Stellar Clusters

1. Basics & Nomenclature

Stars form in dense regions of molecular clouds, typically in galactic disks. The regions of formation typically form numerous stars across a large range of masses. If the region is dense enough, the resulting star cluster becomes gravitationally bound and is long-lived. The *globular clusters* found in the Milky Way and other galaxies are the canonical examples of this case. If not, the star cluster will disperse within a few hundred million years. The canonical example of this case are the *open clusters*. Here we review the observational properties of these cases.

Globular clusters were first found in the Milky Way. There are currently about 150 known. The brightest ones can be glimpsed by eye in dark sites; a number of Messier objects are globular clusters. They have total absolute magnitudes between about $M_V \sim -4$ to -12 and estimated total stellar masses of 10^4–10^6 $M_\odot$ with a roughly log-normal luminosity function. They are a few pc in half-light size. Most of them have constant density *cores* with a power law surface brightness distribution ($r^{-0.75}$), but for about 20% this power law continues through to the center and thus they have a *cusp*.

Globulars tend to not have any net rotation of their stars, and have a typical internal stellar velocity dispersion of 5–10 km s^{-1}. As will become apparent in the discussion of stellar evolution, they appear to have nearly single-age stellar populations. In the Milky Way, the majority of them are old, often $\sim$ 10–12 Gyr. Chemically, they are relatively metal-poor in general.

In the Milky Way are two classes of globular, the halo population and the disk population (and sometimes astronomers refer to the bulge population). The halo population extends to larger distances (out past 10 kpc, and a handful to 50 kpc) and is more metal poor. The disk population is closer ($<$ 10 kpc) and is an oblate distribution and is more metal rich.

Most other galaxies have globular clusters. We define the specific frequency of globular clusters as:

$$S_N = N_{\rm GC} 10^{0.4(M_V+15)}, \tag{1}$$

where estimates of S_N are of order unity, but S_N seems to be an increasing function of galaxy mass. There are indications that the globular cluster metallicity increases with galaxy mass. The bimodal distribution of metallicity seen in the Milky Way is also seen in other systems (sometimes traced by color). In general, extragalactic globular cluster systems are better studied for elliptical galaxies rather than spiral galaxies, because of the smoother background provided by the former for detection of clusters.

Globulars are thought to form in major bursts of star formation within galaxies, not from individual dark matter halos collapsing at high redshift, because of their lack of dark matter. Young massive clusters have been observed in local merging galaxies (Ashman & Zepf 1992), and these clusters are thought to be similar to the birthplace of globulars. This implies that in star forming galaxies as a whole, globular clusters presumably exist with a range of ages (not just very old). In the Milky Way and in other galaxies, it is likely that the luminosity and size distribution of globulars is strongly shaped by internal gravitational effects and gravitational interaction with the Milky Way, and that the remaining globulars are only a fraction of the original population.

Open clusters are smaller and more diffuse. The brightest ones are also visible to the naked eye, for example the Pleiades. They range from a few tens of millions to around a billion years old. Like globulars they appear to be close to single stellar populations. Even over their short lifetimes, internal gravitational effects have strongly affected the distribution of stars, in general causing *mass segregation* and other effects. Open clusters are almost by definition unbound or loosely bound. We believe that the majority and perhaps all stars formed in clusters, most of which were open clusters that dissipated soon after their star formation ended (Lada & Lada 2003).

2. Commentary

3. Key References

- *The Formation of Globular Clusters in Merging and Interacting Galaxies*, Ashman & Zepf (1992)
- *The Harris globular cluster catalog*, Harris (1996)
- *New catalogue of optically visible open clusters and candidates*, Dias et al. (2002)
- *Extragalactic Globular Clusters and Galaxy Formation*, Brodie & Strader (2006)

4. Order-of-magnitude Exercises

1. Estimate (roughly!) what fraction of the stellar mass in the Milky Way is in open clusters. Assume each cluster has about 10^3 $M_\odot$, and that our known catalog of a few thousand is complete to 2–3 kpc but not further.
2. How many open clusters would have to have existed over the lifetime of the Milky Way for all the stars in the Milky Way disk to have formed in one?

5. Numerics and Data Exercises

1. Using the *Gaia* data set, show a color-magnitude diagram in the area around an open cluster found in Dias et al. (2002). Plot the distribution of stars in right ascension and declination, as well as in proper motion space.

2. Using the *Gaia* data set, show a color-magnitude diagram in the area around a globular cluster found in Harris (1996). Plot the distribution of stars in right ascension and declination, as well as in proper motion space.

3. For the open clusters in Dias et al. (2002), plot their estimated metallicities as a function of distance from the center of the Milky Way.

4. For the globular clusters in Harris (1996), plot their estimated metallicities as a function of distance from the center of the Milky Way.

REFERENCES

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Dias, W. S., Alessi, B. S., Moitinho, A., & Lépine, J. R. D. 2002, A&A, 389, 871

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