THE DWARF STARBURST HOST GALAXY OF A TYPE Ia SUPERNOVA AT z = 1.55 FROM CANDELS*  

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ABSTRACT

We present VLT/X-shooter observations of a high-redshift, Type Ia supernova (SN Ia) host galaxy, discovered with HST/WFC3 as part of the CANDELS Supernova project. The galaxy exhibits strong emission lines of Lyα, [O iii], Hβ, [O ii], and Hα at z = 1.5499±0.0008. From the emission-line fluxes and spectral energy distribution fitting of broadband photometry we rule out activity from an active galactic nucleus and characterize the host galaxy as a young, low-mass, metal-poor, starburst galaxy with low intrinsic extinction and high Lyα escape fraction. The host galaxy stands out in terms of the star formation, stellar mass, and metallicity compared to its lower redshift counterparts, mainly because of its high specific star formation rate. If valid for a larger sample of high-redshift SN Ia host galaxies, such changes in the host galaxy properties with redshift are of interest because of the potential impact on the use of SN Ia as standard candles in cosmology.

Key words: galaxies: abundances – galaxies: distances and redshifts – galaxies: starburst

Online-only material: color figures

1. INTRODUCTION

Type Ia supernovae (SNe Ia) are cornerstones of modern cosmology because of their properties as luminous standard candles. The development of these important cosmological tools began in the late 1930s when Zwicky (1938) and Wilson (1939) first suggested that SNe could be used as distance indicators. Theoretical developments in the 1960s suggested that SNe of Type Ia form a homogenous class of objects with a measured peak magnitude of $M_B \sim -19.3 + 5 \log \delta_{\nu}$ (for a modern review, see Hillebrandt & Niemeyer 2000; Kirshner 2010). To first approximation, the light curves of SN Ia form a one-parameter family of models, driven by the decay of radioactive $^{56}$Ni $\rightarrow ^{56}$Co $\rightarrow ^{56}$Fe. The amount of radioactive nickel produced in the initial explosion therefore dictates the shape of the light curve. Later observational work showed that the scatter in the peak magnitude is correlated with other supernova (SN) properties, such as light curve shape and color (Phillips 1993; Riess et al. 1996; Phillips et al. 1999).

SN cosmology achieved its modern prominence at the close of the millennium with the discovery of the accelerating expansion of the universe, based on just a few dozen objects (Perlmuter et al. 1999; Riess et al. 1998). Nearly 15 years later, modern SN Ia samples can now include over 500 well-studied SNe with a dispersion in peak magnitudes of $\sim 0.16$ mag (e.g., Conley et al. 2011; March et al. 2011). This signature of environmental effects calls for further characterization of the host galaxies when SNe are used for cosmography. Riess & Livio (2006) discuss how a change in the host galaxy stellar mass brings the dispersion in absolute peak magnitude down to $\sim 0.1$ mag (Conley et al. 2011; March et al. 2011). This signature of environmental effects calls for further characterization of the host galaxies when SNe are used for cosmography. Riess & Livio (2006) discuss how a change in the progenitor population (like progenitor metallicity and age) at $1.5 < z < 3.0$ could affect the inferred distance in a way inconsistent with dark energy models. The redshift window $1.5 < z < 3.0$ is therefore favorable for disentangling systematic effects arising from environment.

The Cosmic Assembly Near-IR Deep Extragalactic Legacy Survey (CANDELS) survey (Grogin et al. 2011) is a Hubble Space Telescope (HST) multi-cycle treasury program designed to detect high-redshift SNe. The CANDELS collaboration is surveying five well-observed fields (GOODS-N, GOODS-S, COSMOS, EGS, and UDF). With this observation strategy CANDELS will find SNe Ia out to redshifts of $\sim 2$ (see Rodney et al. 2012). The first SN detected in the CANDELS survey was discovered 2010 October 14 in the GOODS-S field and was nicknamed SN Primo. Rodney et al. (2012) present the light curve and grism spectrum of this SN, concluding that SN Primo was of Type Ia.

The aim of this paper is to characterize the host galaxy of SN Primo. We derive its spectral properties from spectroscopic emission-line fluxes and fit the spectral energy distribution

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As measured by the Paranal on-site seeing monitor.

