Constraining the number of classes of gamma-ray bursts: multidimensional modelling with skewed distributions

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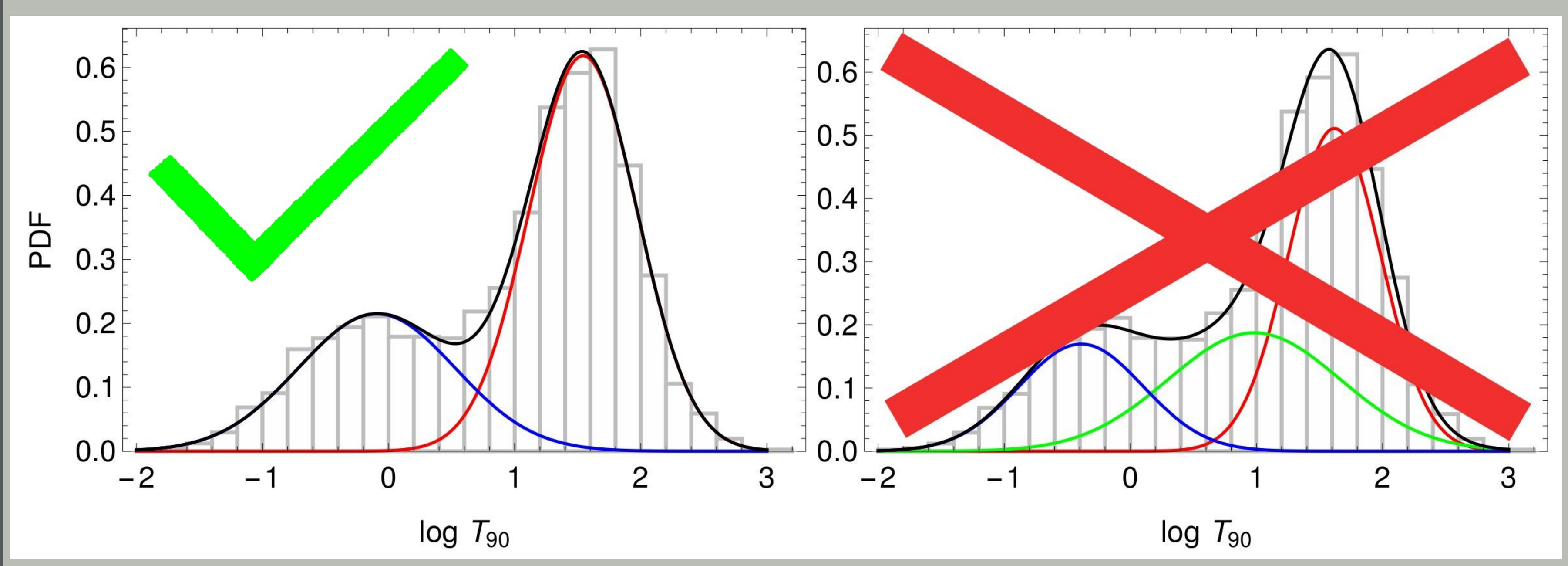
Take-away summary



The duration and multivariate parameter distributions of GRBs (from BATSE, Fermi, Swift, etc.) are adequately described by only **2 components** [1, 2]. This implies that there are 2 main classes, the *short* (mergers) and *long* (collapsars). All-in-all, the existence of a presumed third class of intermediate-duration, soft GRBs is unjustified.

