Stellar Atmospheric Parameters of ∼11,000 RR Lyrae Stars from LAMOST Spectra

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Received 2023 December 10; revised 2024 April 18; accepted 2024 April 18; published 2024 May 22

(The Astrophysical Journal Supplement Series, 272:31 (12pp), 2024 June)

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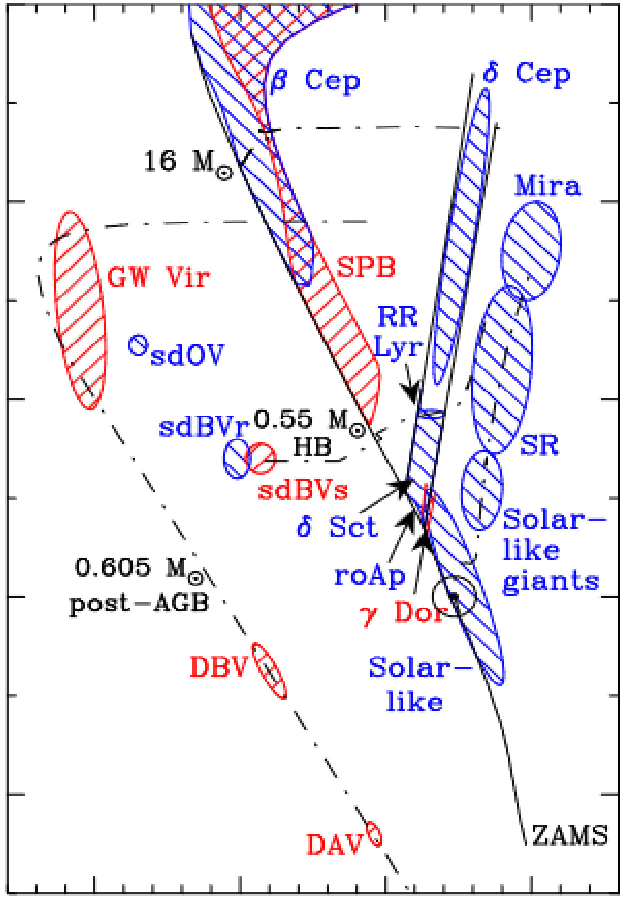
2024-10-14

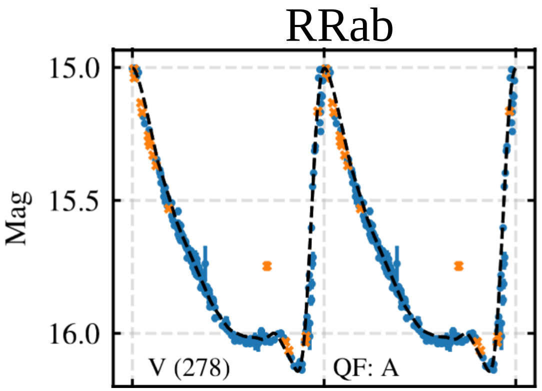
Outline

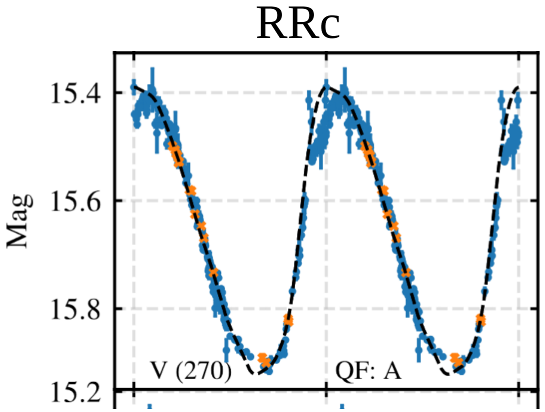
Part I　Introduction

Introduction

- The RR Lyrae stars (RRLs) are low-mass, old (with ages exceeding 10 Gyr), and generically metal-poor. They reside at the intersection of the Classical Instability Strip (IS) and the horizontal branch on the Hertzsprung-Russell diagram (HRD). Their pulsations are driven by the κ mechanism.
- The radial velocities and stellar atmospheric parameters determined through spectroscopy are invaluable for investigating the structure, chemical and kinematic properties of the Milky Way .
- Based on the pulsation modes, RRLs are classified as RRab for the radial fundamental mode, RRc for the first overtone radial mode, and RRd when both modes are present







Introduction

However, the determination of stellar atmospheric parameters for RRLs through spectra is a challenging task.

- The large amplitude of RRLs pulsations causes significant changes in their physical parameters, especially effective temperature. To minimize these effects, large-aperture telescopes are needed for short-exposure, high signal-to-noise (SNR) spectra, which result in high-resolution spectra (HRS) for only a few RRLs.
- In recent years, a multitude of extensive spectroscopic surveys have been initiated, These surveys provide a valuable opportunity to obtain the stellar atmospheric parameters for a large sample of RRLs. However, a significant limitation arises when the parameter is derived from co-added spectra taken across multiple individual exposures. This method can introduce phase contamination, particularly when observations occur over different phases .

This study introduces an improved template matching method to determine key parameters like radial velocity, effective temperature (Teff), surface gravity (log g), and metallicity ([M/H]) using single-epoch spectra from the LAMOST telescope.

Part II The data

The data

RR Lyrae sample

- **Gaia:** The RRLs catalog of Gaia DR3 contains 270,905 RRLs (Clementini et al. 2022)
- **ASAS-SN** : confirmed about 1.5 million variable stars to date, of which ~ 45,065 are RRLs (Christy et al. 2023)
- **ZTF**: A total of 46,393 RRLs have been classified using the light curves from ZTF DR2 (Chen et al. 2020).
- **PS1**: Approximately 239,044 RRLs candidates are obtained using data from the PS1 3π survey. (Sesar et al. 2017).

