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GALAXY EVOLUTION STUDIES OBSERVING EMISSION LINE GALAXIES WITH THE GTC

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RESUMEN

Las galaxias con líneas de emisión son los objetos más fáciles de detectar y estudiar en el Universo a alto desplazamieno al rojo. Están siendo usadas para trazar la evolución de observables críticos del Universo, tales como densidades de tasa de formación estelar, propiedades de los procesos de formación estelar y abundancias. GTC constituirá una herramienta muy potente para el estudio de la evolución de las poblaciones de galaxias con líneas de emisión a diferentes desplazamientos al rojo. Grandes exploraciones como OTELO, llevada a cabo con OSIRIS y extendida mediante espectroscopía infrarroja con EMIR, permitirán a GTC contribuir con un gran impacto en el campo de la Astronomía Extragaláctica.

ABSTRACT

Emission line galaxies are the most easily detected and studied objects in the high redshift Universe. They are being used to trace the evolution of the critical observables of the Universe such as star formation rate densities, starburst properties, and abundances. The GTC will be a very powerful tool for studying the evolution of emission line galaxy populations at different redshifts. Large surveys, such as OTELO, carried out with OSIRIS and extended by follow-up spectroscopic studies in the near infrared using EMIR will enable the GTC to make a major impact in extragalactic astronomy.

Key Words: **GALAXIES : EVOLUTION — GALAXIES**

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1. EMISSION-LINE GALAXY SURVEYS AND GALAXY EVOLUTION

Several surveys of emission line galaxies (hereafter ELGs) have been carried out in recent decades, covering large portions of the sky (see Zamorano et al. 1994 for a review). Most of these surveys have targeted the blue part of the optical spectrum for the detection of strong emission lines, such as [O III] λ5007. A small fraction of these projects focused on the red part of the spectrum and used the presence of the Balmer Hα and the neighboring [N II] λ6548,6584 emission lines. All these surveys were excellent sources for catalogs of extreme star forming galaxies, active galactic nuclei, and bizarre objects, and one of their main goals was to detect low luminosity blue compact galaxies (BCGs) with low metallicities. Surveys carried out in the red were considered to be "contaminated" because of their ability to detect all kinds of star forming galaxies, but this property turned out to be a very powerful tool as the interest of researchers shifted from extreme objects to the average properties of galaxy populations.

The arrival of the *Hubble Space Telescope* (*HST*) and the new generation of 8 m class telescopes determined a whole series of studies about the nature of the galaxy populations of the Universe at different redshifts and their corresponding look-back times. Because emission lines are easier to observe, faint galaxy samples are mostly populated by ELGs. The need for well-studied local reference samples for similar galaxy samples at all redshifts has triggered renewed interest in classic surveys such as the Universidad Complutense de Madrid (UCM) survey for local star forming galaxies (Zamorano et al. 1994, 1996). It is possible now to sketch the overall evolution of observational quantities as a function of look-back time, as illustrated by the pioneering work of Madau et al. (1996) on the evolution of the current star formation rate (SFR) of the Universe. These authors combined 1500 Å UV luminosities of the high redshift galaxies in the Hubble Deep Field (Williams et al. 1996), with 2800 Å UV luminosities of the intermediate redshift galaxies of the Canada–France Redshift Survey (CFRS, Lilly et al. 1996) and the SFR density of the local Universe, which was measured using Hα as a tracer by Gallego et al. (1995).

In recent years, 8 m class telescopes have gathered large samples of galaxies at different redshifts. The overall evolution of properties of the Universe,

