers but:
Overly pessimistic about GRB notice time
4 x higher DE in afterglow than for prompt
1.6 x higher reducing slew time from 100 s to 30 s

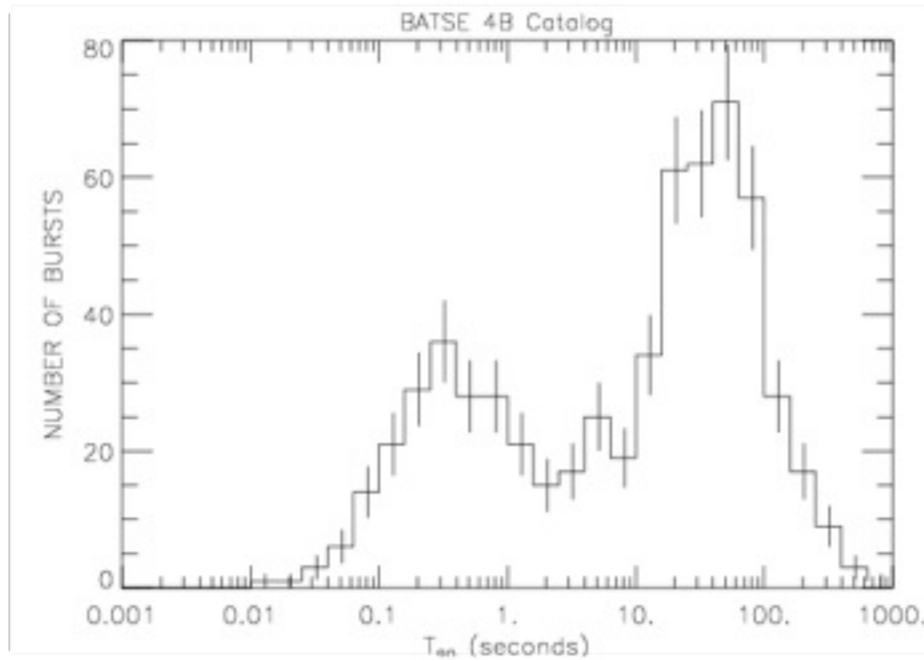
Optimistic 0.07 --> 0.16 with scanning

Baseline 0.037 --> 0.057 with scanning

5 attempts per year with Swift = 0.6 - 1.6 prompt detections

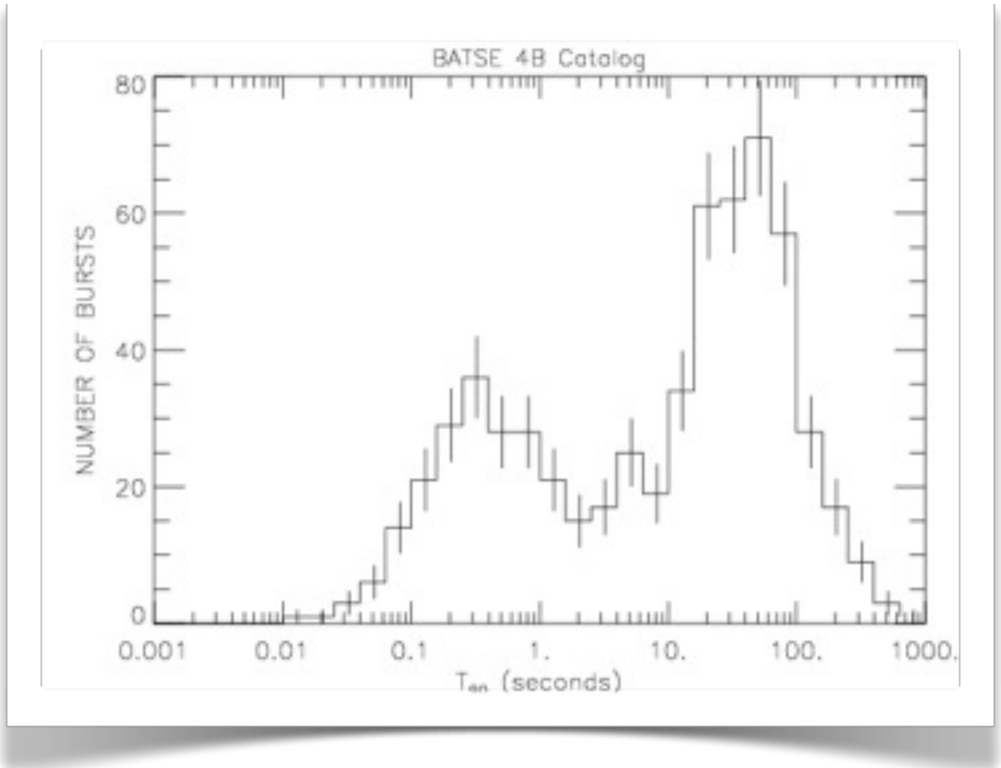
10 attempts with GBM = 0.4 - 1.6 prompt detections

