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THE OTELO PROJECT

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RESUMEN

OTELO (OSIRIS Tunable Emission Line Object Survey), cartografiará objetos con líneas de emisión en ventanas atmosféricas relativamente libres de líneas de emisión del cielo, mediante los filtros sintonizables del instrumento OSIRIS. Se observarán campos de baja extinción a altas latitudes galácticas con una separación angular suficiente hasta cubrir un área total de 1–2 grados cuadrados. Con una profundidad de 8×10^{-18} erg/cm^2/s a 5σ, OTELO detectará objetos con EW$\sim$6, lo cual lo convierte en el cartografiado más profundo en líneas de emisión que existe. OTELO constituye una sonda del espacio profundo que proporcionará una muestra representativa de objetos desde z =0.24 hasta 6.7. Las técnicas de observación con filtros sintonizables permitirán el estudio de volúmenes de Universo bien definidos con un flujo límite bien determinado. En esta contribución se muestra el estado del proyecto así como algunos de los estudios evolutivos más significativos que se abordarán.

ABSTRACT

OTELO, (OSIRIS Tunable Emission Line Object Survey), will survey emission line objects using OSIRIS tunable filters in selected atmospheric windows relatively free of sky emission lines. Different high latitude and low extinction sky regions with enough angular separations will be observed yielding a total area of 1–2 square degrees. A 5σ depth of 8×10^{-18} erg/cm^2/s will allow detecting objects of EW$\sim$6, making OTELO the deepest emission line survey to date. OTELO is a deep space probe that will provide a representative sample of the Universe from z =0.24 through 6.7. Given the observing procedure, OTELO will allow studying clearly defined volumes of Universe at a known flux limit. In this contribution, a review of the project status is presented, together with some of the most significant evolutionary studies that will be tackled.

Key Words: **COSMOLOGY: OBSERVATIONS — GALAXIES: EVOLUTION — GALAXIES: INTERSTELLAR MATTER — SURVEYS**

1. INTRODUCTION

Narrow band imaging surveys are a powerful tool to detect and study the evolution of line emitter objects (see Steidel et. al 2000 and references therein). Since the selection procedure is specifically suited for this kind of objects, selection effects present in other techniques (broad band imaging or spectroscopy) are avoided. However, deep surveys require the ability to observe different emission lines (Hα, Hβ, Oxygen, Lyα) at different redshifts. This requires using a large number of filters that, given the sizes required for most instruments for 8-10m class telescopes, is a very expensive proposition. Tunable Filters (TFs) provide a neatly way to overcome this problem. The tunable filters are conventional Fabry-Perot etalons in that the cavity thickness, defined by high reflectance plates separation, can be adjusted in a wide thickness range with high accuracy. By using gaps at least an order of magnitude narrower thant those employed by conventional Fabry-Perot devices, allow to observe an almost monochromatic fiel-of-vied within the Jaquinot spot (Bland-Hawthorn & Kedziora-Chudczer 2003).

The OSIRIS (OSIRIS Tunable Emission Line Object Survey) instrument TFs (see Cepa el al. 2004, this proceedings) are equivalent to have available several thousands standard filters in the range 365–1000 nm, with the advantage that a TF passband can be narrow than the typical narrow band filters used. Tunable imaging allows obtaining line fluxes simultaneously for all objects within OSIRIS field-of-view, avoiding at the same time sky emission lines, and at an arbitrary selected wavelength compatible with the etalon configuration and with an arbitrary (within the restrictions of the etalon parameters) passband

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width. A great advantage is the reduced contribution of sky and target continuum photon noises when narrower filters are used, and a very good continuum subtraction since off–band images are obtained very near the emission line and with the same spectral response than the on-band image. Moreover, the implementation of charge shuffling techniques, that allows a very good sky subtraction since sky variations are averaged on line, will increase even more this difference.

Surveys using tunable filters, as CADIS (Calar Alto Deep Imaging Survey, Thommes et al. 1996), and the TTF–FGS (Taurus Tunable Filter Faint Galaxy Survey, Jones & Bland-Hawthorn 2001) detect one order of magnitude more objects (when normalizing for telescope size and exposure time) than conventional narrow band surveys as the Suprime-Cam of Subaru (Fujita et al. 2003) and the New UCM Survey by Pascual et al. (2001).

