The Zoo of AGN in the clustering context: quasar clustering and what it tells… or Galaxy formation is Messi, but we have Gotze Klose

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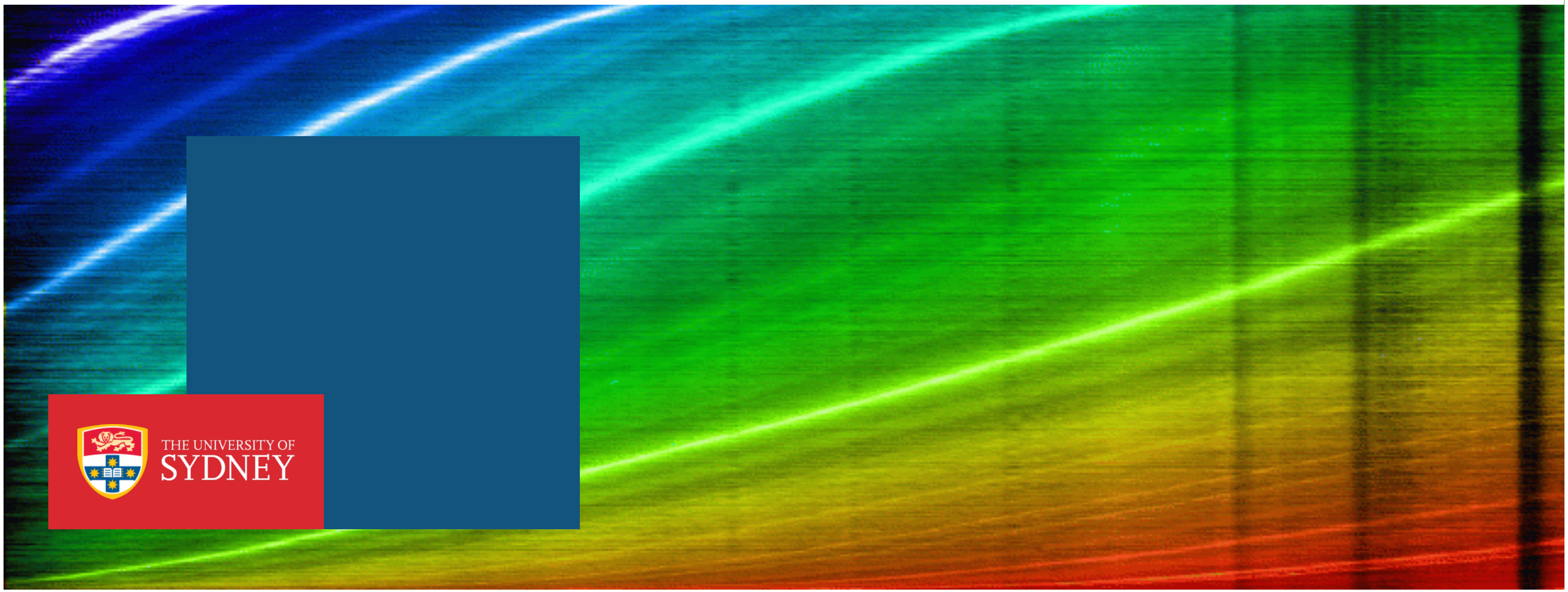


Outline

› Historical perspectives.

› Basic observables of AGN.

› Physical pictures of AGN.

› Large-scale clustering and halo mass.

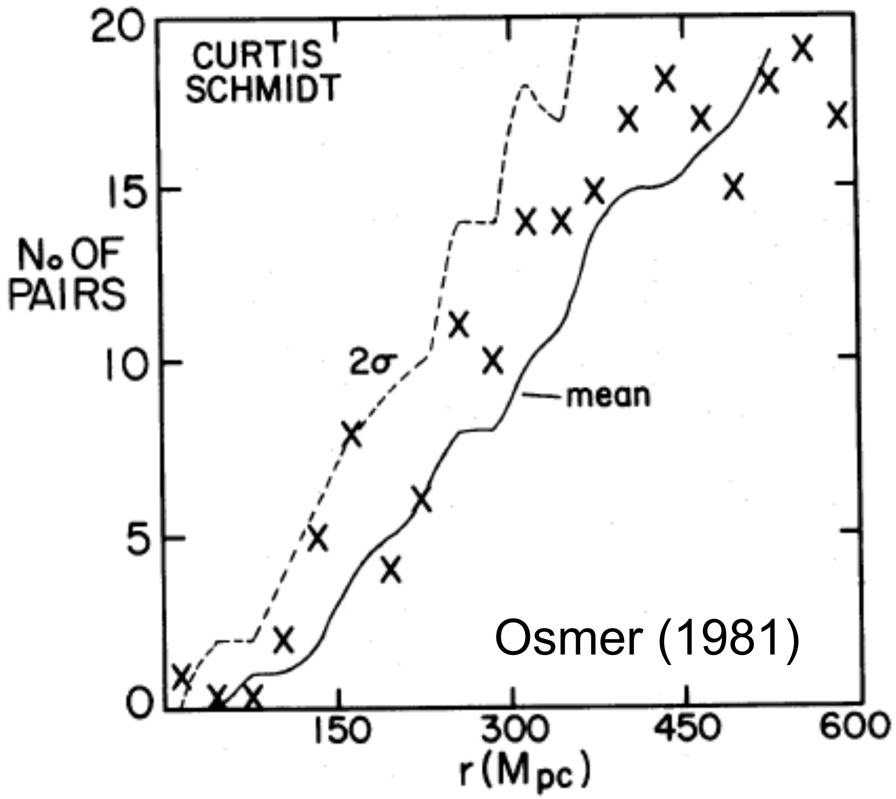
› Small-scale clustering.

› A more complete picture of environment.

› Where next? Questions we still need answered…

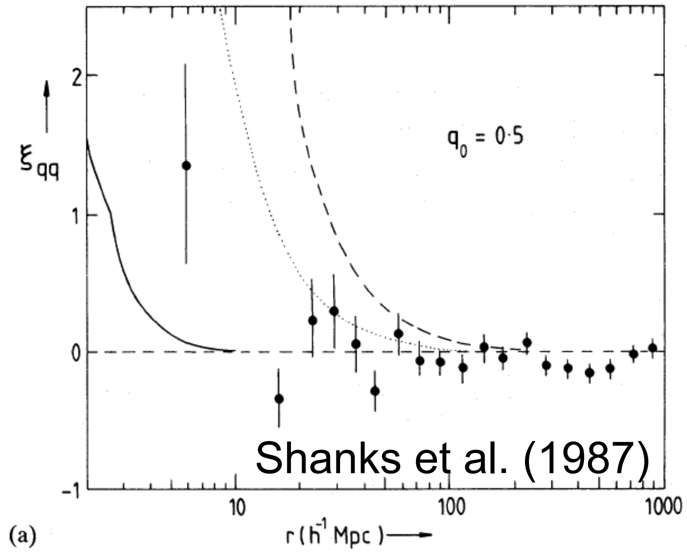
Historical perspectives: Early measurements

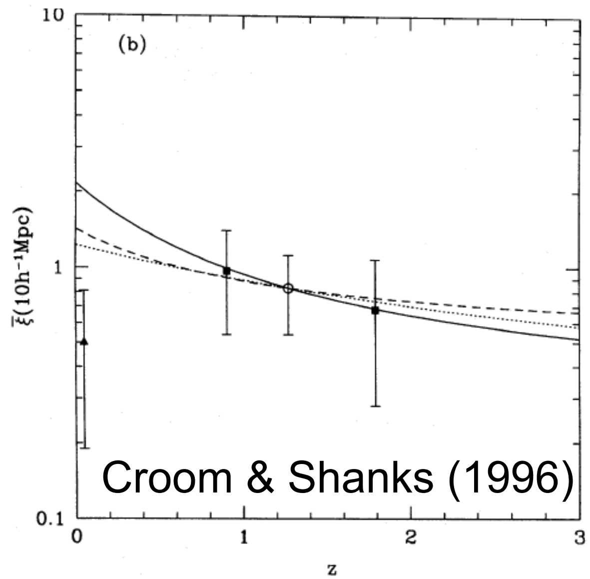
- Discovery of quasars in 1963.
- Framework for clustering analysis defined in early 1970s (Peebles et al.).
- Early analysis was carried out on radio samples such as 4C (e.g. Webster et al 1976).
- Osmer (1981) used CTIO objective prism surveys to measure correlation functions (170 quasars to ~19th mag).
- No detections of clustering…



Historical perspectives: First detections

- First hints of quasar clustering were found in heterogeneous samples (Shaver 1984).
- The deep and uniform Durham/AAT survey (Boyle, Shanks et al.) had the first detections of clustering from a uniform sample, e.g. Shanks et al. (1987); Iovino & Shaver (1988)
- Best results in prior to 2dF and SDSS surveys came from samples of ~500-1000 quasars (e.g. Croom & Shanks 1996; La Franca et al 1998).





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Historical perspectives: survey rationale…

› Original 2QZ science aims (circa 1995):

- LSS on scales 1 to 1000h^{-1}Mpc and tests of CDM.
- Clustering evolution for Ω_m and bias.
- Alcock-Pacynski (1979) test for Ω_Λ.
- QSO Luminosity function.

› In the mean time:

- SNe and Dark Energy.
- M-σ relation.
- Reverberation mapping and “virial methods”.
- WMAP and other CMB measurements.

› **The killer science isn’t always what you expect**.

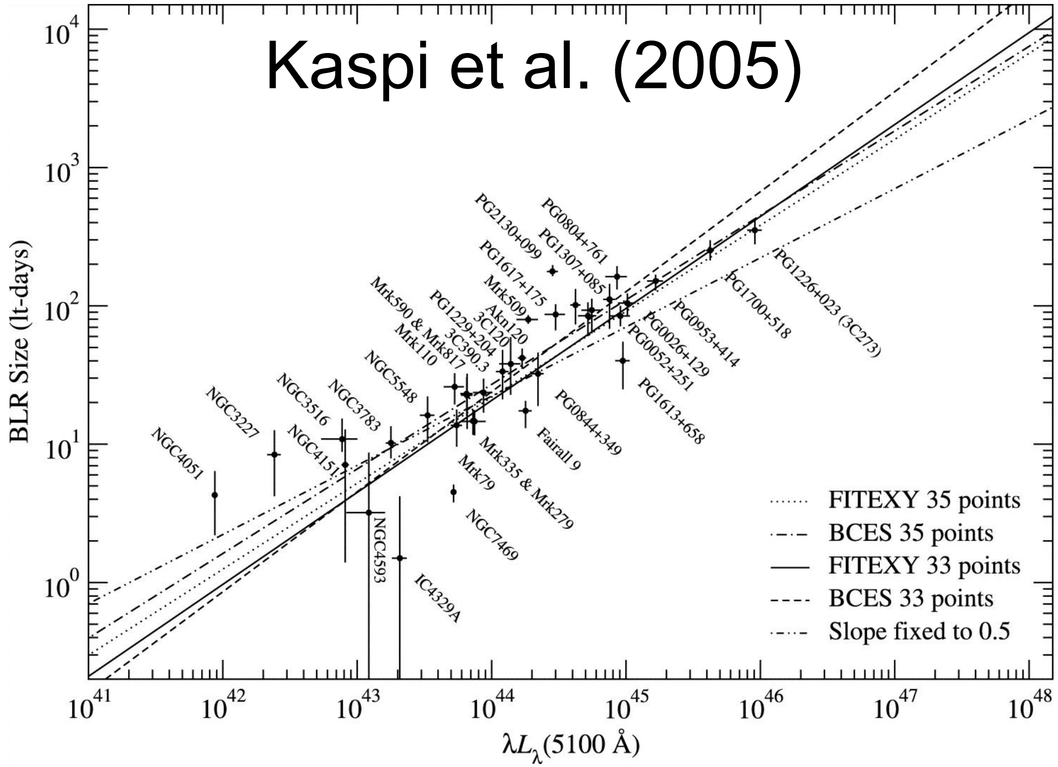
Basic observables: BH mass

- **Black hole mass** is fundamental, but hard to measure directly.
- Most analysis done using virial methods on the BLR, Calibrated on local reverberation mapping results.

$$r \sim L^{0.5}$$

$$M_{BH} \approx \frac{rv^2}{G} \approx fL^{0.5}\sigma^2$$

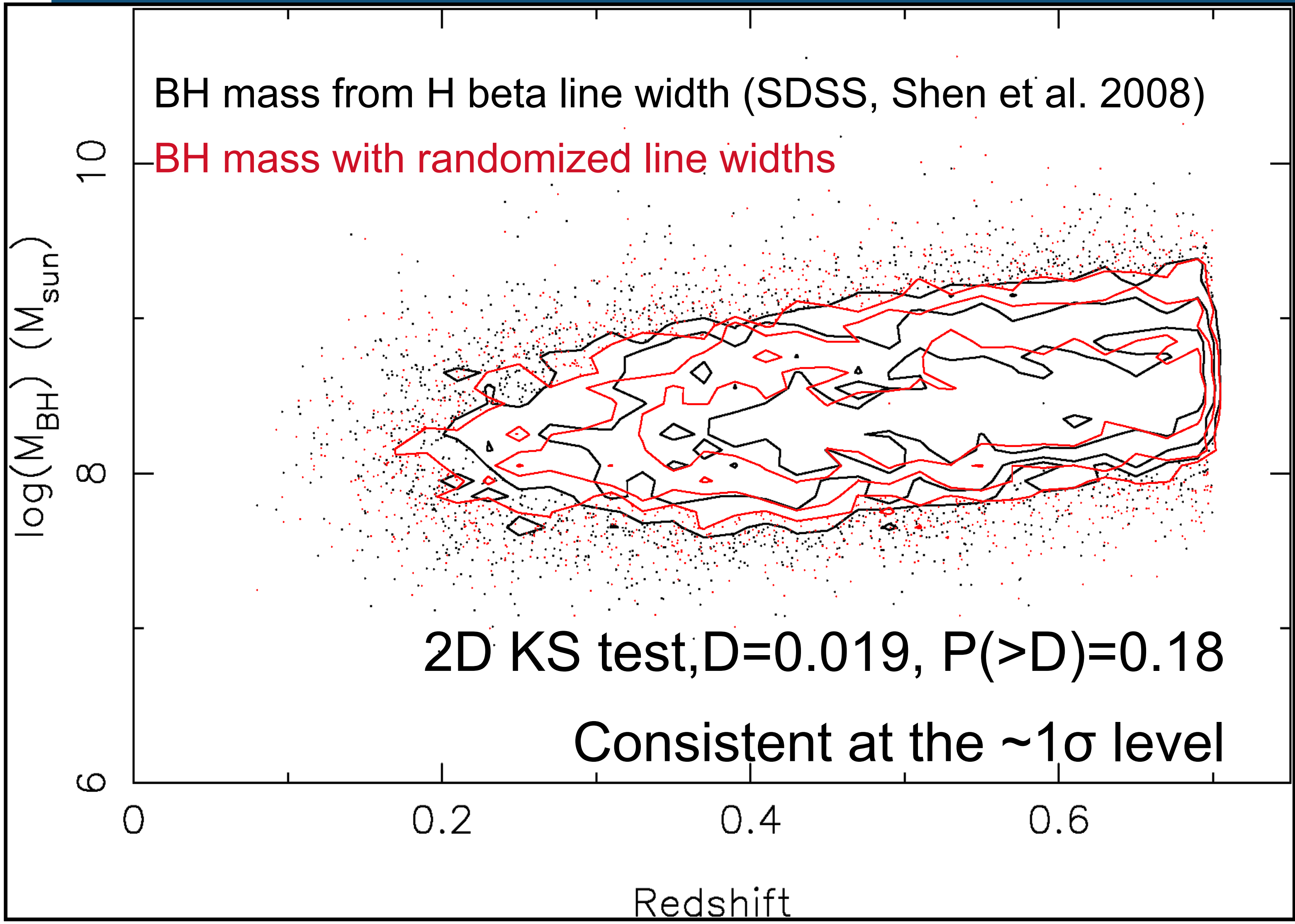
$$L/L_{Edd} \sim L/M_{BH} \sim L^{0.5}/\sigma^2$$



