The Large Quasar Astrometric Catalogue (LQAC) : construction & statistics

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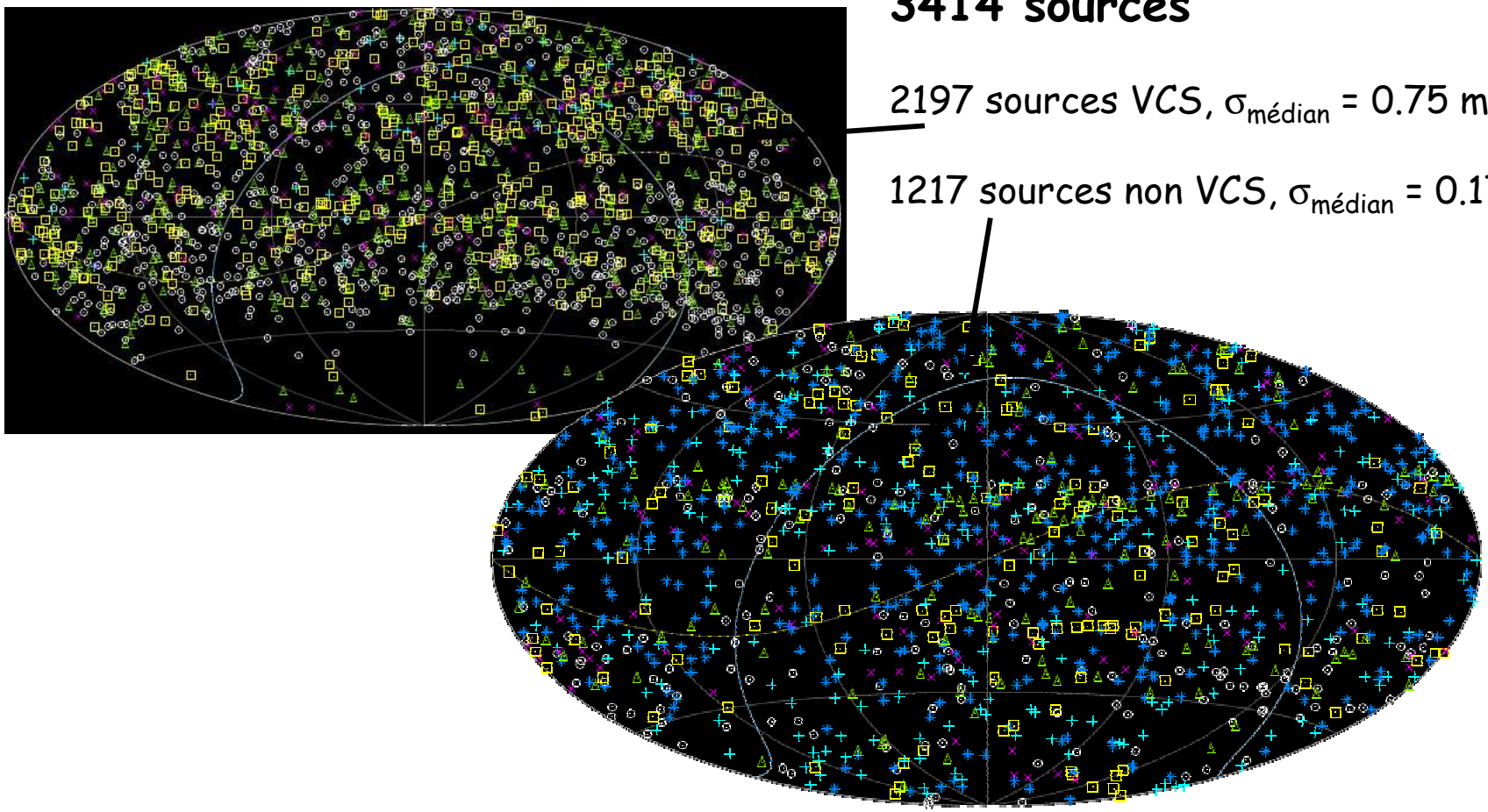
A.H.Andrei, C.Gattano,
S.Bouquillon,
C.Barache, F.Taris,
S.Lambert, D. Suchet,
R. Peralta



EGSG / Nice, September 10-11, 2012

IAU Resolution B3, 13 août 2009, Rio

The ICRF2 is the fundamental celestial reference frame 1er January 2010



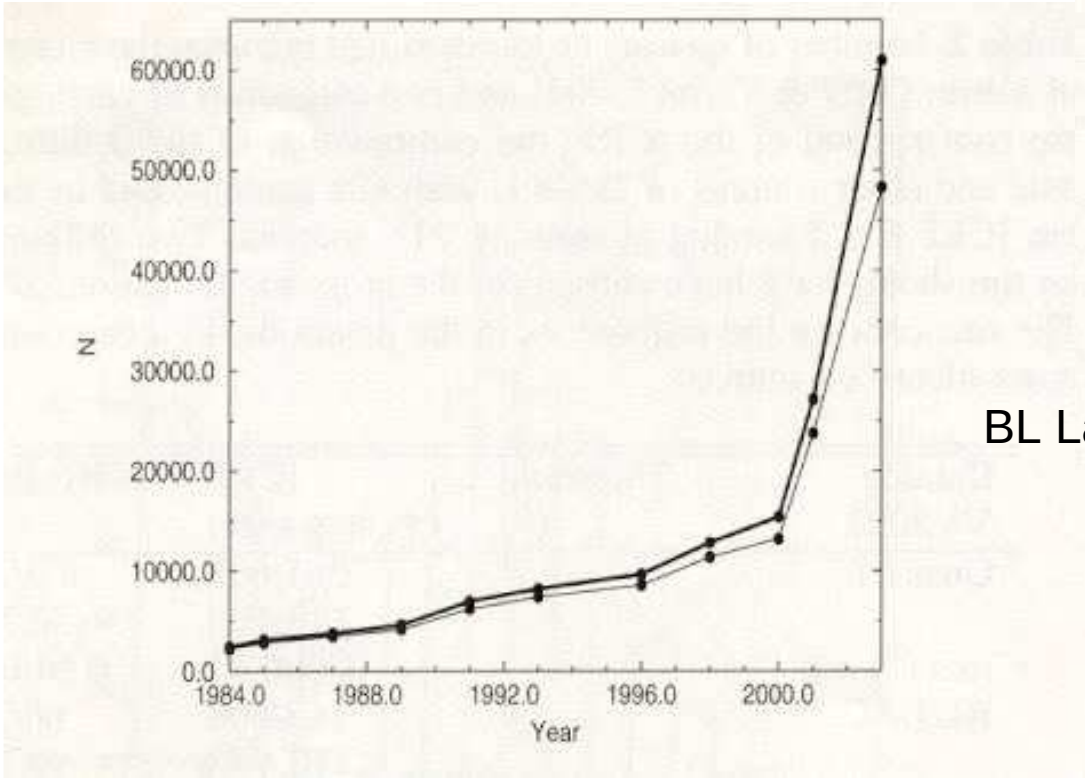
3414 sources

2197 sources VCS, $\sigma_{médian}$ = 0.75 mas

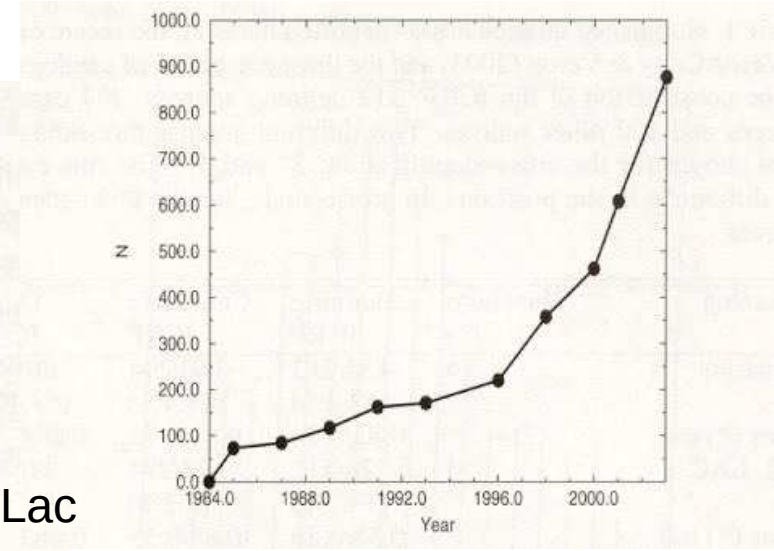
1217 sources non VCS, $\sigma_{médian}$ = 0.17 mas

IERS TN 35/Jacobs 2009/Ma et al. 2009

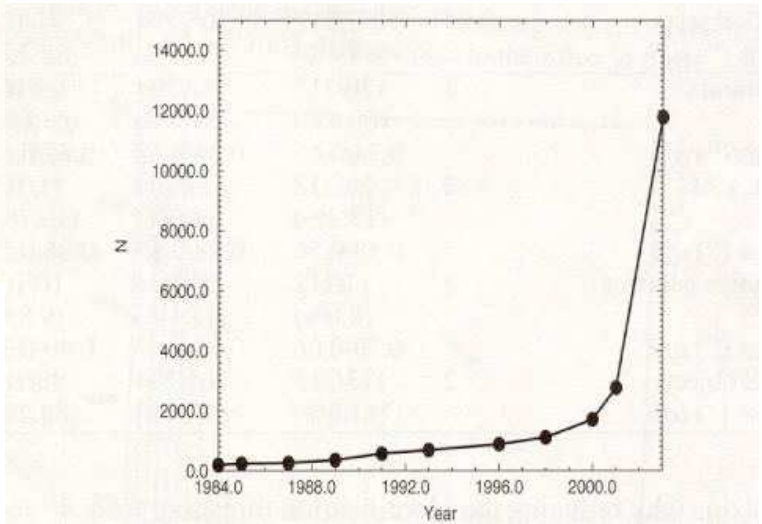
A drastic increase of recorded quasars



QSO's



BL Lac



AGN

Véron-Cetty & Véron (2003)

Construction of the **LQAC**

(Large Quasars Astrometric Catalogue)

Objectives

- Compilation of all the recorded quasars
- Strategy insisting on astrometric quality
- Catalogue flag for cross-identifications
- Complete photometry & redshift
- Absolute magnitudes
- Basis for regular up-dates (=> GAIA)
- Final ASCII file with V.O. tools in parallel
- Comparisons / coherence

Qualitative and quantitative additions of the LQAC-2 (Souchay et al., A&A, 2012) with respect to the LQAC (2009)

- **More quasars** : 187 504 vs. 113 666 (+65%)
- **New cross-identifications**
- **A LQAC name for each object**
- **Morphological characterization of the sources**
- **Recomputation of coordinates** (LQRF, Andrei et al.,2009)

The LQAC-2 : compilation of large catalogues

Catalog Name	Flag	Nature	Nbs of quasars (LQAC2)	Nbs. of quasars (LQAC)
ICRF2	A	radio	3 414	717
VLBA	B	radio	5 198	3 357
VLA	C	radio	1 858	1 857
JVAS	D	radio	2 118	2 118
SDSS	E	optical	126 577	74 868
2QZ	F	optical	23 660	22 971
2df-SDSS LRG	G	optical	9 058	0
FIRST	H	radio	969	969
HB	I	opt. & radio	6 721	7 245
2MASS	J	infrared	25 252	-
GSC2.3	K	optical	154 900	-
B1.0	L	optical	148 894	-
V&V (-SDSS)	M	optic. & radio	80 667	85 189

The LQAC-2 : cross-identifications of large catalogues

Common object : $\rho < 2''$

Table 2. Number of cross-identified objects between the catalogues belonging to the LQAC

Catalog Name	A	B	C	D	E	F	G	H	I	J	K	L	M
A (ICRF2)	**3414**	3414	1595	1569	423	35	0	70	619	1193	2553	2398	1827
B (VLBA)	-	**5198**	1674	1752	528	39	2	96	678	1598	3362	3144	2163
C (VLA)	-	-	**1858**	1271	301	10	0	54	467	752	1385	1326	1182
D (JVAS)	-	-	-	**2118**	384	6	1	53	317	681	1558	1496	1067
E(SDSS)	-	-	-	-	**126577**	2140	736	773	1877	13442	102866	101322	23494
F (2QZ)	-	-	-	-	-	**23660**	765	0	501	722	22283	21255	22883
G(FIRST)	-	-	-	-	-	-	**9058**	3	58	37	7152	4892	8550
H(2dF-SDSS LRG)	-	-	-	-	-	-	-	**969**	134	628	941	944	958
I(HB)	-	-	-	-	-	-	-	-	**6721**	2411	6654	6480	6299
J(2MASS)	-	-	-	-	-	-	-	-	-	**25252**	24731	24571	14226
K(GSC23)	-	-	-	-	-	-	-	-	-	-	**154900**	145755	54278
L(B1.0)	-	-	-	-	-	-	-	-	-	-	-	**148894**	50633
M(VV2009)	-	-	-	-	-	-	-	-	-	-	-	-	**80667**

Morphological Characterization of the LQAC-2 sources

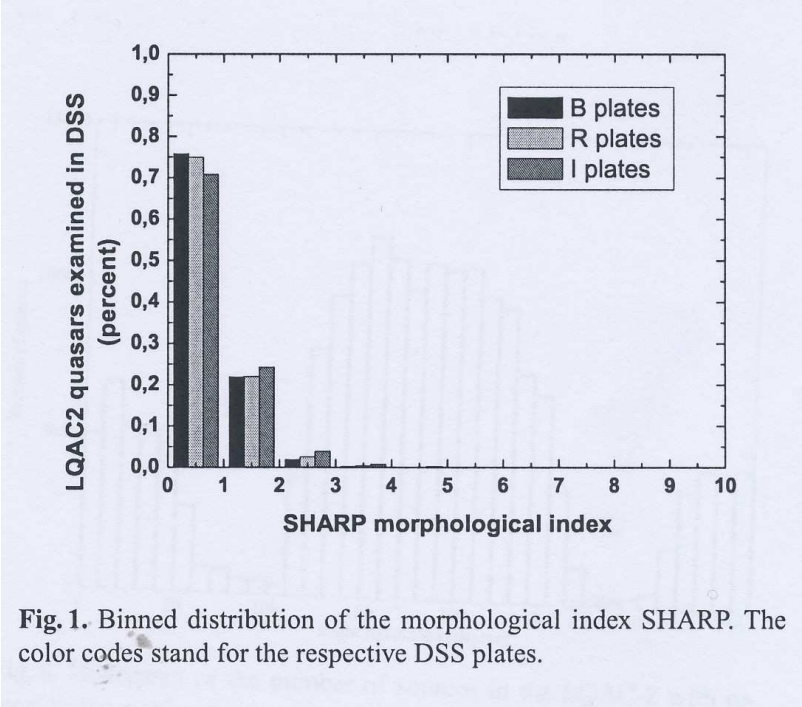


Fig. 1. Binned distribution of the morphological index SHARP. The color codes stand for the respective DSS plates.

Probing skewness

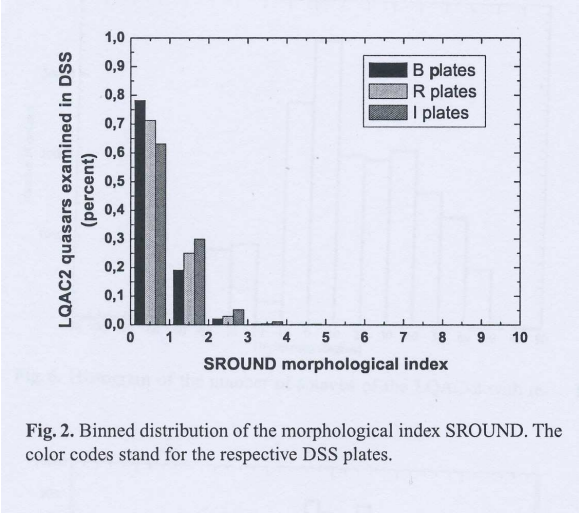


Fig. 2. Binned distribution of the morphological index SROUND. The color codes stand for the respective DSS plates.

Probing roundness

Probing normalness

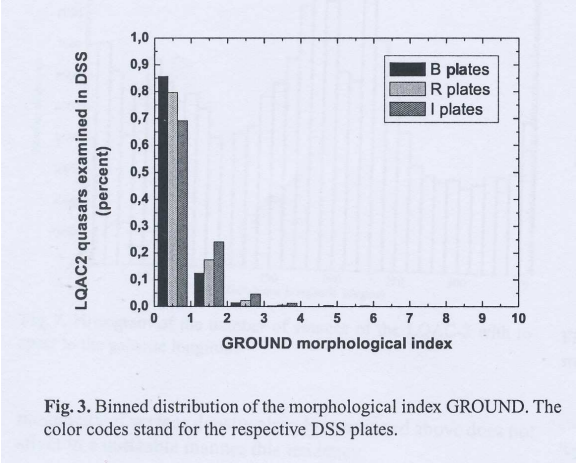


Fig. 3. Binned distribution of the morphological index GROUND. The color codes stand for the respective DSS plates.

