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LONG γ-RAY BURSTS AND TYPE IC CORE COLLAPSE SUPERNOVAE HAVE SIMILAR ENVIRONMENTS

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ABSTRACT

When the afterglow fades at the site of a long-duration γ-ray burst (LGRB), Type Ic supernovae (SN Ic) are the only type of core collapse supernova observed. Recent work found that a sample of LGRB had different environments from a collection of core-collapse supernovae identified in a high-redshift sample from colors and light curves. LGRB were in the brightest regions of their hosts, but the core-collapse sample followed the overall distribution of the galaxy light. Here we examine 263 fully spectroscopically-typed supernovae found in nearby ($z < 0.06$) galaxies for which we have constructed surface photometry from the Sloan Digital Sky Survey (SDSS). The distributions of the thermonuclear supernovae (SN Ia) and some varieties of core-collapse supernovae (SN II and SN Ib) follow the galaxy light, but the SN Ic (like LGRB) are much more likely to erupt in the brightest regions of their hosts. The high-redshift hosts of LGRB are overwhelmingly irregulars, without bulges, while many low redshift SN Ic hosts are spirals with small bulges. When we remove the bulge light from our low-redshift sample, the SN Ic and LGRB distributions agree extremely well. If both LGRB and SN Ic stem from very massive stars, then it seems plausible that the conditions necessary for forming SN Ic are also required for LGRB. Additional factors, including metallicity, may determine whether the stellar evolution of a massive star leads to a LGRB with an underlying broad-lined SN Ic, or simply a SN Ic without a γ-ray burst.

Subject headings: supernovae: general — gamma rays: bursts

1. INTRODUCTION

Type Ic supernovae (SN Ic) are defined by the absence of hydrogen, helium, and strong silicon features in their spectra. They are the only type of supernova observed after the fading of the afterglow from long-duration γ-ray bursts (Galama et al. 1998; Matheson et al. 2003; Stanek et al. 2003; Hjorth et al. 2003; Modjaz et al. 2006). SN Ic represent the extreme in a progression of increasing mass loss along the path to core collapse, ranging from SN II, which have hydrogen in their spectra (Filippenko 1997) through SN Ib, whose spectra lack hydrogen but show helium lines, to SN Ic which have neither hydrogen nor helium in their spectra. The three SN Ic firmly linked to LGRB events all had "broad-lined" spectral features, suggesting ejecta velocities on the order of 30,000 km/s. SN 1998bw was observed at the same position as a coincident LGRB (Galama et al. 1998); in the case of SN 2003dh, a residual SN Ic spectrum was discovered after subtracting a power-law continuum from the LGRB spectrum (Matheson et al. 2003; Stanek et al. 2003; Hjorth et al. 2003; and a SN spectrum was clear in the follow-up spectra to the LGRB counterpart to SN 2006aj (Modjaz et al. 2006; Mirabal et al. 2006; Sollerman et al. 2006; Pian et al. 2006). Although our investigation is not tied to any particular theoretical picture, the qualitative features of "broad-lined" SN Ic are consistent with the collapsar picture that attributes LGRB to tightly collimated jets that emerge during core-collapse SN explosions (Woosley et al. 1993). In this case, the SN Ic spectrum suggests that the star has shed, or burned through deep mixing, much of its hydrogen and helium, making jet escape less difficult while the broad lines in the spectrum suggest that there are high velocities impressed on the bulk of the remaining gas.

Broad-lined SN Ic constitute a small fraction of the observed SN Ic population (Podsiadlowski et al. 2004; Guetta & Della Valle 2007). Because LGRB jets are inferred to be highly collimated, some fraction of broad-lined SN Ic could be LGRB whose jets point in a direction that does not include Earth. From observations of radio emission that is assumed to be isotropic, the hypothesis in which all broad-lined SN Ic have off-axis jets was ruled out at the 84% confidence level (Soderberg et al. 2006), suggesting that poorly-aimed LGRB constitute only a modest percentage of the broad-lined events. Not all broad-lined SN Ic are associated with LGRBs or are especially luminous, and some broad-lined SN Ic-LGRB have computed energies similar to core-collapse SN (Mazzali et al. 2007), so broad-lined SN Ic are not

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simply hyper-energetic or hyper-luminous SN Ic. In a small, but growing, sample, broad-lined SN Ic without an associated LGRB were found to inhabit more metal-rich galaxies than broad-lined SN Ic that have been associated with LGRB, pointing to metallicity as an important factor in determining whether a massive star produces a LGRB (Modjaz et al. 2007).

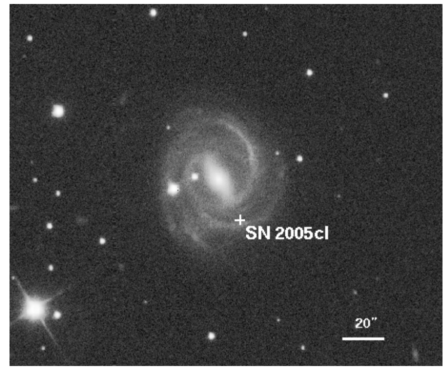
The study of LGRBs has used the locations of events in high redshift hosts to good effect (Bloom et al. 2002; Fruchter et al. 2006). In this paper, we use a technique developed by Fruchter et al. 2006 (F06) for use on distant LGRB host galaxies, applying it to the low-redshift SN host sample to establish the spatial distribution of supernova progenitors in this less exotic setting. Low-redshift SN Ib/SN Ic with host galaxies in the Sloan Digital Sky Survey (SDSS) were recently found to have more metal-rich hosts and occur at somewhat smaller offsets from their hosts' centers than SN II (Prieto et al. 2007). F06 compared the positions of LGRBs to "core-collapse" SN discovered by the GOODS ACS Treasury Program (Riess et al. 2004; Strolger et al. 2004) with the mean redshift of LGRBs 1.25 and the mean redshift of SN 0.63. The Higher-Z team generally did not observe further any SN that did have not the colors of SN Ia. These rejects for cosmology ("Not SN Ia") constitute the F06 core-collapse sample. F06 found that core-collapse SN defined this way follow the light distributions of their hosts: the probability of a SN occurring in a given pixel is proportional to the counts in that pixel. LGRB positions, in contrast, were concentrated at the regions of highest surface brightness in their hosts. This is why F06 concluded that LGRB and core-collapse SN have different environments. In our nearby sample, we have the advantage of more complete spectroscopic information that permits a more refined sorting by supernova type.

