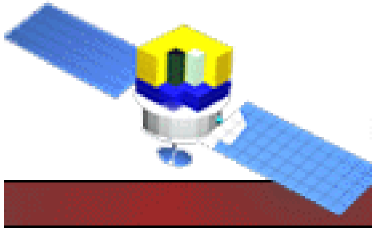
Two recent developments with Gamma Ray Burst Classification

And their implications for GLAST

Eric Charles

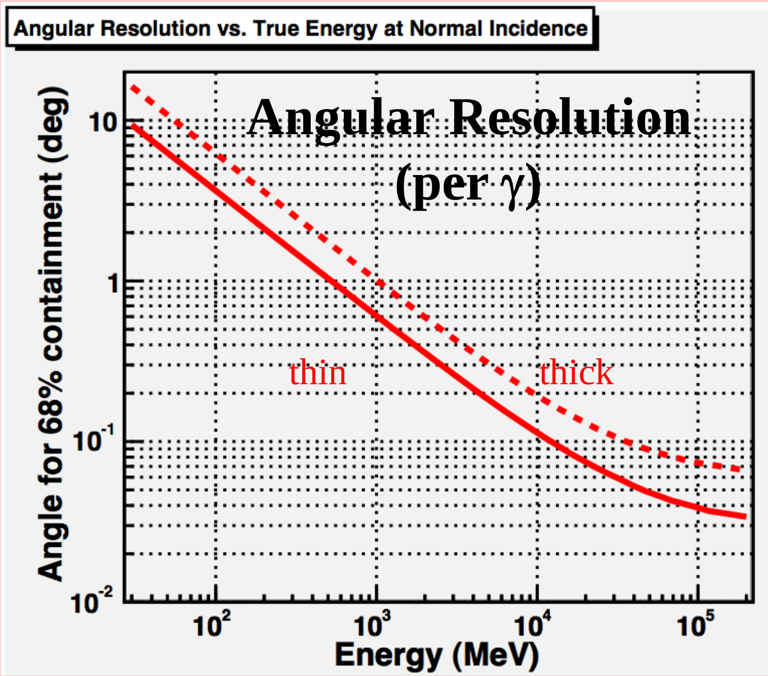


Glast Science Lunch
Nov. 2, 2006

Outline

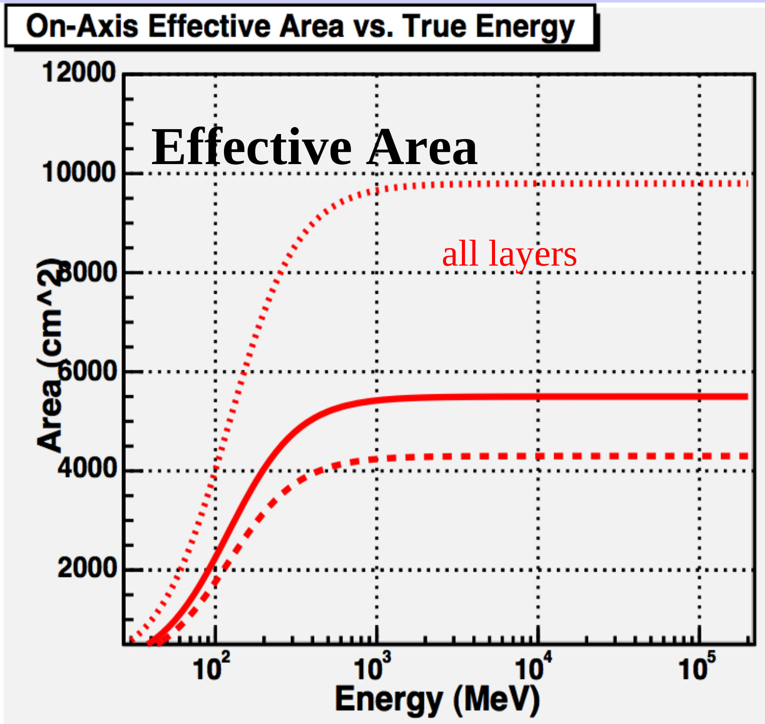
- Numerology, taxonomy and phrenology of GRBs
  - Salient facts for GLAST
    - Rates, spectra, variability, performance
  - Previous observations MeV – GeV
  - GRM models and phenomenology (phrenology?)
- Recent developments
  - Dichotomy in SHB/LSB environment
    - LSB: SFR. Consistent w/ SNe collapse
    - SHB: Older galaxies. Could favor binary merger model.
  - Non-observation of SNe in long bursts
  - Implications for GRB classification w/ GLAST data
- Conclusions

GLAST Performance I: LAT



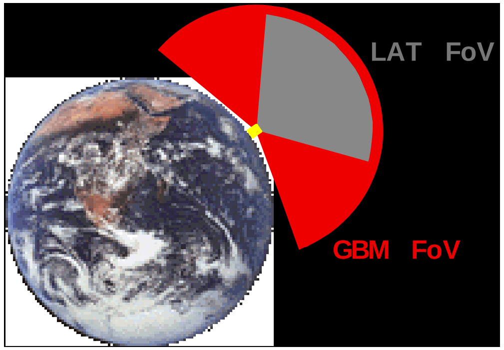
At 30 (100) MeV single photon
Angular resolution ~ 10° (3°)
PSF occupies 0.09 sr (0.0086 sr)

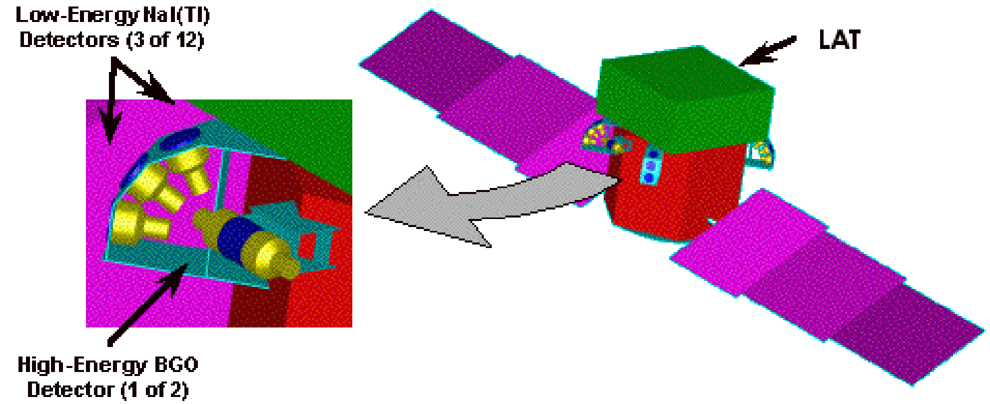
For typical observation angle
F = 40°:
$A_{eff}(40°) \sim 0.75\ A_{eff}(0°)$



http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm

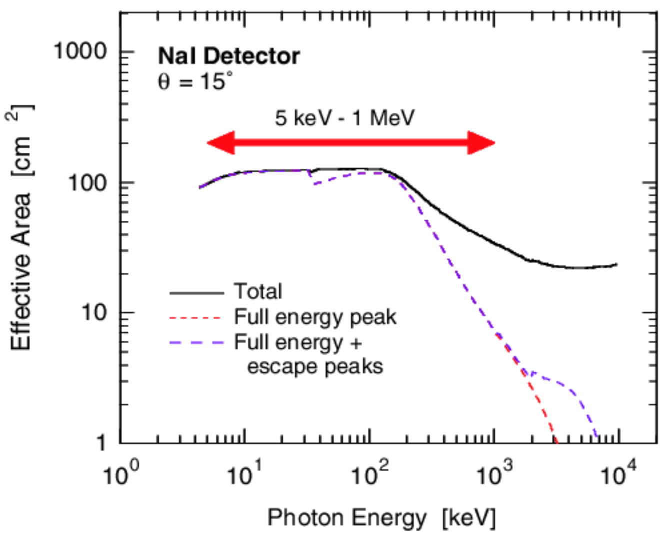
GLAST Performance II: GBM



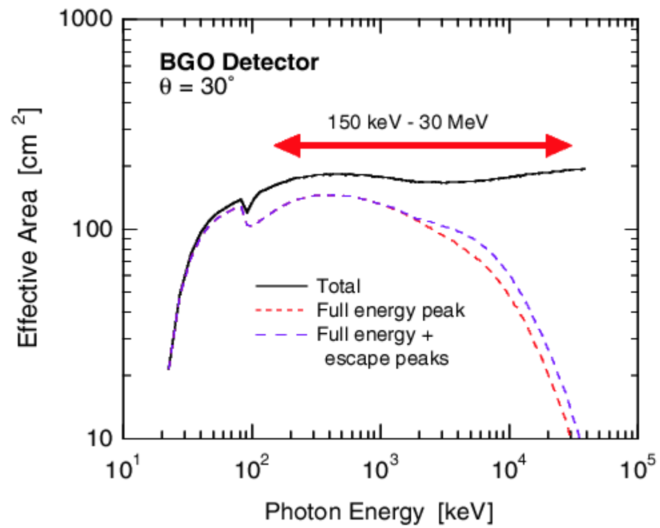


FoV = 9.5 sr

~200 GRBs/year, > 50 in LAT FoV



NaI crystals (12)