PRESENTATION OF THE **LQAC-2** CATALOGUE

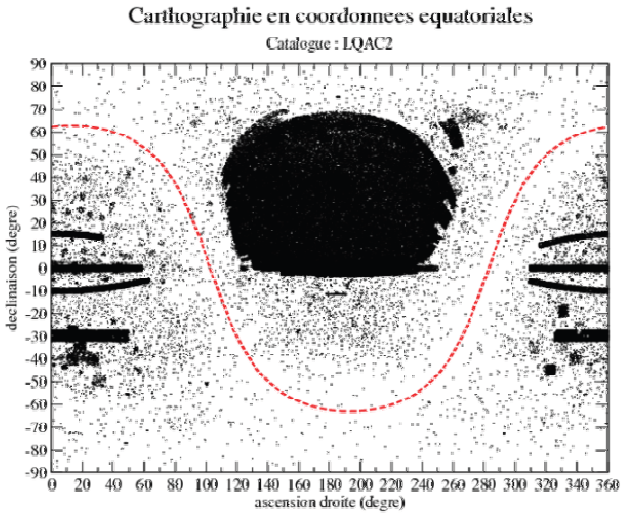
=> 187 504 objects (vs. 113 666 objects in LQAC

LQAC Name	α	δ	α (LQRF)	δ (LQRF)	catalogue			magnitudes								
LQAC_000-000_001	0.000000000	-0.032800000	359.9998660	-0.0328680	----------M	-	0	0.00	19.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
LQAC_000-000_002	0.001996551	-0.451102400	0.0020170	-0.4510710	----E-----KLM	-	0	21.69	21.08	20.09	21.19	20.50	20.14	19.85	0.00	0.00	0.0
LQAC_000-002_001	0.005187500	-2.033383330	0.0053030	-2.0332680	-------H--KLM	-	0	0.00	19.64	0.00	0.00	18.31	18.59	0.00	0.00	0.00	0.0
LQAC_000-030_001	0.005750000	-30.607472222	0.0056940	-30.6074290	-----F----KLM	-	0	19.30	20.10	0.00	0.00	19.50	0.00	0.00	0.00	0.00	0.0
LQAC_000-031_001	0.007333333	-31.373833333	0.0072330	-31.3736930	-----F----K-M	-	0	19.70	20.69	0.00	0.00	19.86	0.00	0.00	0.00	0.00	0.0
LQAC_000+014_001	0.007748564	14.024511000			----E-----KL-	-	0	24.71	21.64	0.00	22.47	20.99	20.23	19.52	0.00	0.00	0.0
LQAC_000-025_001	0.011200000	-25.193600000	0.0111330	-25.1935080	----------M	-	0	0.00	0.00	0.00	0.00	21.00	0.00	0.00	0.00	0.00	0.0
LQAC_000-035_001	0.011700000	-35.059200000			----------M	-	0	0.00	16.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
LQAC_000-027_001	0.022875000	-27.419555555	0.0227550	-27.4195250	-----F----KLM	-	0	18.35	19.43	0.00	0.00	19.14	18.69	0.00	0.00	0.00	0.0
LQAC_000+000_001	0.027230760	0.515331640	0.0272260	0.5153110	----E-----KL-	-	0	20.58	20.42	0.00	20.59	20.49	20.17	20.19	0.00	0.00	0.0
LQAC_000-063_001	0.033300000	-63.593300000			----------M	-	0	0.00	17.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
LQAC_000+000_002	0.033946060	0.276291600	0.0339460	0.2762820	----E-----KL-	-	0	20.30	20.41	0.00	20.36	20.02	19.53	19.31	0.00	0.00	0.0
LQAC_000+015_001	0.038609500	15.298489000	0.0386040	15.2984570	----E-----KL-	-	0	19.90	19.87	0.00	19.77	19.38	19.15	19.31	0.00	0.00	0.0
LQAC_000+013_001	0.039099260	13.938458000	0.0390840	13.9384300	----E-----KL-	-	0	19.25	18.74	18.49	18.89	18.43	18.30	18.08	0.00	0.00	0.0
LQAC_000+023_001	0.039200000	23.954400000			----------M	-	0	0.00	0.00	0.00	0.00	18.93	0.00	0.00	0.00	0.00	0.0
LQAC_000-010_001	0.039264450	-10.464410000	0.0392580	-10.4643970	----E-----KL-	-	0	19.21	19.67	0.00	19.00	18.97	18.78	18.70	0.00	0.00	0.0
LQAC_000-031_002	0.040375000	-31.279972222	0.0403780	-31.2799450	-----F----KLM	-	0	18.40	19.05	0.00	0.00	18.65	18.10	0.00	0.00	0.00	0.0
LQAC_000-030_002	0.041250000	-30.924944444	0.0412790	-30.9248570	-----F----KLM	-	0	17.93	19.12	0.00	0.00	18.37	18.30	0.00	0.00	0.00	0.0
LQAC_000+030_001	0.042100000	30.933300000	0.0420760	30.9331550	----------M	-	0	0.00	0.00	0.00	0.00	0.00	19.30	0.00	0.00	0.00	0.0
LQAC_000-031_003	0.042375000	-31.997222222	0.0423410	-31.9971400	-----F----KLM	-	0	20.28	20.44	0.00	0.00	20.78	0.00	0.00	0.00	0.00	0.0
LQAC_000+014_002	0.047551210	14.929367000	0.0475600	14.9293430	----E-----KLM	-	0	19.64	19.80	19.03	19.47	19.36	19.18	19.02	0.00	0.00	0.0
LQAC_000-008_001	0.048196750	-8.835659400			----E-----KL-	-	0	19.46	19.17	0.00	19.12	19.06	19.13	19.32	0.00	0.00	0.0
LQAC_000+001_001	0.048300000	1.030600000	0.0483680	1.0307250	----------M	-	0	20.43	0.00	19.37	0.00	0.00	0.00	0.00	0.00	0.00	0.0
LQAC_000-031_004	0.048583333	-31.644416666	0.0485590	-31.6443790	-----F----KLM	-	0	19.66	20.27	0.00	0.00	19.38	0.00	0.00	0.00	0.00	0.0
LQAC_000+005_001	0.048700000	5.388100000	0.0488640	5.3881690	----------M	-	0	0.00	16.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
LQAC_000+000_003	0.049839430	0.040358720	0.0498430	0.0403840	----E---IJKLM	-	0	17.99	17.60	17.80	17.78	17.85	17.79	17.71	16.65	14.82	0.0
LQAC_000-000_003	0.051083480	-0.539051090	0.0510860	-0.5390290	----E-----K--	-	0	20.69	20.99	0.00	20.61	20.33	20.19	20.26	0.00	0.00	0.0
LQAC_000+014_003	0.054787210	14.176304000	0.0547890	14.1763000	----E-----KL-	-	0	19.53	18.94	18.86	19.30	19.12	19.15	19.08	0.00	0.00	0.0
LQAC_000-002_002	0.056700000	-2.172200000	0.0568390	-2.1720740	----------M	-	0	0.00	19.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
LQAC_000-000_004	0.057513340	-0.913001400	0.0575340	-0.9129930	----E-----KL-	-	0	20.50	20.13	0.00	20.22	20.06	19.59	19.45	0.00	0.00	0.0
LQAC_000-001_001	0.061780730	-1.175212200	0.0617870	-1.1752070	----E-----KL-	-	0	19.48	19.49	0.00	19.42	19.42	19.21	19.13	0.00	0.00	0.0
LQAC_000+000_004	0.064516770	0.879696740	0.0645210	0.8796560	----E-----KL-	-	0	19.60	20.30	0.00	19.41	19.33	19.03	19.14	0.00	0.00	0.0
LQAC_000-027_002	0.066375000	-27.649083333	0.0663900	-27.6490020	-----F----KLM	-	0	17.92	18.38	0.00	0.00	17.69	17.21	0.00	0.00	0.00	0.0
LQAC_000-031_005	0.068041667	-31.743861111	0.0680360	-31.7438690	-----F----KLM	-	0	17.99	19.08	0.00	0.00	18.16	17.79	0.00	0.00	0.00	0.0
LQAC_000-000_005	0.068473000	-0.309276000	0.0684900	-0.3092950	----E----JKL-	-	0	18.70	18.63	0.00	18.12	17.89	17.76	17.68	16.55	15.09	0.0
LQAC_000-008_002	0.072430900	-8.856605600	0.0724170	-8.8566180	----E--H--KLM	-	0	19.21	18.93	18.63	18.75	18.27	18.27	18.26	0.00	0.00	0.0
LQAC_000+000_005	0.074540060	0.436830590	0.0745500	0.4368380	----E-----KLM	-	0	20.28	20.47	19.85	20.08	19.98	19.74	19.56	0.00	0.00	0.0
LQAC_000-032_001	0.084999781	-32.350342643	0.0850110	-32.3503360	AB------I-KLM	*	0	0.00	18.57	17.00	0.00	17.99	17.86	0.00	0.00	0.00	0.5
LQAC_000-025_002	0.088300000	-25.136700000	0.0881390	-25.1368820	----------M	-	0	0.00	0.00	0.00	0.00	20.90	0.00	0.00	0.00	0.00	0.0
LQAC_000-002_003	0.095400000	-2.454200000			----------M	-	0	0.00	18.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
LQAC_000-025_003	0.095400000	-25.206100000			----------M	-	0	0.00	0.00	0.00	0.00	19.70	0.00	0.00	0.00	0.00	0.0
LQAC_000+002_001	0.098700000	2.211400000			----------M	-	0	0.00	17.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
LQAC_000+015_002	0.100117290	15.334846000	0.1001140	15.3348460	----E-----KLM	-	0	19.38	19.91	19.15	19.21	18.97	19.05	19.13	0.00	0.00	0.0

Distribution & Statistics * from the LQAC-2

* Mignard, Gaia DPAC TN,2008

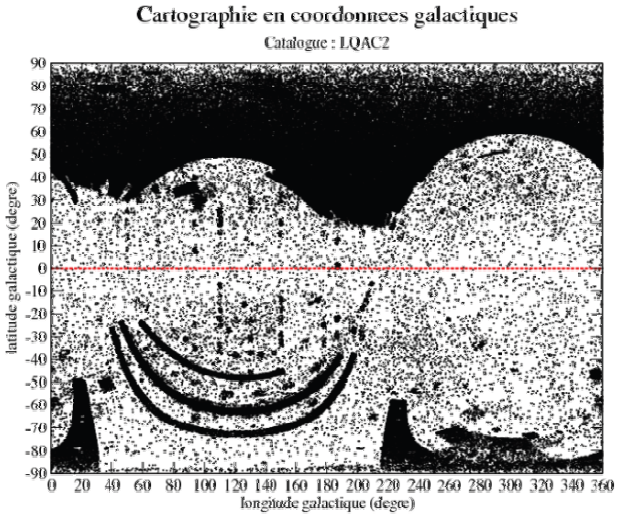
The distribution of recorded quasars



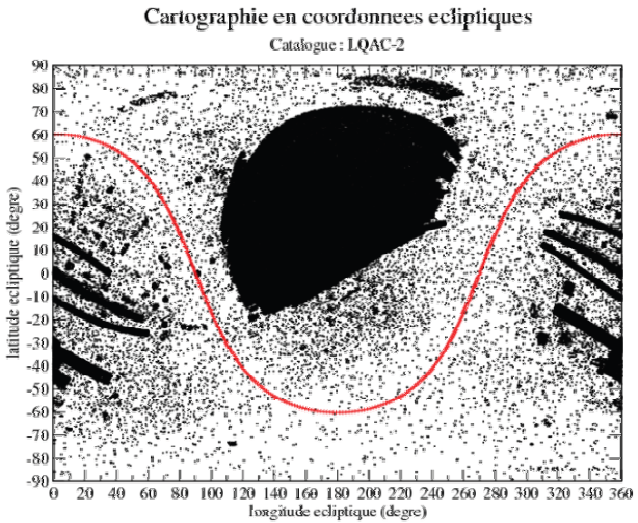
↑ Equatorial Coordinates

← Galactic plane →

↙



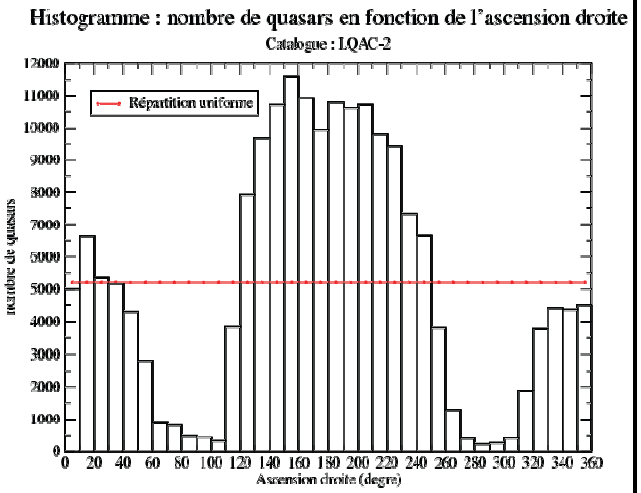
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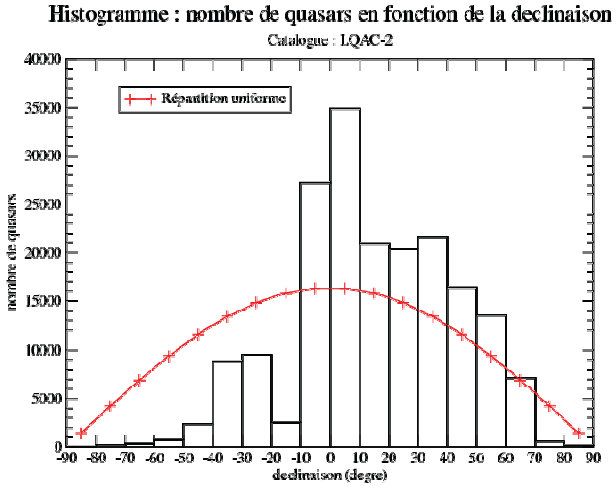


↑ Ecliptic coordinates

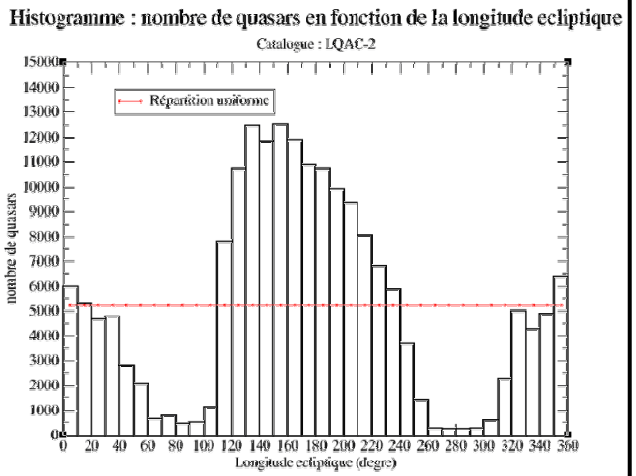
The distribution of recorded quasars

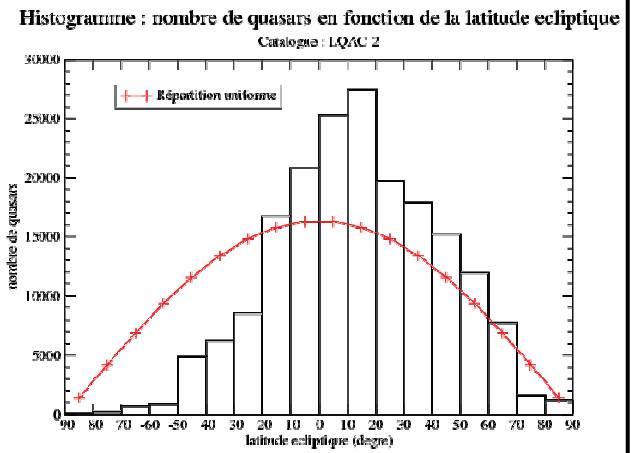
Equatorial coordinates



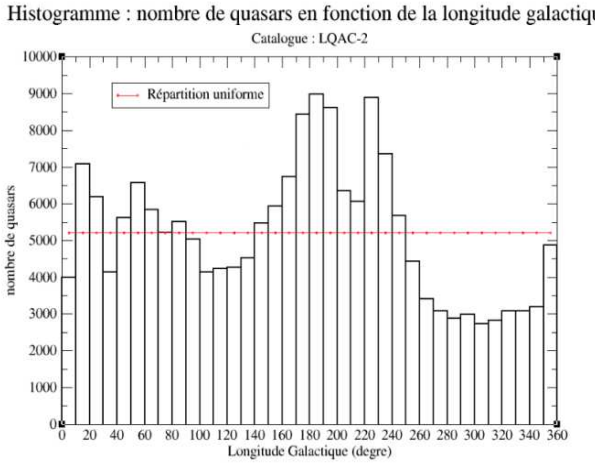


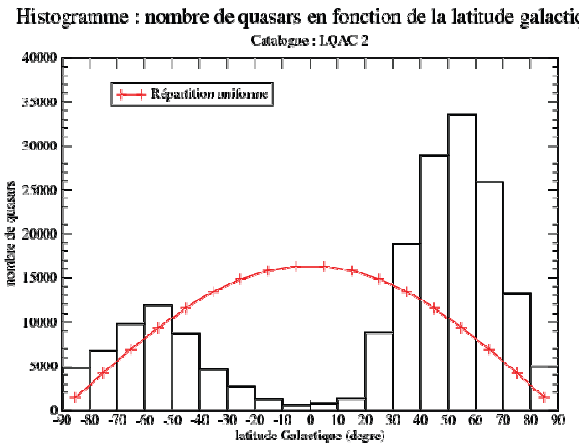
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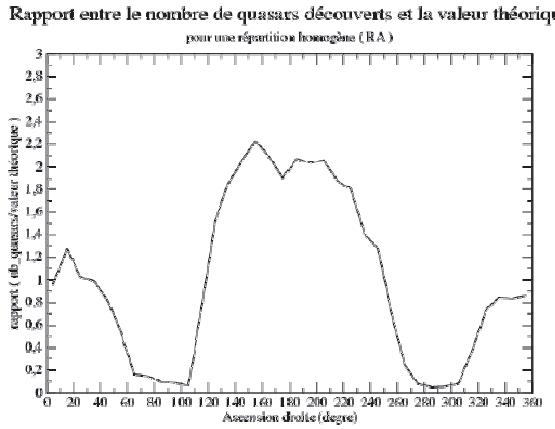
Galactic coordinates

