Afterglow Observations of *Fermi*-LAT Events and the Emerging Class of Hyper-Energetic Gamma-Ray Bursts

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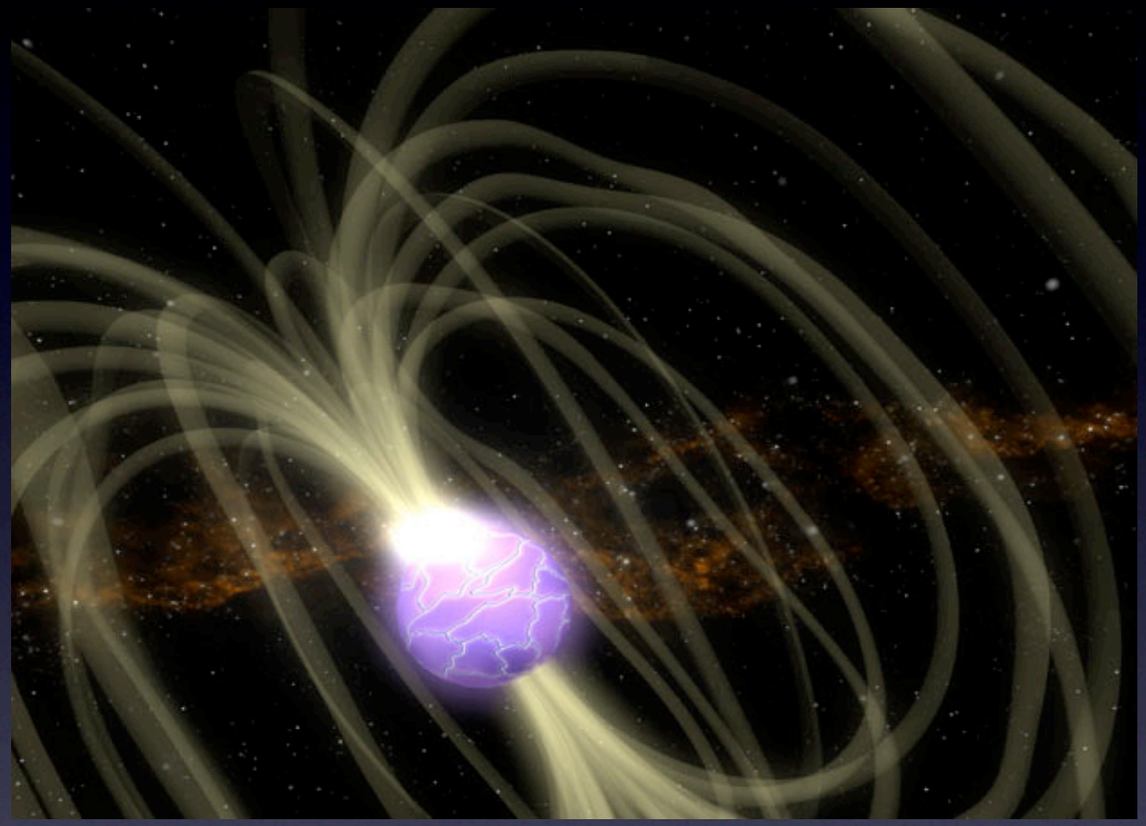
Motivation: Central Engines

