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Kinematic and chemical properties of five open clusters based on SDSS DR7 *

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Abstract We present metallicities and radial velocities for five old open clusters (NGC 6791, NGC 2420, NGC 2682, NGC 2158, and NGC 7789) using data from the seventh public data release of the Sloan Digital Sky Survey (SDSS), which includes the directed stellar program SEGUE: Sloan Extension For Galactic Understanding and Exploration. The radial velocities are used to calculate cluster membership probabilities for stars in each cluster region. NGC 6791, NGC 2420, NGC 2682, NGC 2158 and NGC 7789 are found to have mean metallicities [Fe/H]= $+0.08 \pm 0.09$, -0.38 ± 0.11, -0.08 ± 0.05, -0.41 ± 0.13 and -0.19 ± 0.13 dex (s.d.), respectively. The mean radial velocities for NGC 6791, NGC 2420, NGC 2682, NGC 2158 and NGC 7789 are $V_{\rm r} = -45.9 \pm 0.2$, $+76.1 \pm 0.2$, $+35.0 \pm 0.2$, $+26.9 \pm 0.2$ and $-48.2 \pm 0.2\ {\rm km\ s^{-1}}$(s.e.m.), respectively. We have compared our results with the values from literatures, and found that our metallicity of NGC 6791 is significantly underestimated (by about 0.3 dex) and our radial velocities of the open clusters agree well with the values derived using high-resolution spectroscopy.

Key words: open clusters and associations: general — open clusters and associations: individual (NGC 6791, NGC 2420, NGC 2682, NGC 2158, NGC 7789)

1 INTRODUCTION

Open clusters (hereafter OCs) have long been regarded as powerful tools for studies of the Galactic disk and evolution of stars. Compared to field stars, OCs have the important advantages of being coeval groups of stars, being at the same distance and sharing the same chemical composition and space motion. Distances to OCs can be determined with relatively small uncertainties. Moreover, OCs have relatively stable orbital motions, which can be used as a better tracer of Galactic disk structure. OCs also have a wide range of ages, from several Myrs to some Gyrs, spanning the lifetime of the Galactic disk. Therefore, combining their spatial distribution and kinematic information, OCs become ideal test particles for studying Galactic dynamical evolution. In particular, very young OCs are among the best targets for studies of the stellar initial mass function and the structure of the

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Galactic spiral arms. Furthermore, providing chemical information, OCs can be used to investigate the chemical evolutionary history of the Galactic disk (Carraro et al. 1998; Chen et al. 2003).

At present, the total number of detected OCs and associations is around 1700 (Dias et al. 2002, and updates), about 60% of which have distance and age information and for about half of them proper motions are available. Less than one-fourth of the samples have both measured proper motion and radial velocity parameters, and only a small subset of $\sim$140, about 8% of the total, possesses some metallicity determinations. For metallicity estimation of OCs, in most cases, they have been obtained by means of different photometric observations (e.g. Twarog et al. 2003; Cameron 1985). The lack of large, homogeneous high quality spectroscopic determinations of chemical compositions and radial velocities for OCs will hamper the studies of the Galactic disk. The release of the SDSS-II/SEGUE database provides uniform, precise radial velocity and chemical abundance measurements for a large number of OCS. In this work, we try to probe the kinematic and chemical properties of five open clusters based on the SDSS DR7.

2 OBSERVATIONAL DATA AND TARGET SELECTION

The SDSS and its extensions use a dedicated 2.5 m telescope (Gunn et al. 2006) located at Apache Point Observatory in New Mexico. The telescope is equipped with an imaging camera and a pair of spectrographs, each of which are capable of simultaneously collecting 320 moderate-resolution ($R \simeq 1800$) spectra, with wavelength coverage in the range 3900 Å $\sim$ 9000 Å, over the seven square degree field of view, so that on the order of 600 individual target spectra and roughly 40 calibration-star and sky spectra are obtained on a given spectroscopic "plug-plate" (York et al. 2000).

One of three sub-surveys carried out during the first extension of SDSS, known as SDSS-Π, the Sloan Extension for Galactic Understanding and Exploration (SEGUE), ran from 2005 July to 2008 June. The low-latitude SEGUE photometric observation area includes 15 $2.5°$-wide stripes of data along constant Galactic longitude, spaced at approximately $20°$ intervals around the sky. Meanwhile, the spectroscopic plate pointings sparsely sample sky areas with available imaging data, designed to probe the major known Galactic structures (especially thin and thick regions) (Yanny et al. 2009).

The SEGUE Survey provides a large sample of more than 240 000 spectra of stars with a wide variety of spectral types, both main sequence and evolved (Yanny et al. 2009). Stellar atmospheric parameters ($T_{\rm eff}$, $\log g$, [Fe/H]), based on SDSS $ugriz$ photometry and spectroscopy, are derived by application of the SEGUE Stellar Parameter Pipeline (SSPP) described by Lee et al. (2008a,b) and Allende Prieto et al. (2008). The resulting radial velocity accuracies for stars are $\sigma(\rm RV) \sim 4\,km\,s^{-1}$ at $g < 18$ mag, degrading to $\sigma_{(\rm RV)} \sim 15\,\rm km\,s^{-1}$ at g $\sim$20 mag (Yanny et al. 2009). For the abundance, the typical uncertainty of the SSPP-determined values $\sigma_{([\rm Fe/H])} = 0.13$ (Lee et al. 2008b)

Although there are 416 plates in the SEGUE database, all but 17 of the 212 SEGUE pointings have a bright and faint plates of ~ 580 targets each (Yanny et al. 2009). In this work, only the sample clusters, which lie within 1.5° from the centers of SEGUE plates, have been selected. Finally, we obtain 27 sample clusters after matching the OCs from the new catalog of open clusters (Dias et al. 2002, and updates) with SEGUE plates. In this work, we only select a sample of five open clusters (NGC 6791, NGC 2420, NGC 2682, NGC 2158, and NGC 7789), where an adequate number of star radial velocity values have been determined and can be used to effectively separate cluster member stars from field stars, to investigate their radial velocities and metallicity properties. More details on references for coordinate, age, distance and reddening of the five open clusters can be found in Table 1 (Dias et al. 2002).

