Intrinsic Temporal Properties of long GRBs in the Swift Era: Average Power Density Spectrum

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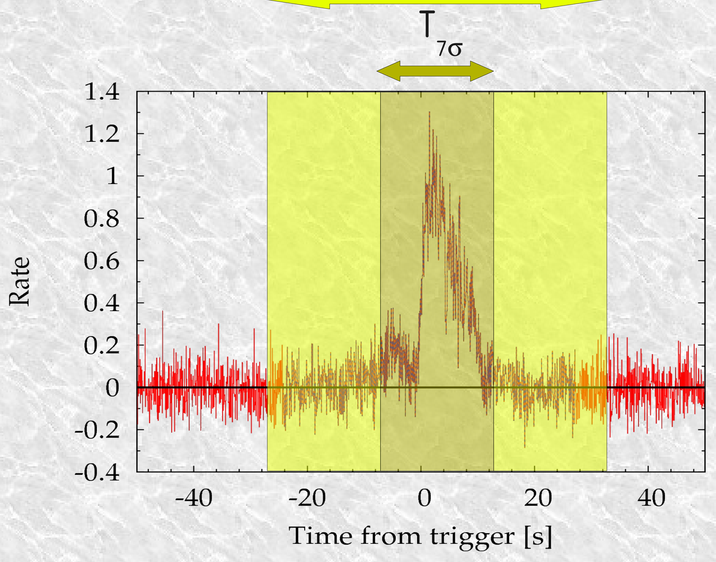
We calculate the average power density spectra (PDS) of 244 long gamma-ray bursts detected with the Swift Burst Alert Telescope (BAT) in the 15-150 keV band from 2005 January to 2011 August. For the first time we derived the average PDS in the source-rest frame of 97 GRBs with known redshift. For 49 of them an average PDS was also obtained in a common source-frame energy band to account for the dependence of time profiles on energy. Previous results obtained on BATSE GRBs with unknown redshift showed that the average spectrum in the 25-2000 keV band could be modelled with a power law with a 5/3 index over nearly two decades of frequency with a break at ~1 Hz. Depending on the normalization and on the subset of GRBs considered, our results show analogous to steeper slopes (between 1.7 and 2.0) of the power law. However, no clear evidence for the break at ~1Hz was found, although the softer energy band of BAT compared with BATSE might account for that. We instead find a break at lower frequency corresponding to a typical source-rest-frame characteristic time of a few seconds. We furthermore find no significant differences between observer- and source-rest frames. Notably, no distinctive PDS features are found for GRBs with different intrinsic properties of the prompt emission either. Finally, the average PDS of GRBs at higher redshifts shows possibly shallower power-law indices than that of low-z GRBs. It is not clear whether this is due to an evolution with z of the average PDS.

Calculation of individual PDS



Recipe

(1) determine $T_{7\sigma}$: interval from first to last 7σ significant bin above background

