THE ASTROPHYSICAL JOURNAL, 173:7–24, 1972 April 1

THE SPECTRA OF 80 GALAXIES IN MARKARIAN'S SECOND LIST AND THE SPACE DENSITY OF THE MARKARIAN GALAXIES

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Received 1971 October 12

ABSTRACT

Low-dispersion spectroscopic observations have been made of 80 objects in Markarian's second list of galaxies with an abnormally strong ultraviolet continuum. Redshifts have been measured for 68 objects which include one bright quasi-stellar object (Markarian 132), which has $z_{em} = 1.75$ and a rich absorption-line spectrum, and 62 emission-line galaxies. These include four galaxies of the Seyfert type (Nos. 79, 106, 124 and 176) and six members of a class of dwarf galaxies with strong, high-excitation, emission lines described by Sargent and Searle.

Markarian's first three lists contain 302 objects, distributed over 2000 square degrees of the sky. We show that the lists are reasonably complete down to $m_p = 15.5$ while at $m_p = 16.5$ they are incomplete by a factor of about 5. Redshifts obtained by various authors have been used to derive absolute magnitudes M_p for 61 out of 70 galaxies in list I and for 94 out of 130 in list II. Down to $m_p = 15.5$ redshifts are available for 109 out of 125 galaxies in these two lists. The V/V_m method devised by Schmidt has been used to determine the incompleteness factor for galaxies with $m_p \leq 15.5$ and to show that it does not vary significantly with M_p. The data have then been used to derive the space density $\Phi(M_p)$, in units of Mpc^{-3} per unit magnitude interval, for Markarian galaxies with $-13 \geq M_p \geq -22$. The results are given in a table and are then compared with estimates of $\Phi(M_p)$ for field galaxies. In particular we show that the dwarf emission-line galaxies have a space density of about 10^{-2} Mpc^{-3} mag^{-1} at $M_p = -14$ while luminous Seyfert galaxies have $\log \Phi(M_p) = -5.7$ at $M_p = -21$.

We discuss some consequences of these estimates of space density in §§ I and V.

I. INTRODUCTION

At the time of writing, Markarian had published three lists of galaxies with a strong ultraviolet continuum which he had discovered on low-dispersion objective-prism plates (Markarian 1967, 1969*a*, *b*). These three lists contain 302 objects in several fields which together cover about 2000 square degrees in the plane of the sky. The majority of the 70 galaxies in the first list have been observed (at a resolution high enough to determine the redshift of the object and to obtain a crude impression of its spectrum) by Weedman and Khachikian (1968, 1969) or by Sargent (1970). The Markarian galaxies exhibit a great diversity of appearance as seen on the *Palomar Sky Survey* prints, and these initial spectroscopic surveys show that the spectroscopic characteristics of the galaxies are also diverse. Their most common property, apart from the ultraviolet continuum which led to their initial isolation, is that the Markarian galaxies almost invariably have emission-line spectra.

As Markarian (1967) surmised in his first paper, there appear to be two distinct kinds of emission-line spectra. Objects in which the emission lines are probably excited by hot stars form the largest group. In these galaxies the emission lines come from a region of measurable angular extent, the lines are sharp at the spectral resolution used in the surveys, and the excitation of the emission lines does not depart from the range exhibited by H II regions. As we shall see in more detail in § III, this first group of Markarian gal-

* This paper was completed while the author was a Visiting Fellow at the Institute of Theoretical Astronomy, Cambridge University, 1971 June–September.

axies are themselves quite diverse in appearance, absolute magnitude, and spectral characteristics. However, those sharp-emission-line objects which are intrinsically faint, say with $M_p \gtrsim -16$, form a fairly homogeneous subgroup. They are uniformly of high excitation, have strong emission lines relative to the continuum, and are physically small, with diameters of only a few hundred parsecs. Sargent and Searle (1970) gave detailed observations of two such objects, I Zw 18 and II Zw 40 in Zwicky's (unpublished) lists of compact galaxies. There seem to be three possible interpretations of these dwarf galaxies. First, they may be young objects about 10^8 years old; second, they may be intrinsically very faint old galaxies which are currently experiencing a burst of star formation which very much exceeds the average rate in the past; finally, they may be galaxies 10^{10} years old which have preferentially produced stars of high mass throughout their lives.

The more luminous Markarian galaxies with sharp emission lines, being diverse in appearance and spectrum, have yet to be classified. Some of them are probably distant examples of the spiral galaxies with nuclear "hot spots" described by Morgan (1958) while others may be giant, luminous, irregular galaxies. An extensive program of large-scale direct photography would be an important first step in our eventual understanding of these objects.

The second group of emission-line galaxies found in the Markarian lists are those with broad lines; we shall term these "Seyfert galaxies." (Morgan 1970 and Sargent 1971 have advocated that purely spectroscopic criteria should be used in the definition of these objects.) Galaxies with broad emission lines constitute at most 10 percent of the objects found by Markarian. However, they are important because the mode of search used by Markarian biased the chance of discovery toward galaxies in which the "Seyfert nucleus," with its characteristic spectrum, produces most of the object's total optical radiation. In the classical Seyfert galaxies the nucleus typically radiates about 10 percent of the total light of the galaxy (Minkowski 1968) and the nucleus has $M_p \sim -18$. The objective-prism plates used by Markarian do not have high spatial or spectral resolution, so that the light from these low-luminosity nuclei tends to be submerged in the redder light from the whole galaxy. Consequently, the Seyfert galaxies found in Markarian's lists frequently have nuclei with $M_p = -21$ rather than the more normal $M_p = -18$. These high-luminosity nuclei are of great astrophysical significance because they provide a link between the nearby Seyfert galaxies, which can be studied in some detail, and the more remote quasi-stellar objects.

Markarian's search covers particular areas of the sky and contains objects between 12 and 17 mag. The foregoing remarks on their general spectroscopic properties have shown that there is an obvious need to obtain the space densities of the various kinds of objects found in the surveys. This is particularly true of the dwarf emission-line galaxies, where a statistical study of the space density should enable us to discriminate between the three possible interpretations of their properties. In outline, if the galaxies are only 10^8 years old, we should find 10 times as many objects of the same kind which are 10^9 years old. If they represent brief bursts of star formation, we should be able to find numerous examples of the systems in their more normal, quiescent phase. If they are old objects which, for some reason, produce only massive stars, then we should find no apparent embryos or metamorphs (Sargent and Searle 1971). Similarly, in the case of the Seyfert galaxies, it is important to compare their space density with Schmidt's (1970) value for the "local" space density of quasi-stellar objects.

In order to derive these space densities we must have observations of a reasonably complete sample of objects over a portion of the sky. We shall present evidence in § IV that the Markarian galaxies are reasonably complete down to 15.5 mag (that is, there is a reasonably well-established, small correction factor for incompleteness down to this magnitude limit) while at 16.5 mag the lists are incomplete by about a factor of 5. Accordingly, we have attempted in our work on the objects in Markarian's second list to complete redshift measurements down to mag 15.5. This work was begun in 1970 January. Fortunately, while our observations were in progress, substantial lists of redshifts were published by Arakelian, Dibai, and Esipov (1970, hereafter called ADE), by Arakelian *et al.* (1970*a*, hereafter called ADEM), and by Ulrich (1971). As a result, redshifts are available for 94 out of the 130 galaxies in Markarian's second list, in addition to the 61 out of 70 galaxies in the first list which were published by the authors cited earlier. In these two lists redshifts are available for 109 out of 125 galaxies brighter than 15.5 mag. This material is used in § IV to derive the space density as a function of M_p; that section also contains a detailed discussion of the completeness of Markarian's lists. Prior to that we give in § II the details of our spectroscopic observations of 80 galaxies in the second list, while § III contains an overall discussion of the spectra of the Markarian galaxies in general.

II. OBSERVATIONS OF GALAXIES IN LIST II

Spectra of the 80 galaxies listed in table 1 were obtained with the Cassegrain image-tube spectrograph on the Hale telescope. In column (1) the galaxies are listed by their number in Markarian's (1969*a*) paper. The footnotes to table 1 contain, where appropriate, other designations such as NGC numbers. For most of the observations a grating was used which gave dispersion of 190 Å mm^{-1} in the range λλ4800–7000. This wavelength region was chosen so as to put Hα near the center of the plate and also to include Hβ in reasonable focus. Six of the more interesting objects (Nos. 78, 79, 106, 124, 151, and 178) were also observed with each of two settings of a 90 Å mm^{-1} grating, which together covered the wavelength range λλ3400–5900.

Fifty-eight of the 80 galaxies in table 1 are also listed in the appropriate volume of the *Catalog of Galaxies and Clusters of Galaxies* (CGCG) by Zwicky and his collaborators. For these objects the photographic magnitudes m_p taken from the CGCG are given in column (5) of table 1. For the remaining objects Markarian's cruder magnitude estimates are given in brackets.

