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COSMOS: A COMPREHENSIVE STUDY OF GALAXIES AT HIGH REDSHIFT WITH EMIR ON THE GTC

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RESUMEN

COSMOS es un programa científico diseñado para el GTC, cuyo objetivo principal consiste en la caracterización de la población de galaxias durante la época de máxima formación estelar en la historia del universo. Estudios recientes han demostrado que esta época corresponde a un desplazamiento al rojo $1 < z < 3$, cuando el universo tenía tan sólo el 10%–40% de su edad actual. A estos desplazamientos al rojo, la ventana óptica –el rango espectral que ha sido mejor estudiado para galaxias cercanas– se encuentra en el infrarrojo cercano (1–2.5 micras). En la actualidad, existen varios programas espectroscópicos que se extienden hasta 1.8 micras para estudiar las propiedades en el rango óptico de la población de galaxias y la formación estelar global del universo hasta $z \sim 2$. COSMOS será el primer programa que extienda estos estudios al universo más lejano utilizando EMIR en el GTC.

ABSTRACT

COSMOS is a scientific program designed for the GTC whose main goal is to characterize the galaxy population during the epoch of maximum star formation in the history of the Universe. According to recent studies, this critical epoch occurred when the Universe was 10–40% of its current age, which corresponds to redshifts $1 < z < 3$. At these redshifts, the optical window—the region of the spectrum that has been most widely studied in nearby galaxies—is shifted into the near infrared (1–2.5 μm). Major spectroscopic surveys down to 1.8 μm are currently being planned to study the rest-frame optical properties of galaxies and the global star formation of the universe at redshifts up to 2. COSMOS will use EMIR on the GTC to become the first major survey to extend these studies to the high z Universe.

Key Words: **COSMOLOGY: OBSERVATIONS — GALAXIES : EVOLUTION — GALAXIES: PHOTOMETRY — — SURVEYS**

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1. DESCRIPTION OF THE COSMOS PROJECT

COSMOS is a scientific program designed for the GTC whose main goal is to carry out a comprehensive study of the rest-frame optical properties of galaxies at redshifts $z > 2$, including morphology, structure, kinematics, dust content, star formation rate (SFR), metallicity, luminosity and mass functions, clustering, and large scale structure. This program is the main scientific drive behind EMIR, a near-infrared multiobject spectrograph for the GTC currently under construction (see contributions by Garzón et al., and Balcells in this volume, p. 23 and p. 71, respectively). The fundamental questions that we are attempting to answer include the following.

What is the nature of the galaxy population at $z > 2$? What are their local counterparts? At $z \sim 2$ the 1–2.5 μm range translates into rest-frame ∼3500–8000 Å, the region of the spectrum that has been most widely studied in nearby galaxies (Figure 1). COSMOS will address these questions by comparing directly the properties of the high redshift galaxies with those of the nearby population in the same parameter space, including half-light radii (R_e), surface brightnesses (SB_e), emission line ratios (e.g., [O II] 3727/[O III] 5007, [O III] 5007/Hβ, [N II]/Hα), star formation rates (from both Hα and [O II] 3727 fluxes), metallicities (from various line strength indices), dust content (using Balmer decrements), and internal kinematics (from Hα velocity widths, σ). This procedure avoids the uncertainties in the calibrations and biases that affect previous studies of high redshift galaxies in the UV rest-frame (e.g., Steidel et al. 1998). A similar approach has been adopted by other major galaxy surveys such as the DEEP project (http://deep.ucolick.org/) to study the nature of the $z \sim 1$ galaxy population and identify their local counterparts (Phillips et al. 1997; Guzmán et al. 1997). Note that a key new aspect common to DEEP and COSMOS is to measure galaxy internal motions. Kinematics (and thus masses) has proved a key parameter to identify the

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local, evolved, counterparts of distant, young galaxies since it is not affected by the luminosity evolution of their stellar population.

