Early-type galaxies across the UV-optical color magnitude diagram

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Abstract

With the aim to clarify the mechanisms driving the evolution of galaxies in nearby groups, we focus on Early-Type galaxies (ETGs) of two groups in the Leo cloud. Using SPH simulations with chemo-photometric implementation, we match kinematical, photometric and morphological properties of ETGs to trace back their evolution. We follow ETG evolution in the rest-frame UV-optical color magnitude diagram (CMD), from the blue cloud (BC) to the red sequence (RS), through the green valley (GV). ETGs brighter than M_r ~ -21 mag are old (13-14 Gyr) and spend up to 10 Gyr in the BC before they reach the RS. ETGs fainter than M_r=-21 mag are slightly younger (11-12 Gyr), and spend about 7-8 Gyrs in the BC. All ETGs cross the GV in about 3-4 Gyr, the turn-off occurs at z~ 0.3-0.4. For UGC~6324, the faintest ETG in our sample, simulations predict strong oscillations in the GV. We conclude that ETGs evolution in the two groups is driven by gravitational mechanisms such as merging and/or interactions which may happen before or during the collapse phase of groups.

1. Introduction

The color distribution of galaxies in the Local Universe is nearly bimodal and relates to galaxy morphology (e.g. Strateva et al. 2001, AJ, 140,1462, Balogh et al. 2004, ApJ, 615, L101). In the CMD, quiescent ETGs populate the RS and late-types, with active star formation, the BC (e.g. Baldry et al. 2004, ApJ, 600,681). This bimodality is ubiquitous, extending from field galaxies to groups and clusters (e.g. Lewis et al. 2002, MNRAS, 428,476). The physical origin of this bimodality is still under debate, although there is strong evidence that the two populations are the result of transformations driven by the environment. The galaxy evolution from BC to RS, i.e. from star-forming to quiescent galaxies, occurs via a transition across an intermediate zone of the CMD, the GV (e.g. Martin et al. 2007, ApJS, 173, 342). UV fluxes are an excellent tracer of recent star formation, therefore RS and BC are well separated in the UV-optical CMDs (e.g. Schawinski et al. 2007, Wyder et et al. 2007, ApJS, 173, 512, 293). ETGs, widely considered evolved ``red & dead'' galaxies, reveal signatures of on-going SF in the form of inner and/or outer blue ring/arm-like structures (e.g. Marino et al. 2011, ApJ, MNRAS, 411, 311, Salim et al. 2012 ApJ, 755, 105). Signatures of ongoing (~9%) or recent (~47%) SF are also found in the nuclear regions of nearby ETGs (Rampazzo et al. 2013, MNRAS, 432, 374) .

The investigation of the evolution of group members in the nearby universe is of great cosmological interest because more than half of galaxies resides in groups. Furthermore, since the velocity dispersion of groups and galaxies are comparable, the probability of merging and the effects of interactions on galaxy evolution are much higher than in clusters. Consequently, groups provide a view on morphological and star-formation evolution of galaxies, before they fall into denser environments (e.g. Wilman et al. 2009, ApJ, 692, 298; Just et al. 2010, ApJ, 711, 192).