➢ collected about 449,093 unique RRLs candidates, of which 174,030 are located within the LAMOST field.

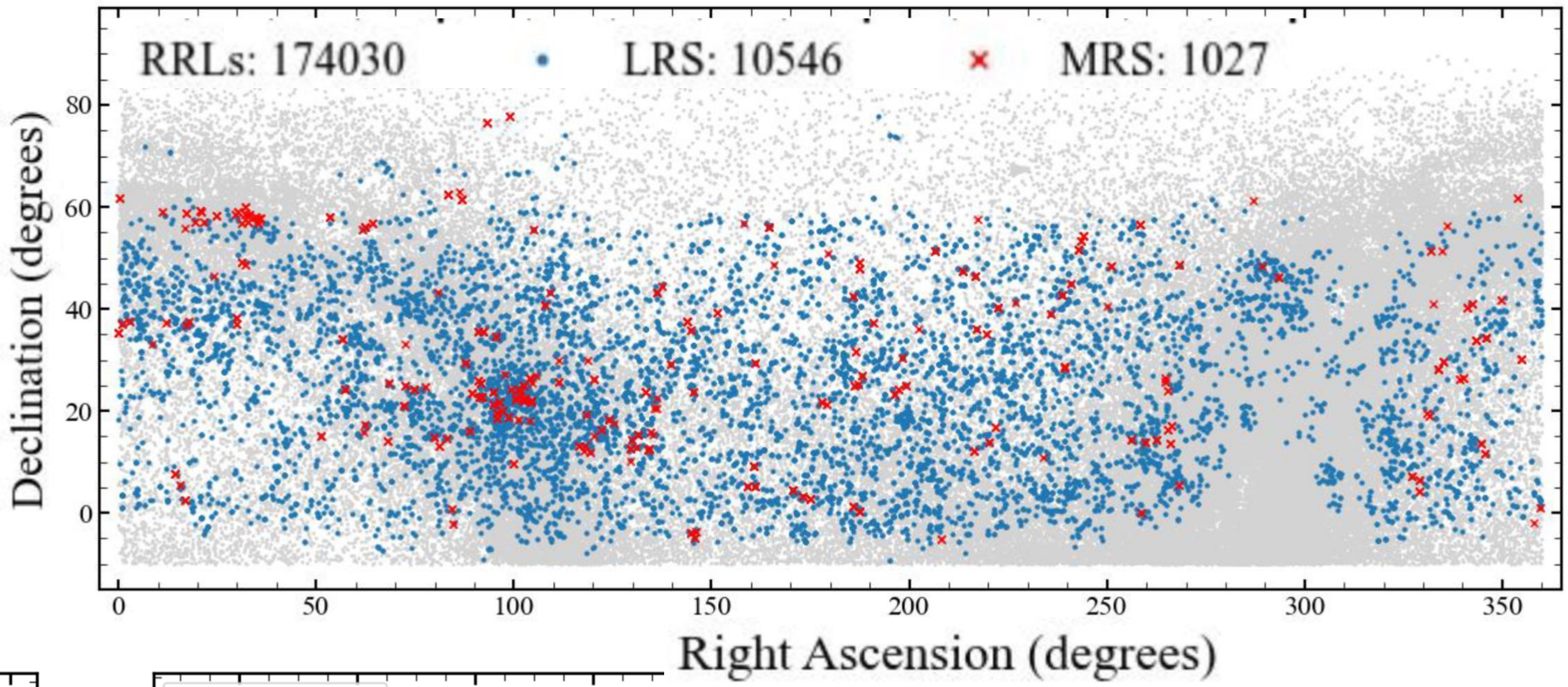
LAMOST Spectroscopy

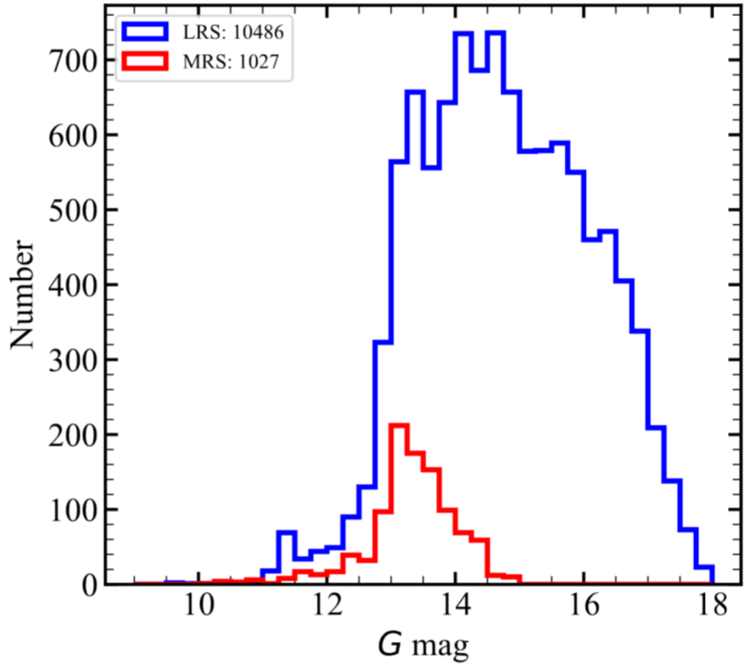
- **LRS** (Low-Resolution Spectra) from LAMOST has a resolution of $R \sim 1800$, processed through the LAMOST 2D pipeline, with blue-arm (3700–5900 Å) and red-arm (5700–9000 Å) coverage.
- **MRS** (Medium-Resolution Spectra) has a resolution of $R \sim 7500$, with blue-arm (4950–5350 Å) and red-arm (6300–6800 Å) wavelength ranges.