2. DATA

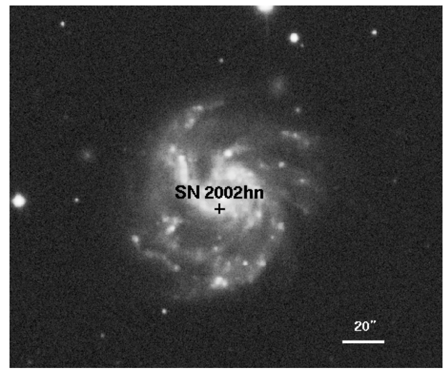
Our sample was drawn from 3,184 SN discoveries reported to the International Astronomical Union (IAU) through 2005 August 27 collected in the Asiago Supernova Catalog (Barbon et al. 1999) as well as 17 more recently discovered SN Ib and Ic. We selected SN in hosts occurring inside SDSS DR6 coverage with $z < 0.06$. Typical galaxies in the sample, M-01-53-20 and NGC 2532, and the locations of SN 2005cl (Type IIn) and SN 2002hn (Type Ic) are shown in Figure 1.

2.1. *Imaging*

Although we assembled mosaics for galaxies that lay on the CCD chip edges, 9 SN with host galaxies (SN 1909A, SN 1951H, SN 1970G, SN 1971I, SN 1981K, SN 1993J, SN 1999gi, SN 2005bk, SN 2005cs) were so large that they were not used because the SDSS pipeline has difficulty with photometry in frames dominated by large galaxies. SN in the Asiago Supernova Catalog are reported with an associated host galaxy, and that host galaxy identification was assumed to be correct. Either from misreporting or problems with the image world-coordinate system, host galaxy centers were inaccurate in the cases of 14 hosts (SN 1901B, SN 1988Y, SN 1990ag, SN 1991R, SN 1995ac, SN 1995T, SN 1995ah, SN 1995bc, SN 1997Y, SN 2001fv, SN 2004A, SN 2004fw, SN 2004hx) which were discarded. The images of six SN host galaxies included nearby bright stars that were impossible to



(a)



(b)

FIG. 1.— Typical galaxies in the sample. (a) SDSS g'-band image of size 0.7×0.7 arcmin^2 of the host galaxy M-01-53-20 for SN 2005cl, a SN IIn. (b) SDSS g'-band image of size 0.9×0.9 arcmin^2 of the host galaxy NGC 2532 for SN 2002hn, a SN Ic.

mask out (SN 1980D, SN 1986E, SN 2001Z, SN 2003U, SN 2003eh, SN 2004co).

The SDSS (York et al. 2000) DR 6 (Adelman-McCarthy et al. 2007) includes 9583 square degrees of 53.9-second imaging in the Sloan filter set (u',g',r',i',z') on a wide-field 2.5 meter telescope in Apache Point, New Mexico. The Sloan filters partition the spectrum from the near-infrared detector sensitivity limit to the ultraviolet atmospheric cutoff in non-overlapping bands (Fukugita et al. 1996). Individual Sloan frames have a 2048 x 1498 array of 0.396" square pixels, creating a 13.5 x 9.9 arcminute field. Mean seeing values in our observations were the following: u' 1.62"$\pm$0.28"; g' 1.53"$\pm$0.19"; r' 1.42"$\pm$0.15"; i' 1.43"$\pm$0.22";z' 1.35"$\pm$0.15".

3. METHODS

3.1. *Fractional Flux*

Our goal is to make measurements of the low-z sample to compare with the data presented by F06. We measure the surface brightness (1) in the pixel at the SN position and (2) by averaging inside a 0.4 kpc aperture centered at the SN position. We used SDSS g'-band images for comparison because the g'-band registers the spectral regions where galaxies emit most of the light detected by F06. Source Extractor (Bertin & Arnouts 1996) was used to find the set of pixels associated with the host galaxy light with signal-to-noise ratios greater than 1. From the distribution of pixel values in the galaxy light distribution and the local SN surface brightness measured in the pixel at the SN location, we calculate the "fractional

