Gamma-Ray Bursts (GRBs) are brief and intense pulses of $\gamma$-rays. They were discovered by the US military Vela satellites in 1967 and for three decades the origin of these explosions was unknown. The bursts last from a fraction of a second to several minutes, coming from random directions in the sky. In 1991, thanks to the Burst And Transient Source Experiment (BATSE, 25-300 keV) onboard the Compton Gamma-Ray Observatory (CGRO), their isotropic distribution and cosmological distance was unveiled. The overall observed fluences for GRBs range from $10^{-4}$ to $10^{-7}$ ergs cm$^{-2}$. This corresponds to isotropic luminosity of $10^{51-52}$ ergs sec$^{-1}$, making GRBs the most luminous objects in the sky. The prompt $\gamma$-rays emission is followed by the afterglow: a lower energy, long lasting emission (in the X-ray, optical, infrared and radio) discovered in the 1997 by the Wide Field Cameras (WFCs, 2-20 keV) onboard the BeppoSAX satellite. The soft X-ray and optical light curves showed a steep typical power-law decay, $F \propto t^{-1.1}$. This immediately clarified why no optical counterparts had been seen earlier: the observations had to be performed very quickly, within at most a few days following the burst. The rapidly available and accurate positions provided initially by BeppoSAX, later with HETE-II, INTEGRAL and today with the Swift mission, made rapid follow-up observations at all wavelengths possible.

The accurate afterglow positions enabled the identification of host galaxies in almost all cases when afterglow was detected and this in turn enabled the determination of the corresponding redshifts, that range from 0.16 to 6.3. Within the host galaxies there is evidence that (long duration) GRBs arise within star forming regions and there is evidence that they follow the star formation rate. Thus, the distance issue was finally settled after 30 years of GRB studies: GRBs originate at cosmological distances, making...
them the most powerful photon emitters in the Universe. While not all observed features are understood there is an overall agreement between the observations and the so-called «relativistic fireball model». According to this model, GRBs are produced when the kinetic energy of an ultra-relativistic flow is dissipated. The GRB itself is produced by internal dissipation within the flow while the afterglow is produced via external shocks with the circum-burst medium.

The general objective of this PhD project was the understanding of the nature of the so-called Dark Bursts, i.e. GRBs which do not show optical afterglows, and their surrounding. The origin of this class of events is still not clear but recent works have suggested some possible scenarios:

- in some cases the non-detection of the optical transient could be simply due to the lack of suitable instrumentation: the slowness of the response or the depth of the surveying combined with some dim or rapid decaying event could bias the determination of the truly Dark Bursts population;
- it is also possible that this kind of bursts have an intrinsically fainter optical afterglow compared to the afterglow of other GRBs at all wavelengths. Bursts with optical transient show a remarkably narrow distribution of flux ratios, which corresponds to an average optical-to-X spectral index of $0.794 \pm 0.054$: about 25% of the Dark GRBs are 4-10 times weaker in optical than in X-rays compared with GRBs with optical transients. This result suggests that the afterglows of most Dark Bursts are intrinsically fainter in all wavelengths and this could happen if the afterglow decelerated in a low density medium;
- if instead GRBs are associated with the death of massive stars then the optical flux of the afterglow could be blocked by a large fraction of interstellar dust along the line of sight or the single event could be the result of a highly absorbed star formation burst placed in a dusty molecular cloud. From X-ray analysis there is evidence for high column densities of gas close to GRBs, but the measured optical extinction is smaller than expected because the hard $\gamma$-ray radiation of the burst destroys the dust in their environment. In this «obscured» scenario, the failed detection of the optical transient could be easily ascribed to extinction by the dust of the host galaxy;
- is now well assessed that GRBs are the most energetic events in the Universe and they have large redshift distribution ($0.1 < z < 6.3$). So a fraction of Dark Bursts could be originated at high-$z$ ($z > 5$) and their emission could be dumped by the Lyman absorption redshifted to the optical-infrared bands.

The advent of Swift satellite pointed out that the number of faint and Dark burst is considerably higher than previous missions. The afterglow recovery rate of Swift in the optical/infrared bands much is higher than previous missions but Swift-events are on average 1.7 magnitude fainter. Deep limits suggest that as many as 30% of the Swift bursts can be optically dark. In order to investigate the properties of Dark Bursts, to constraint
the properties of the host galaxies and to understand the causes of the optical flux extinction, it is clear that fast multi-wavelength observations of the early afterglow are needed. In fact, through a detailed study of the early light curves decay of the afterglows in different bands (from X-ray to near infrared) it will be possible to investigate the density of the medium in which the fireball moves, to set relevant constraints on the fireball model and on the environment properties. So, fast observation of the afterglow and deep follow-up analysis can permit a detailed study of the GRB itself, of the interstellar medium and of the properties of host galaxies. To satisfy the requirements of rapid reaction to GRB triggers and deep follow-up observations of GRB afterglow, I focus my PhD upon two main topics: the REM telescope (Chile) characterization and its prompt observations of GRBs and rapid follow-up observations, in the optical and/or infra-red band, with larger telescopes, like VLT (Chile) or TNG (Canary Islands).

