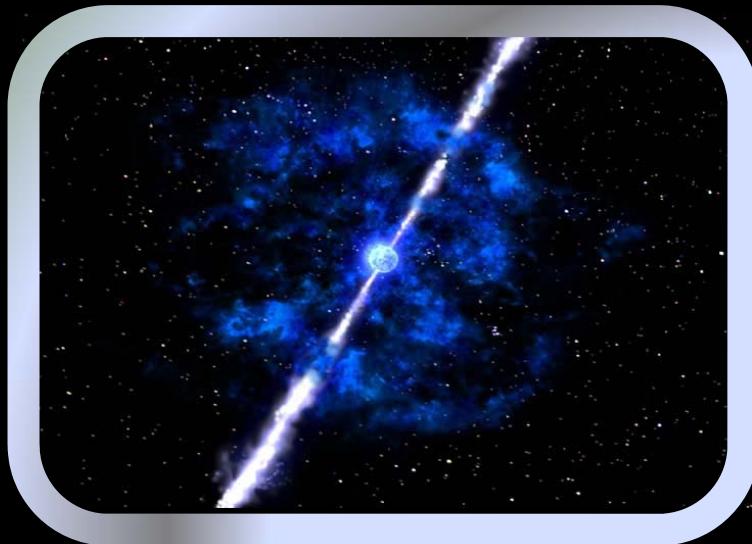


# *Gamma-Ray Bursts as Cosmological Tools*

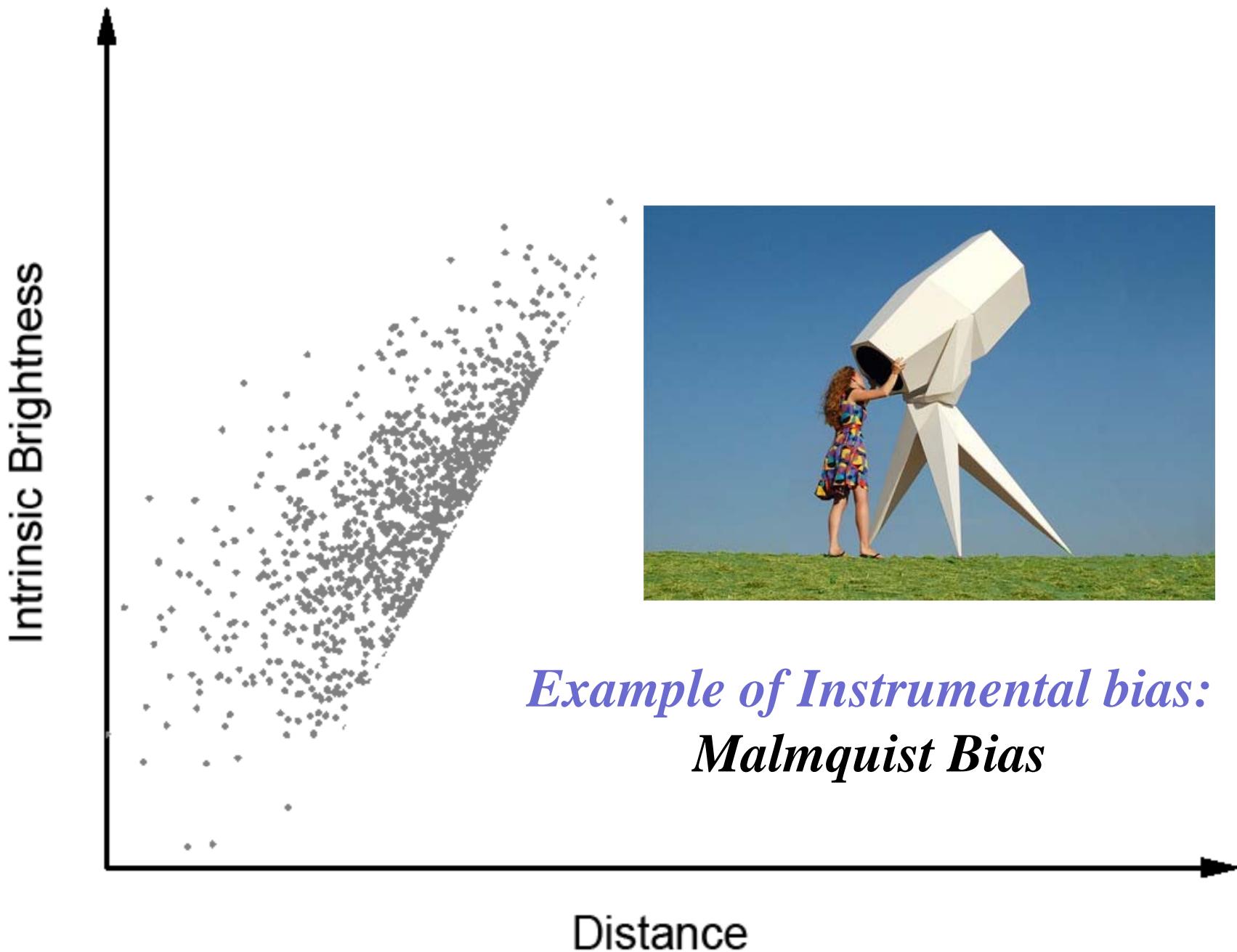


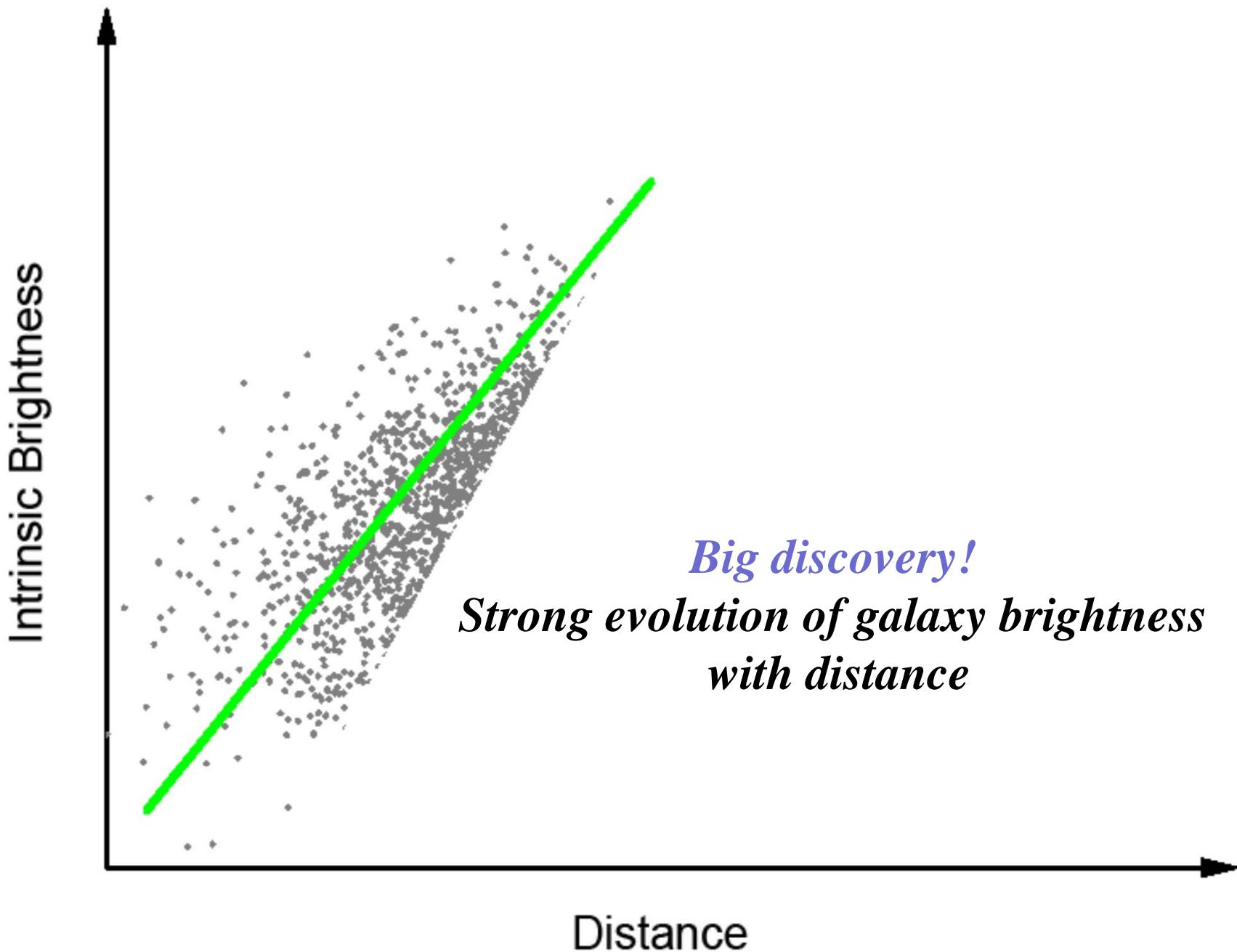
Amir Shahmoradi & Robert J. Nemiroff

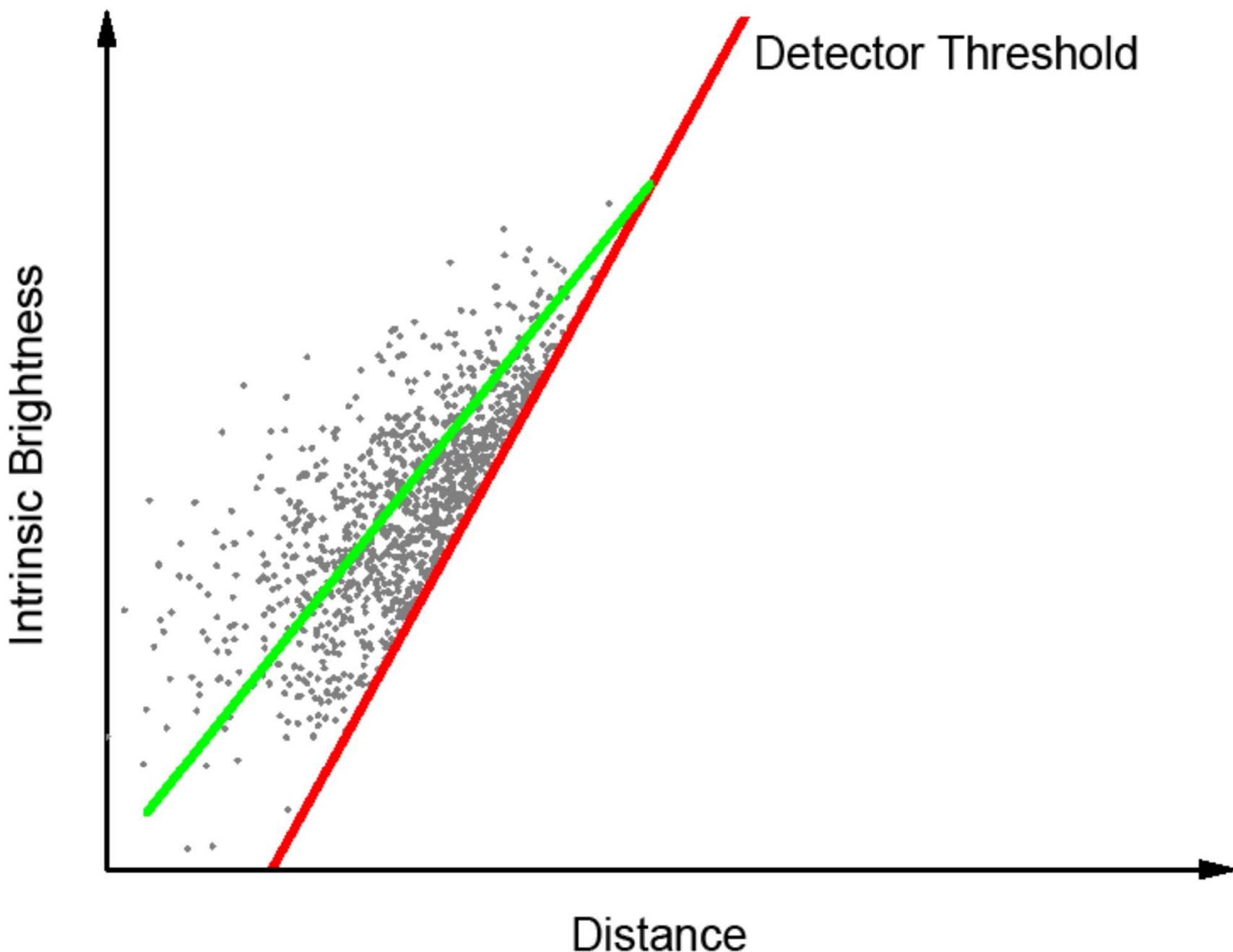
*Department of Physics, Michigan Tech University, Houghton, MI 49931*

