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MORPHOLOGICAL TYPE CORRELATION BETWEEN NEAREST NEIGHBOR PAIRS OF GALAXIES

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I. INTRODUCTION

Although the morphological type of galaxies is one of the most fundamental properties of galaxies, its origin and evolutionary processes, if any, are not yet fully understood. It has been established that the galaxy morphology strongly depends on the environment in which the galaxy resides (e.g. Dressler 1980).

Galaxy pairs correspond to the smallest scales of galaxy clustering and may provide important clues to how the environment influences the formation and evolution of galaxies. Several investigators pointed out that there is a tendency for pair galaxies to have similar morphological types (Karachentsev and Karachentseva 1974, Page 1975, Noerdlinger 1979).

We analyzed morphological type correlation for 18,364 nearest neighbor pairs of galaxies identified in the magnetic tape version of the Center for Astrophysics Redshift Catalogue (Huchra 1987, hereafter CfA Catalog).

II. SAMPLE DEFINITION AND CORRELATION ANALYSIS

a) CfA Catalog

The CfA catalog contains 18,364 galaxies for which radial velocity data are available. This catalog is based on much of the latest velocity data from many sources. There are some galaxies which happen to be registered twice or more. We have adjusted these galaxies as much as we could find, consequently resulting in 18,323 galaxies to be used as sample galaxies in this study.

b) Definition of Nearest Neighbor Pairs

Simply applying the Hubble law, we assigned the distances to the galaxies from us as $r = v/H_0$, where H_0 is the Hubble constant. Thus the distance between a certain galaxy and another is defined by,

$$d^2 = r_1^2 + r_2^2 - 2r_1r_2\cos\theta \tag{1}$$

where θ is the angular separation between the two galaxies. The distances between galaxies of all the possible pairs were calculated using equation (1). Then, the nearest neighboring partners were derived for all the sample galaxies except for one galaxy having two nearest partners at the same distance. We excluded this galaxy in our analysis.

In the CfA catalog, morphology indices are presented, which are mainly based on the Second Reference Catalogue of Bright Galaxies (de Vaucouleurs *et al.* 1976). Galaxies with $-6 \le T \le -4$ are ellipticals, $-3 \le T \le 0$ are S0's, and spirals are $1 \le T \le 9$. Galaxies lacking detailed classification are assigned type indices $T = -7, 15, 16$, and 20 in the CfA Catalog.

We note that our nearest pairs are not always the galaxy pairs in the ordinary sense, for example, when the nearest galaxy to A is B, the nearest to B is not necessarily A but may be a third galaxy C. Other than those exceptional pairs, the same pairs are used twice in the analysis.

c) Morphological Type Correlation

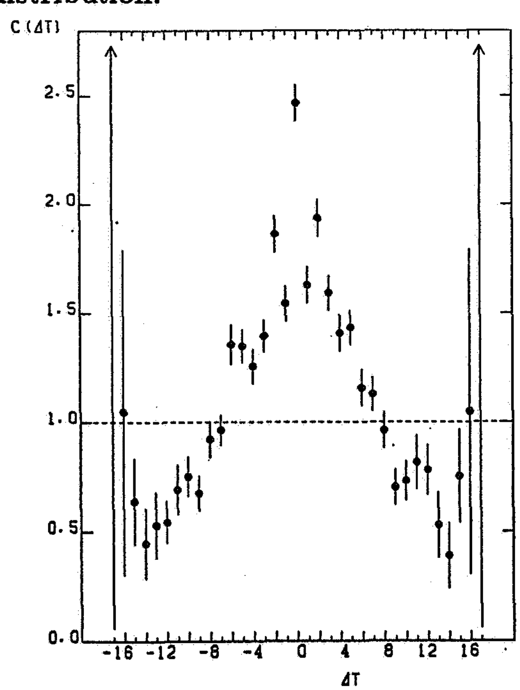
In order to represent the morphological type correlation, we defined the type correlation spectrum $C(\Delta T)$ by

$$C(\Delta T) \equiv \left(\sum_{i-j=\Delta T} n_i^j \right) \Bigg/ \left(\sum_{i-j=\Delta T} n_i \cdot n_j N \right) \quad (2)$$

where n_i^j gives the number of pairs having the type $T = i$ for the sample galaxy and $T = j$ for its nearest neighbor, and n_i, n_j are the total number of galaxies of $T = i, T = j$ respectively. The total number of nearest pairs is given by N.

