Background

RR Lyrae variable stars (RRLs), commonly found in globular clusters (GCs), are important stellar candles used for measuring cosmic distances. Globular clusters, which are dense, old, and metal-poor star clusters, are primarily located in the Milky Way's halo. Due to the limited astronomical data available in the past, the membership ratios of variable stars have not been fully investigated. This motivates the search for the ratio of RR Lyrae stars in globular clusters using the newly released GAIA database.

Goals

- Using GAIA Data Release 3, analyze the **membership ratio** R of RRLs in GCs.
- Determine which cluster parameters influence R most.
- Propose **explanations** regarding the cause of such result.

Methodology

Estimating Number of Stars in Globular Clusters

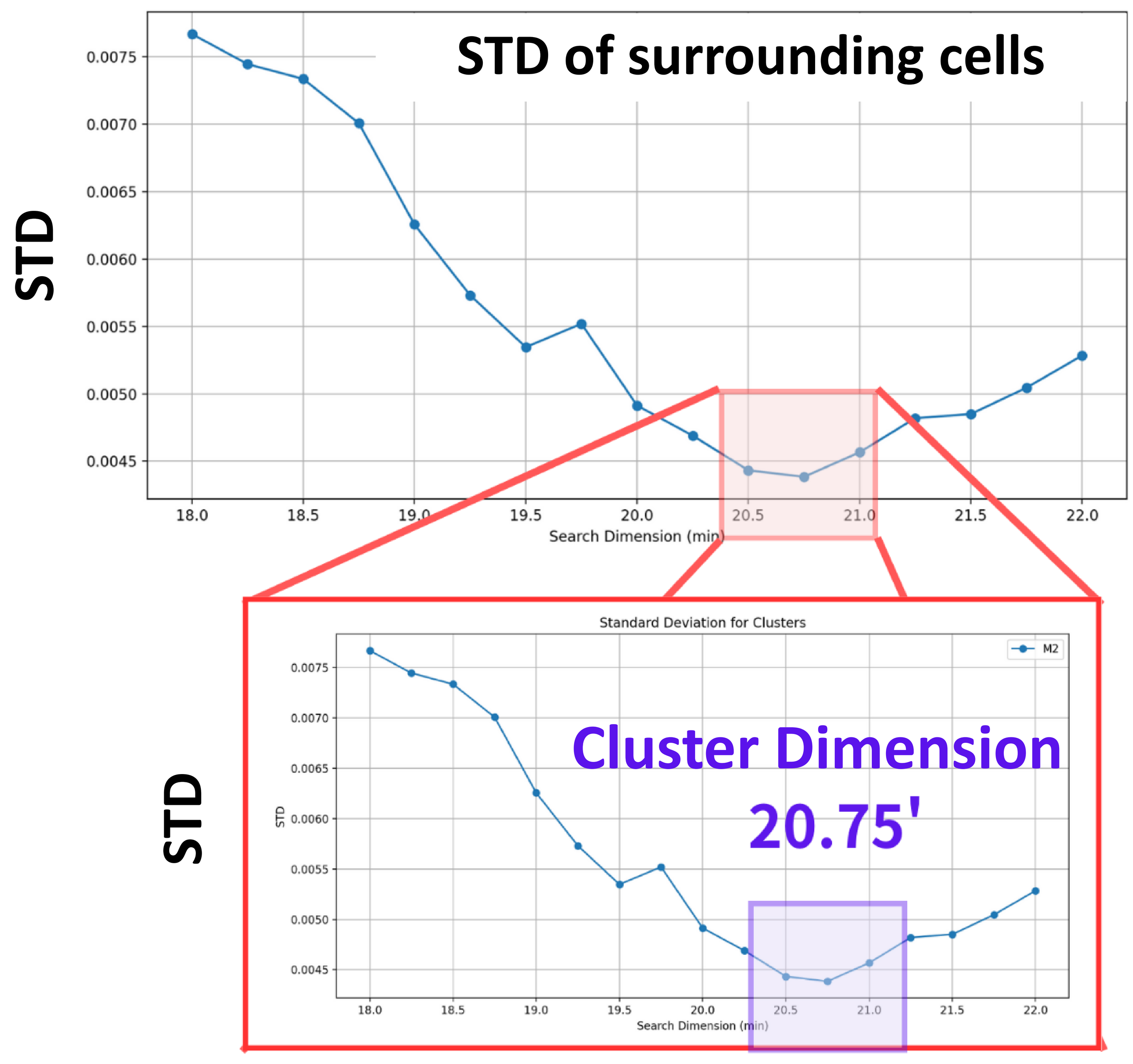
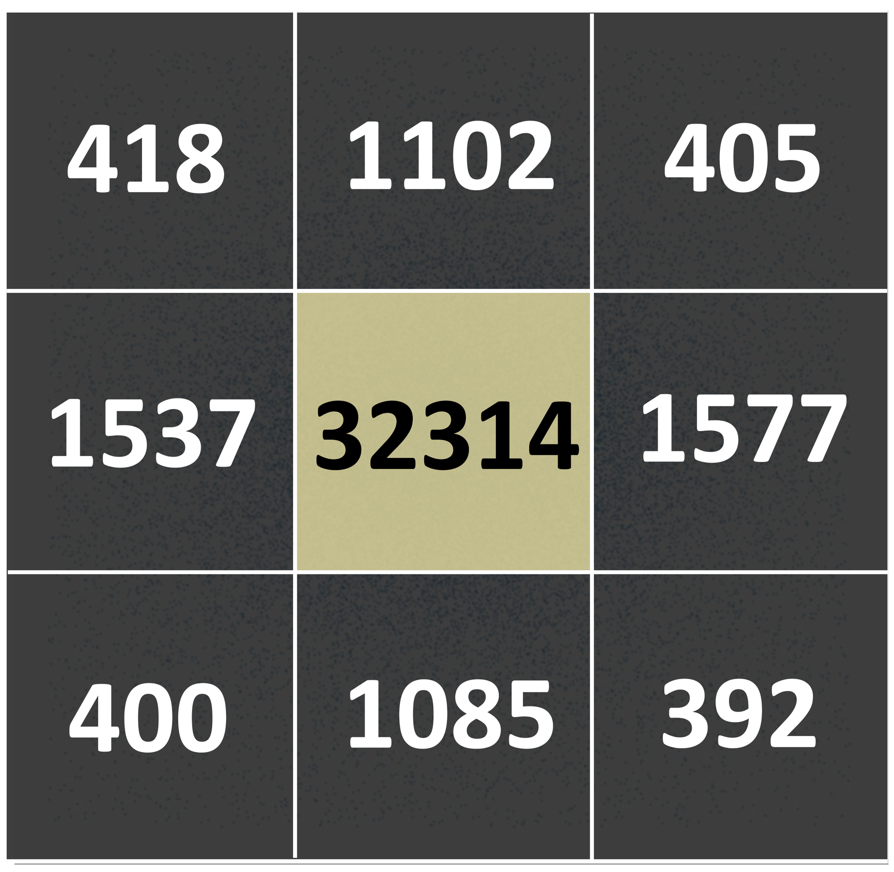


