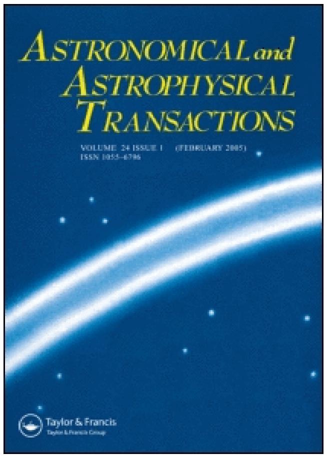

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Two open clusters: Twins with different histories

B. Nordström [ab]; J. Andersen [a]
[a] Astronomical Observatory; Niels Bohr Institute for Astronomy, Physics and Geophysics; University of Copenhagen, Copenhagen, Denmark
[b] Lund Observatory, Lund, Sweden

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TWO OPEN CLUSTERS: TWINS WITH DIFFERENT HISTORIES

B. NORDSTRÖM[1,2] and J. ANDERSEN[1]

[1] *Astronomical Observatory; Niels Bohr Institute for Astronomy, Physics and Geophysics; University of Copenhagen; Juliane Maries Vej 30, DK - 2100 Copenhagen, Denmark*
[2] *Lund Observatory, Box 43, S - 221 00 Lund, Sweden*

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Recent accurate wide-field photometry and radial-velocity studies of the open clusters NGC 3680 and IC 4651 show them to be of identical age ($\sim$ 1.5 Gyr) and metallicity. Their present spatial structure and mass functions show that they have, nevertheless, undergone very different degrees of dynamical evolution: while IC 4651 shows a fully populated main sequence to at least six magnitudes below the turnoff and only weak signs of mass segregation, NGC 3680 is essentially just a surviving cold core of stars in a very narrow mass range, the initial cluster being perhaps a hundred times more massive than now. These twin clusters thus highlight the importance of environmental factors upon the evolution of the stellar population of open clusters.

KEY WORDS Open clusters – stellar evolution – stellar dynamics

1 INTRODUCTION

Star clusters are classic research subjects, useful in a wide range of stellar and galactic astrophysics. Studies of stellar evolutionary tracks or of the age, chemical and spatial structure of the Milky Way disk are typical examples involving open clusters (see also the excellent review by Friel, 1995).

In the idealized case, the cluster we now observe is well-defined and unchanged since its formation. However, not only do real stars evolve themselves, but the structure and stellar population of the entire cluster also evolve with time due to dynamical interactions between the cluster stars and with the external Galactic tidal field. The extent of these changes depends on parameters such as the richness, compactness, and age of the cluster; on the initial mass function (IMF); on the properties of its binary population; and on the environment to which its orbit in the Galaxy has exposed it, in particular any close passages of giant molecular clouds or other massive objects.

Studying human twins is an established method to separate intrinsic and environmental factors in human development. Here we similarly study a pair of 'twin clusters', of the same age, chemical composition, and possibly also mass, but very different in their present structure, no doubt due to the different environments and dynamical interactions they have experienced since their birth.

2 THE TWIN CLUSTERS NGC 3680 AND IC 4651

NGC 3680 and IC 4651 are southern open clusters of nearly identical age (1.5 Gyr), metallicity (similar to the Hyades), and distance ($\sim$ 1.1 kpc), as derived from recent wide-field CCD photometry in the Strömgren *uvby* system for both NGC 3680 (Nordström *et al.*, 1997) and IC 4651 (Meibom, 2000). Multi-epoch radial velocities have been obtained to a limit of $V \sim 14.5$ and show that both clusters also have a similar, fairly high incidence ($\sim$ 55%) of spectroscopic binaries on the upper main sequence. Proper motions exist for NGC 3680 (Kozhurina-Platais *et al.*, 1995), but not for IC 4651. Metallicity and reddening for both clusters were determined by Nissen (1988).

