Host dark halo masses of quasars

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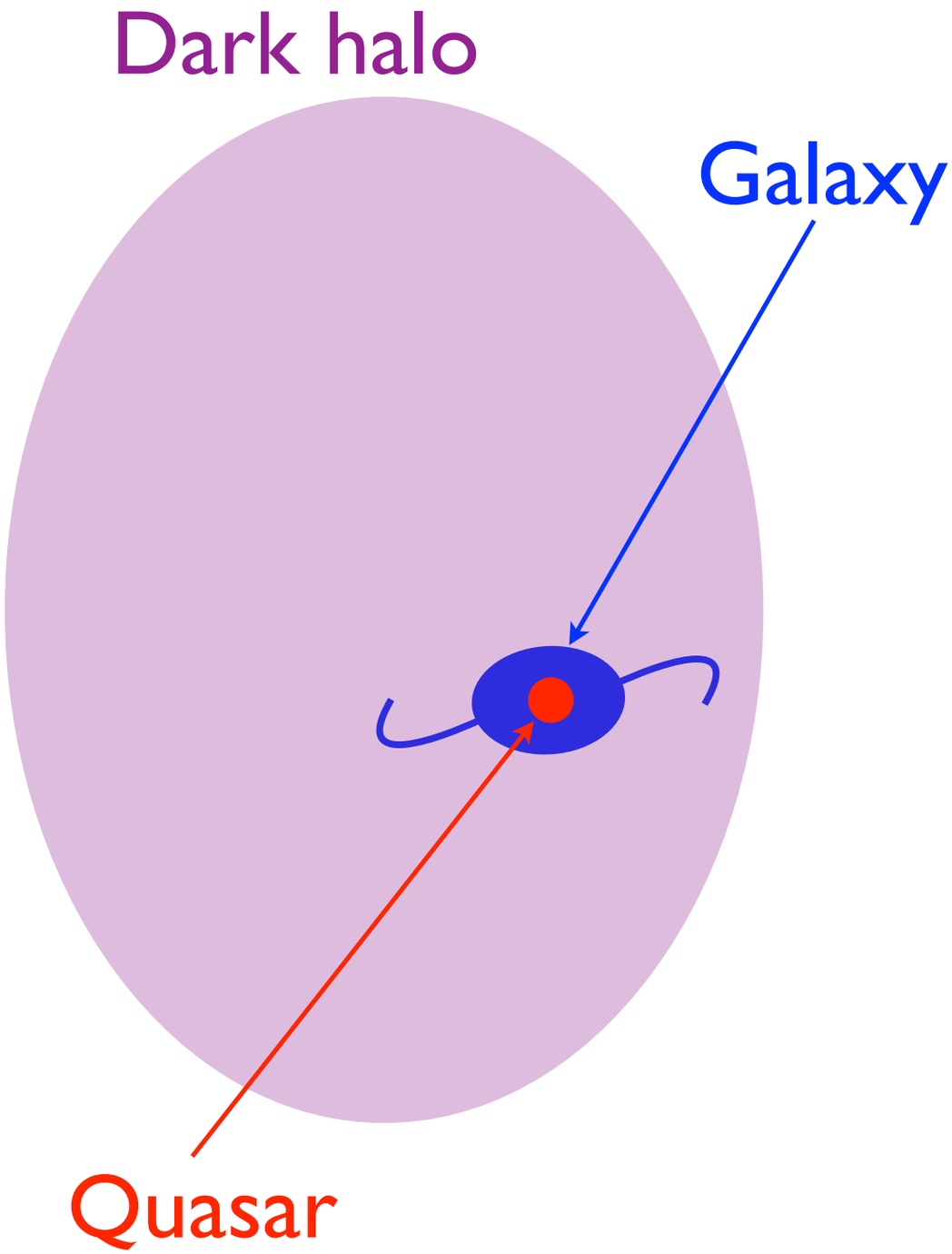
2012/12/19 supermassive black hole in the universe @ Ehime

Quasars (cosmologist's view)

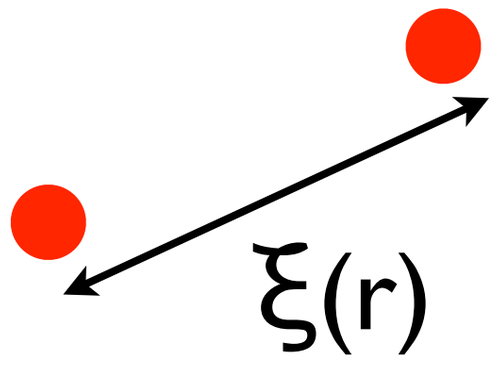


- quasars are luminous nuclei of galaxies
- galaxies lie in dark halos
- understanding relation between quasars and dark halos is a key for uncovering the origin of quasar activity

