Credit: ESO

1° CTAO School, June 16-22, 2024 – Bertinoro (Italy), La Palma (Spain)

Time Delays Between LLE and GBM light curves of GRBs

A CROSS CORRELATION ANALYSIS

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Gamma-Ray Bursts Origin and Classification

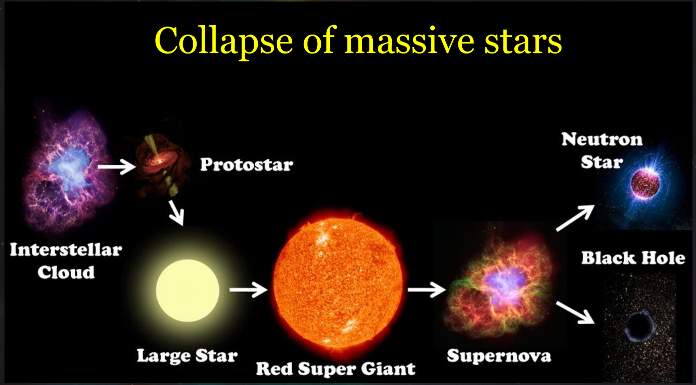
GRBs are classified by duration into:

Long GRBs (> 2 s)

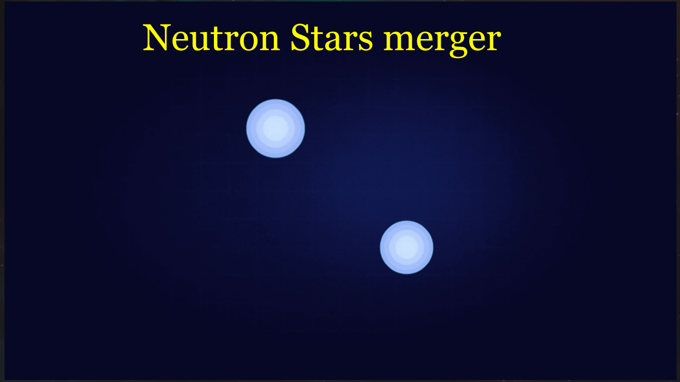
- Collapse of massive stars;
- Found in young, active galaxies.

Short GRBs (< 2 s)

- Neutron Star / Black Holes mergers ;
- Found in older, less active galaxies;
- Lack associated Supernovae.



