to a well-defined observational limit and specifying main characteristics such as Hubble type and apparent magnitude? Many considerations pointed to answering "yes", including the important side effect of ensuring uniformity in the identification numbers to be used in the future.

Since the task would be far beyond what might be done by the ESO staff itself, collaboration with an astronomical institute, preferably in one of the ESO countries, would be the solution and this led the ESO Directorate to approach in the spring of 1973 the Director of Uppsala Observatory, Eric Holmberg. Uppsala Observatory was one of the few in the ESO countries with an established tradition in extragalactic work, including work of statistical nature. A major project published in 1973 was P. Nilson's Uppsala General Catalogue of Galaxies, containing data for nearly 13,000 galaxies north of declination $-2°30'$ and based on the Palomar Sky Survey [23]. In reply to a formal letter of May 16, 1973 of the ESO Director General, Holmberg expressed his interest in the proposition and sketched first outlines for the collaboration in a letter of May 27. Further correspondence and meetings between ESO and Uppsala staff led to a formal agreement between the two institutes of February 8, 1974 [24].

In the course of the negotiations, for ESO the Head of the Sky Atlas Laboratory, Richard West, became more and more involved, and soon took this project, too, under his wings. The agreement specified, among other items, that the Uppsala search was to be made by an astronomer at Uppsala Observatory on copies of the original plates of the Quick Blue Survey especially made for this purpose; an Annex, apart from giving technical details, stated that besides galaxies satisfying certain observational criteria, also a selection of stellar clusters and planetary nebulae were to be included. The criteria to be adopted for the selection of the galaxies were the same as those used by Nilson so that homogeneous coverage of the northern and southern parts of the sky would be assured.

In a letter of February 20, 1974 to the Director General of ESO, Holmberg wrote that, since November 1973, the work had been going full force by Andris Lauberts, and a first batch of 20 plates were under survey. A comprehensive description of the project was published in 1974 by Holmberg, Lauberts, Schuster and West [25].

Acknowledgement

I am indebted to Drs. A. B. Muller and R. M. West for helpful comments on a draft of this article.

References and Notes

Abbreviations used;

EC = ESO Committee, the committee that preceded the ESO Council.

EHA = ESO Historical Archives. See the description in the *Messenger* No. 54 of December 1988.

FHA = Files belonging to the Office of the Head of Administration of ESO.

EHPA = ESO Historical Photographs Archive.

Heckmann Sterne = O. Heckmann, *Sterne, Kosmos, Weltmodelle,* Verlag Piper and Co., München – Zürich, 1976.

[1] I am indebted to Prof. U. Haug of Hamburg Observatory for providing me with the references [2] and [3] below.

[2] Abhandlungen Hamburger Sternwarte Band X, Heft 2, p. 50, 1979.

[3] See O. Heckmann, in *Nature,* Vol. 76, p. 805, 1955 and in *Mitteilungen Astron. Gesellschaft* 1955, p. 57, 1956.

[4] See Fehrenbach's report in the minutes of the 9th meeting of the Instr. Comm., Oct. 18, 1963, p. 10 in FHA. Reference is also made to the minutes of the EC of Nov. 1961, Oct. 1962, in FHA, and to the ESO Annual Rep. 1964.

[5] Minutes of the 6th meeting of the Instr. Comm., p. 3, in FHA.

[6] Minutes Instr. Comm. June 25, 1964, p. 7, in FHA.

[7] Minutes of the 13th meeting of the Instr. Comm., p. 4; Minutes 2nd Cou Meeting, May 1964, both in FHA.

[8] See also, in EHA-I.A.2.10, relevant correspondence between Oort and Heckmann in June and July 1964 and March 1965.

[9] Proceedings of the Conference on "The Role of Schmidt Telescopes in Astronomy", Ed. U. Haug, published jointly by ESO, SRC and Hamburg Observatory, 1972, p. 137–139.

[10] A more extensive description is in the minutes of the Instr. Comm. of March 1964, in FHA.

