CONTINUUM SUBTRACTING LYMAN-ALPHA IMAGES: LOW-REDSHIFT STUDIES USING THE SOLAR BLIND CHANNEL OF HST/ACS

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ABSTRACT

We are undertaking an imaging study of local star-forming galaxies in the Lyman-alpha (Ly\textalpha) emission line using the Solar Blind Channel (SBC) of the Advanced Camera for Surveys onboard the Hubble Space Telescope. Observations have been obtained in Ly\textalpha and H-alpha (H\textalpha) and six line-free continuum filters between \textasciitilde1500 Å and the I band. In a previous article, we demonstrated that the production of Ly\textalpha line-only images (i.e., continuum subtraction) in the SBC-only data set is nontrivial and that supporting data is a requirement. Here we develop various methods of continuum subtraction and assess their relative performance using a variety of spectral energy distributions (SEDs) as input. We conclude that simple assumptions about the behavior of the ultraviolet continuum consistently lead to results that are wildly erroneous, and determine that a spectral fitting approach is essential. Moreover, fitting of a single component stellar or stellar+nebular spectrum is not always sufficient for realistic template SEDs and, in order to successfully recover the input observables, care must be taken to control the contribution of nebular gas and any underlying stellar population. Independent measurements of the metallicity must first be obtained, while details of the initial mass function play only a small role. We identify the need to bin together pixels in our data to obtain signal-to-noise ratios (S/Ns) of around 10 in each band before processing. At S/N = 10, we are able to recover Ly\textalpha fluxes accurate to within around 30\% for Ly\textalpha lines with intrinsic equivalent width (W\textsubscript{Ly\alpha}) of 10 Å. This accuracy improves to \textasciitilde10\% for W\textsubscript{Ly\alpha} = 100 Å. We describe the method of image processing applied to the observations presented in Östlin et al. and the associated data release. We also present simulations for an observing strategy for an alternative low-redshift Ly\textalpha imaging campaign using ACS/SBC using adjacent combinations of long-pass filters to target slightly higher redshift.

Key words: galaxies: starburst – methods: data analysis – techniques: image processing – techniques: photometric

Online-only material: color figures

1. INTRODUCTION

The Lyman-alpha (Ly\textalpha) emission line is a powerful and frequently exploited observational signature through which the galaxy population can be probed at high redshift (z). In principle, Ly\textalpha can be used to probe the ionization fraction during the final stages of re-ionization (Malhotra & Rhoads 2004; Dijkstra et al. 2007), cosmic star formation rates (Hu et al. 1998; Kudritzki et al. 2000; Ajiki et al. 2003), large-scale structure (Venemans et al. 2002; Ouchi et al. 2005), and to identify a potential host of Population III star formation (Malhotra & Rhoads 2002; Nagao et al. 2007). Ultimately, exactly how the Ly\textalpha-emitting (or nonemitting) high-z galaxy population relates to the ultraviolet-selected Lyman break galaxy (LBG) population is uncertain, and studies of the high-z population of Ly\textalpha emitters (LAEs) are interesting in their own right.

In all surveys for which the ultimate science goal is more fundamental than the observed population itself, it is vital to understand what biases, be they observational or astrophysical, may affect the inferred properties and how they manifest themselves. This point is especially consequential for high-z Ly\textalpha-selected studies where typical detections are faint and galaxies often go undetected in the continuum. Ly\textalpha is a resonant line and its formation is strongly affected by a complex radiative transport. On a physical level the regulation and transport of Ly\textalpha is known to be affected by dust, the topology and ionization of the interstellar medium (ISM), H\textsc{i} kinematics, and viewing geometry. Such insights have been gleaned empirically from spectroscopic observations of small samples of local galaxies (Giavalisco et al. 1996; Kunth et al. 1998; Mas-Hesse et al. 2003), flanked by a sophisticated theoretical and computational attack on the problem of Ly\textalpha escape physics (Neufeld 1990; Ahn 2004; Hansen & Oh 2006; Verhamme et al. 2006; Laursen & Sommer-Larsen 2007).

Since Ly\textalpha is a resonance line and can be expected to be substantially spatially decoupled from UV continuum radiation and other nebular lines, the picture yielded by UV-targeted spectroscopy is limited. Thus, the imaging approach becomes an invaluable complement to the previous IUE and HST spectroscopic studies. Ly\textalpha imaging at z \approx 0 is technically possible with HST using the Wide Field Planetary Camera (WFPC2) although the instrumental throughput at Ly\textalpha would make it very inefficient. A much more economical approach would be to use the UV-optimized channels of the Space Telescope Imaging Spectrograph (STIS) or Advanced Camera for Surveys (ACS) which both offer higher system efficiency and better defined and non-red-leaking filters. In HST cycle 11, we began an imaging study to examine a handful of local star-forming galaxies in Ly\textalpha using HST/ACS. First results from this were presented in Kunth et al. (2003), although technical uncertainties about how...
to subtract the continuum prevented a deep analysis and Hayes et al. (2005) demonstrated the need for additional offline observations to aid in the continuum subtraction. These additional data have since been obtained for the remainder of the sample and the entire data set has now been processed. Lyα line-only images are being released to the community (Östlin et al. 2009). However, since the process of subtracting the continuum in this study is far from trivial and future imaging studies depend upon the methodology, this process was deemed to be worthy of an article in its own right. We here perform a series of tests of synthetic Lyα imaging observations of low-z targets using configurations available on HST and compare different approaches to subtracting the continuum.

The article is organized as follows: in Section 2, we explain the complications involved with Lyα observations and why conventional continuum subtraction techniques are not applicable to Lyα with the current instrumentation; in Section 3, we describe the methodology and theoretical tests; in Section 4, we present the results and discuss their significance; in Section 5, we present simulations for a study that target slightly higher redshift and discuss some possible augmentation to the method; and in Section 6 we make some concluding remarks.

2. LOCAL LYMAN-ALPHA IMAGING

2.1. Observing Strategies

The Solar Blind Channel (SBC) of HST/ACS offers the F122M filter through which to observe rest-frame Lyα at 0 < z ≲ 0.035. This filter peaks at 1216 Å and has a rectangular width (W_r) of 128.4 Å although the pivotal wavelength (\lambda_p) at 1273.7 Å is rather offset from the peak due to the red wing. Furthermore, with W_r/\lambda_p \approx 0.1, this filter cannot be considered narrow compared to optical narrowband filters. A number of long-pass filters are available through which to sample the continuum, the most appropriate for z ≲ 0 being F140LP (\lambda_p = 1527 Å; W_r = 252.95 Å). This F122M+F140LP configuration is that used by our imaging campaign and is denoted as configuration 1 in this paper. Due to the very sharp cut-on on the blue side, and the red side being defined by the degrading sensitivity of the detector with wavelength, all the long-pass filters exhibit near identical shapes in the red wing. Adjacent long-pass filter combinations could therefore be appropriate for Lyα imaging of slightly more distant targets (e.g., F125LP+F140LP for 0.028 ≤ z ≤ 0.1) and this combination is also examined here, denoted as configuration 2. Figure 1 shows the bandpasses for both configurations.

