Classification and Energetics of Cosmological Gamma-Ray Bursts

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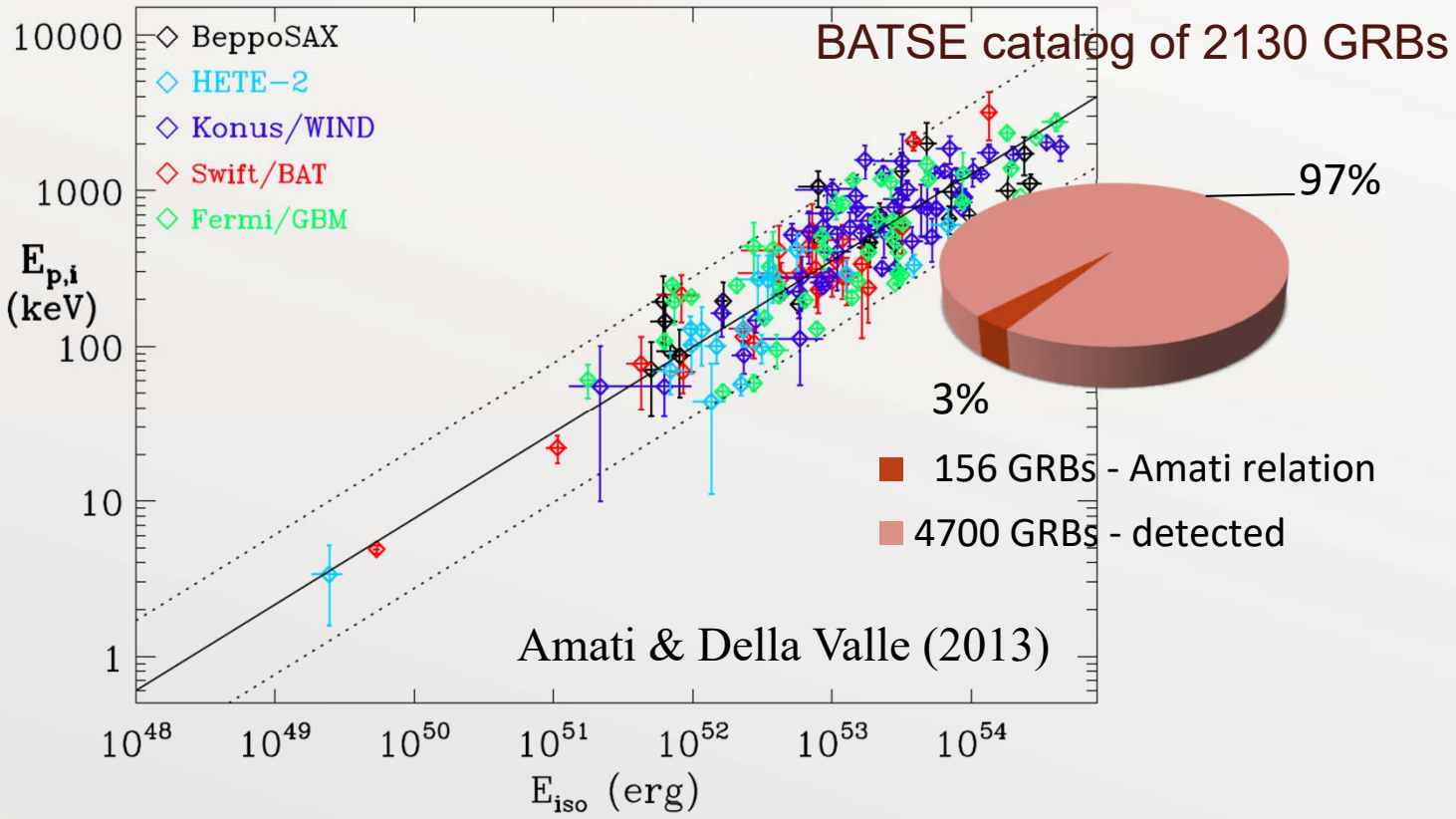
The Amati relation

