Open clusters and the radial abundance gradient of Galactic disc

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Abstract. Open clusters (OCs) have long been used to trace the structure and evolution of the Galactic disk. Based on a most complete open clusters sample with metallicity, age, distance data as well as kinematic information available, some statistical analysis on spatial, kinematical and chemical distributions of open clusters have been made. Especially, an radial abundance gradient about -0.058 dex/kpc has been derived and by dividing clusters into age groups we show that the disk abundance gradient was steeper in the past, by which may constrain the disk chemical evolution model. Based on the great advantages of LAMOST facility, we have proposed a detailed program of open cluster survey with LAMOST (the LOCS). The aim, feasibility, and the scientific goals of the LOCS are briefly summarized.

Keywords. Galaxy: disk, open clusters and associations: general

1. Introduction

Open clusters (OCs) have long been used to trace the structure and evolution of the Galactic disk. From the observational point of view, there are some important advantages of OCs against field stars. In general, for an OC, we are dealing with a group of stars, with nearly the same origin and evolution history as well as similar composition and distance; we can see OCs to a large distances and most of the open cluster sample have distance parameters already derived. Especially, open clusters have relatively more stable orbital motion, by which can be used as a better tracer of the disk structure. Also, OCs have wide range of ages, so together with their spatial distribution and kinematic information we can study the dynamical evolution effects, and very young OCs are ideal objects for the IMF study. Furthermore, combining with the abundance data we can investigate the chemical evolution history of the disk (Carraro et al. 1998, Chen et al. 2003).

At present, the total number of detected clusters and associations is around 1700 (Dias et al. 2002), about 60% of which have distance and age information and for about half of which proper motions are available. Less than one-fourth of the sample have both proper motion and radial velocity parameters, and only a small portion (about 8%) of OCs have mean abundance values determined. We have compiled an updated OC catalog (Chen et al., in prep.), for which data have been extracted from various sources – mainly from the Dias’ catalog (Dias et al. 2002), Kharchenko’s data (Kharchenko et al. 2005a, Kharchenko et al. 2005b) and the WEBDA database (Mermilliod & Paunzen 2003). Based on this large sample, we can make statistical studies of the Galactic OC system.

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2. Spatial and kinematical distributions of open clusters

2.1. Spatial distributions

Using data from our updated OC catalog for 1020 open clusters with distance and age data, we find that when projected onto the galactic plane, there are very few open clusters in the region with galactocentric distances less than 5kpc, this partly due to the much higher extinction in the direction of the galactic center and also due to dynamical processes - strong tidal forces, colliding with molecular clouds and so on. On the whole, young clusters (with ages younger than that of Hyades, 0.8 Gyr) distributed quite uniformly around the Sun while most older OCs are distributed in the outer part of the disk. (see also Chen et al. (2003))

Regarding the spatial distribution perpendicular to the Galactic plane, most OCs represent the typical thin-disk population, with a small scale height of about 66 pc. However, the subsample of old OCs, most of which are found in the outer disk, has a much greater scale height of 221 pc.

2.2. Kinematical parameters of the Galactic thin disk in the solar vicinity

For kinematic data, we have compiled a catalog with both radial velocity and mean proper motion available for 369 open clusters. This provides a chance to constrain the Galactic differential rotation, as well as the Galactic radial motion parameters at the solar neighborhood. We have formed a subsample composed of 117 clusters with distances to the Galactic plane $|z| < 400$pc, the range of heliocentric distances as 0.5 – 2.0 kpc and ages younger than 0.8 Gyr, which can be considered as typical thin-disk objects in the Galaxy, and for which the Oort theory is applicable. The kinematical parameters determined from these clusters can be used to represent the kinematic properties of thin-disk objects in the vicinity of the Sun. Thus, we deduced the Galactic components of (i) the mean heliocentric velocity of the OC system, $(u_1, u_2, u_3) = (-16.1 \pm 1.0, -7.9 \pm 0.4, -10.4 \pm 1.5)$ km s$^{-1}$, (ii) the characteristic velocity dispersions, $(\sigma_1, \sigma_2, \sigma_3) = (17.0 \pm 0.7, 12.2 \pm 0.9, 8.0 \pm 1.3)$ km s$^{-1}$, (iii) the Oort constants, $(A, B) = (14.8 \pm 1.0, -13.0 \pm 2.7)$ km s$^{-1}$ kpc$^{-1}$, and (iv) the radial motion parameters, $(C, D) = (1.5 \pm 0.7, -1.2 \pm 1.5)$ km s$^{-1}$ kpc$^{-1}$ (Zhao et al. 2006). The parameters determined from these clusters have accuracies significantly greater than those obtained from other groups of clusters.