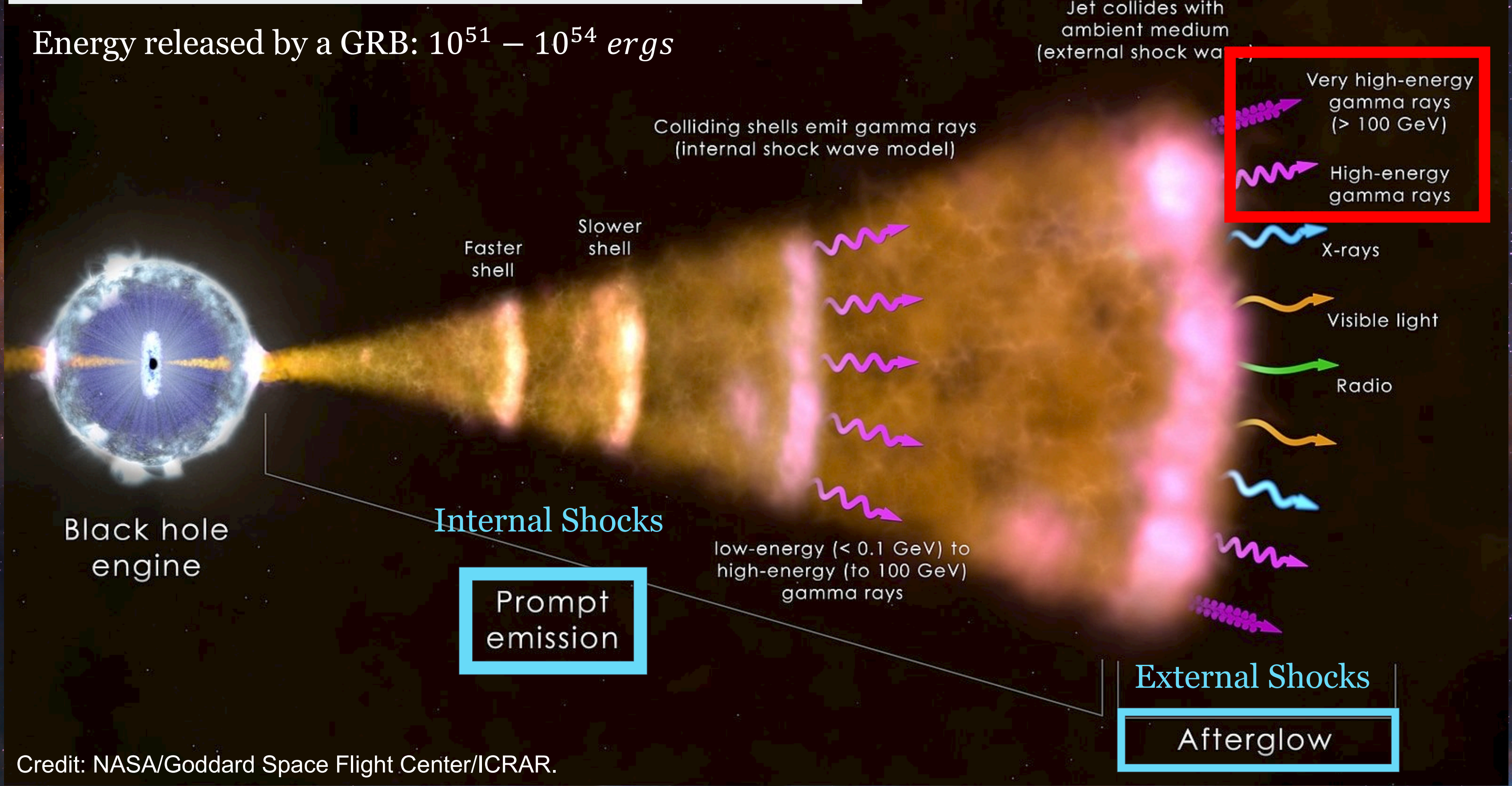
Credit: NASA



Credit: MIT

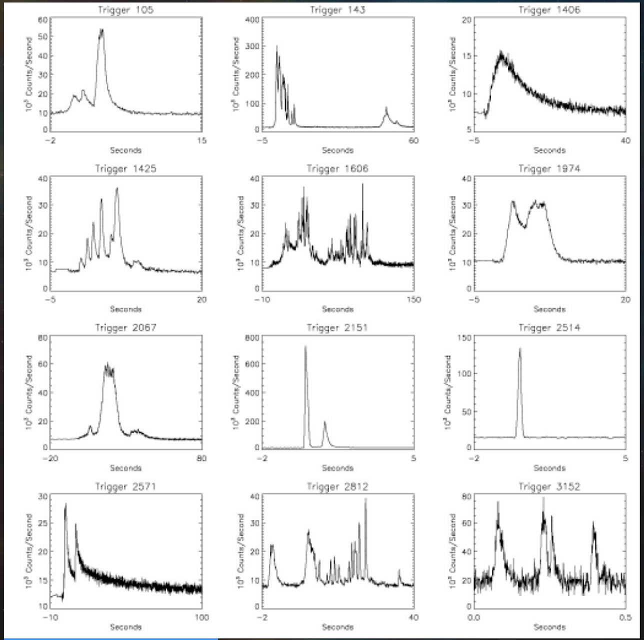
The Fireball Model of Gamma-Ray Bursts

Energy released by a GRB: $10^{51} - 10^{54}\ ergs$

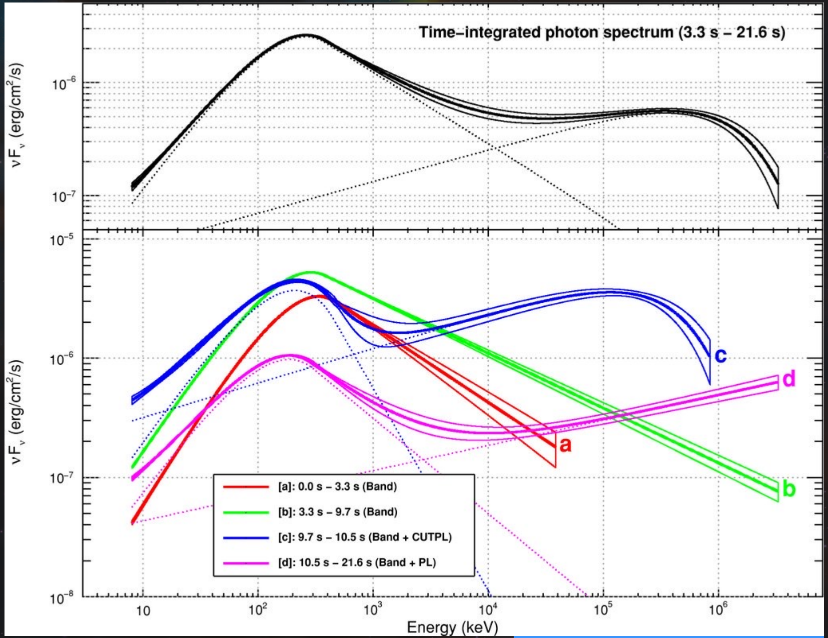


Credit: NASA/Goddard Space Flight Center/ICRAR.

Light Curves and Spectra of Gamma-Ray Bursts



Dereli, 2015

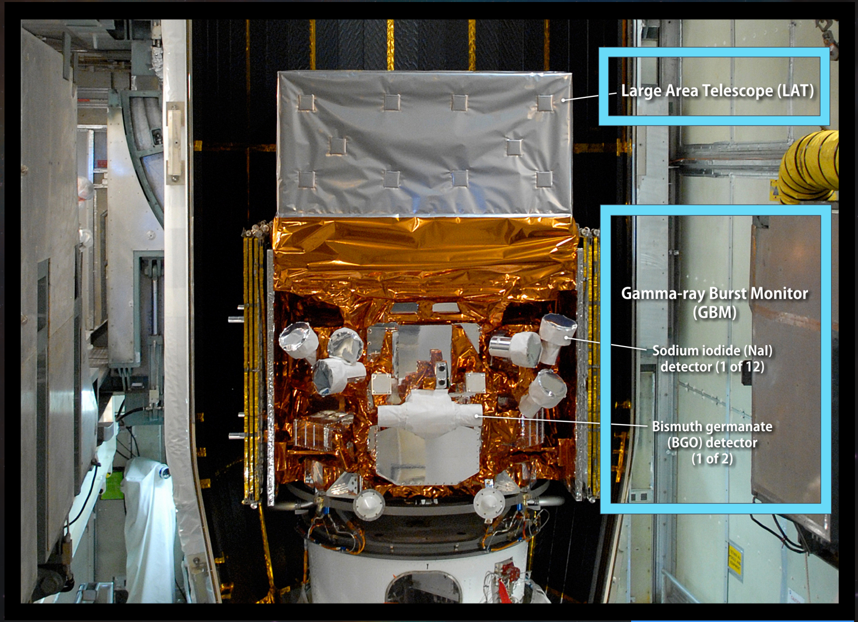


M. Ackermann + 2011

PROMPT + AFTERGLOW ➡️ **BAND FUNCTION + EXTRA COMPONENT**

If you see one GRB …. You see ONLY one GRB!

