THE STELLAR CONTENT OF THE NUCLEI OF SPIRAL GALAXIES

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Numerous studies have been attempted to determine the stellar content of the nuclei of galaxies. In the case of elliptical galaxies observations show that there is a change in spectral type from later to earlier types correlated with a variation from high to low luminosity (e.g. Faber 1977). This has been interpreted for the most part as being due to differences in metal abundances in an old stellar population, although some recent studies suggest a variation in stellar age may be important as well (e.g. O'Connell 1980, Heckman 1980). The nuclear bulges of spiral galaxies also display a change from late to early spectral type along a sequence from high to low luminosity bulges. In this case, however, the assumption has almost universally been made that these differences are due to differences in age of the stellar population. In particular, most stellar models for the nuclear bulges of spiral galaxies have used solar neighbourhood metal-rich stars, and assumed that the strong hydrogen lines and weak metal lines in late-type spiral nuclei are due to the predominance of a very young main-sequence population rather than old metal-poor stars.

McClure, Cowley and Crampton (1980 ; hereafter MC^2) when examining and analyzing image tube spectra of a large sample of galaxy nuclei noticed that spiral and elliptical galaxy nuclei formed a single monotonic relation in a spectral-index versus absolute-magnitude diagram. According to the "conventional" ideas outlined above, such a relationship would be interpreted as being primarily due to a variation in metal abundance for the elliptical galaxies, but as being due to a variation in age for the bulges of spiral galaxies. Since it seemed possible that the cause of the correlation between spectral type and absolute magnitude would be the same for spirals and ellipticals, MC^2 began to investigate the validity of the conventional wisdom and addressed the question of whether the nuclei of spiral galaxies are basically similar to, or fundamentally different from, elliptical galaxies. They concluded that, to a large degree, the change in spectral characteristics in spiral galaxy nuclei with luminosity is due to the same cause as in elliptical galaxies, that is, it is due to metal abundance differences.

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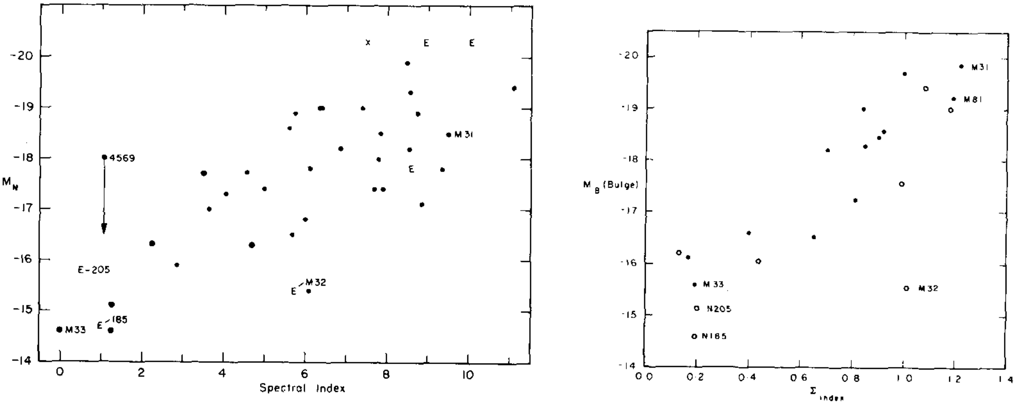
At about this time it became unfashionable to think of the bulges of spiral galaxies being similar to elliptical galaxies. The observations on velocity dispersions and rotation curves which had been measured (Illingworth 1981 and references therein) indicated that elliptical galaxies rotate slowly, whereas the bulges of spiral galaxies are rapid rotators. However, the elliptical galaxies that had been studied at that time were all very luminous, much more so than the bulges of any spiral galaxies. Recently, Davies et al. (1982) have gone to considerable effort to measure velocity dispersions and rotation curves for a sample of low luminosity elliptical galaxies, and they have found that low luminosity ellipticals rotate rapidly, comparable to spiral bulges of similar luminosity. Kinematically, therefore, it appears that spiral galaxy nuclei are the same as ellipticals, and since the spectra are also very similar it may not be so unlikely that their stellar populations may also be similar. As pointed out by O'Connell (1982), the differences in interpretation in age versus metal abundance effects will be very important in the study of galaxy evolution at high redshift.

