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FIR STATISTICS OF PAIRED GALAXIES

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Introduction

Much progress has been made in understanding the effects of interaction on galaxies (see reviews in this volume by Heckman and Kennicutt). Evidence for enhanced emission from galaxies in pairs first emerged in the radio (Sulentic 1976) and optical (Larson and Tinsley 1978) domains. Results in the FIR lagged behind until the advent of the IRAS satellite. The last five years have seen numerous FIR studies of optical and IR selected samples of interacting galaxies (e.g., Cutri and McAlary 1985; Joseph and Wright 1985; Kennicutt et al. 1987; Haynes and Herter 1988). Despite all of this work, there are still contradictory ideas about the level and, even, the reality of an FIR enhancement in interacting galaxies. Much of the confusion originates in differences between the galaxy samples that were studied (i.e., optical morphology and redshift coverage). We report on a study of the FIR detection properties for a large sample of interacting galaxies and a matching control sample. We focus on the distance independent detection fraction (DF) statistics of the sample. The results prove useful in interpreting the previously published work. A clarification of the phenomenology provides valuable clues about the physics of the FIR enhancement in galaxies.

Data Samples

The Catalog of Galaxy Pairs (CPG) (Karachentsev 1972 and review in this volume) was used for this study. The CPG has numerous advantages.

1) **Large Sample:** There are 509 pairs after allowance is made for discordant redshifts, misclassified single galaxies, and pairs not surveyed by IRAS.

2) **Physical Pairs:** Pairs were selected using an isolation criterion expressed in terms of component size and separation. This increases the likelihood that they are physical systems. The existence of complete redshift data permitted us to refine the sample even further in this direction.

3) **Morphological Diversity:** Selection criteria accepted all isolated pairs irrespective of type. The large and unbiased sample means that we are able to discriminate DF as a function of both component Hubble and pair interaction morphology.

4) **Control Sample:** A final advantage is that the CPG can be compared to a catalog of isolated galaxies (CIG) (Karachentseva 1973) that was assembled using many of the same selection criteria. Its advantages are the same ones as listed for the CPG except that there is less morphological data available for most CIG galaxies (see Sulentic 1989 for details).

The FIR data for the optically selected pairs was taken from version II of the IRAS Point

Source Catalog (PSC). The PSC provides data on unresolved sources over 96% of the sky. It is complete to about 0.6Jy at 60μ which is the wavelength of most sensitivity and least confusion for galaxies. The resolution at this wavelength is 1.0 arcmin (FWZI; in-scan direction) which means that the vast majority of our pairs will be unresolved. We accepted all hour-confirmed detections from the PSC.

DF Enhancement For A Spiral Galaxy

Table 1 lists the detection fractions for the principal morphological classes in the CPG and CIG. Initially we distinguish only between spiral-spiral (SS), spiral-E/S0 (ES), and E/S0-E/S0 (EE) pairs. Not surprisingly, we see large differences in DF between these three groups with very few early type galaxies detected in the PSC. After allowance for spiral galaxies misidentified as E/S0, we get a $DF = 0.06 \pm 0.04$ for EE pairs. Comparison of these results with those for the CIG control sample indicates a significant DF enhancement for both SS and ES pairs.

TABLE 1
DETECTION FRACTIONS

TYPE	NUMBER IN CAT.	DETECTION FRACTION	TYPE	NUMBER IN CAT.	DETECTION FRACTION
All Pairs	509	0.63 ± 0.02	All Isolated	1029	0.32 ± 0.01
SS Pairs	297	0.78 ± 0.02	LIN Pairs	92	0.77 ± 0.04
ES Pairs	148	0.54 ± 0.04	ATM Pairs	78	0.40 ± 0.05
EE Pairs	63	0.11 ± 0.04	DIS Pairs	118	0.79 ± 0.04
S Isolated	864	0.35 ± 0.02	JUS Pairs	224	0.57 ± 0.03
E/S0 Isolated	165	0.17 ± 0.03			

We can use the results for ES pairs to estimate the enhancement in DF for a spiral galaxy in a pair. The “normal” detection level for isolated spirals is $DF=0.35$ which implies $DF=0.58$ for two spirals in an optical pair. This is the probability that one or both components are detected and ignores any contribution to the DF from two (individually undetected) spirals whose combined weak emission raises them above the detection threshold. We note, however, that $DF=0.54$ for ES pairs which we can use to estimate the threshold effect. We assume this value to represent the detection probability for an interaction enhanced spiral assuming the E/S0 component contribution to the FIR emission in pairs is negligible. Two such enhanced spirals in a pair would yield $DF=0.79$ as the probability of detection. We observe $DF=0.78$ from the CPG sample of SS pairs. This agreement between prediction and observation suggests that the contribution to DF from threshold crossing pairs is negligible. The difference between the DF for isolated S and for SE pairs will then give us $P=0.19$ for the average enhancement in DF for a spiral galaxy due to membership in a pair. This result applies to pairs brighter than $m_{pg} \approx 15.0$ and within $V_0 \approx 11 \times 10^3$ km/s. The enhancement increases from 0.10 ± 0.05 nearby to 0.30 ± 0.05

at 11×10^3 km/s. At a distance corresponding to 16×10^3 km/s we expect interacting pairs to be the dominant contributor to FIR selected samples. These results suggest that studies restricted to low redshift (i.e. $m_{pg} \leq 13.5$) samples or those containing many early-type galaxies will lead to underestimates of the enhancement.

