

# Analysis of possible anomalies in the QSO distribution of the Flesch & Hardcastle catalogue

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## ABSTRACT

**Aims.** A recent catalogue by Flesch & Hardcastle presents two major anomalies in the spatial distribution of QSO candidates: *i*) an apparent excess of such objects near bright galaxies, and *ii*) an excess of very bright QSO candidates compared to random background expectations in several regions of the sky. Because anyone of these anomalies would be relevant in a cosmological context, we carried out an extensive analysis of the probabilities quoted in that catalogue.

**Methods.** We determine the nature and redshift of a subsample of 30 sources in that catalogue by analysing their optical spectra (another 11 candidates were identified from existing public databases). These have allowed us to statistically check the reliability of the probabilities QSO status quoted by Flesch & Hardcastle for their candidates.

**Results.** Only 12 of the 41 candidates turned out QSOs (7 of which have been identified here for the first time).

**Conclusions.** The probabilities of the QSOs' being the candidates given by Flesch & Hardcastle are overestimated for  $m_B \leq 17$  and for objects projected near ( $\leq 1$  arcmin) bright galaxies. This is the cause of the anomalies mentioned above.

**Key words.** quasars: general – galaxies: statistics – distance scale – catalogs

## 1. Introduction

At present, statistics on QSO distributions can be carried out using the recent public compilations of QSOs identified in the SDSS (Adelman-McCarthy et al. 2007) and 2dF (Croom et al. 2004) surveys. Furthermore, Flesch & Hardcastle (2004, hereafter FH04) present an all-sky catalogue with 86 009 optical counterparts of radio/X-ray sources as QSO candidates (with a probability greater than 40%, according to FH04) that were not identified previously as such. This could be a useful catalogue to look for QSOs in regions that were not covered by SDSS or 2dF, or for deeper magnitudes than their completeness limit. Nevertheless, since the FH04 catalogue does not give the identification of each source but just a statistical estimate of the probability that it be a QSO (or a star, a galaxy, or a wrongly identified optical counterpart of the X-ray/radio source), it must be used with care.

Flesch<sup>1</sup> claims that his catalogue “reveals a few galaxy-centered fields which are populated by QSOs/candidates more thickly than expected by the background density of such QSOs,” which would argue in favour of the hypothesis of QSOs with anomalous redshift and at the same distance as the galaxies with which they are associated (Arp 1998; Burbidge 2001). Because this is against one of the most basic assumptions in standard modern cosmology, we consider it interesting to check it on the basis of rigorous statistical computation. This is the main objective of this paper. In Sect. 2, we analyse in which cases (on

the basis of the probabilities quoted by FH04) there are anomalies in the distribution of QSOs. By conducting optical spectroscopy (Sect. 3), we directly check the nature of a subsample of FH04 sources. On the basis of these observations, in Sect. 4 we check the reliability of the probabilities quoted by FH04. In Sect. 5 we reanalyse the distribution of QSOs and discuss the implications of our results.

## 2. Anomalies in the distribution of QSO candidates

### 2.1. Exploring the whole sky

The average number of QSOs up to  $B$ -magnitude  $m_{B,0}$  is (López-Corredoira & Gutiérrez 2006a, Eq. (2)):

$$N(m_B < m_{B,0})[\text{deg}^{-2}] = \begin{cases} 10^{-2.8+0.8(m_{B,0}-15)}, & m_{B,0} \leq 18.5 \\ 1981.0 - 214.2m_{b_j,0} + 5.792m_{b_j,0}^2, & m_{B,0} > 18.5 \end{cases}, \quad (1)$$

where the conversion of the photographic to the Johnson band-pass is  $m_{b_j,0} \approx m_{B,0} - 0.14 \times (m_{B,0} - m_{R,0})$ .

Given a circular region of angular radius  $R(\text{deg.})$  with  $n$  QSO candidates up to magnitude  $m_{B,0}$ , the probability that FH04 expectations be compatible with the expectations for background QSOs is

$$P = \sum_{m=0}^n P_p(m)P_q(m), \quad (2)$$

<sup>1</sup> See his web-page <http://quasars.org/>

where  $P_p(m)$  is the Poissonian probability of having  $m$  sources in the circle

$$P_p(m) = \frac{[\pi R^2 N(m_B < m_{B,0})]^m e^{-[\pi R^2 N(m_B < m_{B,0})]}}{m!}, \quad (3)$$

and  $P_q(m)$  is the probability that we observe a number of  $m$  QSOs among  $n$  candidates given the a priori probabilities  $p_1, \dots, p_n$ :

$$P_q(m < n) = P_q(n) \sum_{l_1, \dots, l_{n-m}=1; l_1 < \dots < l_{n-m}}^n [(p_{l_1}^{-1} - 1) \dots (p_{l_{n-m}}^{-1} - 1)], \quad (4)$$

$$P_q(n) = \prod_{i=1}^n p_i.$$

The probability of finding at least one region with low probability  $P$  in the whole sky is

$$P_{\text{sky}} = P \times (41252 \text{ deg}^2) \times \text{Minimum} \left[ \frac{1}{\pi R^2}, N(m_B < m_{B,0}) \right]. \quad (5)$$

We have explored the distribution of QSO candidates in several projected circles on the sky to check their compatibility with the expectation from background QSOs. In Table 1, we give the centre and radius of the regions and magnitudes that are very unlikely ( $P_{\text{sky}} < 0.05$ , i.e. 95% C.L.) as a result of chance projection. The table shows many of these cases<sup>2</sup>.