BGO crystals (2)

GBM A_{eff} ~ 100cm

1% of LAT A_{eff}

For E^{-1} ~ E^{-2}

Sensitivity ~ LAT

Salient features of GRBs I: Light curves

Highly variable.
Spikes 1ms and shorter:
LAT single g resolution ~ 0.5 us
LAT deadtime ~ 27 us
GBM deadtime ~ 3 us
EGRET deadtime ~ 200 ms

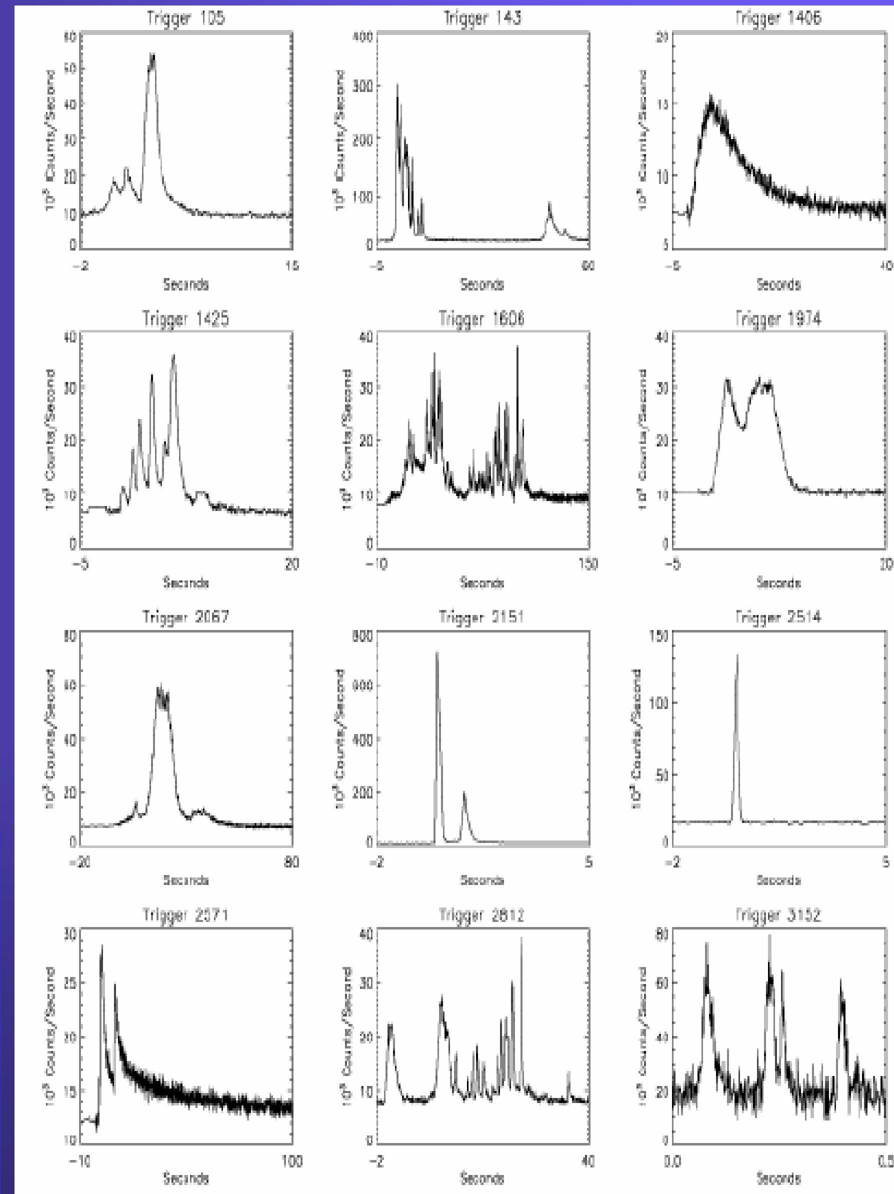
Diverse: no characteristic shape
(Individual spikes are more similar)

Bimodal duration distribution:
~ 0.2 s (short)
~ 20 s (long)

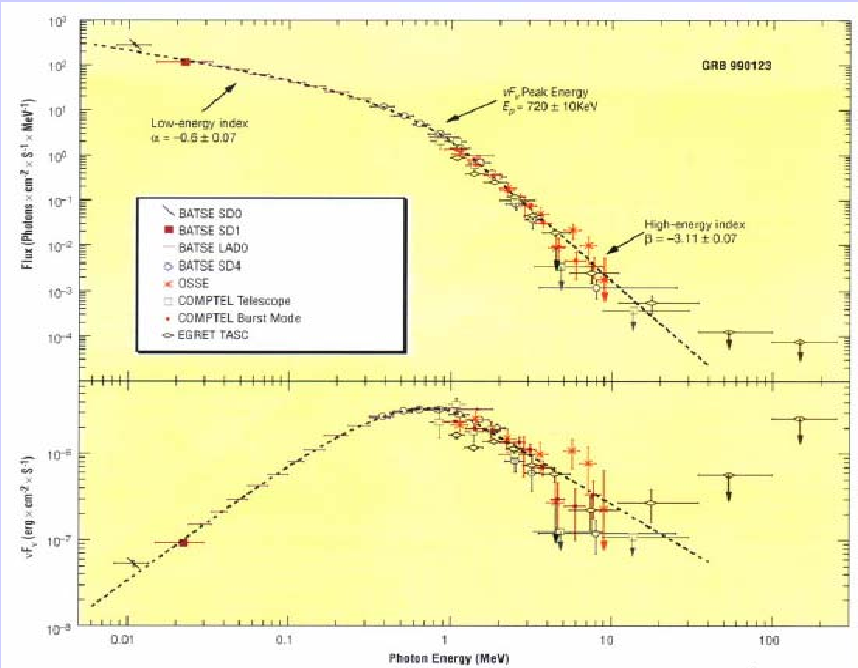
Canonical 2s division for long/short

Caveat:
I suspect some effort went into finding set of 12 bursts that all look different from each other.

Tricky combinatorial problem.
Probably solved with visual search.