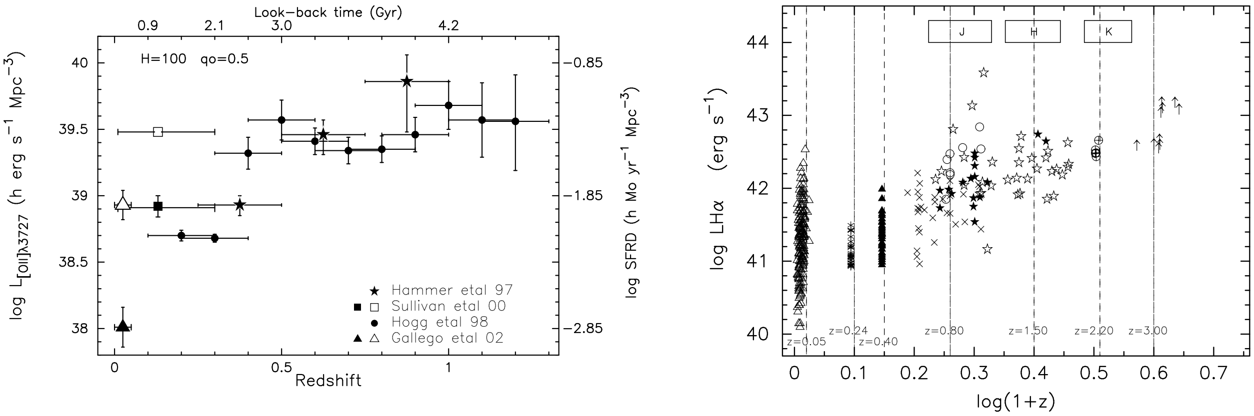

Fig. 1. Left: The evolution of the [O II] $\lambda3727$ luminosity density of the Universe up to $z \sim 1.4$ (Gallego et al. 2002). The observed and extinction-corrected values for the UCM sample are represented as filled and open triangles, respectively. Filled circles correspond to Hogg et al. (1998), filled stars are for the Hammer et al. (1997) values, and the filled and open squares are for the observed and extinction-corrected Sullivan et al. (2000) values. Right: Comparison of the observed Hα luminosities measured by the different surveys of Hα emission line galaxies at various redshifts (See text for details). The cosmology assumed was $H_0 = 50$ km s^{-1} Mpc^{-1}, $\Omega_m = 1.0$, and $\Omega_\Lambda = 0$. Symbols are the same as for Figure 2.

such as the luminosity densities in given emission lines, are now being obtained (see Figure 1). These projects will be also be able to tackle the general evolution of galaxies, large scale structure, and the analysis of new kinds of galaxies. However, because of their simple photometric selection technique (all objects brighter than a given apparent magnitude or a combination of two filters), they will leave further work to be done in specific fields of research.

2. ELG STUDIES WITH OSIRIS

It is clear from Figure 1 that evolution since $z \sim 1$ has been confirmed in the overall properties of star forming galaxy populations. However, these results cannot go much further because they are obtained from poor samples, given that the number of objects per redshift bin is small (sometimes only a few galaxies), and that only bright objects are being selected by current techniques. What remains to be ascertained are the changes in conditions and galaxy properties that motivated this evolution.

The tunable filters to be used with OSIRIS on the GTC (see Cepa et al., this volume, p. 13) will provide to the GTC community with a unique tool for selecting samples at a well-defined redshift range by their luminosities in a specific emission line. OTELO is a proposed GTC key project (see Cepa et al., this volume, p. 66) whose main goal will be to detect and study representative and complete samples of galaxies necessary for the study of the overall properties and physical conditions of emission galaxy populations at specific look-back times.

Table 1 summarizes the main characteristics of OTELO. Tunable filters will be used to scan the sky in three well defined wavelength windows that correspond with Hα redshifted to $z = 0.09$, 0.24, and 0.40. These windows have been selected for their low sky emission. Each window will be covered for a different sky area and a different flux limit to ensure a minimum of Hα emitters close to 500. As a natural result, [O III] λ 5007, Hβ, and [O II] $\lambda3727$ emitters will also be detected, providing a total of nine redshift ranges from $z = 0.09$ to $z = 1.46$ scanned for ELGs. The expected number of ELGs per OSIRIS field has been estimated assuming an evolution coherent with the behavior observed in Figure 1 (Pascual et al. 2001). As a general deep survey, OTELO will also be of great interest in the fields of blue compact galaxies, AGN, quasars, and Galactic astronomy.

