Chapter 8
Introduction to Open Clusters

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8.1 Introduction

Every astronomical journey should begin with beautiful images, lest we forget the romance of the Universe amidst our analytic thinking. Figure 8.1 shows the 150 Myr open cluster M35 behind which is the 1 Gyr open cluster NGC 2158. While in the stellar dynamics world M35 is considered young, in the context of this School even M35 is old and thus both M35 and NGC 2158 are classical open clusters. In the next several chapters of this book we focus on groups of stars that only recently formed compared to these classical open clusters.

8.2 Classical Open Clusters

8.2.1 Definition

In the list below I present a few properties that allow us to identify stellar systems as classical open clusters in the Milky Way. These properties, and especially their limits, are more conceptual for understanding than definitive for classification.

- Age $\gg$ timescale for loss of natal gas (few Myr)
- Age $\gg$ dynamical timescale ('crossing time')
- $10 < M_{\text{cluster}} \lesssim 10^4\,M_\odot$
- Metallicity $\sim$ solar
- Location in Milky Way disc

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Fig. 8.1 Classical open clusters. The 150 Myr M35 (located at a distance of ∼850 pc) is shown in the *upper left*, whereas the more compact 1 Gyr NGC 2158 (located at four times the distance of M35) is shown in the *lower right*. Figure courtesy of D. Willasch

Essentially by definition, classical open clusters have ages greater than the duration of the formation of all the individual stars. Thus their ages are much larger than the timescale for the loss of the natal gas. This timescale is a few Myr.[1]

The age of a classical open cluster must also be larger than its dynamical timescale, or the crossing time ($t_{\rm cross} \sim 2R_{\rm cluster}/v_{\rm dispersion}$). This will become clearer when I provide an overview of collisional stellar dynamics below, but essentially this criterion ensures that the cluster is gravitationally bound.

The next definitional properties are less criteria than observed properties of classical open clusters in the Milky Way. I do not think the approximate upper limit of $10^4\,{\rm M}_\odot$ will surprise anyone. The lower limit of $10\,{\rm M}_\odot$ may be a bit more unexpected. I selected this lower limit to make the point that the difference between an open cluster and a multiple stellar system is somewhat arbitrary. However, in this context we can reflect on the fact that one system is characterised by evolving stellar orbits due to multiple dynamical encounters and the other is characterised by a hierarchical system with stable Keplerian orbits. This distinction also reflects the difference in stability between small-N open clusters and multiple systems (recognising that the evolution of the former eventually leads to the latter). Thus $10\,{\rm M}_\odot$ is rather low compared to commonly studied systems; $\sim 100\,{\rm M}_\odot$ is more typically given as the lower limit for open clusters. This reflects our ability to distinguish them in the field as well as their longevity.

The heavy element abundances of members (metallicities, typically cited as [Fe/H], in logarithmic units relative to the abundances of those elements in the Sun) of open clusters tend to be within a factor of 3 of the solar value. Again, this is not so much a defining property as an observed property, but as described in the Chapters

[1]Estimating stellar ages (and thus the clusters in which they reside) is a complex topic and the reader is referred to Soderblom (2010) for a comprehensive review.

of Reid, in the Milky Way it allows us to distinguish most (young) open clusters from most (old) globular clusters. And in the same spirit the spatial distribution of open clusters in the Milky Way also distinguishes them from globular clusters as discussed below.

There are roughly 2,000 open clusters identified, with a modern useful catalogue today being that of Dias and colleagues (Dias et al. 2012). A complete sample within 850 pc yields about 250 open clusters.

8.2.2 Global Properties

How does our census of open clusters compare to recent infrared surveys of the Milky Way that penetrate through more of the obscuring dust?

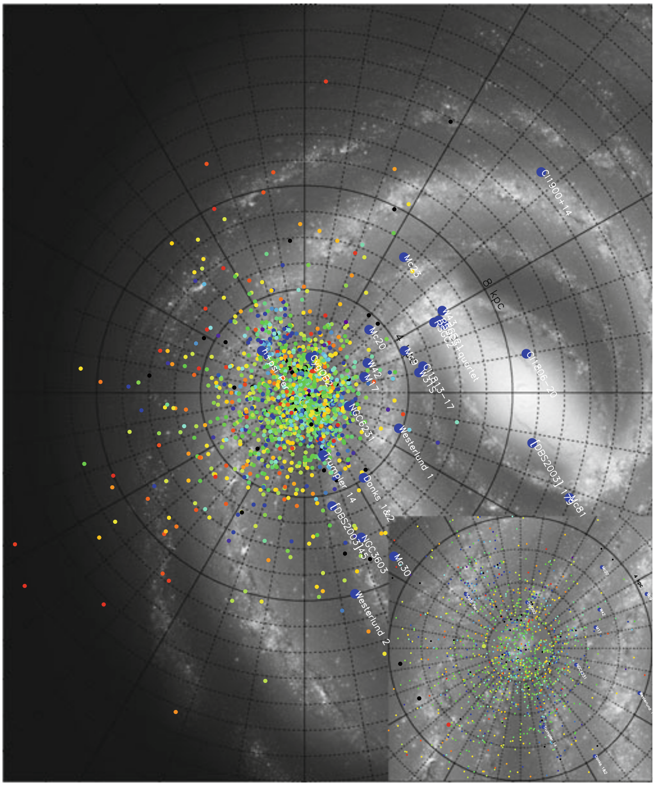

Fig. 8.2 Open clusters from the Dias et al. (2012) catalogue superimposed on a recent schematic model of the Milky Way based on *Spitzer*/GLIMPSE data. The *dots* are colour coded by age from log $\tau = 5$ (*blue*) to 9 (*red*). The inset image shows only the vicinity of the Sun. Figure courtesy of R. Benjamin

It is clear from Fig. 8.2 that our current open cluster database is very biased toward the solar region. In Fig. 8.2 we also zoom in on the solar region to look for an association of the Dias et al. catalogue with the nearby spiral arms. It is not clear that such an association is evident, which I suspect reflects more on the quality of the estimated distances as on the physics of star formation in the Milky Way.[2] *Gaia* will revolutionise Fig. 8.2. Recently, Piskunov et al. (2006) performed a detailed analysis of the open cluster spatial distribution, ultimately based on the All-Sky Catalogue of Stars. Figure 8.3 shows surface density versus distance from the Sun. Within roughly 850 pc the census is approximately complete.

