Galaxy Mergers In An Evolving Universe
ASP Conference Series, Vol. 477
Wei-Hsin Sun, Kevin Xu, Nick Scoville, and David Sanders eds.

The Unusual and Ubiquitous Population of Hα Emitters at $z \sim 4$: Where are all the Mergers?

Hyunjin Shim,[1] Ranga-Ram Chary,[1] Mark Dickinson,[2] Lihwai Lin,[3] Hyron Spinrad,[4] Daniel Stern,[5] and Chu-Hung Yan[3]

[1]*Spitzer Science Center, California Institute of Technology, CA 91125*

[2]*National Optical Astronomy Observatory*

[3]*Institute of Astronomy & Astrophysics, Academia Sinica, Taipei 106*

[4]*Department of Astronomy, University of California at Berkeley, Berkeley, CA 94720*

[5]*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109*

Abstract. We present the evidence that strong Hα emitters (HAEs) comprise more than 70 % of galaxies with spectroscopic redshifts of $3.8 < z < 5.0$, from the clear flux excess observed in the *Spitzer*/IRAC 3.6-μm band. HAEs are strongly star-forming galaxies with star formation rate of 20−500 $M_{\odot}\mathrm{yr}^{-1}$, with unusually large H$\alpha$ equivalent widths (EW) of > 350 Å. The rest-frame UV to optical morphologies for half of the HAEs do not show any signs of mergers or tidal interactions. The large Hα EW of HAEs despite their relatively old stellar population age suggests that HAEs are producing stars continuously at a constant rate, rather than through multiple bursts invoked by major mergers. The observed number density of HAEs is consistent with the predicted number of halos which have gas infall rate comparable to the observed star formation rate. Therefore, HAEs provide indirect evidence supporting that star formation mechanism other than mergers, such as cold gas accretion, is the dominant driver of star formation at $z \sim 4$.

1. Introduction

Gas-rich galaxy-galaxy merger is considered to be important physical mechanism that enables large star formation rate (SFR) in high-redshift galaxies. However, the observed number density of mergers challenges merger to be dominant driver of high-redshift star formation, though the merger rate itself is still a matter of debate (e.g., Ravindranath et al. 2006; Conselice & Arnold 2009). Dekel et al.(2009) presented an alternative scenario, suggesting that at $z \sim 2$, steady, narrow, cold gas stream can penetrate into the shock-heated medium of massive dark matter halos and power the star formation. In order to assess whether merger or cold gas accretion is the main mechanism for galaxy growth, we need observational parameters that describe the ongoing star formation mode.

In this study, we used Hα emission in $z \sim 4$ galaxies that are reflected in photometric information (e.g., Chary, Stern, & Eisenhardt 2005) to describe ongoing star formation activity in these galaxies.

2. Hα Emitter Identification

2.1. $3.8 < z_{spec} < 5.0$ Galaxies in GOODS

We selected 124 galaxies with secure spectroscopic redshifts between $z = 3.8$ and 5.0 over 330 arcmin^2 of Great Observatories Origins Deep Survey (GOODS) North and South field (Vanzella et al. 2005, 2006, 2008; Ando et al. 2004). We then applied S/N ratio cut in *Spitzer*/IRAC 3.6-μm and 4.5-μm photometry for the spectral energy distribution (SED) fitting, and also applied an isolation criteria to get rid of galaxies with close neighbors that possibly contaminate IRAC fluxes. In the end, we are left with 74 galaxies.

2.2. SED Fitting: Estimation of Hα Line Flux and Equivalent Width

We fitted the observed photometry points from *B*-band (*HST*/ACS) to 8.0-μm band (*Spitzer*/IRAC) using stellar population synthesis model (CB07; Bruzual 2007). Among 63 galaxies with reasonable fitting results, we found that more than 70 % (47) show significant flux excess at 3.6-μm compared to the pure stellar continuum. The remaining 40 % also show excess at 3.6-μm which is yet not very significant, thus we define all these galaxies as Hα emitters (HAEs). We converted the excess into Hα line flux and equivalent width (EW). The derived $L(H\alpha)$ ranges between $10^{42.4} - 10^{43.8}$ erg s^{-1}, corresponding to SFRs of $20 - 500\,M_{\odot}$ yr^{-1} (Kennicutt 1998). The derived Hα EW of HAEs is larger than 500 Å. Since the EW reflects strength of current star formation compared to past star formation, the large Hα EW of HAEs show that all HAEs are strong star-forming galaxies.

