BIPOLAR EJECTIONS OF QUASARS FROM GALAXIES

Ari Jokimäki, 2006

ABSTRACT

Question of pair alignments of quasars across galaxies is considered. It is assumed that the pair alignments are ideal bipolar ejections, i.e. that the pair is ejected simultaneously at the same velocity from exactly the opposite sides of the centering galaxy. A model is derived based on those assumptions, and known pair alignments are run through the model. Some statistical tests are performed. Most of the pairs don't seem to be ideal bipolar ejections, but few pairs give good results. Possible application of the model for jets of galaxies and stars is noted.

1. INTRODUCTION

Debate about quasar-galaxy associations and possible intrinsic redshifts related to them has been going on for four decades. One notable issue in the heart of the debate has been pair alignments of high redshift quasars across low redshift galaxies. First suggestion of such pair alignments came from Arp (1966, 1967). He suggested that quasars are ejected from opposite sides of centering galaxies. Debate so far has concentrated mainly to statistical questions, i.e. how probable it is to find two quasars so close and so well aligned across a certain galaxy. Some other arguments used to support the association are similar properties of aligned quasars (such as redshift, brightness, etc.) and the tendency of the alignment to coincide with minor or major axis of centering galaxy. Although the pair alignments mainly involve pairs of quasars, there has been suggestions of other objects aligned across a galaxy as well, such as normal galaxies (Arp, 1967) and even clusters of galaxies (Arp & Russell, 2001).

This work concentrates on the question of bipolar ejections. Are the known pair alignments bipolar ejections? More particularly, are they *ideal bipolar ejections*, i.e. ejected simultaneously at the same velocity from exactly the opposite sides of the centering galaxy? Effort is made to take this question beyond statistical arguments. Mathematical model of the pair alignments is created for that purpose.

2. DERIVATION OF THE MODEL

In order to create a practical mathematical model of a pair alignment of two quasars across a galaxy, we have to make few assumptions:

- Both quasars have been ejected at the same time.
- Ejections have happened exactly on opposite sides of the galaxy.
- Ejection velocity (and current velocity) is same for both quasars.

From now on in this paper, a situation that fulfills these assumptions will be called *ideal bipolar ejection*. Since we are looking at this from the point of view of Arp's hypothesis, it is also assumed that ejected quasars have intrinsic redshift component in addition to cosmological and Doppler (due to peculiar velocities) redshift components. Figure 1 presents a sketch of an ideal bipolar ejection. Known quantities are angles a_1 and b_1, quasar redshifts z_1 for Q1 and z_2 for Q2, and redshift z_G of the galaxy.

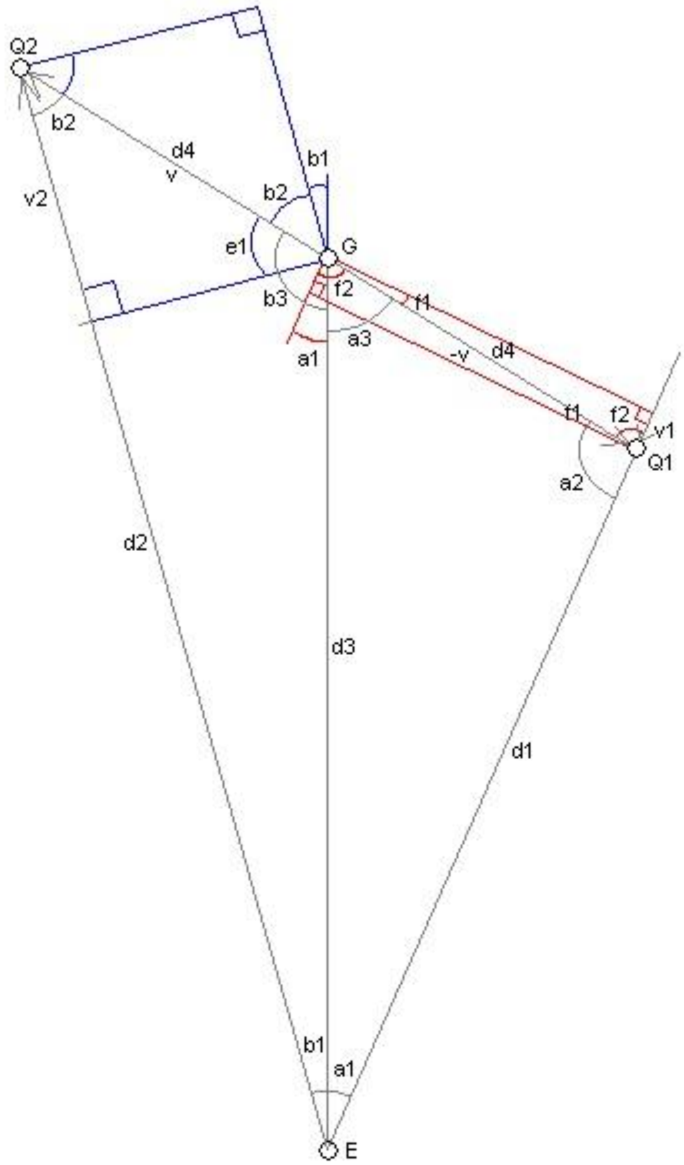

Fig. 1. Ideal bipolar ejection of pair of quasars from a galaxy. E is Earth, G is the ejecting galaxy, Q1 and Q2 are the ejected quasars. Velocities: v is current velocity for both quasars, v_1 is component of velocity of Q1 toward (or away from) Earth and v_2 is component of velocity of Q2 away from (or toward) Earth. Angles: a_1 is the angular distance between the galaxy and Q1, b_1 is the angular distance between the galaxy and Q2. Angle a_1 is bigger than angle b_1, except when the ejection angle a_3 is 90°.

First we define the ejection angle a_3 as a function of angles a_1 and b_1. The law of sines gives us:

$$\frac{d_4}{\sin(a_1)} = \frac{d_3}{\sin(a_2)}$$ [eq. 1a]

$$\frac{d_4}{\sin(b_1)} = \frac{d_3}{\sin(b_2)}$$ [eq. 1b]

Where d_3 is the distance between the Earth and the ejecting galaxy, and d_4 is the distance of the quasars from the ejecting galaxy. Angles a_2 and b_2 are:

$$a_2 = 180 - a_1 - a_3 \quad \text{[eq. 2a]}$$

$$b_2 = 180 - b_1 - b_3 \quad \text{[eq. 2b]}$$

Substituting angles a_2 and b_2 from eq. 1a and 1b with eq. 2a and 2b, and solving the resulting equations for a_3 yields:

$$a_3 = \arctan\left(\frac{2}{\frac{1}{\tan(b_1)} - \frac{1}{\tan(a_1)}}\right) \quad \text{[eq. 3]}$$

Next, we express velocities of quasars toward or away from the Earth (v_1 and v_2) using known angles a_1 and b_1, and the ejection angle a_3. From fig. 1 it can be seen that:

$$v_1 = -v \sin(f_1) \quad \text{[eq. 4a]}$$

$$v_2 = v \sin(e_1) \quad \text{[eq. 4b]}$$

Where v is current velocity for both quasars toward or away from the ejecting galaxy. From fig. 1 it can also be seen that:

$$f_1 = 90 - a_1 - a_3 \quad \text{[eq. 5a]}$$

$$e_1 = 90 + b_1 - a_3 \quad \text{[eq. 5b]}$$

Substituting angles f_1 and e_1 from eq. 4a and 4b with eq. 5a and 5b, and solving equations 4a and 4b both for v and equating them, we get:

$$v_1 = \frac{-v_2(\cos(a_1) - \sin(a_1)\tan(a_3))}{\cos(b_1) + \sin(b_1)\tan(a_3)} \quad \text{[eq. 6]}$$

Substituting angle a_3 from eq. 6 with eq. 3, we get:

$$v_1 = \frac{-v_2 \cos(a_1)\left(1 - \frac{2\tan(a_1)}{\frac{1}{\tan(b_1)} - \frac{1}{\tan(a_1)}}\right)}{\cos(b_1)\left(1 + \frac{2\tan(b_1)}{\frac{1}{\tan(b_1)} - \frac{1}{\tan(a_1)}}\right)} \quad \text{[eq. 7]}$$

Next we determine v_1 from redshifts. Quasar redshifts z_1 and z_2 are:

$$1 + z_1 = (1 + z_{D1})(1 + z_G)(1 + z_i) \quad \text{[eq. 8a]}$$

$$1 + z_2 = (1 + z_{D2})(1 + z_G)(1 + z_i) \quad \text{[eq. 8b]}$$

Where z_{D1} and z_{D2} are the Doppler redshift components of Q1 and Q2 due to the velocities v_1 and v_2, z_G is the measured redshift of the galaxy (= the cosmological redshift component of the quasars), and z_i is the intrinsic redshift component for both quasars. In Arp's hypothesis intrinsic redshift decreases with age due to Machian interactions increasing the mass of the object (Narlikar & Arp 1993), and if the quasars have been created at the same time, then their intrinsic redshift should be the same. However, this might be only an approximation, it is possible that the intrinsic redshifts evolve differently for each object. That might happen for example if other quasar is ejected to an environment where there are lot of massive objects (and hence more Machian interactions) and the other quasar is ejected to an "empty" environment (less Machian interactions). But as this seems quite rare situation, we can assume that the intrinsic redshifts of the two ejected quasars are in general, if not exactly the same, at least very close to each other.

Equations 8a and 8b yield:

$$\frac{1+z_{D1}}{1+z_{D2}} = \frac{1+z_1}{1+z_2}$$ [eq. 9]

We know that z_{D1} and z_{D2} are due to actual motion of Q1 and Q2 toward and/or away from us, so we can use the Doppler redshift equations:

$$1+z_{D1} = \sqrt{\frac{1+\frac{v_1}{c}}{1-\frac{v_1}{c}}}$$ [eq. 10a]

$$1+z_{D2} = \sqrt{\frac{1+\frac{v_2}{c}}{1-\frac{v_2}{c}}}$$ [eq. 10b]

We divide 10a by 10b and equate the result with eq. 9:

$$\frac{1+z_1}{1+z_2} = \sqrt{\frac{\left(1+\frac{v_1}{c}\right)\left(1-\frac{v_2}{c}\right)}{\left(1-\frac{v_1}{c}\right)\left(1+\frac{v_2}{c}\right)}}$$ [eq. 11]

Then we solve that for v_1, and we get:

$$v_1 = \frac{ch + v_2 + hv_2 - c}{h + \frac{hv_2}{c} + 1 - \frac{v_2}{c}}$$ [eq. 12]

where:

$$h = \frac{(1+z_1)^2}{(1+z_2)^2}$$ [eq. 13]

Finally, by equating eq. 7 and eq. 12, we get:

$$v_2 = \frac{c(1-j)}{2j}\left(1+\frac{2}{h-1}\right)\left(1 \pm \sqrt{4j\left(\frac{1-\frac{2}{h+1}}{1-j}\right)^2 + 1}\right)$$ [eq. 14]

where:

$$j = \frac{-\cos(a_1)\left(1 - \frac{2\tan(a_1)}{\frac{1}{\tan(b_1)} - \frac{1}{\tan(a_1)}}\right)}{\cos(b_1)\left(1 + \frac{2\tan(b_1)}{\frac{1}{\tan(b_1)} - \frac{1}{\tan(a_1)}}\right)}$$ [eq. 15]

Equation 14 has two solutions (i.e. the square root's negative and positive outcome). In this work, the solution where the result uses negative outcome of the square root is usually the correct one. Positive outcome of the square root gives correct answers only when the velocity v_2 is greater than c.

