"UNDISTURBED" EVOLUTION IN BINARIES

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ABSTRACT. The use of binary systems as tools for testing models for single-star ("undisturbed") evolution is briefly reviewed. Recent successes and directions for future work are discussed.

1. INTRODUCTION

In many binary systems, interactions between the components are weak enough that the stars can be assumed to evolve initially just as they would have done if they were single. This is not a trivial observation, because some of these binary systems offer possibilities for testing current theory of stellar evolution in ways which are impossible in single stars. Moreover, this first stage provides the initial conditions for the later evolution of some binaries into much more exotic objects, and for constructing models of these advanced phases of evolution.

A comprehensive review of the subject cannot be given in the time and space available here. I shall therefore focus on a few highlights of recent results in the field, drawing heavily on work carried out by a group of colleagues centered at Copenhagen Observatory, who have concentrated on determinations of accurate data for this purpose from observations of suitable detached, double-lined eclipsing binaries.

2. TESTING STANDARD MODELS OF SINGLE-STAR EVOLUTION

Given the initial mass, chemical composition, and age of a star, theory in principle predicts its current mass, radius, temperature or luminosity, and emitted spectrum. Only for the Sun can all these parameters be independently and accurately determined and compared with the best current evolutionary models. However, ambiguities arise from uncertainties in, especially, convection theory and computed opacities. Consequently, the solar constraints are primarily used to fix certain adjustable parameters in the models, notably the mixing-length parameter, α, and the helium abundance, Y. One may then compare, e.g., the observed and predicted mass-radius or mass-luminosity relations, using masses, radii,

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and luminosities determined from binary studies (Straižys and Kuriliene, 1981; Balona, 1984).

Unless very precise mass and radius data are used in such studies, however, observational scatter may obscure the evolutionary effects and the latter be overlooked. In fact, log g as determined directly from the basic data M and R is a very sensitive indicator of evolution, even *within* the main-sequence (MS) band (Nordström, 1988); evolutionary effects of only 5% of the width of the MS can be distinguished in the most accurate data (masses and radii precise to ~1% or better). Still, even with first-rate masses and radii, fundamental ambiguities remain when the composition and age of the stars are not well known.

In stars other than the Sun, the actual age and, usually, the helium abundance cannot be determined independently of the stellar models one wants to test. Close binaries, however, must satisfy the additional constraint that the ages and initial compositions of the components be identical. In stars of near-solar heavy-element abundance Z, the obvious further assumption is for the helium abundance to be also essentially solar. Thus, if the metal abundance of a binary can be determined, e.g. spectroscopically, only its age remains unknown among the fundamental parameters. If evolutionary models with mixing-length parameter and helium abundance normalized to the Sun and with the observed Z can reproduce all observed properties of two substantially different binary components for the *same* age, a non-trivial test has been made. Evidently, the test becomes even stronger if agreement can be demonstrated for binaries with a variety of different metal abundances.

3. RECENT RESULTS

The first detailed test of this kind was made by Popper and Ulrich (1984), using the binary V818 Tau (HD 27130). Its membership of the Hyades provides both its metal abundance, distance, and the information that both stars are on the ZAMS. Popper and Ulrich showed that solar-calibrated stellar models matched the luminosity of the primary satisfactorily; a low helium abundance (Strömgren et al., 1982) was inconsistent with the binary data. This analysis was refined by Schiller and Milone (1987) on the basis of accurate masses and radii of both stars.

A stronger test of the models is possible in the system AI Phe, in which the more massive component (1.24 $M_{\odot}$) has already evolved onto the lower giant branch while the other, only 3% less massive star has just left the main sequence. A complete determination of the masses, radii, luminosities, and metal abundance ([Fe/H] = -0.14) of the system by Andersen et al. (1988*a*) led to remarkably close agreement with solar-normalized VandenBerg (1983, 1985) standard models for these observed parameters *and* the solar helium abundance: Derived ages for the two stars agreed to ±1%. It could be further concluded that convective core overshooting had no observable effect in these stars. It was noted that the same models, for the Hyades metal abundance, also matched the properties of V818 Tau. It was finally *predicted* that the very similar-mass system UX Men should be more metal-rich than the Sun, as those stars were much cooler than the models matching AI Phe.

