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A2_4 The contribution of GRBs to cosmological reionization

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Abstract

High energy gamma ray bursts (GRBs) are considered as an energy source contributing to the cosmological reionization epoch which occurred some 13 billion years ago. The Strömgren radius of a GRB is estimated and compared to the Strömgren radii of other potential sources such as quasars, globular clusters and massive stars. We conclude that GRBs could have an ionizing effect far in excess of these other potential sources given certain assumptions. However, further research is required to determine the overall impact of GRBs on cosmological reionization.

It is widely accepted in the current understanding of the evolution of the universe that a period of cosmological reionization (the ionization of hydrogen in the interstellar medium) occurred roughly between one million and one billion years after the big bang [1]. Several sources of ionizing radiation have been proposed to account for this transition. These include the earliest formed stars, quasars [2] and globular clusters [3]. In this paper we consider the effect of gamma ray bursts in terms of their ionizing potential and compare their effects to those of other ionizing sources.

The UK Swift Science Data Centre suggests that gamma ray bursts can emit up to 10^{54} ergs (1erg = 10^{-7}Joules) of energy if the emission is isotropic [4]. For simplicity we consider only the isotropic case and we assume that all of the emitted energy is of a sufficient magnitude to ionize neutral hydrogen (E_{photon} > 13.6eV), thus negating the requirement for a detailed spectral breakdown of gamma ray bursts. Gamma ray bursts are generally classified into two distinct types (long and short) according to their duration, where the dividing line is taken as two seconds [4]. Here we consider only long GRBs which have an average duration of thirty seconds [4]. We choose only long bursts given that these are the most frequently observed type. We assume that the gas under consideration consists purely of hydrogen and that the hydrogen density is uniform in these regions. We also assume that the number density of hydrogen is 10^3 cm^{-3}, which is consistent with that in galactic haloes in the early universe [5]. We have made several assumptions and approximations, and we justify these given that this is a brief proposal into an as yet un-researched idea. As such, this constitutes a simplified treatment of the problem.

To analyse the ionizing effects we consider the Strömgren sphere, this specifies the surrounding region fully affected by the ionizing source of radiation. That is, all hydrogen within this region is completely ionized. The radius of this sphere is defined by the Strömgren radius

$$R_S = \left(\frac{3L}{4\pi n^2 \alpha h f} \right)^{\frac{1}{3}}, \ [6] \qquad (1)$$

where L is the source luminosity (taken as total luminosity across all frequencies given our assumptions), n is the number density of hydrogen atoms in the surrounding interstellar medium, f is the minimum frequency radiation capable of ionizing hydrogen, and h is Planck's constant. α is the recombination rate coefficient which accounts for the rate at which hydrogen ions recombine with electrons in a plasma and has an approximate value of $3x10^{-13}cm^3s^{-1}$ [7]. To compute the GRB luminosity, we use the previously stated maximum energy output and the average burst duration.

The following table presents the data for the four mentioned ionizing radiation sources. The Strömgren radius for has been calculated using equation (1). The luminosity of each source has been given as approximate order of magnitude only. O type stars have been chosen given that they constitute the biggest and brightest known stars, and thus represent an effective limit for ionizing potential for individual stars.

Radiation source	Bolometric luminosity (ergs/s)	Strömgren radius (parsecs)
O type star	10^{38} [8]	0.5
Globular cluster	10^{40} [3]	2.4
Quasar	10^{42} [9]	11
GRB	10^{52}	$2.4x10^4$

It is clear that GRBs could have an ionizing effect far greater than all other proposed sources if this simple model were close to a realistic approximation. There are however several questions that would require a much greater length and depth of paper to address. For example, a detailed spectral analysis would reduce the luminosity applicable to hydrogen ionization for two reasons. Firstly, we assume that there would in reality be emission across the entire spectrum, thus radiation below the 13.6 eV threshold needs to be considered and removed from calculations. Secondly, the absorption cross section of neutral hydrogen decreases with increasing energy, so in reality each discrete photon energy has a different probability of interacting with a hydrogen atom. Therefore more consideration should be shown to the X-ray and UV components of the burst and the afterglow. However we have used the same set of assumptions for all calculations for the purpose of giving a relative comparison of ionizing potential for each source. A further consideration must be that of the manner in which GRBs emit. A popular theory is that the energy is ejected in a beam like fashion; in this case the total energy would be reduced by a factor of 'beam solid angle'/4pi, and brings about further complications in the volume of gas affected (i.e. not a sphere). We have avoided using the beam theory because of these complications and also the fact that any solid angle we assign to the beam would be arbitrary.

We have shown the potential of GRBs as ionizing sources of radiation for a simple generalised case. The abundance of GRBs relative to other sources is an important factor that has not been considered here, and the burst duration and afterglow period limit the overall impact relative to other sources of prolonged emission. This implies we cannot yet conclude that GRBs had a significant effect in cosmological reionization, and further study is required to obtain a realistic measure. However, given the relative magnitudes of Strömgren radii, we have shown that GRBs warrant consideration in the quest to discover the main causes of cosmological reionization.

References

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