GRB Distance Indicators

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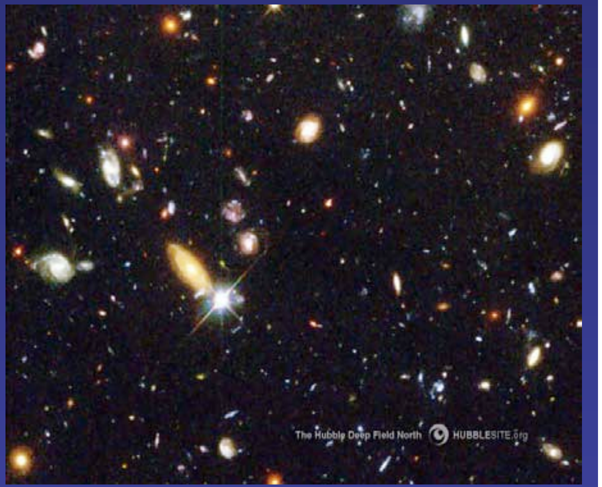
Outline

- Overview of proposed distance indicators
  - Lag-Luminosity
  - Variability-Luminosity
  - Epk-Eiso
  - Epk-Luminosity
- Estimated Redshift Distribution
- Estimated Luminosity Functions
  - via non-parametric techniques
  - Comparison between lag-lum and Epk-Eiso results
- Perils of correlation hunting
  - Examples of bogus distance correlations
  - Simple test to discriminate against them
- The type of distance indicator we really need
  - The promises of Swift

What Can We To Do With GRBs?

- Probe the Early Universe!
  - 28-1800 keV _-rays suffer little extinction
  - Potentially probe out to z ~ 10 or more
- Understand the Progenitor Evolution
  - GRBs linked to massive stars
  - Comoving rate density could trace SFR
  - We Want To Make Madau plots
- Stellar Initial Mass Function (IMF)
  - "Top-Heavy" at high redshift (Larson 1998)
  - More massive progenitors with higher z



Hubble Deep Field, STSci

Distance Indicators

- Lag-Luminosity
  - Norris et. al. 2000
  - Measured with 7 GRBs (BATSE)

$$L = 2.51\times10^{51}(\Delta t_{lag}/0.1)^{-1.14}$$

- Variability – Luminosity
  - Fenimore & Ramirez-Ruiz 2000
  - Measured with 7 GRBs (BATSE

$$L \propto V^{p}$$

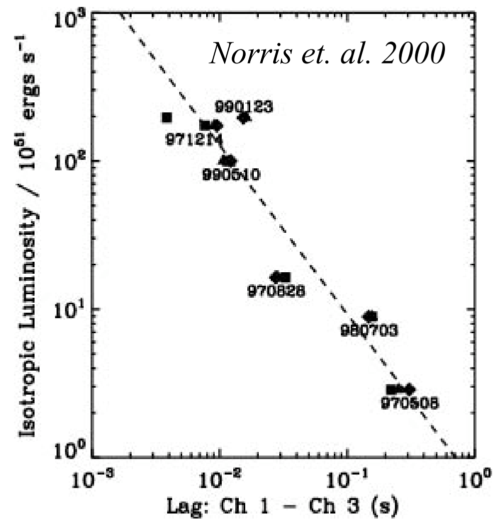
- Epk vs. Erad Correlation
  - Amati et. al. 2002
  - Calibrated with 12 GRBS (BSAX and BATSE)

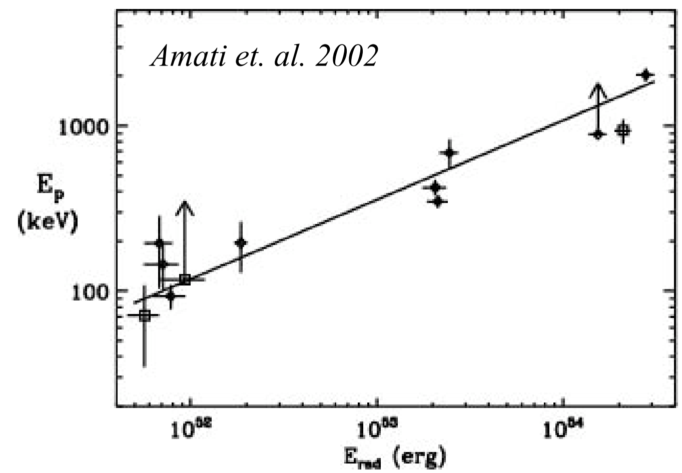
$$E_{pk} \propto E_{rad}^{0.52\pm0.06}$$

