AGES, AGE DIFFERENCES, MASSES OF STARS IN YOUNG OPEN CLUSTERS

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Abstract. An extensive amount of accurate uvby Hβ data has been obtained for stars in young open clusters. Age spread earlier found within the clusters has been confirmed. Many unevolved stars have been observed. The data for these stars are positioned below ZAMS curves in HR diagrams defined by the Strömgren indices. These unevolved stars form a confined lower envelope for all the stars a little below the "normal" ZAMS curves.

A large project of obtaining accurate Strömgren photometry (uvby-Hβ) of mainly B type stars in young open clusters (example NGC 457, 663, 1960, h+χ Per) has now been completed to the distinct stage, where it is possible to derive detailed quantitative knowledge about very young stars, i.e. relationships between observed parameters, and distributions of values of stellar parameters in young open clusters. (In each of the clusters several hundred stars have been observed). These new observations, 1981-83, confirm results obtained in 1977-78, (Jakobsen, Thesis 1980, P.A.S.P. 93, pp. 547, 1981), of a considerable age spread within young open clusters relative to the absolute age of the individual stars (10-100 million years).

The observed results for the individual stars were transformed to log Te, Δ Mbol, and log g values. Plots of these values for each of the example clusters NGC 457, 663, 1960 (data sample restricted as mentioned below), with Hejlesen's (1975-78) isochrones and evolutionary tracks overlaid, infer: an age, mass spread in each of the clusters from (6.5?) 7-8 in log age, 13-2.5 $M_\odot$ in mass. The masses for most stars in NGC 457:4-8 $M_\odot$, in NGC 663:5-8 $M_\odot$ in NGC 1960:2.5-5.5 $M_\odot$. This spread cannot be accounted for, by errors in observations or in the calibrations. Influence of rotation cannot be the reason either, according to a study (Jakobsen 1983) of ~ 2000 nearby B type stars with good uvby Hβ, MK, Vsini data. Unresolved binary stars can at the most effect the position of 5% of the stars in the diagrams, and will in some cases just minimize the age spread. Field star contamination is to a great extent avoided by considering distance, reddening, proper motion (pm) data. For these young clusters, the pm errors are large compared

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to the absolute pm values, hence the use of pm values alone for membership determination is limited. If radial velocities could be obtained for these stars, a more strict definition of the individual cluster or parts of the cluster might be possible. The age spread for a cluster can only be minimized slightly by e.g. varying the composition for the cluster as a whole or for the individual stars. Hence, we are left with a considerable age spread among the stars in the young open clusters.

However, the most striking and surprising result from this new large data sample, where an emphasis was made to observe many more fainter stars than observed before, was that a large amount of these stars were not less massive than the earlier observed brighter stars. Generally, these fainter stars have a mass of the same order as the brighter more evolved stars, but they are younger. Apparently they are so much younger that for a good part of these stars Δ Mbol turns negative, i.e. these stars are positioned below the ZAMS line. Usually, stars "below" the ZAMS curves in different diagrams have been accounted for as being influenced by observational errors, or being peculiar stars. In this case, due to the large samples, these stars cannot be accounted for as being peculiar, as it would lead to a question of what is normal and what is peculiar in an open cluster. Composite stars move the points in the opposite direction. As these data are very accurate and evenly distributed the observational or statistical errors were out of the question too (Jakobsen 1980).

To double check for systematical errors, the whole sample was reanalyzed. The presented sample consists only of data obtained with the 1 channel photometer at the KPNO No. 2, 36" telescope. The transmission curves for the filter set (uvby Hβ) are very close to the original Strömgren filters, the center of mass wavelength of the Hβ filters are very close to prevent reddening effects. Typically, 50 standards were observed per night, well covering spectral, luminosity, reddening range of the program stars. The residuals for the standard stars were $\lesssim 0.003$ mag. Likewise, the agreement between the frequent observations of reference stars within the open clusters was excellent. There is no indication that anything due to observation or reduction could lead to data points systematically "low" in relation to ZAMS curves.