Discussion

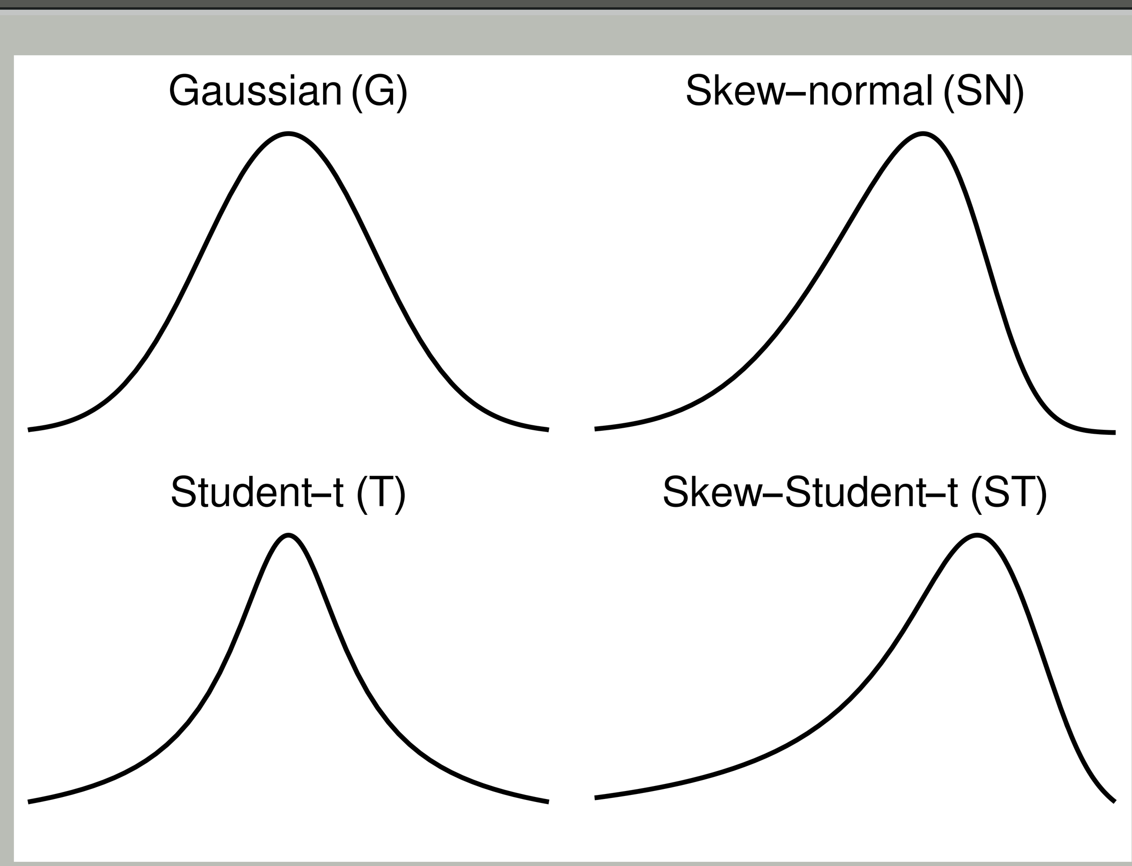


Figure : 1D illustrations of the employed distributions.

Context. •Fitting the distributions of GRB parameters (duration T_{90}, hardness ratio H_{32}, etc.) with mixtures of Gaussians leads to concluding that 3 such components are needed to describe the data accordingly. •However, the data sets gathered by various instruments are at most **bimodal**, hence the existence of a third class is putative. It was already shown [1] that a mixture of **only 2 skewed components** is a better description of the durations than a 3-Gaussian. •This provides a much simpler explanation that does not require introducing yet another physical phenomenon.

Methods. •Mixtures of the following multivariate distributions are examined: Gaussian (2G–8G), skew-normal (2SN–5SN), Student-*t* (2T–5T), and skew-Student-*t* (2ST–5ST). •The models' performance is evaluated based on the information criteria, AIC/AIC_c and BIC [3]. •The best model is the one with the lowest IC score. AIC/AIC_c are inclined toward overfitting, while BIC has a tendency to underfit. So the truth lies somewhere in between.

