The Origins of UV–optical Color Gradients in Star-forming Galaxies at $z \sim 2$:
Predominant Dust Gradients but Negligible sSFR Gradients

F. S. Liu1,2, Dongfei Jiang1,3, S. M. Faber2, David C. Koo2, Hassen M. Yesuf2, Sandro Tacchella4, Shude Mao5,6,7, Weichen Wang8, Yicheng Guo2, Jerome J. Fang2,9, Guillermo Barro2,10, Xianzhong Zheng3,11, Meng Jia1, Wei Tong1, Lu Liu1, and Xianmin Meng6

1 University of California Observatories and the Department of Astronomy and Astrophysics, University of California, Santa Cruz, CA 95064, USA
2 College of Physical Science and Technology, Shenyang Normal University, Shenyang 110034, China; fsliu@synu.edu.cn
3 Purple Mountain Observatory, Chinese Academy of Sciences, 2 West-Beijing Road, Nanjing 210008, China
4 Department of Physics, Institute for Astronomy, ETH Zurich, CH-8093 Zurich, Switzerland
5 Physics Department and Tsinghua Centre for Astrophysics, Tsinghua University, Beijing 100084, China
6 National Astronomical Observatories, Chinese Academy of Sciences, A20 Datun Road, Beijing 10012, China
7 Jodrell Bank Centre for Astrophysics, School of Physics and Astronomy, The University of Manchester, Oxford Road, Manchester M13 9PL, UK
8 Department of Physics & Astronomy, Johns Hopkins University, 3400 N. Charles Street, Baltimore, MD 21218, USA
9 Orange Coast College, Costa Mesa, CA 92626, USA
10 Department of Astronomy, University of California, Berkeley, CA 94720-3411, USA
11 Chinese Academy of Sciences South America Center for Astronomy, China-Chile Joint Center for Astronomy, Camino El Observatorio 1515, Las Condes, Santiago, Chile

Received 2017 April 26; revised 2017 June 10; accepted 2017 June 30; published 2017 July 14

Abstract

The rest-frame UV–optical (i.e., NUV − B) color is sensitive to both low-level recent star formation (specific star formation rate—sSFR) and dust. In this Letter, we extend our previous work on the origins of NUV − B color gradients in star-forming galaxies (SFGs) at $z \sim 1$ to those at $z \sim 2$. We use a sample of 1335 large (semimajor axis radius $R_{\text{SMA}} > 0'18$) SFGs with extended UV emission out to $2R_{\text{SMA}}$ in the mass range $M_\ast = 10^{9}–10^{11} M_\odot$ at $1.5 < z < 2.8$ in the CANDELS/GOODS-S and UDS fields. We show that these SFGs generally have negative NUV − B color gradients (redder centers), and their color gradients strongly increase with galaxy mass. We also show that the global rest-frame FUV − NUV color is approximately linear with $A_V$, which is derived by modeling the observed integrated FUV to NIR spectral energy distributions of the galaxies. Applying this integrated calibration to our spatially resolved data, we find a negative dust gradient (more dust extinguished in the centers), which steadily becomes steeper with galaxy mass. We further find that the NUV − B color gradients become nearly zero after correcting for dust gradients regardless of galaxy mass. This indicates that the sSFR gradients are negligible and dust reddening is likely the principal cause of negative UV–optical color gradients in these SFGs. Our findings support that the buildup of the stellar mass in SFGs at Cosmic Noon is self-similar inside $2R_{\text{SMA}}$.

Key words: galaxies: high-redshift — galaxies: photometry — galaxies: star formation

1. Introduction

Investigating the spatial distribution of star formation is a powerful way to understand how stellar mass is built up and where the star formation is shut down in galaxies as they evolve along the star-forming main sequence (SFMS). It has been known that rest-frame UV–optical (i.e., NUV − B) color is sensitive to both low-level recent star formation (i.e., specific star formation rate—sSFR) and dust ($A_V$), but it is insensitive to the metallicity (Kaviraj et al. 2007; Pan et al. 2015). Thus, UV–optical star formation measurements are ambiguous without accurate dust correction, especially for high-redshift star-forming galaxies (SFGs).

