

**Star Cluster Evolution – Revealed By GAIA**

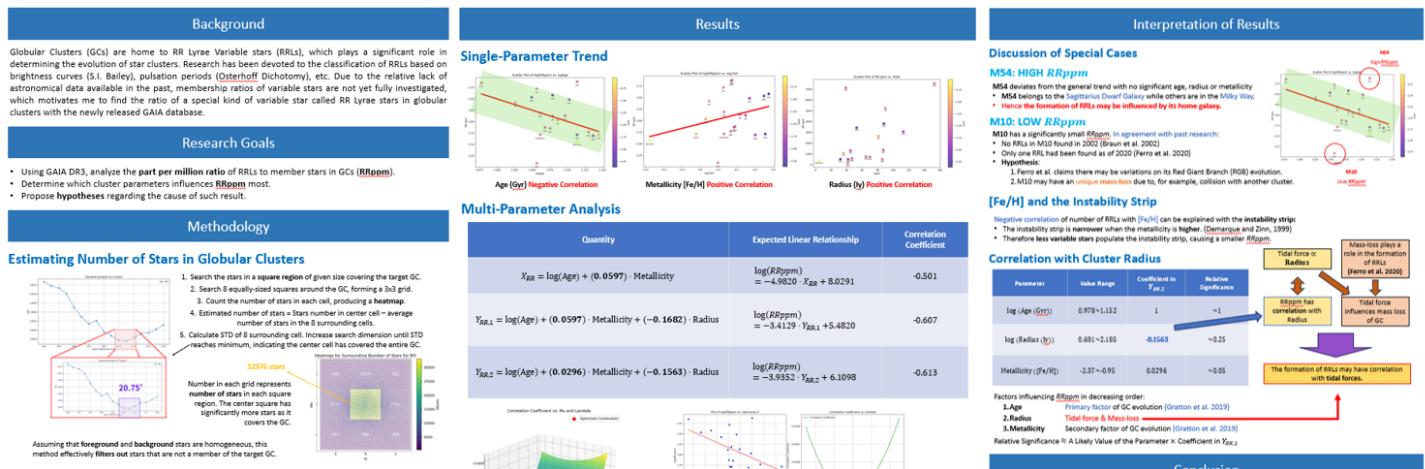
# **Project Data Book**

Cheng-You Ho, Taiwan

MOSTRATEC 2024

# Poster Versions

## January 2024 (TISF format)





# October 12<sup>th</sup> (Final version for MOSTRATEC)

## 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

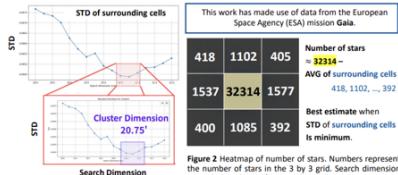


Figure 1 Estimating cluster dimension by calculating the dimension yielding lowest STD of stars surrounding the cluster.

### Key Physical Parameters

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

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

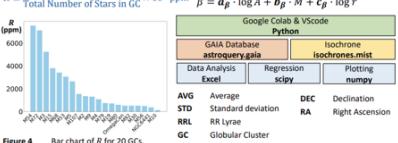


Figure 2 Histograms of number of stars. Numbers represent the number of stars in the 3 by 3 grid. Search dimension expanded until STD of surrounding cells reach minimum.

$$\text{Membership Ratios} \quad \log A \equiv \log_{10} A$$

$$\alpha = a_\alpha \cdot \log A + b_\alpha \cdot M$$

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

Google Colab & VScode

Python

Isocrones

isochrones.mist

Data Analysis

Excel

Regression

scipy

Plothing

numpy

CMD

Globular Cluster

Color-Magnitude Diagram

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.

Membership Ratios

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

$\alpha = a_\alpha \cdot \log A + b_\alpha \cdot M$

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

Figure 4 Bar chart of R for 20 GCs.

## 討論紀錄 Discussion

我與老師大部分的討論使用 Facebook Messenger。對話的圖片是 Facebook 提供的對話紀錄 HTML 檔案截圖。帳戶名稱已在 HTML 檔中修改為「學生」(我)與「老師」，以確保匿名。

I use Facebook Messenger for most of my discussions with my teacher. The pictures of the conversation is a screenshot of the conversation record HTML file provided by Facebook. The account names have been changed to "Student" (me) and "Teacher" in the HTML file to ensure anonymity.

### Notes:

- The teacher agrees that the conversation snapshots be presented here.
- In the research paper, variables  $\alpha$  and  $\beta$  were discussed. I originally named  $\alpha$  as  $X_{RR}$ , so  $X_{RR}$  in this document represents  $\alpha$ . The variable  $\beta$  was previously named  $Z_{RR}$ .

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## Results

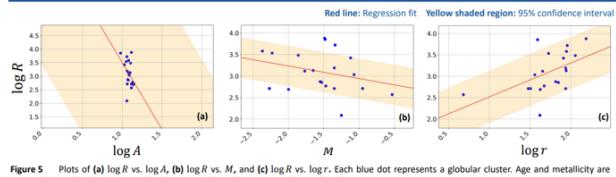


Figure 5 Plots of (a)  $\log R$  vs.  $\log A$ , (b)  $\log R$  vs.  $M$ , and (c)  $\log R$  vs.  $\log r$ . Each blue dot represents a globular cluster. Age and metallicity are negatively correlated to the membership ratio, while radius is positively correlated to it.

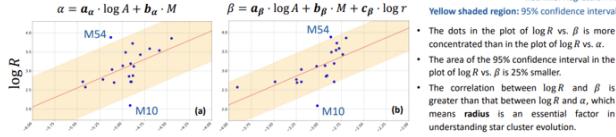


Figure 6 Plots of (a)  $\log R$  vs.  $\alpha$  and (b)  $\log R$  vs.  $\beta$ . Each blue dot represents a globular cluster.

Table 1 Optimal coefficients and correlation coefficient normalized to 1. Most clusters fall inside the 95% confidence interval.

| Quantity | $\alpha$ | $\beta$ | Correlation Coefficient |
|----------|----------|---------|-------------------------|
| $\log A$ | -6.26    | -0.37   | -0.501                  |
| $\log r$ | -7.11    | -0.21   | 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  $\beta$  and its median value.

| Parameter | Value Range  | Median Value | Coefficient in $\beta$ | 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

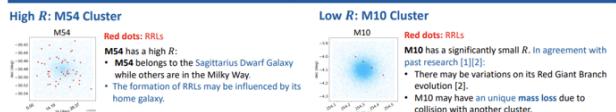


Figure 7 High R: M54 Cluster

Low R: M10 Cluster

## [Fe/H] and the Instability Strip

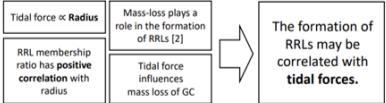
Negative correlation of membership ratio of RRLs with [Fe/H] can be explained with the instability strip:

- 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.

| Parameter | Previous Result [4] |     |     | This Work |     |     |
|-----------|---------------------|-----|-----|-----------|-----|-----|
|           | $A$                 | $M$ | $r$ | $A$       | $M$ | $r$ |
| Weight    | ≡ 1                 | 2   | NA  | ≡ 1       | 3   | 2   |

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



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

- 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 Catalogs," *Astron. J.*, vol. 157, no. 4, p. 122, Apr. 2019.
- 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.*, vol. 499, pp. 4026–4039, 2020.
- 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.*, vol. 139, p. 1398, 2000.
- R. Gratton, A. Bragaglia, E. Carretta, V. O'Draoi, S. Lucatello, and A. Sollima, "What is a globular cluster? An observational perspective," *Astron. Astrophys. Rev.*, vol. 27, pp. 1–136, 2019.

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

| 日期 Date                   | 討論內容與進展<br>Discussion and Progress   | 圖片<br>Snapshots  |
|---------------------------|--|--|
| 2023/07/06~<br>2023/08/05 | <p>我和老師花了一個月的時間討論與決定研究主題。</p> <p>老師建議的主題有恆星、宇宙學與星團。經過討論，決定研究星團內的恆星。由於我有 Python 與 MySQL 的經驗，我和老師決定分析資料庫。</p> <p>My teacher and I spent a month discussing and deciding on the research topic.</p> <p>Topics suggested by teachers include internal mechanisms inside stars, cosmology and star clusters. After discussion, it was decided to study the stars within the cluster. Since I have experience with Python and MySQL, my teacher and I decided to analyze the database.</p> | <p>老師<br/>原理不難<br/>7 月 06, 2023 10:59:24 下午</p> <p>老師<br/>我可以查一下<br/>7 月 06, 2023 10:59:20 下午</p> <p>老師<br/>但這不是宇宙學<br/>7 月 06, 2023 10:59:16 下午</p> <p>學生<br/>是的，但他們好像只有分析資料庫而已<br/>7 月 06, 2023 10:58:47 下午</p> <p>老師<br/>系外行星？<br/>7 月 06, 2023 10:58:02 下午</p> <p>學生<br/> <a href="https://www.sexplores.org/article/2023-regeneron-isef-winners-exoplanets-mpox-insect-pests-suicide-prevention">https://www.sexplores.org/article/2023-regeneron-isef-winners-exoplanets-mpox-insect-pests-suicide-prevention</a><br/>     這是最近做宇宙學得獎的題目，不知道老師有沒有類似的主要？<br/>     Six young researchers took home the top awards, each valued at a minimum of \$50,000. Hundreds more shared nearly \$9 million in prizes at international event.<br/> <a href="https://www.sexplores.org/article/2023-regeneron-isef-winners-exoplanets-mpox-insect-pests-suicide-prevention">https://www.sexplores.org/article/2023-regeneron-isef-winners-exoplanets-mpox-insect-pests-suicide-prevention</a><br/>     7 月 06, 2023 6:32:00 下午</p> <p>學生<br/>像是我找到這個：<br/> <a href="https://esahubble.org/images/potw2321a/">https://esahubble.org/images/potw2321a/</a><br/>     A jellyfish galaxy adrift<br/> <a href="https://esahubble.org/images/potw2321a/">https://esahubble.org/images/potw2321a/</a><br/>     8 月 06, 2023 12:26:15 下午</p> <p>學生<br/>還有移動速率等參數<br/>8 月 06, 2023 12:25:53 下午</p> <p>學生<br/>我想分析一些較新發現的星團的組成<br/>8 月 06, 2023 12:25:45 下午</p> <p>老師<br/>那想做星團的什麼？<br/>8 月 06, 2023 11:57:46 上午</p> <p>學生<br/>另外我有 MySQL 和 Python 的基礎因此操作資料庫我應該可以<br/>8 月 05, 2023 2:35:22 下午</p> <p>學生<br/>老師好，我把我能找到的和星團有關的科展都看過了<br/>8 月 05, 2023 2:34:51 下午</p> |