Figure 1 Estimating cluster dimension by calculating the dimension yielding lowest STD of stars surrounding the cluster.

This work has made use of data from the European Space Agency (ESA) mission **Gaia**.



Number of stars $\approx$ **32314 –**
AVG of surrounding cells
418, 1102, ..., 392

Best estimate when
STD of **surrounding cells**
Is minimum.

Figure 2 Heatmap of number of stars. Numbers represent the number of stars in the 3 by 3 grid. Search dimension expanded until STD of surrounding cells reach minimum.

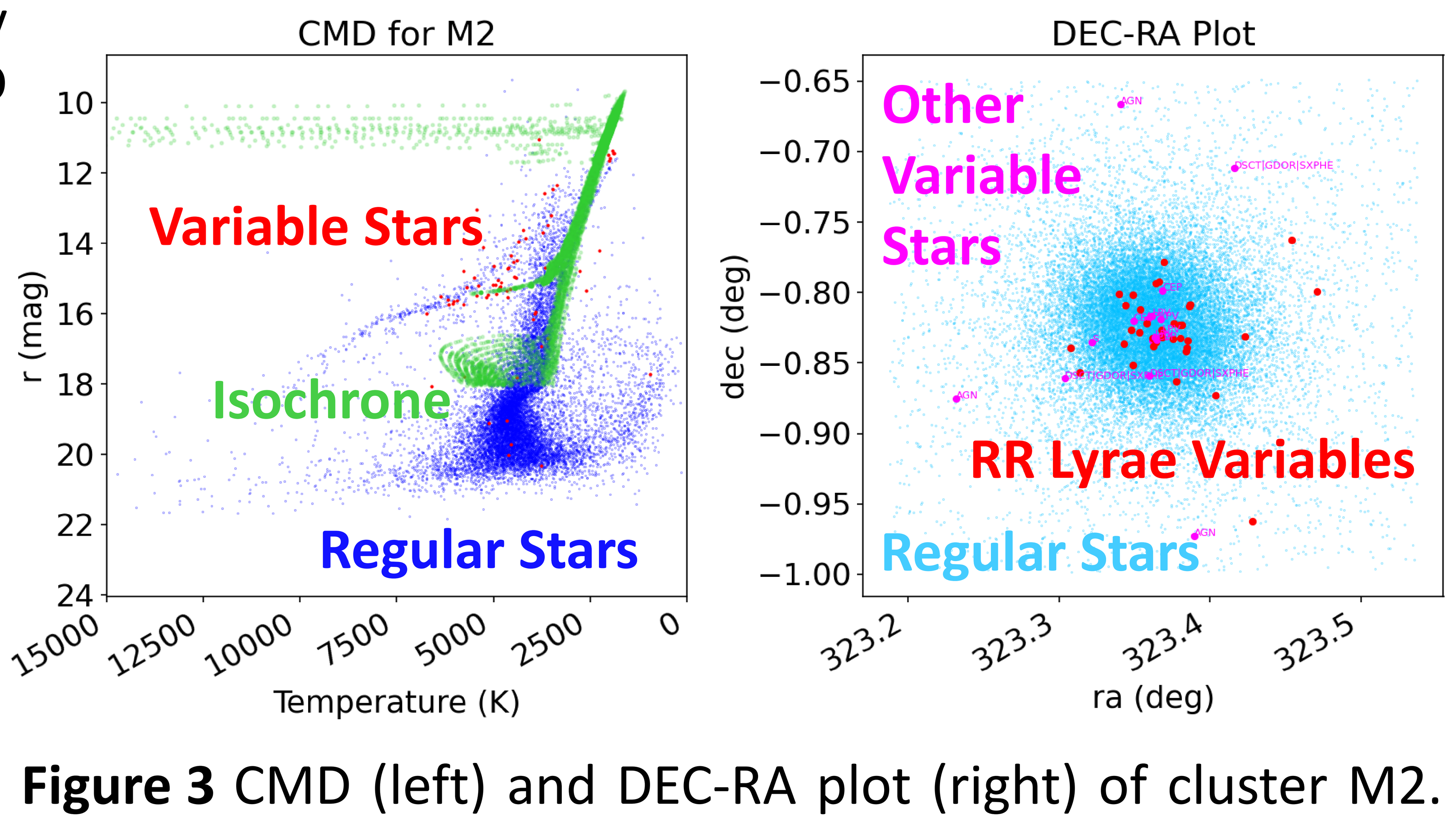


Figure 3 CMD (left) and DEC-RA plot (right) of cluster M2. The isochrone line was shifted to fit the blue dots. Variable stars that deviate from the isochrone line were removed.

