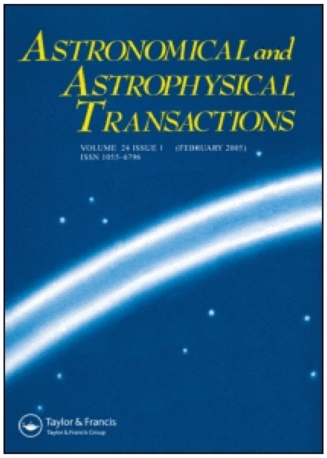

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

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Online Publication Date: 01 January 1998
To cite this Article: Yushchenko, A. V., Baryshev, Yu. V. and Raikov, A. A. (1998) 'Quasar-galaxy associations as lensing by middle-mass objects', Astronomical & Astrophysical Transactions, 17:1, 9 - 13
To link to this article: DOI: 10.1080/10556799808235419
URL: http://dx.doi.org/10.1080/10556799808235419

Astronomical and Astrophysical Transactions, 1998, Vol. 17, pp. 9–13
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QUASAR–GALAXY ASSOCIATIONS AS LENSING BY MIDDLE-MASS OBJECTS

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(Received December 20, 1996)

We discuss the problem of associations between QSOs and galaxies. It is shown that under certain reliable assumptions some of the associations can be explained as gravitational lensing by middle-mass objects, which are situated in the haloes of giant galaxies, dwarf galaxies and globular clusters. The mass distribution of middle mass objects was approximated by the King profile.The large values of the bending angle near the lens core permit the dwarf galaxies and globular clusters to have good lensing properties (if their cores are transparent). The amplification in the central image can reach 5–7^m. We consider the catalogue of Arp's pairs published by Burbidge G. *et al.*, as a catalogue of quasars lensed by middle-mass objects in galactic surroundings. The distributions of redshifts of galaxies and quasars in this catalogue can help to obtain some knowledge on the number density of dwarf galaxies and globular clusters and their masses.

KEY WORDS Gravitational lensing, population of galactic haloes, quasars, quasar–galaxy associations

1 INTRODUCTION

The nature of quasar–galaxy associations (QGA) has caused new interest since the publication of the catalogue by Burbidge *et al.*, (1990). There are several arguments against gravitational microlensing as an interpretation of QGA (Arp, 1990), but there are strong arguments in favour of the gravitational lensing effect (Dar, 1991).

Previously, Barnothy suggested lensing by globular clusters to account for QGAs (Barnothy, 1974). In the present paper we consider gravitational lensing of quasars by middle-mass objects (MMO) populating galactic haloes: globular clusters, dwarf galaxies and clusters of dark matter, consisting of stellar remnants, neutron stars, "Jupiter-like" objects, etc. We assume that all MMO are trasparent – their cores contain no dark matter. This paper is the continuation of our first article (Baryshev *et al.*, 1993b).

2 THE REALITY OF QUASAR–GALAXY ASSOCIATIONS

The main argument in favour of QGAs follows from angular separation – the galactic redshift diagram built for 392 quasar-galaxy pairs by Burbidge *et al.* (1990). This diagram show a nearly linear inverse relation. The linear distance between galaxy and quasar images (in the galactic plane) could be estimated in the 40–100 kpc interval from this diagram.

The QGA phenomenon can be explained in at least two ways:

(a) Quasars are physically connected with galaxies as a result of ejection from corresponding galactic nuclei and are really at 40–100 kpc from them. See, for example, Valtonen and Basu (1991).

However this explanation meets well-known difficulties: the absence of blue-shifts in the quasars' spectra which might be expected in the case of ejection; the presence of parent galaxies; the θ–z diagram for radio-quasars continue that of radio-galaxies; the presence of absorption line systems with intermediate redshifts in quasar spectra; and the cases of remote quasar lensing (see e.g. Dar, 1991).

(b) Quasars are at cosmological distances corresponding to their redshifts and in the case of QGAs we see their lensed images produced by massive objects in the galactic neighbourhood at a mean distance of 40–100 kpc from the centre of the galaxy.

Recent reviews give information in favour of massive surroundings near galaxies (see e.g. Lake, 1992) which we called MMO above.

In the papers of Arp (1990) and Burbidge *et al.* (1990) arguments against microlensing were put forward and the conclusions about the physical connection between quasars and galaxies in QGAs was made on these grounds. Taking into account these difficulties with this kind of interpretation, we will show that Arp's arguments are not valid in the case of MMOs.

