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OPEN CLUSTERS AND OB ASSOCIATIONS: A REVIEW

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RESUMEN

En esta revisión sobre cúmulos y asociaciones discutiré algunas desarollos recienes con contribuciones Latino-Americanas. A continuacion se presentará algunos de los resultados de la misión Hipparcos referentes a asociaciones OB, las Hiadas y otros cumulos abiertos cercanos. Al final discutiré brevemente teorías actuales sobre formación de cúmulos estelares y los prospectos para futuras investigaciones.

ABSTRACT

In this review on open clusters and OB associations I discuss some recent developments to which Latin American astronomers have contributed. Subsequently, results from the Hipparcos mission concerning OB associations, the Hyades and other nearby open clusters will be discussed. I end with a brief discussion of current theories of star cluster formation and prospects for future research.

Key Words: **OPEN CLUSTERS AND ASSOCIATIONS: GENERAL**

1. INTRODUCTION

The study of open clusters and OB associations in our Galaxy is related to several important questions in research on Galactic structure and evolution. The study of young embedded clusters and OB associations will lead to insights in the process of star formation, providing, for example, answers to questions about the initial mass function (IMF) and the origins of the binary population. The study of older open clusters is important for testing models of stellar evolution, understanding the process of cluster dissolution, as well as providing insight into the chemical evolution of the Galaxy. Detailed knowledge of the stellar content of clusters and associations will also lead to insights into the origin of the various Galactic stellar populations. Finally, studies of Galactic clusters and associations are also relevant in the context of extragalactic astronomy. Detailed knowledge of OB associations will aid in the understanding of starburst galaxies and the population of young galaxies in the early universe. The study of the older open clusters has always been of central importance in establishing the Galactic and extragalactic distance scales.

Historically, OB associations have been identified as loose groupings of O and B stars on the sky, such as in the direction of the Orion and Scorpio-Centaurus constellations. However, as we shall see below, OB associations also contain low-mass stars and are formed with a normal initial mass function. Open clusters are traditionally identified with much more concentrated groups of stars on the sky, although the Hyades open cluster forms a notable exception. The question of accurately defining what one means by an open cluster or OB association is not entirely trivial as discussed by, e.g., Brown et al. (1999b), but for the purpose of this review we shall make the simple distinction that gravitationally bound stellar clusters are to be identified with open clusters, and their unbound counterparts with OB associations.

In view of the limited space I have chosen not to review all the extant knowledge on open clusters and OB associations. Rather, I shall confine myself to discussing some recent developments in this field (including contributions from Latin American astronomers) which I think are important. The review is by no means intended to be complete and my personal biases will certainly be reflected in the contents. Reviews discussing OB associations in detail include those by Blaauw (1964, 1991), Brown et al. (1999a, 1999b), Garmany (1994), and

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Massey (1998). A recent review of (old) open clusters can be found in Friel (1995) and conference proceedings containing discussions on both open clusters and OB associations include: Janes (1991), Tenorio-Tagle et al. (1992), Milone & Mermilliod (1996), and McCaughrean & Burkert (1999). A recent summary of theoretical ideas on how star clusters form can be found in Clarke (1998) and Bonnell (1999).

2. RECENT DEVELOPMENTS

In this section some recent developments in the literature to which Latin American astronomers have contributed are discussed. The variety of topics is also meant to serve as an illustration of the relevance of studies of open clusters and OB associations to other fields.

2.1. *A Gradient or Discontinuity in the Galactic Disk Metal Abundances?*

Open clusters are valuable probes of the structure and evolution of the Galactic disk. The main advantage in using open clusters is the more accurate determination of their distances, metallicities and ages due to the sample of cluster stars sharing these properties. Moreover, the Galactic orbits of open clusters are more stable than those of individual stars. Hence, one may expect that, e.g., possible metallicity gradients in the Galactic disk are better preserved in the open cluster record.

In a recent paper Piatti et al. (1995) used an improved calibration of abundances derived from DDO photometry to study a sample of 63 open clusters with a wide range of ages. They performed a least-squares fit of the abundances simultaneously as a function of Galactocentric distance, R, distance to the Galactic plane, Z, and age. They find no age-metallicity relation but they do infer a radial abundance gradient of -0.07 dex kpc^{-1}, and a vertical gradient of -0.34 dex kpc^{-1}. The latter result is controversial although evidence for a vertical metallicity gradient has been found in the past (see references in Piatti et al.).

