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The 6dF Galaxy Survey: a low-redshift benchmark for bulge-dominated galaxies

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Abstract. The 6dF Galaxy Survey provides a very large sample of galaxies with reliable measurements of Lick line indices and velocity dispersions. This sample can be used to explore the correlations between mass and stellar population parameters such as age, metallicity and [α/Fe]. Preliminary results from such an analysis are presented here, and show that age and metallicity are significantly anti-correlated for both passive and star-forming galaxies. Passive galaxies have strong correlations between mass and metallicity and between age and α-element over-abundance, which combine to produce a downsizing relation between age and mass. For old passive galaxies, the different trends of M/L with mass and luminosity in different passbands result from the differential effect of the mass–metallicity relation on the luminosities in each passband. Future work with this sample will examine the Fundamental Plane of bulge-dominated galaxies and the influence of environment on relations between stellar population parameters and mass.

Keywords. galaxies: bulges, galaxies: stellar content, galaxies: abundances

1. The 6dF Galaxy Survey

The 6dF Galaxy Survey (6dFGS; www.aao.gov.au/local/www/6df; Jones *et al.* 2004, 2005) is a redshift and peculiar velocity survey of galaxies in the local universe. The observations for the survey were obtained during 2001–2006 using the UK Schmidt Telescope and the 6dF spectrograph (Watson *et al.* 1998). The 6dFGS covers 92% of the southern sky with $|b| > 10°$. Its primary sample is drawn from the 2MASS Extended Source Catalog (XSC; Jarrett *et al.* 2000) and consists of galaxies with $K_{\rm tot} < 12.65$; for this sample the redshift completeness is 88%. It also includes secondary samples complete down to $H < 12.95$, $J < 13.75$ (from the 2MASS XSC) and $r_F < 15.6$, $b_J < 16.75$ (from the SuperCosmos Sky Survey; Hambly *et al.* 2001). The 6dFGS peculiar velocity survey uses the Fundamental Plane relation to derive distances and velocities for about 15,000 bright early-type galaxies. The 6dFGS database comprises 137 k spectra and 124 k galaxy redshifts, plus photometry and images. The final data release will be made public in August 2007 (Jones *et al.* in prep.; see www-wfau.roe.ac.uk/6dfgs).

As well as its intended purpose as a survey of the structure and motions in the local universe, the 6dFGS also provides a benchmark sample for studying the properties of the low-redshift galaxy population. Here we present some preliminary results from an analysis of the stellar populations in a sample of about 6000 galaxies with high-quality spectra from the 6dFGS Second Data Release (DR2; Jones *et al.* 2005). Velocity dispersions (σ)

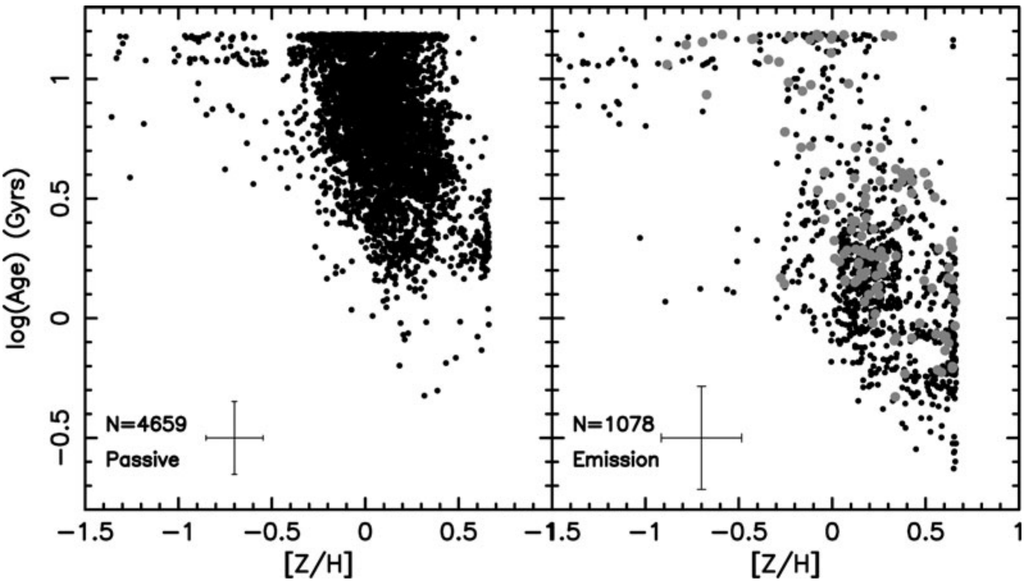

Figure 1. The distribution of age and metallicity for the passive galaxies (left) and the emission-line galaxies (right). Galaxies classified as AGN on the basis of their emission line ratios are shown as grey dots in the right-hand panel. The mean uncertainties in the estimates of age and metallicity are shown by the error bars in the bottom left corner of each panel.

have been measured for these galaxies using the cross-correlation technique of Tonry & Davis (1979). Comparisons with other high-quality samples show good agreement and imply the 6dFGS dispersions have a median error of 10.9% (Campbell *et al.*, in prep.).

