IS THIS DIAGRAMME AN ARGUMENT FOR BINARY ORBITAL EVOLUTION DUE TO MASS-LOSS ?

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ABSTRACT :

In 1963, a diagramme has been established by the author, for visual and spectroscopic binaries, showing the existence of a real correlation between total mass and eccentricity.

The consideration of an up-dated material leads to-day to an identical diagramme confirming the reality and the stability of the mentioned correlation.

This diagramme is discussed with the assumption of a substantial secular mass-loss of the components of the considered binaries.

1) EARLIER RESULTS :

One knows the controversy existing about the reality of a correlation between period and eccentricity of binary orbits. Figure 1 shows this correlation as adopted by various authors but considered by some others to be the result mainly of observational selection effects. A full historical sketch of the question has been given in one of our papers (Dommanget, 1963).

In order to find an explanation for this correlation - that we considered to be real - we made the assumption that it could be the expression of an evolutionary process of the orbital elements of the binaries on the basis of a substantial mass-loss of their components. If the mass-loss by each component is isotropic, the resulting forces in the system are of the "central type" and the areal constant is conservative all along the evolutionary path of the system. If the mass-loss is also secular, the period and the semi-axis major are increasing secularly, but the eccentricity remains practically constant. No exchange of mass or tidal effect should be taken into account here as the components are sufficiently separated (we consider only visual binaries and wide spectroscopic ones).

C. Chiosi and R. Stalio (eds.), Effects of Mass Loss on Stellar Evolution, 507–513.

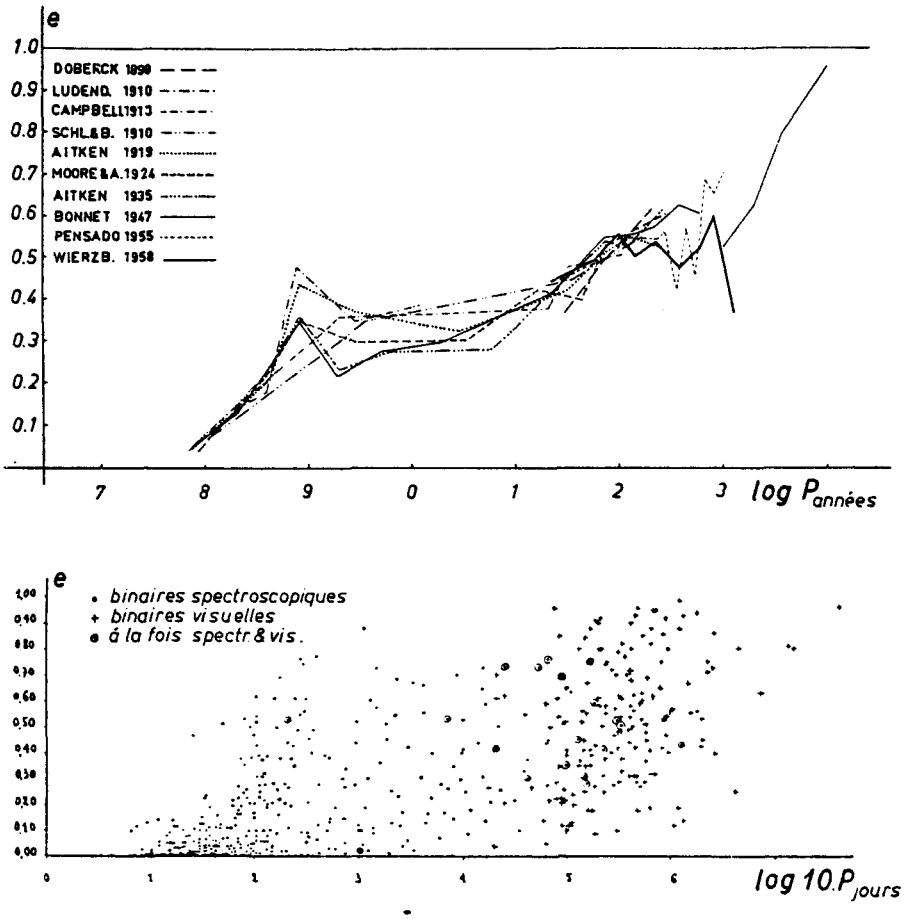

Fig.1.- Period-eccentricity correlation.- Representative curves proposed by various authors (above) and statistical material considered by R. Bonnet (below) - J. Dommanget, 1963.