Basic observables: BH mass

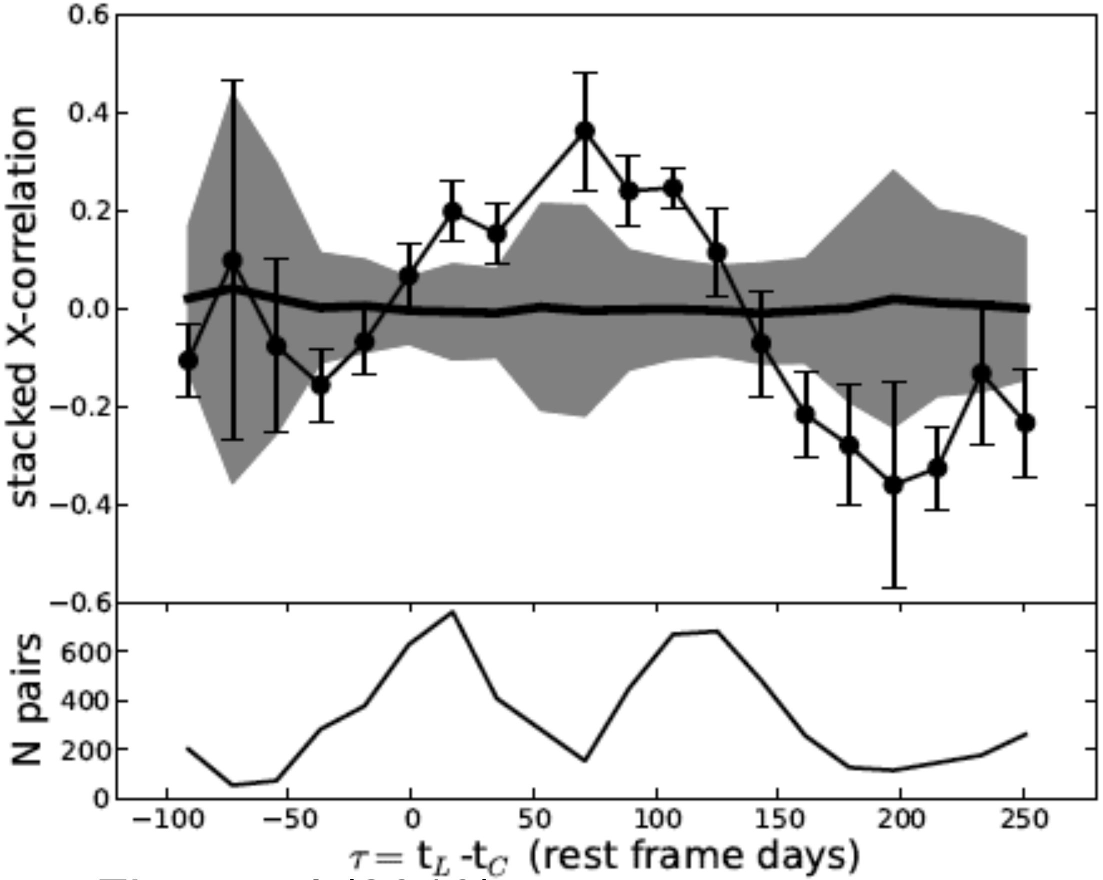
- Need to remember the true observables – much greater dynamic range in L than σ.
- “All quasars look the same”.

Basic observables: BH mass



Croom (2011)

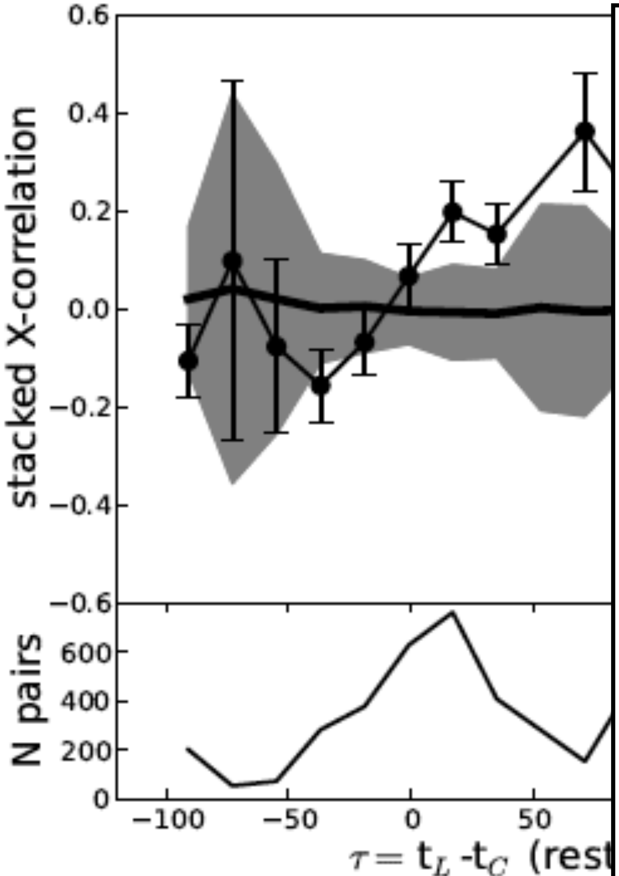
› Statistical reverberation mapping possible with new multi-epoch imaging surveys (PanStarrs, DES, LSST).

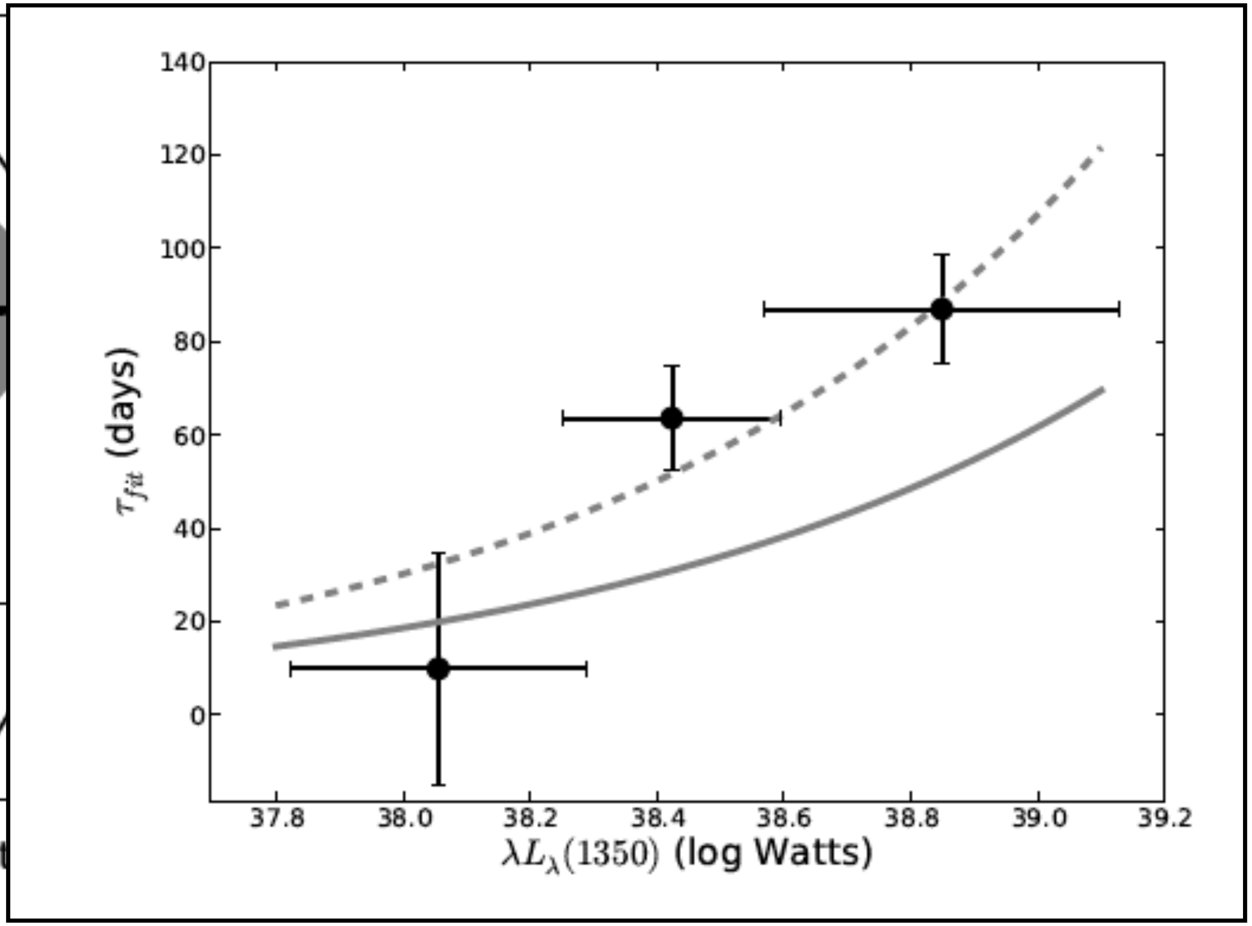


Fine et al (2013)

Basic observables: BH mass

› Statistical reverberation mapping possible with new multi-epoch imaging surveys (PanStarrs, DES, LSST).

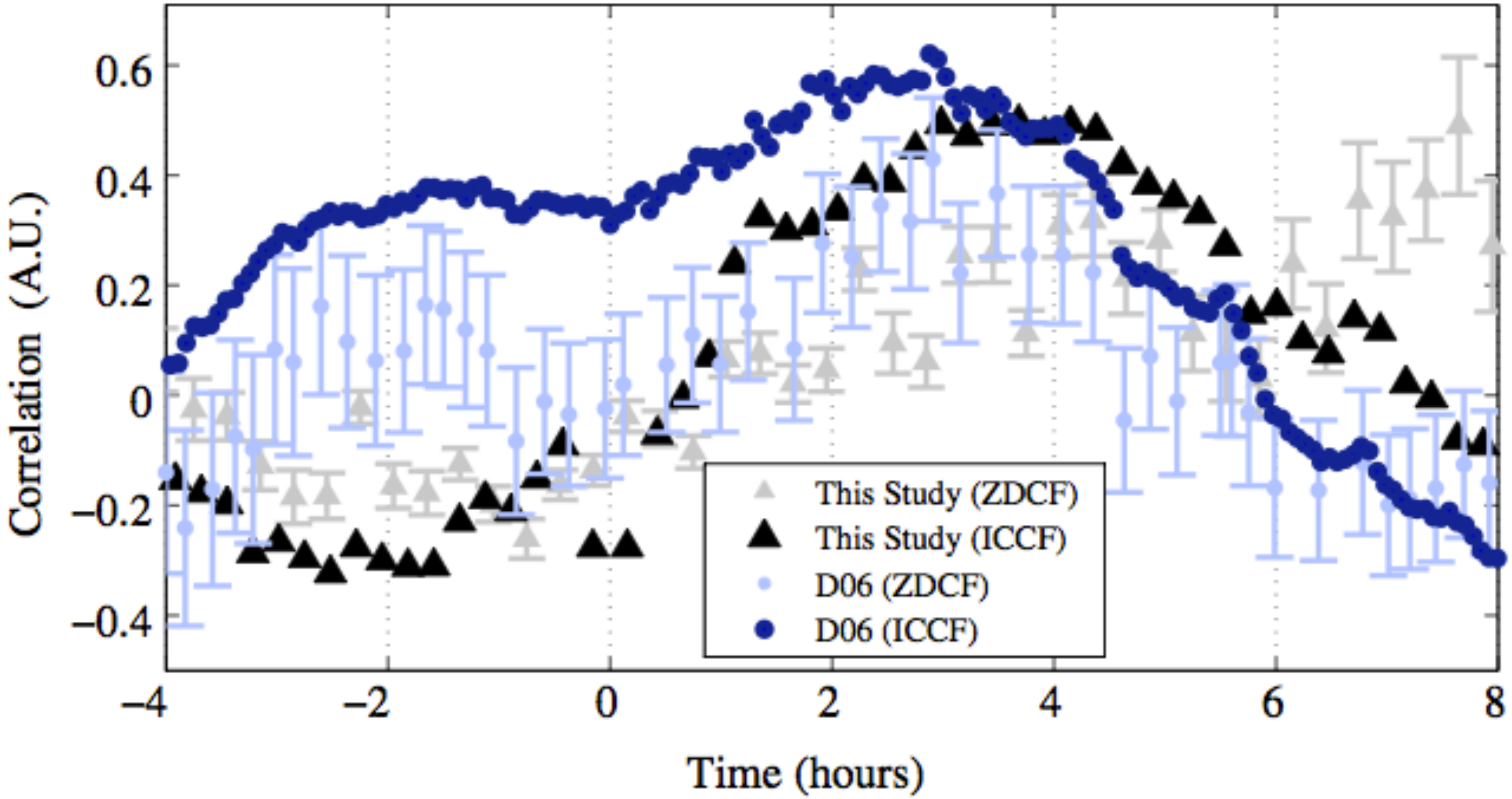




Fine et al (2013)

Basic observables: BH mass

› Also reverberation mapping without any spectra (e.g. Edri 2012 for NGC 4395).



