Gravitational lensing by globular clusters. Search for lensed objects in the vicinity of 6 galaxies

A.V. Yushchenko[1], P.G. Niarchos[2], V. Manimanis[2]
[1]*Astronomical Observatory of Odessa National University, 65014, park Shevchenko, Odessa, Ukraine e-mail: yua@lens.tenet.odessa.ua*
[2]*Department of Astrophysics, Astronomy and Mechanics, University of Athens, GR 157 84 Zografos, Athens, Greece*

Abstract

In previous works we showed, that amplification of small sources by cores of globular clusters or dwarf galaxies can reach 5-10 magnitudes, if these cores are transparent. This amplification can explain the significant part of Arp's objects. The lenses for Arp's objects can be globular clusters in the halos of foreground galaxies. The nuclei of Seyfert galaxies can be sources for this superamplification. The mean number of globular clusters per galaxy is nearly 10^2. These clusters can produce amplification not only of active nuclei, but also of any other sources. Now galaxies are discovered at high redshifts, up to $z > 5$. Globular clusters in the halos of foreground galaxies must act as gravitational lenses. That is why we can expect the overdensity of star-like images near foreground galaxies. We analyzed several digitized surveys of sky with 1m class telescopes and found the overdensity of objects, brighter than 21^m, around foreground galaxies with redshifts from 25000 to 200000 km/s. This overdensity can not be explained by usual clustering of galaxies. The 1.22 meter telescope at Kryonerion observatory, Greece, was used for deep 3-color VRI photometry of regions around 6 galaxies with redshifts from 55000 to 78000 km/s. These data permit us to find the list of objects which can be gravitationally lensed images of more distant galaxies or of objects of other types.

1 Introduction

The first, who proposed gravitational lenses for explanation of quasars, was Barnothy (1965). But later it was shown that neither galaxies, nor stars in the halos of galaxies can explain all observed properties of QSOs. Arp (1968) pointed out that QSOs can concentrate near bright galaxies. There are a lot of papers where authors confirm or reject the clustering of QSOs near galaxies or galaxies near QSOs (see Arp, 1999, Arp & Russel, 2001 or Fried, 1997, as examples). Burbidge et al. (1990) found about 500 associations of QSOs and galaxies.

Baryshev et al., (1993) explained these associations 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. Yakovlev et al. (1983) developed an analytical theory for calculations of amplification of objects like globular clusters.

Yushchenko et al. (1998) reported in 1994 the software for direct calculations of amplification of extended sources by cores of MMO. The amplification can reach 5-10 magnitudes for typical cases and QSO-galaxy associations 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 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. The square ratio of these quantities give us the amplification coefficient from 10^2 to 10^4 or from 5 to 10 magnitudes. The angular sizes of amplified images are equal to that of the cores of globular clusters in the halos of foreground galaxies - these are star-like images for our optical telescopes. Baryshev & Ezova (1997) listed a set of tests for validation of this hypothesis. These tests require precise observations, for example VLBI.

2 Hypothesis & results from sky surveys

Yushchenko & Raikov (1998) proposed, that not only Arp's objects, but significant part or all QSOs can be explained as a result of 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 types of active nuclei with spectral properties similar to that of QSOs. Typically only one globular cluster per foreground galaxy can act as gravitational lens - the number of background Seyfert nuclei is too small.

Yushchenko (1999, 2000) proposed new observational test for verifying this hypothesis. Not only one globular cluster per foreground galaxy can produce the amplification of the images of distant sources, but 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 ordinary galaxies or any other objects located on the higher redshift behind these MMOs can be the sources.

Let us suppose that there are not only Seyfert nuclei at high redshifts, but galaxies of all types. Ordinary galaxies with redshifts higher than 5 exist. For example Hu et al. (1999) found the galaxy with z=5.74 and Yahata et al. (2000) identified nearly 4000 galaxies over the range in redshifts from 0 to 10 and beyond. That is why the sufficient number of sources can exist, and they can be significantly amplified due to gravitational lensing.

It is known that the number of Seyfert galaxies is of order of 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. The number of globular clusters per galaxy is near 10^2. It means that the expected number density of high redshift ordinary galaxies, gravitationally amplified by globular clusters, must be two orders higher than the number density of QSO. The last catalogues of bright QSO contain about 10^4 objects. That is why we can expect near 10^6 extremely lensed high redshifts star-like objects (ELO) near foreground galaxies. The expected spectra of these objects will be similar to the spectra of usual galaxies with correction for redshift and evolution. In any case, their colors must be more redder than the colors of quasars.