At first glance, the above result might suggest that, on average, both components of an SS pair are enhanced at the same level. Of course, the resolution of IRAS does not allow us to say anything about the flux ratio in SS pair components. We have used the ES pairs to overcome, as much as is possible, the resolution problem. If certain assumptions are valid, we are able to estimate the average component enhancement in pairs containing spiral members. It is possible that the flux ratio is sensitive to the details of the encounter geometry. The evidence that threshold crossing pairs contribute little to the DF is one argument that a single component dominates the FIR emission in most pairs. A similar conclusion was reached by Telesco et al. (1988).

DF and Optical Morphology

Figure 1 presents the correlation of DF with: (UL)–Hubble component morphology; (UR)–pair interaction morphology; (LL)–diameter ratio of the pair components; (LR)–component separation. The DF for an unenhanced (i.e., optical) spiral pair is indicated by a dotted line in the latter three panels. We will discuss the four panels of Figure 1 in the following paragraphs.

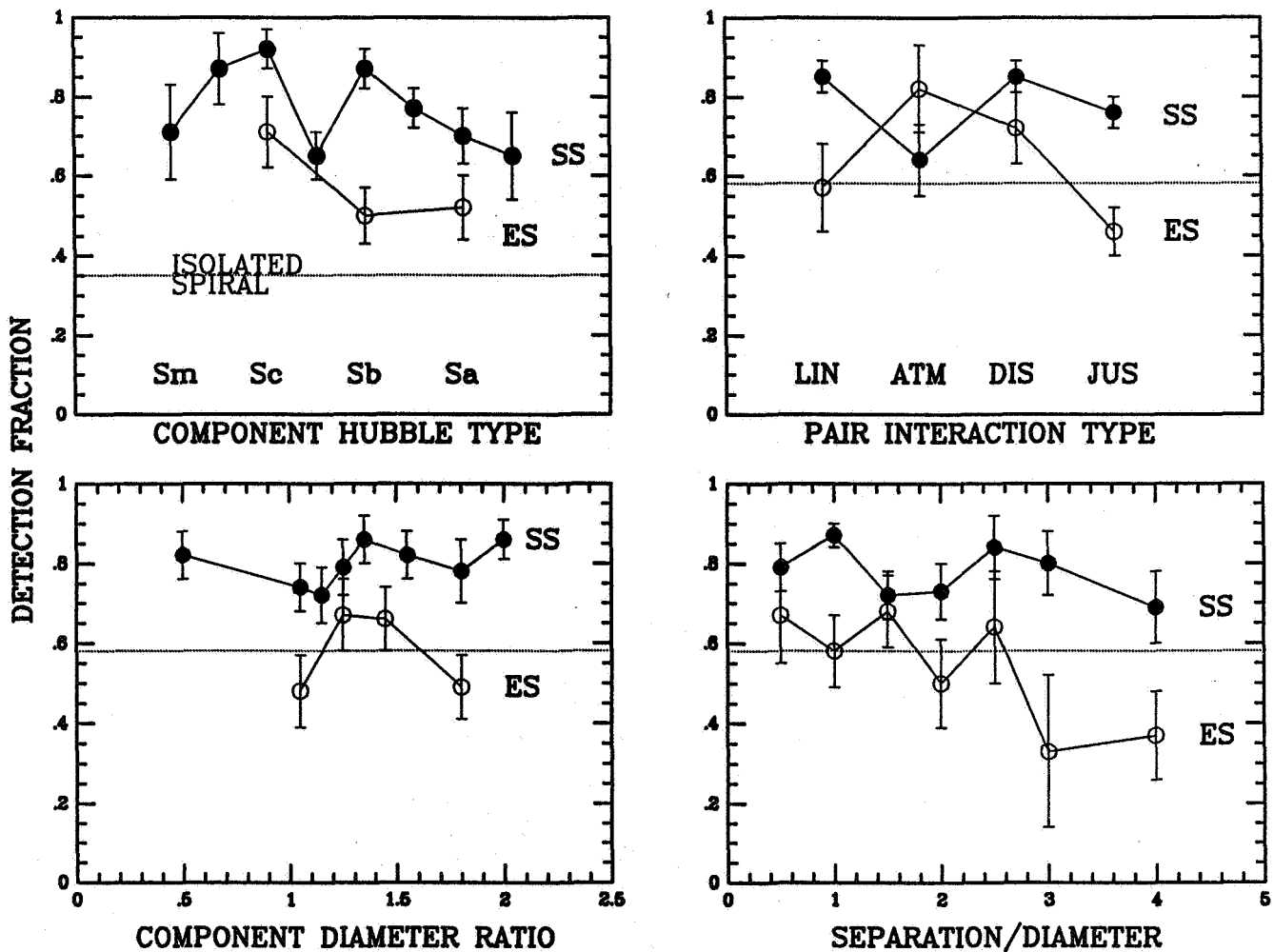
(UL). The principal handicap to a study of the DF–galaxy morphology correlation involves the uncertain (Palomar Sky Survey based) types assigned to CPG and CIG galaxies. Improved Hubble types are now available from 6m (Zelenchuk) plates and from other sources (see Karachentsev 1987). This heterogeneous, but improved, data permits us to study the correlation for the principal spiral types using both SS pairs with two components of like morphology and the ES pairs. A comparison of the DF for early and late type spirals shows that the enhancement in DF is not in close proportion to the average fraction of non-stellar material (as estimated from 21cm studies). Even the relatively gas/dust poor Sa spirals show a significant enhancement. This indicates that the *efficiency* of the enhancement process (encounter geometry, mass ratio, ratio of disk to nuclear emission, etc.) is an important consideration.