We excluded pairs including one or two galaxies having type indices $T \leq -7$ or $T \geq 15$, which means peculiar and/or unclassified morphology. But those pairs are, of course, included in N.

Figure 1 shows the presence of the type correlation at $\Delta T = 0$ for the nearest neighboring pairs of galaxies. If there is no morphological type correlation, then $C(\Delta T) = 1$ for all ΔT (dotted line in Figure). Error bars represent $\pm 1\sigma$ statistical errors due to Poisson distribution.



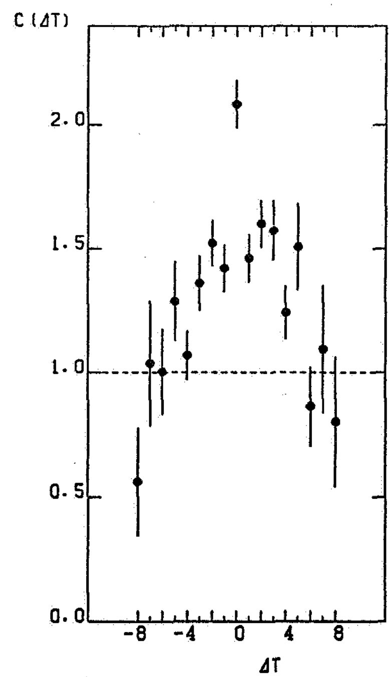


Fig 1 (left). The morphological type correlation spectrum $C(\Delta T)$ for the total sample. The abscissa is the difference of the type indices between nearest-neighbor pairs.

Fig 2 (right). Same as Fig. 1, but the data are limited to spiral-spiral pairs of galaxies.

It is well known that there exists the morphology segregation between spirals and non-spirals (Dressler 1980, Postman and Geller 1984). Moreover the morphological type of galaxies was classified in much more detail for spirals than for ellipticals in our sample. These facts naturally leads to enhancement of $C(\Delta T)$ around $\Delta T = 0$. In order to check these effects, a similar analysis was carried out for a sample limited to spiral-spiral pairs $(1 \leq T_1, T_2 \leq 9)$. By removing elliptical galaxies from sample pairs, it is expected to see the type correlation free of morphological segregation between spirals and non-spirals. The derived type correlation spectrum for spiral-spiral pairs is shown in Figure 2. This figure also assures the presence of an excess of spectrum at $\Delta T = 0$.

d) IRAS catalog

Our sample galaxies were identified with objects in the IRAS catalog to classify them into two categories: an *IRAS galaxy* which has a counterpart in the IRAS catalog within the following error box, and a *non-IRAS galaxy* with no IRAS counterpart. The error box is defined as follows:

$$\begin{cases} |\alpha - \alpha_0| & < 180'' \\ |\delta - \delta_0| & < 180'' \end{cases} \tag{3}$$

where (α_0, δ_0) is the coordinate of the galaxy. The identification yields 5,262 IRAS and 13,061 non-IRAS galaxies. We divided 18,322 nearest neighbor pairs into three classes; the pairs in the first class consist of both non-IRAS galaxies, the pairs consisting of both IRAS galaxies for the second class, and those of an IRAS and a non-IRAS galaxy for the third. The number in each class is 10,201, 2,425, and 5,696 pairs, respectively.

The type correlation spectrum is re-calculated for each of three classes. The total number of pairs with classified types is given by $(N_p \equiv \sum_{i,j=-6}^{11} n_i^j$, and amounts to 3,004, 1,315, and 2,608 for each of three classes respectively.

The results are shown in Figures 3a, b, and c. The strong type correlation peaked around $\Delta T = 0$ can only be seen for pairs of both non-IRAS galaxies (Figure 3a) while no correlation for pairs of both IRAS galaxies showing only statistical fluctuation at the level of $C(\Delta T) = 1$ except for $\Delta T = 0$ (Figure 3b). For the third class, there can be seen only statistical fluctuation around $C(\Delta T) = 1$ (Figure 3c). We note that there are spikes at $\Delta T = 0$ both in figures 3a and 3b but not in figure 3c.