The Fermi Gamma Ray Space Telescope



Credit: NASA/Goddard Space Flight Center.

Atwood + 2009

Gamma-ray Burst Monitor (GBM):

Broad energy range: 8 keV to 40 MeV.

Large Area Telescope (LAT):

20 MeV to over 300 GeV.

LAT Low Energy (LLE) Events:

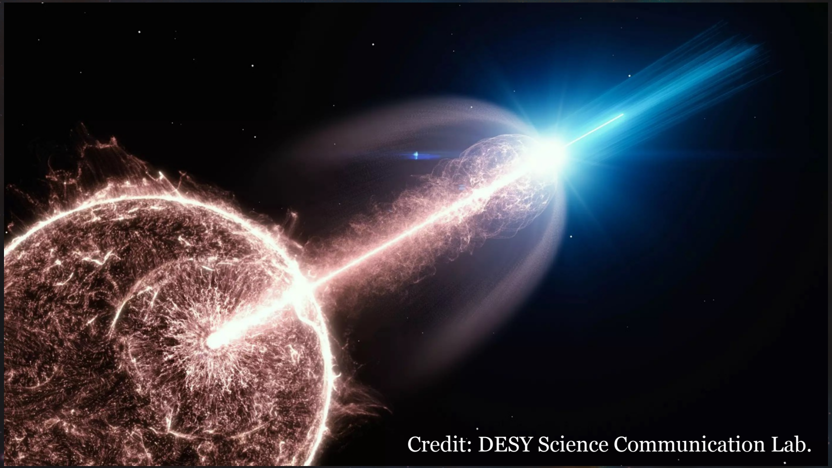
Extends LAT sensitivity down to about 10 MeV.

Cross-Correlation Analysis of GRB Light Curves Using GBM and LLE Data

Meszaros & Rees 1999, Ghirlanda + 2010

Study Overview:
- Cross-correlation of GBM/LLE light curves of GRBs;
- Comparing keV / MeV emissions.

Previous Fundings:
- HE Fermi LAT emission (MeV-GeV) delayed with respect to keV emission;
- May interpreted as an additional component (early afterglow).

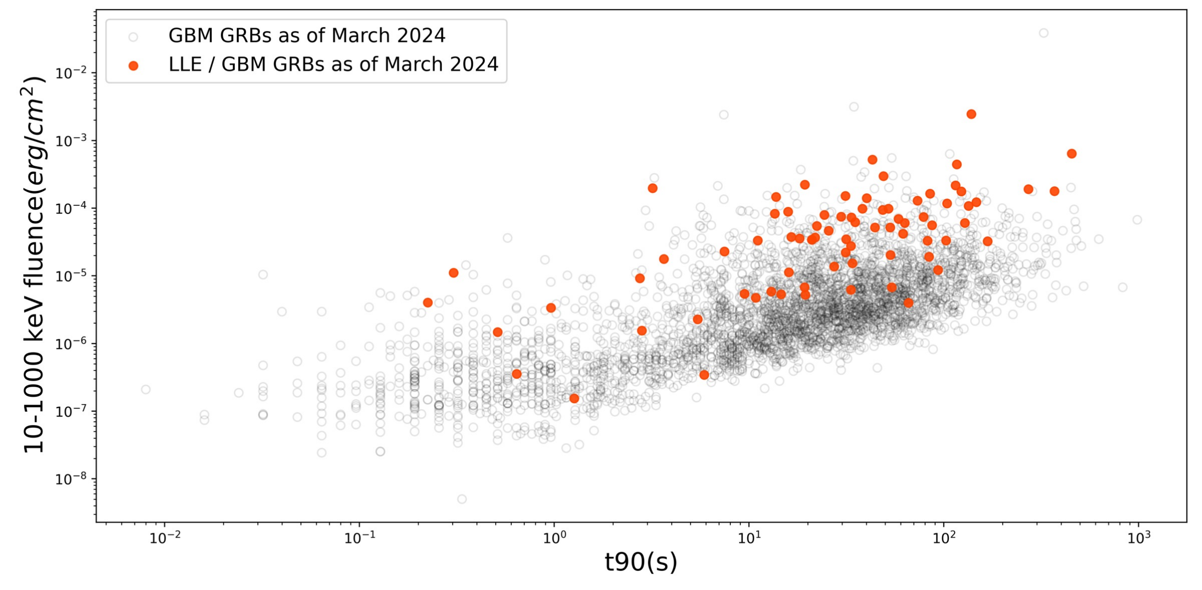

Credit: DESY Science Communication Lab.

Positive Lags:
- Presence of an additional component, likely an early afterglow.

Negative Lags:
- Absence of such component;

- Reflects GRB spectral evolution (emission becomes softer over time).