The conclusion by MC^2 that a variation in metal abundance is of prime importance along the sequence of spiral galaxies was based on spectroscopic observations at 121 Å mm^{-1} with the Yale-CTIO telescope. Indices representing the strength of Ca II, CN, Ca I and CH were estimated and found to be correlated with the absolute magnitude of the nuclear bulge. A combined index composed of the above-mentioned features is shown plotted versus absolute magnitudes of the bulge in Figure 1a. The elliptical galaxies and the nuclei of spiral galaxies follow a similar relation in this diagram and although this could be just a coincidence, it might be an indicator that the change in stellar population along the sequence is similar in the two types of nuclei. MC^2 stressed the extreme difficulty in distinguishing an old metal-poor



Figures 1a (left) and 1b (right). Spectral indices (see text) versus absolute bulge magnitude for spiral galaxies (points) and a few elliptical galaxies (E's in 1a, open circles in 1b).

population from a young main-sequence population on the basis of conventional spectra, but they discovered that a number of luminosity sensitive line ratios indicated that a large fraction of the blue ($\lambda < 4400$ Å) integrated light from the nuclei of spiral galaxies is contributed by evolved (giant) stars rather than main-sequence stars. In a young population of stars (e.g. galactic clusters), only a very small fraction of the integrated blue light is contributed by evolved stars whereas a large fraction of the blue light is contributed by evolved blue-horizontal-branch and post-horizontal-branch stars in old metal-poor globular clusters. Hence, a large fraction of the blue light of the nuclei of spirals must be due to metal-poor stars, and the origin of the spectral type - absolute magnitude correlation is a variation in metal abundance for both spirals and ellipticals.

O'Connell (1982) has disputed these results, and suggests that narrow-band scanner colours for Sc nuclei and globular clusters excludes this possibility. In a colour-colour diagram he shows that globular clusters of a range in metal abundance occupy a different region of the diagram than Sc galaxies, several of the galaxies being significantly bluer than the most metal-poor clusters. He suggests that continuum colours are more sensitive than spectral line-ratios in differentiating young and old populations. However, we wish to stress that the continuum colours he has used have very large corrections for reddening applied. Turnrose (1976) had to invoke these reddenings in order to make the continua derived from the observations fit the models in the same way as the spectral features. Since these reddenings, therefore, are based on models in which it was <u>assumed</u> the population was young