The key science case for the OTELO project will be the evolution of the physical properties of the current star forming galaxy population at different redshifts as traced by their Hα luminosities and equivalent widths. These parameters, when combined with multiband photometric data, allow the estimation of burst age, strength, and metallicity (see Gil de Paz et al. 2000). If additional information is added in the K band, it is also possible to estimate the mass-to-luminosity ratio and the total stellar mass of the system. The complementing photometry will be also used to confirm the nature of the emission line detected using the photometric redshift technique. The OTELO survey will be carried out with sufficient spectral resolution to resolve Hα from the

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TABLE 1

OTELO OBSERVING WINDOWS

Win.	λ range (Å)	Flux limit erg cm^{-2} s^{-1}	z for Hα	Hα ELGs[a]	z for [O III] λ5007	z for [O II] λ3727	Higher z ELGs [b]	Total Hα ELGs	Total ELGs
W1	7075-7250	2×10^{-16}	0.09	0.5	0.43	0.92	1.5	500	2000
W2	8072-8247	3×10^{-17}	0.24	8.8	0.62	1.18	51.7	502	3449
W3	9060-9300	1×10^{-17}	0.40	50.7	0.84	1.46	283.5	507	3342

[a]Expected number per OSIRIS field assuming an evolution as Pascual et al. (2001).

[b]Expected number of Hα+[O III] λ5007 + [O II] λ3727 emitters assuming the same evolution.

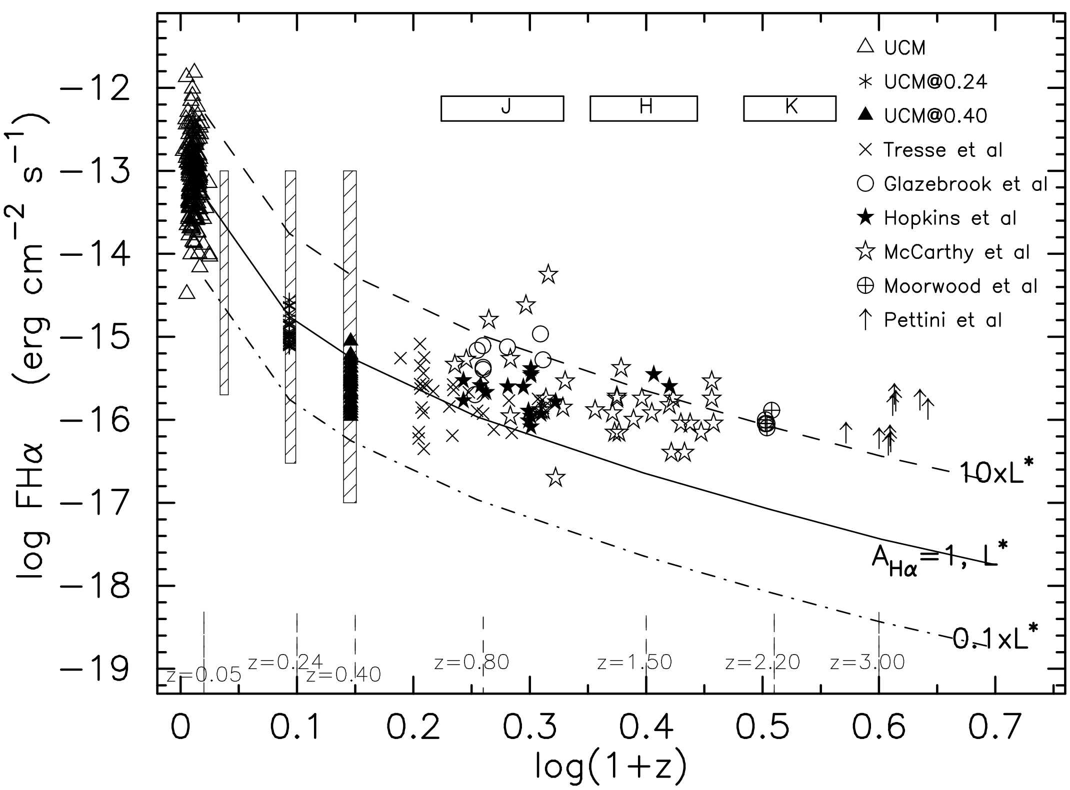

Fig. 2. Comparison of the Hα fluxes measured by the different surveys of Hα ELGs at various redshifts (See text for details). In the upper part of the figure, the corresponding redshifts to observe Hα in the NIR J, H, and K bands have also been represented.

