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Probing the Galactic Halo with RR Lyrae Stars. I. The Catalog

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Outline

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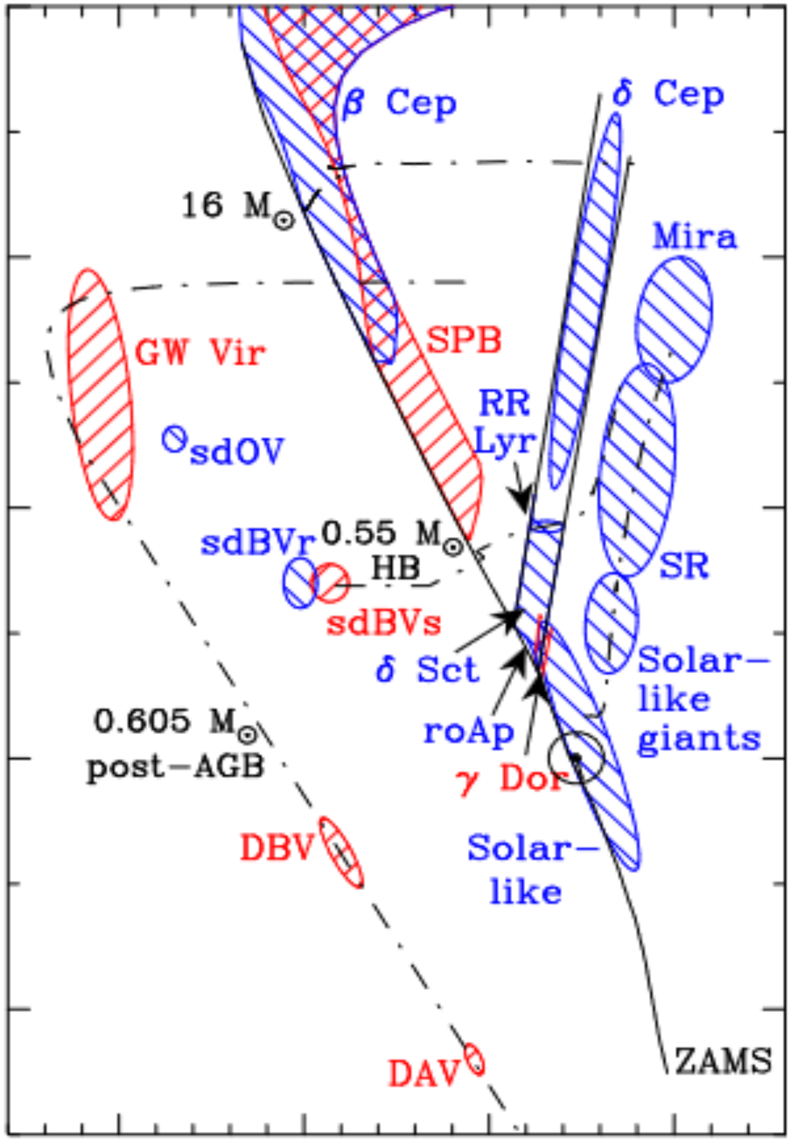
Part I　Introduction

Introduction

- RRLs are old (>9Gyr), low-mass metalpoor stars that reside in the instability strip of the horizontal branch (HB) and thus represent a fair sample of the halo populations.
- Their well defined period-luminosity relation makes them good standard candles.
- They retain a record of the chemical composition of the environment in which they were born, thus can be used to study the early stage chemical evolution of the Galaxy formation.
- They are relatively easy to identify based on their colors and variabilities, enabling the construction of samples of few contaminations.

➢ RRLs are excellent tracers to study the structure, formation, and evolution of the Galactic halo.



Introduction

- The spectroscopic data : metallicity and systemic radial velocity
- light curves provided by photometric surveys : period, phase, and amplitude
- Gaia DR2 : parallax and proper motions

- construct a large sample of RRLs with full phase space information of three-dimensional position and velocity, as well as of metallicity, and to use the sample to probe the formation and evolution of the Galactic halo.
- present a catalog of 5290 RR Lyrae stars (RRLs) with metallicities estimated from spectroscopic data . Nearly 70% of them (3642 objects) also have systemic radial velocities measured.

Part II The data

The data

RR Lyrae Stars from Photometric Surveys

- obtain a list of 32,243 unique RRLs from various time-domain photometric surveys or variable source catalogs.