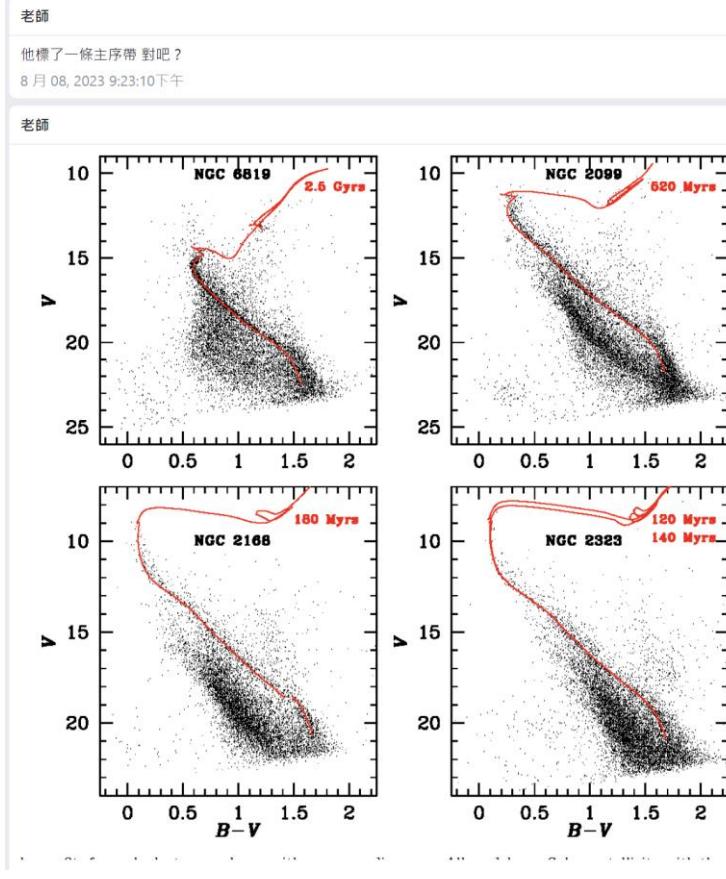
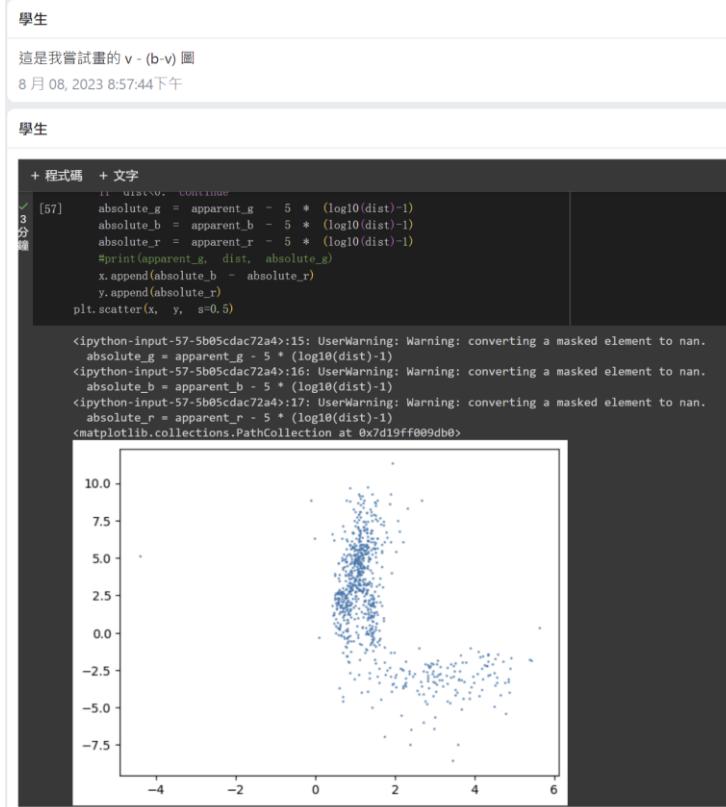
|            |  |   |
|------------|--|---|
| 2023/08/06 | <p>瀏覽近期相關的科展作品，我們最終決定使用GAIA DR3 資料庫分析球狀星團中的星體。</p> <p>參考相關論文，我也草擬了一個大致的研究題目：Revisiting the Variable Stars in star clusters with GAIA data。</p> <p>確認方向後，我開始上網找尋有關星團、變星等資料，充實基本知識。</p> <p>Browsing recent related science exhibition works, we finally decided to use the GAIA DR3 database to analyze stars in globular clusters.</p> <p>Referring to relevant papers, I also drafted a general research topic: Revisiting the Variable Stars in star clusters with GAIA data.</p> <p>After confirming the direction, I started searching online for information about star clusters, variable stars, etc. to enrich my basic knowledge.</p> | <p><b>老師</b></p> <p>這是gaia的data release<br/>8月 06, 2023 8:55:08下午</p> <p><b>老師</b></p> <p><a href="https://www.cosmos.esa.int/web/gaia/dr3">https://www.cosmos.esa.int/web/gaia/dr3</a><br/>Gaia Data Release 3 contents summary<br/><a href="https://www.cosmos.esa.int/web/gaia/dr3">https://www.cosmos.esa.int/web/gaia/dr3</a><br/>8月 06, 2023 8:55:03下午</p> <p><b>老師</b></p> <p>因為新<br/>8月 06, 2023 8:53:29下午</p> <p><b>老師</b></p> <p>做gaia 是一個不錯的idea<br/>● 學生<br/>8月 06, 2023 8:53:26下午</p> <p><b>老師</b></p> <p><a href="https://en.wikipedia.org/wiki/Gaia_(spacecraft)">https://en.wikipedia.org/wiki/Gaia_(spacecraft)</a><br/>Gaia is a space observatory of the European Space Agency (ESA), launched in 2013 and expected to operate until 2025. The spacecraft is designed for astrometry: measuring the positions, distances and motions of stars with unprecedented precision,[5][6] and the positions of exoplanets by measuring att...<br/><a href="https://en.wikipedia.org/wiki/Gaia_(spacecraft)">https://en.wikipedia.org/wiki/Gaia_(spacecraft)</a><br/>8月 06, 2023 8:52:57下午</p> <p><b>老師</b></p> <p>GAIA 是相對較新的資料庫<br/>8月 06, 2023 8:52:37下午</p> <p><b>老師</b></p> <p>如 天琴座RR型變星 會出現在什麼年齡段的星團？<br/>8月 06, 2023 9:39:11下午</p> <p><b>老師</b></p> <p>預期是不同年齡的星團 的變星種類的關係<br/>8月 06, 2023 9:38:46下午</p> <p><b>老師</b></p> <p>我草擬一個題目<br/>Revisiting the Variable Stars in star clusters with GAIA data<br/>8月 06, 2023 9:38:16下午</p> <p><b>學生</b></p> <p>好的!<br/>8月 06, 2023 9:36:40下午</p> <p><b>老師</b></p> <p>再延伸一些<br/>8月 06, 2023 9:35:44下午</p> <p><b>老師</b></p> <p>上面有一個type of variable star 先看一看<br/>8月 06, 2023 9:35:39下午</p> <p><b>老師</b></p> <p>先唸變星的分類與其演化的關係<br/>8月 06, 2023 9:35:19下午</p> |
|------------|--|---|



我根據資料庫的數據繪出初步的 CMD，並老師討論球狀星團 CMD 與 HRD 的圖形，對必備知識有更深的了解。

2023/08/08

I drew a preliminary CMD based on the data in the database, and discussed with the teacher the CMD and HRD plots of globular clusters, which gave me a deeper understanding of the necessary knowledge.



2023/08/08

意識到篩除非成員星或許是本研究中將來會遇到的一大難題。

Realizing that filtering out non-member stars may be a major problem that will be encountered in this study in the future.

|  |
|--|
| 老師   |
| 一般的星星是做不出HRD的<br>8月08, 2023 9:21:13下午  |
| 學生   |
| 是指不能直接從CMD或HRD看出來嗎？是不是還要另外分析其他東西<br>8月08, 2023 9:20:48下午   |
| 老師   |
| 只能說有一些特徵，比如說自行、成份（必然相近）、與背景星的距離（同一星團距離相近）<br>8月08, 2023 9:18:52下午  |
| 老師   |
| 這是一個難題<br>8月08, 2023 9:18:20下午   |
| 老師   |
| 所以之前那些科展，是不是有一些就是在做成員星？<br>8月08, 2023 9:18:16下午  |
| 老師   |
| 你講到重點了！！<br>8月08, 2023 9:18:04下午   |
| 老師   |
| <a href="https://sites.astro.caltech.edu/~george/ay1/lec_pdf/Ay1_Lec09.pdf">https://sites.astro.caltech.edu/~george/ay1/lec_pdf/Ay1_Lec09.pdf</a><br><a href="https://sites.astro.caltech.edu/~george/ay1/lec_pdf/Ay1_Lec09.pdf">https://sites.astro.caltech.edu/~george/ay1/lec_pdf/Ay1_Lec09.pdf</a><br>8月08, 2023 9:17:57下午 |
| 學生   |
| 那要怎麼分辨一群星星是不是星團<br>8月08, 2023 9:17:24下午  |

|  |
|--|
| 老師                                     |
| 是的！<br>8月08, 2023 9:25:36下午            |
| 學生                                     |
| 所以明顯的部分反而是背景星？<br>8月08, 2023 9:25:30下午 |
| 老師                                     |
| 但是這只能粗略分<br>8月08, 2023 9:23:50下午       |
| 老師                                     |
| 那就是背景星<br>8月08, 2023 9:23:42下午         |
| 老師                                     |
| 左下是不是有個寬胖的線<br>8月08, 2023 9:23:39下午    |
| 老師                                     |
| 這四個是疏散星團，星星比較少<br>8月08, 2023 9:23:28下午 |
| 老師                                     |
| 就那一條紅色的線<br>8月08, 2023 9:23:18下午       |

和老師決定使用 Messier Catalog 的星體。

初步嘗試，搜尋 M2 的赤經、赤緯後，搜尋給定半徑範圍內的星體，成功繪出 CMD，但同時也發現背景星問題嚴重。

2023/08/08~

2023/08/09

Me and my teacher decided to use the stars from the Messier Catalog.

A preliminary attempt was made to search for the right ascension and declination of M2, then search for stars within a given radius, and successfully draw the CMD. However, it was also found that the background star problem was serious.

老師  
所以大概至少要抓 他的半徑的2.5倍以上  
8月08, 2023 10:01:13下午

老師  
半徑會有亮度半徑 潮汐半徑 引力半徑等  
8月08, 2023 10:00:55下午

老師  
星團 尤其是球狀星團  
8月08, 2023 10:00:44下午

老師  
這個半徑其實不準哦！  
8月08, 2023 10:00:37下午

老師  
裡面會有半徑  
8月08, 2023 10:00:31下午

老師  
你先查一下 messier catalog  
8月08, 2023 10:00:22下午

學生  
通常要限制多少呢  
8月08, 2023 10:00:08下午

學生  
好的!  
8月08, 2023 9:59:45下午

老師  
看起來正常了  
8月09, 2023 10:54:36上午

學生

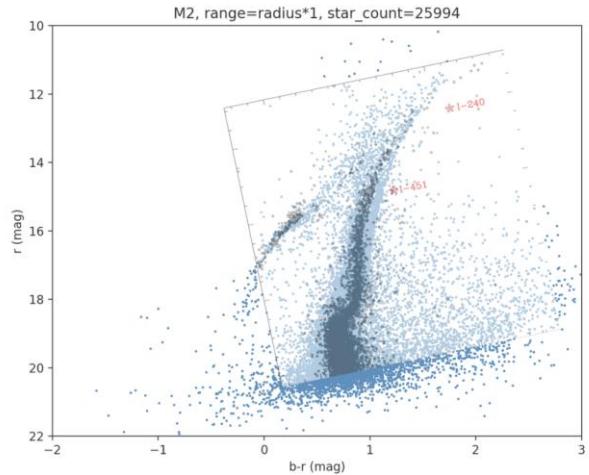
M2, range=radius\*1, star\_count=25994

8月09, 2023 10:54:28上午

學生  
我試試看  
8月09, 2023 10:53:29上午

老師  
若不要旋轉呢？  
8月09, 2023 11:21:57上午

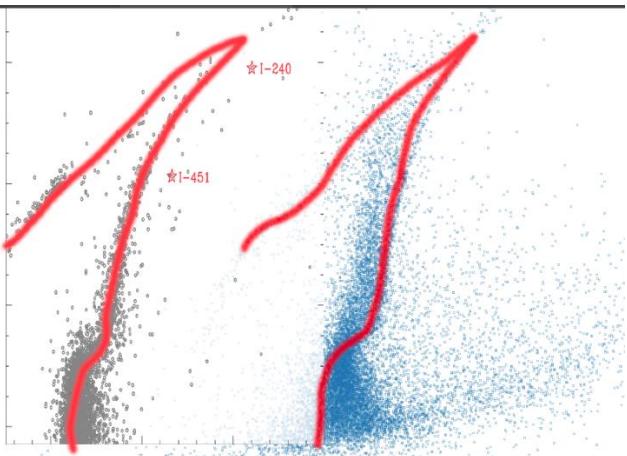
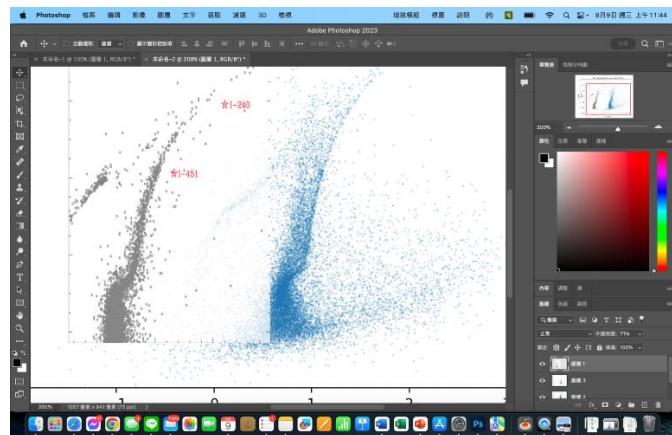
學生



8月09, 2023 11:20:17上午  
老師  
老師撥打了電話給你。  
8月09, 2023 11:02:39上午  
通話時間：3分鐘

2023/08/09

Overlay the existing paper data with the CMD diagram drawn through GAIA to confirm the accuracy of the data.



