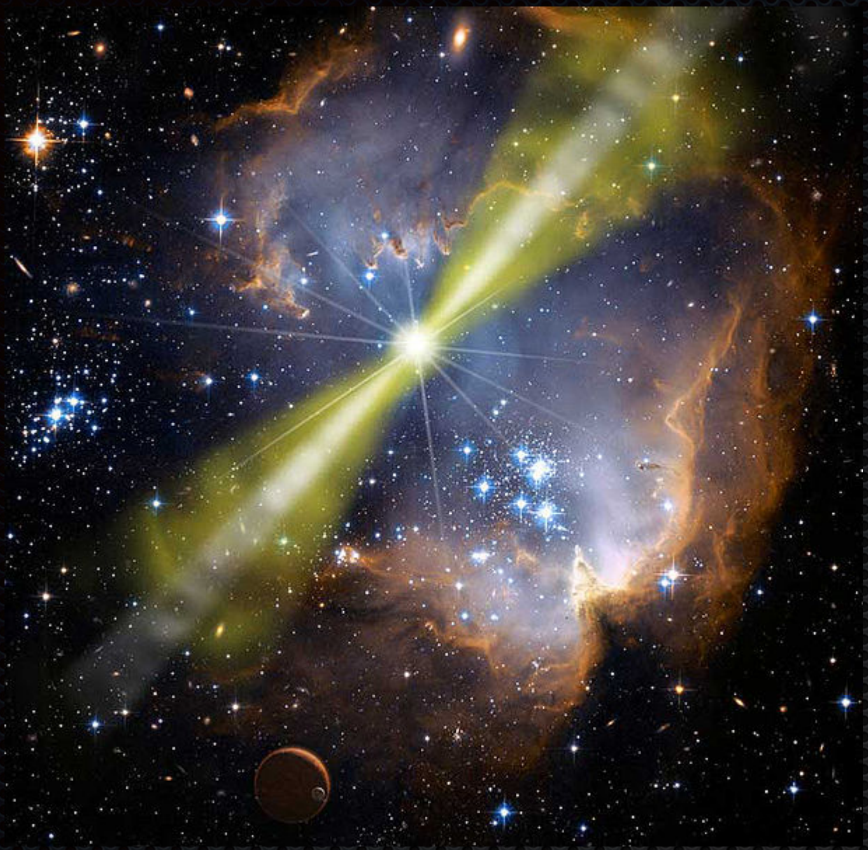

Gamma-ray Bursts in the Fermi Era & Future Prospects

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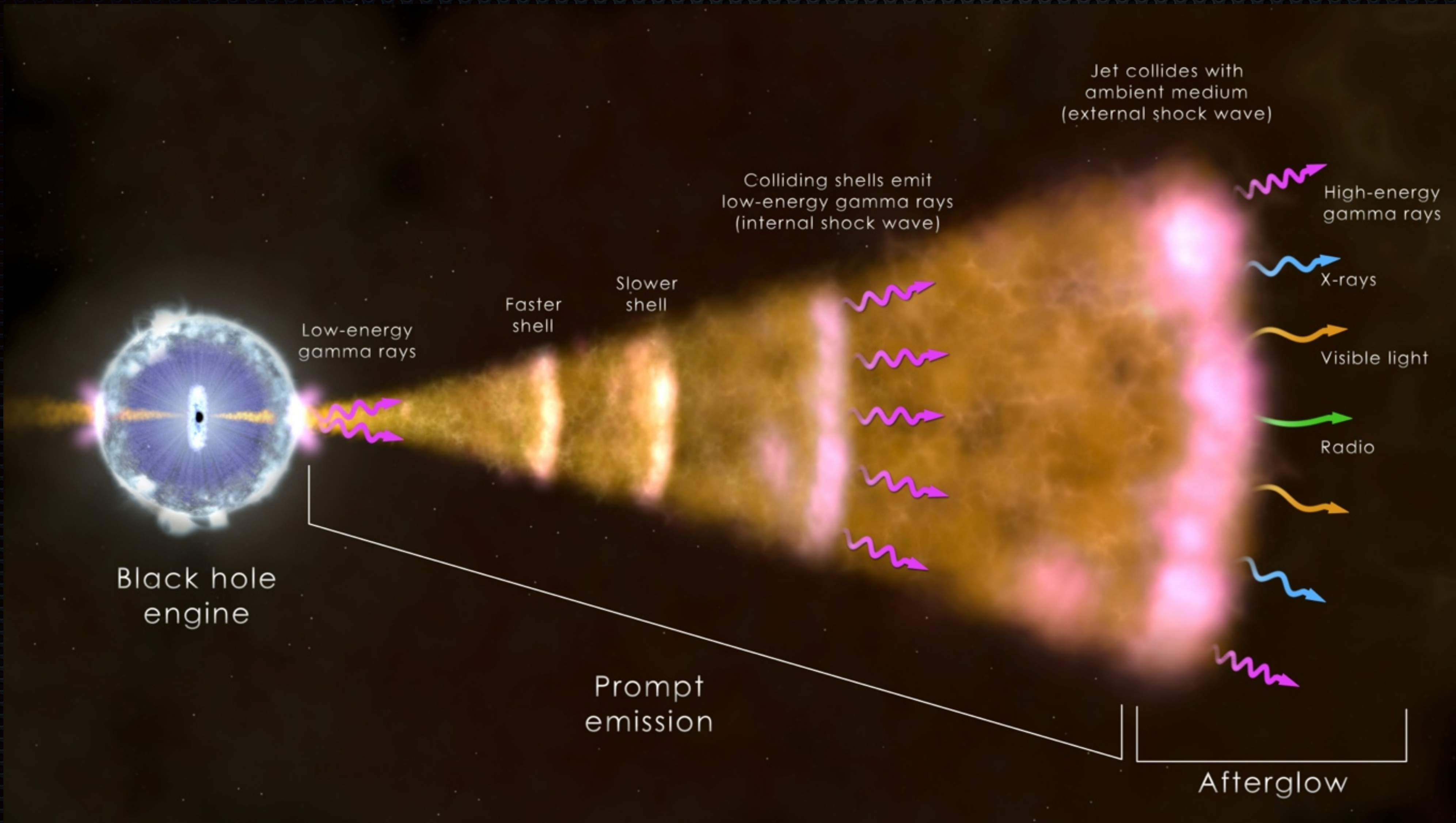


Jet collides with
ambient medium
(external shock wave)
Colliding shells emit
low-energy gamma rays
(internal shock wave)
High-energy
gamma rays
X-rays
Visible light
Radio
Slower
shell
Faster
shell
Low-energy
gamma rays
Black hole
engine
Prompt
emission
Afterglow

