The Formation Mechanism of Ursa Minor dSph using Subaru/HSC Wide-field Data

Kyosuke Sato (Hosei Univ./NAOJ), Yutaka Komiyama, Mikito Tanaka(Hosei Univ.),
Sakurako Okamoto, Masafumi Yagi (NAOJ), Itsuki Ogami (SOKENDAI/NAOJ)

Summary

We analyzed the Star Formation (SF) and Chemical Evolution (CE) History of Ursa Minor dSph (UMi) using the Subaru/HSC g- and i-band data. In this study, we confirm

1. The successful estimation of the SF and CE simultaneously,
2. The detection of two populations ([Fe/H] = −2.0, [Fe/H] = −2.2) suggested in past study,
3. The new finding of another metal-poor population ([Fe/H] = −2.7) at $1r_h < r < 3r_h$.

Introduction

In the current ΛCDM cosmological model, dwarf galaxies are regarded as the smallest building blocks of hierarchical structure formation, spanning from small to large scales. The proximity of UMi allows us to observe them as systems of resolved stars, enabling us to investigate galaxy formation and evolution processes with unparalleled detail. Past studies suggest a variation in the formation mechanisms of dSphs, as indicated by the identification of multiple chemodynamical stellar populations, and its formation mechanism is actively discussed. From the information of metallicity, we can divide the multiple populations and determine the ages of each. It is powerful to constrain what formation mechanisms are plausible.

Data

Subaru/HSC g-/i-bands data. The integration time for g-/i-bands were 10×180 s and 20×180 s, respectively.

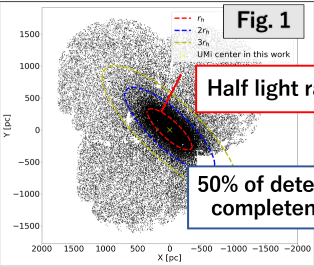


Fig.1 Spatial distribution of whole point sources.
In this figure, the coordinate system is rearranged into projection coordinates.
Each color of the dotted line shows the 1, 3, 5 r_h.

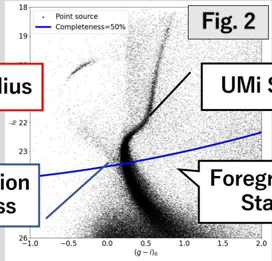


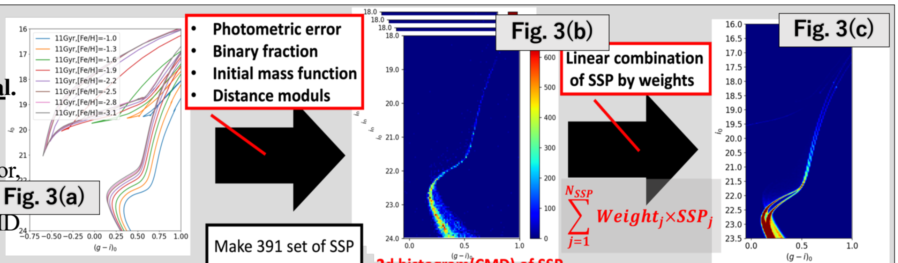
Fig.2 Colour Magnitude Diagram (CMD) of UMi.
The blue solid line is the 50% detection completeness magnitude.

Methods, Results, and Discussion

A) Details of HGA

We built the Hybrid Genetic Algorithm (HGA) (Cignoni et al. 2015)to estimate the SF and CE history of UMi using CMD.

Fig. 3 How to make CMD of model galaxy
We made it using stellar evolutional isochrones, photometric error, IMF, etc..
It allows us to estimate SF and CE history by comparing the CMD of the model galaxy and the CMD of observation using Eq. (1).

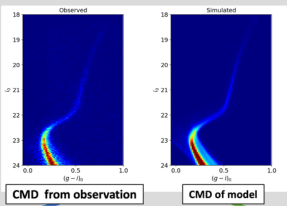


BaSTi isochrone Age($6\sim14Gyr$)
metallicity($-3.2 \le$ [Fe/H] ≤ -1.0)

2d histogram(CMD) of SSP (Simple Stellar Population) made from isochrones

2d histogram(CMD) of model galaxy made from

- **In Eq. (1) we use the chi-square value as a merit function to find the best-fit model CMD for observational CMD (Mighell. 1999).**
- **We use HGA as an optimization technique for the chi-square value.**



W_j are the weights of each SSP and correspond to star formation rate of each.

$$\chi^2 = \sum_{i=1}^{n_{bins}} \frac{\left(Count_{i,obs} + \min(Count_{i,obs}, 1) - \sum_{j=1}^{n_{SSP}} W_j \times Count_{ij,syn} \right)^2}{Count_{i,obs} + 1} \quad (1)$$

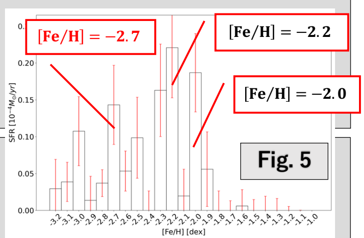


Fig.5 Metallicity distribution of $2r_h <$ area $< 3r_h$.
Errors estimated by bootstrapping.

B) AMD of UMi and detail of derivation.

We derive each AMD (Age Metallicity Diagram) by HGA for 3 regions divided by half-light radius shown in Fig.1.

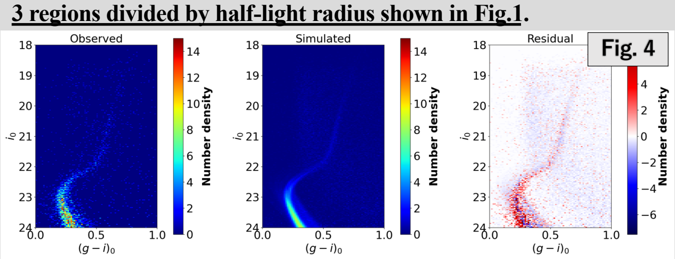


Fig. 4 Observational CMD and model CMD. Each left, center, and right figure indicates the observational CMD, model CMD, and their difference, respectively.We define the control field for UMi using SSP's box area where the galactic latitude corresponds to UMi.

The simultaneous star formation and the candidate of a stellar halo suggest that UMi would have experienced minor mergers.

Fig. 6 AMD of each region.
The color indicates the star formation rate of each population. We detected the metal-rich population ([Fe/H] = −2.0) and the metal-poor population ([Fe/H] = −2.2) correspond to the result by Pace et al. (2020) in whole 3 regions, and SFH of them show that star formation occurred almost simultaneously. The most outer region has a more metal-poor population such as [Fe/H] = −2.7, and it is possible stellar halo of UMi suggested in Sestio et al. (2023).