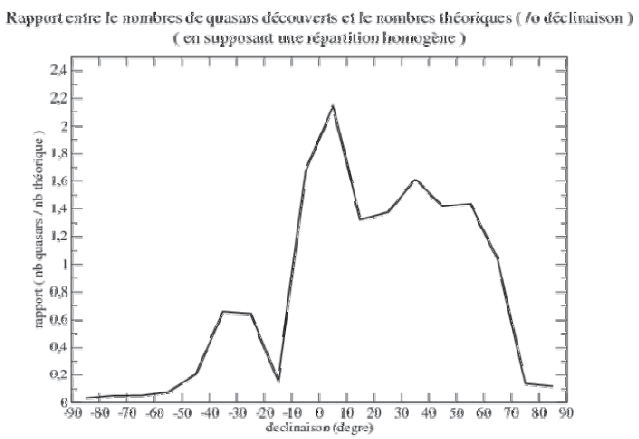




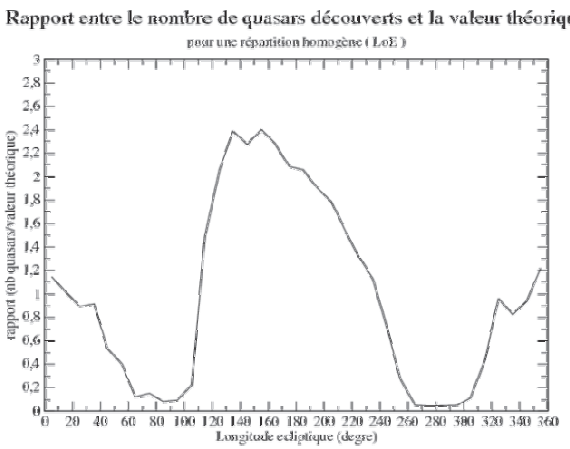
The distribution of recorded quasars

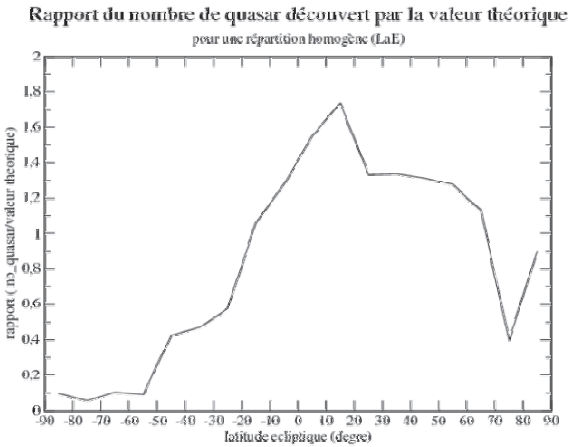
Equatorial coordinates



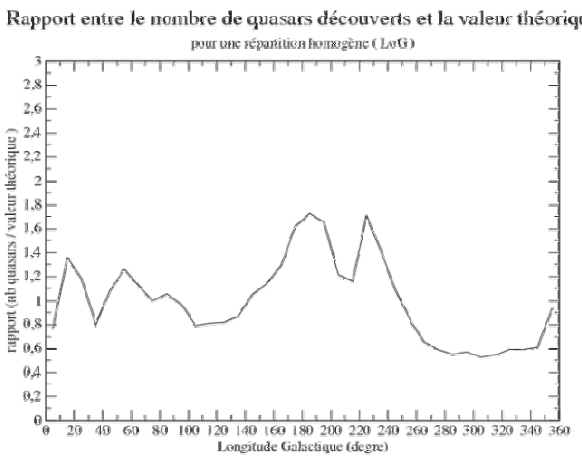


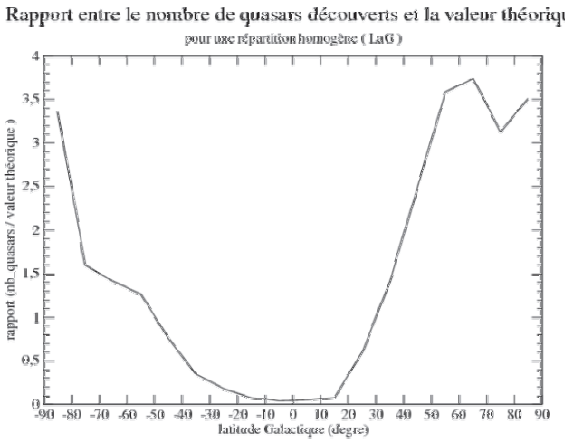
Ecliptic coordinates



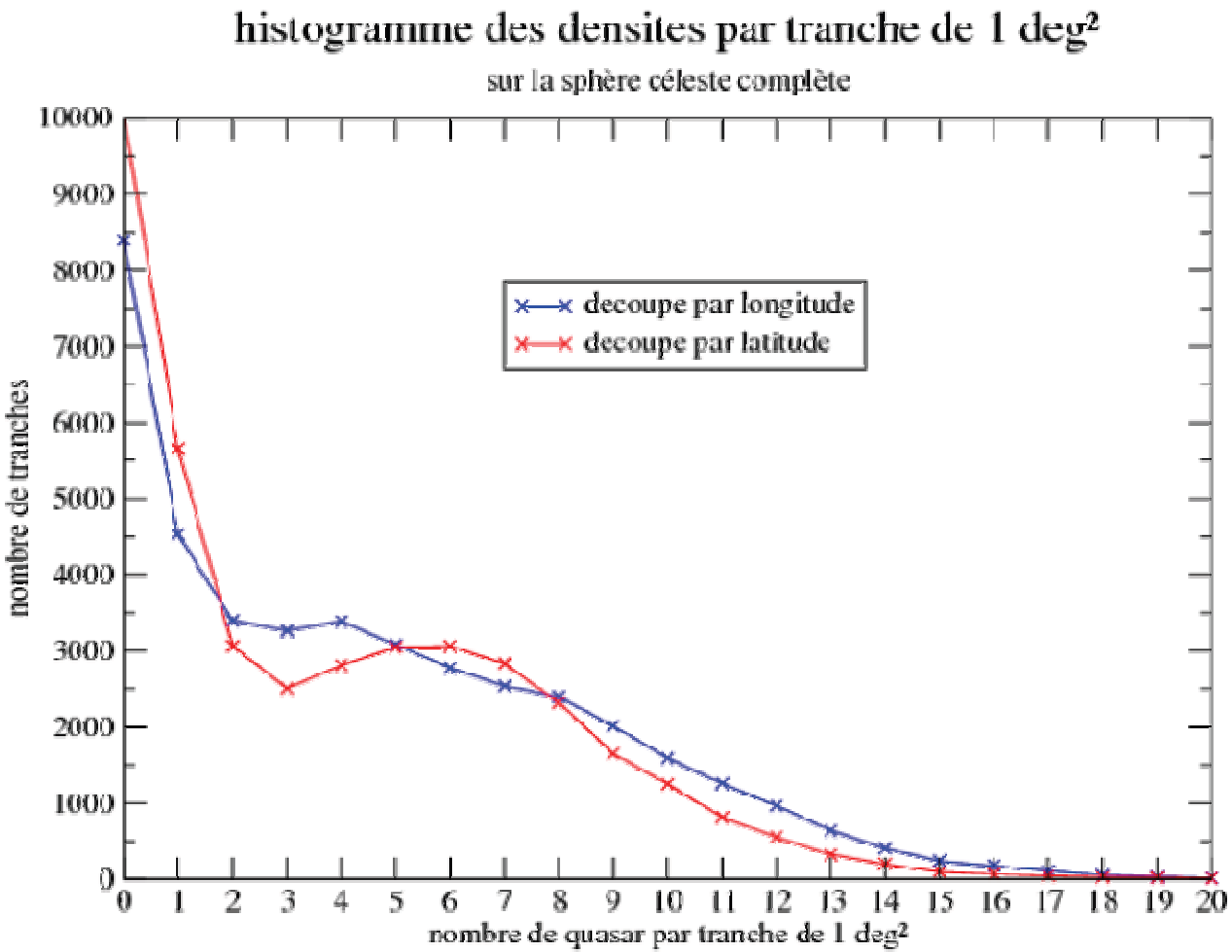


Galactic coordinates





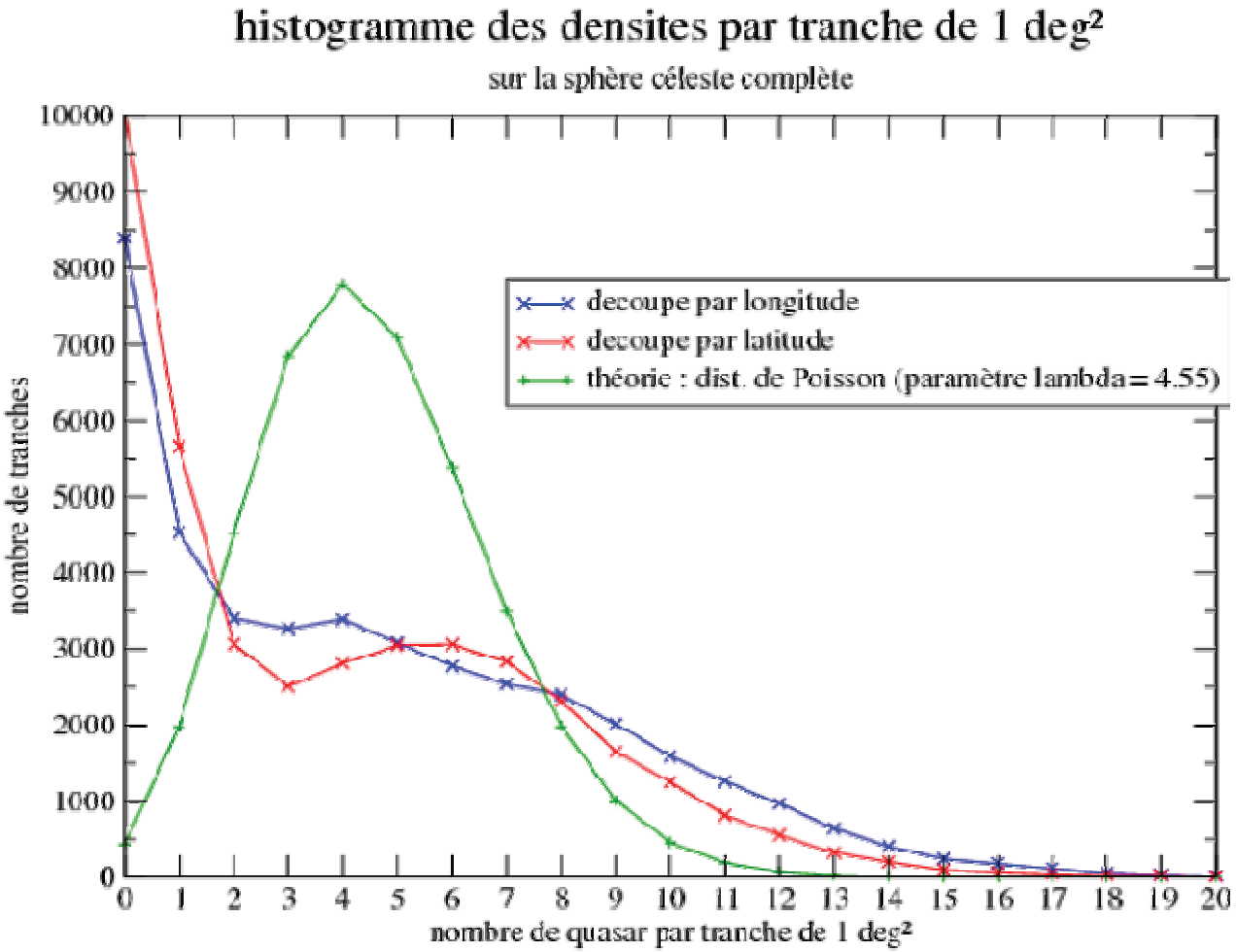
Surface density in the LQAC-2



Division of the celestial sphere in **41 253 zones** with surface equal to 1 square degree.

- division per latitude zones --------
- division per longitude zones --------

Surface density in the LQAC-2



In the homogeneous case :