In order to understand this result Twarog et al. (1997) re-analysed the cluster sample of Piatti et al. (1995), supplemented with a sample of clusters from Friel & Janes (1993). They arrived at an equally surprising conclusion concerning the abundance distribution in the Galactic disk as traced by open clusters. Twarog et al. present evidence that there is in fact a discontinuity in the metallicities in the disk instead of a smooth gradient. Their Figure 3 can be interpreted as showing two groups of open clusters. One group lying within 10 kpc from the Galactic centre with abundances around ~ 0 dex, and another group of clusters at distances larger than 10 kpc which are on average ~ 0.3 dex more metal-poor. In neither of the groups can a metallicity gradient be seen. Twarog et al. (1997) also show that the vertical gradient found by Piatti et al. (1995) is in fact due to the clusters which lie beyond $R = 10$ kpc. These clusters are predominantly older and located at higher Z than clusters lying within 10 kpc from the Galactic centre. The latter are mostly located close ($\lesssim 200$ pc) to the Galactic plane. Hence, if one corrects for the metallicity difference between the two groups the vertical abundance gradient found by Piatti et al. (1995) is no longer evident.

Observational results like these are very important as constraints for models of the formation and (chemical) evolution of the Galaxy (see e.g. the contribution by Chiappini et al. 2001 in this volume). However, the open cluster samples under study, as noted by Twarog et al. (1997), are neither random nor complete. Not all clusters of all ages are included at every Galactocentric distance. Ideally one would like a complete sample of open clusters for which one has accurate indications of membership, distance, space motions, metallicities, and ages. Such a sample will become available in the future from the results of planned space astrometry missions (see § 5).

2.2. *Low Mass Stars in OB Associations*

Historically the study of OB associations has been concentrated primarily on the study of their high-mass (spectral type O and B) members. However, extrapolating the mass function for OB stars, such as derived for Sco OB2 (de Geus 1992), reveals that the bulk of the stars should be of low mass ($\lesssim 2\ M_{\odot}$). Indeed, evidence was found early on for the presence of low-mass stars in the vicinity of the Orion Nebula (e.g., Haro 1953). Unfortunately, large-scale proper motion searches for these fainter members of OB associations suffer from a much larger contamination by field stars, making it hard to identify the members without additional information. Hence, other techniques are employed in the search for low-mass members of OB associations.

The two most widely used are objective prism Hα surveys, which are sensitive to classical T-Tauri stars, and X-ray surveys, also sensitive to weak-line T-Tauri stars.

An *EINSTEIN* observatory X-ray search was used to look for the low-mass population of the Upper Scopius subgroup of Sco OB2 (Walter et al. 1994). After correcting for the incompleteness of the X-ray sampling, it was concluded that the association has a field star mass function between about 0.2 and 10 $M_{\odot}$. The total number of low-mass stars ($< 2\ M_{\odot}$) is about 2000, which is in good agreement with the number of low-mass stars inferred by de Geus (1992). Recent X-ray studies, based on the *ROSAT* all-sky survey (Preibisch et al. 1998, Sciortino et al. 1998) reveal the presence of many more X-ray selected pre-main sequence (PMS) candidates throughout Sco OB2. Preibisch et al. (1998) performed spectroscopic follow-up observations to confirm the PMS character of the X-ray selected sources and also looked for PMS stars among objects without X-ray detections but with proper motions suggesting that they might be members of Sco OB2. No PMS stars were found among these proper motion selected candidates and these authors conclude that the X-ray selected sample of PMS stars is at least 75 per cent complete. However, Sciortino et al. (1998), using *ROSAT* HRI, PSPC and all-sky survey observations, showed that the observations by Walter et al. (1994) were much more incomplete than reported. They concluded that *EINSTEIN* and *ROSAT* data are far from giving a complete characterization of the X-ray population of US, implying the presence of even more PMS stars in Sco OB2.

In Ori OB1 the Kiso Hα survey (Nakano et al. 1995), and the *EINSTEIN* (Walter et al. 1998) and *ROSAT* (Alcalá et al. 1996) X-ray surveys have uncovered hundreds of emission-line and X-ray sources of which many are likely to be PMS or T-Tauri stars. Spectroscopic follow-up observations indeed confirmed the PMS nature of many of these stars (e.g., Alcalá et al. 1996) However, it was shown by Alcalá et al. (1998) that the population of X-ray sources towards Orion consists of a mixture of true Orion PMS stars and young foreground stars. The latter may be related to Gould's Belt or may be $\sim 10^8$ year old stars.