3. The disk abundance gradient based on open clusters

OCs can be used as a powerful tool to understand whether and how the spatial abundance distribution changes with time, since OCs have formed at all epochs and since their ages, distances, and metallicities can be derived more reliably than the same parameters of the field stars. We have compiled an OC sub-sample, containing 144 objects, with metallicity, distance and age parameters. Upper panel of Fig 1 is the metallicity histogram from our sample, which shows that open cluster metallicity distribution peaks at around the solar value with a metal-poor tail. In the lower panel of Fig. 1, the z-scale heights for relatively metal-poor and metal-rich open clusters are shown, their spatial distribution perpendicular to the Galactic plane being significantly different.

From this sample, we obtain a radial metallicity gradient of $-0.058 \pm 0.006$ dex kpc$^{-1}$ (Chen et al., in prep.), for galactocentric distances ranging from about 7 kpc to 17 kpc. By dividing the clusters into young and old sub-samples (see also Chen et al. 2003), we find that the corresponding gradients are significantly different, as shown in the upper panel of Fig. 2. That is, the gradient is steeper in the past, and shallower for younger
Figure 1. (upper) Histogram of the open cluster abundance. (lower) z-scale heights for two abundance subsamples.

clusters. In the bottom panel of Fig. 2, the gradients of the inner and outer sub-samples have similar values.

This abundance gradient is consistent with those from HII regions (Deharveng et al. 2000) or planetary nebula data (Maciel et al. 2006).

Thus, based on OC data we may constrain the disk chemical evolution such that in the early stage of disk formation it showed a steeper abundance gradient, while later on this gradient became flatten out. Anyway, these inferences are not very conclusive, since we still do not have a sufficiently large outer disk cluster sample, which is critical.

4. The chemical evolution model of the Milky Way disk

The observed disk abundance gradient and its evolution offer the opportunity to test theories of star formation and disk chemical evolution. Here we try to discuss the main mechanism that causes disk abundance gradient and its evolution through galactic chemical evolution model.

We assume that the Milky Way has been embedded in a dark matter halo. Primordial gas within the dark halo cools down to form a rotationally supported disk, which is assumed to be sheet-like and a system of a series of independent rings. Star formation and chemical evolution are undergoing in each ring due to gas infalling.

Some basic assumptions are as following, details about the evolution equation can be found from Fu et al. (2008) and also Hou et al. (2000).
The assumption of infall rate is similar to many other phenomenological models, an exponential decaying gas infall rate $f(r, t) \propto \exp[-t/\tau(r)]$ is adopted, where $\tau(r)$ is the infall timescale which is often assumed to be radial dependent, thus mimic the “inside-out” disk formation process.

A modified Kennicutt-Schmidt law, as described in Boissier & Prantzos (1999) is adopted as the star formation law. And also the Instantaneous Recycling Approximation (IRA) is adopted in our calculations (see Chang et al. (1999)).

When comparing with the observed abundance gradients, we mainly refer to oxygen abundance. For open clusters’ data, we convert the abundance gradient of iron to that of oxygen according to the calibration of Maciel et al. 2005.

Our model prediction of the abundance gradient evolutions is plotted in Fig. 3. In the model, we calculated three cases for infall time scale, as was indicated in the figure. The shaded area is the observed oxygen abundance gradient from different PN populations. Also we show gradients from open clusters. From Fig. 3, we can find that all three cases show that the disk abundance gradient is steeper in the early stage of disk evolution. Our model can not only predict the current values of abundance gradient along the Milky Way disk, but also fairly predict the evolution of gradient consistent with observations from PNe and open clusters.

