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arXiv:2503.17216

Investigating High-Energy Time Lags in Gamma-Ray Bursts with *Fermi*-LAT and GBM

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Finanziato dall'Unione europea NextGenerationEU
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Motivation

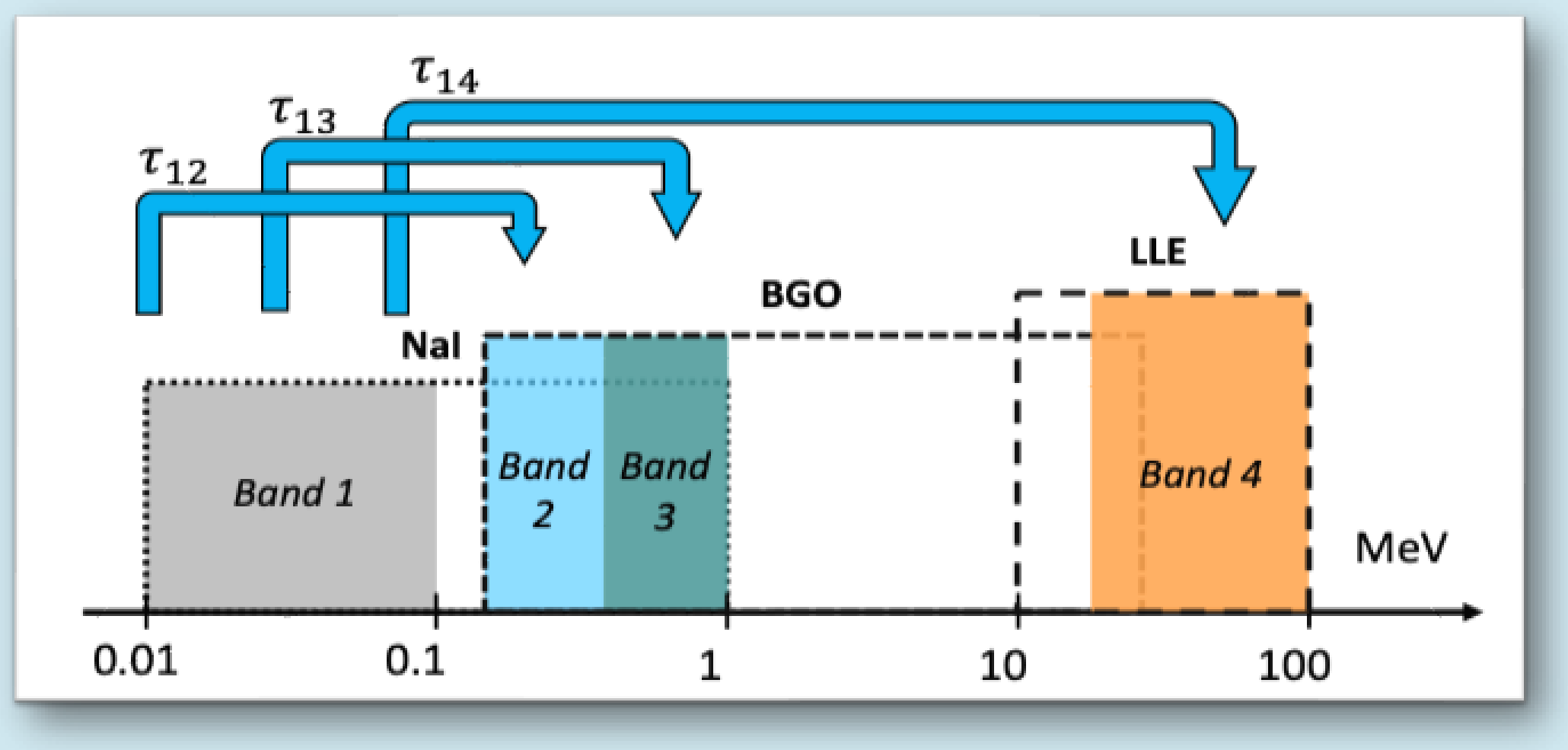
Spectral lags in Gamma-Ray Bursts (GRBs) refer to the time delay between the arrival of high- and low-energy photons. Positive lags, when high-energy photons arrive first, have been often linked to spectral evolution of the prompt emission [1] or relativistic curvature effects [2]. Negative lags, where low-energy photons arrive first, may indicate the rising of an additional high-energy emission component [3]. Traditionally, spectral lags have been measured within the same detector in narrow energy ranges [4]. **In this work, we obtain spectral lags from a sample of 70 GRBs detected by *Fermi*, considering both GBM and LAT/LLE data to explore the potential of spectral lags as a tool for identifying distinct emission processes in GRBs.**

