Possible explanation of the Arp-Burbidge paradox

© B.V. Komberg [1,2], S.V. Pilipenko[1,3]

[1]AstroSpace Center of Lebedev Physical Institute
[2] Email: komberg@asc.rssi.ru
3 Email: spilipenko@asc.rssi.ru

Abstract: 1. Several recent articles (mostly by H. Arp and J. Burbidge) have noticed the observational facts of surface number density of far quasars excess around some nearby galaxies. Authors has interpreted this "paradox" as a confirmation of non-cosmological nature of quasars. The examples of close (Δи<5”) pairs of quasars with different z_q and extended (Δи >5”) pairs of quasars with near the same z_q may belong to the same kind of facts.

2. The appearance of rather representative catalogs of quasars (eg., Sloan Digital Sky Survey - SDSS) leads us to the opportunity of checking the statistical significance of the "paradoxal" facts noted above. For this purpose we use the Minimal Spanning Tree (MST) technique to study nonhomogeneities in the surface distribution of about 32 800 quasars in one of the regions on the sky (б=120-160, д=20-70) covered by the SDSS.

3. We suggest the explanation of the "Arp-Burbidge paradox" in the framework of the existing cosmological paradigm using the effects of gravitational lensing. We pay attention at the fact that there are far and reach X-ray clusters or even superclusters on the line of sight of many of the objects which are the basis of the "paradox". Such clusters are complex transparent gravitational lenses for far quasars, they can change surface density of background objects not only by the net cluster gravitational field, but also by fields of massive galaxies - members of the cluster, and possibly by fields of globular clusters which may constitute up to tens per cent of dark matter mass in galaxy clusters.

1. Introduction

Once upon a time in a galaxy far, far away there were three observers, H.Arp & G.Burbidge, E. Burbidge.

Some recent papers point out the real clustering of galaxies around QSOs. This observational fact confirms the conception that objects with active galactic nuclei more often appear in the regions with galaxy overdensity. In such regions the probability of tidal interactions and galaxy merging is higher. This all is in a good concordance with the “bottom-up” paradigm, in which massive objects form due to a hierarchical merging of less massive ones. However the opposite situation when the surface overdensity of quasars is observed near some nearby galaxies and $z_q >> z_g$ needs some reasonable interpretation. Some authors assume the noncosmological nature of QSO redshifts in order to explain the angular proximity of QSOs and galaxies [1]. The most successive advocates of this point of view are Halton Arp and Geoffrey Burbidge who give a lot of surprising examples in favor of their idea which we call “the Arp-Burbidge paradox”.

For example in work [1] it is shown that there are 41 QSOs with z from 0.1 to 2.6 in 2 □ ^{o} around Sb galaxy NGC 6212 (Sy I, m = 14.7, z = 0.03). QSOs have m = 16 – 23 and the information about them has been taken from several different catalogs implemented on different telescopes. However, we think that the assumption of QSOs being thrown out from the galaxy is in contradiction with the absence of the correlation between angular separation and redshifts of QSOs. Meantime there is a clear and quite usual selection dependence between redshift and magnitude of QSOs.

Recently the question of the correlation between nearby galaxies and far QSOs has been examined on the statistically much richer data, which are simultaneously much more homogeneous. E.g. in the work [2] there has been constructed a sample of 8380 QSO-galaxy “pairs” with the projected separation ≤ 150 kpc (on the galaxy distance). This sample has been constructed on the basis of cross-correlation analysis of catalogs containing 11360 QSOs (z=0.1–3.0) and 77483 galaxies (z<0.25). The sample has been used to calculate the distribution function $N(z_g/z_q)$. This function has two gentle maxima at $z_g/z_q \approx 0$ and 1. Using model calculations and artificial catalogs authors conclude that the maximum at $z_g/z_q \approx 0$ is due to the selection effect and they explain the $z_g/z_q \approx 1$ maximum as a result of gravitational lensing on transparent lenses such as globular clusters.

Other observational “paradoxes” may belong to the same class of phenomena, e.g. pairs of QSOs with the separation between components $\Delta\theta > 5''$, close quasar pairs with different redshifts of members.

2. Nonhomogeneities in the quasar distribution

A.G. Doroshkevich proposed to test the reality of the paradox by studying the nonhomogeneities of the surface distribution of QSOs from the SDSS catalog. For our investigation we have selected the largest continuous region of this catalog on the sky containing 32800 QSOs with $m_I < 19.1$ and $z_q = 0.3–2.3$ (we call this region S2). We have fulfilled the search of nonhomogeneities (“groups” of QSOs) with the help of the minimal spanning tree technique (MST), which is the generalization of the well-known friend-of-friend method. Let’s consider a set of points with given coordinates. If each point is connected to one or several points by segments (“branches”) such there is only one way to travel from one point to another then this construction is called a tree. If the sum of branch’s lengths is minimal then it is called a MST.