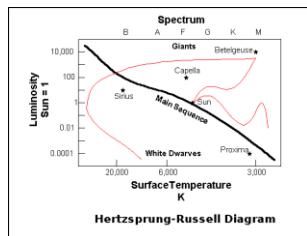
2023/08/09

調整繪圖參數與排版，繪出較漂亮的 CMD，並且發現清楚的 turn-off point。

比較相關資料，發現 GAIA 的資料確實比較充足。

Adjust the drawing parameters and layout to draw a more beautiful CMD and find a clear turn-off point.

Comparing relevant information, I found that GAIA's information is indeed sufficient.



老師

[http://astronomy.nmsu.edu/jasonj/565/docs/11\\_07.pdf](http://astronomy.nmsu.edu/jasonj/565/docs/11_07.pdf)  
%PDF-1.5 %& 15 0 obj > stream x{KG\_vDp@r#qJ#}IsztgUwJ+z/3k^YK?){|[VWl-Xo].[6FqT  
^%CynN6^3q3tNS%\$3%Zwy:#7/ nk0hn\$^ba|ku3)oap6+d' bFgSx,gù  
[http://astronomy.nmsu.edu/jasonj/565/docs/11\\_07.pdf](http://astronomy.nmsu.edu/jasonj/565/docs/11_07.pdf)

8月09, 2023 9:16:07下午

老師

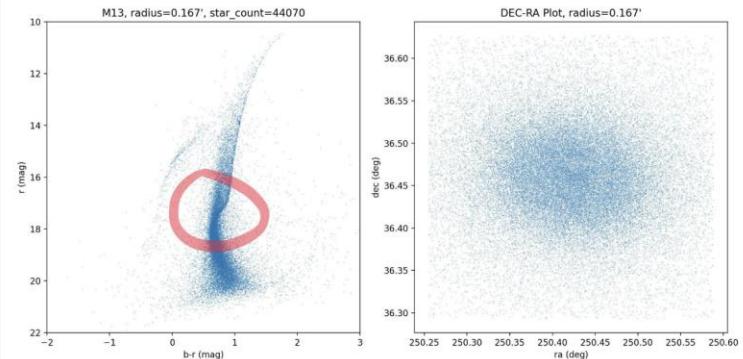
對  
8月09, 2023 9:15:41下午

學生

請問轉折是指這裡嗎？  
8月09, 2023 9:15:22下午

學生

8月09, 2023 9:15:13下午



8月09, 2023 9:15:13下午

老師

比之前的類似的計畫都要厲害  
8月09, 2023 9:26:40下午

老師

但是你比較就會發現 · gaia dr3 相當猛  
8月09, 2023 9:26:30下午

老師

不是“細細”的線 · 那就是背景  
8月09, 2023 9:26:12下午

老師

你細看一下最後這張圖的“轉折”把你的圖的橫軸放大 (只看 - 1~2)你會清楚的看到那一個變化  
8月09, 2023 9:26:02下午

老師

裡面有些以虛線標出來的地方 · 實際就是演化速度快 · 所以不是很清楚的地方  
8月09, 2023 9:24:53下午

老師

不同的位置有不同的意義  
8月09, 2023 9:24:29下午

老師

這個圓解說的比較清楚  
8月09, 2023 9:24:23下午

2023/08/10

Population I & II 與主序帶的討論。

初步尋找星團範圍內的變星，發現 GAIA 將變星分為 24 類。由於發現多數星團皆有天琴座 RR 型變星，我有意圖以此為主要的研究對象。

Discussion of Population I & II and Main Sequence.

After a preliminary search for variable stars within the star cluster, it was found that GAIA classified variable stars into 24 categories. Since most star clusters are found to contain RR Lyrae variable stars, I intend to use this as the main research object.

老師

pop i 是多金屬 ( 佔總質量3%以上 )

8 月 09, 2023 9:31:35下午

老師

pop ii 是少金屬

8 月 09, 2023 9:31:18下午

老師

是理論上無金屬的第一代恆星

8 月 09, 2023 9:31:09下午

老師

這一篇是做星族3 ( polulation III)

8 月 09, 2023 9:31:00下午

老師

像這些就是從理論上 討論不同質量 不同金屬豐度的恆星演化

8 月 09, 2023 9:30:33下午

老師

[https://www.researchgate.net/figure/Evolution-of-massive-Pop-III-stars-15-30-60-200-and-500-M-with-and-without\\_fig1\\_301312628](https://www.researchgate.net/figure/Evolution-of-massive-Pop-III-stars-15-30-60-200-and-500-M-with-and-without_fig1_301312628)

Download scientific diagram | Evolution of massive Pop III stars (15, 30, 60, 200 and 500 M  $\odot$ ) with and without rotation. The adopted initial rotational speeds in units of the Keplerian value are marked by different colors as indicated by the labels. These evolutionary models are taken from Yoon ...

[https://www.researchgate.net/figure/Evolution-of-massive-Pop-III-stars-15-30-60-200-and-500-M-with-and-without\\_fig1\\_301312628](https://www.researchgate.net/figure/Evolution-of-massive-Pop-III-stars-15-30-60-200-and-500-M-with-and-without_fig1_301312628)

8 月 09, 2023 9:30:05下午

老師

要去掉不合理的，所以改在cmd 中標出變星型

8 月 10, 2023 11:22:21上午

老師

有天琴座RR

8 月 10, 2023 11:21:57上午

老師

有造父

8 月 10, 2023 11:21:51上午

學生

BEST\_CLASS\_SCORE : Score of the best class (float)

It describes a quantity between 0 and 1 which is related to the (median) normalised rank of the confidence of the classifier(s) in the identification of the best class (`best_class_name`). In the special case of class 'EP', all scores are set to 1. See Section 10.3.4.1 of the release documentation for details.

8 月 10, 2023 11:21:48上午

老師

score 是什麼？

8 月 10, 2023 11:21:13上午

學生

這個就是 24 種分類

8 月 10, 2023 11:21:00上午

老師

有變星的類型嗎

8 月 10, 2023 11:20:47上午

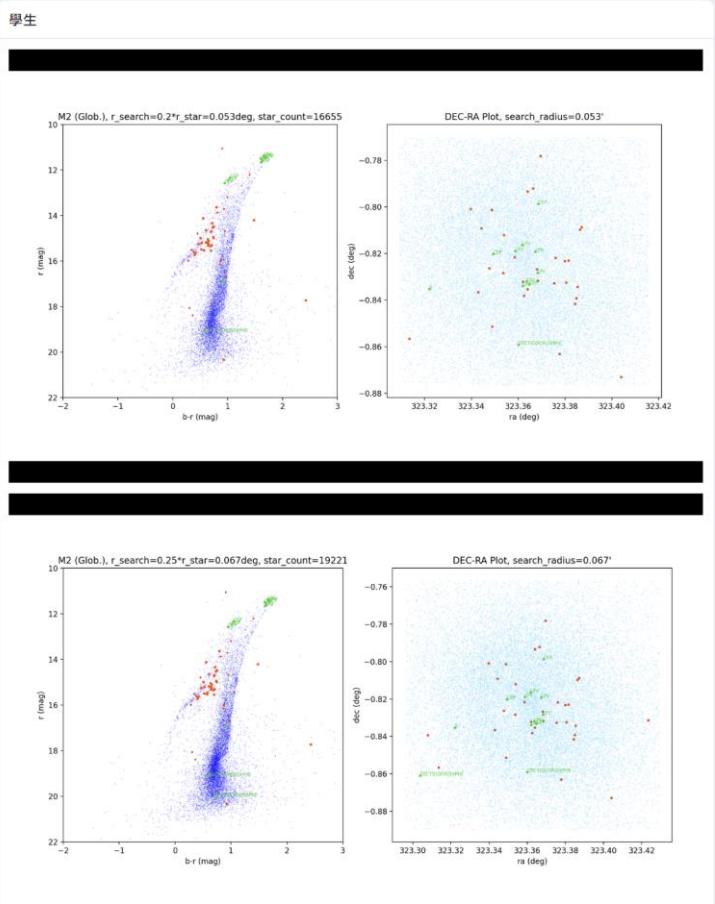
成功在 CMD 與 dec-ra 圖上標示各種類的變星。

透過分析 M44，我發現疏散星團較球狀星團難分析，因此決定以研究後者為主。

2023/08/11

Successfully marked various types of variable stars on CMD and dec-ra diagrams.

Through the analysis of M44, I found that open star clusters are more difficult to analyze than globular star clusters, so I decided to focus on the latter.



老師

1度

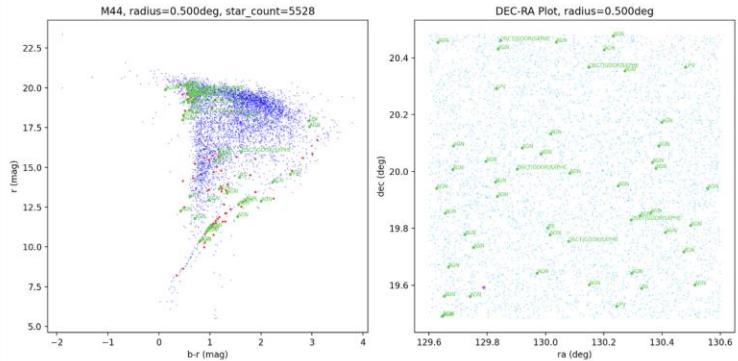
8月 11, 2023 9:32:30下午

老師

m44 超大

8月 11, 2023 9:32:27下午

學生



8月 11, 2023 9:32:12下午

學生

老師這是我剛剛搜尋 M44(疏散) 的結果，從右邊這張圖我看不太出來哪裡有星星聚集，左邊這張也和之前的很不一樣，請問這樣正常嗎？

8月 11, 2023 9:32:12下午

為篩選非成員星，老師首先建議以零齡主序帶 (zero age main sequence, ZAMS) 擬合，嘗試多種相關方程式後發現成效不彰。

我們認為原因可能是球狀星團年齡太老，不能使用 ZAMS 找出星體在 CMD 或 HRD 上應分布的位置。

2023/08/11~  
2023/08/15

In order to filter out non-member stars, my teacher first suggested fitting the zero age main sequence (ZAMS). After trying a variety of related equations, we found that the results were ineffective.

We believe that the reason may be that globular clusters are too old to use ZAMS to find out where the stars should be distributed on the CMD or HRD.