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population. We then compare the properties of the host galaxy (SED) based on broadband photometry to constrain its stellar age and we derive the emission-line fluxes and calculate the escape fraction. To construct the SED for the host of SN Primo, we use photometry from the F160W filter (H band) selected TFIT catalog. The photometry in each band is carried out using the TFIT algorithm (Laidler et al. 2007). This method performs point-spread function (PSF) matched photometry uniformly across different instruments and filters, despite their large variations in PSFs and pixel scales. The final catalog has photometry in VLT/VIMOS (U band), HST/ACS (F435W, F606W, F775W, and F850LP), HST/WFC3 (F105W, F125W, and F160W), VLT/ISAAC (K_s), and two Spitzer/IRAC channels (3.6 μm and 4.5 μm). The SN search uses the HST/WFC3 bands. To get SN free photometry in these bands a set of pre-explosion images from another HST/WFC3 survey (GO-11563, PI: Illingworth, see, e.g., Oesch et al. 2010) was used. The photometry is listed in Table 1. The HST/WFC3 observations are performed as a part of CANDELS project and are further described in Grogin et al. (2011) and Koekemoer et al. (2011). More details on the rest of the filters and observations are given in Dahlen et al. (2010).

3. ANALYSIS

3.1. Broadband SED Fitting

The broadband SED of the host of SN Primo (Table 1) covers rest-frame UV to near-IR (200–2000 nm). We use the SED fitting code FAST (Kriek et al. 2009) to derive properties such as stellar mass, M_* and stellar age, t_*.
Table 1
Photometry of the Host of SN Primo

| Filter | Instrument | λ_eff (nm) | Magnitudea (AB mag) | Correctedb (AB mag) |
|--------|------------|------------|---------------------|---------------------|
| U band | VLT/VMOS   | 375.3      | 24.69 ± 0.02        |                     |
| F435W  | HST/ACS    | 432.8      | 24.84 ± 0.02        |                     |
| F606W  | HST/ACS    | 595.8      | 24.84 ± 0.02        |                     |
| F775W  | HST/ACS    | 770.6      | 24.86 ± 0.03        |                     |
| F850LP | HST/ACS    | 905.3      | 24.80 ± 0.04        | 24.88 ± 0.04       |
| F105W  | HST/WFC3   | 1059       | 24.50 ± 0.01        | 24.56 ± 0.01       |
| F125W  | HST/WFC3   | 1252       | 24.27 ± 0.01        | 24.71 ± 0.01       |
| F160W  | HST/WFC3   | 1544       | 24.36 ± 0.01        | 24.71 ± 0.01       |
| Kσ     | VLT/ISAAC  | 2168       | 24.47 ± 0.17        |                     |
| Channel 1 | Spitzer/IRAC | 3563 | 24.43 ± 0.05 |                     |
| Channel 2 | Spitzer/IRAC | 4511 | 24.49 ± 0.09 |                     |

Notes.
1. The magnitudes before subtraction of the emission-line fluxes.
2. The magnitudes after subtraction of the emission-line fluxes.

Table 2
Summary of SED Fitting Using FAST

| Parametera | Exponentialb | Delayedc | Truncatedd |
|------------|--------------|----------|------------|
| log(t_0 (yr)) | 8.50±0.28 | 8.60±0.51 | 8.65±0.13 |
| log(t (yr)) | 8.80±2.00 | 8.30±2.70 | 9.40±1.60 |
| Z          | 0.0200±0.021 | 0.0200±0.015 | 0.0200±0.016 |
| A_V        | 0.0000±0.000 | 0.0000±0.000 | 0.0000±0.000 |
| log(M_0 (M_☉)) | 8.80±0.13 | 8.81±0.16 | 8.84±0.07 |
| log(SFR (M_☉/yr)) | 0.33±0.77 | 0.32±0.84 | 0.35±0.73 |
| log(sSFR (M_☉/yr)) | -8.4±1.07 | -8.4±1.05 | -8.5±1.05 |
| log(t/t_0) | -30.3±1.25 | 0.30±0.25 | -0.75±2.80 |

R^2 = 19.9

Notes.
1. We have assumed a Chabrier IMF.
2. Exponential star formation history: SFR(t) ∝ exp(−t/τ), τ > 0.
3. Delayed star formation history: SFR(t) ∝ 1 − exp(−t/τ).
4. Truncated star formation history: SFR(t) = constant; for t ∈ [t_0, t_0 + τ], else 0.

and star formation rates (SFRs) derived in Table 2 assuming different SFHs agree within the 1σ uncertainties.