Radial sSFR and dust gradients in distant galaxies have not been fully explored to date. There are only a few related papers on this topic. By stacking the HST multi-band imaging, Wuyts et al. (2012) studied the resolved colors and stellar populations of a few hundred SFGs with $M_\ast > 10^{10} M_\odot$ at $0.5 < z < 2.5$. They found evidence of redder colors, lower sSFR, and increased dust attenuation in the centers of galaxies. Tacchella et al. (2015) used Hα fluxes to measure the sSFR gradients in $z \sim 2$ SFGs. They claimed rather shallow sSFR gradients at low masses ($M_\ast < 10^{11} M_\odot$) and significant sSFR gradients at $M_\ast \sim 10^{11} M_\odot$. Note that they corrected for dust reddening assuming a flat attenuation profile. In a series of papers, Nelson et al. (2012, 2016a, 2016b) studied the maps of sSFR traced by Hα and of dust in SFGs at moderate redshifts ($z \sim 1$ and $z \sim 1.4$) by stacking the spatially resolved spectra of 3D-HST. Nelson et al. (2012) showed that the Hα sizes of massive galaxies are bigger than their rest-frame R-band sizes. Nelson et al. (2016a) showed that the EW(Hα) is flat with a radius for the low-mass ($M_\ast = 10^{7}–10^{9.5} M_\odot$) galaxies, while it falls by a factor of $\sim 2$ on average from the center to twice the effective radius for more massive galaxies. These findings suggested that massive SFGs at moderate redshifts build up their stellar masses from the inside out, while the low-mass SFGs grow in a self-similar way irrespective of the radial distance. Note that dust correction was not done in these two works. Later, Nelson et al. (2016b) corrected the data in their previous papers for dust by using the Balmer decrement (Hα/Hz). As a result, central dust was found to be a huge factor in establishing radial colors and sSFR gradients in galaxies with a mean mass of $\langle M_\ast \rangle \sim 10^{10.2} M_\odot$. Galaxies with $\langle M_\ast \rangle \sim 10^{9.2} M_\odot$ have little dust attenuation at all radii.

Recently, Liu et al. (2016, hereafter Paper I) used high-resolution HST optical-IR imaging (in observed B through H band) to measure the rest-frame NUV − B color gradients in the main-sequence SFGs at $z \sim 1$. In Paper I, after correcting for dust reddening, the radial NUV − B color gradients were shown to be nearly zero in SFGs with $M_\ast < 10^{10} M_\odot$, but significant residual color gradients were found in SFGs with...
$M_h > 10^{10.5} M_{\odot}$. Dust gradients were determined by fitting reddened stellar population models to the spatially resolved spectral energy distributions (SEDs) with FAST (Kriek et al. 2009). These findings implied that at $z \sim 1$ dust reddening is the principal cause of rest-frame NUV $-$ B color gradients in low-mass SFGs, while for high-mass SFGs, age gradients are also an important factor. More recently, Wang et al. (2017) expanded our Paper I and re-visited the dust and sSFR gradients in $z = 0.4$–1.4 SFGs on the main sequence inferred from the UVI ($U$ $-$ V versus $V$ $-$ I) diagrams. Their conclusion is generally consistent with that of Paper I, except that their estimated central sSFR for massive SFGs are 2–3 times smaller than ours. In this work, we extend our Paper I to $z \sim 2$ with a sample of 1335 large SFGs with extended UV emission out to twice the semimajor axis radius in the mass range $M_h = 10^9$–$10^{11} M_{\odot}$ at $1.5 < z < 2.8$ in the CANDELS/GOODS-S and UDS fields. We show that the global rest-frame FUV $-$ NUV color is approximately linear with $A_V$ and the dust-corrected NUV $-$ B color is indeed a good tracer of sSFR. Applying these calibrations to our spatially resolved data, we examine the effects of dust gradients and sSFR gradients on the NUV $-$ B color gradients in these SFGs at Cosmic Noon and further discuss their link to the stellar-mass assembly.

Throughout the Letter, we adopt a cosmology with a matter density parameter $\Omega_m = 0.3$, a cosmological constant $\Omega_{\Lambda} = 0.7$, and a Hubble constant of $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$. All magnitudes are in the AB system.

2. Data

We select galaxies in our sample from the first two publicly available fields of the CANDELS, namely, the Great Observatories Origins Deep Survey (GOODS-S; Guo et al. 2013) and the UKIDSS Ultra-Deep Survey (UDS; Galametz et al. 2013). The CANDELS team has made a multi-wavelength catalog based on source detection in the F160W ($H$) band for each field, combining the newly obtained CANDELS $HST$/WFC3 data with existing public ground-based and space-based data. $HST$ photometry was measured by running SExtractor (Bertin & Arnouts 1996) on the point-spread function (PSF)-matched images in the dual-image mode, with the F160W image as the detection image. Photometry in ground-based and IRAC images, whose resolutions are much lower than that of the F160W images, was measured with TFIT (Laidler et al. 2007), which fits the PSF-smoothed high-resolution image templates to the low-resolution images to measure the fluxes in the low-resolution images. We refer readers to Guo et al. (2013) and Galametz et al. (2013) for details on these data and the reduction procedure.

