
بنام خداوند جان آفرین
حکیم سخن در زبان آفرین

Michigan Tech
Michigan Technological University

Gamma-Ray Bursts as Cosmological Tools

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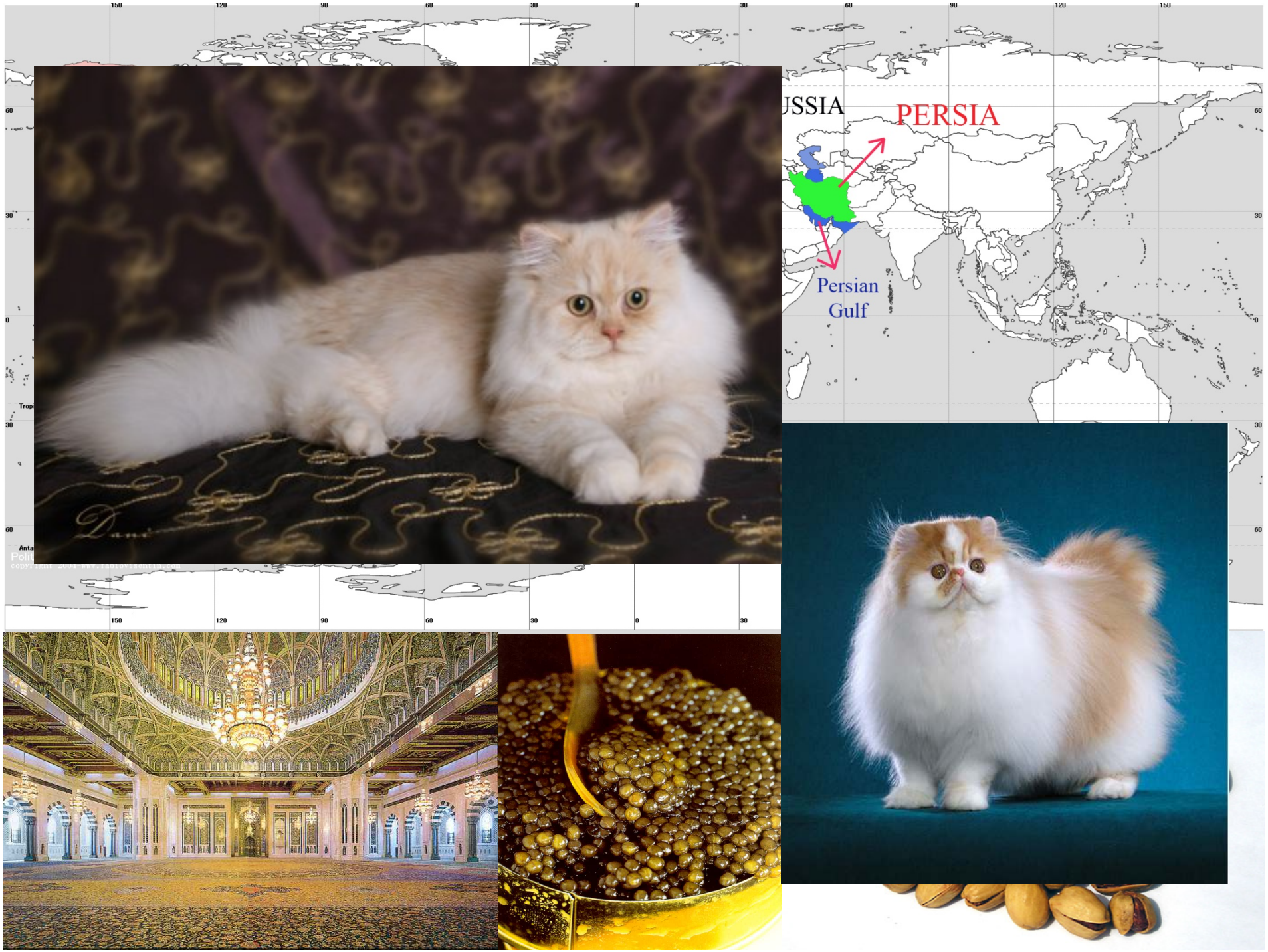
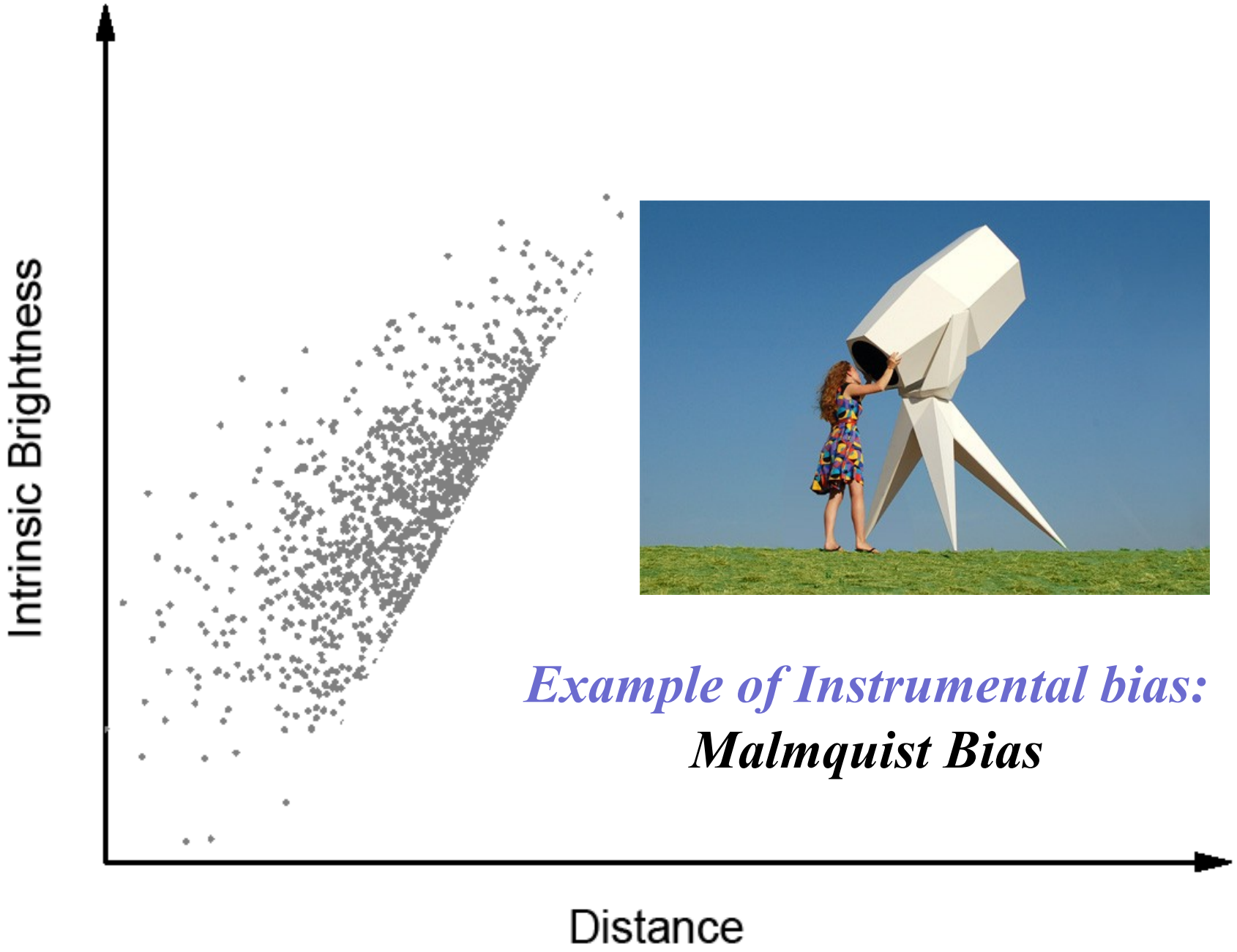
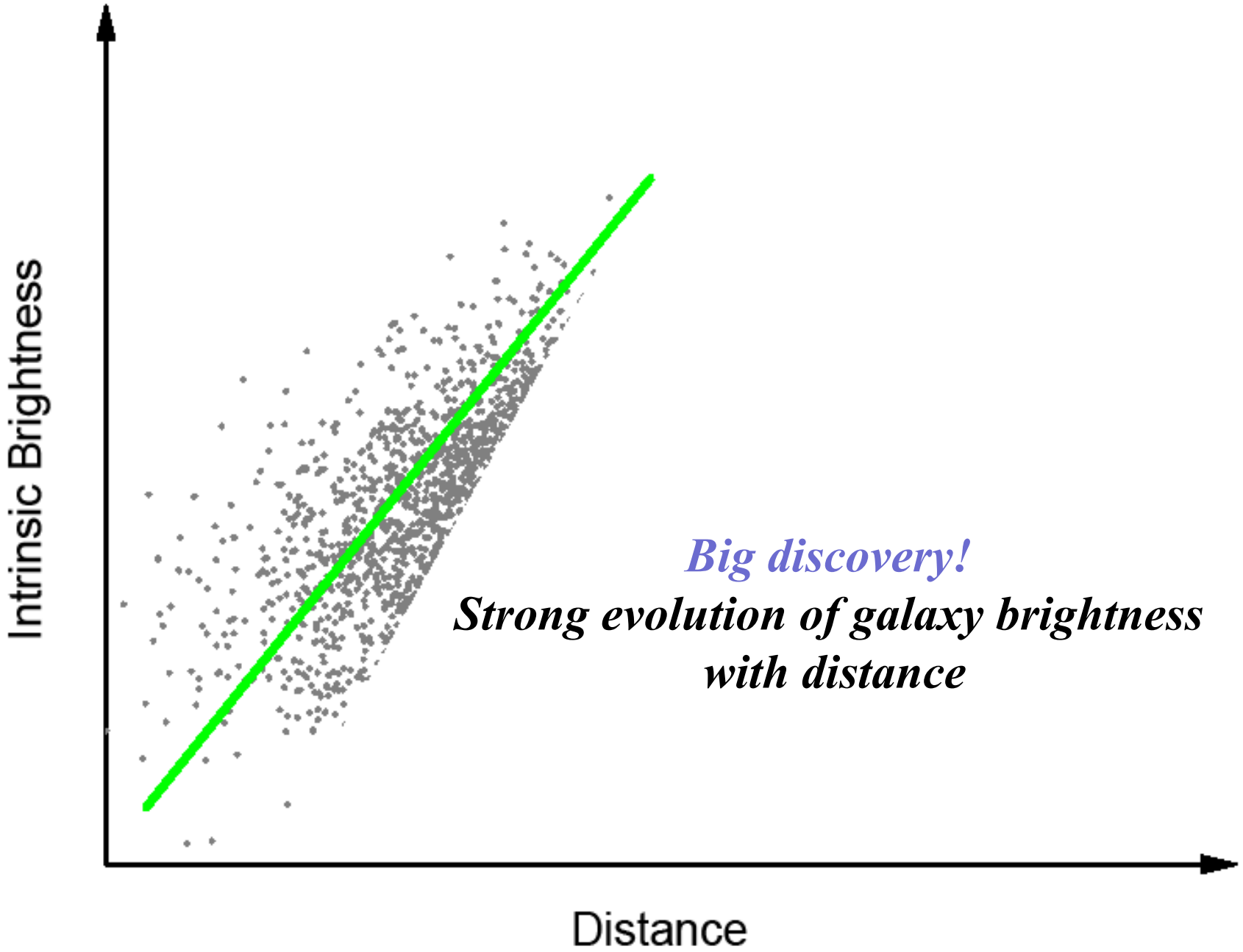

PERSIA
Persian
Gulf



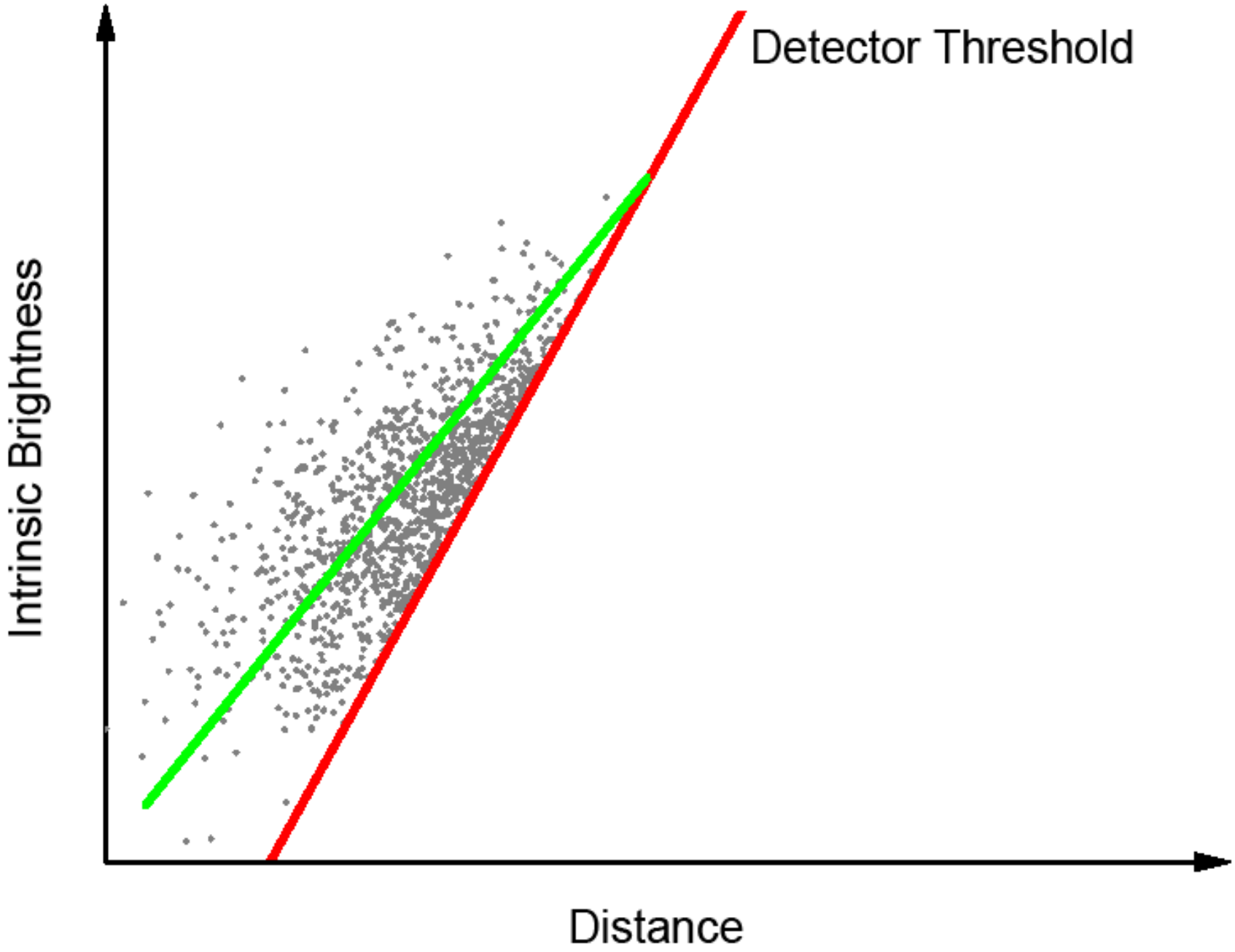
Example of Instrumental bias:

