The 2dF QSO Redshift Survey: Measurements of Large-Scale Structure

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1. **Survey outline and goals**
2. **Why use QSOs for LSS measurements**
3. **Simulations**
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5. **Conclusions**

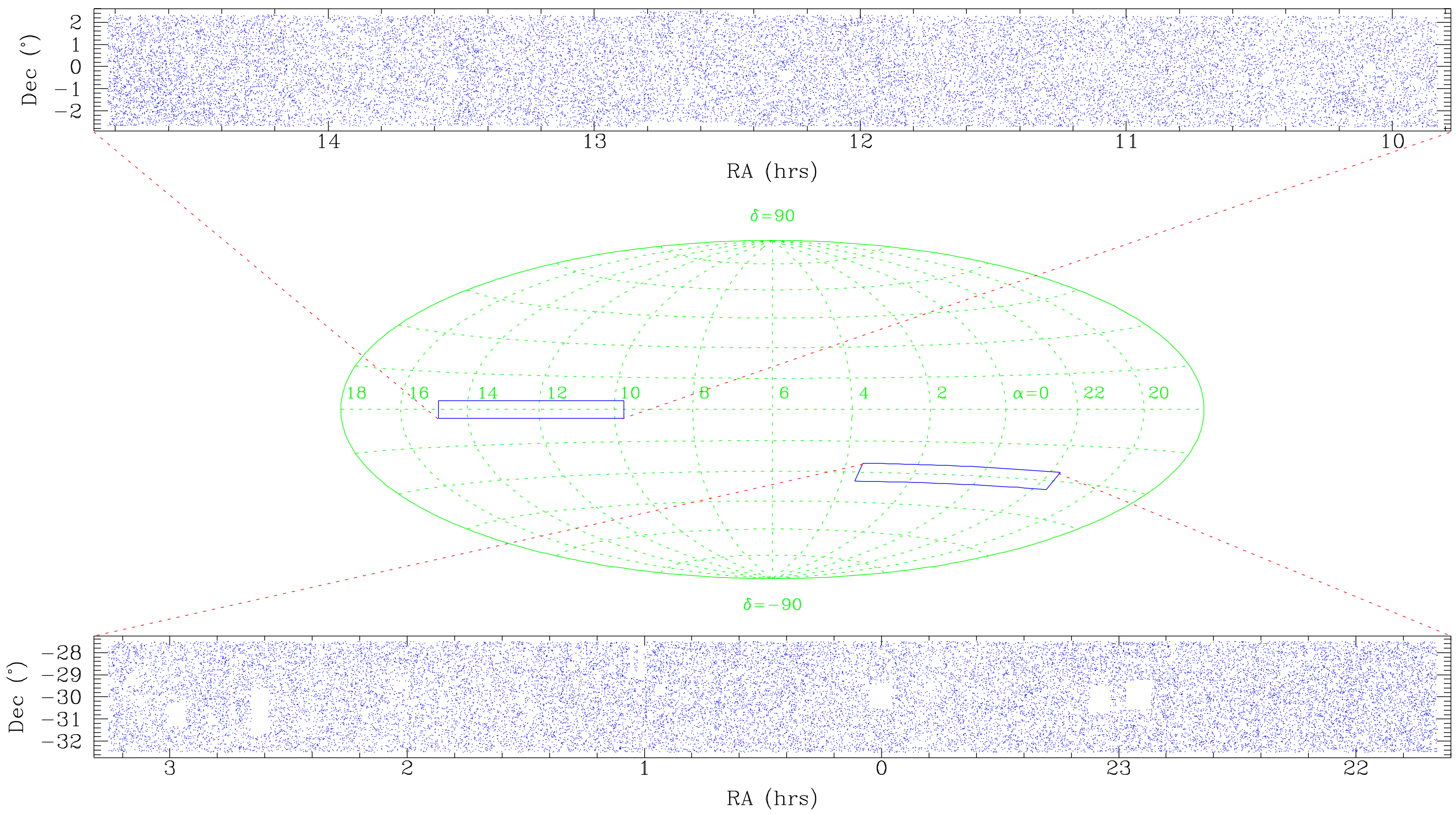
The 2dF QSO Redshift Survey Homepage:

msowww.anu.edu.au/∼rsmith/QSO_Survey/qso_surv.html

The 2dF QSO Redshift Survey Candidate Catalogue

30 J + 30 R + 109 U UKST plates
APM scanned + CCD calibration
Selection: U–B_J and B_J–R colours

Total area of 740 deg^2
Mag. limits: $18.25 \leq B_J \leq 20.85$
Number of candidates 48078



Scientific aims of the 2dF QSO Redshift Survey

The scientific goals of the survey relating to large-scale structure are:

1. Determining the QSO clustering power spectrum, P(k), from 2 to $\sim$1000h^{-1}Mpc.

2. Measuring, λ_0, the cosmological constant from geometric distortions in clustering.

3. Tracing the evolution of QSO clustering from z=0.3 to z=3.0 to get limits on Ω_0 and QSO bias.

Other scientific aims: determining the QSO luminosity function, gravitational lensing studies, absorption line studies, spectral classification of QSOs....

Clustering results from previous QSO samples

The Veron-Cetty & Veron (1998) catalogue contains ~ 11000 QSOs ($M_B < -23$).

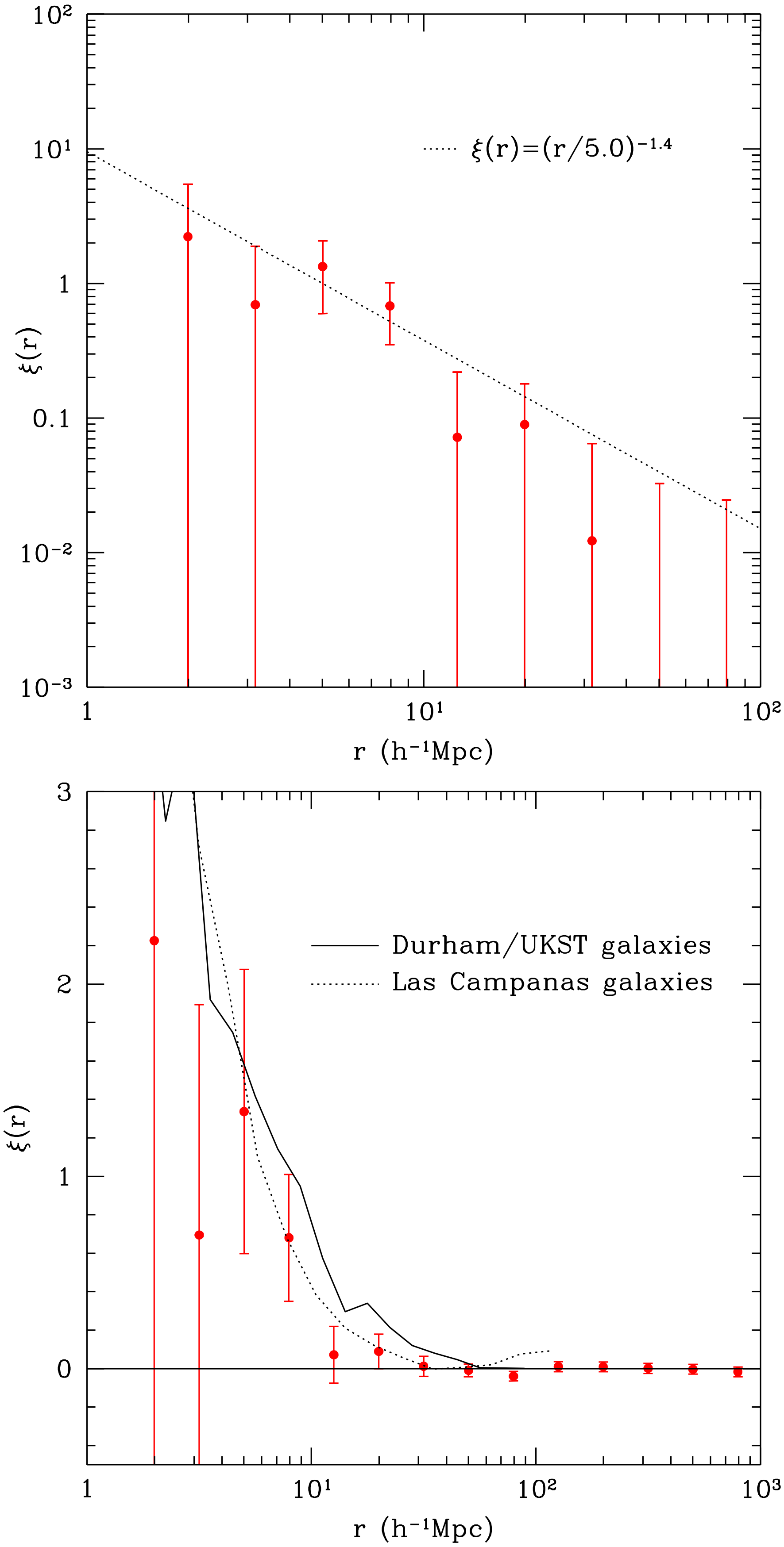
Several large statistically well defined samples have been used to study QSO clustering:
CFHT (Crampton et al. 1989), Durham/AAT (Boyle et al. 1990), LBQS (Hewett et al. 1995) and SGP (La Franca et al. 1998) in the optical, ROSAT surveys (e.g. Carrera et al. 1998) in X-rays, and also radio samples (e.g. Loan et al. 1997).