2.2. Continuum Subtraction Methods

The art of continuum subtraction hinges entirely upon scaling of the stellar continuum sampled by an offline filter to the bandpass of the filter that isolates the line. In the forthcoming discussion, we make use of a quantity known as the continuum throughput normalization (CTN) factor, first defined in Hayes et al. (2005). This is the dimensionless quantity that scales the raw count rate in a continuum filter to that expected in the online filter, accounting for the filter transmission profiles, the instrument sensitivity, and the shape of the continuum. That is,

$$\text{Ly}\alpha = \text{online} - \text{CTN} \times \text{offline}. \quad (1)$$

CTN can be computed with varying degrees of complexity. For known or assumed continuum slopes it can be computed simply from the inverse sensitivity bandpass characteristics.

Figure 1. ACS/SBC filter combinations for Lyα imaging. Solid lines represent the filter that transmits Lyα and dashed lines that for the continuum. Vertical dot-dashed lines are at \lambda = 1216 Å, the wavelength of both Milky Way Lyα absorption and the geocoronal emission line. The red line shows a synthetic spectrum with artificially added Lyα. For illustration, a Milky Way absorption feature has also been added to the templates (log(n_HI) = 20.5 cm^-2). Upper: configuration 1, F122M+F140LP for z ≲ 0.03. Suitable for z ≈ 0 although both geocoronal emission and Galactic absorption fall in the online bandpass and must be accounted for. The spectrum is redshifted to 0.01. Lower: configuration 2, F125LP+F140LP for 0.03 ≲ z ≲ 0.1. Geocoronal Lyα is not transmitted and online system throughput is greatly improved over the upper example. The spectrum is redshifted to 0.06.

(PHOTFLAM) of the on- and offline filters. For any continuum spectrum, CTN can be computed by convolving the spectrum with the instrument throughput profiles of the filters, integrating to estimate the count rate, and calculating the ratio. This permits features such as spectral shape and absorption or emission lines to be accounted for in the process. In essence CTN is simply a color with a nonstandard normalization derived from instrument sensitivities.

There are a number of possible issues that may impede the continuum subtraction of Lyα. First, possible strong stellar Lyα absorption may cancel some or all of the nebular emission. This is perhaps unlikely to be a strong effect where the starburst is very young and dominated by O-stars where deep absorption features have yet to develop. The effect may become very significant when Lyα is scattered and may be superimposed upon older stellar populations with lower effective temperature. Indeed, absorption of stellar continuum by B-stars was initially proposed as an explanation for the weakness or absence of Lyα emission in nearby starbursts and for the early failure to detect Lyα emitters at high-z (Valls-Gabaud 1993). Second, the Lyα feature may be P Cygni with some or all of the emission canceled by absorption, especially directly in front of the brightest clusters. Spectroscopic measurements, if of sufficient resolution, can isolate the emission segment of the P Cygni profile and obtain the emitted flux, although this is not possible with imaging. If the absorption segment falls within the online filter as it will in our case, the local minima in Lyα flux from P Cygni absorption on top of clusters can never be corrected for. Notably, however, this caveat also applies to imaging surveys at high-z. Ultimately, what is called emission is a matter of definition; whether it be defined as the flux in the emission segment of the profile, or the flux integrated over both the absorption and emission segments. Either way, imaging can only assess the latter. Finally, and especially...
for configuration 1, photometry will be directly affected by Milky Way Lyα absorption and geocoronal Lyα emission. Both of these effects can be relatively easily accounted for since they are not expected to vary strongly across the small angles subtended by the SBC field of view. Geocoronal emission can be removed by background subtraction, and Milky Way Lyα absorption computed from the H I column density measured along the line of sight to the target (Dickey & Lockman 1990; Kalberla et al. 2005) and incorporated into the calculation of CTN.

2.2.1. Purely Observational Methods

Typically, for optical emission lines in ground-based observations, continuum is sampled using a filter positioned as close as possible to, but not transmitting, the line in question (or other contaminating spectral features). For example, an offline Hα filter 100 Å redward of the line corresponds to \( \Delta \lambda / \lambda \sim 0.015 \). Were an intrinsically power-law continuum with \( \beta = -2 \) assumed to be flat \( (\beta = 0) \), this would result in an error in the line-center continuum estimate of around 3%.

Typically, this would be considered "good enough."

The same is not true for the FUV filter set available on HST/SBC. Due to the limited choice of filters available, for the F122M+F140LP on- and offline combination, the pivot wavelengths are separated by \( \Delta \lambda / \lambda \sim 0.2 \) which would result in errors of \( \gtrsim 30 \% \) if the same misguided assumption of the continuum slope were made. Errors in line-center continuum estimation of this magnitude could translate into severe errors in continuum subtraction of Lyα since the online bandpass is so broad: if the line does not dominate, then the continuum-subtracted pixel could quite feasibly get the wrong sign (emission could be seen as absorption and vice versa). For a dust-free starburst the slope of the FUV continuum is largely constant \( \beta \sim -2.6 \) over the first few tens Myr, but flattens quite rapidly \( (\beta \) increases \) thereafter, particularly at higher metallicities (Leitherer et al. 1999). Since the UV slope is also a strong function of the dust reddening \( (E_{B-V}) \), it is not possible to reliably predict \( \beta \) globally, let alone how it varies on \( \sim 10 \) pc scales (i.e., pixel-to-pixel, at SBC sampling). One possible alternative would be to sample the blue and red sides of the online filter but there are no filters available for such an observation and spectroscopic observations with the STIS have shown that the continuum on the blue side of Lyα is frequently unpredictable, contaminated by internal or Galactic absorption features. Flux at Lyα due to continuum processes must be estimated from observations on the red side of Lyα only.

The next step would be to take an additional offline observation redward of the offline filter (e.g., ACS/SBC/F150LP or F165LP, WFPC2/F218W, ACS/HRC/F220W, or WFC3/UVIS/F225W) and extrapolate a power-law continuum to the online filter. This way CTN would be computed for a given spectral slope by convolving the throughput profiles with the measured power law, resulting in a different CTN in each pixel. However, this method was demonstrated to result in significant errors in the continuum flux estimation when relatively moderate amounts of dust are present (Hayes et al. 2005; Hayes & Östlin 2006) since typical dust reddening modifies the FUV continuum in such a way that it becomes inconsistent with the power-law approximation. Furthermore, such a method provides no estimate of stellar Lyα absorption which is significant in all but very hottest stars.

