ASYMMETRICAL EJECTION OF MATTER IN A THERMONUCLEAR MODEL OF A SUPERNOVA EXPLOSION

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With the recent Supernova 1987a in the LMC, new and interesting possibilities have arisen for the solution of a problem relating to the explosion mechanism of supernovae. The presupernova was probably a B3Ia, the blue supergiant, and not a red giant as it was earlier thought likely[1 2]. Calculations of the evolution, which have been made recently, show that the loss of hydrodynamical stability may be connected with carbon burning in the stellar core[2] during the blue giant stage. This loss of stability of the CO core is the main factor in our explanation of the recent event of SN 1987a.

Before we consider the thermonuclear model of a supernova based on a thermal flash in the degenerate CO core, let us dwell on the present situation in the theory of supernovae. The main problem in supernova theory is the simultaneity of births of a compact remnant and an expelled envelope. The compact remnant later becomes a neutron star. The expelled envelope determines the curve of brightness. Now, it is clear that a supernova explosion may result in either the total disruption of a star or in the simultaneous production of a compact remnant and an expelled envelope.

What are the sources of the energy in a supernova explosion which is equal, within an order of magnitude, to 10^{51} ergs? In early studies[3 4 5] the gravitational energy, which is released during the birth of the compact remnant, was taken as the source. However, such a mechanism failed[6]. Later the so-called bounce models of supernovae also failed. This gave rise to the conclusion that a model of supernovae based on thermonuclear burning in a degenerate CO or O-Ne-Mg core is the most likely in terms of stellar evolution as well as for supernova simulation.

Including rotation into this model is a further step towards the real physical situation. The first paper on the simulation of a thermonuclear explosion in a rotating stellar CO core resulted in the conclusion that the runaway velocity along the axis of rotation somewhat exceeds that on the equator[8]. However, it was shown[9] that the shock wave from a supernova explosion becomes spherical when it propagates through an interstellar medium with uniform density.

In our study two-dimensional calculations of the thermonuclear burning of a rotating CO core were carried out[10]. As an initial model, a degenerate CO core with a mass of 1.4 $M_{\odot}$ and a central density of $2.33 \cdot 10^9$ g cm^{-3} was assumed. In this model, for rotational parameters $\Omega = 1.95$ s^{-1} $= 0.51\ \Omega_{cr}$, $\Omega_{cr} = (GM/v^3)^{1/3}$ (where Ω is the angular velocity of uniform rotation, G the gravitation constant, M the stellar core mass and v the equatorial radius), the equilibrium configuration of the star should be an ellipsoid of rotation. In Figure 1(a) the initial configuration with a computational grid is shown. The grid

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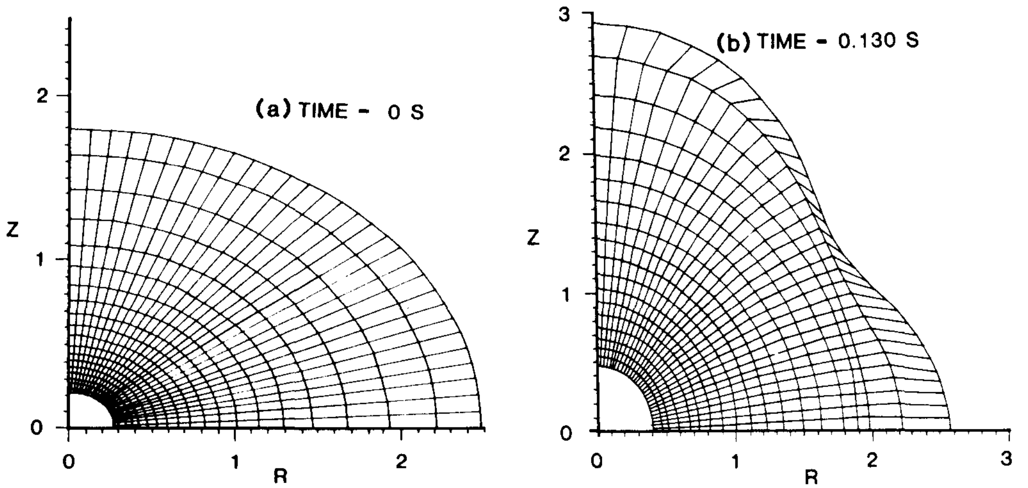

Figure 1

lines, which are parallel to the surface of the core, correspond to levels of equal density. At the initial moment roughly 20% of the total core mass is instantly burned off and 10^{50} erg of nuclear energy is released, generating the detonation wave.

Figure 2 shows the propagation of the burning front across the stellar core. In external layers of the core the detonation burning occurs in the over-driven wave mode. This can be seen from Table I, where the burning front radius (r_f) and velocity (v_f) and the respective Chapman-Juge velocities (v_{CJ}) are given. The overcompressed detonation (over-driven wave) has a tendency to be damped if the supporting pressure profile beyond the burning front is decreased[11]. As can be seen from Figure 2d the burning front reaches the surface of the star in the region of the poles. It leads to the appearance of the rarefraction wave going from the region of the shock wave exit to the surface. Since, in the overcompression detonation mode, the propagation velocity of the burning front is less than the sound velocity, the rarefraction wave may overtake the burning front and damp the detonation wave. Such modes can be observed in tests.