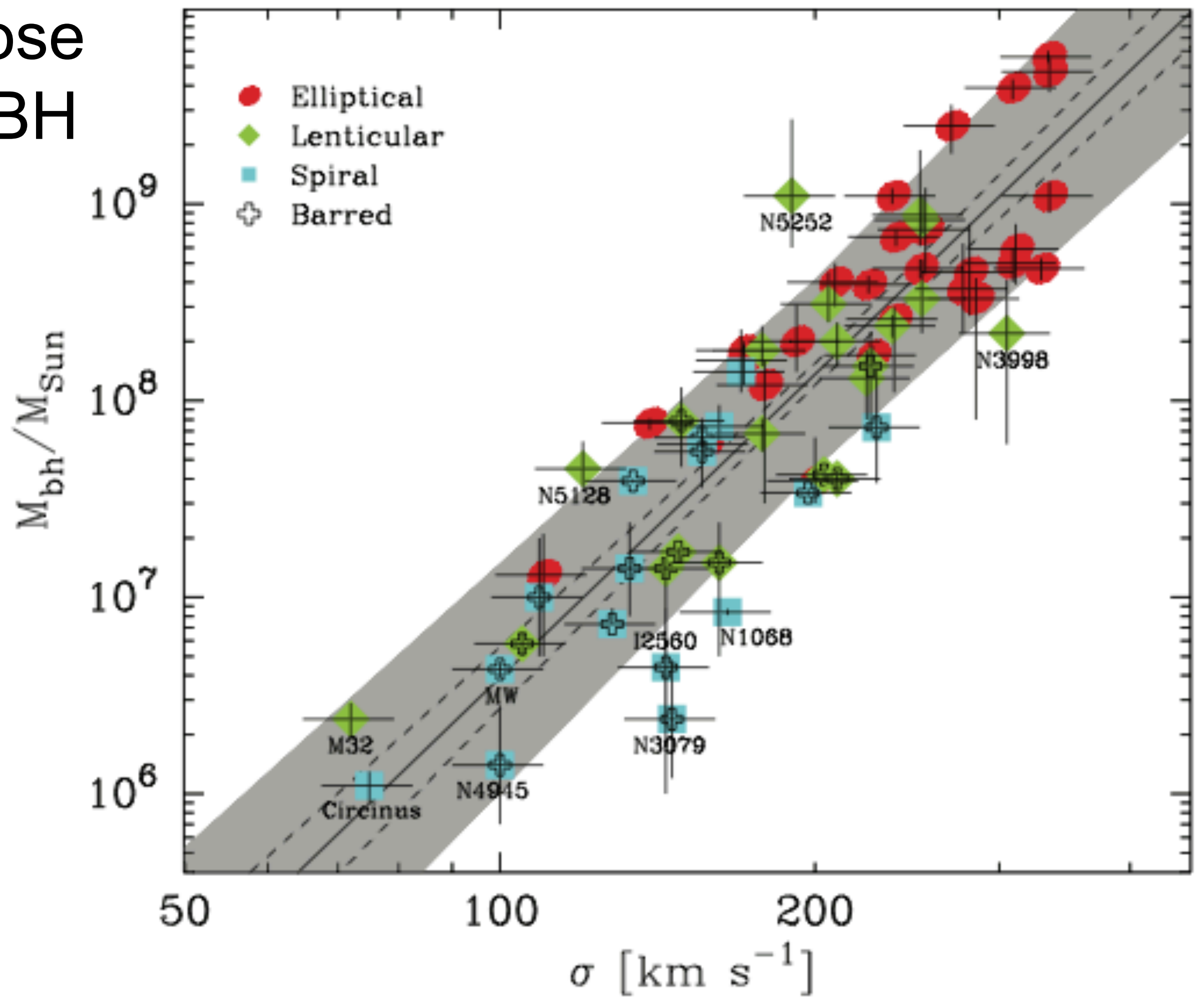
Edri et al. (2012) compared to Desroches et al (2006)

Basic observables: M-σ relation

› M-σ relation infers close connection between BH and host.

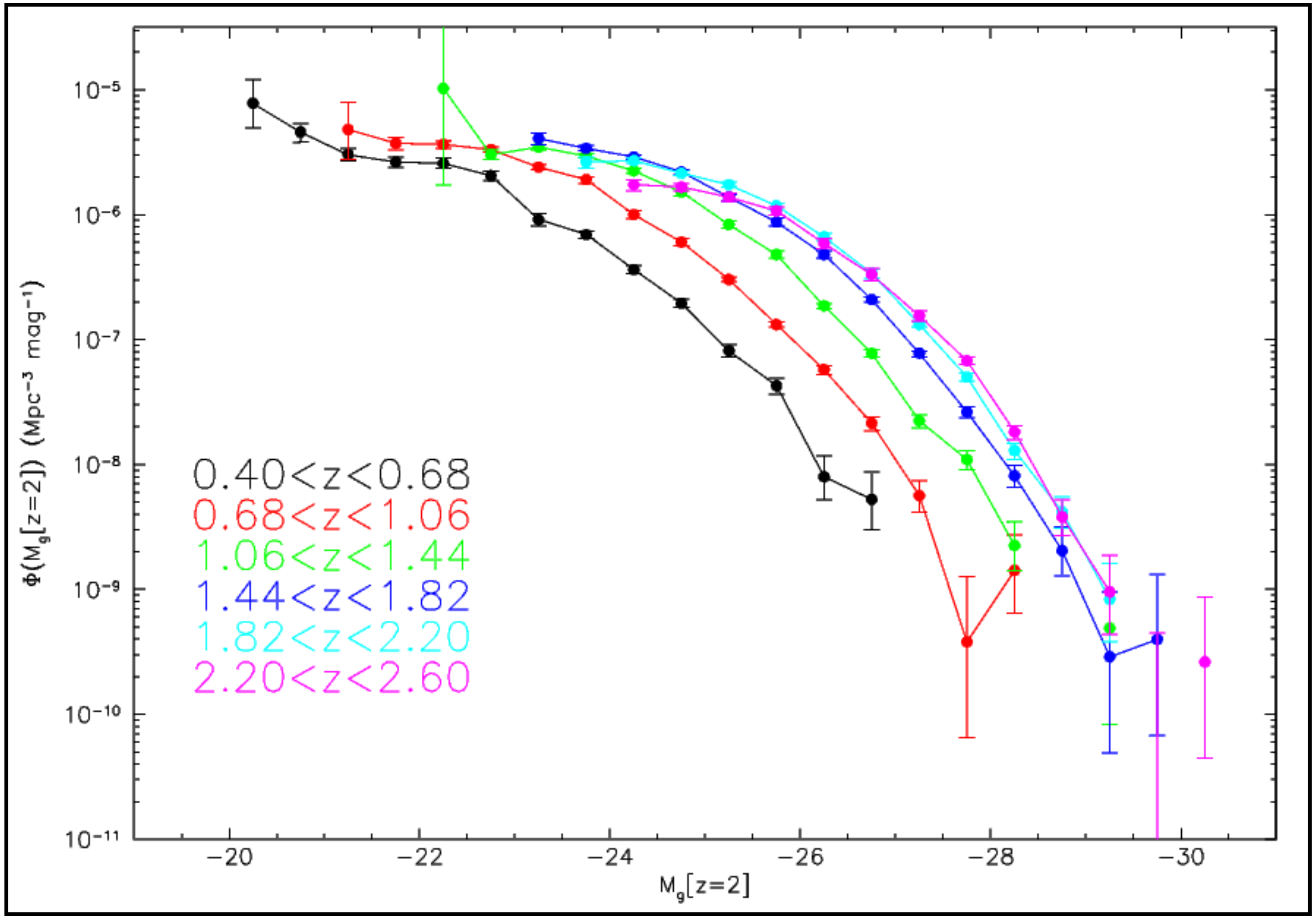
› Steps to clustering:

- AGN Luminosity
- BH mass
- Spheroid σ or M
- Host halo mass
- Large-scale clustering amplitude



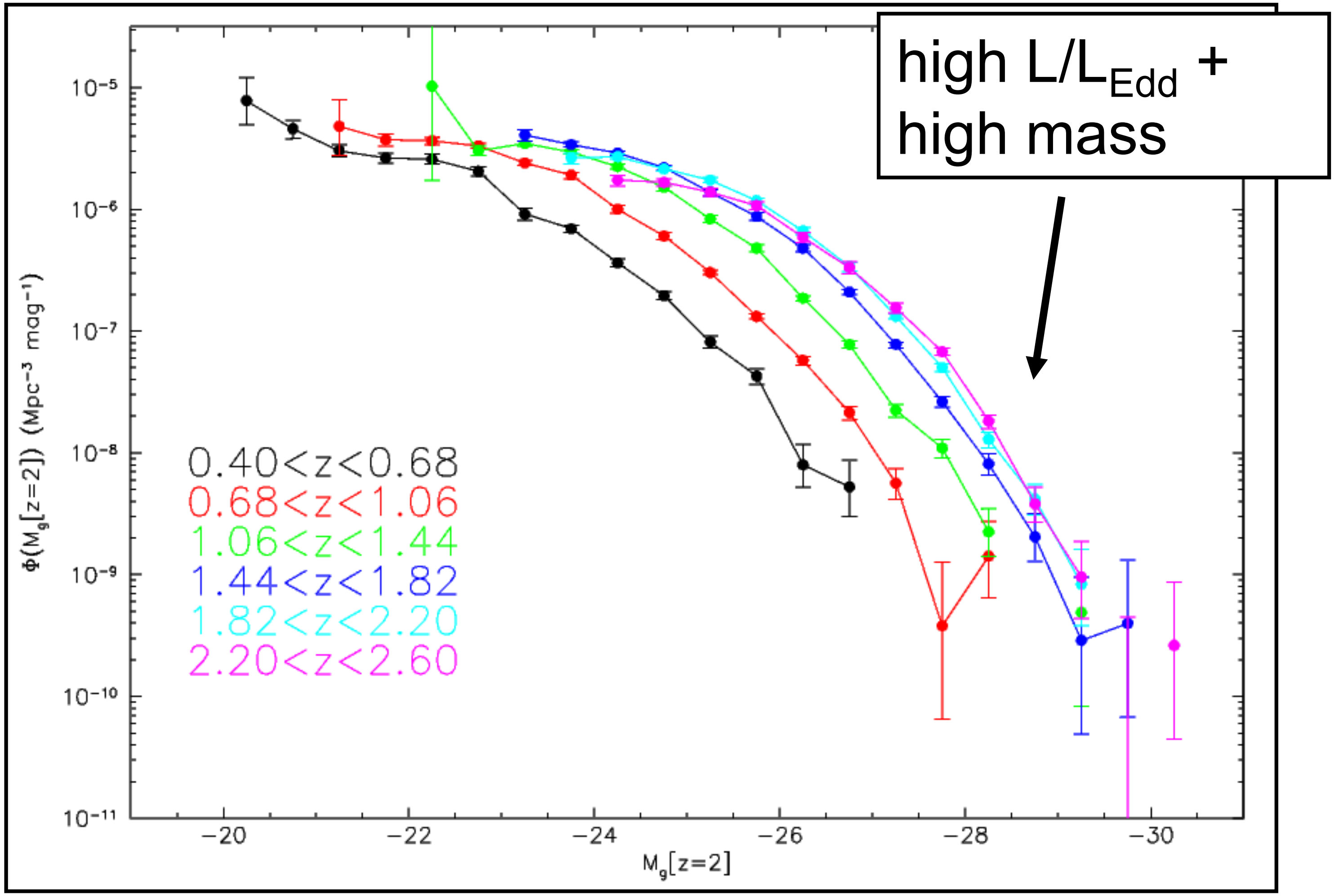
Graham et al. (2011)

Basic observables: LF



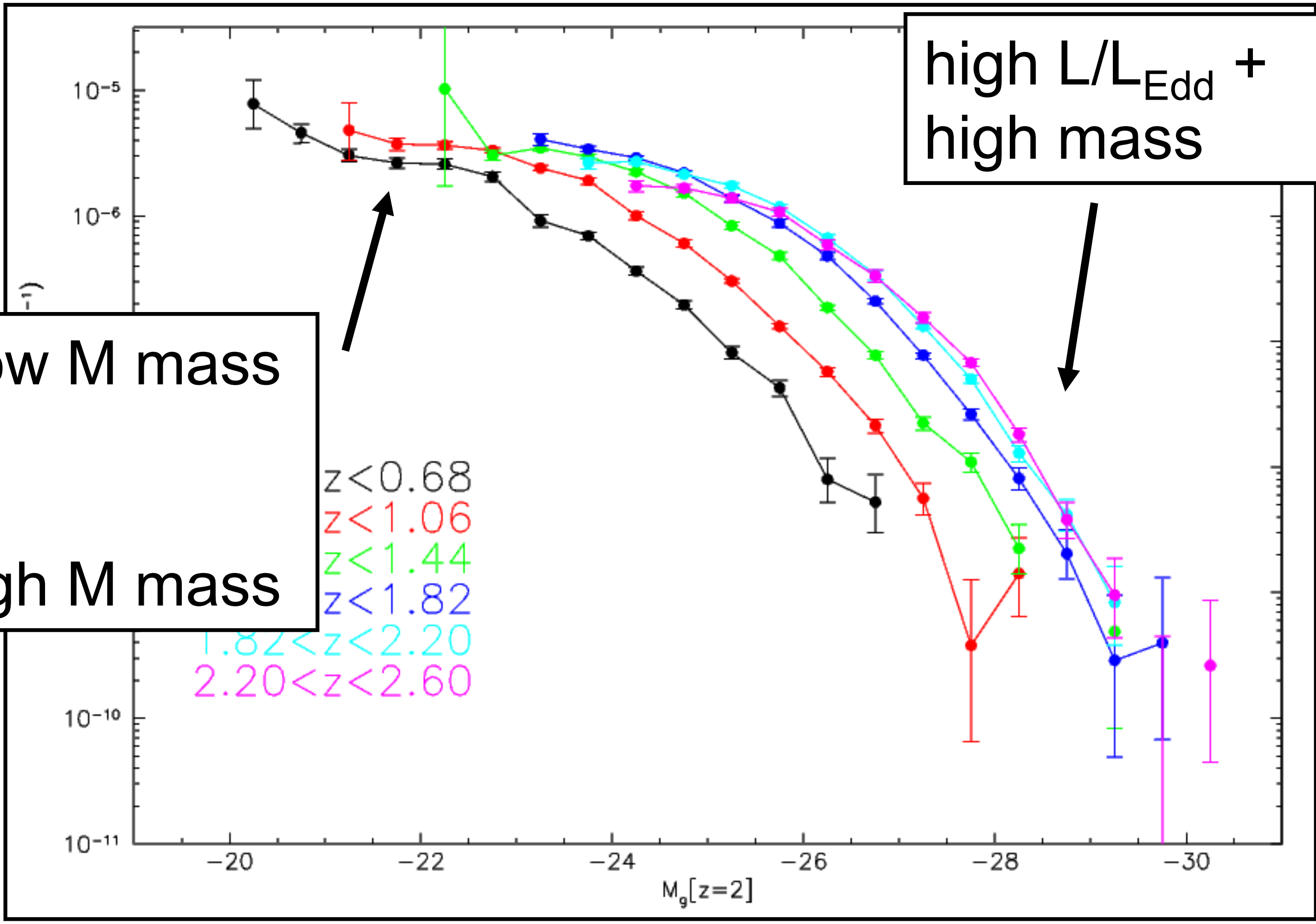
2SLAQ+SDSS, Croom et al. (2009)

Basic observables: LF



2SLAQ+SDSS, Croom et al. (2009)

