GRAVITATIONAL LENSING BY GLOBULAR CLUSTERS. INFLUENCE OF MICROLENSING

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ABSTRACT. Quasar-galaxy associations can be explained as gravitational lensing by globular clusters, located in the halos of foreground galaxies. We propose new observational test for checking this hypothesis. We used SUPERCOSMOS sky survey to find overdensities of star-like sources with zero proper motions in the vicinities of foreground galaxies from CfA3 catalog.. Preliminary results show that our hypothesis is true. We discuss the influence of microlensing on the results of observations. We made CCD VRI photometry on 1.22 meter telescope of Kryonerium observatory (Greece) to select extremely lensed objects around 6 galaxies.

Key words: quasi-stellar objects; galaxies: halos, gravitational lensing

1. Introduction

Quasar-galaxy associations is one of the most intriguing puzzles of modern astronomy. Arp (1968) was the first, who noticed it. There were a lot of papers, with possible explanations of Arp's objects. We must mention a series of Schneider's articles (from Schneider, 1988 to Bartelmann, Schneider, 1993). In these papers it had been shown that the gravitational lensing can be a good hypothesis for explanation of this phenomena. But the nature of objects which can act as gravitational lenses in this case was unknown.

In our previous papers (Baryshev et al., 1993, Yushchenko et al. 1998, Yushchenko & Raikov 1998) we proposed, that gravitational lensing by cores of globular clusters, dwarf galaxies or other middle mass objects (MMO) in the halos of foreground galaxies can be the reason of quasar-galaxy associations. We used Yakovlev et al. (1983) formulae for calculation of amplification of background objects by foreground objects with King's mass distribution, for example by globular clusters. Yushchenko et al. (1998) developed the software which permit to use these formulae for calculations of amplifications of extended sources. The amplification can reach 5-10 magnitudes for typical cases and QSO-galaxy associations can be explained by this effect. Baryshev & Ezova (1997) and Yushchenko (1999) proposed the observational tests for validation of this hypothesis.

Yushchenko (1999, 2000) showed that simple calculations of surface density of star-like sources around galaxies can be a good test. In these papers author predicted that surface density of star-like sources around foreground galaxies must be increased. Why?

Let us imagine, that Arp's objects are produced by gravitational amplification of distant sources by objects in the halos of foreground galaxies. It is well known that gravitational lensing can not strongly influence on the spectral properties of the sources. That is why spectral properties of distant sources must be similar to that of quasars. We must find the class of objects whose spectral properties are quit close to properties of QSO. Seyfert galaxies can be this type of objects. If Seyfert nuclei, amplified by globular clusters in the halos of foreground galaxies, are responsible for quasar-galaxy association, we must to point, that (usually) there are not only one globular cluster in the halo of the ordinary galaxy. There are near 10^2 or more globular clusters in the halo. And every cluster can amplificate the background source by 5-10 magnitudes. If there are sufficient number of sources at high redshifts, the globular clusters will amplificate these source. The result will be the increasing of surface density of star-like sources around foreground galaxies.

Star-like? Baryshev & Ezova (1997) and Yushchenko (1998) showed, that the angular size of extremely amplificated images are equal to angular size of the core of the globular cluster. The angular size of the core of the globular cluster at redshift near 0.01 is near 0.05 arcseconds - it is a point-like source for optical telescope. The extremely high level of amplification will help us to detect the high redshift objects, but the structure of the images of these objects will be broke by gravitational lensing. That is why (in the first approach) we can receive only spectral and coordinate information about extremely lensed objects (ELO). It will be very difficult to investigate internal structure of these objects.

Galaxies with z higher than 5 can be discovered now. For example Hu et al. (1999) found the galaxy with z=5.74, Yahata et al. (2000) identified near 4000 galaxies over the range in redshifts from 0 to 10 and beyond. That is why the big number of sources can exist, and they can be amplified due to gravitational lensing by globular clusters. The number of Seyfert galaxies is near 1% of the total number of galaxies. We must expect, that the surface density of extremely lensed objects must be two orders higher than the surface density of QSOs. The spectral properties of ELOs will be similar to that of ordinary galaxies with correction for redshift and evolution.

We wrote ordinary galaxies. But we have very little knowledge about the properties of objects at high redshifts. That is why it will be better to write that the spectral properties of ELOs will be the same as the spectal properties of unknown objects at high redshifts. The investigations of ELOs, will help us to learn more about the nature of the Univerce at high redshifts.

Yushchenko (1999, 2000) showed that the expected overdensity exist. The USNOA2.0 catalog (Monet D. et al. 1998) was used as a catalog of star-like sources. The vicinities of 35862 galaxies with redshifts more than 3000 km/s from CfA3 catalog (Huchra et al., 1995) were investigated to find or reject overdensities. The well pronounced effect was found.

