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▶ **To cite this version:**

R. Pelló, F. Garzón, M. Balcells, F. Boone, N. Cardiel, et al.. Extragalactic science with EMIR-GTC. Annual meeting of the French Society of Astronomy and Astrophysics, 2011, -, France. pp.161-167. hal-00660201

HAL Id: hal-00660201
https://hal.science/hal-00660201

Submitted on 16 Jan 2012

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SF2A 2011
G. Alecian, K. Belkacem, R. Samadi and D. Valls-Gabaud (eds)

EXTRAGALACTIC SCIENCE WITH EMIR-GTC

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Abstract. EMIR is a wide-field, near-IR spectrograph currently under development for the Nasmyth focus of the Spanish 10.4m GTC at Canary Islands. EMIR will provide imaging and multi-slit spectroscopy in the ∼1-2.5 micron domain at a resolution of R ∼5000-4000. This paper reviews the status of the project, including instrumental developments and main science drivers, focusing the GOYA Survey, a scientific program to be developed mainly using the guaranteed time of the international consortium building EMIR. The GOYA project addresses the formation and evolution of galaxies, in particular the structure, dynamics and integrated stellar populations of galaxies at high redshift. One of the main goals of the GOYA survey is the identification and study of $z \geq 7$ sources, both in lensing clusters and in the field. The aim is to build up a statistically significant sample of galaxies with secure redshifts, and to study their physical properties using their broad-band spectral energy distribution in one hand, and their emission line properties on the other hand. The first results obtained from our photometric surveys in lensing fields and in the blank field CFHT WIRCAM Ultra Deep Survey (WUDS), which are intended to provide a robust selection of targets for GOYA, are also presented and briefly discussed.

Keywords: surveys, galaxies: high-redshift, gravitational lensing: strong, cosmology: dark ages, reionization, first stars

1 Introduction

EMIR is a wide-field, near-IR spectrograph currently under development for the Nasmyth focus of the Spanish GTC at Canary Islands*. EMIR is being built by a consortium led by the IAC, including Spanish and French institutions (Garzón et al. 2006), mainly funded by GRANTECAN and the *Plan Nacional de Astronomía y Astrofísica*. It is one of the first fully cryogenic multi-object spectrographs to be operated on a 10m-class telescope, with the proper resolution to achieve an efficient OH-line suppression. The design of EMIR was determined by its main scientific drivers around the study of distant galaxies, in particular the GOYA project (see e.g. Guzmán 2003; Balcells 2003).

This paper presents an overview of the GOYA Survey with EMIR, a scientific program to be carried out mainly using the guaranteed time of the international consortium building EMIR. The observing strategy for target selection will be also presented, in particular the characteristics of our photometric CFHT WIRCAM Ultra Deep Survey (WUDS), which is intended to provide a robust selection of targets for GOYA. We focus on

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Table 1. Characteristics of EMIR

Spectral Range	0.9-2.5 microns	MOS Mode		Imaging	
Spectral Resolution	5000, 4250, 4000 (JHK)	FOV	6×4 arcmin^2	FOV	6×6 arcmin^2
Spectral Coverage	1 spectral window/exp.	Sensitivity	continuum	Sensitivity	
Detector	HAWAI2 2048^2	$K_{AB} \sim 22$	in 2h S/N∼5	$K_{AB} \sim 24.7$	1h, S/N∼5
Image Scale	0.2 arcsec/pixel		emission lines	0.6 arcsec	aperture
Image Quality	$\theta_{80} < 0.3$ arcsec	1.4×10^{-18}	erg/s/cm^2 S/N∼6		

a particularly important science case for GOYA/EMIR, aimed at constraining the abundance and properties of the first star-forming galaxies in the Universe. WUDS and the complementary photometric survey in lensing clusters are specifically tailored to identify the brightest galaxies at $\geq$7, accessible for observations with EMIR, and therefore to set strong constraints on the cosmic Star Formation Rate (SFR) and the bright end of the Luminosity Function (LF), taking advantage from our privileged access to EMIR/GTC for a precise redshift determination and subsequent emission-line studies.