The large excess of QSO candidates up to  $B$ -magnitude  $\sim 19$  in the region centred at  $\alpha \approx 84.9^\circ = 5\text{h}39\text{m}36\text{s}$ ,  $\delta = -64^\circ$  and radius 0.4 deg (26 QSO candidates in a  $0.50 \text{ deg}^2$  region up to magnitude 19 while an average of  $\sim 1$  QSO is expected as background) might be related with the Large Magellanic Clouds (LMC), whose centre is 7 degrees away. The region around LMC contains a number of X-ray sources (Pietsch & Kahabka 1993; Haberl & Pietsch 1999), many of them background QSOs (Kahabka 2002; Dobrzycki et al. 2005), but many of them are other kinds of objects that could have been confused with QSO candidates by FH04. Particularly, there is a very bright X-ray source exactly in this region: LMC X-3 (Haberl & Pietsch 1999) with  $\alpha = 5\text{h}38\text{m}56.8\text{s}$ ,  $\delta = -64^\circ 05' 12''$ , a black hole binary, a Be star with a period 1.7 days. Most probably, the many ROSAT X-ray sources surrounding it might be attenuated reflections (by the X-ray detector, which might create ghost images when a strong source saturates it) of this very bright X-ray source.

However, the excess of very bright QSOs in many areas given in Table 1 cannot be explained by any similar contamination. For instance, in the circle centred at  $\alpha \approx 69.282^\circ = 4\text{h}37\text{m}7.7\text{s}$ ,  $\delta = -30^\circ$  and radius 60 deg. (Twenty QSO candidates in a 1/4 of the whole sky up to magnitude 14.5, while an average of  $\sim 7$  QSOs is expected as background.)

## 2.2. Exploring the regions near bright galaxies

Here we explore the regions near bright RC3 galaxies (Third Reference Catalog of Bright Galaxies; de Vaucouleurs et al. 1991, updated on 1995, February 16th). The RC3 catalogue is

<sup>2</sup> These probabilities are conservative because: i/ the catalogue ignores QSO candidates with probabilities  $\leq 40\%$ ; ii/ it includes only those QSO candidates that were not classified previously; iii/ it only includes QSOs that emit in radio or X-ray, which is not the whole QSO population; iv/ it is not complete for the faintest fluxes because the radio and X-ray catalogues used do not have the same depth all over the sky.

**Table 1.** Probabilities of QSO excesses.

$\alpha(^{\circ}), \delta(^{\circ})$	$R(^{\circ})$	$m_{B,0}$	$n$	$P$	$P_{\text{sky}}$
324.534, -66.000	6	13.0	2	0.026	0.042
324.534, -66.000	6	13.5	3	0.010	0.041
30.193, -58.000	16	14.0	4	0.0041	0.042
58.476, -70.000	20	13.0	2	0.021	0.035
59.006, -66.000	24	13.0	2	0.023	0.038
62.229, -50.000	40	13.0	3	0.021	0.035
62.229, -50.000	40	14.0	6	0.0034	0.036
63.640, -45.000	45	13.0	3	0.023	0.038
63.640, -45.000	45	14.0	7	0.0021	0.022
63.640, -45.000	45	14.5	12	0.0013	0.027
65.270, -40.000	50	13.0	3	0.026	0.043
65.270, -40.000	50	13.5	5	0.0071	0.029
65.270, -40.000	50	14.0	8	0.0014	0.014
65.270, -40.000	50	14.5	16	$3.1 \times 10^{-4}$	0.0052
67.143, -35.000	55	14.0	8	0.0041	0.043
67.143, -35.000	55	14.5	16	0.0011	0.015
69.282, -30.000	60	14.5	20	$2.3 \times 10^{-4}$	0.0027
71.720, -25.000	65	14.5	19	$8.6 \times 10^{-4}$	0.0083
69.282, -30.000	60	12.5	3	0.058	0.038
71.720, -25.000	65	12.5	3	0.060	0.039
65.270, -40.000	50	15.0	20	0.0020	0.033
67.143, -35.000	55	15.0	22	0.0028	0.038
69.282, -30.000	60	15.0	27	$9.7 \times 10^{-4}$	0.011
71.720, -25.000	65	15.0	27	0.0036	0.035
84.783, -64.200	0.3	19.0	20	$6.3 \times 10^{-8}$	0.0055
84.860, -64.000	0.4	19.0	26	$6.2 \times 10^{-9}$	$5.4 \times 10^{-4}$
84.860, -64.000	0.4	19.5	30	$4.7 \times 10^{-8}$	0.012
84.403, -64.000	0.5	19.0	25	$3.1 \times 10^{-8}$	0.0027
84.936, -64.100	0.7	19.0	29	$4.6 \times 10^{-8}$	0.0039
85.168, -64.400	0.8	19.0	30	$7.0 \times 10^{-7}$	0.0045

Note:  $P$  is the probability of there being  $n$  QSO candidates up to magnitude  $m_{B,0}$  in the FH04 catalogue with the probabilities specified by them within a circle of centre  $(\alpha, \delta)$  (coordinates J2000) and angular radius  $R$ .  $P_{\text{sky}}$  is the probability of finding at least one circle with the small value of  $P$  in the whole sky. Cases with  $P_{\text{sky}} < 0.05$ .

complete for galaxies with  $m_{B,\text{gal}} < 15.5$ , redshift  $z \leq 0.05$ , and an apparent diameter at the  $D_{25}$  isophotal level larger than 1 arcmin. The catalogue contains a total of 23 011 galaxies. From Eq. (1), around all the RC3 galaxies and within a distance of  $d$  arcmin and magnitude  $m_B < m_{B,0}$ , we would expect a number of QSOs:

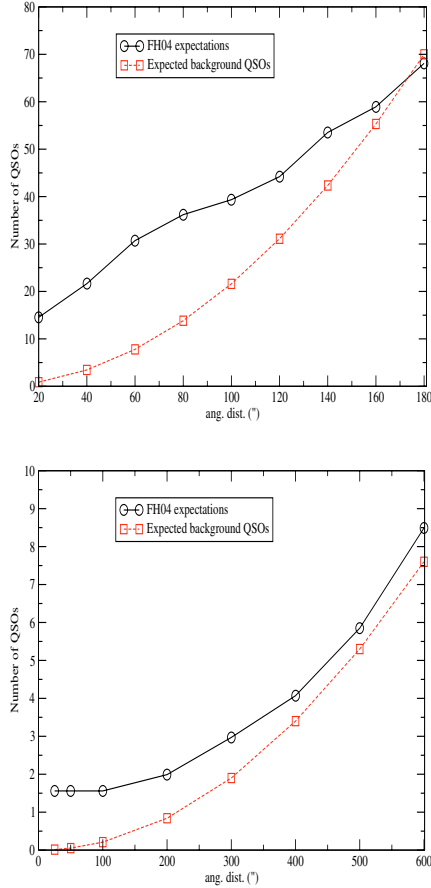
$$N_{\text{RC3}}(m_{B,0}, d) \approx 10^{0.8(m_{B,0}-16.9)} d^2, \quad (6)$$

