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INDUCED NUCLEAR EMISSION-LINE ACTIVITY IN INTERACTING SPIRAL GALAXIES

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ABSTRACT

We have investigated the effect of close galaxy-galaxy interactions on the level of nuclear activity in spiral galaxies by obtaining nuclear spectrophotometry for complete samples of multiple and single systems. Galaxies with nearby companions possess significantly higher nuclear emission-line luminosities and equivalent widths, and their nuclei exhibit a significantly higher level of ionization on average. We also find a much higher fraction of galaxies with Seyfert or Seyfert type nuclei in our sample.

Subject headings: galaxies: nuclei — galaxies: Seyfert

I. INTRODUCTION

Galaxy-galaxy interactions have been suspected as possible mechanisms for triggering and fueling nuclear activity in galaxies (Balick and Heckman 1982, and references therein) and even for many quasars (Bothun *et al.* 1982; Hutchings and Campbell 1983). For normal galaxies, most of the evidence has come from radio surveys, which suggest that galaxies in close pairs and groups possess central radio sources that are stronger, on average, than those of isolated systems (e.g., Hummel 1981). Stauffer (1982) has discovered a similar tendency for galaxies in compact groups to possess stronger than average nuclear emission-line activity. These previous surveys, however, have suffered from poor detection statistics or incomplete sampling.

In this *Letter* we present preliminary results from a survey of optical emission-line activity in a complete sample of spiral galaxies with companions. Both the luminosities and the type of activity are significantly altered in close interactions. Details will be published in a later paper (Keel *et al.* 1984).

II. OBSERVATIONS AND SAMPLE SELECTION

Our basic goals were to remedy the statistical limitations of previous surveys by obtaining high signal-to-noise emission-line spectrophotometry for a complete and objectively defined sample of galaxies with nearby companions, and a comparable control sample of relatively isolated galaxies. To generate a list of close pairs and groups of nearby objects, we used an unpublished list of probable groups compiled by van Albada (1983). His catalog is a list of probable associations, based solely on galaxy angular separations, magnitudes, and background galaxy densities. We selected a subsample composed of all spiral and Irr II galaxies brighter than magnitude $B_T = 13$, north of the equator, and situated in pairs or groups with a probability of 90% or higher of being real. This defines a sample of close systems independently of any visible evidence for violent interactions. We then used published radial velocities in order to eliminate several chance optical pairings, and added two nearby groupings (M81/M82/NGC 2976/NGC 3077 and M101/NGC 5474) which met van Albada's criteria but which were too nearby to be cataloged by him. This "complete" multiple galaxy sample consists of 56 spiral galaxies.

The control sample was taken from Keel's (1983*b*) original survey, 89 spiral and Irr II galaxies complete to magnitude $B_T = 12$ in the declination range $-15°$ to $+40°$ (five galaxies with no visible nuclei and eight galaxies with companions as described above were excluded). The difference in limiting magnitude introduces a slight but manageable bias into the comparisons which follow. (The multiple-galaxy sample was necessarily extended a magnitude fainter in order to obtain a large enough sample.) The absolute luminosity distributions are virtually identical in the two samples (median $M_B = -20.7$ for $H_0 = 50$ km s^{-1} Mpc^{-1}), and the distributions of morphological types are similar as well.

In addition, we obtained nuclear spectra for a blatantly biased sample of 53 other spiral galaxies, those illustrated in the *Atlas of Peculiar Galaxies* (Arp 1966) and the *Atlas and Catalog of Interacting Galaxies* (Vorontsov-Velyaminov 1959) which showed visible signs of strong tidal interactions. The idea here was to examine the maximum effect to be expected in very close encounters. This selection was made independently of any knowledge of the nuclear properties (the nuclear regions are burned out on the prints available to us), and hence the statistical properties of this latter sample should be at least grossly comparable to the other samples. This "Arp" sample is generally much more distant, however, and hence our fixed apertures sample a much larger region of the galaxy disks.