Time Lags between GBM and LLE data

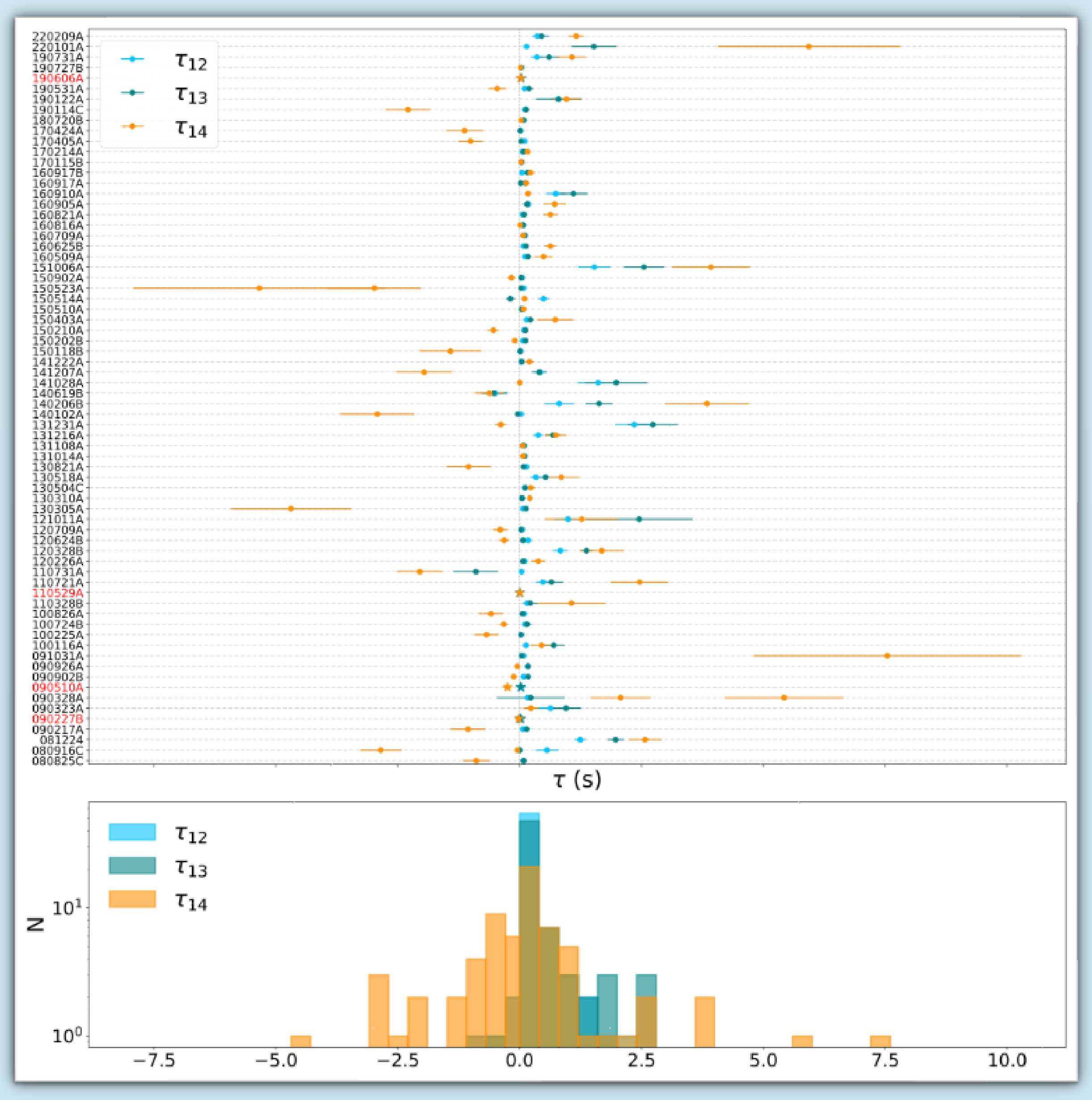
We compute spectral lags between the lowest-energy **GBM-NaI**, defined as **Band 1: 10–100 keV**, and the energy ranges:

- **GBM-BGO - Band 2: 150–500 keV**
- **GBM-BGO - Band 3: 500 keV–1 MeV**
- **LAT-LLE - Band 4: 30–100 MeV**.