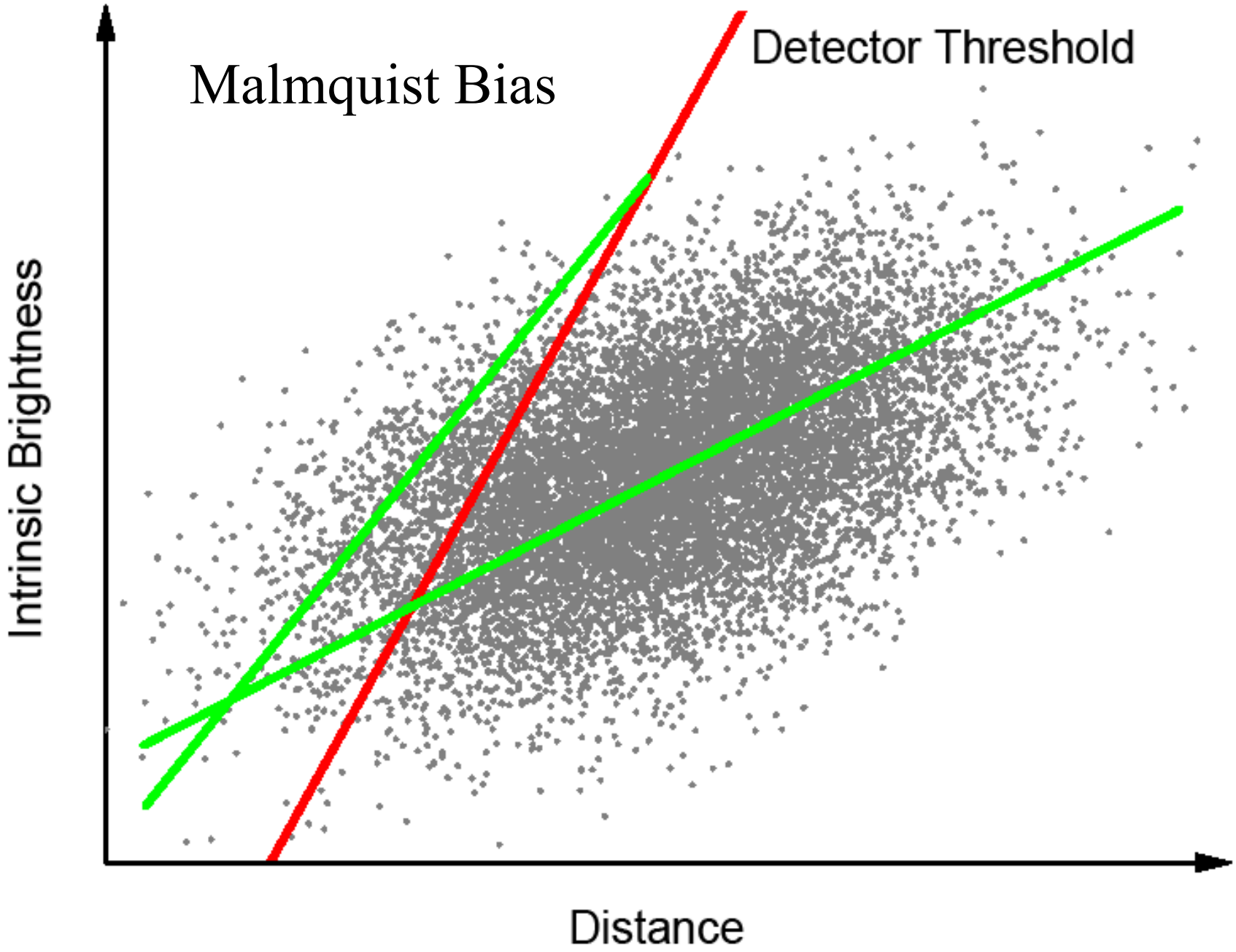
Malmquist Bias



Big discovery!

Strong evolution of galaxy brightness with distance


Detector Threshold
Intrinsic Brightness
Distance


Malmquist Bias
Detector Threshold
Intrinsic Brightness
Distance

Constraining Dark Energy's equation of state

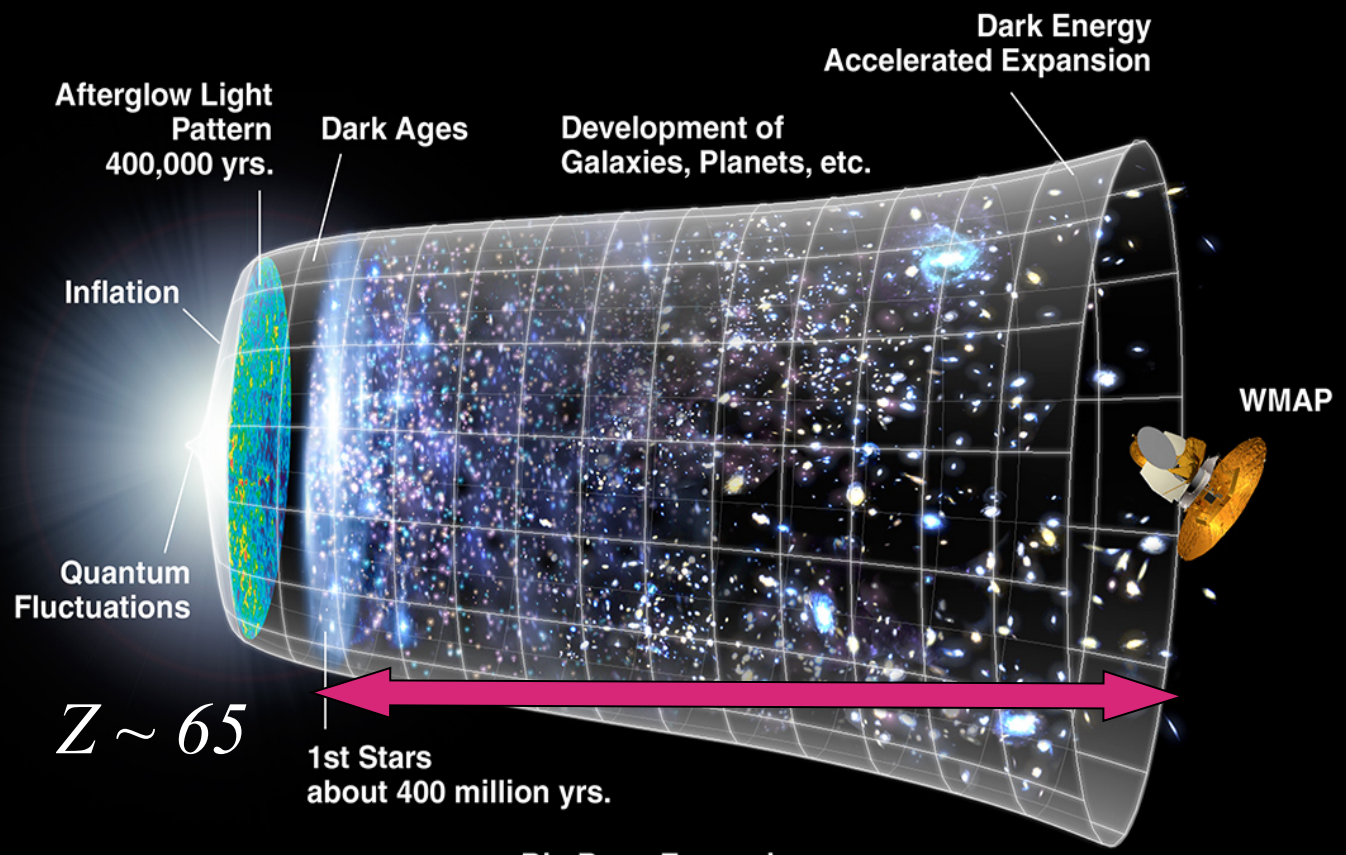
- ✓ *Cosmological Standard Candle*
  - ✓ *Constant Luminosity known*
  - ✓ *Spectroscopic Redshift known*

$$D_L = \sqrt{\frac{1}{4\pi}\frac{\text{Intrinsic Luminosity}}{\text{observed brightness}}}$$

Luminosity distance in the Concordance Cosmology

$$D_L = \frac{C}{H_0}(1+z)\int_0^z dz' \left[(1+z')^3 \Omega_M + \Omega_\Lambda\right]^{-1/2}$$

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

Outline

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

  - *Shahmoradi & Nemiroff, The Possible Impact of GRB Detectors on Cosmological Standard Candles, MNRAS accepted, 2009, arXiv:0904.1464v1*
  - *Shahmoradi & Nemiroff, Hardness as a Spectral Peak Estimator for Gamma-Ray Bursts, MNRAS accepted, 2010, arXiv:0912.2148v2*

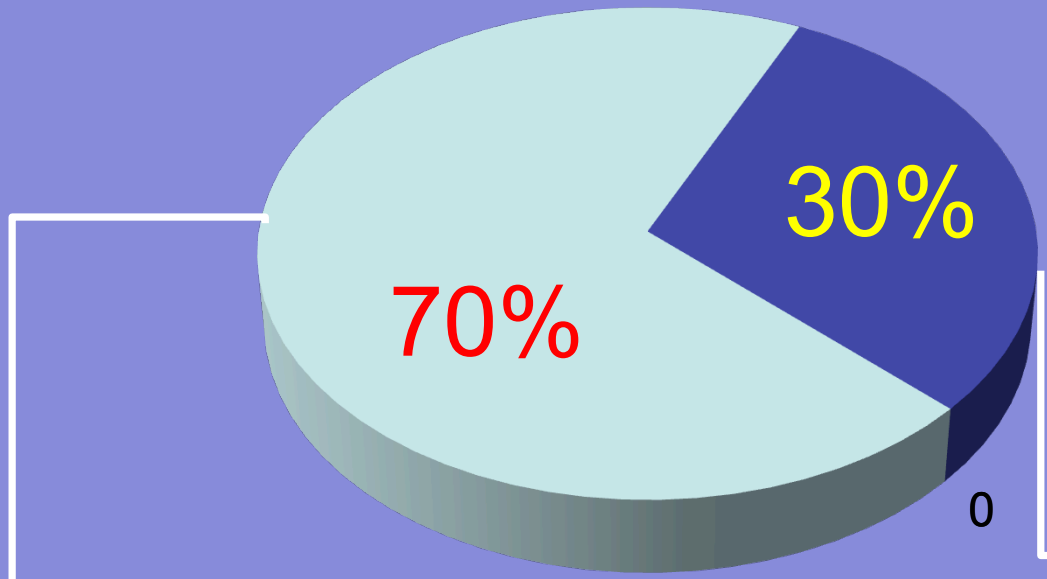
Gamma-Ray Bursts (GRBs)