We used the image dissector scanner (IDS) spectrograph on the Minnesota/UCSD 1.5 m telescope on Mount Lemmon to

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obtain nuclear spectra for 105 galaxies during 1983 April 3–10. A 600 lines mm^{-1} grating yielded spectra covering the range from 3600 Å to 7000 Å with a resolution of approximately 13 Å. A fixed aperture of 4".7 was used. Integration times, usually 16 minutes total, were chosen to obtain high signal-to-noise detections of the Hα and/or [N II] λ6584 emission lines, and to obtain detection limits comparable to those in Keel's control sample. Representative spectra are shown in Figure 1. Eight galaxies, too far north to reach with the Mount Lemmon instrument, were observed at Kitt Peak with the IIDS scanner on the 2.1 m telescope, and with the Cryogenic camera on the 4 m telescope. Data for three other galaxies were taken from the published survey of Heckman, Balick, and Crane (1980).

III. RESULTS

Both samples of multiple/interacting spiral galaxies exhibit marked differences in their nuclear emission relative to isolated galaxies, in terms of the absolute level of activity and of the distribution of emission spectra types present.

a) Emission-Line Equivalent Widths and Luminosities

As in the control sample (Keel 1983*b*), we detected either or both of the Hα and [N II] emission lines in virtually all of the nuclei surveyed in the two multiple galaxy samples, and the emission-line fluxes provide a quantitative means of comparing the level of activity in the different samples. In Table 1 we compare the Hα and [N II] fluxes, both in terms of the median equivalent widths of the emission lines, and in terms of the median emission-line luminosities (assuming $H_0 = 50$ km s^{-1} Mpc^{-1}). The equivalent widths are a less direct index of nuclear emission, but they are less susceptible to distance-dependent selection effects. We list the Hα and [N II] fluxes separately in Table 1 because of the strongly bimodal behavior of the [N II]/Hα distribution among normal spiral nuclei (Heckman 1980; Stauffer 1982; Keel 1983*a*).

A strong increase in emission is evident in both samples of multiple galaxies. The distribution of Hα emission in the three samples is shown in Figure 2. The increase in median emission is due to both an increase in the average luminosity of the emitting nuclei and a sharp decrease in the fraction of nuclei which exhibit no detectable emission. The large luminosity difference in the Arp sample [a factor of 60 in L(Hα)] is partly a selection effect arising from the much larger distance of this sample, but the absence of "inactive" spiral galaxies in this sample (51/53 show emission) and the higher average equivalent width of the emission indicate that much of the enhancement is real. The [N II] emission shows a similar but less dramatic enhancement; this is largely an ionization effect caused by a very different distribution of low-ionization and high-ionization nuclei in the multiple galaxy and control samples (see § III*b*).

An important second-order result is the dependence of the emission strength on projected galaxy separation, since this might provide clues about the physical mechanism involved. Quite surprisingly, we observe no significant dependence of Hα or [N II] equivalent width on separation. Perhaps the critical "impact parameter" is larger than our largest well-sampled separation (~ 3 Holmberg diameters), or projection effects may have masked the dependence. As discussed below, however, we do observe a marked excess of very energetic nuclei among the very close pairs.

b) Classification of Nuclear Spectra

In the spirit of Baldwin, Phillips, and Terlevich (1981), we have classified the nuclear spectra into three broad groups, based on the [O III] λ5007/Hα, [N II] λ6584/Hα, and [S II] $\lambda\lambda$6717, 6731/Hα line ratios. The measurements will be described in detail in Keel *et al.* (1984). The groups are:

1. H II region like spectra, apparently photoionized by OB stars. The most luminous objects of this type are similar to the "starburst" nuclei (Balzano 1983).
2. Low-ionization emission regions, including Heckman's (1980) "Liners," probably shock-heated or photoionized by a flat ultraviolet continuum (Stauffer 1982; Keel 1983*a*).
3. Seyfert-like spectra, characterized either by broad Balmer lines (Seyfert 1) or by high-excitation forbidden-line ratios (Seyfert 2). This class includes galaxies with very high excitation spectra like those in classical Seyfert galaxies, but with narrower lines or lower absolute line luminosities, or both (Phillips, Charles, and Baldwin 1983). These objects are probably ionized by a strong power-law ultraviolet continuum.