Two methods have been used to estimate the radial velocities of stars from the SDSS spectroscopic pipeline. One is the absorption-line redshift obtained by cross-correlating the spectra with templates that were acquired from SDSS commissioning spectra (Stoughton et al. 2002). The other comes from matching the spectra with ELODIE template spectra (Prugniel & Soubiran 2001). The

Table 1 Basic Information on the Five Open Clusters

Cluster	R.A. (J2000.0) (h: m: s)	Dec. (J2000.0) (d: m: s)	$\log(t)$	Distance (pc)	$E(B-V)$ (mag)
NGC 6791	19 20 53	+37 46 18	9.6	5853	0.12
NGC 2420	07 38 23	+21 34 24	9.1	2480	0.04
NGC 2682	08 51 18	+11 48 00	9.4	908	0.06
NGC 2158	06 07 25	+24 05 48	9.0	5071	0.36
NGC 7789	23 57 24	+56 42 30	9.2	1795	0.28

Table 2 Distribution Parameters of the Five Open Clusters

Parameter	NGC 6791	NGC 2420	NGC 2682	NGC 2158	NGC 7789
$n_{\rm c}$	0.41	0.36	0.46	0.48	0.24
$v_{\rm c}$	–45.9	75.9	35.1	26.6	–48.0
$\sigma_{\rm c}$	2.3	2.1	1.5	2.6	3.4
$v_{\rm f}$	–25.6	36.7	48.2	12.0	–42.2
$\sigma_{\rm f}$	34.1	35.7	33.1	22.4	23.9

velocity based on the ELODIE template matches appears to be the best estimate (Lee et al. 2008a), and we adopted this velocity in our work. The metallicity we adopted uses "feha," which is the biweight average of an estimate derived from multiple techniques. The combination of multiple techniques results in estimates of metallicity values that are more robust over a much wider range than those estimated by an individual method (Lee et al. 2008a).

3 RADIAL VELOCITIES AND METALLICITIES

3.1 Determination of Cluster Membership

The estimation of the membership probability involves the radial velocity (RV) distributions for both field and cluster stars. We assume that the RVs of cluster members follow a Gaussian distribution and field stars follow another Gaussian distribution. Then the distribution function for field stars, $\Phi_{{\rm f}i}$, and for cluster stars, $\Phi_{{\rm c}i}$, can be written as

$$\Phi_{{\rm f}i} = \frac{1-n_{\rm c}}{2\pi(\sigma_{\rm f0}^2+\epsilon_i^2)}\alpha_i, \quad \Phi_{{\rm c}i} = \frac{n_{\rm c}}{2\pi(\sigma_{\rm c0}^2+\epsilon_i^2)}\beta_i, \tag{1}$$

$$\alpha_i = \exp\left\{-\frac{1}{2}\left[\frac{(v_i-v_{\rm f})^2}{\sigma_{\rm f0}^2+\epsilon_i^2}\right]\right\}, \tag{2}$$

$$\beta_i = \exp\left\{-\frac{1}{2}\left[\frac{(v_i-v_{\rm c})^2}{\sigma_{\rm c0}^2+\epsilon_i^2}\right]\right\}, \tag{3}$$

where $n_{\rm c}$ is the normalized number of member stars, v_i is the radial velocity of the i-th star and ε_i the estimated observational error. $(v_{\rm f}, v_{\rm c})$ are the RV distribution centers of field stars and cluster members respectively, and $(\sigma_{\rm f0}, \sigma_{\rm c0})$ the intrinsic RV dispersions of field stars and cluster members.

These five parameters, n_c, $(v_{\rm f}, v_{\rm c})$ and $(\sigma_{\rm f0}, \sigma_{\rm c0})$, were estimated by a maximum likelihood method. In order to search for the maximum of the likelihood function, a bipartition algorithm was adopted (Wang 1997). We list distribution parameters of the five open clusters in Table 2.

After the distribution parameters are determined, the membership probability of the i-th star can be calculated as:

$$P_i = \frac{\Phi_{{\rm c}i}}{\Phi_i} = \frac{\Phi_{{\rm c}i}}{\Phi_{{\rm c}i}+\Phi_{{\rm f}i}}. \tag{4}$$

Table 3 SSPP Parameters and Membership Probabilities of Selected Stars for NGC 6791

Plate	MJD	Fid	RA (°)	Dec (°)	RV (km s^{-1})	RV err (km s^{-1})	[Fe/H] (dex)	[Fe/H] err (dex)	S/N	P
2821	54393	179	290.23318	37.69495	–46.1	1.0	0.03	0.05	67.7	0.92
2821	54393	493	290.73611	38.19503	–46.7	0.9	–0.07	0.02	61.1	0.92
2800	54326	496	290.36243	37.83635	–45.1	0.8	0.18	0.08	47.0	0.92
2800	54326	482	290.57947	37.92975	–46.8	0.9	–0.11	0.01	54.5	0.92
2800	54326	180	290.22034	37.75919	–46.8	0.5	0.20	0.08	62.7	0.92
2821	54393	141	290.29285	37.73219	–46.5	1.0	0.05	0.06	47.8	0.92
2800	54326	154	290.25604	37.80142	–46.2	1.3	0.13	0.04	55.2	0.92
2800	54326	190	290.17673	37.76421	–46.3	1.1	0.17	0.05	51.1	0.92
2800	54326	161	290.26886	37.72120	–46.2	1.3	–0.04	0.12	30.3	0.92
2800	54326	185	290.16345	37.74368	–46.7	0.7	0.10	0.06	61.2	0.92
2800	54326	471	290.21030	37.83430	–46.1	1.3	0.23	0.13	36.3	0.92
2821	54393	173	290.23404	37.72550	–46.4	1.2	0.08	0.08	39.8	0.92
2821	54393	174	290.27438	37.76822	–46.0	1.2	0.03	0.06	37.5	0.92
2800	54326	189	290.16876	37.78517	–45.9	1.1	0.12	0.13	38.7	0.92
2800	54326	170	290.21915	37.74116	–45.8	1.3	0.14	0.03	64.4	0.92
2821	54393	472	290.26776	37.82575	–45.6	1.0	0.14	0.09	42.6	0.92
2821	54393	194	290.18384	37.77736	–45.3	1.0	0.06	0.06	49.0	0.92
2821	54393	436	290.12585	37.81327	–45.2	1.1	0.05	0.06	43.5	0.92
2800	54326	424	290.13763	37.82931	–46.0	1.8	0.19	0.04	24.6	0.91
2821	54393	177	290.25525	37.78111	–44.6	1.1	0.05	0.04	40.7	0.91
...	...	...	...	...	...	...	...	...	...	...

Finally, the membership probabilities calculated for each star are used to estimate average metallicities and radial velocities of each cluster. Over all, our membership determination is effective (see Fig. 1), cluster stars are effectively separated from field stars (see Figs. 2, 4, 6 and 8). However, cluster and field stars can not be fully discerned with radial velocity information only. Some stars with high probability located well away from the centers of the clusters (see Figs. 2 and 8) and/or with distinct metallicity (see Figs. 3, 5, 7, 9 and 11) indicate that these stars may be field stars. Particularly, when estimating the mean metallicity of a cluster, we deleted outliers with a 3σ clip. In the following, we will define those with $P_i \geq 0.7$ as true cluster member stars for NGC 6791, NGC 2420, NGC 2682, and NGC 2158 and $P_i \geq 0.6$ for NGC 7789.

In Table 3 we have compiled the RV and metallicity parameters extracted from SDSS DR7 for stars in the region of each of the five OCs, respectively. In Table 3, we listed the plate number, MJD, fiber id, equatorial position, RV, and metallicity as well as the corresponding error estimates. These tables are presented in their entirety in the electronic edition. A portion is shown here for guidance regarding the form and content.