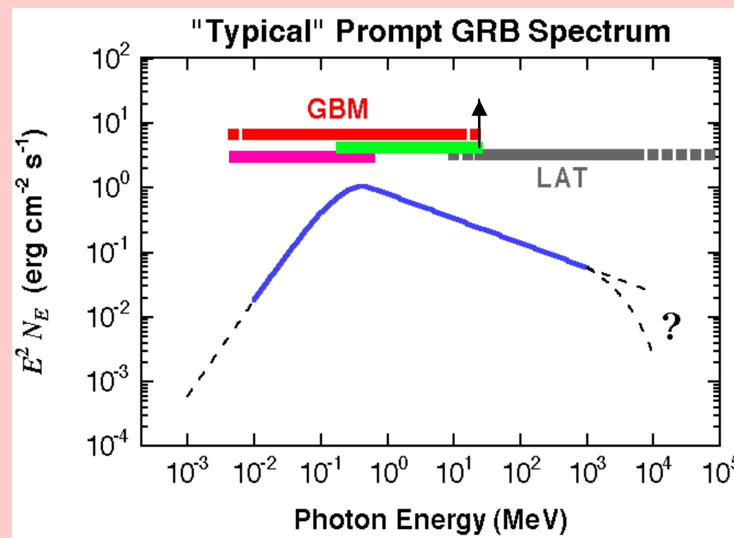


Salient features of GRBs II: spectra

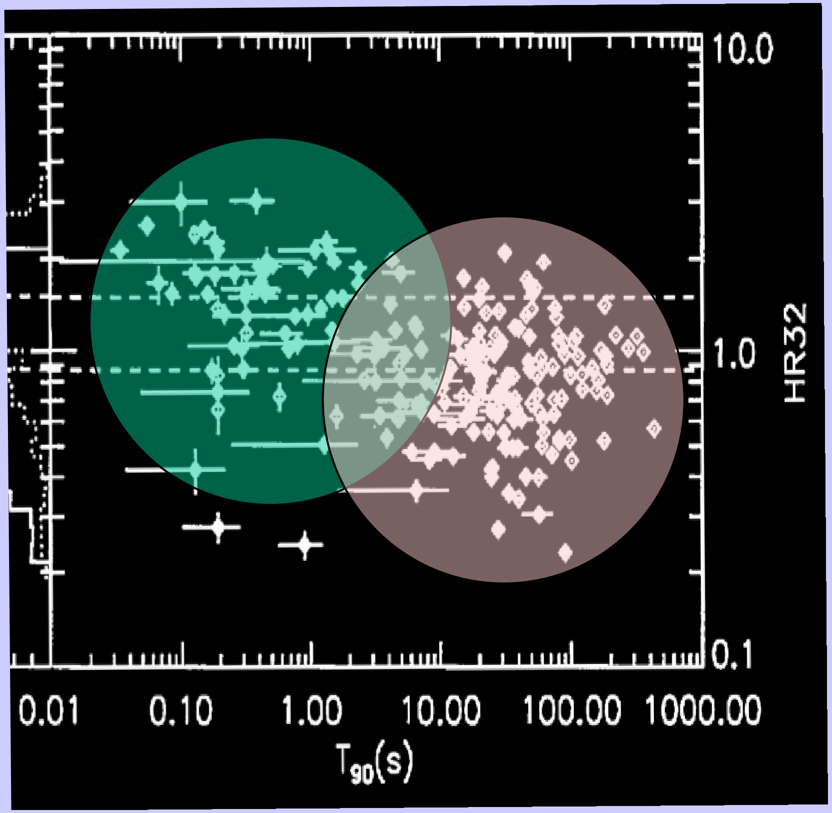


Spectra are well fit with broken power law
Low E (α ~ 1), High E (β ~ 2),
Peak Energy $E_p = E_0\,(2+\alpha)$
E_0 is power law break

Peak of SED falls right in the Middle of GBM band



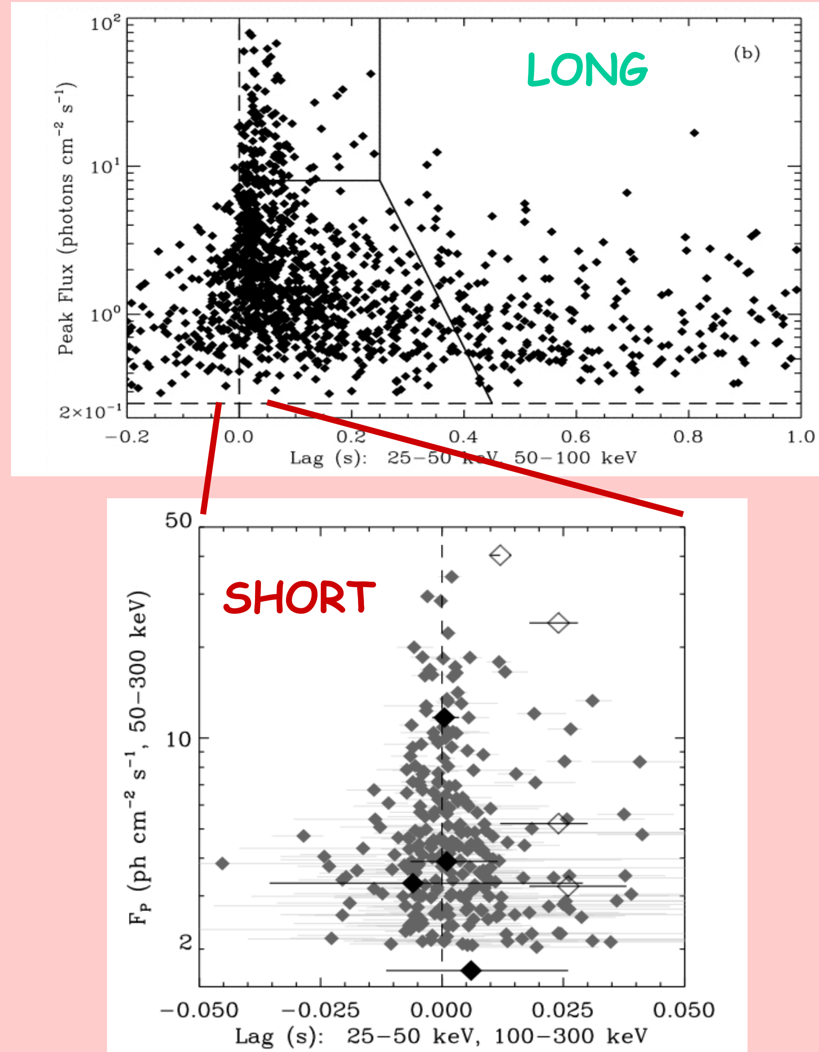
Salient features of GRBs III: classification



Short bursts tend to also be harder.

Short-Hard Burst (SHB) v.
Long Soft Bursts (LSB)

