Precursors from Compact Binary Mergers

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A subclass of hybrid Gamma-ray bursts (GRBs) with long duration and peculiar spectral and timing properties was discovered to be related with compact binary mergers. Their main prompt gamma-ray phase is preceded by a fainter and spectrally softer pulse that we interpret as a precursor, possibly produced by a different physical mechanism.
I present the results from the analysis of the brightest GRBs associated with compact binary mergers (GRB 211211A and GRB 230307A) and compare them with leading models for precursor emission, which occurs either before or immediately after the merger.
I show that the high luminosity of some precursors (>1e49 erg/s) poses a challenge to most models proposed to explain their origin.
Ultimately, their nature can only be unraveled using joint gamma-ray/gravitational wave detections. I briefly discuss how multi-messenger constraints would help narrow down the range of models for precursors emission and place meaningful constraints to the NS equation of state.

Precursors in short GRBs

Previous studies of short GRBs (sGRBs) have identified **precursor signals**, which are characterized by prompt emission light curves where the main part of the emission is preceded by a shorter, spectrally soft and typically dimmer pulse. The time interval between the initial short signal and the onset of the main emission is known as the quiescent time, and it can range from a fraction of a second to several seconds.

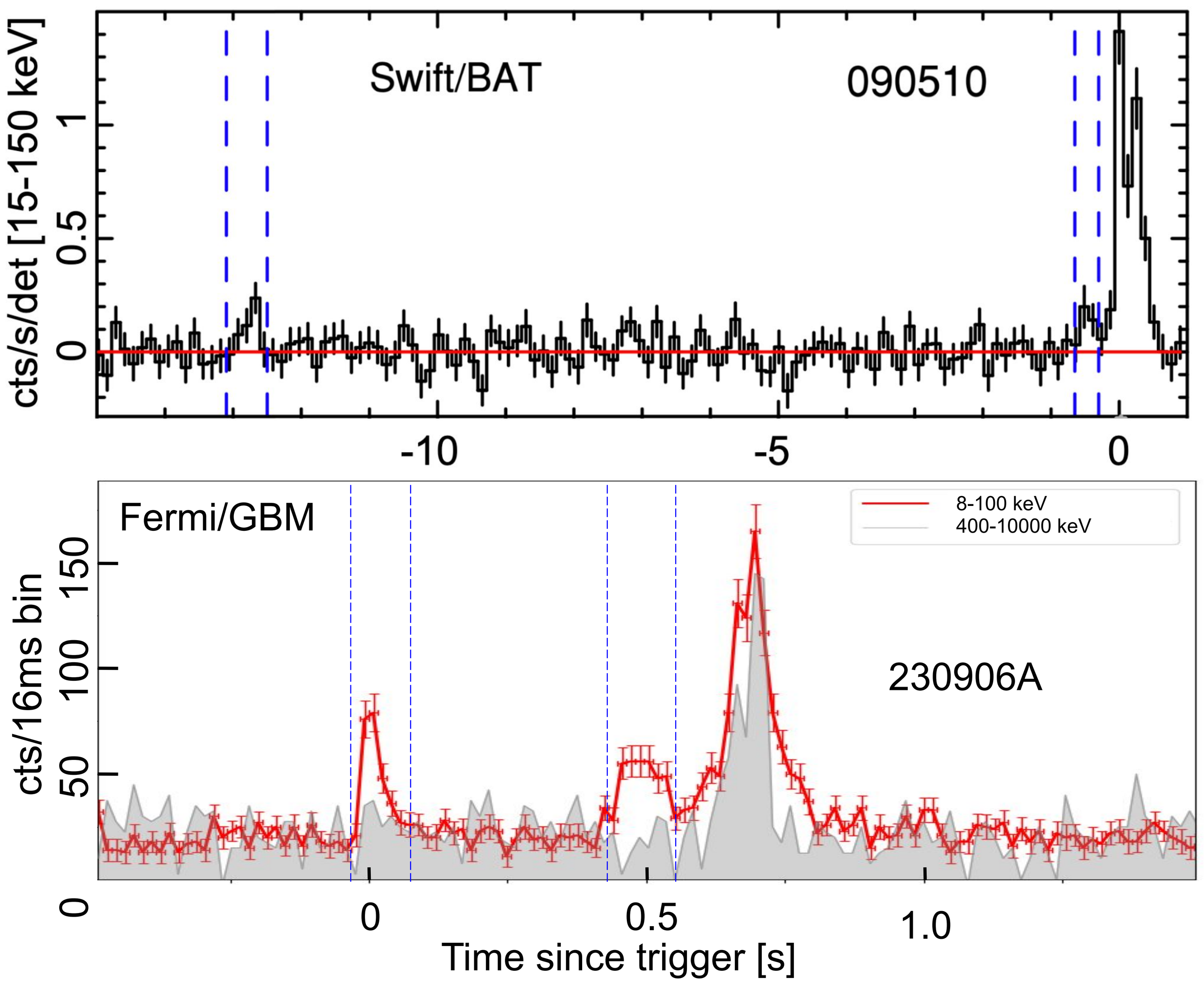


Figure 1: Light curve of two sGRBs with precursosrs with different quiescent times (QT): 090510 (QT~12 s) and 230906A (QT~0,4s). Dashed vertical lines mark the precursor duration. Adapted from [1] and [2]

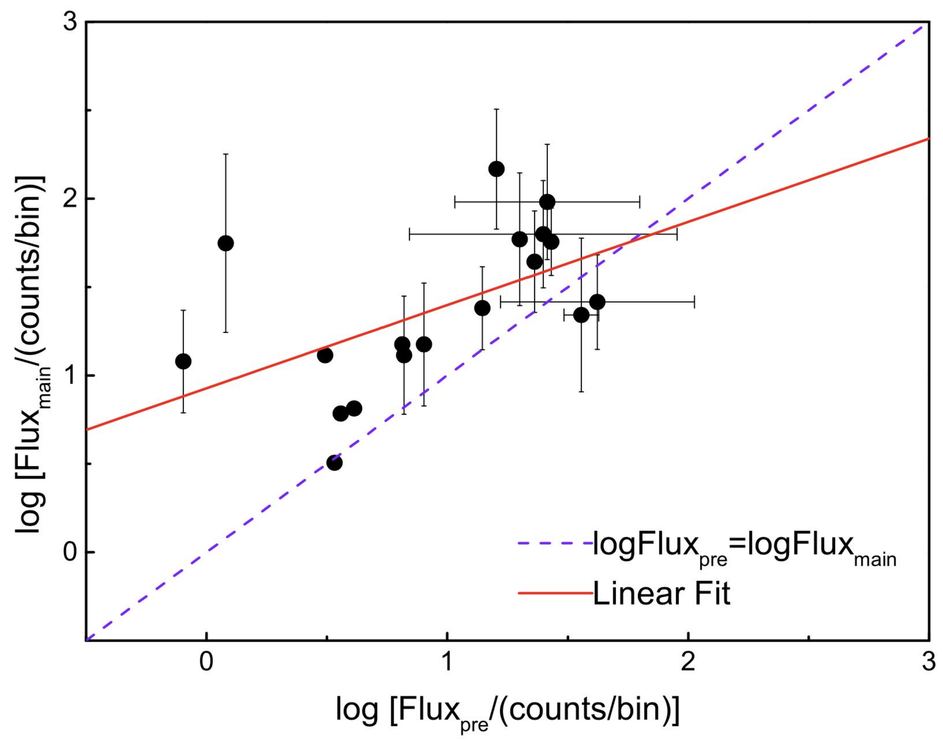


Figure 2: Average flux of precursor signals observed in sGRBs, compared with the average flux of the main emission. In general, the main emission is brighter than the precursor, and the two fluxes appear to be positively correlated. Adapted from [3]

