# ARE QSOs GRAVITATIONALLY LENSED?

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There are now four known cases of multiply imaged QSOs, one with a detected foreground object at roughly half the affine distance to the QSO: 0957+561 (17 mag, z=1.4, separation =6"), 1115+080 (17 mag, z=1.7, s1=1.8", s2=2.3"), 2345+007 (19 mag, z=2.1, s=7") and 1635+267 (19 mag z=2, s=5"). In addition, 1548+115 (19 mag, z=1.9) is a probable lens event with a foreground QSO, but no secondary image has been found. Perhaps 500 candidate QSOs have been surveyed optically for multiple images by all observers. 0957+561 is the only catalogued QSO shown to be multiple. Of the remaining 1548 QSOs currently catalogued, any secondary image is masked by atmospheric scattering of the QSO light. Typically, this sets detection limits of $\gtrsim$ 3 mag fainter and < 2 arcsec separation from the bright component, for any secondary image. Objective prism and grism surveys look directly for multiple QSOs with identical emission lines and have surveyed 1500 QSOs. The remaining three lensed QSOs come from these more efficient surveys. Although the exciting search for multiply imaged QSOs has only begun, sufficient data already exist to test two hypotheses: (A) QSOs are intrinsically luminous and occasionally are multiply imaged through a chance alignment with a foreground galaxy of sufficient mass gradient and (B) all QSOs are the result of gravitational lens magnification of a distant Seyfert nucleus by foreground galaxy(s). I will first address hypothesis B, then A. I assume that mass (seen and unseen) clusters with galaxies and/or clusters of galaxies.

Case B: This appeals to some because QSOs would be no more intrinsically luminous than Seyferts. It also follows that the log N/m relation for case B QSOs has twice the galaxy log N/m slope, independent of other parameters. The data support this 2:1 slope relation, out to $m_V$ = 19 mag for QSOs. Nevertheless, there are several problems with this hypothesis: (1) If foreground galaxies do the lensing, their average velocity dispersion would be 500 km/sec to explain the QSO number density - much larger than observed, since 80% of galaxies are spirals with $\sigma \sim$ 200 km/sec. Furthermore, a large fraction of QSOs would thus appear as multiple images with identical spectra separated by many arcsec. This is not found in optical QSO surveys, and it is not found in a VLA 0.1 arcsec resolution



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survey of 400 QSOs (Perley). Finally, deep CCD multicolor surface photometry and spectroscopy of two bright QSOs shows no evidence for a superposed galaxy other than that one for which the QSO is the nucleus. (2) If galaxy clusters lens every QSO, we would still expect the observed 2:1 slope ratio in the log N/m plots, the required velocity dispersion in the lensing clusters would be acceptable ($\sim 10^3$km/s), but multiple images would not be expected in most cases. However, clusters of this 'Abell' size are not seen superposed on low redshift QSOs, where they can be seen by visual inspection of the Palomar Sky Survey. One might argue that since most QSOs have redshifts > 1, perhaps only higher redshift QSOs are all lensed. I have a deep CCD survey to 27 R mag arcsec$^{-2}$ of 30 higher redshift QSOs (1<z<1.5) with few showing foreground clusters. Thus, the case for all QSOs arising from gravitational lensing appears to be unlikely in the extreme, unless my assumption that mass clusters with galaxies is violated. One would need a cosmological density of dark, compact objects of galactic mass and size, spatially uncorrelated with the observable galaxies. It should be reemphasized (Press and Gunn) that counts of gravitational lenses are one of the few cosmological tests for compact matter.

Case A: Under this hypothesis we treat QSOs as a separate family of objects with their own surface density $N_Q(m_Q)$ on the sky, unrelated to $N_G(m_G)$ for foreground galaxies. What do we then expect for the lensed QSO surface density $N_L(m_Q, m_G)$? Foreground galaxies within the critical angle for lensing, $\Theta_c = 2\sigma_{250}^2$ arcsec, will initiate a lens event. $\sigma_{250}$ is the galaxy's velocity dispersion/250 kms$^{-1}$. By definition, a QSO appears stellar: $m_G - m_Q \geq 3$. Other arguments imply $m_G - m_Q \approx 3$ mag. Thus, $N_L$ is simply the product of known surface densities: $N_L = \pi\Theta_c^2 f N_G(m_G) N_Q(m')$, $m' = m_Q + 2.5 \text{ Log } A$, with $m_G - m_Q = 3$, where f is the fraction of mass in galaxies and A is the average amplification in lens events giving detected secondary images ($A \sim 2$). Using the data for galaxy counts $N_G = 1.5 \times 10^4$ dex$.44(m_G - 24)$ deg$^{-2}$ and QSO counts $N_Q = 3.2 \times 10^{-17}$ dex$.9m_Q$ deg$^{-2}$ for $m_Q < 19$ mag, I get