Recent studies have revealed a significant population of low-mass PMS stars in the region of subgroup 1b of Ori OB1 (Walter et al. 1998). The stars appear to cluster spatially around σ Ori and the narrowness of their PMS locus suggests coevality, at the 2 Myr age of Ori OB1b (cf. Brown et al. 1994). The total inferred mass of this group of stars is comparable to that of the Orion Nebula Cluster. In fact the σ Orionis cluster may be an older analogue of the Trapezium cluster. This result illustrates the difficulty in defining subgroup boundaries in associations. It may be that subgroup 1b actually consists of a 'merger' of several Trapezium-like clusters. Most recently, the detection of brown dwarf candidates around σ Ori has been reported. I refer to Walter et al. (2000) for the details and more material on low-mass stars in OB associations.

2.3. *Chemical Evolution in Orion OB1*

The interstellar medium in the Galaxy is continually enriched in chemical elements by stellar winds and by ejecta from supernovae. OB associations are generally located near molecular clouds and thus are ideal sites for studying ongoing chemical evolution processes in the Milky Way. Abundance patterns of stars in Ori OB1 have been studied by Cunha et al. (1992, 1994, 1998). The abundance analysis shows that the stars in Ori OB1, in common with the Orion Nebula H II region, are underabundant in Oxygen with respect to the Sun. The lowest abundances are found in subgroups 1a and 1b. The Trapezium stars and some stars of subgroup 1c seem to have O abundances that are up to 40 per cent higher than those in subgroups 1a and 1b (although still subsolar). It is suggested that this is due to enrichment of the interstellar gas by mixing of supernovae ejecta from subgroup 1c with the gas that subsequently collapsed to form the Trapezium Cluster (Cunha & Lambert 1992). This enrichment scenario is confirmed by Cunha & Lambert (1994) who observe no abundance variations for C, N, and Fe, but do observe the same variations for Si as for O, as one would predict for cloud material enriched by Type II supernova ejecta. Supernovae must have occurred in Ori OB1 given the Orion–Eridanus bubble. It is estimated that 1 to 2 supernovae occurred in subgroup 1c (Brown et al. 1994).

3. HIPPARCOS RESULTS

In this section I describe results on open clusters and OB associations obtained from the analysis of data from ESA's Hipparcos astrometry satellite (ESA 1997). In particular I will summarise the results described in Perryman et al. (1998) and de Zeeuw et al. (1999) on the Hyades and the nearby OB associations, respectively. A brief discussion on the controversy surrounding the Hipparcos distance to the Pleiades is also included.

3.1. *The Hyades*

The *Hipparcos* positions, proper motions and parallaxes for the Hyades cluster stars were extensively analysed by Perryman et al. (1998). The astrometric data together provide a consistent picture of the Hyades distance, structure and dynamics. The combination of the *Hipparcos* astrometry with radial velocity measurements from ground-based programmes provides three-dimensional velocities which allowed Perryman et al. to carry out candidate membership selection based on 3-dimensional positional and kinematical criteria. A number of new cluster members have been found within 20 pc of the cluster centre. No evidence for systematic internal velocity structure was found; rather, the results were shown to be fully consistent with a uniform cluster space motion with an internal velocity dispersion of about 0.3 km s^{-1}. Spatial distribution, mass segregation, and binary distributions were found to be consistent with N-body simulations.

Outside the tidal radius ($\sim$ 10 pc, Perryman et al. 1998) the stellar distribution was determined to be elongated along the direction of the Galactic centre and anti-centre, and slightly flattened in the direction perpendicular to the Galactic plane. Inside this sphere, the cluster has spherical symmetry with a core radius of $r_c \simeq 2.7$ pc, and a half-mass radius of $\sim$ 6 pc. The presence of objects closely linked kinematically with the cluster core, but well beyond the tidal radius, probably originates from dynamical interactions in the centre combined with diffusion beyond the Lagrangian points.