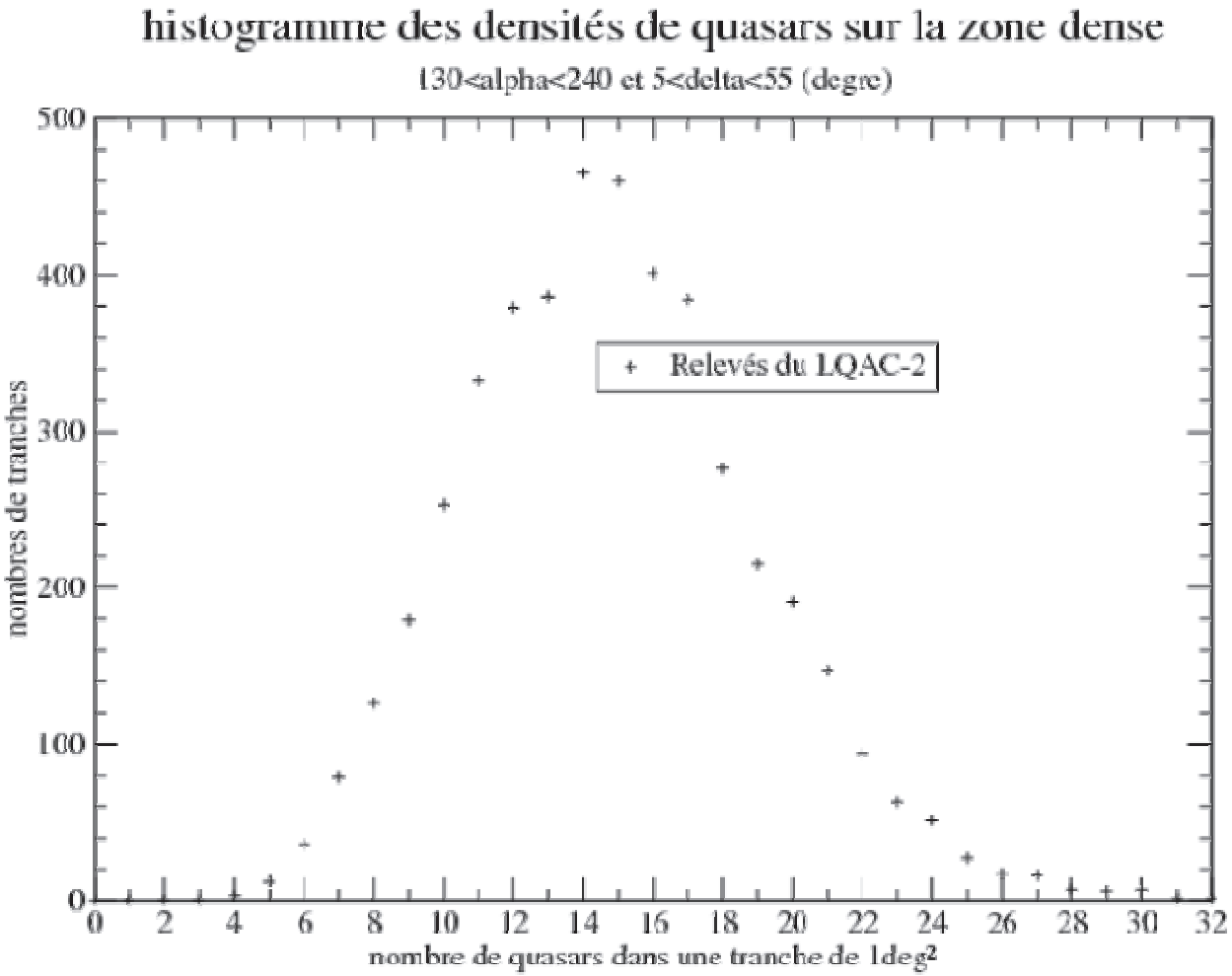
$$P(k) = \frac{4.5^k}{k!} e^{-4.5}$$

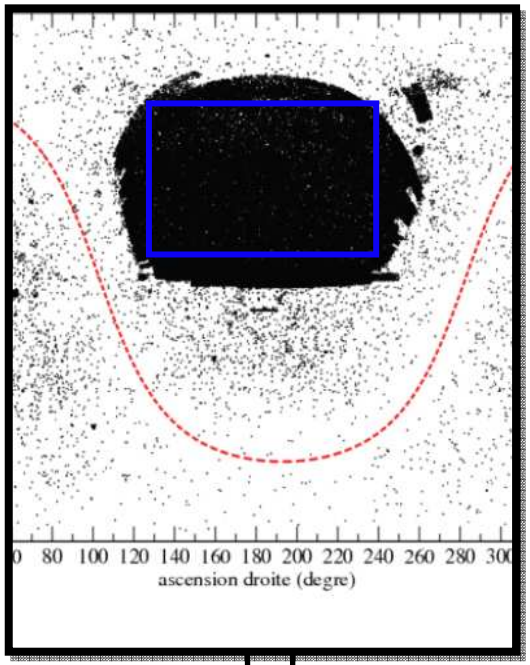
CONCLUSION
Inhomogeneity

⇓

Bias with theoretical curve

Surface density in homogeneous zone

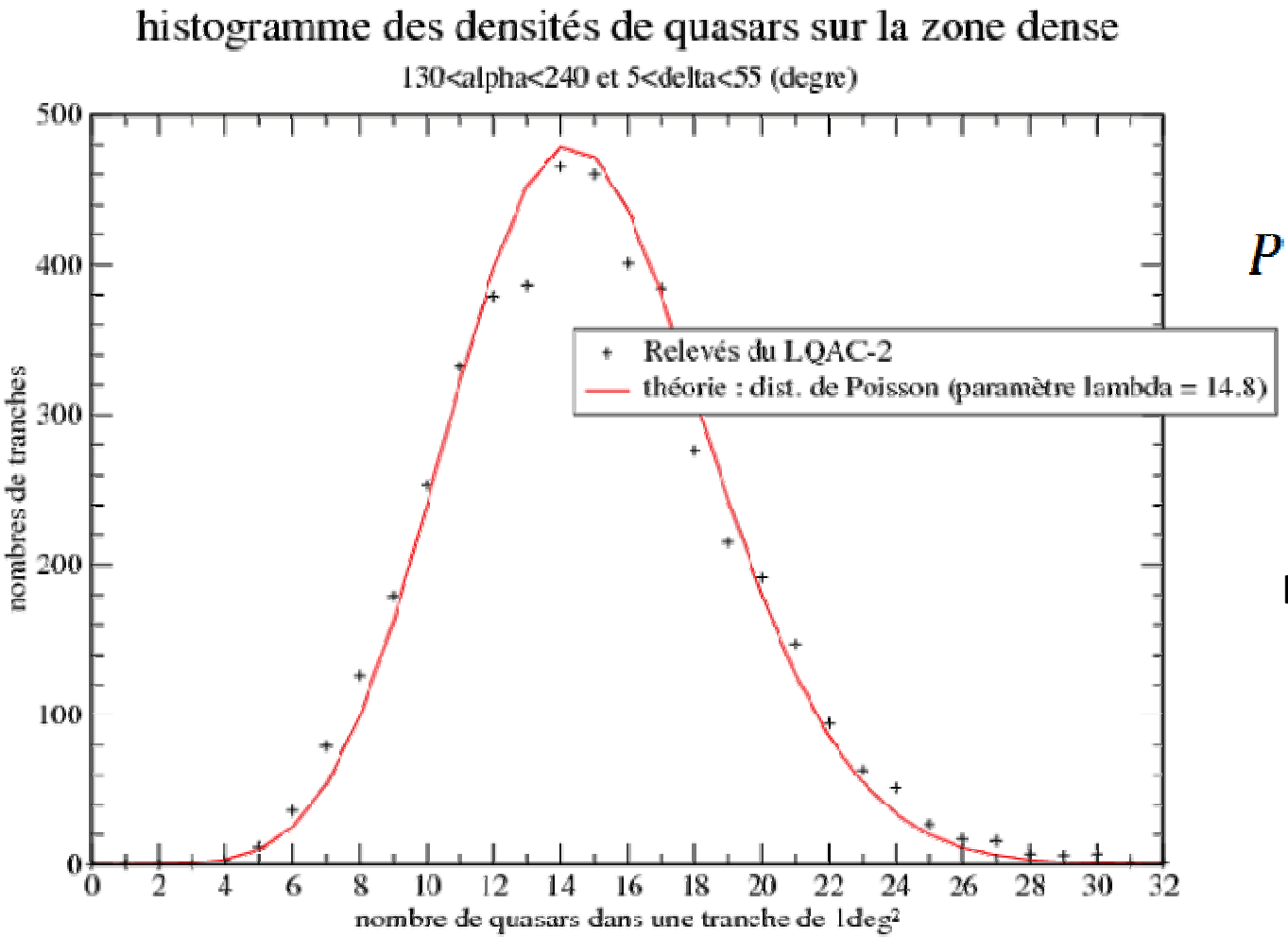




Densiest and most observed zone

Most homogeneous zone

Surface density in homogeneous zone

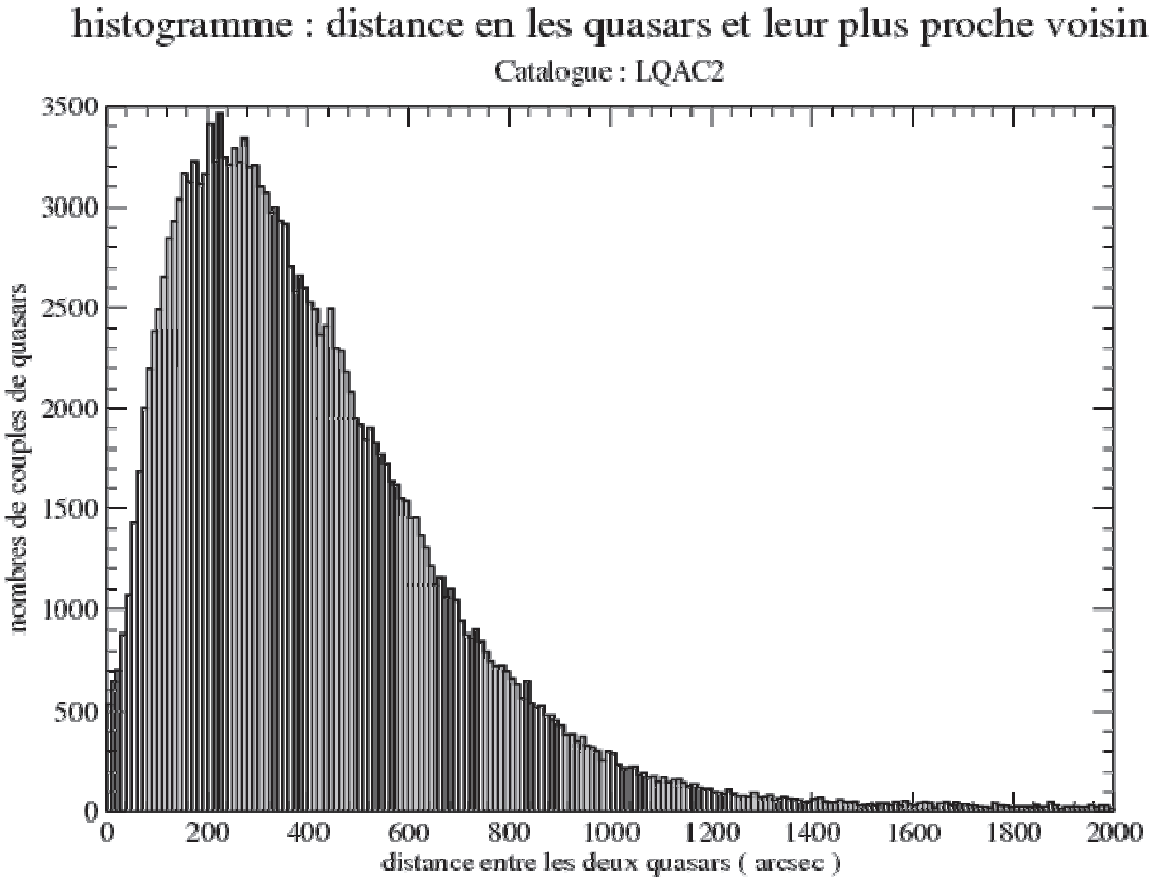


$$P(k) = \frac{14.8^k}{k!} e^{-14.8}$$

CONCLUSION
Homogeneous zone

O-C agreement

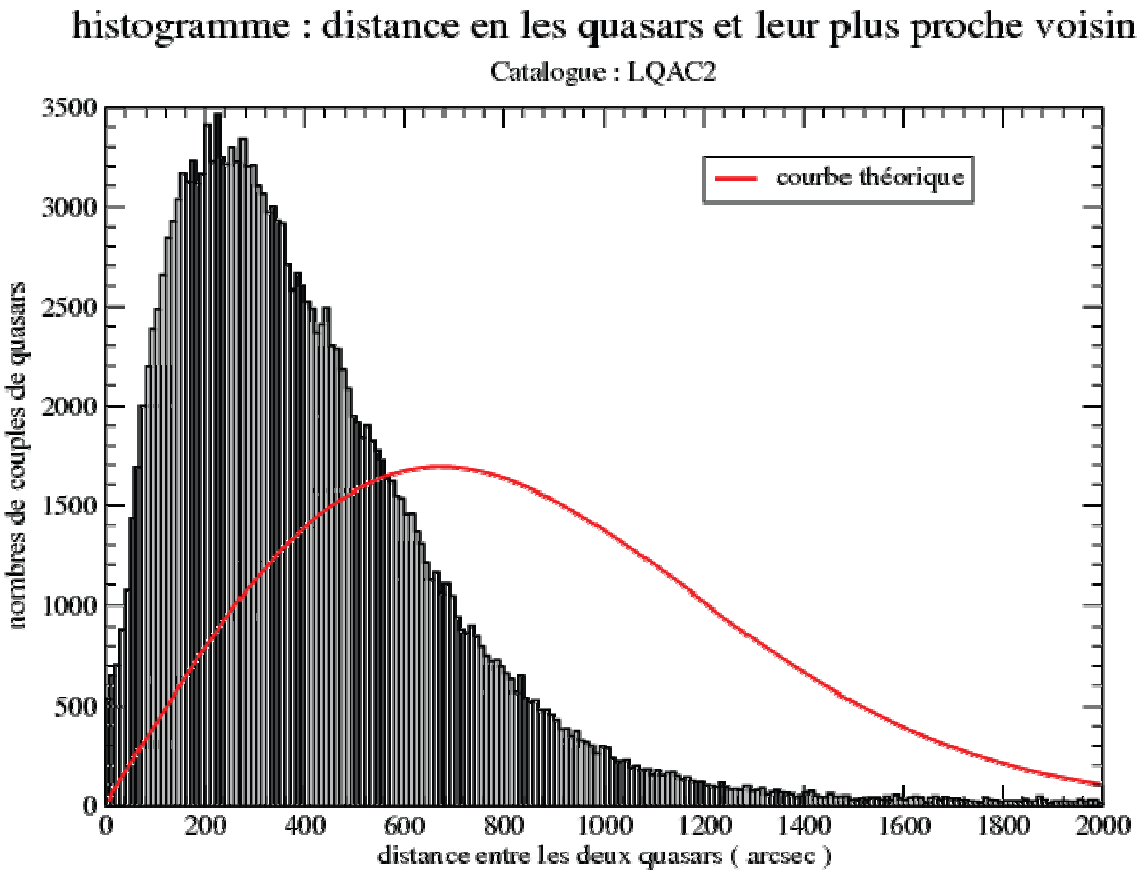
STUDY OF THE CLOSESTS NEIGHBOUR



Comparison with the theory

$$P(r_1 < D < r_2) = \left(e^{-\pi.4{,}5\,.r_1^2} - e^{-\pi.4{,}5.r_2^2}\right) * 187\,504$$

STUDY OF THE CLOSESTS NEIGHBOUR



Comparison with the theory

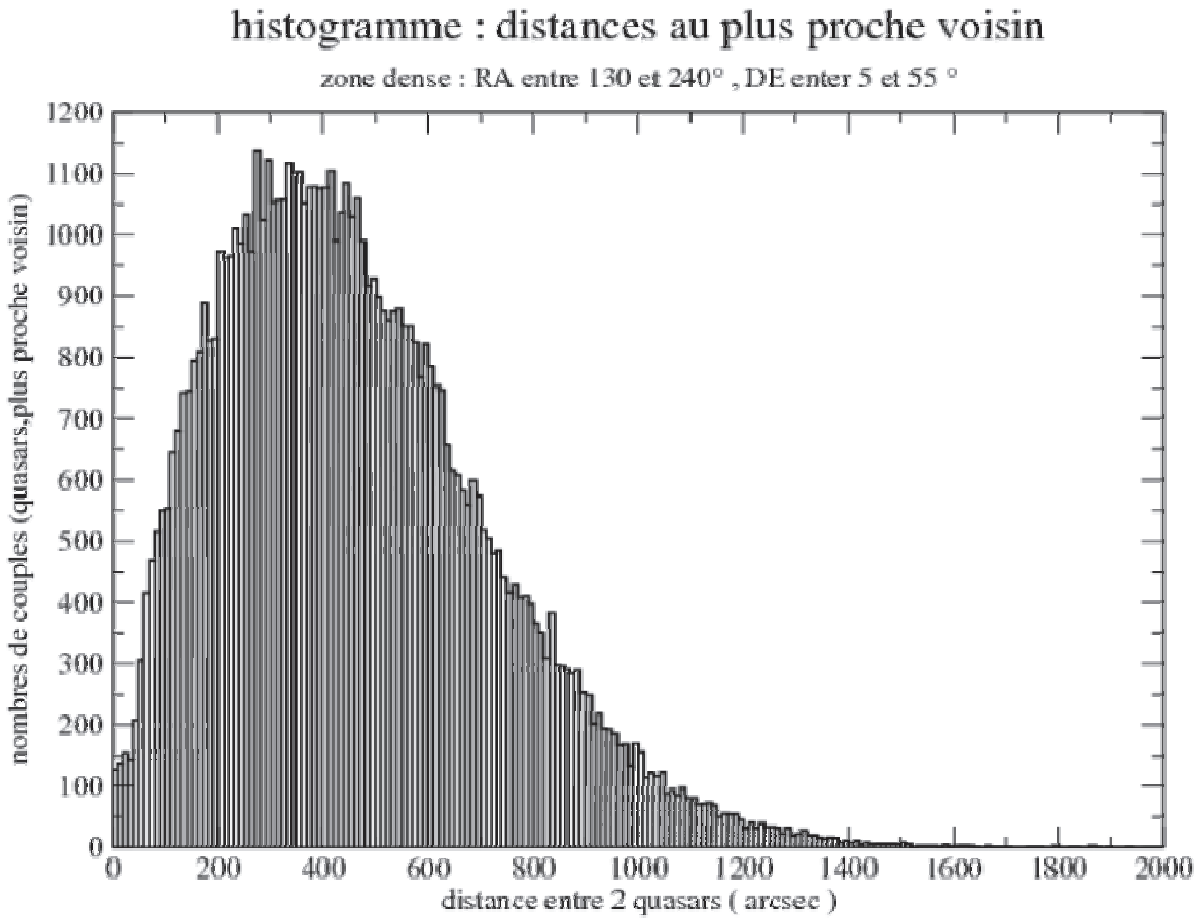
$$P(r_1 < D < r_2) = \left(e^{-\pi.4{,}5\,.r_1^2} - e^{-\pi.4{,}5.r_2^2}\right) * 187\,504$$

CONCLUSION :
Inhomogeneity

?

Bias with theory

STUDY OF THE CLOSESTS NEIGHBOUR : SELECTED ZONE

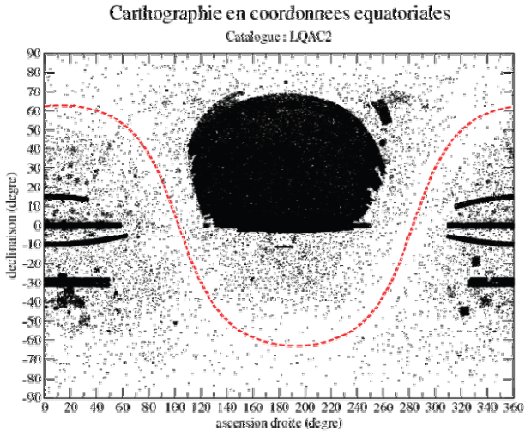


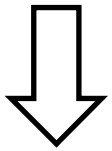
Selection of an homogeneous zone :

α : 130° → 240°

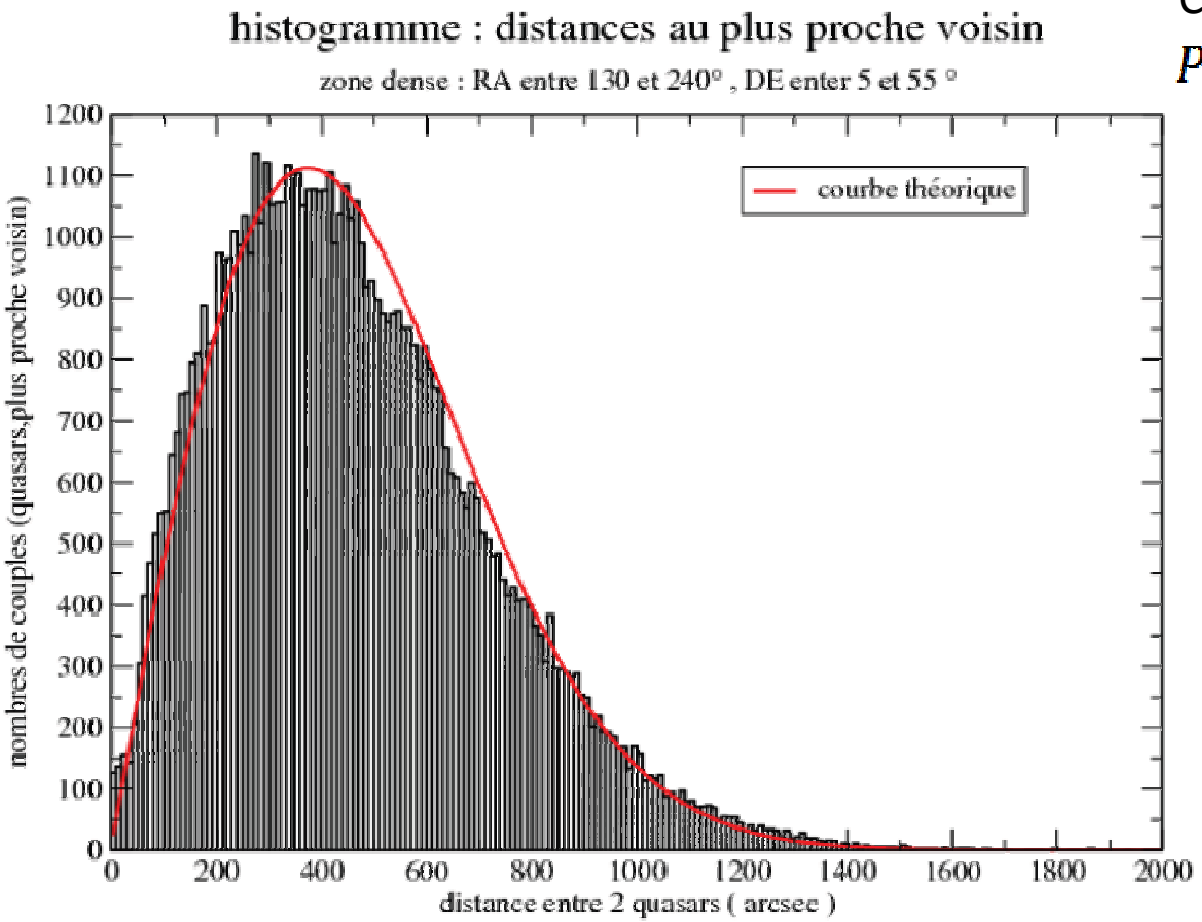
δ : 5° → 55°

Densiest and most homogeneous zone





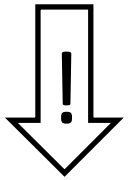
STUDY OF THE CLOSESTS NEIGHBOUR : SELECTED ZONE