There may be at least two types of GRB progenitor: one producing short GRBs, the other long GRBs

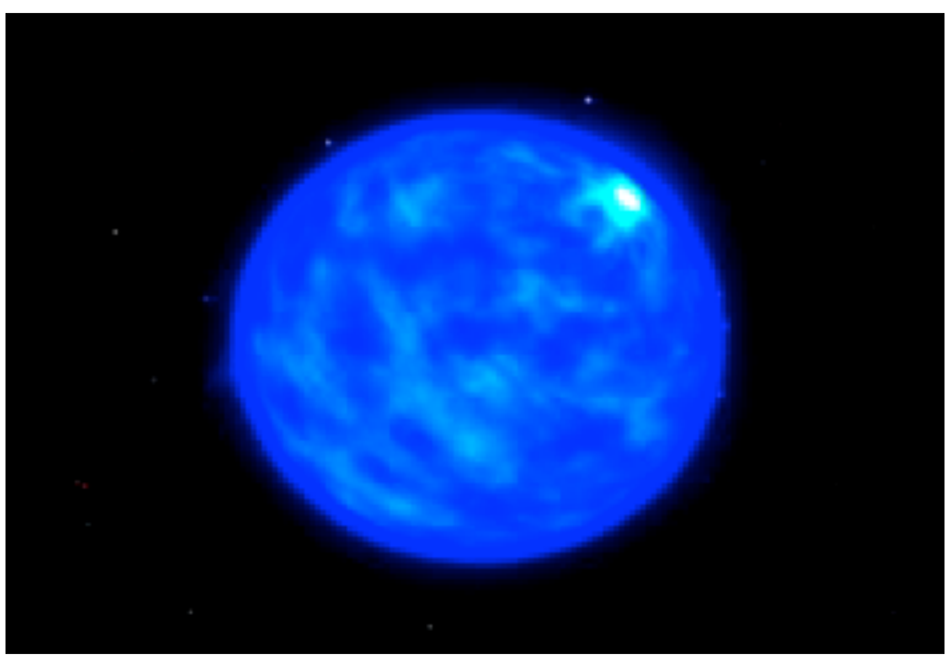


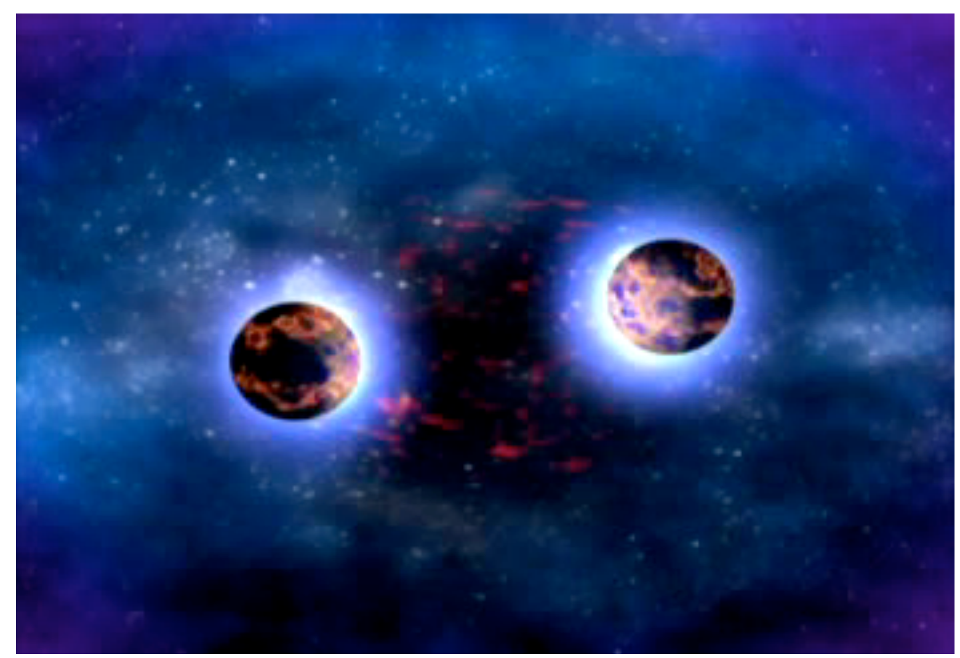
Paciesas et al. 99

There may be at least two types of GRB progenitor: one producing short GRBs, the other long GRBs

