Classifications of the Host Galaxies of Supernovae, Set III

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ABSTRACT. A homogeneous sample comprising host galaxies of 604 recent supernovae, including 212 objects discovered primarily in 2003 and 2004, has been classified on the David Dunlap Observatory system. Most SN 1991bg–like SNe Ia occur in E and E/Sa galaxies, whereas the majority of SN 1991T–like SNe Ia occur in intermediate-type galaxies. This difference is significant at the 99.9% level. As expected, all types of SNe II are rare in early-type galaxies, whereas normal SNe Ia occur in all Hubble types. This difference is significant at the 99.99% level. A small number of SNe II in E galaxies might be due to galaxy classification errors or to a small young-population component in these mainly old objects. No significant difference is found between the distributions over the Hubble type of SNe Ibc and SNe II. This confirms that both of these types of objects have similar (massive) progenitors. The present data show that in order to understand the dependence of supernova type on host-galaxy population, it is more important to obtain accurate morphological classifications than it is to increase the size of the data sample.

1. THE LICK OBSERVATORY SUPERNOVA SEARCH

The present paper represents a continuation of the investigations by van den Bergh et al. (2002, 2003, hereafter Papers I and II), in which we studied the morphologies of the host (parent) galaxies of supernovae (SNe) that were discovered (or independently rediscovered) during the course of the Lick Observatory Supernova Search (LOSS)\(^1\) with the 0.76 m Katzman Automatic Imaging Telescope (KAIT).\(^2\) This is the first step in the LOSS-based calculation of rates of various types of SNe currently being conducted by Leaman et al. (2004).

LOSS, which started in 1997 March (Treffers et al. 1997), has been described by Li et al. (2000), Filippenko et al. (2001), and Filippenko (2003, 2005). During the interval of late-October 2000 through mid-October 2003, it was expanded to the Lick Observatory and Tenagra Observatory Supernova Searches (LOTOS; Schwartz et al. 2000), but thereafter it reverted back to simply LOSS (Filippenko et al. 2003), using KAIT alone, without the assistance of Tenagra Observatory.

KAIT is a fully robotic instrument whose control system checks the weather, opens the dome, points to the desired objects, acquires guide stars (in the case of long exposures), exposes, stores the data, and manipulates the data automatically, all without human intervention. We reach a limit of \(\sim 19\) mag (4 \(\text{J} \text{mag}\)) in 25 s unfiltered, unguided exposures (used in the supernova search), while 5 minute guided exposures yield \(R \approx 20\) mag. Besides conducting a supernova search, KAIT acquires well-sampled long-term light curves of SNe and other variable or ephemeral objects—projects that are difficult to conduct at other observatories that have a large number of users with different interests.

Special emphasis is placed on finding SNe well before maximum brightness. Although the original LOSS sample had only about 5000 galaxies, in the year 2000 we increased the sample to \(\sim 14,000\) galaxies (most with recession speed \(c_z \lesssim 10,000\) km s\(^{-1}\)), separated into three subsets (observing baselines of 2 days for about 100 galaxies, 3–6 days for \(\sim 3000\) galaxies, and 7–14 days for \(\sim 11,000\) galaxies). In early 2004 June, we decreased the sample to 7500 galaxies in order to have a shorter baseline and be better able to determine the explosion date accurately. Specifically, we adopted this last strategy to find SNe Ia for an extensive study of their ultraviolet properties with the Hubble Space Telescope (HST)—in program GO–10182 (PI: Filippenko).

We are able to observe \(\sim 1000\) galaxies per night in unfiltered mode. Our software automatically subtracts new images from
old ones (after registering, scaling to account for clouds, convolving to match the point-spread functions, etc.) and identifies SN candidates, which are subsequently examined and reported to the Central Bureau for Astronomical Telegrams by numerous research assistants (mostly undergraduate students) in our group at the University of California, Berkeley. Interested astronomers elsewhere are also notified immediately.

LOSS found its first supernova in 1997—SN 1997bs (although ironically, it might not be a genuine SN; Van Dyk et al. 2000). In 1998, mostly during the second half of the year, LOSS discovered 20 SNe, thereby breaking the previous single-year record of 15 held by the Beijing Astronomical Observatory Supernova Search. In 1999, LOSS doubled this with 40 SNe. In 2000, LOSS found 38 SNe, even though we spent a significant fraction of the observing time expanding the database of monitored galaxies rather than searching for SNe. With this expanded database, LOSS discovered 68 SNe in 2001, 82 in 2002, 95 in 2003, and 83 in 2004. We discovered SN 2000A and SN 2001A—the first supernova of the new millennium, regardless of one’s definition of the turn of the millennium. During the past few years, KAIT has discovered well over half of all nearby SNe reported worldwide, from all searches combined. Thus, KAIT/LOSS is currently the world’s most productive search engine for nearby SNe.