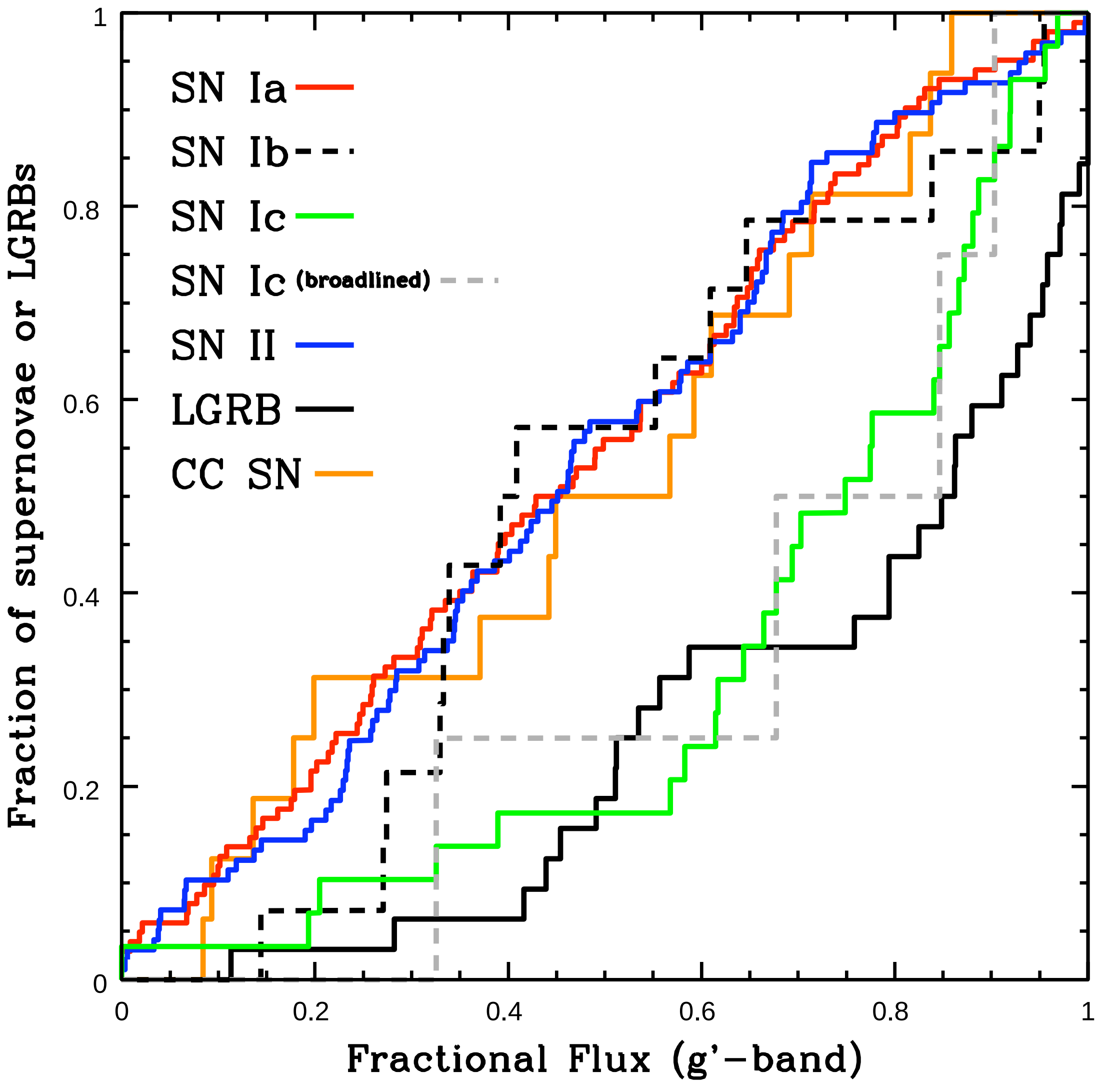


FIG. 2.— Low-redshift SN g'-band and high-redshift core-collapse SN and LGRB (from Fruchter et al. 2006) fractional flux distributions. SN Ic (N=29) (including broad-lined) are in brighter regions of their hosts than SN Ib (N=14) (p=0.018) and SN II (N=97) (p=0.0002). SN Ic are absent from the top 3% of galactic flux fraction distributions, which is likely due to the presence of bright central bulges and further explored in Figure 3. The SN Ib (N=14) distribution has an 8%, SN Ic distribution a 9%, and SN II (N=97) distribution only a 3×10^{-4} % probability of being drawn from the same set as LGRBs. The high redshift core-collapse sample, likely consisting predominantly of SN II, and SN II from our sample are highly similar (p = 0.90). SN Ia (N=102) are also similar to the SN II and the core-collapse (N=16) distributions, with p = 0.96 and p = 0.97 respectively.

flux." The fractional flux is the sum of counts registered in all pixels with fewer counts than measured at the SN location divided by the sum of all counts associated with the galaxy. This simple statistic allows a direct measurement of how SN events are distributed over their hosts. For galaxies with bulges, we make an additional calculation of the fractional flux after removing bulge light by replacing pixels values inside a circular region encompassing the bulge-dominated center with the mean of the perimeter pixel values.

3.2. *Residual SN Light*

From representative light curves (Cappellaro & Turatto 2001), we found that absolute magnitudes decay to fainter than -5 Johnson V magnitudes within one year for SN Ia, II except IIn, and Ib/Ic. We excluded SN when the SDSS observation of the host was made in the time period ranging from 6 months before the supernova report through 24 months after detection. SN IIn sometimes show very slow luminosity evolution, so to avoid contamination, we excluded SN hosts with Sloan data taken over the range two years before detection to 5 years after the SN discovery. Converting SDSS magnitudes to Johnson V-band using kcorrect (v. 4.13), a SED fitting program developed for use with the SDSS filter set (Blanton et al. 2003), we found an absolute Johnson V magnitude of galaxy light in the pixel at the SN position of -8.81 ± 2.04 for SN satisfying the previous time-selection criteria, roughly a factor of 30 times brighter than bright supernovae. These rules put us in a good position to avoid contamination of the galaxy surface brightness by light from the supernova.

