On The Lack of Time Dilation Signatures in Gamma-ray Burst Light Curves

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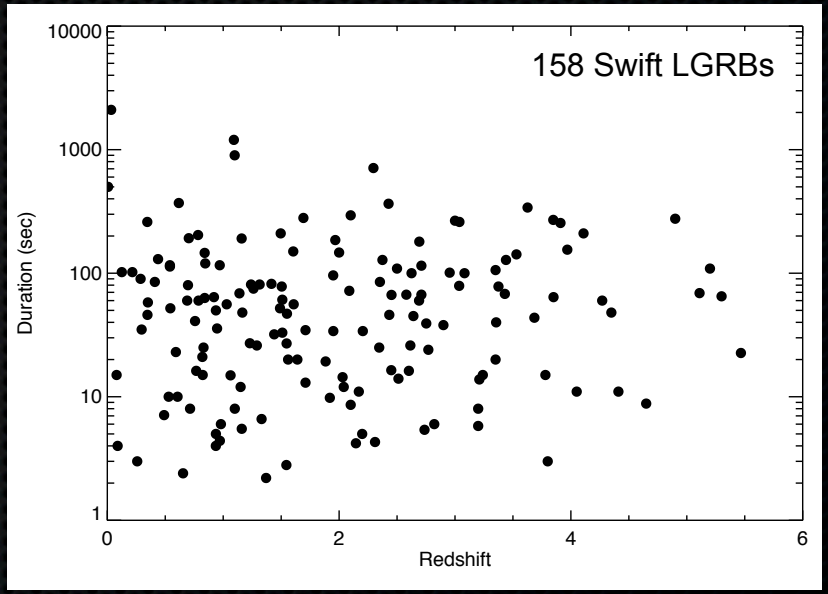
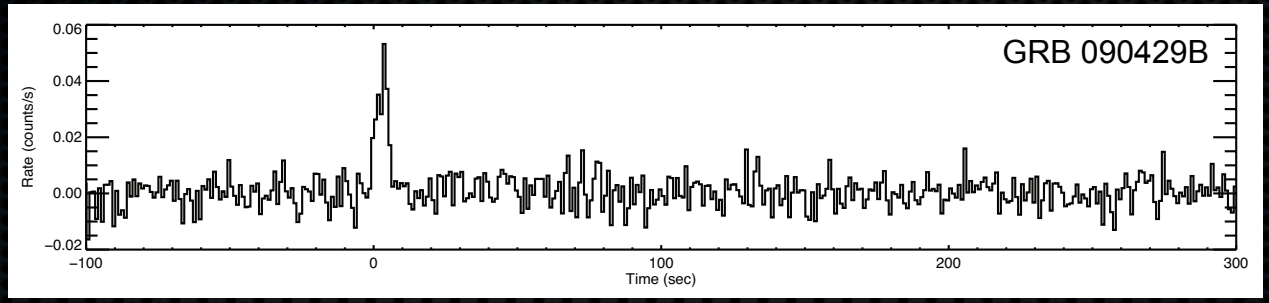
GRB Demographics

- Detected over an large range of redshifts
  - GRB 980425 at z = 0.0085
  - GRB 090429B at z ~ 9.4
- Excellent sources to look for evidence of time dilation due to cosmological expansion
- Almost 200 GRBs with known redshift
- A systematic broadening of GRB durations as a function of redshift has not materialized
  - In either Swift or Fermi detected populations