III. DISCUSSION

a) Completeness in the catalogs

The CfA Catalog contains velocity data from many sources, which are distributed over the whole sky. Galaxies in the CfA Catalog do not form a complete sample, in the sense that each source has different limiting magnitude. We neglected the incompleteness of the catalog in this study. A Complete sample of galaxies can be obtained from the CfA Catalog, if the restricted area of the sky is adopted. One of such examples is called "North Zwicky Forty" (Huchra *et al.* 1983). The type correlation spectra were calculated with the sample limited to the "North Zwicky Forty" region. The results are essentially similar to those of Figures 1 and 2, except for the increase of the statistical fluctuation due to the smaller number of sample galaxies, thus confirming that the incompleteness of the CfA catalog does not affect our conclusion.

As for figures 3, the bias effect is introduced by the difference of the surveyed depth between CfA galaxies and IRAS galaxies. In order to check this effect, the morphological type correlation is calculated for the sample limited to the galaxies having radial velocity less than $5000 kms^{-1}$. Comparing with figures 3, the results are essentially similar except for the increase in statistical uncertainties due to the smaller number of the sample pairs.

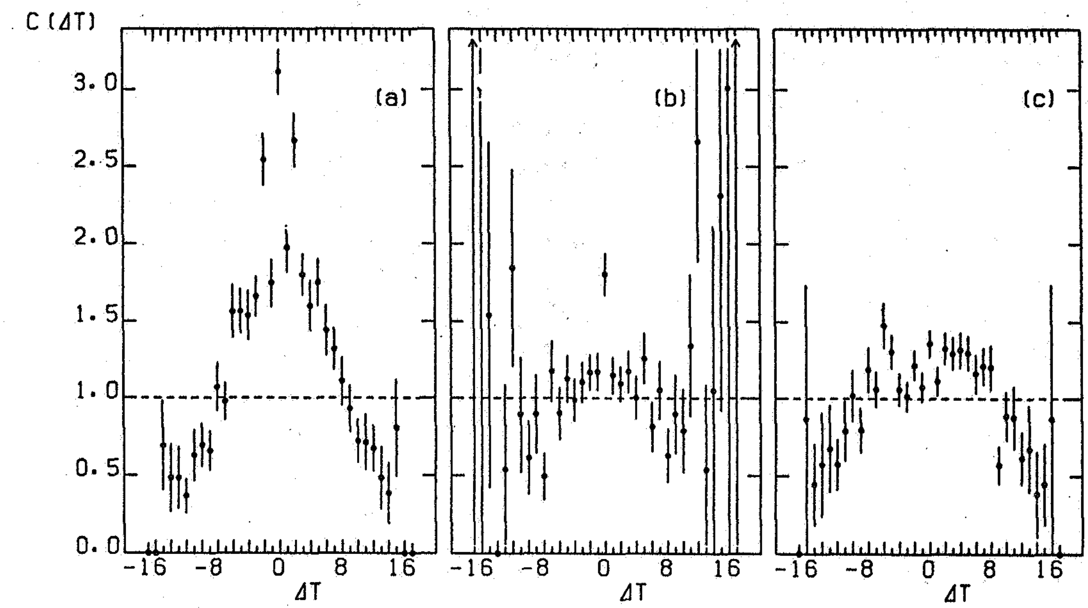


Fig 3. The morphological type correlation spectrum $C(\Delta T)$ for various sub-samples. (a)For the pairs of both non-IRAS galaxies. (b)For the pairs of both IRAS galaxies. (c)For the pairs of IRAS galaxy and non-IRAS galaxy.

In order to clarify that our results are not due to the selection effect, we carried out the morphological correlation analysis upon the sample in which galaxies are distributed randomly in the space of $0 < x, y, z < 30000$. The number of each morphological type is taken as the same as the real sample. As the consequence, there is no correlation seen for this random sample.

b) Morphology Density Relation

It is natural to consider that IRAS galaxies are gas-rich galaxies (e.g., Sanders and Mirabel 1985) which agrees with the fact that IRAS galaxies are mostly spirals (de Jong *et al.* 1984). The gaseous content of field galaxies are richer than that of cluster galaxies (Giovanelli and Haynes 1985, Haynes *et al.* 1984). This is also true for IRAS galaxies, since luminous IRAS galaxies are found in field galaxies and not in cluster galaxies (Bicay and Giovanelli 1987).