Survey	Filters	Area (deg^2)	Range of V Magnitude	The Typical Number of Photometric Observations	Observation Year	Sources	Prior	Reference
Catalina	V	~33,000	12–20	60 ~ 419	2004–2011	23,306	5	1
QUEST	*UBVRI*	380/476	13.5–19.7	15 ~ 40	1998–2008	1857	2	2
NSVS	ROTSE-NT	~31,000	$V < 14$	100 ~ 500	1999–2000	1304	0	3
LINEAR	no spectra filter	8000	14–17	200 ~ 460	1998–2009	5684	4	4
LONEOS	LONEOS-NT	1430	$V < 18$	28 ~ 50	1998–2000	838	0	5
SDSS Str82	*ugriz*	249	15–21	30 ~ 40	1998–2006	601	3	6
GCVS	…	…	…	…	…	7954	1	7

Note. The references are: (1) Drake et al. (2013a, 2014), (2) Vivas et al. (2004), Mateu et al. (2012), Zinn et al. (2014), (3) Kinemuchi et al. (2006), Hoffman et al. (2009), (4) Sesar et al. (2013), (5) Miceli et al. (2008), (6) Watkins et al. (2009), Sesar et al. (2010), Süveges et al. (2012), (7) Samus et al. (2009).

Spectroscopy

- LAMOST Galactic spectroscopic surveys— 3016 common sources ,with a total of 10,667 single-exposure spectra
- Sloan Digital Sky Surey (SDSS) — 3834 common stars, with a total of 20,772 single-exposure spectra.

- A total of 6268 RRLs with a total of 31,439 single-exposure spectra are obtained. Typical S/Ns of those single-exposure spectra are around 15.