2. Stellar population parameters and relations

Stellar population parameters for these galaxies have been derived from Lick index measurements for approximately 15 indices covering the spectral range 4000–5500Å (Proctor *et al.*, in prep.). Ages, metallicities and α-element over-abundances were determined by comparing these index measurements to the simple stellar population models of Korn, Maraston & Thomas (2005) using the χ^2-fitting method introduced by Proctor & Sansom (2002). The method rejects those indices that give poor fits to the models, and this excludes Hβ for galaxies both with and without Hα emission. For passive galaxies without Hα emission, the uncertainties in the derived ages are typically about 0.17 dex in age, 0.15 dex in [Z/H] and 0.10 dex in [α/Fe]. For galaxies that do show significant Hα emission, the fits also reject Hγ and Hδ, which results in somewhat larger uncertainties.

The distribution of age and metallicity is shown in Figure 1 both for passive galaxies (those with no detected Hα emission) and for star-forming galaxies (those in which Hα emission is detected). In general, the passive galaxies have metallicities in the range [Z/H]=−0.3–0.5 and luminosity-weighted ages of 3–14 Gyr, while the star-forming galaxies have solar or higher metallicities and ages less than 3 Gyr. Both samples show a trend of increasing metallicity for younger galaxies that is substantially stronger than the residual correlation between the errors in age and metallicity.

If we just consider the passive galaxies, then as well as the correlation between age and metallicity, there are also correlations between metallicity and velocity dispersion and between age and [α/Fe], as shown in the left and middle panels of Figure 2: more massive galaxies tend to have higher metallicities, while older galaxies tend to have larger

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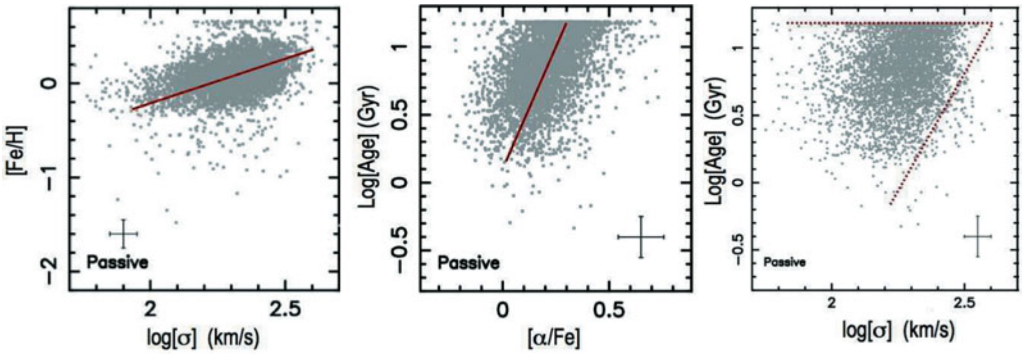

Figure 2. For passive galaxies there are strong correlations between metallicity and velocity dispersion (left panel) and between age and [*alpha*/Fe] (middle panel); there is also a downsizing relation between age and velocity dispersion (right panel).

α-element over-abundances. There is also a downsizing relation between age and velocity dispersion, in which the age of the *youngest* galaxies decreases with decreasing velocity dispersion, as indicated in the right panel of Figure 2. This latter relation would appear to be the projection in the age–log σ plane of the [Z/H]–log σ and age–[α/Fe] relations.

3. Age and metallicity effects on M/L

It is interesting to examine the effects of age and metallicity on the mass-to-light ratios for galaxies in different passbands. If we consider only old galaxies (greater than 10 Gyr), then the left panel of Figure 3 shows the trends of M/L in the B, R and K bands against both dynamical mass and K-band luminosity. Two points are worth noting: (i) the trends with dynamical mass are steeper than those with luminosity in all passbands, and (ii) the trends with both mass and luminosity are steeper in bluer passbands.

