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BROADBAND OPTICAL AND INFRARED OBSERVATIONS OF SEYFERT GALAXIES

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SUMMARY

Broadband observations between 0·3 and 3·4 μ are reported for 11 bright Seyfert galaxies. The ultraviolet and two micron fluxes of NGC 4151 have both increased by ~0·3 mag between 1970 and 1971. 3C 120 was constant to within about ±0·1 mag in the infrared during a period when it varied in the optical by ~0·8 mag. Comparison with published data suggests NGC 4051 is an optical variable.

The spatial distribution of the emitted flux shortward of 2·2 μ suggests that the emission from Seyfert galaxies can be decomposed into a nuclear source showing ultraviolet and infrared excesses and an extended source with normal starlike colours.

The *U–B* and *B–V* colours fall on the two-colour diagram in positions consistent with a mixture of light from sources with galaxy-like and quasar-like colours and can be used to derive the ratio of the light from the nuclear source to that from the surrounding galaxy. This ratio is used to separate the contributions of nuclear source and galaxy in the infrared. The infrared spectrum of the nuclear source in NGC 1068 is steeper than that in the other Seyfert galaxies and more closely resembles that of non-Seyfert infrared galaxies such as M82 and NGC 253 rather than that of quasars. A wide range exists in the proportion of blue light contributed by the nuclear sources but the $(B\text{–}[2{\cdot}2\ \mu])_0$ colours of the combined emission range only by ±0·3 mag implying large differences exist in the $(B\text{–}[2{\cdot}2\ \mu])_0$ of the nuclear source alone, in contrast to the homogeneity of the purely optical colours.

1. INTRODUCTION

The current mythology is that the activity in the nuclei of Seyfert galaxies is of the same nature as that in quasi-stellar objects but on a much reduced scale. Because some Seyfert nuclei are brighter in apparent magnitude than most of the quasars and also because their relationship to the parent galaxy can be seen more clearly, the Seyfert galaxies may give clues as to the nature of the quasar mechanism.

For these reasons there have been several studies in recent years of variations in and the spatial distribution of the optical and infrared fluxes from Seyfert galaxies. Penston *et al.* (1971a) (hereafter called PPNTBV) discussed optical and infrared variations of NGC 4151 showing that the galaxy is variable at 2·2 μ, and that when the energy distributions of the nucleus and surrounding galaxy are separated the former is seen to closely resemble the energy distribution from quasars. A summary of work on this subject up to the beginning of 1971 was given in PPNTBV.

Since then papers on optical variability of Seyfert nuclei (Lyutuj, 1971a, b; MacPherson 1972; de Vaucouleurs & de Vaucouleurs 1972a; de Vaucouleurs 1973) have added NGC 3516, Markarian 10, II Zw 136, NGC 6814, NGC 5548 and

NGC 1566 to the list of optically variable nuclei. Rieke & Low (1972b) have claimed to detect infrared variability (at 10 μ) in NGC 1068 and NGC 4151. On the other hand their results are not confirmed by Stein, Gillett & Merrill (1974) so that the situation regarding longer wavelength variability is still unsettled. Observations of the size of the 10-μ nucleus of NGC 1068 (Becklin *et al.* 1973b) make such variations implausible.

In addition to these papers on variability, *UBV* photometry of Seyfert galaxies and studies of the spatial decomposition of the nucleus and surrounding galaxy therefrom have been reported by Sandage (1967), Dibay & Lyutuj (1971), Smith, Weedman & Spinrad (1972), de Vaucouleurs & de Vaucouleurs (1972b); de Vaucouleurs, de Vaucouleurs & Corwin (1973) and de Vaucouleurs (1973).

Infrared photometry of Seyfert galaxies have also been reported by Neugebauer *et al.* (1971), Rieke & Low (1972a) and Glass (1973).

This paper presents the results of a systematic study made in 1970 and 1971 at optical and near infrared wavelengths of 11 Seyfert galaxies for variability and spatial structure along the lines of PPNTBV. These results are analysed in order to cast light on the mechanisms responsible for the optical and infrared emission from the nuclei of these galaxies.

2. OBSERVATIONAL MATERIAL

The telescopes, technique and equipment used to obtain the photographic, photoelectric and infrared photometry reported here were in general as described by PPNTBV and the reader is referred there for a discussion of methods of avoiding such systematic errors as are likely to be present. In addition a few *UBV* photoelectric data were obtained on the 40-in. reflector of the Wise Observatory, Israel, using equipment described elsewhere (Penston 1973).

Table I lists photoelectric *UBV* data for eight and near infrared [1·6 μ], [2·2 μ] and [3·4 μ] data for 11 bright Seyfert galaxies. The table gives these magnitudes or colours as a function of the date of observation and the diameter of the focal plane aperture, together with the telescope used for that observation. Standard errors are given in this table except for the *UBV* observations made on the 20-in. telescope and some infrared observations. When not explicitly given these errors are as listed separately in Table II. No correction has been made to the infrared photometry in Table I for the effects of emission from the galaxy received by the reference beam. Such a correction would be less than the assigned error in all cases.

Table III presents the photographic magnitudes, m_{pg}, and their standard errors for five of these objects as a function of the date of observation. The calibration of the photographic plates is via the photoelectric sequences whose sources are given in Table IV. These observations form a continuation of the results reported earlier by Cannon, Penston & Brett (1971) which were in most cases differently calibrated. The information in Table V should enable the older results to be put on the present system.

3. VARIABILITY

NGC 4151

The data presented here on the Seyfert galaxy NGC 4151 form a continuation of those of PPNTBV. The new observations covering the period 1970 October to 1971 December are plotted as light curves at six wavelengths from 0·3 to 3·4 μ

TABLE I

Photoelectric and infrared data

NGC 1068

DATE	JD 2440000+	TEL ins	AP secs	V	B-V	U-B	NOTES
1970Sep 0/ 1	0830	20	25.	10.40	+0.80	+0.13	(1)
			48.	9.96	+0.78	+0.04	
1970Sep 1/ 2	0831	20	25.	10.42	+0.86	+0.13	
			48.	9.96	+0.78	+0.04	
1970Sep 2/ 3	0834	20	25.	10.48	+0.88	+0.08	(1)
			48.	10.01	+0.77	+0.03	
1970Sep 3/ 4	0835	20	25.	10.42	+0.83	+0.05	(1)
			48.	9.94	+0.80	-0.00	
1970Sep28/29	0858	20	25.	10.45	+0.83	+0.05	(1)
			48.	10.03	+0.76	+0.04	
1970Sep29/30	0859	20	25.	10.48	+0.79	+0.06	(1)
			48.	9.98	+0.78	+0.05	
1970Oct 0/ 1	0860	20	25.	10.42	+0.84	+0.06	(1)
			48.	9.96	+0.81	+0.03	
			78.	9.63	+0.77	-0.01	
			124.	9.33	+0.74	-0.05	
1970Oct28/29	0888	20	25.	10.44	+0.82	+0.08	(1)
			48.	9.95	+0.79	+0.04	
			78.	9.71	+0.77	+0.07	
			124.	9.41	+0.76	+0.08	
1970Oct29/30	0889	20	25.	10.37	+0.88	+0.14	
			48.	9.93	+0.78	+0.09	
1970Nov23/24	0914	20	25.	10.41	+0.84	+0.11	(1)
			48.	9.98	+0.79	+0.06	
			78.	9.63	+0.73	+0.06	
			124.	9.33	+0.74	+0.04	
1970Nov24/25	0915	20	25.	10.40	+0.84	+0.08	
			48.	9.94	+0.76	+0.06	
			78.	9.60	+0.72	+0.06	
1970Dec 3/ 4	0924	20	25.	10.43	+0.82	+0.12	
			48.	10.04	+0.76	+0.07	
1970Dec29/30	0950	20	25.	10.53	+0.83	+0.03	(2)
1970Dec30/31	0951	20	25.	10.49	+0.82	+0.08	(1)
1971Jan 0/ 1	0952	20	25.	10.46	+0.85	+0.06	(1)
			48.	9.98	+0.78	+0.04	
1971Jan18/19	0970	20	25.	10.44	+0.85	+0.06	(1)
			48.	9.98	+0.78	+0.04	
1971Jan29/30	0981	20	25.	10.46	+0.82	+0.11	(1)

TABLE I—*continued*

NGC 1068 (cont)

DATE	JD 2440000+	TEL ins	AP secs	V	B-V	U-B	NOTES
1971Feb21/22	1004	20	25.	10.50	+0.78	+0.09	(1)
1971Feb24/25	1007	20	25.	10.42	+0.78	+0.10	(1)
			48.	9.89	+0.79	+0.10	
1971Aug22/23	1186	60	10.4	11.19±0.05	+0.95±0.02	+0.04±0.04	
			18.	10.66±0.05	+0.90±0.02	+0.10±0.04	
			33.	10.16±0.05	+0.81±0.02	+0.05±0.04	
1971Sep21/22	1216	20	25.	10.37	+0.86	+0.09	(1)
			48.	9.94	+0.82	+0.04	
1971Sep22/23	1217	20	25.	10.38	+0.86	+0.06	(1)
1971Nov22/23	1278	40	15.	10.82±0.06	+0.97±0.03	-0.03±0.04	(3)
			24.	10.54±0.06	+0.84±0.03	+0.03±0.04	
			30.	10.25±0.06	+0.86±0.03	+0.05±0.04	
			45.	10.01±0.06	+0.83±0.03	-0.04±0.04	
				[1.6μ]	[2.2μ]	[3.4μ]	
1969Nov 4/ 5	0530	100	15.	7.92±0.15	7.23±0.15		(4)
1969Nov27/28	0553	60	25.	7.54±0.10	6.94±0.10		
1969Dec11/12	0567	100	2.0		9.7 ±1.0		
			5.0		7.99±0.10		
			10.0		7.49±0.10		
			15.		7.28±0.10		
			20.		7.13±0.10		
1969Dec14/15	0570	200	2.5	9.54±0.15	8.12±0.15		
			3.8	9.22±0.10	7.97±0.10		
			5.0	8.94±0.10	7.85±0.10		
			7.5	8.59±0.10	7.65±0.10		
1970Sep17/18	0847	60	15.	7.95±0.08	7.42		
			32.	7.49	6.96		
1970Sep24/25	0854	100	9.5	8.33	7.56	5.48	
			13.5	7.96	7.30	5.41	
1970Oct24/25	0884	100	13.5	8.06	7.37	5.29	
1971Jan24/25	0976	60	8.0		7.6 ±0.2	5.4 ±0.2	
			22.	7.55±0.10	7.05±0.10	5.23±0.15	
1971Feb13/14	0996	60	7.9	8.34±0.13	7.66		
			15.	7.73±0.08	7.17		
			32.	7.21	6.66		
1971Feb14/15	0997	60	15.			5.49±0.14	
			32.			5.27±0.11	
1971Mar 7/ 8	1018	60	7.9	9.01±0.12	7.90		
			15.	7.83	7.32		

TABLE I—*continued*

NGC 1068 (cont)

DATE	JD 2440000+	TEL ins	AP secs	[1.6μ]	[2.2μ]	[3.4μ]	NOTES
1971Sep21/22	1216	100	9.5	8.65±0.2	7.82±0.2	5.68±0.2	(4)(5)
			15.	7.84±0.1	7.07±0.1	5.05±0.2	
			28.	7.27±0.1	6.69±0.1		
1971Sep22/23	1217	100	9.5	8.34	7.56	5.29±0.12	
			28.	7.44	6.90		
1971Sep23/24	1218	100	9.8	8.31	7.55	5.3 ±0.2	
			15.			>5.71	(6)
			28.	7.33±0.08	6.84±0.08		
1971Sep27/28	1222	100	10.0	8.49:	7.71		
1971Sep28/29	1223	100	10.0		7.54	5.38	
			20.		7.04	5.31±0.15	
			28.		6.85		
1971Oct19/20	1244	200	7.5	8.58	7.68	5.49	
			10.0			5.48	
1971Nov21/22	1279	100	13.5	7.93	7.30	5.43	

NGC 1275

DATE	JD 2440000+	TEL ins	AP secs	V	B-V	U-B	NOTES
1970Sep 1/ 2	0831	20	25.	12.55	+0.68	-0.19	
			48.	12.22	+0.69	-0.06	
1970Sep 2/ 3	0832	20	25.	12.54	+0.68	-0.21	(1)
			48.	12.25	+0.70	-0.11	
1970Sep 3/ 4	0833	20	25.	12.64	+0.61	-0.14	(1)
			48.	12.08	+0.70	-0.17	
1970Sep29/30	0859	20	25.	12.96	+0.62	+0.06	(1)
			48.	12.38	+0.69	+0.09	
1970Oct 0/ 1	0860	20	25.	12.83	+0.70	-0.04	(1)
			48.	12.36	+0.82	+0.00	
1970Oct29/30	0889	20	25.	12.60	+0.69	-0.01	(1)
			48.	12.24	+0.75	-0.14	
1970Nov23/24	0914	20	25.	12.98	+0.66	-0.10	
1970Dec 3/ 4	0924	20	25.	12.72	+0.69	-0.05	
			48.	12.54	+0.66	+0.03	
1970Dec29/30	0950	20	25.	12.84	+0.66	-0.20	(1)(7)
1971Jan18/19	0970	20	25.	12.90	+0.64	-0.09	(1)

TABLE I—*continued*

NGC 1275 (cont)

DATE	JD 2440000+	TEL ins	AP secs	V	B-V	U-B	NOTES
1971Jan27/28	0979	60	10.4	13.25±0.02	+0.66±0.02	-0.25±0.03	
			18.	12.83±0.02	+0.69±0.02	-0.10±0.03	
			33.	12.53±0.04	+0.71±0.02	-0.18±0.03	
1971Feb23/24	1006	20	25.	12.78	+0.59	-0.14	(1)
1971Feb26/27	1009	20	25.	12.81	+0.64	-0.13	(1)
1971Aug22/23	1186	60	10.4	13.35±0.05	+0.65±0.02	-0.19±0.04	
			18.	12.96±0.05	+0.67±0.02	-0.13±0.04	
			33.	12.54±0.05	+0.73±0.02	-0.07±0.04	
1971Sep22/23	1217	20	25.	12.86	+0.70	-0.08	(1)(4)
1971Nov22/23	1277	40	15.	13.17±0.06	+0.74±0.03	+0.03±0.1	
			24.	13.00±0.06	+0.68±0.03	-0.12±0.1	
			30.	12.87±0.06	+0.75±0.03	-0.07±0.1	
			45.	12.55±0.06	+0.74±0.03	+0.03±0.04	
				[1.6μ]	[2.2μ]	[3.4μ]	
1970Sep18/19	0848	60	10.5	>10.1	9.56±0.14		(6)
			15.3	10.0±0.2	9.32±0.14		
			32.	9.4 ±0.2	9.1 ±0.2		
1970Oct16/17	0876	60	6.2	>10.6	9.8 ±0.2		(6)
			15.3	10.0±0.2	9.4 ±0.2		
			32.	9.2±0.2	8.86±0.13		
1970Oct24/25	0884	100	13.5	10.03±0.10	9.37	8.05±0.15	
			19.	9.82±0.08	9.20		
1971Mar 7/ 8	1018	60	7.9	>10.4	9.8 ±0.2		(6)
			15.3	9.9±0.2	9.2 ±0.2		
1971Sep21/22	1216	100	9.5	10.49±0.1	9.63±0.1	>8.10	(6)
			15.	10.00±0.1	9.29±0.1		
			28.	9.66±0.1	9.04±0.1		
1971Sep27/28	1222	100	10.0	10.40±0.10	9.59		
			19.	10.05±0.08	9.27		

