An unresolved question in galaxy evolution is whether the star formation histories (SFHs) of low-mass systems are preferentially dominated by starbursts or modes that are more quiescent and continuous. Here, we quantify the prevalence of global starbursts in dwarf galaxies at the present epoch and infer their characteristic durations and amplitudes. The analysis is based on the Hα component of the 11 Mpc Hα UV Galaxy Survey (11HUGS), which provides Hα and Galaxy Evolution Explorer UV imaging for an approximately volume-limited sample of ∼300 star-forming galaxies within 11 Mpc. We first examine the completeness properties of the sample, and then directly tally the number of bursting dwarfs and compute the fraction of star formation that is concentrated in such systems. To identify starbursting dwarfs, we use an integrated Hα equivalent width (EW) threshold of 100 Å, which corresponds to a stellar birthrate of ∼2.5, and also explore the use of empirical starburst definitions based on σ thresholds of the observed logarithmic EW distributions. Our results are robust to the exact choice of the threshold, and are consistent with a picture where dwarfs that are currently experiencing massive global bursts are just the ∼6% tip of a low-mass galaxy iceberg. Moreover, bursts are only responsible for about a quarter of the total star formation in the overall dwarf population, so the majority of stars in low-mass systems are not formed in this mode today. Spirals and irregulars devoid of Hα emission are rare, indicating that the complete cessation of star formation generally does not occur in such galaxies and is not characteristic of the interburst state, at least for the more luminous systems with $M_B < -15$. The starburst statistics presented here directly constrain the duty cycle and the average burst amplitude under the simplest assumptions where all dwarf irregulars share a common SFH and undergo similar burst cycles with equal probability. Uncertainties in such assumptions are discussed in the context of previous work.

**Key words:** galaxies: dwarf – galaxies: evolution – galaxies: starburst – galaxies: statistics – stars: formation

**Online-only material:** color figures

### 1. INTRODUCTION

Do cycles of violent, intense, but short-lived global bursts constitute the dominant mode of star formation in low-mass galaxies? This question was originally raised over 30 years ago, in connection with the discoveries of dwarf galaxies that resemble “isolated extragalactic HII regions” (Sargent & Searle 1970). These systems, now commonly referred to as the blue compact dwarfs (BCDs) or HII galaxies, were first identified in Zwickw’s (1964, 1966) catalogs of “compact” and “eruptive” galaxies and in Markarian’s (1967, 1969a, 1969b) survey for objects with large ultraviolet excesses. Star formation histories (SFHs) punctuated by strong “flashes” were then eventually proposed as the most likely solution to the puzzle presented by the anomalously blue colors and low gas-phase metal abundances observed in the lowest luminosity members of these samples (Searle & Sargent 1972; Searle et al. 1973; Huchra 1977b).

Since then, the study of starbursts in dwarf galaxies has significantly grown due to the gradual recognition that these events may have a profound impact on systems with shallow potential wells. For example, starburst episodes have been invoked, although with much ensuing debate, as an agent that transforms gas-rich dwarf irregulars into gas-poor dwarf ellipticals through gas consumption and expulsion (e.g., Vader 1986; Dekel & Silk 1986; Skillman & Bender 1995; Papaderos et al. 1996; Marlowe et al. 1999; van Zee 2001; Gil de Paz & Madore 2005). The stellar winds and supernovae produced by starbursts are argued to drive metal-enriched winds, which may escape the halos of low-mass galaxies and pollute the intergalactic medium (IGM; e.g., Marlowe et al. 1995; Mac Low & Ferrara 1999; Martin 1999; Garnett 2002). Starbursts, therefore, are also implicated in the possibly related phenomenon of the observed decrease of the effective yield and metallicity with decreasing luminosity (e.g., Skillman et al. 1989; Richer & McCall 1995; Lee et al. 2004), rotational velocity (Garnett 2002), and stellar mass (Tremonti et al. 2004; H. Lee et al. 2006). Finally, bursty behavior in dwarf galaxies is a key feature of numerical models, which attempt to reasonably incorporate the effects of supernova feedback (e.g., Pelupessy et al. 2004; Stinson et al. 2007).

Open questions of fundamental importance to all these issues deal with the prevalence of starbursts in dwarfs. We must ask the following questions. What are the characteristic durations, frequencies, and amplitudes of the starburst cycles, which determine their efficacy as critical sinks of fuel and impulsive sources of disruptive energy? What is the mass fraction of stars formed during the burst phases? How do these parameters vary over cosmic time? Moreover, are all low-mass galaxies equally prone to bursting episodes, or rather does the starburst mode only operate in a particular subset of the population?
In order to fully answer these questions, we would require a statistically complete sample of dwarf galaxies that span the total range of star formation activities, from those systems that are presently undergoing a starburst event to those that are in a period of relative quiescence. SFHs would be needed for each of the galaxies in this sample, and the temporal sampling of the SFHs must be fine enough to resolve a burst cycle. The typical modes of global star formation can then be characterized. If violent fluctuations in the star formation rate (SFR) are evident for only a limited subset of galaxies, then one can search for commonalities in the physical properties among those objects that may distinguish them from nonbursting systems.

The trouble is that we typically cannot follow the SFHs of individual systems back through cosmic time. The exception is for the galaxies in and around the Local Group. The stellar populations of these systems can be resolved and observed to sufficient depth such that color–magnitude diagrams (CMDs) can be used to reconstruct detailed SFHs. The aggregate of such studies for dwarf irregulars has shown that some have had only modest fluctuations in their SFRs (e.g., Tosi et al. 1991; Greggio et al. 1993; Marconi et al. 1995; Aparicio et al. 1997a, 1997b; Gallagher et al. 1998; Dalcanton et al. 2007; Weisz et al. 2008). The next generation of extremely large 30 m class telescopes should enable the construction of an appropriate sample. In fact, the difficulty of assembling a robust sample is what has primarily impeded significant progress from being made on this issue since the initial work of Searle & Sargent (1972).

Our particular strategy has been to focus on our nearest neighbors and take an approximately volume-limited (and hence dwarf-dominated) star formation inventory of galaxies within 11 Mpc of the Milky Way. The 11 Mpc Hα UV Galaxy Survey (11HUGS) has obtained narrowband Hα emission-line imaging and is also collecting Galaxy Evolution Explorer (GALEX) UV imaging for all known spirals and irregular galaxies, as well as star-forming early-type galaxies with $d < 11$ Mpc, $|b| > 20^\circ$, and $B < 15$ mag. Here, we use data from the completed Hα component of the parent survey (Kennicutt et al. 2008), which provides tracers of the SFRs and birthrates (ratio of the present to past average SFR) over the past few million years, to calculate the dwarf galaxy starburst statistics described above.

We begin by giving an overview of the 11HUGS program and describing the Hα flux and equivalent width (EW) data set in Section 2. The completeness properties of the sample with respect to blue absolute magnitude and Hα mass are examined. In Section 3, we devise a criterion for quantitatively distinguishing starbursts from more normal systems and then apply the criterion to calculate the number and star formation fractions of dwarf starburst galaxies. We note that in this analysis we are mainly interested in identifying global (galaxy-wide) starbursts that occur in low-mass systems and do not address the highly localized, circumnuclear starbursts observed in more massive galaxies (Kennicutt 1998; Kormendy & Kennicutt 2004 and references therein). In Section 4, our statistics are compared with previous work, and we discuss the implications for the average duty cycle, burst amplitudes, and interburst state. We conclude with a summary of our results in Section 5. $H_\alpha = 75$ km s$^{-1}$ Mpc$^{-1}$ is adopted for calculating distance-dependent quantities when more direct distance measurements (e.g., based on standard candles) are not available.