In Fig. 8.4 I present another view of the Galactic distribution of open clusters, taken from Portegies Zwart et al. (2010). The blue dots are young open clusters, while the red dots are the oldest open clusters. You will notice that the older clusters tend to be found out of the disc. Likely this is an evolutionary selection effect, in the sense that clusters which orbit within the plane of the Galactic disc are continually buffeted by molecular clouds and other dynamical interactions leading them to rapidly evaporate

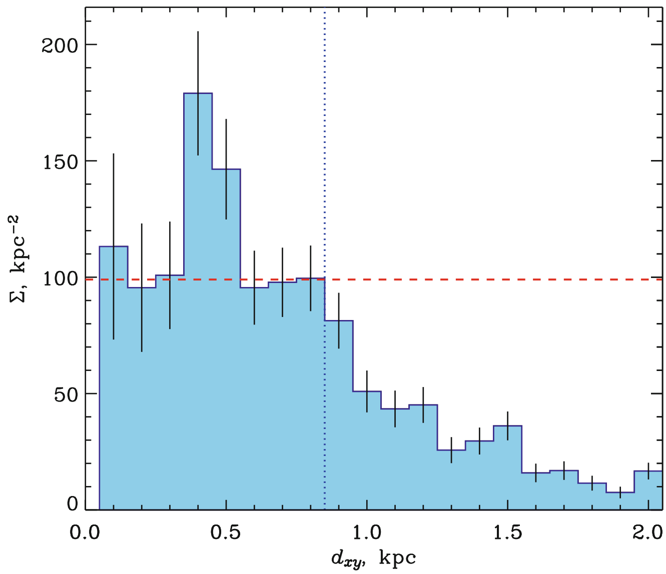

Fig. 8.3 Distribution of the surface density of open clusters as a function of distance from the Sun projected onto the Milky Way plane. The *dotted line* indicates the completeness limit, whereas the *dashed horizontal line* corresponds to the average density of open clusters. Figure from Piskunov et al. (2006)

[2]Ivan King once cautioned to be very careful with compilations. They are extremely valuable, but they are inherently heterogeneous in terms of both the content and the quality of the entries.

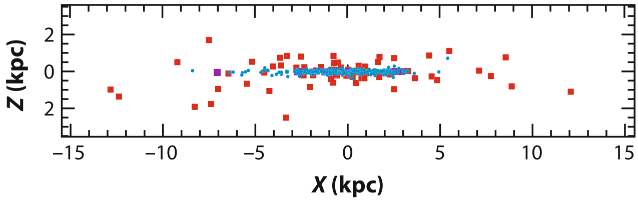

Fig. 8.4 The distribution of open clusters in the z-direction of the Milky Way. *Blue dots* represent young open clusters ($\tau < 100$ Myr), whereas the *red dots* denote older open clusters ($\tau > 3$ Gyr). Figure adapted from Portegies Zwart et al. (2010)

and disappear. Clusters whose orbits lead them to spend most of their time out of the plane of the Milky Way have calmer lives and live longer.[3]

More quantitatively, Röser et al. (2010) derive a scaleheight for all open clusters of about 50 pc cf. 300 pc for the thin disc; see Reid Chaps. 15 and 19, a surface density of about 100 kpc^{-2}, and a volume density of about 1,000 kpc^{-3} (but of course the open clusters do not occupy 1 kpc in height). Considering the actual volume filled by open clusters, one finds a total population in the Milky Way of order 100,000 open clusters.

Figure 8.5 shows the luminosity functions of open clusters, from Piskunov et al. (2008). While the mass distributions of open cluster systems are of considerably more interest to star formation researchers, it is difficult to construct them based on observations as discussed below. Luminosity functions can be constructed directly form observations with relative ease and compared between different regions of the Milky Way or different galaxies. Provided the vagaries mentioned below present consistent challenges between two cohorts, the comparison can be interesting. It is worth noting that the luminosity function of the open clusters in the Milky Way has a slope very similar to what is found for extragalactic clusters, though in the Milky Way we can extend the luminosity function to smaller clusters. Currently the turnover is thought to be real, and probably due to dynamical dissolution processes which we will come back to in Chap. 10. However, I remain somewhat skeptical: we may wish to revisit this issue after *Gaia* observations are available.

How do we measure the mass of these open clusters? It is not easy (in the absence of data from *Gaia*!). One approach is to do a complete census—simply count every single cluster member and assign a mass to each star. Determining which stars projected towards an area of interest on the sky are cluster members is determined probabilistically based on space motions, position in the colour-magnitude diagram, and other factors (e.g. elemental abundances). One has to assess completeness for the lowest-luminosity stars, and extend your census over a fixed area to the true outer radius of the cluster. Thus corrections for incompleteness are required, and your determined cluster mass will be sensitive to the mass function and spatial distrib-

[3]All of the clusters in Fig. 8.4 are in motion about the Milky Way. Those clusters seen far from the disc mid-plane are on orbits with larger average z-components than most of those seen in the disc. Nonetheless, they also pass through and interact with the disc, just on a less frequent basis.