After this, velocity v can be calculated from equations 4b, 3 and 5b, Velocity v_1 from equation 7, z_{D1} and z_{D2} from equations 10a and 10b and the intrinsic redshift component z_i, which is considered to be the same for both quasars, from equation 8a (or 8b).

Additionally, we calculate the distance of the quasars from the centering galaxy (d_4). From the Hubble law, doppler redshift equation and equation 1a we get:

$$d_4 = \frac{c}{H_0} \cdot \frac{(z_G+1)^2 - 1}{(z_G+1)^2 + 1} \cdot \frac{\sin(a_1)}{\sin(a_1 + a_3)}$$ [eq. 16]

The centering galaxy's distance from the Earth (d_3) is:

$$d_3 = \frac{c}{H_0} \cdot \frac{(z_G+1)^2 - 1}{(z_G+1)^2 + 1}$$ [eq. 17]

3. SAMPLE PAIR ALIGNMENTS

Known pair alignments were searched from published papers of Arp. Resulting pair alignments with their relevant data are presented in Table 1. It should be noted that Q1 and Q2 are not always quasars, some pairs have galaxies as well (M49 for example), or even galaxy groups (M82 for example). Most of the data is from NASA Extragalactic Database (NED), but some data are also from Simbad, and for couple of pairs data could only be found from the papers discussing the pairs. There were also lot of pairs which didn't have enough known data to be included to this analysis. Even some included pairs don't have the redshift of the galaxy (z_G), but it only prevents us to calculate the intrinsic redshift and the distances, we can calculate the ejection angle and the velocities.

Table 1 - Data of sample pair alignments

As noted in Table 1, some pairs of quasars have more than one possible parent galaxy. For most of cases like that it is difficult to determine which of the galaxies would be most likely to be the ejecting galaxy, so we'll just use all of them and give alternative results for those pairs that have more than one possible parent galaxy.

NGC 3628 has two possible quasars for Q2. Both are included to this analysis, hence the two pairs for NGC 3628 in Table 1. It is difficult to say which one of the two quasars is better suited as Q2, because for the other quasar the redshift is closer to the redshift of Q1 and for the other quasar the angular distance is closer to the angular distance of Q1.

Angular distances between the galaxy and quasars in Table 1 were calculated from the positional data of the objects. Following equation was used for angular distance a_1 (same equation for b_1 but with Q2 values):

$$a_1 = \cos^{-1}\left(\sin(lat_G)\cdot\sin(lat_{Q1}) + \cos(lat_G)\cdot\cos(lat_{Q1})\cdot\cos(long_G - long_{Q1})\right) \quad \text{[eq. 18]}$$

where lat_G is equatorial (J2000.0) latitude of the galaxy, $long_G$ is equatorial (J2000.0) latitude of the galaxy, lat_{Q1} is equatorial (J2000.0) latitude of the quasar Q1, and $long_{Q1}$ is equatorial (J2000.0) latitude of the quasar Q1.

NED gives heliocentric redshifts, so they were converted to galactocentric redshifts according to conversion formula given in HyperLeda. Conversion formula uses velocities, so first the heliocentric redshifts were converted to heliocentric velocities by Doppler redshift equation (shown in eq. 10a). Then the conversion formula was applied to calculate the galactocentric velocity v_{GAL} of the object:

$$v_{GAL} = v_{HEL} + 232\cdot\sin(glong)\cdot\cos(glat) + 9\cdot\cos(glong)\cdot\cos(glat) + 7\cdot\sin(glat) \quad \text{[eq. 19]}$$

where v_{HEL} is the heliocentric velocity of the object, glong is galactic longitude of the object, and glat is galactic latitude of the object (galactic coordinates are also given in NED). After this, the calculated galactocentric velocity was converted to galactocentric redshift again by Doppler redshift equation. After calculations it turned out that this conversion wasn't really necessary, results are very accurately the same with heliocentric redshifts.

4. RESULTS

Sample pair alignments were run through the mathematical model. The pairs were divided to two groups, the ones with $z_1 < z_2$ and the ones with $z_1 > z_2$. According to the model, quasars in the group where $z_1 < z_2$ are moving away from the galaxy, and from now on these will be called "ejecting out". Quasars in the group where $z_1 > z_2$ are moving towards the galaxy, and they will be called "falling in". Table 2 gives results for the pairs ejecting out and Table 3 gives results for the pairs falling in.

Table 2 - Results for pairs ejecting out

Table 3 - Results for pairs falling in

Distances were calculated using the Hubble constant of the generally accepted 71 km/s /Mpc (Spergel et al. 2003). Question of the value of the Hubble constant is important here, because the assumption of this work, that at least some objects have intrinsic redshifts, might have an effect to the Hubble constant. This has also been suggested (Russell 2005 and references therein), and Hubble constant values of 55-60 km/s /Mpc have been put forth. Smaller value of Hubble constant increases the distances d_3 and d_4, so there's some uncertainty in distance values reported here. Also, many galaxies belong to galaxy groups and their redshift might have a velocity component due to motions inside that group, further increasing the inaccuracy of the crude calculation of distance d_3 based on the galaxy's redshift alone. One further consideration about distances of galaxies is, since we are dealing with intrinsic redshifts, the possibility that galaxies themselves might have intrinsic redshifts (Russell 2005), which would mean that their redshift distance wouldn't be correct. In the future it would be important to find distance measurements independent of redshift for the central galaxies and use those distances instead of Hubble law distances in these calculations.

Most of the data had insufficient data for proper error analysis, so the errors are not given here. Errors were checked for the few cases where there was enough data, and in many cases the errors were less than 1%, but there were some cases with larger errors (especially 53W 003 and NGC 4151, where the errors were over 50% for some values).

4.1. Distribution of ejection angles in actual and random samples

Distribution of ejection angles of the whole sample was compared to distribution of ejection angles in samples with random values. Two sets of random samples were needed for pairs ejecting out, because the angular distances of the actual sample were not evenly distributed (see below for more about this), so this non-even distribution was roughly recreated for random sample 2, but in a manner that it still maintained it's randomness. Random sample 1 is completely random also for angular distances. More details, data, and some calculated values for these random samples are presented in Appendix. Distribution of the ejection angle a_3 in actual sample and in random sample 1 is shown in figures 2 (for pairs ejecting out) and 3 (for pairs falling in). Those pairs with more than one possible parent galaxy are only included once, and the galaxy giving the most favourable values for those pairs have been selected to this analysis.

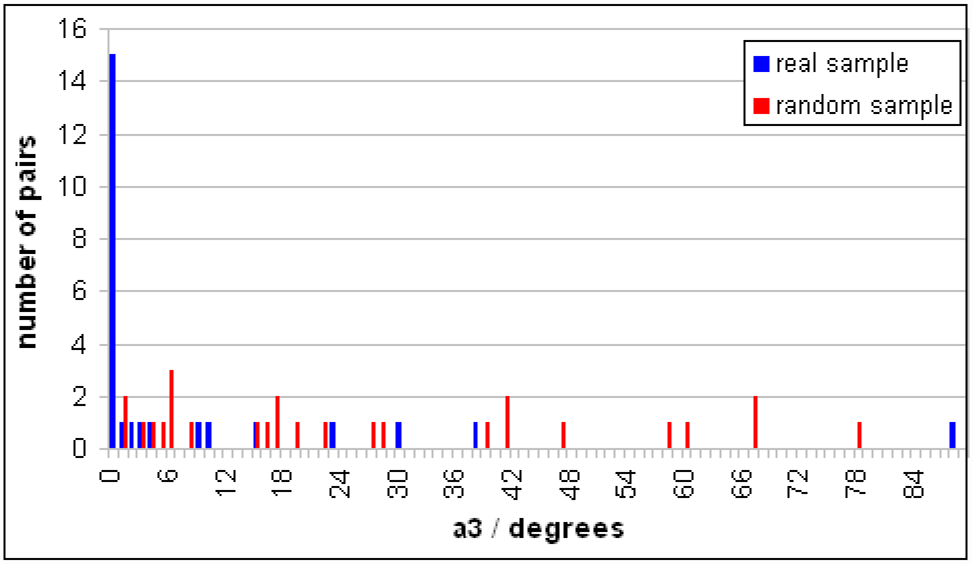

Fig. 2. Distribution of ejection angles for pairs ejecting out compared to random sample 1.

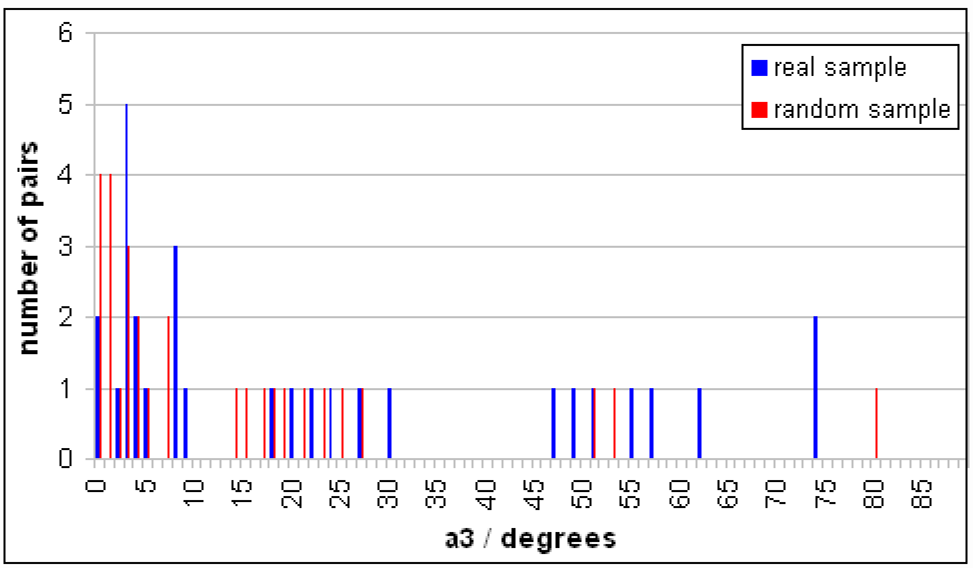

Fig. 3. Distribution of ejection angles for pairs falling in compared to random sample 1.

