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Inside-out formation of massive galaxies

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Abstract

A significant fraction of the present day massive galaxies have compact cores embedded inside their disks or halos. Strikingly, those compact cores are similar to the massive high-redshift quiescent compact galaxies, nicknamed red-nuggets. We present observational evidence supporting an inside-out formation scenario, where present-day massive galaxies can begin as dense spheroidal cores (red-nuggets), around which either a spheroidal halo or a disk are accreted later. This contribution is based on the paper by de la Rosa et al. (2016)[4].

1 Introduction

Approximately 20% of massive galaxies at redshift $z \sim 1.5$ were quiescent compact spheroids (nicknamed *red nuggets*), but virtually none of them has survived to the present day universe [14]. The fate of those red nuggets has been discussed along dozens of studies since their discovery, more than one decade ago [3, 13]. The current paradigm, put forward by [6] and [2], postulates that red nuggets ended up in the centres of present day giant ellipticals. That scenario is consistent with an inside-out growth scenario [8] in which compact cores are formed at high redshift through highly dissipative processes and then grow an extended spheroidal stellar halo through gas-free minor mergers. Nevertheless, an alternative channel dominated by cold gas accretion or/and gas-rich minor mergers has been overlooked until [5] suggested that Late Type Galaxies (LTGs) could have formed their disks around pre-existing red nuggets. Further observational support for this LTG inside-out formation channel has been provided by e.g. [4, 9, 11].

This contribution is based on the study by de la Rosa et al. (2016)[4], in which massive SDSS catalogs of B+D galaxy decompositions [12, 10] are used to characterize the central spheroidal component (called *core*) of all the galaxies without applying any morphological cut, i.e. including both Early and Late Type Galaxies. It is shown that a significant fraction of cores, named *compact cores*, are structurally similar to red nuggets. Additionally, the compact core number density in the present universe is comparable to that of red nuggets at $z \sim 1.5$, supporting an scenario in which red nuggets are not destroyed, but merely hide out in the center of massive galaxies. Finally, a census of galaxies hosting compact cores shows that a comparable fraction of red nuggets ended up in either present day spheroidal or disk massive descendants.

2 Red nuggets and compact cores

Initially, red nuggets were vaguely defined as spheroidal galaxies of $log(M_\star/M_\odot) \sim 11$ and $R_{eff} \sim 1$ *kpc*. The introduction of *compactness criteria* [1, 15, 16] has allowed to carry out a fair comparison with the present day galaxy cores. The criterion [16] used here is

$$\log(\mathrm{R_e/kpc}) < \log(\mathrm{M_\star/M_\odot}) - 10.7. \quad (1)$$

with an additional $\log(\mathrm{M_\star/M_\odot}) \geq 10.6$ cut and $\mathrm{R_e}$ as the circularized half-light radius. Out of an eclectic red nugget sample, compiled from 29 works in the literature, the [16] compactness criterion extracts 534 bona fide compact red nuggets (43 %). The relevant question is, are there present day galaxy cores structurally similar to those compact red nuggets? The answer to this question is positive. However, it is worth mentioning that, in the present universe, almost no entire galaxy fulfills the demanding [16] compactness criterion. Only some compact cores, extracted after a B+D decomposition, accomplish the [16] criterion, i.e. they are structurally similar to red nuggets.

The SDSS catalog of B+D galaxy decompositions [10] (initial size 657,996) has been heavily screened for anomalous B+D decompositions, sample incompleteness, edge-on inclinations, strong bars and poor spatial resolution, leaving a *trusted* sub-sample only one third the size of the parent sample. Merely 5 % (10,566 compact cores) of the B-components in the trusted sub-sample fulfill the [16] compactness criterion. However, as discussed later, this apparently small fraction of compact cores turns into an abundance comparable to that of the $z \sim 1.5$ red nuggets.

In order to exclude the possibility of compact cores being the small-size end of the dispersed mass-size core distribution, we have used their spectra to work out the velocity dispersion. Once again, compact cores and red nuggets share the same parameter space, clearly segregated from the normal ellipticals.

3 Number densities

Compact core and red nugget get their abundances compared. Red nugget number densities are extracted from Figure 19 in [16] and values at redshift interval $\sim$ 1-3 are represented in Figure 1. Due to the heavy screening used to obtain the trusted sub-sample, the 10,566 detected compact cores are likely to provide a lower number density limit, 0.28×10^{-4} Mpc^{-3}.

