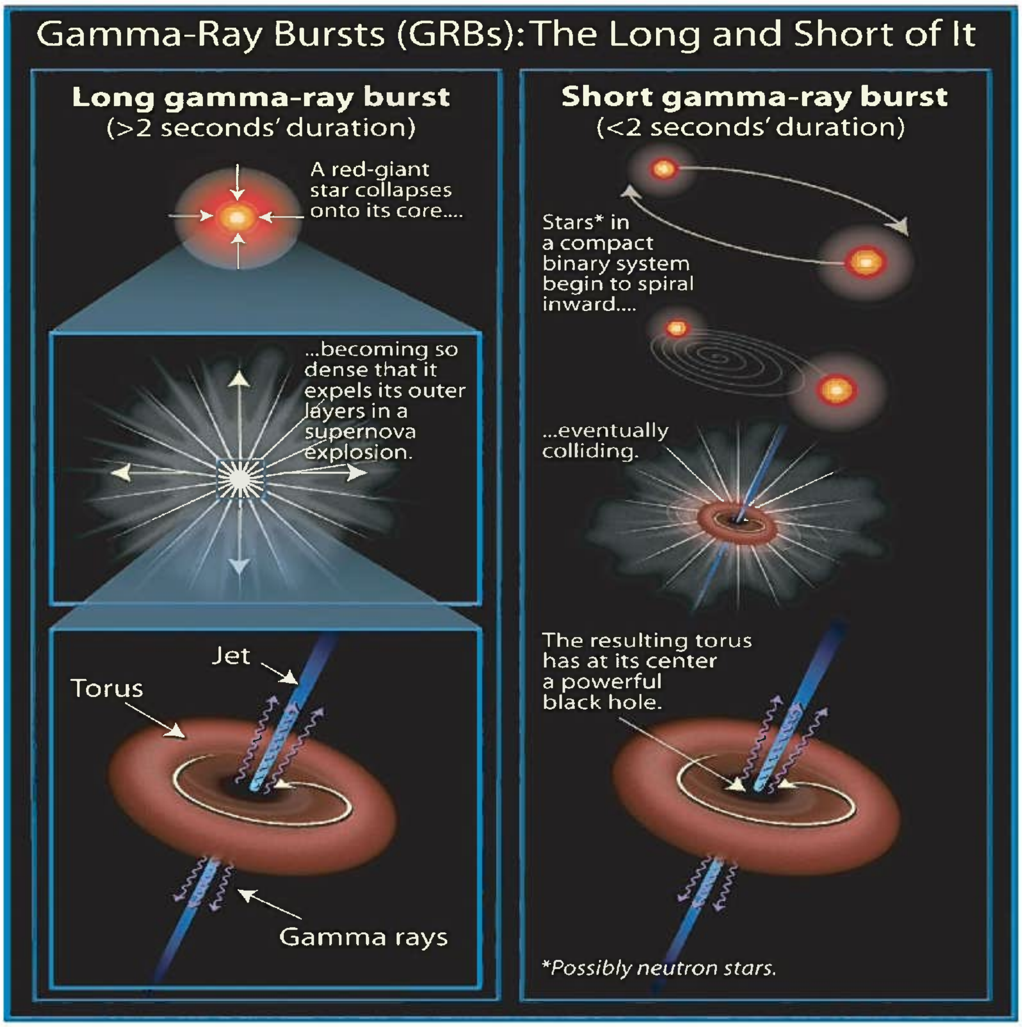
Gamma Ray Bursts (GRBs)

Farhan Ishraq

Introduction

Gamma-ray bursts (GRBs) are flashes of gamma rays associated with extremely energetic explosions that have been observed in distant galaxies. They are the brightest electromagnetic events known to occur in the universe and these bursts can last from ten milliseconds to several minutes. Most observed GRBs are believed to consist of a narrow beam of intense radiation released during a supernova as a rapidly rotating, high-mass star collapses to form a neutron star, quark star, or the most well-known black hole.

They are extremely energetic for a typical burst releases as much energy in a few seconds as the Sun will in its entire 10 billion year lifetime. All observed GRBs have originated from outside the Milky Way galaxy, although a related class of phenomena and it been hypothesized that a gamma-ray burst within the Milky Way which is pointing directly towards the Earth, could cause a mass extinction event, making the study of gamma rays all the more crucial. The GRBs were first detected in 1967 by the Vela satellites, a series of satellites designed to detect covert nuclear weapons tests.