3.2 NGC 6791

NGC 6791 ($\alpha_{\rm J2000}$=19:20:53 and $\delta_{\rm J2000}$= +37:46:18) is an extremely interesting and intriguing open cluster. The combination of old age, high metal abundance, and large distance from the Galactic plane makes it a very attractive target. For this reason it has been the subject of many photometric (Kinman 1965; Kaluzny 1990; Montgomery et al. 1994; Kaluzny & Rucinski 1995; Stetson et al. 2003; Carney et al. 2005; Anthony-Twarog et al. 2007) and spectroscopic (Friel & Janes 1993; Peterson & Green 1998; Friel et al. 2002; Worthey & Jowett 2003; Carraro et al. 2006; Gratton et al. 2006; Boesgaard et al. 2009) investigations. A total mass of $\geq 4000\,M_{\odot}$ was suggested (Kaluzny & Udalski 1992), and an age estimation covers the 6–12 Gyr range, as inferred from both optical and IR photometry (see e.g Kaluzny & Udalski 1992; Tripicco et al. 1995; Chaboyer et al. 1999; Stetson et al. 2003; Carney et al. 2005; Carraro et al. 2006), depending on the adopted reddening and metallicity. Estimates of the cluster reddening also vary, from $E(B-V) = 0.1$ (Janes 1984) to

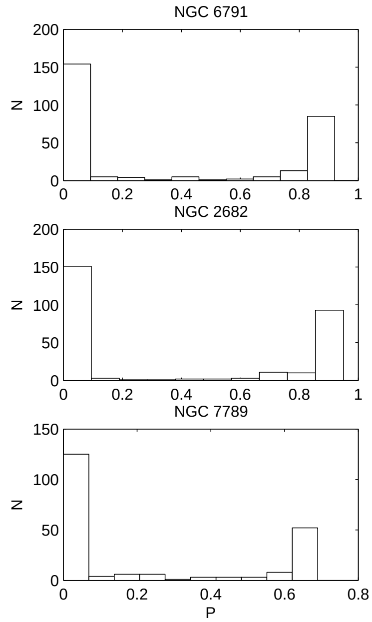

Fig. 1 Histogram of membership probabilities for stars in the five open cluster regions.

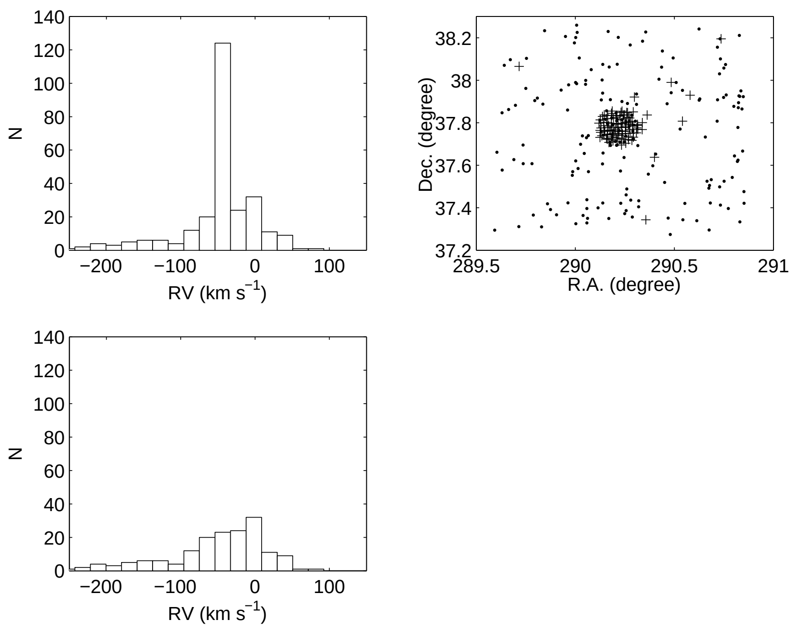

Fig. 2 (*Top left*) Distributions of RVs for all stars in the region of NGC 6791; (*Top right*) The black crosses indicate stars with membership probabilities $P \geq 0.7$ in the region of NGC 6791, and the black dots indicate stars with membership probabilities $P < 0.7$; (*Bottom left*) Distributions of RVs for field stars ($P < 0.7$) in the region of NGC 6791.

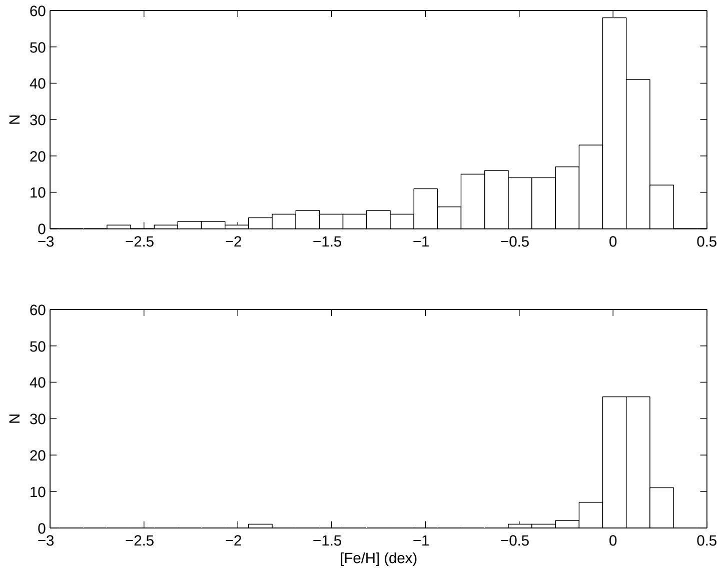

Fig. 3 (*Top*) Distributions of [Fe/H] for all stars in the region of NGC 6791; (*Bottom*) Distributions of [Fe/H] for cluster members ($P \geq 0.7$).

$E(B-V) = 0.22$ (Kinman 1965). Anthony-Twarog et al. (2007) found $E(B-V) = 0.155 \pm 0.016$ based on Strömgren photometry. The low galactic latitude, large distance and high metallicity make it difficult to calibrate the reddening effects (Boesgaard et al. 2009).

Low- and moderate-resolution spectroscopy (Friel & Janes 1993; Peterson & Green 1998; Friel et al. 2002; Worthey & Jowett 2003) have been used to estimate metallicity. Friel & Janes (1993) derived a value of [Fe/H]$= +0.19 \pm 0.19$ from the nine member stars with moderate-resolution spectra. A value of [Fe/H]$= +0.11 \pm 0.10$ was determined by 39 member stars with moderate-resolution spectroscopic data (Friel et al. 2002). The first work that was based on medium-high resolution spectra was the one by Peterson & Green (1998), who measured the coolest BHB star, which was confirmed to be a member star at $R = 20\,000$, finding an iron abundance [Fe/H]$= +0.4 \pm 0.1$. Two high-resolution spectroscopic studies of the Red Giant Branch (RGB) and red clump stars have been performed by Carraro et al. (2006) and Gratton et al. (2006), finding [Fe/H]$= +0.39 \pm 0.05$ and [Fe/H]$= +0.47 \pm 0.08$ respectively. High-resolution infrared spectra at $R = 25\,000$ have also been used to determine the iron abundance; a value [Fe/H]$= +0.35 \pm 0.02$ was suggested (Origlia et al. 2006). Very recently, a high value [Fe/H]$= +0.30 \pm 0.08$ was confirmed on two turnoff stars with high resolution spectroscopy at $R = 45\,000$ (Boesgaard et al. 2009). Most recent metallicity determinations based on high-resolution spectroscopic work seem to agree on a supersolar abundance close to [Fe/H]$= +0.4$ dex.

