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Optical Flash and Radio Flare in Wind Environment

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Abstract. The interaction of a relativistic fireball with its ambient medium is described through two shocks: a reverse shock that propagates into the fireball, and a forward shock that propagates into the medium. We here study very early afterglows from the reverse and forward shocks in winds. An optical flash arises from both the relativistic reverse and forward shock while a radio flare is produced by the forward shock.

Introduction The gamma-ray bursts (GRBs) have been profoundly understood since the discovery of afterglows in 1997 (Piran 1999; Mészáros 2002). The hydrodynamic evolution of a GRB remnant is well described by an ultra-relativistic forward shock that sweeps into an interstellar medium (ISM) and slows down while the resulting afterglow is due to synchrotron radiation of electrons accelerated by the shock. However, the emission from a reverse shock propagating into the shell of the GRB ejecta, was also predicted (Mészáros & Rees 1997; Sari & Piran 1999a). The prompt optical flash of GRB 990123 (Akerlof et al. 1999) motivates investigations of emission from the reverse shock (Sari & Piran 1999b; Kobayashi & Sari 2000; Kobayashi 2000).

Hydrodynamics and light curves We consider a uniform and cold relativistic coasting shell with its rest mass M_0, the energy E, the initial Lorentz factor $\eta = E/M_0c^2$, and the observed width Δ, which sweeps up a wind with the particle number density $n_1 = Ar^{-2}$, where $A = \dot{M}/4\pi m_p v_w = 3\times 10^{35} A_* \mathrm{cm}^{-1}$ (Chevalier & Li 2000). Two shocks develop: a forward shock propagating into the wind and a reverse shock propagating into the shell. There are four regions separated by the two shocks: (1) the unshocked wind, (2) the shocked wind, (3) the shocked shell material, (4) the unshocked shell material. From the shock jump conditions and equality of pressures and velocities along the contact discontinuity, the Lorentz factor γ, the pressure p, and the number density n in both shocked regions can be determined by n_1, n_4, and η (Sari & Piran 1995).

A parameter $\zeta = \eta^{-2}\sqrt{l/\Delta} \simeq 0.005\eta_{300}^{-2}E_{52}^{1/2}A_*^{-1/2}\Delta_{13}^{-1/2}$ is introduced to judge whether the reverse shock is relativistic or not and extend the result of Sari & Piran (1995) to wind environments, where $l = E/4\pi A m_p c^2$ is the Sedov radius (Wu et al. 2002). For $\zeta \ll 1$ the reverse shock is relativistic (RRS), which is more possible in wind.

After RRS crosses the shell, the shocked shell will expands adiabatically with $p_3 \propto n_3^{4/3} \propto r^{-6}$, $\gamma_3 \propto r^{-3/2}, n_3 \propto r^{-9/2}$ and $r \propto t_\oplus^{1/4}$. The hydrodynamic evolution of the relativistic forward shock in the wind has already been discussed in some details (Dai & Lu 1998; Chevalier & Li 2000). We calculate the very early afterglows both on optical and radio bands for $E_{52} = 10$, $A_* = 1$, $\xi_e = 0.6$, $\xi_B = 10^{-2}$, $\Delta_{13} = 0.5$ and $p = 2.5$. The emission from RRS is comparable to that from forward shock at optical frequency, while the radio afterglow is mainly attributed to radiation from the forward shock.

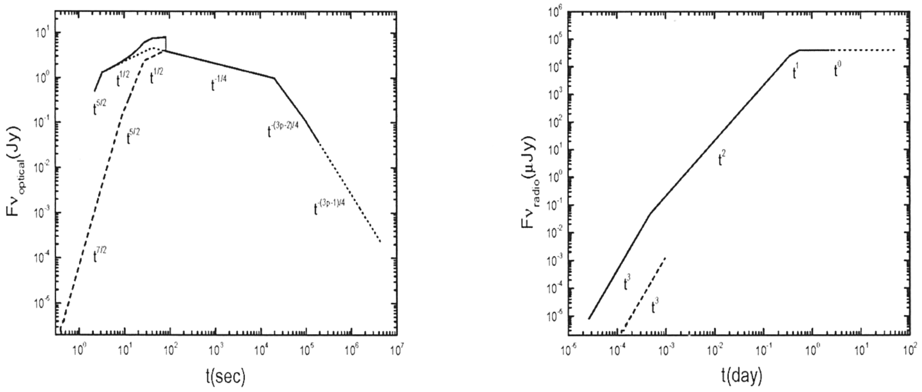

Figure 1. The left panel corresponds to optical flashes at $\nu_{opt} = 4 \times 10^{14}$ Hz, and the right panel to radio flares at 8.46 GHz. The dashed, dotted and solid lines represent the radiation from the relativistic reverse shock and forward shock and their total emission.

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