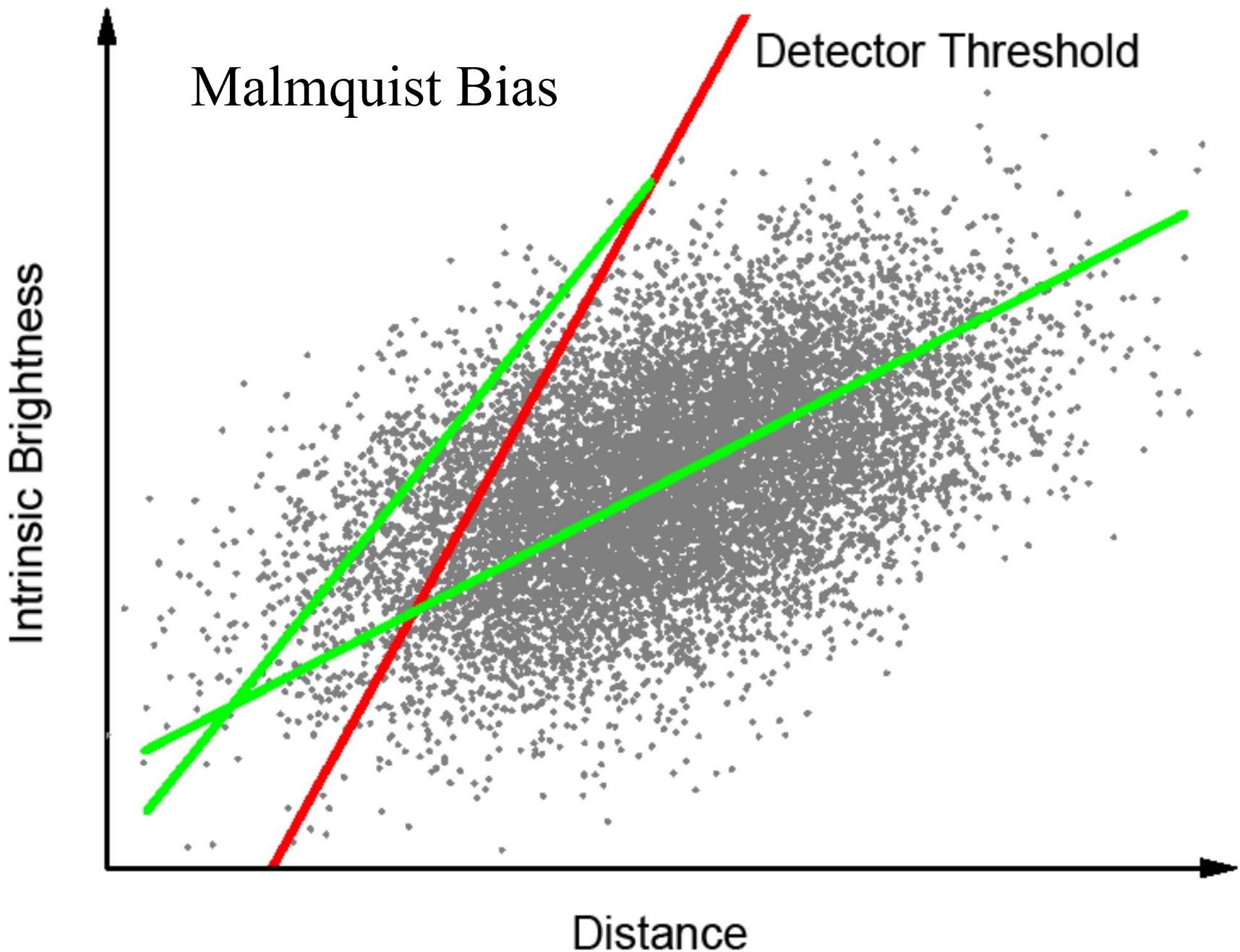
*10th Great Lakes Cosmology Workshop*

*June 14 - 16, 2010*









## *Constraining Dark Energy's equation of state*

✓ *Cosmological Standard Candle*

✓ *Constant Luminosity known*

✓ *Spectroscopic Redshift known*



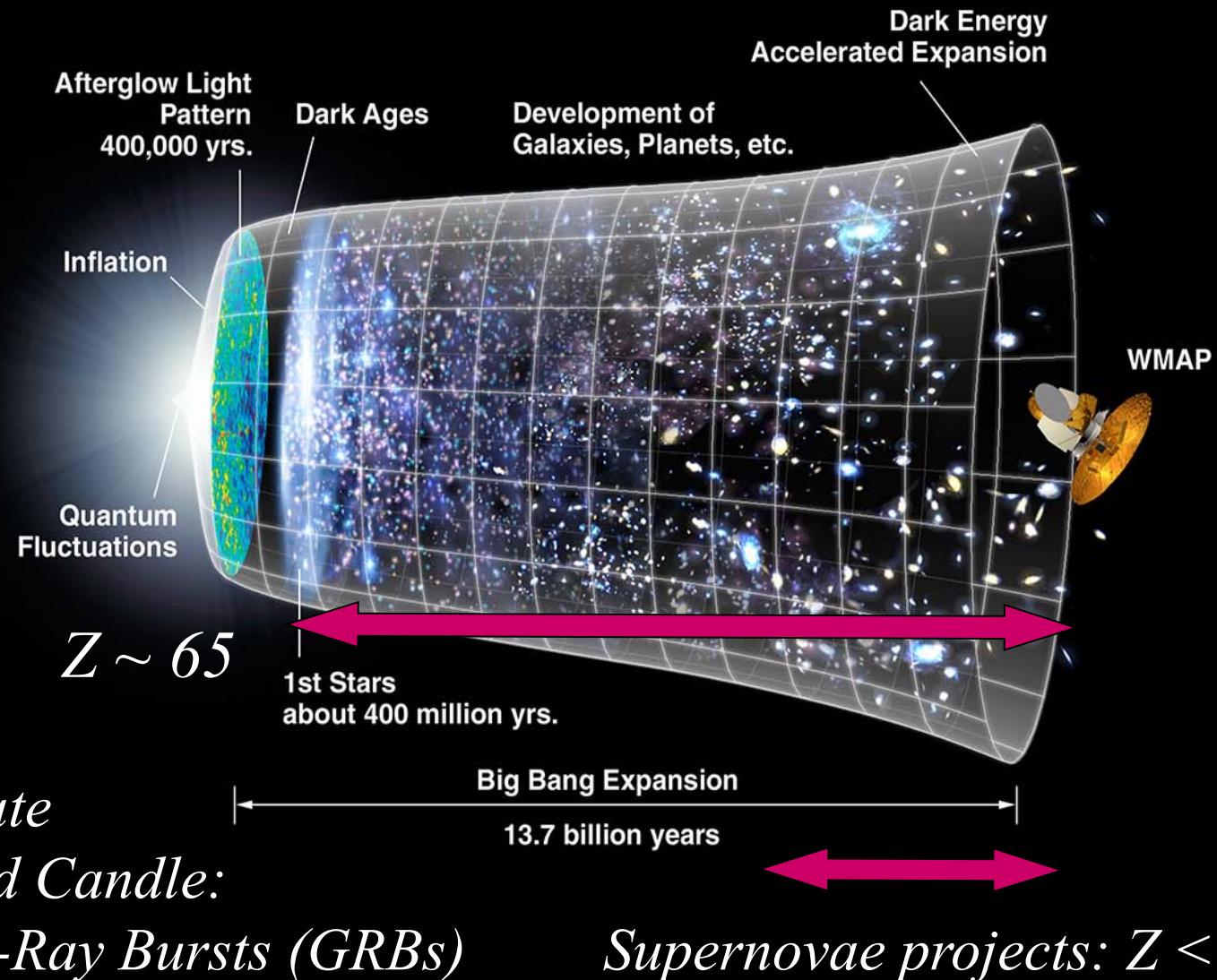
$$D_L = \sqrt{\frac{1}{4\pi} \frac{\text{Intrinsic Luminosity}}{\text{observed brightness}}}$$



*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?*



# *Outline*

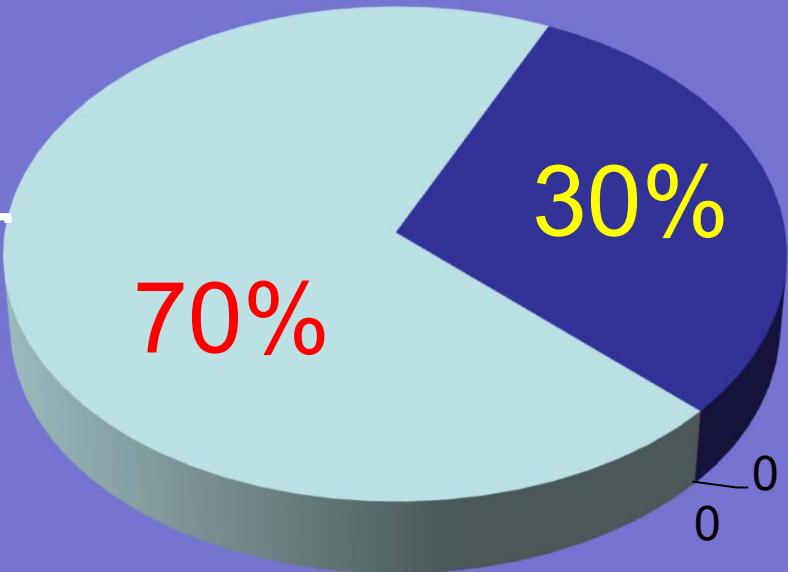
- ✓ *Gamma-Ray Burst (GRB) prompt emission*
- ✓ *GRBs as cosmological tools*
- ✓ *Problems with GRBs as cosmological tools*
- ✓ *The future of GRBs as standard candles*
  - *Shahmoradi & Nemiroff, The Possible Impact of GRB Detectors on Cosmological Standard Candles, MNRAS accepted, 2009, arXiv:0904.1464v1*
  - *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*