Table I.

t ms	$r_f/10^8$ cm	$v_f/10^9$ cm s^{-1}	v_{CJ}
29	0.5	1.5	1.5
48	0.7	1.6	1.4
65	0.95	1.5	1.36
80	1.1	1.7	1.26
102	1.4	1.7	1.2
122	1.8	2.0	1.13
132	2.1	2.1	1.1

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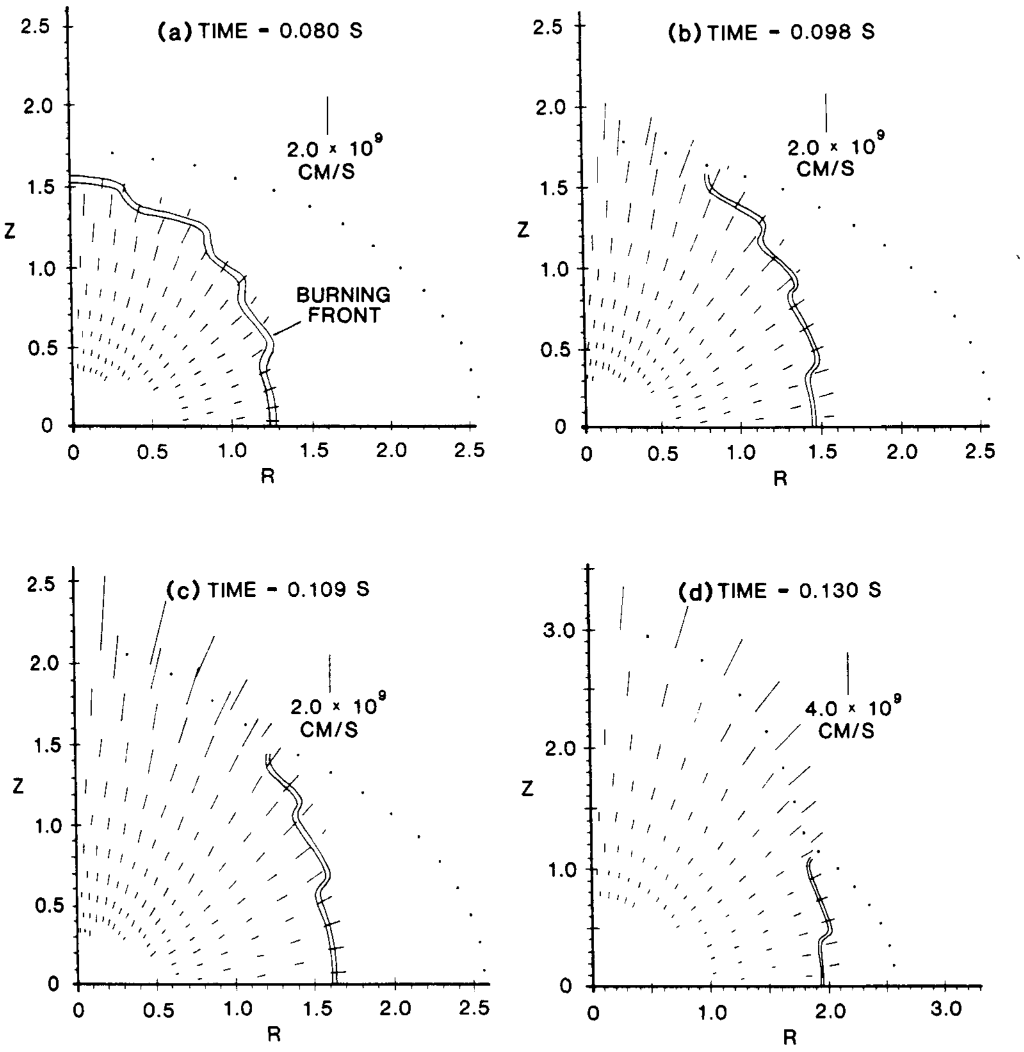

Figure 2

Due to the coarseness of the grid we could not finish the calculations in our model. As recent studies have shown, in the case of the burning instabilities, special computational algorithms are needed to resolve this problem. A similar problem arises in calculations of the deflagrational burning regime[12]. Here a contradiction arises between the small size of the burning zone and the large size of the object under investigation. Therefore there is no self-consistent solution for the transition from spontaneous burning into either the detonational or deflagrational regimes[12].

Calculations were also carried out to investigate burning wave propagation in the spherically symmetric core and at lesser values of the angular velocity. It was shown that for small angular velocities

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the results obtained for the burning front propagation agree with those for the spherically symmetric case.

What astrophysical consequences follow from the results which include the possibility of the formation of a toroidal remnant containing unburnt carbon and oxygen? With further evolution such a remnant will resemble a colder region against a hotter region with an increased content of primary matter from the degenerate stellar core. The relationship between carbon and oxygen is determined by the rate of the reaction $^{12}C + \alpha \rightarrow {}^{16}O + \gamma$ and the star's evolutionary track in the presupernova stage.

Recently, in young supernova remnants, similar structures have been observed[13]. Furthermore, supernovae are known which have an enhanced content of oxygen[14]. These structures and the increased content of oxygen can be explained easily in the framework of this model. It is interesting to note the fact that, depending on the initial rotation of the stellar core, different chemical elements are produced in the thermonuclear explosion.

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