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The Role of Galaxy Interaction in Environmental Dependence of Star Formation Activity at $z \sim 1.2$

Y. Ideue,[1] Y. Taniguchi,[2] and the COSMOS team

[1]*Graduate School of Science ans Engineering, Ehime University, Bunkyo-cho, Matsuyama 790-8577, Japan*

[2]*Research Center for Space and Cosmic Evolution, Ehime University, Bunkyo-cho, Matsuyama 790-8577, Japan*

Abstract. In order to understand environmental effects on star formation in high-redshift galaxies, we investigate the physical relationships between the star formation activitiy, stellar mass, and environment for $z \simeq 1.2$ galaxies in the 2 deg^2 COSMOS field. We estimate star formation using the [O II]λ3727 emission line and environment from the local galaxy density. Our analysis shows that for massive ($M_* \gtrsim 10^{10} M_\odot$), the fraction of [O II] emitters in high-density environments is roughly two times higher than in low-density environments, while the [O II] emitter fraction does not depend on environment for low-mass $M_* \lesssim 10^{10} M_\odot$ galaxies. In order to understand what drives these trends, we investigate the role of companion galaxies in our sample. We find massive [O II] emitters are more likely to have companions in high-density environments. These results suggest that interactions and/or mergers in high-density environment could induce star formation in massive galaxies at $z \simeq 1.2$, increasing the fraction of star-forming galaxies with $M_* \gtrsim 10^{10} M_\odot$.

1. Introduction

A key question in understanding the formation and evolution of galaxies is to find what physical parameters are most sensitive to the star formation process in galaxies. Observational properties of galaxies in the local universe have been extensively studied in the past. Typically, actively star-forming galaxies in the local universe have lower masses than passive galaxies and the most massive galaxies tend to be inactive for star formation (so-called mass-downsizing; Cowie et al. 1996). In addition, the star formation activity strongly depends on environment: star formation rate decreases with increasing galaxy density (e.g., Gomez et al. 2003; Kauffmann et al. 2004) and the fraction of star-forming galaxies also decreases with increasing galaxy density (e.g., Balogh et al. 2004; Mateus & Sodré 2004).

On the other hand, it is well known that the star formation rate density steeply increases in the first ~ 2 Gyrs, peaks at $z \sim 1-3$, and then dencreases by an order of magnitude toward the presend day (e.g., Madau et al. 1996) . These results suggest that the redshift range of $z \sim 1-3$ is the key epoch for the most active cosmic star formation in the history of universe. Therefore, studies of galaxies at $1 < z < 3$ are important for understanding galaxy evolution.

Recently we investigated the relation between the fraction of star-forming galaxies with [O II]λ3727 emission and the local galaxy density at $z \simeq 1.2$ in the COSMOS field (Scoville et al. 2007) and found that the fraction of star-forming galaxies in high-density regions is as high as that in low-density regions (Ideue et al. 2009). Similar trends were also reported by other observational studies (e.g., Elbaz et al. 2007; Cooper et al. 2008) at $z \sim 1$. Since the fraction of star-forming galaxies decreases with increasing galaxy density in the local unicerse as mentioned above, these results suggest that the relation between the star formation activity in galaxies and their environment dramatically changed from $z \sim 1$ to the present day. In order to reveal the origin of the observed difference in the environmental dependence of the star formation activity between $z \sim 0$ and $z \sim 1$, We investigate the relationships between the star formation activitiy, the stellar mass of galaxies, and the environment at $z \sim 1$.

2. Results

In order to understand the origin of that difference between $z \sim 0$ and $z \sim 1$, We investigate the relationships between the star formation, stellar mass, and environment of galaxies at $z \simeq 1.2$ in the COSMOS field. In this study, we use 1654 photo-z selected galaxies with $i' < 24$ at $z_{ph} = 1.17 - 1.20$ (Ilbert et al. 2009).

2.1. The relation between star formation, stellar mass, and environment

In this section, we study the relations between star formation, stellar mass, and environment. As an indicator of star formation, we use the fraction of [O II] emitters. We obtain the sample of [O II] emitters by using a narrowband filter NB816 (λ = 8150Å and $\Delta\lambda$(FWHM)= 120Å, see Takahashi et al. 2007). The stellar mass of galaxies are estimated from SED fitting (Ilbert et al. 2010). We adopt the projected 10th-nearest-neighbor surface density as an indicator of the galaxy environment and define three environment bins: low-density ($\log \Sigma_{10th} \leq 0.2$), intermediate ($0.2 < \log \Sigma_{10th} < 0.6$), and high-density ($\log \Sigma_{10th} \geq 0.6$).

In the left panel of Figure 1, we show the fraction of the [O II] emitters in the photo-z selected sample (hereafter, "[O II] fraction") as a function of stellar mass for the three different environments. In all environments, the [O II] fraction decreases with increasing stellar mass, indicating that most low-mass galaxies are star-forming while non-star-forming galaxies dominate at high mass. This suggests that mass-downsizing is already in place at $z \simeq 1.2$. Several studies have reported similar results for galaxies at $z \sim 0.8$ (Iovino et al. 2010; Sobral et al. 2011).

