The Fermi Era : Towards a Better Understanding of the GRB Prompt Emission

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on behalf of the Fermi GBM and LAT collaborations

NASA POSTDOCTORAL PROGRAM
Administered by Oak Ridge Associated Universities

Fermi Gamma-ray Space Telescope

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Conclusion

- **Thanks to Fermi, we now know A LOT more about GRB prompt emission.**

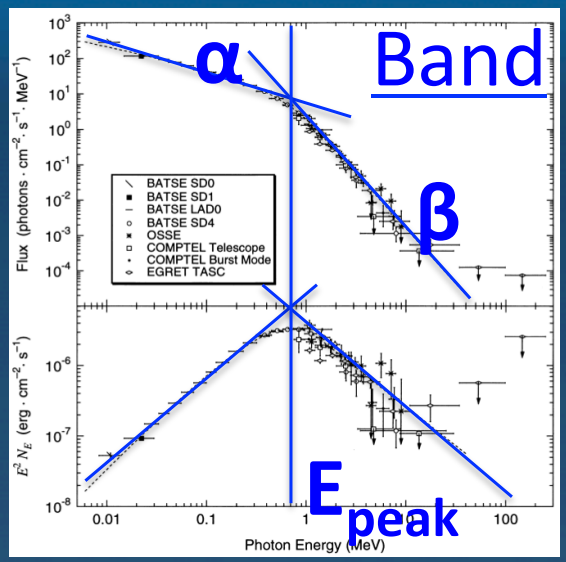
- **But alas NOT everything !**

Outline

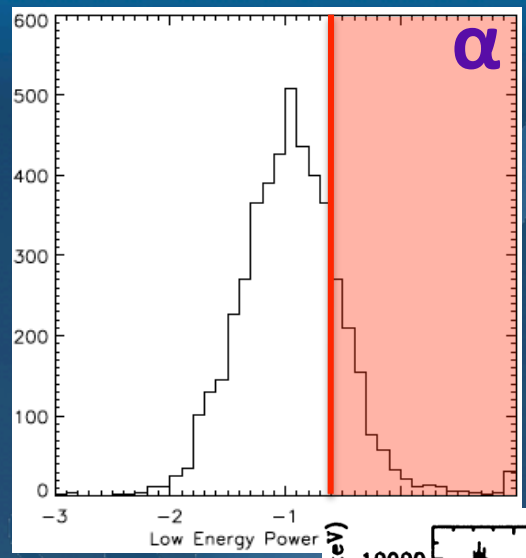
- Pre-Fermi Era (CGRO)
- Fermi Era
- How these observations challenge and support the models ?

Prompt Emission Before Fermi

Band function, an adequate model

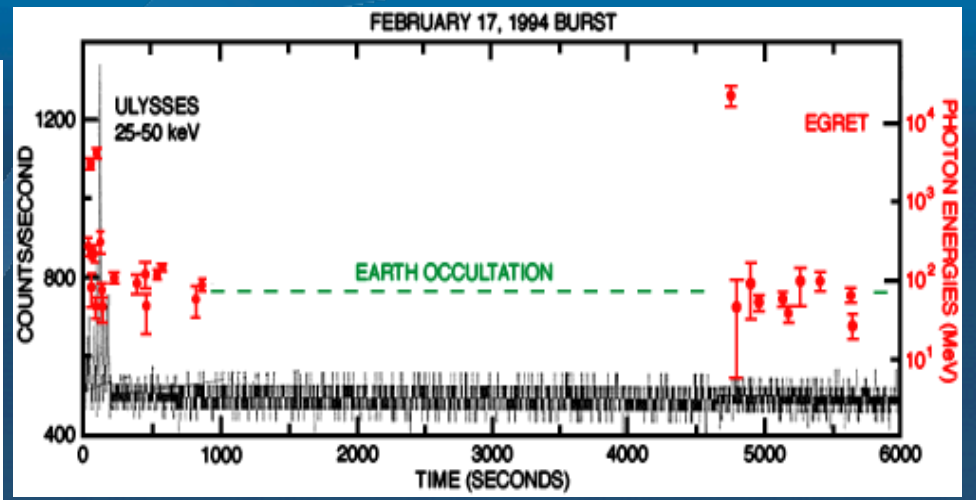


(Briggs et al. 1999, ApJ, 524, 82-91)

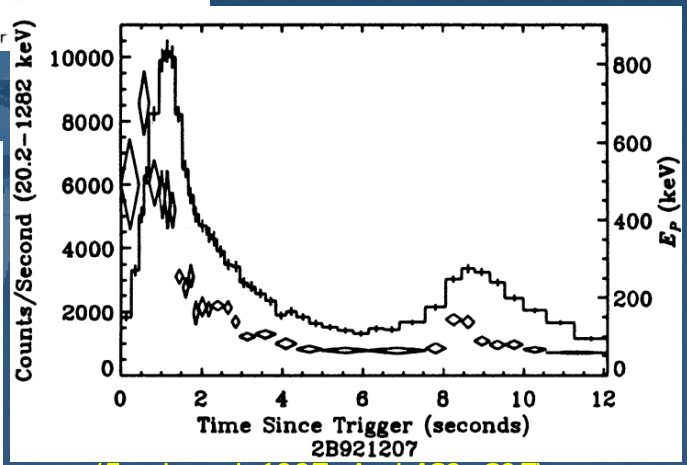


(Preece et al. 2000, ApJS, 126, 19-36)

Extended HE emission

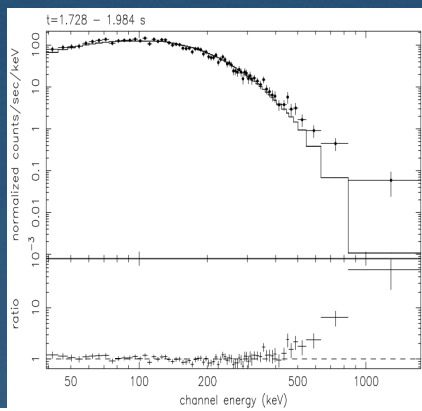


Time-Resolved



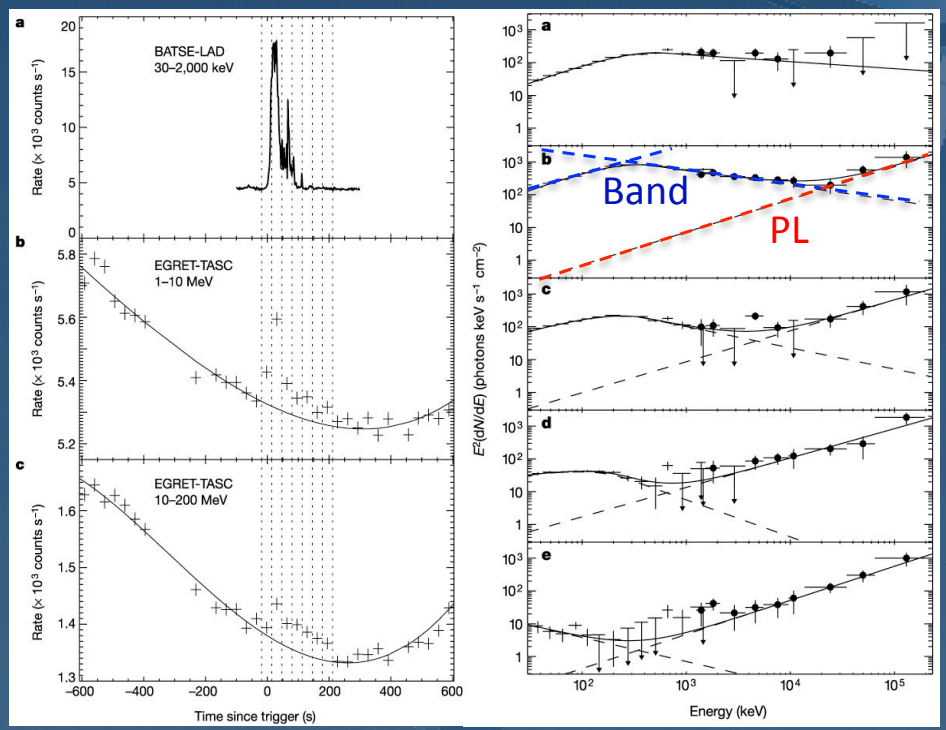
(Ford et al. 1995, ApJ 439, 307)
(Kaneko et al. 2006, ApJS 166, 298K)

Thermal Component

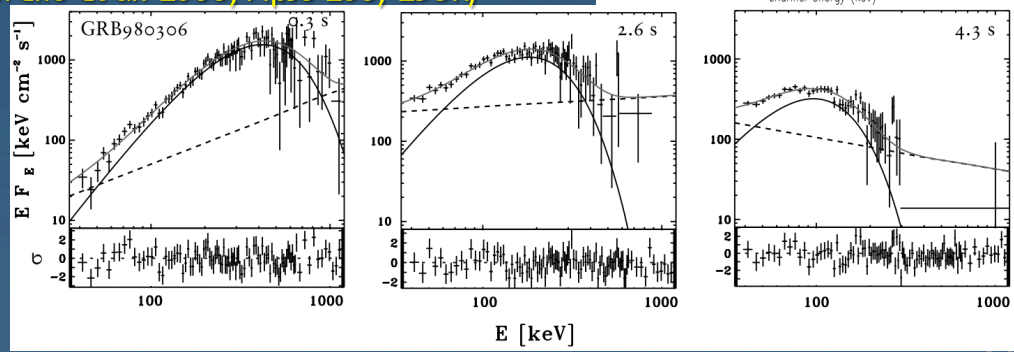


(Ghirlanda et al. 2003, A&A 406, 879)

Additional PL at HE



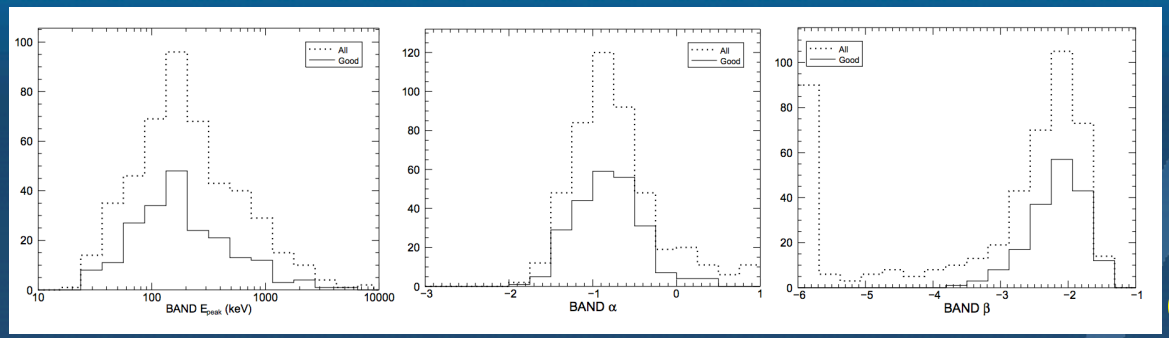
(Gonzalez et al. 2003, Nature 424, 749)



(Ryde et al. 2005, ApJ 625, L95)

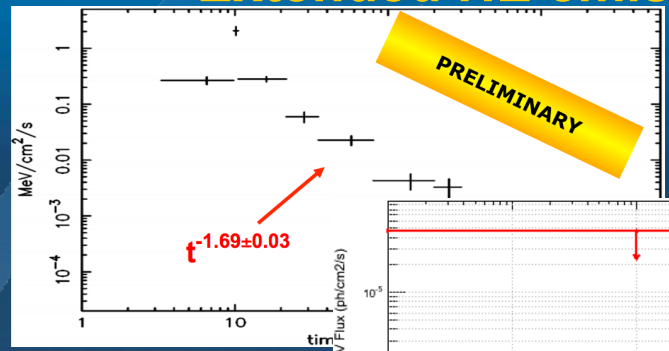
Confirmation in the Fermi Era

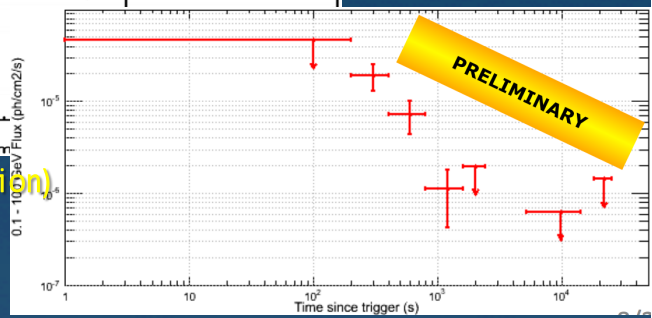
Band function, an adequate model



S. McBreen talk and A. Goldstein's poster P-II-24 & (Goldstein et al. 2012, ApJS 199, 19G)
F. Piron talk & (Abdo et al. in preparation)
(Nava et al. 2011, MNRAS 415, 3153N)
(Zhang et al., 2011, ApJ, 730, 141Z)