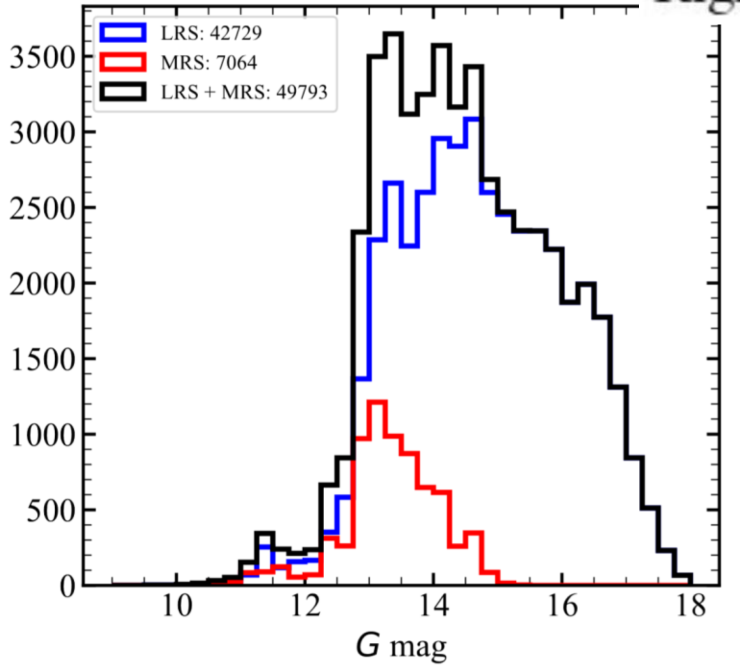
➢ cross-match the coordinates between the RRL sample from survey projects and the LRS and MRS datasets from LAMOST DR10.

- The matching criterion is based on the closest target with a coordinate separation of $\Delta d \leq 3.7$ arcseconds and $SNR \geq 10$.

The data


RRLs: 174030
LRS: 10546
MRS: 1027
Declination (degrees)
Right Ascension (degrees)


LRS: 10486
MRS: 1027
Number
G mag

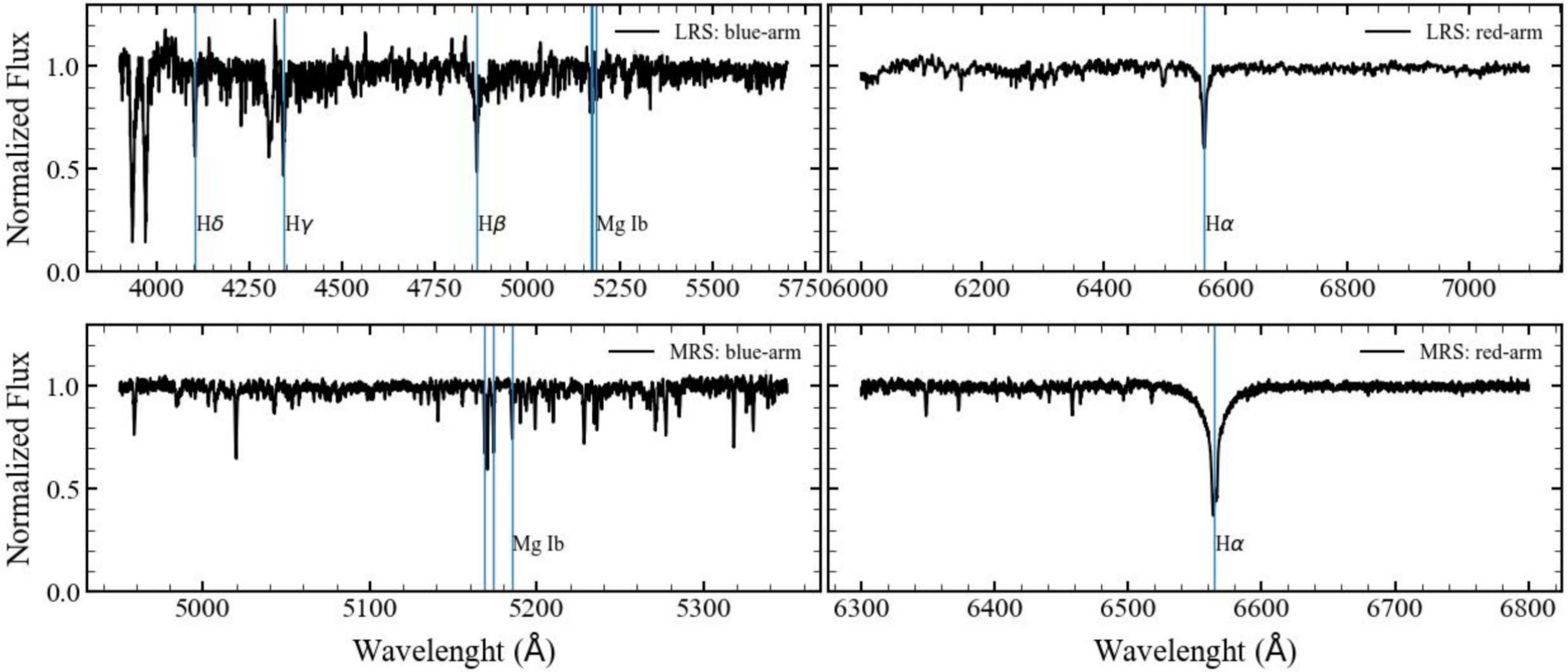

LRS: 42729
MRS: 7064
LRS + MRS: 49793
G mag

Part III
METHODOLOGY

METHODOLOGY

Spectra reduce and Radial velocities

The LRS and MRS are processed using LASPEC pipeline



- **Radial velocities (RV)** for LRS and MRS are determined using the **cross-correlation function (CCF)** in the LASPEC pipeline.
- For **LRS**, RVs are determined for Hα, Hβ, Hγ, Hδ, and metal lines(5000 ~5700 Å), from specific wavelength segments.
- For **MRS**, RVs are determined for Hα and metal lines (5000 ~5300 Å), from corresponding segments.