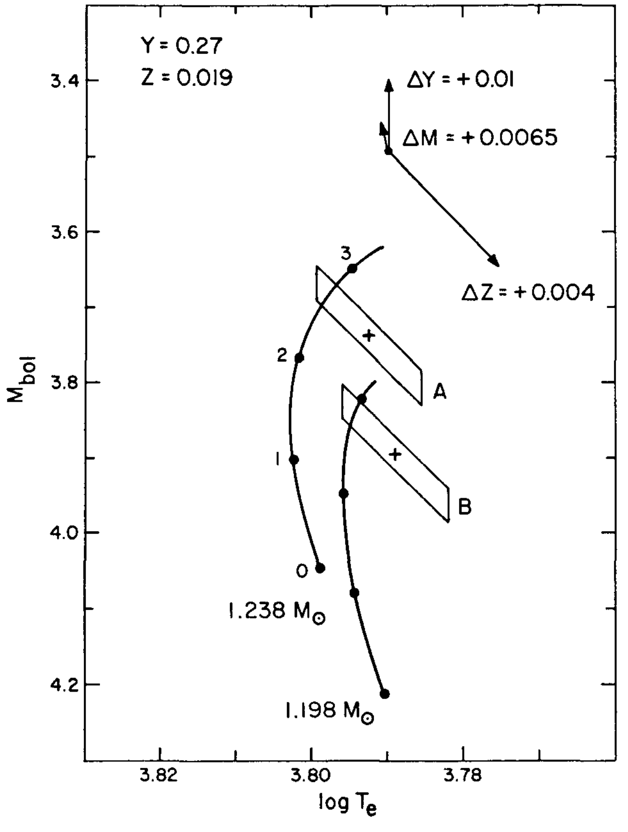

Fig.1. Evolutionary tracks and observed locations for the components of UX Men (Andersen et al., 1988*b*). Ages (Gyr) are labeled along the tracks; arrows show the effects of 1 σ changes in the parameters.

This prediction was confirmed by the subsequent similar study of UX Men by Andersen et al. (1988*b*) who found [Fe/H] = +0.04. The theoretical HR diagram in Fig. 1 compares the theoretical tracks for the observed masses and metal abundance, and the solar helium abundance, with the observed location of the components as derived from temperatures and radii. As will be seen, the agreement is again quite satisfactory.

From these comparisons, we draw the following conclusions: First, standard VandenBerg models with a solar helium content can now successfully predict, *at the 1% level*, all observed properties of binaries with Z from 0.012 (AI Phe) over 0.019 (UX Men) to 0.024 (V818 Tau) as well as the Sun. Second, this is only possible with the newest Los Alamos opacities; models using older (Cox-Stewart) opacities require a significantly lower helium abundance to fit the data. Third, even at this level of refinement, errors in the masses and radii have now ceased to be the limiting factor; the main uncertainty in the comparison with theory is due to that of even the best modern metal abundance determinations.

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4. PROBLEM AREAS AND FURTHER WORK

While these recent successes in using binary systems as "laboratories" in which to study "undisturbed" stellar evolution are quite encouraging, not all problems have been solved and certainly not all work completed. A few main problem areas and directions for the future are listed below.

For very massive (O) stars, similarly informative comparisons are not currently possible, because temperature calibrations are quite uncertain and metal abundances difficult to determine. In addition, the observable consequences of interesting features of stellar models in this domain (convective overshooting, mass loss) are quite subtle in the main-sequence phase. A small discrepancy between observed and predicted *apsidal-motion* constants for standard models may offer additional clues.

In some well-established cases, two stars in different binaries have essentially equal masses and radii, but quite different temperatures, both in B stars (Popper, 1987) and in A stars (Andersen et al., 1984). Present experience suggests that the first hypothesis to explore is that of significantly different metal abundances. Only after such observations have been made should more exotic explanations in terms of helium abundance variations or non-standard evolution be invoked.

Finally, Habets and Zwaan (1988) have shown again how the observed stellar (synchronous or non-synchronous) *rotation* of binary components can be used to probe the evolution of internal structure of the stars.

Our overall conclusion is, however, that the greatest observational need is now for more *abundance* data to match the known masses and radii.

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