which means an average of 70 objects up to 3 arcmin of RC3-galaxies with  $m_B \leq 18$  and 7.6 cases up to 10 arcmin with  $m_B \leq 15.5$ . Figure 1 shows how FH04 average expectations exceed the expected background counts, and Table 2 shows the very low probability (calculated with Eqs. (2) and (6)) of making both numbers compatible, specially for  $d < 1'$  and  $m_B \leq 18$ . For the highest  $d$  values, the probability is somewhat lower due to the incompleteness of the FH04 catalogue rather than to an excess in the number of QSOs.

Among the QSO candidates that are less than 1 arcmin from a RC3 galaxy, we have the examples shown in Fig. 2.

## 3. Selection and observation of QSO candidates

The anomalies in Sect. 2 rely on the probabilities quoted by FH04. To check the reliability of these probabilities, we determined the nature and redshifts of a significant sample of



**Fig. 1.** Cumulative counts of FH4 QSOs (sum of the probabilities given by FH04 to be QSOs) around the complete sample of RC3 galaxies as a function of the maximum distance to a galaxy, in comparison with the expected background QSOs. *Up*: up to magnitude  $m_B = 18$ , *Down*: up to magnitude  $m_B = 15.5$ . QSOs associated to two galaxies count twice with each corresponding distance.

FH04 objects by direct observations. The objects selected follow four criteria:

- sources up to 3 arcmin from RC3 galaxies with  $m_B \leq 18$ , such as those in Fig. 2;
- sources up to 10 arcmin from RC3 galaxies with  $m_B \leq 15.5$ ;
- other sources up to 3 arcmin from galaxies with  $m_B \leq 18$  that do not belong to the RC3 catalogue;
- sources with  $m_B \leq 15.5$  (to test the anomalous distribution of this bright sources in several regions of the sky, as shown in Table 1).

In total, we have identified the 41 sources listed in Table 5: 11 from the public database of SIMBAD (data obtained after the publication of FH04) and 30 from our own spectroscopic observations. A double check was made by observing 5 objects already classified in SIMBAD. The columns of Table 5 are as follows. Column 1 gives number of the source. Column 2: equatorial coordinates (J2000) of the optical counterpart identified by FH04 as a QSO candidate. Column 3: apparent magnitude in the  $B$  filter (FH04). Column 4: probability that the source is a QSO according to FH04. Column 5: radio flux at 1.4 GHz (mJy) or flux in X-ray (counts/hour in ROSAT) [FH04]. Column 6: peculiarity of the source: a) sources up to 3 arcmin from RC3 galaxies with  $m_B \leq 18$ ; b) sources up to 10 arcmin from RC3 galaxies with  $m_B \leq 15.5$ ; c) sources up to 3 arcmin from non RC3 galaxies with  $m_B \leq 18$ ; d) sources with  $m_B \leq 15.5$ . In cases a); b); and

**Table 2.** Probabilities of QSO excesses around RC3 galaxies.

$d$ (")	$m_{B,0}$	$n$	$\langle n_{bg} \rangle$	$P_{RC3}$
0–20	18.0	25	0.86	$3.5 \times 10^{-7}$
20–40	18.0	12	2.6	0.027
40–60	18.0	14	4.3	0.031
60–80	18.0	8	6.0	0.15
80–100	18.0	5	7.8	0.042
100–120	18.0	8	9.5	0.049
120–140	18.0	13	11	0.10
140–160	18.0	8	13	0.013
160–180	18.0	13	15	0.042
0–25	15.5	3	0.013	0.096
0–50	15.5	3	0.053	0.11
0–100	15.5	3	0.21	0.14
100–200	15.5	1	0.63	0.45
200–300	15.5	2	1.1	0.32
300–400	15.5	2	1.5	0.29
400–500	15.5	3	1.9	0.25
500–600	15.5	3	2.3	0.22

Note:  $P_{RC3}$  is the probability of having  $n$  QSO candidates up to magnitude  $m_{B,0}$  in FH04 catalogue with the probabilities specified by them within a circle centred at a RC3 galaxy and angular distance  $d$ .

