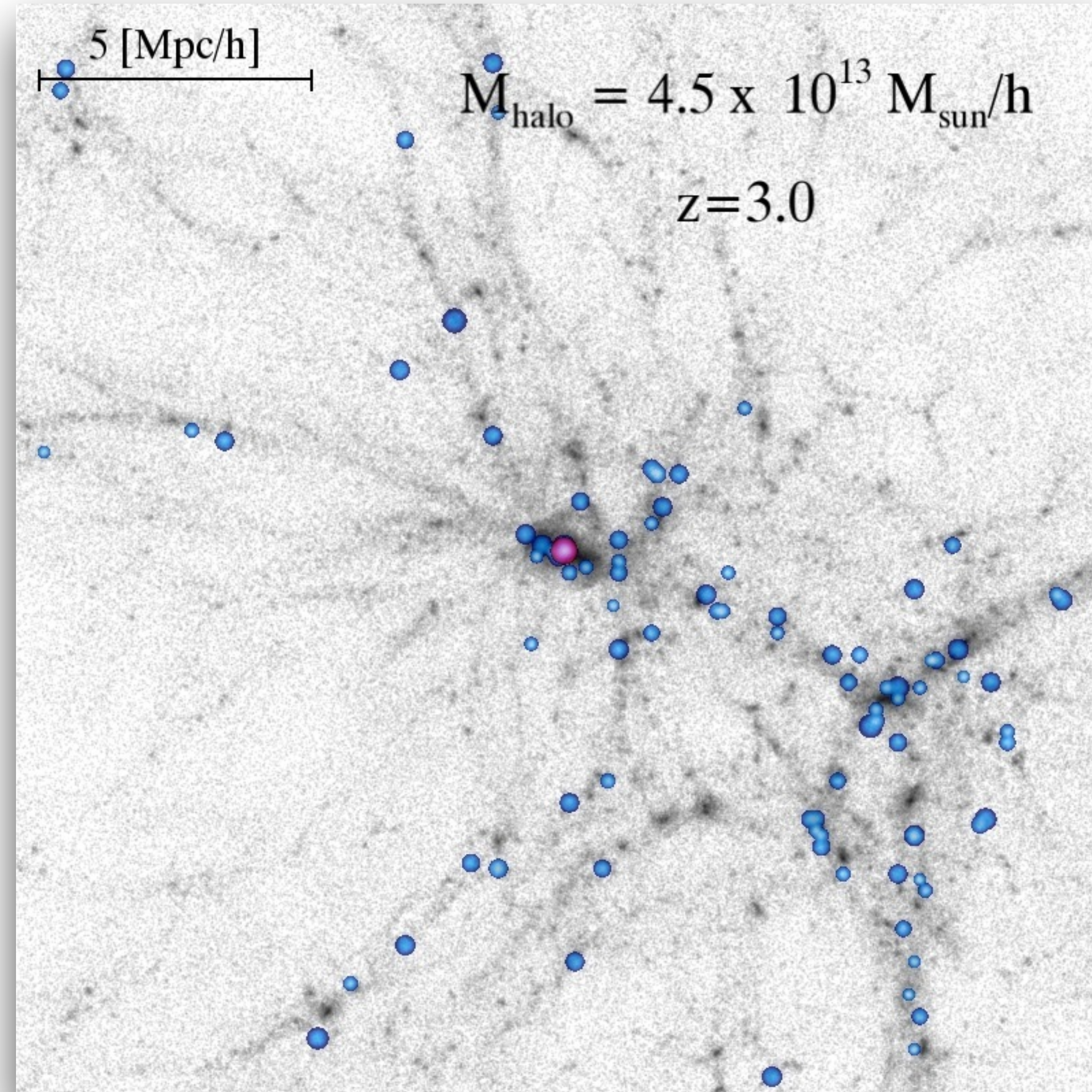
The underlying massive structures revealed by high-redshift radio galaxy and quasar environments