Spectral LAG in long bursts



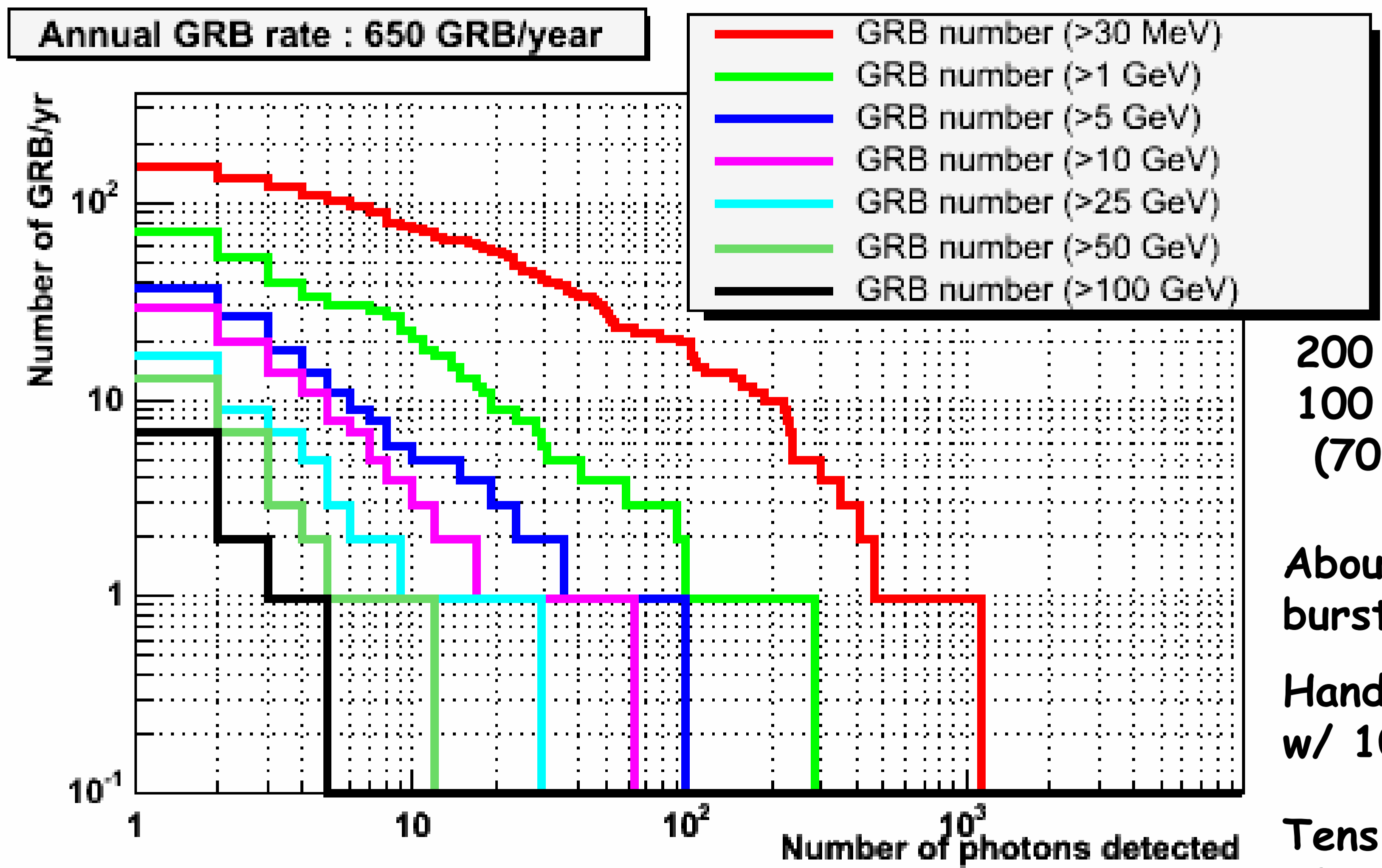
Norris 2002, Norris & Bonnell 2006

Some more GRB Key features

Agreed features:
Collimated, relativistic
Long/short dichotomy
Decaying afterglows/ re-flaring
Cosmological redshifts
Band spectrum
E_p ~ 40 KeV – 1 MeV
Some SNe association
Energy reservoir ~ SNe scale

Disputed features:
Jet opening angle value
Energy transport mechanism
HE γ emission mechanism
Source of high variability, large Δt / t
Observation angle
Bulk Lorentz factor (Γ ~ 30-1000)
Circumburst environment/ fields
Cephid type relations (standard candles?)
Polarziation
Degree SNe association

GLAST Performance III: Projections



200 Burst/ yr in GBM
100 Burst/ yr in LAT
(70 w > 10 counts)

About 20% of Swift bursts in LAT FOV

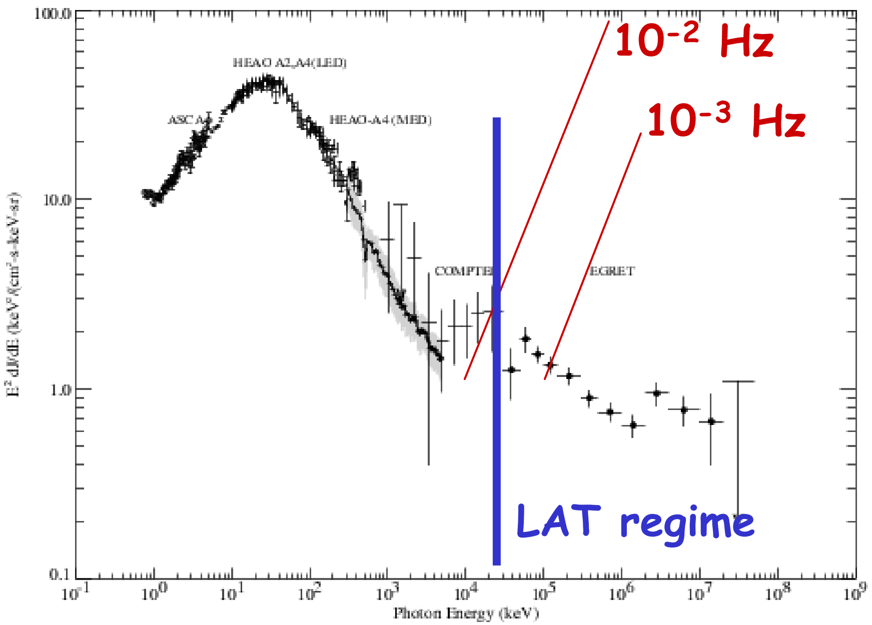
Handful of brigh bursts w/ 10s of γ above 1 GeV

Tens of thousands of burst photons

Extrapolation from BATSE data. Given the large (up to 5 decade) extrapolation and model dependence plot should be

Plot from N. Omodei's talk @ San Servolo, June 2006

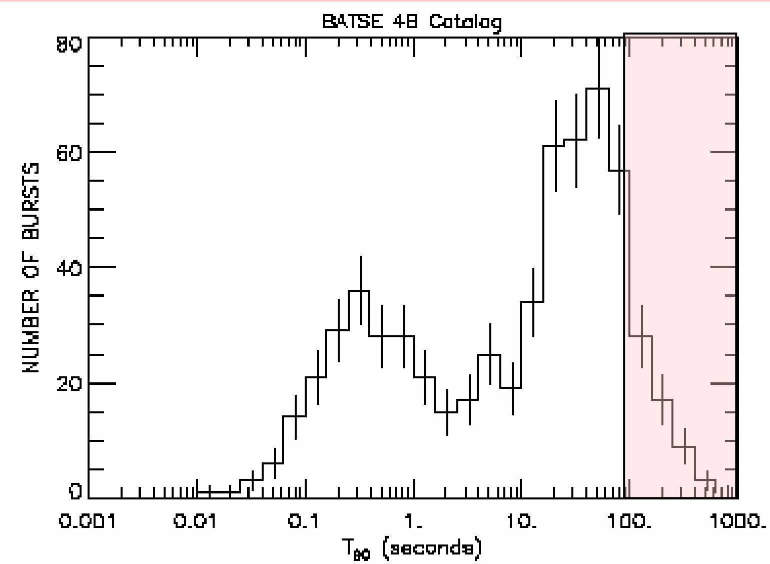
GLAST Performance IV: Backgrounds



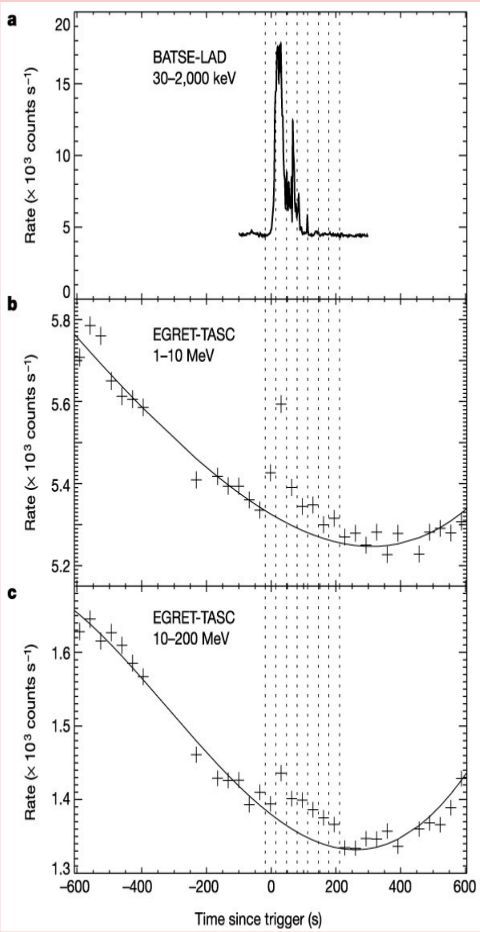
Timescale for random EGB photons in LAT GRB PSF is 10^2-10^3 s

