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THE EVOLUTIONARY PATHS AMONG GALAXY TYPES ON THE RED SEQUENCE AT $0.3 < Z < 1.5$

M. C. Eliche-Moral,[1] M. Prieto,[2,3] M. Balcells, D. Abreu, G. Barro, D. Cristóbal-Hornillos, L. Domínguez Palmero, P. Erwin, J. Gallego, R. Guzmán, A. Hempel, C. López-Sanjuan, P. G. Pérez-González, and J. Zamorano

RESUMEN

Hemos estudiado las principales vías evolutivas entre los distintos tipos de galaxias localizadas en la zona masiva de la Secuencia Roja y en posiciones próximas sobre el Valle Verde durante los últimos ∼9 mil millones de años de historia cósmica. Se han analizado las propiedades morfológicas y de formación estelar de una muestra de estas galaxias a desplazamientos al rojo $0.3 < z < 1.5$ con masas estelares $M_* > 5 \times 10^{10}\ M_\odot$. Presentamos por primera vez evidencia observacional directa de la existencia de dos principales vías evolutivas entre los distintos tipos de galaxias rojas desde $z \sim 1.5$ y de los procesos que han gobernado el ensamblaje de las galaxias masivas quiescentes actuales. Los resultados están en excelente acuerdo con el escenario jerárquico de evolución propuesto en el modelo de Eliche-Moral et al. (2010). Los datos que se están tomando con GTC en el proyecto SHARDS (uno de los Programas de Larga Duración de ESO/GTC aprobados en 2009A) complementarán los resultados de este estudio, arrojando luz sobre algunas de las muchas cuestiones aún no resueltas sobre la formación de la Secuencia Roja a $z < 1.5$.

ABSTRACT

We have studied the main evolutionary paths among the galaxy types residing on the massive end of the Red Sequence and nearby locations on the Green Valley during the last ∼9 Gyr. The morphological and star formation properties of a sample of these galaxies at $0.3 < z < 1.5$ with stellar masses $M_* > 5 \times 10^{10}\ M_\odot$ have been analysed. We present direct observational evidence for the first time of the existence of two main evolutionary paths among the different red galaxy types since $z \sim 1.5$, which provide some clues on the nature of the processes that have governed the assembly of present-day massive quiescent galaxies. The results are in excellent agreement with the hierarchical evolutionary framework proposed in the Eliche-Moral et al. (2010) model. Data from SHARDS (one of the ESO/GTC Large Programmes approved in 2009A) will complement and improve the present findings, shedding some light into many of the still unsettled questions concerning the migration of galaxies from the Blue Cloud to the Red Sequence at $z < 1.5$.

Key Words: galaxies: elliptical and lenticular, cD — galaxies: evolution — galaxies: formation — galaxies: interactions — galaxies: luminosity function, mass function

1. INTRODUCTION

According to hierarchical models of galaxy formation, present-day massive quiescent spheroids (E-S0's) are expected to be the result of the most massive and violent merging sequences in the Universe, being the latest systems to be definitively in place into the cosmic scenario (at $z \lesssim 0.5$, see De Lucia et al. 2006; Hopkins et al. 2008). However, this prediction conflicts directly with recent data indicating that massive galaxies seem to have been in place before their less-massive counterparts (a phenomenon known as downsizing, see Bundy et al. 2006; Cimatti, Daddi, & Renzini 2006). A huge observational effort is thus been devoted to observationally determine the definitive assembly epoch of these galaxies to constraint galaxy evolution models.

The settlement of the Red Sequence depends on the galaxy mass and its environment (di Serego Alighieri et al. 2005; Vikram et al. 2010). Furthermore, it is not made of a homogeneous galaxy population through time, but of a mixing of different galaxy types that has evolved strongly with redshift (Cimatti et al. 2002; Hempel et al. 2011). This makes the tracing of the evolutionary paths among red galaxies difficult, as the transitory evolutionary

[1]Departamento de Astrofísica, Facultad de CC. Físicas, Universidad Complutense de Madrid, E-28040 Madrid, Spain (mceliche@fis.ucm.es).

[2]Departamento de Astrofísica, Universidad de La Laguna, Avda. Astrofísico Fco. Sánchez, E-38200, La Laguna, Canary Islands, Spain (mpm@iac.es).

[3]Instituto de Astrofísica de Canarias, C/ Vía Láctea, E-38200, La Laguna, Canary Islands, Spain.

stages and end products of these tracks coexist at each redshift. Recently, Ilbert et al. (2010) have confirmed that the bulk of the assembly of massive quiescent galaxies is rapidly created at $1 \lesssim z \lesssim 2$, becoming negligible at later epochs. As in many previous studies, they also propose major mergers as drivers of this buildup (see also Bernardi et al. 2011a,b). Nevertheless, no direct observational evidence exists up to the date on the existence of a evolutionary link between major mergers and the assembly of massive quiescent galaxies. In the present study, we provide evidence of this for the first time.

2. GOALS AND METHODOLOGY

In Prieto et al. (MNRAS, submitted), we have tried to advance in the understanding of the formation and evolution of massive galaxies by analysing the physical properties of red galaxies at $0.3 < z < 1.5$ with stellar masses $M_* > 5 \times 10^{10}\ M_\odot$, using data from the GOYA[4] photometric catalogue and Spitzer/MIPS 24 μm. The novelty of our study over previous ones is two-fold. First, we include information about the structural distortion of each galaxy to trace merger remnants (besides considering morphology and star formation properties, as Ilbert et al. do). And secondly, as most objects in their evolution towards the Red Sequence must have gone over nearby Green Valley locations transitorily, we have analysed the red galaxies both lying on the Red Sequence and at close positions on the Green Valley. The galaxy classes resulting from the combination of morphological, structural, and star-formation activity properties allow us to trace the evolution of intermediate stages of major mergers and of their final remnants since $z \sim 1.5$. The observed number evolution experienced by each galaxy type is used to carry out a set of novel observational tests defined on the basis of the expectations of the hierarchical scenario proposed in Eliche-Moral et al. (2010a), which provide direct observational evidence for the first time of the evolutionary paths among the different red galaxy types occurred during the last ∼9 Gyr.

3. RESULTS AND CONCLUSIONS

We find two main evolutionary paths among the different red galaxy types. The first one traces the conversion of blue disks into massive E-S0's through major mergers at all redshifts, accordingly to downsizing trends. This track has dominated the evolution of massive red galaxies in the last ∼9 Gyr, but mainly at $0.7 < z < 1.5$, in excellent agreement with the predictions of Eliche-Moral et al. hierarchical model (see also Eliche-Moral et al. 2010b). The second path traces the appearance of some Sa-Sb's on the massive Red Sequence mostly at $z < 0.7$. This evolution is probably driven by disk rebuilding after a merger and partially by secular processes. These results prove that, although the progressive settlement of the Red Sequence results from different evolutionary mechanisms taking place at different epochs and masses at $z < 1.5$, major mergers have played the dominant role in the definitive buildup of present-day massive E-S0's at $0.7 < z < 1.2$, in agreement with hierarchical scenarios of galaxy formation.

The used limiting flux in Spitzer/MIPS 24 μm naturally isolates galaxies with relevant-to-moderate levels of star formation rate from those with median-to-negligible ones at each redshift, but is biassed towards lower star formation levels at $z < 0.7$. GTC/OSIRIS data taken into the SHARDS project[5] will allow us to perform an unbiased identification of passively evolving galaxies and dust-reddened star-forming ones at $0.7 < z < 1.5$ through the determination of stellar population ages through the direct measurement of the Mg(UV) absorption index.

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S. D. H. & G.

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