學生

老師好，這是直線分割的圖，我等等再試試着用 ZAMS 分割  
8月12, 2023 5:43:08下午

老師

那個0的意思是不考慮紅化消光  
8月11, 2023 10:23:10下午

老師

但原理是靠(b-v)0  
8月11, 2023 10:22:48下午

老師

但沒有金屬  
8月11, 2023 10:22:30下午

老師

裡面有多種模式  
8月11, 2023 10:22:26下午

老師

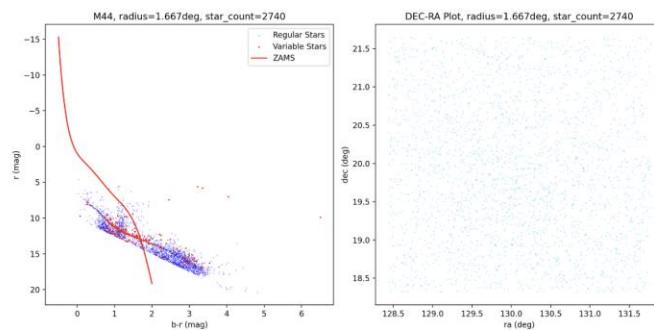
要接受cookie  
8月11, 2023 10:21:03下午

老師

[https://xoomer.virgilio.it/hrtrace/Miscellanea1.htm#\\_top](https://xoomer.virgilio.it/hrtrace/Miscellanea1.htm#_top)  
當時應該是從這個網站找到方程式，用的是編號8“Schmidt-Kaler Luminosity Class V”  
[https://xoomer.virgilio.it/hrtrace/Miscellanea1.htm#\\_top](https://xoomer.virgilio.it/hrtrace/Miscellanea1.htm#_top)

8月11, 2023 10:20:46下午

學生

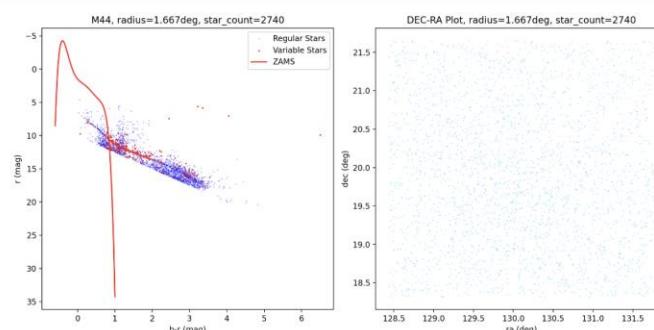


8月12, 2023 7:55:18下午

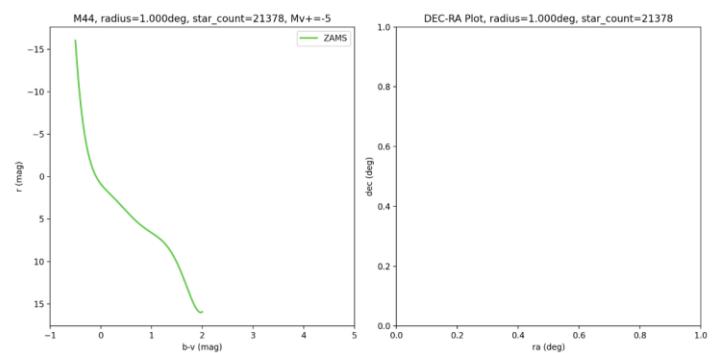
學生

這是KEENAN公式  
請問這樣正常嗎?  
8月12, 2023 7:55:18下午

學生



學生



8月15, 2023 9:38:09上午

老師

你單畫一張zams出來

8月15, 2023 9:37:01上午

老師

我還是覺得怪

8月15, 2023 9:37:01上午

學生

這是用第八個公式的 ZAMS

8月15, 2023 9:33:44上午

老師

你這zams 不對

8月15, 2023 8:27:50上午

老師

不可以

8月15, 2023 8:27:44上午

學生

請問這樣可以嗎

8月14, 2023 9:18:15下午

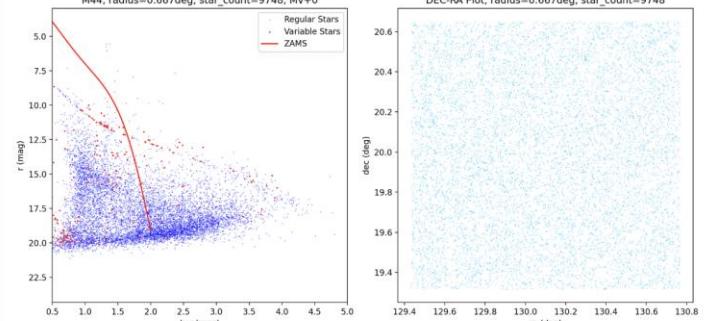
學生

但ZAMS和主序帶沒有很合耶

8月14, 2023 9:18:07下午

學生

M44, radius=0.667deg, star\_count=9748, Mv+0



2023/08/19~

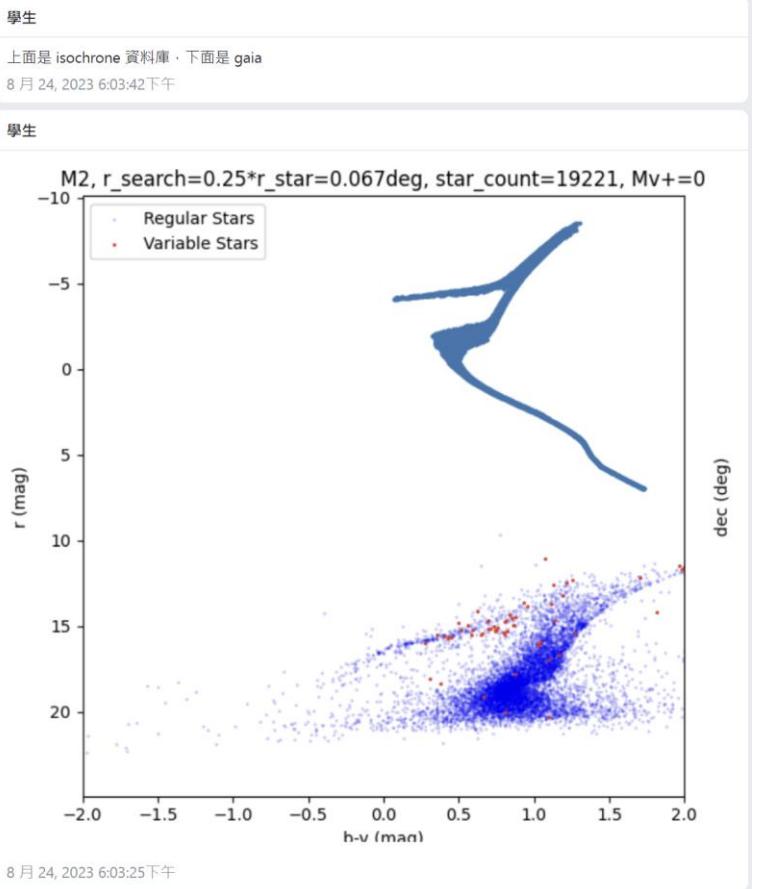
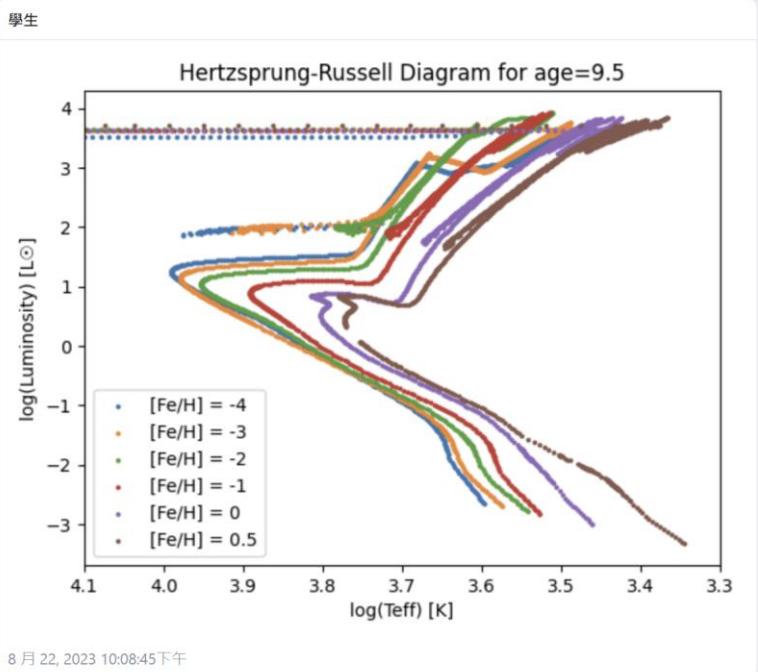
2023/08/24

我從老師給的網站出發，找到了 Python 的 isochrone 模組。和老師討論後，我們認為  $z$  等年齡線 (isochrone) 比 ZAMS 更適合擬合球狀星團。

給定金屬豐度與年齡，isochrone 模組就能給出對應的等年齡線的點的集合。

I started from the website given by the teacher and found the isochrone module of Python. After discussing with the teacher, we believe that the  $z$  isochrone is more suitable for fitting globular star clusters than ZAMS.

Given metallicity and age, the isochrone module can give a set of points on the corresponding iso-age line.



|  |  |   |
|--|--|---|
|  |  | <p>學生</p> <pre>✓ 0 秒 from dust_extinction.parameter_averages import F99 import numpy as np  # Define the wavelengths you're interested in (in microns) wave = np.array([0.65]) # Example: red light  # Instantiate the extinction model and evaluate ext = F99(Rv=3.1) # Rv=3.1 is a common value, but adjust as needed a_lambda = ext(wave) print(a_lambda)  [0.18417568]</pre> <p>8月 26, 2023 9:48:12上午</p> <p>學生<br/>老師好，我代 <math>Rv=3</math>，結果 <math>0.65 \text{ 1/micron}</math> 的紅光被修正到 <math>0.18 \text{ 1/micron}</math>，直接變成藍光，請問這樣正常嗎？<br/>8月 26, 2023 9:48:09上午</p> <p>學生<br/>沒關係那我應該先用常數就好<br/>8月 25, 2023 9:04:10下午</p> <p>老師<br/>最常見就是AOV型的星<br/>8月 25, 2023 9:01:54下午</p> <p>老師<br/>你要找出標準星去校準<br/>8月 25, 2023 9:01:40下午</p> <p>老師<br/>只能用函數下去猜<br/>8月 28, 2023 12:12:55下午</p> <p>老師<br/>對，這裡的AV一定是錯的<br/>8月 28, 2023 12:12:49下午</p> <p>學生<br/>那請問要怎麼用距離修正呢？<br/>8月 28, 2023 11:46:30上午</p> <p>學生<br/>所以Av 應該是錯的？<br/>8月 28, 2023 11:46:09上午</p> <p>老師<br/>垂直方向為 距離加消光<br/>8月 28, 2023 7:30:47上午</p> <p>老師<br/>沒有修正距離<br/>8月 28, 2023 7:30:35上午</p> <p>老師<br/>等等！<br/>8月 28, 2023 7:30:28上午</p> <p>學生<br/>我比較懷疑是不是 Av 的數值有錯？但如果 Av 實際是垂直的移動距離，應該是 20 左右沒錯<br/>8月 27, 2023 2:09:12下午</p> |
|--|--|---|

手動疊合後，我在老師的引導下，根據恆星在CMD上與 isochrone 資料點的距離與方向，設計了能大致篩選非成員星的條件 (rule)。

2023/08/28

After manual overlay, under the guidance of the teacher, I designed a rule that can roughly filter out non-member stars based on the distance and direction of the star from the isochrone data point on the CMD.



