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THE CORRELATION OF OPTICAL ABNORMALITIES AND SMALL RADIO SOURCES IN GALAXY NUCLEI

by

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ABSTRACT

Radio emission from small sources in galaxy nuclei is shown to be correlated with the optical photometric properties. Within the limitations of the small sample available, the following observations are made: (1) no galaxy with a photometrically normal nuclear region contains a small radio source, although it may contain a large source; (2) when a small radio source is present the galaxy nuclei are abnormally red or blue. The opposite is not true, however, since (3) not all photometrically blue or red nuclei contain small radio sources. Finally, (4) the sources in red nuclei are apparently smaller than in blue nuclei and are the ones showing abnormal radio spectra.

A close similarity between the abnormal nuclei and QSS phenomena is noted and it is proposed that the phenomena is either (1) a small scale QSS phenomena or (2) pre and/or post QSS stages.

Four-color multi-aperture photoelectric photometry of nuclear regions of galaxies has shown that certain galaxies contain unusually red or blue nuclei (Tifft, 1968, 1969). Color residuals range from slightly less than 0.1 magnitude to several tenths of a magnitude at an aperture size of 10 arc seconds. The red or blue nuclear anomaly may be present in either elliptical or spiral galaxies. Several classes of galaxies are photometrically distinguished for both spirals and ellipticals. Normal galaxies denoted Sn or En have radial color curves which trend smoothly toward a fairly homogeneous nuclear color. Certain spirals and ellipticals become unusually blue in the center and are denoted Sp and Ep. Others turn unusually red and are denoted Sr and Er. Sr types in particular are set aside distinctly from normal spirals. Comparison of red and normal nuclei suggests that the reddening is consistent with a model of excess interstellar reddening.. The blue nuclear effects involve a continuum source which includes young stars in at least some of the spiral galaxies but very possibly also includes a non-stellar blue continuum. Emission line effects will not explain the bluing since some galaxies with blue nuclei do not contain detectable emission lines. In only a few cases are the abnormal nuclei resolved at 10 arc seconds. In at least one case, M87, the blue nucleus appears to vary in intensity (Tifft, 1969).

Heeschen (1970) has published an extensive study of 11cm radio emission from elliptical and early type sprial galaxies. Only a few of these galaxies are detectable as radio emitters. Table I contains all galaxies detected as radio emitters by Heeschen for which a nuclear photometric classification is available by Tifft (1969). NGC 3031 observations by Wade (1968) are also included. Table II contains all Heeschen galaxies which are not detected as radio emitters and for which a nuclear photometric classification is available. Size and radio spectral characteristics for the radio sources are given when available.

Ten galaxies with normal nuclear colors appear in the tables. Only one contains a radio source and that is entirely of an extended type. The galaxies with small radio sources are all classified r (red) or p (blue) nucleated. Elliptical galaxies with photometrically normal nuclei are apparently not sites of small radio sources. The one occurrence of a large source, however, indicates that they may contain large sources without optical manifestations. In all seven available cases where small sources are present, the nuclei are abnormal photometrically. Further evidence is available on this point using additional spiral galaxies. NGC 2903 and 3351 are strong Sp galaxies photometrically

TABLE I: GALAXIES DETECTED BY HEESCHEN AND WADE

OBJECT	TYPE	VISIBILITY AMPLITUDE (FLUX UNIT)	RADIO SPECTRUM	SMALL NUCLEAR SOURCE		LARGE SOURCE		HALO	
				SIZE	INTENSITY	SIZE	INTENSITY	SIZE	INTENSITY
NGC 3031	Sr	0.14		<2"	40%				
NGC 3623	Sr3	(0.06)	Flat††	<2"†	100%†				
NGC 4552	Er3	0.26	Flat	≤1".5	100%				
NGC 4550	Ep	0.10	Steep	4"	100%				
NGC 4472	Ep	0.14	Normal	4"	<50%	50"	<50%		
NGC 4486	Ep	117.	Normal	Complex*	3%*	30"x70"	77%	10'	17%
NGC 4374	En3	3.87	Normal			110"x50"	100%		

( ) Region confused; position somewhat indeterminate.
† Unpublished observations by C. M. Wade.
†† Inferred from negative observations at all longer wavelengths.
* Also a 3% small source on the jet structure displaced from the nucleus.

TABLE II: GALAXIES NOT DETECTED BY HEESCHEN

OBJECT	TYPE	VISIBILITY AMPLITUDE (FLUX UNITS)	OBJECT	TYPE	VISIBILITY AMPLITUDE (FLUX UNITS)
NGC 4365	En3	N	NGC 4435	Ep	[0.07]
NGC 4406	En3	[0.12]	NGC 4459	Ep	N
NGC 4429	En3	N	NGC 4526	Ep	N
NGC 4621	En3	N	NGC 4636	Ep	N
NGC 4649	En3	N			
NGC 4762	En3i	N	NGC 4438	Er2	N
NGC 5846	En3	N	NGC 4473	Er3	[0.21]
NGC 5866	En3i	N			
NGC 5982	En3	N	NGC 4482	Eb4	N

[ ] Source >3' from galaxy.