We obtain spectral lags **τ_{12}, τ_{13}, and τ_{14}** by means of the discrete Cross Correlation Function method [5].



- **For long GRBs, 98% and 94% of τ_{12} and τ_{13} values are positive**, indicating soft photons lag hard ones, while negative lags are rare and not significant;
- In contrast**, only 60% of τ_{14} values are positive and are significantly longer than τ_{12} and τ_{13}**.

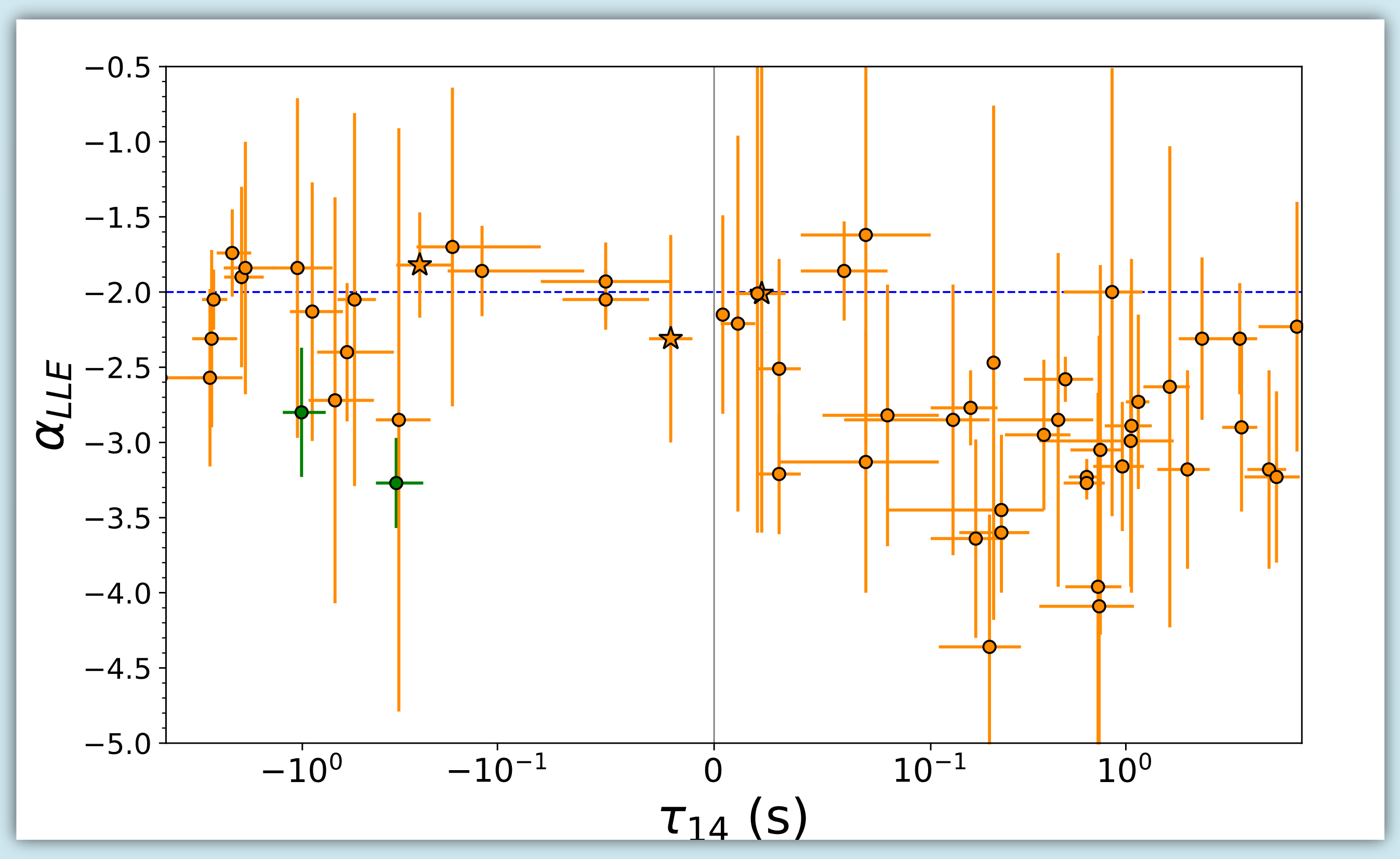


- **Some GRBs** (e.g., 080916C, 090328A, 150523A) **show secondary τ_{14} values** due to double-peaked DCFs;
- **All short GRBs** (in red) **show negligible time lags** (stars), **except for GRB 090510A**, which shows a significantly negative τ_{14} lag.

Time Lags and Spectral Evolution of GRBs

We propose that the LLE emission (30-100 MeV) can either extend the prompt phase or appear as a delayed, harder component.

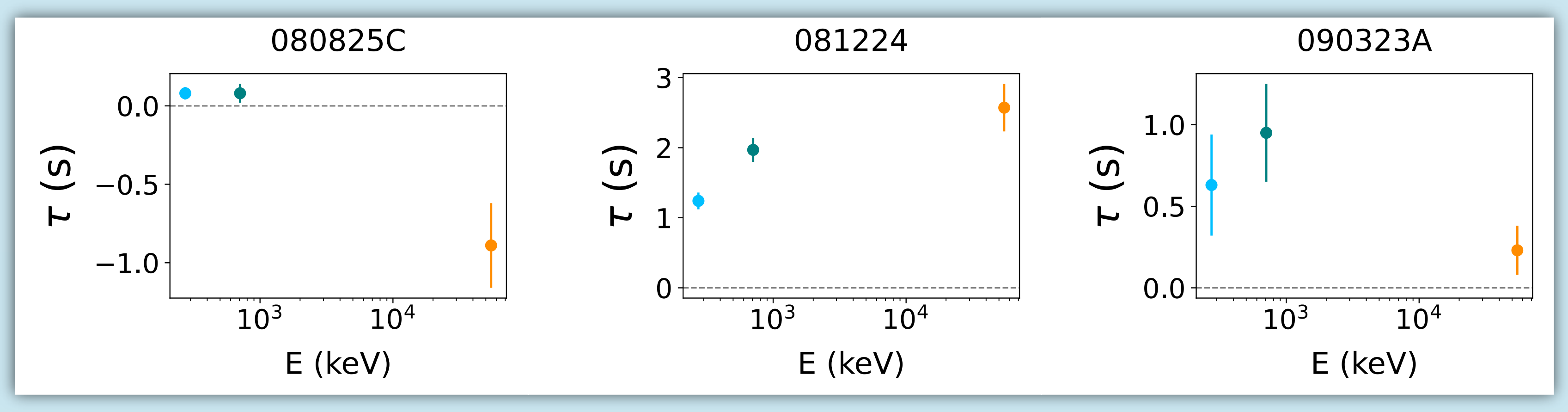
By comparing τ_{14} spectral lags with the LLE photon index α_{LLE}, we find a modest correlation where **positive τ_{14} values suggest a hard-to-soft evolution, while negative τ_{14} points to a new, harder component**. Two GRBs deviate from this expected trend (green points).



Time Lags and Energy

By **comparing the three spectral lag values with the mean energy of the respective channel**s (Band 2, Band 3, and Band 4), **two main trends are seen**:

- **40% of GRBs show a decreasing lag with energy**, transitioning from positive to negative at around 10–100 MeV (left plot);
- **36% of GRBs exhibit increasing lags with energy** (central plot);
- **24% of GRBs display irregular patterns**, likely due to low signal-to-noise ratio or complex light curve structures (right plot).



Conclusion

Lags within the GBM energy range (10 keV – 1 MeV) are predominantly positive (76%), namely lower-energy photons arrive later than higher-energy ones as a possible consequence of a hard to soft spectral evolution. However, when comparing LLE (30–100 MeV) and GBM bands, in 37% of cases high-energy photons are delayed relative to low-energy ones. These negative lags can be interpreted as due to an additional spectral component rising in the LLE energy range as supported by the spectral analysis of these events.

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