3C 120

DATE	JD 2439000+	TEL ins	AP secs	[1.6μ]	[2.2μ]	[3.4μ]	NOTES
1967Aug26/27	730	200	7.5		9.95±0.10		
1967Sep13/14	748	200	7.5		9.87±0.09		
1967Sep25/26	760	200	7.5	10.97±0.12	9.79 ±0.09		

TABLE I—*continued*

3C 120 (cont)

DATE	JD 2440000+	TEL ins	AP secs	[1.6μ]	[2.2μ]	[3.4μ]	NOTES
1968Nov 4/ 5	0165	200	7.5	11.2 ±0.2	9.96±0.15	8.39±0.15	
1969Mar20/21	0301	100	9.8		10.12±0.10		
1969Nov 4/ 5	0530	100	15.	10.9 ±0.2	10.12±0.2		(4)
1969Nov27/28	0553	60	24.		9.86±0.12		
1969Dec11/12	0567	100	9.8		9.86±0.10		
1970Oct24/25	0884	100	20.	11.03±0.12	10.02±0.10	8.3 ±0.2	
1970Dec22/23	0943	200	10.0	11.10±0.08	10.07		
1971Mar12/13	1023	200	10.0		10.04±0.10		
1971Sep22/23	1217	100	9.8	11.11±0.12	9.98		
1971Sep23/24	1218	100	9.8	10.92±0.15	9.94		
1971Sep28/29	1223	100	15.0		9.91	7.9 ±0.3	
1971Oct18/19	1243	200	10.0	10.91±0.08	9.82±0.08		

NGC 2782

DATE	JD 2440000+	TEL ins	AP secs	[1.6μ]	[2.2μ]	[3.4μ]	NOTES
1971Mar 8/ 9	1019	60	15.		>10.0		(6)
			32.	10.1 ±0.2	9.57±0.15		

NGC 3227

DATE	JD 2440000+	TEL ins	AP secs	V	B-V	U-B	NOTES
1971Jan25/26	0977	60	10.4	13.43±0.02	+0.86±0.02	+0.02±0.03	
			18.	12.99±0.02	+0.91±0.02	+0.08±0.03	
			33.	12.51±0.03	+0.89±0.02	+0.17±0.03	
				[1.6μ]	[2.2μ]	[3.4μ]	
1970May 2/ 3	0709	100	9.6	10.09±0.11	9.78±0.10		
			19.3	9.82±0.10	9.39		
1971Feb12/13	0995	60	15.4	9.7 ±0.2	9.4 ±0.2		
			32.	9.3 ±0.2	8.93±0.12		

TABLE I—*continued*

NGC 3516

DATE	JD 2440000+	TEL ins	AP secs	V	B-V	U-B	NOTES
1970Nov23/24	0914	20	25.	12.33	+0.68	-0.17	
1971Jan25/26	0977	60	10.4	12.77±0.02	+0.72±0.02	-0.26±0.03	
			18.	12.50±0.02	+0.74±0.02	-0.15±0.03	
			33.	12.26±0.02	+0.77±0.02	-0.12±0.03	
1971Jan27/28	0979	60	10.4	12.78±0.02	+0.73±0.02	-0.27±0.03	
			18.	12.47±0.02	+0.77±0.02	-0.20±0.03	
			33.	12.20±0.02	+0.80±0.02	-0.14±0.03	
1971Feb24/25	1007	20	25.	12.36	+0.79	+0.17	(8)
				[1.6μ]	[2.2μ]	[3.4μ]	
1971Feb11/12	0994	60	15.4	9.9 ±0.3	9.23±0.14		
1971Feb12/13	0995	60	7.9	9.7 ±0.3	9.6 ±0.2		
			32.	9.2 ±0.2	8.85±0.13		
1971Mar 9/10	1020	60	7.9	9.8 ±0.2	9.6 ±0.2		
			15.4	9.37±0.13	9.11±0.14		
			32.	9.27±0.15	8.87±0.14		

NGC 4051

DATE	JD 2440000+	TEL ins	AP secs	V	B-V	U-B	NOTES
1971Jan25/26	0977	60	10.4	13.59±0.02	+0.72±0.02	-0.16±0.03	
			18.	13.21±0.02	+0.80±0.02	-0.07±0.03	
			33.	12.84±0.03	+0.83±0.02	+0.11±0.03	
				[1.6μ]	[2.2μ]	[3.4μ]	
1970Feb12/13	0599	60	15.4	10.0 ±0.2	9.62±0.15		
1970Jul27/28	0765	200	7.5	10.5 ±0.2	9.9 ±0.2	8.7 ±0.2	(9)
1971Feb11/12	0994	60	15.4	10.4 ±0.3	9.6 ±0.2		
			32.	10.1 ±0.4	9.5 ±0.2		

NGC 4151

DATE	JD 2440000+	TEL ins	AP secs	V	B-V	U-B	NOTES
1970Oct29/30	0890	20	25.	11.61	+0.81	-0.48	
1970Oct30/31	0891	20	25.	11.64	+0.66	-0.52	(1)
			48.	11.32	+0.70	-0.43	
1970Nov23/24	0915	20	25.	11.57	+0.75	-0.50	

TABLE I—*continued*

NGC 4151 (cont)

DATE	JD 2440000+	TEL ins	AP secs	V	B-V	U-B	NOTES
1970Nov24/25	0916	20	25.	11.57	+0.69	-0.45	(1)(4)
			48.	11.25	+0.74	-0.33	
1970Dec 3/ 4	0925	20	25.	11.58	+0.62	-0.48	
			48.	11.18	+0.70	-0.36	
1970Dec29/30	0951	20	25.	11.52	+0.62	-0.59	(1)
			48.	11.20	+0.70	-0.49	
1971Jan18/19	0971	20	25.	11.44	+0.58	-0.67	(1)
1971Jan25/26	0978	60	10.4	11.79±0.02	+0.52±0.02	-0.74±0.03	
			18.	11.57±0.02	+0.57±0.02	-0.63±0.03	
			33.	11.31±0.02	+0.63±0.02	-0.54±0.03	
1971Jan27/28	0980	60	10.4	11.84±0.02	+0.52±0.02	-0.69±0.03	
			18.	11.60±0.02	+0.57±0.02	-0.62±0.03	
			33.	11.33±0.02	+0.64±0.02	-0.53±0.03	
1971Jan29/30	0982	20	25.	11.52	+0.61	-0.66	(1)
			48.	11.22	+0.65	-0.53	
1971Feb24/25	1008	20	25.	11.58	+0.60	-0.58	(1)
			48.	11.24	+0.68	-0.49	
			78.	11.07	+0.65	-0.40	
1971Mar24/25	1036	20	25.	11.65	+0.64	-0.55	(1)(4)
1971Mar26/27	1038	20	25.	11.60	+0.68	-0.49	(1)
			48.	11.29	+0.73	-0.39	
			78.	11.04	+0.74	-0.30	
1971Apr22/23	1065	20	25.	11.58	+0.68	-0.48	(1)
			48.	11.24	+0.76	-0.40	
1971Apr23/24	1066	20	25.	11.60	+0.69	-0.44	(1)
			48.	11.30	+0.74	-0.31	
1971May20/21	1093	20	48.	11.28	+0.66	-0.46	(1)
			78.	11.03	+0.71	-0.38	
1971May22/23	1095	20	25.	11.56	+0.58	-0.58	(1)
			48.	11.24	+0.63	-0.48	
1971May23/24	1096	20	25.	11.53	+0.62	-0.62	(1)
			48.	11.25	+0.68	-0.54	
1971Jun26/27	1130	20	25.	11.64	+0.69	-0.40	(1)
			48.	11.28	+0.77	-0.29	
1971Jun27/28	1131	20	25.	11.66	+0.68	-0.48	(1)
1971Jun28/29	1132	20	25.	11.60	+0.70	-0.46	(1)
1971Jul 0/ 1	1134	20	25.	11.61	+0.70	-0.45	(1)

TABLE I—*continued*

NGC 4151 (cont)

DATE	JD 2440000+	TEL ins	AP secs	V	B-V	U-B	NOTES
1971Nov22/23	1279	40	15.	11.86±0.06	+0.63±0.03	-0.66±0.04	
			24.	11.68±0.06	+0.64±0.03	-0.61±0.04	
			30.	11.49±0.06	+0.75±0.03	-0.56±0.04	
			45.	11.32±0.06	+0.80±0.03	-0.52±0.04	
				[1.6μ]	[2.2μ]	[3.4μ]	
1971Feb11/12	0995	60	7.9	9.2 ±0.2	8.42±0.08		
			15.3	8.84±0.13	8.27±0.08		
			32.	8.51±0.10	7.97		
1971Feb13/14	0997	60	7.9	9.26±0.12	8.37±0.12		
			15.3	8.94±0.11	8.40±0.08		
			32.	8.88±0.15	8.14		
1971Mar 6/ 7	1018	60	7.9	9.6 ±0.2	8.60		
			15.3	9.18±0.15	8.39		
			32.	8.82±0.11	8.18		
1971Mar 8/ 9	1020	60	7.9	9.41±0.15	8.62±0.11		
			15.3	8.93±0.11	8.37		
			32.	8.71±0.10	8.09±0.09		
1971Mar28/29	1040	100	5.0	9.60±0.10	8.70±0.10	7.28±0.15	
			9.5	9.23	8.43	7.19	
			15.0	9.00	8.29	6.96	
			19.5	8.89	8.23		
1971Mar30/31	1042	100	15.0	9.11±0.08	8.47	6.93	
			19.5	9.01±0.08	8.39		
1971Apr22/23	1065	100	5.0		8.8 ±0.2		
			9.5	9.33±0.10	8.53±0.10	7.16±0.12	
			15.0	9.11±0.10	8.40±0.10	7.16±0.12	
			19.5	9.01±0.10	8.31±0.10		
1971May25/26	1098	200	5.0		8.72±0.10		
			9.8	9.33	8.58		
			20.	9.03	8.39		
1971Jun20/21	1124	200	5.0	9.47±0.14	8.62±0.10		
			9.6	9.37	8.55		
			15.	9.10	8.46		
1971Jul 0/ 1	1134	200	5.0	9.53±0.10	8.62±0.10	7.13±0.10	
			10.0	9.17±0.08	8.45	6.97	
1971Jul25/26	1159	200	5.0	10.10±0.12	9.11±0.12		
			9.2			7.11±0.12	
			10.0	9.54±0.12	8.72±0.12		
1971Jul28/29	1162	100	9.6	9.60±0.08	8.87	6.76±0.12	
			13.6	9.40±0.07	8.66	6.08±0.11	
			28.	9.10±0.08	8.50		
1971Nov21/22	1278	100	10.5	9.21±0.10	8.48		
			13.5	9.11±0.07	8.41	7.20	
			19.5	8.88±0.07	8.26		

TABLE I—*continued*

NGC 5548

DATE	JD 2440000+	TEL ins	AP secs	V	B-V	U-B	NOTES
1971Jan27/28	0979	60	10.4	13.93±0.02	+0.66±0.02	-0.47±0.03	
			18.	13.52±0.03	+0.72±0.02	-0.35±0.03	
			33.	13.13±0.02	+0.76±0.02	-0.24±0.03	
				[1.6μ]	[2.2μ]	[3.4μ]	
1970Apr21/22	0698	60	33.	10.1 ±0.3	>9.9		(6)
1971Mar 6/ 7	1017	60	15.4	>10.2	10.0 ±0.2		(6)
			33.	>10.4	9.60±0.14		(6)
1971Jul27/28	1160	100	9.6	11.24±0.15	10.44±0.10	>8.2	(6)
			28.	10.68±0.13	10.18±0.13		

NGC 6814

DATE	JD 2440000+	TEL ins	AP secs	[1.6μ]	[2.2μ]	[3.4μ]	NOTES
1970Sep19/20	0849	60	15.	9.6 ±0.3	10.1 ±0.3		
			32.	9.7 ±0.4	9.9 ±0.3		
1971Jul28/29	1161	100	9.5	10.8 ±0.2	10.51±0.10	>7.94	(6)
			28.	10.17±0.10	9.72±0.09		

NGC 7469

DATE	JD 2440000+	TEL ins	AP secs	V	B-V	U-B	NOTES
1970Sep 0/ 1	0830	20	25.	13.05	+0.45	-0.53	(1)
			48.	12.69	+0.56	-0.33	
1970Sep 1/ 2	0831	20	25.	12.96	+0.60	-0.40	(1)
			48.	12.55	+0.70	-0.44	
1970Sep 2/ 3	0832	20	25.	12.88	+0.59	-0.45	(1)
			48.	12.60	+0.61	-0.30	
1970Sep 3/ 4	0833	20	25.	12.94	+0.58	-0.46	(1)
			48.	12.71	+0.62	-0.39	
1970Sep29/30	0859	20	25.	13.08	+0.60	-0.63	(1)
			48.	12.77	+0.51	-0.30	
1970Oct 0/ 1	0860	20	25.	12.91	+0.60	-0.46	(1)
			48.	12.59	+0.58	-0.34	
			78.	12.30	+0.80	-0.28	
1970Oct28/29	0888	20	25.	12.92	+0.64	-0.54	
			48.	12.82	+0.64	-0.48	

TABLE I—*continued*

NGC 7469 (cont)

