Galaxies Statistics around Highly Luminous Quasars: the ESO sample*

E. Van Drom [1], J. Surdej [1,2†], P. Magain [1‡], D. Hutsemékers [1]
E. Gosset [1‡] , J. F. Claeskens [3], P. Shaver [4] and J. Melnick [3]

[1]Institut d'Astrophysique, Université de Liège, Belgium
[2]Space Telescope Science Institute, Baltimore, USA
[3]European Southern Observatory, La Silla, Chile
[4]European Southern Observatory, Garching-bei-München, Germany

Abstract: We present observational evidence on the correlation between the positions of Highly Luminous Quasars (hereafter HLQs) and those of galaxies for a sample of 136 objects, observed under good seeing conditions. These correlations compare very well with current expectations based on the gravitational lensing magnification bias due to foreground galaxies. Our results are also found to be in good agreement with the observed incidence of multiply imaged quasars discovered in a separate sample of 469 HLQs.

1 Description of the count techniques and statistical analysis

In the present work, we investigate the merged sample (hereafter MS) of the 90 high redshift QSOs sample observed with the New Technology Telescope (NTT) at La Silla (ESO) in August-September 89 (hereafter S1), and the 82 QSOs sample of Magain et al. (1990) (hereafter S2). We discarded all quasars with M_V >-27.0. For the objects present in both the S1 and S2 samples, frames from the NTT were preferred (because of better seeing). We are then left with a sample containing 136 HLQs ($\bar{z}$ =2.3, $\bar{V}$ =17.4 and $\bar{M}_V$ =- 28.0).

Using the MIDAS package, we have defined on each CCD frame two circular fields having a radius of 23.3″ (our optimal choice because of the small angular extent of the NTT field). The first one, named the QSO field, is centered on the quasar; the comparison field is tangent to the previous one, its center being set towards the most distant CCD corner. In order to avoid QSO light contamination, we reject the central region (within 3″), which will in fact be considered later independently. The selected surface of the QSO fields is then divided in three rings of

*Based on data collected at the European Southern Observatory (La Silla, Chile)

†Maître de Recherches au Fonds National de la Recherche Scientifique (FNRS, Belgique) and senior visitor at ESO (Garching bei München, Germany)

‡Chercheur Qualifié au FNRS

Table 1: Results of the galaxy counts in the S1, S2 and MS samples

	Sample	Excess	Student confidence level
Overdensities (in the 3″-13.7″ ring)	S1	1.45	97%
	S2	1.37	90%
	MS	1.46	98%
completeness limit	For S1 and S2: R magnitudes between 22.5 and 23		
R magnitude of the galaxies in excess	S1 : 22.5 ± 0.5		
	S2 : 21.5 ± 0.5		

equal area (560 □″). All objects are detected by eye on a computer monitor and characterized as a galaxy or as a star.

We wish to test whether the mean numbers of galaxies in the QSO fields (or in a ring) and in the comparison fields (or in the corresponding ring) are comparable or not.

First, we apply the well-known Student test (Brownlee, 1965) on the computed means (we have verified the normality of the sample's distributions using a Kolmogorov-Smirnov test).

Secondly, the distribution of objects around other ones was analyzed by computing the distance to the nearest neighbour. We can compute the statistical variable C_j^i:

$$C_j^i = \frac{r_j^i - r_j}{\sigma_{r_j}}, \tag{1}$$

where r_j^i is the distance of the j^{th} nearest neighbour in observed field i, r_j and $\sigma_{r_j}^2$ its theoretical mean distance and variance. If $C_j^i = 0$, the null hypothesis is verified (random distribution); if $C_j^i > 0$ the distribution shows a tendency to deviate towards repulsion; if $C_j^i < 0$ the distribution rather deviates towards contagion. In order to give a global result for all fields, we have constructed one global statistical variable C_j:

$$C_j = \frac{1}{\sqrt{N_j}} \sum_{i=1}^{N_j} C_j^i \ , \tag{2}$$

where N_j is the number of fields containing a j^{th} neighbour.

2 Counts of galaxies in the fields of HLQs

2.1 Galaxy counts within 3 ″ to 13.7 ″ from HLQs

The galaxy number ratios $\bar{n}_Q/\bar{n}_C$ of the samples (S1, S2 and MS), in the 3″- 13.7″ ring, are listed in Table 1. Counts in more remote rings are not further discussed because of the smallness of the respective Student confidence levels. The R magnitude of completeness and an average $\bar{R}$ magnitude of the galaxies (found to be in excess) are also reported.

