“The Mechanism Supernova Explosion”

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In the last decades, scientifics have tried to understand the explosion mechanism of stars that is responsible for the simultaneous formation of neutron star and supernova outburst. The main problem is the determination of a source of energy in the ejection of a supernova envelope. The gravitation energy as a source of energy in supernova is placed first. However, subsequent studies led to certain problems in using gravitation energy if the assumption of neutrino diffusion was adopted. Situation is changed if one takes into consideration large-scale convective instability owing to the neutronization of matter in a protoneutron star during the collapse of star with low initial entropy. The three-dimensional hydrodinamic calculation for $75\times75\times75$ grid with step $0.015\,R$ $(R=2\times10^{7}\,cm)$ shows that large-scale bubbles with 10^{6} cm emerge. When the bubble reaches low density, the neutrinos contained in matter freely escape from it in the regime of volume radiation. The characteristic time of this process is equalled to 0.02 s. The shock from the initial bounce when the collapse in the stellar core stops will then be supported by the neutrino emission, resulting in the ejection of an envelope. In rotating protoneutron star the large-scale bubbles come to the surface of the stellar core along the axis of rotation. Neutrinos with energy 50-100 MeV are contained in the bubbles. Our calculations show that time of neutrino emission from such bubble is equal near 0.01 second with mean energy of neutrino 60-70 MeV.

At the initial time, the mass of matter with excess entropy $(S_{\max}=2.5)$ is $0.07M_{\Theta}$. After $3.5\,ms$, $0.02M_{\Theta}$ of this material approaches the boundary of the neutrino-sphere, where the density is $\rho=10^{11}\ g/cm^{3}$, and becomes transparent to the neutrinos there. The density of these neutrinos is comparable to the density of electrons with mean energy $\sim 60\,MeV$. In this case, the intensity of the neutrino emission can be estimated as

$$L=(0.04M_{\Theta}\cdot 60\,MeV)/(\mu\, m_{n}\cdot 3.5\cdot 10^{-3})\sim 4\cdot 10^{54}\ erg/s,$$

where μ is the mean molecular mass per electron in the absence of electron-positron pairs. We will now estimate the fraction of energy absorbed by matter per gram in the shock wave from this neutrino radiation. By definition, this is

$$\frac{d\varepsilon}{dt}=\varepsilon_{\nu}n_{\nu}n_{e}<\sigma v>/\,\rho\sim L\sigma\, n_{1}/\rho R^{2}\ \ erg\, g^{-1}s^{-1},$$

where R is the radius of the shock, $\sigma=g^{2}\varepsilon_{\nu}^{2}/\hbar^{4}c^{4}\sim 10^{-44}(\varepsilon_{\nu}/m_{e}c^{2})^{2}\ cm^{2}$ is cross-section of the weak interaction, with $g=1.4102\pm 0.0012\cdot 10^{-49}\ erg\, cm^{3}$ being the Fermi constant of weak interaction, $n_{1}=1.688\cdot 10^{28}T_{9}^{3}\ cm^{-3}$ is the density of electron-positron gas in the shock wave when the temperature corresponds to an ultrarelativistic gas with $\rho\le 10^{5}T_{9}^{3}\ g/cm^{3}$, $T_{9}=T/10^{9}K$, ρ is the density of the material in the shock, ε_{ν} is the mean neutrino energy, and n_{ν} is the density of neutrinos in the shock. For $T_{9}=100$, $\rho=10^{8}\ g/cm^{3}$, and $R=10^{7}\ cm$, we obtain $d\varepsilon/dt=0.97\cdot 10^{27}\ erg\, g^{-1}s^{-1}$. This is much more than the neutrino losses from the shock front:

$d\varepsilon_\nu / dt \sim 6 \cdot 10^{10} T_9^6 \sim 6 \cdot 10^{22}\ erg\, g^{-1} s^{-1}$, i.e. the large-scale convection could support a diverging shock wave, leading to the ejection of the supernova envelope.

A number of mechanisms for feeding a supernova shock wave via neutrino emission from the core of the star have been proposed. One of these is based on the convective transport of neutrinos inside or outside the forming neutron star; another is based on the decrease of the opacity to neutrinos at nuclear densities or on the effects that arise in nuclear-neutrino interactions which increases the mean free path of neutrinos in the opaque core. However, in spite of the increase in the neutrino luminosity resulting from these mechanisms, their development requires a long time interval ($\sim 1\, s$) and satisfaction of a number of specific conditions. The mechanism we have considered here is based on the development of large-scale hydro-dynamical instability inside a rotating protoneutron star, and has several advantages over previous models, because it can provide a rapid (over a time $\sim 10^{-2} s$) emission of high-energy neutrinos, which can give the required boost to the energy of the shock. Observations of the central region of **SN 1987A** testify to the presence of two large-scale ejections, in good agreement with our model incorporating the effects of rotation. In addition, the motion of the bubbles along the rotation axis will be accompanied by strong mixing and the intense formation of $^{56}\mathbf{Ni}$, which has been observed during the ejection of supernova shells. Since a large fraction of the evolution of the bubbles occurs at densities $\rho > 10^{12}\ g/cm^3$, where neutrinos move in matter in a diffusion regime, there is no need to take into account the effects of neutrino transport on the development of the large-scale instability. As a bubble approaches the neutrinosphere ($\rho < 10^{12}\ g/cm^3$), these effects become appreciable and lead to changes in the energy and spectrum of the escaping neutrinos.