Next we focus on the environmental dependence of the [O II] fraction. While there is no environmental dependence of the [O II] fraction in low-mass bins ($M_* \lesssim 10^{10} M_{\odot}$), the [O II] fraction in the high-density environment is a little higher than that in the intermediate- and low-density environments in high-mass bins ($M_* \sim 10^{10} - 10^{11} M_{\odot}$), although the uncertainty for the high-density environment is relatively large due to the small number statistics. This may indicate that the star formation activity in relatively massive galaxies is enhanced in high-density regions. This result different from that seen in the local universe where the fraction of red galaxies in high-density environments is higher than that in low-density environments, and this difference becomes larger at lower mass (e.g., Baldry et al. 2006).

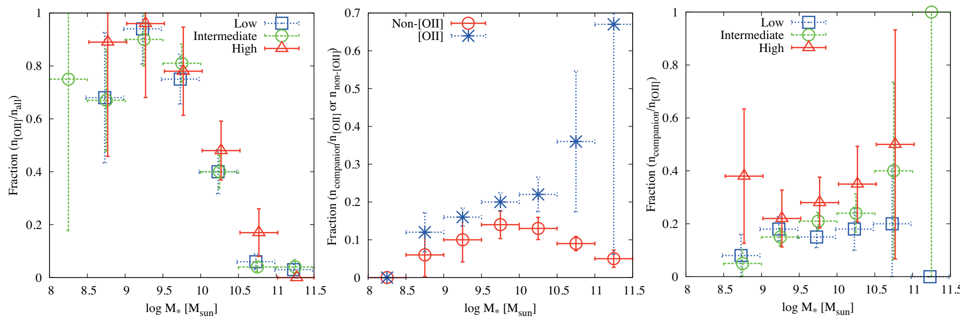

Figure 1. (Left) The fraction of [O II] emitters in the photo-z selected sample as a function of stellar mass in the three deifferent environments. (Middle) The fraction of galaxies with a companion as a function of stellar mass. (Right) The fraction of galaxies with a companion in [O II] emitters as a function of stellar mass in the three different environments.

2.2. Role of interactions and/or mergers

In the previous study (Ideue et al. 2009), we found that the fraction of galaxies with a close companion increases with increasing local galaxy density. Since galaxy interactions and mergers can trigger starbursts in galaxies (e.g., Mihos & Harnquist 1996; Taniguchi & Wada 1996) , we suggested that the high fraction of [O II] emitters in high-density regions may be driven by interactions and/or mergers. On the other hand, in the previous section, we found that the [O II] fraction in the high-density environment is higher only for high mass ($M_* \sim 10^{10} - 10^{11} M_\odot$) galaxies, while there is no evidence for environmental dependence at $M_* \lesssim 10^{10} M_\odot$. Here we study the effects of the interactions and/or mergers on the star formation acitivty and its environmentsl dependence as a function of stellar mass.

Following Ideue et al. (2009), we define a galaxy with a close companion as a system with a nearest neighbor within an progected separation of less than 10 arcsec, corresponding to < 80 kpc at $z = 1.2$. We use galaxies with $i' < 24$ within a redshift slice of $\pm\sigma_{\Delta z}(= 0.02)$ to search for nearest neighbors. Using this definition, we identify 222 galaxies with a close companion from the 1654 photo-z selected galaxies. The other galaxies do not have a close companion. We call hereafter these galaxies “non-companion galaxies”.

The middle panel of Figure 1 shows the relation between the fractino of galaxies with a companion (hereafter “companion fraction”) and stellar mass for [O II] and non-[O II] emitters in all the environments. The companion fraction for [O II] emitters is higher than that for non-[O II] emitters. It is also seen that the companion fraction for [O II] emitters increases with increasing stellar mass, while the fraction for non-[O II] emitters does not. This suggests that the star formation activity may be induced by interactions and/or mergers more preferentially in high-mass galaxies.

In order to understand the relation between this result and the environmental dependence of the star formation activity, we also investigate the companion fraction in [O II] emitters as a function of stellar mass in the three different environments (right panel of Figure1). It is seen that the companion fraction tends to be higher in the higher-density environment, espacially at high stellar mass. We also find that the companion fraction for [O II] emitters in the high- and intermediate-environments increases with increasing stellar mass. These results indicate that the star formation in massive [O II] emitters in higher-density environment may be preferentially triggerd by interactions and/or mergers.

3. Discussion and Conclusion

Our results suggest that high-mass [O II] emitters (star-forming galaxies) contribute significantly to the active star formation in high-density regions at $z \simeq 1.2$. Moreover, it is expected that interactions and/or mergers could trigger star formation in massive galaxies preferentially in high-density environments, while the star formation in low-mass galaxies appears to be independent of environment and does not seem to be affected by the interactions and/or mergers.

From these results, we expect the following scenario; The high-mass star-forming galaxies for which star formation are induced by interactions and/or mergers contribute significantly to the active star formation in high-density regions at $z \simeq 1.2$. These massive star-forming galaxies in high-density regions at $z \simeq 1.2$ could quickly consume most of the accreted cold gas. If this is the case, the star formation acitivty may not be enhanced when interactions and/or mergers occurred in high-density environments at lower redshift. In this context, the quenching of star formation in massive galaxies in high- density environments is expected to lead to the shift of major star formation in the universe from high-density regions to low-density ones at $z \lesssim 1$

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