Classification and Energetics of Cosmological Gamma-Ray Bursts

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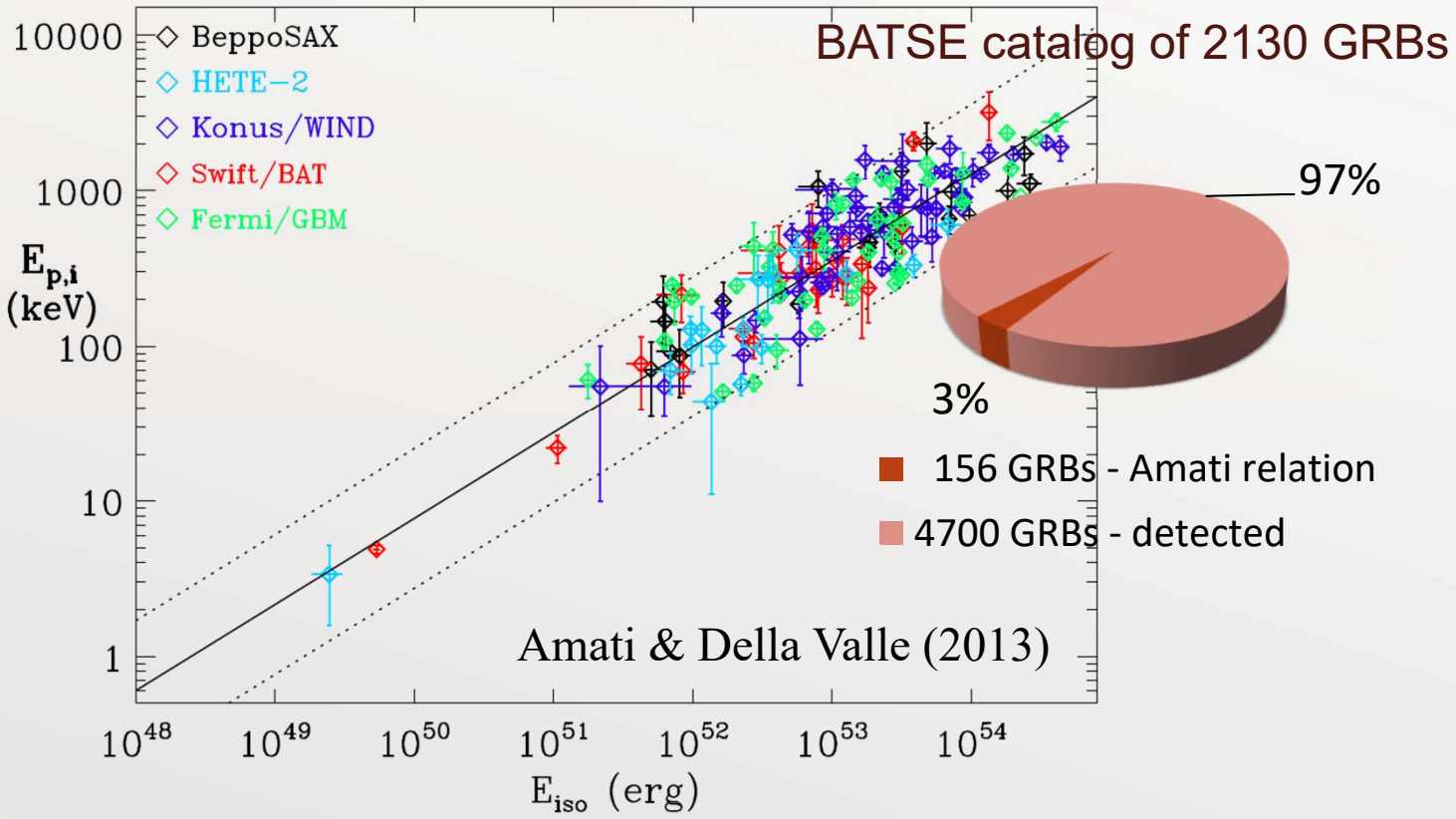
The Amati relation

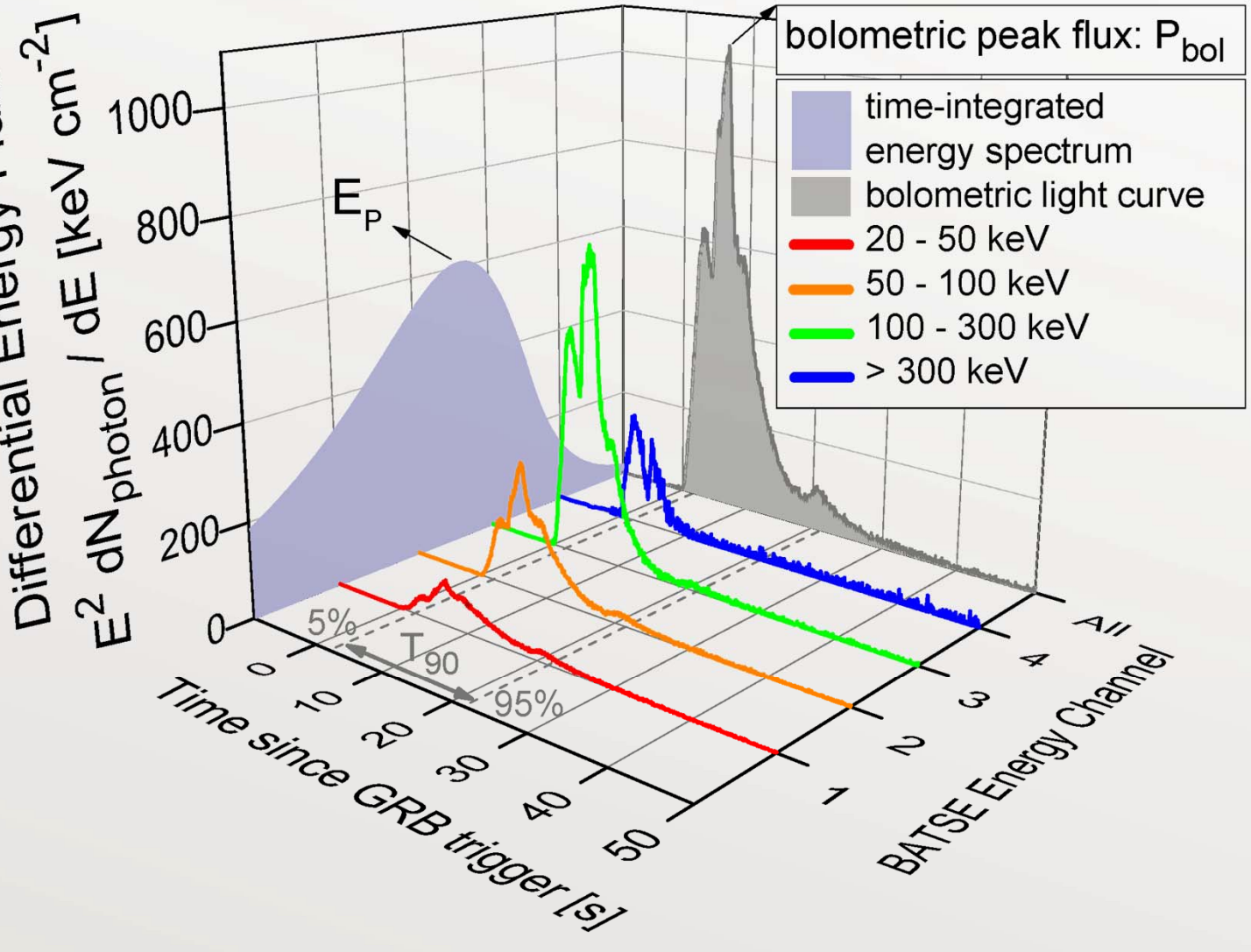
One of the most cited topics in the field of Gamma-Ray Bursts (GRBs)

Do all GRBs obey in the Amati relation?