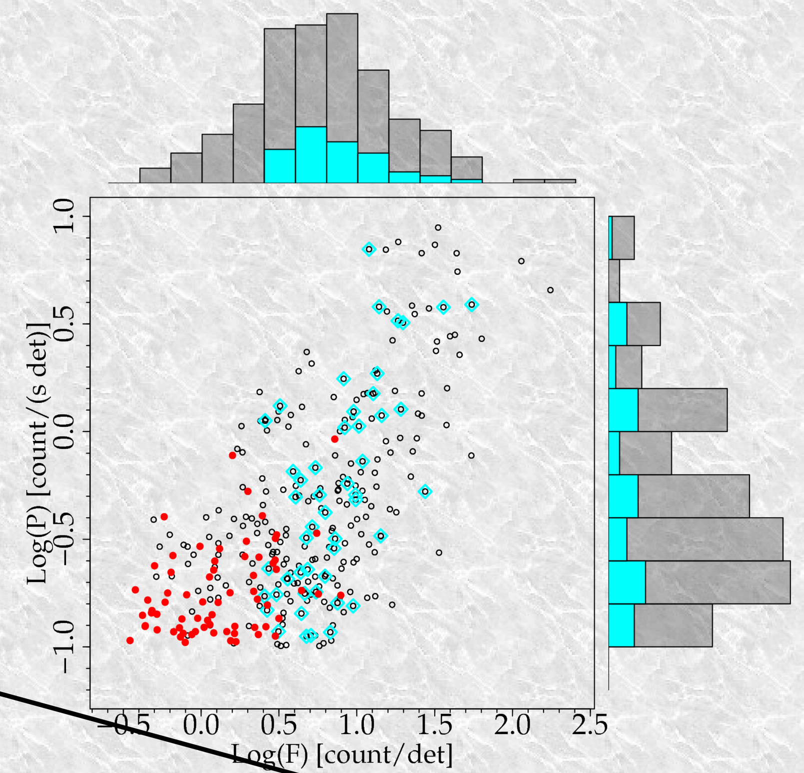
(2) Take 3 x $T_{7\sigma}$

(3) Calculate FFT

(4) Square Modulus of FFT gives the PDS

Interval choice is a trade-off
- Long enough to catch low-frequency power
- Good S/N

Sample Selection



- Full sample (244 GRBs):
  - P > 0.1 cts/(s det)
  - Individual PDS with $N_{bins}(P \geq 3\sigma_P) \geq 4$
  - Rejected
  - Accepted
  - Accepted with known z

Average PDS

3 subsets

Sample	Size	Redshift	Time Dilation Correction	Energy depend. Correction	Energy band (kev)	Bin time (ms)
Full	244	NO	NO	NO	15-150 (O.F.)	64
z-silver	97	YES (0.1<z<8.1)	YES	NO	15-150 (O.F.)	8
z-golden	49	YES (1.4<z<3.5)	YES	YES	66-366 (S.R.F.)	4

2 normalisations → Normalisation: Peak-rate normalised LC; Net-variance normalised PDS — Equal weights for all GRBs

Ansatz

"Each GRB is a single realisation of the same stochastic process."

Average PDS makes physical sense

Ansatz need to be tested. Study of power distribution.

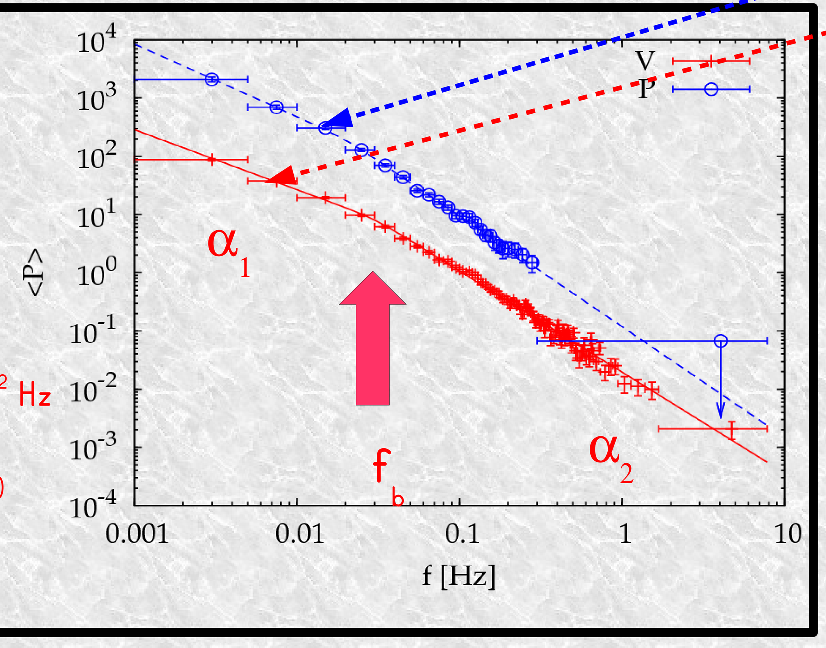
Full sample (Observer frame)

