QSO 0957+561 AND OTHER LARGE-SEPARATED DOUBLE QUASARS: SOME NEW RESULTS AND A FUTURE OBSERVATIONAL PROJECT
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Abstract
We collected from literature the information about large-separated (more than 3") pairs of QSOs, which however once were suspected as gravitationally lensed system. We discuss some new results on time delay determinations including optical-radio correlations for QSO 0957+561. We considered some possible observational effects of gravitational lensing by a cosmic string. A future international project for observations of the gravitational lens system UM425 is briefly discussed.

1 Introduction
QSO 0957+561 is not only most famous and wide accepted gravitational lens system, but also is the prototype of a class of double QSOs with angular separation larger then, say, 3 arcseconds, the 'same' red-shift and 'similar' spectra. If in cases of multiple QSOs with smaller separations interpretation as a gravitational lens systems is more clear, for the class of large angular separation system this task is more difficult. One of the convincing arguments in favor of gravitational lens interpretation could be evidence that light variations of both images are correlated with some time delay. For QSO 0957+561 this argument was got in result of extensive optical and radio monitoring during more then 15 year and numerous statistical investigations of the obtained data. However some problems still saved (Oknyanskij[16]; see also some details in the next section), correlation of light curves for A and B images of QSO 0957+561 is revealed and there are no any doubts in gravitational lens nature of the system, now. Situation for all other known large separated QSOs is rather unclear and they often called 'dark matter lenses' (DMLs), however some part of them must be binary QSOs (Schneider[23]). Both of these possibilities are interesting to stimulate new observational projects. One of these projects will briefly discussed below.
2 Known large-separated double QSOs

We collected from the literature informations (Tabl.1) on the large-separated double QSOs, which were however once suspected as gravitational lens. Only Q0957+561 is accepted case of gravitational lensing. It is possible that most of these listed system is not lens system, but binary QSOs. There are several cases, when spectral similarities say rather on lens origin of the systems. Small spectral difference are possible and even expected, since expected time delay is about year for 5″ separation and more than 1000 years if separation is 2.′6. Additionally microlensing can change line profiles, as well as mean redshifts.

Comments to individual objects in Tabl. 1:

0957+561. This is the first reported example and the best-known lens system. The principal lensing galaxy at z=0.36 is located very close (about 1″) to image B. This main lensing galaxy is situated to the centre of a galaxy cluster. This cluster and possibly one more cluster at z=0.5 must be taken into account for the lens model, thereby the existed models still have large uncertainties. The double quasar 0957+561 A,B is up to now only gravitational lens system for which serious attempts have been made to determine the time delay \( \tau \) between its images, and till now it has been the most attractive system for this task (see arguments in Beskin & Oknyanskij[3]). Determination of \( \tau \) have a great cosmological interest since may be used to determine independently the Hubble constant as well as the age of Universe (Refsdal[21]). In despite of intensive attempts to obtain correct value of the time delay using long-term optical and radio monitoring data sets we have not some time delay value, which would be recognized by all specialists working in this field. Publications on the time delay determination for QSO 0957+561 A,B can be divided on four groups due to different obtained results:

1. The time delay value is about 400-425 days (Schild[24], Schild & Thomson[25][19], Vanderriest et al.[29] Pelt et al.[18][19]).
2. The time delay value is about 520-555 days (Beskin & Oknyanskij [2][4]; Press, Rybicki & Hewitt[18])
3. The time delay value is about 440-455 days (Haarsma et al.[8])
4. The definite time delay value was not found in view of gaps in data sets and possible microlensing effects (Falco et al.[11])

However the value about 425 days is preferred today, we must to note that some room for other possibilities is still saved. The main reason for our doubts in value about 425 days are connected with incorrect methods, which were using to get it. For example, using of "standard" cross-correlation method based on calculation of direct and reverse Fourier transforms (Vanderriest et. al.[29]; Schild[24]) is absolutely incorrect for unequally spaced data (Scargle[22]; Oknyanskij[16]),
We have got the time delay value about 410 days with this method if use only real data for B image, but in place of real measurements for A image take artificial white noise data and add some line trend. The question is how probable chance coincidence of an incorrectly obtained value with the real one? If we take into account that the real time delay should be in the interval 400-600 days and that real accuracy of time delay determination is about 15 days or worse, then we can conclude that probability for this coincidence is not so small. In our opinion we should prefer those from several possible values of the time delay (with about the same significance) which is farther from the possible artifact value. Meanwhile only some new independent observational tests could decide the time delay controversy. For the time delay value $\tau = 420$ days the lens models (see for example, Pelt et al.[19][20]) the Hubble constant estimated to be smaller than 70 km/(s Mpc). For the $\tau=530$ days the same estimation gives limit 55 km/(s Mpc).

