CHEMICAL EVOLUTION OF GALAXIES[1]

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SUMMARY. This paper discusses the initial mass function, the oxygen yield and the helium abundance in irregular and blue compact galaxies.

1. INTRODUCTION

Current problems in the chemical evolution of spiral and irregular galaxies have recently been well reviewed by Güsten (1986) and Peimbert (1986) respectively. I limit myself to two matters related to irregular and blue compact galaxies, namely the question of variability in the initial mass function and yield and that of the dependence of helium abundance on metallicity. I shall discuss these questions on the basis of preliminary results of the extensive survey by Terlevich and Melnick of compact emission line galaxies taken mostly from the Cambridge, Michigan and Tololo objective prism surveys (cf Campbell, Melnick and Terlevich 1986).

2. THE INITIAL MASS FUNCTION AND THE YIELD

Giant HII regions and HII galaxies have violent bursts of star formation with hundreds of O stars formed in $< 10^7$ years (Sargent and Searle 1970; Terlevich and Melnick 1981). Melnick, Terlevich and Eggleton (1985) have calculated evolutionary population synthesis models for such bursts assuming different initial mass functions (IMF) and stellar chemical compositions.

The IMF and evolutionary effects manifest themselves in the electron temperature of the surrounding HII regions: at a given oxygen abundance we expect to find an upper limit corresponding to the zero-age main sequence (ZAMS) with subsequent evolution leading to lower electron temperatures. Fig. 1 shows the data together with some ionisation model computations using G Ferland's "Cloudy" code with the

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ZAMS cluster models, for constant and variable IMF slopes. Clearly the effective temperature of the ZAMS increases towards lower abundances and the fit for a variable slope is quite good.

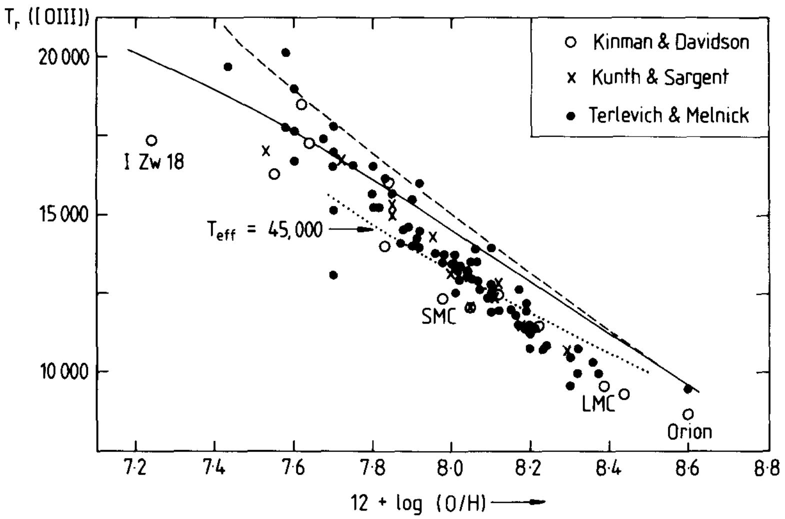

Figure 1. Electron temperature in HII galaxies and some HII regions, plotted against oxygen abundance. The full-drawn curve is for the ZAMS with a constant power-law IMF having slope 3 and upper mass limit $120M_\odot$. The broken curve is for a variable IMF with slope 6.3 + log O/H and the dotted curve is for models with a single ionising star, effective temperature 45,000K (Stasinska 1980).

A variable IMF slope would be expected to affect galactic chemical evolution, leading to a large yield at low abundances. This might explain the lower limit to O/H in extragalactic HII regions discussed by Kunth and Sargent (1986), although their preferred explanation is that HII regions can be self-enriched up to at least the level of IZw18 and untypical of the underlying gas composition.

The questions raised by these possibilities can be investigated by means of the classic tests of chemical evolution based on the simple model which assumes a closed system. This model seemed to be quite well verified by comparisons between oxygen abundances and gas fractions in the Magellanic Clouds (Pagel et al. 1978) and other irregular and blue compact galaxies (Lequeux et al. 1979; Talent 1980; Kinman and Davidson 1981) which mostly fitted the standard relation

$$Z = p \ln(m/g)$$

(where Z is the heavy-element fraction assumed to be 25 O/H, p the yield, m the total mass and g the mass of gas assumed to be essentially HI), but with a low yield, about 0.0025 compared to the canonical value of about 0.01 for the solar neighbourhood. It was also found that the abundance increases systematically with total mass.

