Small-scale AGN clustering measurements

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Based on
IK and Oguri 2012, MNRAS, 424, 1363
IK and Oguri, in preparation

Existence of small-scale pairs

- How to ignite the AGNs
  - Major mergers
  - Tidal torques, minor mergers, …
- Existence of close pairs means they are ignited simultaneously (in quasar lifetime).
  - If major merger results in one quasar, two major merger events should be occurred simultaneously?
  - Tidal interaction or minor mergers ignite two quasars simultaneously?
- Close pairs could be important clue to study the mechanism of triggering.

Lensed quasar or not

- Quasar pairs with several arcsec have found.
  - Optical spectra are similar with little difference in their redshifts
  - Gravitational lenses or physical associated pairs??
  - “Dark lens”??
- Comparing to the expected number of lensed quasars (~a few), number of controversial pairs was too large.

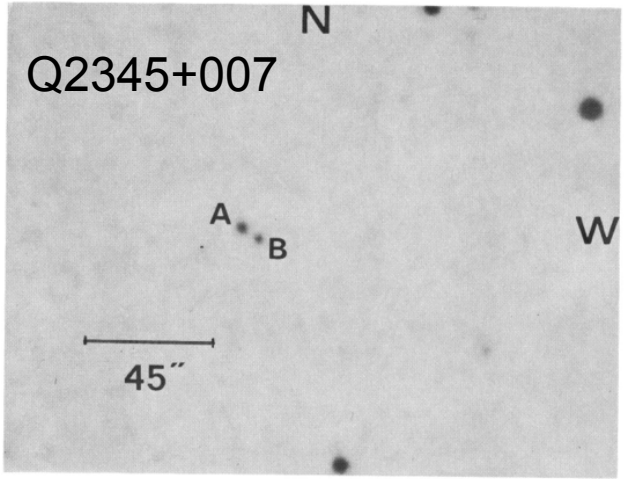
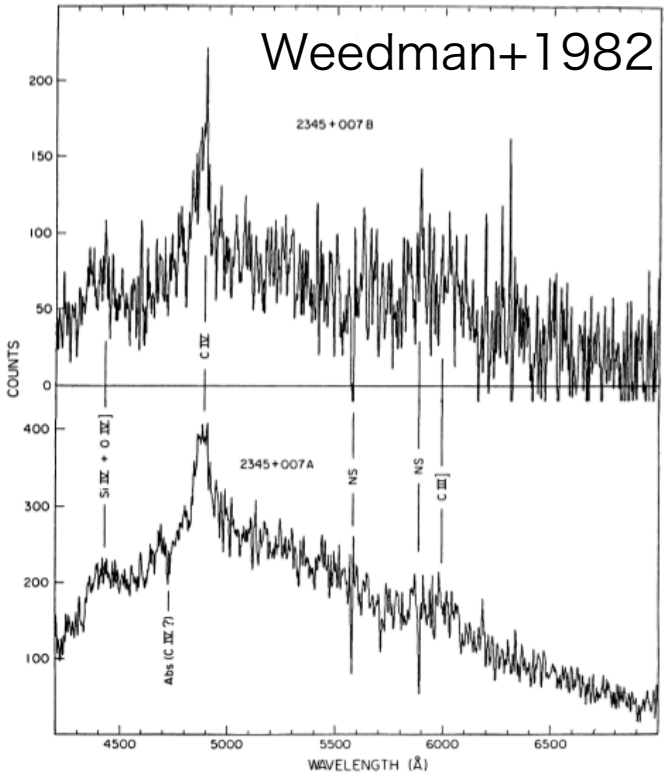
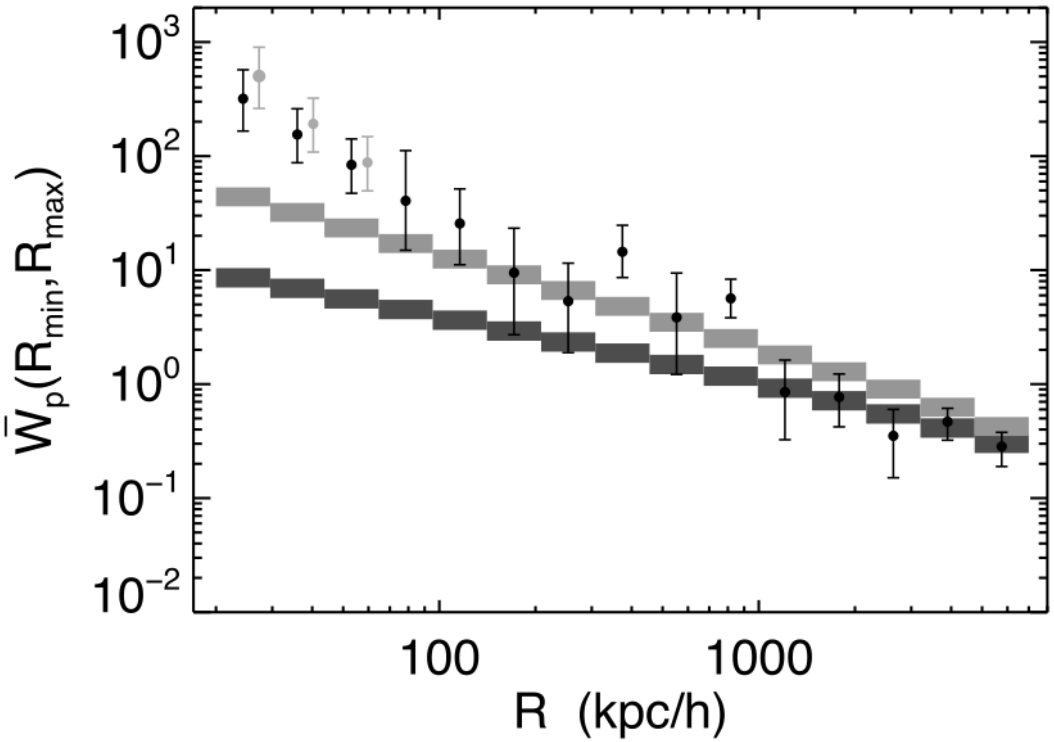


FIG. 1



Reliable measurement of clustering amplitude of quasars at these small-scale is needed.

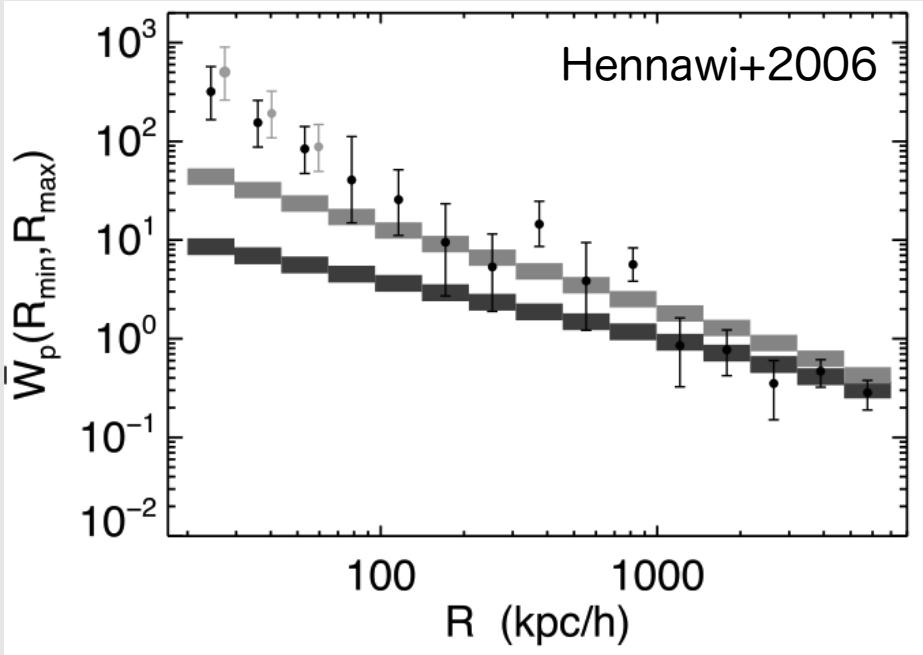
Hennawi+2006



- First massive search for quasar pairs
  - 221 pairs!
  - 24 with θ < 10"
- Found very strong clustering.
- Myers+2008
  - Complete catalogue
  - 10 with 3" < θ < 6"
  - Smaller signal but consistent

