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Secular evolution in action: central values and radial trends in boxy bulges

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Abstract. We determine central values and radial trends in the stellar populations of the bulges of a sample of 28 edge-on S0-Sb disk galaxies, 22 of which are boxy/peanut-shaped (and therefore barred). Our principal findings are the following. (1) At a given velocity dispersion, the central stellar populations of galaxies with boxy/peanut-shaped bulges are indistinguishable from those of early-type (elliptical and S0) galaxies. Either secular evolution affects stellar populations no differently to monolithic collapse or mergers, or secular evolution is not important in the central regions of these galaxies, despite the fact that they are barred. (2) The radial metallicity gradients of boxy/peanut-shaped bulges are uncorrelated with velocity dispersion and are, on average, shallower than those of unbarred early-type galaxies. This is qualitatively consistent with chemo-dynamical models of bar formation, in which radial inflow and outflow smears out pre-existing gradients.

1. Introduction

Secular evolution is believed to be the dominant mode of evolution in galaxies that avoid major mergers, and have non-axisymmetric potential structures that can drive radial redistribution of angular momentum and material. The goal of this work is to quantify the consequences of this evolution for stellar populations. To do this, we compare the stellar populations of the bulges of a sample of galaxies that are good candidates for having undergone secular evolution (barred galaxies) to samples of archetypal non-secularly-evolved galaxies (ellipticals and S0s, i.e. early-type galaxies).

We begin by characterizing the stellar populations of early-types. Firstly, the central (or aperture-integrated) stellar populations are correlated with the stellar velocity dispersion (or mass): more massive galaxies are older, more metal-rich, and more α-enhanced (e.g. Thomas et al. 2005; Kuntschner et al. 2010). Secondly, observations of population gradients in early-types (e.g. Spolaor et al. 2009; Kuntschner et al. 2010) show that, on average, $\Delta\log(\mathrm{age}/\mathrm{Gyr}) \approx 0$ and $\Delta[\alpha/\mathrm{Fe}] \approx 0$. However,

Δ[Z/H] $\approx -0.2 \pm 0.1$, and below a central velocity dispersion of $\approx 150\,\mathrm{km\,s^{-1}}$ (equivalent to a dynamical mass $\approx 3 \times 10^{10}\,\mathrm{M_\odot}$), there is some evidence of a correlation: more massive systems have steeper negative metallicity gradients (e.g. Spolaor et al. 2009; Kuntschner et al. 2010). Above this characteristic mass, the correlation between gradient and velocity dispersion or mass disappears, but the average metallicity gradient is still negative.

Why do we think the situation might be different in galaxies that have undergone secular evolution? Almost by definition, secular evolution implies the radial redistribution of angular momentum and baryons. This means that if there was a radial gradient in any tracer, secular evolution should wash that out. Does it? This article is a summary of Williams et al. (2012).

2. Observations and data

Our sample galaxies are the 28 edge-on galaxies presented in Bureau & Freeman (1999) and Chung & Bureau (2004). Half of the galaxies are S0s, half are spirals, and 22/28 host a boxy or peanut-shaped bulge. Galaxies whose bulges are boxy when viewed edge-on would be barred if viewed from above. That is to say, we have a sample of 22 barred galaxies.

We took long-slit spectra using the Double Beam Spectrograph on the 2.3 m telescope at Siding Springs Observatory. The slit was positioned along the major axis of each galaxy. The spectra cover a range of $\approx$ 1000 Å centred on the Mg *b* triplet. The stellar kinematics of these galaxies (including cylindrical rotation) are discussed in Chung & Bureau (2004) and Williams et al. (2011). Using the stellar kinematics and emission-cleaned spectra, we measure the strengths of the absorption lines present in our data (Hβ, Fe5015, Mg *b*, Fe5270, Fe5335 and Fe5406) in the Lick/IDS system. We compare these Lick index measurements to an interpolated grid of Thomas, Maraston, & Bender (2003) single stellar population (SSP) models, yielding SSP-equivalent luminosity-weighted ages, metallicities Z/H and α-element enhancement α/Fe.

3. Results

The smallest aperture from which it is meaningful to extract data is set by the seeing limit of the observations and the width of the slit, i.e. $3'' \times 1.8''$. In Fig. 1 we show the stellar populations of our sample inside this central aperture as a function of velocity dispersion. We find no evidence that the central populations of our barred disk galaxies differ from those of early types at a given velocity dispersion. This implies that either secular evolution does not affect the stellar populations of the centers of bulges of barred galaxies, or its effects are no different to those of monolithic collapse and mergers, the putative formation mechanisms of early types.

To measure Δ[Z/H], we fit a straight line to Z/H as a function of $\log R$. We use the full radial extent of the data, which cover, on average, the inner $\approx$30 arcsec, i.e. the bulge of these local galaxies. We show Δ[Z/H] as a function of central velocity dispersion in Fig. 2. There is no evidence that Δ[Z/H] in our boxy bulges is correlated with velocity dispersion. Moreover, the boxy bulges of our sample of barred galaxies have shallower metallicity gradients than those of early types, both on average and at a given velocity dispersion. The mean value of Δ[Z/H] for the boxy and peanut-shaped

