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THE SPACE DENSITY AND SPECTROSCOPIC PROPERTIES OF A NEW SAMPLE OF EMISSION-LINE GALAXIES

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ABSTRACT

A moderate-dispersion objective prism survey for low-redshift emission-line galaxies has been carried out in an 825 sq. deg. region of sky. A 4° prism (400 Å mm^{-1} at Hβ) was used with the IIIa-J emulsion to show that a new sample of emission-line galaxies is available even in areas already well searched with the "excess UV-continuum" technique. Spectroscopic observations with a fiber-coupled SIT spectrometer and the objective prism spectra have yielded redshifts for two-thirds of the new emission-line galaxies.

These galaxies occur quite commonly in systems with peculiar morphology indicating gravitational interaction with a close companion or other disturbance. About 10%–15% of the sample are Seyfert galaxies. An additional 20% exhibit the characteristics of starburst galaxies. It is suggested that tidal interaction involving matter infall may play a significant role in the generation of an emission-line spectrum.

The space density of the new galaxies has been investigated and found to be similar to the space density of the Markarian galaxies. The galaxies in the present survey represent about 8% of all nearby galaxies in the absolute magnitude range $-16.5 \geq M_p \geq -22.5$, and are composed of a population which is completely independent of the Markarian sample.

Subject headings: galaxies: redshifts — galaxies: Seyfert

I. INTRODUCTION

Optical emission lines have been observed in extragalactic objects for some time (Fath 1908; Slipher 1917; Mayall 1939; Seyfert 1943). It has been known for many decades that a sizable proportion of galaxies have observable emission lines in their spectra (Humason, Mayall, and Sandage 1956; Mayall 1958). The decades of the 1960s and 1970s brought the realization that some of this emission-line activity was extraordinary and probably related to other puzzling objects at great distances—the QSOs. In fact, the suggestion has been made (Weedman 1976 and references therein) that the nuclei of Seyfert galaxies are related to and represent local versions of the QSOs and that there is a continuity of activity stretching from the QSOs to ordinary galactic nuclei (Rowan-Robinson 1977; Heckman 1980). For this reason and in order to understand better the emission-line phenomenon in extragalactic objects it is of interest to study the statistics and gross properties of such a group, selected solely on the basis of the presence of emission lines in their optical spectra.

Extragalactic objects that show emission lines in their optical spectra comprise a varied group. The emission-line activity observed in such sources, although encompassing a broad range in luminosity, can be explained by ordinary thermal processes (i.e., conventional stars and bursts of star formation), shock-heating, and photoionization by a power-law continuum (Baldwin, Phillips, and Terlevich 1981).

Haro (1956), in an attempt to spectroscopically follow up his three-color method of finding blue objects, was the first to show that an objective-prism/Schmidt telescope combination could be used to detect emission-line galaxies. His moderate-dispersion plates revealed that galaxies with very blue continua were often found to show emission lines of [O II], [O III], the Balmer series, and other elements.

Low-dispersion objective-prism spectroscopy has also been very useful in locating extragalactic emission-line objects. Markarian (1967), Smith (1975), MacAlpine, Smith, and Lewis (1977), and Sanduleak and Pesch (1982) have shown the practicality of the objective-prism/Schmidt telescope combination as a tool for spectroscopic surveys for emission-line galaxies and QSOs.

The Markarian survey, the first results of which were published in 1967, was not undertaken specifically with the intention of finding galaxies with emission-line spectra but rather was an attempt to isolate those galaxies with relatively blue central regions and early-type spectra. Markarian's technique (the same approach has also been used recently by Kazarian 1979) employs the sensitivity dip in the green region of the spectrum of the Kodak IIa-F emulsion to identify galaxies in which the blue portion of the continuous spectrum seems unusually strong, that is, those galaxies the continua of which blueward of the "green dip" are strongly exposed.

The dispersion of the spectra on Markarian's plates (2500 Å mm^{-1} at Hβ) did not usually permit the detection of emission lines: only about 20% of the Markarian objects were noted as definitely possessing emission lines by Markarian. Nonetheless, more than 90% of the Markarian sample has been shown to have optical line emission, and about 10% of his objects have turned out to be Seyfert galaxies (Sargent 1972; Huchra 1977). The correlation between blueness and emission lines seems very good. Even so, since emission lines were not the primary search criterion for Markarian's survey, it seemed possible that many extragalactic emission-line objects were not detected by his method. For example, very few Markarian objects have been found to be QSOs, and Huchra (1977) has found some evidence for selection effects which might hinder the discovery of redder emission-line galaxies by the Markarian technique.

Smith (1975), MacAlpine, Smith, and Lewis (1977), and others have utilized the University of Michigan's 61/91 cm Curtis Schmidt telescope with a "thin" (1°.8) objective prism to search for emission-line objects. These investigators have employed unfiltered IIIa-J plates with unwidened spectra having a dispersion of 1740 Å mm^{-1} at Hβ. This technique has proven very effective in finding high-redshift QSOs. Emission-line galaxies of various types are also found by this technique, but there is indication that no more (and perhaps many less) such objects can be discovered in this way than in a Markarian-like survey (Bohuski, Fairall, and Weedman 1978).

McCarthy and Treanor (1970) and Bidelman (1974) have noted that weak emission lines are more readily detected with higher dispersion because the continuum is diluted while the (narrow) lines are not. It thus seemed desirable, as suggested by Bidelman (1974, 1975), to use an objective-prism/Schmidt telescope technique with relatively high dispersion in a survey for emission-line galaxies. Kinman (1979) has also demonstrated the usefulness of moderate-dispersion objective-prism plates in searches for emission-line galaxies.

A 4° objective prism and the IIIa-J emulsion have been used to survey a region near the north galactic pole (NGP) and have isolated a population of emission-line galaxies not discoverable by the "excess UV continua" approach. Reported here are a list of 96 new moderate to strong emission-line galaxies and an investigation of their space densities and spectroscopic properties.

II. OBSERVATIONS

The 61/91 cm Burrell Schmidt telescope of Case Western Reserve University, located at the Kitt Peak Station of the Warner and Swasey Observatory, equipped with its 4° objective prism, has been used in a survey for extragalactic emission-line objects. This instrumentation provides, when coupled with the sensitivity of the IIIa-J emulsion in the green region of the spectrum, an ideal method for the detection of the [O III] λλ5007, 4959 lines in low-redshift ($z \leq 0.07$) objects. The dispersion and resolution (with 1″ seeing) at Hβ are 400 Å mm^{-1} and 4 Å, respectively. Because of the higher dispersion the 4° plates naturally have a brighter limiting continuum magnitude than the "thin" (1°.8) plates; and this, coupled with the greatly broadened emission lines in the QSOs, will make the moderate-dispersion technique inefficient in surveys for such objects. A well-exposed spectrum is about 7 mm long on the plates and covers the spectral range 3700–5350 Å. The limiting magnitude to which a continuum can be reliably recorded is about $B = 16$. However, because the dispersion of the 4° prism easily allows the resolution of the [O III] λλ5007, 4959 lines, emission-line objects showing these lines can be detected even when a continuum is not visible. This extends the integrated magnitude to which objects with moderate to strong emission lines can be selected to about $B \sim 17$. The survey is complete, however, only to $B \sim 15.7$, as will be discussed in more detail in § V.

The IIIa-J plates were baked for 1 hr 30 min at 65° C in an atmosphere of forming gas (98% N_2, 2% H_2) prior to exposure. No filter was employed, and all plates received an exposure of 60 minutes. The spectra were intentionally widened (in the range 0.05–0.10 mm) to decrease the chance of a plate flaw masquerading as an emission line. The coverage obtained on the sky is shown in Figure 1, a polar stereographic projection of a portion of the celestial sphere. In this figure, a cross denotes the position of the NGP. Each plate covers an area of 5° × 5°, and, in all, approximately 825 sq. deg.

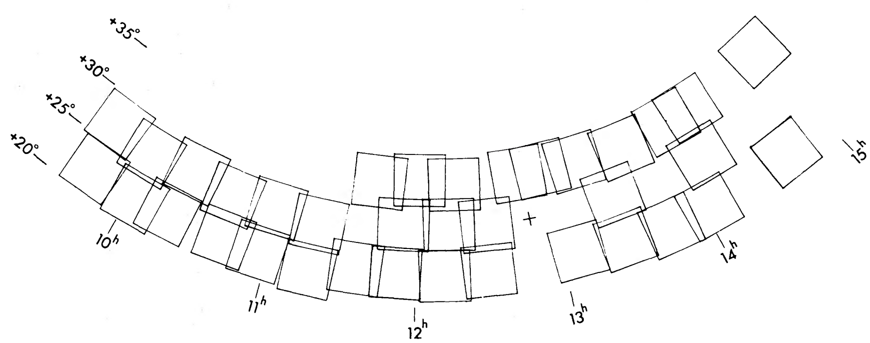

FIG. 1.—Sky coverage of the 36 4° objective-prism plates used in the present survey. A polar stereographic projection is employed. The cross denotes the north galactic pole. Each plate covers approximately 5° × 5°.

