THE STELLAR CONTENT OF ELLIPTICAL NUCLEI

S. M. Faber
Lick Observatory and Board of Studies in Astronomy and Astrophysics, University of California, Santa Cruz

ABSTRACT

New developments in understanding the stellar populations of elliptical nuclei are discussed. Variations in iron-peak spectral features have recently been detected, which are much smaller than changes in CN, Mg, and Na. A study is presently in progress to determine whether this pattern is consistent with lockstep enhancements in all heavy elements. Present evidence on the ultraviolet spectra of ellipticals now suggests that the source of the excess UV light is not young OB stars. A new correlation is also pointed out between UV excess and mean line strength. If real, this trend is further evidence against significant numbers of young OB stars in elliptical galaxies.

To first approximation, only two physical parameters are needed to characterize the spectra of old stellar populations, namely stellar age (or rate of star formation versus time) and composition. My remarks today concern these two quantities as they apply to elliptical-galaxy populations.

Consider composition first. It has long been known that E-galaxy spectra exhibit a sequence in line strength and color, exemplified both by variations among galaxies and by radial gradients within galaxies. As with the phenomenologically similar trend among globular clusters, this sequence has conventionally been interpreted in terms of metallicity variations. Attempts to calibrate the sequence in terms of iron abundance have typically shown that the strongest-lined ellipticals are between two and four times more metal-rich than M32 (Faber 1973; Oke and Schwarzschild 1975; Larson and Tinsley 1974; Cohen 1979). A weakness of these previous calibrations, however, is the fact that they depend largely on the very large line-strength changes seen only in CN, Mg, and Na. No iron-peak features have as yet been used.

Counter to the usual metallicity interpretation, a few authors have proposed instead that only the elements N, Mg, and Na are changing

Richard M. West (ed.), Highlights of Astronomy, Vol. 6, 165–171.

https://doi.org/10.1017/S1539299600005086 Published online by Cambridge University Press

appreciably (O'Connell 1976; Peterson 1976). Prima facie evidence in favor of this view is the fact that fairly stringent upper limits have been placed on changes in the iron λ5270 line, which show them to be at least two to three times smaller than those in CN, Mg, and Na (Faber 1977; Cohen 1979).

The astrophysical interpretation is quite different in the two cases, depending on whether all or only some heavy elements are involved. If all elements are changing, radial line-strength gradients imply overall metallicity gradients, in which case they fit in quite nicely with the usual gaseous collapse picture for galaxies (Eggen, Lynden-Bell, and Sandage 1962). If only a few elements are involved, on the other hand, we are more likely dealing merely with the details of the nucleosynthetic enrichment process, and the variations, though interesting, would lose their truly fundamental character.

With the hope of clarifying this issue, David Burstein and I undertook some seven years ago a large survey of E galaxy spectra. For this sample, we set out to measure two iron-peak blends (λ5270 and λ5335), two TiO bands, and Hβ, in addition to the usual CN, Mg, and NaD. The major difficulty in such a study is the need to correct the line strengths for dilution due to velocity broadening. The problem is especially acute for iron-peak features, since they are considerably weaker than CN, Mg, or NaD. Mindful of the need for accuracy, we have carefully determined all necessary velocity corrections using artifically broadened spectra of a wide variety of standard stars, globular clusters, and narrow-lined galaxies.

Aided recently by graduate student Christina Morea from Padua, Italy, we have now completed line-strength measurements of roughly 225 galaxies. The major result is that unambiguous variations in both measured iron-peak features have been detected. The variations are quite small, however, and amount to only a 15% increase in strength for the strongest-lined galaxies. This variation is slightly smaller than the previous upper limits.

Our next task is to determine whether simple, uniform changes in all heavy elements together - the so-called "lockstep" hypothesis - can simultaneously explain both small changes in iron-peak lines and large changes in other features. We are now investigating this problem using a line-strength calibration versus metallicity based on K-giant stars in the solar neighborhood and in globular clusters. The results of this final phase are not yet known, but if I may be permitted a prediction, I foresee that the abundance changes we derive will be somewhat smaller than previous estimates. This result would in turn affect current views on the strength of radial abundance gradients, the importance of metallicity effects on the physics of M giants, and several other questions of galactic structure.

