Line-strength gradients in NGC 5813

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Summary. We have measured line-strength gradients out to 80 arcsec from the centre of the elliptical galaxy NGC 5813. The line-strength measures include the Mg$_2$ index and the equivalent widths of H$\beta$ and two iron blends at 5270 and 5335 Å. Our results show that Mg$_2$ falls from 0.31 in the nucleus to $\approx 0.1$ in the outer parts of this galaxy and, for the first time, we have detected gradients in the iron features. In the halo of NGC 5813 the strengths of all the features considered here, including H$\beta$ and the iron lines, match those of Galactic globular clusters at similar values of Mg$_2$. The results suggest, with little ambiguity, that the metallicity in this galaxy falls from [Fe/H]$>0$ in the centre, to [Fe/H] $\approx -0.7$ in the outer parts.

1 Introduction

The existence of radial abundance variations in elliptical galaxies and the bulges of spirals has been suspected ever since the early work on colour gradients (e.g. de Vaucouleurs 1961; Tifft 1961). Later studies, using measurements of strong absorption features such as CN and Mg provided unambiguous evidence of line-strength gradients in several early-type galaxies (see Faber 1977 for a review). In addition, line strengths in the centres of ellipticals and S0’s are strongly correlated with total luminosity, suggesting that the stars in the inner parts of giant galaxies are more metal-rich than those in low-mass galaxies (Faber 1973; Burstein 1979; Terlevich et al. 1981).

A major problem in interpreting these results arises from ambiguities in converting line-strength measures into estimates of metallicity. At low metallicities, [Fe/H] $\leq -1.0$, it is possible to calibrate line strengths using galactic globular clusters (e.g. Burstein 1979). For example, the Mg$_2$ index defined by Faber, Burstein & Dressler (1977), which measures the strength of the Mg $b$ triplet and the band-head of MgH, correlates strongly with Kraft’s (1979) metallicity estimates for galactic globulars. A least-squares fit to the data for 13 globular clusters listed in Table 3(a) of Burstein et al. (1984, hereafter BFGK) gives

$$[\text{Fe/H}] = 16.37 \text{Mg}_2 - 2.37$$ (1)
with a correlation coefficient of 0.96. However, BFGK have pointed out that at high metallicities ([Fe/H] ≥ −1) Kraft’s values are systematically higher than those deduced by Pilachowski, Sneden & Wallerstein (1983) from high-resolution studies of cluster giants. Thus, equation (1) can only be considered accurate for Mg2 ≤ 0.1. The strongest lined globular clusters have Mg2 ∼ 0.2, comparable to the central values for small elliptical galaxies, but much lower than those for giant ellipticals (Mg2 ∼ 0.35). Estimating the metallicities of the nuclei of typical ellipticals requires a different approach.

Stellar population syntheses can be used to match the spectra of giant ellipticals with ‘libraries’ of spectra of nearby galactic stars (e.g. Faber 1972; O’Connell 1976, 1980; Gunn, Stryker & Tinsley 1981). These studies have consistently shown that giant elliptical spectra resemble those of the so-called super-metal-rich (SMR) stars (Spinrad & Taylor 1969). Unfortunately, it is still not clear whether the SMR stars are really metal-rich, or whether their conspicuous strong lines are enhanced for other reasons (see Taylor 1982a, b).

Mould (1978) has used theoretical spectral synthesis techniques to study the sensitivity of the Mg index to metallicity, age, and the slope of the initial mass function (IMF). When converted to the Mg2 index his results (for stellar populations with an age of ∼13 Gyr) give

\[ \frac{[\text{Fe/H}]}{\text{Mg2}} = 3.9 \text{ Mg2} - 0.9 \]  

(2)

for \(-0.5 \leq [\text{Fe/H}] \leq 0.3\) (Terlevich et al. 1981). Mould found that the Mg index was insensitive to the slope of the IMF (in agreement with earlier work by Faber 1972). Mould’s analysis is subject to several potential sources of error, such as uncertainties concerning convection and mass loss on the giant branch (the Mg2 index is temperature and gravity sensitive). Further, any selective enhancement of Mg relative to Fe in elliptical spectra would invalidate equation (2) (cf. Peterson 1976). Despite these uncertainties, there can be little doubt that [Fe/H] > 0 in the nuclear regions of giant ellipticals.