METHODOLOGY

Synthetic spectra

- Templates are based on three free parameters: Teff, log g, and [M/H].
- iSpec software is used to generate synthetic spectra, using:

  SPECTRUM code with Kurucz stellar models.

  VALD3 atomic line-lists and solar abundances from Asplund et al. (2009).
- 5824 synthetic spectra are calculated for each resolution: R = 1800 and R = 7500.

Parameters	range	step	LRS	MRS
$T_{\rm eff}$ (K)	5500 - 8000	100	$R = 1800$ $3600 \leq \lambda \leq 9100$ Å	$R = 7500$ $4850 \leq \lambda \leq 5450$ Å $6200 \leq \lambda \leq 6900$ Å
$\log g$ (dex)	1.4 - 4.0	0.2		
[M/H] (dex)	-3.0 - 0.0	0.2		

METHODOLOGY

Stellar Atmospheric Parameters

In order to weaken the influence of pulsation, paper determine the stellar atmospheric parameters of RRLs using an improved template matching method.

1. **Segment Selection**:

•**Teff (Effective Temperature)**: Determined using the Balmer lines (Hα, Hβ, Hγ, Hδ), as they are sensitive to temperature changes but not much to gravity.

•**log g (Surface Gravity)**: Determined using the Mg Ib triplets, which are sensitive to gravity but not to pulsations.

•**[M/H] (Metallicity)**: Determined using metal lines.

•For **LRS**, Teff is determined from the Balmer lines, and log g and [M/H] from metal lines.

•For **MRS**, Teff is determined from the red part of the spectrum ($6300 \leq \lambda \leq 6800$ Å), and log g and [M/H] from the blue part ($5000 \leq \lambda \leq 5300$ Å).

2. **Initial and Final Parameters**:

$$\chi^2 = \frac{1}{N-1}\sum_{i=1}^{N}\frac{(O_i - T_i)^2}{\sigma_i^2}$$

•Initial **Teff** is determined by Balmer lines, then **log g** and **[M/H]** are determined by fixing Teff and using metal lines.

•The final parameters are obtained by minimizing the difference between the observed and synthetic spectra using a weighted average of the optimal template.

The Radial Velocities and Stellar Atmospheric Parameters of LAMOST LRS for 10,486 RRLs

Gaiaid (1)	Obsid (2)	R.A. (3)	Decl. (4)	Period (day) (5)	φ (6)	Type (7)	HJD-2450000.5 (8)	S/N_g ($km\ s^{-1}$) (9)	$RV_{[l,metal]}$ (10)
316067369162854528	159108049	01:38:06.34	+33:00:02.41	0.652606 ± 0.000031	0.66	RRab	6560.7535	36.76	−109 ± 3
3694931747383350272	203012066	12:20:28.08	−01:33:13.73	0.592236 ± 0.000036	0.57	RRab	6659.8917	26.16	170 ± 3
4006725443696129024	508001157	12:09:49.73	+27:33:13.37	0.343563	0.82	RRc	7756.9049	10.24	−103 ± 33

$RV_{[l,H\alpha]}$ ($km\ s^{-1}$) (11)	$RV_{[l,H\beta]}$ ($km\ s^{-1}$) (12)	$RV_{[l,H\gamma]}$ ($km\ s^{-1}$) (13)	$RV_{[l,H\delta]}$ ($km\ s^{-1}$) (14)	T_{eff}[a] (K) (15)	log g[a] (dex) (16)	[M/H][a] (dex) (17)	References (18)	flag (19)
−89 ± 2	−103 ± 2	−110 ± 3	−120 ± 4	6221 ± 98	2.37 ± 0.48	−2.71 ± 0.13	Gaia	[0.99, −3.72, 0, 0]
187 ± 3	170 ± 2	171 ± 2	150 ± 6	6369 ± 95	2.41 ± 0.50	−1.00 ± 0.11	Gaia	[0,0,0.99,0]
−197 ± 7	−171 ± 4	−176 ± 14	−156 ± 10	7286 ± 161	3.47 ± 0.43	−0.58 ± 0.24	Gaia	[0, −10.51, 0.93, 0]

Table 3
The Radial Velocities and Stellar Atmospheric Parameters of LAMOST MRS for 1027 RRLs

Gaia Id (1)	Obsid (2)	R.A. (3)	Decl. (4)	Period (day) (5)	φ (6)	Type (7)	HJD-2450000.5 (8)
1376147275855922176	84338052	15:43:10.94	+36:53:33.97	0.51198 ± 0.000021	0.46	RRab	8567.7684
675464975453569664	84803006	07:54:08.77	+24:10:42.63	0.53255 ± 0.000045	0.94	RRab	8890.6552

