VRIJE UNIVERSITEIT BRUSSEL

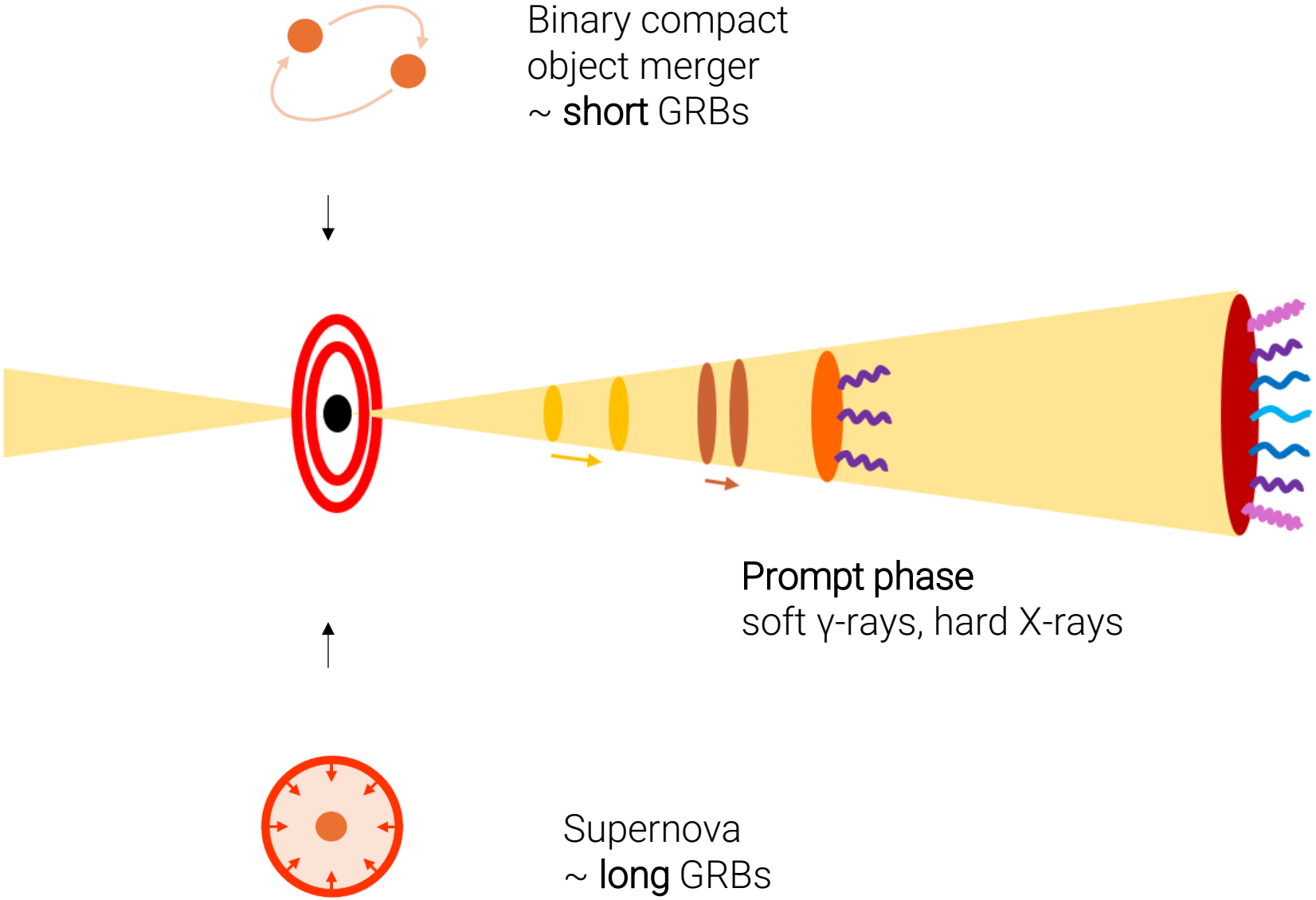
iihe BRUXELLES BRUSSEL

The Biggest Bangs: Traces of turbulence in GRBs?

*Else Magnus**, *Krijn de Vries*, *Nick van Eijndhoven*

*else.magnus@vub.be

Gamma-ray bursts



Binary compact
object merger
~ **short** GRBs

Internal mechanisms?
Radiation mechanisms?
Dissipation mechanisms?

Afterglow phase
γ-rays, X-rays, radio, …

Prompt phase
soft γ-rays, hard X-rays

Supernova
~ **long** GRBs

A GRB light curve

The GRB gamma-ray light curve has in general **three distinct phases**

Prompt emission due to internal shock waves

Precursor emission due to ?

Afterglow emission due to external shock waves

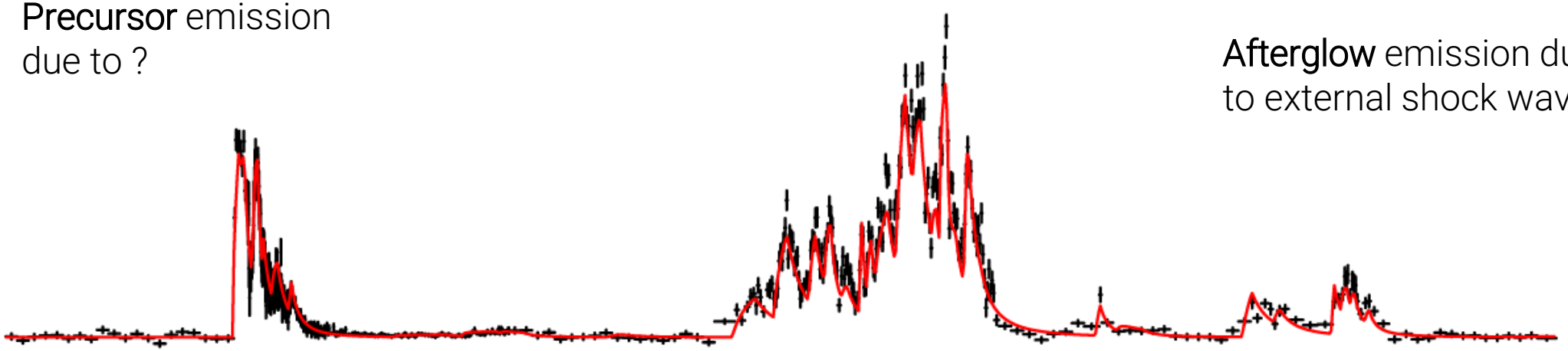
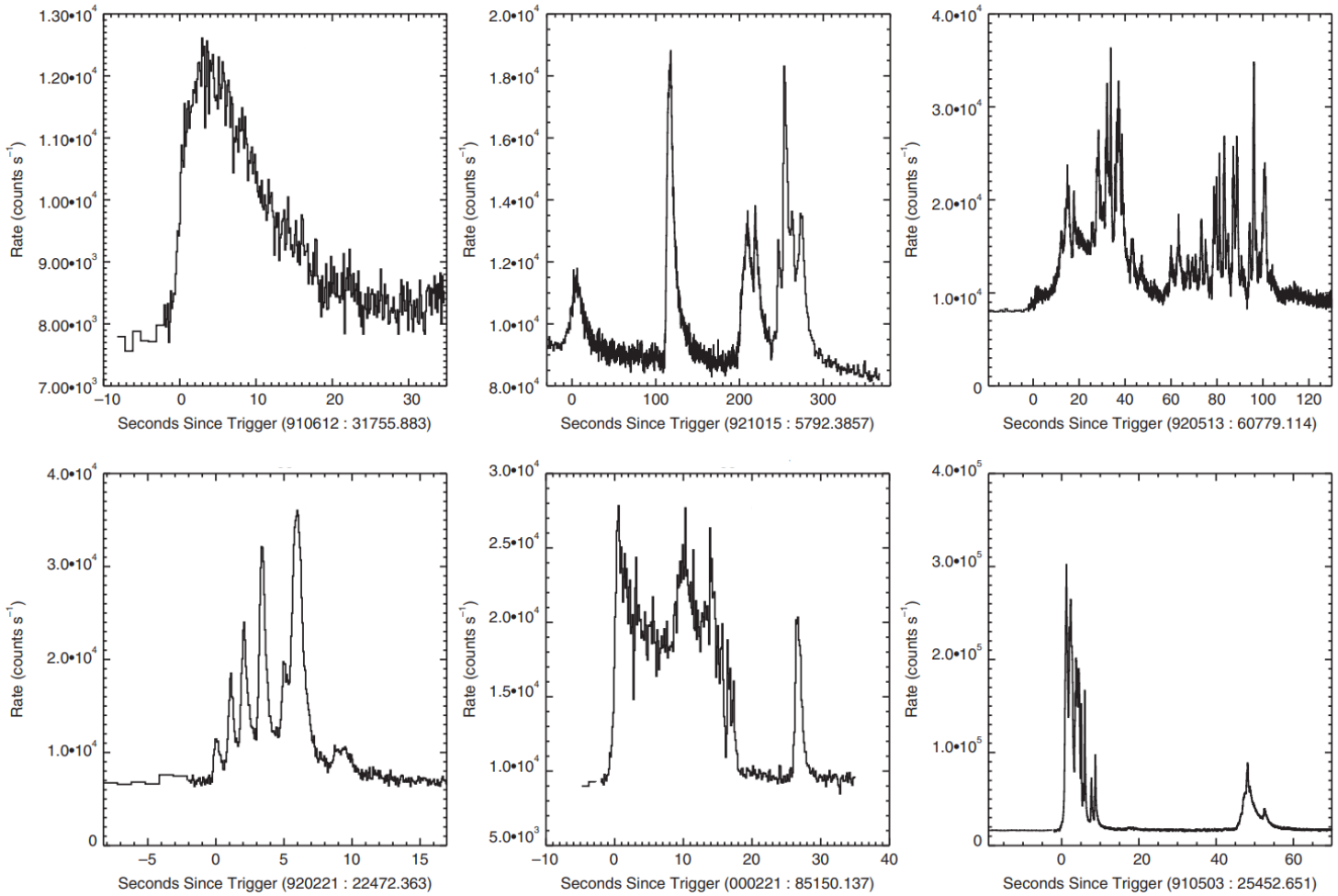