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

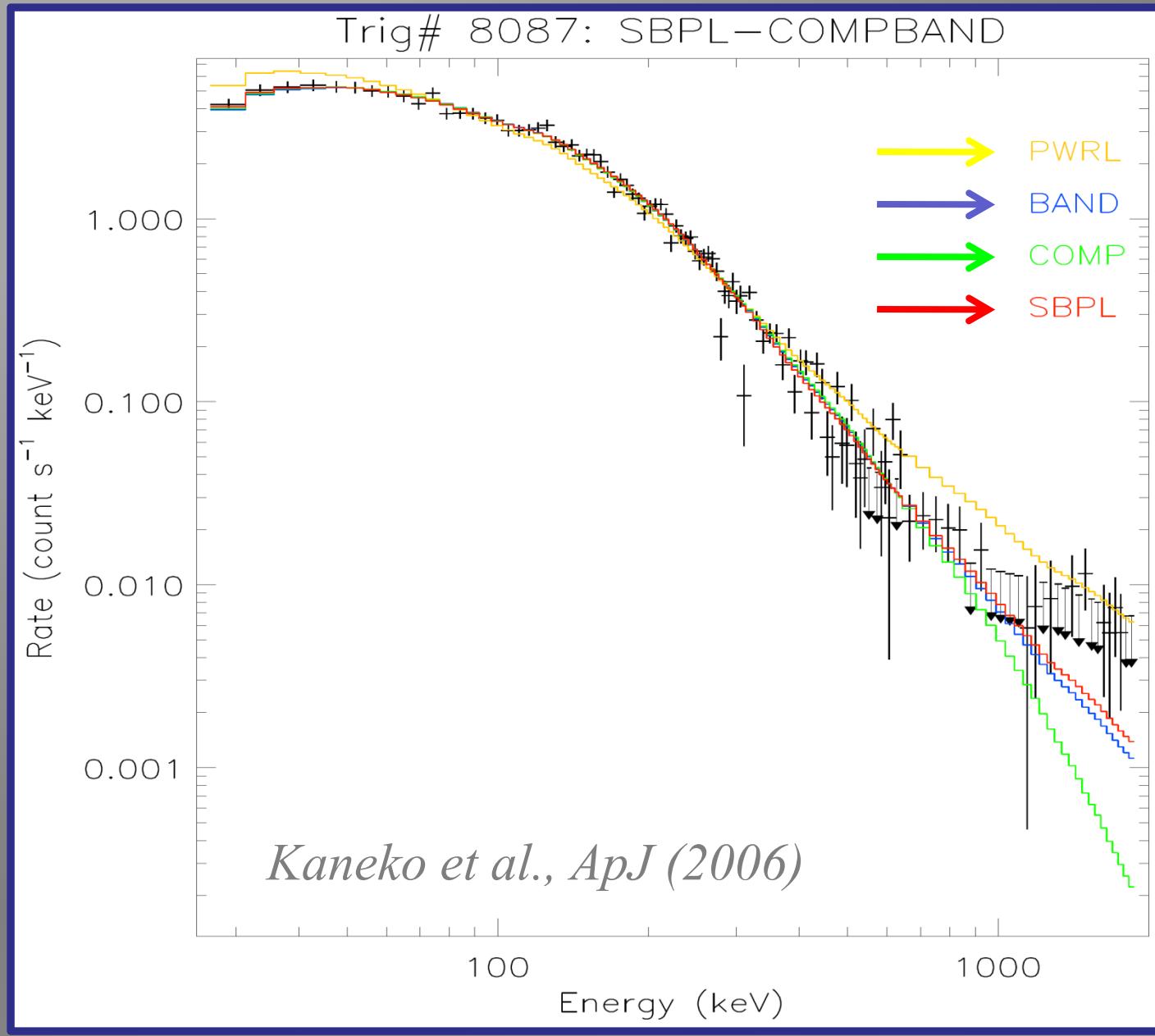
# *GRB types*



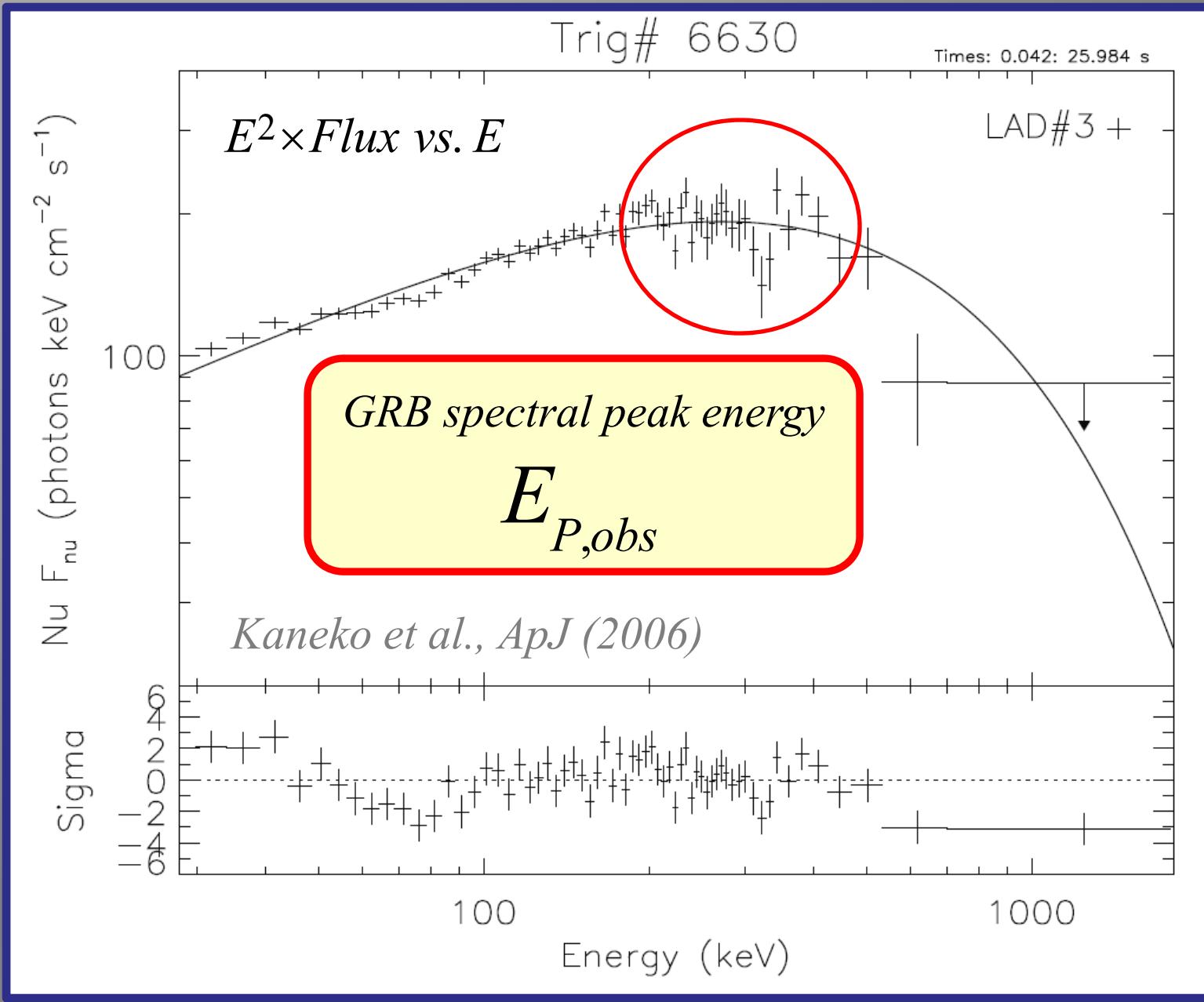
*Long-duration GRBs (LGRBs):  
possibly related to the death of supermassive stars*

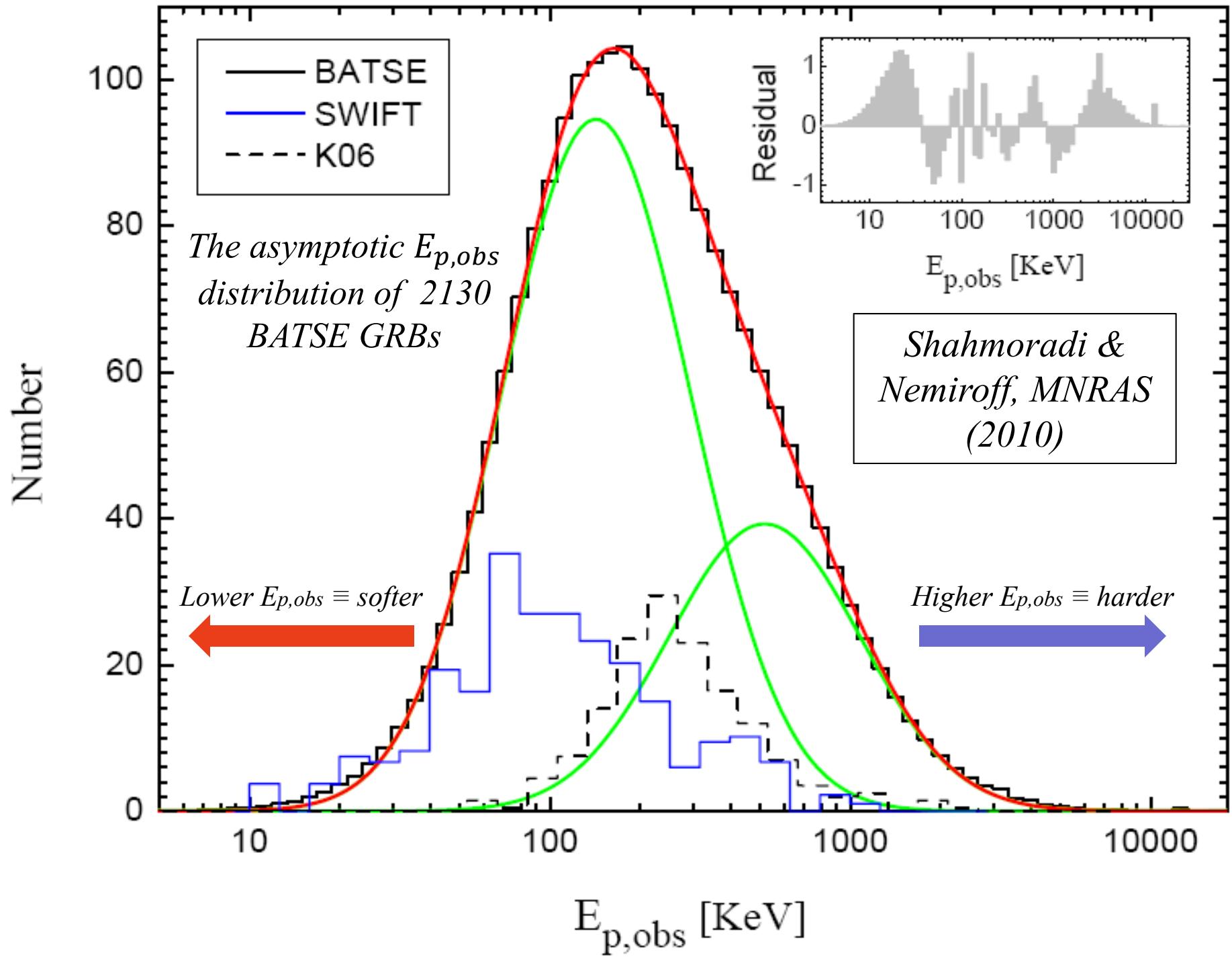
*Short-duration GRBs (SGRBs):  
possibly the merger of binary neutron stars*

# *Example of GRB Spectrum*

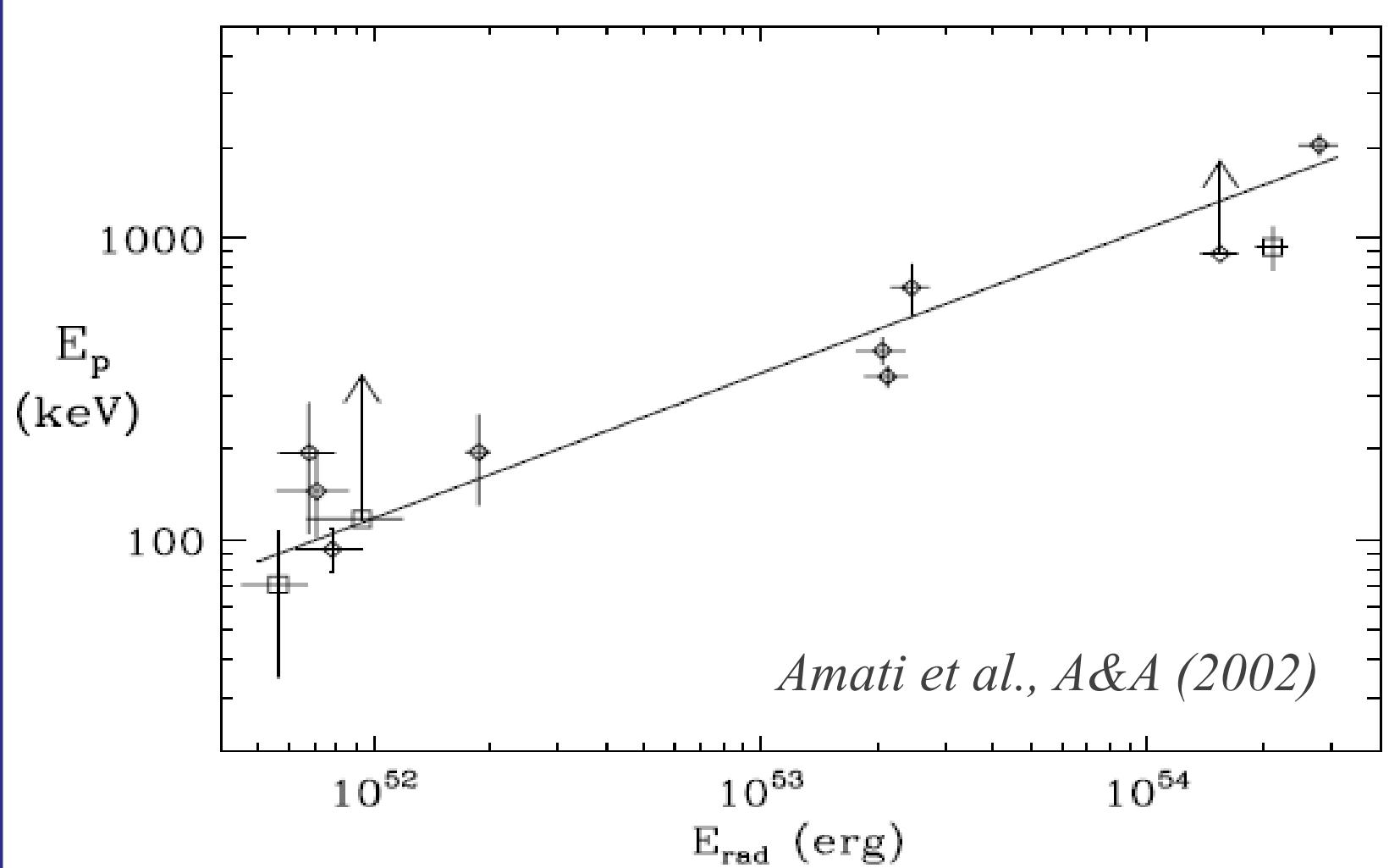


# *Example of GRB Power Spectrum*





# *The Amati relation*



10000

*The Amati Relation*

*GRBs as cosmological tools?!*

$3\sigma$

✓ *Cosmological Standard Candle*

✓ *Constant Luminosity known*

✓ *Spectroscopic Redshift known*



1E46

1E48

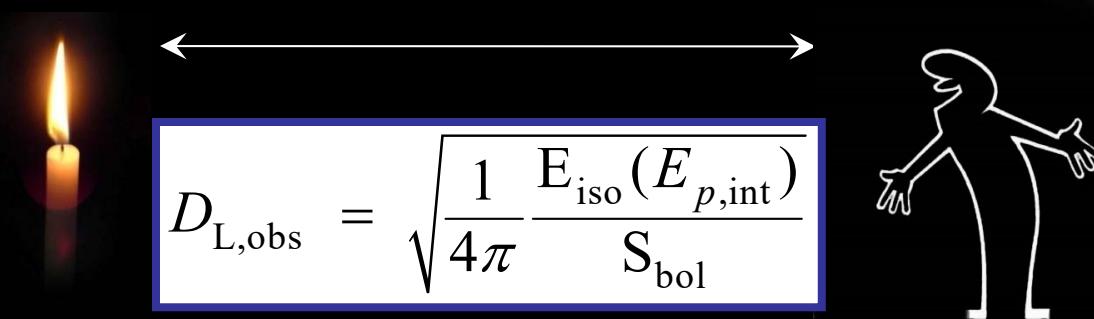
1E50

1E52

1E54

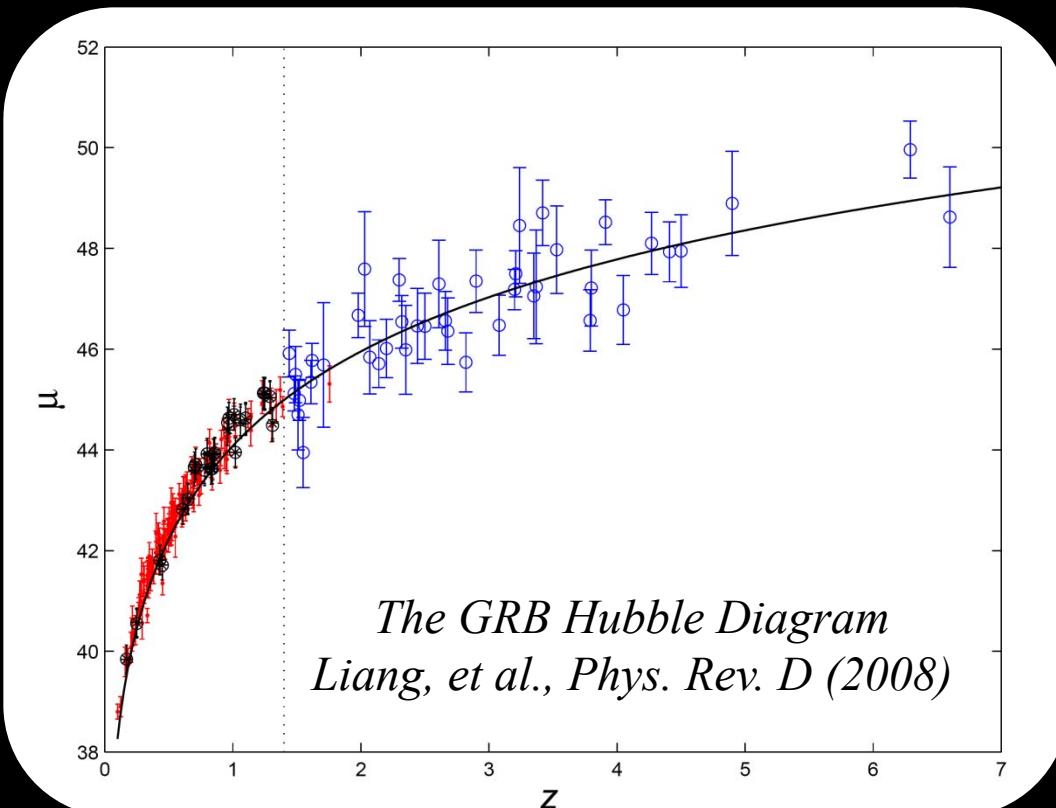
1E56

$E_{\text{iso}}$  [erg]



