Age of UFD Horologium I

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1 Introduction

The purpose of this small research is to estimate the age of an Ultra Faint Dwarfs UFD, Horologium I, to understand if they are fossil structures. It is a classical example of Ultra Faint Dwarfs, a galaxy dominated by dark matter and with a low density of stars. It is located at the edge of the HI Magellanic Stream, equiangular from both the Large and Small Magellanic Clouds and it has a luminosity $M_V \sim$ –3.5 ± 0.3 mag [1], and a mass-to-light ratio of ~ 600 [4].

To proceed in the determination of the age, first of all it is necessary to plot the Color-Magnitude Diagram CMD of the object, a diagram that plots stellar magnitudes V and I obtained using Hubble Space Telescope and its Advanced Camera for Surveys (ACS) with Wide Field Channel (WFC). In particular V corresponds to $F606W$ filter and I corresponds to $F814W$. On x-axis it is plotted the difference in terms of magnitude $V - I$ and on y-axis the filter V. The CMD is shown in figure 1.

2 Plot of isochrones

Once the CMD is created, the second passage is to fit the points with an isochrone. An isochrone is a curve representing a population of stars of the same age. All the isochrones used have been created using the isochrones generator Dartmouth Stellar Evolution Program (DSEP) [1]. Isochrones from this web tool are created for specific age in Gyr and depends on metallicity ratio $[Fe/H]$ (in range $-2.5 < [Fe/H] < +0.5$) and on the ratio $[\alpha/Fe]$ (from -0.2 up to 0.8). It is also possible to choose filters used to obtain images. In this case they are HST/ACS-WFC.

One isochrones files are created, apparent magnitudes given by those files must be corrected by reddening effect and distance modulus. In particular absorption coefficient is given by:

$$A_{F606W} = 2.8782E(B - V) \tag{1}$$

[1] Site: $http://stellar.dartmouth.edu/models/isolf_new.html$

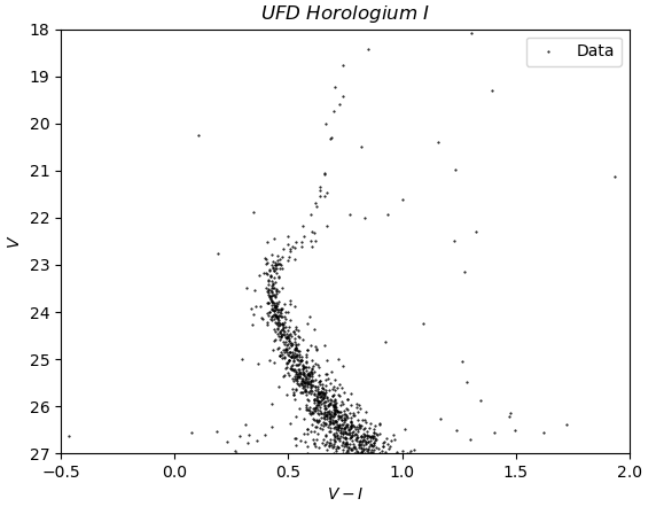

Figure 1: CMD of Horologium I.

$$A_{F814W} = 1.8420 E(B-V) \tag{2}$$

where $E(B-V)$ is the color excess, a value that quantifies the reddening effect in a specific region of observation. From theoretical point of view it is the given by $(B-V)-(B-V)_0$ so it is the difference between the color index observed and the intrinsic color index, obtained measuring some standard stars. However in this case the color excess has been estimated using *Galactic DUST Reddening & Extinction* provided by IRSA, Infrared Science Archive[2]. This service gives the Galactic dust reddening for a line of sight, returning a reddening map, the corresponding 100 micron intensity, and dust temperature, along with statistics for each. Entering the coordinates of Horologium I, this web tool provides a mean value of color excess about 0.0126 ± 0.0002. In data elaboration has been used a value $E(B-V) = 0.012$. In figure 2 there is an image of the field observed with 0.5 deg of size.

On the other side distance modulus, equals to $m-M$, difference between apparent and absolute magnitude, are considered here as a parameter to change in order to have the best fit of the points in CMD.