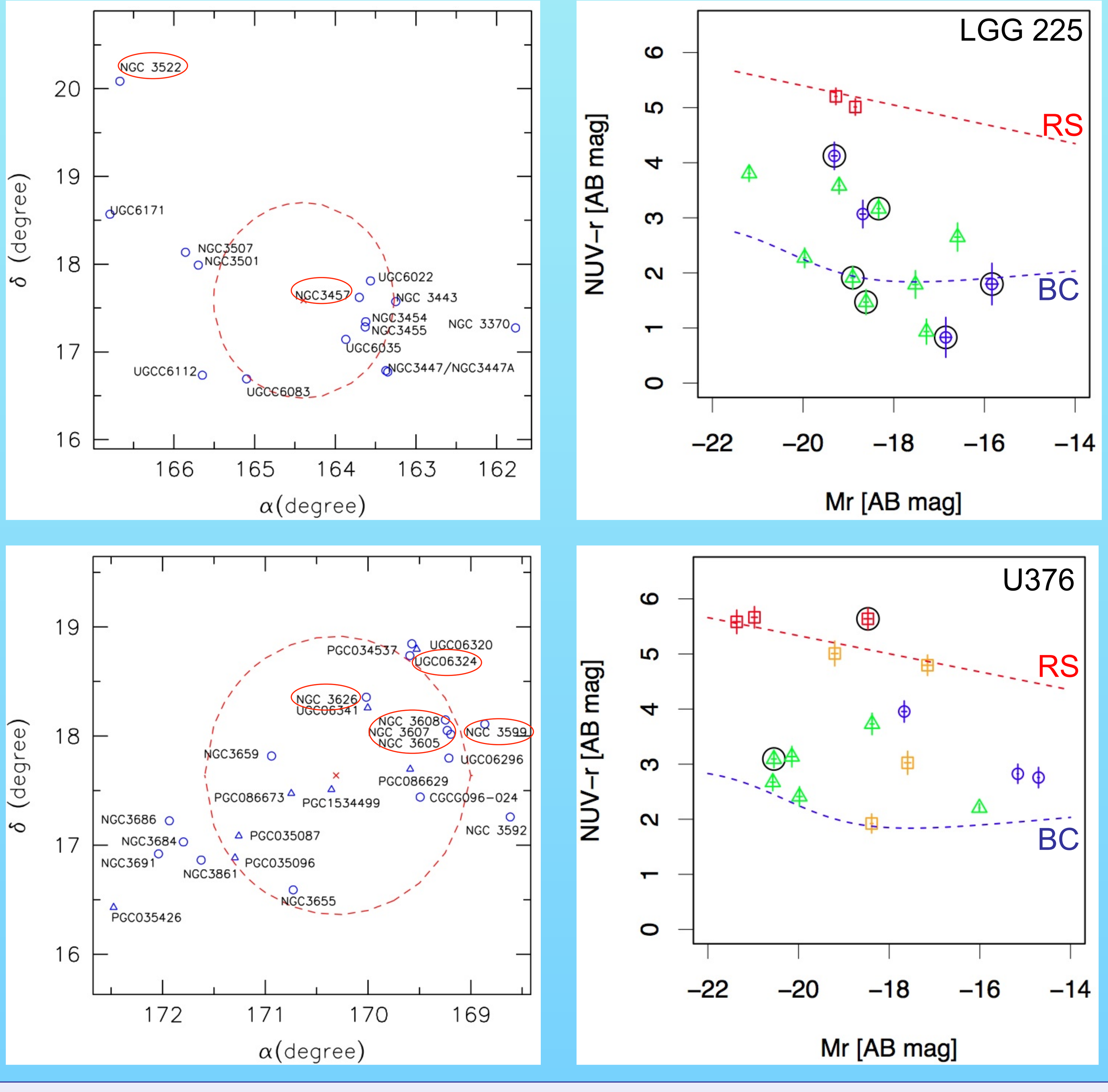

FIG. 1 **Position of member galaxies (left) and CMD (right) of LGG 225 and USGC 376 (U376 hereafter). The dashed red circles and the red ellipses (left panels) show the virial radius and the ETGs respectively. The locus of RS and BC from Wyder et al. 2007 (ApJS, 173,293) is shown (right panels). Triangles indicate Spirals, squares ETGs (red: ellipticals, yellow: S0s), circles irregulars, "?" galaxies without morphological classification. Encircled symbols indicate galaxies with interaction signatures (right panels, Marino et al. 2013, MNRAS, 428, 476).**

2. Comparing data with SPH simulations

- From a grid of physically motivated SPH simulations we selected those best-fitting the global properties, i.e morphology, SED (from far-UV to far-Infrared), kinematics, of the brightest ETGs in our sample. Simulations include self--gravity of gas, stars and DM, radiative cooling, hydro-dynamical pressure, shock heating, viscosity, star formation and feedback from evolved stars and type II Sne, and chemical enrichment (see Mazzei & Curir 2003 (ApJ, 591,784) and Mazzei et al. (ASR, in press, http://dx.doi.org/10.1016/j.asr.2013.06.001). Figure 2 compares observed and simulated morphologies and SEDs of NGC 3607 in U376.