Multiple radial velocities and proper motions enable us to compute cluster membership probabilities and identify spectroscopic binaries on a rigorous mathematical basis for the brighter stars in both clusters. For the fainter stars, one must rely on the colour-magnitude diagram (CMD) alone. Here, both the choice of photometric passbands and the field covered are crucial in defining the lower main sequence; cf. the comparison by Meibom (2000) of the $(v - y) - V$ CMD with the traditional, but far less clear-cut $(b - y) - V$ diagram. Note also that both clusters had been reported to lack stars on the lower main sequence, but including the outer regions of IC 4651 in the photometry nevertheless uncovered a long stretch of the lower main sequence, extending at least six magnitudes below the turnoff. It also revealed that the cluster is in fact twice as large and rich as previously thought, reducing our radial-velocity coverage to only half of the originally intended 100%.

From the complete dataset, the overall stellar content and present-day mass function as well as the spatial distribution of selected subpopulations of both clusters can be determined. They turn out to be strikingly different: NGC 3680 currently consists of about 70 stars, counting all binary components, with a total mass of $\sim 100M_\odot$. Its mass function is restricted to the narrow interval 1.4–2.0$M_\odot$ with only one single star and a few binary components below this range, and the binaries are clearly more strongly concentrated towards the centre than the single stars. In contrast, the present IC 4651 contains some 600–700 stars with a total mass of $\sim 700M_\odot$. No difference in spatial distribution is seen between single or binary stars on the upper main sequence, or between main-sequence stars and giants, but the numerous low-mass main-sequence stars are preferentially found in the outer, newly discovered regions of the cluster.

On the assumption that the samples of the most massive stars in each cluster (1.8–2.0$M_\odot$) are undepleted by the dynamical removal of outlying stars, the total initial mass of each cluster can be estimated by fitting an IMF to the uppermost bin in their mass functions. One then finds that NGC 3680 originally consisted of $\sim$2500 stars of total mass $\sim 1000M_\odot$; only $\sim$ 3% of the initial stars and $\sim$ 10% of the mass now remain. For IC 4651, the corresponding numbers are perhaps ~ 7000 stars and $\sim 4000 M_\odot$, of which now $\sim 10\%$ and $\sim 17\%$ remain. Since the formation of NGC 3680 and IC 4651, their more massive stars have been removed from the CMD because of their internal evolution, while the lower-mass stars have been lost from the clusters and dispersed into the field as also predicted by theoretical models (Terlevich, 1987; de la Fuente Marcos, 1997).

Taken at face value, these results imply that one 'twin' – IC 4651 – was some four times more massive at birth than the other, NGC 3680. However, models suggest that dynamical interactions strong enough to strip NGC 3680 of its entire population of low-mass stars could not have left the upper main sequence unaffected, as assumed in the calculation above. The present NGC 3680 then appears to be basically the surviving cold core of an initially much more massive, but now almost fully evaporated cluster. Hence, it is likely that the initial mass of NGC 3680 exceeded our estimate of $\sim 1000 M_\odot$ by an appreciable, if unknown factor, so that the two clusters were indeed quite closely twins at birth.

3 WHICH ENVIRONMENTAL HISTORIES?

In summary, NGC 3680 and IC 4651 appear to have been born at the same time from matter of similar composition and have lived parallel lives in the Galactic disk. The far more advanced dynamical evolution of NGC 3680 would then be due to its passing through more 'dangerous' regions of the disk than IC 4651. This finding is contrary to expectation, however, because IC 4651 is ~ 1 kpc closer to the Galactic centre than NGC 3680 (and the Sun), i.e. close to the inner boundary of the distribution of present-day clusters of similar age (cf. Fig. 1 of Friel (1995). Moreover, IC 4651 is currently moving *outward* in the disk and is also situated at lower Galactic latitude than NGC 3680. It would thus be expected to have suffered, on average, stronger effects of the tidal field in the inner, denser part of the Galactic disk than NGC 3680, which essentially quietly precedes the Sun on the same circular orbit. A close recent encounter of NGC 3680 with a giant molecular cloud might explain why the opposite is observed, but remains hypothetical at present. Further detailed, comparative studies of the surroundings of both clusters and of their immediate past history should yield additional clues to an understanding of their dynamical history.

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