Summarising, once magnitudes of isochrones are created using the web tool, they have been corrected in the following way:

$$m_{F606W} = m_V + (m-M) + A_{F606W} \tag{3}$$

$$m_{F814W} = m_I + (m-M) + A_{F814W} \tag{4}$$

[2]Site: $https://irsa.ipac.caltech.edu/applications/DUST/$

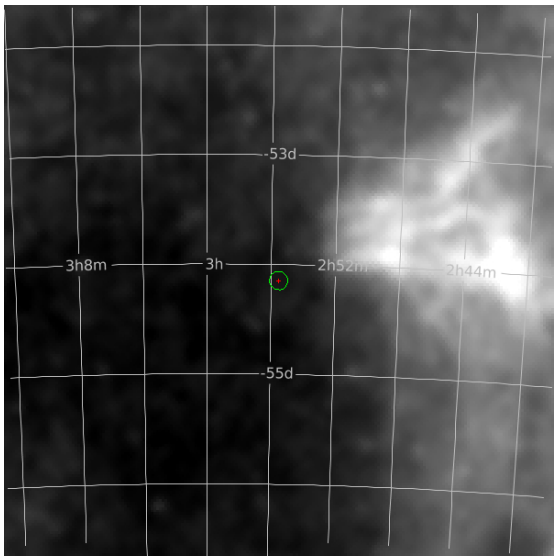

Figure 2: Reddening effect in the observed region.

One this procedure is finished, then those corrected magnitudes have been used to plot isochrones over the CMD with $m_{F606W} - m_{F814W}$ on x-axis and m_{F606W} on y-axis.

According to the purpose (verify if UFD are fossils or not) isochrones corresponding to 14 Gyr, the age value much closer to the age of universe, have been plotted with those specific features:

- one isochrone of 14 Gyr with $[Fe/H] = -2.00$ and $[\alpha/Fe] = 0.20$ (panel 1 in figure 3);
- one isochrone of 14 Gyr with $[Fe/H] = -2.15$ and $[\alpha/Fe] = 0.20$ (panel 2 in figure 3);
- one isochrone of 14 Gyr with $[Fe/H] = -2.49$ and $[\alpha/Fe] = 0.40$ (panel 3 in figure 3).

Analysing the red isochrone in panel 1, it is clear that there is a good plot of turn-off point at the end of main sequence MS phase and also a good fit of red giant branch RGB. However the main sequence is fitted not in a perfect way: the curve is a bit shifted to region of binaries stars. This isochrone has been plotted with distance modulus of 19.39.

On the other side, the blue one in panel 3 fit successfully both MS turn-off and the RGB, but also the main sequence itself. The metallicity is equals to $[Fe/H] = -2.49$ as expected by models for fossils galaxies and it has been plotted with distance modulus of 19.55.

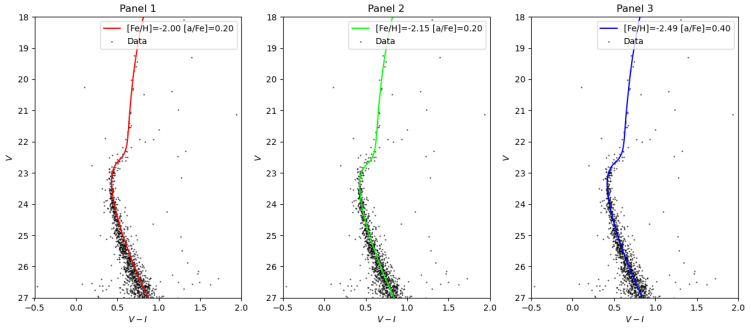

Figure 3: Three isochrones plotted over the CMD.

However the best fit is the green line in panel 2 with a metallicity a bit higher then that of panel 1 in terms of absolute value ($[Fe/H] = -2.15$) but same $[\alpha/Fe] = 0.20$. It gives a better fit of the main sequence and, in particular, of the main sequence turn off, beyond the good fit of RGB branch. This isochrone has been plotted with distance modulus of 19.55.

Figure 4 shows all the isochrones together to see in a practical way their differences and their similarities.

