

The metallicity versus luminosity relationship for early-type galaxies^{*}

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Summary. In the equivalent width (W) vs absolute magnitude (M_B) diagram corresponding to the best metallic features in the visible range, CN and Mg + MgH, field giant E and S0 galaxies are shifted towards weaker line-strengths with respect to galaxies belonging to the Virgo and Fornax clusters. We find evidence that this is a genuine stellar population effect. For part of the deviating galaxies it results from an aperture effect, galaxies at larger redshifts including more of the metal poor component outside their nucleus. For the rest, the shift is due to a variable content of intermediate age components in the range 4–10 Gyr, superimposed on the very old underlying population.

Key words: galaxies: evolution of – galaxies: stellar content of galaxies : elliptical – clusters of galaxies

1. Introduction

The strengthening of absorption lines and the reddening of colours in early-type galaxies when the absolute luminosity increases, is well established and, most probably, a result of metallicity differences. These correlations present however a considerable scatter, for which many explanations have been proposed, either in terms of colours or absolute magnitude dispersions (Faber, 1977; Sandage and Visvanathan, 1978). If related to population effects, this scatter among galaxies at a given luminosity, might result from a variable content of hot stars belonging to a young population rather than to the blue horizontal branch (Véron and Véron-Cetty, 1985). Another source of scattering might be an intrinsic dispersion in the star formation rate at fixed galactic mass (Arimoto and Yoshii, 1987). Space ultraviolet observations (e.g. Bertola et al., 1982) have revealed important colour differences among early-type galaxies which, extrapolated to longer wavelengths could explain the colour dispersion observed in the visible. Some early-type galaxies present an upturn of the flux shortwards of 2000 Å and hence, must contain a hot stellar component. This population could consist of recent residual star formation or blue horizontal branch stars. In the range 2600–3800 Å, giant early-type galaxies also show some relative flux scatter, possibly due to a variable content of intermediate age populations. In the particular case of elliptical

galaxies, the scatter in the line strength vs absolute magnitude relation is correlated to that observed in a similar plot of the velocity dispersion vs absolute magnitude (Terlevich et al., 1981). This correlation of the scatters seems to be associated with the intrinsic axial ratio; it would also be a natural consequence of uncertainties in the absolute magnitude values such as those introduced by departures from a uniform Hubble flow.

2. Discussion

Recent spectral observations of a sample of 35 elliptical and 34 lenticular galaxies have been described in Bica and Alloin (1987). From this data set, we use the sum of the most sensitive metallic indices, namely equivalent widths $W(\text{CN } 4150, 4214 \text{ \AA})$ and $W(\text{Mg} + \text{MgH } 5156, 5196 \text{ \AA})$, to investigate the metallicity versus absolute magnitude M_B relationship in early-type galaxies. However, one should keep in mind that both indices are subject to dilution effects in a composite spectrum if intermediate or young age components are present. Dilution will be stronger for CN, although Mg + MgH might be considerably affected as well, according to our analysis of integrated star cluster spectra (Bica and Alloin, 1986). Thus, we also include in the present study the E and S0 galaxies which contain important contributions from intermediate (NGC 2865, 4382) and young (NGC 5102) age components (Bica and Alloin, 1987). Results are displayed in Fig. 1 where at first glance little correlation appears, while a colour-magnitude relationship exists, especially if one considers ultraviolet and infrared colours and early type galaxies as faint as -14 (e.g. Persson et al., 1979). As a matter of fact our sample consists mostly of luminous galaxies and some of the fainter ones ($-18.5 \leq M_B \leq -16.5$) are certainly atypical. Galaxies which depart most in the right part of the diagram are NGC 4486B, a tidally stripped object (Bica and Alloin, 1987), and NGC 1400 for which the M_B value is quite uncertain. This S0 galaxy, at $M_B = -17.9$, is red and strong-lined with little evidence for tidal stripping and it is probably more luminous than implied by its redshift. It is projected on a small southern group of galaxies, forming a close pair with the group member NGC 1407. The group itself presents a larger redshift with $\Delta V \simeq 700 \text{ km s}^{-1}$ and if NGC 1400 belongs to it, then $M_B = -20.6$. In addition, the velocity dispersion in NGC 1400 is typical of massive galaxies (Kormendy and Illingworth, 1983). Prugniel et al. (1987) have studied the luminosity profile and the velocity dispersion in three M87 dwarf companions which we have also observed. They find that the luminosity profile of NGC 4478 is severely truncated. Indeed, this galaxy lies at the right edge of the relation in Fig. 1a, suggesting that some tidal stripping may have affected it. Its

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^{*} Based upon observational data collected at the European Southern Observatory

