Metallicity of Unresolved Stellar Populations

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The determination of the metallicity of an unresolved population is not easy. An obvious problem is that stars of the same mass, but different metallicities, evolve at different rates and have different luminosities. For example, metal poor red giants are considerably brighter in the optical region than corresponding metal rich stars. The "mean" abundance for a stellar population therfore depends on whether the mean is taken with respect to *mass*, *star number* or *luminosity*. It is inevitable that observational work weights by luminosity, while chemical evolution models usually weight by mass. The two weightings can give rather different means, which may also depend on the "metallicity structure" - i.e. the relative numbers of stars of different metallicities, and rough calculations show that metallicity indicators like colours could give 0.3 dex lower abundance than the mass-weighted mean, if uniform (i.e. single metallicity population) calibrators have been used.

A modern, accurate calibration of the popular Mg_2 index has yet to be published, but a rough estimate of its behaviour is shown in Figure 1, based on Edmunds (1991). It shows that the indicator is quite a good one below solar abundances, but that above solar its behaviour is probably very non-linear with metallicity, and should not yet be trusted.

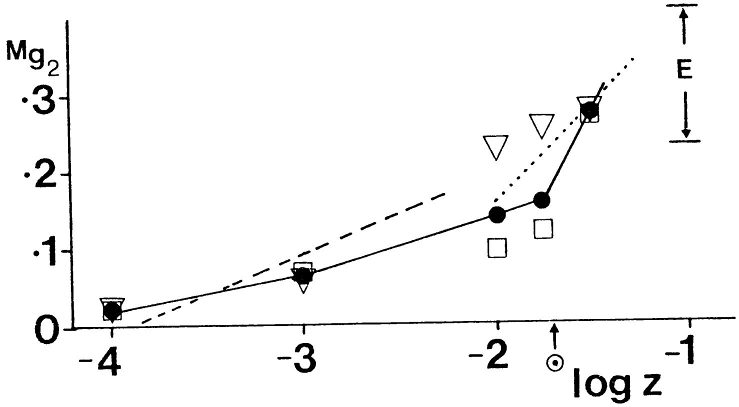

Figure 1. A rough calibration of the Mg_2 index for uniform metallicity, 15 Gyr old stellar populations. The open triangles are red giant indices, the open squares dwarfs, and the filled circles represent the combined population. The dashed and dotted lines are the empirical calibrations of Brodie and Huchra (1990) and Gorgas *et al* (1990).

B. Barbuy and A. Renzini (eds.), The Stellar Populations of Galaxies, 277–280.

An added complication with this index is the uncertainty over what to take as a [Mg/Fe] ratio. Although the [α element/Fe] ratio has sometimes been regarded (like O/Fe) as an age indicator (e.g. Matteucci and Brocato 1990), it can be shown (Edmunds *et al* 1991) that a quasi-secondary behaviour of iron, with the iron yield depending on overall metallicity, could also explain its behavior as observed in Galactic stars. It remains unclear what ratio should be adopted for elliptical galaxy simulations, but detailed analysis of stars in the Galactic bulge - which appear to reach up to metallicities of at least two or three times solar - should help to identify whether $[Mg/Fe] = 0.3$ in old, metal rich populations (as predicted by "age" models) or $[Mg/Fe] \leq 0$ (as predicted by a simple "quasi-secondary" model)

The Yield Problem

Assuming that colour and Mg_2 abundance indicators are giving something like the true abundance in ellipticals, the implication would be that, at least in the centres of large ellipticals, the mean abundance in the stars may reach up to $z \sim 0.06$, i.e. about three times solar. This presents a problem, since although gas abundances can build up to this kind of value quite easily by recycling, it is much more difficult to produce such a high mean abundance in a stellar population. Indeed, as shown in Edmunds (1989), although already a well-known result, a region of a galaxy which suffers outflow, *unenriched* inflow, or no gas flow, can never have a mean abundance which exceeds the "true" yield. By true yield is meant the amount of heavy elements released per mass of interstellar material processed into long-lived stars or remnants. The problem is that irregular galaxies appear to show a yield of order 0.006, and for spiral galaxies there is some evidence (Vila and Edmunds 1992) of a metallicity-dependent yield which, however, could not give rise to a mean population metallicity of more than about 0.004 on the basis of a "simple" chemical evolution model. These values are an order of magnitude below what is required, even ignoring the probable extra factor of two from metallicity/luminosity effects in the abundance indicators. There are possible ways out. Enriched inflow is a possibility, where the central regions form out of gas which already contains considerable heavy element abundance. As an example of an elementary model of this type, Figure 2 shows the (mass-weighted!) mean abundance for a spherical model galaxy with star formation rate proportional to the gas density, and a constant velocity inflow of gas. The "true" yield is p, and the curves are numbered with the parameter $\mathcal{R}$ which represents flow timescale/star formation timescale for the model. For clarity, the $\mathcal{R} = 30$ model is shown dashed. The initial radius of the galaxy is taken to be unity, and the curves show the mean stellar abundance after gas exhaustion. This is one of a series of elementary models considered by Edmunds and Greenhow (1992), a paper which attempts to find general constraints on the effects of flows in more realistic galaxy models than was possible in Edmunds (1989). As is apparent, and known from the "concentration" model of Lynden-Bell (1975) and many numerical models, it is possible for the mean stellar abundance to reach two or three times the yield, at least near the centre. But this may not be enough, and it is quite difficult to fine-tune models to reach higher values. It is tempting to speculate that the true yield may actually vary, and that it this variation (due perhaps to stellar physics or imf variations) which produces the rather high values of mean stellar abundances which are apparently seen in the centres of galaxies.