2. THE 11HUGS DATASET

The goal of 11HUGS is to fill a vital niche in existing multi-wavelength surveys of present-day galaxies with a statistically complete sample of dwarf galaxies that span the total range of star formation activities, from those systems that are presently undergoing a starburst event to those that are in a period of relative quiescence. SFHs would be needed for each of the galaxies in this sample, and the temporal sampling of the SFHs must be fine enough to resolve a burst cycle. The typical modes of global star formation can then be characterized. If violent fluctuations in the star formation rate (SFR) are evident for only a limited subset of galaxies, then one can search for commonalities in the physical properties among those objects that may distinguish them from nonbursting systems.

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robust, approximately volume-complete study of our nearest star-forming neighbors. The data set consists of snapshots of massive star formation as captured via narrowband Hα imaging (recombination emission of gas ionized by O and early-type B stars), as well as GALEX NUV (1500 Å) and FUV (2300 Å) imaging (photospheric emission from O and B stars), which traces star formation over a longer (∼10^8 yr) timescale. Thus, 11HUGS provides a foundation for follow-up resolved studies of the H ii region populations, star formation, chemical abundances, and ISM properties of local galaxies. The scientific scope of 11HUGS is being further expanded with the recent addition of Spitzer mid-infrared and far-infrared imaging through the Local Volume Legacy (LVL) collaboration8 (Lee et al. 2008; D. A. Dale et al. 2009, in preparation). The Spitzer data will provide crucial information on the dust properties and old stellar population content of the sample. Public data releases of our multiwavelength imaging have begun through the NASA/IPAC Infrared Science Archive9 (IRSA), with expected completion of data product deliveries by the end of 2009.

The analysis in this paper is based on the completed Hα imaging component of the survey. Kennicutt et al. (2008; hereafter Paper I) present the resulting integrated Hα flux and EW parent catalog, along with details on the sample selection, observations, and photometry. In this section, we first give a summary of this data set and then examine the completeness limits of the sample.

Our local volume sample is primarily a compilation of all currently known spiral and irregular galaxies within a distance of 11 Mpc, outside of the plane of the Milky Way (|b| > 20°), and brighter than ∼15 B magnitudes (N = 261). These limits define the ranges over which the existing catalogs from which the sample is derived (e.g., the Nearby Galaxies Catalog; Tully 1988a) are relatively complete (e.g., Tully 1998b). Through a combination of new narrowband Hα + [N ii] and R-band imaging for 184 of these galaxies, and data compiled from the literature for another 54, integrated Hα + [N ii] fluxes and EWs are available for 91% of this sample. The galaxies that remain without Hα data are generally southern objects with distances and brightnesses near the sample limits (see Figure 4 in Paper I, and Figure 1(b) below). These galaxies drifted into the sample during revisions (occurring after our primary observational campaigns were completed), which incorporated updated distance estimates and photometry. This is an inherent difficulty associated with efforts to construct a volume-limited sample. The membership of the sample will be necessarily fluid until accurate distance and photometric measurements are available for all of the galaxies that are within the volume and around its periphery. As observing time allowed, Hα data were also taken for another 123 galaxies within the 11 Mpc volume, which were fainter and/or in the zone of avoidance. Data from the literature are available for 52 such other objects. The sum of all these galaxies (N = 436) comprises the overall data set published in Paper I. The work presented below, as well as the follow-on 11HUGS and Spitzer LVL surveys, generally focuses on the subsets of the Paper I sample that avoid the Galactic plane.

2.1. Completeness

Ultimately, the 11HUGS sample is a composite of numerous catalogs with diverse selection criteria. For details on the construction of the sample, the reader is referred to Lee (2006) and Paper I. Here, we estimate the completeness limits of our sample by performing a statistical test described in Rauzy (2001), which is similar to the well known V/Vmax test (Schmidt 1968), but does not require the galaxy distribution to be spatially homogeneous. We also qualitatively compare our number density distributions with independently established B-band luminosity and H1 mass functions.

2.1.1. The Rauzy TC Completeness Statistic

The Rauzy (2001) TC completeness statistic is analogous to the V/Vmax test (Schmidt 1968), but does not rely on assumptions about the spatial homogeneity of the sample. The method is based on the estimation of the uniform variate \( \zeta \), which is a ratio of number densities. Specifically, if \( F(M) \) is the normalized integral of the luminosity function (LF) from \(-\infty\) to \( M \), and \( Z \) is the distance modulus \( m - M \), then

\[
\zeta \equiv \frac{F(M)}{F[M_{\text{lim}}(Z)]},
\]

where \( M_{\text{lim}}(Z) \) is the faintest absolute magnitude that a galaxy at a given \( Z \) can have and still be visible, given a limiting magnitude \( m_{\text{lim}} \).

An estimate of \( \zeta \) is given by

\[
\zeta_i \sim \frac{r_i}{n_i + 1},
\]

where \( r_i \) is the number of galaxies with \( M \leq M_i \) and \( Z \leq Z_i \), and \( n_i \) is the number of galaxies with \( M \leq M_{\text{lim}} \) and \( Z \leq Z_i \). If \( M \) and \( Z \) are uncorrelated, as should be the case for a complete local sample of galaxies, the expectation value of \( \zeta \) is 0.5. The variance is given by

\[
V_i = \frac{1}{12} \frac{n_i - 1}{n_i + 1}.
\]

The \( T_C \) completeness statistic is then computed as

\[
T_C = \frac{\sum_{i=1}^{N_{\text{gal}}} (\zeta_i - 0.5)}{\sqrt{\sum_{i=1}^{N_{\text{gal}}} V_i}}.
\]

The test is preformed by computing \( T_C \) for subsamples truncated at increasing apparent magnitude limits. For complete samples, the values of \( T_C \) will follow a Gaussian distribution, with an expectation value of 0 and variance of order unity. Systematically decreasing negative values of \( T_C \) indicate that the sample becomes incomplete. We use the \( T_C \) statistic to determine the completeness for our main survey volume outside of the zone of avoidance (|b| > 20°) as functions of the B-band brightness, 21 cm (H1) flux, and the Hα+[N ii] flux (Figures 1(a), 2(a), and 3(a)).

By construction, the 11HUGS primary sample has been limited at \( B \sim 15 \) to avoid the severe incompleteness that is known to set in at fainter magnitudes in the original surveys that have provided the bulk of our knowledge about the local volume galaxy population (e.g., Tully 1988b). To select the sample, we primarily used the NASA Extragalactic Database (NED), with initial cuts based on the Local Group corrected recessional velocity and the “indicative optical magnitudes” provided in NED’s “Basic Data” service. Direct distance estimates from the literature and information on group membership were then

8 http://www.ast.cam.ac.uk/ioA/research/lvls
9 http://ssc.spitzer.caltech.edu/legacy/lvlhistory.html
The photometry compilation was refined by adopting measurements from the following large, homogeneous catalogs in the following order of preference: (1) $B_T$ from the collection of dwarf galaxy observations obtained by van Zee and collaborators (van Zee 2000; van Zee et al. 1996, 1997) and Binggeli and collaborators (Barazza et al. 2001; Bremnes et al. 1998, 2000; Parodi et al. 2002); (2) $B_T$ from the RC3 (de Vaucouleurs et al. 1991) as reported on NED; and (3) $B_T$ as compiled and reduced to the RC3 system from HyperLeda. For 31 galaxies, measurements are not available from one of these sources. In these cases, the literature was searched and a $B$ magnitude was taken from smaller data sets of published photometry. As a last resort, the “indicative optical magnitude” given by NED was adopted in seven cases. The resulting collection of data is given in Table 1 of Paper I, and is used to calculate $T_C$ as a function of $B$. Corrections for Galactic extinction, but not internal extinction, are applied. The results are plotted in Figure 1(a). $T_C$ drops precipitously below zero for $B > 15.6$. This limit of $B = 15.6$ for the 11HUGS main survey volume corresponds to a completeness in $M_B = -14.6$ at 11 Mpc. In Figure 1(b), a plot of $M_B$ with the distance is also shown to illustrate the depth of the sample.

