Clues to the Formation of Lenticular Galaxies Using Spectroscopic Bulge–Disk Decomposition

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Abstract. Lenticular galaxies have long been thought of as evolved spirals, but the processes involved to quench the star formation are still unclear. By studying the individual star formation histories of the bulges and disks of lenticulars, it is possible to look for clues to the processes that triggered their transformation from spirals. To accomplish this feat, we present a new method for spectroscopic bulge–disk decomposition, in which a long-slit spectrum is decomposed into two one-dimensional spectra representing purely the bulge and disk light. We present preliminary results from applying this method to lenticular galaxies in the Virgo and Fornax Clusters, in which we show that the most recent star formation activity in these galaxies occurred within the bulges. We also find that the bulges are in general more Fe-enriched than the disks of the same galaxy, and that this enrichment grows stronger as the age of the bulge becomes younger. These results point towards a scenario where the star formation in the disks of spiral galaxies are quenched, followed by a burst of star formation in the central regions from the gas that has been funneled inwards through the disk.

1. Introduction

Spirals and lenticulars (S0s) lie next to each other on the Hubble Sequence, where both display disky morphologies with young and old stellar populations respectively. As a result, S0s are often seen as a possible endpoint of the evolution of spiral galaxies. This idea is backed up by studies such as Dressler (1980), where the fraction of spirals was found to decrease in higher density environments while that of S0s increased, suggesting a direct link between the two morphologies and their environment. Later studies by Dressler et al. (1997), Fasano et al. (2000) and Desai et al. (2007) have also shown a relationship with redshift, where the fraction of S0s increases at lower redshifts while that of spirals decreases with the transition occurring between 2 and 5 billion years ago. These results make S0s in rich clusters the ideal targets with which to study the transformation from spirals.

Many processes have been proposed to explain the transformation of spirals to S0s, most of which focus on the truncation of star formation in the disk followed by passive evolution as the galaxy fades into an S0. Examples of such processes include ram pressure stripping, starvation, tidal stripping by galaxy harassment, and starbursts triggered by unequal mass galaxy mergers and galaxy–cluster interactions, each of which would
affect the bulge and disk in different ways. Therefore, it should be possible to determine the transformation process by studying the star formation histories of the bulge and disk independently.

2. Spectroscopic Bulge–Disk Decomposition

In order to study the star formation histories of the bulge and disk, the light was first separated into individual bulge and disk spectra by spectroscopic bulge–disk decomposition (Johnston et al. 2012). In brief, this procedure involves taking the light profile of the galaxy at each wavelength in the spectrum, and fitting a bulge and disk light profile to this spatial distribution in the same way as for one-dimensional photometric bulge–disk decomposition. In each case, a simple Sérsic bulge plus exponential disk profile was used for the decomposition. Having obtained the bulge and disk parameters at each wavelength from the best fit to the light profile, the total light from each component at that wavelength was calculated through integration and tabulated against wavelength to produce high-quality one-dimensional bulge and disk spectra.

This method was applied to a sample of 30 S0s from the Virgo and Fornax Clusters with inclinations above 40°. The spectra were observed in long-slit mode on Gemini-GMOS (Virgo) and VLT-FORS2 (Fornax). The observations covered a magnitude range of $-22 < M_B < -17$, and a wavelength range of $4100 < \lambda < 5900$ Å. Exposure times were typically between 2 and 3.5 hours to ensure a S/N above 50 at the peak of the spectrum. Of these 30 galaxies, 18 could be decomposed successfully with the simple bulge plus disk model used in this study. The remaining galaxies could not be decomposed due to more complicated light profiles that could not be modelled in this way, or the presence of very compact bulges that could not be fitted reliably.

3. Star Formation Histories of the Bulge and Disk

The decomposed bulge and disk spectra hold clues to their star formation histories within their absorption line strengths. Hydrogen absorption lines are often used as an indicator of the age of the stellar population dominating the light from a galaxy, which in turn tells us how long ago the last star formation event happened. Similarly, magnesium and iron lines can be used to measure the metallicity of the stellar population, and thus provide clues as to the earlier star formation history of the galaxy.

The strengths of these absorption features were measured in all the bulge and disk spectra, and the combined metallicity index, [MgFe]', calculated. These values were then compared to SSP models of Vazdekis et al. (2010) in order to obtain relative light-weighted ages and metallicities for each component. An example of an SSP model for the bulge and disk of a galaxy is given in Fig. [1] in which it can be seen that the bulge contains younger and more metal-rich stellar populations than the disk. This trend appeared in all the galaxies that could be decomposed, as shown on the right of Fig. [1] and suggests that the final star formation event in these galaxies occurred within the bulge after the disk had been quenched.

In order to further interpret this result, the chemical enrichment of the bulges and disks was studied. Since SN II contribute to the Mg abundance soon after star formation begins while SN Ia only enrich the gas with Fe after a timescale of around 1 Gyr, the
relative abundances of magnesium and iron in each component can provide further information on their star formation histories (Thomas et al. 2003).

The Mgb/⟨Fe⟩ ratios of the bulges and disks are shown in Fig. 2, in which the plot on the top left clearly shows that as the age of the bulge increases, it becomes less Fe-enriched. This result suggests that the gas which produced the final star formation event in the older bulges had undergone a shorter period of star formation than in younger bulges. The disks on the other hand (Fig. 2 bottom) show no obvious correlation. A possible explanation for this lack of correlation could be that since the disks are generally quite old, they may have faded significantly since they were quenched, and so their measured ages represent their mean global ages as opposed to the time since they were quenched. However, the plot on the right of Fig. 2 shows that the Mgb/⟨Fe⟩ ratios from the bulge and disk are correlated, with the bulges being generally more Fe-enriched than the disks. This result indicates that the final episode of star formation in the bulge is connected to the star formation history of the disk.

4. Conclusions

We have presented preliminary results of our study of the star formation histories of bulges and disks of S0s. We find that the final star formation event within these galaxies occurs within the bulges, and that older bulges are less Fe-enriched than their younger counterparts. The chemical enrichment of the bulges and disks were also found to be related, with the bulges appearing generally more Fe-enriched than the disks. These results present a scenario for the transformation of spirals to S0s in which the disk star formation is quenched due to ram-pressure stripping, and the residual gas is channelled in towards the centre of the galaxy where it eventually produces a final star formation event within the bulge. Such a scenario ties in with the positive age and negative metallicity gradients seen in S0s in recent studies by Poggianti et al. (2001) and Ferrarese et al.
Johnston et al

Figure 2. Left: The Mg/⟨Fe⟩ ratios of the bulges and disks in the Virgo Cluster against their ages, showing a clear correlation for the bulges. Right: The Mg/⟨Fe⟩ ratios for bulges plotted against those of the disks, which shows that the bulges are generally more Fe-enriched than the surrounding disks.

Sil’Chenko (2006) and Kuntschner et al. (2006), and is starting to reveal a picture consistent with what is seen in the distant Universe, but with far more detailed information on the transformation histories of individual galaxies.

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