Key Physical Parameters

Physical Parameter	Symbol	Unit
Age	$\boldsymbol{A}$	Gyr (10^9 years)
Metallicity [Fe/H]	$\boldsymbol{M}$	dex
Half-light radius	$\boldsymbol{r}$	Light years (ly)
Membership ratio of RRLs	$\boldsymbol{R}$	Parts per million (ppm)

$$\boldsymbol{R} \equiv \frac{\text{Number of RRLs in GC}}{\text{Total Number of Stars in GC}} \times 10^6 \text{ ppm}$$

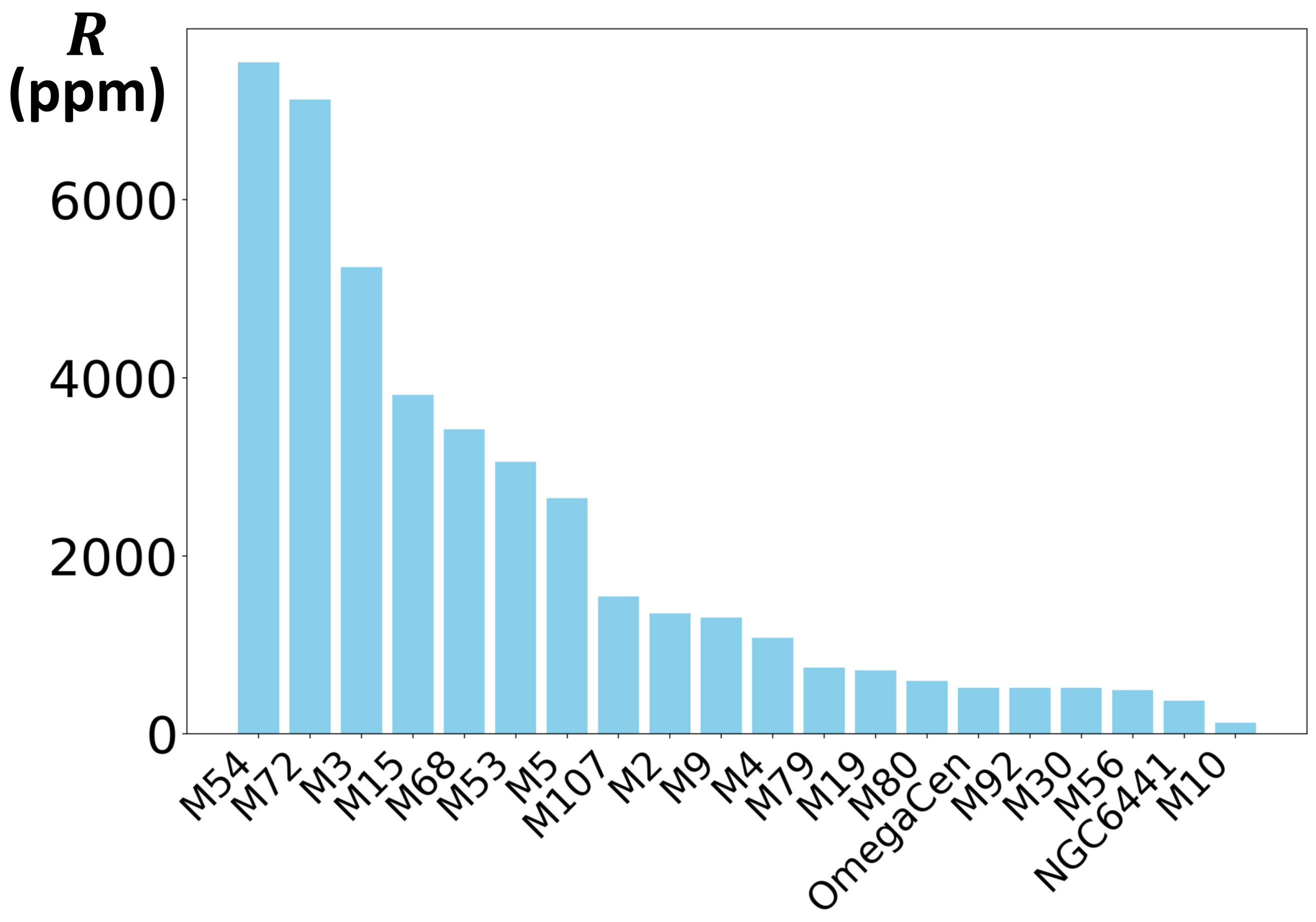


Figure 4 Bar chart of R for 20 GCs.

