RECENT RESULTS ON THE APSIDAL MOTION TEST IN ECLIPSING BINARIES

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ABSTRACT. A selected sample of eclipsing binaries with well-defined apsidal motion rates and accurate absolute dimensions has been analysed and compared with most recent evolutionary models of the stellar internal structure. A reasonably good agreement has been achieved when models including convective-core overshooting, mass loss, and stellar rotation in the evolutionary code, are used. The systematic difference in log k_2 reported by previous authors between observed and theoretically predicted values is no longer detected for stars with well-determined absolute dimensions, and a few anomalous cases can be easily explained in terms of the validity of the adopted assumptions.

1. Introduction

Apsidal motion is one of the classical diagnostics of stellar structure (Schwarzschild, 1958). If the orbit of an eclipsing binary system is eccentric, its detailed analysis permits to *see* inside the stars and determine their internal mass distribution. This is accomplished by measuring the rate of apsidal motion of its orbit through the timing of the changing position of the eclipses. In an isolated binary system, the apsidal motion arises mainly from the classical quadrupole moment produced by the tidal and rotational distortions in the shape of the stars. If the perturbing potential is known as a function of the absolute dimensions and orbital elements of the binary system, the observed apsidal motion rate can be expressed in terms of the second harmonic of the average internal structure constant, log k_2, of the component stars. Methods and possibilities of this kind of research have been reviewed by Giménez (1981, 1990). Additionally, some systems may be used to test the theory of general relativity, but this is out of the scope of the present paper and we refer to articles by Giménez (1985), Guinan and Maloney (1985) and Maloney et al. (1989), as well as references contained therein, for details.

2. Comparison of observational and theoretical data

A detailed comparison between observations and theory for the internal structure constant was carried out on the basis of two assumptions:

a) a selected sample of eccentric eclipsing binaries with well-defined apsidal motion variations and accurate absolute dimensions, and

b) a grid of stellar models computed with standard physics (no overshooting, mass loss or stellar rotation), which adopts the Los Alamos opacity library and an initial chemical composition (X,Z) = (0.70,0.02), as described by Claret and Giménez (1989).

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The main results of such a comparison were discussed by Giménez (1990) and show a long known systematic discrepancy in the sense that models are less concentrated in mass than real stars, particularly for the early-type systems. At the same time, absolute dimensions of the component stars of the same sample are found to be in excellent agreement with the evolutionary models from the point of view of the derived age for each of the stars of the same system, the predicted and observed effective temperature, or the observed rotation and that expected from pseudosynchronization at periastron. The mentioned systematic tendency was moreover found to be correlated with age, or log g, since the discrepancy appears to be larger for the more evolved systems, even within the main sequence.

A series of attempts to remove this discrepancy have been carried out through a careful testing of all possible explanations. Focusing on problems related to theoretical models of the stellar structure, we have studied the effects of convective overshooting in the core, mass loss, stellar rotation and improved opacities. When convective overshooting and mass loss are taking into account, Claret and Giménez (1991a,b) have shown that both effects act to improve the agreement between observations and theory. The observations persist nevertheless to indicate stellar configurations to be slightly, but significantly more centrally concentrated than the models. A comparison of the evolutionary age, derived from the theoretical evolutionary tracks for the primary and secondary components of each system, is shown in Figure 1. Three systems with problematic results are pointed out with a name label. In Figure 2, we show the comparison between effective temperatures derived from theoretical models, for the adopted chemical composition and the observed mass and radius of each of the component stars, and observations. A slight tendency for hotter than observed predicted values is detected in the medium range of temperatures which is removed when models with a realistic rotation are used.

In fact, allowing for the effect of rotation on the model structure appears not only to improve the comparison of the effective temperatures but also to eliminate the remaining discrepancy in the internal structure constant. In Figure 3 we can see the plot of this comparison when the internal rotation effect is taken into account following the results by Claret and Giménez (1991c) which confirm earlier studies by Stothers (1974). On the other hand, the use of newer opacity libraries, as decribed by Iglesias and Rogers (1991), leads to the prediction of stellar models with slightly larger radii, cooler atmospheres and a more centrally concentrated mass distribution. Our preliminary calculations with this new grid of opacities confirm the tests made by Stothers and Chin (1991) and indicate that a change in the new models will go in the same direction as that obtained previously by Claret and Giménez (1989) when changing from tables by Cox and Stewart to Los Alamos. On the other hand, a lower amount of convective overshooting should be necessary to explain the same observational data.