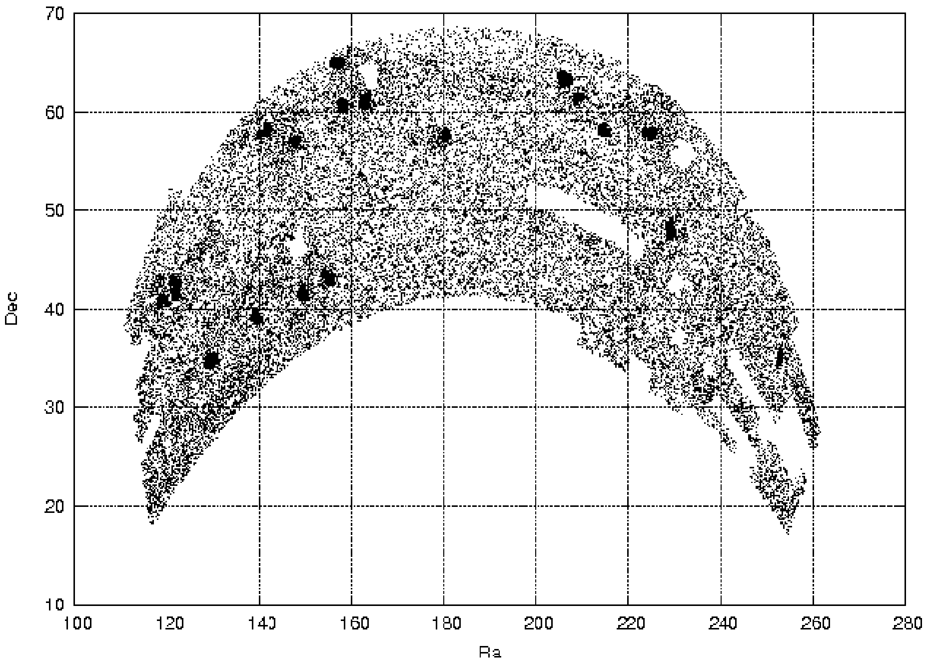

Fig.1 18 groups of QSOs in the SDSS S2 region.

The MST method allows us to select overdense regions (groups) from a set of points by throwing out branches longer than some threshold length, and we leave only rich enough groups. Thus we have two threshold parameters: the maximal branch length l_{max} and the minimal group richness N_{min}. In order to check whether selected groups appear due to the shot noise and measure the statistical significance of our study we fulfill the same analysis for 100 random catalogs, each having the same area, shape and number of QSOs as the part of the SDSS catalog we investigate.

First, we have searched nonhomogeneities in the full data of the SDSS catalog S2 region. The mean number density of QSOs in this catalog is 11.5 QSO/□ ^{o}, the mean branch length $<l>=0.18^{o}$. For the search of groups we have used threshold parameters $l< 0.18^{o}$, $N_q>25$, what corresponds to QSO number overdensity of 1.6 times on the area < 1□ ^{o}. These parameters are comparable to those near galaxies mentioned by H. Arp and G. Burbidge. As a result we have found 18 groups containing 593 QSOs. The probability to find ≥18 groups in random catalog is less than 1%. All 18 groups and the SDSS S2 region are presented on Fig 1, and an examples of groups are plotted on Fig 2. It can be seen that groups found by the MST method have irregular shape.

We also fulfilled our procedure for the homogeneous part of the SDSS catalog. This part contains only quasars selected with the homogeneous and well-defined criterion. For this catalog we find 11 groups (the mean number density of QSOs is different, hence the threshold parameters are also different from the full catalog, $l < 0.23^{o}$, $N_q > 15$). The probability to find 11 groups in random catalogs is rather high: 10%. This result means that the inhomogeneities in quasar distribution are mostly due to inhomogeneities of the catalog. However, the coordinates of four groups from homogeneous and full catalogs coincide, which indicates some non-randomness in QSO distribution.