Examples of each spectrum type are illustrated in Figure 1.

One of the most significant results of this survey was the number of interacting galaxies with Seyfert spectra. The frequency with which high-excitation Seyfert-like nuclei occur among spiral galaxies has been determined by Keel (1983*b*) in his original survey, and by Phillips, Charles, and Baldwin (1983) using Sandage's (1978) redshift survey as a reference sample. They derived frequencies of 4.4%–5.1% (5/98 and 19/436 spiral galaxies, respectively) for all spiral galaxies, and if close pairs and multiples are excluded from their data, the frequencies drop to 3%–4.5% (perhaps a significant result in itself). The frequency of Seyfert or Seyfert-like nuclei in our combined sample of multiple/interacting spiral galaxies is much higher. Of 95 spiral galaxies total, 10 possess Seyfert type spectra (11%), and among the 13 galaxies with companions closer than a Holmberg radius, 5 (38%) possess Seyfert 2 or Seyfert-like nuclei! While the results of the last section supported the notion that close tidal interactions may fuel existing nuclear activity, these results suggest that the encounters may trigger activity as well.

There are other differences in the systematic emission-line properties of the interacting and noninteracting spiral galaxies. In Figure 3, we show the relative fraction of the H II region, low-ionization, and very high ionization "Seyfert" spectra for the noninteracting control sample and the combined multiple/interacting samples (the complete and Arp samples possess similar distributions). Among isolated spiral galaxies, this distribution is a strong function of Hubble type, so we have subdivided the samples accordingly. We find a sharp reduction in the number of low-ionization nuclei, with a correspondingly higher fraction of moderate-excitation to high-excitation H II region like nuclei and little or no dependence on Hubble type. This change in ionization distribution could be due to several effects, a real transformation of relatively dormant Liners into high-ionization nuclei, or alternatively, from nuclear H II regions formed out of lower