- Simulations provide a self-consistent morphological, dynamic and chemo-photometric picture of ETG evolution. Figure 3 shows the comparison between the morphology and the stellar + gas kinematics of NGC 3626, member of U376. This lenticular galaxy is embedded into a HI envelope; gas and stars counter-rotate, a signature of an accretion episode.

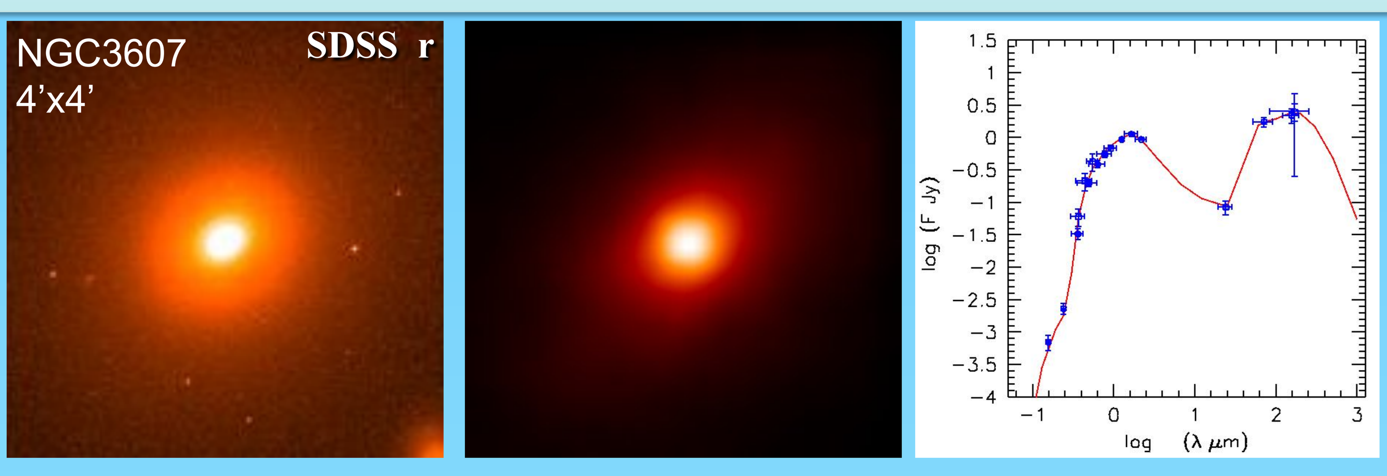

FIG. 2 **SDSS r-band image (left), r-band simulated map on the same scale and resolution (5"/px, middle), measured (dots) and simulated (line) SED of NGC 3607.**

The simulation starts from two triaxial collapsing systems with parallel spins and mass ratio of 2:1. The simulation that consistently best reproduces NGC 3607 data has a total mass of 3 x 10^{12} $M_{\odot}$, and an age of 13.8 Gyr . The stellar systems merged ~8 Gyr ago; the last burst of SF occurred ~3.5 Gyr ago.