Naively, these points could be argued away: only the very youngest star-forming regions produce enough ionizing photons to generate significant Lyα (Charlot & Fall 1993) over which times \( \beta \) is essentially constant. High-resolution imaging studies have, however, demonstrated that in the ISM of active starbursts, particularly surrounding massive young clusters, the nebular emission can be clearly displaced from the ionizing sources (e.g., Maíz-Apellániz et al. 2004). This is most likely due to stellar winds and supernova feedback clearing bubbles in the ISM and is clearly visible in some cases in our sample, well exemplified by ESO 338-IG04 (Östlin et al. 2009). The case is further complicated for Lyα by its resonant nature. As a result of multiple scatterings in H I, Lyα photons diffuse away from their production sites and are likely emitted from a site of last scattering that is not coincident with the nebulae where they were produced (Hayes et al. 2005, 2007; Östlin et al. 2009). ESO 338-IG04 (Hayes et al. 2005) shows a large diffuse emission component which dominates the total Lyα luminosity. High-resolution imaging frequently reveals that starbursts are composed of numerous compact young knots and clusters that dominate the luminosity but do not account for a large fraction of the surface area (Meurer et al. 1995), particularly at UV wavelengths. It is therefore rather likely that the continuum that needs to be subtracted will not be representative of a region young enough to produce Lyα, which can emerge superimposed upon regions that appear too dusty for Lyα to be transmitted (Hayes et al. 2007).

Figure 2 demonstrates inadequacy of assuming a one-to-one relationship between CTN and \( \beta \). Here, the two quantities are computed for various ages and \( E_{B-V} \) by convolving Starburst99 spectra (Leitherer et al. 1999; Vázquez & Leitherer 2005) with the filter throughput profiles. For this demonstration the Calzetti et al. (1994) attenuation law is adopted which is frequently used to represent dust extinction in starbursts and LBGs. The first example shows our own observing strategy using SBC/F122M for Lyα online, SBC/F140LP for offline, measuring \( \beta \) between F140LP and HRC/F220W. The second example shows how, by adopting the F125LP, F140LP, and F150LP configuration, the degeneracy in CTN versus \( \beta \) is significantly reduced. However, with uncertainties still greater than 40% at certain \( \beta \), it is still not sufficient for the broad online filter. In general, the extinction laws of the Milky Way and Magellanic clouds are found to be steeper than the Calzetti et al. (1994) law at given \( E_{B-V} \) over the wavelength domain covered by our filters and the effect is found to be more severe.

2.2.2. Methods Beyond Pure Observation

CTN is the only important quantity to know for the continuum subtraction but unfortunately, as demonstrated in Section 2.2.1, the quantity cannot be easily estimated without some knowledge of the continuum. A solution is to compute CTN from spectral synthesis models using supplementary data to constrain the model. Thus, one must have sufficient information at hand to build the right stellar population; stellar age and star-formation history, \( E_{B-V} \), metallicity, and the initial mass function (IMF) may all have a significant effect.

In Hayes et al. (2005), we demonstrated that we could reliably continuum subtract \( \lambda \) pixel-by-pixel, in our \( HST \) observations (configuration 1) through multicolor spectral modeling using a number of additional broadband \( HST \) observations. In that study four line-free observations were used, together with the Starburst99 spectral evolutionary models. In age–\( E_{B-V} \) space we showed that we could find nondegenerate solutions for CTN.
by sampling $\beta$ (sensitive to both age and dust) and the Balmer/4000 Å break (sensitive primarily to the age of the stellar population). Grids of multiple color indices and CTN were computed from the models for a range of age and coloration. Grids of multiple color indices and CTN were computed for various ages (1 Myr to 1 Gyr) and $\beta$ (sensitive primarily to the age of the stellar population). Grids of multiple color indices and CTN were computed for F125LP and F220W. CTN is clearly not a monotonic function of $\beta$, especially for bluer colors (e.g., $\beta \sim -1$). Lower: same as upper but for the configuration 2. CTN is generated for F122M/F140LP with $\beta$ measured between F140LP and F150LP. The degeneracy still exists although has been quite significantly improved.

(A color version of this figure is available in the online journal.)

If CTN is sensitive to the Balmer/4000 Å break, then a number of contaminants may affect the CTN determination, depending upon how well the stellar and nebular emission regions are resolved. At the earliest times when the nebular emission is strong, the Balmer edge may contribute by bluening the rest-frame $U - B$ color. On the other hand, at later times the 4000 Å break arises from metal line blanketing in late-type stars, reddening $U - B$. Thus, resolved nebular gas and old stellar populations may both affect the SED in the optical but not the FUV; not affecting CTN itself but its determination optical SED data points be relied upon. Since the relative contribution from stellar populations and nebular gas is unknown, and in high-resolution imaging the regions may be clearly resolved, it may become necessary to account for all these populations in our estimation of the true spectrum, and therefore CTN.

Control over the nebular gas contribution may be obtained through additional observations that directly trace the ionized gas. For given temperature in an optically thin nebula, the emission coefficients ($\alpha_{\nu}$) may be computed for any allowed recombination line, and continuous emission coefficient ($\gamma_{\nu}$) computed for given wavelength. Thus, an appropriately strong and well-behaved line (e.g., H{$\alpha$}) can be used to estimate the nebular continuum contribution in each filter, and subtract it from each data point for a given $E_{B-V}$ (again, the filters have been selected in order to avoid the strongest nebular emission lines). CTN may then be computed by using the SED-fitting method to obtain the stellar-only SED (minimizing $\chi^2$ using Equation (2)) and the reconstruction the composite (stellar + nebular) spectrum.

