12. Photographic, Photometric, and Spectroscopic Observations of Seyfert Galaxies

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GALAXIES with strong emission lines can be provisionally classified into the following four groups: (1) classical-type Seyfert galaxies (S type) characterized by broad emission lines in a small very bright nucleus; (2) Seyfert galaxies characterized by broad emission lines in a large bright nuclear region (N-type); (3) galaxies with abnormally strong nuclear emission (eN type) but not unusually broad lines; (4) compact galaxies with abnormally blue nuclear colors (bN type) either with or without nuclear emission (or unknown spectrum).

An S-type Seyfert galaxy is an otherwise apparently normal galaxy, generally an early type spiral (S0/a to Sbc) or lenticular (S0), with an extremely bright, semistellar (compact) nucleus, small compared with the main body, and in which strong emission lines are present, some of high excitation (similar to planetaries), and often abnormal intensity ratios. Some of the lines, in particular the hydrogen lines, have a great width or broad wings (10^3–10^4 km/sec). Several such galaxies are radio sources, some variable, and at least one has variable optical emission in the nucleus. Their colors are bluer than for normal galaxies of the same morphological type, especially in the nuclear region and the color–color relation is peculiar. Typical examples of S-type Seyfert galaxies are: NGC 1068, 3516, 4051, 4151, 5548, 7469 (confirmed); NGC 2782, 3227, 6814 (unconfirmed); NGC 1566 (new, confirmed); 4939 (new, unconfirmed); NGC 4670 (new, unconfirmed). Atypical objects such as NGC 1275 (possibly N type), 3077, and 4258, will be rejected from that group.

The distribution of morphological types of S-type Seyfert galaxies is: S0, S0+, S0/a: two objects; Sa, Sab: four objects; Sb, Sbc: four objects. The frequency of S0 to Sbc types among 1500 bright galaxies with revised types is 50% (750 objects); thus the relative frequency of Sy (S) types is 1.4% of S0 to Sbc types. The number of bright galaxies with known spectra and redshifts is 1100, while the number of Sy (S) types is 7 (definite) to 12 (possible); thus the apparent relative frequency is 1% of the redshift sample.

The number of bright galaxies with known B(0) or m_c magnitudes in the *Reference Catalogue* is as follows:

m	<11	11–12	12–13	13–14
Total	83	240	600	(300)
Sy(S)	2 (2.4%)	3–4 (1.5%)	3 (0.5%)	2 (0.6%)

The number of bright galaxies with known radial velocity V_0 is as follows:

$10^3 V_0$	<1	1–2	2–3	3–5
Total	200	330	180	240
Sy(S)	2 (1.0%)	4 (1.2%)	3 (1.7%)	2 (0.8%)

Conclusion: The apparent frequency is greater among the nearer and brighter galaxies (1.3%, $V_0<3000$; 1.8%, $m<12$). If the true frequency is 2%, about 10 Sy (S) galaxies brighter than $B(0)\approx 13$ remain to be discovered, but only one may be brighter than $m\approx 12$ and the majority are probably in the southern galactic hemisphere where there is a lack of spectral data.

As far as the *apparent distribution* of S-type Seyfert galaxies is concerned, out of 10 to 12 objects, 8 to 10 or 80% to 83% have supergalactic latitudes smaller than 30°. *Conclusion*: most of the brighter Sy (S) galaxies are members of the local supercluster and at the average distance of 12th-magnitude galaxies. Only three or four Sy (S) galaxies are definitely or probably not associated with a recognized group, cloud or cluster and seven or eight are probably members of groups with known distance moduli in the McDonald survey of nearby groups and clusters. At least eight, and possibly up to twelve, Sy (S) galaxies are known within 20 Mpc, implying an average space density $\gtrsim 3\times 10^{-4}$ Mpc^{-3}. For comparison the total density of galaxies in the Lick counts ($m\leq 19.0$) is $\approx 5\times 10^{-2}$ Mpc^{-3}, and the "local" density of quasistellar objects, according to M. Schmidt (1968) is $\approx 10^{-8}$ Mpc^{-3}. The *relative space densities* are therefore as follows: dwarf galaxies ($-16<M<-11$)$\approx 10^2$ (?), giant galaxies ($-21<M<-16$)≈ 1, Sy (S) galaxies ($-21<M<-19$)$\approx 10^{-2}$, Sy (N) galaxies ($-22<M<-20$)$\approx 10^{-4}$, quasistellar galaxies, 10^{-5} (?) and quasistellar objects $\approx 10^{-6}$, respectively.

Apparent magnitudes of S-type Seyfert galaxies are available in the B(0) system for eleven objects and in the m_c system for one object. Total (asymptotic) magnitudes $m_T=B(\infty)$ can be estimated for ten objects. *Apparent diameters* are available in several systems: effective (half-power) diameter D_e for seven objects, one derived from detailed photographic isophotometry (NGC 1566) and six estimated from $B(X)$ curves at $B(X)=B_T+0.75$; standard photographic "face-on" diameters in the $D(0)$ system for eleven objects, corresponding to an approximate brightness level ≈ 24.5 mag sec^{-2} and microphotometric "maximum" diameters D_m for nine objects, three from direct measurements, six from scaled up micrometer values, corresponding to an approximate detection threshold ≈ 26.5 mag sec^{-2}. Diameters and luminosities of S-type Seyfert galaxies are presented in Table I. Total absolute magnitudes for eight objects with known moduli are in the range $-20.8<M_T<-18.9$ and the mean is $M_T=-19.7\pm 0.2$ (m.e.). Luminosity classifications, available for two

TABLE I. Diameters and luminosities of S-type Seyfert galaxies.

NGC	D_e (min)	D_e (kpc)	$D(0)$ (min)	$D(0)$ (kpc)	$D_m \times d_m$ (min of arc)	D_m (kpc)	B_T	M_T	$m-M$	Δ (Mpc)
1068	(1.1)	3.5	4.9	16	10.0 ×8.0	32	9.7	−20.8	30.5	11.0
1566	2.0	6.7	6.6:	22:	11: ×8:	37:	10.4	−19.7	30.1	11.5
2782	(0.7:)	4.2:	2.0	12	(6: ×4:)	(35)	12.35	−19.5	31.85	20.4
3227	...	...	3.1	15	(7.5 ×6:)	(36)	11.5	−19.8	31.3	16.5
3516	(0.3:)	...	1.0	...	...	...	12.6	...	...	...
4051	(2.95)	6.9	4.0	9	8.2 ×6.0	19	10.8	−18.9	29.7	8.0
4151	(1.0:)	3.4:	2.8	9	...	...	11.2	−19.3	30.5	11.5
4939	...	...	4.1	16:	(10: ×6:)	(39)	(11.4)	(−19.5)	30.9?	13.4?
5548	...	...	1.0	...	(2.6 ×2.4)	...	13.1	...	...	...
6814	(1.25)	7.6:	2.2	14:	(4.0 ×3.8)	(25)	12.1	−20.3:	32.4:	21:
7469	...	...	1.2	...	(3.0:×2.3:)	...	12.8	...	...	...
Mean		5.4		14		31:		−19.7		

objects (NGC 4051: II, NGC 6814: I), correspond to $M_T = -19.3$ and -20.3, in good agreement.

Conclusion: Sy (S) galaxies are 1.0 to 1.5 mag brighter than the average normal galaxy of the same morphological type. *Linear diameters* are within the range 3.4–7.6: kpc (mean: 5.4) for D_e diameters, 9–22: kpc (mean: 14) for D (0) diameters and 18–39 kpc (mean: 30) for D_m diameters.

Nuclear diameters and luminosities of S-type Seyfert galaxies are summarized in Tables II and III. The apparent diameter of the small, bright nucleus depends mainly on plate scale and resolution, seeing, and exposure time (Table II). A correct definition will require detailed studies of the luminosity distribution and calculation of the effective (half-power) diameter, corrected for underlying luminosity of the main body and for the instrumental blurring function (see Addendum). This information is not yet available, except for a low-resolution profile of the nucleus of NGC 1566, which has a Gaussian profile with $\sigma = 2''$, corresponding to $d_e(N) = 4''$. For this object the ratio of the half-power diameters nucleus/galaxy is $d_e/D_e = 0.03$. *Photographic diameters* from a homogeneous series of short exposures with the RCA S-20 image tube in red light (RG2 filter, $6100 < \lambda < 7100$ Å) at the Cassegrain focus of the McDonald 82-in. reflector are available for seven objects, and less homogeneous values from miscellaneous photographs in blue light for five objects Nuclear "diameters" d_N in this survey range from 2″ or less (seeing limited) up to 10″ or more. Since small values are determined mainly by instrumental resolution, maximum values (Table III) were adopted. For seven objects with known distances the linear major axes are in the range $0.25 < d_N < 0.50$ kpc with a mean of 0.37 kpc. *Conclusion*: The "photographic" diameter of the average Sy (S) nucleus is only 7% of the average effective diameter of the galaxy or roughly 3% of the standard $D(0)$ and 1% of D_m.

Apparent magnitudes of the nuclei in the B system are available for only four objects, one by direct measurement (NGC 1068), two by extrapolation of $B(X)$ to $X = \log d_N/D(0)$ (NGC 3516, 4051), and one by direct integration of the luminosity profile (NGC 1566). One variable object (NGC 4151) is not included. The magnitude difference $\delta m_N = m_N - m_T$ is in the range 2.1 to 4.1 with a mean value $\delta m_N = 3.2$ (Seyfert obtained $\delta m_N = 2.0$ from photographic estimates of four objects, excluding NGC 4151). *Conclusions*: The average nuclear luminosity in blue light (3900–4900 Å) is about 5% of the

TABLE II. Nucleus of NGC 1068.

Source	Exposure	Nuclear "diameter"
Lick, 120-in. (MFW), IIa-O	1 sec	1″.5×1″.2[a]
IIa-O	30 sec	4″×3″
McDonald, 82-in. (GV), IT+RG 2	IIIa-J, 30 sec	6″×5″
	Ia-O, 10 min	11″×9″.6[b]

[a] "Diameter" of star image 0″.9.
[b] "Diameter" of star image 2″.5.

TABLE III. Nuclear diameters and luminosities of S-type Seyfert galaxies.

NGC	Nuclear diameter (sec of arc)	Nuclear diameter kpc	Apparent magnitude B_N	$m_N - m_T$	Absolute magnitude M_N
1068	9 ×7	0.48	12.4	2.7	−18.1
1566	(7 ×7)	0.33	14.1:	4.4	−16.0
2782	3.5×2.5	0.35			
3227	4 ×3.5	0.32			
3516	5 ×5	...	14.7:	2.1:	...
4051	6.5×6	0.25	14.5	3.7	−15.2
4151	9 ×8	0.50	12.4/14.1	1.5/2.9	−17.8/−16.4
4939	(5 ×3.5)	0.33			
5548	5 ×5	...			
6814	...	...			
7469	7 ×6.5	...			
Mean		0.37		3.2	−16.5

TABLE IV. *U, B, V* Observations[a] of Seyfert galaxies.

Date, 1958	*A*	*X*	*V*	*B*	*U*	*B−V*	*U−B*
			NGC 3516				
April 17	0′.40	−0.41	12.40	13.12	12.89	0.72	−0.23
April 17	1.77	+0.24	11.76	12.60	12.49	0.84	−0.11
May 14	0.40	−0.41	12.42	13.23	13.19	0.81	−0.04
May 14	1.77	+0.24	11.88	12.69	12.76	0.81	+0.07
Δm (27 days)	0.40		+ 0.02	+ 0.11	+ 0.30		
	1.77		+ 0.12	+ 0.09	+ 0.37		
			NGC 4051				
April 17	0′.40	−1.00	12.92	13.59	13.47	0.67	−0.12
April 17	1.77	−0.35	11.36	12.07	12.10	0.71	+0.03
May 15	0.40	−1.00	12.94	13.75	13.75	0.81	0.00
May 15	2.30	−0.24	11.07	11.71	11.81	0.64	+0.10
Δm (28 days)	0.40		+ 0.02	+ 0.16	+ 0.28		
			NGC 4151				
April 13	0′.40	−0.84	11.85	12.56	12.30	0.71	−0.26
April 13	1.77	−0.20	11.00	11.79	11.74	0.79	−0.05
May 15	0.40	−0.84	11.74	12.37	12.03	0.63	−0.34
May 15	2.30	−0.08	10.82	11.53	11.47	0.71	−0.06
Δm(32 days)	0.40		-0.11	-0.19	-0.27		