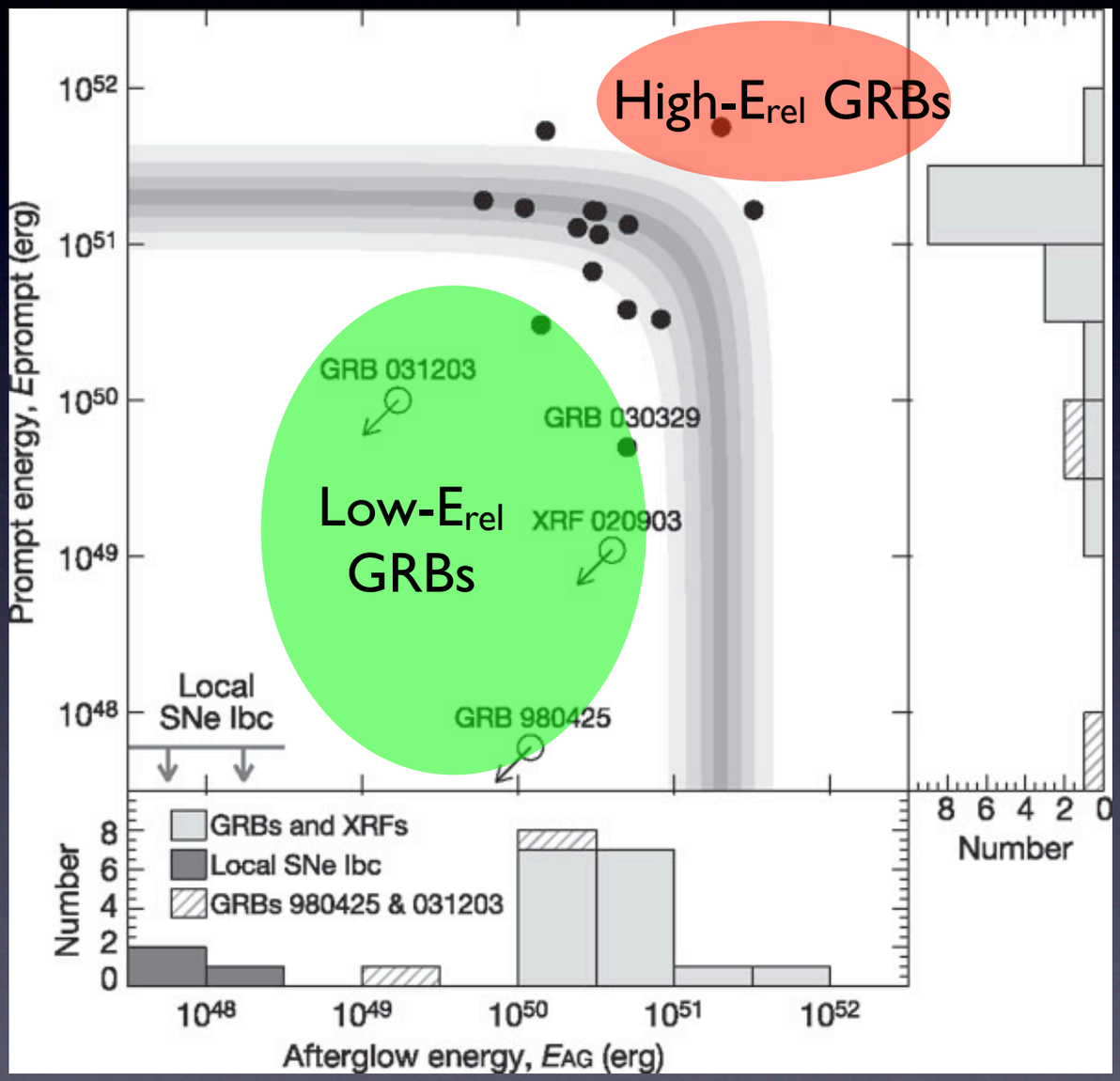
Collapsar: Woosley 93, MacFadyen & Woosley 99
$E_{max} \sim 0.1\ Mc^2 \sim 10^{54}$ erg



Magnetar: Usov 92, Duncan & Thompson 92
$E_{max} \sim I\ \Omega^2 / 2 \sim 3 \times 10^{52}$ erg

Central engine models highly constrained by *geometry* ($\gamma\theta$) and *energetics* (E_{max})

Engine Diagnostics: E_{rel}



Soderberg *et al.* 2004

- Existence of a large population of uncollimated, sub-luminous GRBs suggests a diversity of engine mechanisms

- More recently, growing evidence for a substantial population of over-luminous GRBs with $E_{rel} > 10^{52}$ erg