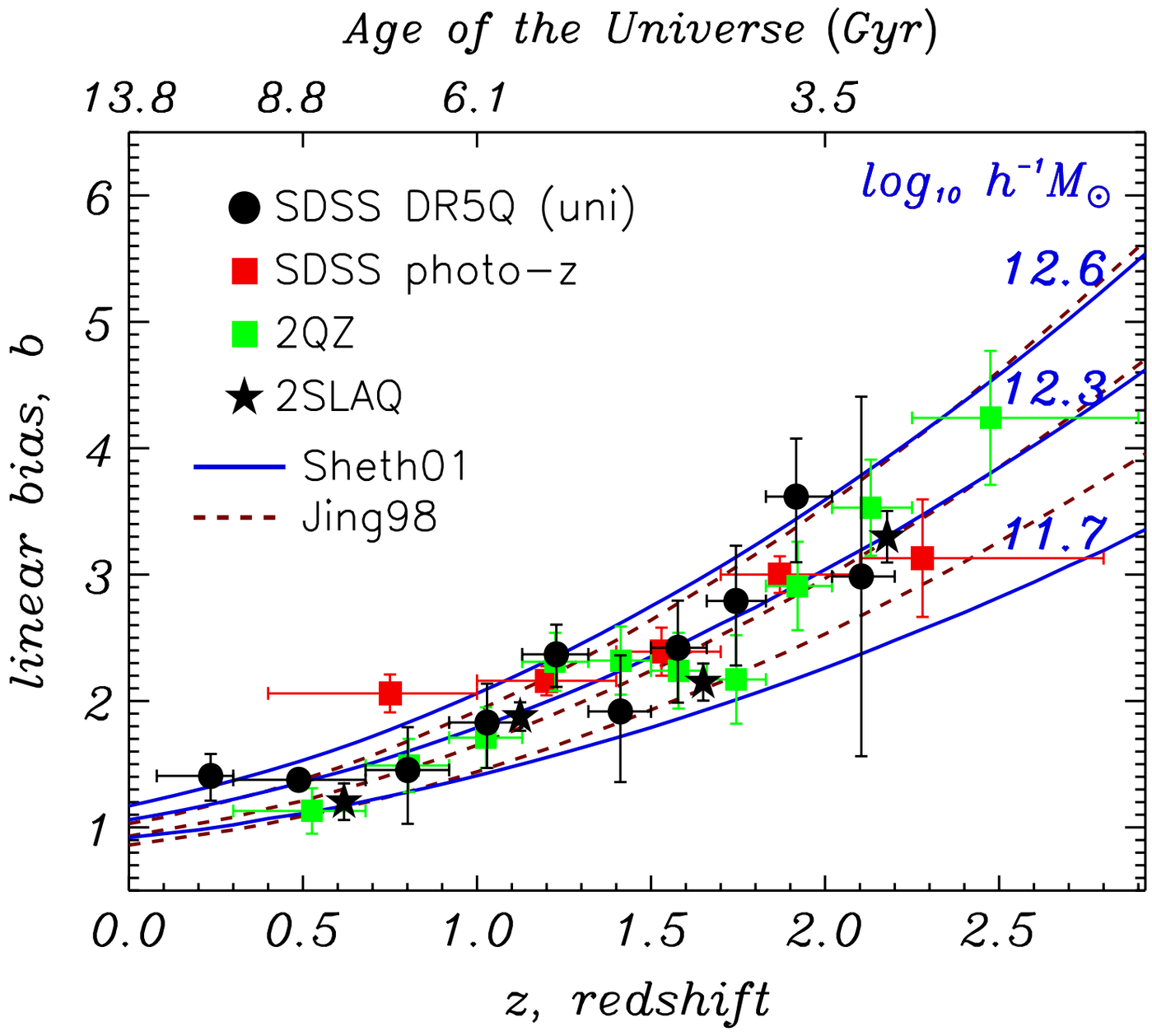
Traditional approach: clustering

- large-scale clustering contains information on bias $\delta_{QSO} = b_{QSO}\delta_{DM}$

- since bias depends on halo mass b=b(M) we can infer host halo masses from clustering



SDSS/2dF measurements



Ross et al. (2009)

- clustering analysis indicates quasars live in halos with $M \sim 10^{12.5} h^{-1} M_{Sun}$ (e.g., Shen et al. 2007; Ross et al. 2009; White et al. 2012)

Are we done?

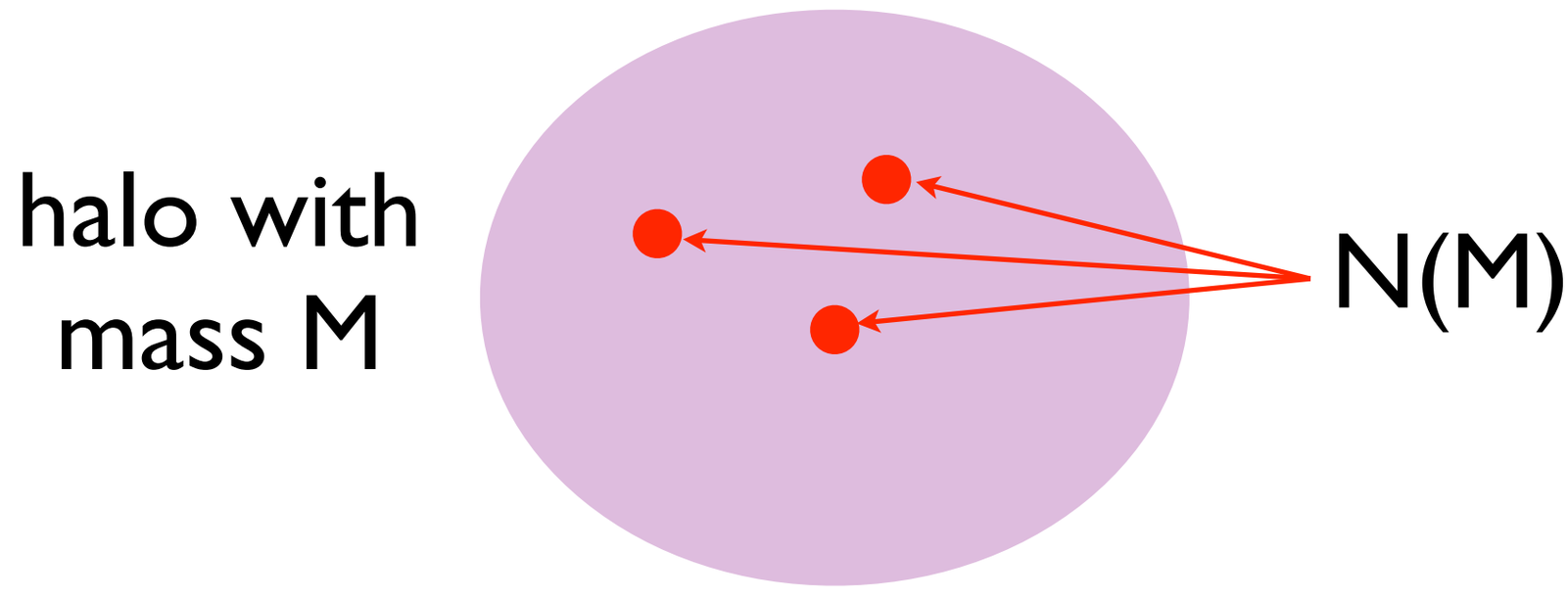
- clustering analysis tells you average host halo masses of quasars

- we want to know the distribution of host halo masses as well

Halo Occupation Distribution (HOD)

- average number of quasars in a halo as a function of its halo mass, $\langle N(M) \rangle$

- The HOD model enables predictions for various observables, including clustering