Comparison with the theory :

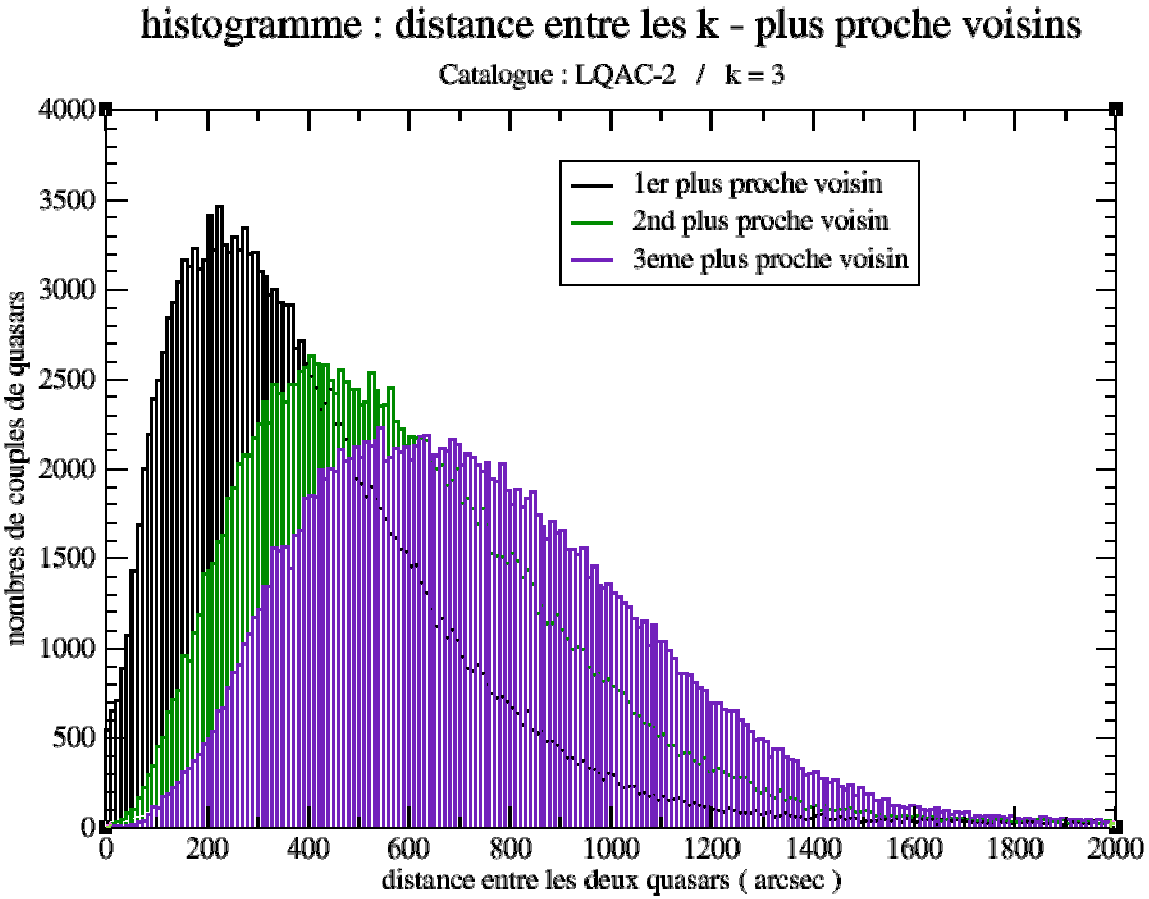
$$P(r_1 < D < r_2) = \left(e^{-\pi.14,8.r_1^2} - e^{-\pi.14,8.r_2^2}\right) * 68\,455$$

CONCLUSION



Good agreement when homogeneous distribution

k th. closest neighbour : theoretical formula

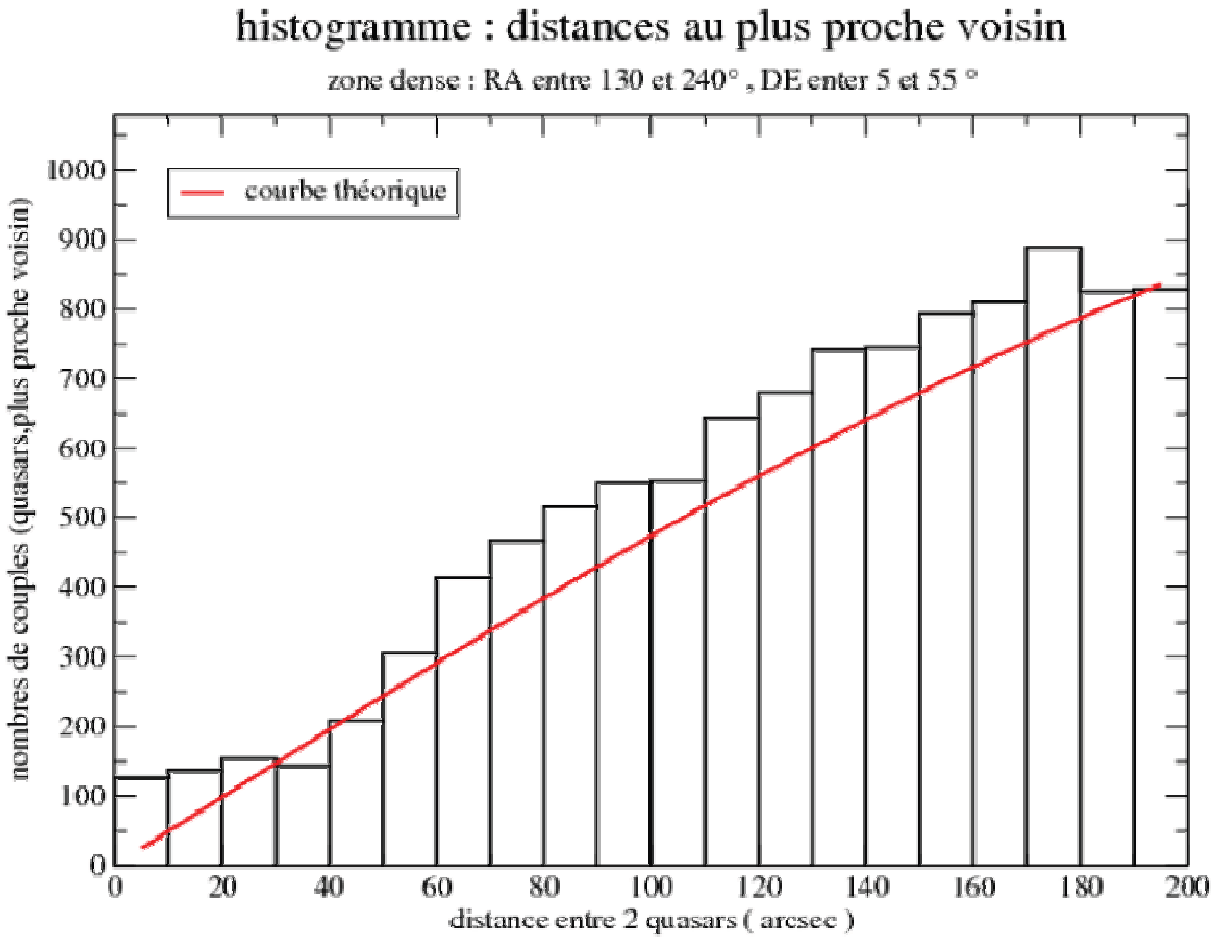


Results on the k th. Closest neighbour (k=1,2,3 , …)

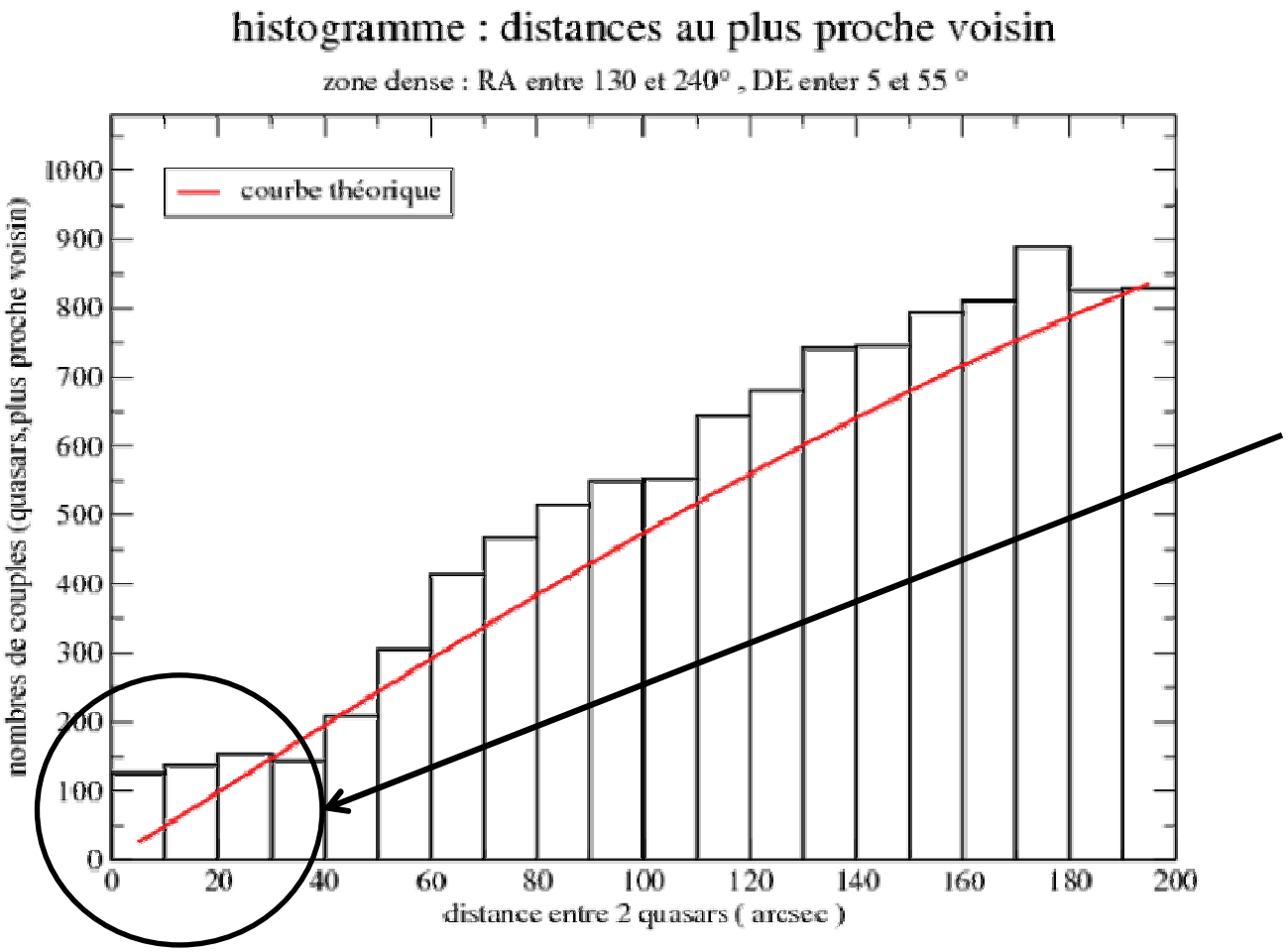
Theoretical probability :

$$f_k(r) = \frac{1}{2^{k-1}(k-1)!\,\sigma}\left(\frac{r}{\sigma}\right)^{2k-1} e^{-\frac{r^2}{2\sigma^2}}$$

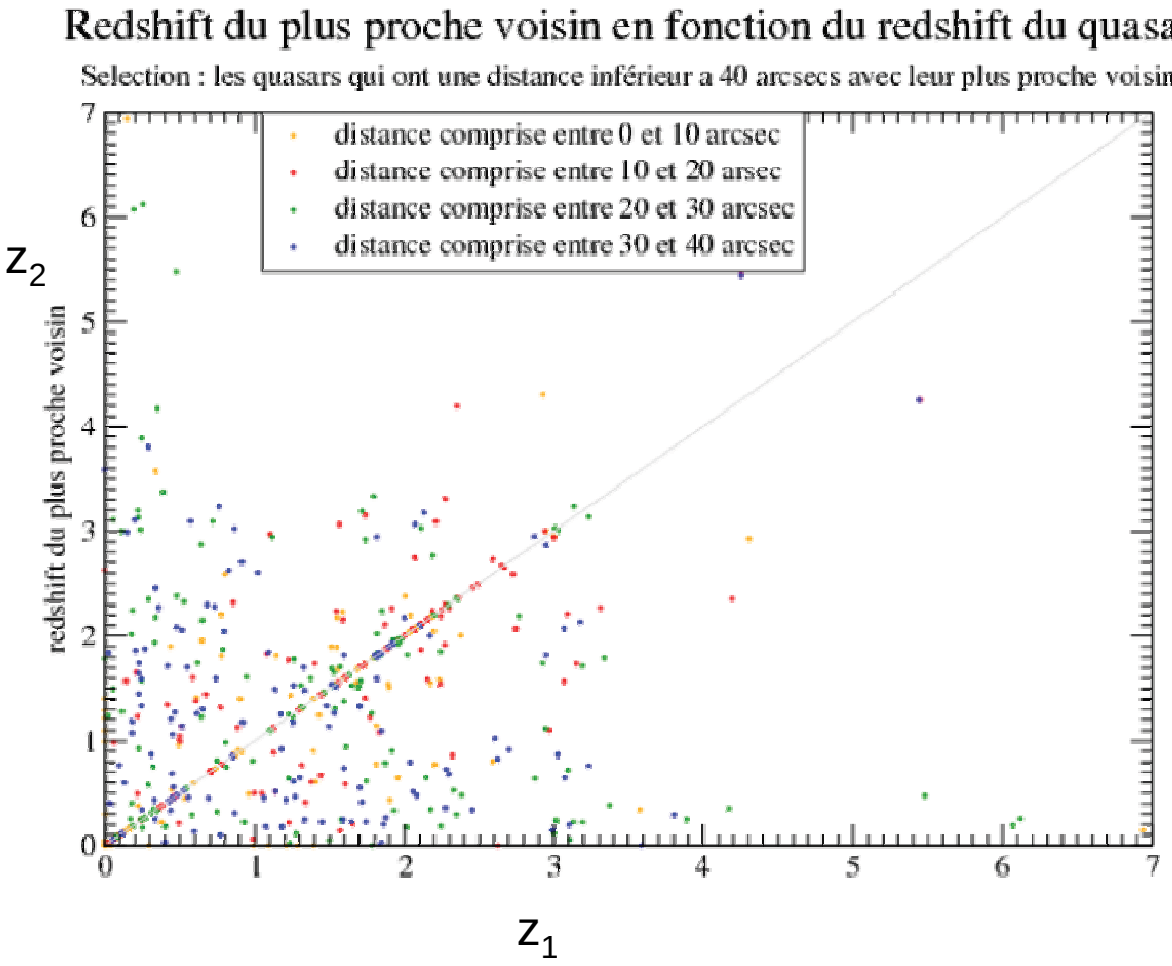
Closest neighbour : anomaly at small angular distances



Closest neighbour : anomaly at small angular distances



Hypothesis : physical link (redshift) between double quasars



Redshift vs. redshift
Accumulation around the diagonal

=>

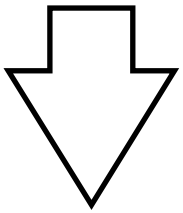
- True (physical) double quasars
- Optical couples
- Same quasar (bad identification)

DEFINITION

Double quasars : Two close quasars with same redshift (and physical interactions ?)