We also check the completeness of the 11HUGS sample with respect to the H1 gas mass. To do this, we have compiled 21 cm single-dish fluxes from the literature. Measurements are available for 96% of the galaxies in the overall 11HUGS target catalog. The data are primarily taken from the following sources, in the following order of preference: the digital archive of Springob et al. (2005; $N = 112$), the H1 Parkes All Sky Survey (HIPASS) catalog as published in Meyer et al. (2004; $N = 75$), and the homogenized H1 compilation of Paturel et al. (2003) as made available through the Hyperleda database ($N = 215$). Finally, data for 16 galaxies are taken from the H1 compilation in the Catalog of Neighboring Galaxies of Karachentsev et al. (2004) and other individual papers.

We evaluate $T_C$ as a function of the H1 flux and plot the results in Figure 2(a). Here, the $T_C$ statistic begins to become systematically negative at integrated fluxes less than 6 Jy km s$^{-1}$. To find the corresponding completeness in the H1 mass, we apply the standard relation $M_{\text{H}1}[M_{\odot}] = 2.36 \times 10^2 F$, where $D$ is the distance in Mpc and $F$ is the 21 cm line flux in Jy km s$^{-1}$. The gas is assumed to be optically thin, and corrections for the presumably small amount of H1 self-absorption ($\lesssim 10$%; Haynes & Giovanelli 1984; Zwaan et al. 2003) are not applied. The H1 mass is plotted against the distance in Figure 2(b). At the edge of the 11 Mpc target volume, a limit of 6 Jy km s$^{-1}$ corresponds to a completeness in $M_{\text{H}1}$ down to $2 \times 10^8 M_{\odot}$.

Finally, we also compute $T_C$ as a function of the H$\alpha$+[N II] flux and show the results in Figure 3(a). At fluxes below $4 \times 10^{-14}$ erg s$^{-1}$ cm$^{-2}$, $T_C$ becomes systematically negative. This corresponds to a completeness of $L$(H$\alpha$) = $6 \times 10^{-8}$ erg s$^{-1}$ at 11 Mpc. To translate this into a limiting SFR, two issues must be kept in mind. Most standard conversion recipes (e.g., Kennicutt 1998, which results in an SFR of 0.005 $M_{\odot}$ yr$^{-1}$) are based on expectations for a solar metallicity population, so using this conversion for metal-poor dwarf galaxies would result in an overestimate of the SFR—a relative deficiency of metals should cause a greater number of ionizing photons to be produced per unit stellar mass formed (e.g., Lee et al. 2002). We compute a calibration that is based on a $Z_{\odot}/5$ population using the Bruzual & Charlot (2003) stellar population synthesis models, assuming Case B recombination and no leakage of Lyman continuum photons from the galaxy. Relative to a solar metallicity conversion derived from the same models, SFR/L(H$\alpha$) is a factor of $\sim 0.7$ lower for the $Z_{\odot}/5$ population. This SFR scale is shown on the right-hand side of Figure 3(b). Another issue is that stochasticity in the formation of high-mass ionizing stars may begin to become important for the ultra-low SFRs in this regime. However, note that a simple calculation, treating the initial mass function (IMF) as a probability distribution function (e.g., Oey & Clarke 2005), shows that such sampling issues become important only at SFRs less than $\sim 10^{-4}$—a constant SFR of 0.0002 $M_{\odot}$ yr$^{-1}$ over timescales greater than 10 Myr will yield roughly 10 O stars.
Figure 1. Plots illustrating the completeness of the sample of galaxies within the 11HUGS main survey volume ($|b| > 20^\circ$, $d < 11$ Mpc). (a) The Rauzy $T_c$ statistic as a function of the $B$-band apparent magnitude corrected for Galactic extinction. Systematically negative values of $T_c$ indicate that the sample is becoming incomplete. (b) The $B$-band absolute magnitude as a function of distance. Nondetections and galaxies without Hα measurements are marked as shown in the figure. (c) Comparison of 11HUGS luminosity densities (black) with LFs based on samples with similar morphological make-up from the literature. The dashed portions of the literature LFs represent extrapolations past the last available data point. 11HUGS luminosity densities renormalized to match the literature LFs are shown in gray. The right axis indicates the number of galaxies in the 11HUGS sample. The sample is complete to $B = 15.6$ or $M_B = -14.6$ at 11 Mpc.

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

Figure 2. Same as Figure 1, but for the 21 cm flux and $H_1$ gas mass. The sample is complete to 6 Jy km s$^{-1}$ or for $M_{HI} > 2 \times 10^8 M_\odot$ within our main survey volume ($|b| > 20^\circ$, $d < 11$ Mpc).

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

at any given time, for a Salpeter IMF and mass limits of 0.1 and 1 $M_\odot$.

2.1.2. Luminosity and Mass Function Comparisons

Another way of examining the completeness of the sample is to compare the 11HUGS number density distributions to luminosity and mass functions that are based on surveys which
Figure 3. Same as Figure 1, but for the H$\alpha$+[N ii] flux and luminosity. The sample is complete to $4 \times 10^{-14}$ ergs s$^{-1}$ cm$^{-2}$ or for $L(H\alpha+[N\text{ii}]) > 6 \times 10^{38}$ ergs s$^{-1}$ within our main survey volume ($|b| > 20^\circ$, $d < 11$ Mpc). No comparable local H$\alpha$ LFs are available to provide secondary checks of completeness at the faint end. (A color version of this figure is available in the online journal.)

have well determined selection functions (Figures 1(c) and 2(c)). Although we do not expect the densities computed from our small main survey volume ($|b| > 20^\circ$, $d < 11$ Mpc) to robustly reflect averages taken over much larger patches of the present-day universe (11HUGS poorly samples massive/luminous galaxies while other surveys suffer from large incompleteness corrections in the dwarf galaxy regime), a qualitative comparison of the relative shapes of the distributions still provides an interesting cross-check against the $T_C$ limits computed above.

In Figure 1(c), we plot the Schechter function fits to LFs from two independent data sets that have morphological make-ups which should be similar to the 11HUGS sample. The blue curve is based on the $B$-band follow-up of the Arecibo $\text{H}_1$ Strip Survey (AHISS; Zwaan et al. 2001), an optically blind survey for galaxies selected on 21 cm emission alone. The red curve is based on spiral and irregular galaxies in the Second Southern Sky Redshift Survey (SSRS2; da Costa et al. 1998; Marzke et al. 1998), which has based its sample on the STScI Guide Star Catalog (Lasker et al. 1990). The SSRS2 LF shown is a composite of two separate Schechter function fits to the spiral and irregular populations. Clearly, the SSRS2 and AHISS LFs are quite different in their determinations for the densities of dwarf galaxies. Each of the functions is constrained by fewer than $\sim 30$ galaxies for $M_B \gtrsim -15.5$. This difference emphasizes the uncertainties and illustrates the probable ranges of such measurements for low luminosity populations. The SSRS2 exhibits a much steeper rise at the faint end, with a slope of $-1.8$, while the slope of the AHISS LF is much flatter at $-1.0$.

The black curve in Figure 1(c) shows the number densities of 11HUGS galaxies in our main survey volume where no internal extinction corrections to the absolute magnitudes have been applied. The densities based on the 11HUGS sample are systematically higher by a factor of $\sim 2$. This is likely due to cosmic variance. Since (1) the characteristic correlation length, the scale on which the density of galaxies exceeds the average by a factor of 2, has been well measured to be $r_c = 5h^{-1}$ Mpc, (2) the power-law slope of the function $\xi = (r_c/r)'^\gamma$, which parameterizes the excess probability over random of finding two galaxies separated by a distance $r$, has also been established to be 1.8 (Longair 1998 and references therein), and (3) the local volume is not centered on a large void, it is not surprising that the densities we compute are higher relative to those based on surveys which average over much larger volumes. Karachentsev et al. (2004) have also found that the integrated luminosity volume density of galaxies within 8 Mpc (based on their Catalog of Neighboring Galaxies) is larger by factors of $\sim 2$ than other global measurements.