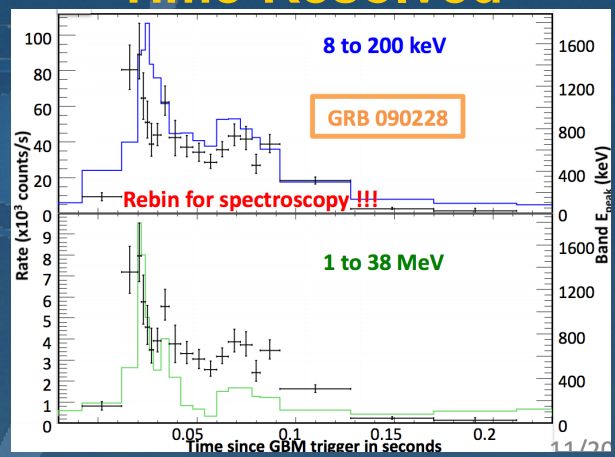
Extended HE emission





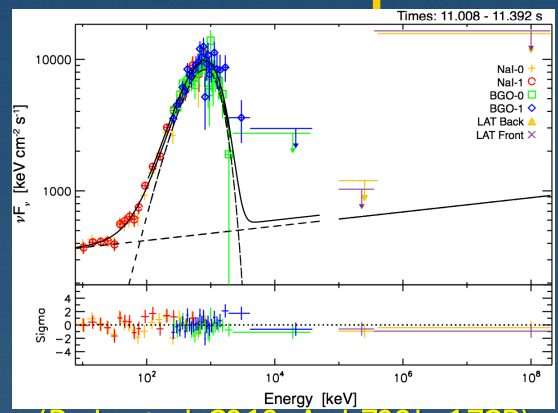
(Abdo et al. in preparation)

Time-Resolved



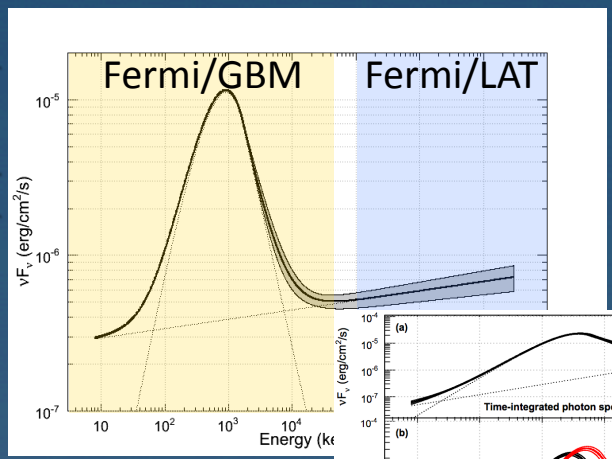
(Guiriec et al. 2012, ApJ 725, 225G)
(Lu et al. 2012, arXiv: 1204.0714)

Thermal Component

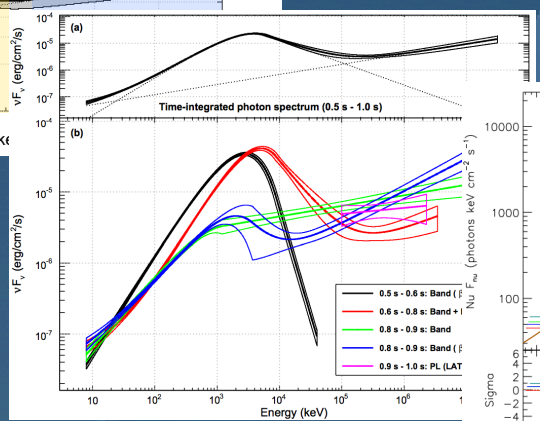


(Ryde et al. 2010, ApJ 709L, 172R)
(Zhang et al., 2011, ApJ, 730, 141Z)

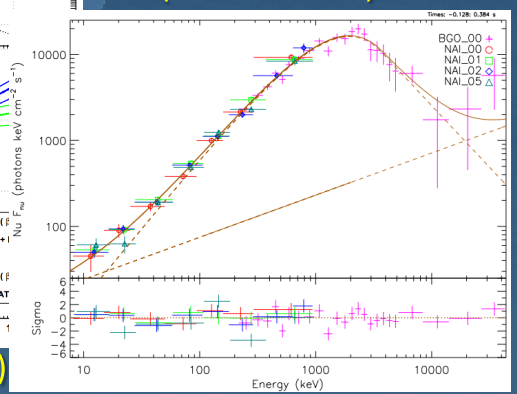
Additional PL



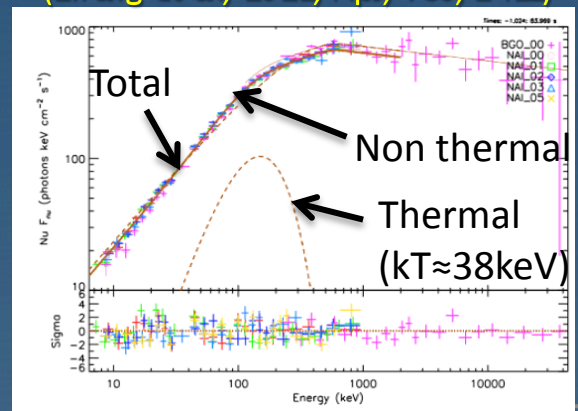
(Abdo et al. 2009, ApJL 706, 138)



(Ackerman et al. 2010, ApJ 716, 1178A)



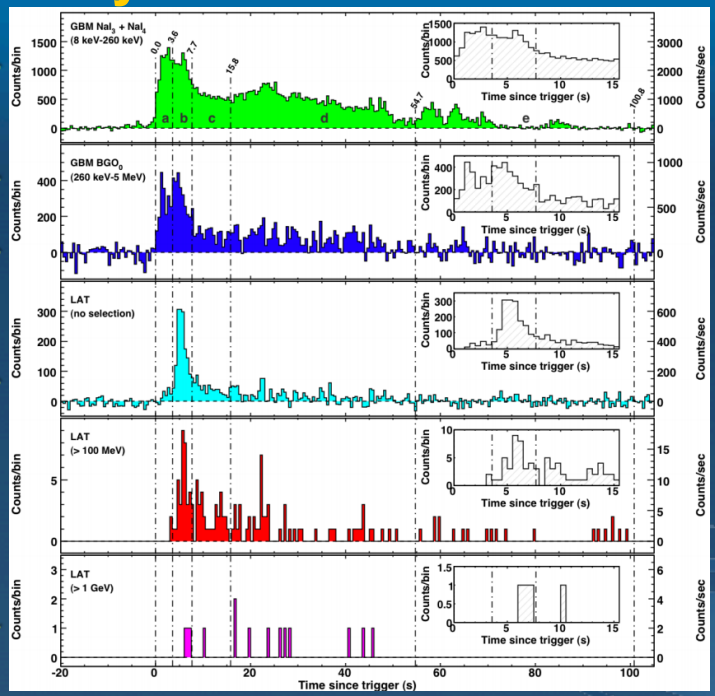
(Guiriec et al. 2010, ApJ 725, 225G)



(Guiriec et al. 2011, ApJL 727, L33)

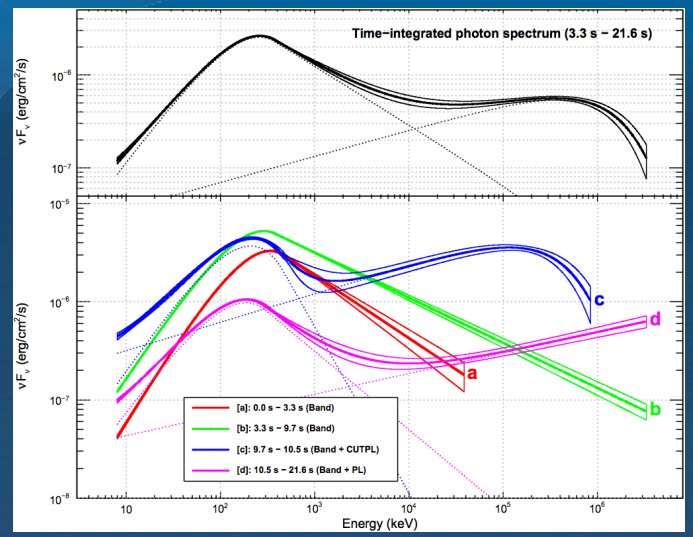
And New Results !

Delayed >100 MeV Emission



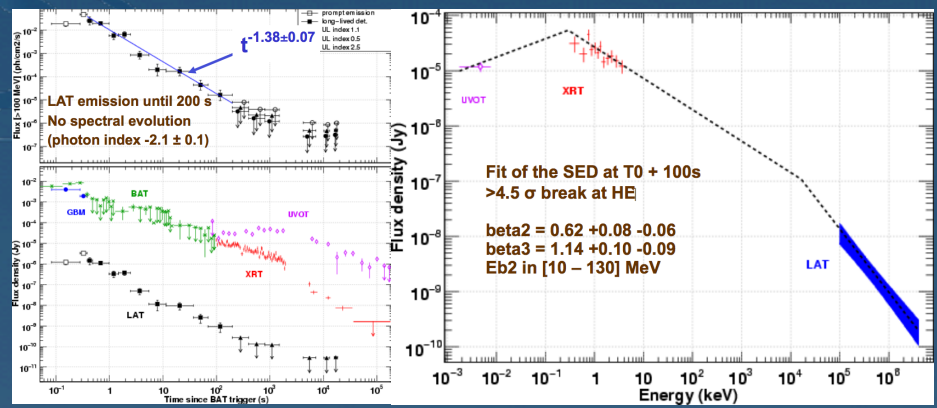
(Abdo et al. 2009, Science, 323, 1688A)

Cutoff in the Additional PL



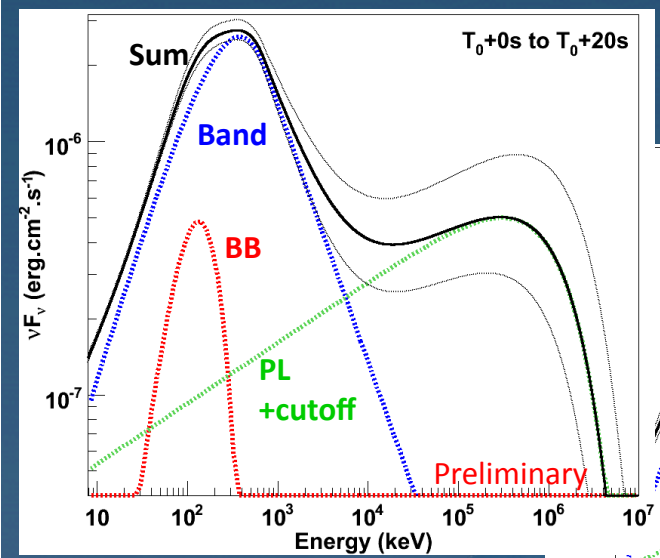
(Ackermann et al. 2011, ApJ 729, 114A)

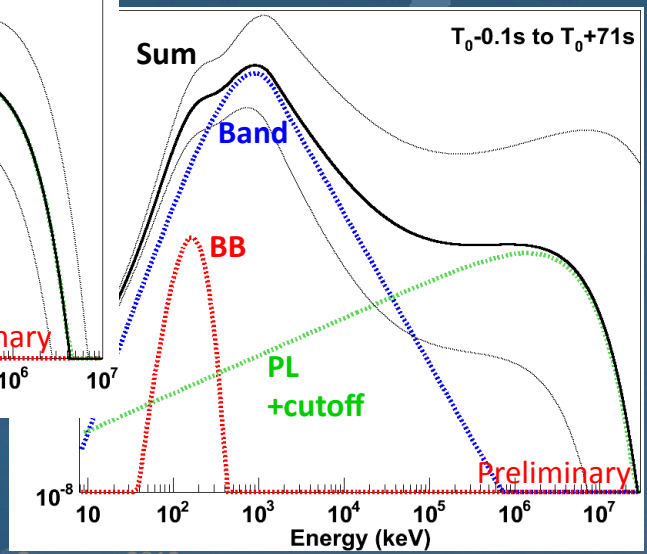
Multi-Wavelength Afterglow



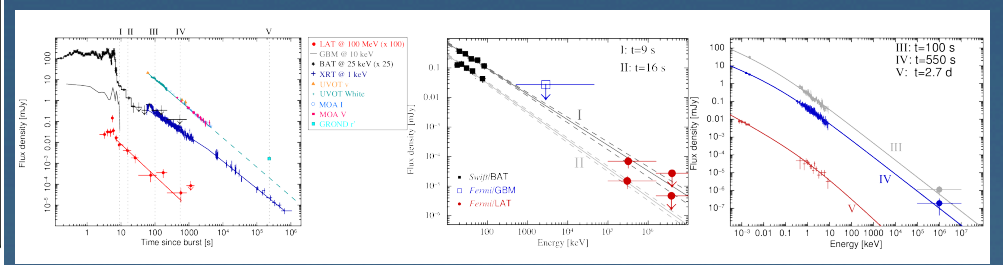
(De Pasquale et al. 2010, ApJL 709, 146)