In Figure 2 we can see that for pairs ejecting out there's a difference between the actual sample and random sample 1. The actual sample has heavy concentration of pairs with $0° < a_3 < 1°$ while the random sample seems to be quite evenly distributed. The reason for this concentration in actual sample is that the actual sample has majority of pairs with angular distances (a_1 and b_1) less than 1°. That leads to small a_3 values because the model works so that with smaller a_1 values b_1 has to be relatively closer to a_1 in order to get higher values for a_3. So there's a tendency for a_3 to get very small values when the value for a_1 is also small, unless the value of b_1 is very close to the value of a_1. The comparison in Figure 2 is meaningless because the angular distances a_1 and b_1 are more evenly distributed in random sample 1, and for that reason we need a random sample that mimics the distribution of the angular distances of the actual sample. See Appendix for a description how this random sample 2 has been produced.

In Figure 3 there is a different situation for pairs falling in. The distribution of ejection angles in the actual sample is not so concentrated near 0°. That is because in this set of pairs the angular distances are more evenly distributed, there is only slight excess of pairs with angular distances (a_1 and b_1) less than 1°. The distribution of ejection angles in actual and random samples are quite similar.

Figure 4 shows the distribution of ejection angles in actual sample and random sample 2 for pairs ejecting out. We can see that there was some bad luck with random sample 2; even the pairs with angular distances a_1 and b_1 above 1° gave very low values for ejection angle. That doesn't matter because the comparison between actual sample and random sample 2 is more interesting for a_3 values below 1° (we already saw in figure 2 that random pairs can give quite even distribution with angular distances above 1°). Figure 5 shows the distribution of ejection angles below 1° in actual sample and in random sample 2.

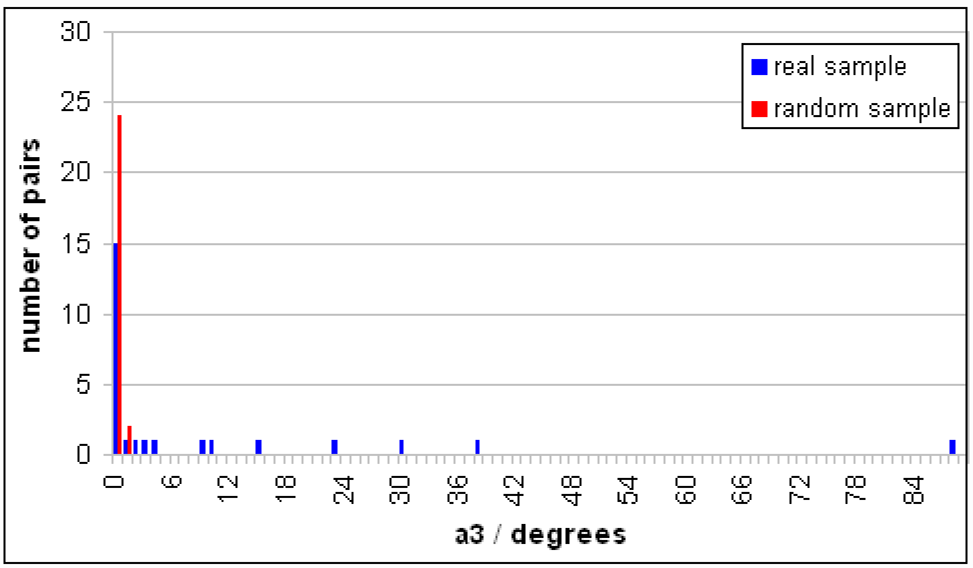

Fig. 4. Distribution of ejection angles for pairs ejecting out compared to random sample 2.

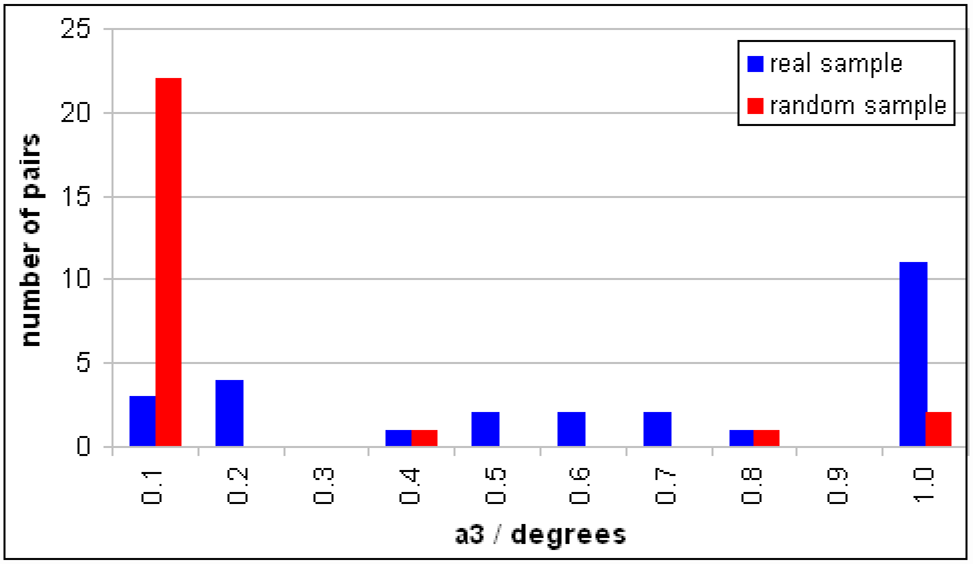

Fig. 5. Distribution of ejection angles below 1° for pairs ejecting out compared to random sample 2. The last values (marked with "1.0") contain all pairs between 1° and 90°.

Figure 5 clearly shows that actual sample is more evenly distributed than random sample 2 for a_3 values below 1°. Almost all random sample 2 pairs give very small values for a_3. As explained earlier, this kind of distribution is expected from random values. So, at this point it seems that the distribution of the actual sample for a_3 values below 1° might be non-random, but with such a small sample it is difficult to say for sure. See section 5.2 for a discussion about this.

4.2. Distribution of velocities in actual and random samples

Similarily as for ejection angles, distribution of velocities of quasars Q1 and Q2 (v) was compared against random samples. Same random samples were used, see Appendix. Figures 6 (pairs ejecting out) and 7 (pairs falling in) show the distribution of velocities in actual and random samples.

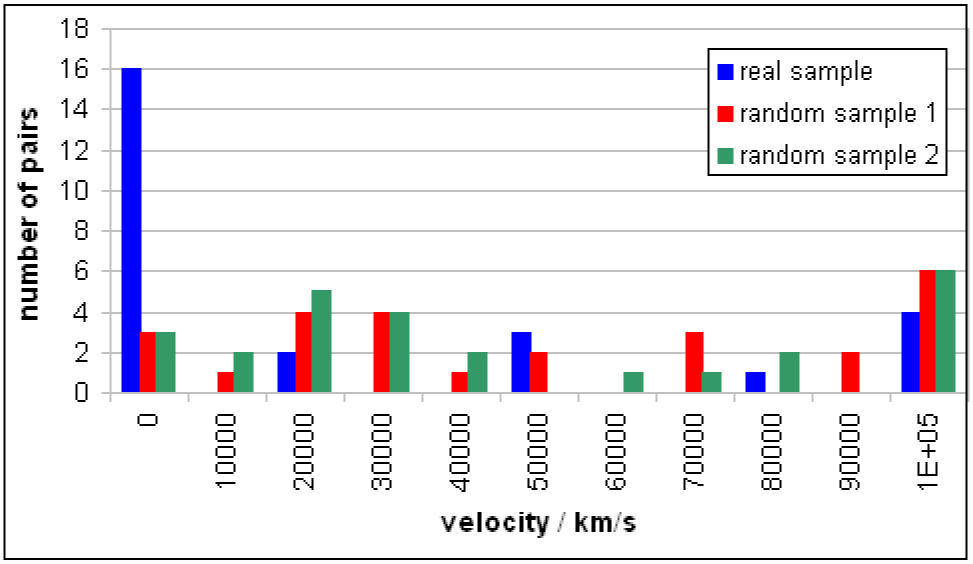

Fig. 6. Distribution of velocity (v) in actual and random samples for pairs ejecting out. The last values (marked with "1E+05") contain all values higher than 100,000 km/s.

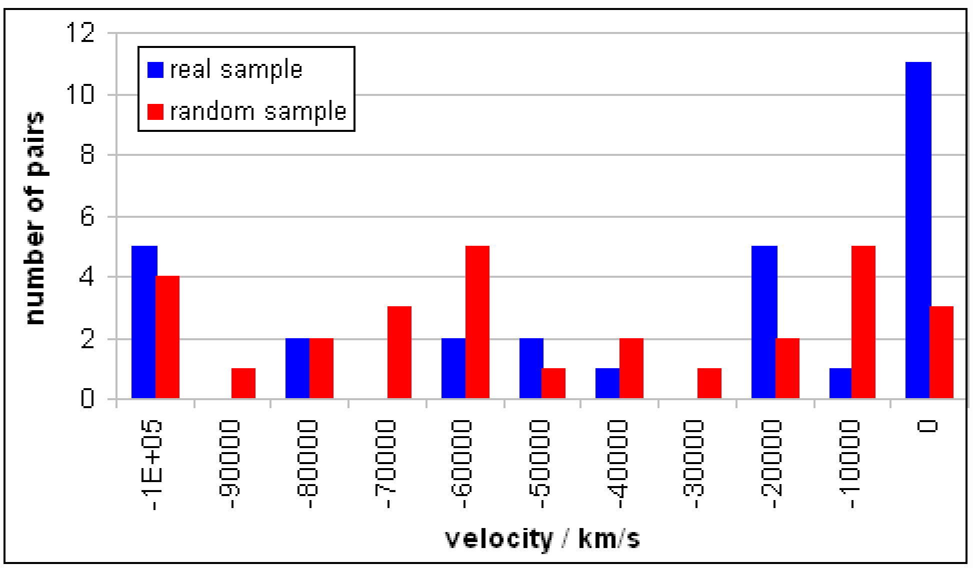

Fig. 7. Distribution of velocity (v) in actual and random samples for pairs falling in. The first values (marked with "-1E+05") contain all values lower than -100,000 km/s.

It can be seen from figures 6 and 7 that the velocities of the actual sample are more clustered to low velocities (-10000 km/s < v < 10000 km/s) than the velocities of random samples. This is because in the actual sample the redshifts z_1 and z_2 are more close to each other than in random samples. Reason for that is not clear (this is further discussed in section 5.2).

4.3. Progression of intrinsic redshift

In Arp's hypothesis, intrinsic redshift of objects decreases with age. If pair alignments in this analysis are ideal bipolar ejections, we should be able to see this decrease in intrinsic redshift of quasars Q1 and Q2 (z_i). For pairs ejecting out, z_i should decrease when distance from the galaxy

(d_4) increases (but only if ejection velocity is same for all ejections). That is shown in Figure 8. For pairs falling in, z_i should decrease when distance from the galaxy (d_4) decreases (again depending on constancy of ejection velocity). That is shown in Figure 9.