The data

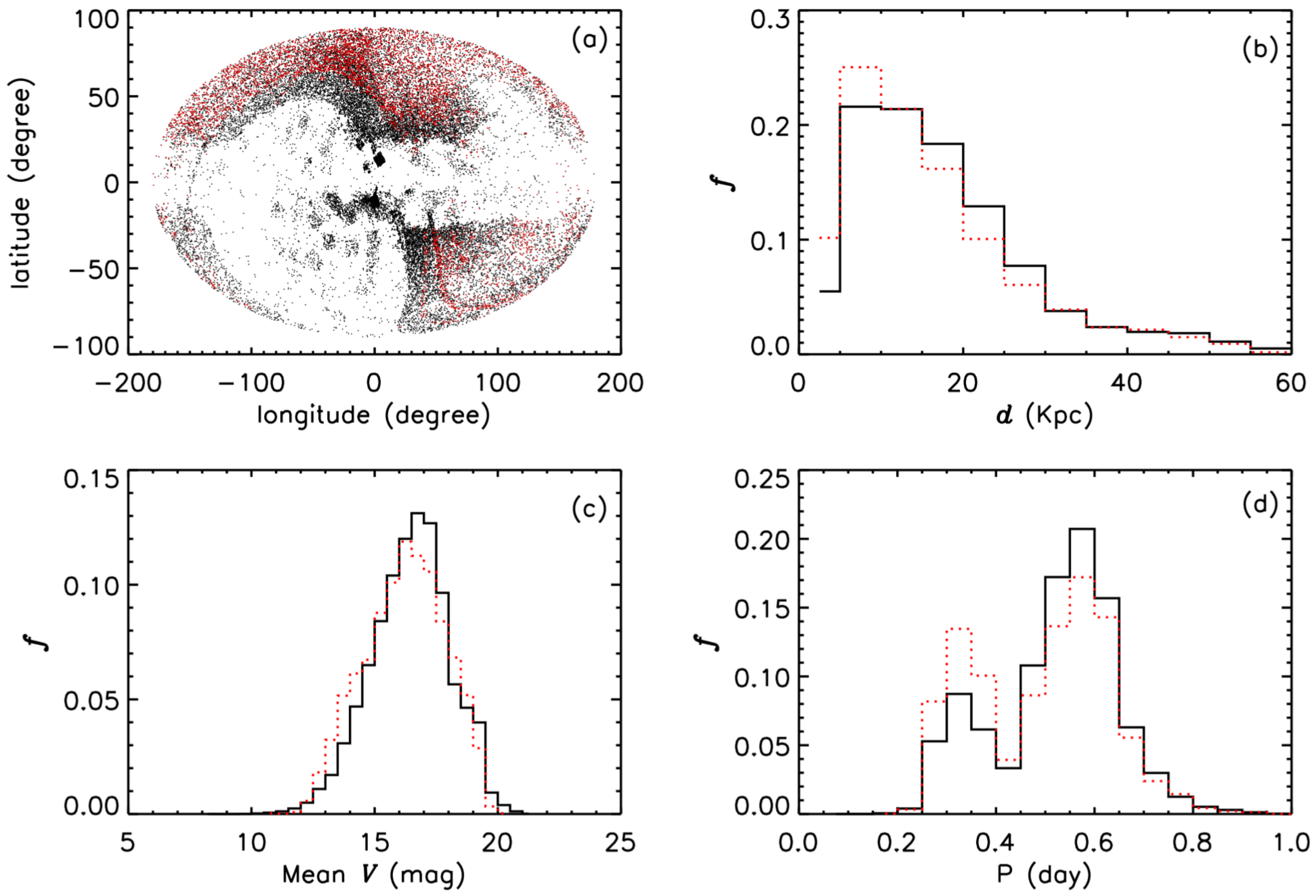


Figure 1. Basic properties of our photometric (black dots/lines) and spectroscopic (red dots/lines) RRL samples. Panel (a) shows the spatial distribution in Galactic coordinates. Panel (b) shows the normalized distribution of distances collected from the literature. Panel (c) shows the normalized distribution of mean *V*-band magnitudes. Panel (d) shows the normalized distribution of periods.

Part III Spectroscopic Metallicities

Spectroscopic Metallicities

template-matching method

Kurucz stellar model

from 3850 to 5600 Å

resolution of 2.5 Å.

- Teff : 6000-7500 K in steps of 100 K