Radio-optical correlation in the Q0957+561 was first preliminary reported by Oknyanskij & Beskin[15] (here after OB) on the base of the VLA radio observation during 1979-1990. OB used a clear idea to take into account the known gravitational lensing time delay to get combined radio and optical light curves and then to use them for determination of the possible radio-from-optical time delay. It was found this way that radio variations (5 MHz) followed optical ones by about 6.4 years with high level of correlation (0.87). Using new radio data (Haarsma et al.[8] and take into account $\tau = 425$ days, we have got for interval 1979-1994 nearly the same value of the optical-to-radio delay as it had been found before. Additionally we suspect that the time delay value linearly increased on about 120 days per year and intensity of radio-response decreased with time. It is interesting task for future observation project: try to get the redshift from radio observations of the object. If it would be obtained then we will have opportunities for exact estimates of the location and velocity of the variable radio source. Now, our constrain depend from the unknown orientation of radio region relative the line of sight. We have made a conclusion that the variable radio source is a compact region which is ejected from the central part of the QSO. Perhaps, Q0957+561 is physically related to Blazar type objects, but it has different orientation relative to the line of sight.

1343+264. However difference between redshifts of components is much smaller then measurement errors, there are a strong differences in line profiles and equivalent widths (Crampton et al.[5]).

2345+007. This object could be called the prototype of "dark matter lenses". The line profiles is very similar (Steidel and Sargent 1991); however, equivalent widths are different. No possible lens has
been found yet (Tyson et al.[28]). Variability of intensity ratio A/B have been reported (Weir & Djorgovski[30]), but regular photometrical monitoring is not started yet.

**1120+019=UM425.** Line shapes is similar (Meylan and Djorgovski[14]), but variability continuum in both components are very different. It was suspected that this difference is connected with microlensing case. The microlensing hypothesis was also pointed out by Courbin et al.[4] to explain difference in light curves of the images. It is known that A image have Broad Absorption Line (BAL) structure in O VI $\lambda$ 1033 and N V $\lambda$ 1240 (Michalitsianos & Olversen[13]). If it will be found that B component have also the BAL structure, then we will have very strong argument in favor of gravitational lensing nature of the system.

**1429-008.** The spectra of the components are very similar, however small but significant line profile difference was found (Hewitt et al.[9]).

**0023+171.** Spectra are similar, but equivalent widths of lines are different in the components. The components have very complex radio structure (Hewitt et al.[9]). Perhaps, this system is triplets.

**1145-071.** The optical spectra are very similar and all emission line (excepting C IV) have the same equivalent widths (Djorgovski et al.[6]). Only the A image is radio source, but the fainter being at least several hundreds times weaker in radio wavelengths. This fact can say against gravitational lensing interpretation, however it can be explained by time delay or existence of some chance intermediate radio source. If these two opportunities will be removed any way, then we must involve some new ideas or refuse gravitation lensing explanation.

**1634+267.** Profiles and continuum shapes are very similar and support the gravitational lensing interpretation of the system (Steidel and Sargent[26]). High-ionization lines have velocity difference up to 1000 km/s, but low-ionization lines have no significant difference.

**HE 1104-1805** Emission line ratios and shapes are very similar, but continuum spectra are significantly different (Wisotzki et al.[31]). Absorption lines are significantly different. The absorption lines in the two components were intensively investigated with aim of setting limits on the sizes of clouds producing the absorption systems (Smette et al.[27]). The low-ionization lines are much weaker in the spectrum of image B. This difference may be explained by microlensing.

