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On the nature of the stellar population in the nucleus of the Sd galaxy NGC 7793

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Summary. Profiles and equivalent widths of hydrogen, Ca^+ and some other lines imply that the blue–violet spectrum of the nucleus of this late-type spiral is dominated by A or early F stars near the main sequence and not by a mixture of globular cluster-like populations.

1 Introduction

This paper addresses the question of the relative significance of age and chemical composition differences in the nuclei of spiral galaxies. Humason, Mayall & Sandage (1956) gave equivalent spectral classifications for the galaxies in their survey and Morgan & Mayall (1957) called attention to the correlation between the spectral types and galactic morphology. The Yerkes system of classification (Morgan 1958, 1959; Morgan & Osterbrock 1969) uses the letters a, f, g and k to denote increasing dominance of the central bulge, because of the corresponding appearance of the blue–violet spectrum. For E-galaxies and the bulges of early-type spirals, there are colour–luminosity and spectrum–luminosity relations which together seem to imply a spectrum–colour relation that is an extension of the corresponding relation for globular clusters and is therefore generally regarded as an indication of a metallicity sequence in a set of uniformly old stellar populations (Faber 1977; Pagel & Edmunds 1981 and references therein); but in late-type spirals, where the bulge component may become so small that it just appears as a semi-stellar nucleus, it has been customary following Morgan (1958) to attribute the early spectral type to the presence of a composite stellar population with young A and F stars near the main sequence (e.g. van den Bergh 1976). A similar picture has been applied in more quantitative form by Alloin, Andrillat & Souffrin (1971), Alloin (1973) and Turnrose (1976) to the stellar populations of emission-line nuclei of spirals of types Sb–Sc.

The problem of 'youth' versus 'metallicity' has been further discussed in the last few years by Burstein (1979), Heckman (1980), McClure, Cowley & Crampton (1980) and

O'Connell (1982). Burstein showed that elliptical and S0 galaxies, like NGC 205, that were known or suspected to have a significant young population, are distinguishable from globular clusters in a diagram in which magnesium line strength is plotted against intrinsic colour, and that their position in this diagram could be explained by displacement along a 'blueing vector' calculated by adding various amounts of light from AF main-sequence stars to an old population with a given metallicity. Heckman, in a somewhat similar spirit, plotted the equivalent width of Hδ in absorption against magnesium strength for a sample of nuclei of galaxies of all Hubble types and compared the observed points with an empirical 'metallicity' line based on data for globular clusters. Departures from this metallicity line, and the presence of broad wings in the Hδ line profiles, led Heckman to conclude that galactic nuclei departing from the region occupied by old, metal-rich populations in the (Hδ, Mg + MgH) diagram are mostly composite systems involving a young population.

A very different point of view has been put forward by McClure *et al.* (1980), who find that the correlation between a blue–violet spectrum line-strength index (based on photographic image-tube spectra) and the absolute magnitude of elliptical galaxies extends to the faint nuclear bulges of late-type spirals as well. From this they conclude that one is actually dealing with a metallicity sequence, supporting this viewpoint with the finding that the spectra show giant characteristics including (apparently) narrow Balmer lines which would be inconsistent with dominance of the light by main-sequence A and F stars. On this hypothesis, the violet spectral region of Sc–Sd nuclei is dominated by horizontal-branch stars and/or red giants of extreme metal deficiency (like M15 or M92), while less metal-poor giants dominate at longer wavelengths.

This conclusion, if true, should lead one to expect that all spectral characteristics of the majority of nuclei of galaxies can be synthesized by a suitable mix of galactic globular clusters, and this is contrary to the findings of both Burstein and Heckman. A similar criticism has been made on the basis of (*UBV*) colours by O'Connell (1982). Before seeing O'Connell's work, we decided, in the course of spectroscopic observations chiefly of emission lines in galactic nuclei, to make quantitative observations of the nucleus of a very late-type galaxy, NGC 7793 (Sd), and of the globular cluster M15, in the hope of throwing some light on this contradiction. NGC 7793 is a member of the Sculptor group of galaxies with many H II regions in its flocculent spiral arms (Elmegreen 1981) as well as in the nucleus itself (Davoust & de Vaucouleurs 1980; Edmunds & Pagel, in preparation). With a nuclear blue absolute magnitude of −13.7 (de Vaucouleurs & Davoust 1980), about a magnitude fainter than M33, NGC 7793 falls just below the range of fig. 1 in McClure *et al.* and should thus provide a useful extreme case.