Clustering measurements by a number of authors, all using a few hundred to a thousand QSOs.

- Detections of clustering on small scales found in faint QSO surveys with high density, e.g. Durham/AAT.

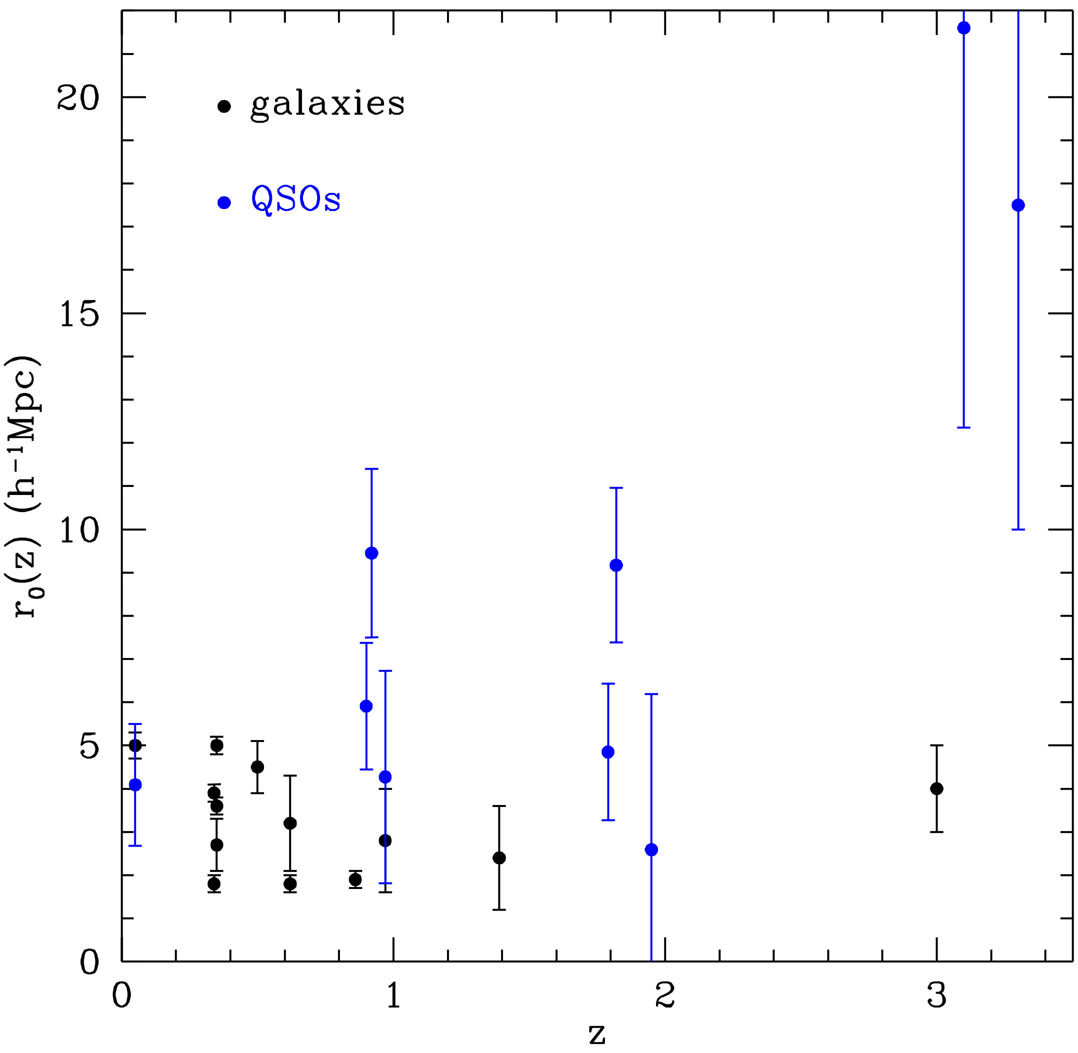
- QSO clustering at high z $\simeq$ local galaxy clustering in comoving coordinates.

- QSO clustering found to increase with redshift (La Franca et al., 1998); stay approximately constant with redshift (Croom & Shanks, 1996); or decrease with redshift (Iovino & Shaver, 1988).



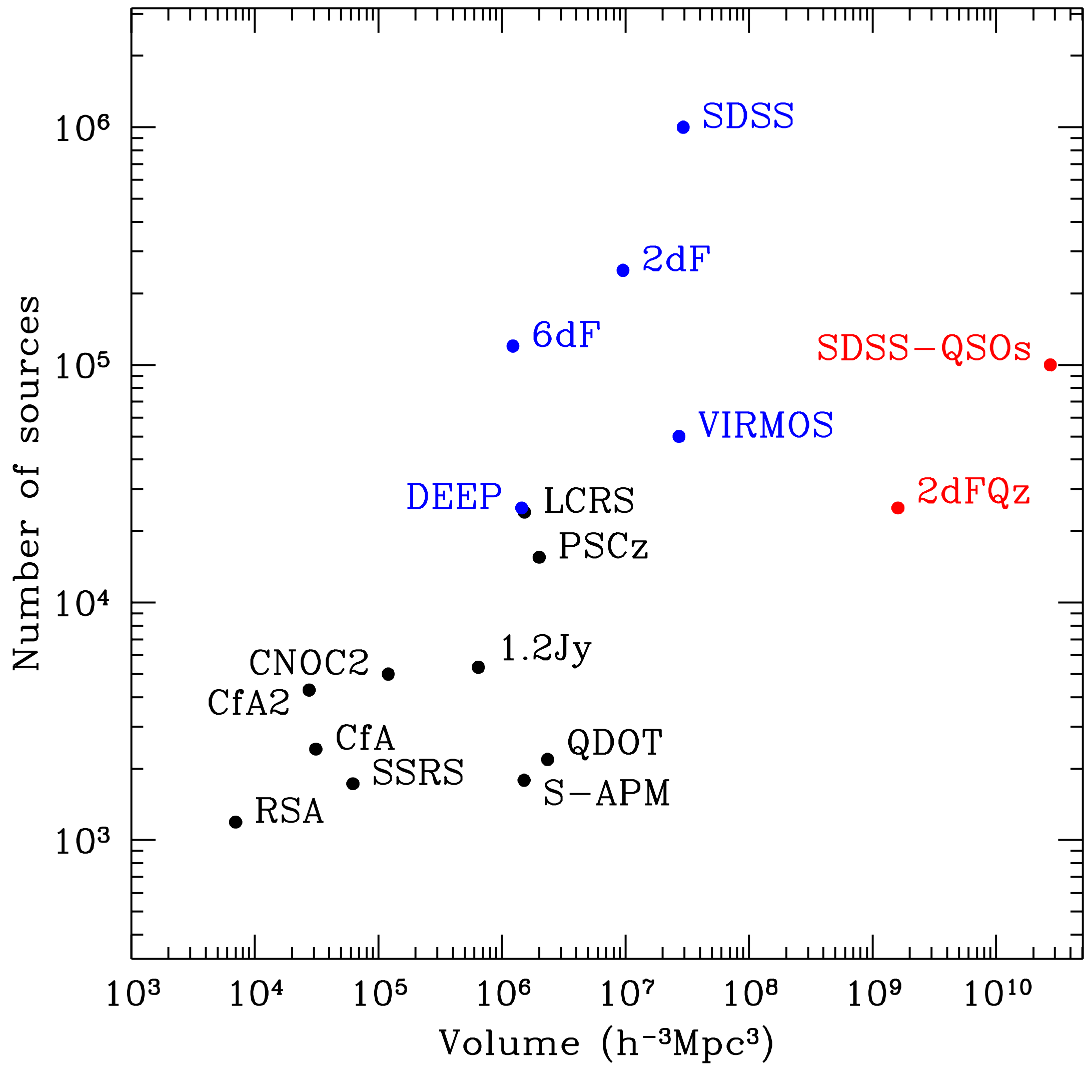
QSO clustering from a combined QSO sample: Durham/AAT, CFHT, ESO/AAT and LBQS (for $0.3<z<2.2$, and $\Omega_0=1$).

Clustering evolution in galaxies and QSOs



Current measurements of galaxy (Steidel et al. 1998; Postman et al. 1998; Carlberg et al. 1998; Carlberg et al. 1997; Shephard et al. 1996; Le Fevre et al. 1996) and QSO clustering (La Franca et al. 1998; Kundic 1997; Stephens et al. 1997; Croom & Shanks 1996; Georgantopolous & Shanks 1994; Boyle & Mo 1993; Iovino & Shaver 1988).

Comparison of Redshift Survey Volumes



From the compliation of Hatton, (1999).