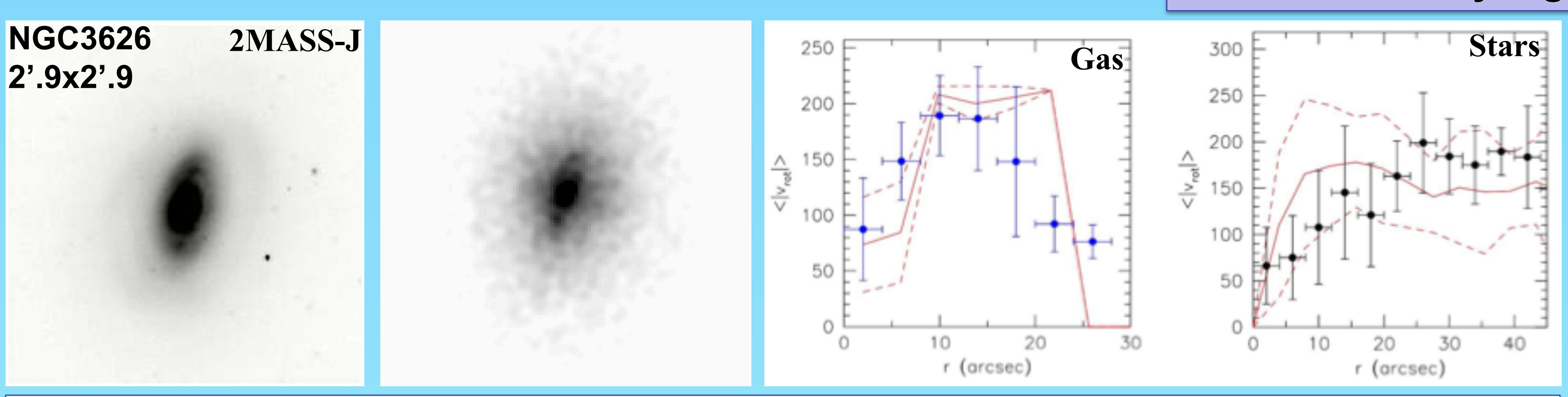

FIG. 3 **from left: 2MASS J-band image; simulated J-band map on the same scale and resolution (2"/pix) of NGC 3626 in U376; rotation curve of gas and stars (Mazzei et al. 2013, ASR in press) compared with our model predictions. The cold gas (T<10^4 K, filled circles, Ciri et al. 1995) and the star) data data (Haynes et al. 2000) are shown with 4" bins. Vertical bars show the velocity dispersion range of simulations. Dashed lines show the velocity dispersion range of simulations.**

3. Insights into evolution of galaxy groups

- Our SPH simulations allow us to follow the transformation of galaxies from star-forming to quiescent, i.e from the BC to the RS crossing the GV. In Figure 4 the evolutionary paths of ETGs in U376 are shown in the (NUV - r) vs. M_r plane.

- ETGs brighter than M_r ~ -21 mag are ~13-14 Gyr old. They spend up to 10 Gyr in the BC before reaching the RS. Fainter ETGs are about 2Gyr younger and spend less time (7-8 Gyrs) in the BC. For UGC~6324, the faintest ETG in U376, simulations predict strong oscillations in the GV.

- The turn-off from the BC occurs at z~0.3-0.4. All ETGs cross the GV in about 3-4 Gyr.

- Merging episodes and interactions are driving the evolution of ETGs in our sample. The measured properties of all ETGs, but NGC 3457 and UGC 06324 in LGG 225 and U376 respectively, are well reproduced by a major merger with a gas rich companion. NGC 3457 and UGC 06324 have the SF quenched by a close encounter.

- The two groups are not completely virialized (see Figure 1). This implies that ETGs in our sample have reached the RC during the collapse phase of their group.