To compare the relative shapes at the faint end, the 11HUGS distribution is shifted down by a factor of 2.3 to force approximate agreement near the knee of the LFs (gray dotted curve). The 11HUGS distributions are not flat at the faint end and show increasing densities for dwarfs that are more consistent with the SSRS2 LF (blue) than the AHISS LF (red). However, the densities do not continue to rise and abruptly drop for $M_B > -14.5$. This is consistent with the conclusion based on the $T_C$ statistic that 11HUGS is complete throughout its main survey volume to $B = -15.6$.

In Figure 2(c), we also compare the 11HUGS number densities as a function of the $\text{H}_1$ mass with $\text{H}_1$ mass functions (HIMFs) based on the optically blind searches of the Arecibo Dual Beam Survey (ADBS; Rosenberg & Schneider 2002; blue curve) and HIPASS (Zwaan et al. 2005; red curve). The Schechter fits for these samples are plotted along with the number densities of the 11HUGS galaxies (black curve). Here, there is a milder discrepancy between the absolute normalizations. The gray dotted curves show the 11HUGS...
distribution shifted down by a factor of 1.4. Again, Karachentsev et al. (2004) have also found that the integrated H I volume density within 8 Mpc is greater by this same factor relative to the HIPASS Bright Galaxy Catalog (Zwaan et al. 2003). The renormalized 11HUGS distribution agrees well with the HIPASS HIMF for \( \log(M_{\text{HI}}) > 8.4 \) and then systematically drops below it at lower masses. This is consistent with the \( T_C \) statistic result that 11HUGS is complete to \( M_{\text{HI}} = 2 \times 10^8 M_{\odot} \). If the renormalized 11HUGS distribution is instead compared with the steeper ADBS HIMF, the relative fall-off of our sample begins at a significantly higher \( \log(M_{\text{HI}}) \) of \( \approx 9 \). However, this is more likely a reflection of the dependence of the HIMF on environment rather than incompleteness. Zwaan et al. (2005) have shown evidence that the HIMF becomes steeper from the field toward higher density regions with \( -1.2 > \alpha > -1.5 \), and the ADBS sample has large contributions from both the Virgo Cluster and the Pisces–Perseus Supercluster.

As for performing this same exercise with our H \( \alpha \) luminosity number densities, there is no local H \( \alpha \) LF that can be used as a fiducial for comparison since the ones that are available have been based on objective-prism surveys and are highly incomplete for galaxies with modest-to-low H \( \alpha \) EWs (see discussion in Paper I). Here, we simply plot the 11HUGS \( L(\alpha) \) number densities in Figure 3(c). The distribution sharply falls off below \( 6 \times 10^{38} \text{ erg s}^{-1} \), which is the limiting luminosity determined from the \( T_C \) statistic.

3. STARBURST STATISTICS

3.1. What is a Starburst?

The goal of this paper is to directly tally the number of currently bursting dwarf galaxies in an approximately volume-limited sample and to compute the fraction of star formation that is concentrated in such systems. These statistics help provide constraints on the average amplitudes and durations of starburst episodes. To proceed, however, we require criteria that distinguish bursting galaxies from the rest of the population. This is a nontrivial issue, and many different (and sometimes subjective) criteria have been previously applied (e.g., see overviews given in the proceedings of the 2004 Cambridge Starbursts Conference by Gallagher 2005, Heckman 2005, and Kennicutt et al. 2005). To some extent, this variation has been driven by the type of data that are available to gauge the star formation state of the systems under consideration. For example, while perhaps the most physically fundamental approach is to define starbursts as those galaxies that form stars near the maximum possible rate set by causality (i.e., the rate that results when all of the gas in a system is consumed in one dynamical time; Heckman 2005), measurements of the total gas masses and global velocity dispersions that are required to compute the limiting SFRs may not be available, particularly for large samples. An alternate approach, which is less absolute but can be reasonably applied to present-day galaxies, is to develop a characterization of normal star formation activity based on the overall population of galaxies, and then to identify starbursts as the subset of galaxies that form stars at an anomalously prodigious rate with respect to this fiducial (e.g., Gallagher 2005; Kennicutt et al. 2005, and references therein). We follow such strategies here.

One frequently used definition of a starburst is a galaxy whose current SFR exceeds its average past value by a factor of 2–3 (e.g., Hunter & Gallagher 1986; Salzer 1989; Gallagher 2005; Brinchmann et al. 2004; Kennicutt et al. 2005). The ratio of the current SFR to the past average is commonly referred to as the stellar birthrate (i.e., the \( b \) parameter) and can be observationally traced by the integrated, galaxy-wide H \( \alpha \) EW (i.e., the H \( \alpha \) flux divided by the continuum flux density under the line). The integrated EW is thus also related to the specific SFR, the current SFR normalized by the total mass of stars. Using the model grids computed in Kennicutt et al. (1994), and updated in Lee (2006) by using the population synthesis code of Bruzual & Charlot (2003), an approximate mapping between \( b \) and EW may be constructed. Assuming a Kennicutt IMF (\( \Gamma = -1.5 \); Kennicutt 1983), Case B recombination, no leakage of Lyman continuum photons from the galaxy, and no internal extinction, galaxies with \( b > 2–3 \) should have \( \text{EW}(\text{H} \alpha) \geq 80–110 \) Å. Thus, one way of operationally identifying starbursts is by using such thresholds in the H \( \alpha \) EW.

Given the close relationship between the EW and \( b \), it is interesting to study the EW distribution of the galaxies in our sample and ask whether EW values of \( \sim 80–110 \) Å coincide with any particular features of the distribution. In Lee et al. (2007), we initially examined trends in the \( M_B–\text{EW} \) plane by using the measurements given in Table 2, Paper I, and showed that local star-forming galaxies trace a continuous sequence in EW as well as in the morphological type. The sequence exhibits two characteristic transitions. At \( M_B \sim -15 \), a narrowing of the galaxy locus occurs as the luminosities increase and morphologies shift from predominantly irregular to late-type spiral (termed the “main sequence of star-forming galaxies” by Noeske et al. 2007). Above \( M_B \sim -19 \), the high luminosity end of the sequence turns off toward lower EWs and becomes mostly populated by intermediate and early-type bulge-prominent spirals. In the current analysis, we focus on the low-luminosity galaxies below the upper transition at \( M_B \sim -19 \) and divide the galaxies into three equal sized bins: two in the narrow EW “waist” (\( -19 \leq M_B < -17 \) and \( -17 \leq M_B < -15 \)) and one containing the most extreme dwarf galaxies, which lie below the lower transition where the EW distribution broadens (\( -15 \leq M_B < -13 \)). Histograms of the logarithmic EW in these three bins are shown in Figure 4. A histogram of the higher luminosity galaxies (\( -22 \leq M_B < -19 \)) is also provided for completeness.