Redshifts v_r were measured for 68 of the 80 objects studied; the rest either were galactic stars or had spectra with no discernible features. These redshifts are listed in column (2) of table 1, where they are rounded off to the nearest 10 km s^{-1} and corrected to the Galactic center by adding 250 sin $|l|$ cos $|b|$ km s^{-1} to the measured value. They were measured on a Grant comparator. Eleven of the galaxies were also measured by Ulrich (1971). Leaving out Markarian 78, which has double lines on our spectra, we find that the mean difference $v_r(\mathrm{Ul}) - v_r(\mathrm{Sa}) = 28$ km s^{-1} and that the standard deviation of a single observation is 45 km s^{-1}. Ulrich's redshifts are given in the notes to table 1, as are the redshifts measured by ADE and by ADEM. These latter redshifts are quoted to only three significant figures and appear, in comparison, to be of lower accuracy than those measured by Ulrich and by the writer.

The apparent magnitudes in column (5) and the redshifts in column (2) were used together with a value of $H = 75$ km s^{-1} Mpc^{-1} to calculate the absolute magnitudes M_p given in column (6). A correction of 0.24 cosec $|b|$ mag was applied in each case to allow for galactic absorption. In column (7) the linear size of each object is given, based on Markarian's estimates of the angular sizes.

The spectra of the galaxies observed are described briefly in column (3) of table 1. The meaning of the descriptions is as follows.

Sharp em. The emission lines normally observed in the spectra of galactic H II regions —principally [O II] λ3727, [O III] N1 and N2, [Ne III] λλ3869 and 3968, [N II] λλ6548 and 6583, and the Balmer series—are present and are so sharp as to be unresolved at the dispersion used. This corresponds to a full half-width of less than 450 km s^{-1} at 190 Å mm^{-1} and about half this value at 90 Å mm^{-1}. The emission-line strengths have been roughly estimated on a four-step scale—weak (w), medium (m), strong (s), and very strong (vs); these designations are also given in column (3).

TABLE 1

THE GALAXIES OBSERVED

Markarian No.	v_r (km sec^{-1})	Spectrum	Markarian Class	m_p	M_p	Size (kpc)
72	13170	Ca II abs.; λ3727 em. (w)	d3e:	(17)	(-19.6)	6.8
73	4510	Sharp em. (w)	sd3e	14.9	-19.5	4.4
74	11030	Sharp em. (w)	d3	(16)	(-20.3)	5.0x7.1
75	8960	Sharp em. (w); Ca II abs.	ds3	(16)	(-19.8)	5.8
76	-	Blue continuum	ds3e	(15.5)	-	-
78	11260	Sharp em. (vs); "D" abs.	ds1e	(15)	(-21.3)	7.2x0.8
79	6640	Broad em.	s1e	13.3	-22.0	8.6x17.2
80	-	Prob. gal. star	d3e:	(17)	-	-
81	-	Poss. abs. lines	sd2e:	14.3	-	-
82	5730	Sharp em. (w)	s2e:	(15.5)	(-19.5)	3.7
83	14500	Sharp em. (m)	s3e:	(16.5)	(-20.4)	6.6
84	6120	Sharp em. (w); "D" abs.	s2	13.6	-21.5	4.0x11.9
85	3580	Ca II abs.	s3e:	13.8	-20.0	5.8
87	2870	Ca II abs.; sharp em. (m)	sd3e	13.4	-19.9	2.8x3.7
88	9200	Hyd. abs.; sharp em. (m)	d2e:	14.3	-21.5	8.9
89	1750	Sharp em. (m)	sd2e:	(15)	(-17.8)	0.9x1.4
90	4280	Hα, Hβ em. (w)	s3	13.9	-20.3	5.5x9.6
91	5150	Sharp em. (m); "D" abs.	sd12	14.7	(-19.9)	3.0x4.0
92	4330	Sharp em. (s)	s1e	(15)	(-19.2)	2.8
93	5330	Sharp em. (s)	sd1e	15.7	-19.0	2.4x3.5
94	750	Sharp em. (vs)	d1e	(16.5)	(-13.9)	0.34
96	7090	Sharp em. (m)	sd1e	(15.5)	(-19.8)	4.1
97	7130	Hα, Hβ em. (m)	ds3	15.3	-20.0	4.6x9.1
98	3580	Sharp em. (m)	d1e	15.0	-18.8	2.3x2.8
100	3690	Hα, [N II], Hβ em. (w)	s2e	14.2	-19.7	6.7
101	4800	Sharp em. (m); Ca II and Hyd. abs.	s1	13.6	-20.9	6.2x9.3
102	4260	Sharp em. (m)	ds3e:	14.3	-19.8	3.5x4.6
103	9500	Hβ em. (w)	s3	15.6	-20.4	4.9x10.9
104	2250	Sharp em. (m)	s1e:	14.7	-18.0	1.5x1.9
105	3630	Sharp em. (m)	s2	(16)	(-17.8)	1.4x1.9
106	37070	Broad em.	s1	(16)	(-22.9)	12.0
107	8700	Sharp em. (m)	d3e:	14.7	-21.1	7.2x11.7
108	1520	Sharp em. (vs)	d1e	15.1	-16.8	0.8x1.3
109	9120	Sharp em. (vs)	d3	15.6	-20.3	5.8x8.7
111	3750	Sharp em. (m)	s2e:	13.9	-20.0	4.8x7.3
113	-	Prob. galactic star	s2	(14.5)	-	-
114	7530	Hα, [N II] em. (m)	s3	14.5	-20.9	7.2x14.4
115	7790	Sharp em. (w)	s2	15.4	-20.0	5.0
118	2450	Hα, Hβ, 5007 em. (w)	d3	15.2	-17.7	2.5x3.4
121	6610	Sharp em. (w)	sd2	15.3	-19.9	4.3
122	-	Continuum	s3	14.3	-	-
123	7692	Sharp em. (w)	ds3	(15.5)	(-19.8)	3.9x7.4
124	16970	Broad em.	s1e:	(16)	(-21.1)	7.7
127	10890	Sharp em. (w)	s2e	(16.5)	(-19.5)	5.6
129	4620	Ca II abs.	sd3	15.1	-19.2	3.0x4.4
131	-	Blue continuum	sd2	13.8	-	-
132	z_{em} = 1.75	QSO with abs. lines	s1e:	(15)	-	-
137	-	Blue continuum	ds2e:	15.6	-	-
139	-	Continuum	sd2	14.7	-	-
140	1650	Sharp em (s)	sd1e	15.0	-17.0	1.1x1.6
143	-	Continuum	d3	15.6	-	-
144	8290	Ca II abs.; Hβ and λ3727 em. (m)	ds3	15.0	-20.5	6.3
145	10120	λ3727 and Hβ em. (w)	d3e:	15.4	-20.6	6.5
146	3330	Hα, [N II] em. (m)	s1	14.1	-19.4	4.3
147	7110	λ3727, Hβ and λ5007 em. (m)	d3	15.5	-19.7	3.2x5.4
150	3680	Sharp em. (m)	sd1e	15.0	-18.8	2.1x2.9
151	1550	Sharp em. (s)	s2	15.1	-16.7	1.0x1.5
152	7020	Hβ, λ3727 em. (w)	s2	14.9	-20.2	4.5x11.2
158	2140	Sharp em. (m)	s2e:	13.0	-19.5	4.9x6.3
159	-	Blue continuum	s1	14.6	-	-
161	5940	Sharp em. (w)	s2e:	13.4	-21.4	7.7x11.5
166	3240	Sharp em. (w)	s1e:	(15.5)	(-17.9)	1.7
168	10260	Sharp em. (s)	d1e:	(16)	(-19.9)	6.6
170	1060	Sharp em. (s)	ds2e:	14.9	-16.1	1.0x3.0
171	3060	Sharp em. (s)	sd1e+d1	11.8	-21.5	5.9x11.5
175	3750	Ca II abs.	ds3e:	14.1	-19.7	4.8x8.4
176	8080	Multiple system: see footnote.	sd2e	14.7	-20.8	4.2x31.5
178	270	Sharp em. (vs)	sd2e	13.9	≥-14	∼0.3x0.5
180	-	Blue continuum. Poss. abs. at λ5200	s1e	15.5	-	-
181	6130	λ3727, Hβ, λ5007 em. (m)	ds3	(14.5)	(-20.3)	5.9x8.6
183	12420	Ca II abs.; λ3727, Hβ em. (w)	d3e	15.4	-21.0	7.9x10.3
185	3090	Ca II abs.	sd3	13.0	-20.4	5.9x10.8
186	690	Sharp em. (m)	ds1e	13.2	-16.9	0.9x1.6
188	2500	Ca II abs.	sd3	12.6	-20.3	4.8x8.8
190	1020	λ3727, Hβ em. (m)	sd2	13.1	-17.8	2.3
194	-	Blue continuum	s1e:	15.2	-	-
195	1500	Sharp em. (m)	s1e	14.3	-17.5	1.7x2.4
197	2320	Sharp em. (w)	s2e:	14.7	-18.7	3.8
198	7220	Sharp em. (s)	sd2e	15.2	-20.0	5.6
199	2290	λ3727, λ5007 em. (w)	d2	15.4	-17.3	1.2x3.7

NOTES TO TABLE 1

For convenience we give an abbreviated translation of Markarian's comments on each object in quotation marks together with our remarks.

72. "Compact."

73. "Spheroidal system with faint corona." Compact in CGCG III. Emission from region 4″ = 1.2 kpc in extent along the slit.

74. Emission from region 3″ = 9 kpc in extent.

75. "Spheroidal; compact." λ3727 from region 8″ = 4.6 kpc in extent.

76. "Hα emission." This was not observed by Ulrich (1971) or on our spectrogram which showed a smooth, fairly red, continuum from an object at least 5″ in extent.

78. "Elliptical galaxy with very strong emission lines." Our redshift is in reasonable agreement with those quoted by ADEM and by Ulrich (1971). On our 90 Å mm^{-1} widened spectrograms, Hβ and [O III] N1 and N2 are all double emission lines. The components are sharp, of equal intensity, and are separated by 14 Å or 840 km s^{-1}. The unwidened 190 Å mm^{-1} spectrogram, obtained with the slit E-W, shows that the prominent emission lines are all tilted; they extend very strongly about 13″ = 9 kpc along the slit—this is the same as the size of the optical object. Very faint N1 emission can be seen out to 20″ = 14 kpc along the slit. If the line doubling and tilting are due to rotation, then the galaxy has a mass $M \geq 1.8 \times 10^{11} M_\odot$ and $M/L_p > 3.8$. The object is not a Seyfert galaxy as claimed by ADEM.

79. "Stellar nucleus; likely to be a Seyfert galaxy." MCG 8-14-33. The redshift is in good agreement with the values given by Ulrich (1971) and by Arakelian *et al.* (1970*b*). The object is starlike as seen at the telescope. The spectrum shows broad Balmer lines with sharp (i.e., unresolved at 90 Å mm^{-1}) cores, together with weak He II, λ4686 and strong, sharp [O III] N1 and N2. The wings of Hβ can be seen out to 3800 km s^{-1} on either side of the line center. The continuum is smooth with no absorption lines.

80. "Small faint galaxy." A rather weak, widened spectrogram appears to be that of a galactic G star. Its radial velocity is roughly −180 km s^{-1}.

81. "Lenticular with luminous envelope and sharply bounded central condensation." Possible absorption lines at λλ5231 and 5328; no emission lines. The object is obviously extended.

82. "Spheroidal compact." Redshift in good agreement with value by ADEM.

83. "Very compact and strongly condensed." Redshift agrees with that by ADEM.

84. "Elongated in δ, with stellar nucleus." Redshift agrees with value by ADEM. Emission from region 6″ = 2.5 kpc in extent.

85. "Spheroidal with sharp boundary." NGC 2534.

87. "NGC 2544. Nucleus of 14 mag barred spiral, Hα emission." Emission from a sharp core 6″ = 1.1 kpc in extent. The Ca II absorption comes from the core and from a much more extended region out to the edge of the 42″ slit.

88. "Compact with little condensation." Noted as "extremely compact" in CGCG III. Redshift in good agreement with that by ADEM. Emission extends 20″ = 12 kpc along slit.

89. "Elongated in α." Redshift in good agreement with that by ADEM and ADE. Emission from region 10″ = 1.1 kpc in extent.

90. "Peculiar spiral with starlike nucleus." Emission from region 10″ = 2.7 kpc in extent.

91. "Has corona. Extended in δ." Noted as "compact" in CGCG III. Emission from region 8″ = 2.6 kpc in extent.

92. "Spheroidal compact component to SE may be a Seyfert galaxy." Redshift only in fair agreement with $z = 0.013$ obtained by ADE. The slit was placed on the starlike object to the S of the main galaxy.

93. "Elliptical shape. λ3727 + Hα emission. Possible Seyfert galaxy." Redshift in poor agreement with $z = 0.016$ by ADE. Emission from region 6″ = 2 kpc in extent.

94. "Very compact object on outskirts of a galaxy. λ3727, N1, N2, Hβ, and Hα emission." Object is close to a galaxy, $m_p = 14.0$, in CGCG III and may be a giant H II region like NGC 5471 in the outer part of M101; its diameter is about the same as that of NGC 5471 and the spectrum has the same high-excitation character.

96. "Very compact, with sharp boundary. Possible Seyfert galaxy." Redshift in poor agreement with $z = 0.022$ by ADE and ADEM. Emission from a region 6″ = 2.7 kpc in diameter.

97. "Elongated in δ." Emission from region 3.0 kpc in extent.

98. "Resembles a small comet. Hα and λ3727 emission." Redshift in good agreement with $z = 0.011$ by ADE and by ADEM. Emission from region 6″ = 1.3 kpc in extent.

100. "Spheroidal galaxy with sharp boundary and stellar nucleus." Redshift in poor agreement with $z = 0.015$ by ADEM.

101. "Sharp image on direct photographs. Starlike with corona on objective-prism plates. May be quasi-stellar object with corona." The galaxy has emission lines from a region 10″ = 3.1 kpc in extent near the center. There is a starlike object slightly N of the nucleus which has absorption lines at near zero redshift; this seems to be a galactic star. Another starlike object about 1′.5 S of the nucleus showed a smooth continuum on a widened 190 Å mm^{-1} spectrogram of the region λλ4800–6800.

102. "Spheroidal with sharp boundary." Noted as "compact" in CGCG III. Emission from region 10″ = 2.7 kpc in extent.

103. "Small galaxy." Emission from region 8″ = 4.8 kpc in extent.

104. "Centrally condensed spheroidal galaxy; candidate for Seyfert galaxy." Redshift in good agreement with $z = 0.007$ by ADE. Emission from region 5″ = 0.7 kpc in extent.

105. "Compact galaxy; stellar component." Our redshift, measured on a 190 Å mm^{-1} widened spectrogram, is in good agreement with the mean of the values given by ADEM ($z = 0.013$) and by ADE ($z = 0.011$). The object appears stellar at the telescope. ADE claim that it is a Seyfert galaxy; however, all the emission lines appear sharp on our plate.

106. "Stellar object in center; probable Seyfert nucleus." The redshift given is the mean of values measured on four plates and agrees well with ADE's value of $z = 0.122$. The object appears stellar at the telescope. The spectrum is that of a Seyfert galaxy of the NGC 4151 type in which the forbidden lines are sharp while the Balmer lines have sharp cores and very broad wings.

107. "Close pair in common envelope." The emission comes from a region 15″ = 8.3 kpc in extent.

108. IC 2458. Object 124 in Holmberg (1958). Our redshift agrees well with Ulrich ($v_r = 1500$ km s^{-1}) and only poorly with ADEM ($z = 0.004$). IC 2458 is a companion of NGC 2820 ($m_p = 13.1$); the two are connected according to CGCG IV. The objects appear to be in a cluster. IC 2458 may be a giant H II region in the outer part of NGC 2458 (see note on Markarian 94). The emission comes from a region 20″ = 2 kpc in extent.

109. "Close double system, contains spheroidal galaxy." The object is 1′ S of a 15.7-mag galaxy which is noted as being "compact" in CGCG III. The emission comes from a region 20″ = 11 kpc in extent.

111. "Galaxy with peculiar structure." The redshift is in good agreement with $z = 0.012$ given by ADE. The object is 1′ S of a 14.3-mag galaxy. The emission comes from several regions extending over 20″ = 4.8 kpc.

113. "Possible quasi-stellar galaxy." Two spectrograms both show absorption lines at nearly zero redshift.

114. "Spiral of type SBbc with starlike nucleus." The emission comes from a region 15″ = 7.5 kpc in extent.

115. "Spheroidal with starlike nucleus." Redshift is in good agreement with $z = 0.026$ by ADEM. Noted as "very compact" in CGCG III.

118. "Has considerable tail to the SE." The emission comes from a region 20″ = 3 kpc in extent.

121. "W component of double system." The object is identified as NGC 2957 in the CGCG IV; it is 1′ N of NGC 2963, a 14.3-mag galaxy. The emission comes from a region 5″ = 2 kpc in extent.

122. "NGC 2963. Has stellar core to the south." Our spectrogram shows only a narrow, blue continuum.

123. "Lenticular; has faint blue companion 25″ away." The emission comes from a region 5″ = 2.5 kpc in extent.

124. "Image stellar with faint 18–20 mag objects to E and W." The quoted redshift is in fair agreement with ADE ($z = 0.055$). The object appears stellar at the telescope. The Balmer lines are broad, and the forbidden lines are sharper, although they appear to be just resolved at 90 Å mm^{-1}.

127. "Very compact." Redshift in fair agreement with ADEM ($z = 0.037$).

129. "NGC 3073. Spheroidal, centrally condensed, with faint corona." The 190 Å mm^{-1} spectrogram of the region λλ4800–6800 is featureless.

132. "Stellar image; possible quasi-stellar object." This object is a bright QSO with an emission line redshift of 1.75 derived from Lα, C III] λ1909, C IV λ1550, and Si IV λ1397. Prominent absorption lines in the blue wings of Lα, C IV, and Si IV lead to an absorption line redshift of $z_{abs} = 1.73$. At least one other absorption-line redshift is present; a detailed analysis of the spectrum by McKee and Sargent is in progress. Markarian 132 is one of the most intrinsically luminous QSOs yet found.

137. "Spheroidal, with faint corona and Hα emission." There are no certain features on a well exposed 190 Å mm^{-1} spectrogram covering λλ3500–6000.

139. "Elongated in δ." Continuous spectrum; the object is definitely nonstellar.

140. "Pair of interacting galaxies. Possible Seyfert." Redshift in good agreement with ADEM ($z = 0.005$) and Ulrich (1971) ($v_r = 1650$ km s^{-1}). Noted as "compact" in CGCG III. Emission from a region 6″ = 0.7 kpc in extent.

143. "Spheroidal, with faint corona." Underexposed; no definite features on spectrogram.

144. "Has noticeable curved tail." Emission from region 5″ = 2.6 kpc in extent.

145. "Elongated galaxy with faint continuous spectrum." Emission from region 5″ = 3.2 kpc in extent.

146. "Spheroidal galaxy with sharp boundary and 15-mag starlike nucleus." Redshift in fairly poor agreement with ADEM ($z = 0.012$). Hα emission from region 5″ = 1 kpc in extent. Continuum is very blue.

147. "Northeastern components of double system." Noted as "double system" in CGCG IV. The emission extends over 8″ = 3.6 kpc and appears to come from two regions 5″ apart.

150. "Elongated in α. Continuous spectrum of moderate intensity; λ3727 + Hα emission." Redshift in fair agreement with ADEM ($z = 0.013$) and good agreement with Ulrich (1971) ($v_r = 3740$ km s^{-1}). Emission from region 8″ = 1.9 kpc in extent.

151. "Lenticular galaxy with 15.5-mag stellar nucleus." Redshift (mean of three spectrograms) in good agreement with ADEM ($z = 0.005$). Strong emission from region 8″ = 0.8 kpc in extent, with faint extentions to 20″.

NOTES TO TABLE 1—*Continued*

152. "Spiral, type SBab, with starlike nucleus." Emission from region 5″ = 2.2 kpc in extent.

158. "Comparatively large and bright galaxy with 15-mag starlike nucleus." Identified as NGC 3471 in CGCG IV. Redshift in good agreement with ADEM (z = 0.007) and Ulrich (v_r = 2160). Emission from region 5″ = 0.7 kpc in extent near center. Continuum is much more extended.

159. "Two interacting objects; starlike one is possible quasi-stellar object." The object appears starlike at the telescope; there is a 14.6-mag galaxy 2′ SE. ADEM and ADE both give z = 0.027; however, our trailed 190 Å mm^{-1} spectrogram of the region λλ4800–6800 shows only a blue continuum.

161. "Morphological type indeterminate. Has 15-mag starlike nucleus." Redshift in good agreement with ADEM (z = 0.020); Ulrich (1971) did not observe any lines. The object has bright spiral arms. Our spectrogram was obtained by trailing the nucleus along the slit.

166. "Very compact." Redshift in poor agreement with ADEM (z = 0.012) and ADE (z = 0.012).

168. "Spherical and compact. Faint companion of 18 mag to NW." Emission from region 7″ = 4.6 kpc in extent.

170. "Irregular form." Emission from region 3″ = 0.2 kpc in extent. The continuum is equally concentrated, although Markarian's optical size is 15 × 30″.

171. "Double system; Holmberg 256." VV 18. Object 299 in Arp's (1966) Atlas. (Not object 296 as is stated in the Atlas.) Identified as NGC 3690 + IC 694 in CGCG IV, where it is described as "disrupted double system, star superposed." Our spectrogram was obtained with the slit E-W centered on the nucleus of NGC 3690 and passing through the inner spiral arms. The strong emission lines come from both the nucleus and the arms. There is no detectable difference in the character of the emission-line spectrum between the different regions. Our redshift is in very good agreement with Ulrich (1971) (v_r = 3060 km s^{-1}). The values of z = 0.005 given for both NGC 3690 and IC 694 by ADEM must be in error. De Vaucouleurs and de Vaucouleurs (1967) give v_r = 3097 km s^{-1} for NGC 3690 and 3212 km s^{-1} for IC 694. The object to the NW of the pair is a compact galaxy in one of Zwicky's unpublished lists. It has an early-type absorption spectrum and a redshift of 3100 km s^{-1}.

176. VV 150, quintuple chain of compact galaxies, illustrated in Arp's (1966) Atlas as object 322. The spiral galaxy at the E end of the chain is a Seyfert galaxy (Burbidge and Burbidge 1961). The redshift given is the mean of the five. The velocity dispersion leads to a mass-to-light ratio of M/L_p = 38 for the system (Burbidge and Sargent 1971). VV 150 is close to the peculiar galaxy NGC 3718 which, however, has a much lower redshift, v_r = 1128 km s^{-1}.

178. "Double with spheroidal and irregular components in a common nebulous envelope. The spectral characteristic refers to the spheroidal component." On our spectra, strong line emission comes from a region about 15″ ∼ 0.25 kpc in extent with fainter emission out to 40″. The continuum is faint and blue and is definitely extended. The object is of high excitation with strong [O III] and possible weak He II λ4686. The low redshift of Markarian 178 might indicate that it is a planetary nebula, but the extended continuum and high galactic latitude of the object are arguments against this. It is probably a dwarf emission-line galaxy of the kind described by Sargent and Searle (1970).

180. "Spheroidal, with sharp boundary. Stars of 15–16 mag to south. Possible Seyfert galaxy." Our widened spectrum of the nucleus, covering the region λλ4800–6000, shows a possible absorption feature at λ5200 on a blue continuum. Noted as "extremely compact" in CGCG IV.

181. "Elliptical shape, main part to south." The emission lines come from two knots, 5″ = 2 kpc apart, with faint emission between them.

183. "Elliptical shape." Emission from region 5″ = 4 kpc in extent.

185. "NGC 3811. Morphological type Sb. Stellar nucleus 14.5 mag."

186. "NGC 3870. Elliptical shape with envelope. Center very condensed but not stellar." Redshift in good agreement with ADEM (z = 0.002) and Ulrich (1971) (v_r = 800 km s^{-1}). Emission from a region 5″ = 0.23 kpc in extent.

188. "NGC 3888. Morphological type SABc. Nuclear condensation of 15.5 mag."

190. "NGC 3928. Very centrally condensed." Emission from region 8″ = 0.5 kpc in extent.

194. "Spherical, with 19-mag companion. Possible Seyfert galaxy." Noted as "very compact nucleus" in CGCG IV. Our spectrogram of the brighter of two starlike central components shows a blue continuum with no features. ADEM give z = 0.051.

195. "Lenticular form with starlike nucleus. Possible Seyfert galaxy." Our redshift is in good agreement with Ulrich (1971) (v_r = 1540 km s^{-1}) but in poor agreement with ADEM (z = 0.004) and ADE (z = 0.003). The emission lines come from a region 5″ = 0.5 kpc in extent.

197. "Spherical compact galaxy with 15-mag starlike nucleus." Our redshift in good agreement with ADEM (z = 0.008). Emission from region 3″ = 0.45 kpc in extent.

198. "Spherical with sharp edge." Redshift in good agreement with Ulrich (1971) (v_r = 7250 km s^{-1}) and with ADEM (z = 0.025). ADEM call this object a Seyfert galaxy, although on our widened 190 Å mm^{-1} spectrogram the lines are sharp. The spectrum is peculiar in that the Balmer lines are abnormally weak: [N II] is as strong as Hα while [O III] N1 and N2 are much stronger than Hβ. This was also noted by Ulrich.

199. "Chain of three 17-mag galaxies." Our 190 Å mm^{-1} spectrogram, obtained with the slit E-W along the minor axis of the chain, shows faint emission from a region 3″ = 0.4 kpc in extent.

Broad em. Objects given this designation all have broad Balmer emission lines together with forbidden emission lines which may be broad or sharp. The spectra of these objects thus resemble those of the classical Seyfert galaxies.

λ3727 em. The [O II] line at this wavelength is seen in emission and is sharp according to the definition given above.

Hα, [N II] *em.* The Hα line and the [N II] lines at λλ6548 and 6583 are present in emission and are sharp according to the definition above.

Ca II *abs.* The H- and K-lines of Ca II are present in absorption. This kind of spectrum is characteristic of normal elliptical, S0, and early-type spiral galaxies.

"D" abs. The Na I D-lines are present in absorption.

Hyd. abs. The Balmer series is present in absorption.

Blue continuum. No absorption or emission features are seen.

More detailed comments on the spectra are given, where appropriate, in the notes to table 1; the emission spectra of the Markarian galaxies in general, including those in table 1, are discussed in § III. Table 2 contains relative emission-line strengths for the galaxies in table 1 with sharp emission lines. These are eye estimates and are used in the discussion of the correlation between the excitation of the emission lines and the absolute magnitude which is given in § III.

III. OVERALL SPECTROSCOPIC CHARACTERISTICS

About 80 percent of the Markarian galaxies have spectra with sharp emission lines, accompanied in some cases by absorption lines. In an earlier paper (Sargent 1970) we discussed these objects as a group. We shall now extend this discussion, using the data in table 2 and the observations published by Weedman and Khachikian (1968, 1969) and by ADE, ADEM, and Ulrich (1971). These authors, with the exception of Ulrich who gave a list of line intensities, published photographs of their spectrograms. Consequently it was possible to estimate the strength of the emission lines relative to the continuum in a manner similar to that used in preparing table 1 as well as estimate the relative strengths of the emission lines where this had not previously been done. From the resulting data, which are necessarily rough because they are largely based on eye estimates, we have looked for correlations between the absolute magnitude M_p, the

TABLE 2

ESTIMATED EMISSION-LINE STRENGTHS

Markarian No.	λ6583, [N II]: Hα	λ5007, [O III]: Hβ	Markarian No.	λ6583, [N II]: Hα	λ5007, [O III]: Hβ	Markarian No.	λ6583, [N II]: Hα	λ5007, [O III]: Hβ
73	0.3	1.0	101	...	1.0	150	0.2	4.0
74	...	1.0	102	0.2	4.0	151	<0.2	3.0
75	n.o.	<0.3	104	0.3	5.0	158	0.4	0.5
78	0.7	5.0	105	0.2	1.5	161	0.7	1.5
82	0.3	n.o.	107	0.2	1.5	166	0.3	1.2
84	0.3	1.0	108	<0.1	6.0	168	...	3.0
87	...	<0.3	109	0.1	4.0	170	n.o.	3.0
88	...	1.0	111	0.2	3.0	171	0.7	1.2
89	0.1	4.0	114	0.4	n.o.	178	<0.1	8.0
91	0.3	1.0	115	0.3	1.0	181	0.7	n.o.
92	0.4	0.8	118	n.o.	1.5	186	0.2	1.0
93	0.1	5.0	121	0.3	1.0	195	0.3	1.0
94	<0.1	6.0	123	n.o.	1.0	197	0.7	...
96	0.3	1.5	140	0.1	3.0	198	0.7	6.0
98	<0.2	2.0	146	0.3	...	199	n.o.	<2.0
100	0.3	...	147	n.o.	1.0			

NOTE.—n.o. means "not observed."

degree of excitation of the emission lines as revealed by the ratios [O II] λ3727:Hβ, [O III], N1, and N2:Hβ, and [N II] λ6583:Hα, the strength of the emission lines relative to the continuum, and the presence of absorption lines along with the emission lines. The following general results emerged clearly from the data.

a) The sharp-emission-line spectra can in general be regarded as a single-parameter sequence. That is, when the ratio [O II]:Hβ or [N II]:Hα is high, the ratio [O III]:Hβ is low and vice versa. In more physical terms the various spectroscopic criteria do not give conflicting indications as to the degree of excitation of the hot gas which produces the lines. (Such conflicting indications are, of course, found in the spectra of supernova remnants and radio galaxies where, for example, one may find a high [O III]:Hβ or [Ne V]:Hβ ratio in the same object, where [O I]:Hβ and [N II]:Hα are high.)

b) As was emphasized by Sargent (1970) on the basis of a smaller body of data, the range in excitation of the emission lines is the same as that exhibited by galactic H II regions.

c) The strengths of the emission lines relative to the continuum are positively correlated with the excitation as revealed by the line ratios mentioned earlier.

d) The excitation and the strengths of the emission lines are correlated with absolute magnitude. It is not clear whether this is an overall smooth correlation. More likely, the apparent correlation is due to the existence of a well-defined group of low-luminosity objects; all the 11 objects with $M_p \geq -16.5$ in lists I and II are given in table 3. Column (5) shows that all have sharp emission lines with no absorption lines, and in nine cases out of 11 the emission lines are described as "strong" or "very strong." They are all physically small for extragalactic systems. Moreover, all of them are high-excitation objects as indicated by the ratios [O III]:Hβ, [O II]:Hβ, and [N II]:Hα. Thus, the objects of table 3 are a fairly homogeneous group. Among the sharp-emission-line galaxies with $M_p \leq -16$, there are some high-excitation objects, but the mean excitation is lower and the dispersion about the mean is much higher than for the low-luminosity objects.

As we mentioned in § I, the 11 dwarf galaxies listed in table 3 have many characteristics in common with the two Zwicky compact galaxies, I Zw 18 and II Zw 40, described by Sargent and Searle (1970). All of them have relatively low redshifts, and these objects should be observed for 21-cm emission, following the work on the two Zwicky galaxies by Chamaraux, Heidmann, and Lauqué (1970). I Zw 18 and II Zw 40 are particularly remarkable for their colors: they have $B - V \sim 0.0$ and $U - B \sim -0.6$, which is abnormally blue for any type of galaxy. Weedman and Khachikian (1969) have measured UBV colors for two of the galaxies in table 3. Markarian 36 has $B - V = +0.13$

TABLE 3

PROPERTIES OF GALAXIES WITH $M_p \geq -16.5$ IN MARKARIAN'S FIRST TWO LISTS

Markarian No. (1)	v_r (km s^{-1}) (2)	m_p (3)	M_p (4)	Spectrum (5)	Size (kpc) (6)
5........	870	(17)	(−13.5)	Sharp em. (vs)	0.4
22........	1500	15.7	−16.1	Sharp em. (vs)	0.7×1.3
27........	2220	(17)	(−15.5)	Sharp em. (s)	1.4
32........	920	(16)	(−14.7)	Sharp em. (s)	0.6×0.8
36........	660	(15.5)	(−14.5)	Sharp em. (vs)	0.4×0.6
51........	960	15.2	−15.6	Sharp em. (m)	0.6×1.2
67........	1080	(16.5)	(−14.4)	Sharp em. (m)	0.7
94........	754	(16.5)	(−13.9)	Sharp em. (vs)	0.34
116........	420	(16.5)	(−12.7)	Sharp em. (vs)	0.14 and 0.16
170........	1055	14.9	−16.1	Sharp em. (s)	1.0×3.0
178........	267	13.9	−16.1	Sharp em. (vs)	0.3×0.5

and $U - B = -0.64$, which is comparable with the two Zwicky galaxies. Markarian 51 has $B - V = +0.21$ and $U - B = -0.13$. This is abnormally blue for any kind of galaxy in the normal Hubble sequence according to the data published by de Vaucouleurs (1961). Sargent and Searle (1971) have emphasized the importance of investigating the statistical distribution in color of a large number of these dwarf, blue galaxies. Such a statistical study would test whether they are (*a*) young, (*b*) old, intrinsically faint, objects which experience brief bursts of star formation, or (*c*) old objects which only produce very massive stars.

Overall, the correlations which we have found in their spectroscopic properties are consistent with the idea that the vast majority of Markarian galaxies with sharp emission lines, including the homogeneous group of dwarf objects just described, are excited by hot stars. Even the fact that the most highly excited objects show no stellar absorption lines is consistent with this hypothesis because the H II regions in other galaxies frequently show a faint stellar continuum with no visible absorption lines (Searle 1971).

The Seyfert galaxies.—Table 4 contains a list of the galaxies with broad emission lines. This table includes objects in Markarian's third list discovered by Arakelian *et al.* (1970*b*, *c*) which have so far been described only very briefly. The objects in lists I and II have been described by the various authors cited earlier. Table 4 is included partly for use in the statistical investigations in the following section. Several Markarian objects which other authors called Seyfert galaxies are not included in the table for various reasons. First, we have not included Markarian 1, 3, and 6, although Weedman (1969) has shown that, when examined at higher spectral resolution than is commonly used in the surveys, these objects show lines several hundred km s^{-1} wide. Weedman's conclusion that these objects are nonthermal sources of optical radiation and that therefore they belong to the same family as the conventional Seyfert galaxies and quasi-stellar objects

TABLE 4

MARKARIAN GALAXIES WITH BROAD EMISSION LINES*

Markarian No.	z	m_p	M_p	Notes
9	0.039	15.2	−21.2	"Compact" in CGCG IV
10	0.029	14.0	−21.8	
34	0.051	(16)	(−21.8)	
40	0.020	(16)	(−18.9)	VV 144
42	0.024	15.2	−20.0	
50	0.023	(15.5)	(−19.6)	
64	0.184	(17)	(−22.4)	B234: Braccesi *et al.* (1968)
69	0.076	(16.5)	(−21.2)	
79	0.022	13.3	−22.0	
106	0.124	(16)	(−22.9)	
110	0.036	(16)	(−20.1)	
124	0.059	(16)	(−21.1)	
141	0.039	15.2	−21.0	"Double system" in CGCG IV
142	0.045	(16.5)	(−20.0)	
176	0.027	(16.5)	(−19.2)	VV 150; quintuple system
205	0.070	(14.5)	(−23.7)	Inside NGC 4319
231	0.041	(16.5)	(−19.8)	
268	0.039	15.3	−20.6	Double system
270	0.009	14.3	−18.4	NGC 527
273	0.038	15.0	−21.9	"Long jet" in CGCG III
279	0.032	14.5	−21.3	
290	0.029	(15)	(−20.6)	
291	0.035	(15)	(−20.7)	
298	0.034	15.2	−20.4	IC 1182; "system with jet" in CGCG II

* Objects above the horizontal line are from lists I and II; objects below are from list III.

seems entirely reasonable. No doubt other objects of this kind will turn up when more Markarian galaxies are examined in detail. In the meantime we shall leave these intermediate objects out of our statistical considerations. We have also omitted Markarian 78, which we found to have double lines rather than very broad single ones (see the notes to table 1), and Markarian 105 and 198 for reasons which are also evident from the notes to table 1.

As we have remarked earlier, the most striking thing about table 4 is that the Seyfert galaxies in the Markarian lists are intrinsically luminous, with $\langle M_p \rangle = -20.9$. Despite the fact that most of the objects are much too distant for the nonthermal nucleus to be resolved, the spectra in general show emission lines in a smooth continuum with no signs of absorption lines due to stars. Thus most of the light is radiated by the nucleus if these objects are anything like the nearby Seyfert galaxies in structure.

IV. SPACE DENSITIES

At the time of writing, Markarian had published three lists of ultraviolet galaxies. List I contains 70 objects, list II contains 130 objects, and list III contains 102 objects. Of the 302 galaxies, 168 are listed in the CGCG. This catalog is intended to be complete down to 15.7 mag. The magnitudes in the CGCG are more accurate than Markarian's estimates, which are only given to the nearest half-magnitude. Most of the galaxies which Markarian estimates to be brighter than $m_p = 15.5$ appear in the CGCG, but a few do not—probably because they are hard to distinguish from stars. As we have seen earlier, spectroscopic observations of galaxies in lists I and II have resulted in the measurement of 155 redshifts for the 200 objects. These two lists cover a main area of 650 square degrees which extends from 7^h20^m to 12^h20^m in right ascension between declinations $+45°$ and $+75°$. In addition, several special areas, covering in all 250 square degrees, were surveyed in list I. Hence we shall take the total area of the survey to be 900 square degrees. Over this area there is one object in every 4.5 square degrees, and one object brighter than $m_p = 15.5$ every 7.2 square degrees.

Before we turn to a consideration of space densities, we must first look into the question of the completeness of the Markarian lists. They contain objects with apparent magnitudes ranging from 12 to 17 mag, but there is clearly a dearth of faint objects in the sample. This is shown by figure 1, which is a plot of log $N(m_p)$ versus m_p for the 302 objects in the first three lists. (In this plot magnitudes from the CGCG were used where available.) Here $N(m_p)$ is the number of objects brighter than apparent magnitude m_p. The dashed line shows the slope of 0.6 which is obtained for a complete sample of objects which are uniformly distributed in Euclidean space. We infer from figure 1 that the Markarian lists are reasonably complete down to 15.5 mag, but that they are increasingly incomplete for fainter apparent magnitudes. For example, at mag 16.5 the sample appears to be incomplete by roughly a factor of 5. The error bars on the points in figure 1 are computed by taking $\sqrt{N}$; this is not strictly correct since the numbers, being cumulative, are not independent. However, a plot of the differential counts, d log $N(m_p)$ versus m_p, whose slope should also be 0.6, leads to a similar result. On the basis of figure 1 it was decided to try to complete observations of the objects in lists I and II down to mag 15.5. They together contain 200 objects, of which 125 have $m_p \leq 15.5$. Redshifts are available for 109 (or 87 percent) of these. Spectroscopic observations were made of most of the remaining 16 objects. In several cases they appeared to be galactic stars (perhaps, in some cases, superposed on a background galaxy), and several showed continuous spectra. None showed discernible emission lines, which were easily seen on the vast majority of spectrograms. For this reason we have not corrected the space densities (which are calculated later) for the fact that redshifts are available for only 87 percent of the sample. In any case such a correction would be smaller than the other errors.

In table 5 we give the apparent magnitudes and absolute magnitudes (where known) for all the galaxies in Markarian's first two lists. The table contains a code for identifying

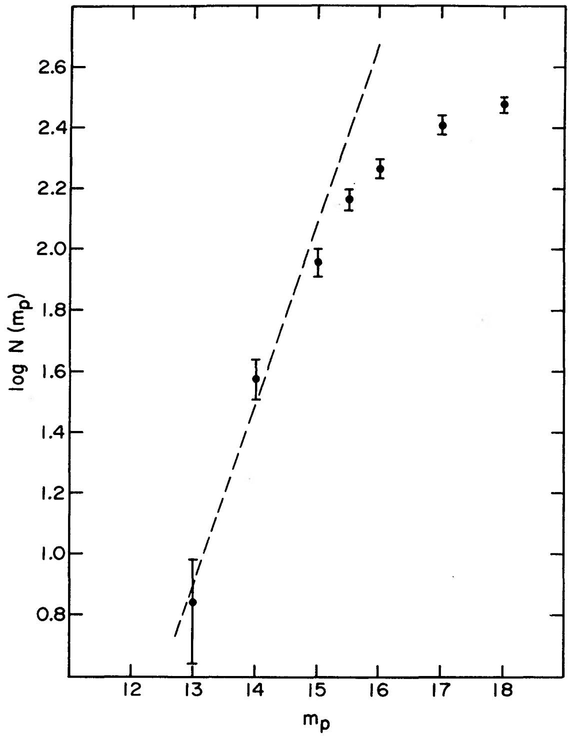

FIG. 1.—Plot of log $N(m_p)$ versus m_p for all the 302 galaxies from Markarian's first three lists. Magnitudes are taken from the CGCG where available. Error bars correspond to $\sqrt{N}$ for each point. This method of assessing the error is not correct, as is discussed in the text. The departure from a straight line with a slope of 0.6 shows that the Markarian lists are increasingly incomplete for $m_p \gtrsim 15$.

the author responsible for the redshift used in evaluating M_p. Other authors who have also studied the same object are referred to in brackets; a key to the code is given at the foot of the table. The data in table 5 may be used to construct a diagram similar to figure 1. Such a diagram shows that, while the errors are larger due to the smaller number of available objects, lists I and II should also be substantially complete down to 15.5 mag.

A more convenient test for the completeness of the sample in figure 1 is the V/V_m method devised by Schmidt (1968). In this test we calculate for each object the volume V contained in a sphere whose radius is the distance to the object. We also compute the volume V_m to contain a sphere whose radius is the distance the object would have if its apparent magnitude were equal to the limiting apparent magnitude of the sample, in our case $m_p = 15.5$. The mean value of the ratio V/V_m (which we shall denote by $\langle V/V_m \rangle$) should be 0.5 for objects which are uniformly distributed in Euclidean space. Moreover, a plot of the distribution of values of V/V_m (which lie, necessarily, between 0 and 1) should be flat. We note that only the observed apparent magnitude for each object and the limiting apparent magnitude of the sample are required to calculate V/V_m and $\langle V/V_m \rangle$ if one is not concerned with distinguishing between objects of different *absolute* magnitudes and if one is sure that the redshifts are sufficiently small that it is a reasonable approximation to treat space as Euclidean.[1]

[1] Strictly, in applying the V/V_m test to our sample, we should correct the observed values of m_p to a standard rest wavelength; that is, we should apply a K-correction. This has not been done because we have no data on which to base a K-correction for these diverse objects, whose continuous energy distributions deviate markedly from those of elliptical galaxies. We are unable to analyze the effect of this deficiency in the calculations.

TABLE 5

ABSOLUTE AND APPARENT MAGNITUDES FOR GALAXIES IN MARKARIAN'S FIRST AND SECOND LISTS

Markarian No.	m_p	M_p	Source	Markarian No.	m_p	M_p	Source
1	15.2	−19.3	WK	60	(15.5)	(−18.9)	S
2	14.2	−20.6	WK	61	(17)	...	S
3	13.8	−20.4	WK	62	(16.5)	...	S
4	15.0	−19.5	WK	63	(17)	...	S
5	(17)	(−13.5)	WK	64	(17)	...	S
6	14.8	−20.0	WK	65	(15.5)	(−20.8)	WK
7	13.9	−19.7	S	66	(15)	(−20.0)	WK
8	13.8	−20.0	WK	67	(16.5)	(−14.4)	WK
9	15.2	−21.2	WK	68	(17)	(−17.5)	S
10	14.0	−21.8	WK	69	(16.5)	(−21.2)	S
11	14.4	...	WK(S)	70	(16)	...	...
12	12.7	−21.5	S	71	11.6	−18.3	HMS
13	14.5	−17.5	WK	72	(17)	(−19.6)	S
14	14.4	−19.1	WK	73	14.9	−19.5	S(A_1,A_2)
15	(17)	(18.1)	S	74	(16)	(−20.3)	S
16	14.6	−18.3	S	75	(16)	(−19.8)	S
17	(17)	(−18.2)	WK	76	15.1	...	S, U
18	13.1	−18.7	S	77	(16.5)	...	...
19	15.6	−18.6	WK	78	(15)	(−21.3)	S(A_2, U)
20	14.7	−19.1	S	79	13.3	−22.0	S(A_1, U)
21	15.1	−20.4	S	80	(17)	...	S
22	15.7	−16.1	WK	81	14.3	...	S
23	15.6	−20.1	WK	82	(15.5)	(−19.5)	S(A_2)
24	(17)	(−19.5)	S	83	(16.5)	(−20.4)	S(S_2)
25	14.2	−18.8	WK	84	13.6	−21.5	S(A_2)
26	15.5	...	WK	85	13.8	−20.0	S
27	(17)	(−15.5)	S	86	11.7	−17.5	HMS
28	(17)	(−18.6)	S	87	13.4	−19.9	S
29	(16.5)	(−19.9)	S	88	14.3	−21.5	S(A_2)
30	(17)	(−18.4)	S	89	(15)	(−17.8)	S(A_1, A_2)
31	14.7	−20.6	S	90	13.9	−20.3	S
32	(16)	(−14.7)	S	91	14.7	−19.9	S
33	13.2	−18.7	WK	92	(15)	(−19.2)	S(A_1)
34	(16)	−20.8	WK	93	15.7	−19.0	S(A_1)
35	12.9	−18.0	WK	94	(16.5)	(−13.9)	S
36	(15.5)	−14.5	WK	95	15.5	−18.5	A_1
37	15.2	...	WK	96	(15.5)	(−19.8)	S(A_1, A_2)
38 }	15.2	{ −20.0	S	97	15.3	−20.0	S
39 }		{ −20.0	WK	98	15.0	−18.8	S(A_1, A_2)
40	(16)	(−18.9)	WK	99	(16.5)	(17.3)	A_1(A_2)
41	15.0	...	WK	100	14.2	−19.7	S(A_2)
42	15.2	−20.0	WK	101	13.6	−20.9	S
43	(16)	(−18.8)	S	102	14.3	−19.8	S
44	15.3	−19.8	S	103	15.6	−20.4	S
45	15.6	−18.5	S	104	14.7	−18.0	S(A_1)
46	(17)	(−16.8)	S	105	(16)	(−17.8)	S(A_1, A_2)
47	(16)	(−18.7)	S	106	(16)	(−22.9)	S(A_1, A_2)
48	15.6	−18.7	*S*	107	14.7	−21.1	S
49	14.5	−16.9	WK	108	15.1	−16.8	S(A_2, U)
50	(15.5)	(−19.6)	S	109	15.6	−20.3	S
51	15.2	−15.6	WK	110	(16)	(−20.1)	A_2
52	13.4	−18.9	WK	111	13.9	−20.0	S(A_1)
53	15.5	−18.7	S	112	(16.5)	...	...
54	15.1	−21.3	WK	113	(14.5)	...	S
55	(16)	(−18.2)	S	114	14.5	−20.9	S
56	15.4	−19.7	S	115	15.4	−20.0	S(A_2)
57	15.4	−19.8	S	116	(16.5)	(−12.7)	A_2
58	15.1	...	WK	117	16	...	...
59	12.8	−17.5	WK	118	15.2	−17.7	S

SOURCE.—S, Sargent (1971); U, Ulrich (1971); A_1, Arakelian, Dibai, and Esipov (1970); A_2, Arakelian *et al.* (1970*a*); WK, Weedman and Khachikian (1968, 1969); HMS, Humason, Mayall, and Sandage (1956).

TABLE 5—*Continued*

Markarian No.	m_p	M_p	Source	Markarian No.	m_p	M_p	Source
119.......	14.1	−19.3	A_2	160.......	(16.5)	...	...
120.......	(17)	...	...	161.......	13.4	−21.4	S(A_2, U)
121.......	15.3	−19.9	S	162.......	14.6	−20.3	U(A_2)
122.......	14.3	...	S	163.......	(17.5)	...	...
123.......	(15.5)	(−19.8)	S	164.......	(17)	...	...
124.......	(16)	(−21.1)	S(A_1)	165.......	14.8	−18.8	U(A_2)
125.......	(15)	(−20.3)	U	166.......	(15.5)	(−17.9)	S(A_1, A_2)
126.......	(15.5)	(−20.8)	U	167.......	(17.5)	...	...
127.......	(16.5)	(−19.5)	S(A_2)	168.......	(16.0)	(−19.9)	S
128.......	(16)	...	...	169.......	14.2	−17.7	U(A_2)
129.......	15.1	−19.2	S	170.......	14.9	−16.1	S
130.......	(16.5)	...	...	171.......	11.8	−21.5	S(U, A_2)
131.......	13.8	...	S	172.......	(17.5)	...	...
132.......	(15)	QSO	S	173.......	(16.5)	...	...
133.......	12.8	−18.2	U	174.......	(16.5)	...	...
134.......	(17)	...	...	175.......	14.1	−18.7	S
135.......	(16)	(−20.5)	U	176.......	14.7	−20.8	S
136.......	(17)	...	...	177.......	(16)	...	...
137.......	15.6	...	S	178.......	13.9	−16.1	S(U)
138.......	(16)	...	...	179.......	13.6	−19.5	U(A_2)
139.......	14.7	...	S	180.......	15.5	...	S
140.......	15.0	−17.0	S(A_2, U)	181.......	13.9	−20.9	S
141.......	15.2	−22.0	U(A_1, A_2)	182.......	(17)	...	...
142.......	(16.5)	(−20.0)	A_2	183.......	15.4	−21.0	S
143.......	15.6	...	S	184.......	(16)	...	...
144.......	15.0	−20.5	S	185.......	13.0	−20.4	S
145.......	15.4	−20.6	S	186.......	13.2	−16.9	S(U, A_2)
146.......	14.1	−19.4	S(A_2)	187.......	(17.5)	...	...
147.......	15.5	−19.7	S	188.......	12.6	−20.3	S
148.......	15.4	...	...	189.......	(16)	...	...
149.......	14.4	−17.7	U(A_2)	190.......	13.1	−17.8	S
150.......	15.0	−18.8	S(U, A_2)	191.......	15.3	−20.6	A_2
151.......	15.1	−16.7	S(A_2)	192.......	(17)	...	...
152.......	14.9	−20.2	S	193.......	(16.5)	(−18.1)	U(A_2)
153.......	14.6	−18.2	A_2	194.......	15.2	−21.6	A_2(S)
154.......	15.5	...	...	195.......	14.3	−17.5	S(U, A_1, A_2)
155.......	13.2	−19.0	A_2	196.......	(17)	...	...
156.......	14.5	−16.9	U(A_2)	197.......	14.7	−18.7	S(A_2)
157.......	14.0	−17.7	U(A_2)	198.......	15.2	−20.0	S(A_2, U)
158.......	13.0	−19.5	S(U, A_2)	199.......	15.4	−17.3	S
159.......	14.6	−20.9	A_1(A_2)	200.......	(17)	...	...

In table 6 the V/V_m test is applied to the sample of 109 objects with $m_p \leq 15.5$ in Markarian's first two lists. For all the objects $\langle V/V_m \rangle = 0.41$. An examination of the distribution of V/V_m in the table shows that there is clearly a dearth of objects with high V/V_m. In other respects the distribution is not peculiar; it is consistent with a small degree of incompleteness which increases with increasing m_p. The V/V_m method also enables us to test for completeness as a function of absolute magnitude. This is also done in table 6 where we list $\langle V/V_m \rangle$ for each value of M_p from −14 to −22; the table also gives the actual distribution of V/V_m for each value of M_p. The final column gives the expected standard deviation of the quoted value of $\langle V/V_m \rangle$ calculated for an ideal flat distribution of V/V_m. Table 6 shows that at all values of M_p (except $M_p = -14$, for which there is only one object in the sample) $\langle V/V_m \rangle < 0.5$ and, moreover, that the individual values of $\langle V/V_m \rangle$ are not significantly different from the value $\langle V/V_m \rangle = 0.41$ for the sample as a whole. This latter result is very important. It shows that there

TABLE 6

DISTRIBUTION OF V/V_m WITH M_p FOR MAIN SAMPLE ($m_p \leq 15.5$)

	RANGE OF V/V_m											
M_p	0→ .1	.1→ .2	.2→ .3	.3→ .4	.4→ .6	.5→ .6	.6→ .7	.7→ .8	.8→ .9	.9→ 1.0	$\langle V/V_m \rangle$	EXPECTED* σ
−14......	0	0	0	0	0	0	0	0	0	1	1.0	0.29
−16......	0	1	0	0	1	1	0	0	0	0	0.36	0.17
−17......	3	1	3	0	1	1	1	0	1	0	0.32	0.09
−18......	4	2	3	1	0	1	1	0	0	2	0.33	0.08
−19......	6	4	1	3	1	5	1	0	0	3	0.39	0.06
−20......	4	7	1	2	1	4	2	3	3	4	0.48	0.05
−21......	5	3	2	2	0	2	1	1	2	2	0.40	0.06
−22......	1	1	0	0	0	0	2	0	0	0	0.37	0.14
All.....	23	19	10	9	4	14	8	4	6	12	0.41	0.03

* For an ideal flat distribution with $\langle V/V_m \rangle = 0.5$.

is no significant tendency for the degree of incompleteness to vary with M_p. In other words, there is no significant tendency for Markarian to pick out different kinds of objects at different apparent magnitudes.

In order to correct the sample for incompleteness it is sufficient to multiply the space densities by a constant factor which does not vary with *absolute* magnitude. There are in principle several ways of doing this. First we note that a plot of log $N(m_p)$ versus m_p for the 109 objects in the main sample shows a deviation of 0.3 in log $N(m_p)$ from the theoretical slope of 0.6 at 15.5 mag. This implies that the correction for incompleteness is roughly a factor of 2. A more refined procedure for obtaining the correction factor is to observe that, for any given limiting magnitude m_p^l, a complete sample of objects uniformly distributed in Euclidean space should have $\langle m_p^l - m_p \rangle = 1.667 \log_{10} e = 0.724$ mag. With the given sample we find that $\langle m_p^l - m_p \rangle$ rises steadily above 0.724 for $m_p^l > 14.1$ mag. It is then a simple matter to progressively add objects at each 0.1-mag interval between 14.1 and 15.5 mag so as to keep the value of $\langle m_p^l - m_p \rangle$ equal to 0.724. If this is done, we find that the number of objects given in table 7 must be added at each apparent magnitude. We must add 141 objects to the sample of 109 galaxies. This means that the correction which must be applied to the space densities is a factor of 2.29.

