Mem. S.A.It. Vol. 84, 75

Memorie della

Ultraviolet properties of Galactic globular clusters with GALEX

E. Dalessandro[1], R. P. Schiavon[2], F. R. Ferraro[1], S. T. Sohn[3], B. Lanzoni[1], and R. W. O' Connell[4]

[1] Dipartimento di Fisica e Astronomia, Universitá degli Studi di Bologna, Viale Berti Pichat 6/2, I-40127 Bologna, Italy; e-mail: emanuele.dalessandr2@unibo.it
[2] Astrophysics Research Institute, Liverpool John Moores University, Twelve Quays House, Egerton Wharf, Birkenhead CH41 1LD, UK
[3] Space Telescope Science Institute, 3700 San Martin Dr., Baltimore, MD, 21218, USA
[4] Astronomy Department, University of Virginia, P.O. Box 400325, Charlottesville, VA 22904, USA

Abstract. We present ultraviolet (UV) integrated colors of 44 Galactic globular clusters (GGCs) observed with the Galaxy Evolution Explorer (GALEX) in both FUV and NUV bands. We find for the first time that GCs associated with the Sagittarius dwarf galaxy have $(FUV - V)$ colors systematically redder than GGCs with the same metallicity. M31 GCs show almost the same UV colors as GGCs, while M87 are systematically bluer. We speculate about the presence of an interesting trend, suggesting that the UV color of GCs may be correlated with the mass of the host galaxy, in the sense that more massive galaxies possess bluer clusters.

Key words. globular clusters: general - stars: evolution - stars: horizontal-branch - ultraviolet: stars

1. Introduction

The main contributors to the UV emission from any stellar system are the hottest stars. Indeed extreme horizontal branch (HB) and post-HB stars are well known to be among the hottest stellar populations in globular clusters (GCs) and contribute substantially to the UV radiation observed from old stellar systems (Greggio and Renzini 1990; Dorman et al. 1995 - hereafter DOR95). The relative contributions of the various types of stars and the factors that might lead to larger or smaller populations of UV-bright stars have remained an open question (Greggio and Renzini 1990; DOR95; Rich et al. 2005; Sohn et al. 2006).

In distant extragalactic systems one can ordinarily observe only the integrated light of unresolved stellar populations, from which the hope is to gain knowledge about the underlying stellar population. Galactic globular clusters (GGCs) play an important role in understanding the integrated UV colors of extragalactic systems, especially the so called "UV-upturn" observed in the spectral energy distributions of elliptical galaxies (Code & Welch 1979). In fact, GCs are the closest example in nature to a single stellar population (SSP), moreover they span a large range of metallic-

Send offprint requests to: E. Dalessandro ities, a small range of ages, and perhaps some range of helium abundance. GGCs are the ideal target to study the impact of hot and bright populations (as the AGB-manqué stars) on the integrated UV light and represent a crucial local template for comparison with integrated properties of distant extragalactic systems.

With this motivation in mind we observed 44 GGCs with the *Galaxy Evolution Explorer* (GALEX) in FUV and NUV. This is the largest homogeneous sample ever collected for GGCs in UV so far. We obtained resolved photometry in Schiavon et al. (2012) and integrated colors in Dalessandro et al. (2012).

2. The UV integrated colors.

The integrated UV magnitudes have been obtained by fitting the observed surface brightness profiles in each available band with proper King models (see Dalessandro et al. 2012 for details). In order to investigate any possible link between the UV colors and chemical compositions of the Milky Way GCs, we adopted the [Fe/H] values quoted by Carretta et al. (2009).

From the top panel of Fig. 1 one can see that, for the GCs in our sample, $(NUV - V)_0$ decreases by about 2 magnitudes as [Fe/H] decreases from ~ -0.7 to ~ −1.5. For smaller values of [Fe/H], $(NUV - V)_0$ is roughly constant, or perhaps increases slightly as [Fe/H] decreases. This clear, although non-monotonic, trend of $(NUV - V)_0$ with metallicity is confirmed by a Spearman correlation rank test, according to which the probability of a correlation is 99.99% (>4σ). Interpretation of the dependence of colors involving FUV magnitudes as a function of [Fe/H] requires a little more care. $(FUV - V)_0$ varies by almost 5 magnitudes. Indeed, a Spearman test gives a probability P~99% (corresponding to ~2.3 -2.5σ) that $(FUV - V)_0$ is correlated with metallicity. The Kendall test gives correlation probability of ~2.1σ. At face value, therefore, $(FUV - V)_0$ correlates with [Fe/H] in a similar way as $(NUV-V)_0$, although in a less strong or noisier fashion.