To characterize the distributions plotted in Figure 4, we first checked whether simple Gaussian functions with means and standard deviations directly computed from the logarithmic EWs in a given luminosity bin would yield an adequate description of the data. The gray dashed curves plotted in each panel represent these functions. For galaxies with \( -19 \leq M_B < -17 \), the gray curve provides a good fit, but for the lower luminosity galaxies (bottom panels), the curves appear somewhat too broad; this is due to the outliers appearing at the tails of the distributions. Thus, to attempt to place more weight on the central components of the distributions, Gaussian fits to the histograms minimizing \( \chi^2 \) were also performed. This second set of Gaussian functions is overplotted in yellow, and appears to provide an improved fit to the majority of the data with \( -17 \leq M_B < -15 \) and \( -15 \leq M_B < -13 \). This suggests that one way to describe the distribution of EWs is as a log-normal function with non-Gaussian excesses at the tails. In order to check this, we performed Anderson–Darling (A–D) tests for normality (Anderson & Darling 1952) on both the complete set of logarithmic EWs in each luminosity bin and the sets that were clipped at \( 3\sigma \), where \( \sigma \) was provided by the fits to the histograms (see Table 1). The A–D statistic is similar to the Kolmogorov–Smirnov (K–S) statistic in that
Figure 4. Logarithmic $\text{H}\alpha + [\text{N} \text{II}]$ EW frequency distributions for galaxies in the 11HUGS main survey volume (black histograms). The gray dashed curves represent Gaussian functions with means and standard deviations directly computed from the logarithmic EWs in a given luminosity bin, while the best-fit ($\chi^2$ minimized) Gaussian functions to the histograms are shown in yellow. The integrated EWs of local galaxies can be characterized by log-normal distributions, but with excess at the tails. For galaxies with $-19 < M_B < -15$, the correspondence of the upper 3σ point of the yellow curves to birthrate parameter values around the starburst threshold ($b \sim 3$) suggests that dwarf galaxies currently undergoing global starbursts may be identified as the outliers at the high EW end.

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

Figure 5. (a) Cumulative $\text{H}\alpha + [\text{N} \text{II}]$ EW frequency distributions for galaxies in the 11HUGS main survey volume. The smooth curves show the cumulative distributions of the best-fit Gaussian functions plotted in yellow in Figure 4. For starbursts defined as objects with EW greater than 100 Å ($b \gtrsim 2.5$), the number fraction is $6.4^{+4.2}_{-2.8}$.

(b) The cumulative distribution of $L(\text{H}\alpha + [\text{N} \text{II}])$ as a function of EW($\text{H}\alpha + [\text{N} \text{II}]$). About a quarter of the overall star formation in dwarf galaxies occurs in the starburst mode.

(A color version of this figure is available in the online journal.)
it examines differences between two cumulative distribution functions to determine if one sample is consistent with being drawn from the other (the null hypothesis). On the other hand, whereas the K–S test is most sensitive near the median values of the distribution and does not perform as well at detecting statistically significant deviations at the ends of distributions, the A–D test is “stabilized” by accounting for the variance of the distribution and does not perform as well at detecting where the K–S test is most sensitive near the median values. Applying the A–D test to our data, we find that the logarithmic EWs for galaxies with $-19 < M_B < -17$ are consistent with a Gaussian function insofar as the null hypothesis cannot be rejected. As would be expected from the consistency of the gray and yellow curves, clipping removes no galaxies from the sample in this bin. However, for the subsets of EWs in the $-17 < M_B < -15$ and $-15 < M_B < -13$ bins, the A–D test rejects the null hypothesis at the 99% and 90% levels, respectively. However, after these subsets are clipped at 3$\sigma$, the null hypothesis can no longer be rejected with any confidence. We note that clipping with different thresholds (e.g., 2$\sigma$, 4$\sigma$) yields distributions that also violate the assumption of normality. Thus, this exercise provides some support that the central components of the EW distributions can be adequately represented by log-normal distributions (as described by the yellow curves in Figure 4), although, of course, it by no means proves that the underlying lognormal distributions are Gaussian.

What is interesting about this characterization of the EW distributions is the coincidence between their upper 3$\sigma$ points and the frequently adopted starburst birthrate thresholds discussed above. In the two luminosity bins that are bounded by the EW transitions ($-19 < M_B < -17$, $-17 < M_B < -15$; note that the sample, as discussed in Section 2, is complete within this regime), the means and dispersions of the yellow Gaussian curves (Table 1) are essentially the same. Here, the EW values of $\sim 80–110$ Å, which correspond to starburst-like birthrates of 2–3, occur where the distributions drop steeply, and the upper value of this range is close to the upper 3$\sigma$ points of the curves (107 Å and 105 Å for $-19 < M_B < -17$ and $-17 < M_B < -15$, respectively). Although our sample is not large enough to cleanly define the 3$\sigma$ ranges, the correspondence suggests that for a complete sample of field galaxies with $-19 < M_B < -15$, the upper 3$\sigma$ point of the central component of the logarithmic EW distribution may provide one empirical criterion for identifying dwarf galaxies currently undergoing global starbursts, at least in the local universe. Such a definition will not nominally predetermine the starburst number fraction to be 0.135% (the $\sigma$ probability for a normal distribution) since it appears that a sufficiently populated distribution should show significant non-Gaussian excesses at the tails, as has already been discussed. These excesses are also illustrated in Figure 5(a) where the observed logarithmic EW cumulative number distributions are compared with those of the best-fit Gaussians. We speculate that the low EW outliers are postburst galaxies.

In the analysis that follows, we compute starburst number and star formation fractions for a range of EW thresholds, which roughly span stellar birthrates of 2–3, using both fixed EW values and those determined by $\sigma$ limits (Table 1). In the interest of clarity in the discussion, however, we will primarily adopt results based on an intermediate EW cut of 100 Å, which maps...
in the formation of high-mass ionizing stars may affect the interpretation of Hα luminosity as an SFR indicator. As noted at the end of Section 2.1.1, such effects may become important for SFR \( \lesssim 10^{-3} \, M_\odot \, yr^{-1} \), but as shown in Figure 6, galaxies with \( M_B = -15 \) generally have an average SFR of 0.01 \( M_\odot \, yr^{-1} \). Therefore, the subsequent discussion will be based on the statistics from this bin. Within this luminosity range, systems with EW > 100 Å are rare—there are only six galaxies with EWs this high, and this represents 6% of the population. (A listing of these starbursting dwarf galaxies along with some basic properties is given in Table 2, and images are shown in Figure 7.) The dominant component of the uncertainty in the starburst number fraction is likely due to Poisson noise, so we quote the primary result as 6 \( \pm 4 \)%.

All the uncertainties given here and below span the 68% confidence interval as tabulated in Feldman & Cousins (1998). Again, it is important to note that the shape of the distribution ensures that this result is not critically dependent on the exact EW threshold that is adopted, for those values that map to \( b \sim 2 \text{–} 3 \). If the threshold is dropped down to 80 Å, the results do not change since there are no galaxies between 80 Å and 100 Å within this luminosity range in the sample. If the 3σ point of 105 Å is instead used, the results remain the same as well. Finally, if the threshold is dropped down to 2σ above the mean (EW = 71 Å), the number count increases to seven systems (8%).

For the higher luminosity galaxies (\( -19 \leq M_B < -15 \)), the tails of the EW distribution do not show excesses and there are no global starbursts based on a EW \( \gtrsim 100 \, \text{Å} \). This can partly be attributed to small number statistics, since there are \( \sim 35 \)% fewer galaxies in this bin as compared with the \( -17 \leq M_B < -15 \) bin. If we assume that the starburst number fraction is also 6% here, then there should be \( 4^\pm 2 \) galaxies with EW > 100 Å for a sample of 59, so it is reasonable that no galaxies with such high EWs are observed. A Poisson upper limit for the observation of zero events may also be computed, which yields a fraction of \( \lesssim 2 \% \) in this luminosity regime. If an EW > 80 Å threshold is instead applied, the fraction is 2% \( (N = 1) \). Dropping further to the upper 2σ point (EW = 71 Å), the fraction becomes 3% \( (N = 2) \). Comparison of these numbers with those computed for the \( -17 \leq M_B < -15 \) bin shows that it is possible that the starburst number fraction decreases for more massive systems.

