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CIRCULARIZATION AND SYNCHRONIZATION TIMES IN DETACHED MAIN-SEQUENCE ECLIPSING BINARIES

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ABSTRACT. We have studied a sample of selected eclipsing binaries with accurate absolute dimensions in order to check the validity of available theories of tidal evolution in terms of synchronization and circularization time scales. The use of integrated values, using theoretical evolutionary tracks to compute the change with time of radius, luminosity and internal structure, provides a powerful tool for the prediction of observable parameters. Pseudo-synchronization at periastron is the best approximation to stellar rotation in eccentric systems. While most systems are found to show synchronized velocities, the presence of eccentric orbits shows that circularization process are still active during the main sequence stage.

1. Introduction

We have analyzed a sample of eclipsing binaries with accurate absolute dimensions selected from different sources, namely, Popper (1980), Harmanec (1988) and Andersen (1991), with the aim of testing the validity of tidal evolution theories to explain the observed levels of synchronization and circularization in these systems. Some of the binaries in our sample also show apsidal motion (Giménez and Claret, 1991) and they were studied with particular attention since eccentric binaries present an evolutionary stage at which tidal effects should still be working and, thus, they can be used to estimate limits for the efficiency of such interactions.

Using evolutionary models by Claret and Giménez (1991), which include a moderate amount of convective-core overshooting and mass loss, we can compute for each individual component of the selected binary systems its evolutionary track from the ZAMS up to its actual stage. In this way, we can derive the radius, luminosity, moment of inertia and mechanism for the transport of energy as a function of time and also whether the envelope of a star is radiative or convective at any given location of the HR diagram. Numerical integration of available equations for time scales allow us then to determine the expected age at which the orbital eccentricity of a given binary system should have dropped to about 1% of its original value. A similar procedure is also applicable to the prediction of synchronization ages. This age, corresponding to the circularization of the orbit or synchronization of the components rotation within the limits of observational errors, is defined by the critical time, t_{cri}, equivalent to a critical value of the radius, R_{cri} or the surface gravity, log g_{cri}. For the purpose of the present study, we have considered stellar models with masses between 1 and 25 solar masses to generate the tidal evolution history of a grid of synthetic binaries with adopted mass ratio of 1 and different orbital periods, assumed constant, in the range

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between 0.3 and 150 days. Critical values for circularization and synchronization of the different relevant parameters, namely age, log g, and R, were computed as a function of the orbital period. In this way it is relatively simple to compare the observed stellar parameters with their critical values to assess the expected level of synchronization and circularization of each system.

2. Rotational velocities

Concerning the observed rotational velocities for the stars in our sample of binary systems, we can immediately appreciate that:

a) rotational velocities of the component stars are lower than typical values for isolated stars of the same spectral type,

b) rotational velocities in eccentric binaries are systematically larger than those corresponding to synchronization with the average orbital velocity and the observed differences are correlated with orbital eccentricity.

c) the component stars of eccentric binary systems are in fact generally found to have achieved pseudo-synchronization at periastron, with the possible exception of some late-type stars and systems with small eccentricity due to the effectiveness of convective envelopes in tidal evolution and the relative relevance of the passage through periastron.

Evidences of the first two statements were shown in a preliminary analysis by Giménez and Andersen (1983) while, in Figure 1, we present the comparison of observed rotational velocities with predicted values under the assumption of pseudo-synchronization, defined as the corrotation with the orbital angular velocity at periastron.

Because of the applicability to stars with different structure, we have adopted throughout the formalism by Tassoul (1988) for the computation of time scales. In the case of rotation, a comparison between the observed level of synchronization, which is general in our sample, is in perfect agreement with predictions derived from the observed stellar parameters and the computed critical values. Nevertheless, one should be cautious about definitive conclusions since we can only observe rotational velocities of the stellar envelopes and different values may dominate in the stellar interior.

3. Orbital eccentricity

Concerning circularization, the situation is clearly different since we find both circular and eccentric orbits is our sample. As an example of the adopted procedure to estimate critical values for the stellar evolution parameters, we show in Figure 2 the results of integrating time scales for circularization using the equations by Tassoul (1988). Only a small range of masses has been plotted for the sake of clarity but it is obvious that for a given orbital period and average mass of the component stars, a critical value of the time dependent log g is derived which can be compared with the observed parameter. This figure is particularly useful in the interpretation of results obtained for evolved binaries beyond the main sequence.