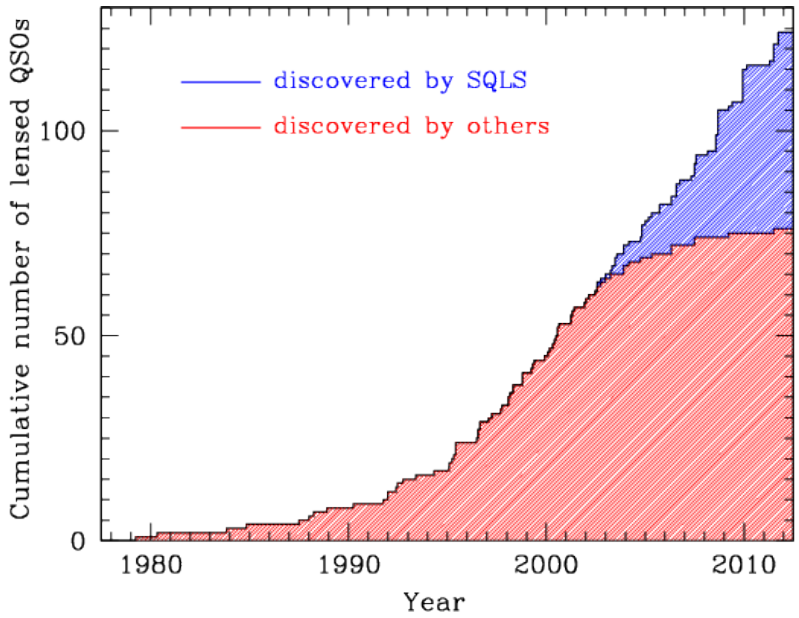
Quasar Environment

- Dense region?
  - Strong clustering

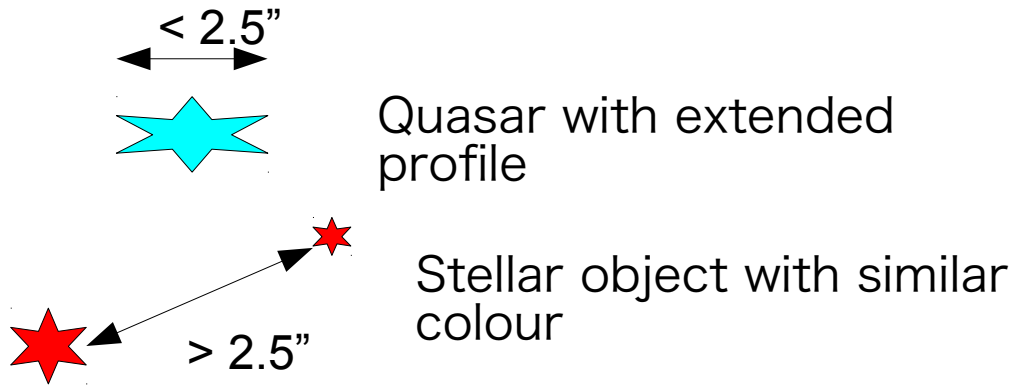


- Not very dense?
  - Small velocity difference (e.g. Farina+2011)
  - Little number of associated galaxies (e.g. Fukugita+2004)
- Property of quasar pairs is not different from isolated quasasr (Green+2011)

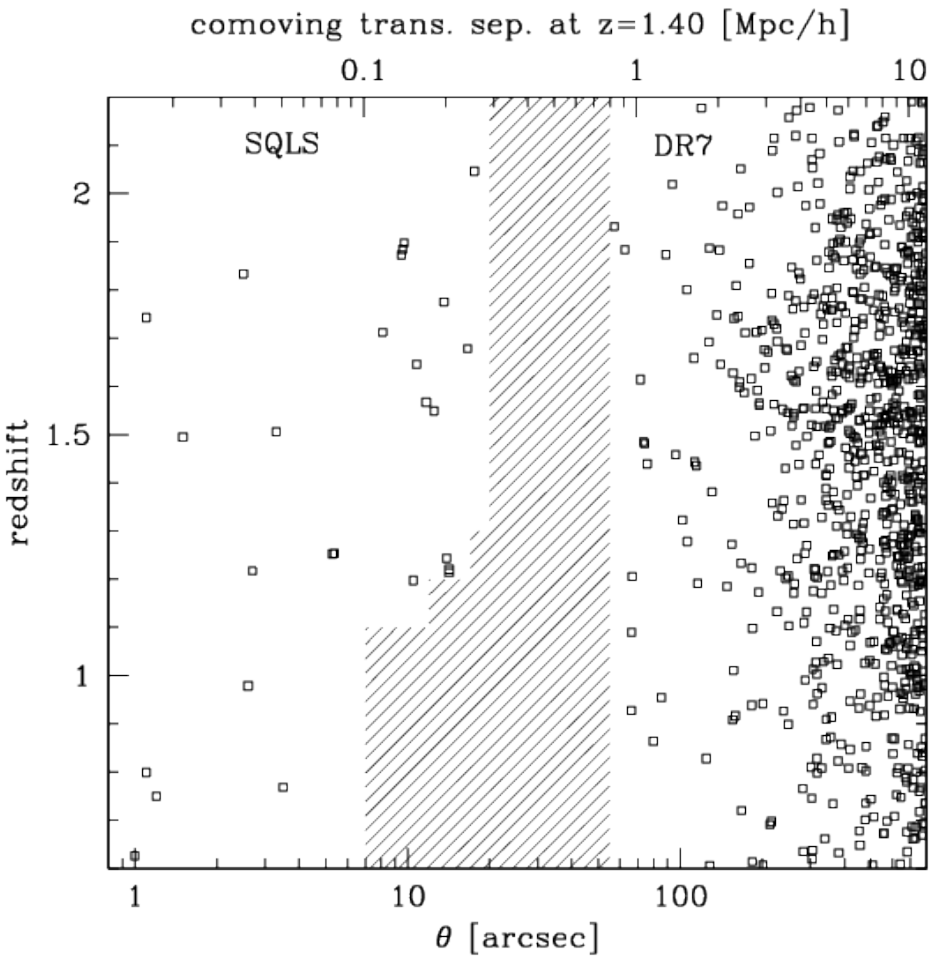
SQLS (SDSS Quasar Lens Search)



- A project to find gravitationally lensed quasars from SDSS Quasar catalogue
  - We have found ~60 lenses out of 500 candidates (which are from 50,000 quasar source catalogue).