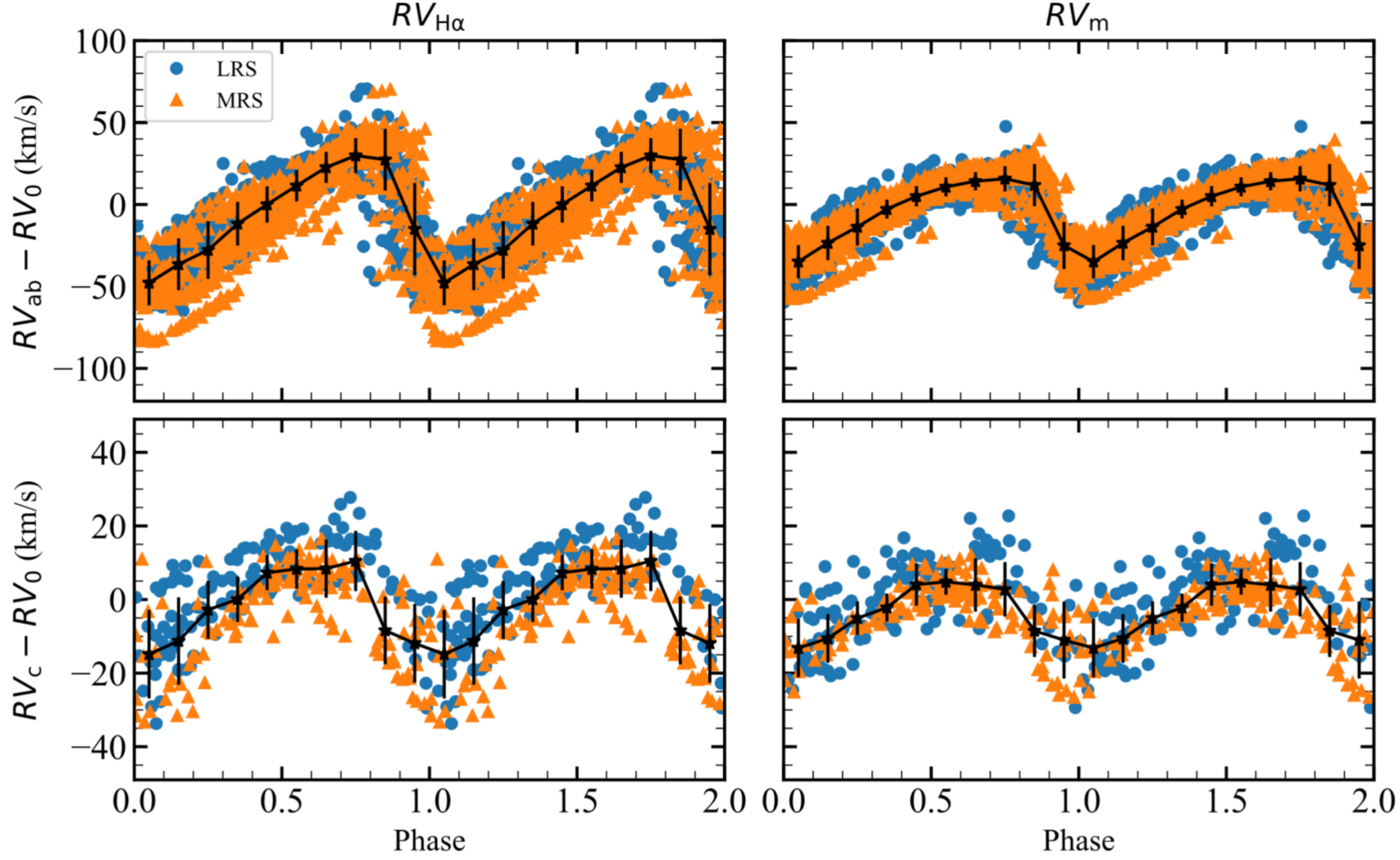
S/R_b (9)	$RV_{[m,metal]}$ ($km\ s^{-1}$) (10)	$RV_{[m,H\alpha]}$ ($km\ s^{-1}$) (11)	T_{eff} (K) (12)	log g (dex) (13)	[M/H] (dex) (14)	References (15)	Flag (16)
31.31	−58.8 ± 0.2	−66.1 ± 0.4	6040 ± 89	2.62 ± 0.65	−1.20 ± 0.10	Gaia	[0, −45.71, 0, 0]
13.46	−122.6 ± 1.2	−132.0 ± 2.0	7445 ± 50	3.23 ± 0.17	−1.24 ± 0.09	Gaia	[0.99, 0, 0.75, 0]

Part Ⅳ
Result Analysis

Result Analysis

Pulsation Variation

To study the **pulsation characteristics** of RR Lyrae stars, the paper selects targets with at least **three measurements** of stellar atmospheric parameters and **S/N ≥ 30** (g band for LRS, blue arm for MRS). The dataset includes:**121 RRab** and **25 RRc** in LRS.**98 RRab** and **21 RRc** in MRS.



Result Analysis

Pulsation Variation

1.Teff (effective temperature):