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

- ✓ *The most powerful explosions in the Universe*

$$10^{47} ergs < E_{iso} < 10^{55} ergs$$

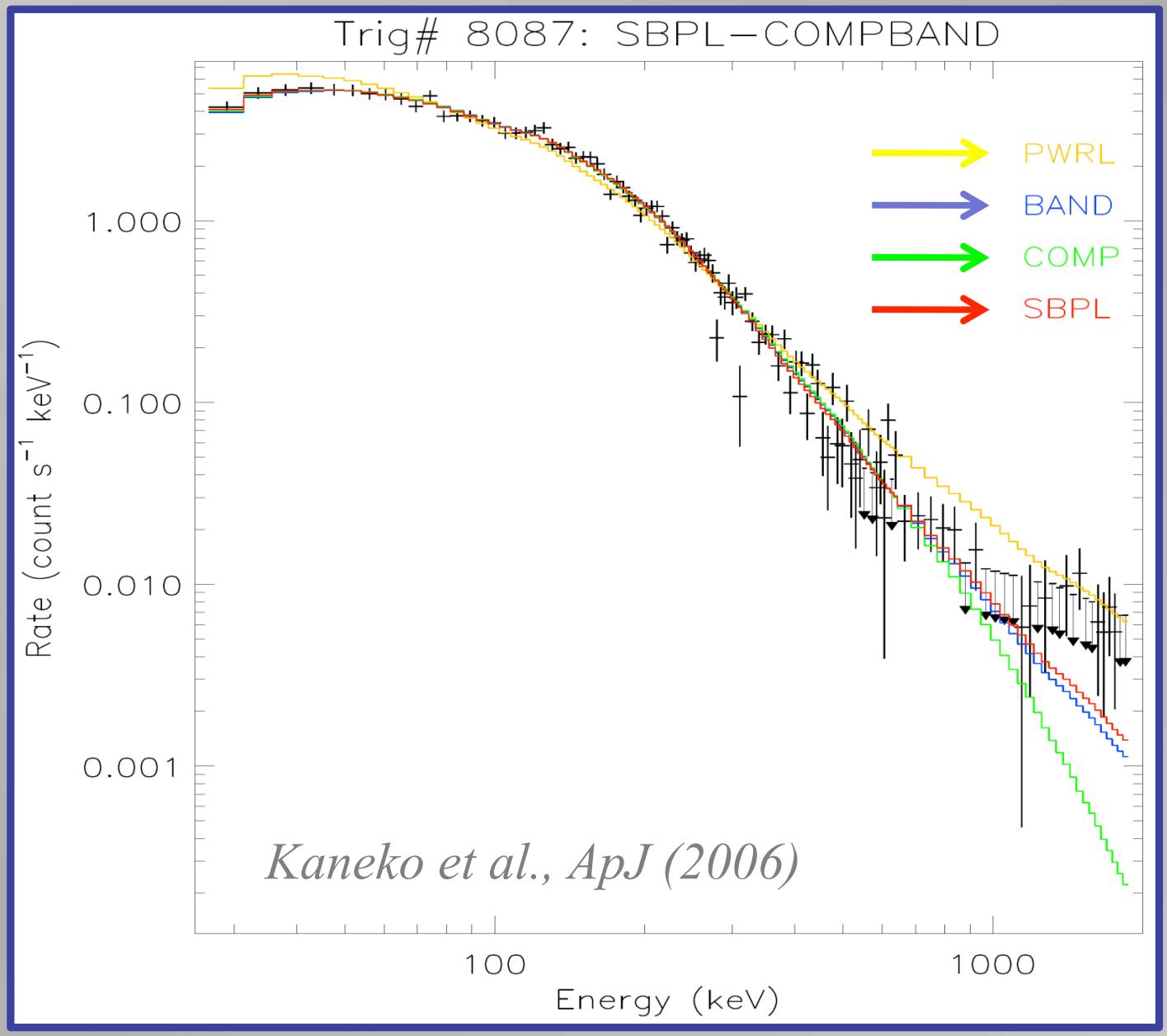
GRB types



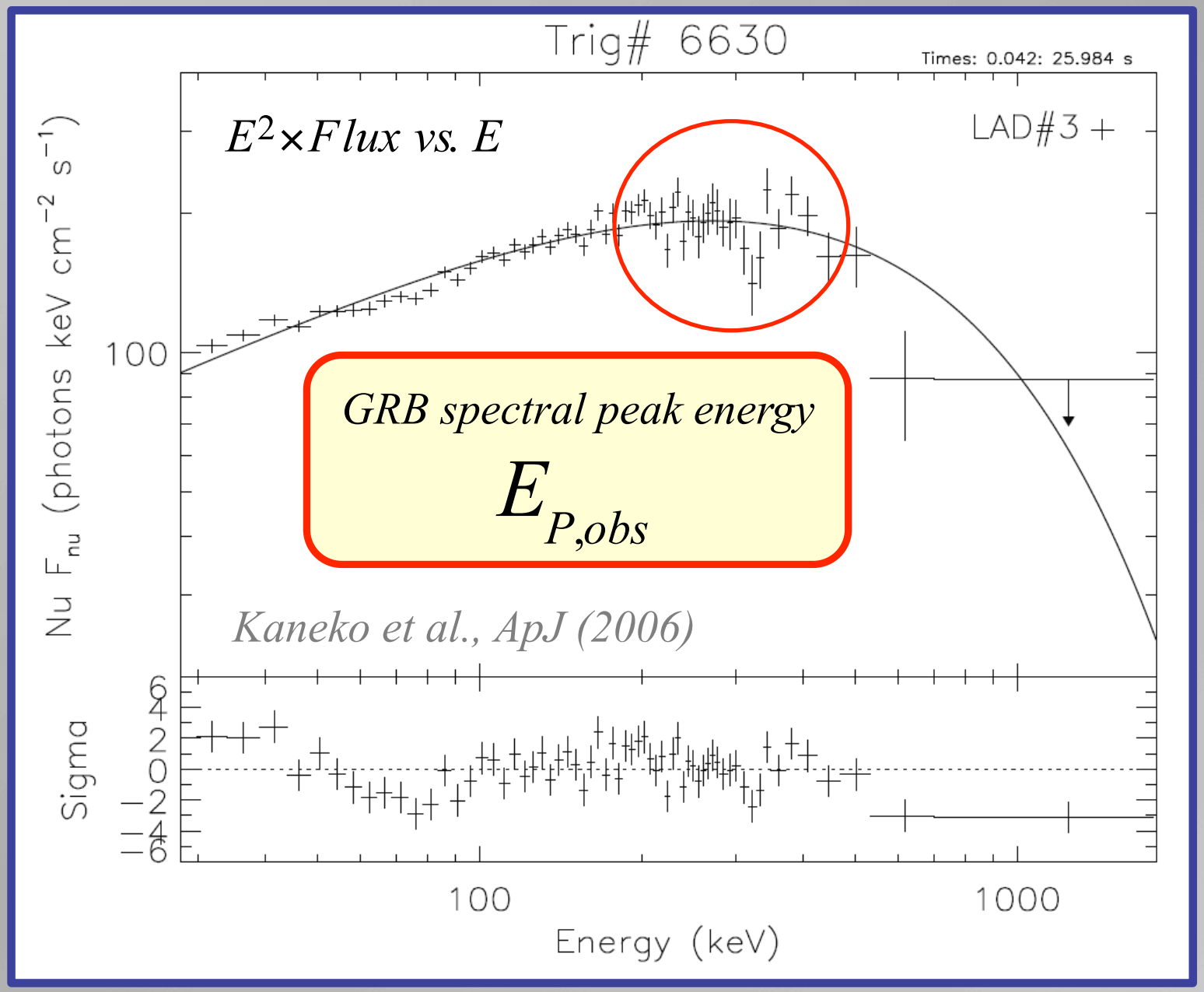
*Long-duration GRBs (**LGRB**s):*
possibly related to the death of supermassive stars

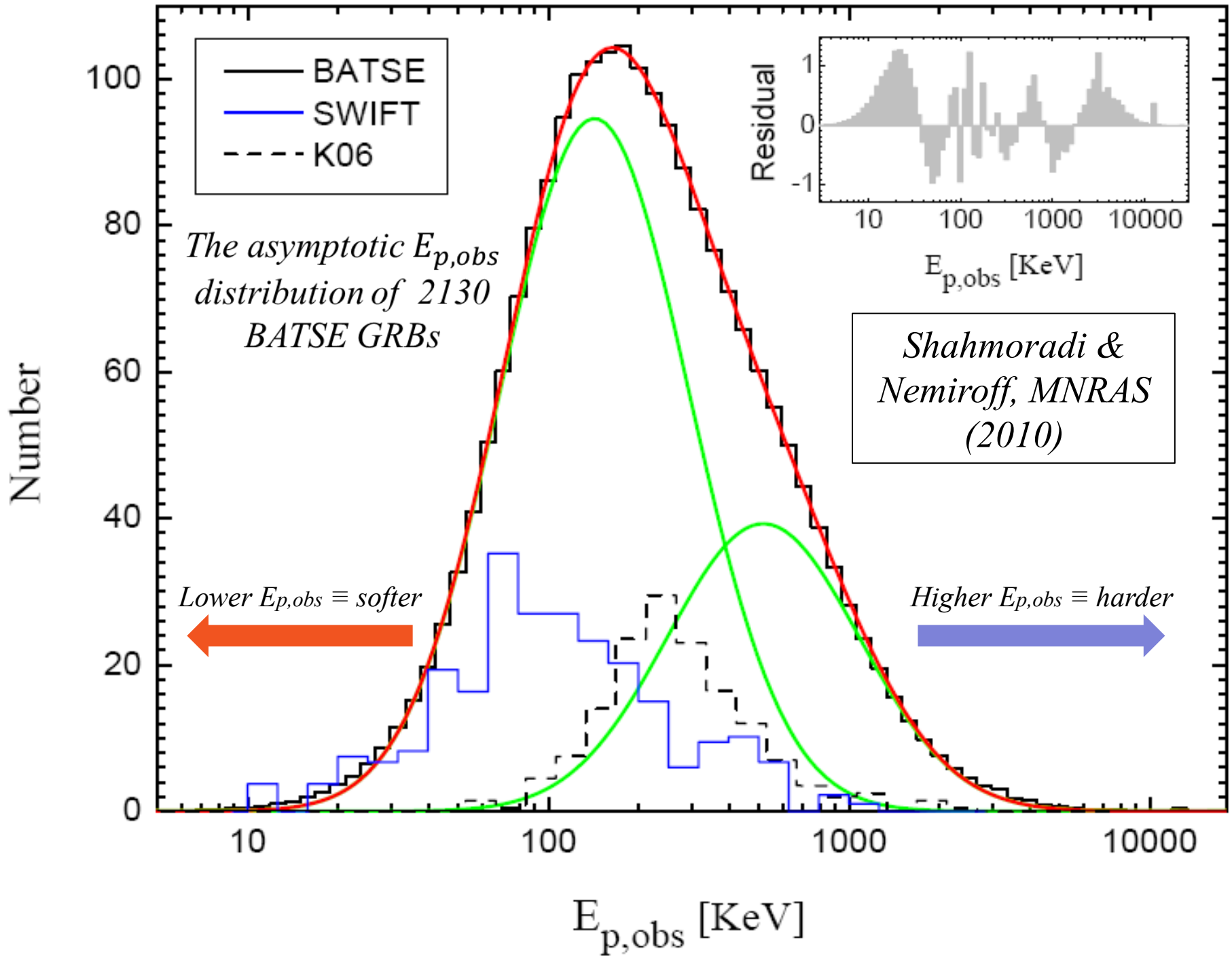
*Short-duration GRBs (**SGRB**s):*
possibly the merger of binary neutron stars

Example of GRB Spectrum

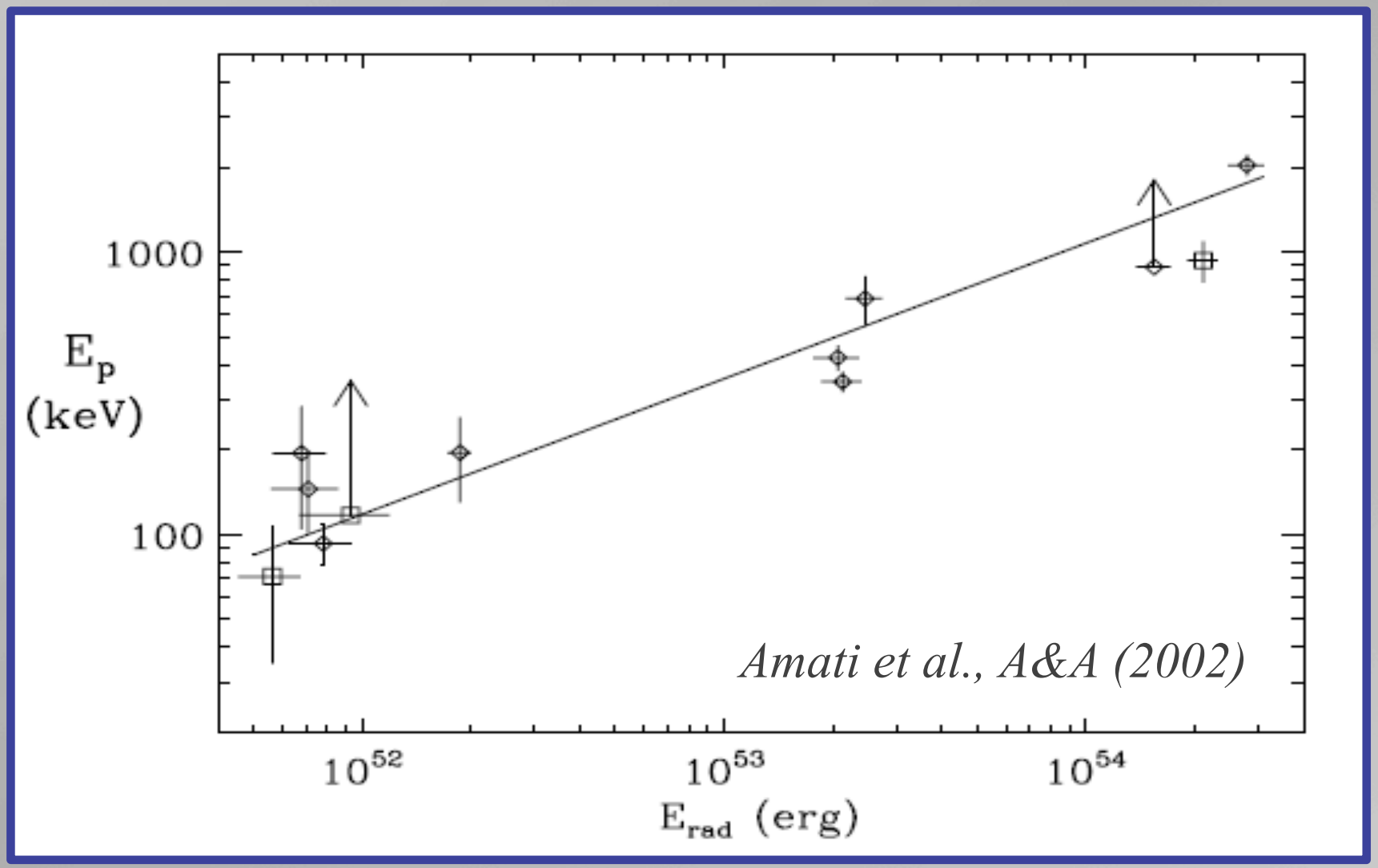


Example of GRB Power Spectrum



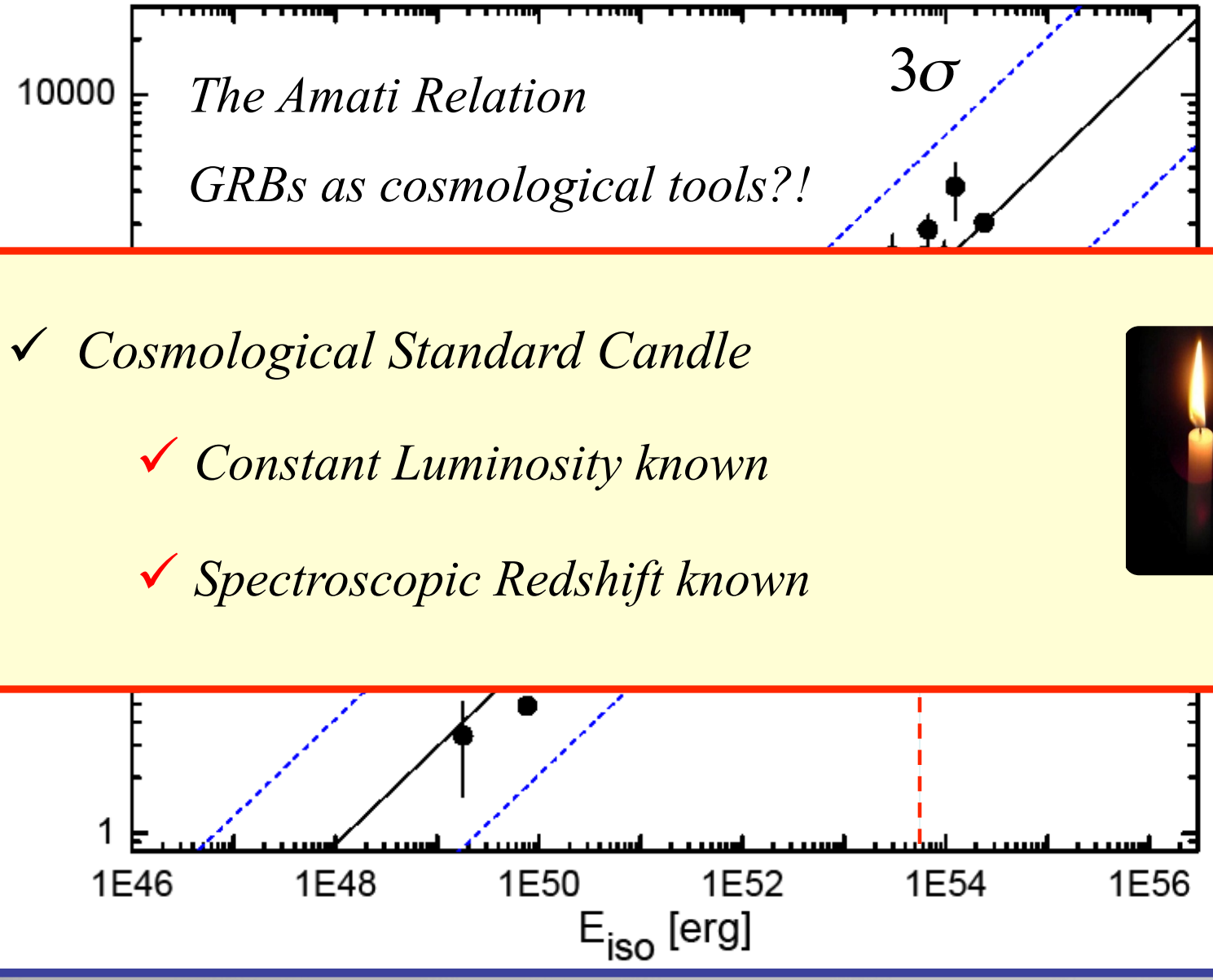

BATSE
SWIFT
K06
The asymptotic $E_{p,obs}$ distribution of 2130 BATSE GRBs
Shahmoradi & Nemiroff, MNRAS (2010)
Residual
$E_{p,obs}$ [KeV]
Lower $E_{p,obs}$ ≡ softer
Higher $E_{p,obs}$ ≡ harder
Number
$E_{p,obs}$ [KeV]

The Amati relation



The Amati Relation

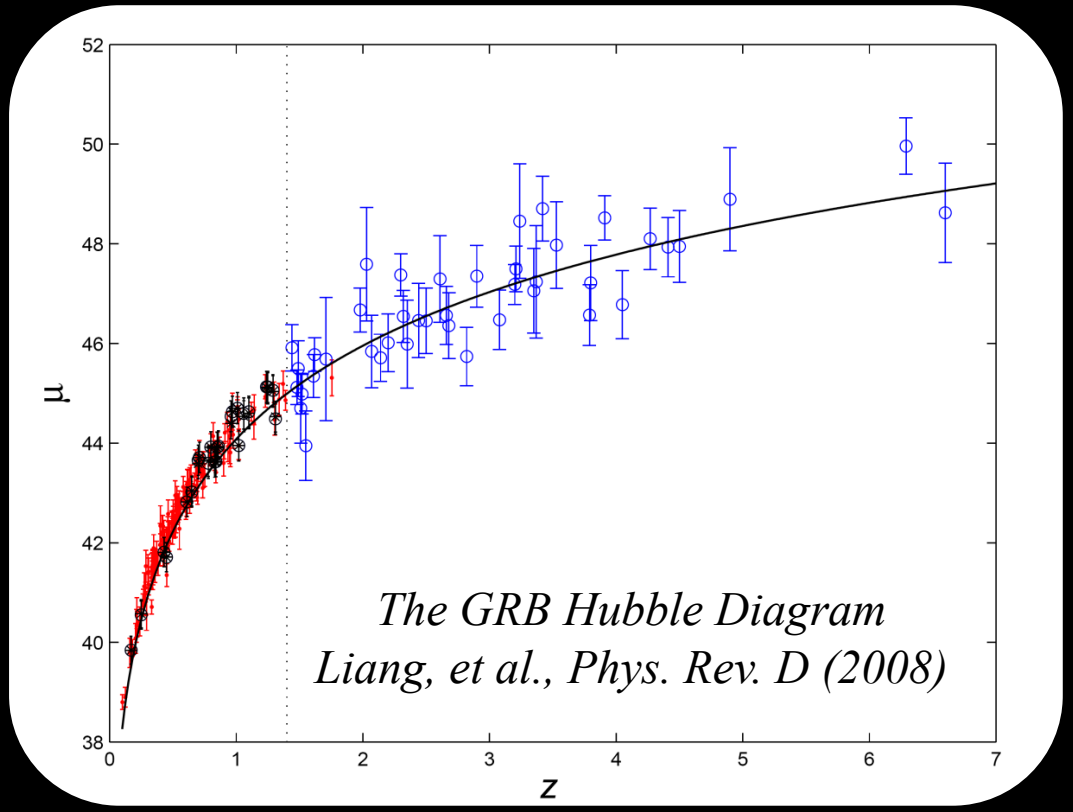
GRBs as cosmological tools?!