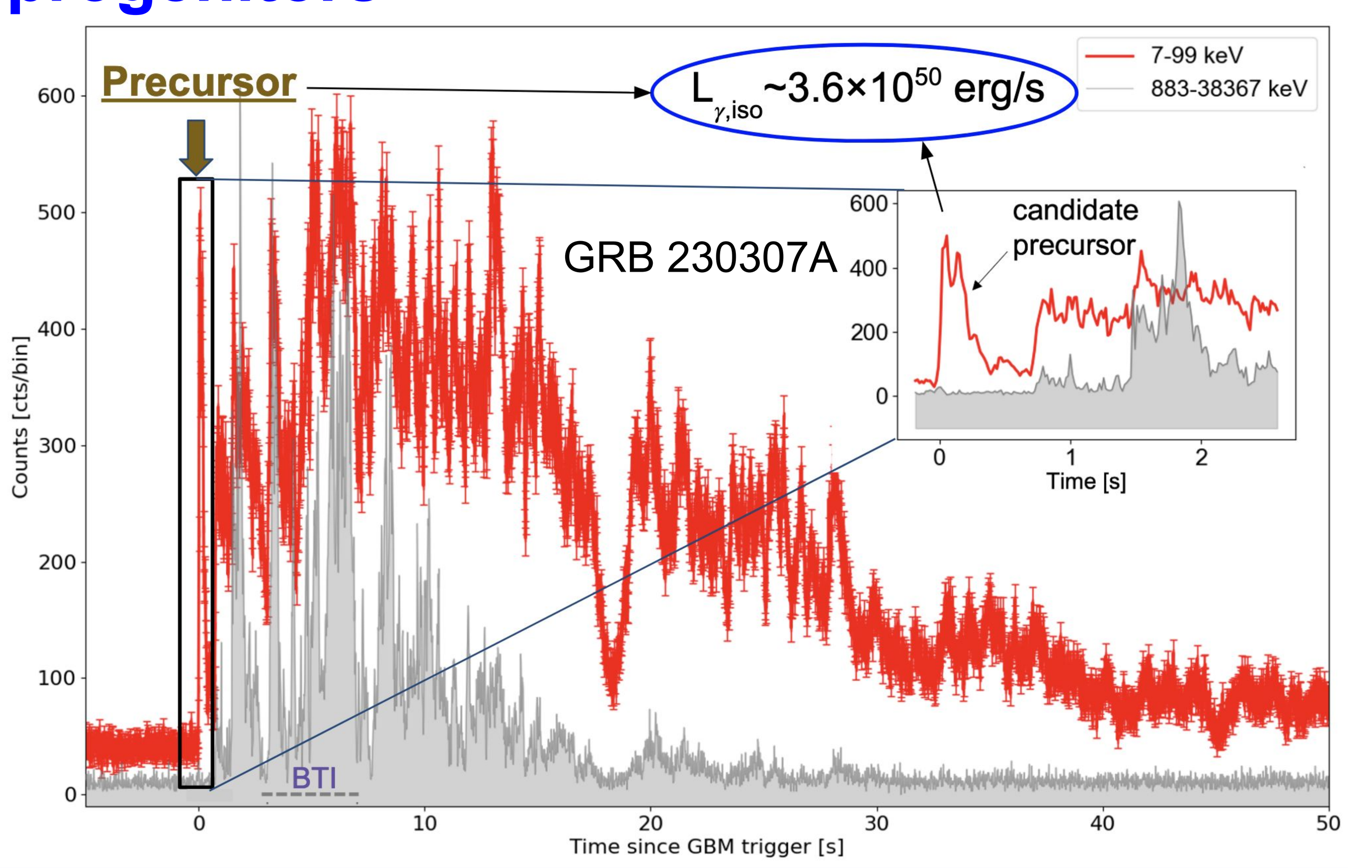
Precursors in sGRBs are characterized by different peculiar properties (see Figure 2)

However **spectral and timing analysis** of these signals are dominated by a **large degree of uncertainty**, <u>due to the short duration and the faintness of the signal</u>

Long GRBs with binary merger progenitors

GRB 211211A and GRB 230307A are **very bright** long GRBs directly linked to kilonova emission and compact binary mergers. The first pulse in both events is exceptionally bright, allowing precise measurements. This pulse have a **soft spectrum** and **short minimum variability timescale.**
These properties **deviates significantly from the standard trend observed in the main emission**, where shorter minimum variability timescales are associated with harder spectra