The quality of the individual distance determinations allowed Perryman et al. to accurately model the cluster zero-age main sequence. The helium abundance was determined to be $Y = 0.26 \pm 0.02$ which, combined with isochrone modelling including convective overshooting, yields a cluster age of 625 ± 50 Myr. While the importance of the *Hipparcos* results is to provide individual distances to cluster members, rather than a mean cluster centre of mass (a concept meaningful only in the restricted context of the cluster members contained in the *Hipparcos* Catalogue), the estimated distance to the observed centre of mass for the objects within 10 pc of the cluster centre is 46.34 ± 0.27 pc, corresponding to a distance modulus $m - M = 3.33 \pm 0.01$ mag. This mean distance is only marginally modified (by about 0.4 pc) for the derived centre of mass for *Hipparcos* objects within $r < 20$ pc of the cluster centre. A possible bias in the cluster distance due to the Lutz-Kelker effect was found to be small and of the same size as the error in the mean distance.

3.2. *The Nearby OB Associations*

A comprehensive census of the stellar content of the OB associations within 1 kpc from the Sun was carried out by de Zeeuw et al. (1999), based on *Hipparcos* positions, proper motions, and parallaxes. The study forms a key part of a long-term project to study the formation, structure, and evolution of nearby young stellar groups and related star-forming regions.

OB associations are unbound 'moving groups', which can be detected kinematically because of their small internal velocity dispersion. The nearby associations have a large extent on the sky, which traditionally has limited astrometric membership determination to bright stars ($V \lesssim 6^{m}$), with spectral types earlier than ~B5. The *Hipparcos* measurements allowed a major improvement in this situation. De Zeeuw et al. (1999) identified moving groups in the *Hipparcos* Catalogue by combining a refurbished convergent point method (de Bruijne 1999) with the 'Spaghetti method' of Hoogerwerf & Aguilar (1999). Astrometric members were listed for 12 young stellar groups, out to a distance of ~650 pc. These are the 3 subgroups Upper Scorpius, Upper Centaurus Lupus and Lower Centaurus Crux of Sco OB2, as well as Vel OB2, Tr 10, Col 121, Per OB2, α Persei (Per OB3), Cas–Tau, Lac OB1, Cep OB2, and a new group in Cepheus, designated as Cep OB6. The selection procedure corrected the list of previously known astrometric and photometric B- and A-type members in these groups, and identified many new members, including a significant number of F stars, as well as evolved stars, e.g., the Wolf–Rayet stars γ^2 Vel (WR11) in Vel OB2 and EZ CMa (WR6) in Col 121, and the classical Cepheid δ Cep in Cep OB6. In the nearest associations, notably in Sco OB2, the later-type members include T Tauri objects and other stars in the final pre-main sequence phase. This provides a firm link between the classical high-mass stellar content and the low-mass members discussed in § 2.2.

Astrometric evidence for moving groups in R CrA, CMa OB1, Mon OB1, Ori OB1, Cam OB1, Cep OB3, Cep OB4, Cyg OB4, Cyg OB7, and Sct OB2, was found to be inconclusive. OB associations do exist in many of these regions, but they are either beyond ~500 pc where the *Hipparcos* parallaxes are of limited use, or have unfavourable kinematics, so that the group proper motion does not distinguish from field stars in the disk.

The mean distances of well-established groups were found to be systematically smaller than pre-*Hipparcos* photometric estimates. While this may partly be caused by the improved membership lists, a recalibration of the upper main sequence in the Hertzsprung–Russell diagram may be called for. Finally, the positions with respect to the Sun and the mean motions of these groups are now much more accurately determined and will allow for a substantial improvement in the characterisation and understanding of Gould's Belt.

3.3. *The Pleiades Controversy*

One of the surprising results to come out of the *Hipparcos* data was the distance to the Pleiades cluster based on the parallaxes of its members. Early reports by van Leeuwen & Hansen–Ruiz (1997) and Mermilliod et al. (1997) mentioned a parallax of 8.6 milli-arcsecond (mas) corresponding to 116 pc; in apparent contradiction to the "standard" value of 132 pc (see e.g., Pinsonneault et al. 1998). A somewhat more refined analysis of the *Hipparcos* data led to Pleiades cluster parallaxes of 8.45 ± 0.25 mas (van Leeuwen 1999) and 8.46 ± 0.22 mas (Robichon et al. 1999), corresponding to a distance of 118^{+4}_{-3} pc, and thus still quite a bit smaller than 132 pc. Note that the Pleiades is not the only cluster for which there is a discrepancy between the *Hipparcos* distance and the traditional value thereof. However, the discrepancy for this well-studied cluster seems the most serious.