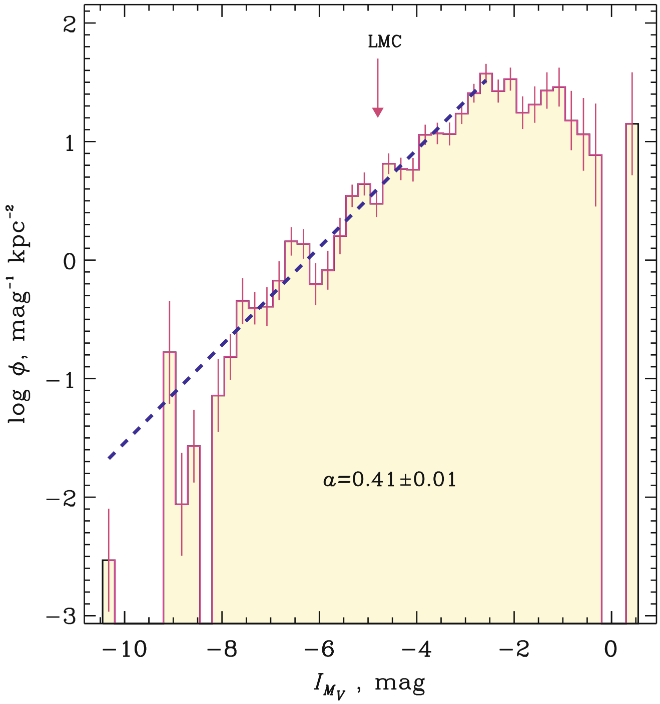

Fig. 8.5 Luminosity function of open clusters. The *dashed line* shows a linear fit for the brighter part of the histogram where a is the corresponding slope. Figure from Piskunov et al. (2008)

ution you assume (consistent with the observations) but extrapolated to parameter space not covered in the survey.

One must be especially cautious in interpreting tabulated values for cluster radii: many published values from the historical literature are meaningless. They are often the result of the visual impression derived by someone of an image, dictated by observational constraints, that does not correspond to anything quantitative or astrophysical. If you are going to work on open clusters, make sure that you are using a (trustworthy) core radius, a half-mass radius, or a tidal radius.

Another way to determine a cluster mass is dynamical, perhaps by simply using the virial theorem or by fitting more sophisticated dynamical models for clusters. As discussed below, this is difficult for open clusters, mainly because the stellar velocity dispersions are so small and difficult to measure. One also has to consider whether the sample used to fit the model is complete or representative, as a function of relative brightness and spatial distribution. Again, *Gaia* will help, although we will discuss later how the frequency of binary stars are going to affect such analyses.

Finally, Ivan King suggested an intermediate approach between a full census and dynamical modelling. Put very simply, if you determine the tidal radius and know the galaxy gravitational potential, then you can derive the cluster mass. It is an elegant idea. Unfortunately the mass depends on the tidal radius to the third power, and thus deriving adequately precise tidal radii is a challenge for deriving useful masses.

So in the end, it is not trivial to determine the masses of any clusters. If you want to do it accurately (as compared to precisely), it requires great technical skill and care. Piskunov et al. (2008) used masses estimated from tidal radii to derive the mass distribution of current open clusters (which due to evolution is not their initial mass distribution). As mentioned earlier, their range is 10 to perhaps $10^5\,M_\odot$, with the majority between 100 and $10^4\,M_\odot$ and an average mass of about $700\,M_\odot$.

Figure 8.6 from Portegies Zwart et al. (2010), shows the half-mass radius versus mass for open clusters, globular clusters, and the recently discovered young massive clusters that are the subject of their review. The half-mass radius is that physical radius within which is located half of the total mass of the cluster. Notice that the half-mass radii of open clusters, young massive clusters, and globular clusters are roughly similar. Of course, the masses of open clusters and globular clusters are different, $10-10^4\,M_\odot$ compared with $10^5-10^6\,M_\odot$ respectively. Even so, their stellar densities within half-mass radii are not as distinct as often presumed; indeed across the distributions they overlap. Yet the central densities of globular clusters, and especially post-collapse globular clusters, can be much higher than found in open clusters.

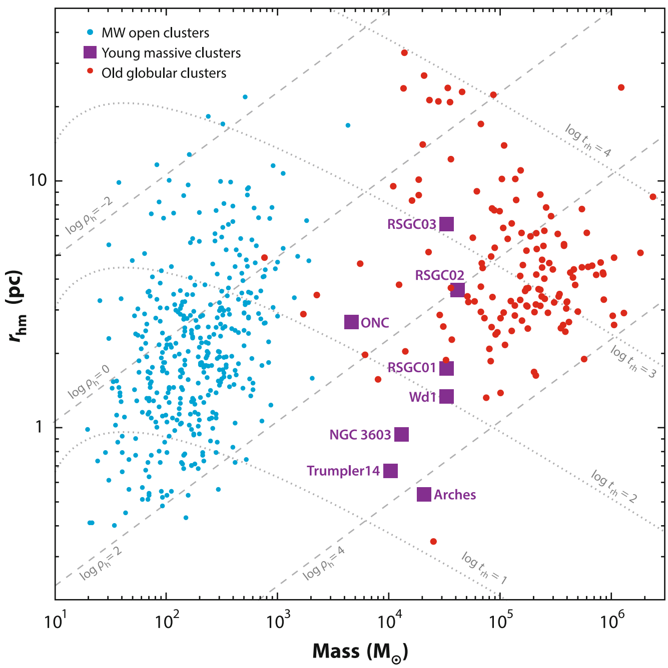

Fig. 8.6 The mass-radius diagram of Milky Way open clusters, young massive clusters, and old globular clusters. Figure from Portegies Zwart et al. (2010)