The nearest neighbour analysis of the MS sample for the nine nearest neighbours leads us to the results found in Table 2. The following conclusions may be drawn: for the comparison

Table 2: Values of the C_j's for the quasar fields (first line) and for the comparison fields (second line)

j^{th} nearest neighbour								
1	2	3	4	5	6	7	8	9
-0.4	-0.9	-3.3	-2.3	-2.4	-2.4	-0.4	0.1	-0.5
0.8	-0.5	-0.5	0.1	0.0	0.3	-0.5	-0.2	-0.2

Table 3: Main individual deviations in the separate fields

Field	Neighbour	deviation
QSO	4^{th} neighbour	$3\sigma > . > 2.5\sigma$
QSO	4^{th} neighbour	$3\sigma > . > 2.5\sigma$
	6^{th} neighbour	$. > 3\sigma$
QSO	3^{rd} neighbour	$. > 3\sigma$
QSO	2^{nd} neighbour	$3\sigma > . > 2.5\sigma$
	3^{rd} neighbour	$. > 3\sigma$
COMP	3^{rd} neighbour	$3\sigma > . > 2.5\sigma$
COMP	5^{th} neighbour	$. > 3\sigma$

fields, there is no significant deviation ($> 1\sigma$) to the null hypothesis; for the QSOs, on the contrary, we note four important deviations: see the orders 3, 4, 5 and 6 in Table 2. The first deviation is the most significant one ($> 3\sigma$). We therefore conclude that there exists a tendency towards contagion. Although statistics on individual fields are less sensitive than the global statistics, we consider them in the following. The strongest individual deviations for both QSO and comparison fields are listed in Table 3.

In summary, for the QSO fields analysed, we find a tendency for galaxies to cluster around HLQs but not so markedly for the first and second neighbours. There probably exist two populations: QSOs with a few randomly distributed neighbours and, on the other hand, some fields with many neighbours in clusters. This conjecture moreover is in good agreement with the fact that only a few fields show one significant deviation.

2.2 Galaxy counts within 3 $''$ from HLQs

These 136 HLQs were systematically inspected visually, in a search for possible non-stellar images (extension, fuzz, ...) or companions, either stellar or diffuse within $3''$. In addition, the point spread function (PSF) was subtracted from the QSO image whenever possible. The residuals were then examined for a possible superposition by a galaxy or by a stellar image. We were able to detect 5 objects tentatively identified as galaxies within $3''$ of the QSOs, whereas we were expecting to find just 1.8 such galaxies in the total sample of 136 quasars. This corresponds to an overdensity (ratio between the galaxy density within the solid angle considered around the QSOs and the average galaxy density determined in comparison fields) by a factor 2.8 at a 96% CL. Combination of this overdensity with the overdensities between $3''$ and $13.7''$ from the HLQs (see Table 1, MS) is shown in figure 2. As we assume that the galaxy counts around QSOs are affected by poissonian noise, the error bars on these values have been determined