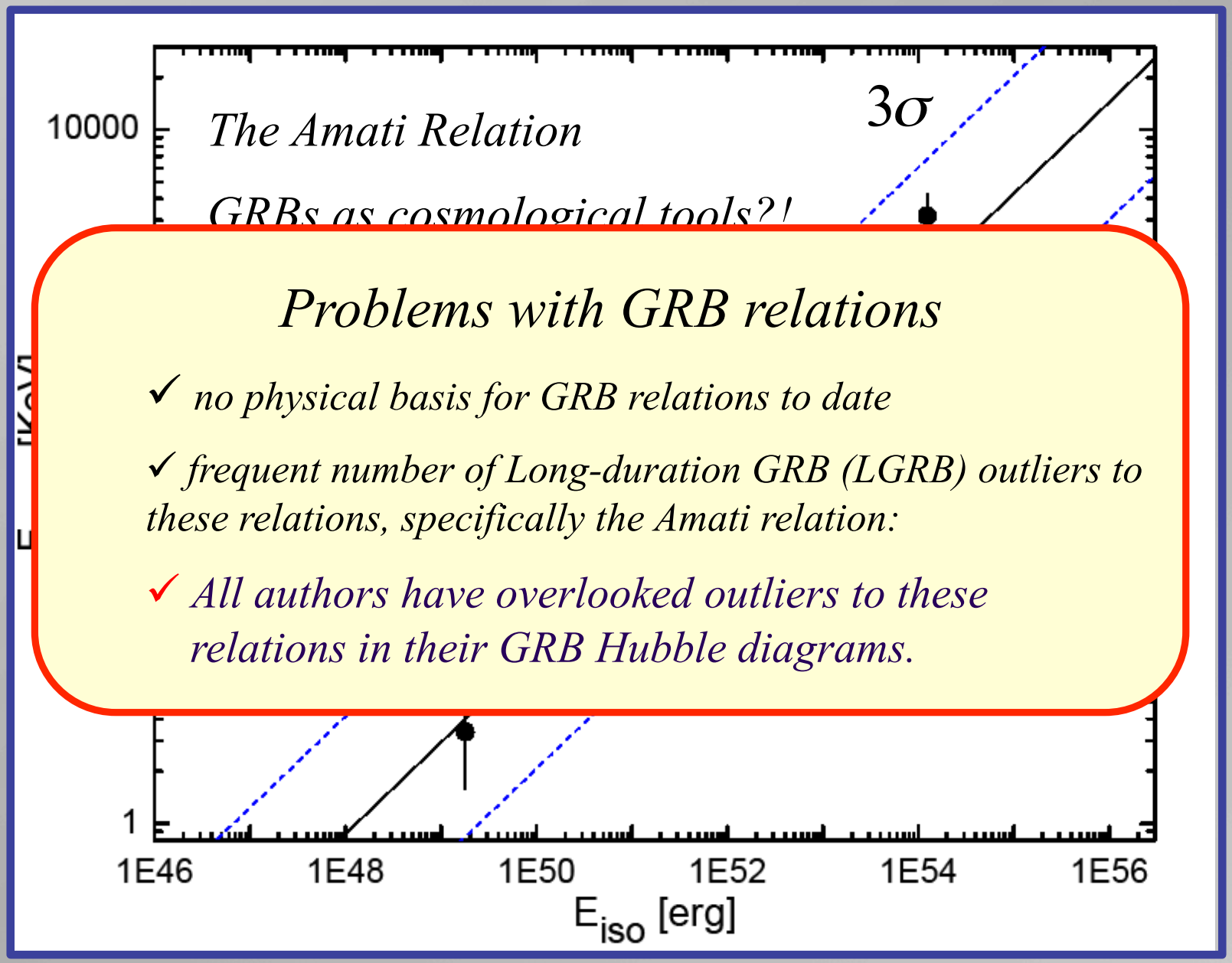
- ✓ *Cosmological Standard Candle*
  - ✓ *Constant Luminosity known*
  - ✓ *Spectroscopic Redshift known*

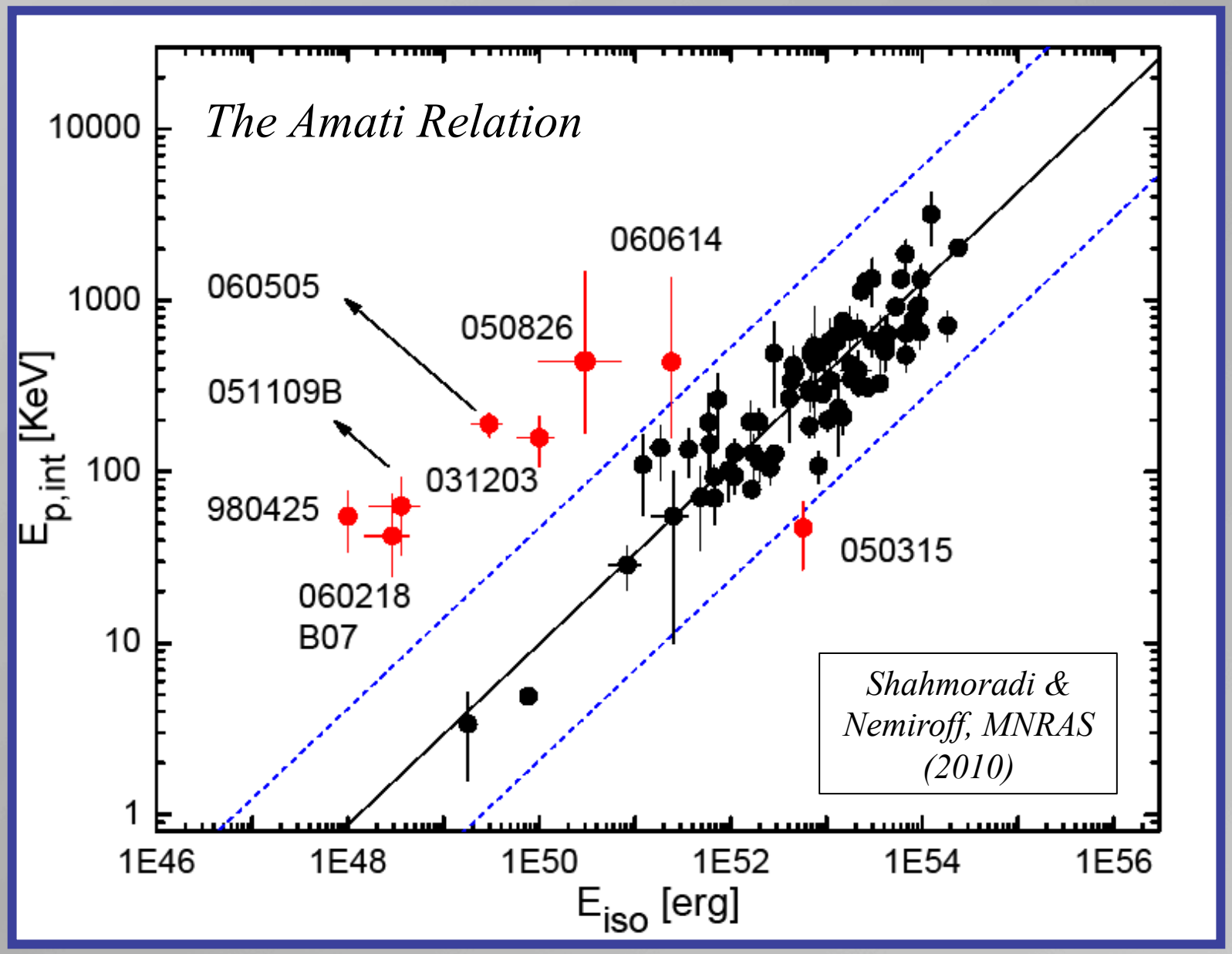
$$D_{\mathrm{L,obs}} = \sqrt{\frac{1}{4\pi}\frac{\mathrm{E_{iso}}(E_{p,\mathrm{int}})}{\mathrm{S_{bol}}}}$$