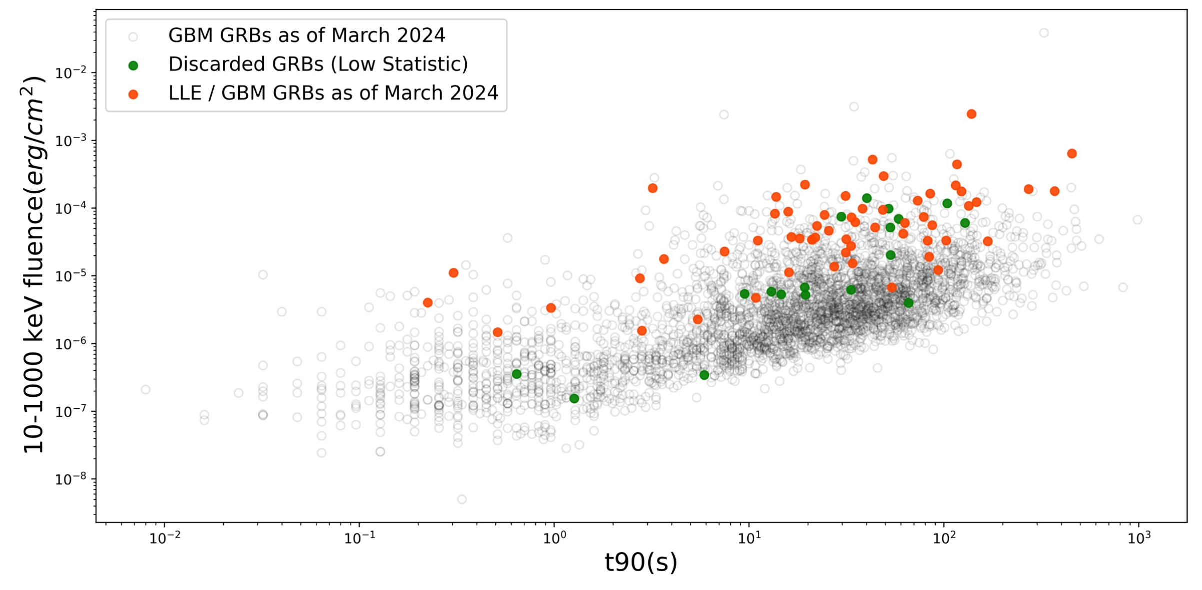
The Data Sample



Maraventano + 2024 (in prep.)

- Original sample composed of 77 GRBs (as of March 2024);
- Successfully analysed : 59 ;
- Of these, 4 are SGRBs (T90 < 2 s).

The Data Sample



Maraventano + 2024 (in prep.)

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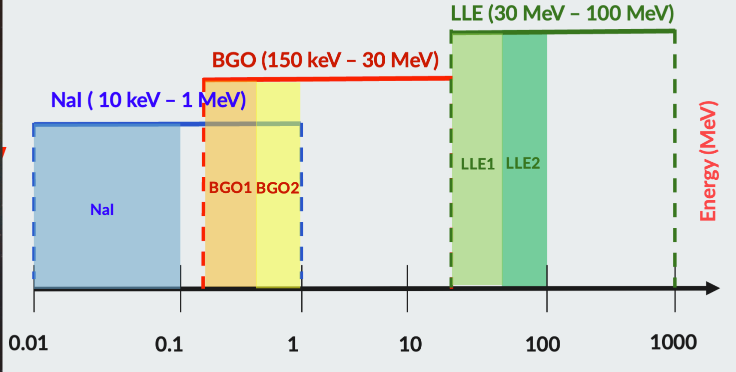
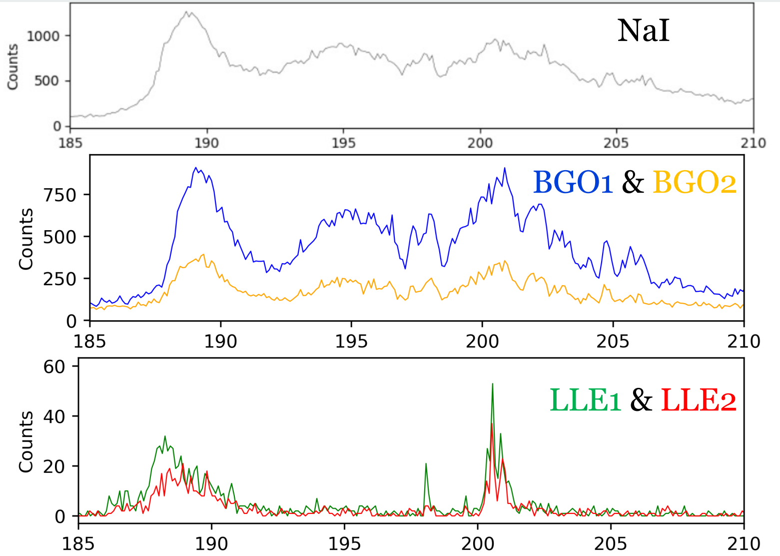
GBM / LLE data selection and Cross-Correlation Analysis



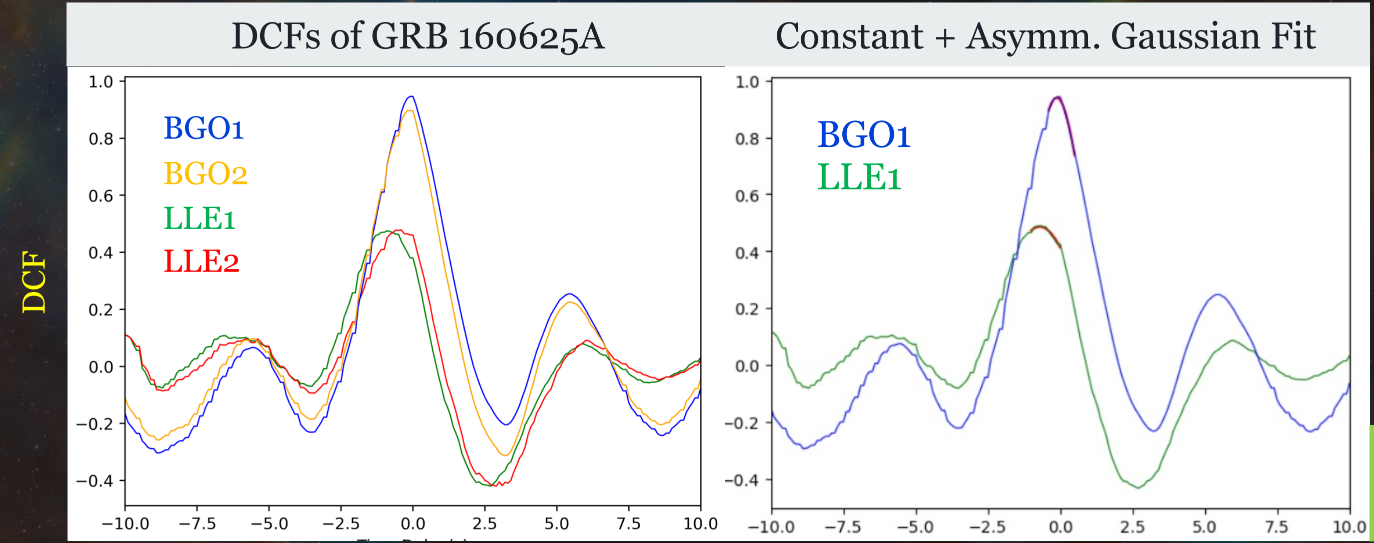
NaI : 10 keV – 100 keV	60 % of total NaI events
BGO1 : 150 keV – 500 keV BGO2 : 500 keV - 1 MeV	90 % of total BGO events
LLE1 : 30 MeV – 50 MeV LLE2 : 50 MeV – 100 MeV	90 % of total LLE events

