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PROBING THE CHEMICAL ABUNDANCES IN DISTANT GALAXIES WITH 10 M CLASS TELESCOPES

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RESUMEN

La determinación de abundancias químicas en galaxias con formación estelar, y el estudio de su evolución sobre escalas de tiempo cosmológicas son piezas clave en la comprensión del proceso global de formación y evolución de las galaxias. Esta contribución presenta los últimos resultados en este campo. Se muestra cómo el estudio detallado de abundancias químicas en galaxias seleccionadas en el ultravioleta, ya sean galaxias H II o galaxias con brotes de formación estelar nuclear, junto con el desarrollo de nuevos modelos de evolución química, pueden imponer fuertes restricciones sobre el estado evolutivo de estos objetos en términos de su tasa de formación estelar. Finalmente, se presenta un resumen del estado actual del conocimiento sobre las propiedades químicas de galaxias lejanas. Aunque las muestras son aún demasiado pequeñas para estudios estadísticos, estos resultados proporcionan una primera visión sobre la naturaleza y la evolución de las galaxias lejanas con formación estelar y su relación con las galaxias actuales. Sin lugar a dudas, los futuros surveys espectroscópicos a gran escala sobre telescopios de la clase de 10 m proporcionarán resultados fundamentales sobre estos temas.

ABSTRACT

The determination of chemical abundances in star forming galaxies and the study of their evolution on cosmological timescales are powerful tools for understanding galaxy formation and evolution. This contribution presents the latest results in this domain. We show that detailed studies of chemical abundances in UV-selected, H II and starburst nucleus galaxies, together with the development of new chemical evolution models, put strong constraints on the evolutionary stage of these objects in terms of star formation history. Finally, we summarize our current knowledge of the chemical properties of distant galaxies. Although the samples are still too small for statistical studies, these results give an insight into the nature and evolution of distant star forming objects and their link with present-day galaxies. No doubt that the next large scale spectroscopic surveys on 10 m class telescopes will shed light on these fundamental issues.

Key Words: **GALAXIES: ABUNDANCES — GALAXIES: STARBURST — GALAXIES: EVOLUTION**

1. INTRODUCTION

Tracing the star formation history (SFH) of galaxies is essential for understanding galaxy formation and evolution. The chemical properties of galaxies are closely related to their SFHs, and can be considered as fossil records, enabling us to track galaxy formation history up to the present.

There is a lot of observational evidence suggesting that the SFH of galaxies has not been monotonic with time, but exhibits instead significant fluctuations. Galaxies in the Local Group are excellent examples showing a variety of SFHs. Further evidence for the “multiple-burst” scenario was recently found in massive starburst nucleus galaxies (SNBGs, Coziol et al. 1999; Lançon et al. 2001). Even the small mass and less evolved H II galaxies seem to be formed of age-composite stellar populations indicating successive bursts of SF (Raimann et al. 2000). Kauffmann et al. (2001) recently explored numerical models of galaxy evolution in which star formation occurs in two modes: a low efficiency continuous mode and a high efficiency mode triggered by interaction with a satellite. With these assumptions, the SFH of low mass galaxies is characterized by intermittent bursts of SF separated by quiescent periods lasting several Gyr, whereas massive galaxies are perturbed on timescales of several hundred Myr and thus have fluctuating but relatively continuous SFHs.

Examining the chemical evolution and physical nature of star forming galaxies over a range of redshifts will shed light on this issue. Emission lines from H II regions have long been the primary means of chemical diagnosis in local galaxies; this method,

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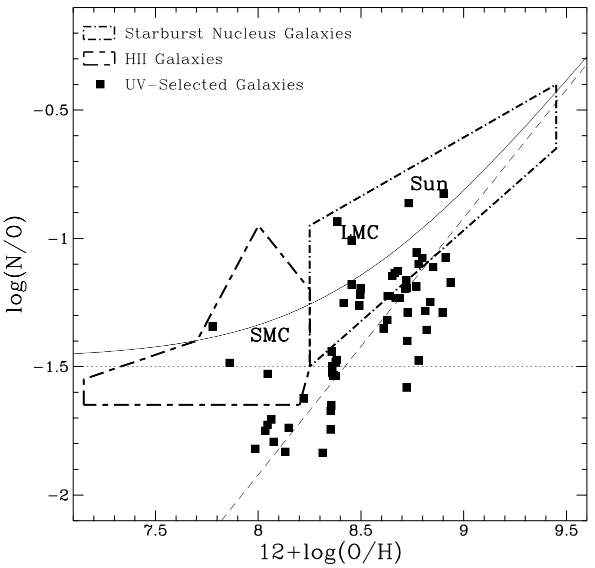

Fig. 1. N/O versus $12 + \log(O/H)$ for the UV-selected galaxies (squares) and two comparison samples of nearby star forming galaxies: Starburst nucleus galaxies and H II galaxies (see Contini et al. 2002 for references).