If true, the *Hipparcos* result implies problems with the main-sequence fitting method, traditionally used to determine the Pleiades distance. This prompted Pinsonneault et al. (1998) to scrutinise both the main-sequence fitting method and the *Hipparcos* data. Relying exclusively on the Yale stellar evolution code, they investigated both the internal errors of the main-sequence fitting method (such as the transformation between the theoretical and observational HR-diagrams and the sensitivity to metallicity variations) as well as observational effects (e.g., stellar activity in young clusters, abundance scale, reddening, systematic errors in photometry) and conclude that the discrepancy between the *Hipparcos* and main-sequence fitting distances to the Pleiades is much too large to be explained as due to errors in the main-sequence fitting method. Instead they propose that at least in the area on the sky close to the Pleiades cluster centre there are systematic errors in the *Hipparcos* parallaxes at the ~ 1 mas level. Pinsonneault et al. (1998) ascribe the cause of these systematic errors to the asymmetric distribution of the *Hipparcos* observations over the parallax ellipse of the Pleiades members.

In essence the *Hipparcos* parallaxes are globally (that is all over the sky) free from systematic errors above the 0.1 mas level (see chapters 20 and 21 of Volume 3 of the *Hipparcos* and Tycho Catalogues, ESA 1997). However, in the case of clusters where the stellar densities are higher systematic errors may arise due to the closely correlated observations of the stars in the same cluster. Robichon et al. (1999) therefore re-examined the *Hipparcos* distances of open clusters located at more than 500 pc, for which the problem of correlated observations should be most severe. A comparison of *Hipparcos* parallaxes with in this case much better determined photometric parallaxes reveals no systematic errors in the astrometric data. Focusing on the nearest clusters, Robichon et al. point out that in fact no systematic trends can be seen in the differences between *Hipparcos* distances and several main-sequence fitting distances. In fact, the differences between any *Hipparcos* distance and main-sequence fitting distance are of the order of 0.2 magnitudes, of the same order as between any two main-sequence fitting distances. This suggests that the errors of the main-sequence fitting method have been underestimated. It is worth pointing out here that Pinsonneault et al. (1998) mainly addressed the internal errors of a specific set of stellar structure models.

Investigating in more detail the case of the Pleiades, Robichon et al. (1999) show that the suggestion by Pinsonneault et al. (1998) for the cause of possible systematic errors in the *Hipparcos* parallaxes is not correct. Furthermore, they find no other possible causes for systematic errors to be present in the *Hipparcos* parallaxes for the Pleiades stars. Interestingly, they also show that the outcome of several studies on the Pleiades depend rather sensitively on the exact sample of Pleiades members used (especially samples from the cluster centre vs. the outer parts, cf. Narayanan & Gould 1999). This suggests that the structure and/or kinematics of the Pleiades cluster may not be as regular as expected, thus invalidating some of the assumptions that enter into various methods for estimating the cluster distance.

Clearly this issue is not yet resolved. However, the fundamental value of precise astrometric data has been clearly demonstrated by forcing a careful re-examination of what we thought we knew about open clusters and the main-sequence fitting method. My own assesment is that although systematic errors in the *Hipparcos* parallaxes in the specific case of the Pleiades have not been convincingly ruled out, a more extensive consideration of the external errors on main-sequence fitting is necessary. This includes among others a comparison of results from different (i.e., independently developed) sets of stellar models, evaluating the external errors on the metallicity scale, the effects of Helium abundance variations, and the errors introduced by using inhomogeneous photometry. A settling of the issue will have to await future high-precision astrometric missions (cf. § 5).

4. ON THE FORMATION OF STELLAR CLUSTERS

From observations of star forming regions we know that most stars form in multiple systems ranging from binaries to clusters. Hence, one of the most important reasons for studying stellar clusters is that one can learn more about the dominant mode of star formation. I will not go into the extensive observational material on young clusters but instead I will discuss recent theoretical progress that has been made on how star clusters form. The observational material is reviewed in, e.g., Lada et al. (1993) and Zinnecker et al. (1993).

A number of observations that theories of cluster formation need to explain are: The evidence for mass and age segregation in very young clusters (where the mass-segregation cannot be explained by dynamical relaxation, see e.g., Hillenbrand 1997), the initial mass function, the variations of binary frequency as a function of star formation environment, and the distinction between the formation of bound open clusters and unbound OB associations. Currently there are no theories that can explain how large numbers of stars can form in a mutually bound environment. This is due both to a lack of knowledge on the initial conditions for cluster formation and to the difficulties of fragmenting a star-forming cloud into the required number of fragments (cf. Bonnell 1999).