TABLE 1

The Catalog of New Emission-Line Galaxies

No.	R.A. (1950)	Decl. (1950)	*m*	*M*	*Z*	*Z* Ref.[a]	Cont.
1	$9^h34^m42^s$	+23°25′.5	14.1	−20.5	0.0217	2	B1
2	9 43 11	22 37.2:	15.6:	−20.0	0.0329	1	ov
3	9 48 34	26 52.8:	17.1:	...	...		B0
4	9 53 28	27 28.2	14.0	−17.4	0.0047	2	B1
5	10 07 47	22 15.5:	16.4:	...	...		B1
6	10 08 10	25 45.3:	16.4:	...	...		B0
7	10 09 28	28 07.3:	14.0	...	...		B1d
8	10 16 16	21 32.0	15.0	−15.6	0.0033	1	B1
9	10 19 56	21 07.1:	14.9	−20.1	0.0245	1	B1
10	10 21 18	21 20.3:	15.6:	−18.8	0.0188	1	B1
11	10 24 42	20 42.9:	13.9:	...	...		B1
12	10 28 19	29 03.3	13.8	−17.6	0.0048	1	B2
13	10 29 31	27 55.7:	13.0	−16.0	0.0016	3	B2
14	10 40 48	25 13.8	10.9	−18.2	0.0017	3	B0
15	10 42 36	27 35.5:	16.4:	...	...		B1
16	10 48 15	25 29.7:	15.1	...	...		B1
17	11 05 58	22 54.8:	16.6:	...	...		B0
18	11 07 14	24 31.1:	14.3	−20.3	0.0209	1	B0
19	11 07 22	22 52.7:	16.4:	...	...		B1
20	11 21 11	21 07.5:	16.9:	...	...		B0
21	11 23 36	28 07.9	13.9	−22.8	0.0534	2	B2
22	11 26 37	20 51.4	14.7	−16.6	0.0044	1	B0
23	11 32 48	33 34.8	15.2	−16.4	0.0053	2	B2
24	11 33 24	32 39.9:	15.6:	−17.3	0.0094	1	B2
25	11 38 30	32 42.3	15.4:	−16.3	0.0054	2	B1
26	11 38 40	22 14.0:	14.9:	−22.1	0.0626	1	B0ov
27	11 38 53	32 37.5	15.2	−16.3	0.0050	1	B3
28	11 38 59	32 33.6	15.4:	...	...		B0
29	11 40 45	31 43.8:	15.2	...	...		B0
30	11 40 56	31 44.0	15.0	−16.1	0.0040	1	B2
31	11 42 08	33 36.4:	15.2	−20.2	0.0306	1	B2
32	11 45 30	22 06.3	16.4:	−18.8	0.0267	1	B1ov
33	11 45 52	26 02.7	15.0	−21.3	0.0447	2	B2
34	11 46 55	24 25.5:	16.9:	−16.4	0.0112	1	B0
35	11 47 44	26 15.0:	14.1	...	...		B1d
36	11 52 05	26 13.0	15.8:	−18.2	0.0155	1	B2
37	11 54 54	31 21.6	15.2	−19.6	0.0232	1	B2
38	11 55 14	25 33.2	14.0	−20.0	0.0158	3	B2d
39	11 57 30	30 35.6	16.4:	−18.4	0.0230	2	B2
40	11 57 59	20 21.1	12.7	−18.2	0.0038	3	B0
41	11 59 11	20 36.8:	14.9	...	...		B1d
42	11 59 14	21 21.7	15.3	−19.5	0.0231	2	B2d
43	11 59 52	29 44.9	15.1	−17.8	0.0093	2	B2
44	12 00 33	21 05.6:	15.3	...	...		B1d
45	12 02 10	31 27.7:	13.7	−21.3	0.0244	1	B2
46	12 03 38	25 50.3:	14.4	−20.1	0.0202	3	B1
47	12 04 03	25 23.4	15.3	−17.9	0.0109	2	B2
48	12 06 55	22 22.9	15.3	−19.9	0.0277	2	B0
49	12 11 46	29 48.3	15.4:	−21.6	0.0628	1	B1
50	12 13 23	26 56.3	14.3	−20.8	0.0265	1	B2
51	12 15 48	29 32.6:	15.4:	...	...		B1
52	12 17 26	28 50.1:	15.9:	−16.7	0.0083	1	B0
53	12 18 59	28 38.9:	16.1:	...	...		B0
54	12 20 08	24 50.7:	16.9:	...	...		B0
55	12 21 24	28 17.1:	16.9:	...	...		B1
56	12 22 29	30 06.8	15.9	−20.7	0.0516	1	B2?
57	12 26 14	23 06.0	12.8	−16.7	0.0020	3	B1d
58	12 29 36	27 57.7:	16.4:	...	...		B1
59	12 34 17	26 35.1:	16.9:	...	...		B0
60	12 39 04	26 19.5:	13.9	−20.1	0.0156	1	B1
61	12 39 45	33 34.2:	15.4:	−20.8	0.0430	1	B3
62	12 40 21	26 54.9:	15.2	−19.6	0.0227	3	B1
63	12 44 12	29 44.5:	16.4:	...	...		B0
64	12 55 53	31 25.6	15.5:	−19.5	0.0253	1	B2
65	12 56 12	23 25.0:	15.9:	...	...		B0
66	13 13 42	29 38.6	16.6:	−19.3	0.0372	1	B2
67	13 16 05	31 43.8	13.6	−20.8	0.0187	1	B2
68	13 17 19	30 31.1	14.1	−18.1	0.0068	1	B2
69	13 23 31	33 19.4	16.8:	−16.9	0.0139	1	B1

TABLE 1—*Continued*

No.	R.A. (1950)	Decl. (1950)	m	M	Z	Z Ref.[a]	Cont.
70	13 24 05	29 26.4:	16.4:	...	...		B2
71	13 25 12	27 51.3:	13.9:	...	...		B1
72	13 27 01	22 53.1:	16.9:	...	...		B0
73	13 27 59	31 35.3	14.6	−19.5	0.0164	1	B2
74	13 31 26	29 01.1	17.4:	...	...		B0
75	13 32 00	31 32.5	14.9:	−21.0	0.0381	2	B2
76	13 32 34	26 27.9:	14.9:	−20.2	0.0266	3	B2d
77	13 35 43	26 36.0:	14.6:	...	...		B1
78	13 36 58	25 01.7:	14.5	...	...		B0
79	13 38 46	23 32.5:	14.8	−20.3	0.0259	1	B2
80	13 40 31	22 24.1	14.9	...	...		B2
81	13 54 54	29 27.9:	15.9:	−16.7	0.0082	1	B0
82	13 56 03	23 07.8	14.8	−17.9	0.0088	1	B3
83	13 56 05	23 10.7	15.0	−17.7	0.0088	1	B1
84	13 56 38	31 51.6:	16.4:	...	...		B0
85	13 57 21	30 09.1	16.4:	−19.8	0.0423	1	B0
86	13 58 44	29 48.1	15.0	−20.3	0.0281	2	B1
87	13 58 46	21 28.9	14.8	−20.4	0.0267	2	B3
88	13 58 49	29 46.5:	14.8	...	...		B1d
89	14 01 45	26 02.0	14.9:	−20.7	0.0325	1	B2
90	14 08 38	25 47.9:	15.9:	−19.6	0.0307	1	B0
91	14 12 40	31 04.5:	16.9:	...	...		B0
92	14 52 05	30 24.7	15.0	−17.8	0.0091	1	B1
93	14 54 30	30 25.9	13.6	−18.4	0.0063	1	B2
94	14 55 30	30 09.9	13.2	−18.2	0.0046	1	B1
95	14 55 42	33 22.1	14.9	−20.5	0.0299	1	B2
96	15 08 58	31 39.8	16.9:	−18.8	0.0336	1	B0

[a] References: 1 = BMO; 2 = objective prism velocity; 3 = see accompanying notes.

NOTES TO TABLE 1

1. NGC 2930, Holm 134A; in small group, Irr with 5 major condensations.

2. Slightly noncircular nucleus with disk apparent. Small concentration to west and slightly north is emitter.

3. *Not* Ton-N 459; object is red with small condensation to east.

4. IC 2520, UGC 5335, Reiz 98; E0 pec.; radio source: 21 ± 3 MJy at 2380 MHz (Dressel and Condon 1978).

5. Faint, diffuse.

6. Object stellar and blue.

7. UGC 5499, Reiz 212; SBb: (UGC); nearly edge-on spiral, possibly distorted.

8. Reiz 277; two slightly elongated condensations embedded in asymmetrical haze, possibly interacting. Western component is the stronger emitter, but possible λ5007 and λ4959 in eastern component.

9. Amorphous blue patch near star.

10. Condensation to south connected to fan-shaped haze. Distorted system.

11. Apparent spiral; emission very weak.

12. NGC 3265, UGC 5705, Reiz 473; E: (UGC); a fairly blue elliptical about E3.

13. NGC 3274, UGC 5721, Reiz 481; pec spiral with many H II regions. V_r(obs) = +474 km s^{-1} (Sandage 1978).

14. NGC 3344, UGC 5840, Reiz 562, Kara. 73B 435; Sc with many H II regions. Two particularly bright patches in the spiral arm to the north are the emitters; radio source: 33 ± 3 Jy at 2830 MHz (Dressel and Condon 1978), also 120 MJy source at 408 MHz (Gioia and Gregorini 1980).

15. 2 objects in contact, both with fairly stellar nuclei. Northern component is stronger emitter. Southern component possibly shows λ5007.

16. Elongated bright patch with diffuse edges.

17. Faint, mainly stellar but elongated slightly N-S.

18. UGC 6207, Arp 301, VV 229 A+B, Reiz 868, 867, Holm 231 A+B, Kara. 72 271 A+B; Interacting pair, spiral + Irr. Eastern (Irr) component is the stronger emitter. Western component shows weak λ3727; V_r(obs) = 5996 km s^{-1} (UGC).

19. Stellar.

20. Small faint patch in a group of similar objects.

21. NGC 3678, UGC 6443, Reiz 1146; SB-c (UGC); somewhat stellar nucleus and possibly distorted disk.

22. IC 700, UGC 6487, Reiz 1205; interacting quadruple system. Westernmost component is the emitter.

23. UGC 6561, Holm 267 A+B; diffuse elongated patch with 2 emission centers; western one is blue.

24. Condensed nucleus with faint ringlike structure.

25. Bright elongated patch with two knots. Eastern knot is the emitter. Near Nos. 27 and 28.

26. Stellar with condensation 33′ to W. On 4° plate most of continuum overlapped with that of bright star. Hβ broad.

27. Markarian 746; stellar nucleus.

28. Irregular with bright emitting patch to south.

29. UGC 6684; Irr with bright emitting patch to south. Pair with No. 30.

30. Semistellar, slightly elongated E-W. Pair with No. 29.

31. NGC 3855 = 3856; possibly distorted Sc, nucleus elongated SE-NW.

32. Possibly interacting system; semistellar nucleus with nearby knot to SW.

33. In small group, nearest comp. at 21″. Possibly irregular.

34. Mainly stellar with some diffuse component.

35. UGC 6806, Reiz 1671; possibly interacting Sb with nebulous blue patch at 2′ NE, which is UGC 6807.

36. 2 components in contact.

37. UGC 6932, Reiz 1819; pec spiral with stellar, fairly blue nucleus.

38. NGC 3997, UGC 6942, Holm 308 B, Reiz 1831; distorted SB in group, shows 2 blue knots. V_r(obs) = 4769 km s^{-1} (UGC).

39. Faint, blue, elliptical-shaped patch.

40. NGC 4032, UGC 6995, Reiz 1880; irregular with large bright nucleus. 4 small, blue condensations in outer regions. V_r(obs) = 1186 km s^{-1} (de Vaucouleurs, de Vaucouleurs, and Nieto 1979).

41. SB with bright stellar-like nucleus and blue condensations in arms.

42. Elongated NE-SW with enhancement on western side. In loose cluster.

NOTES TO TABLE 1—*Continued*

43. Reiz 1898; possible spiral in loose cluster.

44. Stellar nucleus with uniform diffuse component.

45. UGC 7064, Holm 323 A; bright nucleus with symmetric disk, with 2 nearby (1′) companions, radio source: 14 ± 3 MJy at 2380 MHz (Dressel and Condon 1978), V_r(obs) = 7462 km s^{-1} (Chincarini and Rood 1972).

46. NGC 4101, UGC 7093, Reiz 1967; S0 with poss. jet to NE, V_r(obs) = 6089 km s^{-1} (Gregory and Thompson 1978).

47. Elliptical-shaped patch in small group.

48. UGC 7137; distorted spiral with bright nucleus and interacting companion.

49. Small patch elongated slightly N of E-W line with 2 emission knots.

50. Irregular aligned approx. E-W with bright knot on western edge which is the emitter. V_r(obs) = 7689 km s^{-1} (Gregory and Thompson 1978).

51. UGC 7342; possible SBc with 1 blue condensation in the arms.

52. Small, bright elongated nucleus with disk.

53. Small, slightly elongated patch.

54. Small, faint, stellar object with jet to NE and a blue condensation nearby (11″).

55. Semistellar with pronounced asymmetry to NE, in small faint group. Spectrum possibly shows line near λ4300.

56. Pair at 40″, emitter is to the NE and appears stellar with a jet.

57. NGC 4455, UGC 7603, Reiz 2403; Sc nearly edge-on with large H II region at extreme north end, radio source: 17 ± 4 MJy at 2380 MHz (Dressel and Condon 1978), V_r(obs) = 598 km s^{-1} (Sandage 1978).

58. Stellar.

59. Faint but very blue object in very faint cluster.

60. NGC 4614, UGC 7851, Arp 34, Holm 439 B, Kara. 72 348A, Reiz 2701; elongated disk with bright central region, SB0-a NGC 4615 group (UGC), V_r(obs) = 4917 km s^{-1} (Tifft and Gregory 1976).

61. Small, elongated patch with diffuse component.

62. Spiral seen obliquely, V_r(obs) = 6797 km s^{-1} (Tifft and Gregory 1976).

63. Faint, blue, stellar patch with similar companion at 19″, in relatively compact group.

64. Elongated patch with blue condensation with $m \sim 17$ to the SW at 10″.

65. Stellar with slight diffuse component and small condensation near (12″).

66. Blue, semistellar nucleus with diffuse component. Listed by Usher 1981 (No. 483).

67. NGC 5074, Reiz 3370; distorted with semi-ring of diffuse material to south.

68. NGC 5089, UGC 8371; Sb with condensation to south.

69. Blue, stellar object with slight diffuse component.

70. Starlike, in small, faint cluster.

71. Elliptical shaped, in small group.

72. Faint, stellar but slightly elongated.

73. VV 69, UGC 8496, Reiz 3455; interacting system with three members, emitter is on SE side of group.

74. Extremely faint, small, blue, diffuse patch apparently situated in a distant cluster.

75. Slightly elongated nucleus with bright jet to the NE which contains 2 blue, stellar condensations one of which may be the actual emitting site.

76. Arakelian 422; S0, V_r(obs) = 7956 km s^{-1} (Kirshner, Oemler, and Schechter 1978).

77. Small, stellar nucleus in a possible spiral galaxy.

78. VV 133, UGC 8638; irregular with about 6 blue condensations. The westernmost condensation is very blue and is the probable emitter.

79. IC 910; peculiar object with bright nucleus and small nearby (26″) companion. Probably interacting system. In small group.

80. Slightly elongated bright patch with symmetrical diffuse component and 1 condensation to SW. In small group.

81. Stellar, near NGC 5375.

82. Spiral seen nearly edge-on. Pair with No. 83.

83. Face-on spiral with 1 blue condensation to NW. Pair with No. 82.

84. Amorphous patch with definitely blue condensation.

85. Object is small elongated patch with slight diffuse component near (20″) to a similar object.

86. Spiral seen obliquely with blue central region.

87. VV 277, UGC 8929, a pair with connecting luminous filaments, an interacting system.

88. SB with large, blue central region.

89. Stellar with slight diffuse component and nearby (27″) companion.

90. Stellar with one faint condensation to NW and connecting bridge. Redshift uncertain; based on single feature.

91. Probably an interacting triplet with both the NW and SW components emitting.

92. UGC 9588; distorted, interacting pair with much diffuse matter.

93. NGC 5789, UGC 9615, Reiz 4390; possibly disrupted spiral with a blue patch on SE end which is emitter.

94. NGC 5798, UGC 9628, Reiz 4400; large, irregular with a few condensations. Pair with No. 93.

95. Starlike elongated on a NE-SW line. Small, blue condensation at 21″.

96. Interacting system, 2 components separated by 10″. Northernmost is the strong emitter, but southern component shows weak λλ5007, 4959, and Hβ.

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of sky between declinations +20° and +35° and right ascensions 9^h30^m and 15^h00^m were surveyed on 36 plates.

The plates (19.7 cm × 19.7 cm) were visually scanned with a low-power (∼12×) binocular microscope in a scanning frame that allowed coverage in a series of horizontal strips approximately 1.9 cm wide. After the completion of scanning, the spectrum of each marked object was reconsidered along with its direct image on the Palomar Observatory Sky Survey (POSS) prints, and questionable objects were rejected. Generally, at least two spectral lines (usually λλ5007, 4959 and/or λ3727) were required for a classification as an emission-line galaxy, though one authentic line coupled with an extended (galactic) image on the POSS prints was sufficient in a few cases for the inclusion of an object in the survey list. Consideration of the direct POSS images also aided in the positive identification of the marked objects as galaxies, although at the high galactic latitudes ($b^{II} > 45°$) surveyed most objects showing [O III] λλ5007, 4959 would be expected to be extragalactic in nature.

A total of 132 emission-line galaxies were found on the 36 Burrell 4° prism plates which met at least the following quality standards: (1) no worse than 5″ seeing (avg.: 3″), (2) spectra no wider than 0.12 mm (avg.: 0.07 mm), (3) little or no cloud/haze interference, (4) hour angle at the end of exposure no greater than 4^h30^m (avg.: 1^h49^m). Of these 132 objects, 23 were previously published Markarian emission-line galaxies and 13 others were from the list of Haro (1956) or elsewhere in the literature. The remainder, 96 new emission-line galaxies, are listed in Table 1. Other designations and information on each object are given in the notes to this table. Of the 96 new galaxies, only 52 (54%)

were previously cataloged as galaxies at all, the rest being either too faint or too stellar-like on the POSS prints to be included in the existing catalogs of galaxies.

One object in Table 1 (No. 27) is also known as Markarian 746; but since no indication could be found in the literature that it is a known or suspected emission-line system, it was included in the list of new emission-line galaxies.

Figures 2*a*, 2*b*, 2*c*, and 2*d* are finder charts for the new emission-line galaxies of Table 1. They are drawn from the POSS E-prints and the faintest stars shown are about 18th magnitude. The objects were drawn to scale as much as possible and emission centers are denoted by two lines. All fields are $5' \times 5'$, with north up and west to the right.

Astrometric positions for the mean equinox 1950.0 were obtained for the 96 new emission-line galaxies found on the Burrell Schmidt 4° plates using the Warner and Swasey Observatory X-Y measuring machine and a reduction program by Stephenson (1974). For most of the galaxies the positions are accurate to about 6″ in both R.A. and decl. Since the $\lambda 5007$ line was the standard measuring fiducial, it was necessary to correct for the objects' recessional velocities, which can cause considerable error ($\sim 30''$ for $z = 0.07$) in the declination coordinate (the dispersion of the 4° spectra runs north-south on the plates). Thus, for galaxies whose redshifts were unknown at the time of measuring, the declination coordinate may be in error by as much as 30″. The measured positions are listed in Table 1. A colon (:) in the Declination column signifies that this coordinate is accurate only to $\pm 30''$.

One distinct advantage of the higher-dispersion 4° plates, besides their greater resolution, is the fact that if both the $\lambda 5007$ and $\lambda 3727$ features are visible in a given spectrum, the redshift can be measured by the length of spectrum method. Briefly, the amount of linear displacement on the plate due to a given Doppler shift differs for different wavelengths and thus the separation on the plate of any two lines is a function of redshift. In the objective-prism case, the dispersion curve of the prism also affects the displacements since the dispersion is proportional to wavelength. This topic will be discussed in more detail in § III.

Spectrophotometric observations were attempted for 70% of the new sample of emission-line galaxies with a fiber-coupled spectrograph (FCS) and SIT vidicon spectrometer (Ramsey *et al.* 1980) during the winter and spring of 1982 with the 1.6 m telescope of the Black Moshannon Observatory (BMO). The spectrograph is physically decoupled from the telescope and mounted on a vibrationless table in a temperature-humidity controlled environment. It was optically coupled to the telescope with a 20 m length of 204 μm fused-silica fiber optic cable (Galite 4000 LC). The data were recorded in a 500-pixel array onto floppy disks with a PDP 11/03 microcomputer. A 300 line mm^{-1} Bausch and Lomb grating blazed at 5000 Å yielded a dispersion of 260 Å mm^{-1} and an effective resolution of ~ 20 Å. The spectral coverage was in the range 4400–7200 Å. Integration times were typically 10–30 minutes. Because of the fiber diameter, all the SIT observations were equivalent to using a 4″ circular aperture; the morphological character of each object was noted on the television acquisition/guider system of the 1.6 m telescope. In all, reducible spectra for 41 of the new emission-line galaxies were obtained.

III. REDUCTION AND ANALYSIS

a) Radial Velocities

Radial velocities were determined for 41 of the new emission-line galaxies using a cross-correlation technique on the PDP-11/23 microcomputer of the Department of Astronomy of The Pennsylvania State University. Each galaxy spectrum was transferred onto a logarithmic wavelength scale to eliminate differential redshift effects across the spectrum and was then numerically cross-correlated against emission-line spectra of IC 4997 and M42. Wavelength calibration was performed by the determination of a third-order polynomial dispersion curve for each galaxy and standard individually, using night sky lines from the object's spectrum and comparison lines from a Ne-Ar source and astrophysical objects (IC 4997, M42 and various flux standard stars). The rms residuals for the fits, which covered the range 4800–7000 Å, were typically less than 0.7 Å. The average standard deviation of the radial velocity determinations was 65 km s^{-1} as determined by cross-correlation of each object with five different standard spectra. Comparison with literature values for Markarian galaxies observed and reduced identically, indicates that the BMO redshifts are accurate to ± 100 km s^{-1}.

Radial velocities were also measurable directly from the objective prism plates, using the length of spectrum method. The linear separations on the plates between the $\lambda 3727$ and $\lambda 5007$ emission lines were measured for 47 galaxies in the sample using the X-Y measuring machine of the Warner and Swasey Observatory. This separation, which varies with radial velocity due to the convolved effects of the prism dispersion curve and the stretching of the spectrum due to the redshift, was correlated with the redshift using 20 galaxies from Table 1 which had radial velocities from the BMO data and 12 previously known emission-line galaxies from the literature. The resulting radial velocity calibration curve is shown in Figure 3. The rms deviation of these data from a linear least squares fit is 600 km s^{-1}. This precision, while not adequate for dynamical studies, is useful for the general investigation of the luminosity function of the sample. Table 2 lists the redshifts and sources for the literature data. This procedure was used to measure redshifts for 14 galaxies in Table 1.

In addition, eight galaxies in the new sample had published redshifts; these sources are detailed in the notes to Table 1. In all, radial velocities were obtainable for 63 of the 96 new emission-line galaxies. These observed radial velocities were corrected for solar motion using:

$$V_0 = V + 300 \sin l \cos b \text{ km s}^{-1}$$

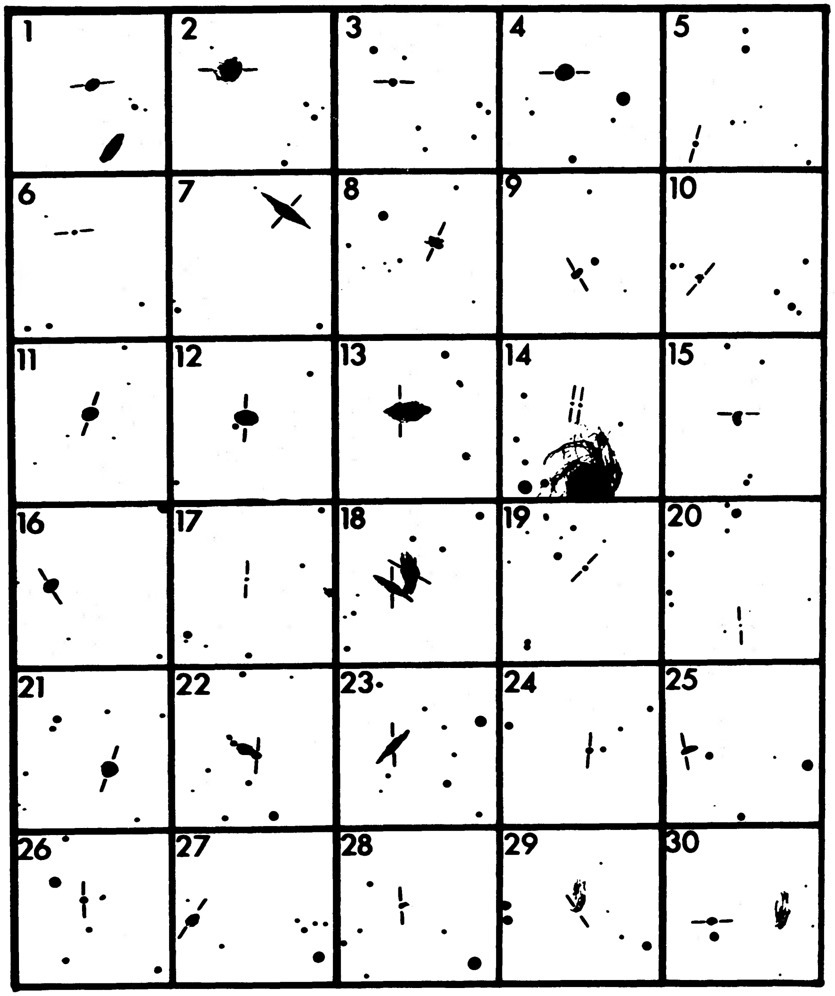


FIG. 2*a*

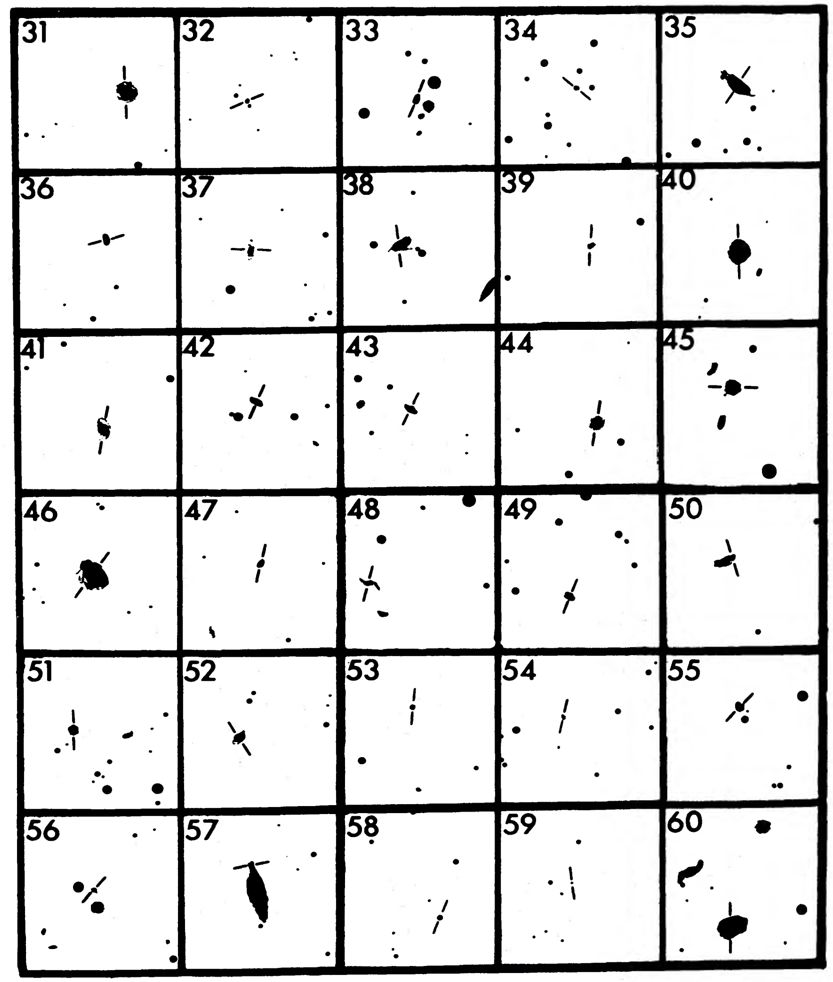
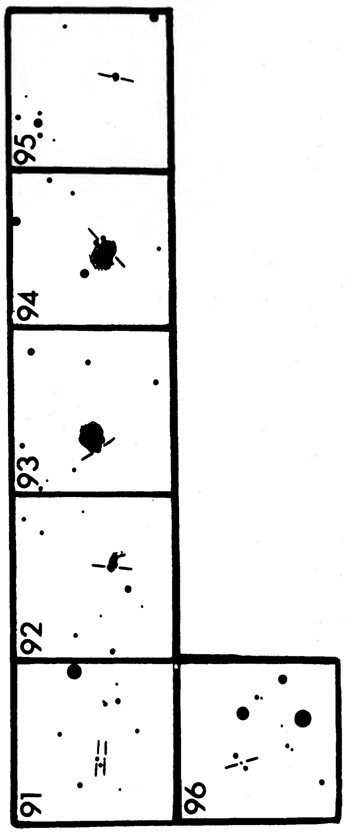


FIG. 2*b*

FIG. 2.—(*a*)–(*d*) Finding charts for the 96 new emission-line galaxies drawn from the POSSE-prints. All fields are 5′ × 5′, with north up and west to the right. Emission-line-producing regions are marked by two lines.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96

FIG. 2d

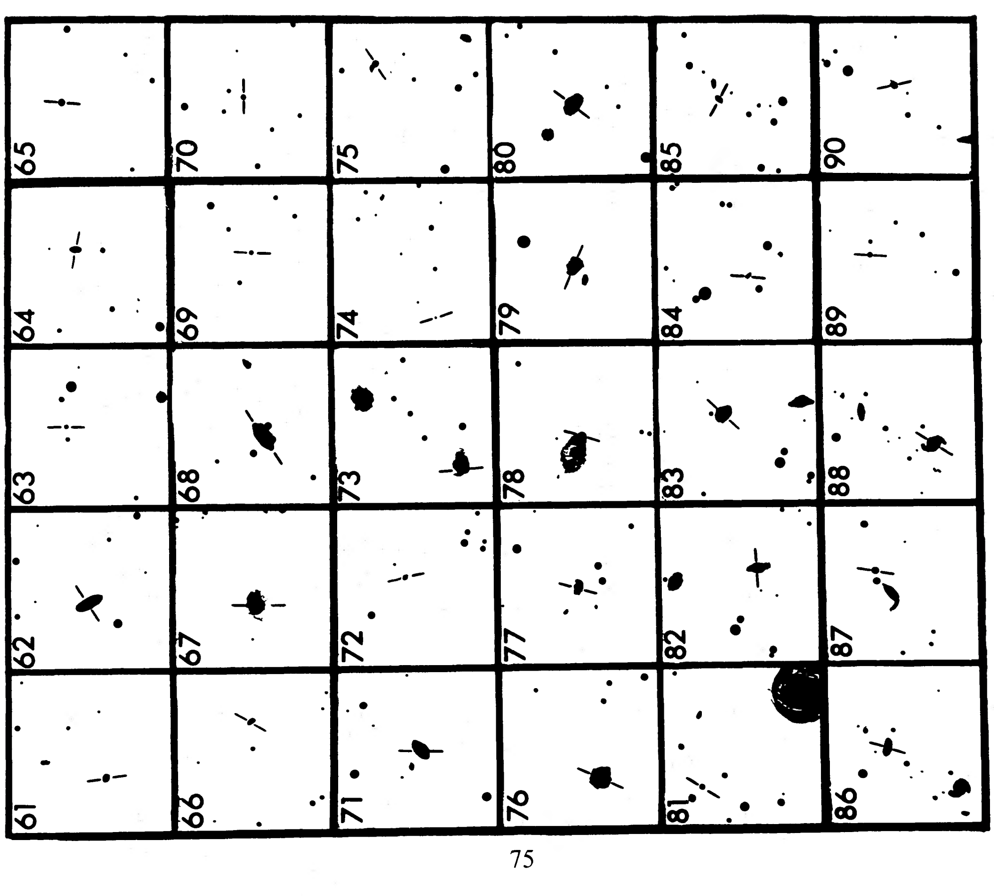
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FIG. 2c

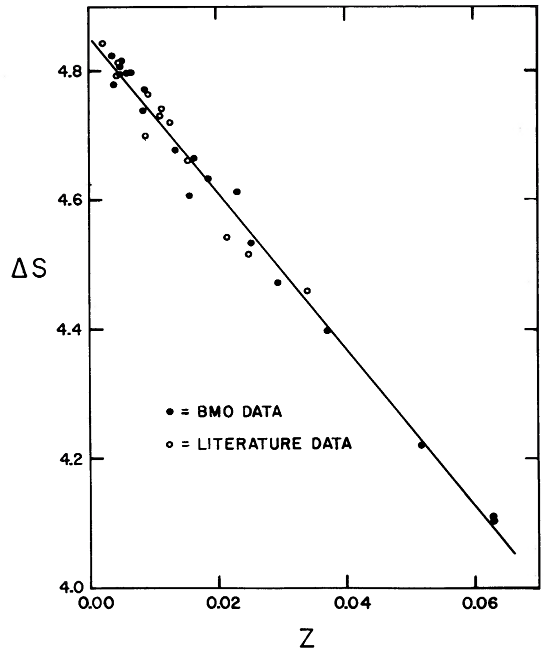

FIG. 3.—The radial velocity calibration of the objective prism plates. ΔS is the linear separation on the plates of the [O III] $\lambda 5007$ and [O II] $\lambda 3727$ emission lines in mm for 32 galaxies which have redshifts determined either in this investigation (Table 1) or in the literature (Table 2). The rms deviation is 600 km s^{-1}. This calibration allows redshifts to be measured directly from the objective prism plates.

(de Vaucouleurs, de Vaucouleurs, and Corwin 1976), where l and b are galactic longitude and latitude, respectively. The corrected velocities are listed as $Z = V_0/c$ in Table 1. The column following the redshift value gives it source.

TABLE 2

LIST OF LITERATURE RADIAL VELOCITIES USED IN OBJECTIVE-PRISM CALIBRATION

Galaxy	Z	Z Ref.[a]
Haro 23	0.0047	1
Mrk 416	0.0044	2
Haro 25	0.0215	1
Haro 4	0.0022	3
Mrk 744	0.0092	4
Haro 5	0.0110	5
NGC 3995	0.0112	6
Mrk 432	0.0115	2
NGC 4253	0.0128	7
Haro 30	0.0153	8
Mrk 651	0.0249	9
Mrk 455	0.0340	2

[a] Redshift references: (1) DuPuy 1970. (2) Denisyuk and Lipovetsky 1974. (3) Weedman and Khachikian 1969. (4) de Vaucouleurs, de Vaucouleurs, and Corwin 1976. (5) Mayall and de Vaucouleurs 1962. (6) Humason, Mayall, and Sandage 1956. (7) Weedman 1978. (8) Tifft and Gregory 1976. (9) Denisyuk, Lipovetsky, and Afanas'ev 1976.

b) Magnitudes

Observed photographic apparent magnitudes from the *Catalogue of Galaxies and Clusters of Galaxies* (CGCG) (Zwicky and Herzog 1963, 1966) or the *Second Reference Catalogue of Bright Galaxies* (RCBG2) (de Vaucouleurs, de Vaucouleurs, and Corwin 1976) were adopted when possible. The CGCG magnitudes were corrected for systematic errors using the results from the comparison of the CGCG photometry and photometric values taken from RCBG2 performed by Kirshner, Oemler, and Schechter (1978):

$$B = \frac{m_{\rm CGCG} - 0.36}{1.04}$$

These magnitudes can be expected to be accurate to 0.4–0.5 mag (Huchra 1976; Bothun and Schommer 1982). Photographic magnitudes for the remainder of the sample (47 galaxies) were estimated from the POSS O-prints and have an accuracy of about 0.5 mag. All the observed magnitudes were corrected for galactic absorption with a cosecant law, with the absorption at the NGP taken to be 0.11 mag after Peterson (1970). The corrected magnitudes m_0 are listed in Table 1 (a colon [:] signifies a POSS print magnitude).

Absolute magnitudes were then calculated for the 63 galaxies having known radial velocities by using the corrected values of the radial velocities and apparent magnitudes with $H_0 = 75$ km s^{-1} Mpc^{-1}.

c) Relative Fluxes and Optical Morphologies

Relative $\lambda 5007$ and Hβ fluxes were measured from the BMO spectra and are listed in Table 3. For these fluxes, sensitivity variations of the vidicon tube were taken into account, but pixel-to-pixel variations were not considered, since the contributions to the uncertainties from this source are small compared to those from other sources such as determining a reliable continuum level. Measurement of the [O III] $\lambda 5007/\lambda 4959$ flux ratios, which should be 3, indicate that the ratios given in Table 3 are accurate to about 25%. Optical morphologies, as judged on the BMO TV guiding system, are also given in Table 3.

d) Continua

An estimate of the strength of the continuum in the blue-violet spectral region was made for each galaxy from the objective-prism spectra. It must be emphasized, however, that it was not possible to get such an estimate for all galaxies in the sample because for many of the objects there was no continuum visible above the plate noise. The four classification categories into which the continua were placed are: (1) B0 = none observed, (2) B1 = continuum not blue (continuum not visible in the $\lambda 3700$ region), (3) B2 = continuum of moderate strength out to about $\lambda 3700$, (4) B3 = strong continuum out to and blueward of $\lambda 3700$ region. Variation in plate quality, fog density, and galaxy brightness will obviously affect these estimates somewhat, but they are of sufficient consistency for general statistical use. The continuum

TABLE 3
RELATIVE FLUXES AND OPTICAL MORPHOLOGIES

Galaxy	$F(\lambda 5007)/F(\mathrm{H}\beta)$	Morphology[a]
2	10.1	s
5	5.3	d
8	2.2	d
10	5.9	d
12	0.4:	s-s + d
18(east)	3.0:	s-s + d
22	2.4:	d
24	2.2:	d
26	1.7	s
27	3.9	s-s + d
30	3.0	d + s?
31	9.3:	s?
32	5.6	s?
34	2.5	?
36	4.2	d
37	3.2	?
45	6.5	s
49	4.5	d
50	2.1:	?
52	3.8	d
56	2.7	s?
61	2.6	s
64	1.7	d + s
66	3.4	s
67	1.7	d
68	2.4	d
69	4.5	s?
73	2.0	d
79	2.9:	d + s-s
81	2.8	?
82	1.1:	d
83	3.1	d
85	1.7	?
87	5.5	s
89	3.3	s-s
92	2.9	d
93	3.7	d
94	0.7:	d
95	2.5	s-s
96	6.2	s

[a] Morphology key: s = stellar; s-s = semistellar; d = diffuse.

estimates are given in the last column of Table 1. The estimates may be modified by d = diffuse or ov = overlapped with nearby stellar spectrum.

The observations show that 21 recovered Markarian galaxies in the sample have an average continuum classification of B2.2, which can be characterized as moderately blue. The average continuum classification for the 67 new emission-line galaxies which have observed continua is B1.5, which may be interpreted as weakly blue. Since the apparent magnitude distributions for the galaxies used in this comparison are similar ($12.8 \leq M_{\mathrm{pg}} \leq 16.9$; $\bar{M}_{\mathrm{pg}}(\mathrm{Mk}) = 15.1 \pm 0.9$ S.D., $\bar{M}_{\mathrm{pg}}(4°) = 15.0 \pm 0.9$ S.D.), it seems that the 4° plates have isolated a sample of emission-line galaxies with relatively weak blue continua, which were not detected by the UV-excess technique because of the lack of a strong blue continuum and the lower dispersion of Markarian's plates.

This general absence of strong UV continua is of interest. It indicates either that there is significant reddening by dust within the galaxies or that they contain a relatively small number of hot, blue stars, or both. Given the present observational data it is difficult to discern which if either is the dominating effect, but since it is likely that the 4° sample contains predominantly galaxies that show emission lines due to photoionization by stars, dust-reddening may play a determining role in the colors of these systems.

IV. SPECTROSCOPIC AND MORPHOLOGICAL PROPERTIES

a) *Surface Density*

Preliminary plates not taken in the vicinity of the NGP suggested that about 1.5 new emission-line galaxies per 10 sq. deg. could be found with the moderate-dispersion objective-prism technique, even in areas previously searched for such objects. The final sample of new galaxies presented here (Table 1) confirms this, since approximately 1.2 new emission-line galaxies per 10 sq. deg. were discovered. This indicates that although most of the galaxies isolated by the lower-dispersion technique of Markarian have emission lines, there are a considerable number of emission-line objects which elude detection by the UV-excess continuum criterion. In fact, the new galaxies in the present survey do not show, on the whole, excessive UV-continua.

Bohuski, Fairall, and Weedman (1978) have shown that virtually all of the emission-line galaxies found on "thin" prism plates taken with the University of Michigan Curtis Schmidt telescope at the Cerro Tololo Inter-American Observatory would be discovered by a Markarian-like survey and that in fact only about one-third of the Markarian sample would have strong enough emission lines to be detected by the "thin" prism plates. Thus, the 4° prism moderate-dispersion method, with its sensitivity to even fairly weak lines, allows the isolation of a group of emission-line galaxies not found by previous search techniques. There is evidence, however, of a fairly close overlap between the 4° prism plates and "thin" prism plates taken with the Burrell Schmidt (Pesch and Sanduleak, private communication). This seems curious in light of the results of Bohuski *et al.*, but may be due to the fact that these authors considered only certain cases with strong emission lines and did not include weak but suspected galaxies in their list.

It should be restated that the 4° emission-line galaxy sample is entirely spectroscopically selected since emission lines were the only search criterion, and it can therefore be expected that the galaxies in Table 1 will represent a highly heterogeneous group with members from many classes of extragalactic emission-line objects except the QSOs.

Markarian has found about 1.5 galaxies with excess UV continua per 10 sq. deg. Since about 90% of these objects show emission lines when observed spectroscopically, there are about 1.3 Markarian emission-line galaxies per 10 sq. deg. The 4° prism technique has therefore isolated about the same surface density of emission-line galaxies as the Markarian survey; but since these are non-Markarian objects, it can be concluded that to a limiting magnitude of $B \sim 16$, a reasonable lower limit to the surface density of emission-line galaxies is 2.5 per 10 sq. deg. on the average. Clearly, the surface density derived for the 4° prism galaxies is more uncertain since it is based on a more limited survey area.

b) *Interacting Systems*

During the screening procedure involving inspection of the direct images of the suspected emission-line galaxies on the POSS prints, it quickly became apparent that a large proportion of the systems were irregular, interacting, distorted, or in other ways peculiar. In the entire galaxy sample listed in Table 1 about 33% of the objects clearly show such disturbed morphologies. The true fraction is no doubt even higher since it was impossible to discern much about many of the galaxies due to small apparent size and lack of resolution on the POSS prints.

That tidal interaction between galaxies might be responsible for enhancing ionization conditions in such systems has long been suspected (Mayall 1958). Theoretical work (Toomre and Toomre 1972; Larson amd Tinsley 1978) has demonstrated that close gravitational interaction would be expected to produce enhanced star formation and emission-line activity in galaxies, and the suggestion has been made that the activity in the nuclei of some galaxies may be related to cloud-cloud collisions and tidal flows induced in interacting systems (Hummel 1980; Bergvall, Ekman, and Lamberts 1981; Bergvall 1981; Wasilewski 1981; Condon *et al.* 1982). Though there is indication that the distribution of star formation (H II regions) is not generally peculiar in interacting systems of galaxies (Hodge 1975), it may be that matter infall from halos or companion galaxies can lead to stochastically propagating star formation (Shore 1981) and thus leave behind a random-appearing H II region pattern.

The unusually high proportion of Markarian galaxies that are found in interacting systems (Heidmann and Kalloghlian 1973) is further confirmation that emission-line galaxies are commonly found in close gravitational association with other galaxies. Balzano (1983) has also found that interacting systems are common amongst the galaxies with starburst nuclei. (Weedman *et al.* 1981.)

c) *Seyfert Galaxies*

Out of approximately 120 known Seyfert galaxies (Weedman 1976, 1978), only about 20% are classified as Seyfert 2. Whether or not this is a real disproportionality is an interesting question. The Markarian survey, which accounts for about 60% of the known Seyfert galaxies, discovered largely (~60%) Seyfert 1 galaxies. But it is just these systems which have extensive UV continua that one would expect Markarian's technique to be most sensitive to. Seyfert 2 galaxies, on the other hand, which do not generally have excessively bright UV continua (Weedman 1973; Neugebauer *et al.* 1976) even though usually possessing intense emission lines, could easily elude the UV-excess search method as discussed in § II. Thus, the apparent deficiency of Seyfert 2 galaxies may perhaps be a result of survey selection effects. Since there appear to be real physical differences in the two classes of Seyfert nuclei, disparities in spatial distribution and immediate galaxian environment would also be of interest. Clearly if selection effects have been important, then no reliable statistical conclusions may be drawn about such issues.

Shuder and Osterbrock (1981) have given evidence for a correlation between emission-line widths and flux ratios. They have found that $F(\lambda 5007)/F(\mathrm{H}\beta) \geq 3$ is a good discriminator of Seyfert 2 galaxies from other narrow-line galaxies. Based on the flux ratios given in Table 3 and on their stellar appearance on the BMO TV acquisition/guider, the following galaxies can be classified as Seyfert 2's: numbers 2, 31, 32, 45, 66, 87, 96. Based on a resolved Hα profile with FWHM = 1200 km s^{-1}, No. 26 can be classified a Seyfert 1. Consideration of the BMO data and the recovered previously known galaxies shows that Seyfert 2 galaxies outnumber the Seyfert 1's by a factor of 3. Since not all the galaxies in the objective-prism sample were observable at BMO, the true ratio may be somewhat different, but is still probably greater than unity. In any case, the suggestion seems clear that the deficiency in the number of known Seyfert 2 galaxies is more a result of survey selection effects than actual rarity. It is feasible, then, that about 10–15% of the new 4° galaxies are Seyferts. This is a rate similar to that for the Markarian galaxies. It appears, though, that the higher-dispersion technique isolates comparatively more Seyfert 2 galaxies, probably because of their large [O III] intensities.

V. SPACE DENSITIES

Redshifts are available for 63 of the 96 galaxies in Table 1. It will be shown that the 4° sample is approximately complete to $m_{\mathrm{pg}} = 15.7$ and that 51 of the 65 galaxies with magnitudes equal to or brighter than $m_{\mathrm{pg}} = 15.7$ can be used to investigate the density distribution of the new emission-line galaxies. The assumption of uniform distribution will be made. This assumption can introduce some systematic error into the space densities (Kirshner, Oemler, and Schechter 1979). In particular, it may artificially increase the estimates for the intrinsically faint galaxies since these are ones which lie nearby and are probably members of the Local Supercluster. Also, since for the 4° sample $Z \leq 0.07$, the volume surveyed can be assumed to be Euclidean.

a) *Completeness of the Survey*

The method used here to estimate the space densities of the 4° galaxies is to calculate for an apparent magnitude-limited catalog the mean density of galaxies in intervals of absolute magnitude with $\Delta M_{\mathrm{pg}} = 1$, within the volume of space for which the survey is complete. Sargent (1972), Huchra and Sargent (1973), and Huchra (1977) have estimated the space densities of the Markarian galaxies as well as that of normal field galaxies. Felten (1977) has reviewed much of the major work in the determination of the field-galaxy luminosity function. A recent determination using a much larger and fainter sample is given by Davis and Huchra (1982). In the present discussion a method similar to that of Huchra and Sargent (1973) will be followed with the following modification: the "classical" (i.e., naive) estimator rather than the Schmidt estimator will be utilized in the computation of the densities. The reason for this choice of estimator will be discussed later in this section. The space densities of the 4° galaxies will then be compared to those for the Markarian, Tololo, starburst, and field galaxies. For the galaxies considered in this investigation the optical apparent magnitudes will not be affected significantly by intergalactic absorption, redshift effects (K term), or age effects.

The completeness of a magnitude-limited sample can be checked through the use of a test devised by Schmidt (1968). In this test one calculates for each object the volume V contained in a sphere, the radius of which is the distance to the object, and the volume V_m which is that of a sphere the radius of which is the distance the object would have if its apparent magnitude were equal to the limiting apparent magnitude of the sample. The mean value (averaged over the entire catalog) of the ratio V/V_m (commonly written as $\langle V/V_m \rangle$) should be 0.5 for a complete sample of objects uniformly distributed in Euclidean space. This ratio can be calculated for any object the apparent magnitude of which is known, since

$$\begin{aligned} M &= m_1 + 5 - 5 \log (r_1) - A \\ &= m_0 + 5 - 5 \log (r_0) - A \end{aligned}$$

leads to:

$$\frac{V}{V_m} = \left(\frac{r_0}{r_1}\right)^3 = \text{dex}\,[0.6(m_0 - m_1)]$$

in which the quantities with the subscript 1 refer to those corresponding to the object having the limiting magnitude of the sample and those with the subscript 0 correspond to the actual observed magnitudes and distances.

Figure 4, a plot of $\langle V/V_m \rangle$ versus $m_{pg}(1)$, supports the conclusion that the 4° catalog is nearly complete to $m_{pg} = 15.7$ and becomes increasingly incomplete for fainter apparent magnitudes. It was thus decided to adopt $m_{pg} = 15.7$ as the limiting magnitude for the survey. In order to correct for the incompleteness existing in the catalog up to the adopted limiting magnitude, the sample was analyzed in 0.1 mag steps by the V/V_m method (Huchra and Sargent 1973). At each magnitude step $\langle V/V_m \rangle$ is calculated, and if this quantity deviates from 0.5, galaxies are added with $m_{pg} = m_{step}$ until $\langle V/V_m \rangle = 0.5$. Each succeeding step uses the cumulative total ($N_{sample} + N_{added}$) to calculate $\langle V/V_m \rangle$. In practice, of course, only an integer number of galaxies can be added at any given m_{step}, and thus the count for N_{added} which caused the value $|\langle V/V_m \rangle - 0.5|$ to be minimized was used. The results of this procedure are shown in Table 4.

In all, 54 galaxies were added to the 51 galaxies which had known redshifts and $m_{pg} \leq 15.7$. This yields a correction factor of 2.06 which is applied to the computations for the space densities at all absolute magnitude classes. It is possible that incompleteness in the sample is a function of absolute magnitude, but the present statistics are too small to allow a reliable assessment of the magnitude of this effect.

b) The Space Densities

Huchra and Sargent (1973) have used the Schmidt estimator

$$\Phi_S(M_{pg}) \equiv \frac{4\pi}{\Omega} \sum_i \frac{1}{V_m^i} \text{ mag}^{-1} \text{ Mpc}^{-3}$$

to compute the luminosity function for both Markarian

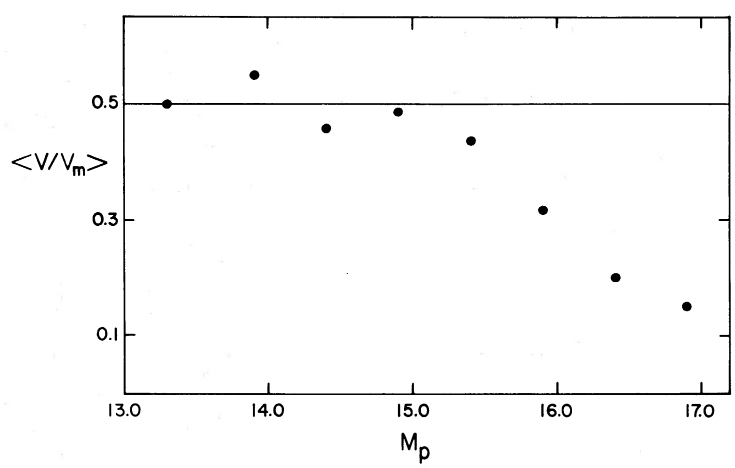

FIG. 4.—The variation of $\langle V/V_m \rangle$ with photographic apparent magnitude for the sample of emission-line galaxies. This test, devised by Schmidt (1968), indicates that the sample is reasonably complete to $m_{pg} = 15.7$, but increasingly incomplete at fainter magnitudes. Note: $\langle V/V_m \rangle = 0.5$ for a complete, uniformly distributed sample.

TABLE 4

RESULTS OF THE COMPLETENESS ANALYSIS

m_1	N_{sample}	$\langle V/V_m \rangle$	N_{added}
13.7	8	0.523	0
13.8	9	0.516	0
13.9	11	0.550	0
14.0	13	0.559	0
14.1	15	0.555	0
14.2	15	0.484	1
14.3	17	0.489	0
14.4	18	0.458	2
14.5	18	0.399	2
14.6	19	0.382	2
14.7	20	0.366	3
14.8	23	0.408	1
14.9	29	0.488	0
15.0	35	0.524	0
15.1	36	0.471	3
15.2	41	0.482	2
15.3	44	0.460	4
15.4	47	0.439	6
15.5	48	0.395	8
15.6	51	0.383	8
15.7	51	0.333	12

galaxies and field galaxies. Felten (1976), however, has shown that the more naive "classical" estimator

$$\Phi_C(M_{\text{pg}}) \equiv \frac{N(M_{\text{pg}})}{(\Omega/4\pi)V(M_{\text{pg}})} \text{ mag}^{-1} \text{ Mpc}^{-3}$$

provides a slightly superior estimate when $|b| > 30°$ and when the interval in absolute magnitude $\Delta M_{\text{pg}} = 1$. Since these conditions hold for the present investigation, it was decided to use the "classical" estimator with Ω, the area of sky covered = 0.253 sr (825 sq. deg.) and

$$V(M_{\text{pg}}) = \frac{4\pi}{3} \text{dex} \, [0.6(m_1 - M_{\text{pg}} - 25 - 0.11)] \text{ Mpc}^3$$

in which m_1, the limiting magnitude of the sample, is taken equal to 15.7. This approach uses 0.11 mag as an average absorption for the entire sample.[1] For the $M_{\text{pg}} = -22$ and -23 classes, the Z-limited survey volume is used.

Table 5 gives the calculated space densities for the 4° emission-line galaxy catalog corrected for incompleteness as described above and arrived at through the use of the "classical" estimator. Column (2) shows the results for the 4° sample. Column (3) lists the results for the Markarian galaxies from the first four lists as derived by Huchra and Sargent (1973). (Huchra 1977 has given a further determination for the Markarian galaxy space density which is in close agreement with this earlier work.) Column (4) shows the space density for field galaxies from Davis and Huchra (1982) for the north galactic cap. Their values have been transformed to an $H_0 = 75$ km s^{-1} Mpc^{-1} scale for comparison with the other luminosity functions. Also, the field galaxy space density for the $M_{\text{pg}} = -23$ class was taken from Huchra and Sargent (1973).

An inspection of Table 5 shows that for $-16.5 \geq M_{\text{pg}} \geq -22.5$ the density of the 4° galaxies is closely similar to that for the Markarian galaxies, except for the $M_p = -21$ class. In this absolute magnitude range, the 4° galaxies represent about 8% of all galaxies. The variation of the 4°/field ratio with absolute magnitude indicates that the 4° sample is heavily represented at the intrinsically faint luminosities. The density in the highest luminosity class ($M_{\text{pg}} = -23$) is sufficiently uncertain that no dependable ratio may be calculated, but the data confirm the conclusion of Huchra and Sargent (1973) that at such high luminosities the majority of galaxies are emission-line objects because they are Seyferts.

At the fainter end, the very high density of galaxies at $M_{\text{pg}} = -16$ can be taken as an indication that, at faint intrinsic luminosities, emission-line galaxies are very common. It is possible, however, that the high density is produced artificially, by the assumption of uniform distribution used in the space density calculations. Indeed, 77% of the galaxies in Table 1 with $V_0 \leq 2000$ km s^{-1} have $M_p \geq -17.6$. However, field galaxy densities at such faint luminosities may be extremely underestimated due to the difficulty in discovering and observing such systems. Thus, it may simply be easier to find dwarf emission-line galaxies than their nonemission counterparts.

Bohuski, Fairall, and Weedman (1978) have made a determination of the space densities of emission-line galaxies discovered with the Curtis Schmidt telescope (Tololo galaxies). They found that these galaxies had space densities that were 2–4 times lower than the Markarian objects and concluded that although some of the difference could be attributed to incompleteness of their follow-up observations, most of the disparity was real. The space densities of the field, Markarian,

TABLE 5

SPACE DENSITIES

M_p (1)	log Φ (4°) (2)	log Φ (Mrk)[a] (3)	log Φ (Field)[b] (4)
−16	−1.79(6)	−2.32(5)	...
−17	−2.56(4)	−2.55(14)	−1.37
−18	−2.73(11)	−2.97(17)	−1.76
−19	−3.76(4)	−3.34(31)	−2.27
−20	−3.76(16)	−3.52(75)	−2.87
−21	−4.72(7)	−4.19(60)	−3.52
−22	−5.65(2)	−5.36(12)	−5.12
−23	−5.95(1)	−6.61(3)	−6.65[a]

NOTE.—Φ is in units of mag^{-1} Mpc^{-3}. ( ) = number of galaxies entering into the densities.

[a] From Huchra and Sargent 1973.

[b] From Davis and Huchra 1982 (see text).

[1] The catalog forms an incomplete strip 15° wide that stretches from $b^{\text{II}} = 46°$ at $l^{\text{II}} = 207°$, over the north galactic pole to $b^{\text{II}} = 63°$ at $l^{\text{II}} = 30°$. The largest absorption, assuming a cosecant law, is (at $b^{\text{II}} = 46°$) 0.15 mag, so that the use of a single value of the absorption in calculating the surveyed volume at a given absolute magnitude will not contribute much uncertainty in the density estimates.

Tololo and 4° galaxies are graphically summarized in Figure 5. With the lowest densities, the Tololo galaxies probably do represent essentially a subset of the Markarian galaxies (Bohuski, Fairall, and Weedman 1978). The 4° galaxies, however, were discovered in a region of the sky well searched by Markarian (Lists 1, 2, 3, 5, 7, 8, 13, 14, and 15), and the space densities reported here were calculated from an apparent magnitude-limited catalog with a completeness limit ($m_{pg} = 15.7$) similar to that used by Huchra and Sargent (1973) ($m_{pg} = 15.55$) for the Markarian galaxies. Since there is no overlap in the two samples, the 4° galaxies belong to a different population from the Markarian sample and represent an independent group of emission-line galaxies with a space distribution similar to that of the Markarian galaxies. This is also indicated by Figure 6, two histograms showing the radial velocity distribution of the 4° sample and of 880 Markarian galaxies (Huchra, private communication). These histograms are plotted in a cumulative sense so that at any Z all galaxies with redshifts $\leq Z$ are included. Comparison of these histograms suggests that the 4° sample is comparatively richer in galaxies with 750 km s$^{-1} \leq V_0 \leq$ 4500 km s^{-1}. This indicates that it includes more galaxies from the Local Supercluster, and in fact all the galaxies in the new sample with redshifts in this range are low-luminosity objects ($M_p \geq -18.2$), thus confirming that the trend shown in Figure 5 for the 4° galaxies to have higher space densities than the Markarian galaxies in the range $-15.5 \geq M_p \geq -18.5$ is real.

That the 4° and Markarian search techniques do isolate independent samples of emission-line galaxies is further emphasized by the relatively small overlap between the two surveys. Out of 113 Markarian galaxies that fall in the area surveyed (shown in Fig. 1) only 20% were noted as emission-line objects on the 4° plates. Thus, a large fraction of Markarian galaxies must have emission lines that are too weak to detect with the higher dispersion technique. At the same time, the UV-excess criterion is not efficient in selecting emission-line objects if they are not accompanied by a blue continuum.

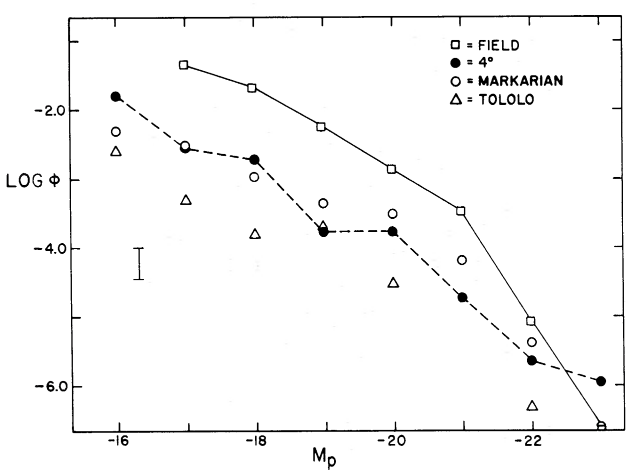

FIG. 5.—Space densities for galaxies in the present survey, Markarian galaxies, Tololo galaxies, and field galaxies. ϕ is in units of mag^{-1} Mpc^{-3}. The typical error bar for the 4° values is shown at left.

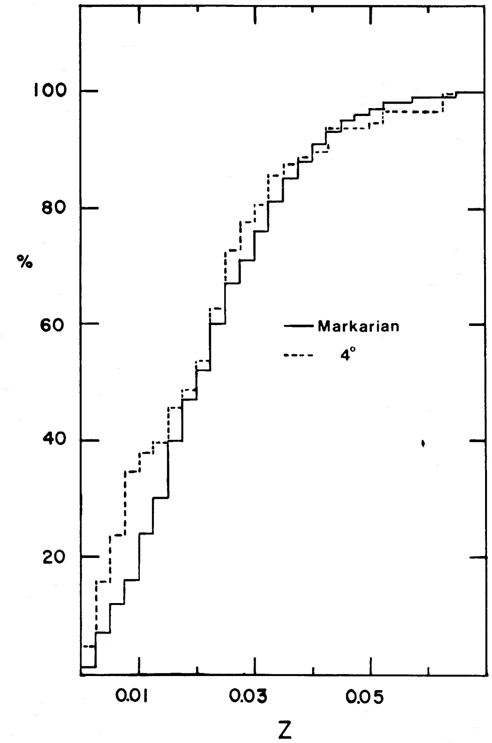

FIG. 6.—Histogram showing distribution of radial velocity for two-thirds of the new sample of emission-line galaxies and for 880 Markarian galaxies. These histograms are binned in a cumulative sense so that at any Z, all galaxies with redshifts less than or equal to Z are included. This procedure is adopted to reduce the noise in the distribution of the new galaxies. The 4° sample is apparently richer in galaxies with 750 km s$^{-1} \leq V_0 \leq$ 4500 km s^{-1}.

Table 3, which lists the relative [O III] $\lambda 5007/\mathrm{H}\beta$ flux ratios and optical morphologies for about one-half of the present sample, can be used to estimate the proportion of the new emission-line galaxies that have star-burst nuclei. These data show that about 15% (numbers 12, 56, 61, 79, and 95) of the galaxies listed have line ratios $\lambda 5007/\mathrm{H}\beta < 3$ and stellar or semistellar nuclei characteristic of starburst galaxies. Thus, approximately 15%–30% of the new sample have starburst nuclei. In the absolute magnitude range $-17.5 \geq M_{pg} \geq -22.5$ the 4° galaxies have a total space density of approximately 0.0050 Mpc^{-3}. If 20% of these galaxies have starburst nuclei, this yields 0.0010 Mpc^{-3} as the total space density for starburst galaxies in the sample. Balzano (1983) has estimated, from observations of essentially a subset of the Markarian galaxies, that galaxies with starburst nuclei with absolute magnitudes in the range $-17.5 \geq M_{pg} \geq -22.5$ ($H_0 = 75$ km s^{-1} Mpc^{-1}) have a total space density of 0.0011 Mpc^{-3} (about 3% of all field galaxies). The similarity of these two estimates is no doubt largely fortuitous, especially in view of the small number of objects involved in the

4° value. Further, it is unclear how the completeness corrections made by Balzano (1983) and in this investigation, as well as selection effects inherent in the two samples, will affect the overlap between them (though there are no galaxies common to both). The results can be used, however, to place constraints on the space density of starburst nuclei. In the case that the two estimates are wholly independent of each other, the density of starburst galaxies may be approximately a factor of 2 higher than Balzano's estimate. In the other extreme, i.e., complete overlap of the estimates, the density estimate given here confirms Balzano's result, in a general sense.

The emission-line galaxy sample considered here is, then, like the Markarian sample, quite heterogeneous spectroscopically, being composed of approximately 10–15% Seyferts and 15–30% starburst galaxies, with the remainder being primarily various types of diffuse objects or galaxies with large H II regions. These galaxies represent a population of objects independent from the Markarian galaxies but having a similar spatial distribution. The Markarian and 4° samples taken together account for about 20% of all nearby galaxies.

VI. SUMMARY

A moderate-dispersion objective-prism survey for low-Z emission-line galaxies has been carried out in an 825 sq. deg. region near the north galactic pole with the Burrell Schmidt telescope, located at the Kitt Peak Station of the Warner and Swasey Observatory. A 4° prism yielding a dispersion of 400 Å mm^{-1} at Hβ was used along with the fine-grained IIIa-J emulsion to show that a new sample of emission-line galaxies is available even in areas already searched by Markarian with the "excess UV-continuum" technique. The 4° prism plates, with their relatively higher dispersion, also allow the measurement of redshifts accurate to 600 km s^{-1}, if both the [O II] λ3727 and [O III] λ5007 features are visible. The redshift limit of the sample, imposed by the IIIa-J emulsion, is $Z = 0.07$. Table 1 lists the 96 new emission-line galaxies discovered on the objective prism plates.

Astrometric positions accurate to $\pm 6''$ were obtained for the sample of new emission-line galaxies. This catalog represents an average of approximately 1.2 galaxies per 10 sq. deg.—a value quite similar to that for the Markarian survey. The 4° galaxies on the whole, however, do not appear to have excessive UV-continua and are possibly composed largely of galaxies in which significant dust-reddening is common.

Spectrophotometric observations of the new emission-line galaxies made with a fiber-coupled SIT vidicon spectrometer have yielded redshifts and relative line fluxes for about 43% of the sample. A logarithmic cross-correlation technique allowed the measurement of radial velocities accurate to ± 100 km s^{-1}. Redshifts for an additional 23% of the sample have been obtained from the objective-prism plates or the literature. Relative [O III] λ5007/Hβ fluxes, emission-line widths, and optical morphologies have been used to identify Seyfert and starburst galaxies in the new sample. The proportion of Seyfert galaxies in Table 1 is in the range 10%–15%. An additional 15%–30% exhibit the characteristics of starburst galaxies. There is indication in the data that the previous deficiency in the number of known Seyfert 2 galaxies compared to Seyfert 1 galaxies is more a result of selection effects inherent in previous surveys than an actual rarity of such objects.

The frequency, in Table 1, of galaxies with peculiar morphology indicating gravitational interaction with a close companion or other disturbances is high (at least 33%), and it is suggested that tidal interaction involving matter infall may play a significant role in the generation of an emission-line spectrum.

The space density of the new sample of emission-line galaxies, which represents a population of objects independent of the Markarian sample, has been investigated, and it is found to be similar to the space density of the Markarian galaxies. The results (Table 5) indicate that the 4° galaxies represent about 8% of all galaxies in the absolute magnitude range $-16.5 \geq M_{\rm pg} \geq -22.5$, based on a comparison with Davis and Huchra's (1982) field-galaxy luminosity function. The total density of starburst galaxies in the new sample is ~ 0.001 Mpc^{-3}.

The data and analysis presented here suggest possibilities for future investigations of active galaxies.

A most promising facet of the emission-line galaxy phenomenon that deserves increased attention is the examination of the effects of disturbed or interacting mosphology on the generation of an emission-line spectrum (and vice versa). The evidence seems quite strong that peculiarity and emission lines occur together rather commonly and in a broad range of systems. An analysis of velocity flows in some of the interacting or greatly disturbed systems, especially those with a Seyfert component, can be useful in providing possible evidence of a causal link between tidal interaction and enhanced star formation or even greater modes of activity in galactic nuclei. Direct imagery at high resolution of such systems should also aid in clarifying the situation.

Further, the 4° objective-prism/Schmidt telescope combination can be used to continue the survey for emission-line galaxies, and it may be expected to yield a sample comparable in size to the Markarian survey. The thin-prism survey of Pesch and Sanduleak (1981) with the Burrell Schmidt may, however, discover a similar population of objects, though the present lack of overlap between the two surveys leaves this point inconclusive. In any case, the higher dispersion prism does offer the advantages of greater resolution including the measurement of redshifts and information about line intensities and profiles.

The moderate-dispersion objective-prism technique can also be applied to the study of emission-line galaxies in individual clusters. For example, X-ray luminosity contours in some galaxy clusters are clumpy and in many cases are concentrated on individual galaxies. Since this clumped X-radiation may be used to infer the presence of a hot, intracluster gas, it will be interesting and important to find out if this gas is related to the optical activity in the nuclei and disks of galaxies around which it is found.

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