**Hazard 1146+111 B,C.** This object is best example of very large separated (more than 1’) multiple QSOs with similar redshifts and spectra (Arp & Hazard[1]). We found in literature 5 pairs or triplets of QSOs, which have very close types of spectra, red shifts and separations about several arc min (Oknyanskij[17]). It is clear that usual galaxy could not be a lens for this case, so a cosmic string hypothesis was several times discussed for this system (see for example, Gott[7]). The
last few years the cosmic string hypothesis for explaining twin QSOs with several arc min separations was not used, because observations of microwave background decreased the limit and, consequently the possible angular separation of QSOs lensed by a cosmic string. We must to note that amplitude of microwave background depend from direction of the cosmic string speed and we can admit existence of a cosmic string with linear density $\mu$ more than value of the CBG anisotropy ($\delta T/T$). The rejection of the Q1146+111 B,C as possible effect of cosmic string lensing have other additional reasons. First of all we must expect several other double images, however one of other D, N, H, K QSOs in the same field. Note that this problem can have very simple solution if we take into account possible variability of QSOs and different local time for the images. Second images perhaps exist, but have low for observation intensities in present moment of time. In the case of gravitational lensing by an Alice cosmic string we can expect more different brightnesses, redshifts and spectra of double images, because they correspond actually to the two different QSOs: from usual and "mirror" matter (Khlopov & Sazhin[12]; Oknyanskij[17]). That give us some opportunity to use the lensing by a cosmic string as possible interpretation not only for Q1146+111 system for other twin QSOs with several arc min separations. Meanwhile, we should to state, that in the absence of any new positive evidence and in the presence of reported differences in the UV and IR spectra for the 1146+111 B,C the interest to this object as possible gravitational lens is weaker now than before.

3 How to recognize a cosmic string between large-separated double QSOs?

1. In case of lensing by cosmic string we must observe only pair of QSOs images or several pairs along the straight line, but in case of triplet images some other model of lens must be involved without any doubts.
2. We must we sure that there are no some other type of lensing objects (for example, clusters of galaxies).
3. In case of gravitational lensing by a cosmic string the position angle of polarization must be the same in both images.
4. If the effect mentioned above (3) will be found for some system then it is interesting to search additional images of lensing objects in vicinity of the pair of QSOs along the direction determined by the position angle of polarization.
5. In the Alice string case we can expect variations of the broad line redshift values with the same period in both images of some lensed
QSO (Oknyanskij[17]).

6. In the Alica string case we can expect significant difference in brightnesses, spectra and variability of components (Oknyanskij[17]). So we can expect that some of images along the cosmic string will have brightness below than the observational limit, and therefore only single QSOs could be observed in place of some pairs images.

4 Observational project

In collaboration with Drs. Courbin and P.Magain (Liege, Belgium) we are going to apply for observations with the 6-m telescope of very interesting object UM425 using 6-m telescope. The following are main goals of the observational project:

- We wish to obtain deep R and B images of UM 425 in order to combine the high S/N final images with HST and NTT high resolution images in order to study the weak deformations of background galaxies, as well as to continue the monitoring of this unique lensed quasar.

- We would like to obtain a simultaneous spectrum of the 2 components of the lensed system in order to test the microlensing hypothesis pointed out by Courbin et al.[4], as done for HE1104-1805 at La Silla Observatory (Wisotzki et al.[31]; Smette et al.[27]).

- We wish to reach a limiting magnitude of R $\sim 26$ and B $\sim 27$. This is feasible in 4 hours of exposure using the 3.5m NTT in La Silla, Chile, in imaging mode. The same kind of performance can be expected from the 6-m telescope.

5 Conclusion

Ten to twenty quasars are now known to be multiply imaged by gravitational lensing. The study of these objects opens important prospects in cosmology since the phenomenon of gravitational lensing is very rich in applications: it provides us with a unique probe of the distant Universe and large-scale distribution of matter; a testing range for the theories of gravitation; a ruler for the size measurements of intergalactic clouds; the most sensitive test for the value of the cosmological constant; a new handle on the values of other cosmological parameters. Lensed quasars should allow the determination of the Hubble constant and, possibly, the deceleration parameter, independently of the classical methods of observational cosmology.

However, the determination of these cosmological parameters, which is based on a measure of the time delay between the different images, requires the knowledge of the deflecting potential. All the galaxies (or
clusters of galaxies) which contribute to the bending of the light rays should be identified and their mass distribution precisely estimated. So far, in many cases, even the main lensing galaxy has not been detected yet. Finally we can conclude that some room for involving of any type exotic ‘dark matter lens’ still saved.