Narrow band surveys with Tunable Filters in large telescopes will constitute a deep sky probe with unprecedented sensitivity. Whereas there are other instruments using TFs in operation (the Kyoto 3D spectrograph) or in project (the Prime Focus Imaging Spectrograph of the SALT Telescope, Buckley 2001), OSIRIS will be an unique instrument, thanks to its larger FOV (8.5'x*.5'), range (365–1000 nm) and telescope size (10.4m). No other wide field TF in common user instruments for 8–10m class telescopes will be available at or near GTC Day One, OSIRIS will provide GTC with unique capabilities compared with similar telescopes, and the OSIRIS Tunable Emission Line Object survey (OTELO) will supply a unique database in survey area, sensitivity and target discrimination, as shown in Table 1.

2. OTELO CONCEPT

2.1. *Introduction*

OTELO can be defined as a "flux limited survey of emission line objects in large and perfectly defined volumes of Universe". The survey will yield emission line objects at redshifts ranging from z =0.24 up to 6.7, the latest representing objects with 10% of the current Universe age. This redshift range will be surveyed one order of magnitude deeper than other studies and covering a wide sky area. Atmospheric windows through OH sky lines will be scanned to achieve the required depth. The windows will be selected to avoid the natural emission-line features, as well as possible man-made features. With narrow-band passbands, the sky background is greatly reduced, a great advantage when it is compared with broadband images. We will observe taking a set of images of the same FOV with the TF tuned at different contiguous wavelengths, the images providing information about line and continuum flux.

We plan to observe regions at high galactic latitude and with low extinction, with angular separation enough to cover an area of 1-2 square degrees.

An auxiliary multiple wavelength broad band survey at the UBVRIK bands at a limiting magnitude B=27 of the same sky areas is currently under way, in collaboration with GOYA project (Balcells et al. 2004), to identify the emission line observed with OTELO and to identify the morphology of the target.

From the operation point of view, a single exposure measures all the emission objects in the field of view. The targets are automatically selected by the property that it is measured, their line emission. These is better than standard narrow band surveys, as there is lower sky and continuum photon noise. We have a much better continuum subtraction, and in the case of Hα, allows separating the neighbouring NII lines.

Compared to spectroscopic surveys, we have a higher throughput, as there are not slit losses or problems with differential refraction.

2.2. *OTELO main characteristics*

The main characteristics of the survey are the following:

- **Flux limited (i.e. not distance limited) at every redshift:** Since narrow band imaging of a given emission line automatically selects redshift, the one defined by the wavelength tuned, exposure time drives the depth of the image. Then flux-limited images of a preselected redshift are easily obtained.

- **Covers similar comovile volumes of universe at different redshifts (to compare targets at different redshifts:** mosaic of images defines the angle covered on the sky, while the wavelength scanned defines the redshift and the redshift interval, covered. In this way, assuming a model of the Universe, it is possible to completely define equal comovile volumes of the Universe at each redshift.

- **Separation of Hα from [NII]λ658.4 nm:** Hα can be separated from [NII]λ658.4 nm by appropriately selecting the TF FWHM and the wavelength interval between images of the same field, allowing for studies on chemical evolution.

TABLE 1

SUMMARY OF OTELO CHARACTERISTICS AND COMPARISON WITH OTHER SURVEYS

Name	Area (sq.deg.)	5σFlux[a] (erg/cm^2/s)	z[b]	Sources[c]	[NII]	AGN id.	Reference[d]
UCM	471	3×10^{-14}	<0.04	191	No	Yes	1
TTFFGS	0.27-5 $\times$ 10^{-17}	~0.39	696	No	No	No	2
KISS	62.2	5×10^{-15}	<0.06	1128	No	No	3
New UCM	0.19	$>7\times10^{-16}$	~0.24	68	No	No	4
CADIS	0.14	$\geq3\times10^{-17}$	≤0.40	438	No	Yes	5
SUBARU	0.20	1.2×10^{-17}	~0.24	348	No	No	6
OTELO	**1.0**	$\mathbf{8\times10^{-18}}$	**≤0.40**	**12000**	**Yes**	**Yes**	This paper

[a]**Very important note:** OTELO flux at 5σ corresponds to the completeness limit (i.e. routinely achieved) up to the redshift indicated, while the fluxes at 5σ of the other surveys represent the minimum flux achieved in some cases.