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adjacent [N II]λ6548,6584 emission lines. The Hα over [N II] λ6584 ratio is also a good indicator of the nitrogen gas metallicity and it will be used to trace its evolution with redshift and better estimate the SFR from the Hα luminosity (Weilbacher & Fritze-v.Alvensleben 2001).

In Figure 2 are plotted the Hα fluxes that have been measured by the various surveys of Hα ELGs at different redshifts. The full curve is the expected flux for an $L^*_{H\alpha}$ at $z = 0$ with $\log(LH\alpha) = 42.15$ erg s^{-1} (Gallego et al. 1995), assuming an extinction correction of $A_{H\alpha} = 1$ mag and a cosmology of $H_0 =$ 50 km s^{-1} Mpc^{-1}, $\Omega_m = 1.0$, and $\Omega_\Lambda = 0$. The dashed and dot–dashed curves are for $10 \times L^*_{H\alpha}$ and $0.1 \times L^*_{H\alpha}$. The local Universe is represented by the UCM survey (Gallego et al. 1997). The Universe at $z = 0.24$ and $z = 0.40$ are the narrow band filter surveys carried out by Pascual et al. (2001) and Jones & Bland-Hawthorn (2001). The other objects at higher redshift are from near infrared spectroscopy obtained with 8 m telescopes (Tresse et al. 2002; Glazebrook et al. 1999) and serendipitous discoveries in slitless spectroscopy observations with NICMOS (McCarthy et al. 2001; Hopkins et al. 2001). At $z = 2.2$, there are a few objects available that have been detected by Moorwood et al. (2001) using a narrow band filter in K. Finally, the $z \sim 3$ values are rough estimates from the observed Hβ fluxes published by Pettini et al. (2001).

It is clear from Figures 1 and 2 that we only know about the most luminous fraction of the star forming galaxies at high redshift. The hatched rectangles at $z = 0.09$, 0.24, and 0.4 in Figure 2 correspond to the three planned OTELO redshift ranges and flux limits. The values selected (see Table 1) are those corresponding to an Hα emission line luminosity of $\sim 10^{40}$ erg s^{-1} at that redshift. This luminosity is fainter than $0.1 \times L^*_{\mathrm{H}\alpha}$ in the local Universe and will allow us to cover a wide range in luminosities, including the expected but still unknown population of low luminosity star forming galaxies that are supposed to play a key role in the overall evolution of the SFR density of the Universe. The number density and physical properties of this kind of object will provide galaxy evolution models with critical contour conditions. OSIRIS could be also used to obtain optical spectroscopy for more detailed studies of specific subsamples of objects.

3. ELGS STUDIES IN THE NEAR-INFRARED

The GTC will be an even more powerful tool for studying galaxy evolution when the imager and multiobject spectrograph in the near infrared (EMIR) is commissioned. An obvious extension of OTELO with EMIR will be the follow-up near infrared spectroscopy of those [O II] λ3727 and [O III] λ5007 emitters selected from the tunable filter images. This work will extend up to $z = 1.46$ the same analysis carried out for the Hα emitters at $z = 0.09$, 0.24, and 0.40. EMIR could also provide deep imaging in the NIR bands. Another extension of the OTELO project will be to use OSIRIS equipped with an eventual tunable filter in the NIR, or simulate its functionality using narrow band filters with EMIR in the imaging mode. A new IR–OTELO would allow us to build new analogous samples of Hα ELGs from $z \sim 0.8$ up to $z \sim 2.5$.

Only with well focused science case studies will the GTC attain long-lasting impact in key fields of astronomical research.

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