|  |  |   |
|--|--|---|
|  |  | <p><b>老師</b><br/>因為變星可能會變亮，所以是小於 0.5<br/>8月 29, 2023 11:44:59 上午</p> <p><b>老師</b><br/>或某個值<br/>8月 29, 2023 11:44:39 上午</p> <p><b>老師</b><br/>或0.5<br/>8月 29, 2023 11:44:32 上午</p> <p><b>老師</b><br/>就是離你的點大於1 就是不要<br/>8月 29, 2023 11:44:10 上午</p> <p><b>老師</b><br/>一個簡單的規則<br/>8月 29, 2023 11:43:54 上午</p> <p><b>老師</b><br/>左下兩個 右側兩個<br/>8月 29, 2023 11:43:40 上午</p> <p><b>老師</b><br/>有四個點<br/>8月 29, 2023 11:43:33 上午</p> <p><b>老師</b><br/>不在線附近或上方的<br/>8月 29, 2023 11:43:29 上午</p>   |
|  |  | <p><b>學生</b><br/>老師好，這是我新的程式碼<br/>8月 30, 2023 8:39:54 上午</p> <p><b>學生</b><br/><a href="https://colab.research.google.com/drive/1undRWqeSxdT96mJxE7NL_un4fE0ALpM?usp=sharing">https://colab.research.google.com/drive/1undRWqeSxdT96mJxE7NL_un4fE0ALpM?usp=sharing</a><br/><a href="https://colab.research.google.com/drive/1undRWqeSxdT96mJxE7NL_un4fE0ALpM?usp=sharing">https://colab.research.google.com/drive/1undRWqeSxdT96mJxE7NL_un4fE0ALpM?usp=sharing</a><br/>8月 30, 2023 8:39:37 上午</p> <p><b>學生</b><br/>我再調調看好了<br/>8月 29, 2023 9:21:52 下午</p> <p><b>老師</b><br/>左上角要鏟掉那麼多嗎？<br/>8月 29, 2023 9:18:56 下午</p> <p><b>老師</b><br/>換一個星團呢？<br/>8月 29, 2023 9:18:43 下午</p> <p><b>學生</b><br/> <pre>Discarded Variable Stars: 0 Return length: 65 65 /usr/local/lib/python3.10/dist-packages/numpy/core/_asarray.py:286: UserWarning: Warning: converting a masked element to nan.   data = np.asarray(data, dtype=dtype, copy=copy)</pre> </p> |

|  |  |   |
|--|--|---|
|  | <p>大部分的程式完成後，我開始分析 Messier Catalog 中的 10 個星團。</p> <p>此時我仍在嘗試分析球狀星團，過程中遇到了諸如 M103 等較不易分析的星團。</p> <p>2023/09/10~<br/>2023/09/20</p> <p>After most of the programming was completed, I started analyzing the 10 star clusters in the Messier Catalog.</p> <p>At this time I was still trying to analyze globular clusters, and in the process I encountered clusters such as M103 that were less easy to analyze.</p> | <p>學生<br/>老師好，我目前的程式可以分析球狀星團了<br/>但資料庫沒有疏散星團的 isochrone<br/>請問我要怎麼篩選變星呢<br/>9月11, 2023 9:10:00上午</p> <p>學生<br/>或是老師有沒有印象課本中有沒有寫呢?<br/>9月10, 2023 4:33:44下午</p> <p>學生<br/>前人是否有做過<br/>9月10, 2023 4:30:02下午</p> <p>學生<br/>像是有沒有說球狀星團比較容易出現造父變星<br/>等等的?<br/>9月10, 2023 4:29:52下午</p> <p>老師<br/>哪一類?<br/>9月10, 2023 4:29:10下午</p> <p>學生<br/>老師哪請問對於球狀或疏散星團有什麼樣的星星(或變星)<br/>目前有沒有甚麼已知的理論呢?<br/>9月10, 2023 4:21:14下午</p> <p>9月20, 2023 8:39:44下午</p> <p>學生<br/>老師請問這個疏散星團的主序帶是哪一個呢<br/>9月20, 2023 8:39:44下午</p> <p>老師<br/><a href="https://www.cysh.cy.edu.tw/p/404-1008-95376.php">https://www.cysh.cy.edu.tw/p/404-1008-95376.php</a><br/>&lt;p color="#000000" fontfamily="標楷體" fontsize="16" lineheight="150%" paddingtop="0" paragraphlevel="0" paragraphstartindent="48" rootdefinition="0" rowspacing="0" textindent="-48"&gt;主旨：<br/>函轉國立臺灣科學教育館(以下簡稱科教館)辦理「2024年臺灣國際科學展覽會國內....<br/><a href="https://www.cysh.cy.edu.tw/p/404-1008-95376.php">https://www.cysh.cy.edu.tw/p/404-1008-95376.php</a></p> <p>9月20, 2023 2:04:21下午</p> |
|--|--|---|

在 ChatGPT 3.5 幫助資料整理下，我選定了 15 個 Messier Catalog 的球狀星團 (M2, M3, M9, M10, M19, M28, M30, M54, M56, M68, M72, M79, M80, M92, M107)，並將重點放在分析 RR 型天琴座變星 (RRL)。

此時，我開始將 CMD、dec-ra 圖、星團參數、等年齡線平移量等參數以 PowerPoint 彙整，以方便和老師討論。

不過，這個時候的程式碼尚有一些 bug。程式碼經過修正後，得到的數據才用在最終的分析上。

2023/09/20~

2023/09/27

With the help of ChatGPT 3.5, I selected 15 Messier Catalog globular clusters (M2, M3, M9, M10, M19, M28, M30, M54, M56, M68, M72, M79, M80, M92, M107), and focus on the analysis of RR-type Lyrae variables (RRL).

At this time, I began to compile the CMD, dec-ra diagram, star cluster parameters, isoage line translation and other parameters in PowerPoint to facilitate discussion with the teacher.

However, the code at this time still has some bugs. After the program code was modified, the data obtained was used in the final analysis.

學生

目前注意到比較特別的就是 M3, M68 都有很多天琴座 RR 但兩個都不是天琴座的  
然後這些 RR 分布很接近

9月23, 2023 6:02:00下午

學生

下載檔案：  
[your\\_activity\\_across\\_facebook/messages/inbox/huangguanfu\\_10160632118289602/files/globularvari0923\\_296530459760790.pdf](your_activity_across_facebook/messages/inbox/huangguanfu_10160632118289602/files/globularvari0923_296530459760790.pdf)

9月23, 2023 6:01:38下午

學生

下載檔案：  
[your\\_activity\\_across\\_facebook/messages/inbox/huangguanfu\\_10160632118289602/files/AgeComparisonGrand\\_7126152884061630.xlsx](your_activity_across_facebook/messages/inbox/huangguanfu_10160632118289602/files/AgeComparisonGrand_7126152884061630.xlsx)

9月23, 2023 6:01:31下午

學生

老師好，這裡有十個球狀星團的資料

9月23, 2023 6:01:30下午

學生

好的

9月22, 2023 10:03:57下午

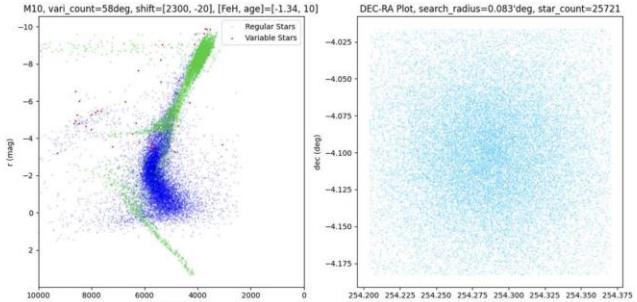
Table of Globular Clusters

| Name | ra_h | ra_m | ra_s  | dec_deg | dec_min | dec_sec | dim_min     | Age |
|------|------|------|-------|---------|---------|---------|-------------|-----|
| M2   | 21   | 33   | 27.02 | 0       | -49     | -23.7   | 16.12.5 Gyr |     |
| M3   | 13   | 42   | 11.62 | 28      | 22      | 38.2    | 18.11.39Gyr |     |
| M9   | 17   | 19   | 11.78 | -18     | -30     | -58.5   | 9.3         |     |
| M10  | 16   | 57   | 8.92  | -4      | -5      | -58.07  | 20          |     |
| M19  | 17   | 2    | 37.69 | -26     | -16     | -4.6    | 17          |     |
| M28  | 18   | 24   | 32.89 | -24     | -52     | -11.4   | 11.2        |     |
| M30  | 21   | 40   | 22.12 | -23     | -10     | -47.5   | 12          |     |
| M54  | 18   | 55   | 3.33  | -30     | -28     | -47.5   | -1          |     |
| M56  | 19   | 16   | 35.57 | 30      | 11      | 5       | -1          |     |
| M68  | 12   | 39   | 27.98 | -26     | -44     | -38.6   | -1          |     |
| M72  | 20   | 53   | 27.7  | -12     | -32     | -14.3   | 1           |     |
| M79  | 5    | 24   | 10.59 | -24     | -31     | -27.3   | -1          |     |
| M80  | 16   | 17   | 2.41  | -22     | -58     | -33.9   | -1          |     |
| M92  | 17   | 17   | 7.39  | 43      | 8       | 9.4     | -1          |     |
| M107 | 16   | 32   | 31.86 | -13     | -3      | -13.6   | -1          |     |

M10

Total stars: 99833Stars after rule and db search: 54Discarded Variable Stars: 0  
age, feh, av, shiftx, shifty, ic\_barrier, ic\_nx, x\_search\_error, y\_search\_error, df\_error

10 | -1.34 | 20 | 2300 | -20 | 0 | 1000 | 500 | 2 | 1.0



|                           |  |  |
|---------------------------|--|--|
|                           | <p>我發現大部分的星團除了有 RRL 外，還有蝕雙星 (eclipsing binary, ECL)。和老師討論後，我們認為這種變星的統計意義較小，因此確認以分析 RRL 成員星比例 (membership ratio) 為研究主軸。</p> <p>老師在這段期間有和我提到分析 RRL 可能可以推論出和恆星演化 (star formation) 有關的結論。當時我還不知道其關聯性，是到十月中得到結果後才比較有概念。</p>   | <p><b>老師</b><br/>幾乎可以說應該與星星數成正相關<br/>9月23, 2023 9:36:55下午</p> <p><b>老師</b><br/>有一點，但不多<br/>9月23, 2023 9:36:34下午</p> <p><b>學生</b><br/>所以是不是說不太具有統計意義呢?<br/>9月23, 2023 9:36:23下午</p> <p><b>老師</b><br/>就是雙星，但繞行盤面與視線方向平行<br/>9月23, 2023 9:33:42下午</p> <p><b>老師</b><br/>ECL 是機率<br/>9月23, 2023 9:33:20下午</p> <p><b>學生</b><br/>RR 是唯二每個星團都有的變星<br/>另一個是 ECL (eclipsing binary)<br/>之前您說過不是我們討論的變星<br/>9月23, 2023 9:33:04下午</p> <p><b>老師</b><br/>star formation<br/>9月23, 2023 9:39:46下午</p> <p><b>老師</b><br/>恆星演化<br/>9月23, 2023 9:39:38下午</p> <p><b>學生</b><br/>那請問除了這些變星的比例還有甚麼可以探討的嗎<br/>像是從這個數據不知道老師有沒有看到其他可以分析的東西<br/>9月23, 2023 9:39:10下午</p> <p><b>學生</b><br/>好的<br/>我再查一下!<br/>9月23, 2023 9:44:14下午</p> <p><b>老師</b><br/>一時想不到了<br/>9月23, 2023 9:43:11下午</p> <p><b>老師</b><br/>變星能持續多久<br/>9月23, 2023 9:42:53下午</p> <p><b>老師</b><br/>變星為什麼這麼少<br/>9月23, 2023 9:42:42下午</p> <p><b>老師</b><br/>那是演化中末期發生了啥事<br/>9月23, 2023 9:42:34下午</p> <p><b>老師</b><br/>若要跟變星有關<br/>9月23, 2023 9:42:19下午</p> |
| 2023/09/20~<br>2023/09/27 | I found that in addition to RRL, most star clusters also have eclipsing binary (ECL) stars. After discussing with the teacher, we believed that the statistical significance of this type of variable star was small, so we confirmed that the analysis of the membership ratio of RRL stars would be the main focus of our research.<br><br>During this period, the teacher mentioned to me that analyzing RRL might be able to deduce conclusions related to star formation. I didn't know the correlation at the time. I had a better idea only after I got the results in mid-October. |  |

2023/09/29

我得到初步的 RRppm 數據，並嘗試找出其和金屬豐度、質量、星團半質量半徑的關聯。其中，我最先發現 RRppm 和半徑的正相關。

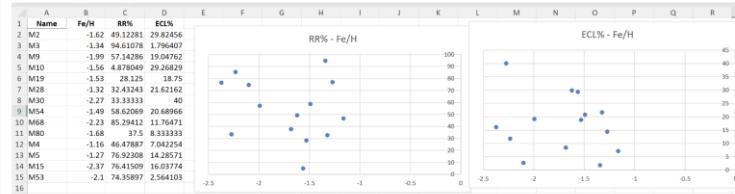
I got preliminary RRppm data and tried to figure out how it relates to metallicity, mass, and cluster half-mass radius. Among them, I first discovered the positive correlation between RRppm and radius.