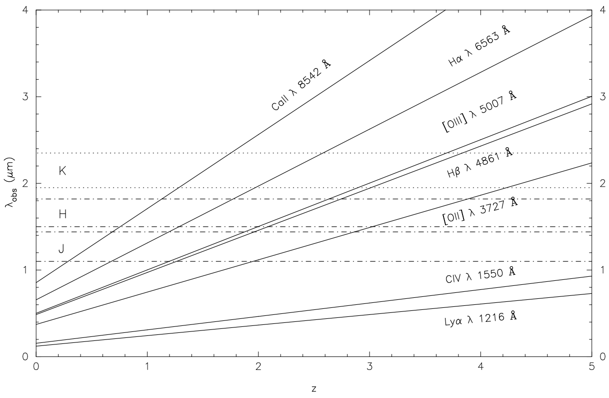

Fig. 1. Observed wavelengths of the most representative emission and absorption spectral lines of normal galaxies in the rest-frame optical range at various redshifts.

What is the actual evolution of the star formation history of the Universe with look-back time? It is now widely assumed that the star formation rate (SFR) density of the Universe peaked at $\sim$1 and from then, it descended to the local value (e.g., Madau et al. 1996; Figure 2). However, the interpretation of this figure should be approached with caution, given the likely differences in the calibrations for the various SFR tracers used, incompleteness of the datasets, and uncertainties in the corrections for dust (e.g., Gallego, this volume, p. 226). Indeed, new estimates of the global SFR rate density at high redshifts differ in more than a factor $\sim$4 among various researches. Most of the caveats surrounding these estimates can be avoided by measuring the SFR using Hα emission, one of the best SFR tracers. This is the method adopted by Gallego et al. (1995) to estimate the local value of the global SFR density and will also be used by the VIRMOS project (http://www.astrsp-mrs.fr/virmos/) to derive the value at $1 < z < 2$. COSMOS will be the first major survey to measure Hα emission at $2 < z < 3$ and, combined with similar surveys at lower redshift, will define a homogeneous, unambiguous picture of the star formation history of the Universe from $z \sim 2.5$ till the present. In addition, since [O II] 3727 is also a fair measure of the star formation rate, COSMOS will be able to provide a well-calibrated measurement of the global star formation rate to $z \sim 6$ via observations of the [O II] 3727 emission down to 2.5 μm.

What is the earliest epoch of galaxy formation? The quest to observe the birth and for-

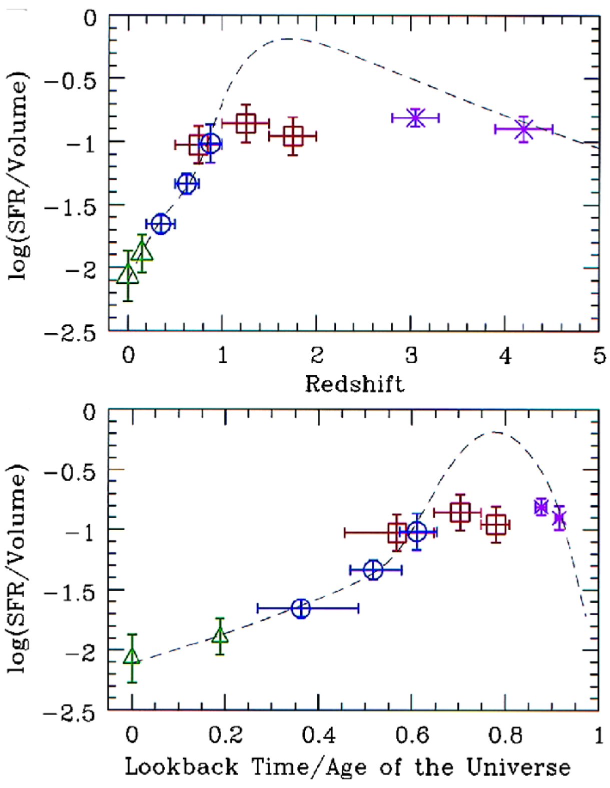

Fig. 2. Evolution of the global star formation rate density of the universe with redshift and look-back time.