The current starburst may be superimposed upon any underlying stellar population. Since this is likely to show a significant 4000 Å break but little FUV contribution, it may affect the reliability of CTN determination that relies upon age fitting. Thus, it may be necessary to treat more than one stellar population per pixel. Old stellar populations may dominate the integrated light at red wavelengths and such an observation may facilitate the decomposition of starburst and underlying stellar components. Equation (2) can be modified to include two populations, $a$ and $b$, each with differing normalization as

$$
\chi^2 = \sum_i [C_a \cdot m_{a,i} + C_b \cdot m_{b,i} - d_i]^2 \cdot W_i, \tag{4}
$$

where $m_{a,i}$ and $m_{b,i}$ represent the model SED data points, with $C_a$ and $C_b$ being the normalization factors for each population. For a given set of models $m_a$ and $m_b$, an analytic solution exists for the values of $C_a$ and $C_b$ that provide the best fit, as

$$
C_a = \frac{S_3 S_2 - S_1 S_4}{S_2^2 - S_1 S_4},
$$

$$
C_b = \frac{S_3 - C_a S_1}{S_2}, \tag{5}
$$

where

$$
S_1 = \sum_i m_{a,i}^2 W_i,
$$

$$
S_2 = \sum_i m_{a,i} m_{b,i} W_i,
$$

$$
S_3 = \sum_i m_{a,i} d_i W_i.
$$
The extremely high H\textalpha absorption feature is completely absorbed and it is likely that, at least for the neighboring O stars, and column to even the nearest O stars, absorption, filled in P Cygni, or emission (net equivalent widths of a few Å are expected, Klein & Castor 1978). However, due to the deep Galactic H\textalpha column to even the nearest O stars, the intrinsic Ly\alpha profile is completely absorbed and it is likely these predictions can never be empirically tested. Some B stars however are near enough to be observed at Ly\alpha and NLTE atmosphere models appear to be able to match the observed profile (Ly\alpha absorption equivalent widths of a few Å). Since no observational tests are available, it is not deemed meaningful to pursue this issue further, although it is worth pointing out that the stellar feature is accounted for, within the limits of current understanding.

In the following sections, we assess the relative power of the various methods described above in recovering Ly\alpha observables from our imaging observations. Ideally, we would like to test the various methods of continuum subtraction against real observational data for which the true Ly\alpha fluxes and equivalent widths are known (i.e., spectra). Unfortunately, there are no real object spectra that span the wavelength range between Ly\alpha and 9000 Å with sufficient spectral resolution, taken in constant apertures for us to test the various methods against real data, and we are forced to rely only upon synthetic input sources.

In this study, we present a number of computational tests to assess the performance of various methods. To this end we generate a set of template spectra using various combinations of Starburst99 models (Leitherer et al. 1999; Vázquez & Leitherer 2005), for various stellar populations (or combinations thereof), $E_{B-V}$, and modify them by adding Ly\alpha lines of chosen equivalent width. We then convolve the template spectra with the $HST$ bandpasses to generate synthetic SED data points and feed these into our SED-fitting and continuum subtraction software. Thus, we have full knowledge of the intrinsic spectrum, and we are able to compare our output results directly to the known input values (CTN, $F_{Ly\alpha}$, $W_{Ly\alpha}$), and test the ability of our fitting methods to recover ages and reddening in the stellar population(s).

We simulate noise by randomizing each SED point for a given error and, adopting a Monte Carlo approach, we compute various statistics of the recovered distributions. For the real $HST$ data we employ adaptive binning techniques to obtain a minimum threshold S/N, but the choice of this value requires testing. Therefore, by performing these simulations we are able to test the results obtained against input S/N, and directly test the optimum threshold.

The method of generating the “real” input spectra is outlined in Section 3.1. The various methods of subtracting the continuum are described in Section 3.2, and the actual quantitative tests are described in Section 3.3.
it is reddened using a given extinction law and $EB_s$ spectrum before addition. To complete the rest-frame spectrum, the nebular gas continuum flux density and applied to the gas

Simplicity, the two stellar components are generated from the all contributing different fractions of the stellar components of variable ages, and a single gas component, respectively. The templates thereby consist of two to the starburst at 4500 Å ($\alpha$)

Figure 1. For the optical component of this configuration, For configuration 2 the filter set replaces F122M with F125LP observe redshifted Hα ($\alpha$)

The most important returned values are, of course, $F_{Ly}$ and $W_{Ly}$, although from methods where SED fitting is employed, age(s), normalization factor(s), and $E_{B-V}$ are also returned. Monitoring these returned values in addition to those relating to Ly$\alpha$ permits a deeper examination of the performance of the SED fitting.

We begin by defining a fiducial template spectrum, denoted as $f_{fid}$. This is generated from what is thought to be a typical starburst, capable of producing Ly$\alpha$ with moderate extinction and metallicity and a Salpeter IMF. For the starburst, a single stellar population of age of 5 Myr is selected since ionizing photons are a requirement for the production of Ly$\alpha$. According to the Starburst99 template spectra, the nebular gas contribution

3.1. Input SED Generation

We have previously discussed the fact that SED is likely to be the sum of the contributions from a current episode of star formation (starburst; sb), an underlying component of field stars (fs), and emission from nebular gas (neb). All template input spectra are generated from a combination of these three components, scaled to a given normalization relative to the starburst at 4500 Å ($\sim B$ band); these normalizations are assigned the $n_{fs}$ and $n_{neb}$ for the field stars and nebular components, respectively. The templates thereby consist of two stellar components of variable ages, and a single gas component, all contributing different fractions of the $B$-band luminosity. For simplicity, the two stellar components are generated from the same metallicity and IMF. The H$\alpha$ luminosity is computed from the nebular gas continuum flux density and applied to the gas spectrum before addition. To complete the rest-frame spectrum, it is reddened using a given extinction law and $E_{B-V}$. Finally, the spectrum is redshifted. Further information on the generation of input spectra can be found in Section 3.3 and Table 1.

For each template spectrum, we generate a set of "observed" SED data points by convolving the spectra with the $HST$ filter profiles. For configuration 1 (our current imaging campaign) the complete filter list is: SBC/F122M (Ly$\alpha$ online), SBC/F140LP (∼ 1500 Å continuum), HRC/F220W (∼ 2200 Å continuum), HRC/F330W (∼ $U$ band), WFC/F435W (∼ $B$ band), WFC/F550M (medium $V$ band, serving as line-free continuum filter near H$\alpha$), WFC/FR656N (linear ramp narrowband filter centered upon rest-frame H$\alpha$), and HRC/F814W (∼ $I$ band). For configuration 2 the filter set replaces F122M with F125LP while F140LP remains the FUV continuum filter as shown in Figure 1. For the optical component of this configuration, we sample the UV/optical continuum using WFPC2/F336W, F439W, and F814W, using the fixed narrowband filter F673N to observe redshifted H$\alpha$.

3.2. Continuum Subtraction Methods

For each SED, we apply various methods of estimating and subtracting the continuum and examine how well they return the known rest-frame quantities that were input. We identify five possible methods of estimating CTN and subtracting the continuum at Ly$\alpha$.