Multiple Spectral Components





(Guiriec et al. in preparation)

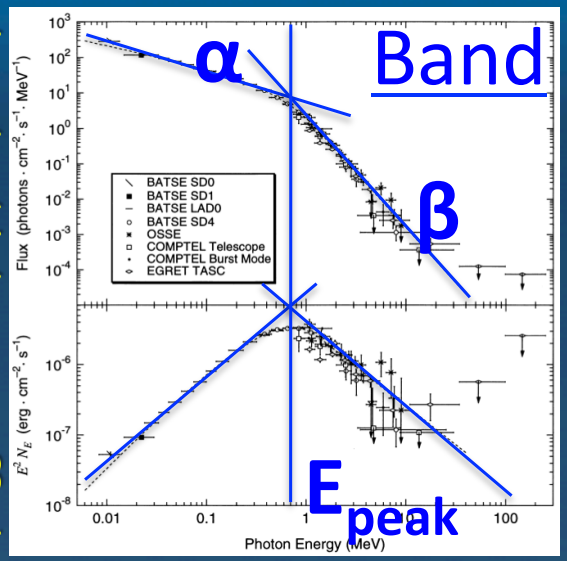


J. Bregeon talk & (Abdo et al. in preparation)

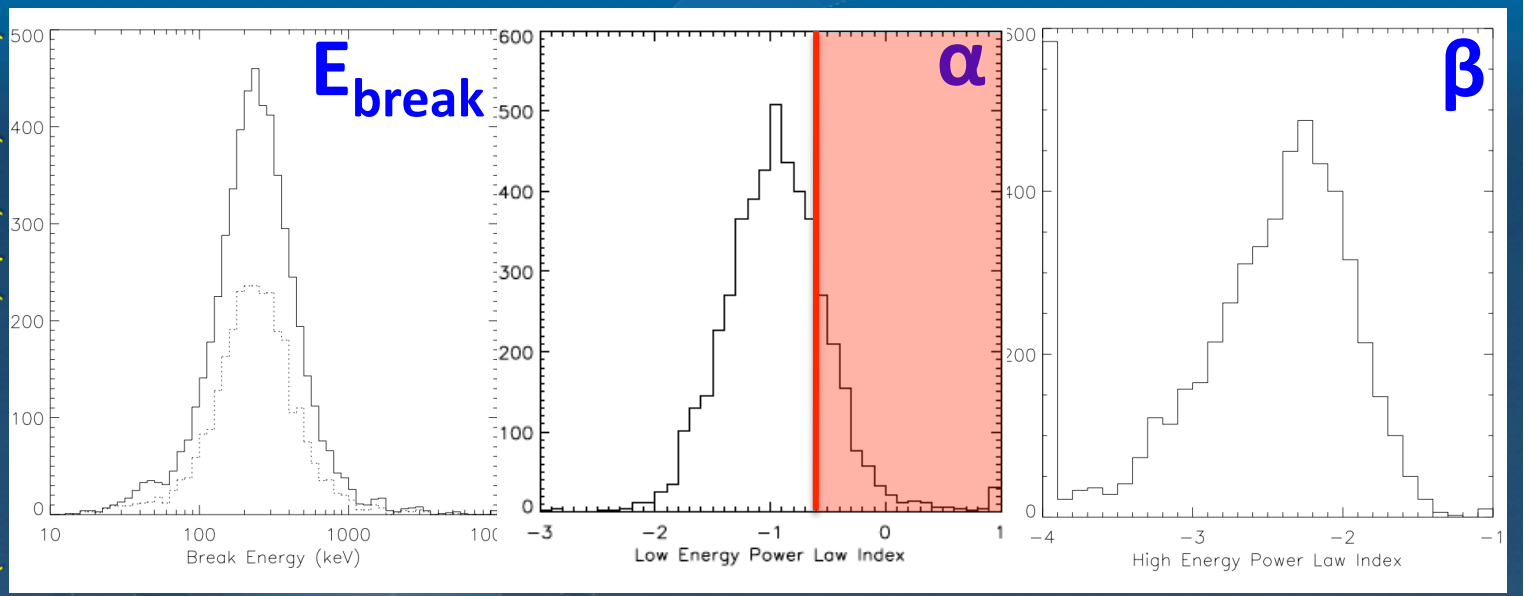
General Catalogues

BATSE

(Briggs et al. 1999, ApJ, 524, 82-91)

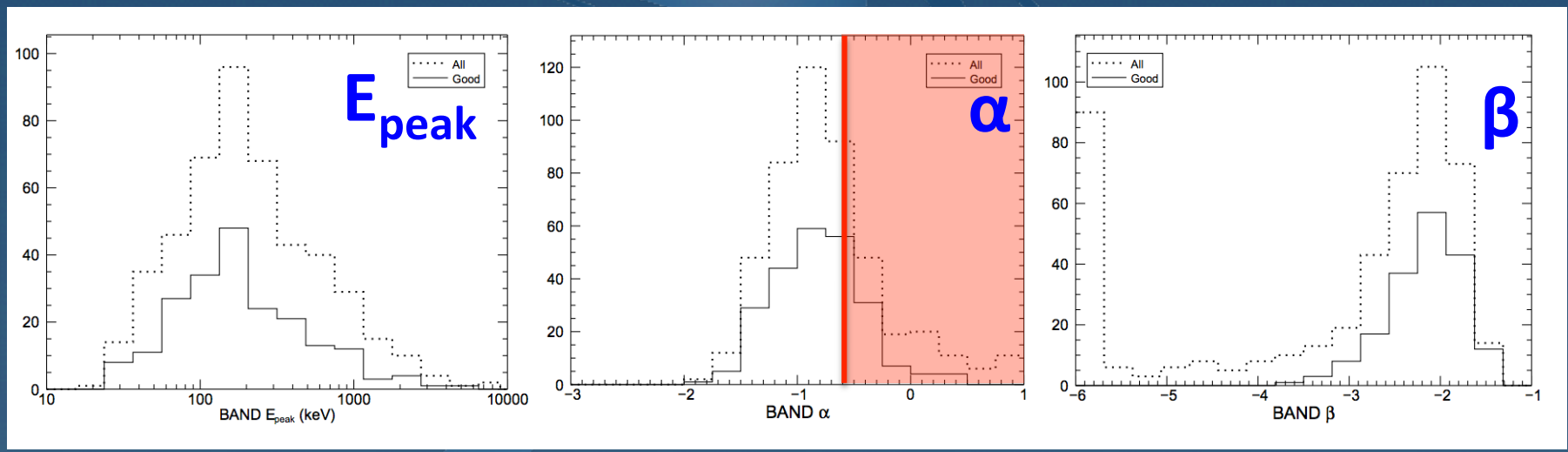


(Preece et al. 2000, ApJS, 126, 19-36)



GBM

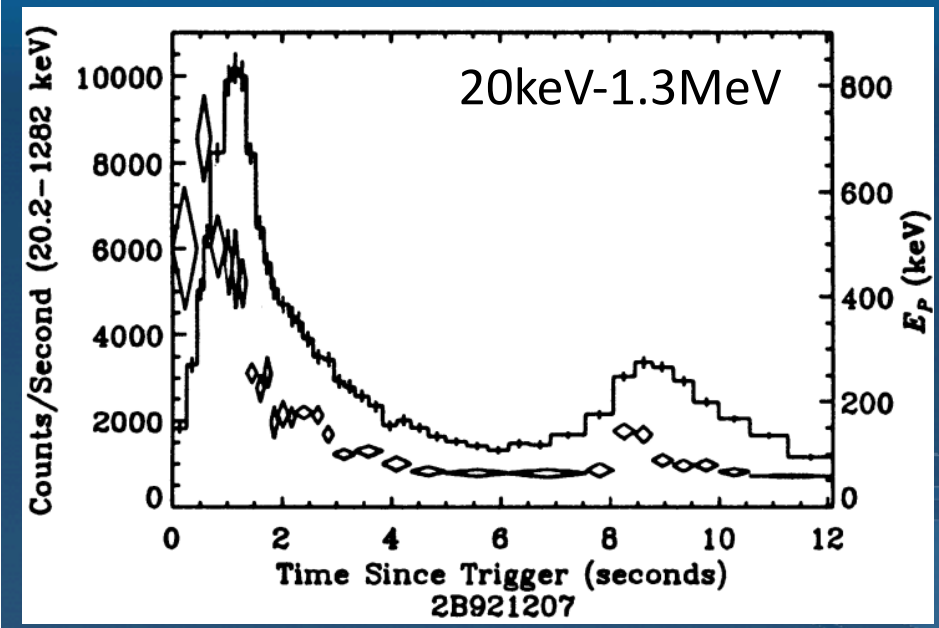
(Goldstein et al. 2012, ApJS 199, 19G)
A. Goldstein's poster P-II-24



- GBM results are compatible with BATSE ones.
- GBM can measure lower and higher E_{peak} and better constrain β.
- A large fraction of α values are NOT compatible with synchrotron models.

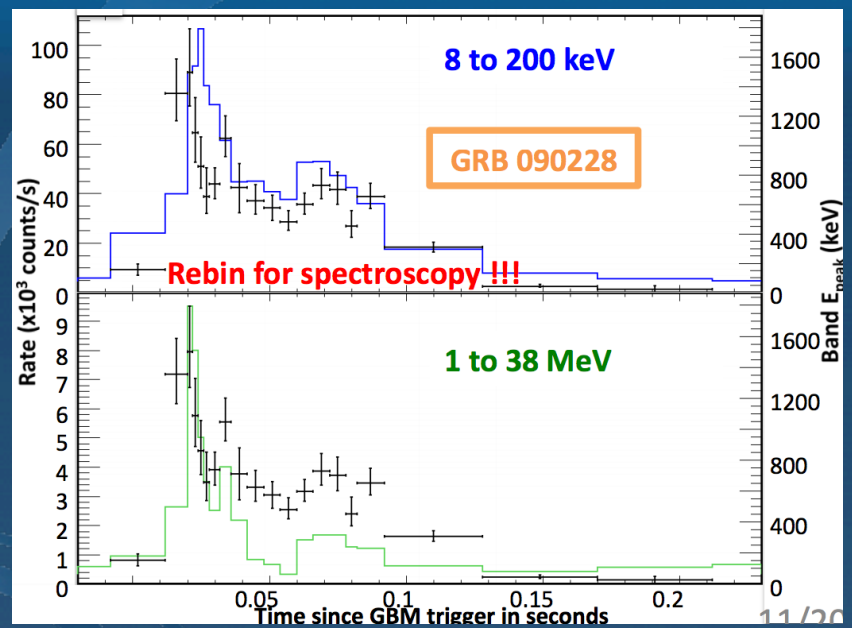
Time Resolved Spectrocopy

BATSE



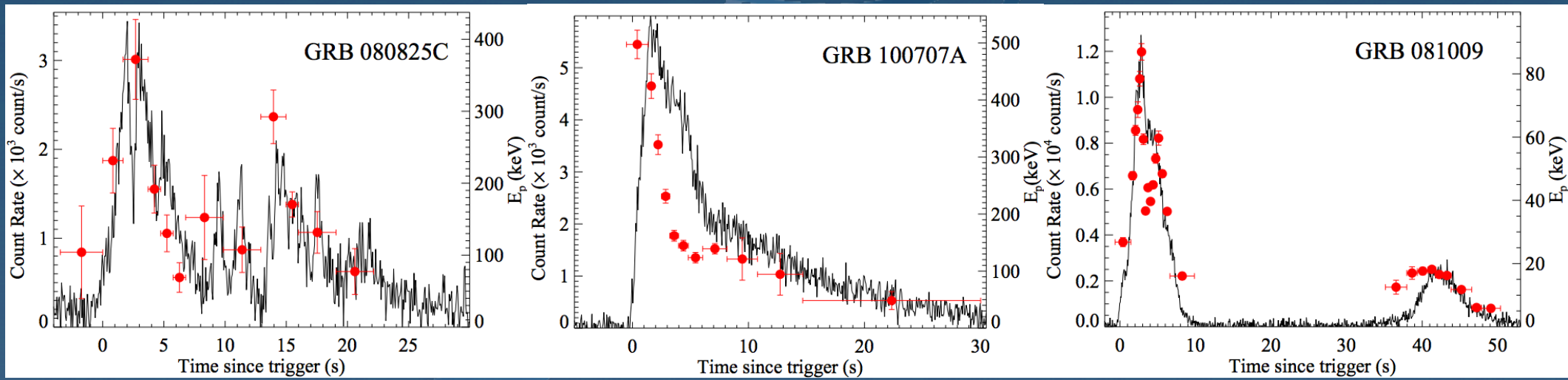
(Ford et al. 1995, ApJ 439, 307)