At the Lick and Keck Observatories, we spectroscopically confirm and classify nearly all of the SNe that other observers have not already classified. Thus, the sample suffers from fewer biases than most. Our observations and Monte Carlo simulations have already shown that the rate of spectroscopically peculiar SNe Ia is considerably larger than had previously been thought (Li et al. 2001a, 2001b). Follow-up observations for the discovered SNe are emphasized during the course of LOSS. Our goal is to build up a multicolor database for nearby SNe. Because of the early discoveries of most LOSS SNe, our light curves usually have good coverage from premaximum brightening to postmaximum decline. Moreover, LOSS SNe are automatically monitored in unfiltered mode as a by-product of our search; these can sometimes be useful for other studies (e.g., Matheson et al. 2001). The positions of SNe in KAIT images were used to identify the same SNe at very late times in HST images (Li et al. 2002), allowing us to determine the late-time decline rates.

LOSS also discovers novae in nearby galaxies (e.g., M31), cataclysmic variable stars, and occasionally comets (Li 1998; Li et al. 1999). Although it records many asteroids, we do not conduct follow-up observations of these, so most are subsequently lost.

2. NEW MORPHOLOGICAL CLASSIFICATIONS

In Papers I and II, morphological classifications were given for the host galaxies of 177 and 231 SNe, respectively. In Table 1 of the present paper lists an additional 212 SNe, including (1) the SN name, (2) the host-galaxy name, (3) the SN classification, (4) the type of the host galaxy on the Yerkes system (Morgan 1958, 1959), (5) the host-galaxy type on the David Dunlap Observatory (DDO) system (van den Bergh 1960a, 1960b, 1960c), and (6) the published radial velocity of the SN host galaxy. The database examined in the present investigation extends through the end of the year 2004.

However, recent careful inspection of the monitoring data of all the host galaxies classified in Papers I and II reveals that for 15 galaxies, the corresponding SNe (discovered and reported by other observers) were actually not successfully imaged by KAIT: either the SNe were too faint, or all the KAIT images for a particular galaxy were plagued by bad weather. Moreover, the host galaxy of SN 1998dl (NGC 1084) was included in both Papers I and II. Thus, we need to exclude classification for 16 galaxies in our sample, leaving the total number of host galaxies classified in Papers I through III at 604. The 16 galaxies that need to be removed from the study are listed in Table 2.

The Yerkes classification system provides a one-dimensional classification along the sequence “a-of-f-g-g-k-k.” Objects of type “a” have the lowest central concentration of light, and those of type “k” exhibit the strongest central concentration. In contrast, the DDO system of morphological classification is three-dimensional. The first DDO classification parameter is the Hubble type (Hubble 1936), and the second is bar strength measured along the four-stage sequence S−S(B)−S(B)−SB. As a third parameter, the DDO system uses both spiral-arm morphology and surface brightness to assign galaxies to luminosity classes I (supergiant), II (bright giant), III (giant), IV (subgiant), and V (dwarf). In Table 1 uncertain values are followed by a colon (:), and very uncertain ones by a question mark (?).

The original Hubble classification system and its subsequent evolution in the hands of Sandage (1961) was optimized for the classification of galaxy images on photographic plates obtained with large reflecting telescopes. On the other hand, the DDO system was devised to classify the lower resolution images of galaxies on the Palomar Observatory Sky Survey (POSS). The DDO system is therefore particularly well suited to the classification of lower resolution paper prints of the galaxy images from the POSS-I blue and red surveys. For some galaxies, it was also possible to consult the higher resolution POSS-II blue images. Furthermore, the KAIT images provide useful information on the structure of the cores of many images that were burned out on the POSS. The accuracy and long-term stability of the DDO system have been discussed in detail in Paper II. A drawback of the lower quality images that can be used for classifications on the DDO system is that they do not (except in the case of some edge-on galaxies) allow one to distinguish between elliptical (E) and lenticular (S0) galaxies.

3. SUPERNOVA CLASSIFICATIONS

The spectral classifications of SN type (see Filippenko 1997 for a review) that are given in Table 1 were drawn from the
# Table 1: Classifications of SN Host Galaxies