*Standard Candle*

*Observer*



10000

*The Amati Relation*

*GRBs as cosmological tools?!*

$3\sigma$

## *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.

1  
1E46

1E48

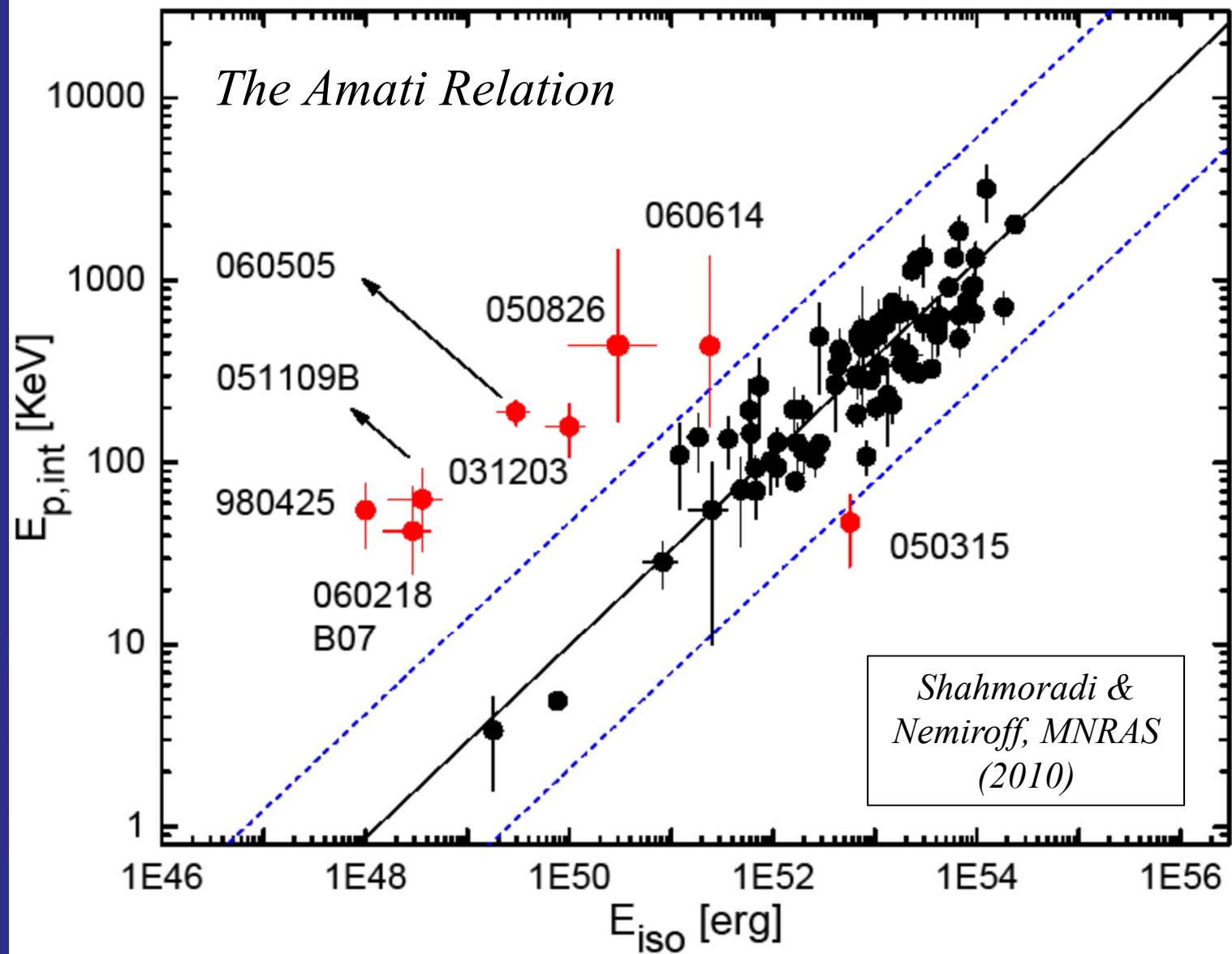
1E50

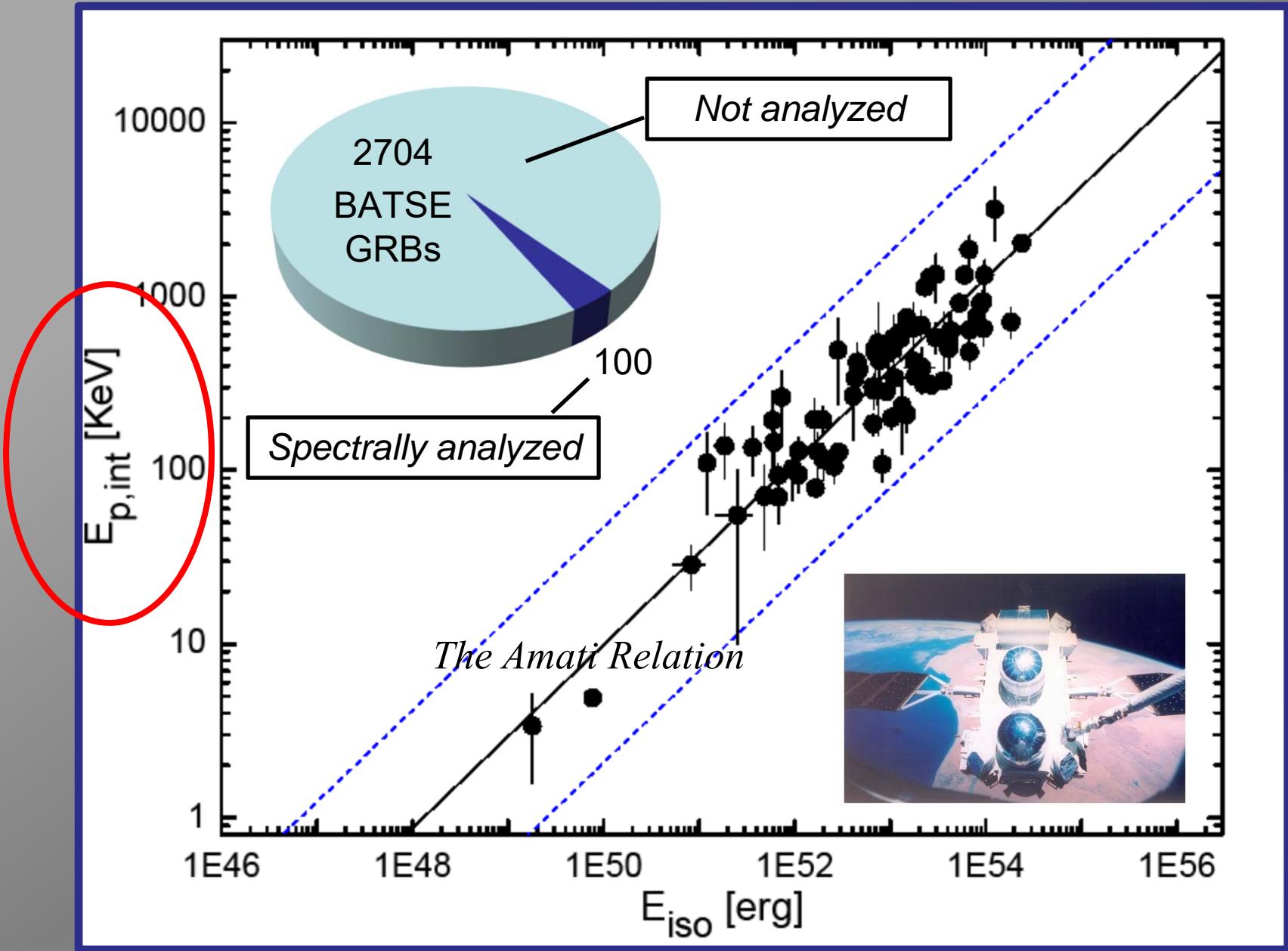
1E52

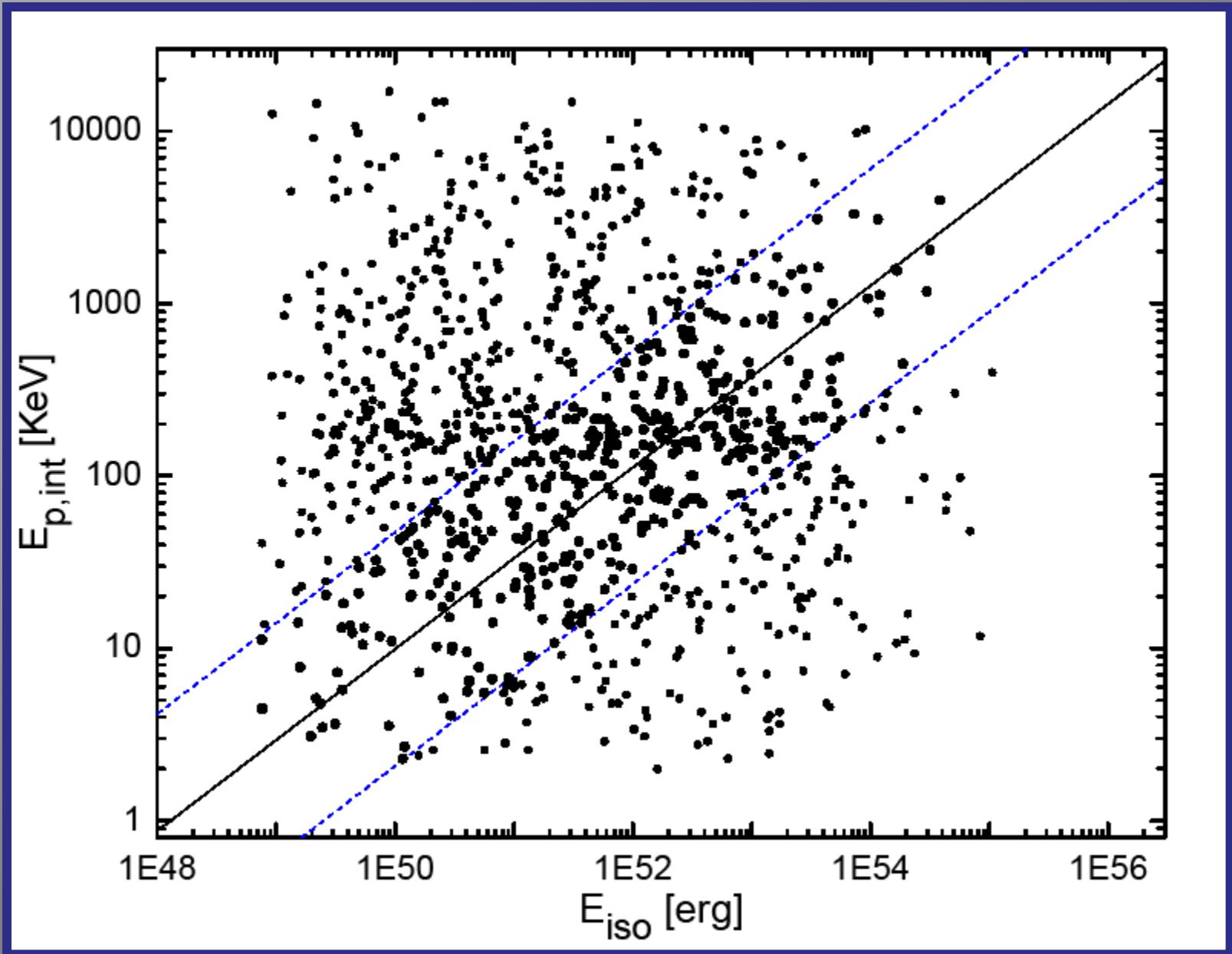
1E54

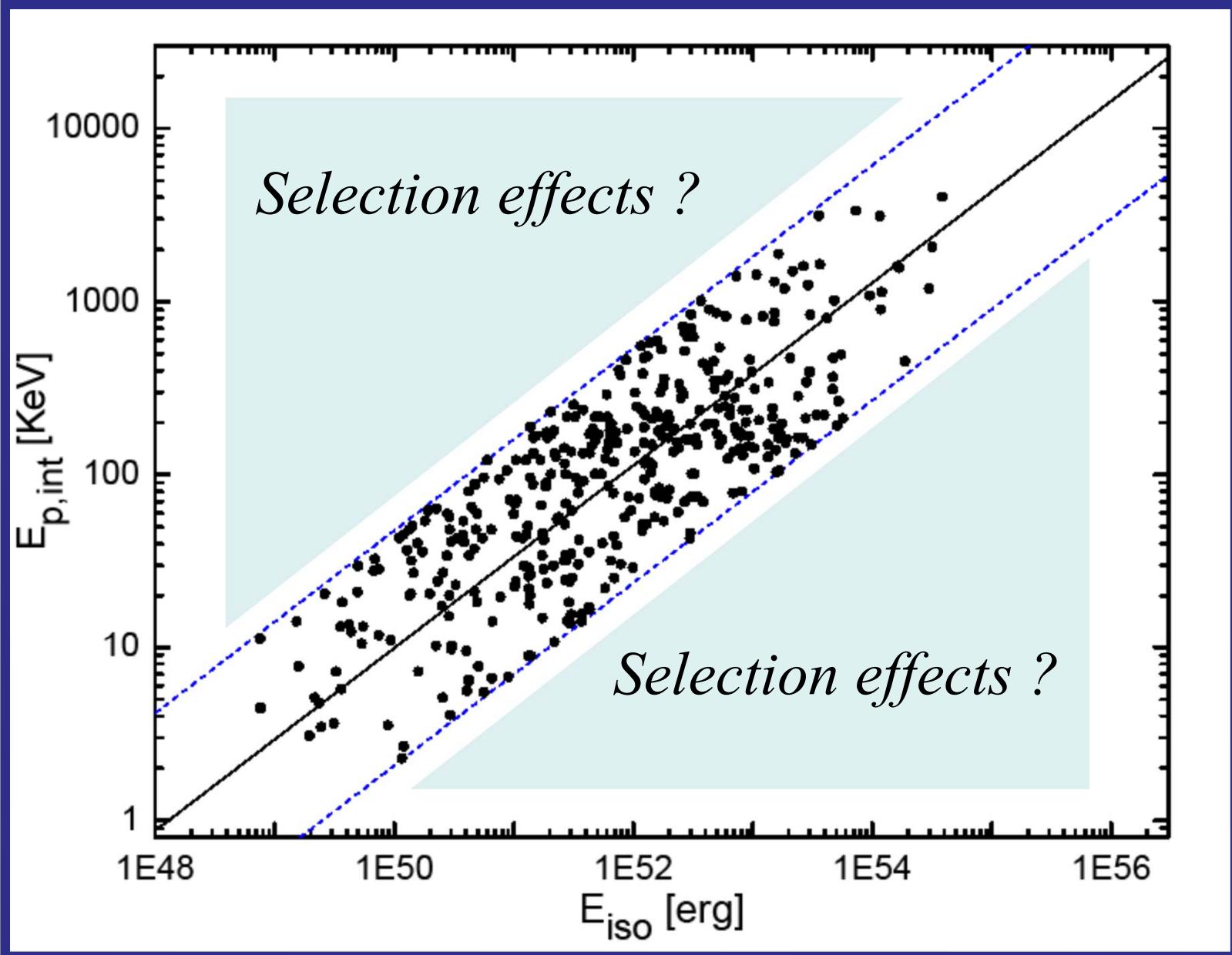
1E56

$E_{\text{iso}}$  [erg]