We find a mean abundance [Fe/H]$= +0.08 \pm 0.09$ (s.d.) from 91 member stars using the abundance provided by SSPP, which is significantly lower than the values obtained based upon moderate- and high-resolution spectra (about 0.3 dex). Metallicities of four member stars in our work have also been determined by high-resolution spectroscopic work (see Table 4).

The mean radial velocity for NGC 6791 has been measured many times in the past. Kinman (1965) estimated a value of $-68\ \mathrm{km\,s^{-1}}$ based on low-resolution spectra. Geisler (1988) reported a value of $-44.5 \pm 1.9\ \mathrm{km\,s^{-1}}$(s.d.) based on medium-resolution spectra of 11 member stars. Using moderate-resolution spectra of nine member stars, Friel et al. (1989) obtained $-48 \pm 9\ \mathrm{km\,s^{-1}}$.

Table 4 Comparison of the SSPP-derived Metallicities with Metallicities Derived from Higher Resolution Spectra of the Same Stars in NGC 6791

ID	R.A. (J2000.0)	Dec (J2000.0)	$[\mathrm{Fe/H}]^{\mathrm{a}}$	$[\mathrm{Fe/H}]^{\mathrm{b}}$	P
10898	19 21 01.13	+37 42 13.80	0.38 ± 0.08	0.15 ± 0.05	0.90
11814	19 21 04.27	+37 47 18.90	0.34 ± 0.08	0.07 ± 0.06	0.91
8082	19 20 52.89	+37 45 33.40	0.38 ± 0.05	0.20 ± 0.08	0.92
2014	19 21 01.10	+37 46 39.60	0.40	0.08 ± 0.06	0.81

Notes: $[\mathrm{Fe/H}]^{\mathrm{a}}$ are the metallicity values based on high-resolution spectra; stars 10898, 11814 and 8082 are from Carraro et al. (2006) and star 2014 is from Gratton et al. (2006); $[\mathrm{Fe/H}]^{\mathrm{b}}$ values are calculated by SSPP; P is the membership probability in this work.

Garnavich et al. (1994) reported a value of $-47.6 \pm 1.7\ \mathrm{km\,s^{-1}}$ using low-resolution spectra of RGB candidates. Scott et al. (1995) derived a mean value of $-57 \pm 2\ \mathrm{km\,s^{-1}}$ based upon moderate-resolution spectra of 41 stars. Friel et al. (2002) reported $-57 \pm 10\ \mathrm{km\,s^{-1}}$ from 39 member stars based on low-resolution spectra. Carraro et al. (2006) obtained a mean value of $-47.1 \pm 0.8\ \mathrm{km\,s^{-1}}$ with a dispersion of $\sigma_{\mathrm{r}} = 2.2 \pm 0.4\ \mathrm{km\,s^{-1}}$ from 15 member stars based on high-resolution spectra.

We obtain a weighted mean (weighted by membership probability) radial velocity $V_{\mathrm{r}} = -45.9 \pm 0.2\ \mathrm{km\,s^{-1}}$(s.e.m.) from 101 member stars ($P \geq 0.7$), which is in excellent agreement with some values derived from moderate- and/or high-resolution spectroscopic studies. The radial velocity dispersion of NGC 6791 calculated in Table 2 agrees well with the value derived by Carraro et al.'s (2006).

3.3 NGC 2420

NGC 2420 (α_{J2000}=07:38:23 and δ_{J2000}=+21:34:24) is an old, moderately metal-deficient open cluster beyond the solar circle. The orbit has a significant eccentricity and a large epicyclical amplitude (Carraro & Chiosi 1994a). In the 1960s and 1970s, several high-quality photometric works already appeared for the cluster (Sarma & Walker 1962; West 1967; Cannon & Lloyd 1970; van Altena & Jones 1970; McClure et al. 1974, 1978). Several photometric and spectroscopic observations have been done to determine the metallicity of the cluster, with the result of finding it has a value around that of 47 Tuc (Pilachowski et al. 1980; Cohen 1980; Canterna et al. 1986; Smith & Suntzeff 1987; Anthony-Twarog et al. 1990). A recent photometric study finished by Anthony-Twarog et al. (2006) gave the value [Fe/H]$= -0.37 \pm 0.05$ based on CCD photometry of the intermediate-band vbyCaH system. In our work, the mean metallicity of the 191 member stars is [Fe/H]$= -0.38 \pm 0.11$(s.d.), which is in excellent agreement with that of Anthony-Twarog et al. (2006) but slightly higher than the value determined by Gratton (2000) using high-resolution spectra of a single member star ([Fe/H]$= -0.44$) and the one [Fe/H]$= -0.47$ which was derived based on high-resolution spectra of four giant stars (Smith & Suntzeff 1987). Friel & Janes (1993) reported a value [Fe/H]$= -0.42$ based on medium- and low-resolution spectroscopy of nine member stars. Friel et al. (2002) determined [Fe/H]$= -0.38 \pm 0.07$ based on medium-resolution spectra of 20 member stars. Very recently, Lee et al. (2008b) computed a value [Fe/H]$= -0.38 \pm 0.10$ from 163 member stars using the same data as us. A recent work should be mentioned that high-resolution spectra ($R \sim 30\,000$) of three red clump stars in the cluster have been used to analyze iron and other key element abundances; a value of $-0.05 \pm 0.03(\pm 0.10)$ for the iron abundance was reported (Pancino et al. 2010).

Concerning the RV of the open cluster, the first value $\sim 115\ \mathrm{km\,s^{-1}}$ was obtained from three member stars by McClure et al. (1974). Using two of the same stars which McClure et al. (1974) observed, Cohen (1980) determined a mean velocity $\sim +75\ \mathrm{km\,s^{-1}}$. Smith & Suntzeff (1987) published a value $+73\ \mathrm{km\,s^{-1}}$ from four of the brightest giant stars which they observed. Collier Cameron & Reid (1987) found a velocity $+68 \pm 9\ \mathrm{km\,s^{-1}}$ based on low-resolution spectra of 16