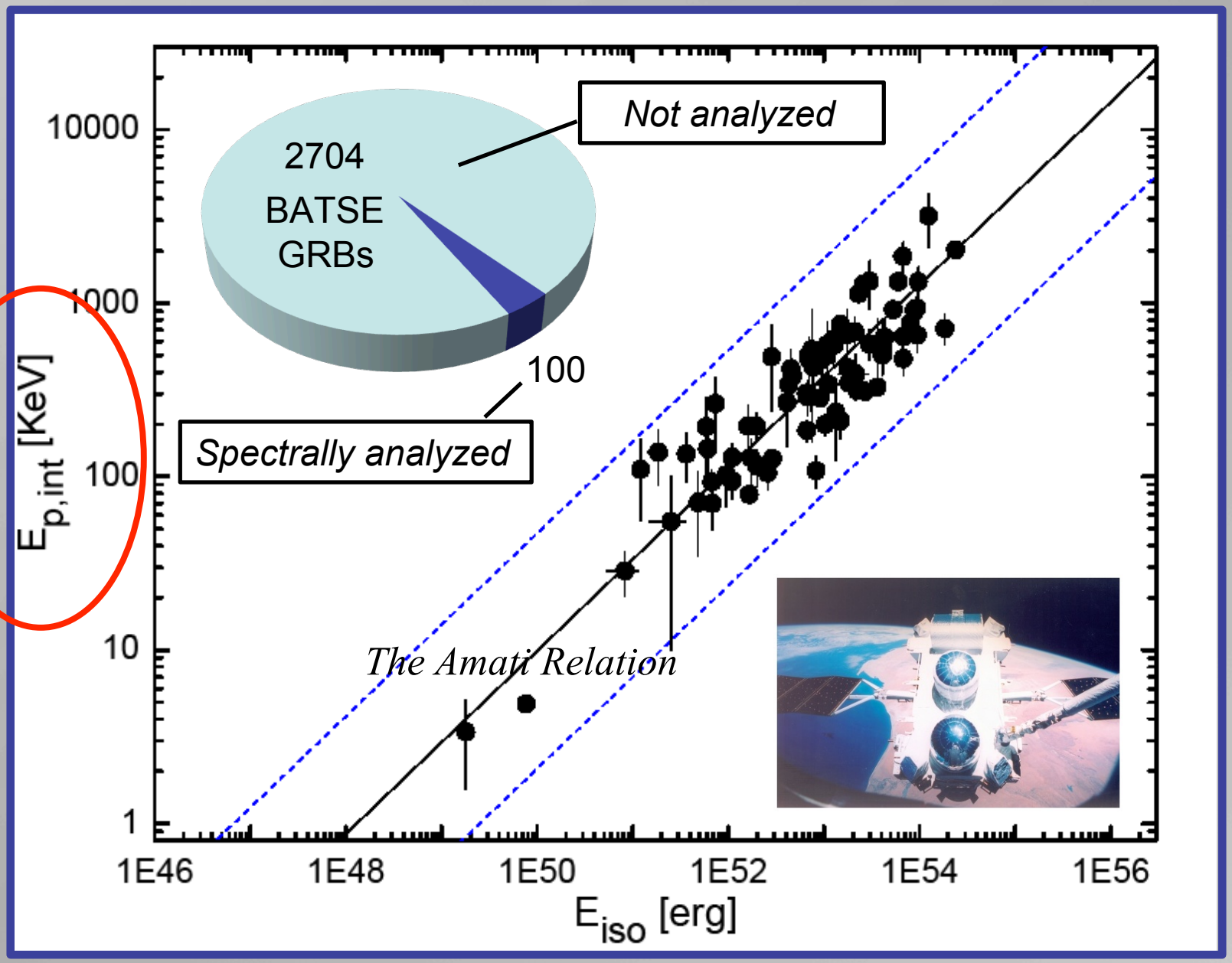
Standard Candle *Observer*

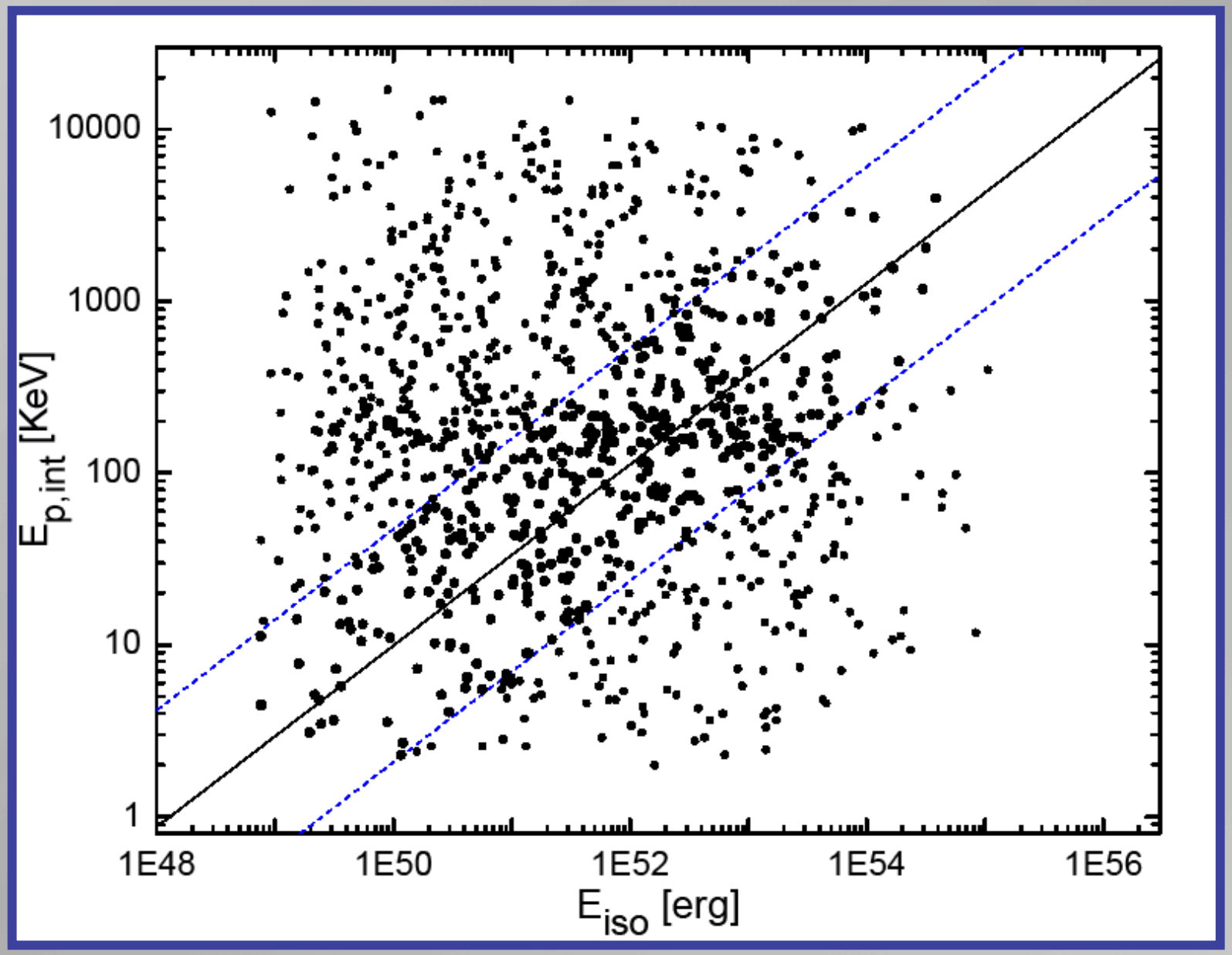


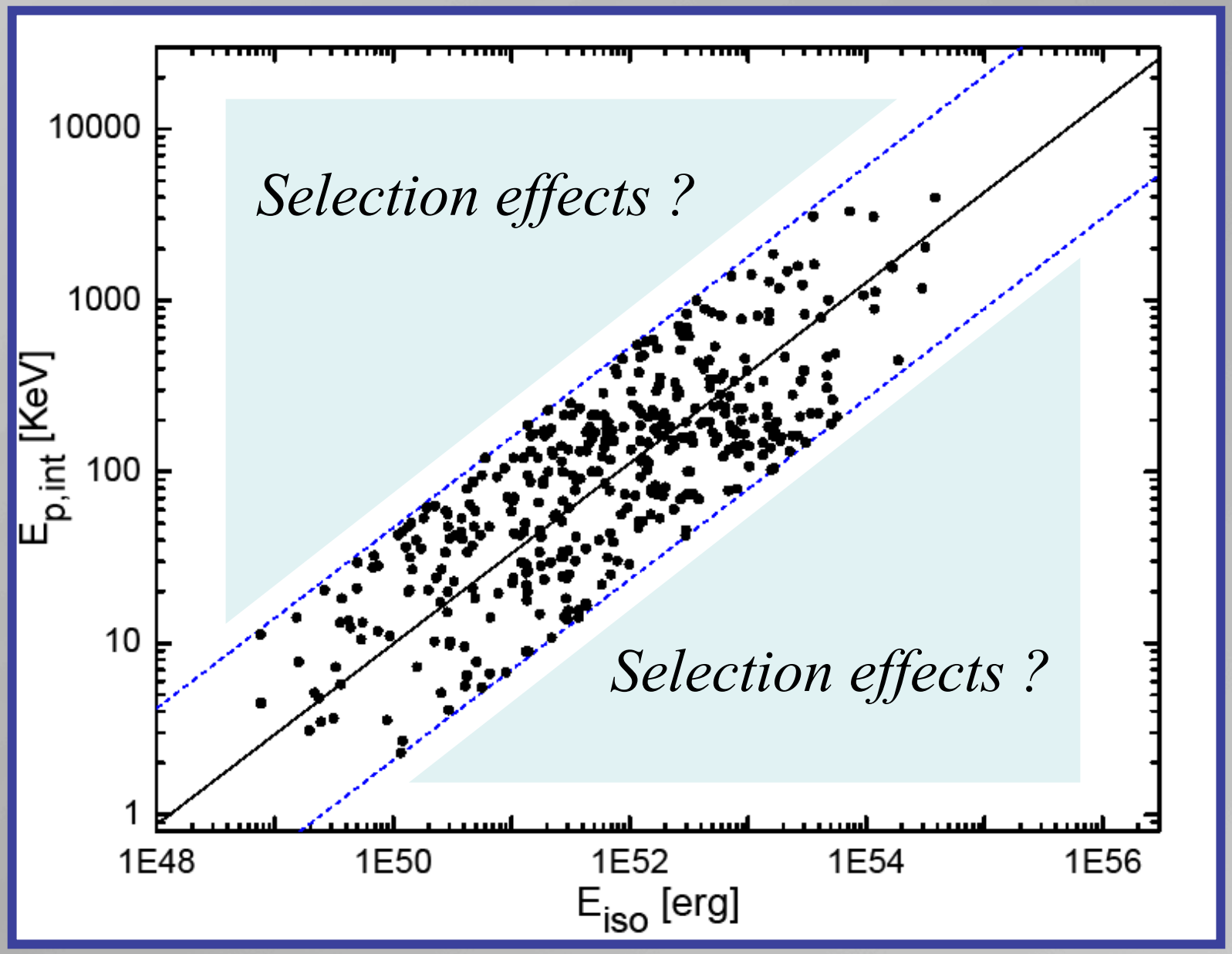
The GRB Hubble Diagram
Liang, et al., Phys. Rev. D (2008)

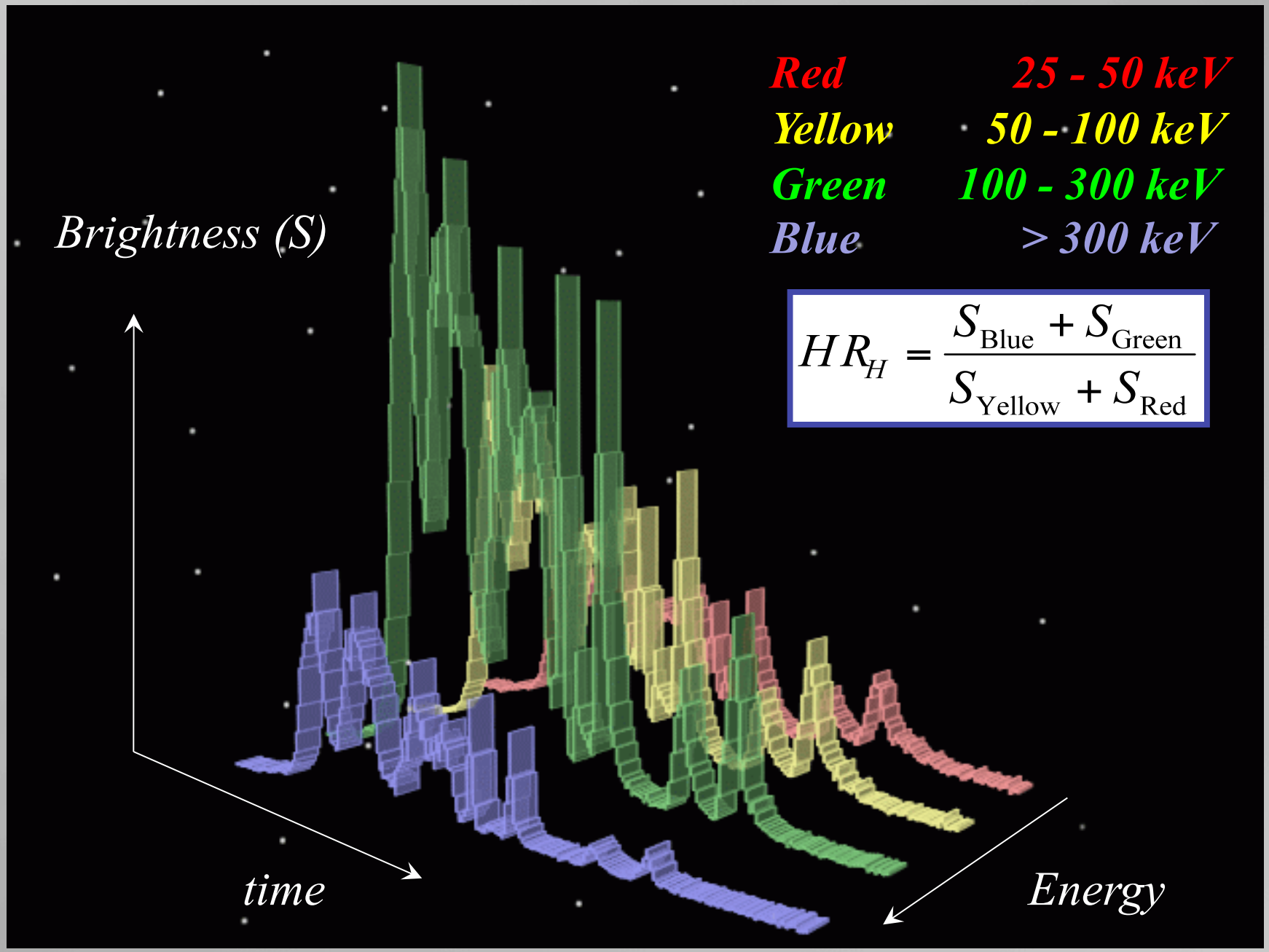

10000
1
1E46
1E48
1E50
1E52
1E54
1E56
E_{iso} [erg]
3σ
The Amati Relation
GRBs as cosmological tools?!
Problems with GRB relations
✓ no physical basis for GRB relations to date
✓ frequent number of Long-duration GRB (LGRB) outliers to these relations, specifically the Amati relation:
✓ All authors have overlooked outliers to these relations in their GRB Hubble diagrams.

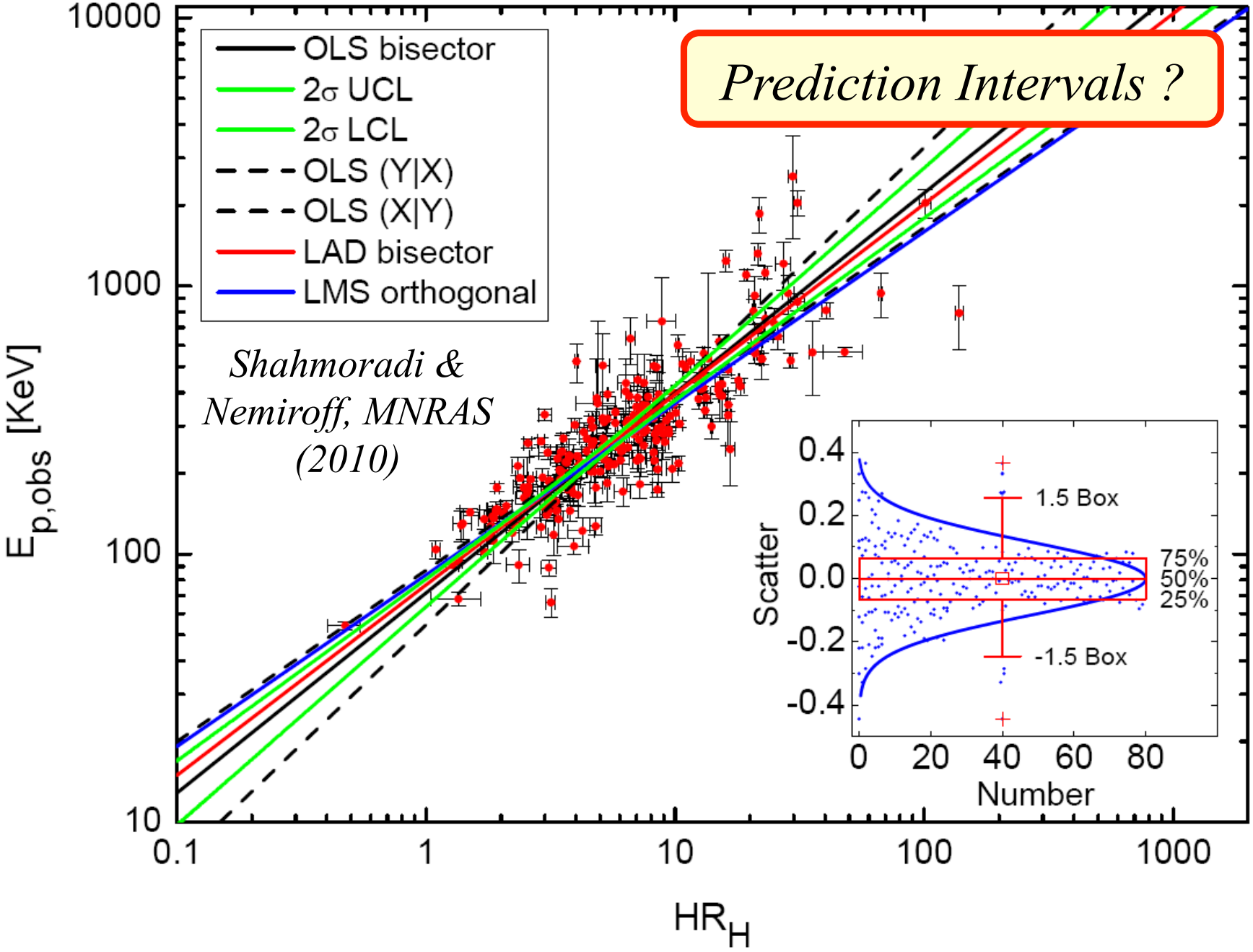

The Amati Relation
10000
1000
100
10
1
$E_{p,int}$ [KeV]
1E46
1E48
1E50
1E52
1E54
1E56
E_{iso} [erg]
060614
060505
050826
051109B
031203
980425
060218
B07
050315
Shahmoradi & Nemiroff, MNRAS (2010)


2704
BATSE
GRBs
Not analyzed
100
Spectrally analyzed
10000
1000
100
10
1
$E_{p,int}$ [KeV]
1E46
1E48
1E50
1E52
1E54
1E56
E_{iso} [erg]
The Amati Relation

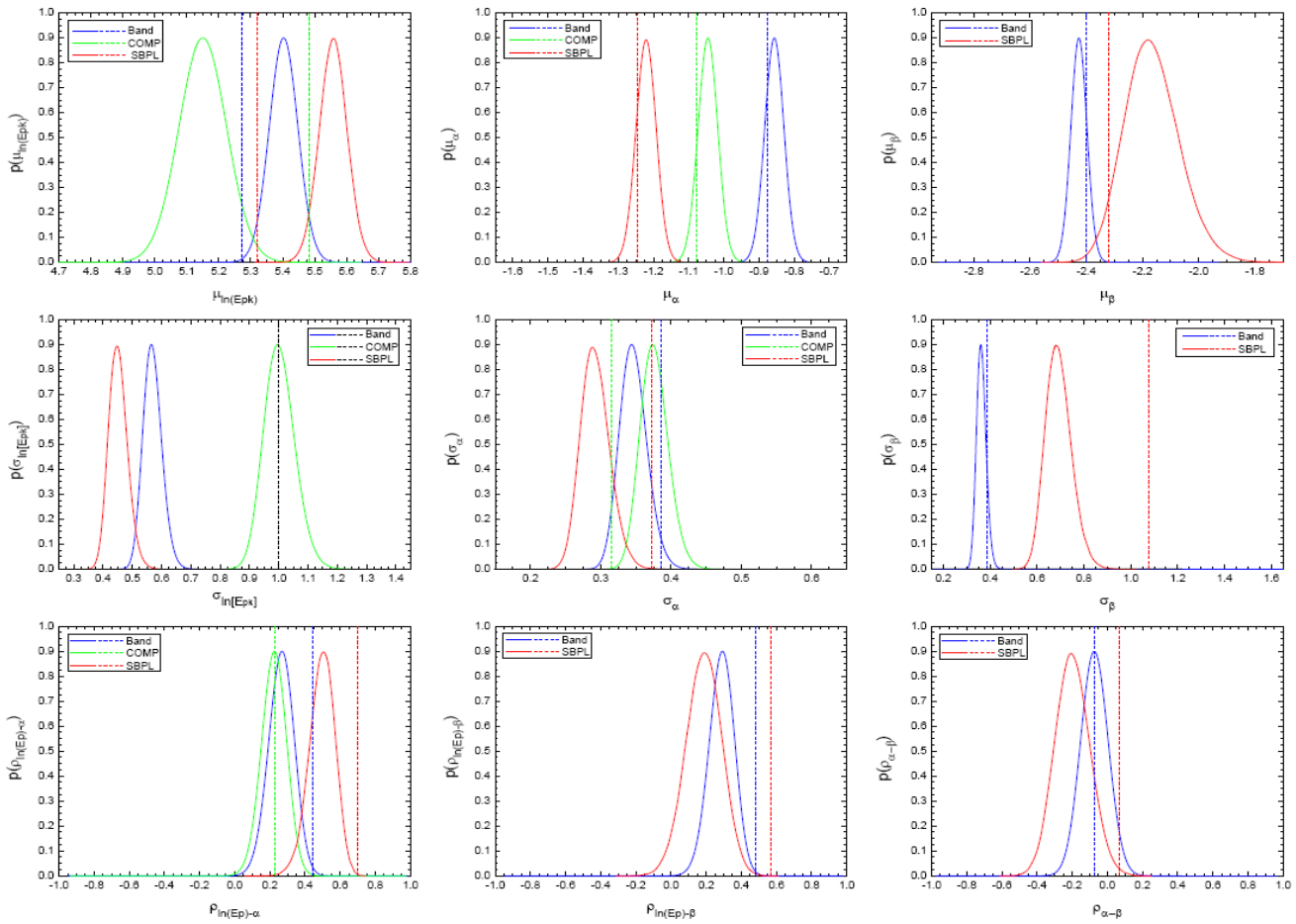

10000
1000
100
10
1
$E_{p,int}$ [KeV]
1E48
1E50
1E52
1E54
1E56
E_{iso} [erg]