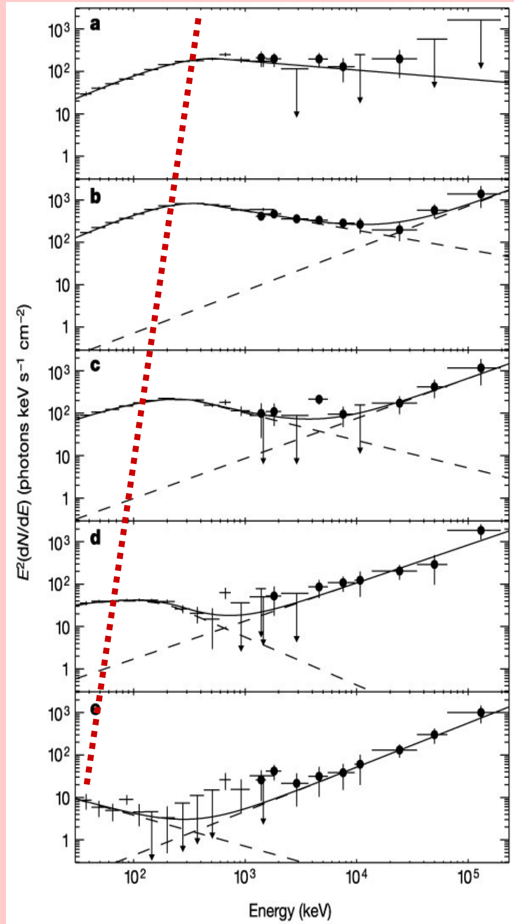
Prompt emission is nearly background free
Observing delayed emission on timescale of hours requires background subtraction/ statistics
Likewise, observing several bursts

Only the tails of the T_{90} distribution get to 10^2-10^3 s



Egret observations I: High energy component



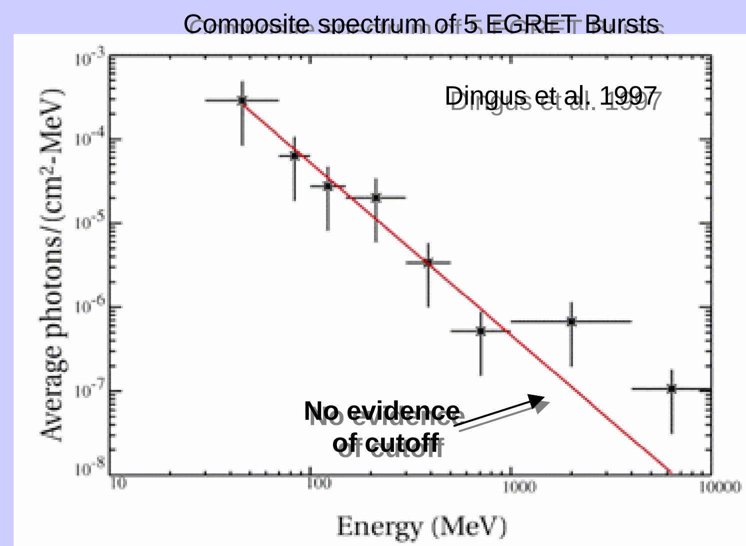


Evidence of HE component in GRB 941017

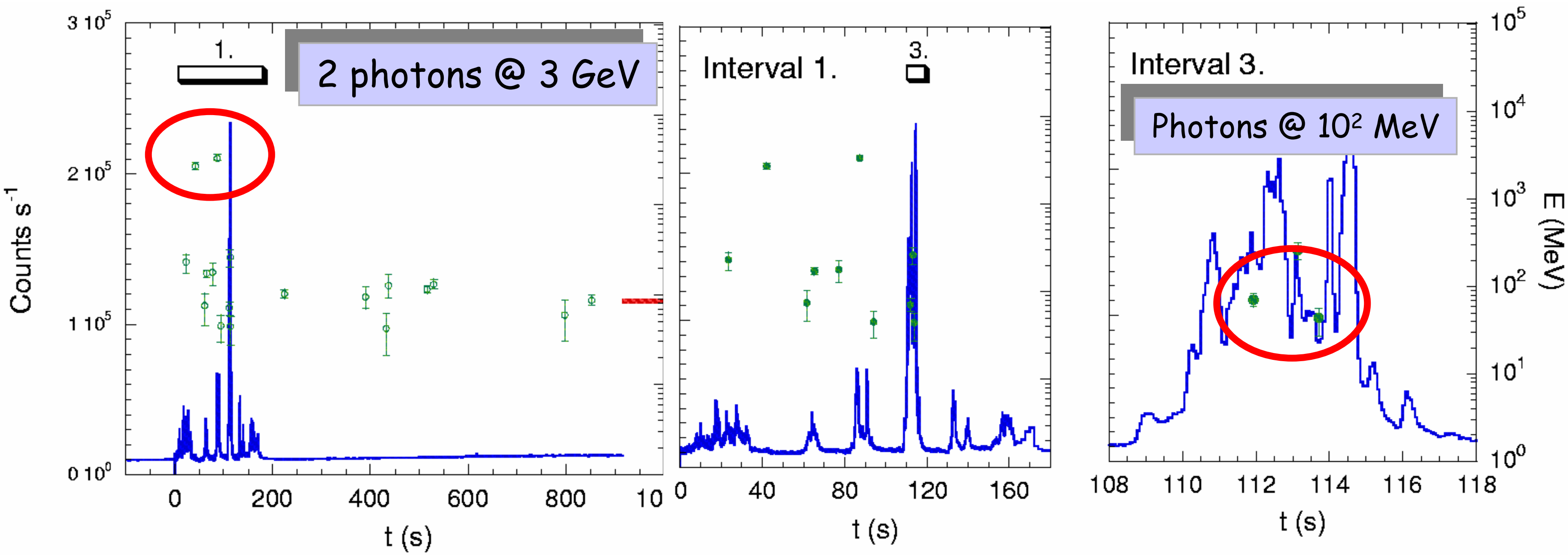
M.M. Gonzalez et. al. Nature 2003

Taking composite spectra of several GRB show no sign of HE cutoff

Caveat: diversity of GRBs could Introduce artifact in this type of analysis



Egret observations II: photons



Do observe photons co-incident w/ bursts
However Egret GRB observations only marginally quantitative

Particularly hampered for short bursts
1) Deadtime for pointing photons is similar to short burst time of 200ms
2) Short bursts are fainter, need more active area

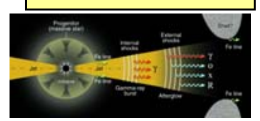
Delayed emission observed, but statistics too low to say much beyond that

Summary: GLAST results will quickly re-define HE emission picture

Taxonomy of GRB models

Type | Progenitor | Source of HE γ | Emission Model

- Long Bursts
  - SNe related
    - Cannonballs
    - Hadronic
      - Proton Synch.
      - pp,pn,pγ
    - EM Flux
    - Leptonic shocks
      - Internal
      - External
        - Forward
        - Reverse
  - Not SNe related
- Short bursts
  - Compact Merger → Diverse Theories
  - Magnetar → Diverse Theories



Larger variety of observations of long bursts.

Main point of this slide is to show wealth of models

GRB model predictions for GLAST

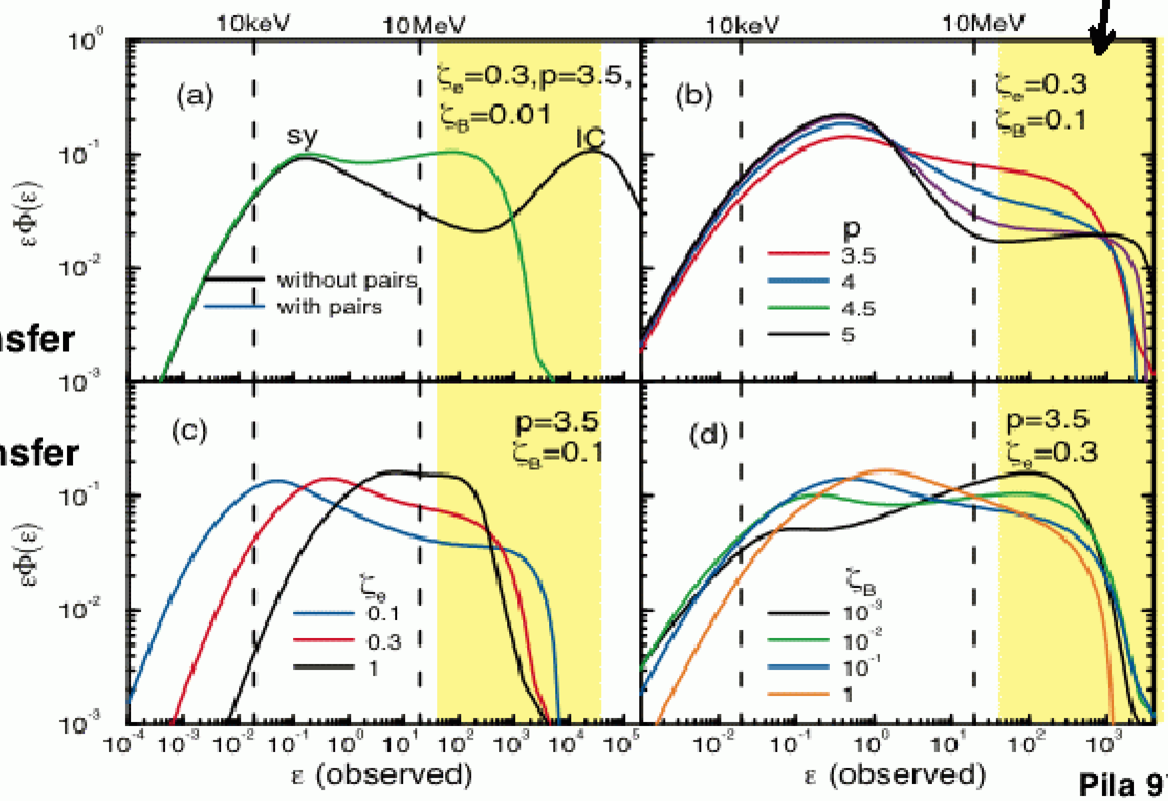
- **More elaborate model calculation.**
  - **Pair creation taken into account.**
  - **Parameter dependence studied.**