- 244 GRBs
- 15-150 keV
- Observer frame

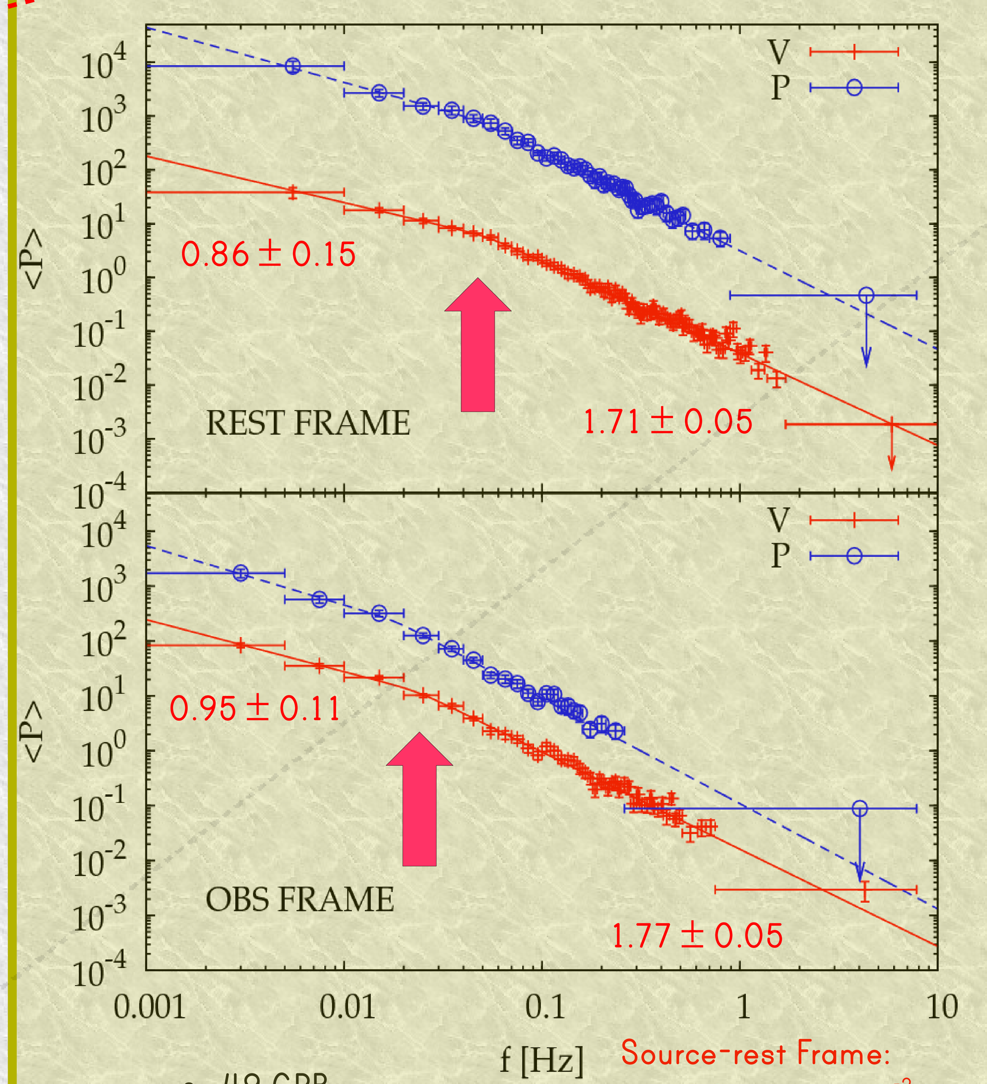
α_1 = 1.03 ± 0.05

f_b = 3.0(-0.4,+0.5)x10^{-2} Hz

α_2 = 1.73 (-0.03,+0.04)