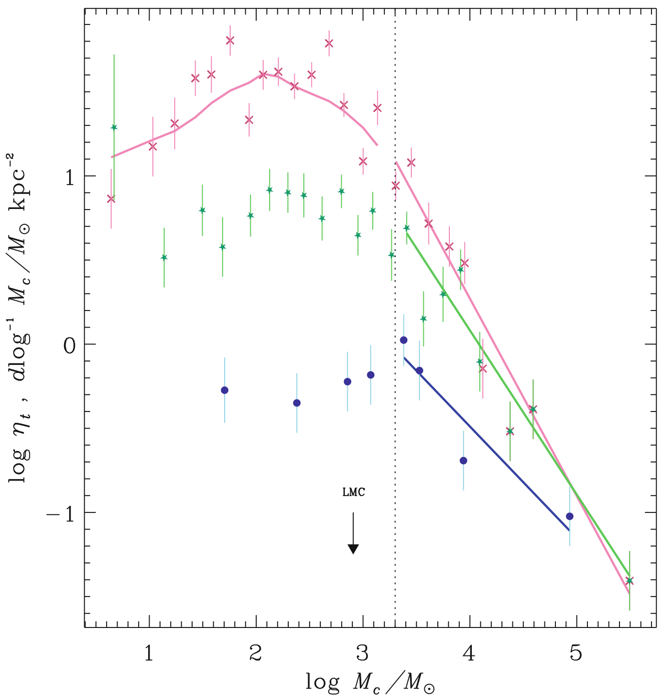

Fig. 8.7 Evolution of the mass function of Galactic open clusters. Different symbols denote samples with different upper limits of cluster ages. Blue filled circles represent clusters with ages $\log \tau < 6.9$, green stars for ages $\log \tau < 7.9$ and magenta crosses for $\log \tau < 9.5$. The *arrow* indicates the lower mass limit reached for open clusters in the LMC. Figure from Piskunov et al. (2008)

Turning to the open cluster mass function, one finds a power-law distribution that tends to flatten to lower masses (see Fig. 8.7). Again, this power law is similar to what is seen in other galaxies. Piskunov et al. (2008) show the mass function for clusters with ages less than 10 Myr as proxy for a cluster initial mass function (IMF). They find the mass function slope to decrease, as expected: as clusters age, they evaporate, losing stars through dynamical interactions and stellar evolution. The largest clusters i.e. 'disappear', and all clusters evolve into smaller ones leading to a steepening of the slope with time. Perhaps most interesting is that the estimated i.e. 'initial' power-law slope of -1.7 is very similar to that found for embedded clusters, as we will discuss later.

Piskunov et al. (2008) use their proxy for the cluster IMF to derive a formation rate for classical open clusters of 0.4 kpc^{-2} Myr^{-1}. This is a factor of 10 smaller than the formation rate from embedded clusters of $2-4$ kpc^{-2} Myr^{-1}, which we will discuss in Chap. 12. It is this order-of-magnitude difference that contributes to the frequent statement that roughly 10 % of the stars are made in open clusters. (In fact, Röser et al. (2010) conclude that 37 % of thin disc stars are made in open clusters.)

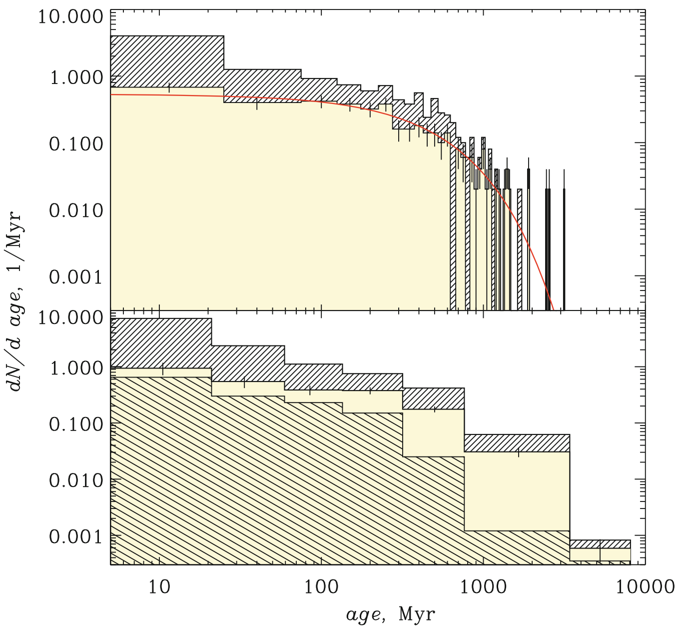

Fig. 8.8 Distributions of open cluster age. The *upper panel* shows the distributions of Piskunov et al. (2006), with the filled distribution representing their complete sample. The *solid curve* represents a fit to the age distribution curve. The *lower panel* shows the evolution in the data since the classic paper of Wielen (1971, hatched). Figure from Piskunov et al. (2006)

Finally, the age distribution of open clusters is a venerable field of study in which the classic works of Wielen (e.g. Wielen 1971) should be particularly noted. Piskunov et al. (2006) revisited the question with their modern cluster database, as shown in Fig. 8.8. There is some difference between the 1971 findings and today, with the currently derived mean lifetime being about 300 Myr. The sharp drop in the number of clusters with ages greater than a few Gyr has long been taken to be evidence for dynamical evolution (see Chap. 10).

8.2.3 Internal Properties

The global properties of clusters tend to be of great interest to those who study the Milky Way, and other galaxies, while the internal properties draw the attention of stellar dynamicists and those studying stellar evolution. Much like macro- and micro-economics, the two are distinct but intimately connected.