- Erad vs. Luminosity Correlation
  - Yonetoku et. al. 2000
  - Produced with 24 GRBs (BSAX and BATSE)

$$L = \left[E_{pk}(1+z)\right]^{1.94\pm0.19}$$

- Can Solve for z thru numerical iteration





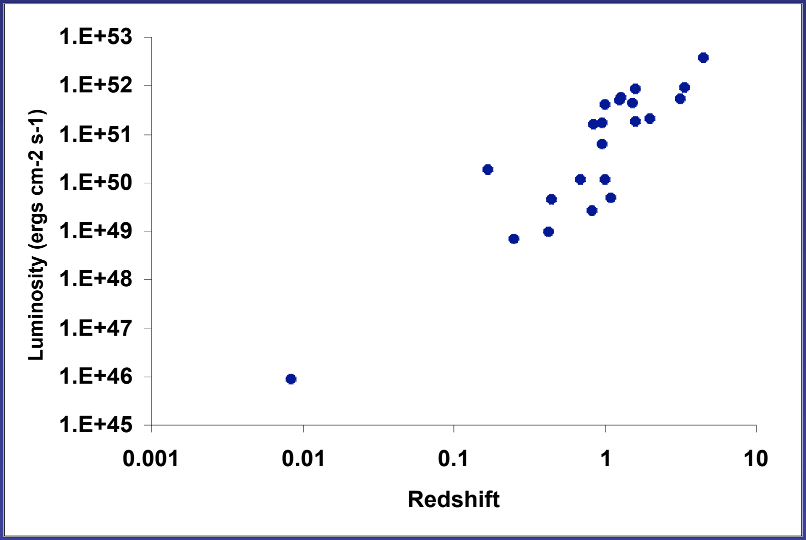
GRB With Known Redshift

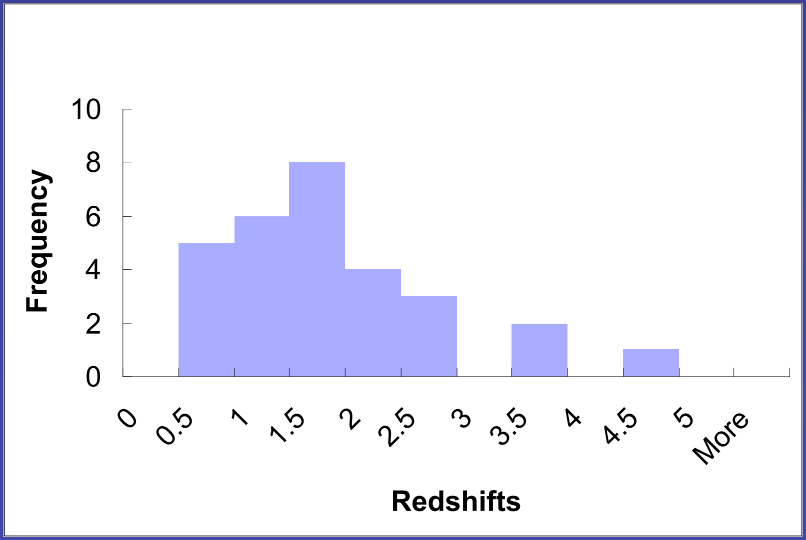
- About 30 GRBs With Known Redshift

- Like To Understand GRB $L(z)$ Function
  - How does L vary with distance, if at all
  - Get the comoving rate density
  - Could tell us about the progenitor