**Notes.** Model parameters in the third column constitute the $f_{fid}$ fiducial template spectrum case, with the nonfiducial values for $W_{Ly}$ constituting standard cases of $f_{fid}$ ($w=50$, $f_{fid}$, and $f_{fid}$ 100).

| Parameter | Unit | Fiducial Value | Nonfiducial/Range | Code |
|-----------|------|----------------|--------------------|------|
| $W_{Ly}$ | Å    | 10             | −50, 0, and 100    | [fid, w=10; fid, w=50; fid, w=0; fid, w=100] |
| $E_{B-V}$ | mag  | 0.2            | 0.0 and 0.5        | [eb0, w...; eb05, w...]| |
| Reddening law | | | | [cal, w...]| |
| Starburst age | Myr | 5              | 20 and 100         | [agesb20, w...; agesb100, w...]| |
| Field star age | Myr | 5000           | 200                | [agesf200, w...]| |
| $n_{fs}$ |     | 0.5            | 0 and 5            | [nfs0, w...; nfs5, w...]| |
| $n_{neb}$ |     | 0.05           | 0 and 1            | [nneb0, w...; nneb1, w...]| |
| IMF |     | −2.35          | −1.85 and −2.85    | [imf185, w...; imf185, w...]| |
| Metallicity | Z   | 0.08           | 0.001 and 0.040    | [metsub, w...; metsuper, w...]| |
| Stellar atmosphere | | | | [atm3, w...; atm4, w...]| |
| Redshift | | | | [atm5, w...; atm4, w...]| |

| Parameters for SED Generation |
|--------------------------------|
| **Range** | **Code** |
| 0.01 | [fid, w0; fid, w100] |
| $E_{B-V}$ | mag  | 0.2            | 0.0 and 0.5        | [eb0, w...; eb05, w...]| |
| Reddening law | | | | [cal, w...]| |
| Starburst age | Myr | 5              | 20 and 100         | [agesb20, w...; agesb100, w...]| |
| Field star age | Myr | 5000           | 200                | [agesf200, w...]| |
| $n_{fs}$ |     | 0.5            | 0 and 5            | [nfs0, w...; nfs5, w...]| |
| $n_{neb}$ |     | 0.05           | 0 and 1            | [nneb0, w...; nneb1, w...]| |
| IMF |     | −2.35          | −1.85 and −2.85    | [imf185, w...; imf185, w...]| |
| Metallicity | Z   | 0.08           | 0.001 and 0.040    | [metsub, w...; metsuper, w...]| |
| Stellar atmosphere | | | | [atm3, w...; atm4, w...]| |
| Redshift | | | | [atm5, w...; atm4, w...]| |

Notes. Model parameters in the third column constitute the $f_{fid}$ fiducial template spectrum case, with the nonfiducial values for $W_{Ly}$ constituting standard cases of $f_{fid}$ ($w=50$, $f_{fid}$, and $f_{fid}$ 100).

a Defined relative to starburst population at 4500 Å (i.e., ∼ relative $B$-band luminosity).

b Defined relative to starburst population at 4500 Å. 0.05 corresponds to typical default unresolved nebular fraction at 5 Myr from Starburst99. 0 and 1 correspond therefore to zero nebular contribution and a “boost” by a factor of ∼ 20.

c Designated Starburst99 codes. Atm3 is Lejeune atmospheres for stars with plane-parallel atmospheres and Schmutz atmospheres for stars with strong winds. Atm4 is like Atm3 but with Hillier atmospheres for stars with strong winds. Atm5 is like Atm4 with Pauldrach models for O stars.

**3.1. Input SED Generation**

The most important returned values are, of course, $F_{Ly}$ and $W_{Ly}$, although from methods where SED fitting is employed, age(s), normalization factor(s), and $E_{B-V}$ are also returned. Monitoring these returned values in addition to those relating to Ly$\alpha$ permits a deeper examination of the performance of the SED fitting.

We begin by defining a fiducial template spectrum, denoted as $f_{fid}$. This is generated from what is thought to be a typical starburst, capable of producing Ly$\alpha$ with moderate extinction and metallicity and a Salpeter IMF. For the starburst, a single stellar population of age of 5 Myr is selected since ionizing photons are a requirement for the production of Ly$\alpha$. According to the Starburst99 template spectra, the nebular gas contribution
at 4500 Å ($n_{mb}$, defined relative to the stellar spectrum of an unresolved point source) is $\sim 0.05$ at this age, and this value provides the fiducial $n_{mb}$. For the fiducial model we add a moderate field-star population with age (arbitrarily selected) 5 Gyr, scaled to give a contribution of 50% the starburst luminosity at 4500 Å ($n_{f} = 0.5$). The fiducial reddening for the composite spectrum was selected to be $E_{B-V} = 0.2$ using the SMC law (Prevot et al. 1984). The value of $E_{B-V}$ is an approximate midpoint in the measured extinction for most of our galaxies (see Atek et al. 2008). The choice of law is motivated by the fact that the SMC law appears to provide the best fits to the resolved spectra of blue compact and irregular galaxies (e.g., Mas-Hesse & Kunth 1999). Since $W_{Ly\alpha}$ can essentially take any value between damped absorption and super-recombination values, we add $Ly\alpha$ lines with a range of equivalent widths: $-50$ Å to represent the deep absorption seen in some local objects (e.g., I Zw 18); 0 Å, corresponding to no $Ly\alpha$ feature; 10 Å to approximate the global values measured in some of low-z objects (e.g., Giavalisco et al. 1996); and 100 Å corresponding to high-z $Ly\alpha$-bright galaxies or diffuse emission regions in resolved objects at $z \approx 0.0$. We define a number of modifications to all of the ingredient parameters in the input spectrum which are listed in Table 1.

Firstly, all tests are performed at infinite S/N to test the reliability of the code by insuring all the input parameters are returned.

Observational S/N per resolution element varies significantly with position as a result of natural morphological variation in surface brightness, and band-to-band as morphology differs with wavelength. In our ACS data set we make use of adaptive binning to bin together pixels until a threshold S/N has been met, conserving surface brightness in each conglomerate bin (“spaxel”). Without investigation it is not possible to know what S/N is required in order for the various techniques to become optimal; either converging on the input values or to some systematically offset values. By varying S/N in our simulations, we are able to test this directly. To each data point in the input SED (see Section 3.1), we assign an error, based upon the S/N we want to test. Using this error we then regenerate 1000 SEDs using Gaussian variates and apply all our continuum subtraction methodologies to each one. Performing such Monte Carlo simulations with increasing S/N allows us to investigate the optimum S/N required to return mean values consistent with the those input, or find convergence of the mean to systematically offset observables. For each of the model galaxy SEDs defined in Table 1, we run 1000 Monte Carlo iterations at each S/N with S/N varying between 1 and 50. Important statistics of $F_{Ly\alpha}$ and $W_{Ly\alpha}$, the mean and median, standard deviation, and skewness of the derived distribution are retained.