2 Observations and reductions

Spectra of the nuclei of NGC 7793 and M15 were observed using the Anglo-Australian telescope, RGO spectrograph (25-cm camera) and Image-Photon counting system (Boksenberg & Burgess 1973) as described in Table 1. The data have been reduced using standard SDRSYS and STARLINK programs.

3 Results

Fig. 1 shows the general appearance of the low-dispersion spectra and Fig. 2 the high-dispersion spectra, both being plotted in such a way as to give comparable continuum levels for the two objects. Fig. 1 confirms the striking similarity in the region from, say, Hγ to the Balmer jump, contrasted with the presence in NGC 7793 of an Mg I feature – very weak

Table 1. Observational details.

Date	1979 Nov 17	1981 Oct 1	1981 Oct 2	1981 Oct 4
Wavelength range (Å)	3500–7500	3500–7500	4220–5150	6100–7025
Dispersion (Å mm^{-1})	140	140	33	33
Slit width (arcsec)	1.2	1.2	1.4	1.4
Standard star	L930 – 80			
NGC 7793 $\alpha = 23^h 55^m 15^s.4$, $\delta = -32° 52' 07''$ (1950):				
Dwell time(s)	279	1000	1500	1000
Maximum counts per channel	400	883	176	312
M15, $\alpha = 21^h 27^m 33^s.4$, $\delta = +11° 56' 51''$ (1950):				
Dwell time(s)	–	800	1000	1000
Maximum counts per channel	–	380	170	250