DATE	JD 2440000+	TEL ins	AP secs	V	B-V	U-B	NOTES
1970Oct29/30	0889	20	25.	12.97	+0.59	-0.42	(1)
			48.	12.53	+0.61	-0.34	
			78.	12.43	+0.64	-0.42	
			124.	12.11	+0.64	-0.33	
1970Nov23/24	0914	20	25.	12.88	+0.56	-0.56	(1)
			48.	12.61	+0.57	-0.45	
1970Nov24/25	0915	20	25.	12.88	+0.58	-0.58	(1)
			48.	12.64	+0.59	-0.49	
1970Dec 3/ 4	0924	20	25.	12.85	+0.59	-0.60	
			48.	12.54	+0.65	-0.38	
1970Dec29/30	0950	20	25.	13.18	+0.82	-0.56	
			48.	12.70	+0.63	-0.43	
1971Jan18/19	0970	20	25.	12.94	+0.67	-0.47	(1)
1971Jun26/27	1129	20	25.	12.90	+0.56	-0.46	(1)
1971Jun27/28	1130	20	25.	12.84	+0.54	-0.49	(1)
1971Jul 0/ 1	1133	20	25.	12.99	+0.56	-0.48	(1)
1971Aug22/23	1186	60	10.4	13.27±0.05	+0.44±0.02	-0.72±0.04	
			18.	12.99±0.05	+0.57±0.02	-0.64±0.04	
			33.	12.67±0.05	+0.58±0.02	-0.54±0.04	
1971Sep21/22	1216	20	25.	12.92	+0.54	-0.66	(1)
1971Sep22/23	1217	20	25.	12.82	+0.56	-0.50	(1)
1971Nov22/23	1278	40	15.	13.20±0.06	+0.45±0.03	-0.66±0.1	
			24.	12.95±0.06	+0.53±0.03	-0.57±0.1	
			30.	12.65±0.06	+0.62±0.03	-0.47±0.1	
			45.	12.71±0.06	+0.60±0.03	-0.59±0.04	
				[1.6μ]	[2.2μ]	[3.4μ]	
1970Jun29/30	0767	100	8.5	10.10±0.10	9.32±0.07	8.25±0.14	
1970Jul15/16	0783	60	7.9	>10.60	9.6 ±0.2		(6)
			15.3		9.31±0.15		
1970Jul16/17	0784	60	15.3	>9.17	9.4 ±0.2		(6)
			32.	9.4 ±0.2	8.9 ±0.2		
				±			
1970Sep18/19	0848	60	10.5	9.8 ±0.2	9.36±0.15		
			15.3	10.2 ±0.3	9.3 ±0.2		
			32.	9.9 ±0.2	9.27±0.14		
1970Oct16/17	0876	60	6.4	>10.3	9.6 ±0.2		(6)
			15.3	10.0 ±0.3	9.23±0.14		
			32.	10.0 ±0.4	8.80±0.11		

TABLE I—*continued*

NGC 7469 (cont)

DATE	JD 2440000+	TEL ins	AP secs	[1.6μ]	[2.2μ]	[3.4μ]	NOTES
1971Jul27/28	1160	100	9.5	9.91±0.09	9.30	8.7 ±0.3	
			20.	9.82±0.08	9.27		
			28.	9.70±0.09	9.11		
1971Sep21/22	1216	100	9.5	9.80±0.1	9.11±0.1	7.7 ±0.2	
			15.	9.73±0.1	9.15±0.1		
			28.	9.68±0.1	9.01±0.1		

Notes to Table I

(1) Mean of two observations.
(2) Cloud?
(3) Near dawn.
(4) Poor night.
(5) Centring?
(6) 3 σ limit.
(7) Large error.
(8) *U* observation dubious.
(9) Observation through cloud.

TABLE II

UBV photoelectric photometry errors on 20-in.

Object	Standard error of single observation σ_V	σ_{B-V}	σ_{U-B}
NGC 1068	0·03	0·03	0·04
1275	0·08	0·07	0·13
3516	0·08	0·07	0·1
4151	0·05	0·03	0·06
7469	0·06	0·07	0·06

Minimum standard errors for infrared photometry

$\sigma_{[1\cdot 6\mu]}$	$\sigma_{[2\cdot 2\mu]}$	$\sigma_{[3\cdot 4\mu]}$
0·07	0·07	0·10

in Fig. 1. The 1970 range of variation is represented by the arrows at the left-hand edge. As found by PPNTBV the photographic and photoelectric *B* light curves agree well after a zero-point correction necessitated by the smaller effective observing aperture of the photographic observations has been applied.

The optical curves show maxima in late 1971 January and late 1971 May and as before the pattern of variation is clearer at the shorter wavelengths. Lyutuj (1971a), who also reported *UBV* photometry up to 1971 March, confirms the January maximum but his magnitudes appear systematically brighter by 0·05–0·1 mag. In general NGC 4151 was brighter in the optical in 1971 than in the 1970 season.

The 1·6 and 2·2 μ infrared curves show a constant plateau followed by a possible decline in 1971 July. Unfortunately the optical and infrared observations were not made on the same days (in general the optical observations were performed in the dark of the Moon and the infrared measures near Full Moon). Even

TABLE III

Photographic data

DATE	JD 2440000+	m_{pg}	NOTES	DATE	JD 2440000+	m_{pg}	NOTES
			NGC 1068				
1970Sep28/29	0859	12.64±0.10		1970Oct 2/ 3	0863	12.51±0.10	
1970Oct19/20	0880	12.63±0.10		1970Nov 3/ 4	0894	12.64±0.10	
1970Nov 5/ 6	0897	12.52±0.10		1970Nov 8/ 9	0900	12.60±0.10	
1970Nov24/25	0915	12.59±0.10		1970Nov25/26	0916	12.41±0.12	
1970Nov26/27	0917	13.01±0.14		1970Dec21/22	0942	12.40±0.10	
1971Feb21/22	1004	12.49±0.10		1971Sep 1/ 2	1197	12.42±0.10	
1971Sep16/17	1212	12.39±0.10		1971Nov13/14	1269	12.41±0.10	
1971Nov22/23	1278	12.47±0.10					
			NGC 1275				
1970Sep 1/ 2	0832	13.59±0.06		1970Sep28/29	0859	14.55±0.05	
1970Sep29/30	0860	14.29±0.06		1970Oct 2/ 3	0863	14.23±0.05	
1970Oct19/20	0880	14.29±0.05		1970Nov 3/ 4	0894	14.02±0.05	
1970Nov 5/ 6	0896	13.75±0.05		1970Nov 8/ 9	0900	14.01±0.05	
1970Nov25/26	0916	14.18±0.06		1970Nov26/27	0917	14.36±0.05	
1970Dec 1/ 2	0923	14.20±0.05		1970Dec 4/ 5	0926	14.14±0.05	
1970Dec 6/ 7	0928	14.23±0.05		1970Dec21/22	0942	14.30±0.05	
1971Feb21/22	1004	14.10±0.05		1971Sep16/17	1212	14.28±0.07	
1971Sep18/19	1214	14.42±0.05		1971Oct14/15	1240	13.65±0.05	(1)
1971Oct19/20	1245	14.02±0.05		1971Nov19/20	1276	14.34±0.09	
1971Nov22/23	1278	14.22±0.05		1971Dec19/20	1305	14.27±0.05	
			3C 120				
1970Oct 2/ 3	0863	15.10±0.05		1970Oct26/27	0887	15.18±0.05	
1970Nov 3/ 4	0895	15.12±0.05		1970Nov24/25	0916	15.04±0.05	
1970Nov26/27	0918	15.02±0.05	(1)	1970Dec 6/ 7	0928	14.94±0.05	
1971Jan 1/ 2	0954	14.77±0.05		1971Jan18/19	0971	14.78±0.05	
1971Feb18/19	1001	14.85±0.05		1971Sep19/20	1215	14.86±0.05	
1971Oct19/20	1245	15.02±0.05		1971Oct27/28	1253	15.17±0.07	
1971Oct28/29	1254	15.10±0.05	(1)	1971Nov14/15	1271	14.93±0.05	
1971Nov18/19	1275	14.85±0.07	(1)	1971Nov19/20	1276	14.92±0.05	(1)
1971Nov22/23	1278	14.91±0.05					
			NGC 4151				
1971Jan 0/ 1	0953	12.32±0.05		1971Jan 1/ 2	0954	12.28±0.05	
1971Feb22/23	1006	12.40±0.05		1971Mar27/28	1039	12.66±0.05	
1971Apr19/20	1061	12.61±0.05		1971Apr21/22	1063	12.63±0.05	
1971May21/22	1093	12.44±0.05	(1)				
			NGC 7469				
1970Aug30/31	0830	14.10±0.05		1970Sep28/29	0858	14.12±0.05	
1970Oct 2/ 3	0862	14.02±0.05		1970Oct 6/ 7	0866	14.03±0.05	
1970Oct26/27	0886	14.04±0.05		1970Nov24/25	0915	13.97±0.05	
1970Nov25/26	0916	13.75±0.10		1970Dec21/22	0942	13.93±0.05	
1971Aug24/25	1189	14.01±0.13		1971Sep17/18	1213	13.79±0.05	
1971Oct12/13	1237	14.02±0.08		1971Nov19/20	1275	13.78±0.05	
1971Nov23/24	1279	13.77±0.05		1971Dec18/19	1304	13.93±0.05	

Note to Table III

(1) Mean of two plates.

TABLE IV

Sequences used to calibrate photographic magnitudes

Object	Reference
NGC 1068	Penston *et al.* (1971b)
1275	Pagel (unpublished)
3C 120	Kinman (1968)
NGC 4151	Kinman (unpublished)
7469	Penston *et al.* (1971b)

TABLE V

To convert the blue magnitudes, B_{CPB}, or mean iris readings, $(MIR)_{CPB}$, of Cannon et al. (1971) *to the m_{pg} systems of Table III use these relationships*

Object	Relationship
NGC 1068	$m_{pg} = 0{\cdot}45 + 0{\cdot}950\ B_{CPB}$
1275	$= 14{\cdot}48 - 0{\cdot}134\ (\mathrm{MIR})_{CPB}$
4151	$= 1{\cdot}81 + 0{\cdot}863\ B_{CPB}$
7469	$= 13{\cdot}99 - 0{\cdot}069\ (\mathrm{MIR})_{CPB}$

taking account of this caution, it is likely that the optical and infrared light curves are different from each other. A possible match however exists when the optical curve is delayed by one month but a delay of two months as found in 1970 by PPNTBV does not fit the new data.

It is however noteworthy that on the average the infrared emission shares with the optical the property of being brighter (by 0·25 mag at 2 μ) in 1971 than in either 1970 (PPNTBV) or 1972 (Becklin & Neugebauer, unpublished; Selmes, unpublished). This change in general level cannot be explained as an instrumental effect and seems strong evidence that the 2·2-μ variations found here and in PPNTBV are real, and that *on the time scale of one year the optical and infrared fluxes of NGC 4151 vary together*.

The observations at 3·4 μ show no clear behaviour with time and it remains uncertain whether variability exists. A possible case can be made for NGC 4151 being brighter at 3·4 μ in 1971 than in 1970 by an amount of order 0·3 mag since this relies on the mean of several observations.

PPNTBV found that in 1970 the infrared 2·2 μ maximum followed that of the optical flux by about two months, consistent with a dust re-radiation model for the infrared flux. In 1971 the delay which fits the data is one month suggesting either that the dust cloud surrounding the nucleus of NGC 4151 has different structures at different times or that the dust model should be discarded. The dust model also predicts that the re-radiated flux cannot vary in magnitude by more than the illuminating source but the PPNTBV data showed as large magnitude variations at 2·2 μ as in the U band after subtracting the flux from contaminating starlight emitted by the body of the galaxy. Only if the bolometric variations exceed those observed in U will the dust model stand.

Even if the dust model is incorrect, a basic conclusion from the difference of the optical and infrared light curves found by PPNTBV and in the present data is that the optical and infrared emission either have different mechanisms or emanate from different regions.

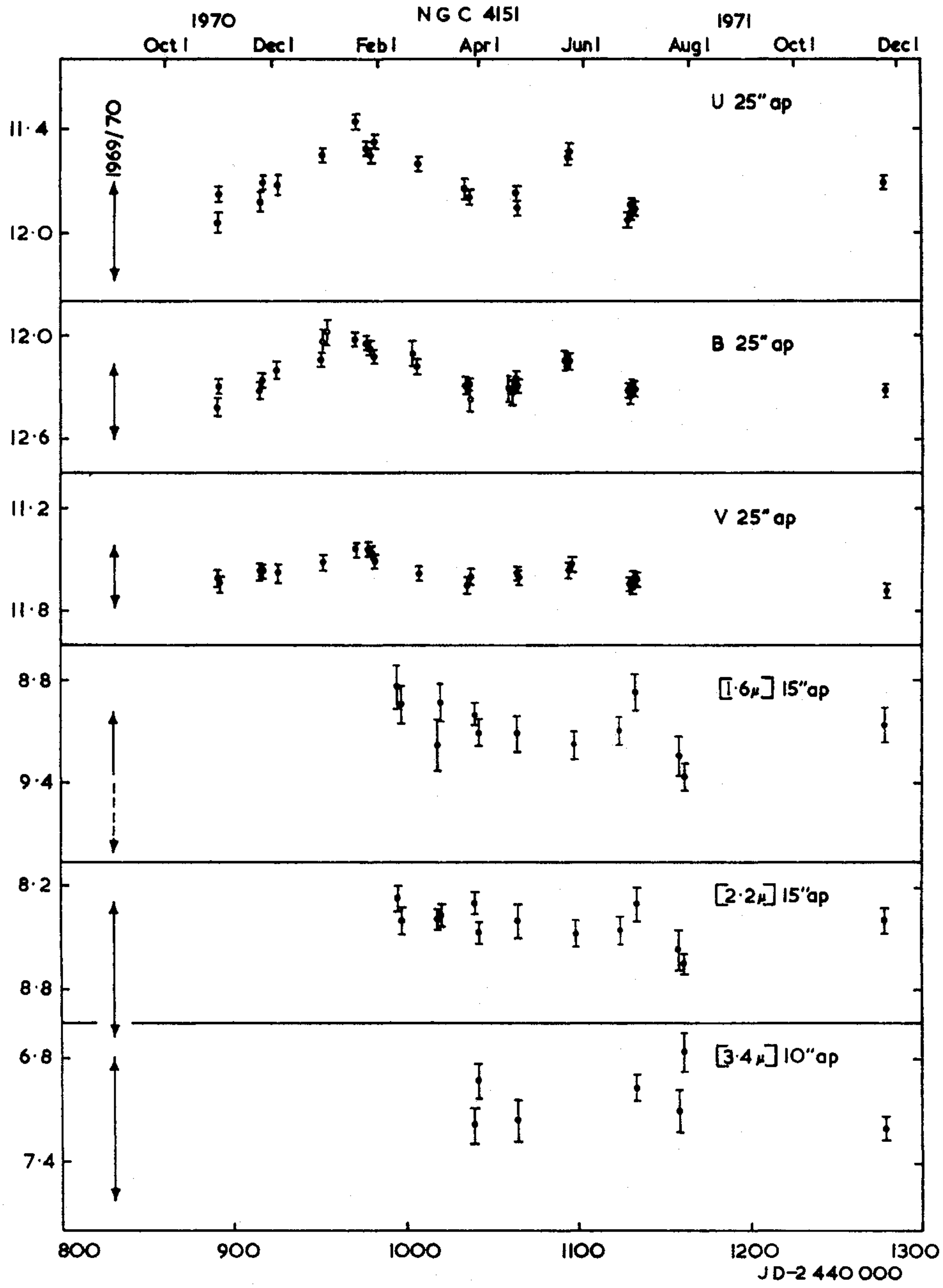

FIG. 1. *Light curves at six wavelengths of NGC* 4151. *In the B light curve, open circles represent photographic observations from which* 0·3 *mag has been arbitrarily subtracted. Arrows at the left-hand side of the diagram give the range of variations reported by PPNTBV.*

3C 120

For this object no *UBV* photoelectric photometry is presented here but Fig. 2 presents photographic and infrared light curves over a 4-yr interval 1967–71. Fig. 2 shows that the galaxy is variable in m_{pg} by 0·8 mag.