However, the issue of cloud fragmentation and subsequent cluster formation is now being explored through numerical simulations. Starting from a cloud with large-scale structures already in place, Klessen et al. (1998) have recently showed that its collapse leads to filamentary structures which fragment into a significant number of stars. These stars then fall together to form a cluster. The evolution of the cluster once the stars have formed but before the destruction of the parental molecular cloud has been investigated by Bonnell et al. (1997). They investigated the effects of dynamical interactions between the stars in the cluster and the ongoing accretion of gas. Essentially what they found is that stars that spend more time near the centre of the cluster accrete more mass compared to stars spending more time in the outer parts of the cluster. This is due to the higher gas densities at the centre, which are caused by the fact that most of the gas will sink to the centre of the cluster, where the deepest part of the potential well is. Moreover, gas is efficiently transported to the centre of the cluster thus replenishing the accreted gas. This process of so-called "competitive accretion" leads both to a mass spectrum among the stars in the cluster and to a mass-segregated cluster, the most massive stars being formed at the centre. These dynamical processes occurring in forming clusters may also explain how one can form very massive ($> 10\ M_\odot$) stars. It is well known that forming such massive stars is very difficult because their radiation pressure will reverse the infall-process once the central star reaches ~ 10 Solar masses. However in the very dense environment of the core of cluster in the process of forming, stellar collisions between intermediate mass stars (between about 2 and 10 Solar masses) may lead to the formation of massive ($\gtrsim 50\ M_\odot$) stars (Bonnell et al. 1998). This would explain why these massive stars are found near the centres of young stellar clusters and would naturally lead to age-segregation within the cluster.

An alternative theory for the formation of star clusters has been put forward by Elmegreen (1999). In this theory stars are formed through random selection of cloud pieces in clouds which have a self-similar hierarchical structure (e.g., fractals). The selection probability is assumed to be proportional to the square root of the density, with a lower mass cut-off included, due to the lack of self-gravity for low-mass gas clumps. This model does not specify how stars form from the gas. It is assumed that the mixture of different processes through which stars form is the same everywhere on average if sufficient numbers of stars are formed. The model thus provides a mathematical way to describe the average outcome of the star formation process. Elmegreen (1999) shows that with this model one can explain the observations of the IMF in open clusters and OB associations as statistical fluctuations around a universal (Salpeter) IMF. The fluctuations are due to the generally small numbers of stars used to determine the IMF. The model is also able to explain the tendency for massive stars to form closer to the centre as well as later in time. The fundamental difference between this model and others is that it starts from a highly structured cloud in which small-scale structures need to coalesce in order to form stars, whereas other models start from more uniform initial conditions and then address the question of getting a cloud to fragment into self-gravitating clumps from which cluster stars form. It is obviously of great interest to try and ascertain which model for cluster formation is the correct one. Constraints on such models must come from detailed observations. The next section discusses some of the future prospects for obtaining these.

5. FUTURE PROSPECTS

Several open problems relating to (the formation) of open clusters and OB associations have been discussed in the previous sections. Essentially in all cases significant progress can be made by characterising in detail the internal structure of stellar clusters. In the case of the Hyades the *Hipparcos* data already provide detailed data on its internal structure (§ 3.1).

Naturally, the models for the formation of stellar clusters can be further constrained by confirming and extending the observations of mass/age segregation in clusters. However, another important observational constraint comes from the detailed characteristics of the binary population as a function of position in the cluster. In both models discussed in § 4 one may expect in the denser central regions where massive stars form that the dynamical interactions will more easily lead to disruption of binaries. Hence there will be less binaries in the central regions of clusters as well as a bias towards close binaries among systems with massive primaries. Conversely the outer, less dense, regions of the cluster should contain more wide binaries. The model proposed by Elmegreen (1999) can be further tested by determining the IMF in many (young) clusters. If their slopes vary much more than is expected statistically this would falsify his model.

Detailed knowledge on the internal structure of the Pleiades and other clusters would shed much light on the problem of determining their distances. On the other hand settling the issue discussed in § 2.1 would additionally require precise knowledge of cluster positions and orbits.