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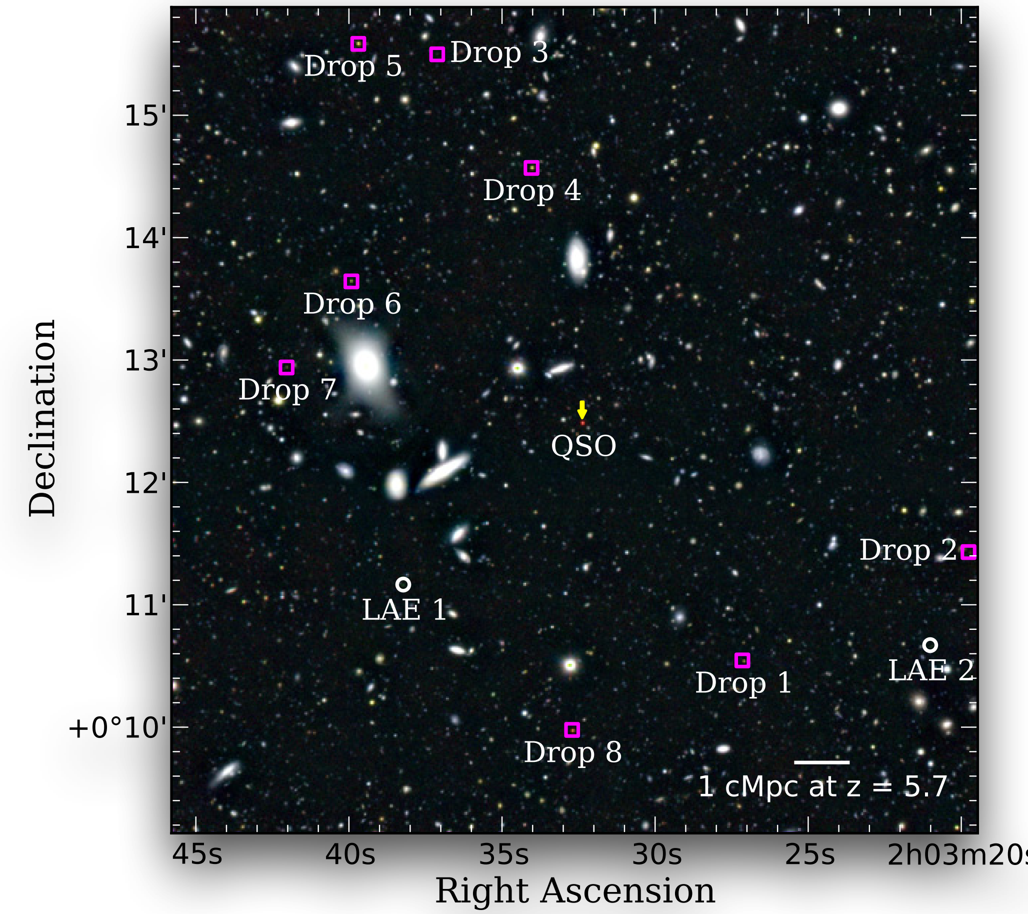
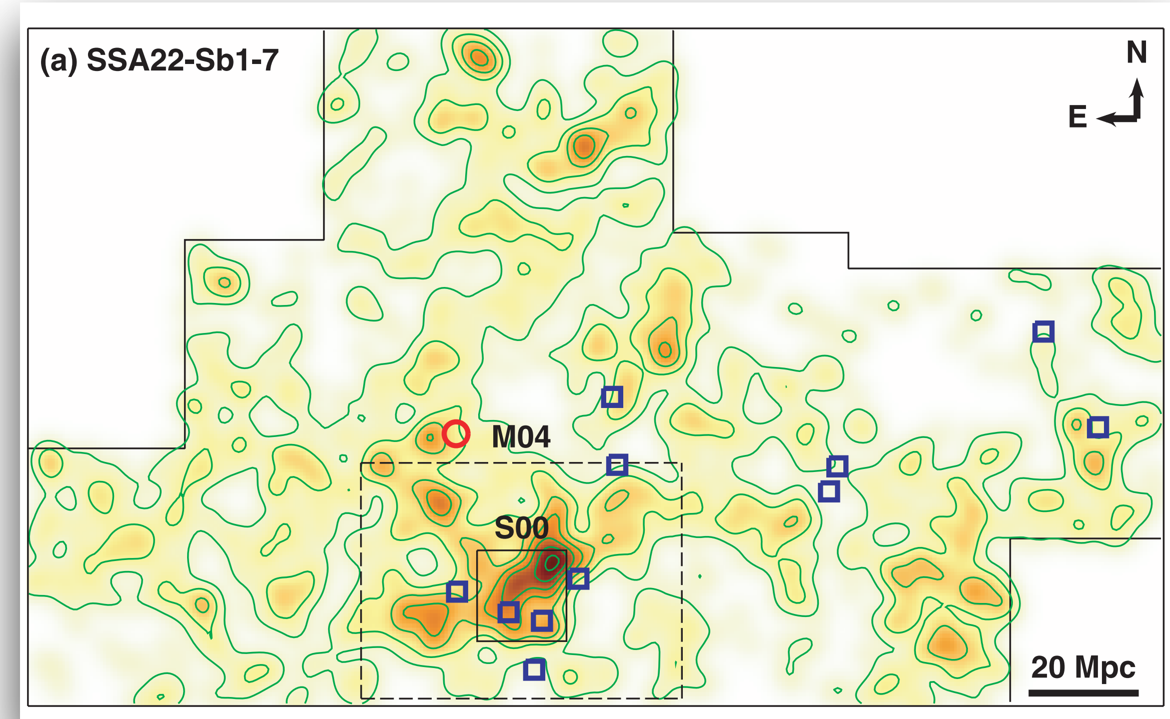
Evolving galaxies in evolving environments, 15-19 September 2014 Bologna, Italy