In Sect. 2 we summarize the present state of the art regarding the development of EMIR for the GTC. The GOYA Survey is introduced in Sect. 3. Sect. 4 describes the particular science case around the first star-forming galaxies in the Universe. We present in this section the REGALDIS Project, in preparation for the GOYA Survey, as well as the technical aspects regarding the selection of high-z galaxies, and the current results achived in this framework, both in lensing fields and in the blank field of WUDS. Conclusions and perspectives are given in Sect. 5.

2 EMIR at the GTC

The Gran Telescopio Canarias (known as GTC) is a single-dish 10.4m telescope on the island of La Palma (Spain). It started its scientific operations in March 2009 (first light in July 2007). Only one instrument, OSIRIS, is currently available, and a second one, CanariCam, is presently being commissioned. The next and last first-generation instrument will be EMIR (2012). Observing time with GTC is available to astronomers from the partner institutions in Spain, México and U. of Florida, as well as to european astronomers as part of the ESO-GTC collaboration, in addition to International Time Programs.

EMIR will provide imaging and multi-slit spectroscopy in the ∼1-2.5 micron domain for up to 50 targets using a cryogenic multi-slit mask, at a resolution of R∼5000-4000. Table 1 summarizes the main characteristics of this instrument, and Fig. 1 presents the general layout, together with several subsystems shown in thumbnails. Among the key modules of EMIR are the cryogenic configurable slit unit, and the detector translation unit (respectively CSU and DTU in Fig. 1). For these new mechanical concepts, extremely long phases of prototyping, testing and qualification were required before the final acceptance. A particularly demanding development in the optical design corresponds to the "pseudo-grisms", i.e. large grisms with a high refractive index which are needed to meet the specifications. All these critical elements were developed in close collaboration with industrial partners. More details can be found in Garzón et al. (2006) and Garzón et al. (2007).

The development plans and schedule till the first light of EMIR can be summarized as follows. During 2011, the pseudo-grisms developed at LAM (Marseille) will be integrated into the EMIR grism unit (GU in Fig. 1) and tested under cryogenic conditions. Also the development of the EMIR cryostat and auxiliary elements such as EIT (EMIR Integration Tool), ETT (EMIR Transport Tool),..., is expected to be completed by the end of September 2011. The final integration phase of EMIR subsystems and verification phase should start in October 2011, for a period of about one year. The EMIR commissioning phase at GTC is expected to start during the last quarter of 2012, with a first scientific light in mid-2013.

3 The GOYA Survey

The Galaxy Origins and Young Assembly (GOYA) Survey[†] is a scientific program to be developed mainly using the guaranteed time of the international consortium building EMIR. The GOYA project addresses the formation