[b]Maximum redshift at which Hα is observed. At the depth of most emission line surveys only Hα emission is detected. The deepest surveys such as OTELO will detect other emission lines of objects at higher z.

[c]This is the total number of emission line sources detected at any redshift.

[d](1) Gallego et al. 1996; (2) Jones & Bland-Hawthorn 2001; (3) Salzer et al. 2002; (4) Pascual et al. 2001; (5) Hippelein 2001; (6) Fujita et al. 2003.

- **Provides a statistically significant number of sources of each class per redshift:** The number of sources per image, given the redshift and the depth, can be estimated by using a luminosity function plus evolution models. Then the desired number of sources will define the number of fields to be observed.

- **Morphological type identification:** The morphological identification needed for metallicity studies will be done via an auxiliary broad band survey, that is part of OTELO preparatory activities. This broad band survey will also serve to distinguish stars and QSO in OTELO.

- **Emission line identification:** Finally, the broad band survey will provide an approximate redshift for each source. Then the emission line observed can be unambiguously identified.

Given the depth of OTELO survey, not only Hα emitters at z≤0.40 will be observed, but also many sources at redshifts up to 1.5 for the emission lines [OIII]λ500.7 nm, Hβ and [OII]λ372.7 nm. These emitters will provide an important database to study the evolution of galaxies. The expected detected sources will be around 12000, within one square degrees (see Table 1), distributed into Hα emitters (~ 1000), that indicate areas of active star formation, other emitters in [OII], [OIII], or Hβ (~ 6000) at z < 1.5, Lyα galaxies (~ 400) at z < 7 (10% of the age of the universe), AGNs (~ 3000), and QSOs (~1200).

2.3. *Comparison with other surveys*

Table 1 summarises the characteristics of OTELO survey, together with other existing emission line surveys. It shows that OTELO is the deepest and richest emission line survey to date, with the additional important advantages of surveying perfectly defined Universe volumes at the same limiting flux, not including [NII] in the Hα but measuring [NII] and discriminating the AGN phenomena. The scientific potential of such database will position GTC+OSIRIS at the forefront of world Astronomy.

3. OTELO SCIENCE

The subject of the OTELO survey are emission line targets. These objects encompasses a wide variety of objects: normal stars forming galaxies, starburst galaxies, emission line elliptical galaxies, AGNs, QSOs, Lyman alpha emitters, and peculiar stars, are some of the examples.

Except peculiar stars, the emission line objects consist of galaxies. These Emission Line Galaxies (ELGs) have revealed as one the key components of the galaxy population of the Universe at all lookback times. They include star-forming galaxies, Active Galactic Nuclei, and dwarf galaxies. A deep survey for ELGs samples will provide at all the Universe epochs with observables that constitute fundamental benchmarks for all cosmological theories of galaxy formation and evolution.

When the emission is due to star formation, the star formation properties as star formation rates, luminosity functions and gas metallicity can be derived for each galaxy class, and its evolution studied. Also, it can be determined the luminosity function of low luminosity galaxies Otherwise, luminosity functions of different types of AGNs and QSOs, their spatial density, together with its evolution can be derived. At high redshifts, targets as Ly-α emitters allow surveying the first known galaxies and structures in the universe. In our neighbourhoud Milky Way and Solar System studies are possible, as galactic structure, tidal tails, peculiar stars, Kuiper Belt Objects, etc

A list of scientific programs is being developed by the Scientific Team that is currently being formed. Moreover, even the branching of the projects presented before is wide enough to allow many other astrophysicists to be actively involved. Some OTELO applications for other studies are described in the contributions of J. Gallego, J. González–Serrano, M. Sánchez–Portal and E. Alfaro, that can be found in the present volume. Below there is a short description of possible scientific programs.