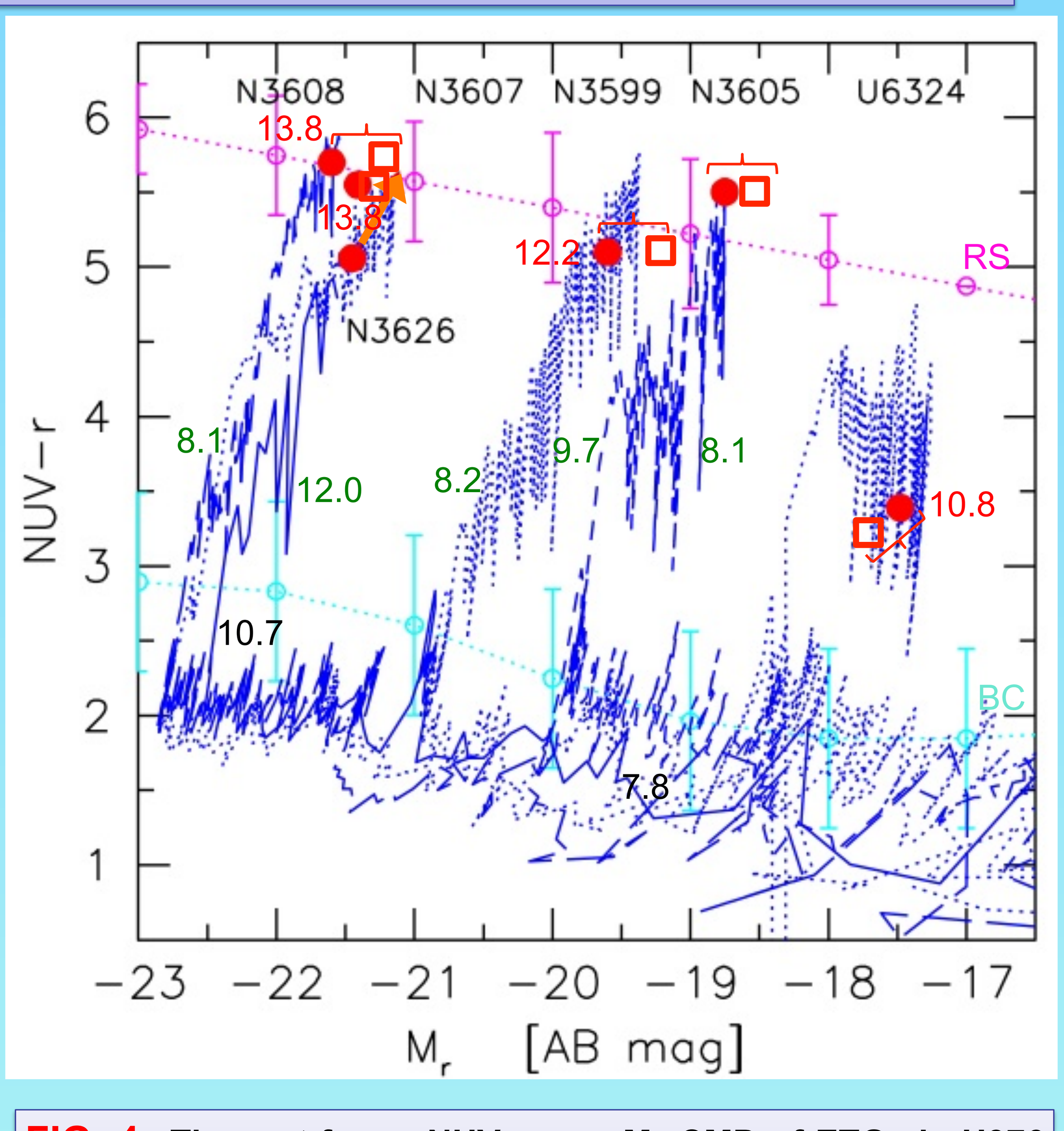

FIG. 4 **The rest-frame NUV - r vs. M_r CMD of ETGs in U376 from our chemo-photometric SPH simulations (Mazzei et al. 2013, ASR in press; Mazzei et al. in prep). Some relevant evolutionary times in Gyr (turn-off from BC, crossing GV, current) are indicated. Red dots mark the current positions of galaxies in the simulations and red squares the measurements. The arrow shows the reddening for NGC 3626.**

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