We also run the SED fitting without any correction to the broadband SED, but excluding the J and H bands to get a second measure of the physical parameters. This second measure quantifies the systematic shift that the correction procedure can put on the physical parameters. We check that the best-fitting parameters of this second fit is within the 1σ error bars. For reference the shift in log(M_0) is 0.07 higher for the second fit, compared to the upper error bar of 0.13 on our main SED fit.

3.2. Resampling of the X-shooter Spectrum

We correct the spectrum for Galactic extinction in the same manner as the broadband photometry. To obtain a robust estimate of the uncertainties in the spectral quantities such as the metallicity or line ratios, we re-sample the X-shooter spectrum 10,000 times. For each wavelength bin we re-sample the flux using the error spectrum (assuming Gaussian error). In each iteration the spectral lines are fitted with a Gaussian line profile and the centroid, the FWHM, and the total flux is calculated (see Table 3 and Figure 3). The redshift is determined from Hα, [O II] λ3729, [O III] λλ4959, 5007 in each iteration. All reported values that are derived from the spectrum are the median values and 68% error bars of the 10,000 samplings. The heliocentric velocity correction is 6.54 km s^−1, calculated using the IRAF task rvcorrect.

Special care is taken when fitting [O II] λλ3726, 3729 and Hβ in each re-sampling: The blue component of the [O II] doublet, [O II] λ3726, is located on top of a sky line. After masking out the sky line it is impossible to fit the peak of [O II] λ3726. We therefore fit a double-Gaussian line profile to [O II] λλ3726, 3729. We fix the peak of the blue components, λ_blue, to the peak of the red component, λ_red, by requiring λ_blue/λ_red = 372.6032 nm/372.8815 nm. The flux ratio of the two components is left as a free parameter.

Hβ is also located on top of a sky line with the wings visible. We remove the sky line in the same manner as for [O II] λ3726 and fix the wavelength, λ_0, and FWHM of the fit. λ_0 is fixed to λ_Hβ(1 + z), where λ_Hβ = 486.1325 nm. The FWHM is fixed to the measured FWHM of Hα in velocity units. The instrumental broadening of spectral lines is constant if measured

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12 Quoted from the NASA/IPAC Extragalactic Database (NED) Web site http://ned.ipac.caltech.edu/
in velocity units and therefore affects Hα and Hβ equally. The derived flux may be biased if a Gaussian line profile is not a correct description of the line. Due to the uncertainties in the Hβ detection we will not use the derived flux, other than for constraining the Balmer decrement. For all other purposes we set the flux of Hβ equal to the flux of Hα divided by 2.86 (see discussion in Section 3.3).

We do not detect [N ii] λ6583 in the spectrum. To derive an upper limit of the flux, we measure the standard deviation of the flux density at the location of the line, λNII(1 + z) ± 2Δλ, where λNII = 658.346 nm and Δλ = λ/R is the size of one resolution element. Table 3 lists the 5σ upper limit of the non-detection.

3.3. Host Extinction

We correct the X-shooter spectrum for Galactic extinction in the same manner as for the broadband SED. We test if the AV from SED fitting is consistent with the spectrum. To gauge the intrinsic extinction from the spectrum we measure the Balmer decrement, Hα/Hβ. By comparing the measured Balmer decrement, B, with the expected B = 2.86 given in Osterbrock & Ferland (2006) (case B recombination, Te = 10^4 K), we calculate the extinction as

$$A_V = -2.5 \log \left( \frac{B}{B_0} \right) \frac{k(V)}{k(\text{H}\alpha) - k(\text{H}\beta)},$$

(2)

where $k(\lambda) = A_\lambda / (B - V)$, $k(V) \equiv R_V = 3.1$, $k(\text{H}\alpha) = 2.468$, and $k(\text{H}\beta) = 3.631$ (Calzetti 2001). We assume $R_V = 3.1$ because the SED and the spectrum probe the luminosity-weighted average $R_V$ of the host of SN Primo and not just the SN sight line, where a lower $R_V$ (down to ~1.7) can be measured (Phillips 2011).

The value $A_V = 0.6^{+0.7}_{-0.6}$ derived from the Balmer decrement is consistent with the value derived from the SED fitting. The large uncertainty in $A_V$ is due to the difficulty in estimating the...