- Difficult to accommodate within magnetar framework

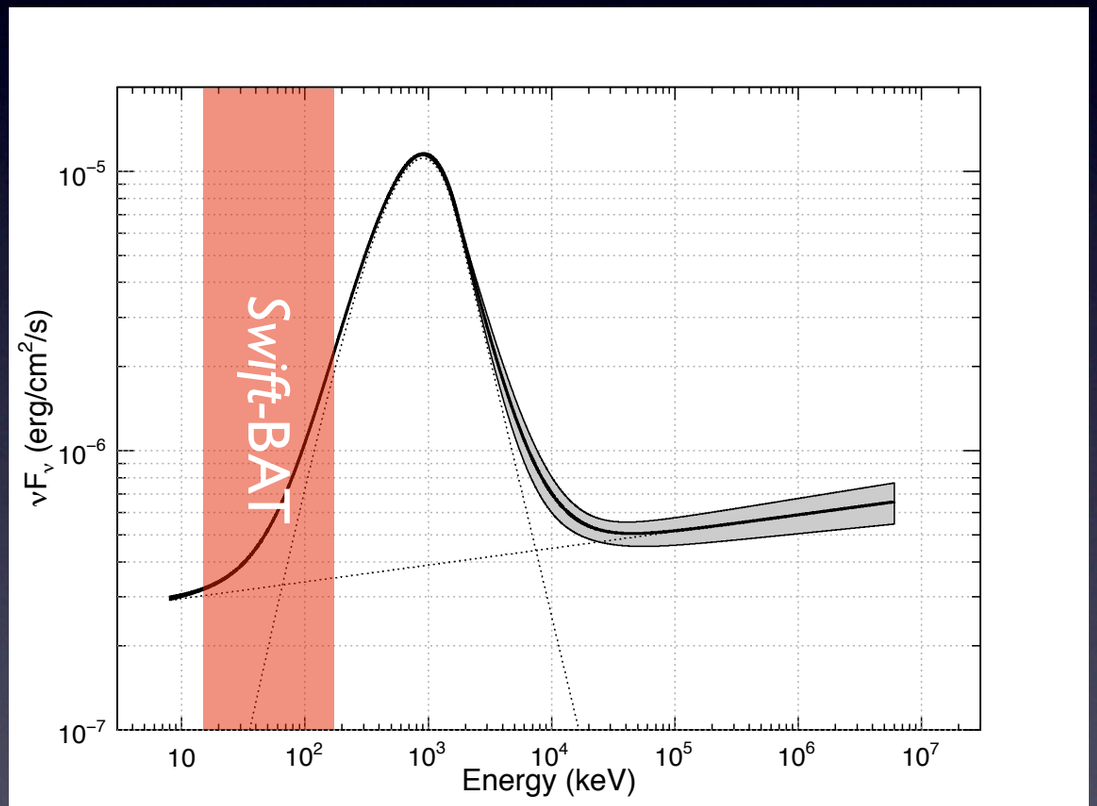
Puzzling Energetics of *Swift* GRBs

- Despite extensive searches, only a small fraction of *Swift* events with jet breaks (θ) measurements

- Faint, distant afterglows difficult for detailed follow-up studies

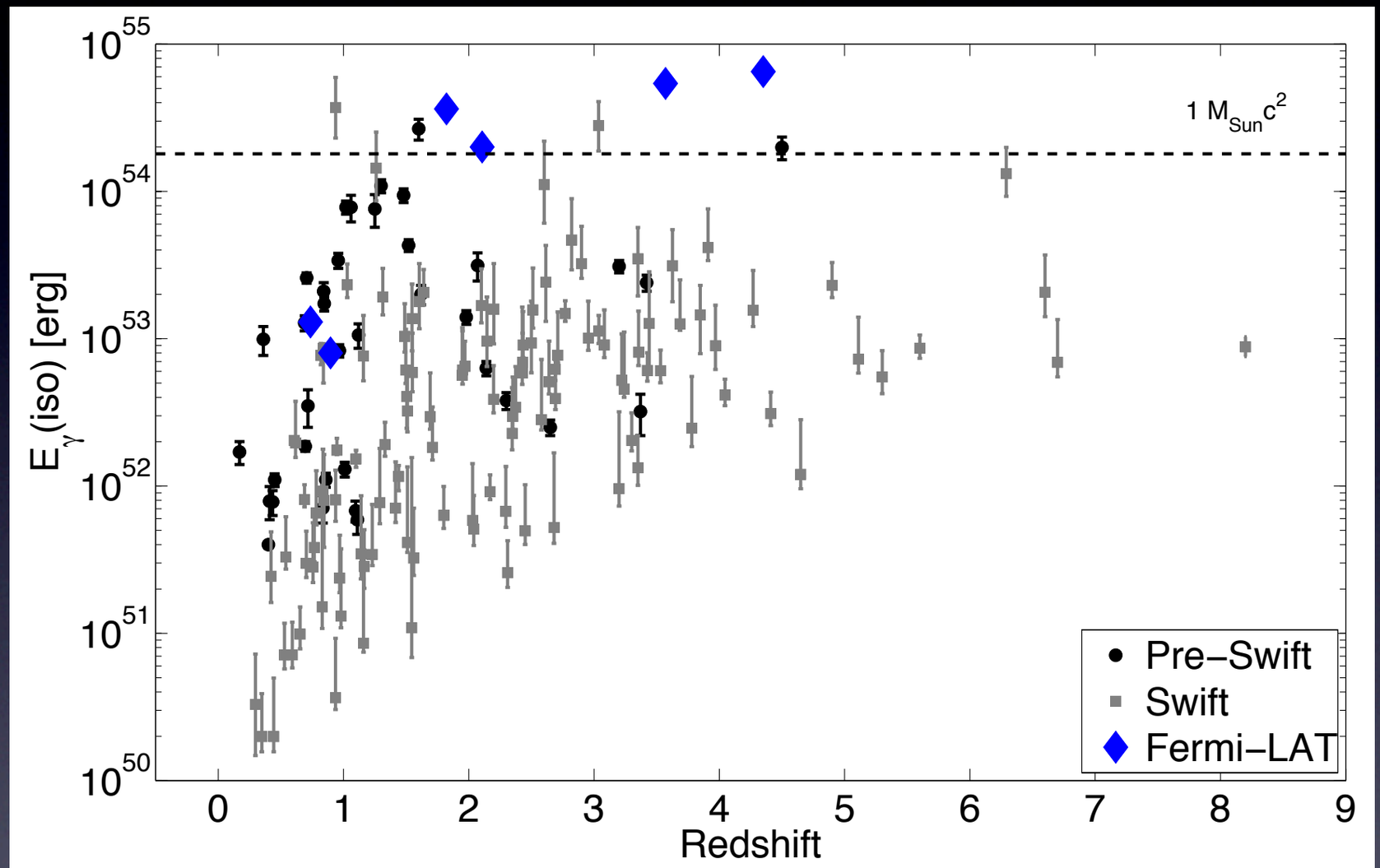
- Poor constraints on E_γ from limited bandpass of *Swift*-BAT