Later investigations (Matteucci and Chiosi 1983; Gallagher and Hunter 1984; Kunth and Joubert 1985) threw doubt on the existence of both of these relationships. One problem is that masses are uncertain in the absence of detailed rotation curves and so several authors have used absolute blue magnitudes with the assumption of a constant mass:light ratio of about 1. Dwarf galaxies show virtually no correlation between O/H and M_B, and Wyse and Silk (1985), noting that a correlation does set in for $M_B < -18$, have suggested a threshold effect whereby only bright, big galaxies are capable of holding processed material.

In my view, the use of a constant mass:light ratio for dwarf galaxies with HII regions is even more dangerous than the use of dynamical masses because the light in such galaxies is dominated by one or two recent bursts of star formation. I therefore still prefer the dynamical masses and Fig 2 (after Pagel 1986) indicates that the evidence for the old simple relationships is still quite good, although IZw 18 is a conspicuous exception (Lequeux and Viallefond 1980). Fig 3 shows the relation between oxygen abundance and total mass, and also the mass-metallicity relation for elliptical galaxies after Mould (1984), which fits on to the HII regions quite well and also extrapolates smoothly down to dwarf spheroidals. There is no suggestion that HII regions are overabundant relative to stellar populations in galaxies of a given total mass and the existence of a lower abundance limit would seem to be more probably related to the existence of a lower mass limit to galaxies that contain HII regions.

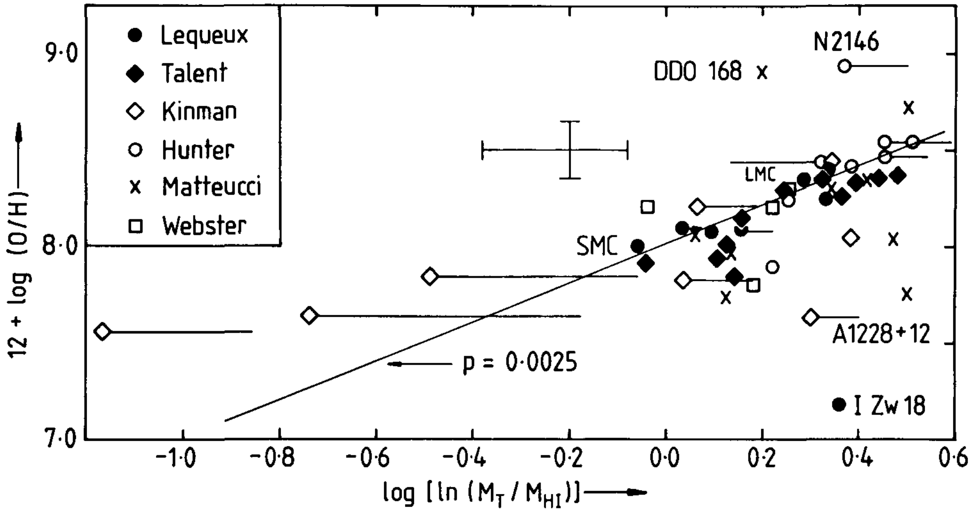

Figure 2. Logarithm of oxygen abundance in irregular and blue compact galaxies plotted against the double logarithm of the gas fraction. Data are from Lequeux et al. (1979), Talent (1980), Kinman and Davidson (1981), Hunter et al. (1982) and Matteucci and Chiosi (1983). Horizontal lines join alternative mass estimates and the straight line represents the prediction of the simple galactic chemical evolution model with a constant yield of 0.0025.

From Fig 2, it seems that the question of a variable yield at the lowest abundances must be regarded as not proven. Above the SMC, there is no evidence for a variable yield and when we come to spirals the yield actually goes up (cf. Peimbert and Serrano 1982; Edmunds and Pagel 1984a).

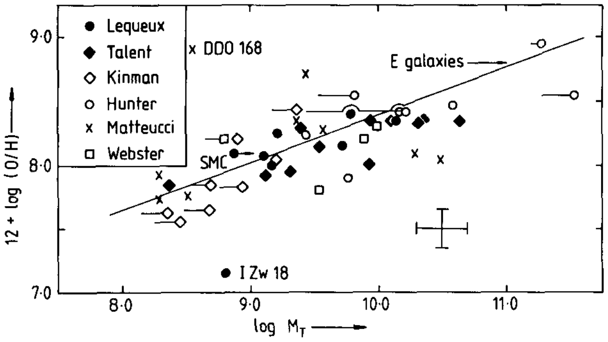

Figure 3. Logarithm of oxygen abundance plotted against total (dynamically estimated) mass of the galaxy. Sources of data are as in Fig. 2. The straight line shows the mass-metallicity relation for elliptical galaxies after Mould (1984), assuming $[Fe/H]_{stars} = [O/H]_{HII}$.