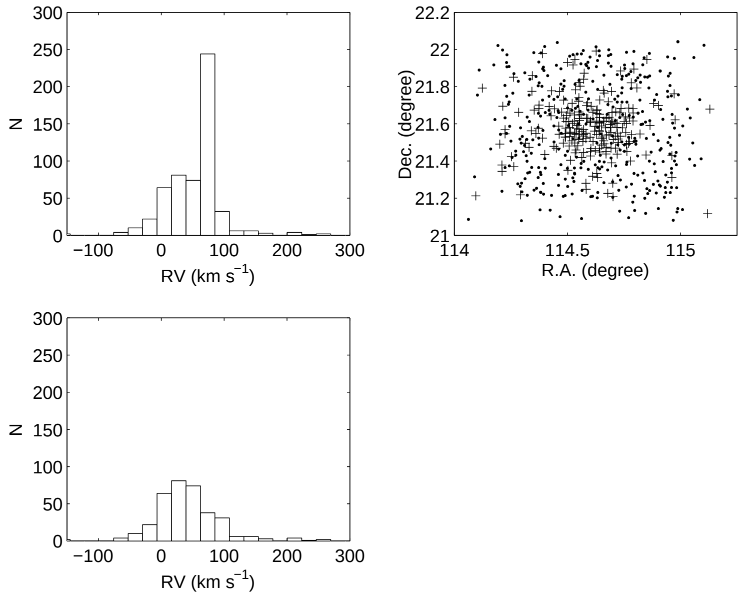

Fig. 4 (*Top left*) Distributions of RVs for all stars in the region of NGC 2420; (*Top right*) The black crosses indicate stars with membership probabilities $P \geq 0.7$ in the region of NGC 2420, and the black dots indicate stars with membership probabilities $P < 0.7$; (*Bottom left*) Distributions of RVs for field stars ($P < 0.7$) in the region of NGC 2420.

member stars. Liu & Janes (1987) gave a value of $+70 \pm 1.4$ km s^{-1} based on high-resolution spectra of six member stars. Scott et al. (1995) reported $+67.0$ km s^{-1} from 19 member stars. Friel et al. (2002) derived $+67 \pm 8$ km s^{-1} using low-resolution spectra of 20 member stars. Lee et al. (2008b) derived a mean value of $+75.1 \pm 5.9$ km s^{-1} using similar data as us. Mermilliod et al. (2008) improved the value to $+73.57 \pm 0.15$ km s^{-1} from 18 member stars based on high-resolution spectra. Our estimate is $+76.1 \pm 0.2$ km s^{-1} based on 207 member stars.

3.4 NGC 2682 (M 67)

Among the old OCs, NGC 2682 ($\alpha_{\rm J2000}$=08:51:18 and $\delta_{\rm J2000}$=+11:48:00) is very close to us. With its low reddening (Table 1) and solar metallicity, it is one of the well studied OCs. Among the vast literatures on NGC 2682, there are several determinations of its metallicity with various methods, and there has been a rather wide scatter in the estimates of the metallicity. Photometric studies led to several values of metallicity, [Fe/H]= -0.23 (Eggen 1983), –0.05 (Janes & Smith 1984), -0.06 ± 0.07 (Nissen et al. 1987). Early spectroscopic studies also gave wide scatter values, for example, +0.6 by Spinrad & Taylor (1969) and –0.1 by Burstein et al. (1986). Garcia Lopez et al. (1988) determined a mean metallicity [Fe/H]= $+0.04 \pm 0.04$ based on high-resolution observations ($R \sim 20\,000$) of seven turnoff stars. Friel & Boesgaard (1992) reported [Fe/H]= $+0.02 \pm 0.12$ from three F dwarfs observed with moderate-resolution spectroscopy. Friel et al.(2002) found a value [Fe/H]= -0.15 ± 0.05 based on 25 moderate-resolution spectra. Gratton (2000) derived a value [Fe/H]= $+0.02$ from the high-resolution analysis of a single member star. Shetrone & Sandquist (2000) estimated [Fe/H]= -0.05 based on high-resolution spectra of ten blue stragglers and MTO stars. Yong et al. (2005) determined a value [Fe/H]= $+0.02 \pm 0.03$ from a high-resolution ($R \sim 28\,000$) spectroscopic analysis of three member stars. Randich et al. (2006) found an av-

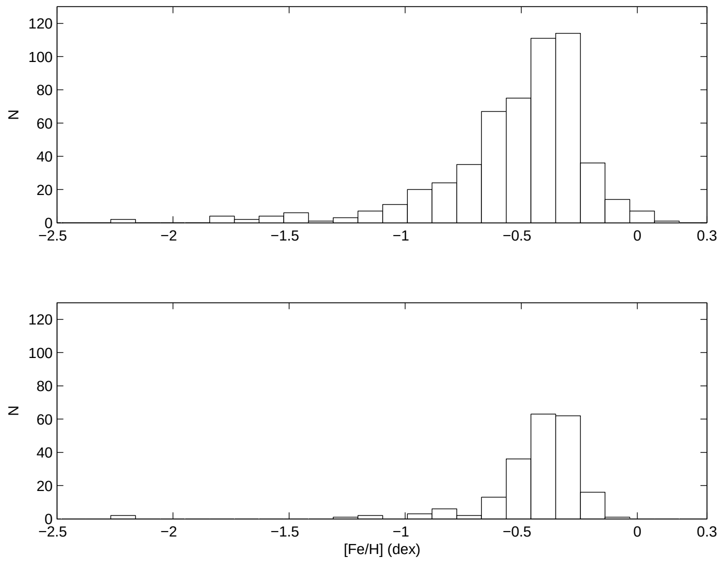

Fig. 5 (*Top*) Distributions of [Fe/H] for all stars in the region of NGC 2420; (*Bottom*) Distributions of [Fe/H] for cluster members ($P \geq 0.7$).

erage metallicity [Fe/H]= 0.03 ± 0.01 from spectra of eight unevolved and two slightly evolved member stars. A value of [Fe/H]=-0.08 ± 0.07 was reported by Lee et al. (2008b) using the same data as us. Very recently, Pancino et al. (2010) gave a value [Fe/H]= $+0.05 \pm 0.02(\pm 0.10)$ based on high-resolution ($R \sim 30\,000$) spectra of three red clump giants. We find a mean metallicity [Fe/H]= -0.08 ± 0.05 from 94 member stars, which is consistent with the values derived based on several high-resolution spectroscopic studies.

For the RV of NGC 2682, Girard et al. (1989) derived $+33.6 \pm 0.72$ km s^{-1}, based on a large set of member stars. Scott et al. (1995) reported $+32$ km s^{-1} from 26 member stars. A value of $+33 \pm 8$ km s^{-1} from 25 member stars was estimated by Friel et al. (2002). Yong et al. (2005) obtained a very similar value, $+33.3$ km s^{-1}, from three members stars. Mermilliod et al. (2008) confirmed a value of $+33.52 \pm 0.29$ km s^{-1} from 23 member stars. The values published above are all in good agreement with our mean value $+35.0 \pm 0.2$ km s^{-1}, which was calculated from 111 high probability ($P \geq 0.7$) member stars.

3.5 NGC 2158

NGC 2158 is a rich northern open cluster of intermediate age, located low in the galactic plane toward the anti-center direction ($\alpha_{\rm J2000}$=06:7:25 and $\delta_{\rm J2000}$=+24:05:48). It is quite an interesting object due to its shape, for which in the past it was considered a possible globular cluster, It also presents an unusual combination of age and metallicity. In fact, it is an intermediate-age open cluster, but a rather metal poor one. It is a crucial object in determining the Galactic disk abundance gradient and the abundance spread at a time and place in the disk. The cluster is rather populous, and therefore it is an ideal candidate to be compared with theoretical models of intermediate-low mass stars (Carraro & Chiosi 1994b; Carraro et al. 1999).