Table 3

| Line        | Wavelength (nm) | Observed FWHM (km s⁻¹) | Flux (10⁻¹⁷ erg s⁻¹ cm⁻²) |
|-------------|-----------------|-------------------------|---------------------------|
| Hα λ6563   | 1673.43 ±0.01   | 117 ±7                  | 5.1 ±0.3                  |
| [O ii] λ5007 | 1276.71 ±0.02   | 102 ±11                 | 6.0 ±0.6                  |
| [O ii] λ4959 | 1264.43 ±0.04   | 75 ±16                  | 2.1 ±0.4                  |
| Hβ λ4861a  | ...             | ...                     | 1.4 ±0.4                  |
| [O iii] λλ3726,3729c | 950.90 ±0.08 | 112 ±21                 | 2.6 ±1.0                  |
| [N ii] λ6586d | ...             | ...                     | <0.3                      |
| Lyα λ1216c | ...             | ...                     | 11.2 ±3.9                 |

Notes.

a Fit of the observed flux corrected for Galactic extinction (E(B - V) = 0.008).
b In each re-sampling the following fit was performed: the central wavelength of the line was fixed to λHβ(1 + z), where λHβ = 486.1325 nm and z is the redshift. FWHM(Hβ) was fixed to FWHM(Hα) in velocity units. Only the peak intensity was allowed to vary.
c The wavelength is that of [O ii] λ3729 (the red component) only, the flux is the sum of both components.
d 5σ upper limit of the non-detection.
e The Lyα flux is the co-added flux from ν = 0 to 600 km s⁻¹. The error bars only cover the statistical errors. The systematic error is ~40%.

For all other elements Table 3 lists the 5σ upper limit of the non-detection.

(A color version of this figure is available in the online journal.)
from the SN light curve is to determine the metallicity. We take the average of the two calibrations (McGaugh 1991; Kobulnicky & Kewley 2004); the procedure of Kobulnicky & Kewley (2004) is used in Kewley & Ellison (2008). The $R_{23}$ diagnostic has the problem of being double valued, meaning that from a measured $R_{23}$ value two metallicities can be inferred (see Figure 4). We therefore need an independent measure to break this degeneracy. The upper limit on $[N\text{ II}]$ $\lambda6586$ gives an upper limit on

$$\log\left(\frac{[N\text{ II}]_{\lambda6586}}{[O\text{ II}]_{\lambda3726,3729}}\right) < -1.0.$$  

This constrains the metallicity to the low-metallicity branch of $R_{23}$ (see Kewley & Dopita 2002, their Figure 3). The low-metallicity branch of $R_{23}$ changes with ionization parameter, $q$. To break the $q$-degeneracy, we need the line ratio

$$O_{32} = \log\left(\frac{[O\text{ III}]_{\lambda5007}}{[O\text{ II}]_{\lambda3726,3729}}\right),$$  

to determine the metallicity. We take the average of the two $R_{23}$ calibrations (McGaugh 1991; Kobulnicky & Kewley 2004) as used in Kewley & Ellison (2008) whose procedure we follow.

The $R_{23}$ diagnostic is independent of the systematic error in conversion factor to cosmological Ly$\alpha$. We check whether the emission lines of the host of SN Primo are powered by star formation or activity from an active galactic nucleus by plotting $\log([N\text{ II}]$ $\lambda6586/H\beta)$ versus $\log([O\text{ III}]$ $\lambda5007/H\beta)$ in a BPT diagnostics diagram (Baldwin et al. 1981). The host of SN Primo is located in the star-forming region of Figure 5. We therefore conclude that the H$\alpha$ flux is powered by star formation. We derive the SFR from the H$\alpha$ luminosity. We report the SFR for different IMFs for comparison (Kennicutt 1998; Brinchmann et al. 2004; Mannucci et al. 2010). Using the stellar mass from SED fitting we calculate the specific SFR, $sSFR = SFR/M_*$ from the spectrum and obtain a value of $\sim 10^{-8}$ yr$^{-1}$, independent of the IMF and SFH, making the host of SN Primo a starburst galaxy. Our definition of a starburst is based on the sSFR (see, e.g., Sullivan et al. 2006 for a review), see Section 4 for discussion on other definitions.

3.6. Ly$\alpha$

We detect Ly$\alpha$ emission at 2.8$\sigma$ in the spectrum (see Figure 6). This is possibly the lowest redshift ground-based detection of a cosmological Ly$\alpha$ emitter. The significance of the detection is independent of the systematic error in conversion factor.
between counts and cgs units (i.e., the flux calibration) at Lyα (Section 2.2).