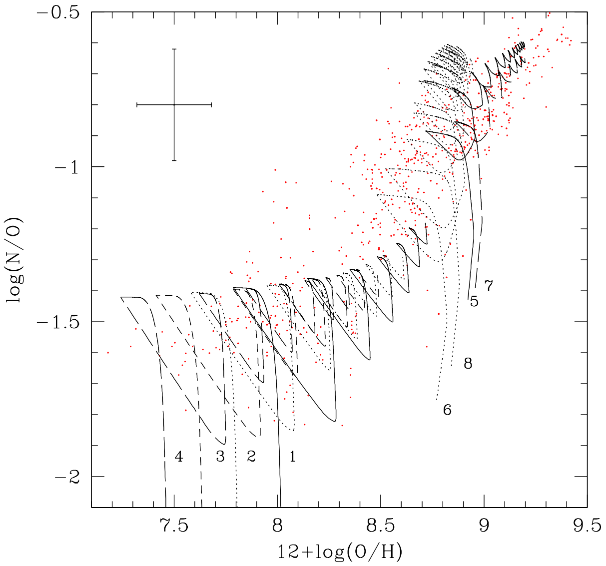

Fig. 2. N/O versus $12+\log(O/H)$ for the samples of star forming galaxies (dots) described in Figure 1. Model predictions assuming bursting SF scenario are shown. Model parameters are listed in Mouhcine & Contini (2002).

however, has only recently been applied to galaxies at cosmological distances following the advent of infrared spectrographs on 8 to 10 m class telescopes (Pettini et al. 1998; Kobulnicky & Zaritsky 1999; Kobulnicky & Koo 2000; Hammer et al. 2001; Pettini et al. 2001) .

2. THE CASE OF UV-SELECTED GALAXIES

Contini et al. (2002) recently derived the chemical properties of a UV-selected sample of galaxies. These objects are found to be intermediate between low mass, metal-poor H II galaxies and more massive, metal-rich SBNGs (see Coziol et al. 1999 for the dichotomy), spanning a wide range of oxygen abundances, from ∼0.1 to 1 $Z_\odot$.

The behavior of these starburst galaxies in the N/O versus O/H relation (see Figure 1) has been investigated in order to probe their physical nature and SFH (see Contini et al. 2002 for details). At a given metallicity, the majority of UV-selected galaxies have low N/O abundance ratios whereas SBNGs show an excess of nitrogen abundance when compared to H II regions in the disks of normal galaxies (see also Coziol et al. 1999). The interpretation of these types of behavior is not straightforward. A possible interpretation of the location of UV-selected galaxies and SBNGs in the N/O versus O/H relation could be that UV galaxies are observed at a special stage in their evolution, following a powerful starburst that enriched their ISM in oxygen (Contini et al. 2002), whereas SBNGs experienced successive starbursts over the last Gyrs to produce the observed nitrogen abundance excess (Coziol et al. 1999).

3. CONSTRAINING THE SFH OF GALAXIES

At a given metallicity, the distribution of N/O abundance ratios shows a large dispersion, both at low and high metallicity (Coziol et al. 1999; Contini et al. 2002). Only part of this scatter is caused by uncertainties in the abundance determinations. The additional dispersion must therefore be accounted for by galaxy evolution models. Various hypotheses (localized chemical "pollution", IMF variations, differential mass loss, etc.) were suggested as responsible for such scatter (e.g., Kobulnicky & Skillman 1998) but none of these is able to reproduce the full N/O scatter at a given metallicity.

A natural explanation for the variation of N/O at constant metallicity might be a significant time delay between the release into the ISM of oxygen by massive, short-lived stars and that of nitrogen produced in low mass longer-lived stars. The "delayed-release" model assumes that SF is an intermittent process in galaxies, while maintaining an universal IMF and standard stellar nucleosynthesis (Edmunds & Pagel 1978; Garnett 1990).