Background Physics of GRBs

Astronomers now understand what GRBs are after 3 decades of its discovery, and also theorise on gamma ray bursts are and how the various spikes in gamma ray emissions have been attributed to gamma ray bursts. The only known way to generate high intensities of GRBs is through gravitational collapsing, and the formation of black holes can be very efficient at turning this energy into such intense power and almost all astronomers now agree that long duration GRBs coincide with hypernovae, which are powerful supernovae that occur when a massive star collapses to a black hole. Furthermore, almost all GRBs happen in galaxies containing large numbers of very massive stars.

Background Information of Research Papers

Hundreds of theoretical models were proposed to explain these bursts in the years following this discovery, such as interstellar collisions. Little information was available to verify these models until the 1997 when the detection of the first X-ray and optical afterglows occurred which led to the distances and energy outputs to be discovered, the very first time for the GRB to be pinpointed so quickly and accurately. These discoveries, and subsequent studies of the galaxies and supernovae associated with the bursts, clarified the distance and luminosity of GRBs. These facts definitively placed them in distant galaxies and also connected long GRBs with the explosion of massive stars, the only possible source for such a large energy output.

In the last Galactic year (Gy), two mass extinction events occurred, the Permian-Triassic extinction event and the Cretaceous-Paleogene extinction event. A.L. Melott et al. believe that these were likely due to GRBs within the Milky Way galaxy. GRBs produce significant atmospheric ionization and dissociation of Nitrogen gas, resulting in ozone depletion and thus allowing DNA damaging ultraviolet solar flux to reach the surface of Earth for up to 10 years. Visible opacity of NO2 is sufficient to reduce solar energy at the surface by a few percent, with the greatest effect at the poles and this may be sufficient to initiate glaciation. They use a computational model, inputting various parameters, such as altitude and latitude, and observe various outcomes to understand the effects a GRB within our galaxy have on Earth.

GRBs produce a flux of radiation detectable across the observable Universe. A GRB within our own galaxy could do considerable damage to the Earth's biosphere. Earth has experienced mass extinctions at least five times in the existence of life itself, each time eliminating a large percentage of its biota. Many possible causes have been documented, GRB being one of them. The late Ordovician mass extinction approximately 440 million years ago has many indefinite causes, GRB being one of them. Furthermore, intense rapid cooling and glaciation occurred at the end of that period, identified as the probable cause of the mass extinction. However, a GRB has the ability to trigger global cooling which occurred then. A.L. Melott et al. try to find out if a GRB within our galaxy had initiated this mass extinction.

Brian C. Thomas et al. used a two-dimensional atmospheric model to perform the first computation of the effects upon the Earth's atmosphere of one such impulsive event. All simulations began with initial conditions obtained from a long-term run such as 40 years in the intention to bring the model to equilibrium for analysis. They, with the aid of simulations, tried to find how much ozone would depleted if a GRB within the Milky Way galaxy were to occur. If a significant amount of ozone is depleted, then widespread extinctions are likely, based on extrapolation from Ultraviolet B sensitivity of modern organisms which sides with the hypothesis that a GRB may have initiated the late Ordovician mass extinction.

Douglas Galante and Jorge Ernesto Horvath presented the effects that could be caused on Earth by a GRB through analytical and numerical calculations, considering atmospheric and biological implications. Here GRBs are classified into four distinct categories and analysed separately. Direct γ Flash, UV Flash, Ozone Layer Depletion and Cosmic Rays are the 4 types of GRBs. The effectiveness of each of these effects is compared and distances for significant biological damage are given for each one.

High energy cosmic ray jets from nearby mergers or accretion induced collapse (AIC) of neutron stars (NS) that hit the atmosphere can produce lethal fluxes of atmospheric moons in all places of Earth, destroying the ozone layer and causing the environment to become radioactive. They could have caused most of the massive life extinctions on planet Earth in the past 600 million years and biological mutations due to ionizing radiations could explain the fast appearance of new species after the massive extinctions. Arnon Dar et al. correlate neutron star (NS) merger with GRBs. The paper is upon Cosmic Jet Rays, which come from GRBs. They carry out research to find the rate of mass extinction on Earth when binary NS merger occurs and GRB occurs in our galaxy, and also finding the distance from which GRBs are not lethal to the Earth's biota.