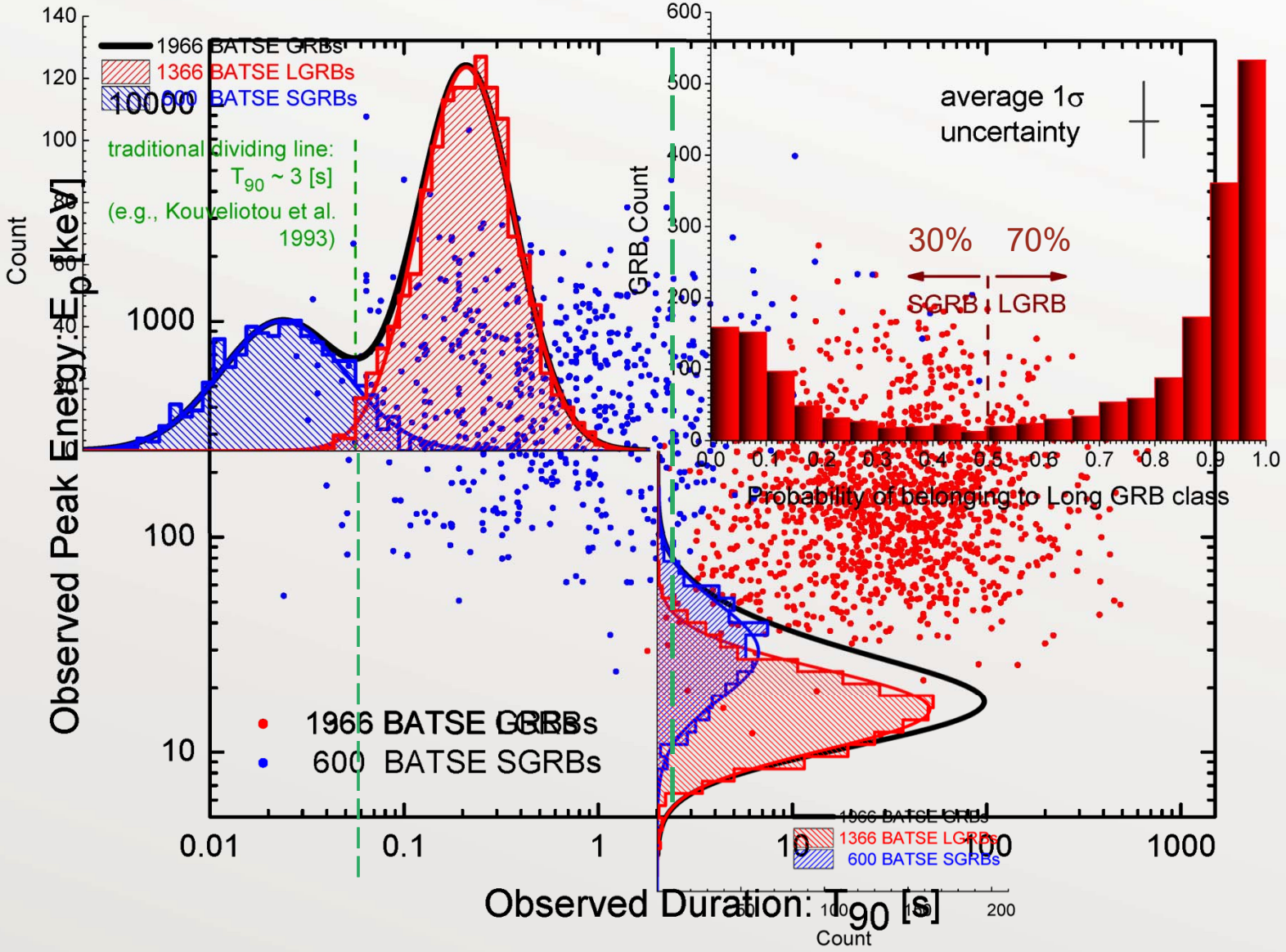
Example GRB lightcurve and spectrum

(BATSE GRB trigger 1085)



Classification of BATSE GRBs: fuzzy clustering vs. cutoff line

(Shahmoradi & Nemiroff, 2011, MNRAS, **411**, 1843–1856)