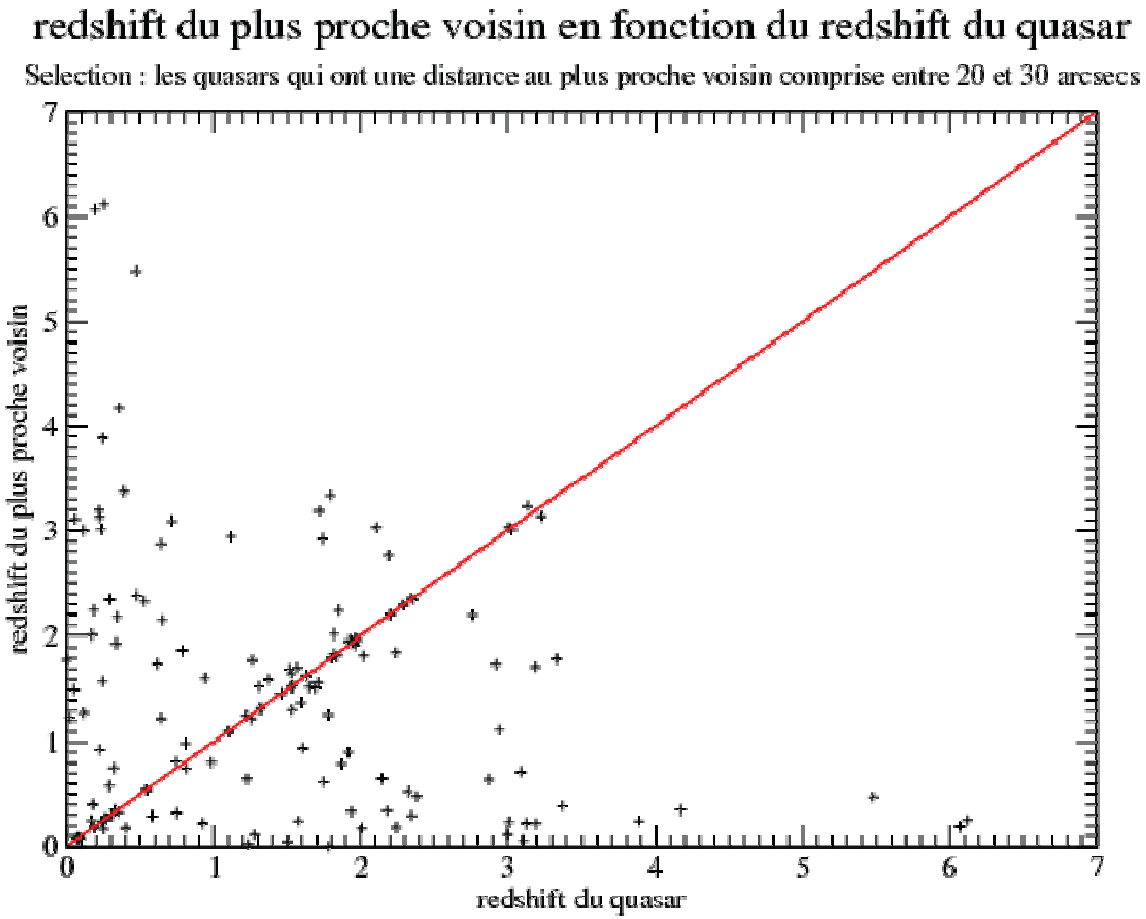
Optical binary quasar: Two quasars with close real positions but different redshifts

False binary : single quasar recorded in two well differenciated



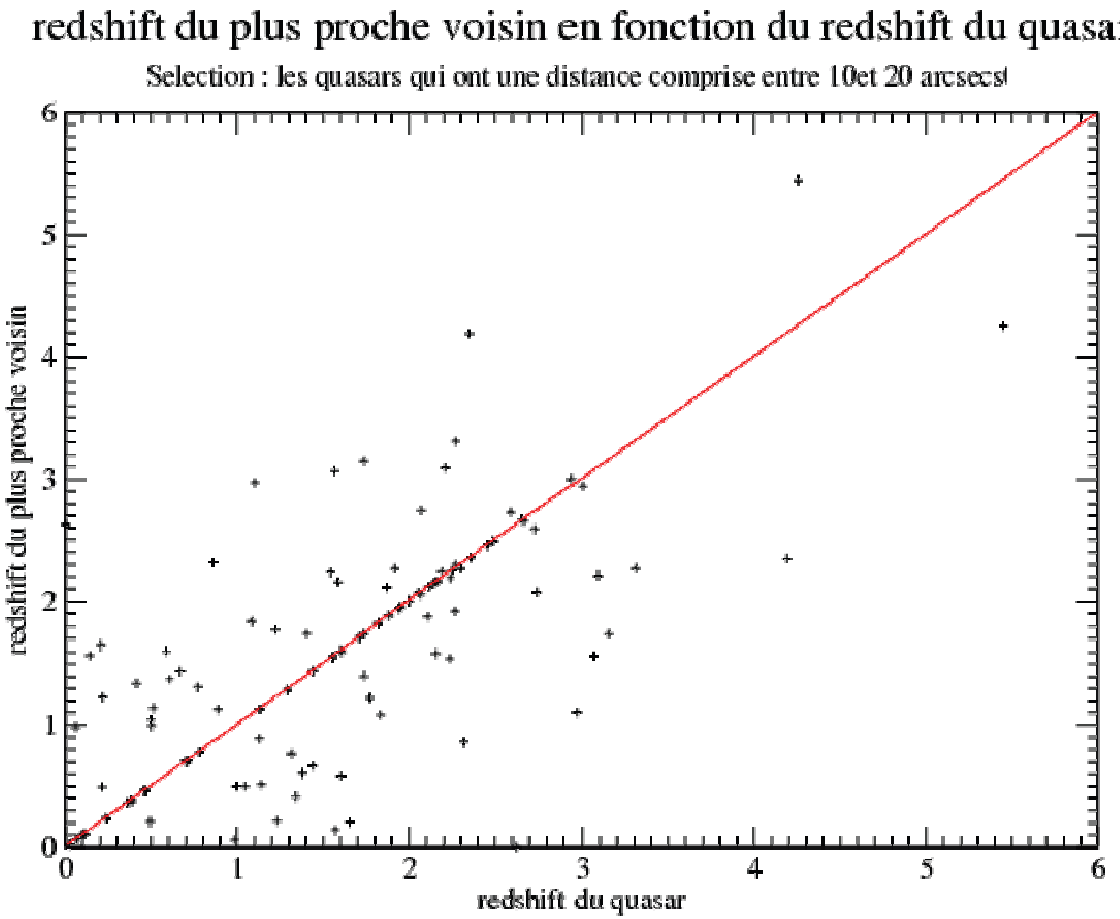
Differenciate between the couples of quasars with same redshift and small ρ double quasars from optical binaries

Find the images : http://cas.sdss.org/astro/en/tools/search/IQS.asp
Analyse of images with Aladin



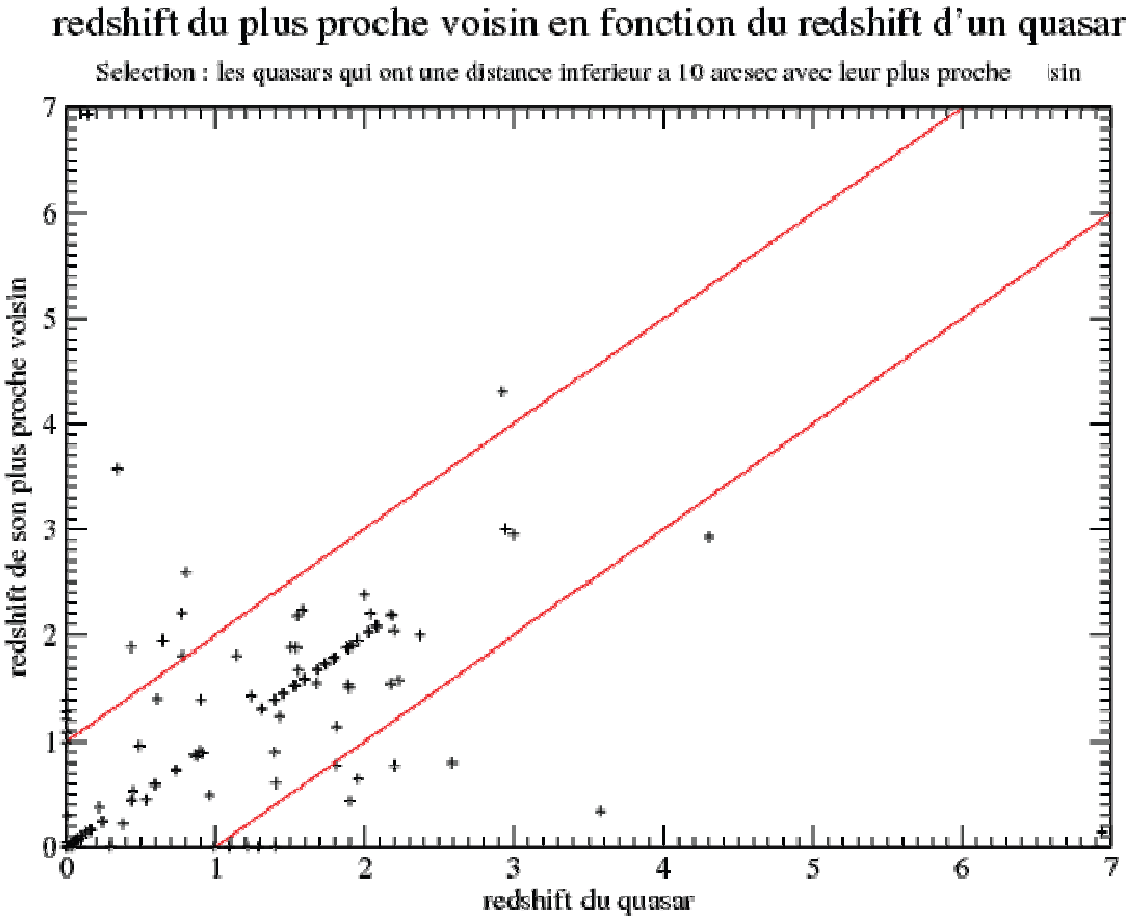
Close objects

20” < ρ < 30”



Close objects

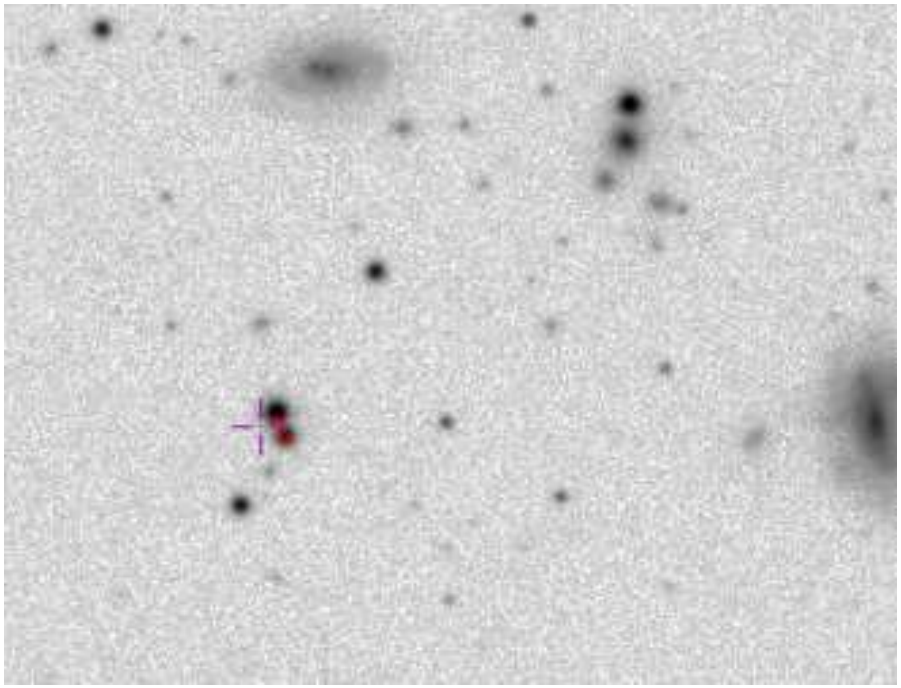
10 ’’ < ρ < 20 ’’



Close objects

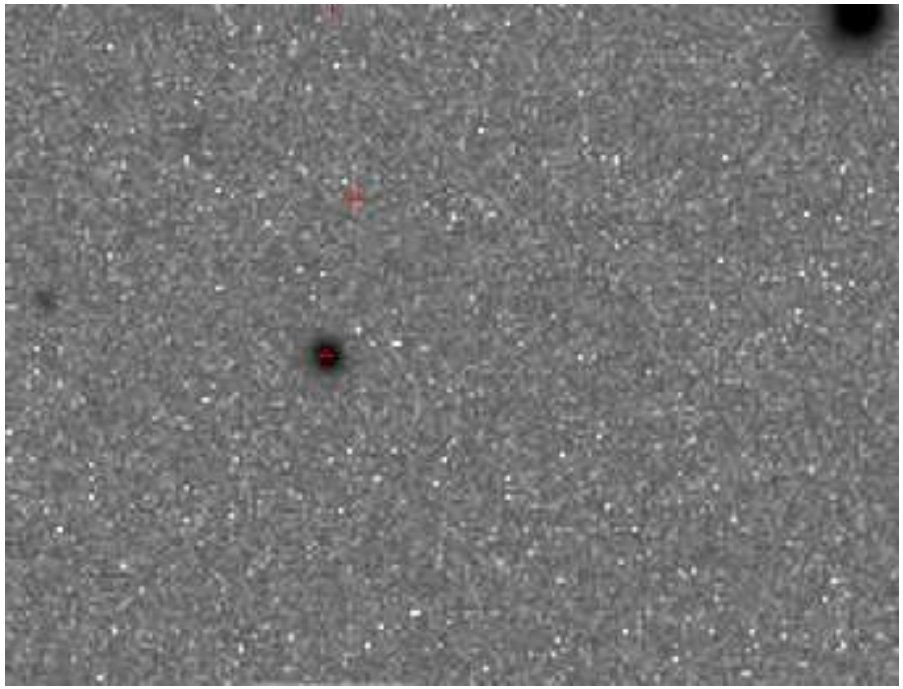
$0'' < \rho < 10''$

Differenciation « by eye » between double quasar and false pair



Example of double quasar

Example of single quasar with coordinate shift



Results concerning differenciation « double quasars – binaries »

From the **289** couples of quasars selected with criteria for double QSO's

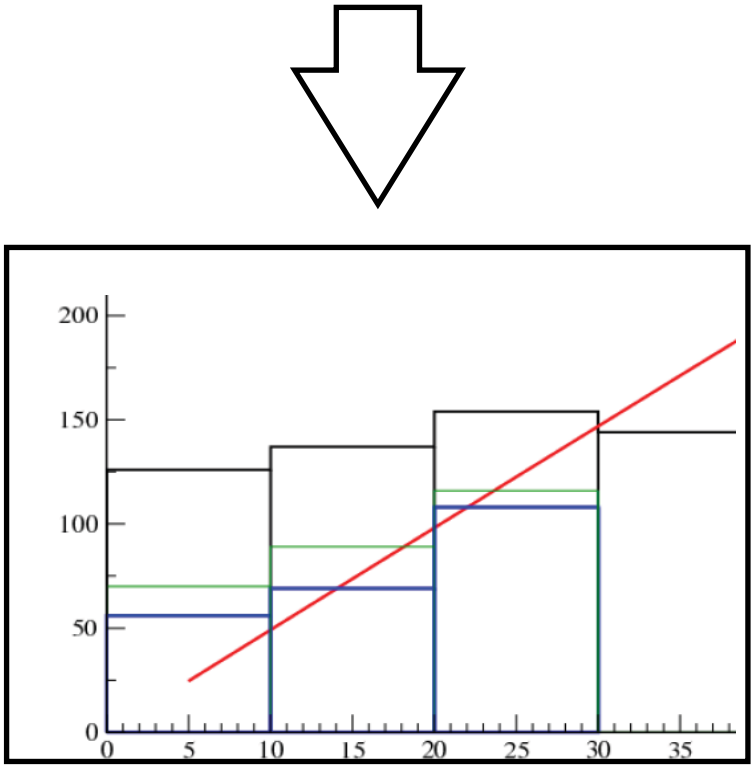
- ρ < 30 arcsecs
- difference from the first diagonal of redshifts < 0.02

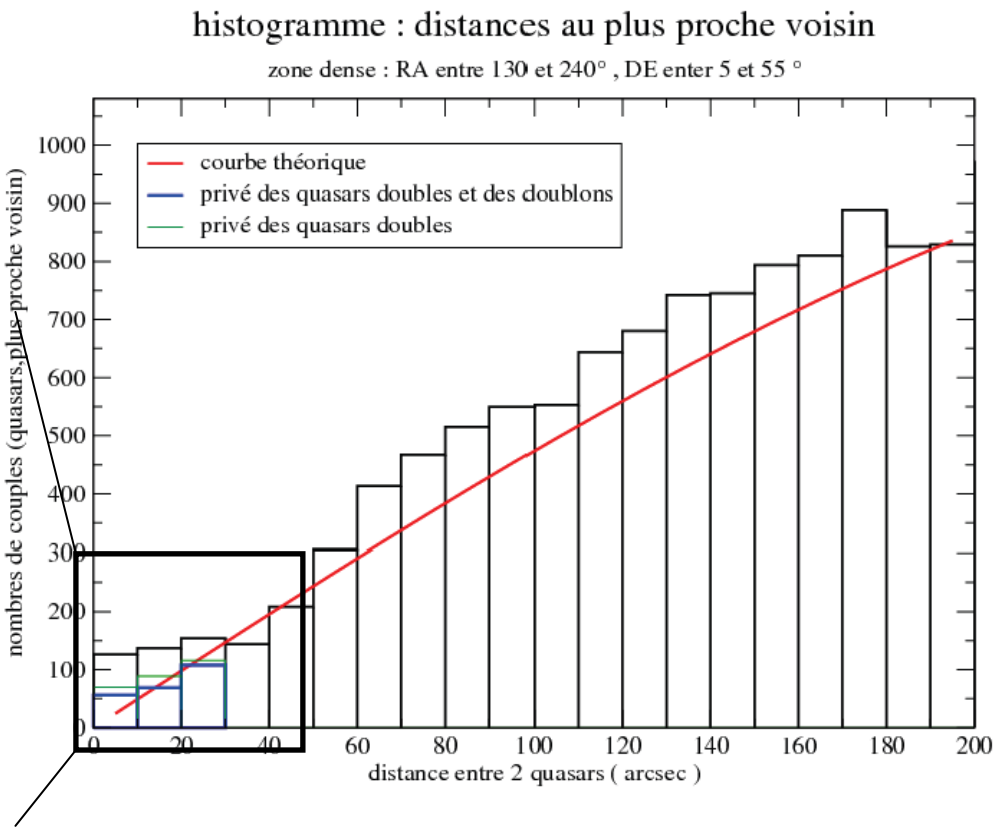
We have found :

- **35** binary quasars (with 5 doubtful)
- **159** double quasars (with 3 doubtful)

Remaining **97** couples are not in the SDSS frames database => to check

Corrections after removing double quasars and false pairs





The SDSS quasar catalog

(Schneider et al, A.J. 130, 2005)

- Dedicated telescope (2.5 m) at Apache Point
- CCD camera => u,b,v,g,r,i,z images over 10 000 deg^2
- Properties of each detected object in the 5 bands
- Photometric and astrometric calibration
- Pre-selection of quasars in multidimensional color space
- Quasar catalog constructed on
    - creation of a quasar candidate database
    - visual examination of the candidates'spectra
    - application of luminosity and emission line velocity
- Luminosity limit of M_i=-22, photometry ~0.03 mag.
- Automated line measuring-routine
- 27 entries for each quasar !

