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EMIR SCIENCE PROSPECTS

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RESUMEN

Presento un repaso a los programas científicos que se pueden abordar con EMIR. Es un repaso sesgado hacia estudios a alto z y no es exhaustivo. A continuación, describo las actividades de preparación científica que estamos llevando a cabo en el grupo científico de EMIR.

ABSTRACT

I present an overview of the types of science programs that may be feasible with EMIR. This is biased toward high-z studies and is not exhaustive. I then describe the science preparation activities of the EMIR science team.

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

1. INTRODUCTION

When the GTC starts science operations in 2004, it will have been over 10 years since Keck-I first opened its dome onto the sky. Other 8–10 m class telescopes (the VLT, HET, Gemini-N, Subaru) have since come into operation, with more in the pipeline (Gemini-S, LBT, SALT). The success of the GTC in producing forefront science rests to a large extent on securing unique instrumentation. It, of course, also needs good proposals for the use of the instruments. Fortunately, the GTC will have such unique instrumentation. OSIRIS will have two features that make it stand above similar instruments, e,g., LRIS on Keck. Tunable filters will allow flexible narrow band imaging, and charge shuffling will allow photon-limited sky subtraction. See the presentation by Cepa et al., elsewhere in these proceedings (p. 13). CanariCam will offer coronography and diffraction-limited imaging in the mid-infrared (see Telesco, this volume, p. 19).

EMIR, the third GTC instrument, also offers unique features among 10 m class telescopes: wide field imaging and multiobject spectroscopy in the thermal near infrared (NIR). EMIR is described by Garzón et al. (this volume, p. 23).

2. SCIENCE PROSPECTS

The scientific applications of an instrument such as EMIR exploit its singularity as well as its placement on a telescope with a 10 m aperture and good image quality.

Hence we want to exploit:

- The ability to follow redshifted spectra into the NIR. A NIR spectrograph can map the rest-frame optical spectrum of distant galaxies, which is cosmologically redshifted to the NIR. EMIR will extend the wavelength domain of currently planned, warm NIR spectrographs, e.g., NIRMOS, beyond their limit at $\lambda \approx 1.6$ μm,
- The ability to study faint objects within dust-obscured regions.
- The ability to observe the emission from the coolest stellar atmospheres.
- The ability to resolve stars to greater distances.

A 10 m telescope such as the GTC provides an excellent means to carry out spectroscopy for sources imaged at high spatial resolution, most notably from the *Hubble Space Telescope* (*HST*). Therefore, many top science applications of the GTC will naturally be coupled to *HST* imaging programs. *HST* surveys have been limited to date by the small field of view of the *HST*. The deployment of the ACS in early 2002 and WFPC3 in late 2003 (the latter closely matching the start of GTC operations) will undoubtedly change this situation. We can expect a plethora of new imaging data at ultraviolet (UV), visible and NIR wavelengths, ready for breakthrough discoveries via GTC spectroscopy.

The multiobject capability offers in principle the possibility of very efficient observing. Taking advantage of this feature depends critically on good preparation, including both top level project planning and detailed execution of the preparation activities.

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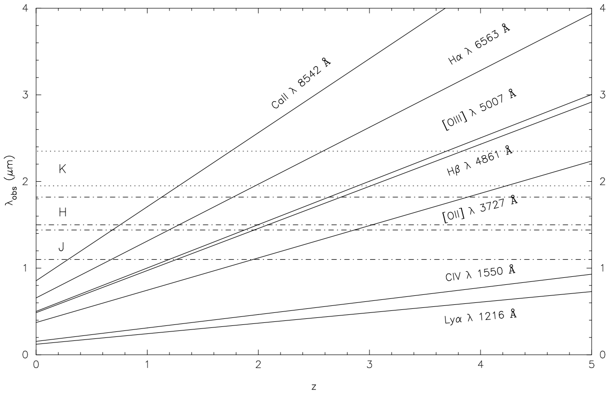

Fig. 1. Observed wavelength of familiar UV–optical diagnostic lines vs. redshift.

