ON THE POSSIBLE DIRECTIONS OF EVOLUTIONARY TRENDS OF STARS IN THE HERTZSPRUNG-RUSSEL DIAGRAM

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The evolution of a star depends on the initial conditions existing during its formation and on the course of the main processes changing its chemical composition and mass. If it is assumed that stars are formed from diffuse matter, the initial conditions are restricted to three factors : 1) mass, 2) chemical composition, 3) angular momentum. The mass of the star can be determined by the conditions of gravitational instability of diffuse matter, which, according to our hypothesis, consisted of solid primary bodies, similar to cometary nuclei, and a gas and dust nebula formed by them [1, 2]. The upper limit for the possible mass of a star is evidently determined by its angular momentum, which cannot exceed a certain critical value [2].

There is a relation between the mass and chemical composition of a star being formed. As was shown recently by E. L. Ruskol [3] only stars with $M \gg M_{\odot}$ can be formed from a gas and dust nebulae. The formation of stars from gas nebulae is in general impossible. It is easy to show that stars with a small mass $M \ll M_{\odot}$ can be formed only from nebulae consisting mainly of dust. If the mean dust content is adopted according to van de Hulst [4] we come to the conclusion that the hydrogen (X), helium (Y) and heavier elements (Z) abundances and the mean atomic weight (μ) of the stars formed should be different for stars of large and small masses.

	X	Y	Z	μ
$M \ll M_{\odot}$	0.75	0.0	0.25	0.61
$M \gg M_{\odot}$	0.88	0.10	0.02	0.54

However, as we shall see, this difference is not of decisive significance for stellar evolution. In any case it is evident that stars similar to white dwarfs (with large Z and X almost zero) [5] had evolved during a long period of time before their chemical composition changed radically.

The exceedingly small number of massive stars ($M \geqslant 10M_{\odot}$), their rapid energy generation and the actually observed outflow of gas from their surfaces (Be, WR and supergiant stars) show that at definite stages these stars evolve with decreasing mass. The decrease in mass is accompanied by a sharp decrease in the angular momentum of the star [6] which rapidly lessens the role of this factor in the further evolution of the star. The large rotational velocities and momenta of the Oe and Be stars, not met with for stars of other classes, show on the one hand that the Oe and Be stars are young, on the other that those stars into which the Oe and Be stars are subsequently transformed have lost a large part of their mass and momentum during this transition.

It is also difficult to imagine that stars similar to the Sun, with rotational velocities of the order of 1 to 2 km/sec could have been formed from diffuse matter with such a small angular momentum. There are reasons [7] to suppose that the present slow rate of rotation of the Sun can be explained by the loss of a considerable part of its mass in the past. Of course the decrease in stellar mass cannot be considered as a uniform process, leading to the evolution of the star along the main sequence. Such a formulation of the problem cannot be founded convincingly.

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It seems to us that the essence of the evolutionary processes taking place in stars cannot be understood by basing it only on the analysis of different stellar models calculated on the hypothesis of the hydrostatic equilibrium of the star as a whole. In fact, neither the mechanical disturbances, nor even more so, the thermal disturbances in a star can be transferred instantaneously from one layer to another. Some layers can be in equilibrium while others are not. The large dimensions of the cosmic bodies condition the inertia of the hydrodynamical and thermodynamical processes there.

The changes in pressure and density in a gas medium are transferred by acoustic (and sometimes shock) waves which at high temperatures have sufficiently large velocities. Therefore the lag of hydrodynamical processes cannot play an essential role in the evolution of a star. It is quite the contrary when we deal with the transfer of thermal energy. In those parts of the star where the energy is transferred by radiation, the progressive change in temperature will lead to a change in the flow of energy, which spreads with an exceedingly small velocity of thermal oscillations. The estimation of these velocities for various stellar models gives, for the zone of radiative transfer, the same timelag (t) of the change of the flow of energy for a layer 5×10^{10} cm thick, equal to $t \approx 10^7$ years. For massive O and B stars t increases to 10^8 years. The changes in the energy generation in a stellar core can reach the surface only after an interval of the order of 10^7 to 10^8 years. Only the accompanying changes in pressure spread rapidly inside the star and cause it to contract (if the energy generation decreases) or expand (if the energy generation increases). The luminosity of the star remains practically constant during this process. One must bear in mind that contractions can take place freely only near the core of the star. In the outer regions contraction will lead to the heating of the gas. The latter in turn will cause the contraction to cease immediately because of a constant thermal flow. In order that contraction takes place in all parts of the star it is necessary that there be a decrease of $\frac{1}{\rho} \cdot \mathrm{grad}\, P$ (ρ = density, P = pressure) everywhere.

Let us turn to the facts which may indicate the directions of stellar evolution. Close binary stars are of great importance for the solution of this problem as they are the only stellar systems for which the common origin of the components is indisputable [2]. Therefore in such systems both stars are always of equal age. At the same time we have a strict criterion for the stationarity of the stars. The expansion of at least one of these stars rapidly leads to the filling-in of the inner critical Roche surface and to the following outflow of gas from the system. If this phenomenon is not observed we can be sure that the dimensions of the stars are constant. The contraction of a star is also apparently excluded since usually the figures of the stars are only a little smaller than the critical Roche figures and if we suppose a considerable contraction of the star we must at the same time allow that the star in its initial state was nonstationary. However, the outflow of gas from the surface of a star can cease only after the star has lost a considerable part of its mass and after a complete alteration of its equilibrium configuration. The new configuration must be stationary [8].