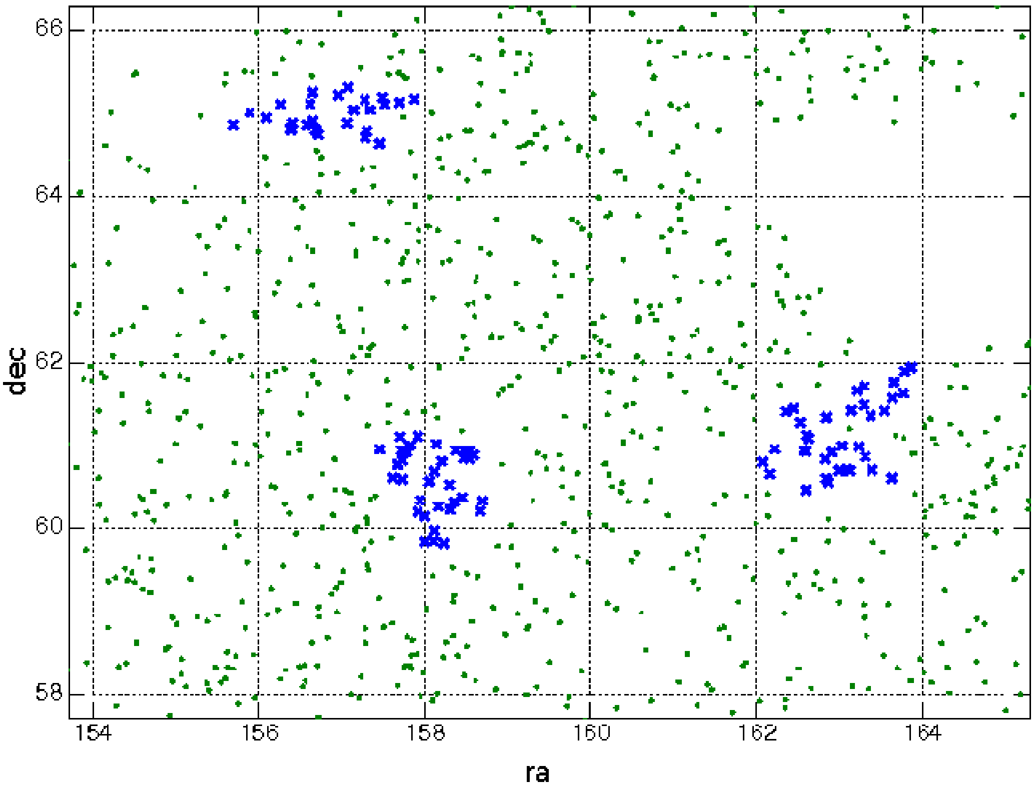

Fig 2. Examples of 3 quasar groups.

3. The possible explanation of the paradox

It is convenient to think that gravitational lensing of QSOs leads to multiple images with the same z and small angular separation $\Delta\theta < 5''$. This can be provided with the models of strong gravlensing on opaque lenses, e.g. central parts of massive galaxies. For our case when large regions (tens of arcmins) of quasar overdensity are observed, more favorable is to consider clusters or even superclusters of galaxies as transparent lenses, which can increase the number density of QSOs by both the image splitting (strong lensing) and the increase of quasar brightness (weak lensing). Due to the features of such systems only rather far ($z>0.3$) clusters can focus as a lens. Let's explain this basing on the calculations from [3]. A far point source of light observed through a transparent gravitational lens of diameter $2R_L$ on it's axis is seen as a point object if the observer is closer than the focus distance (χ_F) to the lens. The χ_F depends on the matter distribution within the lens:

$$\chi_F = R_L^2 / 3r_g \text{ for a homogeneous sphere,}$$

$$\chi_F = c^2 / 2\pi G\sigma_0 \text{ for the King model } \sigma(p) = \sigma_0[1+(p/r_c)^2]^{-1},$$

where p is the impact parameter, r_c – the kernel radius, y_0 - the surface density.

If the observer is at the focus distance or farther from the lens, then the image looks like a point in the center surrounded by a brighter ring. If the source is not exactly on the axis connecting the lens and the observer, then the observer sees two banana-like segments instead of the ring. From the formula above we conclude that in order to achieve a split image of a source (a strong lensing) a massive and far cluster is needed as a lens. E.g. if the central part of the cluster has $R_L=300$ kpc and $M_L=3\cdot 10^{14}$ M¤ than $\chi_F = 1.7\cdot 10^3$ Mpc what corresponds to $z_{cl}>0.3$.

The angular separation between images of one source can reach several arcmin. Even such separations are insufficient to explain the Arp-Burbidge paradox, which envelopes areas of about 0.5 square degrees. Perhaps, one should consider gravitational lensing on superclusters involving all their substructure (clusters and massive galaxies).