Basic observables: LF



high L/L_{Edd} + high mass

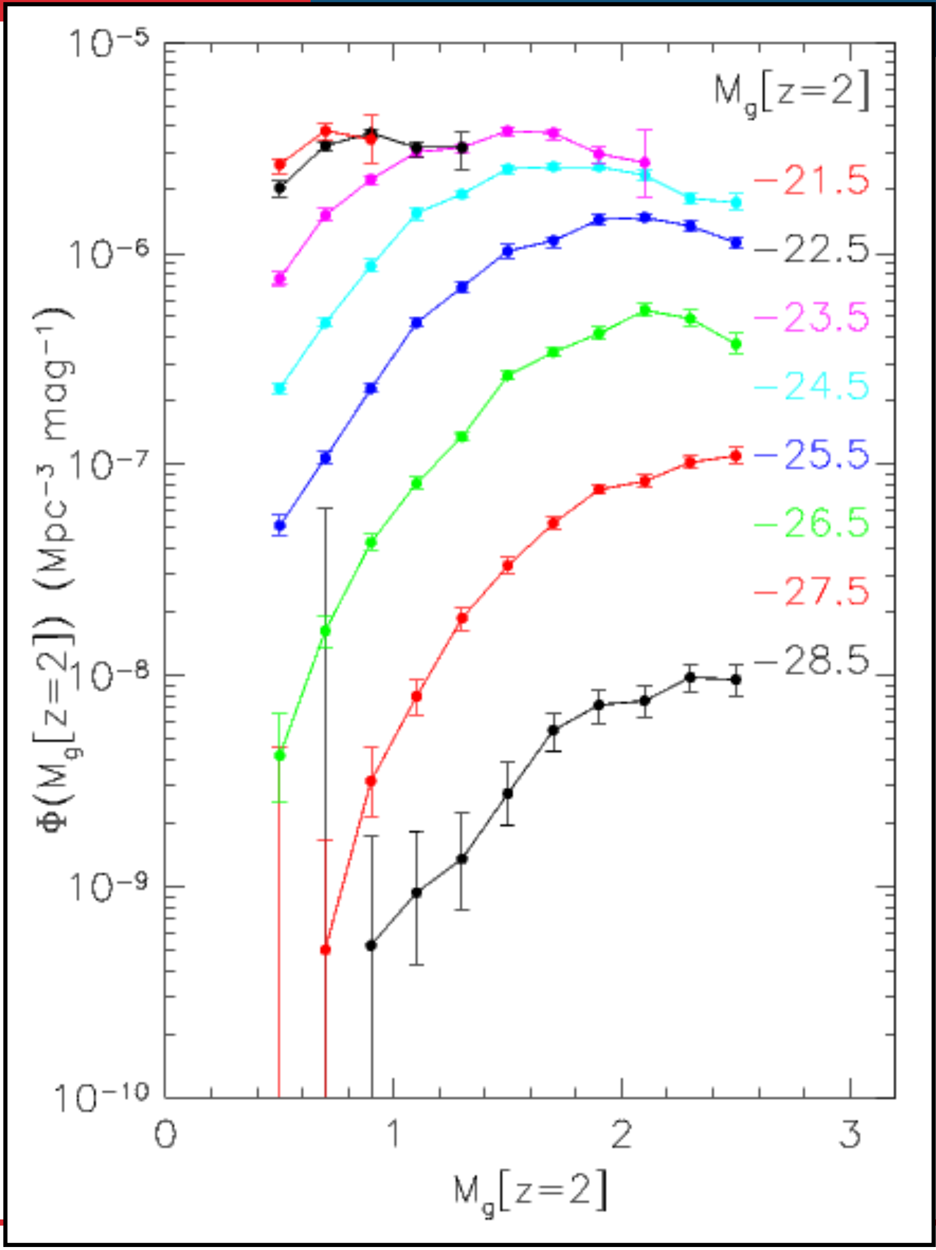
high L/L_{Edd} + low M mass

Or

low L/L_{Edd} + high M mass

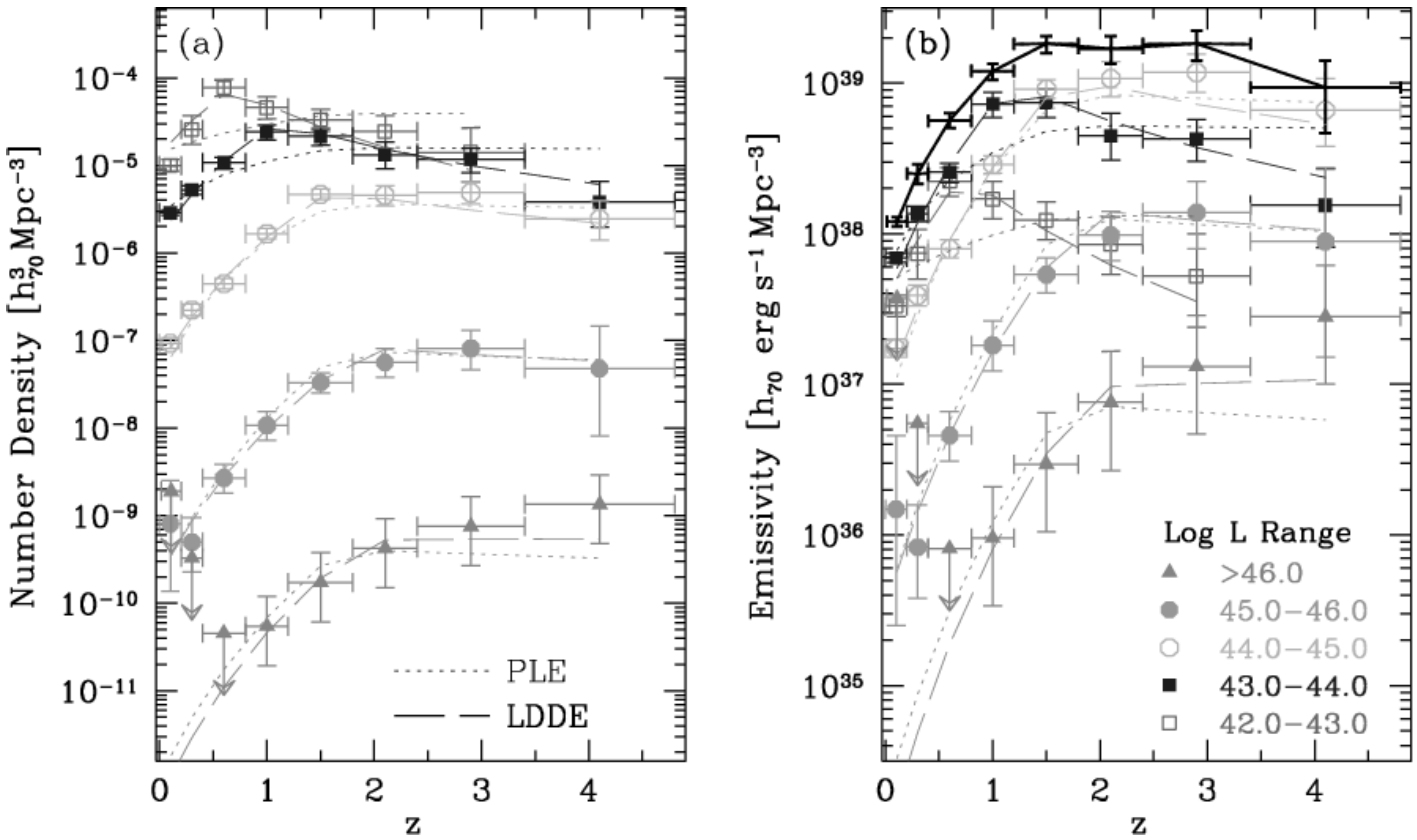
2SLAQ+SDSS, Croom et al. (2009)

Basic observables: LF



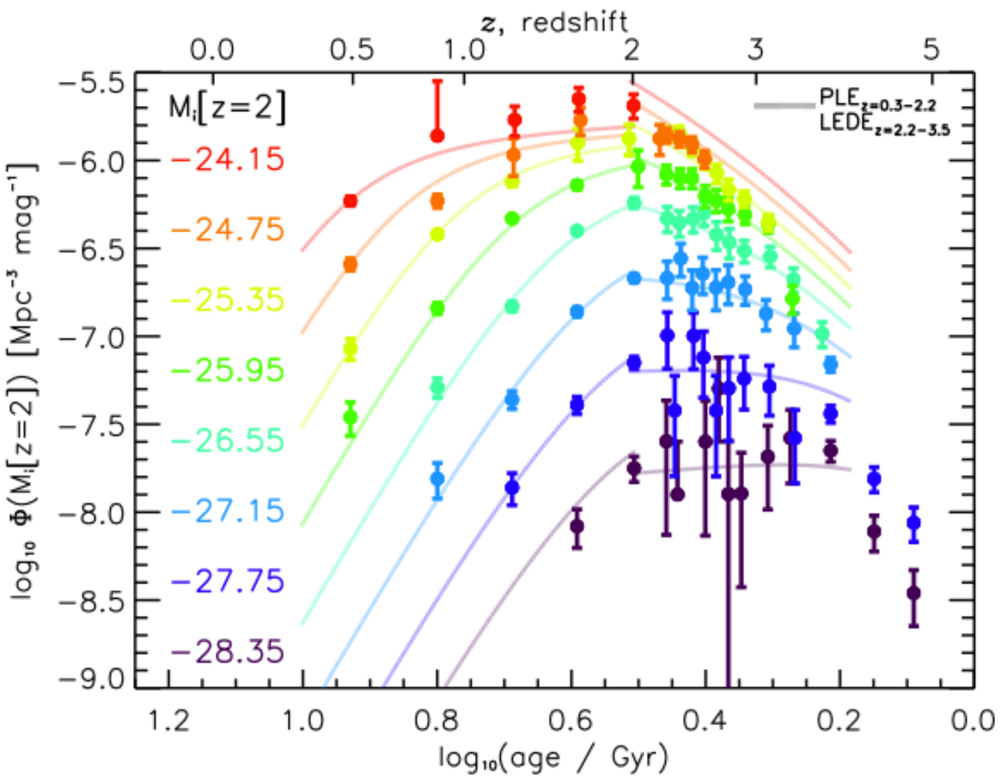
- Brightest quasars peak at z~2.5.
- Faintest quasars peak at lower z.
- x100 increase for luminous quasars.
- DMH merger rates ~$(1+z)^{2-2.3}$ (Fakhouri & Ma 2008) → x15 to z=2.5.

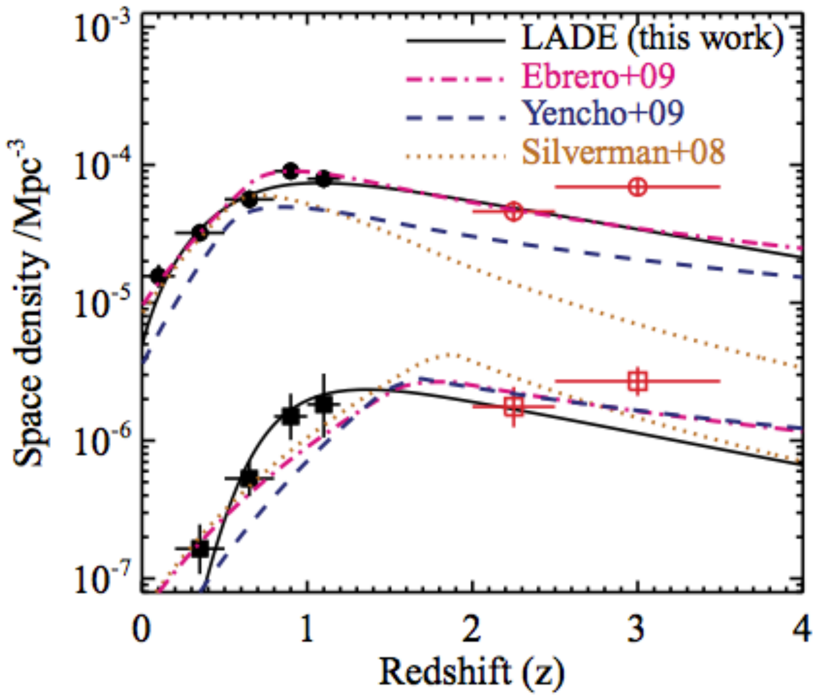
Basic observables: LF



0.5-2 kev X-rays, Hasinger et al. (2005)

› Less evidence of 'downsizing' from BOSS (Ross et al. 2013) and 2-10kev X-ray (Aird et al. 2010).





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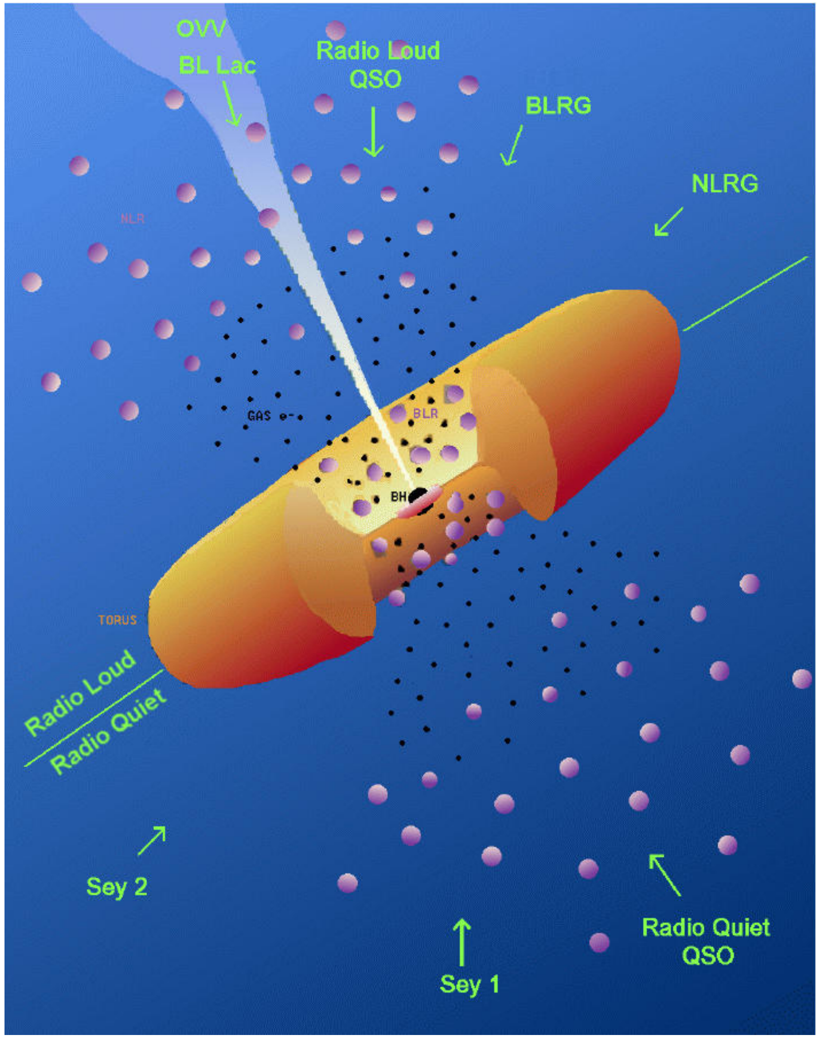
Physical models

› Standard picture…

› Complicated by:

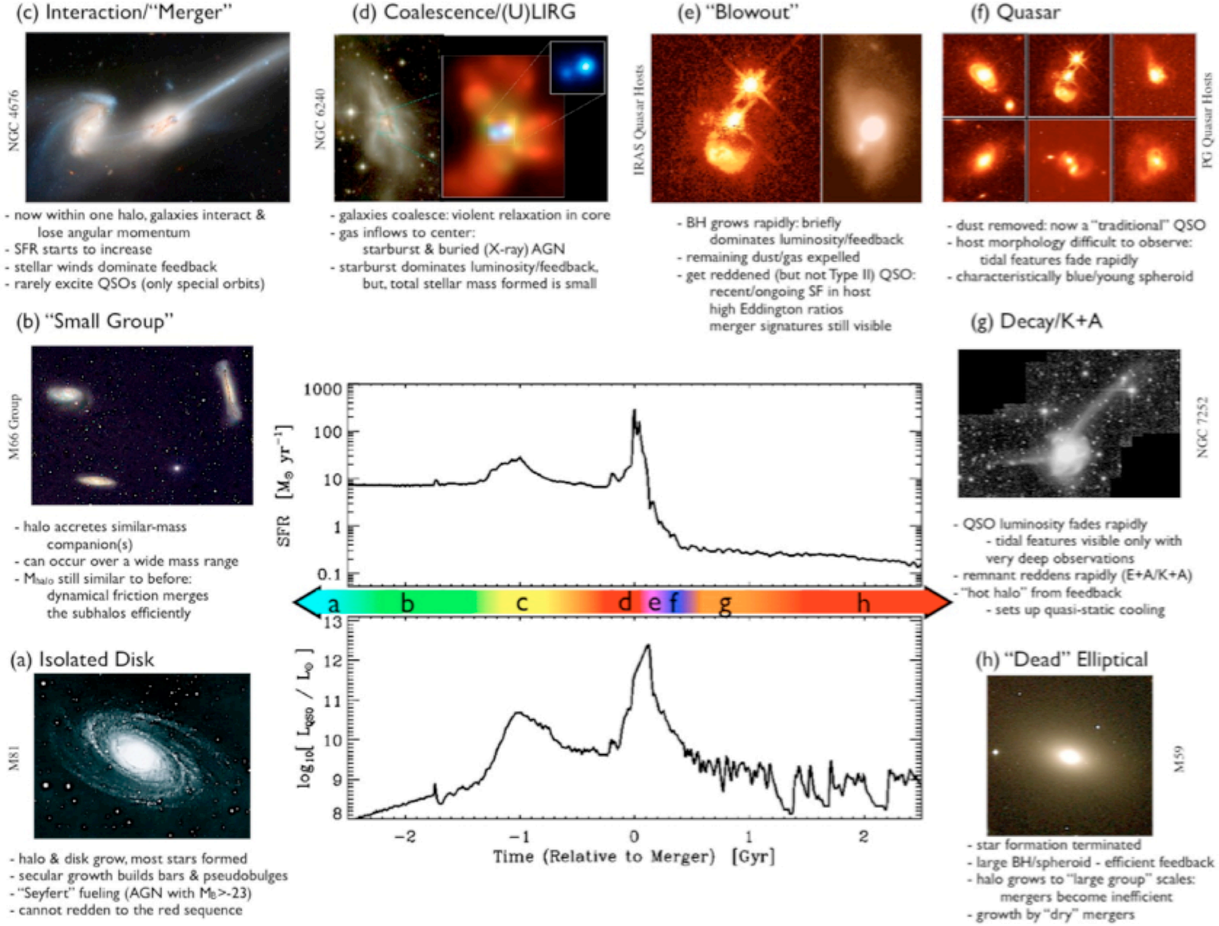
- Outflows
- Evolution
- Accretion mode
- Clumpy torus
- ….



Antonucci & Miller (1985), Urry & Padovani (1995)

Physical models

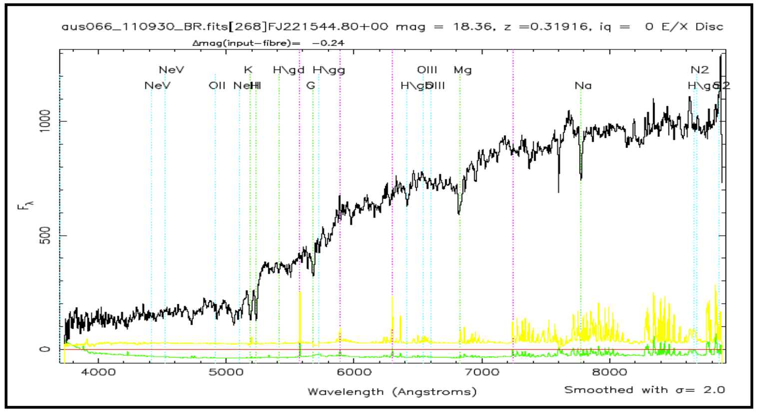
› Mergers an expected triggering route for high luminosity AGN (e.g. Hopkins et al 2008), but likely NOT for low-luminosity…

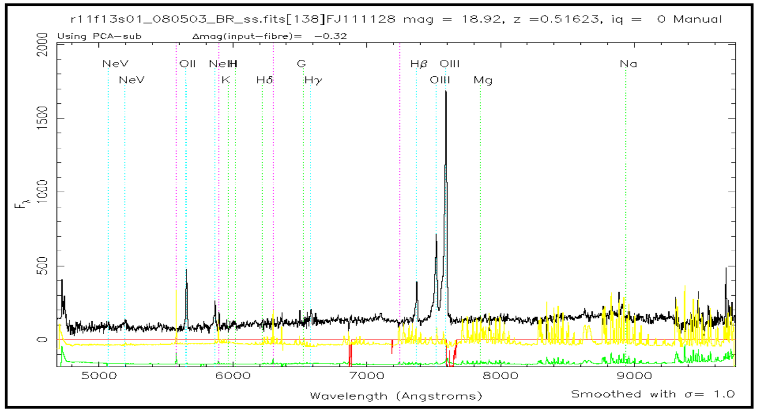


Physical models

- ***Hot mode = radio mode = low ionization.***
- No UV/optical AGN signatures.
- Radiatively inefficient accretion, no thin disk.
- X-ray emission from jet (syncrotron?), hot halo?

- ***Cold mode = quasar mode = high ionization.***
- High-ionization emission lines.
- Strong continuum (if type 1).
- Radiatively efficient accretion disk.
- X-ray emission from inner disk and/ or corona.

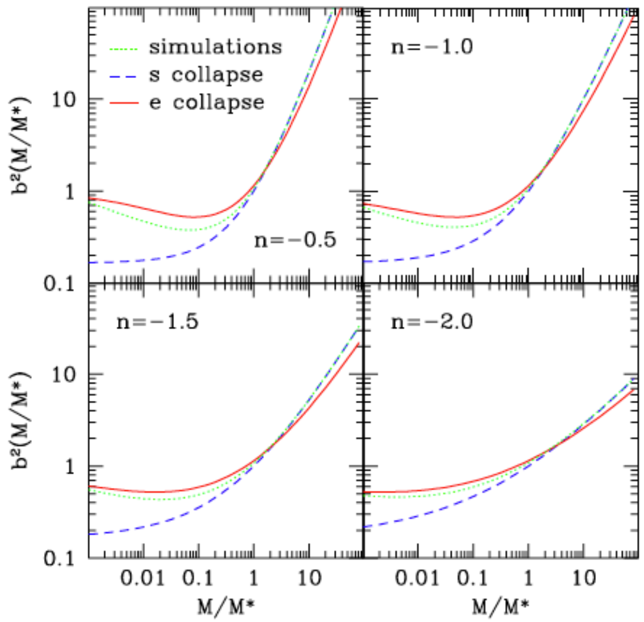




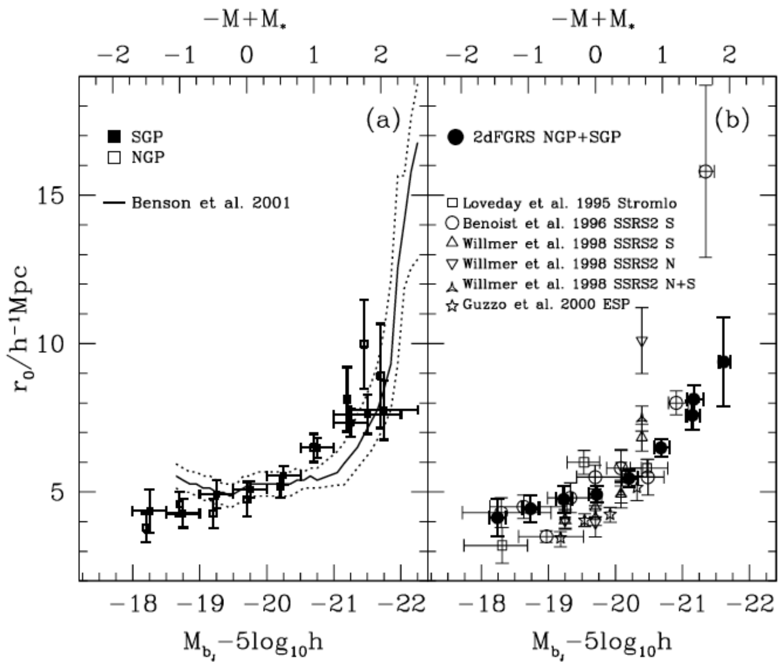
Dichotomy in radio galaxies: accretion mode? (e.g Hardcastle et al 2007)

Clustering and halo mass

- Solid theory to relate linear bias to halo mass, Mo & White (1996), Sheth, Mo & Tormen (2001) and others.
- Clearly seen in the L-dependence of galaxy clustering.
- Leads to halo mass, ages/time-scales, duty cycle…



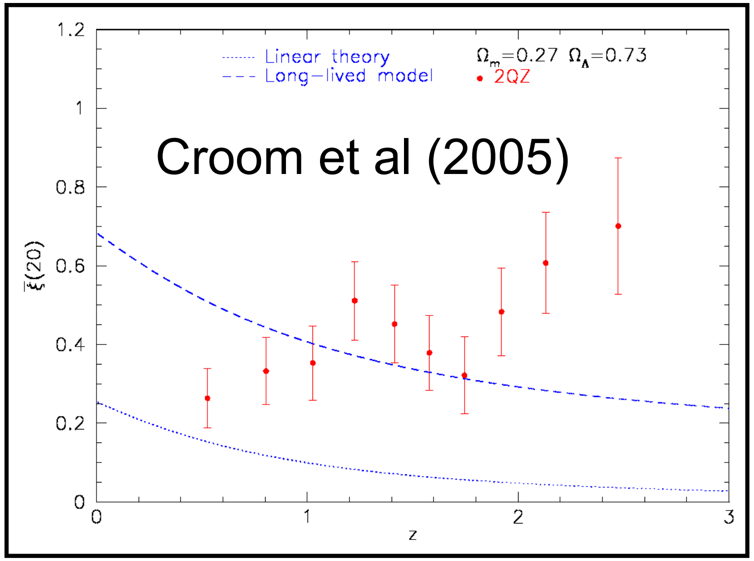
Sheth Mo & Tormen (2001)

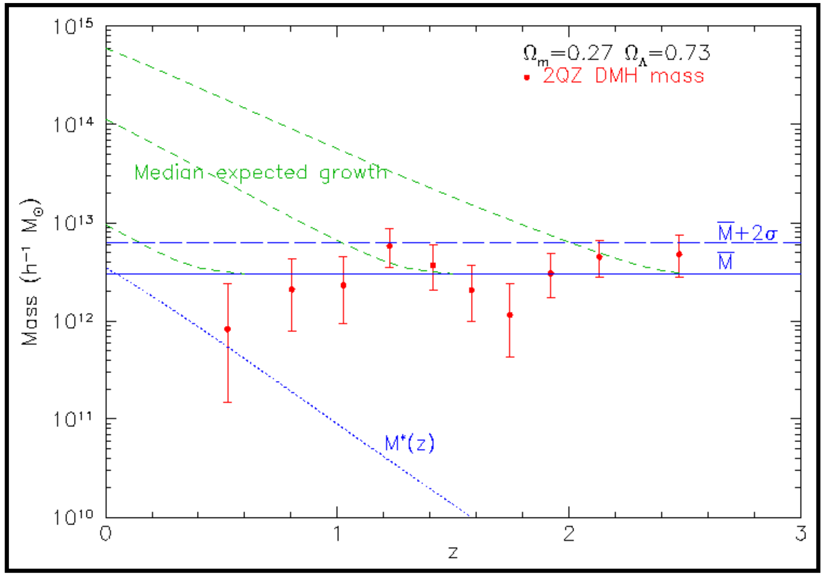


Norberg et al. (2001)

Clustering and halo mass

- Quasar halo mass $\log(M_{DH}) \approx 12\text{-}13$.
- Little change in halo mass with redshift (but not the same luminosity).
- Constraint on lifetime from expected mass growth ~10^9 yr.
- Constraint on lifetime from halo abundance ~$10^{7\text{-}8}$ yr (e.g. Martini & Weinberg 2001), i.e. duty cycle.

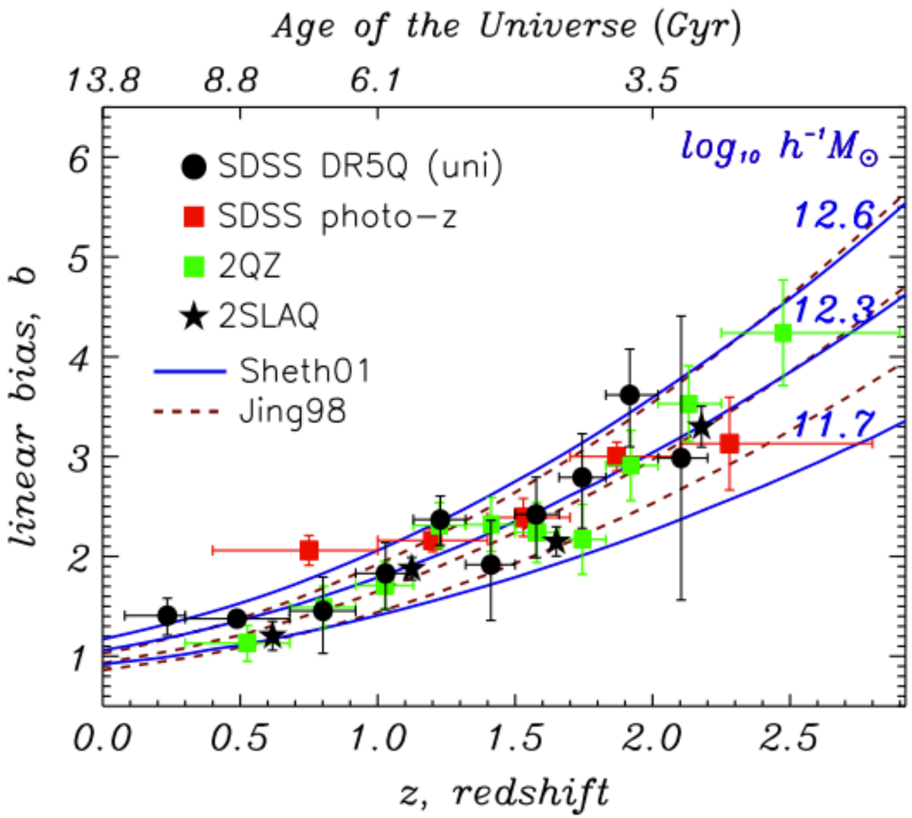


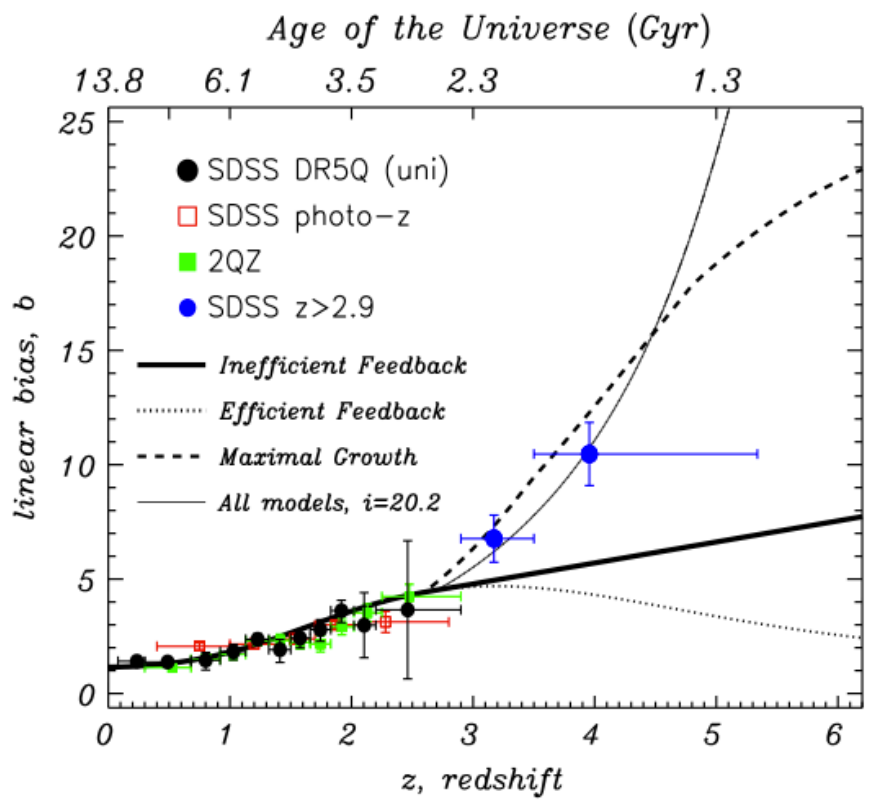


Clustering and halo mass

› First phot-z quasar samples + clustering (Richards et al., 2004; Myers et al. 2006) are key step to higher precision.

