GLOBULAR CLUSTERS AS GRAVITATIONAL LENSES. RESULTS OF SUPERAMPLIFICATION

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In previous works we showed that amplification of small sources by cores of globular clusters or dwarf galaxies can reach 5–10 magnitudes, if the cores are transparent. This amplification can explain the significant part of Arp's objects. The lenses for Arp's objects are globular clusters in the halos of foreground galaxies. The nuclei of Seyfert or other active galaxies can be sources for this superamplification. VLBI or other high-precision observations will confirm or reject this hypothesis.
Here we propose new simple observational test. Let this hypothesis is valid. It is known that there can be near 10^2 globular clusters near ordinary galaxy. These globular clusters can produce amplification not only of active nuclei, but of ordinary nuclei and any other sources. Now ordinary galaxies are discovered at high redshifts, up to $Z = 5$. If globular clusters in the halos of distant foreground galaxies can act as gravitational lenses, we can expect the overdensity of star-like images near foreground galaxies. We analyzed USNO A2.0 catalog in the vicinity of 35862 galaxies with redshifts 0.01–0.33, and found that mean overdensity of objects brighter than 21^m is near 100 objects per galaxy. We show that this overdensity can not be explained by usual clustering of galaxies.

Quasi-stellar objects were discovered near 40 years ago. The first who proposed gravitational lensing for explanation of quasars was Barnotti [3]. But it was shown that neither galaxies nor stars in the halos of galaxies cannot explain all observed properties of quasars. Arp pointed that quasi-stellar objects can concentrate near bright galaxies [1]. There are a lot of papers where authors confirm or reject the clustering of quasars near foreground galaxies or clustering of galaxies near quasars (see [2] or [8] for example). Burbidge *et al.* [6] found about 500 associations of quasars with foreground galaxies. It is near one tenth of the total number of bright quasi-stellar objects. But small statistics do not permit them to find or reject the clustering and explain its nature.

Baryshev, Raikov and Yushchenko [4] proposed that these associations can be explained as gravitational lensing of distant active nuclei by cores of globular clusters, dwarf galaxies, and other middle mass objects (MMO) located in the halos of foreground galaxies. It should be noted that Yakovlev *et al.* [11] developed an analytical theory for calculations of amplification of objects like globular clusters. They showed that amplification by core of transparent object of this type can reach infinity for point sources.

In 1994 Yushchenko, Baryshev and Raikov [12] developed the software for direct calculations of amplification by cores of objects like globular clusters for extended sources. They found that amplification can reach 5–10 magnitudes for typical cases and quasar-galaxy associations (Arp's objects) can be explained by this effect. The superamplification by the cores of MMO can be easily explained. Under some reliable conditions all light rays from the source to the solid angle of the core of MMO will be focused near observer. That is why the amplification can be estimated as the ratio of angular squares of the MMO's core and of the source. The typical diameter of the core of MMO is 10–50 pc, while the size of emitting region of quasi-stellar objects can be significantly less than 1 pc. The square ratio of these quantities give us the amplification coefficient from 10^2 to 10^4: from 5 to 10 magnitudes. The angular sizes of amplified images are equal to the angular sizes of the cores of globular clusters in the halos of foreground galaxies - these are star-like images for our optical telescopes.

Later the detailed investigation of this effect was published by Baryshev & Ezova [5]. They listed a set of observational tests for validation of this hypothesis. We can only say that these tests require new precision observations and are quit hard for observers.

Yushchenko & Raikov [13] proposed that not only Arp's objects, but significant part or all quasi-stellar objects can be explained as gravitational lensing by cores of globular clusters and dwarf galaxies.

This hypothesis can work if the cores of globular clusters are transparent. The necessary condition is also the existence of distant Seyfert nuclei or other active nuclei with spectral properties similar to that of quasars. Typically, only one globular cluster per foreground galaxy can act as gravitational lens because the number of background Seyfert or other active nuclei is too small.