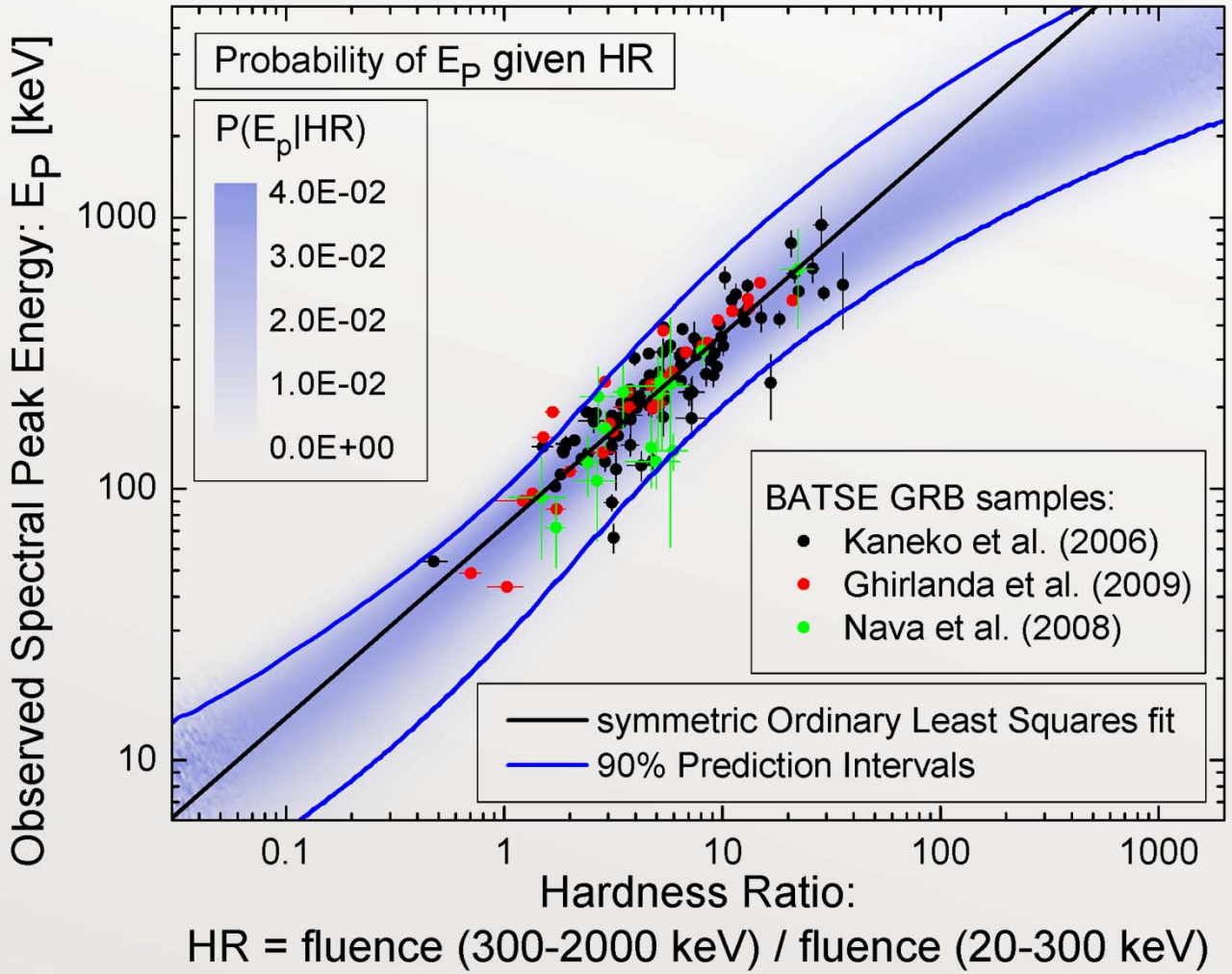
One of the most cited topics in the field of Gamma-Ray Bursts (GRBs)

Do all GRBs obey in the Amati relation?