Unresolved Questions Prior to Fermi

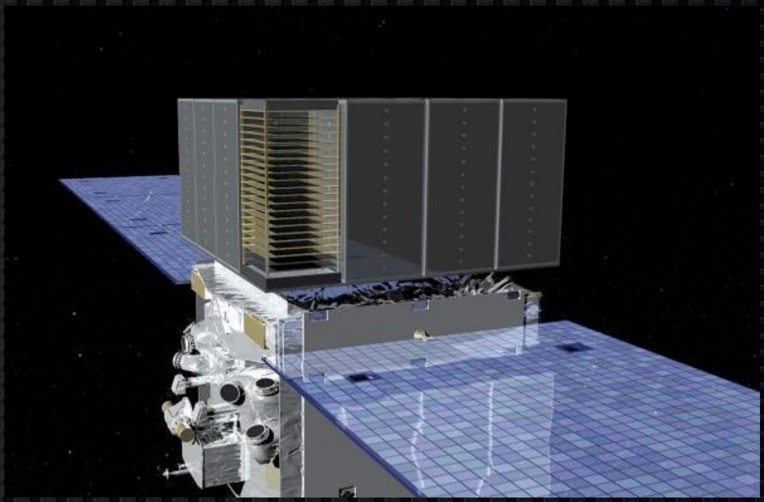
- Band model adequately fits a large majority of bursts
  - No physical emission mechanisms predicts this spectral shape
- Relatively narrow E_{pk} values
  - Synchrotron via internal shocks: $E_{pk} \propto B_{\perp}\Gamma_{rel}$
- Bursts with very hard α values above synchrotron “line of death”
  - Significant fraction of bursts harder than $\alpha < -2/3$
- Bursts with high-energy spectral indices of $\beta > -2$
  - Where do these bursts turn over?
- Where is the photospheric emission?
  - The fireball model naturally predicts thermal emission

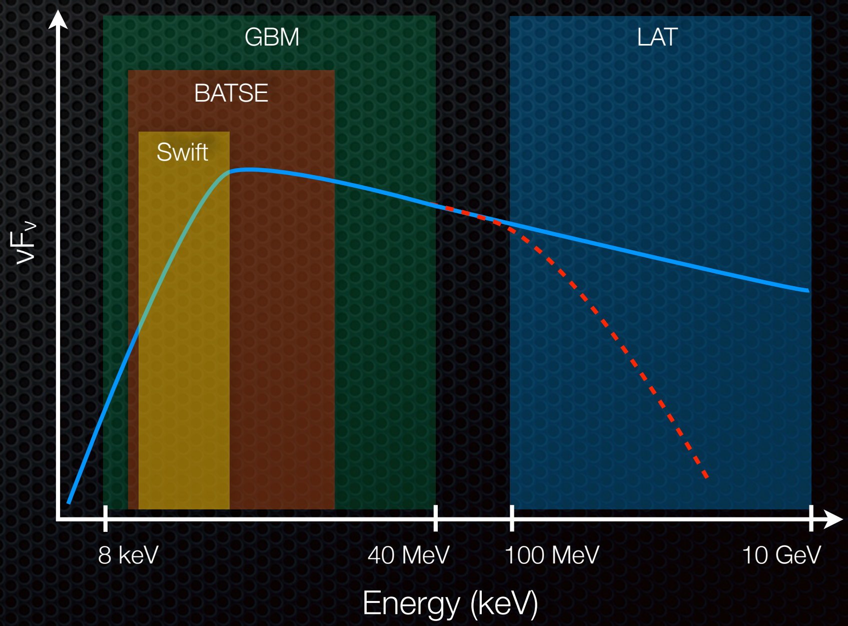
Unresolved Questions Prior to Fermi

- Where is the evidence for pair attenuation?
  - No definitive detection of turnovers in BATSE or EGRET spectra
- Nature of the long lived components seen by EGRET?
  - How common where these late-time high-energy emission?
- Where are the IC and SSC components?
  - Is E_{pk} the SC or the IC/SSC peak or are those peaks at higher energies?
- What are the origins of the x-ray flares and plateaus in afterglow light curves?
  - Late-time energy injection?
- What is the ratio of the magnetic and electron energy densities of the jet?
  - Are these magnetically dominated outflows?

The Fermi Spacecraft

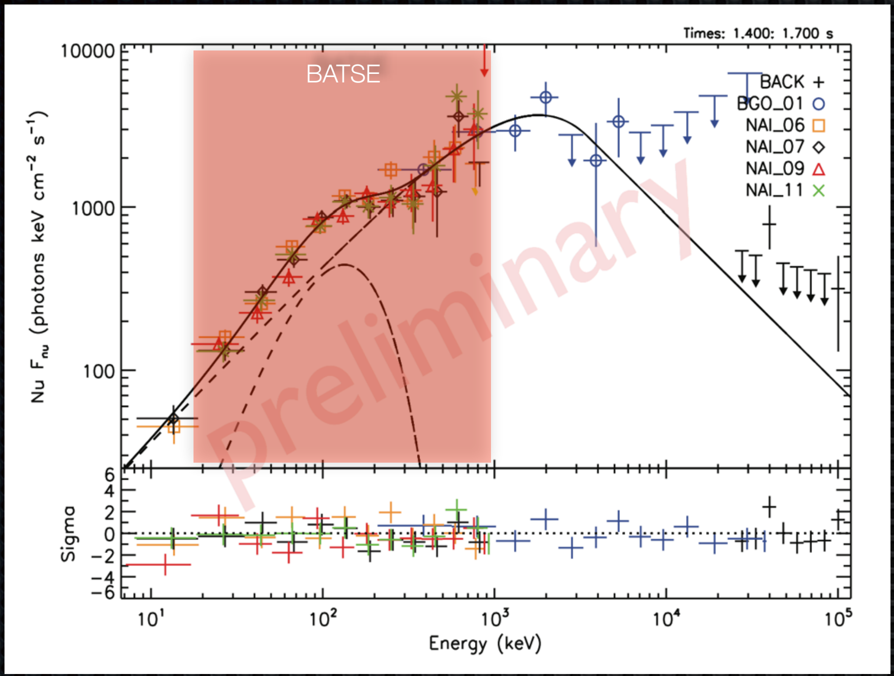
- Fermi Gamma-ray Burst Monitor (GBM)
  - Scintillation detectors
  - 12 NaI: 8 keV - 1 MeV
  - 2 BGO: 200 keV - 40 MeV
- Fermi Large Area Telescope (LAT)
  - Pair conversion telescope
  - Energy coverage: 0.1 to >300 GeV
- GRB Detections
  - GBM Detections >1800 (~240 GRBs/yr)
  - LAT Detections: >130 (~15 GRB/yr)





