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TOWARD NEW INSIGHTS ON THE GAMMA RAY BURST PHYSICS: FROM X-RAY SPECTROSCOPY TO THE IDENTIFICATION OF CHARACTERISTIC TIME SCALES

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The PhD project is aimed at studying Gamma-Ray Burst (GRB) sources discovered by *Swift* both from the observational and the theoretical point of view. It is basically divided into three parts: the first is dedicated to the development of a software able to automatically reduce *Swift* X-ray data; the second part contains the analysis and interpretation of three particularly interesting GRBs in the context of different theoretical models: the problems and the failure of most of them is shown. Finally, a third part is dedicated to the development of a temporal analysis alternative to the Fourier Transform: the Temporal Analysis in the Time Domain (TTD). Although optimized for GRB sources, this technique can be widely used to study the time properties of any source.

***Swift* GRB catalogue in the 0.3-10 keV energy band.** I present a homogeneous X-ray analysis of the GRBs for which the X-Ray Telescope (XRT) on board *Swift* did the follow up. The software is designed to automatically reduce and analyze the data. In particular, for each source the catalogue contains: count-rate light-curves in the 0.3-10 keV, 0.3-1 keV, 1-2 keV, 2-3 keV and 3-10 keV energy bands extracted in three different ways; hardness ratio information; time resolved spectral information; flux and luminosity calibrated light-curves in the different energy bands, where the calibration is done using the time resolved spectral information (this is the major improvement with respect to the existing *Swift*-XRT catalogue by Evans et al., 2009). Although written for GRB data, the software can be run on any source detected by XRT.

Observational constraints to the GRB theoretical models.
GRB 060904B, possible detection of Nickel emission: the detection of an extra component in the GRB 060904B X-ray spectra in addition to the standard single power law behavior is reported. This component can be fit with different models but the addition of a spectral line corresponding to Nickel emission provides the best correspondence: this would add a piece of information we still lack to the GRB-Supernova connection. I investigate the physical properties that the surrounding medium must have in order to produce a spectral feature that can explain the detected emission. I analyze and discuss how and if the detected spectral excess fits in different theoretical models developed to explain the nature of line emission during the afterglow phase of Gamma Ray Bursts (GRB) sources. Transmission and reflection models have been considered. The detected feature can be explained in a funnel scenario with typical opening angle $\theta \sim 5$ degrees, nickel mass $\sim 0.1\,M_{\odot}$ and $T = 10^6$ K. For $\theta \sim 20$ degrees, assuming the reprocessing material to be in the SuperNova (SN) shell, the detected emission implies a nickel mass $\sim 0.4\,M_{\odot}$ at $T \sim 10^7$ K and a metallicity ~ 10 times the solar value. If the giant X-ray flare that dominates the early XRT light-curve is identified as the ionizing source, the SN expansion began ~ 3000 s before the GRB event.
GRB 090111, extra soft X-ray emission and peculiar re-brightening: I present a detailed study of GRB 090111, focusing on its extra soft power-law photon index $\Gamma > 5$ at the very steep decay phase emission (power-law index $\alpha = 5.1$, steeper than 96% of GRBs detected by *Swift*) and the following peculiar X-ray re-brightening. The spectral analysis supports the hypothesis of

a comoving Band spectrum with the the peak of the νF_ν spectrum evolving with time to lower values: a period of higher temporal variability in the 1-2 keV light-curve ends when the $E_{\rm peak}$ evolves outside the energy band. The X-ray re-brightening shows extreme temporal properties when compared to a homogeneous sample of 82 early flares detected by Swift. While an internal origin cannot be excluded, I show these properties to be consistent with the energy injection in refreshed shocks produced by slow shells colliding with the fastest ones from behind, well after the internal shocks that are believed to give rise to the prompt emission have ceased.

GRB 081028, an unusually late X-ray afterglow re-brightening: *Swift* captured for the first time a smoothly rising X-ray re-brightening of clear non-flaring origin after the steep decay in a long gamma-ray burst (GRB): GRB 081028. This offers the precious opportunity to study for the first time the rising phase which is likely present in all GRBs but is usually hidden by the prompt tail emission. This constitutes the first manifestation of what is later to give rise to the shallow decay phase. Contemporaneous optical observations reveal a rapid evolution of the injection frequency of a fast cooling synchrotron spectrum through the optical band, which disfavours the onset of the forward shock as the outflow decelerates as the origin of the observed re-brightening. I investigate alternative origins and show that the observations are consistent with the off-axis jet predictions. However, the high energy budget required by this interpretation suggests a different physical origin for the prompt and steep decay phases vs. the afterglow emission component. Strong spectral softening takes place from the prompt to the steep decay phase with the peak energy of the νF_ν spectrum evolving as fast as t^{-7}. I track the evolution of the spectral peak energy from the γ-rays to the X-rays and highlight the problems of the commonly assumed high latitude and adiabatic cooling interpretations. An abrupt switch-off of the central engine after the prompt emission is disfavored: the detected spectral evolution requires some forms of persistent central engine activity during the steep decay. Notably, a softening of both the high and low spectral slopes with time is also observed. I discuss the low on-axis radiative efficiency of GRB 081028 comparing its properties against a sample of *Swift* long GRBs with secure $E_{\gamma,\rm iso}$ measurements: the efficiency results are consistent with the different physical origin hypothesis of the prompt and re-brightening components.

Time in the Time Domain (TTD) analysis and short term GRB variability. The time variability in the afterglow and prompt light-curve can provide important clues to the nature of the source that powers the GRB emission and to its surrounding. The power spectrum analysis in the time domain is developed starting from the findings of Li 2001: unlike the Fourier transform this is suitable to study the rms variations at different time scales. A complete characterization of the output of the technique is performed. Although optimized to study the GRB signal, the TTD is able to provide the the variability information of any kind of short, non-repetitive, non-stationary signals. The timing analysis of 252 15-150 keV light-curves of *Swift*-detected events, reveals the existence of three different classes of GRBs. Moreover, when the cosmological time dilation effect is considered, the distribution of the GRB characteristic variability time scales is found to cluster around 0.6-1 s. A showcase for the application of the TTD analysis to the GRB prompt emission is represented by the naked-eye GRB 080319B: this burst shows the presence of two characteristic variability time scales. Both undergo a remarkable evolution during the prompt emission and are strongly energy dependent. Different theoretical interpretations are discussed: none of them is able to account for all the observational findings.

The TTD analysis provides an unprecedented description of the temporal properties of the prompt emission: a full interpretation of its meaning and a robust connection to the physics and related models will be the next step of the research.