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THE INFRARED PROPERTIES OF GALAXY CLUSTERS: *IRAS*[1] OBSERVATIONS OF THE HERCULES CLUSTER (ABELL 2151)

E. YOUNG, B. T. SOIFER, F. J. LOW, G. NEUGEBAUER, M. ROWAN-ROBINSON, G. MILEY, P. E. CLEGG, T. DE JONG, AND T. N. GAUTIER

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ABSTRACT

A total of 41 sources have been detected at 60 μm to a level of 50 mJy in a 1°.6 × 0°.5 field centered on the rich galaxy cluster Abell 2151. Twenty-four of these sources can be identified with late-type spiral galaxies of estimated photographic magnitude 17 or brighter. Galaxies classified as E or S0 are notably absent in the infrared data. Within the field, eleven of the *IRAS* sources cannot be easily identified with galaxies in the Hercules Cluster. If the brightest 60 μm cluster source (NGC 6045) is neglected, the integral luminosity function in the far-infrared can be fitted well with two power laws of slope −1.1 and −2.5.

Subject headings: galaxies: clustering — infrared: sources

I. INTRODUCTION

Abell 2151 is an excellent spiral-rich cluster for an initial study at middle-infrared and far-infrared wavelengths of galaxies within a cluster. The individual galaxies are generally distinct at the *IRAS* angular resolution, yet the main part of the cluster fits within a 0°.5 × 1°.6 scan. In this *Letter*, we report the preliminary results of a number of deep integrations on the classical Hercules Cluster.

II. OBSERVATIONS AND RESULTS

The *IRAS* survey instrument has been described by Neugebauer *et al.* (1984). Eight observations of the Hercules Cluster were made, each by scanning the telescope six times over the field center covering an area of 1°.6 × 0°.5. The input data were digitally filtered to enhance point sources and to suppress large-scale structure in the maps. The eight observations were co-added by weighing the signal-to-noise ratio to produce a minimum-variance grid. The final co-added maps have noise-equivalent flux densities for point sources of 5.4, 7.8, 8.0, and 40 mJy in the 12, 25, 60, and 100 μm bands respectively.

The 60 μm map is shown in Figure 1. Individual sources have been extracted using a simple thresholding algorithm (see Table 1). A detection must have a signal-to-noise ratio greater than 6.0 relative to the median noise in the whole grid and greater than 4.5 relative to the noise in the region immediately around the source. This form of dual thresholding tends to eliminate noise spikes. Obviously confused sources were separated by hand into individual components; this process is subjective, and the results should be treated with caution. Positions given are flux-weighted centroids for unconfused sources and best estimates of the peak for highly confused detections. Flux densities have no correction for galaxy colors. No flux in Table 1 means an upper limit of 6 σ. Uncertainties in the absolute photometric calibration are estimated to be 30%.

III. DISCUSSION

a) *Optical Identifications*

The Hercules Cluster is included in plate 108 of the *Catalogue of Galaxies and Clusters of Galaxies*, Volume 2 (Zwicky and Herzog 1963, hereafter CGCG). Classifications and redshifts for many of these CGCG galaxies have been published by Tarenghi *et al.* (1979) and by Dressler (1980). Identifications given in Table 1 are based on the Dressler positions. For the CGCG galaxies, the classifications of Tarenghi *et al.* have been used.

Twenty-nine of the 60 μm sources can be associated with galaxies. For unconfused sources, positions agree with those of Dressler (1980) with a standard deviation of 23″ in the cross-scan direction and 14″ in the in-scan direction. Dressler estimates that his positions are accurate to 3″–6″.

The contamination from field galaxies can be estimated using data of Soifer *et al.* (1984) who find a density of 0.25 *IRAS* sources per square degree brighter than 500 mJy at 60 μm and identifiable with galaxies brighter than $B \sim 18$ mag. This number extrapolates to eight galaxies per square degree at our 48 mJy threshold. Hence, as many as a third of the Hercules sources could be part of the general population.

For 12 of the sources included in the CGCG, Tarenghi *et al.* (1979) have published redshifts. All except CGCG Z108-107 (which is part of Abell 2152) are members of Abell 2151. Twelve additional galaxies from Dressler's (1980) list are similar to the CGCG galaxies and are probably part of the cluster. A more definite statement on the association of the remaining galaxies must await redshift measurements.