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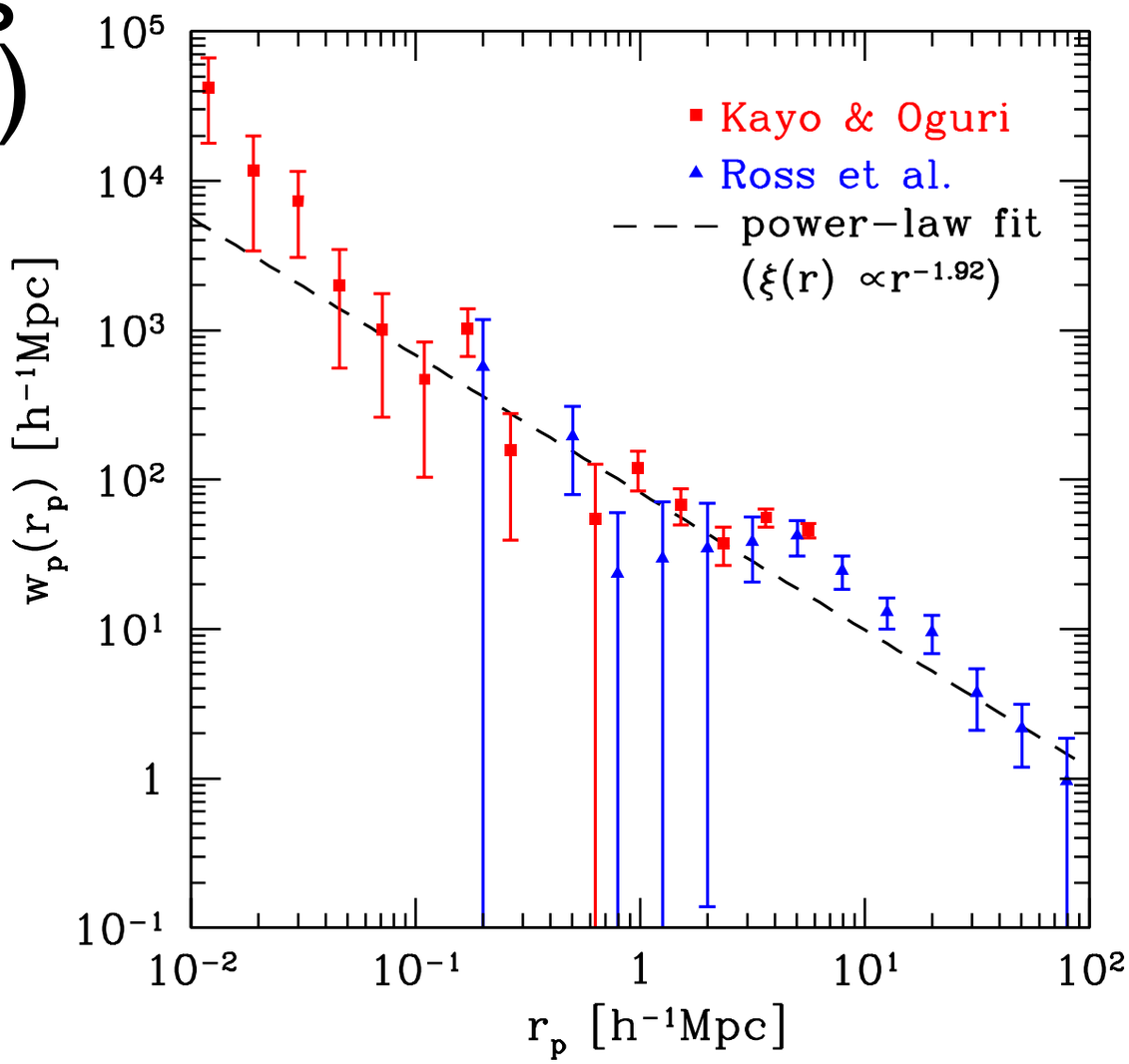
HOD analysis of clustering

- interpreting the full clustering signals with HOD
- data: small-scale clustering from Kayo & Oguri (2012) and large-scale clustering from Ross et al. (2009)

[see Issha Kayo's poster]



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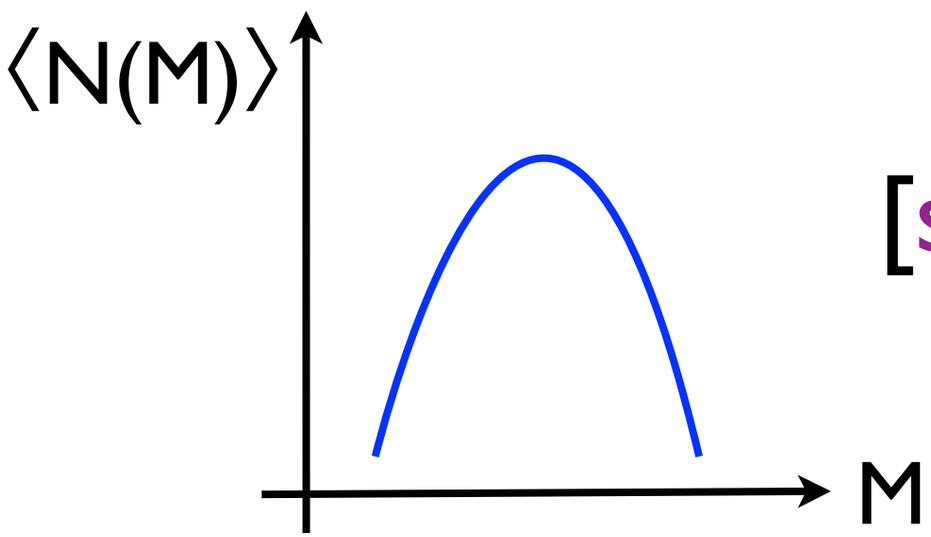
Our HOD model

- log-normal ⟨N(M)⟩ with a constant satellite fraction f_{sat} (i.e. very different from galaxy HOD)
- Idea: weak luminosity dependence of quasar clustering implies weak halo mass dependence of quasar luminosities, triggering quasar activity may require gas-rich mergers, while cold gas is deficient in cluster galaxies....



[see Issha Kayo's poster]

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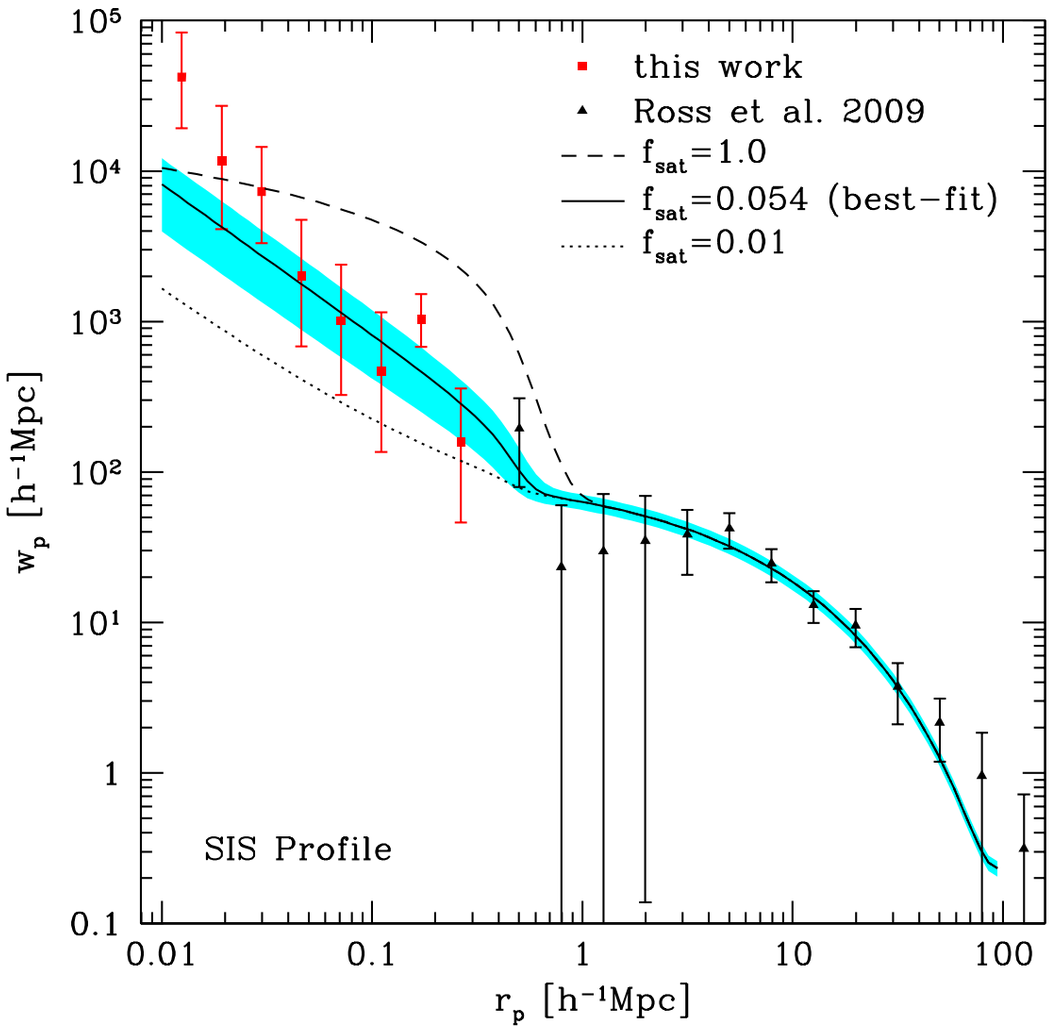
Analysis result

