ON THE NATURE OF \( \gamma \)-RAY BURSTS

O. F. PRILUTSKI and V. V. USOV

Space Research Institute, Academy of Sciences, Moscow, U.S.S.R.

(Received 24 September, 1974)

Abstract. The hypothesis on the \( \gamma \)-ray burst generation in the process of the collapse of supermassive bodies in the nuclei of active galaxies is considered. It is shown that \( \gamma \)-ray burst properties observed may be interpreted within the frames of the given model. A statistical test for choosing a hypotheses on \( \gamma \)-ray burst nature is discussed.

1. Introduction

In processing the data obtained on-board the 'Vela' satellites intense \( \gamma \)-ray bursts were found in the range from 0.2 to 1.5 MeV (Klebesadel et al., 1973). About 5 bursts, on the average, were observed in a year. The burst duration was 0.1–30 s and the total energy flux per pulse was \( 10^{-5} \) to \( 2 \times 10^{-4} \) erg cm\(^{-2} \) (the lower limit of the range is defined by the sensor sensitivity). The OSO-7 and IMP-6 sensors recorded burst spectra. The spectra observed are characterized by both the exponential cut-off at about 150 keV (Cline et al., 1973) and the decay according to the power law in the range 11–110 keV (Wheaton et al., 1973).

Gamma-ray burst experiment on board the Vela satellites was based on Colgate's hypothesis (1968) on hard \( \gamma \)-radiation production with a relativistic shock wave emerging on the supernova surface. However, Colgate's original hypothesis gives durations (\( \tau \sim 10^{-5} \) s) and energies (\( \varepsilon_\gamma \sim 1 \text{ GeV} \)) of \( \gamma \)-ray bursts that strongly differ from the parameters observed. The increase of the pre-supernova radius up to \( \sim 10^{12} \) cm recently suggested by Colgate (1974) allows generation of \( \gamma \)-ray bursts of durations and energies close to the values observed. But the problem of appropriate energy arises in this case since the relativistic shock wave for the stars with low parabolic velocities (with large radii) is weak (Nadezhin and Frank-Kamenetsky, 1964) and the energy emitted in \( \gamma \)-range is not sufficient to account for \( \gamma \)-radiation fluxes observed.

At present the type of astronomical objects generating \( \gamma \)-bursts and the mechanism of \( \gamma \)-radiation production are not clear. Hence, it is important to consider alternative models of \( \gamma \)-ray bursts.

In this paper the possibility of \( \gamma \)-burst production at the final evolution stage of supermassive bodies with strong magnetic fields in active galaxy nuclei is considered and the statistical test to locate the sources of \( \gamma \)-ray burts is proposed.

2. Galactic Nuclei

Numerous observational data show that the source of activity of quasars and galactic nuclei is a supermassive body which rotates and possesses a magnetic field (see
The mass of such a supermassive rotator is \( \sim 10^5 - 10^6 M_\odot \) for active galaxies and \( \sim 10^7 - 10^8 M_\odot \) for quasars. Usually its thermal radiation maximum is in the UV spectral band. Therefore, pure thermal radiation of a supermassive rotator cannot explain intense IR radiation of quasars and active galaxies. The analysis of supermassive rotator properties shows that a combination of significant non-thermal (infrared) radiation \( (L_{\text{infra}} \gtrsim L_{\text{th}}) \) with a long period of quasi-static evolution (\( \tau_{\text{evol}} \sim 10^6 \text{ yr} \)) is possible only in the presence of strong poloidal magnetic field (Ozernoy and Usov, 1973), that is the rotator magnetic energy should be comparable with its gravitational energy. In this case the strength of the magnetic field on the rotator surface is equal to \( H_p \sim 10^7 (M/10^5 M_\odot) (R/10^{14} \text{ cm})^{-2} \text{ Oe} \).

Supermassive rotator energy emission results in its contraction. However, the final result of this contraction is still rather obscure. Most probable are the following possibilities: rotator evolution into a disk with subsequent fragmentation into stars, nuclear explosion or relativistic collapse. Further on we assume that the supermassive rotator evolution results, as a rule, in its collapse.

In the case of collapse, an electric field is induced outside the supermassive rotator; the former accelerates plasma particles around the rotator. As shown below, emission of these particles can account for energy fluxes observed and the behavior of \( \gamma \)-ray burst spectrum.

The mean distance from the sources of \( \gamma \)-ray bursts observed will be determined in accordance with our model. To do this, the number of active galaxies within the photometric metagalaxy radius will be calculated. Hubble's constant being \( H = 75 \text{ km s}^{-1} \text{ Mpc}^{-1} \), the photometric radius is \( D = c/H = 4000 \text{ Mpc} \). Spatial density of spiral galaxies is known to be \( n \sim 0.03 \text{ Mpc}^{-3} \) (Ginzburg and Syrovatskiy, 1963), and active galaxies constitute one percent of this number (Vorontsov-Veljaminov, 1968). Thus, there are about \( 10^7 - 10^8 \) active galaxies within the photometric radius. Since the quasi-static evolution duration measures up to about \( 10^6 \text{ yr} \) (Ozernoy and Usov, 1973), then \( 10^{-2} \) supermassive rotator collapses per year should occur within the photometric radius. This number is quite close to the \( \gamma \)-ray burst rate observed. Therefore, apparently the major part of all the collapses of supermassive rotators happening in the Universe can be recorded even with the available sensitivity of \( \gamma \)-ray-sensors on board the Vela satellites. Hence, the mean distance from the sources of \( \gamma \)-ray bursts observed, with the application of our model, is of the order of \( D \sim 10^{28} \text{ cm} \). Luminosity \( L_\gamma = 4 \pi D^2 F \sim 10^{52} - 10^{53} \text{ erg s}^{-1} \) corresponds to this distance, with the \( \gamma \)-radiation flux density observed equal to \( F \sim 10^{-5} - 10^{-4} \text{ erg cm}^{-2} \text{ s}^{-1} \).

Gamma-radiation produced in case of the collapse of a supermassive rotator with \( M \sim 10^5 M_\odot \) is considered below.

### 3. Collapse of a Supermassive Rotator and \( \gamma \)-Ray Bursts

In case of collapse the supermassive rotator is contracting with gravity free velocity. Due to the frozen-in magnetic field its magnetic moment \( d \) changes with contraction...