Example: Light curves of GRB 160625B



Times (s) from Trigger Time

The Discrete Correlation Function (DCF) Method



Maraventano + 2024 (in prep.)

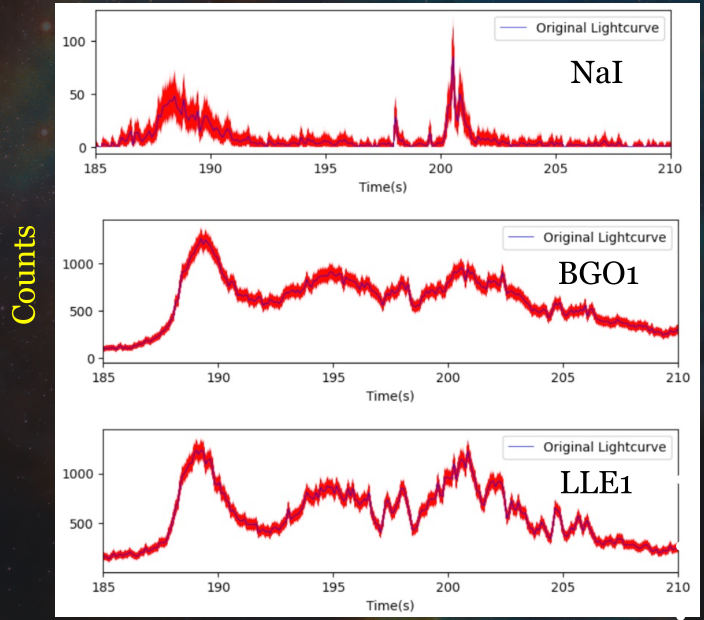
Times (s) from Trigger Time

A maximum in the DCF indicates a direct correlation of the data

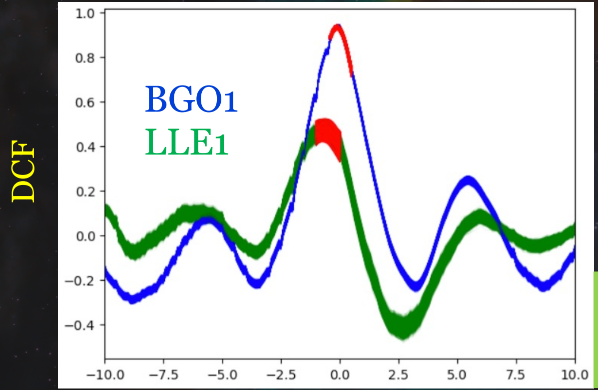
Methodology introduced by Edelson & Krolik 1998
Followed in Pian + 2000, Del Monte + 2011, Ackermann + 2013.

Quantifiying Significance of Time Lags via Monte Carlo simulations

Simulated light curves and DCFs of GRB 160525B



Times (s) from Trigger Time



Maraventano + 2024 (in prep.)

Times (s) from Trigger Time

Generated N = 10.000 random GBM and LLE LCs;

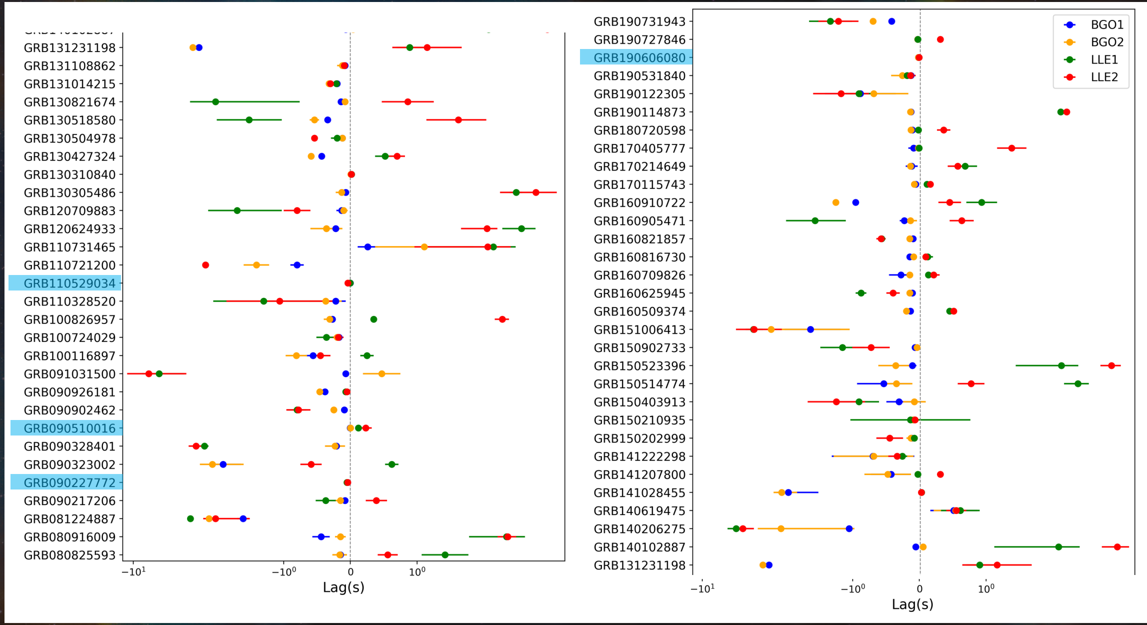
Pairwise correlation using DCF method;

