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THE INITIAL MASS FUNCTION IN HII GALAXIES

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Abstract

Observation of a large sample of HII galaxies shows that the emission line ratios of the youngest objects change systematically with gaseous oxygen abundance, which we interpret as resulting from changes in the initial mass function (IMF) of the ionising cluster. Comparison with cluster/nebula models shows that both the slope and the upper mass limit of the cluster IMF vary with abundance. In HII galaxies with oxygen abundance about 1/10 that of Orion, the IMF for massive stars must have a slope which is about a factor of 2 smaller than in the Solar Neighbourhood.

Introduction

"HII galaxies", dwarf galaxies with the spectra of giant HII regions, are ionised by massive O stars formed during a recent intense burst of star formation. Although the very strong, narrow emission lines which characterise these objects have been used in several studies to determine physical conditions in the ionised region (eg Searle and Sargent 1972, French 1980, Kinman and Davidson 1981, Kunth and Sargent 1983, Campbell, Terlevich and Melnick 1986a; CTMa), little is known about their ionising clusters.

The nebular excitation of low-abundance HII galaxies is higher than can be explained by a solar neighbourhood IMF (Lequeux et al 1981, Bergvall 1985). Giant HII regions in spiral galaxies show trends in emission line ratios which indicate that the temperature of the ionising cluster, T_{ion}, increases smoothly as the abundance decreases (eg Shields and Tinsley 1976, Stasinska 1980). The observed change in T_{ion} can arise if the IMF of the ionising cluster in giant HII regions and HII galaxies is abundance-sensitive: Shields and Tinsley (1976) proposed a systematic change in the upper mass limit of the IMF, while Terlevich (1982) suggested that the slope of the IMF decreases with decreasing abundance.

Studies of the ionising cluster in HII galaxies have so far been based almost entirely on UV/optical/infrared colours, mass-to-light ratios, and recombination line equivalent widths; the easily-observed emission line ratios, which carry important information about the mass distribution and age of the ionising cluster, have been almost totally neglected. We report here the results of a comparison between the line ratios of a sample of $\sim$ 50 HII galaxies and those of model nebulae ionised by clusters with a variable IMF.

Modelling strategy

The ionising clusters of HII galaxies evolve very rapidly, on timescales of order the lifetime of a massive star, a few Myr. As the cluster evolves, T_{ion} falls and the "hardness" of the ionising spectrum decreases, leading to a rapid change in the relative strength of lines from different ionisation stages of a given element. A least-squares fit to the distribution of HII galaxies in a T_{ion} -sensitive emission line ratio will therefore always underestimate the T_{ion} of the cluster IMF (as distinct from the cluster's current T_{ion}) and consequently cause us to either overestimate the IMF slope or underestimate its upper mass limit. If we wish to study the abundance behaviour of the IMF, it is therefore crucial to remove the effect of cluster evolution.

In principle, there exists a set of HII galaxies, covering a range in abundance, in which the ionising cluster is at close to zero age: a "zero age sequence" (ZAS) which will appear as an upper envelope in T_{ion} -sensitive emission line diagrams. Identification and modelling of this ZAS using zero-age main sequence cluster models will allow us to determine the abundance behaviour of the HII galaxy IMF for stars more massive than $\sim 20\ M_{\odot}$.

Model HII galaxies

We have used the cluster code of Melnick, Terlevich and Eggleton (1985) to produce zero-age main sequence model clusters of mass $10^6\ M_{\odot}$. The cluster mass distribution is specified by a power-law IMF with slope α between 0.1 $M_{\odot}$ and a maximum of 200 $M_{\odot}$. We next pass the ionising part of the cluster's spectrum to a model nebula code (Ferland and Truran 1981) and construct low-density, clumpy, radiation-bounded HII regions with oxygen abundances spanning the range covered by the data. The models are discussed in greater detail in Campbell, Terlevich and Melnick (1986b; CTMb).