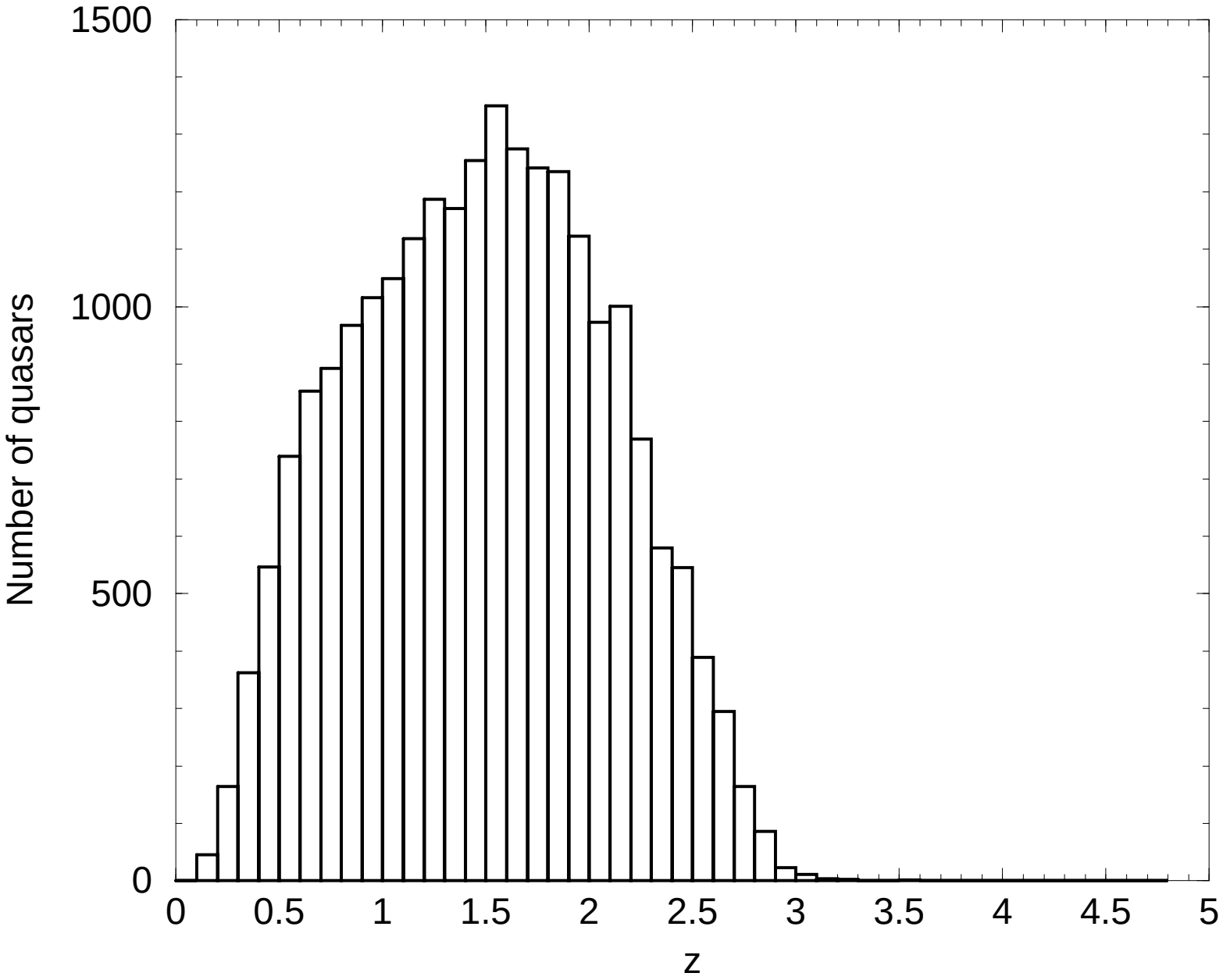
The 2df QSO Redshift Survey

(Croom et al.,MNRAS 349,2004)

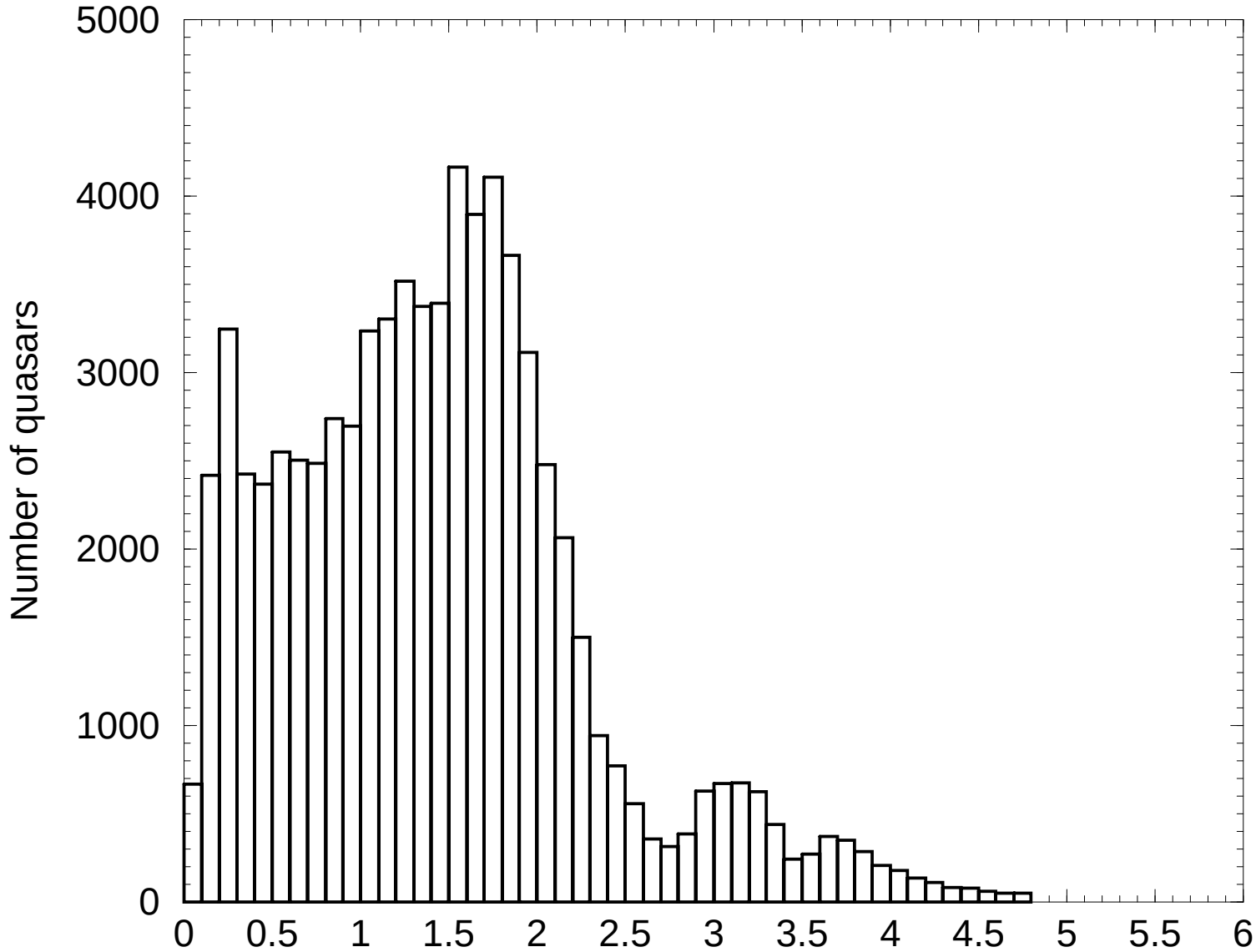
- Pre-selection of QSO candidates on broadband ub_Jr from UK Schmidt Telescope photographic plates
- 30 UKST fields, arranged in two 75°x5° declination str ips
- Spectroscopic observations at the AAT (Anglo Australian Telescope)
- Multifibre spectrograph

  => simultaneous spectra for 400 objects / 2° field of view
- 44 756 initial objects => spectra classified using automated routines to fit each spectrum to QSO's (stellar, galaxy)
- QSO's selected on broad emission lines (> 1000 kms^{-1})
- Quality flag

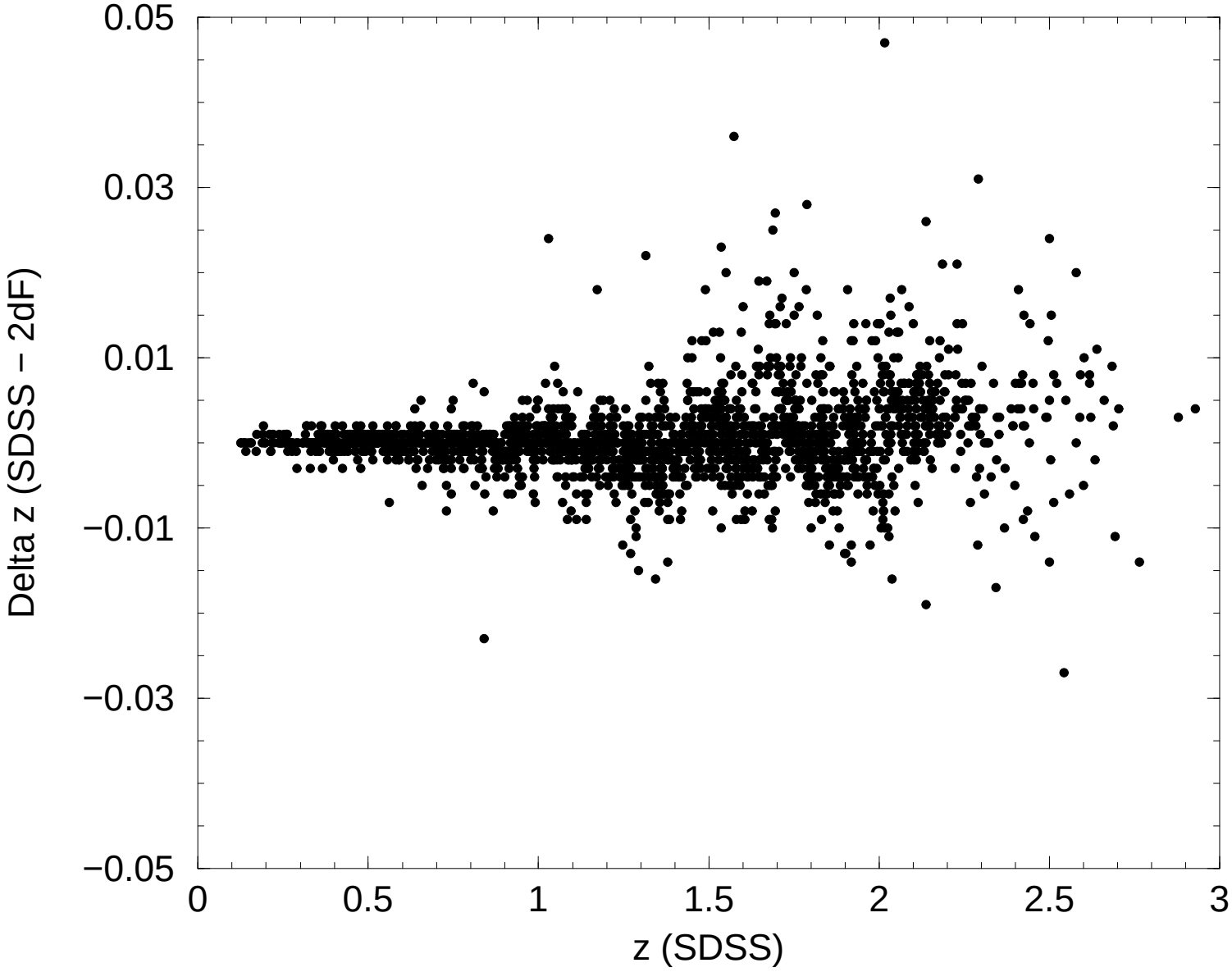
Histogram of redshifts /2QZ (2dF)



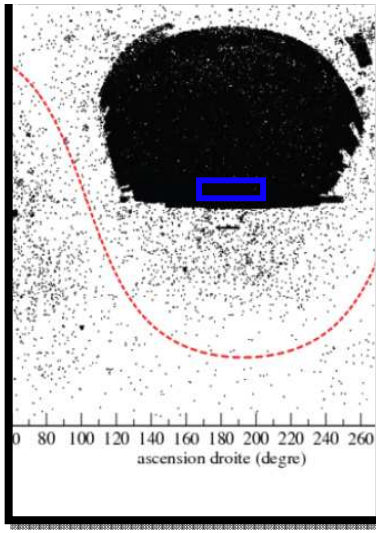
Histogram of redshifts /SDSS-DR5

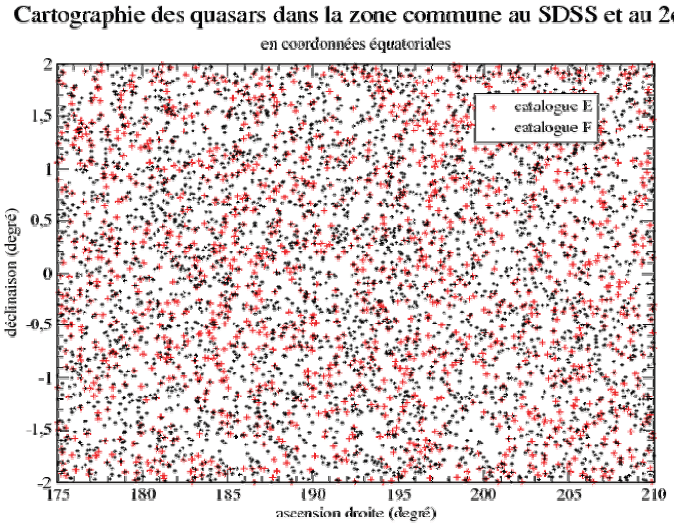


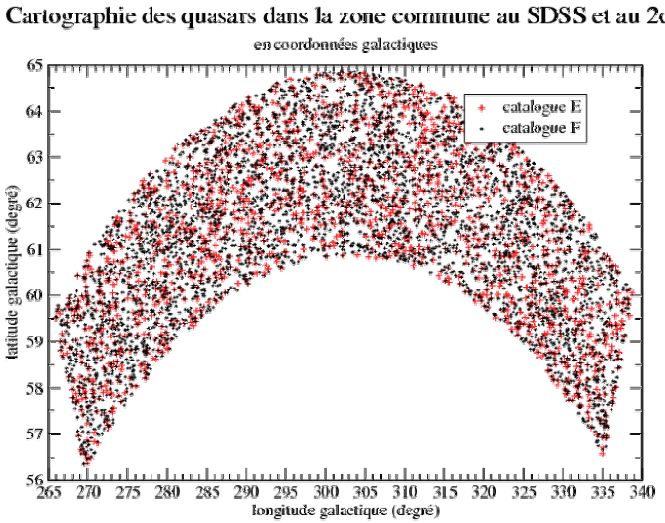
Redshift accuracy



Cross-identification SDSS – 2dF







Selection of Common zone SDSS - 2dF :

- $175° < \alpha < 210°$
- $-2° < \delta < 2°$

We count :

- 4 326 quasars w.r.t. 23 660 in 2dF (18,28%)
- 1 731 quasars w.r.t. 126 577 in SDSS (1,36%)

Results of the cross-identification :

- 900 quasars in common to the two catalogues (17,45%)
- 831 quasars in SDSS only (16,11%)
- 3 426 quasars in 2dF only (66,43%)

= 5 157 quasars

Extrapolation :

~ **1 520 000** quasars should be detected in the whole sky

CONCLUSION

LQAC-2 compilation catalogue as a precious tool for the preparation of the Gaia Space Mission

- **A kind of « Input Catalogue »** with the best astrometry and the maximum of information (photometry, radio fluxes, redshift)

- Put an evidence on **deficient zones**

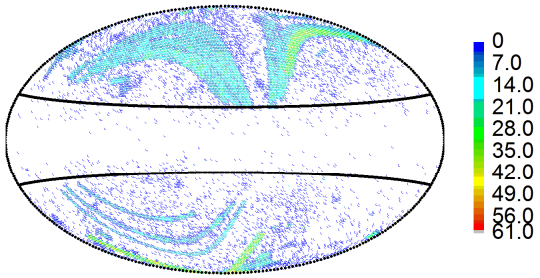
- Calculation of **all-sky expected number of quasars ~ 1 500 000** to be adjusted (galactic extinction, magnitude threshold) for Gaia