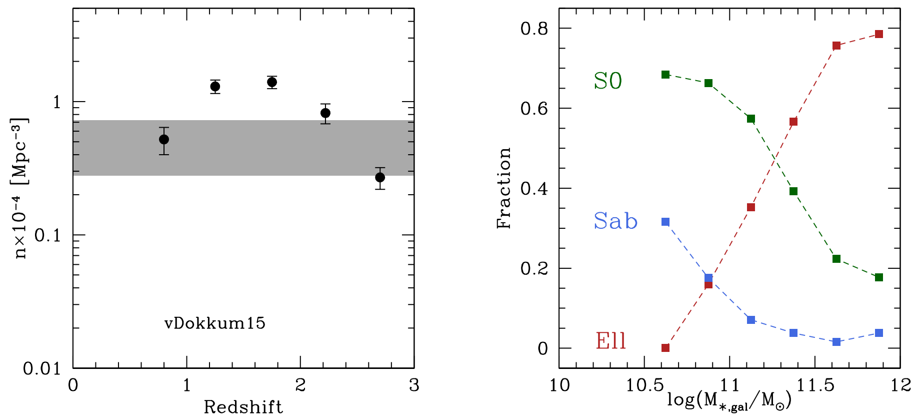

Figure 1: Left panel shows the number density evolution with redshift of red nuggets, as measured by [16] (black dots). The grey band shows our compact core number density measurements at $z \sim 0.1$. The right-hand panel shows the morphology of the galaxies hosting a compact core, pointing to how their fractions vary with $M_{\star,\mathrm{gal}}$.

By relaxing the sub-sample constraints on inclination, bars and spatial resolution, a more realistic number density value is obtained at $0.72{\times}10^{-4}$ Mpc^{-3}. These number densities are represented in Figure 1 as the upper and lower margins of the horizontal grey band. Actually, the extended band serves only for comparison, because the number density should be restricted to a single point in the sub-sample redshift interval, $0.025 \leq z \leq 0.15$.

The maximum number density attained by the red nuggets at $z \sim 1.5$ is $1.40{\times}10^{-4}$ Mpc^{-3}, two times the upper limit of the compact cores. This is a reasonable result, considering that a fraction of the red nuggets can be destroyed and never become compact cores. In agreement with our result, a recent cosmological hydrodynamical simulation [17] finds that about half of the red nuggets acquire an *ex situ* envelope and end up as the core of a more massive descendant.

4 Host galaxy morphology

The information on the morphology of the galaxies hosting compact cores has been extracted from the [7] catalog. Figure 1 shows the variation along $M_{\star,\mathrm{gal}}$ of the three morphology class fractions, aside from the Scd class, which contributes a negligible amount. By integrating along the whole mass range, $log(M_\star/M_\odot) \geq 10.6$, we conclude that host galaxy morphology essentially divides into a 50:50 mixture of elliptical and disk morphology. Note that the majority of the sample is in early-type systems: E + S0.

5 Summary

In the study by de la Rosa et al. (2016)[4], the base for this contribution, we have tested the hypothesis that high-redshift compact, quiescent and massive galaxies, nicknamed *red nuggets*, have survived as the compact cores of massive present-day elliptical or disk galaxies.

• We confirm that a small but significant fraction (>5%) of cores in present-day galaxies (regardless of morphology) is structurally similar to z∼1.5 red nuggets. In the mass-size relations, the red nuggets and compact cores are significantly segregated from the normal elliptical galaxies, with average sizes $\sim$ 4 times smaller than normal ellipticals at a given mass (e.g. $M_\star \sim 10^{11}\mathrm{M}_\odot$).

• Not only do such compact cores exist, but their abundance matches approximately that of the red nuggets at $z \sim 1.5$ [16].

• Galaxies hosting compact cores show varied morphological classes extending from ellipticals to spirals (Scd). The integrated fractions of morphology classes with $\log(M_{\rm gal}/\mathrm{M}_\odot) > 10.6$ are: 50.9% (E), 43.4% (S0), 5.4% (Sab) and 0.3% (Scd). These findings are consistent with red nuggets becoming cores of both present-day elliptical and disk galaxies.

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