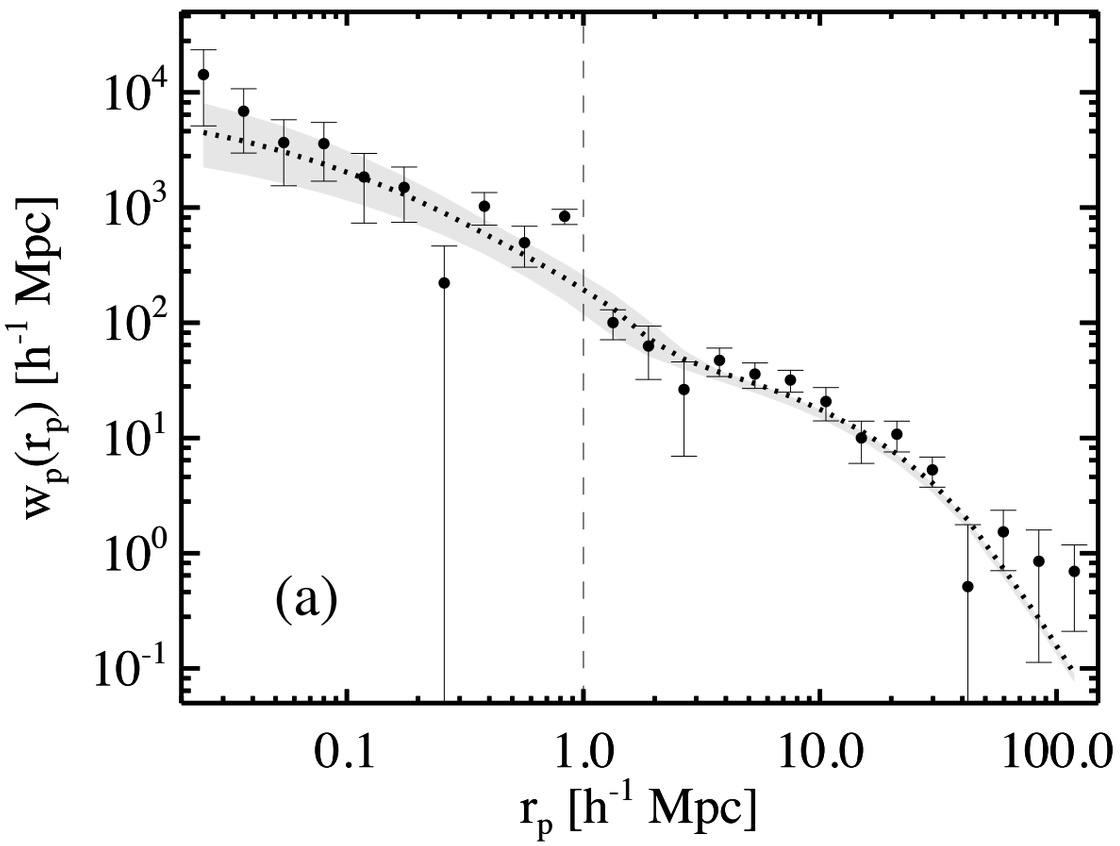
- our HOD model successfully fits the data
- implied satellite fraction f_{sat} ~ 5%