[11] Editions du Centre National de Recherche Scientifique, Paris 1990, p. 404.

[12] See ESO Annual Reports 1964–1966 and minutes Cou Meetings 1965 and 1966, in FHA.

[13] FHA-Cou minutes Dec. 1968, p. 4.

[14] Heckmann Sterne, p. 216 and 321–322.

[15] In a letter of January 10, 1990, Prof. U. Haug of Hamburg Observatory points out to me, that in the case of the Hamburg Schmidt, whereas Strewinski was responsible for the mechanical design of the mounting, the combination optics-telescope tube was primarily handled by Zeiss-Jena, including a solution for the alignment telescope-tube/guiding-telescopes.

[16] Ref. [2], p. 79.

[17] *"Astronomy With Schmidt Telescopes",* Ed. M. Capaccioli, Reidel, 1983, p. 13.

[18] *Mitteilungen Ver. Drehbank-Fabriken* No. 15, March 1958, p. 1, in EHA-III.

[19] According to a letter by D. Shane to J. H. Oort of August 22, 1960; in EHA-I.A.1.13.

[20] See note [9].

[21] Documentation pertaining to the development of the ESO-SRC collaboration is contained in FHA-2.8.3, "Cooperation with SRC", including copies of correspondence between West, Blaauw and Reddish and the legal advisors of ESO and SRC from April 20, 1972 and draft texts for the Agreement from November 1972 till the final version of January 1974.

[22] See, for instance, the internal Memo ref. SK/74/186/RW/FP of October 10, 1974 from West to various ESO Officers: "List of plates which have been distributed" in EHA-III.

[23] *Uppsala Astron. Obs. Ann.,* Vol. 6, 1973.

[24] I am much indebted to Prof. E. Holmberg and Dr. A. Lauberts for providing me with copies of the early correspondence in the files of Uppsala Observatory: letters of May 27 and Sept. 26, 1973. The ESO FHA-2.8.6. contain, for the period reported here, copies of correspondence and drafts as well as the final contract, beginning Sept. 26, 1973. See also the ESO Annual Reports.

[25] E.B. Holmberg, A. Lauberts, H.-E. Schuster and R.M. West, The ESO/Uppsala Survey of the ESO (B) Atlas of the Southern Sky. I., in *Astron. Astrophys. Suppl* **18,** p. 463–489, 1974.

Open Clusters Under the Microscope

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Stellar Evolution Models

Our use of, and faith in, stellar evolution models underlie much of contemporary astrophysics. Stellar evolution theory has provided a framework within which, in broad terms, we can fit the apparently bewildering variety of single and double stars into a logical order described by a physical theory.

Stellar evolution models are used to calculate the ages of observed stars and their lifetimes in various evolutionary phases. They also describe the transformation of lighter to heavier chemical elements within the stars, and the amounts of processed material returned to the interstellar environment at various stages during their evolution. Thus, stellar evolution models are an essential basis for models of galactic chemical evolution, a subject of much current interest.

How well do these models correspond to the real stars? Open clusters are an excellent place to make the comparison, but care is required in interpreting what one sees. We have attempted to look a bit deeper into this question than is often done.

Weak Points

Among the weak points of current stellar evolution models is their treatment of the energy transport in the stellar interior.

At the microscopic level, the effect of the absorption, reemission, and scattering processes encountered by a photon on its way towards the surface of the star is described by *opacity tables*. Here, the 1970 Cox-Stewart (C-S) opacities have now been superseded by the more recent Los Alamos Opacity Library (LAOL). The LAOL opacities are, on average, significantly larger than those by C-S, leading to cooler and less luminous stellar models (see Guenther et al., 1989).

At the macroscopic level, the treatment of convective energy transport in stellar interiors has long been recognized as one of the weakest points in stellar evolution theory. Standard models use the classical mixing-length approximation, but it has long been argued that the convective motions will "overshoot" into the classically stable, radiative regions. Overshooting from the convective cores of massive stars increases the amount of hydrogen fuel available in the main-sequence stage. Hence, main-sequence models with convective overshooting are brighter than standard models, and the stars leave the main sequence with higher ages and larger helium cores, modifying their later evolution.

