ON THE QUESTION OF THE ORIGIN OF PLANETARY NEBULAE

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While the physics of some processes which are going in planetary nebulae grows to be one of the most elaborated parts of theoretical astrophysics, the origin of these objects is enigmatic. Ten years ago Shklovsky (1956) made a supposition that the formation of planetary nebulae occurs at the last evolutionary stage of a red giant as a result of the violation of mechanical equilibrium in the envelope of the star. In connection with this the possibility of the separation of an envelope of a red giant under the influence of a shock wave which moves with the velocity of the order of 100 km/sec was considered by Kaplan and Klimishin in 1959. Later on numerical calculations of the motion of a weak shock wave in the envelope of a red giant, were made which showed the basic possibility of formation of a planetary nebula with a mass of the order of 0·5 $M_{\odot}$ and an initial velocity about 95 km/sec (Sakashita and Tanaka, 1962). The ballistic character of the mechanism of the formation of the planetary nebulae has been recently discussed also by Abell and Goldreich (1966).

Usually the appearance of a shock wave on the surface of a star is more naturally associated with phenomena like novae or supernovae. An intrinsic peculiarity of such phenomena is the presence of an essential velocity gradient, owing to which the envelope quickly dissipates into space. That is why the possibility of formation under the influence of a shock wave of such compact envelopes as we have in the case of planetary nebulae could be considered a disputable one.

However, it is not difficult to show that the motion of an ejected envelope is defined by conditions such that either the undisturbed envelope was in thermal equilibrium or in convection. Such calculations have been done recently by us (Klimishin, 1967) with the help of the quasi-stationary method of Chisnell-Withem.

From general considerations it follows that the strength of the shock wave (the jump of pressure p/p_0 at the front of the wave) will grow in direct proportion to the value $m(r)=(\mathrm{d}\ln p_0)/(\mathrm{d}\ln r)$. Since at each non-dimensional distance in the convective envelope the value $m(r)$ is about half of its corresponding value for the thermal envelope, patterns of the velocity changes of the shock wave with the distance for envelopes of different structures are not the same. In the thermal envelope the velocity of the shock quickly grows with the distance, and the ejected envelope moves with a large gradient of velocity and quickly dissipates in the space. This is typical for nova outbursts.

As for the convection envelope, the velocity of the shock wave is practically con-

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stant, the velocity gradient in the envelope is 0, and the ejected envelope moves as a whole. This is probably the most attractive peculiarity of the shock-wave mechanism for the formation of planetary nebulae.

These calculations enable us to conclude that both phenomena (the flashes of nova and the formation of planetary nebulae) can be interpreted in terms of the same mechanism, namely shock waves. Nevertheless, the shock-wave mechanism of formation of planetary nebulae meets some serious difficulties.

Let us note in particular that the radius of a remnant of the star after the envelope has been ejected (that is, the possible nucleus of the nebula) according to calculations by Sakashita and Tanaka, is of the order of 50 $R_{\odot}$. At the same time it is known (Sobolev, 1966) that the observed radii of nuclei of planetary nebulae are about 10^{10} cm or about 0·1 R. This means that the escape velocity on the surface of such a star is 2000 km/sec and the energy of separation of the envelope with mass 0·10 $M_{\odot}$ is 10^{49} ergs. The velocity of the shock wave producing the separation of the envelope with the following formation of a planetary nebula is 2600 km/sec. As the velocity of the shock will increase during its way out of the chromosphere, the formation of each new planetary nebula must be accompanied by a rather intensive explosion. In other words, the combination of the small radii of nuclei with the ideas of the small velocity of the shock in the envelope of red giants seems to be impossible.

In conclusion, with regard to the hypothesis of Shklovsky, we should remark that it has not proven possible to build models of red giants and supergiants at low stellar temperatures. Numerical calculations inevitably lead to a rapid increase of density at small distances from the surface of the star, that is, to the appearance of a spherical layer with nothing inside (Nadezhin, 1967). In conclusion, one should note that in the atmospheres of red supergiants the assumption of hydrostatic equilibrium does not hold and it is very likely that it is there that we should search for the answer of the question of the formation of planetary nebulae.

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