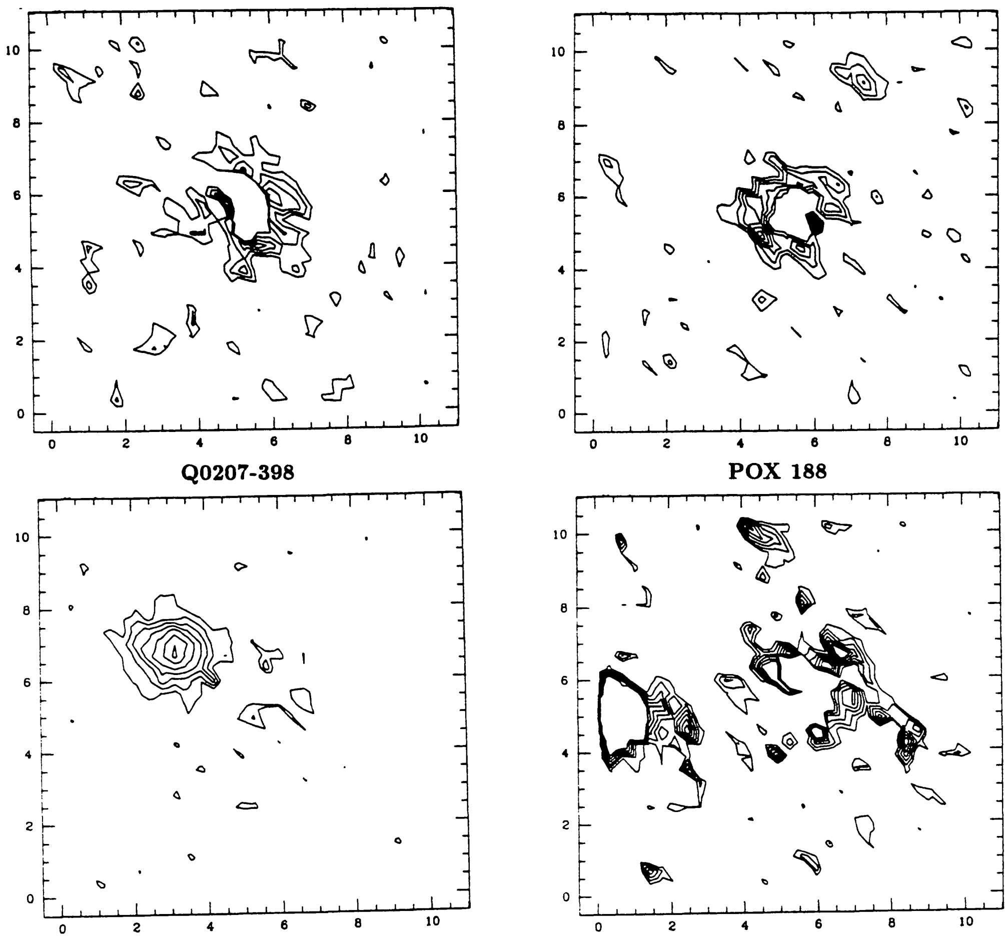

Figure 1: Four contour plots of tentative galaxy detections within 3″ from the HLQs. Images are residuals after a PSF subtraction

from the square root of the galaxy counts in the comparison fields. Except for the well-known gravitational lens UM673 [SUR87.1], we show in Fig. 1 the 4 frames where a tentative galaxy is detected within 3″ of the QSO after subtraction of the PSF. The 5 quasars concerned have apparent visual magnitudes between 17.0 and 17.5, and their absolute magnitude is brighter than -28.0, which means that they belong to the most luminous objects of the sample.

3 Discussion and conclusions

Figure 2 clearly indicates that the observed overdensity (q) of galaxies near HLQs increases with the inverse of their angular distance d. As we shall see hereafter, this observational result is found to be in good agreement with theoretical expectations based upon the gravitational lensing magnification bias of distant quasars by foreground galaxies. Indeed, since it is well known that highly luminous quasars are seriously affected by the magnification bias (Turner, Ostriker and Gott, 1984; [SUR93.1],[SUR92.3]), a non negligible fraction of these are amplified by (foreground) lenses and are therefore over-represented in a flux limited sample of quasars.

