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Statistical Analysis of Discrepant Redshift Associations Quintets of Galaxies

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Summary. We study in this paper the statistical significance of discrepant redshift quintets of galaxies. Taking into account the small number of known redshifts, we find that the probability that they might be chance projections of field galaxies is only $2 \cdot 10^{-3}$ to $3 \cdot 10^{-4}$. It is concluded that the problem of anomalous redshifts in compact groups of galaxies still remains.

Key words: galaxies, groups of — redshift

I. Introduction

Through the discussion on anomalous redshifts (see Arp, 1976; Pecker, 1976, for reviews on the subject), statistical arguments have been often used and led to different conclusions. In this Paper I, we reanalyse the significance of discrepant redshift quintets of galaxies. Paper II (Moles and Nottale, 1977) will consider quasar-galaxies and quasar-quasar associations.

There has been constant interest for discrepant redshift within compact groups of galaxies since the discovery by Burbidge and Burbidge (1961) that the redshift of NGC 7320 was $\sim 6000\ \mathrm{km\ s^{-1}}$ smaller than the mean in Stephan's quintet. Sargent (1968) found a discrepant redshift of $\sim 20\,000\ \mathrm{km\ s^{-1}}$ in the chain VV172; Burbidge and Sargent (1971) have shown that a galaxy in VV115, known as Seyfert "Sextet" had a redshift $\sim 15\,000\ \mathrm{km\ s^{-1}}$ in excess. A great number of contradictory papers were published, especially about Stephan's quintet and VV115. Allen (1970), Lynds (1972), Shostak (1974a,b), Ciatti and Rosino (1977) conclude that the discrepant redshift galaxies in Stephan's quintet lie at different distances, while Arp (1972), Balkowski et al. (1973) or Arp and Lorre (1976) reach a different conclusion. The same discrepant results are found in Walker et al. (1974), Martins and Chincarini (1976) from one side, Arp (1973), Arp and Lorre (1976) from the other in the case of VV115.

Such a disagreement is also found in statistical analysis. Sargent (1968) finds a probability of chance projection 1/300 to 1/5000 in the case of VV172. Joss et al. (1976) insist on the difficulty related to the a posteriori use of probabilities. Finally, only the systematic survey by Rose (1977) allows one to calculate reliable probabilities, because observed data can be compared to a global population.

In the present paper, we calculate the probability that the three known cases of discrepant redshift quintets might be chance projection effects. We also take tentatively into account a new discrepant association discovered by Arp (1976, 1977).

II. Quintets with one Discrepant Redshift

1. Introduction

Rose (1977) derived from inspection of Palomar Observatory Sky Survey plates that the total number of triplets, quartets and quintets were respectively of the order of $N = 2800$, $N = 430$–550 and $N \cong 33$. The compact groups he defines are associations for which the faintest galaxy has a blue magnitude $B \leqq 17.5$ and $A\sigma \leqq 0.0035$ (A: area subtended by the group; σ = surface density of field galaxies brighter than the faintest of the group).

Then he finds the expected number of discrepant redshift quintets (1 quartet + 1 field galaxy) to be $Nd = N_4 \sigma A = 1.5$–2.0, in good agreement with the known number of 3. He then concludes that these three cases are only due to chance projection.

2. Analysis

The trouble with this calculation is that it does not take into account the fact that not all quintets have known redshifts for each member. To avoid this possible bias we have searched the literature for redshifts of galaxies in quintets following Rose's criteria. Eight quintets were

Table 1. The table gives the list of quintets of galaxies having published redshifts. (1) Name of the quintet in Vorontsov-Velyaminov (1959, 1977) or other. (2) Mean of concordant redshifts in the group. (3) Discrepant redshift, if any. (4) Reference: a: Arp (1973), b: Sargent (1968), c: Burbidge, Sargent (1971), d: Arp (1976, 1977)

(1) Name	(2) ⟨V⟩	(3) Discrepant V	(4) Reference
VV288 (Stephan)	6375	800	a
VV115 (Seyfert)	4400	19 900	a
VV172	15 765	36 880	b
VV116	6680		a
VV150	8075		a
VV165	12 742		c
VV197	11 861		c
VV208	7932		c
Chain Wof N4151	47 900	18 030 13 200:	d

Table 2. A list of quintets of galaxies found in the Catalogue of Interacting Galaxies, parts I and II (Vorontsov-Velyaminov, 1959, 1977). They are designated by their VV number. Possible cases are given between brackets

(101)	(212/3)	523
115	242	656
116	251	657
129	288	(668)
(134)	(314)	(669)
(140)	(342)	675
150	495	676
(161)	505	677
165	506	680
167	508	
172	509	
197	517	
208	522	

found, three of them with one discrepant redshift (Table 1). An additional quintet with two discrepant redshifts, reported by Arp (1976) near NGC 4151 is also given in Table 1. Blue magnitudes are given by Arp (1977) for two objects in the chain ($B = 18.36$ and $B = 18.98$). Then this chain does not fulfill Rose's criterium $B \leqq 17.5$.