First, we set S/N to be the same in all bandpasses; if the worst quality band is chosen to generate the binning pattern, S/N in the corresponding bins in other bands should exceed the threshold. However, due to differing morphologies, this is unlikely to be the case in general, and some bins, in some images, may fall short of the desired S/N threshold. We assess the impact of this to the overall fitting by systematically dropping S/N to zero in individual bands for the fiducial SED. This allows us to examine the robustness of returned $Ly\alpha$-related quantities in the case where lower-quality data have been obtained in certain bandpasses. Similar tests are then performed dropping S/N to zero in adjacent pairs of filters simultaneously.

To test the reliability of the methods for a wide array of model galaxies we augment the fiducial SED, one parameter at a time, always running the SED-fitting and continuum subtraction code using the standard Starburst99 parameters and SMC reddening law. Age and reddening, of course, are always the free parameters in the fitting (both age components are fit for method ν). This way we can assess the reliability of our results at different stellar ages, $E_{B-V}$, and with different contributions from the underlying stellar population and nebular gas. The same is also true when we test metallicity, IMF, reddening law, enabling us to test the impact of failing to select the correct values for the fitting. The effect of metallicity is found to be have sufficient impact that additional tests are performed, see Section 4.2.3. The parameter space covered is listed in Table 1. Parameter dependency tests are performed for both observational configurations with a detailed discussion of the results for configuration 1, including the effects of poor S/N in certain filters, presented in Section 4. A summary of the results for configuration 2 is presented in Section 5.

4. RESULTS AND DISCUSSION

4.1. The Fiducial Model

In this subsection, we first present and discuss the results obtained for the fiducial SED with the same S/N in all bandpasses in Section 4.1.1, followed by results where single and adjacent pairs of filters have S/N = 0 in Section 4.1.2.

4.1.1. Equal S/N in All Bands

Figure 4 shows the returned statistics for the fiducial model as a function of S/N. Statistics shown include the mean (upper), standard deviation (center), and skewness (lower). First, these plots demonstrate that simple assumptions about the continuum slope (either $\beta = 0$ (method 1) or $\beta$ extrapolation (method 2)) both result in an overestimate of CTN. Therefore, the continuum is over-subtracted and a 10 Å emission line is seen as an absorption feature with $W_{Ly\alpha} \sim -40$ Å. This is the result of: (a) the large offset in $\lambda$ between the off- and online filters; (b) the fact that the $\sim 100$ Å wide online bandpass is far from line-dominated; and (c) the modest value of $E_{B-V} = 0.2$ is sufficient to reduce the total flux in F122M below that of F140LP. It is clear that a good understanding of the continuum is essential, not only between the filters but across the online bandpass itself, and that spectral modeling of some level of sophistication is a requirement. It should be noted that at S/N = 10 in the individual bandpasses, S/N in the continuum-subtracted $Ly\alpha$ distribution is only around 0.5, although obviously this improves with increasing $W_{Ly\alpha}$ as the line starts to dominate. For the $f_{id} \leq 100$ case, S/N = 4 is seen in the returned $Ly\alpha$ flux distribution for S/N = 10 in all filters. Of the three SED-fitting methods, technique ν slightly outperforms in and iv, thanks to its inclusion of treatment of the underlying stellar population and nebular gas, even though they are only minor contributors to the FUV flux for the $f_{id}$ SED. It should also be noted that all the continuum subtraction methods show a positive skew in the $W_{Ly\alpha}$ distribution, even at S/N > 30. This is due to fact that W is a ratio, and that the inverse of a Gaussian distribution always shows positive skewness—this should be present in all equivalent width estimates, irrespective of data set or observational methodology (for a discussion see Dawson et al. 2004; Hu et al. 2004; Hayes & ¨Ostlin 2006).

An estimate of the age of the stellar population also provides, in part, the solution to another potential problem, that of the unknown underlying stellar absorption at $Ly\alpha$. While still poorly tested, $Ly\alpha$ features in the models still provide the best estimate
The upper panel of Figure 5 shows the effect of removing a single filter from the fitting routine for the \texttt{fid_w10} SED. Naturally, only the three continuum subtraction methods that employ SED fitting are shown. We now show the mean $W_{\text{Ly}\alpha}$ obtained with the filter removed, normalized by that obtained with all filters included, with the same S/N in all included bandpasses. This normalized distribution has clearly been shown to converge in flux at S/N \( \approx 5 \) (Figure 4). The results are noisier than those shown previously for two reasons: first because the fits are intrinsically noisier due to one fewer data point being present, and secondly because of added noise from the normalization. The example shown illustrates the removal of the F220W filter, although results are largely indistinguishable when other single filters are removed. This is because we have a maximum of five model parameters to fit and in the case where a single filter is removed, we still have sufficient data points remaining to avoid a degeneracy. Provided we obtain the minimum S/N threshold of 10 as shown in Section 4.1.1 in five of our six continuum bandpasses, we can feel safe about the recovery of Ly\( \alpha \) fluxes.

The situation changes, however, when two filters are removed from the fit as can be seen in the lower panel of Figure 5. This plot shows the same as the upper panel when the two UV filters (F220W and F330W) are assigned S/N = 0. The two single stellar component fitting methods (iii and iv) now consistently overestimate $W_{\text{Ly}\alpha}$ by around 20\% at S/N \( \sim 10 \) which actually becomes worse as S/N increases in the other filters. This is due to more consistent selection of the wrong stellar parameters by the code and the example has been selected to show poorly recovered observables; the loss of both UV filters is the most detrimental. Without either F220W or F330W, we have no sampling of the FUV continuum slope or the Balmer/4000 Å break, essentially resulting in the recovery of any ages and $E_{B-V}$. Clearly maintaining S/N \( \sim 5 \) sampling of the Balmer break is preferable to obtaining extremely high S/N observations in other bandpasses; as discussed in Wiklind et al. (2008) the Balmer break is instrumental in resolving the
degeneracy between age and reddening. We cannot conclude that methods iii and iv outperform v in this case but we can be quite certain that we need to reach the threshold S/N in five of our six continuum bandpasses in order for any of the SED-fitting methods to yield robust results. Four filters are not deemed to be sufficient for method v.

4.2. Parameter Dependencies

We now assess the impact of modifying the various parameters that go into the construction of a composite galaxy spectra. The fiducial parameters are always used internally for the fitting (third column in Table 1), fitting only ages and $E_B-V$.

4.2.1. Stellar Ages and Dust reddening

Table 1 shows the various parameter modifications made to the fid galaxy template for starburst age, field star age, and $E_B-V$. For the SED-fitting methods (iii, iv, and v) results are found not to be significantly discrepant from those presented for the fiducial case. In fact, aside from details in the noise, the flux and equivalent width plots are indistinguishable from those in Figure 4. This is not the case for methods i and ii which vary wildly with starburst age and $E_B-V$. Naturally, the behavior of the modeling methods is to be expected since age and $E_B-V$ are our primary fitting parameters and the effect of dust can be well controlled in the event that the chosen extinction law well describes the intrinsic deviation from the dust-free starburst.