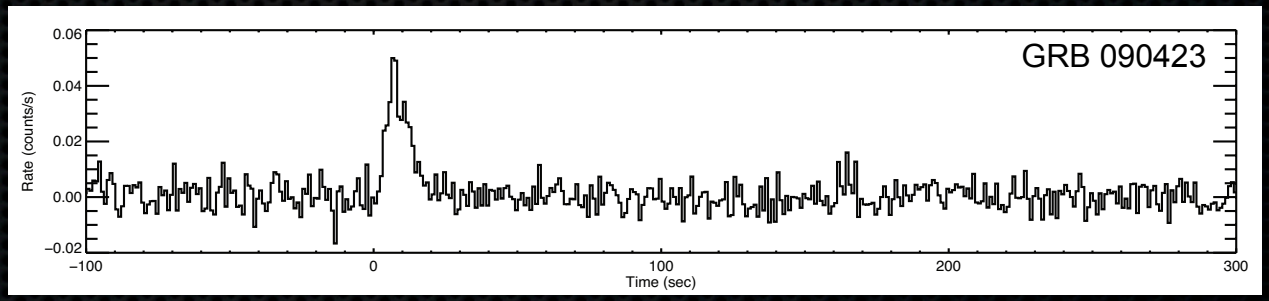


Most distant GRBs are short

- GRB 090429B at z = 9.4, Δt_{obs} ~ 5.5s, Δt_{src} ~ 0.5s

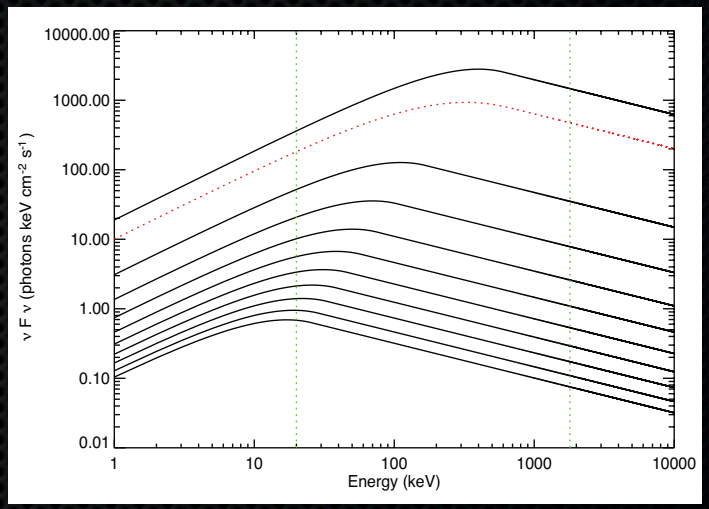


- GRB 090423 at z ~ 8.1, Δt_{obs} ~ 10.3s, Δt_{src} ~ 1.13s



- GRB 080913A at z ~ 6.7, Δt_{obs} ~ 8.1s, Δt_{src} ~ 1.04s

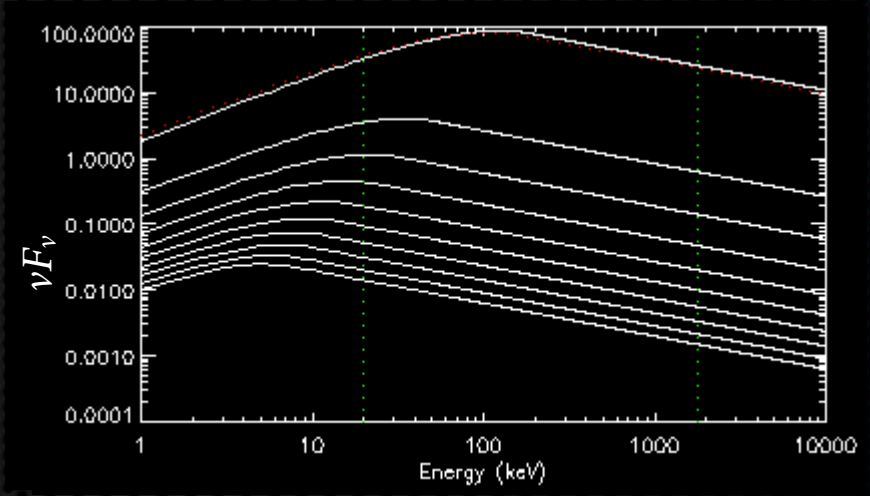
Effects of Cosmological Time Dilation and Redshift