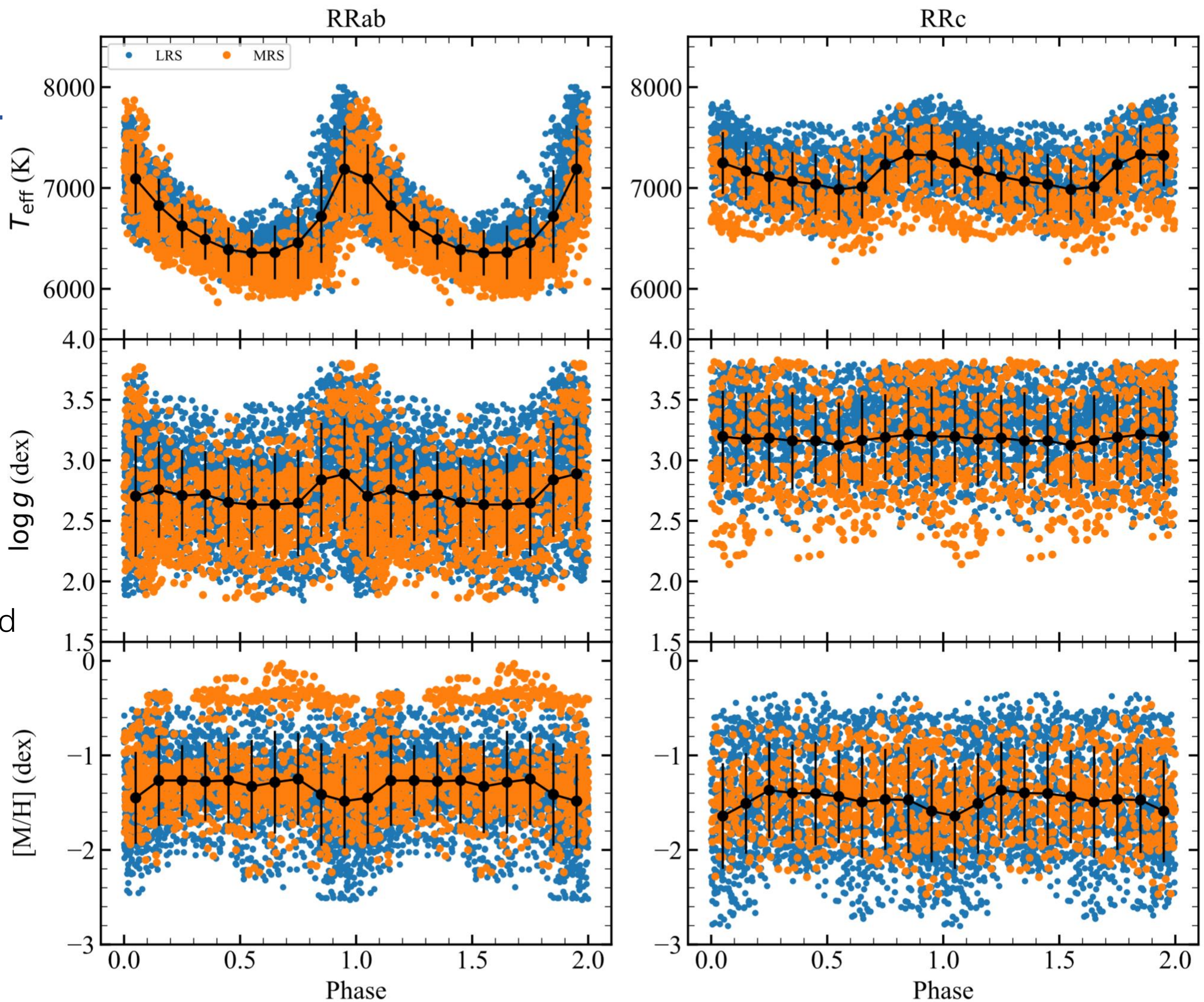
1. **RRab**： **6264 K** to **7194 K**;
2. **RRc**： **6924 K** to **7333 K**

2.log g (surface gravity):

1. **RRab**: **0.22 dex**
2. **RRc** stars show almost no variation.

3.[M/H] (metallicity):

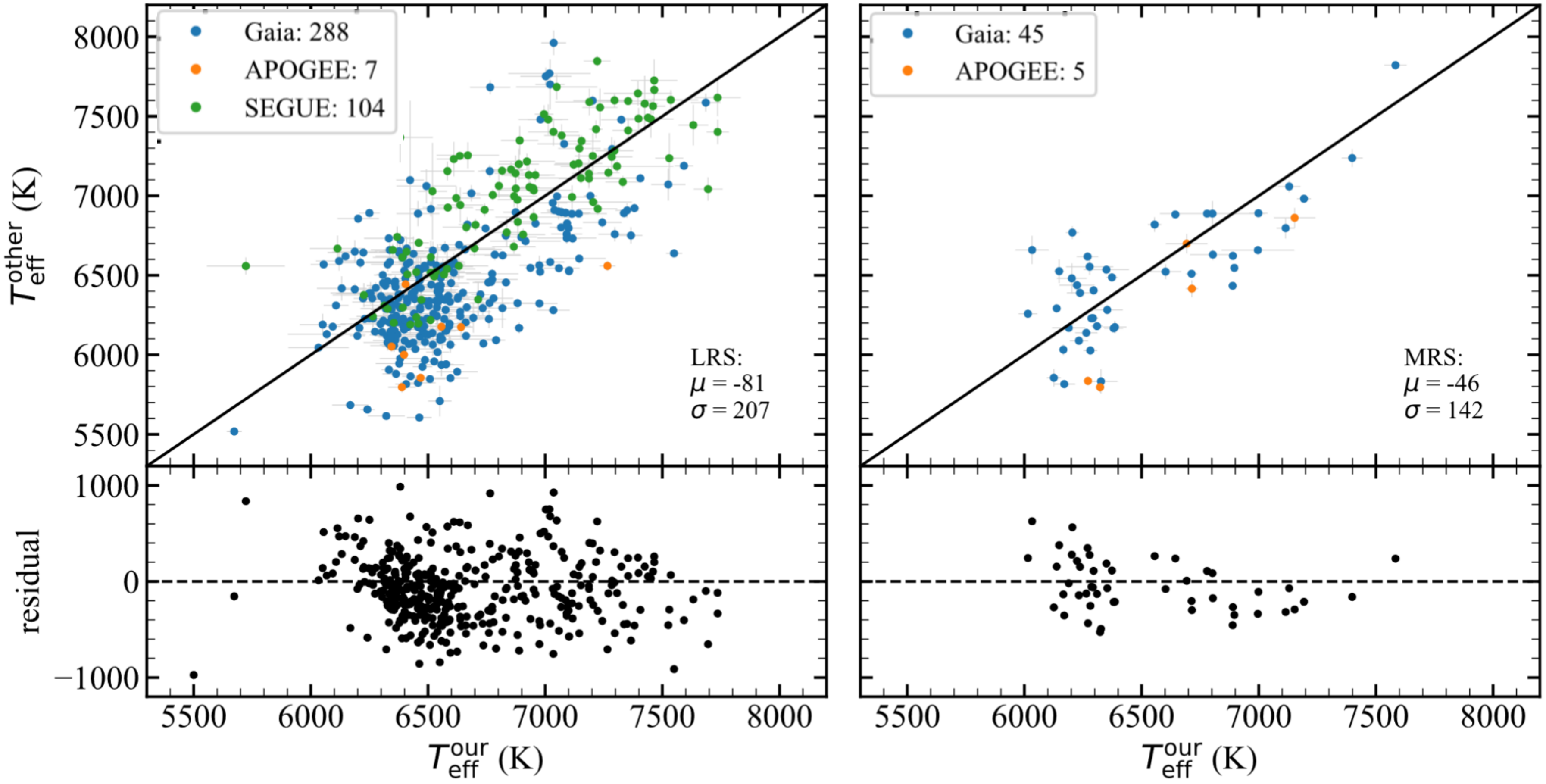
1. Both RRab and RRc display small changes in **[M/H]**, around **0.25 dex** for RRab and **0.28 dex** for RRc. while the values for the other phases remain almost consistent.
2. Many **RRab** stars from MRS data show metallicity values near **−0.50 dex**, which stay almost constant through the cycle.