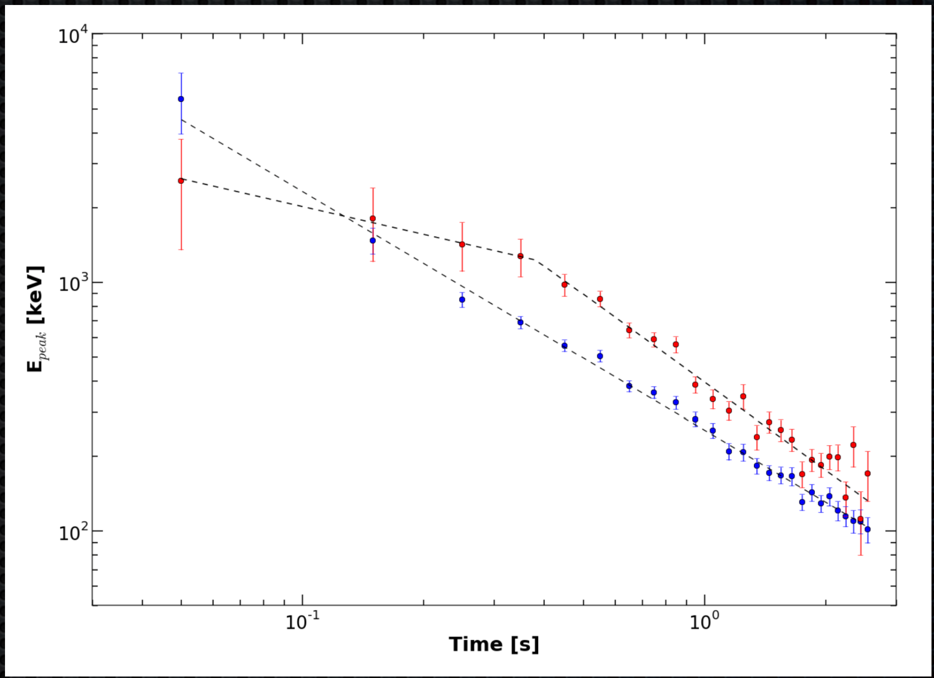
Peak Spectral Energy (E_{pk})

GRB 110721A



Ryde 2012

GRB 130427A

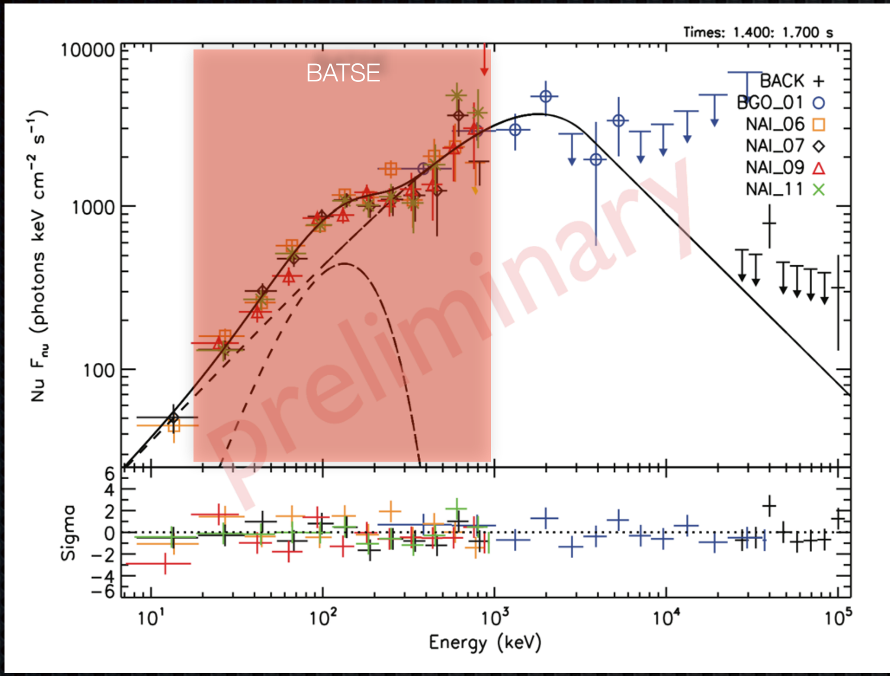


Preece et al. 2013

- Bursts with E_{pk} > 1 MeV are not uncommon
- Time-resolved analysis shows that E_{pk} can be extremely hard at the burst onset
- Time-integrated fits yield a E_{pk} distribution centered near peak sensitivity
- 110721A would have appeared as $\beta > -2$ spectra in the BATSE era

