Space structure and dynamical evolution of the open star clusters

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Abstract. A characteristic of the structure and the evolution of open clusters is presented in this short review. Simple methods for analysing both issues are sketched and the literature references are given.
Key words: Open clusters and associations: general

Пространствена структура и динамична еволюция на разсеяни звездни купове

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В този кратък обзор е представен преглед на основните сведения за строежа и еволюцията на разсеяните купове. Представени са прости методи за анализ, както и съответните литературни източници.

Introduction

Open clusters are not trivial stellar systems and their dynamical evolution is not yet fully understood. Most of them are not very populous assemblages of a few hundred stars. The least massive clusters do not survive longer than a few hundred Myr. The dynamics of more massive and populous clusters is driven by internal forces to considerable degree, which leads to evaporation of low-mass members and to a mass segregation effect. To obtain a complete picture of a cluster, it is necessary to study not only its most dense central region (the core) but also the expanded and sparse coronal region (the halo or corona). Cluster member stars incessantly evolve along the stellar evolution paths, what makes an open cluster a vivid system evolving in time.

1 Structure

Among open clusters there are systems of a few tens of hardly bounded stars, as well as ensembles of a few thousand of stars. The density of cluster members is the greatest within the core. A typical core linear radius is 1 pc. Coming from the cluster centre, the stellar density gradually decreases and the cluster corona merges with the stellar background of the Milky Way. A typical linear diameter of a corona is $2-3$ pc but one can observe extremely small ones of $1-2$ pc and extremely large reaching 10 or more parsecs. Determining the cluster limiting radius is important for further investigations and is not a trivial task. The angular diameter of a cluster depends on the limiting magnitude of the survey because the faint cluster members are located mainly in the outskirts of the system while the brightest ones tend to occupy the central region. The limiting radius also depends on the properly determined level of the background density, so a relatively wide field of view of a telescope is desired. Open clusters seem to be larger in the near infrared than in optical bands (Sharma et al. 2006), thus the band of the acquired cluster image is important, too.

From the observational point of view, the study of the morphology of a cluster can be done by analysing the number of stars per unit of sky area in various cluster regions. King (1966) spotted that the mean stellar density ρ can be approximated as a function of angular distance from a cluster centre r by an empirical formula of the form

$$\rho(r) = f_0 \left(\frac{1}{[1+(r/r_\mathrm{c})^2]^{\frac{1}{2}}} - \frac{1}{[1+(r_\mathrm{t}/r_\mathrm{c})^2]^{\frac{1}{2}}} \right)^2 . \tag{1}$$

In this formula r_c is the characteristic angular distance from a cluster centre – the core radius and r_t denotes the tidal radius beyond which the external gravitational forces generated by the galactic environment become dominating. If cluster members cross r_t they become gravitationally unbounded and finally leave the system. If r_t is much greater than r_c, then f_0 can be interpreted as the stellar density in the centre of a cluster and $\rho(r_\mathrm{c}) = \frac{1}{2} f_0$. If r_c is small comparing to the cluster limiting (total) radius, then the system is concentrated.

The formula (1) approximates the stellar radial distribution for rich stellar clusters and dwarf elliptical galaxies. In the case of open clusters, the stellar density is relatively small and fluctuations caused by the inhomogeneity of the galaxy background become significant. Therefore, fitting the formula (1) to the observations usually gives an unrealistic great value of r_t (Kałużny & Udalski 1992). In these cases a simplified version of formula (1) is used in the following form

$$\rho(r) = f_0 \left(\frac{1}{1+(r/r_\mathrm{c})^2} \right) . \tag{2}$$

Analysis of the radial density profiles is a commonly used method for investigating a cluster structure. It loses information on the 2-dimensional cluster morphology but it provides a uniform description of its structure with a few basic parameters instead. Nilakshi et al. (2002) presented the first results of an extensive study of the spatial structure of 38 rich open clusters based on star counts performed on images taken from the Digital Sky Survey (DSS).

However, one must be aware that the methodology described above is a simplicity and the cluster morphology is far from being spherically symmetrical. There are clusters which shape can be better approximated by e.g. ellipses (Chen et al. 2004).