Fermi



(Guiriec et al. 2012, ApJ 725, 225G)

Fermi



(Lu et al. 2012, arXiv: 1204.0714)

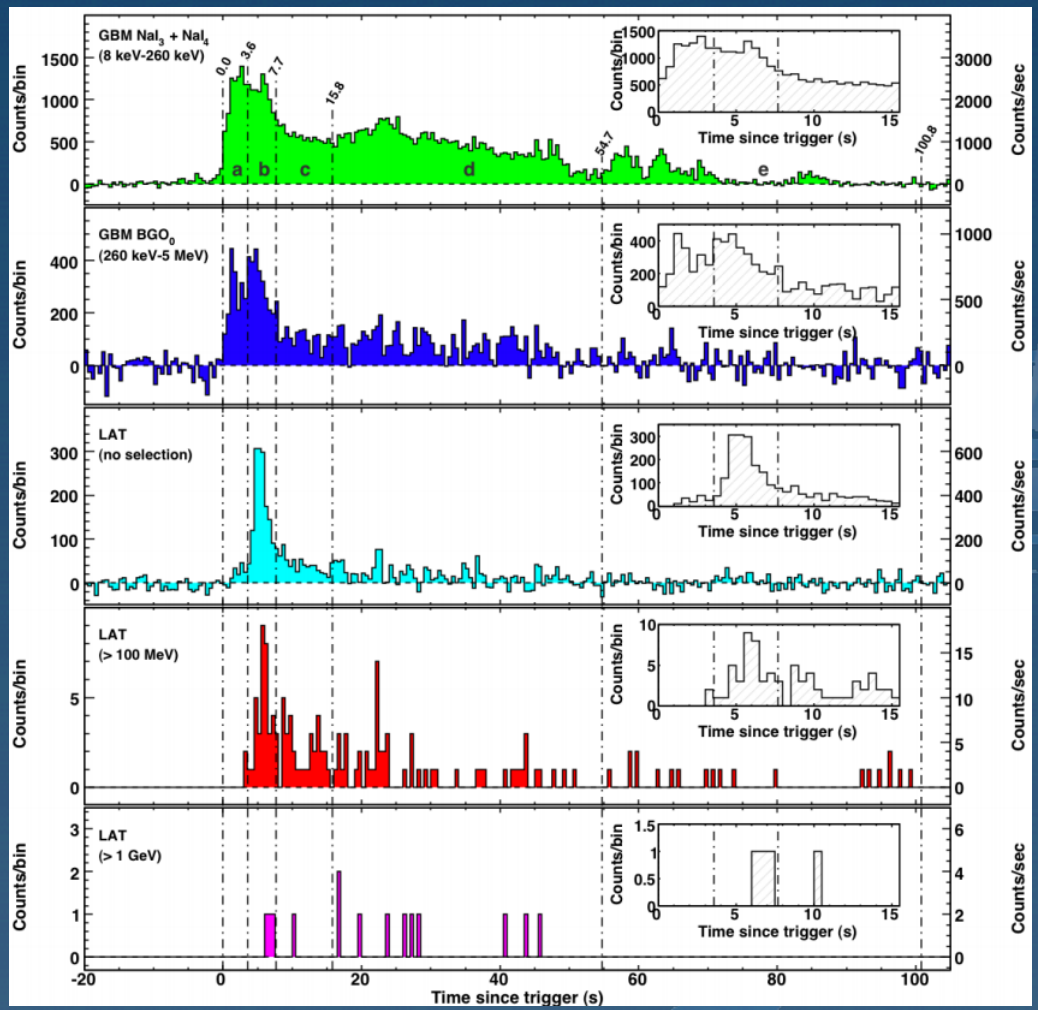
- With GBM, time resolved spectroscopy down to 2 ms time scale.
- Various behavior : hard-soft, soft-hard-soft and tracking evolution for E_{peak}.

High Energy Emission Temporal Properties

Delayed >100 MeV Emission

Long GRB 080916C

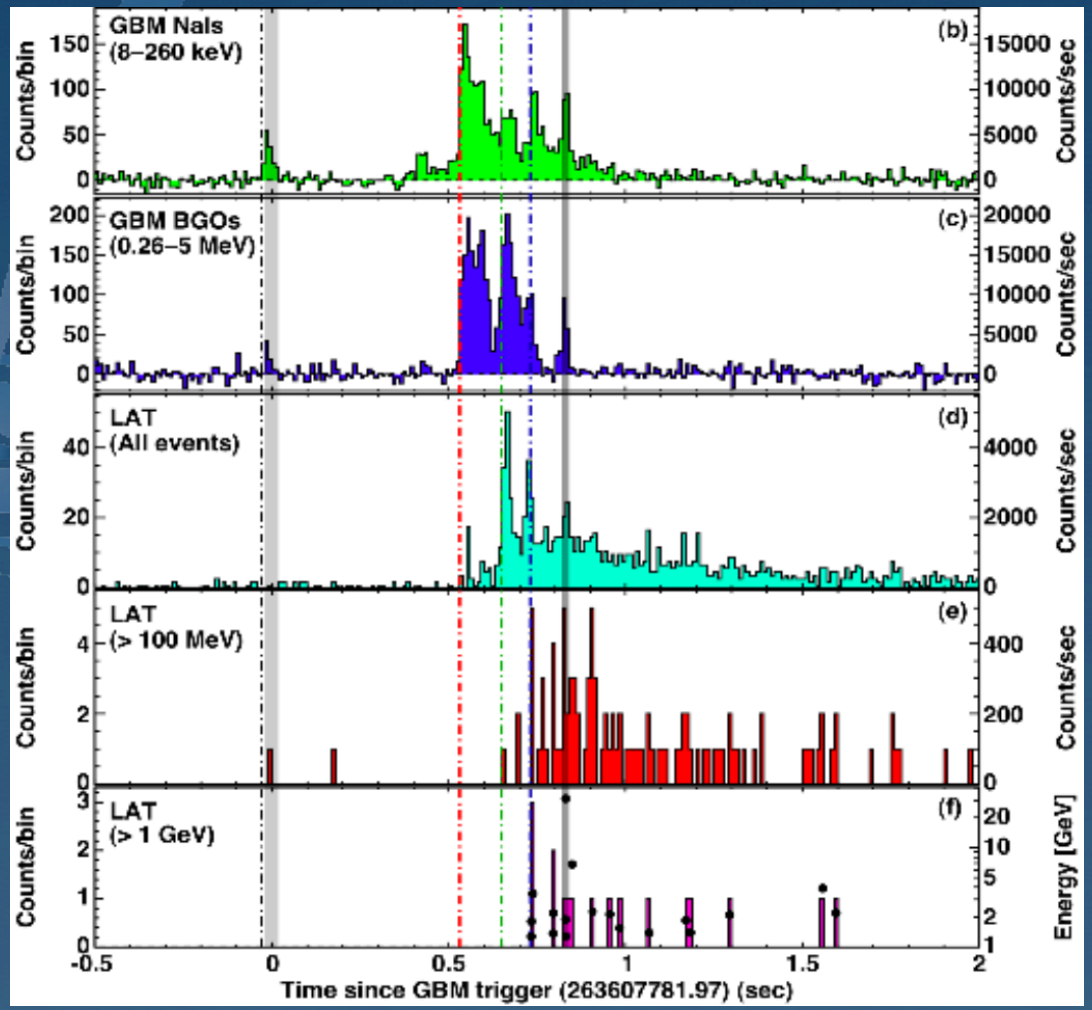
(Abdo et al. 2009, Science, 323, 1688A)



- First LAT peak coincides with the second GBM pulse.
- Delay in HE onset : ~4-5 s

Short GRB 090510

(Ackerman et al. 2010, ApJ 716, 1178A)

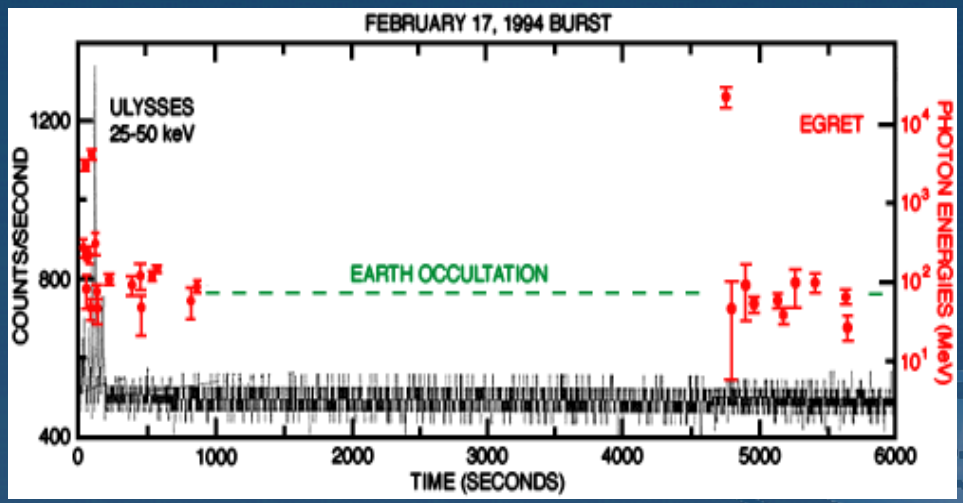


- The first few GBM peaks are missing but later peaks coincide.
- Delay in HE onset : ~0.1-0.2 s

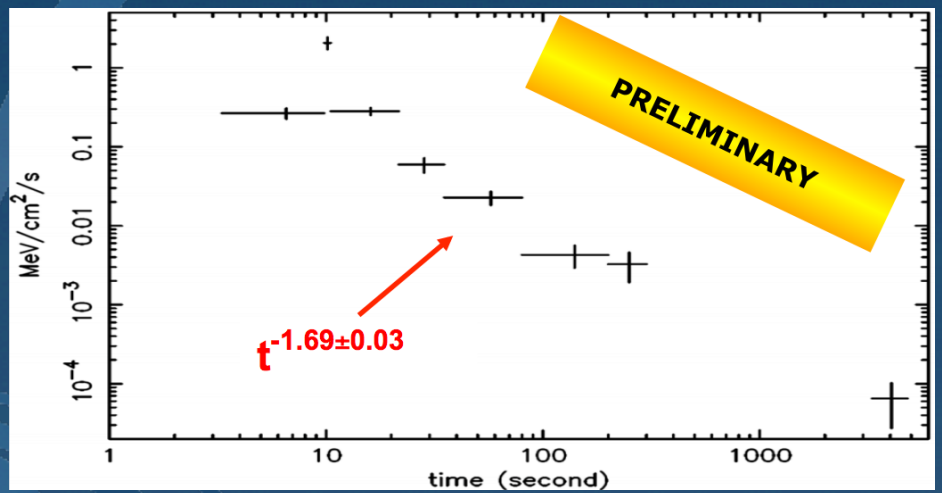
High Energy Emission Temporal Properties