If one uses the galaxy classification of Tarenghi *et al.* (1979), the dichotomy between strongly emitting types and weakly emitting types is quite striking. The only prominent early-type

[1] The *Infrared Astronomical Satellite* was developed and is operated by the Netherlands Agency for Aerospace Programs (NIVR), the US National Aeronautics and Space Administration (NASA), and the UK Science and Engineering Research Council (SERC).

TABLE 1

OBSERVATIONS OF CLUSTER MEMBERS

Number	RA(1950)	Dec(1950)	Flux Density (mJy)[a] 12 μm	25 μm	60 μm	100 μm	Identifications Dressler	CGCG	Other	Classification[b]	mp[c]
1	16:04:11	18:34:59		22	134	327				(stellar)	
2	16:04:50	18:29:58			96	181				(galaxy)	
3	16:04:02	18:29:57	10500	4590	743	604			R Her	Mira variable	
4	16:03:31	18:30:02			60	(408)				(galaxy)	
5	16:03:13	18:28:32		36	332	1980	142			Sc	16
6	16:04:18	18:23:53	16	75	414	1290	133			S	16
7a	16:04:00	18:18:59	31	83	550	1830	126	144	I1189=Mk300	Sc(B)IV	15.06
							127	139		Sc(B)III	15.26
7b	16:03:38	18:21:16			120	(1000)	128	136		Sc IV	15.26
8	16:03:50	18:14:48			112	<240	118	138		SbII	15.16
9a	16:03:46	18:12:00			121	(283)				(stellar)	
9b	16:03:26	18:14:00			120	270	157?			E	16
10	16:03:25	18:11:22			108	545	114	129		Sa	16
11	16:03:58	18:05:27			101	380	100			Sc	16
12	16:04:21	18:02:03			54	164	95	149		Sc(Rn)III-IV	15.7
13	16:03:15	18:03:47			88	522	97			Sa/0	16
14	16:04:18	17:54:55		34	110	687	74			Sb	15.66
15a	16:03:23	17:56:20			207	(600)	78	126	I1182=Mk298	S0p	15.2
15b	16:03:11	17:57:55			207	<200	90			S	16
16	16:04:20	17:51:01			99	<120	56			Sa/03p	16
17a	16:02:55	17:53:32	77	142	1290	5730	82	112	N6045=Arp 71	Sc(B)II	14.76
17b	16:03:20	17:54:00		56	296	1540	80 (79?,77?,155?,156?)			Sc(RN)III-IV	15.66
18	16:03:06	17:43:59			150	614				(blank)	
19	16:02:18	17:41:26			54	<200				(galaxy)	
20a	16:02:27	17:35:00	50	45	233	1240	30	108		Sbc II	15.7
							31	98		Sc I-II	15.7
20b	16:02:57	17:33:30			120	850	24	113	I1173	SbII-III	15.6
21	16:03:32	17:29:18			187	(1850)	19	133	I1186=Mark 299	Sc(BRd)III	15.4
22	16:02:03	17:34:29		32	118	600	25			S	17
23	16:03:31	17:26:25		32	130	(436)	14			Sp	16
24	16:03:00	17:28:00		24	64	<120				(spiral)	
25	16:02:27	17:29:05			123	(1200)	20			Sc	16
26	16:03:34	17:21:24			64	<120				(blank)	
27a	16:02:46	17:22:36		45	176	388				(stellar)	
27b	16:03:13	17:21:24			121	360				(stellar)	
28	16:01:53	17:20:34			235	990	5			Sd/I	17
29a	16:02:57	17:14:36			104	(1100)				(stellar)	
29b	16:03:19	17:12:09			107	(883)				(stellar)	
30	16:03:12	17:06:04			125	600				(compact, some nebulosity)	
31	16:02:51	17:05:47			54	<220				(stellar)	
32	16:02:38	17:00:28			396	883		107	MCG+03-41-081	Sd(B)IV	15.7
33	16:01:57	17:02:46			64	<220				(stellar)	
34	16:02:40	16:57:02			271	1110				(spiral)	

[a] The 100 μm fluxes in parentheses are uncertain due to a possible confusion of sources.

[b] If a luminosity classification is given, the galaxy classifications are taken from Tarenghi *et al.* 1979; otherwise, the classifications of Dressler 1980 have been used. Classifications in parentheses are from an examination of the POSS at the *IRAS* position.