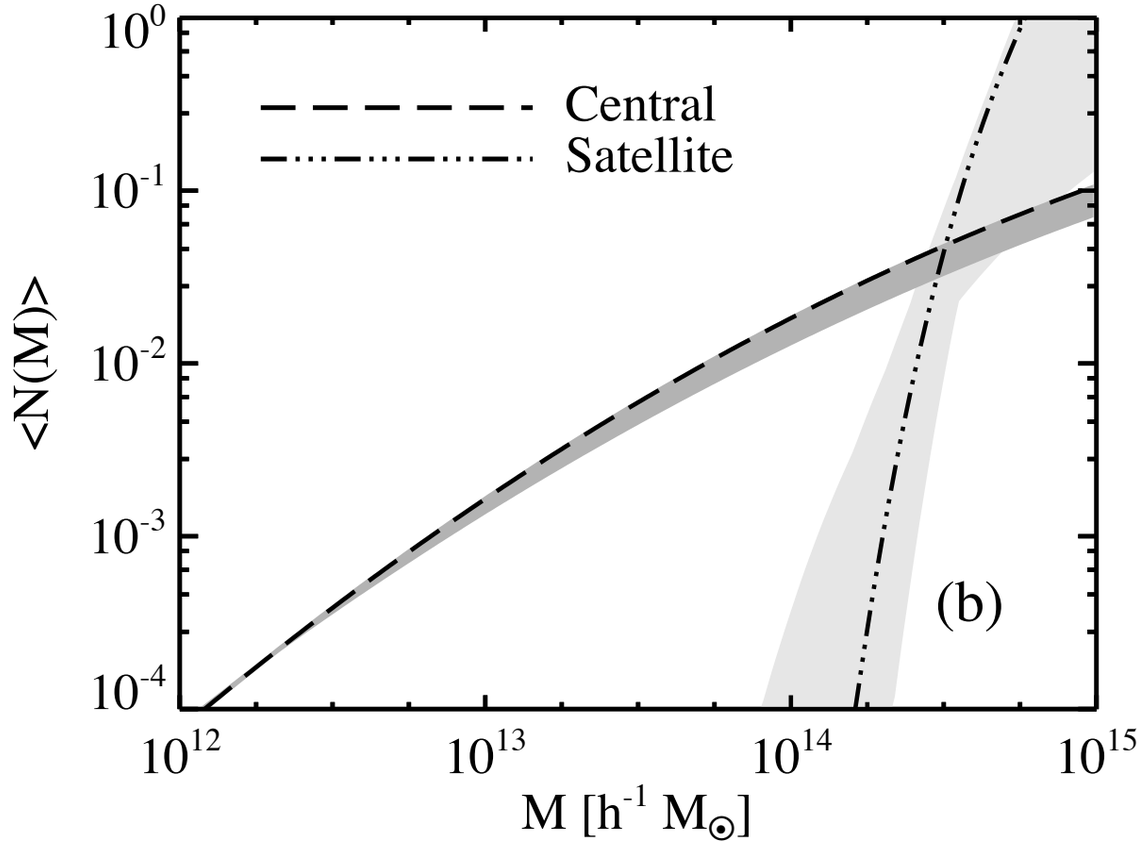


[see Issha Kayo's poster]

However, ...

- Richardson et al. (2012) considered a totally different (galaxy-like) HOD model and successfully explained the clustering signals (!)

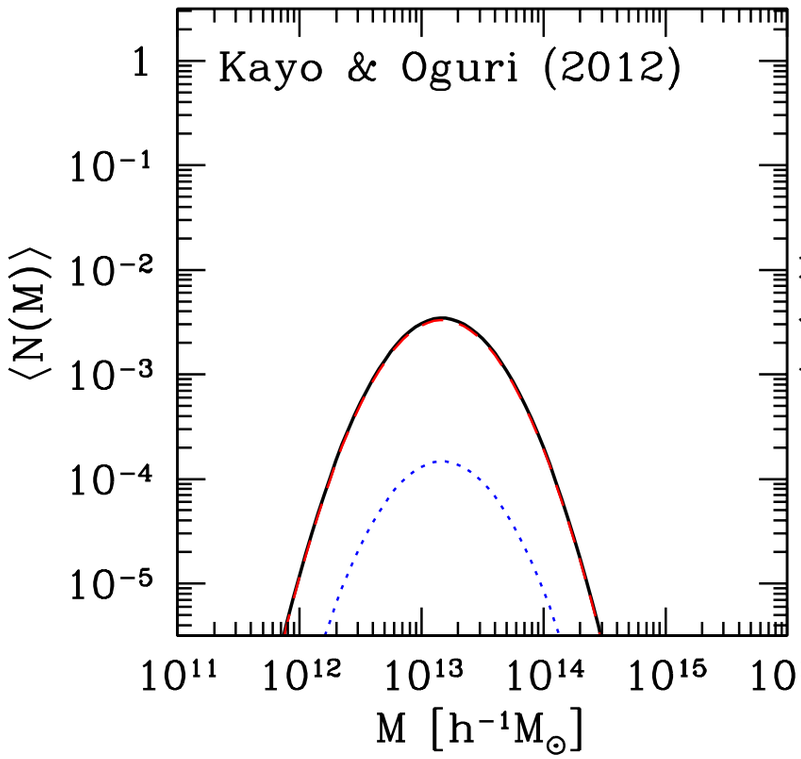


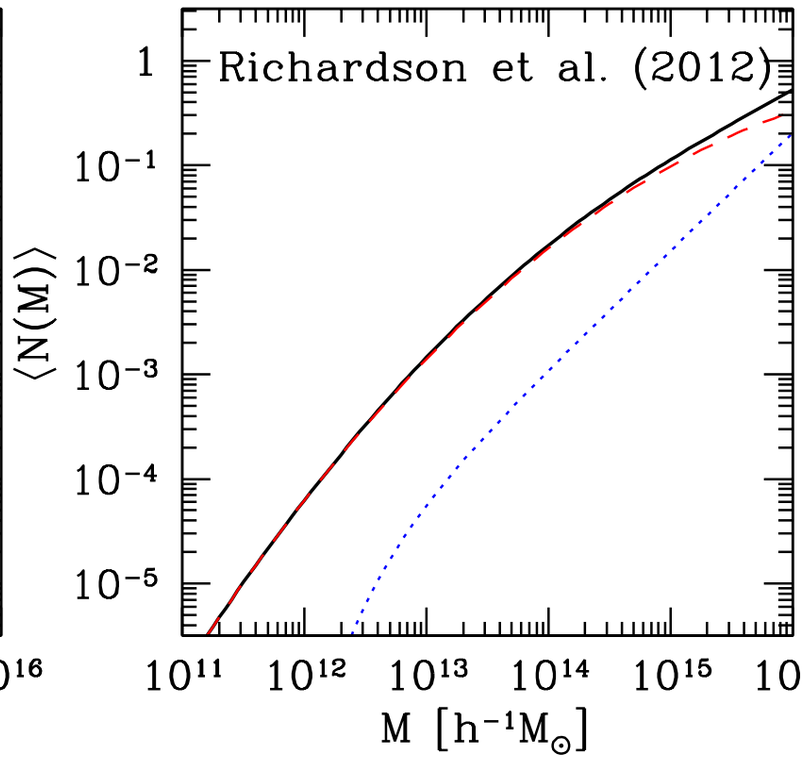


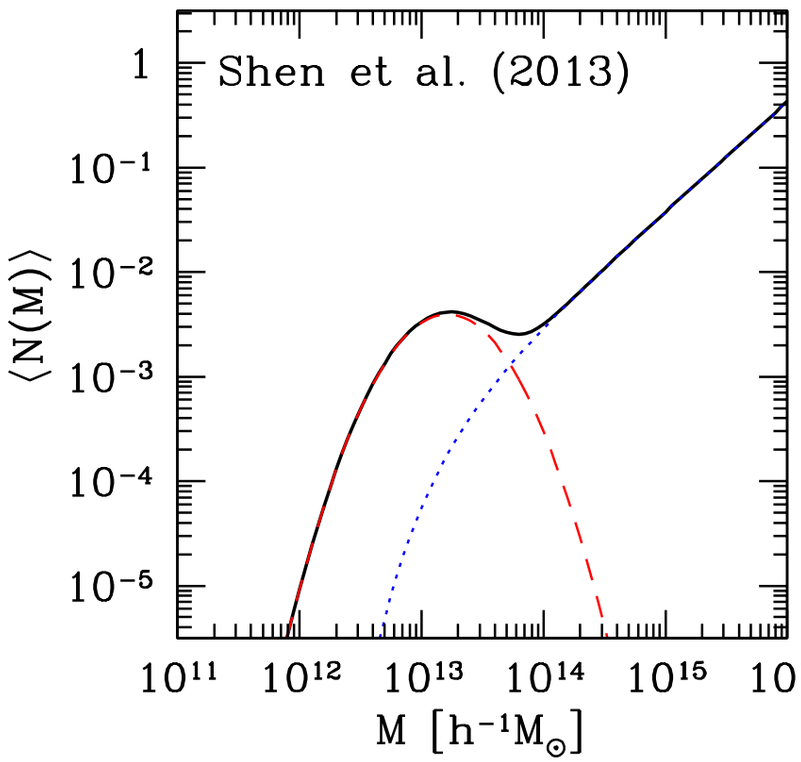
A question

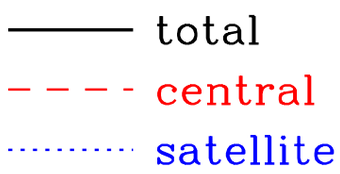
- how can we break the degeneracy in the HOD models?