(UR). The CPG also assigned interaction types to pairs. We display the principal interaction types for SS and ES pairs in this panel. The LIN class represents pairs with the clearest signs of interaction involving bridges or tails. The ATM class represents pairs with components imbedded in a common envelope. The DIS class involves pairs where one or both components show signs of distortion. This is a more subjective criterion but, still, one assigned independently of the IRAS survey. The JUS class represents pairs with no obvious signs of disturbance. The importance of an efficiency measure is again emphasized by the small difference in DF between pairs with and without optical signs of interaction. Apparently obvious optical signs of interaction do not always accompany the enhancement process. The picture is yet incomplete, since we do not consider here the intrinsic properties of the detected pairs (see Xu and Sulentic this volume).

(LL). We have used uneven binning in this display in order to keep the 1σ rms at about

0.07. The leftmost SS point represents ratios between 1.0 and 1.1. A search for a correlation of DF with the ratio of component major axis diameters offers an opportunity to study the efficiency mechanism in a different way. This is the simplest approach to searching for a possible correlation with the component mass ratio. We are restricted in this test to relatively equal size pairs because the selection criteria for the CPG are biased against the inclusion of hierarchical pairs. Over the range of ratios represented, there is no evidence for equal size pairs to be more frequently detected. This suggests that a companion can still be an effective perturber even if it is as much as a factor of four smaller in mass than the primary (again, we are not considering average FIR luminosities here). This result offers additional support for the idea that a single component of most pairs contributes most of the flux (see also Telesco et al. 1988). This interpretation is clouded because we do not yet know how efficiently gas rich "dwarf" companions are stimulated by their larger neighbors.

FIGURE 1



(LR). A study of DF vs. the primary diameter/separation ratio offers the chance to detect the critical separation at which FIR enhancement sets in. We see only weak evidence for enhanced DF in closer pairs, especially among the SS pairs. This may indicate that most spirals in pairs are stimulated to emit in the FIR but that the luminosity of close pairs is higher. Another possibility is that the enhancement persists long after the initial stimulation either through slow nuclear fuelling or amplification of a stochastic star formation process. Only at separations of three or four times the primary diameter do the DF levels fall towards "isolated" levels.

Summary

1) In determining existence and level of an FIR enhancement in pairs one must consider both **morphology** and **redshift coverage**.

2) An enhancement exists in both SS and ES pairs. It is strongest in SS pairs but it is significant in ES pairs.

3) The strongest enhancement occurs for pairs with LIN(br) and DIS interaction morphologies but an enhancement also exists in JUS (plain) pairs.

4) The weak correlation of component Hubble type with DF suggests that DF is not a simple function of gas/dust content but that **efficiency** of encounter stimulation plays an important role. This is also supported by the lack of correlation between DF and component size ratio.

5) There is little correlation between DF and component separation.

6) We are probably missing the most dramatic examples of FIR enhancement when considering samples of binary galaxies with an isolation criterion. It is not the primordial pairs but the random encounters that are likely to exhibit the strongest effects.

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DISCUSSION

S. Schneider: Did you see any far-infrared enhancement in the discordant redshift pairs?

J. Sulentic: There is no sign of enhanced DF for the discordant pairs, although 14 were classified as LIN, ATM, or DIS in the CPG.