Mouhcine & Contini (2002) recently investigated this possibility in order to quantify the SFH of star-

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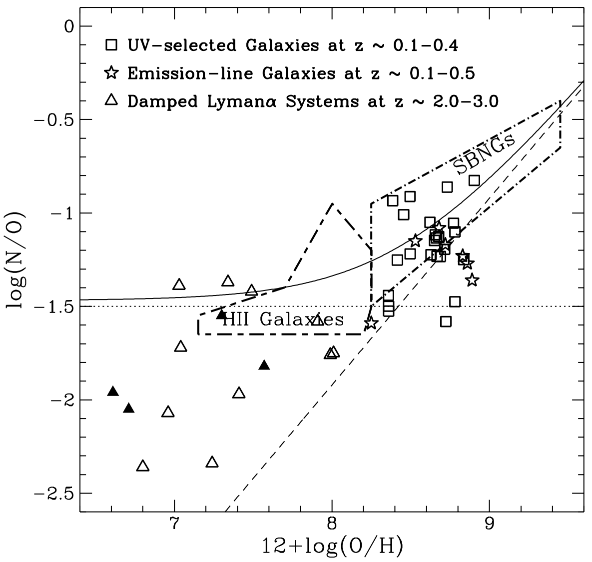

Fig. 3. N/O as a function of metallicity for distant star forming galaxies. All chemical abundance data published so far for high z galaxies are on this plot (see text for references). The location of damped Lyman α systems (triangles; Pettini et al. 2002) at z ~2.0–3.0 is also shown. Filled triangles indicate upper limits.

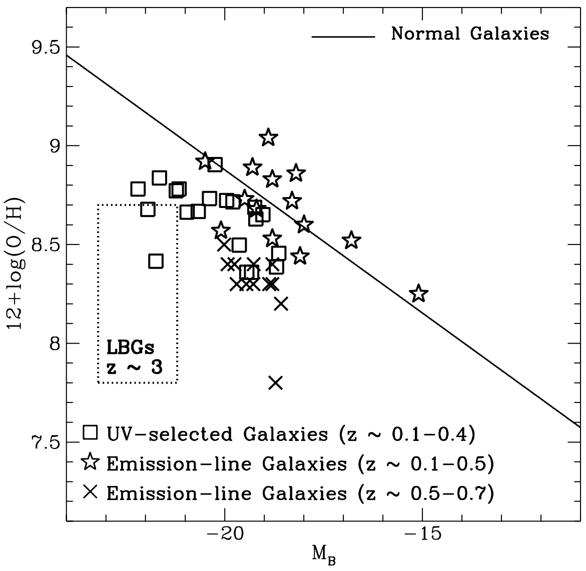

Fig. 4. Absolute B band magnitude as a function of metallicity for distant galaxies (see text for references). The location of high redshift ($z \sim 3$) Lyman break galaxies is indicated as a box encompassing the range of O/H and M_B derived for these objects (Pettini et al. 2001).

burst galaxies over a wide range of mass and metallicity. The observed dispersion in the well-known metallicity–luminosity relation has been used as an additional constraint. It was confirmed that *continuous* SF models are unable to reproduce the scatter observed in both N/O and M_B versus O/H scaling relations. The dispersion associated with the distribution of N/O as a function of metallicity can indeed be explained in the framework of *bursting* SF models. Figure 2 shows the oscillating behavior of the N/O ratio due to the alternating bursting and quiescent phases. In this case, the observed dispersion in the N/O versus O/H relation is explained by the time delay between the release of oxygen by massive stars into the ISM and that of nitrogen by intermediate mass stars. During the starburst events, as massive stars dominate the chemical enrichment, the galaxy moves towards the lower right part of the diagram. During the interburst period, when no SF is occurring, the release of N by low and intermediate mass stars occurs a few hundred Myr after the end of the burst and increases N/O at constant O/H. The dilution of interstellar gas by the newly accreted intergalactic gas is also observed during the quiescent phases.

Extensive model computations (see Mouhcine & Contini 2002 for details) show that no possible combination of the model parameters (i.e., burst duration, interburst period, SF efficiency, gas accretion timescale, etc.) is able to account for the observed spread for the whole sample of galaxies. They found that metal-rich spiral galaxies differ from metal-poor ones by a higher SF efficiency and starburst frequency. Low mass galaxies experienced a few bursts of SF whereas massive spiral galaxies experienced numerous and extended powerful starbursts.

