Probing Galaxies through Quasar Absorption Lines
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Adaptive optics imaging search for damped Lyα absorbers toward APM 08279+5255

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Abstract. We present initial results from an high-resolution imaging search for damped Lyα absorbers toward the high-redshift quasar APM 08279+5255 by using the Adaptive Optics system (AO) attached to the Subaru telescope. We detected in total 11 objects within a $23'' \times 23''$ field around the quasar. Among these detected objects, we identified a possible candidate for the galaxy giving rise to the damped Lyα absorption at z_{abs}=2.974 with a criteria of distance from the sight-line toward the quasar and luminosity.

1. Introduction

Damped Lyα (DLA) systems observed in the spectra of background quasars trace high HI column density regions with log N(HI) [cm^{-2}] > 20.3. DLA systems are the statistically dominant population at high redshift, whose number density is 10−100 times higher than typical L* galaxies. Thereby, they are believed to arise in the progenitors of present-day galaxies. In order to reveal the formation process of galaxies, it is important to find the galaxies associated with high-redshift DLA systems.

Despite extensive searches for the galaxies giving rise to high-redshift DLA systems, the number of identified galaxies is too small to learn their statistical properties. A major reason is that the galaxies associated with DLA systems should be located at close proximity to the line-of-sight toward background quasars and are hidden by the point spread function (PSF) of the bright quasars. Thus, high spatial resolution imaging is essential to discover the hidden DLA galaxies.

In this context, we conducted a high-resolution K$'$-band imaging around the quasar APM 08279+5255 using an **adaptive optics system (AO)** which compensates for the disturbed wavefront by the Earth's atmosphere and provides nearly diffraction limited spatial resolution in a best case. The AO system increases the sensitivity to detect faint galaxies located in close proximity to a bright object, since the flux of the AO PSF is highly concentrated in the diffraction limited core. Thus, the AO system is suited to fulfil both the sensitivity and spatial resolution which are essential for detecting DLA galaxies.

2. Observations and data reduction

The gravitationally lensed quasar APM 08279+5255 (z_{em} = 3.911) has been given much attention since its discovery by Irwin *et al.* (1998), as it is one of the most luminous objects in the Universe even after correction for the gravitational lensing induced amplification. There are two bright gravitationally lensed images A and B with a separation of $0''.38$ and the faint third image C located between A and B with a separation of

A-C= 0″.15. Petitjean *et al.* (2000) reported that there are two DLA systems in the sight-line toward the quasar at z_{abs} = 1.062, 1.184 and a probable DLA system at z_{abs}=2.974, which has a neutral hydrogen density of $19.8 < \log N(HI) < 20.3$.

Observations were carried out using the infrared camera and spectrograph (IRCS, Kobayashi *et al.* 2000) and the Subaru AO system (Takami *et al.* 2004), both mounted together at the Cassegrain focus of the Subaru 8.2m telescope (Iye *et al.* 2004) at Maunakea, Hawaii. We used the quasar APM 08279+525 ($R \sim 15.6$) itself as the wavefront reference star for the AO system. Near-infrared K'-band (2.12μm) images were obtained with the IRCS slit-viewing camera with a pixel scale of 0.23 arc-sec/pixel during an echelle spectroscopy of APM 08279+5255 itself (see Kobayashi *et al.* 2002). The position angle of the slit was set to 32° (North-to-East) so that all of the lensed images (A, B, and C) were aligned along the slit. The object was moved along the slit from 1″.5 to 2″.0 for sky subtraction.

The data reduction process included the following steps: flat fielding, bad pixel correction, sky subtraction, and combination into a single frame. Total integration time was 1.7 hours for the combined image. Since we moved the quasar between two positions along the slit, the images at different points were subtracted from each other for sky subtraction. Therefore negative features appeared on the left and right sides of the objects in the resultant combined image.

The achieved 5σ limiting magnitude for the combined image is $K' \sim 22.5$ mag with high-spatial resolution of 0″.2 in the stellar FWHM. Note that because of the photon noise of the quasar, the limiting magnitude becomes brighter as the apparent distance from the quasar becomes smaller. Fig. 1a shows the K'-band image of the $23'' \times 23''$ field around the APM 08279+5255. In total 11 objects were detected in the K'-band image. Because of the negative features due to sky subtraction, we could not detect any objects on the left and right side of the quasar and the 11 detected objects.