3. Star Formation Mechanism at $z \sim 4$

3.1. Rest-frame UV Morphologies

Figure 1 show the light profile of 63 $z \sim 4$ HAEs in HST/ACS z-band image that reflects rest-frame UV morphologies. Light profiles of visually classified mergers and non-mergers are clearly distinguished, i.e., mergers/interacting systems are likely to show asymmetric or skewed light profile. 32 out of 63 HAEs ($\sim$ 50 %) are classified as mergers/interacting systems. The visual classification of mergers and non-mergers in rest-frame UV is consistent with the classification in rest-frame optical: we have verified the result using the CANDELS WFC3 data in GOODS-S. There is no significant difference for Hα EW, stellar mass, and SFR between mergers and non-mergers, suggesting that mergers at $z \sim 4$ may not be the only and most efficient star formation mechanism.

3.2. Star Formation History of HAEs

While the morphologies of HAEs do not insist the importance of mergers in $z \sim 4$ star formation, we investigate the star formation history of HAEs through the comparison

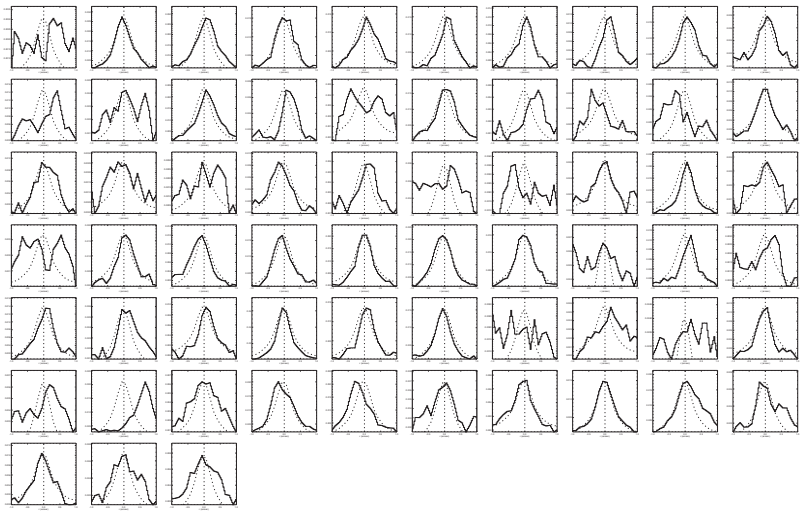

Figure 1. Rest-frame UV (HST/ACS z-band) light profile of 63 $z \sim 4$ HAEs. x-axis indicates radius from the galaxy center, ranges [-1, 1] arcsecond corresponding to physical size of ± 7 kpc at $z \sim 4$. y-axis indicates flux at the given radius in an arbitrary unit. Overplotted dotted line indicates the light profile of a point source scaled to match the peak flux of each object.

between Hα EWs and parameters from stellar population fitting. Figure 2 shows a comparison between Hα EW and the stellar population age. HAEs are quite heterogeneous galaxy population; 40 % (24) follows bursty star formation history with stellar population younger than 10 Myrs old, while 60 % (39) prefers continuous star formation history with relatively old stars, > 100 Myrs old. Overplotted model tracks suggest that the large Hα EW is reproduced by (1) young age, (2) continuous star formation history, (3) low metallicity, and (4) top-heavy stellar initial mass function (IMF).