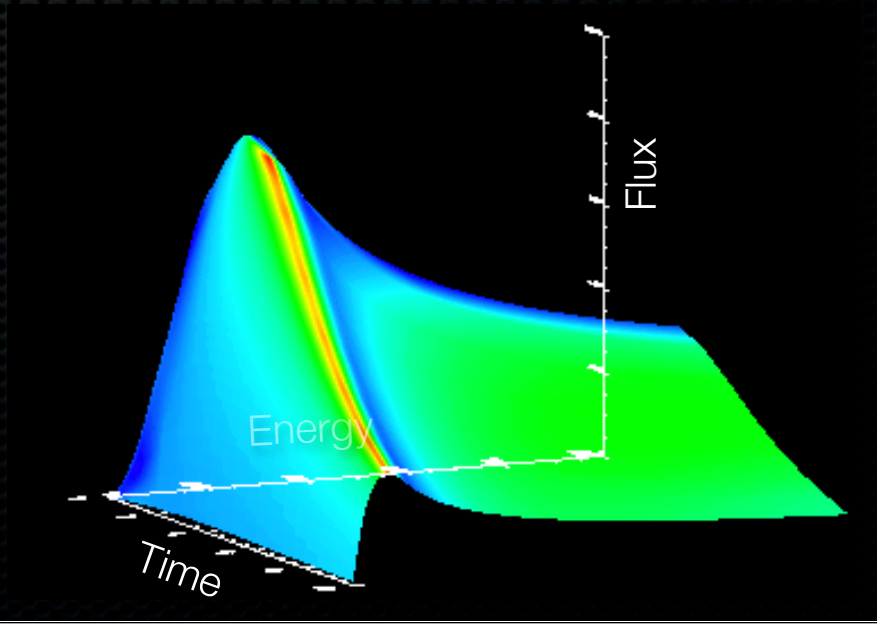


- GRB spectra evolve with time
  - Typically hard to soft evolution
- Time dilation delays this evolution
- $E_{pk,obs}$ is redshifted to lower energies
  - Energies which become increasingly difficult to detect
- Net effect: soft and faint emission becomes difficult to observe.
- We miss long soft tails for these GRBs
- We turn to simulations to quantify this effect

Step 1: Simulate the GRB

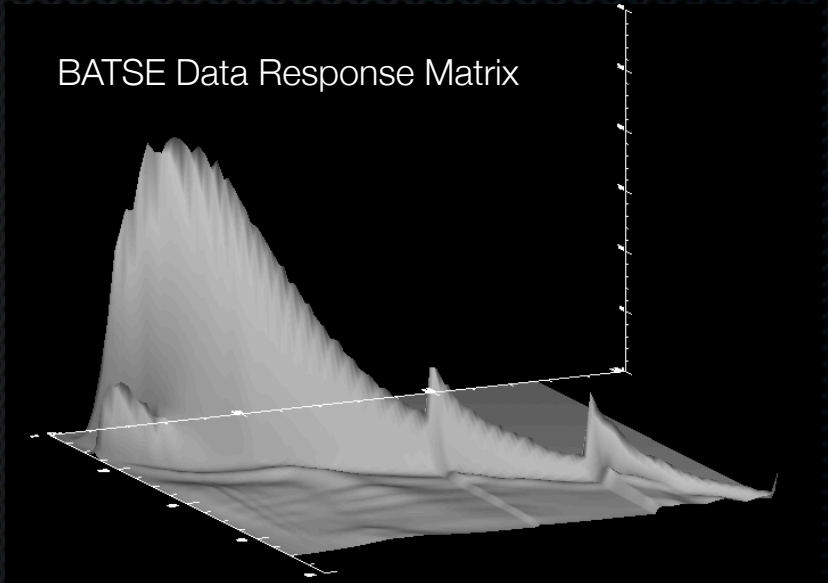
- Assume a spectral shape
  - Use Batse α, β, E_{pk} distributions
- Assume some spectral evolution
  - Consistent with relativistic curvature
  - $E_{pk} \sim t^{-1}$; Flux ~ E_{pk}^2
- Assume source frame duration distribution
- Proscription produces FRED pulse profiles