4. RESULTS

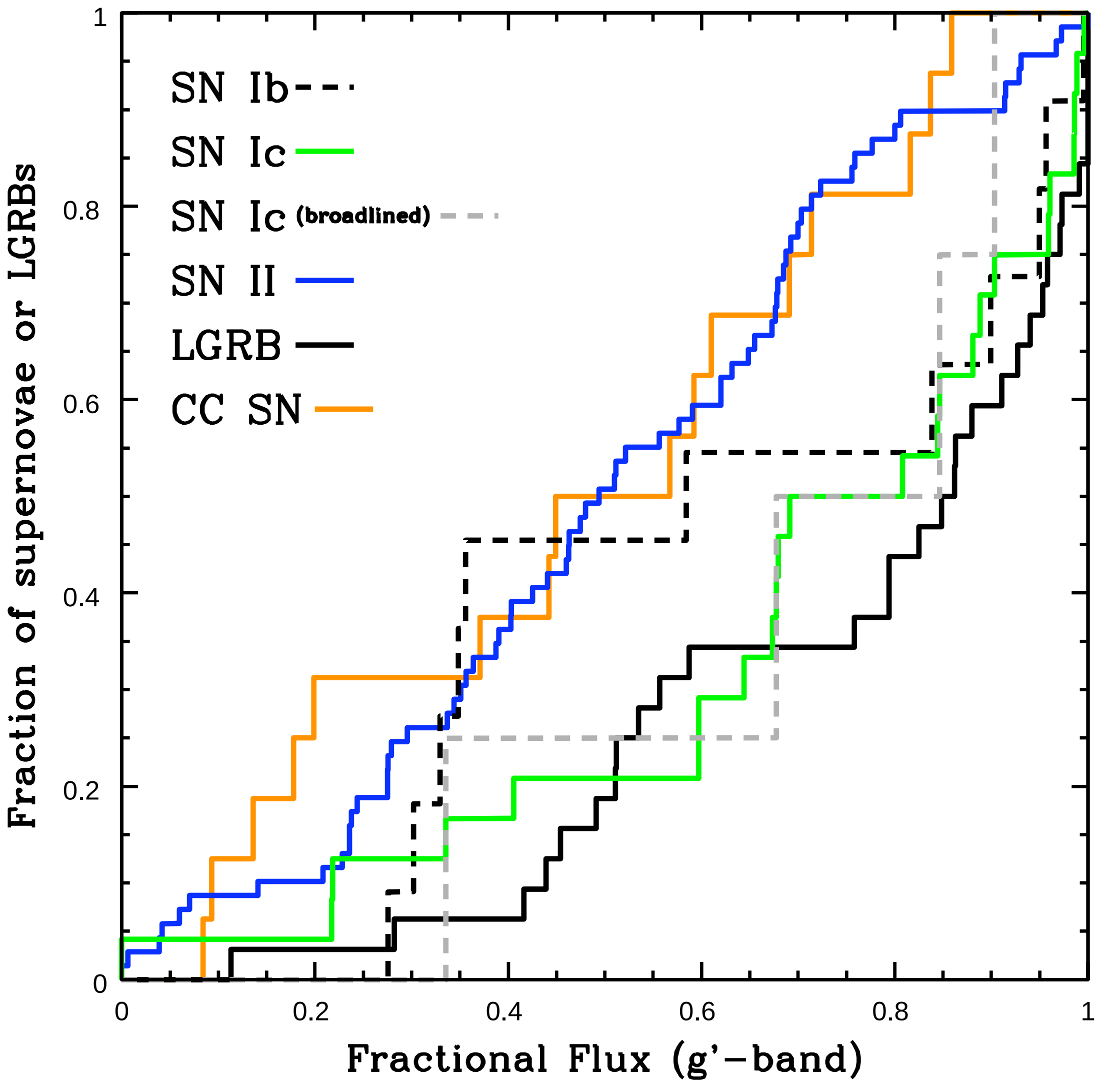


FIG. 3.— Bulge-subtracted low-redshift SN g'-band and high-redshift core-collapse SN and LGRB (from Fruchter et al. 2006) fractional flux distributions. After removing the bulge light that is present in low-redshift SN hosts but not the high-redshift and irregular LGRB hosts, there is a very high probability (p=0.86) that the SN Ic (N=24)(including broad-lined) and the LGRB (N=32) distributions are drawn from the same set. In contrast, it is highly unlikely that SN II (N=69) and LGRB are drawn from the same set (p=2x10^{-5}). Bulge subtraction in SN II hosts does not strongly affect the SN II distribution, which remains linear and in good agreement with core-collapse SN (N=16) (p=0.56). There is a 12% probability that the SN Ib (N=11) distribution is identical to the LGRB distribution.

We plot the cumulative distribution of the "fractional flux" statistic in Figure 2: The Y-axis indicates the fraction of the supernova population with "fractional flux" values less than the X-axis value. If the population follows the light distribution, the "fractional flux" plot will be just a straight line connecting (0,0) and (1,1).

As can be seen in Figure 2, SN Ic are much more likely than SN Ib and SN II to be found in the brightest regions of their host galaxies. The distribution of the four "broad-lined" SN Ic in this Figure is consistent with the distribution of the larger SN Ic population. Broad-lined SN Ic are the type found at the sites of LGRB, but we have too few cases in our sample to say whether they track that distribution more closely than other SN Ic. In contrast to the strongly skewed SN Ic, the SN Ia, SN Ib, and SN II all have linear distributions with slopes of one that intersect the origin, indicating that they are evenly positioned throughout their hosts' light distributions. A Kolmogorov-Smirnov (KS) test finds a very low probability (p = 0.0002) that SN Ic (N=29) and SN II (N=97) are drawn from the same population, and low probability (p = 0.018) that SN Ic are drawn from the same population as SN Ib.

Figure 2 compares our fractional flux results for low redshift SN, all of which have spectroscopic types, to the results reported by F06 at high redshift. Both LGRB and SN Ic samples are concentrated in the bright regions of their hosts, in sharp contrast to SN II. We see good agreement between the "core-collapse" SN (N=16) from F06, which probably consists primarily of SN II and our low-redshift sample of SN II (N=97) (p = 0.90). If the observed ratio of (SN Ib + SN Ic)/SN II seen at low redshift is similar to that in the GOODS sample, then ∼1/5 of the core-collapse sample will be SN Ib or SN Ic, the fraction found in nearby surveys (van den Bergh & Tammann 1991; Mannucci et al. 2005). Further, it is likely that a number of SN Ib and SN Ic were mistaken for SN Ia on the basis of their colors. If the true connection of LGRB with core-collapse events is only with SN Ic, then this signal may well have been lost in the noise of a sample dominated by SN II. Unlike LGRBs, SN Ic are absent from the very brightest pixels in their hosts with no fractional flux values greater than 0.97. This difference may arise because the brightest few pixels in the low-redshift supernova galaxies are dominated by bulge light.

