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Prompt and early afterglow emission in GRBs(*)

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Summary. — We compare the dynamics of the internal and reverse shocks in the standard scenario of GRBs. We show that the two series of shocks are very similar and should a priori contribute in the same energy range. If internal shocks (IS) are responsible for the gamma-ray emission and the reverse shock (RS) for the early optical signal, the postshock physical conditions must somehow differ between the two cases. We briefly discuss different possibilities for this to occur.

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1. – Introduction

The internal/external shock model has been quite successful in explaining the highly variable gamma-ray burst profiles [7, 3] and the long term afterglow evolution at lower wavelengths [10, 9]. The early afterglow is a more complex phase with a reverse shock (RS) propagating back into the ejecta and possibly interacting with the internal shocks (IS). It is generally believed that it is responsible for the early optical emission observed in at least two bursts, GRB 990123 and GRB 021211, and characterized by a steep temporal evolution, $F(t) \propto t^{-2}$ [8, 6]. This seems to imply that the IS and RS have very distinct properties so that their respective contributions are separated by five orders of magnitude in energy. It is therefore critical to compare their dynamics and post-shock characteristics to understand how this can be possible.

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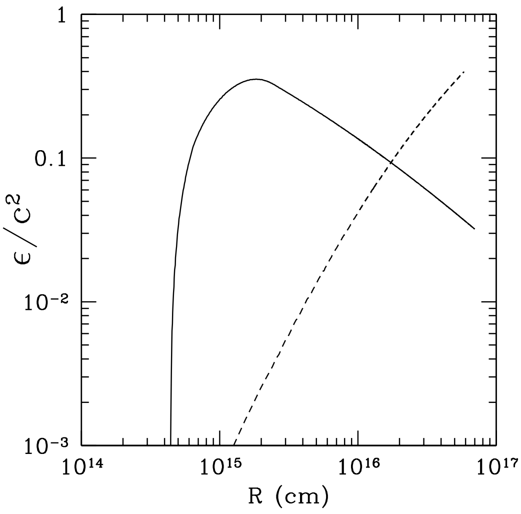

Fig. 1. – Dissiped energy per unit mass behind the IS (full line) and RS (dashed line) as a function of the distance to the source.

2. – Physical parameters in IS and the RS

If the radiation from the IS and the RS is due to the synchrotron emission of shock accelerated electrons the typical electron Lorentz factor, the magnetic field strength or/and the bulk Lorentz factor of the emitting material must strongly differ between the two cases. This is however not naturally expected since the dynamics of the IS and RS are very much alike. Both are midly relativistic (in the fluid rest frame), occur at comparable distance from the central source and dissipate similar amounts of energy. This can be illustrated with a simple example. Consider a relativistic outflow emitted by the central engine of a GRB and made of a "slow" shell of Lorentz factor $\Gamma = 100$ ejected prior to a more rapid part having $\Gamma = 400$. Internal shocks then develop in the flow as the rapid part catch up with the slower shell. At the same time the ejected material starts to be decelerated by the external medium and a reverse shock propagates back into the ejecta. We suppose that the isotropic kinetic energy of the outflow is $E = 10^{53}$ erg and we adopt a uniform density in the external medium $n = 1\,\mathrm{cm}^{-3}$. We have represented in fig. 1 the dissipated energy ϵ (per unit mass) in the comoving frame of the shocked material behind the IS and RS, respectively. It appears that, except at short radii, the values of ϵ behind the IS and RS are of same order. With the standard assumption that a fraction α_e of the dissipated energy is injected into a non-thermal distribution of electrons (representing a fraction ζ of the total number of electrons) and another fraction α_B into a disordered magnetic field, the typical energy of the emitted synchrotron radiation

$$E_{\mathrm{syn}} = C_{\mathrm{syn}} \Gamma B \Gamma_e^2$$

with $C_{\mathrm{syn}} = (3/4\pi)(eh/m_e c)$, depends on ϵ, on the post-shock density ρ and on the Lorentz factor Γ of the radiating material in the following way:

$$E_{\mathrm{syn}} = C_{\mathrm{eff}} \Gamma \rho^{1/2} \epsilon^{5/2},$$

where

$$C_{\mathrm{eff}} = C_{\mathrm{syn}}(8\pi\alpha_B c^2)^{1/2}\left(\frac{\alpha_e}{\zeta}\frac{m_p}{m_e}\right)^2 .$$

Since IS and the RS take place in the same region (between 10^{15} and 5×10^{16} cm from the central source in the example shown) the density, together with ϵ, will be comparable for both shocks and differences between the values of E_{syn} should result from the choices made for the parameters α_e, α_B or ζ. This is indeed the case since the value $\zeta = 1$, *i.e.* all the electrons are accelerated — is generally adopted in RS calculations [8] while Daigne and Mochkovitch [3] have shown that a small ζ is required for IS if they are to contribute in the gamma-ray range. Different values of the shock parameters can easily be justifed for the forward shock which is separated from the ejecta (where the IS and FS occur) by the contact discontinuity. For example the magnetic field in the ejected shell can contain a large-scale component anchored to the source and absent in the external medium, leading very different effective α_B values.

3. – The RS contribution: in the visible or in X-rays?

We have seen that the similarity of the IS and RS dynamics imposes different assumptions for the post-shock electron distribution or magnetic field in order to produce gamma-rays in one case and visible radiation in the other case. One is therefore confronted to a series of possibilities:

i) Adopt the same α_e, α_B and ζ in IS and RS which, after all, could seem logical in view of their similar dynamics. If for example one take a small value of ζ for both, IS will (normally) produce the gamma-ray emission but the RS will also contribute at high energy, and participate in the X-ray afterglow [4]. If conversely a large ζ is adopted, the RS, but also the IS will manifest themselves in the optical and another origin for the prompt gamma-ray emission should be found.

ii) A second possibility remains indeed to adopt different assumptions for the post-shock parameters in IS and RS. To see if this is realistic, one should look for all what can distinguish the two kinds of shocks. The main difference seems to be that, in most cases, IS occur (slightly) before the RS, which then moves through an already shocked material. This can introduce a distinction between IS and the RS if the ejecta coming out from the central source was magnetized. IS in a moderately magnetized flow have been studied by [5]. They have shown that reconnection induced by IS can dissipate energy and increase the efficiency (or the value of ϵ) compared to the case without magnetic fields. If, following a first reconnection episode, the field geometry is more regular when comes the RS, the post-shock energy density and hence, the electron Lorentz factor and magnetic field will be smaller. This could possibly explain why IS contribute at high energy and the RS in the visible but naturally such a proposal still needs to be confirmed by detailed calculations.

iii) A more radical assumption is finally to consider that neither IS nor RS occur, as in the electromagnetic model proposed by Blandford and Lyutikov [2]. In this model the gamma-ray emission comes from reconnection events in an instable magnetic shell with essentially no baryonic ejecta. In the absence of a RS the prompt optical emission should be explained by changes in the early evolution of the forward shock such as pair loading by a radiative precursor with pre-acceleration of the external medium [1].

4. – Conclusion

We have presented a short critical discussion about the respective contributions of the IS and RS to the GRB radiative output. While the gamma-ray emission is attributed to the IS, the RS is generally supposed to be at the origin of the early optical emission, producing for example the bright optical flash of GRB 990123. We have however shown that this "standard" point of view supposes to adopt different assumptions for the physical state of the post-shock material in IS and RS in spite of the fact the dynamics of both series of shocks are very similar. We have suggested that this might be possible if the ejecta is magnetized so that IS benefit from the dissipation of magnetic energy which is less efficient during the RS phase.

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