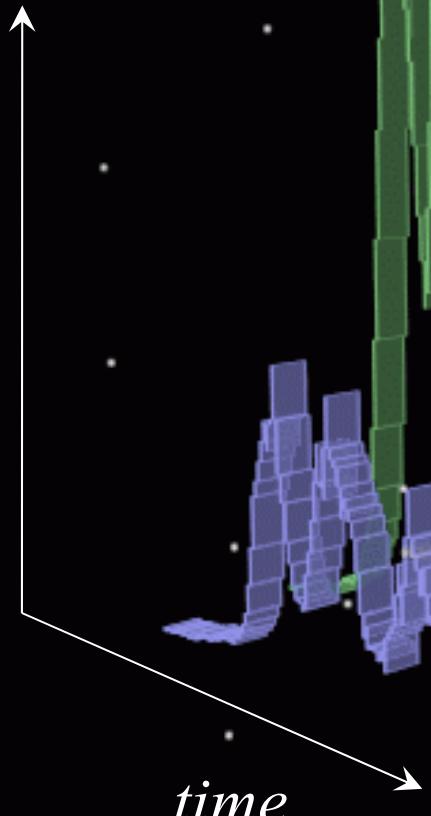








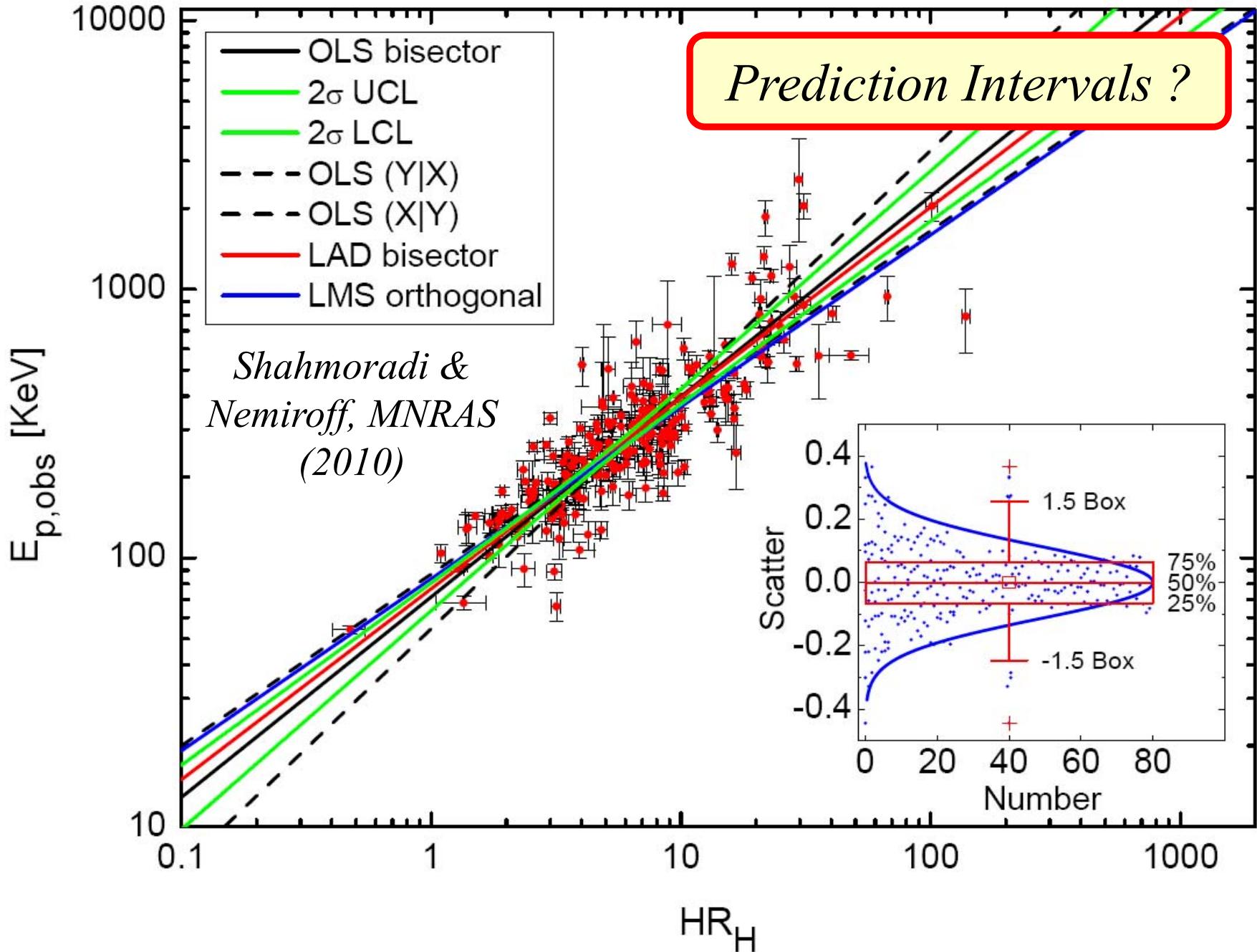
*Brightness (S)*



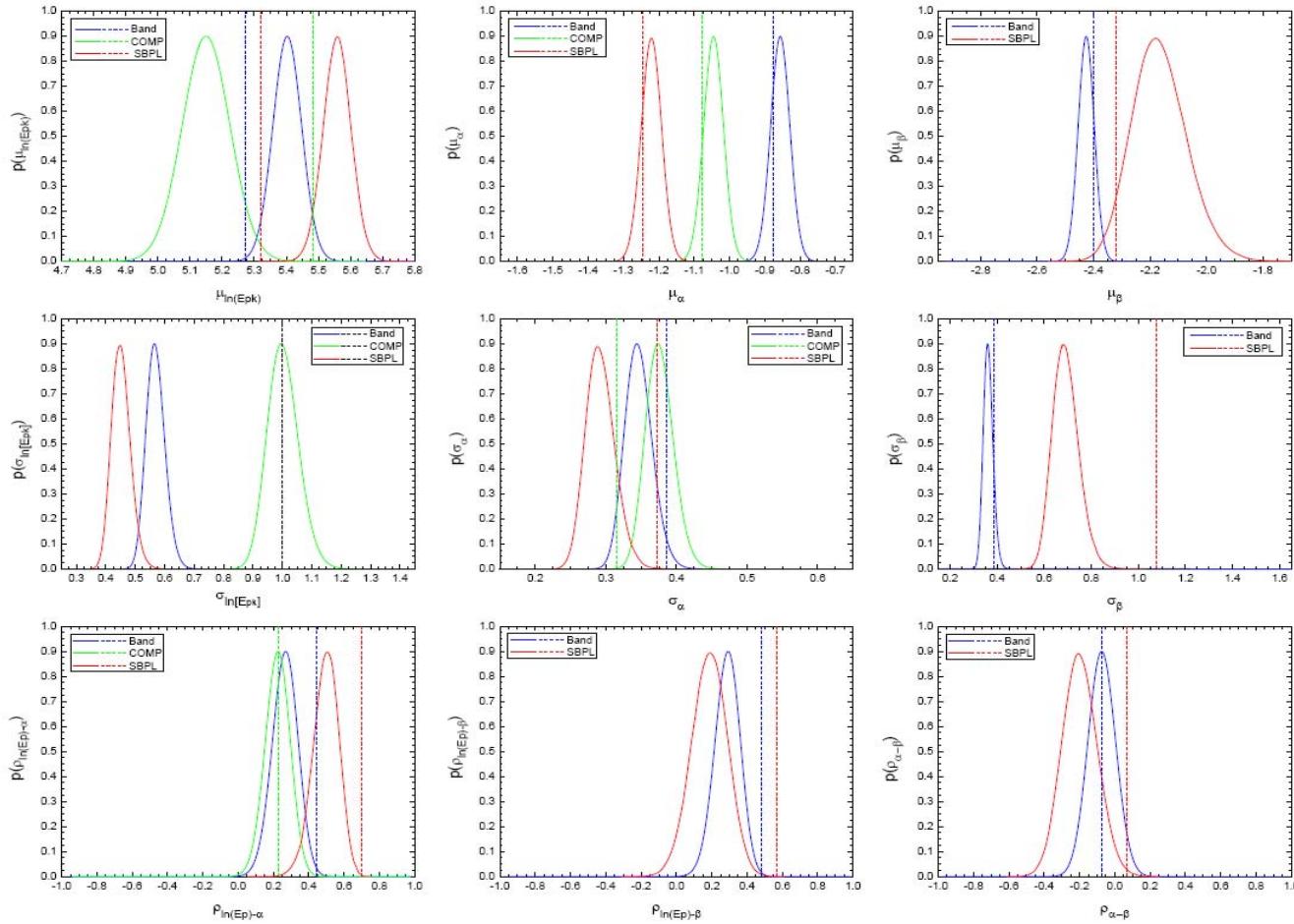
*Red*             $25 - 50 \text{ keV}$   
*Yellow*         $50 - 100 \text{ keV}$   
*Green*         $100 - 300 \text{ keV}$   
*Blue*             $> 300 \text{ keV}$

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

*Energy*



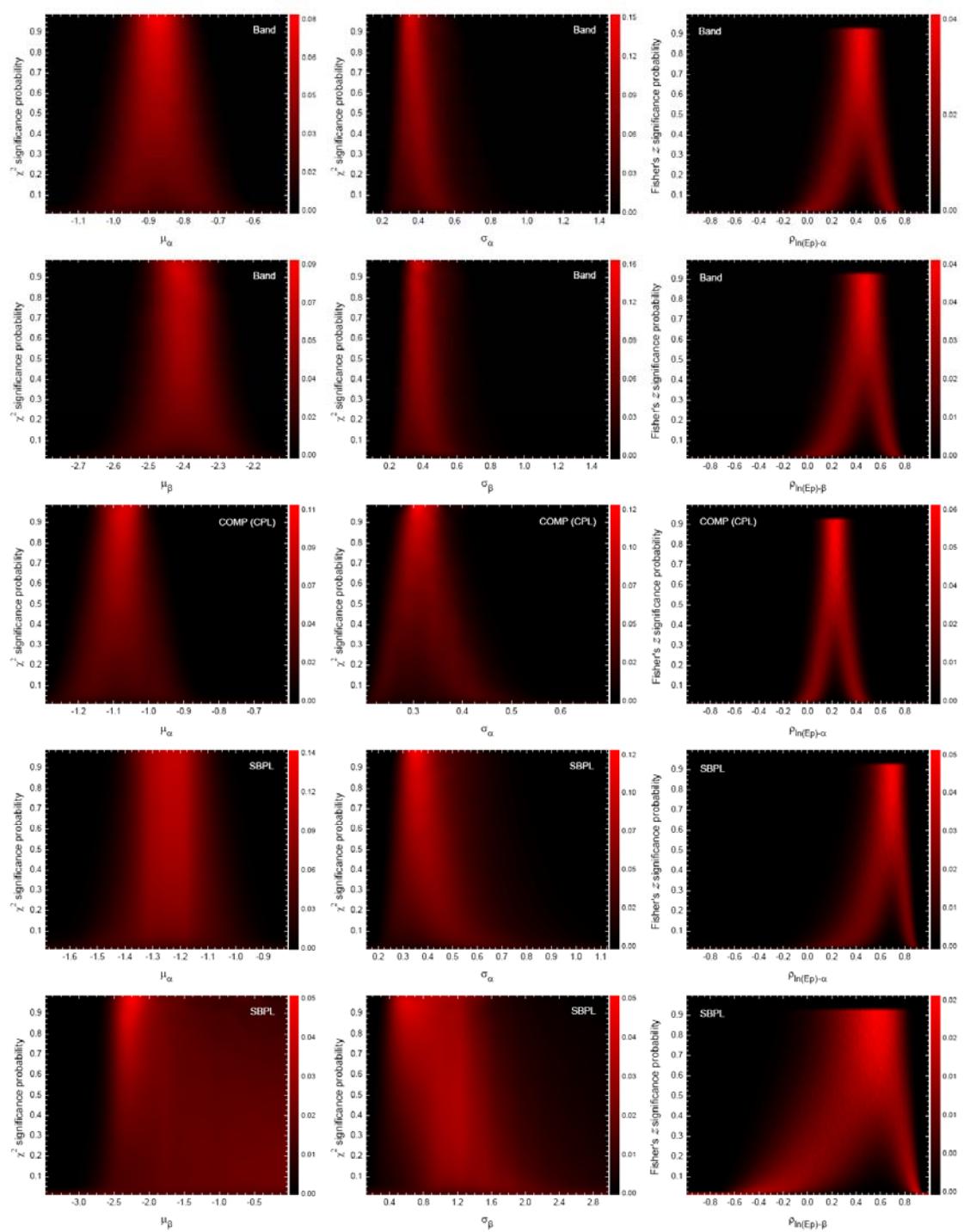
*Parameter estimation based on  
Bayes Theorem and Markov Chain Monte Carlo techniques.*