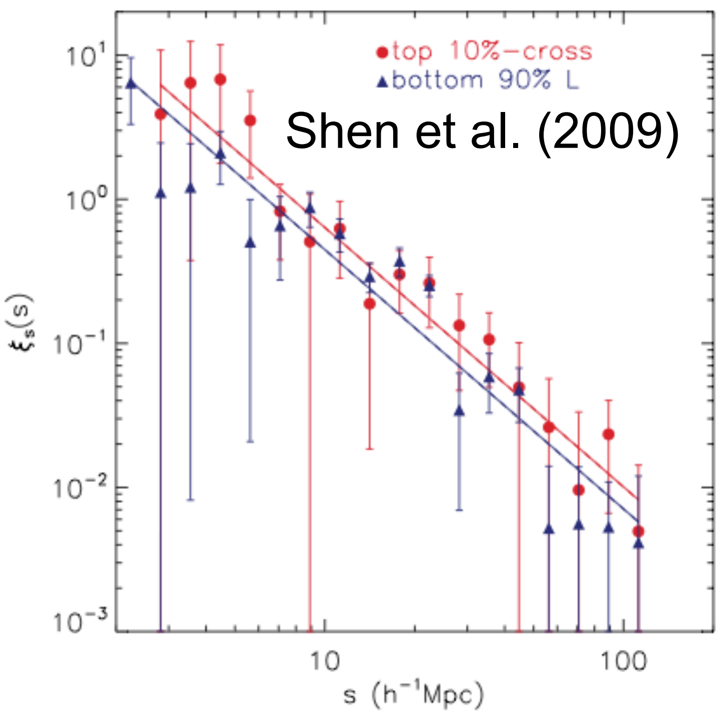
› Then SDSS (Shen et al. 2007; Ross et al. 2009).

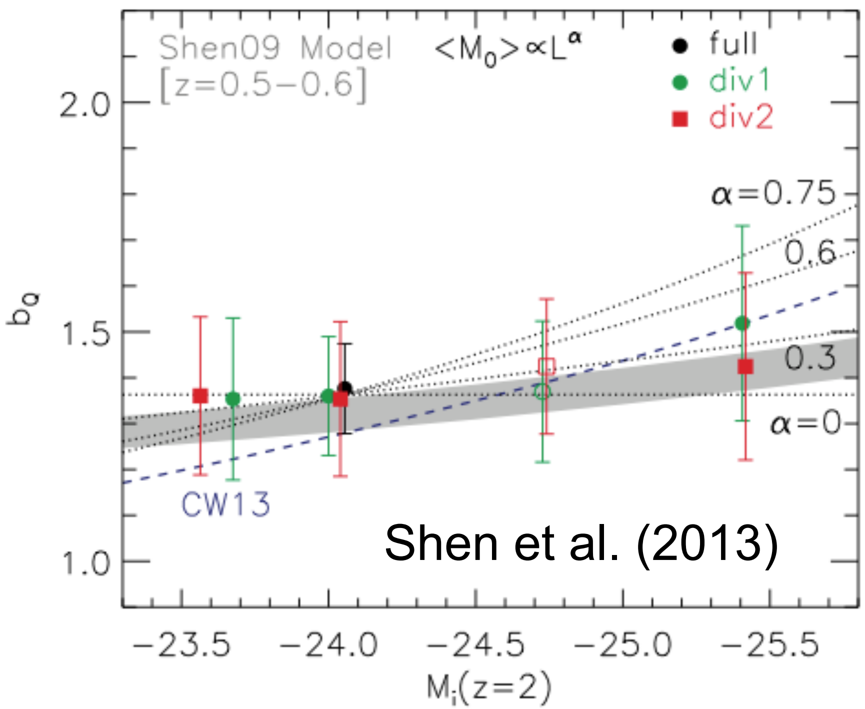




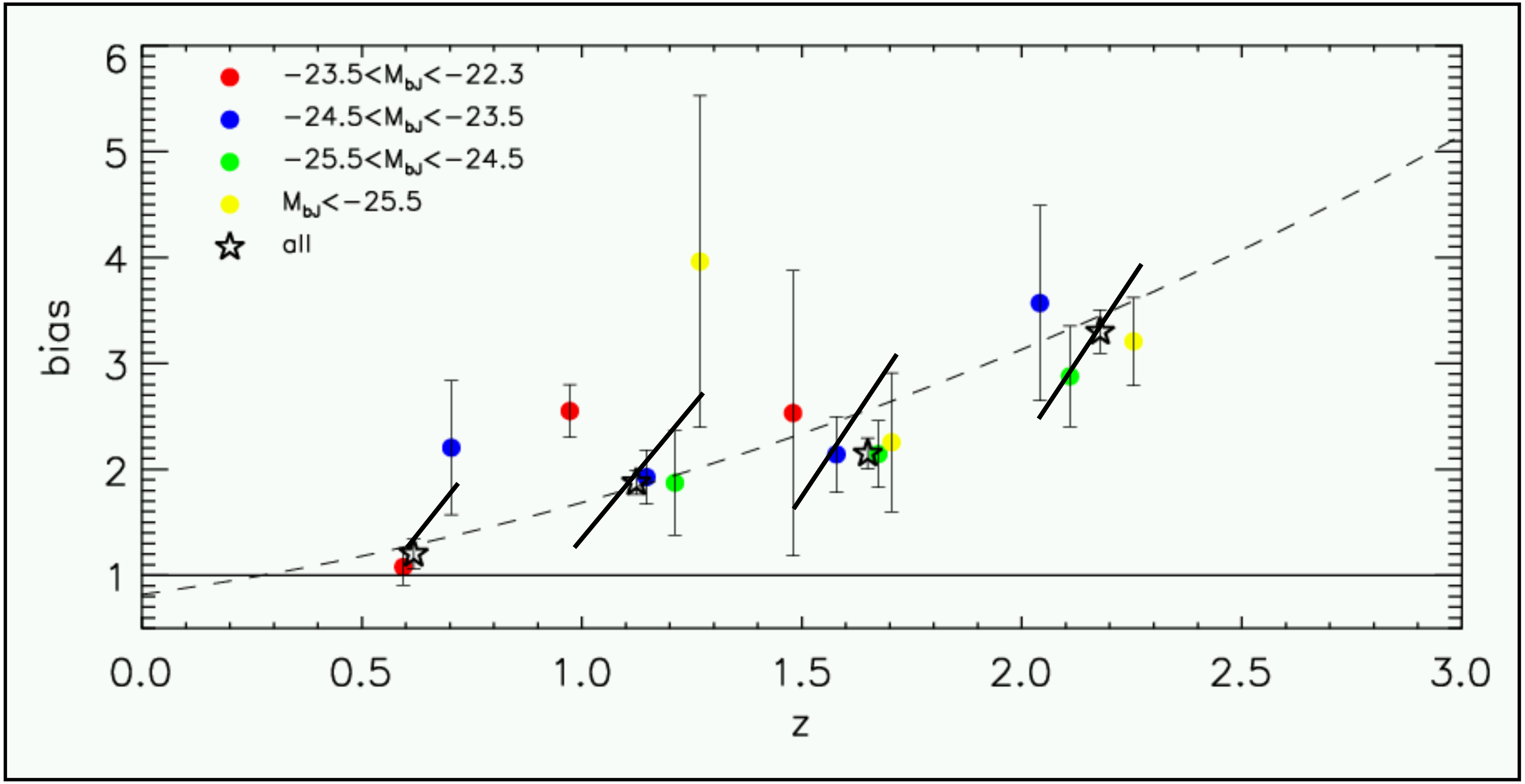
Clustering and halo mass: luminosity dependence

› Various attempts to measure luminosity dependence (e.g. Croom et al., 2002; Porciani & Norberg 2006; da Angela et al. 2008; Shen et al. 2009; Shen et al 2013 and others), with ~2σ at best detections.





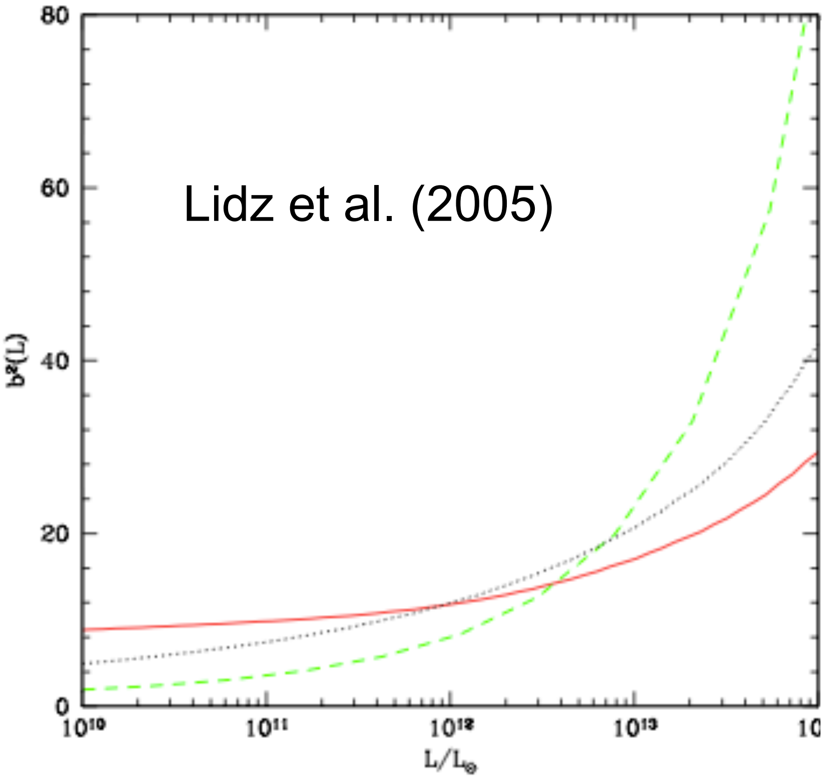
Luminosity dependent clustering

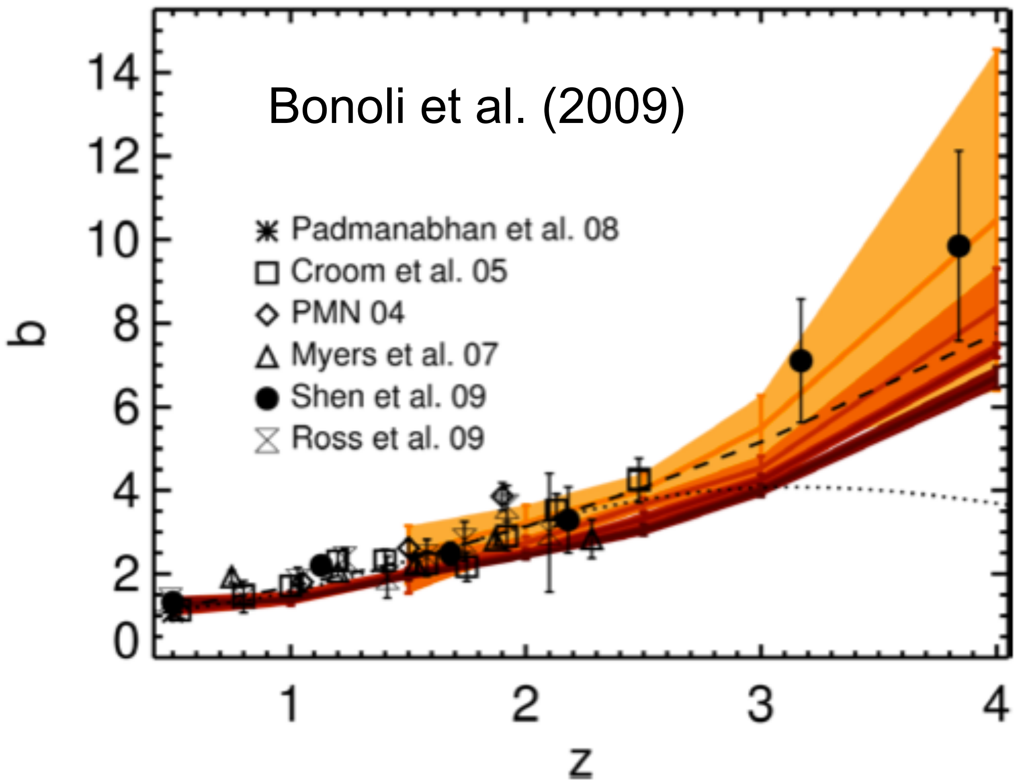


2SLAQ: da Angela et al. (2008)

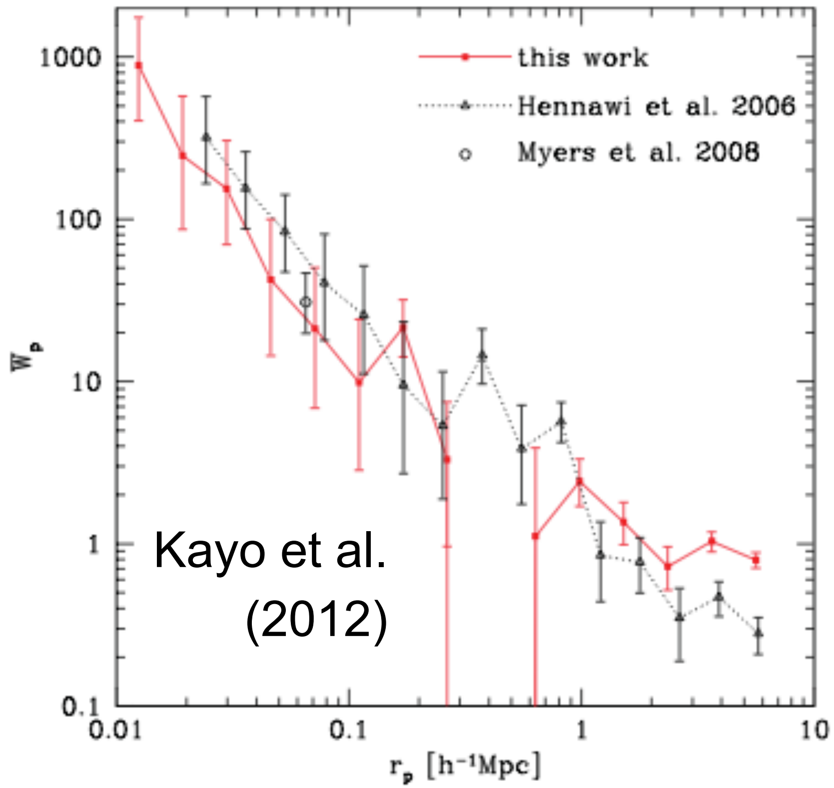
Clustering and halo mass: luminosity dependence

› In general agreement with theory (e.g. Lidz et al. 2005; Thacker et al. 2009; Bonoli et al. 2009; Fanidakis et al., 2013) … wide range in L for given M.





