Abstract

The widely popular and successful standard fireball model for Gamma Ray Burst (GRB) afterglows is based on ultra-relativistic external shocks sweeping up matter around the explosion site to accelerate electrons up to GOV energies and boost the magnetic field to values close a few Gauss in its downstream. According to the model, the afterglow radiation is the synchrotron emission from these electrons gyrating around the enhanced magnetic field. A contribution from inverse Compton scattering may also appear in the total flux at higher frequencies.

The synchrotron spectrum is characterized by 'breaks' which arise due to various physical processes. The spectral slope changes due to the synchrotron self-absorption below a frequency Va. The synchrotron peak frequency (I'm) corresponds to the emission by electrons at the lower limit of the power law distribution of energies and the cooling break 14 corresponds to the electron energy above which synchrotron radiation loss becomes very significant. Apart from these, the light curves exhibit achromatic slope changes due to dynamical processes within the fireball. The ejected matter is collimated and initially undergoes a radial expansion. Later, the lateral expansion of the jet takes over and this is reflected as an achromatic break (jet break) in the light curve. The next achromatic change of slope marks the transition of the fireball into the non-relativistic regime.

The spectrum of afterglow radiation itself evolves with time, reflecting the expansion of the fireball, hence a data set well sampled in both spectral and in temporal domain is essential for useful study.

Multiband modelling of GRB afterglow (AG) light curves is at present the best available tool to understand the true nature of the explosion and its surroundings. Apart from that, detailed modelling also holds the key to the secrets of particle acceleration processes in collision less shocks.

By modelling the well-sampled data set of an afterglow, the energy content (Etot) of the jet, its angle of collimation (00), the density profile of the ambient medium (n(r) where r is the distance from the site of the explosion) and some relevant parameters of shock microphysics (p, the power law index of the distribution of electrons which are radiating via synchrotron mechanism, G, the fraction of energy in those electrons and that in downstream magnetic field) can be obtained.

Afterglow data of the nearby (z 0.16, one of the nearest GRBs) GRB 030329 was unprecedentedly rich in both optical and radio bands (but unfortunately poor in x-rays) which enabled detailed and well constrained modelling attempts. The rigorous monitoring campaign revealed an unexpected behavior of the radio flux, for which one explanation was that that the early optical emission and the late radio emission arose in two different jets. However, our detailed modelling using the rich data set allowed us to propose a new mechanism in which the initial outflux of energy is 'refreshed' by a later episode of injection.

The standard fireball model uses certain simplistic assumptions owing to our lack of knowledge of the shock acceleration process. One common assumption is that of a universal spectrum of the accelerated electrons, a steep non thermal energy distribution with power law of index 2.2. It owes its origin to theoretical simulations of shock acceleration which often produce a steep ($p > 2$) spectrum. This also fits many observed cases of such energy distributions. Further, this assumption leads to a simplification in theoretical models, since the upper cut off energy of the distribution plays virtually no role.

The presence of harder, $p < 2$ spectrum, in a minority of cases, has hence not received a fair share of attention. Calculations to derive the physical parameters of the burst in such cases are often not done consistently. Early attempts to model GRB afterglows with hard electron energy spectrum had several loopholes. In this thesis, we have done these calculations consistently and applied them to a few afterglows with good temporal and spectral coverage.

Apart from multiband modelling, this thesis also presents late time observations of the GRB030329 afterglow in low frequency radio bands. Radio observations have always been special since they allow the estimation of the self-absorption frequency, thus giving a direct clue to the size of the fireball. Afterglows are long lived in low radio frequencies (< 1 GHz) while they quickly decay below visibility in all other bands, even at high radio frequencies (say 15 GHz). Hence monitoring at low radio frequencies is the only way to study the late time evolution including the transition from relativistic to non-relativistic dynamics.

GRB030329 had one such rare bright radio afterglow and we followed it up in low frequencies (1280 MHz and 610 MHz) using the Giant Meter wave Radio Telescope (GMRT). The follow up campaign is continuing thanks to the slow evolution in low radio frequencies. This afterglow has hence become the longest (N 1000 days) observed, beating the earlier record of 500-day long observations of Radio afterglow of GRB970508. It also is the only one which is seen in frequencies below 1 GHz.

This thesis is organized in the following manner:

Chapter 1 gives a general introduction to GR13s and their afterglows. After describing the properties of the burst and the afterglow, we proceed to explain the standard fireball model in detail. The dynamics of the external shock and the profile of the bulk Lorentz factor (I") vs. r is described. We explain the jet break (tj) and non-relativistic transition (tnr), two major developments in the life of the fireball. We then give a detailed description of the synchrotron radiation mechanism, which is the source of afterglow radiation. The spectral breaks (va, I'm and 14) and their time evolution is explained. We conclude this chapter by listing a few unanswered questions relevant to this thesis.