Figure adapted from Willingale & Meszaros (2017)

Many, many light curves

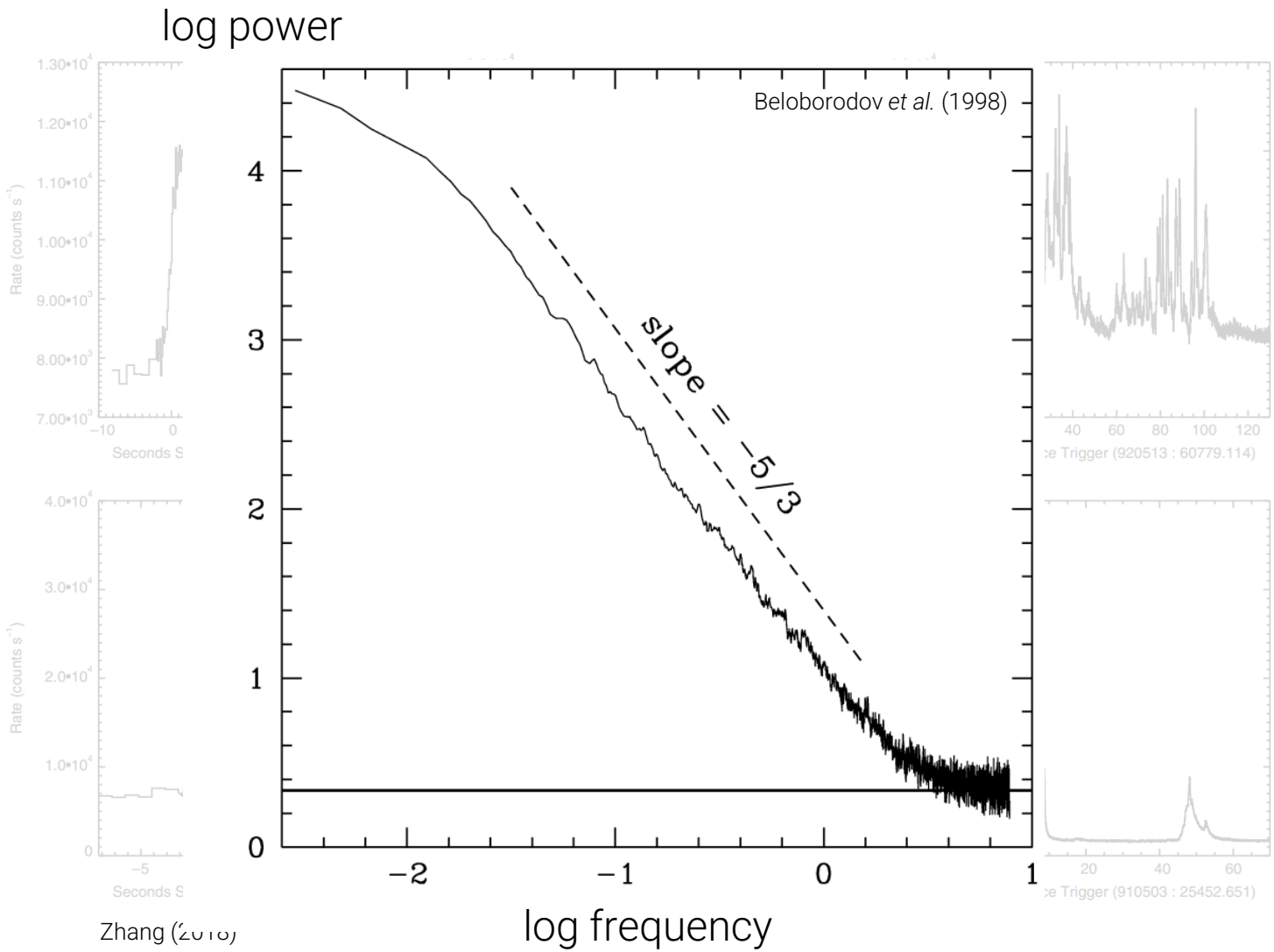


Zhang (2018)

Light curves have many shapes, **what do they tell us?**

Study **temporal features** in Fourier space by the **power-density spectrum** (PDS).

Many, many light curves



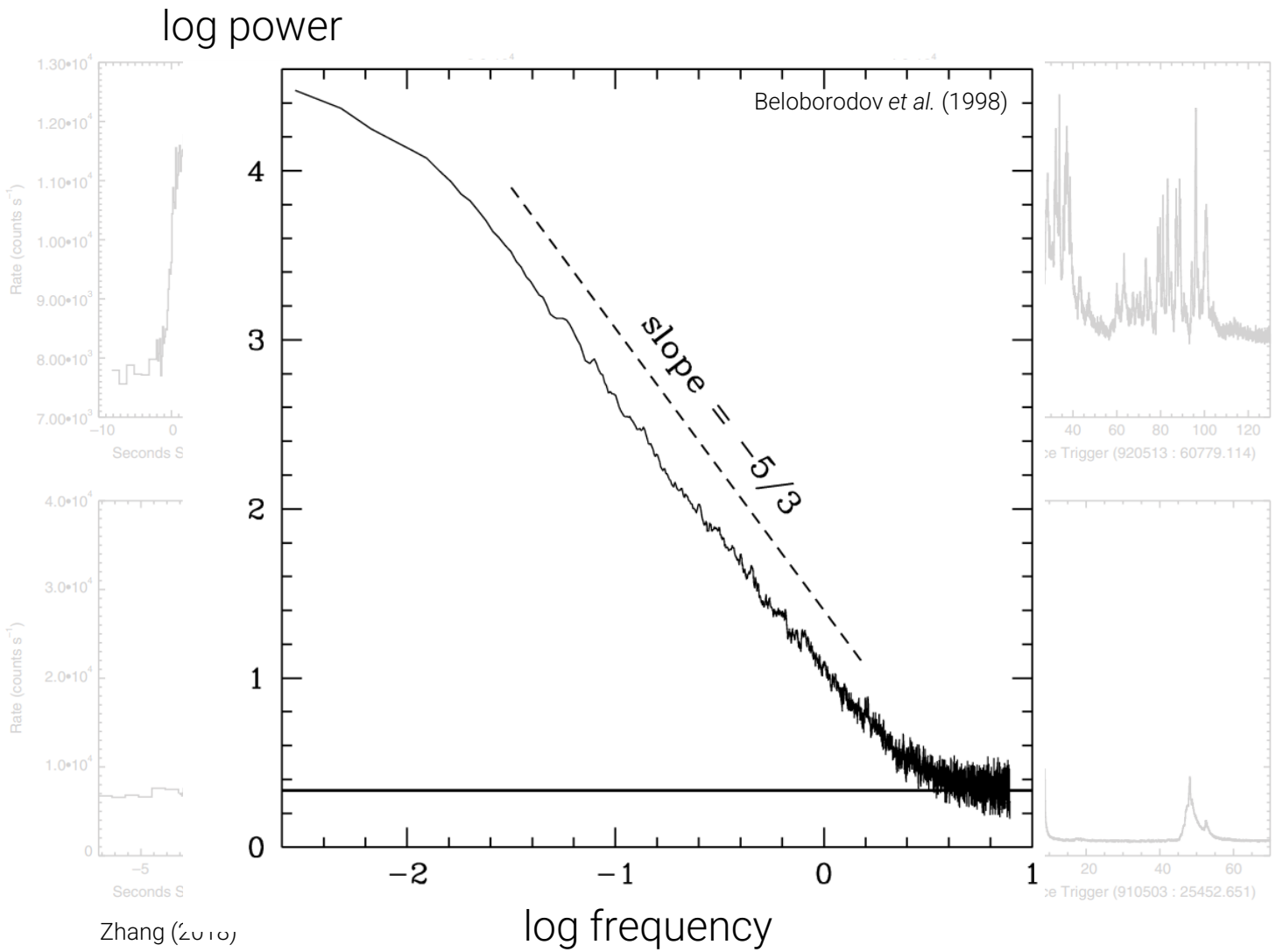
Light curves have many shapes, **what do they tell us?**

↳ Study **temporal features** in Fourier space by the **power-density spectrum** (PDS).