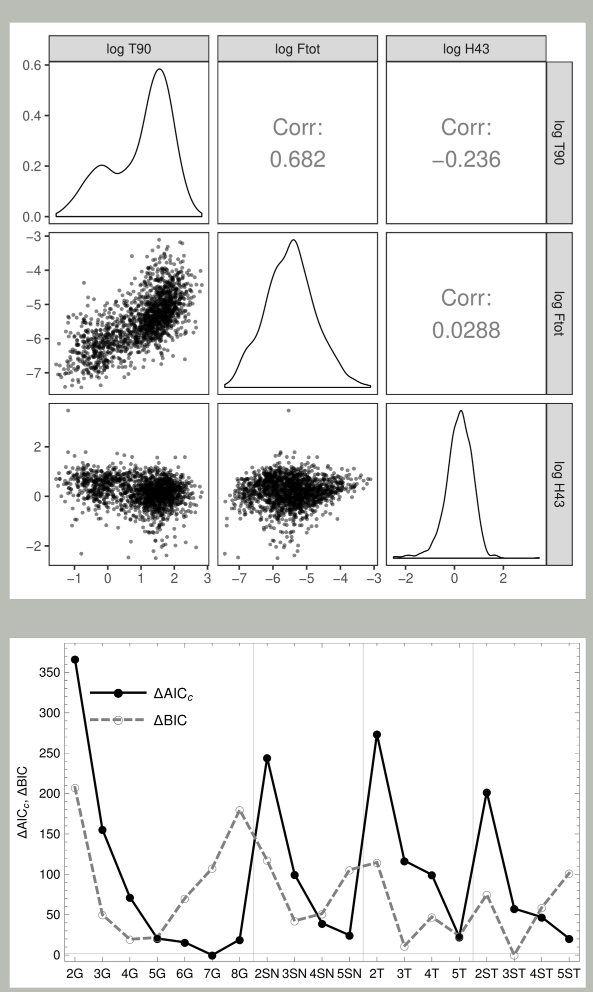
Results 1. •The $T_{90} - H_{32}$ plane was analysed with 2- and 3-component mixtures. It was found [2] that a **2-component mixture of skewed distributions** is a better description of the BATSE and Fermi data than any of the examined 3-component ones. •For Swift and Konus no clear answer was obtained, however both AIC_c and BIC point at **skewed distributions**. •In case of RHESSI, **2-component** mixtures are unequivocally pointed at. •Suzaku, the smallest data set examined, can be confidently modelled with only **2 Gaussian components**.

Results 2. •A multivariate analysis of BATSE data in spaces of various parameters, ranging from 2D and 3D, up to a 4D space of $T_{90} - F_{\rm tot} - H_{32} - P_{256}$ ($F_{\rm tot}$—total fluence, P_{256}—peak flux at a 256 ms time scale), yielded inconclusive results, pointing at **either 2 or 3 components**. •A Monte Carlo testing implied that additional components might be **artifacts** owing to the **finiteness of the data** and be a result of examining a **particular realisation** of the data as a random sample, thus resulting in **spurious identifications**.

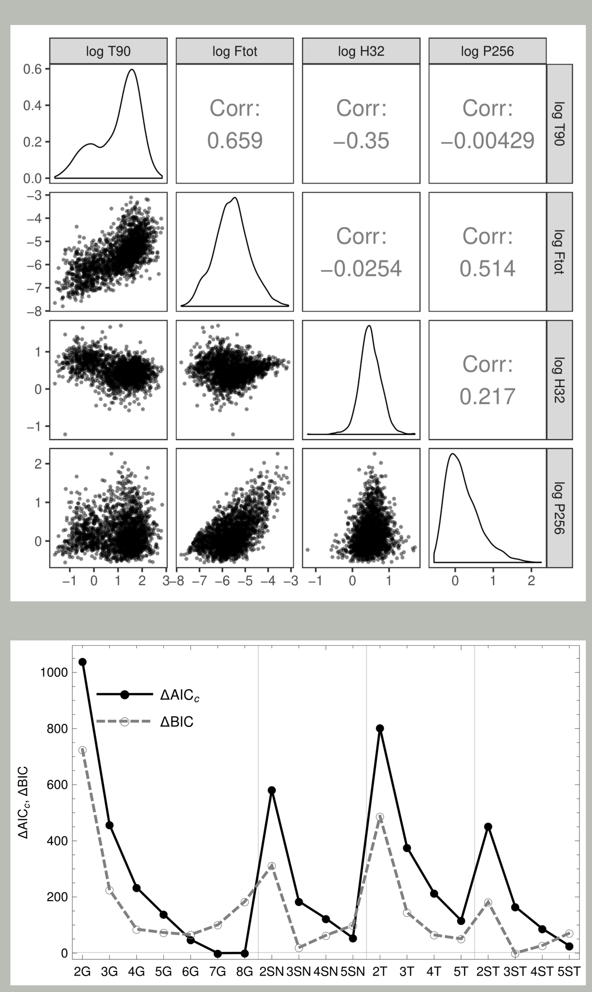
Results 3. •In case of Fermi GRBs, the space $T_{90} - F_{\rm tot} - P_{256}$ yielded **3 skewed components** as the best description. •However, the 5D space of $T_{90} - F_{\rm tot} - E_{\rm peak} - \alpha - \beta$ (where $E_{\rm peak}, \alpha, \beta$ are the Band parameters) requires only **2 skewed components**.