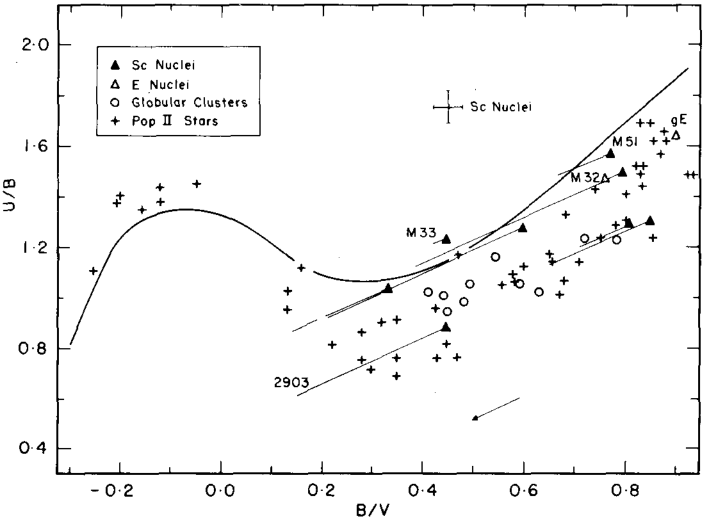


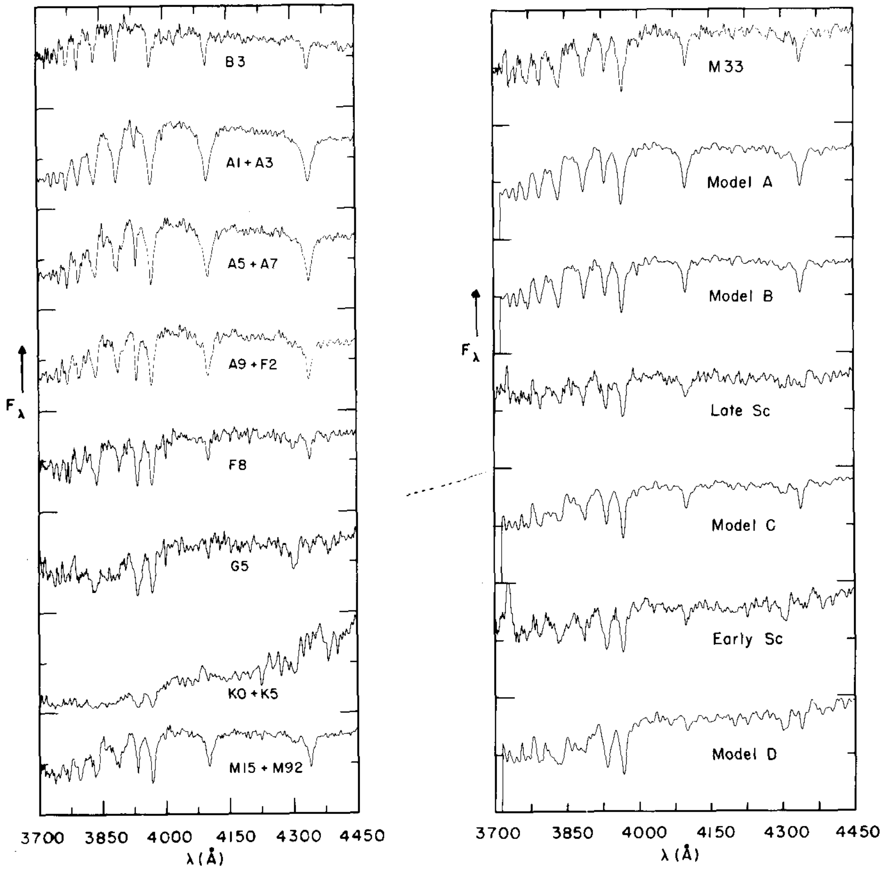
Figure 2. A colour-colour diagram adapted from O'Connell (1982) showing the positions of Sc nuclei, with no corrections for reddening, among other stellar populations. The lines attached to each point indicate how far the points move if reddening corrections are applied.

metal-rich stars, there is a circular argument in using these data in an age versus metal-abundance debate. If the stellar population were assumed to be an old metal-poor one instead, one would not expect these reddening corrections. We show O'Connell's (1982) diagram in Figure 2 with the points representing observed colours of Sc galaxy nuclei rather than reddening corrected colours, and we note that the bluest galaxy nuclei are no longer bluer than the most metal-poor globulars. Although there is more scatter in the galaxy points, they do lie in the general vicinity of the globular clusters in this diagram. Some galaxy colours are redder than the globulars, but these lie in the vicinity of elliptical galaxies and their redness is likely due to their being more metal rich than the Population II objects.

In a further investigation, Cowley, Crampton and McClure (1982 ; hereafter C^2M) obtained intensified reticon scanner observations of the nuclei of a sample of 44 spiral galaxies with ∿ 3 Å resolution with the McGraw Hill telescope. A similar luminosity vs. line strength (measuring Ca II K, Hδ, G band and Mg b features) relationship was found as is shown in Figure 1b. Flux corrected spectra of a range of stars and globular clusters were combined to produce models to compare with similar data for the nuclei of late-type spiral galaxies. Figure 3 shows a series of spectra of stars of a range of spectral types, and also includes a spectrum of the combined light of two of the most metal-poor globular clusters, M15 + M92. Comparison of the latter spectrum with those of young main-sequence stars in the spectral range A5-F2 emphasizes the difficulties in distinguishing between old metal-poor, and young stellar populations. Although the hydrogen lines are broader in the young stars, these can easily be weakened when a more composite stellar population is formed, and the differences become quite subtle between the two types of stellar population.

