The Clustering of Low-redshift $z \leq 2.2$ SDSS Quasars

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Motivation

• Quasars (luminous AGN) long suspected of being powered by accreting SMBH at galaxy centre (Salpeter, Zel’dovich, Lynden-Bell 1960s; Rees 1970s/80s)

• More recent (local) evidence suggests all massive galaxies have SMBH with $M_{\text{BH}} \sim L \sim \sigma^4$ (e.g. Magorrian98, Gebhart00) e Galaxy/Star Formation and evolution connection, AGN Feedback (??)

• Clustering measurements can give you $M_{\text{halo}}, t_Q,e,$ (Martini01, Wyithe05). Also can give strong constraints for theoretical models/simulations (especially at $z>2$).

• Quasars can be seen to large distances e.g. at $z=2.2$ 80% age of Universe e evolution of clustering
Motivation

• Quasars relatively rare objects, need to cover large areas
• Mid-1990s, largest quasar samples $\approx 10^3$ objects
• Need: clean photometry, multiplexing instrument, large FoV
• SDSS ideal for large quasar survey:
  ➢ High quality 5-band photometry, select targets
  ➢ Very large area coverage (1000s deg$^2$)
  ➢ Multi-fibre spectroscopic follow-up, moderate resolution spectra
• Two major quasar surveys over last 10 years:
  ➢ 2dF QSO Redshift (2QZ, Croom’04, 23,338 QSOs)
  ➢ SDSS Quasar Survey ($>100,000$ objects observed)
Data

- **SDSS DR5 Quasar Catalogue**: 77,429 quasars ($M_i<-22$ and one line $>1000$ km s$^{-1}$).
- “Primary” target flag: Selected in $ugri$ colour-space, $i<19.1$ ($z_{MB}$); $griz$ $i<20.2$ for $z\geq 3$; or point-source match to FIRST at $i<19.1$ e 55,577 objects, 46,272 at $zM2.2$, 5713 deg$^2$.
- “UNIFORM” (Richards06, Shen07 at $z>2.9$); e 38,208 objects; 30,239 at $0.3\leq z\leq 2.2$ over 4013 deg$^2$
- Avoid $2.2<z<2.9$ due to low-completeness
Uniform sample coverage

DR5Q

Uniform
Data

- $M_I$ vs. redshift ($z$)

77,429 (dr5q)
30,239 (uni)
\( e(r) \) represents the excess probability of finding a PAIR of objects compared with a random distribution:

\[
dP_{12} = n^2 \left( 1 + x(r) \right) dV_1 dV_2
\]

- **Power Law behaviour:**

\[
x(r) = \frac{-g}{r - r_0}
\]

- **Measure the redshift-space CF which include peculiar velocities due to cluster infall and random motions leading to “redshift-space distortions”:**

\[
x(s, p)
\]

- **Can measure \( e \) in two dimensions, with perpendicular, \( e \) and parallel, \( e \) to line-of-sight where**

\[
S^2 = s^2 + p^2
\]
Results: $\xi(s)$

- **SDSS DR5**
  - $e(s), i<19.1$
  - $s_o=5.95e0.45 \, h^{-1} \, \text{Mpc}$
  - $e=1.16e0.14$
  - (also $x(s,p)$)

- **2QZ**
  - Croom 2005
  - $18.25 < b_J < 20.85$
  - ($g \approx 20.80, i \sim 20.4)$

- **2SLAQ**
  - da Angela 2008
  - $18 < g < 21.85$

Ross et al. (2008, in prep.)
Results: $\xi(r,z)$

- Evolution of clustering; real-space
- SDSS (optical) quasars
  - Myers et al. 2006
- X-ray selected AGN from deep, small area surveys e.g. Chandra Deep Fields; XMM-COSMOS
Results: Linear bias $b(z)$ ($z < 3$)

- $\xi_Q = b^2 \xi_m$
- Basilakos'08 models, at $z < 3$ gives:
  $M_{DMH} \sim 5 \times 10^{12} - 1 \times 10^{13} h^{-1} M_{\odot}$
- Jing98: $5 \times 10^{11} - 2 \times 10^{12} h^{-1} M_{\odot}$
- Sheth01: $5 \times 10^{11} - 4 \times 10^{12} h^{-1} M_{\odot}$
Results: Linear bias $b(z)$ (high-z)

- High-z quasars from Shen et al. (2007)
- LBGs from McLure et al. (0805.1335)
- Hopkins’07 models e “Uniform Growth”
Results: Radio and Brightest quasars

Shen et al. (2008, in prep.)
Conclusions

• Measured clustering of 30,239 SDSS Quasars at $z \approx 2.2$
• Single power-law acceptable fit over $1<s<25 \, h^{-1} \, \text{Mpc}$, $s_0=5.95e0.45 \, h^{-1} \, \text{Mpc}$; $e=1.16e0.14$ and very similar clustering behaviour to 2QZ and 2SLAQ surveys.
• Evolution of $\xi$ very weak at $z<2$, stronger at $z>2$
• $r_0$ values generally lower than deep X-ray surveys (also see Ryan Hickox talk…)
• Linear bias evolution $M_{DMH} \sim 5 \times 10^{12}-1 \times 10^{13} \, h^{-1} \, M_{\odot}$ and "Uniform Growth" model describes high-$z$ data very well. LBGs progenitors $L^* \, z<2$ quasars (?)
• Radio and most Luminous 10% quasars highly-clustered.
• Final SDSS Quasar catalogue (DR7) doubles no. quasars
Results: $\xi(\sigma, \pi)$

- SDSS Quasar
  $\xi(e, e)$
- $e = e_m^{0.6}/b$
  $= 0.43e^{0.01}$
  (at $z=1.27$)
- Potential for cosmology; growth of structure but low space-density of quasars
  e low S/N
Results: $\xi(s,z)$

- Evolution of clustering redshift-space
- Not strong, $s_0=6-7\ h^{-1}\text{Mpc}$
- SDSS Quasars
  - 2QZ (Croom’05)
  - SDSS AGN (Wake’04)
Results: $\xi(s)$

- 2-Point Correlation Function; use LS estimator
- Jackknife errors
- Redshift-space
- Single PL; $s_0 = 5.95 \pm 0.45 \ h^{-1} \ Mpc$; $e = 1.16 \pm 0.14$

Ross et al. (2008, in prep.)