Quasar Pair Catalogue



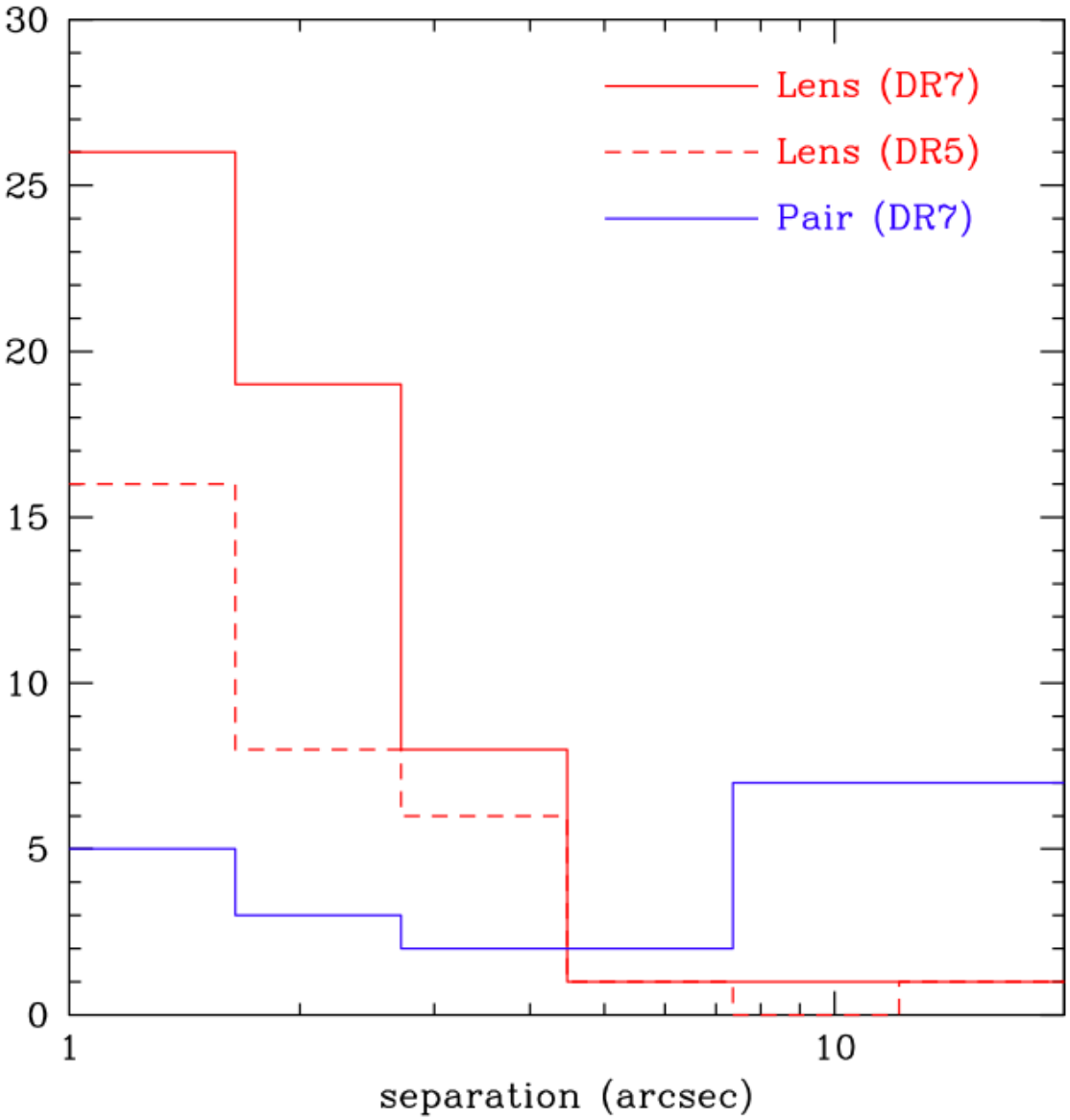
- Follow-up observations reject many false candidates, but some are realized to be quasar pairs with little redshift difference.
- “Garbage Collection” from a complete survey of quasar lenses.
  - 6(known)+20(new)=26

Table 1. Binary quasar sample from the SQLS (Inada et al. 2008, 2010, 2012). The typical error on the velocity measurement is a few hundred km s^{-1}.

Name	RA (A) (J2000)	Dec. (A) (J2000)	RA (B) (J2000)	Dec. (B) (J2000)	z_A	z_B	i_A [a] (mag)	i_B [a] (mag)	$\Delta\theta$ (arcsec)	$\lvert\Delta v\rvert$ (km s^{-1})
SDSS J0740+2926[b]	07 40 13.44	+29 26 48.3	07 40 13.42	+29 26 45.7	0.978	0.980	18.41	19.66	2.6	230
SDSS J0847−0013	08 47 10.41	−00 13 02.7	–	–	0.626	0.627	18.61	19.04	1.0	190
SDSS J0909+5801	09 09 55.55	+58 01 43.3	09 09 56.50	+58 01 40.5	1.712	1.712	18.96	20.17	8.1	0
SDSS J0918+2435	09 18 08.86	+24 35 50.1	09 18 09.07	+24 36 04.0	1.218	1.223	18.52	19.60	14.2	680
SDSS J0942+2310	09 42 34.98	+23 10 31.2	09 42 35.04	+23 10 28.9	1.833	1.833	18.99	19.70	2.5	0
SDSS J1000+5406	10 00 34.18	+54 06 28.6	10 00 34.86	+54 06 41.5	1.212	1.215	18.65	19.14	14.2	430
SDSS J1008+0351	10 08 59.55	+03 51 04.4	–	–	1.745	1.740	19.10	20.28	1.1	550
SDSS J1012+3650	10 12 11.30	+36 50 30.7	10 12 11.07	+36 50 14.4	1.678	1.678	18.81	20.01	16.6	0
SDSS J1035+0752[b]	10 35 19.37	+07 52 58.0	10 35 19.23	+07 52 56.4	1.216	1.218	19.03	20.11	2.7	270
SDSS J1120+6711[c]	11 20 12.11	+67 11 15.9	–	–	1.495	1.495	18.47	19.55	1.5	50
SDSS J1216+4957	12 16 47.22	+49 57 20.4	12 16 47.62	+49 57 10.6	1.200	1.195	18.34	19.55	10.5	680
SDSS J1250+1741	12 50 22.32	+17 41 44.5	12 50 22.32	+17 41 44.5	1.246	1.241	19.06	18.63	13.9	650
SDSS J1254+6104[b]	12 54 21.98	+61 04 22.0	12 54 20.52	+61 04 36.0	2.051	2.041	18.91	19.27	17.6	1010
SDSS J1358+2326	13 58 09.87	+23 26 10.1	13 58 10.68	+23 26 04.5	1.555	1.543	18.92	19.93	12.5	1400
SDSS J1400+2323	14 00 12.28	+23 23 46.7	14 00 12.86	+23 23 51.9	1.877	1.867	18.34	19.27	9.5	1040
SDSS J1430+0714[d]	14 30 02.88	+07 14 11.3	14 30 02.66	+07 14 15.6	1.246	1.261	19.01	19.68	5.4	1990
SDSS J1433+1450	14 33 50.94	+14 50 08.2	14 33 51.09	+14 50 05.6	1.506	1.506	18.82	19.19	3.3	0
SDSS J1511+3357	15 11 09.85	+33 57 01.7	–	–	0.799	0.799	18.94	19.63	1.1	80
SDSS J1518+2959	15 18 23.06	+29 59 25.5	15 18 23.43	+29 59 27.6	1.249	1.256	18.86	19.88	5.3	900
SDSS J1539+3020	15 39 37.74	+30 20 23.7	15 39 37.10	+30 20 17.0	1.644	1.648	18.67	19.73	10.8	450
SDSS J1552+0456	15 52 18.09	+04 56 35.3	15 52 17.94	+04 56 46.8	1.567	1.567	18.20	18.62	11.7	0
SDSS J1552+3009	15 52 25.63	+30 09 02.1	–	–	0.750	0.750	18.86	19.43	1.2	0
SDSS J1606+2900[d]	16 06 02.81	+29 00 48.7	16 06 03.02	+29 00 50.9	0.769	0.769	18.31	18.38	3.5	0
SDSS J1635+2052	16 35 20.05	+20 52 25.2	16 35 19.51	+20 52 13.9	1.775	1.775	19.03	20.07	13.6	90
SDSS J1655+2605	16 55 02.01	+26 05 16.5	16 55 01.32	+26 05 17.5	1.890	1.879	17.63	17.77	9.6	1140
SDSS J2111+1050	21 11 02.61	+10 50 38.4	21 11 02.41	+10 50 47.6	1.897	1.897	18.87	19.02	9.7	120