Let n be the number of quintets due to chance projection of a field galaxy on a quartet, q the number of quintets whose redshifts are known (here $q = 8$). If one assumes that all "false" quintets are due to chance projection, then $n = 3$. Present data are the combination of two events.

(E_1) the number of "false" quintets is $n = 3$, while the expected number was $Nd = N_4 \sigma A = 1.75$ for $N_4 \simeq 500$.

(E_2) While only q quintets have known redshifts, among these the n "false" quintets were discovered.

Since E_1 and E_2 are independent, the probability of observing present data is $P = P_{E_1} \times P_{E_2}$.

3. *Computation of P*

Since the probability to find one object projected on a quartet is $p \simeq 0.0035 \ll 0.1$, the probability P_{E_1} is well approximated by a Poisson law, $p(x) = e^{-\nu}\nu^x/x!$ with $\nu = Nd = 1.75$. We are not interested in the probability of the precise value $n = 3$, but in the probability of the digression of the actual value from the expected one, then

$$P_{E_1} = p(x \geqq 3) = 1 - \sum_{x=0}^{2} e^{-\nu}\nu^x/x!$$

With $\nu = 1.75$, one finds $P_{E_2} = 0.25$.

To compute P_{E_2}, we assume that q quintets were randomly drawn out of a total number of $N_5 + n$ (real and "false" quintets), and that the n "false" quintets were all found among them. The probability of this event is given by the hypergeometric law:

$$P_{E_2} = \frac{C_n^n C_{(N_5+n)-n}^{q-n}}{C_{N_5+n}^q} = \frac{C_{N_5}^{q-n}}{C_{N_5+n}^q}$$

where $C_x^y = x!/y!(x-y)!$

We adopt for N_5 the value 33 estimated by Rose. As noticed by him, this value is highly uncertain, since it is based on the discovery of only two quintets in his survey of 69 POSS plates. To test this number, we searched for quintets in the Catalogue of Interacting Galaxies, vol. I and II (Vorontsov-Velyaminov, 1959, 1977) and found 35 quintets (among which 9 are only probable). Their VV numbers are given in Table 2. So we think that $N_5 = 33$ is an underestimation of the actual number of quintets, so that the real value of P_{E_2} is still smaller than our calculated value with

$N_5 = 33, \quad q = 8, \quad n = 3$, i.e.:

$P_{E_2} = 7.81 \cdot 10^{-3}$.

Finally the probability that the three discrepant redshifts quintets are due to chance projection is only

$P \lesssim 2 \cdot 10^{-3}$.

This result can also be obtained in a different way. Indeed since only 5 quintets on 33 have measured (non discrepant) redshifts, the expected number of discrepant quintets should be only $1.75 \times 5/33 = 0.25$, to be compared with the known number of 3. Then the probability is given by a Poisson law with parameter $\nu = 0.25$,

$$P = \sum_{x=3}^{\infty} \exp(-0.25) \frac{0.25^x}{x!}.$$

This leads to the same result $P = 2 \cdot 10^{-3}$.

III. Quintets with Two Discrepant Redshifts

Rose (1977) remarks that the probability to find two discrepant redshifts in a quintet is very faint. The expected number should be:

$$Nd = \tfrac{1}{2}N_3(\sigma A)^2 = 0.017.$$

However, this result concerns an association of a triplet with two field galaxies. What about associations of triplets with pairs? We need to have an estimation of the density of pairs of galaxies with $B \leqq 17.5$. Turner (1976) found 137 real pairs with $\delta \geqq 0$, $|b^{\mathrm{II}}| > 40°$, and $m \leqq 15$, which gives a total number on the sky of 767. If one assumes a homogeneous spatial distribution of pairs, one derives a number of 24 200 pairs with $m \leqq 17.5$, which leads to a density 0.59 per square degree and to $A\sigma_p = 1.15 \cdot 10^{-4}$.

Then the expected number of quintets with two equal discrepant redshifts is

$$Nd = N_3 A\sigma_p = 0.32$$

since $N_3 = 2800$. This number is not negligible, and must be taken into account, especially if one keeps in mind that one association of this type is now known (see Table 1) though having $B > 17.5$.

IV. A Correlation for Compact Groups

In the course of this study, we have been led to obtain the total number of real pairs with $B \leqq 17.5$ from Turner's survey (1976) which, combined with Rose's data (1977), gives information on the number of compact groups having 2 to 5 members. We find a strong correlation between log N and n (n: number of members, N: number of groups with n members) also valid for isolated objects, as reported in Figure 1.

A linear best fit gives $\log N = 6.70 - (1.04 \pm 0.07)n$. Consequently, while there are uncertainties, a relation of the form $N \propto 10^{-n}$ is plausible. In this study, we used values corrected for contamination by chance projection. Thus physical associations only are concerned, so that this relation might be connected with the conditions of formation of these compact groups. However, it could also be in part a consequence of the criteria used by Rose (1977) to define compact groups. For example, the relation $A\sigma \leqq 0.0035$ induces a dependence of density on the number of galaxies in a group. It should be useful to confirm this law by a survey of compact groups having more than five members and by a more precise determination of the number of quintets.

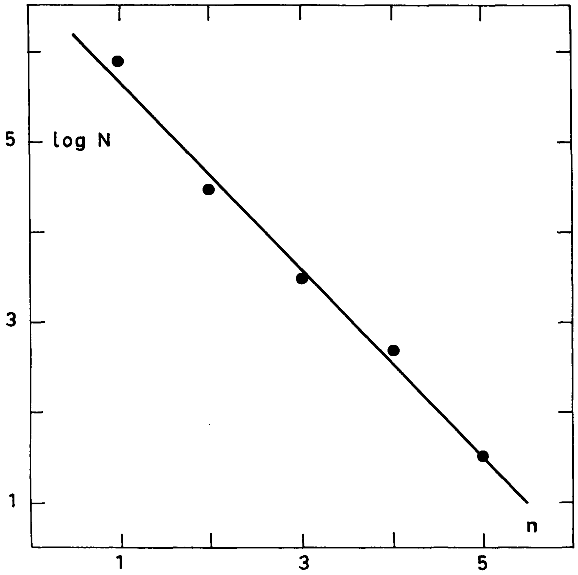

Fig. 1. Linear relation between log N and n, N being the number of compact groups having n members

V. Discussion

The value obtained in Section II for the probability to observe present data on discrepant redshift quintets essentially depends on two parameters.

(1) The value of N_5. We have already argued that $N_5 = 33$ is certainly an underestimation of the actual number of quintets. If one uses in the statistical calculation a greater value, the probability would be still smaller.

(2) The limit at $B = 17.5$. This limit was chosen to include the three cases of discrepant redshift quintets.

But if one extends this limit, one must take into account Arp chain near NGC 4151. The exact number of members is difficult to define, since it is composed of 5 or 6 close galaxies and 1 or 2 outlying members. If one accepts the close chain is a quintet with $B \leqslant 19$, we can extrapolate the numbers N_5 and N_d[1] assuming a homogeneous spatial distribution of quintets, and compute tentatively the probability that three quintets with one discrepant redshift (expected number: 14) and one quintet with two discrepant redshifts (expected number: 2) appear by chance projection:

$$P = \frac{C^5_{264} C^3_{14} C^1_2}{C^9_{280}} = 3 \cdot 10^{-4}.$$

If one considers that there is only one discrepant redshift in Arp's chain, (galaxy 3—Arp, 1977—has two redshift systems at $cz = 47\,700$ and $cz = 13\,200$ more doubtful) the probability becomes:

$$P = \frac{C^5_{264} C^4_{14}}{C^9_{280}} = 4 \cdot 10^{-4}.$$

Thus we find smaller probabilities when the magnitude limit is extended.

One can also discuss about the basic hypothesis

[1] (By adjusting the volume and thus these numbers by using the fainter magnitude limit)

assumed in this analysis: the quintets having known radial velocities have been randomly chosen for redshifts measurements. In fact there is no way to predict that a compact group will be a discrepant redshift one before knowing the redshifts for all its members—for example, the discrepant redshift in Stephan's quintet was the last to be measured (Burbidge and Burbidge, 1961).

VI. Conclusion

The main conclusion of this paper is that the probability that the known cases of discrepant redshift quintets should be due to chance projection of field galaxies is only $0.002 > P > 0.0003$. We do not conclude that the discrepant redshift galaxies are associated with their groups, but only that a statistical calculation on present data favors this second assumption for at least some of them, and thus that the problem of anomalous redshifts in compact groups still remains.

The only way to be thorough with this problem would be to obtain redshifts for all members of quintets following Rose's criteria. Only in the case when no new or few discrepant redshifts are found, could one conclude that they are chance projection of field galaxies on quartets of galaxies.

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Note added in proof. 1. In this paper, we have calculated the probability that the known cases of discrepant redshifts might be chance projection effects, independently of any discussion of the physical characteristics of these groups. It must be kept in mind that they are strongly interacting systems completely known to astronomers and well studied in the literature (see introduction). These signs of interaction clearly add to the statistical arguments against chance projection effects.

2. In a recent paper (Ciatti and Rosino, 1977) a supernova was studied in NGC 7343, a galaxy near Stephan's quintet. The magnitude and the redshift of the supernova as well as a luminosity classification (we propose to classify NGC 7343 $S(B)cI$) lead to a coherent radial velocity around 6000 km s^{-1}, which is the same order as the four concordant redshifts in Stephan Quintet. However the redshift of NGC 7343 is given to be $cz =$ 1216 km s^{-1} by Humason et al. (1956). This is probably a misidentification as noted in RC1 (de Vaucouleurs and de Vaucouleurs, 1964). Indeed a spectrum of NGC 7343 was obtained at Haute-Provence Observatory by Le Denmat and Nottale (1977) and a preliminary measure of the radial velocity favors the greater value $\sim$6000 km s^{-1}.

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