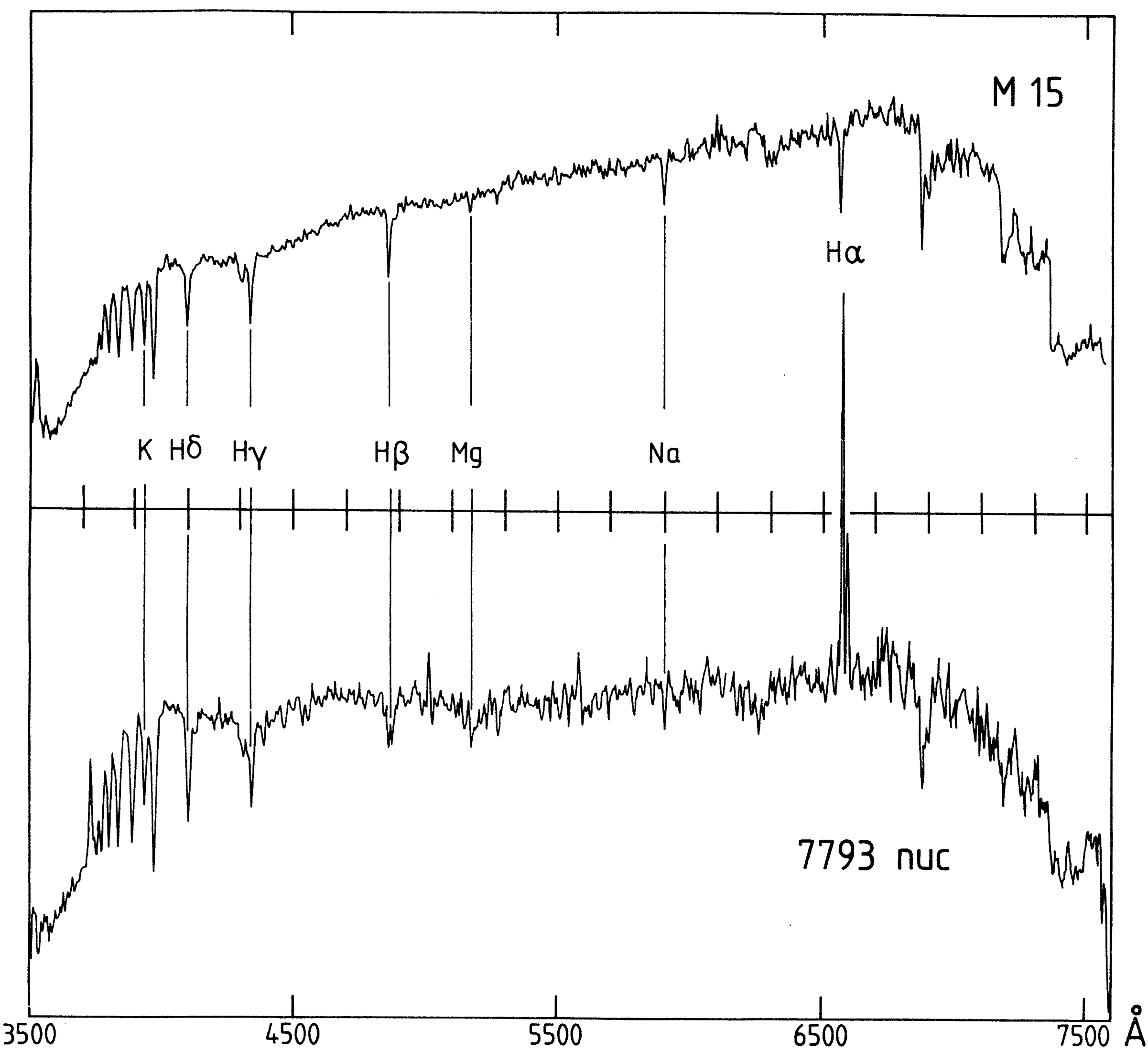

Figure 1. Low-resolution (6 Å) spectra of M15 and the nucleus of NGC 7793, smoothed with a Gaussian, $\sigma = 2^{1/2}$ channels.

in the globular cluster – at λ 5175; these effects are entirely in accordance with the claims of McClure *et al.,* although detailed measurements show that both Balmer and metal lines are stronger in NGC 7793 (Table 2). Fig. 2, on the other hand, shows a marked difference in the profiles of the Balmer lines. In M15, these are quite sharp, typical of the chromospheric Balmer lines shown by metal-deficient red giants in globular clusters (Cohen 1976; Mallia & Pagel 1978), whereas in NGC 7793 they are broad (FWHM ≃ 20 Å or 1200 km s^{-1}) and typical of early-type stars near the main sequence. In Table 2 we give the equivalent widths of lines measured in the two spectra, together with typical values for an F0 (III or V) star and a G0 (III or V) star taken from Joly (1974) with minor corrections (D. Alloin, private communication). Evidently F0 gives a good fit to NGC 7793 throughout the blue region, whereas G0 fits in the green and yellow. A model computed by D. Alloin, which conforms to these constraints, involves the following relative contributions at λ 3933: B0 stars 20 per cent, A0 stars 40 per cent, A5 stars 15 per cent, F0 stars 5 per cent, G0 stars 5 per cent, gK0 stars 5 per cent, gK5 5 per cent and gM0 5 per cent. We believe that such a mix of stellar populations can account for the presence of giant characteristics as noted by McClure