| SN (1) | Galaxy (2) | SN Type (3) | Yerkes Type (4) | DDO Type (5) | Redshift (km s\(^{-1}\)) (6) | Remarks (7) |
|--------|------------|-------------|-----------------|-------------|-----------------------------|-------------|
| 1998C  | U3825      | II          | fg              | Sbc II       | 8281                        |             |
| 1998S  | N3877      | II          | f               | Sbc          | 895                         | 2           |
| 1998aq | N3982      | II          | fg              | Sc II        | 1109                        |             |
| 2000dx | U1775      | la          | fg              | S pec        | 9108                        | 3           |
| 2000ej | I1371      | Ia-pec (91bg)| k              | E2           | 9102                        |             |
| 2000fe | U4870      | II          | gk              | Sb           | 4218                        |             |
| 2000fm | N1612      | II          | fg              | Sbc          | ...                         |             |
| 2000fo | P70148     | la          | g               | Sab          | 7152                        |             |
| 2001U  | N5442      | la          | g               | Sb: t        | 8517                        |             |
| 2001ah | U6211      | Ia-pec (91T)| f              | Sbc I        | 16788                       |             |
| 2001ak | U11188     | II          | af              | Sc           | 5285                        | 2           |
| 2001bb | I4319      | lc          | g               | Sab:         | 4653                        |             |
| 2001gb | I582       | la          | g               | S            | 7714                        |             |
| 2001ge | U3375      | la          | fg              | Sc II        | 5783                        |             |
| 2001hf | M –03-23-17| II          | ?               | S            | 4486                        | 12          |
| 2001hh | M –02-57-22| II          | gk              | Sa           | 7445                        |             |
| 2002ct | Anonymous  | Ia-pec (91bg)| f              | S            | 10804                       | 2           |
| 2002fk | N1309      | la          | fg              | Sc           | 2136                        |             |
| 2002kg | N2403      | II          | f               | Sc III       | 131                         |             |
| 2003bt | M –01-28-06| la          | fg              | S(B)¢e       | 7972                        |             |
| 2003cb | N4885      | II          | gk              | Sa?          | 3366                        |             |
| 2003db | M +05-23-21| II          | g               | Sab:         | 8067                        |             |
| 2003eg | N4727      | II          | g               | S(B)b II     | 7495                        |             |
| 2003ei | U10402     | Ilm         | f               | St + Pec     | ...                         | 5           |
| 2003ej | U7820      | IIb         | f               | Sc II        | 5090                        |             |
| 2003ek | Anonymous  | Ia-pec (91bg)| f              | S            | 10804                       | 2           |
| 2003el | N5000      | lc          | fg              | SBbc I       | 5608                        |             |
| 2003em | ESO 478–G6 | la          | fg              | Sc I         | 5332                        |             |
| 2003ep | N7053      | la          | k               | E2/Sa        | 4708                        |             |
| 2003ev | Anonymous  | lc          | g               | Sab          | 7200                        |             |
| 2003ez | PGC 42782  | la          | g               | Sb pec       | 14343                       |             |
| 2003fa | M +07-36-33| Ia-pec (91T)| g              | Sb: t        | 1800                        |             |
| 2003fb | U11522     | II          | g               | Sc           | 5259                        |             |
| 2003fc | M –03-51-05| lc          | fg              | S            | 10400                       |             |
| 2003fd | U8670      | la          | fg              | Sc: II       | 17911                       |             |
| 2003gd | N628       | II          | fg              | Sc I         | 657                         |             |
| 2003gf | M –04-52-26| lc          | ?               | Pec          | 2600                        |             |
| 2003gg | H1321      | II          | g               | S(B)?b II    | 6660                        |             |
| 2003gi | H1561      | la          | f               | Sbc          | 3899                        |             |
| 2003gz | N7017      | Ia-pec (91bg)| k              | E1 + E0      | 10119                       | 1           |
| 2003gk | N7460      | lb          | g               | Sc II        | 3192                        |             |
| 2003gl | N7782      | la          | g               | Sb II        | 5379                        |             |
| 2003gm | N5334      | Ilm         | f               | S(B)? III-IV | 1382                       |             |
| 2003gn | CGCG 452–024| la         | gk              | Sab          | 10328                       |             |
| 2003go | ESO 595–G001| Ilm        | g               | Sa:          | 10765                       |             |
| 2003gp | U10160     | II          | gk              | SBab         | 9967                        |             |
| 2003gq | N7407      | Ia-pec (91T)| f              | Sbc II       | 6430                        |             |
| 2003gr | M –04-55-14| la          | g               | SBb          | 7691                        |             |
| 2003gs | N936       | Ia-pec (91bg)| k              | SBa          | 1430                        |             |
| 2003gt | N6930      | la          | g               | Sb t         | 4694                        |             |
| 2003gu | U12331     | IIb         | g               | Sab:         | 5794                        |             |
| 2003gv | M +05-03-66| II          | fg              | Sbc:         | 10423                       |             |
| 2003gw | U3252      | II          | f               | Sc I-II      | 6115                        |             |
| 2003hc | U1993      | II          | ?               | S            | 8018                        | 2           |
| 2003hd | M –04-05-10| II          | g               | Sbc:         | 11842                       |             |
| 2003he | M –01-01-10| la          | fg              | Sb           | 7649                        |             |
| 2003hf | U10586     | II          | g               | Sab          | 9384                        |             |
| Year | SN     | Galaxy   | SN Type     | Yerkes Type | DDO Type | Redshift (km s\(^{-1}\)) | Remarks  |
|------|--------|----------|-------------|-------------|-----------|--------------------------|----------|
| 2003 | hg     | N7771    | II          | f           | S pec     | 4277                     | ?        |
| 2003 | hh     | U12890   | Ia-pec (91bg) | k          | E4        | 11602                    |          |
| 2003 | hk     | N1085    | II          | g           | Sb II     | 6789                     |          |
| 2003 | hl     | N772     | II          | f           | Sbc t?    | 2472                     |          |
| 2003 | hm     | U2295    | Ia          | g           | Sb        | 4172                     |          |
| 2003 | hp     | U10942   | Ic-pec      | fg          | Sb t?     | 6378                     |          |
| 2003 | hs     | U11149   | Ia-pec (91bg)| k          | E3/Sa     | 14990                    |          |
| 2003 | ht     | U2457    | II          | g           | Sab:      | 10218                    |          |
| 2003 | hv     | N1201    | Ia          | k           | E4        | 1671                     |          |
| 2003 | hw     | Anonymous| Ia          | g           | Sb:       | 6                        |          |
| 2003 | hx     | N2076    | Ia          | gk          | Sa        | 2142                     | 4        |
| 2003 | hy     | E5145    | IIa         | g           | Sb II     | 7355                     |          |
| 2003 | hb     | PGC 17866| Ia          | fg          | Sb:       | 6047                     |          |
| 2003 | ib     | M/H11002 | II          | g           | E0/Sa:    | 700                      |          |
| 2003 | ic     | M/H11002 | Ia          | fg          | Sb:       | 5881                     |          |
| 2003 | ii     | M/H11002 | II          | f           | Sc II     | 4963                     |          |
| 2003 | ij     | U4185    | Ia          | ?           | Sc        | 7115                     | 2        |
| 2003 | ik     | Anonymous| Ia          | k           | Sa        | 5804                     |          |
| 2003 | il     | I1956    | Ia          | fg:         | Sb        | 6401                     |          |
| 2003 | im     | U327     | II          | g           | Sa        | 5398                     |          |
| 2003 | in     | N772     | II          | fg          | Sbc t?    | 2472                     |          |
| 2003 | io     | U3726    | II          | g           | Sb        | 7657                     |          |
| 2003 | ip     | I1430    | Ic          | f           | Sc        | 5482                     |          |
| 2003 | iq     | U40      | Ia          | g           | SBB:      | 7531                     |          |
| 2003 | ir     | M +02-08-14 | Ia           | k           | E1        | 10285                    |          |
| 2003 | is     | N7102    | II          | f           | Sc:       | 4866                     |          |
| 2003 | it     | U3746    | Ia          | g           | Sa        | 7668                     |          |
| 2003 | iz     | U1485    | Ia          | ?           | Sc        | 7115                     | 2        |
| 2003 | ja     | N846     | II          | fg          | SBB II    | 5118                     |          |
| 2003 | je     | M -01-58-18 | II          | f           | Sc:       | 6029                     |          |
| 2003 | jf     | M -01-59-21 | Ic-pec       | f          | Sb:       | 5654                     |          |
| 2003 | jg     | N2668    | II          | gk          | S(B)bcs   | 7529                     |          |
| 2003 | jh     | M -02-11-30 | IIa         | fg          | Sbc II    | 8898                     |          |
| 2003 | jj     | U5225    | Ia          | k           | E0        | 4906                     |          |
| 2003 | jk     | M +06-50-20 | II          | f           | Sc III-IV | 5761                     |          |
| 2003 | jl     | U3432    | Ic          | ?           | S0/Sb:    | 4998                     | 2        |
| 2003 | jm     | M +05-23-37 | Ia          | fg          | Sc I?     | 10003                    |          |
| 2003 | jn     | U2468    | Ia          | k           | E0/Sa:    | 2356                     |          |
| 2003 | jo     | M +06-22-09 | IIa         | fg          | Sb:       | 6176                     |          |
| 2003 | jp     | M -02-16-02 | Ia          | af          | S IV      | 2215                     |          |
| 2003 | jr     | M +05-27-49 | II          | g           | Sa (pec?) | 8012                     |          |
| 2003 | jk     | U148     | II          | ?           | Sc?       | 4213                     | 2        |
| 2003 | jl     | N1376    | II          | fg          | Sc I      | 4155                     |          |
| 2003 | jm     | U6711    | II          | gk          | Sa        | 2702                     |          |
| 2003 | jn     | U5       | Ia          | fg          | Sb II     | 7271                     |          |
| 2003 | jo     | PGC 11402 | Ia          | fg          | ?         | 13000                    |          |
| 2003 | jp     | N6207    | II          | f           | Sc/Irr    | 852                      |          |
| 2003 | jk     | N3683    | Ic          | f           | S         | 1716                     | 2        |
| 2003 | jl     | U6916    | II          | fg          | Sb        | 6182                     |          |
| 2003 | jm     | PGC 46239| Ia          | gk          | Sa pec    | 8936                     |          |
| 2003 | jn     | N1285    | IIa         | g           | Sc        | 5239                     |          |
| 2003 | jk     | N5668    | II          | f           | Sc III-IV | 1583                     |          |
| 2003 | jl     | U1072    | Ia-pec (91bg)| k          | E2        | 9497                     | 7        |
| 2003 | jm     | N1072    | II          | g           | Sb        | 8018                     |          |
TABLE 1 (Continued)