Tracers of protoclusters at high redshifts

- Hot gas in X-rays (z≲2)
- Galaxy over-densities
- Lyα blobs
- Radio galaxies
- Quasars



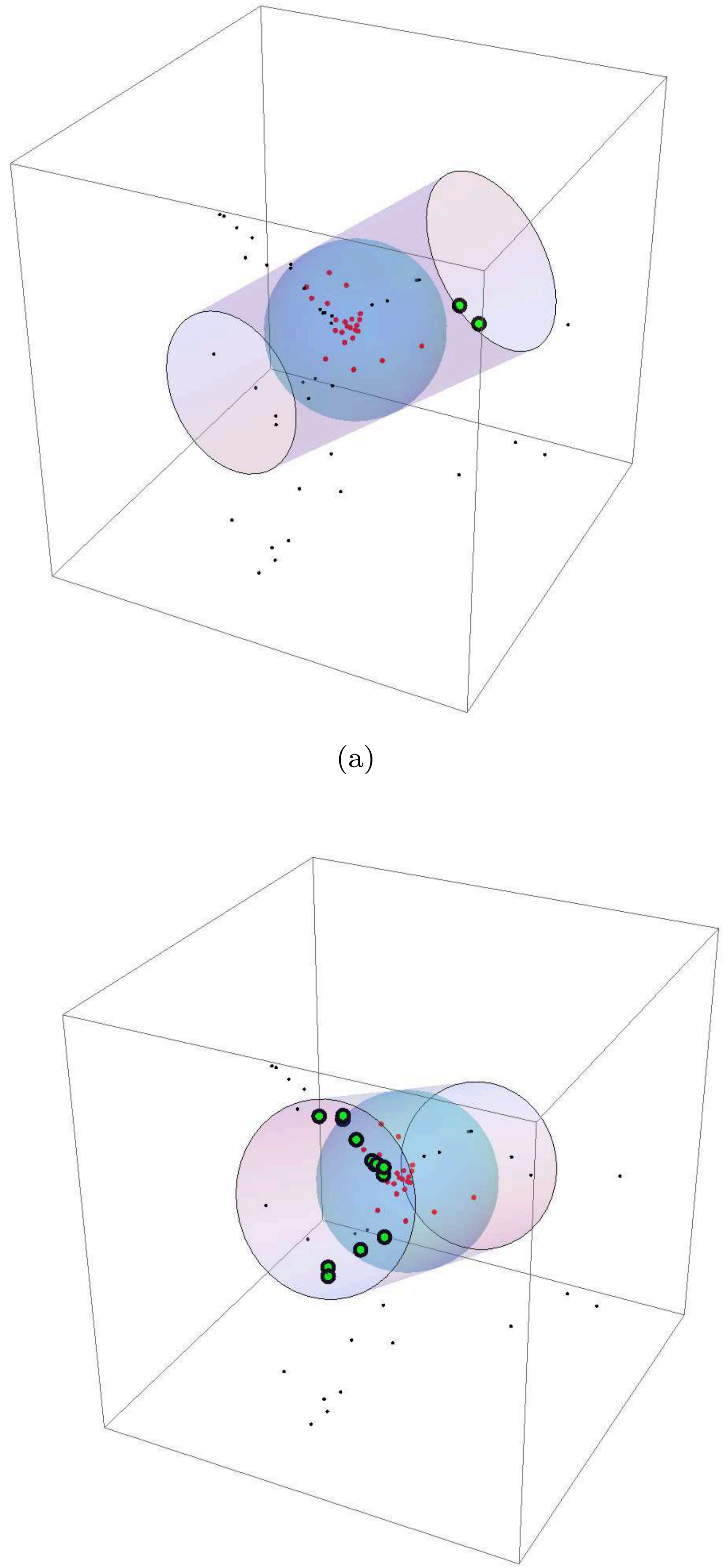
Bañados et al. (2013)