➡ **Precursor signal powered by a different mechanism**



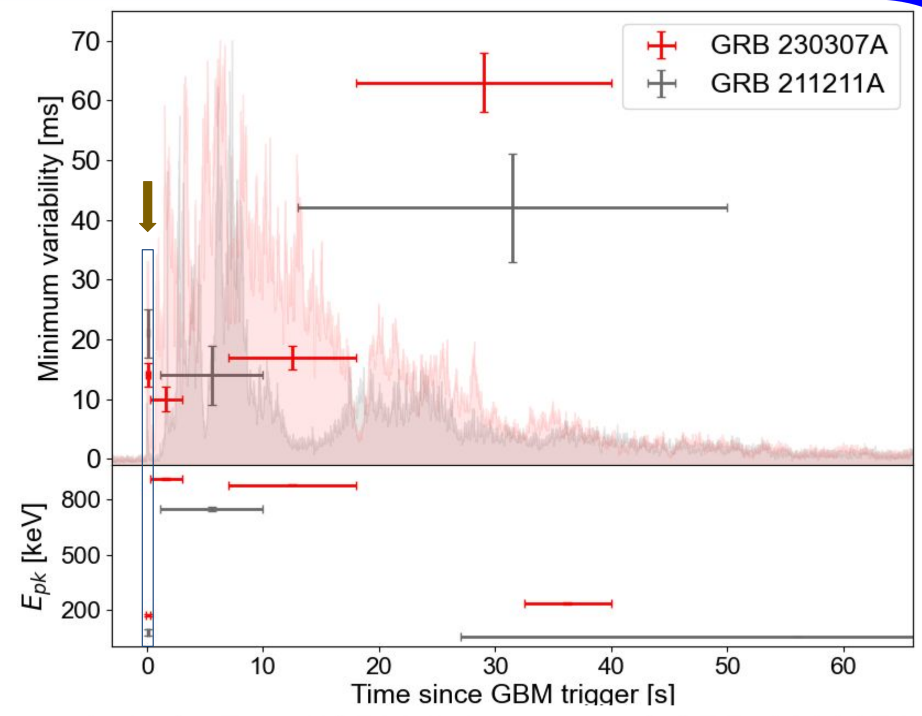


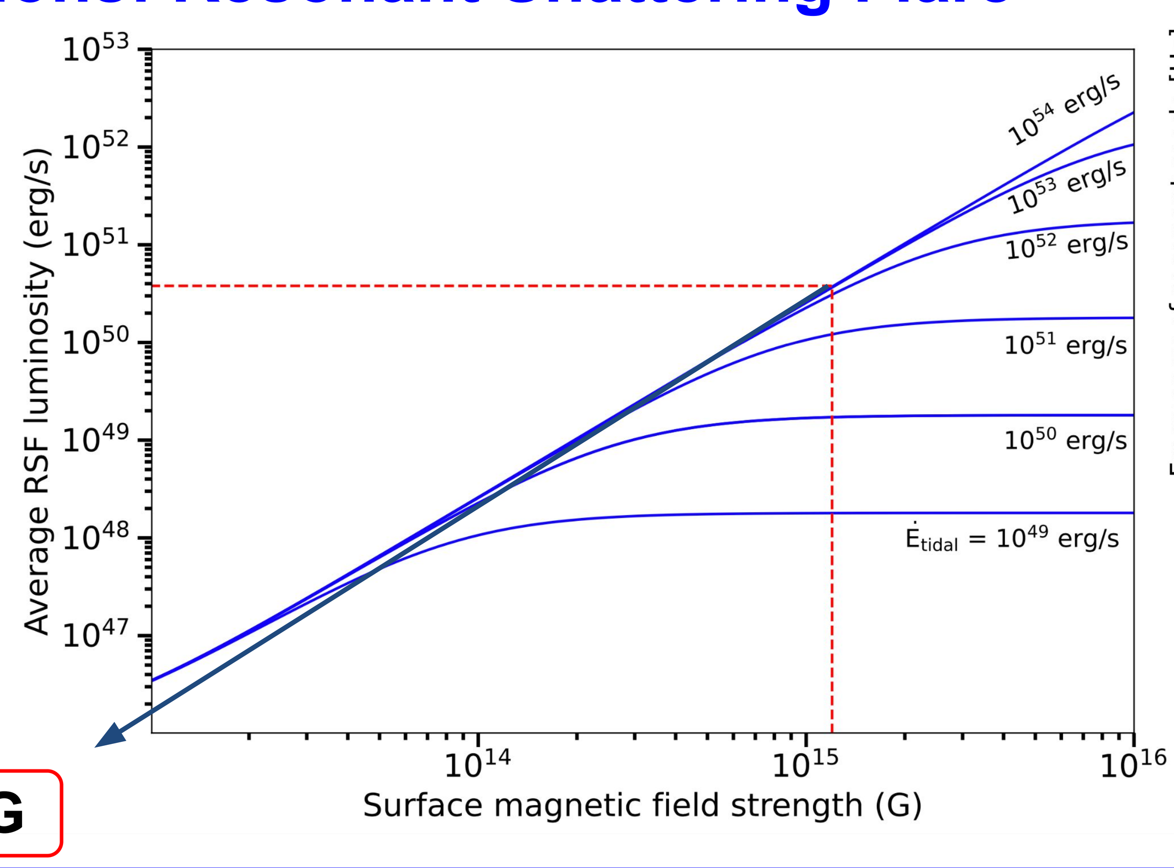
Figure 3: Left: Fermi/GBM light curve of GRB 230307A in different energy ranges. The insert shows the first soft, pulse . Right: The properties of first peak deviates from the main emission as it has short minimum variability and soft spectrum. Adapted from [4]

Possible interpretations: Resonant Shattering Flare

The high luminosity of these precursor signals challenges most of the models proposed to explain this first signals.