mation of normal galaxies like our own has proved to be a very elusive one—till now. The advent of the 10 m class telescopes combined with powerful new instrumentation has yielded in only two years over 600 high redshift candidates of which $\sim$250 are spectroscopically confirmed galaxies at $2 < z < 4$ (Steidel et al. 1996; Lowenthal et al. 1997; Steidel et al. 1998). This is obviously the beginning of a new era of discovery of primeval galaxies in the early Universe. The near-infrared spectrographs currently available on 10 m class telescopes will allow systematic searches for primeval galaxies at $z < 3.5$, by looking for [O II] 3727 from emission line galaxies, and Ca H+K and 4000 Åbreak from absorption line objects over the range 0.9 to 1.8 μm. COSMOS will be able to extend this search to $z \sim 5.7$ using EMIR + GTC—and to much higher redshifts via observations of Lyα—by extending the wavelength coverage to 2.5 μm (e.g., R. Pelló & Schaerer, this volume, p. 231).

2. PREPARATIONS FOR COSMOS

COSMOS is a program specifically designed for EMIR, an instrument which is currently scheduled to be fully operative at the GTC in 2006. Although the research program briefly described above focuses

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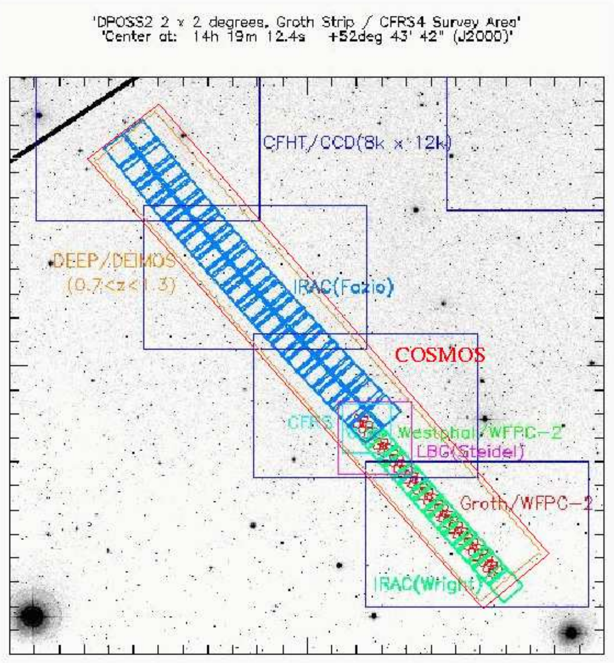

Fig. 3. The COSMOS "Groth" field. Current and planned observations at various wavelengths by other groups are also shown, including the *HST*/WFPC2 Groth strip, the GTO *SIRTF*/IRAC and *SIRTF*/MIPS observations by Fazio and Wright, the *XMM* deep pointing, and ground-based deep K band photometry by the COSMOS team using INGRID at the WHT and OMEGA at CAHA.

on the observations with EMIR, the groundwork in preparation for COSMOS has already started. Since 1999 our collaboration has been actively working on two key aspects of the COSMOS project: the selection of the galaxy sample at $z > 2$, and the study of similar galaxies in the nearby Universe to provide a reference sample.

2.1. *The selection of the galaxy sample at $z > 2$*

Four main fields were selected for the COSMOS survey according to the following criteria: i) location in areas of low galactic extinction in Schlegel's (1997) maps; ii) coordination with other surveys that will provide complementary photometric and spectroscopic data, either publicly available or through already well-established collaborations (e.g., see Figure 3); and iii) a wide range in right ascension to ensure continuous visibility during the whole year. In addition, two of the fields were selected to be equatorial so that they can be observed using large telescopes in both the northern and southern hemispheres to which our collaboration has access. The total area to be surveyed is at least 1800 arcmin^2. Given the number density of galaxies at $z > 2$ detected in other surveys (Steidel et al. 1998), we estimate this area will yield well over a thousand galaxies. This number will provide an excellent sample to study the statistical properties of the galaxy population at $z > 2$, even if the total sample is divided in various subsamples according to their redshift range or intrinsic properties.

Galaxies at $z > 2$ will be identified using the well-known photometric redshift technique. The code to measure photometric redshifts has been developed by R. Pelló and is already at hand.[1] Deep $UBRIJK$ imaging required to measure photometric redshifts is currently being obtained using a wide array of 4 m class telescopes in La Palma, Calar Alto, and Kitt Peak. The limiting magnitudes of the photometric survey, defined as the AB magnitude with $S/N = 5$ within 1 arcsec aperture, are 26 mag in U, B, R, and I, and 22 mag in J and K. This depth ensures the detection of the population of today's L^* galaxies at $z > 2$, considering a conservative luminosity evolution of $\sim$2 magnitudes in rest-frame R from $z \sim 2$ till the present.