Results 2—BATSE [5]

Best model—3ST

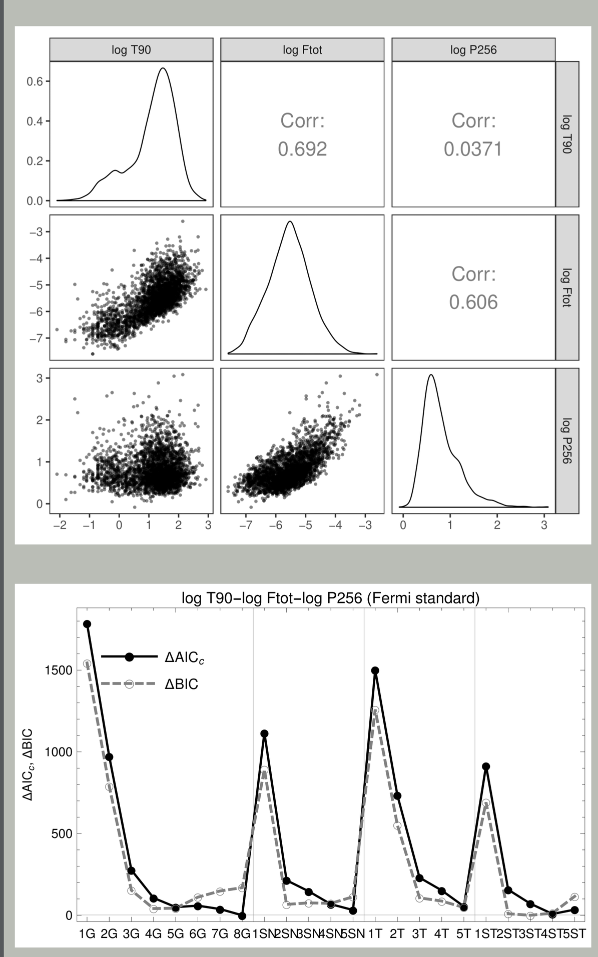


Best model—3ST

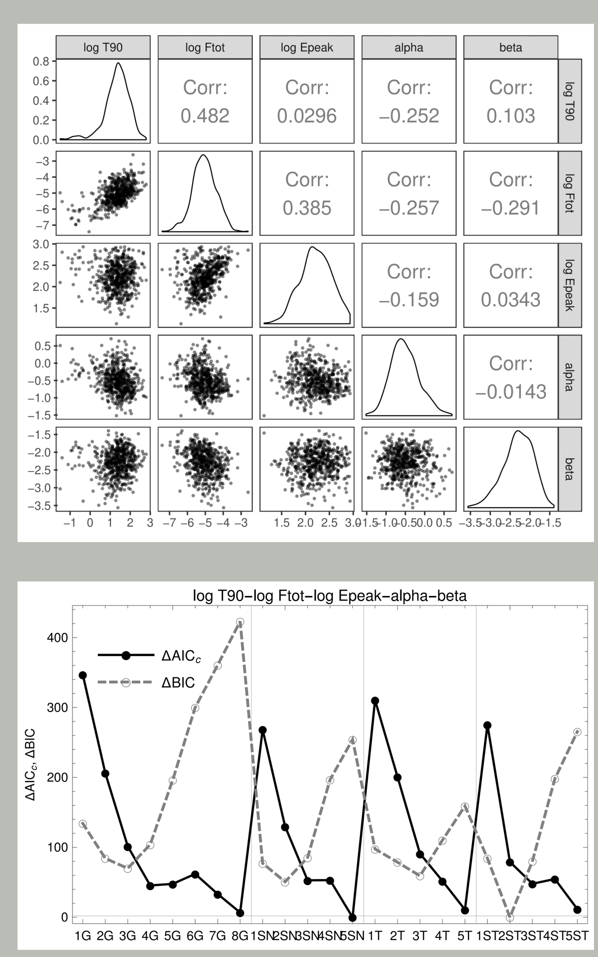


Results 3—Fermi

Best model—3ST



Best model—2ST



Conclusions

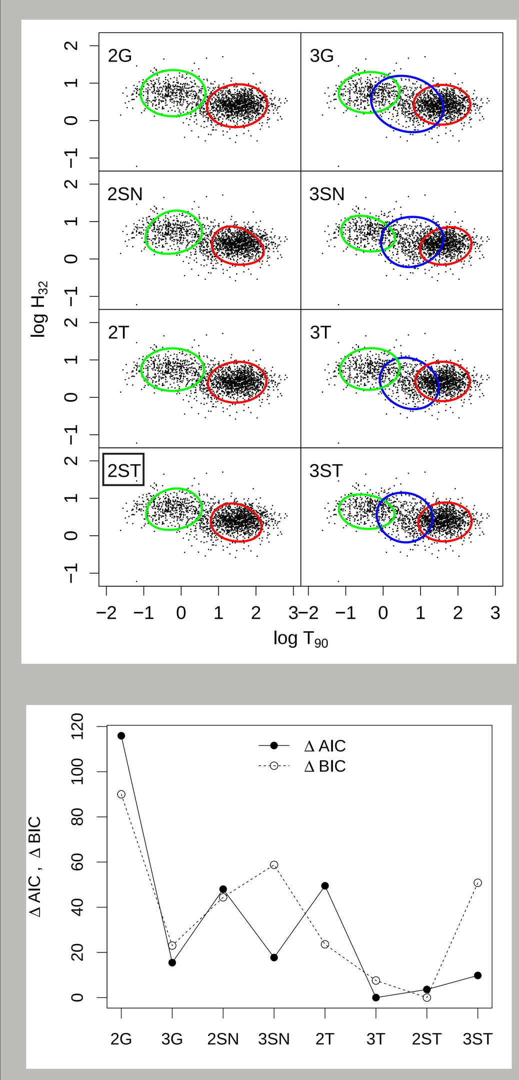
•**No definite signs** of the presumed third GRB class are visible among the examined data sets. •The asymmetry of the data, manifested via skewed distributions, might arise from a **non-symmetric distribution of the envelope masses** of the progenitors of long GRBs, or other inherently asymmetric distributions of physical parameters governing the progenitors or GRBs themselves. •The asymmetry **cannot** result from the impact of the redshift distribution on the observables [6].

Results 1 [2, 4]

Contours depict FWHM. Best models are framed.

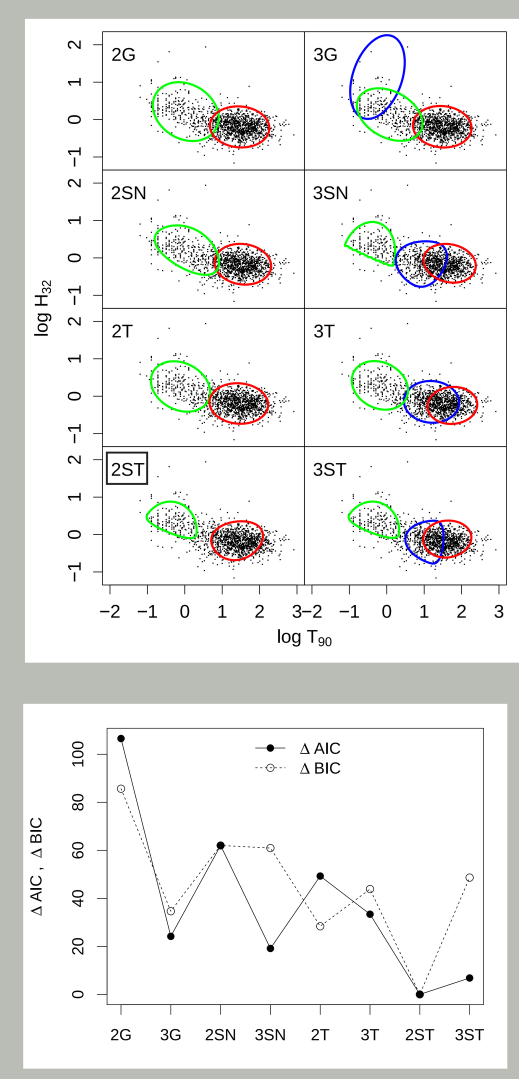
BATSE [7] (1954 GRBs)