#### 學生

若我做的資料正確  
單純看組成比例看不出明顯的關聯...

9月29, 2023 12:23:17下午

#### 學生



9月29, 2023 12:22:50下午

#### 老師

金屬豐度是否與變星的出現有關

9月29, 2023 12:20:14下午

#### 老師

我的意思是

9月29, 2023 12:20:01下午

#### 學生

所以可能這三個是同一件事情?

9月29, 2023 5:28:34下午

#### 老師

半徑 ... 這其實也許跟質量也有關 ?

9月29, 2023 5:27:27下午

#### 老師

質光關係

9月29, 2023 5:27:02下午

#### 老師

星團星等其實就是質量

9月29, 2023 5:26:57下午

#### 學生

下載檔案：  
your\_activity\_across\_facebook/messages/inbox/huangguanfu\_10160632118289602/files/AgeComparisonGrand\_1032637544716736.xlsx

9月29, 2023 5:22:55下午

#### 學生

老師好，我發現  
1. 原本預期會有關係的 Fe/H 看不出明顯趨勢  
2. RR ppm 和星團半徑、星團星等、星團質量有關連性

9月29, 2023 5:20:55下午

2023/09/29

此外，我提出了一個有趣的發現，即球狀星團半徑似乎趨向一最小值，不過這並非最終研究結果所強調的結論之一。

為量化半徑的正相關，老師建議我找出 power law 關係式。以  $\log RR_{ppm}$  與 log 半徑作圖，我發現的確有正相關。

In addition, I made an interesting finding that the radii of globular clusters seem to tend toward a minimum value, although this was not one of the conclusions emphasized by the final results.

In order to quantify the positive correlation of radius, the teacher suggested that I find the power law relationship. Plotting  $\log RR_{ppm}$  versus log Radius, I found that there is indeed a positive correlation.

學生

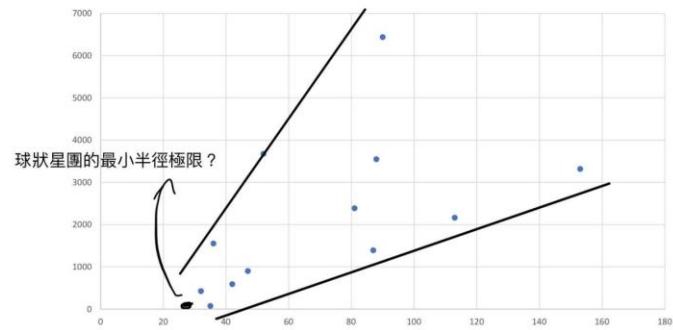
這是一個我覺得有趣的地方

9月29, 2023 5:32:02下午

學生

## RR ppm

RR ppm vs. Radius (ly)



9月29, 2023 5:31:55下午

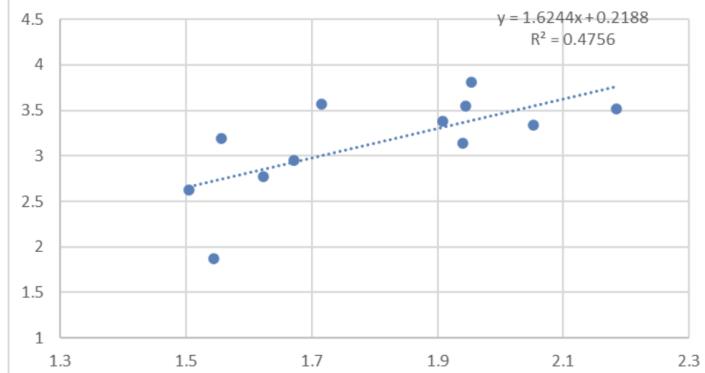
學生

好像真的有耶

9月29, 2023 5:45:35下午

學生

## logRRppm vs logRadii



9月29, 2023 5:45:29下午

學生

我查到的是  $y=ax^k$  的公式

如果  $x, y$  取  $\log$  會預期有線性關係

9月29, 2023 5:45:24下午

老師

數量取個  $\log$

9月29, 2023 5:35:21下午

老師

不知，你先查一下 power law 的概念

9月29, 2023 5:35:11下午

2023/09/29

老師建議我同時考慮兩個參數，分析和 RRppm 的相關性，即在年齡的參數前乘上一參數。

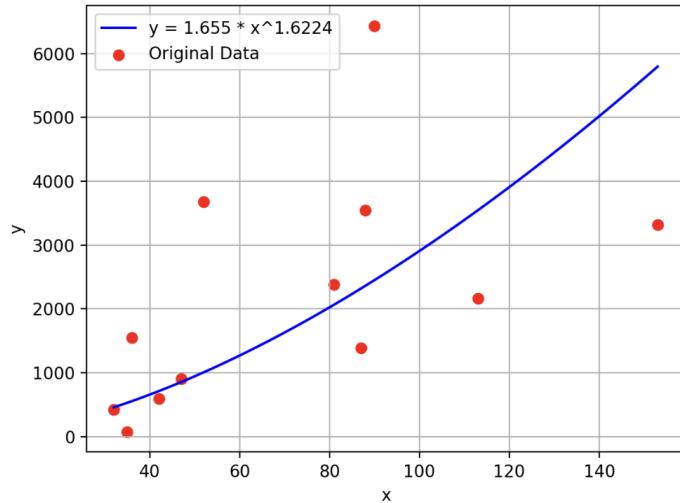
The teacher suggested that I consider two parameters at the same time and analyze the correlation with RRppm, that is, multiply the age parameter by a coefficient.

學生

所以我要把半徑和年齡用某個權重結合  
然後一樣作圖  
找相關係數最高的權重嗎？

9月29, 2023 6:40:07下午

學生



9月29, 2023 6:35:57下午

老師

或 1.0 7 0.3

9月29, 2023 6:31:07下午

老師

1.0 9 0.8

9月29, 2023 6:30:59下午

老師

或是取中間最大

9月29, 2023 6:30:51下午

老師

或反過來

9月29, 2023 6:30:45下午

老師

越年輕權重越小

9月29, 2023 6:30:42下午

老師

ex 130 或 140 倍當 1

9月29, 2023 6:30:32下午

老師

能不能加個年齡的權重項

9月29, 2023 6:30:18下午

老師

同時想一個理由為什麼會有關係

9月29, 2023 6:29:41下午

2023/09/29~  
2023/10/15

此時我完成了大部份的「觀測」部分，也就是彙整了所有數據，Python 的係數  $\lambda, \mu$  的優化 (optimization of coefficients) 部分也告一段落。

不過，我觀察數據趨勢的敏銳度較差，一開始以為 RRppm 只和年齡有負相關及和半徑有正相關。後來認真分析  $X_{RR}, Y_{RR}$  變數時，才發現 RRppm 與金屬豐度的關聯性。

At this point, I have completed most of the "observation" part, that is, aggregating all the data, and the optimization of coefficients  $\lambda$  and  $\mu$  in Python has also come to an end.

However, my sensitivity in observing data trends is poor. At first, I thought RRppm was only negatively correlated with age and positively correlated with radius. Later, when I carefully analyzed the  $X_{RR}$  and  $Y_{RR}$  variables, I discovered the correlation between RRppm and metallicity.

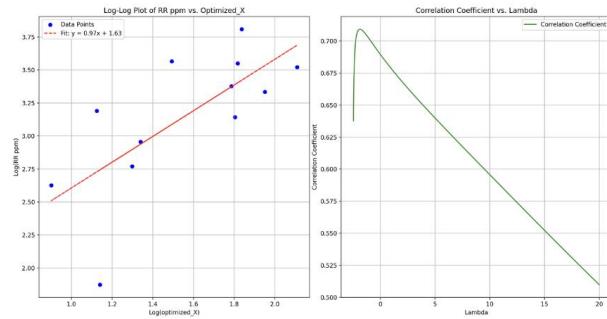
學生

老師好，我發現加了權重做雙變數的迴歸時，得到的最佳相關係數不會和只用半徑當變數時差太多  
9月 30, 2023 9:18:14 上午

學生

RR ppm

$X = \text{半徑} + \lambda \times \text{年齡}$ , 尋找使  $\log(\text{RRppm})$  vs.  $\log(X)$  相關係數最高的 lambda  
Optimized Lambda: -1.8589  
Highest Correlation Coefficient: 0.7092  
Regression:  $y = 0.97x + 1.63$ , 右圖在 lambda 繼續變大時單調遞減



9月 29, 2023 9:07:54 下午

學生

似乎有一點 尤其是FeH 的圖有一點特別 不知道為什麼會長成U型  
10月 15, 2023 8:51:05 上午

老師

看圖的趨勢

10月 15, 2023 8:46:45 上午

老師

我覺得其他也有負相關？

10月 15, 2023 8:46:37 上午

老師

這就是你的結論

10月 15, 2023 8:45:33 上午

學生

下載檔案：  
your\_activity\_across\_facebook/messages/inbox/huangguanfu\_10160632118289602/files/starsummary1015\_354826183637410.pdf

10月 15, 2023 8:45:27 上午

學生

老師好，我後來把星團數增加到 20 個，目前數據都處理完了，但除了RRppm和年齡有一點負相關外，其他的似乎沒什麼明顯的趨勢，因此我不太確定要怎麼下結論.....

10月 15, 2023 8:45:11 上午

老師

我覺得你的觀測部份結束了

10月 15, 2023 8:51:42 上午

老師

但這需要理論來驗證

10月 15, 2023 8:51:30 上午

老師

也是個結論？

10月 15, 2023 8:51:19 上午

|                           |  |   |
|---------------------------|--|---|
|                           |  | <p><b>學生</b></p> <p>review 的來源只有一篇嗎?</p> <p>10月18, 2023 12:40:42下午</p> <p><b>老師</b></p> <p>來源是這篇</p> <p>10月18, 2023 12:39:58下午</p> <p><b>老師</b></p> <p>那個是review</p> <p>10月18, 2023 12:39:43下午</p> <p><b>學生</b></p> <p>vol 221 no 4</p> <p>10月18, 2023 12:39:32下午</p> <p><b>學生</b></p> <p>好像不是</p> <p>10月18, 2023 12:39:27下午</p> <p><b>老師</b></p> <p><a href="https://articles.adsabs.harvard.edu/pdf/1996AJ....112.1487H">https://articles.adsabs.harvard.edu/pdf/1996AJ....112.1487H</a><br/> %PDF-1.5 % 12 0 obj &gt; endobj xref 12 13 00000000023 00000 n 0000000534 00000 n 0000000822 00000 n<br/> 0000000983 00000 n 0000001037 00000 n 000001160 00000 n 000002214 00000 n 000002414 00000 n<br/> 000002523 00000 n 0000009739 00000 n 000012550 00000 n 000017031 00000 n 000000653 00000 n<br/> trailer<br/> <a href="https://articles.adsabs.harvard.edu/pdf/1996AJ....112.1487H">https://articles.adsabs.harvard.edu/pdf/1996AJ....112.1487H</a></p> <p>10月18, 2023 12:28:12下午</p> |
| 2023/10/15~<br>2023/10/25 |  | <p><b>老師</b></p> <p>其十分接近宇宙年齡，因此，透過研究球狀星團，我們能夠對宇宙的演化窺知一二。</p> <p>10月22, 2023 10:38:42下午</p> <p><b>老師</b></p> <p>分析其在“演化歷程”的研究</p> <p>10月22, 2023 10:37:03下午</p> <p><b>老師</b></p> <p>上有重要意義</p> <p>10月22, 2023 10:36:30下午</p> <p><b>老師</b></p> <p>摘要 且在“恆星演化”</p> <p>10月22, 2023 10:36:23下午</p> <p><b>老師</b></p> <p>收到</p> <p>10月22, 2023 10:29:08上午</p> <p><b>學生</b></p> <p>老師好，我目前只剩參考資料的部分，想請老師看一下摘要與結論的部分是否需要修改，謝謝老師</p> <p>10月22, 2023 8:51:53上午</p> <p><b>學生</b></p> <p>下載檔案：<br/> <a href="your_activity_across.facebook/messages/inbox/huangguanfu_10160632118289602/files/20231022xingtuankezhancaogao_3235823690050930.pdf">your_activity_across.facebook/messages/inbox/huangguanfu_10160632118289602/files/20231022xingtuankezhancaogao_3235823690050930.pdf</a></p> <p>10月22, 2023 8:42:04下午</p> <p><b>學生</b></p> <p>另外這是我目前的進度，有找到一個 power law，目前還要解釋半徑的正相關<br/> 請老師先看一下</p> <p>10月18, 2023 4:15:12下午</p>  |