Membership Ratios

$$\log A \equiv \log_{10} A$$

$$\alpha = \boldsymbol{a_\alpha} \cdot \log A + \boldsymbol{b_\alpha} \cdot M$$

$$\beta = \boldsymbol{a_\beta} \cdot \log A + \boldsymbol{b_\beta} \cdot M + \boldsymbol{c_\beta} \cdot \log r$$

Google Colab & VScode
Python

GAIA Database
astroquery.gaia

Isochrone
isochrones.mist

Data Analysis
Excel

Regression
scipy

Plotting
numpy

AVG	Average
STD	Standard deviation
RRL	RR Lyrae
GC	Globular Cluster
CMD	Color-Magnitude Diagram
DEC	Declination
RA	Right Ascension

Star Cluster Evolution — Revealed by GAIA

Cheng-You Ho, Taiwan

Results

Red line: Regression fit **Yellow shaded region:** 95% confidence interval

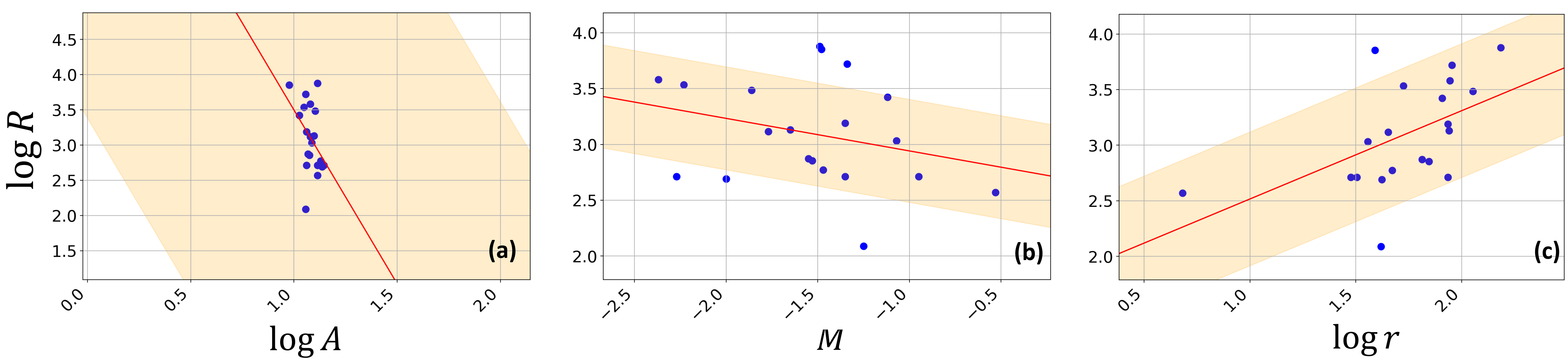


Figure 5 Plots of **(a)** $\log R$ vs. $\log A$, **(b)** $\log R$ vs. M, and **(c)** $\log R$ vs. $\log r$. Each blue dot represents a globular cluster. Age and metallicity are negatively correlated to the membership ratio, while radius is positively correlated to it.

$$\alpha = \boldsymbol{a_\alpha} \cdot \log A + \boldsymbol{b_\alpha} \cdot M \qquad \beta = \boldsymbol{a_\beta} \cdot \log A + \boldsymbol{b_\beta} \cdot M + \boldsymbol{c_\beta} \cdot \log r$$

