THE ASTROPHYSICAL JOURNAL, Vol. 150, December 1967

OPTICAL VARIATION OF THE NUCLEI OF THREE COMPACT GALAXIES TOGETHER WITH NEW PHOTOMETRIC DATA FOR SEYFERT GALAXIES

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Received October 30, 1967

ABSTRACT

Optical variations of the N-type galaxies 3C 109, 3C 390.3, and I Zw 1727+50 have been found, which, together with 3C 371, bring the known number of optically variable nuclei to four. New photometry of radio and non-radio N-type galaxies continues to show a clear separation of quasi-stellar sources and compact galaxies in the $U - B$, $B - V$ diagram. Variation of optical or radio intensity can no longer be used as an argument against the cosmological interpretation of redshifts because the optically variable galaxies, and the radio-variable Seyfert nuclei, NGC 1275 (Per A) and 3C 120, all follow the Hubble expansion law.

Photoelectric monitoring of the optical flux from N-type galaxies has continued, following the recent discovery of changes in the magnitude and color of the nucleus of 3C 371 (Oke 1967; Sandage 1967). Observations with the Hale reflector in October, 1965, and September, 1967, show positive evidence of a 30 per cent variation in the optical flux of the N-type radio galaxy 3C 390.3. This galaxy, dominated by a star-appearing nucleus, has a fuzzy appearance on plates taken with the Palomar Schmidt. A finding chart is given by Wyndham (1966), and the spectrum and redshift are described elsewhere (Sandage 1966).

The strongly nucleated galaxy 3C 109, identified by Longair (1965), and described with a finding chart by Wyndham (1966), was also found to vary by 0.3 mag. Finally, the non-radio compact galaxy I Zw 1727+50 (Zwicky 1966) has brightened by 0.21 mag in V and has become appreciably bluer in the one-month interval from August 11/12, 1967, to September 12/13, 1967. Oke, Sargent, Neugebauer, and Becklin (1967) independently found this galaxy to vary.

The photoelectric data are given in Table 1, where the diameter of the measuring aperture is indicated in the last column. The data are divided according to aperture to permit the variation to be more immediately apparent. Although all three galaxies appear almost starlike to the eye at the telescope, it is obvious that 3C 390.3 and II Zw 1727+50 have disks which are larger than 12″ diameter, because the intensity grows with increasing aperture.

It might, therefore, be objected that a real variation has not occurred in 3C 109 because the galaxy was measured with different apertures on the two nights between which a variation is claimed. But the aperture effect cannot be the cause of the measured magnitude difference because the redshift of 3C 109 is so large at $\Delta\lambda/\lambda_0 = 0.3057$ (Lynds 1966; Burbidge 1967) and the distance, therefore, so great that a diaphragm of 7″.6 includes nearly all the light of even a giant elliptical galaxy (see Appendix A of Humason, Mayall, and Sandage [1956] for justification), which means that all the light of the highly nucleated system 3C 109 should certainly enter this aperture.

The probable errors of the photometry in Table 1 are all below ± 0.04 mag in V, and most are below ± 0.02 mag, which shows that the measured variations are real. In agreement with the behavior of 3C 371, each object gets bluer as it brightens.

In view of the connection between the violent events in quasi-stellar sources, in N-

type galaxies (radio and non-radio), and in the nuclei of Seyfert galaxies which many people have suspected, we have recently made new three-color observations of selected members of each class. New data for 3C 79, 3C 135, and the variable galaxy 3C 371 are given in Table 2. Also listed is photometry for the two compact galaxies I Zw 1439+53 and III Zw 1622+41 described by Zwicky (1966), and data on the nuclei of the Seyfert galaxies NGC 1068, NGC 4051, NGC 4151, NGC 7469, and the variable radio source 3C 120 (Kellermann 1966; Kellermann and Pauliny-Toth 1967; Burbidge 1967; Kinman 1967; Sargent 1967). Values of the total magnitude of the Seyfert galaxies are also listed as obtained by Holmberg (1957), or from Pettit's (1954) measurements as reduced by Humason *et al.* (1956, Appendix A, Table A1).