Selection effects ?
Selection effects ?
10000
1000
100
10
1
$E_{p,int}$ [KeV]
1E48
1E50
1E52
1E54
1E56
E_{iso} [erg]


Red 25 - 50 keV
Yellow 50 - 100 keV
Green 100 - 300 keV
Blue > 300 keV
$HR_H = \frac{S_{\text{Blue}} + S_{\text{Green}}}{S_{\text{Yellow}} + S_{\text{Red}}}$
Brightness (S)
time
Energy


OLS bisector
2σ UCL
2σ LCL
OLS (Y|X)
OLS (X|Y)
LAD bisector
LMS orthogonal
Prediction Intervals ?
Shahmoradi & Nemiroff, MNRAS (2010)
$E_{p,obs}$ [KeV]
HR_H
10000
1000
100
10
0.1
1
10
100
1000
Scatter
0.4
0.2
0.0
-0.2
-0.4
1.5 Box
-1.5 Box
75%
50%
25%
0
20
40
60
80
Number

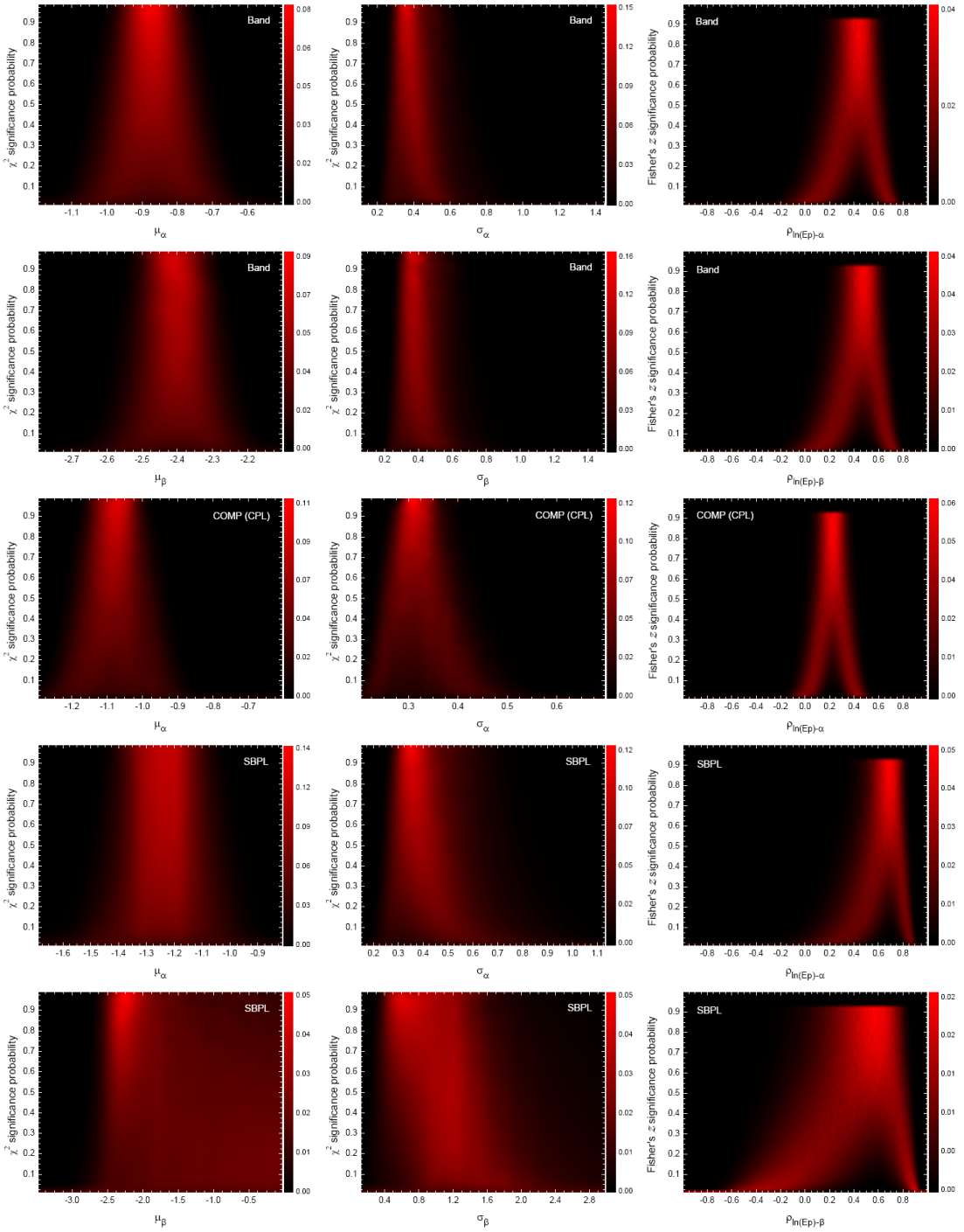
Parameter estimation based on
Bayes Theorem and Markov Chain Monte Carlo techniques.

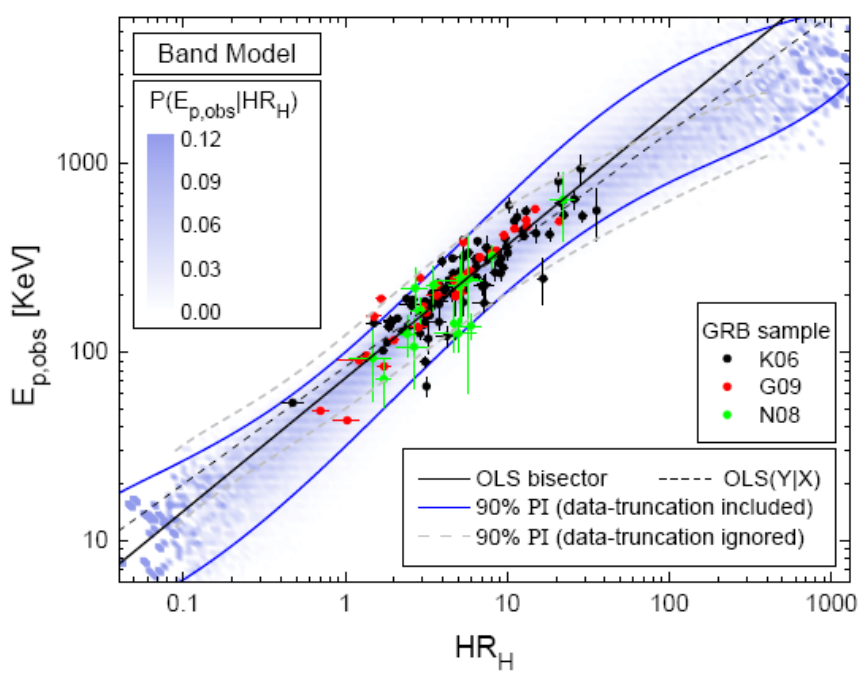


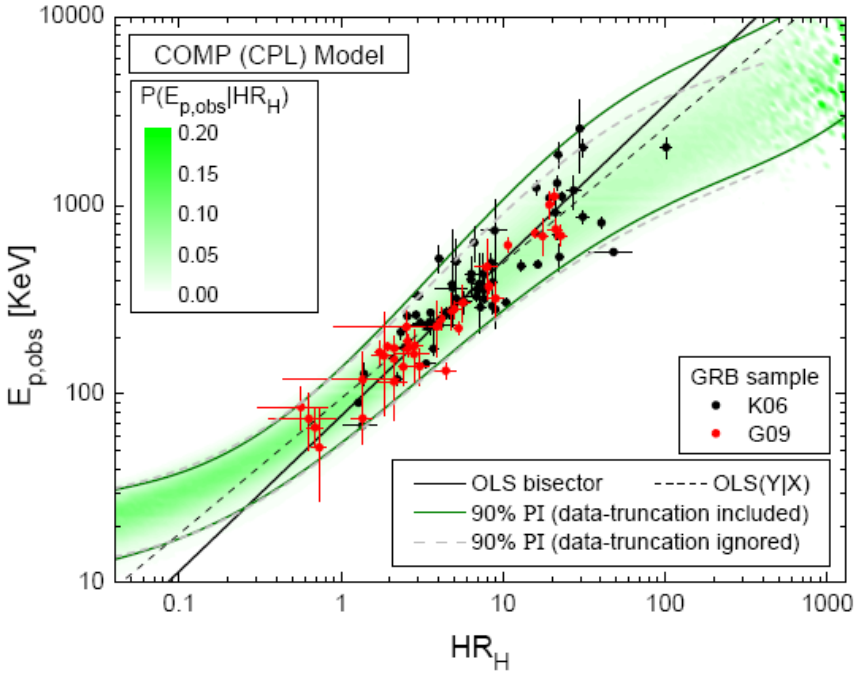
Posterior distributions of the parameters of the truncated multivariate normal distributions considered for the spectral parameters of the 3 GRB models: Band, COMP(CPL) & SBPL
Shahmoradi & Nemiroff, MNRAS (2010)

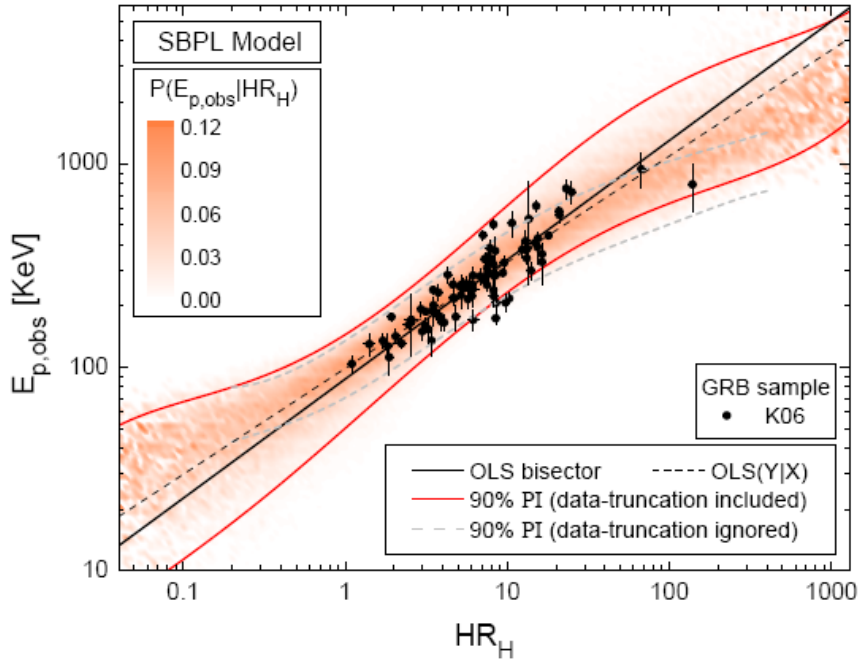
Parameter estimation based on Minimum χ2 & Mimimum Kolmogorov-Smirnov distance techniques.

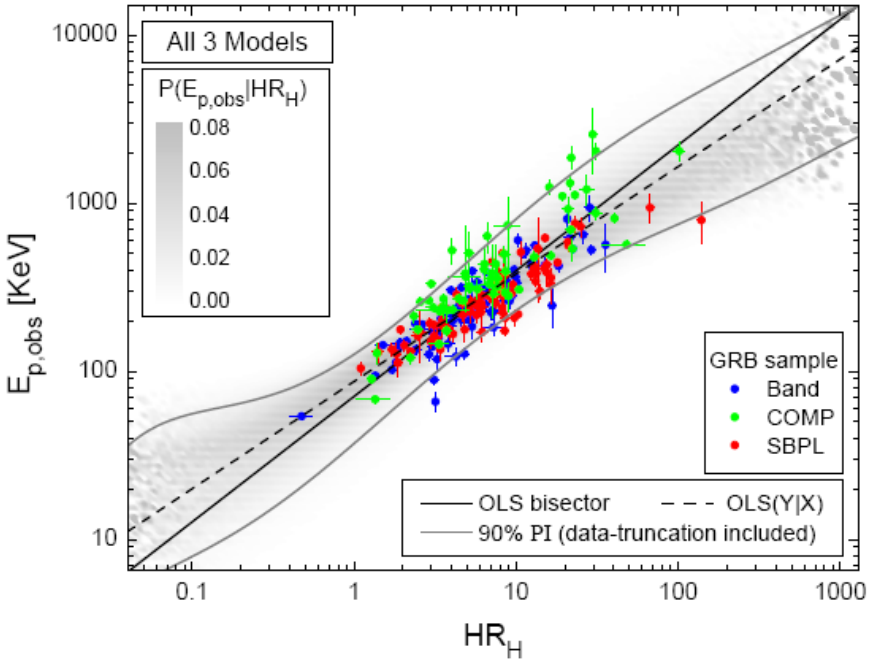
Marginalized likelihood contour plots of the observed data given different parameter values of the truncated multivariate normal distribution assumed for the spectral parameters of the three GRB models.
Shahmoradi & Nemiroff, MNRAS (2010)