Observed: Power-law behaviour with slope **-5/3 ~ -1.67**.

Kolmogorov turbulence?

Many, many light curves



Light curves have many shapes, **what do they tell us?**

↳ Study **temporal features** in Fourier space by the **power-density spectrum** (PDS).

Observed: Power-law behaviour with slope **-5/3 ~ -1.67**.

Kolmogorov turbulence?

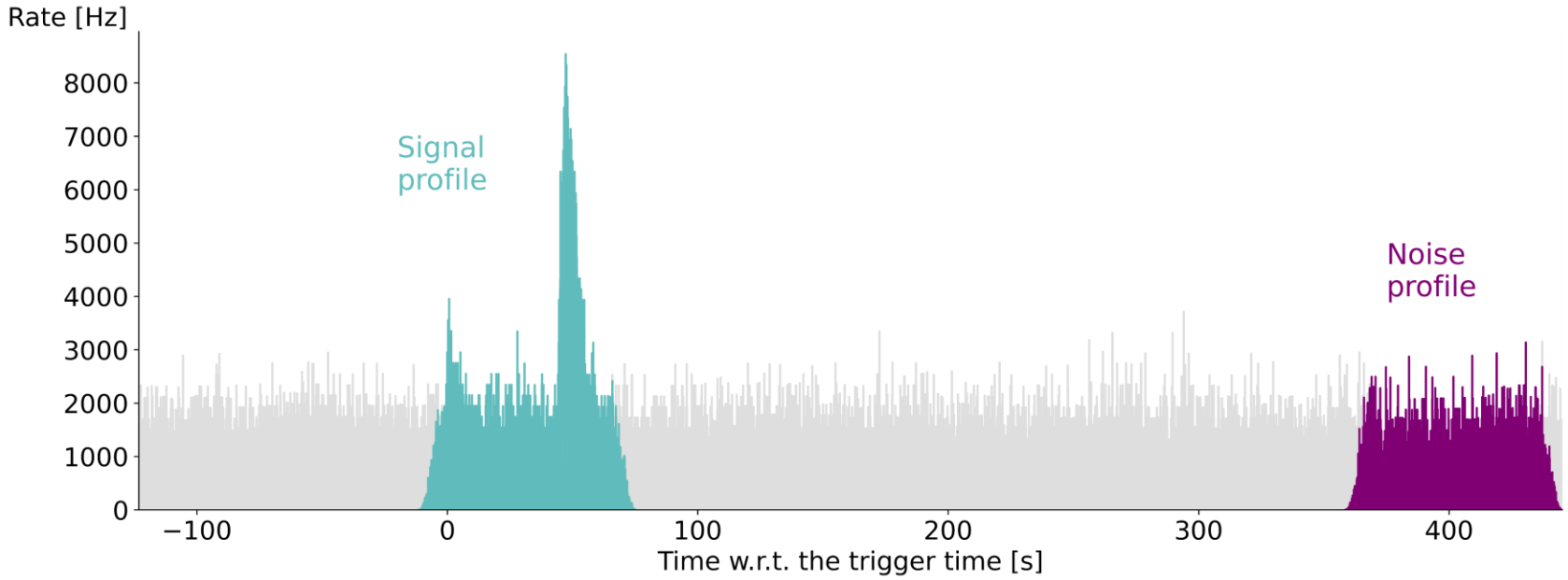
How does the slope evolve for different groups or phases of GRBs?

Step by step

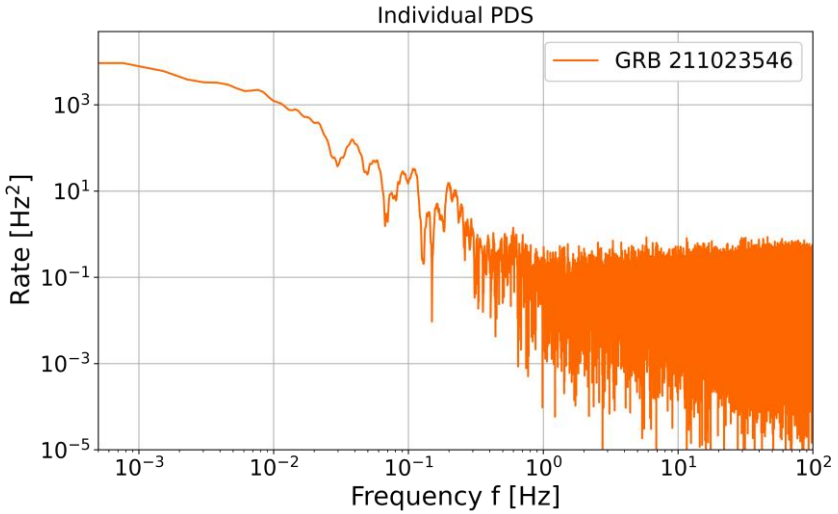
Dataset: Fermi-GBM GRBs with redshift observed between 2007-2023.

1. Generate the **redshift-corrected** light curve of each GRB;
2. Isolate the emission zones;
3. Generate the PDS of signal profile + noise profile.

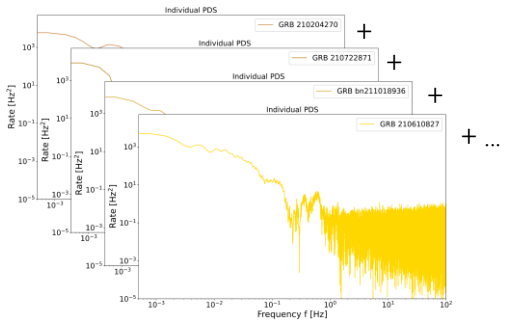
   Are the power-law features **inherent** to the gamma-ray signal?