- log g : 1.5 - 4.0 dex in steps of 0.25 dex
- [Fe/H] : −3.0 - 0.0 dex in steps of 0.1 dex.
- [α/Fe] : 0.4

➢ In order to more precisely obtain the parameters Teff and [Fe/ H], author match the observed spectra with the synthetic ones by two steps.

1. **measure the Teff by least-χ2 fitting.**

Considering that the Balmer lines (Hα, Hβ, and Hγ) are most sensitive to effective temperature, author give two times the weights of the spectral pixels that cover for lines during the fitting process.

2. **determine the [Fe/H] and the log g**

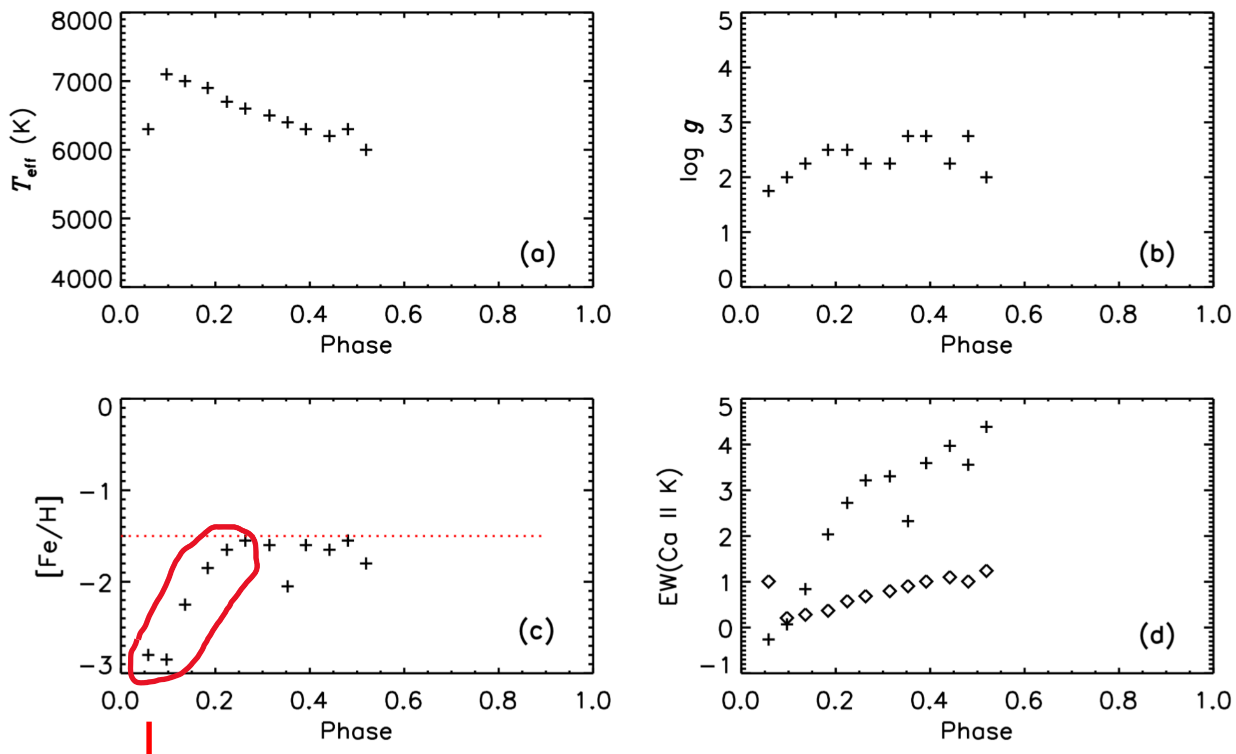
① Use the Teff value derived from the first step as input.