Photometric redshifts were estimated from a variety of different codes available in the literature, which are then combined to improve the individual performance (Dahlen et al. 2013). Rest-frame total magnitudes in various standard filters, from FUV to $K$, were computed using the best-available redshifts (spectroscopic or photometric) and multi-wavelength photometry using EAZY (Brammer et al. 2008), which fits a set of galaxy SED templates to the observed photometry. Stellar masses come from the CANDELS official catalog released by Santini et al. (2015), which combine the results from 10 separate SED-fitting methods. A Chabrier (2003) initial mass function (IMF) is assumed. Semimajor axis radius ($R_{\text{MA}}$) and axis ratio ($b/a$) were measured from the $HST$/WFC3 F160W images using GALFIT (Peng et al. 2002) by van der Wel et al. (2012). SFRs come from rest-frame NUV luminosities at $\lambda \approx 2800$ Å that are corrected for extinction by assuming a Calzetti et al. (2000) extinction law ($A_{2800} \approx 1.79A_V$): 

$$SFR_{\text{NUV,corr}}[M_\odot \text{yr}^{-1}] = 2.59 \times 10^{-40} L_{\text{NUV,corr}}[L_\odot].$$

(Kennicutt & Evans 2012). We prefer this approach because of its simplicity and more direct relation to the observed SED. The rates of star formation derived from a combination of unobscured UV and IR emission ($SFR_{\text{UV+IR}}$) are nominally a more faithful measure than $SFR_{\text{NUV,corr}}$, as it incorporates a direct measure of obscured star formation. However, $L_{\text{IR}}$ is usually overestimated in galaxies above $z \sim 1.5$, where observed 24 $\mu$m probes PAH emission (Tielens 2008). Fitting local IR templates will return a value of $L_{\text{IR}}$ that is systematically too high (Salim et al. 2009). Given the theoretical uncertainties still surrounding the origin of warm dust in galaxies, it is reasonable to adopt the NUV–NIR SED-fitting rates, as we do here, pending further developments in our understanding of mid-IR galaxy SEDs. The median $A_V$ was computed by combining results from four methods (labeled 2$\alpha$, 12$\alpha$, 13$\alpha$, and 14$\alpha$) in Santini et al. (2015). The four methods were chosen with the same assumptions (Chabrier IMF and Calzetti extinction law).

The $HST$ based multi-wavelength and multi-aperture photometry catalogs with improved local background subtraction were built for galaxies in the CANDELS fields (F. S. Liu et al. 2017, in preparation), which include the radial profiles of observed surface brightness and cumulative magnitude in the $HST$/WFC3 (F105W, F125W F140W, and F160W) bands and $HST$/ACS (F435W, F606W, F775W, F814W, and F850LP) bands if available. The photometry were performed on the multi-band, PSF-matched images.

3. Sample Selection

The full GOODS-S and UDS catalogs contain 34,930 and 35,932 objects, respectively. The parent sample used in this work is constructed by applying the following cuts to the above data:

1. Observed F160W($H$) magnitude $H < 24.5$ and the GALFIT quality flag = 0 in F160W (van der Wel et al. 2012) to ensure well-constrained GALFIT measurements and eliminate doubles, mergers, and disturbed objects.
2. Photometry quality flag PhotFlag = 0 to exclude spurious sources.
3. SExtractor CLASS_STAR < 0.9 to reduce contamination by stars.
4. Redshifts within $1.5 < z < 2.8$ for GOODS-S and $2.2 < z < 2.8$ for UDS to roughly cover rest-frame FUV to $B$ simultaneously. Note that the shortest observed band in GOODS-S available is F435W($B$) and the shortest one in UDS is F606W($V$).
5. Stellar masses at $10^9 < M_h/M_\odot < 10^{11}$ to maintain the $\sim$90% ($\sim$75%) completeness limit at $z = 1.5$ ($z = 2.8$) for SFGs (van der Wel et al. 2014; Morishita et al. 2015).
6. $R_{\text{MA}} > 0.18$ (3 pixels) to minimize the effect of PSF-matching on color gradient measurement.
7. Well-constrained measurements of surface brightness profiles from center to $2R_{\text{MA}}$ in observed F435W($B$) for $1.5 < z < 2.2$ in GOODS-S and ones in observed F606W($V$) for $2.2 < z < 2.8$ in both GOODS-S and
UDS to guarantee sample galaxies with extended rest-frame UV emission.