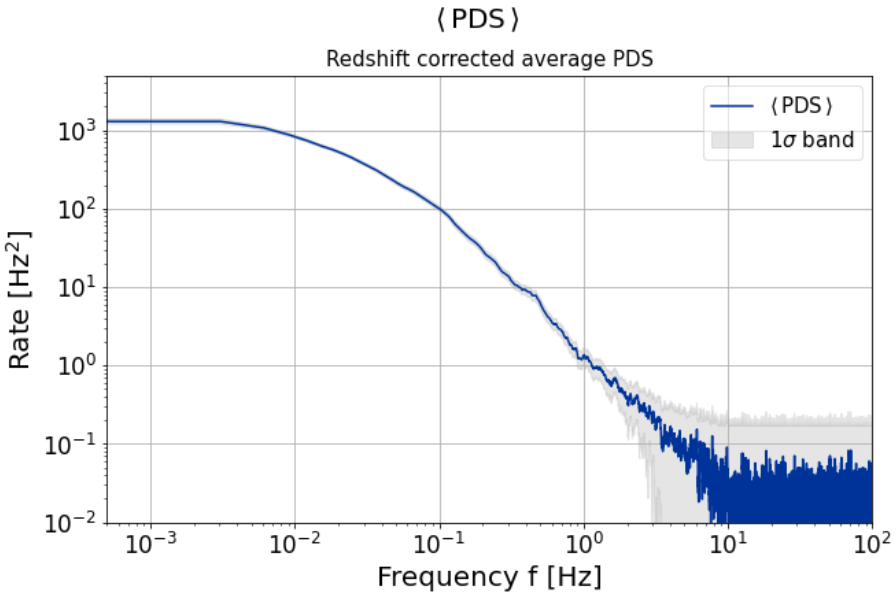
Step by step



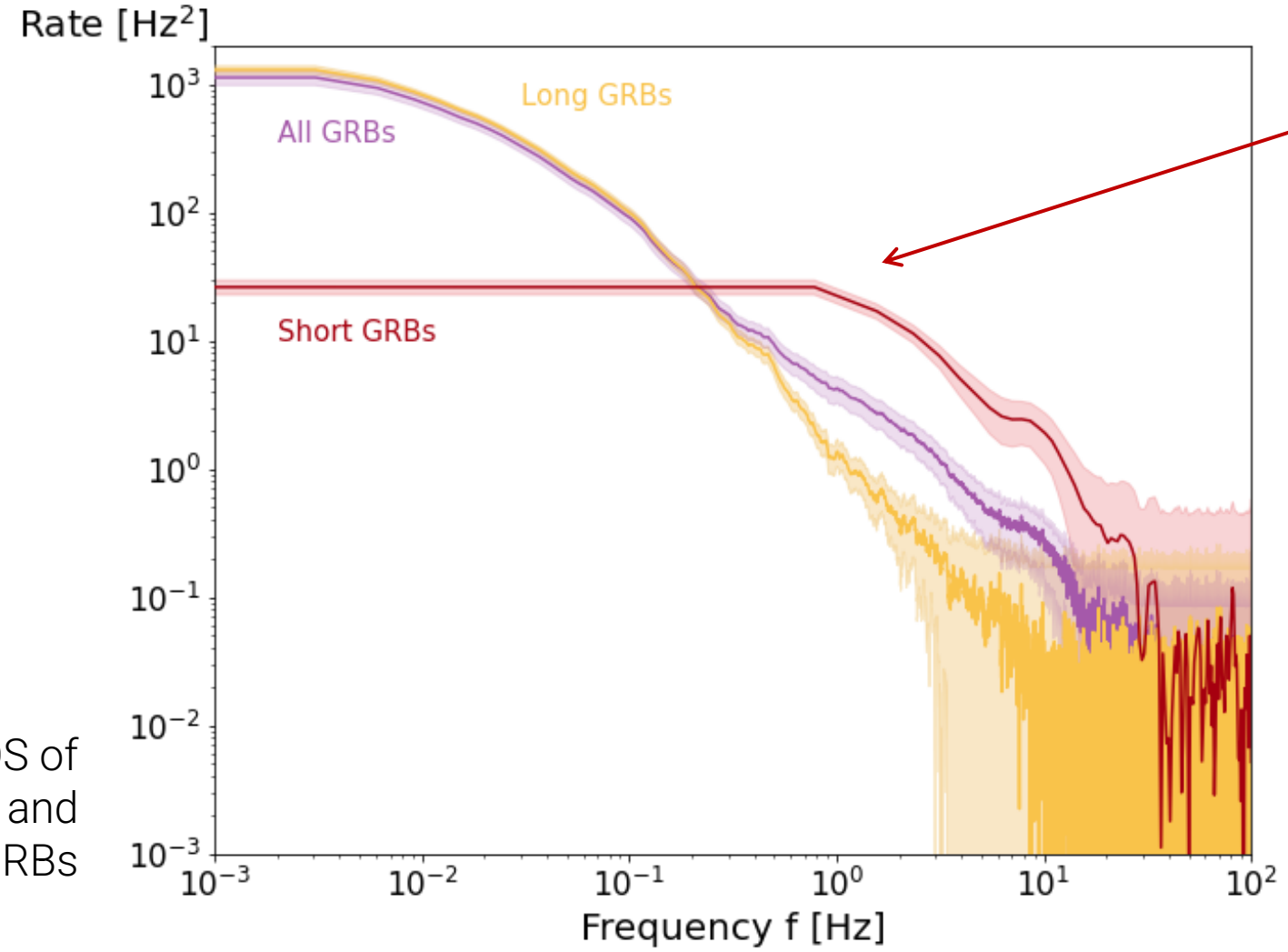
Power-density spectrum of individual GRB



Average PDS of group of GRBs



Long vs. short bursts



Short GRBs kick in at higher frequencies.

Short and long GRBs cannot be investigated as one group.

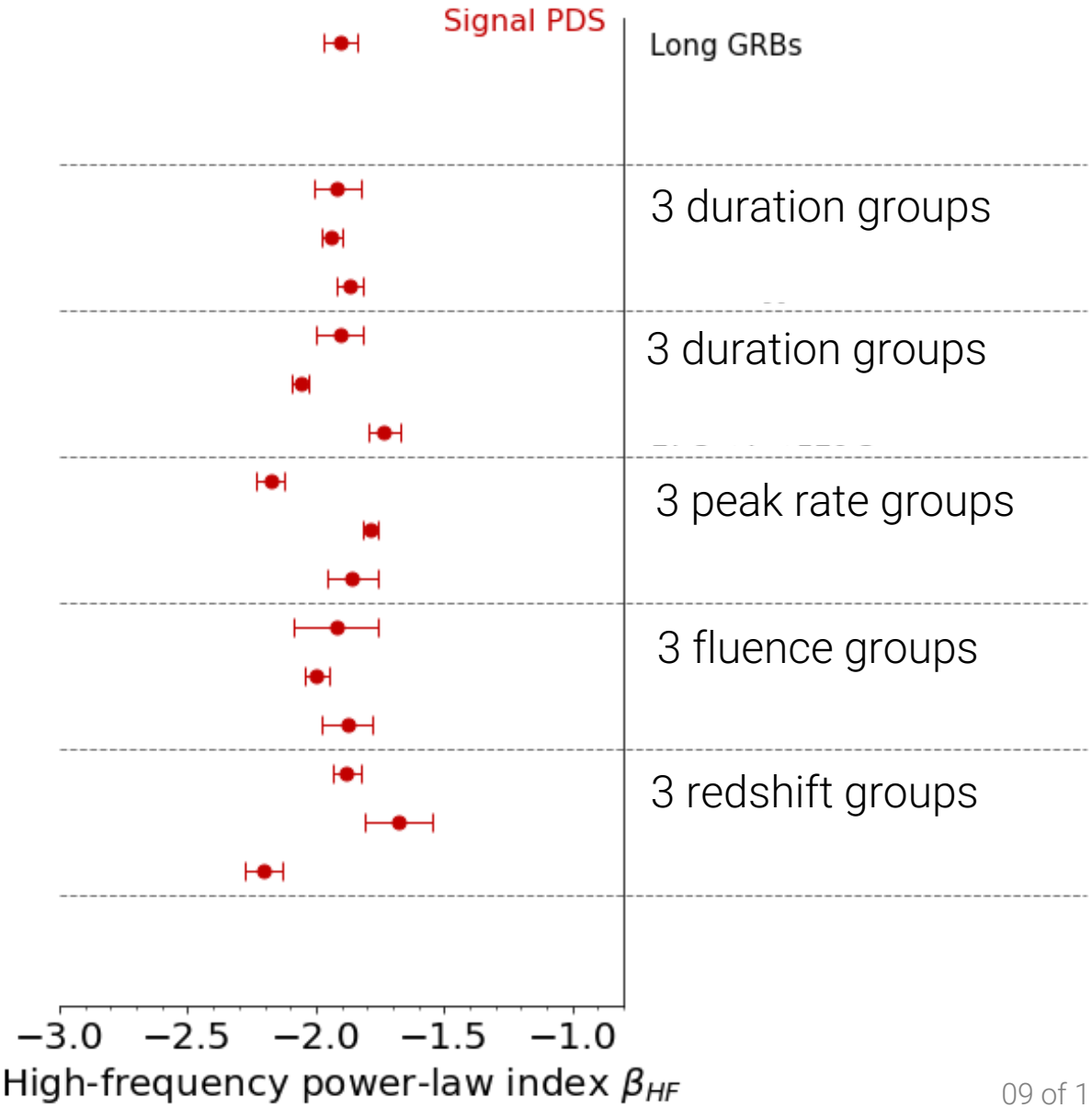
Study them separately.