[†] http://www.astro.ufl.edu/GOYA/home.html

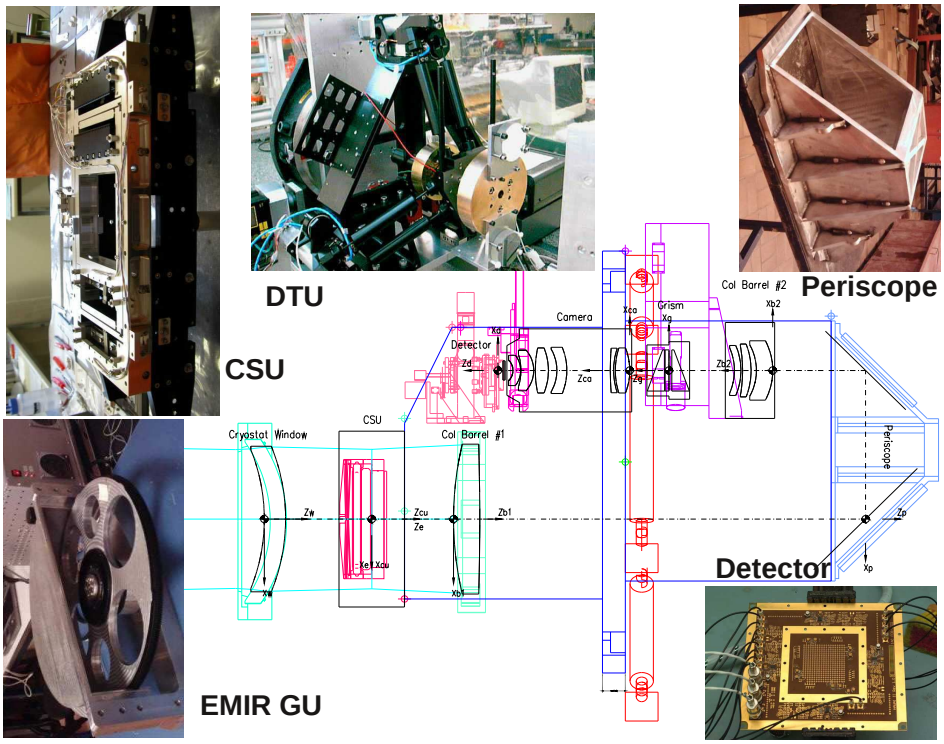


Fig. 1. EMIR layout. Several subsystems are shown in thumbnails.

and evolution of galaxies, in particular the structure, dynamics and integrated stellar populations of galaxies at high redshift. Indeed, near-IR spectroscopy is needed to target the relevant spectral features providing physical diagnostics (SFR, reddening, metal abundances, AGN contribution,...) all the way from the local universe to the highest redshifts. The main goals of the GOYA Survey can be summarized as follows:

- The characterization of the early-type population of galaxies at $1 \leq z \leq 2$. This epoch is particularly important for the formation of the red sequence. Ages and metallicities will be derived using different spectral indicators (e.g. Δ_{4000}, H_β, Mg2, Fe lines...), as well as kinematical properties and virial masses. Scaling laws will be obtained providing the empirical relations between structural and kinematical properties and stellar population parameters (see also Balcells 2007; Domínguez-Palmero et al. 2008).
- The characterization of the star-forming galaxies at the epoch of maximum activity ($1 \leq z \leq 5$), using emission-line indicators to trace the evolution of different properties: SFR densities (based on H_α, [OII], [OIII],...), metallicity, extinction (H_α/H_β), kinematics and virial masses (velocity widths). The efficiency of EMIR and the typical density of sources should allow us to address the clustering properties of these populations. (see also Gallego 2003).
- The parameterization of the groth of SMBH in AGNs at the epoch of maximum QSO activity ($1 \leq z \leq 4$). This includes the determination of SMBH masses.
- The identification and study of the first galaxies in the universe ($z \geq 7$; see Sect. 4).

In preparation for the exploitation of EMIR, the GOYA team carried out different wide-field photometric surveys in the optical and near-IR bands, mainly using the WHT (see e.g. Vallbe I Mumbrú et al. 2007; Cristóbal-Hornillos et al. 2003), including our CFHT WIRCAM Ultra Deep Survey (WUDS; see Sect. 4.1). These surveys are needed for an appropiate target selection, because most science cases of GOYA require a stellar-mass preselection and a redshift determination before using EMIR (either photometric or spectroscopic redshift). Needless to say that GOYA observations will be optimized to fulfill different science cases in a single shot/mask. This requires a careful sample selection and mask design.