In this paper, we describe line-strength gradients along the major axis of the elliptical galaxy NGC 5813. The observations have been described in detail by Efstathiou, Ellis & Carter (1982) and were made primarily to study the dynamical properties of this galaxy. The spectra cover the wavelength range 4200–5540 Å with a spectral resolution of 2.4 Å (FWHM) and the total exposure time was nearly 10 hr with the Anglo–Australian Telescope. The spectra are of high enough quality that we can measure line strengths of weak features, including the iron blends at 5270 and 5335 Å, out to large radii. Faber (1982) has stressed the importance of measuring gradients in iron peak features as well as damped lines such as the Mg b triplet (see also Cohen 1979; Pritchett & Campbell 1980). In addition, the line strengths in the outer parts of this galaxy overlap with the range seen in galactic globular clusters, allowing us to make a direct comparison.

2 Data reduction

We have measured the Mg1, Mg2, Hβ, Mg b, Fe 5270 (henceforth Fe52) and Fe 5335 (henceforth Fe53) indices defined by BFGK. The analysis is relatively straightforward and we summarize only a few key steps. The observations were made with the Image Photon Counting System (IPCS) which suffers from S-distortion. This must be corrected, otherwise the shape of the continuum will vary from one side of the galaxy to the other. We have solved this problem by fitting the photon counts and determining the position of the galaxy centre as a function of wavelength. The resulting map of the central position, over the wavelength range appropriate to each line-strength index, was fitted to a low-order polynomial. This was used to ‘straighten’ the spectra by linear interpolation along the spatial (scan) direction. The residual effects of S-distortion are the dominant source of systematic error in the line strengths measured in the central regions (0.012 mag in Mg2) but these are not important in the present study.
In the outer parts of the galaxy, the main causes of systematic errors arise from two separate effects, one associated with intrinsic variations in the sky brightness over the duration of each galaxy exposure (600 s interlaced with 100-s exposures of a blank field of sky) and the second associated with variations in the response of the detector in both the wavelength and spatial directions. There are two ways of testing for the first effect: (1) the observations were spread over two nights and have good signal-to-noise so we can separately analyse each night's data, (2) we can purposely mis-subtract sky. These tests show that plausible variations in the sky level (<5 per cent) do not lead to significant systematic errors in our line strengths. To check for the second effect, we have used the sky exposures to map the sensitivity of the IPCS. This shows that the large-scale response of the detector is flat (to within 2 per cent) at $r<60$ arcsec. At larger radii this effect could lead to systematic errors of up to 0.025 in the Mg$_2$ index, which has widely separated sidebands, but should not affect the atomic line indices.

We have calibrated the effects of velocity dispersion broadening by convolving spectra of 15 G and K giants with Gaussian distributions. These corrections are significant for the Mgb, Fe52 and

![Figure 1. Sky-subtracted spectra at three positions along the major axis of NGC 5813 plotted on a logarithmic wavelength scale. (Note that $F_\lambda$ is the flux in units of erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$). The spectra have been shifted to the rest frame. The principal features used in this study are indicated. These spectra have not been smoothed and the one at 72 arcsec is only 25 per cent above the sky background.](image-url)
Fe53 indices but should be accurate to better than 5 per cent. They are unimportant for Mg$_1$ and Mg$_2$ and have been ignored. We used the velocity dispersion estimates for NGC 5813 listed in table 2 of Efstathiou, Ellis & Carter (1982).

The reduced spectra were then binned to have a minimum of $5 \times 10^5$ photons per spectrum. These were calibrated to an absolute scale using the Oke (1974) flux standard L749B, which was observed during the run.

3 Results

Fig. 1 shows spectra at three positions (we use luminosity-weighted radii throughout). The decrease in strength of the Mg $b$ triplet is clearly visible. Fig. 2 shows the Mg$_2$ index plotted against log($r/r_e$), where $r_e$ is de Vaucouleurs' effective radius listed in the Second Reference Catalogue of Bright Galaxies (de Vaucouleurs, de Vaucouleurs & Corwin 1976). The gradient at $r < 2$ arcsec may be underestimated because of seeing, which varied between 1.5 and 2.5 arcsec (FWHM) over the two observing nights. As described above, the outer points with Mg$_2 < 0.1$ may be systematically in error by 0.025 mag. However, there is clear evidence for a steep fall in Mg$_2$ in this galaxy.

