Contents of Dark Matter in UFD Horologium I

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1 Introduction

The purpose of this small research is to analyse Horologium I in order to infer presence of dark matter. Horologium I is an Ultra Faint Dwarf galaxy characterized by very 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 $M_V \sim -3.5 \pm 0.3$ mag [1], and a mass-to-light ratio of ~ 600 [2].

To reach this goal we start inferring fraction of binaries of this stellar system and then compare this value with the relation between fraction of binaries and absolute magnitude in visual band.

2 Color-Magnitude Diagram and isochrone

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.

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. Isochrone used here has been created using the isochrones generator Dartmouth Stellar Evolution Program (DSEP) [1].

One isochrone file is created, apparent magnitudes must be corrected by reddening effect and distance modulus. In particular absorption coefficient is given by:

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

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

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

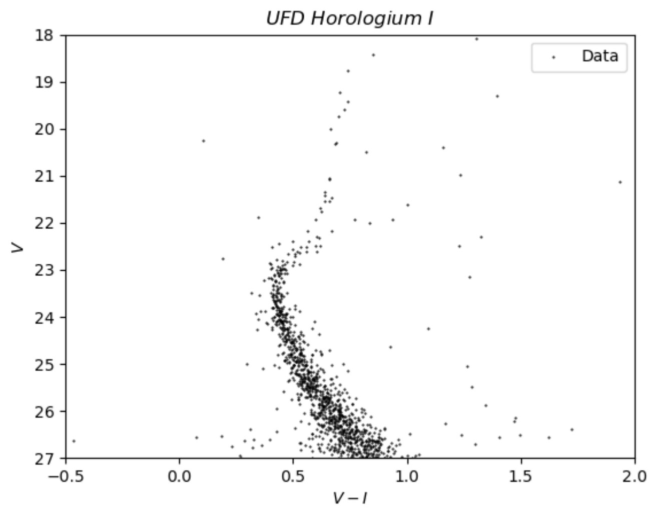

Figure 1: CMD of Horologium I.

where $E(B-V)$ is the color excess, a value that quantifies the reddening effect in a specific region of observation. In this case the color excess has been estimated using *Galactic DUST Reddening & Extinction* provided by IRSA, Infrared Science Archive[2]. 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 $E(B-V) = 0.012$.

On the other side distance modulus, equals to $m - M$, difference between apparent and absolute magnitude, is considered here as a parameter to change in order to have the best fit of the points in CMD. In this case distance module is $m - M = 19.55$.

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

The best fit isochrone has age of 14 Gyr, metallicity equals to $[Fe/H] = -2.15$, ratio $[\alpha/Fe] = +0.2$ and Helium content of $Y = 0.245$.

3 Binaries estimation

The next step is to calculate binary fraction. To do this we have to introduce mass ratio $q = \frac{M_2}{M_1}$ where M_1 and M_2 are masses of first and second star inside the binary system. In general binaries stars are located on the right side of Main Sequence but only stars with $q > 0.5$ can be detected from an observational

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

point of view, up to the limit $q = 1$ that corresponds to a system with both stars having same mass.

On CMD binaries are mainly located in terms of magnitude between 24 and 27 (observational limit for faint magnitudes) and in terms of color index between 0.45 (that corresponds to the limit of Turn-Off Point) and 0.85. For this reason it is necessary to determine a lower limit on the right side of MS, corresponding to curve with $q = 0.5$ and an upper limit, corresponding to curve with $q = 1$.

These curves have been plotted for values on x-axis limited to the color index interval of isochrone said before. On the contrary, values on y-axis, are the result of the following relation:

$$m_{bin} = m_1 - 2.5log\left(1 + \frac{F_2}{F_1}\right) \tag{3}$$

where m_{bin} is the magnitude of binary system, m_1 is the magnitude of first star, F_1 and F_2 are fluxes of first and second stars. This formula can be re-written with masses has:

$$m_{bin} = m_1 - 2.5log\left(1 + \left(\frac{M_2}{M_1}\right)^{2.3}\right) \tag{4}$$

thanks to the relation between flux and luminosity, as stated in this formula:

$$\frac{L}{L_\odot} = \left(\frac{M}{M_\odot}\right)^{2.3} < 0.4M_\odot \tag{5}$$

Taking into account that $q = M_2/M_1$, equation 4 can be used with $\frac{M_2}{M_1} = 0.5$ and $\frac{M_2}{M_1} = 1$ respectively for points of curve for $q = 0.5$ and $q = 1$.

The result of this process of selection is shown in figure 2.

In this figure it is visible as a red curve the best fit isochrone for 14 Gyr that plot quite well the MS. Light blue points and blue points indicate respectively the lower limit and the upper limit of a region called B region where are located all the binaries we are able to detect. Left and right limits to this region are given by color index values said before: 0.45, that corresponds to the limit of Turn-Off Point, and 0.85, beyond which observational errors are too high (so points here must be rejected). These vertical limits are indicated in grey.