NGC 2158 has been studied several times in the past. The first investigation was carried out by Arp & Cuffey (1962), who obtained photographic BV photometry for about 900 stars down to $V = 18.5$ mag. Photographic photometry was also obtained by Kharchenko et al. (1997) for

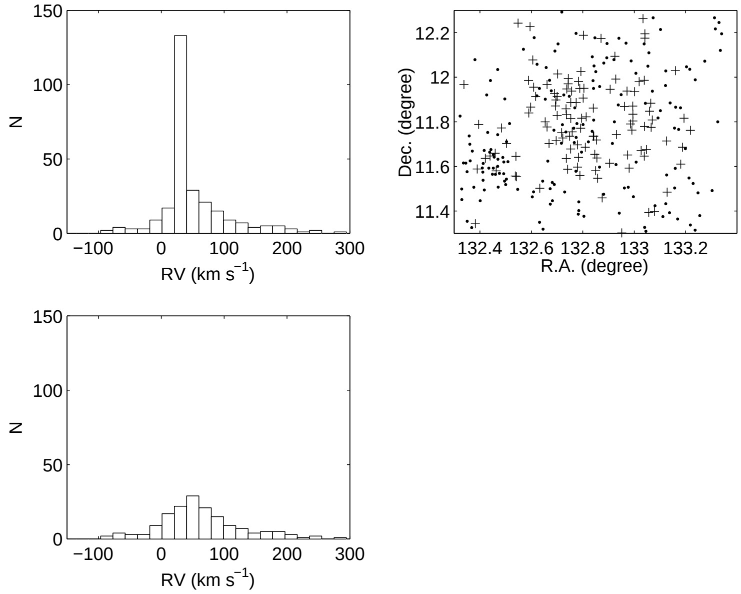

Fig. 6 (*Top left*) Distributions of RVs for all stars in the region of NGC 2682; (*Top right*) The black crosses indicate stars with membership probabilities $P \geq 0.7$ in the region of NGC 2682, and the black dots indicate stars with membership probabilities $P < 0.7$; (*Bottom left*) Distributions of RVs for field stars ($P < 0.7$) in the region of NGC 2682.

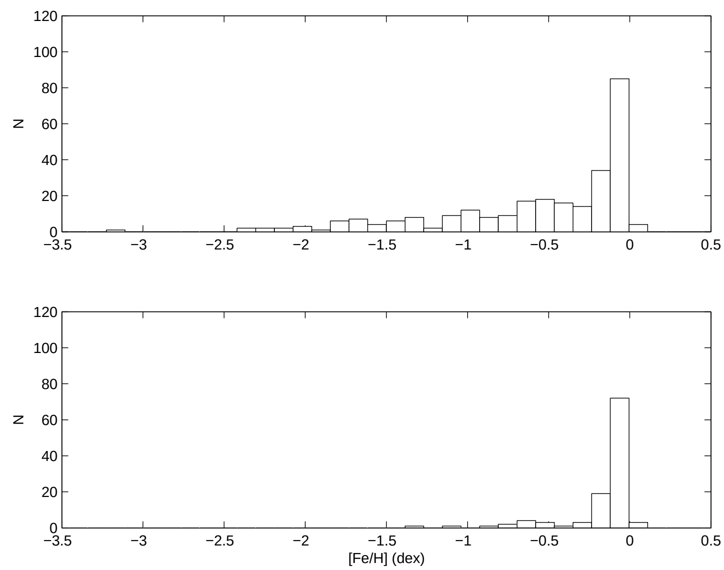

Fig. 7 (*Top*) Distributions of [Fe/H] for all stars in the region of NGC 2682; (*Bottom*) Distributions of [Fe/H] for cluster members ($P \geq 0.7$).

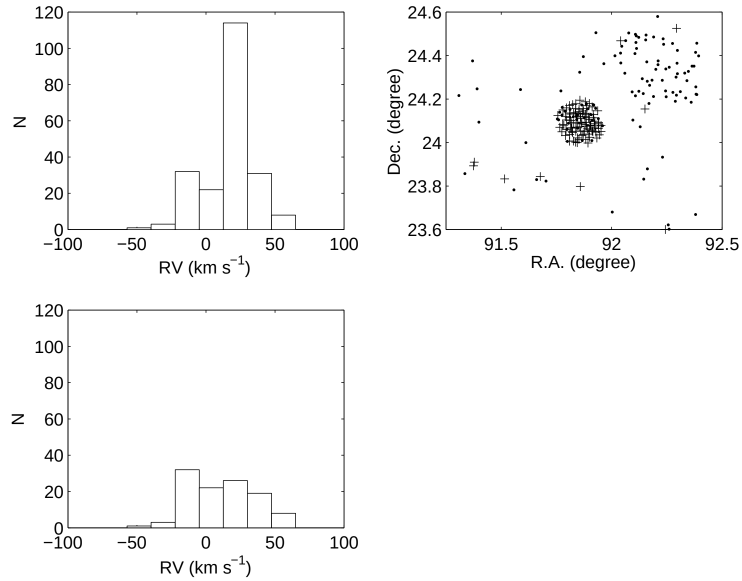

Fig. 8 (*Top left*) Distributions of RVs for all stars in the region of NGC 2158; (*Top right*) The black crosses indicate stars with membership probabilities $P \geq 0.7$ in the region of NGC 2158, and the black dots indicate stars with membership probabilities $P < 0.7$; (*Bottom left*) Distributions of RVs for field stars ($P < 0.7$) in the region of NGC 2158.

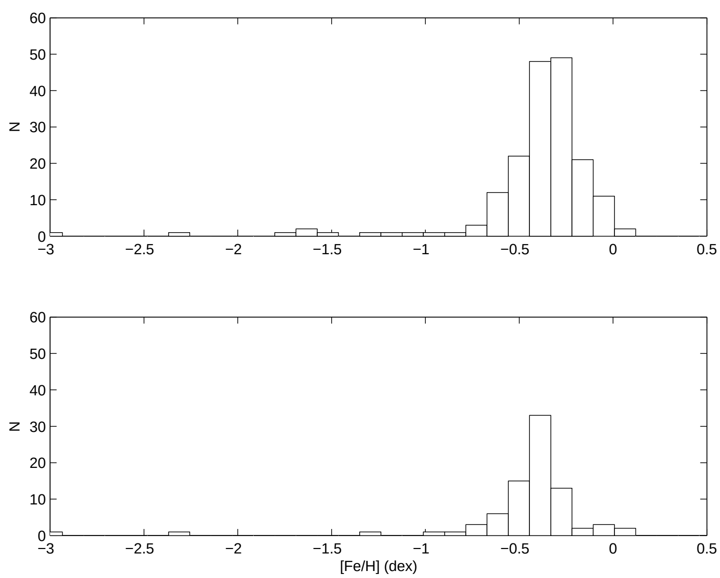

Fig. 9 (*Top*) Distributions of [Fe/H] for all stars in the region of NGC 2158; (*Bottom*) Distributions of [Fe/H] for cluster members ($P \geq 0.7$).