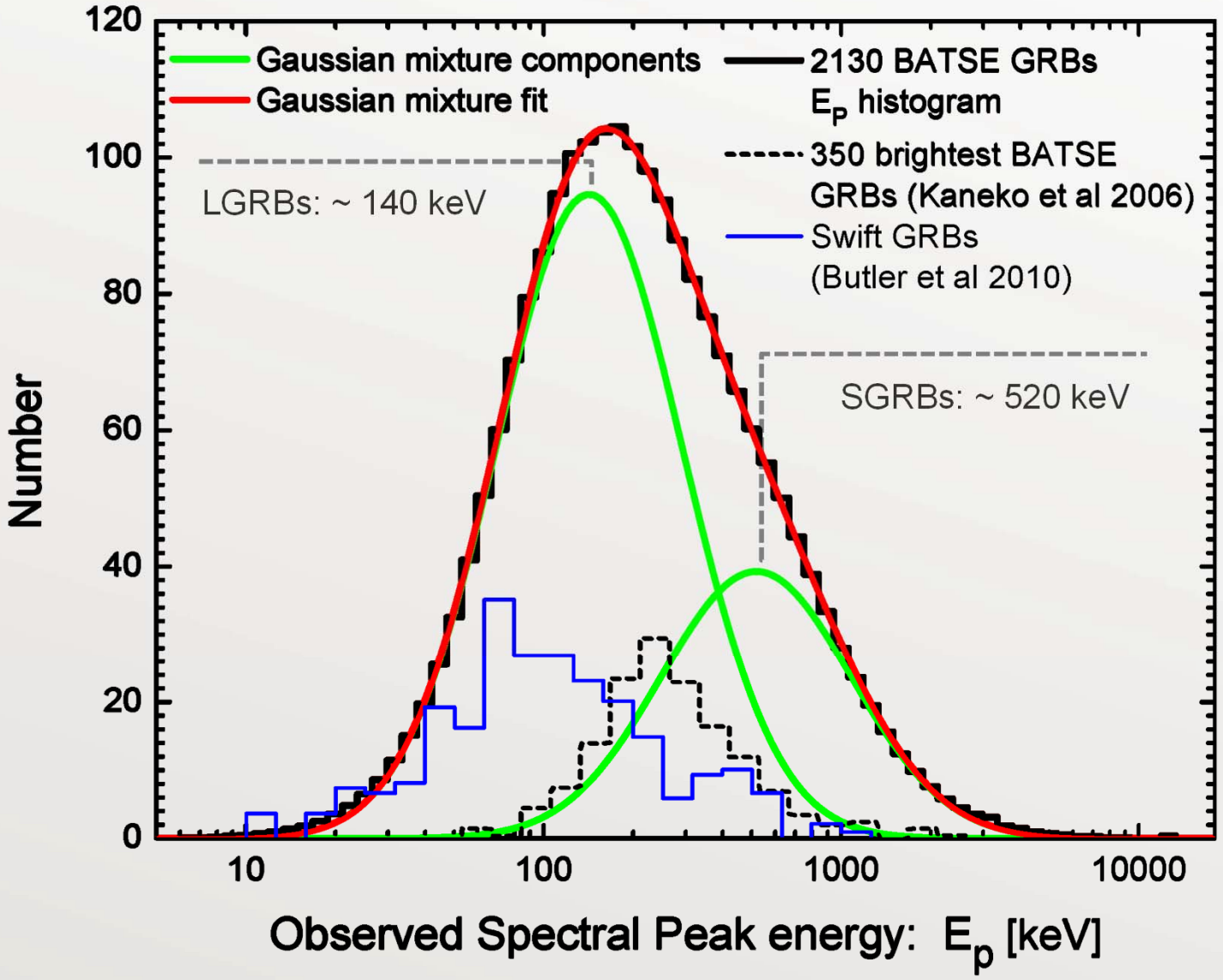
Hardness as a spectral peak estimator for GRBs