To introduce you to the internal properties of open clusters, I will use a cluster—NGC 188—which at the moment happens to be a target of much current research (however not especially young with an age of 7 Gyr).

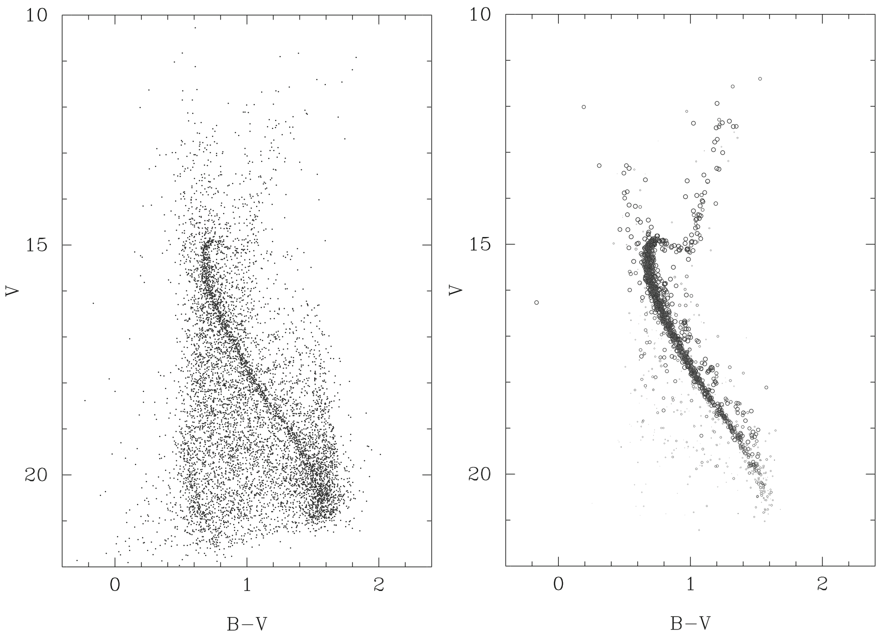

Fig. 8.9 V, $B-V$ colour-magnitude diagrams of NGC 188. *Left panel*: All stars in the field of NGC 188 within the magnitude limits. *Right panel*: 1490 probable cluster members, with proper motion members probabilities between 10 and 99 %. The size of each circle is proportional to the membership probability. Figure adapted from Platais et al. (2003)

Before attempting any astrophysical study with an open cluster, one has to first address the issue of cluster membership. If you take all of the stars in the field of NGC 188 out to a radius of ∼17 pc and make a V, $B-V$ colour-magnitude diagram, it looks like the left panel of Fig. 8.9. There is no doubt that the cluster is there, and likely there is a giant branch; although it would be hard to select which of the stars are cluster members versus non-members (dominated by field star giants).

So how does one determine which stars are cluster members? The answer depends a bit on the intended scientific study. In the chapters of I. Neill Reid it is suggested to use the intersection of the many expected properties of cluster members—kinematic, photometric, spectroscopic and more (see Chap. 16). This will certainly provide you with a very secure sample of members. On the other hand, if you require that all of these properties to indicate membership, then you are going to miss the unusual—and often the most interesting—stars, the gems among the common pebbles.

Whatever the scientific goal, one property that is clearly necessary for membership is kinematic association in three dimensions, and preferably distance association, if you have adequate precision such as *Gaia* will provide. In Fig. 8.10 I show three key figures in the membership process, taken from the proper motion study of NGC 188 of Platais et al. (2003). The left panel of Fig. 8.10 is the proper motion vector-point diagram. The cluster proper motion centroid is evident. Equally evident is that the

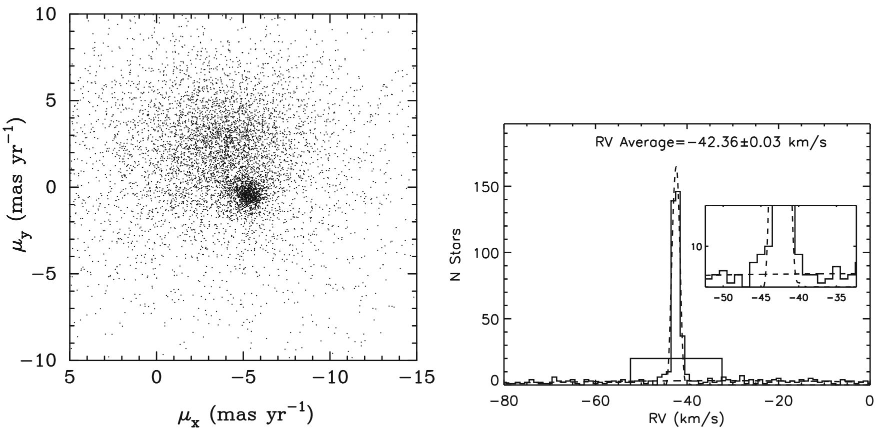

Fig. 8.10 *Left panel*: The proper motions of all stars in the field of NGC 188 within the magnitude limits. The concentration of cluster members is evident against the more dispersed field stars (from Platais et al. 2003). *Right panel*: A one-dimensional distribution of radial velocities of stars in the field of NGC 188. Gaussian fits to the field and cluster distributions, used for membership probability determinations, are shown (from Geller et al. 2008)

cluster centroid lies within the Milky Way proper motion distribution. Thus inevitably there are field stars with the same proper motions as the cluster. The right panel of Fig. 8.10 shows the proper motion distribution in one dimension, again showing the narrow cluster proper motion distribution and the broad field distribution. Typically two two-dimensional Gaussian functions are simultaneously fit to both the cluster and the field, and the membership probability for a star of any given proper motion is defined as the ratio of the value of the cluster Gaussian divided by the sum of the cluster and field Gaussians, all evaluated at that proper motion. The result is a membership probability. Clearly the higher the precision of the proper motion measurements and the larger the difference in the systemic velocities of the cluster and field stars, the better able we are to distinguish cluster and field members. Finally, the same process can be done with precise radial velocities, albeit with some minor complication from spectroscopic binaries, in order to provide three-dimensional kinematic selection (e.g. Geller et al. 2008) or valuable one-dimensional kinematic information when appropriate data for proper motion analyses are not available (e.g. Milliman et al. 2014).