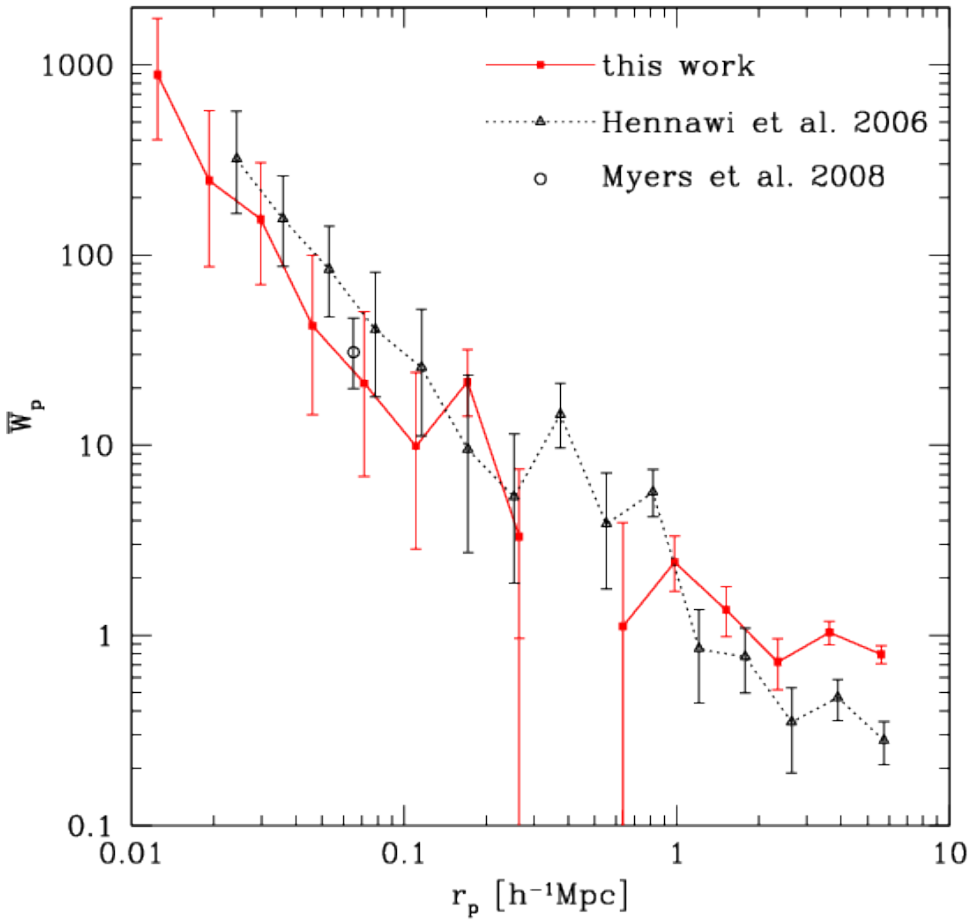
[a] i-band point spread function magnitudes with Galactic extinction correction.
[b] Originally reported in Hennawi et al. (2006).
[c] Originally reported in Pindor et al. (2006), and also included in Hennawi et al. (2006).
[d] Originally reported in Myers et al. (2008).

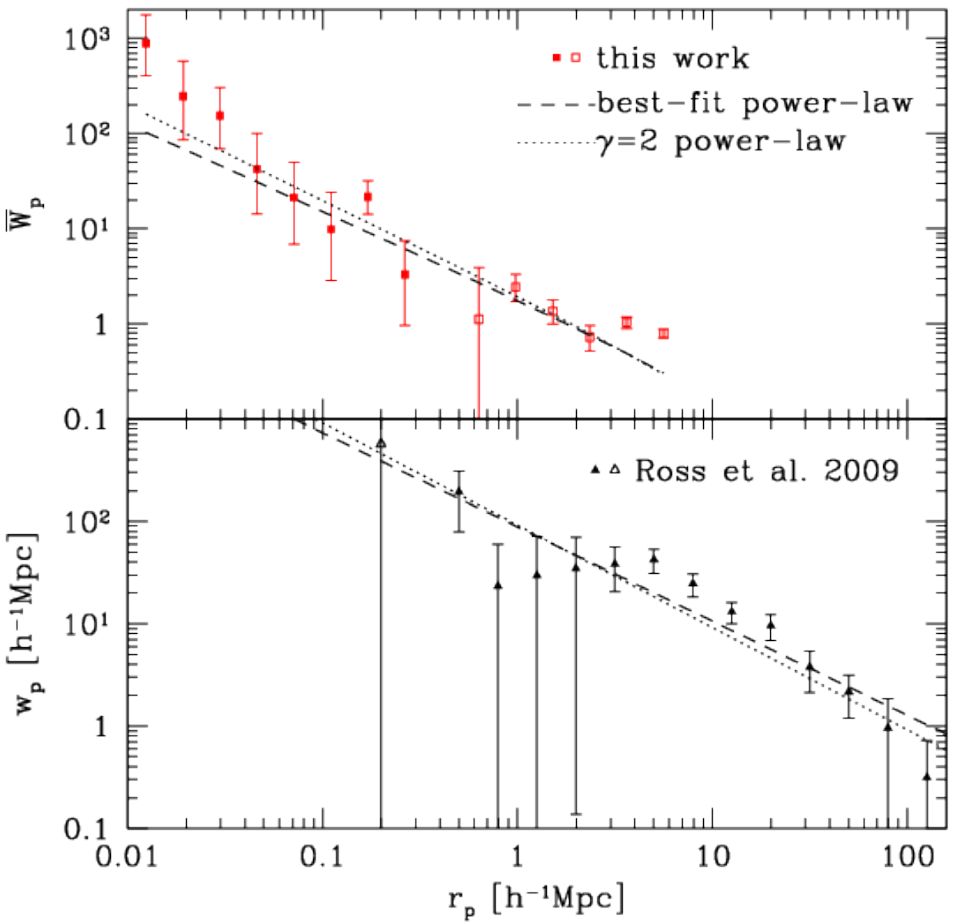
#lenses and #pairs in SQLS



- Lenses dominate at ~ a few arcsec.
  - The major lensing objects are galaxies.
- Pairs become majority over several arcsec.
  - Lensing by groups or clusters is rare.