| SN (1) | Galaxy (2) | SN Type (3) | Yerkes Type (4) | DDO Type (5) | Redshift (km s\(^{-1}\)) (6) | Remarks (7) |
|-------|------------|-------------|----------------|--------------|-----------------|-------------|
| 2004J | ESO 554-G33 | Ia | fg | S | ... | |
| 2004K | ESO 579-G22 | Ia | gk: | S(B)b: | 10832 | |
| 2004L | M +03-27-38 | Ia | g | S(B)b | 9686 | |
| 2004P | U8561 | Ia | fg | Sc | 7120 | |
| 2004Q | ESO 507–G11 | II | ? | Sc pec? | 7483 | |
| 2004T | U6038 | II | gk | Sa | 6437 | |
| 2004U | Anonymous | II | gk: | SBb | ... | |
| 2004V | Anonymous | II | k: | E:0 | 12500 | |
| 2004W | N4649 | Ia-pec (91bg) | ? | E1 | 1117 | 8 |
| 2004X | Anonymous | II | k | E3 | 3917 | |
| 2004Y | Anonymous | Ia | k | E2 | 20760 | |
| 2004ab | N5054 | Ia | fg | Sc I | 1741 | |
| 2004ak | U4436 | II | f? | S | 7214 | 2 |
| 2004ul | ESO 565–G25 | II | g | Sa | ... | |
| 2004am | N3034 | II | ? | Pec | 203 | |
| 2004an | I4483 | II | fg | Sa | 8979 | |
| 2004ao | U10862 | Ib | f | SBb | 1691 | |
| 2004ap | PGC 29306 | Ia | k | E2 | 7177 | |
| 2004aq | N4012 | II | g: | Sa | 4182 | |
| 2004as | Anonymous | Ia | af | S/Irr | 9300 | 9 |
| 2004at | M +10-16-37 | Ia | ? | Irr ? | 6935 | |
| 2004au | M +04-42-2 | II | g | Sa | 7800 | |
| 2004av | ESO 571–G15 | Ia | ? | S | 7057 | 2 |
| 2004aw | N3997 | Ic | ? | St + St | 4771 | 1 |
| 2004ax | N5939 | Ibc | g | Sbc | 6687 | |
| 2004ay | U11255 | IIc | ? | Sc/Irr | 9723 | 2 |
| 2004az | U6853 | Ia | k | E:4 | 8639 | |
| 2004bd | N3786 | Ia | g | Sb pec | 2678 | 3 |
| 2004be | ESO 499–G34 | II | af | S IV: | 2282 | |
| 2004bf | U8739 | Ic | ? | S | 5032 | 2 |
| 2004bh | U5161 | II | g | S/Irr | 10079 | |
| 2004bi | U5894 | Iib | g | Sb | 6537 | |
| 2004bj | M +01-34-13 | Ia | k | E0 | 15033 | |
| 2004bk | N5246 | Ia | gk | SBb | 6906 | |
| 2004bl | M +00-31-42 | Ia | ? | S/Irr | 5192 | 2 |
| 2004bm | N3437 | Ic | g: | Sbc ? | 1283 | |
| 2004bn | N3441 | II | g | Sa: | 6533 | |
| 2004bo | ESO 576–G54 | Ia | k | E3 | 7024 | |
| 2004bq | ESO 597–G32 | Ia | gk | Sa: | ... | |
| 2004br | N4549 | Ia-pec (91T/00cx) | k | E1 t? | 6943 | |
| 2004bs | N3323 | Iib | fg | S(B)9b | 5164 | |
| 2004bt | U9178 | Unknown | f | S(B)9c: | 8704 | |
| 2004bv | N6907 | Ia-pec (91T) | ? | S pec | 3161 | 3 |
| 2004bw | M +00-38-19 | Ia | fg | Sc | 6355 | |
| 2004by | N7116 | II-pec | ? | Sb | 3532 | 3? |
| 2004bz | M +02-56-25 | Ia | g | Sab: | 10232 | |
| 2004ca | U11799 | Ia | ? | S | 5338 | 10 |
| 2004ci | N4568 | Ic | f: | S pec | 2255 | 3 |
| 2004cm | N5980 | II | g | Sb | 4092 | |
| 2004cn | N5486 | II | g | Sbc: | 1390 | |
| 2004cq | U9882 | Ia | ? | S | 6595 | 2 |
| 2004cs | U11001 | Ibc | f | Sc pec | 4215 | |
| 2004cu | N5550 | Iib | fg: | Sbc: | 7427 | |
| 2004db | N7377 | Ia | k | E:2 | 3351 | |
| 2004dc | I1504 | Ic | fg | Sb: | 6271 | |
| 2004dd | N124 | II | fg | Sc | 4060 | |
| 2004dh | M +04-01-48 | II | f | S | 5794 | |
| 2004dj | N2403 | II | f | Sc III | 131 | 11 |
TABLE 1 (Continued)

