The "standard" afterglow model of gamma-ray bursts

After the GRB fireball starts to decelerate at $r_{dec} \sim 5 \times 10^{16} (E_{53}/n_{ext})^{1/3} \Gamma_{2.5}^{-2/3}$ cm (as discussed in http://www.astro.psu.edu/users/nnp/fbal.pdf) the Lorentz factor will start to slow down as it sweeps up more and more matter. The generic behavior from the relativistic hydrodynamics of spherical explosions [1, 2] is

$$\Gamma \propto r^{-g} \propto t^{-g/(1+2g)}, \tag{1}$$

where $g = (3/2, 3)$ in the adiabatic (radiative) regime. In the case of a GRB fireball, even if jet-like, can be considered as spherical as long as the jet opening angle $\theta_j > \Gamma^{-1}$. As Γ decreases, one expects the decreasing Doppler boost to shift the peak synchrotron radiation of the fireball shock model to longer wavelengths [3, 4].

The first detailed self-consistent afterglow calculations [5] took into account both the dynamical evolution and its interplay with the relativistic particle acceleration and the specific radiation mechanisms where, as the radiation softens, the timescales stretch as $t \propto \Gamma^{-(1+2g)/g}$. This resulted in quantitative predictions for the entire spectral evolution, from X-ray over days to optical over weeks to radio over months. E.g. in the adiabatic regime $g = 3/2$ the forward shock flux at a given frequency ν_m decay as

$$F_\nu \propto t^{-(3/2)\beta} \quad , \quad \nu_m \propto t^{-3/2} \; . \tag{2}$$

This is referred to as the "standard" (adiabatic) model, where $\beta = d\log F_\nu / d\log \nu$ is the photon spectral energy flux slope [5]. More generally the forward shock flux and frequency peak are $F_\nu \propto t^{[3-2g(1-2\beta)]/(1+2g)}$ and $\nu_m \propto t^{-4g/(1+2g)}$. The first X-ray [8], optical [9] and radio afterglows were discovered a few months after the theoretical prediction, in good overall agreement with it. It is the detection of afterglows that led to redshift measurements, the identification of host galaxies, and the confirmation that GRB were indeed at cosmological distances. Important further developments on afterglow theory came in [10, 11, 12, 13, 7, 14, 15]. The characteristic synchrotron spectrum, including peak and cooling breaks, were discussed in [7, 14] and more clearly in [15]. A reverse shock component is also expected [6, 5, 16, 17], with high initial brightness in the optical but much faster decay rate than the forward shock. This is one likely origin for the occasionally observed "prompt" optical flashes. A light curve break associated with jet edge effects were discussed in [16, 17, 18]. This generic "standard" afterglow model has been widely confirmed in its main features. Much new data and theory has been upcoming since then, and many new questions have arisen, but this afterglow model and the fireball shock model continue being the main workhorses used for fitting and interpreting the data.

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