GLAST band

p: Fermi-acceleration index

ζ_e: fraction of energy transfer to electrons

ζ_B: fraction of energy transfer to magnetic energy



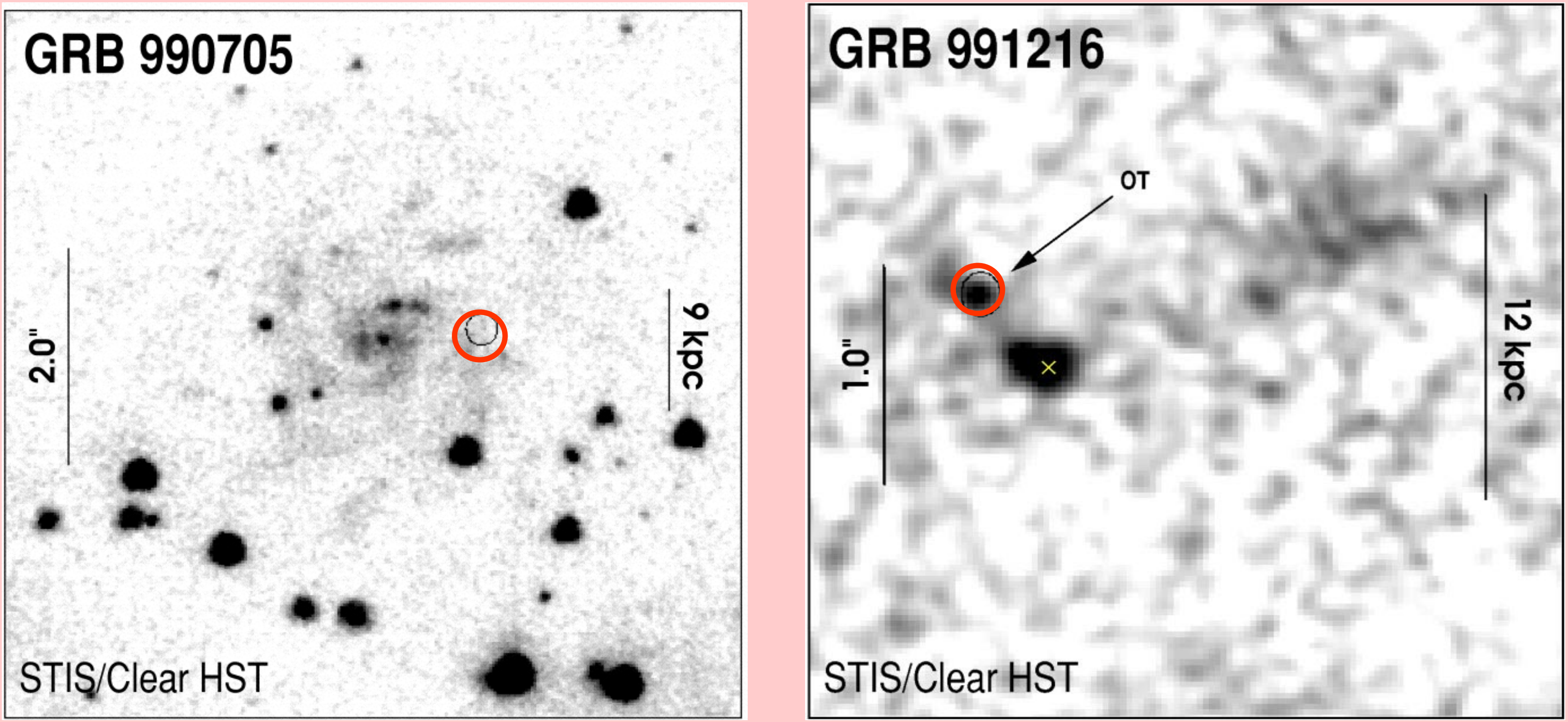
Pila 97

Entire slide stolen from H. Tajima's glast science lunch talk in 2004.
Could have taken slide from any of many talks.
Point is that w/ Glast w/ get a first quantitative look at important energy band for GRB

GLAST input on key questions

- Unification schemes
  - ie. viewing angle dependence, standard energy reservoir
    - GLAST good for model testing
- Bulk Lorentz factor
    - Glast measures cut-off in MeV-GeV spectra
- Time Variability
  - Glast has Δt resolution down to ~30us
    - Temporal localization of MeV-GeV emission
- Energy transport
  - Significant number of photons in MeV-GeV range
  - Measure position/ ration of SED peaks
    - Constrains energy fraction ε_B ε_e
  - High energy power law fits
    - Constrains emitter energy distribution

