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GALAXIES AT Z>7: PROBING GALAXY FORMATION WITH THE NEW GENERATION OF NIR INSTRUMENTS

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RESUMEN

Presentamos los resultados obtenidos en nuestro sondaje de cúmulos-lentes para determinar la abundancia de galaxias con formación estelar a z∼6-11. La magnificación por efecto de lente gravitatoria mejora la eficacia tanto en la búsqueda como en el estudio espectroscópico de las fuentes con la nueva generación de espectrógrafos multi-objecto en el IR próximo (e.g. EMIR/GTC). La Función de Luminosidad UV obtenida a partir de los candidatos fotométricos no muestra el decremento encontrado a z∼6-7 por Bouwens et al. (2005) en la parte brillante. El resultado es una densidad de formación estelar compatible con un valor constante hasta z∼10. Este efecto sistemático puede ser debido a la varianza campo a campo, a un efecto de sesgo positivo por efecto de lente gravitatoria sobre EROs a redshift intermedio, y/o contaminación residual por fuentes espurias.

ABSTRACT

We present the results obtained from our deep survey of lensing clusters aimed at constraining the abundance of star-forming galaxies at z∼6-11. Lensing magnification improves the search efficiency and subsequent spectroscopic studies with the new generation of NIR multi-object spectrographs (e.g. EMIR/GTC). The UV Luminosity Function derived from the photometric sample of candidates does not show the turnover observed at z∼6-7 by Bouwens et al. (2005) towards the bright end. For this reason, the SFR density is consistent with a constant value up to z∼10. This systematic trend with respect to blank fields could be due to field-to-field variance, positive magnification bias from mid-z EROs, and/or residual contamination by spurious sources.

Key Words: **COSMOLOGY: EARLY UNIVERSE — GALAXIES: EVOLUTION — GALAXIES: HIGH REDSHIFT — INFRARED: GALAXIES**

1. INTRODUCTION

Constraining the abundance of $z > 7$ sources is an important challenge of modern cosmology. Recent WMAP results seem to place the first building blocks at redshifts up to $z \sim 10 - 15$ (Spergel et al. 2006). Distant star-forming systems could have been responsible for a significant part of the cosmic reionization. From the observational point of view, considerable advances have been made during the last years in the exploration of the early Universe, reaching from detailed studies of z∼4-5 galaxies found in deep multi-wavelength surveys, to the discovery of galaxies at z∼6-7, close to the end of reionisation epoch (e.g. Hu et al. 2002, Kodaira et al. 2003, Cuby et al. 2003, Kneib et al. 2004, Stanway et al. 2004, Bouwens et al. 2004). Extending the searches beyond z∼7 requires extremely deep observations in the near-IR bands. Indeed, astounding depths can be reached in ultra-deep fields, such as demonstrated recently with J and H imaging of the NICMOS Ultra-Deep Field (UDF; Thompson et al. 2005; Bouwens et al. 2005) from which faint (H_{AB} ∼27) candidates at z∼7-10 have been identified.

In this paper we summarize the results obtained in our deep survey of lensing clusters aimed at constraining the abundance of star-forming galaxies at $z \sim 6 - 10$, taking benefit from lensing magnification to improve the search efficiency and subsequent spectroscopic studies.

2. PHOTOMETRIC SURVEY

Two lensing clusters were selected for this study: AC114 ($z = 0.312$) and A1835 ($z = 0.252$). AC114 exhibits a large number of multiple-images spectroscopically identified at high redshift. A1835 is the most X-ray luminous cluster in the $XBACS$ sample and it displays strongly lensed features. Detailed lensing models are available for these two clusters. The reader should refer to the paper by Richard et al. (2006, hereafter R2006) for all details and technical issues presented in this section.