2dF QSO Redshift Survey geometry:

- **$2\times75^\circ\times5^\circ$ strips at $\delta=0^\circ$, -30°**
- **z=0.3 to 2.9, complete at 0.3<z<2.2.**
- **$\bar{z}$=1.6.**
- **$75^\circ\times5^\circ \Rightarrow 3000\times200\mathrm{h}^{-1}$Mpc at $\bar{z}$ (Ω_0=1, λ_0=0).**
- **$75^\circ\times5^\circ \Rightarrow 4200\times280\mathrm{h}^{-1}$Mpc at $\bar{z}$ (Ω_0=0.3, λ_0=0.7).**

QSO Surveys from the Hubble Volume Simulation

The 2dF QSO Redshift Survey Team
The Virgo Consortium
F. Hoyle & C. Baugh (Durham)

Simulation parameters:

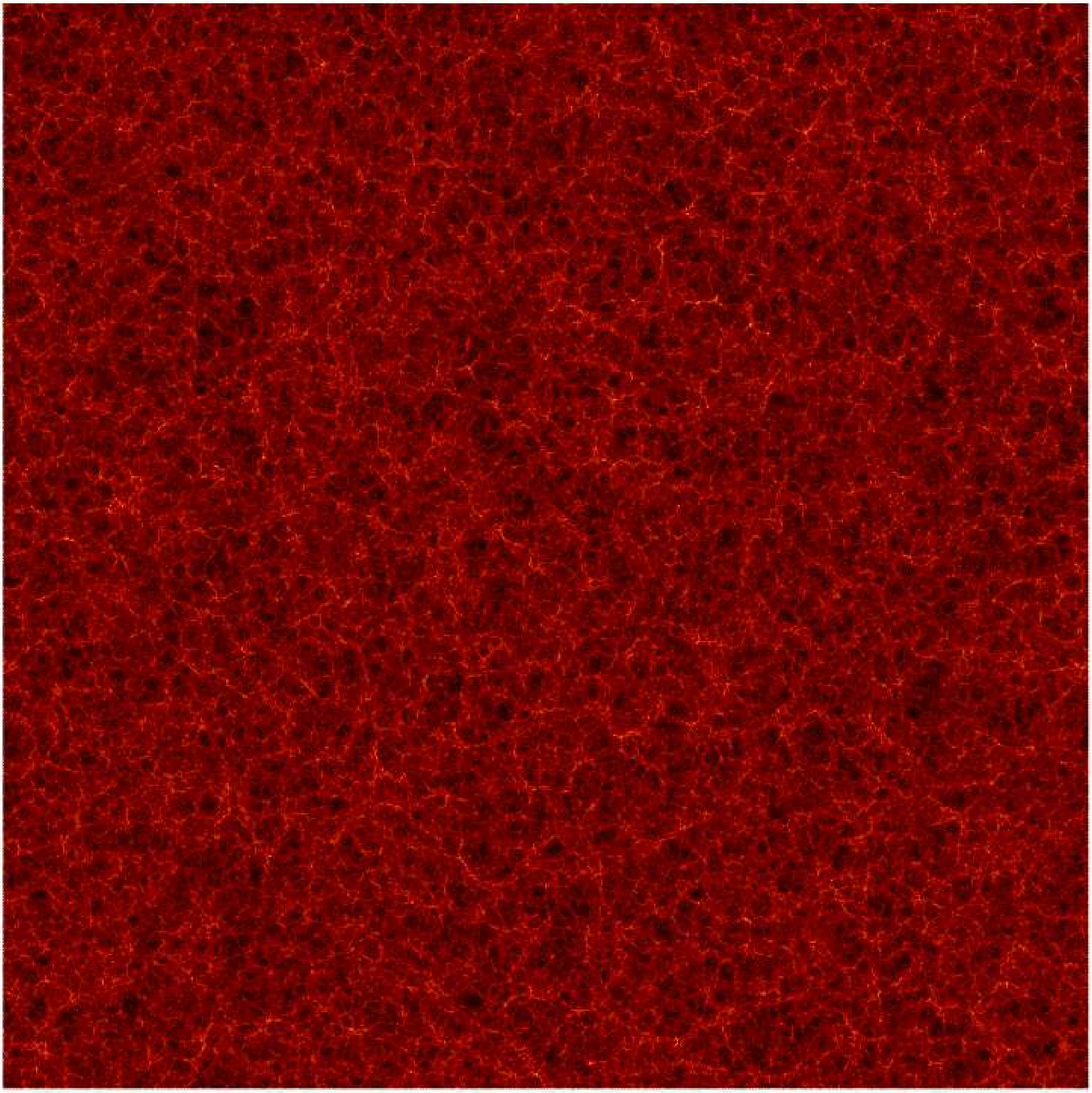
- 1024^3 particles each of mass $2.2 \times 10^{12} h^{-1} M_\odot$.
- Cosmology: Ω_0=0.3, λ_0=0.7, σ_8=0.9.
- Box size: $3000 h^{-1}$Mpc on a side.
- Output: Use light-cone output in a $15^\circ \times 75^\circ$ slice out to $5000 h^{-1}$Mpc ($z \sim 4$, using the periodic boundary conditions).
- QSO selection: try a variety of simple *ad hoc* and observationally based biasing schemes.

Primary aims: to find the best methods of measuring LSS from QSO surveys, and to test the robustness of results against different biasing schemes.

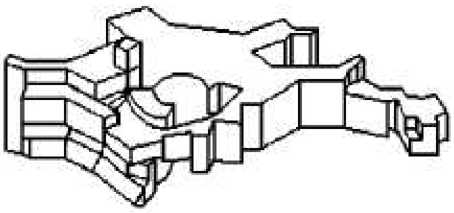
Particular tests:

- Estimates of $\xi(r)$ on small to intermediate scales.
- P(k) on large scales.
- Test the ability of geometric distortions to measure λ_0.

The Hubble Volume Simulation

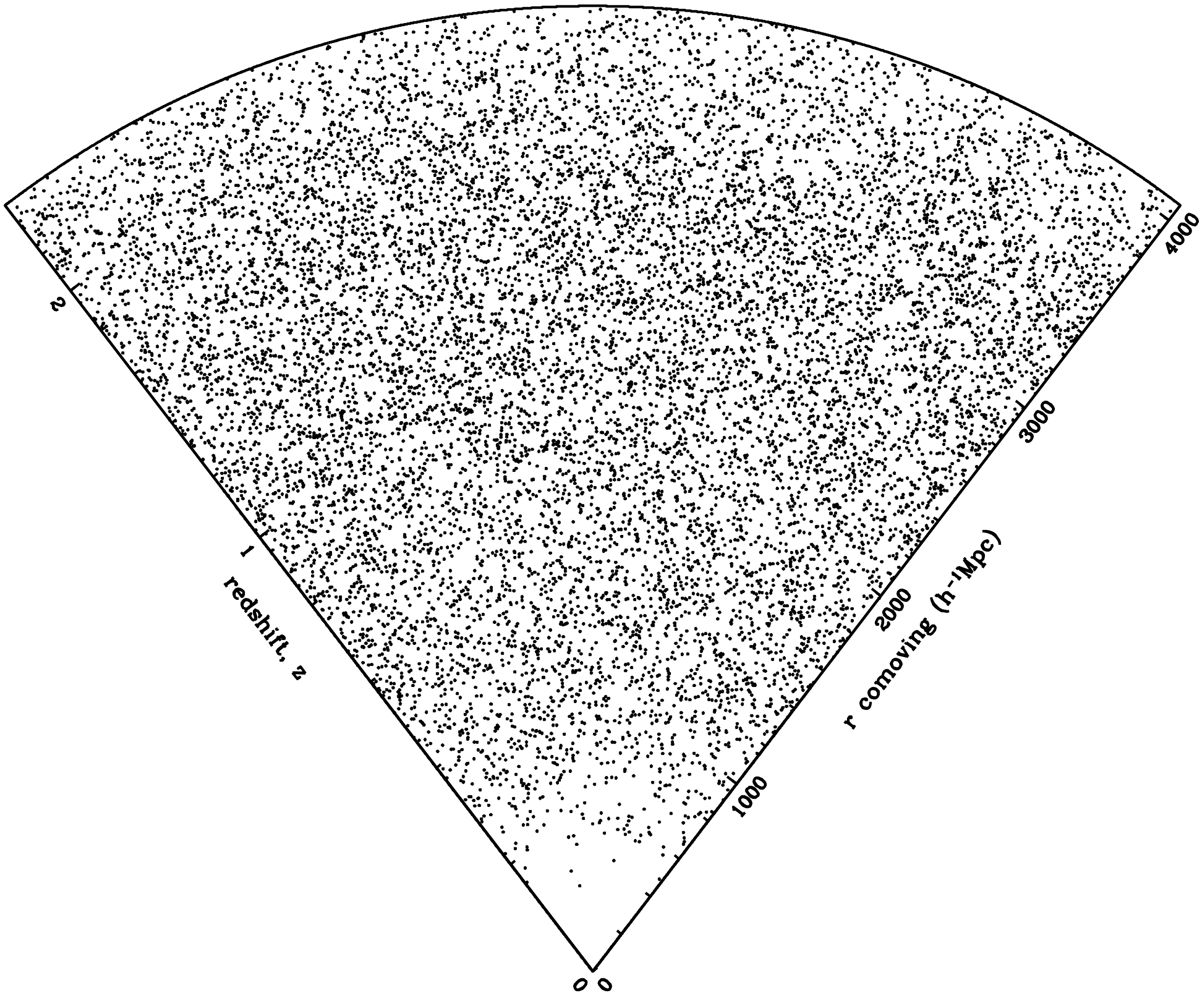


MacFarland, Colberg, White (München), Jenkins, Pearce, Frenk (Durham), Evrard (Michigan), Couchman (London, CA), Thomas (Sussex), Efstathiou (Cambridge), Peacock (Edinburgh)



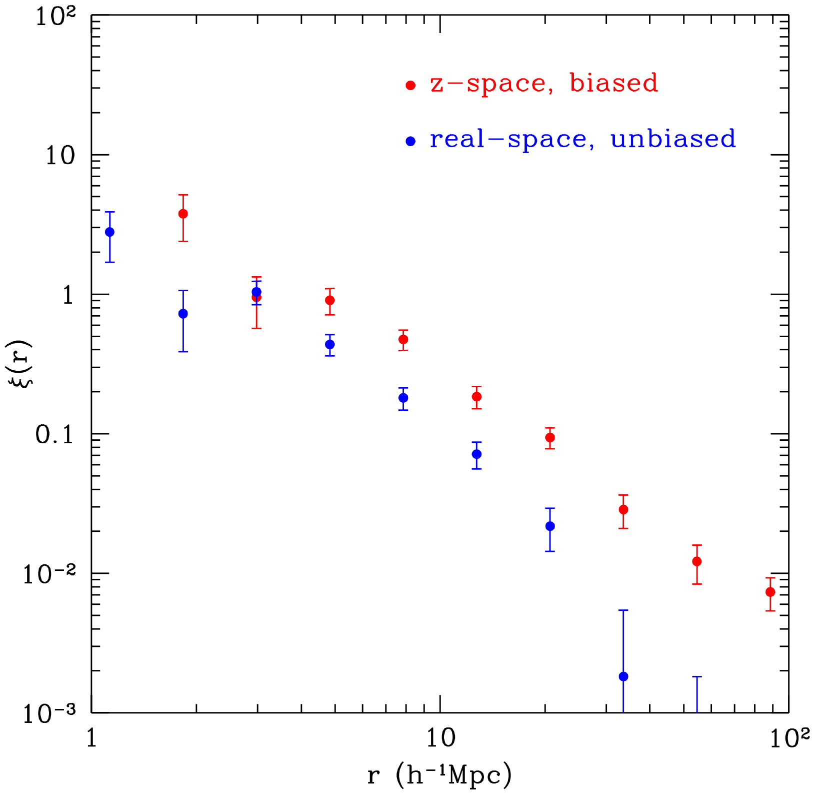
$2000 \times 2000 \times 20\,(\mathrm{Mpc/h})^3$

A simulated 2dF QSO Redshift Survey slice

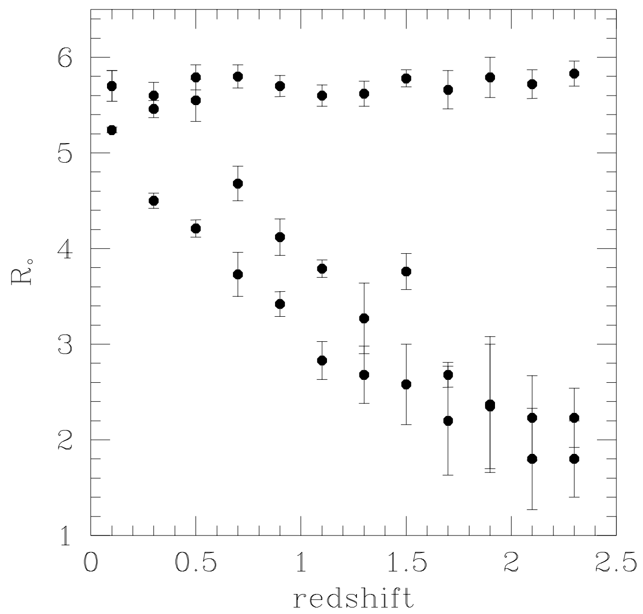


12500 QSOs with the same n(z) distribution as the observed 2dF QSOs. Biasing chosen so that clustering is un-evolving in comoving coordinates, with r_0=5h^{-1}Mpc.

Simulation $\xi(r)$

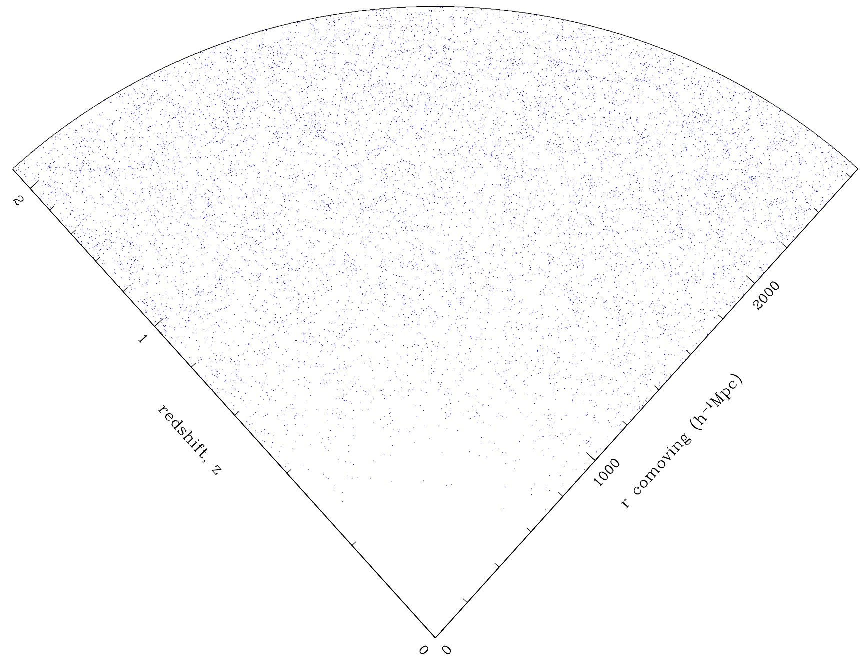


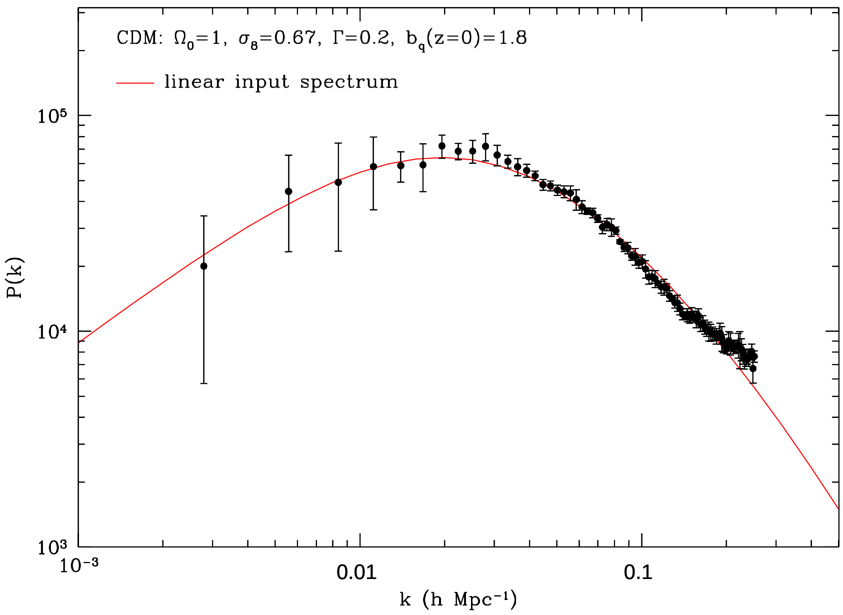
Simulation $\xi(r)$ in real- and redshift-space.



Evolution of simulation $\xi(r)$. Real-space mass (blue); redshift-space mass (red); and redshift space QSOs (black). 12500 QSOs used with the same radial and angular selection functions as one slice of the 2dFQz.

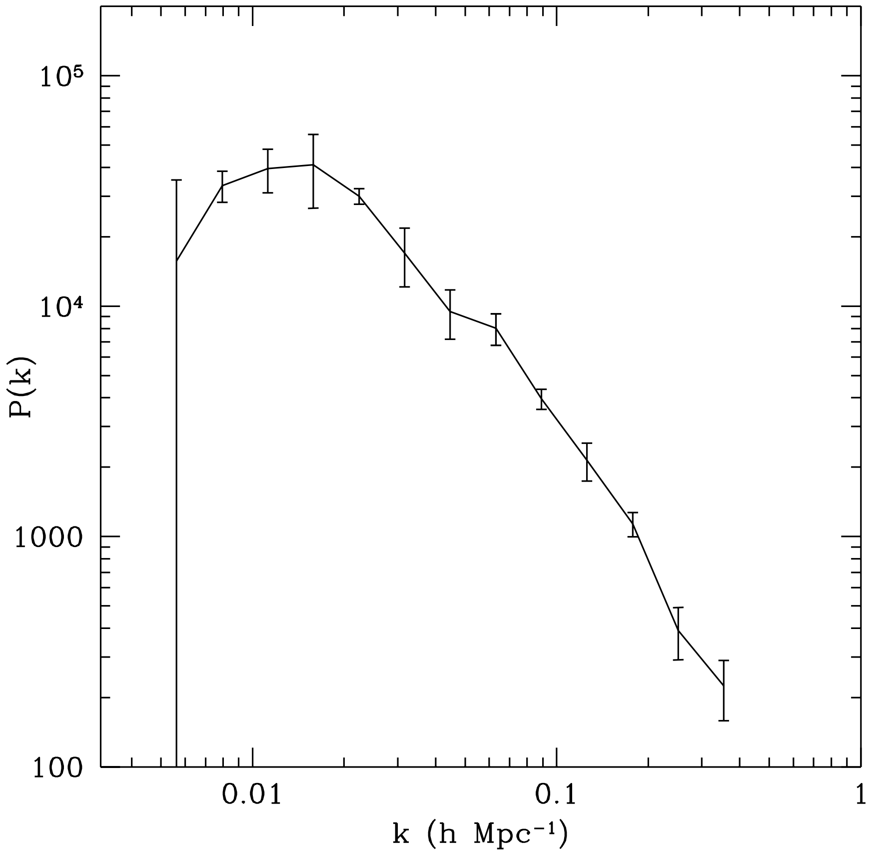
P(k) from Zeldovich Simulations





Zeldovich approximation simulation to estimate P(k), including evolution of the mass density field and bias. We use the measured N(z) distribution of the 2dF QSO sample, and assume 12500 QSOs in a single slice.