Three HOD models

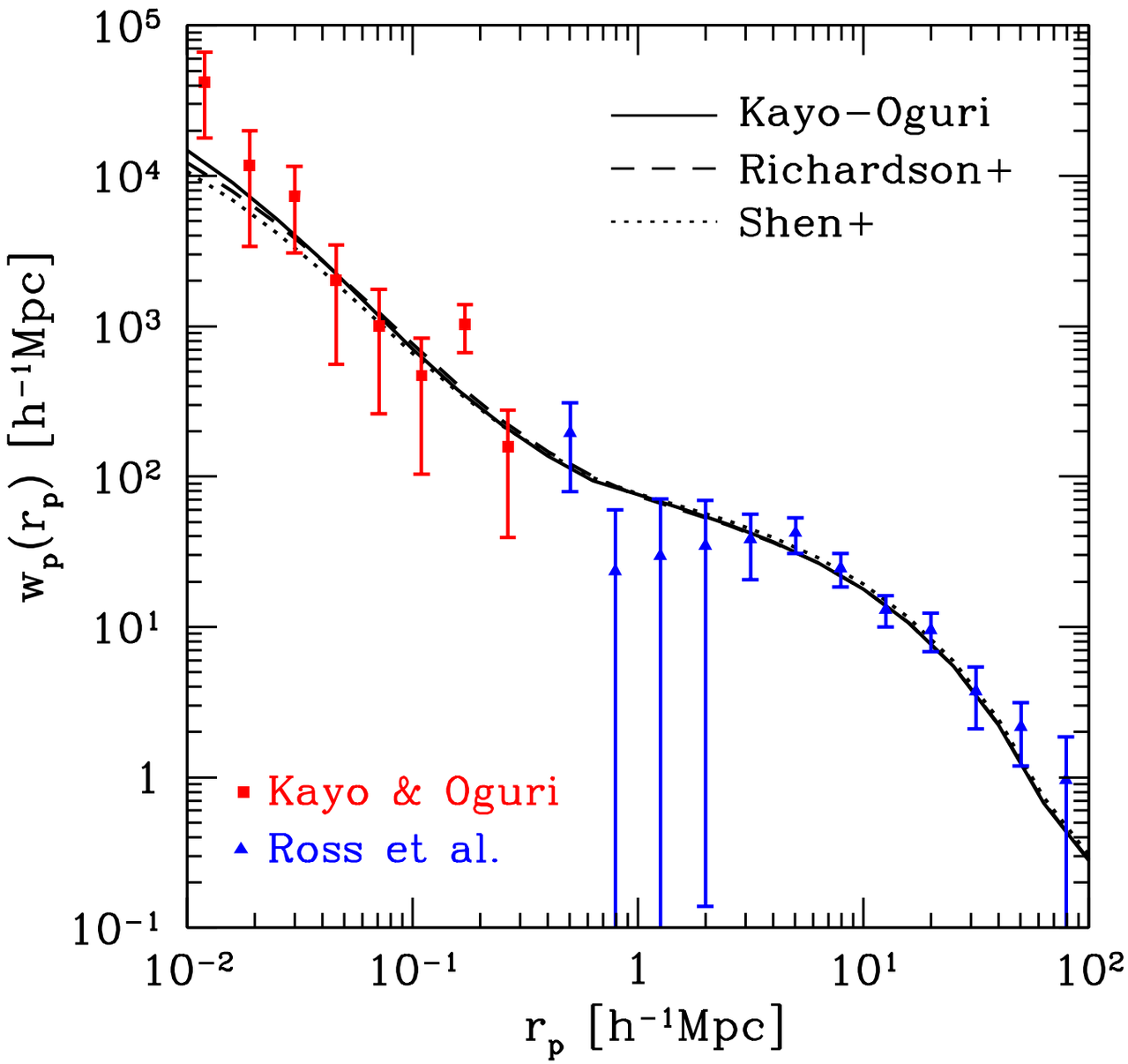








... that reproduce the same $w_p(r_p)$



Possible approaches

- examining halo masses of each binary quasar
- stacked weak lensing around quasars
- quasar-cluster cross-correlation
- velocity differences of binary quasars
  (not today)