Exchanging the SMC extinction law for the attenuation law of Calzetti et al. (1994) is more detrimental: these two curves are not near equivalent over the wavelength domain we are sampling. For the cal_w10 case, techniques iii and iv result in convergent $W_{\text{Ly} \alpha}$ estimates of 75 and 112 Å, respectively, while method v converges at $W_{\text{Ly} \alpha} = 20$ Å by S/N = 10 (still an overestimate by a factor of 2). For strong emission (cal_w100), method v overestimates $W_{\text{Ly} \alpha}$ by just 10% at S/N = 10 while iii and iv still consistently fail by a factor of 2. However, clearly an accurate model of the internal extinction law in the target galaxy is a key parameter in the method.

Several solutions to this exist. First, the reddening law itself could be incorporated as a free parameter, only increasing computation time by a factor of a few. Including individual extinction laws (e.g., SMC, LMC, or Galactic curves) in the SED fitting is physically rather poorly motivated and a better alternative may be to base the choice of law on observation. For example FUV spectroscopy of the objects could indicate the presence or absence of a 2175 Å graphite feature to motivate the choice of curves (see Puget & Leger 1989 and the discussion in Mas-Hesse & Kunth 1999).

4.2.2. Nebular Gas and Underlying Stellar Population

Figure 6 shows the average returned $W_{\text{Ly} \alpha}$ as a function of S/N when the nebular gas component contributes equally with the starburst at 4500 Å (nneb1_w10; left), and when the underlying population contributes five times that of the starburst (nneb5_w10; right). The left plot demonstrates how a single component fit (iii) breaks down in the nneb1_w10 model when the nebular gas component is dominating the SED (i.e., regions where wind-blown H II shells or filamentary structure are resolved). Method iii converges with a returned $W_{\text{Ly} \alpha}$ of around 40 Å in this case, and a similar arithmetic (+30 Å) overestimate for all the input equivalent widths. This demonstrates the need for an independent measure of the nebular gas spectrum as methods iv and v well recover $W_{\text{Ly} \alpha}$.

The right plot shows the necessity to also control the underlying stellar population when fitting stellar ages. The ordinate axis does not show methods iii or iv which both converge at $W_{\text{Ly} \alpha} \sim 200$ Å. This corresponds to an overestimate of an order of magnitude, with overestimates seen for all input $W_{\text{Ly} \alpha}$. Notably, $W_{\text{Ly} \alpha}$ converges at around 400 Å in the nneb5_w100 case and almost +100 Å in the nneb5_w-50 case using methods iii and iv.

4.2.3. Metallicity

Two additional metallicities were initially tested: the minimum subsolar value ($Z = 0.001$; metsub) and maximum supersolar value ($Z = 0.040$; metsuper). The upper panel of Figure 7 shows the returned values of $W_{\text{Ly} \alpha}$ for the models with modified metallicities metsub_w10 and metsuper_w10, again normalized by the returned values for the fid_w10 model as...
described for Figure 5. Interestingly, while one represents a decrease in metallicity and one an increase, both modifications have a similar impact on the resulting observables: the continuum flux in the online filter is consistently underestimated. The underestimate is around 5% in both cases but, for the weak emission cases this is enough to cause overestimates of $S/N$ as poor fits are consistently found. However, the two-component stellar fit method always recovers a mean $W_{\text{Ly} \alpha}$ that scatters around the 1-line. This results from the fact that IMF and star-formation history both alter the current stellar mass distribution: fitting two components appears to mimic the effect of a singly modified IMF.

4.2.5. Stellar Atmosphere

Changing the UV stellar atmosphere model makes no appreciable difference to any of the methodologies. All SED-fitting methods appear to return $W_{\text{Ly} \alpha}$ consistently around the desired value and results are indistinguishable from those presented in Figure 4. While testing one stellar atmosphere model against another in this manner may not be greatly meaningful, it is at least reassuring that the choice of atmosphere does not impact upon the recovered values. The stellar atmosphere models differ quite significantly in their ionizing output and in the detail of line features. However, the ionizing output only affects the nebular fluxes which are treated independently, and the discrete line features have only a minor impact upon integrated colors, even in the FUV.

5. FUTURE STUDIES AND POSSIBLE FURTHER IMPROVEMENTS

So far we have only discussed simulations relating to the data sets we have already obtained, targeting the lowest redshifts possible. However, this redshift severely limits the number of potential target galaxies, and any future Ly$\alpha$ imaging studies will require larger volumes, especially in order to target the more luminous analogues of high-$z$ star-forming galaxies. Beyond $z \approx 0.03$ the optimal choice of filters changes, and can be performed using ACS/SBC and adjacent pairs of long-pass filters. Here, we present some simulations for such a study. We also discuss some methodological alternatives using augmented data sets.

5.1. A Potential Local Ly$\alpha$ Imaging Study with HST

As discussed in Section 2.1 and illustrated in Figure 1, we adopt here the combination of F125LP/F140LP, restricting us to the broad redshift range of 0.028–0.09, although any adjacent pair of long-pass filters can be used. With the current inactive status of ACS CCD channels and uncertain future of WFC3, we opt for bandpasses available on WFPC2 to cover the optical domain, although this setup could easily be ported to configurations on both these cameras. Filters chosen for the continuum and H$\alpha$ observations are listed in Section 3.1. It is also worth noting that with this configuration, we have no medium-band line-free filter near H$\alpha$ and the continuum subtraction of H$\alpha$ must rely on interpolation between F439W and F814W. Simulations presented here adopt the redshift $z = 0.029$ so as to shift Ly$\alpha$ into the online bandpass without shifting H$\alpha$ out of F673N.

Figure 8 shows some example results from simulations using configuration 2. They are the same results as shown for
configuration 1 in Figure 6. These figures show the recovered 
Lyα equivalent width from the nebular-gas-dominated and field-
star-dominated templates, and are highly resemblant of those
presented for configuration 1. Configuration 2 has the slight
advantage over 1 of using two filters with near-identical red
wings, which isolates a well defined online bandpass shifted
slightly nearer to the pivotal wavelength of the continuum
measurement. However, configuration 2 does still suffer from
the same drawback of a wide online bandpass and, for S/N = 10
in all bands, S/N in the continuum subtraction is still around
0.5 for the fid_w10 model, the same as configuration 1
(Section 4.1.1).