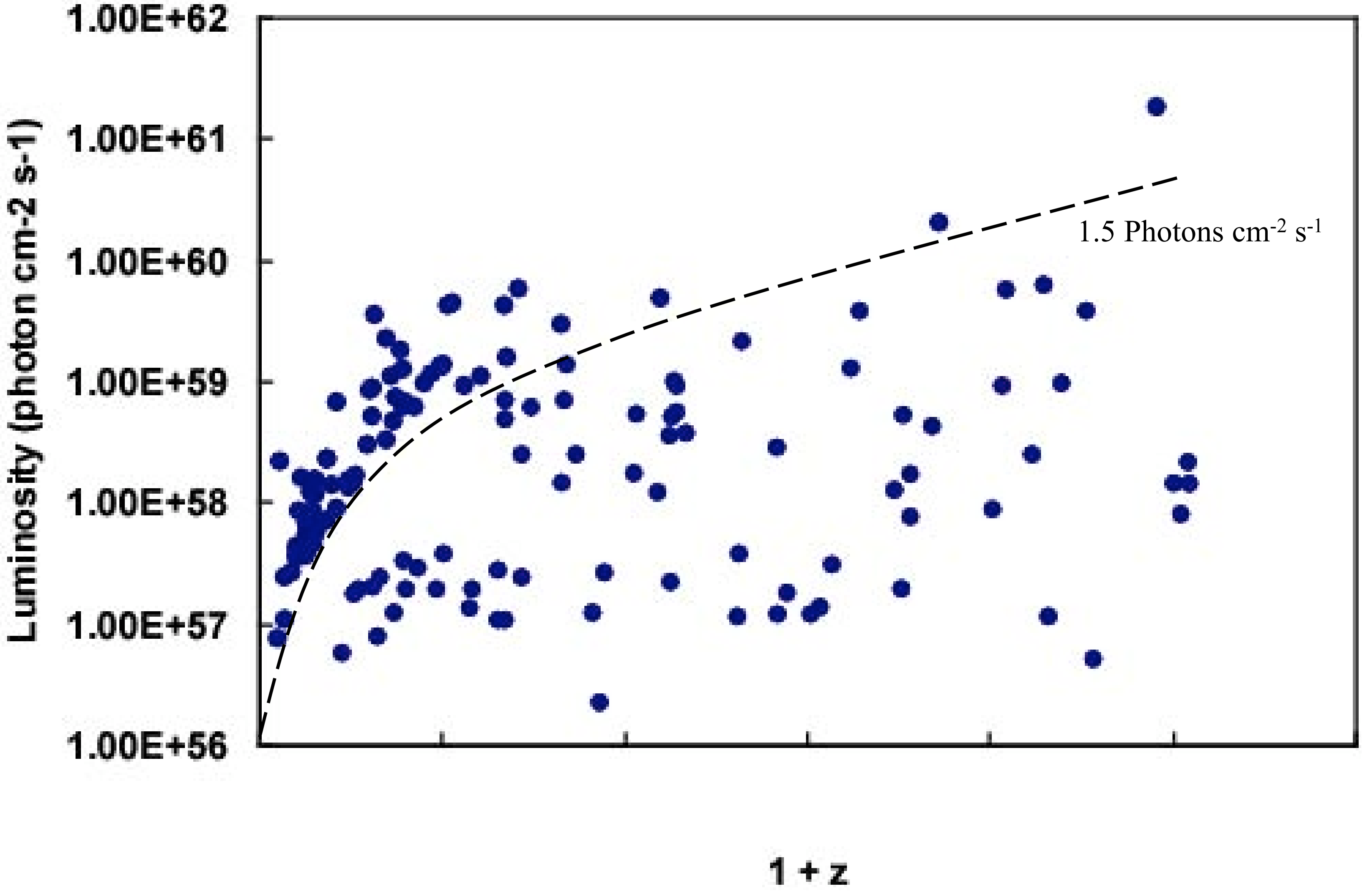
- Just Plot L(z) vs. z, right?
  - $L(z) \sim (1 + z)^{2.47}$
  - Compare to QSOs
  - $L(z) \sim (1 + z)^{3.0}$ $z < 1.5$
  - $L(z) \sim$ constant $1.5 < z < 3$

- Need to account for truncation effects!
  - Need large sample of L and z
  - 24 GRBs not enough!
  - Pseudo Redshifts to the Rescue





Not So Fast

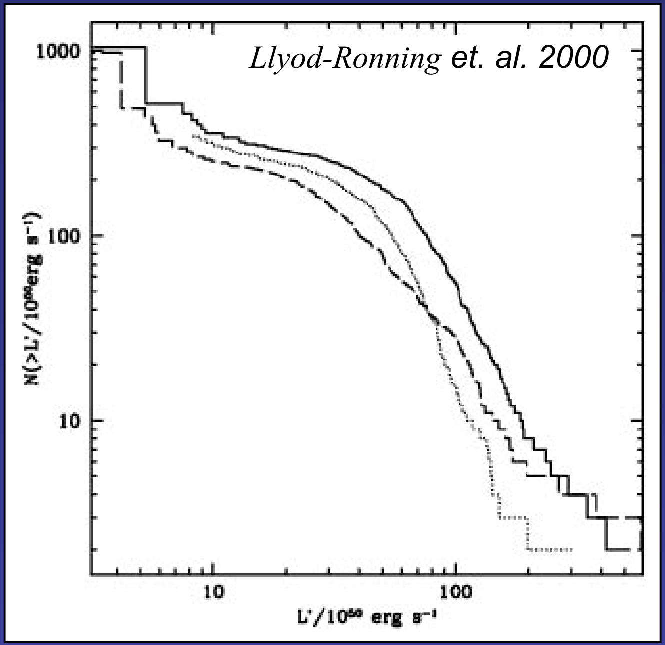

1.00E+62
1.00E+61
1.00E+60
1.00E+59
1.00E+58
1.00E+57
1.00E+56
Luminosity (photon cm-2 s-1)
1.5 Photons cm-2 s-1
1 + z

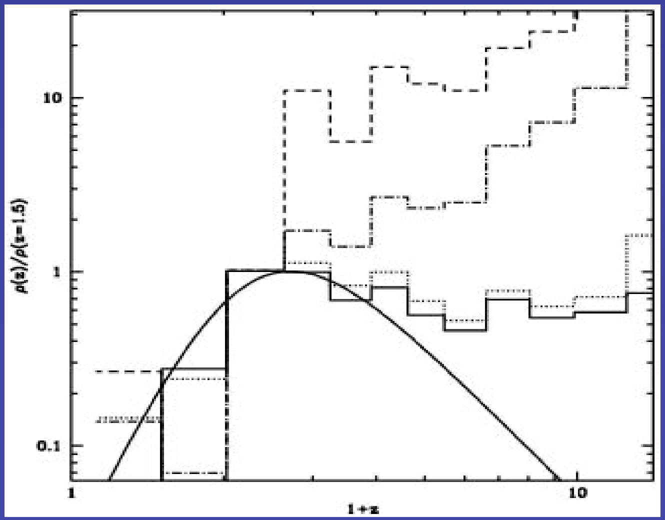
Accounting for Truncation Effects

- Must Account for Data Selection Effects
  - Lynden-Bell C Method (Lynden-Bell 1969)
  - Straightforward if selection bias is known
  - Based on maximum likelihood arguments