After cuts 1–5, we obtain 2388 galaxies: 1666 from GOODS-S and 722 from UDS. After cuts 1–7, we obtain 1430 galaxies in total. We then utilize the rest-frame $UVJ$ ($U - V$ versus $V - J$) diagram ($U - V < 0.88 \times (V - J) + 0.49$; Williams et al. 2009) to select 1405 SFGs (see the left panel in Figure 1). Furthermore, we follow the method used in Paper I to select SFGs near the ridge-line of the SFMS (see the right panel in Figure 1). After excluding 70 transition galaxies, which are defined as galaxies with offsets from the best-fit main-sequence relation ($\log sSFR_{NUV, cor}/yr^{-1} = -0.25 \pm 0.01 \times \log M_*/M_\odot - 0.20 \pm 0.13$) of $\Delta \log sSFR_{NUV, cor} < -0.45$ dex (below the dashed line), we focus on 1335 main-sequence SFGs. We note that the majority of very dusty SFGs are excluded by selection cuts 6 and 7 (see the left panel in Figure 1), which are not probed in this analysis.

4. Results and Analysis

We investigate the global properties of the sample galaxies to find an accessible and good indicator of dust attenuation ($A_V$) that can be used in our spatially resolved analysis and check whether rest-frame $NUV - B$ color is a good tracer of sSFR after removing dust effect. One of the most common methods for dust determination at high redshift is fitting reddened stellar population models to the integrated broad-band SEDs of galaxies (e.g., Kriek et al. 2009). The long-wavelength (i.e., rest-frame $J$) data is usually needed by this method. It has been shown that this method is closely related to the $UVJ$ method that distinguishes dust reddening from old stars (Patel et al. 2011). Unfortunately, the high-resolution $HST$ imaging in CANDELS ends at the observed $H$ band, which roughly corresponds to a cut at rest-frame $B$ to $V$ for our galaxies. The lack of long-wavelength high-resolution data cannot meet the need of distinguishing dust reddening from age in spatially resolved analysis. Nevertheless, the rest-frame $FUV - NUV$ color is accessible in both integrated and resolved data, which has been widely applied to evaluate the $UV$ slope $\beta$ and thus determine dust attenuation (e.g., Buat et al. 2005; Muñoz-Mateos et al. 2007; Reddy et al. 2012). In the left panel of Figure 2, we show the relation of global $A_V$ versus rest-frame $FUV - NUV$ for our SFGs. It can be seen that rest-frame $FUV - NUV$ color is approximately linear with $A_V$. The best linear fit is given as $A_V = 1.38 \pm 0.02 \times (FUV - NUV) + 0.30 \pm 0.01$. In the right panel of Figure 2, we show the relation of $\log sSFR_{NUV, cor}$ versus $(NUV - B)_c$. The dust correction exploits the median $A_V$ derived by modeling the observed integrated FUV to NIR SEDs and assumes a Calzetti law. This plot demonstrates that the dust-corrected $NUV - B$ color is indeed a good tracer of sSFR for our SFGs. The best polynomial fit to this relation is given as $\log sSFR_{NUV, cor}/yr^{-1} = 0.62 \pm 0.01 \times (NUV - B)_c - 1.78 \pm 0.02 \times (NUV - B)_c^2 - 7.88 \pm 0.13$.

Applying the above calibrations from integrated photometry and SED modeling to our spatially resolved data, we can infer the radial $A_V$ gradients and sSFR gradients to disentangle their effects on the $NUV - B$ color gradients. For this work we computed the rest-frame $FUV$, $NUV$, and $B$ band surface brightness profiles of each sample galaxy using $EAZY$ (Brammer et al. 2008) as well (refer to Figure 2 in Paper I). In Figure 3, we show the raw dust-reddened $FUV - NUV$ profiles and inferred $A_V$ profiles, which are normalized by their $R_{SMA}$ in arcsec (upper) and are shown in physical radius (lower), respectively. The individual galaxy profiles are shown with gray lines. To quantify the general trends, we used the linear model $1m$ function in $R$ programming language to fit a straight line as a mean of the individual profiles between PSF FWHM ($0^\prime.18$) and $2R_{SMA}$ in each panel. The best-fit slopes and intercepts are presented in Table 1. The best-fit models with $2\sigma$ lower and upper limits are shown as shaded regions in