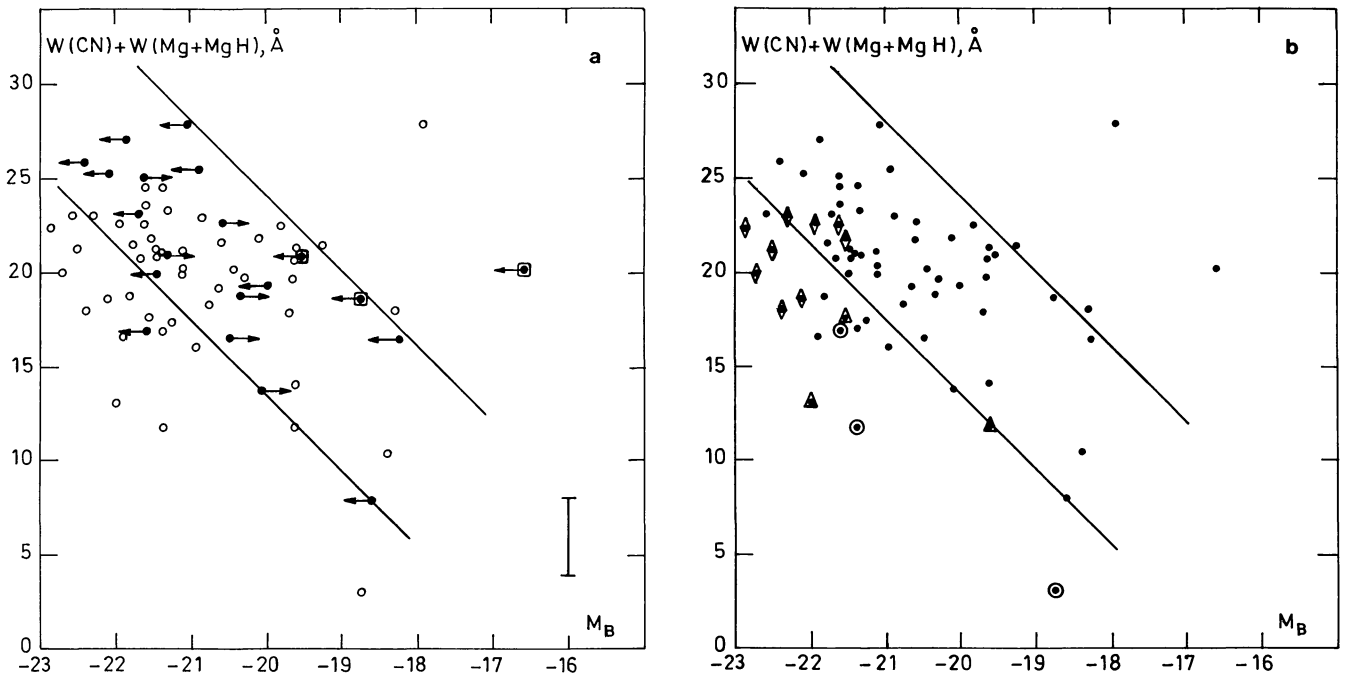


Fig. 1. **a** Best metallicity index, $W(\text{CN}) + W(\text{Mg} + \text{MgH})$, as a function of absolute magnitude for early-type galaxies. Members of small groups and field galaxies are shown with open circles. Virgo and Fornax members are represented with black dots and the arrow attached to each point shows the effect of correcting for the Virgo-centric infall (Fornax galaxies correspond to arrows pointing to the right and Virgo galaxies to the left). Notice the systematic lowering of this index in the case of luminous field galaxies. The three points within squares indicate tidally stripped objects. The error-bar is provided in the lower right corner. Light continuous lines enclose 90% of the Virgo and Fornax members. **b** All points are shown again without discriminating between field and cluster galaxies. Points within diamonds indicate galaxies for which the projected slit was larger than 4 kpc^2 ; points within circles indicate galaxies in which age effects have been demonstrated in Bica and Alloin (1987); points within triangles are for galaxies in which age effects are suspected from their strong $\text{H}\beta$ absorption. Therefore, the systematic effect just described (Fig. 1a) can be understood in terms of a metal-poor population around the nucleus or in terms of young nuclear stellar components. Galaxies discussed in the text are given with their $(M_B; W)$ values: NGC 1400 $(-17.94; 27.8)$, NGC 2865 $(-21.37; 11.6)$, NGC 4382 $(-21.60; 16.8)$, NGC 4387 $(-18.75; 18.6)$, NGC 4476 $(-18.62; 7.9)$, NGC 4478 $(-19.55; 20.7)$, NGC 4486 $(-22.08; 25.2)$, NGC 4486B $(-16.59; 20.1)$, NGC 4649 $(-21.87; 27.0)$, NGC 5018 $(-21.99; 13.0)$, NGC 5061 $(-21.54; 17.5)$, and NGC 5102 $(-18.73; 2.9)$

central velocity dispersion is moderate however (150 km s^{-1}). According to Fig. 1a, NGC 4486B should be a highly stripped object, a conclusion in agreement with its large central velocity dispersion (200 km s^{-1}) typical of massive galaxies. Its luminosity profile shows some truncation too, although not as much as in the case of NGC 4478. On the other hand NGC 4476 is definitely not a tidally stripped galaxy since its luminosity profile follows an $r^{1/4}$ law and its central velocity dispersion is small (132 km s^{-1}). It represents a genuine low metallicity, low luminosity elliptical galaxy with a spectrum similar to that of a globular cluster in the range $-1.0 \leq [Z/Z_\odot] \leq -0.5$ (Bica and Alloin, 1987). Another dwarf galaxy NGC 4387 falls at the edge of the relationship in Fig. 1a. This galaxy lies near the centre of the Virgo cluster and, because of its high surface brightness, is suspected to be a stripped object.