5. The LOCS – LAMOST Open Cluster Survey project

Regarding the present status of our OC database, we need a much larger sample with both abundance and three-dimensional spatial motion data in order to study the global disk dynamical and chemical evolution. In particular, for our study of the disk chemical evolution, we need more outer-disk cluster data so that we can determine the abundance gradient evolution decisively. Equally important, a unified observational data set for different clusters is very much needed.

Recently we have proposed the LOCS project – the LAMOST Open Cluster Survey. The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) is located at Xinglong Observing Station of the National Astronomical Observatories, China. The full system is scheduled to finish its final assembly in 2009.
Figure 3. Time evolution of radial abundance gradient. Model predictions are plotted by dashed and solid lines for various infall time scales. The shaded area is the observed oxygen abundance gradients from PNe (Maciel et al. 2003). Open circles are sulphur abundance gradients from different aged PNe (Maciel et al. 2003). The open squares (Friel et al. 2002) and crosses (Chen et al. 2003) are oxygen abundance gradients from open clusters, which are transferred from iron abundance gradients according to the calibration of Maciel et al. 2005. Two observed points at the top right corner show very shallow current abundance gradients. They are from young open clusters. The black point is the current oxygen abundance gradient obtained from HII regions (Rudolph et al. (2006)).

On the whole, LAMOST is a 4-meter aperture quasi-meridian reflecting Schmidt telescope, with large field of view of about 20 square degree and can get 4000 spectra at a single pointing using a parallel controllable fiber positioning technique.

For the LOCS proposal, the main advantage of using LAMOST is that it can be most efficient for the open cluster survey. With its multiple fibers and large field of view, we can complete a spectroscopic survey observation for at least one cluster per observing night. This type of survey observations will have deep enough magnitude limits to reach most of the old clusters within 5 – 8 kpc.

With the great ability of spectroscopic observation with LAMOST, one will expect to explore a much larger sample of open clusters, about 450 in number, to obtain stellar radial velocities as well as abundance information of stars complete to $R \sim 16$ mag in each cluster field.

Below lists some possible scientific contributions by the LOCS:

1. Significant improvements in obtaining reliable essential parameters of Galactic open clusters

   The large amount of up-to-date homogeneous open cluster data from LAMOST would lead to the most reliable membership determination for sample clusters, using accurate
radial velocity data. These, then will significantly purify the color-magnitude diagrams of hundreds of open clusters and provide the best basis for obtaining the essential parameters of clusters, such as distances and ages.

2. Probing spatial and dynamical structure of the Galactic disk with open clusters

Open clusters are excellent tracers of the potential of galactic disk. By utilizing radial velocities and proper motions from outside catalogs, one would be able to trace the structure and kinematics of the disk as a function of position in the Galaxy. Especially, a) Kinematic data of OCs will also allow us to systematically study the galactocentric rotation velocity, which will provide definitive estimates of the mass of the Galaxy, a fundamental parameter that at present has errors of determination; b) Furthermore, combining with chemical abundance and age of OCs, one will be able to probing the correlations between age, velocity, abundance and as a function of position in the Galaxy. This will be an ideal data set for studying the dynamical evolution of the thin disk.

3. Chemical evolution of the Galactic disk

From the homogeneous OCs abundance database of LAMOST, we are able to: a) Decisively determine the disk metallicity gradient, with a large span of galactocentric distance parameter of the OCs; b) Together with the OCs age parameter, investigate spatial variation and temporal evolution of the metallicity gradient, thus providing key constraints on the chemical evolution model of the Galaxy. c) Furthermore, the Galactic age-metallicity relation, the kinematic and dynamical characters of the Galactic disk as well as their relation to the chemical properties will also be improved greatly.

4. Stellar candidates with special astrophysical interests in open clusters

From LAMOST OCs survey data, with a complete membership list and distance, age etc. parameters available, we are able to make further studies on circum-stellar disks, X-ray emission, multiplicity, as well as objects like T Tauri, HH stars, magnetic binary, Cepheid, Blue Stragglers, etc. in the star clusters.

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References