Very small scale clustering of quasars from a complete quasar lens survey

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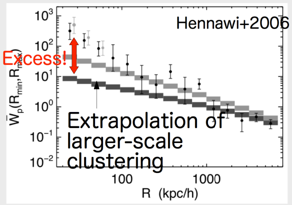
MNRAS, 242, 1363 (2012)

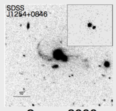
We measure the small-scale two-point correlation function of quasars using a sample of 26 spectroscopically confirmed binary quasars at 0.6 < z < 2.2 from the Sloan Digital Sky Survey Quasar Lens Search (SQLS). Thanks to careful candidate selections and extensive follow-up observations of the SQLS, which are aimed at constructing a complete quasar lens sample, our sample of binary quasars is also expected to be nearly complete within a specified range of angular separations and redshifts. The measured small-scale correlation function rises steeply towards smaller scales, which is consistent with earlier studies based on incomplete or smaller binary quasar samples. We interpret the measured correlation function within the framework of the halo occupation distribution (HOD). We propose a simple model that assumes a constant fraction of quasars that appear as satellites in dark matter haloes, and find that measured small-scale clustering signals constrain the satellite fraction to $f_{sat}=0.054^{+0.017}_{-0.016}$ for a singular isothermal sphere number density profile of satellites. We note that the HOD modelling appears to under-predict clustering signals at the smallest separations of r_p~10 h^{-1} kpc unless we assume very steep number density profiles (such as a Navarro-Frenk-White profile with the concentration parameter c_{vir}≳30), which may be suggestive of enhanced quasar activities by direct interactions.

Environment of Quasar?

- 'Excess' of small-scale clustering



- Direct evidence of interacting quasars



Green+2000

- Environment is not very dense
  - Velocity difference of pairs is not large (Farina+2011)
  - Not many galaxies around quasars (Fukugita+2004)
- Characters of paired quasars and isolated quasars are not different (Green+2011)

We address the small-scale environment of quasars by constructing a much larger (and almost complete) sample of quasar pairs from the SDSS quasar catalogue.

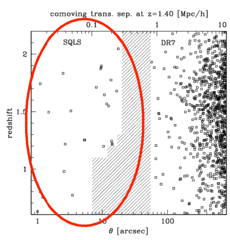
"Garbage collection" from SQLS data

The candidates of quasar-lens systems in SQLS (SDSS Quasar Lens Search) lead by Inada & Oguri contains many false positive and some of them are physically associated quasar pairs. From them, we have found 26 pairs!

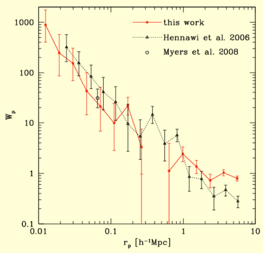
Table 1. Binary quasar sample from the SQLS (Inada et al. 2008, 2010, 2012). The typical error on the velocity measurement is a few hundred km s^{-1}.

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)	$\|\Delta v\|$ (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	[illegible]	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	[illegible]
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	[illegible]	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	[illegible]	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).



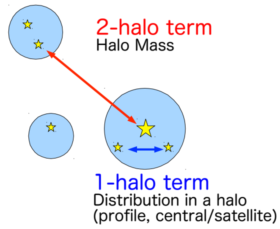
Resulting Two-point correlation function

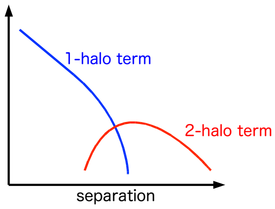


- Complete catalogues show weaker correlation.
- Still, correlation function extends steeply to the very small scale.

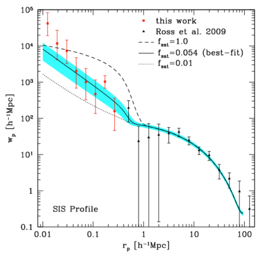
Interpretation with HOD Modeling

- Halo Occupation Distribution



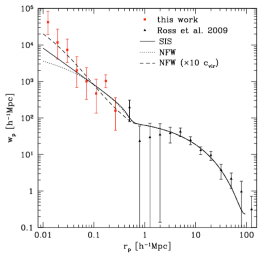


Satellite Fraction



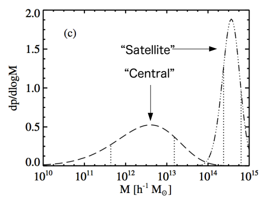
- Halo Mass: $10^{12\text{-}13}M_{\odot}/h$
- Satellite fraction: 5%
- "Central" and "Satellite" quasars are not distinguished in our model (See M. Oguri's talk!)

Number density profile



- 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?

A Note: Richardson+2012



- Using Hannawi+2006 correlation data.
- Different HOD model
  - Distinguish central and satellite with different HODs
- Satellite quasars should live in rich cluster-size environment.