Average PDS of 159 long and 24 short GRBs

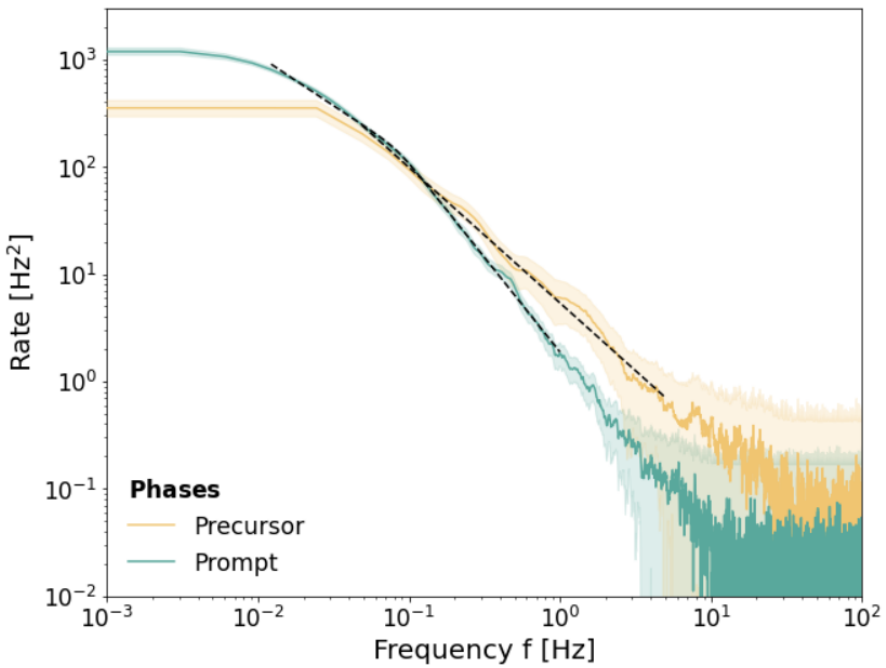
Long bursts

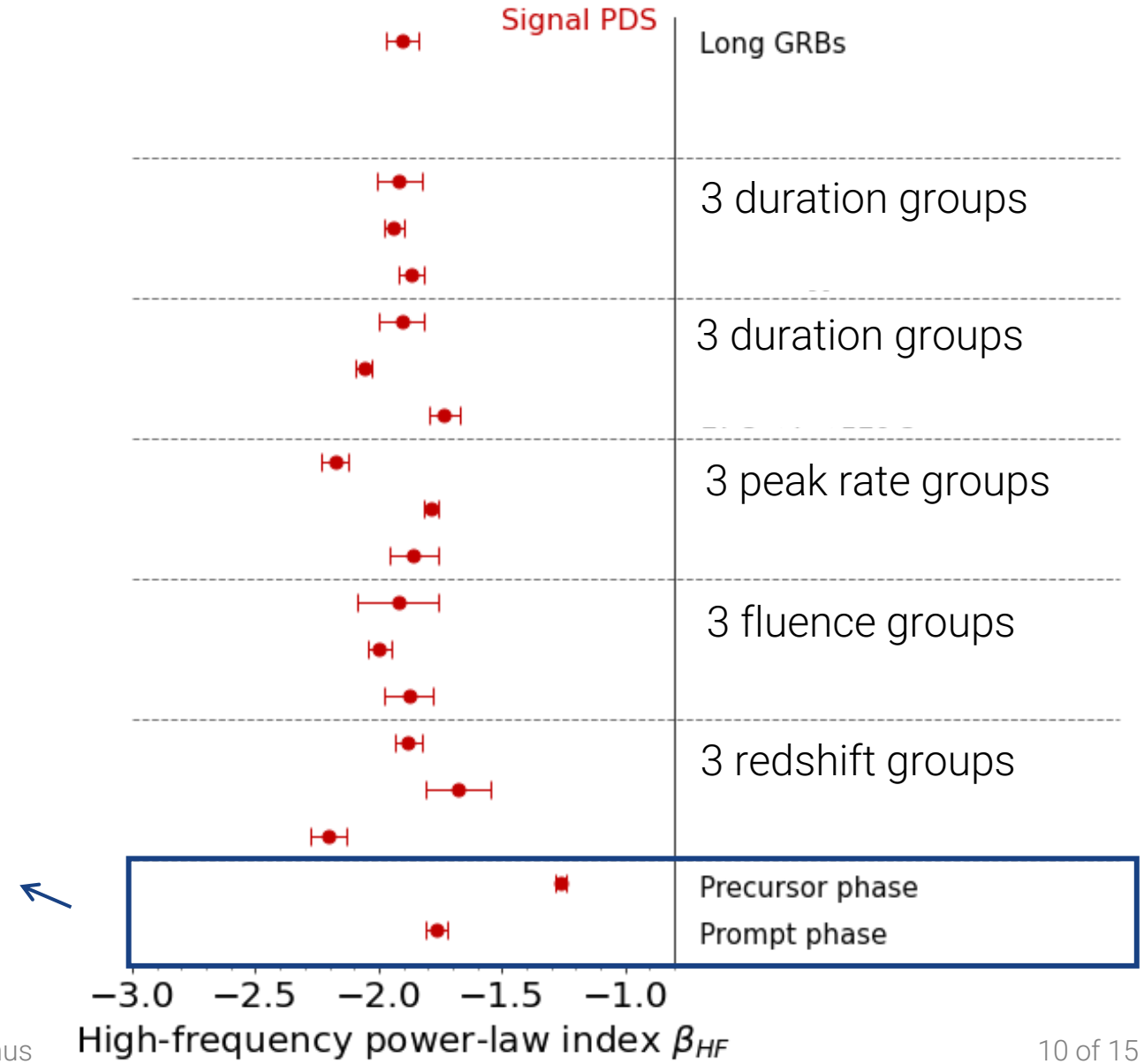
In general

- Within long bursts: no significant trend.
- All high-frequency slopes: around −1.9.



Long bursts





Prompt phase (159)

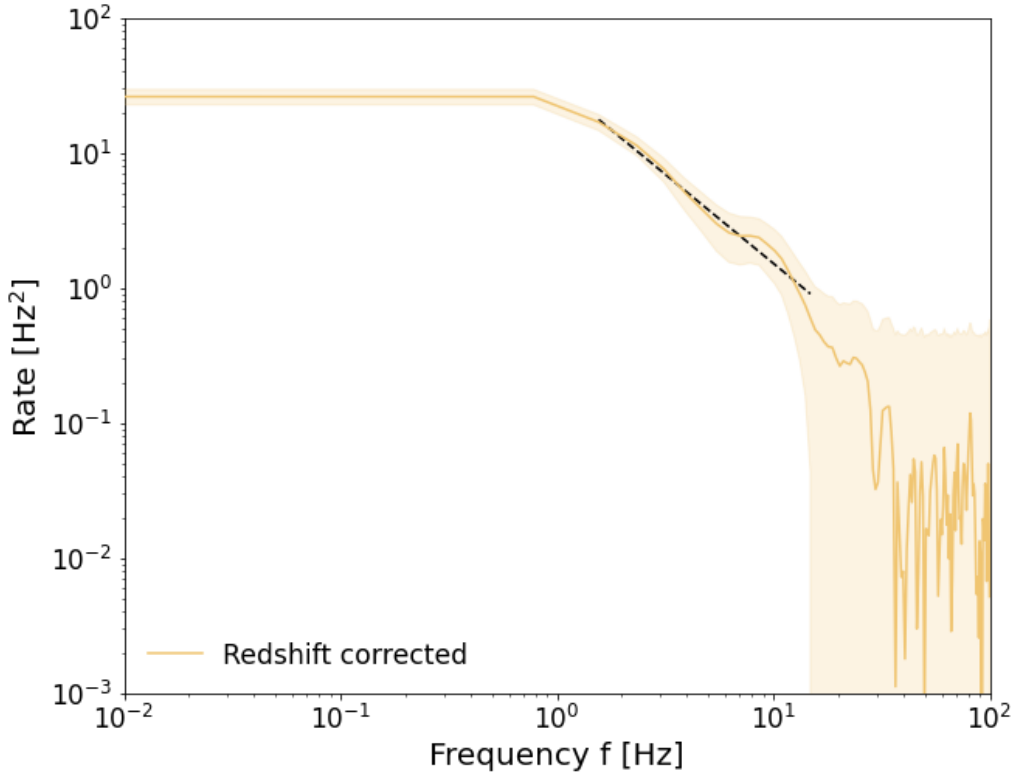
- Consistent with long bursts.

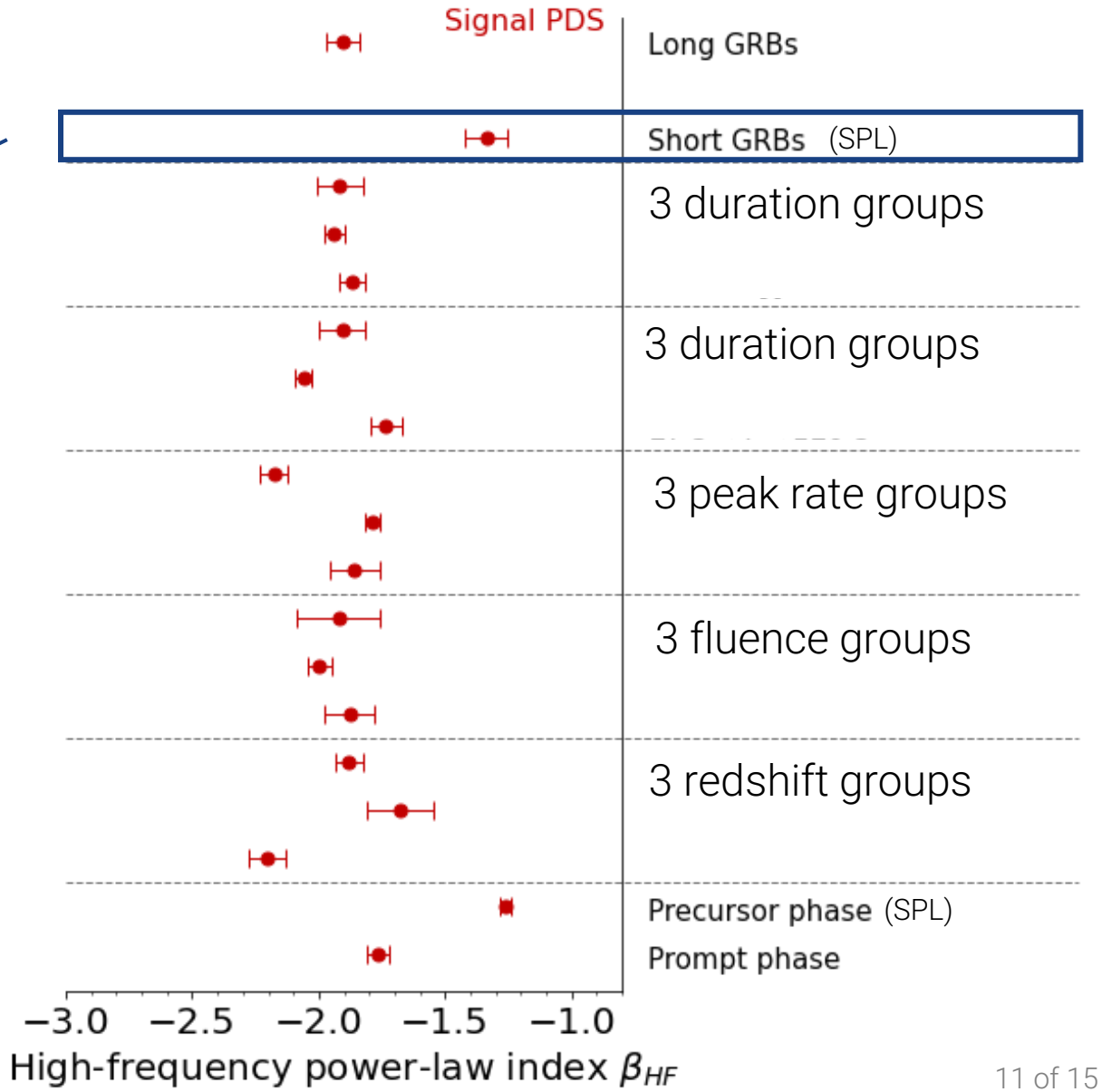
Precursor phase (26)

- Significantly diff. from prompt phase.