![Figure 1](image1.png)

**Figure 1.** Left panel: rest-frame global $UVJ$ diagram for the parent samples after applying selection cuts 1–5 and 1–7 (see Section 1), respectively. The solid lines indicate the classification criterion provided by Williams et al. (2009). The arrow shows the Calzetti vector. Right panel: sSFR vs. stellar mass for only SFGs only after cuts 1–7.
Figure 2. Correlations of $A_V$ vs. FUV − NUV (left) and log sSFR$_{NUV, cor}$ vs. (NUV − $B_{dc}$) (right) for global (integrated) SFGs. The red line in the left panel is the best linear fit to the relation. The red line in the right panel is the best polynomial fit to the relation. The two plots will be used as calibrations to infer dust and sSFR radial profiles of the galaxies in this study.

Figure 3. It is observed that these SFGs generally have negative FUV − NUV color gradients (redder centers) and thus have negative dust gradients (more dust extinguished in the centers). A steady increase of negative dust gradient (the slope tends to become steeper) with galaxy mass is also observed.

In Figure 4, we show the profiles of raw dust-reddened NUV − $B$, dust-corrected NUV − $B$, and inferred sSFR in each adopted mass bin, respectively. The shaded regions show the best-fit linear models with 2σ lower and upper limits to all individual profiles. The best-fit slopes and intercepts are also presented in Table 1. The dust correction exploits inferred $A_V$ profiles shown in the bottom panels of Figure 3 and assumes a Calzetti law. sSFR profiles were computed with the (NUV − $B_{dc}$) profiles after applying the calibration shown in the right panel of Figure 2. It can be seen that these SFGs generally have negative NUV − $B$ color gradients (redder centers), and the color gradients strongly increase with galaxy mass. However, after correcting for dust reddening, the NUV − $B$ color profiles become nearly flat (the slopes are within ±0.05), which results in nearly flat sSFR gradients.

To evaluate the PSF smearing effect, the individual rest-frame FUV, NUV, and $B$ band surface brightness profiles in each mass bin are stacked together (taking median values) based on the angular distance in arcsec. We then fit the stacking surface brightness profiles in each band with a single-Sérsic model convolving with CANDELS PSF in F160W. The resulting profiles based on PSF-deconvolved Sérsic models in each bin are shown with green dashed lines in Figures 3 and 4, respectively. The slopes and intercepts of the best linear fits to these profiles are listed in Table 1 as well. The same conclusions can be drawn from these PSF-deconvolved data.

5. Discussion and Conclusion

In this Letter, we extend our previous work on the origins of UV–optical color gradients in SFGs at $z \sim 1$ (Liu et al. 2016) to those at $z \sim 2$, using a sample of 1335 main-sequence SFGs with extended UV emission in the mass range $M_\star = 10^9$–$10^{11} M_\odot$ at 1.5 < $z$ < 2.8 in the CANDELS/GOODS-S and UDS fields. By fitting reddened stellar population models to the integrated SEDs from observed FUV to NIR, we calibrate $A_V$ with the rest-frame FUV − NUV for these SFGs. We demonstrate that rest-frame NUV − $B$ color is indeed a good tracer of sSFR after correcting for dust reddening. Applying these calibrations to our spatially resolved data that ends at observed $H$, we infer the radial $A_V$ gradients and sSFR gradients and demonstrate their effects on the NUV − $B$ color gradients. We find a steady increase of a negative dust gradient with galaxy mass. The SFGs generally have negative NUV − $B$ color gradients, and the color gradients strongly increase with galaxy mass. After correcting for dust gradients, the NUV − $B$ color profiles become nearly flat regardless of galaxy mass, which indicates that the sSFR gradients are negligibly small. These findings imply that dust reddening is likely the principal cause of negative UV–optical color gradients in these SFGs. The findings support that at $z \sim 2$ the SFGs build up their stellar masses in a self-similar way.