Because high-redshift LGRB hosts have no bulge component while some low-redshift hosts do, we subtract the bulge from our low-redshift hosts and remeasure fractional flux values. Figure 3 plots the fractional flux distributions for SN in hosts where we have removed bulge light by constructing a circular aperture encompassing the bulge and replacing enclosed pixel values by the mean of pixel values on the perimeter. We now find an 86% probability that the LGRB (N=32) and SN Ic (N=24) distributions could be drawn from a single underlying population. It remains highly unlikely that SN Ic and SN II (N=69) are drawn from the same set (p=0.005) and that SN II and LGRB are drawn from the same set (p=2x10^{-6}).

SN were only included in Figure 3 if we could (1) visually identify and then subtract the bulge or (2) rule out a significant bulge. We therefore excluded bulge-dominated and edge-on galaxies but included SN with dwarf galaxy hosts. The absolute magnitudes of the dwarf galaxy hosts are listed in Table 1. 11 of 14 SN Ib hosts and 24 of 29 SN Ic hosts either had their bulges removed or had no significant bulge and so were included in Figure 3.

To complement fractional flux, which measures the brightness at the SN or LGRB location *relative* to light across the entire host galaxy, Figure 4 plots surface brightnesses in the *g'*-band in a 400 parsec aperture at the SN location. SN Ic (N=20) locations have higher surface brightnesses than SN Ib (N=9) and SN II (N=94), with low probabilities (p = 0.068 and p=0.006) that they are drawn from the same population.

All data plotted in this paper is collected in Table 2.

5. SAMPLE COMPARISON

The low-z imaging used in this paper and the Hubble Space Telescope high-z data set used by F06 differ. A possible consequence is that the surface brightness cutoffs imposed by the S/N>1 requirement could be somewhat dissimilar. While it is beyond the scope of this paper to make a thorough exploration of the surface brightness in the two samples, there are good indicators suggesting that any such difference is not very significant.

Despite not correcting for $(1+z)^4$ cosmological dimming, F06 in fact found that fractional flux measurements for SN types and LGRB were not significantly different across the redshift range of their hosts from z∼0.3 to z∼3. F06 also varied their surface brightness threshold by a magnitude and found this had no significant effect on their results, a step we repeated in our data set with the same outcome. Almost no SN II in this paper or "core-collapse" SN in F06 have a zero fractional flux value despite the fact that their populations linearly follow their hosts' light distribution in both data sets, indicating that a high fraction of host light is captured in both data sets.

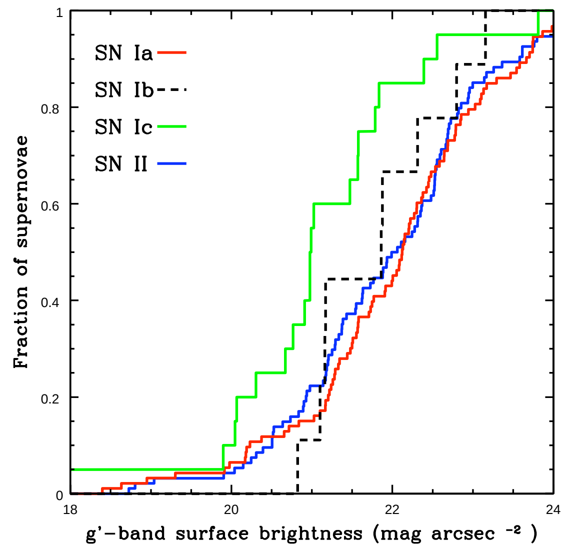


Fig. 4.— Surface *g'*-band brightnesses in 400 parsec apertures at the sites of SN. This plot shows that the *g'*-band surface brightnesses at SN Ic (N=20) sites are greater than those at SN Ib (N=9) and SN II (N=94) sites with p = 0.068 and p = 0.006. In contrast, there is a 77% probability that the SN Ib and SN II distributions are drawn from a single distribution.

The sizes of galaxies in this local sample and those studied in F06 differ, which may be partly attributed to the targeting biases in local SN searches toward luminous hosts. F06 measured the absolute Johnson V-band magnitudes and absolute sizes of galaxies, r_{80}, the elliptical semi-major axis containing 80% of the galactic light, using SExtractor and found that LGRB hosts were smaller than core-collapse (CC) SN hosts: CC SN 9.62 ± 5.58 and LGRB 3.36 ± 1.82 (kiloparsecs). We repeat these measurements for our sample: SN Ia 21.6 ± 13.1; SN II 19.48 ± 10.8; SN Ic 21.5 ± 10.0; and SN Ib 11.73 ± 2.75 (kiloparsecs).

6. CONCLUSIONS AND SUMMARY

SN Ic are generally found in the brightest parts of their host galaxies, a pattern that becomes even more extreme when only the star-forming disk population is considered. F06 has shown a similar result for LGRB in their irregular hosts, which lack bulges. These are presumably star-forming regions where conditions are right for forming SN Ic and, in some cases, LGRB. A reasonable suggestion is that these are the places where the most massive stars form. In the case where stellar evolution branches in one direction, perhaps because of low abundance of heavy elements (Modjaz et al. 2007), the result may be a massive Wolf-Rayet star with no surface H or He, a compact envelope, and high angular momentum at the time of collapse that can become a LGRB (Yoon & Langer 2005; Woosley & Heger 2006). In more metal rich sites, stellar evolution takes another branch which results in a SN Ic that has similar chemistry of its atmosphere, but a less energetic core collapse. Whether it is the state of mass loss at the time of collapse or the energy release of the collapsing core that determines whether a star becomes a LGRB or a SN Ic remains to be established. It is interesting to speculate that the distribution of broad-lined SN Ic in their hosts may have an even stronger connection to the sites of long γ-ray bursts and provide a better understanding of the violent deaths of stars.