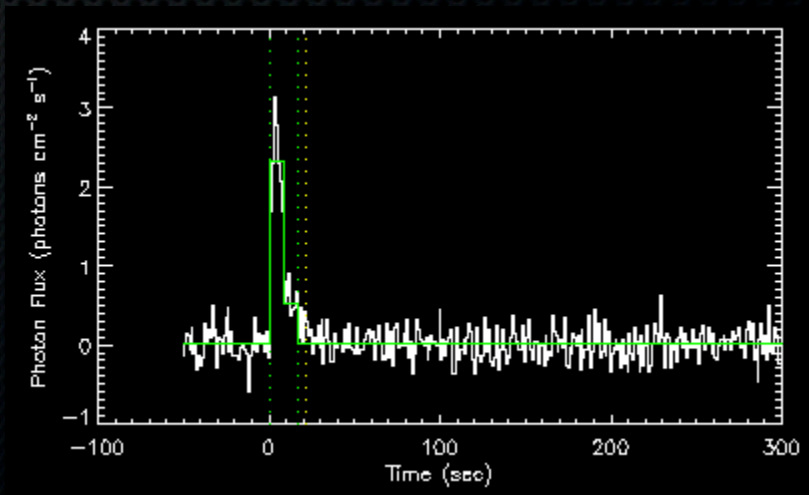




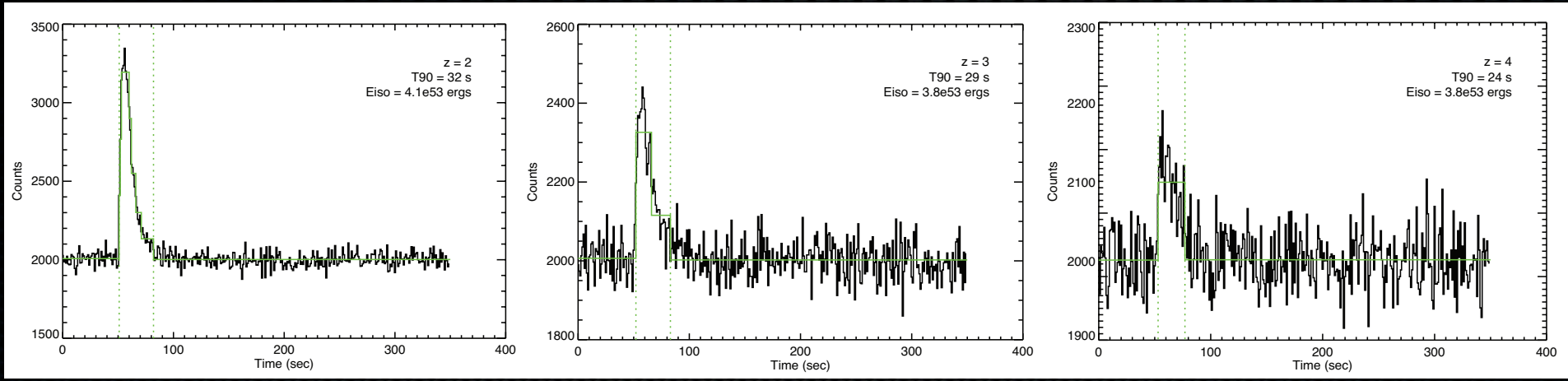
Step2: Simulate the detector

- Run simulated time-integrated spectrum through a detector response function
  - Gives us the sensitivity vs. energy
- Produce count light curves
  - Assume background noise level
- Determine if spacecraft would have triggered on GRB
  - If so, find duration using Bayesian Block algorithm





Duration vs. Redshift



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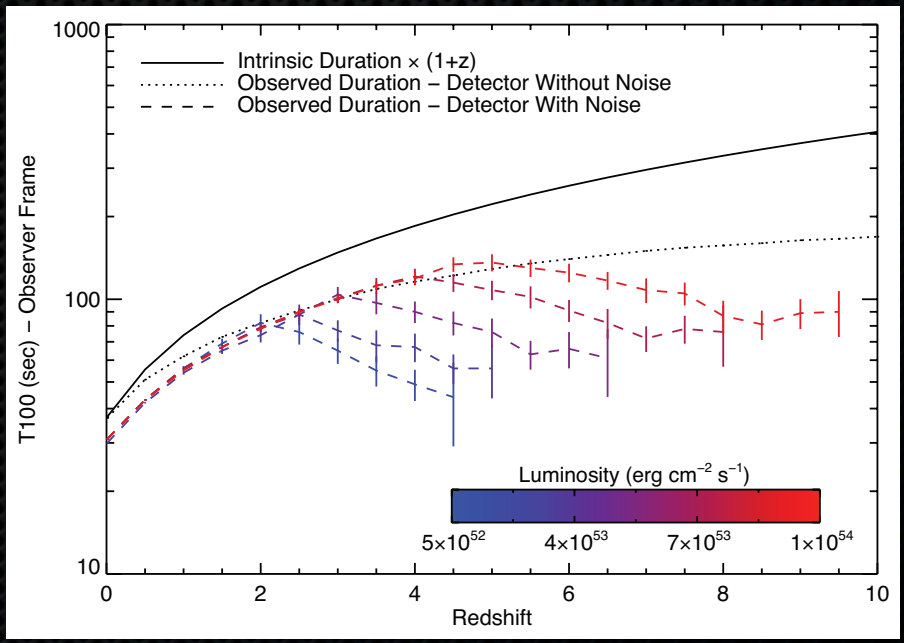
- Regions of low signal to noise become difficult to detect
- Duration actually falls as a function of redshift
- The “tip of the iceberg” effect
- Similar to problem of measuring galaxy size vs distance