Here, we compare our results to those of Tacchella et al. (2015, 2017), who explored sSFR gradients in $z \sim 2$ galaxies for a small sample. In Tacchella et al. (2015), they corrected for dust reddening assuming a flat attenuation profile and claimed rather shallow sSFR gradients in low-mass ($M_\star < 10^{10} M_\odot$) galaxies but significant sSFR gradients in galaxies with $M_\star \sim 10^{11} M_\odot$. In Tacchella et al. (2017), they used the UV − $\beta$ technique to correct for dust reddening and found flat sSFR profiles for $z \sim 2$ galaxies in the mass range $M_\star = 10^{10}$–$10^{11} M_\odot$, which is consistent with our finding. Our finding is also consistent with that from cosmological zoom-in simulations (Tacchella et al. 2016).

If the sSFR profiles appear to be constant with radius at all radii and all times, this would yield SFGs with constant stellar-mass effective radii. In contrast, light-weighted effective radii are seen to increase roughly as $M_\star^{0.3}$ (e.g., Patel et al. 2013; van Dokkum et al. 2013). It has been known that mass-weighted...
radii are smaller than light-weighted for SFGs (Szomoru et al. 2013). The discrepancy can also be reconciled if galaxies grow mainly outside $2R_{\text{SMA}}$ via star formation (Tacchella et al. 2016) or minor mergers (Welker et al. 2017). We leave this problem open because our data only sample the regions inside $R_{\text{SMA}}$.

We note that the HST drizzled WFC3 images have the spatial resolution of $0.18''$ (three pixels). Therefore, the color gradients in this very central region are missed by this analysis.

This is the best that can be done with the present imaging data available. We stress that major conclusions in this Letter depend on the SED modeling assumptions applied to the CANDELS data. The majority of our assumptions are single-τ solar metallicity models and the dust extinction law is assumed to be the Calzetti law. Wang et al. (2017) showed that the dust reddened radial color variance for the main-sequence SFGs at $z \sim 1$ run almost parallel to the Calzetti vectors in the $UVI$

![Graph showing rest-frame dust-reddened FUV – NUV profiles and inferred $A_v$ profiles in each mass bin.]

**Figure 3.** Rest-frame dust-reddened FUV – NUV profiles and inferred $A_v$ profiles in each mass bin, which are normalized by their $R_{\text{SMA}}$ in arcsec (upper) and are shown in physical radius (lower), respectively. The individual profiles are shown with gray lines. The shaded regions show the best-fit linear models with 2σ lower and upper limits to all individual profiles (no PSF-correction). The green dashed lines are PSF-corrected median profiles. The gray hatching indicates the regions within the median PSF FWHM (0.18). The vertical dashed lines indicate the positions of $2R_{\text{SMA}}$ (median values for the profiles in kpc).
### Table 1
Parameters of the Best-fit Linear Models to Our Profiles

| Contents | 9.0 < log$M_*$ < 9.5 | 9.5 < log$M_*$ < 10.0 | 10.0 < log$M_*$ < 10.5 | 10.5 < log$M_*$ < 11.0 |
|----------|----------------------|------------------------|------------------------|------------------------|
|          | Slope                | Intercept              | Slope                  | Intercept              |
|          |                      |                        |                        |                        |
| FUV - NUV| $-0.104 \pm 0.045$   | $0.223 \pm 0.007$      | $-0.141 \pm 0.025$     | $0.420 \pm 0.004$      |
|          | $-0.143 \pm 0.062$   | $0.607 \pm 0.010$      | $-0.195 \pm 0.035$     | $0.879 \pm 0.006$      |
|          | $-0.069 \pm 0.006$   | $0.753 \pm 0.019$      | $-0.071 \pm 0.005$     | $0.942 \pm 0.001$      |
|          | $-0.008 \pm 0.029$   | $0.424 \pm 0.005$      | $0.049 \pm 0.019$      | $0.488 \pm 0.003$      |
| log sSFR | $-0.017 \pm 0.029$   | $-8.503 \pm 0.004$     | $-0.012 \pm 0.004$     | $-8.590 \pm 0.001$     |

Profiles Scaled by $R_{50}$ in arcsec (No PSF-correction)

| Contents | 9.0 < log$M_*$ < 9.5 | 9.5 < log$M_*$ < 10.0 | 10.0 < log$M_*$ < 10.5 | 10.5 < log$M_*$ < 11.0 |
|----------|----------------------|------------------------|------------------------|------------------------|
|          | Slope                | Intercept              | Slope                  | Intercept              |
|          |                      |                        |                        |                        |
| FUV - NUV| $-0.073 \pm 0.052$   | $0.261 \pm 0.024$      | $-0.167 \pm 0.029$     | $0.503 \pm 0.013$      |
|          | $-0.101 \pm 0.071$   | $0.659 \pm 0.034$      | $-0.231 \pm 0.040$     | $0.993 \pm 0.018$      |
|          | $-0.003 \pm 0.036$   | $0.753 \pm 0.017$      | $-0.126 \pm 0.031$     | $1.028 \pm 0.014$      |
|          | $0.046 \pm 0.034$    | $0.403 \pm 0.016$      | $-0.004 \pm 0.022$     | $0.502 \pm 0.010$      |
| log sSFR | $-0.044 \pm 0.033$   | $-8.466 \pm 0.016$     | $-0.004 \pm 0.023$     | $-8.600 \pm 0.011$     |