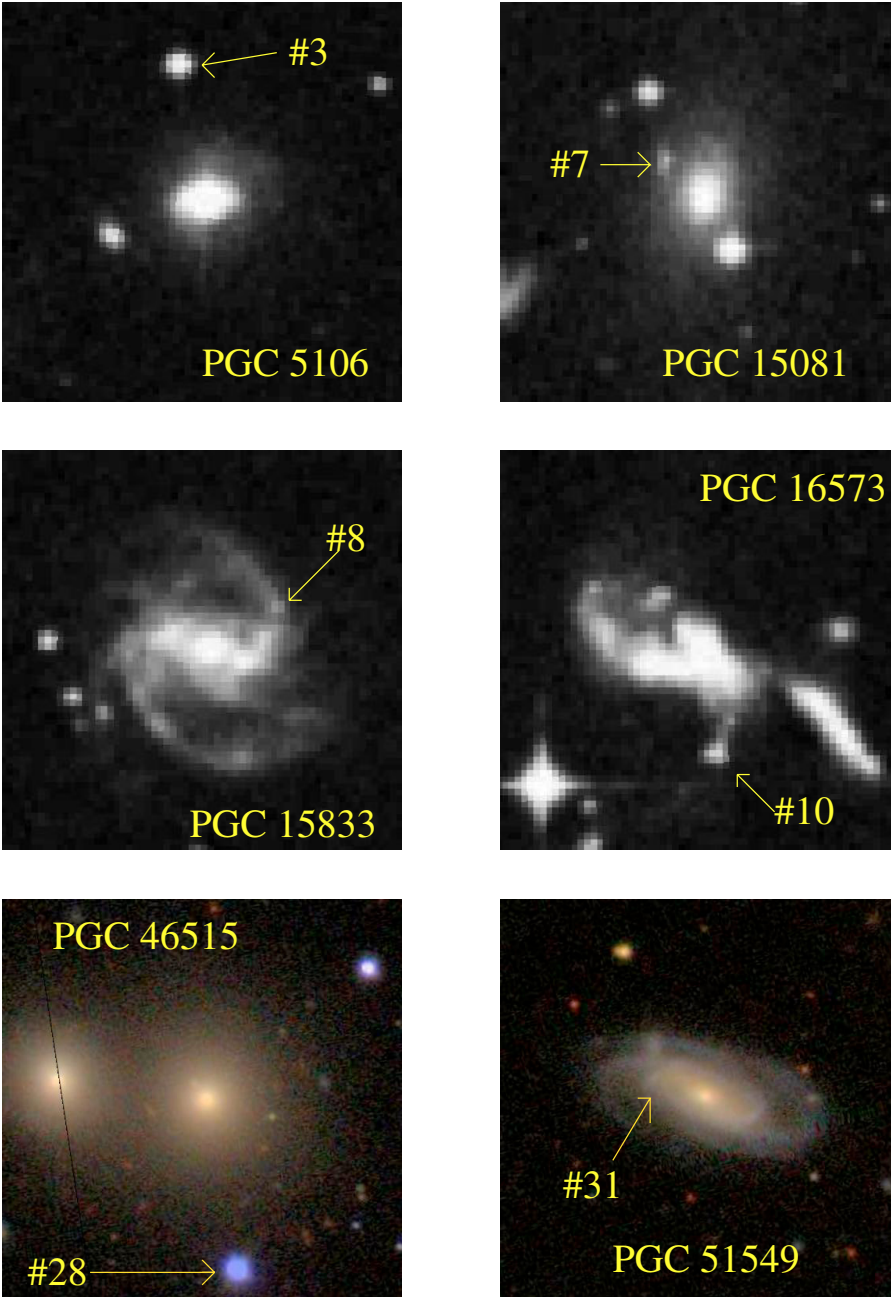
c): the RC3 galaxy (or non-RC3 for case # 6) from which the source is closest, and the distance (in arcseconds) between the QSO candidate and the galaxy are specified. Column 7: exposure time in seconds (with the superindex  $^{np}$  means non-photometric), date of observation and telescope (CA: 2.15 m CASLEO, San Juan, Argentina; OH: 1.93 m OHP, Haute-Provence, France; IU: 2 m IUCAA, India) or “SIMBAD-database” when the data were publicly available on the SIMBAD web-page. Column 8: spectroscopic identification. Column 9: spectral lines: CIV is at 1549 Å, CIII is at 1909 Å, MgII is at 2798 Å, NeIII is at 3869 Å, HeI is at 3889 Å, CaII is the doublet H and K at 3933/3970 Å, H $\delta$  is at 4102 Å, H $\gamma$  is at 4340 Å, HeII is at 4686 Å, H $\beta$  is at 4861 Å, OIIIa is at 4959 Å, OIIIb is at 5007 Å, MgI is at 5180 Å, NaI is at 5892 Å, OI is at 6300 Å, NIIa is at 6548 Å, H $\alpha$  is at 6562 Å, NIIb is at 6584 Å, SIIa is at 6717 Å, SIIb is at 6731 Å; “A:” means absorption, “E:” means emission, superindex  $b$  means “broad”. Column 10: redshift.

We used the following telescopes and instrumental setups:

- 2.15 m CASLEO, in “El Leoncito” Observatory, San Juan, Argentina. REOSC Ds Spectrograph, grism # 270, slit width: 2.5". Wavelength range: 3630–7120 Å, 3.41 Å/pixel.
- 1.93 m OHP, Haute-Provence, France. CARELEC Spectrograph, whose grating provides a resolution of 133 Å/mm, slit width: 2". 1.78 Å/pixel. Wavelength range: 3965–7600 Å.
- 2 m IUCAA, India. 2 m f/10 Cassegrain telescope. IFOSC (IUCAA Faint Object Spectrograph and Camera), f/4.5. Grism FOSC7, wavelength range 3800–6840 Å, dispersion 1.39 Å/pixel, slit width: 1.5".

We followed a standard method of reduction. A summary of the identifications is presented in Table 5. Only 7 of the 30 objects turned out to be QSOs, while the other 23 were stars, HII regions, or galaxies. The spectra of the seven QSOs are plotted in Fig. 3. For the 11 SIMBAD database objects, there were another 5 QSOs, so we found 12 QSOs from a total number of 41 objects observed.





**Fig. 2.** Some of the QSO candidates of FH04 observed in the present work (number # as in Table 5). PGC 5106, PGC 15081, PGC 15833, PGC 16573 images from the Digitized Sky Survey, size  $108'' \times 108''$ . PGC 46515, PGC 51549 images from the Sloan Digital Sky Survey, size  $100'' \times 100''$ . None of these candidates is a QSO.

### 3.1. Notes on some objects

- #7: this is a Seyfert 2 galaxy at only 13 kpc projected distance from a cD galaxy (PGC 15081) within the same cluster.
- #8,#24, #31: these are star-forming regions that were probably considered as QSO candidates on the basis of their blue colours.
- #11,#16, #20, #32: white dwarfs are also usually misidentified as QSO candidates because of their blue colours.
- #15: this is a cold M5 star with emission lines presumably caused by photospheric activity, which gives strong X-ray emission.