Uncertainty given as std of the lag distribution.

Methodology by Peterson + 1998 and Zhang + 1999

Time Lags of All The 59 Analysed GRBs

ANALYSED GRB

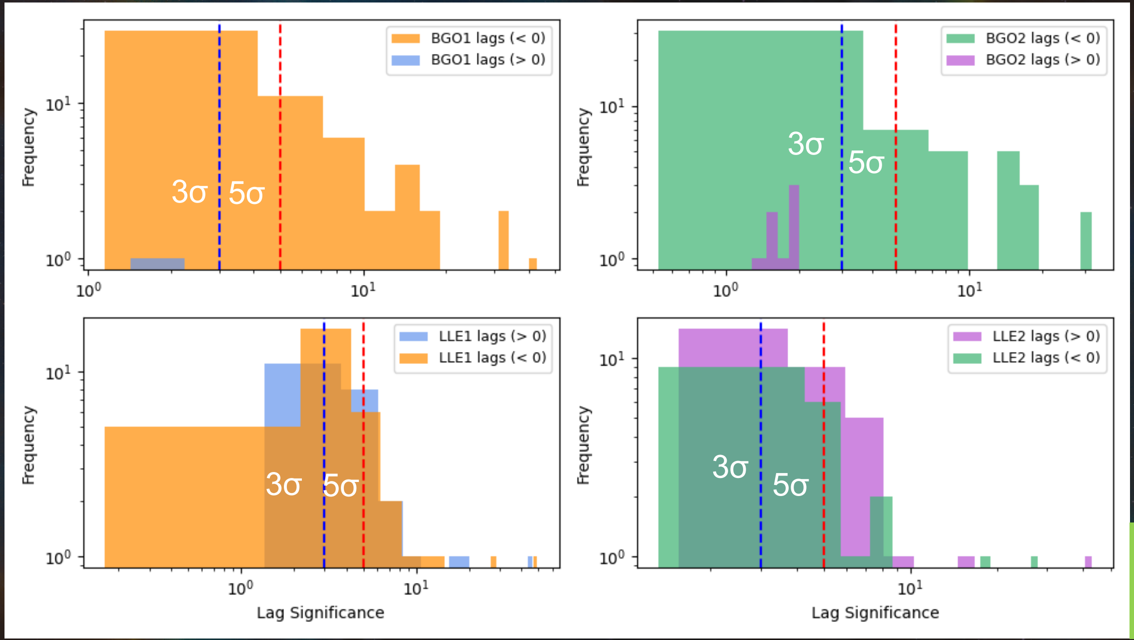


Maraventano + 2024 (in prep.)

- BGO/NaI delays are fraction of seconds and tipically negative;
- LLE/NaI lags are larger (few seconds), both positive and negative.

Similar results found for LAT data in Abdo + 2009, Giuliani + 2010, Del Monte + 2011, Ackermann + 2011, 2013