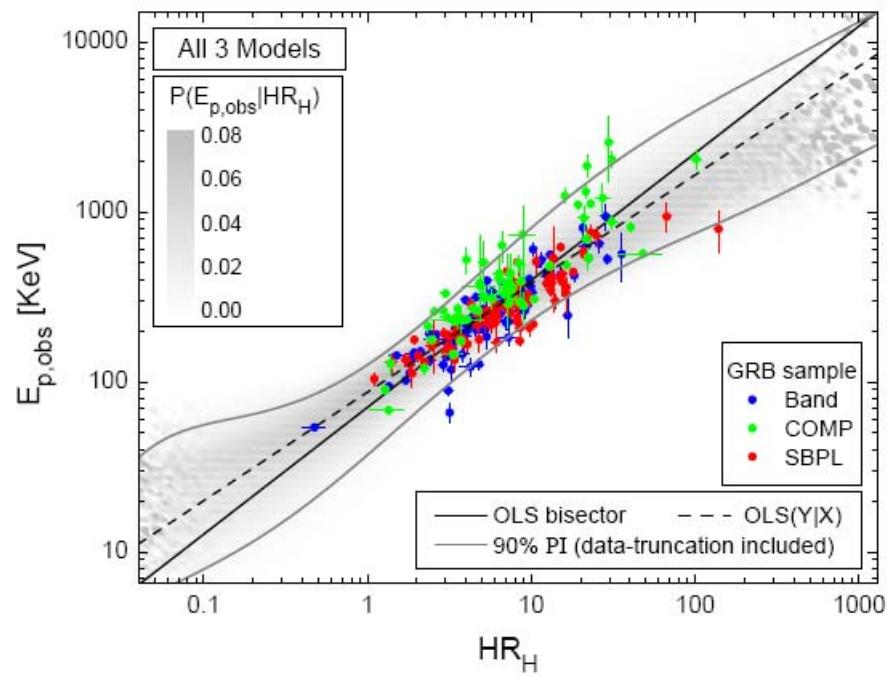
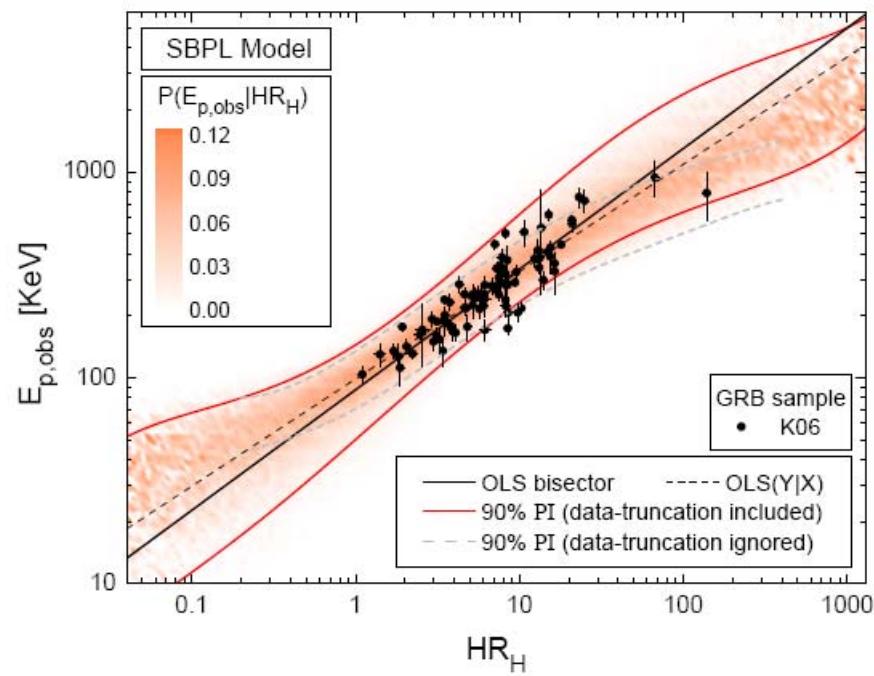
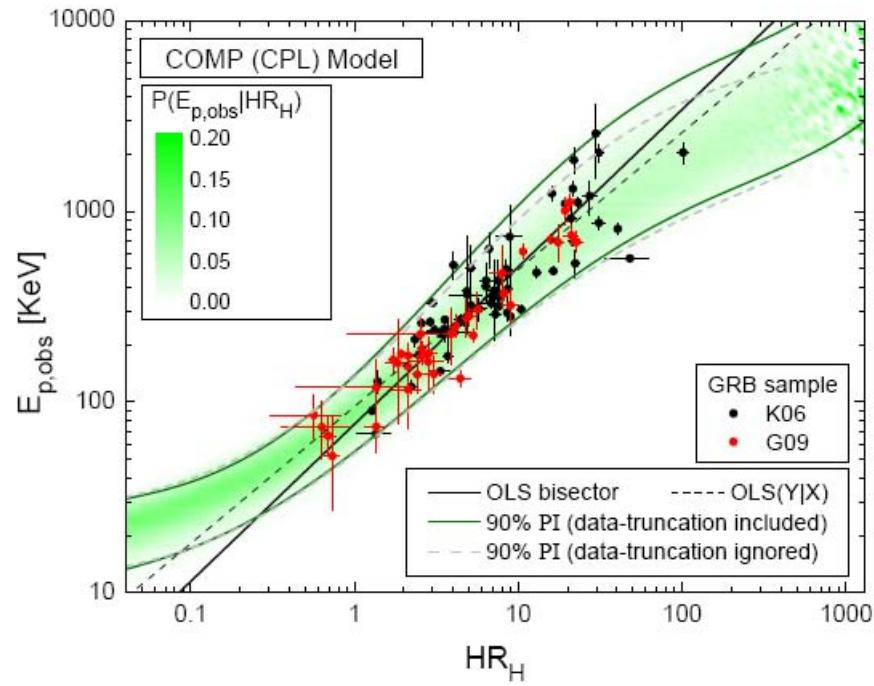
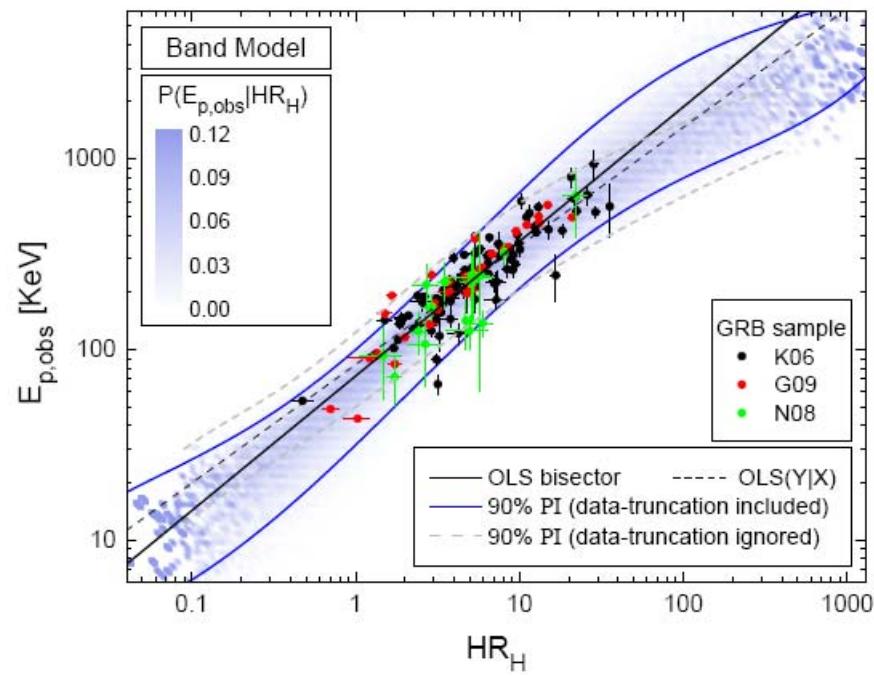


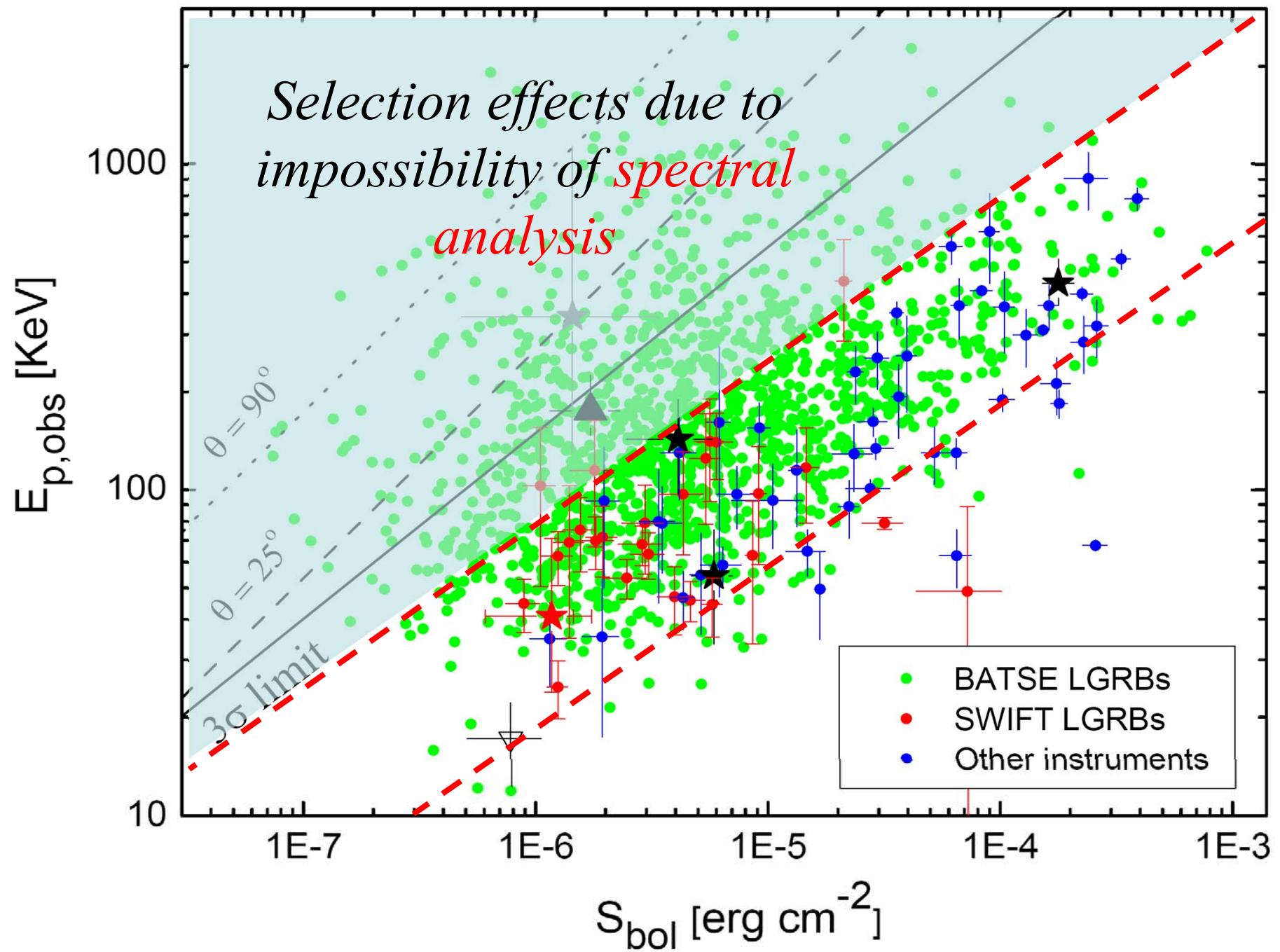
*Posterior distributions of the parameters of the truncated multivariate normal distributions considered for the spectral parameters of the 3 GRB models: Band, COMP(CPL) & SBPL  
Shahmoradi & Nemiroff, MNRAS (2010)*

*Parameter estimation  
based on Minimum  $\chi^2$   
& Minimum  
Kolmogorov-Smirnov  
distance techniques.*

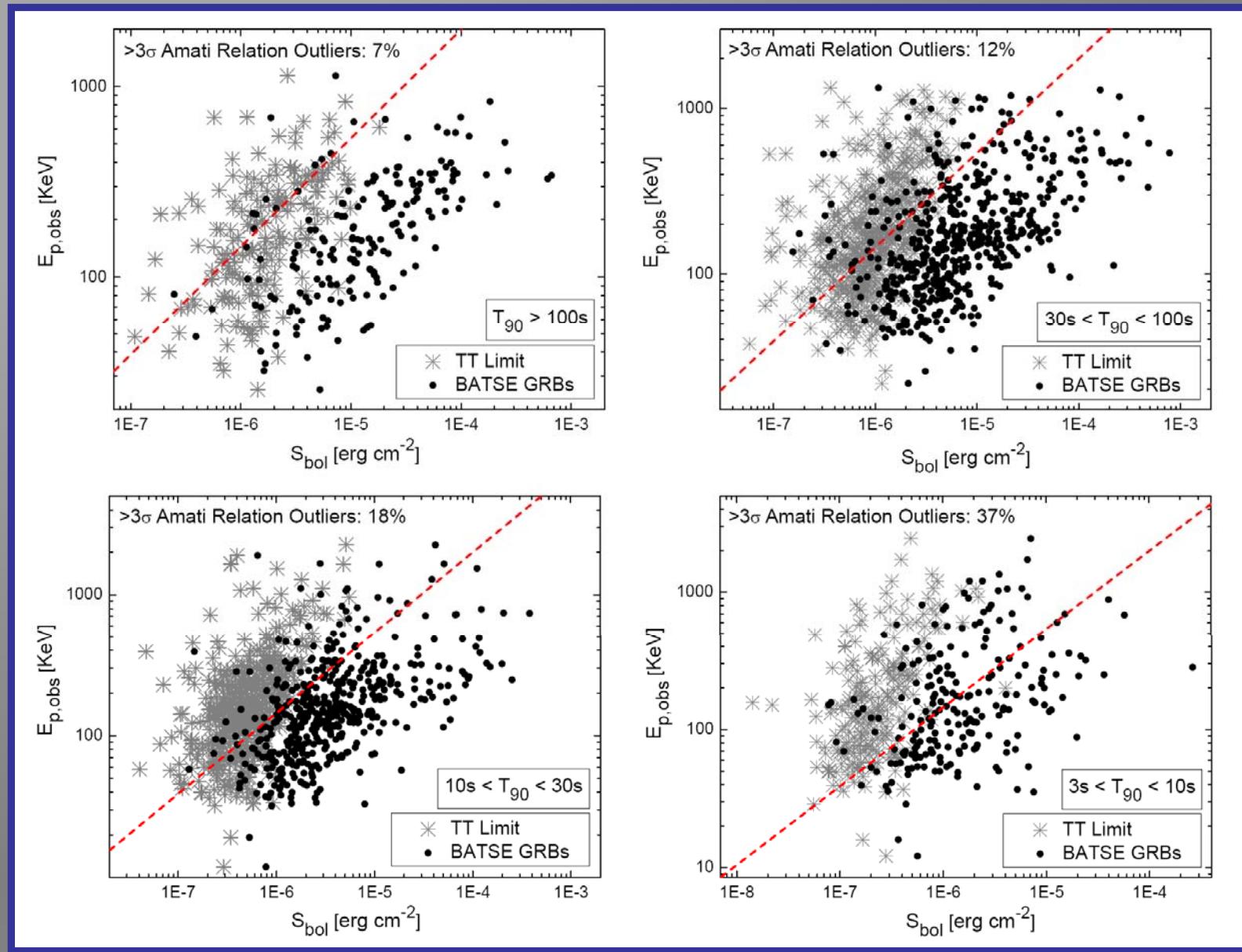
*Marginalized likelihood  
contour plots of the  
observed data given  
different parameter values  
of the truncated  
multivariate normal  
distribution assumed for  
the spectral parameters of  
the three GRB models.  
Shahmoradi & Nemiroff, MNRAS  
(2010)*