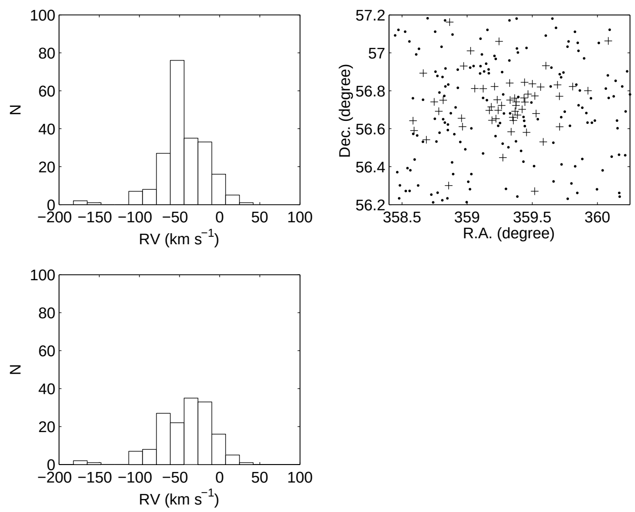

Fig. 10 (*Top left*) Distributions of RVs for all stars in the region of NGC 7789; (*Top right*) The black crosses indicate stars with membership probabilities $P \geq 0.6$ in the region of NGC 7789, and the black dots indicate stars with membership probabilities $P < 0.6$; (*Bottom left*) Distributions of RVs for field stars ($P < 0.6$) in the region of NGC 7789.

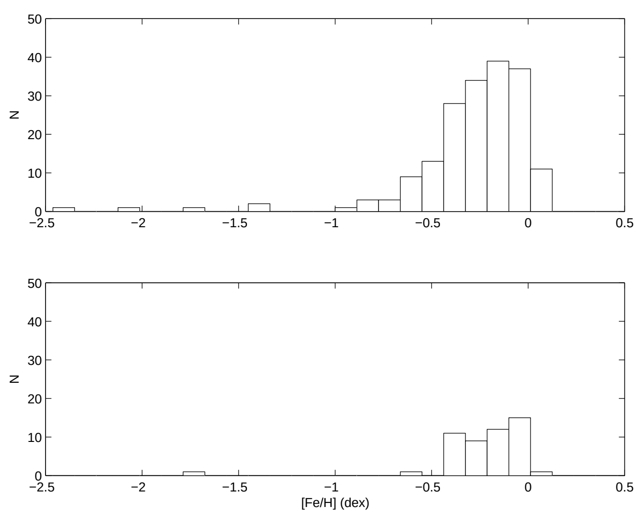

Fig. 11 (*Top*) Distributions of [Fe/H] for all stars in the region of NGC 7789; (*Bottom*) Distributions of [Fe/H] for cluster members ($P \geq 0.6$).

more than 2000 stars down to the same limiting magnitude together with proper motions. CCD photometric work was provided by Christian et al. (1985) and Piersimoni et al. (1993). There are some disagreements in the literature about the fundamental parameters of NGC 2158, especially with respect to the cluster metallicity (~ -0.2 to ~ -0.9 dex), and reddening (~ 0.5 to ~ 0.6 mag), as recently summarized by Jacobson et al. (2009).

Estimates of cluster metallicities have been obtained by several authors with both photometry and spectroscopy, and, although different, they all point to a sub-solar metallicity. Janes (1979) reported [Fe/H]= -0.64 ± 0.25 based on the *DDO* photometric study. A mean cluster abundance [Fe/H]= -0.88 ± 0.10 was given by Geisler (1987) based on photometry using the revised Washington system. Twarog et al. (1997) found [Fe/H]= -0.238 ± 0.064 (0.032 s.e.m.) based on *DDO* data from Janes (1979). Friel et al. (2002) determined [Fe/H]= -0.25 ± 0.09 based on moderate-resolution spectroscopy of seven member stars. Very recently, Jacobson et al. (2009) reported a value [Fe/H]= -0.03 ± 0.14 (s.d.) for the first time based on high-resolution ($R \sim 28\,000$) echelle spectra from one member star. We derived a value [Fe/H]= -0.41 ± 0.13 from 75 member stars. Our value is significantly lower than that of Jacobson et al.'s.

For the RV of NGC 2158, we derived an average value of $+26.9 \pm 0.2$ km s^{-1} from 100 cluster member stars. Geisler (1988) derived a weighted mean value of $+15.6 \pm 5.8$ km s^{-1} (s.d.) based on moderate-resolution spectra of two member stars. Scott et al. (1995) derived a mean value of $+28 \pm 4$ km s^{-1} (s.e.) based on seven member stars. Minniti (1995) reported a mean velocity of $+14 \pm 9$ km s^{-1} (s.d.) with typical measurement uncertainties of ~ 6 km s^{-1}. Friel et al. (2002) determined an average cluster velocity of $+28 \pm 10$ km s^{-1} (s.d.) based on seven member stars. Jacobson et al. (2009) derived a value of $+26.9 \pm 2.0$ km s^{-1}(s.d.) based on high-resolution ($R \sim 20\,000$) single-order spectra of ~ 20 stars in the region of NGC 2158, which is in excellent agreement with our value.

3.6 NGC 7789

NGC 7789 ($\alpha_{\rm J2000}$=23:57:24 and $\delta_{\rm J2000}$=+56:42:30) is a rich and intermediate-age OC, with a well defined giant branch, a well-populated main-sequence turnoff, a peculiar distribution of red clump stars in the color-magnitude diagram (Girardi et al. 2000), and a substantial population of blue stragglers (McNamara 1980; Twarog & Tyson 1985; Milone & Latham 1994), which make it an ideal target for studies of star structure and evolution. Several photometric studies have been carried out (Kustner 1923; Reddish 1954; Burbidge & Sandge 1958; Janes 1977; Martinez Roger et al. 1994; Jahn et al. 1995; Gim et al. 1998a; Vallenari et al. 2000; Bartašiutė & Tautvaišienė 2004; Bramich et al. 2005; Wu et al. 2007). Its fundamental parameters have been well studied several times: derived ages range from 1.2 Gyr (Martinez Roger et al. 1994) to 1.6 Gyr (Gim et al. 1998a), and 1.4 ± 0.1 Gyr (Wu et al. 2007); the reddening is determined as 0.28 ± 0.02 (Wu et al.2007); the distance modulus is reported to be $(m-M)_0 = 11.36 \pm 0.2$ mag (Burbidge & Sandge 1958), 11.31 mag (Arp & Cuffey 1962), 11.5 mag (Janes 1977), $(m-M)_v = 12.3 \pm 0.2$ mag (Martinez Roger et al. 1994), and recently $(m-M)_0 = 11.27 \pm 0.04$ mag (Wu et al. 2007).