3. Discussion

We identified a possible candidate for the galaxy giving rise to the DLA at z_{abs}=2.974 with a criteria of distance from the sight-line toward the background quasar (impact parameter) and luminosity. We first eliminated the objects that are located at a large impact parameter. We give an upper limit on the impact parameter for DLA galaxies by assuming that DLA systems are disk progenitors of today's spiral galaxies. If one assumes that the size-luminosity relation and the ratio of the HI radius to the optical radius for high-redshift DLA galaxies are the same as today's galaxies, the radius of the HI disk (R) is described as R = R* [L/L*] 0.4, where R* is the typical HI disk size of present-day L* galaxies ($\sim 17.25\mathrm{h}^{-1}$ kpc: Lanzetta *et al.* 1991). However, the predicted number density of the DLA galaxies with this HI radius could not account for the observed number density in the spectrum of quasars, suggesting that there has been an evolution in the size or number density of galactic disks. Colbert & Malkan (2002) introduced a factor of 2 size evolution into the HI disk at $z \sim 3$ (R* $\sim 34.5\mathrm{h}^{-1}$ kpc) to match the predicted number density to the observed one. In this case, the radius of the HI disk could be an upper limit on the impact parameter for DLA galaxies. We use this upper limit of the impact parameter to select the candidate for z_{abs}=2.974 DLA galaxy (see dot-dashed line in Fig. 1b). We also eliminated the objects that are too bright to be galaxies at $z \sim 3$. Weighting a Schechter luminosity function by the cross section, which are expected from the size-luminosity relation, and integrating, we can determine that the percentage of expected DLA systems with a magnitude brighter than L* for $z \sim 3$ Lyman break galaxies (LBG) is less than 3% (Colbert & Malkan 2002). Thus, we have

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placed an upper limit on the luminosity at L*(LBG) (dotted line in Fig. 1b). With these two criteria, we considered object no. 1 most likely to be a candidate for the DLA system at z_{abs}=2.974.

4. Summary

We conducted high-resolution K'-band imaging with the Subaru AO system around APM 08279+5255 and detected in total 11 objects within the $23'' \times 23''$ field of view. Among the 11 objects, we identified a possible candidate (object No. 1) for the galaxy giving rise to the DLA system at z_{abs}=2.974 with a criteria for the impact parameter and luminosity. Although we cannot know the nature of high-redshift DLA galaxies from this one example, we have demonstrated that high-resolution imaging with an adaptive optics system is a viable method for discovering high-redshift DLA galaxies.

We note that if DLA systems are dwarf galaxies, 60-90% of the DLA systems could be located within impact parameters of 3 kpc (Okoshi & Nagashima 2005), where we do not have the ability to resolve with the present data. Even higher resolution imaging (FWHM $<$ 0.15) with a laser-guided adaptive optics system, which produces an artificial bright star for wavefront reference at any given point of the sky, would be best suited for discovering such DLA galaxies.

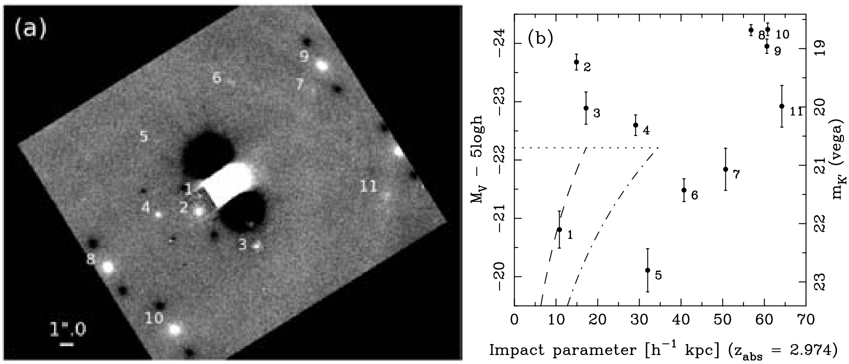

Figure 1. **(Left)** K'-band image of the $23'' \times 23''$ field around APM 08279+5255. The 11 detected objects are marked with ID numbers. The point spread function of the quasar was subtracted in the vicinity of the objects No. 1 and 2. **(Right)** Impact parameter vs. V-band absolute magnitude diagram for the 11 detected objects. We assumed that the galaxy lies at the redshift of the DLA (z_{abs}=2.974) system. The various lines demonstrate the limits inside which we believe it could be possible for the observed galaxies to be DLA systems. The inner dashed line represents no size evolution for a disk galaxy, while the dot-dashed line shows an increase in disk size by factor of 2. The horizontal dotted line shows the magnitude of an L*(LBG) galaxy.

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