2.1. *Cosmology: The distant Universe*

The area perhaps most in need of NIR spectroscopy is the study of distant galaxies. The cosmological redshift pushes the rest-frame visible spectrum of distant galaxies into the NIR. Hence, the Hα line, a fundamental tracer of star formation activity, enters the J band at a modest $z = 0.67$, leaving the $\lambda \leq 1.6\mu$m wavelength region available to warm NIR spectrographs at $z = 1.5$, and sits on the K band for $2.0 \leq z \leq 2.8$ (see Figure 1). A galaxy at $z = 2.4$ has Hα in the K band, Hβ and [O III] 5007Å in the H band, and [O II]λ3727 in the J band. These numbers indicate the power of EMIR for mapping the types of emission lines that have traditionally provided us with measurements of star formation, excitation, and extinction, allowing direct comparison of distant and nearby galaxies. The redshift surveys planned with VIRMOS/NIRMOS on the VLT will provide thousands of sources at $z > 1$ ready for detailed studies with the GTC.

Going further out, the O II line enters the J band at $z \sim 2$, and lies in the K band at $4 \leq z \leq 5$. We expect to be able to map this line for far infrared (FIR) sources detected with sub-mm instruments, such as SCUBA and ALMA.

Further out still, primeval galaxies at $z \geq 10$ might be detected in the NIR by the strong Lyman continuum emission of zero metallicity, very massive stars (see Pelló & Schaerer, this volume, p. 231).

With a spectral resolution of $R = 4000$, EMIR is poised to make key contributions to the study of the internal kinematics of galaxies at $z \geq 0.6$, via rotation curves and velocity dispersion measurements (e.g., Vogt et al. 1997; Pettini et al. 2001).

These capabilities will enable astronomers to undertake comprehensive studies of galaxy populations over range of redshifts and environments. Emission line galaxies are prime targets for the ease with which they can be selected via Lyman break and related techniques (Steidel et al. 1996). Absorption line galaxies, however, are highly dimmed in the visible because of the strong K correction penalty of old stellar populations, hence their study is exclusively reserved for NIR instruments such as EMIR. An important field of study will be the internal properties and merger activity of galaxies in clusters at $z \geq 1$ (e.g., van Dokkum et al. 2001a). High-z cluster selection is readily performed by a combination of X-ray imaging (*ROSAT*, *Chandra*, *XMM*) and deep visible–NIR imaging (e.g., Stanford et al. 2002). In the field, photometric redshifts including NIR photometric data will allow to efficiently select field ellipticals at $z \geq 1$.

Another important source of targets will be the deep surveys currently under way in the radio, FIR, and X-ray regions of the spectrum.

The observing efficiency of a multiobject spectrograph lends itself to spectroscopic surveys aimed at the mapping of galaxy global relations such as the Tully–Fisher relation (e.g., Vogt et al. 1997), the fundamental plane (e.g., van Dokkum et al. 2001b), and luminosity functions.

2.2. *Dusty Universe*

NIR imaging and spectroscopy are the only means of observing dust-enshrouded objects. This includes the nuclei of external galaxies as well as molecular clouds in our own Galaxy. In external galaxies, spectroscopy of the hydrogen Paschen lines will provide the types of H II region diagnostics we are used to deriving from Balmer lines. In old populations, the CO band-head at 2.3 μm should provide an ideal means of obtaining dynamical information on dusty galaxies such as starburst and merger remnants. The CO lines contain useful population age diagnostics (Mobasher & James 2000).