② Fit the Ca II K line (which is mostly sensitive to metallicity) and the continuum with the synthetic spectra, but keep Teff fixed to the value from the first step.

③ During the fitting process, mask out the spectral pixels covering the Ca II H line and the Balmer lines.

Spectroscopic Metallicities

- **Atmospheric parameters of single-exposure spectra obtained by template-matching for a RR Lyrea star with 12 exposures**



reflecting the significant effects of shock waves during those phases during the pulsation cycle.

Considering that the Ca II K line is easily affected by the shock wave effects, adopt its equivalent width (EW) as a criteria to assess whether a spectrum is affected by shock waves or not.

$$\min[\mathrm{EW(Ca\ II\ K)}] = 15.62 - 0.0037\,T_{\mathrm{eff}} + 2.21 \times 10^{-7}\,T_{\mathrm{eff}}^{2}.$$

- If EW(Ca II K) < Min[EW(Ca II K)]

consider that spectrum to be affected by shock waves, and the corresponding [Fe/H] value is ignored.

Spectroscopic Metallicities

Validation of Metallicities

- Comparison of Results from Multi-epoch Observations

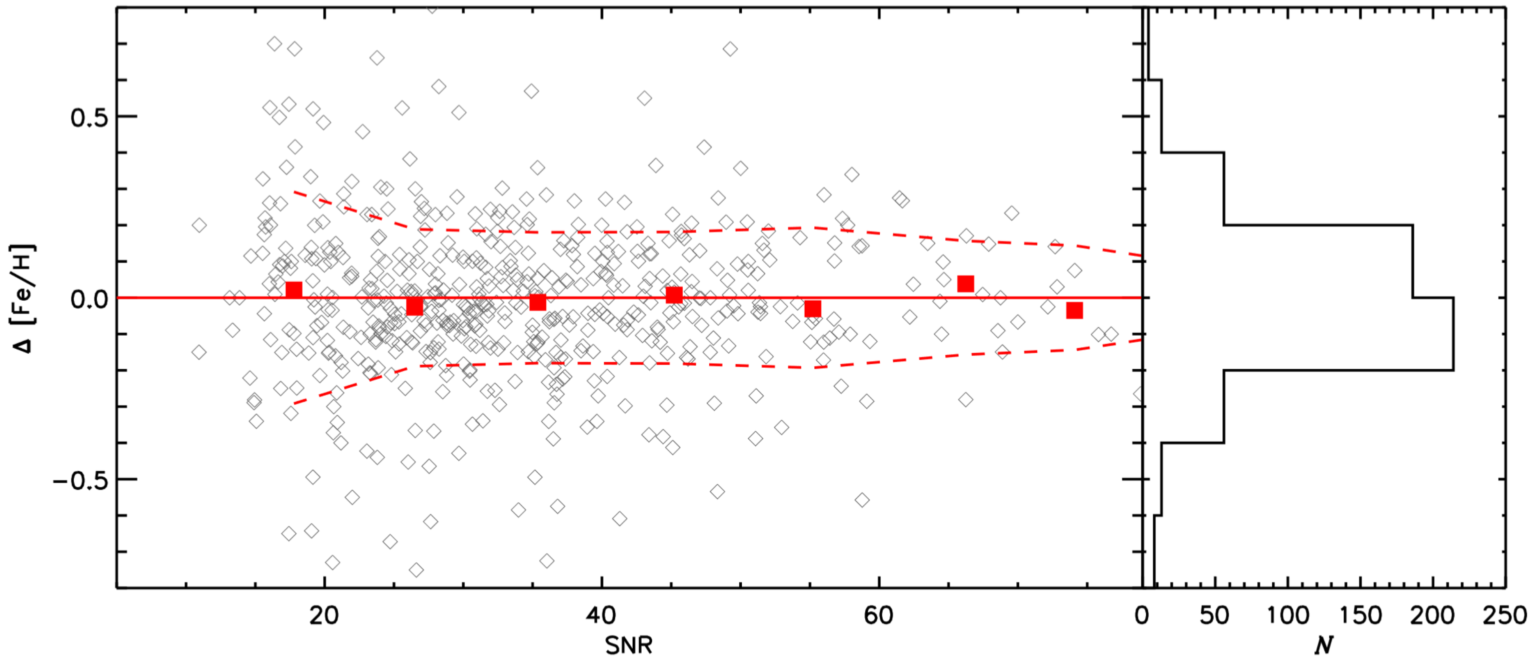


Figure 3. Left panel: difference of metallicities yielded by multi-epoch observations plotted against S/Ns. The red dashed lines mark the standard deviations. The red squares indicate the average of the differences in the individual S/N bins and the red solid line delineates zero differences. Right panel: histogram of the differences.

- the median differences are almost zero, with no significant systemic trend.
- For the observations reported here, the typical standard deviation is about 0.2 dex.

Spectroscopic Metallicities

Validation of Metallicities

- Comparison of Results with Reference Stars

- 47 reference stars
  GC members / from high-resolution spectroscopy
- a negligible offset (−0.04)
- a standard deviation of 0.22 dex