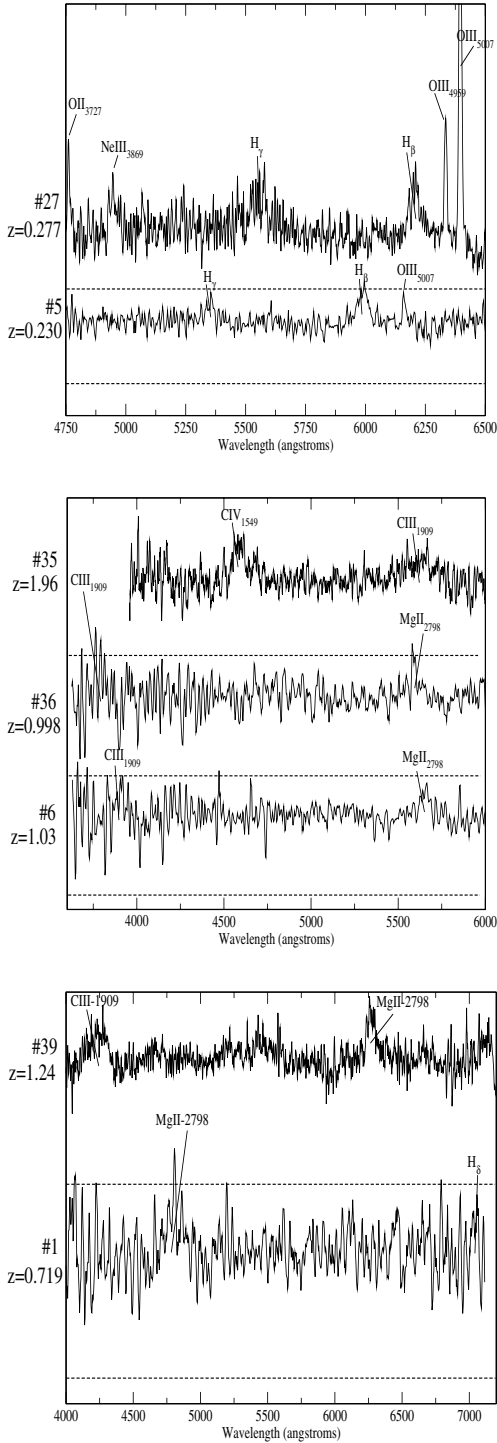
The rest of the non-QSO objects are other types of stars. The number of contaminating objects in case a) (up to magnitude 18 within  $180 \text{ deg}^2$ ) or b) (up to magnitude 15.5 within  $2000 \text{ deg}^2$ ) is not surprising since the number of stars in high galactic latitude fields is  $\sim 10^5 - 10^6$  (Robin et al. 2003) for both cases a)

and b), and among them a fraction  $\sim 10^{-4} - 10^{-5}$  might be white dwarfs or stars with some activity or feature that make them susceptible to being detected in radio or X-ray.

## 4. The reliability of FH04 probabilities

### 4.1. As a function of the apparent magnitude

Given the observed number of QSOs that have different magnitudes with the a priori probabilities of FH04 (4th column of Table 5), we can calculate  $P(\leq m)$  with Eq. (4), the probability that FH04 expectations are correct given that we have detected a number of  $\leq m$  QSOs among the  $n$  candidates. They are given in Table 3. Clearly, for magnitudes  $m_B < \approx 17$ , the a priori probabilities given by FH04 are overestimated. However, for  $m_B > \approx 17$  our results are compatible with the probabilities given by FH04. Figure 4 and Table 3 show the expected and the observed average probabilities of the FH04 candidates being QSOs.



**Fig. 3.** Continuum normalized spectra of the seven objects classified as QSOs from a total of 30 FH04 candidates. Dashed lines stand for zero flux.

Given that none of the 13 QSO candidates with  $m_B \leq 15.1$  are in fact QSOs, this means that the excesses of Table 1 with  $m_B \leq 15$  are not real QSO excesses, so there is no incompatibility with background expectations.

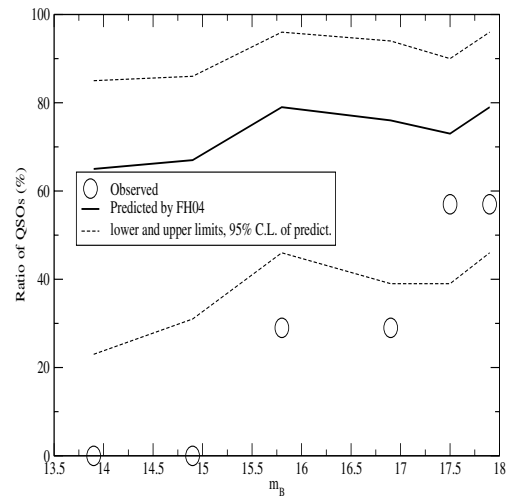
#### 4.2. As a function of the distance to an RC3 galaxy

For the subsample a) of Table 5, there are 26 objects with  $m_B \leq 18$  at distances less than  $180''$  from an RC3 galaxy,

**Table 3.** Probabilities that FH04 expectations are correct as a function of the magnitude.

$m_B$	$n$	$m$	$m_{\text{FH04}}$	$P(\leq m)$
13.4–14.4	6	0	$3.9^{+1.2}_{-2.5}$	$1.1 \times 10^{-4}$
14.7–15.1	7	0	$4.7^{+1.3}_{-2.5}$	$5.2 \times 10^{-5}$
15.2–16.5	7	2	$5.5^{+1.2}_{-2.3}$	$2.4 \times 10^{-3}$
16.7–17.2	7	2	$5.3^{+1.3}_{-2.6}$	0.011
17.3–17.7	7	4	$5.1^{+1.2}_{-2.4}$	0.23
17.8–18.0	7	4	$5.5^{+1.2}_{-2.3}$	0.14

Note: Column 2:  $n$ : number of FH04 QSO candidates observed. Column 3:  $m$  number of these which are identified spectroscopically as QSOs. Column 4: expected number of QSOs according to FH04 ( $\pm$ ; 95% C.L.). Column 5:  $P(\leq m)$ , probability that FH04 expectations are correct given that we have detected a number  $\leq m$  of QSOs among the  $n$  candidates.



**Fig. 4.** Observed ratio of QSOs as a function of magnitude among the 41 FH04 candidates with spectroscopic identification given in this paper. Comparison with predictions of FH04 (limits within dashed line are 95% C.L.).

36 cases if we count the repetitions<sup>3</sup>. Table 4 gives the probability  $P(\leq m)$  that FH04 expectations are correct given that we detected a number of  $\leq m$  QSOs among the  $n$  candidates, as a function of the distance of the RC3 galaxy. Figure 5 and Table 4 show the expected and the observed average probability of the FH04 candidates being QSOs. We conclude that the FH04 probabilities are highly overestimated in the regions within  $\sim 1$  arcmin from an RC3 galaxy. There is also overestimation at distances  $\sim 2$ – $3$  arcmin.

This result solves the second anomaly. Since only 1 object among 11 candidates at distances less than 1 arcmin is really a QSO, the probabilities given by FH04 are not valid, and the announced excess announced in Sect. 2.2 is not supported.

## 5. Discussion and conclusions

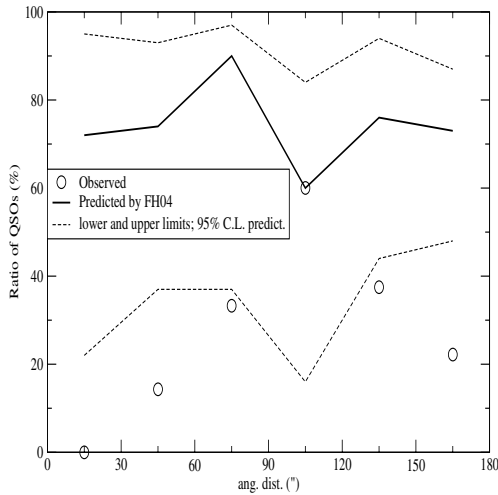
In FH04 there are 88 different objects (106 cases with repetitions) with  $m_B \leq 18$  within a radius of 3 arcmin of RC3 galaxies. Of these 88 objects, there are spectroscopic observations of the

<sup>3</sup> There are some cases of two RC3 galaxies projected very close in the sky. For these cases QSOs projected near such galaxies are counted twice (we will refer to these cases as “cases with repetition”), so this raises the number of QSO/galaxy associations to 36.

**Table 4.** Probabilities that FH04 expectations are correct as a function of the distance to RC3 galaxies.

$d''$	$n$	$m$	$m_{\text{FH04}}$	$P(\leq m)$
0–30	4	0	$2.9^{+0.9}_{-2.0}$	$4.2 \times 10^{-3}$
30–60	7	1	$5.2^{+1.3}_{-2.6}$	$1.1 \times 10^{-3}$
60–90	3	1	$2.7^{+0.2}_{-1.6}$	0.022
90–120	5	3	$3.0^{+1.2}_{-2.2}$	0.68
120–150	8	3	$6.1^{+1.4}_{-2.6}$	0.015
150–180	9	2	$6.6^{+1.2}_{-2.3}$	$8.8 \times 10^{-4}$

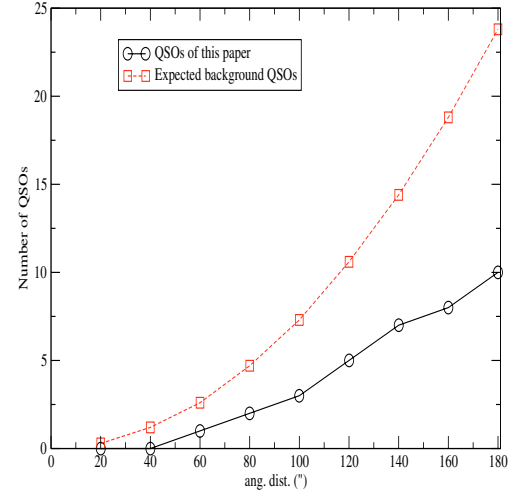
Note: Column 1: range of distances from an RC3 galaxy. Column 2:  $n$ : number of FH04 QSO candidates observed. Column 3:  $m$  number of these which are identified spectroscopically as QSOs. Column 4: expected number of QSOs according to FH04 ( $\pm$ ; 95% C.L.). Column 5:  $P(\leq m)$ , probability that FH04 expectations are correct given that we have detected a number  $\leq m$  of QSOs among the  $n$  candidates.

**Fig. 5.** Observed ratio of QSOs as a function of distance to an RC3 galaxy among the 36 FH04 candidates (including repetitions, i.e. objects associated with more than one galaxy) with spectroscopic identification given in this paper. Comparison with the predictions of FH04 (limits within dashed line are 95% C.L.).

optical counterparts in 26 cases (36 cases including repetitions), and 10 of these (the same number with repetitions) are in fact QSOs (while the 16 other objects (26 with repetitions) are stars, galaxies, or HII regions). The average expected number of background cases around all RC3 cases should be  $\approx 70$  (Sect. 2.2) and, in our subsample, should be  $\approx \frac{36}{106} \times 70 = 24$  cases, which is higher than the value derived from the observations. This stems from the incompleteness of the FH04 catalogue.

Within a radius of 10 arcmin of RC3-galaxies, there are 14 objects (no repetitions) with  $m_B \leq 15.5$ , of which five (36% of the sample) were observed and only one (# 5 with  $m_B = 15.4$ ) turned out a QSO. The average expected number of cases around all RC3 galaxies is 7.6 (Sect. 2.2), and in our subsample should be  $\frac{5}{14} \times 7.6 = 2.7$  cases. This result agrees with expectations from a background distribution of QSOs.

Limiting the study to RC3 galaxies by  $m_{B,\text{gal}} \leq 14.5$ ,  $m_{B,\text{gal}} \leq 13.5$ , and  $m_{B,\text{gal}} \leq 12.5$ , the number of galaxies is reduced to 7,675/2,566/883. For the subsample with  $m_b \leq 18$ ,  $d \leq 3'$  we obtained 5/2/2 QSOs to be compared with the expected 7.8/2.7/0.92. For the subsample with  $m_b \leq 15.5$ ,  $d \leq 10'$ , we obtained 1/0/0 to be compared with 0.50/0.17/0.06. There

**Fig. 6.** Cumulative counts of QSOs of this paper up to magnitude  $m_B = 18$  [34% (36/106) of the QSO/RC3-galaxy pairs] as a function of the maximum distance to the galaxy. QSOs associated with two galaxies count twice with each corresponding distance.

is no statistical inconsistency with the claim that all QSOs are background QSOs rather than being associated with the galaxies.