A number of these observational problems can be solved already. For example, the characterization of the binary population in young clusters can be greatly enhanced by exploiting the *Hipparcos* data in combination with ground-based surveys for binaries. However, in order to carry out the observational programme above for large samples of open clusters and OB associations what is ideally needed is a large and precise astrometric survey in combination with radial velocity and photometric surveys. Astrometric data in combination with radial velocities are necessary to establish membership in stellar clusters and to determine their orbits. The photometric data can then be used to derive physical parameters (such as masses and ages) for the stars. The astrometric and radial velocity data will also provide information on the binary population in clusters.

Currently several space astrometry missions aiming at a 10 micro-arcsecond, or better, level of precision are proposed or being developed. The most advanced of these projects is NASA's Space Interferometry Mission (SIM, see Shao 1998), which is a pointed mission aiming at 4 μas precision for wide-angle and 1 μas for narrow-angle astrometry. The aim is to reach objects as faint as $V = 20$. SIM is scheduled for launch in 2005. Three other proposals are Germany's DIVA, USNO's FAME and the European Space Agency's *GAIA* mission. All three are survey-type missions and will observe large numbers ($\sim 10^7$ or more) of objects throughout the Galaxy. The DIVA proposal (Röser et al. 1997) aims at 0.15 mas precision for star brighter than $V = 8$ and FAME (Reasenberg & Phillips 1998) aims at ~ 50 mas for stars brighter than $V = 9$. Both these proposals include multi-colour photometry for all objects observed.

The most ambitious of all these proposals is *GAIA*, which is short-listed as a candidate cornerstone mission of ESA (Gilmore et al. 1998), with a possible launch date in 2009. The scientific objectives of *GAIA* are to measure positions, proper motions and parallaxes for all objects out to $V = 15$ with a precision of 10 μas (yr^{-1}) and to measure all objects out to $V = 20$ with less precision reaching about 0.2 mas at the faint end. These astrometric observations are to be complemented by both radial velocities (precision of a few km s^{-1} for $V < 15$) and multi-colour, multi-epoch photometry collected by on-board instruments. Broad-band photometry (4 channels) will be collected for all objects and 6-channel narrow-band photometry is foreseen for all objects at $V \lesssim 18$. In carrying out a mission like this it is entirely infeasible to work with an input catalogue as in the case of *Hipparcos*, hence *GAIA* will use an on-board detection scheme and measure all detected objects. This will lead to a complete survey of Galactic phase-space to $V = 20$, meaning some 1.3×10^9 objects.

The scientific returns of *GAIA* will be fantastic, impacting on every area of Galactic astronomy. For stellar clusters *GAIA* will provide a complete survey of their membership to $V = 20$, reaching the Brown Dwarf limit for all clusters and associations within 500 pc. For clusters located further away one can expect a significant extension of the current knowledge on their stellar content as well as accurate determinations of their orbits.

A bright future for open cluster and OB association studies lies ahead of us.