Long lived HE Emission

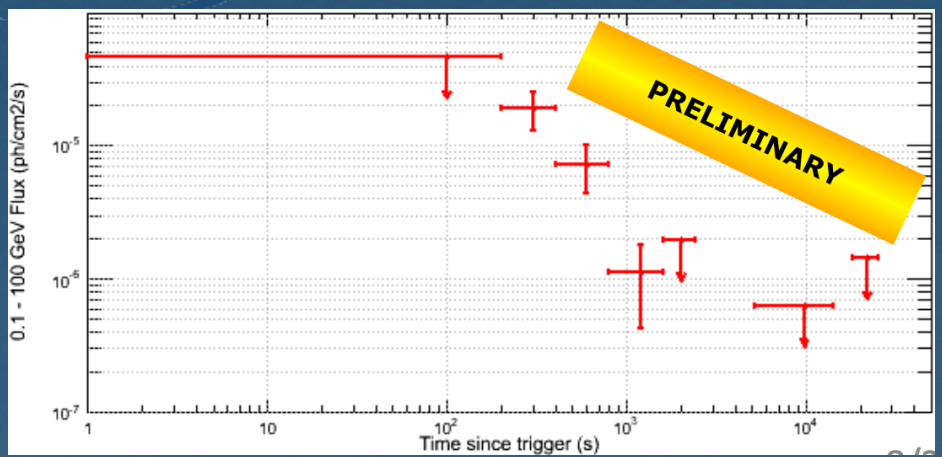
EGRET



LAT



5 σ detection up to 4800s



5 σ detection up to 1600s

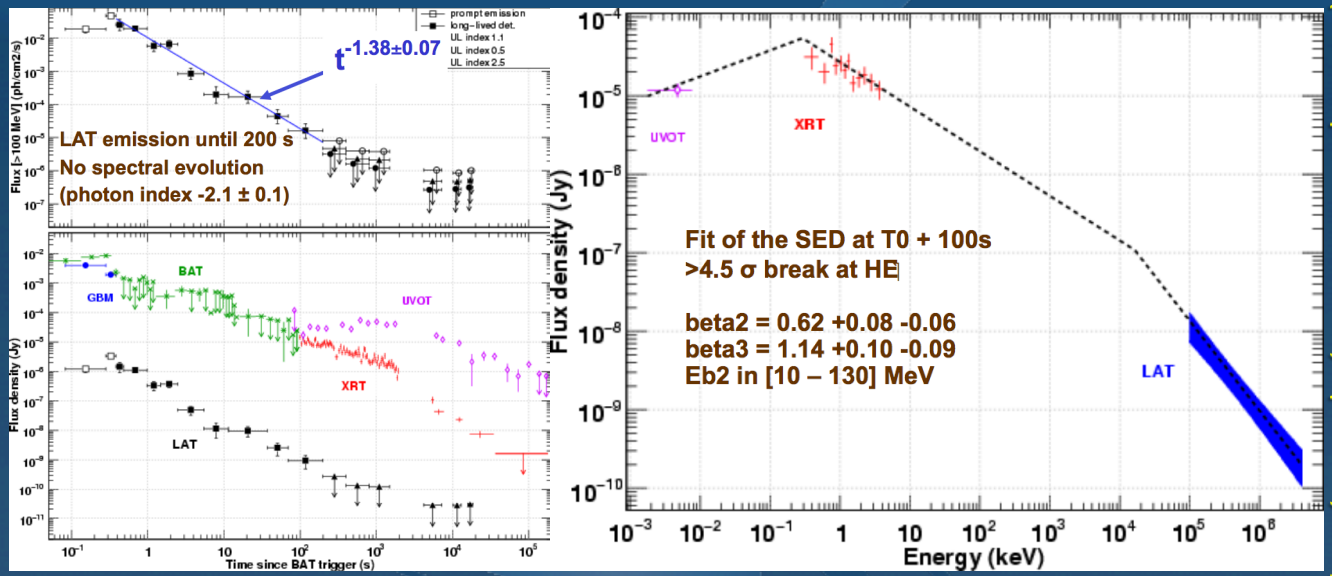
(Abdo et al. in preparation)

For search of extended GBM emission see G. Fitzpatrick's poster P-II-3

High Energy Emission Temporal Properties

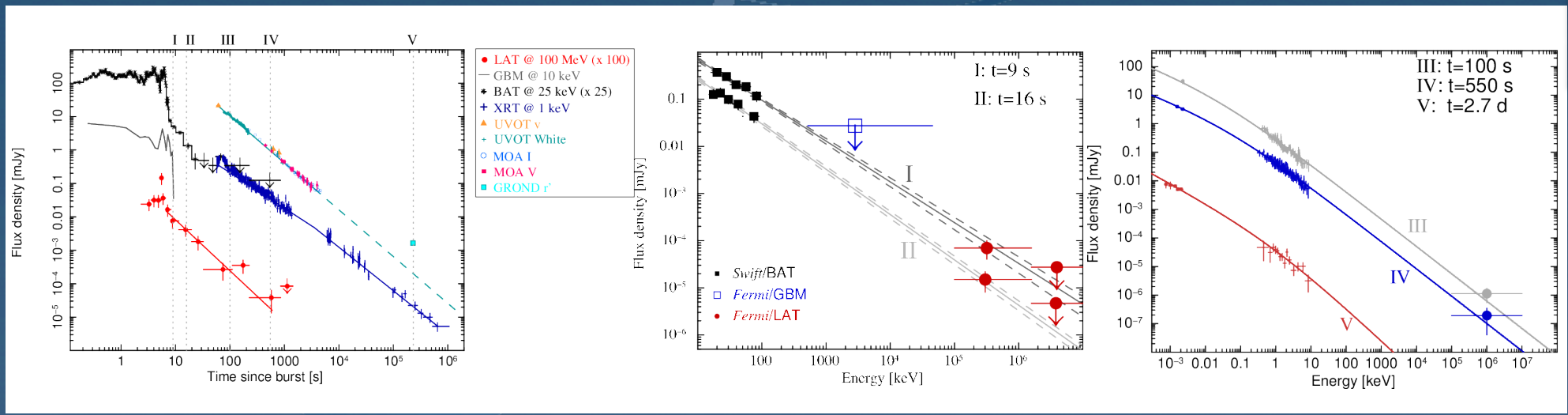
Long lived HE Emission & Multi-Wavelength Observations

Short GRB 090510



(De Pasquale et al. 2010, ApJL 709, 146)

Long GRB 110731A

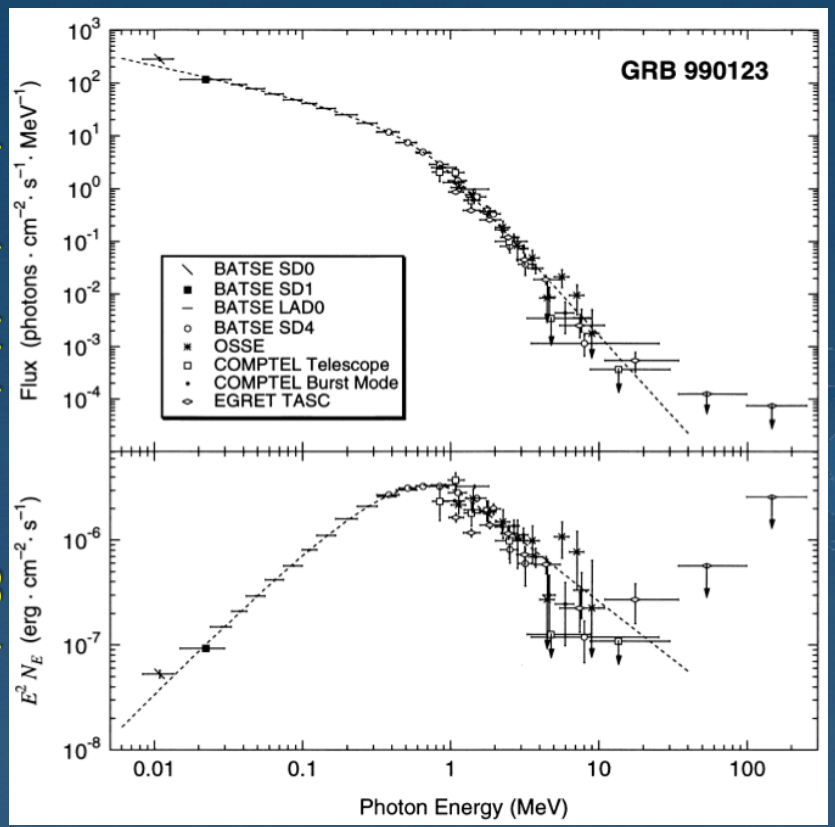


J. Bregeon's talk & (Abdo et al. in preparation)

Forward shock model can reproduce the spectrum from the optical up to GeV energies !
(non thermal synchrotron emission from the decelerating blast wave)

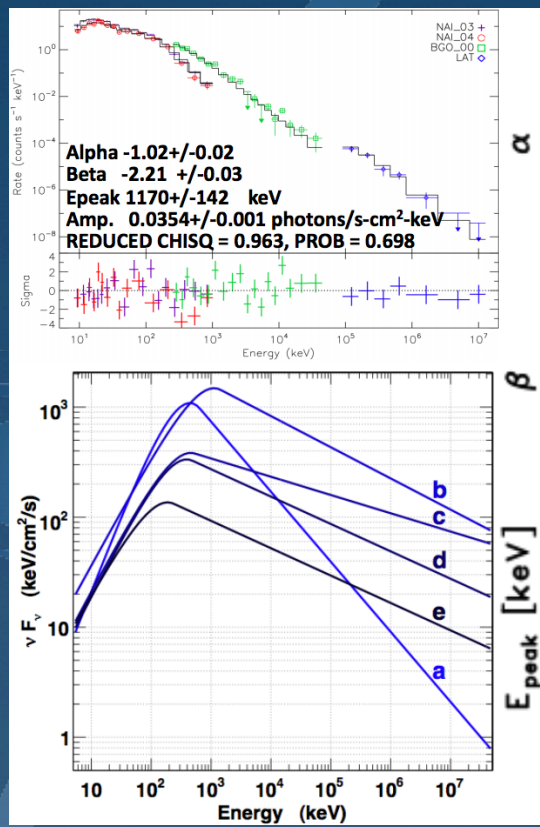
Single Band Function from keV to GeV

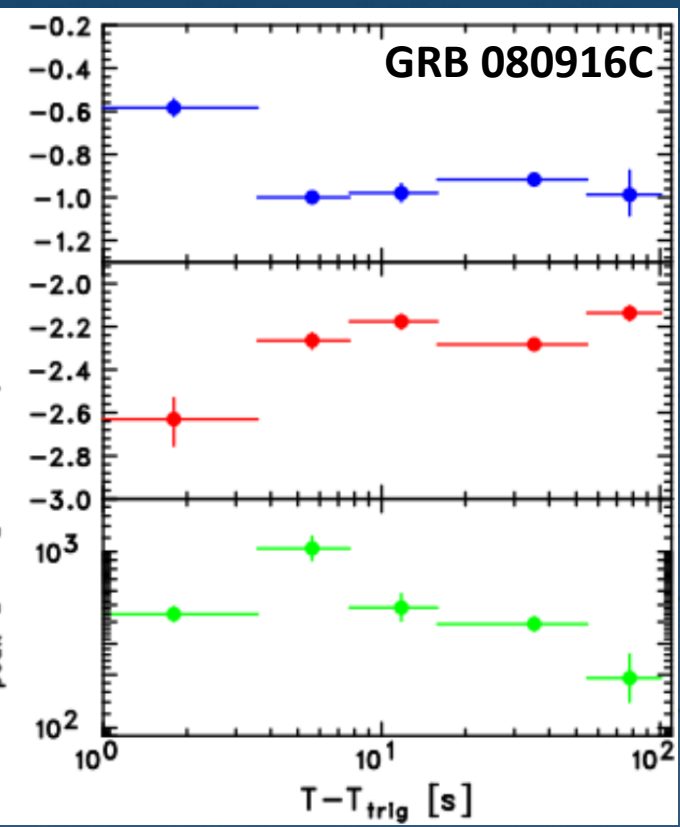
CGRO



(Briggs et al. 1999, ApJ, 524, 82-91)

Fermi





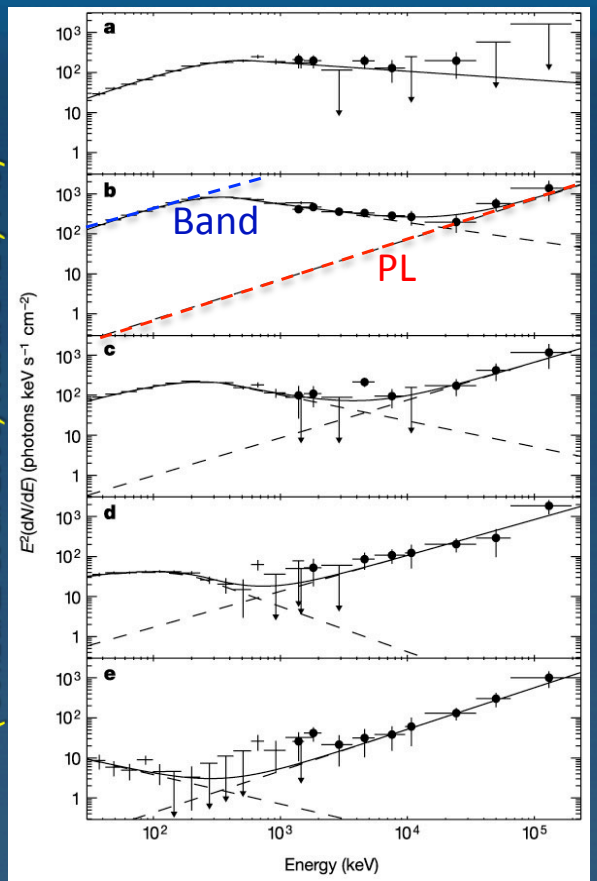
(Abdo et al. 2009, Science, 323, 1688A)

- Consistent with a single Band function from 8 keV to 10 GeV.
- Global soft-hard-soft evolution.