Short bursts

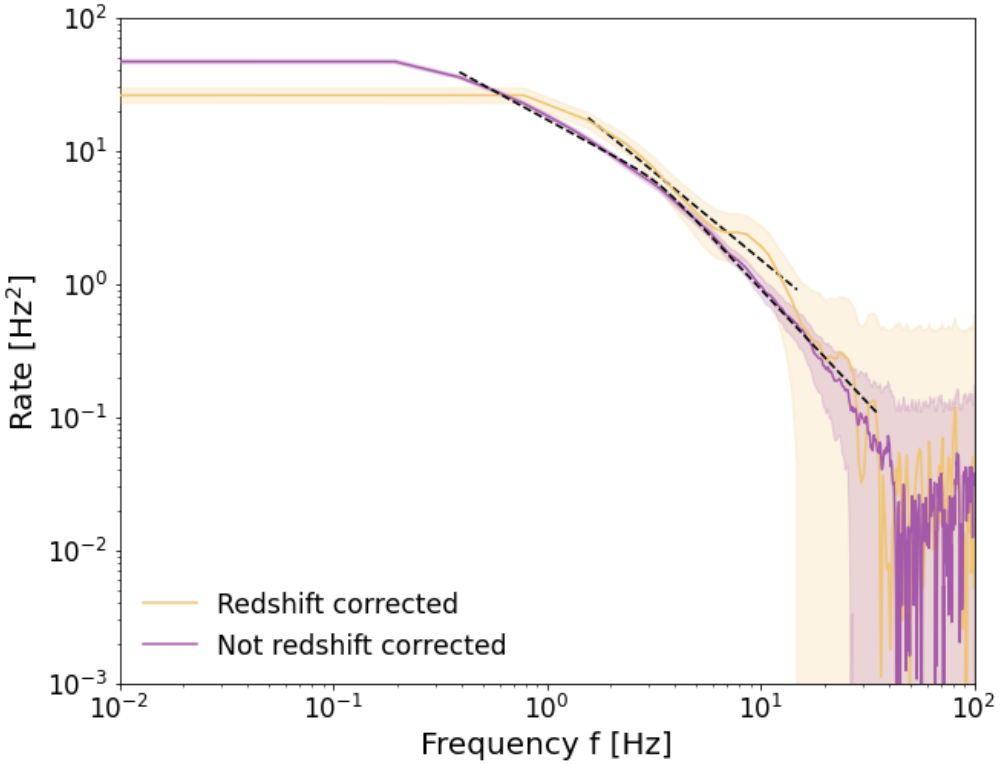
24 short GRBs with redshift

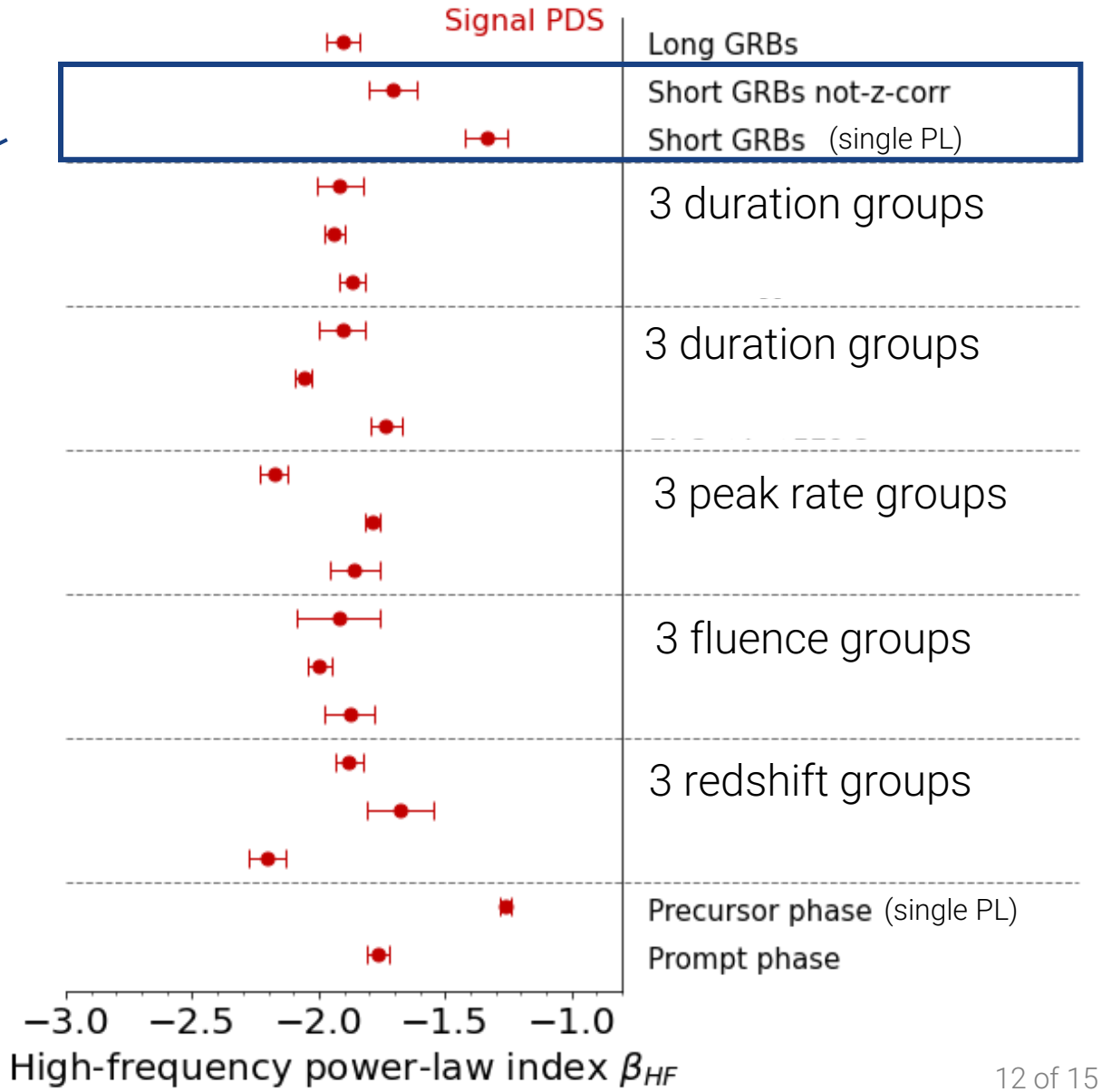




Short bursts

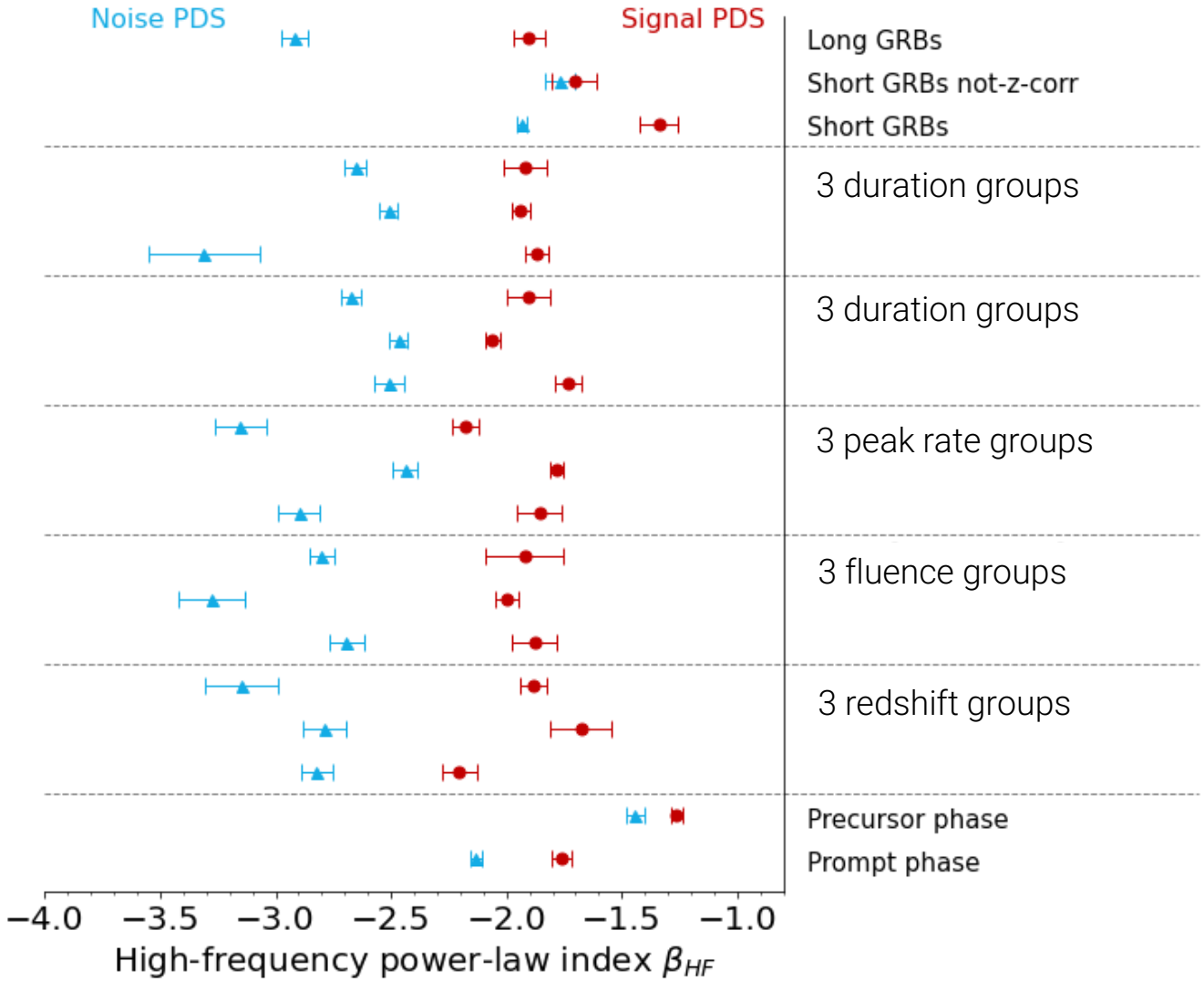
24 short GRBs with redshift
399 short GRBs with + without redshift