Result Analysis

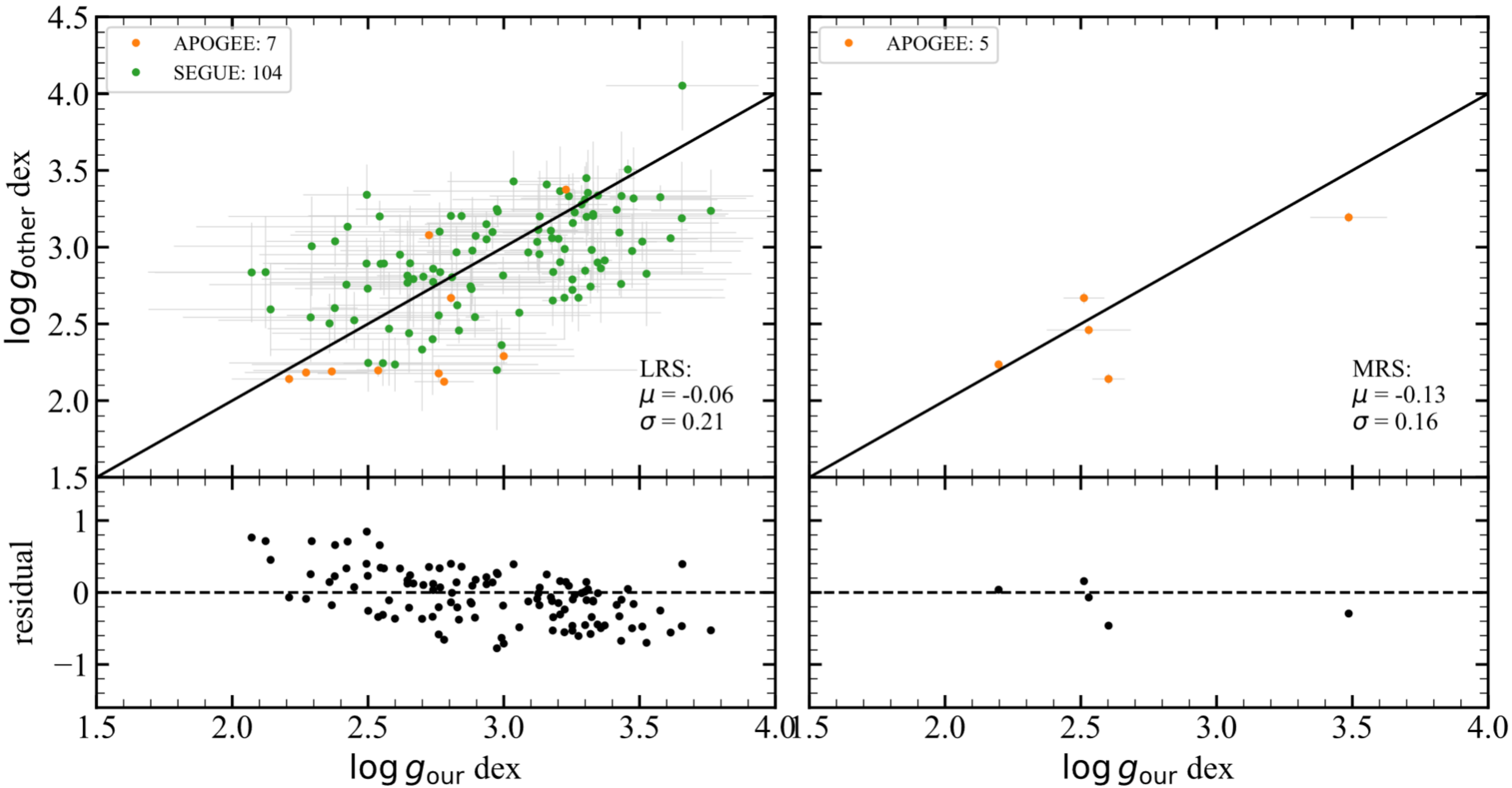
Comparison with Other Databases (Gaia, APOGEE, SEGUE, and Liu et al. (2019).)