Projected 2PCF

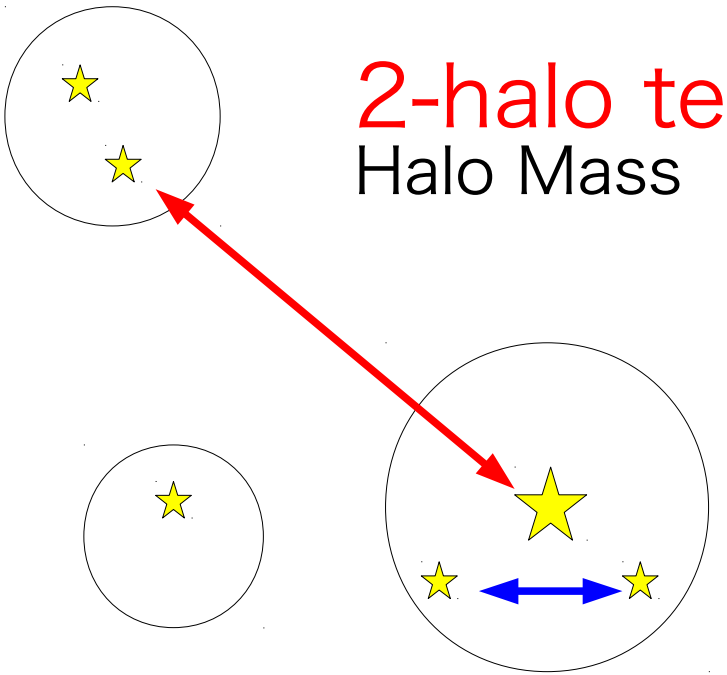




Strong clustering down to ~10 kpc/h

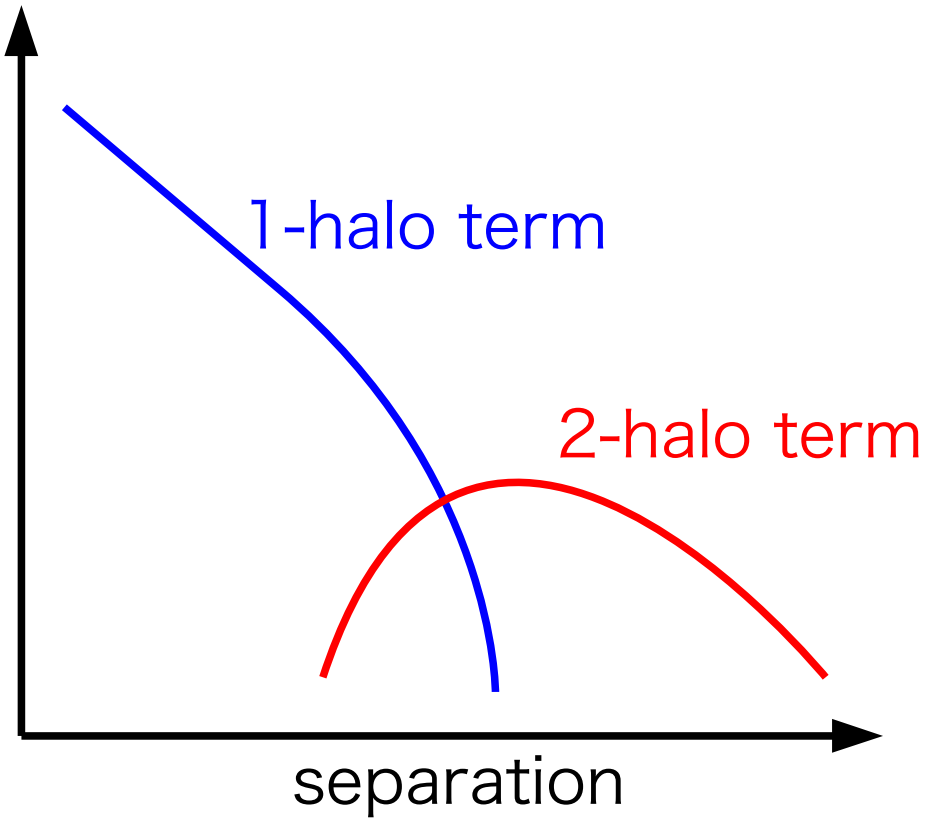
HOD Modeling

- Halo Occupation Distribution

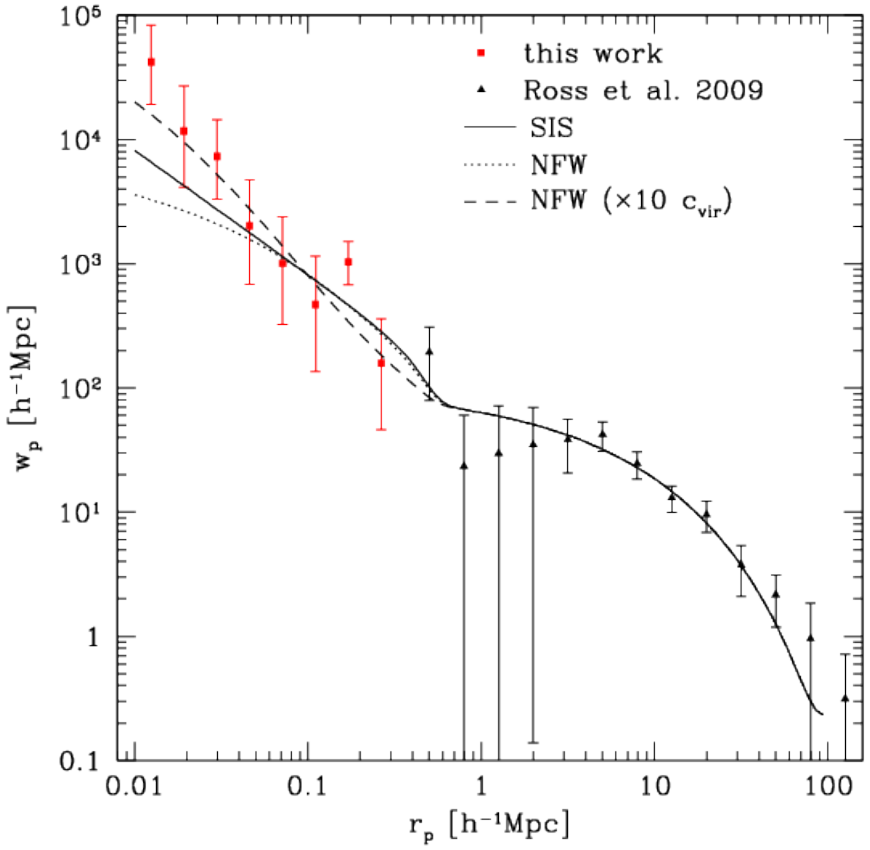


2-halo term
Halo Mass

1-halo term
Distribution in a halo
(profile, central/satellite)