Configuration 2 does include two fewer continuum filters than
1, which was previously shown (Section 4.1.2 and Figure 5)
to be inadequate: the lower panel shows how W_{Lyα} is very
poorly recovered when the NUV and U-band filters are removed.
This was designed to exemplify the poor recovery of Lyα
observables and this case was especially bad due to the loss
of both UV filters, and no sampling of the FUV slope or
Balmer/4000 Å break. The inclusion of both F220W and
F330W for configuration 1 is likely to include some level of
redundancy. The continuum filters of configuration 2 are ideally
placed and the most important spectral features remain well
sampled: F140LP+F336W samples β, F336W+F439W samples
the Balmer/4000 Å break, and F439W+F814W simultaneously
allows for the continuum subtraction of Hβ and the constraint
of the field star population. In light of these results and those
presented in Section 4.1.2, we determine this to be the absolute
minimum requirement in SED coverage.

5.2. Stellar and Nebular Extinction

One area in the methodology that could be identified as a
weakness is the treatment of reddening: we treat stellar (E_{B−V,∗})
and interstellar extinction (E_{B−V,IS}) in the same, possible sub-
optimal, way: by locking them together. E_{B−V,∗} and E_{B−V,IS}
are known to differ quite substantially in some cases, with
derived values of E_{B−V,∗} lower than E_{B−V,IS} (Fanelli et al.
1988; Calzetti et al. 1994). This seems to be a geometric effect
due to winds from massive stars expelling the ionized ISM and
dust, reducing the extinction derived from the stellar UV slope
and concentrating the dust in the H II shells and filamentary
structures (Maiz-Apellaniz et al. 1998). Mas-Hesse & Kunth
(1999) found that the discrepancy grew with increasing age
over timescales consistent with stellar evolution and supernova
enrichment. It is frequently the case that we can resolve nebular
structure down to the resolution limit, although we will can
never know the geometry along the line of sight. How the dust
in front of stars and in ionized regions combine depends upon
the unresolved ISM geometry and it may, in such cases, be
preferable to treat nebular and stellar reddenings independently
in the method.

Decoupling could be achieved simply in the fitting procedure,
by introducing E_{B−V,IS} as an extra fitting dimension that applies
only to the nebular SED, allowing both values of E_{B−V,∗} to vary independently. However, the number of SED data points
is not sufficient for the inclusion of an extra degree of freedom,
and currently we deem this too computationally expensive to
include in the fitting algorithm when we have \gtrsim 10^6 pixels
per image. While an empirical relationship has been presented
between the two quantities by Calzetti et al. (2000): E_{B−V,∗} =
(0.44 ± 0.033) E_{B−V,IS}, it was derived for a sample of galaxies
observed with much poorer resolution and, in individual HST
pixels, the spread between the quantities is likely to be so large
that the two quantities are completely decoupled. Alternatively,
E_{B−V,IS} may be measured directly by using an emission line
decrement. Typically the Balmer decrement Hα/Hβ would be
used where Hβ could also be obtained from HST using linear
ramp or selected narrowband filters. A further possibility would
be to use a NIR emission line (e.g., Paα or Brγ) observed from
the ground using a large adaptive optics imager. Indeed,
an independent evaluation of the nebular reddening is precisely
what is required for an appropriate astrophysical comparison
with Lyα. A direct measurement of the interstellar reddening
would permit us to lock E_{B−V,IS} on the nebular gas component
and fit E_{B−V,∗} to the stellar continuum. To this end, we are
in the process of observing a subset of our current sample in the
Brγ line. Such methods will be tested in a forthcoming study.

Ultimately, however, the continuum we need to estimate and
subtract is predominantly stellar, and it may simply be that
treatment of reddening on the stellar continuum is all that is

Figure 8. Example results using observing configuration 2. Input W_{Lyα} is 10 Å. Left: nebular emission-dominated region (nneb1_w10). Again, methods i and u converge well below the lower limit of the ordinate. Right: region dominated by and old stellar population (ntw5_w10). Methods iv and rv converge above the upper
limit of the ordinate. All continuum subtraction methods are shown and color-coded as in Figure 6.
(A color version of this figure is available in the online journal.)
required. Further dedicated tests will be presented when the data have been acquired and processed.

6. CONCLUSIONS AND SUMMARY

Using synthetic spectra of starburst galaxies we have examined various methods of producing continuum-subtracted line-only Lyα images using currently available imaging modes on the HST. We have assessed and compared various methods of continuum subtraction that vary in their complexity and attention paid to possible behavior of the continuum. We have presented examples covering a wide array of starburst parameters for continuum subtraction that vary in their complexity and attention as follows.

1. Making simple assumptions about the shape of the far ultraviolet continuum slope ($\beta$; e.g., assuming its slope or extrapolating the slope from observations on the red side only) leads to estimates of the Lyα flux and equivalent width that are seriously discrepant with the true values. Some spectral fitting is shown to be essential, even for the most basic cases.

2. In our methodology we fit only the age of the stellar population and the dust reddening, requiring at least data points on the SED that sample the UV continuum slope and Balmer/4000 Å discontinuity. All other parameters (extinction law, metallicity, IMF, etc.) take assumed values; we then investigate the systematic effects incurred when these quantities differ from their true values.

3. We need to bin together pixels until S/N of between 5 and 10 has been obtained.

4. Age determinations may be contaminated by boosted nebular gas emission or an underlying stellar population. These can be accounted for by constraining the nebular gas contribution using an estimate based upon the Hα emission flux, and contribution from old stars by fitting multiple stellar components, respectively. This requires a data point redward of Hα, both for the continuum subtraction of Hα and an estimate of the contribution from field stars. We have determined the I band to be functional.

5. The IMF is shown not to be a necessary parameter to include in the fitting process and results are largely unchanged when nonstandard IMFs are tested. Metallicity has a much more significant impact upon the recovery of the Lyα flux, since it changes the rate of stellar evolution and reddens stellar continua. This requires an independent determination of the metallicity. The choice of stellar atmosphere model has no discernible impact upon the recovered Lyα observables.

6. If the metallicity and reddening law are known quantities and S/N = 5 has been obtained in all bandpasses, no significant systematic effects are seen in our continuum-subtracted fluxes or equivalent widths. Increasing S/N to 10 is shown to significantly reduce the scatter. For input $W_{1350} = 10$ Å, we are able to recover Lyα fluxes accurate to within 30% of the true value for all tested parameter space. This improves to better than 10% for stronger Lyα emission with $W_{1350} = 100$ Å.

7. We have also presented simulations for a very similar study that uses adjacent combinations of SBC long-pass filters to isolate Lyα. Due to the near-identical red wings, this could naively be thought to mitigate many of the issues surrounding continuum subtraction. However, due to the broad nature of the bandpass, we still determine a similar level of care to be necessary in the method.

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