In contrast there is no evidence of variability of 3C 120 in the infrared since the root mean square dispersions of the observations about mean values of $[1{\cdot}6\,\mu] = 11{\cdot}02$ and $[2{\cdot}2\,\mu] = 9{\cdot}94$ mag, are 0·11 mag in both cases. These are comparable with root mean square values of the standard errors of 0·14 and 0·10, respectively. Before it is concluded however that the optical and infrared light curves are really different, it should be stressed again that the optical and infrared observations were not usually made at the same time. In fact the best documented instance of different behaviour in the optical and infrared is in late 1970 when an increase in m_{pg} of 0·3 mag occurred when the infrared observations do not allow an increase of more than about 0·1 mag. This optical increase was also observed photoelectrically by Lyutuj (1971b) although, as in NGC 1275 and NGC 7469, there is a zero-point difference in the magnitude scales. The difference of the m_{pg} and infrared light curves suggests that in this galaxy too the optical and infrared emission mechanisms are different.

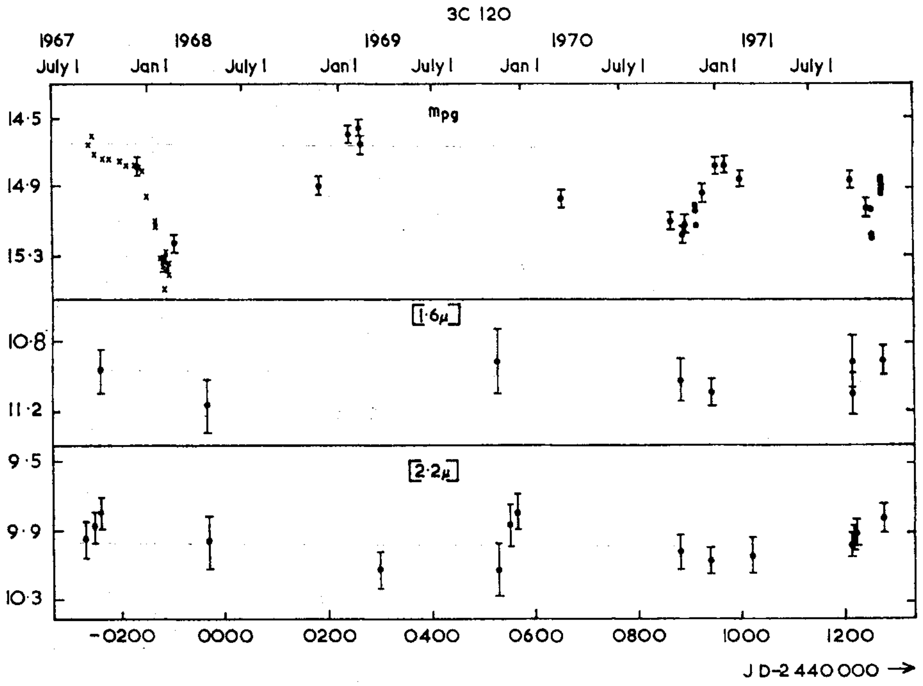

FIG. 2. *Light curves at three wavelengths of 3C 120. The photographic light curve includes results reported by Cannon et al.* (1971). *Overlapping error bars are omitted in a few cases. The crosses in the photographic light curve represent the results of Kinman* (1968).

NGC 1275 and NGC 7469

Light curves for these two galaxies are shown in Figs 3 and 4, respectively. The photographic and photoelectric results for NGC 1275 can be brought into good agreement if the photographic results are corrected by addition of a constant flux (the light from stars in NGC 1275 falling outside the effective aperture of the photographic measurements but inside the aperture of the *UBV* photometer). This result is extremely satisfactory and shows there are no systematic errors present in either type of observation. The optical light curve shows irregular activity with a time scale of a month. Variations are once again clearer in the bluer colours but the changes are quite apparent at *V*. Observations by Lyutuj (1971b), while again systematically brighter than ours, confirm the first maximum.

In the optical curves of NGC 7469, the correction of the photographic measures

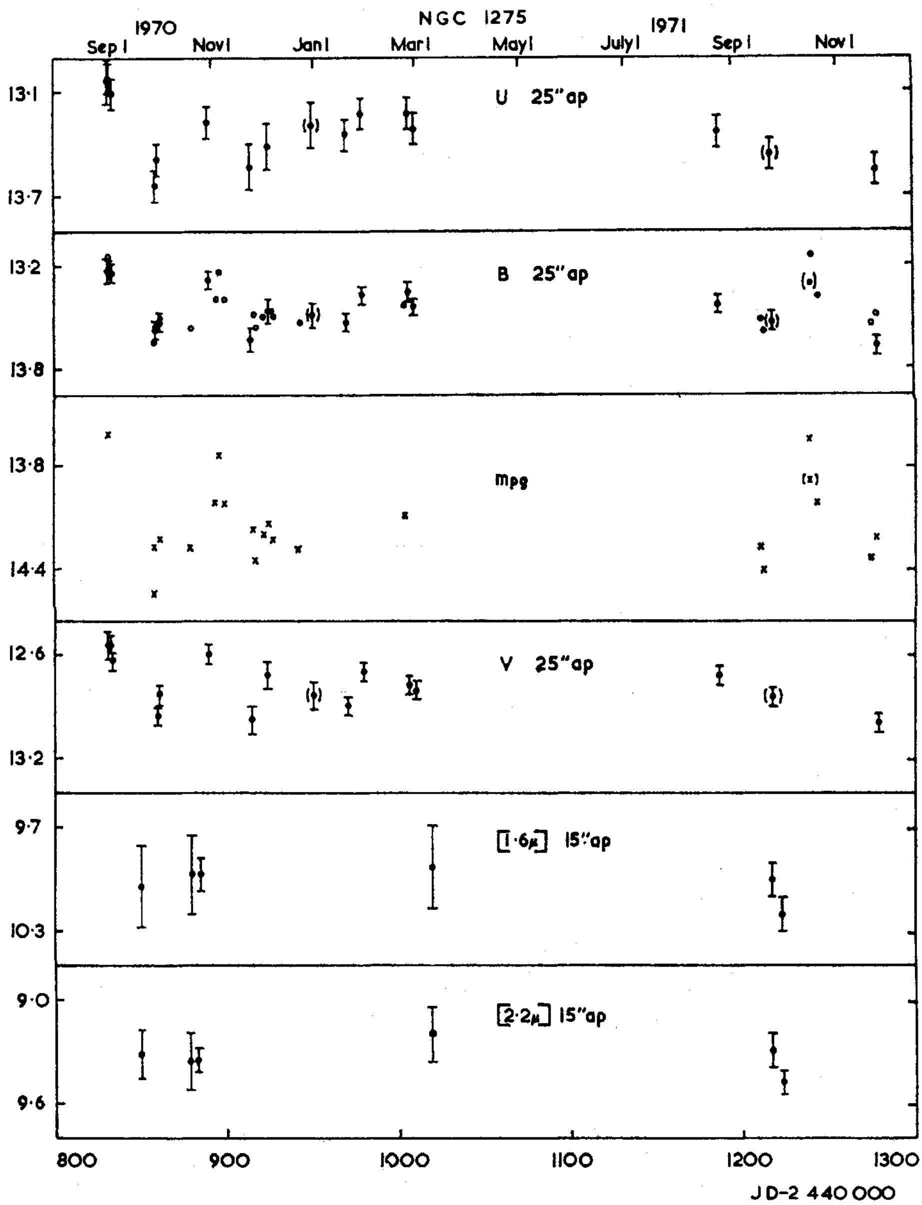

FIG. 3. *Light curves at six wavelengths of NGC* 1275. *In the B light curve, open circles represent photographic values when corrected by the addition of a constant flux equivalent to that of a star with B* = 14·25. *Doubtful observations are bracketed.*

by the addition of a constant flux is again applied.* In this case there is weaker evidence for optical variability. Except for *UBV* data taken on 1970 December 29–30 which are fainter in all colours and which cannot be easily explained as a centring error because the larger aperture data show the same effect, only subtle variations of order 0·1 mag seem to have occurred. There is some evidence however of a change of this order between the 1970 and 1971 observing seasons. The *UBV* data of Sandage (1967) and de Vaucouleurs & de Vaucouleurs (1972b) although not

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* The more approximate procedure applied to NGC 4151 of a constant magnitude correction is justified in that case by the smaller fraction of the light attributable to the normal starlight from the central regions of that galaxy.

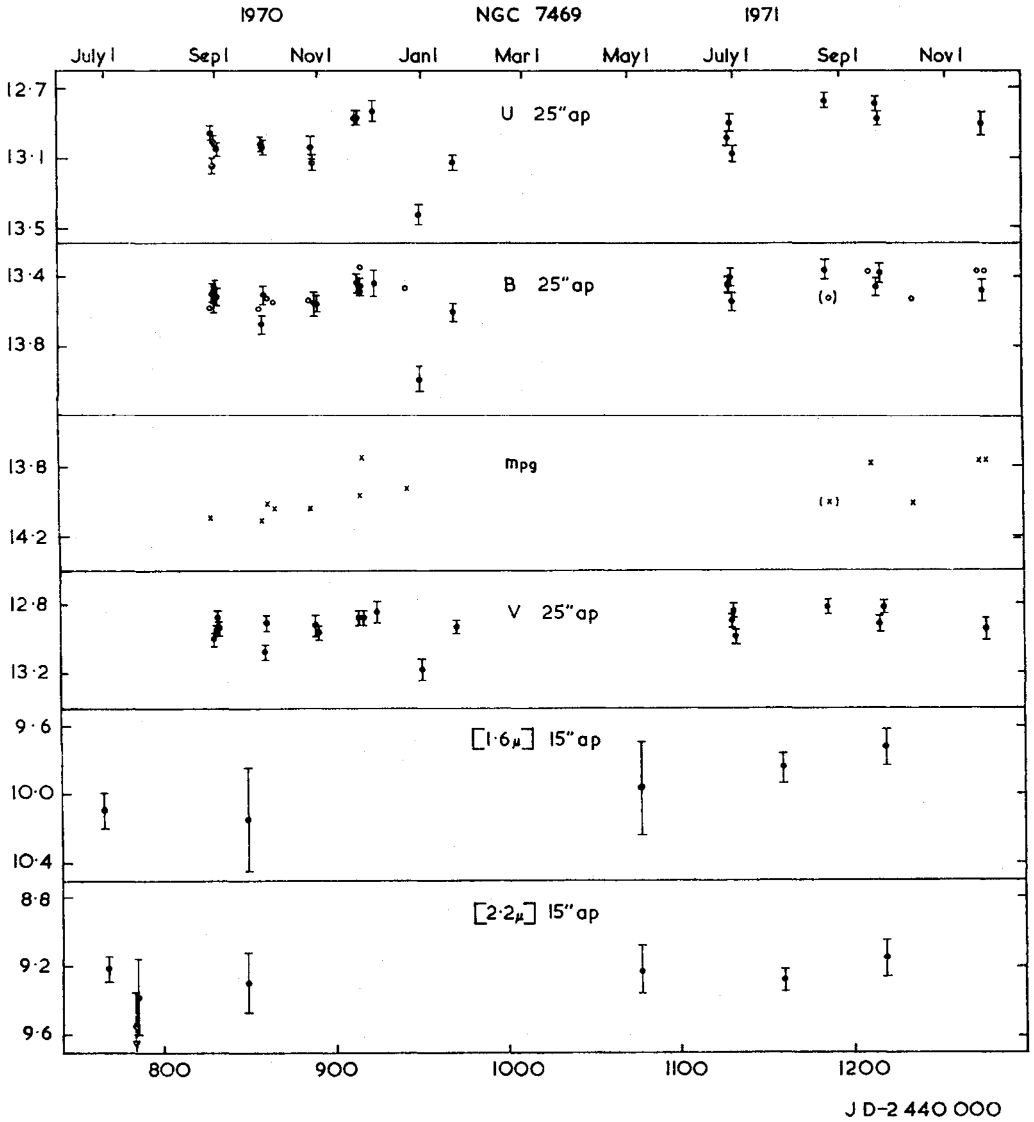

Fig. 4. *Light curves at six wavelengths of NGC* 7469. *Notation as Fig.* 3, *in this case the correction is by the addition of the flux of a star with B* = 14·6.

taken with the same diameter apertures apparently lie within the range of *UBV* magnitudes reported here.

Unfortunately the infrared observations of NGC 1275 and NGC 7469 are neither accurate nor numerous enough to cast much light on possible variability at these wavelengths. Both galaxies might either be constant at 2·2 μm or, equally well, vary in the infrared by the same range as they do in the optical region.

NGC 1068

None of the present observations in either optical or infrared show any sure sign of variability in this object and therefore no light curves are shown here. Table VI however summarizes the way in which this non-variability can be exhibited. The root mean square residuals from the mean magnitudes observed in *UBV* on the 20-in. telescope through the 25-arcsec diameter aperture are compared with the root mean square errors. The root mean square residuals and errors are similarly given for the m_{pg} magnitudes observed at Herstmonceux.

Finally, Table VI also contains the root mean square (rms) residuals of the infrared magnitudes for a 15-arcsec aperture, found if necessary by interpolation or extrapolation.

These values of the rms residuals can again be compared with the rms error in each colour. It is seen that any variations must be very small, in *UBV* they are certainly less than 0·05 mag rms and for m_{pg}, [1·6 μ], [2·2 μ] and [3·4 μ] less than about 0·1 mag rms. It is interesting to note that because the photographic magnitudes refer to a smaller angular diameter, the limits placed on the variability of the nucleus alone by the *B* and m_{pg} results are comparable.

TABLE VI

Limits on variability of NGC 1068

Colour	Aperture (arcsec)	No. of Obs	Mean	Rms residual	Rms standard error
U	25	21	11·36	0·05	0·04
B	25	21	11·28	0·05	0·04
V	25	21	10·44	0·04	0·05
m_{pg}*†	—	22	12·52	0·10	~0·1
[1·6 μ]	15	15	7·94	0·11	0·09
[2·2 μ]	15	17	7·28	0·10	0·08
[3·4 μ]	15	10	5·35	0·12	0·11

* One discrepant observation omitted.
† Includes data from Cannon *et al.* (1971).

Comparison of our *UBV* magnitudes with those of Sandage (1967) and de Vaucouleurs & de Vaucouleurs (1972b) also show no variation after allowance is made for the different apertures used. The *V* photometry of Smith *et al.* (1972) seems systematically fainter but agreement in *U* and *B* suggests this is a systematic difference affecting that band alone. The *U* magnitude of Lyutuj (1971a) is too bright by about 0·1 mag to fit the present data but since systematic differences in the same sense have been noted in his observations of other objects this probably does not denote variability either.

NGC 3227, NGC 3516, NGC 4051 and NGC 5548

The other galaxies were not observed so systematically and little can be said about their variability from the present results alone. However, comparison with the *UBV* data of others gives more information to tackle this question.

In the case of NGC 3227, the only published data against which to make a comparison is that of de Vaucouleurs & de Vaucouleurs (1972b). The present data agree with their observations of 1968.

NGC 3516 has already been established as a variable by Lyutuj (1971a) and de Vaucouleurs (1972a). The present observations agree with Lyutuj's in showing a fading in *U* between 1970 November and 1971 January. His zero-point difference is again present in the same sense as for the other objects. The 1970–71 observations reported here place NGC 3516 at the level found by the de Vaucouleurs in *V* in 1972 and in *U* lies intermediate between their 1968 and 1972 values.

For NGC 4051, comparison with the observations of de Vaucouleurs & de Vaucouleurs (1972b) places the galaxy fainter by about 0·2 mag in *V* and 0·35 mag in *U* when observed for this programme. There is also a suggestion that the galaxy

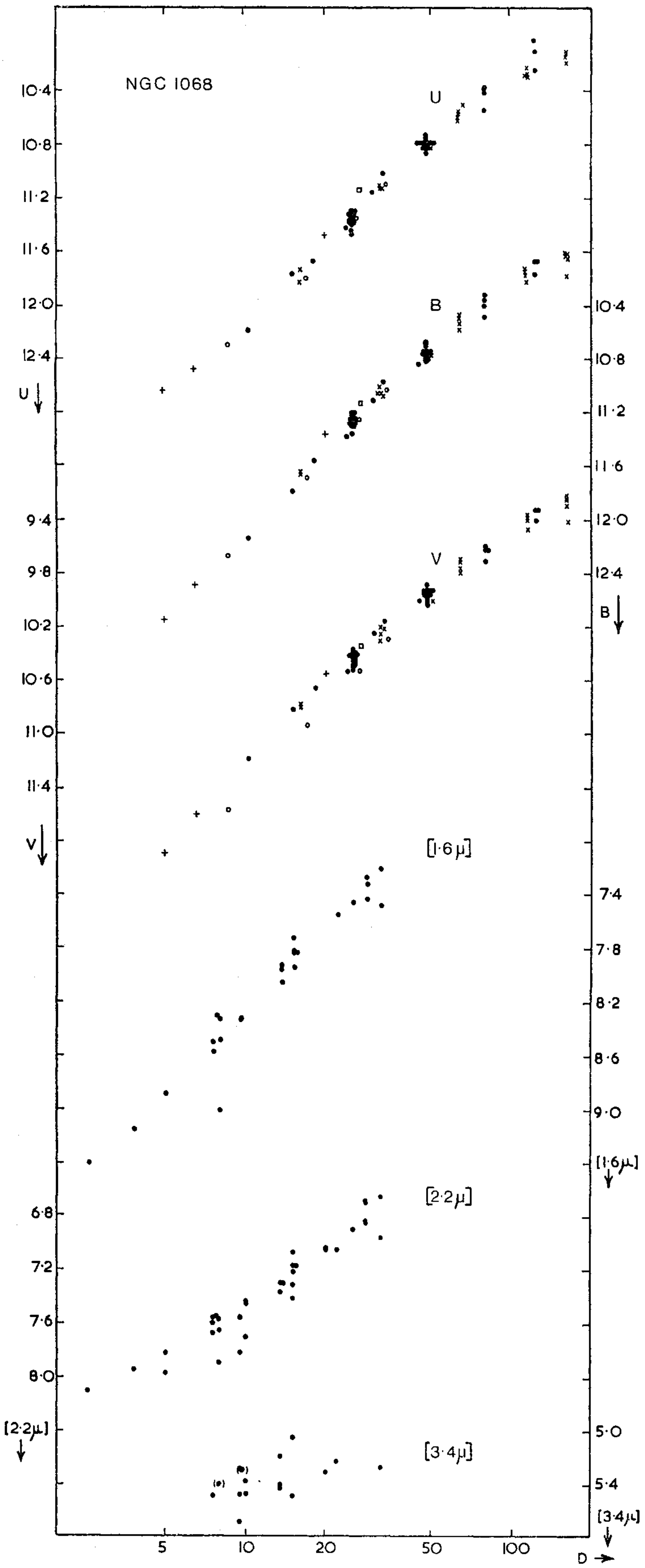

Fig. 5. *Magnitudes of NGC* 1068 *plotted against observing diameter in UBV,* [1·6 μ], [2·2 μ] *and* [3·4 μ]. *Points are this paper's data, pluses, squares, circles and crosses represent the results of Sandage* (1967), *Lyutuj* (1971*a*), *Smith et al.* (1972) *and de Vaucouleurs & de Vaucouleurs* (1972*b*) *respectively. Less accurate points are bracketed.*

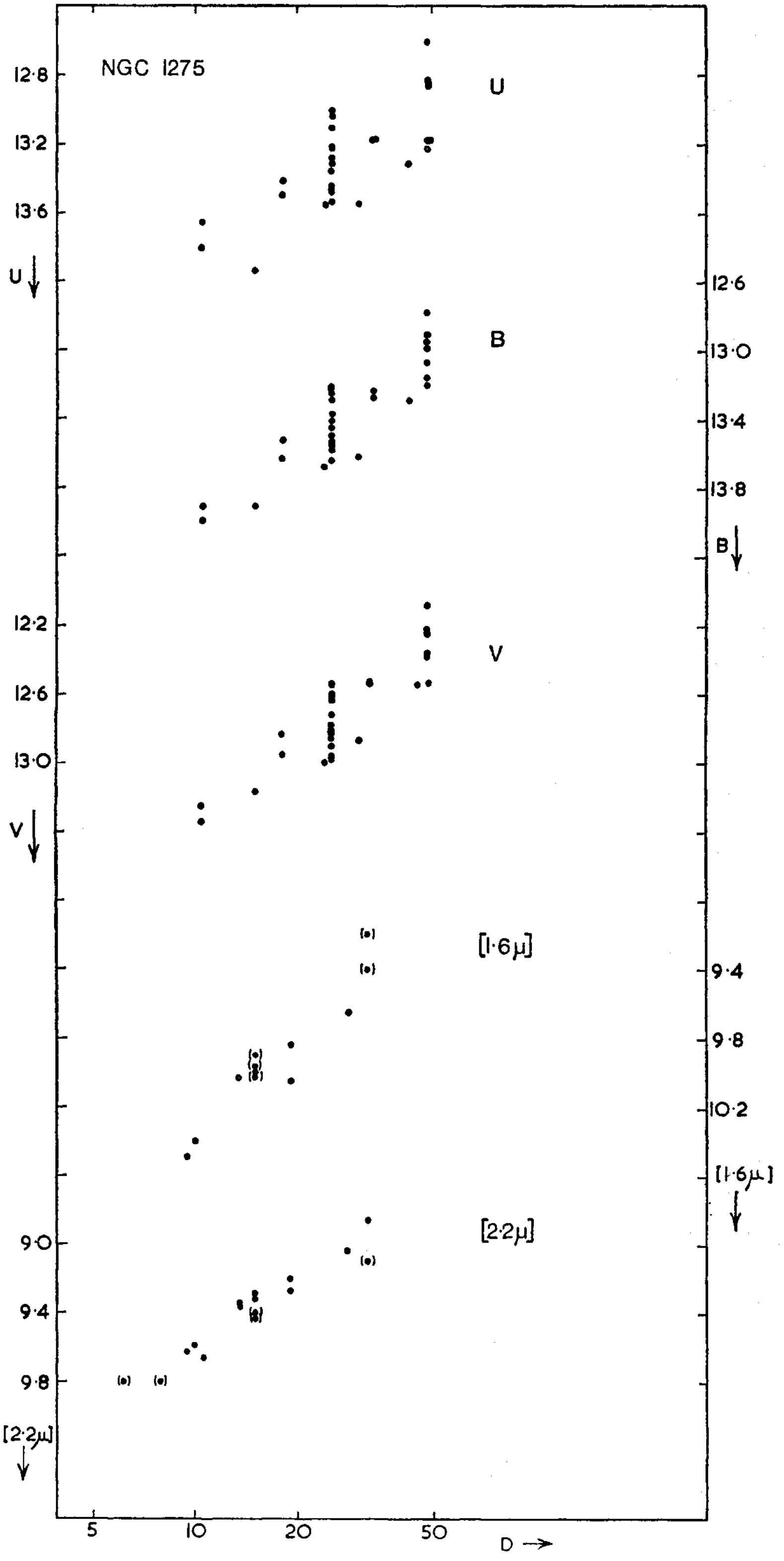

FIG. 6. *Magnitudes of NGC 1275 plotted against observing diameter in UBV,* [1·6 μ] *and* [2·2 μ]. *Notation as Fig.* 5.

was brighter in *U* when observed by Sandage (1967). This result adds NGC 4051 to the growing list of variable galaxies.

De Vaucouleurs & de Vaucouleurs (1972a) have also established the variability of NGC 5548. The present observations made in early 1971 agree well with the de Vaucouleurs' *V* data from 1971–72 but are possibly slightly fainter by 0·05 mag in *U*.

The infrared observations of these galaxies show no sign of variability except possibly in the case of the 2 μ observations of NGC 5548. Even for this object, the case for variability is very weak however.

NGC 2782 and NGC 6814

For the last two galaxies NGC 2782 and 6814, only infrared observations are presented. NGC 2782 indeed shows an infrared excess as is confirmed by the

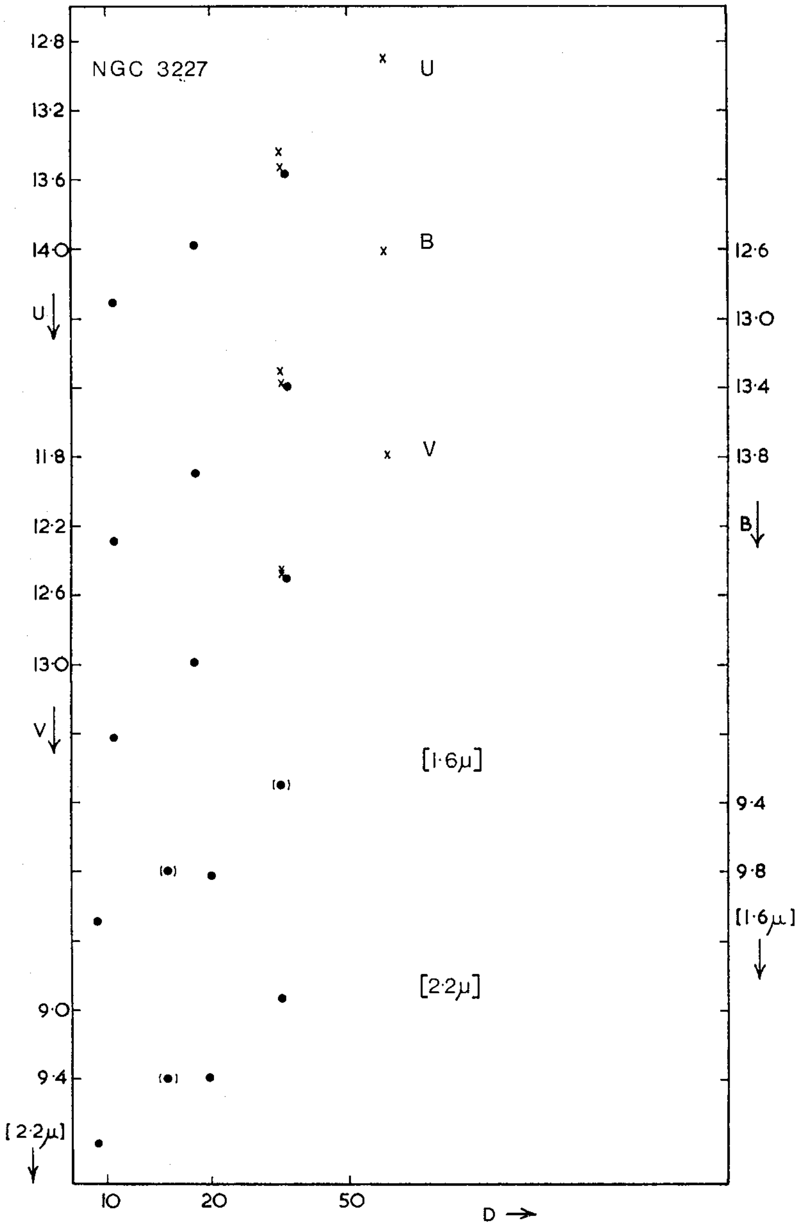

FIG. 7. *Magnitudes of NGC* 3227 *plotted against observing diameter in UBV*, [1·6 μ] *and* [2·2 μ]. *Notation as Fig.* 5.

10 μ observations of Rieke & Low (1972a). It also shows an ultraviolet excess (de Vaucouleurs & de Vaucouleurs 1972b). By contrast observations of NGC 6814 show no strong infrared excess nor is any such seen by Rieke & Low at 10 μm. Neither does this galaxy show an ultraviolet excess according to the de Vaucouleurs data. Thus the classification of NGC 6814 as a Seyfert galaxy must still be in some doubt. MacPherson (1972) on the other hand reported variability in this object—in view of the lack of well-authenticated variability in normal galaxies, however, this result needs confirmation.

4. SPATIAL DISTRIBUTION

In order to investigate the spatial distribution of the light from Seyfert galaxies the data of Table I are presented in Figs 5–12 in the form of plots of magnitude against the logarithm of observing aperture diameter. Where appropriate similar

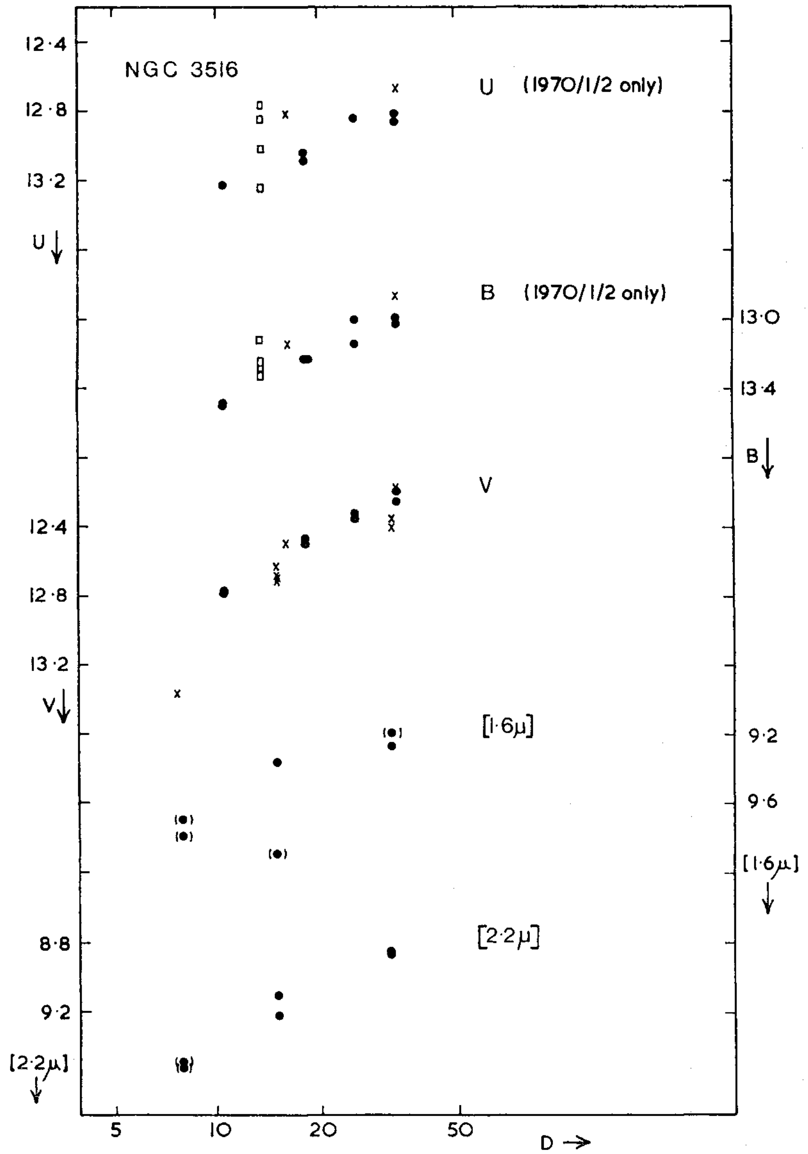

FIG. 8. *Magnitudes of NGC* 3516 *plotted against observing diameter in UBV*, [1·6 μ] *and* [2·2 μ]. *Because of the variability of this galaxy only the U and B data from* 1970 *to* 1972 *are plotted. Notation as Fig.* 5.

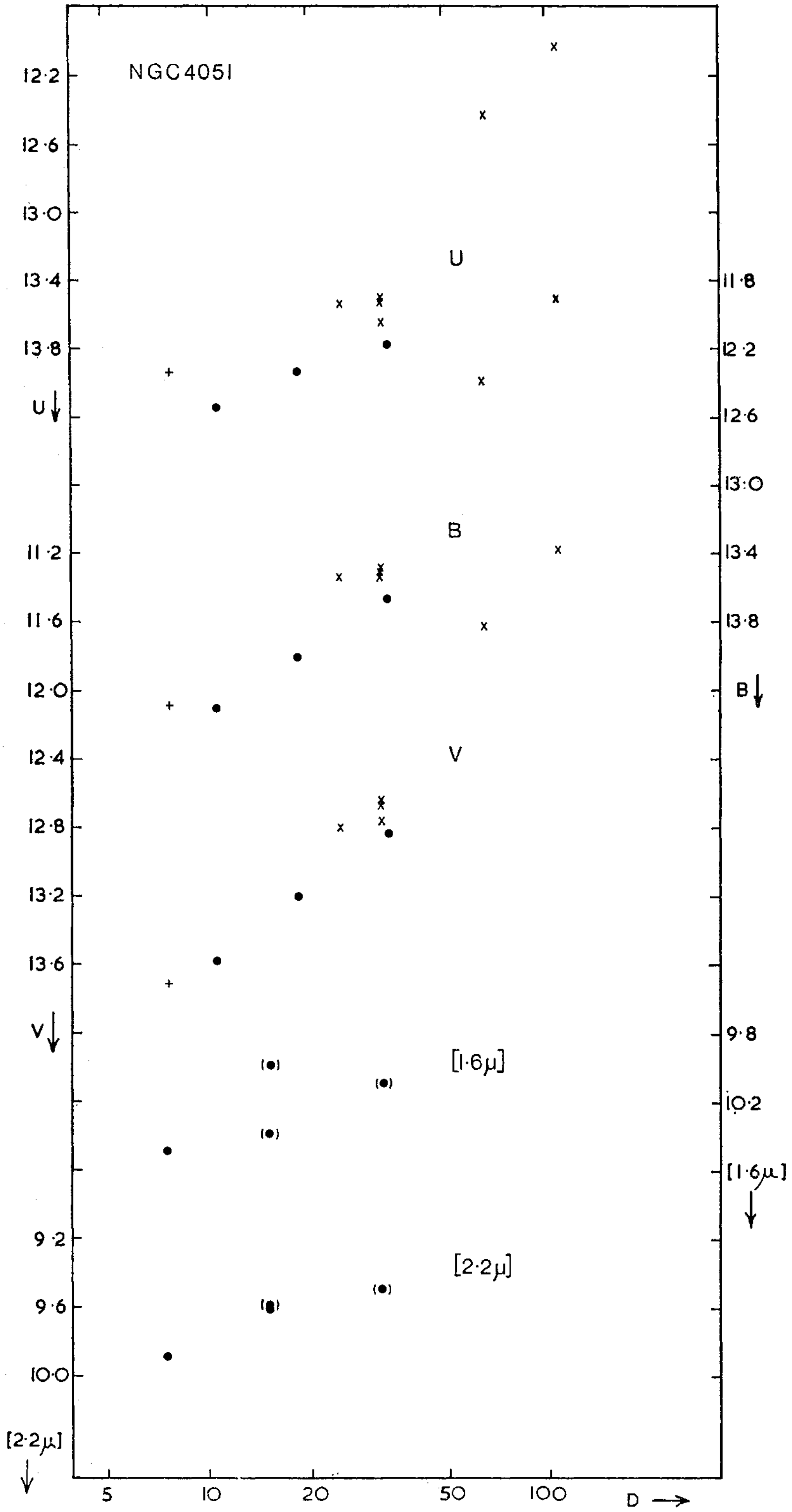

FIG. 9. *Magnitudes of NGC* 4051 *plotted against observing diameter in UBV,* [1·6 μ] *and* [2·2 μ]. *Notation as Fig.* 5.

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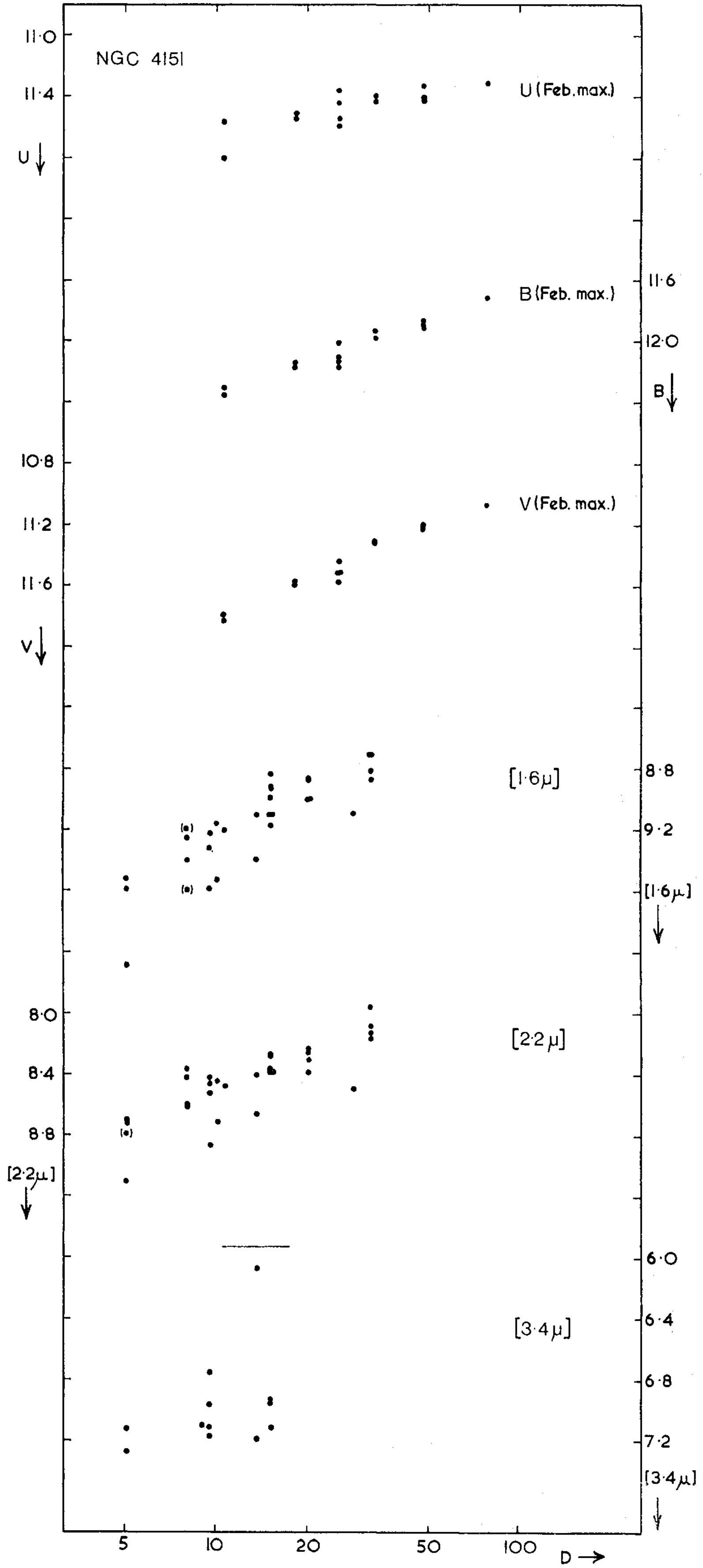

FIG. 10. *Magnitudes of NGC* 4151 *plotted against observing diameter in UBV,* [1·6 μ], [2·2 μ] *and* [3·4 μ]. *Because of the variable nature of the galaxy only the UBV data taken between* 1970 *December* 3 *and* 1971 *February* 24 *are plotted. Notation as Fig.* 5.

UBV data from other observers have been included. For some objects part of the scatter in these plots is caused by the variability; in the cases of NGC 3516, 4151 and 5548 the figures include only data taken at a limited range of epochs. The way in which the magnitude–diameter curves change as NGC 4151 varies is discussed in PPNTBV.

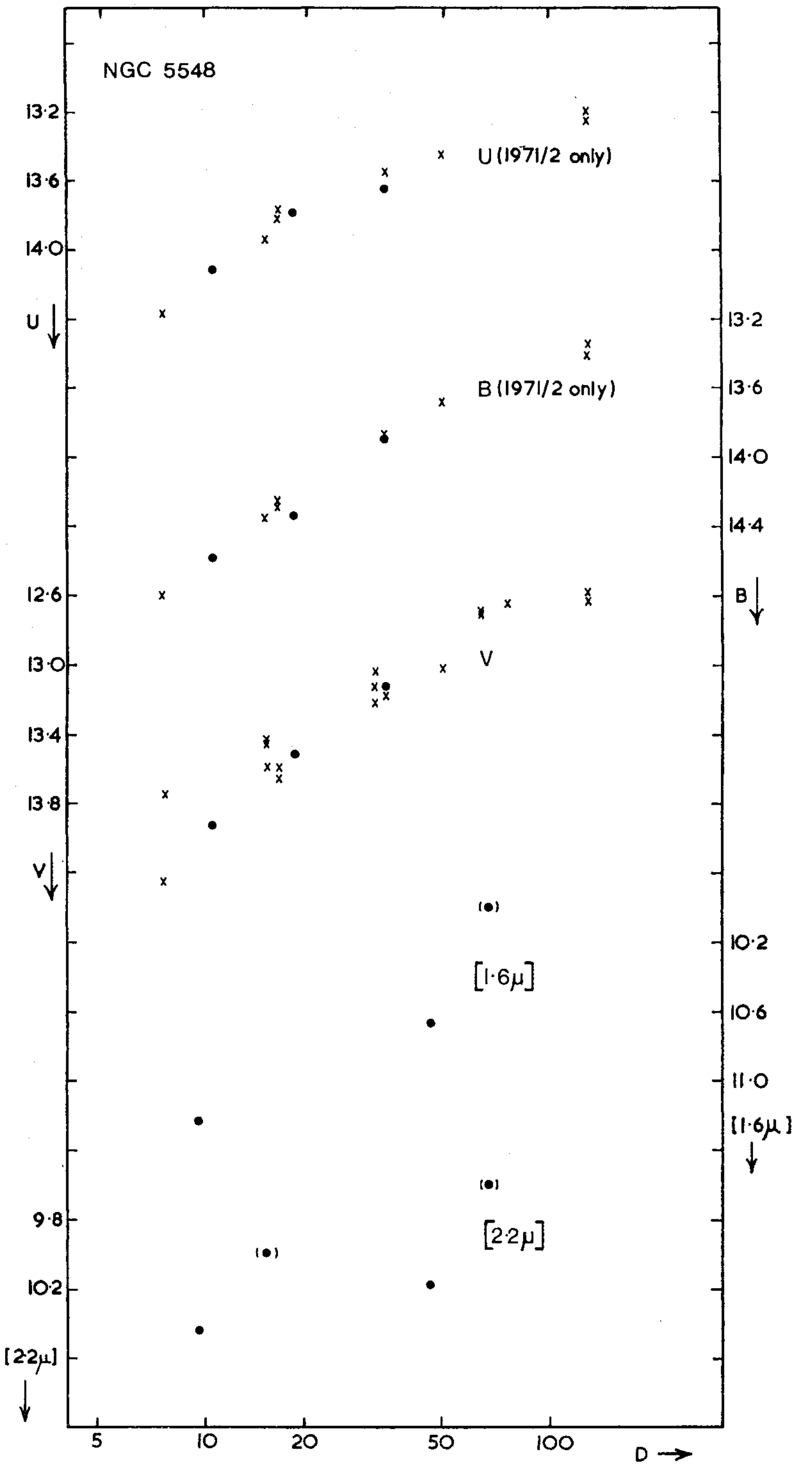

FIG. 11. *Magnitudes of NGC* 5548 *plotted against observing diameter in UBV*, [1·6 μ] *and* [2·2 μ]. *Because of the variability of this galaxy only the U and B data from* 1971 *are plotted. Notation as Fig.* 5.

The agreement with other observers is in general good in the light of what is known about the variability of the Seyfert galaxies but Fig. 9 shows sufficient scatter in the magnitude–diameter plots of NGC 4051 to support the suggestion noted in the last section that this galaxy is a hitherto unannounced variable.

All the galaxies show clear signs of increasing brightness with increasing aperture diameter in all the colours discussed here. It is thus important that photometry of these extended objects be reported with the appropriate aperture size certainly for all wavelengths short of 3·4 μ. On the other hand for each object there is a wide range in the slope of the magnitude–diameter relationships for different wavelengths. These slopes are presented in Table VII in the form of the difference between magnitudes appropriate to 10- and 20-arcsec apertures for each

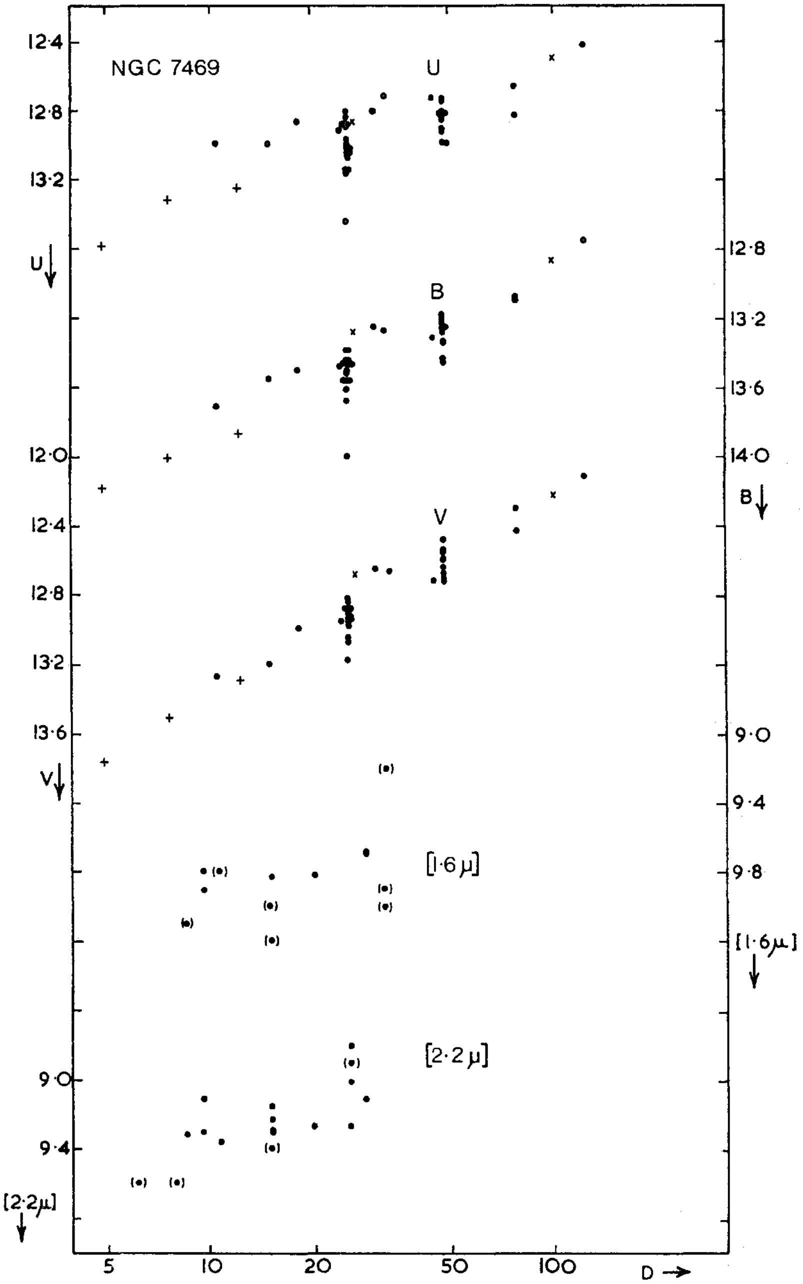

FIG. 12. *Magnitudes of NGC 7469 plotted against observing diameter in UBV,* [1·6 μ] *and* [2·2 μ]. *Notation as Fig.* 5.

object and each colour. These differences are deduced from magnitudes interpolated from Figs 5 to 12. Because some galaxies have been observed more than others there is a wide range in the accuracy of these differences.

Inspection of Table VII shows that in general, the magnitude–diameter plots for a given galaxy are flatter in U than in B and flatter in B than in V. The only exception to this trend is NGC 1068 which is known to show considerable colour variations over the extra-nuclear regions of the galaxy (Smith *et al.* 1972).

TABLE VII

Mean difference in magnitude between 10- *and* 20-*arcsec apertures* (*i.e. the slope of the magnitude–diameter plots*)

Galaxy	ΔU	ΔB	ΔV	$\Delta[1{\cdot}6\ \mu]$	$\Delta[2{\cdot}2\ \mu]$	$\Delta[3{\cdot}4\ \mu]$
NGC 1068	0·60	0·65	0·60	0·61	0·43	0·2::
1275	0·33	0·44	0·44	0·55	0·43	
3227	0·43	0·51	0·55	0·39:	0·37:	
3516	0·22	0·31	0·37	0·3::	0·34	
4051	0·27	0·37	0·47	0·3::	0·15:	
4151	0·15	0·19	0·28	0·28:	0·20:	0·1::
5548	0·34	0·40	0·49	0·3::	0·2::	
7469	0·17	0·27	0·33	0·1::	0·13:	

Values less accurate than ~0·05 mag are characterized by a colon those less accurate than ~0·15 mag by a double colon.

As is also apparent in Table VII, in the infrared the magnitude–diameter plots for a given galaxy are flatter at the longer wavelengths. Thus it may be concluded that the infrared and ultraviolet excesses in these galaxies are produced by a source primarily or wholly within the nucleus of the galaxy (PPNTBV; Neugebauer *et al.* 1971; de Vaucouleurs & de Vaucouleurs 1972b).

How small one can say the nuclear source is depends on the smallest observing aperture used. In most cases this limit is 10-arcsec diameter but for NGC 4151 and 1068 limits of 5 and 3 arcsec, respectively apply. The 10-μm nucleus of NGC 1068 has a diameter of order 1 arcsec (Becklin *et al.* 1973b). In the case of NGC 4151 there is a further limit on the size of the infrared emitting regions because of the variability.

In summary, it seems that the decomposition into a nuclear source showing ultraviolet and infrared excesses plus an extended source with normal galaxy colours, proposed in the case of NGC 4151 by PPNTBV, can be extended generally to all Seyfert galaxies.

5. SPECTRAL DISTRIBUTION

The data in this paper are well suited for a further examination of the view that the peculiar colours of the nuclei of Seyfert galaxies are caused by underluminous quasars harboured in the nuclei of these galaxies.

Table VIII gives the colours of the emission from both the inner 10- and 20-arcsec diameter regions of the galaxies under study, after correction for the effects of reddening in our own galaxy. It has been assumed that the visual absorption $A_V = 0{\cdot}15$ cosec b^{II} magnitudes, where b^{II} is the galactic latitude of the galaxy and that the extinction is related to the absorption by

$$A_V\colon E_{U-B}\colon E_{B-V}\colon E_{[1\cdot6\mu]-[2\cdot2\mu]}\colon E_{V-[2\cdot2\mu]}\colon E_{[2\cdot2\mu]-[3\cdot4\mu]} = 1\cdot00\colon 0\cdot25\colon 0\cdot33\colon 0\cdot04\colon 0\cdot90\colon 0\cdot04$$

This extinction follows approximately the van der Hulst No. 15 law (1949). The corrected colours show the characteristic ultraviolet and infrared excesses noted in the last section. It is interesting to note however that large infrared colours are not confined to Seyfert galaxies and there exist galaxies without Seyfert characteristics with large infrared colours (Becklin *et al.* 1971; Rieke & Low 1972a; Becklin *et al.* 1973a; Glass 1973).

TABLE VIII

Interpolated unreddened colours in 10- and 20-arcsec apertures

NGC number	Diam. (arcsec)	$(U-B)_0$	$(B-V)_0$	$([1\cdot6\ \mu]-[2\cdot2\ \mu])_0$	$(V-[2\cdot2\ \mu])_0$	$([2\cdot2\ \mu]-[3\cdot4\ \mu])_0$
1068	10	−0·01	0·87	0·74	3·54	2·06:
	20	+0·04	0·82	0·56	3·27	1·82:
1275	10	−0·38	0·42	0·71	3·10	
	20	−0·27	0·42	0·59	3·09	
3227	10	−0·05	0·81	0·32	3·58	
	20	+0·03	0·85	0·30	3·14	
3516	10	−0·33	0·65	0·23:	3·18	
	20	−0·24	0·71	0·29:	3·15	
4051	10	−0·22	0·67	0·51:	3·64	
	20	−0·16	0·77	0·5::	3·40	
4151	10	−0·69	0·46	0·71	3·17	1·54:
	20	−0·65	0·55	0·63	3·09	1·3::
5548	10	−0·52	0·61	0·8::	3·4::	
	20	−0·46	0·70	0·7::	3·1::	
7469	10	−0·77	0·37	0·63	3·81	
	20	−0·67	0·43	0·63	3·61	

If the fluxes observed in the 20- and 10-arcsec apertures are subtracted, the colours of the emission from the resulting annulus (where they can be reliably obtained) are roughly those of normal galaxies. In the case of NGC 1275 which has an A-type spectrum (Minkowski 1968) they correspond to a galaxy with $B-V \sim 0\cdot4$ mag (similar to the nucleus of M33). For all the other galaxies however the colours of the annuli, where accurate, are redder than this and resemble those observed in the nucleus of M32 (Penston 1973).

Fig. 13 is the $(U-B, B-V)$ two-colour diagram plotting the appropriate colours from Table VIII. With the exception of NGC 1275 the points lie close to a line representing a mixture of ‘ quasar ’ light with colours $U-B = -1\cdot0$, $B-V = 0\cdot0$ and ‘ galaxy ’ light with $U-B = 0\cdot4$ and $B-V = 0\cdot9$. In all cases the points, representing the colours observed in the 10-arcsec aperture, lie nearer the quasar end of the curve than do those for the 20-arcsec aperture. NGC 7469, 4151 and 5548 lie in the same region as the quasars, while NGC 3227 and 1068 fall closer to the normal galaxies. NGC 1275 lies away from this line in the manner expected if the underlying galaxy is as blue as is indicated by the colours of the annulus mentioned above. These results are in essence identical to those obtained by Weedman

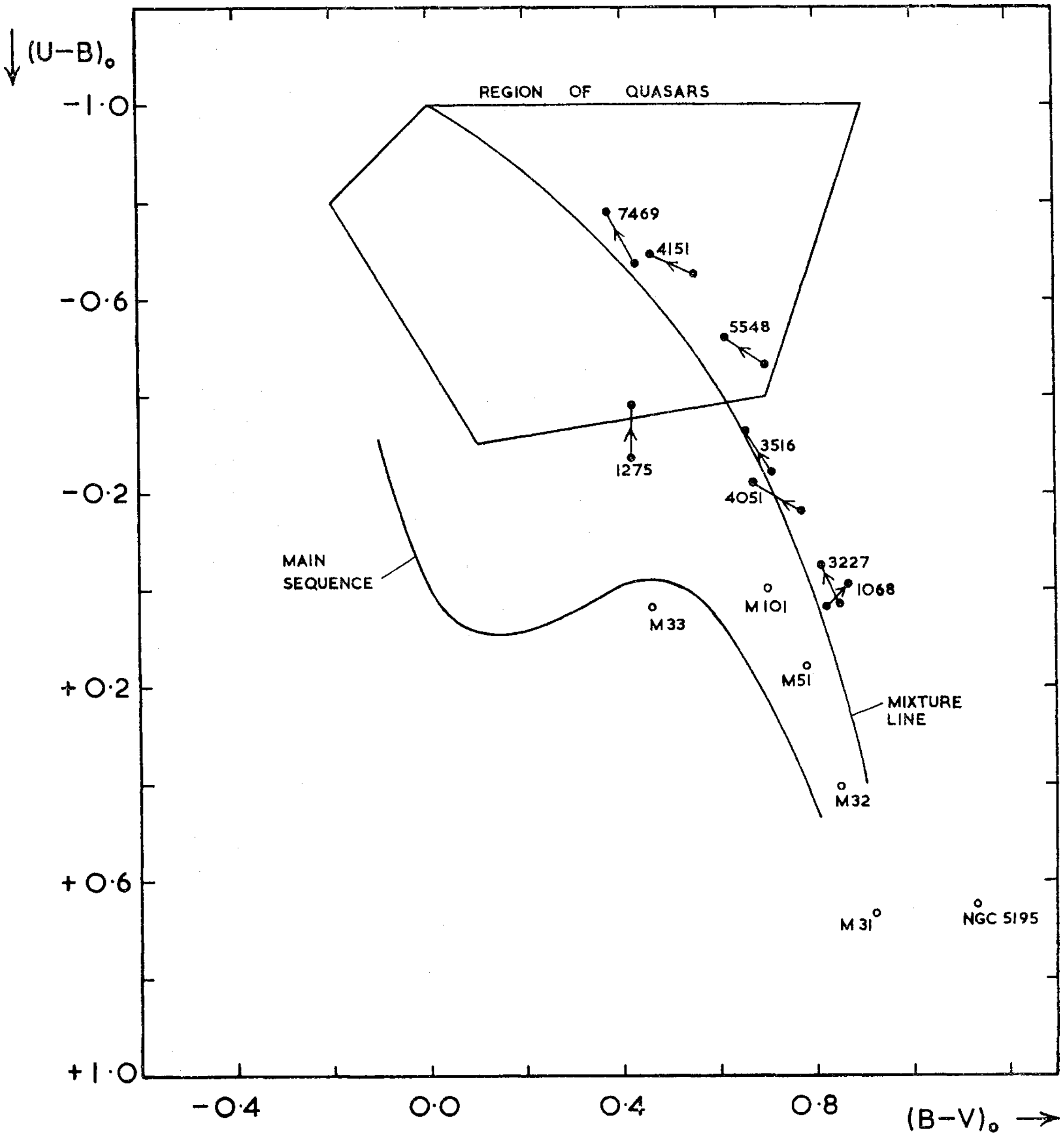

FIG. 13. *The two-colour* (U–B, B–V) *diagram for the nuclei of Seyfert galaxies corrected for reddening in our own galaxy. Closed circles appropriate to* 10- *and* 20-*arcsec diameter apertures are plotted for each object joined by an arrow pointing towards the smaller aperture. The colours of a few normal galaxies from Penston* (1973) *are plotted as open circles. The region occupied by the quasars is marked, as is the main-sequence locus. The 'mixture line' traces the positions accessible to a mixture of light with* U–$B = -1{\cdot}0$, B–$V = 0{\cdot}0$ *and with* U–$B = 0{\cdot}4$, B–$V = 0{\cdot}9$; *all the Seyferts except for NGC* 1275 *fit this line well.*

(1973). The optical colours are therefore quite consistent with the presence of an underluminous quasar in the nuclei of the galaxies.