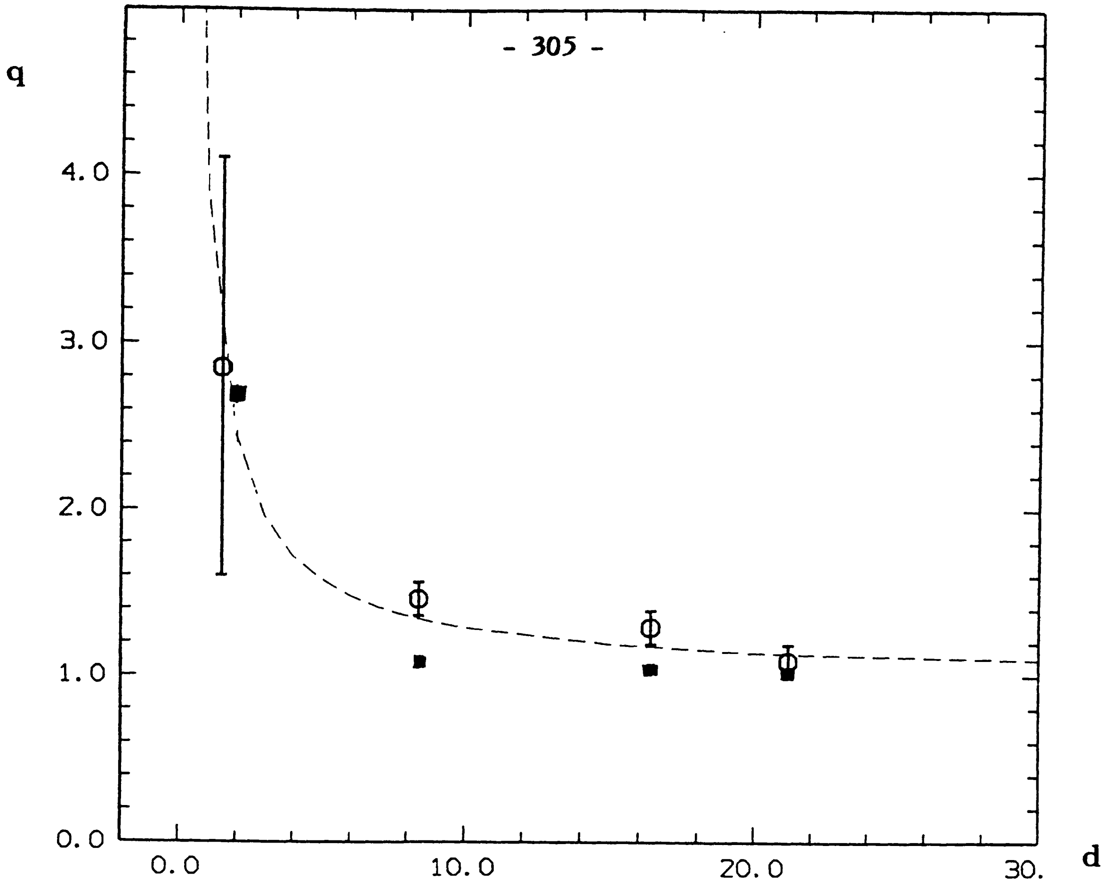

Figure 2: The overdensity q of galaxies as a function of the distance d (in arcsecond) to the HLQ (predictions are represented by the dashed line [Schneider et al. 1992] and by black squares [Claeskens and Surdej, 1994], see text)

Consequently, these are also expected to be surrounded by an excess of foreground galaxies which act as gravitational lenses. We also expect this excess to increase with the inverse of the angular distance between the QSO and the deflector since gravitational lensing amplification does also increase with decreasing values of the impact parameter.

The theoretical approach described by Schneider et al. (1992) shows that for a flux limited and statistically complete sample of QSOs and galaxies, the expected overdensity q of galaxies around background quasars should be the same as that of QSOs around the foreground galaxies. If the solid angle that is probed for an overdensity of QSOs consists of an annular region around a singular isothermal sphere deflector, it can be shown that

$$q = 1 + \frac{2.89}{d('')} ,$$

to be compared (see the dashed line in Fig. 2) with the observations.

More realistic calculations of the expected overdensity of galaxies near HLQs have been made by Claeskens and Surdej (1994). These authors have used a singular isothermal sphere (SIS) model to describe the lensing properties of foreground galaxies, assumed to be distributed cosmologically and characterized by a Schechter luminosity function. They calculated the magnification bias adopting the count number of quasars derived by Hartwick and Schade (1990). They also took into account a limiting R magnitude for the detection of galaxies on CCD frames, with adequate K-corrections. Results of their calculations are shown by the black squares in Fig. 2, for an average apparent visual magnitude $\bar{V} = 17.3$ and redshift $\bar{z} = 2.3$ of the quasars and for an R limiting magnitude of 21. The result concerning galaxies within $3''$ is found to represent very nicely the observed excess of galaxies. The discrepancy between the observed overdensity and the model in the two next rings may be caused by galaxy clustering effects, which we did not take into account.

Our level of quasar-galaxy association ranges between the results of Tyson (1986) (q=8.4 ± 5) and those of Yee et al. (1992) (q=1.0 ± 0.2). An understanding of the differences between the various conclusions concerning the presence of an overdensity of galaxies around the quasars is of course essential, although difficult to assess. Two main points may be of concern: the way the comparison fields were chosen is generally different for each sample and, above all, counts could be quite sensitive to selection criteria of the samples. In addition, we note that the detection of galaxies is also sensitive to the effective F/D ratio of the instrument used.

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