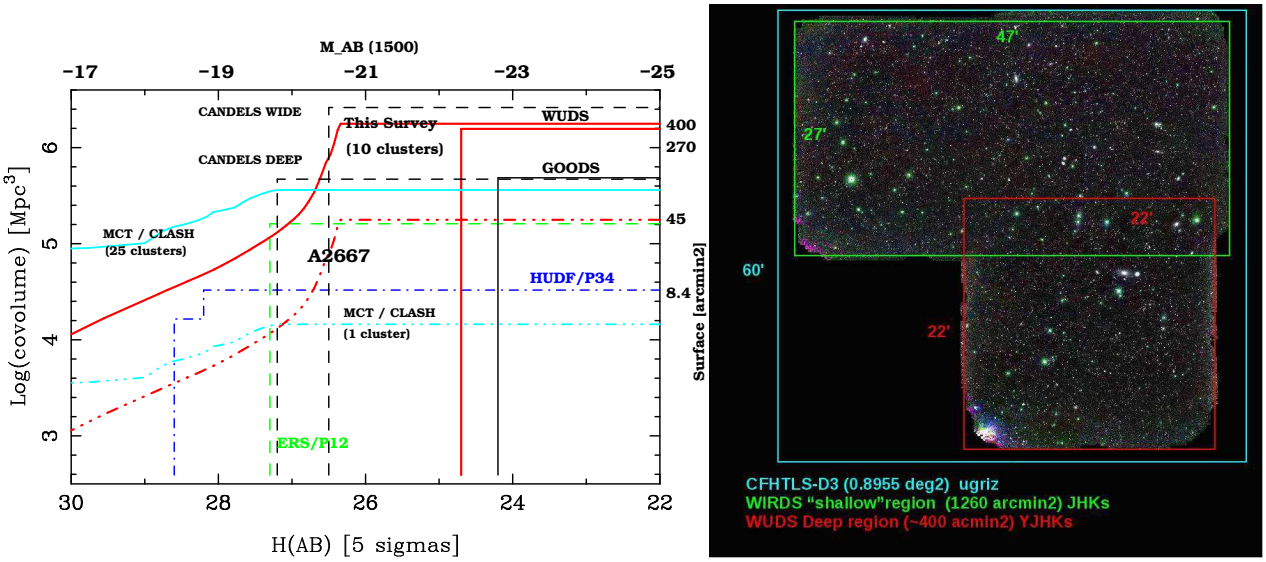


Fig. 2. Left: Characteristics of the $z \geq 7$ survey (thick red lines) compared to other surveys. The effective (unlensed) area and the $z \sim$ 7-9 covolume sampled by each survey is given as a function of effective H magnitude limit (5σ) and corresponding M_{AB}(1500Å). The different surveys are: our CFHT/WUDS survey (solid red line); the survey on A2667 (red dash-dotted line); the HST/MCT CLASH Survey (cyan, 1 cluster like A2667 and the whole survey); and the compilation of deep imaging JHK data available for dropout searches (from Wilkins et al. 2010): GOODS field (solid thin black line), ERS/P12 (dashed green line), and HUDF/P34 fields (dot-dashed blue line). **Right:** Layout of the WUDS Survey showing the regions covered by the deep and wide regimes as compared to the CFHTLS-D3 field (Groth Strip).

4 An important Science Case for EMIR/GTC: Constraining the abundance and properties of the first star-forming galaxies

One of the main goals of the GOYA survey is the identification and study of $z \geq 7$ sources. This is an important challenge for modern cosmology, as star-forming sources at $z \sim 7-12$ could have been responsible for a significant part of the cosmic reionization. Detailed studies of these "primordial" systems require the use of new ground-based and space facilities becoming available during the last few years (e.g. VLT/Hawk-I, HST/WFC3, Herschel,...), including ALMA and EMIR. The REGALDIS project [‡] was born in 2009 precisely to take advantage from our privileged access to these key facilities (through granted -open or guaranteed- time) to build up a statistically significant sample of galaxies with secure redshifts, together with an additional sample of candidates based on photometric redshifts and wide multi-wavelength coverage. The aim is to study the physical properties of these galaxies using their broad-band spectral energy distribution in one hand, and their emission line properties on the other hand.