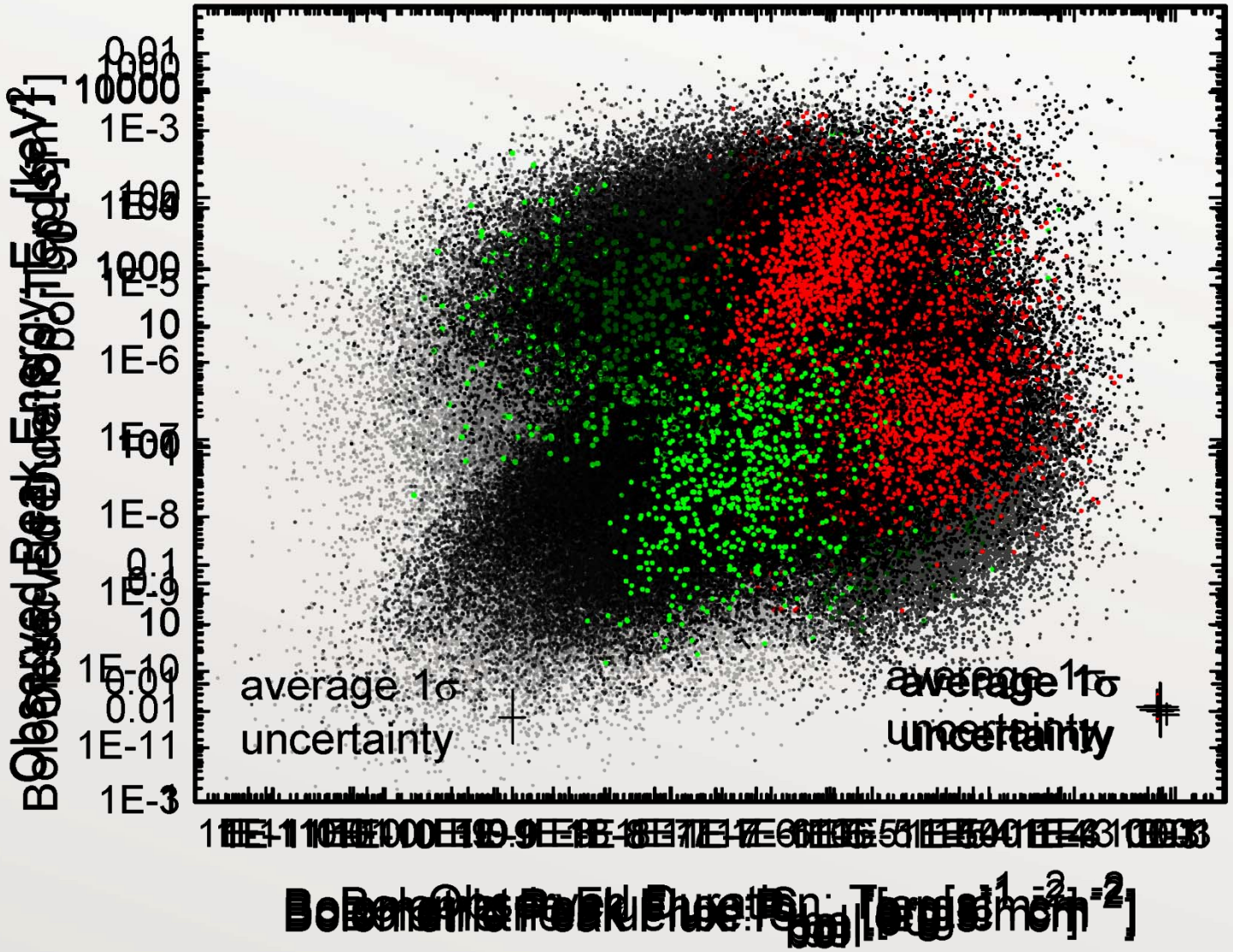


Model Construction - There is a need for multivariate Luminosity Functions (Shahmoradi, 2013, ApJ, **411**, 1843–1856)

- **Goal:** constraining GRB energetics and prompt emission correlations
- **Data:** 1966 BATSE GRBs
- **Model:** multivariate (4-dimensional) log-normal distribution subject to BATSE trigger threshold
- **Parameters in the model:**
  - isotropic peak luminosity (L_{iso})
  - total Isotropic gamma-ray emission (E_{iso})
  - rest-frame spectral peak energy ($E_{P,z}$)
  - rest-frame duration ($T_{90,z}$)
  - redshift (z) → unknown for BATSE GRBs
    - Star Formation Rate + metallicity evolution + binary merger delay (for short GRBs)
- **Method:** Maximum Likelihood via Metropolis-Hastings algorithm

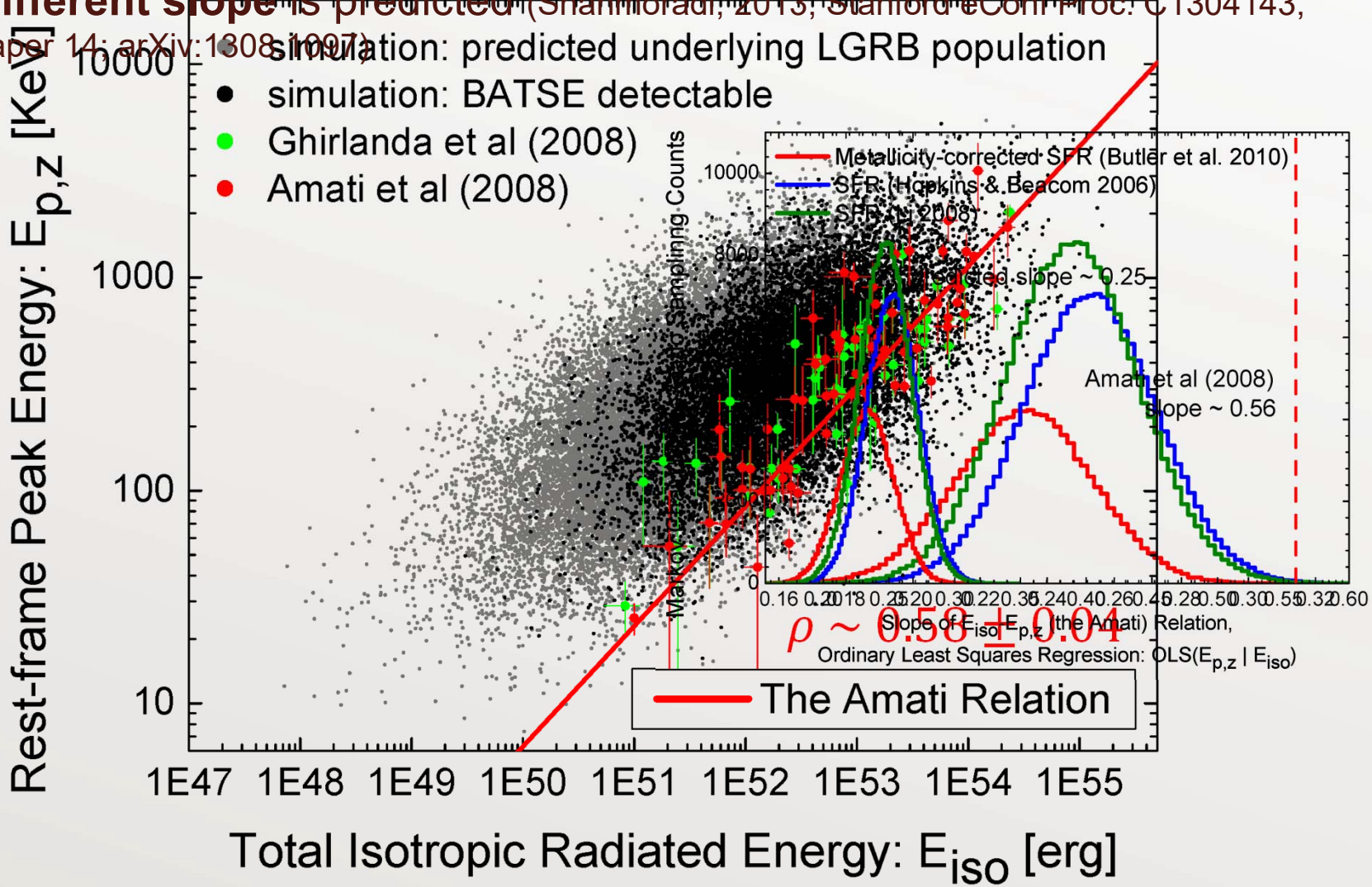
Colors bear the same meaning in all plots:

- simulation: predicted underlying LGRB population
- simulation: predicted underlying SGRB population
- 1366 BATSE LGRBs detected
- 600 BATSE SGRBs detected
- simulation: BATSE detectable



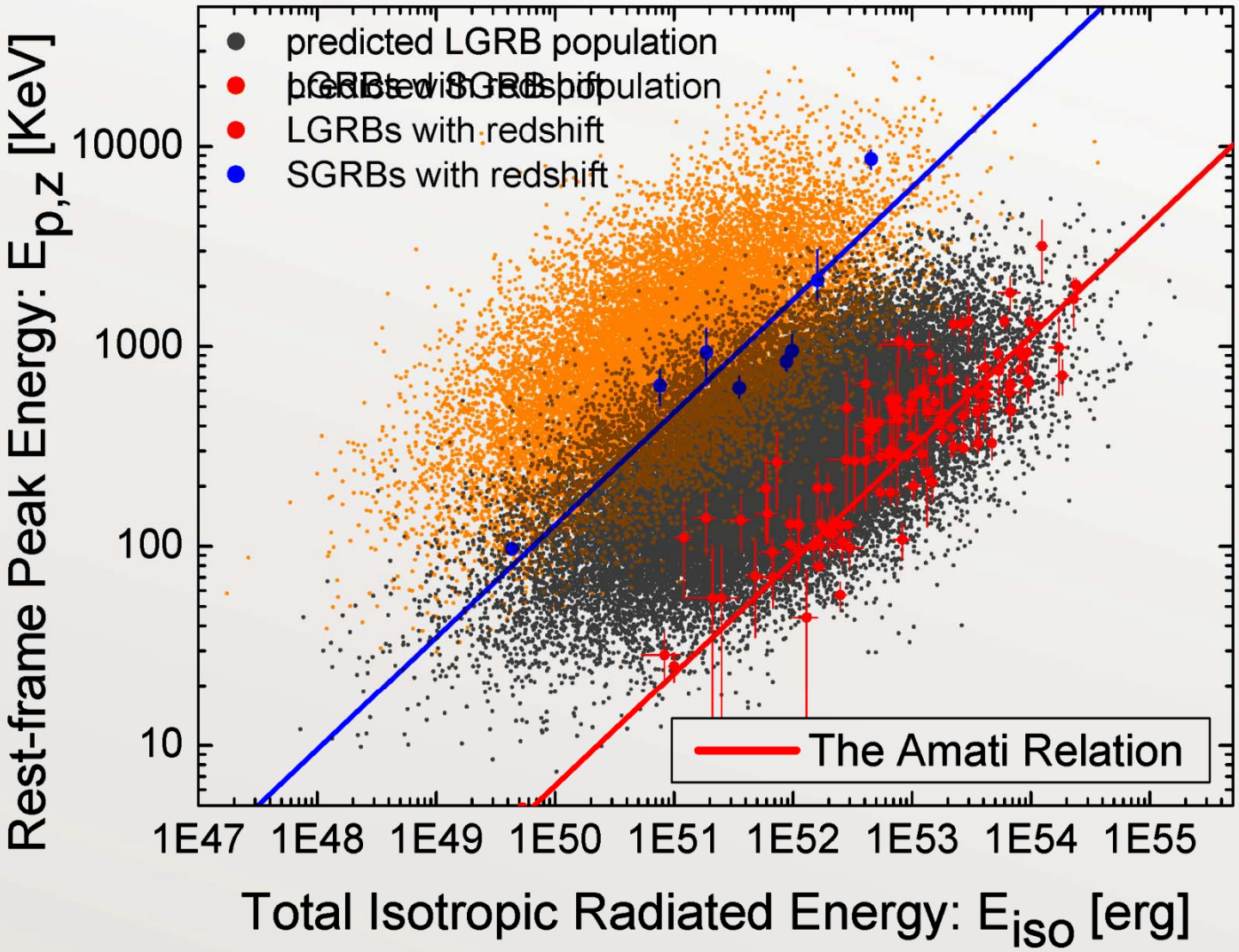
The Amati relation

- **Larger dispersion** is predicted (Shahmoradi, 2013, ApJ, 766, 111)
- **Different slope** is predicted (Shahmoradi, 2013, Stanford eConf Proc. C1304143, paper 14; arXiv:1308.1097)



Short and long GRBs exhibit similar prompt correlations

(Shahmoradi & Nemiroff, 2014, in preparation)