GRB 090902B



Abdo *et al.*, 2009

Fermi-LAT and the Brightest GRBs

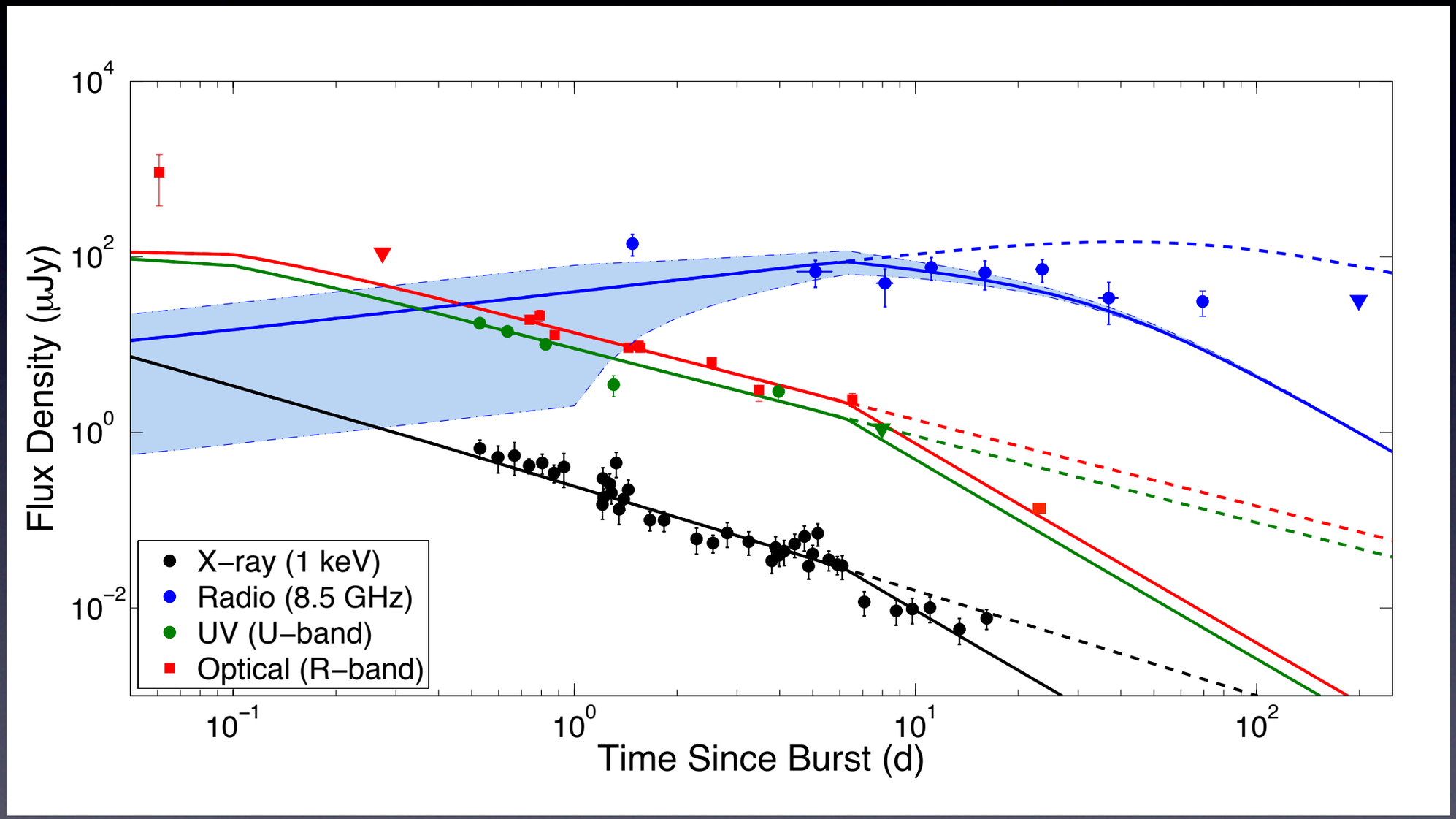


The *Fermi*-LAT offers an efficient way to target large $E_{\gamma,iso}$ events

Plan of Attack

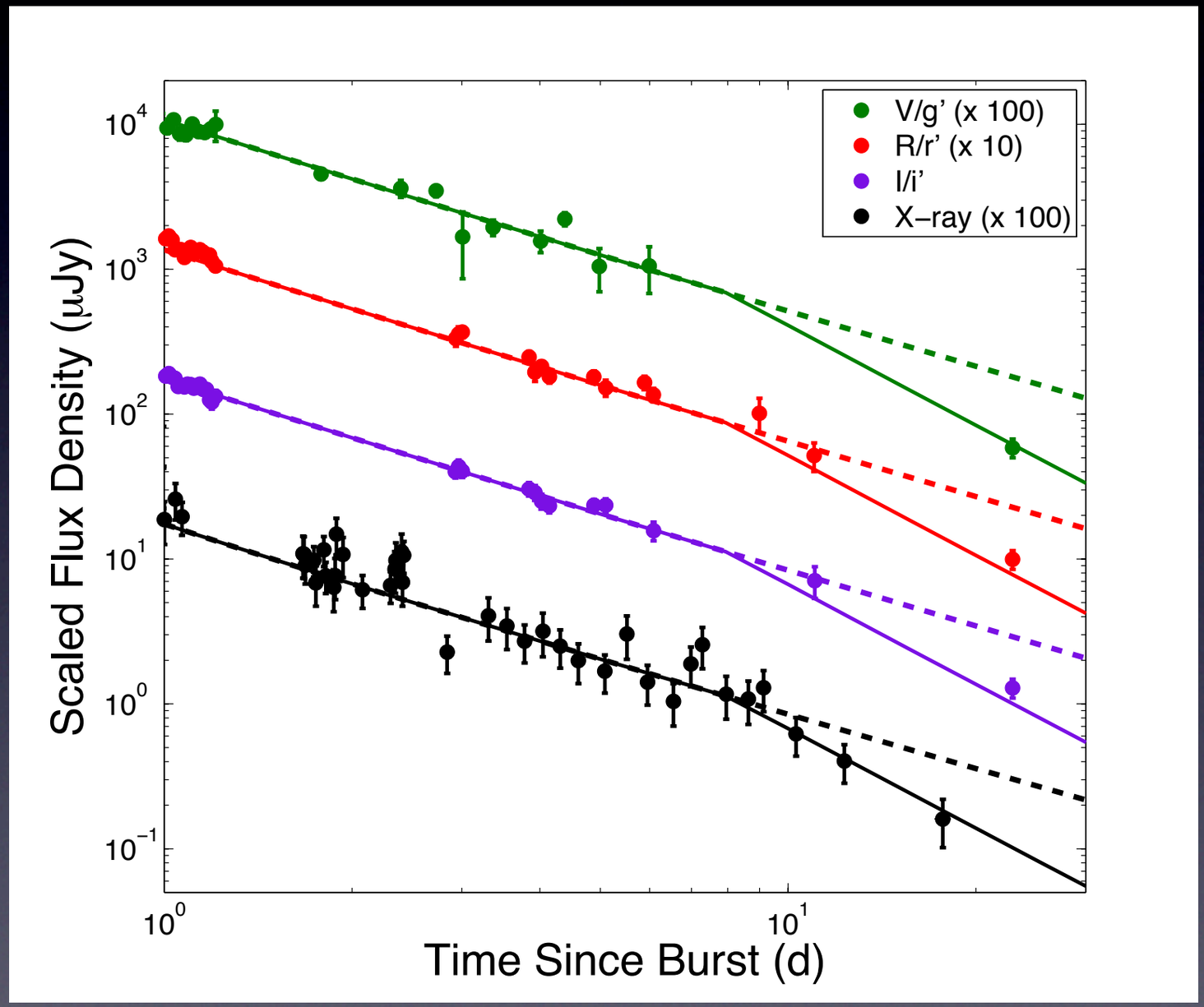
- Focus on brightest (↑ $E_{\gamma,iso}$) GRBs, brightest afterglows, easiest jet breaks and hence opening angles to measure
- Fermi-*LAT* efficiently targets these GRBs, while also providing robust $E_{\gamma,iso}$ and γ measurements
- Detailed afterglow follow-up in X-ray, optical, and radio out to late times
- Broadband modeling to infer opening angles, energetics, and circumburst density (this work)
- Host galaxy spectroscopy and photometry to correlate with larger scale environment (in prep)