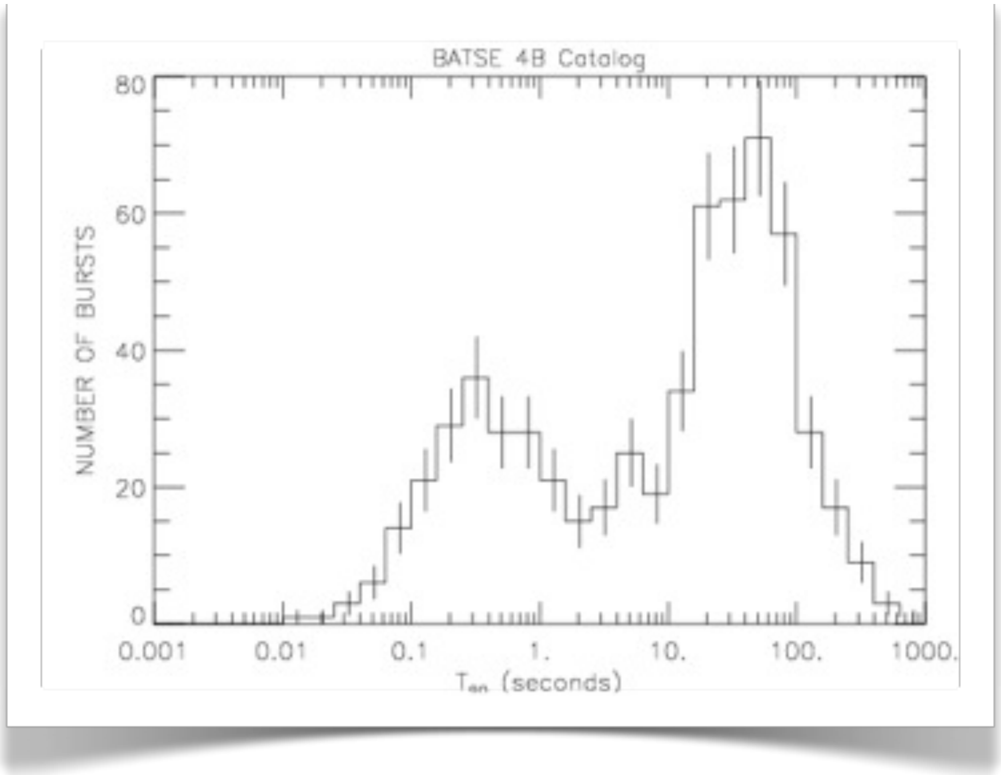


Paciesas et al. 99

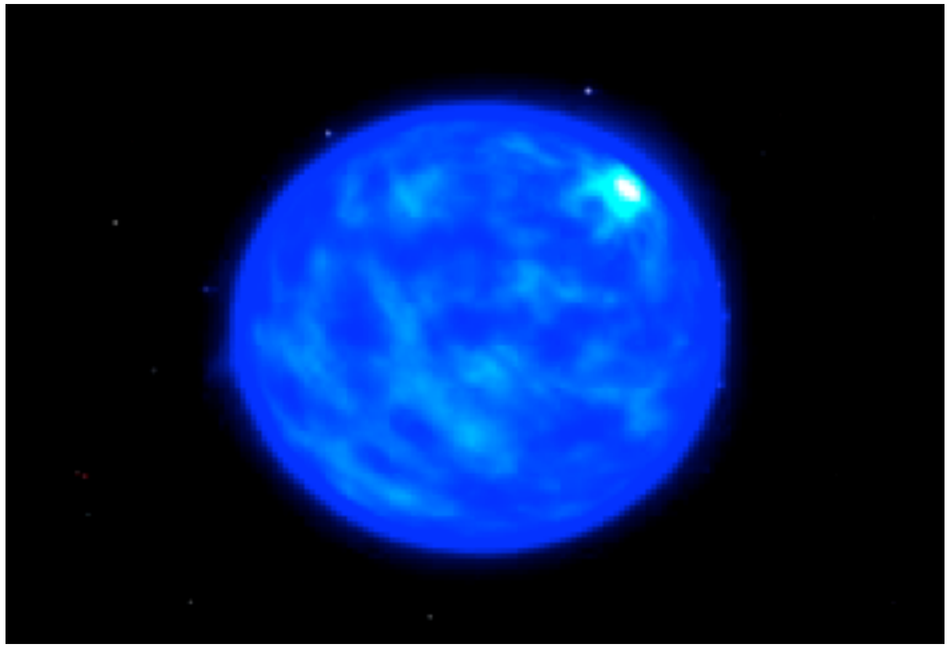