Given the low significance of the detection we can only give an order-of-magnitude estimate of the Lyα escape fraction (as defined in Atek et al. 2009; Hayes et al. 2011, among others)

$$f_{\text{esc}} = \frac{F_{\text{Ly} \alpha}}{8.7 F_{\text{H}\alpha}}. \tag{6}$$

We derive the line flux $F_{\text{Ly} \alpha}$ by co-adding the flux in all pixels from $\lambda = 309.97–310.68$ nm (corresponding to $v = 0–600$ km s$^{-1}$). The derived flux estimate is corrected for extinction in the host galaxy. The deviation from the expected value of 8.7 (case B recombination; Brocklehurst 1971) will be due to conditions in the interstellar medium (ISM) like the presence of dust, ISM clumpiness or due to geometric effects that will suppress or enhance the amount of Lyα photons that can escape the galaxy. At a redshift of $z = 1.5$ the universe is fully ionized; absorption of Lyα in the intergalactic medium is therefore not important. We will not try to distinguish between these different scenarios. We include a systematic uncertainty of 40% in the derived Lyα escape fraction, due to the uncertainty in the conversion factor between counts and cgs units at the Lyα wavelength.

4. DISCUSSION AND CONCLUSIONS

We have performed a photometric and spectroscopic study of the SN Primo host galaxy. We find a young Large Magellanic Cloud (LMC)-sized ($\sim 4.5$ kpc) galaxy with LMC-like ($\sim 1/3 Z_\odot$) metallicity and low intrinsic extinction. We confirm that the emission lines are generated by star formation and derive an SFR of almost one order of magnitude larger than that of the LMC. The stellar mass derived from SED fitting is one order of magnitude lower than the LMC. From the Lyα line we estimate a high escape fraction of Lyα photons. All host properties are summarized in Tables 2 and 4.

In Figure 7, we plot the SFR versus stellar mass for the host of SN Primo in comparison to both a low redshift (Lampeitl et al. 2010, $z < 0.21$) and two high-redshift samples from HST (Thomson & Chary 2011, $0.95 < z < 1.8$) and SNLS (Sullivan et al. 2010, $0.2 < z < 1.0$) samples. The host of SN Primo clearly stands out from the low-z sample, due to its high specific

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**Notes.**

$^a$ Assuming a solar oxygen abundance of 8.69 (Asplund et al. 2009).

$^b$ The value in parenthesis covers the systematic uncertainty on the flux of Lyα of 40%.

**Table 4**

| Parameter | Value | Assumed IMF |
|-----------|-------|-------------|
| Redshift (heliocentric) | $z = 1.5499^{+0.0008}_{-0.0004}$ | | |
| Metallicity | $12 + \log (Z/Z_\odot) = 8.12^{+0.09}_{-0.10}$ | | |
| Extinction | $A_{\text{V}} = 0.6^{+0.11}_{-0.07}$ mag | | |
| Lyα escape fraction | $f_{\text{esc}} = 0.25 \pm 0.09 (\pm 0.10)^b$ | | |

**Star formation rate**

| | SFR = 6.4 ± 0.3 $M_\odot$ yr$^{-1}$ | Salpeter |
| | SFR = 4.3 ± 0.2 $M_\odot$ yr$^{-1}$ | Kroupa |
| | SFR = 3.8 ± 0.2 $M_\odot$ yr$^{-1}$ | Chabrier |

**Specific star formation rate**

| | log($sSFR$ (yr$^{-1}$)) = $-7.8 \pm 0.2$ | Salpeter |
| | log($sSFR$ (yr$^{-1}$)) = $-8.0 \pm 0.2$ | Kroupa |
| | log($sSFR$ (yr$^{-1}$)) = $-8.1 \pm 0.2$ | Chabrier |

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**Figure 7.** SFR–mass relation for SN Ia host galaxies. The (red) asterisk denotes the host of SN Primo with error bars. Filled (blue) circles mark star-forming hosts in each sample. The (magenta) crosses marks the passive hosts in each sample. The solid and dotted (green) lines show the correlation between SFR and stellar mass for $z \sim 0$ (bottom), $z = 1$ (middle), and $z = 2$ (top) from Daddi et al. (2007, $z = 2$) and Elbaz et al. (2007, $z \sim 0$ and $z = 1$). The solid section of each line marks the range of validity of the relations. (a) The low-redshift sample ($z < 0.21$) from SDSS (Lampeitl et al. 2010). The dashed line marks the cut, log($sSFR$) = $-10.6$, between star-forming and passive galaxies. The contours mark the region enclosing 68% and 95% of the star-forming sample. (b) The high-redshift samples from HST (Thomson & Chary 2011, $0.95 < z < 1.8$, open (orange) circles) and SNLS (Sullivan et al. 2010, $0.2 < z < 1.0$, filled (blue) circles/(magenta) crosses). The apparent upper diagonal ridge line for the Sullivan et al. (2010) data is due to shortcomings in their SED fitting.