Hubble Volume P(k)



P(k) from one 2dF QSO Survey slice in the Hubble Volume simulation. Errors from the RMS of 3 slices. Calculation done via direct FT on small scales and FFT on large ($k<0.1$) scales.

QSOs biased so that clustering is constant in comoving coordinates.

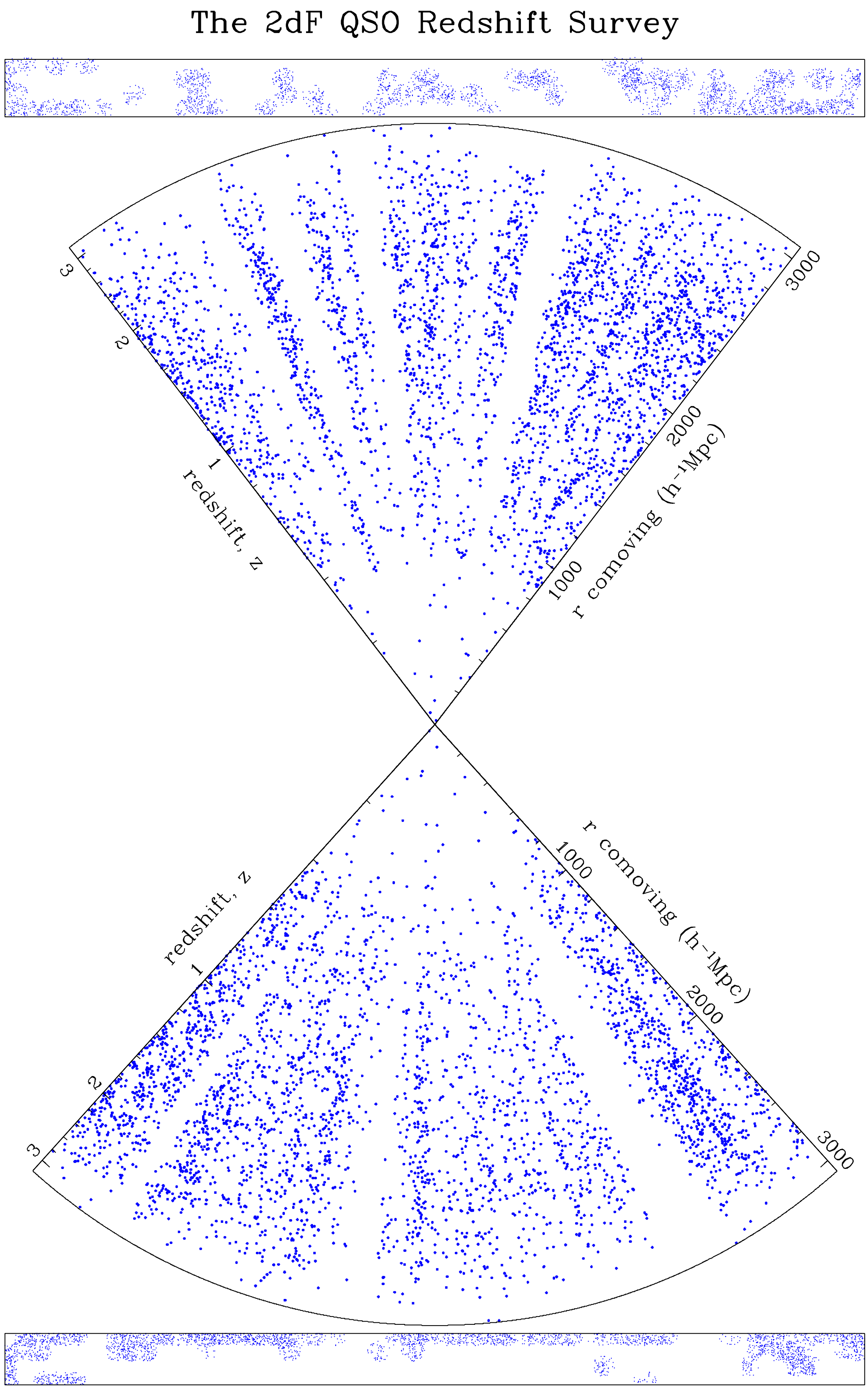
Errors larger due to increased shot-noise power in ΛCDM simulation.

Measuring $\xi(r)$ from the current 2dF QSO catalogue

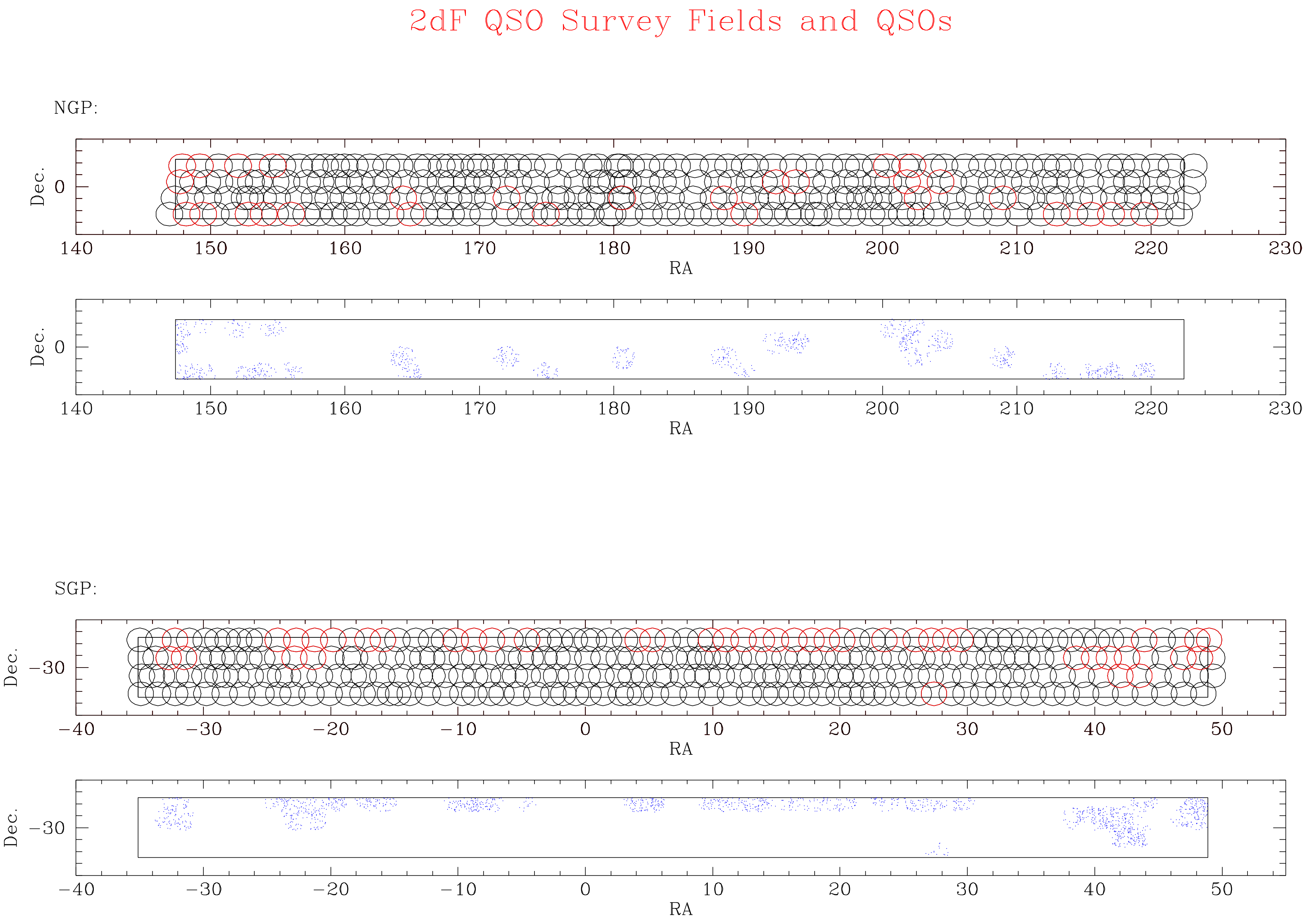
We define a current "complete" sample of QSOs from the 2dF Catalogue, containing 2765 QSOs. Not including QSO? IDs or QSOs in fields with low ID rates. Includes data up to May 1999 Observing runs.