The abundance and properties of $z \sim 7-12$ galaxies have been discussed during the last few years in a context of international competition, based on deep photometric observations in the near-IR, both in blank and lensing fields (e.g. Bouwens et al. 2008; Richard et al. 2008; Bouwens et al. 2011, and the references therein). There is increasing evidence for a strong evolution in the UV LF between $z \sim 7-10$ and $z \sim 3-4$, the SFR density being smaller at very high-z up to the limits of the present surveys, in particular towards the bright end of the LF, in such a way that cosmic reionization should be dominated by low-luminosity galaxies. The extent of this effect is still a matter of debate. Together with field-to-field variance, there are two main issues. The first one is the limited surface covered by current "deep" surveys, both space or ground-based (i.e. lensing or in blank fields), compared to the needs in order to derive statistically significant results. Another issue is the lack of secure spectrocopic confirmation for all present $z \geq 7$ samples, and this is where an efficient facility such as EMIR is needed.

[‡] http://regaldis.ast.obs-mip.fr/

4.1 Photometric selection of high-z galaxies

The selection of high-z galaxies is based on the Lyman-break or dropout technique. Different redshift intervals within $6 \leq z \leq 12$ can be defined using an appropriate set of near-IR filters in combination with optical data (see e.g. Laporte et al. 2011). An homogeneous and deep coverage of the near-IR domain is crucial to achieve a reliable identification of high-z photometric candidates.

As shown by Maizy et al. (2010), the presence of a strong lensing cluster along the line-of-sight strongly improves the global efficiency of the survey with respect to blank fields, in particular to explore the $z \sim 6-12$ domain, and for relatively "shallow" surveys (i.e., the typical near-IR ground-based surveys). However, although lensing clusters are more efficient to conduct detailed (spectroscopic) studies in this redshift domain and to explore the faint-end of the LF, observations of wide blank fields are complementary to set reliable constraints on the brightest end of the UV LF, given the strong field to field variance in number counts in this regime. Our project combines the two approaches. Observations of lensing clusters with FORS2 + Hawk-I at VLT, and new (ACS and WFC3) HST images (cycle 17, PI J.P. Kneib) are being gathered in the framework of REGALDIS, together with Spitzer/IRAC+MIPS imaging data and Herschel data from the "Herschel Lensing Survey" (HLS Egami et al. 2010), available for all our target clusters, and ongoing APEX/LABOCA observations (see Boone et al. 2011).

The blank-field counterpart is our WIRCAM Ultra Deep Survey (WUDS) at CFHT, which is also intended to provide a robust selection of targets for other science cases of GOYA. The survey was specifically tailored to set strong constraints on the cosmic SFR and the bright end of the LF. WUDS has been carried out on the CFHTLS-D3 field (Groth Strip), in 4 near-IR bands ($YJHK_s$), the same bands used in lensing studies. The right panel in Fig. 2 provides the layout of the survey, showing the regions covered by the deep (WUDS) and wide (WIRDS) regimes. Data processing was performed at Terapix/IAP and CFHT. The final version of the stacked images was made available to the collaboration end 2010, and a public release of these data is foreseen by the end 2011. The typical depth for the ∼400 arcmin^2 "deep" area reaches between ∼26.8 in Y and J, and ∼26 in H and K_s (AB, 3σ in $1\farcs3$ aperture), for a completeness level of ∼80% at Y∼26 and H and K_s∼25.2, and excellent seeing conditions (ranging between $0\farcs55$ and $0\farcs66$). The corresponding depth of the CFHTLS-D3 images in this region ranges between 28.6 and 29 in ugr, 28.2 in i and 27.1 in z (same S/N ratio and aperture). The WUDS survey will be presented in a forthcoming paper.

