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Helium rich stars produce the UV upturn

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Abstract. We measure the evolution of the UV upturn color for galaxies on the red sequence in clusters at $0 < z < 0.7$ and to luminosity levels $L \sim L^*$. We show that the UV upturn color does not change until at least $z = 0.55$ but becomes significantly redder at $z = 0.7$. This is the first detection of evolution in the UV upturn. Our observations are inconsistent with all models proposed for its origin except the presence of a population of helium enriched stars, with helium abundances above 42 % and formed at $z > 4$.

Keywords. ultraviolet: galaxies, galaxies: stellar content, galaxies: elliptical and lenticular, cD, stars: horizontal-branch

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1. Introduction

The Ultraviolet Upturn is an unexpected rise in the spectra of early-type galaxies at $\lambda < 2500$ Å, where no flux is expected to be produced by their old, metal-rich and quiescent stellar populations (e.g., see reviews by Yi 2008, Yi 2010). It is generally agreed that hot horizontal branch stars are the most likely sources of the UV flux (Greggio & Renzini 1990) but they are not expected to occur in significant numbers given the stellar populations that predominate in early-type galaxies. Possible origins include: very metal poor stars (Park & Lee 1997), metal-rich stars with extra mass loss (Yi *et al.* 1998), binaries (Han *et al.* 2007) and helium-rich stars (Chung *et al.* 2017). Each of these has significant implications for the dependence of the UV upturn in galaxy properties and especially its evolution with redshift. Observations so far have been limited to very bright galaxies in distant clusters and show little significant evolution in the FUV-V upturn color (e.g., Boissier *et al.* 2018).

2. Observations

We have used a set of archival data from the Hubble Space Telescope to measure the evolution of the UV upturn in red sequence (therefore quiescent and cluster members) galaxies in a series of clusters at $z = 0.2$ (Abell 1689), $z = 0.31$ (Abell 2744), $z = 0.55$ (MACS 0717+37 and MACS 1149+22) and $z = 0.68$ (SDSS 1004+41). These clusters have deep optical-IR images to select a sample of red sequence early-type cluster members and deep images in the UV (HST filters F225W or F275W) to probe the rest-frame ~ 1550 Å bandpass (slight mismatches with the local FUV band are of course unavoidable). Unlike previous studies, our samples of galaxies reach to the level of normal ($\sim L^*$) galaxies and not just the most massive systems.

Figure 1 shows the main results of our investigations, that can be found in a series of papers by Ali *et al.* 2018a,c,c. We find no evolution to $z = 0.55$, an observation that in itself rules out metal poor or metal rich stars. However, in our highest redshift cluster we find no galaxy that can be detected with our data, except the brightest cluster

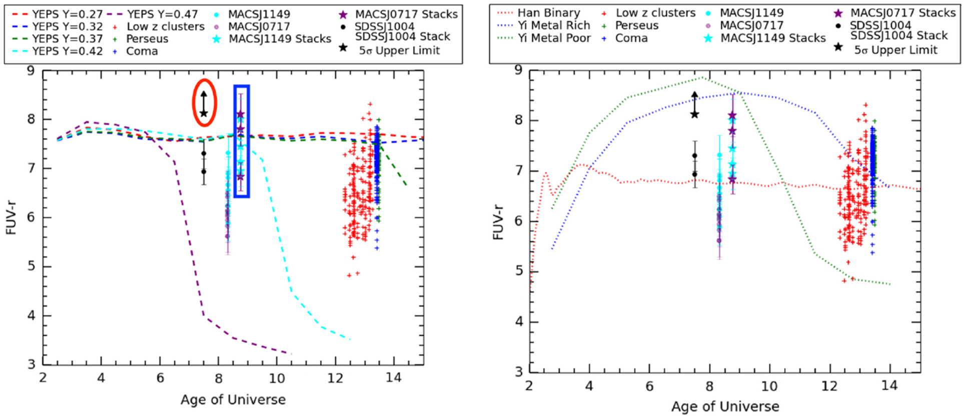

Figure 1. Left: Evolution of the UV upturn color and YEPS models from Chung *et al.* (2017). We observe a significant reddening in the UV upturn color at $z > 0.6$. Right: Comparison with other models for the evolution of the UV upturn. No model fits the data.

galaxy (which has usually bluer UV colors). We derive a significant upper limit to the stacked FUV-V color for red sequence galaxies in this cluster and demonstrate that it is significantly redder than similar stacks for galaxies in the two $z = 0.55$ clusters.

3. Implications

As shown in Figure 1 the evolution observed in the UV upturn is only consistent with a stellar population that is enriched in helium, at $Y > 0.42$. Given the timescale for the evolution of the UV upturn sources, these stars were formed at least by $z = 4$ and possibly earlier. We rule out all other proposed explanations as they do not fit the data across the entire redshift range.

This suggests the existence of a new nucleosynthesis channel in early stellar populations, as a similar phenomenon must account for the second parameter effect in local globular clusters (Bastian & Lardo 2018).

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