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TABLE 1
Dwarf galaxy absolute magnitudes

SN	Absolute Magnitude
2002dg	M(g') = -14.24
2004ib	M(g') = -13.32
2005hm	M(g') = -15.05
2005mn	M(g') = -13.66
2006jo	M(g') = -15.95
2006qk	M(g') = -12.71
2007I	M(g') = -16.64
2007bg	M(B) $\sim$ -12

Note. — The faint absolute magnitudes of these host galaxies indicate that they are likely dwarf galaxies without a significant bulge, and we include them in Figure 3.

TABLE 2
Measurements at SN Locations

SN	Type	Morph.	Fractional Flux	Fractional Flux No Bulge	g' Surface Brightness (mag)
1954B	Ia	Scd	0.69	0.71	21.55
1959C	Ia	SBc	0.45	...	22.05
1960B	...	S0	0.16	...	23.01
1960I	I*	SBc	0.33	...	22.64
1960M	I	SBbc	0.42	...	21.90
1960N	I	Sd	0.46	...	22.06
1960R	Ia	S0/a	0.27	...	22.47
1961F	IIB-L:	SBbc	0.97	0.97	20.64
1961H	Ia	E	0.80	...	18.63
1962A	Ia*	Sb	0.32	...	...
1962B	I	Sa	0.54	...	21.12
1963I	Ia	SBcd	0.79	0.79	21.75
1963K	I:	S0/a	0.33	...	22.37
1963M	I:	Sc	0.49	...	22.19
1963P	Ia	Sc	0.18	0.18	21.77
1964L	Ic	Sc	0.97	0.99	...
1971G	I	SBa	0.20	...	23.11
1979B	Ia	Scd	0.10	0.11	23.74
1982W	Ia	S0	0.13	...	23.66
1983G	Ia	S0	0.76	...	20.17
1983U	Ia	SBa	0.63	0.69	21.28
1984A	Ia	SBa	0.32	...	21.34
1984E	IIL	Sa	0.23	0.28	22.70
1984L	Ib	SBc	0.95	1.00	21.17
1985B	Ia	SBa	0.36	0.40	22.53
1985F	Ib/Ic	SBd	0.99	...	19.90
1985G	IIP	Sbc	0.80	0.80	19.90
1986A	Ia	SBc	0.72	0.76	21.10
1986I	IIP	Sc	0.78	0.81	20.31
1987F	IIn	Sc	0.66	0.63	21.29
1987K	IIb:	Sc	0.61	0.65	20.51
1987N	Ia	Sb	0.83	0.87	20.73
1988Q	II	...	0.59	0.58	21.14
1989A	Ia	SBbc	0.22	0.32	22.85
1989E	Ib	Sc	0.41	...	22.80
1989F	II	SBd	0.07	...	...
1989K	II	SBab	0.03	0.06	24.10
1989N	II	Sbc	0.73	0.76	21.37
1990B	Ic	Sbc	0.87	0.88	20.31
1990G	Ia	Sab	0.96	1.00	19.30
1990H	II	Sc	0.67	0.68	20.90
1990N	Ia	SBbc	0.07	0.09	23.86
1991F	Iapec	S0	0.26	...	21.57
1991L	Ib/Ic	Sc	0.40	0.42	23.09
1991N	Ic	SBbc	0.92	...	17.89
1991S	Ia	Sab	0.20	...	23.70
1991ak	Ia	SBa	0.47	0.56	22.85
1991am	Ia	S	0.54	...	23.09
1991bc	Ia	S0/a	0.61	...	21.24
1992G	Ia	Sc	0.85	0.86	20.72
1992I	II	SBbc	0.00	0.00	...
1992P	Ia	Sbc	0.28	...	22.64
1993G	II	IBmpec	0.28	...	22.31
1993I	Ia	S0	0.00	...	25.30
1993Z	Ia	Sab	0.54	...	21.17
1994D	Ia	S0	0.81	...	18.95
1994J	Ia	...	0.58	...	22.20
1994M	Ia	E	0.26	...	23.98
1994O	Ia	Sa	0.61	...	20.18
1994Q	Ia	S0	0.43	...	22.00
1994S	Ia	Sab	0.40	...	22.78
1994W	IInP	Sbc	0.48	...	21.34
1994Y	IIn	SBbc	0.64	0.69	21.63
1994ae	Ia	Sc	0.18	0.18	22.69
1994ak	IIn	SBa	0.23	0.28	22.81
1995F	Ic	Sa	0.87	...	20.07
1995H	II	Sc	0.87	0.93	21.20
1995J	II	SBd	0.24	0.24	23.61
1995L	Ia:	SBa	0.40	0.47	22.64
1995P	Ia	...	0.66	...	21.99
1995R	Ia	Sbc	0.99	0.99	20.37
1995V	II	SBc	0.53	...	21.18
1995al	Ia	Sbc	0.35	...	20.93
1996B	II	Sbc	0.71	0.76	21.43
1996V	Ia	SBapec:	0.02	...	...