- Applied in Quasar Studies
  - Performed by Meloney & Petrosian 1999

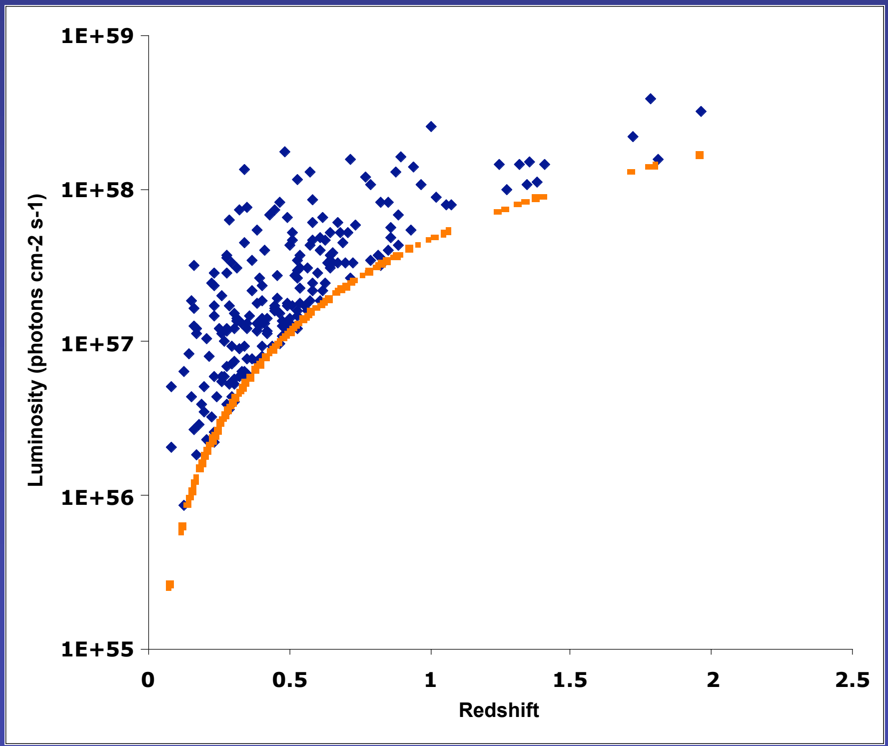
- Applied in GRBs
  - Llyod-Ronning et. al. 2002
  - Used L-Varibility correlation for 220 GRBs
  - Found $L(z) \sim (1+z)^{1.4}$
  - Found constant GRB/SFR rate after $z \sim 2$