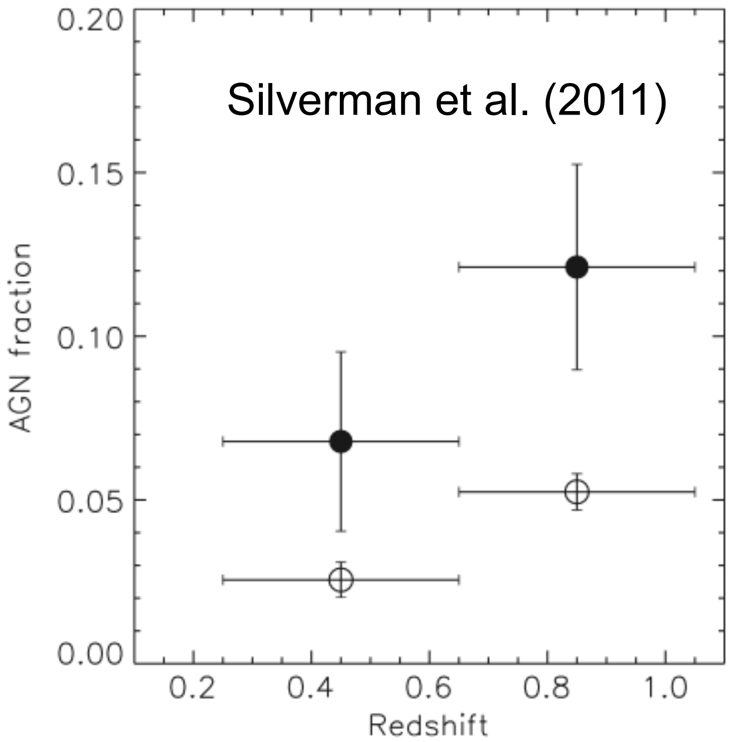
- Clustering on small scales probes 1-halo term, satellite fraction, evidence of interaction induced excesses (Hennawi et al. 2006; Myers et al. 2008; Kayo et al. 2012).
- Largely using explicit samples of close pairs (including from lensing studies).
- General picture is for small satellite fraction, and evidence for excesses on very small scales.

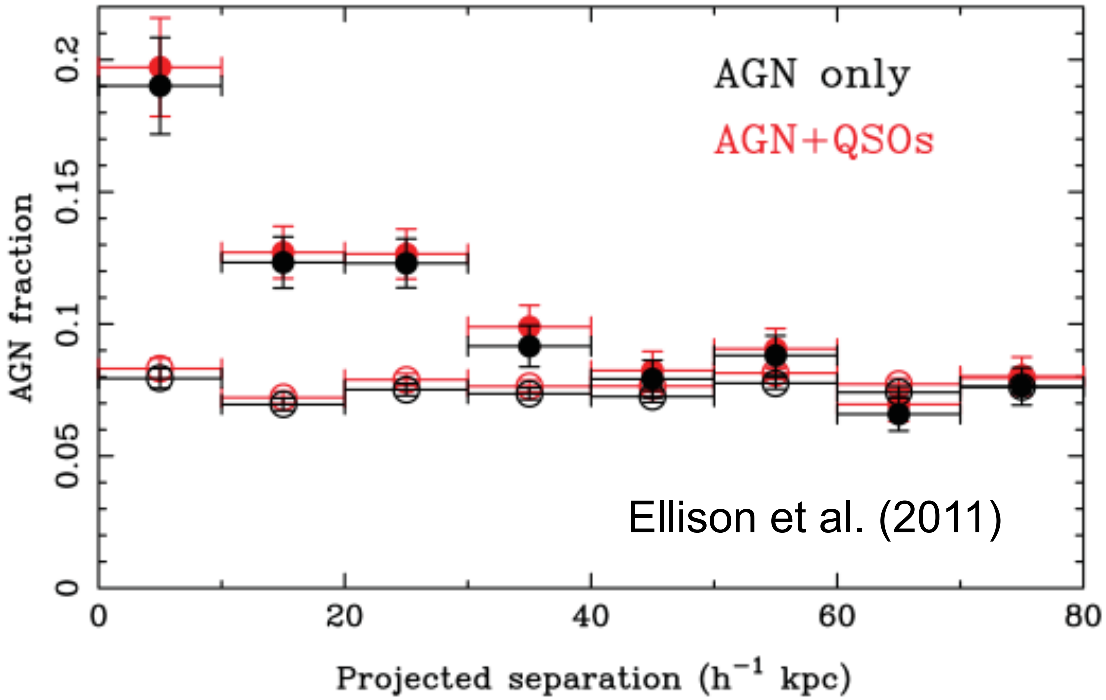


Small scales: close pairs

› Now clear evidence that close pairs enhance AGN activity, even for relatively low luminosity:

- SDSS close pairs: Ellison et al. 2011
- zCOSMOS close pairs: Silverman et al. 2011.

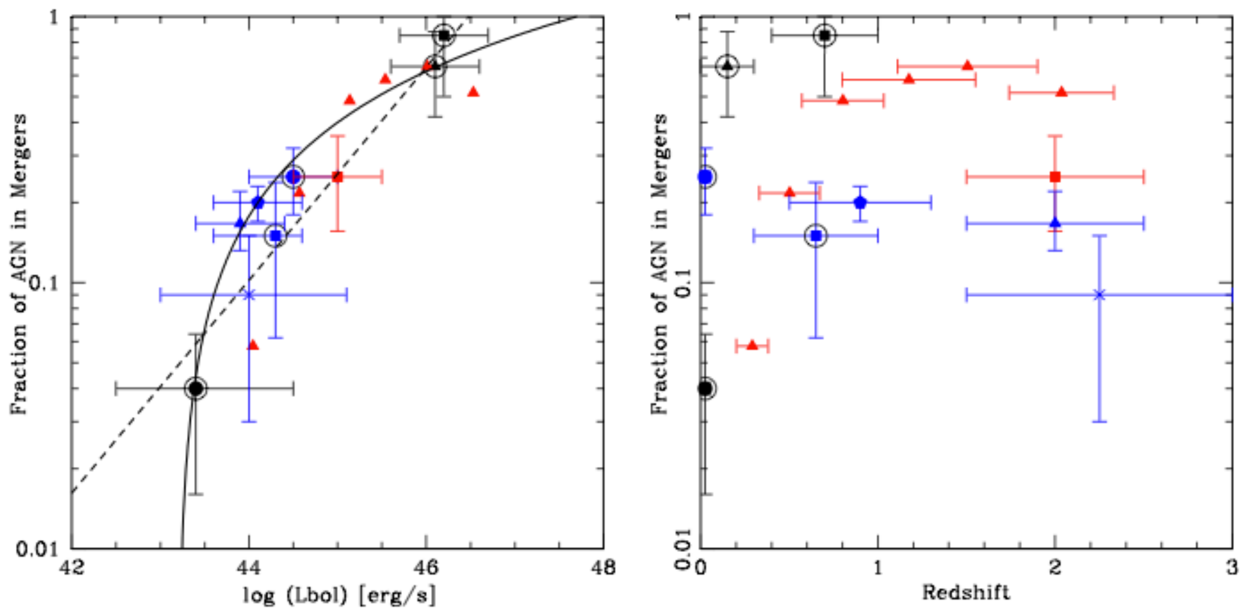




Small scales: when are mergers important?

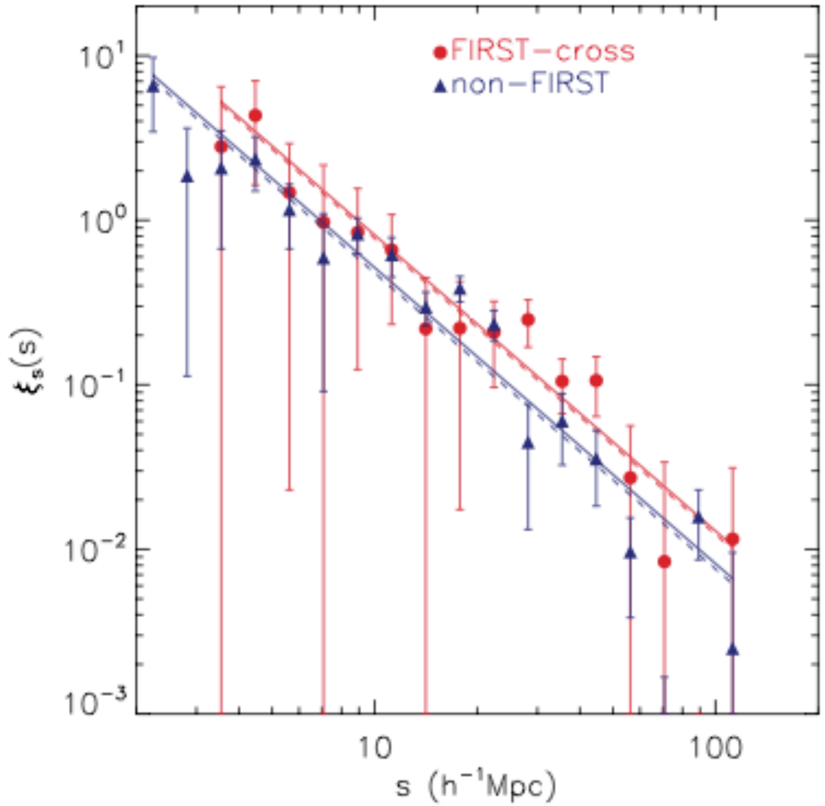
› Very mixed direct evidence for AGN triggering via mergers when looking at morphology (e.g. Cisternas et al. 2011; Villforth et al., 2014).

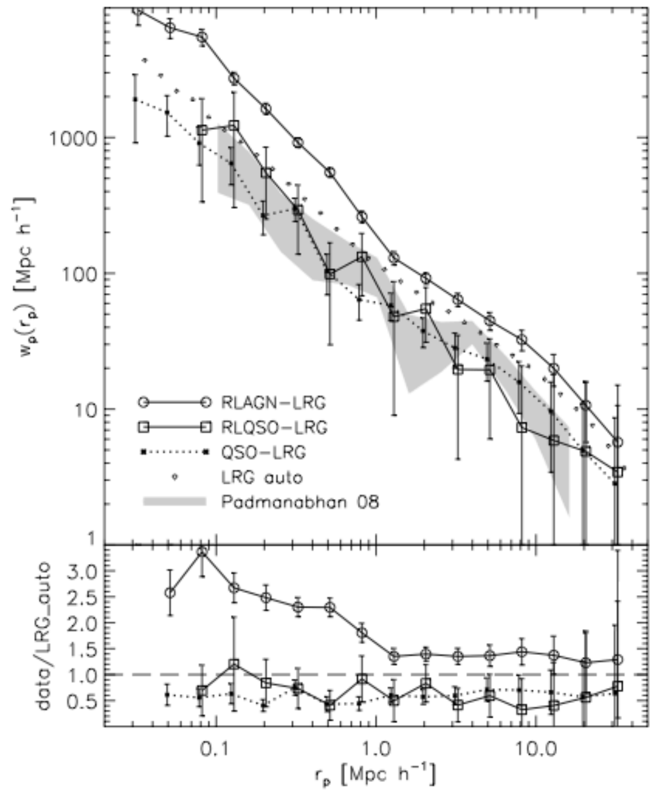
› Treister et al. (2012) suggest mergers only important at highest bolometric luminosities.



Clustering and halo mass: radio-loudness

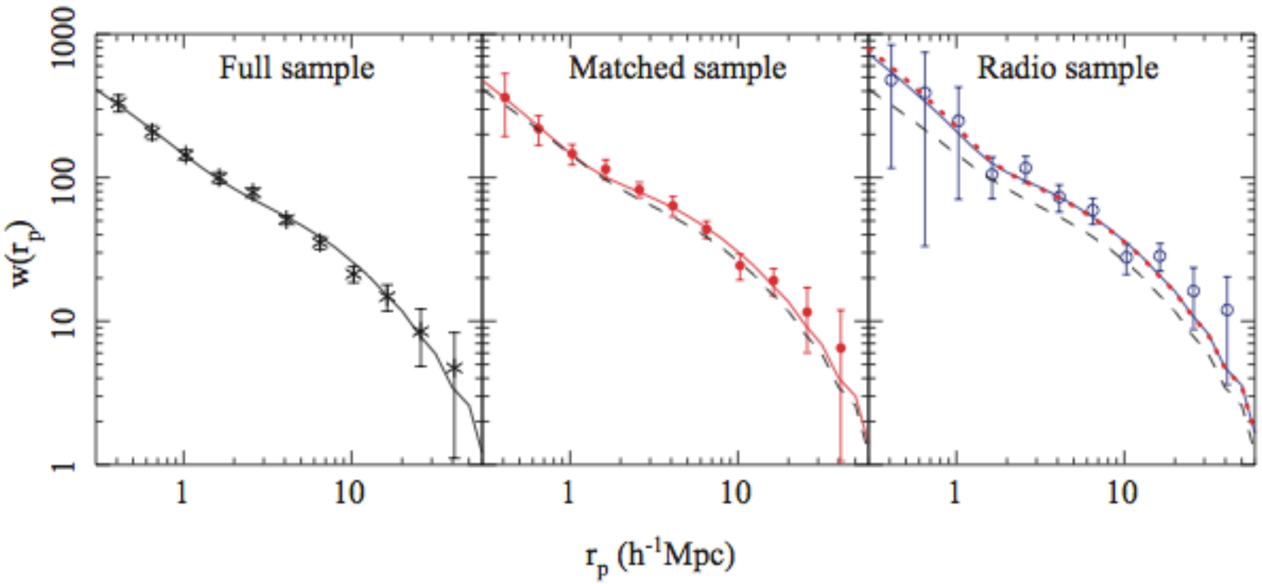
- Evidence that quasars with powerful radio jets are clustered more strongly (e.g. Shen et al. 2009, z~1.5).
- But some disagreements (Donoso et al. 2010, z~0.5).