Profiles in kpc (No PSF-correction)

| Contents | 9.0 < log$M_*$ < 9.5 | 9.5 < log$M_*$ < 10.0 | 10.0 < log$M_*$ < 10.5 | 10.5 < log$M_*$ < 11.0 |
|----------|----------------------|------------------------|------------------------|------------------------|
|          | Slope                | Intercept              | Slope                  | Intercept              |
|          |                      |                        |                        |                        |
| FUV - NUV| $-0.214 \pm 0.021$   | $0.263 \pm 0.004$      | $-0.252 \pm 0.013$     | $0.454 \pm 0.002$      |
|          | $-0.296 \pm 0.029$   | $0.662 \pm 0.005$      | $-0.348 \pm 0.017$     | $0.926 \pm 0.003$      |
|          | $-0.184 \pm 0.021$   | $0.772 \pm 0.003$      | $-0.197 \pm 0.024$     | $0.971 \pm 0.004$      |
|          | $0.028 \pm 0.005$    | $0.421 \pm 0.001$      | $-0.013 \pm 0.015$     | $0.480 \pm 0.002$      |
| log sSFR | $0.035 \pm 0.006$    | $-8.522 \pm 0.001$     | $0.015 \pm 0.018$      | $-8.594 \pm 0.003$     |

PSF-corrected Stacking Profiles Scaled by $R_{50}$ in arcsec

| Contents | 9.0 < log$M_*$ < 9.5 | 9.5 < log$M_*$ < 10.0 | 10.0 < log$M_*$ < 10.5 | 10.5 < log$M_*$ < 11.0 |
|----------|----------------------|------------------------|------------------------|------------------------|
|          | Slope                | Intercept              | Slope                  | Intercept              |
|          |                      |                        |                        |                        |
| FUV - NUV| $-0.214 \pm 0.021$   | $0.348 \pm 0.010$      | $-0.223 \pm 0.015$     | $0.543 \pm 0.008$      |
|          | $-0.296 \pm 0.029$   | $0.780 \pm 0.014$      | $-0.308 \pm 0.021$     | $1.048 \pm 0.010$      |
|          | $-0.184 \pm 0.021$   | $0.845 \pm 0.010$      | $-0.187 \pm 0.023$     | $1.030 \pm 0.012$      |
|          | $0.028 \pm 0.005$    | $0.432 \pm 0.002$      | $0.006 \pm 0.013$      | $0.475 \pm 0.006$      |
| log sSFR | $0.035 \pm 0.006$    | $-8.536 \pm 0.003$     | $-0.007 \pm 0.015$     | $-8.588 \pm 0.008$     |

PSF-corrected Stacking Profiles in kpc
However, whether the extinction curve of SFGs at $z \sim 2$ also follows the Calzetti law is still unknown. These assumptions are standard and have been used in all high-$z$ studies. This Letter does not attempt to justify these current state of the art assumptions, but takes the standard assumptions as given and aims to see where they lead to. Future works should investigate the consequences of more realistic stellar population models, metallicity, and extinction law.

This work was supported by the National Science Foundation of China (grant No. 11573017 to F.S.L. and Nos. 11333003, 11390372 to S.M.). X.Z. is supported by the

Figure 4. Rest-frame NUV – B profiles (both dust-reddened and dust-corrected) and inferred sSFR profiles in each mass bin, which are normalized by their $R_{\text{SMA}}$ in arcsec (upper) and are shown in physical radius (lower), respectively. Only the individual profiles of dust-reddened NUV – B and inferred sSFR are shown with gray lines. The shaded regions show the best-fit linear models with 2σ lower and upper limits to all individual profiles (no PSF-correction). The green dashed lines are PSF-corrected median profiles. The gray hatching indicate the regions within the median PSF FWHM (0.18 arcsec). The vertical dashed lines indicate the positions of $2R_{\text{SMA}}$ (median values for the profiles in kpc).
National Basic Research Program of China (973 Program 2013CB834900) and the Chinese Academy of Sciences (CAS) through a grant to the CAS South America Center for Astronomy (CASSACA) in Santiago, Chile.