Models vs. Real Stars

As no satisfactory physical overshooting theory exists (Renzini, 1987), its existence and eventual importance must be ascertained by comparison with real stars (Chiosi, 1990; Maeder, 1990). So let us assume that we have a real star of known mass, composition, and age, and use our favourite evolution code to construct a computer model of this star. How well do the observable properties, radius, effective temperature or luminosity, and surface composition

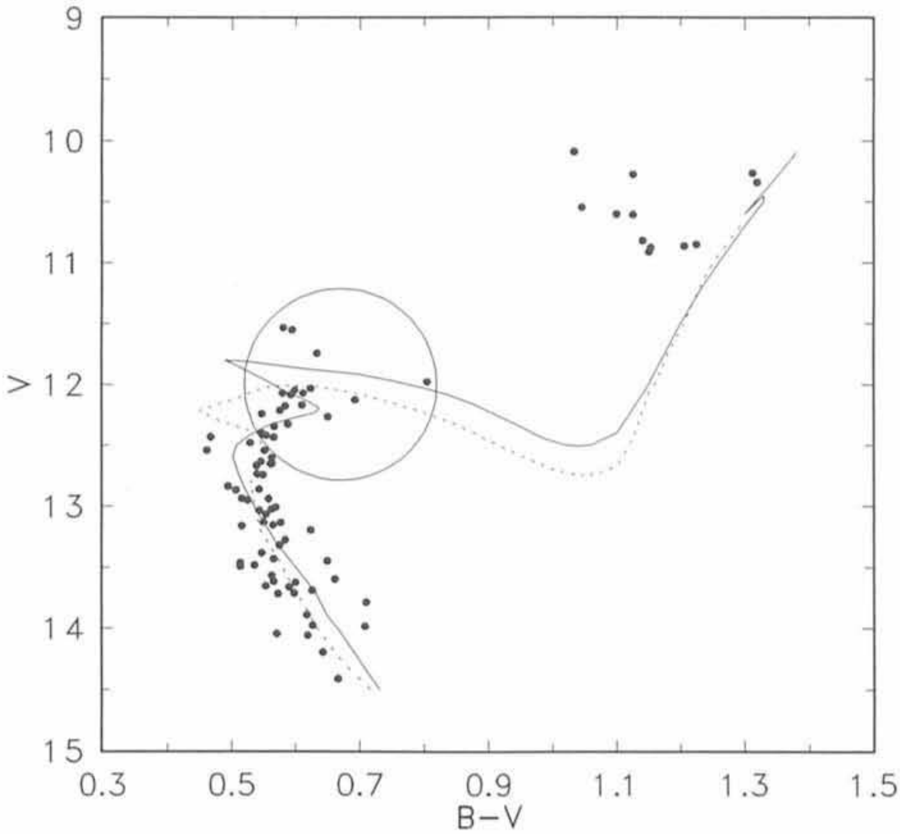

Figure 1: *CM diagram of IC 4651, from Anthony-Twarog et al. (1988). Isochrones from Maeder (1990) are shown, for the observed reddening and metal abundance: Dotted: No overshooting, 2.2 10^9 yr. Solid: With overshooting, 4.0 10^9 yr.*

(which might also have evolved) match those of the observed star?

Well, for which real stars do we know the mass, radius, effective, temperature, chemical composition, *and* age, accurately and *without reference to stellar models*? The answer is: Only for one star, the Sun. So, the minimum requirement for a trustworthy evolution code is to produce a satisfactory solar model. In fact, no set of standard solar models has been found to account for all of the observations mentioned above *and* for the observed solar neutrino flux, oscillation spectrum, and surface lithium abundance as well (Sackmann et al., 1990). But how about stars of other masses and ages?

