METAL–RICH STARS IN THE GALACTIC BULGE AND THEIR IMPLICATIONS FOR ELLIPTICAL GALAXIES

ELAINE M. SADLER
Anglo–Australian Observatory
P.O. Box 296
Epping, NSW 2121
Australia

ABSTRACT. A new study of more than 400 K giants in the inner Galactic bulge confirms that many have high metallicity ([Fe/H] $\geq$ 0). Such stars are valuable templates in understanding the stellar populations of elliptical galaxies, and may help explain some of the puzzling line–strength anomalies seen in the integrated spectra of giant ellipticals.

1. INTRODUCTION

Understanding the stellar population of elliptical galaxies is a difficult and long–standing problem, since we can study giant ellipticals only in their integrated light rather than focussing on individual components of their population.

Whitford (1978) suggested that giants in the Galactic nuclear bulge might be useful templates in constructing population models of unresolved galaxies, and studies by Rich (1988) and Terndrup (1988) confirm that the bulge has many old, metal–rich stars. Here I describe a new study of K giant stars in the Galactic bulge, discuss ways of calibrating [Fe/H] for above–solar abundances, and compare the line indices measured in bulge giants with those observed in elliptical galaxies, both within their nuclei and further out.

2. NEW OBSERVATIONS OF BULGE GIANTS

Over the past three years, Don Terndrup, Michael Rich and I have observed a large sample of Galactic bulge K giants with fibre–fed spectrographs at the AAT and CTIO. Our aim is to probe the dynamics and abundance distribution in the inner bulge in detail, and to identify metal–rich stars which may be good templates for elliptical galaxies.

Our sample comprises 440 stars in Baade's Window (BW) originally catalogued by Arp (1965) for which proper motions have been measured by Jones et al. (1991, in preparation). We have measured radial velocities for all 440 stars and line–strength indices (Faber et al. 1985) for most, so that in principle we know both the metallicity and the three–dimensional space motion of each star in the sample.

B. Barbuy and A. Renzini (eds.), The Stellar Populations of Galaxies, 41–46.

3. MODEL SPECTRA FOR METAL–RICH STARS

In studying large samples of stars, it is obviously useful to be able to estimate the metal abundance reliably from medium or low–resolution spectra. In studying the integrated light of elliptical galaxies this is essential, since line broadening from the internal velocity dispersion of the galaxy rules out high–resolution spectral studies. The usual approach is an empirical calibration of several line–strength indices via a grid of standard stars whose abundance is well determined from high–resolution studies. This, however, may be difficult to extend to very metal–rich stars, since few of the well–studied stars in the solar neighbourhood have abundances much above solar and the exact abundance of the so–called 'super metal rich' (SMR) stars is still under debate (e.g. Taylor 1991).

I describe here an alternative approach based on a grid of model spectra constructed for metal–rich stars by Roger Bell and Bob Dickens (private communication). It is possible to produce models for any desired combination of T_{eff}, log g and [Fe/H], and to study in a quantitative way how various line strength indices respond to changes in each of these parameters. This in turn can show which indices are most useful in studying the integrated light of ellipticals.

The model spectra discussed here cover the temperature range T_{eff} 4400–5400 K, surface gravity log g 1.5–4.5 and [Fe/H] −0.5 to +1.0. They do not yet include the TiO bands which become important at temperatures below 4000 K (Bell and Gustafsson 1989), and the predicted Balmer lines are too weak, but nevertheless the models give useful insights into the behaviour of the observed indices.