Fig. 2 displays a comparison between our survey (lensing and WUDS fields) and other surveys in the $z \sim 7-9$ redshift domain. In the case of the CLASH Survey, we assumed that all clusters are as efficient as A2667, which is a rather optimistic assumption. The present survey will cover the same volume as all the presently available deep HST (ACS+WFC3) fields, but it is a factor of ∼7 larger at $M_{AB}(1500\text{Å})\leq$-20.3 (i.e. $\gtrsim L^*$ at $z \sim 7-9$). As compared to the large ongoing HST "Multi-cycle Treasury" (MCT) programs, and in particular the CLASH survey with ACS and WFC3, our survey is quite complementary. It will cover an **effective** volume which is ∼5 times larger at $z \sim 7-9$ in the intermediate-luminosity domain (M_{AB} ∼-20.5 to -23). It is therefore better-suited to trace the most sensitive region of the LF, and also for the selection of spectroscopic targets. Only the CANDELS Survey with HST is expected to provide a similar and larger area. However, all HST surveys lack deep data in the K-band, which is particularly useful to identify high-z sources and to determine the slope of the UV continuum.

4.2 First results in lensing & WUDS fields

We have obtained a complete dataset at ∼0.8-2.5 microns with ESO/VLT HAWK-I and FORS2 on the lensing cluster A2667, as part of the REGALDIS project (see Laporte et al. 2011). The selection function is based on deep I, z, Y, J, H and Ks-band images (AB∼26-27, 3σ), including IRAC data between 3.6 and 8 μm, and MIPS 24μm when available. 13 candidates are selected within the $\sim 7' \times 7'$ field of view of HAWK-I ($\sim$ 33 arcmin^2 of effective area once corrected for contamination and lensing dilution at $z \sim 7-10$), namely 1 J-drop, 8 Y-drops and 4 z-drops. Fig. 3 displays the brightest 10 optical-dropouts reported by (Laporte et al. 2011), with H_{AB} =23.4 to 25.2 and magnification factors between 1.1 and 1.4. Best-fit photometric redshifts are obtained at high-z for all these candidates using a variety of template SEDs ($z \sim 7.5$ to 9), with a less significant solution at $z \sim 1.7$ to 2.8. Several of these sources seem too bright to be at $z \geq 7.5$, suggesting some contamination by mid-z interlopers which must be also present in other current surveys. Indeed, two candidates from Laporte et al. (2011) have been recently detected in the Herschel and LABOCA/APEX IR bands, making the high-z identification unlikely (Boone et al. 2011).

Regarding the contamination by mid-z interlopers, it could be between ∼50-75% depending on the redshift

bin, based on the comparison with the WUDS results on a larger field of view. Indeed, preliminary results using the same color selection (but the 5 optical bands of the CFHTLS-D3 instead of 2 in A2667) indicate 3 J-drop (+1 dubious), 13 Y-drops and 12 z-drops (+3 dubious) within the deep WUDS region. This means a relatively low density of potential targets for this programme (typically ∼0.1 target/arcmin, i.e. ∼2-3 targets within the EMIR FOV). The number of potential targets in a lensing field is expected to be at least a factor of 2 (and up to a factor of 5) larger within the EMIR FOV, depending on the depth of the selection window.

The first results obtained on the LF of $z \gtrsim 7$ galaxies based on A2667 observations are consistent with a sharp decrease in the number of bright galaxies beyond $z \sim 8$, in agreement with other previous findings (e.g. Bouwens et al. 2011, see also Laporte et al., this conference).