Comparison of models and data: the ([OIII]/[OII], O/H) diagram

The T_{ion} -sensitive line ratio [OIII]/[OII] is insensitive to O/H and thus allows us to examine directly the behaviour of T_{ion} with abundance. The ZAS, from which objects evolve downwards, is easily visible in figure 1. The curves in figure 1a are the loci of model HII galaxies ionised by clusters with a constant IMF specified by the M_u and α shown. All these models are poor fits to the data. Those with $\alpha = 3.0$ produce values of [OIII]/[OII] which fall nearly an order of magnitude below the ZAS for $O/H \simeq 4 \times 10^{-5}$, while those with $\alpha = 1.0$ grossly overestimate the position of the ZAS for 6×10^{-5}. It is immediately evident that for any M_u , a "flat" IMF ($\alpha \sim 1.0$) is required at low abundance. The steep turn-down of the [OIII]/[OII] envelope with increasing abundance requires a systematic decrease in M_u or increase in α .

The strongest dependence of α and M_u on abundance which can be accommodated without conflicting with their observed values at the Solar Neighbourhood oxygen abundance are

$$M_u = 5.9\ (O/H)^{-0.3} \qquad (1)$$
$$\alpha = 1.2\ \log\ (O/H) + 6.9 \qquad (2)$$

The loci of models in which M_u and α vary according to equations (1) and (2) are shown in figures 1b and 1c respectively. The fit of the variable-M_u models is little better than that of constant IMF models, owing to the small change in the cluster mass distribution caused by changes in M_u . Variable α models do much better, but still overestimate the position of the envelope for $O/H \gtrsim 1.5 \times 10^{-4}$.

It seems therefore that a systematic change with abundance of both α and M_u is required to fit the [OIII]/[OII] envelope. We have constructed two such models, one in which α increases with abundance in the variable-M_u model (equation (1)), and another in which M_u decreases with abundance in the variable-α model (equation (2)). Figure 1d demonstrates that these closely similar models both produce a very good fit to the ZAS.