Light Curve Modeling: I



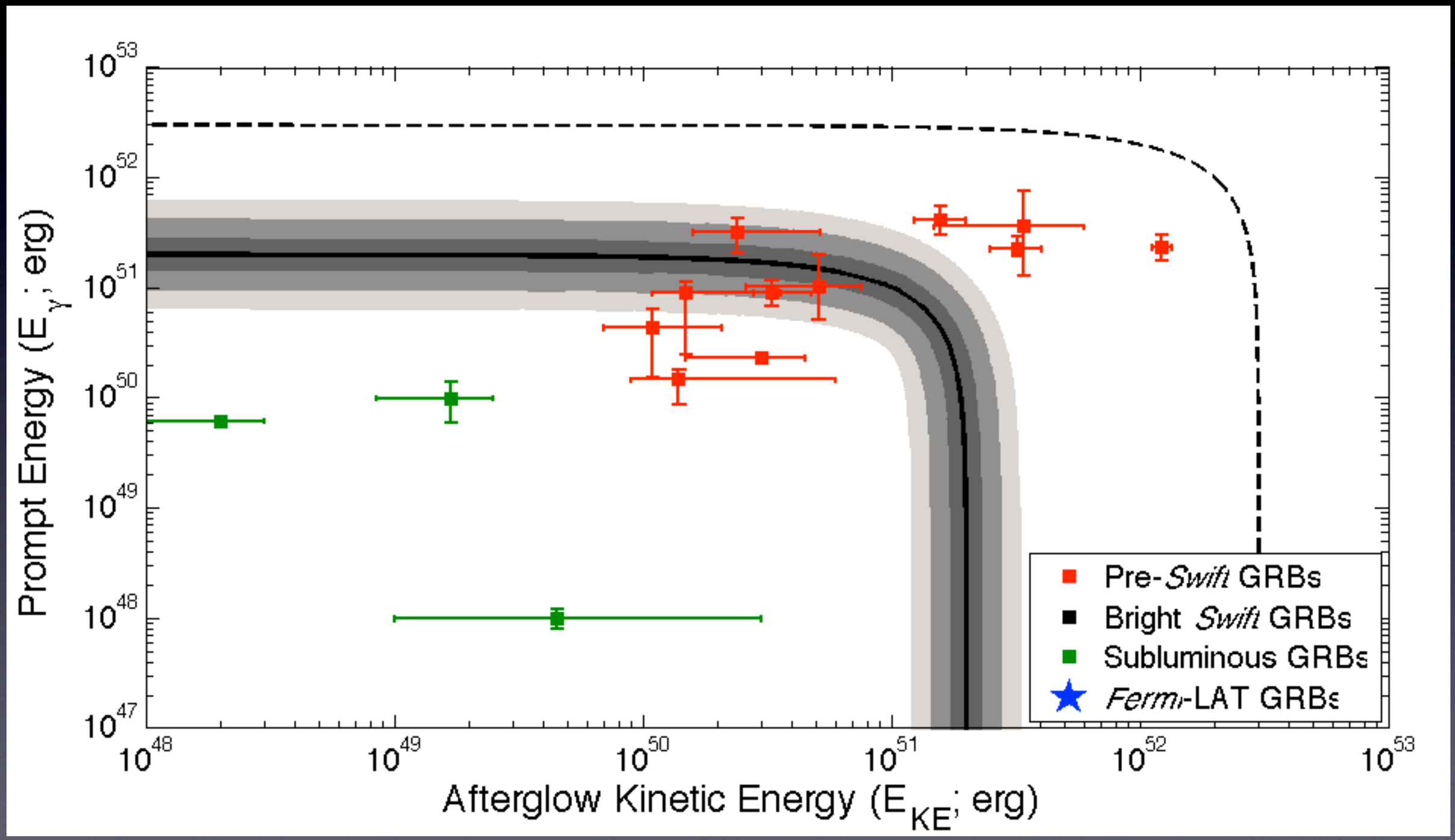
GRB 090902B: $\theta \sim 3°$; $E_{rel} \sim 7 \times 10^{51}$ erg