As well as eliminating age effects by selecting only old galaxies, we can also attempt to remove the dependence on metallicity in these relations. The right panel of Figure 3 shows as thick solid lines the same binned relations as in the left panel; it also shows these relations after correcting the mass-to-light ratio for differences in metallicity (dashed lines). These corrections are determined from the luminosities predicted by Bruzual & Charlot (2003) models for stellar populations having the metallicity (based on the mass–metallicity relation) and age of each mass or luminosity bin, and converting to the predicted luminosity for a stellar population with the same metallicity as the highest mass or luminosity bin. The corrected mass-to-light ratios resulting from this procedure have almost identical dependences on mass or luminosity, regardless of passband, as can be seen by comparing the dashed lines in the right panel of Figure 3 with the thin solid lines (which are just the corrected relations for the K-band). Thus the variations of M/L with passband for this sample of old galaxies can be fully accounted for by the mass–metallicity relation. It is worth noting that the correction has almost no effect in the K-band, underlining the minimal impact of metallicity on K-band luminosities and the usefulness of this passband for studies of M/L and the Fundamental Plane.

4. Conclusions

The 6dFGS provides a large sample of galaxies with spectra of sufficiently high quality and spectral range to allow reliable measurements of both line indices and velocity dispersions. This sample can be used to explore the correlations between mass, age, metallicity

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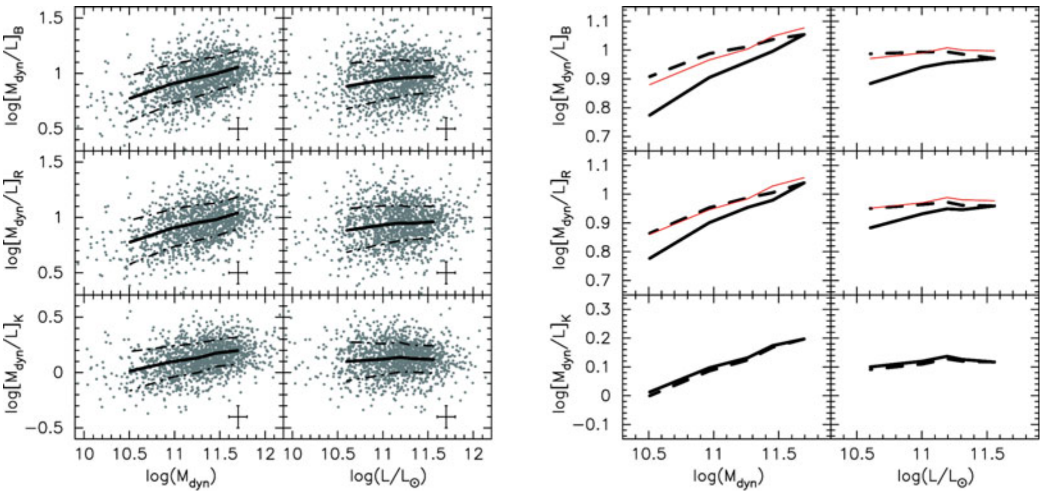

Figure 3. At left, the dynamical mass-to-light (M/L) ratios of old galaxies (age >10 Gyr) in B, R and K bands is plotted against dynamical mass and K-band luminosity. Solid lines are means in five bins along the x-axis; the rms scatter is indicated by dashed lines. The average error on individual points is shown at the bottom right of each panel. At right, the mean M/L ratios are shown before (solid line) and after (dashed line) correction for the effect of the mass–metallicity relation on the luminosity. The thin solid lines in each panel show the K-band relation for the purposes of comparison.

and [α/Fe]. Some preliminary results from such an analysis are presented here; a more detailed study will appear in Proctor *et al.* (2007, in prep).

We find that age and metallicity are significantly anti-correlated (younger galaxies are more metal-rich) for both passive and star-forming samples. Passive galaxies show the well-known strong correlation between mass and metallicity (more massive galaxies are more metal-rich), but also a strong correlation between age and α-element over-abundance (older galaxies have higher over-abundances). These two effects combine to produce a downsizing relation between age and mass, such that the age of the *youngest* galaxies decreases with decreasing mass. For old (>10 Gyr) passive galaxies, the different trends of M/L with mass and luminosity in different passbands result from the differential effect of the mass–metallicity relation on the luminosities in each passband.

Future work will examine the Fundamental Plane of bulge-dominated galaxies and the influence of environment on relations between stellar population parameters and mass.

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