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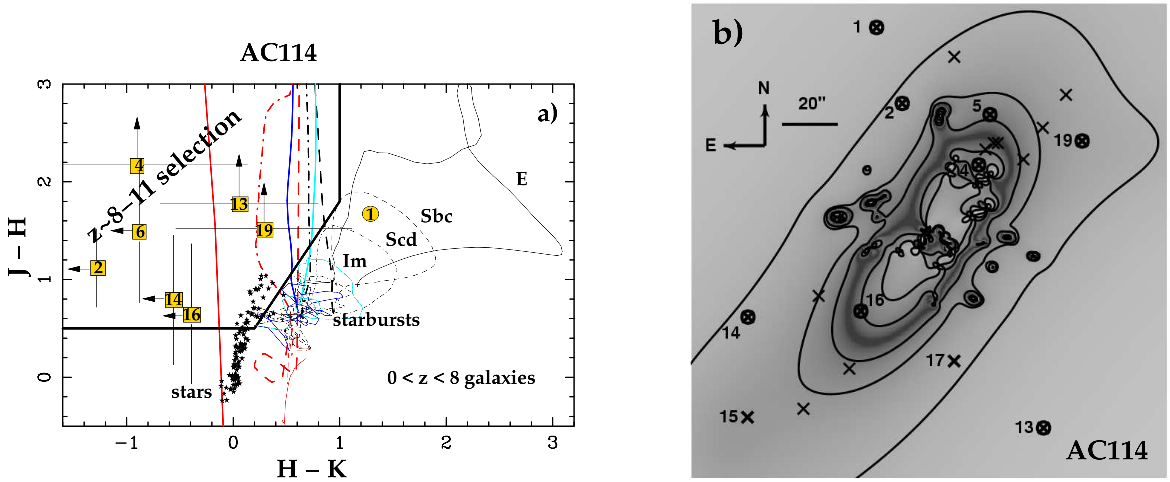

Fig. 1. **a)** Color-color diagram (Vega system) showing the position expected for galaxies at $z \sim$ 0-11 together with the location of optical-dropouts detected in AC114, and the delimitation of the selection region used in the $z \sim 8-11$ redshift domain. Thin and thick lines display models below and above $z = 8$ respectively (see also R2006). **b)** H band image representation of AC114 showing the contours for magnification values of 1, 2 and 3 magnitudes, computed for sources at $z = 9$, although the position of these lines is weakly sensitive to source redshift within the relevant range $z \sim 6-12$. Only first/second-category dropouts are circled.

2.1. *Selection of high-z candidates*

Observations were obtained at VLT with ISAAC and FORS in the near-IR domain ($\sim$ 0.9 to 2.2 μm) between September 2002 and April 2004, covering the z, SZ, J, H, and K bands. Optical images at shorter wavelengths (from U to I band), including *HST* images, are available in our group from previous surveys, or from archival data. We have defined an H band selected sample, as all the high-z candidates are expected to be detected in this band. The reduction procedure was optimized to detect faint compact sources. The survey reached (Vega) $SZ \sim 25.6$, $J \sim$ 24.3-24.4, $H \sim 23.5$ and $Ks \sim 23.1$ (AC114) to 23.5 (Abell 1835) (3 σ level within 1.5$''$ aperture), i.e. AB$\sim$ 25-25.5 in $JHKs$ and AB$\sim$26.3 in SZ. The *minimum* magnification factor over the region covered by the near-IR survey is $\sim$ 0.7 magnitudes, and at least $\sim$ 1 magnitude over 50% of the ISAAC field of view.

High-z candidates were selected among optical dropouts (flux below 1σ within 1.5$''$ aperture) using near-IR color-color diagrams (e.g. see Figure 1). For the brightest candidates, individual probability distributions and photometric redshifts were derived. We have identified 18(8) first and second-category optical dropouts in A1835 (AC114), detected in more than one filter up to $H_{AB} \sim 25.2$, uncorrected for lensing. This sample includes mid-z EROs. The UV slope of the high-z candidates (derived from $H-K$) is extremely blue, between $\beta = -0.7$ and -3.5, a trend also reported by Bouwens et al. (2004) for their sample of $z \sim 7-8$ candidates.