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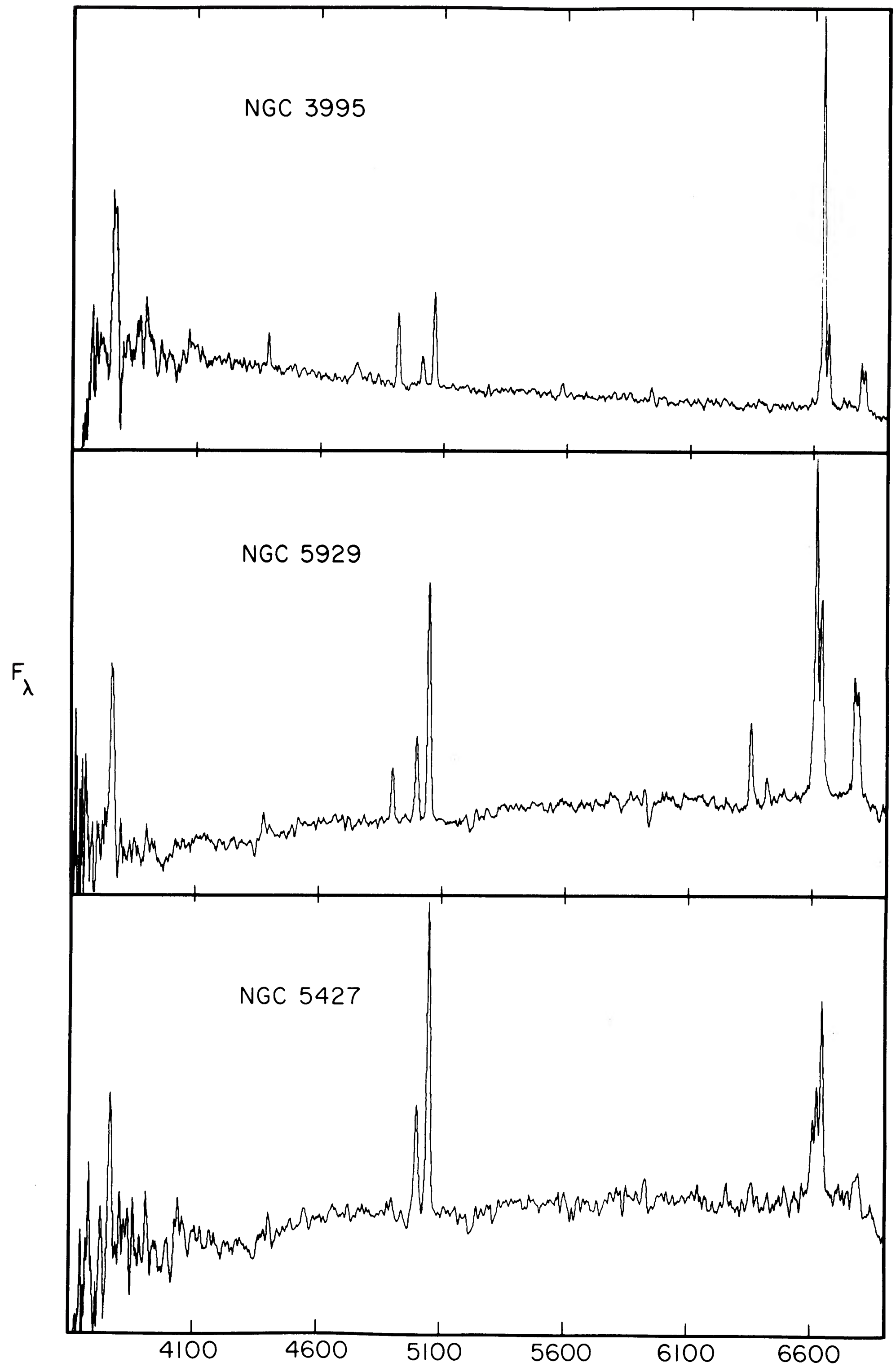

FIG. 1.—Representative IDS spectra of interacting spiral nuclei, taken with 4.7 s circular apertures. (*Top*) NGC 3995, showing an H II region emission spectrum and very blue stellar continuum; (*middle*) NGC 5929, a Seyfert 2 nucleus with relatively strong low-ionization lines of [O I] and [S II]; (*bottom*) NGC 5427, with a typical Seyfert 2 emission spectrum. Wavelengths are in the observed frame; the horizontal lines mark the zero levels for each spectrum. The feature near 4750 Å in the NGC 3995 spectrum is an artifact, and residual night-sky [O I] appears at 5577 Å.

TABLE 1

MEDIAN EMISSION-LINE PROPERTIES

Parameter[a]	Control Sample	"Complete Pairs"	"Arp" Pairs
Number	89	56	53
Hα equivalent width (Å)	4 ± 2	17 ± 4	21 ± 5
[N II] equivalent width (Å)	4 ± 0.5	9 ± 2	13 ± 2
LOG L (Hα) (ergs s^{-1})	38.9	39.4	40.7
LOG L ([N II]) (ergs s^{-1})	39.4	39.4	40.2
M_B (galaxy)	−20.7	−20.7	−21.5
Projected aperture (pc)	1000	800	2500

[a] $H_0 = 50$ km s^{-1} Mpc^{-1}.

