Structure and morphology of relic galaxies in the Local Universe

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Abstract. Red Nugget galaxies found at high-z have analogues in the Local Universe which are called relic galaxies. Because of their proximity to Earth, the relics allow a more detailed analysis of their properties and can help us understand the formation of massive early-type galaxies, since Red Nuggets could be their first phase of formation. The main goal of this work is to characterize the structure and morphology of candidates and confirmed relic galaxies in the Local Universe to further search for similar objects observationally and within cosmological simulations.

**Keywords.** galaxy: formation, galaxy: structure, relic, photometry

1. Introduction

Considering the two-phase galaxy formation scenario of massive early-type galaxies (Huang *et al.* 2016), the compact core forms first (at z > 3), followed by the growth of mass and size through mergers with other galaxies (from z < 2). Given the stochastic nature of the mergers, we can expect that some compact seeds of galaxies that formed in the beginning of the Universe are left almost untouched until the present epoch. Thus, we expect to find them in the Local Universe (Quilis & Trujillo 2013; Beasley *et al.* 2018). These compact ($R_e \leqslant 2$ kpc) massive galaxies ($M_\star \sim 10^{11} M_\odot$) when found at high redshift are called Red Nuggets and they have analogues in the Local Universe with old (t $\geqslant 10$ Gyr) stellar populations that are called relics (Ferré-Mateu *et al.* 2015; Yıldırım *et al.* 2017). It is important to study these relics because they are probes to understand the formation of massive early-type galaxies that we observe today.

2. Data & Method

The first sample studied in this work is composed of 16 galaxies with public images from the Hubble Space Telescope (HST) in H and I bands. The sample was first selected by Yıldırım *et al.* (2017) and 14 galaxies in the sample are very likely to be relics. The second sample studied was composed of 87 candidate relic galaxies (see Lohmann *et al.* 2020 in this IAU proceedings volume) with public images from the Sloan Digital Sky Survey (SDSS) in *g*, *r* and *i* bands (see Lohmann *et al.* in this volume). The objects were found in the MaNGA survey database and selected as outliers in terms of their radii from the galaxy mass-size distribution at z = 0.25 (van der Wel *et al.* 2014). A secondary SDSS control sample was built using galaxies with similar central dispersion velocities to those of the relic candidates.

To characterize the structure of the galaxies we used the Sérsic profile (Sérsic 1968; Graham & Driver 2005), performing single and double 2D profile fitting with the software IMFIT (Erwin 2015) for all the galaxies in both samples (Fig. 1).
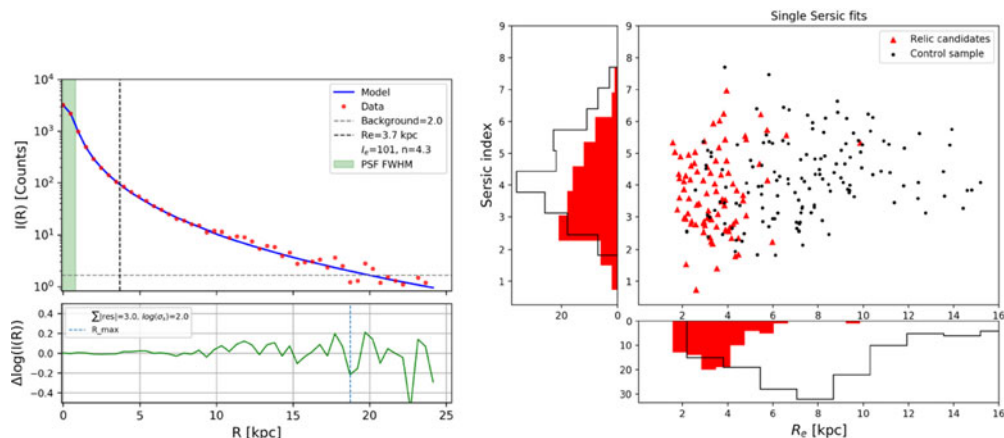
Figure 1. *Left:* Profile fitting (r-band) for the galaxy 1-48084 of the SDSS sample. *Right:* Results for relic candidates sample with single Sérsic profile fittings applied to r-band images for the SDSS sample. Red triangles are the candidates and black dots are the control sample.

3. Results & Discussion

HST sample. From the double Sérsic fitting of the HST sample we found that almost all of the galaxies can be well modeled with a small ($R_e < 2$ kpc) and concentrated ($n \geqslant 4$) component plus a larger ($R_e > 2.5$ kpc) component with low Sérsic index ($n \leqslant 1$), hinting that the structure of this objects is more complex than just central compact nuggets.

SDSS sample. From the single Sérsic fitting (Fig. 1) of the relic candidates in SDSS r-band images we noted that many objects have Sérsic index n ~ 2.5, and effective radii $R_e \sim 3.0$ kpc, while the control sample seems to have different peaks in the distribution of the same parameters. We show in Fig. 1 a profile fitting example and the results for the structural analysis of the SDSS sample:

In addition, a two-sample Kolmogorov-Smirnov test at significance level of 0.05 shows that the Sérsic indices of the control and candidate samples probably come from different distributions, suggesting that the sample of relic candidates could be a population of compact objects in the Local Universe with structure that could resemble confirmed relic properties, such as disk-like morphology if $n \leqslant 2.5$ Buitrago *et al.* (2018).

The next step of this work is to search for similar objects in cosmological simulations in order to analyze their formation and evolution environments.

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