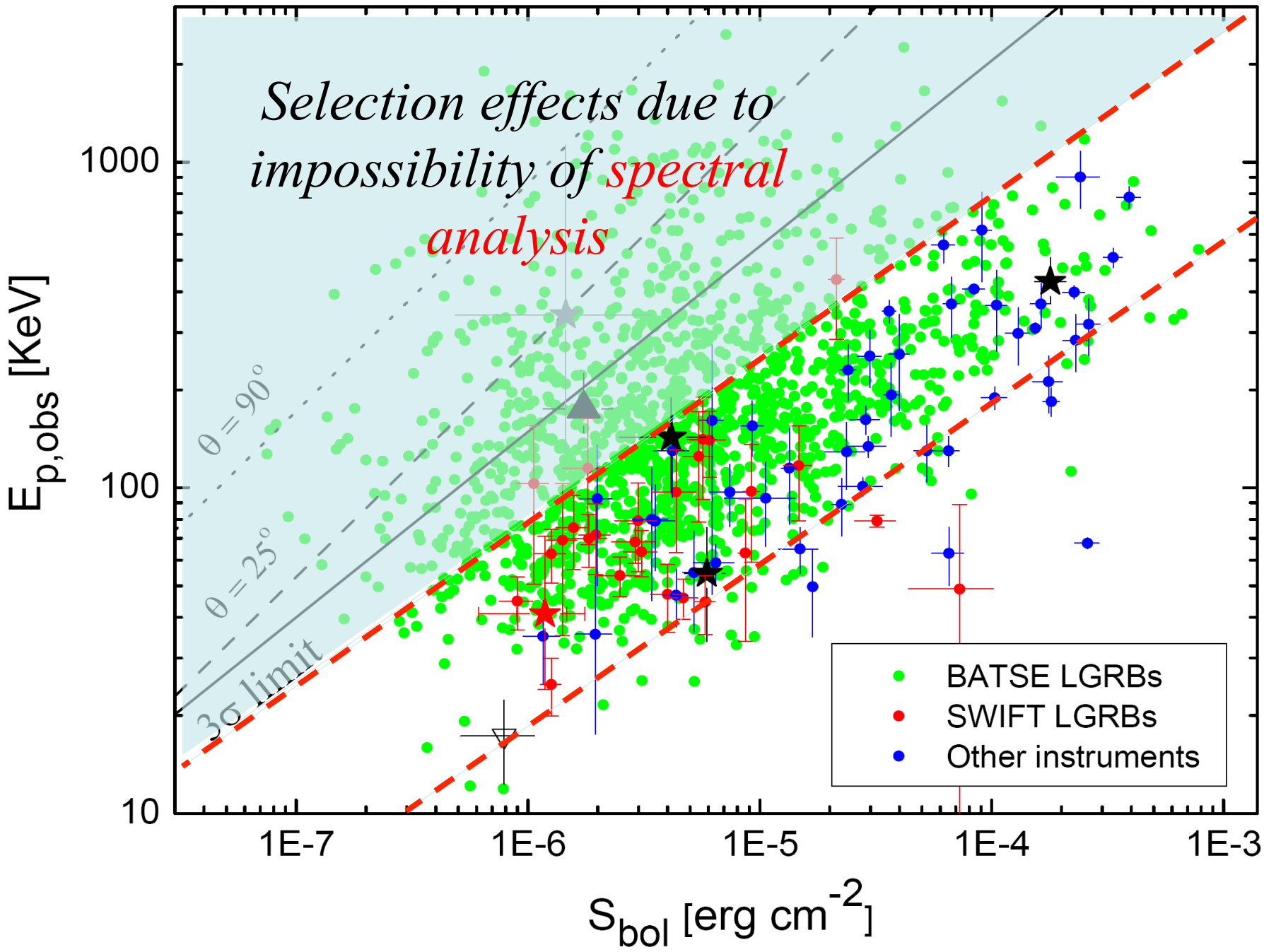



Band Model
P(E_p,obs|HR_H)
0.12
0.09
0.06
0.03
0.00
GRB sample
K06
G09
N08
OLS bisector
OLS(Y|X)
90% PI (data-truncation included)
90% PI (data-truncation ignored)
E_p,obs [KeV]
HR_H
10
100
1000
0.1
1
10
100
1000

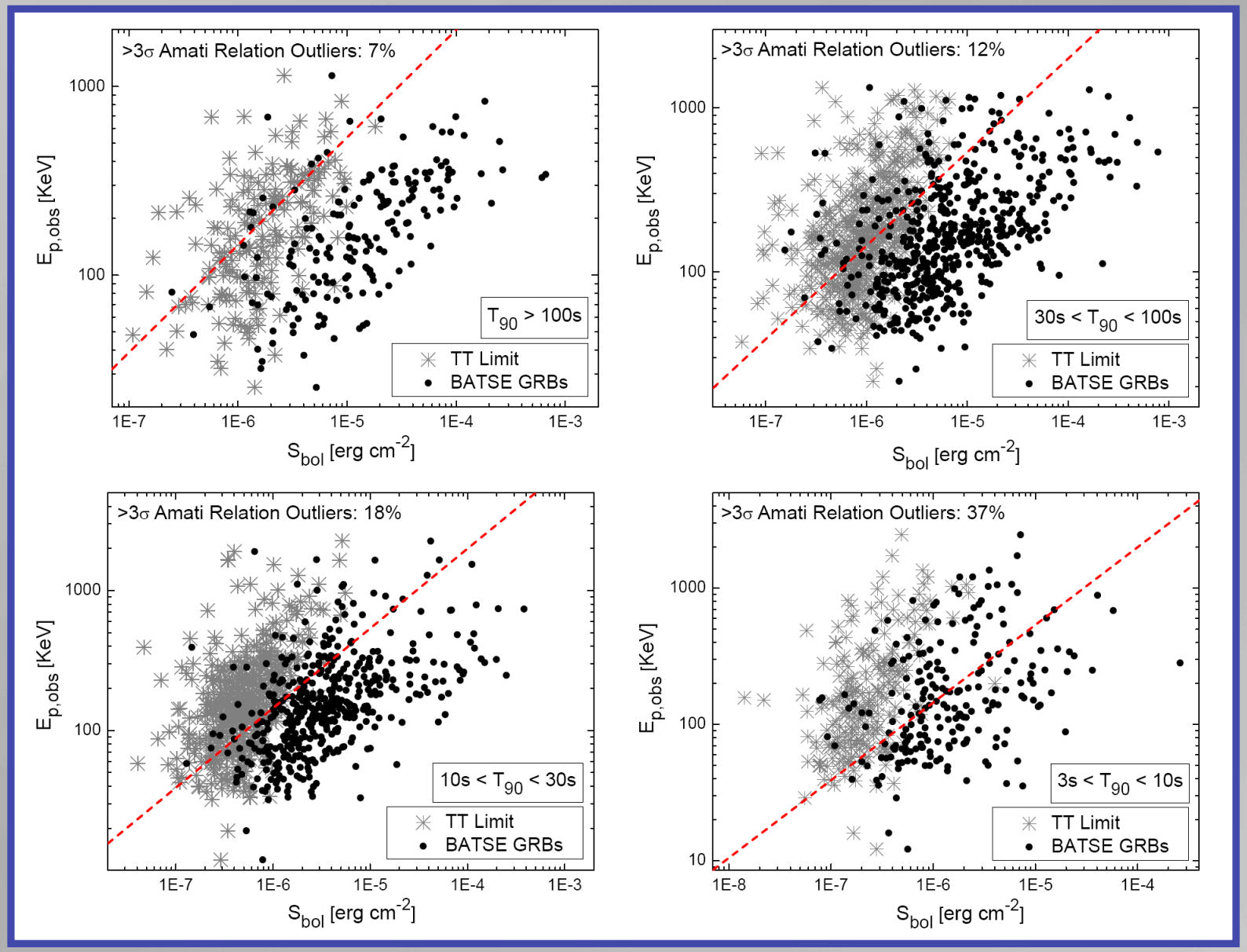

COMP (CPL) Model
P(E_p,obs|HR_H)
0.20
0.15
0.10
0.05
0.00
GRB sample
K06
G09
OLS bisector
OLS(Y|X)
90% PI (data-truncation included)
90% PI (data-truncation ignored)
E_p,obs [KeV]
HR_H
10
100
1000
10000
0.1
1
10
100
1000

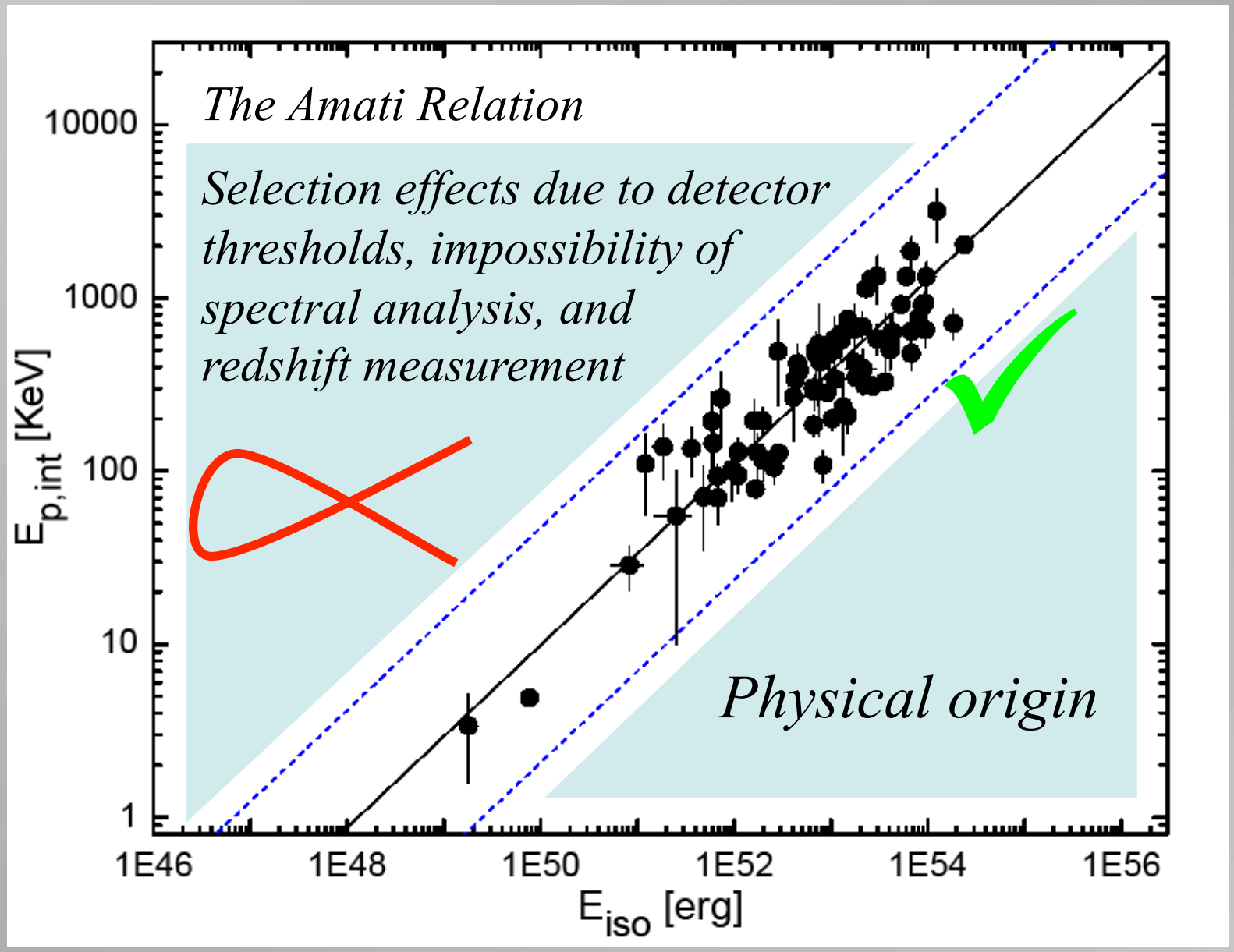

SBPL Model
P(E_p,obs|HR_H)
0.12
0.09
0.06
0.03
0.00
GRB sample
K06
OLS bisector
OLS(Y|X)
90% PI (data-truncation included)
90% PI (data-truncation ignored)
E_p,obs [KeV]
HR_H
10
100
1000
0.1
1
10
100
1000


All 3 Models
P(E_p,obs|HR_H)
0.08
0.06
0.04
0.02
0.00
GRB sample
Band
COMP
SBPL
OLS bisector
OLS(Y|X)
90% PI (data-truncation included)
E_p,obs [KeV]
HR_H
10
100
1000
10000
0.1
1
10
100
1000


Selection effects due to impossibility of spectral analysis
θ = 90°
θ = 25°
3σ limit
BATSE LGRBs
SWIFT LGRBs
Other instruments
1000
100
10
1E-7
1E-6
1E-5
1E-4
1E-3
E_p,obs [KeV]
S_bol [erg cm^-2]