The hypothesis of a secular mass-loss had already been studied by many authors since more than half a century but unsuccessfully for explaining this correlation, because of the ensuing secular constancy of the eccentricity. Therefore, E.L. MARTIN (1934) introduced the idea of a periastron effect that could produce a sensible change in the eccentricity, but no observational evidence was available to confirm it.

Forgetting in a first approach of the problem, the question of the eventual increase of the eccentricity, we felt it might be useful to have a look at the behaviour of the areal constant of the orbits in the period-eccentricity diagramme, or in any equivalent diagramme where period and eccentricity appear as parameters.

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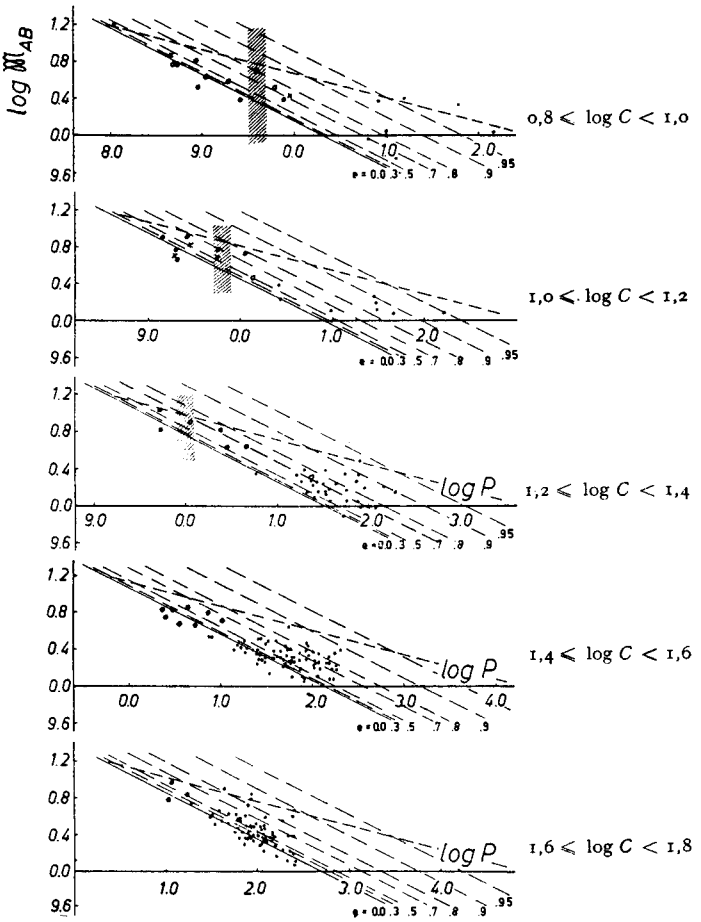

Fig.2.- The five most typical of the eleven diagrammes (log P, log $\mathfrak{M}_{AB}$) established by the author in 1963 and showing on each of them, the existence of an upper limit to the masses of the binaries as a function of the period.

Having classified 212 visual and 98 spectroscopic binaries - selected for their quality - in eleven categories following the value of their areal constant, we found diagrammes of which the five most typical are given in figure 2.-. These diagrammes, established with as coordinates : log $\mathfrak{M}_{AB}$ and log P, are equivalent to those established with as coordinates : e and log P, because of the known expression of the double of the areal constant :

$$C = 2\pi \mathfrak{M}_{AB}^{2/3} \; P^{1/3} \; (1 - e^2)^{1/2} \qquad (1)$$

When C is given, a diagramme (log $\mathfrak{M}_{AB}$, log P) including a network of