I. halo masses of binary quasars

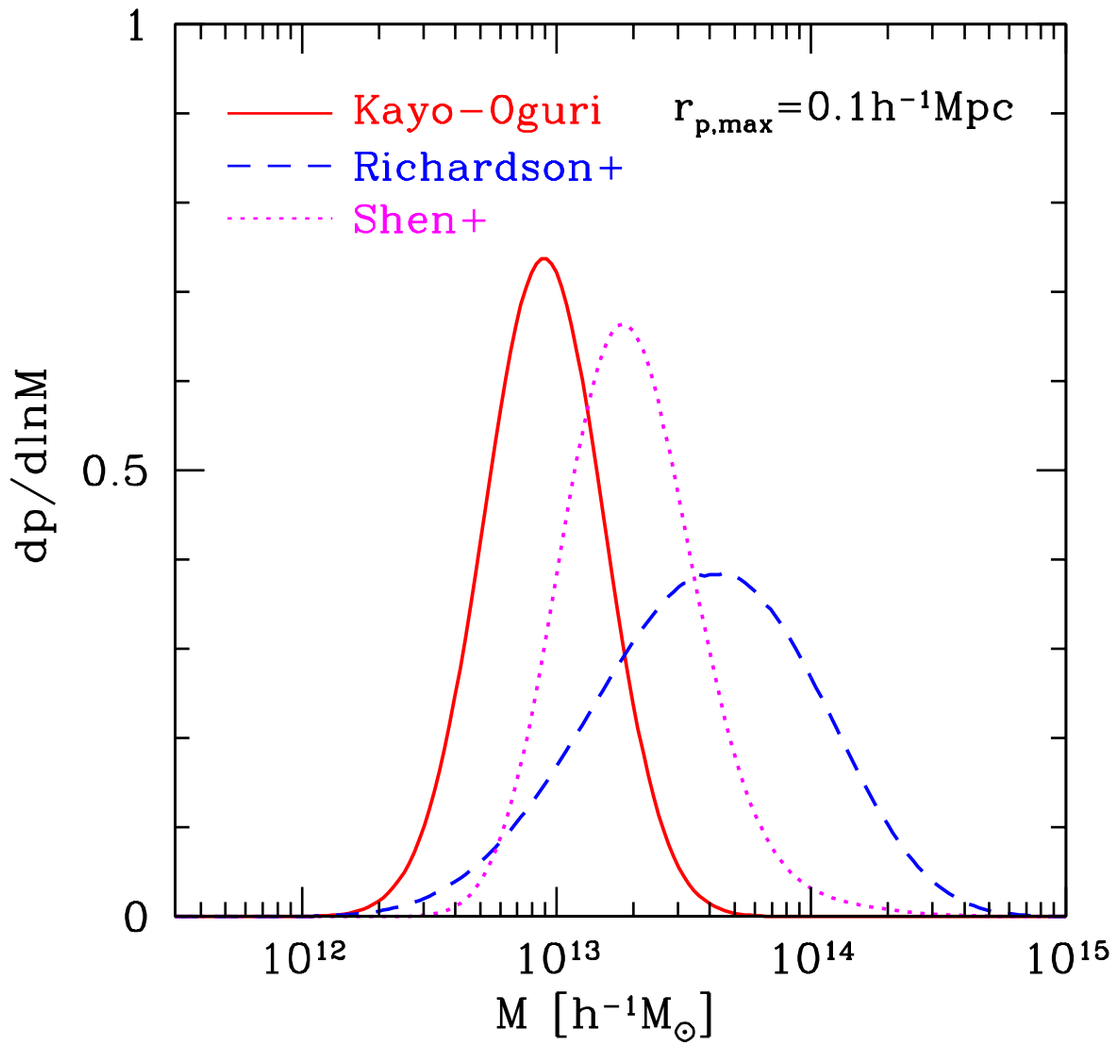
- small-separation binary quasars live in the same halo (1-halo term)
- with the HOD model we can derive PDF of the host mass of the pair as

$$f(< r_{p,\max}) = \frac{1}{n_{\rm q}} \int dk\, r_{p,\max} J_1(k r_{p,\max}) \int dM \left[2\langle N_{\rm cen}(M)\rangle \langle N_{\rm sat}(M)\rangle u(k;M,c_{\rm q}) + \langle N_{\rm sat}(M)\rangle^2 |u(k;M,c_{\rm q})|^2 \right] \frac{dn}{dM}$$

$$\frac{dp}{dM} = \frac{1}{f(< r_{p,\max}) n_{\rm q}} \int dk\, r_{p,\max} J_1(k r_{p,\max}) \left[2\langle N_{\rm cen}(M)\rangle \langle N_{\rm sat}(M)\rangle u(k;M,c_{\rm q}) + \langle N_{\rm sat}(M)\rangle^2 |u(k;M,c_{\rm q})|^2 \right] \frac{dn}{dM}$$

- this can be compared with detailed follow-up observations of individual binary quasars

I. halo masses of binary quasars



- indeed, halo mass PDFs for small pairs are quite different!
- how can we measure halo masses in obs? deep X-ray, deep WL, # of galaxies, ...
- note: Green et al. 2011 observed 7 pairs with Chandra and detected no extended emission

II. stacked weak lensing

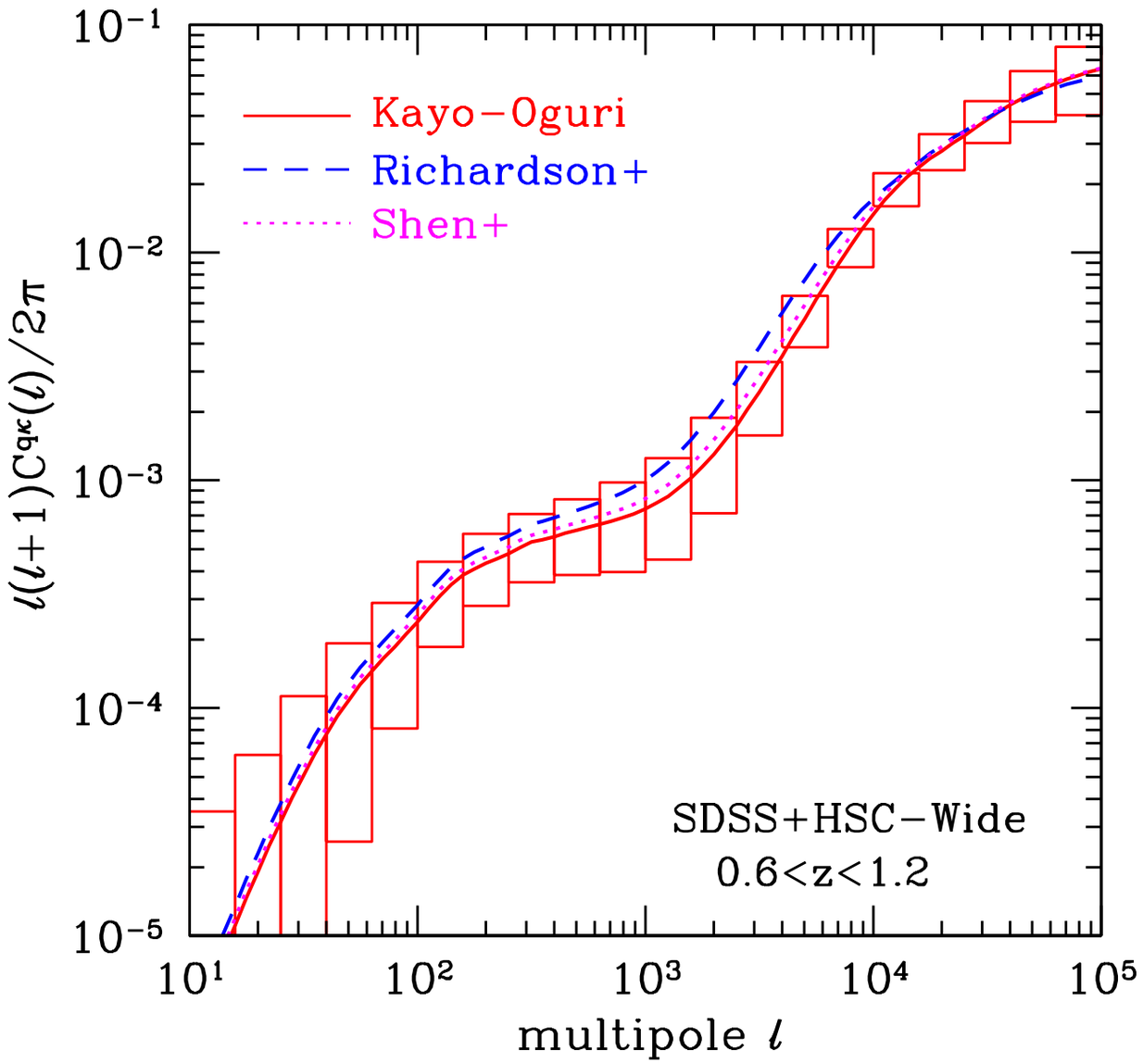
- stacked weak lensing provides alternative way to constrain HOD models
- may be able to break the degeneracy