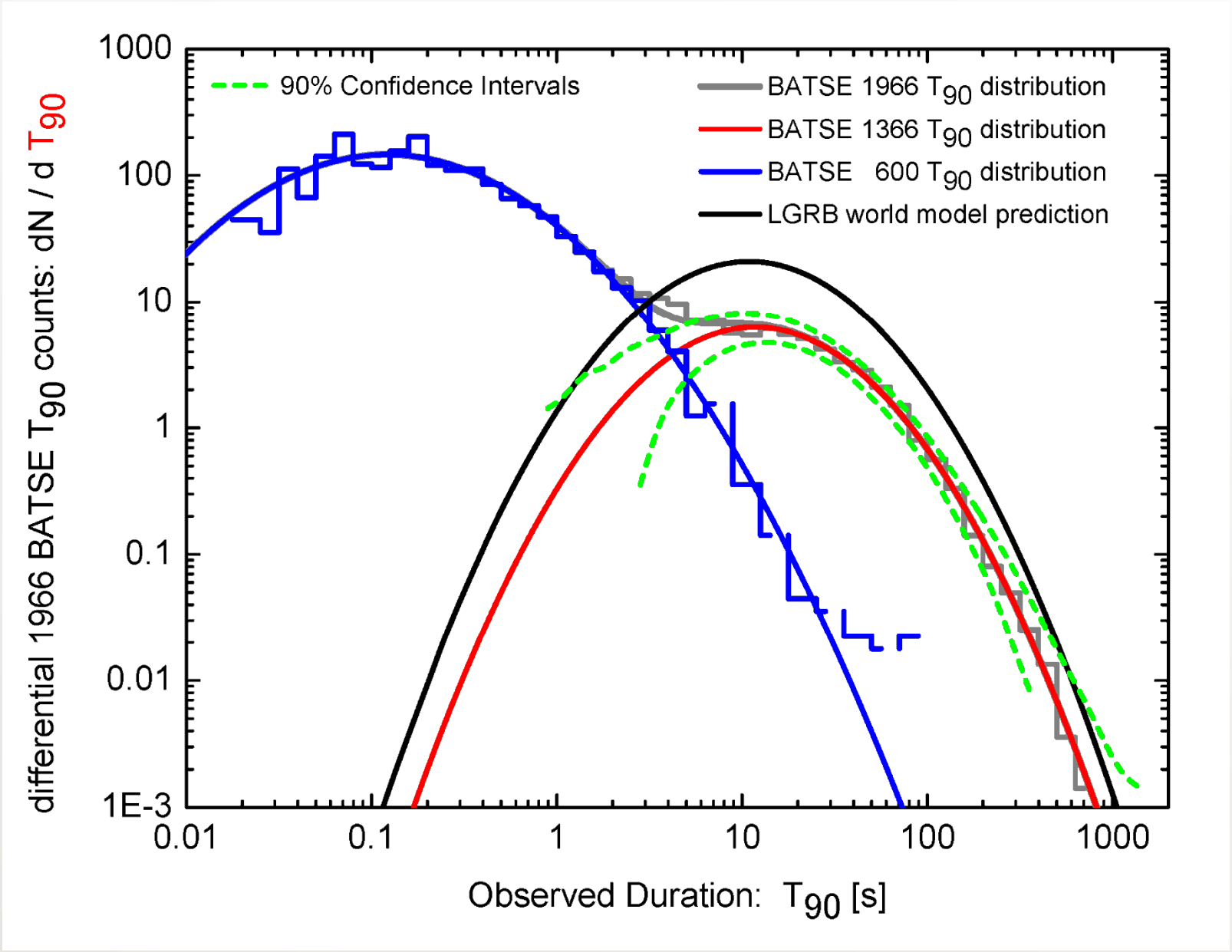


Summary

- Multivariate log-normal distribution provides good fit to BATSE short and long GRB prompt emission data (*peak luminosity, isotropic emission, intrinsic peak energy, intrinsic duration).*
- The Amati (E_{iso}-$E_{P,Z}$) relation is confirmed, but with significantly **higher dispersion** and **shallower slope** of the regression line: **0.25** vs. **0.55**.
- Short GRBs exhibit very similar prompt emission correlations to long GRBs prompt correlations.
- BATSE Long GRBs data favor, a cosmic rate tracing metallicity evolution consistent with a cutoff $Z/Z_{\odot} \sim 0.2–0.5$, assuming no luminosity–redshift evolution.
- This methodology can be used as a quantified method of GRB classification based on prompt emission data.

Further results on GRB energetics & correlations

- Shahmoradi & Nemiroff, 2014, in preparation, to be submitted to MNRAS
- Shahmoradi, 2013, ApJ, **766**, 111
- Shahmoradi, 2013, Stanford eConf Proc. C1304143, paper 14; arXiv:1308.1097
- Shahmoradi & Nemiroff, 2010, MNRAS, **407**, 2075–2090
- Shahmoradi & Nemiroff, 2011, MNRAS, **411**, 1843–1856
- Shahmoradi & Nemiroff, 2009, AIP Conf Proc, **1133**, 425


90% Confidence Intervals
BATSE 1966 T90 distribution
BATSE 1366 T90 distribution
BATSE 600 T90 distribution
LGRB world model prediction
differential 1966 BATSE T90 counts: dN / d T90
Observed Duration: T90 [s]
1000
100
10
1
0.1
0.01
1E-3
0.01
0.1
1
10
100
1000

Short and long GRBs exhibit similar prompt correlations

Correlating Parameters	Long GRBs Pearson correlation	Short GRBs Pearson correlation
Peak Luminosity – Isotopic Emission $L_{iso} - E_{iso}$	**0.93**	**0.92**
Peak Luminosity - Peak Energy $L_{iso} - E_{P,z}$	**0.47**	**0.54**
Peak Luminosity - Duration $L_{iso} - T_{90,z}$	**0.43**	**0.55**
Isotropic Emission - Peak Energy $E_{iso} - E_{P,z}$	**0.58**	**0.61**
Isotropic Emission - Duration $E_{iso} - T_{90,z}$	**0.58**	**0.63**
Peak Energy – Duration $E_{P,z} - T_{90,z}$	**0.29**	**0.14**

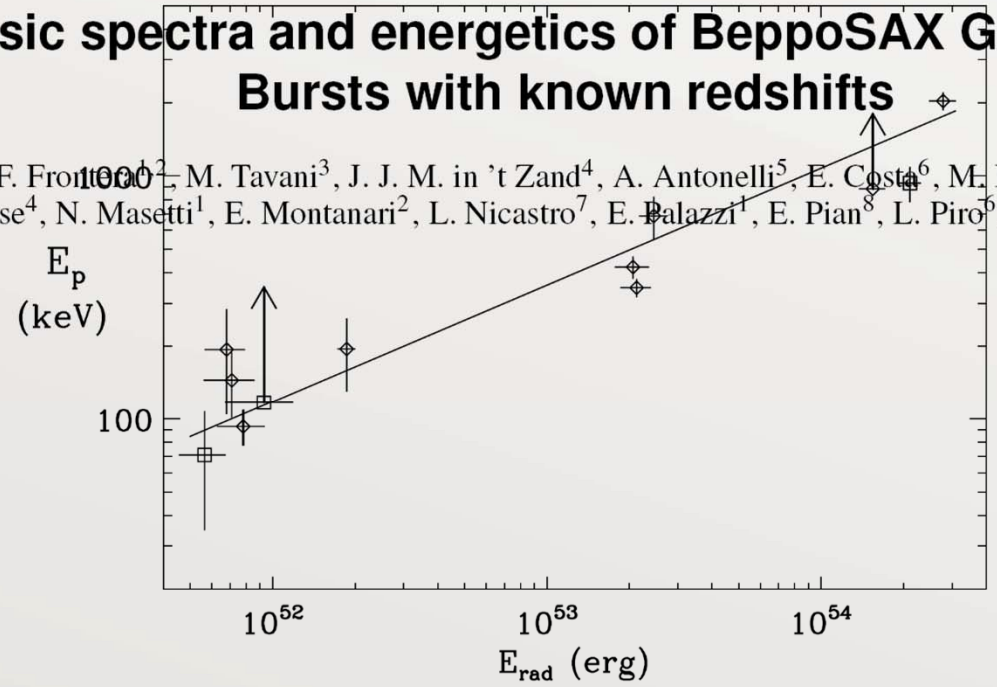
Intrinsic prompt duration and peak energy are **similarly** positively correlated with the peak luminosity and isotropic emission.