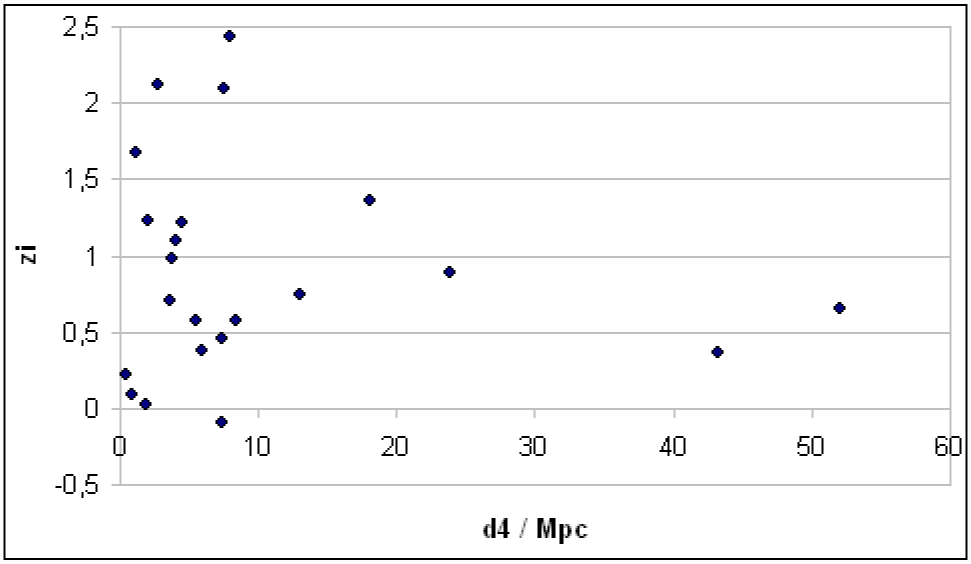

Fig. 8. Intrinsic redshift as a function of distance from galaxy for pairs ejecting out. Few pairs with distance from galaxy > 100 Mpc have been omitted.

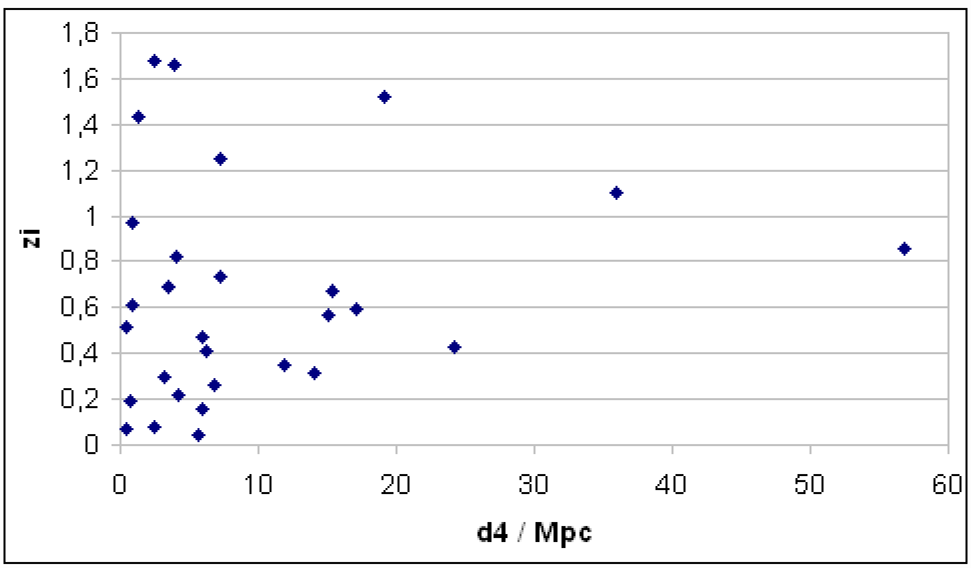

Fig. 9. Intrinsic redshift as a function of distance from galaxy for pairs falling in.

There seems to be no clear signs of expected z_i progression in Figures 8 and 9.

Another thing that should be seen in Figures 8 and 9 is that z_i should be on average smaller for pairs falling in than for pairs ejecting out (because pairs falling in should be older and therefore less redshifted). This is not evident in Figures 8 and 9 either. However, the calculated average z_i for pairs ejecting out is 0.85, while it's 0.65 for pairs falling in.

4.4. Other tests to the whole sample

If all the pairs were due to coincidence, we would expect the model to give values that show roughly half of the pairs ejecting out and half of the pairs falling in. The sample has 55 pairs (number contains only one pair for those cases where there are more than one possible centering galaxy), and roughly a half, 26 pairs, are ejecting out and 29 pairs are falling in.

Tests to the whole sample are further discussed in section 5.2.

5. CONCLUSIONS AND DISCUSSION

5.1. Individual pairs - The good, the bad, and the possible

There are certain properties that quite conclusively show that a pair is bad ideal bipolar ejection candidate:

- **Very high velocities** - In Arp's hypothesis the quasars are suggested to have quite high velocities (0.1c for example), but they are not expected to travel near the speed of light. Therefore some pairs can be rejected on the basis of their high velocity. It is difficult to say what would be the correct limit for this, but we adopt 100,000 km/s as highest tolerable velocity, and we leave it to the reader to decide if that's too high or too low. From Table 2, following pairs exceed the limit: ARP 145, ARP 196 NED01 and NED02, NGC 5223, and VV 120A and VV 120C. From Table 3, following pairs exceed the limit: ARP 130 NED01 and NED02, ARP 197 NED01 and NED02 pair 2, M63, NGC 4194, NGC 5228 and NGC 5233, and UGC 4551 pair 1. Of these, NGC 5223 (v = 6c) and NGC 5233 (v = 5.5c) have velocities faster than speed of light.
- **Huge distance** - In Arp's hypothesis the paired quasars are expected to be in the neighborhood of the central galaxies, not hundreds of megaparsecs away. Also for this it is difficult to determine correct limit. We use a limit of 10 Mpc for distance d_4. But it should be noted here that distance calculations in this work have more uncertainties than other values (as was explained in section 4), so there's some benefit of doubt for pairs that are rejected based on their huge distance from central galaxy. Following pairs from Table 2 exceed the 10 Mpc limit: 3C 212, 3C 345 pairs 1 and 2, 53W 003, ARP 102A and ARP 102B, ARP 196 NED01, NGC 2916, NGC 5985, and VV 120A and VV 120C. Following pairs from Table 3 exceed the 10 Mpc limit: ARP 55, ARP 125 NED01 and NED02, ARP 139 NED01 and NED02, ARP 141, ARP 148, ARP 197 NED01 pair 1, ARP 220 pair 2, NGC 2444 and NGC 2445, UGC 4551 pair 2, and VV 291A.
- **Far away with high velocity** - Of those pairs that haven't been rejected for very high velocity or huge distance, we can reject some that are far away from their parent galaxy and travelling with high velocity. Velocities of quasars should slow down after ejection, so high velocities should be found only from those cases where the quasars are very close to the parent galaxy. Here we shall reject those pairs with distance d_4 between 5 and 10 Mpc travelling with velocity between 20,000 and 100,000 km/s. Pairs with those properties from Table 2: NGC 1365, NGC 3842, and UGC 4551 pair 3. Pairs with those properties from Table 3: IC 982 and IC 983, NGC 214, and VV 248A and VV 248B.
- **Negative intrinsic redshift** - If quasar's redshift decreases with age, then we cannot have negative intrinsic redshifts (= intrinsic blueshift) for recently ejected quasars, because that would mean that they are older than our own galaxy. Of course, one might argue that

perhaps some quasars could be older than our galaxy, but currently that's certainly not part of Arp's hypothesis. Also, the pair alignment wouldn't probably be intact after ten billion years (which is roughly the currently accepted age of our galaxy). However, if we abandon the age-related redshift assumption of Arp's hypothesis, and simply assume that quasars have been ejected from the galaxy and that the intrinsic redshift mechanism is not known, then we can't reject the pairs based on negative intrinsic redshift. Pairs with negative intrinsic redshifts are: 3C 212, 3C 345 pair 2, and NGC 5223, all of which were already rejected for other reasons.

It should be noted on bad candidates that even though they give bad values when run through the ideal bipolar ejection model, that doesn't mean that they are not associated to their parent galaxies, nor that they have not been ejected from central galaxy. We can only say that they are not ideal bipolar ejections, i.e. the assumptions (given in section 2) that the model is based on are not fulfilled in these pairs.

There is one possible way to rescue those bad candidates that were rejected due to their huge distance from the parent galaxy. If the parent galaxies themselves have intrinsic redshifts, then they are closer to us than their redshift distance. That would also decrease the distances of quasars from their parents. There is a good example of this in our sample. 3C 345 has two quasar pair alignments, but 3C 345 is also part in ARP 125 pair alignment as an ejected object. If 3C 345 is indeed ejected from ARP 125 NED 01 or ARP 125 NED02, then 3C 345 has intrinsic redshift component (which was calculated to be 0.57). In that case we should use the redshift of ARP 125 NED 01 or ARP 125 NED02 when we are calculating distances for 3C 345 pairs. This calculation gives distance d_4 = 38 Mpc for 3C 345 pair 1 and d_4 = 45 Mpc for 3C 345 pair 2. These distances are still too large, but there might be other cases where this procedure might make them possible candidates. It should also be noted on 3C 345 that it's position in the sky is very close to the position of galaxy NGC 6212, much closer than ARP 125, so in that sense NGC 6212 would be more natural parent to 3C 345 than ARP 125.

3C 345 pair 2 also has negative intrinsic redshift, but if we assume that 3C 345 is in ARP 125's reference frame and use ARP 125's redshift for calculations, it turns out that the intrinsic redshift of 3C 345 pair 2 is in that situation clearly positive ($z_i \sim 0.5$). So the question of intrinsic redshifts in galaxies, or the true distance of galaxies from us, is very important for these calculations.

There are also some properties that as such doesn't make pair a bad candidate, but make the pair somewhat suspicious for ideal bipolar ejection candidate:

- **Pair is falling in** - All the pairs that are falling in are less probable ideal bipolar ejection candidates than the pairs ejecting out, because there has been more time for pairs falling in to have their alignment disturbed after their ejection. However, there's no reason to assume that all such pair alignments have been disturbed, so this is no reason to reject all the pairs that are falling in, just to be little more suspicious about them. At least we can expect that the calculated values for pairs falling in are less accurate than the calculations for pairs ejecting out.

- **Small ejection angle** - Tendency of clustering of ejection angles to values below 1°, as was seen in section 4.1, seems to indicate that pairs with small ejection angles are not good candidates for ideal bipolar ejection, but since there is no reason why certain pair couldn't have small ejection angle, it isn't a reason to reject all pairs with small ejection angle. So when we look at these pairs individually, we just have to accept small ejection angle, because we can't tell which pair genuinely has small ejection angle and which pair is exhibiting it's failure with small ejection angle.

