Astrophys Space Sci (2012) 342:113–116
DOI 10.1007/s10509-012-1160-0

ORIGINAL ARTICLE

Turbulence induced additional deceleration in relativistic shock wave propagation: implications for gamma-ray burst

Xue-Wen Liu

Received: 10 March 2012 / Accepted: 13 June 2012 / Published online: 3 July 2012

Abstract The late afterglow of gamma-ray burst is believed to be due to progressive deceleration of the forward shock wave driven by the gamma-ray burst ejecta propagating in the interstellar medium. We study the dynamic effect of interstellar turbulence on shock wave propagation. It is shown that the shock wave decelerates more quickly than previously assumed without the turbulence. As an observational consequence, an earlier jet break will appear in the light curve of the forward shock wave. The scatter of the jet-corrected energy release for gamma-ray burst, inferred from the jet-break, may be partly due to the physical uncertainties in the turbulence/shock wave interaction. This uncertainties also exist in two shell collisions in the well-known internal shock model proposed for gamma-ray burst prompt emission. The large scatters of known luminosity relations of gamma-ray burst may be intrinsic and thus gamma-ray burst is not a good standard candle. We also discuss the other implications.

Keywords Gamma-ray burst · Turbulence · Shock wave

1 Introduction

Gamma-ray burst (GRB) is the most explosive event in the universe. The standard picture for GRB is the relativistic fireball shock model (Paczýnski 1986; Goodman 1986; Shemi and Piran 1990; Rees and Mészáros 1992, 1994; Mészáros and Rees 1993). Within such a picture, an initially hot fireball composed of photons, electron-positron pairs, and a small amount of baryons expands outward because of the large optical depth, converts most of its thermal energy into the bulk kinetic energy of the baryons to form a relativistic cold shell; the expanding shells interact with each other and with the surrounding medium, causing their kinetic energy to be radiated in shock waves and producing the observed GRB prompt and afterglow emissions. Within such a scenario, the relativistic shock generates the magnetic field via Weibel instability (Weible 1959; Medvedec and Loeb 1999) and the energetic electrons via first order Fermi acceleration which cool down, most likely via synchrotron emission (Mészáros et al. 1994; Tavani 1996). Although the standard fireball model can explain the general features of GRB: the early-time rapid temporal variability and late-time smooth afterglow, there are some observational features beyond the expectations of this model such as the early X-ray plateaus, various rebrightenings and chromatic breaks (Zhang 2011). Different extensions of the basic model are invoked to explain the observed deviation from the model. The extensions include the modification of the total energy of the ejecta, the environment, the microphysics parameters and the radiative mechanism (Zhang 2011). However, often these are tailored on a burst by burst basis.

Most astrophysical system, e.g., accretion disks, solar/stellar winds, and the interstellar medium (ISM) are in turbulent states with embedded magnetic fields that influence almost all of their properties (Biskamp 2005; Frisch 1995; Goldstein et al. 1995; Elmegreen and Scalo 2004; Scalo and Elmegreen 2004). Narayan and Kumar (2009) and Lazar et al. (2009) have proposed a relativistic turbulence model instead of the internal shock model as the production mechanism for fast variable GRB light curves and applied it to GRB 080319B (Kumar and Narayan 2009). Zhang and Yan (2011) have also developed a new model of GRB

X.-W. Liu (✉)
Department of Physics, Sichuan University, Chengdu 610065, People's Republic of China
e-mail: astrolxw@gmail.com