Light Curve Modeling: II

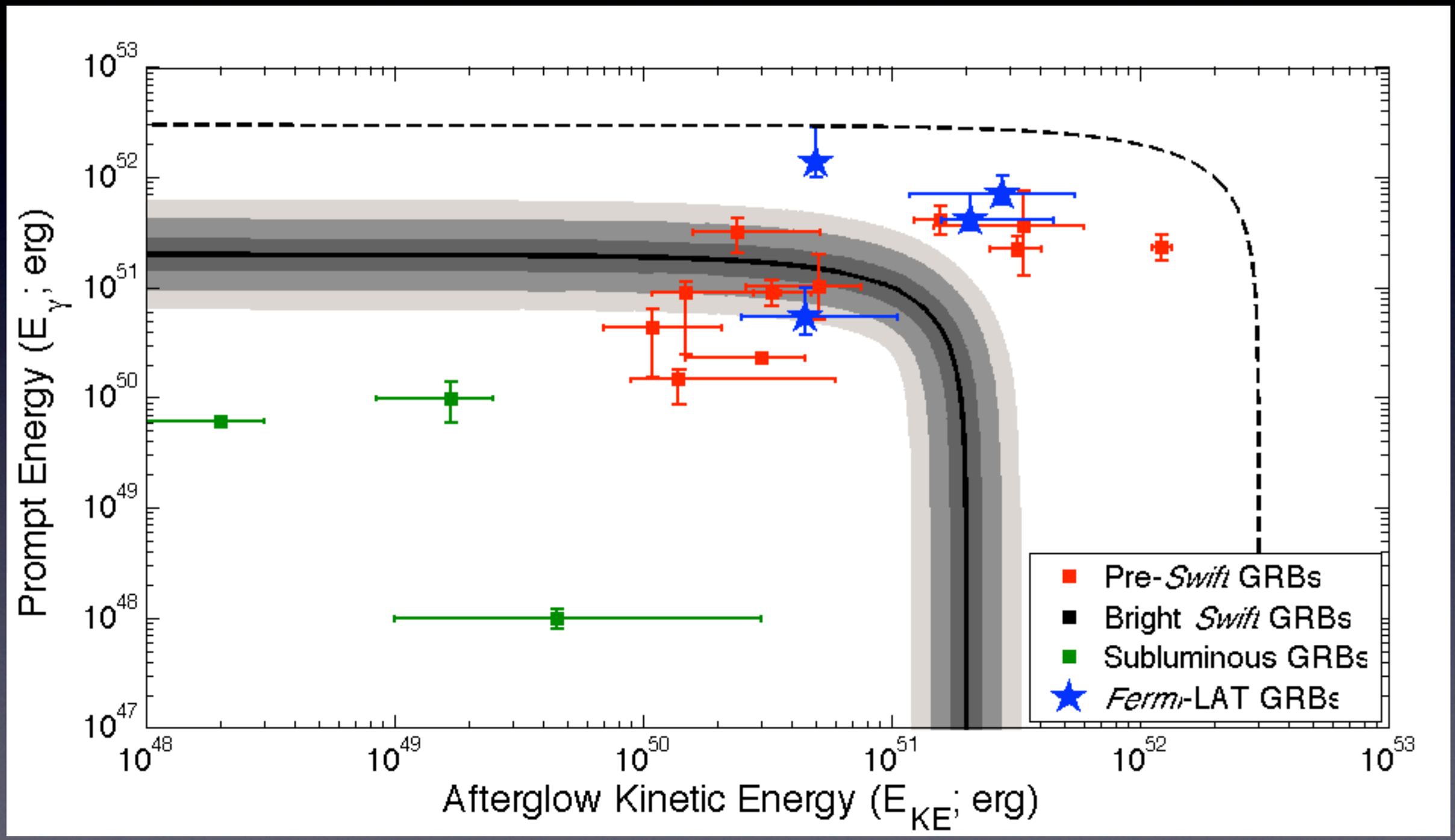


GRB 090926A: $\theta \sim 7°$; $E_{rel} \sim 2 \times 10^{52}$ erg

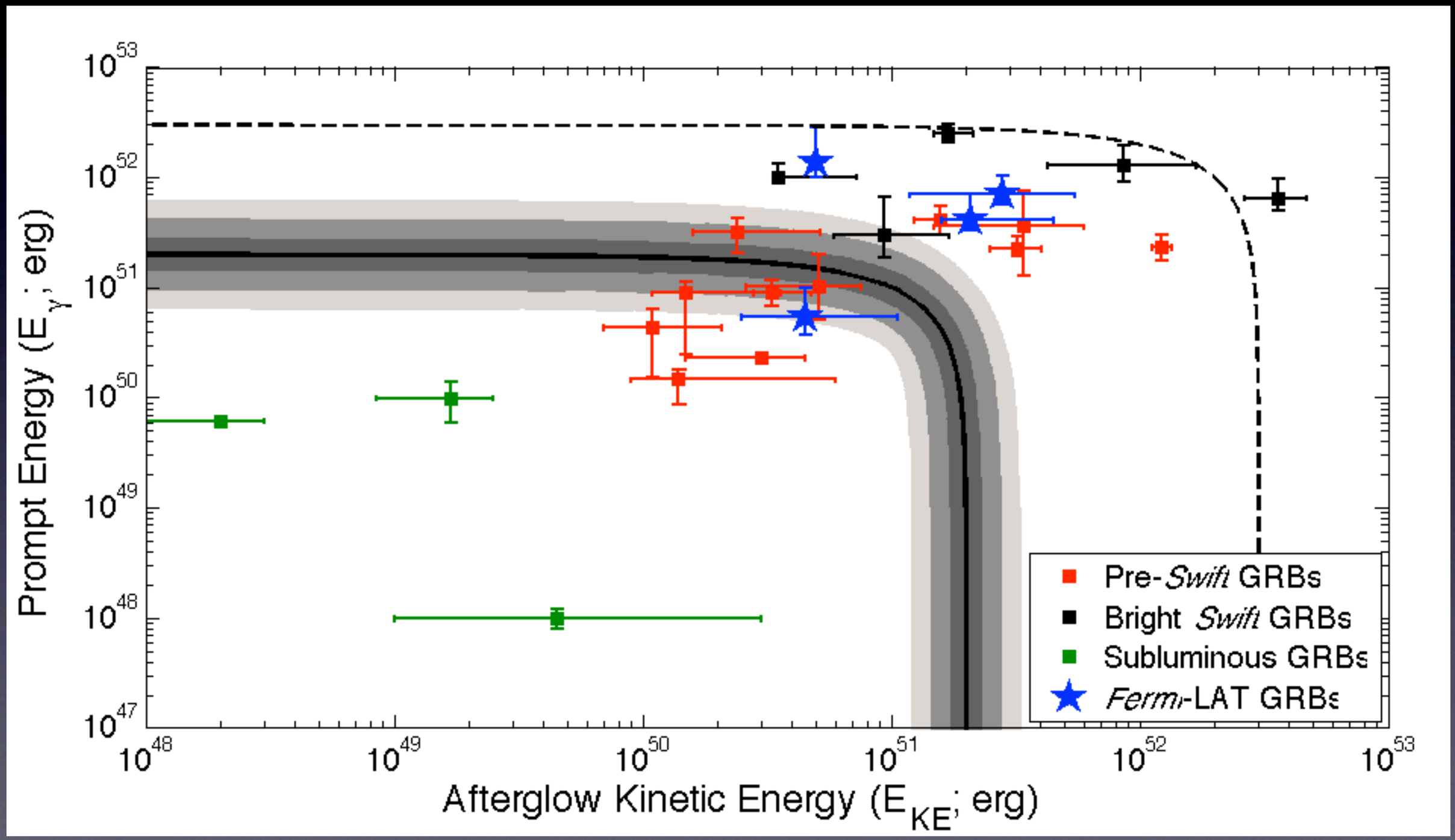
Results: Energetics



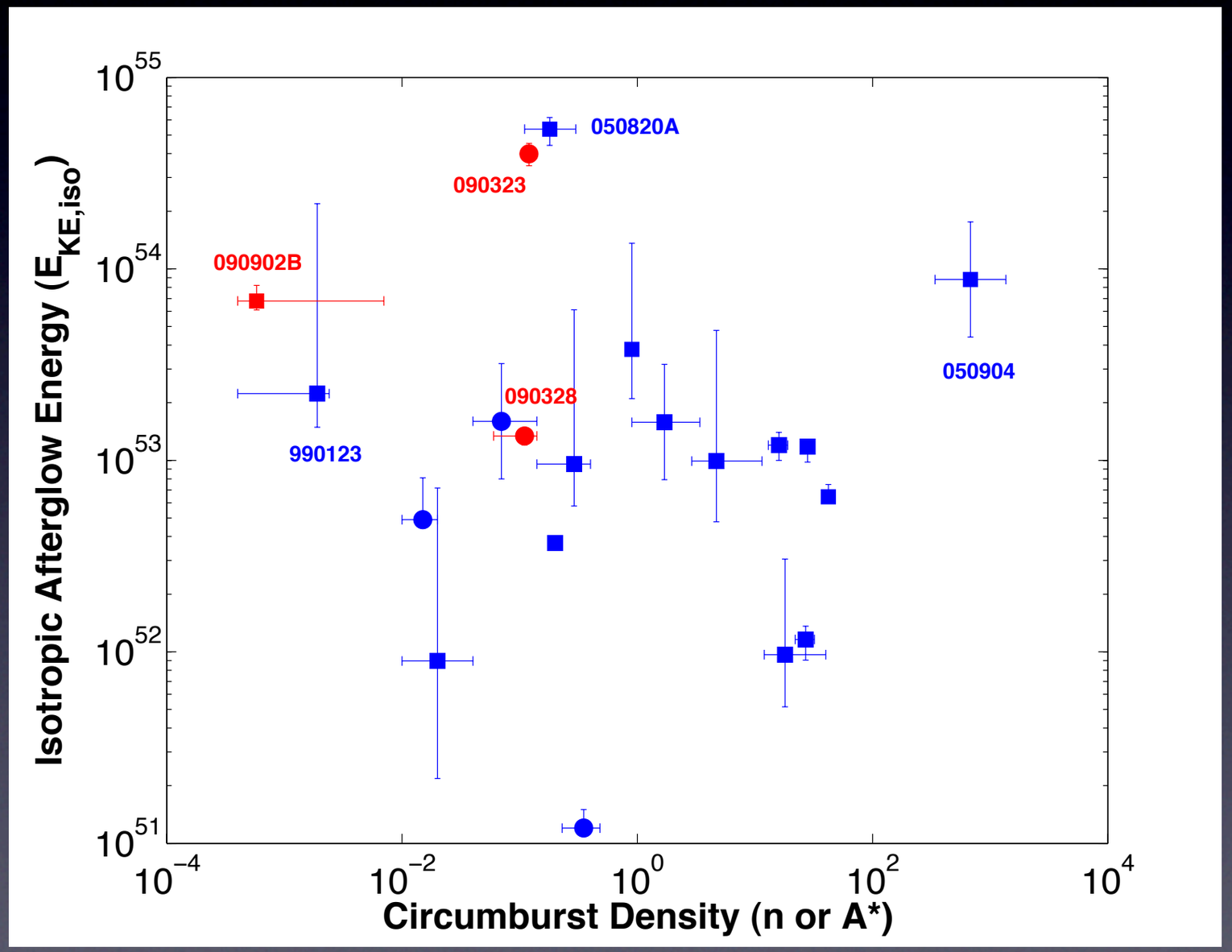
Results: Energetics



Results: Energetics



Results: Circumburst Environment



Conclusions

- Use broadband afterglow observations to constrain collimation and energetics from 4 *Fermi* LAT GRBs
- All 4 tightly collimated ($\theta \sim 3\text{-}7^\circ$)
- At least 1 event (090926A) has E_{rel} in excess of 10^{52} erg $\Rightarrow$ collapsar origin
- Low circumburst densities (consistent with rapidly rotating progenitors)
- Radio calorimetry with EVLA will soon provide independent confirmation of inferred E_{rel}