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Catching spiral – S0 transition in groups. Insights from SPH simulations with chemo-photometric implementation

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Abstract

We are investigating the co-evolution of galaxies within groups combining multi-wavelength photometric and 2D kinematical observations. Here we focus on S0s showing star formation in ring/arm-like structures. We use smooth particle hydrodynamical simulations (SPH) with chemo-photometric implementation which provide dynamical and morphological information together with the spectral energy distribution (SED) at each evolutionary stage. As test cases, we simulate the evolution of two such S0s: NGC 1533 and NGC 3626.

The merging of two halos with mass ratio 2:1, initially just composed of DM and gas, well match their observed SEDs, their surface brightness profiles and their overall kinematics. The residual star formation today "rejuvenating" the ring/arm like structures in these S0s is then a mere consequence of a major merger, i.e. this is a phase during the merger episode. The peculiar kinematical features, e.g. gas-stars counter rotation in NGC 3626, depends on the halos initial impact parameters. Furthermore, our simulations allow to follow, in a fully consistent way, the transition of these S0s through the green valley in the NUV-r vs. M_r colour magnitude diagram, which they cross in about 3–5 Gyrs, before reaching their current position in the red sequence. We conclude that a *viable* mechanism driving the evolution of S0s in groups is of gravitational origin.

Keywords: Galaxies: evolution; Galaxies: interactions; Galaxies: individual: NGC 3626, NGC 1533; Method: numerical

1. Introduction

The investigation of the co-evolution of galaxies and groups in the nearby Universe is of great cosmological interest since more than half of galaxies reside in groups. Since the velocity dispersion of galaxies in groups is low, i.e. comparable to the stellar velocity dispersion, mergers of galaxies are highly favoured with respect to clusters. Nearby groups provide a close-up view of phenomena driving the morphological and star formation (SF) evolution of galaxy members before they fall into clusters e.g (Boselli and Gavazzi, 2006; Wilman et al., 2009; Just et al., 2010).

Among open questions, the old controversy about the *nature* vs. *transformation* origin of S0 galaxies rises above the others. Since Es and S0s are the typical inhabitants of nearby clusters, at expense of Spirals (Sps), a debate about the transformation of Sps into S0s in such environments arose.

The processes possibly driving the Sp→S0 transformation are, indeed, still uncertain and debated (e.g. Bekki, 2009). They include feedback from AGN (Schawinski et al., 2009) which may shut down SF, environmental effects which reduce the HI reservoir of Sps, (Boselli and Gavazzi, 2006; Hughes and Cortese, 2009; Cortese and Hughes, 2009) and the interplay between cold gas flows and shock heating (Dekel and Birnboim, 2006). Wetzel et al. (2012) find that galaxies in groups and clusters experience no significant environmental effects until they cross within the virial radius of a more massive host halo. Boselli and Gavazzi (2006) claim that the interaction with the intergalactic medium is not the origin of the cluster S0s,

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which likely form by Sps through gravitational interaction. Studying 116 X-ray selected galaxy groups at redshift 0.2–1, George et al. (2012) conclude that strangulation and disk fading are insufficient to explain the observed morphological dependence on environment, and that galaxy mergers or close tidal encounters must play a role in building up the population of quenched galaxies with bulges seen in dense environments at low redshift.

The comparison of clusters at $z \approx 0.1$–0.2 with some at intermediate distance, $z \approx 0.4$–0.5, shows that a sort of morphological conversion in the galaxy population from Sps→S0s took place about 1–4 Gyr ago (Fasano et al., 2000). This transformation anti-correlates with the local density, i.e., in low concentration clusters the transformation happened only about 1–2 Gyr ago.

The effects of the possible galaxy morphological transformation manifest themselves also in the nearly ubiquitous bimodal distribution of galaxies in the colour-magnitude diagram (CMD) (e.g. Strateva et al., 2001; Lewis et al., 2002; Baldry et al., 2004). The red disk galaxy population should be the result of transformations of the blue, late-type galaxies via mechanisms of gas depletion and consequently of SF quenching. The galaxy transition from star forming to quiescent, is highlighted by the presence of an intermediate zone, the so-called *green valley* (GV), on CMDs (Martin et al., 2007; Wyder et al., 2007; Fang et al., 2012). Investigating galaxies in the GV should shed light on the mechanisms governing the *on-off* state of the SF. S0s in groups, in particular, are key elements in identifying both the mechanisms and the environmental influence on their possible transformation.