As for the distribution of the QSOs with magnitude or distance from RC3 galaxies, as pointed out in Sect. 4, there is no longer any inconsistency with background predictions: almost all the confirmed QSOs in our subsample are faint (all of them with magnitudes  $m_B \geq 17.0$ , except #5) and distant enough from the centres of RC3 galaxies to be compatible with background expectations. See Fig. 6 for the distance distribution and note how the observed QSOs are fewer than the background expectations for all distances. Some of the most troublesome candidates, such as those shown in Fig. 2, were in the end confirmed to be objects different from QSOs.

The only QSO with  $m_B \leq 15.5$  (# 5) within 10' from an RC3 galaxy is associated with NGC 1136, which was previously reported as a galaxy with peculiar associations (Arp 1981). Objects claimed by Arp to be anomalous are much fewer than 23 011 RC3 galaxies. They are  $\sim 10^2$ , so the probability of finding a QSO with  $m_B \leq 15.5$  within 10' from some of them is  $P \sim 0.06$ . It is not few enough to claim it separately from other facts as a possible anomalous case, but a fact to be added in the discussion of the case of NGC 1136.

For the object # 6, now confirmed to be a QSO with  $m_B = 16.5$  at only 30'' from PHL 1459 (a galaxy with  $m_B = 17.2$  and X-ray emission), we are not within the statistics of RC3 galaxies. There are  $\approx 4.3 \times 10^5$  galaxies in the whole sky up to the magnitude  $m_B = 17.2$  (Metcalf et al. 1991), so, using Eq. (1), the expected number of cases like this within a 30-arcsec distance of these galaxies is 2.2. The discovery of only one case is not enough to claim any statistical anomaly. If we take into account the peculiarity that PHL 1459 is an X-ray source and has  $\approx 120$  counts/h in ROSAT (Voges et al. 1999, 2000), the probability is somewhat lower. There are  $\sim 0.4$  galaxies/deg<sup>2</sup> up to this X-ray flux (Voges et al. 1999; Zickgraf et al. 2003), i.e. around 16 000 galaxies like this in the whole sky. The probability of finding a QSO with  $m_B = 16.5$  within 30'' of one of them is 0.09; not low enough to discard a background projection coincidence.

Summing up, within the subsample of 41 objects from FH04, we have not found any statistical anomaly with respect to the expectation of QSOs as background sources. Since we observed a representative subsample of the most controversial cases that

Table 5. Observed FH04 QSO candidates (column description in Sect. 3).