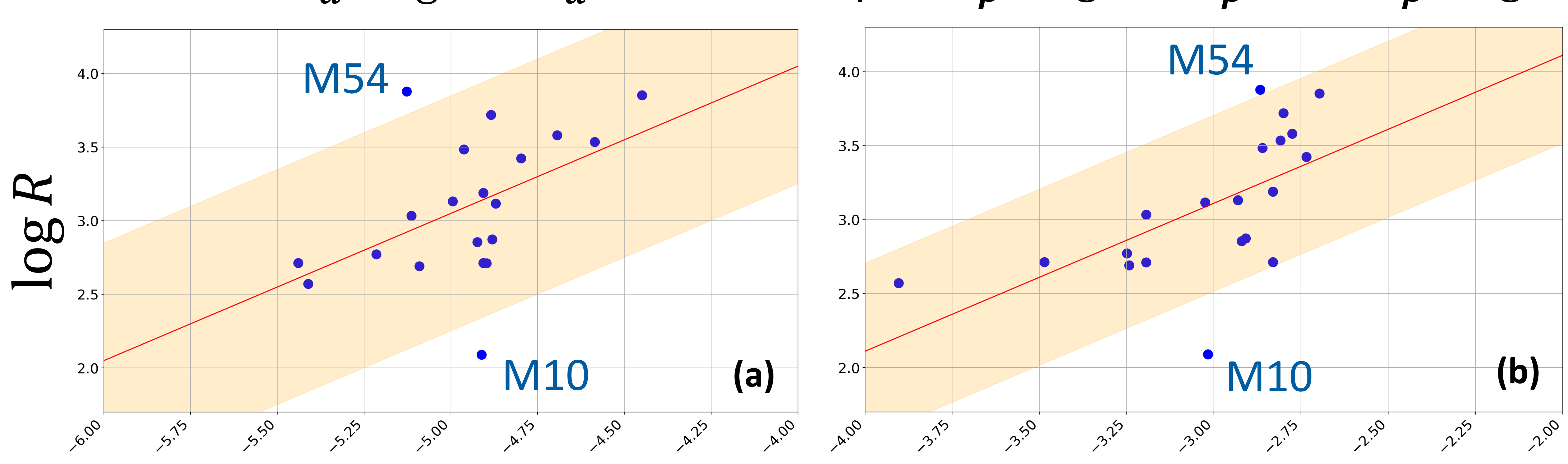


Figure 6 Plots of **(a)** $\log R$ vs. α and **(b)** $\log R$ vs. β. Each blue dot represents a globular cluster. The slope is normalized to 1. Most clusters fall inside the 95% confidence interval.

Red line: Regression fit

Yellow shaded region: 95% confidence interval

- The dots in the plot of $\log R$ vs. β is more concentrated than in the plot of $\log R$ vs. α.
- The area of the 95% confidence interval in the plot of $\log R$ vs. β is 25% smaller.
- The correlation between $\log R$ and β is greater than that between $\log R$ and α, which means **radius** is an essential factor in understanding star cluster evolution.
- Clusters M54 and M10 have a high and low R respectively.

Table 1 Optimal coefficients and correlation coefficient between α, β and $\log R$.

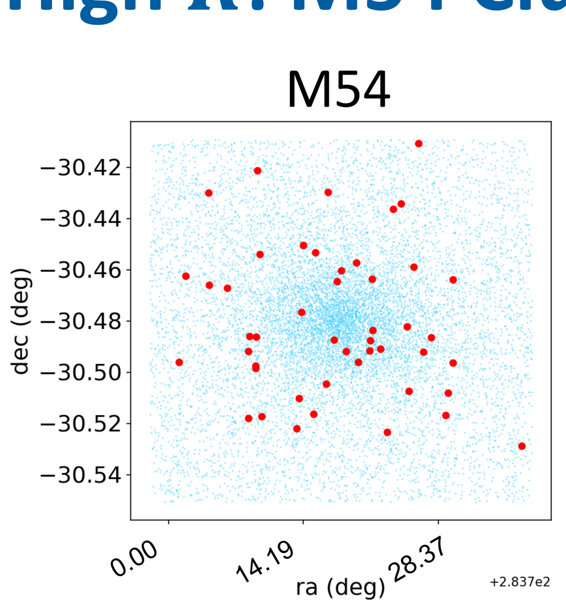
Quantity	a	b	c	Correlation Coefficient
α	-6.26	-0.37	-	0.501
β	-7.11	-0.21	1.11	0.613

Table 2 Relative significance of $\log A$, $\log r$ and M. Relative significance is estimated by the product of a parameter's coefficient in β and its median value.