Additional Power Law to the Band Function

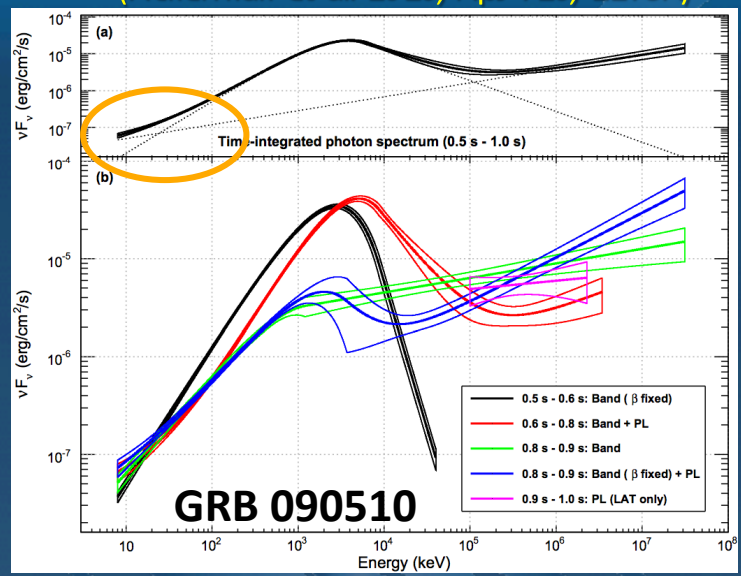
CGRO

(Gonzalez et al. 2003, Nature 424, 749)

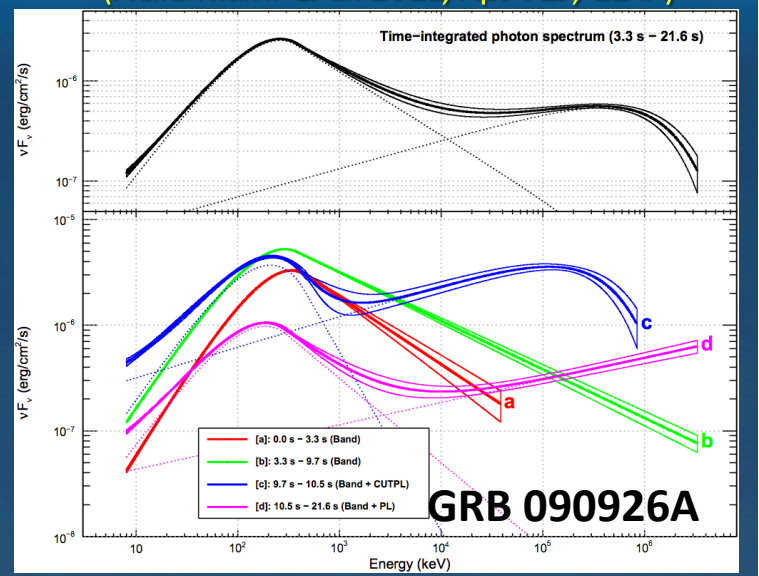


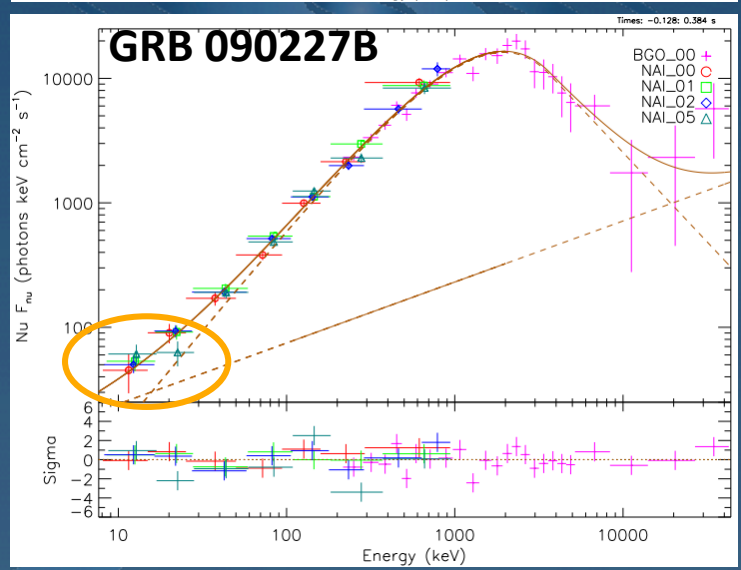
Fermi

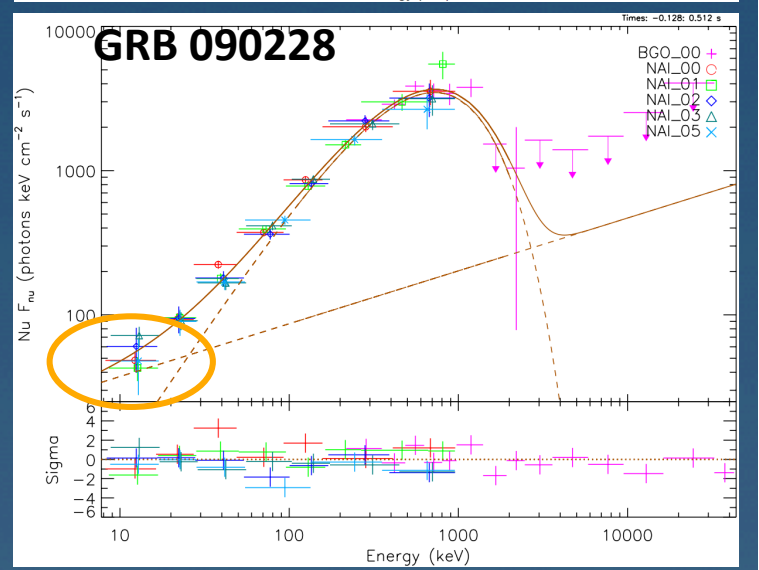
(Ackerman et al. 2010, ApJ 716, 1178A)



(Ackermann et al. 2011, ApJ 729, 114A)







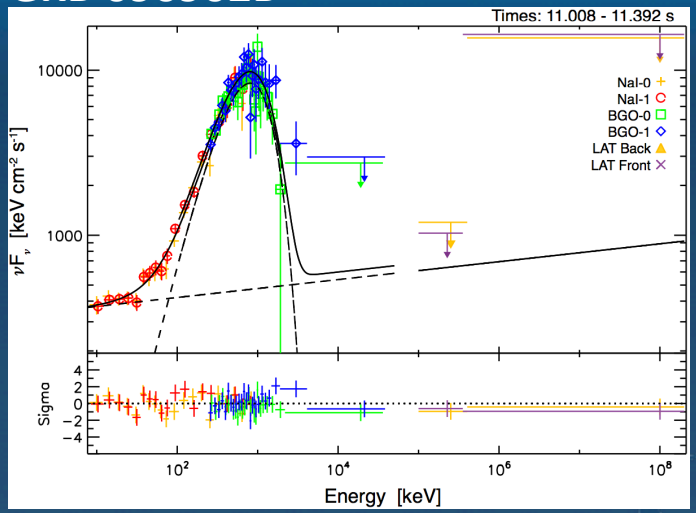
(Guiriec et al. 2010, ApJ 725, 225G)

- Additional PL can be identified in GBM data alone.
- PL overpowers the Band spectrum at both low and high energy (See D.Tierney's poster P-II-2 or low energy deviation).
- Additional PL does not always extend to high energies.

Thermal Emission

Dominant BB Component

GRB 090902B

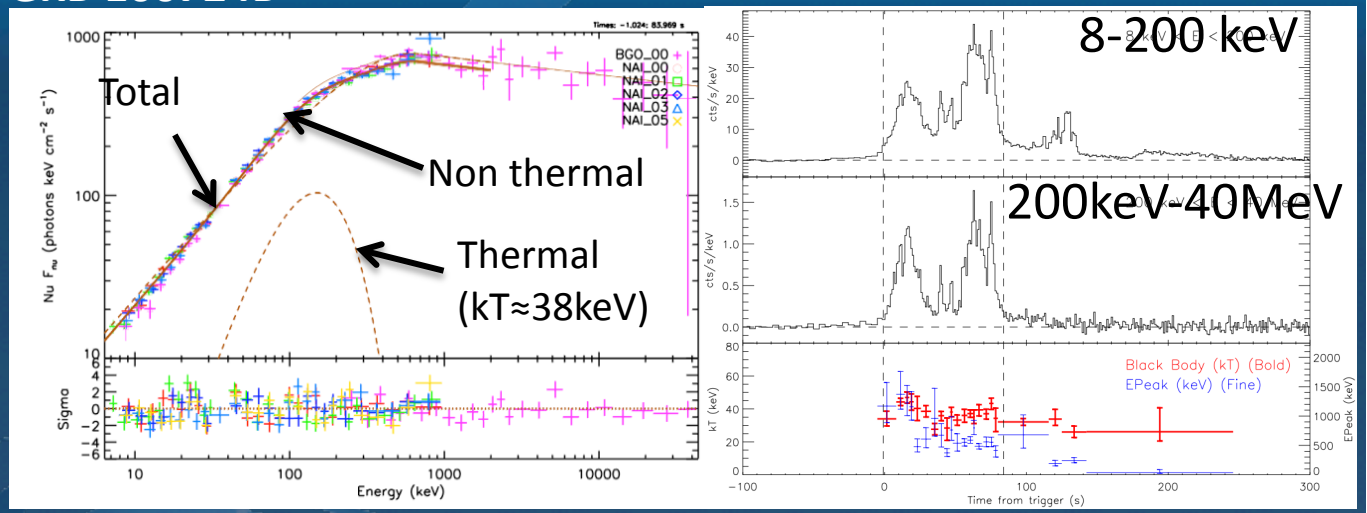


(Ryde et al. 2010, ApJ 709L, 172R)
(Zhang et al., 2011, ApJ, 730, 141Z)

- Photospheric emission modelized with a "multicolor black body".

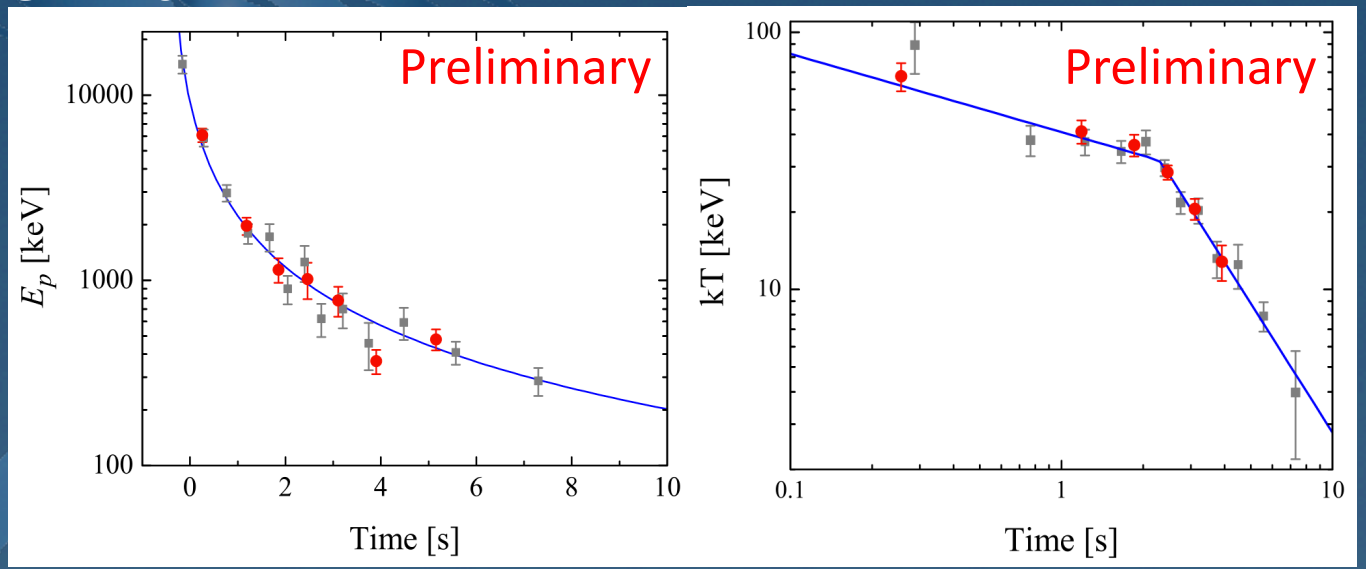
Subdominant BB Component

GRB 100724B



(Guiriec et al. 2011, ApJL 727, L33)