Findings of Research Papers

NO2, a brown gas, has the ability to block considerable blue and near-UV light rays. Also, major ionizing events might easily generate enough opacity to cool the climate, allowing the possibility of glaciation to occur. Due to the increased transmission of UVB, O3 depletion occurs and this gives way to some increased heating. Also the energy absorbed by the NO2, which is only generated in significant amounts within the stratosphere, will be re-radiated as infrared rays, partially reaching the ground. Thus climate change may be possible for several years such as reduction in sunlight reaching the surface of Earth resulting in reducing the melting of ice.

It is believed that the likelihood of GRB contributing to the Ordovician mass extinction is high. A 10s average GRB can easily strip 50% of the ozone almost instantaneously, causing all the organisms dwelling on earth at that time to be exposed to UV radiation. Furthermore, GRB has the ability to cause glaciation to occur and this results in dramatic climate changes, destroying various habitats and killing organisms. Also due to the exposure of radiation, the food chain gets poisoned which will further cause inclination in death. This displays the fact that indeed GRB ties in well as the culprit of the Ordovician mass extinction.

When a large input of gamma rays into the atmosphere occurs, NOy compounds (most importantly NO and NO2) are created through dissociation of N2 in the stratosphere which then reacts quickly with O2 to generate NO. Subsequent reactions create NO2 and other compounds. Together, these react catalytically to deplete O3 through the cycle below.

$NO + O_3 \rightarrow NO_2 + O_2$ (1)
$NO_2 + O \rightarrow NO + O_2$ (2)

Averaged ozone depletion of Earth reaches about 35% and a peak depletion of about 55% immediately after the burst. Significant global depletion, which is taken as 10% O3 depletion or more, lasts for over 5 years after the burst.

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The Ordovician extinction is associated with a brief glaciation in the middle of a period of stable warm climate. It is speculated that there may have been a significant perturbation by the opacity of NO2, which would cut off a few percent (ranging up to 35% for a month or so during polar fall) of solar radiation. This would occur primarily at high latitudes. The removal of O3 (a greenhouse gas) also may cause some cooling, but this effect should be negligible compared to that due to the increase in NO2.

As in the case of GRBs, they found that the most effective mechanism is UV Flash, because it is able to displace a lethal effect at the greatest distance among the 4 types of GRBs. However, this type of occurrence should happen very close to Earth for catastrophic effects to happen, so close that in fact the researchers do not expect to occur in the history of the planet.

GRBs from neutron star mergers may have caused the massive continental and marine life extinctions which interrupted the diversification of life on our planet several times. They explain the complicated biological and geographical extinction patterns as well as the biological mutations induced by the ionizing radiations which are produced by the GRBs, explaining the appearance of completely new species after extinctions. Isotopic anomaly signatures of GRB extinctions may be present in the geological layers which recorded the extinctions in the Earth's layers. If nearby neutron star mergers are responsible for mass extinctions, then an early warning of future extinctions due to neutron star mergers can be obtained through the means of identifying, mapping and timing all the nearby binary neutron stars systems, thus giving time for preparation if possible.

As it can be seen from the above research papers, GRB is indeed a phenomenal discovery of astronomers and its power is so immense that it can wipe out our atmosphere with ease. It can be seen that through GRB it is possible several cases of mass extinction has occurred on Earth and a series of events followed which resulted in dramatic changes to Earth and cause the organisms who survived to adapt to the adverse living condition, survival of the fittest against the conditions such as radiation, UVB, poisoning of the food chain etc.

Future Study

It is essential to carry out studies in the field of GRBs due to the fact that it could potentially harm our home planet at any given point of time. The fact that GRBs carry such a huge amount of energy which could easily destroy us could be used to our advantage, harvesting its energy when technology permits in the near future hopefully for the fossil fuel reserves are running out and they have the ability to project as much energy as the Sun every will in its entire lifespan in just 10 seconds, far exceeding the bounds of solar power. Furthermore, by learning more about these effects the GRB can cause such as glaciation, it could allow further experimentation and come up with a means to solve the global warming problem by initiating a Ice Age ourselves to cool down the planet and all ice to be restored. This will benefit humanity, allowing us to inhabit this planet by using a cleaner means of energy and not further destroy our atmosphere and ensure our environment is at its prime.

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