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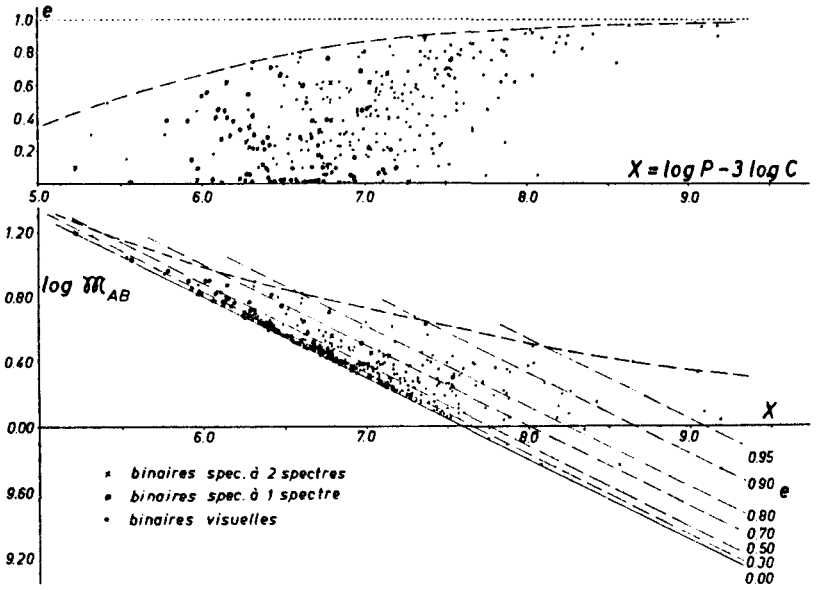

Fig.3.- Diagrammes (X,e) and (X, log $\mathfrak{M}_{AB}$) established by the author in 1963. The interrupted curved lines represent the empirical upper limits of e and log $\mathfrak{M}_{AB}$ as functions of X.

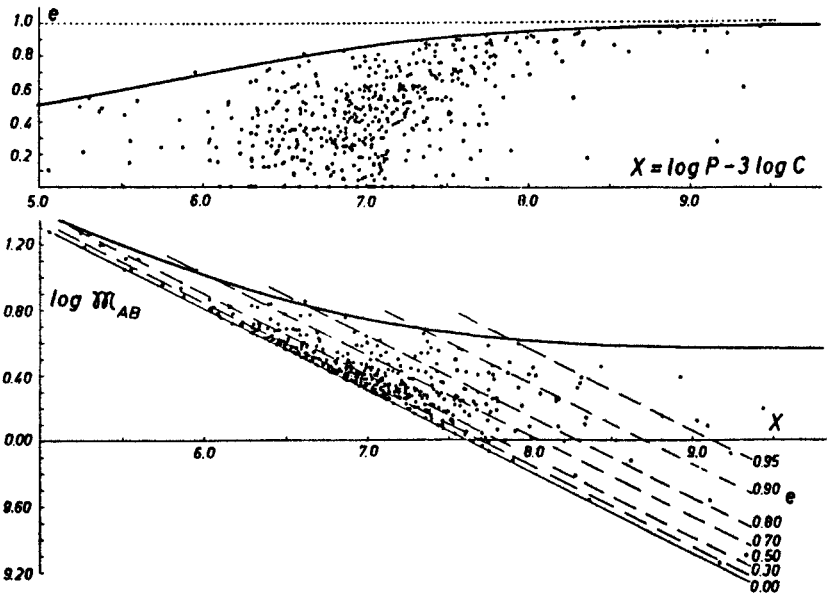

Fig.4.- Diagrammes (X,e) and (X, log $\mathfrak{M}_{AB}$) obtained with the up-dated material. The continuous curved lines represent the equation : $e^{2,8}\mathfrak{M}_{AB}$ = 3,60, in good agreement with the limits drawn on fig. 3.

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constant values for e is equivalent to a diagramme (e, log P) including a network of constant values for $\mathfrak{M}_{AB}$. But the first one seems to be more convenient for discussing the present problem.

In the diagrammes of figure 2.-, the network of constant eccentricity - being thus of theoretical origin - makes evident the existence of the lower limit of the masses (e = 0) that can be observed for any given period. However, it does not explain the existence of the upper limit appearing in each of the diagrammes with the same features and shape.

It has been shown that this upper limit cannot be the result of a selection effect either for visual or for spectroscopic pairs. Finally, in view to establish this upper limit with the best accuracy, all diagrammes have been brought together by an appropriate shift of the abscissae, the new abscissae being : X = log P - 3 log C. The resulting diagrammes are given in figure 3.