In summary, then, one finds that the behavior of GGCs in the $(FUV - V)_0$–[Fe/H] and $(NUV - V)_0$–[Fe/H] planes is essentially the same. On both planes, three sub-families of clusters can be recognized: 1) GGCs with [Fe/H]>-1.0, which are predominantly red; 2) GGCs with -1.5< [Fe/H]<-1.0, the "second parameter region", where GGCs have a wide range of colors, about ~2 mag in $(NUV - V)_0$ and ~4 mag in $(FUV - V)_0$; and 3) GGCs with [Fe/H]< -1.5, which are all blue. It is worth noticing that, intermediate-metallicity ([Fe/H]≈-1.5) clusters are the bluest in the three colors combinations. This was also highlighted by DOR95. The extension of their HBs (see Schiavon et al. 2012) is compatible with

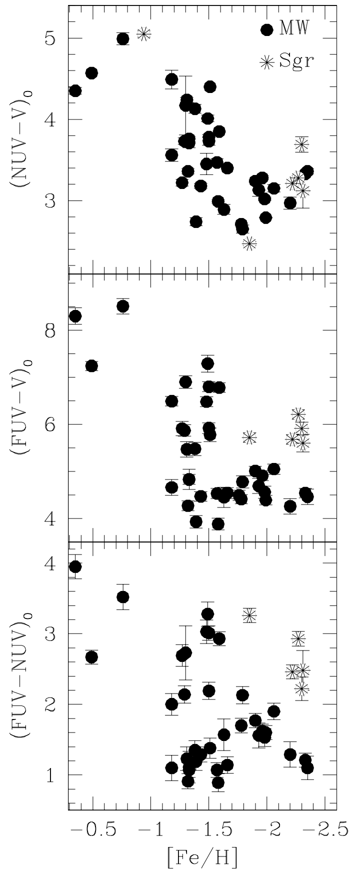

Fig. 1. UV integrated colors as a function of metallicity in Carretta et al. (2009) scale. Clusters possibly connected with the Sagittarius stream are plotted as asterisks.

their integrated colors. On average, the metal-poor ([Fe/H]<-1.7) GCs have redder HBs than the intermediate ones.

2.1. GCs in the Sagittarius stream

Careful inspection of the $(FUV - NUV)_0$ or $(FUV - V)_0$ *vs* [Fe/H] plots in Fig. 1 clearly reveals that the color spread at [Fe/H]<-1.5 is due to a subset of clusters (plotted as asterisks), which are systematically redder by ~1.5 and 1.0 mag in $(FUV - NUV)_0$ and $(FUV-V)_0$, respectively, than the other GCs in the same metallicity regime. Interestingly these clusters (NGC 4590, NGC 5053, NGC 5466, Arp 2 and Terzan 8) are potentially connected with the Sagittarius dwarf galaxy stream (Law & Majewski 2010), and thus may have an extra-Galactic origin. The other candidate Sagittarius GC is the relatively metal-rich ([Fe/H]=−0.94) Palomar 12, for which we were not able to get FUV magnitude. These clusters are coeval within the uncertainties (Salaris & Weiss 2002 and Dotter et al. 2010).

We used the *R'-parameter* reported by Gratton et al. (2010) to highlight possible differences. The *R'-parameter* is defined as the ratio between the number of HB stars and that of RGBs brighter than the HB level magnitude $V_{\rm HB} + 1$. This quantity is an indirect estimate of Helium abundances (Y). It is interesting to note that these clusters have *R'* values smaller than other clusters with similar metallicity [Fe/H]<-1.5. Given the statistical uncertainties of these measurements, the difference in *R'* between any two given clusters is somewhat uncertain. Therefore we performed a t-test to check the significance of the difference between the mean values of the two distributions. We find that for the clusters potentially connected with the Sagittarius stream <R'>=0.48±0.01 while for GGCs <R'>=0.74±0.18. The t-test gives a probability P> 99.9% that they are different. This difference might be an indication that those clusters have lower He abundances than GGCs in the same metallicity regime, and this is likely the main responsible of the differences in FUV integrated colors.

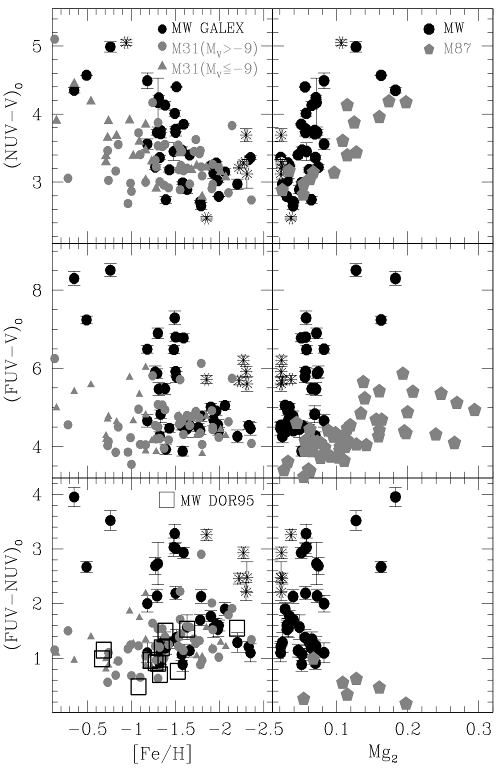

Fig. 2. *Left panel*. GALEX colors of our GGC sample (black) compared to the GCs in M31 (from Kang et al. 2011). In the lower panel our GGC sample has been supplemented with clusters observed with ANS and OAO2 by DOR95 (open squares). *Right panel*. UV colors of GGCs (black dots and asterisks) compared to those of M87 (grey pentagons) as a function of the Mg_2 metallicity index (Sohn et al. 2006).