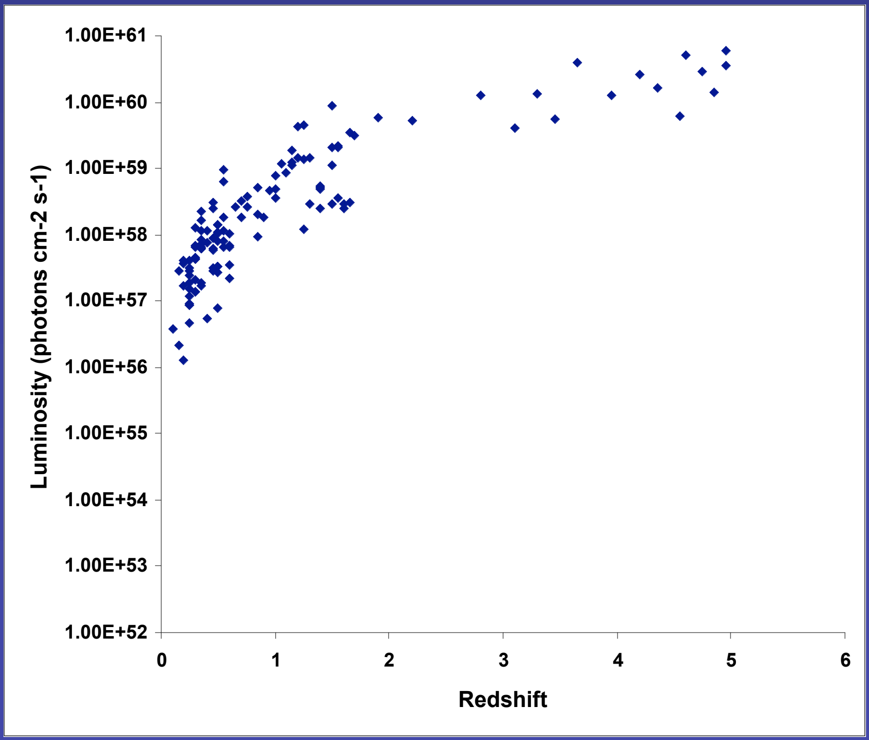




Pseudo Redshift Distributions

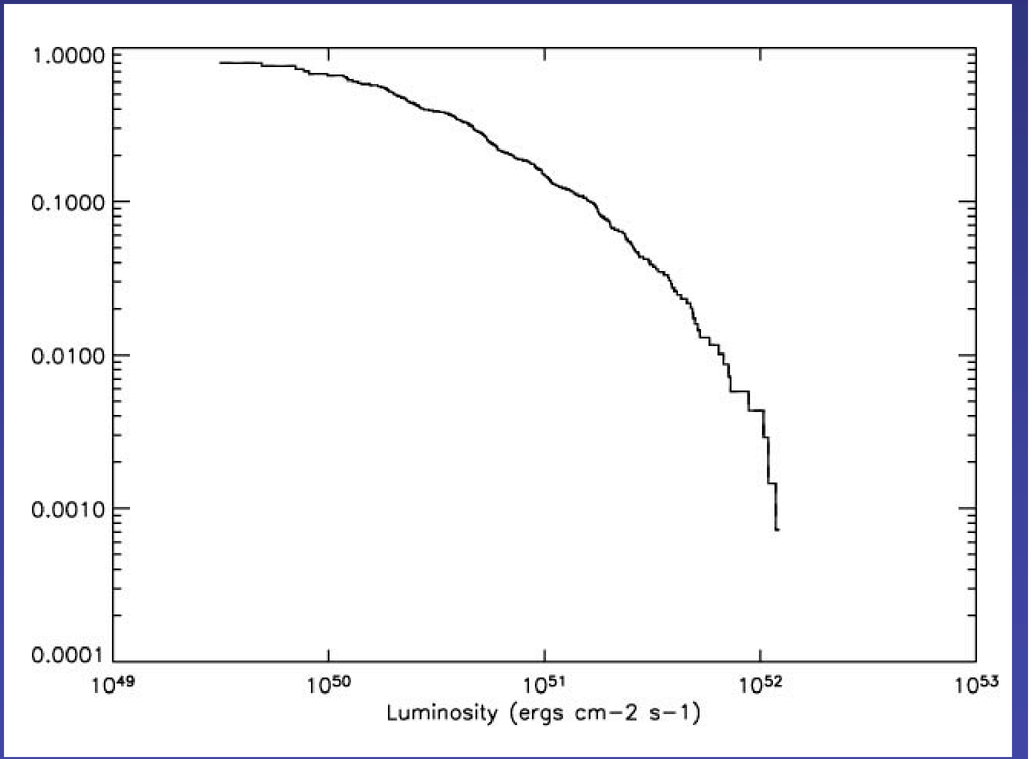
- Lag-Luminosity
  - about 200 BATSE GRBs
  - CCF analysis (chan 1-3)
- Epk-Eiso
  - about 150 BATSE GRBs
  - time resolved spectral fits





Luminosity Functions

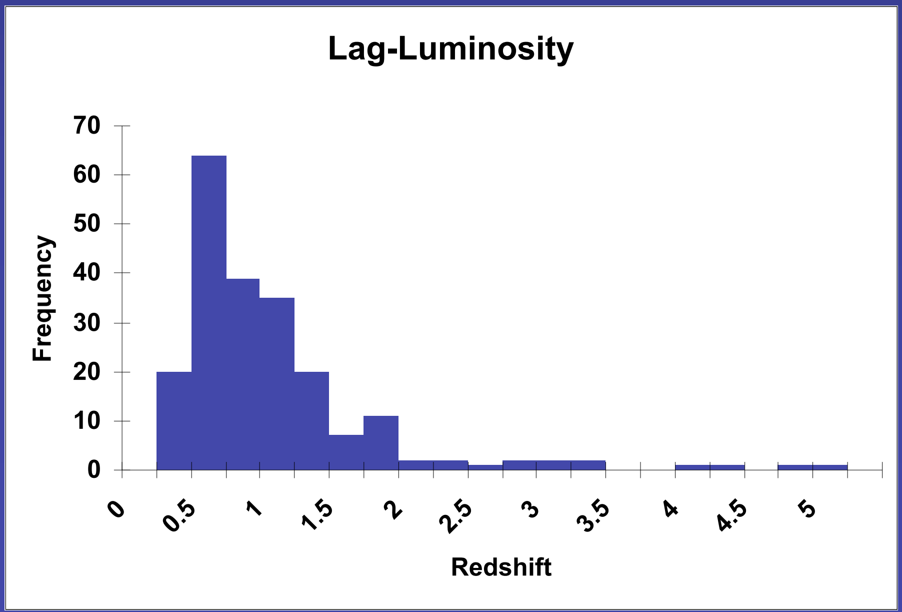
- Lag-Luminosity
  - about 200 GRBs
  - $L \sim (1+z)^{1.6}$
  - $N(>L`) \sim L^{-0.5}$
  - $N(>L`) \sim L^{-2.5}$
  - Similar to L-V results
    - Llyod-Ronning et. al. 2002