The Binary Test

Apart from the Sun, two alternative kinds of test object exist: eclipsing binaries and star clusters. The former have the great advantage that their masses, radii, and effective temperatures can be determined with great accuracy in a fundamental manner. Metal abundances can be determined by standard spectroscopic methods. The ages are not known, but must be the *same* for both components. Thus, one binary system provides us with two points of known mass (the key parameter determining the evolution of a star) on a model isochrone, the locus for models of different mass, but the same age.

Precise masses and radii of eclipsing binary stars for such comparisons have long been a pet subject of ours. Here, we shall just quote a couple of relevant recent results: Standard models (VandenBerg, 1985) gave a superb fit to the evolved system AI Phe at 1.2 solar masses when LAOL (but not C-S) opacities were used (Andersen et al., 1988). However, at just slightly larger masses (1.5–2.5 solar masses), binary stars near the top of the main sequence can only be fitted reasonably by overshooting models (Andersen et al., 1990).

Later precise studies of additional binaries in this mass range confirm this conclusion. But what do the clusters tell us?

The Cluster Test

As test objects for stellar evolution models, star clusters have the advantage of populating the entire isochrone, defining its shape much more precisely than possible with the mere two points supplied by a binary system. For this reason, cluster colour-magnitude (CM) diagrams have been compared extensively with theoretical model isochrones

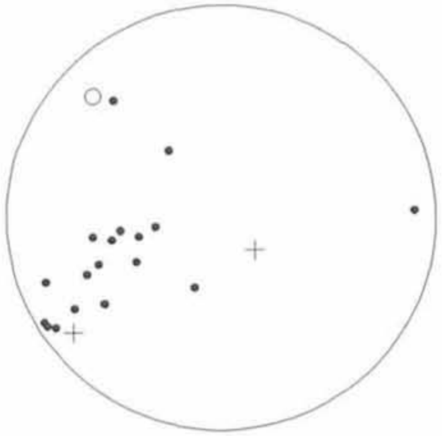

Figure 2: *Close-up of the circled region of Figure 1, where CORAVEL radial-velocity observations have been made. Dots: Likely single members. Crosses: Established non-members. Circle: Uncertain (broad-lined star).*

(e.g. VandenBerg, 1985), and quite precise age determinations have been reported (e.g. Mazzei and Pigatto, 1988). We concentrate in the following on the age range covered by the open clusters.

As tools for testing stellar models, CM diagrams of star clusters also have a number of drawbacks: First, of course, the true masses of the stars are in principle unknown. Second, defining the correct effective temperature and luminosity scales in the cluster requires that the reddening and distance of the cluster have been accurately determined. Next, the metal abundance must be accurately measured by photometric and spectroscopic observations of cluster stars. Then, some cluster stars will be unresolved binaries and appearing brighter and generally redder than the more luminous component by itself (if both are main-sequence stars). Finally, most cluster CM diagrams also contain a significant number of non-member or field stars.

All of these effects combine to produce more ambiguity in fitting theoretical isochrones to observations than often meets the eye in published diagrams. If reddening, metal abundance, and distance have not been determined separately, but *included* in the fit, any systematic errors in the model colours or luminosities will be hidden, but reappear as systematic errors in the derived ages. Errors will also occur if reddening or metal abundance determinations were based partly on non-member stars.

Further uncertainty in the interpretation of details in the isochrones is introduced if, in addition, one can pick and choose which stars to exclude from the fit as presumed binaries and non-members. We have examined this point closely in two open clusters of intermediate age, IC 4651 and NGC 3680. Our results show that these "nitty-gritty details" are far from inconsequential when one wishes to actually *test* stellar models: The purpose of a critical test is not to play with enough free parameters to fit the data with one's favourite model, but to see whether at least *some* of the competing models are in fact excluded by the data.