$$H_{32} = \frac{F_{100-300\,\rm keV}}{F_{50-100\,\rm keV}}$$



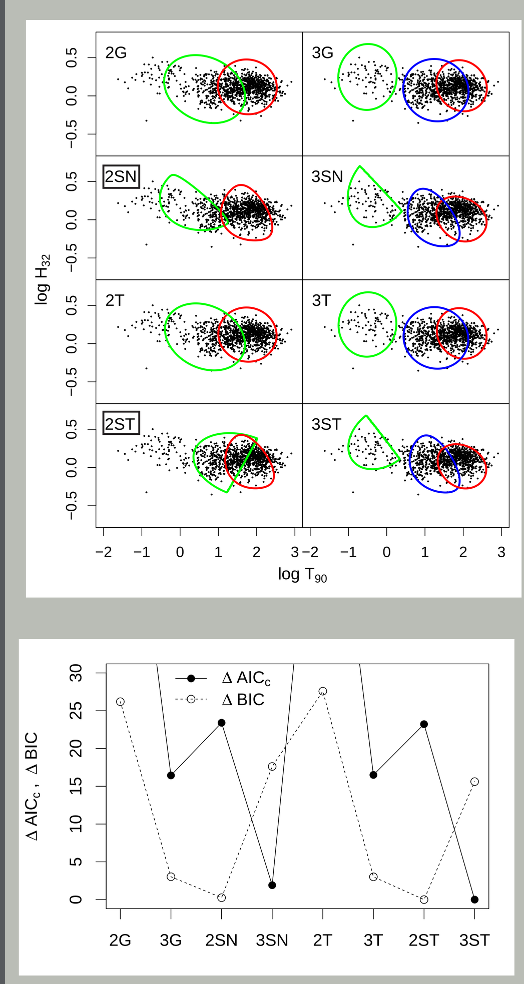
Fermi [8] (1376 GRBs)

$$H_{32} = \frac{F_{50-300\,\rm keV}}{F_{10-50\,\rm keV}}$$



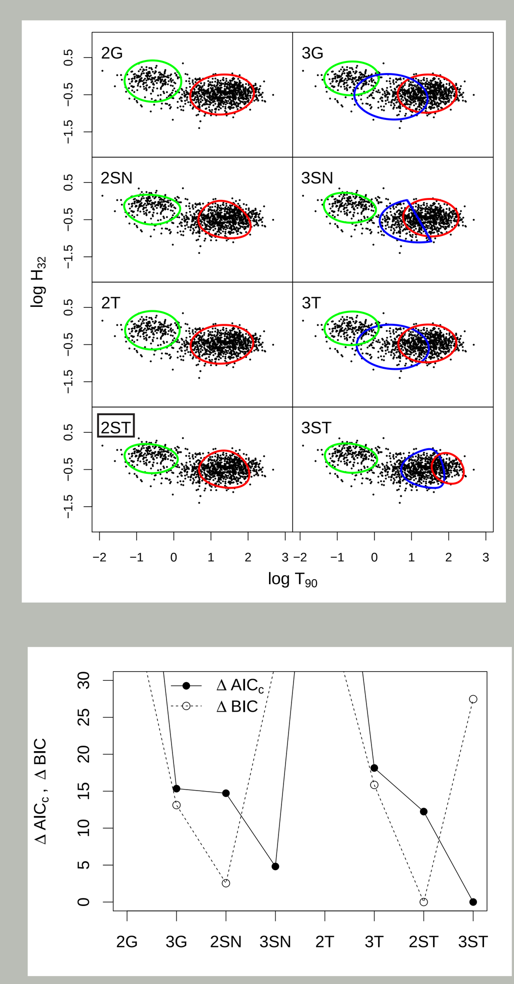
Swift [9] (1033 GRBs)