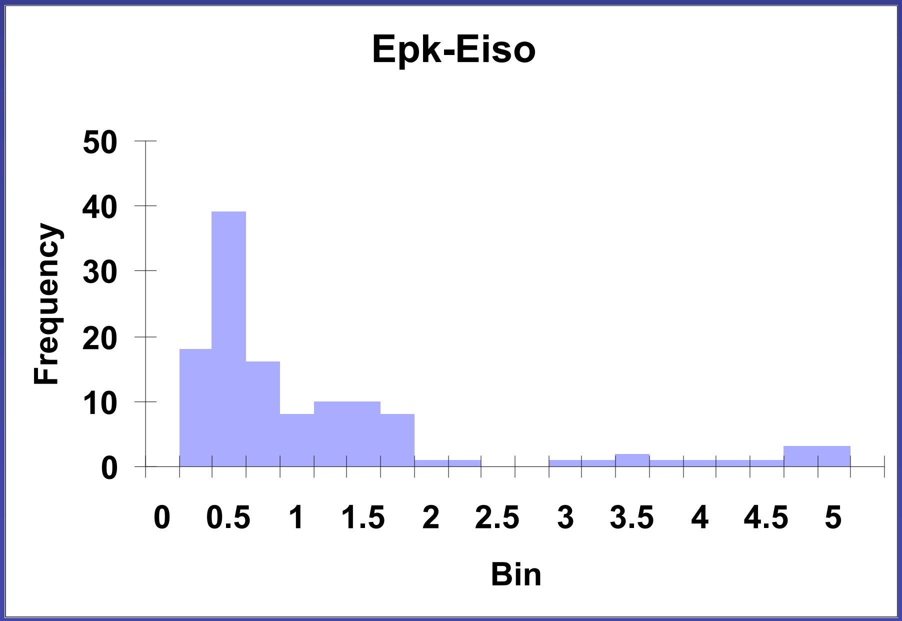


Pseudo Redshift Distributions

- Lag-Luminosity
  - about 200 GRBs
- Epk-Eiso
  - about 150 GRBs

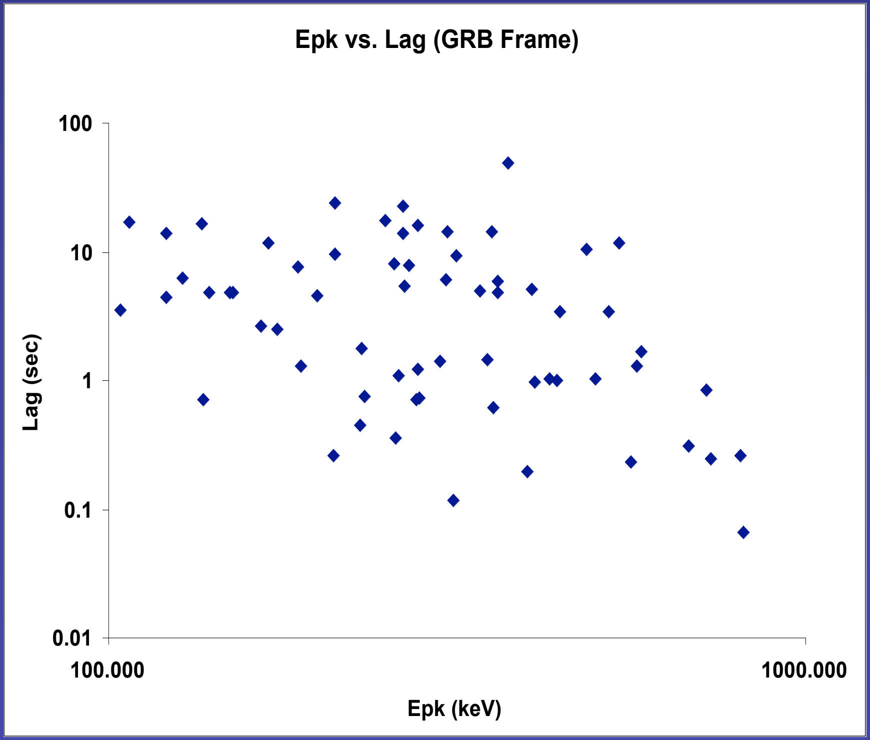
- Similar Distributions
  - Individual redshifts do not necessarily correlate!