TABLE 1

PHOTOMETRY OF THREE N-TYPE GALAXIES WITH OPTICALLY VARIABLE NUCLEI

Object	Date	V	$B-V$	$U-B$	Diameter
3C 109.....	Feb. 14/15, 1965	17.76	0.89	−0.08	12″.2
	Sept. 10/11, 1967	18.05	.93	− .15	7.6
3C 390.3.....	Oct. 18/19, 1965	15.49	.80	− .59	7.6
	Sept. 10/11, 1967	15.20	.66	− .69	7.6
	Oct. 18/19, 1965	15.40	.81	− .59	12.2
	Oct. 19/20, 1965	15.38	.82	− .56	12.2
	Sept. 8/9, 1967	15.12	.67	− .66	12.2
	Sept. 10/11, 1967	15.11	.68	− .69	12.2
	Sept. 11/12, 1967	15.14	.67	− .69	12.2
I Zw 1727+50.	Aug. 11/12, 1967	16.18	.68	− .34	7.6
	Sept. 12/13, 1967	15.97	.58	− .46	7.6
	Aug. 11/12, 1967	16.02	.75	− .30	12.2
	Sept. 12/13, 1967	15.81	0.65	−0.45	12.2

Several points of interest are presented in Table 2:

1. The nucleus of 3C 371 continued to brighten and to become bluer in both $B - V$ and $U - B$ during the interval between the August and the September measurements.

2. The two non-radio, blue compact galaxies of Zwicky have finite disks as shown by the intensity increase with increasing measuring apertures. A similar effect is known for radio N's but not for quasi-stellar sources.

3. As the measuring aperture is increased in the photometry of Seyfert galaxies, the intensity increases because light from the normal underlying galaxy provides increasing contamination, and, as expected, the measured colors become redder because the underlying starlight shows a relatively late-type composite spectrum.

4. The ratio of the light of the Seyfert nucleus to the total light of the galaxy differs among this list of Seyfert's. The magnitude differences between the total light and the nucleus are $\Delta V \geq 3.0$ mag for NGC 1068, 3.5 mag for NGC 4051, 1.2 mag for NGC 4151, 1.8 mag for NGC 7469, and only 0.4 mag for 3C 120.

The two-color diagram is shown in Figure 1, where the dots are confirmed quasi-stellar objects whose colors were known to September, 1967; vertical crosses are radio-quiet quasi-stellar objects; open circles are the nuclei of Seyfert galaxies from Table 2 as measured with the smallest aperture; the ×'s are the three blue compact galaxies of Zwicky (1966) from Tables 1 and 2, and the open triangles are the radio N galaxies taken from Table 2 and from a previous discussion (Sandage 1967).

The previously noted separation of the N galaxies from the QSS is maintained. The three blue compact galaxies of Zwicky do not interlace the distribution of QSS but lie

closer to the radio N's. Four of the five Seyfert nuclei fall among the redder QSS, but the nucleus of NGC 1068 is redder and falls with the N types.

The Hubble diagram for some of these objects is given in Figure 2. Dots are the radio galaxies shown previously (Sandage 1967), crosses are the two compacts from Table 2 with redshifts from Zwicky (1966), open circles are the Seyfert galaxies from Table 2 plotted at total light with redshifts from Humason *et al.* (1956), and from Burbidge (1967), Kinman (1967), and Sargent (1967) for 3C 120, and triangles are the N galaxies listed previously (Sandage 1967, Table 1). Again, it is to be emphasized that N galaxies follow the Hubble diagram defined by radio ellipticals. There is no evidence that such galaxies show excess redshift relative to normal, non-radio ellipticals. Also, the two compact galaxies isolated by Zwicky show no significant deviation from the Hubble diagram.