Matsuda et al. (2011)

Measuring over densities

- Over-density measurement depends on the view angle
- Projection effects smear out the over-density signal
- Redshift uncertainties
- Redshift-space effects

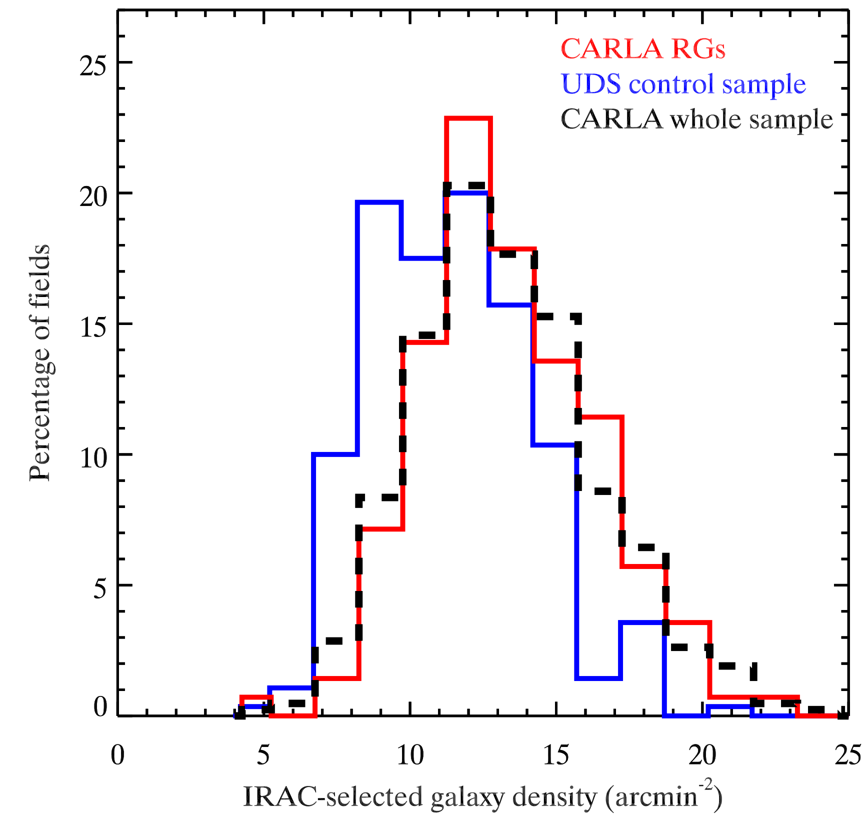


(a)