Yushchenko [14] proposed a new observational test for verifying this hypothesis. This is a very simple test. Not only one globular cluster per foreground galaxy can produce the amplification of the images of distant sources. All globular clusters and dwarf galaxies in the halo can do it. But the number of active nuclei as sources is insufficient. That is why the sources must be ordinary galaxies or any other objects located on the higher redshift behind these MMOs.

Let us assume that there are not only Seyfert nuclei at high redshifts, but galaxies of all types. Now ordinary galaxies up to redshifts near 5 can be discovered (see [7] for example). That is why the sufficient number of sources exist, and they can be significantly amplified due to gravitational lensing.

It is known that the number of Seyfert galaxies is of order only 1% of all galaxies. If all types of galaxies are gravitationally amplified by cores of globular clusters and dwarf galaxies by 5–10 magnitudes we can expect the excess of number density of star-like images near foreground galaxies. We know that the usual number of globular clusters per galaxy vary from 10 to 10^4. The mean value is near 10^2.

That is why the expected number density of high redshift ordinary galaxies, gravitationally amplified by globular clusters, must be two orders higher than the number density of quasi-stellar objects. The last catalogues of bright quasars contain near 10^4 objects. Thus, we can expect near 10^6 high redshifts star-like objects located near foreground galaxies. The expected spectral properties of these objects will be similar to spectral properties of usual galaxies with a correction for redshift and evolution. In any case, their colors will be more redder than quasars.

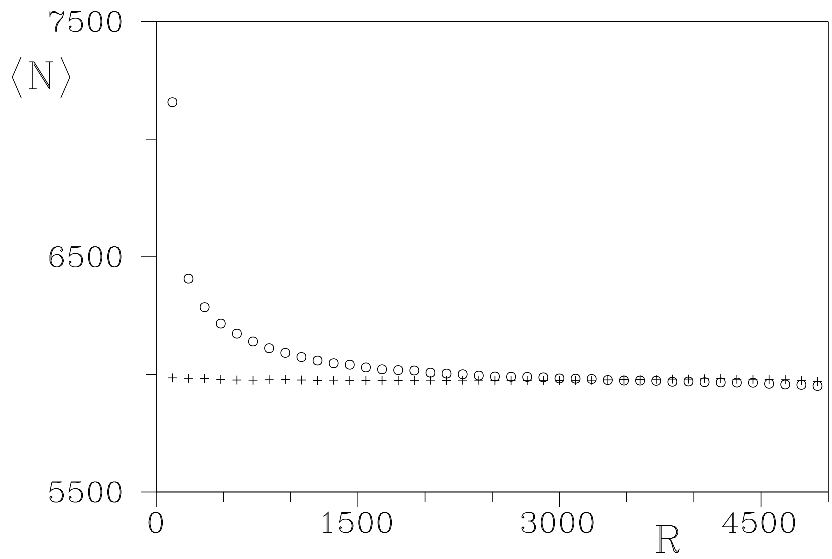

Figure 1: The mean density of objects in concentric rings around 35862 galaxies (circles), and around random centers (crosses). The axes are the radii of concentric rings in arcseconds and mean density of objects per square degree

For checking the validity of our assumption we used digitized Palomar survey with extension to southern sky – USNOA2.0 catalog [10] – as a catalog of star-like images. This catalog contains more than 500 millions of objects brighter than 21^m. We used CfA catalog [9] as a catalog of foreground galaxies. We selected 35862 galaxies with redshifts more than 3000 km/s from CfA catalog. We calculated the number densities of all objects in the concentric rings around each galaxy up to 1.5 degree in diameter. We made calculations for two values of the distances between concentric rings – 20 arcseconds and 2 arcminutes. The similar calculations were made for four random centers around each galaxy at the distance 1.5 degree.

The mean results are shown in Fig. 1 (see also [14]). We can see a well detected over-density of objects around galaxies. Random centers show zero overdensity. The overdensity around galaxies is near 100 objects per galaxy. It should be noted that the mean density of objects in the investigated regions is near 6000 objects per square degree. 100 objects is near 1.5% over-density. Only mean results for 35862 galaxies permit us to claim that the overdensity exist. This means that about $35862{\times}10^2$, *i.e.*, several millions objects in USNOA2.0 are star-like images of distant galaxies amplified by cores of globular clusters or dwarf galaxies by 5–10 magnitudes.

We should mention that USNOA2.0 catalog does not contain star/galaxy classification of the objects. Therefore, we can expect that part of the overdensity can be explained by usual clustering of galaxies. But in this case we must detect the stronger effect for foreground galaxies with small redshifts and weaker effect for foreground galaxies with higher redshifts. Is it true?

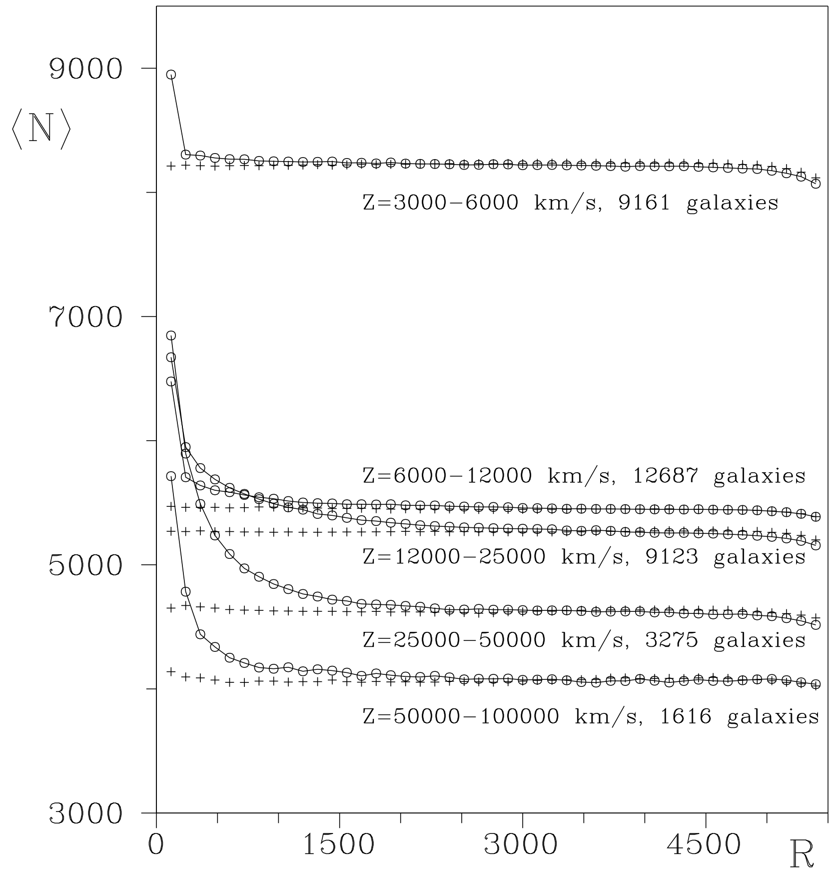

Figure 2: The same as Fig. 1 but for groups of foreground galaxies with different redshifts, namely 3,000–6,000 km/s, 6,000–12,000 km/s, 12,000–25,000 km/s, 25,000–50,000 km/s, 50,000-100,000 km/s

The statistics is sufficient and we were able to plot the overdensity as a function of galaxy redshifts. Fig. 2 shows the same as Fig. 1 but for groups of foreground galaxies with different redshifts. We can see that the strongest overdensity is observed for the groups of galaxies with redshifts from 12,000 km/s to 50,000 km/s and that the overdensity for nearest group of galaxies is the smallest.

This result permit us to claim that usual galaxy clustering can not strongly influence on the overdensity of objects around galaxies.

Different mean density of objects per square degree in different groups (see Fig. 2) can be easily explained by different mean galactic latitude of galaxies with different redshifts.

We predicted and found the overdensity of star-like images around galaxies. These star-like images are the images of high redshift galaxies, amplified by cores of globular clusters (or dwarf galaxies). Only small part of this overdensity can be explained by usual images of galaxies.

The overdensity of objects near galaxies is an observational fact and in any case it is necessary to investigate this problem in detail. Even if our explanation is false, it will be necessary to find other reason for this overdensity.

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