Duration Bias

- Even a perfect detector without noise would never observe time dilation ~ 1+z because of its limited energy window
  - E_{pk} is increasingly redshifted out of the instrument's energy window
- Adding noise results in a falling duration as a function of redshift
- The redshift at which the duration begins to decrease depends on the burst's intrinsic luminosity and hence SN
- The burst's signal to noise is a good indicator of the severity of the bias



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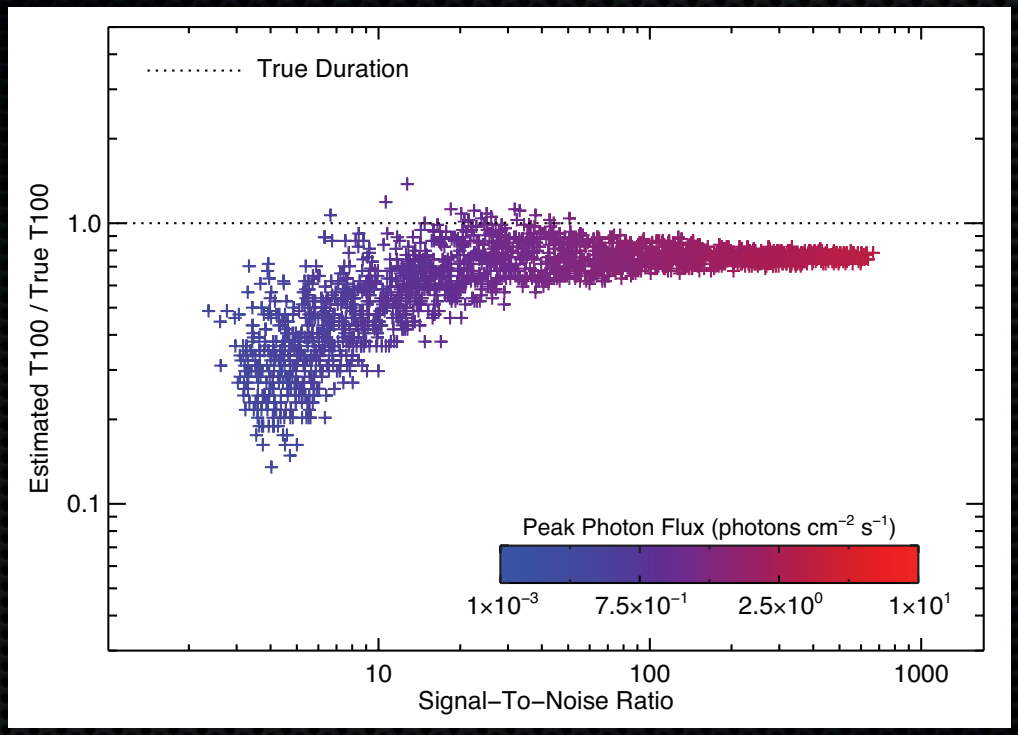
Duration Bias vs. Signal to Noise



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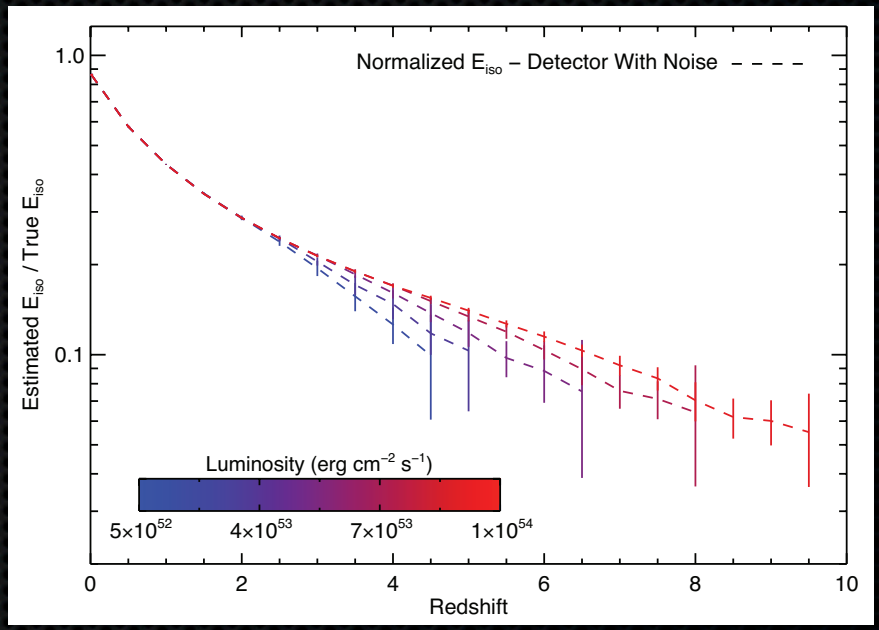
- The burst's signal to noise is a good indicator of the severity of the bias
- In our simulations, bursts with SN < 25 suffered from the largest duration bias
- A burst's observed signal to noise is a good indicator of the severity of the bias