For checking the validity of our assumption we used USNOA2.0 (Monet D. et al., 1998) as a catalog of star-like images and CfA3 (Huchra et al., 1995) as a catalog of foreground galaxies. We selected 35862 galaxies with redshifts more than 3000 km/s from CfA3 catalog. We calculated the number densities of all objects in the concentric rings around each galaxy. The similar calculations were made for random centers. We found a well detected overdensity of objects around galaxies. Random centers showed the zero overdensity (Yushchenko 1999, 2000).

Recently we repeated this work using SUPERCOSMOS sky survey (Hambly et al., 2001). We selected only star-like images with zero proper motions as background images. We found the expected overdensity in the vicinities of galaxies with redshifts from 25000 to 200000 km/s. Results will be published.

3 Observations & Results from VRI photometry

Results, obtained from digitized photographic sky surveys can give us only common properties of ELO. For final validation of our hypothesis we must find several ELO and measure their redshifts.

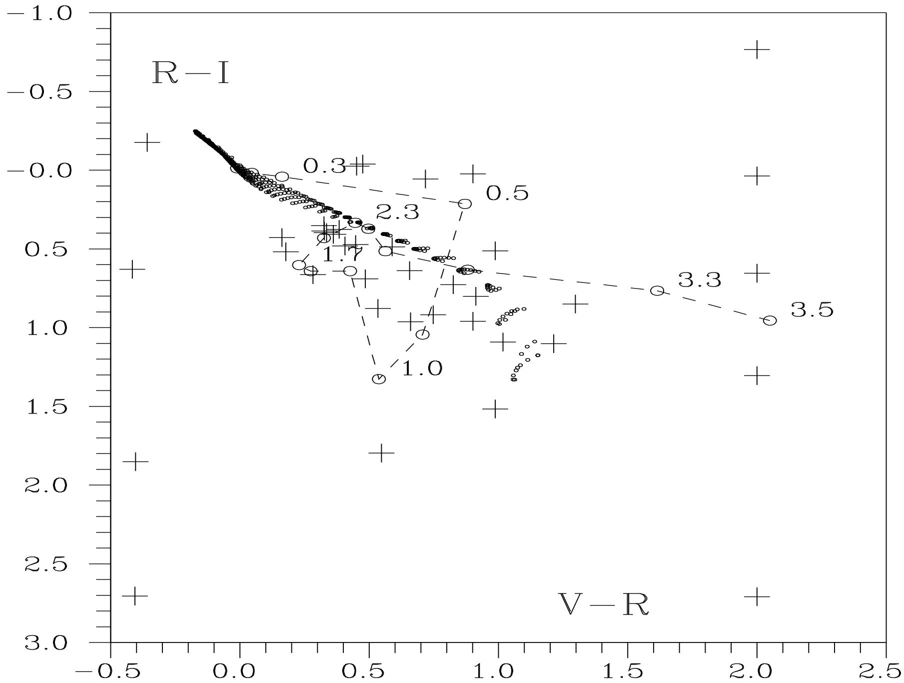

Figure 1: Two color diagram for the 2.5x2 arcmin region around the galaxy A1943+5440. Small circles: theoretical Kurucz's colors; Dashed line: reddening curve for main sequence stellar model with effective temperature 10000 K. Labels near the line show the values of redshifts; Crosses: results of our VRI observations in instrumental system. Five crosses with $V - R = 2.0$ show five objects, observed only in R,I filters. See text for details.

How we can find ELO? ELO is star-like objects with high redshifts, but their spectra must be similar to that of normal galaxies. We can not expect to observe emissions in their spectra. We must search for ELO in the vicinities of bright galaxies. As a first step we attempted to made a multicolor photometry of several regions around galaxies. Usual two-color diagrams can help us to find objects with unusual colors. Redshifts of these objects can be measured with big telescopes.

