THE MAGNETOHYDRODYNAMIC ROTATIONAL MODEL OF SUPERNOVA EXPLOSION

G. S. BISNOVATYI-KOGAN*, Y. U. P. POPOV**, and A. A. SAMOCHIN**

*Space Research Institute, U.S.S.R. Academy of Science, Moscow, U.S.S.R.
**Institute of Applied Mathematics, U.S.S.R. Academy of Science, Moscow, U.S.S.R.

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Abstract. The calculations of supernova explosion are made, using the one-dimensional nonstationary equations of magnetic hydrodynamics for the case of cylindrical symmetry. The energy source is supposed to be the rotational energy of the system (the neutron star in the centre and the surrounding envelope). The magnetic field plays the role of a mechanism of the transfer of rotational momentum. The calculations show that the envelope split up during the dynamical evolution of the system, the main part of the envelope joins the neutron star and becomes uniformly rotating with it, the outer part of the envelope (~10% mass) expands with large velocity, carrying out a considerable part of rotational energy and rotational momentum.

These results correspond qualitatively with the observational picture of supernovae explosions.

1. Introduction

The mechanism of supernova explosion, construction and investigation of the mathematical models of the explosion represent one of the most timely astrophysical problems.

The spherically-symmetrical supernova model is the simplest and the best studied one. One distinguishes two types of explosion models: in the first type the explosion follows the hydrodynamical instability; and in the second type, the thermal instability. In the first case it is supposed that nuclear fuel is burned in the central parts of the star up to Fe\(^{56}\) formation. The hydrodynamical instability occurs and the compression begins, which lead to the formation of the stable neutron star with density of the order of \(10^{15}\) g cm\(^{-3}\) (Fowler and Hoyle, 1964). The supernova explosion occurs as a result of the reflection of the infalling matter from the stable neutron core, the possible nuclear explosion in the envelope, and because of the interaction of the powerful neutrino flux with the matter of the envelope. The calculations of the spherically-symmetrical models (Colgate and White, 1966; Arnett, 1967; Ivanova et al., 1969; Wilson, 1971) suffer from some shortcomings, connected with comparably small energy output in the photon emission and kinetic energy of the outbursting matter. The main part of energy is lost by the weakly interacting neutrinos. The role of neutrino in supernova explosion has been reconsidered now (Wilson, 1974) in connection with the discovery of the neutral currents in weak interactions.

The formation of the degenerate stellar core of C\(^{12}\) or O\(^{16}\) is postulated in the second type of model. The development of thermal instability in the degenerate core is supposed to lead to the explosion. The investigations of this model have been carried
in the works of Arnett (1969), Buchler et al. (1971); Bruenn (1973), Ivanova et al. (1973). The main difficulty of this model is the total disruption of the star for realistic initial conditions, which contradicts the visible existence of the neutron stars - pulsars - in some supernova remnants. The difficulties of the spherically-symmetrical models may be overcome by further investigations and better agreement with the observations may be reached.

The very important properties of the star, such as rotation and magnetic field, are however ignored in all these models. The stellar rotational velocity on the Main Sequence reaches the value 200 km s\(^{-1}\) on the equator (Slettebak, 1970). During the compression leading to the formation of a neutron star the rotational energy may reach the value \(10^{52}-10^{53}\) erg s\(^{-1}\), which is comparable with the total energy of supernovae. The observations of pulsars show the presence of large magnetic field (~ 10\(^{12}\) G) on their surfaces (ter Haar, 1972) and fast rotation with periods up to 0.033 s. The observed rotational velocity of pulsars is much smaller than the limiting velocity at which the centrifugal force on the equator is equal to gravitational one (the period \(~6 \times 10^{-4}\) s). The rapidly rotating Main Sequence star reaches the limiting velocity well before the neutron star density is attained, so that the loss of momentum occurs during the neutron star formation. If the intense loss of momentum proceeds after formation of the neutron star, the huge rotational energy of the object may be released and give the phenomenon of supernova explosion.

The model of supernova explosion was proposed in the work of Bisnovatyi-Kogan (1970), where the rotation was the main source of energy. The single mechanism which may give a rapid momentum transfer from the core to the outer parts of the star is magnetic interaction. The mechanism of supernova explosion due to rotational energy was proposed also by Ostriker and Gunn (1971), but they proposed the momentum transfer due to magnetodipole vacuum radiation. Let us note that electromagnetic radiation of inclined rotator may be absent if sufficiently dense plasma surrounds the neutron star. In this situation, which is apparently realistic, magnetohydrodynamic momentum transfer will occur, as proposed by Bisnovatyi-Kogan (1970). The interesting two-dimensional computation of the compression of a strongly magnetized star was carried out by LeBlanc and Wilson (1970), but they did not consider the possibility of shock wave formation. The simplified problem of the rotational energy transfer due to magnetic field from the core to the envelope and envelope acceleration was considered by Amnuel et al. (1972).

The model of supernova explosion is investigated in the present paper, in which the magnetic transfer of the rotational energy from the neutron core to the envelope is considered as a single mechanism of explosion. The consideration is carried out for a one-dimensional magnetohydrodynamic nonstationary model with cylindrical symmetry and gravitation. The problem was solved for the outer part of a cylinder, imitating the neutron star. Accordingly, the magnetic field was considered to have a radial component without the z-component. The computations were carried out for different values of the surface magnetic field. The approximate formula were used for equation