The evolutionary tracks and isochrones of Becker (1983) have been compared in detail to those of Hejlesen (1975-79). There exist some differences, but these are small compared to the questions at this stage. For given (log Te, log g, composition) the age, mass are approximately the same in the two models, as well as is the ZAMS boundary. The apparent problem does then exist in the stage from converting the observed indices to e.g. atmospheric parameters, log Te, log g. The main problem is in establishing the absolute scale, not the relative scale, for particularly the parameters: log g, Mbol, Δ Mbol; and in the definition of the ZAMS curves. Log g or Mbol, Δ Mbol are highly correlated with β, and for fixed lum. class, log Te is highly correlated with $[c_1]$, c_0 or $[u-b]$.

Therefore plots like ($[c_1]$ or $[u-b]$, β) were made, which did not involve any assumption of established ZAMS curves. Using the restricted sample of observations from NGC 457, 663, 1960 makes it possible to cover the whole B type range very well concerning "unevolved" stars, compared to the earlier samples of ~ 2000 B type stars in the field and the brighter stars in open clusters, used by Crawford, Olsen, Strömgren (C.,O.,S.) for establishing ZAMS curves. For a single cluster the data points are rather evenly distributed around these ZAMS curves. NGC 1960 does not contain as many massive stars as in NGC 457, 663, but as it is closer, the observations contain many well observed unevolved late B type (including A0-2) to A-type stars. The reddening is rather constant in NGC 1960 too. Therefore determination of a lower envelope (also in the (β, M_V) diagram) for the late B type stars is now possible by using these new NGC 1960 data. According to Strömgren (1983), the sparseness of unevolved late B type stars has so far created problems in establishing e.g. accurate ΔMbol calibrations. Relatively, NGC 1960 does only contain few unevolved early B type stars, this range seems, though, to be plentily covered by unevolved stars in NGC 457, 663. The total area of rather evenly distributed points has a distinct lower envelope, which is positioned in average ~ 0.2 mag in β below (i.e. higher β values) the ZAMS curves of C.,O.,S. The latter ZAMS curves differ slightly, mostly around B7 with ~ 0.01 mag. (0.02 mag in β is roughly comparable to 0.5 mag in M_V or 0.25 in log g.)

Moving the ZAMS curves to the new envelopes determined by these newly observed stars in the involved calibrations, for obtaining ages, masses for the stars, will not minimize, but enhance the age spreads within the clusters, even if these unevolved stars were omitted from the age spread considerations within the clusters.

So far, calibrations for B type stars including ZAMS curves have mainly been based on field stars and the brighter parts of young clusters. These clusters are relatively far away, so it has mainly been the apparent brightest part of stars in these clusters, which has been observed and thereby formed the basis for the calibrations. By this natural selection of stars down to a limiting magnitude, or that the observed part of the total number of stars with a certain magnitude is decreasing with magnitude, it is possible that it is slightly evolved stars, which have determined ZAMS. Concerning the use of field stars as a basis, it is also plausible that they are not as unevolved as the unevolved stars in the open clusters.

This new extensive and accurate sample of data for stars in young open clusters looks very promising as a basis for dealing with the above mentioned problems. An evaluation is being made of the results from all the observed clusters. This is a description of work in progress and any comments or suggestions are highly appreciated.

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DISCUSSION

Frogel: Please comment on 1) field star contribution to your C-M diagram, 2) contamination in your aperture from faint companion stars.

Jakobsen: 1) Field star contribution is to a great extent avoided by considering distance, reddening, proper motion data. However, radial velocities would be very helpful.

2) The data shown are all obtained on nights with very good seeing, and use of a small aperture. The used finding charts were enlargements from Palomar plates, where stars 5 mag fainter than the observed ones were easily visible, so appropriate precautions could be taken. If there was any doubt about such a contamination, then the validity of the measurements was decided on from several observations with different centering, or e.g. by moving the star gradually out of the aperture.