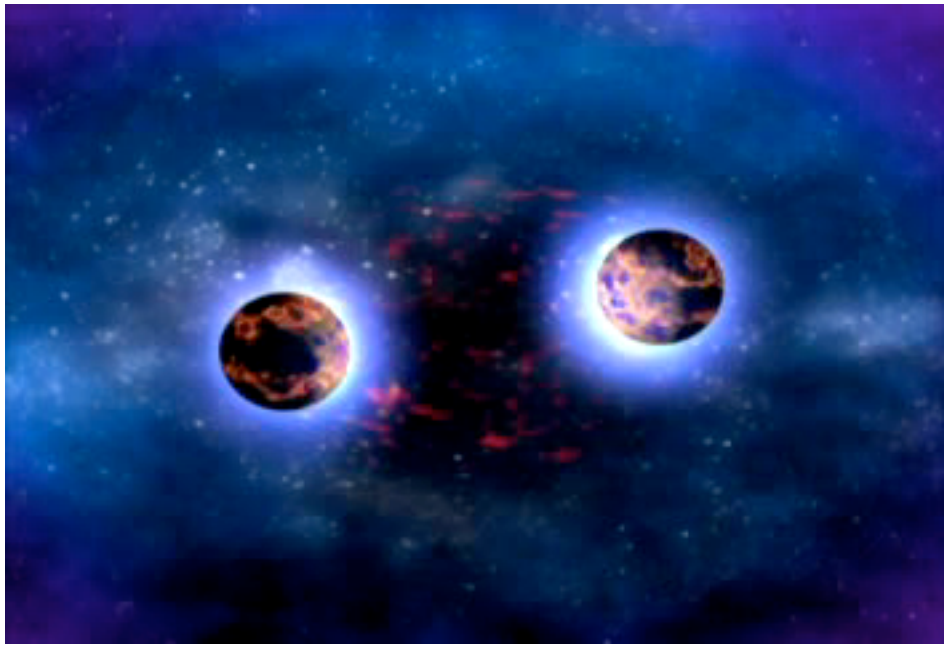


There may be at least two types of GRB progenitor: one producing short GRBs, the other long GRBs