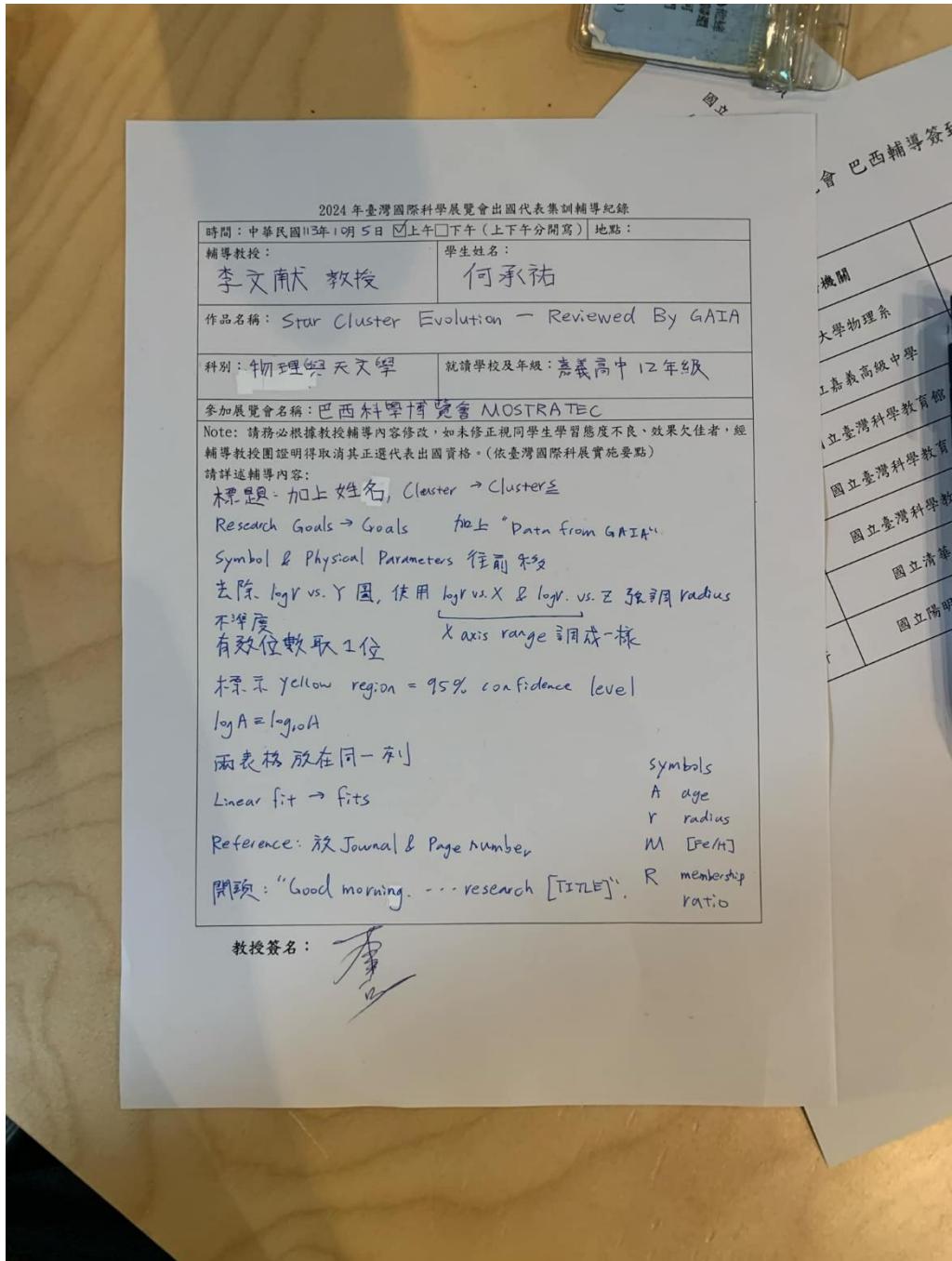
|  |  |   |
|--|--|---|
|  | <p>進行研究報告的最終修改，主要圍繞在怎麼寫結論和報名資料填寫等。</p> <p>另外，我和老師也討論了許多較細節的部份，如呈現相關係數、RRppm 範圍等。</p> <p>The final revision of the research report mainly focuses on how to write the conclusion and fill in the registration information.</p> <p>In addition, the teacher and I also discussed many more detailed parts, such as the presentation of correlation coefficients, RRppm range, etc.</p> | <p><b>學生</b></p> <p>老師好，請問這樣改可以嗎?<br/>10月 26, 2023 6:15:45下午</p> <p><b>學生</b></p> <p>以上研究結果說明除了一般被認為主導星團演化的年齡與金屬豐度會影響 RRppm 外，星團半徑亦和 RRL 於星團中的組成有正相關。目前對此現象的研究較少，推測其原因可能為</p> <ul style="list-style-type: none"> <li>• 星雲說解釋：一團星雲形成眾多小星團。星團形成時，較大者會因萬有引力和較小者融合，因此半徑較大的星團成員星的組成較為多樣，可能有利於變星的形成。</li> <li>• 偶發生成解釋：半徑較大的星團由於星體間萬有引力交互作用較顯著，成員星密度較高，使星體間碰撞、潮汐作用等交互作用較頻繁，進而導致變星的生成。不過，受限於觀測技術，在無法看到所有成員星的情況下，較難直接透過觀測成員星密度。</li> <li>• 潮汐作用解釋：在半徑大的星團中，星體間潮汐作用較顯著，影響質量蒸發，使星團中較大比例的星體演化為變星。此假說呼應 Ferro 等人認為質量蒸發與 RRL 形成有關的論點。</li> </ul> <p>以上三個假說中，潮汐作用解釋有較完備的理論背景，推測最為可能的機制。對於為何星團半徑與變星組成比例有正相關十分值得探討。</p> <p>10月 26, 2023 6:15:38下午</p> <p><b>學生</b></p> <p>好的 我修完再跟老師討論<br/>10月 26, 2023 4:16:30下午</p> <p><b>學生</b></p> <p>有<br/>10月 28, 2023 1:14:10下午</p> <p><b>學生</b></p> <p>有 但有意義嗎?<br/>10月 28, 2023 1:14:07下午</p> <p><b>老師</b></p> <p>負相關的相關係數?<br/>10月 28, 2023 1:13:55下午</p> <p><b>老師</b></p> <p>平均值有嗎<br/>10月 28, 2023 1:13:23下午</p> <p><b>老師</b></p> <p>變星的rpm 的範圍寫上去<br/>10月 28, 2023 1:13:05下午</p> <p><b>學生</b></p> <p>沒有<br/>10月 28, 2023 1:12:44下午</p> <p><b>老師</b></p> <p>偏差平均值有嗎<br/>10月 28, 2023 1:12:33下午</p> <p><b>學生</b></p> <p>老師請問結論這樣寫可以嗎?<br/>10月 28, 2023 1:11:50下午</p> |
|--|--|---|

|                           |   |   |
|---------------------------|---|---|
|                           |   | <p>學生</p>  <p>12 月 14, 2023 12:24:21下午</p> <p>老師</p> <p>國際科展有過初審</p> <p>12 月 14, 2023 12:13:18下午</p>   |
| 2023/12/14~<br>2023/12/30 | <p>通過初審後，製作英文簡報、英文解說影片等。</p> <p>其中，我和老師在標題上討論許久，因為除了要強調「RR 型天琴座變星的成員星組成比例」外，也要讓標題簡潔有力，我還使用 ChatGPT 幫助。</p> <p>After passing the preliminary review of 2024 Taiwan Internatinoal Science Fair, English briefings, English explanation videos, etc. were being produced.</p> <p>Among them, the teacher and I discussed the title for a long time, because in addition to emphasizing the "proportion of member stars of the RR Lyrae variable star", we also need to make the title concise and powerful. I also used ChatGPT to assist.</p> | <p>學生</p> <p>Compositional Analysis of RR Lyrae Variables in Globular Clusters Using GAIA Data?</p> <p>12 月 25, 2023 6:55:32下午</p> <p>老師</p> <p>或你修一下</p> <p>12 月 25, 2023 6:54:44下午</p> <p>老師</p> <p>percentage of variable star in the cluster?</p> <p>12 月 25, 2023 6:54:36下午</p> <p>老師</p> <p>怪怪的</p> <p>12 月 25, 2023 6:54:04下午</p> <p>學生</p> <p> You<br/>Turn this paper title into a more professional one:<br/>"Analyzing the Composition of RR Lyrae Variables in Globular Clusters with GAIA Data"</p> <p> ChatGPT<br/>To enhance the professionalism of the paper title "Analyzing the Composition of RR Lyrae Variables in Globular Clusters with GAIA Data," you could consider the following revision:<br/><br/>"Investigating the Stellar Populations of RR Lyrae Variables within Globular Clusters Using GAIA Observations"<br/><br/>This title maintains the essence of the original while employing more formal and specific scientific language.<br/>白 凸 ↗ ⚡</p> <p>12 月 25, 2023 6:53:52下午</p> |

## Main Remarks from Professor Li After TISF 2024 (2024/1 ~ 2024/10)

- Emphasize the discovery that the cluster radius is important.
- Change of symbols for key parameters.
- Presentation changes on the poster: table caption, figure caption.
- Analyze factor weights.
- Revised presentation script.

## Notes



Caption: Table 在上, Fig 在下 Page 3

Linear Fit  $\rightarrow$  Figs

不确定度只取到一位

Table 更小、更少

2 Tables put on same line

→ 缩小、垂直长度 Title 可能是同一张  
删除 p-value column ↳ 放名字

可以把 Y 删掉, 用 X 和 Z 表达圆 radius 的大小

+ Key Physical Parameter, \* Applying this method to  
拿掉 log 的 () consider the effect from  
radius + other star clusters,