| SN (1) | Galaxy (2) | SN Type (3) | Yerkes Type (4) | DDO Type (5) | Redshift (km s⁻¹) | Remarks (7) |
|-------|------------|-------------|-----------------|--------------|------------------|-------------|
| 2004dk ... N6118 | Ic | f | Sbc II | 1573 |
| 2004dn ... U2069 | Ic | ? | Sc III-IV | 3779 |
| 2004dr ... ESO 479−G42 | II | af | S pec | 6917 |
| 2004ds ... N808 | II | f | Sb II | 4964 |
| 2004dt ... N799 | Ia | g | Sbc | 5915 |
| 2004du ... U11683 | IIn | ? | S | 5025 |
| 2004dv ... M −01-06-12 | II | f | Sc pec? | 4754 |
| 2004dy ... I5090 | II | g | Sb: | 9340 |
| 2004dz ... Anonymous | Ia | f | S/Irr | ... |
| 2004ea ... M −03-11-19 | Ia | af | S pec | 1953 |
| 2004eb ... N6387 | II | ? | St? | 8499 |
| 2004ef ... U12158 | Ia | g | Sc I | 9290 |
| 2004eg ... U3053 | II | ? | Sc? | 2407 |
| 2004ep ... I2152 | II | gk | Sb II: | 1875 |
| 2004er ... M −01-07-24 | II | fg | Sbc: | 4411 |
| 2004es ... U3825 | II | fg | Sc: | 8281 |
| 2004et ... N6946 | II | f | Sc I | 48 |
| 2004ex ... N3430 | II | g | Sc II | 1586 |
| 2004fc ... N701 | II | g | S pec | 1829 |
| 2004fd ... N132 | Ic | g | Sc | 5361 |
| 2004ff ... ESO 552−G40 | Ic | gk | Sb | 6790 |
| 2004fg ... M +05-56-07 | Ia | fg | Sc | 9034 |
| 2004fx ... M −02-14-03 | II | ? | S | 2673 |
| 2004gd ... N2341 | IIn | gk | Sab: | 5227 |
| 2004ge ... U3555 | Ic | g | Sc t? | 4835 |
| 2004gg ... U3053 | II | f | Sc: | 6017 |
| 2004gh ... M −04-25-06 | II | g | S(B?)b | 3662 |
| 2004gi ... M −05-25-32 | Ia | f | Sc | 3244 |
| 2004gj ... I701 | IIb | f | Sc | 6143 |
| 2004gk ... I3311 | Ic | ? | S | −122 |
| 2004gm ... M −02-33-80 | Ia | f | Sab | 4975 |
| 2004gn ... N4527 | Ic | fg | Sbc | 1736 |
| 2004go ... I270 | Ia | k | El | 8745 |
| 2004gp ... N1832 | Ic | g | S(B?)bc II | 1939 |
| 2004gr ... N3678 | II | g | Sc: | 7210 |
| 2004gs ... M +03-22-20 | Ia-pec (91bg) | gk | Sa | 7988 |
| 2004gt ... N4038 | Ic | a | Sc? pec t | 1642 |