Parameter	Value Range	Median Value	Coefficient in β	Relative Significance
$\log A$	0.978~1.152	1.08	-7.11	**~1**
$\log r$	0.681~2.185	1.77	1.11	**~0.26**
M	-2.37~-0.95	-1.51	-0.21	**~0.04**

Interpretations

High R: M54 Cluster

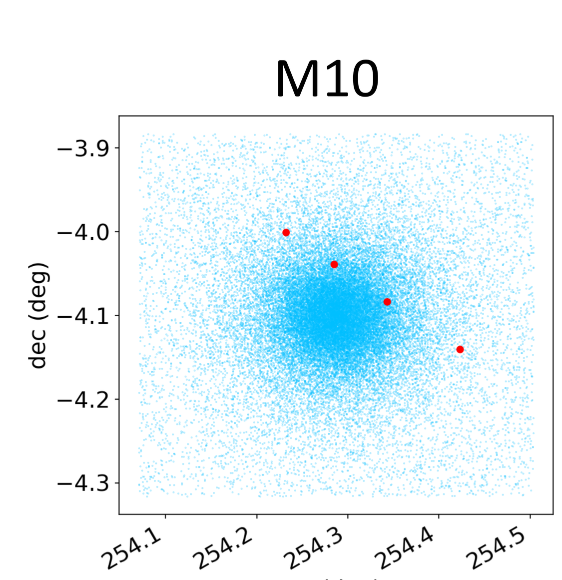


Red dots: RRLs

M54 has a high R:

- **M54** belongs to the Sagittarius Dwarf Galaxy while others are in the Milky Way.
- The formation of RRLs may be influenced by its home galaxy.

Low R: M10 Cluster



Red dots: RRLs

M10 has a significantly small R. In agreement with past research [1][2]:

- There may be variations on its Red Giant Branch evolution [2].
- M10 may have an unique **mass loss** due to collision with another cluster.

[Fe/H] and the Instability Strip

Negative correlation of membership ratio of RRLs with [Fe/H] can be explained with the **instability strip:**

- The instability strip is **narrower** when the metallicity is **higher** [3].
- Therefore **less variable stars** populate the instability strip, causing a smaller R.

Table 3 Parameters and weights of previous result and this research.

	Previous Result [4]			This Work		
Parameter	A	M	r	A	M	r
Weight	$\equiv 1$	2	NA	$\equiv 1$	3	**2**

NA: Not Applicable A: Age M: Metallicity r: Half-Light Radius

Tidal force ∝ **Radius**

RRL membership ratio has **positive correlation** with radius

Mass-loss plays a role in the formation of RRLs [2]

Tidal force influences mass loss of GC

The formation of RRLs may be correlated with **tidal forces.**

Conclusions

- 20 globular clusters were analyzed using GAIA Data Release 3.
- I found that **radius** is a key factor that must be considered in understanding star cluster evolution. The impact of radius is mainly from the **mass-loss** and **tidal forces**.
- The **instability strip** explains how **metallicity** affects the RR Lyrae membership ratio.
- In addition to age and metallicity, I found that **radius** is even more essential than metallicity in analyzing the membership ratio of RR Lyrae stars.

Future Prospects

- Similar analyses could be conducted on open clusters, given that member stars can be properly distinguished from background and foreground stars.
- Applying this method to consider the effect from radius to other star clusters.

References

[1] K. Braun, M. Mateo, K. Chiboucas, A. Athey, and D. Hurley-Keller, “Photometry Results for the Globular Clusters M10 and M12: Extinction Maps, Color-Magnitude Diagrams, and Variable Star Candidates,” *Astron J.*, 124(4), 2067–2082, 2002.

[2] A. Ferro *et al.*, “The globular cluster M10: reassessment of stellar membership, distance, and age using its variable and HB stars,” *Mon Not R Astron Soc*, 499(3), 4026–4039, 2020.

[3] P. Demarque, R. Zinn, Y.-W. Lee, and S. Yi, "The Metallicity Dependence of RR Lyrae Absolute Magnitudes from Synthetic Horizontal-Branch Models," *Astron J.*, 119(3), 1398, 2000.

[4] R. Gratton, A. Bragaglia, E. Carretta, V. D’Orazi, S. Lucatello, and A. Sollima, "What is a globular cluster? An observational perspective," *Astron Astrophys Rev.*, 27(1), 1–136, 2019.

This work has made use of data from the European Space Agency (ESA) mission Gaia (https://www.cosmos.esa.int/gaia). Processed by the Gaia Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement.