Constraining the composition of pristine material through multiple populations in Globular Clusters

Maria Vittoria Legnardi

Dipartimento di Fisica e Astronomia "Galileo Galiei", Università di Padova

Abstract

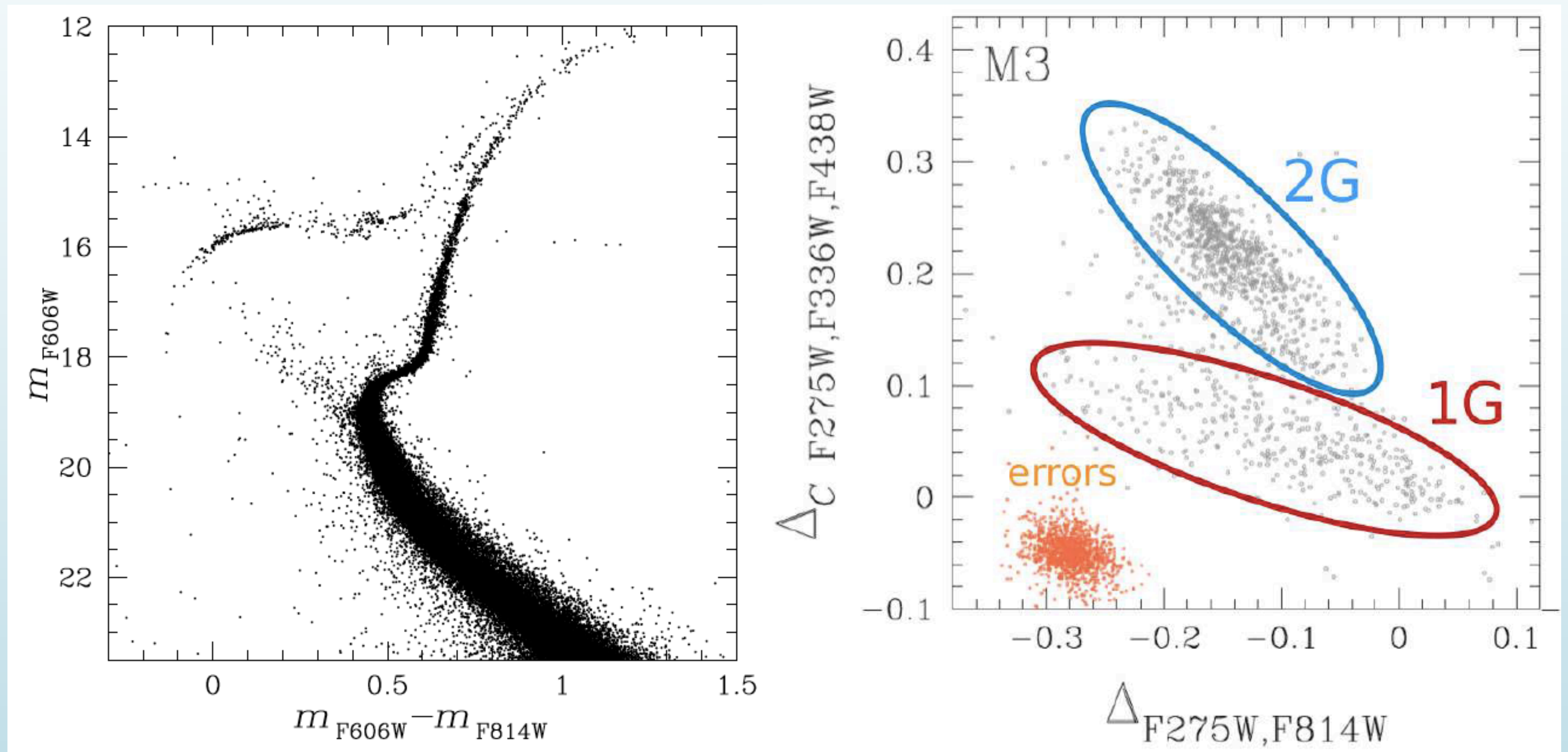
Until a few years ago globular clusters (GCs) were considered the prototypes of simple stellar populations, composed of coeval stars with same chemical composition. Indeed, their color-magnitude diagrams (CMDs), including those diagrams obtained from high-precision Hubble Space Telescope (HST) photometry, were similar to single isochrones. Thanks to innovative techniques of photometric data reduction and new color combinations sensitive to chemical differences among stars, it has been discovered that GCs are much more complex than previously thought: all the evolutionary phases of their CMDs contain indeed multiple distinct sequences that correspond to stellar populations with different content of light-elements and helium. GCs therefore host multiple stellar populations, including a first population with the same chemical composition of halo field stars at the same metallicity, and one or more second populations enhanced in He, N, and Na and depleted in C and O. One of the most unexpected discoveries, mostly based on evolved red giant branch (RGB) stars of more than 50 GCs, is that the first population is not chemically homogeneous. With the aim of shedding new light on this phenomenon, we combined multi-band HST photometry of GCs and synthetic spectra analysis techniques, to investigate for the first time chemical variations among unevolved main sequence (MS) stars. We present here the results of NGC 6362 and discuss the implications on the chemical composition of the pristine material from which they formed.

First Generation stars as fossils of pristine matter

It is now widely accepted that nearly all GCs are composed of multiple stellar populations with different chemical composition. Indeed, more than one thousand papers, in the past two decades, have demonstrated that GCs host a **first population** (1G) composed of stars with the same chemical composition as halo-field stars with similar metallicity and one or more **second population** (2G) of stars enhanced in He and N and depleted in C and O.

The chemical composition of 1G stars may reflect the composition of pristine material from which they formed. Since Galactic GCs are among the most ancient objects of the Galaxy, their **1G stars provide a unique opportunity to trace the chemical composition of the primordial clouds.**

A powerful tool to infer the relative chemical compositions of 1G and 2G stars is the **'Chromosome map'** (ChM), a pseudo two-color diagram, build with appropriate HST filters, which is sensitive to the chemical composition of GCs and maximizes the separation among distinct stellar populations (Milone et al. 2017; see Figure 1).



The distribution of 1G stars is not consistent with observational errors alone. Similar features are observed in the ChMs of RGB stars of more than fifty GCs.

One of the most-unexpected discoveries based on ChMs of RGB stars is that 1G stars of most GCs are not chemically homogeneous (Milone et al. 2015).

Two main possibilities could explain the extended sequence of 1G stars:

- star-to-star chemical variations due to stellar evolution.
- chemical inhomogeneities in the pristine material from which the stars formed.

Fig. 1: *Left.* Color-magnitude diagram of the Galactic GC NGC 5272 (M3) in the F606W and F814W filters of HST (from Anderson et al. 2008). Clearly, it is not possible to disentangle multiple populations in these optical bands. *Right.* ChM of RGB stars of M3 (gray points). The red ellipse marks 1G stars, whereas 2G stars are enclosed in the blue ellipse. The orange points indicate the distribution expected for a simple population of stars with the same chemical composition.

Insights from the main sequence of NGC 6362

To disentangle between these two possibilities, we extend the investigation to **unevolved MS stars**. We derived high-precision multi-band HST photometry of the Galactic GC NGC 6362 and the ChM of MS stars (Figure 2).

The color distribution of 1G MS stars is wider than observational errors, in close analogy with what is observed for RGB stars, thus demonstrating that 1G stars are not chemically homogeneous. **This is the first time that this phenomenon is clearly observed among unevolved stars.**

The discovery of extended 1G sequence among unevolved MS stars, roles out the possibility that chemical inhomogeneities are the result of stellar evolution. Hence, we conclude that **1G stars of GCs are records of the chemical inhomogeneities of the primordial cloud where they formed at high redshift**.

To constrain the chemical composition of 1G stars, we select two groups of $1G_A$ and $1G_B$ stars as shown in the inset of Figure 3. We compared the color distances between $1G_A$ and $1G_B$ stars, calculated at m_{F814W} = 19.25 with the colors inferred from a grid of synthetic spectra with appropriate chemical compositions (see Milone et al. 2018 for details). We conclude that 1G stars share the same abundances of C, N and O and that, for a fixed luminosity, 1G stars exhibit internal variation in their effective temperature. This fact indicates that **the color broadening of the 1G is due either to helium variations (ΔY=0.025) or to iron variations (Δ[Fe/H]=0.06).**

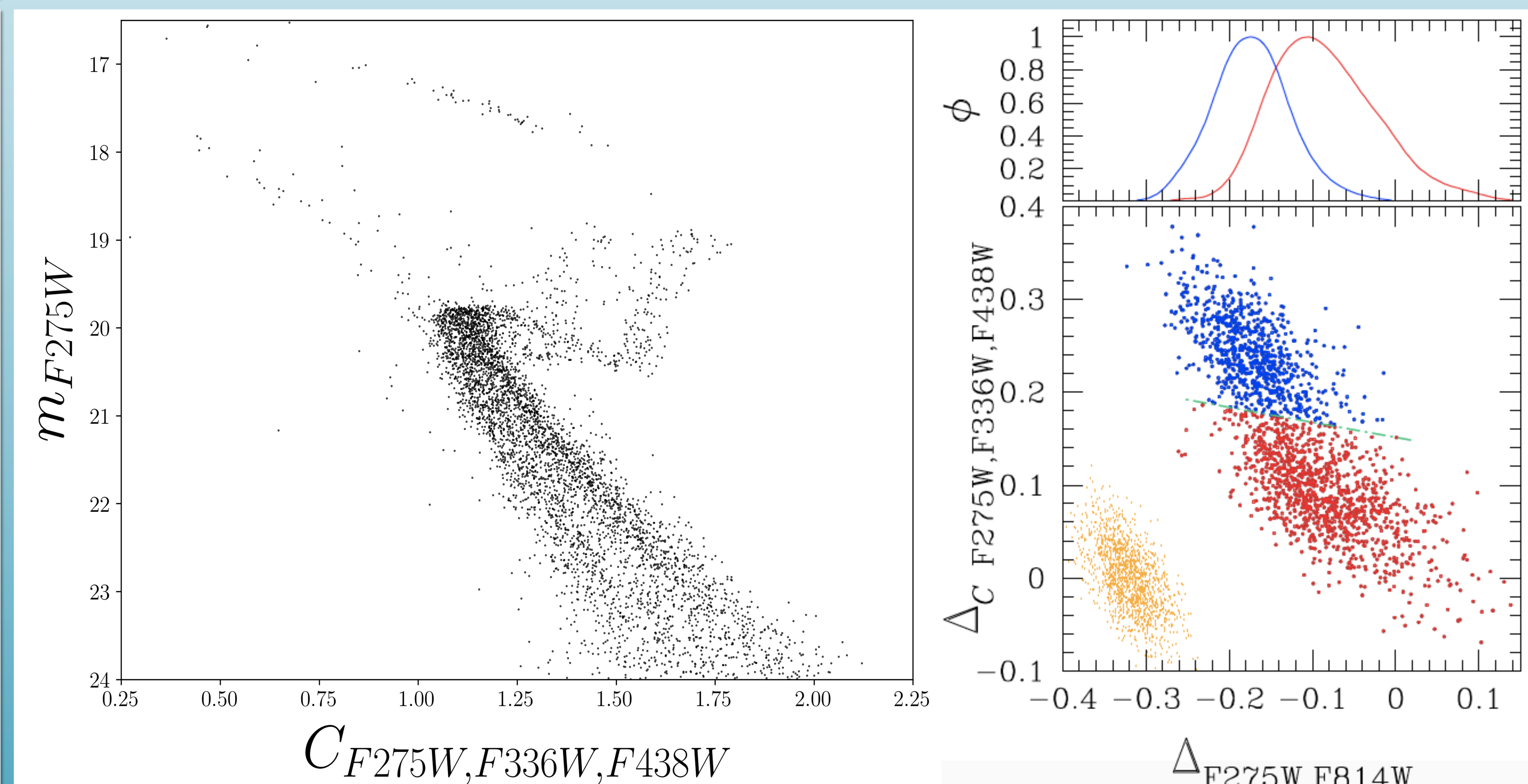


Fig. 2: *Left.* m_{F275W} vs. $C_{F275W,F336W,F438W}$ pseudo-CMD of NGC 6362. *Right.* ChM of MS stars in NGC 6362. 1G and 2G stars are colored red and blue, respectively, while the error distribution is represented by orange points on the bottom-left corner. The kernel-density distributions of 1G and 2G stars are plotted on the top panel.

