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Gamma-Ray Bursts and Fermi Bubbles

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Abstract

According to a recent calculation, 10^{58} erg of radiant energy was released by Sgr A*, when it formed the Fermi bubbles. Here, it is argued that this explosion constituted a long gamma-ray burst.

Keywords

Gamma-Ray Burst, Supermassive Black Hole

1. Fermi Bubble

In a recent calculation, it was shown that Sgr A* released 10^{58} erg of radiant energy, when it suddenly changed from supermassive to intermediate-mass status [1]. The temperature ranged up to 10^9 K, corresponding to 100 keV x-rays. Before the explosion, the radiation was confined to a metastable black hole of radius 1.2×10^{12} cm. Therefore, the duration of the explosion was 40 seconds, with an average luminosity $L = 10^{56}\ \text{erg} \cdot \text{s}^{-1}$. The flash of light was recorded in the Magellanic Clouds, where ionized hydrogen was found [2]. The ionizing light formed a cone along the axis of the Galaxy, while nothing was seen in the galactic plane. This suggests that there was a considerable loss of energy, before the burst left the Milky Way.

Between 10^{13} and 10^{15} cm, the burst encountered the accretion disk, which must have suffered a catastrophic end. Today, there is no more than $10^{-4}\ M_\odot$ in the disk [3]. The violent collision with the disk created an afterglow, which may have lasted for many years. It would have initiated the production of gamma-ray photons via inverse Compton scattering. A toroidal disk could account, in part, for the axial orientation of the prompt signal.

It is known that Sgr A* is surrounded by a cluster of 10 million stars, within a radius of 1 parsec. It is also known that the stars are missing from the inner 0.5 parsec—there is a void surrounding Sgr A* [4]. These missing stars would have absorbed a great deal of energy from the blast. At a distance of 10^{17} cm from the black hole, the intensity of the radiation would have been $10^{21}\ \text{erg} \cdot \text{s}^{-1} \cdot \text{cm}^{-2}$. A red giant star presents a cross-section of roughly 10^{27} cm^2, so that the energy striking the star during the 40 second burst would have been 10^{50} erg. This exceeded the gravitational binding energy and caused the star to disintegrate. The vaporization of several million stars would explain the mass and kinetic energy that are observed today in the Fermi bubbles.

Sgr A* now contains an intermediate-mass black hole with a mass of $4\times10^6\ \mathrm{M}_\odot$. A black hole of similar mass should be found at the origin of all Fermi bubbles. One example is that of NGC 3079, with a mass of $2.4\times10^6\ \mathrm{M}_\odot$.

2. Gamma-Ray Burst

The prompt that emerged from the Galactic Center was strongly filtered by its encounter with the accretion disk and with the cluster of nearby stars. A large fraction of its energy was lost to the resulting afterglow. The fact that life on Earth survived attests to this. The amount of energy removed from the signal could have reduced its luminosity to that of a typical burst, *i.e.*, 10^{49} - 10^{53} erg·s^{-1}. The discoveries in the Magellanic Stream reveal a broad, cone-shaped path centered on the galactic axis. Such directionality is thought to be a common feature of gamma-ray bursts. The final state of Sgr A* is a black hole of mass $4\times10^6\ \mathrm{M}_\odot$ and an afterglow mass of $10^6 - 10^7\ \mathrm{M}_\odot$. Any gamma-ray burst with such a final state would be a Fermi bubble.

3. Addendum: Explosion in Ophiuchus

A black hole of mass $10^7\ \mathrm{M}_\odot$ would be near the critical mass. If it were to become unstable and release its electromagnetic radiation, then it might fail to achieve equilibrium as a quantum gas. Runaway annihilation could ensue, with the complete conversion of mass into radiant energy: $10^7\ \mathrm{M}_\odot c^2 = 10^{61}\ \mathrm{erg}$. An explosion of this magnitude occurred in the Ophiuchus Cluster [5].

4. Summary

This paper identifies two distinct sources of explosive radiation. The first involves a metastable black hole below the critical mass. It releases 10^{58} erg of electromagnetic radiation and then reaches equilibrium as a quantum gas. The second involves a black hole above the critical mass. It releases its radiation but is too massive to establish equilibrium as a quantum gas. Its entire mass is converted into 10^{61} erg of radiant energy. Remnants of such explosions have been found in the past few years: one in our own Galaxy, another in Ophiuchus. It is suggested that some gamma-ray bursts may be explained in similar terms.

The stable black hole states are reproduced here for convenience:

Intermediate-mass				
M ($\mathrm{M}_\odot$)	$R > R_s$ (cm)	ρ_0 (g·cm^{-3})	P_0 (Pa)	ε_{F0} (eV)
10^3	4.8 (10^{13})	2.6 (10^{-5})	3.9 (10^9)	2.1

Continued

10^4	$2.25\ (10^{13})$	$2.6\ (10^{-3})$	$8.4\ (10^{12})$	$4.5\ (10)$
10^5	$1.05\ (10^{13})$	$2.6\ (10^{-1})$	$1.8\ (10^{6})$	$9.6\ (10^{2})$
10^6	$4.8\ (10^{12})$	$2.6\ (10)$	$3.9\ (10^{19})$	$2.1\ (10^{4})$
$4\ (10^6)$	$3.0\ (10^{12})$	$4.2\ (10^{2})$	$4.0\ (10^{20})$	$1.4\ (10^{5})$
$8\ (10^6)$	$2.4\ (10^{12})$	$1.7\ (10^{3})$	$3.9\ (10^{22})$	$3.3\ (10^{5})$

Supermassive				
M ($M_\odot$)	$R = R_s$ (cm)	ρ_0 ($g \cdot cm^{-3}$)	P_0 (Pa)	kT_0 (eV)
$8\ (10^6)$	$2.4\ (10^{12})$	$2\ (10^{3})$	$3.9\ (10^{22})$	$1.1\ (10^{5})$
10^7	$3\ (10^{12})$	$1.3\ (10^{3})$	$2.5\ (10^{22})$	$1.1\ (10^{5})$
10^8	$3\ (10^{13})$	$1.3\ (10)$	$2.5\ (10^{20})$	$6.2\ (10^{4})$
10^9	$3\ (10^{14})$	$1.3\ (10^{-1})$	$2.5\ (10^{18})$	$2.3\ (10^{4})$
10^{10}	$3\ (10^{15})$	$1.3\ (10^{-3})$	$2.5\ (10^{16})$	$8\ (10^{3})$
10^{11}	$3\ (10^{16})$	$1.3\ (10^{-5})$	$2.5\ (10^{14})$	$2\ (10^{3})$

A critical mass of $8 \times 10^6\ M_\odot$ defines the transition region.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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