The 1.22 meter telescope at Kryonerion observatory, Greece, was used for deep 3-color CCD photometry (VRI) of regions around 6 galaxies with redshifts from 55000 to 78000 km/s. To reach faint stars we observed each region from 5 to 10 times in each filter with exposure time 120 seconds. Individual frames were coadded. In R and I filters we were able to measure all stars of USNOA2.0 catalogue. The limiting magnitude in V filter is slightly less. We were able to measure near 90% of USNOA2.0 objects in our V frames. Processing and coadding CCD observations was performed with our own software.

In the present work we give results for the vicinity of the galaxy A1943+5440 from CfA3 survey. The redshift of the galaxy is 78850 km/s. We studied 2.5x2 arcmin region centered on this galaxy. We measured VRI magnitudes for 33 objects and only RI magnitudes for 5 objects. The obtained (V-R)-(R-I) plot in the instrumental system is shown in Fig. 1. On this plot we show the results of our observations and theoretical predictions - the standard V-R and R-I colors for calculated stellar atmosphere models (Kurucz, 1994) and the curve of cosmological reddening for main sequence stellar model with effective temperature 10000 K. As a result of the analysis of this plot we selected 10 objects for spectral observations. These are 5 objects observed only in RI filters and 5 objects with negative V-R colors. High redshifts can be expected for these objects. Similar results were obtained for other 5 distant galaxies: A2046+1925, A2021+6127, A0051-0038, A2153+0109, A0008-0001. Detailed results will be published later.

4 Discussion

We predicted and found the overdensity of star-like images around galaxies. These are extremely lensed star-like 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.

Our previously published results show only mean properties of ELO. In this paper we selected objects for spectral observations. These observations 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.

One can argue that cosmological redshifts of these objects can exist, but these objects can be not amplified by gravitational lensing. ELO can be observed in the vicinities of bright galaxies, but they are not related with these galaxies. The redshifts of ELO must be cosmological. That is why they must be significantly amplified by gravitational lensing. Otherwise we will have other problems. The expected number of ELO is one or two orders higher than the number of QSO. The main problem for QSO was the nature of high luminosity of these objects. Let ELO are not gravitationally amplified, and their redshifts are cosmological. In this case we must explain their high luminosity. In what way?

Microlensing effects in the cores of MMO can strongly influence our results for relatively close galaxies. A detailed study about the influence of microlensing on expected results is in preparation. The overdensity of objects near galaxies is an observational fact and in any case it is necessary to investigate this problem.

References

Arp H. 1968, ApJ, 1968, 153, L33
Arp H. 1999, ApJ, 1999, 525, 594
Arp H., Russel D., 2001, ApJ, 549, 802
Burbidge G., Hewitt A., Narlikar J.V., Das Gupta P. 1990, ApJS, 74, 675
Barnothy J.M. 1965, AJ, 70, 666
Baryshev Yu.V., Raikov A.A., Yushchenko A.V. 1993, in: Proc. of 31 Liege Astrophys. Coll. Gravitational lenses in the Universe, ed. J. Surdej (Liege, Belgium), 307
Baryshev Yu.V., Ezova Yu.L. 1997, Astronomy reports, 41, 436
Fried J.W. 1997, A& A, 319, 365
Hu E.M., McMahon R.G., Cowie L.L. 1999, ApJ, 522, L9
Hambly N.C., MacGulliver H.T., Read M.A. et al. 2001, MNRAS (in press)
Huchra J.P., Geller M.J., Clemens C.M., Tokarz S.P., Michel A. 1995, ADC CD ROM, Vol. 3
Kurucz R.L, 1994, CD ROM 18
Monet D. et al. 1998, USNOA2.0. A catalog of astrometric standards (CD edition)
Yahata N., Lanzetta K.M., Fernandez-Soto A., Pascarelle S.M., Chen H.-W. 2000, American Astron. Soc. meeting, 197, 117.04
Yakovlev D.G., Mitrofanov I.G., Levshakov S.A., Varshalovich D.A. 1983, Astrophys. and Space Sci., 91, 133
Yushchenko A.V., Baryshev Yu.V., Raikov A.A. 1998, Astron. Astrophys. Transactions, 17, 9
Yushchenko A.V., Raikov A.A. 1998, in: Proc. of the II conf. Selected problems of astronomy and astrophysics, ed. I. Vakarchuk (Lviv, Ukraine), 204
Yushchenko A.V. 1999, Odessa Astron. Publ., 12, 85
Yushchenko A.V. 2000, Kinematics and Physics of Selectial Bodies Suppl. Ser., 2000, V. 3, 174