TESTS OF EVOLUTION MODELS USING ECLIPSING BINARIES

J. ANDERSEN
Niels Bohr Institute for Astronomy, Physics, and Geophysics
Astronomical Observatory
Brorfeldevej 23
DK - 4340 Tølløse, Denmark

1. Introduction

Stellar models are the means by which we describe and understand the distribution of stars in the HR diagram. A stellar model is, in principle, completely specified by the three fundamental parameters mass, chemical composition, and age. Comparing the properties of models and real stars with the same parameters will tell us if our recipe for constructing stellar models is realistic. Unfortunately, the only star for which all three are known independently of stellar models is the Sun. For stars of other masses and ages we must devise observational tests in which at least one fundamental parameter is unknown. Two such popular test objects are double-lined eclipsing binaries and star clusters.

In suitable eclipsing binaries we can determine both masses and chemical composition; the absolute age is unknown, but the *same* for both stars. Since evolution depends most sensitively on the mass, eclipsing binaries provide a very direct test of the models, but only for two points on a single isochrone. In star clusters, neither ages nor individual masses are known, but the detailed shape and population of a well-observed cluster sequence in the HR diagram provide a number of additional probes into the models.

In both tests, one may proceed with two fundamentally different attitudes and aims:

- Adopting a particular set of stellar models as representing the state of the art, one seeks to identify the largest possible body of observational data that agree with the models.

I. Appenzeller (ed.), Highlights of Astronomy, Vol. 10, 419–422.

- Assuming that the best test involves the fewest adjustable parameters, one assembles test objects in which *all* observable parameters are determined with the highest possible accuracy. In other words, the aim is to increase the chances of failure, not of success.

For eclipsing binaries, the latter approach implies that individual masses and radii should be determined to about 1% or better, effective temperatures be determined from reddening- corrected colour indices, and the chemical composition also determined observationally, preferably by high-resolution spectroscopy. In star clusters, interstellar reddening and chemical composition can also be determined by standard techniques, but in addition, the single cluster members (to which the models apply) must be identified from non-member and binary stars. Relaxing any of these requirements improves the chance of obtaining agreement between models and data, but also greatly diminishes the predictive power of the test: No new information on stellar models is obtained if all can be made to fit the data!

In the oral presentation of this contribution, comments were also made on the use of open cluster data for testing stellar models, taking NGC 3680 as a specific illustration of the dangers of insufficient allowance for interstellar reddening, non-members and binaries, and calibration of the photometry. The present written version will concentrate on the discussion of the binary data. For further discussion of tests based on cluster data, we refer to the review by Mermilliod (1995) elsewhere in this volume, and to the detailed discussion of new radial-velocity and other data on NGC 3680 by Nordström et al. (1995).

2. The available data

The available data on accurate stellar masses and radii for use in testing stellar models were reviewed by Andersen (1991, but see also Nordström & Johansen 1994). The distribution of the stars along the main-sequence band in the log M - log g diagram is shown in Fig. 1. As will be seen, conclusions from data on *masses and radii alone* on the importance of convective overshooting ($\alpha = d/H_p = 0$ or 0.25) depends on the location of the TAMS lines in Fig. 1. As discussed e.g. by Stothers & Chin (1991), the TAMS moves upwards if more recent (larger) opacities are used and/or if a high metal abundance ($Z = 0.03$) is assumed for Population I stars. However, valid models must correctly describe the evolution in radius for both components of a given binary system *simultaneously*, a non-trivial condition if the two masses are substantially different (stars connected by lines in Fig. 1). Models for which the TAMS is sufficiently high to fit the evolved stars without the assumption of overshooting have not been proved valid unless they also fit individual systems for a single age.

The difficulties inherent in assuming rather than actually determining metal abundances can, in favorable cases, be demonstrated already from masses and radii alone. Fig. 2 shows the young binary GG Lup in the log M - log g diagram (Andersen et al. 1993), together with models by Claret & Giménez (1992), incorporating the latest opacity data. It appears that the surface gravity of the secondary is too large (or the radius too small) to allow a fit by any ZAMS or post-ZAMS models of even solar composition ($Z = 0.02$), let alone $Z = 0.03$ as preferred by Stothers & Chin (1991). We conclude that studying average relations for binary components in which some key parameters are left adjustable, like the chemical composition in the above example, is unlikely to advance the subject substantially, especially if the equal-age condition in individual systems is disregarded.

