پامنار با وارده در آرامش همیشه کم‌سرعت در زبان‌شناسی
Gamma-Ray Bursts as Cosmological Tools

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Example of Instrumental bias: Malmquist Bias
Big discovery!

Strong evolution of galaxy brightness with distance
Constraining Dark Energy’s equation of state

✓ Cosmological Standard Candle

✓ Constant Luminosity known

✓ Spectroscopic Redshift known

\[ D_L = \sqrt{\frac{1}{4\pi}} \rho_{\text{intrinsic luminosity}} \]

Luminosity distance in the Concordance Cosmology

\[ D_L = \frac{C}{H_0} (1+z) \int_0^z dz' \left[ (1+z')^3 \Omega_M + \Omega_\Lambda \right]^{-\frac{1}{2}} \]
How to constrain the expansion rate of the universe in the distant universe?

Candidate Standard Candle:
Gamma-Ray Bursts (GRBs)    Supernovae projects: \( Z < 1.7 \)

\( Z \sim 65 \)

\begin{itemize}
  \item Afterglow Light Pattern 400,000 yrs.
  \item Dark Ages
  \item Development of Galaxies, Planets, etc.
  \item Dark Energy Accelerated Expansion
  \item Inflation
  \item Quantum Fluctuations
  \item 1st Stars about 400 million yrs.
  \item WMAP
  \item Big Bang Expansion 13.7 billion years
\end{itemize}
Outline

✓ Gamma-Ray Burst (GRB) prompt emission
✓ GRBs as cosmological tools
✓ Problems with GRBs as cosmological tools
✓ The future of GRBs as standard candles

Gamma-Ray Bursts (GRBs)

- Discovered by Vela nuclear test detection satellite (1960s).
  Top-secret project before the collapse of USSR

- The most powerful explosions in the Universe

\[ 10^{47} \text{ ergs} < E_{iso} < 10^{55} \text{ ergs} \]
GRB types

Long-duration GRBs (LGRBs): possibly related to the death of supermassive stars

Short-duration GRBs (SGRBs): possibly the merger of binary neutron stars
Example of GRB Spectrum

Example of GRB Power Spectrum

Graph showing $E^2 \times \text{Flux vs. } E$

GRB spectral peak energy $E_{P,\text{obs}}$

The asymptotic $E_{p,\text{obs}}$ distribution of 2130 BATSE GRBs

Lower $E_{p,\text{obs}} \equiv$ softer

Higher $E_{p,\text{obs}} \equiv$ harder

The Amati relation

The Amati Relation

GRBs as cosmological tools?!

- Cosmological Standard Candle
  - Constant Luminosity known
  - Spectroscopic Redshift known
\[ D_{L,\text{obs}} = \sqrt{\frac{1}{4\pi}} \frac{E_{\text{iso}}(E_{p,\text{int}})}{S_{\text{bol}}} \]

**Standard Candle**

**Observer**

**The GRB Hubble Diagram**

The Amati Relation

GRBs as cosmological tools?!

Problems with GRB relations

✓ no physical basis for GRB relations to date

✓ frequent number of Long-duration GRB (LGRB) outliers to these relations, specifically the Amati relation:

✓ All authors have overlooked outliers to these relations in their GRB Hubble diagrams.
The Amati Relation


\[ E_{p,\text{int}} \text{ [KeV]} \]

\[ E_{\text{iso}} \text{ [erg]} \]
The Amati Relation

Spectrally analyzed

Not analyzed

$E_{p,\text{int}}$ [KeV] vs. $E_{\text{iso}}$ [erg]

The Amati Relation
Brightness ($S$)

Red: $25 - 50$ keV
Yellow: $50 - 100$ keV
Green: $100 - 300$ keV
Blue: $> 300$ keV

$HR_H = \frac{S_{\text{Blue}} + S_{\text{Green}}}{S_{\text{Yellow}} + S_{\text{Red}}}$

Prediction Intervals?
Parameter estimation based on Bayes Theorem and Markov Chain Monte Carlo techniques.

Posterior distributions of the parameters of the truncated multivariate normal distributions considered for the spectral parameters of the 3 GRB models: Band, COMP(CPL) & SBPL
Parameter estimation based on Minimum $\chi^2$ & Minimum Kolmogorov-Smirnov distance techniques.

Marginalized likelihood contour plots of the observed data given different parameter values of the truncated multivariate normal distribution assumed for the spectral parameters of the three GRB models. Shahmoradi & Nemiroff, MNRAS (2010)
Selection effects due to impossibility of spectral analysis.
Selection Effects due to GRB Detectors?
The Amati Relation

Selection effects due to detector thresholds, impossibility of spectral analysis, and redshift measurement

Physical origin

Prospects & Conclusions

✓ What are Gamma-Ray Bursts?
   The most powerful events known in the universe, possibly related to the death of super-massive stars.

✓ Are GRBs useful cosmological probes?
   With the current knowledge of GRBs, NO.

✓ Can GRBs serve as cosmological standard candles in the future?
   Likely YES:
   - GRBs are the farthest cosmological events detectable out to Z > 10

   However:
   - A robust theoretical interpretation for GRB relations must be given.
   - The proposed GRB relations must be free from biases & selection effects.
   - The effects of GRB jet opening angle and luminosity evolution with redshift on GRB relations must be well understood.

Further analysis coming soon...
Thank you!

Questions?

Photo: Alborz Mountain, Northern Persia
General Conclusions
(Applicable to any field of Science)

✓ **Outliers!** Take them seriously in data analysis.

✓ **Strong Correlation, No Outlier!** Then why should there be such strong

![Graph showing data points and trend line]

*Instrumental effects*

*or*

*Physical origin?*
Prospects & Conclusions

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Total energy release of the Sun during 10 billion years:
\(~10^{51}\) ergs

Butler et al. (2010)
Credit: Edo Berger, Harvard CfA
Duration distribution of 1900 BATSE GRBs

SGRB

LGRB

Number

\(T_{90} \text{ [sec]}\)
GRB light-curve diversity

- LGRB
- SGRB
- LGRB
- LGRB
- LGRB
- SGRB
- LGRB
- ?
- LGRB
- LGRB
- LGRB
- LGRB
- LGRB