Two representative Sc galaxy spectra are shown in Figure 4. The one labelled "Late Sc" is made up of a combination of five very late Sc galaxy spectra, all of which have a ratio of H to K lines very similar to that of M33; the other is composed of a combination of four earlier Sc galaxies, where the K line is significantly stronger. In both cases, the observed spectra were fit best with models composed of old metal-poor stars, with a smaller proportion of young main-sequence stars. This leads us to believe that the underlying stellar component in the nuclear regions of Sc galaxies is an old metal-poor population, but that there is an additional young main-sequence component as well. The top spectrum in Figure 4 shows the observed data for M33. Note in this case that the feature near λ 3800 Å (H9 + metal lines) is very strong compared to the neighbouring H lines. This feature is very prominent in main-sequence F stars where, although the H lines are still quite strong, the metal lines are beginning to strengthen also in the progression towards cooler stars. This feature is not unusually strong in the spectra of metal-poor globular clusters, consequently it is a good discriminant of age versus metallicity at this spectral type.

In the case of M33, models containing predominantly metal-poor stars do



Figures 3 (left) and 4 (right). Spectra of stars of different spectral types, globular clusters, Sc galaxies and models for the latter.

not fit the observations very well. The best fit (model B) includes a predominantly young population of stars (in terms of fraction of integrated blue light) with an underlying old metal-poor population comprising only $\sim$ 25% of the light. The prime effect of the addition of the metal-poor population is the weakening of the H lines.

The difference between the spectrum of the nucleus of M33 and that of the other late Sc nuclei may be related to the fact that M33 is much closer to us and so the fixed 3" x 10" entrance aperture used in our observations samples somewhat different populations. The nucleus of M33 contains a bright semi-stellar object that is comparable in size and luminosity to a large globular cluster. A significant young population of stars may reside in this object which exhibits strong Hα emission (Hua and Nguyen-Trong 1981). It is interesting to note that Mayall and Aller (1942) and Walker (1964) have shown that the area surrounding the semi-stellar nucleus of M33 is redder and of later spectral type than the nucleus, suggesting that it contains a different population of stars. The other Sc galaxies which we observed are much more distant than M33 so that the area included by the entrance slot is much larger in linear size and may more adequately sample the underlying population.

The UV observations of spiral galaxies by Code and Welch (1979) and Gunn, Stryker and Tinsley (1981) have been interpreted as indicating the presence of hot young O stars in the nuclei. We do not argue with this interpretation in that some hot OB stars <u>are</u> probably present, but we point out that the UV light may equally <u>well</u> originate in stars like Barnard 29 in the (metal-poor) globular cluster M13. These stars, for which there are numerous examples (Zinn, Newell and Gibson 1972, H. Harris, private communication), lie up to several magnitudes above the horizontal branch. Because some of these stars have very blue colours ($B-V < -0.3$), their spectral energy distribution must mimic O stars. Although these stars are rare, perhaps less than one per globular cluster, the nuclei of galaxies must contain stars of this type which could equally well account for the observed UV flux.

Our conclusion is that there is no indisputable evidence that the bulges of Sc spiral galaxies contain a large fraction of hot young stars as opposed to blue, old metal-poor stars. On the contrary, our observations are most readily interpreted by postulating that the underlying stellar population is composed of old stars of all metal abundances; a large fraction of the integrated blue light of the nuclei is contributed by old metal-poor stars, with an admixture of hot young stars. We do not suggest that no young stars are contained in the nuclei of galaxies. Indeed, there are numerous examples of very late-type spirals, irregular and peculiar galaxies, such as NGC 5102, that are bluer than the most metal-poor clusters, and this must be due to a predominantly young population. For normal spirals, however, we suggest that the principal underlying population of the nuclear bulge is an old one.

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