*Selection Effects due to **GRB Detectors**?*





✓ *Shahmoradi & Nemiroff, 2009, MNRAS*

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.*

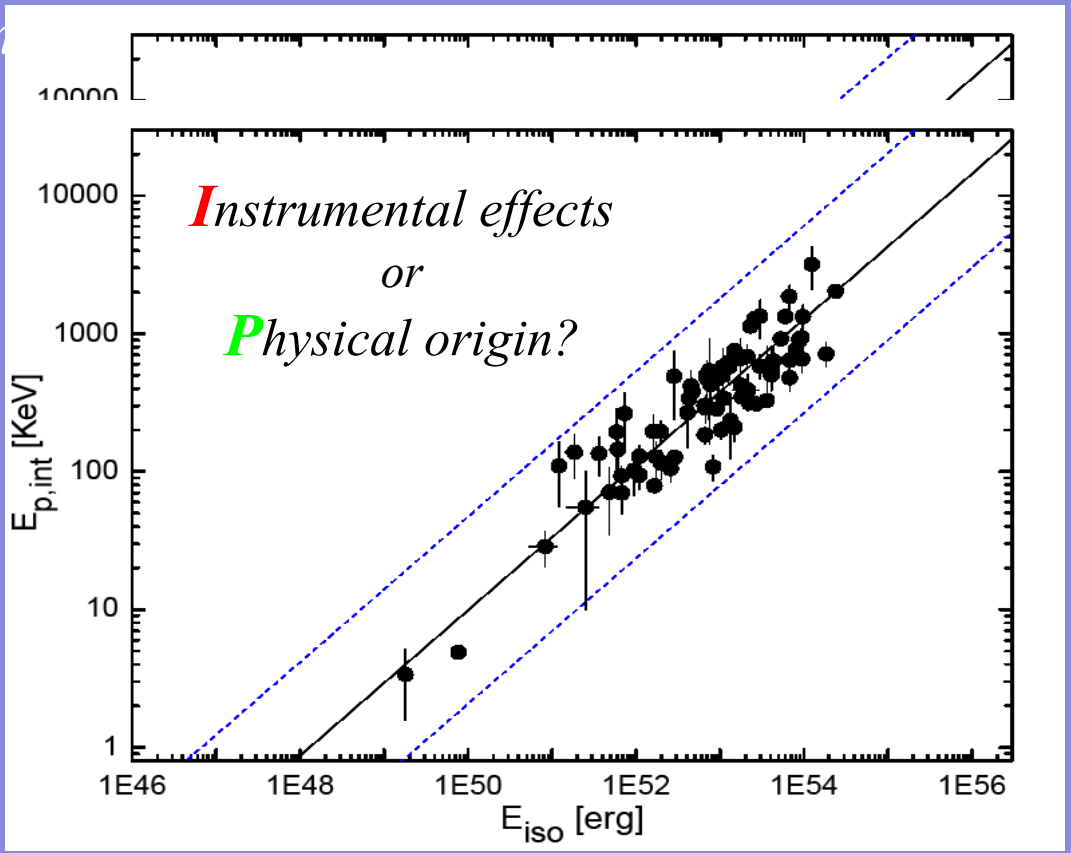
Further analysis coming soon…


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 stron*



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- ✓ *What are Gamma-Ray Bursts?*
  The most powerful events known in the universe, possibly related to the death of super-massive stars.
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- ✓ *Can GRBs serve as cosmological standard candles in the future?*
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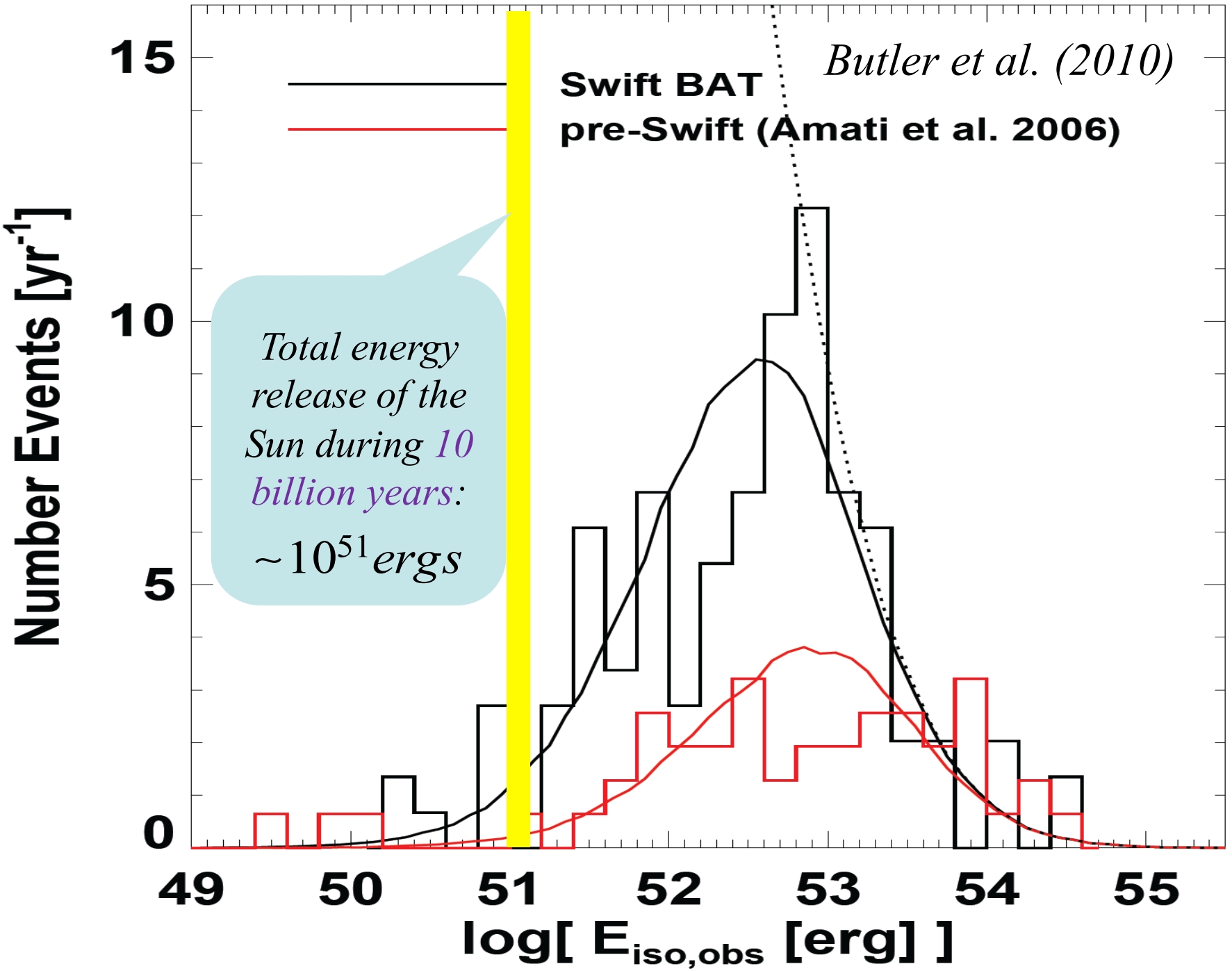
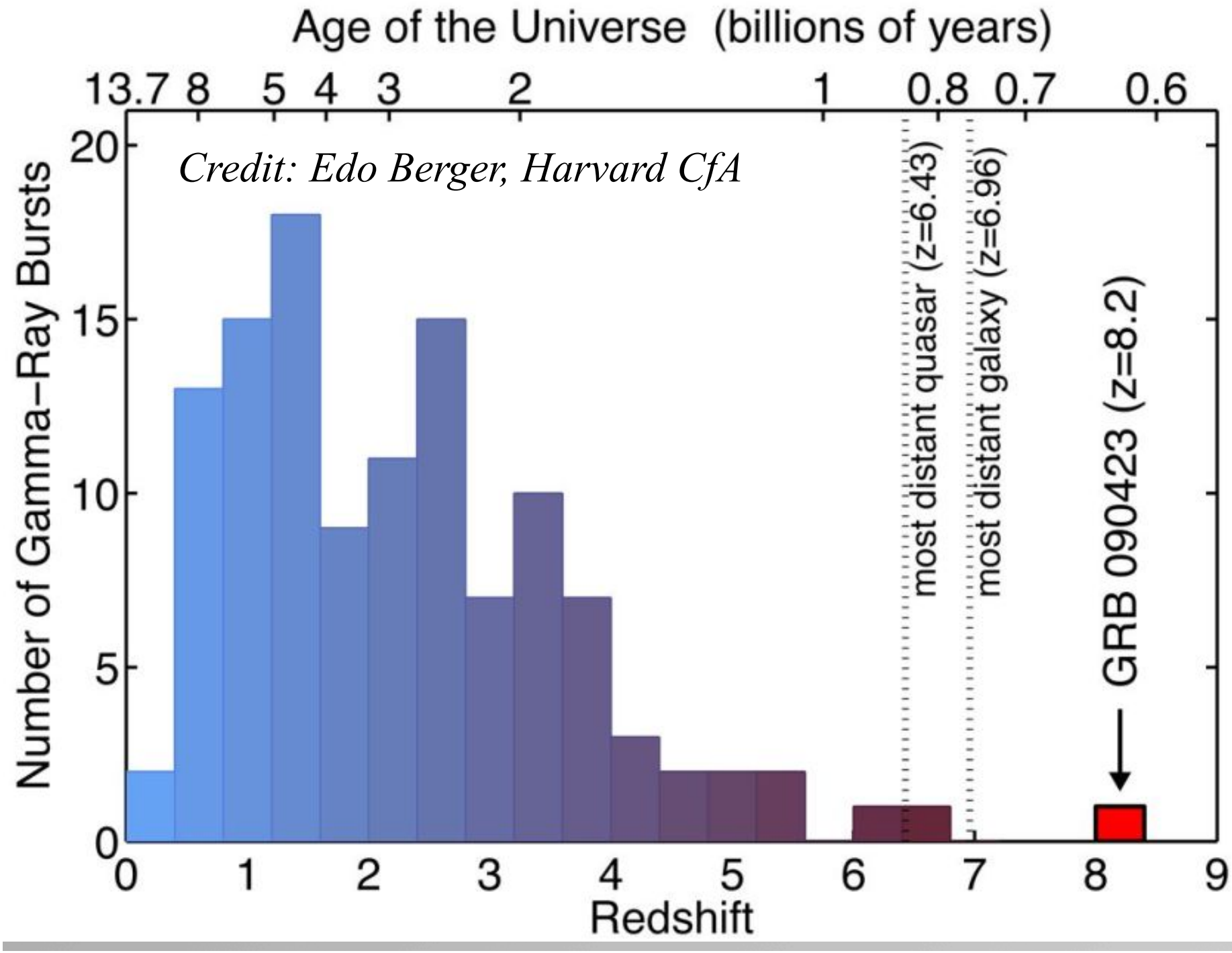
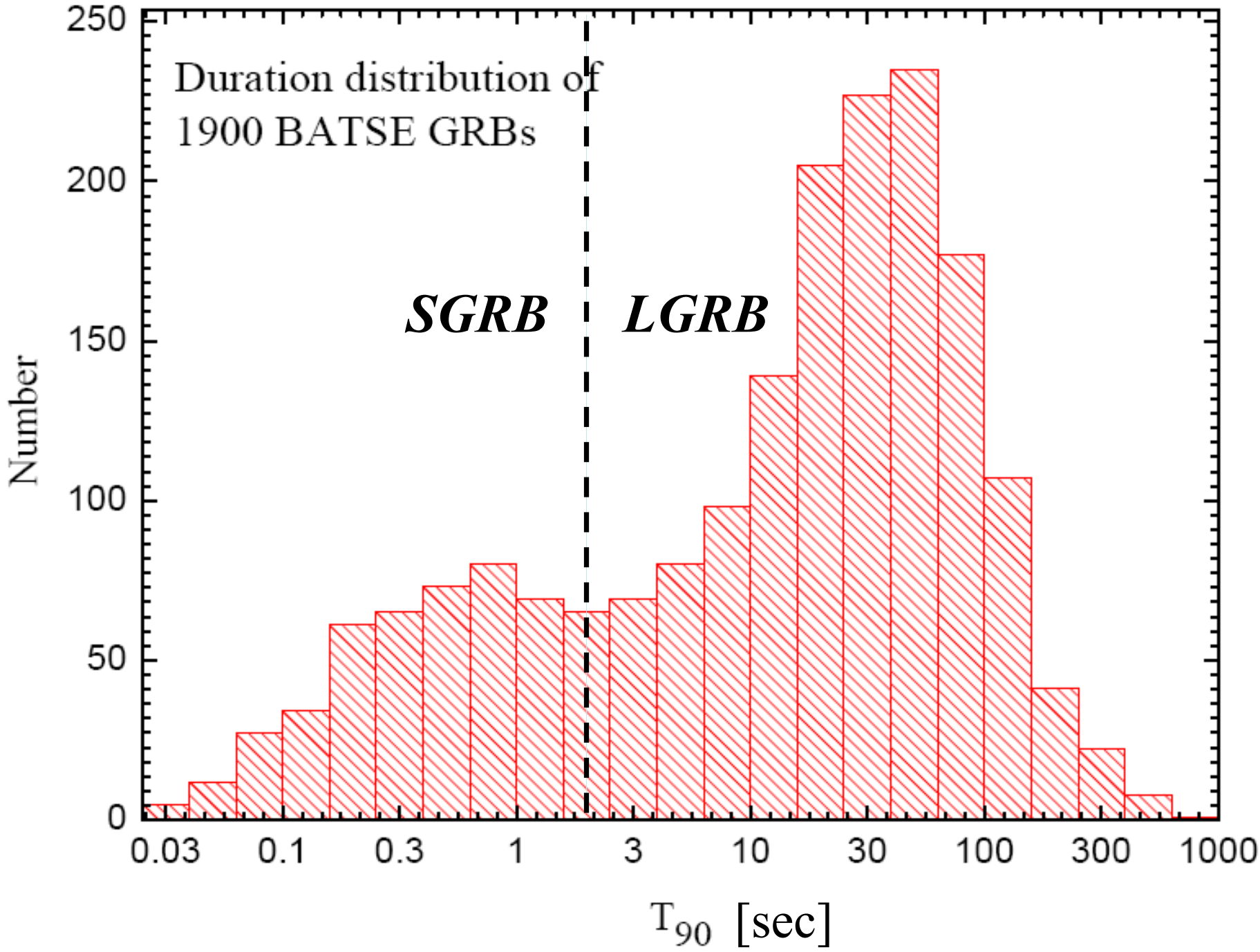
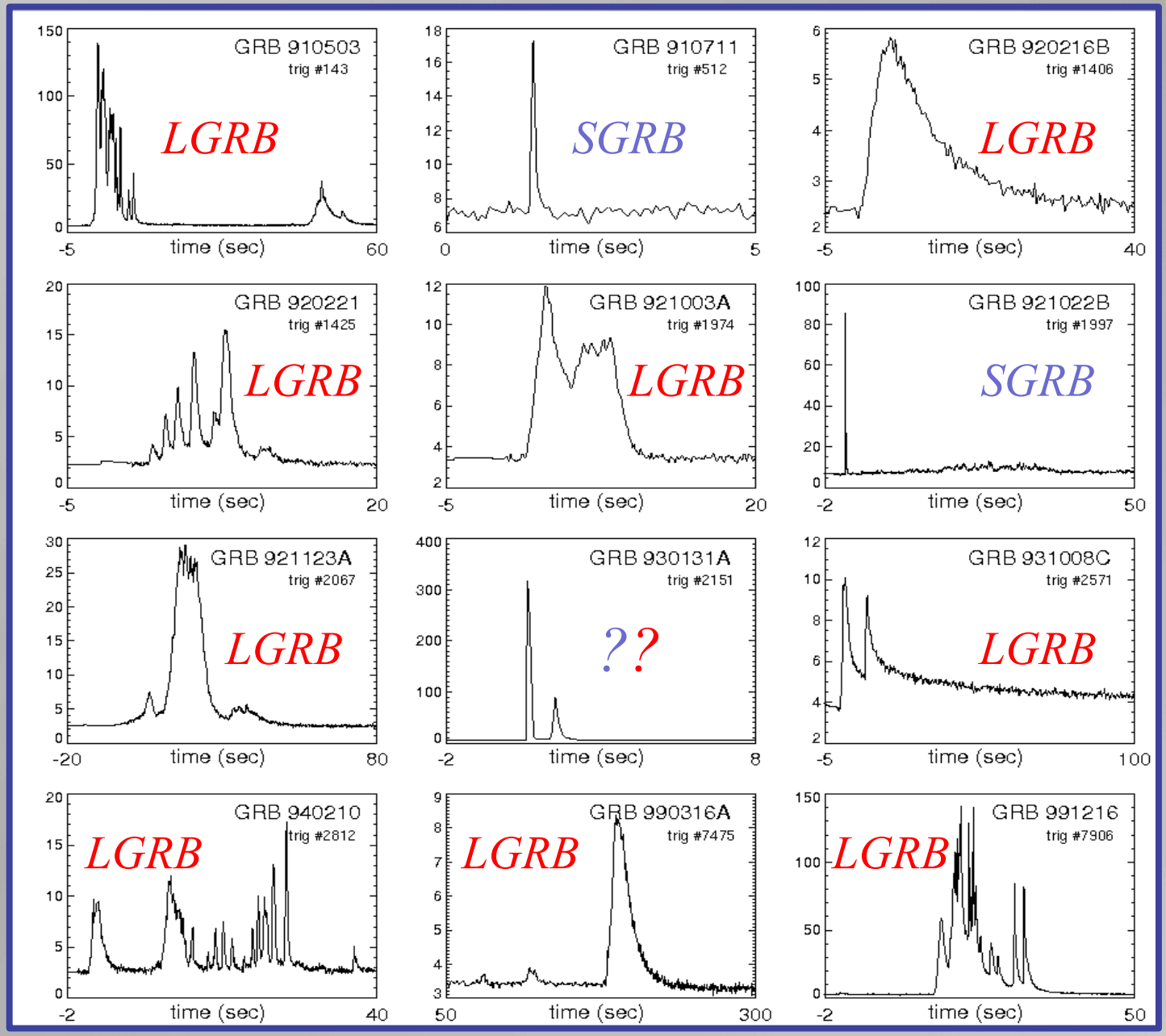
Further analysis coming soon …


Butler et al. (2010)
Swift BAT
pre-Swift (Amati et al. 2006)
Total energy release of the Sun during 10 billion years:
~10^51 ergs
Number Events [yr^-1]
15
10
5
0
49
50
51
52
53
54
55
log[E_iso,obs [erg]]


Age of the Universe (billions of years)
13.7
8
5
4
3
2
1
0.8
0.7
0.6
Credit: Edo Berger, Harvard CfA
Number of Gamma−Ray Bursts
0
5
10
15
20
most distant quasar (z=6.43)
most distant galaxy (z=6.96)
GRB 090423 (z=8.2)
0
1
2
3
4
5
6
7
8
9
Redshift


Duration distribution of
1900 BATSE GRBs
SGRB
LGRB
Number
250
200
150
100
50
0
0.03
0.1
0.3
1
3
10
30
100
300
1000
T90 [sec]

GRB light-curve diversity



Shahmoradi & Nemiroff , MNRAS (2009)