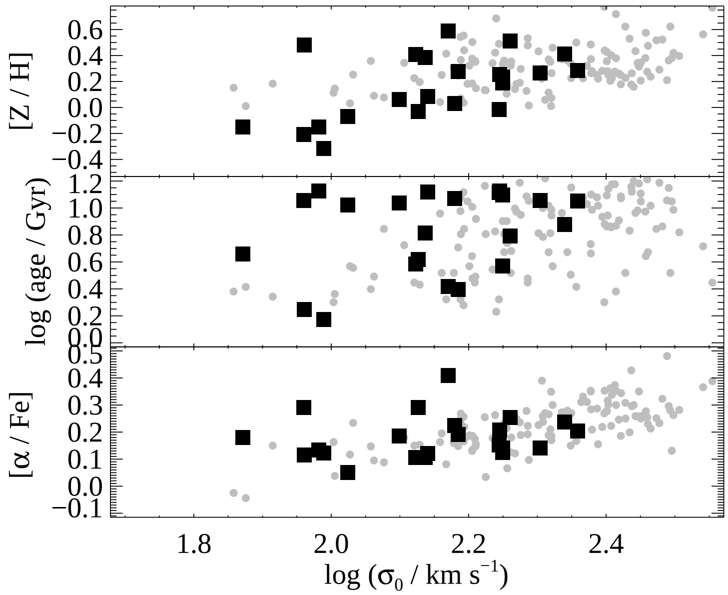

Figure 1. SSP-equivalent population parameters as a function of central stellar velocity dispersion. Large black squares are our boxy bulges. Error bars are omitted for clarity; the typical uncertainties are ±0.1 dex in Z/H, log(age/Gyr) and α/Fe. The smaller gray circles are comparison early-type galaxies taken from Thomas et al. (2005)

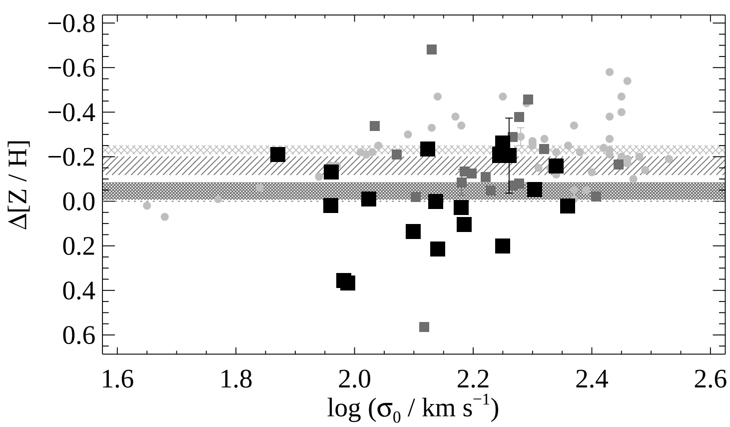

Figure 2. Radial Z/H gradients as a function of central velocity dispersion. Large black squares are our boxy bulges. For clarity, the median uncertainties are shown as error bars only on a representative data point. Smaller symbols are comparison data; dark gray squares are barred S0–Sb galaxies from Pérez & Sánchez-Blázquez (2011), light gray circles are early types from Spolaor et al. (2010). The shaded regions are the mean of ΔZ/H for each sample (from top to bottom: heaving shading for our boxy bulges, medium cross-hatching for the Pérez & Sánchez-Blázquez (2011) barred galaxies, and light hatching for the Spolaor et al. (2010) early types). The width of these shaded regions are the uncertainties on the means.

bulges is -0.06 ± 0.04 and there are several cases of positive metallicity gradients. In contrast, the mean Δ[Z/H] of the Spolaor et al. (2010) catalogue of early types is -0.23 ± 0.02 and there are no strong positive gradients in that sample. These results are qualitatively consistent with the simulations of Friedli et al. (1994), who find that outflows and inflows in barred galaxies make pre-existing radial gradients less steep.

One may reasonably worry that line-of-sight effects in our sample of edge-on barred galaxies are responsible for some or all of the flattening of their radial gradients. While we cannot quantify this effect, we argue that it must be small for two reasons. (1) There is no systematic difference between the radial gradients of our 14 S0s (edge-on galaxies largely free of dust) and 14 spirals (edge-on galaxies with prominent dust lanes). This suggests the role of dust is small. (2) As shown in Fig. 2, we see a similar result — shallower gradients in barred galaxies — in data taken from the bulges of a face-on sample of barred galaxies that cannot suffer from line-of-sight flattening (Pérez & Sánchez-Blázquez 2011). The statistical significance of the difference between metallicity gradients in the Pérez & Sánchez-Blázquez (2011) galaxies and unbarred early types is admittedly weak (the mean Δ[Z/H] for the Pérez & Sánchez-Blázquez (2011) sample is -0.15 ± 0.04), but the strong and clear correlation between Δ[Z/H] and σ seen in unbarred early types with $\log(\sigma/\mathrm{km\,s^{-1}}) < 2.2$ (Spolaor et al. 2010) is totally absent from both our sample of boxy bulges and the Pérez & Sánchez-Blázquez (2011) barred galaxies.

To sum up, the stellar populations at the very centres of the bulges found in barred S0–Sb galaxies do not differ from those of early types of the same velocity dispersion. On larger physical scales, however, these bulges do differ: they lack the correlation between metallicity gradient and velocity dispersion, and their average stellar population metallicity gradients are shallower than unbarred early types with the same velocity dispersion. It seems that secular evolution is sub-dominant in the very centres of early-type bulges, while having some effect on the radial distribution of stellar populations. More work is needed to make quantitative comparisons between these observations and simulations of galaxy evolution.

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