However in CMD are also visible many stars below the MS. These points can be observational errors and are not binaries so it is important exclude them from the count. For this reason we have individuated also a sub limit of MS (green point in the diagram) beyond which the program created must not count points.

Then all these limits have been interpolated with curves (yellow ones in the diagram) providing analytic forms of these functions.

So at the end of this process we have two regions: the B region (with N stars) located in limits said before and A region (with N+M stars) that contain stars of B region and stars below the curve limit for $q = 0.5$ up to the lower limit of the MS. Therefore the fraction of binaries has been calculated with this simple relation:

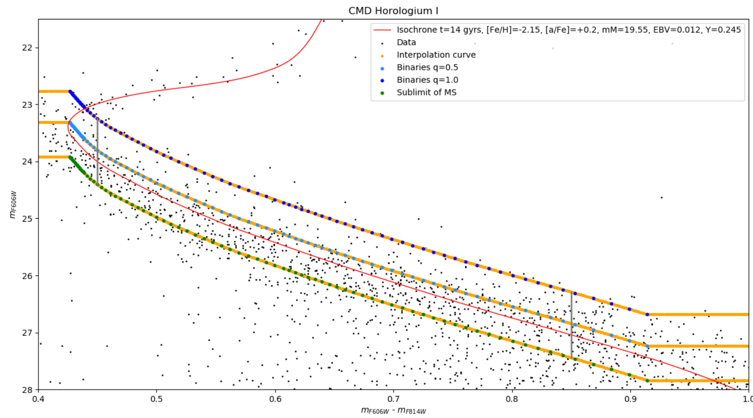

Figure 2: CMD of Horologium I with plot of the isochrone (in red), curve for $q = 0.5$ (in light blue), curve for $q = 1$ (in blue) and sub limit of MS (in green). In yellow are show the interpolation curves.

$$f_{bin} = \frac{N}{N + M} \tag{6}$$

From our calculation the fraction of binaries of Horologium I is 0.21.

4 f_{bin}-M_v relation

Once the fraction of binaries is known, it is possible to enter it inside the f_{bin}-M_v relation. This relation is a straight line with angular coefficient of 0.249 and intercept of 0.027 (from [3]): the x variable is the absolute magnitude while y variable is the fraction of binaries.

As stated before, from previous calculations, binary fraction is 0.21. Absolute magnitude M_v of Horologium I is -3.5.

Plotting a point with these values and a straight line representing the relation, is obtained a graphic like one shown in figure 3.

5 Conclusions

From figure 3 it seems that there is no predominant content of dark matter. By definition Ultra Faint Dwarf galaxies are dominated by dark matter but for some reasons here there is not a significant content of it.

Moreover it seems that a polynomial fit of higher degree like a parabola can be better then a linear fit assumed in [3] for f_{bin}-M_v relation.

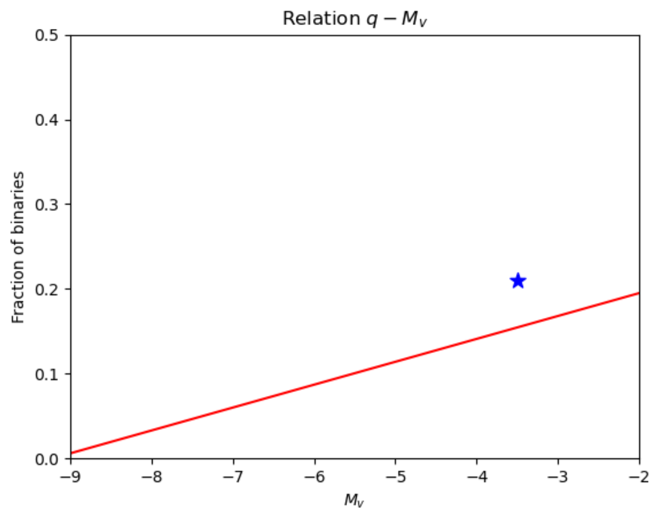

Figure 3: f_{bin}-M_v relation in red and Horologium I case in blue point.

Of course we have to take into account all observational errors, instrumental photometric limitations or errors connected to the isochrones. Indeed binaries magnitude are based on selected magnitude of the isochrone so if isochrone is not the best fit, error propagate also in the other magnitudes. Finally we didn't take into account field stars or artificial stars that can vary the binary fraction.

In any case Horologium I seems to be a peculiar UFD not dominated by dark matter (even if it is present) so more accurate studies must be done on this object.

References

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[3] A. P. Milone, G. Piotto, L. R. Bedin, A. Aparicio, J. Anderson, A. Sarajedini, A. F. Marino, A. Moretti, M. B. Davies, B. Chaboyer, A. Dotter, M. Hempel, A. Marín-Franch, S. Majewski, N. E. Q. Paust, I. N. Reid, A. Rosenberg, and M. Siegel. The ACS survey of Galactic globular clusters. XII. Photometric binaries along the main sequence. , 540:A16, April 2012.