The distribution of close pairs according to periods is connected with the possible tracks of stellar evolution. The fact is that there cannot be a monotonous secular decrease of the period of a close binary. The change of the orbital period can in the first place be the result of a change in the masses of the components, caused by the outflow of gaseous streams. Only during a short period of time, when the slow outflow of the gas from the surface of one of the stars leads to a gradual filling-in of the space between the inner and outer Roche surfaces and then to a just as slow outflow of gas from the external critical point, could the period decrease with the change of mass (according to Kuiper [9]). As soon as the rate of outflow of the gas reaches the value observed for β Lyr and similar systems, the outflow of gas will lead to a secular increase of the period.

Jeans [10] showed that the effect of tidal friction can under no conditions strongly influence the period of a close pair. The same in general can be said about the effect of radiative friction [11]. Therefore the only real possibility is that of an increase of the period of a close pair. It follows that stars with small masses, whose surfaces are close to those of the inner Roche surface and whose orbital period is a fraction of a day (the systems of classes "e" and "f", according to the author's classification) could never formerly have had large masses. The known subgiants and main sequence stars with A to M spectra (systems of classes "c" and "d") could also not have had very large masses. Of course such a conclusion does not testify that B, Be and red supergiant stars cannot become main sequence stars of smaller mass. However evidently such transformations are comparatively rare phenomena. The majority of stars from the very onset of their existence have masses of the order of the solar mass or smaller.

Moreover, if we consider eclipsing binaries, we become convinced that in systems of massive stars (classes "a" and "g") the giant or supergiant star has as a rule the larger mass (ε Aur, ζ Aur and others). Sometimes this more massive star is nonstationary (β Lyr). If we take into account that the more massive stars run their evolutionary course more rapidly than stars with smaller masses, it becomes evident that nonstationary Be and WR stars, as well as red supergiants, represent the second stage of evolution of massive O and B stars. Since there exist at the same time stationary O and B stars in the same system, the initial stage of evolution of a massive star then undoubtedly is a relatively stable equilibrium configuration.

The passage of a star from the stationary to the nonstationary stage is apparently connected with the exhaustion of hydrogen and its transformation into helium. The following contraction in the central part of the star and the increase of its central temperature to $T > 3 \times 10^8$, at a constant luminosity (in its outer layers), must inevitably give rise to a pressure momentum on the outer layers and lead to the expansion of the star as a whole. We cannot as yet say definitely to what degree and in which case the formation of nuclei of elements heavier than C^{12} [12] is possible for $T > 3 \times 10^8$. However we have all reasons to suppose [6] that the further contraction inside the star, after the formation of C^{12}, can lead to an equilibrium distribution and a partial restoration of the light elements.

The stationary stage of evolution of stars with smaller initial masses (systems of classes "b" and "c") lasts longer than that of the more massive stars. Evidently this circumstance conditions the considerable population of late B and A stars on the HR diagram. The passage of these stars to the phase of giants cannot be proved with such certainty as was possible for the more massive stars, although in several cases the giant stars combine in a close pair with B and A stars (TV Cas, SX Cas, U CrB, RV Tel and others). However, more frequently the second, and often nonstationary star, (U Cep and others) is a subgiant. Since usually the more massive star of the pair is a stationary B or A star, it may seen that the theoretical conclusions of a more rapid evolution of stars with the larger masses does not hold for the "b" and "c" systems. However in reality we cannot be sure that the companion of the principal star (B or A) has not already lost a considerable part of its mass. In the past it could have been a more massive star. The presence of giant and subgiant stars with very different masses in the "b" and "c" systems most probably shows that we observe systems where the decrease

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of mass of the nonstationary star has already started, as well as systems where this process has advanced to a considerable extent.

Therefore there is a genetic relation between the "flat" subsystem stars of different classes on the HR diagram. The star begins its evolution on the main sequence (spectral classes from O to G), which corresponds to the stationary stage of evolution. Then it expands and "jumps" with constant luminosity to the right towards stars with extended envelopes (supergiants, giants, subgiants). Then, losing a considerable part of its mass, it becomes a star with lower luminosity. It is regrettable that with regards to this latter transition we can only draw up more or less probable hypothesis. The existence of close pairs, in which one of the stars is a main sequence A or F star and the other a G, K or M star (systems "d", α CrB and similar stars) can be explained by the supposition that both stars, staying stationary, keep their initial masses and luminosities, as well as by the supposition that the smaller star runs its evolutionary course more rapidly than its companion and has lost a large part of its mass. Previously this component must have been a more massive star.

At first glance the relation between some nonstationary red supergiants and white dwarfs (long-period variables, o Cet) seems to be somewhat unusual. However, as it is known, the majority of long-period variables belong to the spherical and not to the flat subsystem of the Galaxy. Therefore these variables cannot be considered as being ordinary red giants or supergiants.

More striking is the system α CMa. If we assume that Sirius and its companion have a common origin, then we must acknowledge that some fraction of the main sequence stars can become white dwarfs. Since this hypothesis is problematic we shall not dwell upon it.

It was not the purpose of the present paper to discuss the evolution of stars of the "spherical" subsystems.

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