DETECTION AND STUDY OF HIGH-REDSHIFT GALAXIES THROUGH CLUSTER-LENSES

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Abstract

We discuss a method to build up and study a sample of distant galaxies, with 2\(\lesssim z \lesssim 5\), using the gravitational amplification effect in cluster-lenses for which the mass distribution is well known. The candidates are selected close to the critical lines at high-z, through photometric redshift estimates on a large wavelength range. With respect to other methods, this procedure allows to reduce the selection biases in luminosity, thanks to the cluster magnification of \(\sim 1\) magnitude, and towards active SFRs when the near-IR domain is included. Some new results obtained with this technique are presented and discussed.

1 Introduction

We present the first results on the identification and study of very distant field galaxies in the core of cluster-lenses. Clusters of galaxies as gravitational lenses allow to study the stellar content and evolutionary state of galaxies much fainter than the usual spectroscopic field surveys. The amplification close to the critical lines is typically \(\Delta m \sim 2\) to 3 magnitudes, but it is still \(\sim 1\) magnitude at 1’ from the center. Sources are selected according to two criteria: 1) they are close to the critical lines at high-z, and 2) they have a photometric redshift compatible with \(z \geq 2\). The former implies the use of well known cluster-lenses, where the mass distribution is highly constrained by multiple images, in order to keep the amplification uncertainties below \(\Delta m_{\text{lensing}} \sim 0.3\) magnitudes. To identify multiple images, HST images are needed to set morphological constraints, and also photometry on a large wavelength domain. As an example, Figure 1 shows the central region of the cluster A2390, as well as the location of the critical lines at different redshifts, according to the lens model by Kneib et al. (1998). The expected 2D distribution of arclets (mean redshift and surface density) in the particular cluster A2218 can be found in Bézecourt et al. (1998). Some recent discoveries on cluster-lenses strongly encourages this approach. Among the first examples are the star-forming source #384 in A2218, at \(z=2.51\) (\[4\]), and the luminous \(z=2.7\) galaxy behind the EMSS cluster MS1512+36 (\[14\]). More recently, 3 galaxies at \(z \sim 4\) have been found in Cl0939+47 (\[14\]), a lensed galaxy at \(z=4.92\) in Cl1358+62 (\[14\],\[14\]), and a red lensed galaxy at \(z=4.04\) in A2390 (\[14\], hereafter H3).

The aim of this program is to determine the redshift distribution, the luminosity function and the main characteristics of the galaxy population at \(z \geq 2\). For this exercise, we use an
independent sample of galaxies, much less biased than the field samples in luminosity, or towards galaxies with a strong star-formation activity. This is particularly true if the photometric redshift is obtained through a large wavelength domain, including near-IR.

**Figure 2:** *Left:* Photometric redshift distribution in the field of A370. *Right:* Photometric redshift distribution in the field of A2390 (see text).

### 2 The photometric redshift approach

Photometric redshifts were derived according to the standard minimization method described by Miralles & Pelló (1998). The observed spectral energy distribution (SED) of each galaxy, as obtained from its multicolor photometry, is compared to a set of template spectra. The Bruzual & Charlot evolutionary code (GISSEL98, [2]) was used to build 5 synthetic star-formation histories, all of them with solar metallicity. The template database includes 255 synthetic spectra. This method has allowed to identify sources at $z \geq 2.0$ in the field of 3 cluster-lenses: A2390, A370 and A2218. In all cases, the photometric database includes deep near-IR J and K' images and/or U images. As an example, we show the redshift distribution obtained in A2390 and A370 (Fig. 2). In A2390, the selection criteria were based on the morphology of the images (surface brightness, elongation and orientation), and all images are located on the very central region of the HST frames. In A370, the selection criteria aimed to avoid the bright and obvious cluster members. Nevertheless, contamination by faint galaxies at $z = 0.37$ appears
clearly in Fig. 2. Most of the $z \geq 2.0$ sources identified on these clusters are too faint to be confirmed spectroscopically using 4m telescopes. For a selected sample of spectroscopically confirmed objects, we have tested further on the photometric redshift accuracy as a function of the relevant parameters, namely SFR, age and metallicity of the stellar population. These sources were observed during spectroscopic surveys at CFHT, WHT and ESO (NTT, 3.6m), and they are part of an extended Toulouse/ Cambridge/ Barcelona collaboration. We have also cross checked on the consistency between the photometric, the spectroscopic and the lensing redshift obtained from inversion methods ([1]). The agreement between the three methods is fairly good up to $z \leq 1.5$. For higher redshifts, a spectroscopic sample is urgently needed to conclude.