Notes.—(1) merger; (2) edge-on; (3) tides; (4) dusty; (5) SN closest to peculiar galaxy; (6) SN in small distant galaxy, not in nearer large SBb; (7) might also be classified E2/Sa; (8) our images of M60 (= NGC 4649) are overexposed, so the adopted E1 classification is from van den Bergh (1960c); (9) has bright Sc II companion; (10) strong Galactic foreground absorption possible; (11) galaxy too large to classify with present images, so we have adopted the Sc III classification from van den Bergh (1960c); (12) bright foreground star superimposed on the nucleus.

IAU Circulars. Supernovae of Type Ia were divided into “normal” and “peculiar” categories on the basis of careful inspection of the spectroscopic information in the IAU Circulars. Objects that showed the strong Si II λ5970 feature or Ti II absorption lines near 4200 Å (which are evidence for a subluminous SN 1991bg–like event; Filippenko et al. 1992b), or weak Si II λ6150 absorption or strong Fe II absorption (which indicates a possibly overluminous, SN 1991T–like event; Filippenko et al. 1992a), were classified as “peculiar” SNe Ia. Also in this category are true mavericks, such as SN 2000cx (Li et al. 2001c) and SN 2002cx (Li et al. 2003; not in the LOSS sample), which cannot be put into the conventional SN Ia classification scheme.