4. PHYSICAL PROPERTIES OF DISTANT GALAXIES

In Figure 3, we compare the location of intermediate redshift ($z \sim 0.1$–0.4) emission line (EL; Kobulnicky & Zaritsky 1999) and UV-selected (Contini et al. 2002) galaxies with nearby samples of H II and SBNGs in the N/O versus O/H plane. Most of these distant objects have chemical abundances typical of massive and metal-rich SBNGs (i.e., $12 + \log(\mathrm{O/H}) \geq 8.5$). Some of them show high N/O abundance ratios ($\log(\mathrm{N/O}) \gtrsim -1$), which could be owing to a succession of starbursts over the last few Gyrs (e.g.,Coziol et al. 1999). None of these intermediate redshift galaxies are located in the region occupied by nearby metal-poor H II galaxies. The fact that intermediate redshift galaxies are mostly metal rich objects is likely to be a selection effect arising from the well-known metallicity–luminosity relation-

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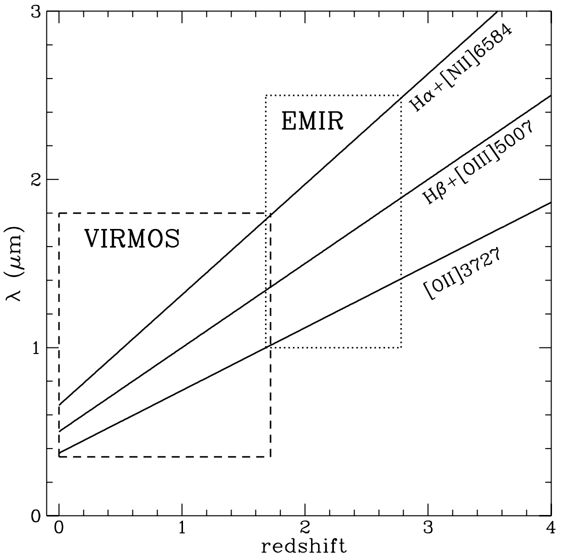

Fig. 5. Location of the main optical emission lines as a function of redshift. With the new generation of visible/infrared multiobject spectrographs, such as VIRMOS/VLT and EMIR/GTC, both the O/H and N/O abundance ratios will be estimated in thousands of star forming galaxies up to $z \sim 3$.

ship. Only the most luminous, and thus metal-rich objects, are detected so far with the current instrumentation on 8 m class telescopes. It is interesting to note that, like a significant fraction of UV-selected galaxies, some optically selected EL galaxies also show strikingly low N/O ratios.

Figure 4 shows the location of distant galaxies in the metallicity–luminosity relation. Three samples of intermediate redshift galaxies are considered: EL galaxies at $z \sim 0.1$–0.5 (Kobulnicky & Zaritsky 1999), luminous and compact EL galaxies at $z \sim 0.5$–0.7 (Hammer et al. 2001), and the UV-selected galaxies (Contini et al. 2002). The location of high redshift ($z \sim 3$) Lyman break galaxies (LBGs) is shown as a box encompassing the range of O/H and M_B derived for these objects (Pettini et al. 2001). Whereas EL galaxies with redshifts between 0.1 and 0.5 seem to follow the metallicity–luminosity relation of "normal" galaxies (solid line), there is a clear deviation for both UV-selected and luminous EL galaxies at higher redshift ($z \sim 0.5$–0.7). These galaxies thus appear 2–3 mag brighter than "normal" galaxies of similar metallicity, as might be expected if a strong starburst had temporarily lowered their mass-to-light ratios. Hammer et al. (2001) argue that luminous and compact EL galaxies could be the progenitors of present-day spiral bulges. The deviation is even stronger for LBGs at $z \sim 3$. Even allowing for uncertainties in the determination of O/H and M_B, LBGs fall well below the metallicity–luminosity relation of "normal" local galaxies and have much lower abundances than expected from this relation given their luminosities. The most obvious interpretation (Pettini et al. 2001) is that LBGs have mass-to-light ratios significantly lower than those of present-day "normal" galaxies.

Although the samples are still too small to derive firm conclusions on the link between distant objects and present-day galaxies, the present results give new insight into the nature and evolution of distant star forming galaxies. No doubt the next large-scale spectroscopic surveys on 10 m class telescopes (e.g., VIRMOS on VLT and COSMOS/EMIR on the GTC, see Figure 5) will shed light on these fundamental issues by producing statistically significant samples of galaxies over a wide range of redshifts.

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