Electron density (n_e) is given by the Debye formula:

\[
\begin{align*}
\text{when } L < L_0 & : \quad n_e = \frac{Z \cdot e^2}{\sqrt{3} \cdot \sqrt{\pi} \cdot 4 \pi \cdot \lambda^3} \\
\text{when } L > L_0 & : \quad n_e = \frac{Z \cdot e^2}{\sqrt{3} \cdot \sqrt{\pi} \cdot 4 \pi \cdot \lambda^3} \exp \left( \frac{-\lambda}{L - L_0} \right)
\end{align*}
\]

(1)

\[
\frac{\partial u}{\partial \nu} = -u, \quad \frac{\partial}{\partial \nu} = -u
\]

(2)

The basic equations describing the problem are:

2. Basic equations

Introduction

The relationship between the electron density and the magnetic field is described by the following equations:

\[
\begin{align*}
\frac{\partial \mathbf{u}}{\partial \nu} &= -\mathbf{u} \\
\frac{\partial}{\partial \nu} &= -\mathbf{u}
\end{align*}
\]

(3)

The effective density of the parent galaxy is given by the formula:

\[
\left( \frac{\partial \mathbf{u}}{\partial \nu} \right)_{\text{eff}} = -\frac{Z \cdot e^2}{\sqrt{3} \cdot \sqrt{\pi} \cdot 4 \pi \cdot \lambda^3} \exp \left( \frac{-\lambda}{L - L_0} \right)
\]

(4)

Optical counterparts of cosmological GRBs due to heating of ISM in the parent galaxy.
This system was solved numerically using a full conservative difference scheme with flux corrected transport, because there is a strong density gradient in the solution (shock wave).

3. Main results

For GRB with the energy $10^{52} \text{ erg}$ we considered following densities of the surrounding interstellar medium: $10^5 \text{ cm}^{-3}$, $300 \text{ cm}^{-3}$, $0.25 \text{ cm}^{-3}$, $1.6 \cdot 10^{-3} \text{ cm}^{-3}$. Main results of calculations in optically thin approximation are presented in our publications Timokhin & Bisnovatyi-Kogan (1995, 1996). According these calculations a counterpart of cosmological GRB due to the influence of GRB on the surrounding medium could be observed if density of the medium is greater then $300 \text{ cm}^{-3}$. For such dense interstellar clouds optically thin approximation is not valid because of large optical depth in main emission lines.

Then we considered a simplified picture of conversion of UV photons into optical ones in optically thick regions allowed us to get optical and UV light curves of counterparts (see details in Bisnovatyi-Kogan & Timokhin 1997). We considered GRBs with energies $10^{52}, 10^{51} \text{ ergs}$ and following initial conditions in a gaseous cloud of radius $R$:

1. $n_0 = 10^5 \text{ cm}^{-3}, T_0 = 20 \text{ K}, R = 1.5 \text{ pc}$
2. $n_0 = 10^4 \text{ cm}^{-3}, T_0 = 20 \text{ K}, R = 5 \text{ pc}$

The results of calculations are presented in Fig. 1. Dashed lines give the lower boundary for luminosity, and solid lines - the upper one. For GRB with total energy output $10^{51}$ and $10^{52} \text{ ergs}$ maximal luminosities of counterparts differ by one order of magnitude too. It means that relative maximum brightness of the counterparts depends weakly on the total energy output. The total duration of the counterpart radiation decreases 2 times when the total output decreases 10 times. A more detailed description of the results is given in Bisnovatyi-Kogan & Timokhin (1997).

4. Conclusions

It is shown, that counterparts of cosmological GRB due to interaction of gamma-radiation with dense interstellar media are "lounging" objects, existing for years after GRB. To distinguish GRB counterpart from a supernova event, having similar energy output, it is necessary to take into account its unusual light curve and spectrum. In optical region of the spectrum the strongest emission lines are $H_{\alpha}$ and $H_{\beta}$.

The volume occupied by dense interstellar medium in the parent galaxy is relatively small, so the probability to get bright counterpart of such kind is also small. Nevertheless, discovery of even one optical counterpart of GRB with properties described above could be a decisive argument in favor of the cosmological nature of GRB.

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References

G.S. Bisnovatyi-Kogan, A.N. Timokhin, 1997, Astronomy Reports, 41, #4, 423