In Chapter 2, we present the theoretical modifications required for the standard model to accommodate electron energy spectra with power-law indices less than 2. The energy spectrum requires a new parameter 7i, which is the Lorentz factor corresponding to the upper cut-off of the hard energy distribution. Above 'i, the distribution either terminates or steepens (double slope electron distribution) to a value of p larger than 2. The functional form of this cut-off is decided by the particle acceleration processes, which are at present poorly understood. We therefore parameterized the temporal evolution of in terms of the bulk Lorentz factor of the shock. We discuss two possible origins for the cut off. As a result of this cut-off in the energy spectrum, a new break Vi is introduced in the radiation spectrum, which is the synchrotron frequency corresponding to 7i. Apart from that, the expressions for l.'m and va differ from the standard scenario. We have calculated the shock dynamics using the method adopted by Huang et. al. 2000, which allows a smooth transition from ultra-relativistic to nonrelativistic regime of the fireball. Using this profile of I' vs. observed time, we calculated the synchrotron spectral evolution from a double slope electron energy distribution semi-analytically. The self-Compton emission also is calculated. For ultra-relativistic and non-relativistic regimes, analytical solutions are presented for both ISM n(r) r^0] and stellar wind driven [n(r) ambient medium density profiles.

The way one identifies potential candidates which could have an underlying hard electron energy spectrum, is by looking at the light curve decay index past the jet break. The choice is confirmed by the optical and x-ray spectral indices. According to the standard model, the flux in higher frequencies, past jet break, decay as a power-law of index p; the spectrum below 14 should have a slope of (p — 1)/2 and above it should fall as pp. The value of p one thus obtains from all these methods is expected to be consistent. In chapter 3, we chose three such afterglows (GRB010222, GRB020813 and GRB041006), which show shallow decay of fluxes in the optical as well as in x-ray bands and relatively flat spectra. Out of a dozen such afterglows, these three have well sampled multi-band light curves. We fitted the data set with the model and estimated the physical parameters. For GRB041006, we have estimated the contribution of the associated supernova by subtracting the afterglow model from the total emission. We found the contribution from Compton emission to be negligible in all these cases. Interestingly, all these afterglows had relatively low cooling frequency, which could perhaps be due to some unknown relation to the acceleration mechanism itself.

Chapter 4 and 5 are devoted to GRB030329, one of the best monitored afterglows till date. The 4th Chapter focuses on the radio observations of the afterglow done with the GMRT at low frequencies. To begin with, we give a brief introduction to the interferometric techniques and the instrument. GMRT, an interferometric array with 30 elements, each of diameter 45 meters has an excellent sensitivity at low frequencies which allowed it to detect and monitor the afterglow for a long time. We then present observations in 1280 MHz and 610 MHz bands during the second year of the afterglow Thanks to this long coverage, we were able to pin-point the location of va and the transition of the fireball to the Newtonian regime.

Chapter 5 describes the multiband modelling of this afterglow. The evolution of the afterglow was complex. While the afterglow flux in optical as well as in x-ray exhibited a jet break around half a day, the radio flux past 0.5 days did not follow the expectations from a jet which has already entered the lateral expansion regime. Instead, it showed an achromatic steepening around 10 days. Hence, a novel suggestion of two co-aligned jets, one narrow and one wide, together giving rise to the observed flux has emerged (Berger et. al. 2003). We test the predictions of this conjecture and get a refined set of parameters, prompted primarily by the additional data from GMRT. We then proceed to suggest a different scenario in which the initial jet which gave rise to the x ray and optical flux is reenergized by the central engine during its lateral expansion that makes it once again collimated, now to a wider opening angle. This new jet enters a lateral expansion phase around 10 days, resulting in the jet break seen in radio bands. One peculiarity of this GRB was its association with a supernova (SN2003dh) which dominated the optical flux beyond a week. The refined afterglow flux calculation allowed us to subtract the afterglow contribution from the total optical flux and compare the resulting supernova contribution with the stereotype SN1998bw. While being similar in light curve, SN2003dh is fainter compared to a redshifted SN1998bw. The contribution of this thesis lies in presenting a consistent modelling platform for 'hard' electron energy spectra as well as in the low frequency campaign of GRB030329 afterglow and the interpretation of its evolution. Chapter 6 concludes the thesis along with a few suggestions for future directions.