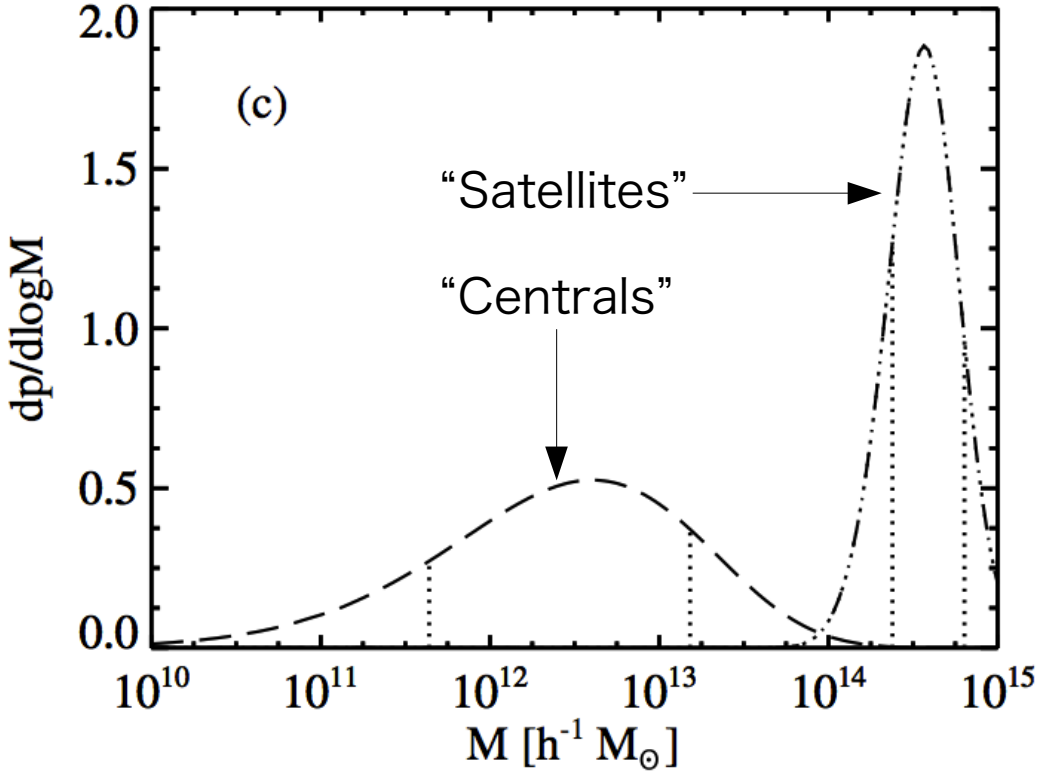


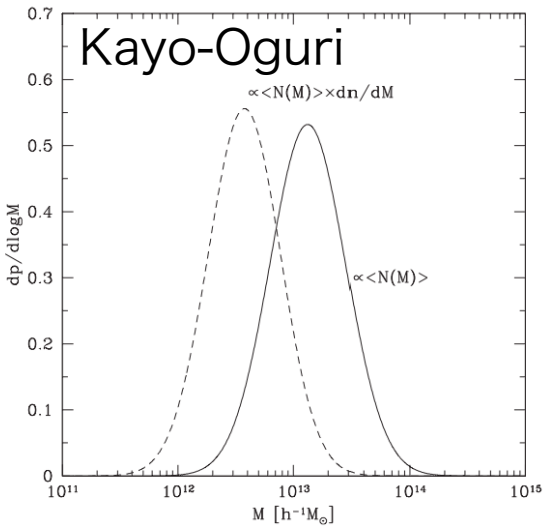
HOD results

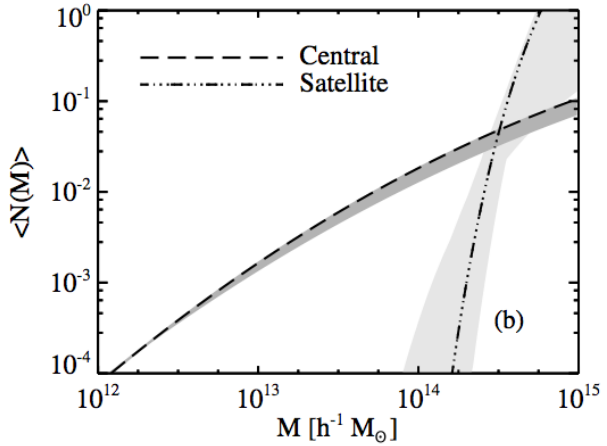


- Halo Mass: $10^{12\text{-}13} M_\odot/h$
- SIS or normal NFW profile cannot reproduce the steep correlation.
  - We need strongly concentrated profile.
  - ~10 times larger concentration parameter
- A sign of direct interaction to ignite the quasars?

Richardson+2012

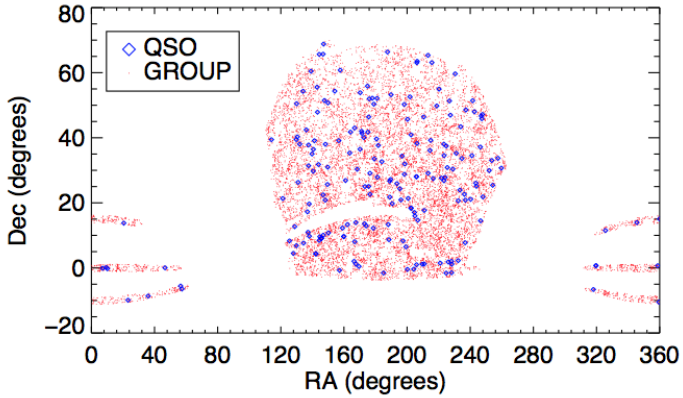


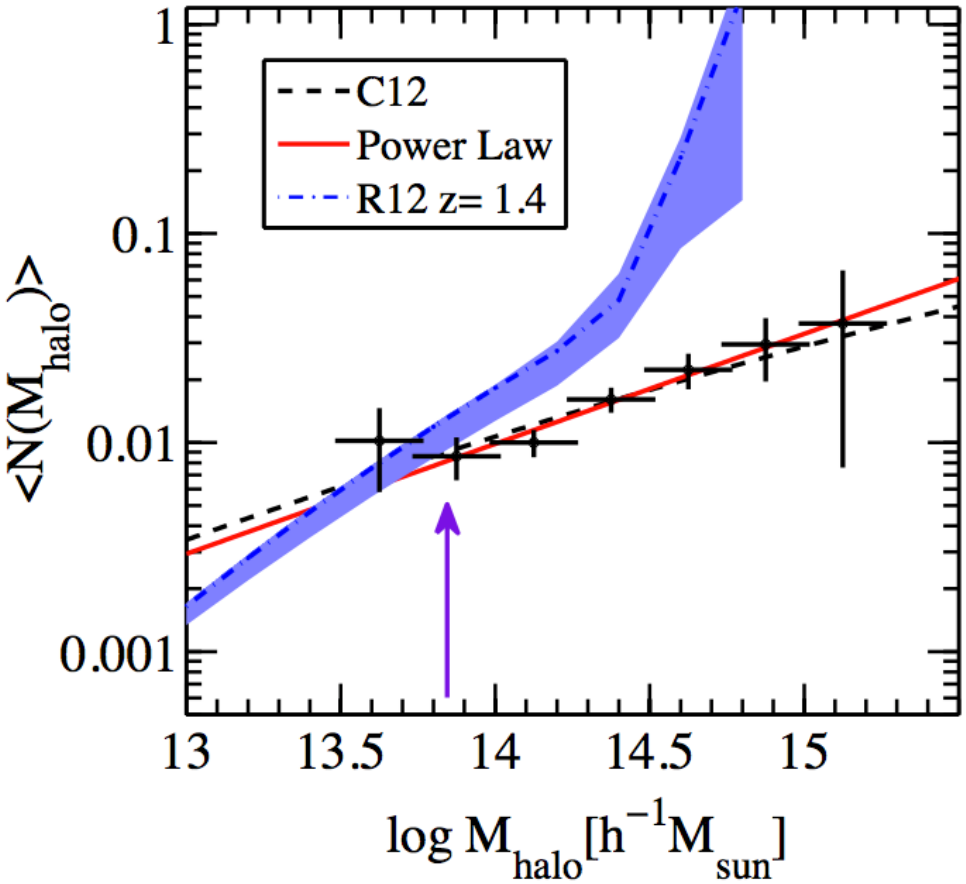




- Quasar pair catalogue of Hennawi+2006
- Predicts that satellite quasars locate in cluster environment
  - Very different from KO-HOD results.
- Prediction of satellite fraction is also very different
  - 0.7% (5% in KO)