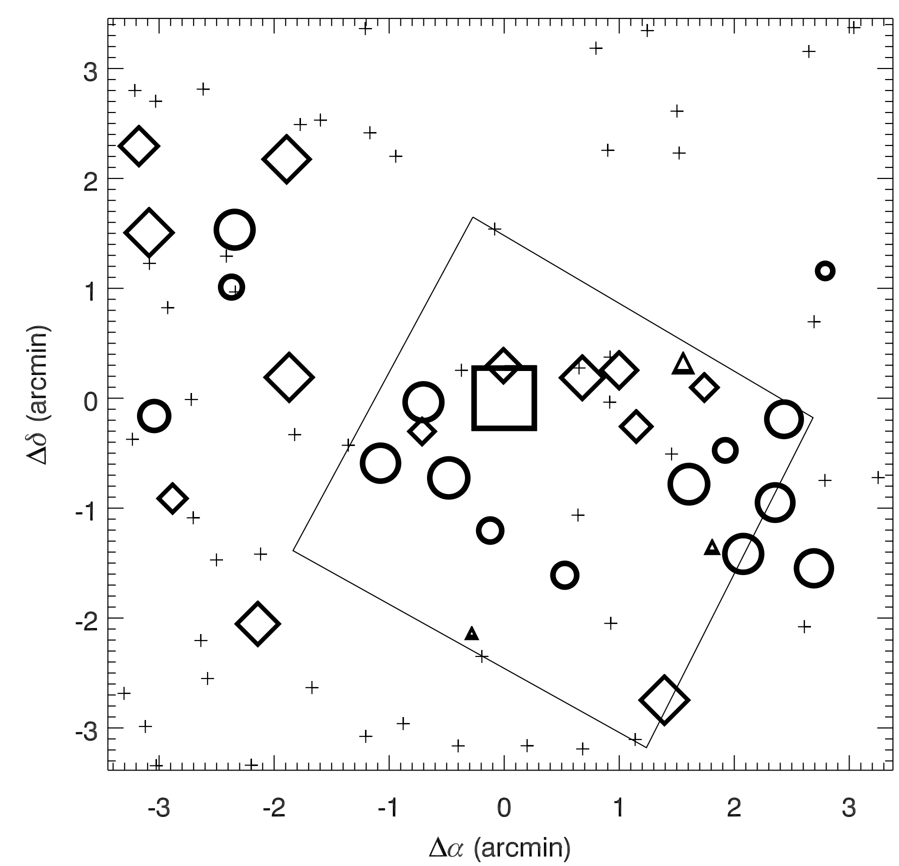
(b) Shattow et al. (2013)

Quasars and radio galaxies as tracers of massive structures

- Radio galaxies typically found in denser environments
  - Even denser than average galaxies with the same mass (Hatch+2014)
- Emission-line galaxies, such as Lyα emitters are ideal tracers of environments at high redshift
  - Narrow-band and spectroscopic detections, low σ_z
  - Venemans et al. (2005, 2007) derived $M_{\rm DM} \approx 3 - 6 \times 10^{14} M_\odot$



Hatch et al. (2014)

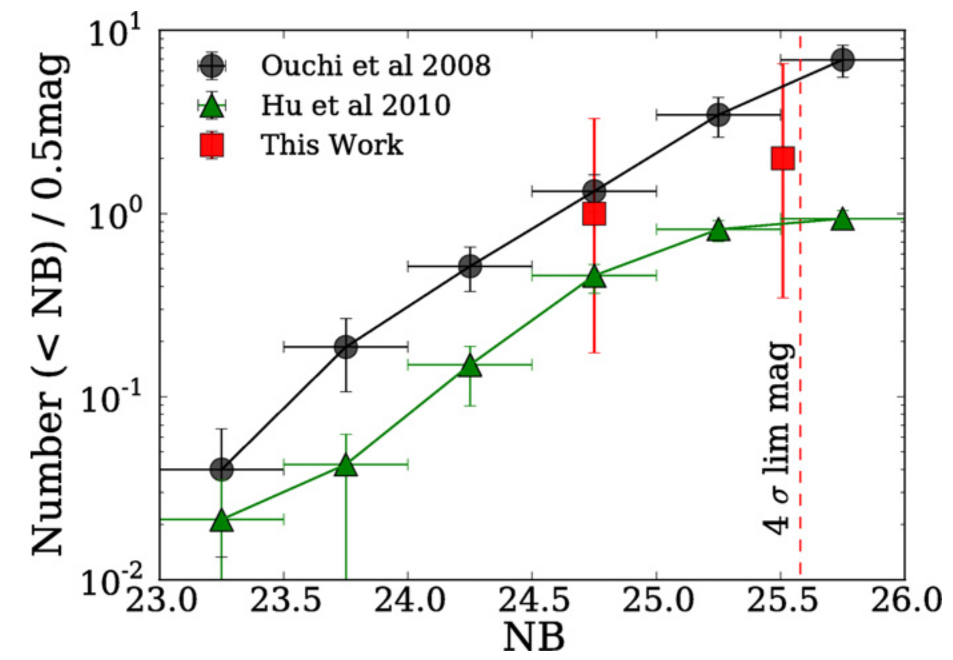


Venemans et al. (2005)

