N87-24305

FAR-INFRARED PROPERTIES OF CLUSTER GALAXIES

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ABSTRACT. Far-infrared properties are derived for a sample of over 200 galaxies in seven clusters: A262, Cancer, A1367, A1656 (Coma), A2147, A2151 (Hercules), and Pegasus. The IR-selected sample consists almost entirely of "IR normal" galaxies, with < Log [L(FIR)] > = 9.79 $L_\odot$, < [L(FIR)/L(B)] > = 0.79, and < Log [S(100μm)/S(60μm)] > = 0.42. None of the sample galaxies has Log [L(FIR)] > 11.0 $L_\odot$, and only one has a FIR-to-blue luminosity ratio greater than 10. No significant differences are found in the FIR properties of HI-deficient and HI-normal cluster galaxies.

I. INTRODUCTION

The synthesis of optical, radio, and X-ray measurements of galaxies and clusters has provided evidence of interaction of galaxies with an intracluster medium (ICM). IRAS observations allow us to expand the scope of studies to examine what effect environmentally driven mechanisms have on a galaxy's rate of star formation. Of particular interest is the question of whether the passage of a spiral disk through the ICM serves to stimulate star formation, especially in the central regions of the disk, or whether the stripping of the interstellar gas quenches star formation processes. We examine the far-infrared (FIR) properties of galaxies in seven clusters and attempt to find correlations with HI deficiency, a quantity that serves as a global probe of a galaxy's interstellar gas content and that is assumed to expose recently stripped galaxies.

II. THE SAMPLE

The noise-limited sample was obtained by coadding months-confirmed IRAS observations for fields six degrees square, centered roughly at the cluster cores. The resultant maps contained over 1700 points which satisfied the criterion S(60μm) > 3σ; this figure was typically 0.15-0.2 Jy. The flux-weighted IR positions were then matched to optical positions listed in the RCBG2, UGC, MCG, and CGCG catalogs, using a search radius of 90 arcsec (2 arcmin for galaxies of large angular extent). This procedure yielded a set of ~350 galaxies. By using redshift information to identify foreground and background objects, and by selecting the most probable IR source in confused fields (based on positional coincidence, morphology, and angular size), we were left with a sample of 206 galaxies with known redshift. The basic parameters for the seven clusters studied can be found in Giovanelli and Haynes (1985:GH).

TABLE I

MEAN OPTICAL / HI / INFRARED PROPERTIES OF CLUSTER GALAXIES

(1) Cluster	(2) N(IR)	(3) N(HI)	(4) a	(5) m	(6) r/r(A)	(7) Log L(B)	(8) Log D(L)	(9) Log M(H)	(10) HI def	(11) Log S(60)	(12) Log S(100)	(13) IR color	(14) Log (FIR)	(15) Log L(FIR)	(16) IR excess
A262	36	24	1.56	14.29	0.77	10.02	1.31	9.37	>0.17	−0.28	0.20	0.45	−13.21	9.62	−0.41
CANCER	32	27	1.58	14.83	0.90	9.78	1.33	9.45	>0.02	−0.25	0.23	0.44	−13.18	9.70	−0.09
A1367	34	28	1.10	15.05	1.01	9.87	1.33	9.38	0.09	−0.25	0.24	0.37	−13.16	9.99	0.07
A1656	56	36	1.01	15.01	1.29	9.93	1.33	9.30	>0.21	−0.36	0.09	0.41	−13.31	9.90	−0.05
A2147	20	15	0.88	15.39	1.34	10.21	1.46	9.71	>0.17	−0.37	0.10	0.40	−13.29	10.28	0.04
A2151	28	20	0.86	15.30	1.79	10.20	1.45	9.75	>0.16	−0.39	0.07	0.40	−13.33	10.25	0.02
PEGASUS	19	10	1.53	14.80	0.65	9.55	1.16	9.29	0.01	−0.23	0.28	0.42	−13.12	9.45	−0.09
ALL CLUSTERS	206	146	1.24	14.89	1.10	9.92	1.33	9.42	>0.12	−0.30	0.17	0.42	−13.23	9.79	−0.10
HI–DEFICIENT	43	43	1.38	14.70	0.78	10.00	1.37	8.99	>0.58	−0.31	0.20	0.46	−13.21	9.84	−0.18
NON HI–DEF	103	103	1.31	14.88	1.21	9.93	1.36	9.55	−0.07	−0.24	0.23	0.41	−13.18	9.89	−0.06

Note that the A2147 and A2151 fields overlap. All distant-dependent quantities assume a Hubble constant of 100 km/s/Mpc.