[a] G. de Vaucouleurs, *Lowell Obs. Bull.* No. 97, 4, 105, 1959; *Astrophys. J. Suppl.* No. 48, 5, 233, 1961.
A =aperture in min of arc, $X = \log A/D(0)$.

total luminosity of the galaxy and the average surface brightness ratio nucleus/galaxy within the corresponding effective diameters is 50.

Absolute magnitudes in the B system for three nuclei are in the range $-15.2 < M_N < -18.1$ (mean: -16.5). If 10% of the energy is in the emission lines, then the average magnitude of the nucleus in emission is -14. This is not much greater than the emission-line output of a supergiant H II region (e.g., 30 Dor, NGC 604).

Integrated magnitudes and colors in the *U, B, V* system are available for seven S-type Seyfert galaxies, either from new Lowell and McDonald photoelectric observations (1958–1967) or from transformed older photographic or photoelectric data (1932–1954). Optical variability can be detected by abnormal scatter in the $B(X)$ and $U(X)$ integrated luminosity curves (X is the ratio of field aperture to "face-on" diameter). There are no data or insufficient data for six objects (NGC 1566, 2782, 3227, 4939, 5548, 7469). Scatter within normal photometric errors (0.1 mag) is present for two objects (NGC 1068, 6814), but the scatter is in excess of normal photometric errors for two other objects (NGC 3516: 0.1 mag in B, 0.3 mag in U between April and May 1958; NGC 4051: 0.2 mag in B, 0.3 mag in U between April and May 1958) (see Table IV). Definite variability has been established for NGC 4151 ($\Delta m = -0.6$ mag in B, -1.0 mag in U between 1958 and 1967). In only three objects (NGC 3516, 4051, 4151) are color discrepancies between successive observations with the same equipment (Table IV) greater than normal photometric errors. In NGC 4151 recent color data confirm variations amounting to 0.1 mag in $B-V$, and 0.6 mag in $U-B$, between 1958 and 1967.

TABLE V. Absolute magnitudes and diameters of N-type Seyfert galaxies.

Object	D	D(O)	B(O)	B-V	U-B	Zo	m-M	M_T
3C120	1′+	1′	14.5:	0.8:[a]	−0.6:[a]	0.0327	35.5.	−21.0:
N1275	1′.5	1′.3	13.14	0.85	−0.1:[a]	0.0176	34.0:	−21.:
3C227			17.3:	0.98	−0.36	0.0855	37.3:	−20.:
3C371			15.5	0.72	−0.36	0.0508	36.0:	−20.5:

[a] Variable.

Color–color relations for Sy (S) objects may be compared with normal galaxies. Corrections for galactic absorption and redshift range from 0.05 to 0.12 mag and 0.22 mag in one case (NGC 6814). Main-body corrected standard colors, $(B-V)_0(0)$ are available for seven objects from several sources, plus three from a less reliable source, and $(U-B)_0(0)$ is available for five objects. Mean values are $(B-V)_0(0) = +0.66$ and $(U-B)_0(0) = -0.07$. Normal galaxies in the same range of the classification sequence have average corrected colors near $(B-V)_0 = +0.74$, $(U-B)_0 = +0.20$. *Nuclear colors* measured with apertures $A \approx d_N$ are available for only four objects (NGC 1068, 1566, 4051, 4151). Mean corrected values are $(B-V)_0(N) = +0.56$ and $(U-B)_0(N) = -0.33$. The negative color trend toward smaller apertures is largest for NGC 4151 and peculiar