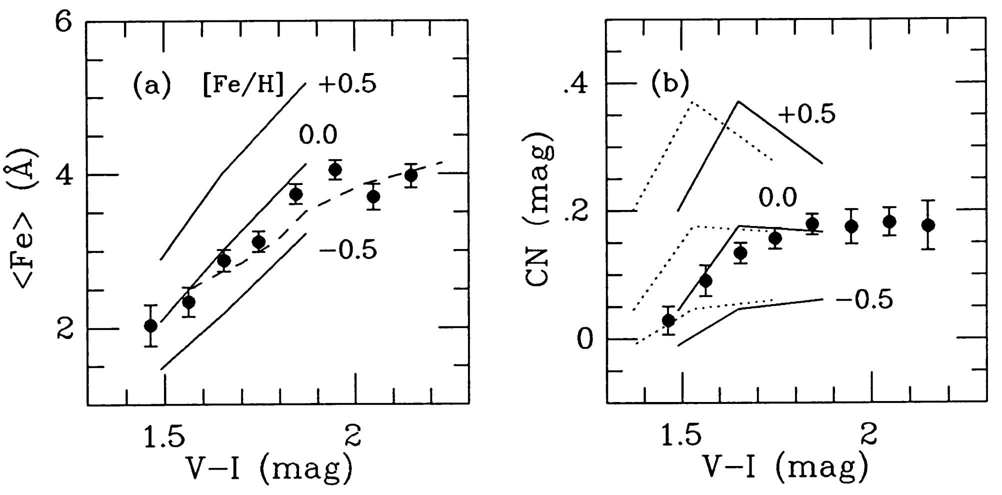

Figure 1: Predicted line strengths for models with [Fe/H] = −0.5, 0.0 and +0.5 (solid lines) and mean data for BW giants (V≥15.5 mag) binned by V−I colour. (a) <Fe> index: the dashed line shows the empirical relation for solar abundance derived by Faber et al. (1985); (b) CN index: the dotted and solid lines correspond to E(V−I)=0.58 and 0.70 mag respectively.

V magnitudes and V−I colours have been measured for our sample by Terndrup (1988), while Bessell (1979) gives an empirical relation between V−I colour and T_{eff} and shows that V−I is not seriously affected by blanketing or gravity effects. Thus a plot of index against V−I is essentially a plot against T_{eff}. For a first look, I have simply binned the sample in 0.1 mag bins of V−I and calculated the mean line strength index in each bin. Figure 1 shows the results for the <Fe> and CN indices. <Fe> is relatively insensitive to changes in surface gravity, while CN shows only small variations with temperature for all but the hottest K stars.

The abundance derived from <Fe> depends sensitively on the assumed reddening. In Figure 1a, an error of 0.1 mag in E(V−I) corresponds to ±300 K in T_{eff}, and this in turn means a change of 0.3 dex in [Fe/H], or a factor of two in abundance. The extinction in BW is not uniform and taking the same mean E(V−I) over the whole field may not be appropriate but I have adopted E(V−I)=0.70 mag for now, following Walker and Mack (1986), because this seems to fit the 'kink' in the CN distribution in Figure 1b.

Preliminary results from this study suggest that <[Fe/H]>∼ 0 in Baade's Window, in agreement with previous work, and that about 40% of K giants with V > 15.5 have above–solar abundance.

4. STELLAR POPULATIONS IN ELLIPTICAL GALAXIES

Extensive studies of line–strength indices and line–strength gradients in ellipticals have been carried out by Burstein et al. (1984) and Gorgas et al. (1990). Here, I discuss two of the puzzles raised by these studies, the plots of Hβ and <Fe> indices versus Mg_2.

Burstein et al. (1984) pointed out that the Hβ absorption lines in elliptical nuclei are stronger than predicted by extrapolation from globular clusters. However Figure 2a shows that the mean indices for bulge stars overlap with Galactic globular clusters at the low abundance end and with the brightest elliptical galaxies at higher abundances. Since the bulge, like Galactic globulars, lacks an intermediate age population (Terndrup 1988), it is tempting to identify a single sequence of old populations extending from globular clusters to the brightest elliptical nuclei and differing only in metallicity. The radial Hβ gradients within ellipticals are flat or very shallow (Gorgas et al. 1990, Faber et al. 1992), so the outer parts of giant ellipticals also lie on this sequence.

The Hβ index is largely insensitive to both metallicity and surface gravity for $Mg_2 > 0.15$ mag, so the only way to move a population to higher Hβ strength in Figure 2a is to increase the mean temperature, i.e. to add either an intermediate–age population or (perhaps less plausibly) a significant fraction of extremely metal–poor stars.

Figure 2b shows the Mg_2 versus <Fe> plot. Here, bulge K stars extend the sequence described by Galactic globular clusters and low–luminosity ellipticals, which is tightly defined because changes in temperature and abundance have roughly equal and opposite effects. Giant ellipticals lie well off the relation defined by the other objects. Increasing surface gravity will move a star off the sequence, since dwarfs have stronger Mg_2 than giants, but dwarfs would have to contribute almost 50% of the V light in the nuclei of the most metal–rich galaxies to fit the data, and this appears unlikely.