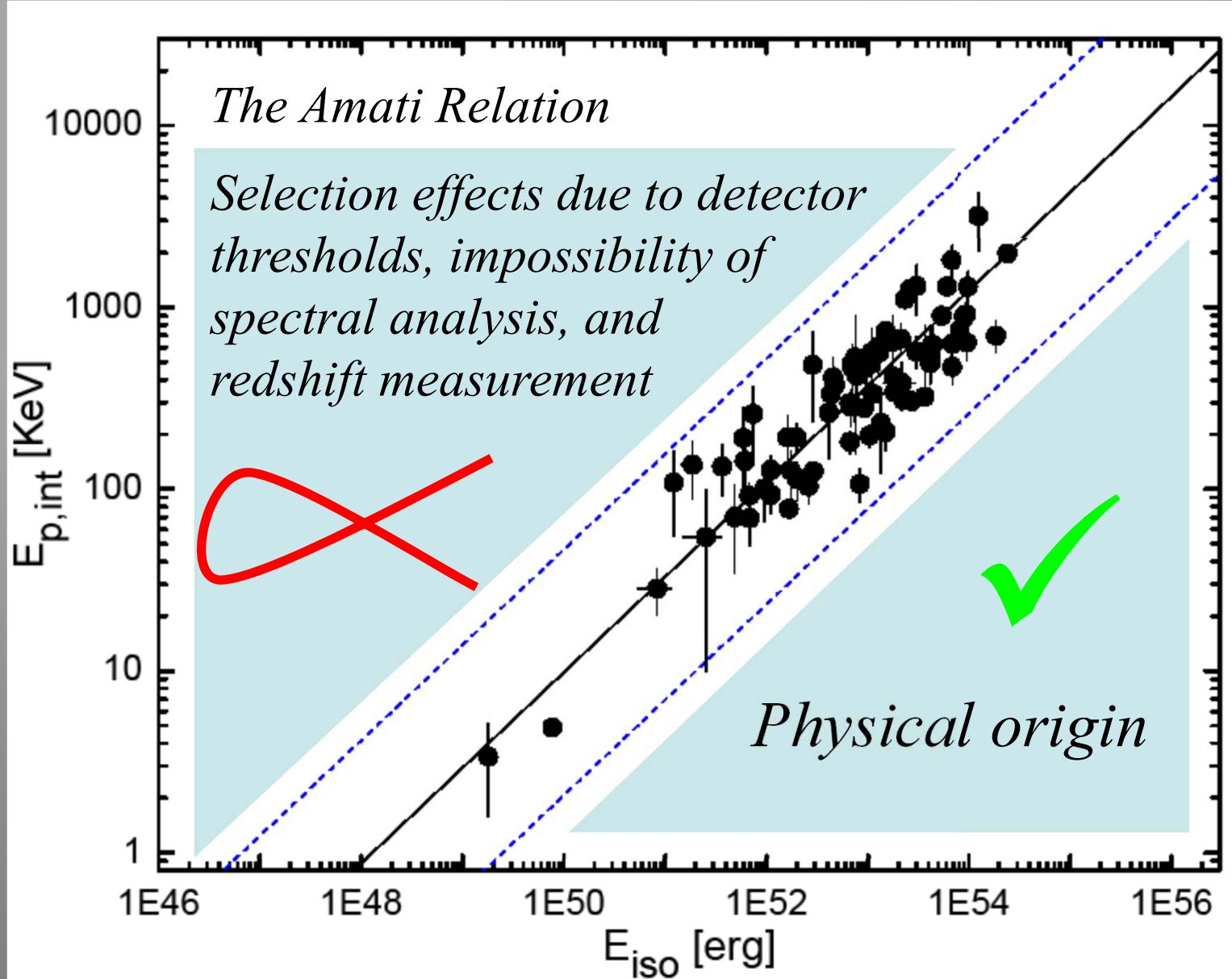






# *Selection Effects due to GRB Detectors?*





✓ 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...*

A scenic landscape featuring a calm lake in the foreground. Two horses are grazing on a grassy hillside above the water. In the background, majestic mountains rise, their slopes covered in patches of green vegetation and white snow. The sky is clear and blue.

*Thank you!*

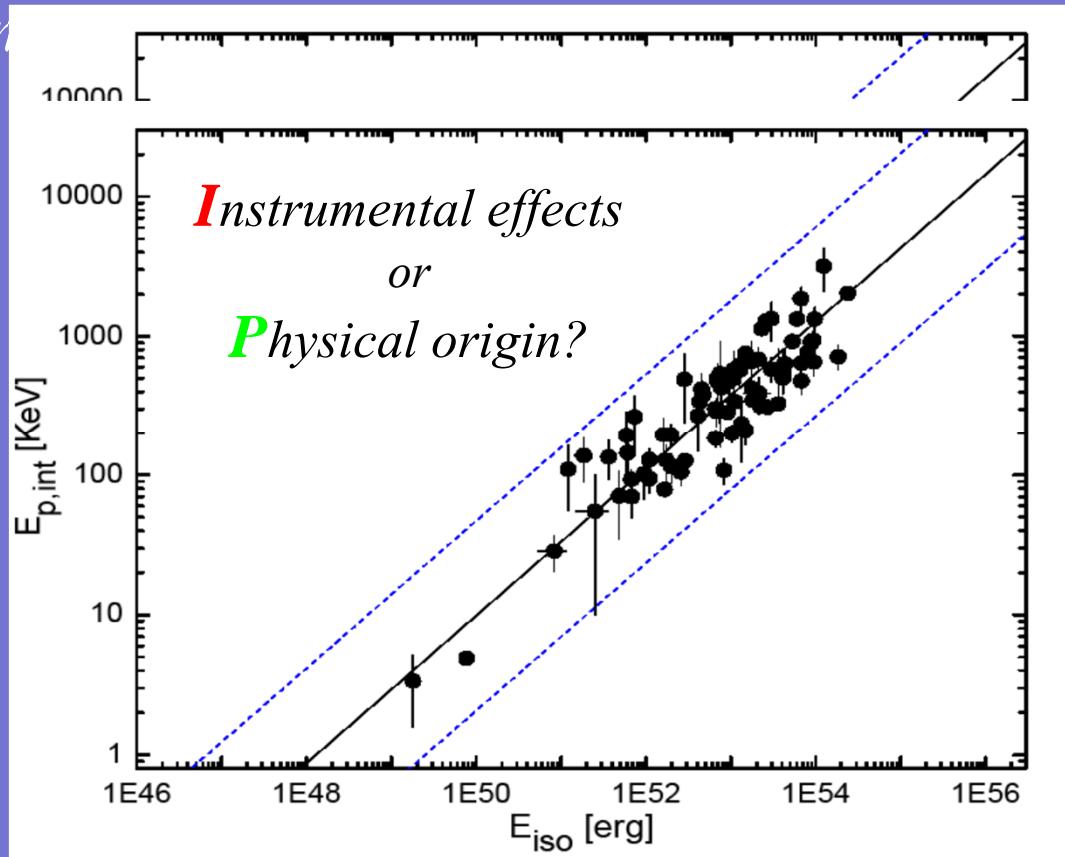
*Questions?*

*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 correlation?*



# *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.*

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*Further analysis coming soon ...*

# References

1. Shahmoradi, Amir and Nemiroff, Robert J, 2015, MNRAS, **451**, 126-143
2. Shahmoradi, Amir, 2013, The Astrophysical Journal (ApJ), **766**, 111
3. Shahmoradi, Amir, 2013, Stanford eConf Proc. C1304143, paper 14; arXiv:1308.1097
4. Shahmoradi, Amir and Nemiroff, Robert J, 2010, MNRAS, **407**, 2075–2090
5. Shahmoradi, Amir and Nemiroff, Robert J, 2011, MNRAS, **411**, 1843–1856
6. Shahmoradi, Amir and Nemiroff, Robert J, 2009, AIP Conf Proc, **1133**, 425
7. Shahmoradi, Amir and Nemiroff, Robert J, 2009, AIP Conf Proc, **1133**, 323

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@article{shahmoradi2015short,
  title={Short versus long gamma-ray bursts: a comprehensive study of energetics and prompt gamma-ray correlations},
  author={Shahmoradi, Amir and Nemiroff, Robert J},
  journal={Monthly Notices of the Royal Astronomical Society},
  volume={451},
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  pages={126--143},
  year={2015},
  publisher={Oxford University Press}
}

@inproceedings{shahmoradi2014similarities,
  title={On the similarities of the prompt gamma-ray emissions in Short and Long Gamma-Ray Busts},
  author={Shahmoradi, Amir},
  booktitle={APS April Meeting Abstracts},
  year={2014}
}
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# References

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@inproceedings{nemiroff2009causes,  
    title={What Causes GRB Time Dilation?},  
    author={Nemiroff, Robert and Shahmoradi, Amir},  
    booktitle={AIP Conference Proceedings},  
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@inproceedings{shahmoradi2009real,  
    title={How Real detector thresholds create false standard candles},  
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    volume={1133},  
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    pages={425--427},  
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}
```

# References

```
@inproceedings{nemiroff2010detection,  
    title={Detection Threshold Effects on GRBs as a Cosmological Standard Candle},  
    author={Nemiroff, Robert J and Shahmoradi, A},  
    booktitle={Bulletin of the American Astronomical Society},  
    volume={42},  
    pages={228},  
    year={2010}  
}  
  
@article{shahmoradi2010hardness,  
    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},  
    number={4},  
    pages={2075--2090},  
    year={2010},  
    publisher={Blackwell Publishing Ltd Oxford, UK}  
}
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@inproceedings{miller2011quantifying,  
    title={Quantifying GRB Pulse Shape Evolution to Study the Pulse Scale Conjecture},  
    author={Miller, Daniel and Nemiroff, RJ and Holmes, J and Shahmoradi, A},  
    booktitle={Bulletin of the American Astronomical Society},  
    volume={43},  
    year={2011}  
}
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@inproceedings{shahmoradi2011cosmological,  
    title={A Cosmological Discriminator Designed to Avoid Selection Bias},  
    author={Shahmoradi, Amir and Nemiroff, RJ},  
    booktitle={Bulletin of the American Astronomical Society},  
    volume={43},  
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```