Such bright emission could be interpreted in the framework of the **Resonant Shattering Flare** (RSF) models [5,6,7,8]. This imply very high magnetic field on the surface of the merging neutron star before the merger.

For 230307A **B≳ 10^{15} G**



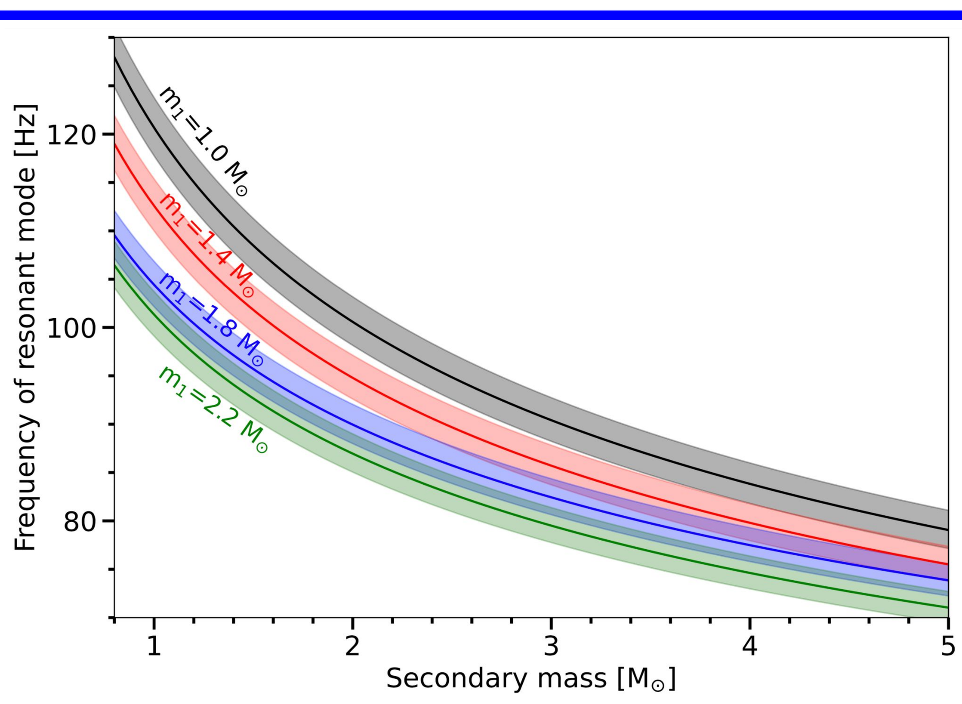


Figure 4: Left: Average luminosity of the RSF as a function of the NS surface magnetic field, for different tidal energy transfer rates. Right: The i-mode frequency that could produce the GRB 230307A precursor as a function of the merger secondary mass. Adapted from [4]

<u>The precursor duration provide a combined i-mode frequency/chirp mass constraint</u>

Future EM-GW multimessenger observation will allow strong constraints on the i-mode frequency

Strong constraints on the nuclear physics parameters that determine the nuclear matter equation of state

References
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SUMMARY

- Short signals preceding the main emission were found in the light curves of short GRBs and long GRBs associated with kilonovae (GRB 211211A and GRB 230307A)
- The combination of <u>soft spectrum</u> and <u>short variability</u> deviates from the general trend of prompt GRB emission
  ➡ **precursor signal powered by a different mechanism**
- Possible explanations:
  - **Pre-merger** models (as the one invoking a **Resonant Shattering Flare**) require the merging NS to retain a **high magnetic field** (≳ 10^{15} G). See [4] for more information
  - **Post-merger** models invoke a **rapidly spinning, highly magnetized NS**, where the rotational energy is extracted by some MHD processes and then released into a high-entropy fireball (e.g. [9]).

what is the origin of these precursor signals?

➡ **an enigma for multi-messenger astronomy!!!!**

Future simultaneous detection of gravitational waves would provide crucial insights into the nature of the signals and could help constrain the properties of tidal resonant shattering, the magnetic field, and the equation of state of dense matter