Another possibility is that M giants affect the line–strength indices measured from integrated light in metal–rich ellipticals. Late M giants in BW have very high Mg_2 and low <Fe> because of gross continuum effects from their strong TiO bands. Simulations adding M–giant light (using a template made from bulge M giants) to a pure K giant population

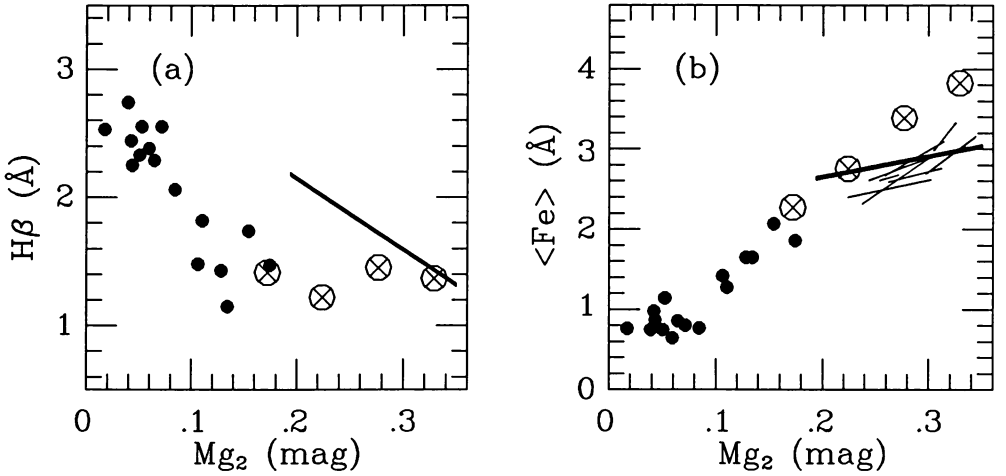

Figure 2: (a) Hβ index versus Mg_2 for bulge K giants from our study (⊗), and for Galactic globulars (•) and elliptical nuclei (solid line) from Burstein et al. (1984). (b) <Fe> versus Mg_2 with the same symbols, thin lines show gradients within individual ellipticals observed by Davies and Sadler (1992).

show that the Mg_2 and <Fe> strengths in nearby ellipticals observed by Davies and Sadler (1992) can be reproduced if M giants contribute roughly 10% of the V light in the nucleus and 5% at the half–light radius R_e. If this is correct, these galaxies probably have [Fe/H] in the range 0.0 to +0.3 in the nucleus and −0.3 to 0.0 at R_e.

In summary, it appears that optical spectra of the brightest ellipticals can be understood in terms of an old population alone. This does not appear to be true of less luminous ellipticals, and I suspect that as we go to lower luminosities we see evidence of progressively more recent star formation.

References

Arp, H., 1965. Astrophys. J., **141**, 43.

Bell, R.A. and Gustafsson, B., 1989. MNRAS, **236**, 653.

Bessell, M.S., 1979. PASP, **91**, 589.

Davies, R.L. and Sadler, E.M., 1992, in preparation.

Burstein, D., Faber, S.M., Gaskell, C.M. and Krumm, N., 1984. Astrophys. J., **287**, 586.

Faber, S.M., Friel, E.D., Burstein, D. and Gaskell, C.M., 1985. Astrophys. J. Suppl. Ser., **57**, 711.

Faber, S.M., Worthey, G. and Gonzalez, J.J., 1992, this meeting.

Gorgas, J., Efstathiou, G. and Aragon Salamanca, A., 1990. MNRAS, **245**, 217.

Rich, R.M., 1988. Astron. J., **95**, 828.

Taylor, B.J., 1991. Astrophys. J. Suppl. Ser., **76**, 715.

Terndrup, D.M., 1988. Astron. J., **96**, 884.

Walker, A.R. and Mack, P., 1986. MNRAS, **220**, 69.

Whitford, A.E., 1978. Astrophys. J., **226**, 777.

https://doi.org/10.1017/S0074180900120078 Published online by Cambridge University Press

Discussion

RICH: I see two possibilities to account for the differences in mean metallicity between our two samples. First, the mean log abundance is lower than the log mean abundance. Second, my use of J$-$K, combined with the Cayrel standards, was a completely empirical approach. It will be interesting to see what abundances you derive for stars measured at high resolution. Finally, Terndrup's mean abundance was based on the giant branch colour. Bulge giants, however, are known to have colours too blue for their metal abundance.