TABLE 2 — *Continued*

SN	Type	Morph.	Fractional Flux	Fractional Flux No Bulge	g' Surface Brightness (mag)
1996ai	Ia	Sbc	0.80	...	19.28
1996an	II	Sc	0.95	...	19.04
1996aq	Ic	Scd	0.88	0.89	21.79
1996bk	Ia	S0	0.55	...	19.91
1996cc	II	SBc:	0.37	...	22.24
1997bn	II	Scd	0.94	0.97	21.19
1997co	II	Sb	0.46	0.51	21.88
1997dd	IIb	Sc	0.04	...	...
1997ef	Ic-bl	Sc	0.90	0.94	21.47
1997ei	Ic	Sbc	0.86	0.96	21.02
1998C	II	Sbc	0.26	...	23.00
1998R	II	Sa	0.67	0.67	20.15
1998aa	Ia	S	0.94	...	18.40
1998ab	Iapec	SBbcpec	0.41	0.45	22.08
1998aq	Ia	Sb:	0.31	...	21.26
1998cc	Ib	Sbc:	0.33	0.33	22.38
1998cs	Ia	Sb	0.60	...	22.69
1998ct	IIn	Scd:	0.93	0.93	21.21
1998dk	Ia	Sc:	0.72	0.73	21.50
1998dl	II	Sc	0.40	...	20.25
1999Z	IIn	Sb	0.78	0.91	21.29
1999aa	Iapec	Sc	0.63	0.70	22.30
1999ap	II	...	0.70	0.70	22.48
1999bc	Ic	Spec	0.64	0.68	...
1999bu	Ic	Sapec	0.92	1.00	20.76
1999cb	Ia	Sc	0.11	...	23.29
1999cc	Ia	Sc	0.47	...	22.13
1999cd	II	Sbc	0.34	0.36	22.32
1999cf	Ia	SBbc	0.00	...	...
1999df	II	...	0.85	...	21.77
1999dg	Ia	S0	0.63	...	21.48
1999eh	Ib	Sc:	0.27	0.28	22.31
1999ew	II	S0/a:	0.61	...	20.93
1999gj	Ia	SBbc	0.26	0.29	22.15
1999gk	II	Scd	0.47	0.47	22.53
1999gq	II	Sm	0.26	...	23.58
2000J	II	Sbc	0.00	...	25.86
2000K	Ia	S0	0.02	...	24.15
2000O	Ia	S:	0.15	0.17	23.17
2000bs	II	Sb	0.06	0.07	23.76
2000ck	IIpec	Sa	0.11	...	22.51
2000cm	Ia	...	0.67	0.67	22.15
2000cp	Ia	Sab	0.61	...	21.22
2000cr	Ic	Sbpec	0.78	0.81	20.99
2000cs	IIpec	S?	0.54	0.62	22.36
2000db	II	Sbc:	0.64	0.69	20.04
2000df	Ia	E/S0	0.20	...	23.03
2000du	II	Sb	0.43	0.52	22.06
2000dv	Ib	Sb	0.55	0.58	21.16
2000ez	II	SBm	0.42	0.46	21.37
2000fn	Ib	Sab	0.34	0.35	21.88
2001D	II	SBb	0.19	0.21	22.94
2001F	Ia	Sc	0.78	...	21.91
2001H	II	Scd	0.92	1.00	20.57
2001J	II	SBcd:	0.68	0.70	22.28
2001K	II	Sbc	0.45	0.46	21.54
2001N	Ia	Sb:	0.83	...	19.98
2001R	II	Sbc:	0.23	0.24	22.95
2001V	Ia	Sb	0.07	...	23.47
2001ab	II	SBbc:	0.23	0.24	22.52
2001ad	IIb	Sc	0.23	...	23.80
2001ae	II	SBb:	0.67	0.91	20.94
2001ax	II	...	0.31	0.39	21.93
2001ay	Ia	Sbc	0.10	0.11	...
2001bk	II	...	0.07	...	24.56
2001cg	Ia	SB0:	0.39	...	21.71
2001cj	Ia	SBb	0.00	...	...
2001ck	Ia	Sb	0.34	...	22.45
2001cm	II	Sb	0.28	0.36	22.72
2001co	Ib/Icpec	SBb	0.24	0.26	22.47
2001dq	Ic?	Sc	0.66	0.69	21.83
2001em	Ic:	Sab	0.57	0.60	21.57
2001fe	Ia	Sa	0.53	...	21.51
2001gb	Ia	Sbc	0.25	0.25	22.59
2001hg	II	Sbc	0.46	0.48	21.62
2002G	Ia	SB?	0.24	...	22.22