A&A 390, 81–89 (2002)
DOI: 10.1051/0004-6361:20020722

Astronomy & Astrophysics

Intrinsic spectra and energetics of BeppoSAX Gamma–Ray Bursts with known redshifts

L. Amati[1], F. Frontera[1,2], M. Tavani[3], J. J. M. in 't Zand[4], A. Antonelli[5], E. Costa[6], M. Feroci[6], C. Guidorzi[2], J. Heise[4], N. Masetti[1], E. Montanari[2], L. Nicastro[7], E. Palazzi[1], E. Pian[8], L. Piro[6], and P. Soffitta[6]



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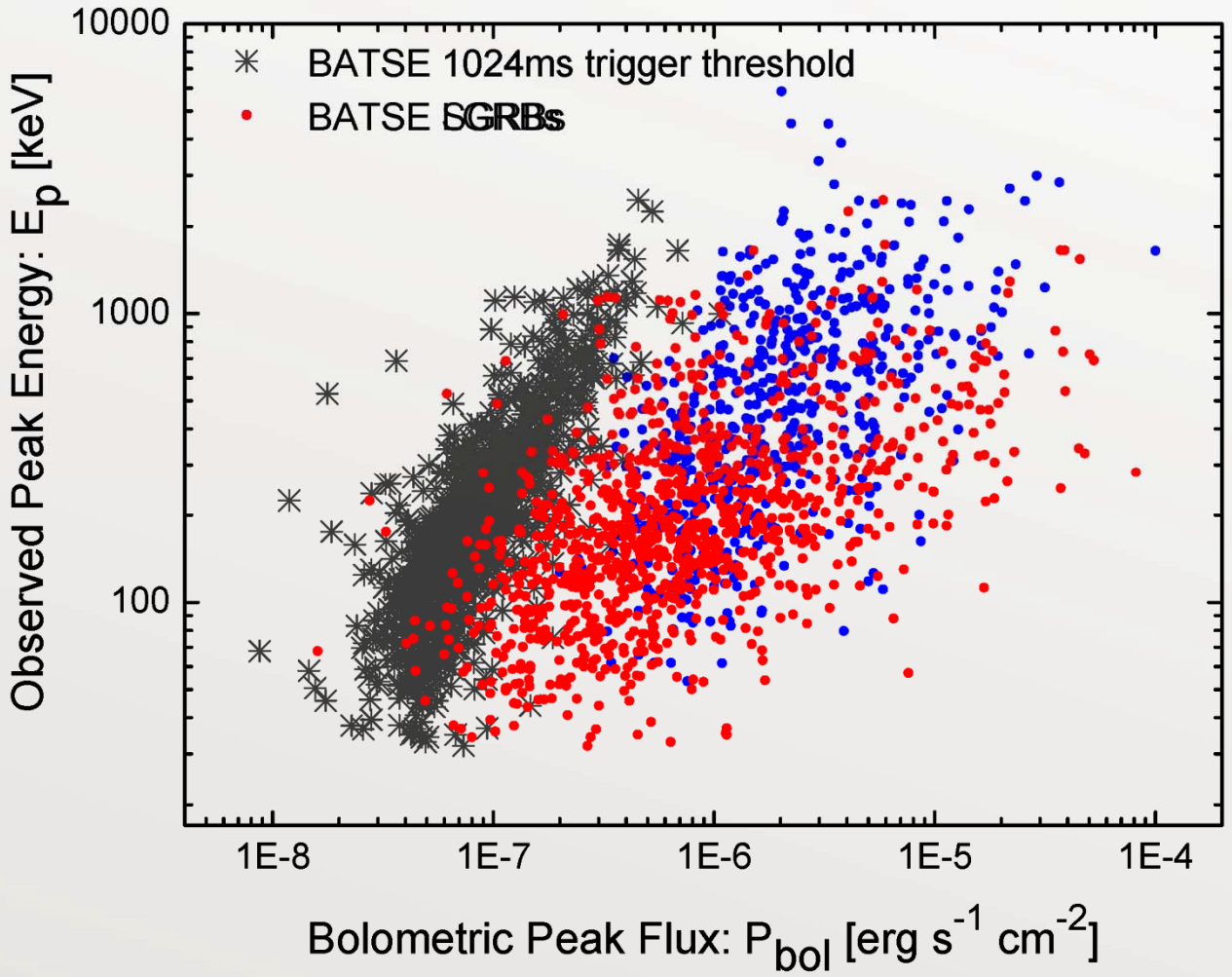
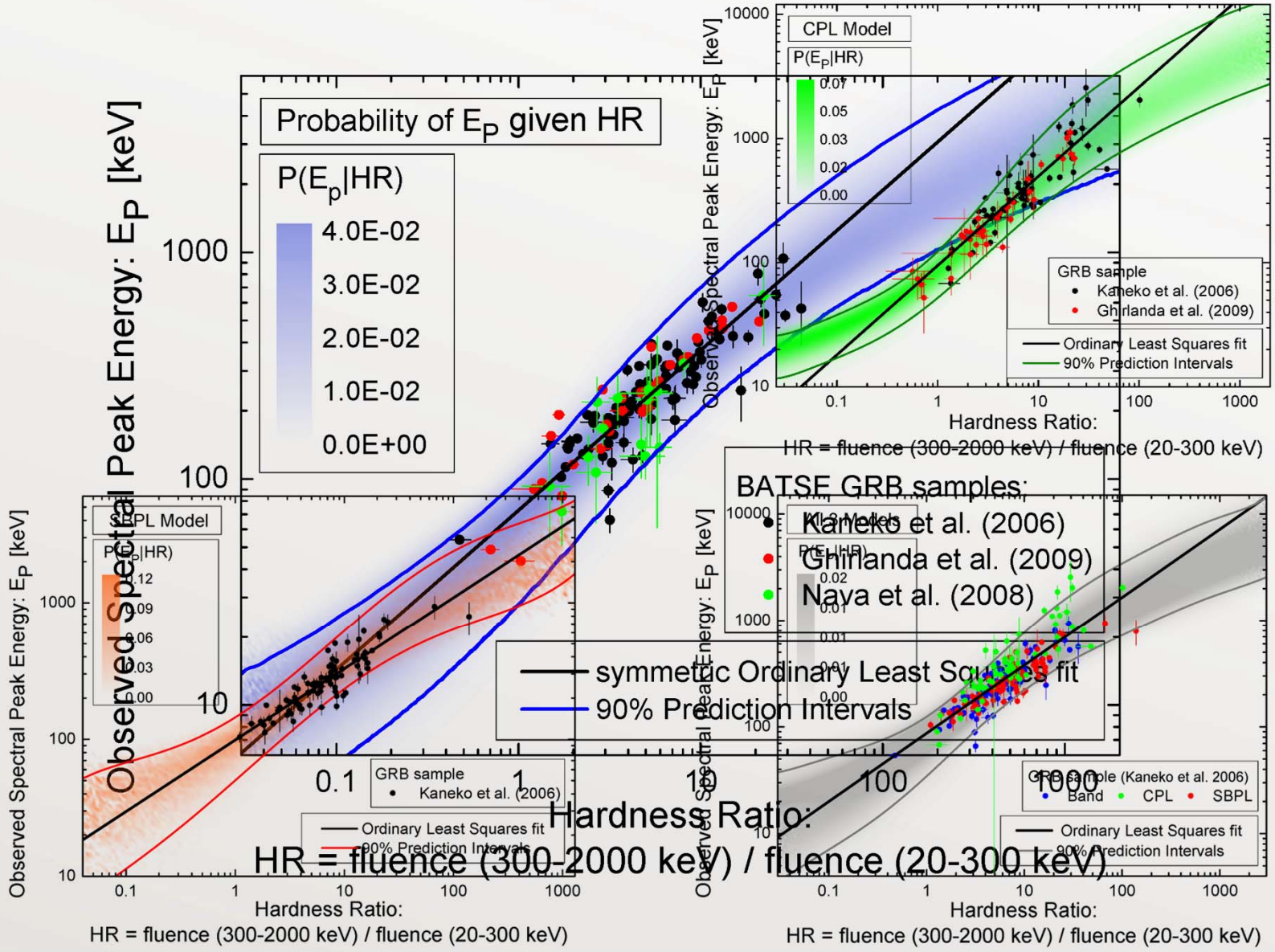