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



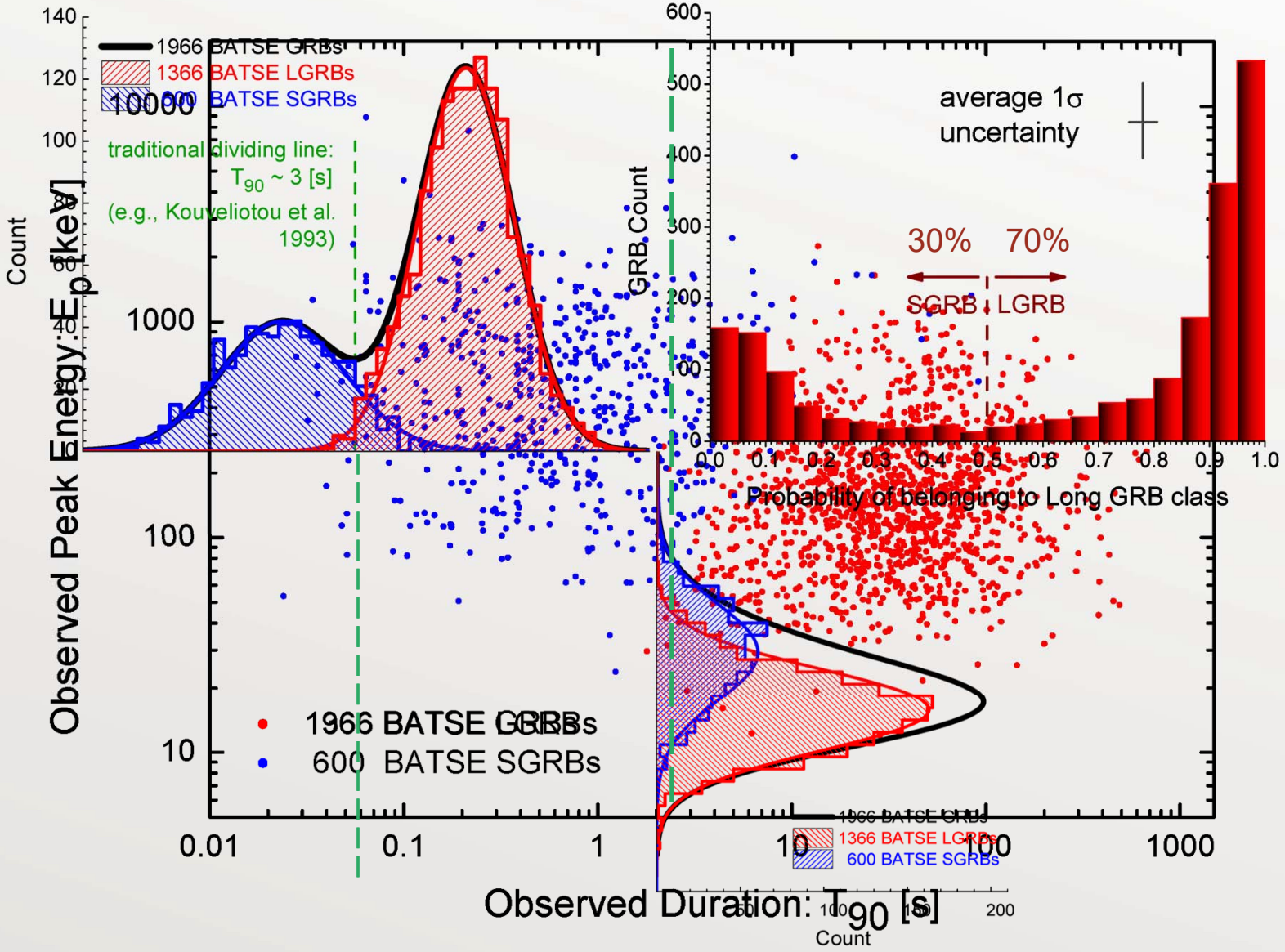
The peak energy distribution of 2130 BATSE GRBs