The value of this work is evident in the right panel of Fig. 8.9, where the giant branch and the blue straggler population are now clearly evident. Even so, I stress that no one star can have 100 % membership probability based on kinematic data alone. If you have a thousand stars with 99.7 % membership probability, do not forget that a few of them will be field stars. And if you decide to write a paper on a fascinating star that you have found in a star-forming region, you had better be very careful to wrestle with this statistical uncertainty.

Note that once the kinematic measurement precision is better than the internal velocity dispersion of the cluster or star-forming region, additional precision is not of help, unless the goal is detailed investigation of sub-structure (e.g. spatially dependent mass segregation). Thus *Gaia* improvement in proper motion precision will be of limited help for bulk dynamics of nearby clusters, but of great help in more distant clusters. Furthermore, *Gaia* will certainly help in terms of distance determinations to clusters (either through direct parallax measurements or estimated using convergent-point methods), distance determinations for stars within (nearby) clusters, assessing mass segregation and/or bulk rotation, and in providing comprehensive data for all clusters.

Now with membership probabilities in hand, let us turn to the spatial distributions of stars in open clusters. For classical clusters we will consider only radial distributions, recognising that non-radial effects are expected from both rotation and the Galactic tidal field. For well-relaxed classical open clusters, multi-mass King models fit the stellar spatial distributions well, with one example being shown in the left panel of Fig. 8.11 for the open cluster M11. Such models provide measures of the core radii, and with adequate radial extent of the data also measures of tidal radii.

The large range of stellar masses in open clusters have always made them prime laboratories for studying mass segregation as a consequence of energy equipartition processes (see Mathieu 1984; Chap. 3). Mass segregation means the greater central concentration of more massive stars. While evident in the left panel of Fig. 8.11, cumulative distributions are more effective presentations of mass segregation, such as shown in the right panel of Fig. 8.11 where the more massive stars are evidently more centrally concentrated. This approach also immediately allows the application of the Kolmogorov-Smirnov test to determine whether two sub-samples have been drawn from the same parent population.

Of course the spatial distributions of stars are an instant in time reflection of the motions of the stars in their self-gravitating potential. One would like to measure energy equipartition and tidal truncation directly in the velocity distributions. This turns out to be very challenging because the stellar velocity dispersions, both in these clusters and in star-forming regions, are very small, of order 1 km s^{-1} or less in one dimension. The radial distribution of velocity dispersions in NGC 188 are shown in Fig. 8.12, for a reasonably massive open cluster.

It is important to remember that many stars in the Milky Way are members of multiple systems and this fact will have an impact on single-epoch observations of star cluster kinematics. Suppose you are granted time on the VLT with the FLAMES multi-object spectrograph. You place 300 fibres on stars in a young star-forming region and from these spectra you measure highly precise radial velocities, compute a velocity dispersion, analyse the physical implications, and publish the results. With high probability, your analysis of the physical implications will be wrong! Because within all of those velocities are the orbital motions of the $\sim$50 % of the stars that are binaries. So what you are measuring is the internal motions of the cluster itself convolved with the orbital motions of the binaries. Now if you make multiple observations, you will be able to identify and remove the short-period binaries (or obtain centre-of-mass velocities from orbital solutions). But the short-period binaries