BRIEF EXPLANATION OF TABLE:

Col. 1 – "HI–deficient" galaxies are those with (HI def) > 0.3; see explanation for col. 10.
Col. 2 – Number of galaxies with IRAS measurements.
Col. 3 – Number of galaxies with high–quality HI measurements.
Col. 4 – Major blue diameter (arcmin).
Col. 5 – Apparent photographic magnitude.
Col. 6 – Projected distance of galaxy from cluster center, in units of Abell radius.
Col. 7 – Optical luminosity (solar units), with corrections applied for systematic effects in the CGCG, galactic extinction, redshift, and internal absorption.
Col. 8 – Linear (major) diameter of galaxy (kpc), obtained from angular diameter in Col. 4.
Col. 9 – Neutral–hydrogen mass (solar units).
Col. 10 – HI–deficiency (logarithmic units), as defined in Giovanelli and Haynes (1985). Positive values denote an HI–deficiency with respect to a suitably defined sample of isolated galaxies.
Col. 11 – IRAS 60um flux density (Jy).
Col. 12 – IRAS 100um flux density (Jy).
Col. 13 – IR color index, Log (S(100um)/S(60um)).
Col. 14 – Total far–infrared (FIR) flux, in units of W/(m*m). FIR is computed from eq. (1) of Soifer et al. (1986), under the assumption that the grain emissivity function is proportional to frequency.
Col. 15 – Total FIR luminosity (solar units).
Col. 16 – FIR to blue luminosity ratio, Log (L(FIR)/L(B)), a measure of infrared excess.

III. INFRARED PROPERTIES AND CORRELATIONS WITH HI PROPERTIES

The mean optical, HI, and infrared properties of the sample galaxies are given in Table I. Note that the A2147 field (~3 degrees square) is fully contained within the A2151 field. Furthermore, the central Hercules cluster (A2151) was examined to a flux density level of S(60μm)=50 mJy by Young et al. (1984). The quantities in columns 7 and 9 of Table I are derived following the precepts of Haynes and Giovanelli (1984:HG). The HI-deficient galaxies are those with HI content less than half (HI def > 0.3) of the value found for an isolated galaxy of the same morphology and linear diameter (see GH for details). The mean values in Table I were computed on a reduced sample (i.e. upper limits excluded), with the exception of "HI def" (for which lower limits were included). Since the sample is flux-limited, it clearly suffers from the Malmquist bias, as seen in the figures of col. 15. In the context of the current study, however, the most important derived FIR properties are Log [S(100μm)/S(60μm)], the IR color index, and the FIR-to-blue luminosity ratio Log [L(FIR)/L(B)]. For convenience, we will refer to these quantities as "IR color" and "IR excess", respectively.

The sample galaxies in our study are found in clusters of various morphologies, ranging from centrally concentrated clusters (A262, A1656) to loosely organized systems (Cancer, Pegasus). Yet, inspection of Table I reveals that there is little variation in the mean values of IR color and IR excess, with one exception: the IR excess of A262 is significantly lower than any of the other clusters. This is due, in part, to the high proportion of early-type galaxies in the A262 sample and the associated high values of optical luminosity. The fraction of E-S0 galaxies in A262 is 10/34, twice that of the other clusters. Table II shows that, on the whole, IR excess is lower in E-S0 cluster galaxies than in later types. This is certainly not surprising, in light of the fact that E and S0 galaxies have low amounts of the dust associated with FIR emission.

TABLE II

DISTANCE-INDEPENDENT FIR PROPERTIES AS FUNCTIONS OF MORPHOLOGICAL TYPE

	IR COLOR Log [S(100)/S(60)]			IR EXCESS Log [L(FIR)/L(B)]		
	All	HI-def	non HI-def	All	HI-def	non HI-def
All galaxies	0.42(0.14)	0.46(0.17)	0.41(0.13)	−0.10(0.35)	−0.18(0.34)	−0.06(0.31)
E − S0a	0.45(0.15)	——	——	−0.30(0.35)	——	——
Sa − Sab	0.40(0.18)	0.54(0.17)	0.37(0.13)	−0.14(0.42)	−0.36(0.34)	−0.09(0.41)
Sb − Sbc	0.43(0.15)	0.47(0.16)	0.40(0.13)	−0.12(0.32)	−0.13(0.31)	−0.11(0.32)
Sc − Scd	0.45(0.08)	0.39(0.03)	0.45(0.08)	−0.08(0.21)	0.06(0.02)	−0.09(0.22)
Pec., Dist.	0.34(0.10)	0.39(0.03)	0.33(0.10)	−0.02(0.39)	−0.32(0.21)	−0.03(0.28)

Figures in parentheses are standard errors of the mean.