(A color version of this figure is available in the online journal.)
SFR. The relation between SFR and stellar mass is expected to evolve with redshift as seen in observations (Daddi et al. 2007; Elbaz et al. 2007). If SN host galaxies are representative of field galaxies the blue points in Figure 7 are expected to shift upward in the same way as the green dashed lines (signifying $z$ galaxies the blue points in Figure 7 are expected to shift upward Elbaz et al. 2007). If SN host galaxies are representative of field galaxies (Gallagher et al. 2005; Prieto et al. 2008). We plot the metallicity–luminosity relation for SN Ia host galaxies. The (red) main sequence (MS) of galaxies (indicated in Figure 7(a)) is consistent with the FMR relation defined in Mannucci et al. (2010) which relates metallicity, stellar mass, and SFR. Mannucci et al. (2011) updated the metallicity–luminosity relation for SN Primo the host galaxy has a lower metallicity than any of the low-$z$ galaxies (see Figure 8). The host of SN Primo also falls below the mass–metallicity relation (Tremoniti et al. 2004). We check why this could be the case by comparing the host of SN Primo to the Fundamental Metallicity Relation (FMR) of star-forming galaxies (Lara-López et al. 2010; Mannucci et al. 2010) which relates metallicity, stellar mass, and SFR. Mannucci et al. (2011) updated the metallicity–luminosity relation for SN Primo and the FMR relation is $\Delta[12+\log(O/H)] = 0.07 \pm 0.15$. The host of SN Primo is therefore consistent with the FMR relation defined in Mannucci et al. (2011). The FMR relation is consistent with a simple model (Dayal et al. 2012) where the balance of gas infall, outflow, and star formation brings out the relation between SFR, metallicity, and stellar mass seen in the FMR relation.

The stellar age of $\sim 10^{9.8}$ yr (Table 2) could give an upper limit on the delay time of SN Primo, assuming there is no underlying old stellar population. This would put SN Primo in the prompt progenitor distribution (see Sullivan et al. 2006 for a review). There are, however, caveats to the values derived from our SED fitting. It is assumed that there is no underlying old stellar population, which cannot be ruled out. This is also seen in Table 2 where ages up to $\sim 10^{9}$ are still consistent within $1 \sigma$.

In this paper, we have used a redshift-independent definition of a starburst based on the value of the SFR ($\log(sSFR) > -9.5$, Sullivan et al. 2006). Alternatively a starburst can be defined based on the SFR and $M_*$ of galaxies at the same redshift—the so called main sequence (MS) of galaxies (indicated in Figure 7(a)). The evolution of the MS with redshift, however, is not fully settled (see Daddi et al. 2007; Wuyts et al. 2011; Whitaker et al. 2012, among other). As indicated in Figure 7(a) the MS fits at $z = 1$ and $z = 2$ would have to be extrapolated down to the mass of the host of SN Primo.

Gallagher et al. (2005) showed that the light curve shape correlates with the Hubble type of the host galaxy and Meyers et al. (2012) showed that both light curve shape and SN peak color are different between early-type and late-type galaxies. Sullivan et al. (2011) showed by splitting up the SNLS3 sample of SNe Ia into a high and low sSFR sample, that the host galaxy has an influence on the mean SN peak brightness and the correction of light curve shape and color correction. Galaxy evolution models find that sSFR increases with redshift to at least $z = 2$. Using the mass of the host of SN Primo the "host term" of Kelly et al. (2010) is 0.3 mag (superluminous SN). These dependencies highlight that the bulk of the training sample of SNe Ia lies below $z < 1$ where the host galaxies are older and in general have a smaller sSFR. As a consequence, this could introduce a potential bias in the distances derived to the high sSFR host galaxies, when not explicitly including the host correction. As the sample of high redshift and high sSFR SNe grows the size of this effect can be investigated further.

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