Figure 6, (a) (c) X 在 range 里 -> 才可以 X 和 Z 表达

1. Age

2. Meta.

3. Radius

框起来

Factor Weight

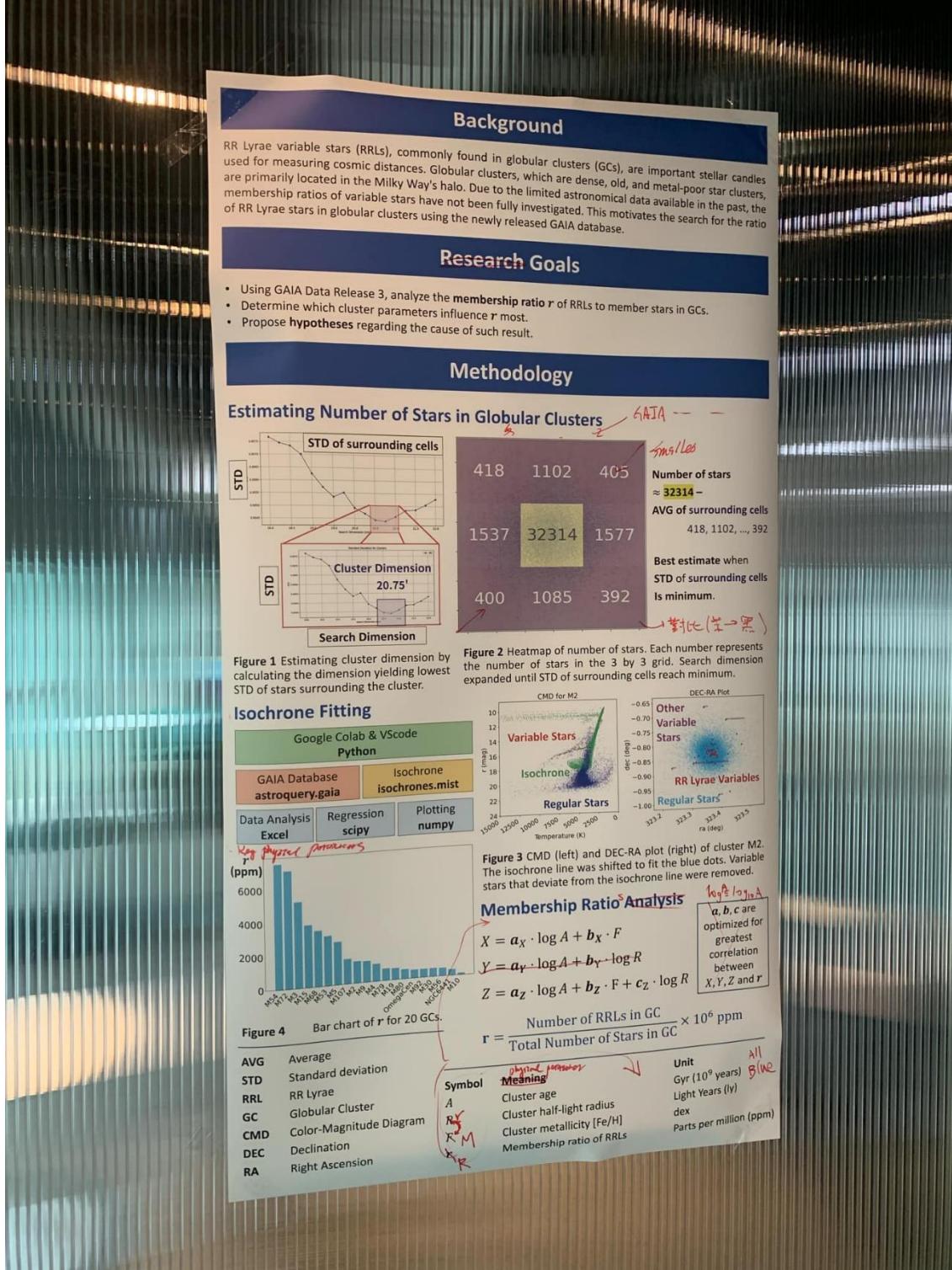
| Factor weight | Previous Result |    | This Study |   |
|---------------|-----------------|----|------------|---|
|               | A               | M  | A          | M |
| 1             | 2               | NA | 1          | 3 |
| 2             | 1               | 2  | 2          | 1 |

in blue  
emph.

\* Journal

Page

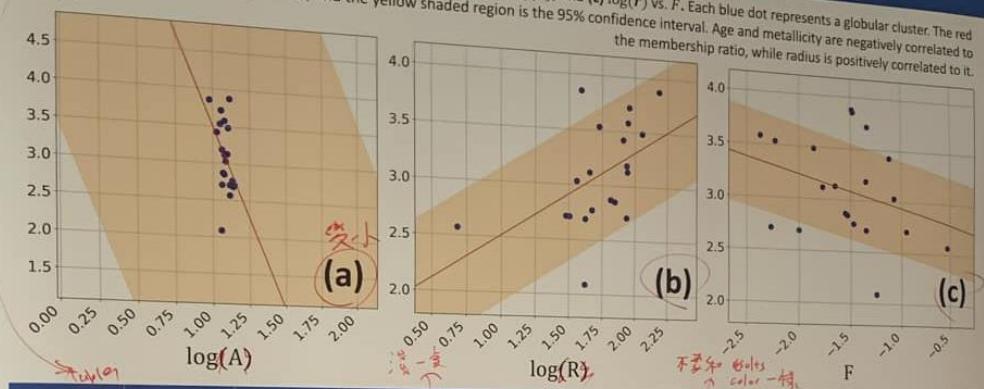
可以不写 Title



## Results

**Figure 5**

Plots of (a)  $\log(r)$  vs.  $\log(A)$ , (b)  $\log(r)$  vs.  $\log(R)$ , and (c)  $\log(r)$  vs.  $F$ . Each blue dot represents a globular cluster. The red line is the linear regression, and the yellow shaded region is the 95% confidence interval. Age and metallicity are negatively correlated to the membership ratio, while radius is positively correlated to it.



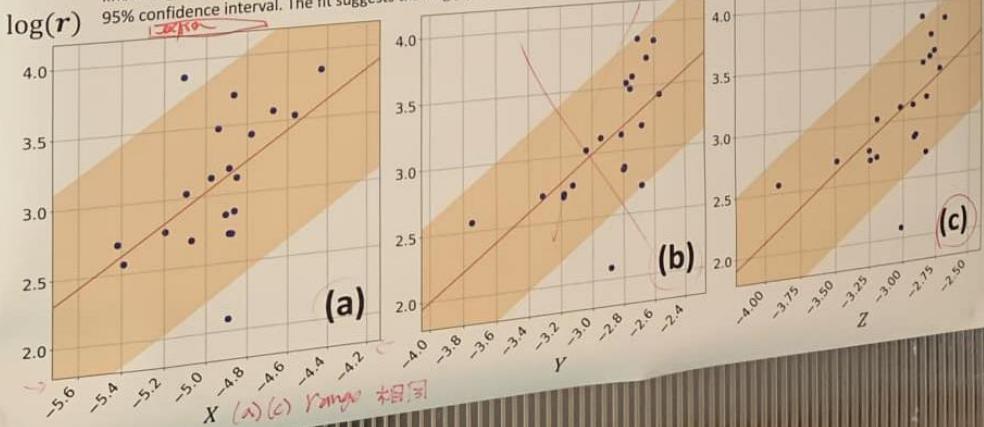
| Quantity | a       | b      | c      | Linear Fit                                     | Correlation Coefficient | P-value |
|----------|---------|--------|--------|--|-------------------------|---------|
| X        | -6.264  | -0.374 | -      | $\log(r) = (1.00 \pm 0.41)X + (8.03 \pm 2.01)$ | 0.501                   | 0.0244  |
| Y        | -43.829 | 8.004  | -      | $\log(r) = (1.00 \pm 0.31)Y + (5.99 \pm 0.90)$ | 0.605                   | 0.0047  |
| Z        | -71.096 | 11.110 | -2.102 | $\log(r) = (1.00 \pm 0.30)Z + (6.11 \pm 0.92)$ | 0.613                   | 0.0040  |

| Parameter | Value Range   | Coefficient in Z | Relative Significance |
|-----------|---------------|------------------|-----------------------|
| $\log(A)$ | 0.978 - 1.152 | -71.096          | ~1                    |
| $\log(R)$ | 0.681 - 2.185 | 11.110           | ~0.22                 |
| F         | -2.37 - 0.95  | -2.102           | ~0.05                 |

**Table 1** Optimal coefficients, linear fit, correlation coefficient and p-value between  $\log(r)$  and X, Y, and Z. The small p-values indicate there is a statistically significant association between X, Y, Z and r.

**Table 2** Relative significance of  $\log(A)$ ,  $\log(R)$  and F. Relative significance is estimated by the product of a quantity's coefficient in Z and its typical value range. Age, radius, and metallicity are primary factors that influence the membership ratio r, listed in decreasing order of impact.

**Figure 6** Plots of (a)  $\log(r)$  vs. X, (b)  $\log(r)$  vs. Y, and (c)  $\log(r)$  vs. Z. Each blue dot represents a globular cluster. The red line is the linear regression, and the yellow shaded region is the 95% confidence interval. The slope is normalized to 1. Most clusters fall inside the 95% confidence interval. The fit suggests that  $\log(r)$  is moderately correlated with X, Y and Z.



## Interpretation

### High $r$ : M54 Cluster

- M54 has a high membership ratio with no significant age, radius or metallicity
- 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.

M54

### [Fe/H] and the Instability Strip

- Negative correlation of number 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 smaller  $r$ .

### Correlation Between Radius and Membership Ratio

- Tidal force  $\propto$  Radius
- RRL membership ratio has **correlation** with Radius
- Mass-loss plays a role in the formation of RRLs (Ferro et al. 2020)
- Tidal force influences mass loss of GC

### Low $r$ : M10 Cluster

- M10 has a significantly small  $r$ . In agreement with past research:

- No RRLs in M10 found in 2002 [1] X
- Only one RRL found as of 2020 [2] X

#### Hypothesis X

- It is claimed [2] that there may be variations on its Red Giant Branch (RGB) evolution.
- M10 may have an unique mass loss due to, for example, collision with another cluster.

### Cluster Parameters Influencing $r$

#### 1. Age

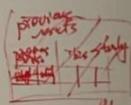
Primary factor of GC evolution [4]

#### 2. Radius

Tidal force & mass-loss

#### 3. Metallicity

Secondary factor of GC evolution [4]



| RR | TS | M |
|----|----|---|
| 1  | 2  | 3 |
| 4  | 5  | 6 |
| 7  | 8  | 9 |

The formation of RRLs may be correlated with tidal forces.

## Conclusions

- No bold
- Using **GAIA Data Release 3**, 20 globular clusters were analyzed.
  - The number of stars in GCs were found with the method of **heatmaps**. After fitting with isochrone curves, the membership ratio  $r$  was calculated. By defining  $X$ ,  $Y$ , and  $Z$ , the influence of cluster parameters was quantitatively analyzed.
  - Age, Radius and Metallicity were found to have the greatest influence on the RRL membership ratio, in decreasing order.
  - The roles of Age and Metallicity is in agreement with literature.
  - The impact of Radius can be explained with mass-loss and tidal forces.
  - From the clusters that deviate from the main-trend, it is concluded that the home galaxy or RGB evolution may influence RRL formation. Moreover, the **instability strip** explains how metallicity affects the RRL membership ratio.

## Future Prospects

- Similar analyses could be conducted on open clusters, given that member stars can be properly distinguished from background and foreground stars.
- Apart from RRL, other types of variable stars could also be analyzed.
- Deeper analysis into globular clusters could reveal insights of the early ages of the universe.

## References

- [1] Braun, K., et al. (2002). "Photometry Results for Globular Clusters M10 and M12." *Journal of the Royal Astronomical Society*, 43, 381–392.
- [2] Ferro, A. A., et al. (2020). "Globular Cluster M10: Reassessment of Stellar Membership, Distance, and Age."
- [3] Demarque, P., & Zinn, R. (1999). "Metallicity Dependence of RR Lyrae Absolute Magnitudes."
- [4] Gratton, R., et al. (2019). "Globular Cluster: An Observational Perspective."

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.

## 2024 年臺灣國際科學展覽會出國代表集訓輔導紀錄

|   |   |                    |
|---|---|--------------------|
| 時間：中華民國113年10月9日 <input checked="" type="checkbox"/> 上午 <input type="checkbox"/> 下午 (上下午分開寫)  |   | 地點：科教館             |
| 輔導教授：   | 學生姓名：<br>李文獻 教授 何承祐                       |                    |
| 作品名稱：   | Star Cluster Evolution — Revealed by GAIA |                    |
| 科別：   | 物理與天文學科                                   | 就讀學校及年級：嘉義高中 12 年級 |
| 參加展覽會名稱：  |   |                    |
| <p>Note: 請務必根據教授輔導內容修改，如未修正視同學生學習態度不良、效果欠佳者，經輔導教授團證明得取消其正選代表出國資格。(依臺灣國際科展實施要點)</p> <p>請詳述輔導內容：</p> <p>This work ... mission Gaia 框起來<br/> <math>R = \dots \Rightarrow R = \dots</math><br/>     References 月份不用 no. 不用 pp 不用 Journal <math>\rightarrow</math> J.<br/>     This work ... agreement 分三句<br/>     References 美排<br/>     Factor Weight <math>\rightarrow</math> Weight NA: Applicable<br/>     This Research <math>\rightarrow</math> This Work Fig 5<br/>     藍 blue <math>\rightarrow</math> darkblue<br/>     Using GAIA ... 移到後面<br/>     Conclusion 第二段前加入 "I found r is a key factor<br/>     Figure 5 缩小<br/>     Figure 6 (b)(c)易位<br/>     that must be considered in<br/>     understanding star cluster evolution."<br/>     Red &amp; Yellow 用藍色<br/>     Yellow region area ↓ by 3%<br/>     包含 M54, M10   </p> |   |                    |

教授簽名：