Energetics Bias

- The duration bias automatically translates into an energetics bias
- An underestimation of duration results in an underestimation of fluence and hence E_{iso}
- The ratio of E_{iso} to $E_{iso,true}$ falls rapidly with increasing redshift
- E_{iso} can be underestimated by as much as 90% for low SN bursts
- L_{iso} will not suffer from such a bias and may be an unbiased energetics indicator



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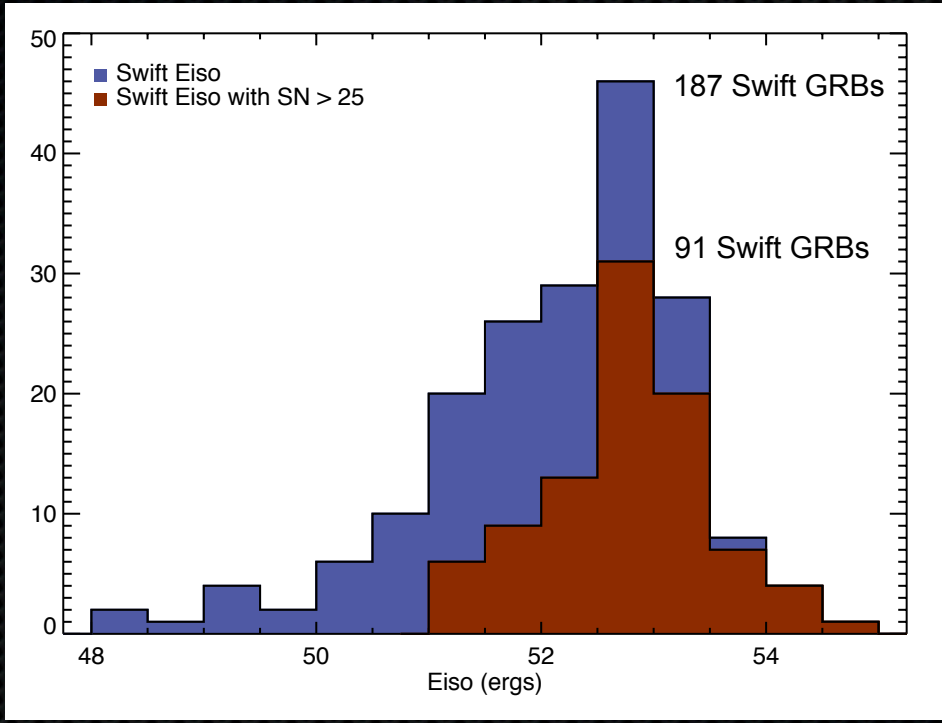
Swift E_{iso} Distribution



- E_{iso} distribution narrows when considering only GRBs detected with SN > 25
- The low SN bursts most likely have underestimated E_{iso} values
- The high end of the E_{iso} distribution is likely incomplete

Conclusions

- Our simulations show GRBs originating from the early Universe will not necessarily be characterized by extremely long durations
- Our duration and energetics estimates should really be considered as lower limits for weakly detected bursts
- L_{iso} will not suffer from such a bias and may be a better energetics indicator
- A burst's observed signal to noise is a good indicator of the severity of the bias
- Additional caution against using simply duration to define "short" GRBs
- Bimodal hardness-T90 distribution means that this effect does not produce arbitrarily small durations for long GRBs
- GRBs with soft, short pulses that are separated by long period of quiescence could actually be the tell tail sign of high redshift bursts