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Primordial Flares, Flux Tubes, and Gamma-ray Bursts

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Abstract. Given the prevailing physical conditions in the cosmic environment, the similarity of solar transients and cosmic gamma-ray bursts suggests that the most promising energy source for the latter may be primordial flares, which derive energy from magnetic reconnection.

1. Introduction

In the present study, we conjecture that solar transients (like flares, plasma accelerated flows in the flux tubes, and dissipation of energy by MHD waves) and Gamma-Ray Bursts (GRBs) are produced by the same physical phenomena. We investigate in detail whether any such MHD phenomena in the cosmic environment are responsible for the creation of GRBs. In the following, we give a summary of this investigation. It is found that *primordial flares*, which are similar to solar flares but derive their energy from reconnection (Parker 1994; Priest 1981) of oppositely directed magnetic field lines of primordial origin, may be the most promising energy source for creation of GRBs.

2. Results and Discussion

(i) If *primordial flares* are responsible for the creation of GRBs, the following physical conditions in the cosmic environment are needed in order to explain the observed (Meegan et al. 1997) maximum amount of energy released by GRBs. The source region requires a length scale of $\sim 10^{12}$ cm, an annihilating magnetic field of strength $\sim 10^{10}$ G, and a plasma inflow velocity of $\sim 10^{9}\,\mathrm{cm\,s^{-1}}$ if we assume that the thickness of the source region is equal to the length scale of the reconnection region. Finally, by taking the typically observed length scale ($\sim 10^{22}$ cm) of the cosmic environment and conservation of magnetic flux, we estimate the strength (10^{-10} G) of the initial magnetic field, which is similar to the expected strength of the magnetic field of primordial origin. With a typically observed galactic velocity flow ($\sim 200\,\mathrm{km\,s^{-1}}$), the rate of GRBs per galaxy is estimated to be $\sim 10^{5}$ yr.

(ii) If *plasma flows* (that dissipate and release the required amount of energy) in primordial flux tubes are responsible for the creation of GRBs, the required length of the flux tube may be $\sim 10^{15}$ cm. Assuming that the total amount of energy released from the current sheath (Gokhale & Hiremath 1986) of the flux tube is the same as the amount of energy released in the GRB, it is estimated that the magnetic field strength of the flux tube is $\sim 10^{5}$ G.

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(iii) Finally, we consider *nonlinear interaction and dissipation of MHD waves* (Wentzel 1976) in the cosmic environment and estimate the energy flux released. In the case of Alfvén waves, and in order to get the observed GRB flux, it is estimated that the amplitudes of the waves that dissipate into shocks may be $\sim 0.01\,\mathrm{cm\,s^{-1}}$. Similarly, in the case of fast and slow MHD waves, the required amplitudes of the waves may be $\sim 10^9\,\mathrm{cm\,s^{-1}}$ and $\sim 10^{10}\,\mathrm{cm\,s^{-1}}$, respectively.

It is unlikely that either plasma flows from flux tubes or dissipation of MHD waves can create GRB phenomena. However, primordial flares appear to be promising candidates. This can be gauged from the following similarities: (a) observed properties of solar flares and GRBs, and (b) the inferred physical parameters from a model of primordial flares with the observed parameters (e.g., strength of the primordial magnetic field and rates of GRBs) of the cosmic environment. GRBs are similar to solar flares in the following important observed properties: (i) the source size is compact, (ii) time scales are $\sim$ seconds to minutes, (iii) radiation is observed in most of the electromagnetic spectrum, (iv) the energy spectrum is nonthermal, and (v) the polarization of synchrotron radiation is $< 30\%$.

The difficulty in primordial flare theory is how to annihilate such a large-scale region of strong magnetic field within a few seconds. The answer lies in the instabilities (Hood 1986) created by attaining such a structure of magnetic fields. Once an instability starts, reconnection begins with in a few seconds, accelerates the particles very close to velocity of light, and a shock structure forms which results in the creation of a nonthermal spectrum.

In summary, this study indicates that solar-like transient MHD phenomena, especially primordial flares, may be the most promising energy sources for the creation of GRB phenomena. Additional observations are required in order to prove our proposed conjecture in this study.

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