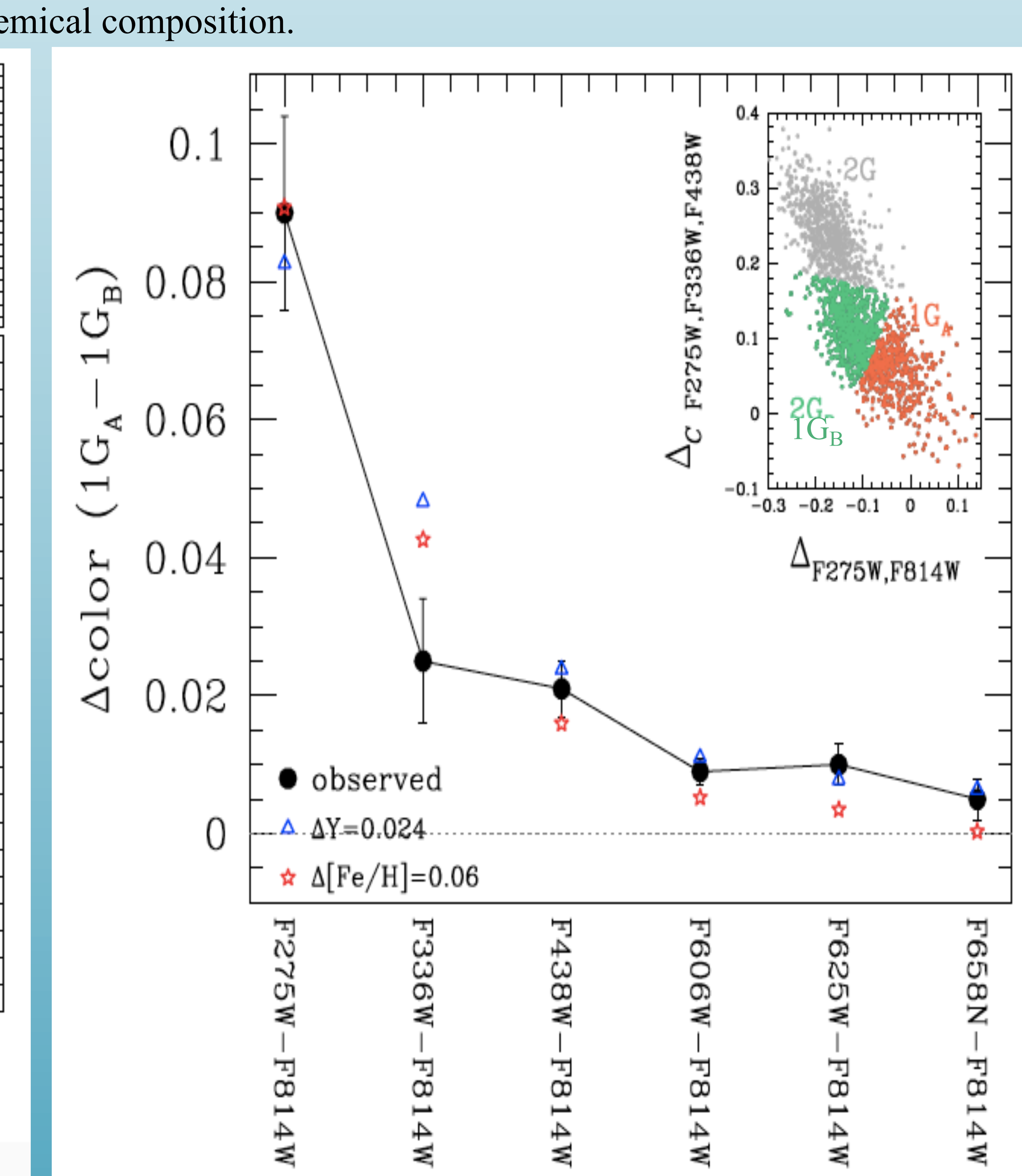


Fig. 3: Comparison between the observed color differences of the two sub-groups of $1G_A$ and $1G_B$ stars (selected in the inset) with the colors inferred from synthetic spectra with different iron and helium abundances.

References

- Anderson, J., Sarajedini, A., Bedin, L. R., et al. 2008, AJ, 135, 2055, doi: 10.1088/0004-6256/135/6/2055
- Milone, A. P., Marino, A. F., Piotto, G., et al. 2015, ApJ, 808, 51, doi: 10.1088/0004-637X/808/1/51
- Milone, A. P., Piotto, G., Renzini, A., et al. 2017, MNRAS, 464, 3636, doi: 10.1093/mnras/stw2531
- Milone, A. P., Marino, A. F., Renzini, A., et al. 2018, MNRAS, 481, 5098, doi: 10.1093/mnras/sty2573

Acknowledgements:

This work was done in collaboration with the GALFOR group (A. P. Milone, A. F. Marino, E. P. Lagioia, M. Tailo, G. Cordoni, E. Dondoglio, M. G. Carlos, S. Jang, J. E. Nastasio, A. Mohandasan).

Join GALFOR on:

http://progetti.dfa.unipd.it/GALFOR/index.html

Correspondence to:

mariavittoria.legnardi@studenti.unipd.it