1. S/N limitation: the S/Ng of LRS and S/Nb of MRS are higher than 20.
2. Weakening pulsation effects: the phase was restricted to a range of 0.2~0.8 to avoid anomalous variations in stellar atmospheric parameters near the 0.9 phase.
3. adopt the weighted average of the stellar atmospheric parameters.



Result Analysis

Comparison with Other Databases (Gaia, APOGEE, SEGUE, and Liu et al. (2019).)



Result Analysis

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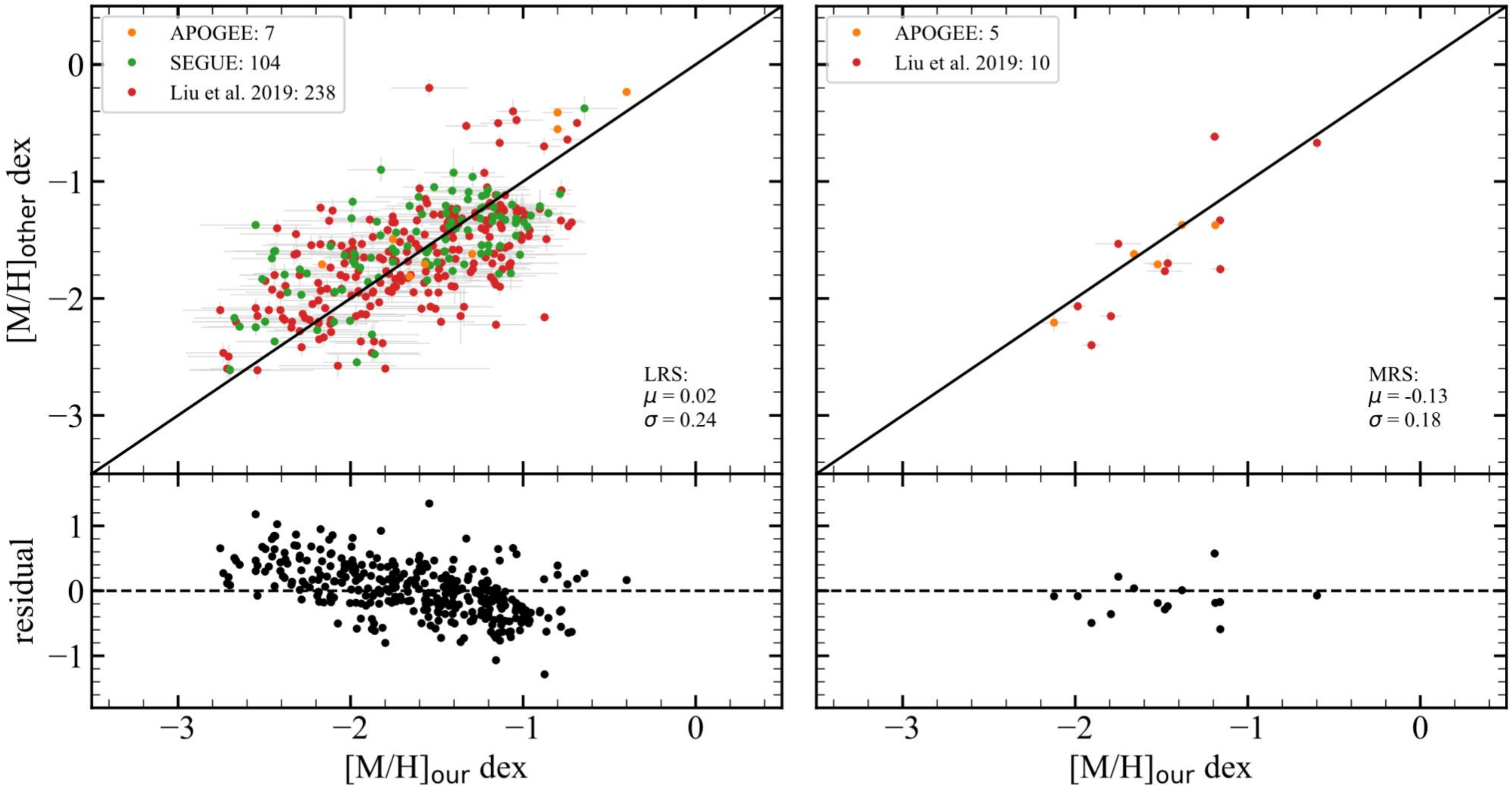

Part V Summary

Summary

1. Sample Data:

•Collected approximately 449,093 RR Lyrae stars (RRLs) from the Gaia, ASAS-SN, ZTF, and PS1 surveys, with 174,030 RRLs located in the LAMOST field. After cross-matching, 42,729 LRS and 7,064 MRS spectra were obtained.

2. Radial Velocity (RV) and Atmospheric Parameters:

•Determined RVs for Hα, Hβ, Hγ, Hδ, and metal lines for LRS, as well as RVs for Hα and metal lines for MRS.

•Optimized template-matching method to estimate stellar atmospheric parameters for the RRL sample.

3. Main Findings:

•Significant differences in the variation of **RV**, **effective temperature (Teff)**, **surface gravity (log g)**, and **metallicity ([M/H])** during the pulsation cycle between RRab and RRc stars.

•RRab stars exhibit larger Teff variation, while log g and [M/H] show minor changes near phase $\varphi \approx 0.9$.

4 .Scientific Importance:

•These findings are crucial for studying the **metallicity-luminosity relationship**, improving the accuracy of the **infrared period-luminosity relation**, and constraining the edges of the **instability strip (IS)**.

•RV analyses provide insights into the kinematics and dynamics of different atmospheric layers, aiding the study of the **Blazhko effect** and asteroseismology in combination with light curves.

Thank you!

Thank you for your attention!