2.3. *Resolved Universe*

The GTC's good image quality will allow EMIR to resolve stars to greater distances than with 4 m telescopes. We can expect to map NIR color–magnitude diagrams (CMDs) out to ~ 3 Mpc, i.e., the distance to Cen A. CMDs are well-known powerful tools for unveiling the star formation history of galaxies (e.g., Gallart et al. 1999). NIR spectroscopy is the key to abundance studies of Local Group red giants and supergiants. Data on these stars are needed to improve on population synthesis model predictions in the NIR.

NIR imaging will also allow us to obtain data on the faint end slope of the stellar luminosity function

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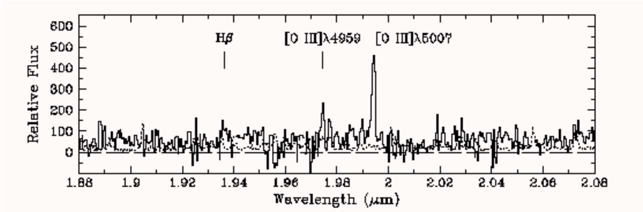

Fig. 2. NIR K band spectrum of a Lyman break galaxy ($z = 2.979$) showing Hβ, [[O III] 5007Å] and the stellar continuum. The dotted line is the 1σ error spectrum. From Pettini et al. (2001).

and on the density and distribution of brown dwarfs (Béjar et al. 2001).

3. EMIR SCIENCE TEAM—SCIENCE PREPARATION ACTIVITIES

The EMIR science team was organized for the COSMOS proposal. Indeed, the COSMOS project, initially put forward by Rafael Guzmán, was the trigger for building EMIR.

Given EMIR's ability to go beyond warm NIR spectrographs and its expected opening up of the wavelength domain beyond $\lambda \sim 1.6$ μm to multi-object spectroscopy, the science focus of the EMIR team has been intermediate resolution spectroscopy of galaxies beyond $z > 1.5$ μm, with emphasis on the $2 \leq z \leq 2.8$ domain, where Hα sits in the K band. This region partially overlaps the z-selection function of U-dropout Lyman break galaxies (LBGs), which is centered on $z \approx 3$. VLT/ISAAC and Keck-II/NIRSPEC are showing us the types of line diagnostic studies of individual objects (e.g., Pettini et al. 2001, see Figure 2) that EMIR will be able to address for large samples of galaxies. But we are also going to study other redshifts as well.

The main science program has three targets, emission line objects, absorption line objects, and primeval objects at $z > 5$. The goal is to study the physical properties of distant galaxies using the same parameter space as in the local Universe in order to obtain fundamental constraints on the theories of galaxy formation and evolution.

A number of parallel programs are being carried out in association with the main science program. These are motivated by the range of expertise and interests of the team members and fulfill an essential role in studying similar types of objects at other redshifts.

3.1. *The COSMOS survey*

We are carrying out a NIR-visible survey, called the COSMOS Survey (Cristóbal-Hornillos et al. 2002; see also Cristóbal-Hornillos et al., and Serrano et al., this volume, p. 274 and p. 318, respectively). The survey will cover 0.5 degree^2 in the $UBRIJK$ bands. We have two target depths, a deep survey reaching AB magnitudes of $K = J = 22$, $U = B = R = I = 26$ and a shallower survey which is roughly one magnitude brighter. The combination of depth and area are unique among K-band surveys, leading to good galaxy count statistics in the $K \sim 20$ magnitude range. The survey observations started in 2000 using WHT/INGRID and CAHA 3.5 m OMEGA PRIME. Fields observed include the Groth strip (Groth et al. 1994), the Coppi field (Coppi & Guzmán 2001), the SA68 field of the Koo–Kron survey, the NOAO deep field at 2 h, and the SIRTF-FLS at 17 h. We used usual field selection criteria for deep extragalactic surveys, plus the availability of existing public data at other wavelengths and/or with the *HST*.

An essential function of the COSMOS K_{s} survey will be to allow us to define samples selected on as red as possible a band. At $z = 1$, we will be selecting on rest-frame J; at $2 < z < 3$, it will be rest-frame R. While not entirely unsensitive to ongoing star formation, the selection function will be much less biased toward low mass, star forming galaxies than current U-dropout selected samples.