#	$\alpha$ (h. m. s), $\delta$ (d. ' ")	$m_B$	ProbQSO(%)	Rad./X flux	Peculiarity	Observation	Spect. ident.	Spect. lines	Redsh.
1	00 57 19.7, -48 54 07	17.1	80	Rad.: 77+392	a) PGC 3436/171	3600/Oct.8'05/CA	QSO	E: MgII <sup>b</sup> , H <sub>β</sub> <sup>b</sup> , NeIII	0.719
2	01 00 22.8, -33 41 27	17.2	66	Rad.: 3	a) PGC 3589/180	SIMBAD-database	Star		
3	01 23 46.8, -58 47 44	15.7	71	X-ray: 60	a) PGC 5106/33	3600 <sup>pp</sup> /Oct.5'05/CA	Star	A: CaII, H <sub>α</sub> , H <sub>β</sub> , MgI	
4	02 26 40.0, -05 52 37	14.3	99	Rad.: 107	d)	1200 <sup>pp</sup> /Oct.4'05/CA	Star	A: H <sub>β</sub> , MgI	
5	02 49 58.7, -55 03 20	15.4	95	X-ray: 137	b) NGC 1136/552	600/Oct.7'05/CA	QSO	E: H <sub>γ</sub> , H <sub>β</sub> <sup>b</sup> , OIII <sup>b</sup>	0.230
6	02 52 27.8, -20 32 41	16.5	98	R: 37, X: 134	c) PHL 1459/30	3000/Oct.7'05/CA	QSO	E: MgII <sup>b</sup> , CIII <sup>b</sup>	1.03
7	04 25 52.4, -08 33 34	16.7	71	X-ray: 3377	a) PGC 15081/17	5400 <sup>pp</sup> /Oct.5'05/CA	Seyfert 2	E: H <sub>α</sub> , HeII	0.038
8	04 41 47.1, -01 17 56	17.1	73	X-ray: 299	a) PGC 15833/13	10200 <sup>pp</sup> /Oct.6'05/CA	HII-reg.	E: H <sub>α</sub> , NIIb	0.029
9	04 54 45.4, -18 08 34	16.3	55	X-ray: 192	a) PGC 16315/138	700/Oct.7'05/CA	Star	A: MgI, NaI	
10	05 01 37.6, -04 15 57	17.7	63	X-ray: 27	a) PGC16573/29	SIMBAD-database	Part of a galaxy		
11	05 27 16.4, +01 48 40	14.8	40	Rad.: 27	d)	900/Nov.1'05/OH	White dwarf?		
12	05 35 47.6, -05 10 30	14.3	54	X-ray: 96	d)	900/Nov.1'05/OH & SIMBAD	Star	A: H <sub>α</sub> , H <sub>β</sub> <sup>b</sup> , H <sub>γ</sub> <sup>b</sup> , H <sub>δ</sub> <sup>b</sup>	
13	05 35 54.4, -04 48 05	15.1	75	X-ray: 105	d)	900/Nov.1'05/OH & SIMBAD	Star	E: H <sub>α</sub> , H <sub>β</sub> , H <sub>γ</sub> , H <sub>δ</sub> ; A: MgI	
14	05 36 06.3, -05 41 56	14.2	54	X-ray: 88	d)	900/Nov.1'05/OH & SIMBAD	Star	A: H <sub>α</sub> , H <sub>β</sub> , H <sub>γ</sub> , H <sub>δ</sub> , MgI, NaI	
15	05 42 32.0, +15 25 05	14.8	49	X-ray: 438	d)	900/Nov.1'05/OH & SIMBAD	Star	E: H <sub>α</sub> , H <sub>β</sub> , H <sub>γ</sub> , H <sub>δ</sub>	
16	06 33 50.4, +10 41 23	13.8	74	X-ray: 548	d)	300/Mar.17'05/OH	Cold Star (M5)	A: H <sub>α</sub> , H <sub>β</sub> , H <sub>γ</sub> , H <sub>δ</sub>	
17	07 05 11.8, +37 18 42	15.1	71	Rad.: 33+65	d)	600/Mar.17'05/OH	White dwarf	A: H <sub>α</sub> , H <sub>β</sub> , H <sub>γ</sub>	
18	08 19 28.0, +70 42 21	13.4	43	X-ray: 723	a)b) PGC 23324/113	SIMBAD-database	Star	A: H <sub>α</sub> , H <sub>β</sub> , MgI, NaI	0.507
19	08 20 08.2, +34 59 54	14.7	96	Rad.: 4	b) PGC 23341/593	600/Mar.15'05/OH & SIMBAD	HII-reg.	A: H <sub>α</sub> , H <sub>β</sub> <sup>b</sup> , H <sub>γ</sub> <sup>b</sup> , H <sub>δ</sub> <sup>b</sup>	0.718
20	08 41 03.8, +03 21 17	15.1	51	X-ray: 4345	d)	600/Mar.15'05/OH	White dwarf		
21	08 43 08.0, +10 44 19	17.8	97	Rad.: 7	a) PGC 24492/149	SIMBAD-database	QSO		
22	09 28 45.1, +38 31 13	18.0	52	X-ray: 187	a) PGC 26895/1110	SIMBAD-database	QSO		
23	11 47 13.0, +55 42 44	17.9	66	X-ray: 293	a) PGC 36774/142	SIMBAD-database	galaxy		
24	12 04 42.4, +31 10 31	17.4	83	X-ray: 92	a) PGC 38231/68	1800/May 2'06/II	HII-reg.	E: H <sub>α</sub> , H <sub>β</sub> , OI, OII, OIII, HeI, HeII	0.025
25	12 05 25.8, +51 31 41	17.6	87	X-ray: 99	a) PGC 38295/57	SIMBAD-database	QSO		0.504
26	12 07 03.4, +65 24 05	17.5	92	R: 42, X: 36	a) PGC 38482/129	SIMBAD-database	QSO		0.277
27	12 21 57.7, +26 04 57	17.8	95	X-ray: 228	a) PGC 40040/162	1800/May 2'06/II	QSO	E: H <sub>β</sub> <sup>b</sup> , H <sub>γ</sub> <sup>b</sup> , OII, OIIIa,b, NeIII	
28	13 20 14.2, +33 07 53	15.7	91	X-ray: 237	a) PGC 46515/43	1200/May 2'06/II	Star	A: H <sub>α</sub> , H <sub>β</sub> , H <sub>γ</sub> , H <sub>δ</sub>	1.225
29	13 42 10.6, +60 47 40	17.9	97	Rad.: 2	a) PGC 48534/75	SIMBAD-database	QSO		
30	14 17 58.8, +25 05 33	15.9	69	X-ray: 5645	a) PGC 51074/160	SIMBAD-database	Star		
31	14 26 18.6, +26 14 52	17.2	77	X-ray: 59	a) PGC 51549/48	1800/May 2'06/II	HII-reg.	E: H <sub>α</sub> , NIIa,b	0.030
32	14 40 06.0, +75 05 33	14.8	88	X-ray: 1655	d)	600/Mar.15'05/OH & SIMBAD	White dwarf	A: H <sub>α</sub> , H <sub>β</sub> <sup>b</sup> , H <sub>γ</sub> <sup>b</sup> , H <sub>δ</sub> <sup>b</sup>	
33	16 12 50.8, +00 02 53	15.2	73	Rad.: 39+54	b) PGC 57505/531	900/Jul.17'06/CA	Star	A: H <sub>α</sub> , H <sub>β</sub>	
34	17 37 42.6, -59 53 41	17.3	42	X-ray: 7	a) PGC 60594/170	5400/Jul.16,17'06/CA	Star	A: H <sub>β</sub>	1.96
35	18 24 36.2, +73 10 45	17.5	94	X-ray: 7	a) PGC 61833/120	1800/May 2'06/II	QSO	A: CIV <sup>b</sup> , CIII <sup>b</sup>	0.998
36	20 09 38.2, -49 17 45	17.0	86	X-ray: 47	a) PGC 64185/126	2000/Oct.8'05/CA	QSO	E: MgII <sup>b</sup> , CIII <sup>b</sup>	
37	20 12 42.6, -54 00 29	14.4	64	X-ray: 156	b) PGC 64288/332	1800/Jul.16'06/CA	Star	A: H <sub>α</sub> , H <sub>β</sub>	
38	20 43 46.6, -26 35 03	17.8	74	Rad.: 20+15	a) PGC 65268/121	3000/Oct.8'05/CA	Star	A: H <sub>α</sub> , MgI	
39	22 37 49.3, +23 45 41	17.7	46	X-ray: 10	a) PGC 69364/99	2000/Sep.25'06/OH	QSO	E: MgII <sup>b</sup> , CIII <sup>b</sup>	1.24
40	22 57 52.3, +26 06 38	17.9	67	Rad.: 19	a) PGC 70116/100	4000/Sep.25,26'06/OH	Star	A: MgI, NaI	
41	23 38 41.6, +26 48 04	16.9	76	X-ray: 35	a) PGC 71995/124	SIMBAD-database	Star		



could in principle present some excesses of QSOs, we think that there should be in principle no reason to expect statistical anomalies in the FH04 catalogue, which is anyway a useful database for looking for QSOs in regions not covered by other surveys, such as SDSS or 2dF, or for deeper magnitudes. Nevertheless, there are still anomalies in the QSO distributions presented with some other catalogues (e.g. Arp 1998; Burbidge 2001) that require further attention. Further rigorous statistical analysis like those presented here and in López-Corredoira & Gutiérrez (2006a,b) are necessary.

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