TABLE 2 — *Continued*

SN	Type	Morph.	Fractional Flux	Fractional Flux No Bulge	g' Surface Brightness (mag)
2002I	Ia	SBb:	0.36	0.45	21.92
2002bf	Ia	SBb:	0.73	0.97	21.20
2002bl	Ic-bl	SBb:	0.33	0.34	22.39
2002bo	Ia	Sapec	0.49	...	21.33
2002bz	Ia	S:	0.73	...	21.44
2002ca	II	SBab	0.36	0.44	21.93
2002cg	Ic	Sb	0.84	0.99	20.91
2002df	Ia	Sab	0.09	0.10	23.58
2002dg	Ib	...	0.14	...	23.16
2002ea	IIn	Sb	0.65	0.68	20.39
2002ew	II	...	0.28	...	21.73
2002ha	Ia	Sab	0.39	...	22.45
2002hm	II	SBdm:	0.84	...	20.84
2002hn	Ic	Sc	0.96	0.99	20.05
2002ho	Ic	SBb	0.62	0.64	21.58
2002ji	Ib/Ic	Sc:	0.25	0.25	21.51
2003A	Ib/Ic	Sb	0.65	...	21.15
2003I	Ib	S?	0.33	0.36	21.86
2003J	II	SBb	0.58	0.62	21.38
2003Y	Ia	S0	0.20	...	22.77
2003ab	II	Scd:	0.48	0.49	22.59
2003ag	Ia	SBbc	0.31	0.32	22.30
2003aq	IIP	SBbc	0.58	0.59	22.37
2003au	Ia	S0:	0.74	...	21.29
2003bk	II	Scd?	0.68	...	20.98
2003bm	Ic	Scd	0.19	0.22	23.81
2003cn	II	Scd?	0.04	0.04	24.02
2003cq	Ia	Sbc	0.21	0.22	22.79
2003da	II	Scd:	0.41	0.43	21.88
2003dg	Ib/Icpec	Scd:	0.86	...	21.40
2003du	Ia	SBdm	0.43	...	23.13
2003ej	II	Scd:	0.67	0.68	22.52
2003gm	II:	SBc:	0.71	0.72	22.61
2003gs	Iapec	SB0	0.65	...	20.65
2003hi	II	S?	0.22	0.24	22.53
2003ia	Ia	S?	0.50	...	22.36
2003ic	Ia	SB0?	0.69	...	21.58
2003jb	Ia	SB0	0.31	...	22.11
2003je	II	Sab	0.35	0.39	22.69
2003jz	Ia	S:	0.64	...	20.84
2003ky	II	Sa	0.21	0.28	21.55
2003ld	II	S?	0.78	0.78	20.52
2004C	Ic	SBc	0.69	...	20.67
2004G	II	Scd	0.34	0.35	22.82
2004H	Ia	E	0.65	...	21.17
2004I	II	SBb	0.71	0.71	20.50
2004T	II	Sb	0.56	0.56	22.35
2004W	Ia	E	0.25	...	22.48
2004Z	II	...	0.20	0.23	23.14
2004ak	II	Sbc	0.12	...	23.26
2004ap	Ia	...	0.08	...	...
2004aq	II	Sb	0.26	0.28	22.96
2004at	Ia	Sb	0.01	...	24.54
2004bj	Ia	E:pec	0.39	...	22.95
2004bn	II	S?	0.46	0.51	20.89
2004cm	II	...	1.00	...	20.53
2004cn	Ia	...	0.94	...	22.27
2004cq	Ia	Scd:	1.00	...	20.23
2004ct	Ia	S?	0.57	0.61	21.57
2004dg	II	Sb	0.42	0.46	21.63
2004di	Ia	S0	0.10	...	23.74
2004dt	Ia	SBa	0.77	...	21.73
2004dv	II	SBb	0.01	0.01	24.87
2004eb	II:	...	0.35	...	20.73
2004el	II	Sc	0.14	...	23.17
2004es	II	Sbc	0.39	0.40	22.85
2004ey	Ia	SBc:	0.66	0.69	22.12
2004ez	II	Sc	0.14	0.14	23.36
2004gk	Ic:	Sdm:	0.75	...	21.67
2004gl	Ia	...	0.65	...	22.42
2004gu	Ia	...	0.54	...	22.38
2004gv	Ib/Ic:	S0/a:	0.66	0.75	21.61
2004hu	Ia	...	0.49	...	22.09
2004ib	Ic-bl	...	0.85	0.85	...
2004ie	Ia	...	0.22	...	23.54
2005E	Ib/Ic	S0/a	nan	0.00	...

TABLE 2 — *Continued*

SN	Type	Morph.	Fractional Flux	Fractional Flux No Bulge	g' Surface Brightness (mag)
2005G	Ia	Scd:	0.14	...	23.11
2005H	II	S0:pec	0.63	...	18.80
2005J	II	Sb	0.28	0.30	22.69
2005O	Ib	SBbc	0.61	0.90	20.82
2005S	Ia	Scd:	0.88	0.95	21.03
2005T	II	Sbc	0.47	...	22.09
2005U	IIb	...	1.00	...	18.73
2005Y	II	Sa	0.71	...	21.17
2005ab	II	Sb	0.31	0.34	22.68
2005ad	II	Sc	0.04	0.04	23.62
2005au	II	Scd:	0.66	0.68	21.25
2005bb	II	Sbpec	0.65	0.65	21.10
2005bi	II	Sbc	0.34	0.34	22.11
2005bj	Ic:	...	0.20	0.22	...
2005bw	II	SBbc	0.45	...	21.99
2005cl	IIn	SBb	0.35	0.40	22.55
2005cr	Ia	...	0.90	...	20.19
2005dh	Ia	S?	0.16	...	22.21
2005eo	Ic	Sbc	0.39	0.41	...
2005hm	Ib	...	0.95	0.95	...
2005kl	Ic	Sa	0.70	...	...
2005mf	Ic	Scd	0.61	0.67	...
2005mn	Ib	...	0.84	0.84	...
2005nb	Ic	SBdpec	0.77	0.84	...
2006cb	Ib	Sbc	0.39	0.96	...
2006ck	Ic	Sd	0.89	0.96	...
2006fo	Ic	...	0.58	0.60	...
2006jc	Ib/Icpec	SBbc	0.44	0.44	...
2006jo	Ib	...	0.27	0.30	23.05
2006lc	Ib/Ic	S0/apec:	0.48	0.48	...
2006lv	Ib/Ic	Sbc	0.53	0.55	...
2006nx	Ib/Ic	...	0.01	...	...
2006qk	Ic-bl	...	0.90	0.90	20.98
2007I	Ic-bl	...	0.68	0.68	22.56
2007ag	Ib	Scd:	0.65	...	...
2007bg	Ic	...	0.00	0.00	...

NOTE. — We list data values for the ambiguously typed SN Ib/Ic, even though they are not included in plots in the main text. Each SN type plotted in this Letter includes all subtypes and SN with peculiar ("pec") designations. These subtypes include broad-lined ("Ib-bl") for SN Ic and linear ("IIL"), plateau ("IIP"), with narrow emission lines ("IIn"), and the transitional type ("IIb") for SN II. A colon (":") indicates some uncertainty in the classification while an asterisk ("*") denotes classification made using a light curve.