We must mention that there are two words for the different cases of lensing: *lensing* or *macrolensing* refers to galaxies as lenses; *microlensing* refers to stars as lenses. Giraud (1993) proposed the word *millilensing* for objects with the masses 10^5–$10^7 M_\odot$ as lenses. We will use this word for our case.

3 ARP'S ARGUMENT AGAINST GRAVITATIONAL MICROLENSING IN QGAs

Here we consider the first four of Arp's (1990) arguments against gravitational lensing.

(1) In QGAs the average observable distances between quasars and galaxies are estimated as 40–100 kpc. There are not enough stars at such distances from galactic nuclei and therefore no gravitational microlensing.

This argument is not valid in the case of millilensing by MMOs which are most probably situated in precisely this distance interval.

(2) QGAs are more frequently met in groups of galaxies and it is not clear why star lensing is more preferable in groups of galaxies compared with single ones.

In the case of MMOs this argument becomes one in favor of lensing, because in groups the MMO density is expected to be higher then that in a single galaxy.

(3) Arp points to the case of QGAs consisting of the nearby galaxy M33 and a QSO with redshift $z = 2$, arguing that it is no reason for stars to prefer distant objects.

We guess that this argument is inconsistent with the z_q–z_g diagram showing a uniform distribution of the (z_q, z_g) plane. It is true that in the case of uniform matter distribution the probability of gravitational lensing of remote objects by nearby ones falls to zero with the lens distances (Turner *et al.*, 1984) and in this sense argument (3) is proposed. However, Baryshev *et al.* (1993) have shown that in the case of a fractal distribution of dark lensing matter the above mentioned probability $(1/\tau)(d\tau/dz)$ could be constant.

(4) The microlensing explanation of QGAs requires very steep ($\alpha < 2.6$) slopes for the unamplified quasar luminosity function, but quasars in the relevant magnitude range have an apparent magnitude slope too flat that is much α. The quasars are so rare that it is not possible to obtain statistically significant overdensities near galaxies.

This argument strongly depends on the assumed nature of quasars and may be avoided by the assumption that unamplified quasars are nuclei of active galaxies.

4 MILLILENSING IN QGA

It is clear from the above discussion that microlensing could not account for the QGA phenomenon. The same is valid for macrolensing. The only probable mechanism is millilensing by MMOs.

MMOs could be presented by globular clusters, dwarf galaxies or dark matter clusters consisting of stellar remnants, neutron stars, "Jupiter-like" objects, etc. The transparent objects of this kind could provide a greater effective amplification area than point mass gravitational lenses.

We approximated the mass distribution of MMOs by the empirical King model (1966). This model describes with high accuracy the observed surface brightness distributions of a wide class of galaxies, galactic clusters and stellar globular clusters (Kholopov, 1981). The analytical expression for the bending angle for this distribution was derived by Yakovlev *et al.* (1983).

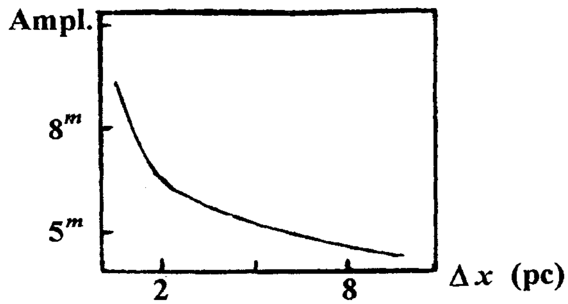

Figure 1 Plot of image amplification versus displacement from the lens axis. The mass of the lens is $10^9 M_\odot$, the radius of the lens core is 400 pc, the ratio of the lens radius to the lens core radius is 3, the redshift of the lens is 0.17, the redshift of the source is 3.0 ($\Omega = 0.3$), and the size of the source is 2 pc.

We must mention that MMOs were excluded from the list of objects which are able to affect the images of distant sources. See Yakovlev *et al.* (1983), for example. This exclusion is valid if we take in account only the Einstein ring or images "1" and "3" in the notation of Yakovlev *et al.* Image "2" (the image formed by the lens core) was investigated by Yakovlev *et al.* (1983). They found that at some conditions the image amplification tends formally to infinity. This is valid in the case of a source of small angular size.

We developed computer software which permit us to calculate the amplification for sources with different sizes and geometry. Figure 1 shows the plot of image amplification versus displacement from the lens axis.