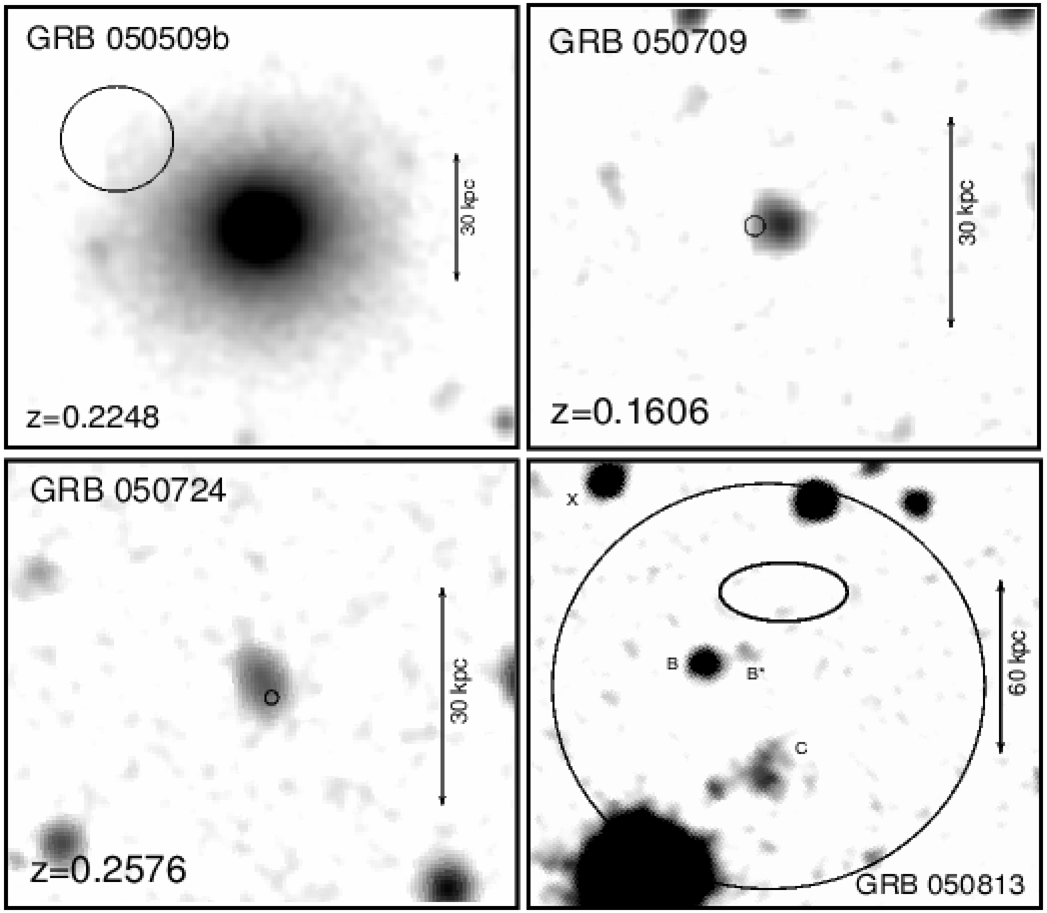
Long Burst Host Galaxy Associations

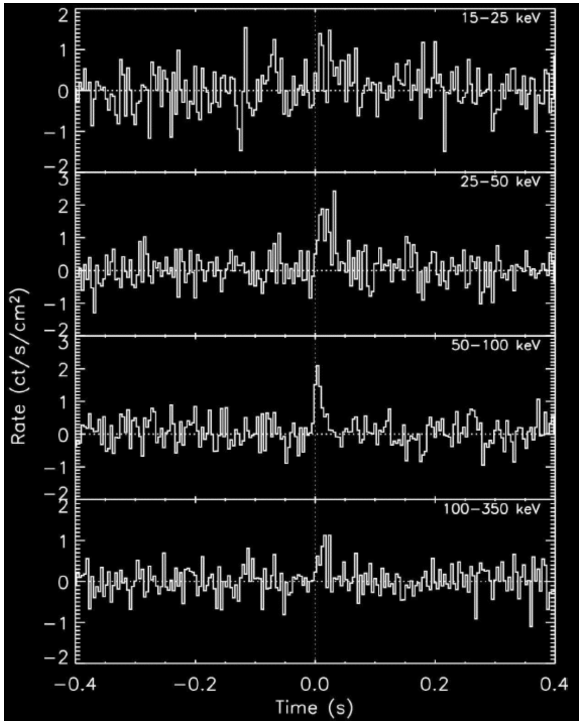


Bloom et al., ApJ,2002

Long-soft bursts localized to SF galaxies
No observed offset from galaxy core

First Short Burst Host Associations





Swift detection of rapidly decaying afterglow (~300s) of short (40ms) GRB 050509b Allowed host association

Prochaska+05 Gorosabel+05, Fox+05, Pedersen+05, Covino+05, Berger+05, Soderberg+06, Levan+06

Gehrels et. al. 2005

Gathering evidence of different progenitors

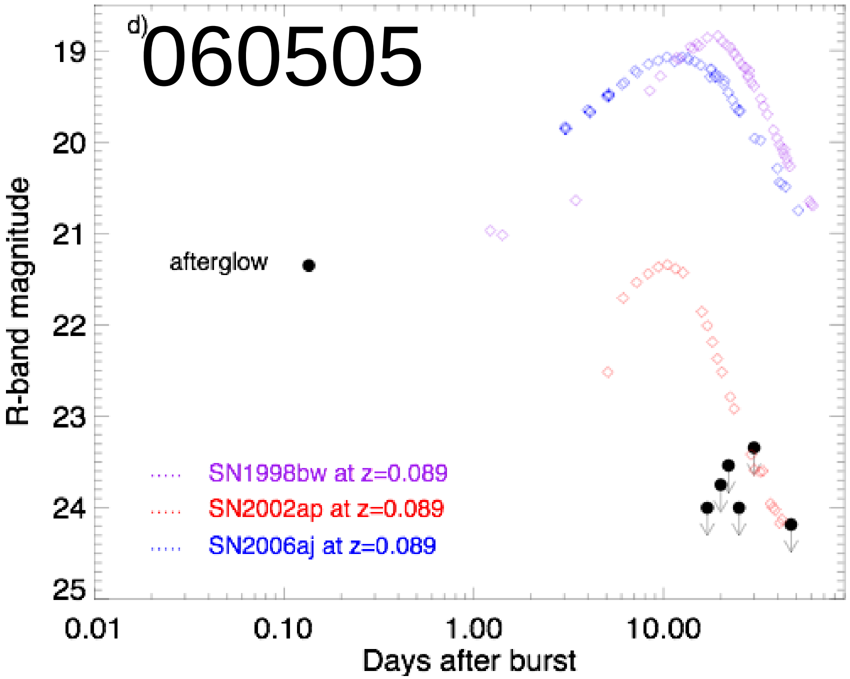
Properties of Short-Hard Burst hosts

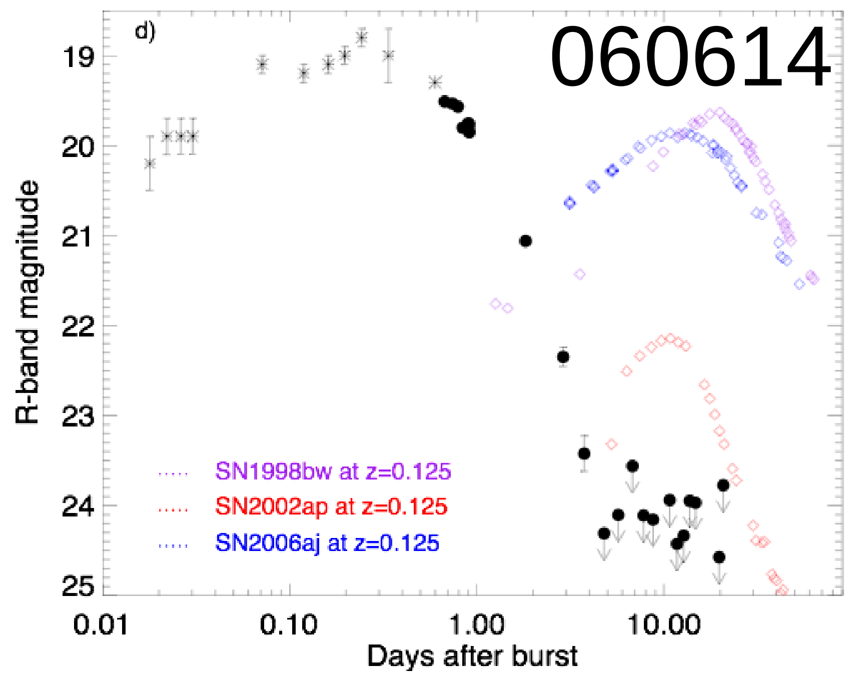
	redshift	host classification	SFR ($M_{\odot}\,yr^{-1}$)	burst offset [kpc]
050509B	0.225	E	< 0.1	39 ± 13
050709	0.160	Irr/late-type dwarf	> 0.3	3.5 ± 1.3
050724	0.258	early (E+S0)	< 0.05	2.4 ± 0.9
050813	0.722 (1.7?)	E?	< 0.2	33.2 ± 17.6

Diverse star forming rates. But lower than for long bursts
Offset from galaxy centers.