In Figure 1, the IR color is plotted as a function of HI deficiency for all cluster galaxies within a projected Abell radius [r/r(A)] of 1.4. This latter constraint not only gives us uniform IRAS coverage for each of the clusters but is also the radius within which most of the HI-deficient galaxies reside. If one considers only the reduced sample (dashed line), no correlation is found. However, a very marginal correlation is apparently present when the limits are incorporated (solid line), using the algorithm for doubly-censored data given in Schmitt (1985). This "correlation" must be considered suspect, however, when one notes that typical logarithmic uncertainties are 0.15-0.2 in both HI deficiency and IR color. To quantitatively judge the significance of this result, we applied nonparametric statistical tests suitable for censored data. We find that the difference in the IR color distributions of HI-deficient and HI-normal galaxies to be less than a 2σ effect.

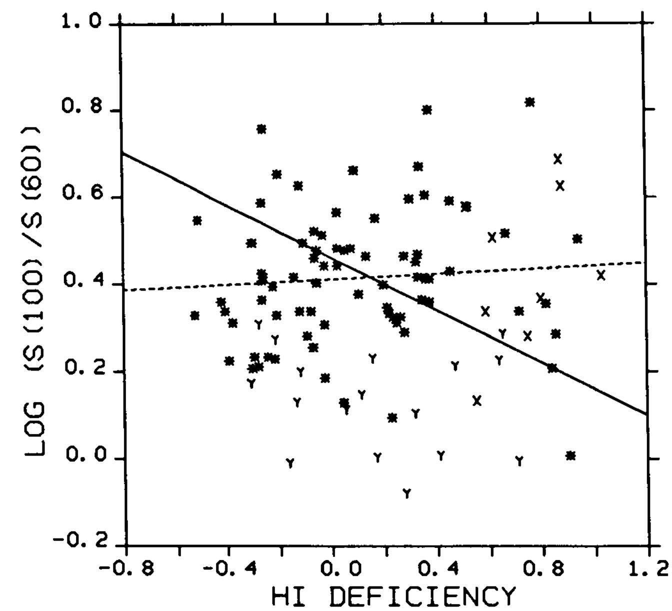

Figure 1

A plot of IR color as a function of HI deficiency for all cluster galaxies with known redshift and [r/r(A)] < 1.4. "X" denotes a lower limit in HI deficiency; "Y" denotes an upper limit in IR color. The results of two regressions are superimposed. The dashed line excludes IR limits, but includes HI limits. The solid line is a result of applying the Schmitt (1985) algorithm for doubly-censored data. The correlation coefficients are 0.07 and 0.49, respectively.

IV. SUMMARY AND CONCLUSIONS

The following points are made with respect to the > 200 sample galaxies:

(1) The sample consists almost entirely of "IR normal" galaxies. Included in the noise-limited sample are 31 E-S0a galaxies (18% of the sample galaxies with known morphology).

(2) The derived IR properties are (nearly) normally-distributed, with < Log [L(FIR)] > ~ 9.8 $L_\odot$, < [L(FIR)/L(B)] > ~ 0.8, and < Log [S(100μm)/S(60μm)] > ~ 0.4. None of the galaxies has Log [L(FIR)] > 11.$0_\odot$. Only one, the distorted double system NGC 3808 (VV 300) in A1367, has a FIR-to-blue luminosity ratio > 10.

(3) 12% of the galaxies with known morphology are classified as peculiar, disturbed, interacting, etc. Clearly, the tidally-induced disruption of a galaxy is not a necessary condition for FIR emission.

(4) Under the assumption that dust emissivity is proportional to frequency, the mean FIR color temperature is 30-35 K, with no variation seen among different spiral types. There is no way to tell if this is an integrated temperature due to the two components suggested by de Jong et al. (1984).

(5) There is NO significant correlation between derived IR properties and either projected Abell radius or, more importantly, HI deficiency.

(6) The absence of IR luminous galaxies leads us to conclude that if star formation is stimulated by the interaction of cluster galaxies with the ICM or the general cluster environment, it occurs at a negligible rate or over a time scale that is very small when compared with that of determinable HI gas deficiency.

This study was partially supported by NASA grant NAS7-918 and by the National Astronomy and Ionosphere Center, operated by Cornell University under contract with the National Science Foundation.

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