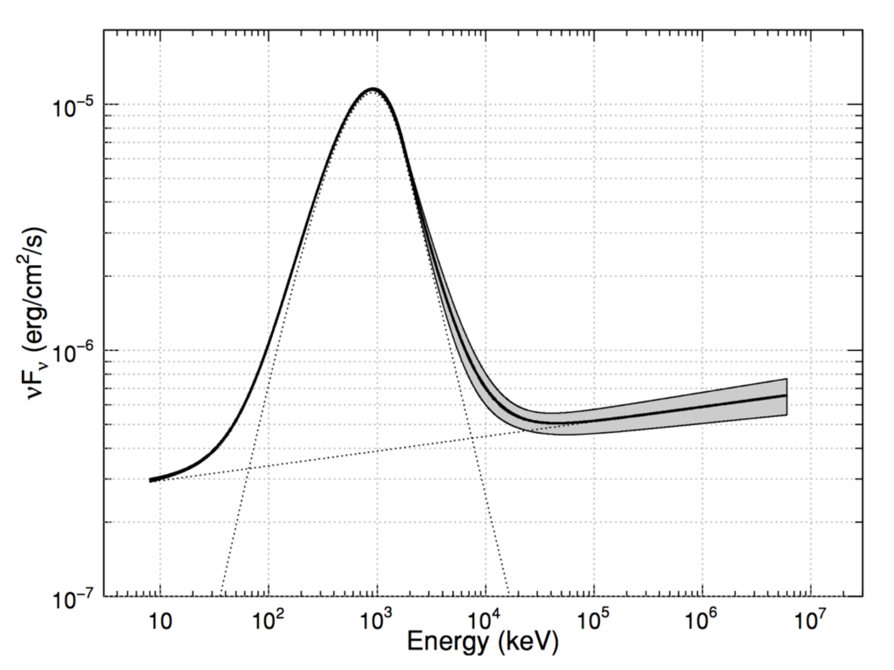
Photospheric Blackbody Components

GRB 110721A



Ryde 2012

GRB 090902B



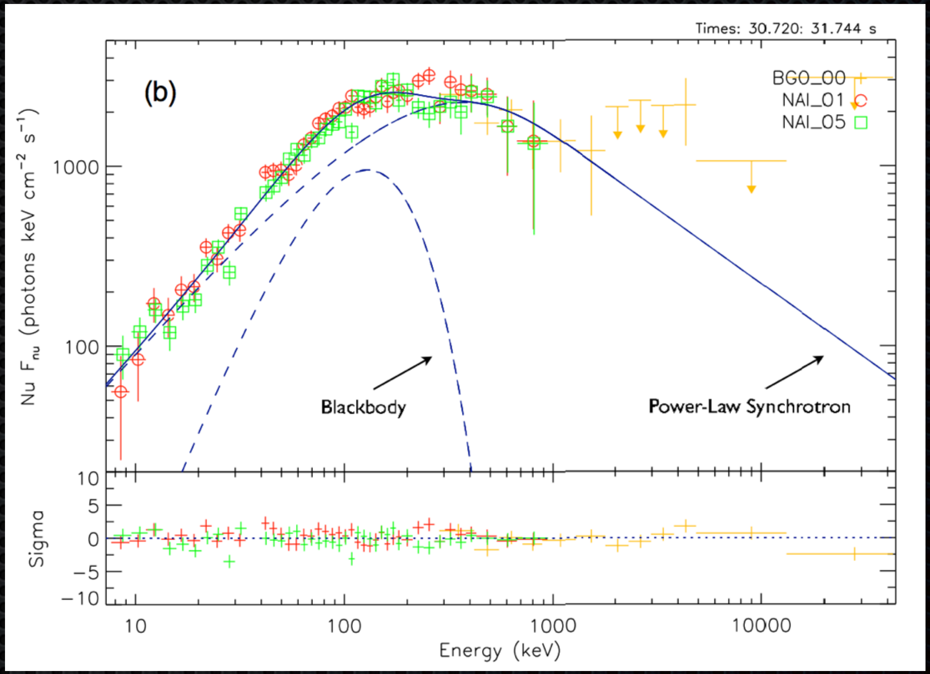
Abdo et al. 2009

- 110721A: Double peaked spectra, possible subdominant blackbody component
- 090902B: Broadened blackbody plus a power law
- Blackbody peak is less dependent on the Lorentz factor
- Growing evidence for photospheric emission broadband fits

Direct Fits to Physical Models

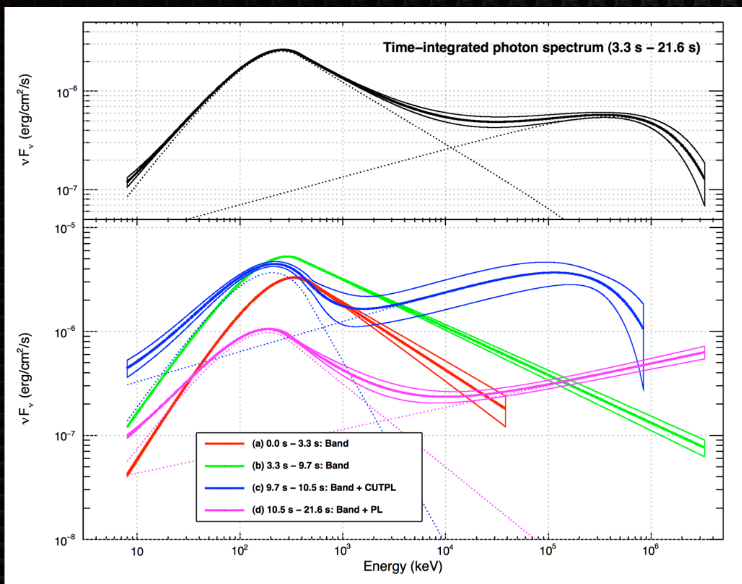
- Direct fits to blackbody and synchrotron spectra
- Line-of-death issue can be overcome naturally with this combination
- The Planck like spectral contribution allows for steeper νF_ν spectra near the peak than is allowed by synchrotron alone
- This approach directly constrains physical model parameters as opposed to phenomenological ones
- Bright GBM & LAT bursts are challenging the simple Band model