This was the situation in 1963.

2) NEW STATISTICAL RESEARCH :

Since nearly twenty years, the number of computed visual binary orbits has been seriously increased : our personal catalogue contains some more than 800 such orbits ! It thus was felt interesting to look whether the mentioned diagrammes would be confirmed with this extended observational material.

From this material, only 551 visual orbits have been retained (no multiple or astrometric systems !). Spectroscopic binaries have not been considered here. The new diagrammes (fig. 4) do not show any particular difference with those obtained previously : the upper limit remains at the same place and has the same general shape.

Consequently, it seems now evident that these diagrammes have a physical significance, expressing the existence of a real correlation between mass and eccentricity : a more reliable one than that suspected between period and eccentricity and that can now be explained as derived from the superposition of the (log P, e) diagrammes obtained for all possible values of the areal constant.

The upper limit of the eccentricity is well represented by the expression :

$$e^{2,8} \cdot \mathfrak{M}_{AB} = 3,60 \qquad (2)$$

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3) ORBITAL EVOLUTION UNDER ISOTROPIC SECULAR MASS-LOSS :

With regard to the distribution of the visual (and spectroscopic) pairs in the above mentioned diagrammes (X, $\log \mathfrak{M}_{AB}$) and under the assumption of an important secular isotropic mass-loss, the evolution of a binary could finally be described as follows from a purely orbital point of view :

1° birth from a common original cloud, followed by the formation of a very close pair;

2° evolution due to mass-loss, mass-exchange, tidal effects etc. as far as necessary to reach a separation between the components such that only mass-loss may be the basic remaining phenomenon of evolution. The resulting pairs have low orbital eccentricity (< 0,4);

3° evolution due to mass-loss only and with conservative areal constant. Such an evolution would be situated inbetween the two following extreme cases :

a) pairs with small eccentricity and already fairly well separated components :

period and semi-axis major increasing secularly; eccentricity remaining constant (no periastron effect); evolutionary path in the diagramme (X, $\log \mathfrak{M}_{AB}$) of figures 3 and 4, corresponding to a straight line (e = constant) parallel to the lower limit;

b) pairs with substantial eccentricity (around 0,3-0,4) and well separated components at their apastron only :

period and semi-axis major increasing secularly; eccentricity increasing by periastron effect; evolutionary path following the upper limit on diagrammes of figures 3 and 4; after this effect has weakened, evolution with constant eccentricity as explained under item a), but with higher constant eccentricity than 0,4.

About the periastron effect - which should thus exist along the upper limit on the diagrammes (X, $\log \mathfrak{M}_{AB}$) - E.L. MARTIN (1934) has proposed the following expression of mass-loss :

$$d\mathfrak{M}_{AB} = -\alpha \mathfrak{M}_{AB}^{n} \frac{1}{r^2} dt \qquad (3)$$

and L. CHIARA (1956-57) has shown that if the law of mass-loss has the more general expression :

$$d\mathfrak{M}_{AB} = \frac{k(t)}{r^2} dt \qquad (4)$$

the product : $e \times \mathfrak{M}_{AB}$ of the mean (not osculatory !) eccentricity and the total mass, is a constant. This leads to the idea that a more particular law of periastron effect than (3) may have equation (2) as a general consequence.

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4) CONCLUSION :

The diagramme (X, $\log \mathfrak{M}_{AB}$) offers evident advantages for discussing correlations between orbital and physical parameters of binaries, when compared to the period-eccentricity diagramme. The introduction of the areal constant - a supplementary parameter of dynamical significance - made it possible to reject any criticism concerning selection effects from the observational material on the diagramme.

This diagramme is thus the expression of the true distribution of physical and orbital parameters of the binaries and must therefore have an evolutionary significance. An easy explanation can be found from the orbital point of view by assuming an important secular mass-loss from their components even when these are main-sequence stars.

Now, if such a substantial mass-loss ought to be considered unacceptable from an astrophysical point of view, the diagramme (X, $\log \mathfrak{M}_{AB}$) should still need an explanation of a probably evolutionary nature.

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