If we again apply a threshold value of 100 Å to the most extreme dwarfs (for \( -15 \leq M_B < -13 \)), the starburst number fraction is 5% \( (N = 5) \). However, the situation is more complicated for this lowest luminosity bin. First, as discussed in Section 2, the completeness steeply drops at \( M_B = -14.6 \), so statistics reported for this population must be interpreted with caution. However, it is likely that starburst mass and star formation fractions computed in this bin represent upper limits

10 Exactly when IMF sampling issues begin to become relevant is an issue of current debate (e.g., Weidner & Kroupa 2006; Elmegreen 2006). Depending on additional assumptions about the cluster mass function, and the relative order in which high- and low-mass stars form in individual molecular gas clouds, it is claimed that Hα could underestimate the SFR by factors \( \gtrsim 20 \) beginning at \( L_{H\alpha} \sim 10^{39} \) (Pflamm-Altenburg et al. 2007). Further analysis with the 11HUGS GALEX UV data will be important in constraining these effects since the UV emission probes star formation over a timescale that is 10 times longer than Hα (due to its sensitivity to relatively lower mass B stars), and is less prone to statistical high-mass star formation “flickering.” A comparative analysis of the 11HUGS Hα and FUV SFRs (J. C. Lee et al. 2009, in preparation), as well as independent simulations that probe the impact of Poisson noise on both the UV and Hα emission (C. A. Tremonti et al. 2009, in preparation), is underway. Preliminary results from both studies (Lee et al. 2007; Tremonti et al. 2007) confirm that SFRs \( \gtrsim 0.001 \, M_\odot \, yr^{-1} \) should be relatively robust to at least these simple stochastic effects.
since the low surface brightness dwarfs are more likely to be missing from the sample than the higher surface brightness starbursting systems. Second, the EW starburst criterion changes because the distribution widens in this regime, so the $3\sigma$ threshold is higher than for the more luminous dwarfs. This may be partly due to stochastic sampling of the upper part of the IMF as discussed above and/or burstier star formation in the lowest mass systems. If the $2\sigma$ and $3\sigma$ values of this bin are instead used (i.e., 115 Å and 242 Å), the number fractions are 5% and 3%, respectively.

Finally, the results from all three bins (for EW > 100 Å) may be compared. Beginning with the most luminous bin, the starburst number fractions are $\lesssim 2\%$, 6$^{\pm5}\%$, and 5$^{\pm3}\%$, respectively. The local starburst number fraction may thus only be a weak function of luminosity.

3.3. The Fraction of Star Formation Occurring in Starbursting Dwarfs

Arguably, however, a more important statistic is the fraction of star formation that occurs in starburst episodes. If the star formation fraction is high, this could be evidence that the burst mode dominates the evolution of dwarfs, even if the number fraction is low. This statistic is also more robustly measured, as it is relatively immune to incompleteness in the less active galaxies that are most likely to be missed, as such systems would not add considerably to the H$\alpha$ volume density.

To estimate the star formation fraction, we sum the observed H$\alpha$+[N II] luminosities ($L_{H\alpha}$+[N II]) as a function of the EW. Again, applying corrections for internal extinction and the contribution of the [N II] lines to the observed flux as described in Paper I does not significantly impact the results.\(^\text{11}\) The percentages of $L_{H\alpha}$+[N II] contained in galaxies with EW > 100 Å ($b \sim 2.5$), EW > 80 Å ($b \sim 2$), as well as above and below the $1\sigma$, $2\sigma$, and $3\sigma$ ranges of the EW are reported in Table 1, and the cumulative $L_{H\alpha}$+[N II] distributions as functions of the EW are plotted in Figure 5(b).

For galaxies with $-17 \leq M_B < -15$, the six systems with EW > 100 Å are responsible for 23% of all of the star formation occurring in this luminosity bin. A simple translation of the Poisson error in the number fraction results in an error of $\sim 10\%$ in the $L_a$ fraction. From Figure 5(b), it can be seen that the starburst system that has the largest SFR contributes $\sim 10\%$ (NGC 3125), so our simple estimation of the error appears to be reasonable. This quantity is also not highly sensitive to the exact EW value used to classify starbursts. A lower EW > 80 Å cut or a slightly higher $3\sigma$ point of 107 Å does not change the result, while applying a lower $2\sigma$ threshold only causes a small increase of the fraction to $25^{\pm16}\%$.

For $-19 < M_B < -17$, no systems are observed with EW > 100 Å as described in the previous section. However, the two galaxies with EWs higher than the $2\sigma$ threshold of 71 Å produce 9% of the H$\alpha$ luminosity, this is consistent with the ratio of seven galaxies with $-17 < M_B < -15$ and EW > 71 Å producing 25% of the H$\alpha$ luminosity in that bin. Therefore, estimating that each starburst galaxy is on average responsible for $\sim 4\%$ of the total star formation occurring in the population, we infer that the fraction of star formation due to EW > 100 Å galaxies in this luminosity range must be less than $\sim 5\%$. Application of an EW > 80 Å cut yields a star formation fraction of 4%, and a further drop to the $2\sigma$ point results in 9%.

Finally, the fraction of star formation occurring in the lowest luminosity starbursts is computed, keeping in mind the caveats on incompleteness and stochasticity in the formation of ionizing stars that affect the sample in this bin. Systems exceeding EWs of 100 Å are responsible for 16% of the star formation. Dropping the cut to an EW of 80 Å results in a small increase of the starburst star formation fraction to 20%. If the $\sigma$ thresholds defined by the broader EW distribution for $-15 < M_B < -13$ are instead used, galaxies with EW greater than 115 Å ($2\sigma$) and 242 Å ($3\sigma$) are responsible for 16% and 13% of the star formation, respectively.

From these calculations, it is clear that a significant amount of the overall star formation in present-day dwarf galaxies takes place in starbursts. However, the results also clearly show that a more continuous, steady state of star formation dominates in the present epoch, both in terms of being the mode that operates during the vast majority of the time and in which most of the stars are being created. The average burst amplitude does not appear to strongly vary with luminosity, with 4% of the total star formation density in a given luminosity bin being concentrated in individual starbursting systems.

4. DISCUSSION

4.1. Comparison with Previous Work

Based on the 11HUGS sample, 61$^{\pm4}\%$ of late-type dwarf galaxies are starbursting and 23$^{\pm3}\%$ of the overall star formation in dwarfs occurs in the starburst mode. The numbers are quoted from the luminosity bin where the sample is both complete and has tolerable number statistics (for $-17 < M_B < -15$), but the flanking bins (for $-19 < M_B < -17$ and $-15 < M_B < -13$) do appear to have fractions that are consistent within the Poisson errors. In this section, we compare these results with previous estimates.

With respect to the starburst number fraction, there is good consistency between our result and previous estimates, which is notable because the studies cover a range of independent approaches to the problem and use different starburst selection criteria. Early work compared the space densities of low-luminosity UV-selected Markarian galaxies with those of field galaxies (Sargent 1972; Huchra 1977a) in order to constrain the fraction of “flashing” systems. These studies produced tentative estimates of 7% at $M_p = -17$ and 10% at $M_p = -14$, based on very small samples containing about a dozen objects each and large incompleteness corrections. Later, Salzer (1989) also examined the space densities of active galaxies, using the University of Michigan [O III] L$\alpha$007 emission-line selected survey. The comparison set of normal galaxies was derived from the magnitude-selected Catalog of Galaxies and Clusters of Galaxies (Zwicky 1961–1968) and the UGC (Nilson 1973). The number statistics of the Salzer (1989) samples were improved relative to the earlier Markarian studies, with $N \sim 40$ and $N \sim 30$ in the emission-line selected and general population samples, respectively. Using the numbers reported there, we calculate that the low-luminosity Michigan emission-line galaxies ($-17 < M_B < -15$) represent $\sim 10\%$ of the general population in that luminosity range.