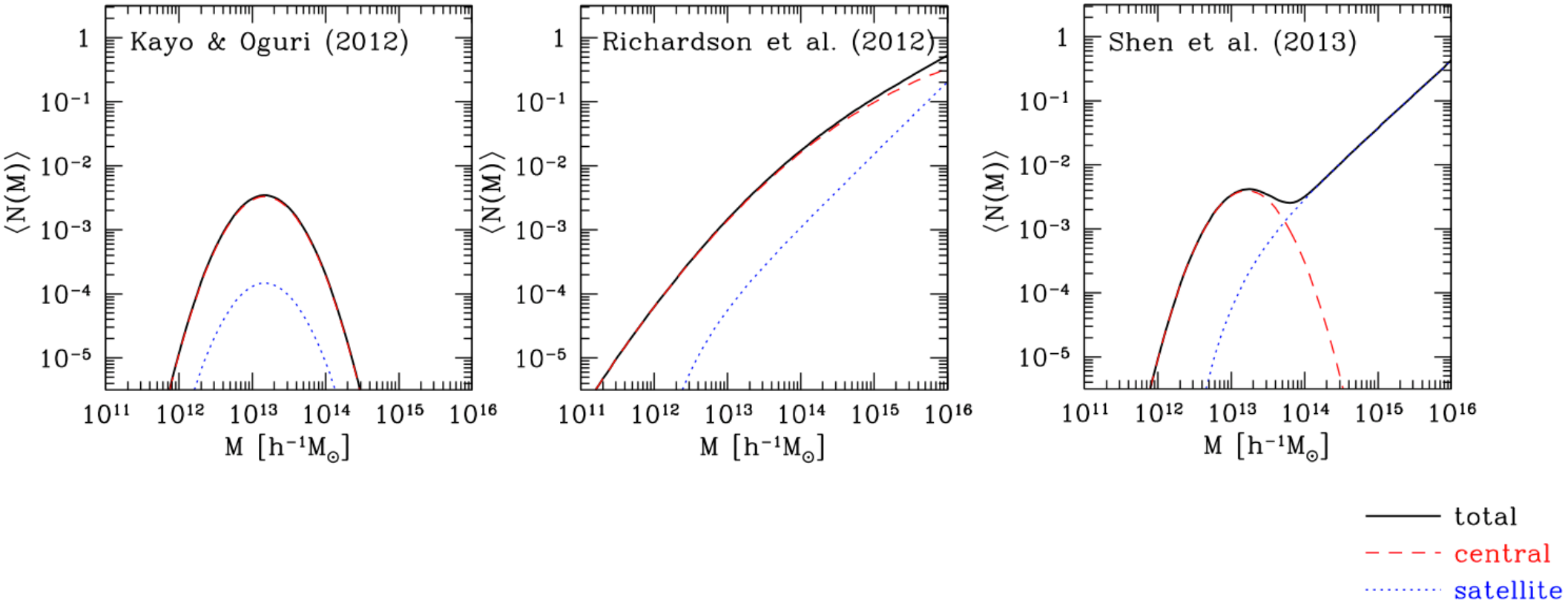
Chatterjee+2014





- Direct construction of HOD
  - By low-z quasar – group of galaxies matching
  - Found power-law increase of <N> with halo mass.
  - KO-HOD is unlikely
- Exciting talks will be given in this session. We are so lucky!

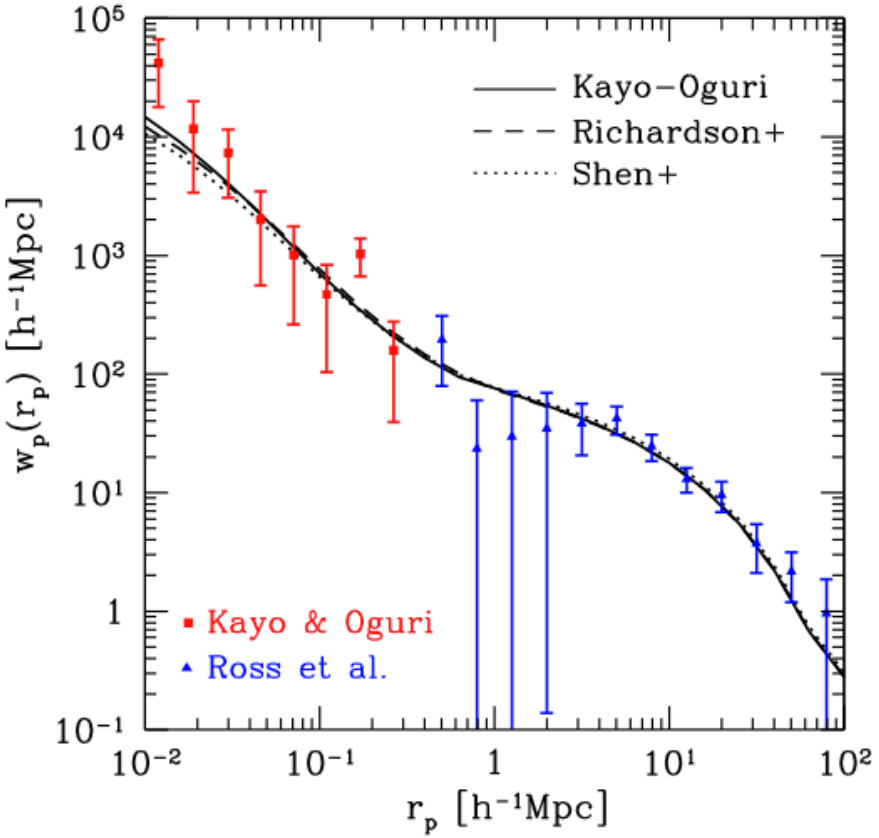
Limitation of projected 2PCF



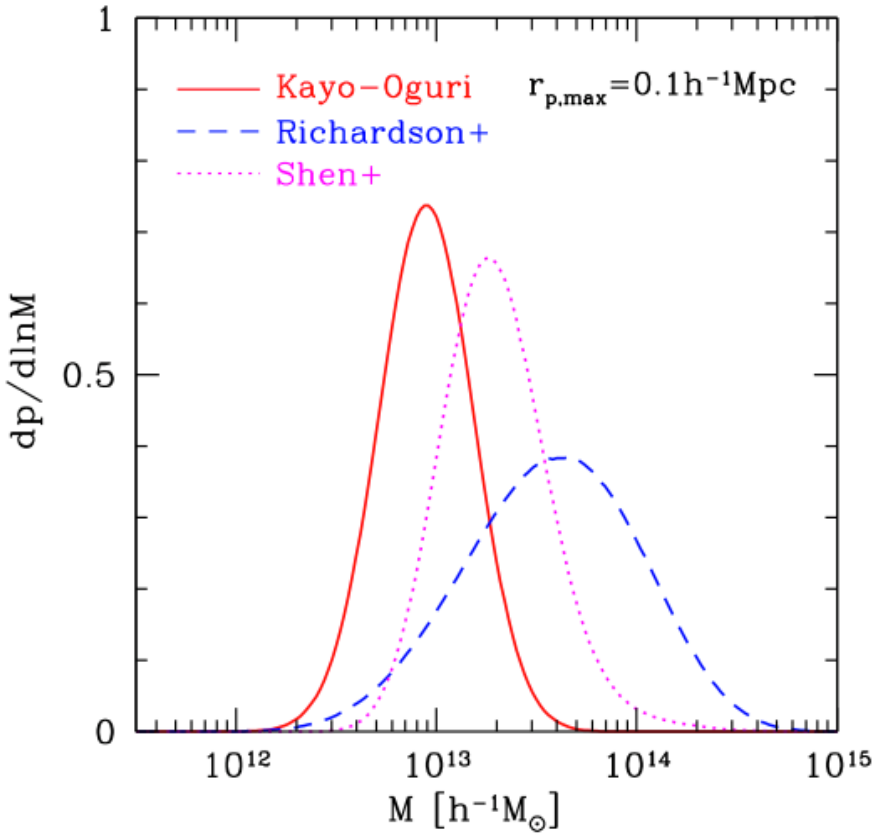
Very different HODs predict...