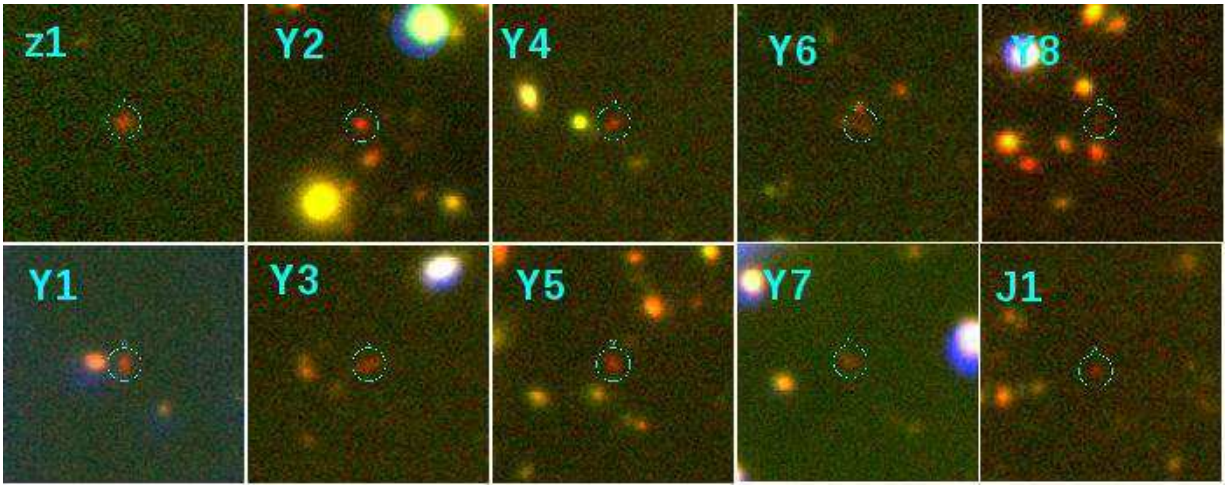


Fig. 3. Color thumbnails showing the 10 brightest optical-dropouts found in the lensing cluster A2667 (see Laporte et al. 2011, for more details).

5 Conclusions and Perspectives

Due to a lack of efficient near-IR spectrographs, very few galaxies at $z \gtrsim 7$ have been spectroscopically confirmed till now. The identification and study of the first galaxies require an extensive multi-wavelength coverage of their SED. Detailed studies of spectral signatures for $z \geq 7$ galaxies, including a precise redshift determination, need near-IR observations at wavelengths beyond 1 micron. Spectroscopy is mandatory for (at least) a robust/reference sample of photometric candidates. It is also needed to understand the nature of (extreme) mid-z interlopers presently found in deep surveys. The arrival of EMIR/GTC, and the start of the spectroscopic part of the GOYA Survey in 2013, is expected to introduce a substantial progress in this area. The spectroscopic follow up of WUDS candidates in particular is already planned with EMIR/GTC.

Our ongoing photometric survey for the selection of $z \geq 7$ candidates, combining both lensing and blank fields, is quite complementary with respect to large HST "Multi-cycle Treasury" (MCT) programs, in particular the CLASH survey. It is therefore better-suited to trace the $L \gtrsim L^*$ region of the LF, and also for the selection of spectroscopic targets for EMIR and ALMA.

Part of this work was supported by the French CNRS, the French Programme National de Cosmologie et Galaxies (PNCG), as well as by the Swiss National Science Foundation. We acknowledge support from the Spanish Programa Nacional de Astronomía y Astrofísica under grant AYA 2006-02358. Partially funded by the Spanish MEC under the Consolider-Ingenio 2010 Program grant CSD2006-00070: First Science with the GTC (`http://www.iac.es/consolider-ingenio-gtc/`). This work recieved support from Agence Nationale de la recherche bearing the reference ANR-09-BLAN-0234. This paper is based on observations collected at the European Space Observatory, Chile (71.A-0428, 082.A-0163). Based on observations obtained with WIRCam, a joint project of CFHT, Taiwan, Korea, Canada, France, and the Canada-France-Hawaii Telescope (CFHT) which is operated by the National Research Council (NRC) of Canada, the Institut National des Sciences de l'Univers of the Centre National de la Recherche Scientifique of France, and the University of Hawaii.

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