There still are many pairs left that weren't rejected above. We now take a closer look at these pairs individually:

- **ARP 197 NED02 pair 1** - This pair might have been rejected by now, but NED doesn't have the redshift for the parent galaxy, so the distances couldn't be calculated. The pair is falling in and it has quite high velocity, so this pair is suspicious but still possible. Appearance of this alignment is very poor, it deviates 36° from straight alignment (Arp 1967), hardly an alignment at all. This pair has alternative parent galaxy, ARP 197 NED01, and was rejected in section 5.2 due to huge distance. ARP 197 is a galaxy pair where the other galaxy (ARP 197 NED01) is considerably larger, and there's a bridge between them suggesting that they are interacting. If the two galaxies are interacting, it means that ARP 197 NED02 is at the same distance from us as ARP 197 NED01, and therefore ARP 197 NED02 is likely to have similar distance values as ARP 197 NED01 in our model, and should also be rejected. The appearance of the two galaxies suggests that ARP 197 NED01 is more probable source of the ejection because ARP 197 NED02 looks like it might have also been ejected out of ARP 197 NED01, and because ARP 197 NED02 doesn't look nothing like an active galaxy.
- **ARP 220 pair 1** - Distance of quasars from the parent galaxy is quite large, but very low velocity of the quasars compensates that nicely. One possible interpretation for this pair would be that quasars are very near to their turning back point. This is quite good candidate. Appearance of the alignment is excellent (Arp 2001a).
- **ESO 185-G054** - Pair is quite far from the parent galaxy, and falling in. Velocity of quasars (which in this case are galaxy clusters) is very low. This pair is possible, if not good candidate. Appearance of the alignment is good (Arp & Russell 2001).
- **IC 1767** - Pair is falling in with quite high velocity. Distance from the galaxy is small. This pair is possible candidate. Appearance of the alignment is good (Arp 1980).
- **M49** - Pair is falling in quite far from the galaxy and with quite high velocity. This pair is perhaps possible, but just barely. Appearance of the alignment is quite good (Arp 1967).
- **M82** - Pair is falling in with tolerable velocity, and quite close to the galaxy. Low intrinsic redshift fits to the picture well. This is a good candidate, with some suspicion on the side. Appearance of the alignment is not particularly good (Arp & Russell 2001).
- **M101** - Three pairs around M101 (There is a fourth pair also (pair 2), but it didn't have enough data in NED to be included in this work): **Pair 1** - Pair is very close to the galaxy, ejecting out. Velocity is quite high. Intrinsic redshift is low, which would suggest an older quasar in Arp's hypothesis. We'll label this pair possible candidate, but it's quite close to being good. Appearance of the alignment is not particularly good (Arp 2001b). **Pair 3** - Pair is falling in very close to the galaxy. Velocity is very low, perhaps even uncomfortably low, but perhaps this pair has just turned around and is only just starting to

pick up speed again. Very low intrinsic redshift suggests that the quasars in this pair are older objects. This is slightly suspicious good candidate. Appearance of the alignment is not particularly good (Arp & Russell 2001). **Pair 4** - Pair is ejecting out with quite low velocity, and close to the galaxy. Very low intrinsic redshift suggests that the quasars are older objects. This is good candidate. Appearance of the alignment is not particularly good (Arp & Russell 2001). **M101 overall** - All three pairs are good candidates, or close, making this system very interesting. Fourth pair has two quasars with redshifts 0.646 and 0.66. Positional data of the fourth pair should be found out in order to calculate the values for that pair too.

- **M106** - Pair is falling in very close to the galaxy, but velocity seems too high for that. This pair is barely possible candidate. Appearance of the alignment is excellent (Burbidge 1995).
- **NGC 470** - Pair is ejecting out with moderate velocity, but the pair is uncomfortably far from the galaxy, so let's call this a possible candidate. Appearance of the alignment is quite good (Arp & Russell 2001).
- **NGC 613** - Two pairs around NGC 613 (and third pair waiting for positional data): **Pair 1** - Pair is ejecting out with moderate velocity, but the pair is uncomfortably far from the galaxy. Intrinsic redshift is very high. This is only a possible candidate. Appearance of the alignment is good (Arp 2003). **Pair 2** - Pair is falling in with moderate velocity, quite far from the galaxy. This is a possible candidate. Appearance of the alignment is not very good (Arp 2003).
- **NGC 936** - Pair is ejecting out with moderate velocity, but the pair is very far from the galaxy, so this is only remotely possible candidate. Appearance of the alignment is quite good (Arp 2003).
- **NGC 2639** - Pair is quite far from the galaxy, falling in with quite low velocity. This is a possible candidate. Appearance of the alignment is quite good (Arp 1997a).
- **NGC 3384** - Two pairs around NGC 3384: **Pair 1** - Pair is far from the galaxy, ejecting out with very low velocity. Pair is perhaps reaching it's turning back point. Ejection angle is small. This is a possible candidate. If pairs would be closer to galaxy, this would be good candidate. Appearance of the alignment is quite good (Arp *et al.* 1979). **Pair 2** - Pair is quite far from the galaxy, ejecting out with moderate velocity. Ejection angle is small. This is almost good candidate, but for now let's call it possible. Appearance of the alignment is good (Arp *et al.* 1979). **NGC 3384 overall** - This is an interesting system. Pair 2 is closer to galaxy, and has higher velocity and higher intrinsic redshift than pair 1. If only the distances of the pairs from the galaxy wouldn't be so big. Another suspicious thing is that both pairs have small ejection angle.
- **NGC 3628** - One pair with two possible candidates for Q2 around NGC 3628: **Pair 1** - Pair is far from the galaxy, ejecting out with quite low velocity. Ejection angle is small. This is a possible candidate. Appearance of the alignment is very good (Arp *et al.* 2002). **Pair 2** - Pair is far from the galaxy, ejecting out with high velocity. Ejection angle is small. This is just barely possible candidate. Appearance of the alignment is very good (Arp *et al.* 2002). **NGC 3628 overall** - Out of the two alternative pair candidates pair 1 has better properties.
- **NGC 4151** - Pair is quite far from the galaxy, ejecting out with very low velocity. Intrinsic redshift is also very low. This pair might be just about to turn back. Only thing

casting suspicion on this pair is small ejection angle, otherwise this is a good candidate. Appearance of the alignment is quite good (Arp 1977).

- **NGC 4235** - Pair is far from the galaxy, falling in with high velocity. This is only marginally possible candidate. Appearance of the alignment is not very good (Arp 1997c).
- **NGC 5820** - Pair is far from the galaxy, falling in with moderate velocity. This is only marginally possible candidate. Appearance of the alignment is not good (Arp 1967).
- **NGC 6217** - Pair is far from the galaxy, ejecting out with very low velocity. Ejection angle is small. This is a possible candidate. Appearance of the alignment is quite good (Arp & Russell 2001).
- **UGC 1839** - Three pairs around UGC 1839: **Pair 1** - Pair is far from the galaxy, falling in with moderate velocity. Ejection angle is small. This is a possible candidate. Appearance of the alignment is quite good (Arp 2003). **Pair 2** - Pair is far from the galaxy, falling in with moderate velocity. This is a possible candidate. Appearance of the alignment is not very good (Arp 2003). **Pair 3** - Pair is quite close to the galaxy, ejecting out with moderate velocity. This is a good candidate. Appearance of the alignment is not very good (Arp 2003). **UGC 1839 overall** - Two pairs falling in with quite bad values, and one pair ejecting out with good values. Overall this system is not particularly exciting.
- **VV 291B** - This pair might have been rejected by now, but NED doesn't have the redshift for the parent galaxy, so the distances couldn't be calculated. The pair is falling in and it has high velocity, so this pair is suspicious but still possible. The alignment deviates from straight line by 22° (Arp 1967). This pair has alternative parent galaxy, VV 291A, and was rejected in section 5.2 due to huge distance. VV 291 (= ARP 109) is a pair of galaxies where both galaxies seem quite similar, so it's difficult to say which one of the two galaxies would be more probable galaxy for ejecting quasars.

Out of the 55 pairs we have 29 bad, 20 possible, and 6 good candidates for ideal bipolar ejection. This is quite good result concerning the tight assumptions of the model. But it has to be emphasized that these are only candidates, it is not certain that the good candidates actually are ideal bipolar ejections. We have to perform more tests similar to ones that were performed in section 4 to a set of good candidates only to know better.

Those pairs that have good calculated values but not so good appearance might be cases where the ejection is not ideally bipolar, but still quite close to it.

5.2. Tests on the whole sample and limited sample

In section 4.1 a possible non-random feature was found from the distribution of ejection angles of pairs ejecting out for a_3 values below 1°. The actual sample was more evenly distributed than random sample. This might be due to a selection effect. It's possible that those quasars that are on opposite sides of a galaxy and have similar angular distance from the galaxy might be more easily noticed.

Another interesting feature was noted in section 4.3. Distribution of velocity of quasars in the actual sample seemed to be more concentrated to low velocities than in random sample. This also might be due to a selection effect. Pairs with very similar redshifts might be more easily noticed.

Considering the possibility of selection effects suggested above, it should be noted that papers suggesting these pairs don't give any reasons to assume the reality of the selection effects. In many cases the quasars in the pairs have been only known quasars at the vicinity of certain galaxy during the time when the pairs have been reported.

It might be interesting to look how the intrinsic redshift as a function of distance from the galaxy looks like with the good and possible pairs. That is shown in Fig. 10. There we can see that there doesn't seem to be very clear trends showing. What would be expected is a decreasing line of squares starting from upper left corner proceeding to the middle of the right edge of the diagram, then turning back but still decreasing while same time changing to a line of triangles that proceeds to the lower left corner of the diagram. (However, in fig. 10 there seems to be more pairs ejecting out in the upper section of the diagram and more pairs falling in in the lower section of the diagram, but let's not get overly excited about this vague trend that this small sample shows.)

Of course, we could now reject all the pairs that don't fit to the expected trend, but that would be cherry picking and therefore wouldn't tell us anything. What is needed is to collect considerably larger set of pairs with good (or preferably excellent) values, and then produce this diagram again to see if the expected trend shows up. It also must be remembered that the expected intrinsic redshift progression depends on ejection velocity; if ejection velocity is not same for all ejections, then some quasars fly further before they fall back and some quasars start to falling back when they're closer to the galaxy. Also, some quasars may exceed the escape velocity of the parent galaxy and never fall back.