[c] Photographic magnitudes with zero, one, or two decimal places have been taken from Dressler 1980, CGCG, and either Strom and Strom 1978 or Peterson, Strom, and Strom 1979 respectively. Dressler's V magnitudes have been corrected to B using $(B - V) = 1.0$ mag.

spiral is source 15a (IC 1182 = Markarian 298), a peculiar S0 galaxy with evidence of a jet (Schommer, Sullivan, and Bothun 1981). Indeed, once a sufficiently large data base has been acquired, the infrared properties of a galaxy may prove as useful as conventional morphological classifications in understanding some aspects of galaxy evolution. It is important to note that the infrared properties of a galaxy can be a probe of the recent star formation activity, while the morphological classification reflects the history of the galaxy from its formation.

The most luminous infrared source in the Abell 2151 field is source 17a, identified with Sc(B) II galaxy NGC 6045. It is number 71 in the catalog by Arp (1966) and shows signs of interaction with nearby galaxies. The total luminosity detected in the four *IRAS* bands is 5.8×10^{10} $L_\odot$ (using a Hubble constant of 75 km s^{-1} Mpc^{-1}). If indeed the warped disk is due to an interaction, the enhanced infrared luminosity may be due to a star formation event triggered in the galaxy.

b) *Cluster-Wide Properties*

By defining a far-infrared luminosity L as the sum of the power in the 60 and 100 μm bands and assuming a Hubble constant, an integral luminosity function of the cluster can be derived for these wavelengths. Figure 2 is a plot of log $N(L)$

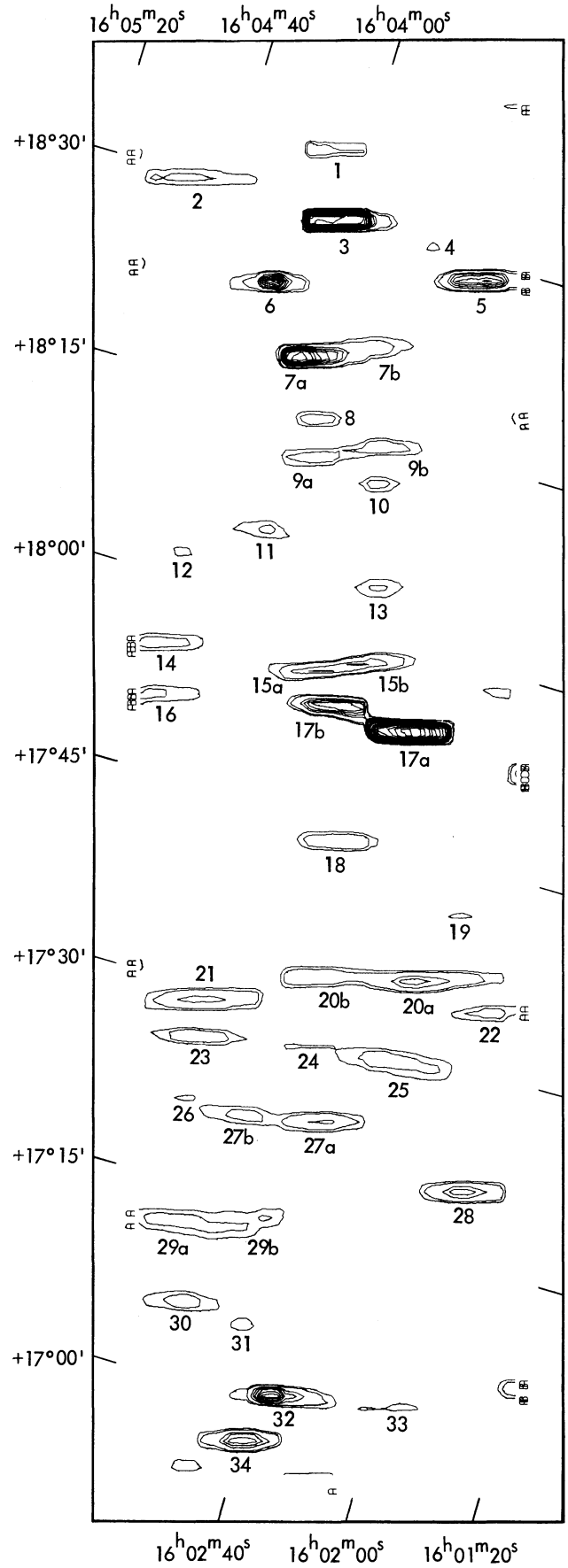

FIG. 1.—Co-added 60 μm map of the central region of Abell 2151. The data have been filtered to bandpass point sources. Contour intervals are 6, 10, 20, 25, 30, 35, 40, 45, and 50 times the 8 mJy peak flux.