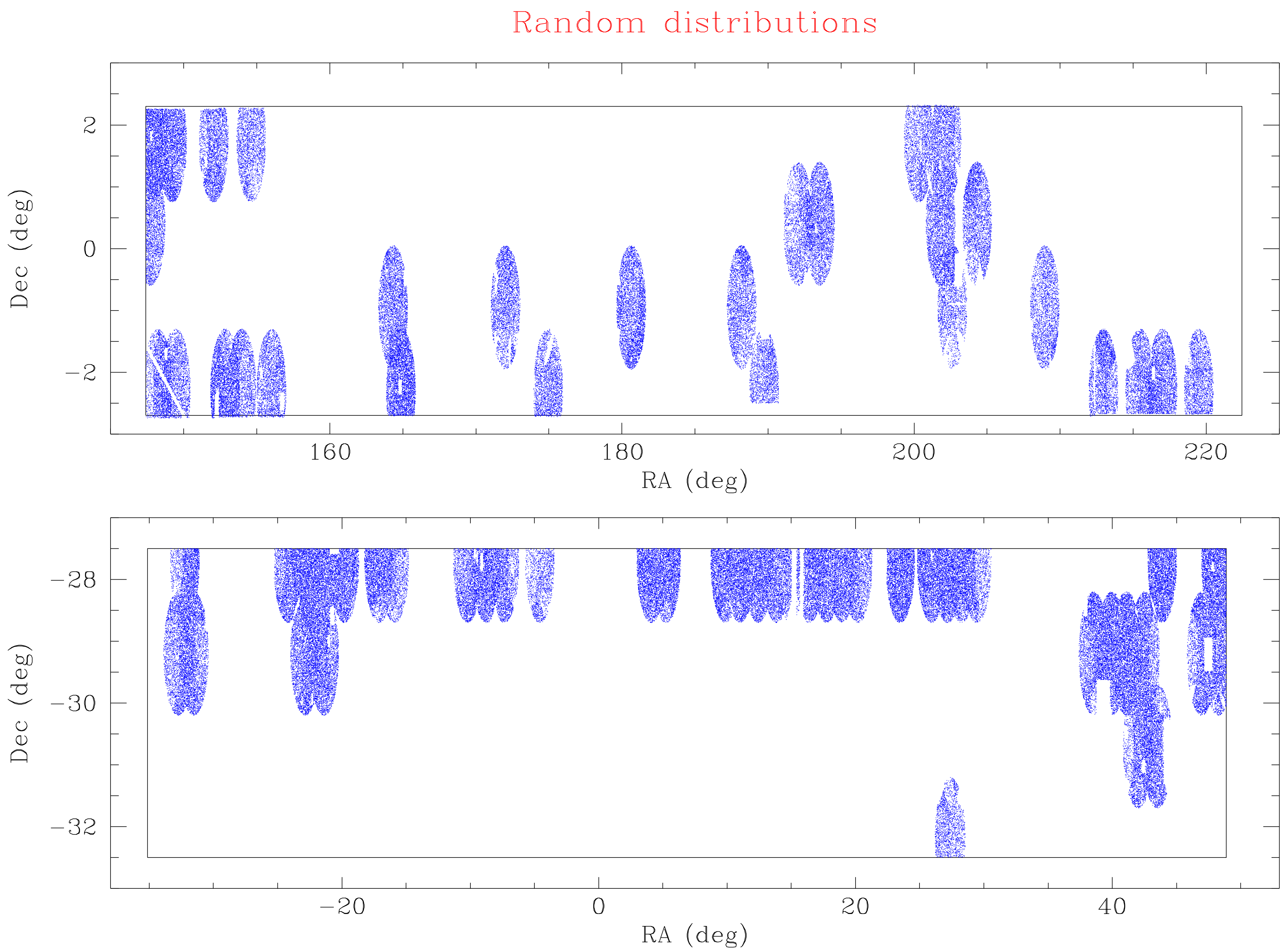
We have to correct for a number of selection effects:

1. **Partial coverage due to overlapping fields:** Modulate random distribution by the fraction of objects observed in each region.
2. **Deficeit of close pairs due to 2dF positioner:** Calculate $\omega(\theta)$ and weight randoms so that $\omega(\theta) = 0$ on small scales.
3. **Gradient in in candidate density:** Normalise within UKST fields.
4. **Galactic dust extinction:** Use Schlegel et al. extinction maps and weight randoms by the expected under-density of QSOs.

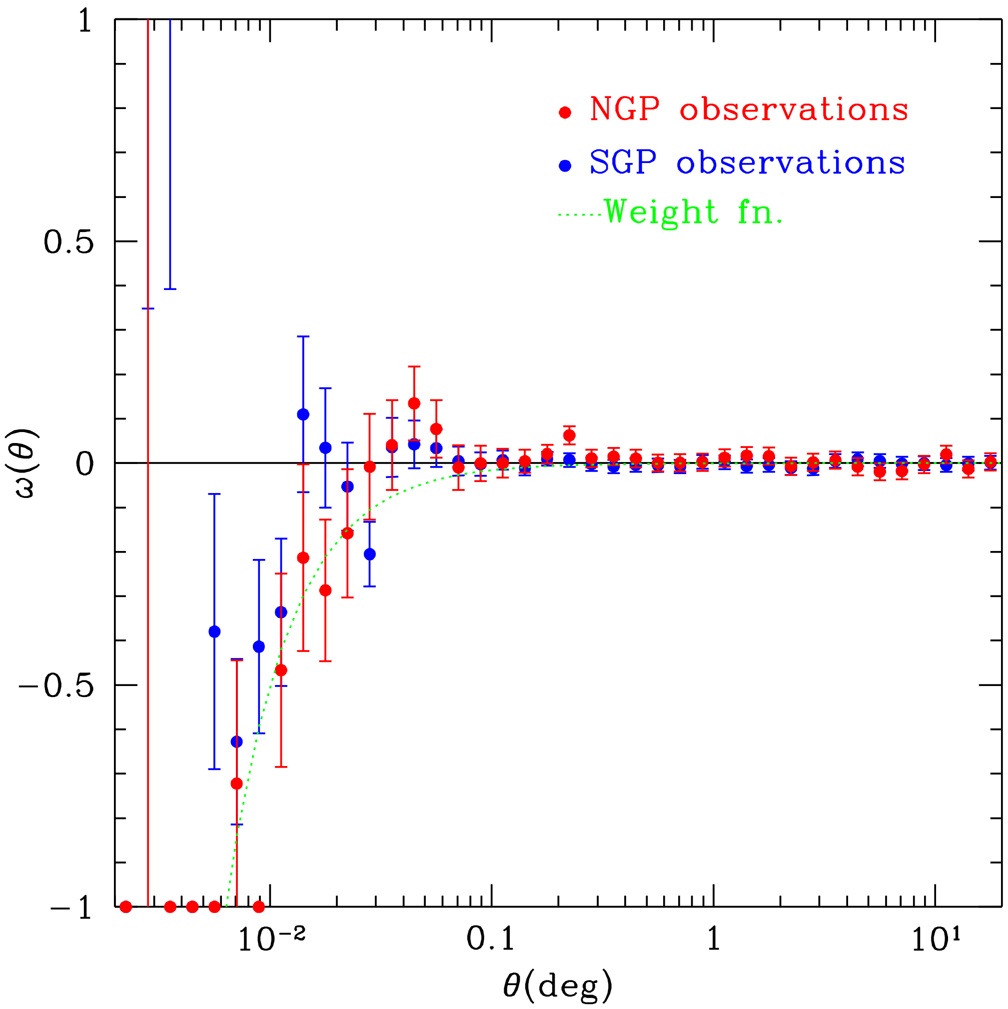


The 2dF QSO Redshift Survey
redshift, z
1
2
3
r comoving (h⁻¹Mpc)
1000
2000
3000
redshift, z
1
2
3
r comoving (h⁻¹Mpc)
1000
2000
3000


2dF QSO Survey Fields and QSOs
NGP:
Dec.
0
140
150
160
170
180
190
200
210
220
230
RA
SGP:
−30
−40
−30
−20
−10
0
10
20
30
40
50


Random distributions
Dec (deg)
2
0
−2
160
180
200
220
RA (deg)
Dec (deg)
−28
−30
−32
−20
0
20
40
RA (deg)

Close pairs correction



$\omega(\theta)$ for all observed QSO candidates in the NGP (2678 objects) and SGP (4201 objects) strips, after correcting for partial coverage and candidate density gradients.