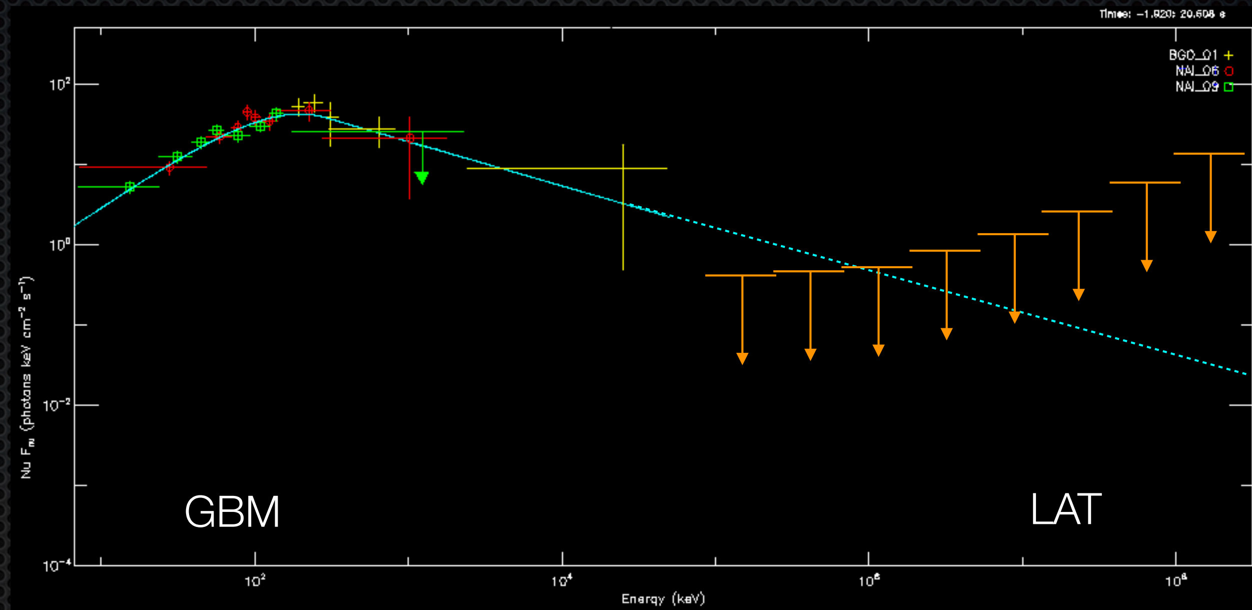
GRB 090820A



Burgess et al. 2011

Evidence for MeV Spectral Cutoffs

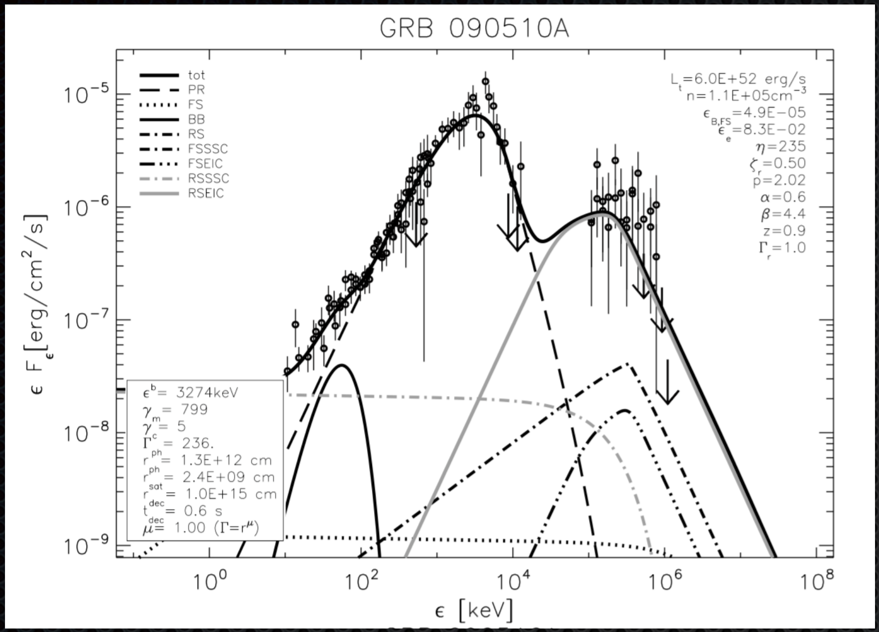




- Both direct and indirect evidence for spectral cutoffs
- High energy cutoff in the extra power-law seen in 090926A
- Inclusion of the BGO and LAT data tends to soften hard bursts with $\beta > -2$
- Other bursts cannot accommodate the LAT limits and require a break at MeV

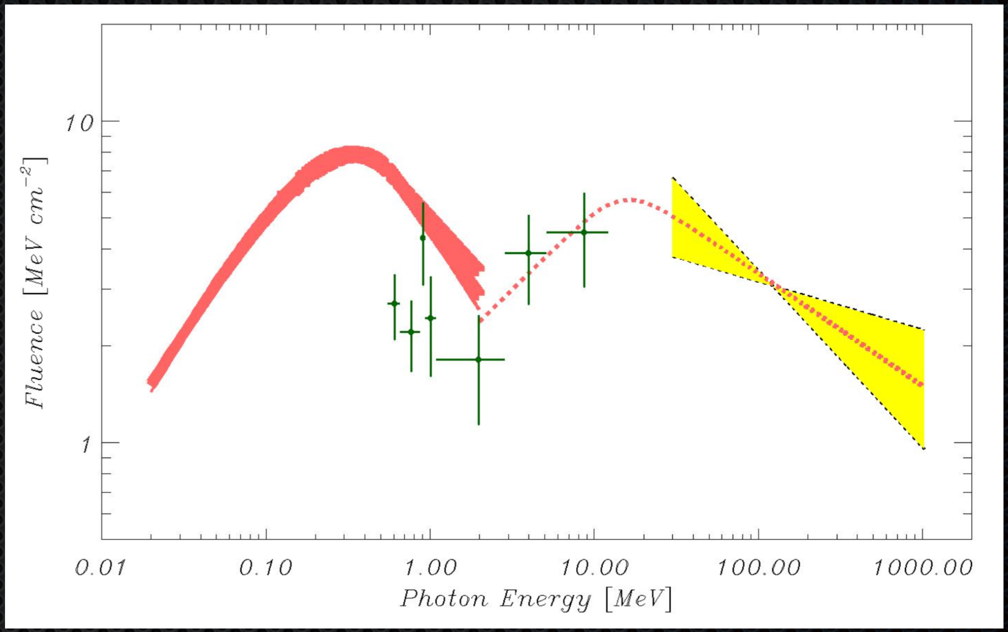
Evidence for IC/SSC Emission?

GRB 090510



Veres et al. 2012

GRB 131108A



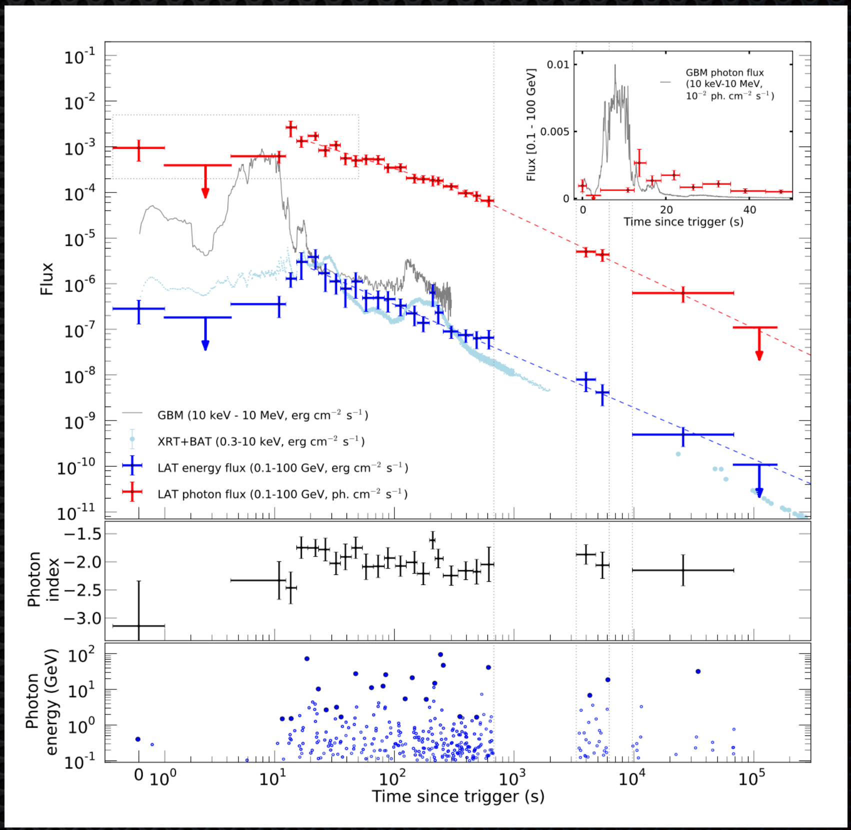
Giuliani et al. 2014

- Several authors have fit the prompt GBM and LAT data to double peaked spectra
- GBM emission could be due to phosphoric emission and LAT is due to IC emission
- Delayed nature of the high-energy emission makes this interpretation challenging

Origin of LAT Detected Emission?