REFERENCES

Alcalá, J. M., et al., 1996, A&AS, 119, 7
Alcalá, J. M., Chavarría–K., C., & Terranegra, L. 1998, A&A, 330, 1017
Blaauw, A. 1964, ARA&A, 2, 213
Blaauw, A. 1991, NATO ASI Ser. C, Vol. 342 (Dordrecht: Kluwer), 125
Bonnell, I. A., Bate, M. R., Clarke, C. J., & Pringle, J.E. 1997, MNRAS, 285, 201
Bonnell, I. A., Bate, M. R., & Zinnecker, H. 1998, MNRAS, 298, 93
Bonnell, I. A. 1999, NATO ASI Ser. C Vol. 540, (Dordrecht: Kluwer), p. 479
Brown, A. G. A., de Geus, E. J., & de Zeeuw, P. T. 1994, A&A, 289, 101
Brown, A. G. A., Walter, F. M.,& Blaauw, A. 1999a, ASP Conf. Ser. (San Francisco), in press
Brown, A. G. A., Blaauw, A., Hoogerwerf, R., et al., 1999b, NATO ASI Ser. C Vol. 540, (Dordrecht: Kluwer), p. 411
de Bruijne J.H. J. 1999, MNRAS, 306, 381
Chiappini, C., et al., 2001, these proceedings
Clarke, C. J., ASP Conf. Ser., 142 (San Francisco), p. 189
Cunha, K., & Lambert, D.L. 1992, ApJ, 399, 586
Cunha, K., & Lambert, D.L. 1994, ApJ, 426, 170
Cunha, K., Smith, V.V., & Lambert, D.L. 1998, ApJ, 493, 195
Elmegreen, B.G. 1999, ApJ, 515, 323
ESA, 1997, The *Hipparcos* and Tycho Catalogues, ESA SP–1200
Friel, E.D. 1995, ARA&A, 33, 381
Friel, E.D., & Janes, K.A. 1993, A&A, 267, 75
Garmany, C.D. 1994, PASP, 106, 25
de Geus, E. J. 1992, A&A, 262, 258
Gilmore, G. F., et al., 1998, in Astronomical Interferometry, SPIE Proc. Vol. 3350, ed R.D. Reasenberg, p. 541
Haro, G. 1953, ApJ, 117, 73
Hillenbrand, L. A. 113, 173
Hoogerwerf, R., & Aguilar L. A. 1999, MNRAS, 306, 394
Janes, K. A., ed., 1991, The Formation and Evolution of Star Clusters, ASP Conf. Ser., 13 (San Francisco)
Klessen, R., Burkert, A., & Bate, M. R. 1998, ApJ, L205
Lada, E. A., Strom, K. M., & Myers, P. C. 1993, Protostars and Planets III, eds E. H. Levy & J. I. Lunine, UAP, p. 168
van Leeuwen, F. 1999, A&A, 341, L71
van Leeuwen, F., & Hansen–Ruiz, C.S. 1997, in *Hipparcos* Venice '97, ESA SP–402, 689
Massey, P. 1998, in The Stellar Initial Mass Function, eds G. F. Gilmore & D. Howell, ASP Conf. Ser., 142, p. 17
McCaughrean, M. J., & Burkert, A., eds, 1999, The Orion Complex Revisited, ASP Conf. Ser. (San Francisco), in press
Mermilliod, J.-C., et a;l., 1997, in *Hipparcos* Venice '97, ESA SP–402, 643
Milone, E.F., & Mermilliod, J.-C., eds, 1996, ASP Conf. Ser., 90 (San Francisco)
Nakano, M., Wiramihardja, S. D., & Kogure, T. 1995, PASJ, 47, 889
Narayanan, V. K., & Gould, A. 1999, ApJ, 532, 328
Perryman, M. A. C., Brown, A. G. A, & Lebreton, Y., et al., 1998, A&A, 331, 81
Piatti, A. E., Claria, J. J., & Abadi, M. G. 1995, AJ, 110, 2813
Pinsonneault, M. H., Stauffer, J., Soderblom, D. R., King, J. R., & Hanson, R. B. 1998, ApJ, 504, 170
Preibisch, T., Günther, E., Zinnecker, H., Sterzik, M., Frink, S., & Röser, S., 1998, A&A, 333, 619
Reasenberg, R. D., & Phillips, J. D. 1998, in Space Telescopes and Instruments V, eds P.Y. Bely & J.B. Breckinridge, SPIE Proc. Vol. 3356, 622
Robichon, N., Arenou, F., Mermilliod, J.-C., & Turon, C. 1999, A&A, 345, 471
Röser, S., Bastian, U., de Boer, K. S, et al., 1997, in Hipparcos Venice '97, ESA SP–402, p. 777
Sciortino, S., Damiani, F., Favata, F., & Micela, G. 1998, A&A, 332, 825
Shao, M. 1998, in Astronomical Interferometry, SPIE Proc. Vol. 3350, ed R.D. Reasenberg, p. 536
Tenorio–Tagle, G., Prieto, M., & Sánchez, F., 1992, Star Formation in Stellar Systems, Cambridge University Press
Twarog, B. A., Ashman, K. M., & Anthony–Twarog, B. J. 1997, AJ 114, 2556
Walter, F. M., Vrba, F. J., Mathieu, R. D., Brown, A., Myers, P. C. 1994, AJ, 107, 692
Walter, F. M., Wolk, S. J., Sherry, W. 1998, ASP Conf. Ser. 154, p. 1793
Walter, F. M., et al., 2000, Protostars and Planets IV, eds V. Mannings, A. P. Boss, S. Russell, U. Arizona Press, p. 273
de Zeeuw, P. T., Hoogerwerf, R., de Bruijne, J. H. J., Brown, A. G. A., Blaauw, A., 1999, AJ, 117, 354
Zinnecker, H., McCaughrean, M. J., & Wilking, B. A. 1993, in Protostars and Planets III, eds E.H. Levy & J.I. Lunine, University of Arizona Press, p. 429