Bloom+05, Gorosabel+05; Gehrels+05, Prochaska+05…

Missing SNe in LSB GRB



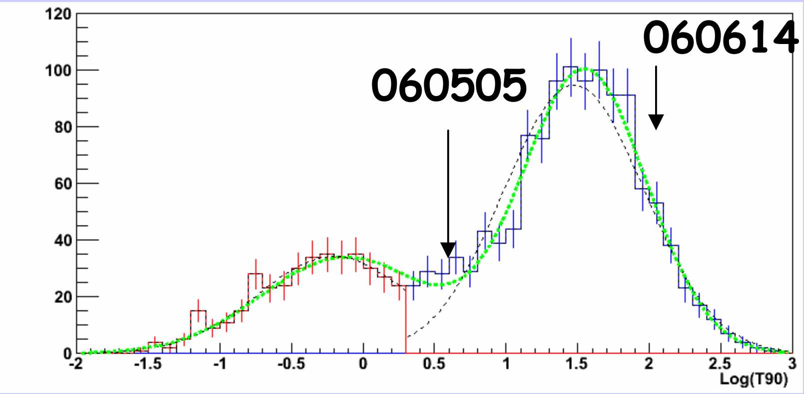


Non-observation of SNe in long bursts to less that 0.01 of "standard SN"

GRB	z	t_{90}	notes
060505	0.089	4s	faint burst
060614	0.125	102s	hard to soft evolution

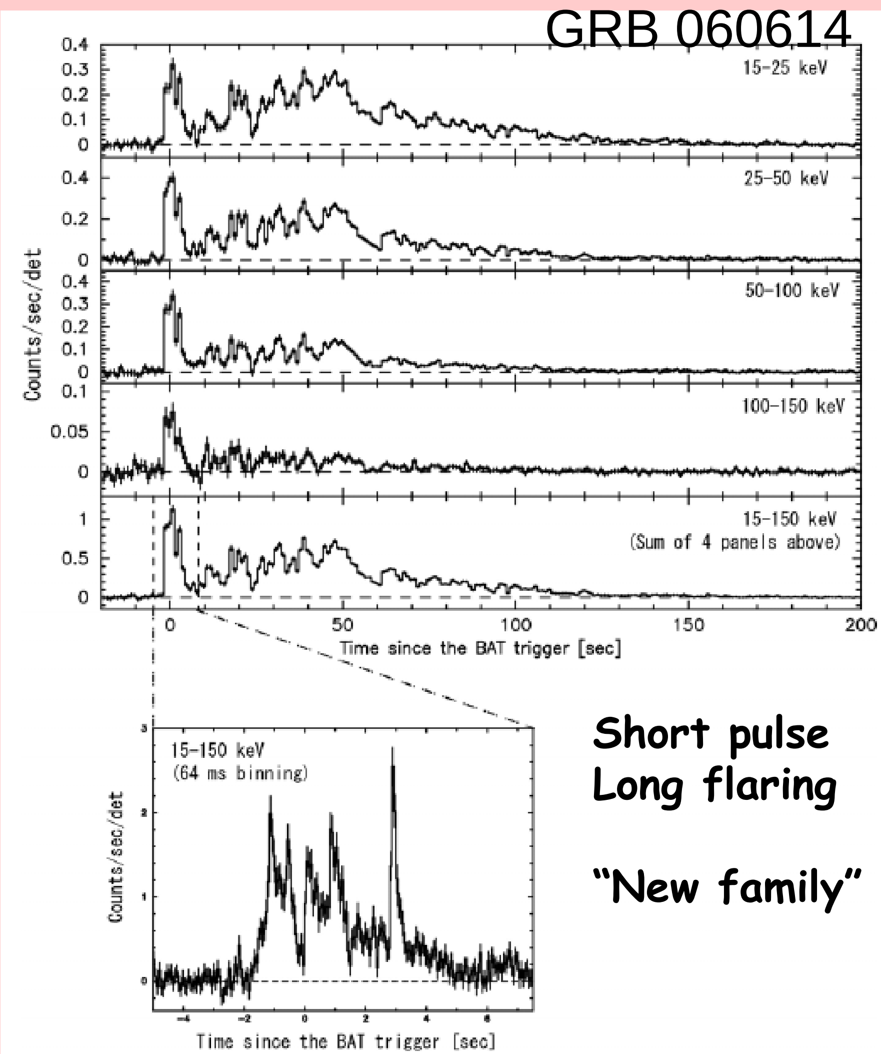
astro-ph/0608313. Fynbo et.al.

But were they really long-soft bursts?



Canonical 2s is:
1) Bandpass dependent
2) Minimum of $N(T_{90})$, not 50% probability point

Further analysis of SNe missing bursts raises issues w/ classification



Short pulse
Long flaring

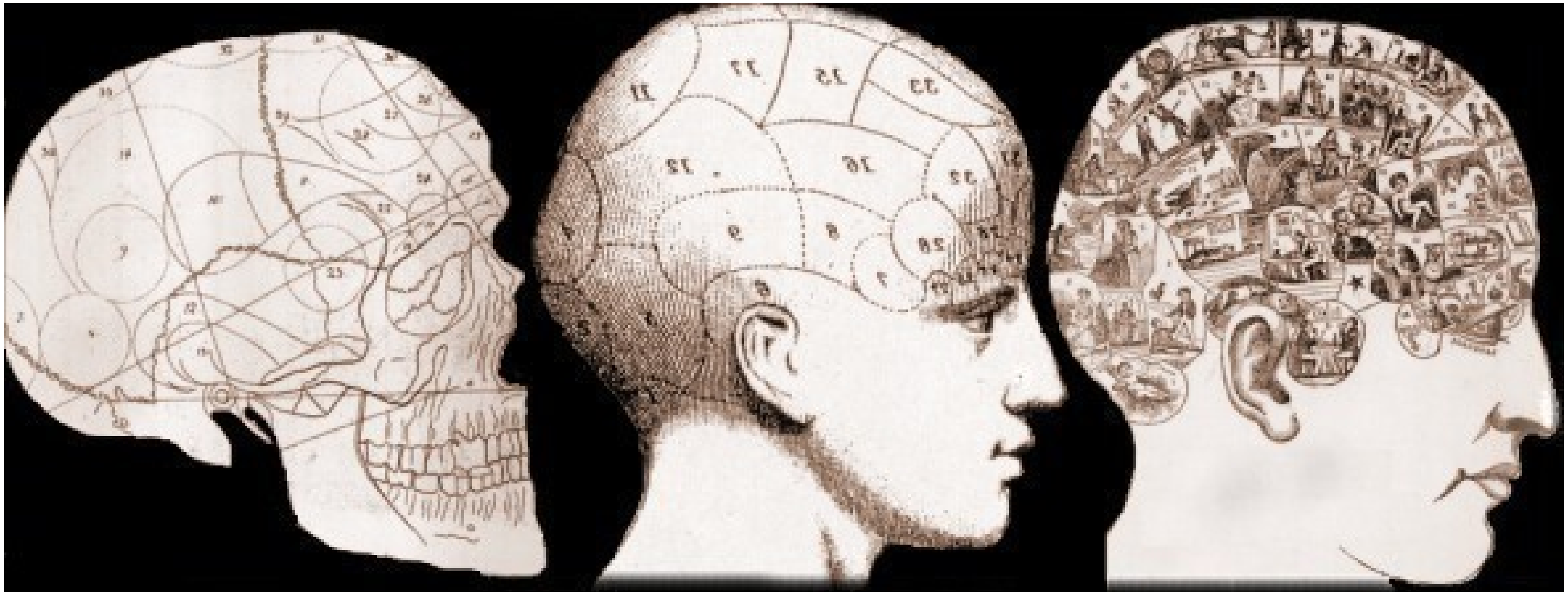
"New family"

astro-ph/0610635. Gehrels et.al.

Points about GRB classification w/ GLAST

- Clear evidence for at least two types of GRB progenitors
  - Duration, spectral index, host galaxy type, afterglow
- Accurate taxonomy required for obvious reasons
  - Model building/testing work better without outliers to explain
  - Using GRB for cosmology require accurate inputs
    - Low statistics, measurements can be badly pulled by outliers
- Any information that GLAST can add to taxonomy question is useful
  - Study GLAST specific burst classifications
    - Many GLAST bursts w/ no prompt SWIFT data
    - Provide x-correlation for those bursts which do
  - 25-35% of GBM bursts have significant number of LAT γs
    - What can LAT γs add to GRB classification?

Lessons from Phrenology



"Be cautious in the interpretation of bumps"

Conclusions

- Recent results have refined (or challenged) existed GRB taxonomy
  - Localization of Short-Hard burst to halo of older, elliptical galaxies favor compact binary merger models over SNe
  - Missing SNe in two recent bursts prompt re-examination of Long/Short burst differentiation
- GLAST will be have much to add to this discussion
  - GBM covers critical 8 KeV – 30 MeV range
    - Measuring peak of prompt spectra past 1MeV
  - Sensitivity in 5MeV – 100 GeV range commensurate w/ Swift
    - Constrains emission mechanism model
    - May provide good discrimination between burst types
  - Improved time resolution may add information about HE emission
- Will need to re-examine GRB classification in light of GLAST data before running off to measure dark energy