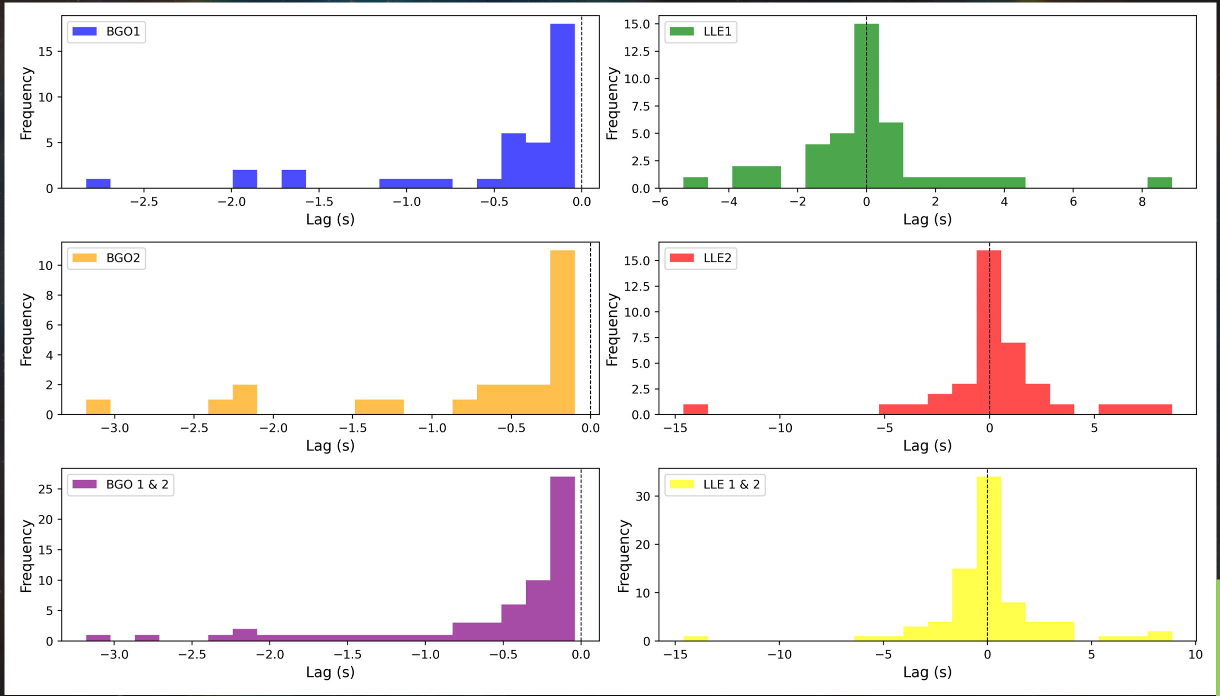
Time Lag Significances



Maraventano + 2024 (in prep.)

- Positive lags in NaI-BGO correlations lack statistical significance;
- LLE 1&2 lags show no significant difference between positive and negative values.

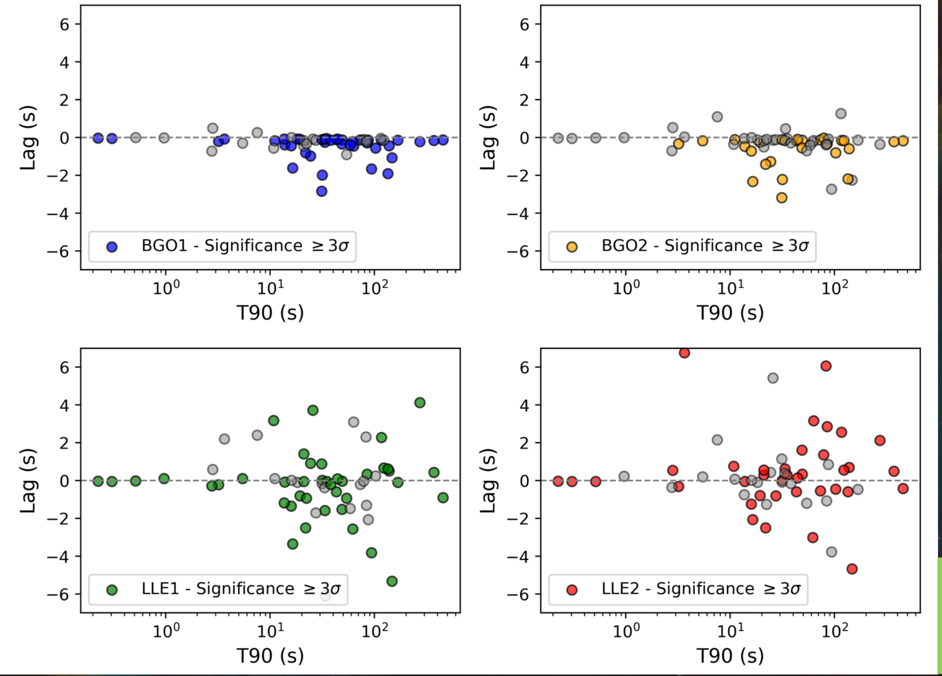
Time Lags Distribution of All The 59 Analysed GRBs



Maraventano + 2024 (in prep.)

- Emissions above 30 MeV have variable delays;
- Sub-100 keV emissions consistently lag behind higher energy emissions by fractions of a second.

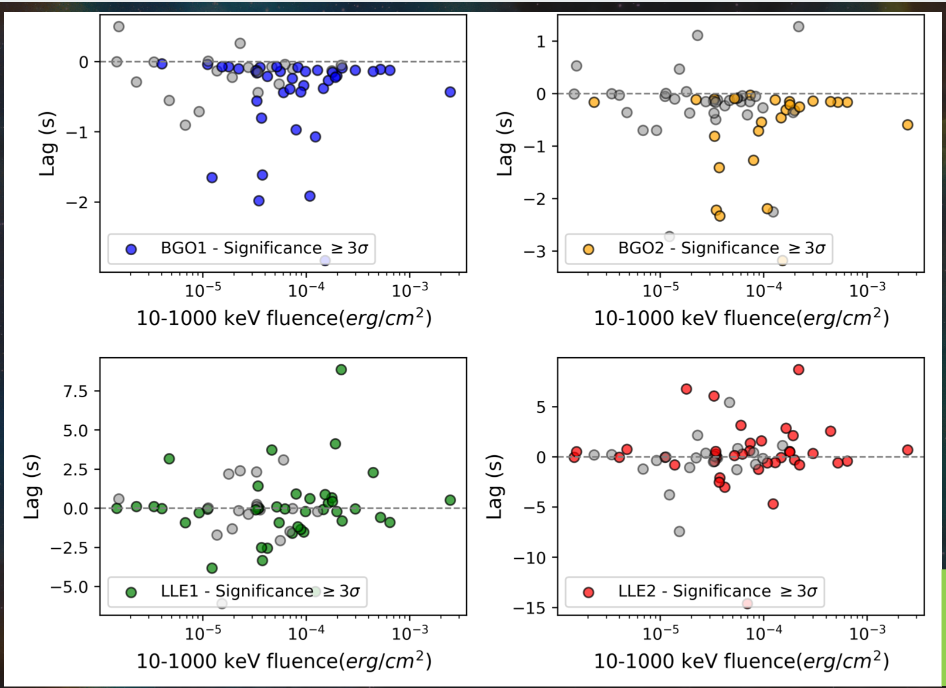
Time Lag VS T90



Maraventano + 2024 (in prep.)