(Tifft, 1963) and contain small 11cm radio source (Wade, personal communication). NGC 3031 which contains a small unresolved 11cm radio source (Wade, 1968) is an Sr galaxy on the basis of nuclear colors (Tifft, 1961).

Although the presence of a small high frequency radio source appears to correlate, within the limitations of the small sample, with the presence of r or p optical nuclei, the opposite is not the case since a number of r and p galaxies appear in Table II, hence, do not possess detectable small radio sources. This suggests that radio emission need not be present in all abnormal nuclei or need not be present at all times. This is similar to the QSS situation where the QSO is optically identical to the QSR except in radio emission. M31 is a possible Sr galaxy which contains no small nuclear radio source.

Although the data are severely limited, one further correlation is at least suggested by the data. The three galaxies with the smallest sources, NGC 3031, 3623, and 4552 are r type systems. The galaxies with resolvable small sources, NGC 4472 and 4550 are photometrically of p type. NGC 4486 is highly active and complex in structure (Miley and Hogg, 1970) with both resolved and unresolved sources. The radio spectrum of the small (r related) source is of QSR type. The galaxies containing larger (p related) sources show a more normal spectrum (Heeschen, 1970b).

Tifft (1969) has shown that p and r galaxies tend to be associated spatially and are probably two stages of a transient event. Heeschen (1970b) has proposed that the initial small radio source seen in r nuclei develops and evolves by increasing in size as relativistic electrons diffuse outward. The small source and the associated optically red nucleus may thus be inferred to represent an early state in an active nucleus. Combining optical and radio evidence, the following temporal sequence of active nuclear development is suggested.

Before nuclear activity begins a galaxy is presumably radio quiet and enters the red optical state. Among the optically brightest radio-quiet galaxies with nuclear photometric classification the r type is conspicuous. NGC 2841 is an example which is optically bright, radio quiet, and of Sr photometric class. Comparison of colors of red nuclei with normal nuclei suggests that a nuclear buildup of interstellar material can account for the observed reddening (Tifft, 1969). Further evidence for reddening in active nuclei has been provided by Wampler (1968) who has shown that reddening is present in Seyfert galaxy nuclei.

In the early red stage of nuclear development, no driving source for high energy electrons is present. At some point in time, perhaps through a nuclear collapse phenomena of accumulated material, an energy source is provided. Initial very high magnitic field strength and an electron energy spectrum deficient in low energy particles such as might be expected in a collapsed system could produce a peaking of energy in the visible initially. R galaxies do contain a distinct excess of optical light, strongly concentrated to the nucleus, compared to normal galaxies (Tifft, 1969). Energy which is initially concentrated in the optical would be expected to extend to progressively longer wavelengths as source magnetic field strengths and relativestic electron energy decreases in an expanding core. When energy is detected in the radio spectrum, it appears first at high frequency and later at lower frequencies. Thus, only the high frequency small radio nucleus is seen initially as in NGC 3623, 4552, and M81; blue optical emission, if present up to this stage, may be blocked by interstellar material so the photometric appearance remains type r. As the nuclear source evolves, residual material around the source is driven outward rendering a blue nuclear continuum visible. That radial cloud motions are present in active nuclei has been shown by Walker and Hayes (1967) who detected rapid cloud motions near the M87 nucleus. Walker (1968) has found similar motions in Seyfert Galaxy nuclei. Spectra of blue nuclei in elliptical galaxies show no trace of hydrogen absorption lines as would be expected if young luminous stars produced the blue continuum. This supports arguments for a non-thermal origin of the blue continuum.

The migration of relativistic particles outward proposed by Heeschen (1970b) eventually fills out the radio spectrum to low frequency and the source expands enough to become resolved. The outward migration of interstellar material might be expected to produce a red ring about a blue nucleus. Such a zone is observed in p galaxies (Tifft, 1969). In spirals with a high dust content, an outward pressure wave might be expected to induce active star formation in the disc outside the nucleus. Sp galaxies such as NGC 2903 do in fact contain a strong young population surrounding the nucleus (Tifft, 1961).

Rough arguments based upon the spatial correlation of r and p galaxies in the Virgo Cluster suggest a short life time of the entire r through p sequence (Tifft, 1969). Multiple radio structure in some galaxies and perhaps optical structure in some spirals suggests the process is repetitive or cyclical.

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