According to Postman and Geller (1984), the fraction of spirals or ellipticals is constant in the region of the galaxy density less than 5 galaxies Mpc^{-3}, that is, no morphology density relation is shown, while a clear relation is present for galaxy density greater than 5 galaxies Mpc^{-3}. These facts suggest the possibility that most of IRAS galaxies reside in the region of the galaxy density less than 5 galaxies Mpc^{-3}, while non-IRAS galaxies are considered to be in the region of the density greater than 5 galaxies Mpc^{-3}, if we assume that the origin of the strong correlation in non-IRAS galaxy pairs and no correlation for other pairs is the same as that of the morphology density relation. The morphology segregation is existent even within spiral galaxies (Giovanelli *et al.* 1986). Thus, the same tendency of the morphological type correlation seen in the spiral-spiral pairs (Figure 2) is naturally understood.

c) Twin Galaxies

As seen in Figure 3a, the spiky enhancement of $C(\Delta T)$ at $\Delta T = 0$ is exceptionally high. Moreover, there can also be seen the enhancements of $C(\Delta T)$ at $\Delta T = 0$ for both-IRAS pairs (figures 3b). It is not clear whether these are completely ascribed to the morphology density relation. One explanation is that mechanisms in the early phase of galaxy formation should be responsible to these enhancements. This fact leads us to point out the existence of twin galaxies which are the extreme case of morphological type correlation (Yamagata *et al.* 1989). Twin galaxies are defined as pairs of galaxies which have not only the same morphological type but also similar internal structures. Our nearest neighboring pairs with $\Delta T = 0$ are possible candidates for twin galaxies. It is interesting that the spiky enhancement is seen only in the galaxy pairs with similar IR characteristics (i.e. both-IRAS-galaxy pairs and both-non-IRAS-galaxy pairs). This may suggest that the infrared properties are also similar in twin galaxies as well as other characteristics. All the candidates of twin galaxies were examined by Palomar Sky Survey or ESO prints confirming that both-IRAS pair candidates are mostly spirals. Many of both-IRAS pair candidates have no disturbed shapes expected from galaxy-galaxy collision, thus implying that far-infrared emission in both-IRAS pair candidates is not always due to galaxy interaction.

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DISCUSSION

Zasov: Could it be that a correlation between morphological types of nearby galaxies is just another manifestation of the so-called Holmberg effect, that is, a colour-index correlation of galaxies in pairs and probably in groups?

Yamagata: The main difference is that our sample doesn't always consist of binary galaxies but nearest-neighbor pairs. The number of pairs in our sample is larger than in any other previous work. A similar analysis was done by Page (1975) for only 427 pairs found by Zonn and Cook (1963). Therefore, the Holmberg effect is one interpretation of our morphological-type correlation.

Mamon: (answer to Zasov's comment) - Hickson's compact groups show morphological correlations as shown by Sulentic (1987) and Hickson, Kindl, and Huchra (1988). I've looked for the same effect for the quartets and quintets in the CFA group catalog of Geller and Huchra (1983) and found no correlation: the fraction of groups with concordant general type (E + L versus S) is consistent with the expected fraction. If morphological correlations are caused by initial conditions at galaxy formation, then one needs to explain why this effect is more pronounced for Hickson's groups than for Geller and Huchra's looser quartets and quintets.

Sulentic: While morphologically concordant pairs certainly exist in great numbers, I would point out that <u>one</u> out of <u>four</u> "physical" pairs in the CPG of Karachentsev (1972) are of <u>mixed</u> (E + S) morphology. They are a striking challenge for galaxy formation theories that correlate galaxy morphology with environmental conditions.

Yamagata: I think it very interesting to investigate whether there is difference between the spatial distribution of the pairs of mixed morphology and that of concordant pairs. Because if there's a difference, we may then know the spatial distribution of the primordial proto-galaxy cloud.

Dey: You showed that there is an effect for spiral-spiral pairs to be of the same morphological type, but that there is very little effect for "IRAS active" pairs. Could you comment on this?

Yamagata: The detection limit of IRAS galaxies is brighter than that of CFA galaxies. We checked the correlation for distance-limited data ($V < 5000$, $V < 6000$, $V < 7000$), the results are essentially the same....no correlation, but enhancement at $\Delta T = 0$. Several possibilities for this phenomena are considered. For example, morphology segregation in spirals existed only in "IRAS-quiet" galaxies, but, frankly speaking, an exact interpretation is not available.

Keel: How much of your type-correlation signal is due to nearest neighbors that are too far apart to be considered physical pairs of galaxies?

Yamagata: As to the separation distance of the pairs, there is essentially no effect on the conclusion. (We checked by the separation-distance-limited data. The correlation is stronger.)