3 Conclusion - Is Horologium I a true fossil?

The results obtained from isochrones plotted over the CMD of Horologium I suggest that the age of this UFD is quite similar to that of the universe, about 14 Gyr, suggesting that this stellar structure is a fossil one in which star formation was suppressed by a global outside influence, such as the reionization of the universe. Moreover the metallicity of the best fit (green curve in panel 2 of figure 3) about $[Fe/H] = -2.15$ tells that this UFD is metal poor, according to what is expected, even if it is not so metal poor as models predict, maybe due to interactions with other galaxies. From the best fit the distance modulus is 19.55.

However on literature results are different. Jerjen and colleagues [3] in 2018 found that he isochrone which best represents the bulk of the Horologium I population has an age of 13.7 Gyr, a metallicity of $[Fe/H]$ = –2.40 dex and $[\alpha/Fe]$ = +0.2 dex, shifted to a distance modulus of m–M = 19.18 mag. $[\alpha/Fe]$ is the same (equals to +0.2) but in this research I obtained a metallicity of -2.15 while the paper gives -2.40 telling that it is a very metal poor object. The ages are quite similar but they found that the UFD is a bit younger. Moreover the distance modulus $m - M$ is smaller (about 19.18) than that found here (about 19.55). The discrepancy should be connected to the selection of data used to derive those properties. Indeed in this small research have been used data from HST in V and I filters while in this paper authors used data

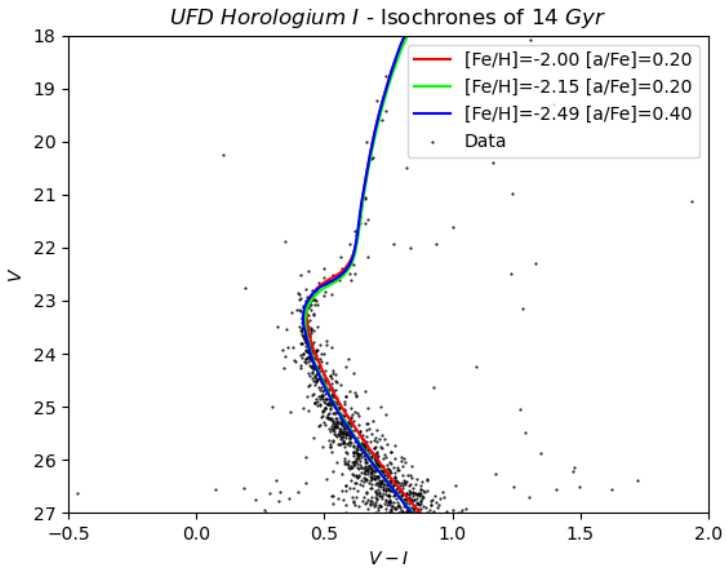

Figure 4: All isochrones plotted on CMD.

from Gemini/GMOS-S in filter g and r. Indeed different sensitivity of filters and instrumental response could give different results. Another and additional explanation of the discrepancy could be a different selection of data used for the elaboration.

3.1 UFD in literature

Brown and colleagues in 2014 [2] studied star formation histories of six ultra-faint dwarf galaxies: Bootes I, Canes Venatici II, Coma Berenices, Hercules, Leo IV, and Ursa Major I. They found that at least 75% of the stars formed by $z \sim 10$ (13.3 Gyr ago). All of the galaxies are consistent with 80% of the stars forming by $z \sim 6$ (12.8 Gyr ago) and 100% of the stars forming by $z \sim 3$ (11.6 Gyr ago).

This research does not concern Horologium I but assuming that those structures are similar to Horologium I (ultra faint dwarfs galaxies with very low stellar density and dominated by dark matter) then we can assume that results of Brown and colleagues are true also for this UFD. According to those results, then the 75% of stellar population has been formed around 13.3 Gyr ago, which is a values not completely in agreement with my research (age about 14 Gyr) and with studies of Jerjen and colleagues (age about 13.7 Gyr). The explanation for this partial disagreement can be that Horologium I is a UFD with some specific features or, in general, more accurate studies and data are needed to understand better this topic.

References

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