With this method, we have computed critical ages for all systems in our sample of eclipsing binaries with accurate absolute dimensions. A plot of the actual orbital eccentricity versus the logarithmic difference between the critical and actual age of each binary is shown in Figure 3. A reasonably good separation of highly eccentric systems and those with moderate values or circular orbits is given by the zero line representing $\log t = \log t_{cri}$. The few anomalous cases have been identified with multiple systems or the existence of pulsational instabilities and resonances like α Vir. The large eccentricity found for the younger binaries reflects the initial values present

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when these binaries were born.

On the other hand, since most of the binaries in our sample are within the main sequence, it is evident that circularization processes are still active during this evolutionary phase while synchronization seems to be achieved at very early stages. The kind of analysis presented here, using integrated time scales, was already found to be necessary to explain the observed rotational rates and orbital eccentricities of the evolved binaries TZ For (Andersen et al., 1991) and BW Aqr (Clausen, 1991).

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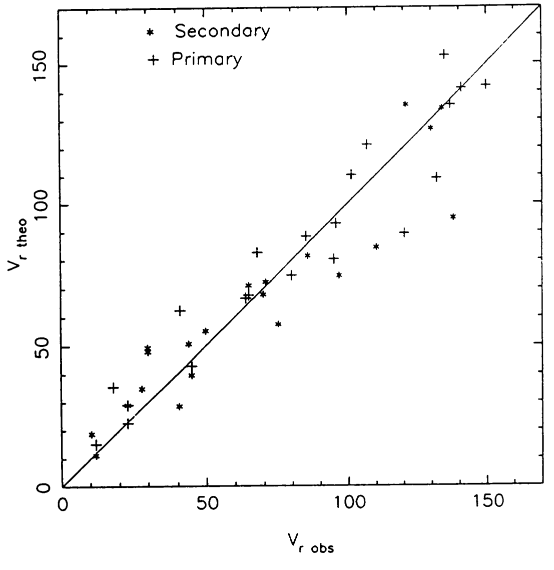

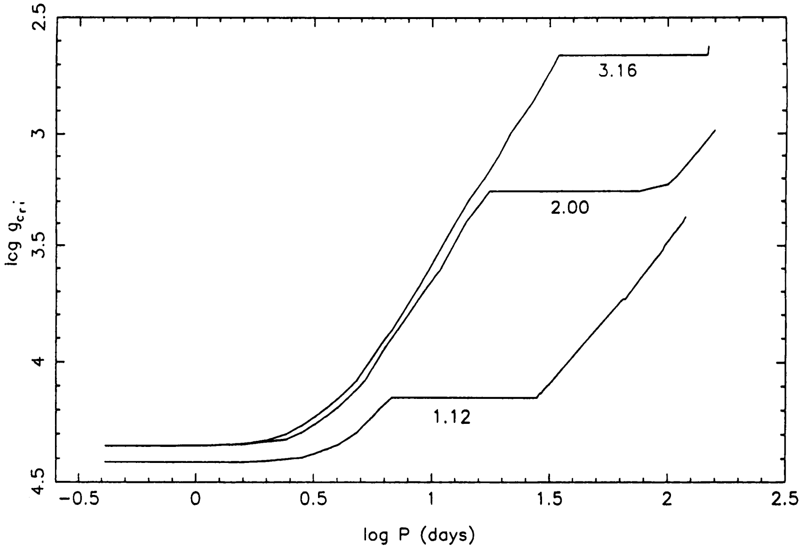

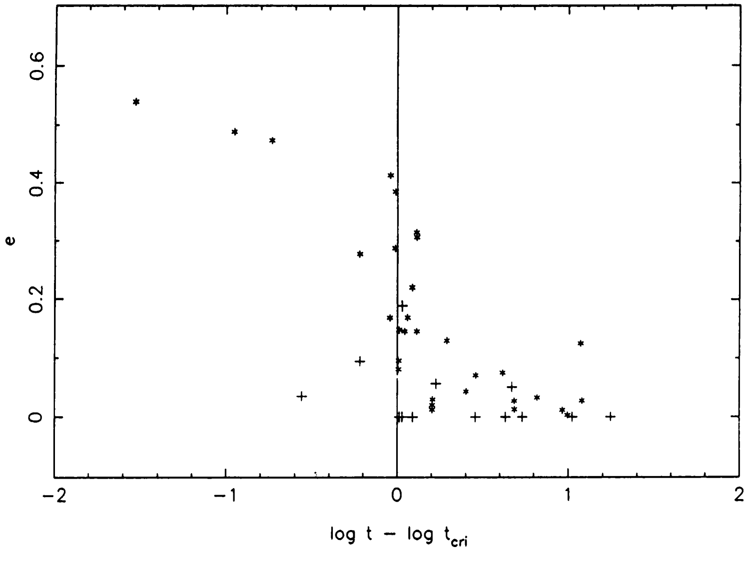

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