GRB 110721A

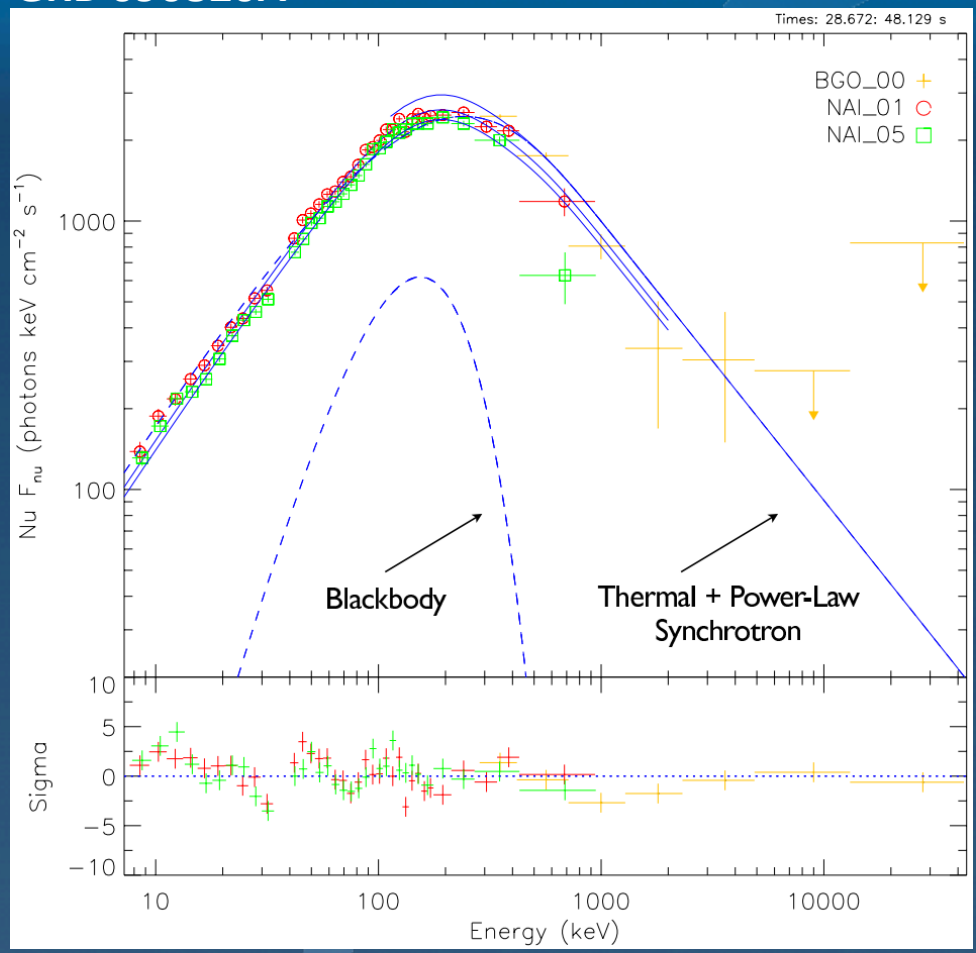


See F. Ryde's talk and S. McGleen's talk

- E_{peak} and kT evolve independently.
- kT evolution : constant or slow cooling, or clear cooling.
- With BB, Band more compatible with synchrotron models.

Direct Fit of Synchrotron Models

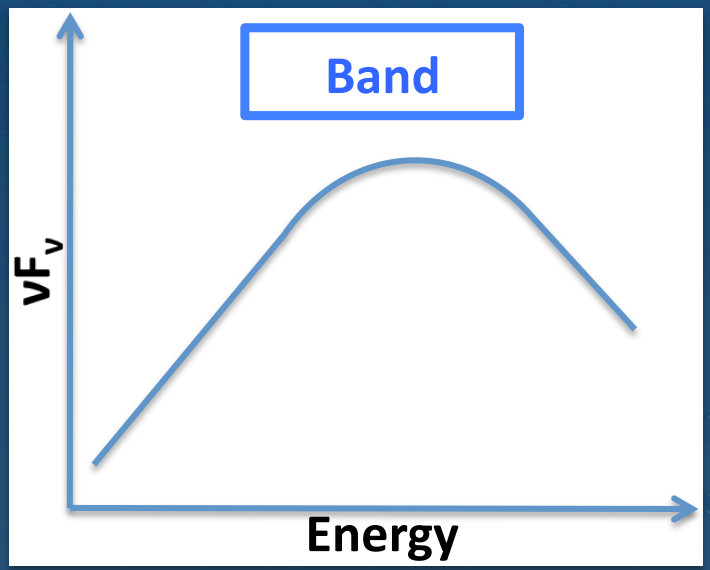
GRB 090820A

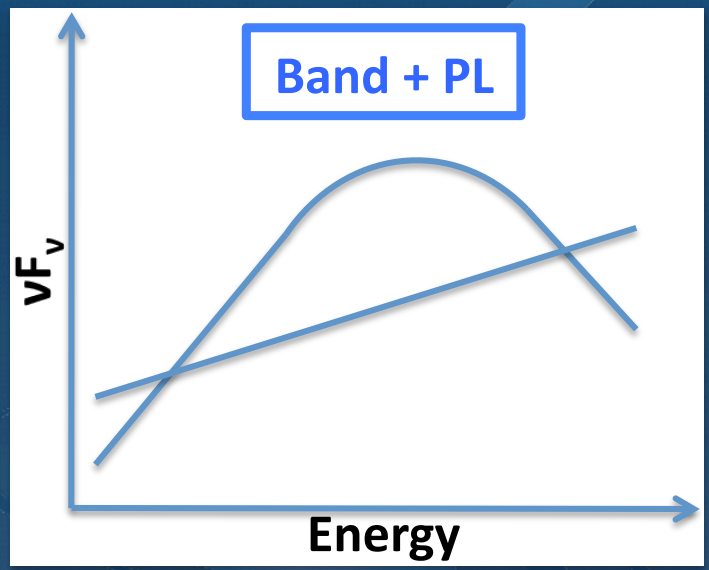


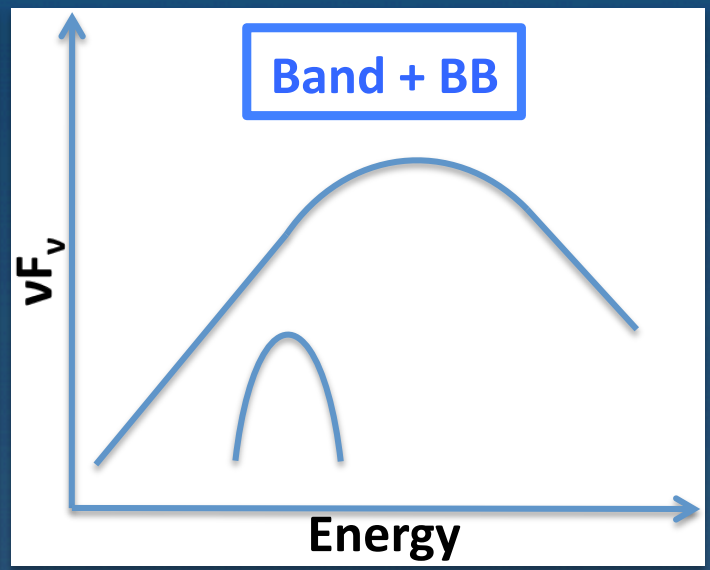
(Burgess et al., 2011, ApJ, 741, 24B)

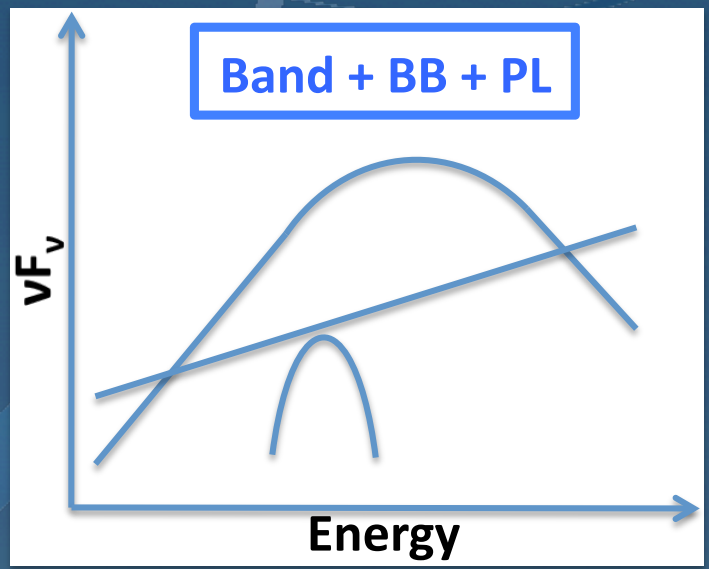
- **Fit of the analytical synchrotron model only possible in combination with BB.**

Spectral Shapes





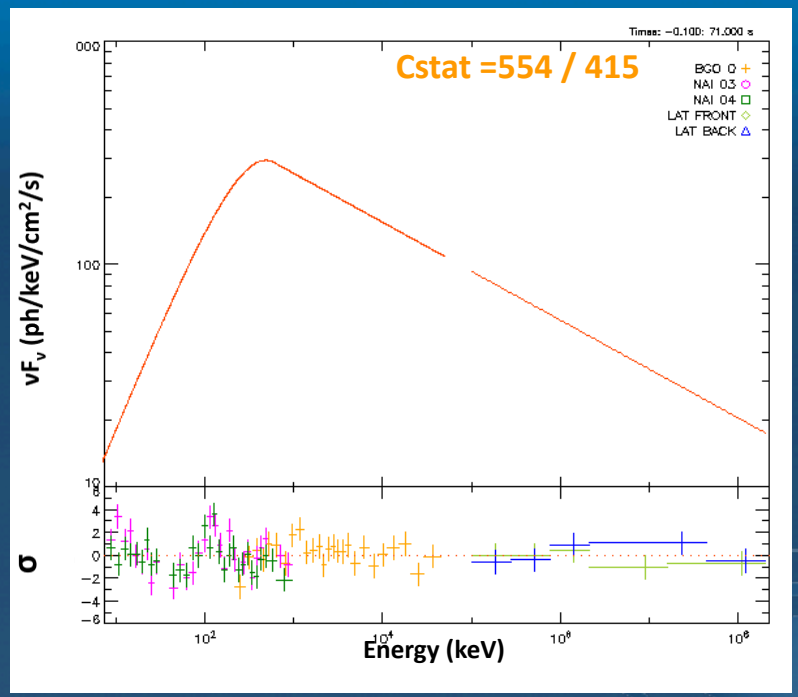


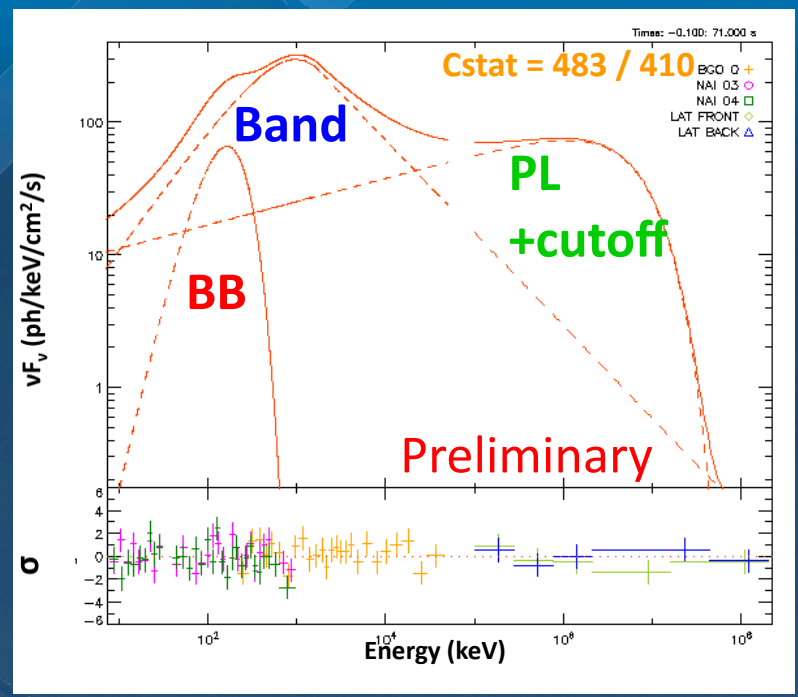


?