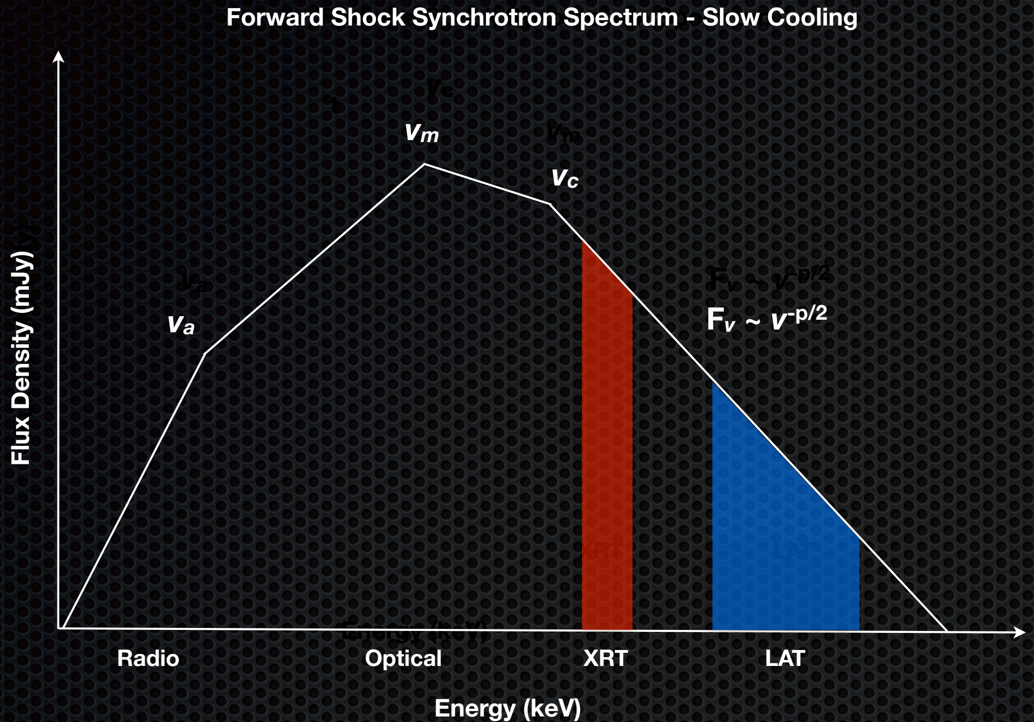
- Delayed onset of >100 MeV emission compared to keV emission in most bursts
- Prompt correlated emission > 100 MeV does exist
- Extended in nature, lasting hours in some cases
- Power-law decays, with slopes that resemble afterglow decays
- Kumar & Barniol Duran 2009 proposed a simple external shock origin to this emission
- Multi-wavelength observations of GRBs 110731A & 130427A support an external shock origin of their late-time high-energy emission
- Observed properties disfavors direct IC and SSC of prompt keV emission