Hardness as spectral peak estimator for GRBs

(Shahmoradi & Nemiroff, 2010, MNRAS, **407**, 2075–2090)



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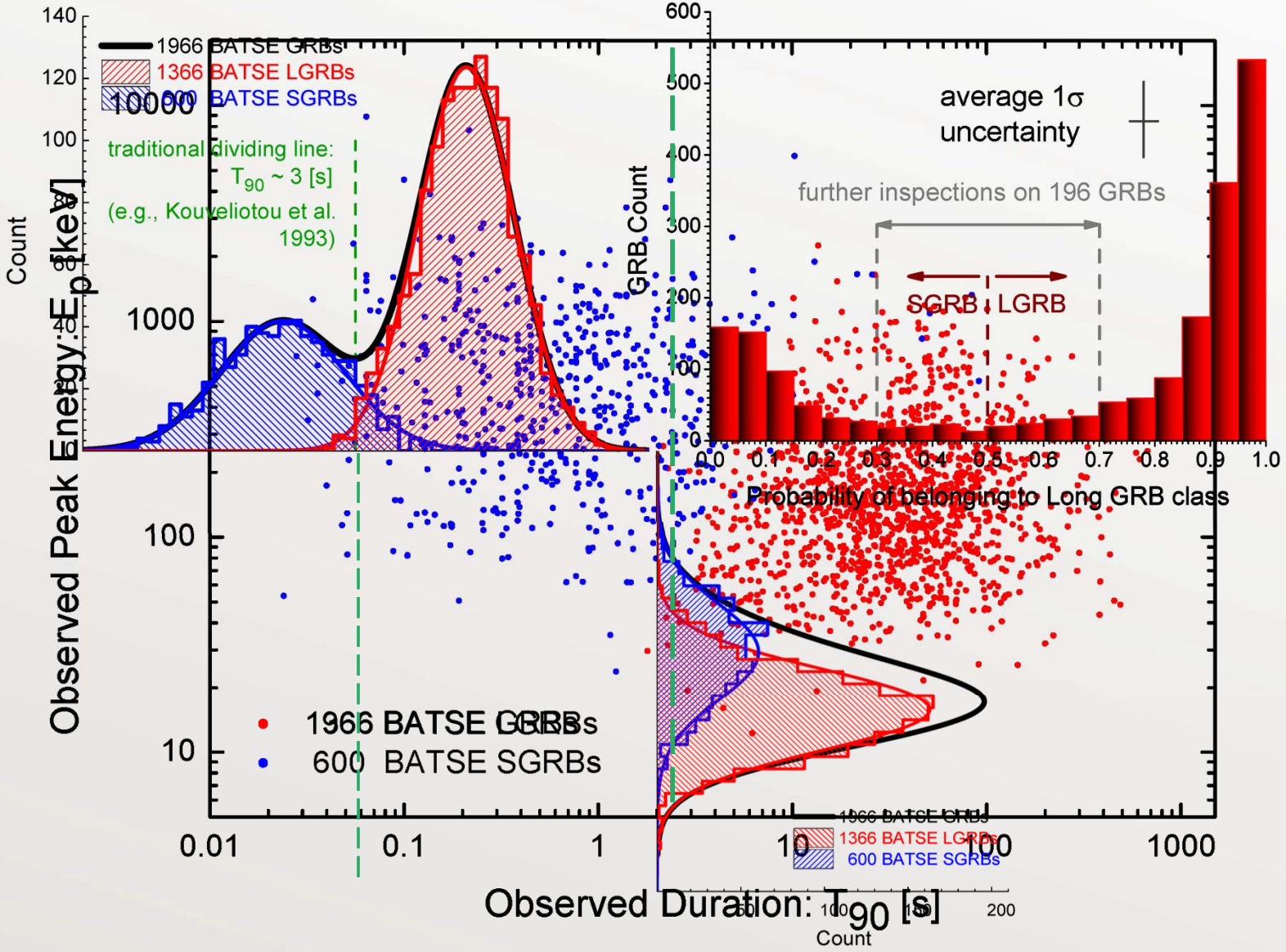