But one can point, that USNOA2.0 catalog contain only cooordinate and magnitude information. There is no objects classification information in this catalog. That is why usual clustering of galaxies can strongly influence on surface densities, calculated with these data. To avoid contamination of the results by galaxy clustering we must use catalog with stellar/galaxy classification of the objects.

2. SUPERCOSMOS sky survey

SUPERCOSMOS sky survey (Hambly et al., 2001) is a digitization of photographic survey of the southern hemisphere obtained with 1-meter class Schmidt telescopes at two different epochs. It is full up to 21 magnitude. For each object this catalog contains classification of the object (star/galaxy), coordinates, magnitudes in three filters, proper motions and other information.

For testing of our hypothesis we used SUPERCOSMOS catalog as a catalog of star-like images. We selected from the catalog only star-like images with zero proper motions as a background images. We investigated the expected overdensity in the vicinities of more than 19 thousands galaxies from CfA3 catalog. We calculated the number densities of selected objects in the concentric rings (the widths of the rings are 120 arcseconds) around each galaxy. The similar calculations were made for random centers. Random centers showed the zero overdensity.

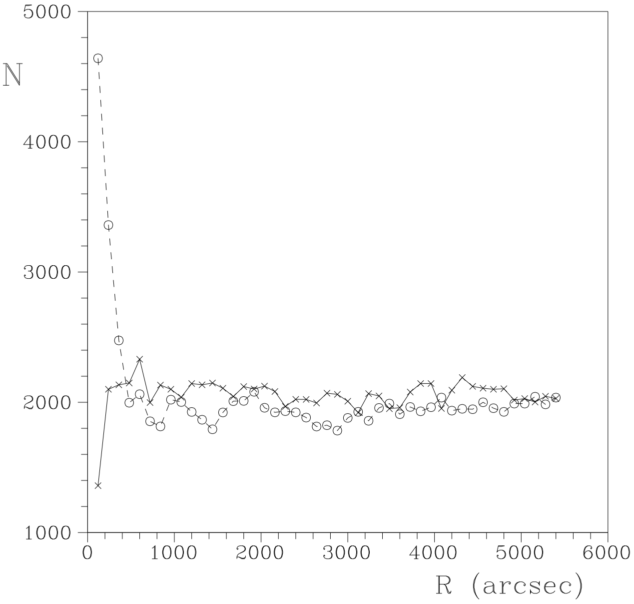

Figure 1: Surface density of star-like sources with zero proper motions in the vicinities of two groups of galaxies. The axes are the distance from the galaxy center in arcseconds and the surface density of investigated objects per square degree. Circles and dashed line - mean of 5 regions around galaxies with redshifts from 60,000 to 65,000 km/s. Crosses and solid line - mean of 5 regions around galaxies with redshifts from 5,000 to 6,000 km/s.

Results for the regions with the galaxies in their centers are more interesting. As we have wrote, we expected to find overdensity of star-like sources with zero proper motions around galaxies. But it appeared, that the results are quit different for different groups of galaxies. We are able to show only preliminary results in this article. On the fig. 1 one can see mean resuts for two different groups of galaxies. The first group consist of 5 galaxies with redshifts from 60,000 to 65,000 km/s. The second group consist of 5 galaxies with redshifts from 5,000 to 6,000 km/s.

The expected overdensity is well detected for the first group of galaxies - for the galaxies with higher redshifts. The overdensity begins from the distance near 300 arcseconds from the galaxy centers. It corresponds to the linear distance near 1 Mpc from the galaxy centers. Globular clusters and dwarf galaxies can concentrate around host galaxy in the radii less than 1 Mpc and produce amplification of distant sources due to gravitational lensing. We expected to find this effect and we found it.

Now we discuss the second group of galaxies - the galaxies with redshifts from 5 to 6 thousands km/s. We see no overdensity for these galaxies. We can see underdensity of the star-like objects with zero proper motions in the vicinities of these galaxies. We have wrote that these data are preliminary. But we can write that for all distant galaxies with redshifts less than, say, 20 thousands km/s we can observe underdensity, not overdensity. That is why we must point the reason of this underdensity.

We must also explain the reason of zero overdensity for foreground galaxies with redshifts more than 300,000 km/s. The rezults are also preliminary, but big number of galaxies permit us to claim that the final result will be changed unsignificantly.

In all our previously cited papers we considered the properties of the globular clusters as gravitational lenses neglecting microlensing effects. Let us consider the influence of microlensing on amplification properties of globular clusters.