- **Curves of distribution and statistics** (density, closest neighbour) w.r.t. expected theoretical ones (Mignard,2008)

- Estimation of the relative number **of double quasars (~ 1/800)**

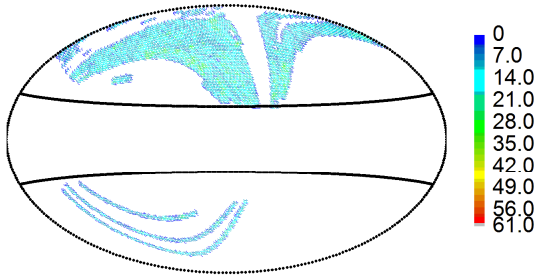
Quasars' sky distribution – 1deg^2 cells count

(courtesy : A.H. Andrei)



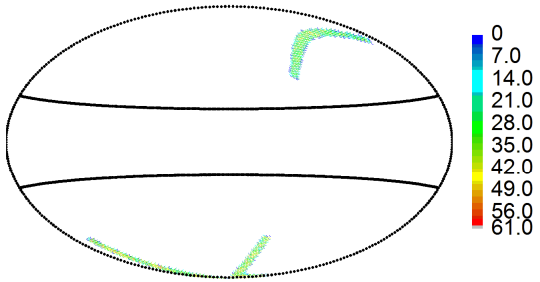
V&V

85,221 sources



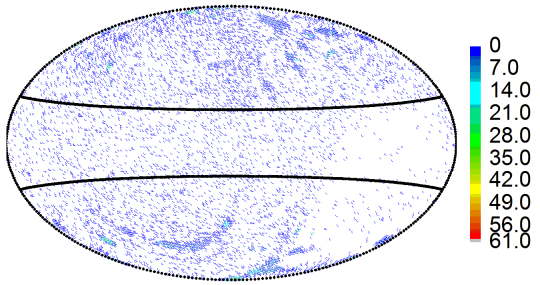
SDSS DR5

74,869 sources



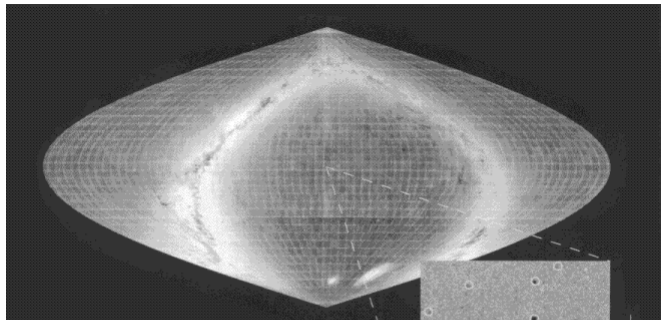
2dF – QSO

23,803 sources



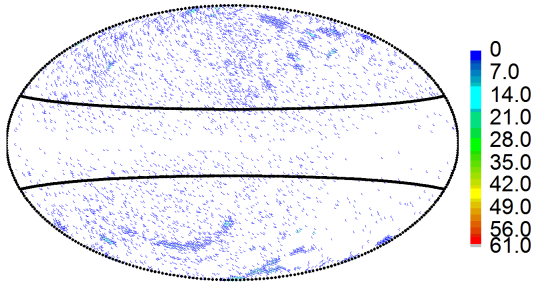
All Radio QSOs

11,781 sources



B1.0

All sky up to V=21

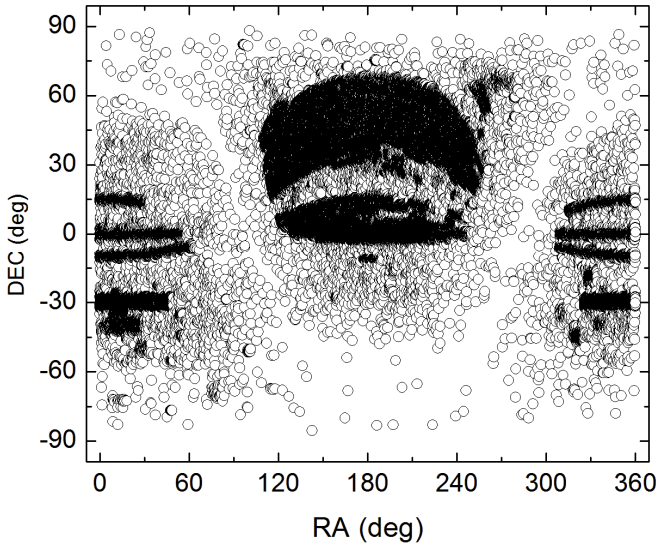


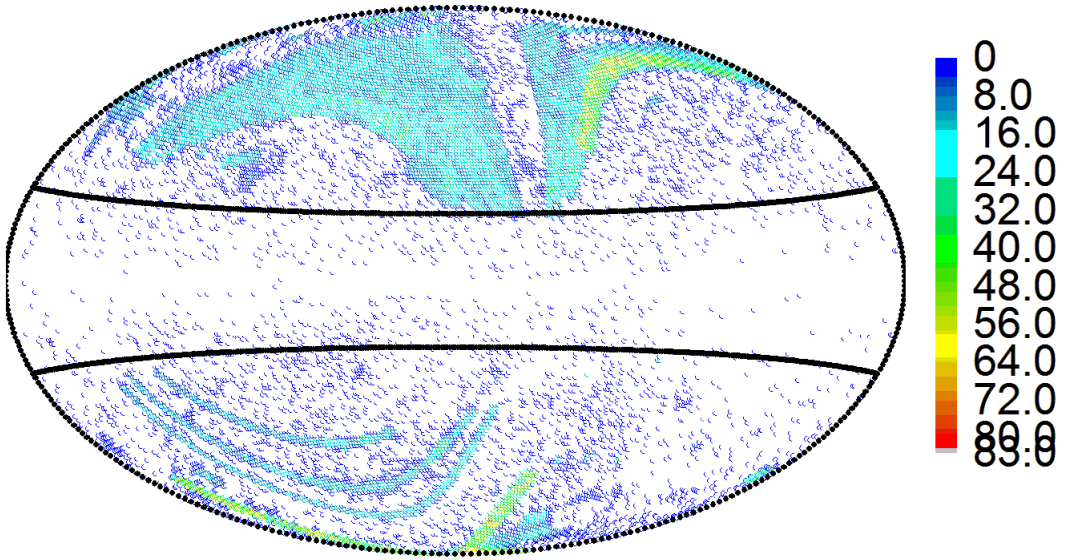
Radio QSOs found in B1.0

6,941 sources

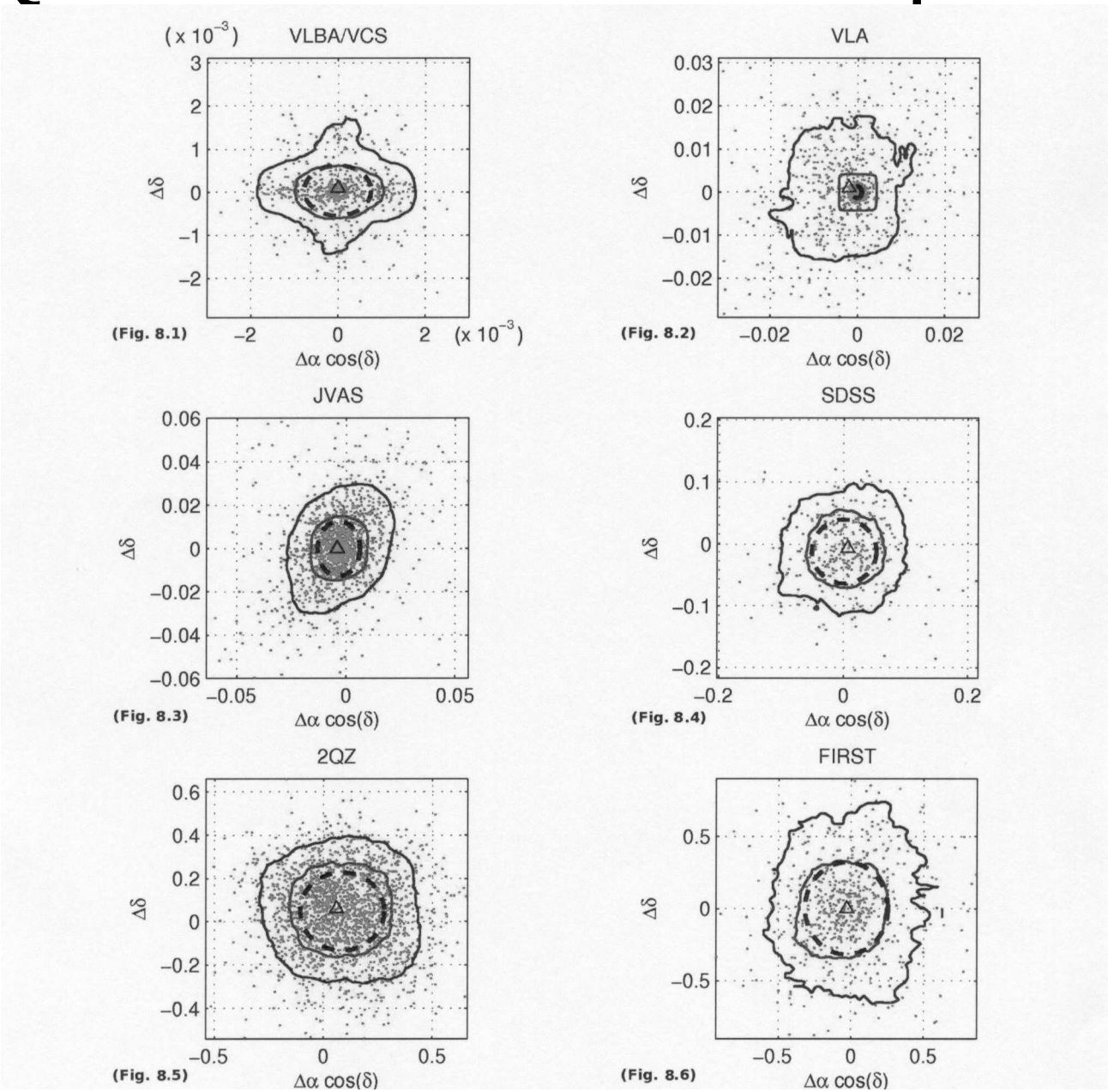
The consolidated sample

The consolidated sample contains 128,257 candidates QSOs. There is at least one redshift determination for 98.75%, and at least one magnitude determination for 99.20%





LQAC : astrometric comparisons



Absolute magnitudes

Cosmological parameters and hypothesis

Friedmann-Lemaître-Robertson-Walker metrics

Ω_k=0, q_0=-0.58, H_0=72 km/s/Mpc

Use of HST and WMAP experiments for constraints

Ad hoc expression for
the luminosity distance $D_L(z)$

$$D_L = \frac{(1+z)\,c}{H_0} \int_1^{1+z} \frac{du}{\sqrt{\frac{1}{3}(1-2q_0) + \frac{2}{3}(1+q_0)\,u^3}},$$

$M - m = 5 - 5 \log D_L - A - K$

A => galactic extinction

K => K- term related to the effect of redshift at given bandwidth

Luminosity distance & K-correction

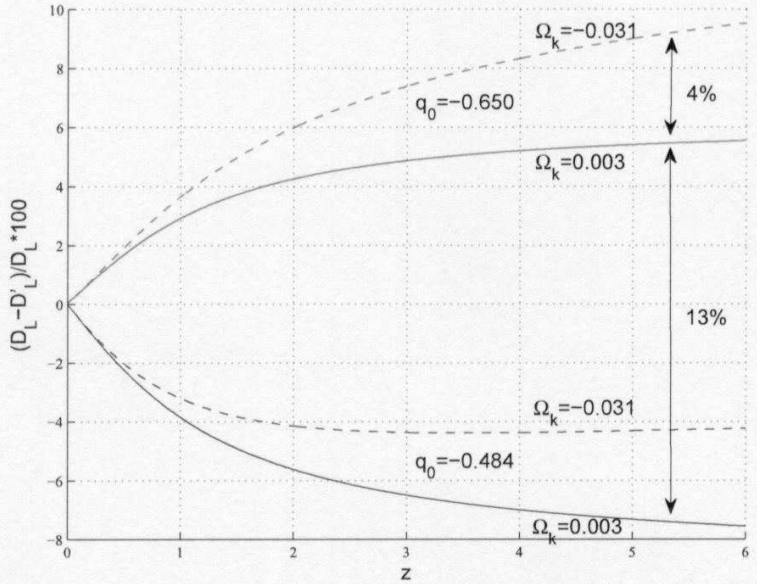


Fig. 16. Relative difference between the luminosity distance D_L computed with the nominal values $q_0 = -0.58$ and $\Omega_k = 0$ and the luminosity distance D'_L computed with the limits values of the same parameters, vs. the redshift z of the sources. Dashed lines for $\Omega_k = -0.031$, solid lines for $\Omega_k = 0.003$ green lines (upper lines) for $q_0 = -0.650$ and black lines (lower lines) for $q_0 = -0.484$.

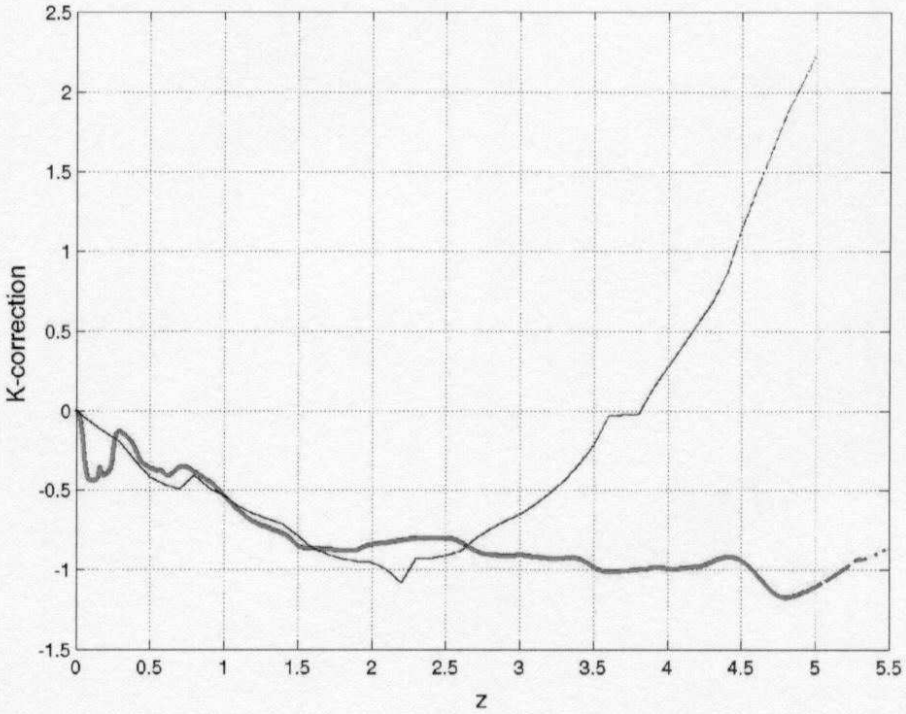


Fig. 17. The K-correction in infrared bandpass K_i (bold line) and in blue bandpass K_B (thin line) vs. the redshift.

Absolute magnitudes

M_i and M_b

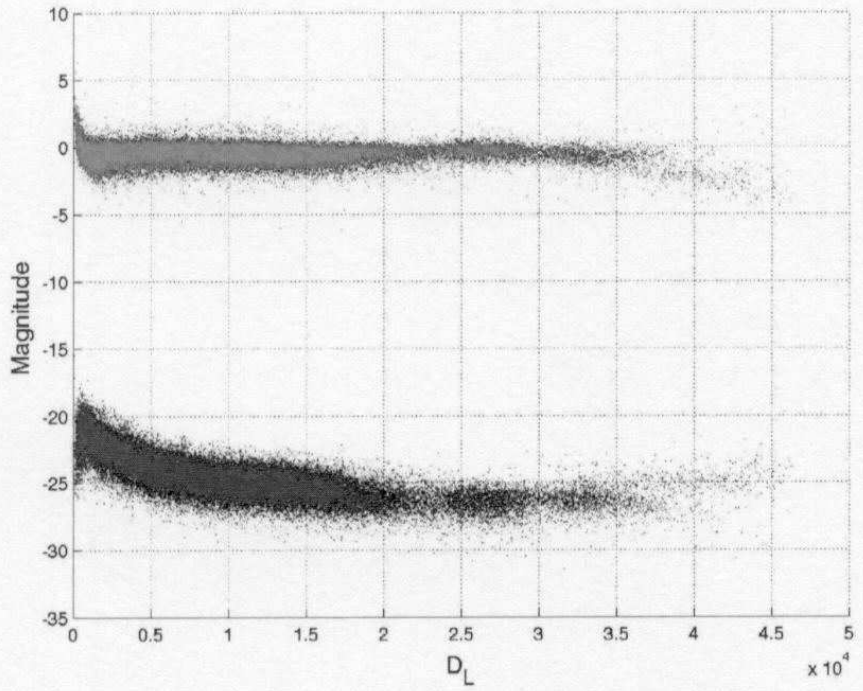


Fig. 18. The blue absolute magnitude M_B (lower line) and the difference between the absolute magnitude in infrared and blue bandpass $(M_i - M_B)$ (the upper line) for the LQAC sources, vs. their luminosity distance.