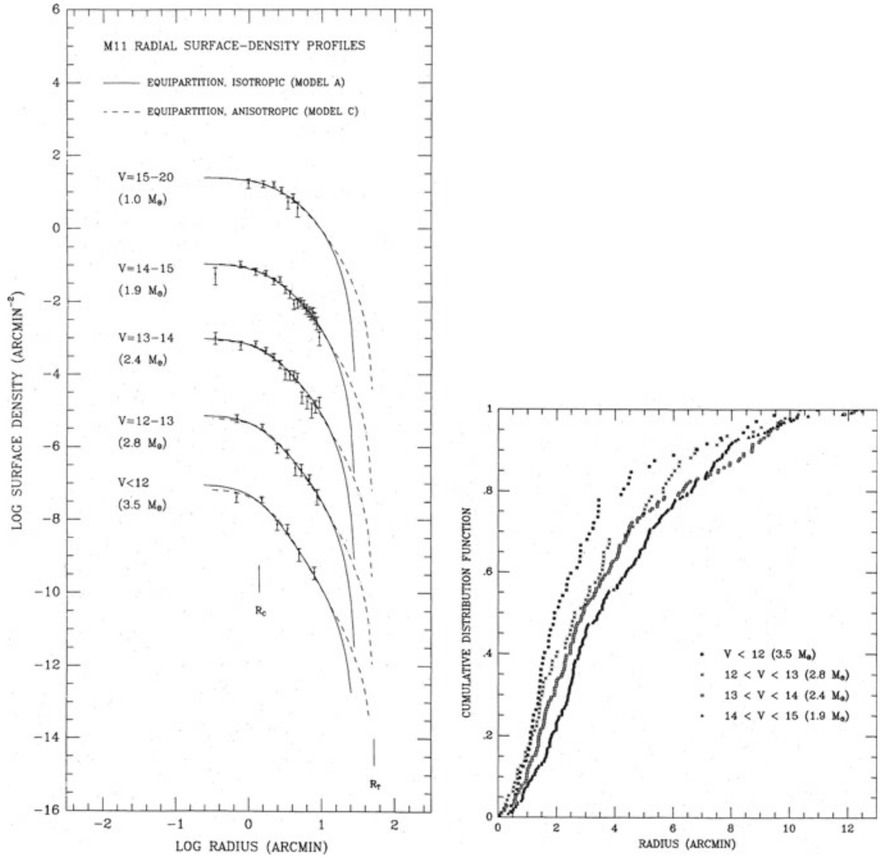

Fig. 8.11 Spatial distribution of stars in the open cluster M11. *Left panel*: Multi-mass King model fits to stellar surface densities. *Right panel*: Cumulative radial distributions of stellar positions, clearly showing the presence of mass segregation. Figure adapted from Mathieu (1984)

are not your greatest problem; because of their high orbital velocities, single velocity measurements were likely significant outliers from the observed velocity distribution of the star-forming region. Thus you would likely identify them (incorrectly, of course) as non-members. The greatest problem you face are the long-period binaries that have orbital motions of a few $\mathrm{km\,s^{-1}}$ and periods of many tens of years. They are the ones that are populating the 2–3σ tail of your velocity distribution. And even with multiple measurements on the timescale of a dissertation, you are not going to identify them as binaries! If you adopt a binary population, you can correct for their influence (e.g. Mathieu 1985; Geller et al. 2010; Cottaar et al. 2012). Of course, the issue of undetected binary companions is a general issue in stellar astronomy, and one recognised only relatively recently in the study of young stars. You ignore them at your peril.

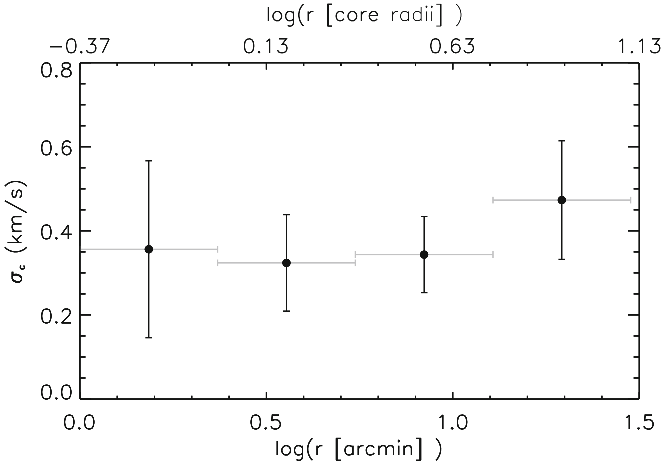

Fig. 8.12 Radial velocity dispersion as a function of radius in NGC 188. The *horizontal bars* show the region included in each measurement. Figure adapted from Geller et al. (2008)

Next let us turn to the stellar mass functions in open clusters. Figure 8.13 shows a whole set of open cluster mass functions, along with those for associations and globular clusters. Typically, cluster mass functions at the high-mass end tend to be similar to each other and the field, to within the effects of stellar evolution, and well fit by similar power-laws. The low-mass end is more difficult to determine technically and results have tended to show significant differences between clusters. In addition dynamical evolution effects make the interpretation of observed differences at the low-mass end problematic. (Note also the lack of low-mass stars among the globular clusters, likely due to preferential evaporation of low-mass members.) All this said, some of the more recent results seem to suggest that the low-mass end is also fairly stable (De Marchi et al. 2010).

8.2.4 OB Associations

Let me briefly bring OB associations into our discussion, with an homage to Adrian Blaauw. The ages of OB associations are larger, but not much so, than the timescale for the loss of the natal gas. Near almost all associations, there are still regions actively forming stars. Typically, association ages are less than 25 Myr or so, for an important physical reason. Ambartsumian argued definitively from the densities of OB associations that they are not bound (Ambartsumian 1947). If we take their three-dimensional internal motions to be 4 km s^{-1} (a bit higher than reality), in 25 Myr the stars travel 100 pc. So this upper limit on their ages is effectively set by their dissolution time. Of course, many are much younger.

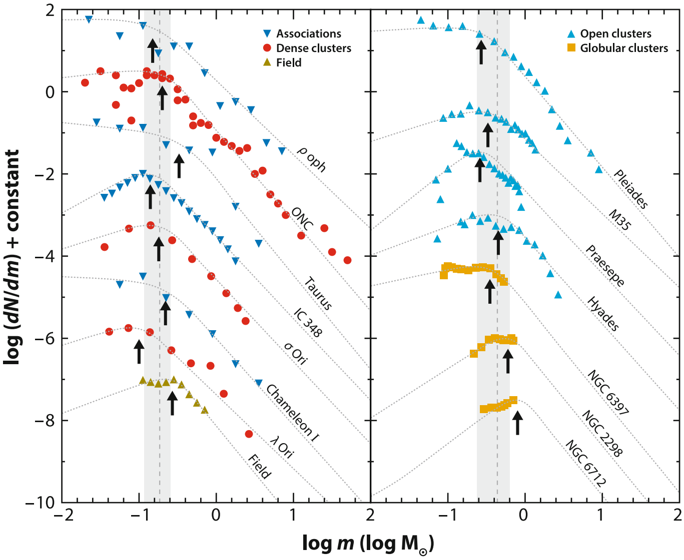

Fig. 8.13 The derived present-day mass function of a sample of open clusters spanning a large age range and old globular clusters. The *black arrows* show the characteristic mass of each fit. Figure from Bastian et al. (2010)

OB associations are associated with molecular clouds. They are located in the Milky Way disc with a scaleheight similar to the young open clusters. Their total masses tend to be similar to the open clusters, although more to the higher end. (This last is likely a statistical phenomenon related to the infrequency of OB stars in the IMF. Smaller mass associations without OB stars are known, but are more difficult to identify.)