Of particular interest are the open circles for the Seyfert galaxies NGC 1275 (Per A) at $V_{25} - K_V - A_V = 11.49$ and $\log cz = 3.735$ (the photometry is from unpublished data on radio galaxies which provide the dots in Fig. 2), and 3C 120 at $V_{25} - K_V -$

TABLE 2

PHOTOMETRY OF N GALAXIES, BLUE COMPACTS, AND SEYFERT NUCLEI

Object	Date	V	$B-V$	$U-B$	Diameter	Class
3C 79	Sept. 10/11, 1967	18.75	0.79	−0.27	7″.6	N
3C 135	Sept. 11/12, 1967	17.40	1.31	+ .33	12.2	N
3C 371	June 20/21, 1966	14.90	0.68	− .38	7.6	N
	June 21/22, 1966	14.81	0.72	− .35	7.6	
	Aug. 11/12, 1967	14.30	0.61	− .44	7.6	
	Sept. 8/9, 1967	14.22	0.55	− .48	7.6	
	Sept. 10/11, 1967	14.22	0.58	− .48	7.6	
	Sept. 11/12, 1967	14.26	0.59	− .48	7.6	
	Sept. 12/13, 1967	14.20	0.57	− .48	7.6	
I Zw 1439+53	Aug. 11/12, 1967	15.03	1.02	− .26	7.6	
	Aug. 11/12, 1967	14.84	1.01	− .22	12.2	
III Zw 1622+41	Aug. 11/12, 1967	15.55	0.56	− .53	7.6	Radio-quiet blue compact
	Sept. 12/13, 1967	15.48	0.55	− .63	7.6	
	Aug. 11/12, 1967	15.38	0.62	− .50	12.2	
	Sept. 12/13, 1967	15.35	0.58	− .58	12.2	
NGC 1068	Sept. 10/11, 1967	11.90	0.85	− .11	4.9	Seyfert
	Nov. 25/26, 1962	11.61	0.88	− .01	6.4	
	Nov. 25/26, 1962	10.56	0.80	+ .11	20.0	
	Holmberg (total)	8.91	0.82	.....	Total	
NGC 4051	Jan. 14/15, 1966	13.72	0.57	− .36	7.6	Seyfert
	Holmberg (total)	10.20	0.71	.....	Total	
NGC 4151	Jan. 14/15, 1966	11.74	0.37	− .71	7.6	Seyfert
	HMS (total)	10.5	0.7	.....	Total	
NGC 7469	Sept. 12/13, 1967	13.77	0.42	− .61	4.9	Seyfert
	Sept. 12/13, 1967	13.51	0.50	− .65	7.6	
	Sept. 12/13, 1967	13.30	0.57	− .62	12.2	
	HMS (total)	12.0	0.7	.....	Total	
3C 120	Sept. 11/12, 1967	14.21	0.46	− .79	7.6	Radio Seyfert
	Sept. 11/12, 1967	14.11	0.49	− .78	12.2	
	Sept. 11/12, 1967	14.02	0.52	− .75	18.8	
	Sept. 11/12, 1967	13.92	0.57	− .74	30.6	
	Total	13.78	∼0.6	∼−0.7	Total	

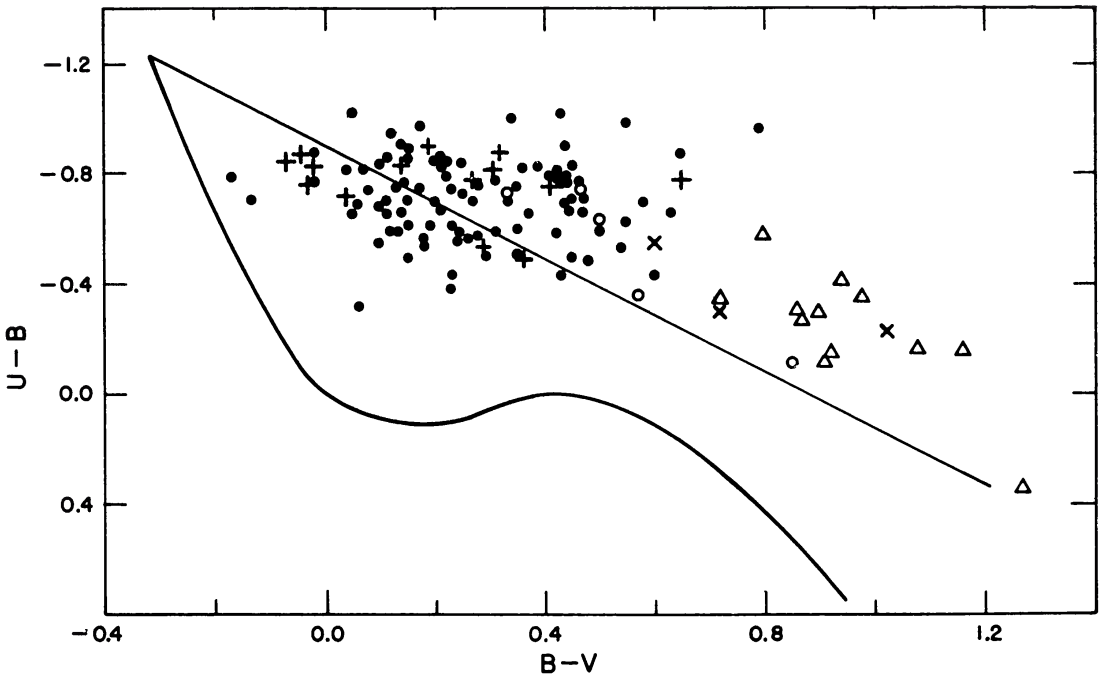

FIG. 1.—The two-color diagram for all QSS with photometry known to September 1967 (*dots*), radio-quiet QSS with known redshifts (*crosses*), Seyfert nuclei (*open circles*), non-radio blue compact galaxies (×), and radio N galaxies (*triangles*).

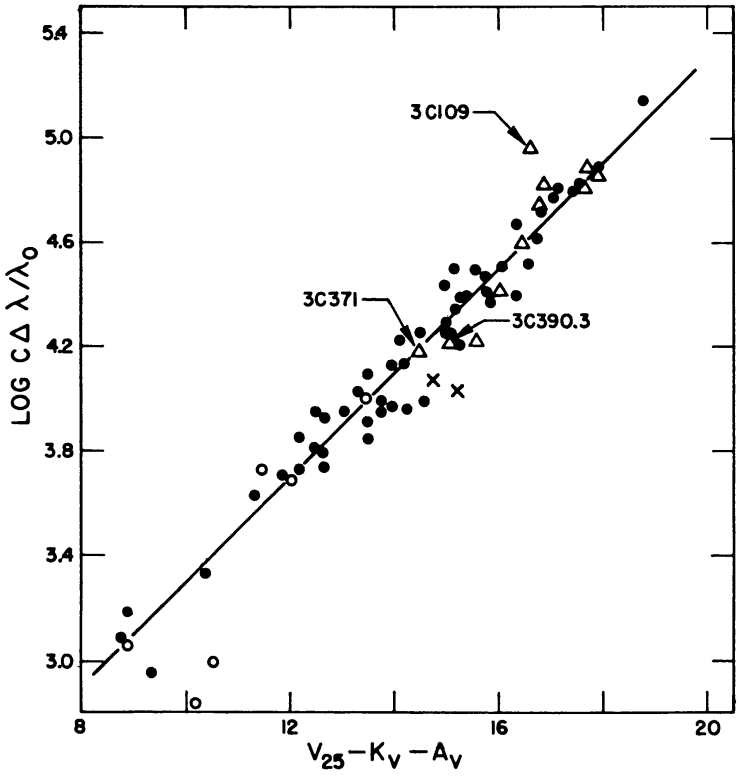

FIG. 2.—The Hubble diagram for all known radio elliptical galaxies with available redshifts and photoelectric photometry to September 1967 (*dots*), Seyfert galaxies plotted at total light (*open circles*), the two compact galaxies of Zwicky (1966) from Table 2 with known redshifts (*crosses*), and the radio N-type galaxies (*open triangles*). The line has a slope of 5. The three optically variable N-type galaxies are marked.

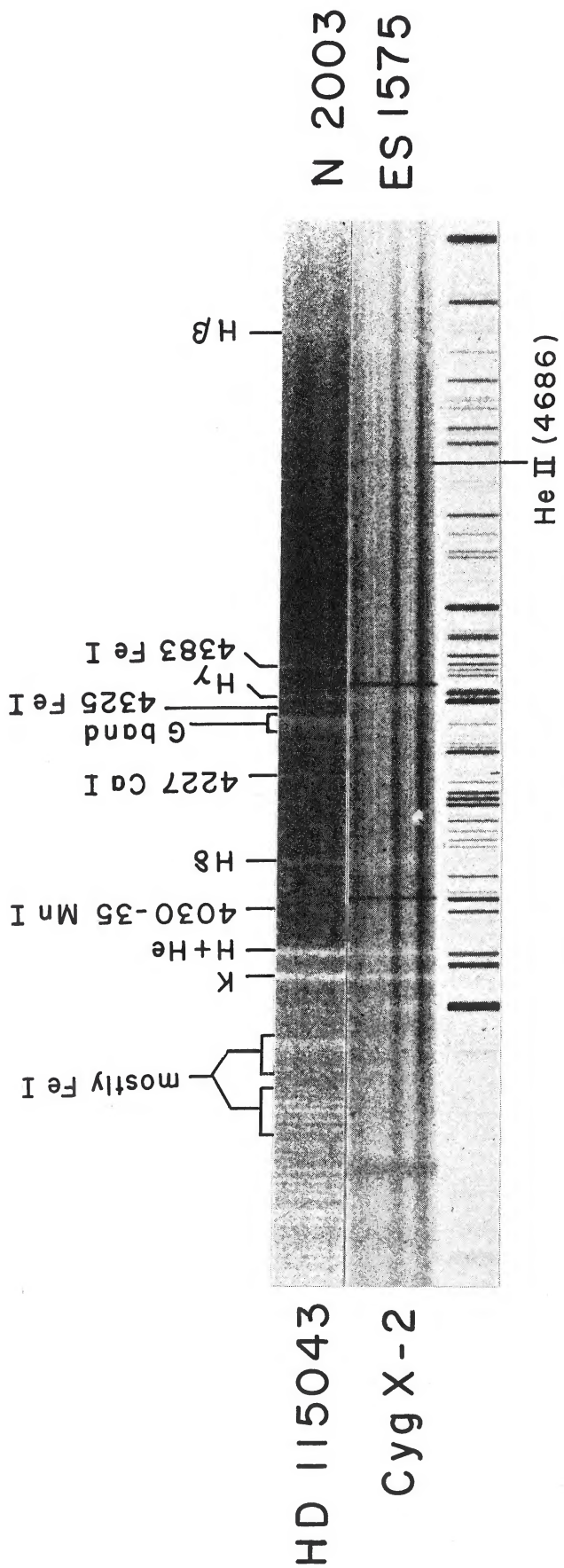

FIG. 1.—Spectrum of Cyg X-2 and HD 115043 (G1 V). The lower spectrum is somewhat out of focus shortward of Hδ because the Solid-Schmidt has no field flattener. The standard G1 V spectrum was obtained with the Palomar nebular spectrograph (190 Å/mm); plate numbers are on the right. Because of differences in the optical systems at Lick and Palomar, the two spectra cannot be precisely registered over the whole range. Metallic lines in the spectrum of Cyg X-2 are noted. The higher members of the Balmer series are clearly contaminated by the strong lines of Fe I present in a G-type star shortward of K.

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$A_V = 13.48$ and $\log cz = 4.000$. Both galaxies exhibit large variations of radio flux (Dent [1966] for Per A, and Kellermann and Pauliny-Toth [1967] for 3C 120). This fact, together with the optical variation now found for 3C 109, 3C 390.3, and 3C 371, would seem clear and positive evidence that variation of radiation on a time scale of days, as for 3C 371 (Oke 1967), cannot contradict the cosmological distance scale because Figure 2 shows that the Hubble law applies for the five variable objects (NGC 1275, 3C 120, 3C 371, 3C 390.3, and 3C 109).

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