$$C^{\mathrm{q}\kappa,\mathrm{1h}}(\ell) = \frac{1}{n_{\mathrm{A,q}}} \int dz \frac{d^2V}{dz d\Omega} \int dM \left[\langle N_{\mathrm{cen}}(M)\rangle + \langle N_{\mathrm{sat}}(M)\rangle \tilde{p}_{\mathrm{nfw}}(\ell; M, c_{\mathrm{q}})\right] \tilde{\kappa}_{\mathrm{nfw}}(\ell; M, c) \frac{dn}{dM},$$

$$C^{\mathrm{q}\kappa,\mathrm{2h}}(\ell) = \int dz W_{\mathrm{q}}(z) W_{\kappa}(z) \left(\frac{d\chi}{dz}\right)^{-1} \frac{1}{\chi^2} P_m(k = \ell/\chi),$$

[see also Joel Zinn's poster]

II. stacked weak lensing



- with HSC-wide+SDSS we can detect weak lensing signals very significantly
- signals indeed depend on HOD models

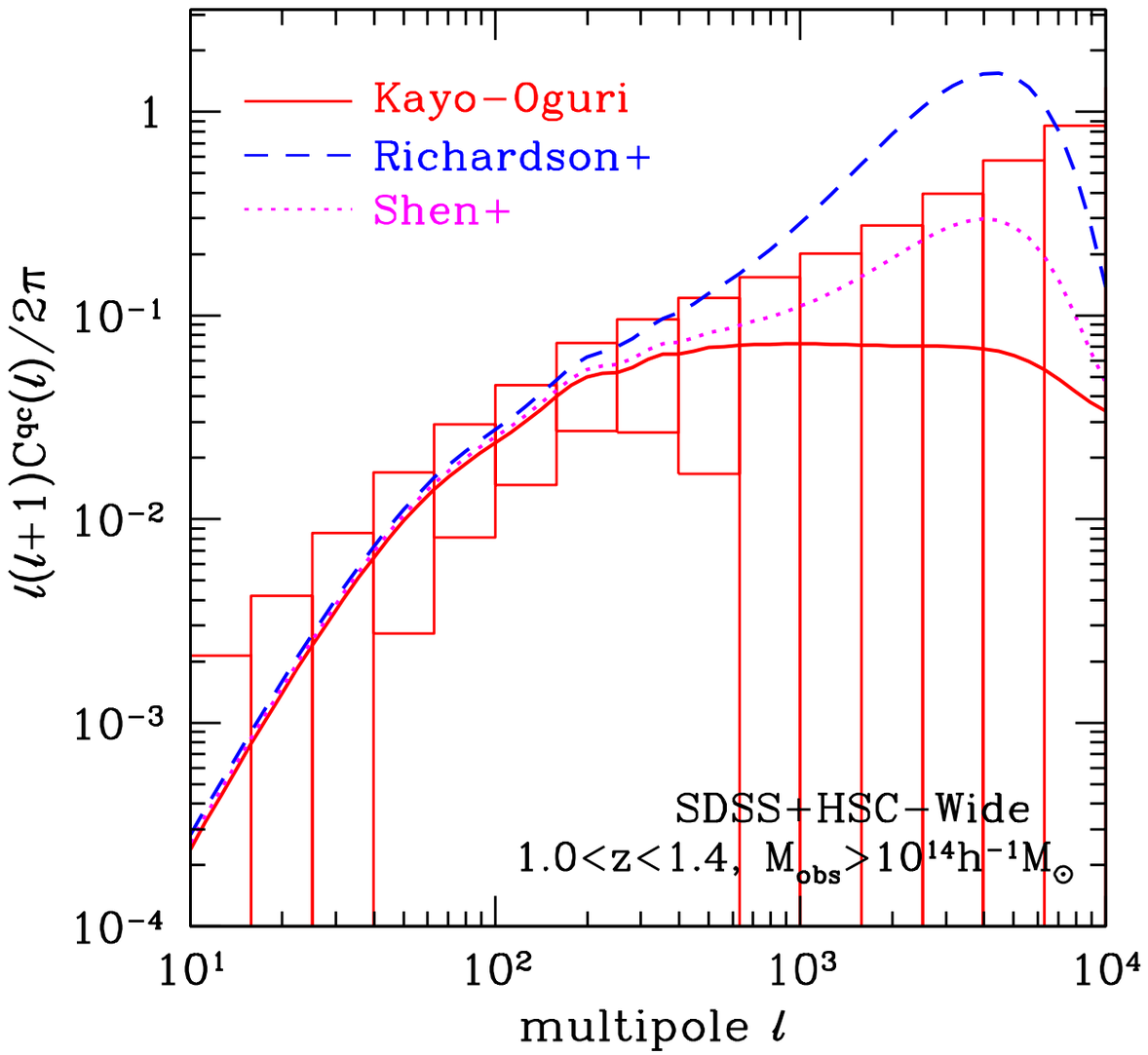
III. quasar-cluster cross-correlation

- quasar-cluster cross-correlation might tell you how HOD extends toward high halo masses
- reliable cluster catalog up to z~1.4 can be constructed with HSC-wide

$$C^{\mathrm{qc,1h}}(\ell) = \frac{1}{n_{\mathrm{A,q}} n_{\mathrm{A,c}}} \int dz \frac{d^2V}{dz d\Omega} \int dM \left[\langle N_{\mathrm{cen}}(M) \rangle + \langle N_{\mathrm{sat}}(M) \rangle \tilde{p}_{\mathrm{nfw}}(\ell; M, c_{\mathrm{q}}) \right] S(M) p_{\mathrm{off}}(\ell) \frac{dn}{dM},$$

$$C^{\mathrm{qc,2h}}(\ell) = \int dz W_{\mathrm{q}}(z) W_{\mathrm{c}}(z) \left(\frac{d\chi}{dz} \right)^{-1} \frac{1}{\chi^2} P_m(k = \ell/\chi),$$

III. quasar-cluster cross-correlation



- again, cluster-quasar cross-correlations can be detected with HSC+SDSS
- large 1-halo term difference, may be useful

Summary

- auto-correlation alone cannot constrain quasar HOD very well
- there are several ways to break the degeneracy in the HOD models
- HSC data will be very useful for some of them (HSC-SDSS overlap is a big advantage!)
- other possibilities?