**REM and follow-up of afterglows early stage**

Theory predicts that few minutes after a burst, afterglows reach their luminosity maximum, several magnitudes brighter than one day later, and also a small ground-based telescope can easily detect them. For this reasons robotic telescopes are the more promising tool. In this contest, I spend the first period of my PhD project in the scientific characterization of the infrared camera (REM-IR) of the robotic telescope REM. I participated to the REM-IR camera characterization activities through an intense calibration campaign. During such an activity I defined and constraint REM-IR performances through aimed tests (e.g. linearity, quantum efficiency, gain, readout noise and dark current). After many tests I can conclude that: 1) the detector of REM-IR has a great linearity within a broad counts dynamical range (5000-40000 ADUs); 2) the gain \( G = 4.8 \text{ e}/\text{ADU} \) and the dark current \( \text{DC} = 0.07 \text{ e}^- \) values are nominal in respect to laboratory tests; 3) the readout noise \( \text{RON} = 44 \text{ e}^- \) is slightly larger than the standard value expected for this array (probably due to an external source of noise present in the actual instruments configuration); 4) the REM-IR infrared camera mainly operates (especially in the K' filter) in sky limited and this has a little effect on the general performance of the instrument.

The telescope REM has been primarily designed to follow up the early phases of NIR/optical afterglow of gamma ray bursts detected by dedicated satellites such as HETE-II, INTEGRAL and in particular SWIFT. During 2004, REM observed many GRBs detected by both HETE-II and INTEGRAL. Unfortunately, in all cases events happened during Chilean daytime so the fully automatic reaction was not tested and only upper limits on the afterglow emission could be derived. The SWIFT satellite is now providing more triggers (100/yr) and in the first months of 2005 we had the possibility to observe a couple of GRB fields in less then 30 sec but no afterglows were detected. As I showed in my thesis the non-detection of Swift afterglows by the REM telescope (also after a prompt reaction) was the result of the intrinsic faintness of the afterglows detected by Swift. The number
of faint (Dark) burst detected by Swift is considerably higher than for previous missions. This means that not only small ground-based telescopes like REM must be employed rapidly after the burst localization, but also larger telescopes should react as soon as possible to increase the number of successful afterglow detections in optical and infrared bands. Anyway, for all the consideration done about the study of Dark Bursts, the REM telescope, with its ability to react quickly to GRB triggers, remains one of the more promising robotic facilities to promptly follow-up GRBs and investigate their early light curves.

Afterglows early and late stages follow-up

During the last part of my PhD I have studied more in detail the follow-up observations of two particular cases, from which it is possible to infer some information on the properties of GRBs:

- GRB031220: this is a classical example of Dark Burst. To constraint the properties of the host galaxy and to understand the causes of the optical flux extinction, I led a team that made a multi-wavelength analysis (X-ray, UBRIJHK') of this optically obscured burst. The multi-wavelength observations performed starting from hours since months after the burst event did not reveal any clear optical-infrared transient. This is the result of dust extinction in the circum-burst medium or inside the host galaxy, that has an estimated redshift of $1.9 \pm 0.3$ and an extremely red colour ($R-K' \sim 5$). The rest-frame column density of hydrogen atoms for this burst is $N_H^z = 0.5 \times 10^{22} \text{ cm}^{-2}$ and this is an indication of the presence of medium in the vicinity of this source (or inside the host galaxy) with a density comparable with the observed column density inside the disk and the bulge of our Galaxy. From the fit parameters of the redshift estimation it is possible to infer also some properties of the host galaxy, that seems to be not typical. The spectral energy distribution of the host galaxy of GRB031220 is well reproduced by a massive ($M \sim 2 \times 10^{11} \text{ Mo}$) elliptical galaxy with an evolved (age $\sim 2$ Gyr) stellar population. This is not typical for a long GRB as GRB031220 ($T \sim 23$ seconds), for which we can expect a small stellar mass, bluer colours than present-day spiral galaxies and an integrated star formation rate of $\sim 1-10 \text{ Mo/yr}$. However, not all long GRBs are associated with starburst galaxies (younger and sub-luminous) and the spiral hosts of GRB980425 and GRB990705 are two examples. In the same manner, not all short GRBs are associated to old elliptical galaxies, like the case of GRB050709 host galaxy.

- GRB040827: this is an example of an X-ray afterglow with intrinsic absorption. On behalf of a large team I participated to the analysis of this bursts doing the optical and infrared photometry of the afterglow. The analysis of this long burst ($T \sim 40$ seconds) was performed principally in the X-ray band and showed that the spectrum of the afterglow was affected by an absorption significantly higher than the galactic value (by a factor $\sim 5$). The observed spectral and temporal properties are consistent with isotropic expansion into an homogeneous medium or into a stellar-wind profile environment, a
typical behaviour of X-ray afterglows. Coupling constrains derived from X-ray spectral fitting and optical-infrared photometry of the host galaxy it was possible to estimate a column density $N_H \sim 0.4 - 2.6 \times 10^{22} \text{ cm}^{-2}$ in the GRB host galaxy, likely located at a redshift $0.5 \leq z \leq 1.7$. With only X-ray observations it is impossible to understand the nature of the medium surrounding GRB progenitors. The most promising way to study the circum-burst medium it is to study the prompt emission in several bands in order to better discriminate different contributions to the global observed properties of GRB afterglows and hosts galaxies.