Kauffmann et al. (2003a, 2003b) have used an entirely different method to calculate the fraction of bursty galaxies

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\(^{11}\) Dust corrections for individual objects in the sample may also be computed by using the Spitzer MIPS imaging data that are being obtained by the LVL Survey (see Section 2). Consistency between burst statistics incorporating such corrections and those reported here should be checked in future work, particularly for the higher luminosity dwarfs ($M_B \lesssim -17$).
as a function of stellar mass in the Sloan Digital Sky Survey (SDSS). In this work, an extensive grid of stellar population synthesis models, spanning a range of metallicities and SFHs, is constructed. A Bayesian technique is then used to compare the observed and modeled Hδ absorption and 4000 Å break to generate a likelihood distribution of the fraction of stellar mass formed in bursts for each galaxy in their sample. Two statistics are reported: (1) “$F_{\text{burst}}(50\%) > 0$,” the fraction of galaxies whose likelihood distribution of burst masses has median values greater than zero, and (2) “$F_{\text{burst}}(2.5\%) > 0$,” the fraction of “high confidence bursty galaxies” whose likelihood distributions have their lower 2.5 percentile point above zero.

For galaxies with $8.0 < \log M_\star < 8.5$ (which corresponds to $-16 \lesssim M_B \lesssim -14.5$ assuming an approximate $M/L_B = 1$), which is typical for dIrr galaxies; e.g. Miller & Hodge 1994; Lee 2006), Kauffmann et al. found that the fraction of galaxies with $F_{\text{burst}}(50\%) > 0$ is over 50%, while that for $F_{\text{burst}}(2.5\%) > 0$ is 9%. For higher mass dwarfs with $8.5 < \log M_\star < 9.0$ ($-17 \lesssim M_B \lesssim -16$), the values instead are 36% and 4%, respectively. Clearly, the number fractions estimated using $F_{\text{burst}}(50\%) > 0$ to discriminate whether a galaxy has undergone a burst in the recent past are too large to be consistent with any of the other estimates discussed above. This is perhaps not too surprising since half of the models that are consistent with the observations for the $F_{\text{burst}}(50\%) > 0$ galaxies have SFHs in which there have not been any bursts at all, and the burst number fractions computed in this way are probably overestimates. However, the fractions of “high confidence bursty galaxies” are in good agreement with the other measurements. Thus, it appears that the starburst number fraction for dwarf galaxies with $M_B \gtrsim -15$ is well determined and, moreover, relatively robust to the method used to pick out starbursts. Past estimates consistently lie between 4% and 10%, and our 11HUGS measurement of $6^{+4}_{-2}\%$ is representative of these values.

Kauffmann et al. (2003a, 2003b) have also reported a decrease of the burst number fractions with increasing stellar mass. When their $F_{\text{burst}}(50\%) > 0$ criterion is used to identify galaxies with recent bursts, the number fraction of starbursts drops from 54% at $\sim 10^8 M_\odot$ to 12% at $\sim 10^{10} M_\odot$. However, when the analysis is restricted to the “high confidence bursty galaxies,” the absolute decline is much smaller, changing from 9% to 1%. The latter result is more consistent with our finding that the number fraction is $\lesssim 10\%$ over 7 mag in $M_B$.

As for the fraction of star formation that takes place in bursting systems, there appear to be few prior studies that have attempted to place constraints on this quantity for dwarf galaxies per se. Based on the SDSS, Brinchmann et al. (2004) have found that starbursts (which they define as galaxies with $b \geq 2–3$) are
responsible for 20% of the local star formation density. Although this is consistent with our 11HUGS estimate of $23^{+14}_{-9}$% for dwarf galaxies, the Brinchmann measurement refers to the total galaxy population.

As another check on the starburst star formation fraction, we perform a coarse calculation using the KPGO International Spectroscopic Survey (KISS; Salzer et al. 2000), a second-generation CCD-based, emission-line selected, objective-prism survey. We use the sample of Hα-selected galaxies cataloged in List 1 (Salzer et al. 2001), which contains 1128 candidates identified from the objective-prism images. Follow-up slit spectroscopy has been completed for all of these candidates and 907 of them are classified as star-forming galaxies based on their [O III]/Hβ, 5007/Hδ and [N II]/λ6584/Hα line ratios. Completeness of the sample has been assessed through the standard $V/V_{\text{max}}$ test (Schmidt 1968), and limiting volumes have been calculated for each object (J. J. Salzer 2006, private communication; also see Lee et al. 2002). We use these volumes to calculate SFR densities as a function of the Hα EW. The Hα fluxes and EWs that are measured from the objective-prism spectra are used in this calculation, since they are less likely to suffer from aperture effects and will be closer to the integrated values than those measured from the slit spectra. For $-17 < \log M_B < -15$ (N = 61), we find that KISS galaxies with $EW > 100$ Å ($N = 21$) and $EW > 70$ Å ($N = 34$) are responsible for 22% and 38% of the total $L_{H\alpha}$ output in this bin. We can also compute the starburst number fractions comparing the number densities of high EW KISS galaxies with those from a sample that better represents the overall population of dIrrs. Using the B-band LF determined by Zwaan et al. (2001), which is based on the H I selected sample from the Arecibo H I Strip Survey (AHISS; Zwaan et al. 1997) to provide the denominator of the fraction, we find that galaxies with $EW > 100$ Å comprise 5% of the dwarf population, while it is 12% for the lower threshold of $EW > 70$ Å. These results, which are based on better number statistics for the high EW galaxies, are in good agreement with the fractions estimated from 11HUGS and elsewhere.

4.2. Constraints on the Dwarf Galaxy Starburst Duty Cycle and Associated Uncertainties

Our star formation census within 11 Mpc robustly shows that dwarfs that are currently experiencing massive global bursts (as identified as galaxies with integrated Hα EWs exceeding 100 Å) are just the $\sim 6$% tip of a low-mass galaxy iceberg, and that the bulk ($\sim 70$%) of star formation in the overall population takes place in a more continuous mode. To make more detailed inferences regarding the characteristic values of burst parameters, some assumptions must be made. The starburst number and star formation fractions of a volume-limited galaxy sample provide constraints on the duty cycle since the relative number of galaxies observed in various phases of the cycle will scale with the relative durations of those phases. The statistics can be interpreted most directly in the simplest scenario where (1) there are only two phases, an “on” (burst) phase and an “off” (quiescent) phase, and (2) the objects share a common average SFH such that bursts can occur with equal probability in all galaxies on which the statistic is based. Under such “equal probability” assumptions, the fraction of star formation due to starbursts is equivalent to the fraction of stellar mass formed in the burst mode, the starburst number fraction is equivalent to the fraction of time spent in the burst mode, and the ratio of the two reflects the average amplitude during the burst. Based on the 11HUGS sample then, the duty cycle is $6^{+4}_{-3}$%, the fraction of stars formed in the bursts is $23^{+14}_{-9}$%, and the SFR in the burst mode is on average $\sim 4$ times greater than in the quiescent mode. With the additional assumption that the typical duration of a global starburst is $\sim 100$ Myr (based on the CMD-based SFHs of N1569, Vallenari & Bomans 1996; Sextans A, Dogiel-Permer et al. 1998; DDO 165, Weisz et al. 2008), such events can roughly be estimated to occur every 1–2 Gyr. If the equal probability assumptions are incorrect, and instead the starburst mode only operates in a particular subset of the population, then the statistics represent lower limits on the duty cycle and frequency.