Although S0s are early-type galaxies (ETGs), so they are widely considered evolved "red & dead" galaxies, *GALEX (Galaxy Evolution Explorer)* far-UV (FUV) and/or Hα images revealed signatures of on-going SF in their disks in the form of outer blue ring/arm-like structures in some of them. Salim et al. (2012, and references therein) show a wide collection of these kind of galaxies. Signatures of ongoing ($\approx 9^{+4}{}_{-3}$%) or recent ($\approx 47^{+8}{}_{-7}$%) SF are also found in the nuclear regions of nearby ETGs (e.g. Rampazzo et al., in press).

The presence of a disk and the occurrence of SF in ETGs imply that cold gas has played an important role in their evolution. In Fig. 1 we show the optical (left panels) and UV colour composite images (middle panel) of examples of nearby S0s with outer ring/arm-like structures detected in the FUV band: NGC 404 (Thilker et al., 2010), NGC 1533, NGC 2962, NGC 2974 (Marino et al., 2011a), and NGC 1317 (Gil de Paz et al., 2007). All the S0s in Fig. 1 are located in low density environments. These galaxies also have cold gas, distributed either over the main body of the galaxy or forming large-scale structures around the galaxy, as shown by HI contours over plotted in the right panels of Fig. 1.

The paper explores the evolution of these S0s, using SPH simulations accounting for chemo-photometric evolution, i.e providing the SED at each evolutionary time (snapshot hereafter). The SED takes into account chemical evolution, stellar emission, internal extinction and re-emission by dust in a self-consistent way, as already described in Mazzei and Curir (2003, MC03 hereafter), Spavone et al. (2009, and references therein), and Spavone et al. (2012). The SED extends over four orders of magnitude in wavelength, i.e., from 0.1 to 1000 μm. Each simulation self-consistently provides morphological, dynamic and chemo-photometric evolution.

Simulations of groups, focusing on galaxy morphological transformation have been approached with different techniques (e.g. Kawata and Mulchaey, 2008; Bekki and Couch, 2011; Villalobos et al., 2012). Kawata and Mulchaey (2008) used a cosmological chemo-dynamical simulation to study how the group environment affects the SF properties of a disk galaxy. Bekki and Couch (2011), starting from already formed galaxies, show that Sps in group environments can be strongly influenced by repetitive, slow encounters so that galaxies with thin discs can be transformed into thick disks, and gas poor S0s. Villalobos et al. (2012) perform 17 experiments in order to study the general evolution of disc galaxies, composed of a stellar disc embedded in a DM halo, within a group environment. This is modelled as an N-body DM halo following a Navarro et al. (1997) density profile including a spherically symmetric stellar component at its centre.

None of the quoted simulations explores the merger scenario combining the chemo-dynamical code with evolutionary population synthesis (EPS) models providing the galaxy SED at each evolutionary time (snapshot hereafter). This upgrade in galaxy simulations is the novelty of this paper.

As a case study we focus on simulations of two S0s with ring/arm like structures, detected in the far UV and/or narrow band optical images, immersed in extended HI emission, namely NGC 1533 (Fig. 1) and and NGC 3626 (Fig. 2). Both galaxies are members of groups (Marino et al., 2013, 2011b). NGC 3626, is located within the virial radius of USGC U376 (Ramella et al., 2002; Mazzei et al., 2013) and NGC 1533 is a member of the Dorado group. They have extended SEDs, from FUV to far-IR (FIR), that we will use, together with their B-band absolute magnitude, to constrain our simulations. The detailed surface photometry and the 2D kinematical properties of the gas and stars of NGC 3626, also available from the literature, will be a further constraint.

The SPH simulations best-fitting their global properties are selected over a large grid of encounters from halos initially composed of DM and gas. In addition, our simulations highlight the evolutionary path through the GV in the CMD, of such galaxies.

The structure of the paper is as follows. Section 2 describes the observed properties of NGC 3626 and NGC 1533. Section 3 provides the details of our grid of SPH simulations. In Section 4 we compare the global measured galaxy properties with the results of our simulations. Section 5 discusses the galaxy evolution provided by the simulation focusing on the path of the near-UV(NUV)/optical colours in the (*NUV-r*) vs. M_r CMD. In Section 6 we draw our conclusions.