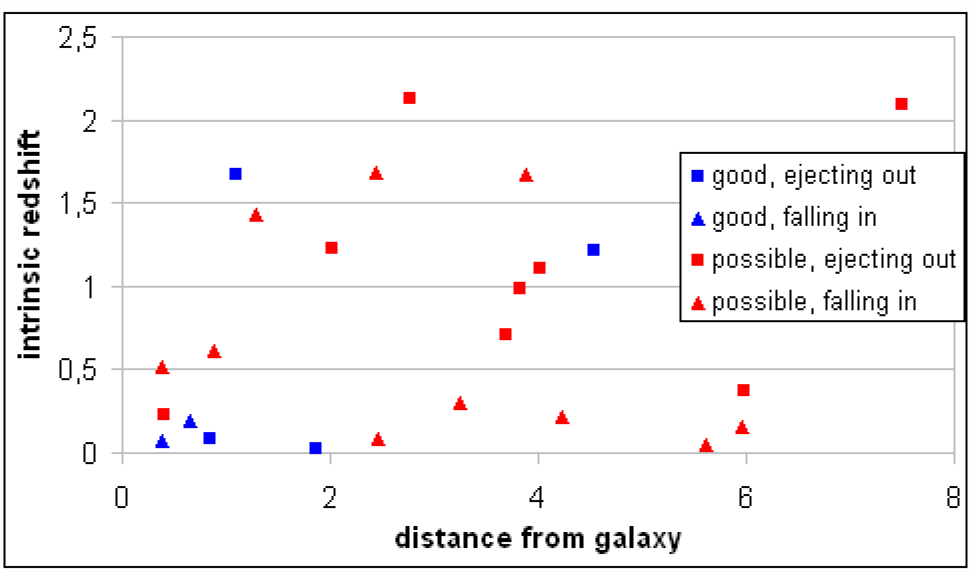

Fig. 10. Intrinsic redshift as a function of distance from galaxy (Mpc) for good and possible ideal bipolar ejection candidate pairs. Blue squares represent good pairs

ejecting out, red squares represent possible pairs ejecting out, blue triangles represent good pairs falling in, and red triangles represent possible pairs falling in.

Another interesting thing what we could do with larger set of good pairs is to see how the luminosity of objects evolves as a function of distance from the galaxy. Luminosity is expected to increase with age in Arp's hypothesis. Therefore the pairs falling in should be more luminous than the pairs ejecting out. Also, for pairs ejecting out, the luminosity should increase as the distance from the galaxy increases. For pairs falling in, the luminosity should increase as the distance from the galaxy decreases.

5.3. Other considerations

The model derived here is not restricted to galaxies ejecting pairs of quasars. The model can be used for other similar processes as well. One possible process where this model might be useful is jets of galaxies and stars. If we can determine points in a jet and a counterjet which are of same distance from the source of the jets, we can calculate the ejection angle of those jets (provided that they are exactly bipolar). That could be helpful for example when trying to determine the inclination of a galaxy. Also, if we know the redshifts in those points that are of equal distance from the source, we can calculate the velocity of the jets (and their length, if we know how far the source of the jets is from us). However, as far as the Author knows, there are no redshifts found from the jets of the galaxies yet.

5.4. Final notes

We have derived a model for ideal bipolar ejections of quasars from galaxies, and used that model to a set of known pairs of quasars aligned across galaxies. While most of the pairs didn't give very convincing values, there still was few good pairs found which might be ideal bipolar ejections.

However, it is clear that the result of this work is inconclusive, and follow-up studies are needed. First priority in the future is to find a large set of good pairs, i.e. pairs that give good results when run through the ideal bipolar ejection model.

ACKNOWLEDGEMENTS: Author wishes to thank David Russell for his presence in many Internet discussions, where he has turned out to be an endless source of information in the matters relating to this work. Thanks are also in order to all the people responsible of putting astronomical data and information accessible online to such places as NASA ADS, NED, Simbad, HyperLeda, etc. Without such resources this kind of work, done by a layman, wouldn't be possible.

REFERENCES

- Arp, H. 1966, Science, 151, 1214 (Abstract only) "Peculiar Galaxies And Radio Sources"
- Arp, H. 1967, ApJ, 148, 321 "Peculiar Galaxies And Radio Sources"
- Arp, H. 1977, ApJ, 218, 70A "Neighborhoods of Galaxies. II. NGC 4151"

- Arp, H.; Sulentic, J. W.; di Tullio, G. 1979, ApJ, 229, 489A "Quasars Aligned Across NGC 3384"
- Arp, H. 1980, ApJ, 236, 63A "Ultraviolet Excess Objects in the Region of a Companion Galaxy to NGC 2639"
- Arp, H. 1981, ApJ, 250, 31A "Quasars Near Companion Galaxies"
- Arp, H. 1984, ApJ, 283, 59A "Two Newly Discovered Quasars Closely Spaced Across a Galaxy"
- Arp, H. 1997a, A&A, 319, 33A "Identification of X-ray Sources ~2) Quasars Near Active Galaxies"
- Arp, H. 1999b, A&A, 341L, 5A "A QSO 2.4 Arcsec from a Dwarf Galaxy - the Rest of the Story"
- Arp, H. 2001a, ApJ, 549, 780A "The Surroundings of Disturbed, Active Galaxies"
- Arp, H. 2001b, cghr.confE, 9A "Origins of Quasars and Galaxy Clusters"
- Arp, H. & Russell, D. 2001, ApJ, 549, 802 "A Possible Relationship Between Quasars and Clusters of Galaxies"
- Arp, H.; Burbidge, E. M.; Chu, Y.; Zhu, X. 2001, ApJ, 553L, 11A "X-ray-emitting QSOs Ejected from ARP 220"
- Arp, H.; Burbidge, E. M.; Chu, Y.; Flesch, E.; Patat, F.; Rupprecht, G. 2002, A&A, 391, 833A "NGC 3628: Ejection Activity Associated with Quasars"
- Arp, H. 2003, arXiv preprint, astro-ph/0312198 "Alignment of Radio Emission and Quasars Across NGC 613 and NGC 936 and Radio Ejection From NGC 941"
- Arp, H.; Gutiérrez, C. M.; López-Corredoira, M. 2004, A&A, 418, 877A "New Optical Spectra and General Discussion on the Nature of ULXs"
- Burbidge, E. M. 1995, A&A, 298L, 1B "Spectra of Two Quasars Possibly Ejected from NGC 4258"
- Narlikar, Jayant; Arp, Halton 1993, ApJ, 405, 51N "Flat spacetime cosmology - A unified framework for extragalactic redshifts"
- Russell, David G. 2005, Ap&SS, 298, 577R "Evidence for Intrinsic Redshifts in Normal Spiral Galaxies" [arXiv preprint]
- Spergel, D. N.; Verde, L.; Peiris, H. V.; Komatsu, E.; Nolta, M. R.; Bennett, C. L.; Halpern, M.; Hinshaw, G.; Jarosik, N.; Kogut, A.; Limon, M.; Meyer, S. S.; Page, L.; Tucker, G. S.; Weiland, J. L.; Wollack, E.; Wright, E. L. 2003, ApJS, 148, 175S "First-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Determination of Cosmological Parameters" [arXiv preprint]
- Stockton, A. & Ridgway, S. E. 1998, AJ, 115, 1340S "Deep Spectroscopy in the Field of 3C 212"

Other resources used in this work:

NASA Extragalactic Database
Simbad
HyperLeda
Tool for converting equatorial coordinates to galactic coordinates from FUSE website

TABLES

Table 1 - Data of sample pair alignments

First column is the designation of the galaxy (and pair). Second column is the galactocentric redshift of the galaxy, z_G. Third column is the designation of the quasar Q1. Fourth column is the galactocentric redshift of Q1, z_1. Fifth column is the angular distance (a_1) between the galaxy and Q1. Sixth column is the designation of the quasar Q2. Seventh column is the galactocentric redshift of Q2, z_2. Eighth column is the angular distance (b_1) between the galaxy and Q2. References and notes are given in ninth column. Table contains links to data pages of each object in NED or Simbad.

GALAXY (pair)	z_G	Q1	z_1	a_1/deg.	Q2	z_2	b_1/deg.	Ref.
3C 212	1.048	3C 212:[RS97] f	0.928	0.0023	3C 212:[RS97] g	1.053	0.0016	Stockton & Ridgway 1998
3C 345 pair 1	0.593	Anon.	0.625	0.23	Anon.	0.704	0.12	Arp 1997b ***NOTE 3***
3C 345 pair 2	0.593	Anon.	0.54	0.32	Anon.	0.594	0.14	Arp 1997b ***NOTE 3***
53W 003	0.05	[KCW99] 02	2.381	0.075	[KCW99] 04	2.393	0.012	Arp 1999a
ARP 55	0.039	3C 216	0.670	1.84	3C 219	0.174	1.61	Arp 1967
ARP 102A ARP 102B	0.024 0.024	3C 352	0.807	3.35 3.29	3C 356	1.079	2.08 2.14	Arp 1967 ***NOTE 1***
ARP 125 NED01 ARP 125 NED02	0.029 0.028	3C 337	0.635	2.93 2.93	3C 345	0.593	2.31 2.30	Arp 1967 ***NOTE 1***
ARP 130 NED01 ARP 130 NED02	0.021 0.020	3C 9	2.009	4.38 4.38	3C 467	0.632	3.96 3.96	Arp 1967 ***NOTE 1***
ARP 139 NED01 ARP 139 NED02 ARP 196 NED01	0.038 0.039 0.073 -	3C 287 3C 287 Coma A Coma A	1.055 1.055 0.085	5.44 5.44 4.80 4.80	Coma A Coma A 3C 287 3C 287	0.085 0.085 1.055	3.09 3.08 3.73 3.74	Arp 1967 ***NOTE 1***

ARP 196 NED02			0.085			1.055		
ARP 141	0.009	3C 184	0.994	3.65	3C 173.1	0.292	1.39	Arp 1967
ARP 145	0.018	3C 66	0.021	1.65	3C 65	1.176	1.36	Arp 1967
ARP 148	0.035	3C 252	1.100	5.39	3C 247	0.749	2.36	Arp 1967
ARP 197 NED01 pair 1 ARP 197 NED02 pair 1	0.021 -	3C 263.1	0.824	3.33 3.31	3C 258	0.165	1.87 1.88	Arp 1967 ***NOTE 1***
ARP 197 NED01 pair 2 ARP 197 NED02 pair 2	0.021 -	3C 256	1.819	3.83 3.83	NGC 3862	0.022	3.42 3.41	Arp 1967 ***NOTE 1***
ARP 220 pair 1	0.018	ARP 220:[ABC2001] 9	1.249	0.13	WARP J1535.1+2336	1.258	0.12	Arp 2001a
ARP 220 pair 2	0,018	[A2001] Arp 220 20.3S	0.463	0.72	[A2001] Arp 220 20.3N	0.233	0.50	Arp *et al.* 2001 ***NOTE 4***
ESO 185-G054	0.015	Abell 3651	0.060	1.81	Abell 3667	0.056	1.52	Arp & Russell 2001
IC 0982 IC 0983	0.018 0.018	3C 293.1	0.709	3.94 3.97	3C 300	0.270	3.62 3.58	Arp 1967 ***NOTE 1***
IC 1767	0.018	3C 57	0.669	0.67	[HB89] 0155-109	0.616	0.66	Arp 1980
M49	0.003	3C 273	0.158	5.95	M87	0.004	4.40	Arp 1967
M63	0.002	3C 280.1	1.659	3.43	3C 285	0.079	1.16	Arp 1967
M82	0.0007	Abell 910	0.206	2.60	Abell 873	0.182	1.64	Arp & Russell 2001
M101	0.000	MRK 0273	0.03	3.06	3C 295	0.46	2.47	Arp

