A MORPHOLOGICAL CATALOG OF GALAXIES IN THE *HUBBLE DEEP FIELD*

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ABSTRACT

We present a catalog of morphological and color data for galaxies with $21 < I_{814} < 25$ mag in the *Hubble Deep Field* (Williams *et al.* 1996). Galaxies have been inspected and (when possible) independently visually classified on the MDS and DDO systems. Measurements of central concentration and asymmetry are also included in the catalog. The fraction of interacting and merging objects is seen to be significantly higher in the *Hubble Deep Field* than it is among nearby galaxies. Barred spirals are essentially absent from the deep sample. The fraction of early-type galaxies in the *Hubble Deep Field* is similar to the fraction of early-types in the Shapley-Ames Catalog, but the fraction of galaxies resembling archetypal grand-design late-type spiral galaxies is dramatically lower in the distant HDF sample. © *1996 American Astronomical Society.*

1. INTRODUCTION

Recently published results from the *Hubble Deep Field* (HDF) survey (Abraham *et al.* 1996a), in conjunction with earlier data from the *Medium Deep Survey* (MDS) (Griffiths *et al.* 1994; Glazebrook *et al.* 1995; Driver *et al.* 1995; Abraham *et al.* 1996b), and samples of local galaxies such as that given in the Shapley-Ames Catalog (SAC) (Shapley & Ames 1932), allow one to study the morphological evolution of galaxy populations as a function of look-back time. On the basis of bulk measurements of central concentration, C, and asymmetry, A, for galaxies in the HDF and MDS (calibrated using an artificially redshifted sample of local galaxies with Hubble types earlier than Scd), Abraham *et al.* (1996a) conclude that by $I_{814}=25$ mag[1] the fraction of "peculiar" objects has risen to at least 30% of the galaxy population. The exact nature of these peculiar systems remains enigmatic: they may be luminous very-late-type spirals or irregulars seen in the rest-frame ultraviolet, mergers, or else systems with no local counterpart. The UV-optical colors of these peculiar systems suggests that a substantial fraction of faint peculiars might be at very high redshifts ($z>3$).

Parameters such as C and A have the important benefit of being objective *measurements*, but these simple parameters describe only a subset of the morphological information contained in the HDF images, and are not designed to detect relatively subtle features (e.g. bars and tidal tails), which at present still require subjective visual inspection (and human expertise) in order to be detected. In the present paper we present a morphological catalog of $21<I_{814}<25$ mag galaxies in the *Hubble Deep Field*, including both visual classifications on the MDS (Glazebrook *et al.* 1995; Abraham *et al.* 1996b) and DDO (van den Bergh 1960a, 1960b) systems, as well as measurements of the morphological parameters C and A studied in Abraham *et al.* (1996a). The plan of this paper follows. In Sec. 2 we describe the format of the HDF catalog, and outline the steps that have been taken in order to allow meaningful comparisons to be made between the visual classifications of objects in the HDF and visual classifications in the MDS and SAC. In Sec. 3 we show specific examples of different classes of peculiar objects, in order to clarify the terminology used in the catalog. In Sec. 4 we discuss the relative fractions of various morphological types in the HDF, MDS, and SAC catalogs. A number of model-independent statements can be made directly from this comparison, which both support and expand upon the conclusions given in Abraham *et al.* (1996a). A major new conclusion is that both barred and "grand-design" spiral structure is rare in HDF galaxies. In Sec. 5 we attempt to understand more about the nature of peculiar systems in the *Hubble Deep Field*, by determining the fraction of peculiar

[1]Note that the WFPC2 filters only crudely approximate the "standard" Johnson filter set. To emphasize this, in the present paper we will use subscripts to denote specific filters in the WFPC2 filter set, i.e., I_{814} is the WFPC2 F814W filter.

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galaxies that show evidence for tidal interactions. New evidence is presented suggesting that a substantial fraction of the peculiar systems in the HDF and MDS are tidally distorted. Section 6 summarizes our conclusions.

2. THE HDF CATALOG

The HDF data catalog is presented in Table 1 which has a format similar to that of the MDS data recently published by Abraham *et al.* (1996b). The table lists (1) the galaxy ID number, (2) the J2000 coordinates, (3) the pixel coordinates on the version 2 "drizzled" HDF frames released by STScI,[2] (4) the I_{814} magnitude, (5) the $U_{300}-B_{450}$ color index, (6) the $B_{450}-V_{606}$ color index, (7) the $V_{606}-I_{814}$ color index, (8) the asymmetry, and (9) central concentration measures from Abraham *et al.* (1996a), (10) the visual classification by RSE into three large bins (E=elliptical, S=spiral, P=irregular/peculiar/merger), (11) the visual classification by vdB on the numerical "MDS system" used by RSE to classify the data in Glazebrook *et al.* (1995), and described in detail in Abraham *et al.* (1996b),[3] and (12) the galaxy classification by vdB on the DDO system. Remarks on the DDO classifications are shown as footnotes, and include, for example, references to a few HDF galaxies that have a peculiar morphology that simulations suggest might possibly be the result of band-shifting effects which will be discussed below. The remarks also draw attention to a few objects classified as E0 which might, in fact, be Galactic foreground stars. All uncertain classifications are followed by a colon. The catalog was constructed using the prescription given in Abraham *et al.* (1996a). (Note particularly that the colors presented have have been obtained using the instrumental calibrations of Holtzman *et al.* 1995). The 42 high-z candidates with red UV-optical colors ($U_{300}-B_{450}>-0.2$) and blue optical-near IR colors ($V_{606}-I_{814}<0.6$), indicating the possible presence of the Lyman discontinuity in the U_{300}-band spectral energy distribution (Steidel *et al.* 1996), are indicated in boldface in the first column. A montage showing all these galaxies is shown in Fig. 1 (Plate 5). The morphological characteristics of these objects are described in Sec. 6 below.

The large redshift range of the HDF and MDS datasets is an important consideration when making comparsions between these surveys and local galaxy catalogs. Bandshifting effects result in the MDS and HDF samples having very inhomogeneous rest-frame color selection criteria. For objects with $z<1$ the effects of bandshifting are (to first order) compensated for by the fact that most nearby galaxy catalogs (such as the SAC) were constructed in the B-band, whereas the MDS and HDF images were obtained in I_{814}-band. However, at higher redshifts galaxies are being observed in the rest-frame ultraviolet, where their morphological properties are less well-understood than in B-band. For fainter galaxies, bandshifting effects have been estimated by comparing the appearance of galaxies in the HDF survey to the results from simulations[4] in which local galaxies (with Hubble types between E and Sc) were artificially redshifted to $z=2$, and to preliminary data from an ongoing U-band survey of local galaxies (being prepared in Cambridge). The main conclusion from these simulations is that faint "chain-like" linear galaxies need to be interpreted with some caution, since the appearance of these objects is quite similar to the expected appearance of distant late-type spirals seen edge-on in the rest-frame ultraviolet.

A major objective of the present catalog is to provide precise classifications for objects using the morphological bins of the DDO system (in which the great majority of local objects find a home). Objects (such as probable mergers) that do not naturally fit into the DDO scheme (or which cannot be "shoe-horned" into the system by assuming a reasonable contribution from bandshifting effects) have been flagged as peculiar by being designated 7 or 8 in the numerical MDS system. Since these objects cannot be classified on the DDO system they have instead been given a general qualitative remark (e.g., "merger," for probable mergers, or "tadpole galaxy" for head-tail systems) in the last column of Table 1. We emphasize that classifying peculiar objects into broad categories (such as mergers) is particularly subjective (see Sec. 5 below), but since the merger fraction is of great interest it seems useful to flag the subset of peculiar galaxies that are at the best candidates for being interacting systems.

It is important to emphasize that many of the objects that cannot be classified into the DDO system exhibit "generic" features similar to those seen in local spiral galaxies (e.g., an amorphous disk with a bulge), but the poorly defined spiral structure in these objects does *not* correspond closely to the images of local archetypal spirals defining the Hubble sequence within the DDO system, or to the artificially redshifted spirals in our (incomplete) local galaxy sample. In addition to peculiar objects that resemble distant spiral galaxies in a general sense, large numbers of peculiar systems are seen that do not resemble spirals at all. For example, inspection of the images of HDF images reveals the existence of a class of head-tail galaxies resembling tadpoles [see Fig. 2 (Plate 6)], which comprise about 3% of the galaxies in the HDF. The only local analog of such an object that we are aware of is NGC 3991, which is illustrated in plate I of Morgan (1958).

"True-color" images of the HDF galaxies brighter than $I=25$ mag were produced by stacking the B_{450}, V_{606}, and I_{814} band frames into blue, green, and red channels. Qualitative remarks on the colors of individual galaxies are also shown in the body of Table 1 and in the remarks to this table. In these remarks we have used the following abbreviations: vB=very blue, B=blue, R=red and vR=very red. In general the "true-color" images revealed that (a) The majority of "tadpole" galaxies were quite blue in color. (b) A few images that appeared chaotic or irregular on the I_{814}-band im-

[2]The first digit in the ID numbers corresponds to the WF/PC2 chip on which the object lies. Note also that positions were originally measured on the version 1 drizzled images, and were converted to version 2 coordinates using $(x,y)_{\mathrm{version\ 1}}=76+(x,y)_{\mathrm{version\ 2}}$ (M. Dickinson, private communication).

[3]The numerical designations are as follows: -1=compact, 0=E, 1=E/S0, 2=S0, 3=Sab, 4=S, 5=Scdm, 6=Ir, 7=peculiar, 8=merger, and 9=defect.

[4]As described in Abraham *et al.* (1996b), the local galaxies used in these simulations are K-corrected on a pixel-by-pixel basis, with the spectral energy distribution appropriate to each pixel estimated from optical colors.

TABLE 1. Catalog of HDF classifications

ID	RA	Dec	X	Y	I	$U-B$	$B-V$	$V-I$	A	C	RSE	vdB	Description
3-296	12 36 57	62 12 59	1646	885	21.02	−0.98	0.74	0.70	0.18	0.35	S	8:	merger? [k]
2-135	12 36 49	62 13 15	246	543	21.12	−0.07	1.35	1.16	0.18	0.41	S	4	multi-nucleus spiral?
3-426	12 36 51	62 12 21	351	1402	21.13	0.21	1.28	1.03	0.08	0.61	E	2	S0 / Sa
4-312	12 36 43	62 12 41	299	1058	21.29	0.43	2.27	2.03	0.13	0.68	E	0	E3 [R]
2-280	12 36 49	62 14 07	1496	1050	21.39	−0.47	1.03	1.35	0.13	0.55	E	3	Sa [R]
4-280	12 36 46	62 11 52	1706	1013	21.49	0.94	1.89	1.39	0.11	0.74	E	0	E1
3-350	12 36 55	62 12 46	1224	1089	21.56	−0.26	1.36	1.67	0.09	0.49	S	4	Sb pec [y]
3-90	12 36 49	62 12 57	390	396	21.56	−0.35	1.24	1.17	0.23	0.55	S	3	Sa pec
2-403	12 36 52	62 13 55	982	1452	21.57	−0.40	0.35	0.63	0.41	0.32	P	8	multiple merger [f,B]
2-134	12 36 49	62 13 14	230	467	21.75	−0.56	0.83	0.73	0.07	0.62	E	0	E3
4-672	12 36 41	62 11 42	1592	1955	21.75	−0.45	1.79	1.52	0.19	0.45	S	3	Sa [g,R]
4-665	12 36 39	62 12 20	536	1950	21.80	−1.00	0.95	1.07	0.21	0.42	S	8?	merger?
4-660	12 36 40	62 12 08	889	1906	21.86	0.20	1.39	1.79	0.05	0.60	E	0	E1
4-147	12 36 45	62 12 46	403	535	21.88	−0.05	1.61	1.85	0.03	0.60	E	−1	E0 (or star)
4-487	12 36 43	62 11 49	1555	1583	21.99	−0.22	1.29	1.78	0.06	0.40	S	4	Sb [R]
3-131	12 36 55	62 13 11	1463	488	21.99	−0.62	2.00	2.11	0.06	0.52	E	0	E0
4-56	12 36 48	62 12 21	1188	309	22.02	−1.02	0.54	1.11	0.16	0.31	S	8	mrg., 5 components [f,v]
3-512	12 36 57	62 12 27	1292	1657	22.02	−0.74	1.20	1.08	0.18	0.32	P	4	1-armed S or merger [x,y]
2-482	12 36 53	62 13 55	886	1661	22.03	−0.45	0.86	1.40	0.10	0.38	S	4	pec
3-543	12 36 56	62 12 21	1144	1749	22.08	−0.64	2.11	2.04	0.05	0.53	E	0	E0
4-18	12 36 49	62 12 17	1362	172	22.08	−0.19	1.53	1.95	0.17	0.44	S	4?	Disk w/ 3 knots [R]
3-283	12 36 57	62 13 00	1775	920	22.14	−0.79	0.75	0.47	0.12	0.39	S	3:	Sa + knot, or merger
3-128	12 36 50	62 12 56	563	517	22.15	−0.71	0.95	0.65	0.10	0.49	S	8?	merger?
4-105	12 36 48	62 12 14	1304	512	22.22	−0.82	0.74	1.39	0.10	0.21	P	5	S(B)c t [x,y]
4-357	12 36 43	62 12 18	885	1216	22.24	−1.02	0.71	1.10	0.07	0.54	E	3	Sa pec
2-553	12 36 55	62 13 55	765	1882	22.24	−0.61	0.62	1.18	0.13	0.28	S	4?	nucleated Ir? [x,y]
2-86	12 36 48	62 13 21	449	445	22.27	−1.10	0.50	0.92	0.12	0.27	S	8	merger (proto-spiral?) [a]
4-683	12 36 38	62 12 31	226	1928	22.27	−0.63	1.88	1.51	0.18	0.33	S	2?	S0?
2-164	12 36 50	62 13 18	265	693	22.27	−0.44	1.61	1.83	0.10	0.32	S	4	distorted spiral [R]
4-455	12 36 44	62 11 43	1782	1434	22.28	−0.77	0.61	1.17	0.26	0.21	P	8	merger [f,x,y]
3-153	12 36 57	62 13 15	1861	549	22.32	−1.10	0.39	0.90	0.39	0.29	P	8	merger [f]
4-137	12 36 47	62 12 30	847	502	22.32	−0.90	0.94	0.70	0.16	0.48	S	3	Sab pec [b]
2-116	12 36 48	62 13 30	679	513	22.34	−0.70	0.71	1.32	0.19	0.32	P	8?	merger?
2-85	12 36 48	62 13 20	434	446	22.37	−1.06	0.74	1.25	0.13	0.23	P	8	Merger (proto-spiral?) [a,x,y]
3-376	12 36 53	62 12 35	771	1199	22.41	−0.76	0.92	0.93	0.19	0.43	S	2?	S0 pec?
4-162	12 36 48	62 11 49	1958	598	22.47	−0.71	1.01	1.51	0.08	0.49	E	3	Sa pec
2-301	12 36 49	62 14 16	1683	1178	22.55	0.01	0.39	0.46	0.25	0.18	P	8	multiple, mergers [B]
4-466	12 36 43	62 11 52	1487	1512	22.56	−0.73	0.29	0.64	0.07	0.64	E	0?	E3 pec?
2-592	12 36 55	62 14 03	978	1971	22.57	−0.41	1.24	1.16	0.07	0.34	S	4	2 nuc. in disk, merger?
4-348	12 36 44	62 12 01	1385	1198	22.58	−0.97	1.23	0.94	0.06	0.33	S	4	Sb pec
2-383	12 36 51	62 14 02	1184	1390	22.62	−0.74	1.05	1.05	0.21	0.43	S	1?	S0? pec [b]
2-139	12 36 46	62 14 08	1725	582	22.66	−0.64	0.55	0.46	0.26	0.57	E	0	E3 [g]
3-312	12 36 55	62 12 49	1271	1013	22.69	−0.62	0.64	1.29	0.14	0.26	P	8	merger [f]
2-352	12 36 50	62 14 19	1709	1307	22.71	−0.97	0.64	1.17	0.09	0.30	P	4	1-arm S + cpct. comp. [b,ac]
4-627	12 36 40	62 12 04	1044	1814	22.72	−0.86	0.50	1.09	0.39	0.30	P	7	tad. gal., mult. nuc.
2-278	12 36 51	62 13 34	527	1096	22.74	−0.58	0.83	1.41	0.04	0.35	S	0:	E1? [R]
3-475	12 36 52	62 12 21	501	1481	22.74	−1.00	1.00	0.71	0.09	0.62	E	0	E4
4-341	12 36 45	62 11 54	1588	1174	22.77	1.38	1.00	0.60	0.36	0.31	P	8	merger, in group [R]
4-585	12 36 39	62 12 28	385	1737	22.78	−0.25	0.54	0.52	0.15	0.31	P	8	S + St, merger
3-174	12 36 50	62 12 52	523	620	22.79	−0.62	1.16	1.06	0.07	0.20	S	8?	merger? [a,x,y]
3-294	12 36 56	62 13 01	1602	812	22.80	−0.75	0.56	1.29	0.06	0.53	E	0	E0 [R]
4-626	12 36 40	62 12 06	1002	1773	22.81	0.42	0.63	0.65	0.20	0.58	E	3	Sa pec [g]
2-121	12 36 49	62 13 19	348	533	22.84	−0.73	0.50	0.89	0.16	0.49	S	4?	Sbt?
2-445	12 36 52	62 14 05	1214	1572	22.85	−0.75	1.00	1.17	0.45	0.34	P	8	multiple merger [ae]
4-258	12 36 44	62 12 40	413	909	22.87	−1.04	0.54	1.21	0.14	0.26	P	8	merger [f]
3-629	12 36 56	62 12 11	1000	1983	22.87	−0.62	0.98	0.66	0.12	0.35	S	3	Sab pec
2-220	12 36 49	62 13 52	1094	966	22.91	−0.95	0.53	1.20	0.31	0.21	P	8	multi-component mrg. [x]
3-666	12 36 58	62 12 16	1352	2002	22.91	−0.93	0.32	0.86	0.09	0.48	E	1	E3 / Sa
4-85	12 36 47	62 12 32	831	400	22.92	−0.77	0.77	1.28	0.06	0.47	E	3	Sa
3-581	12 36 58	62 12 23	1483	1851	22.92	−1.14	0.61	0.87	0.08	0.51	E	3	Sa pec
2-84	12 36 48	62 13 19	417	377	22.93	0.20	1.43	1.13	0.04	0.54	E	0	E3

TABLE 1. (continued)

ID	RA	Dec	X	Y	I	$U-B$	$B-V$	$V-I$	A	C	RSE	vdB	Description
2-416	12 36 51	62 14 21	1687	1496	22.93	−0.92	0.92	0.70	0.12	0.31	S	4	peculiar one-arm S? [ad]
4-286	12 36 46	62 11 45	1897	1012	22.94	−1.13	0.16	0.68	0.34	0.22	P	8?	merger? [a,x,y]
4-132	12 36 49	62 11 56	1813	518	22.96	−1.00	0.20	0.66	0.06	0.64	E	0	E2
4-510	12 36 41	62 12 15	814	1594	22.97	0.74	2.14	2.02	0.12	0.64	E	0	E3 [R]
2-520	12 36 55	62 13 32	176	1738	23.02	−0.52	0.50	1.08	0.10	0.28	S	4	S? pec [y]
4-340	12 36 45	62 11 55	1551	1172	23.04	0.13	2.02	2.02	0.12	0.53	E	0	E1, in group
2-535	12 36 53	62 14 18	1452	1825	23.05	−0.58	1.07	0.95	0.06	0.41	S	2	S0 pec [b]
2-243	12 36 48	62 14 17	1806	960	23.06	0.35	0.46	0.55	0.30	0.52	S	0	E3
3-188	12 36 55	62 13 03	1339	642	23.08	−0.11	2.25	2.00	0.17	0.63	E	0	E3 [R]
3-598	12 36 52	62 12 03	302	1888	23.09	2.08	1.31	0.95	0.20	0.71	E	0	E1 t, in cpt. group
3-607	12 36 59	62 12 23	1600	1903	23.11	−1.17	0.92	0.76	0.26	0.26	P	4?	S? [s]
2-140	12 36 46	62 14 08	1736	562	23.13	−1.05	0.45	1.22	0.18	0.50	P	4	S, near E3 [R]
3-651	12 36 52	62 11 58	142	1989	23.13	−0.86	1.19	0.82	0.10	0.30	S	4	S pec [a]
2-187	12 36 47	62 14 14	1832	752	23.14	−0.35	1.29	1.37	0.14	0.43	S	0	E4 pec + star [R]
3-606	12 36 59	62 12 22	1619	1925	23.14	−1.22	0.71	1.00	0.25	0.26	E	3	Sa
2-99	12 36 47	62 13 43	1090	425	23.16	−0.49	0.31	0.66	0.16	0.64	E	0	E0 t
3-365	12 36 50	62 12 26	119	1158	23.18	−0.85	0.30	0.90	0.27	0.39	S	3:	? [h]
3-169	12 36 49	62 12 46	170	620	23.19	−0.99	0.94	0.78	0.18	0.35	S	7	pec
3-367	12 36 50	62 12 27	133	1142	23.21	0.10	0.46	0.53	0.26	0.38	S	7	tadpole galaxy [l]
2-74	12 36 47	62 13 32	798	349	23.21	−1.13	0.58	1.35	0.07	0.24	S	4?	clumpy, has nucleus [x,y]
2-299	12 36 49	62 14 15	1663	1184	23.24	0.20	0.50	0.69	0.25	0.24	P	8	multiple, mergers [B]
2-127	12 36 48	62 13 24	503	510	23.24	−0.80	0.37	0.55	0.28	0.38	E	6?	E0 t + Ir? [z]
4-270	12 36 44	62 12 27	743	962	23.26	0.27	0.45	0.69	0.16	0.49	S	4?	merger or Sa pec [b]
4-282	12 36 45	62 12 02	1435	1004	23.27	−1.08	0.93	1.11	0.21	0.36	S	4?	pec, three nuclei
3-111	12 36 51	62 13 00	700	452	23.28	−0.64	0.60	0.52	0.13	0.23	P	6	Ir
2-585	12 36 55	62 14 01	908	1958	23.29	−0.91	0.92	0.98	0.13	0.33	S	4	disk [b,h]
3-481	12 36 53	62 12 23	639	1489	23.31	−0.78	0.24	0.33	0.30	0.40	S	8	merger [f,B]
3-589	12 36 59	62 12 26	1756	1874	23.35	−0.09	0.37	0.39	0.17	0.25	P	8	merger [f,B]
4-625	12 36 41	62 12 03	1073	1749	23.36	1.74	0.95	0.53	0.29	0.40	P	0	E1, in a group
3-297	12 36 56	62 12 58	1570	891	23.37	−0.70	1.20	1.01	0.14	0.41	S	2	S0 pec
4-678	12 36 39	62 12 12	749	1956	23.40	−0.87	1.20	1.77	0.11	0.57	E	0	E1 [vR]
2-380	12 36 52	62 13 46	734	1382	23.41	−0.03	0.32	0.45	0.32	0.30	P	8	multiple merger [f,vB]
2-96	12 36 49	62 13 12	220	398	23.42	−0.86	0.37	1.01	0.20	0.58	E	3	Sa
3-60	12 36 54	62 13 14	1425	373	23.43	−1.04	0.87	0.79	0.08	0.39	S	8?	Ir? or merger
2-313	12 36 53	62 13 24	190	1193	23.44	−0.32	0.26	0.44	0.27	0.49	S	7	St + inter. comp. [B]
4-654	12 36 39	62 12 14	713	1884	23.45	−0.15	1.49	1.79	0.12	0.35	S	4	disk [b,w,R]
3-135	12 36 55	62 13 11	1414	463	23.50	−1.00	0.74	0.56	0.11	0.41	P	8?	?
3-148	12 36 49	62 12 49	275	588	23.52	−0.82	0.97	1.20	0.05	0.48	E	−1	E0 or Star
2-82	12 36 48	62 13 16	368	316	23.53	−0.63	0.81	1.63	0.11	0.35	P	3	Sa pec, merger? [R]
4-31	12 36 47	62 12 51	358	245	23.53	−1.11	0.76	1.08	0.09	0.31	S	4	Sb pec [b]
4-640	12 36 42	62 11 36	1800	1858	23.54	−0.95	0.93	1.18	0.07	0.38	S	3?	pec [b]
2-234	12 36 48	62 14 13	1707	922	23.54	−0.78	0.48	0.99	0.18	0.28	P	7	tadpole galaxy [aa]
4-682	12 36 38	62 12 33	181	1874	23.55	−0.41	0.93	0.66	0.04	0.35	S	2	S0 [l]
4-375	12 36 45	62 11 44	1819	1290	23.55	−1.11	0.74	0.84	0.25	0.36	P	7	tadpole galaxy
4-253	12 36 47	62 11 52	1780	866	23.56	−1.04	0.45	1.10	0.11	0.46	S	3	Sa pec [b]
4-184	12 36 44	62 12 50	231	662	23.60	−0.19	0.28	0.42	0.28	0.25	P	8	merger [f,vB]
4-235	12 36 46	62 12 06	1411	805	23.60	−0.01	0.64	0.57	0.01	0.42	E	0	E1
3-344	12 36 58	62 12 51	1722	1150	23.60	−0.79	0.95	0.61	0.15	0.34	S	4?	Sb?
4-218	12 36 44	62 12 39	484	788	23.61	−0.94	0.45	1.14	0.08	0.17	P	5	Sc pec [a]
2-513	12 36 54	62 13 48	650	1744	23.63	0.37	0.33	0.36	0.27	0.39	S	8	merger [g,B]
4-7	12 36 47	62 12 54	297	187	23.65	1.63	0.97	0.60	0.17	0.30	P	8	merger
4-387	12 36 41	62 12 38	280	1323	23.67	1.39	0.22	0.35	0.25	0.31	P	0?	E2? t [h,B]
2-33	12 36 44	62 14 10	1955	213	23.67	0.33	0.11	0.28	0.28	0.41	P	8	E + fuzz = merger [B]
4-698	12 36 42	62 11 32	1883	1942	23.68	−1.06	0.77	0.50	0.06	0.29	P	4?	faint edge-on disk
3-315	12 36 56	62 12 53	1481	1008	23.69	−0.47	1.30	1.86	0.11	0.37	E	0	E1 t [h,vR]
3-402	12 36 52	62 12 27	473	1287	23.71	0.07	2.00	2.10	0.06	0.54	E	1	E1 / Sa [vR]
2-93	12 36 46	62 13 57	1503	389	23.75	−0.90	0.75	1.28	0.15	0.39	S	3	Sa pec
2-509	12 36 54	62 13 52	755	1734	23.77	−0.97	0.61	1.13	0.09	0.32	S	3	Sa [R]
3-374	12 36 50	62 12 28	282	1179	23.77	−1.07	0.88	1.11	0.19	0.28	P	7	3 nuclei, merger?
4-241	12 36 44	62 12 43	349	827	23.78	−0.56	0.29	0.35	0.26	0.33	P	7	tadpole gal. or mrg. [B]
3-412	12 36 55	62 12 35	1024	1312	23.79	−0.24	1.29	1.87	0.09	0.53	E	1	E4 / S0 [R]

TABLE 1. (continued)

ID	RA	Dec	X	Y	I	$U-B$	$B-V$	$V-I$	A	C	RSE	vdB	Description
3-15	12 36 49	62 13 07	495	173	23.80	−1.01	0.32	1.02	0.14	0.37	S	3?	Sa pec?
3-323	12 36 58	62 12 56	1781	1031	23.80	−1.19	0.93	0.74	0.21	0.40	S	4	S [g]
3-56	12 36 54	62 13 14	1381	354	23.80	0.12	0.35	0.38	0.07	0.60	E	−1	E1 (or star)
4-584	12 36 39	62 12 31	320	1692	23.80	−1.03	0.82	1.06	0.03	0.44	S	3	Sa [g]
4-152	12 36 49	62 11 52	1915	563	23.81	−1.28	0.27	0.94	0.11	0.35	P	7	?
3-279	12 36 55	62 12 53	1243	905	23.81	−0.91	0.63	0.87	0.02	0.30	P	4?	clumpy, edge-on, mrg.?
2-242	12 36 48	62 14 18	1854	967	23.81	0.29	0.40	0.50	0.24	0.36	S	8	merger [B]
4-352	12 36 44	62 11 55	1540	1220	23.82	−1.05	0.43	1.22	0.02	0.32	P	7	?, in group
4-197	12 36 46	62 12 28	827	699	23.88	−0.17	0.45	0.64	0.24	0.35	E	0	E2 t
3-601	12 37 00	62 12 27	1826	1891	23.91	−1.22	0.10	0.71	0.06	0.41	S	3	Sa pec
3-42	12 36 54	62 13 16	1308	278	23.91	−0.94	0.37	0.84	0.09	0.41	S	3	Sa:
4-405	12 36 41	62 12 35	345	1370	23.92	−1.02	0.96	0.94	0.12	0.56	E	0	E1
2-349	12 36 52	62 13 49	874	1298	23.92	−0.87	0.86	0.85	0.04	0.41	E	0	E4
3-531	12 36 54	62 12 18	809	1700	23.92	−0.56	0.29	0.46	0.27	0.31	P	7	Edge-on w/ 3 knots [r,B]
2-228	12 36 48	62 14 15	1772	903	23.94	−1.05	0.42	1.10	0.08	0.57	E	3	Sa pec
4-203	12 36 46	62 12 13	1255	713	23.96	−1.40	0.49	0.73	0.29	0.36	P	7	pec [b]
3-217	12 36 54	62 12 58	1225	739	23.97	−1.40	0.41	1.18	0.25	0.26	P	6	Ir [x,y]
4-103	12 36 47	62 12 15	1271	522	23.98	−1.21	0.80	0.73	0.08	0.47	E	0	E2 [t]
2-131	12 36 45	62 14 12	1874	523	24.01	0.51	0.37	0.38	0.13	0.26	P	8?	? / merger? [B]
2-473	12 36 54	62 13 31	240	1565	24.01	−0.91	0.92	0.87	0.09	0.28	S	4?	1-armed S? prob. merger
2-374	12 36 51	62 14 12	1475	1395	24.01	−0.57	0.15	0.23	0.27	0.30	P	0	E1 + pec, prob. i/a [vB]
4-102	12 36 48	62 12 14	1324	444	24.01	−1.13	0.63	0.98	0.11	0.31	P	6:	Ir?
4-259	12 36 46	62 12 03	1436	891	24.01	−1.18	0.80	0.67	0.17	0.44	S	3	Sa t
3-599	12 36 52	62 12 05	373	1880	24.03	−1.11	0.19	0.70	0.05	0.60	E	0	E3
2-555	12 36 54	62 14 08	1161	1876	24.03	−0.05	0.33	0.34	0.16	0.28	P	8	merger [vB]
3-631	12 36 54	62 12 04	604	1994	24.03	−0.49	0.61	1.14	0.07	0.40	S	3	Sab pec
3-278	12 36 49	62 12 37	162	886	24.04	0.11	0.44	0.54	0.06	0.38	S	3	Sa pec [ag]
2-146	12 36 48	62 13 44	1054	574	24.04	−0.90	0.69	1.15	0.07	0.24	P	8	merger
3-208	12 36 57	62 13 07	1711	694	24.05	0.36	1.76	2.04	0.08	0.45	S	3	Sa [vR]
2-514	12 36 53	62 14 11	1285	1741	24.06	1.38	1.24	0.60	0.14	0.44	S	3	Sa pec [h]
4-209	12 36 47	62 12 03	1514	742	24.06	−1.26	0.60	1.32	0.09	0.25	P	8	merger [R+B]
3-243	12 36 58	62 13 06	1849	787	24.06	−1.03	0.95	0.82	0.21	0.30	P	7	tadpole galaxy
4-555	12 36 40	62 12 33	281	1653	24.08	−0.92	0.39	0.94	0.17	0.46	E	3	S a t [i]
3-406	12 36 59	62 12 50	1998	1306	24.09	−0.76	0.34	0.74	0.13	0.39	S	3	Sa
2-285	12 36 50	62 14 00	1268	1099	24.09	−0.82	0.25	0.71	0.08	0.50	E	3	Sa pec (outer knot)
2-298	12 36 49	62 14 15	1674	1142	24.10	−1.17	0.60	1.19	0.11	0.25	P	6	Ir [e,R]
3-268	12 36 50	62 12 43	276	767	24.10	−1.17	0.49	0.88	0.13	0.25	P	7	clumpy, edge-on [j]
4-608	12 36 42	62 11 46	1560	1782	24.10	−0.74	0.22	0.39	0.25	0.37	P	8?	pec [B]
4-273	12 36 46	62 12 00	1494	969	24.12	−0.87	1.18	0.82	0.02	0.27	S	4	St
2-275	12 36 50	62 14 02	1324	1089	24.13	0.84	0.44	0.49	0.20	0.42	S	8	merger [B]
2-579	12 36 52	62 14 37	1960	1944	24.13	−0.70	0.99	0.58	0.12	0.29	S	8?	2 nuc. in disk, merger?
3-610	12 36 55	62 12 12	938	1917	24.14	−0.62	0.36	0.73	0.12	0.50	S	0	E1
4-350	12 36 43	62 12 28	624	1199	24.15	−1.12	0.46	1.07	0.08	0.49	S	0	E2 pec, in group [b]
2-548	12 36 55	62 13 50	641	1872	24.17	−1.04	0.41	1.12	0.13	0.46	S	0	E1 [R]
2-167	12 36 47	62 14 04	1559	673	24.18	−0.54	0.39	0.43	0.03	0.33	P	6	Ir, near star [vB]
2-353	12 36 53	62 13 31	360	1302	24.18	1.61	1.04	0.58	0.40	0.34	P	0	E1 + E2, prob. i/a
2-124	12 36 47	62 13 54	1358	511	24.19	−0.91	0.94	0.76	0.11	0.29	S	6?	dIr / merger?
4-628	12 36 40	62 12 05	996	1811	24.21	−0.80	0.91	1.51	0.05	0.47	E	0	E: 3 [g,R]
2-346	12 36 50	62 14 15	1633	1275	24.21	−0.79	0.53	1.07	0.11	0.25	P	6?	Ir?
3-393	12 36 52	62 12 30	630	1264	24.22	0.23	1.45	1.43	−0.01	0.28	S	2:	S0: [R]
4-596	12 36 40	62 12 21	567	1765	24.23	−1.00	0.84	0.67	0.26	0.21	P	8	merger
4-242	12 36 44	62 12 44	305	876	24.23	−0.88	1.85	1.89	0.12	0.39	S	0	E0 t [vR]
2-65	12 36 45	62 14 06	1807	299	24.23	−0.15	0.37	0.65	0.08	0.41	P	4?	compact, clumpy [B]
4-317	12 36 45	62 11 55	1586	1125	24.25	−0.65	0.56	1.02	0.10	0.49	E	0	E0 t [g]
3-623	12 36 58	62 12 18	1446	1960	24.25	−0.65	1.13	0.91	0.05	0.35	S	3	Sab
3-409	12 36 50	62 12 22	214	1310	24.28	−1.26	0.79	0.79	0.12	0.46	S	3	Sa
3-578	12 36 58	62 12 25	1574	1839	24.29	–	2.08	1.02	0.19	0.33	P	8	merger
3-264	12 36 49	62 12 49	330	610	24.30	1.27	1.22	0.65	0.13	0.56	E	0	E1 pec
4-92	12 36 49	62 12 08	1527	405	24.30	−0.93	0.67	1.27	0.10	0.37	S	3	Sa pec [b,R]
4-494	12 36 41	62 12 30	428	1515	24.31	0.13	0.54	0.73	0.08	0.25	S	4?	S pec or merger
2-40	12 36 46	62 13 29	779	244	24.31	−0.34	1.00	0.66	0.12	0.18	P	6	Ir

TABLE 1. (continued)

ID	RA	Dec	X	Y	I	$U-B$	$B-V$	$V-I$	A	C	RSE	vdB	Description
2-443	12 36 54	62 13 36	376	1541	24.31	−0.76	0.40	1.16	0.09	0.23	S	7	core + disk [b]
4-260	12 36 46	62 12 05	1400	902	24.32	−1.15	0.12	0.54	0.15	0.24	P	7	tidal debris? [B]
3-300	12 36 57	62 12 56	1618	966	24.33	−1.35	0.93	0.80	0.12	0.33	S	3	Sa
4-109	12 36 48	62 12 16	1284	431	24.33	0.48	0.97	1.09	0.36	0.28	P	8	merger
2-104	12 36 48	62 13 25	557	445	24.35	−1.01	0.22	0.72	0.15	0.47	S	3	Sa
2-224	12 36 50	62 13 43	875	908	24.36	−0.73	0.36	0.74	0.12	0.37	S	8	elongated, pec
4-556	12 36 42	62 11 51	1463	1668	24.36	−1.30	0.20	0.72	0.06	0.46	E	0?	E2 pec?
4-570	12 36 41	62 12 01	1155	1716	24.36	−1.23	1.16	0.77	0.04	0.27	S	7	S pec or Ir
4-313	12 36 43	62 12 38	383	1073	24.36	0.72	0.36	0.31	0.24	0.35	P	6	merger [B]
4-78	12 36 46	62 12 54	229	385	24.37	−1.13	0.47	1.23	0.04	0.40	S	3	Sa
4-589	12 36 42	62 11 39	1784	1731	24.38	−0.91	0.24	0.65	0.04	0.43	S	3	Sa:
3-617	12 36 53	62 12 03	382	1948	24.39	−0.04	0.33	0.42	0.26	0.34	P	8	merger [f,B]
4-671	12 36 40	62 11 53	1277	1941	24.39	−0.84	0.45	0.53	0.09	0.42	S	3	Sa
2-290	12 36 48	62 14 22	1917	1082	24.40	−0.97	0.22	0.90	0.11	0.47	S	0	E2t + Sa:t
4-454	12 36 44	62 11 45	1759	1374	24.42	−1.23	0.65	0.79	0.14	0.46	S	0	E2 pec [i]
3-399	12 36 58	62 12 46	1671	1282	24.42	−1.04	0.73	1.14	0.03	0.43	S	3	Sa
2-401	12 36 50	62 14 28	1922	1438	24.43	−0.91	0.64	0.86	0.06	0.43	S	0	E4
4-274	12 36 43	62 12 41	361	953	24.44	0.11	3.78	1.35	0.15	0.49	S	1	E0 / Sa t
4-562	12 36 41	62 12 11	893	1691	24.45	−0.82	1.08	0.80	0.01	0.36	S	0	E0
4-63	12 36 49	62 12 15	1362	330	24.45	−1.21	0.41	1.03	0.30	0.26	P	8	merger
3-621	12 36 55	62 12 09	836	1960	24.46	−1.49	0.35	1.24	0.25	0.26	P	7	tadpole galaxy
2-531	12 36 55	62 13 37	316	1797	24.47	−1.18	0.47	0.98	0.05	0.34	S	3	Sa pec
3-572	12 36 55	62 12 16	989	1823	24.47	−0.81	0.22	0.62	0.10	0.27	S	4	S pec [B]
2-571	12 36 54	62 14 08	1137	1921	24.48	−0.54	0.26	0.50	0.15	0.46	S	3	Sa: [B]
4-576	12 36 39	62 12 37	151	1711	24.48	−0.31	0.41	1.28	0.09	0.30	S	8	merger
2-25	12 36 45	62 13 48	1332	187	24.50	−0.10	0.60	0.42	0.14	0.39	P	8	Ir / merger
3-379	12 36 51	62 12 28	358	1211	24.50	−0.15	0.32	0.27	0.21	0.27	P	8:	tadpole gal. or merger [B]
2-12	12 36 43	62 14 09	1968	120	24.51	0.87	0.45	0.65	0.20	0.25	P	8	Ir / merger
4-372	12 36 42	62 12 32	473	1273	24.54	0.05	0.39	0.50	0.11	0.52	E	0	E2
2-487	12 36 55	62 13 36	354	1643	24.55	−0.83	0.22	0.63	0.06	0.22	S	4?	pec / merger? [B]
2-169	12 36 46	62 14 18	1980	670	24.55	−1.23	0.62	0.96	0.03	0.24	S	?	core + envelope [a]
2-302	12 36 51	62 13 50	962	1144	24.56	2.15	0.73	0.52	0.20	0.40	S	8	Pec + St (merger) [ab]
3-468	12 36 51	62 12 18	304	1461	24.56	0.81	0.53	0.74	0.21	0.38	S	8	binary merger
4-667	12 36 42	62 11 28	1998	1941	24.56	−1.10	0.84	0.83	0.08	0.44	S	0	E1
2-193	12 36 50	62 13 31	589	804	24.57	0.22	0.35	0.46	0.10	0.45	P	8	E + ?, merger [B+vB]
3-183	12 36 54	62 13 01	1159	634	24.58	−0.69	0.50	1.01	0.07	0.25	S	7	pec
2-356	12 36 53	62 13 27	243	1320	24.59	0.59	0.47	0.47	0.14	0.25	P	6	Ir / merger [h,B]
3-462	12 36 53	62 12 24	624	1450	24.59	−1.11	0.58	0.97	0.04	0.52	E	0	E2 [p]
3-526	12 36 57	62 12 28	1364	1656	24.60	−0.63	0.41	0.85	0.02	0.34	P	3	Sa:
4-365	12 36 44	62 11 58	1451	1243	24.60	−1.25	0.62	0.71	0.13	0.52	E	−1	E0 or star
3-511	12 36 58	62 12 31	1504	1633	24.60	−0.83	0.64	0.94	0.14	0.33	S	4	S
2-221	12 36 49	62 13 53	1121	983	24.61	0.19	0.27	0.32	0.18	0.42	S	0	E3 pec, near merger [c,B]
4-355	12 36 43	62 12 16	953	1230	24.61	−1.49	0.76	0.86	0.08	0.21	S	6	Ir
4-227	12 36 48	62 11 47	1952	777	24.61	–	0.87	0.53	0.15	0.38	P	4	S? t
4-509	12 36 44	62 11 35	1997	1472	24.65	–	2.08	1.99	0.08	0.41	S	0	E1 [R i]
3-23	12 36 56	62 13 24	1712	214	24.65	−1.10	1.57	2.01	0.02	0.45	E	3	Sa [vR]
4-179	12 36 46	62 12 33	714	640	24.65	−1.23	0.55	1.19	0.06	0.33	S	1	E6 / Sa
2-22	12 36 45	62 13 45	1260	178	24.65	−1.16	0.71	0.43	0.05	0.36	S	4	E? / Sa pec [b]
2-351	12 36 52	62 13 41	630	1291	24.65	1.95	1.04	0.54	0.21	0.45	S	−1	E0 or Star
4-535	12 36 43	62 11 36	1922	1604	24.66	2.41	2.33	2.02	0.03	0.39	E	−1	E0 or Star [vR]
3-332	12 36 51	62 12 34	417	1060	24.67	−0.42	0.31	0.36	0.10	0.37	S	3	Sa pec [B]
3-57	12 36 54	62 13 13	1313	345	24.69	−1.11	0.05	0.34	0.19	0.35	P	8?	pec or merger [B]
3-425	12 36 51	62 12 22	310	1370	24.69	−1.17	0.36	0.87	0.08	0.44	S	1	E1 / S0 [n]
4-33	12 36 49	62 12 20	1266	224	24.71	0.77	0.46	0.40	0.07	0.39	P	7	? [h]
2-522	12 36 52	62 14 23	1638	1756	24.72	−0.54	0.17	0.33	0.25	0.38	S	7	Star + backround gal.? [B]
3-43	12 36 55	62 13 18	1468	284	24.74	−0.60	1.90	1.73	0.08	0.36	S	−1	E0 (or Star) [R]
4-408	12 36 41	62 12 41	181	1344	24.75	−1.23	1.02	0.98	0.01	0.28	S	3?	Sab pec?
4-165	12 36 46	62 12 26	931	605	24.75	–	0.48	0.26	0.30	0.37	P	0	E0 + E1 t [B]
4-59	12 36 49	62 12 13	1423	305	24.75	0.01	0.37	0.35	0.06	0.39	P	4:	pec [B]
3-298	12 36 56	62 12 56	1564	935	24.76	−0.96	0.44	1.01	0.15	0.34	S	7	? [l]
3-616	12 36 58	62 12 18	1374	1946	24.76	1.09	0.41	0.51	0.03	0.42	S	3	Sa pec

TABLE 1. (continued)

ID	RA	Dec	X	Y	I	$U-B$	$B-V$	$V-I$	A	C	RSE	vdB	Description
3-491	12 36 59	62 12 39	1769	1530	24.77	0.71	1.36	1.36	0.01	0.34	E	−1	E0 or Star [R]
4-90	12 36 47	62 12 36	720	388	24.78	0.35	1.30	0.90	0.04	0.32	E	3	Sa
4-308	12 36 45	62 12 06	1283	1094	24.78	−0.20	0.26	0.36	0.17	0.21	P	8	merger [vB]
4-368	12 36 41	62 12 43	180	1254	24.79	2.05	0.81	0.44	0.01	0.19	S	6	d Ir
2-233	12 36 48	62 14 08	1586	909	24.80	−1.28	1.04	1.53	0.02	0.33	S	3	Sa pec [vR]
2-459	12 36 54	62 13 43	550	1613	24.80	0.66	0.31	0.39	0.24	0.28	P	8	triple merger [af]
4-188	12 36 47	62 12 11	1312	662	24.81	−0.94	0.22	0.49	0.13	0.28	P	5	pec or merger [vB]
4-318	12 36 45	62 11 46	1827	1133	24.82	−0.86	0.25	0.99	0.07	0.39	P	7	?, near bright S
2-467	12 36 55	62 13 32	232	1623	24.83	−0.77	0.30	0.96	0.07	0.32	S	2	E3 / Sa [g]
4-392	12 36 44	62 11 51	1603	1321	24.84	−2.15	3.14	1.77	0.15	0.29	P	4	S: t [vR]
2-367	12 36 51	62 14 09	1393	1368	24.87	−0.69	0.67	1.10	0.03	0.35	S	0?	E1 pec? (tidal tail?)
2-569	12 36 56	62 13 41	373	1923	24.88	1.13	0.41	0.80	0.17	0.24	P	8:	
2-67	12 36 47	62 13 35	893	317	24.88	−1.06	0.37	1.05	0.03	0.27	S	4?	Sb:
4-571	12 36 42	62 11 47	1558	1705	24.89	−1.47	0.33	1.02	0.10	0.36	S	4?	S?
2-526	12 36 54	62 13 49	668	1769	24.91	1.30	0.62	0.48	0.28	0.29	P	7	tadpole galaxy [h,B]
3-494	12 36 56	62 12 30	1279	1562	24.92	−0.67	0.26	0.42	0.09	0.20	P	7	Ir or merger [B]
4-388	12 36 41	62 12 38	266	1351	24.92	0.73	2.77	1.29	0.03	0.40	S	0	E1 [u]
3-448	12 36 52	62 12 26	521	1353	24.92	−0.35	0.23	0.21	0.28	0.34	P	7	tadpole galaxy [B]
3-192	12 36 53	62 12 57	942	653	24.93	−1.20	0.80	0.73	0.00	0.34	S	4	S? [h]
3-465	12 36 53	62 12 25	698	1461	24.94	−0.92	0.13	0.26	0.31	0.28	P	8	binary merger [B]
2-24	12 36 46	62 13 36	998	182	24.95	−1.20	0.58	0.83	0.08	0.33	E	0	E2 [d]
2-463	12 36 52	62 14 15	1465	1617	24.95	−1.30	0.32	1.02	0.17	0.24	P	7	compact / Ir?
3-26	12 36 48	62 13 02	291	219	24.96	−0.85	1.23	0.77	0.03	0.39	E	−1	E0 or Star
2-83	12 36 48	62 13 17	362	360	24.96	−0.38	1.08	0.82	0.03	0.32	S	4?	S pec?, merger
3-267	12 36 50	62 12 44	298	741	24.98	0.24	0.37	0.48	0.02	0.33	P	3:	? [i,B]
2-491	12 36 52	62 14 21	1618	1658	24.99	−0.62	0.23	0.40	0.05	0.38	S	0	E3 pec [b,B]
4-655	12 36 39	62 12 14	710	1916	25.00	1.34	1.04	0.43	0.25	0.47	S	7	pec

[a]possibly a very distant Sc viewed in UV.
[b]asymmetrical.
[c]companion to 2-220.
[d]has faint companions.
[e]companion to 2-299.
[f]good example of merger.
[g]has companions.
[h]has companion.
[i]has bright companions.
[j]companion to 3-267.
[k]has bright bar-like core.
[l]has bright companion.
[m]part of spiral (?) arm of 3-296.
[n]companion to 3-426.
[o]star off center.
[p]companion to 3-426.
[q]companion to 3-517.
[r]chain galaxy?
[s]interacting with 3-606.
[t]companion to 4-105.
[u]companion to 4-387.
[v]gravitational lens?
[w]companion to 4-655.
[x]red nucleus.
[y]blue outer knots.
[z]Ir? companion vR.
[aa]"tadpole" with R head and B tail.
[ab]Pec component vB.
[ac]blue compact companion.
[ad]has one blue arm.
[ae]one component R.
[af]triple merger, all components B.
[ag]or tadpole galaxy.
[af]E1 galaxy is *R*, companion is B.

age contained a single red knot, which can presumably be identified with their stellar nuclear bulge, in the pseudo-color image. In some other images bluish clumps cluster around a relatively red central region. Presumably these are objects that are in the early stage of evolving into conventional spiral galaxies. (c) Although most E galaxies appeared to be red, a few of them had quite blue colors. Presumably these are (proto?) ellipticals that have only recently formed stars, or possibly misclassified stars.

3. REPRESENTATIVE IMAGES OF HUBBLE DEEP FIELD GALAXIES

The following are examples of some of the unique types of objects represented in the HDF catalog, intended to illustrate the general criteria used in the catalog when classifying galaxies as "peculiar."

HDF 2-234 (Fig. 2). $I_{814}=23.54$ mag, $B_{450}-V_{606} = 0.48$. This is a good example of a "tadpole" (head-tail) galaxy. It is, however, slightly atypical because the head is relatively red, whereas the tail is blue. In most tadpole galaxies both the head and tail are blue.

HDF 2-86 [Fig. 3 (Plate 7)]. $I_{814}=22.27$ mag, $B_{450} - V_{606}=0.50$. This image may show an early phase in the formation of a spiral galaxy. The central knot, has a slightly orange tinge in the figure, indicating that at least a few evolved stars are present. It is embedded in a chaotic structure of blue knots in which active star formation presently seems to be taking place.

HDF 2-403 [Fig. 4 (Plate 8)]. $I_{814}=21.57$ mag, $B_{450} - V_{606}=0.35$. This image shows a multiple merger of at least a half dozen blue knots. Most of these knots are seen to have a high surface brightness.

HDF 3-312 [Fig. 5 (Plate 9)].$I_{814}=22.69$ mag,

TABLE 2. Number of different DDO classifications in SAC, MDS, and HDF.

Type	HDF[a]	MDS	SAC
E	68 (33.5)	68 (37.5)	[b]
E/S0	3 (1)	8 (7.5)	208
S0	8 (6)	21.5 (15.5)	[b]
S0/Sa	1 (1)	0 (0)	0
E/Sa	6 (2)	4 (0)	12
Sa	44.5 (20.5)	27 (17)	64.5
Sab	5 (2)	17 (7)	2
Sb	7 (6)	54 (16)	252
Sbc	0 (0)	16 (9)	3
Sc	3 (2)	75 (29)	214.5
Sc/Ir	0 (0)	5 (2)	2
Ir	13 (3.5)	45 (14.5)	19
S	18.5 (18.5)	81.5 (33)	93.5
Unclassified	113 (44)	86 (38)	65.5
Total	290 (140)	508 (226)	936

[a]If two images appeared equidistant from the field center then the classification of the first object was used.
[b]The SAC makes no distinction between E, E/S0, and S0.

$B_{450}-V_{606}=0.64$. This object may represent a spiral galaxy at an early stage in its evolution. It contains a relatively red nucleus, which is located asymmetrically within a structure containing many blue knots. The observed colors suggest that the light of the bulge is dominated by evolved stars, whereas the knots surrounding it contain young blue stars. It is interesting to note that objects such as HDF 3-312, with relatively red bulges surrounded by rather chaotic structure including a number of blue knots, seem to be excellent protospiral candidates, and supply rather direct evidence in support of the widely-held view that bulges form before disks.

HDF 3-531 [Fig. 6 (Plate 10)]. $I_{814}=23.92$ mag, $B_{450}-V_{606}=0.29$. This string of blue knots may be related to the "chain galaxies" recently reported by Cowie *et al.* (1995) and, perhaps, more distantly, to the "tadpole galaxies" discussed above.

HDF 4-105 [Fig. 7 (Plate 11)]. $I_{814}=22.22$ mag, $B_{450}-V_{606}=0.74$. This object, which was classified S(B)ct on the DDO system, is the *only* barred spiral in the entire HDF sample. An alternative interpretation of its morphology is that this object is a peculiar spiral that is being tidally deformed by an elliptical companion. The fact that only one barred spiral is observed in the HDF shows that *the frequency of barred objects is an order of magnitude lower than it is among nearby galaxies*. This point is discussed in more detail below.

TABLE 3. Binned DDO morphological types.

Type	HDF	MDS	SAC
E+S0	79 (40.5)	97.5 (60.5)	208
S0/Sa+E/Sa	7 (3)	4 (0)	12
Sa+Sab	49.5 (22.5)	44 (24)	66.5
Sb+Sbc	7 (6)	70 (25)	255
Sc+Sc/Ir	3 (2)	80 (31)	216.5
Ir	13 (3.5)	45 (14.5)	19
S	18.5 (18.5)	81.5 (33)	93.5
unclassified	113 (44)	86 (38)	65.5

TABLE 4. Percentage of galaxies in various DDO classification bins.

Type	HDF	MDS	SAC
E+S0	27% (29%)	19% (27%)	22%
S0/Sa+E/Sa	2 (2)	1 (0)	1
Sa+Sab	17 (16)	9 (11)	7
Sb+Sbc	2 (4)	14 (11)	27
Sc+Sc/Ir	1 (1)	16 (14)	23
Ir	4 (2)	9 (6)	2
S	6 (13)	16 (15)	10
unclassified	39 (31)	17 (17)	7

4. FREQUENCY OF MORPHOLOGICAL TYPES

Because the comparison between the morphologically segregated number counts and no-evolution models presented in Abraham *et al.* (1996a) is dependent upon assumptions made with regard to the normalization and faint-end slope of the local luminosity function, it is interesting to consider what model-independent statements can be made directly from the observed fractions of various morphological types given in Table 1. The numbers of galaxies of various DDO classification types in the HDF, MDS, and SAC[5] are listed in Table 2. These data represent the finest morphological binning that can be made, on a strictly comparable basis, for all three surveys. In Table 3 the morphological data have been grouped together into somewhat wider morphological bins. The corresponding percentages of galaxies in each classification bin are given in Table 4. Finally, Table 5 lists the coarsest possible binning within the DDO system in which galaxies have been designated either E/S0 (E, E/S0, S0, S0/Sa, E/Sa), or Spiral/Irr (Sa, Sab, Sb, Sc, Sbc, Sc/Ir, Ir, S), or "not classified." In Tables 2–5 below (and in the next paragraph) the numbers given in parentheses correspond to values for $I_{814}<24$ mag in the HDF, and $I_{814}<21$ mag in the MDS. Because the morphological classification of galaxies in both the HDF and MDS samples was extended to rather low signal-to-noise limits, the numbers in parentheses are our most robust (and conservative) estimates.

Inspection of the data in Tables 2–5 shows that the fraction of unclassified galaxies in the DDO system rises from 7% in the SAC to 39% (31%) in the distant HDF sample. In other words, almost half the galaxies in the HDF cannot be directly incorporated into the Hubble scheme (cf. Abraham *et al.* 1996a). While the interpretation of this result is somewhat sensitive to the (currently unknown) redshift distribution of galaxies in the HDF and MDS, the fraction of peculiar systems in the MDS and HDF is nearly an order of

[5]The only differences between the DDO morphological classification systems used for classifying galaxies in the *HST* data, and the system used to classify galaxies in the SAC, are as follows: (1) E and S0 galaxies could not be distinguished on the prints of the *Palomar Observatory Sky Survey* (POSS) used for the SAC, and therefore both classes of object were denoted by E in van den Bergh (1960c). (2) "Probable collisions" in the SAC are referred to as "probable mergers" in the classification of MDS and HDF galaxies. Both the classifications of MDS and HDF galaxies were made by interactive inspection of images that displayed intensity on a logarithmic scale. This made these images quite comparable in texture and contrast to SAC galaxies classified on the POSS prints. The present data are therefore well-suited to an intercomparison between the galaxy populations in the HDF, MDS, and SAC.

TABLE 5. Coarse binning of galaxy classifications.

Type	HDF[a]	MDS	SAC
E/S0	30% (31%)	20 (27%)	24%
S/Irr	31% (38%)	63 (56%)	69%
not classified	39% (31%)	17 (17%)	7

magnitude greater than the fraction of very-late-type spirals predicted from no-evolution models (Glazebrook *et al.* 1995, Abraham *et al.* 1996a, 1996b). It thus appears that the majority of MDS and *HST* "peculiars" do not appear distorted as the result of bandshifting effects. *An even more dramatic evolution occurs for barred spirals* which account for 22% of the nearby SAC sample, 4% of the MDS galaxies and only 0.3% of the distant objects in the HDF. On the other hand, the fraction of E/S0 galaxies remains approximately constant from nearby Shapley-Ames galaxies at $24\% \pm 2\%$, to distant HDF galaxies at $30\% \pm 3\%$ ($31\% \pm 5\%$). It is emphasized that while redder galactic features (e.g., bars) may appear dimmer at high redshifts due to bandshifting effects, artificial redshifting of local barred spiral galaxies [Figure 8 (Plate 12)] suggests that most bars should be detectable out to redshifts beyond $z = 1.5$.[6]

5. INTERACTING AND MERGING SYSTEMS

The distinction between tidally distorted/merging systems and other categories of peculiar objects is difficult to make without dynamical information. Because this distinction is so important, however, and because some characteristics of tidal interaction are rather evident from visual inspection alone (e.g., tails, multiple nuclei), an attempt has been made to place galaxies in the HDF, MDS, and SAC into in a sequence ranging from objects showing no tidal distortion ($w=0$), through objects showing possible tidal effects ($w=1$), via galaxies exhibiting probable tidal distortions ($w=2$), to possible mergers ($w=3$) and finally to objects that are almost certainly merging ($w=4$). Such information on galaxies in the HDF, MDS, and SAC samples is collected in Table 6. These data allow one to define a normalized interaction index:

$$I_i = \sum_j \frac{w_{ij}}{N_i}, \tag{1}$$

in which w_{ij} is the w value for the jth galaxy in the ith sample, and N_i is the number of galaxies in that sample. From the data listed in Table 1 it is found that $I = 0.96$ for the distant HDF sample, $I = 0.26$ for the MDS galaxies, and $I = 0.18$ for nearby objects in the SAC catalogue. These results show that the normalized interaction index increases precipitously with increasing magnitude (and, by implication, look-back time).

[6]Nuclear bulges are evident in many spiral or spiral-like systems in the HDF. If bars and bulges are of similar color, as is the case locally, then prominent bars and bulges should be detectable to similar redshifts.

TABLE 6. Frequency of tidal interactions and mergers.

Survey	$t?$ ($w=1$)	t ($w=2$)	$m?$ ($w=3$)	m ($w=4$)
HDF	2	20	27	39
MDS	19	37	8	4
SAC	22	65	0	3[a]

[a]Objects listed as "colliding" in SAC.

6. DISCUSSION

Intercomparison of galaxies in the SAC, MDS, and HDF catalogs allows one to probe the observed changes in the morphology of galaxies with increasing look-back time. The present results indicate that the observed fraction of Es and S0s remains constant at 1/4 or 1/5 of all galaxies in all three surveys. However the observed fraction of canonical grand design spiral galaxies of types Sb + Sbc + Sc is an order of magnitude smaller in the HDF relative to the RSA. In the HDF only 3% of all galaxies belong to types Sb-Sc, compared to 29% in the MDS and 50% in the SAC. The data in Table 5 show that the fraction of galaxies that do not find a home in the DDO/Hubble classification scheme rises steeply from 7% in the SAC to 39% in the HDF. This observation appears consistent with scenarios (Toomre 1977) in which there was "a great deal of merging of sizable bits and pieces (including quite a few lesser galaxies) early in the career of every major galaxy."

The majority (26/42) of high-redshift candidates selected on the basis of red UV-optical colors ($U_{300} - B_{450} > -0.2$) and blue optical-near IR colors ($V_{606} - I_{814} < 0.6$) shown in Fig. 1 are classified as mergers, peculiars, or irregulars on the DDO system (8, 7, or 6 on the MDS system). With effective exposure times an order of magnitude shorter than those of the HDF, Giavalisco *et al.* (1996) found that candidate high-z galaxies (selected on the basis of UV-optical colors) do *not* generally appear to extended and distorted, as reported here. Instead Giavalisco *et al.* find that high-z candidates appeared to exhibit a fairly narrow range of compact and generally spherically symmetric morphologies. They also note that in several cases these compact objects are surrounded by low-surface-brightness asymmetric nebulosities. Many high-z candidate galaxies in the HDF fit this description, but such objects appear to constitute a minority (~30%) of high-z candidates. The possible discrepancy between these results may simply be due to (a) the much greater depth of the HDF images, which can emphasize the extended, irregular structures around compact cores, (b) to the slightly different UV cutoff prescriptions used to define the high-z candidates, or (c) to the relatively small number statistics involved. (There are 19 high-z candidates in Giavalisco *et al.*, but only 11 of these are brighter than $m_{AB} = 25$ mag. In the present HDF catalog 42 high-z candidates are at $I_{814} < 25$ mag).

The relatively constant fraction of ellipticals in the RSA, MDS, and HDF catalogs must be accounted for if merger models for the origin of ellipticals are to prove succesful. The importance of bandshifting effects prevents us from being able to estimate the volume density of ellipticals directly from the observational data, without reference to detailed modelling of the number counts. A determination of the redshift distribution of the ellipticals in the HDF catalog would likely prove extremely interesting: if most early-type galaxies existed before spiral galaxies were assembled (hinted at by the large fraction of ellipticals at faint magnitudes), then ellipticals are unlikely to have formed from merging spirals. A similar conclusion has previously been reached by van den Bergh (1982, 1990) from the observation that the specific frequency of globular clusters in ellipticals is higher than it is in spirals. Recently, Geisler *et al.* (1996) have shown that the peak of the metallicity distribution function of metal-poor globular clusters is located at a systematically higher value of [Fe/H] in ellipticals than it is in spirals. This observation appears difficult to reconcile with a model in which ellipticals are formed from merging spirals, since such a scenario one would have expected the distribution functions for metal-poor globular clusters to peak at the same value in elliptical and spiral galaxies.

The absence of barred spirals may exclude scenarios (e.g., Pfenniger 1993) in which galactic bulges are formed from bars. Because of the importance of our conclusion that barred spirals are very rare among the galaxies in the HDF, we have re-examined the images of the 65 galaxies with $I_{814}<23.0$ mag, looking for even the *slightest evidence* for a nuclear bar. Since these objects also tend to be among the largest galaxies in the HDF it is possible to observe their structure in more detail than is the case for the smaller and fainter images. This detailed re-inspection supports our conclusion that barred spirals are very rare in the HDF. The following are comments on the 6 (9%) of these bright galaxies with $I_{814}<23.0$ mag of that exhibit an extended nuclear structure that *might* be interpreted as being related to a nuclear bar:

HDF 3-296: While this object is classified as a ''merger?,'' it could also be reinterpreted as a dwarf galaxy of type S(B) IV.

HDF 4-105: Classified as ''S(B)c t,'' this object might also be an Sc that is presently being distorted by a nearby compact companion.

HDF 2-553: The nuclear region of this object is slightly elongated. This galaxy might also be interpreted as being of type S(B)/Ir(B).

HDF 2-352: This one-arm spiral has an elongated nuclear bulge.

HDF 2-121: Classified as ''Sbt?,'' this galaxy has an elongated nuclear region.

HDF 2-416: This object is a peculiar one-arm spiral with slightly elongated bulge.

It is therefore concluded that the observed absence of barred spirals in the *Hubble Deep Field* is unlikely to be the result of low signal-to-noise in the data. The absence of nuclear bars in faint galaxies may prove to be an important clue to the origin of galactic structure, although a detailed interpretation of this effect will depend, like so many other effects, upon the redshift distribution of galaxies in the HDF.

We thank Bob Williams for his foresight in making the HDF images publicly available. We are also indebted to Daniel Durand of the Canadian Astronomy Data Centre for help with displaying HDF images, and to the Cambridge APM group for advice on generation of the HDF catalog.

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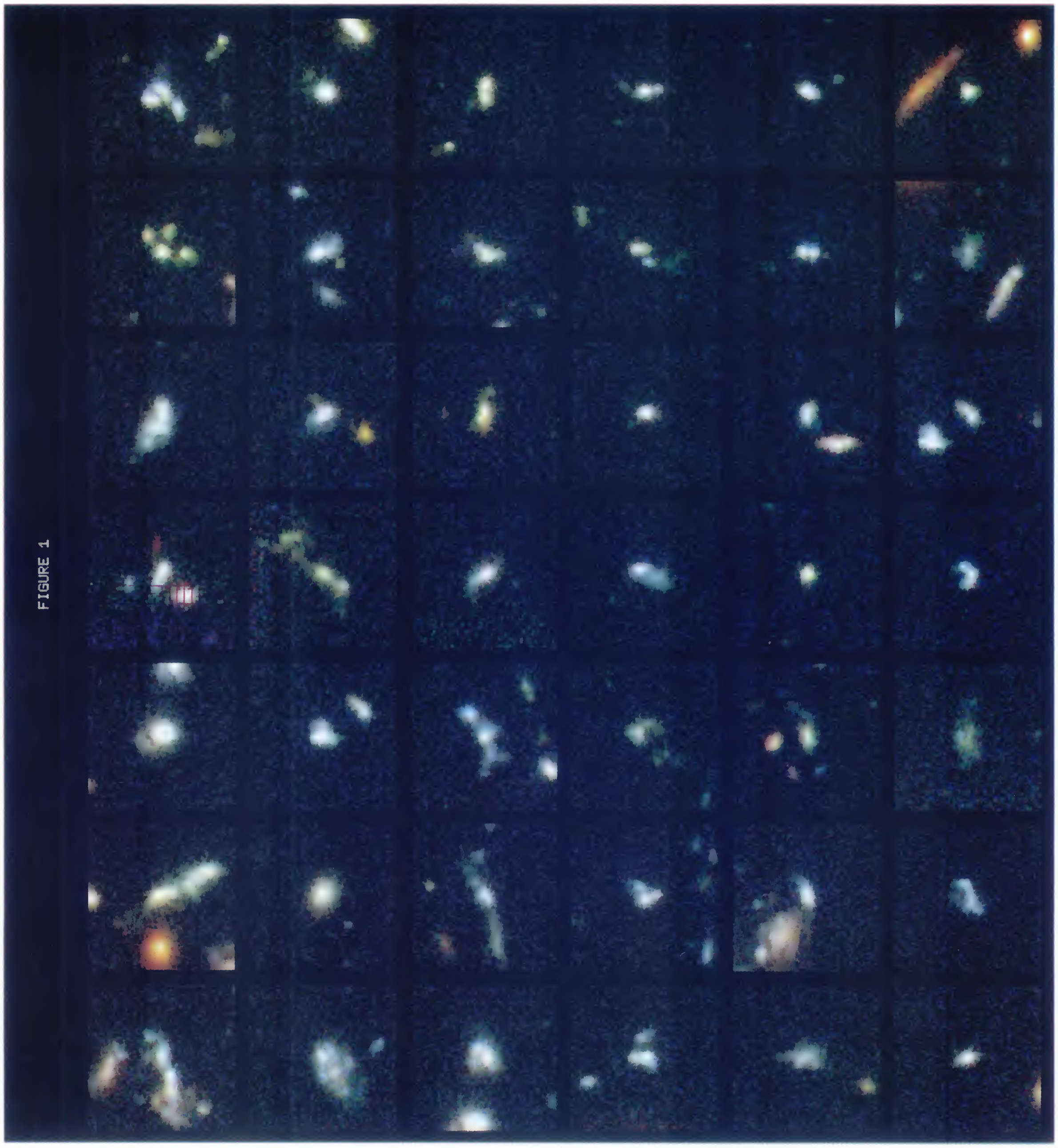

FIG. 1. Montage showing high-z candidates in the HDF, selected by the color criterion of $U-B>-0.2$ and $V-I<0.6$. Galaxies are displayed along six rows, sorted by magnitude left to right, starting from the brightest galaxies in the top row. **(Row 1:)** HDF 2-301, HDF 4-341, HDF 2-243, HDF 3-367, HDF 3-589, HDF 4-625, HDF 2-380. **(Row 2:)** HDF 4-184, HDF 4-235, HDF 2-513, HDF 4-7, HDF 4-387, HDF 2-33, HDF 3-56. **(Row 3:)** HDF 2-242, HDF 2-131, HDF 2-555, HDF 3-278, HDF 2-514, HDF 2-275, HDF 2-353. **(Row 4:)** HDF 4-313, HDF 3-617, HDF 2-25, HDF 3-379, HDF 4-372, HDF 2-302, HDF 2-193. **(Row 5:)** HDF 2-356, HDF 2-221, HDF 4-227, HDF 2-351, HDF 4-33, HDF 4-165, HDF 4-59. **(Row 6:)** HDF 3-616, HDF 4-308, HDF 4-368, HDF 2-459, HDF 2-526, HDF 3-267, HDF 4-655.

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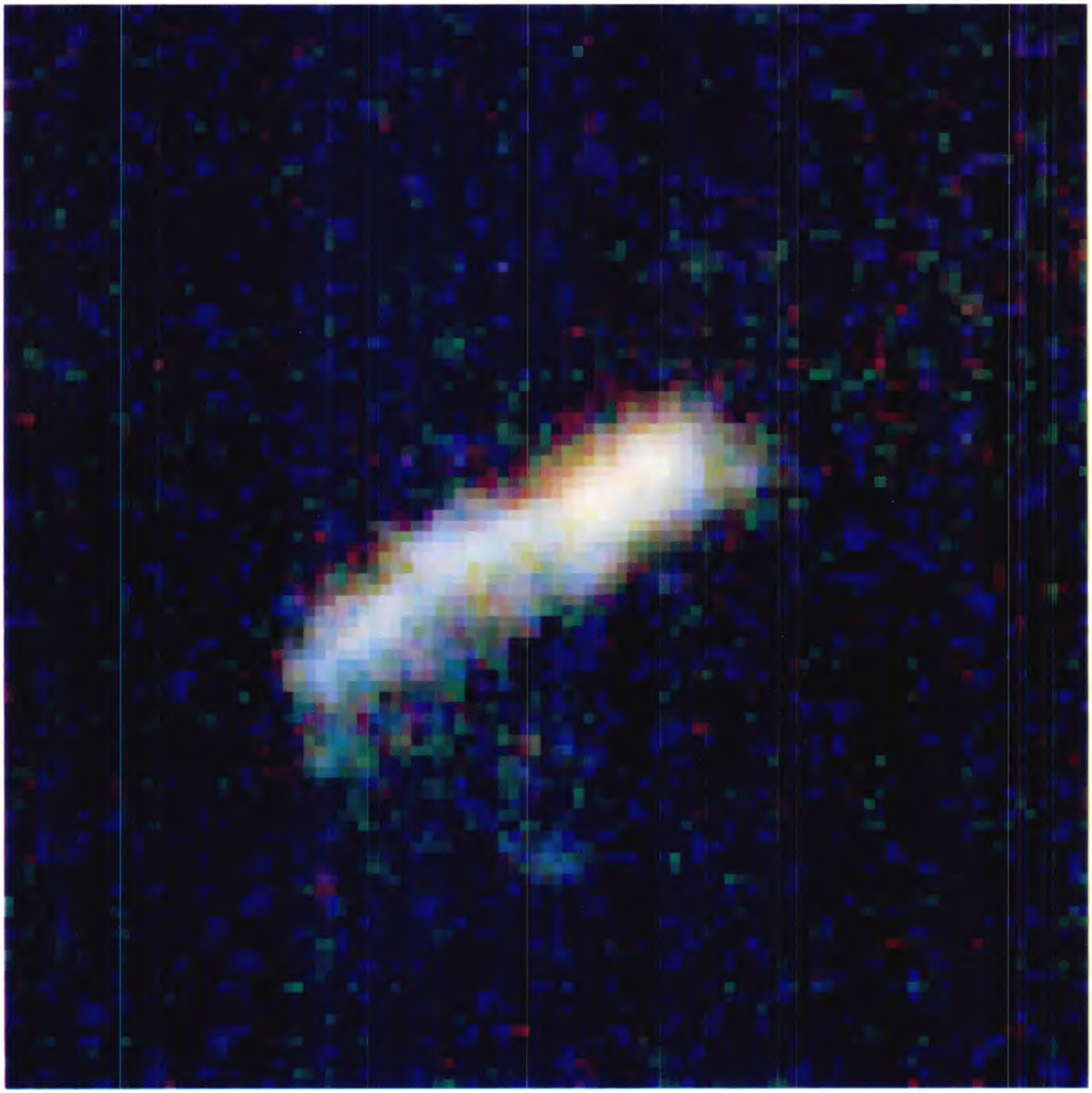

FIG. 2. Example of a ''tadpole'' (head-tail) galaxy (HDF 2-234). Most objects of this type are blue indicating that their light is dominated by young stars.

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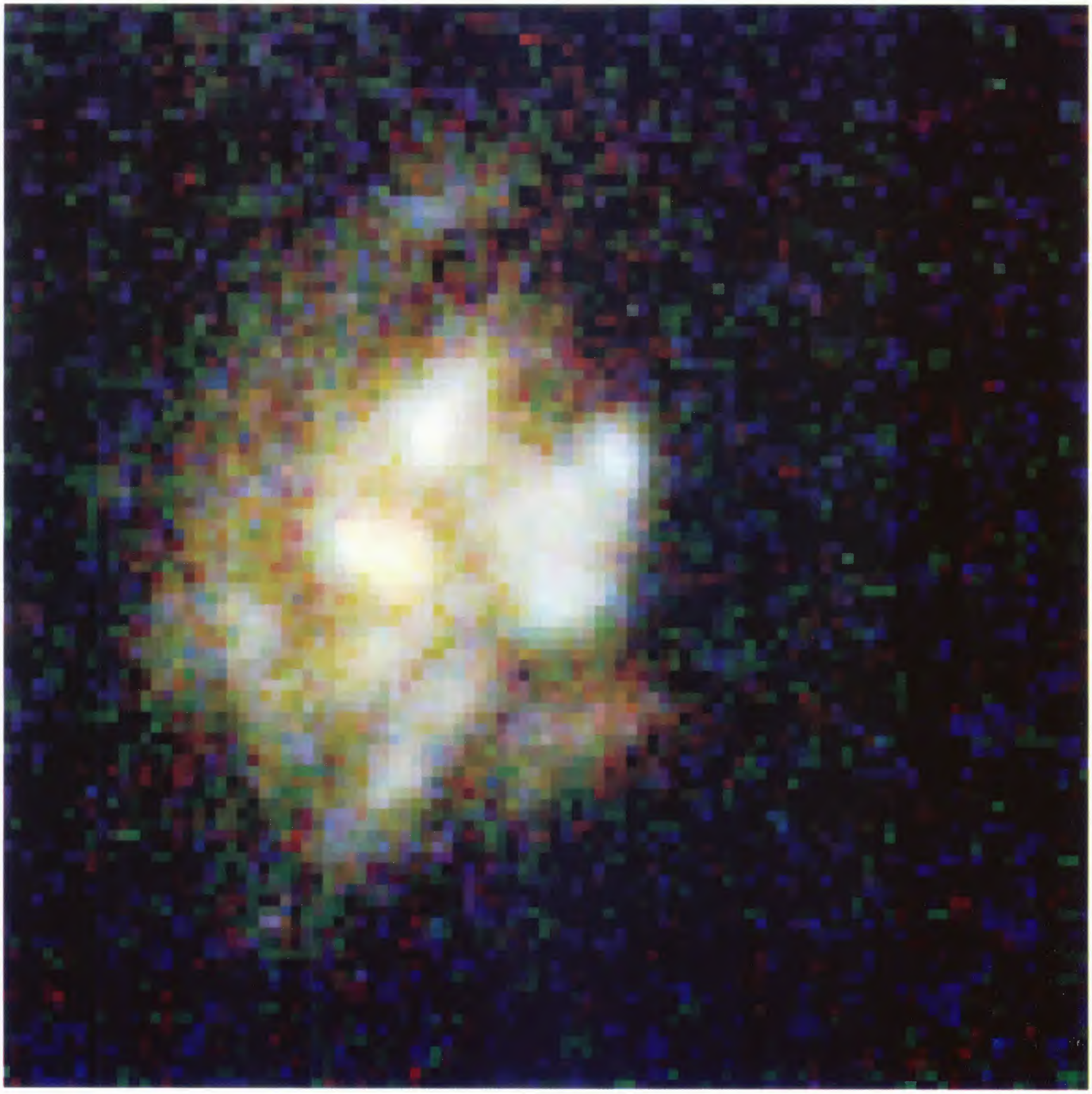

FIG. 3. Example of a possible protospiral (HDF 2-86) with an orange nucleus surrounded by blue knots.