$$H_{32} = \frac{F_{50-100\,\rm keV}}{F_{25-50\,\rm keV}}$$



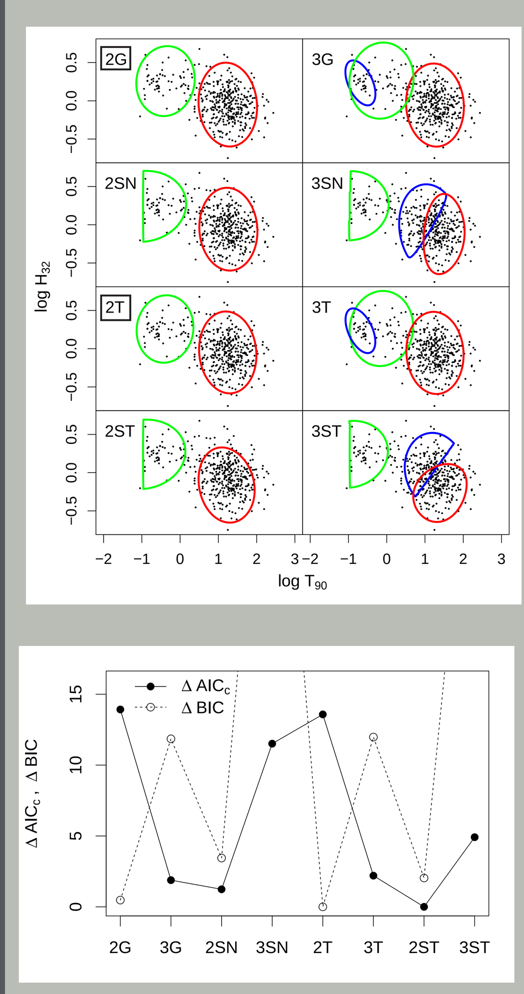
Konus [10] (1143 GRBs)

$$H_{32} = \frac{F_{200-750\,\rm keV}}{F_{50-200\,\rm keV}}$$



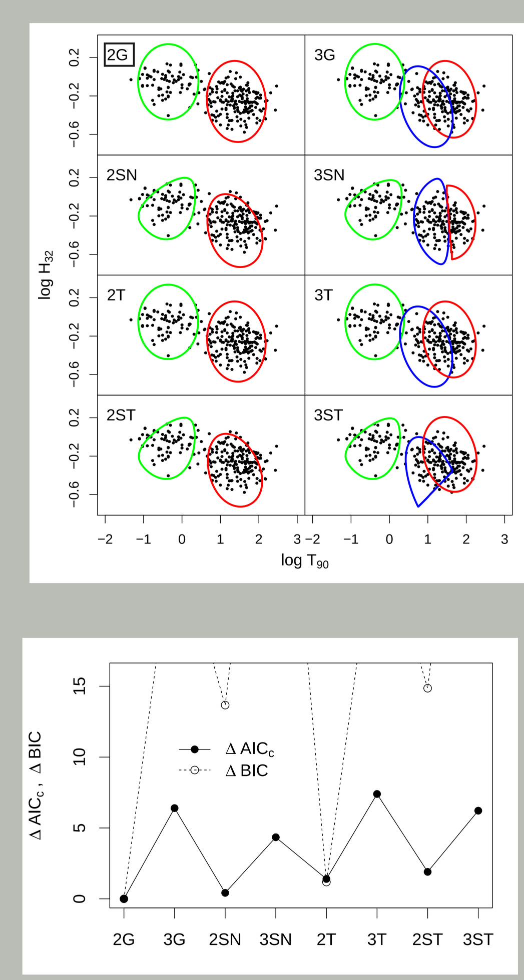
RHESSI [11] (427 GRBs)

$$H_{32} = \frac{F_{120-1500\,\rm keV}}{F_{25-120\,\rm keV}}$$



Suzaku [12] (259 GRBs)

$$H_{32} = \frac{F_{240-520\,\rm keV}}{F_{110-240\,\rm keV}}$$



Acknowledgments

The author is grateful to Peter Veres for the Fermi data, Dmitry Svinkin for the Konus data, Norisuke Ohmori for the Suzaku data, and Amy Lien for help with the Swift data
Support by the Polish National Science Center through an OPUS grant No. 2017/25/B/ST9/01208 is acknowledged.

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