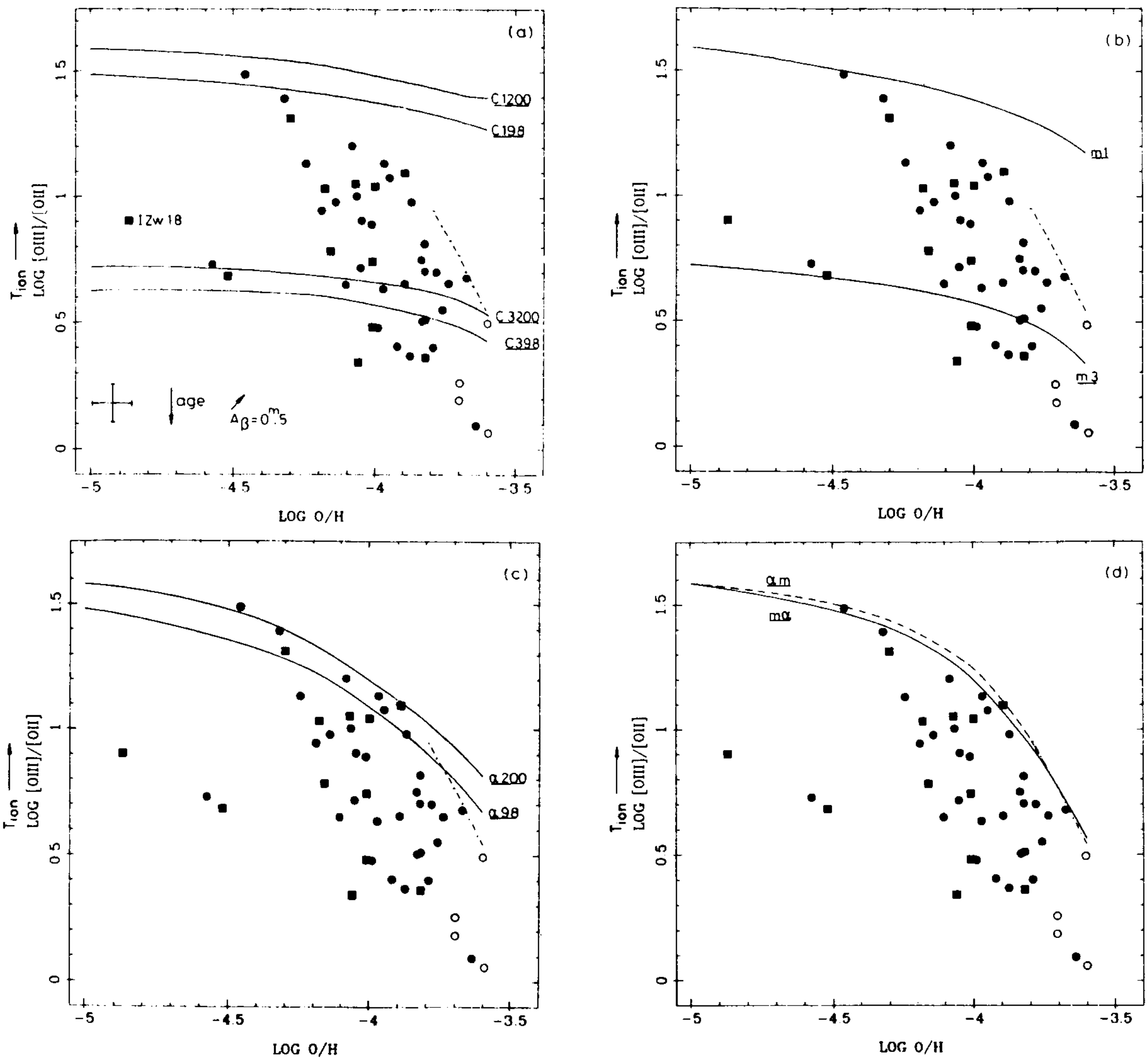

Figure 1

The distribution of the sample in the ([OIII]/[OII], O/H) plane. Circles: data from CTMa; squares: data from Kunth and Sargent (1983). IZw18 is from Kinman and Davidson (1981). The short dash-dot line represents the adopted zero-age envelope for O/H $> 1.5 \times 10^{-4}$, as explained in CTMb. The model loci are labelled as follows: C398: constant IMF, $\alpha = 3.0$, $M_u = 98\ M_\odot$; C3200: constant IMF, $\alpha = 3.0$, $M_u = 200\ M_\odot$; C198: constant IMF, $\alpha = 1.0$, $M_u = 98\ M_\odot$; C1200: constant IMF, $\alpha = 1.0$, $M_u = 200\ M_\odot$; M3: IMF with $\alpha = 3.0$ and variable M_u (eq.1); M1: IMF with $\alpha = 1.0$ and variable M_u ; α 98: IMF with $M_u = 98\ M_\odot$ and variable α (eq.2); α 200: IMF with $M_u = 200\ M_\odot$ and variable α ; M α : the variable M_u model (eq.1) with $1.0 < \alpha < 2.7$; α M: the variable α model (eq.2) with $200 > M_u > 73\ M_\odot$.

Discussion

An excellent fit to our adopted zero-age sequence in the ([OIII]/[OII], O/H) diagram has been obtained by allowing the mass distribution of the ionising clusters of HII galaxies to vary systematically with abundance. Our models indicate a very pronounced change in the IMF in the oxygen abundance range 2.5 x

10^{-5} to 2.5×10^{-4}; α is required to vary from $\simeq 1.5$ to 2.7 and M_u from $\simeq 200$ to $\simeq 75\ M_\odot$. The dependence of the IMF slope on abundance is closely similar to that derived (using different methods) for giant HII regions and HII galaxies by Terlevich (1982).

Conclusions

Assuming trends in emission line ratios are due to changes in the stellar mass distribution of the ionising clusters of HII galaxies, the main results of the emission line modelling can be summarised as follows:
1) No constant IMF can reproduce the values of the T_{ion} -sensitive line ratio [OIII]/[OII] observed in the youngest ("zero age") objects over the oxygen abundance range $2.5 \times 10^{-5} < O/H < 2.5 \times 10^{-4}$.
2) A systematic change with abundance of M_u alone also fails to reproduce the zero age range in [OIII]/[OII], owing to the small effect which even large changes in M_u have on the mass distribution of the ionising cluster.
3) Models in which only α varies cover much more of the zero-age range in [OIII]/[OII] and if $M_u \simeq 200\ M_\odot$, are correct for oxygen abundances $\lesssim 1 \times 10^{-4}$. Above this they slightly overestimate the position of the [OIII]/[OII] envelope.
4) Models in which both α and M_u vary with abundance reproduce the data envelope very well over the full range in oxygen abundance of 2.5×10^{-5} to 2.5×10^{-4}. The detailed abundance behaviour of α and M_u is given in CTMb.
5) For the lowest-abundance HII galaxies, eg IZw18 ($O/H \simeq 1.5 \times 10^{-5}$), the predicted IMF slope is $\simeq 1.2$, irrespective of M_u . IZw18 is an evolved object in which T_{ion} is currently considerably lower than its zero-age value.

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