IC 4651

IC 4651 is a fairly rich open cluster with turnoff stars of mid-F type. The most recent photometric studies of it are by Anthony-Twarog et al. (1988) and Nissen (1988), who found its age to be about 2.5 10^9 yr, based on the VandenBerg (1985) standard models. Mazzei and Pigatto (1988) derived an age of 1.3 10^9 yr with models incorporating strong overshooting, which they found to be superior to standard models. Maeder (1990), on the other hand, derived ages of 4 10^9 yr and 2.2 10^9 yr, respectively, from models with and without overshooting – from the same CM diagram!

Which of all these wildly conflicting estimates can one believe? And, to ask the underlying key question, does the CM diagram of IC 4651 provide unambiguous evidence for significant overshooting in the cluster stars, or does it not?

The CM diagram of IC 4651 is shown in Figure 1. The isochrones are those by Maeder (1990), fitted with the reddening and (solar) metallicity determined directly by Nissen (1988). Clearly, the main differences between the two curves are in the upper part of the turnoff: The overshooting isochrone extends significantly higher above the turnoff than the standard isochrone, and also curves gently towards the red before reaching the "red hook".

The issue is decided by the true nature of the encircled group of stars: Are they all binary and field stars which should be disregarded? If so, the standard models without overshooting and the associated (low) age are to be preferred. Or are they mostly single cluster members? In that case, the standard isochrone is clearly not an acceptable match to the observations, and the high age estimate must prevail.

IC 4651 under the Microscope

Let us look for the answer by putting the turnoff region of IC 4651 under the microscope. Our "microscope" in this case is the radial-velocity scanner CORAVEL (Mayor, 1985), mounted on the Danish 1.5-m telescope at La Silla. For distant clusters such as IC 4651, accurate radial velocities (1 km s^{-1} or better) are the most reliable indicator of membership: If repeated observations show a constant velocity equal to the cluster mean, there is a very strong probability that the star is both single and member of the cluster.

Figure 2 shows what the "microscope" reveals after two seasons of observations: The large majority of the stars do indeed appear to be single cluster stars. Granted, a couple may turn out to be long-period binaries in the cluster, which we happened to observe just when they were close to the mean velocity. Sure, one or two may be field stars with nearly the same velocity as IC 4651. But certainly not *all* the stars in Figure 2 are binaries and non-members, as would be required for the standard isochrone to be the appropriate choice. *IC 4651 does appear to show unambiguous evidence for the presence of convective core overshooting.*

NGC 3680

NGC 3680 is a cluster very similar to IC 4651 in age and metal abundance (both marginally higher than IC 4651). We show its CM diagram in Figure 3, assembled from the photometry of Anthony-Twarog et al. (1989), Nissen (1988), and Eggen (1969). The CM diagram is less neat than that in Figure 1, due to the larger influence of field stars. A striking feature is the apparent dichotomy of the main sequence into two parallel sequences, the so-called "bimodal turnoff" discussed extensively by both Nissen (1988) and Anthony-Twarog et al. (1989). No credible explanation for a real feature of this type could be found.

Again, we have focused our CORAVEL "microscope" on the encircled stars in Figure 3. Although our 1989–1990 observations of NGC 3680 are much more complete than those of IC 4651, what we see is not quite as clear-cut as that in Figure 2. This is because the fraction of stars with broad lines and/or variable or slightly discrepant velocities is much larger. More data are needed to clearly separate the various categories of stars. We expect to obtain these during the 1991 observing season. However, several robust conclusions are already emerging:

First, about 2/3 (!) of the stars in Figure 3 appear not to be members of NGC 3680 at all. Also, binaries are rather frequent among both cluster and field stars. Then, when binaries are identified and field stars removed, the "bimodal turnoff" dissolves into a single sequence of stars. Interestingly, this sequence shows the shallow slope on the upper main sequence and the large vertical extent and redward curvature of the turnoff which distinguish the overshooting isochrone in Figure 1: Overshooting seems definitely present in NGC 3680 also.

Some Lessons

One lesson is immediately obvious: If significant conclusions on stellar models or cluster age depend on the correct interpretation of minor features of a cluster CM diagram, careful star-by-star identification of non-members and binaries is essential. The microscope may reveal that initial, and perhaps biased, impressions are in fact wrong.