2 Dynamical evolution

Let's think of star clusters as N-body collisionless systems. The fundamental Boltzmann equation of the stellar dynamics can be applied

$$\frac{\partial f}{\partial t} + \boldsymbol{v} \cdot \nabla f - \nabla \Phi \cdot \frac{\partial f}{\partial \boldsymbol{v}} = 0 , \tag{3}$$

where f is the stellar density, v – the velocity in a given system, and Φ – the gravitational potential (Binney & Tremaine 1987). Particles move under the influence of the mean potential generated by all the other particles. This static model works for galaxies or globular clusters which contain more than 10^5 stars and stellar encounters are not important. However, stellar encounters occur and perturb a star from the course. After a relaxation time of a system (10^7 yr for open clusters, $10^9 - 10^{10}$ yr for globular clusters) the equipartition of energy occurs and stellar velocities are described by the Maxwellian distribution. We have

$$\frac{\partial f}{\partial t} + \boldsymbol{v} \cdot \nabla f - \nabla \Phi \cdot \frac{\partial f}{\partial \boldsymbol{v}} = \Gamma[f] \,, \tag{4}$$

where $\Gamma[f]$ denotes the rate of change of stellar density due to encounters (Binney & Tremaine 1987). That equation cannot be solved in an analytic way, thus numerical N-body simulations are the only way to investigate the dynamical evolution of open clusters (see e.g. de la Fuente Marcos 1995, 1996a, 1996b, 1997, de la Fuente Marcos & Fuente Marcos 2002).

The stellar encounters influence the structure of a stellar system in three important ways. (1) First of all, they cause that the structure of the system becomes less dependent on the initial conditions. The evolution runs towards a state of a higher entropy with a small dense core and an extended low-density halo. That process is called a relaxation. (2) Encounters tend to produce the equipartition of kinetic energy. The most massive stars lose energy to less massive ones and then sink towards the cluster centre. That process generates a mass segregation that is commonly observed in open clusters of the Galaxy and Magellanic Clouds (Lamers at al. 2006 and references therein). (3) From time to time encounters give a star enough energy to escape from the system.

A permanent mass loss is a characteristic feature of open clusters (de la Fuente Marcos 2000). It is caused by the stellar evolution as a result of supernova explosions, envelope ejections in late stages of stellar evolution, or stellar winds. The system becomes less bounded and its radius increases. From the other hand, the phenomenon of the escape (evaporation) of low-mass stars from cluster outskirts occurs and the system's radius tends to decrease.

Analysis of a cluster mass function brings information about the stage of the system dynamical evolution. Studying the slope of the mass function within an overall cluster area gives insight into the total number of cluster members, the total cluster mass, or the scale of the evaporation of low-mass stars. Comparing the slope of the mass function within the core and the corona results in parametrizing the mass segregation within a cluster volume. Studying many open clusters allow to investigate paths of the cluster dynamical evolution (see e.g. Bonatto & Bica 2005, Bica & Bonatto 2005, and Maciejewski & Niedzielski 2007).

Summary

While basic astrophysical parameters, such as an age or a distance from the Sun, are known for the prominent number of open clusters, structural and dynamical evolution parameters remain unstudied for the majority of them. The wide-field surveys, which are based on commonly available all-sky catalogues or dedicated observations gathered with Schmidt telescopes, may throw new light on the structure and the dynamical evolution of galactic clusters.

Figure 1 is an addition to show the recommended simple manner of picture including.

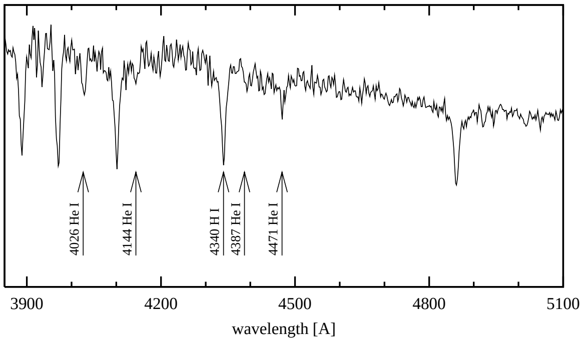

Fig. 1. Keep in your mind, please: If the letters and/or numbers inside your figures are too small or low contrasty, like these in Fug.1, the Editor will be disappointed and may return your article as "invalid" without explanations.

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