The scatter observed in the diagram for luminous galaxies is of the same order as that in the optical colours (Faber, 1977; Sandage and Visvanathan, 1978). The formal error-bar in $W(\text{CN}, \text{Mg} + \text{MgH})$ is $\pm 2.1 \text{ \AA}$, suggesting that the scatter in Fig. 1a is intrinsic. As recalled in the introduction, it could be accounted for in many ways. However, if only Virgo and Fornax members are considered, a tighter correlation appears, especially when one disregards the tidally stripped galaxy (NGC 4486B) and the case of NGC 4382 for which age effects are obvious. Remaining scattered galaxies in this diagram are field objects or they belong to small groups. Figure 1a indicates that luminous field galaxies

present with respect to giant cluster members, a systematic shift towards weaker line strengths.

Absolute magnitudes for our sample galaxies were derived assuming a uniform Hubble flow (Sandage and Tammann, 1981). More specifically, M_B values for Virgo and Fornax members were computed using the mean velocity of the corresponding cluster. The infall of the Local Group towards Virgo (Aaronson et al., 1981) changes the relative positions of Virgo and Fornax galaxies as indicated by arrows in Fig. 1a. Indeed correcting for this effect reduces slightly the scatter in the relationship based upon these two clusters. The distribution of Virgo plus Fornax members with respect to the rest of the sample remains essentially unchanged.

The effect of departures from the Hubble flow on the present sample taken as a whole does not seem to be responsible for the observed scatter either. Sandage and Tammann (1984) suggest that the 600 km s^{-1} infall of the Local Group with respect to the microwave background can be decomposed into a motion towards Virgo and another of Virgo towards the Hydra-Centaurus supercluster. Davies et al. (1986) think rather, that the local volume of the Universe, 120 Mpc across, is moving with 600 km s^{-1} towards $l = 312^\circ$ and $b = +6^\circ$, with respect to the microwave background. Regardless of the motion direction and of which fraction of the local Universe takes part into these coherent motions, the inclusion of galaxies in their apex and antiapex would introduce at most, a scatter of $\pm 600 \text{ km s}^{-1}$ in the observed radial velocities of a given galaxy sample. The mean recession velocity in

our sample is 2000 km s^{-1} , implying that departures from the Hubble flow amount to ± 0.6 magnitude in Fig. 1a. This is too small to account for the total scatter or for the systematic difference between field and cluster giant galaxies. We suggest instead that this difference is due to a stellar population effect.

3. Concluding remarks

Indeed, Larson et al. (1980) found a significant difference in the colour-magnitude diagram between field and cluster galaxies: this effect could be due to star formation in field galaxies which, because of their isolation, have kept gas for a longer time. Positions in Fig. 1b of the galaxies NGC 2865 and 4382 containing a 1 Gyr component (Bica and Alloin, 1987), together with NGC 5018 and 5061 showing strong $H\beta$ absorptions with respect to the remaining redder giant galaxies (Bica and Alloin, 1987), suggest that the latter form a sequence with variable amounts of an additional intermediate age component in the range 4–10 Gyr. From our simple diagram however, we cannot exclude an interpretation of this effect in terms of a variable content of a low metallicity component. In fact, this seems to be the case for galaxies at large redshifts for which the aperture includes more contribution from the metal-poor zones outside the nucleus. This is particularly important for galaxies with $M_B < -22$, where all deviating points correspond to apertures larger than 4 kpc^2 (Fig. 1b). The age effect remains the best explanation in the region $-22 \leq M_B \leq -21$, where most of the galaxies are seen through slit surfaces similar to those of Virgo and Fornax galaxies, because they present W values between those of the cluster galaxies and of objects in which age effects have been clearly demonstrated.

We suspect that the shift in Fig. 1 is not due to a very recent star formation from residual gas if this is related to the ultraviolet upturn shortward of 2000 \AA , because two of the most typical examples of the latter phenomenon, NGC 4649 and 4486 (Bertola et al., 1982) are Virgo giants at the top of our diagram. A better explanation to the shift is in terms of an intermediate age stellar component. The spectral differences observed among nearby massive E and S0 galaxies indicate also that the visible line indices

or colours may be misleading as luminosity criteria for deriving distances of more distant galaxies, even after aperture effects have been taken into account.

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