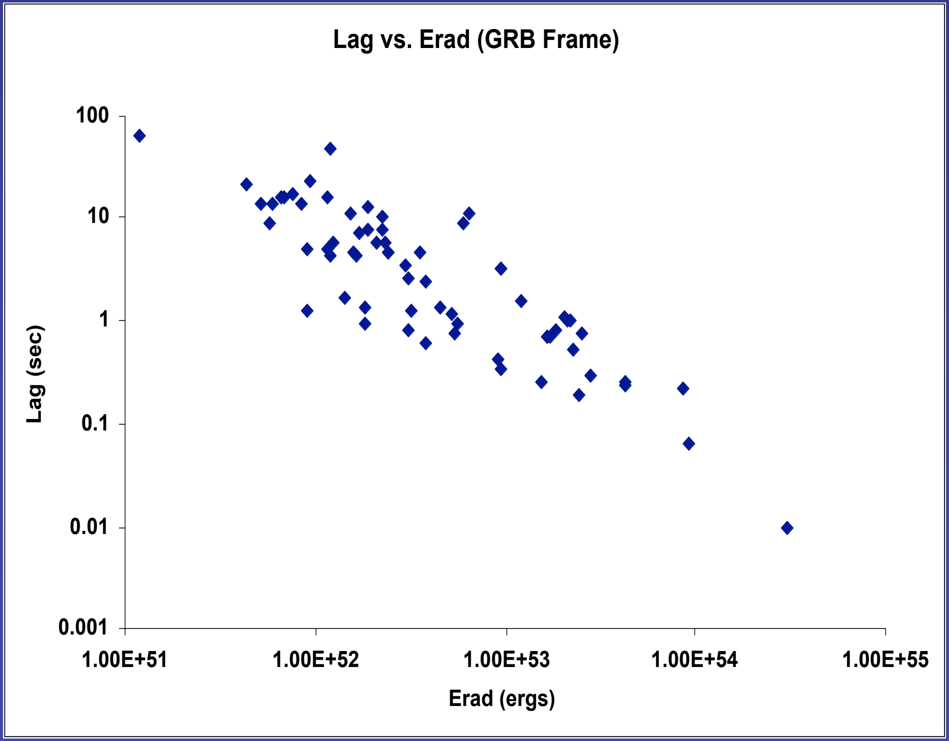




Intrinsic Parameter Correlations

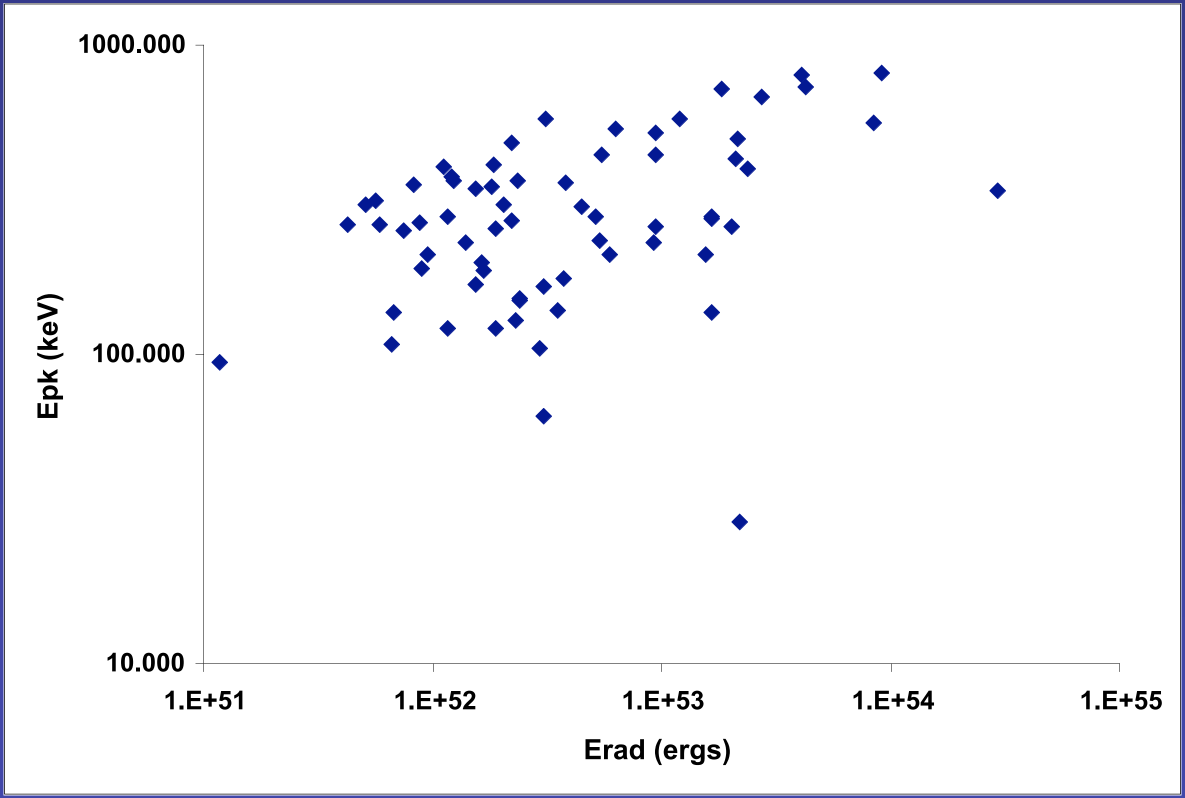
- Intrinsic lag does not correlate to Epk
  - Partially correlated to Eiso
  - Expected if lag-lum, Epk-Eiso, Epk-Lum were all true