Example GRB lightcurve and spectrum

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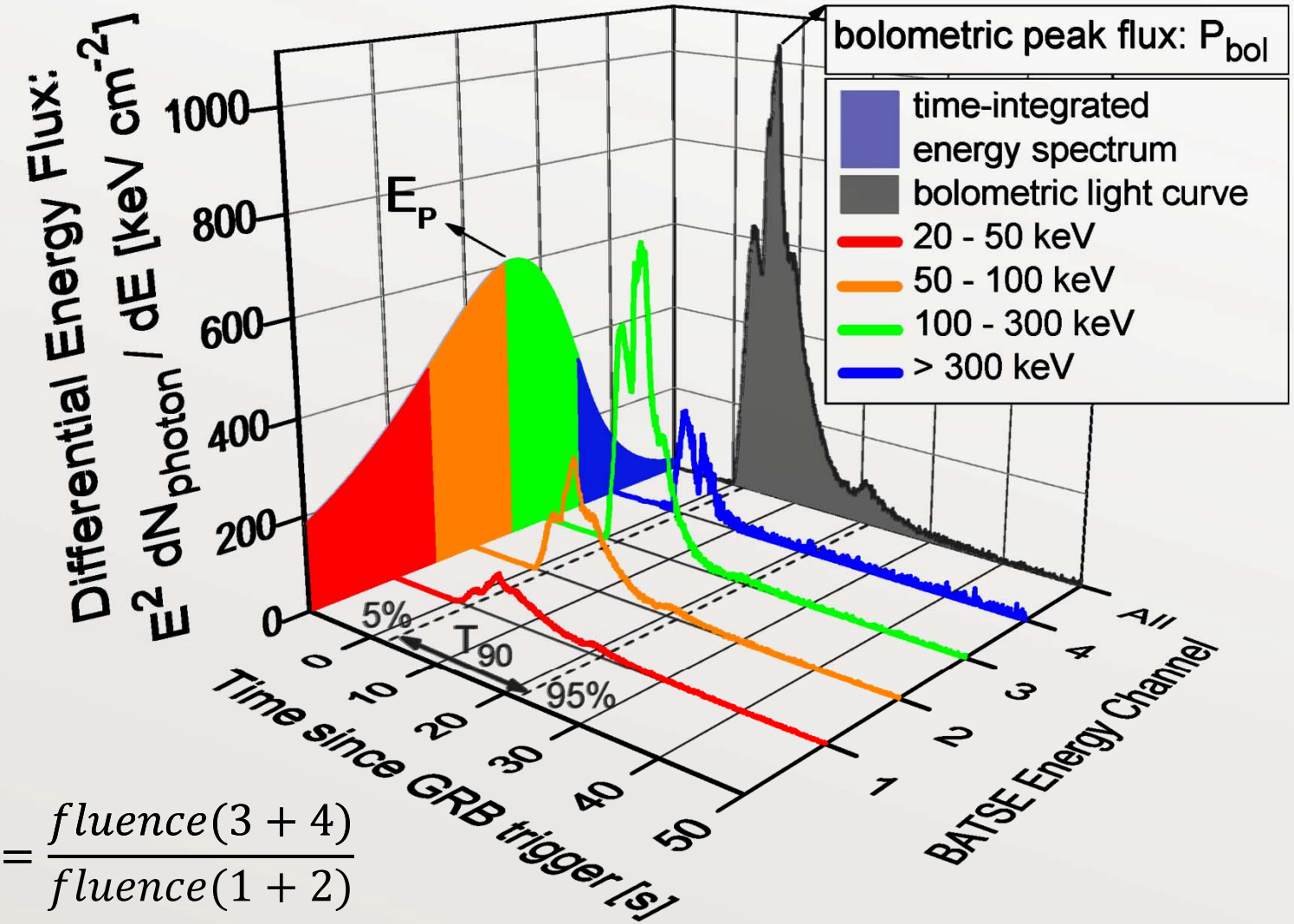
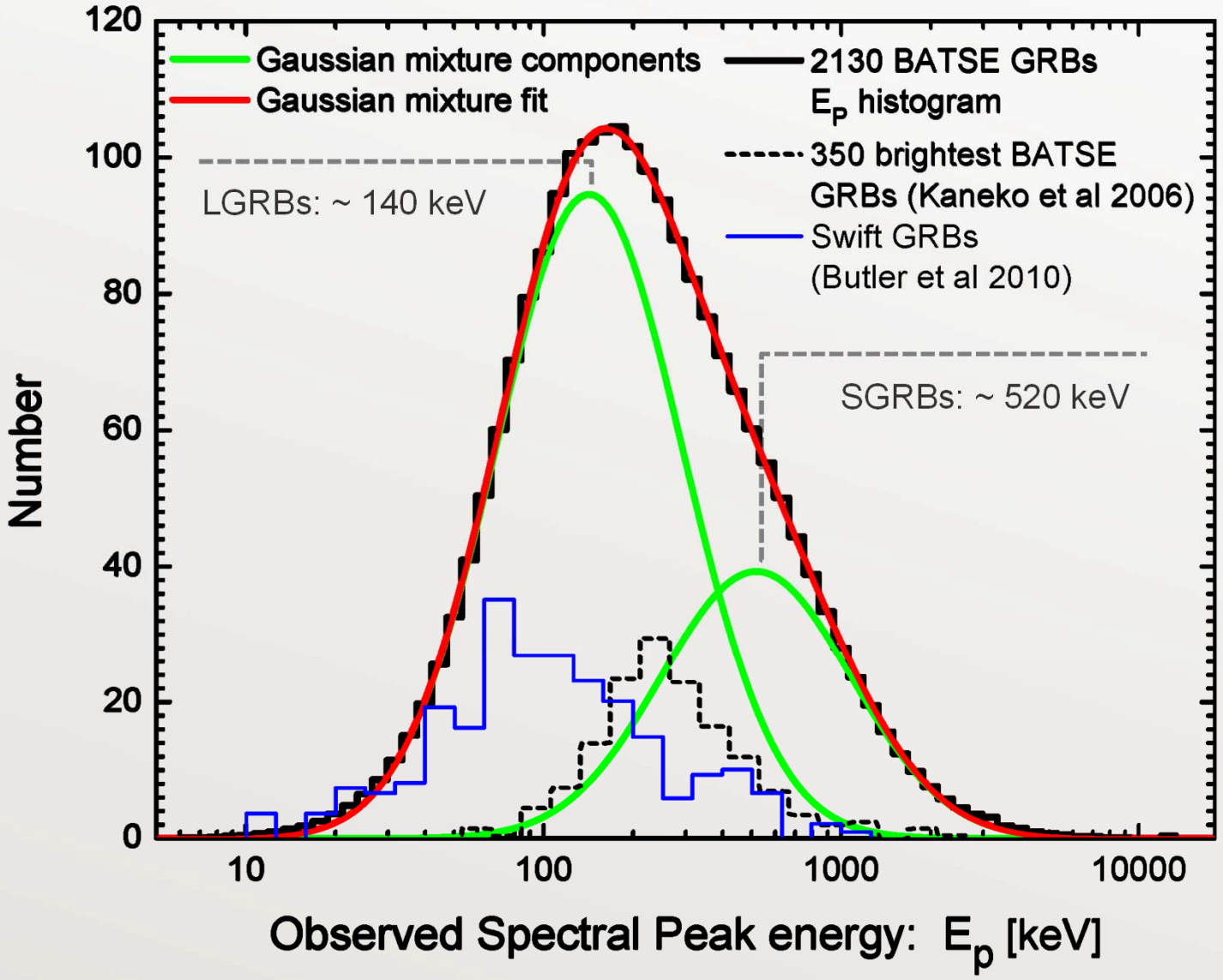


$$HR = \frac{fluence(3+4)}{fluence(1+2)}$$

The peak energy distribution of 2130 BATSE GRBs

(Shahmoradi & Nemiroff, 2010, MNRAS, **407**, 2075–2090)



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  author={Shahmoradi, Amir and Nemiroff, Robert J},
  journal={Monthly Notices of the Royal Astronomical Society},
  volume={451},
  number={1},
  pages={126--143},
  year={2015},
  publisher={Oxford University Press}
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  title={On the similarities of the prompt gamma-ray emissions in Short and Long Gamma-Ray Busts},
  author={Shahmoradi, Amir},
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  year={2014}
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  title={Detection Threshold Effects on GRBs as a Cosmological Standard Candle},
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  booktitle={Bulletin of the American Astronomical Society},
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  title={Hardness as a spectral peak estimator for gamma-ray bursts},
  author={Shahmoradi, Amir and Nemiroff, Robert J},
  journal={Monthly Notices of the Royal Astronomical Society},
  volume={407},
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 title={A Multivariate Fit Luminosity Function and World Model for Long Gamma-Ray Bursts},
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 year={2013}
}

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 title={Classification and Energetics of Cosmological Gamma-Ray Bursts},
 author={Shahmoradi, Amir and Nemiroff, RJ},
 booktitle={American Astronomical Society Meeting Abstracts\# 223},
 volume={223},
 year={2014}
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