Obtaining the survey is a long-term enterprise. Fortunately, much science lies along the way; in a way, EMIR made us start to produce science before arriving at the GTC. Obvious steps are number counts, visible–infrared color distributions, photometric redshift distributions, SED(spectral energy distribution)-based stellar mass estimates, and photometric and structural properties for those fields with *HST* imaging available. A fundamental aspect of preparatory work, sample selection criteria require the study of observational biases as a function of z, and such studies reveal a great deal about the nature of the objects under study and their variations with redshift. At this conference, we present number counts in Groth and and Coppi fields (see posters by Cristóbal-Hornillos et al., and Serrano et al., this volume, p. 274 and p. 318, respectively).

3.2. *Science projects*

Because of cosmological dimming, the visibility of $z > 2$ galaxies is strongly skewed toward high surface brightness galaxies; hence, it is of prime importance to us to establish the relation of observed $z > 2$ galaxies to other compact galaxies at intermediate redshifts, namely LBCGs (Guzmán et al. 1996, 1997; Guzmán, this volume, p. 214), H II galaxies in the

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local Universe, blue ellipticals, and bulges. Guzmán (this volume, p. 214) describes in detail our study of LBCGs, a prototype of the types of studies we have started. The LBCG project consists of a study of LBCGs at zero and intermediate redshift and seeks structure, luminosities, colors, kinematics, and stellar masses. Our goal is to learn enough about the nature of these objects so that evolution can be adequately gauged by comparison with similar objects observed with EMIR at $2 < z < 3$, and with local star formation rate determinations (Gallego et al. 1995).

In a related project, we are studying bulge components and disk–bulge decomposition of field galaxies at intermediate redshift. Bulge–disk visible–NIR color differentials will provide a measure of bulge-disk age differences. This test, when performed at zero redshift, leads to indistinguishable age differences between bulges and disks (Peletier & Balcells 1996). Going out to $z \sim 0.5$ will provide a sensitive test concerning the question of which formed first, the bulge or the disk, and on the relation of bulges to LBCGs and to spheroid formation in LBGs at $2 < z < 3$

3.3. *Tools*

The team has devoted time to the development of essential tools for observational cosmology. The COSMOS UCM team is working on NIR reduction strategies for COSMOS imaging and spectroscopy (Cardiel et al., this volume, p. 75; Gallego et al., this volume, p. 226). These feed the GTC community through the contract between UCM and GTC for development of GTC Data Factory components. Photometric redshift tools are available to us via the Hyper-z package, developed by Pelló and collaborators at Toulouse (Bolzonella et al. 2000). Finally, the COSMOS IAC team has developed COSMOPACK, an IRAF package for redshifting galaxy images (see Balcells, Cristóbal-Hornillos, & Eliche-Moral, this volume, p. 266), which allows us to generate simulated galaxy samples redshifted with recourse to K-corrections or evolutionary corrections.

3.4. *EMIR science with other GTC instruments*

Both in the preparatory work and during the exploitation proper of the GTC, many of our studies will benefit from use of other GTC instruments. For the COSMOS project, OSIRIS offers the closest collaboration. OSIRIS will map the UV spectrum of the EMIR targets and thus provide the UV continuum measurement of star formation, which is complementary to that based on Hα. There is much to be gained from planning together the preparatory survey work for COSMOS and the OTELO survey (see Cepa et al., this volume, p. 66).

Rafael Guzmán, Roser Pelló, Jesús Gallego, Mercedes Prieto, David Cristóbal, Angel Serrano, and Francisco Garzón are active collaborators on the papers and projects relevant to this contribution. The present outline of EMIR science prospects summarizes an earlier study by current and previous EMIR science team members. We owe thanks to many astronomers from the Spanish community for their contributions.

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