An interesting property of the elementary inflow model of Figure 2 is its metallicity structure near the centre, which is shown in figure 3. This shows that for large values of the

$\mathcal{R}$ parameter (i.e. slow flow), the metallicity distribution can mimic the structure that a "simple" closed -box model would have with a true yield twice that actually present. This might be a good model for the Galactic bulge, as observed by Rich (1990).

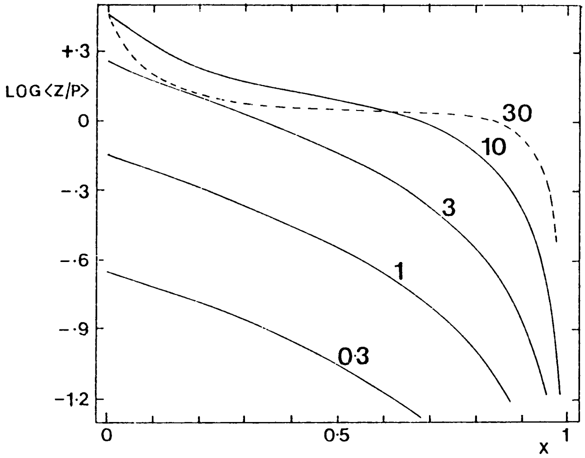

Figure 2. Mass-weighted mean stellar abundance as a function of radius x in a spherical inflow model (see text for details).

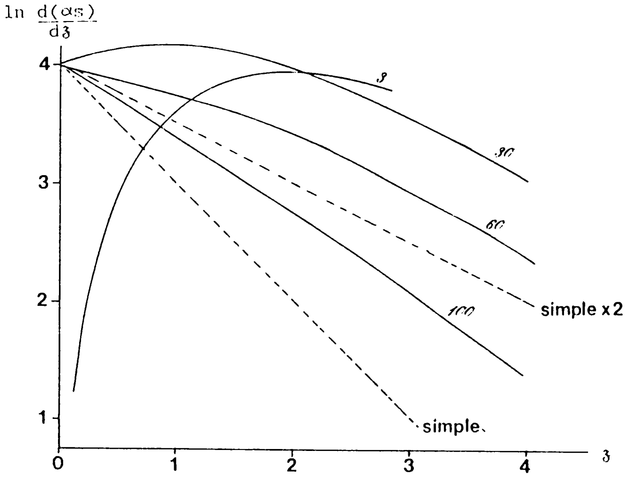

Figure 3. Metallicity structure of the spherical model of Figure 3 at radius x = 0.05. The curves are marked with the value of the $\mathcal{R}$ parameter, and the dashed lines show the metallicity structure of "simple" closed box models with yields of p and 2p.

The Importance of Surface Density

As a final provocative comment, I would like to re-emphasise the possiblity that the *surface density* or *surface brightness* of a system may be an important parameter in its chemical evolution. For spiral (Vila and Edmunds 1992), irregular (Phillipps, Edmunds and Davies 1990) and elliptical (Edmunds and Phillipps 1989) galaxies there does seem to be a link between surface density or surface brightness and metallicity, which may be more fundamental than absolute magnitude/metallicity relations. The latter may be dominated by sample selection effects, but not everyone will agree. Perhaps *both* luminosity and surface density/brightness are important. At least it is a problem that can be addressed by observation of larger data sets.

References

Brodie, J.P. and Huchra, J.P. 1990, Astrophys.J.,**362**,503.

Edmunds M.G. 1990, MNRAS,**246**,678.

Edmunds, M.G. 1991 in *Galaxies and the Cosmos* ed. R.J. Terlevich and M.G. Edmunds, Cambridge Univ. Press, *in press*.

Edmunds, M.G., Greenhow, R.G., Johnson, D., Kluckers, V. and Vila, B.M. 1991, MNRAS,**251**,33p.

Edmunds, M.G. and Greenhow, R.G. 1992, MNRAS, *submitted.*

Edmunds, M.G. and Phillipps, S. 1989, MNRAS,**241**,9p.

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

Lynden-Bell, D. 1975, Vistas in Astron.,**19**,299.

Matteucci, F. and Brocata, E. 1990, Astrophys.J.,**365**,539.

Rich, M. 1991, Astrophys.J.,**362**,604.

Phillipps, S., Edmunds, M.G. and Davies, J.I. 1990, MNRAS,**244**,168.

Vila, B.M. and Edmunds, M.G. 1992, MNRAS, *submitted.*

Discussion

G. Worthey: Just a word of comfort: you are exactly right about Mg_2. Models by Peletier and theoretical ones by Mould, as well as detailed ones by myself, confirm the steepening of the Mg_2/z relation near solar abundances.

R.Bender: Surface brightness alone is not sufficient to parameterise metallicity. From what I showed in my talk, there is a mass-term which combines with surface brightness in a way that Mg_2 seems to be correlated directly with velocity dispersion, with no correlation between residual scatter and surface brightness.

S.Faber: If you confine attention to just the bright ellipticals, have you tried plotting abundance vs log σ , as opposed to surface brightness? Bender's results suggest that surface brightness does not work nearly so well, and here the selection effects you referred to are small.

M.Edmunds: I havn't looked at correlations with log σ , and for ellipticals things seem to depend on whether the plot is of a *colour* based abundance indicator or Mg_2.

M.Bershady: In the magnitude limited redshift survey of Koo and Kron, I have found a peculiar population of low redshift, compact blue galaxies ($z \leq 0.1$). These objects are intrinsically faint and blue in optical and near-infrared, similar to, and bluer than, NGC 4449. Yet in optical-near-IR colour magnitude diagrams, these faint galaxies are too red, and display an "earlier" type C-M relation. It is possible that these objects are another example of a "2nd parameter" in the metallicity-absolute magnitude relation, namely compactness. So here surface mass density may be more relevant than surface brightness.