References

[1] Arp, H., Hazard, C. 1980, Ap. J., 240, 726.
[2] Beskin, G.M. & Oknyanskij, V.L., 1992, in: Kayzer R., Schramm T., Refsdal S. (eds), Lecture Notes in Physics 406, Gravitational Lenses, Springer, Heidelberg, p.67
[3] Beskin, G.M. & Oknyanskij, V.L., 1995, A&A, 304, 341
[4] Courbin, F. et al. 1995, A&A, 303, 1
[5] Crampton, D. et al. 1988, ApJ, 330, 184
[6] Djorgovski, S. et al. 1987, ApJ, bf 321, L21
[7] Gott, J.R. 1985, ApJ, 288, 422
[8] Haarsma D.B. et al. 1996 in: Kochanek C.S. & Hewitt J.N. (eds), Astrophysical Application of Gravitational Lensing, IAU Sym 173, p.43
[9] Hewitt, J.N. et al. 1987, ApJ, 321, 706
[10] Hewitt, P.C. et al. 1989, ApJ, bf 346, L61
[11] Falko, E.E., Wambsganss, J., & Schneider P., 1991, MNRAS, 251, 698
[12] Khlopov, M. Yu., & Sazhin, M.V. 1989, AZh, 66, 191
[13] Michalitsianos, A.G. & Olversen, R.J. 1996, in: Kochanek C.S. & Hewitt J.N. (eds), Astrophysical Application of Gravitational Lensing, IAU Sym 173, p. 257
[14] Meylan and Djorgovski 1989, ApJ, 338, L1
[15] Oknyanskij V.L. & Beskin G.M., 1993 in: Surdej J. et al. (eds), 31st Liege International Astrophysical Colloquium: Gravitational lenses in the Universe, p.65
[16] Oknyanskij V.L., 1996, in: Kochanek C.S. & Hewitt J.N. (eds), Astrophysical Application of Gravitational Lensing, IAU Sym 173, p.45
[17] Oknyanskij, V.L. 1996, in: Khlopov M.Yu. et al. (eds), ”Cosmion-94”, Proceeding of international conference, Editions Frantieres, p.321
[18] Press, W.H., Rybicki G.B., & Hewitt J.N. 1992, ApJ, 385, 404
[19] Pelt, J. et al. 1994, A&A, 286, 453
[20] Pelt, J. et al. 1996, A&A, 305, 97
[21] Refsdal, S. 1964, MNRAS, 128, 307
[22] Scargle J.D. 1989. Ap.J., bf 343, 887
[23] Schneider, 1993 in: Surdej J. et al. (eds), 31st Liege International Astrophysical Colloquium: Gravitational lenses in the Universe, 47
[24] Schild, R.E.1990, AJ, 100, 1771
[25] Schild, R.E. & Thomson, D.J. 1996, in: Kochanek C.S. & Hewitt J.N. (eds), Astrophysical Application of Gravitational Lensing, IAU Sym 173, p. 51
[26] Steidel, C.C. & Sargent, W.L.W. 1991, AJ, 102, 1610
[27] Smette, A. et al., 1996, in: Kochanek C.S. & Hewitt J.N. (eds), 
Astrophysical Application of Gravitational Lensing, IAU Sym 173, 
p. 103
[28] Tyson, J.A. et al. 1986, AJ, 92, 691
[29] Vanderriest, C. et al. 1989, A&A, 215, 1
[30] Weir, N., & Djorgovski, S. 1991, 101, 66
[31] Wisotzki et al., 1993, A&A, 278, L15
Table 1: List of known large separated double QSOs.

| Object               | $\vartheta$ | $z$ | $\Delta v (km/s)$ | $B_1:B_2$ |
|----------------------|-------------|-----|-------------------|-----------|
| 0957+561             | 6.1''       | 1.41| 0                 | 17.5:17.7 |
| 1343+264             | 9.75''      | 2.03| 100               | 20.2:20.1 |
| 2345+007             | 7.73''      | 2.15| 15                | 19.5:20.1 |
| 1120+019=UM425       | 6.75''      | 1.46| 200               | 16.2:20.8 |
| 1429-008             | 5.71''      | 2.08| 260               | 17.7:20.8 |
| 0023+171             | 4.78''      | 1.35| 0                 | 22.8:23.4 |
| 1145-071             | 4.72''      | 1.35| 100               | 18:19     |
| 1634+267             | 3.78''      | 1.96| 150               | 19.2:20.8 |
| HE 1104-1805         | 3.70''      | 2.30| 300               | 16.7:18.6 |
| Hazard 1146+111      | 2.8''       | 1.01| 150               | 18.9:19.5 |