The still remaining anomalous cases are evident in Figure 3 and they can not be explained easily in terms of changes in the input physics of the adopted models without seriously affecting other tests of the evolutionary calculations. Focusing now on problems related to the observational evidences adopted, they can be discarded for the comparison with theoretical predictions. Three systems have been isolated as outlayers in the general good agreement between observations and theory and they are actually found to have the worst determinations of both apsidal motion and absolute dimensions, as shown in Figure 1. Moreover, in a recent paper by Smeyers et al. (1991), it has been discussed the effect of considering dynamic tides, instead of the currently adopted theory based on equilibrium tides, to estimate the rate of apsidal motion in close binaries. Significant differences are only expected at very high eccentricities with relatively short orbital period or for special locations of the forced oscillations period with respect to the nearest resonant period of a free oscillation mode. This may actually be the case in at least two of the discrepant binaries, namely, α Vir (with a pulsating primary component) and V380 Cyg (with a primary component very close to its critical Roche surface at periastron). The third anomalous case, HR 7551, has so poorly determined radii that no detailed discussion can be based on it. A gratifying conclusion to a classical problem may thus have been reached by a concerted effort on both the observational and theoretical fronts.

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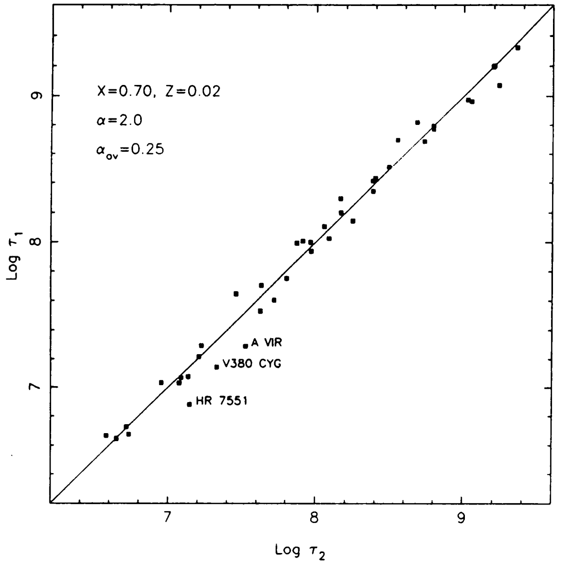

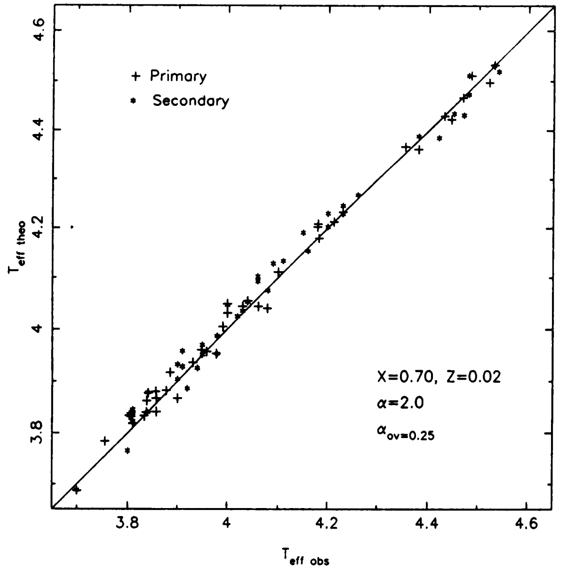

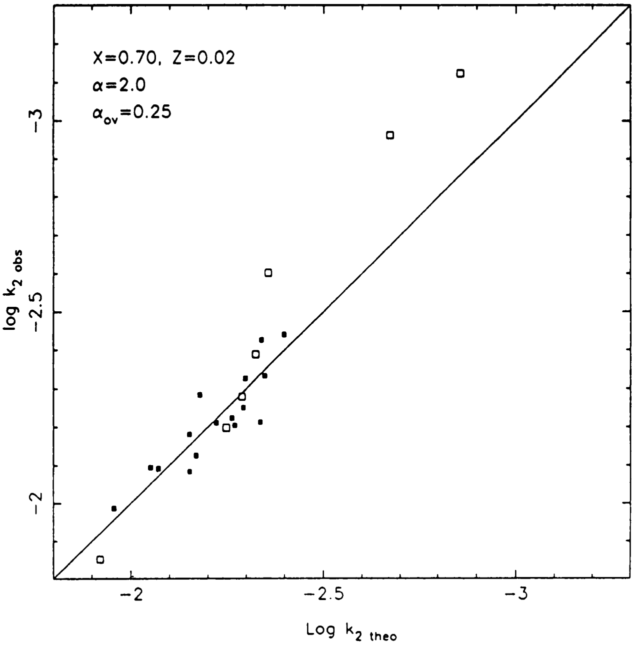

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