Using Hα EW vs. age relation, it is possible to divide HAEs into two subgroups of galaxies– HAEs with burst-like star formation and HAEs with continuous star formation. However, no significant correlation is found between star formation timescales and morphologies. Merger fraction is also comparable: 13 out of 24 (54 %) instantaneous burst galaxies are apparent mergers/interacting systems and 19 out of 39 (49 %) continously star-forming galaxies are classified as mergers/interacting systems. The lack of relation between morphology and other parameters shows that morphology alone is insufficient to reveal how star formation is going on in high-redshift galaxies.

4. Indirect Evidence of Cold Gas Accretion

The observed number density of $z \sim 4$ HAEs is 5.4×10^{-5} Mpc^{-3}, among which half of them are either classified as non-mergers (from rest-frame UV morphology analysis) and/or classified as galaxies with continuous star formation (from Hα EW vs. age analysis). The number is the lower limit for galaxy number density with star formation larger than 100 $M_\odot$ yr^{-1}. Dekel et al.(2009) presented the number of halos with specific gas infall rate at different redshifts: the predicted number of 10^{12} $M_\odot$ halos with gas

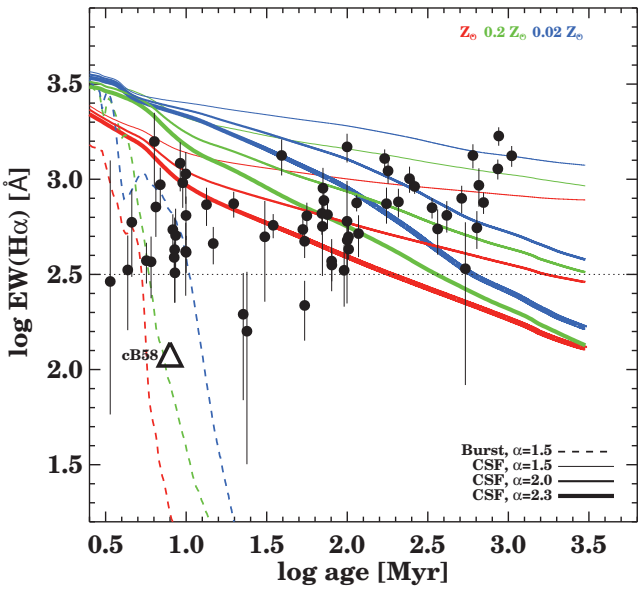

Figure 2. Hα EW vs. the stellar population age constrained from the SED fitting. Overplotted lines are the expected Hα EW vs. age tracks from models with different star formation history, metallicity, and stellar initial mass function (STARBURST99; Leitherer et al. 1999). More than half of the HAEs are consistent with continuously star-forming galaxies rather than bursty star-forming galaxies. Some of the highest Hα EW HAEs require low metallicity, and top-heavy IMF models to explain their Hα EWs.

infall rate consistent to the SFR of HAEs is in good agreement with the observed number of HAEs. This means that cold gas accretion scenario at 10^{12} $M_\odot$ halos can explain more than half of the observed $z \sim 4$ HAEs. While no direct observational evidence that supports cold gas accretion has been reported yet, the consistent number density of HAEs which are not powered by merger provides an 'indirect' evidence for cold gas accretion scenario at $z \sim 4$.

References

Ando, M., Ohta, K., Iwata, I., Watanabe, C., Tamura, N., Akiyama, M., & Aoki, K. 2004, ApJ, 610, 635
Bruzual, G. 2007, From Stars to Galaxies: Building the Pieces to Build Up the Universe (ASP Conf. Ser. 374), ed. A. Vallenari et al. (San Francisco, CA: ASP), 303
Chary, R.-R., Stern, D., Eisenhardt, P. 2005, ApJL, 635, 5
Conselice, C. J., & Arnold, J. 2009, MNRAS, 397, 208
Dekel, A. et al. 2009, Nature, 457, 451
Kennicutt, R. C. 1998, ARA&A, 36, 189
Ravindranath, S. et al. 2006, ApJ, 652, 963
Vanzella, E. et al. 2005, A&A, 434, 53
Vanzella, E. et al. 2006, A&A, 454, 423
Vanzella, E. et al. 2008, A&A, 478, 83