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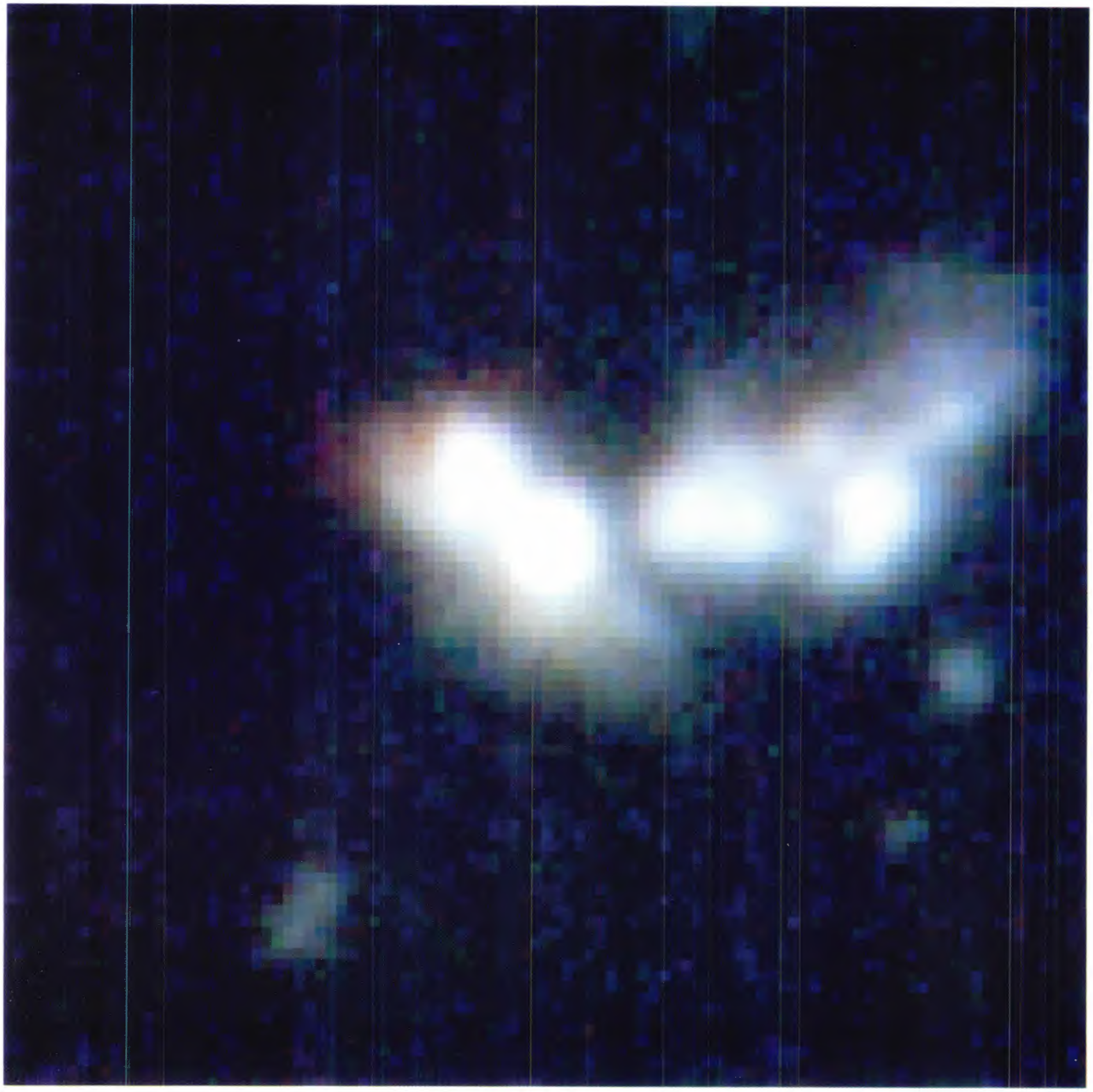

FIG. 4. Example of a multiple merger of compact blue objects (HDF 2-403).

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1996AJ....112..359V

FIG. 5. Possible proto-spiral with asymmetrically located reddish nucleus embedded in a structure containing blue knots (HDF 3-312).

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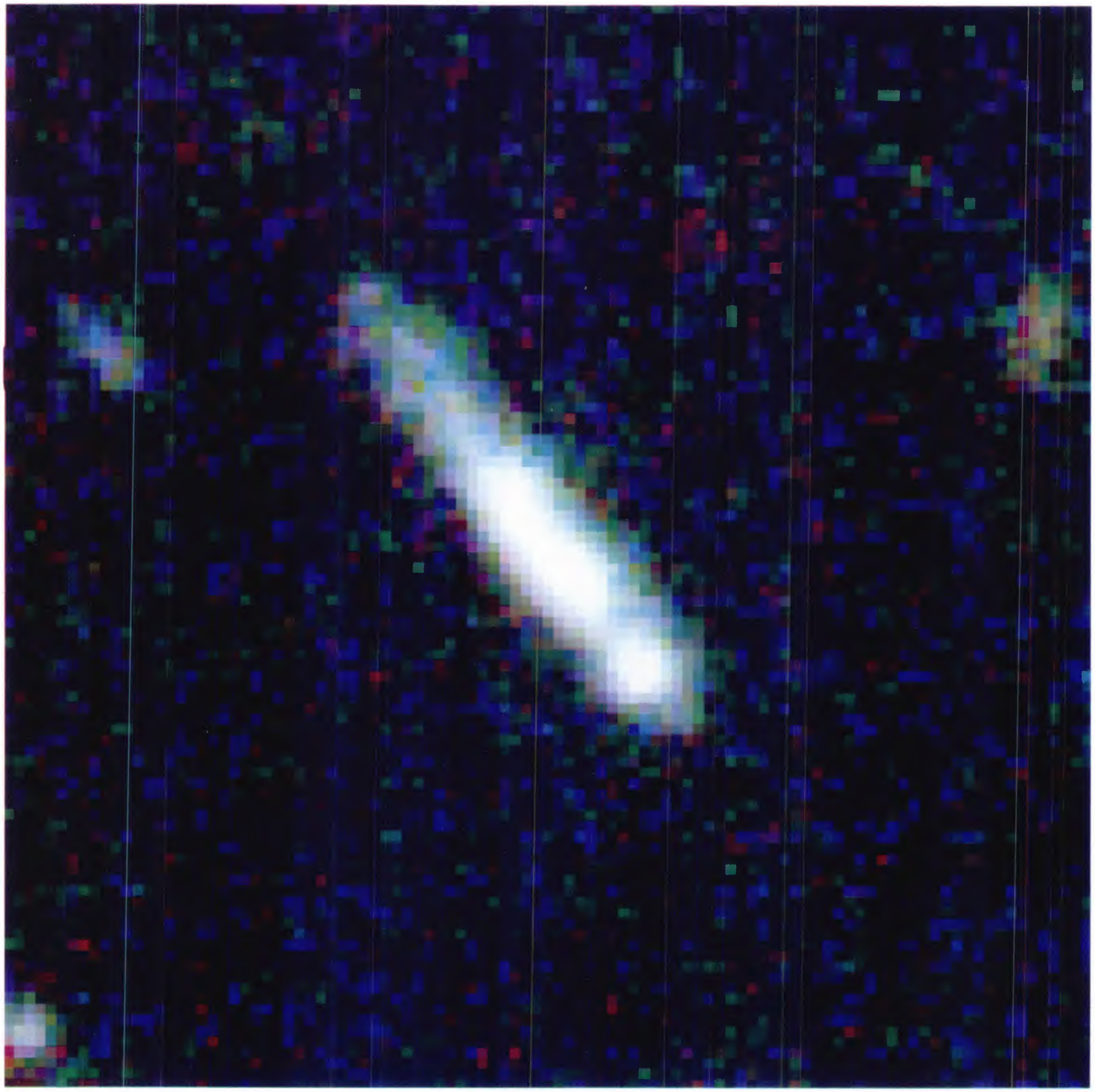

FIG. 6. Example of a blue chain of knots (HDF 3-531). Such objects (first reported by Cowie *et al.* 1995) may be related to ''tadpole'' galaxies.

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FIG. 7. This is the *only* example of a possible barred spiral in the HDF survey (HDF 4-105). Alternatively this object may be interpreted as a spiral that was distorted by a recent tidal encounter with a compact companion.

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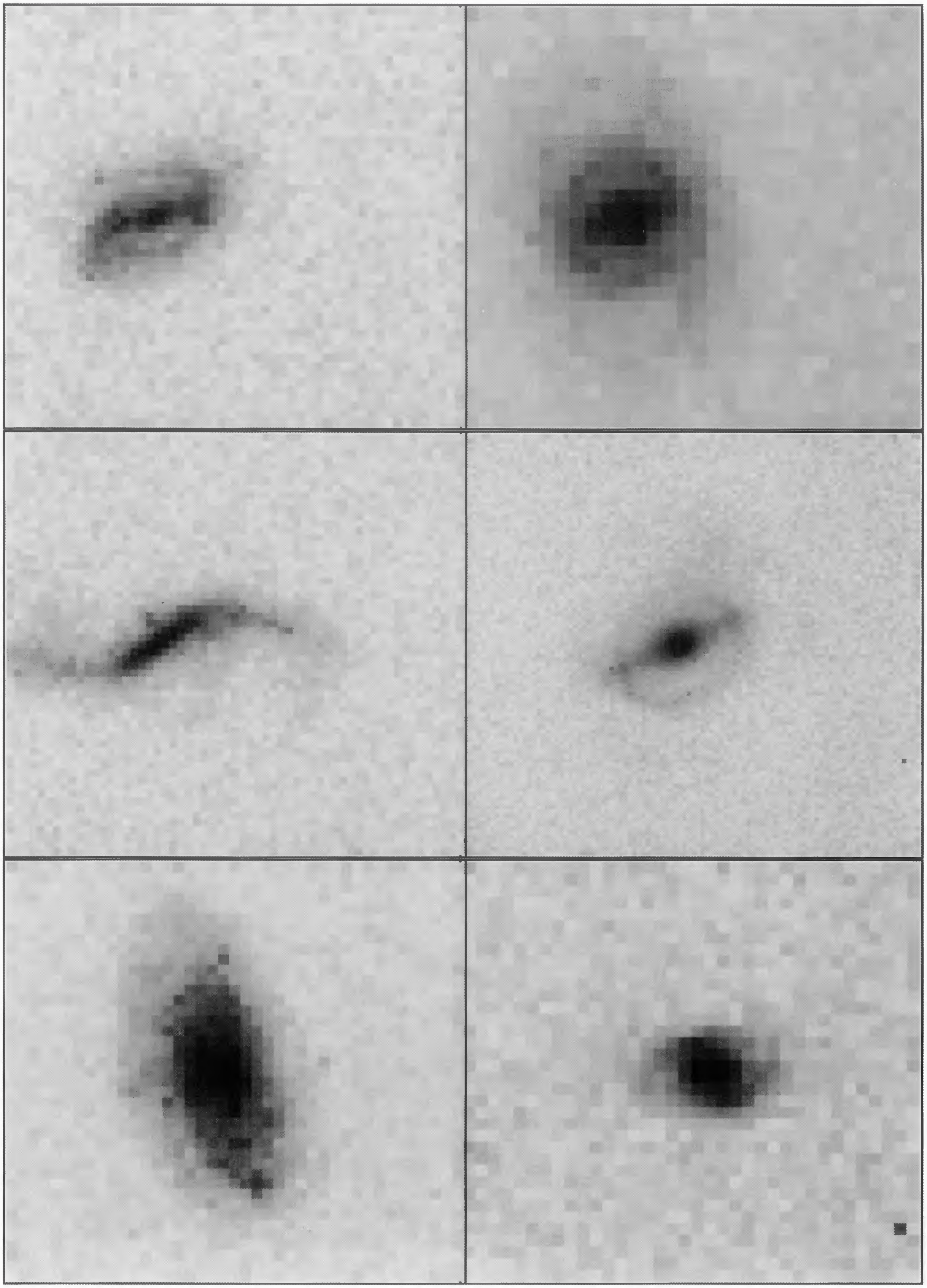

FIG. 8. Montage showing barred spirals in the Frei *et al.* sample artificially redshifted to $z=1$, assuming HDF exposure times and resolution. The barred structure of most galaxies remains evident.

van den Bergh *et al.* (see page 367)