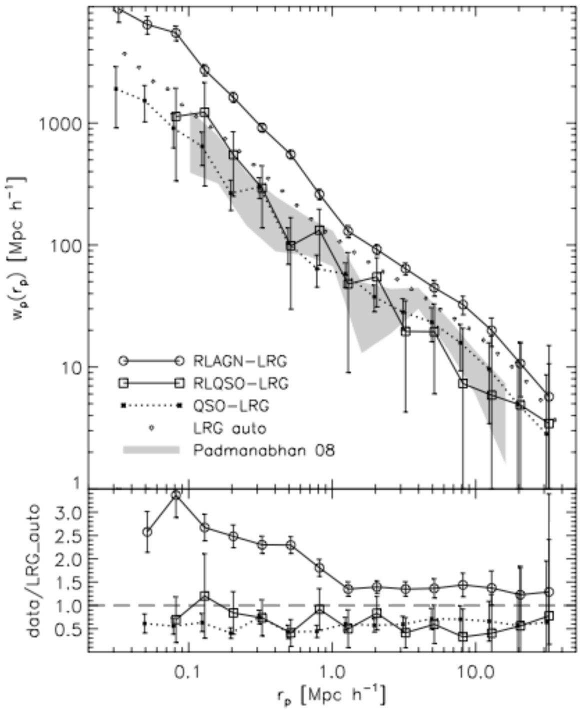




Connections to radio galaxies

› Radio galaxies cluster more strongly than mass/colour matched non-radio galaxies (2SLAQ; Wake et al. 2008)

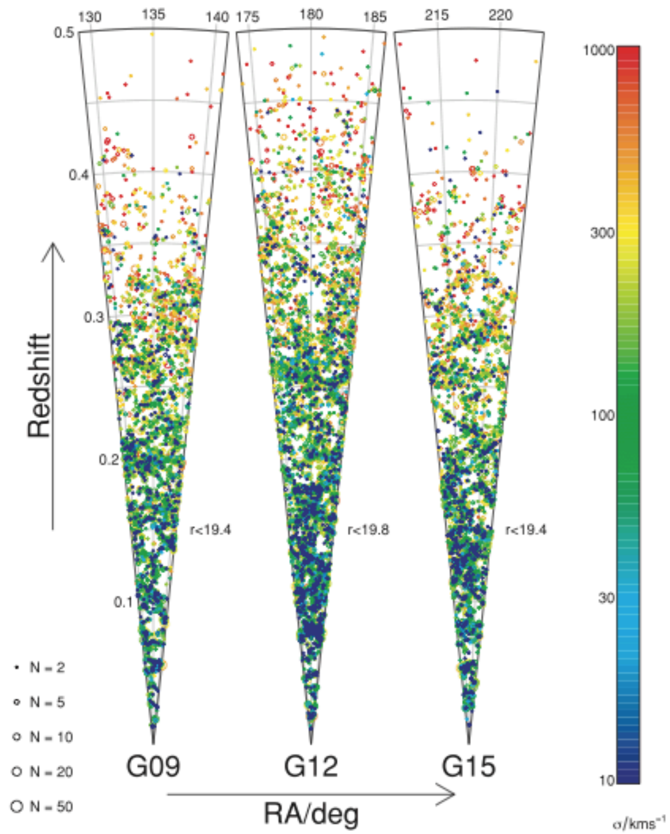


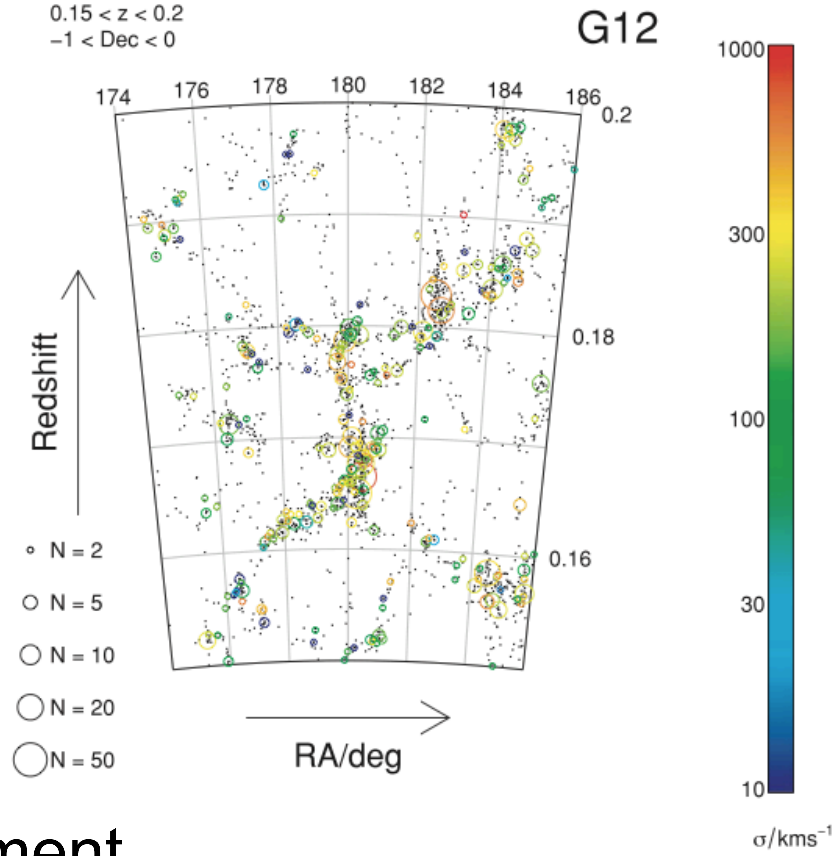


› Also Donoso et al. (2010) – radio galaxies also more strongly clustered than radio-loud quasars. Not the same objects!

Going further – a deeper view of environment

- GAMA groups (Robotham et al. 2011). Deep, r<19.8 spectrscopy for high fidelity groups in the local Universe.





- More that just statistical environment.

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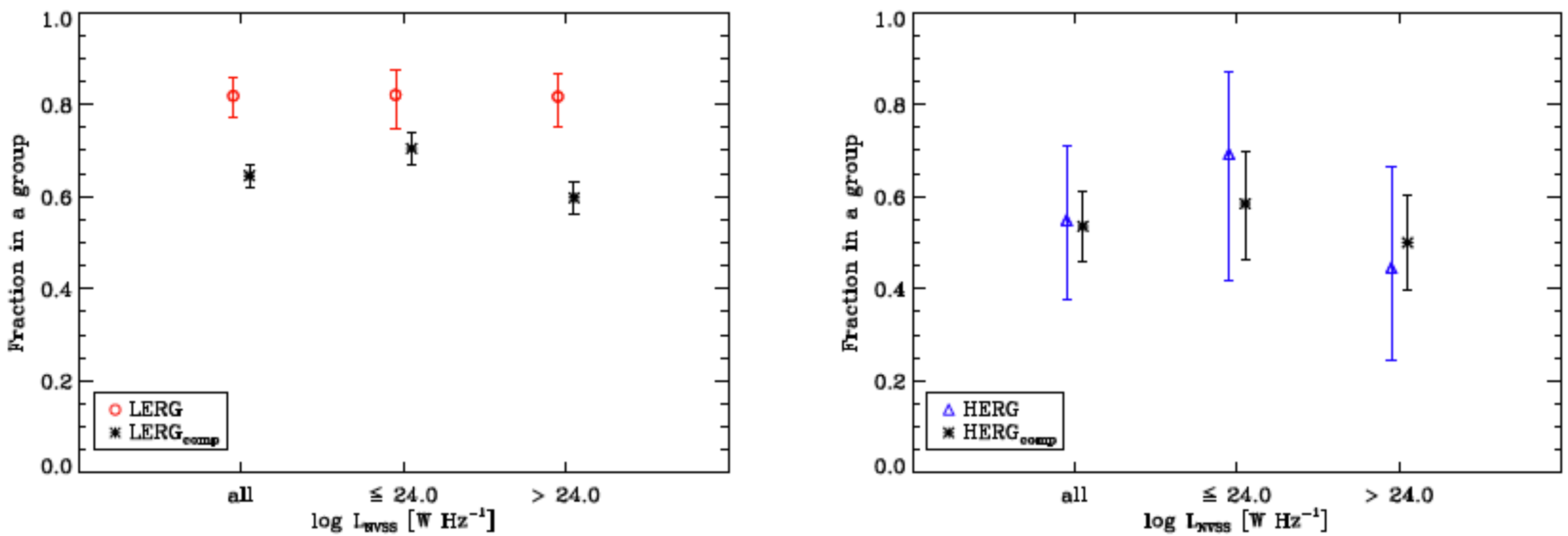
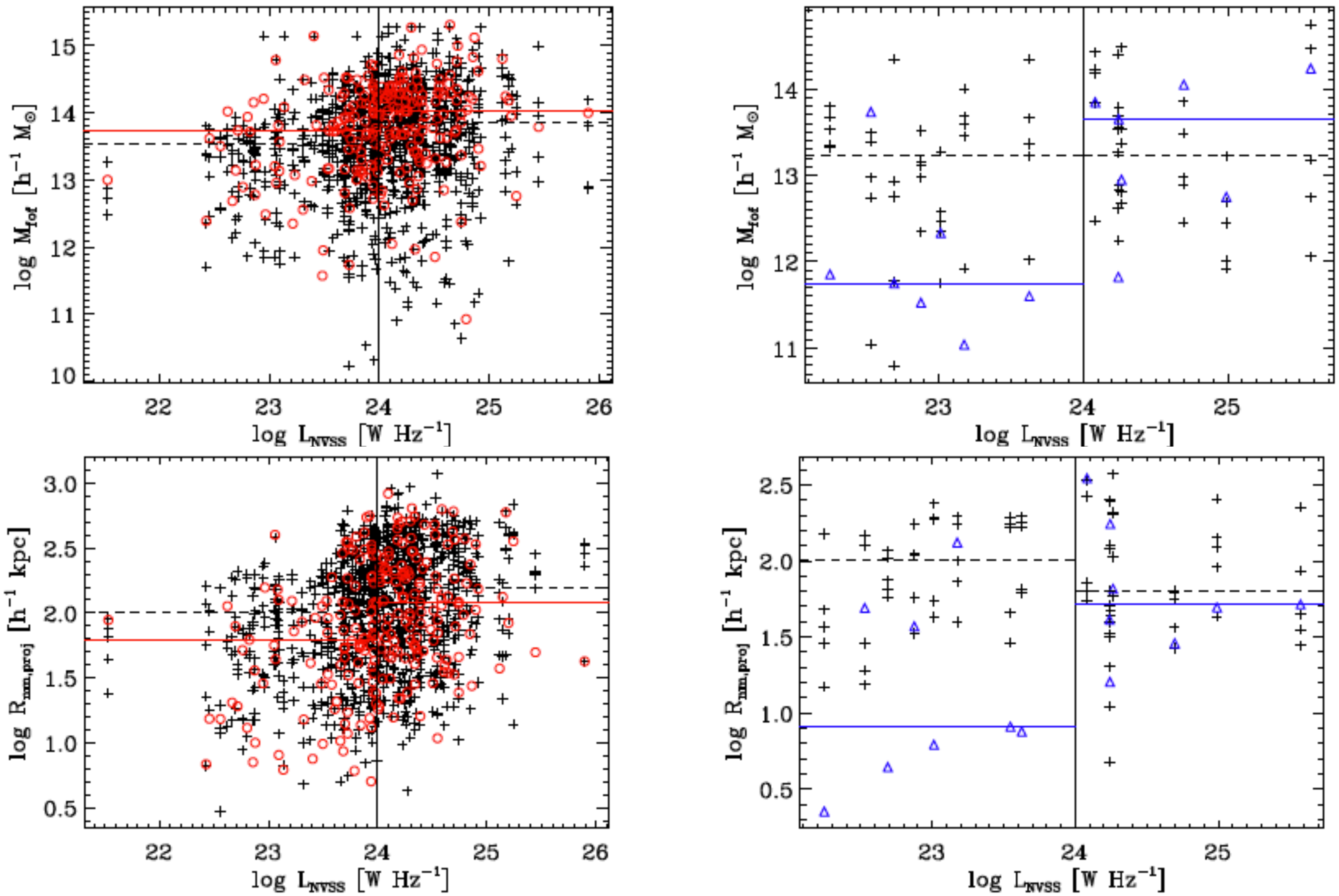
Going further – a deeper view of environment

- Ching et al (in prep), new radio galaxy survey within GAMA and WiggleZ surveys. Particular focus on GAMA and groups.



- Higher fraction of LERGs in groups, consistent with LERGs in higher halo mass.
- If matched for mass/colour and in a group – little difference.

Going further – a deeper view of environment

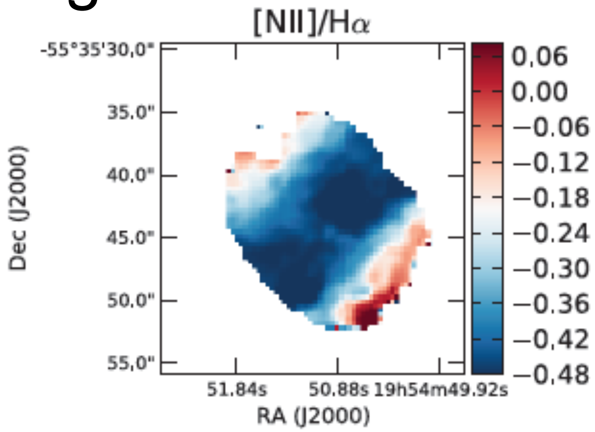


Questions that remain

- Still no clear picture of the triggering mechanisms and how this varies with luminosity/mass/z.
- How meaningful is the halo model for an ‘event’ such as a quasar? Considered parameter degeneracy etc. (e.g. see Chatterjee et al 2013).
- Why are RGs in higher mass halos? And what triggers those jets anyway?
- How degenerate are the models? More than one way to get the right answer?

Opportunities

- Next generation of spectroscopy surveys – eROSITA/4MOST, eBOSS, DESI…
- Dynamic range in z and L important to constrain models.
- Narrow band surveys, e.g. J-PAS (Abramo et al. 2012).
- Huge value in having the high-z parent samples for the AGN.
- More than just a redshift – multi-object IFU surveys now underway, SAMI has observed 1000 z~0.04 galaxies:
  - Feedback within the context of the surrounding LSS.
  - Connecting AGN to dynamical mass.
  - Dynamical disturbance as a merger indicator.
  - …



Summary

› Clear picture of the halos that quasars occupy, but not yet clear where within halos.

› Luminosity dependence is weak – not surprising given the multiple steps from L to halo mass.

› Good evidence that mergers play a role – when and where still somewhat open.

› New surveys will present a rich diversity of opportunities…