z-golden sample



- 49 GRBs
- 66-366 keV
- Source-rest frame

Source-rest Frame: f_b = 5.3(-0.9,+1.2)x10^{-2} Hz

Obs Frame: f_b = 2.4(-0.4,+0.5)x10^{-2} Hz

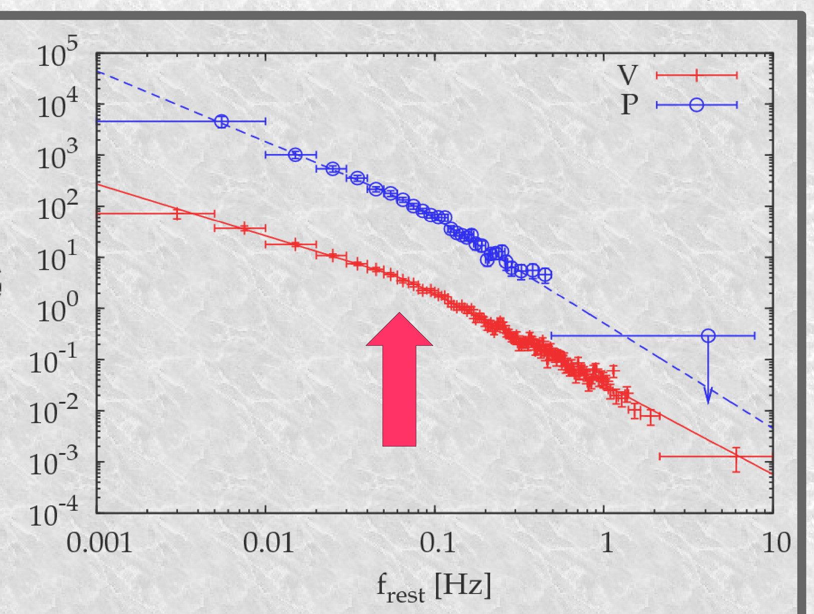
z-silver sample

- 97 GRBs
- 15-150 keV (obs)
- Rest frame

α_1 = 1.01 ± 0.08

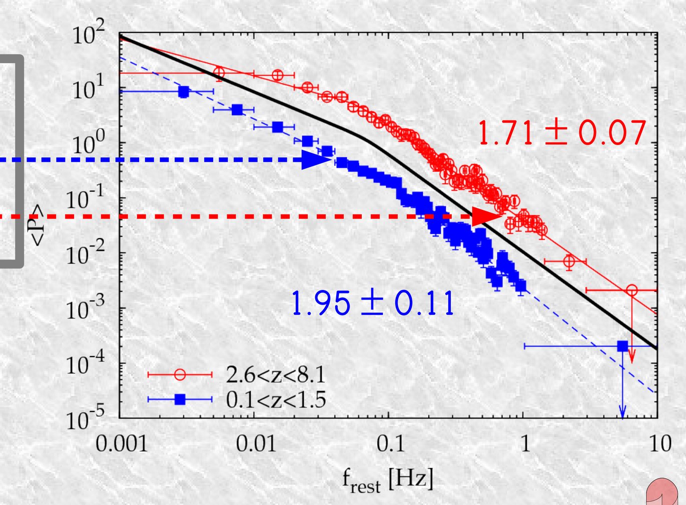
f_b = 6.9(-1.2,+1.5)x10^{-2} Hz

α_2 = 1.77 (-0.05,+0.05)



Evolution with redshift?

- 0.1 < z < 1.5
- 2.6 < z < 8.1



Known z GRB rest-frame PDS

Smoothed Broken Power-law

$$PDS(f) = 2^{1/n} F_0 \left[\left(\frac{f}{f_b}\right)^{n\alpha_1} + \left(\frac{f}{f_b}\right)^{n\alpha_2} \right]^{-1/n}$$

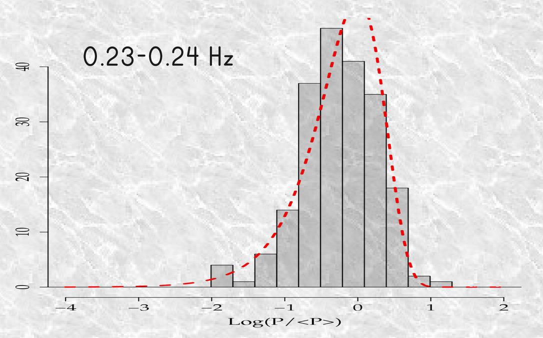
Power distribution: Ansatz test

Power is χ^2_2-distributed:

$dN/dP_f \propto \exp(-P_f/\langle P_f\rangle)$

P_f = power at frequency f

Result: acceptable



Possible Interpretations

- α_2=5/3 (10^{-2} < f < 1 Hz): fully developed turbulence in Kolmogorov velocity spectrum (Beloborodov+1998,2000)
- Relativistic outflow of a jet making its way out through stellar envelope (high freq power results from inner engine variability) (Morsony+2010)
- MHD turbulence in the Internal-Collision-induced MAgnetic Reconnection Turbulence (ICMART, Zhang&Yan 2011): 5/3<α_2<2.
- Pair-annihilation dominated neutrino cooling triggered by magneto-rotational instabilities (Carballido & Lee 2011)
- Many other processes (e.g., fine tuning of parameters of the relativistic shells' wind; Panaitescu+1999).

Conclusions

- Correcting for cosmological time dilation effects on both time and energy does not change the average PDS remarkably (apart from typical characteristic time scales of individual pulses of a few seconds in the source-rest frame)
- 1.7 < α_2 < 2.0 in the 10^{-2} -1 Hz range.
- No correlation between average PDS and intrinsic properties such as Eiso, Liso for 64 GRBs.
- Possible evolution with z (further GRBs having shallower PDS): need for larger samples.
- Average PDS can be interpreted in different contexts.
- Don't stick too much to α_2=5/3. Beware of imbuing it with a mystical sense of universality.

References

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