3. Recommended procedure

It would appear that the most informative comparisons of stellar data and stellar models are made when the former are as complete and accurate as possible and the latter computed directly for the observed stars. This approach has been demonstrated in practice by Andersen et al. (1988, 1989, 1991). A primary objective of our current research in this area is to enlarge the sample of eclipsing binary systems in which masses, radii, luminosities, *and* metal abundances are known with sufficient accuracy for use in such work.

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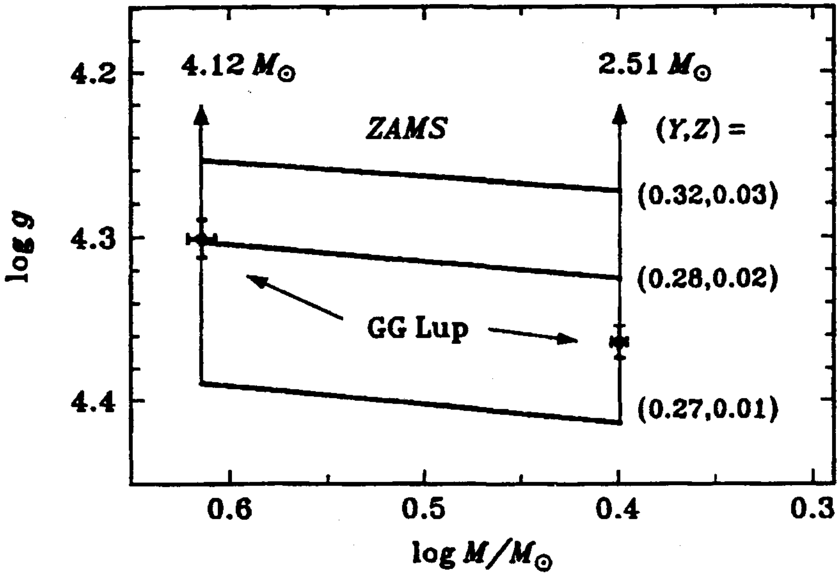

Figure 1. Data: Andersen (1991). ZAMS and TAMS relations: Claret & Giménez (1991).

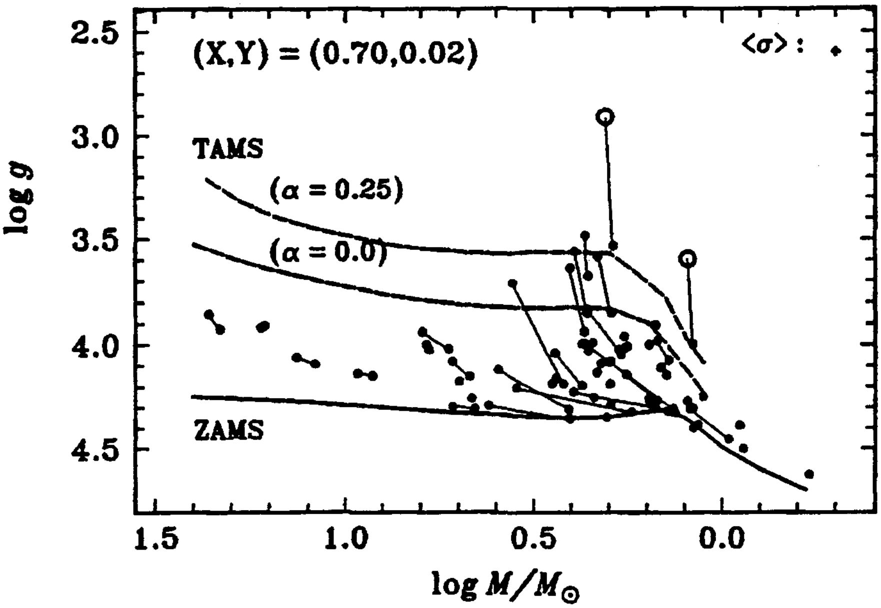

Figure 2. GG Lup (Andersen et al. 1991), with models by Claret & Giménez (1992).