Then, together with the binary evidence, the cluster data seem to show that convective overshooting does exist as an observable phenomenon in stars of these masses. Future stellar evolution models will have to take this into account. With their precise photometry and membership data, clusters such as IC 4651 and NGC 3680 will be very valuable in helping to calibrate the model parameters used in the convection prescription. We hope to extend this type of work to clusters of other ages, and subject new generations of stellar models to tests based on both binary and cluster data.

A third significant consequence of accepting the validity of overshooting models is that higher ages (~4 10^9 yr) are estimated for the stars in IC 4651 and NGC 3680 than with standard models, by almost a factor of two (cf. Fig. 1). This result appears to be typical for evolved main-sequence stars (cf. Table 1 in Andersen et al., 1990), and should be of some significance for models of the evolution of the Galactic thin disk population.

Why did Mazzei and Pigatto (1988) derive ages a factor of three *lower* from their overshooting models, when they considered their ages accurate to ~10 %? Their determination of reddening in the isochrone fit itself is a likely reason: Their values of E(B-V) are ~0.15 mag larger than those observed directly, maybe because the C-S opacities lead to their models being too hot. Overcorrecting for reddening by 0.15 mag will, of course, lead to significantly lower age estimates.

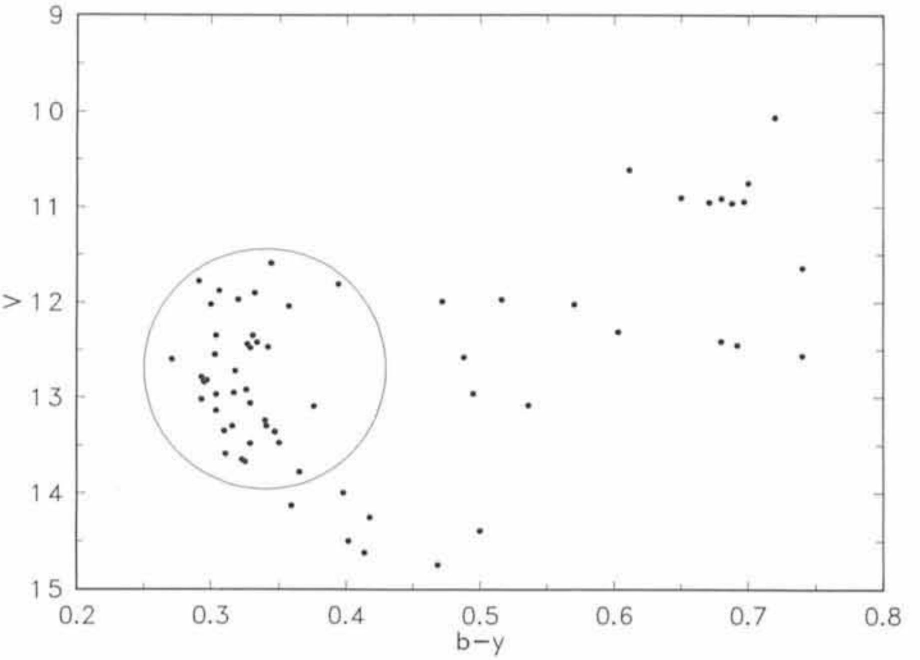

Figure 3: *CM diagram of NGC 3680 from Anthony-Twarog et al. (1989), Nissen (1988), and Eggen (1969, transformed to b-y). Note the apparent bimodality of the main sequence; CORAVEL data for the circled stars show this to be an artifact of binary and non-member contamination.*

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The Oldest Stars

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Introduction

Traditionally, young stars have been favourite objects for investigations of galactic structure and dynamics. Among the reasons for this preference, the generally high luminosity of hot stars has played a major role. As a result, our knowledge of the young population in the Galaxy is relatively advanced. The same is definitely not true for the oldest populations in the Galaxy. The major reason for our limited insights into the early generation of galactic stars is their low luminosities and generally incon-