GRB 130427A

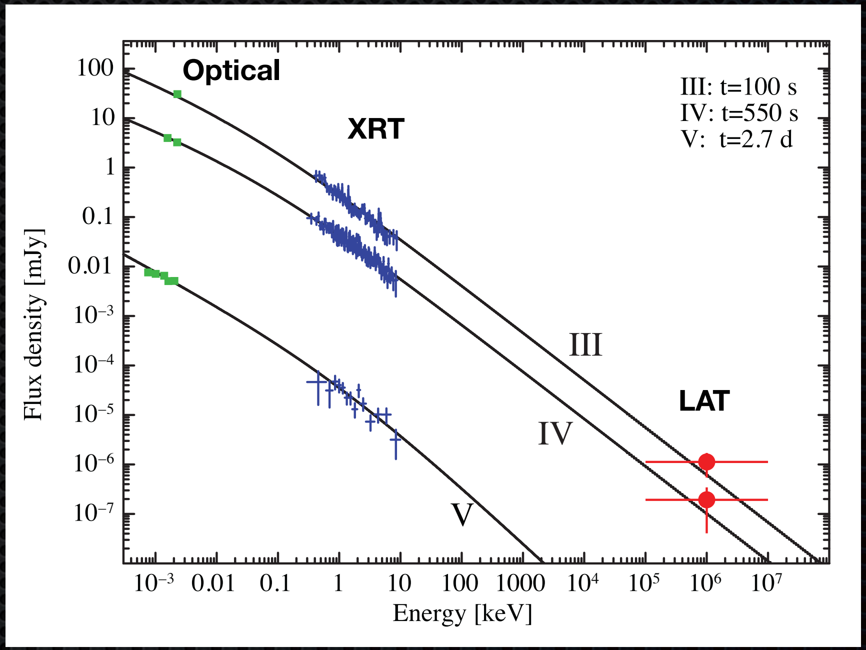


Ackermann et al. 2013

High-Energy Afterglow Emission



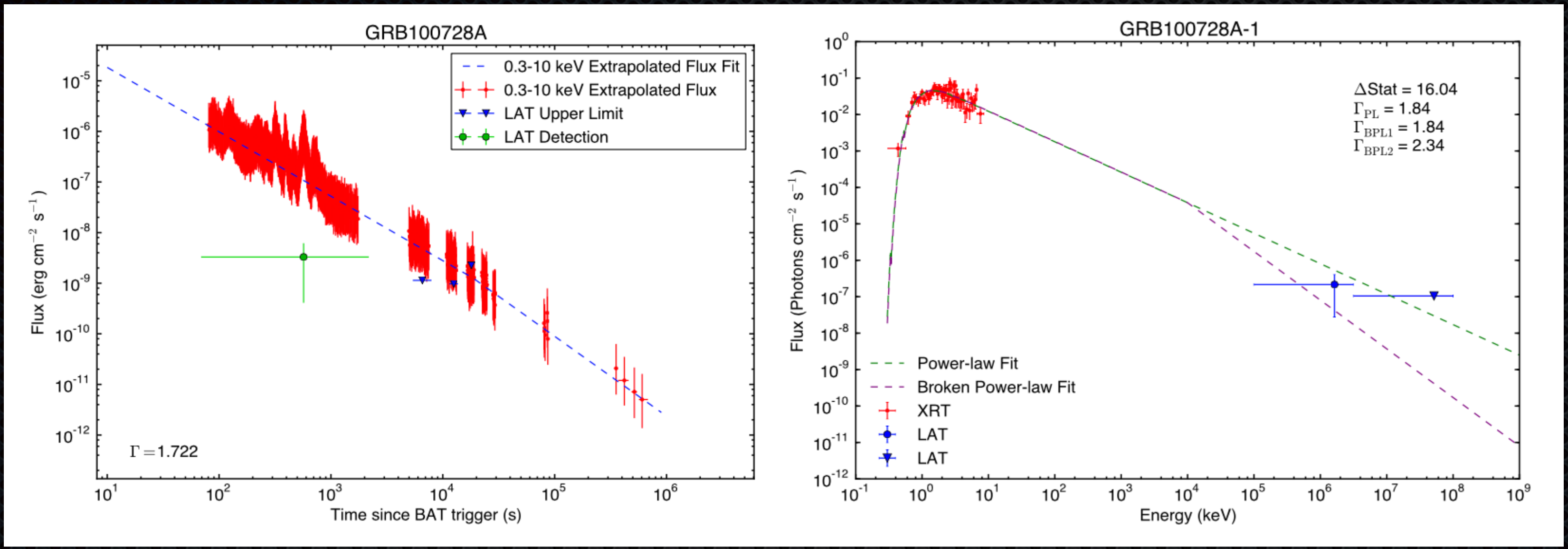
GRB 110731

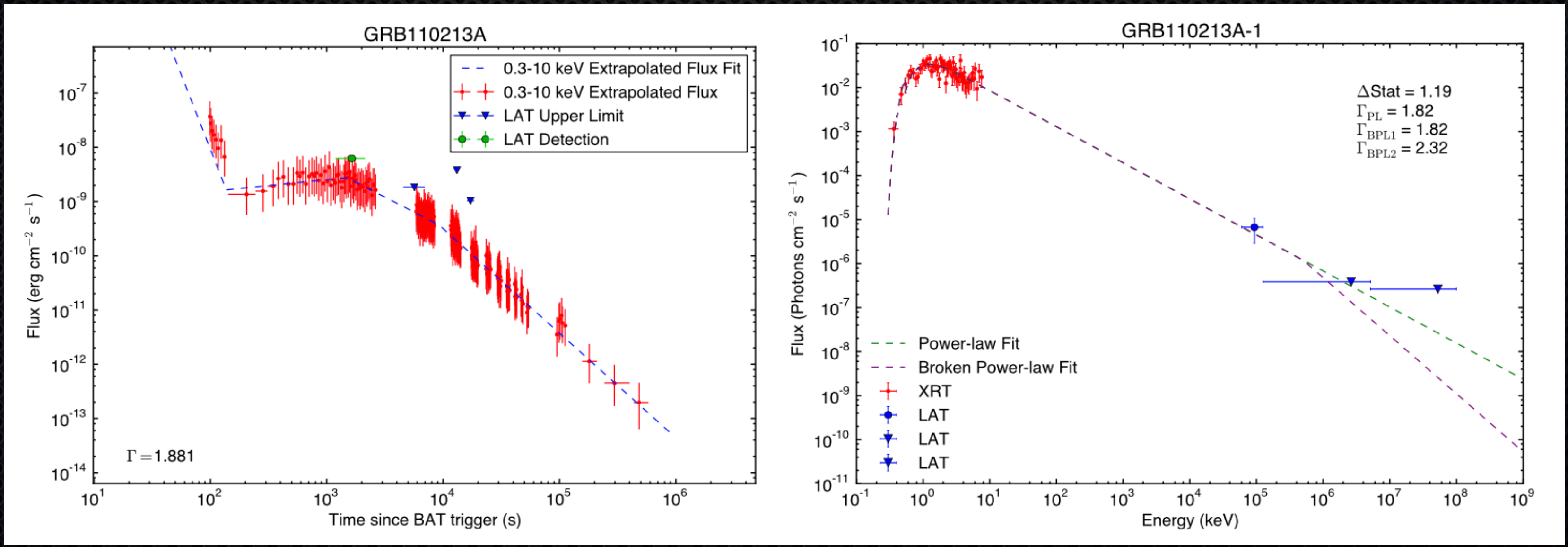


Ackermann et al. 2012

- Late-time high-energy emission seems to be an extension of the afterglow spectrum
- Only observable in the brightest and hardest afterglows
- There are no LAT bursts with emission in excess to that expected from the x-ray spectrum

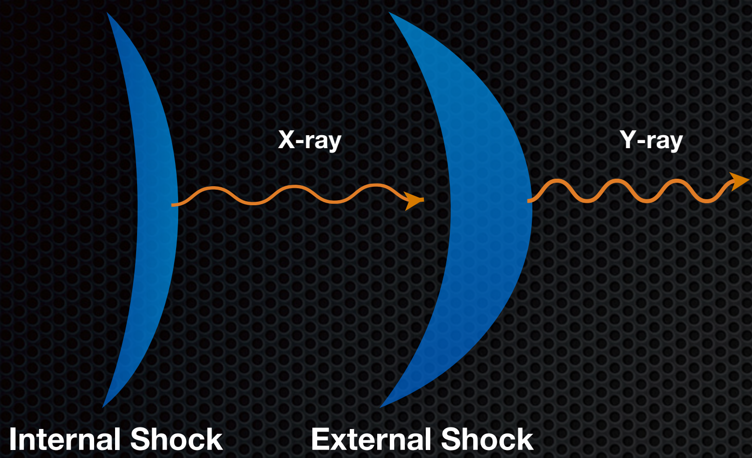
No Evidence For IC/SSC Emission



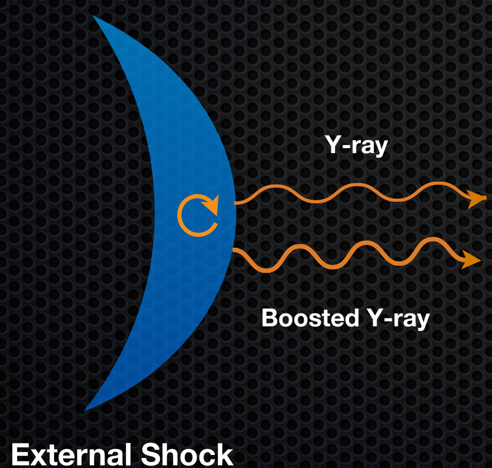


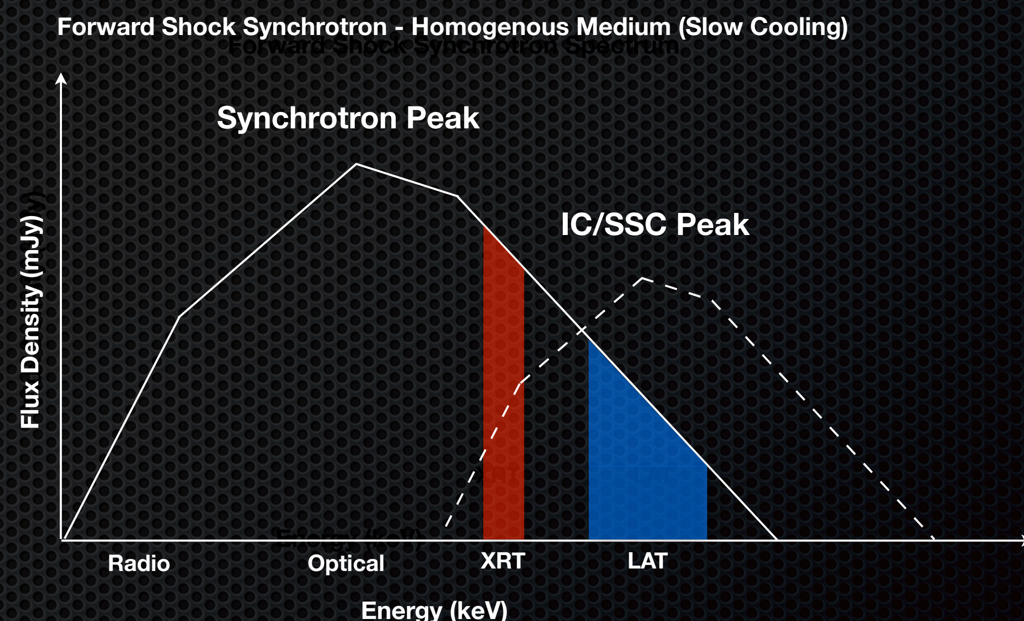
Where is IC/SSC Emission?