$$N_L = 2.5 \times 10^{-28} \; f \; \sigma_{250}^4 \; A^{2.2} \; 10^{1.3 m_Q} \; \text{deg}^{-2}$$

for the surface density of lensed QSOs as a function of their apparent magnitude. Note the strong dependence on $m_Q$. Taking f = 1 and A = 2 this leads to $N_L(19) = 230\sigma_{250}^4$/sky to 19th mag. Taking $\sigma = 210$ kms$^{-1}$ gives $N_L(19) = 115$/sky. Since $6.3 \times 10^{-3}$ of the sky was surveyed to 19th in the current QSO catalogue (1040 QSOs <19 mag vs 164,000 predicted over the entire sky by complete surveys over small areas), I expect 0.7 lensed QSOs to be found in the current catalogue to 19th mag out of 1000. In fact, one was found (0957+561). The grism (700) and objective prism (800) surveys are more efficient, and account for the remaining three out of 1500. Thus, surprisingly good agreement is obtained using canonical values for σ, f, A. Since the prediction is that we should eventually find ∿ 100 lensed QSOs over the sky to 19th V mag, there will then be sufficient data to test the steep $m_Q$ dependence. Counting lensed QSOs survives as one of the best ways to test cosmology by sampling the mass distribution at z ∿ .3 - 1.

## Discussion

*G. Burbidge:* Searches for close pairs of QSOs using the grism technique will tend to find objects with the same redshift. However, what we really need to find out is how many close pairs there are with arbitrary redshifts. Close pairs with very different redshifts need to be explained.

*Tyson:* What I have done is to compare two hypotheses for the origin of close multiple QSO images with identical spectra. In obtaining lens count data for both of these hypotheses, we want to use an observing technique with the highest efficiency for detection of multiple QSO images with identical spectra. Grism or objective prism surveys complete in a given area of sky and to a given apparent flux have higher efficiency for this purpose than any inhomogeneous compilation of QSOs based on BSO or radio properties. I agree that to address a third hypothesis that somehow discrepant redshift QSOs are correlated on the sky, we should choose another observation technique, but I am not addressing that hypothesis here. If by invoking nothing more radical than general relativity and the observed galaxy and QSO surface densities we arrived at the observed lensed QSO surface density, there is no compelling reason to consider more complicated models to explain this surface density.

*J. Barnothy:* The B) solution was, as you well know, proposed by me in 1965. I think in your calculations you have forgotten three factors: 1) A gravitational lens with distributed mass can have 2 - 10 times greater intensification than a lens of the same compact mass; 2) Your inference that very few double images have been observed is not a valid argument against lensing in general. The few magnitude intensification needed to render a Seyfert nucleus visible through lensing can be achieved with medium mass intervening galaxies. But then the spacing between the two crescent images will be merely a fraction of an arcsec, not resolvable with optical telescopes. To see a double QSO, a separation of at least 5 arcsec is needed. This would mean that the mass of the lens has to be 100 - 1000 times larger, which, of course, would make it a rather rare event; 3) If our universe is not an expanding universe, and thus a Doppler effect is not present in the luminosity distance, a much lower intensification is needed, so that the nucleus of a Seyfert galaxy should become observable by lensing. For example, in the FIB cosmology, 90% of the QSOs seem to be lensed, while the remaining 10% of not-lensed Seyfert galaxies are to be found at very low z values and around the antipode at $z = 3.81$.

*Tyson:* I did not consider alternative cosmologies, nor did I intend to imply that QSO counts themselves are inconsistent with your suggestion. The problem is with the multiple QSO counts. I disagree with your statement that > 3 mag lens-intensified QSOs would have multiple images separated by a fraction of an arcsec. The inferred velocity dispersion, mass, and the luminosity of the lensing galaxy in 0957+561 are consistent with the 6-arcsec image separation.

I must remark that it is a testimonial to Zwicky, the Barnothys, and, ultimately, to Einstein that gravitationally-lensed objects were predicted before they were discovered!

*Gorenstein:* On a related topic, I would like to announce that N.L. Cohen, I.I. Shapiro, E.E. Falco, A.E.E. Rogers and I have obtained high-resolution and high-sensitivity radio maps of 0957+561 A,B using VLBI techniques. With these data we have also detected a new compact radio component which may be either a third image of the quasar, or the radio core of the elliptical galaxy situated near the B image. The preliminary maps of the A and B images appear consistent with the gravitational light-bending hypothesis.

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