3. Microlensing?

Microlensing is the lensing by individual stars or planets. Now we will try to estimate the importance of this effect for our observations. The extremely high level of amplification of the MMO can be explained in the following way. All light rays from the source to the solid angle of the core of MMO will be focused near the 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, the size of emitting region of QSO can be of the order of 1 pc or less. The square ratio of these quantities give us the amplification coefficient from 10^2 to 10^4 or from 5 to 10 magnitudes. If we observe not overdensity, but underdensity of the objects, it means that above described effect is destroyed. How it can be destroyed?

Individual star in the core of MMO must produce its own Einstein ring. In the first approach all light beams from Einstein ring of the star will reach the observer. All light beams from the area inside the Einstein ring must be strongly declined and will not rich the observer. If the total square of Einstein rings of individual stars will be of the order of the square of the core of MMO, then all light beams from the source will be strongly declined and will pass beside the observer. That is why the amplification coefficient will be not very large. In this case it can be less than 1.0.

Let the typical radii of the core of MMO is 10 pc, the typical number of 0.2 solar mass stars within this radii is of the order of 10^5. Let the sources distance is near 3000 Mpc.

For the first group of galaxies with z near 60,000 km/s we can estimate the linear radii of Einstein ring to be near 10^{-2} pc. The total square (the optical depth) of 10^5 circles is near 10 pc^2 or near one tenth of the total square of the core of MMO.

For the second group of galaxies with z near 5,000 km/s we can estimate the linear radii of Einstein ring to be near $2*10^{-3}$ pc. The total square of 10^5 circles is near 0.4 pc^2 or less than 10^{-2} of the total square of the core of MMO.

In both cases low massive stars can not strongly influence on the lensing properties of MMO. The optical depth due to microlensing by stars is small and we can neglect microlensing produced by stars if the redshift of MMO is less than 100,000 km/s. For foreground galaxies with higher redshifts the influence of microlensing by stars must be significant, The effect of overdensity of star-like objects around these galaxies can disappear.

We can see, that microlensing by stars can explain the zero overdensity of ELOs in the regions around foreground galaxies with redshifts more than 300,000 km/s.

We must to mention, that recently Sahu et al. (2001) pointed that the number of planets in globular cluster M22 can be 3 orders higher than the number of stars. Let us suppose that all globular clusters contain the similar number of planets. If we repeat previous calculations with 0.0002 solar mass objects and the number of these objects will be 10^8 we can obtain that the optical depth of the cluster will be increased by factor near 2.

That is why the optical depth of globular cluster with redshift higher than 60,000 km/s will be increased and it will be impossible to have a high level of amplification for clusters with significantly higher redshift.

It should be noted that de la Fuente Marcos and C. de la Fuente Marcos (2001) performed detailed numerical simulations and showed that the existence of a big number of the planets in the globular clusters is impossible.

In any case we can not neglect the microlensing produced by planets. Now we are preparing the software for direct calculation of influence of microlensing on the lensing properties of globular clusters.

4. How we can find ELOs?

For final testing of our hypothesis we must find several ELOs and measure their redshifts. Results, obtained from digitized photographic sky surveys can help us to find individual ELOs. ELOs are star-like objects with zero proper motions and with high redshifts. The spectra of ELOs must be similar to that of normal galaxies. We can not expect to observe emission lines in their spectra. We must search for ELOs in the vicinities of bright foreground galaxies. Usual two-color diagrams permit us to find objects with unusual colors. Spectra of these objects can be measured with big telescopes. With high probability objects with unusual colors can show cosmologocal redshifts in their spectra.

We observed the vicinities of six galaxies, namely A2046+1925, A2021+6127, A0051-0038, A2153+0109, A0008-0001 from CfA3 catalog. The 1.22 meter telescope at Kryonerion observatory, Greece, was used for VRI CCD photometry of regions around these galaxies. The redshifts of the galaxies are from 55000 to 78000 km/s. The full list of selected objects will be published later.

4. Conclusion

We predicted and found the overdensity of star-like images with zero proper motions (ELOs) around foreground galaxies. But it appears that this overdensity exist only for intermediate-redshift groups of galaxies. For galaxies with highest redshifts we observed the zero overdensity. For nearest galaxies we observe the negative overdensity - underdensity.

We are able to explain the observations for intermediate and high-redshift groups of galaxies. We have some difficulties with the nearest groups of galaxies. Now we are perparing software for direct calculation of imaging by globular clusters with full inclusion off all stars (planets?). The first results obtained with this software show, that it is possible that central image produced by globular cluster can be high amplificated at intermediate redshifts, but degenerated at low redshifts. It can be a good explanation of observational data.

In the previous section of this paper we show a way for selection the individual ELOs. Spectral observations of preselected objects will be performed in the nearest time. We hope that at least part of these objects will show cosmological redshifts. It will be direct spectral confirmation of our hypothesis.

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