3.1. *Large Scale Structures*

The OTELO survey has the potential to contribute a great deal in the area of observational cosmology. For example, pre-selecting galaxies that exhibit strong optical emission lines is an efficient way to carry out redshift work to probe large scale structures. The surface density of the survey is sufficiently high that OTELO selected galaxies could quickly map out the spatial distribution of field galaxies at different surveys in the areas studied.

3.2. *Evolution of galaxies*

The OTELO sample will be useful as low and intermediate redshift comparison group to the galaxy population at higher redshift. We will be able to measure more accurately than ever before the space densities of starburst galaxies locally, which may well have an impact on resolving the faint blue galaxy problem. In addition, the survey will also provide a more accurate estimate of the local star formation rate (SFR) density (e.g. Gallego et al. 1995; Madau et al. 1996) which, when combined with high-redshift studies, will lead to a more precise understanding of the evolution of the SFR as a function of cosmic epoch.

3.3. *Chemical evolution of the Universe*

An important set of observables from the very early universe are the abundances of the primordial elements (e.g. He, D, Li). Key among these is helium. The effect to determine the primordial abundance of helium accurately would be aided by the existence of a larger sample of very metal poor galaxies. Ideal work for this work would possess strong emission lines, to facilitate the abundance determination. Further, they would tend to have weak oxygen lines, due to their low metallicity. The focus of previous searches on the contents of the [OII]-selected surveys may then have created a huge bias against finding more low metallicity galaxies. Selecting by Hα, as OTELO does, may well lead to the discovery of many previously unidentified low metallicty galaxies with which to investigate the primordial helium abundance.

3.3.1. *Nitrogen as metallicity estimator*

The [NII]λ658.4 nm is the most intense nitrogen line that can be observed at optical wavelengths. It is usually assumed to be too affected by excitation with respect to the [OII]+[OIII] to be used as metallicity indicator. However, it is more difficult to determine metallicity via the oxygen indicators in far away galaxies. For this reason, several authors (Kewley et al. 2001; Denicoló et al. 2002; Melbourne & Salzer 2002, among others) have suggested the use of [NII]λ658.4/Hα as metallicity estimator, providing different empirical calibrations from 1/50th to twice the solar value (Denicoló et al. 2002).

OTELO survey will be able not only of separating Hα from [NII]λ658.4 nm, but to measure [NII]λ658.4 nm accurately enough down to Z=1/10 solar, for more than 1000 objects of a wide variety of morphological types.

3.3.2. *Chemical evolution of galaxies*

Although some theoretical models exists (Edmunds & Phillips 1997), the data available are still too scarce and biased towards low extinction targets. They essentially consist (Figure 1) in (i) Lyman Break Galaxies at high z by Pettini et al. 1994 (ii) 14 ELGs at $0.11<z<0.5$ by Kobulnicki & Zaritsky 1999 and (iii) 68 UV selected galaxies at $0<z<0.4$ by Contini et al. 2002a.

However, Contini et al. 2002a and Pettini et al. 2002 have detected more dispersion in [NII] with respect to oxygen. They claim that it might be due to a delay in the release of nitrogen, produced in intermediate stars as primary element, with respect to oxygen, produced in Type II supernovae. Nevertheless, this could be caused by the bias towards low extinction targets (of low dust content) of their samples, that might be undergoing their first metal production. This effect could be overcome by OTELO survey, much less biased towards this type of objects. Also, it should not affect objects with continuous star formation such as spirals. To check the impact of this delayed nitrogen release in the metallicities, specially in the case of dwarfs, oxygen lines will be also observed in a subsample of OTELO targets selected within a range of morphological types and nitrogen content within each type. This will allow checking the nitrogen-metallicity calibration as well.

To study the chemical evolution of galaxies it is necessary to distinguish morphological types, since the evolution is very different for spiral-irregulars, dwarfs and early-types. For this reason, OTELO narrow band survey must be accompanied by a broad band survey of the same fields. This broad band auxiliary survey will allow not only identifying morphological types but providing an approximate redshift that will help to distinguish whether the emission line observed corresponds, for example, to Hα of a dwarf at z=0.4 or to [OIII] of a irregular at z=0.9. This survey is underway (c.f. Section 2.1).