Why is the yield so low in irregular and blue compact galaxies? In principle, the effective yield (i.e. that deduced by applying the simple model) can be reduced by inflow of unprocessed gas or outflow of processed gas. However, mass loss is more efficient than inflow in cutting down the effective yield, which then goes down in the ratio $(1 + \lambda/\alpha)$ where λ/α is the ratio of mass lost to mass locked up in small stars and compact remnants (Hartwick 1976; Edmunds and Pagel 1984b, Mould 1984, Peimbert 1986). So with $\lambda/\alpha = 3$ we can understand a yield about 1/4 of that in the solar vicinity. As discussed most recently by Wyse and Silk (1985), such loss could be due to galactic winds permitted by the existence of shallow gravitational potential wells, but I see no basis for the threshold effect suggested by them at $M_B < -18$, corresponding to $\log M \simeq 9.4$. Alternatively, it may be that low-mass galaxies make a lot of low-mass stars with fewer low-mass stars forming at the higher metallicities found in spirals (Peimbert and Serrano 1982). Thus the question of inflows or outflows versus variable IMF is still wide open at the moment, but there is no good evidence that the yield in irregular and blue compact galaxies is anything other than constant.

3. ABUNDANCE OF HELIUM IN HII GALAXIES

Peimbert and Torres-Peimbert (1974) pointed out the usefulness of extragalactic HII regions as a source of information on primordial helium abundance from the Big Bang, noting that the helium abundance in the Magellanic Clouds and in the blue compact galaxies I Zw 18 and II Zw 40 previously studied by Searle and Sargent (1972) is slightly but perceptibly lower than in the Orion Nebula. They suggested that the helium abundance Y in any object exceeds the primordial value Y_p by an amount proportional to metallicity Z, itself assumed proportional to the readily measurable oxygen abundance, according to

$$Y = Y_P + Z\, dY/dZ$$

While Y_P is not very relevant to this discussion, dY/dZ is an interesting parameter from the point of view of galactic chemical evolution and in principle it can be measured by observing the dependence of helium abundance on oxygen abundance in HII regions although of course we have no guarantee that it is constant.

The most significant published estimates of Y_P and dY/dZ are those of Lequeux et al. (1979) who found dY/dZ ≃ 3 and Kunth and Sargent (1983) who found dY/dZ ≃ 0. Both are open to criticism because they involved a limited number of objects including II Zw40 (where λ5876 is absorbed by Galactic Na) and because they involved ionization corrections based on very dubious assumptions that have no basis in modern photo-ionisation models like those of Stasinska (1980) and Rubin (1985). These model calculations suggest that the icf is in fact negligible for ionising stars with effective temperatures exceeding 37,500K. The best strategy, then, is to select HII regions for which the icf can be expected to be negligible - a strategy adopted by Peimbert (1986) for a few objects ranging from the SMC to M17 and by myself in using the spectroscopic survey by Terlevich and Melnick from which I have selected 12 objects having very high excitation supplemented by 13 objects, also of very high excitation, taken from Lequeux et al. and from Kunth and Sargent. I Zw 18 was not included in the solution because of large discrepancies in the spectrophotometry by different authors (see Davidson and Kinman 1985).

Fig 4 shows the results, still in preliminary form. A dY/dZ slope is definitely present with 3σ significance and it essentially agrees with the results of Lequeux et al. (1979) and Peimbert (1986). A few objects may have upward deviations due to local enrichment by WR shells analogous to the galactic WR shells studied by Kwitter (1984) which have overabundances of He and N. Such objects will need to be eliminated in a more careful analysis. But the basic result is clear.

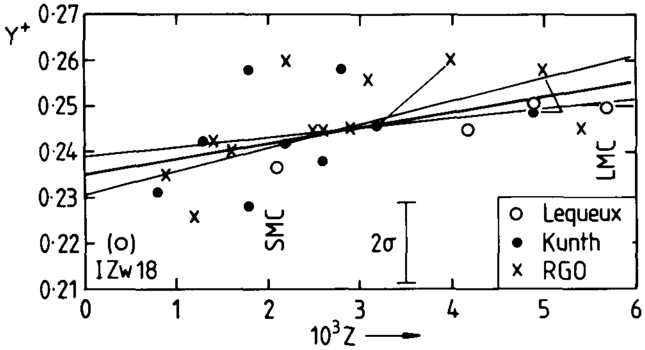

Figure 4. Plot of helium mass fraction Y(= Y^+) against Z = 25(O/H). The full and broken lines represent the least-squares regression of Y on Z with ± 1σ limits. Thin lines join points for galaxies in common with Kunth and Sargent.

We find

$$Y_P = 0.235 \pm .004,\ dY/dZ = 3.5 \pm 1.2,$$

i.e. quite a low value of Y_P (though not low enough to cause serious embarrassment in cosmology) and a high value of dY/dZ which in combination with Peimbert's recent results seems to extend all the way up to M17 with $Z \simeq .02$.

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