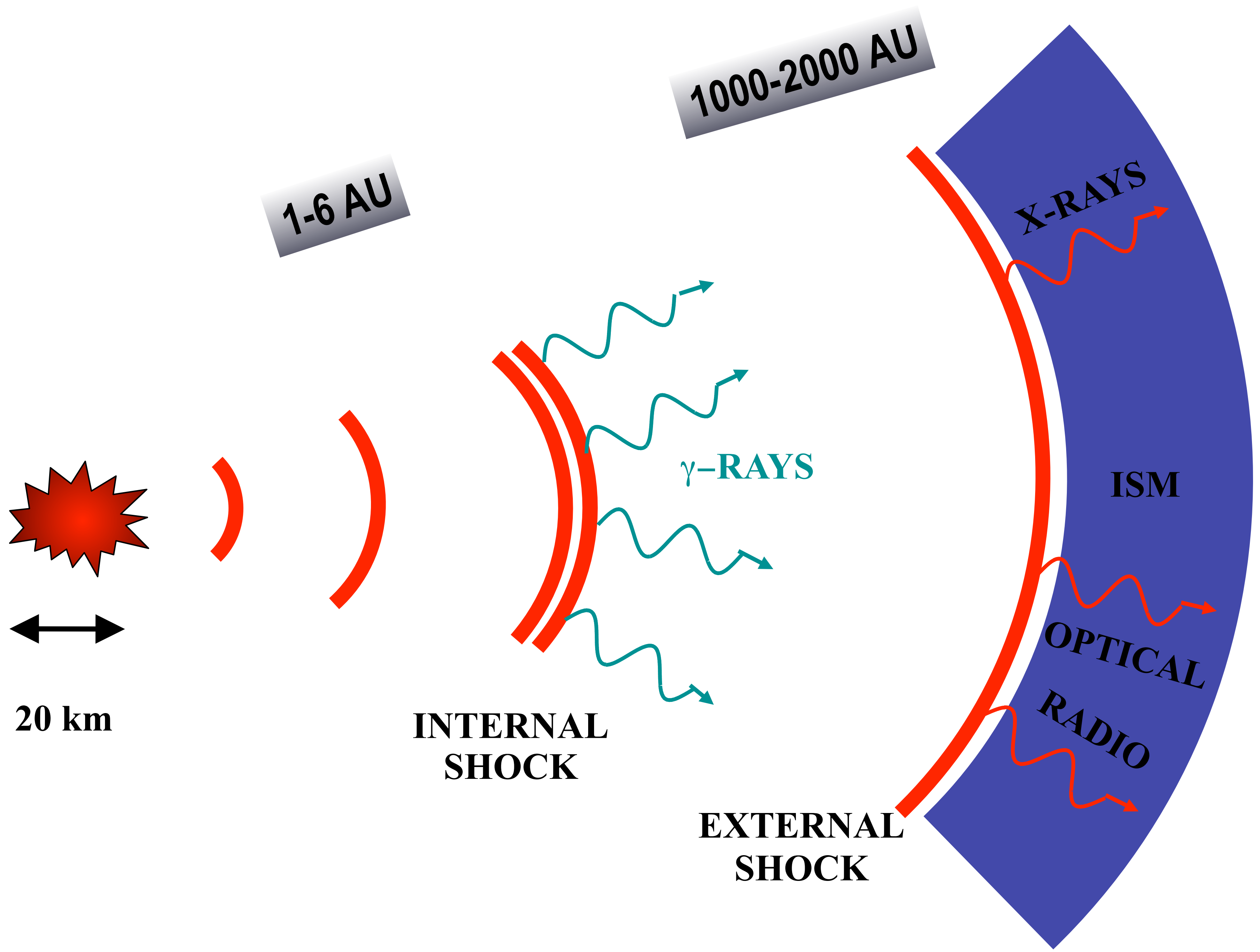


Paciesas et al. 99





The Cosmological Fireball



From Chuck Dermer