If the cores of MMOs contain no dark matter, the amplification of distant sources by cores of MMOs will be significant. We must mention that we consider only the image formed by the lens core. This image gives the main part of the amplification. This is one image: the limit on the masses of compact objects in galactic haloes derived with the use of image separation is not valid for our case.

To provide the observed lensing probability in QGAs the active sizes of MMOs should be in the 1–100 pc interval and their masses about 10^6–$10^9 M_\odot$. The mean number of MMOs per galaxy is about 10–100 and they are 40–100 kpc away from the parent galaxy. Such transparent lenses must give amplification for background quasars with redshift about 3 and size about 1 pc not less then 5^m within 1–10 pc displacement from the lens axis.

5 CATALOGUE OF QGA AS A CATALOGUE OF LENSED OBJECTS

Let us consider the catalogue of Arp's pairs (Burbidge *et al.*, 1990) as a catalogue of quasars lensed by MMOs in galactic surroundings. The majority of galaxies in this catalogue have a visible magnitude of about 15.5, and redshifts of about 0.01. This redshift corresponds to a distance of 40 h^{-1} (75) Mpc. The quasars accociated with them, on average, have visible magnitudes of 19.5 and redshifts of about 1. Under the mean amplification of about 5–7^m the visible magnitudes of unlensed quasars are about 25–27^m. According to deep galaxy counts by Tyson (1988) and Peterson *et al.* (1991) the total number of galaxies up to 27–28^m is about 10^5 per square degree. If about 10% of them are galaxies with active nuclei then the average number of "true" quasars is about 10^4 per square degree and the mean angular separation between them is about 70 seconds. The mean square in angular units per "true" quasars is therefore about 10^3 arcsec^2.

If the region of active lensing in MMOs is 20 pc in diameter then at 40 Mpc from the observer it covers a square of about 10^{-2} arcsec^2: this is an estimation of the lensing cross-section per MMO. The effective cross-section per galaxy depends upon the number of MMOs and their density profiles, which determine the amplification.

To account for the observed number of QGAs (about 10^2) compared with about 10^5 galaxies up to 15^m we could expect an average cross-section of about 1 arcsec^2. This quantity seems resonable, combining considerations about the average number of MMOs per galaxy (10–100) and their amplification parameters which could reveal fainter and consequently more densely distributed background quasars.

Acknowledgements

The authors wish to thank Alexander Sergeev and Alexander Tron for helpful discussions.

References

Arp, H. (1990) *Astron. Astrophys.* **229**, 93.
Barnothy, J. M. (1974) *Bull. Amer. Astron. Soc.* **6**, 212.
Baryshev, Yu. V., Raikov, A. A., and Tron, A. A. (1993a) In: J. Surdej *et al.* (eds.), Proc. 31st Liege Internat. Astrophys. Colloqu. on Gravitational Lenses in the Universe, Liege 1993, June 21–25, p. 365.
Baryshev, Yu. V., Rajkov, A. A., and Yushchenko, A. V. (1993b) In: J. Surdej *et al.* (eds.), Proc. 31st Liege Internat. Astrophys. Colloqu. on Gravitational Lenses in the Universe, Liege 1993, June 21–25, p. 307.
Burbidge, G., Hewitt, A., Narlikar, J. V., and Das Gupta, P. (1990) *Astron. Astrophys. Suppl. Ser.* **74**, 675.
Dar, A. (1991) *Astrophys. J.* **382**, L1.
Giraud, E. (1993) In: J. Surdej *et al.* (eds.), Proc. 31st Liege Internat. Astrophys. Colloqu. on Gravitational Lenses in the Universe, Liege 1993, June 21–25, p. 187.
Kholopov, P. N. (1981) *Stellar Clusters*, Nauka, Moscow.
King, I. (1966) *Astron. J.* **71**, 64.
Lake, G. (1992) *Sky Tel.* **84**, 613.
Linder, E. V. and Schneider, P. (1988) *Astron. Astrophys.* 204, L8.
Peterson, B. A. *et al.* (1991) *The Messenger ESO*, No. 64, 1.
Turner, E. L., Ostriker, J. P., and Gott, J. R. (1984) *Astrophys. J.* **284**, 1.
Tyson, J. A. (1988) *Astron. J.* **96**, 1.
Valtonen, M. J. and Basu, D. (1991) *J. Astrophys. Astron.* **12**, 91.
Yakovlev, D. G., Mitrofanov, I. G., Levshakov, S. A., and Varshalovich, D. A. (1983) *Astrophys. Space Sci.* **91**, 133.