Let us turn now to the star-formation history of elliptical galaxies. This question divides logically into two parts - when did the bulk of the stellar population form, and when did the youngest stars form? The first question is the more difficult of the two. The answer is equivalent to determining the main-sequence turnoff for the main population, which, according to all estimates, lies somewhere between 5 and 15 billion years in age, or between late F and late G in spectral type, depending on composition. The major difficulty with this determination is the fact that there are three potential stellar contaminants to the pure old population that radiate at wavelengths similar to or slightly bluer than the turnoff stars. These contaminants are blue stragglers, horizontal-branch stars, and young stars. The uncertain contribution from these other components masks the true temperature of the turnoff stars with exasperating effectiveness.

Based on ground-based spectral scans and population models, O'Connell (1980) recently proposed an age as young as five billion years for a significant fraction of the stars in M32. A much greater age of ten billion years or older was later convincingly defended by Gunn, Stryker, and Tinsley (1981) for giant ellipticals. The analysis of these authors, plus the observed lack of a significant color change in E galaxies at large lookback times, suggests for the moment at least that the bulk of the population in giant E's must have formed well before five billion years ago. The bulk age of blue ellipticals like M32, on the other hand, is much harder to determine using population models. The uncertainty is worse for M32 because the turnoff stars are hotter and are thus more thoroughly masked by the three potential contaminant groups. A redetermination of the age of M32 using all available data, including satellite UV scans, is a worthwhile exercise but may in the end prove impossible.

A somewhat more tractable problem than the bulk age of ellipticals is whether they have made a few stars very recently and whether they are perhaps even continuing to form stars today. There are two reasons why we should entertain such a possibility, despite overwhelming evidence that the vast majority of stars is old. The first is the fact that gas is without doubt now being shed by dying stars in elliptical galaxies. Although most of this gas may be exhausted as a galactic wind (Mathews and Baker 1971), any residue left behind could provide the raw material for new stars, particularly near the nucleus. The second reason is the well known excess of far ultraviolet light below 1800 Å, which has been detected in every early-type galaxy thus far observed. When it was first discovered, this excess generated a flurry of excitement as evidence of possible recent star formation. Almost immediately, however, there arose the counter proposal that the hot sources are simply normal members of the old stellar population, perhaps planetary nuclei or hot horizontal-branch stars. Discriminating between these possibilities is important astrophysically, as a residue of continuing star formation would have a dramatic impact on the colors and magnitudes of E galaxies at large lookback times (Bruzual 1981).

Early attempts to distinguish between old and young stars utilized only broad-band, ultraviolet spectral information, and it is well

https://doi.org/10.1017/S1539299600005086 Published online by Cambridge University Press

known now that these data alone are inconclusive (e.g., Wu et al. 1980). Lately, however, IUE observations have provided a variety of new information, with the result that gradually, in my opinion, the weight of evidence has shifted to favor old stars. Let me summarize this new evidence just briefly.

1. Welch (1982) has recently compared the strength of several absorption lines in the bulge ot M31 near 1300 Å with their strength in local O and B main-sequence stars and finds that they are too weak to be produced by such stars. The implication, then, is that the hot stars in M31 cannot be normal, young, metal-rich, main-sequence stars.

2. Welch further estimates that if the M31 flux within the IUE aperture is produced by B0 III stars, only five objects are needed. If the flux comes from 06 V stars, only one is needed. The IUE long-slit spectra should therefore clearly show individual, discrete sources if such young stars are present, yet none are seen. The hot stars are evidently considerably fainter in intrinsic luminosity than normal O and B main-sequence stars.