For the well analyzed Dark Bursts GRB031220, it was clear that the «darkness» of this burst was the result of dust extinction in the circum-burst medium or inside the host galaxy. This is in favour of the obscured scenario as origin of Dark Bursts, for which the extinction is ascribed to dust in the host galaxy. However, recent studies show as the non-detections of optical-infrared counterparts for many GRBs should be ascribed to the faintness of the associated afterglow. This could happens because the relativistic flow can moves into a low density medium. Moreover, it is also possible that the high-energy emission of the GRB destroys circum-burst dust grains (within a radius of ~ 1 pc). This could be the case for GRB040827, another clear example of high intrinsic absorption. For this burst the same conclusion like in the case of GRB031220 can be reached. The rest-frame column density of hydrogen atoms and the host galaxy redshift are in fact comparable to that of GRB031220 host galaxy. After the analysis of these two bursts, I can point out that in order to better constraint the distribution of Dark Bursts and understand their truly nature, fast multi-wavelength observations are needed. In this contest, near-infrared observations are particularly suited to test the nature of Dark Bursts. Indeed, as the peak of optically detected population is at redshift around 1 (with some exceptions at high redshift, like GRB000131 and GRB050904) and cause of the optical darkness could be the intergalactic Lyman absorption, near-infrared observations could reveal the predicted population of high redshift afterglow. So far, only the afterglow of GRB050904 has been detected like a «Lyman dropped-out» GRB. The final discrimination between these two possible scenarios proposed (dust extinction or high-$z$) for the origin of Dark Bursts could not be reached without rapid follow-up near-infrared observations of GRB. So far, the contribution of high redshift effects to the optical darkness of many GRBs is very little or negligible and, for few cases of which the distance has been determined, the probably explanation for the optical dimmed afterglow is dust extinction in the circum-burst medium. However, the sample of well studied Dark Bursts is still small and it is not possible to completely rule out any high redshift effect. Moreover, without prompt observations in the optical and infrared bands, and taking into account the global properties of GRB afterglows (like a rapid power law decay), many GRBs would be classified as «Dark». This suggest that the total number of Dark Bursts should be systematically reduced with prompt follow up during the very first hours after the burst.
Future prospects

The localization of GRB afterglows to arcseconds accuracy and the rapid follow-up observations will permit more detailed studies of the environment in which the GRB occur (e.g. through high-resolution spectroscopy). This will permit also a better understanding of the global properties of GRB host galaxies. The current Swift rate of detection of burst (~ 100/yr) will increase rapidly the sample of bursts, allowing studies of the star formation, inter-galactic or and inter-stellar medium. First of all, rapid and accurate localizations in many spectral bands (optical, near-infrared and X-rays) will remove, in the next future, observational bias on the true fractions of dust obscured bursts (Dark Bursts). If the total number of this particular class of GRBs will persist this will support a progenitor scenario that prefer low density environments. Second, fast follow-up observations have allowed the detection and identification of short-bursts host galaxies. The increasing number of host galaxy associations for short-hard bursts (GRB050509B, GRB050709, GRB050724 and GRB050813 to date), detected through rapid follow-up, has permitted to understand the different nature of this class of burst compared with long-soft bursts. Short bursts seem to be associated with elliptical galaxies (with the exception of GRB050709 that is associated with a star-forming galaxy), that do not exhibit any emission line, with no evidence of recent star formation, consistent with a population of very old stars (supporting the progenitor model of coalescence of binary systems of neutron stars or a neutron star-black hole pair). The majority of long bursts are associated with sub-luminous, blue galaxies with strong star formation, consistent with a younger population of stars (supporting the progenitor model of core-collapse of massive stars). The lack of an associated supernova for all the short bursts detected so far is a strong evidence against a core-collapse origin. Finally, GRBs may probe the high-redshift Universe (GRB050904, z = 6.3) to redshift higher than quasars and then they will probe the re-ionization epoch and the inter-galactic medium to z > 7. In this contest, infrared observation are more promising for the understanding of the properties of intergalactic and circum-burst environments at these redshifts. When a significant number of high-z bursts will be measured it will be possible to sample the star formation rate of the Universe within the first Gyr from the Big Bang. In the end, in the context of rapid follow-up observations, one of the most promising field related to the study of the properties of the emitting regions and circum-burst environments is polarization. My future efforts will be dedicated to the study of this field. It is now clear and well established that the optical afterglow of GRBs can show some degree of linear polarization. Recently polarization ≥ 10% has been detected during the prompt emission and this is closely related to the physics of expanding material. Polarization is necessarily related to reddening, so modelling the spectral shape of optical afterglows the total amount of dust along the line of sight can be constrained, allowing the study of the intrinsic polarization and dynamics of GRBs fireball.
Essential references