pair 1	8		8			4		2001b
M101 pair 3	0.0008	Abell 1904	0.071	6.50	Abell 1767	0.070	6.12	Arp & Russell 2001
M101 pair 4	0.0008	Abell 1616	0.083	10.9	Abell 1999	0.099	7.41	Arp & Russell 2001
M106	0.002	HELLAS 290	0.654	0.16	RX J121808.4+471610	0.398	0.14	Burbidge 1995
NGC 214	0.015	CRSS J0030.5+2618	0.5	2.58	Abell 0104	0.082	2.12	Arp 2001b
NGC 470	0.008	3C 37	0.672	0.57	3C 39	0.765	0.46	Arp & Russell 2001
NGC 613 pair 1	0.005	2QZ J013445.8-292842	2.059	0.12	2QZ J013356.8-292223	2.222	0.090	Arp 2003
NGC 613 pair 2	0.005	2QZ J013508.4-293023	1.482	0.20	2QZ J013345.0-291708	1.413	0.18	Arp 2003
NGC 936	0.005	[HB89] 0225-014	2.037	0.16	SDSS J022723.99-010623.4	2.176	0.075	Arp 2003
NGC 1365	0.006	"BL Lac"	0.308	0.206	"X-ray source"	0.904	0.127	Arp *et al.* 2004 ***NOTE 2***
NGC 2444 NGC 2445	0.014 0.013	3C 194	1.184	5.57 5.58	3C 186	1.067	1.25 1.24	Arp 1967 ***NOTE 1***
NGC 2639	0.011	SDSS J084419.29+503152.4	0.323	0.344	NGC 2639 U10	0.305	0.299	Arp 1997a
NGC 2916	0.012	NGC 2916 UB05	0.732	0.205	NGC 2916 UB2	0.793	0.124	Arp 1981
NGC 3384 pair 1	0.002	QSO B1045+128D	1.107	0.181	QSO B1045+1250	1.111	0.076	Arp *et al.* 1979 ***NOTE 4***
NGC 3384 pair 2	0.002	QSO B1045+128E	1.192	0.288	QSO B1045+128	1.280	0.191	Arp *et al.* 1979 ***NOTE 4***
NGC	0.003	1WGAJ1120.4+134	0.98	0.096	RIXOS F259_011	0.99	0.049	Arp *et*

3628 pair 1 NGC 3628 2	0.003	0 1WGAJ1120.4+134 0	1 0.98 1	0.096	QSO B1117+137	5 2.15	0.069	*al.* 2002 ***NOTE 4***
NGC 3842	0.021	QSO B1141+2013	0.33 5	0.021	QSO B1141+202	0.94 6	0.017	Arp 1984 ***NOTE 4***
NGC 4151	0.003	NGC 4151:[A77] G1	0.02 1	0.113	NGC 4156	0.02 3	0.087	Arp 1977
NGC 4194	0.008	3C 266	1.27 5	6.45	3C 277.1	0.32 0	5.78	Arp 1967
NGC 4235	0.008	PG 1216+069	0.33 1	0.770	[A97b] 2-1	0.13 0	0.599	Arp 1997c
NGC 5223 NGC 5228 NGC 5233	0.024 0,026 0,026	3C 288 3C 286 3C 286	0.24 6 0.84 9 0.84 9	4.25 4.33 4.26	3C 286 3C 288 3C 288	0.84 9 0.24 6 0.24 6	4.24 4.16 4.24	Arp 1967 ***NOTE 1***
NGC 5820	0.011	3C 319	0.19 2	3.76	3C 303	0.14 1	3.00	Arp 1967
NGC 5985	0.008	HS 1543+5921	0.80 7	0.616	SBS 1537+595	2.12 5	0.199	Arp 1999b
NGC 6217	0.005	RIXOS F122_021	0.37 6	0.098	RIXOS F122_014	0.38 0	0.051	Arp & Russell 2001
UGC 1839 pair 1	0.005	SDSS J022152.95- 003226.1	1.71 2	0.173	SDSS J022254.64- 004046.8	1.64 9	0.120	Arp 2003
UGC 1839 pair 2	0.005	SDSS J022058.11- 002946.8	1.70 6	0.402	SDSS J022346.43- 003908.3	1.68 0	0.320	Arp 2003
UGC 1839 pair 3	0.005	SDSS J022430.17- 004131.2	1.66 6	0.506	SDSS J022050.26- 002534.6	1.70 3	0.458	Arp 2003
UGC 4551 pair 1	0.006	QSO B0842+498	2.00 0	0.331	NGC 2639 U10	0.30 5	0.309	Arp 1980 ***NOTE 4***
UGC 4551 pair 2	0.006	NGC 2639 U15	1.54 3	0.536	QSO B0840+499D	1.52 2	0.067	Arp 1980 ***NOTE 4***

UGC 4551 pair 3	0.006	NGC 2639 U14	2.132	0.408	QSO B0840+501	2.800	0.210	Arp 1980 ***NOTE 4***
VV 120A VV 120C	0.026 0.025	3C 293	0.045	3.09 3.09	3C 294	1.779	1.11 1.11	Arp 1967 ***NOTE 1***
VV 248A VV 248B	0.015 0.016	3C 220.3	0.680	4.63 4.61	3C 61.1	0.188	4.08 4.10	Arp 1967 ***NOTE 1***
VV 291A VV 291B	0.038 -	3C 309.1	0.905	4.60 4.63	3C 330	0.550	4.08 4.06	Arp 1967 ***NOTE 1***

NOTE 1: Same pairs of quasars have more than one possible parent galaxies.
NOTE 2: values are from Arp et al. (2004).
NOTE 3: values are from Arp (1997b).
NOTE 4: values for Q1 and/or Q2 are from Simbad.

Table 2 - Results for pairs ejecting out

First column is the designation of the pair. Second column is the velocity component of Q1 in our direction. Third column is the Doppler component of the redshift of Q1. Fourth column is the velocity component of Q2 in our direction. Fifth column is the Doppler component of the redshift of Q2. Sixth column is the velocity of both quasars away from the galaxy. Seventh column is the intrinsic redshift component of both quasars. Eighth column is the ejection angle. Ninth column is the distance of the galaxy from Earth. Tenth column is the distance of the quasars from the galaxy.

PAIR	v_1 / km/s	z_{D1}	v_2 / km/s	z_{D2}	v / km/s	z_i	a_3 / deg.	d_3 / Mpc	d_4 / Mpc
3C 212	-9380	-0.031	9380	0.032	9381	-0.028	0.011	2600	445
3C 345 pair 1	-7110	-0.023	7110	0.024	7110	0.045	0.48	1830	586
3C 345 pair 2	-5160	-0.017	5170	0.017	5170	-0.016	0.52	1830	700
53W 003	-531	-0.002	531	0.002	531	2.226	0.028	206	150
ARP 102A ARP 102B	-20800 -20800	-0.067 -0.067	21200 21200	0.073 0.074	21500 21600	0.891 0.891	10.8 12.1	100 101	23.9 21.8
ARP 145	-107000	-0.313	109000	0.464	112000	0.460	15.4	75.7	7.43
ARP 196 NED01 ARP 196 NED02	-88400 -88400	-0.262 -0.262	96700 96700	0.397 0.397	108000 108000	0.370 NA **	30.4 30.5	299 NA **	43.3 NA **
ARP 220 pair 1	-599	-0.0020	599	0.0020	599	1.213	2.08	75.9	4.55

M101 pair 1	-50000	-0.155	52200	0.192	56100	0.227	23.9	3.38	0.397
M101 pair 4	-1900	-0.0063	2500	0.0084	2920	0.089	38.6	3.38	0.840
NGC 470	-8110	-0.027	8120	0.027	8140	0.704	4.58	33.3	3.69
NGC 613 pair 1	-7780	-0.026	7780	0.026	7780	2.124	0.766	20.8	2.76
NGC 936	-6720	-0.022	6720	0.023	6720	2.09	0.276	20.1	7.49
NGC 1365	-55600	-0.171	55600	0.207	55600	0.570	0.661	23.0	5.46
NGC 2916	-5190	-0.017	5190	0.017	5190	0.741	0.621	52.2	13.0
NGC 3384 pair 1	-284	-0.0009	284	0.0009	284	1.10	0.265	9.91	4.01
NGC 3384 pair 2	-5900	-0.019	5900	0.020	5900	1.23	1.13	9.91	2.02
NGC 3628 pair 1 NGC 3628 pair 2	-1060 -68300	-0.0035 -0.207	1060 68300	0.0035 0.261	1060 68300	0.982 1.49	0.202 0.498	11.8 11.8	3.83 1.92
NGC 3842	-55800	-0.172	55800	0.207	55800	0.579	0.199	88.0	8.35
NGC 4151	-176	-0.0006	176	0.0006	176	0.019	0.733	14.0	1.87
NGC 5223	-84400	0.335	178000	0.982	1770000	-0.089	88.5	100	7.45
NGC 5985	-80100	-0.240	80100	0.315	80100	1.36	0.586	35.3	18.1
NGC 6217	-435	-0.0015	435	0.0015	435	0.372	0.214	19.1	5.99
UGC 1839 pair 3	-2040	-0.0068	2040	0.0068	2070	1.67	9.46	21.6	1.10
UGC 4551 pair 3	-28900	-0.092	28900	0.102	28900	2.43	0.861	24.5	7.89
VV 120A VV 120C	-136000 -136000	-0.386 -0.386	136000 136000	0.633 0.633	136000 136000	0.658 0.659	3.44 3.44	110 106	52.1 50.3

*** value cannot be calculated because* z_G *is unknown.*

Table 3 - Results for pairs falling in

First column is the designation of the pair. Second column is the velocity component of Q1 in our direction. Third column is the Doppler component of the redshift of Q1. Fourth column is the velocity component of Q2 in our direction. Fifth column is the Doppler component of the redshift of Q2. Sixth column is the velocity of both quasars towards the galaxy. Seventh column is the intrinsic redshift component of both quasars. Eighth column is the ejection angle. Ninth column is the distance of the galaxy from Earth. Tenth column is the distance of the quasars from the galaxy.