Currently, we are about two-thirds towards completion of the photometric survey in preparation for COSMOS. Our main efforts over the last three years have focused on gathering the K band images of all survey fields (see Cristóbal et al. 2003 and Serrano et al. 2003) since a significant amount of optical data were already available to us. The complete catalog of galaxies at $z > 2$ in our COSMOS fields, including astrometry, photometry, and photometric redshifts, will be ready by OSIRIS first light in 2004. We plan to use OSIRIS to study the rest-frame UV spectral properties of our galaxy sample, as well as to measure accurate spectroscopic redshifts prior to EMIR.

2.2. *The reference galaxy sample in the local Universe*

A most important issue in any study about the nature and evolution of galaxies over cosmological timescales is the identification of a similar sample of galaxies in the local Universe to serve as a reference for comparison. There are a wide variety of systematic effects that can bias the selection of galaxies at high redshifts which will severely affect any conclusions regarding their nature and evolution. Perhaps the two most important such effects are the k-correction and the cosmological dimming. We are currently investigating the bias introduced by those two effects on galaxy samples selected at different redshifts by simulating observations of nearby galaxies as seen at various redshifts but in the same rest-

[1]See http://webast.ast.obs-mip.fr/hyperz/.

frame optical band and depth corresponding to our K band images of $z > 2$ galaxies (see Cristóbal et al., this volume, p. 274). Based on these simulations, we have identified a sample of ∼50 galaxies from the SDSS whose selection function matches the selection function of high redshift galaxies in our survey. A detailed photometric and spectroscopic follow-up at UV, optical, infrared, mm, and cm wavelengths is already being pursued using a wide array of public databases and telescopes, including KPNO, IRAM, and Arecibo. The resulting combined data set aims to be a cornerstone for future surveys of similar galaxies at high redshifts, including COSMOS.

3. FINAL REMARKS

When GTC sees first light in 2003, it will have to compete with other 10 m class telescopes and instruments that have been fully operational for nearly a decade. The COSMOS program will allow GTC to claim its own place among the world-class observatories. We note that COSMOS' science is not unique. The goals briefly described here are also the focus of a broad effort by various international groups which have guaranteed access to infrared spectrographs already operating in 10 m class telescopes, such as ISAAC at the VLT or NIRSPEC at Keck. What is truly unique in COSMOS is the use of a wide field near-infrared spectrograph with multiobject capability in a 10 m telescope—such as EMIR + GTC—to conduct an unparalleled survey of the high redshift Universe. For instance, we estimate that 50 nights of observations with ISAAC at the VLT will yield the spectral data required for such an extensive study as that described in this paper for approximately 50 galaxies at $z > 2$. Using EMIR at the GTC, COSMOS will be able to study up to 1000 galaxies at $z > 2$ in the same number of nights. While current scientific programs in this area of research will be pioneers in providing the first detailed look into distant galaxies, COSMOS will be the first major survey to carry out a complete characterization of the rest-frame optical properties of the galaxy population in the early Universe.

The COSMOS project is a collaborative effort of several institutions, including the IAC, Universidad Complutense, Observatoire Midi-Pyreneés, and the University of Florida. Special thanks go to my collaborators Marc Balcells, Mercedes Prieto, David Cristóbal, Roser Pelló, Jesús Gallego, Nicolás Cardiel, and Angel Serrano, and to Francisco Garzón, the new EMIR PI. I am grateful to a very large group of astronomers that contributed with their ideas and enthusiasm during the early stages of this project, especially to A. Aragón-Salamanca, I. Arétxaga, F. Castander, L. Colina, A. Díaz, J. Lowenthal, R. González, M. Más, C. Muñoz, R. Peletier, E. Pérez, E. Terlevich, R. Terlevich, J. Vílchez, and J. Zamorano. Further information about EMIR and COSMOS can be found at http://ucm.es/info/emir.

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