Intrinsic Parameter Correlations

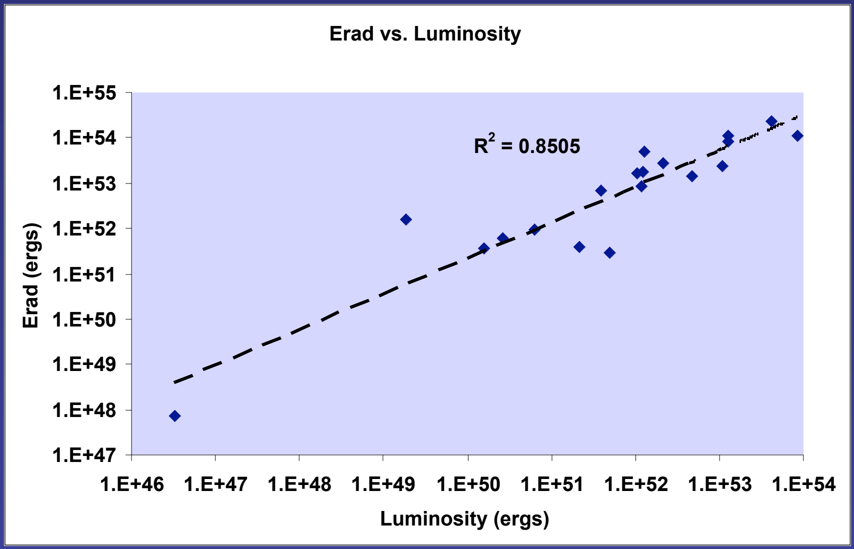
- Intrinsic Epk-Eiso Not Consistant with Lag-Lum
  - Redshifts found from lag-lum
  - Epk and Eiso found using z(lag-lum)

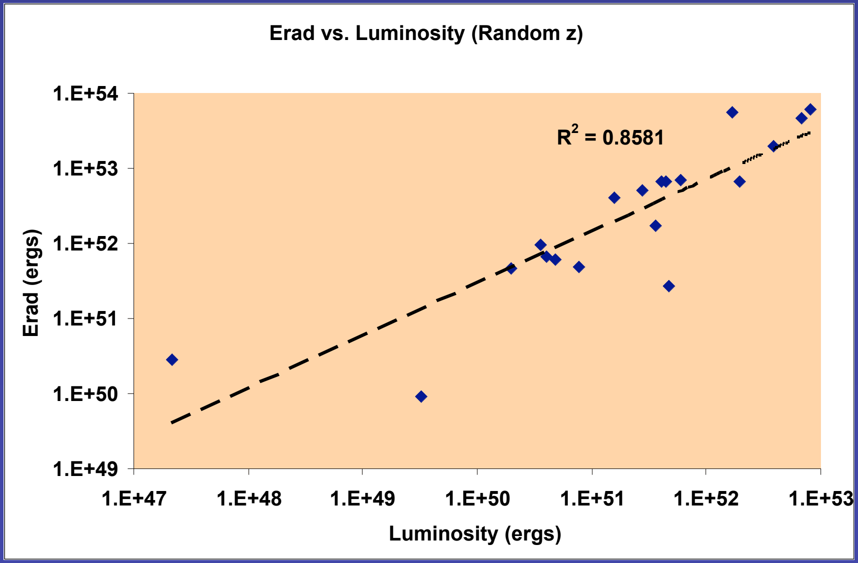


How to Test For Fake Correlations

- Correlation hunting is dangerous!
  - artificial correlations are easy to produce
  - Redshift on both sides of equation!
  - At best: partial correlations
  - At worst: complete tautology

- Easy method of checking
  - Randomize the redshifts and recalculate the correlation coefficients
  - Repeat 1000+ times





The Promise of Swift

- Need Distance Indicator That Does Not Involve z!
  - Need distance independent parameter correlated to Lum/Eiso
  - B-V for supernova Ia is a nice example!

- The Promise of Swift
  - Large number of GRBs with known z (~ hundreds)
  - Hopefully find such a parameter
  - Ability to test/confirm proposed distance indicators
    - Lag should still be detectable, Epk not so much
  - Extend/test distance correlations to lower energies (XRF)?

Conclusions

- lag-lum and Epk-Eiso partially consistent
  - Although resulting distributions are similar, individual redshift do not necessarily correlate
  - Similar estimates on Luminosity evolution
  - Similar luminosity functions
  - Intrinsic parameters partially correlate
- Spurious correlations are a problem
  - Need distance independent method of finding Lum
  - Must test all proposed distance indicators!