3 Constraining the stellar population of high-z sources

The SEDs of these high-z sources, determined from broad-band photometry, can be fitted by different synthetic stellar populations. There is a degeneracy to consider in the SFR-age-metallicity-reddening space. When the IMF and the upper mass limit for star-formation are fixed, the allowed parameter space can be constrained using the GISSEL98 code.

![Figure 3: H5 likelihood map showing in dark the most probable regions and the degeneracy in the parameter space defined by SFR, age, metallicity and reddening. The dotted line is the age limit corresponding to $z = 4.05$ ($H_0 = 50\, km\, s^{-1}Mpc^{-1}$, $q_0 = 0$).]

We present as an example two $z \sim 4$ sources found in A2390 (H3 and H5 in Fig. 1). The two sources are at the same redshift, but their stellar contents are different. The redshift of H3 was already measured by Frye & Broadhurst (1998), and H5 is coming from our CFHT/WHT program ([1]). Figure 3 displays the likelihood map of H5. H3 and H5 are necessarily dominated by massive OB stars at the wavelengths seen in the visible bands. Also, the presence of Ly$\alpha$ in emission points towards star-forming systems. Two kinds of SFRs were considered: an instantaneous burst, and a continuous star-forming system, both with the Salpeter IMF (1955), mass-limits for star-formation $0.1M_\odot \leq m \leq 125M_\odot$, and an extinction law of SMC type ([1]). H3 is better constrained than H5, the weight of the old stellar population being more important in H3 than in H5. As a consequence, it is more difficult to reproduce the SED of H3 through an arbitrary set of the reddening value. In a short-burst model, H3 should be older than H5. H3 and H5 are well fitted by burst models of 0.2 solar or even higher metallicities, but H5 is also in fair agreement with a reddened system undergoing a continuous star-formation activity. The two sources are intrinsically bright ($M_B^* - 2$ to -1 magnitudes, depending on $A_v$), slightly brighter than the $z \sim 4$ objects found by Trager et al. (1997) in Cl0939+4713, and
also brighter than the $z = 5.34$ galaxy of Dey et al. (1998). This fact, combined with the high gravitational amplification, has allowed us to obtain a spectroscopic redshift for them using a 4m telescope. A subsequent spectroscopic survey using a 10m telescope will go further on this study, especially to estimate more precisely the metallicities using the UV absorption lines.

4 Discussion and perspectives

The uncertainty in the amplification factor is typically 0.3 magnitudes for a large magnification case. Thus, the intrinsic luminosities and stellar masses are known with an accuracy of $\sim 30\%$. This source of error has the same importance than the model uncertainties for a relatively well constrained SED. This gives an idea of the limitation arising from lens modelling when using clusters as gravitational telescopes to access the background sources. Only the well constrained clusters are useful for this project.

H3 and H5 are the first spectroscopically confirmed images of sources at $z \geq 2$ in A2390. The selection of high-z candidates using a photometric redshift approach, including the near-IR bands, is strongly supported by the present results. For most statistical purposes, photometric redshifts should be accurate enough to discuss the properties of these extremely distant galaxies. Inversely, the spectroscopic confirmation of the redshifts of such gravitationally amplified sources could help on the calibration and improvement of the photometric redshift techniques. A large VLT Program is presently going on, involving different european institutions (ESO/IAP-DEMIRN/Toulouse/Roma/MPE- Heidelberg among others), and also the U. of Chile, aiming to perform the spectroscopic follow up of high-z candidates selected from the preparatory visible and near-IR photometry at the NTT and 3.6m telescope of ESO.

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