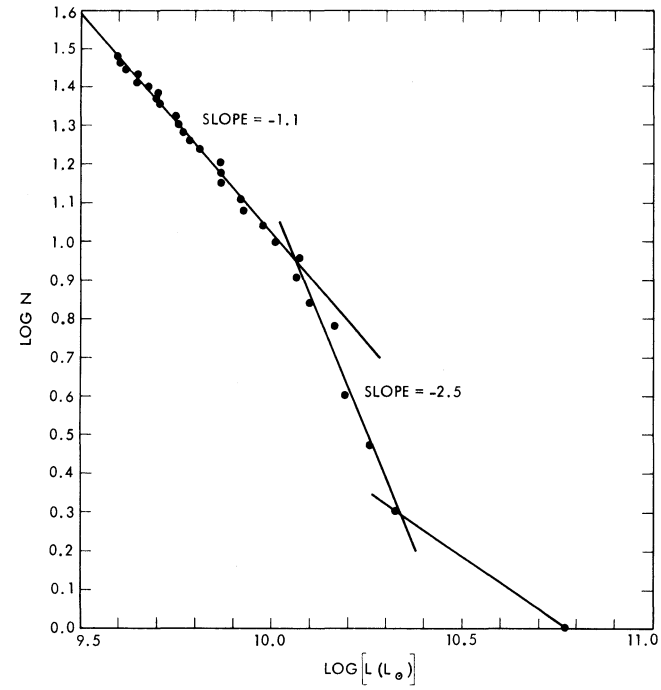

FIG. 2.—Integral luminosity function for Abell 2151. Luminosity is the sum of the in-band 60 μm and 100 μm powers, assuming a Hubble constant of 75 km s^{-1} Mpc^{-1}.

as a function of log L, where $N(L)$ is the number of galaxies with far-infrared luminosity greater than L. Except for the brightest cluster member, NGC 6045, the data can be fitted well with two power laws, one of slope -2.5 for the brighter galaxies and one of slope -1.1 for the fainter galaxies. The break point occurs near the ninth-ranked member, which has a far-infrared luminosity of approximately 1.2×10^{10} $L_{\odot}$. These functions bear a general resemblance to those found by Abell (1975) for the photographic luminosity function, although the slopes in the far-infrared are considerably steeper.

A measure of the infrared activity of an object is the ratio of the luminosities at 80 μm and at the B photometric band (Soifer *et al.* 1984). For the identified galaxies in Abell 2151 that were detected by *IRAS*, this ratio ranges between 0.17 and 4.8. The galaxies with high ratios of infrared to B luminosity (sources 5, 6, 17a, 22, and 28) are quite comparable to the starburst galaxy M82 in this respect. The initial impression of a high density of infrared-bright galaxies may, in fact, be a selection effect. Redshifts of the visually faint galaxies are needed to understand better the background contribution to the infrared sample.

c) *Unidentified Far-Infrared Objects*

Eleven of the 60 μm sources do not have an obvious galaxy within the 3 σ positional error box. Nine of these, however, have a stellar object at the *IRAS* position. To the limit of the

Palomar Observatory Sky Survey (POSS), there is roughly 0.5–1 stellar source per arcmin^2 in the Abell 2151 field. Hence, the probability of a fortuitous positional coincidence is quite high. Sources 18 and 26 have no optical counterparts on the POSS.

Soifer *et al.* (1984) find that in the *IRAS* minisurvey the galaxies with the most extreme 80 μm to visual luminosity ratios can be positionally associated with galaxies as faint as $B = 18$ mag. Since the present observations are roughly 10 times more sensitive than the survey at 60 μm, the same population of objects could be expected down to $B = 20.5$ mag. These objects would be near the plate limit of the POSS. Significantly better positions for the infrared sources will be required to make meaningful identifications with galaxies as faint as $B = 20$ mag.

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