Out of the 604 SNe that have their host galaxies classified in Papers I through III, only 15 SNe (2.5% of the total) were not spectroscopically classified.

4. DISCUSSION

4.1. Frequency Distribution over Hubble Types

In Table 3 the combined data from Table 1 of the present paper and those given in Papers I and II have been sorted by...
host-galaxy Hubble type and by supernova type. Galaxies that could not be confidently assigned to a Hubble type are excluded. Also, the 16 galaxies listed in Table 2 have been removed from the statistics. In doing the statistics that are discussed below, galaxies of intermediate morphology such as Sc/Irr were counted as 0.5 Sc and 0.5 Irr. By the same token, one supernova (SN 2002bt) that occurred in UGC 8584, a triple-galaxy system with DDO type “St/E/S,” was counted as 0.33 St, 0.33 E, and 0.33 S. The new data show patterns that are broadly similar to those previously found in Papers I and II.

A Kolmogorov-Smirnov (K-S) test shows no significant difference between the distributions of the small numbers of SNe IIb and SNe IIn over Hubble type. Similarly, no significant difference is found between the distribution over Hubble types of normal SNe II and of the combined data for SNe IIb and SNe IIn. In the subsequent discussion, the data on all 209 SNe II have therefore been combined.

A comparison between the distributions over Hubble types of normal SNe Ia and of SNe II is shown in Figure 1. Normal SNe Ia are common among early-type (E–E/Sa) galaxies, whereas all types of SNe II are rare in such early-type galaxies. A K-S test shows that there is only a 0.01% probability that the SNe Ia and SNe II in our sample were drawn from the same parent population of morphological types.

In Paper II we discussed five SNe Ibc and SN II that unexpectedly occurred in early-type galaxies. Two additional objects of this type occur in the new data contained in Table 1: SN 2004V, whose host galaxy we assign type E0, and SN 2004X, which occurred in a host that was assigned to type E3. The host galaxy of SN 2004V is small (0.3 × 0.2), and our classification based on the low-resolution images is quite uncertain. Clearly it would be important to use images obtained with larger telescopes (or with HST) to search for a subpopulation of massive young stars in these two host galaxies, which appear to be of very early type. Another approach is to measure the integrated colors for all the early-type galaxies in our sample and search for possible differences between the galaxies with recorded core-collapse SNe and all the others. This is beyond the scope of the current paper. However, here we give two examples for which we have some relevant information. From de Vaucouleurs et al. (1991), we find that NGC 3720, an “E1” galaxy that is the host of the Type II SN 2002at, has quite blue colors of $B - V =$

![Normalized Frequency Distribution](image)

**Fig. 1.**—Normalized (total = 100) frequency distribution of SNe Ia and SNe II vs. host-galaxy Hubble types.
0.69 ± 0.01 mag and $U - B = 0.01 ± 0.03$ mag. This suggests that it does indeed contain a significant young-population component. On the other hand, NGC 2768, an “E3/Sa” galaxy that is the host of the Type Ib/c SN 2000ds, has quite red integrated colors of $B - V = 0.99 ± 0.01$ mag and $U - B = 0.53 ± 0.01$ mag, implying that it is dominated by an old population.

Inspection of the numbers in Table 3 also shows that most peculiar SN 1991bg–like SNe Ia occur in early-type (E or E/ Sa) galaxies. On the other hand, the majority of peculiar SN 1991T–like SNe Ia were discovered in intermediate-type spirals. Figure 2 shows the Hubble-type distribution of the host galaxies of various subclasses of SNe Ia, and we clearly see the dichotomy between early-type hosts for the SN 1991bg–like objects and late-type hosts for the SN 1991T–like ones. A K-S test shows that there is only a 0.1% probability that the SN 1991T–like and the SN 1991bg–like objects were drawn from the same parent population. The observed difference is in the sense that would be expected if the more luminous SN 1991T–like objects have younger progenitors than do the fainter SN 1991bg–like objects. A K-S test shows that the distribution over Hubble type of the 12 SN 1991T–like SNe Ia does not differ significantly from that of “normal” SNe Ia. On the other hand, there is only a 0.01% probability that the normal SNe Ia and the SN 1991bg–like ones were drawn from the same parent population. The observed difference is in the sense that would be expected if the subluminous SN 1991bg–like SNe Ia (which mostly occur in E and E/Sa galaxies) typically have old progenitors. Similar results have previously been obtained by Hamuy et al. (1996, 2000) and by Howell (2001).

A comparison between the distributions over Hubble types of normal SNe Ia and SNe Ibc shows that there is only a 0.04% probability that these two samples were drawn from the same parent population. On the other hand, a K-S test shows no significant difference between the distributions over Hubble types of SNe Ibc and the sum of all three subtypes of SNe II. We therefore conclude that SNe Ibc and SNe II occur among similar stellar populations.

