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A1_1 Tick, tick, tick… GRBoom!

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Abstract

This paper considers the possibility that a gamma ray burst (GRB) will cause a mass extinction on our planet. The distance over which a low energy GRB would expose a human to a lethal amount of radiation is calculated and found to be approximately 90 kiloparsecs. This indicates that we only need to consider GRBs occurring within the Milky Way galaxy. GRBs are also highly directional; the probability of a GRB striking the Earth is calculated to be 0.061%. From these calculations it is found that a lethal GRB is likely to impact on the Earth once every 328 million years.

Introduction

Gamma ray bursts (GRBs) consist of pulses of gamma rays that are the result of stellar explosions. They are some of the most energetic events which occur in the universe; lasting on average between 20-40 seconds. GRBs are highly collimated; travelling close to the speed of light in a uniform distribution across the sky and generally originate outside the Milky Way [1], [2].

A single GRB could cause a mass extinction on the Earth. For this report we will assume that all the gamma rays reach the surface of the Earth. This article will examine the possibility of this occurring.

Discussion

To calculate the radius from the source over which a GRB would be fatal, we consider the flux f of uniform radiation (over an area A) from a point source with luminosity L,

$$f = \frac{L}{A}. \quad (1)$$

The energy of a GRB is not emitted evenly over a spherical surface, but instead as a beam that projects in a cone from both sides of the source. The cross sectional area at the far end of each cone is approximately circular, with an area of $A = \pi a^2$ where a is the radius of the circle. When the gamma rays have travelled a distance r, $a = r\theta$ where θ is the angle the radiation disperses by. Using Equation 1 we can write,

$$f = \frac{1}{2}\frac{L}{\pi r^2 \theta^2}, \quad (2)$$

where the factor of one half arises because the beam extends from both sides of the source. Rearranging Equation 2 yields,

$$r = \sqrt{\frac{L}{2f\pi\theta^2}}. \quad (3)$$

As a radiation dose of 6 sieverts is adequate to kill over 50% of humans [3]; and assuming that the average human has a mass of 70 kg and a cross sectional area of about 1 m^2 (half the surface area [4]); it would require a flux of $f = 420$ W m^{-2} striking the Earth for it to be lethal. This assumes that the gamma rays reach the surface of the earth. The luminosity of a GRB is in the region of $L = 10^{51} - 10^{54}$ erg s^{-1} [5].

The most likely angle of dispersion (the angle by which the cones of the directed gamma rays expand) is $\theta = 4° = \pi/45\,\text{rads}$ [6].

Using the lower limits of these data to solve Equation 3, we find that $r \cong 90.4\,\text{kpc}$. The Milky Way is approximately $30\,\text{kpc}$ in diameter [7] and the nearest galaxy is approximately $766\,\text{kpc}$ away [8]; so from these numbers it is clear that only GRBs from within our galaxy pose a realistic threat.

It is also important to deduce the probability of a GRB hitting the Earth, as we assume their sources only emit in two cones spreading at just $4°$. The equation for the solid angle Ω subtended by one cone is,

$$\Omega = \int_0^{2\pi} \int_0^{\pi/90} \sin\theta \;\, \mathrm{d}\theta \, \mathrm{d}\phi. \quad (4)$$

It is necessary to multiply Ω by a factor of 2 because an average GRB is emitted in two cones travelling in opposite directions. The probability P of a GRB randomly striking the Earth is given by,

$$P = \frac{2\Omega}{4\pi}, \quad (5)$$

where 4π is the solid angle of a sphere. It follows that $P = 6.09 \times 10^{-4} = 0.061\%$.

From the preceding discussion we have found that only GRBs originating from within our galaxy pose a lethal threat. There are between $10^{-5}$and 10^{-6} GRBs per year in the Milky Way [9]. Taking the midpoint of this frequency and multiplying it with the probability of a GRB striking the Earth, it is calculated that a potentially lethal GRB is likely to strike the Earth approximately once every 328 million years.

Conclusions

Popular scientific magazines have discussed the possibility that a GRB caused a mass extinction 443 million years ago [10]. This document estimates that the frequency of a mass extinction by GRBs is once in every 328 million years. This number seems to be rather too frequent, as life took hundreds of millions of years to evolve. This evolution would likely be set back by frequent GRBs, however there are other factors that have not been taken into account. This could include GRBs being blocked by objects such as stars in the galactic bulge.

References

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