Our main results are shown in Fig. 3, where we compare our line-strength estimates with those measured by BFGK for galactic globular clusters. The line strengths for NGC 5813 have been corrected to a velocity dispersion of 220 km s$^{-1}$, corresponding to the spectral resolution used by BFGK. As Fig. 1 shows, the weak lines are difficult to measure at large radii, so we have averaged the results from either side of the galaxy in groups of about four (except for the central point at Mg$_2 = 0.31$). The crosses in Fig. 3 show the mean line strengths and the 1$\sigma$ random errors. The solid lines in the figure show the mean relations given by BFGK for the nuclear regions (1.6 $\times$ 4 arcsec) of elliptical galaxies. As discussed by BFGK, the line indices should vary continuously between galactic globular clusters and the nuclei of ellipticals if only one parameter, metallicity, governed the line strengths of old stellar populations. This is true of all but one of the line strength indices considered by BFGK. The exception is H$\beta$, which is much stronger in the nuclei of small ellipticals (such as M32) than in galactic globulars with similar values of Mg$_2$. 'Anomalous' Balmer line strengths in the nuclei of ellipticals have been noticed before and a variety of explanations have been proposed to account for them. For example, Gunn et al. (1981) favour the presence of young stars in the nuclei of giant ellipticals, though other explanations such as blue stragglers are not excluded. The faint elliptical M32 has been investigated in detail by

![Figure 2](https://example.com/figure2.png)

**Figure 2.** Radial variations of the Mg$_2$ index along the major axis of NGC 5813 (we have averaged results from either side of the centre). The error bar shows our estimate of 1$\sigma$ systematic error (0.025 mag) which could affect the outermost data points.
Figure 3. A comparison of the line strengths in NGC5813 (crosses) with those of galactic globular clusters (filled circles). The sizes of the crosses give an indication of 1σ random errors. The solid lines show the mean relations deduced by Burstein et al. (1984) for the nuclear regions of elliptical galaxies. The units of Fe52, Fe53, (Fe), Mg and Hβ are in Ångstroms and those of Mg2 and Mg1 are in magnitudes.

O'Connell (1980) and BFGK. O'Connell favours a young age of ~5 Gyr (corresponding to a main-sequence turn-off at about late F) rather than the more ‘conventional’ value of ~10 Gyr. This conclusion is consistent with the results of BFGK.

Fig. 3 shows that within the observational errors, the line strengths in the outer regions of NGC 5813 match continuously with those of galactic globular clusters. This remarkable continuity strongly suggests that the stellar population in the outer parts of NGC 5813 has low metallicity and resembles that in galactic globulars. Applying equation (1) with Mg2=0.1, we deduce that [Fe/H]≤−0.7 at r>60 arcsec, though this could be an overestimate if the cluster metallicities of Pilachowski et al. (1983) are correct.

As Fig. 3 shows, we have detected radial gradients in the two iron line indices, Fe52 and Fe53. (We also plot the mean ⟨Fe⟩=0.5(Fe52+Fe53), which has smaller random errors than either of the two indices). One of the major ambiguities in previous studies of metallicity gradients in ellipticals has been the lack of a firm detection of gradients in iron peak features. Cohen (1979) has suggested that at high metallicities ([Fe/H]>0), the strengths of the two Fe blends should ‘saturate’, but this explanation does not seem to have gained wide acceptance (cf. BFGK, section IIIe). Nevertheless, the Fe strengths vary strongly with metallicity in globular clusters, so at low metallicities one should observe a decrease in the Fe indices in ellipticals if they are made of the same stellar population. This is confirmed in Fig. 3.

As a further check of some of these results, we have analysed less extensive data (r<25 arcsec).
along the major and minor axes of NGC 5813 obtained in an earlier observing run (Efstathiou et al. 1980). The line strengths are in good agreement with those presented above. In addition, these results indicate that the metallicity contours ('isochromes') are not significantly flattened (note that at $r \sim 25$ arcsec the isophotes of NGC 5813 have ellipticity $e \sim 0.2$). Although the line-strength gradients are suggestive of dissipative models of the formation of ellipticals (Larson 1974), the lack of a strong elongation of the isochromes and the dynamical properties of NGC 5813 are incompatible with the flattened rapidly rotating models described by Larson (1975). Recently, Carlberg (1984) has presented a dissipative scheme for the formation of slowly rotating ellipticals which does not lead to a strong flattening of the isochromes.

4 Conclusions

The line strengths of several absorption features in NGC 5813, including H$\beta$ and two iron blends, vary with radius from values typical of elliptical nuclei to those typical of galactic globular clusters. The continuity with globular clusters strongly suggests that the metallicity in this galaxy falls from $[Fe/H]>0$ in the central regions to $[Fe/H]<-0.7$ at $r=60$ arcsec.

The discontinuous change of the H$\beta$ index between elliptical nuclei and galactic globular clusters suggests that another parameter, apart from mean metallicity varies between these stellar populations. BFGK have suggested that the stars in faint elliptical nuclei may be younger than those in galactic globular clusters but, as they point out, this is not a unique interpretation. The hypothesis can be further tested by making more extensive observations of the type reported here. Gravity-sensitive indices, such as CN, might be especially interesting.

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