On the Formation Timescale of Massive Cluster Ellipticals Based on Deep Near-infrared Spectroscopy at $z \sim 2$

TANAKA, Masayuki (NAOJ)
TOFT, Sune (Dark Cosmology Centre)
MARCHESINI, Danilo (Tufts University)
ZIRM, Andrew (Dark Cosmology Centre)
DE BREUCK, Carlos (European Southern Observatory)
KODAMA, Tadayuki, KOYAMA, Yusei (NAOJ)
KURK, Jaron (Max-Planck Institute for Extragalactic Physics)
TANAKA, Ichi (NAOJ)

The formation and evolution of massive galaxies is a long-standing issue since the seminal work by [1]. One of the ways to address the issue is to observationally constrain the formation timescale of those galaxies. We focus on one of the most prominent proto-cluster PKS1138 at $z = 2.16$, where deep multi-wavelength data are available.

We have obtained deep (~7 hours) near-infrared spectra of some of the massive galaxies in the system with MOIRCS [2]. By combining the spectra and the broadband photometry, we perform a detailed analysis of spectral distribution of galaxies to constrain redshifts and physical properties of galaxies simultaneously. We spectroscopically confirm, for the first time, that massive quiescent galaxies populate in high-density environment. Fig. 1 shows the color-magnitude diagram of galaxies, in which the quiescent galaxies as shown by the red stars occupy the reddest part of the red sequence. This likely suggests that the red sequence in the process of forming.

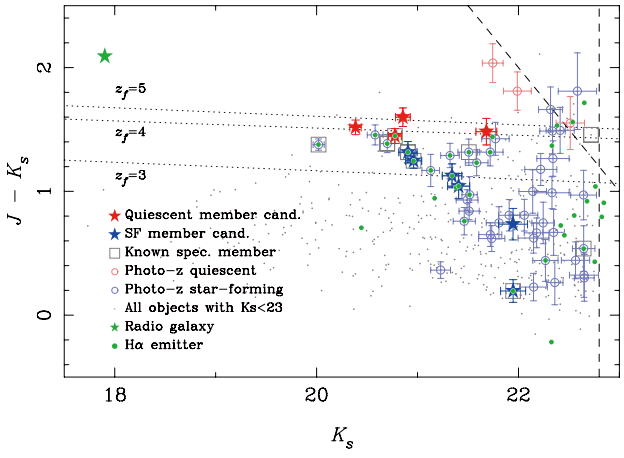

Figure 1: Color-magnitude diagram of galaxies in the field of PK1138. The filled stars are the member candidates identified with the MOIRCS spectra, and the red and blue colors indicate quiescent and star forming nature of galaxies.

We then combine the spectra of these quiescent galaxies as shown in Fig. 2. The spectrum is typical of quiescent galaxies with a clear 4000 Å break. A hint of the CaII H+K absorption is observed. If real, this is the first detection of such a feature in high-z quiescent galaxies in dense environments.

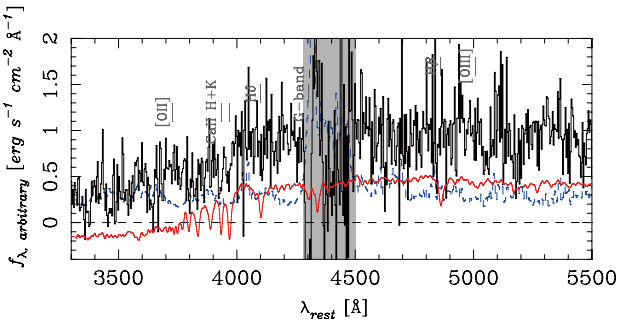

Figure 2: Stacked spectrum of the 4 quiescent galaxies. The dashed spectrum is the noise spectrum and the smooth, solid spectrum is the best-fitting model spectrum shifted downwards for clarity. The shaded area is strongly affected by the atmospheric absorption.

Finally, we constrain the formation timescale of these quiescent galaxies using (1) the location and dispersion of the red sequence, (2) full spectral analysis, and (3) two spectral features that are sensitive to different star formation timescales. The bottom-line of these analyses is that the quiescent galaxies likely form at $3 \lesssim z \lesssim 4$ with a timescale of $z \lesssim 0.5$ Gyr. This is a very short timescale and it remains a puzzle how to form massive, compact galaxies on such a short timescale.

References

[1] Eggen, O. J., Lynden-Bell, D., Sandage, A. R.: 1962, *ApJ*, **136**, 748.
[2] Tanaka, M., Toft, S., Marchesini, D., et al.: 2013, *ApJ*, **772**, 113.