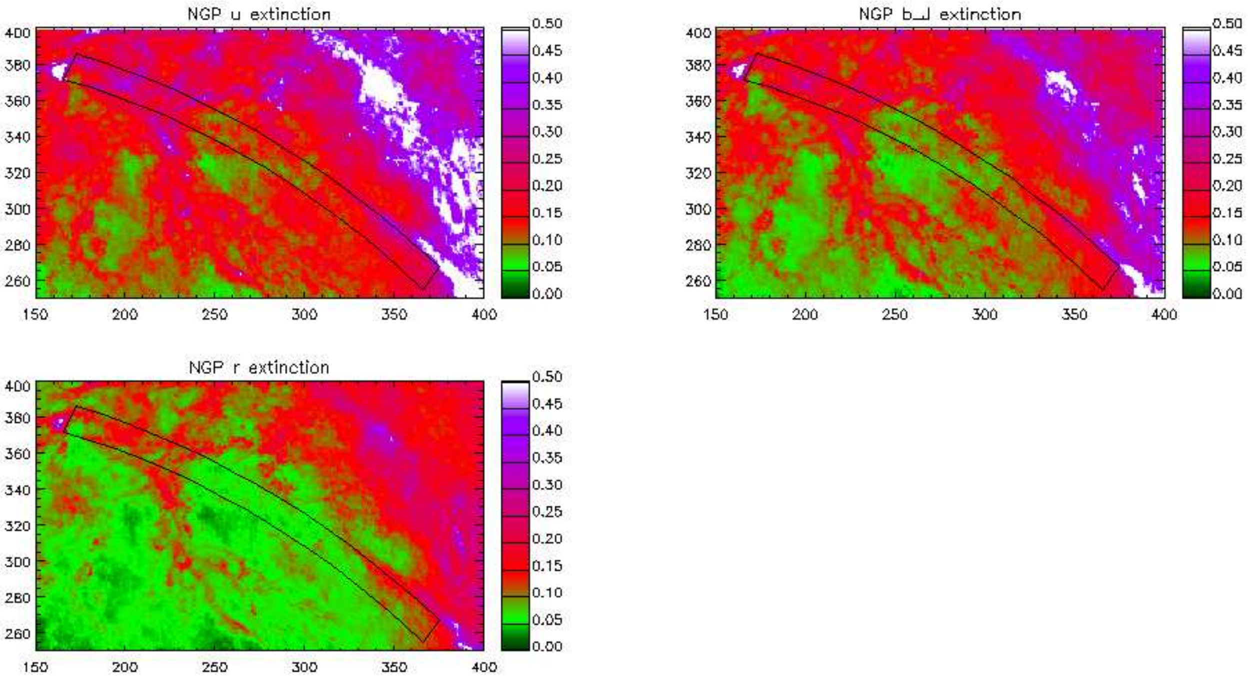
Weighting fn:

$$W(\theta) = 0.0005\theta^{-1.5}$$

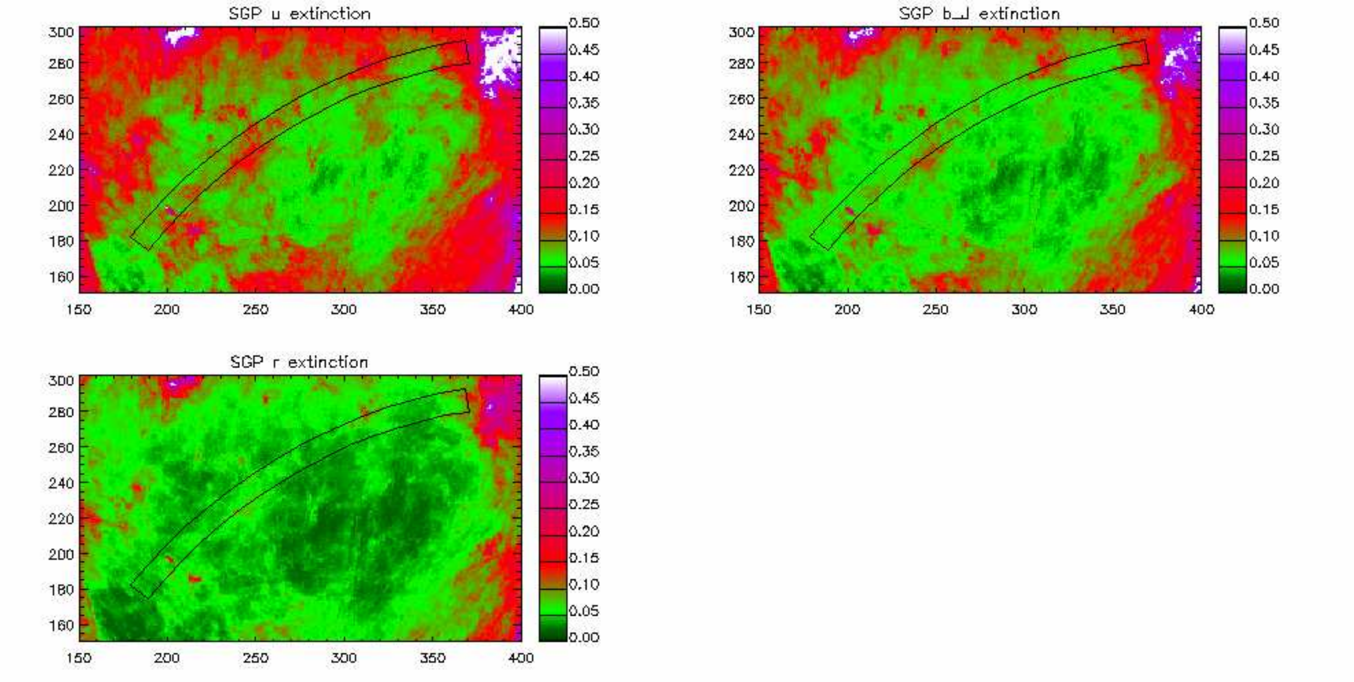
But, negligable effect on $\xi(r)$ due to projection effects. Most close angular pairs have different redshifts

Extinction in the 2dF QSO Redshift Survey

NGP:

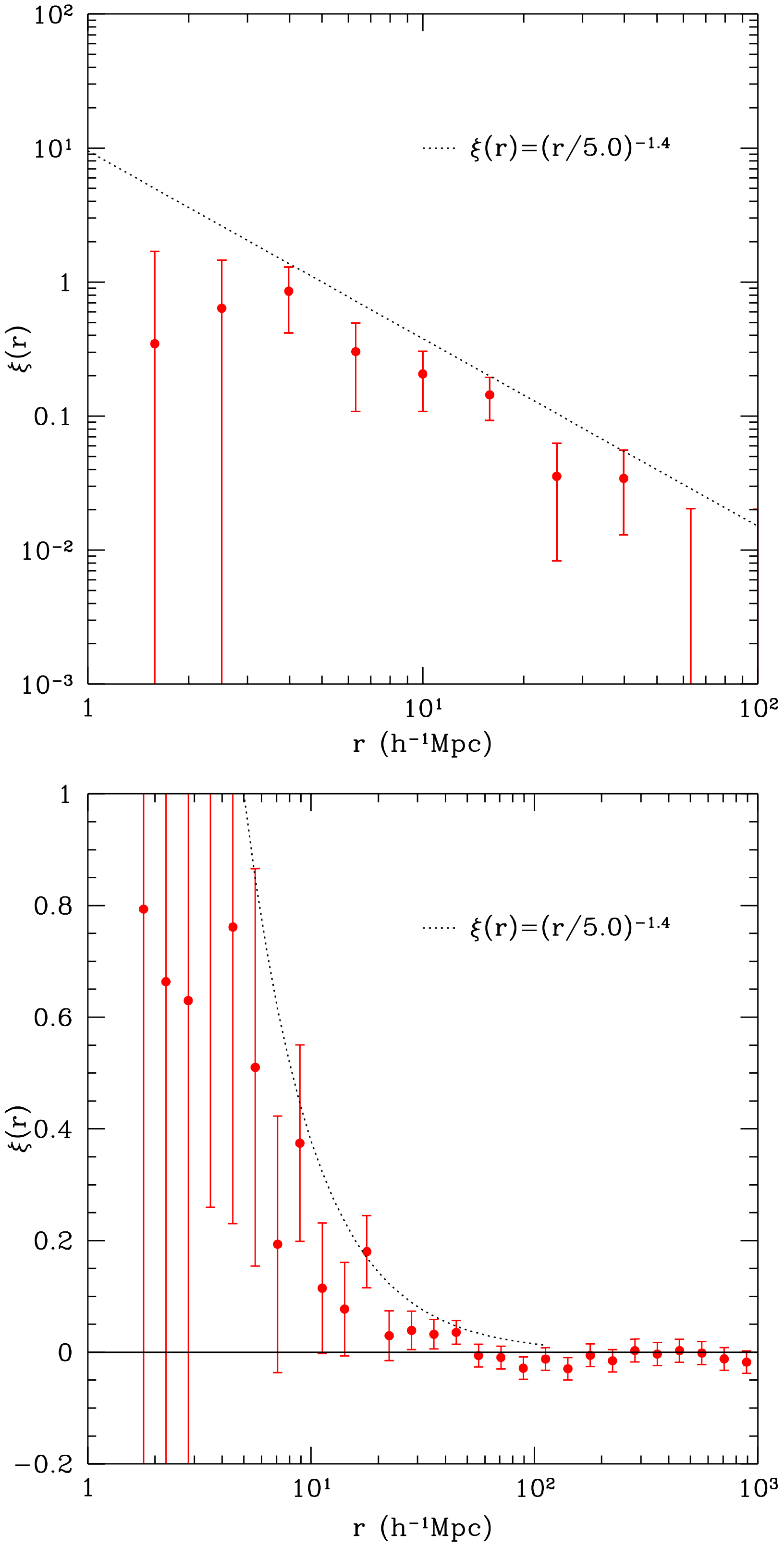


SGP:



Schlegel, Finkbeiner & Davis, (1998)

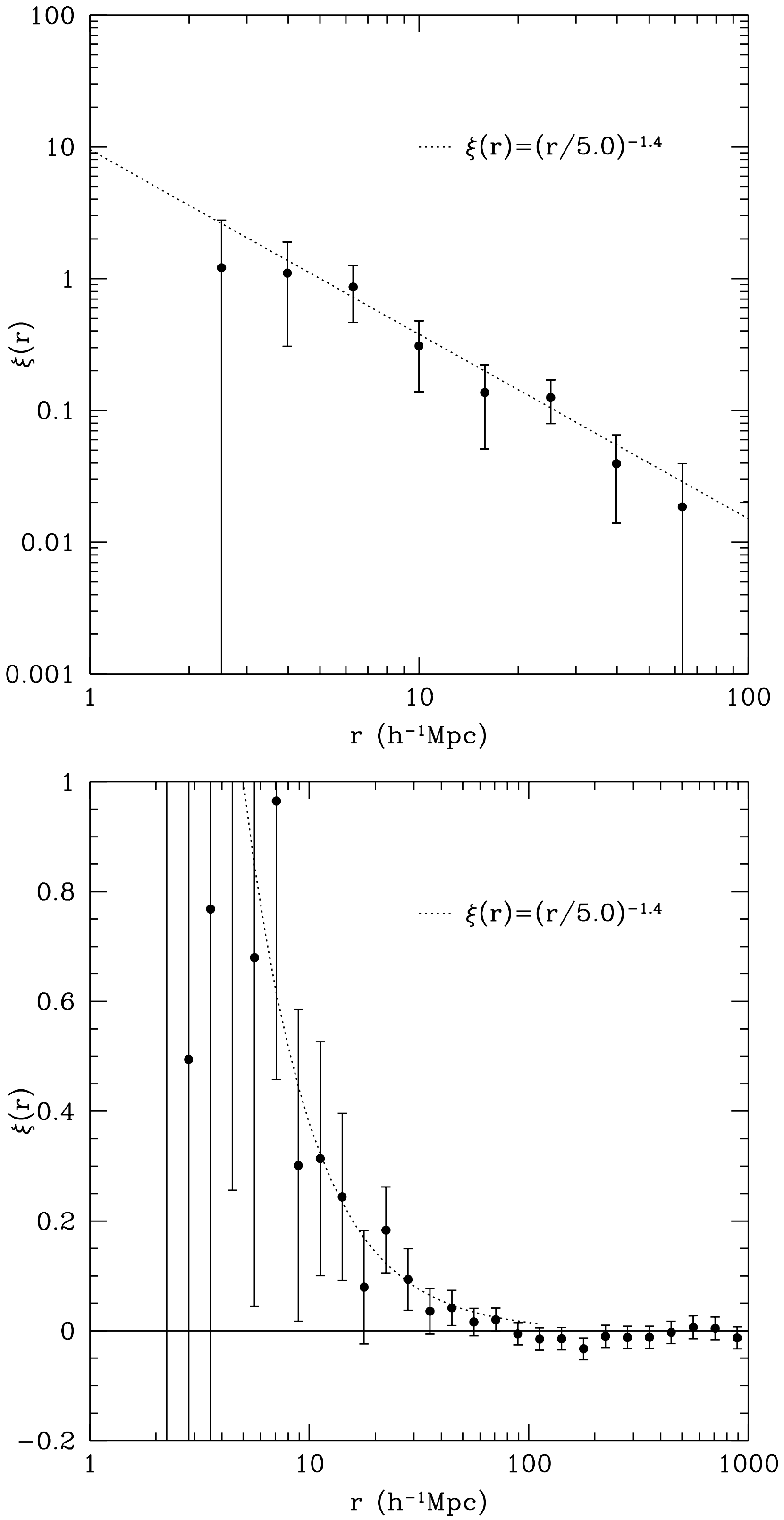
2dF QSO Redshift Survey $\xi(r)$



0.3<z<2.2, $\Omega_0 = 1$. 2376 QSOs.

Best fit: r_0=3.28$^{+0.88}_{-1.20}$$h^{-1}$Mpc, γ=1.43$^{+0.31}_{-0.32}$

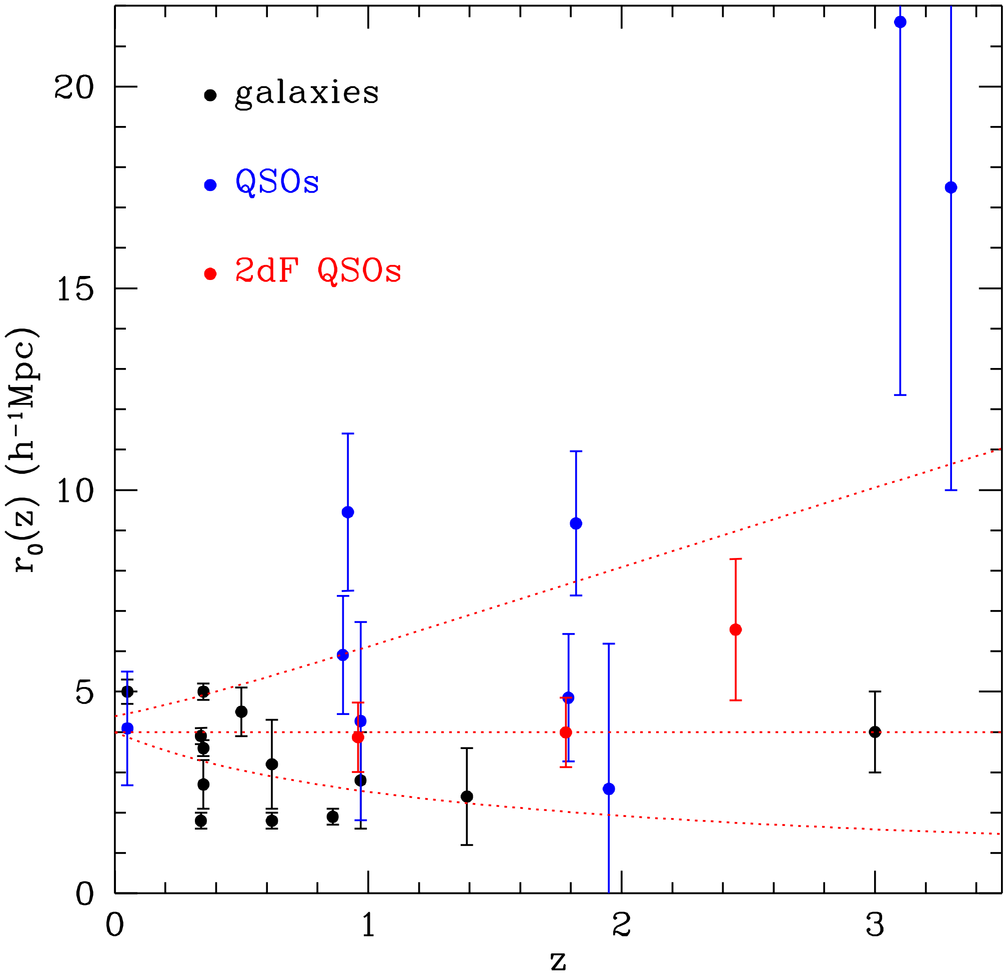
2dF QSO Redshift Survey $\xi(r)$ (λ_0=0.7)



0.3<z<2.2, Ω_0=0.3, λ_0=0.7 2376 QSOs.

Best fit: r_0=4.79$^{+1.01}_{-1.30}h^{-1}$Mpc, γ=1.46$^{+0.26}_{-0.27}$

2dF QSO clustering evolution



Clustering evolution compared to 3 simple models:

- Matarrese et al. 1997, transient model, $M_{min}=10^{13}M_{\odot}$ (top).
- Stable clustering in comoving coordinates (middle).
- Stable clustering in proper coordinates (bottom).

Clearly these simple models cannot adequately describe clustering evolution.

Summary

The current 2dF QSO Redshift Survey contains 6824 QSOs (Aug. 99). We have taken a sample of 2765 QSOs (data up to March 99) to measure large-scale structure, $\xi(r)$, and its evolution.

- At z=0.3–2.2 and Ω_0=1:
  $r_0=3.28^{+0.88}_{-1.20} h^{-1}$Mpc, $\gamma=1.43^{+0.31}_{-0.32}$
- At z=0.3–2.2 and Ω_0=0.3, λ_0=0.7:
  $r_0=4.79^{+1.01}_{-1.30} h^{-1}$Mpc, $\gamma=1.46^{+0.26}_{-0.27}$
- Evolution: constant in comoving coordinates up to z$\sim$2, possible increase at higher z (currently marginally significant).

Simulations:

- We use both Zeldovich approx. and full N-body (Hubble Vol.) simulations to test measurements of LSS with QSOs
- On small scales we can measure r_0 to $\sim$5% and γ to $\sim$3%.
- On large scales P(k) can be measured to K$>$0.01 h Mpc^{-1}.
- Accuracy of P(k) depends on the shot noise power.
- Continuing work on biasing, geometric distortions...