On the scatter of the present-day stellar metallicity-mass relation of cluster dwarf galaxies

Christoph Engler,1 Thorsten Lisker,1 and Annalisa Pillepich2, 3

1Astronomisches Rechen-Institut, Zentrum für Astronomie der Universität Heidelberg,
  Mönchhofstraße 12-14, D-69120 Heidelberg, Germany
2Max-Planck-Institut für Astronomie, Königstuhl 17, 69117 Heidelberg, Germany
3Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138

Submitted to RNAAS

INTRODUCTION

The mass-metallicity relation (MZR) is one of the fundamental relations of galaxies, manifesting itself observationally for cluster galaxies in color-magnitude relations (Smith Castelli et al. 2008) or relations of absorption line indices with stellar mass (Toloba et al. 2014). Satellite galaxies, however, have been found to be more metal-rich than centrals of the same mass, both in nature (Pasquali et al. 2010) as well as in cosmological simulations (Bahé et al. 2016; Genel et al. 2016). In this research note, we examine the scatter of the relation between stellar mass $M_*$ and stellar metallicity $Z_*$ for cluster dwarf galaxies in the cosmological simulation Illustris (Vogelsberger et al. 2014a, b; Genel et al. 2014; Nelson et al. 2015). We focus on galaxies in the stellar mass range $10^8 M_\odot \leq M_* < 10^{10} M_\odot$ in a cluster of total mass $3.8 \cdot 10^{14} M_\odot$ at redshift $z = 0$. This mass range is particularly interesting, since early-type galaxies were found to have large ranges of enrichment (Michielsen et al. 2008), stellar ages (Paudel et al. 2010a) and rotational support (Ryš et al. 2014). We find the MZR to exhibit the smallest intrinsic scatter at times of peak stellar mass, i.e. when the galaxies were at their respective maximum stellar mass. This suggests stellar mass stripping to be the primary effect for the rather broad relation observed at present.

RESULTS

The left panel of Figure 1 shows the MZR for the low-mass galaxies of the cluster, which experienced a major merger 3.5 Gyr prior at $z = 0.31$. The relation depicts a broad scatter with a pronounced tail towards its high-metallicity side (0.180 dex at 1σ). Most high-metallicity outliers fell early into a group environment, which we define here as halos of total mass $\geq 10^{12} M_\odot$. The subsample of galaxies with early group infall yields a scatter of 0.210 dex, while the scatter for late infallers is at 0.099 dex. Clearly, the environment and the time the galaxies spent therein is connected to the broadening of the MZR.

In the right panel of Figure 1 we consider the galaxies at their individual times of peak stellar mass. With a scatter of 0.077 dex, this relation is narrower than any of the equal-time relations we examined, such as the MZR of the galaxies’ progenitors at $z = 1$ (scatter: 0.106 dex) or the time at which 50% of the progenitors had experienced group infall ($z = 0.76$, scatter: 0.109 dex). Observationally derived MZRs necessarily exhibit larger scatter, since observers only have access to equal-time MZR, cannot distinguish the galaxies by their respective infall times, and cannot easily reconstruct the galaxy evolution.

We examine the time evolutions of stellar masses and stellar metallicities and find that stripping of stellar mass (more pronounced in more massive cluster hosts) is the primary process responsible for the broad MZR at present-day times. However, for about 40% of galaxies in the high-metallicity tail, mass stripping coincides with an increased enrichment of stellar metallicity. This is possibly caused by the stripping of low-metallicity stars in the galaxy outskirts (Bahé et al. 2016; Genel et al. 2016) or perhaps gas inflows inducing starbursts (Janz et al. 2016).
DISCUSSION

Our findings rely on the realism of Illustris galaxies. However, galaxy sizes in Illustris are generally too large by a factor of $\sim$2-3 for galaxies with $M_\star \lesssim 10^{10.7} \, M_\odot$ (Nelson et al. 2015; Snyder et al. 2015), compared to simulations of isolated dwarf galaxies (Vandenbroucke et al. 2016) or observed dwarfs in the Virgo cluster (Janz et al. 2014). Having their stars spread over such an extended radius makes the low-mass galaxies even more susceptible to external influences (Bialas et al. 2015), thereby increasing the efficiency of stellar mass stripping.