References

Bertin, E., & Arnouts, S. 1996, A&AS, 117, 393
Brammer, G. B., van Dokkum, P. G., & Coppi, P. 2008, ApJ, 686, 1503
Buat, V., Iglesias-Páramo, J., Seibert, M., et al. 2005, ApJL, 619, L51
Calzetti, D., Armus, L., Bohlin, R. C., et al. 2000, ApJ, 533, 682
Chabrier, G. 2003, PASP, 115, 763
Dahlen, T., Mobasher, B., Faber, S. M., et al. 2013, ApJ, 775, 93
Galametz, A., Grazian, A., Fontana, A. & the CANDELS Team 2013, ApJS, 206, 10
Grogin, N. A., Kocevski, D. D., Faber, S. M., et al. 2011, ApJS, 197, 35
Guo, Y., Ferguson, H. C., Giavalisco, M., et al. 2013, ApJS, 207, 24
Kaviraj, S., Rey, S.-C., Rich, R. M., et al. 2007, MNRAS, 381, L74
Kennicutt, R. C., & Evans, N. J. 2012, ARA&A, 50, 531
Koekemoer, A. M., Faber, S. M., Ferguson, H. C., et al. 2011, ApJS, 197, 36
Kriek, M., van Dokkum, P. G., Labbé, I., et al. 2009, ApJ, 700, 221
Laidler, V. G., Papovich, C., Grogin, N. A., et al. 2007, PASP, 119, 1325
Liu, F. S., Jiang, D., Guo, Y., et al. 2016, ApJL, 822, L25
Morishita, T., Ichikawa, T., Noguchi, M., et al. 2015, ApJ, 805, 34
Muñoz-Mateos, J. C., Gil de Paz, A., Boissier, S., et al. 2007, ApJ, 658, 1006
Nelson, E. J., van Dokkum, P. G., Brammer, G., et al. 2012, ApJL, 747, L28
Nelson, E. J., van Dokkum, P. G., Förster Schreiber, N. M., et al. 2016a, ApJ, 828, 27
Nelson, E. J., van Dokkum, P. G., Momcheva, I. G., et al. 2016b, ApJL, 817, L9
Pan, Z., Li, J., Lin, W., et al. 2015, ApJL, 804, L42
Patel, S. G., Kelson, D. D., Holden, B. P., Franx, M., & Illingworth, G. D. 2011, ApJ, 735, 53
Patel, S. G., van Dokkum, P. G., Franx, M., et al. 2013, ApJ, 766, 15
Peng, C. Y., Ho, L. C., Impey, C. D., & Rix, H.-W. 2002, AJ, 124, 266
Reddy, N., Dickinson, M., Elbaz, D., et al. 2012, ApJ, 744, 154
Salim, S., Dickinson, M., Michael Rich, R., et al. 2009, ApJ, 700, 161
Santini, P., Ferguson, H. C., Fontana, A., et al. 2015, ApJ, 801, 97
Szomoru, D., Franx, M., van Dokkum, P. G., et al. 2013, ApJ, 763, 73
Tacchella, S., Carollo, C. M., Forster Schreiber, N. M., et al. 2017, arXiv:1704.00733
Tacchella, S., Carollo, C. M., Renzini, A., et al. 2015, Sci, 348, 314
Tacchella, S., Dekel, A., Carollo, C. M., et al. 2016, MNRAS, 458, 242
Tielens, A. G. G. M. 2008, ARA&A, 46, 289
van der Wel, A., Bell, E. F., Häussler, B., et al. 2012, ApJS, 203, 24
van der Wel, A., Franx, M., van Dokkum, P. G., et al. 2014, ApJ, 788, 28
van Dokkum, P. G., Leja, J., Nelson, E. J., et al. 2013, ApJL, 771, L35
Wang, W., Faber, S. M., Liu, F. S., et al. 2017, MNRAS, 469, 4065
Welker, C., Dubois, Y., Devriendt, J., et al. 2017, MNRAS, 465, 1241
Williams, R. J., Quadri, R. F., Franx, M., van Dokkum, P., & Labbé, I. 2009, ApJ, 691, 1879
Wuyts, S., Förster Schreiber, N. M., Genzel, R., et al. 2012, ApJ, 753, 114