The largest catalog of far galaxy clusters is achieved by A.A. Vikhlinin [4] who basing on the results of the ROSAT satellite found 240 clusters on 400 square degrees of the sky. These clusters have redshifts up to 0.7. By comparing their coordinates and objects under interest we find that some of them are almost at the same lines of sight. This is true for 7 of our 18 groups of quasars, for galaxies NGC 6212, 1365, 1068, 2639, 4151, 4258, 3628 around which the overdensity of QSOs is observed, and for several large QSO-pairs with similar z.

The precision with which the coordinates coincide is about several arcmin and even up to one degree. However, this may be enough if these clusters are only parts of larger superclusters. And we don't see other members of superclusters in the Vikhlinin's catalog because the effective sight of view of the ROSAT satellite is only 17'.5x17'.5. The coordinates of galaxies from the works of H. Arp and G. Burbidge are presented in Table 1.

Galaxy	z	Coordinates	No. In the Vikhlinin's catalog	z of cluster	Coordinates of the XR CL
NGC 1068	0.0038	0242–001	RCS 02 24 – 00 02	0.78	0224-0002
NGC 1365	0.0055	0333–362	35(56)	0.372 (0.32)	0351–3650
NGC 2639	0.0111	0843+503	58	0.423	0842+5023
NGC 3079	0.0037	1001+557	81(100)	0.214	0958+5516
NGC 3516	0.0088	1107+725	–	–	-
NGC 3628	0.0028	1117+138	101(124)	0.340	1123+1409
NGC 4051	0.00234	1203+446	–	-	-
NGC 4151	0.0033	1208+396	115 (141)	0.340	1211+3912
NGC 4258	0.0015	1218+475	119 (149)	0.70	1221+4918
NGC 6212	0.0303	1643+398	(208)	0.365	1642+3959

Table 1. Galaxies around which the excess of QSO surface density is observed and X-Ray clusters from the Vikhlinin's catalog and others.

4. Conclusions

On the basis of our results we conclude that the observational data do not contradict with the assumption that the Arp-Burbidge paradox may be explained with the help of gravitational lensing on far rich galaxy clusters serving as transparent lenses. Such clusters may accidentally appear at the lines of sight of some nearby galaxies and they may lead to the increasing of the number of far quasars near these nearby galaxies. The gravlensing in this case must have complex form because in addition to the lensing on the total mass field of the cluster the lensing on individual galaxies may be substantial.

However, there is a problem of achieving large enough "optical thickness", ϕ. For a cluster of radius $R_{cl}=1$ Mpc and containing about $n_g=1000$ galaxies of radius $R_g=10$ kpc we have $\phi_g=R_g^2\cdot 2R_{cl}\cdot n_g \approx 0.05$, i.e. only 5% of background quasars will be lensed what is insufficient for the explanation of the paradox. Maybe the assumption of the presence of intergalactical globular clusters of stars is needed to reach substantial ϕ.

There are several observational consequences of our main assumption:
1. At the directions of quasar groups we have identified far and rich X-ray clusters must be observed. The same is true for the galaxies mentioned by H. Arp and G. Burbidge.
2. The excess of the surface number density of other far objects such as galaxies, radio and X-ray sources and even possible gamma-ray bursts may be observed at these directions.
3. The excess of the number of close QSO pairs and also arcs, arcletts may be observed at the same directions.
4. The Suynajev-Zel'dovich effect can lead to the decrease of the CMB temperature in these directions on angular scales up to tens of arcmin.
5. Lensed radio-sources behind massive galaxy clusters must have peculiarities in their polarization properties due to the passing of radio-waves through magneto-active media of the cluster.
6. If farther observations confirms the possibility to explain the Arp-Burbidge paradox by means of the gravitational lensing then this may be an indirect confirmation of a large amount of globular cluster-like intergalactic objects.

We'd like to thank A.G. Doroshkevich and A.V. Zasov for the useful discussion and especially V.G. Vakulik for the consultations about modeling gravlensing effects on rich galaxy clusters.

References

1. Burbidge G. //ApJ. 586, L119 (2003).
2. Бухмастова Ю.Л. // Письма в Астрон. журн. 29**,** 253 (2003)
3. Блиох П.В., Минаков А.А.. Гравитационные линзы, Киев: Наукова Думка, 1989.
4. Burenin R.A., Vikhlinin A., Horhstrup A. et al // ApJSS. 172, 561 (2007)