2.2. *Luminosity Function and SFR density at z>6*

Lensing magnification and dilution effects are carefully taken into account when computing number densities and derived quantities in these fields. Photometric incompleteness and spurious detections were also corrected. The combined L_{1500} Luminosity Functions (LF) for two redshift intervals ($6 \lesssim z \lesssim 10$ and $8 \lesssim z \lesssim 10$) are given in Figure 2, together with the STY fits ($L^* = 10^{41.5}$ ergs s^{-1} Å $^{-1}$ for a fixed value of $\alpha = -1.6$), and other LFs from the literature. We also display the LF derived from simplistic models, using Press-Schechter formalism, assuming 10% of the baryonic mass converted into stars within $6 \lesssim z \lesssim 11$, and two extreme IMFs (see R2006 for details). LFs in these lensing fields are consistent with the LF for LBGs at $z \sim 3$, and also compatible with the LF derived by Bouwens et al. (2005) for their sample of $z \sim 6$ candidates in the UDF, UDF-Ps and GOODS fields in the low-luminosity regime, i.e. for $L_{1500} \lesssim 0.3L^*_{z=3}$, but we don't see the turnover observed by these authors towards the bright end.

The cosmic SFR value has been derived by integrating this LF down to $0.3L^*_{z=3}$ (vertical grey line in Figure 2): $\sim$3 10^{-2} M$_\odot$ yr^{-1} Mpc^{-3}, depending on the redshift interval. This value is consistent with a constant SFR density up to z$\sim$10 and higher than the usual values derived from small blank fields. The

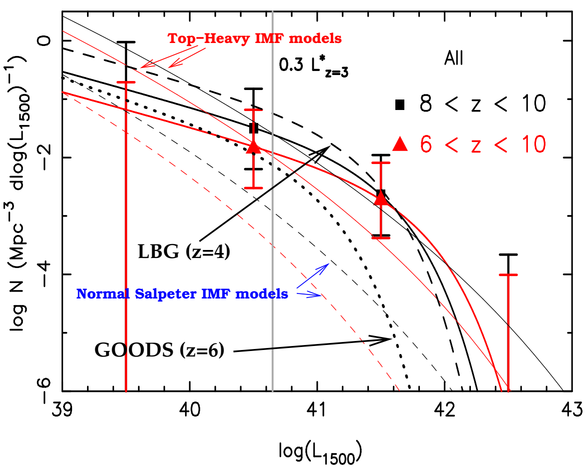

Fig. 2. L_{1500} LFs derived for the photometric sample of high-z candidates in our 2 lensing fields (adapted from R2006). Data points are corrected for spurious sources, and error bars combine Poisson noise statistics and uncertainty in the effective completeness. STY fits to the LF data are presented by thick solid lines, and compared to the LF by Steidel et al. (2003) for LBGs at $z \sim 4$ (thick dashed line), as well as the $z \sim 6$ fit from Bouwens & Illingworth (2006) (thick dotted line). We also display the LFs corresponding to the simple models presented in § 2.2, for two extreme IMFs.

difference is related to the bright end of the LF. In all cases the sources are photometric candidates providing, therefore, upper limits to the actual UV flux densities.

3. CONCLUSIONS AND PERSPECTIVES

A first attempt was made to constrain the density and the properties of star-forming galaxies at $z \sim 6 - 10$ using lensing fields. Taken at face value, our results are consistent with a constant SFR density up to z∼10. The systematic trend observed in the LF with respect to blank fields could be due to to field-to-field variance, a positive magnification bias from mid-z EROs, and/or residual contamination by spurious sources. Spectroscopic follow-ups are underway to determine the efficiency of our selection technique, and the contamination level by mid-z interlopers. Additional deep photometry in various bands are being collected with HST, IRAC/Spitzer, and from the ground to improve the SEDs characterization of the high- candidates.

Lensing clusters seem more efficient than present blank fields to explore the z∼6-12 domain (with the same photometric depth and FOV). Positive magnification bias is expected from straightforward simulations, and seems to be confirmed by our first results in two lensing clusters. Also the spectroscopic follow up with the new generation of near-IR multi-object spectrographs is optimized in lensing fields, because of their typical FOV and multiplexing capabilities (e.g. EMIR at GTC). However, a positive magnification bias could also exist for very faint mid-z interlopers, such as the extremely-faint source A1835#35 (Richard et al. 2003). This effect is presently uncorrected in our sample, and it could affect the bright end of the LF (see more details in R2006). Large field-to-field variance is also present in the strong magnification regime, in particular towards the bright end of the LF. All present surveys, either space or ground-based, are still dramatically small in terms of effective surface. Wide and deep optical+ near-IR surveys in blank fields are needed to set strong constraints on the bright end of the LF.

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