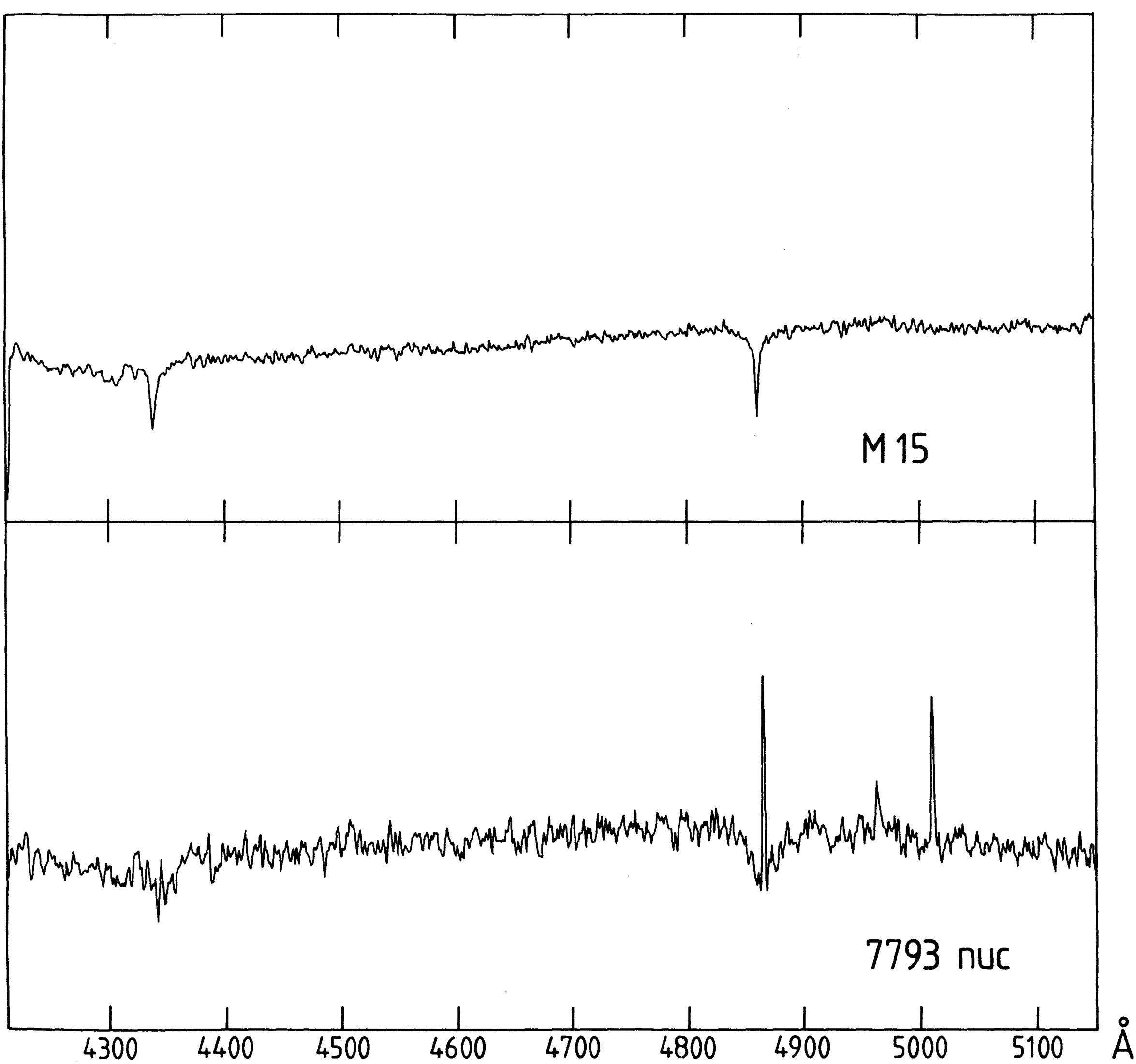

Figure 2. High-resolution (1.5 Å) spectra of M15 and the nucleus of NGC 7793, smoothed with a Gaussian, $\sigma = 2^{1/2}$ channels.

Table 2. Equivalent widths* in NGC 7793 (nucleus) and M15.

λ	NGC 7793 Emission	NGC 7793 Absorption	F0 V	G0 V	Model (Alloin)	M15 Absorption	140283§	Halo giants
3727 [O II]	5.7 ± 0.2							
3750 H 12						1.6 ± 0.1	2.2	
3771 H 11		4.8 ± 0.2	5			2.1 ± 0.1	2.4	
3798 H 10		5.7 ± 0.2	7			3.0 ± 0.1	3.0	
3835 H 9		9.2 ± 0.4				4.3 ± 0.2	2.5	
3889 H 8 + He		9.2 ± 0.4	8.5	5		5.9 ± 0.2	2.8	
3933 Ca II		5.5 ± 0.2	6	14	4.7	4.8† ± 0.1	3.3	
3969 Ca II + Hε		10.5 ± 0.4	13	9	11.0	8.1 ± 0.2	6:	
4102 Hδ		8.3 ± 0.3	9	3	8.5	4.9 ± 0.2	2.3	
4300 CH		2.7 ± 0.1	1	7	3.7	2.3 ± 0.1		
4340 Hγ		7.3 ± 0.7	9	3	7.4	5.1 ± 0.3	2.2	
4384 Fe		1.4	0	1.5			0.1	0.2¶
4470 ?		1.5						
4861 Hβ	4.3 ± 0.2	9.3 ± 0.5				3.5 ± 0.3	1.9	
5007 [O III]	1.8 ± 0.1							
5168–84 Mg		2.9 ± 0.1	0	2:	3:	1.0 ± 0.1	0.6	1.0¶
5890–96 Na		1.3 ± 0.1	0	1	3.1	2.1‡ ± 0.1	0.2	0.4¶
6548 [N II]	1.5 ± 0.1							
6563 Hα	13.8 ± 0.4					5.8 ± 0.4	2.1	(2:)‖
6584 [N II]	3.4 ± 0.1							
6717 [S II]	1.7 ± 0.1							
6731 [S II]	1.8 ± 0.1							