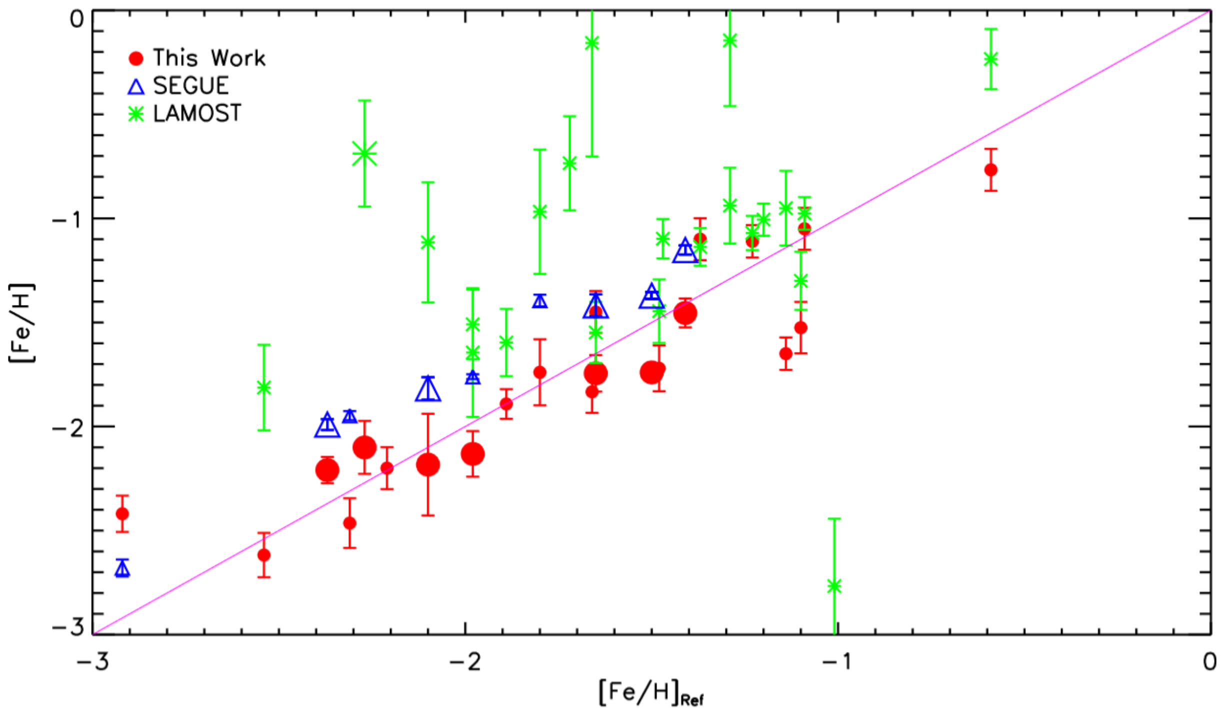
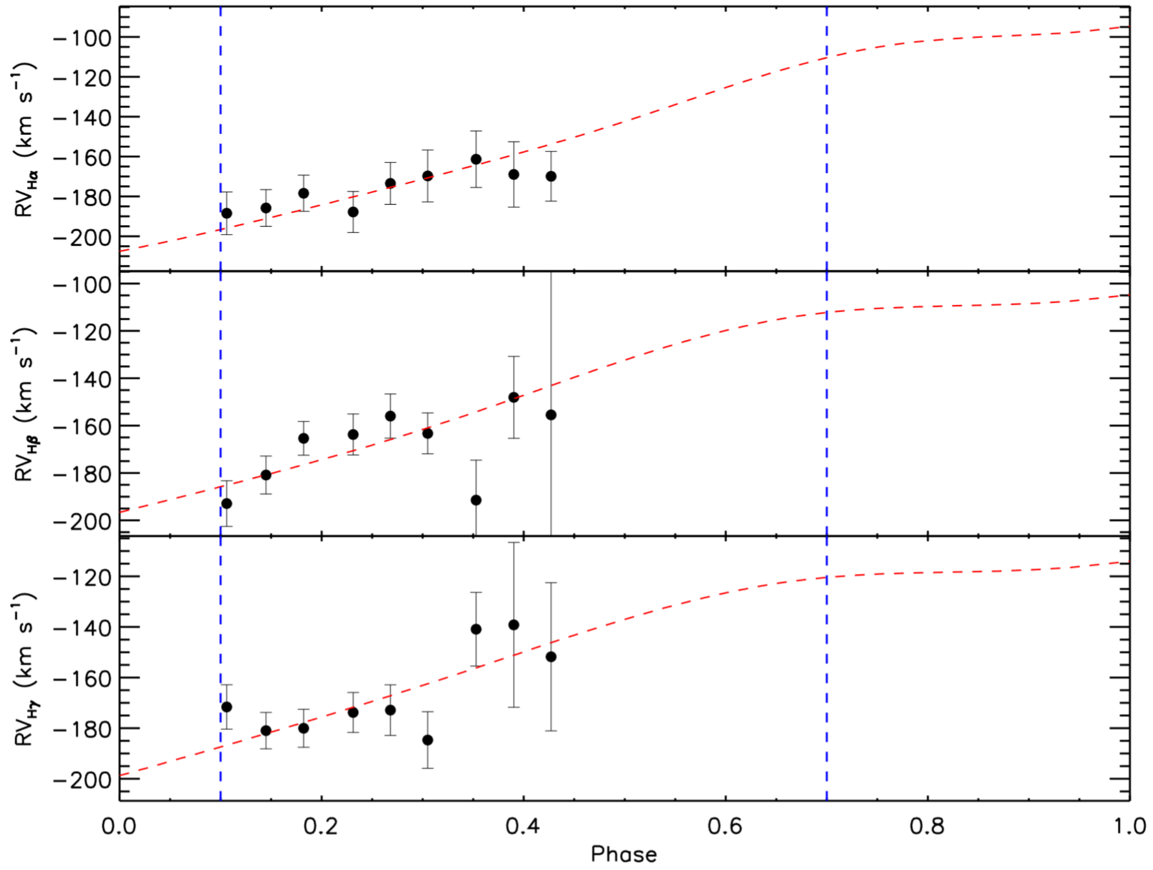


Figure 4. The metallicities of reference stars estimated in the current work (red dots), and those given by the default SEGUE (blue triangles) and LAMOST (green stars) pipelines, are plotted against the literature values. Stars in globular clusters are averaged in a single dot and represented by larger symbols.

Part IV Systemic Radial Velocities

Systemic Radial Velocities

adopt the empirical template radial-velocity curves of ab-type RRLs constructed by Sesar (2012) for Hα,Hβ, and Hγ lines. (4325 to 4357 Å for Hγ lines, 4845 to 4878Å for Hβ lines, and 6548 to 6580 Å for Hα lines, are respectively used in the fits.)



