# A Deep Survey of $z = 7$ Ly$\alpha$ Emitters and Reionization with the Red-sensitive CCDs on the Subaru Telescope Suprime-Cam

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We conducted a deep narrowband NB973 (FWHM = 200 Å centered at 9755 Å) survey of $z = 7$ Ly$\alpha$ emitters (LAEs) in the Subaru/*XMM-Newton* Deep Survey Field, using the fully depleted CCDs newly installed on the Subaru Telescope Suprime-Cam, which is twice more sensitive to $z = 7$ Ly$\alpha$ at ~1 $\mu$m than the previous CCDs[1] (Figure 1). Reaching the depth 0.5 magnitude deeper than our previous survey in the Subaru Deep Field that led to the discovery of a $z = 6.96$ LAE[2,3], we detected three probable $z = 7$ LAE candidates (Figure 2).

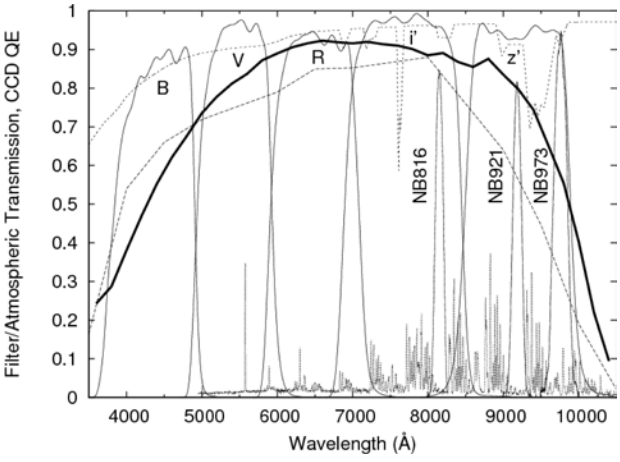


**Figure 1**: Suprime-Cam filter transmission, skylines, atmospheric transmission and quantum efficiencies of old CCDs and new fully depleted CCDs (thin-solid, thin-dotted, shortdashed, long-dashed and thick-solid curves, respectively). New CCDs are twice more sensitive to $z = 7$ Ly$\alpha$ at ~9730 Å.

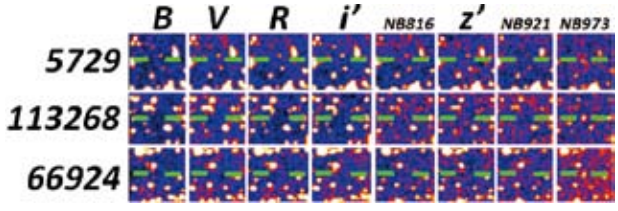


**Figure 2**: The multi-waveband images of the three candidate $z = 7$ LAEs. They are detected only in NB973.

Even if all the candidates are real, the LAE number density $n_{\mathrm{Ly}\alpha}$ and Ly$\alpha$ luminosity density $\rho_{\mathrm{Ly}\alpha}$ at $z = 7$ are ~7.7–54% and ~5.5–39% of those at $z = 5.7$ to the Ly$\alpha$ line luminosity limit of $L(\mathrm{Ly}\alpha) \sim 9.2 \times 10^{42}$ erg s$^{-1}$ (Figure 3). This could be due to evolution of the LAE population at these epochs as a recent galaxy evolution model predicts that the LAE modestly evolves from $z = 5.7$ to 7[4]. However, even after correcting for this effect of galaxy evolution, $n_{\mathrm{Ly}\alpha}$ and $\rho_{\mathrm{Ly}\alpha}$ still show deficits from $z = 5.7$. This might reflect the attenuation of Ly$\alpha$ emission by neutral hydrogen remaining at the epoch of reionization and suggests that reionization of the universe might not be complete yet at $z = 7$, supporting the possible higher neutral fraction at the earlier epochs at $z > 6$ suggested by the previous surveys of $z = 5.7$–7 LAEs, $z \sim 6$ quasars and $z > 6$ $\gamma$-ray bursts.

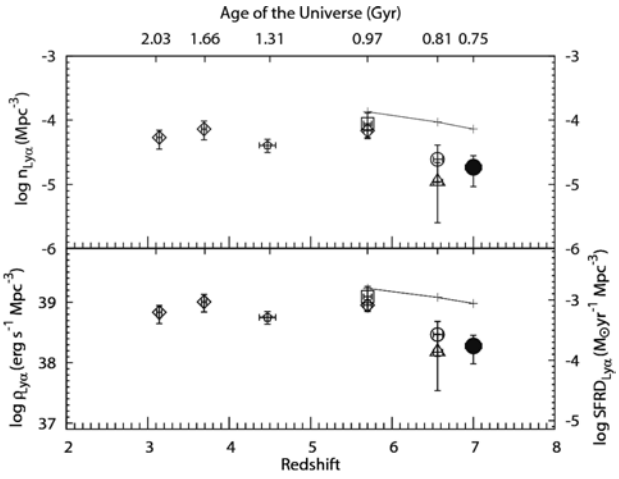


**Figure 3**: Number density $n_{\mathrm{Ly}\alpha}$, Ly$\alpha$ luminosity density $\rho_{\mathrm{Ly}\alpha}$ and star formation rate density SFRD$_{\mathrm{Ly}\alpha}$ of LAEs at $z = 3.1$, 3.7, 4.5, 5.7, 6.6, 7 to Ly$\alpha$ luminosity limit $9.2 \times 10^{42}$ erg s$^{-1}$ (See [1] for details). Horizontal errors are the redshift range of each survey. The vertical errors include both cosmic variance and Poisson errors. The plus symbols with solid lines show the expected densities, when the universe is fully reionized, calculated by using a LAE evolution model[4].

## References

[1] Ota, K., et al.: 2010, *ApJ*, **722**, 803.
[2] Iye, M. N., et al.: 2006, *Nature*, **443**, 186.
[3] Ota, K., et al.: 2008, *ApJ*, **677**, 12.
[4] Kobayashi, M. A. R., et al.: 2010, *ApJ*, **708**, 1119.