3. From IUE long-slit luminosity profiles and also from comparison of satellite fluxes through various apertures, it is now known that the hot component is smoothly distributed in radius essentially like the old stellar population (Welch 1982; Deharveng et al. 1982; Bertola et al. 1980; Oke, Bertola, and Capaccioli 1981). Young stars, by contrast, would more likely be patchily distributed and possibly also strongly concentrated to the nucleus.

4. The far ultraviolet component has a very steep spectral slope in all cases observed so far, indicating that it consists almost entirely of stars hotter than 30,000 K. If continuing star formation were taking place, we would expect significant light from cooler B, A, and F stars as well (e.g., Gunn et al. 1981), yielding a considerably flatter UV continuum than is seen. We conclude that, if young stars are the source of the far UV flux, the initial mass function (IMF) must be dramatically skewed to high-mass stars compared to the solar-neighbornood IMF.

5. As circumstantial evidence in favor of young stars, it has sometimes been claimed (O'Connell 1980; Gunn et al. 1981) that the amount of continuing star formation needed to match the spectral-energy distributions of elliptical galaxies is closely compatible with the amount just needed to consume the mass shed by dying stars. Such statements have been based on ground-based scans of elliptical galaxies down to only 3500 Å, however. Satellite UV fluxes yield considerably more stringent limits on star formation, and the new observations no longer substantiate these earlier claims. I should emphasize that any limit on star formation derived in this way is highly dependent on the assumed initial-mass function and, in particular, on the numbers of O and early-B stars formed. The model young stellar population presented by Gunn et al. (1981) approximates star formation continuing at a

uniform rate and with a solar-neighborhood IMF. If this model is scaled to a rate just adequate to consume all gas shed by dying stars in M31, the resultant flux at 1550 Å is six times too high. An alternative IMF preferred by Larson and Tinsley (1978) because it provides a better match to the colors of spiral galaxies, would predict a flux that is 20 times too high.

Since only O and early-B stars contribute to the flux at 1550 Å, such a mismatch could admittedly be cured simply by reducing the star-formation rate or by reducing the assumed IMF by a factor of six to 20 at the relevant masses. The point I am making, however, is not that star formation is impossible - it is always possible if the stars have low enough mass - but rather that the fit between the observations and the minimum-assumption model is not quite as close as was thought earlier.

6. The occurrence of Type I supernovae in ellipticals has formerly been considered evidence that massive young stars must now be forming in these galaxies (Gunn et al. 1981). However, Renzini (preprint) has recently shown how Type I supernovae can arise from a wide variety of masses including solar-mass stars via binary mass-transfer. The need for massive young stars in E galaxies is thereby reduced.

The previous six points are all evidence against young stars. Another observation which has up to now seemed to favor young stars is the highly variable nature of the far UV flux from galaxy to galaxy, which changes in amplitude by as much as a factor of ten in an apparently random manner. Such randomness would perhaps be understandable with young stars, since the rate of star formation should depend rather sensitively on purely local conditions, which might vary widely from galaxy to galaxy.

In the course of preparing this review, however, I noticed that the amplitude of the UV flux is not completely random after all. On the basis of present data (six galaxies), the flux appears to correlate with line-strength and hence, in all likelihood, with metallicity. This correlation is plotted in Fig. 1, which shows ultraviolet color (1550-3100) versus magnesium line-strength index. The dotted line represents the radial gradient in the bulge of M31 between 4" and 12" from the nucleus, based on the ultraviolet data of Deharveng et al. (1982) and Welch (1982). All E galaxies with observations are included in the plot, except for M87, which has a peculiarly blue spectral-energy distribution even at visible wavelengths and is thus qualitatively different from the remaining objects.