Noise profiles

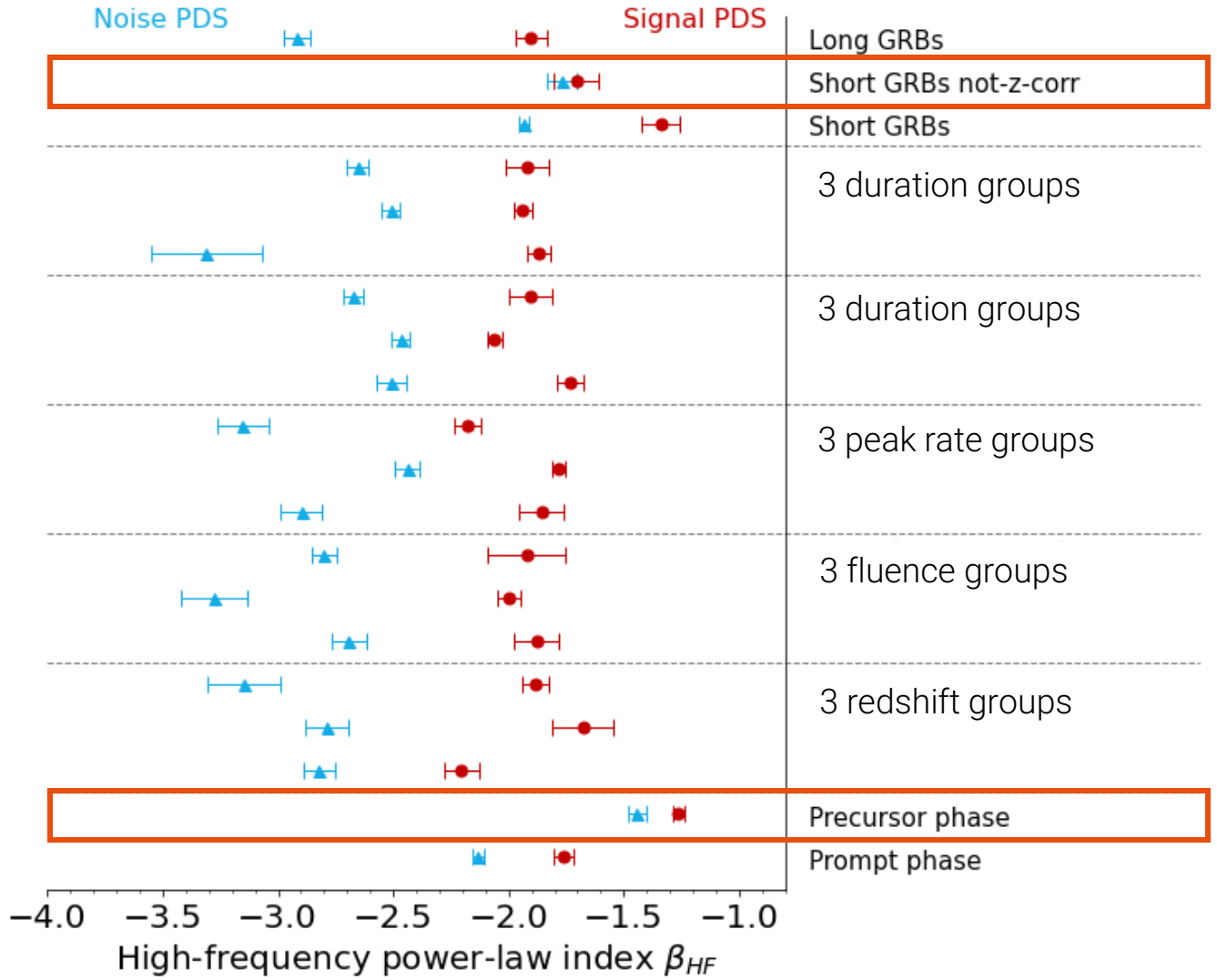
Are the power-law features **inherent** to the gamma-ray emission or **can they be produced by noise as well?**



Noise profiles

Are the power-law features **inherent** to the gamma-ray emission or **can they be produced by noise as well?**

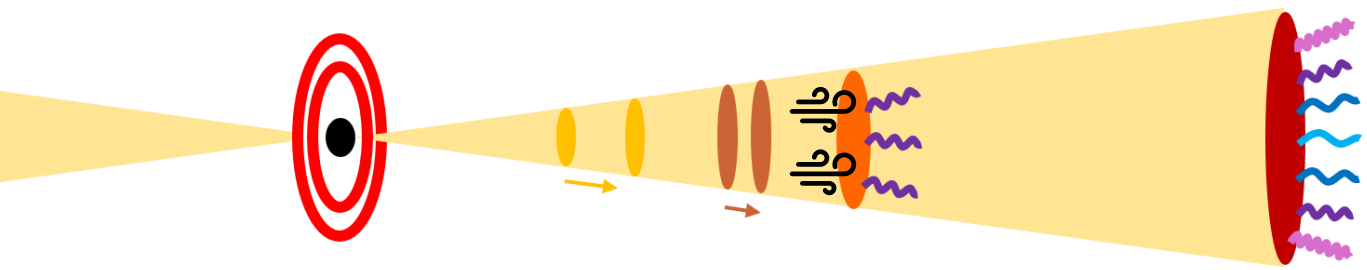
The answer is no!
Except for **short GRBs (not redshift corrected)** and **precursor emission**… there we don't know for sure.



To conclude

What can we learn from the very variable GRB light curves?

- Average PDS: Power-law behaviour → **Scale-free processes.**
- Suggestion of turbulent regions at the source of gamma-rays.
- Tension with -5/3 (Kolmogorov turbulence) → **Adaption of Kolmogorov theory?**



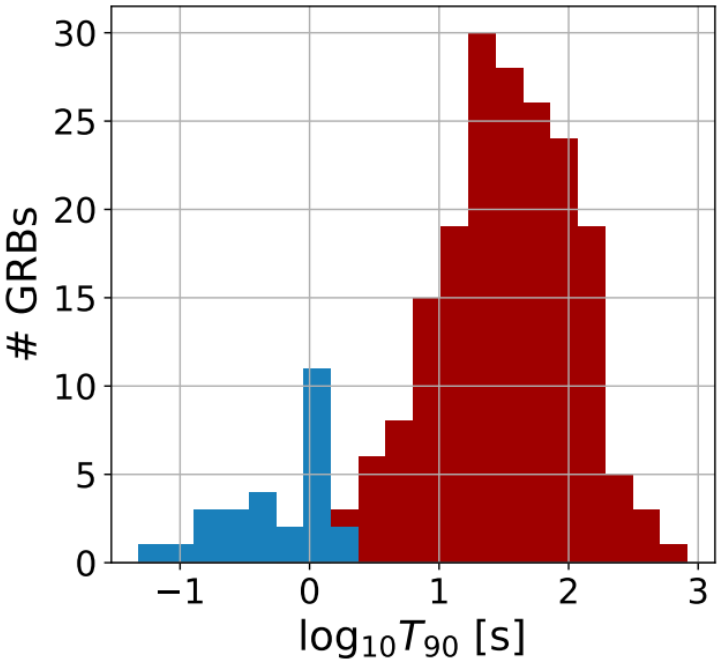
Published in
PRD 112, 083038
Arxiv:2506.09610