Photometry and low/medium-resolution spectroscopy have been used to analyze the abundance of the cluster. Photoelectric Vilnius seven-color photometry was performed for a sample of 24 red giant branch and clump stars in NGC 7789 (Bartašiutė & Tautvaišienė 2004), and a mean overall metallicity was found to be [Fe/H] $= -0.18 \pm 0.09$ (s.d.). A metallicity with the solar composition was derived by comparing the observed spectral energy distributions of NGC 7789 stars with theoretical ones (Wu et al. 2007). Using the high-resolution spectra ($\Delta\lambda = 0.2$ Å) of six giant stars in the cluster, Pilachowski (1985) determined [Fe/H]= -0.1 ± 0.2. From the medium-resolution spectra, Friel & Janes (1993) derived [Fe/H]= -0.26 ± 0.10 for this cluster. From high-resolution spectra ($R \sim 30\,000$) of six giants and three core-helium-burning clump stars in the open cluster, Tautvaišienė et al. (2005) obtained a value of [Fe/H]= -0.04 ± 0.05. Very recently, Pancino et al. (2010) reported a value [Fe/H]= $+0.04 \pm 0.07(\pm 0.10)$ based on high-resolution ($R \sim 30\,000$) spectra of three red clump stars. We determined an overall value of [Fe/H]= -0.19 ± 0.13 from 48 member stars, which is in good agreement with the value obtained by Bartašiutė & Tautvaišienė (2004). Our value is also consistent with Friel et al.'s, but a little lower than the values based on high-resolution spectra.

Table 5 Radial Velocities and Metallicities of the Five Open Clusters

cluster	[Fe/H] (dex)	n^a	V_r (km s^{-1})	n^b	$[\mathrm{Fe/H}]_\mathrm{L}$ (dex)	n^c	V_{rL} (km s^{-1})	n^d	$[\mathrm{Fe/H}]_\mathrm{H}$ (dex)	Ref (a)	V_{rH} (km s^{-1})	Ref (b)
NGC 6791	$+0.08^{+0.09}_{-0.09}$	91	$-45.9^{+0.2}_{-0.2}$	101	$+0.11^{+0.1}_{-0.1}$	39	-57^{+10}_{-10}	39	$+0.39^{+0.05}_{-0.05}$	C	$-47.1^{+0.8}_{-0.8}$	C
NGC 2420	$-0.38^{+0.11}_{-0.11}$	191	$+76.1^{+0.2}_{-0.2}$	207	$-0.38^{+0.07}_{-0.07}$	20	$+67^{+8}_{-8}$	20	$-0.05^{+0.03}_{-0.03}$	P	$+73.57^{+0.15}_{-0.15}$	M
NGC 2682	$-0.08^{+0.05}_{-0.05}$	94	$+35.0^{+0.2}_{-0.2}$	111	$-0.15^{+0.05}_{-0.05}$	25	$+33^{+8}_{-8}$	25	$+0.03^{+0.01}_{-0.01}$	R	$+33.52^{+0.29}_{-0.29}$	M
NGC 2158	$-0.41^{+0.13}_{-0.13}$	75	$+26.9^{+0.2}_{-0.2}$	100	$-0.25^{+0.09}_{-0.09}$	7	$+28^{+10}_{-10}$	7	$-0.03^{+0.14}_{-0.14}$	J	$+26.9^{+2.0}_{-2.0}$	J
NGC 7789	$-0.19^{+0.13}_{-0.13}$	48	$-48.2^{+0.2}_{-0.2}$	54	$-0.24^{+0.09}_{-0.09}$	57	-64^{+9}_{-9}	57	$-0.04^{+0.05}_{-0.05}$	T	$-51.2^{+1.3}_{-1.3}$	P

Notes: [Fe/H] and V_r from this work; $[\mathrm{Fe/H}]_\mathrm{L}$ and V_{rL} from Friel et al. (2002); $[\mathrm{Fe/H}]_\mathrm{H}$ and V_{rH} from high-resolution spectroscopic work; n^a, n^b, n^c and n^d are the number of stars used to calculate the values [Fe/H], V_r, $[\mathrm{Fe/H}]_\mathrm{L}$ and V_{rL}, respectively.

References: C: Carraro et al. (2006); J: Jacobson et al. (2009); M: Mermilliod et al. (2008); P: Pancino et al. (2010); R: Randich et al. (2006); T: Tautvaišienė et al. (2005).

Concerning the RV of the open cluster, we determined a mean value of -48.2 ± 0.2 km s^{-1} from 54 member stars ($P >$0.6). It should be noted that for NGC 7789, the membership estimation based on RV data is not very effective because the peak of the RV distribution of cluster member stars is very close to the peak of the RV distribution of field stars (see Fig. 10). In literature, a mean RV of -45 ± 7 km s^{-1} for NGC 7789 was derived from a total of seven K giants (Strom & Strom 1970). Scott et al. (1995) reported a mean value of $= -64 \pm 1$ km s^{-1}(s.e.m) from 49 member stars. From high-resolution spectra of 50 member stars, Gim et al. (1998b) suggested a mean value -54.9 ± 0.12 km s^{-1} with a dispersion of 0.86 km s^{-1}. From low-resolution spectroscopic work, Friel et al. (2002) published a mean value of $V_r = -64 \pm 9$ km s^{-1} for 57 member stars. Pancino et al. (2010) measured the RVs of three red clump stars in NGC 7789 based on high-resolution ($R \sim 30\,000$) spectra and obtained -51.06 ± 0.99 km s^{-1}, -49.06 ± 0.81 km s^{-1} and -53.37 ± 0.81 km s^{-1} for the three stars, respectively.

4 CONCLUSIONS AND DISCUSSION

We have presented both metallicities and radial velocities of five old open clusters (NGC 6791, NGC 2420, NGC 2682, NGC 2158, and NGC 7789) based on SSPP (SEGUE Stellar Parameter Pipeline) data of SDSS DR7. Our metallicities are consistent with the values determined by Friel et al. (2002) (see Table 5). The mean metallicity of NGC 6791 derived in our work is significantly lower (~ 0.3 dex) than the values obtained based on high-resolution spectra by several authors, which all point to a value of $\sim +0.4$ dex (Table 4). As was noted that in SDSS DR6, the SSPP underestimated metallicity (by about 0.3 dex) for stars approaching solar metallicity. This was fixed in DR7 by adding synthetic spectra with super-solar metallicities to two of the synthetic grid matching techniques (NGS1 and NGS2), and by recalibrating the CaIIK2, ACF, CaIIT, and ANNRR methods. Two new techniques (ANNRR and CaIIK3) were also added to the SSPP metallicity estimation schemes, and contributed to the high-metallicity performance improvement (Abazajian et al. 2009). In this work, comparing our metallicity value for NGC 6791 with those from high-resolution spectroscopy implies that the SSPP of DR7 has still underestimated metallicity for stars with solar or super-solar metallicities. In addition, our derived RVs of the five open clusters agree well with the values derived from high-resolution spectra.

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