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



Classification of BATSE GRBs: fuzzy clustering vs. cutoff line

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

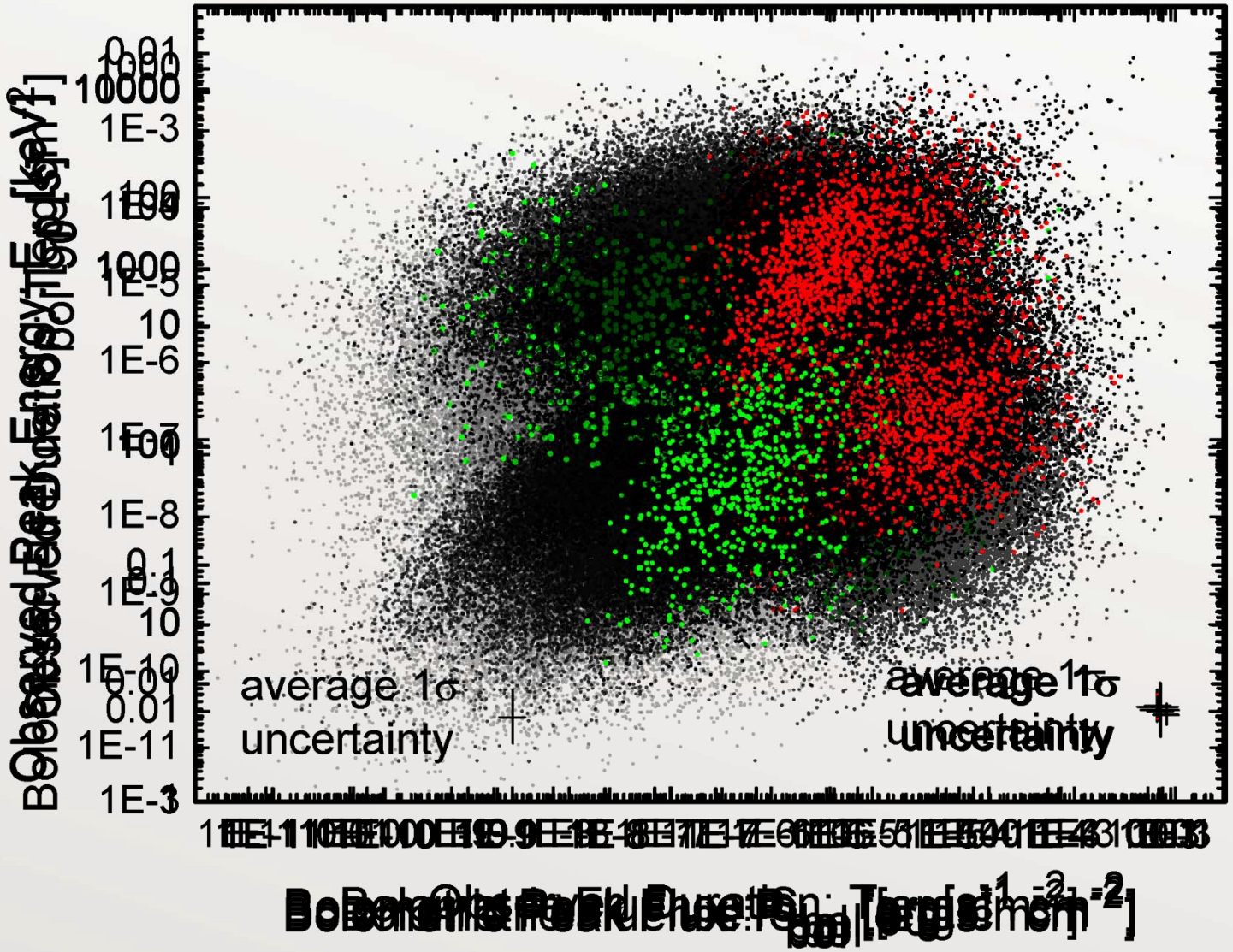


Model Construction - There is a need for multivariate Luminosity Functions (Shahmoradi, 2013, ApJ, **411**, 1843–1856)