SADLER: Yes, it is important to remember that $<$[Fe/H]$>\neq\log<z>$, where z is the abundance. I don't think the published $<$[Fe/H]$>$ of roughly $+0.08$ for your sample (Rich 1988) is inconsistent with the value of 'close to zero' estimated from the models, but I have made the check you suggest by comparing abundance standard stars with the models. The agreement is good for hotter stars, but the models may underestimate [Fe/H] for the standards by 0.2–0.3 dex for T_{eff} below about 4800 K. Figure 1a compares a solar abundance model with the Faber et al. (1984) observed mean relation for solar abundance standards.

GUSTAFSSON: We certainly know that the models you have used are underblanketed in the UV and blue. This may cause scale errors in the abundances, possibly also depending on T_{eff}. In using saturated lines these problems are more severe. For more detailed future work on SMR stars, more recent opacity data such as those of Kurucz should be used.

FROGEL: (1) The model Whitford and I made predicted $\sim$10% V light from M giants, in agreement with your estimate. (2) Terndrup, Whitford and I have rederived $<$[Fe/H]$>$ for bulge M giants using atomic Na and Ca lines at 2.7 μm. We get $\sim +0.3$ in agreement with Rich and Whitford, but find no spread. As others have commented, one must allow for effects of variable reddening and selection biases between M and K stars.

MOULD: Just a reminder to observers of the abundance distribution in the bulge that the distribution you find will depend on selection effects. If you observe M stars you will tend to find metal–rich stars and if you observe blue stars you will tend to find low metallicity, just because this is the part of the HR diagram where these stars live. To estimate the distribution in the population, you have to correct for these colour or type selection effects.

PELETIER: One of the parameters that could move objects away from the relation that you showed between Mg_2 and $<$Fe$>$ is the [O/Fe] ratio in galaxies, since Mg_2 is correlated with the O abundance. The [O/Fe] ratio is determined primarily by the timescale of formation. Have you thought about this?

SADLER: No, not in any detail. I made some simple calculations for M stars because we know they must be present in any old metal–rich population, but certainly there could be other effects as well.

PETERSON: The O/Fe ratio affects K giant spectra significantly at the metal–rich end. (1) O correlates with Mg. An Mg excess alters ionization fraction by its contribution of excess electrons, and makes neutral lines appear stronger. (2) O alters CN by greater CO formation. N/Fe also changes CN strength, and N/O is known to vary from HII work. So CN is very sensitive to abundance ratios of CNO elements.

SADLER: Your cautions are certainly valid. The attraction of CN is that it is much less affected by temperature than the other indices.

GREGG: (1) I agree with your assertion that as one goes from high to low luminosity ellipticals the amount of young or intermediate–age population increases, but this may be due in part to the presence of both high and low surface brightness ellipticals in the sample. The low surface brightness objects contain a younger population than the M32–like dwarfs which form a continuum with the more luminous high surface brightness ellipticals (see my contribution for details). (2) On the other hand, the work of Francois Schweizer shows that galaxies with more fine structure probably have larger proportions of young or intermediate age populations and these objects also tend to be the most luminous objects, in conflict with your suggestion that the brightest ellipticals have the oldest populations.

SADLER: The low luminosity galaxies I was discussing all fall into your high surface brightness category, so I don't think this is a problem. Most of the ellipticals which Roger Davies and I studied were in clusters, so this may have some effect.

SCHWEIZER: Whether one finds or does not find intermediate–age populations in ellipticals may depend on how one selects one's sample. In our study of correlations between line-strength indices and fine structure (Schweizer et al. 1990 Ap. J. Lett **364**, L33) we concentrated on field galaxies and avoided rich clusters. We find evidence for enhanced intermediate–age populations (enhanced $H\beta$, weak CN and Mg_2) in luminous ($M_B < -21.4$) ellipticals with much fine structure (e.g. NGC 3610, 5018, 3640, 596). There is some evidence that ellipticals in clusters may have formed earlier and may, therefore, have little or no intermediate–age population, as Elaine found.