For a given star that has RVobs measured at several phases, and each line:

$$\mathrm{RV}_{\mathrm{obs}}(\Phi_{\mathrm{obs}}) = A_{rv} T(\Phi_{\mathrm{obs}}) + \mathrm{RV},$$

The final value of RV of a target is calculated by combining results from all three Balmer lines:

$$\mathrm{RV} = \frac{\mathrm{RV}_{\mathrm{H}\alpha}/\sigma_\alpha^2 + \mathrm{RV}_{\mathrm{H}\beta}/\sigma_\beta^2 + \mathrm{RV}_{\mathrm{H}\gamma}/\sigma_\gamma^2}{1/\sigma_\alpha^2 + 1/\sigma_\beta^2 + 1/\sigma_\gamma^2},$$

Systemic Radial Velocities

Validation with Reference Stars

- Reference Stars :108 common stars are foundfrom highresolution spectroscopy

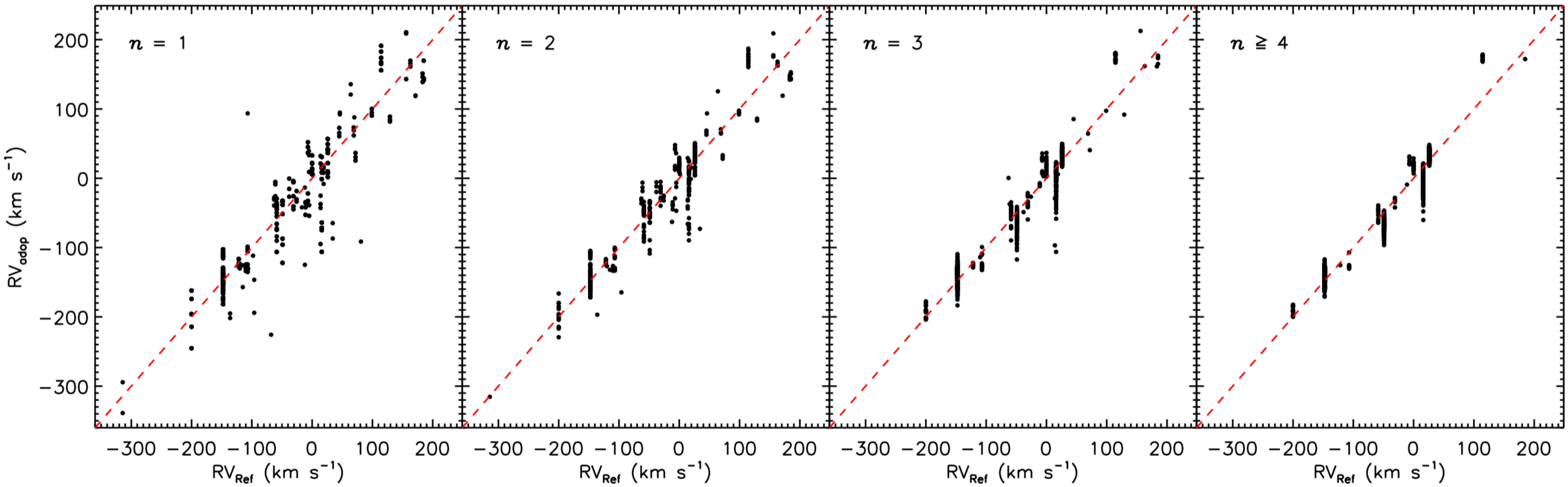


Figure 7. Comparisons of systemic radial velocities derived in the current work and those from literature. The standard deviations are 20.6, 14.6, 9.7 and 4.5 km s^{-1} for $n = 1$, 2, 3, and $\geqslant 4$, respectively.

- n > 2, the standard deviation of the systemic velocity derived is likely to be less than 10 km s−1.
- n⩾4, The expected uncertainty drops to only 4.5 km s−1

Part Ⅴ The final catlog and Conclusions

The final catlog and Conclusions

The final catlog

1. The authors compiled a catalog of 6268 RRLs(By combing the SDSS and LAMOST spectroscopic data with the photometric data of objects in the literature)
2. Measured metallicities for 5290, systemic radial velocities for 3642, and distances for 4919 of them.
3. They plan to incorporate more data to obtain precise measurements across the whole sky, benefiting the study of the Galactic halo's formation and evolution.

Conclusions

1. They present metallicity estimates for 5290 RRLs, with ~70% having radial velocity measurements. Using single-exposure spectra and excluding shock-affected data,
2. They derive systemic radial velocities through template fitting with 5-21 km/s errors, providing vital information for studying the Galactic halo.

Thank you for your attention!