4.2.1. Non-detections—Inferences Regarding the Interburst Phase

As mentioned in Paper I, spiral and irregular galaxies that are completely devoid of recent star formation appear to be rare. This has also been noted by Meurer et al. (2006) and James et al. (2008) who have carried out complementary Hα imaging surveys of nearby galaxies (SINGG, Meurer et al. 2006; HαGS, James et al. 2004). In the overall sample given in Paper I, Hα emission is undetected in only 22 out of 410 galaxies which have been observed. All of these galaxies are in our secondary sample (with $B > 15$ or $|b| < 20^o$ or $T \leq 0$) and were added to the data set as observing time allowed or as available from the literature. Three galaxies, NGC 5206, UGC 2689, and NGC 3115, have S0 morphologies, so a lack of Hα emission is not surprising. The characteristics of the non-detections (in our main survey volume, $|b| > 20^o$; $N = 20$) are illustrated in Figures 1(b), 2(b), and 3(b) (green symbols), where $M_B$, $M_{H\alpha}$, and $L_{H\alpha+[N\alpha]}$ are plotted as a function of distance, respectively. The $L_{H\alpha}$ upper limits shown in Figure 3(b) correspond to 5σ point source detections. Of the 19 Hα non-detections with late-type morphologies, all are extremely low-luminosity galaxies with $-13.6 < M_B > -7.9$. H I measurements are available for most of these latter systems, and show that they uniformly have very low gas masses ($\lesssim 10^8 M_\odot$). Two of these, LGS3 and Leo T, are “transition”-type systems (e.g., Grebel et al. 2003), with morphologies between that of dIs and dE/dS0s. Thus, the lack of Hα emission either reflects the lack of sufficient fuel for star formation or SFRs that are so low that the probability of forming a high-mass ionizing star and/or of observing an H ii region at any given time is small.

The Hα luminosities are $< 10^{37}$ erg s$^{-1}$, which is in the regime of nebular photionization by single O stars (e.g., Oey & Kennicutt 1997). Thus, Poisson fluctuations can result in an absence of O stars (and, hence, Hα emission), although low-mass star formation may still be occurring. Recent and/or ongoing star formation in the majority of Hα nondetections in our sample, therefore, cannot be ruled out.

The fact that Hα emission is observed in 95% of the galaxies in the 11HUGS sample may not be too surprising, however, given the general morphological restriction to spiral and irregular galaxies in our original sample selection. After all, spirals are classified as such precisely because of the presence of star formation due to spiral density waves; that is, visible spiral patterns are due to concentrations of young stars and H ii regions and not concentrations of faded older populations unaccompanied by recent star formation. The same can thus be said for the dwarf irregulars, whose lumpy structure must be

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12 In Figure 1(b), two galaxies (LGS3 and Leo T) are fainter than the lower bound of the plot. In Figure 2(b), one galaxy (BK3N) does not have a published 21 cm flux and is not shown.
indicative of current star formation. The interesting implication, however, is that if all of the dwarfs in this sample are equally prone to bursting, as in the simple “equal probability” scenario above, and the interburst phase is represented by the normal galaxies in the sample, then “off” modes rarely occur and the interburst state must be characterized by lower levels of star formation rather than by its complete cessation. This is consistent with the CMD analysis of the starburst dwarf galaxy N1705 by Annibali et al. (2003), who found no evidence of consistent with the CMD analysis of the starburst dwarf galaxy prone to bursting, as in the simple “equal probability” scenario however, is that if all of the dwarfs in this sample are equally indicative of current star formation. The interesting implication, rather they argue that only the highest surface brightness, most compact dwarf irregulars are thought to host such events.

In Table 2, we list the dwarf galaxies with the highest EWs (2σ above the mean logarithmic EW as given in Table 1) in both the 11HUGS main (|b| > 20°) and secondary (|b| < 20°) surveys volumes. In Figure 7, Hα+[N II] and R-band images are shown for the six galaxies with EWs exceeding 3σ of the logarithmic mean in our best populated and complete luminosity bin (−17 < M_B < −15). The objects picked out by our starburst criterion are generally well studied (given that they are nearest such systems), and many have been examined in previous structural studies (e.g., N1705, N3125, N5253, Marlowe et al. 1999; N1705, ESO435-IG020, Gil de Paz & Madore 2005). They are typical of the compact, high surface brightness cores embedded in exponential envelopes. Thus, if the conclusions of the structural studies are correct and only the dwarf irregulars with similarly compact exponential profiles undergo bursts, then the duty cycle may be much larger than the 6% calculated here. Follow-up analysis of the broadband structural parameters of the 11HUGS complete sample may thus provide more insight into the statistics of the progenitor population and alternate constraints on characteristic burst cycle properties. Such constraints are likely to be upper limits, and thus when combined with the statistics reported here, they may reasonably bound the range of true values.

5. CONCLUSIONS

In this paper, we have used the Hα component of 11HUGS to quantify the prevalence of global starbursts in dwarf galaxies in the present-day universe and to infer their characteristic duty cycles and amplitudes. A summary of our findings is as follows.

1. The galaxy sample within the 11HUGS main survey volume (|b| > 20°, d < 11 Mpc) is found to be complete to M_B < −14.6 and M_{HI} > 2 × 10^8 M_☉ using the T_C statistic of Rauzy (2001). Ancillary checks involving the comparison of 11HUGS luminosity densities to independently derived LFs are consistent with these limits.

2. To identify dwarf galaxies currently undergoing global starbursts, we use an integrated Hα EW threshold of 100 Ǻ, which corresponds to a stellar birthrate of ~2.5, and also explore empirical starburst definitions based on σ thresholds of the observed logarithmic EW distribution. The distribution of integrated Hα EWs can be characterized by log-normal functions that show non-Gaussian excesses at the tails. For galaxies with −19 ≤ M_B < −15, the correspondence of the upper 3σ point of the central components of these distributions to birthrate parameter values around the starburst threshold (b ~ 3) suggests that dwarf galaxies in the local universe currently undergoing global starbursts may be identified as outliers at the high EW end. We speculate that the low EW outliers are postburst galaxies.

3. The dwarf galaxy starburst number fraction is shown to be 6.4 ± 2% while the fraction of stars formed in such systems is 23^±14%. These results are primarily based on (1) galaxies with −19 ≤ M_B < −15, which is the luminosity bin that is most robustly populated and statistically complete in the present sample, and (2) a definition which identifies dwarf starbursts as those systems with integrated Hα EW exceeding 100 Ǻ. From these statistics, we conclude that a continuous, steady state of star formation dominates in the present epoch, both in terms of being the mode that
operates during the vast majority of the time and in which most of the stars are being created. These results are not sensitive to modest changes in the EW threshold used to define starbursts. There is good consistency between our results and previous estimates, which is notable because the studies cover a range of approaches to the problem and use different starburst selection criteria.

4. Spiral and irregular galaxies that are devoid of recent star formation appear to be rare. The Hz nondetection rate for our sample is \( \sim 5\% \). The majority of the undetected galaxies are extremely low-luminosity irregulars (\( M_B < -13.6 \)), where lack of Hz emission may not necessarily indicate a lack of current star formation, because of stochastic effects in the production of high-mass stars in galaxies where the lifetime-averaged SFRs are on the order of \( 10^{-3} \ M_\odot \) yr\(^{-1}\). An inference is that “off” modes rarely occur in starburst cycles and that the interburst state must be characterized by low levels of star formation rather than by its complete cessation, at least for dwarfs with \( M_B \gtrsim -15 \).

5. In the simplest scenario where all the dwarf galaxies in our sample share a common average star formation history such that bursts can occur with equal probability in every system, (1) the \( 6 \pm 5\% \) dwarf galaxy starburst number fraction can be directly interpreted as the duty cycle (the fraction of time spent in the burst state), (2) the fraction of stars formed in the burst mode is \( 23 \pm 9\% \), and (3) the SFR in the burst mode is on average \( \sim 4 \) times greater than in the quiescent mode. If the assumptions are incorrect, and instead the starburst mode only operates in a particular subset of the population, then the statistics represent lower limits on the duty cycle. Whether this assumption holds has been the subject of the long-running debate on studies of dwarf galaxies, but future work on the resolved stellar populations of larger samples of dwarf irregulars in conjunction with the analysis presented here have the potential of clarifying this issue.

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