Limitation of projected 2PCF

identical clustering,

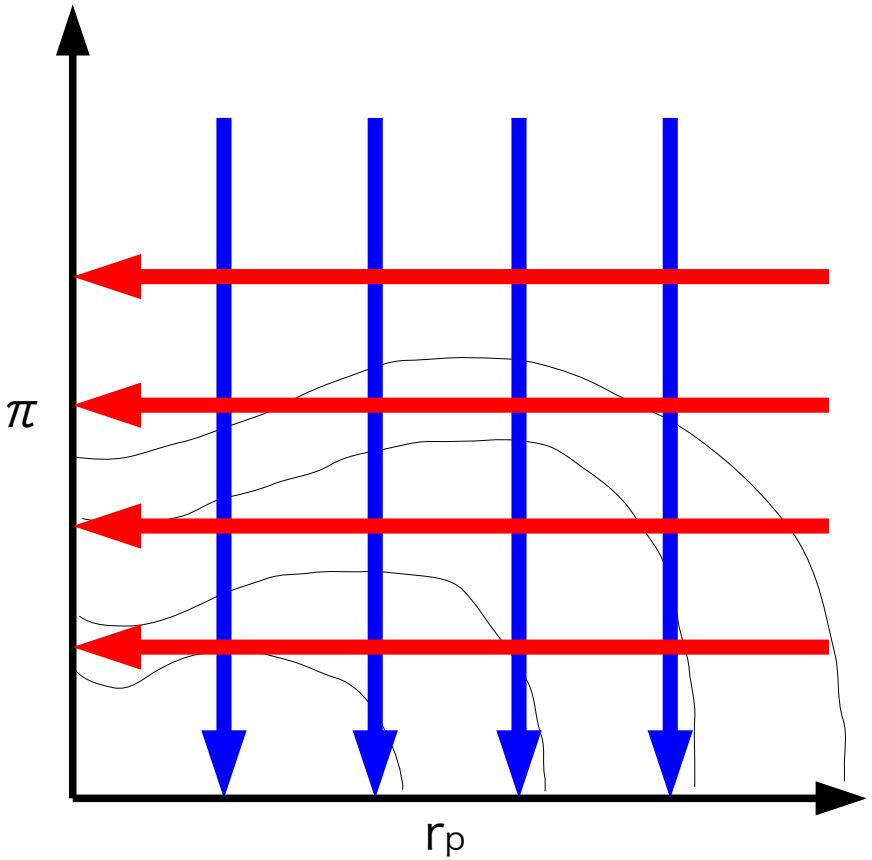


but very different pair environment!!!



Halo mass of quasar pairs < 0.1Mpc/h

Using RSD to Assess Halo Mass



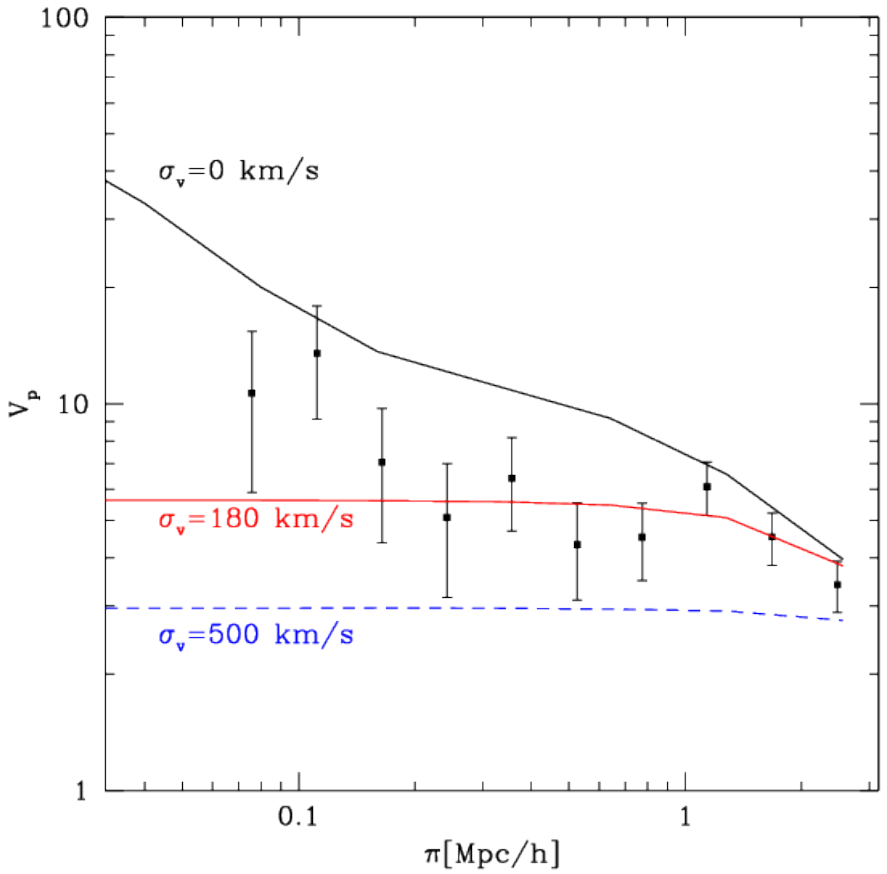
$$P(k,\mu) = \underbrace{(1+\beta\mu^2)^2}_{\text{Kaiser effect}} P(k) \underbrace{D(k\mu\sigma_v)}_{\text{Dumping}}$$

$$D(x) = \exp[-x^2/2]$$

Velocity dispersion is related to halo mass

$$\sigma_v \sim 100 \left(\frac{M}{10^{12} M_\odot/h}\right)^{1/3} \text{km/s}$$

Preliminary Result



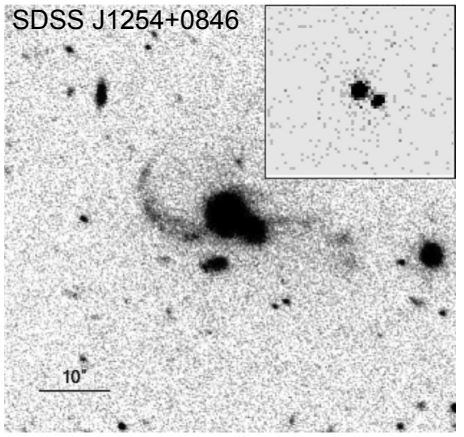
- σ_v=180±40 km/s
- Comparing with

$$\sigma_v \sim 100 \left(\frac{M}{10^{12} M_\odot / h} \right)^{1/3} \mathrm{km/s}$$

it is unlikely these pairs reside in the massive cluster region...?

Future work

- More precise measurement of the velocity difference.
- Direct observation of the environment
  - Existence of member galaxies?
  - Distortion of host galaxies?
    (We won Subaru time → failed by bad weather..)
- SZ effect by stacking Planck data?
  - Not enough resolution?



Green+2010

Summary

- Small-scale clustering analysis shows strong correlation at scale of 10 kpc/h.
  - Quasars are not random sample of galaxies. More strongly concentrated.
  - Importance of direct interaction to stimulate quasar activities.
- (Real-space, projected)small-scale clustering is not that powerful to know the environment of quasar pairs
  - Direct observation (Alexis, My and Kalle's talks)
  - Velocity information (redshift distortion)