# References

```
@article{shahmoradi2011vizier,
  title={VizieR Online Data Catalog: Gamma-ray bursts spectral peak estimator (Shahmoradi+, 2010)},
  author={Shahmoradi, A and Nemiroff, RJ},
  journal={VizieR Online Data Catalog},
  volume={740},
  year={2011}
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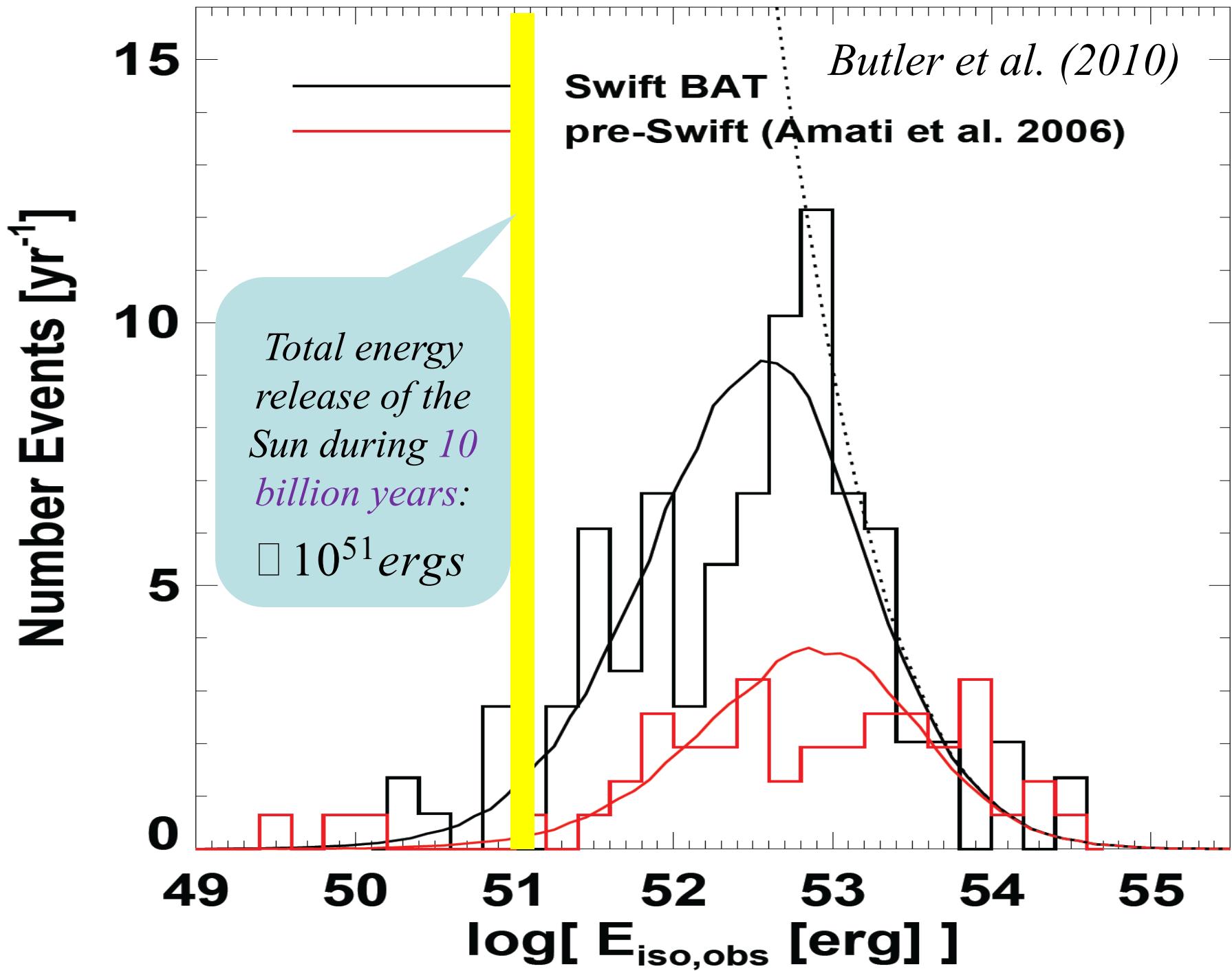
@article{shahmoradi2011possible,
  title={The possible impact of gamma-ray burst detector thresholds on cosmological standard candles},
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# References

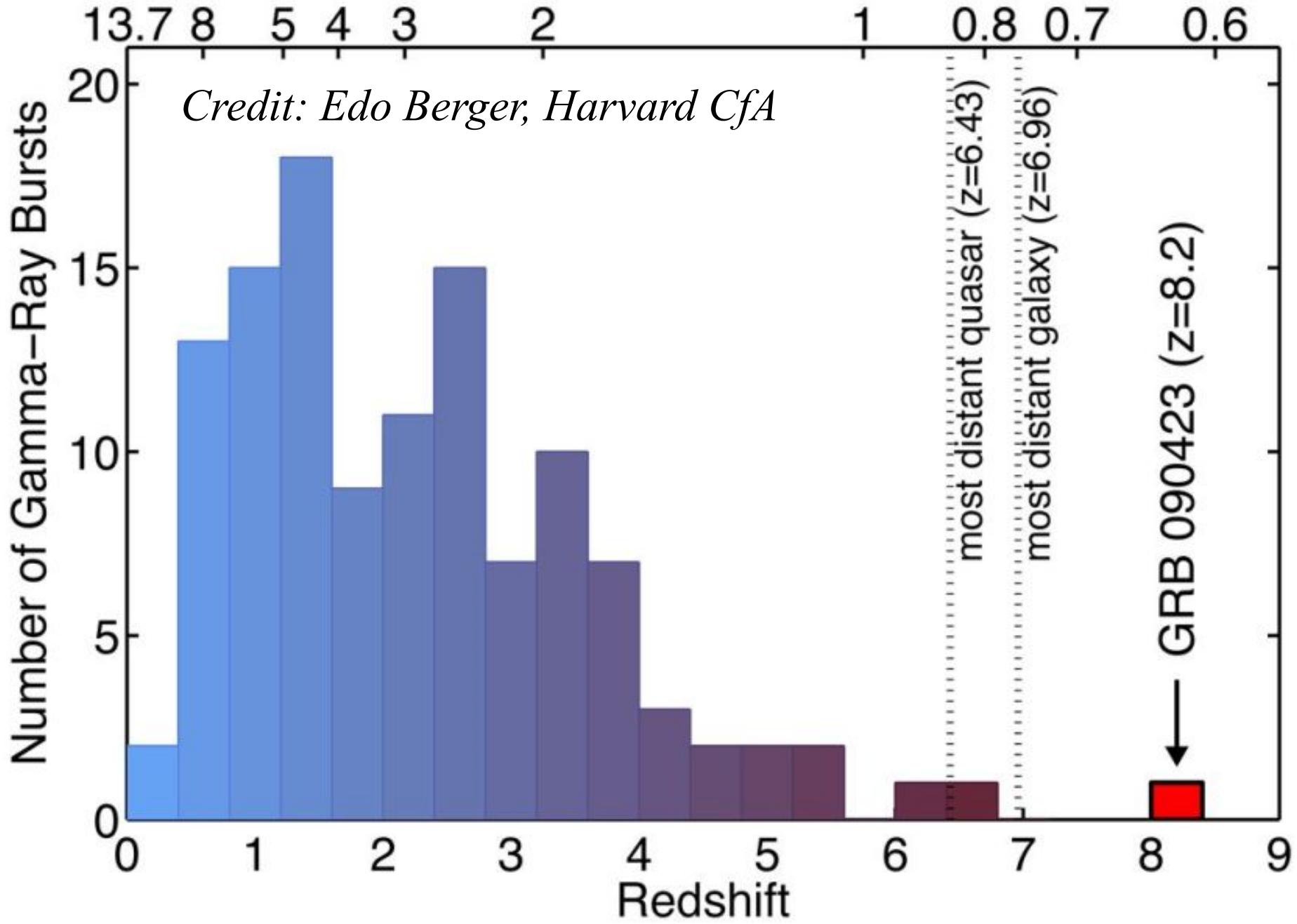
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@article{shahmoradi2013multivariate,
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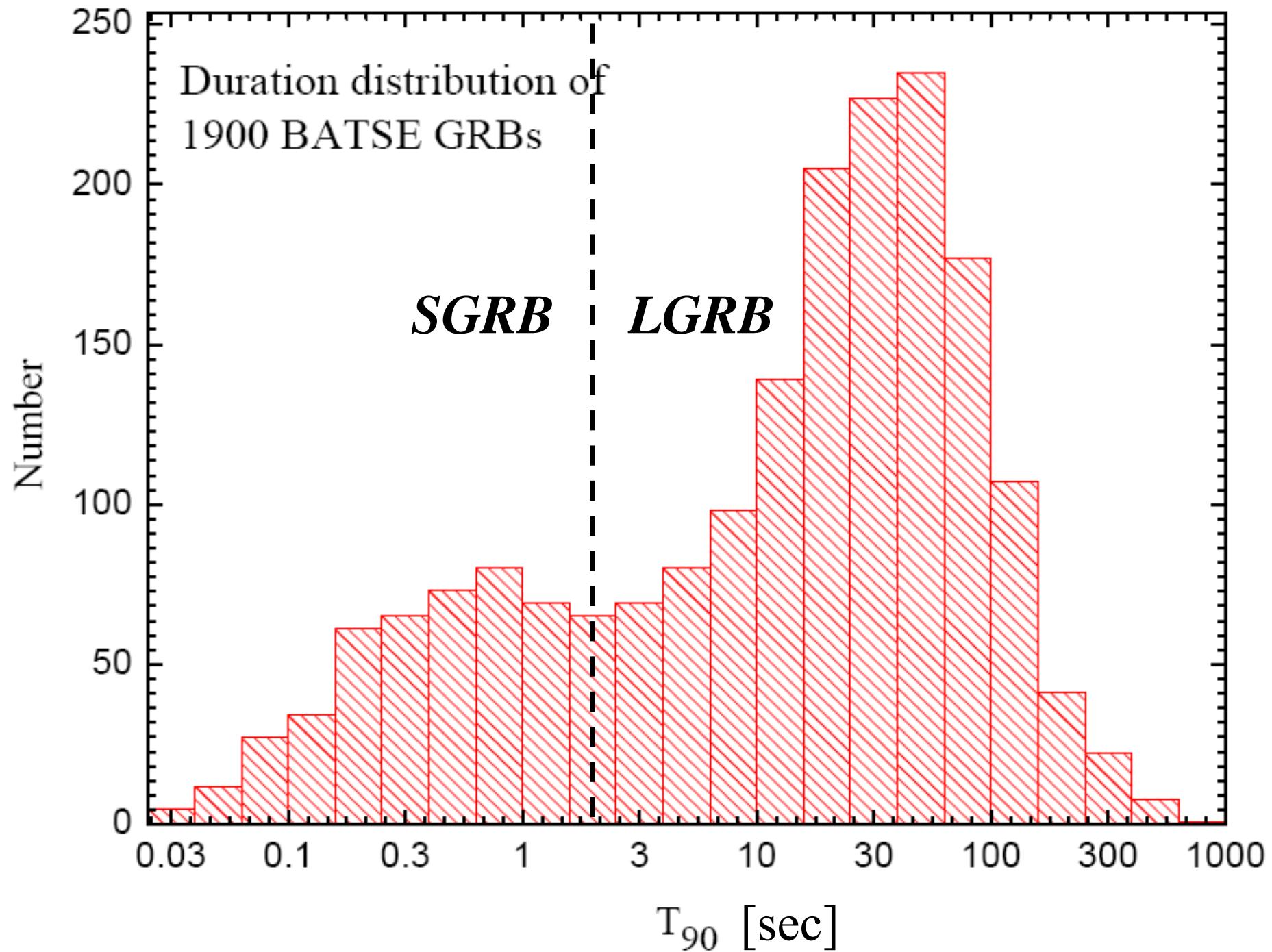
@article{shahmoradi2013gamma,
  title={Gamma-Ray bursts: Energetics and Prompt Correlations},
  author={Shahmoradi, Amir},
  journal={arXiv preprint arXiv:1308.1097},
  year={2013}
}

@inproceedings{shahmoradi2014classification,
  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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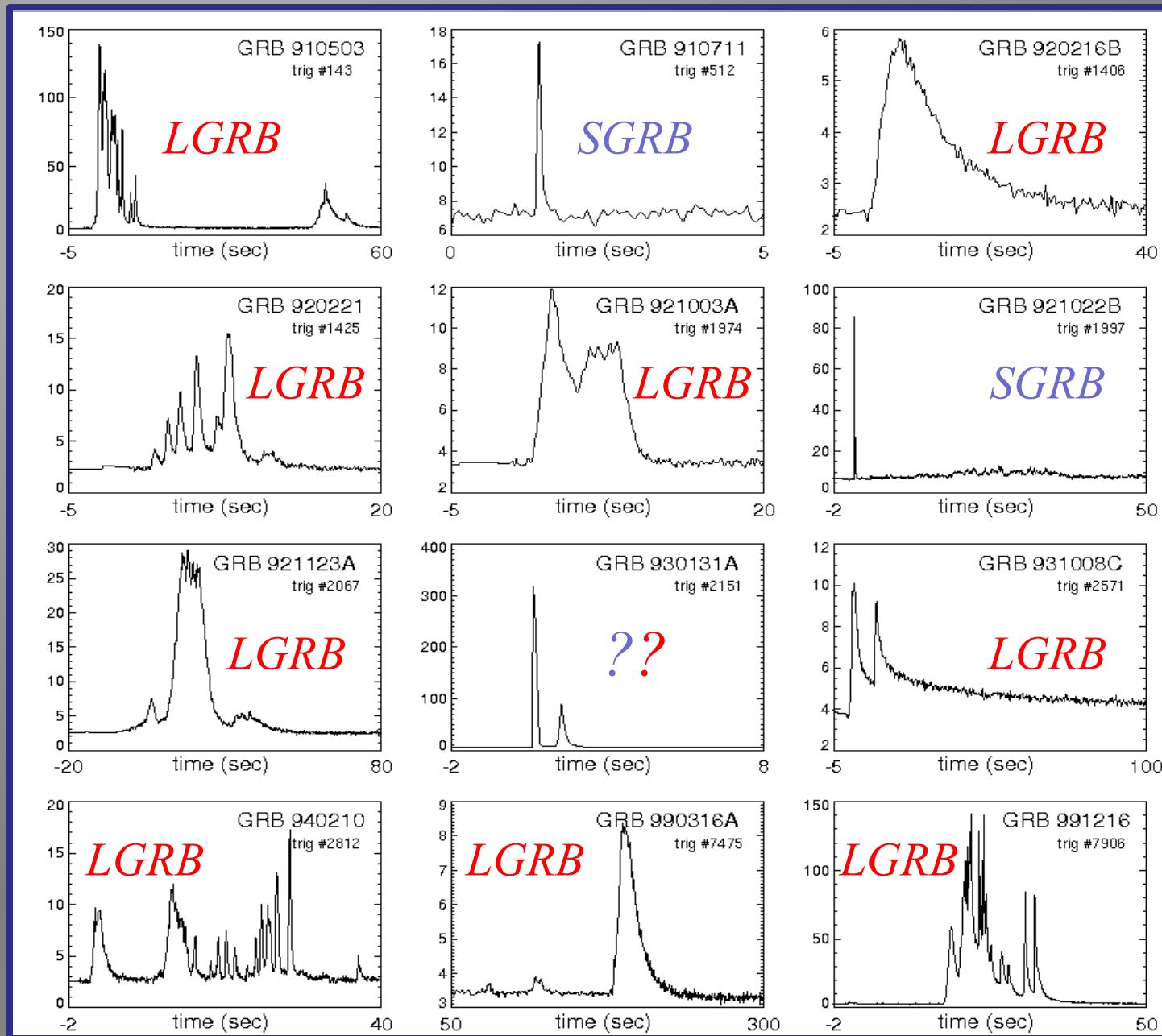


# Age of the Universe (billions of years)





# *GRB light-curve diversity*



*Shahmoradi & Nemiroff, MNRAS (2009)*