- **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

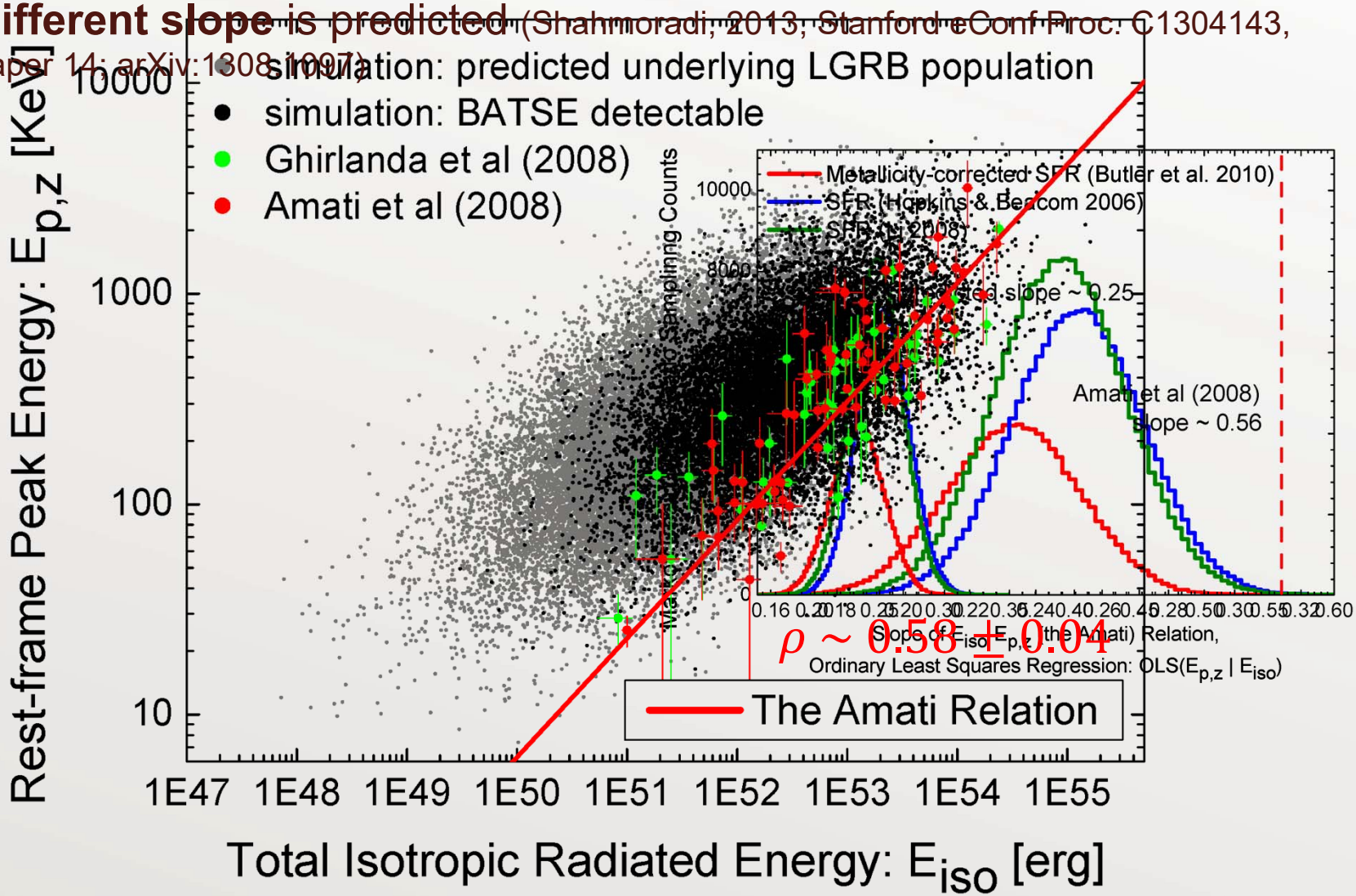
Colors bear the same meaning in all plots:

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

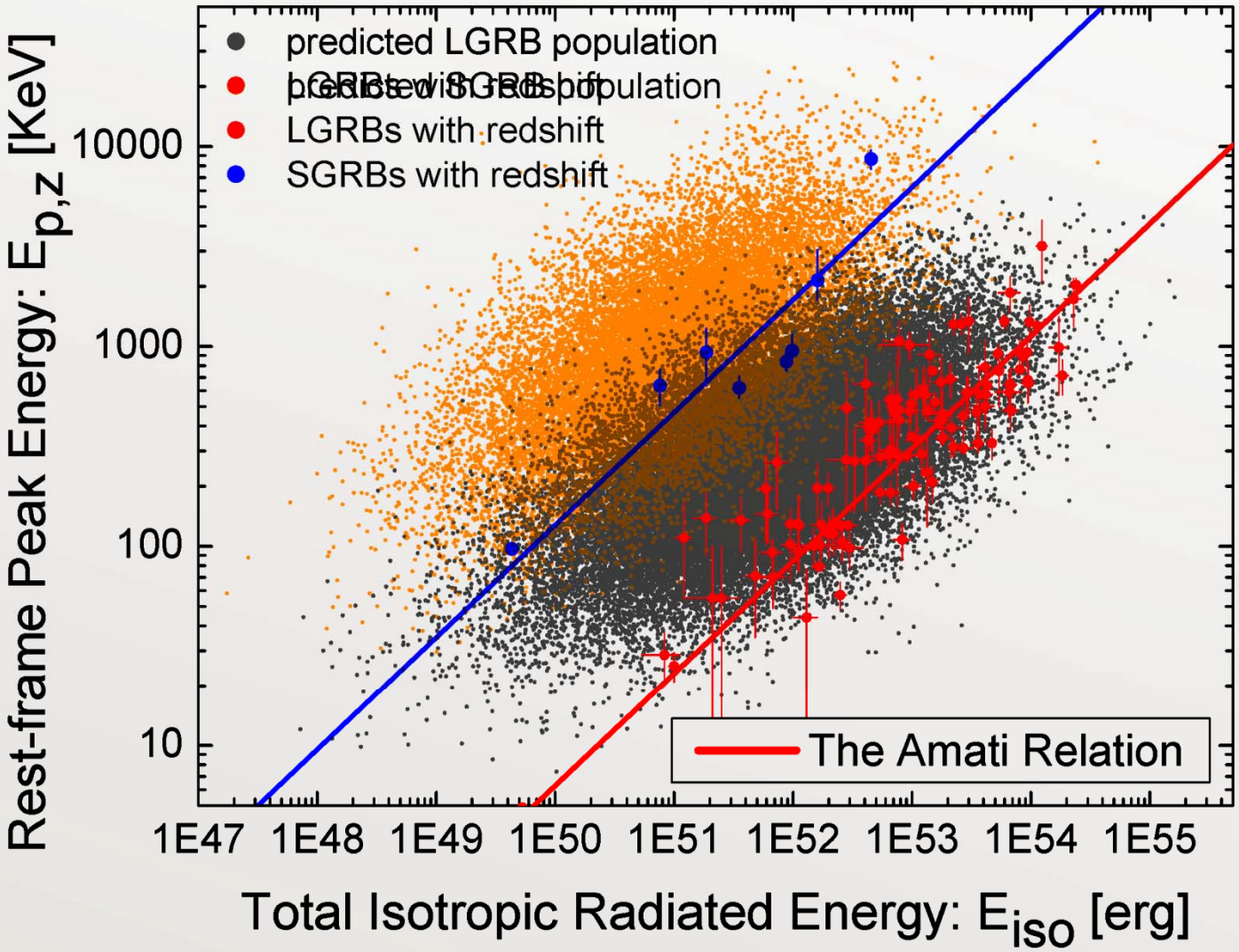


The Amati relation

- **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



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.

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, though do not necessitate, 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.

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