Following a procedure analogous to the 'colour-given' method of Sandage (1973) will enable the magnitudes and colours of the nuclear sources alone, and in particular their infrared properties, to be determined. The mixture line in Fig. 13 may be parametrized by the proportion of light contributed by this nuclear source. This parameter permits the computation of the optical magnitudes of the underlying galaxy, from which the infrared flux of the galaxy may be inferred. Hence by

TABLE IX

Assumed colours for 'colour-given' method

	$(U-B)_0$	$(B-V)_0$	$([1{\cdot}6\,\mu]-[2{\cdot}2\,\mu])_0$	$(V-[2{\cdot}2\,\mu])_0$	$([2{\cdot}2\,\mu]-[3{\cdot}4\,\mu])_0$
NGC 1275	−0·01	0·42	0·2	2·0	
Other galaxies	0·4	0·9	0·2	2·9	0·2
Nuclear source	−1·0	0·0			

subtraction from the observed value, one obtains the infrared flux of the nuclear source.

To use the colour-given method, colours of the underlying galaxy must be assumed. These are given in Table IX and are based on the observed colours of M32 or, in the case of NGC 1275, those of M33. Also one must pick at least one colour for the nuclear source. By picking both $U-B$ and $B-V$ to be those of the bluest[*] (i.e. least contaminated) quasars, one obtains two estimates for the proportion of, for instance, blue light contributed in the 10-arcsec aperture by the nuclear source. These two values may be averaged to give a best estimate for the ratio of nuclear source to total light, R. Using the optical colours for the nuclear source listed in Table IX, Table X gives the value of R for a 10-arcsec aperture and of R_c corrected to a projected 3-kpc aperture.

TABLE X

Proportion of blue light in 10-*arcsec aperture from nuclear source*

Object	1068	1275	3227	3516	4051	4151	5548	7469
R	0·11	0·28	0·16	0·37	0·32	0·64	0·46	0·72

Proportion of blue light in projected 3-*kpc aperture from nuclear source*

Object	1068	1275	3227	3516	4051	4151	5548	7469
R_c	0·045	0·38	0·075	0·35	0·15	0·48	0·59	0·86

TABLE XI

Colours of nuclear components

Name	$(U-B)_0$	$(B-V)_0$	$([1{\cdot}6\,\mu]-[2{\cdot}2\,\mu])_0$	$(B-[2{\cdot}2\,\mu])_0$	$([2{\cdot}2\,\mu]-[3{\cdot}4\,\mu])_0$
1068	−1·4:	0·6::	1·9:	6·0:	2·7:
1275	−1·0:	0·4:	1·0	4·6	1·6::
3227	−1·2:	—	0·5	5·5:	
3516	−1·0	0·0:	0·3::	3·8	
4051	−0·9	0·0:	0·8:	4·9	1·6::
4151	−1·0	0·1	1·3:	3·5	1·9:
5548	−1·1	0·1:	1·7::	4·2::	
7469	−1·1	0·1	0·8	4·3	1·3::

The proportion of blue light from the nuclear source within a 10-arcsec aperture varies from as low as 11 per cent for NGC 1068 to 72 per cent for NGC 7469.

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[*] Changing the colours assumed for the nuclear source has only a small effect on the results which follow. For example if $U-B$ and $B-V$ are picked to be those of an average quasar, the resulting values of R (Table X) increase by a uniform factor ~1·3 and the values of $(B-[2{\cdot}2\,\mu])_0$ (Table XI) increase by less than 0·3 mag.

These values have been deduced solely from the colours of the light emitted from the innermost 10 arcsec of the galaxy. An entirely independent check on this procedure can be constructed from the slopes of the magnitude–diameter plots as noted in the last section. Accordingly Fig. 14 plots as solid circles the values of ΔB (the slope of the B magnitude–diameter plot) against the deduced values of R. A correlation is found as expected since a dominant central source naturally implies a flatter growth of flux with observing aperture. On the other hand the open circles, which are the values of the slopes after subtraction of a nuclear source of the strength deduced by the colour-given method, show only a scatter diagram. This gives confidence to the values of R in Table X.

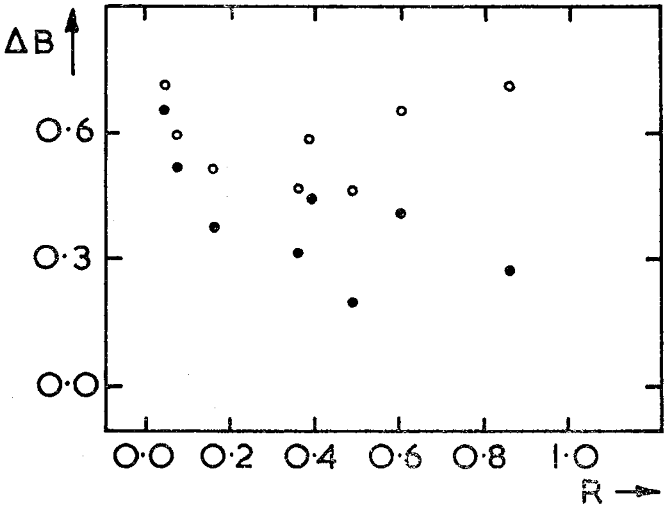

FIG. 14. *A plot of* ΔB *(the difference in blue magnitude between 10- and 20-arcsec apertures) against* R_C *(the proportion of blue light within a projected 3-kpc aperture emitted by the point source). The closed points are the observed values and show a good correlation, the open points are after subtraction of the light of the point source. The latter appear scattered and provide an independent check on the method of separating galaxy and point source.*

Using the values of R in Table X and the colours of the underlying galaxy listed in Table IX, the fluxes of the nuclear source in the Seyfert galaxies can be deduced at each wavelength including the infrared. The resulting colours of the nuclear components are given in Table XI and their energy distributions plotted in Fig. 15. For NGC 1068 and 3227, the derived visual flux of the nuclear source is much weaker than that of the underlying galaxy and its value is particularly sensitive to observational errors and to the assumed colours of the galaxies. Thus the B–[2·2 μ] colour is given in Table XI in preference to V–[2·2 μ]. Taking account of all the various sources of error shows however that except for the V magnitudes of these objects, errors are unlikely to exceed $\sim$0·3 mag in the colours of Table XI and are probably better than this in most cases.

The U–B and B–V colours of the nuclear source in Table XI have been imposed by the colour-given method and thus fall close to those initially assumed but the infrared colours are by contrast entirely unconstrained and derived quite freely.

It is interesting to note that in the nuclear sources the $([2{\cdot}2\ \mu]-[3{\cdot}4\ \mu])_0$ colour far exceeds $([1{\cdot}6\ \mu]-[2{\cdot}2\ \mu])_0$. The energy distribution in this spectral region therefore differs from that of a single blackbody for which these colours are approximately equal, but could be explained (Allen 1973) by a combination of two or more

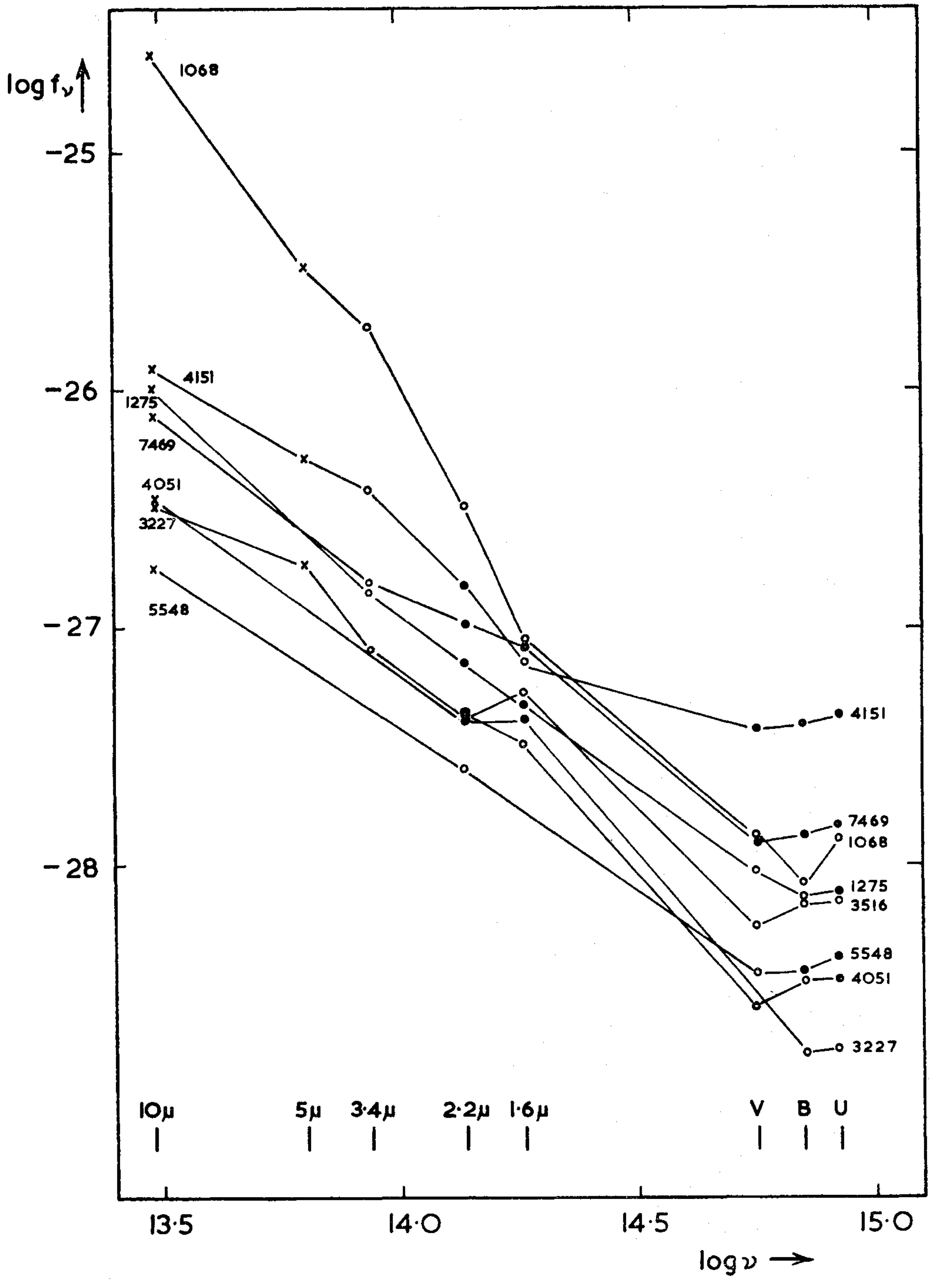

FIG. 15. *Energy distributions of the nuclear point sources in eight bright Seyfert nuclei. Circles mark the fluxes deduced for the point sources according to the method given in the text. Closed and open symbols mark more and less accurate results respectively. The long wavelength data of Rieke & Low* (1972*a*) *are plotted as crosses.*

blackbodies (i.e. a dust shell with a range of temperatures). It could also however be produced by some non-thermal radiation mechanism.

The steepness of the infrared energy spectrum of the nuclear source in NGC 1068 is striking compared with the other objects. This galaxy also differs from the others in the width of its permitted lines (Anderson 1970). The nucleus of NGC 1068 has been found to be extended at 10 μm (Becklin *et al.* 1973b) and shows no

2-μ variations. By contrast the 2-μ variability of NGC 4151 shows that in that galaxy there is a compact 2 μ component. In these ways NGC 1068 resembles non-Seyfert infrared galaxies such as NGC 253 and M82 (Rieke & Low 1972a), while the others show greater similarities to quasars (Oke, Neugebauer & Becklin 1970).

The scatter in the $([1{\cdot}6\ \mu]-[2{\cdot}2\ \mu])_0$ and $(B-[2{\cdot}2\ \mu])_0$ colours from nucleus to nucleus is in marked contrast to the homogeneity of the optical colours demonstrated in Fig. 15. This suggests the optical and infrared emission mechanisms are independent.

There is a correlation (significant at the 5 per cent level) of the $(B-[2{\cdot}2\ \mu])_0$ colours of the nuclei with R_c, the proportion of blue light contributed by the nucleus to a projected 3-kpc aperture. Nuclei weaker compared to their parent galaxies have redder colours. This correlation reflects the fact that the *observed* $(B-[2{\cdot}2\ \mu])_0$ colours of the combined nuclear and galaxy light cover only a small range in spite of a wide range in the proportion of blue light from the nucleus. One attractive suggestion for this effect is that nuclei faint in blue light are highly reddened. However, other observations do not support this picture, in particular such reddening would affect the $U-B$ and $B-V$ colours producing a poorer fit to the mixture line of Fig. 13 than is found. Moreover neither $(B-[2{\cdot}2\ \mu])_0$ for the nucleus nor R_c correlate with the reddening deduced from the Balmer decrements (Anderson 1970) or the infrared-to-blue sulphur line ratios (Wampler 1968).* No other explanation for this effect springs to mind and furthermore it should be noted that correlation appears only after the contaminating light of the galaxy has been removed.

6. CONCLUSIONS

The optical results of this study are in good accord with the presence of underluminous quasars in the nuclei of Seyfert galaxies. The colours can be well understood from the presence of objects with ultraviolet excesses characteristic of quasars in the nuclei, as Fig. 13 shows. Work by other authors suggests the spectra are also apparently related. To date all but two (NGC 1068 and 3227) of the nine major Seyferts discussed in this paper have been shown to be variable in the optical region. For the variability to be evident over the diluting effect of the radiation from stars in the Seyfert galaxies, the amplitudes must be larger than those typically found in quasars.

All the Seyfert nuclei studied have spectra that turn up towards the infrared. While such infrared excesses are present in all the objects studied, this is evidently a phenomenon not confined to the Seyfert class and most Seyferts have considerably weaker excesses than a number of optically more normal galaxies. Usually the infrared signal from the nucleus does not completely dominate the normal starlight emitted by the galaxies at wavelengths shortward of 3 μ.

NGC 4151 has been found to show correlated variations on a 1 yr time scale between the short wavelength infrared and the optical; more work is needed on other galaxies. What is known about the relationship of optical to infrared month-to-month variability suggests that the emission mechanisms are different or that the emission arises from different regions. The simple dust model discussed by

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* Note that the relationship between these two line ratios claimed by Wampler (1968) is less convincing when Anderson's (1970) data are used.

PPNTBV for the source of the 2-μ radiation from Seyferts must be modified to fit the data presented here for NGC 4151.

There is an interesting contrast between NGC 1068 and NGC 4151. In the former, the extended 10-μ nucleus suggests that dust re-radiation is the infrared emission mechanism whereas in the latter, the present results on variability make a non-thermal emission mechanism more likely. A future task of some importance must be to relate Seyfert galaxies to the non-Seyfert infrared emitting galaxies and determine if the infrared radiation has a similar mechanism in both cases.

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