With so few data points, it would be premature to dwell overly long on the significance of this correlation. One cannot help notice, however, that the sense of the trend is opposite to the usual color-metallicity effect in that more metal-rich galaxies are bluer, not redder. Recall, though, that the usual rules of thumb are suspended here in the far ultraviolet. At 1550 Å we are dealing with very hot

https://doi.org/10.1017/S1539299600005086 Published online by Cambridge University Press

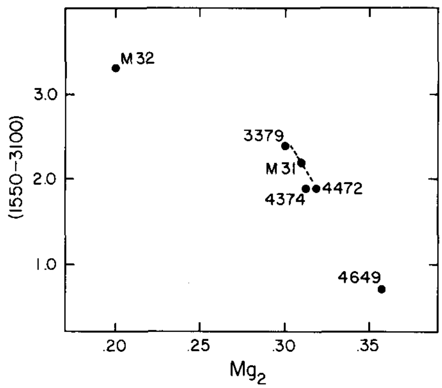

Fig. 1 - UV color versus line-strength index, Mg_2.

stars, on which line-blanketing has little effect. Furthermore, all other things being equal, it is the flux at 3100 Å which should be depressed at high metallicities, owing to lower T_e and higher line-blanketing for the turnoff stars. Whether this effect can account for the full factor of ten spread among these galaxies is doubtful but it must play a role at some level.

If this correlation is real, it provides yet another strong piece of evidence against young stars, as there is no known reason why star-formation rate should correlate closely with composition. More likely, we must be seeing a hot component in the old stellar population, whose amplitude depends on a composition in some as-yet-unknown way. At any rate, the trend, tenuous as it is, suggests several new and simple observations with IUE and Space Telescope which could easily test this correlation and thus place even tighter constraints on the origin of the far UV flux.

In summary, the major conclusions of this review are as follows:

1. Iron-line variations in elliptical galaxies have now been detected at a level three to four times smaller than the previously known large changes in CN, Mg, and Na. Whether or not this pattern of large and small variations is consistent with lockstep changes in all heavy elements is now under active investigation.

2. Unless the IMF in ellipticals is severely underabundant in O and early-B stars by a factor of between six and 20, E galaxies cannot now be making stars at a rate sufficient to consume all gas shed by dying stars.

3. Preliminary data suggest an inverse correlation between the amplitude of far ultraviolet flux and mean line strengths. If true, this correlation provides further evidence in favor of old hot stars as the primary contributors of the UV flux, thus placing even more stringent limits on the number of OB stars currently being formed.

REFERENCES

Bertola, F., Capaccioli, M., Holm, A. V., and Oke, J. B.: 1980, Ap. J. (Letters), 237, L65.
Bruzual, A. G.: 1981, Ph.D. thesis, University of California.
Cohen, J. G.: 1979, Ap. J. 228, 405.
Deharveng, J. M., Joubert, M., Monnet, G., and Donas, J.: 1982, A. Ap., 106, 16.
Eggen, O. J., Lynden-Bell, D., and Sandage, A. R.: 1962, Ap. J., 136, 748.
Faber, S. M.: 1973, Ap. J., 179, 731.
_____. 1977, in The Evolution of Galaxies and Stellar Populations, ed. B. M. Tinsley and R. B. Larson, Yale University Press, p. 157.
Gunn, J. E., Stryker, L., and Tinsley, B. M.: 1981, Ap. J., 248, 48.
Larson, R. B., and Tinsley, B. M.: 1974, Ap. J., 192, 293.
_____. 1978, Ap. J., 219, 46.
Mathews, W. G., and Baker, J. C.: 1971, Ap. J., 170, 241.
O'Connell, R.: 1976, Ap. J., 206, 370.
_____. 1980, Ap. J., 236, 430.
Oke, J. B., and Schwarzschild, M.: 1975, Ap. J., 198, 63.
Oke, J. B., Bertola, F., and Capaccioli, M.: 1981, Ap. J., 243, 1981.
Peterson, R.: 1976, Ap. J. (Letters), 210, L123.
Renzini, A.: 1982 (preprint).
Welch, G.: 1982, Ap. J., 259, 77.
Wu, C. C., Faber, S. M., Gallagher, J. S., Peck, M., and Tinsley, B. M.: 1980, Ap. J., 237, 290.

https://doi.org/10.1017/S1539299600005086 Published online by Cambridge University Press