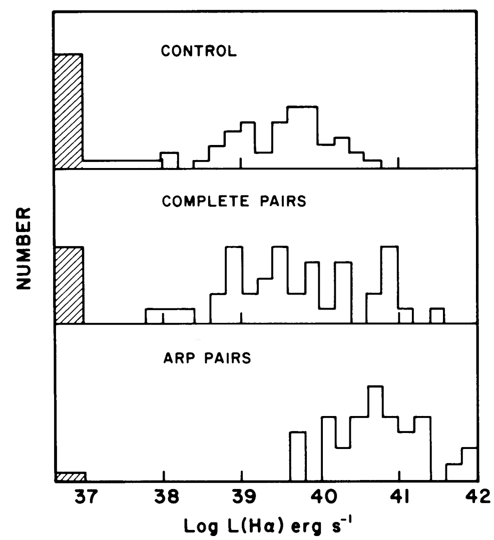

FIG. 2.—Distribution of logarithmic Hα luminosity, derived assuming $H_0 = 50$ km s^{-1} Mpc^{-1}. Shaded areas to the left are galaxies with no measurable emission. Note the logarithmic scale. The large luminosity enhancement in the Arp sample is partly a distance effect, as discussed in the text. The number of galaxies in each sample is given in Table 1.

metallicity gas that has been brought in from the surrounding disk. We are obtaining emission-line imagery of many of the program galaxies, and we will combine this information with the spectrophotometry and available radio continuum maps in hopes of separating the effects.

IV. DISCUSSION

The suspicion that close galaxy interactions may fuel nuclear activity is not a new one. The present results mainly strengthen the statistical basis for the conclusions reached earlier by Stauffer (1982) and Hummel (1981) in their spectroscopic and radio surveys of galactic nuclei respectively. Taken together, the radio and optical results make a strong case for the presence of environmentally influenced nuclear activity in a significant fraction of spiral galaxies.

Our preliminary data do not place very meaningful constraints on the physical mechanisms involved in triggering the nuclear activity, but the scenario first offered by Toomre and Toomre (1972) remains an attractive one. Tidal disruption of the disk during a close encounter may drive gas into the nuclear regions and either fuel nuclear activity directly or lead to a burst of star formation within the inner nuclear disk.

If the very high frequency of high-ionization nuclei among the most strongly interacting systems were confirmed with better statistics, it would lend support to the idea that most galaxies possess central mass concentrations which are capable of generating energetic nuclear activities, and that it is the availability of gaseous fuel which is critical in determining the level and the character of the activity. In any case, it is clear that conditions in the nuclei are not isolated from the outer disks.

Several additional observations and analyses should clarify some of the questions raised here. We have obtained Hα and continuum imagery of a substantial fraction of the program galaxies, in order to separate true nuclear activity from star formation in the surrounding disk, and to study any perturbations in the gas distributions. High-resolution VLA radio observations have been obtained in order to compare the nonthermal radio and optical activities in the galaxies. We also hope to improve the statistics of our spectral survey of very close interacting systems, and to use more detailed analyses of the available spectrophotometry to better constrain the ionization mechanisms of the nuclei. While it will be difficult to improve the statistics of our survey, a complementary study of the companions of known active galaxies (Dahari 1983) would be very valuable.

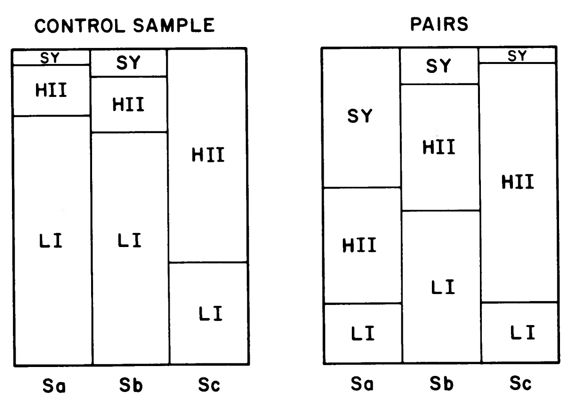

FIG. 3.—Distribution of nuclear spectrum types as defined in the text. LI denotes low-ionization nuclei; HII denotes moderate-ionization to high-ionization HII region type spectra; and SY denotes Seyfert or very high ionization Seyfert 2 like nuclear spectra.

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