PAIR	v_1 / km/s	z_{D1}	v_2 / km/s	z_{D2}	v / km/s	z_i	a_3 / deg.	d_3 / Mpc	d_4 / Mpc
ARP 55	51500	0.190	-53000	-0.164	-57300	0.351	24.1	163	11.9
ARP 125 NED01 ARP 125 NED02	3850 3850	0.013 0.013	-3990 -3990	-0.013 -0.013	-4210 -4200	0.569 0.570	20.9 20.5	119 117	15.0 15.0
ARP 130 NED01 ARP 130 NED02	79300 79500	0.311 0.312	-98400 -98200	-0.289 -0.288	-158000 -156000	1.247 1.249	55.5 55.0	108 81.4	7.81 7.22
ARP 139 NED01 ARP 139 NED02	90700 90700	0.367 0.367	-94400 -94400	-0.278 -0.278	-96200 -96100	0.449 0.447	14.0 13.9	155 161	44.3 46.1
ARP 141	63800	0.241	-64300	-0.196	-64400	0.592	4.49	38.0	17.1
ARP 148	27000	0.095	-27700	-0.088	-27800	0.854	8.32	143	56.7
ARP 197 NED01 pair 1 ARP 197 NED02 pair 1	65600 65600	0.249 0.249	-66600 -66600	-0.202 -0.202	-67000 -67100	0.431 NA **	8.49 8.66	85.6 NA **	24.3 NA **
ARP 197 NED01 pair 2 ARP 197 NED02 pair 2	130000 130000	0.593 0.594	-150000 -150000	-0.423 -0.422	-210000 -207000	0.734 NA **	47.7 47.1	85.6 NA **	7.30 NA **
ARP 220 pair 2	25600	0.089	-25600	-0.082	-25600	0.319	3.17	75.9	14.1
ESO 185-G054	603	0.0020	-615	-0.0021	-644	0.042	18.6	62.0	5.62
IC 982 IC 983	39500 40400	0.142 0.145	-48800 -47900	-0.151 -0.149	-83100 -72400	0.470 0.466	57.7 52.1	76.2 76.0	5.94 6.33
IC 1767	4630	0.016	-5050	-0.017	-18700	0.615	75.0	73.2	0.881
M49	20200	0.070	-22500	-0.072	-25000	0.079	30.4	14.0	2.45
M63	126000	0.567	-127000	-0.364	-127000	0.694	3.48	7.09	3.53
M82	2930	0.0098	-2970	-0.0099	-2990	0.193	8,78	2.87	0.661
M101 pair 3	41.2	0.00014	-98.8	-0.00033	-271	0.070	74.8	3.38	0.387
M106	25100	0.088	-25100	-0.081	-25100	0.518	2.46	6.29	0.387
NGC 214	47700	0.174	-49300	-0.153	-52600	0.259	22.4	63.4	6.77
NGC 613 pair 2	4220	0.014	-4230	-0.014	-4230	1.435	3.06	20.8	1.29

NGC 2444 NGC 2445	8200 8200	0.028 0.028	-8290 -8290	-0.027 -0.027	-8300 -8300	1.097 1.097	3.22 3.18	56.6 56.0	36.0 35.7
NGC 2639	2070	0.0069	-2070	-0.0069	-2070	0.300	4.59	46.7	3.26
NGC 4194	62600	0.236	-96100	-0.283	-176000	0.826	62.8	34.2	4.11
NGC 4235	24500	0.085	-24500	-0.079	-24600	0.217	5.39	33.8	4.23
NGC 5228 NGC 5233	41900 -72700	0.151 -0.219	-74500 -170000	-0.224 -0.474	-228000 -1640000	0.566 1.31	75.1 88.3	107 110	8.23 8.19
NGC 5820	6330	0.021	-6730	-0.022	-7370	0.154	27.1	46.7	5.97
UGC 1839 pair 1	3500	0.012	-3500	-0.012	-3500	1.67	0.786	21.6	3.89
UGC 1839 pair 2	1420	0.0048	-1430	-0.0047	-1430	1.68	3.16	21.6	2.44
UGC 4551 pair 1	118000	0.516	-118000	-0.341	-120000	0.968	9.17	24.5	0.861
UGC 4551 pair 2	1220	0.0041	-1220	-0.0040	-1220	1.52	0.154	24.5	19.1
VV 248A VV 248B	46700 46300	0.170 0.169	-56100 -56500	-0.173 -0.174	-80600 -84800	0.414 0.415	49.9 52.3	63.5 66.3	6.29 6.35
VV 291A VV 291B	27800 28100	0.098 0.098	-33800 -33500	-0.107 -0.106	-49900 -47400	0.672 NA **	51.5 49.1	158 NA **	15.3 NA **

*** value cannot be calculated because z_G is unknown.*

APPENDIX - Data and results for random samples

Pairs with random values were generated for comparison with actual sample. Actual sample has 55 pairs, 26 pairs with $z_1 < z_2$ and 29 pairs with $z_1 > z_2$ (those pairs with more than one possible parent galaxy are counted only once).

Random sample 1: Random pairs were assigned with similar redshift and angular distance range as the actual sample, so for pairs that have $z_1 < z_2$ redshift range is from z = 0.02 to z = 2.8 and angular distance range from 0.01° to 10°. For pairs that have $z_1 > z_2$ redshift range is from z = 0.01 to z = 2 and angular distance range from 0.2° to 6.5°. Data and calculated values for ejection angle (a_3) and velocity of quasars (v) are presented in tables A1 and A2.

Random sample 2: Distribution of angular distances was not homogenous in the actual sample for pairs that have $z_1 < z_2$. Second random sample was needed in order to get random angular distance distribution that would correlate better with the actual sample. Second random sample was generated with 19 pairs having angular distances from 0.002° to 0.7° and 7 pairs having angular distances from 1° to 10°. Data and calculated values for ejection angle (a_3) and velocity of quasars (v) are presented in table A3.

Table A1. Random sample 1, pairs with $z_1 < z_2$.

PAIR	a_1 / degrees	b_1 / degrees	z_1	z_2	a_3 / degrees	v / km/s
1	5.2651	4.9008	2.6666	2.7427	67.9	8290
2	8.4494	5.4982	1.0034	1.5217	28.7	40000
3	8.8361	7.4325	0.2325	0.494	58.4	56400
4	9.0352	4.4013	0.5626	0.9516	16.6	35300
5	8.7747	5.4926	1.3047	2.6225	27.0	76500
6	8.7322	2.1207	1.6684	2.4464	5.57	38800
7	8.9317	6.5048	1.6767	2.5793	39.7	57800
8	4.9824	4.6552	0.6159	0.9319	67.9	71800
9	9.3552	0.6393	0.9512	1.0105	1.37	4530
10	6.3043	2.4823	0.3321	0.4982	8.12	17900
11	0.792	0.6445	1.1077	1.4241	6.89	21100
12	6.143	4.9453	0.2652	1.5464	41.4	136000
13	7.2841	0.5278	0.0459	1.7952	1.14	137000
14	8.8542	6.9149	1.0159	2.7213	47.6	136000
15	2.7801	2.633	1.2665	1.4376	60.1	21900
16	8.0953	2.3785	1.1655	1.5314	6.69	23800
17	6.5027	6.2244	0.3887	1.9775	78.8	547000
18	3.3929	1.1126	1.8191	2.6077	3.31	36900
19	4.9374	3.3117	0.7767	2.2426	19.3	93500
20	5.8574	3.4109	2.4936	2.5117	15.9	813
21	9.0424	1.9257	0.196	1.0397	4.87	79400
22	3.379	2.454	0.8128	1.3804	17.4	42700
23	9.5255	5.2554	0.9534	2.5601	22.2	96600
24	3.8822	2.6941	1.8686	2.3532	17.1	24500
25	9.7026	7.0602	0.7199	1.9308	41.9	108000
26	6.9781	2.2157	0.6409	2.451	6.46	108000

Table A2. Random sample 1, pairs with $z_1 > z_2$.

PAIR	a_1 / degrees	b_1 / degrees	z_1	z_2	a_3 / degrees	v / km/s
27	5.2647	2.2237	1.0322	0.8731	7.64	-12400
28	5.2098	1.1087	1.6045	0.4938	2.81	-81700
29	3.1362	1.271	1.6976	0.9911	4.26	-45400
30	3.513	1.0645	1.2487	0.2191	3.05	-89300
31	6.0795	5.2695	1.4627	0.9915	54.0	-54700

32	2.7518	2.0235	1.353	0.5307	14.9	-65900
33	4.011	1.8937	1.8752	0.9155	7.13	-60700
34	2.7802	0.5453	1.1161	0.9397	1.36	-13100
35	4.5852	2.8792	1.7511	1.1342	15.1	-39500
36	5.9329	5.7382	1.9794	0.7132	80.7	-492000
37	2.0617	1.7056	1.5485	0.6987	19.0	-63500
38	0.5982	0.2789	0.6941	0.1084	1.04	-62700
39	6.1902	3.786	1.3413	1.3054	18.8	-2470
40	1.6593	0.3413	1.7091	1.3829	0.86	-19200
41	1.7237	1.0862	0.876	0.8611	5.85	-1200
42	4.1027	2.9959	1.0577	0.0433	21.2	-106000
43	5.3113	3.7077	0.6356	0.4343	23.2	-21600
44	1.4367	0.2423	1.1132	0.564	0.58	-44800
45	5.8725	3.5421	0.6884	0.4211	17.3	-27300
46	4.6387	4.1131	1.1545	0.1962	51.7	-139000
47	2.483	2.1031	1.5533	0.6663	25.6	-70100
48	4.8133	1.3241	0.9757	0.8286	3.65	-11700
49	6.1883	0.5037	1.8001	1.459	1.10	-19500
50	5.3526	0.2897	1.0962	0.3287	0.61	-67400
51	3.9587	1.3885	1.7653	1.7274	4.27	-2080
52	6.0797	4.3065	0.8654	0.2257	27.2	-70600
53	2.4079	0.553	1.1093	0.0973	1.44	-94700
54	0.8268	0.2534	1.1739	0.3388	0.73	-71300
55	4.6953	1.3256	1.6334	0.3169	3.69	-100000

Table A3. Random sample 2, pairs with $z_1 < z_2$.

PAIR	a_1 / degrees	b_1 / degrees	z_1	z_2	a_3 / degrees	v / km/s
1	0.5973	0.5703	2.6666	2.7427	0.41	3360
2	0.3678	0.0091	1.0034	1.5217	0.00033	34300
3	0.6496	0.1091	0.2325	0.494	0.0046	28800
4	0.3323	0.2804	0.5626	0.9516	0.063	33200
5	0.4313	0.1546	1.3047	2.6225	0.0084	66700
6	0.6918	0.025	1.6684	2.4464	0.00091	38100
7	0.5784	0.1362	1.6767	2.5793	0.0062	43300
8	0.3269	0.152	0.6159	0.9319	0.0099	26700
9	0.4302	0.0229	0.9512	1.0105	0.00084	4490

10	0.6185	0.2258	0.3321	0.4982	0.012	17600
11	0.2658	0.1863	1.1077	1.4241	0.022	20900
12	0.698	0.5834	0.2652	1.5464	0.12	102000
13	0.2898	0.1734	0.0459	1.7952	0.015	137000
14	0.2426	0.0348	1.0159	2.7213	0.0014	89100
15	0.5419	0.4525	1.2665	1.4376	0.095	11000
16	0.5903	0.0231	1.1655	1.5314	0.00084	23400
17	0.4821	0.2818	0.3887	1.9775	0.024	109000
18	0.199	0.002	1.8191	2.6077	0.000071	36800
19	0.6638	0.2994	0.7767	2.2426	0.019	87600
20	5.4481	1.798	2.4936	2.5117	0.093	782
21	6.3412	1.3515	0.196	1.0397	0.060	78800
22	8.5527	2.2678	0.8128	1.3804	0.11	41300
23	7.3369	5.8919	0.9534	2.5601	0.80	128000
24	9.6886	1.4211	1.8686	2.3532	0.058	23700
25	8.5623	7.3968	0.7199	1.9308	1.08	171000
26	4.1483	3.8517	0.6409	2.451	1.08	228000