2.2. Comparison with GCs in M31 and M87

We compared UV colors of old M31 GCs obtained with GALEX by Kang et al (2012) with those of GGCs (see left panel of Fig. 2). M31 seems to show a lack of red clusters with respect to the Galaxy. However, this is likely due to the limited sensitivity of GALEX to detect relatively red populations in distant systems. Hence for the comparison we focus on the bluest systems, $(FUV - NUV)_0$<1.5, $(FUV - V)_0$<5 and $(NUV - V)_0$<3.5, which, for the GGCs, correspond to a metallicity range -2.5<[Fe/H] <-1.0. In this metallicity regime the distributions in the Milky Way and in M31 are quite similar. The bluest colors reached are essentially the same, and the distributions show little variations with metallicity. The case is very different at higher metallicity, [Fe/H]>-1. In order to make the comparison with M31 GCs as complete as possible, we have supplemented our GALEX sample with 12 additional GGCs from DOR95 not observed by GALEX. In the Milky Way sample there are only red GGCs, while in M31 there are many blue GCs. In the left panel of Fig. 2 it is possible to note that roughly half of the blue, metal-rich M31 GCs are indeed quite massive ($M_V \leq$-9). Hence, the relative paucity of hot, metal-rich GCs in the Milky Way could be due in part (but only in part) to the fact that there are only two massive metal-rich clusters in our supplemented sample. It is also possible that many GGCs with high metallicity and a blue HB are missed because of their location towards highly extinguished regions of the Galaxy.

We also compare GGCs colors with those obtained for the giant elliptical galaxy M87 using *Hubble Space Telescope* STIS images (Sohn et al. 2006). As appears in the right panel of Fig. 2, M87 GCs are on average bluer by ~1.5 mag both in $(FUV - NUV)_0$ and $(FUV - V)_0$, while they do not show any appreciable difference in $(NUV - V)_0$.

3. Conclusions

From the comparison between GGCs and those belonging to three other galaxies (the Sagittarius dwarf, M31 and M87), different behaviors emerged. In fact the clusters associated with the Sagittarius dwarf are on average redder than the MW ones, the M31 clusters have colors comparable to those of the GGCs, while the M87 star systems are bluer. We note that there may be a possible trend between the mass of the host galaxy and the color distribution of its globulars, in the sense that the higher is the galaxy mass, the bluer are the GC UV colors. We argued that most of the observed differences between colors involving the FUV band are explainable invoking different Helium contents. This would lead us to speculatively think that galaxies with larger masses may have, on average, more He-rich populations. In that case, He abundance differences could be a by-product of chemical evolution differences, in some way connected to the mass of the host galaxy. This could be also connected with the formation and dynamical history of clusters in galaxies with different masses, as suggested by Valcarce & Catelan (2011). In particular they argue that clusters hosted by more massive galaxies are more likely to undergo a more complex history of star formation thus having a larger spread in stellar populations properties.

Acknowledgements. This research is part of the project COSMIC-LAB funded by the European Research Council (under contract ERC-2010-AdG-267675). Photometric catalogs and integrated colors can be downloaded from http://www.cosmic-lab.eu.

References

Carretta, E., et al. 2009, A&A, 508, 695
Code, A. D., & Welch, G. A. 1979, ApJ, 228, 95
Dalessandro, E., et al. 2012, AJ, 144, 126
Dorman, B., O'Connell, R. W., & Rood, R. T. 1995, ApJ, 442, 105 (DOR95)
Dotter, A., et al. 2010, ApJ, 708, 698
Gratton, R. G., et al. 2010, A&A, 517, A81
Greggio, L., & Renzini, A. 1990, ApJ, 364, 35
Kang, Y., et al. 2012, ApJS, 199, 37
Law, D. R., & Majewski, S. R. 2010, ApJ, 718, 1128
Rich, R. M., et al. 2005, ApJ, 619, L107
Salaris, M., & Weiss, A. 2002, A&A, 388, 492
Schiavon, R. P., et al. 2012, AJ, 143, 121
Sohn, S. T., et al. 2006, AJ, 131, 866
Valcarce, A. A. R., & Catelan, M. 2011, A&A, 533, A120