It should be noted that the frequency distributions discussed above may be affected by several selection effects and observational biases. For example, the distribution reflects the SNe discovered in the sample of galaxies monitored by LOSS. As discussed by Li et al. (2001b), the LOSS sample galaxies were selected from several large galaxy catalogs, and the very late-type spiral (Scd, Sd, and Sdm) and irregular (Irr) galaxies are underrepresented. More generally, galaxies having low optical luminosity or low surface brightness are underrepresented. Observational biases, such as the Malmquist bias caused by the differences in the intrinsic luminosities of SNe, may also affect the apparent frequency distribution of the host-galaxy types. A more detailed discussion of the various observational biases that affect the discovery rate of SNe Ia can be found in Li et al. (2001a). The intrinsic frequency distributions of various types of SNe in galaxies of different Hubble types (i.e., the SN rates) will need to consider all of the selection and observational biases. The SN rate calculation for LOSS is currently being investigated, and the initial results are reported in Leaman et al. (2004). Finally, inspection of the data in Table 3 suggests that one of us (S. vdB.) had a strong classification bias in favor of Hubble types Sa, Sb, and Sc, and against the intermediate types Sab and Sbc.

### 4.2. Frequency Distribution over Broader Morphological Classes

The images of many of the distant host galaxies are so small that it is not possible to assign them with confidence to a Hubble type. Nevertheless, many of these objects can be placed in the broader “spiral” category. Furthermore, it is often difficult (or impossible) to distinguish between E and S0 galaxies on the Schmidt images of the Palomar Sky Survey. Consequently, only highly flattened [(1 – b/a) ≈ 0.7] objects are classified as being of type S0 on the DDO system. In order to take maximum advantage of the present observational material, we have therefore sorted the supernova host galaxies into morphological classes E, S0, S, Irr, other, and “?” (Table 4). Again, galaxies of intermediate morphology were counted in all possible morphologies, according to their probabilities. SN 1999gf, for example, with a host galaxy having a DDO type “cD” or “E/Sa,” was counted as 0.25 E and 0.25 S in Table 4.
These data allow one to compare the distribution of 200 normal SNe Ia with that of 251 SNe of types II, Iib, and IIn. A K-S test shows that there is only a 0.3% probability that these two samples were drawn from the same parent population. This result is less significant than the 0.01% probability that was previously found from the data in Table 2, showing that the confidence in our results is more dependent on accurate morphological classifications than on sample size. A similar conclusion can be drawn from a comparison of the 200 normal SNe Ia and the 88 SNe Ibc in Table 4. A K-S test shows that the probability that these samples were drawn from the same parent population is 1%, compared to a 0.04% probability found from the smaller number of normal SNe Ia and the SNe Ibc in Table 3. Clearly, fine morphological subdivision is important when the properties of supernovae are a sensitive function of the Hubble types of their host galaxies.

### 4.3. Frequency Distribution over Yerkes Morphological Classes

In the Yerkes classification system (Morgan 1958, 1959), galaxies are classified according to their central concentration of light. Such a classification system has the advantage that it is more easily adapted to automatic digital classification than is Hubble’s tuning-fork system. Yerkes classifications of the host galaxies of newly discovered supernovae are listed in Table 1. As expected, these data show that the host galaxies of normal SNe Ia are, on average, more centrally concentrated than those of SNe II (including SNe Iib and IIn). However, mainly due to the smaller database of Yerkes types, this result is of lower statistical significance than the comparable result from the Hub-

### TABLE 4

| Galaxy Type | Ia | Ia(T) | Ia(bg) | Ibc | II | Iib | IIn |
|-------------|----|-------|--------|-----|----|-----|-----|
| E           | 37.58<sup>a</sup> | 1.5 | 18.5 | 1.5 | 3 | 0 | 1 |
| S0          | 2.5 | 0 | 1.5 | 1 | 2 | 1 | 0 |
| S           | 146.92<sup>b</sup> | 12.5 | 15 | 82.5 | 193.5 | 11 | 27.5 |
| Irr         | 4.5 | 0 | 0 | 0 | 3 | 0 | 1 |
| Other       | 3.5 | 0 | 0 | 2 | 4 | 0 | 1.5 |
| ?           | 5 | 0 | 1 | 1 | 1.5 | 0 | 1 |
| Total       | 200 | 14 | 36 | 88 | 207 | 12 | 32 |

<sup>a</sup> The fractional number 0.58 comes from $0.33 + 0.25$, due to SN 2002bt (which occurred in a triple-galaxy system) and SN 1999gf (with a DDO type of “cD or E/Sa”); see text for details.

<sup>b</sup> The fractional number 0.92 comes from $0.67 + 0.25$, which is due to SN 2002bt (occurred in a triple-galaxy system) and SN 1999gf (with a DDO type of “cD or E/Sa”); see text for details.

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