Contact:
Else Magnus
else.magnus@vub.be

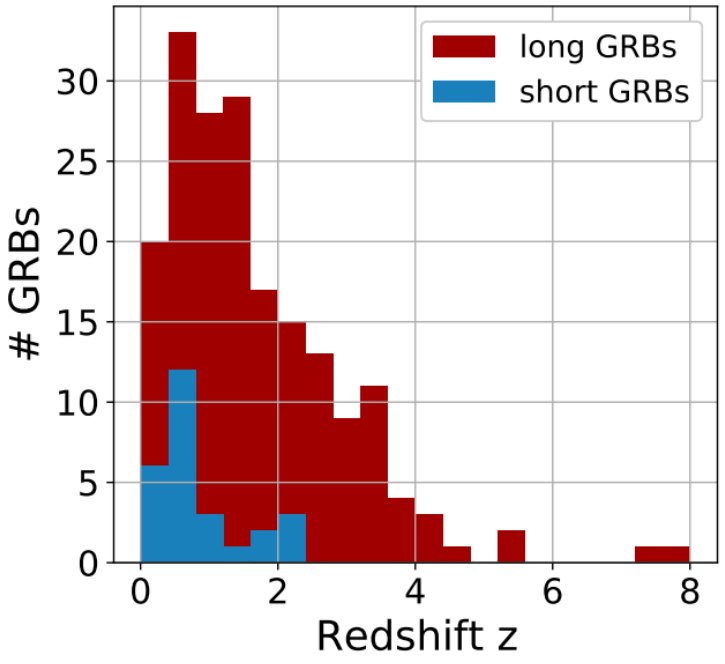
GRB information

- Fermi data from July 2008 – December 2023
- 27 short GRBs and 187 long GRBs with redshift
- 606 short bursts between July 2008 and December 2023 without redshift.

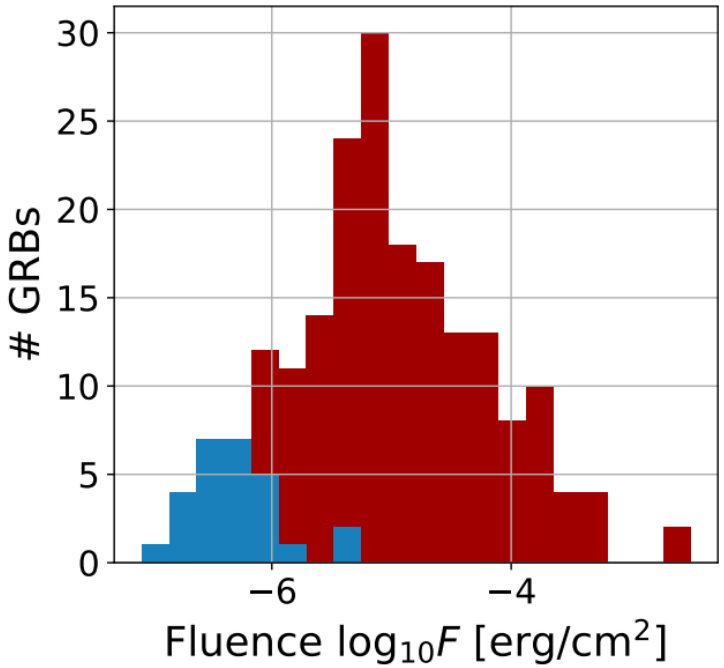
Minimal T90: 0.048 s
Maximal T90: 828.672 s



Minimal redshift: 0.0093
Maximal redshift: 8.0

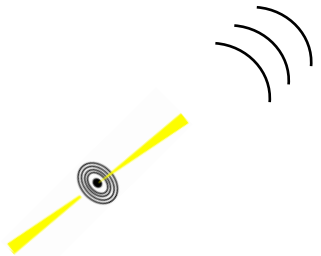


Minimal fluence: $8.2 \cdot 10^{-8}$ erg/cm²
Maximal fluence: $3.1 \cdot 10^{-3}$ erg/cm²

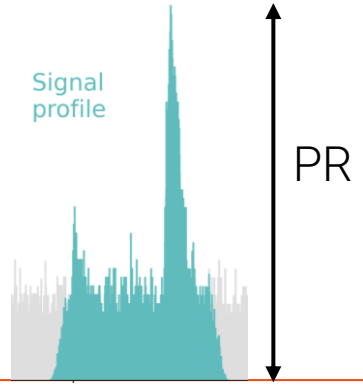


Step by step

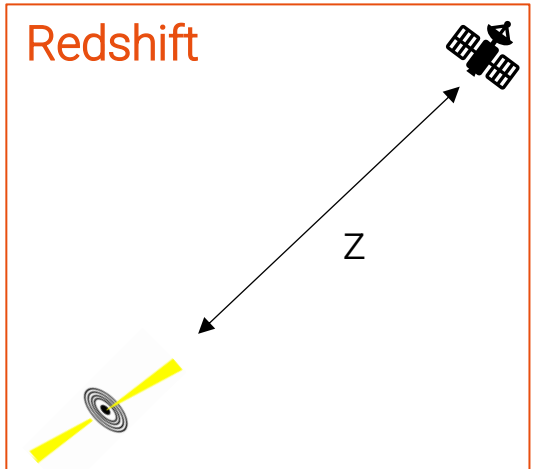
Fluence



Peak rate

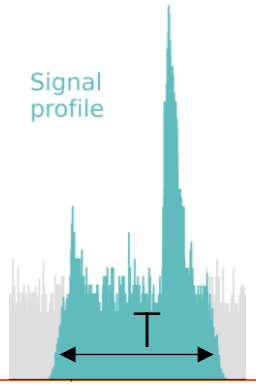


Redshift



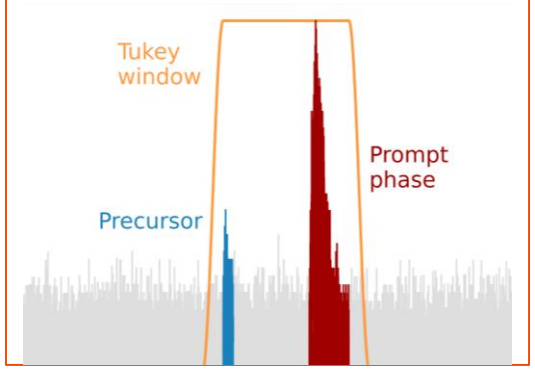
Duration

- T90 (Fermi)
- Intrinsic duration T



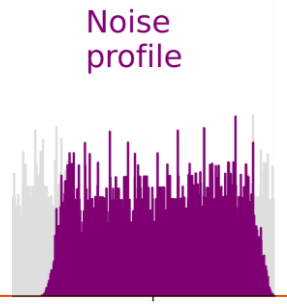
GRB phases

- Precursor
- Prompt



GRB phases

- Noise



VRIJE UNIVERSITEIT BRUSSEL

Investigate power-law behaviour for 215 Fermi-GRBs with known redshift, observed between July 2008 and December 2023.

Gamma-Ray Burst Monitor (GBM)

NaI detectors: 8 keV – 1 MeV

Fermi Gamma-Ray Space Telescope

Credit: NASA's Goddard Space Flight Center

VUB VRIJE UNIVERSITEIT BRUSSEL

Sources

- [1] NASA Universe Web Team (2024, Feb 23). *Gamma-ray Bursts: Harvisting Knowledge From the Universe's Most Powerful Explosions.* NASA. (Credit: NASA/Swift/Cruz deWilde)
  https://science.nasa.gov/universe/gamma-ray-bursts-harvesting-knowledge-from-the-universes-most-powerful-explosions/
- [2] NASA's Goddard Space Flight Center (2024, July 15). *Doomed Neutron Stars Create Blast of Light and Gravitational Waves.* Scientific Visualization Studio. (Credit: NASA's Goddard Space Flight Center/CI Lab)
  https://svs.gsfc.nasa.gov/12740/
- [3] NASA's Goddard Space Flight Center (2023, May 3). *NASA's Fermi Spots 'Fizzled" Burst from Collapsing Star.* NASA.
  https://svs.gsfc.nasa.gov/13886
- [4] Von Kienlin, A., Meegan, C. A., Paciesas, W. S., Bhat, P. N., Bissaldi, E., Briggs, M. S., ... & Wilson-Hodge, C. A. (2020). The Fourth Fermi-GBM Gamma-Ray Burst Catalog: A Decade of Data. *The Astrophysical Journal, 893*(1), 46.
- [5] F. Reddy (2023, Mar 28). *NASA Missions Study What May Be a 1-In-10,000-Year-Gamma-ray Burst.* NASA.
  https://www.nasa.gov/universe/nasa-missions-study-what-may-be-a-1-in-10000-year-gamma-ray-burst/
- [6] Zhang, B. (2018). *The Physics of Gamma-Ray Bursts*. Cambridge: Cambridge University Press.
- [7] Beloborodov, A. M., Stern, B. E., & Svensson, R. (1998). Self-similar temporal behavior of gamma-ray bursts. *The Astrophysical Journal, 508*(1), L25.
- [8] Sanderson, G. [3Blue1Brown]. (2018, November 7). *Why 5/3 is a fundamental constant for turbulence* [Video]. Youtube. https://youtu.be/_UoTTq651dE