IC Emission



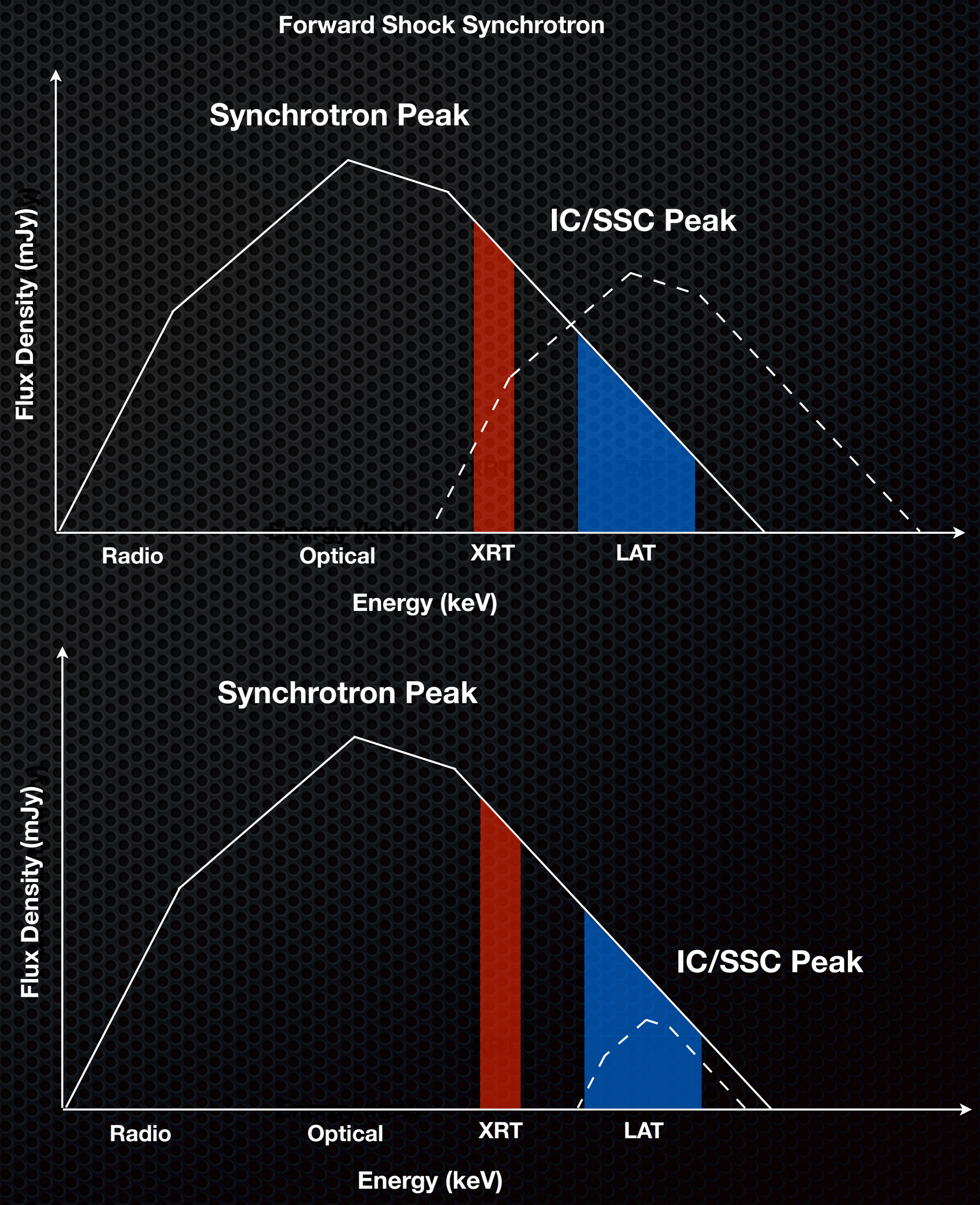
SSC Emission





IC/SSC Constraints

- No evidence for late-time IC/SSC emission within the LAT energy range from any segment of the afterglow phase
    - IC scattering from x-ray flare photons, plateau emission, or SSC from the forward shock
- Blast wave with large fraction of total energy in energetic electrons and/or a very low magnetic field density will generate a prominent SSC peak
- Our results favor a magnetically dominated blast wave with $\epsilon_B >> \epsilon_E$
- Other possibility is the SSC peak is outside the LAT energy range
    - If synchrotron peak is in x-ray, would require a very high electron lorentz factor of $\Upsilon_m > 1000$
- Magnetically dominated jets could produce highly polarized emission



New Questions!

- How common are blackbody-like components in the prompt emission?
- Where is the transition from prompt to afterglow emission at MeV-GeV energies?
- What accounts for the delay in the prompt MeV-GeV emission
- What is the origin of the extra power-law components
- How common are spectral cutoffs at MeV energy for LAT non-detections
    - How do they evolve and depend on other burst properties
- Are GRB jets magnetic or kinetic energy dominated?
- Is there a single component in the X-ray and GeV spectra in the afterglow emission
- Where is the SSC peak?
- How polarized is the prompt and extended emission?

What do we need in a future mission?

- Wide field of view sensitive keV triggering instrument
  - In order to characterize the soft gamma-ray temporal and spectral properties
  - Accurate localizations with ability to repoint the spacecraft
- Sensitive MeV instrument with an effective area optimized at 10's of MeV
  - Measure the energy and evolution of the peak νF_ν spectra for faint and bright bursts
  - Measure the energy and evolution of the high-energy spectral cutoffs and hence Γ
  - Measure MeV afterglows to test single synchrotron component interpretation
- Polarization!
  - The holy grail for GRB science
  - Could finally settle the issue of photospheric vs optically thin emission
  - Could put constraints on magnetic versus baryonic dominated jets