- Above 30 MeV, larger and positive time lags arise;
- Short GRBs exhibit minimal or zero time lags *As found also in Bernardini, Ghirlanda 2014*

Time Lag VS GBM fluence (10 - 1000 keV)



Maraventano + 2024 (in prep.)

- Significant lags are harder to detect at low fluence due to low statistics;
- Larger lags seem to occur at intermediate fluence within the sample.

Interpretation of GBM/LLE Time Lags

Spectral Evolution:

Delays may result from the spectral evolution between keV and MeV-GeV energies emission.

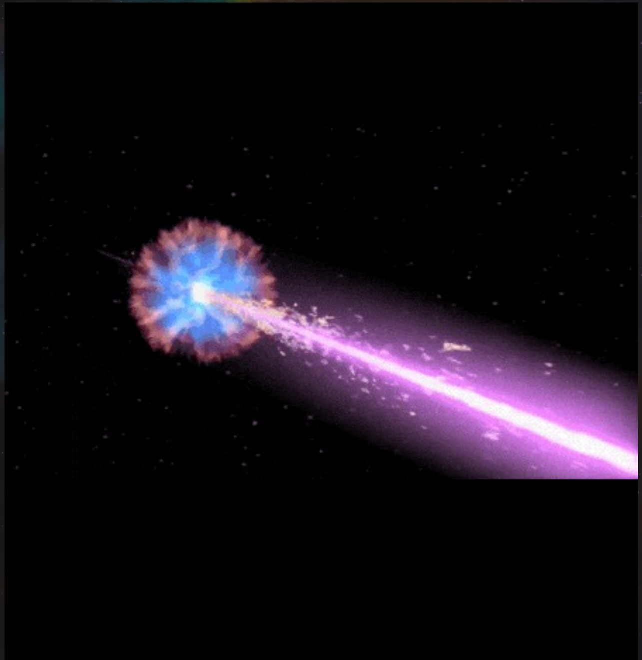
Emission Mechanisms:

Differences in emission mechanisms could explain observed delays.

Emission Regions:

Variations in emission regions may also contribute to these delays.

Meszaros & Rees 1999, Ghirlanda + 2010

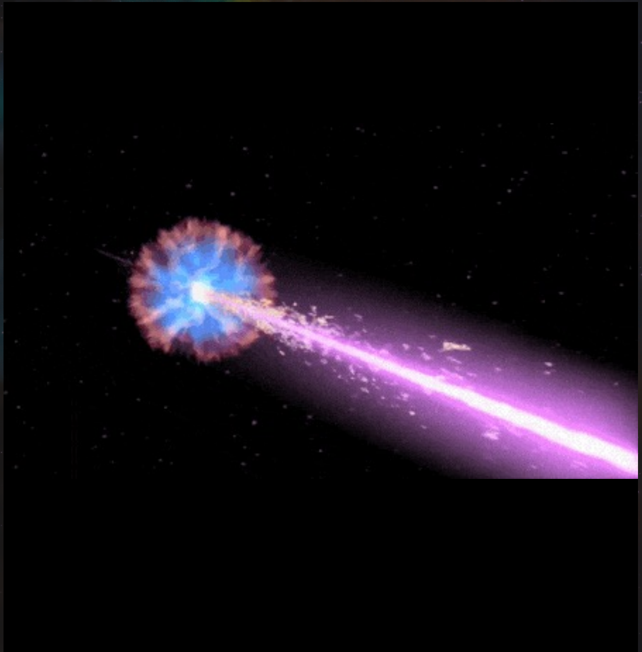


Credit: NASA/Swift/Cruz deWilde

Ongoing research

- Current focus is on analyzing GBM and LLE spectra for GRBs;
- Seeking variations in spectral index and additional components, particularly around 30 MeV when positive lags appear;
- Evidence from literature supports the existence of early afterglows for some GRBs with positive delays at MeV energies.

Ghirlanda, Ghisellini 2010, Dichiara + 2022, Maselli, Ghirlanda 2013, Ravasio + 2018 and many more …



Credit: NASA/Swift/Cruz deWilde

Potential Insights

Analyzing cross-correlations may reveal additional components in GRB emission.

Handling Low-Statistics Challenges:

- Providing an alternative method for studying GRB emission with limited data;

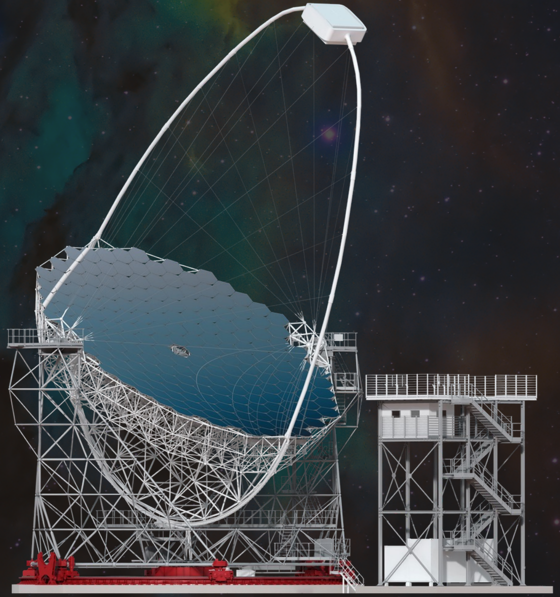
- Temporal analysis of GRBs can help us reveal features hard to detect in low-statistics spectra.

How can CTA be useful in studying GRBs?

- CTA's high sensitivity will enhance detection rate of VHE GRBs;

- Detailed VHE data from CTA will provide insights into energy, spectral shape, temporal evolution, and physical conditions of GRBs;

- Overall, CTA observations will significantly advance our understanding of GRB environments and jet properties.



(Rendering Credit: G. Pérez, IAC, SMM, license CC BY-NC-ND 2.0)