The correction factor for incompleteness having been established, it is a straightforward task to calculate the space density of the Markarian galaxies as a function of absolute magnitude from the data in table 5. The results for the sample with $m_p \leq 15.5$ are shown in table 8 which gives log $\Phi(M_p)$ as a function of M_p. Here $\Phi(M_p)$ is defined to be the number of objects per cubic megaparsec per unit magnitude interval. In parentheses we note the number of objects on which the determination is based. In column

TABLE 7

CORRECTIONS TO NUMBER OF OBJECTS BRIGHTER THAN 15.5 MAGNITUDES

m_p	No.	m_p	No.	m_p	No.	m_p	No.
14.2.......	1	14.6......	4	15.0......	6	15.3......	19
14.3.......	2	14.7......	16	15.1......	13	15.4......	21
14.4.......	4	14.8......	11	15.2......	12	15.5......	18
14.5.......	3	14.9......	11				

TABLE 8

SPACE DENSITIES LOG $\Phi(M_p)$* FOR MARKARIAN GALAXIES†

M_p (1)	FIELD GALAXIES‡ (2)	MARKARIAN GALAXIES $m_p \leq 15.5$ (3)	MARKARIAN GALAXIES $m_p \leq 16.5$ (4)	MARKARIAN SEYFERTS $m_p \leq 16.5$ (5)
−13.......	...	...	−1.7(1)	...
−14.......	...	−2.0(1)	−1.9(3)	...
−15.......	...	...	−2.9(1)	...
−16.......	(−1.55)	−2.7(3)	...	...
−17.......	−1.65	−2.8(11)	...	...
−18.......	−1.80	−3.3(14)	...	...
−19.......	−2.15	−3.6(24)	...	...
−20.......	−2.50	−4.1(31)	...	...
−21.......	−3.30	−4.9(21)	...	−5.9(5)
−22.......	−4.60	−6.2(4)	...	−7.5(2)
−23.......	(−6.65)	...	...	−7.7(1)

* Units of $\Phi(M_p)$ are Mpc^{-3} mag^{-1}.

† The number of galaxies used in each determination is given in parentheses in columns (3), (4), and (5).

‡ Van den Bergh (1961); corrected to $H = 75$ km s^{-1} Mpc^{-1}.

(2) of Table 8 we show, for comparison, van den Bergh's (1961) data for field galaxies, suitably corrected to the value of $H = 75$ km s^{-1} Mpc^{-1} which we have used in our calculations. The comparison shows that for $-20 \geq M_p \geq -22$, the Markarian galaxies constitute about 2.5 percent of all galaxies and that there are indications, based on small numbers, that this proportion is more like 7 percent for $M_p \geq -17$.

We emphasized in §§ I and III the importance of the dwarf emission-line objects in the Markarian lists, namely, those objects with $M_p \geq -16$. There are very few of these in the main sample (that is, with $m_p \leq 15.5$), so for these objects we have extended the sample to $m_p = 16.5$ and used the rough factor 5 mentioned earlier to correct for incompleteness. This leads to the space densities in column (4) of table 8. We emphasize that the numbers in this column are of low accuracy; however, they follow the trend set by the more accurate values for more luminous objects and indicate that the space density of dwarf emission-line galaxies with $M_p \sim -14$ is roughly 0.01 Mpc^{-3} mag^{-1}. There are no good comparable numbers for field galaxies of this absolute magnitude; however, van den Bergh (1966) has estimated that at $M_p = -15$ there is roughly 0.1 dwarf galaxy per cubic megaparsec and that 60 percent of these are Irregulars. We thus conclude that there is some preliminary evidence that the proportion of Markarian galaxies rises as one goes to fainter intrinsic luminosities and that about 10 percent of all galaxies exhibit strong ultraviolet continua at $M_p \sim -14$.

In column (5) of table 7 we give an estimate of the space density of the Seyfert galaxies in Markarian's first two lists. In order to make this estimate, it is necessary to extend the sample to $m_p = 16.5$ and to multiply the observed density by the factor of 5 in order to allow for incompleteness. To get some idea of the accuracy of these numbers, we may extend the sample to Markarian's third list using the data in table 4. There are six objects at $M_p = -21$ in this sample brighter than $m_p = 15.5$, and the resulting space density for this absolute magnitude is 3.6×10^{-6} Mpc^{-3} mag^{-1}. This may be compared with the estimate of 1.2×10^{-6} Mpc^{-3} mag^{-1} from the five objects brighter than $m_p = 16.5$ in table 8; the agreement is seen to be very satisfactory in view of the small numbers involved. Accordingly, from table 8 we estimate that at $M_p = -21$ only 0.5–1 percent of all galaxies shows Seyfert characteristics. The more normal Seyfert galaxies whose *nuclei* have $M_p \sim -18$ constitute about 2 percent of all spiral galaxies and have a space density of about 10^{-3} Mpc^{-3} mag^{-1}. These very luminous Seyfert galaxies in the Markarian lists are almost stellar in appearance; if removed to somewhat greater distances, they would be indistinguishable from quasi-stellar objects. (Note that the lists do contain at least two QSOs—B234 [Markarian 64, $z = 0.184$] and Markarian 132 [$z = 1.75$].) In this connection it is noteworthy that Schmidt's (1970) estimate of the "local" space density of QSOs is $\log \Phi(M_v) = -6.3$ at $M_v = -21$ and $\log \Phi(M_v) = -7.0$ at $M_v = -22$. These estimates are close to those we have made and lend support to the view that Schmidt's sample includes distant galaxies with luminous nonthermal nuclei among the intrinsically fainter QSOs.

V. CONCLUSIONS

The main result of this statistical investigation is that the Markarian galaxies comprise about 2.5 percent of all galaxies with $-20 \geq M_p \geq -22$ and that the proportion probably rises to 7 percent at $M_p = -17$ and is perhaps as high as 10 percent at $M_p = -14$. We have also shown that Markarian's work has led to the isolation of an homogeneous group of low-luminosity ($M_p \gtrsim -16$) emission-line galaxies which are physically small and which resemble the higher-excitation galactic H II regions in their spectroscopic properties. The preliminary result that they comprise up to 10 percent of all galaxies in the local field at $M_p = -14$ forms an important clue as to their possible origin, whose implications will be discussed elsewhere (Searle and Sargent 1972).

We have also found that the space density of very luminous Seyfert galaxies is about 3×10^{-6} Mpc^{-3} mag^{-1} at $M_p = -21$ and that these galaxies comprise about 0.5–1 percent of all galaxies at this absolute magnitude. Since most of the light is radiated by the nonthermal Seyfert nucleus in these objects, the background galaxy, which is just discernible on direct photographs, must be fainter than $M_p = -21$. Thus the timescale of the nonthermal outburst in these objects cannot exceed 1 percent of the Hubble time, or roughly 10^8 years, if we assume that all galaxies go through such a phase. (The timescale can, of course, be 10^{10} years if only particular galaxies exhibit the Seyfert phenomenon.) More important, since a faint background galaxy is seen, Seyfert galaxies with $M_p = -21$ cannot be more than 2–3 mag fainter than this in their quiescent phase. Since they constitute about 0.1 percent of all galaxies having absolute magnitudes in the range $-18 \gtrsim M_p \gtrsim -19$, the outburst of the nucleus must have a timescale which exceeds 10^7 years, or 0.1 percent of the Hubble time. This means that Seyfert galaxies of absolute magnitude -21 radiate at least 10^{58} ergs in optical energy alone during their lifetimes.

As we have emphasized, the Seyfert galaxies in the Markarian lists constitute less than 10 percent of the objects. It seems fairly certain that the optical radiation of the much more common galaxies with sharp emission lines is produced by hot stars. The main problem with these objects in general is to know whether they represent transient phases in the evolution of galaxies of the Hubble sequence or whether they are a rare, entirely separate morphological class. The systematic accumulation of a large number of direct photographs with a large scale seems to be the obvious next step in the solution of this problem.

I wish to thank Drs. L. Searle, M. Schmidt, and M. Rees for discussions, Mrs. G. Knox for measuring the redshifts, and G. Tuton and J. Carrasco for their efficient handling of the Hale telescope.

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Notes Added in Proof

a) The object Markarian 116, which appears in tables 3 and 5, is identical to the object I Zw 18 discussed by Sargent and Searle (1970).

b) As noted in the text and in table 2, the objects Markarian 78 and Markarian 198 are peculiar in that the intensity ratios [N II]:Hα and [O III]:Hβ are both high. I thank Dr. Leonard Searle for pointing out to me that this is a spectroscopic peculiarity which is characteristic of Seyfert galaxies. Consequently, they should be included among the Seyfert galaxies in table 6, contrary to the view expressed in the text and despite the fact that both objects have sharp lines at the resolution used in this work.