Figure 8.14 shows a post-*Hipparcos* map of the OB associations in the solar neighbourhood. It is an honour to the work of Prof. Blaauw that the map was little changed from his earlier work (e.g. Blaauw 1991). What did improve, of course, is our knowledge of the systemic motions of the associations and the identification of members, which improved tremendously with *Hipparcos*, as shown in Fig. 8.15.

Figure 8.15 also makes the point that Upper Scorpius is much more concentrated than Upper Centaurus, which is more concentrated than Lower Centaurus. This is generally interpreted as the sequential dissolution of unbound systems, with Upper Sco being the most recently unbound and the currently embedded ρ Ophiuchus region soon to be the next in the sequence. We are actually seeing the systems unbind.

The memberships of young associations are one aspect of the dynamics of star-forming regions where *Gaia* will make a huge difference. Only because of apparent brightness, *Hipparcos* was unable to provide kinematics and membership for stars of later than spectral type A, i.e. for all the lower-mass stars. But they are assuredly there, for example as shown in Fig. 5 of Preibisch et al. (2002) where there certainly is no deficit of low-mass stars. These deep ground-based surveys which show that

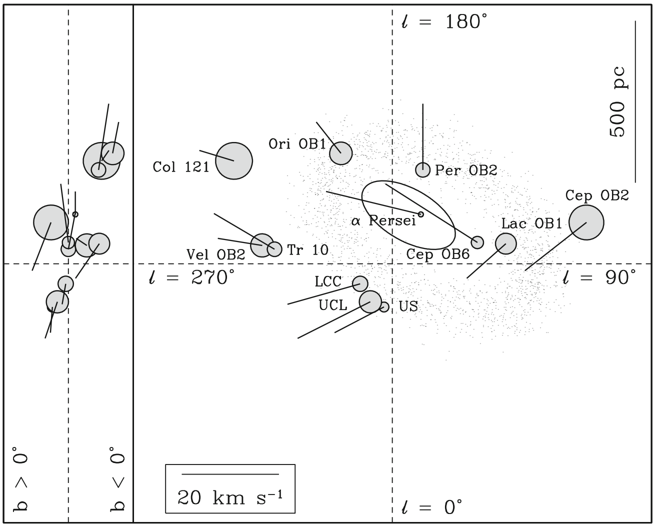

Fig. 8.14 Locations of the kinematically detected OB associations projected onto the Galactic plane. *Circles* represent the physical dimensions, the *ellipse* represents the Cas-Tau association, and the *vectors* represent the common streaming motions. Figure from de Zeeuw et al. (1999)

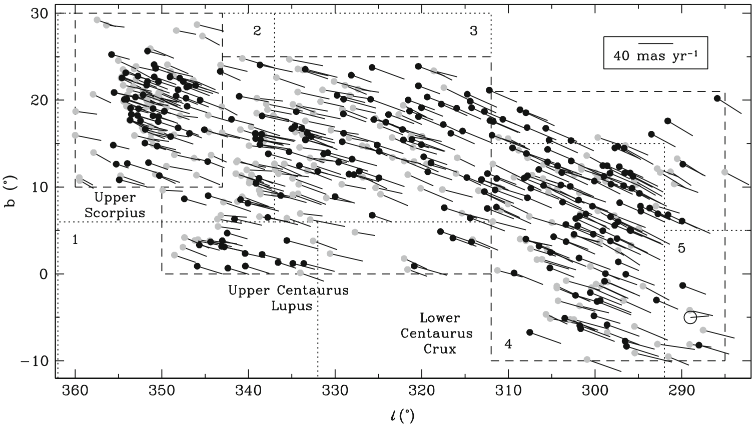

Fig. 8.15 Proper motions for 532 members of the Scorpius-Centaurus association, selected from 4156 candidate *Hipparcos* stars. The *dashed* and *dotted lines* are schematics boundaries of the three sub-associations. Figure adapted from de Zeeuw et al. (1999)

in fact associations have the entire IMF down to at least 0.1 $M_\odot$ are very hard work, but they are absolutely critical from the star formation point of view. *Gaia* should greatly expand our understanding of the global properties of low-mass star formation and mass functions.

8.3 Closing Thought

Do most stars form in OB associations? The distinction between OB associations and clusters is of historical origin. As we shall see, whether it remains an important physical distinction today in terms of the formation and evolution of star-forming regions is not clear. Open clusters are bound, OB associations are unbound. In 1930, that was a profound statement. But now, if you take a broader view of star formation and molecular clouds, and you see star formation as occurring throughout the molecular clouds with greater rates in some areas, then it becomes clear that the young stars in certain locations a few pc in size will end up being bound in clusters, and the rest of the young stars in the cloud will necessarily disperse as the gas disappears. Associations, OB or otherwise, are nothing more than the inevitable consequence of star formation (of low efficiency) going on in molecular clouds without global densities high enough to remain bound. Whether a particular grouping is an OB association depends on whether or not OB stars happened to have formed there.

So I think the real question is: are most stars formed in unbound groupings? The comparison of embedded star formation to the open cluster statistics suggests the answer is yes. However, we need to understand what fraction of stars are formed in small-scale, high-star-formation-efficiency regions in clouds and whether they dissolve before we can find them. Whether they are OB associations or T associations or clusters is, perhaps, historical jargon that is best left to history.

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