3.3.3. *SFR and metallicity*

Star Formation Rates are usually derived from Hα or [OII] luminosities via a constant ratio (Hunter & Gallagher 1986, Kennicutt 1998).

It is generally assumed that SFR derived from [OII] can be heavily affected from different metal content, and that this line is not as good SFR indicator as Hα. However, even using Hα, the constant depends on different factors, including metallicity. From population synthesis models using a Salpeter IMF, Weilbacher & Fritze-v.Alvensleben (2001) found that SFR derived from Hα can suffer from large errors due to different metallicity content, including the IMF used. For example the SFR of blue compact dwarf galaxies, that have metallicities as low as 1/10 $Z_\odot$, or of low metallicity systems, can be overestimated by more than a factor 3. OTELO will provide a first order correction of this effect.

3.3.4. *Metallicity and CO conversion factor*

The most used mm emission lines in extragalactic astronomy are those of CO in the different transitions between rotational states, such as the fundamental J=1⟶0 transition at 115 Ghz (2.6 mm).

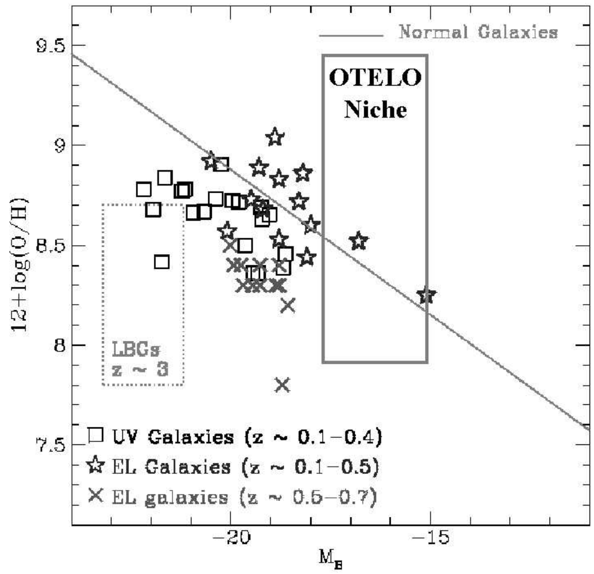

Fig. 1. Metallicity vs. absolute blue for different samples of ELG, including Lyman Break Galaxies (LBGs). Figure from Contini et al. 2002b. OTELO niche is marked by the rectangle in the scarcely populated right hand side of the plot.

The observation of these lines is then heavily dependent on the metal content of the galaxy observed. This might be a problem when observing dwarf metal poor galaxies at any z or less evolved galaxies, especially since the molecular hydrogen content is evaluated via CO lines intensity using conversion factors that depend on the metal content. For example, for a galaxy of [12+log(O/H)]=7.6, the molecular hydrogen content derived from CO observations would be underestimated by almost an order of magnitude. It follows that the study of the metal content of the different Hubble types vs. redshift is a useful preparation for ALMA observations.

4. CONCLUSIONS

OTELO will search for emission line objects using the OSIRIS Tunable Filters in selected atmospheric windows relatively free of sky emission lines. Different high latitude and low extinction sky regions with enough angular separations will be observed yielding a total area of 1-2 square degrees. Some of the potential results of the study will be highly exciting. Going 1.5 magnitudes above the deepest survey, it will allow to measure the faint end of the star-forming galaxies function. The possibility of measurement of [NII]λ658.4 allows a pure Hα flux determination, and as consequence reliable metallicity studies. The large number of expected targets detected will allow studies of statistically significant samples of faint galaxies, and the area covered makes the survey suitable for cosmological studies by avoiding the effect of clustering.

Given the observing procedure, OTELO will allow studying a clearly defined volume of the universe at a known flux limit. Co-ordination with surveys at other wavelengths is expected and already established in some cases, as for examples synergies with the PACS instrument of the Herschel observatory. Although the final aim is producing a catalogue that will be available to the Spanish astronomical community, and whose final version is scheduled for 2010, the first scientific results are expected to be published soon after the start of the OTELO observations.

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