It stands to question how strongly the MZR has been affected by these processes and how different it might appear with galaxies in the successor simulation IllustrisTNG (Marinacci et al. 2017; Naiman et al. 2018; Nelson et al. 2018; Pillepich et al. 2018b; Springel et al. 2018), which incorporates improved galaxy models resulting in smaller and more realistic galaxy sizes at low masses (Weinberger et al. 2017; Pillepich et al. 2018a). First studies show signs of systematic chemical pre-processing in the gas-phase metallicities of infalling galaxies (Gupta et al. 2018). Comparing the effects on the MZR in Illustris and IllustrisTNG as well as the further importance of mass stripping and metallicity enrichment for the evolution of low-mass galaxies remain to be investigated more comprehensively.

Figure 1. MZRs for Illustris low-mass galaxies residing in a $z = 0$ cluster of $3.8 \cdot 10^{14} \, M_\odot$, color-coded by early ($z \geq 0.76$, lookback time $\geq 6.65$ Gyr) and late infall into a group of at least $10^{12} \, M_\odot$. Left: MZR of all galaxies at $z = 0$. Right: MZR using mass and metallicities at the galaxies’ individual times of peak stellar mass.
REFERENCES

Bahé, Y. M., Schaye, J., Crain, R. A., et al. 2016, MNRAS, 464, 508
Bialas, D., Lisker, T., Olczak, C., et al. 2015, A&A, 576, A103
Genel, S., Vogelsberger, M., Springel, V., et al. 2014, MNRAS, 445, 175
Genel, S. 2016, ApJ, 822, 107
Gupta, A., Yuan, T., Torrey, P., et al. 2018, MNRAS, arXiv: 1801.03500
Janz, J., Laurikainen, E., Lisker, T., et al. 2014, ApJ, 786, 105
Janz, J., Norris, M. A., Forbes, D. A., et al. 2016, MNRAS, 456, 617
Marinacci, F., Vogelsberger, M., Pakmor, R., et al. 2017, ArXiv e-prints, 1707.03396
Michielsen, D., Boselli, A., Conselice, C. J., et al. 2008, MNRAS, 385, 1374
Naiman, J. P., Pillepich, A., Springel, V., et al. 2018, MNRAS, arXiv: 1707.03401
Nelson, D., Pillepich, A., Genel, S., et al. 2015, Astronomy and Computing, 13, 12
Nelson, D., Pillepich, A., Springel, V., et al. 2018, MNRAS, 475, 624
Pasquali, A., Gallazzi, A., Fontanot, F., et al. 2010, MNRAS, 407, 937
Paudel, S., Lisker, T., Kuntschner, H., et al. 2010, MNRAS, 405, 800
Pillepich, A., Springel, V., Nelson, D., et al. 2018a, MNRAS, 473, 4077
Pillepich, A., Nelson, D., Hernquist, L., et al. 2018b, MNRAS, 475, 648
Ryš, A., van de Ven, G., Falcón-Barroso, J. 2014, MNRAS, 439, 284
Smith Castelli, A. V., Bassino, L. P., Richtler, T., et al. 2008, MNRAS, 386, 2311
Snyder, G. F., Torrey, P., Lotz, J. M., et al. 2015, MNRAS, 454, 1886
Springel, V., Pakmor, R., Pillepich, A., et al. 2018, MNRAS, 475, 676
Toloba, E., Guhathakurta, P., Peletier, R. F., et al. 2014, The Astrophysical Journal Supplement Series, 215, 17
Vandenbroucke, B., Verbeke, R., De Rijcke, S. 2016, MNRAS, 458, 912
Vogelsberger, M., Genel, S., Springel, V., et al. 2014a, Nature, 509, 177
Vogelsberger, M., Genel, S., Springel, V., et al. 2014b, MNRAS, 444, 1518
Weinberger, R., Springel, V., Hernquist, L., et al. 2017, MNRAS, 465, 3291