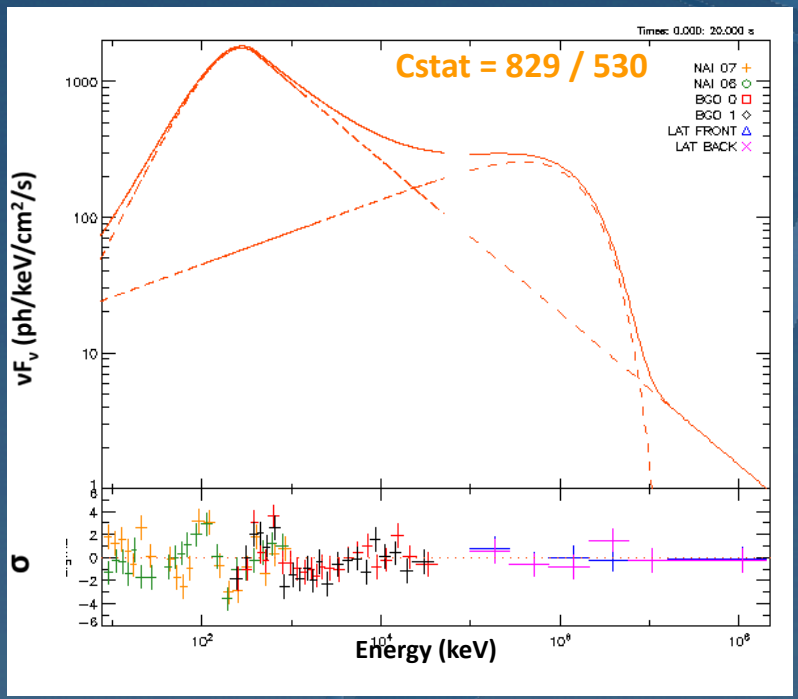
Multiple Spectral Components

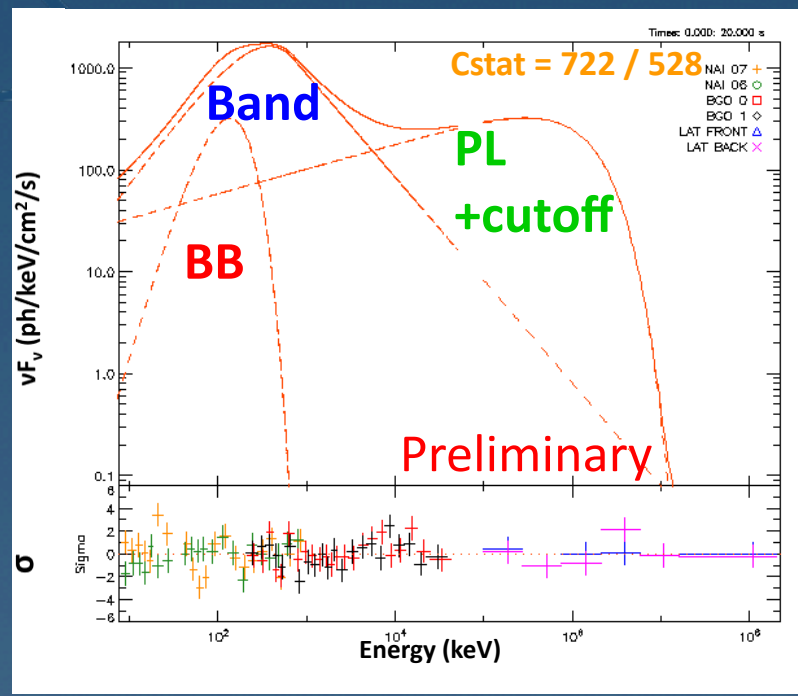
GRB 080916C





GRB 090926A

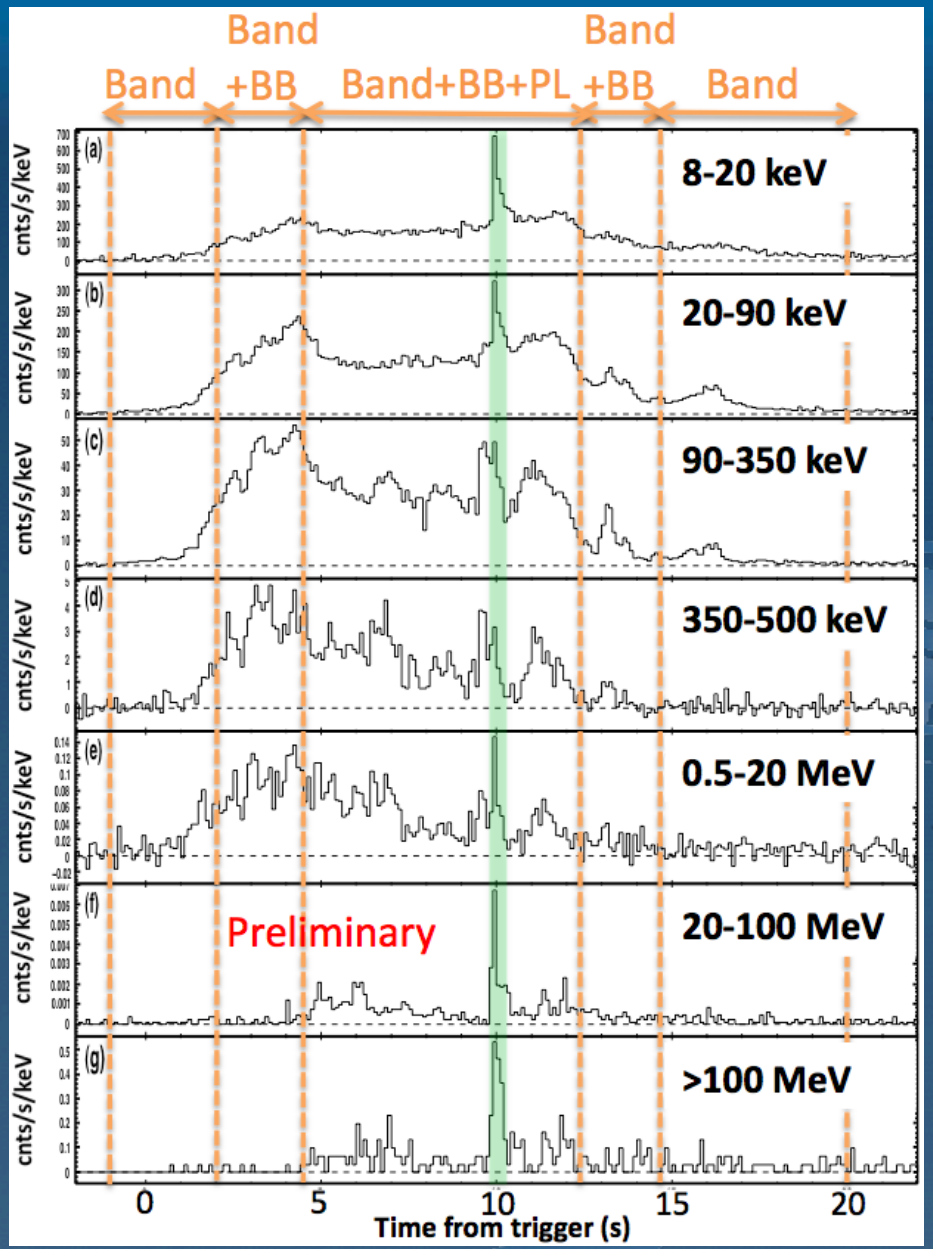




(Guiriec et al. in preparation)

Multiple Spectral Components

GRB 090926A



(Guiriec et al. in preparation)

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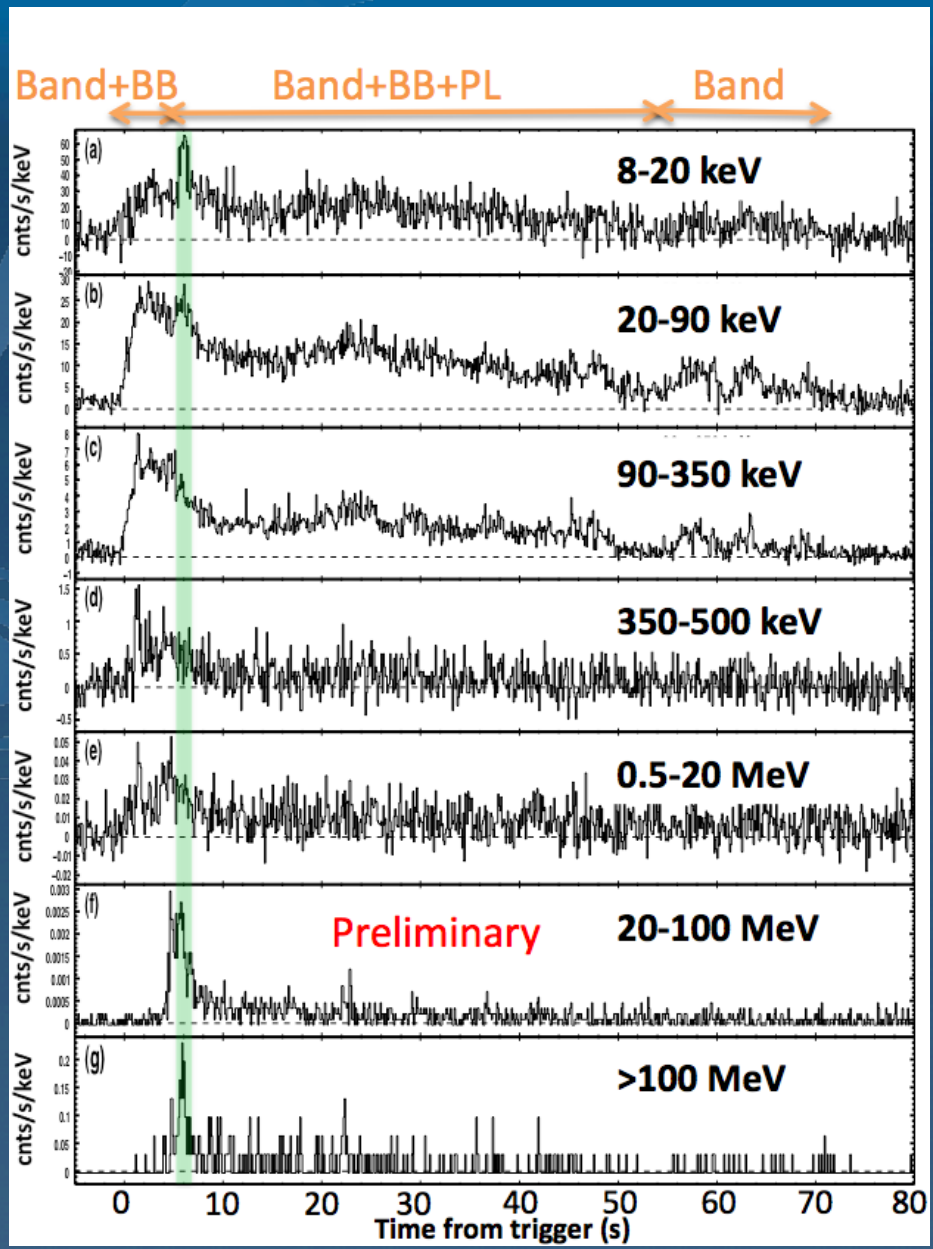

(Guiriec et al. in preparation)

- Fine time-resolved spectroscopy possible with multiple components.
- Additional PL associated with light curve structures extended from the very low to the very high energies.

Summary of Fermi Results

- GBM results compatible of BATSE ones.
- Time resolved spectroscopy possible down to the ms time scale for bright events.
- Delayed >100 MeV emission onset.
- Long lasting GeV emission (external forward shock ?).
- Additional PL to the Band function with cutoffs.
- Detection of possible dominant and sub-dominant thermal components.
- Possible detection of multiple spectral components (Band+BB+PL) and association of these component with structure in light curves.

How these Observations Challenge and Support the Models ?

See D. Lazzati's talk later today

- Leptonic models (inverse-compton or SSC)
  - Hard to produce a delayed onset longer than the spike widths.
  - Hard to produce a low energy (<50 keV) power-law excess.
- Hadronic models (pair cascades, proton synchrotron)
  - Late onset : time to accelerate protons & develop cascades.
  - Hard to produce correlated variability at low and high energies (e.g. spike of GRB090926A and GRB080916C).
  - Proton synchrotron radiation requires large magnetic field.
  - Synchrotron emission from secondary e± pairs produced via photo-hadron interactions can naturally explain the power law at low energy.
- Early afterglow (e+e- synchrotron from external shock)
  - Can account for the delayed onset of the PL.
  - Short variability time scales in LAT data argues against external shock.
- Photospheric emission
  - Subdominant black body requires an outflow highly magnetized close to the source.
  - The lack of variability at short time scale for the temperature challenges the internal shock model.

R. Hascoet's poster P-II-20

Conclusion

- **Thanks to Fermi, we now know A LOT more about GRB prompt emission.**

- **But alas NOT everything !**

BACKUP

GRB080916C : Band vs Band+BB+Compt