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BINARY STARS AND CLUSTERS AS TESTS OF STELLAR EVOLUTION MODELS

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ABSTRACT

Precise masses, radii, and luminosities from eclipsing binaries and colour-magnitude diagrams for open clusters are classic tools in empirical tests of stellar evolution models. We review the accuracy and completeness required for such data to discriminate between current models and describe some recent results with implications for convection theory.

Key Words : stellar evolution, binary stars, star clusters

I. INTRODUCTION

For a given initial mass and chemical composition, stellar evolution theory predicts the radius, temperature, and luminosity of a star as a function of time. Thus, with a series of empirical masses, radii, and luminosities as can be determined in double-lined eclipsing binaries one can test these predictions. Or, with many coeval stars of the same composition but different masses (i.e. a cluster), one can compare the detailed shapes of predicted and observed isochrones.

Both methods are text-book classics; each has its strengths and caveats which we review below. The bottom line is that the more fitting parameters that are not constrained by accurate observations, the less one learns about stellar evolution.

II. ECLIPSING BINARIES

The basics of this subject were reviewed in detail by Andersen (1991) and again by W. Tobin at this meeting, so only a brief update on current developments is needed here. The key to this method is that in suitable eclipsing binaries, mass, radius, and temperature/luminosity are determined independently for two stars on an isochrone. Thus, if the age and helium abundance of the models have been fixed by a fit to one of the two stars (and the mixing length by a fit to the Sun), there are no adjustable parameters left when computing a model for the other star. Thus, agreement with observation is a non-trivial test if the two masses are different - and if observational errors are small enough ($\lesssim$ 1%) that not all competing models can fit the data.

As an example of a significant result based on only masses and radii (but no temperatures), the young B-type system GG Lup must have a metallicity below solar because the less massive star is simply too small to fit ZAMS models of solar or higher [Fe/H] (Andersen et al. 1993). Since this result pertains directly to the chemical composition of the entire star, not just the surface layers, it is a significant counterexample to the notion that metallicity in the solar neighbourhood is monotonically increasing with time.

As an exercise in accurate model fitting for a system of known [Fe/H], the evolved system AI Phe (ref. in Andersen 1991) remains unsurpassed for the precision of the fit achieved. However, a colour-temperature relation based on additional types of data remains necessary and critical.

Current developments can be summarized as follows: *(i)* More suitable systems are being identified, especially stars with masses in the poorly covered ranges below 1 and above 15 solar masses, including systems in the Magellanic Clouds (see Tobin, this volume); *(ii)* more accurate masses are being determined using better spectra and recent advances in analysis software that allow the determination of reliable orbits from blended spectra (Zuker & Mazeh 1994), and even optimum reconstruction of the two individual spectra (Simon & Sturm 1994); *(iii)* more reliable [Fe/H] determinations for systems with good masses and radii are on the way (J.V. Clausen, priv. comm.). Thus, the next couple of years should see much improvement in the quality and quantity of data available for tests of stellar models.

III. CLUSTERS

Good binary data are not available for all stellar types, however, and fitting model isochrones to observed cluster colour-magnitude diagrams (CMDs) remains the most popular way to test stellar models. Since the masses of cluster stars are not known directly, the detailed fit to the shape of the observed CMD is the critical part of the test. The three main caveats are: *(i)* The reddening should be known so the turnoff colour is fixed; *(ii)* field stars and binaries must be identified since the models pertain to single cluster members only; *(iii)* again, accurate colour transformations are needed to transpose the computed isochrones to the observational plane.

The system of (old) open galactic clusters were recently reviewed by Friel (1995), and isochrone fitting has been discussed e.g by VandenBerg (1985) and Demarque et al. (1994). Thus, it suffices here to illustrate our main points using the intermediate-age cluster NGC 3680 as an example. The observational history of the cluster, new CCD and radial-velocity data, and a detailed analysis are given in Nordström et al. (1996a,b).

The specific question discussed is whether the detailed shape of the cluster turnoff does (Mazzei & Pigatto 1988, Carraro et al. 1993) or does not (Castellani et al. 1992) show that convective core overshooting is significant. The answer is of some importance for the resulting ages and the structure of post-main-sequence stars, but it also exemplifies the general issue of drawing significant conclusions from minor features in the CMD, here the amount of curvature of the turnoff. Three of the critical features of such tests are:

First, in most previous model fits, the reddening has been treated as a free parameter, thus discarding the first-order age information contained in the turnoff colour in favour of the second-order information from the turnoff shape. Large deviations from the actually measured reddening were often found. As shown by Demarque et al. (1994), such fits can give almost any desired age, but are of course not acceptable, let alone usable as tests.

Second, before fitting the cluster itself, we plotted the solar-abundance 2-Gyr isochrones from different authors in the B, V CMD. We found a spread of nearly 0.06 mag in $B-V$ at the turnoff for these supposedly identical models. Yet, their effective temperatures agree well; i.e., very different colour transformations are in use, even at solar metallicity (see also Bell et al. 1994). We therefore decided to disregard all the computed broad-band isochrone colours and use a single colour transformation to the Strömgren $b-y$ colour for all models.

Third, previous authors were free to select what subset of stars in the main-sequence region of the CMD to fit. We identify the (numerous) field stars and binaries by combining recent proper motions with our new radial-velocities spanning an 8-year period. A tight cluster sequence emerges which only overshooting models fit; however, the actual amount of overshooting in present models still seems somewhat too large.

Two interesting by-products were: *(i)* The entire lower main sequence of NGC 3680 has been lost due to dynamical evolution of the cluster; depending on the assumed IMF, only ~0.25 %(!) of the original cluster stars remain today. *(ii)* The putative non-classical evolutionary phenomenon of a 'bimodal turnoff' discussed by Nissen (1988) and Anthony-Twarog et al. (1989) is explained by fortuitous alignments of cluster binaries and field stars, combined with the non-standard shape of real (overshooting) isochrones.

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REFERENCES

Andersen, J. 1991, ARA&A, 3, 1991

Andersen, J., Clausen, J.V., Giménez, A. 1993, A&A, 277, 439

Anthony-Twarog, B.J., Twarog, B.A., Shodhan, S. 1989, AJ, 98, 1634

Bell, R.A., Paltoglou, G., Trippico, M.J. 1994, MNRAS, 268, 771

Carraro, G., Bertelli, G., Bressan, A., Chiosi, C. 1993, A&AS 101, 381

Castellani, V., Chieffi, A., Straniero, O. 1992, ApJS, 78, 517

Demarque, P., Sarajedini, A., Guo, X.-J. 1994, ApJ, 426, 165

Friel, E.D. 1995, ARA&A, 33, 381

Mazzei, P., Pigatto, L. 1988, A&A, 193, 148

Nissen, P.E. 1988, A&A, 199, 146

Nordström, B., Andersen, J., Andersen, M.I. 1996a, A&AS 118, 407

Nordström, B., Andersen, J., Andersen, M.I. 1996b, A&A, to be subm.

Simon, K.-P., Sturm, E. 1994, A&A, 281, 291

VandenBerg D.A. 1985, ApJS, 58, 711

Zuker, S., Mazeh, T. 1994, ApJ420, 806