High redshift galaxies through gravitational lensing

José A. de Diego\(^1\), Jordi Cepa\(^2\), Mario De Leo\(^1\) & Ángel Bongiovanni\(^2\)

\(^1\) Instituto de Astronomía, Universidad Nacional Autónoma de México, Ciudad Universitaria, 04510 México D.F., MX
\(^2\) Instituto de Astrofísica de Canarias, C/ Vía Láctea, s/n, E38205 - La Laguna (Tenerife), SP
E-mail: jdo@astroscc.unam.mx

Abstract. The technique and some preliminary results about the study of the luminosity function (LF) of Lyman Alpha Emitters (LAEs) through gravitational lensing (GL) is presented. Clusters of galaxies, with suitably modeled gravitational lenses are observed using the tunable filters (TF) of the instrument OSIRIS at the GTC. The combination of these natural gravitational telescopes, and the higher contrast achievable by the TF, will allow the detection of very faint LAEs, not only reaching a step forward in understanding this primordial objects, but also achieving a better determination of the mass distribution on the inner regions of galaxy clusters.

1. Introduction
LAEs and Ly\(\alpha\) blobs are distant dust-free galaxies that emit Ly\(\alpha\) radiation. Typical LAEs are about 1 kpc in size, and the gas is completely ionized, through photoionization, by the first generation of massive blue stars responsible for the reionization of the universe. The much more extended Ly\(\alpha\) blobs have sizes up to 100 kpc, and the ionized gas in these objects is mechanically warmed. LAEs and Ly\(\alpha\) blobs are important in cosmology because they trace high redshift galaxies, their dark matter halos and subsequently the evolution of matter distribution in the universe.

2. LAEs detection
Usually, LAEs have been detected in the optical bands (2 < \(z\) < 7) using deep field narrowband imaging with bandpass around 70 Å to study discrete redshifts (e.g. Subaru Deep Field [1, 2, 3]). The actual record is a \(z = 8.6\) galaxy [4]. With OSIRIS and its set of tunable filters we plan to reduce the bandpass to \(\sim 15\) Å and obtain a higher contrast for LAE detections (Fig. 1).

3. Gravitational lensing
We plan to use GL by clusters of galaxies to study faint high redshift sources. Galaxy clusters behave as GL natural telescopes, and they allow the study of different GL regimes, from strong GL forming the impressive arcs around the cluster centers, to the weak GL on the outskirts of the clusters that can be studied through statistical techniques. We expect to detect LAEs at high redshift, reaching luminosities \(\sim 10^{42}\) erg s\(^{-1}\) for highly magnified objects [5]. This will lead to constrict the limits of the LF at high redshift, to study the magnification bias [6, 7], and to improve accurate modeling of the cluster masses. We have already modeled some GL
clusters using archive data from the Keck and Hubble telescopes, such as MS 0440.5+0204, to characterize the critical lines and calculate probabilities of amplification (Figs. 2 and 3).

4. Methodology
Three spectral regions not contaminated by strong sky lines will be observed: 6750 - 6930; 8100 - 8230; and 9110 - 9250 Å with the red TF. These regions correspond to the Lyα line up between 4.6 < z < 6.6. From the LF of LAEs [7], we expect to detect about 20 such objects per cluster field with fluxes ≥ 2 × 10^{-17} erg s^{-1} cm^{-2}, to characterize the LF of LAEs, to improve GL models and to study the magnification bias by comparison between blank fields and different lensing regimes available from each 8 × 8 arcmin² OSIRIS field of view. The observations will also be useful to search for SFR of Pop. III dual Lyα -HeII(1640 Å) emitters [10] around z = 4.6 (Fig. 4).

5. Available and future data
Observations of MS 0440.5+0204 have been already performed. Data is already reduced and will be analyzed during the next months. Other observations, including 2.5 h of OSIRIS granted time, are in the queue. Figure 5 shows observations of the cluster of galaxies MS 0440.5+0204.

Figure 1. OSIRIS TF with a bandpass of 12 Å (color Gaussians) are shifted half the bandpass for optimum detection. The black Gaussian shows the Lyα emission for a LAE at z = 6.6 with a FWHM of ~ 9 Å (~ 300 km s^{-1}). The thick line with symbols shows the SNR for 200 s exposures with GTC, computed with the OSIRIS calculator developed by J. Ignacio González-Serrano at IFCA.

Figure 2. GL model developed for MS 0440.5+0204. (Figure from [8]).

Figure 3. Magnification probability for galaxies in a region around 15'' the caustic lines of MS 0440.5+0204 (Figure from [8]).
obtained during November 2009. Raw data show strong sky features due to the variations of the wavelength across the field of view, an expected characteristics of the OSIRIS TF. Data also suffers from a remarkable dark current stamp which adds an unexpected noise to the observations; fortunately, this dark current problem has been already solved and will not affect future observations.

This work has been supported by CONACyT grant 50296 and has been partially funded by the Spanish MICINN under the Consolider-Ingenio 2010 Program grant CSD2006-00070: first Science with the GTC (http://www.iac.es/consolider-ingienio-gtc).

References
[1] Kashikawa, N., et al., 2006, ApJ 648, 7.
[2] Shimasaku, K., et al., 2006, Publications of the Astronomical Society of Japan 58, 313.
[3] Ouchi, M., et al., 2008, ApJS 176, 301-330.
[4] Lehnert et al. 2010, Nature, 467, 940.
[5] Santos, M.R., et al., 2004, ApJ 606, 683.
[6] Bouwens, R. J. et al., 2009, ApJ, 690, 1764.
[7] Narayan, R. & Bartelmann, M., 1996, astroph, 6001.
[8] Verdugo, T., 2008, PhD Thesis, Instituto de Astronomía, Univ. Nac. Autónoma de México.
[9] Le Delliou, M., et al., 2006, MNRAS 365, 712.
[10] Nagao, T., et al., 2008, ApJ 680, 100.