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THE CENTRAL BULGES OF GALAXIES AT $0.3 < z < 1.0$

L. Domínguez-Palmero,[1] M. Balcells,[1] M. Prieto,[1,2] D. Cristóbal-Hornillos,[1] P. Erwin,[1] and C. Eliche-Moral[1]

We have studied the colors of the bulge component of 133 galaxies from the HST Groth Strip Survey (Groth et al. 1994), covering redshifts $0.3 < z < 1.0$. We selected all objects apparent radii $R > 1.4''$, and inclination above 50 degrees in order to avoid reddening from dust in the disk on one side of the bulges. We find that, as in the Local Universe, the minor axis color profiles are negative (bluer outside), and fairly gentle, indicating that bulge colors are not distinctly different from disk colors. In most cases, dust bands are the most important morphological structure in the color maps. In a subsample of 76 galaxies with spectroscopic redshifts, we analyze central rest-frame colors using K-corrections. Bulge colors do not globally become bluer at higher redshifts. This suggests that there were 'old' bulges at $z = 0.8$. The color-magnitude distribution of intermediate-z bulges is steeper than that of bulges in the Local Universe. The most massive bulges are as red as local bulges, while the remainder are significantly bluer, a possible sign of late bulge formation.

Color profiles and color maps

We measured color profiles on both semi-minor axes of each galaxy. Different colors on both sides most likely result from dust reddening on the side of the bulge seen through the disk. Color profiles on the 'clean' side are generally smooth, with mild negative gradients (bluer outward). Bulge-disk decompositions indicate that bulge colors are not significantly different from disk colors. This result is identical to that for bulges in the Local Universe, where bulge-disk color differences are smaller than the color differences between galaxies (Peletier & Balcells 1996), and where dust bands are the most important morphological structures observed in the color maps.

All of our objects have been imaged in six bands as part of the GOYA Photometric Survey (U, B with INT/WFC, F606W and F814W with HST/WFPC2, J and Ks with WHT/INGRID).

[1]Instituto de Astrofísica de Canarias, La Laguna, Tenerife, Spain.
[2]Departamento de Astrofísica, Universidad de La Laguna, Tenerife, Spain.

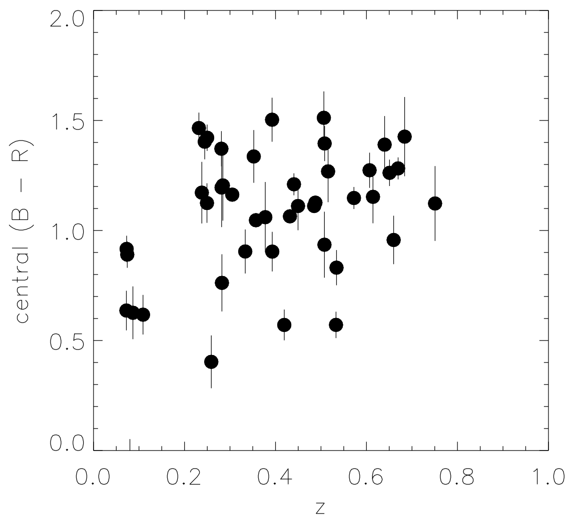

Fig. 1. Rest-frame central B - R colors of the subsample with spectroscopic redshifts vs redshift. K corrections were computed using COSMOPACK (Balcells et al. 2003).

Physical correlations with central colors

We estimated bulge colors from the colors measured on the 'clean' side of the galaxies at 1.3 times the PSF of the HST images. This corresponds to 0.87 kpc at $z = 0.3$ to 1.56 kpc at $z = 1.0$. K-corrections for colors and magnitudes were computed using COSMOPACK (Balcells et al. 2003).

In figure 1 we show rest-frame central colors vs redshift. The upper envelope of the distribution does not become bluer with redshift, which indicates that there were old bulges already at $z = 0.8$.

In figure 2 we show rest-frame central B - R colors vs R-band galaxy absolute magnitude (solid circles). More luminous galaxies have redder central colors, as in the Local Universe. However, the relation at $z = 0$ is much shallower (solid line in figure 2, from Schweizer & Seitzer 1992). Bulges at intermediate z are bluer, hence they are younger and/or less metal-rich than at $z = 0$. The crosses and diamonds are Local Universe bulge colors with and without dust, respectively, from Peletier & Balcells (1996). In the

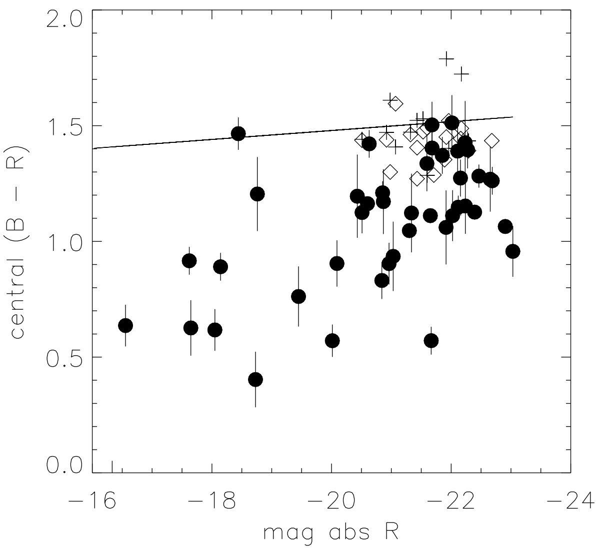

Fig. 2. Rest-frame central B - R colors of the subsample with spectroscopic redshifts vs R-band galaxy absolute magnitude (solid circles). The crosses and diamonds are Local Universe bulge colors with and without dust, respectively, from Peletier & Balcells (1996). The solid line represents the color distribution of eliptical galaxies in the Local Universe.

luminous range of local bulges, high-z bulges show a spread of colors. Some are as red as local bulges, indicating that their populations have comparatively similar ages and metallicities: ages of these bulges must approach 10 Gyr. Bluer bulges probably harvest young populations, a likely indication of late bulge formation. Finally, all the fainter galaxies have significantly bluer central colors than those at $z = 0$. Their colors indicate an active star formation activity, and it is unclear whether these galaxies harbor 'bona-fide' bulges.

Selection effects

We are studying selection biases in our intermediate-z sample, (1) to understand how local and distant samples compare to each other, and (2) to perform volume corrections to the distant sample. Comparison of local and distant samples is carried out by artificially shifting images of local galaxies to redshifts from $z = 0.3$ to $z = 1.0$, using the COSMOPACK package (Balcells et al. 2003). Cosmological dimming, K- and evolutionary corrections, sky brightness, pixelation, etc., are taken into account to mimic the F814W HST/WFPC2 images of the Groth Strip, with Kcor and Ecor computed using GISELXX (Bruzual & Charlot 2003).

We find that our intermediate-z selection ($R > 1.4''$) corresponds to local samples with typically $R > 10kpc''$, i.e. disks with large scale-lengths are selected, whereas there is no correlation with the central surface brightness of the disks, nor do the bulge properties affect the selections.

Discussion

The evolutionary corrections are uncertain given the uncertainties in the formation redshift and the cosmological model.

Are the bluest bulges really 'bulges'? We defined bulges through a bulge-disk decomposition of the 1D surface brightness profiles. Such decompositions are difficult due to the small size of the images and the high galaxy inclinations.

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