Notes

* In Å. Errors are based on photon statistics and do not include uncertainties in the continuum.
† Including interstellar components with equivalent width ≃ 0.34 Å (Butler 1975).
‡ Including interstellar components with equivalent width 1.0 Å (Cohen 1979).
§ Baschek (1959).
¶ Wallerstein *et al.* (1963).
‖ Estimated from FWHM in two members of M25 (Kraft, Preston & Wolff 1964).

et al. (other than narrow Balmer lines!) in the spectra of galactic nuclei having stronger metallic features than NGC 7793. Table 2 also gives equivalent widths measured in M15, together with corresponding equivalent widths for the subdwarf HD 140283, which has a broadly similar spectrum in the blue (Morgan 1956), and for some halo red giants. The Barbier–Chalonge–Divan classification parameters (λ_1, D) are (3770, ~ 0.15) for both M15 and 7793, corresponding to F5 V (Chalonge 1958).

Table 3 lists relative fluxes (a) in the optical and (b) in the ultraviolet continuum of NGC 7793, as deduced from our data and data in the literature or in preparation, together with fluxes predicted by Alloin's (1973) model. The latter gives an excellent fit to the ultraviolet data (assuming NGC 7793 to be unreddened) for $\lambda < 2800$; we do not have satisfactory data for the region λ 3100–3700. The fact that the flux F_λ from NGC 7793 increases steadily from λ 2500 to λ1550, whereas the 'hottest' globular cluster observed by van Albada, de Boer & Dickens (1979), NGC 6752, only has a flat spectrum and M15 and other clusters have spectra that actually go down towards shorter wavelengths, confirms the assumption in the model that early B-type stars are present.

Table 3. Relative fluxes (F_λ) in continuum.

(a) Optical.

λ	3500	3933	4300	5184	5890	7000
Model*	0.65	1.00	0.97	1.04	1.12	1.10
NGC 7793†		1.00 ± 0.04	0.96 ± 0.04	0.73 ± 0.04	0.59 ± 0.05	0.43 ± 0.09
M15‡		1.00 ± 0.02	1.05 ± 0.02	0.96 ± 0.03	0.83 ± 0.03	0.73 ± 0.07

Notes
* From D. Alloin (private communication).
† This work, assuming no reddening.
‡ This work, assuming $E(B-V) = 0.12$.

(b) Ultraviolet.

λ	1550	1800	2200	2500	3300
Model*	2.65	2.13	1.55	1.00	0.52
NGC 7793†	2.35 ± 0.47	2.18 ± 0.35	1.53 ± 0.32	1.00 ± 0.14	
M15‡	0.44 ± 0.10	0.54 ± 0.07	0.98 ± 0.12	1.00 ± 0.18	

Notes
* Computed from Alloin's model using stellar ultraviolet distributions from Wu *et al.* (1980).
† Ellis & Gondhalekar (in preparation), assuming no reddening.
‡ Dupree *et al.* (1979) assuming $E(B-V) = 0.12$.

4 Discussion

Synthetic population models of M15 and similar globular clusters (van Albada *et al.* 1979; Welch & Code 1980; Nesci 1981) predict that the horizontal branch contributes only a small proportion of the light in the ground-based spectral region. We can confirm this on the basis of the K-line strength given in Table 2, since the equivalent calcium II spectral type of the RR Lyrae stars studied by Butler (1975) is A0 corresponding to an equivalent width of only 1 Å (Joly 1974). Thus the far violet of M15 is probably dominated by stars near the turn-off from the main sequence resembling HD 140283 and the longer-wavelength part of the spectrum by red giants. If the nucleus of NGC 7793 could be synthesized from globular cluster populations, then the strength of *its* K-line would likewise require dominance by stars redder than the main-sequence turn-off which could not possibly account for the broad Hβ and Hγ that we observe. The latter effect leads to a requirement for relatively early-type stars (F0 or a B–A–F mixture) which then have to be metal-rich in order to account for the longer wavelengths (Hγ and Hβ). To the extent that NGC 7793 is typical of late-type spirals, then, we conclude (in broad agreement with Heckman and O'Connell) that their nuclei contain a composite population of near-normal metal content resembling what is found in the contiguous H II regions (Edmunds & Pagel, in preparation), rather than a purely old population having a significant extremely metal-poor component. The relation between spectral index and nuclear magnitude found by McClure *et al.* could – if it is valid – be due to a systematic effect in the rate at which gas is used up in star formation. However, like O'Connell, we are somewhat doubtful as to its validity because the nuclei of massive hotspot galaxies such as NGC 1365 (Edmunds & Pagel 1982) would tend to fill up the top left corner of their diagram.

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