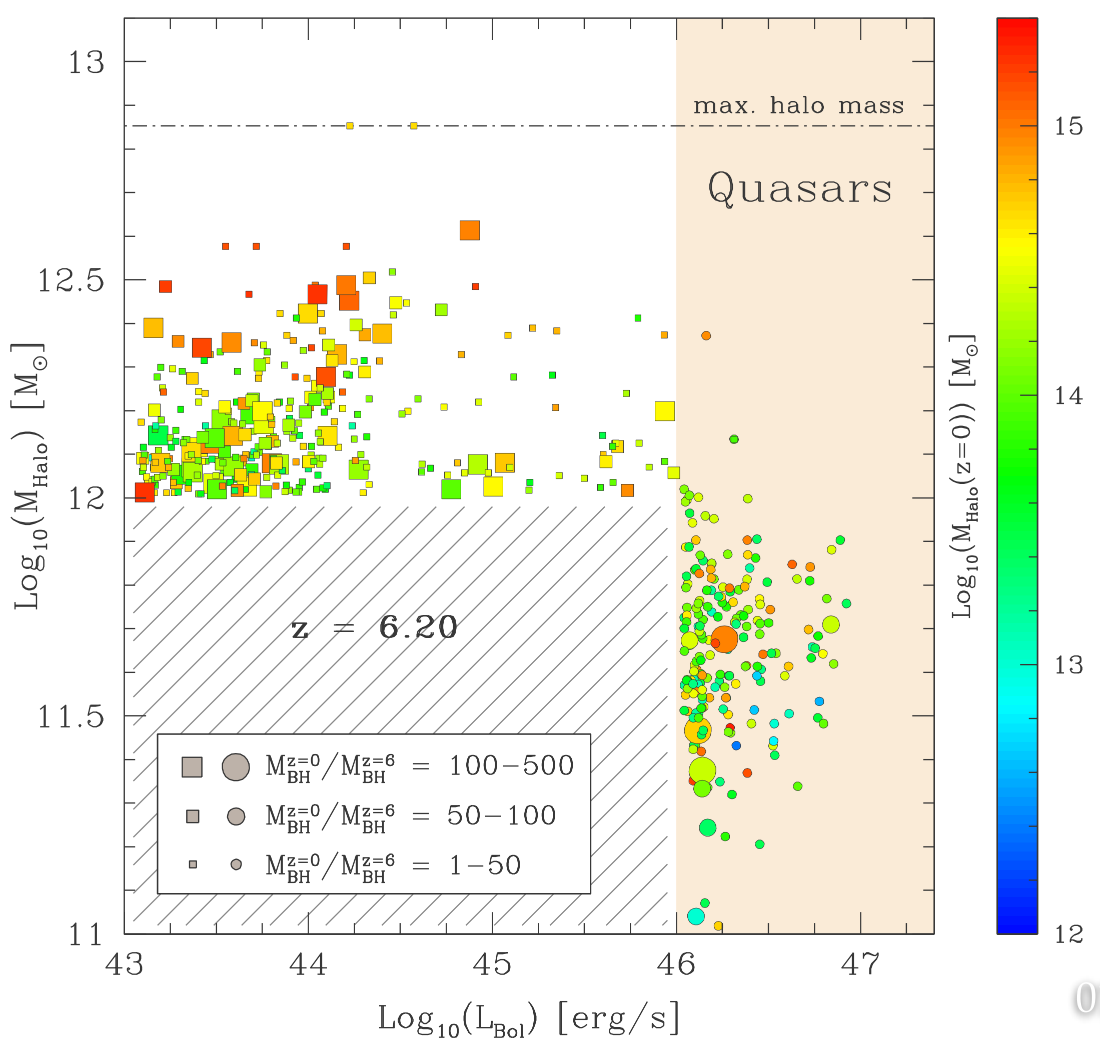
Quasars and radio galaxies as tracers of massive structures

- Quasars typically regarded as tracers of massive structures
- Contradictory evidence for over densities around QSOs (e.g. see Husband+13, Bañados +13)
- AGN feedback predicted to be effective in massive haloes, shutting off quasar activity (Fanidakis+13)

Bañados et al. (2013)



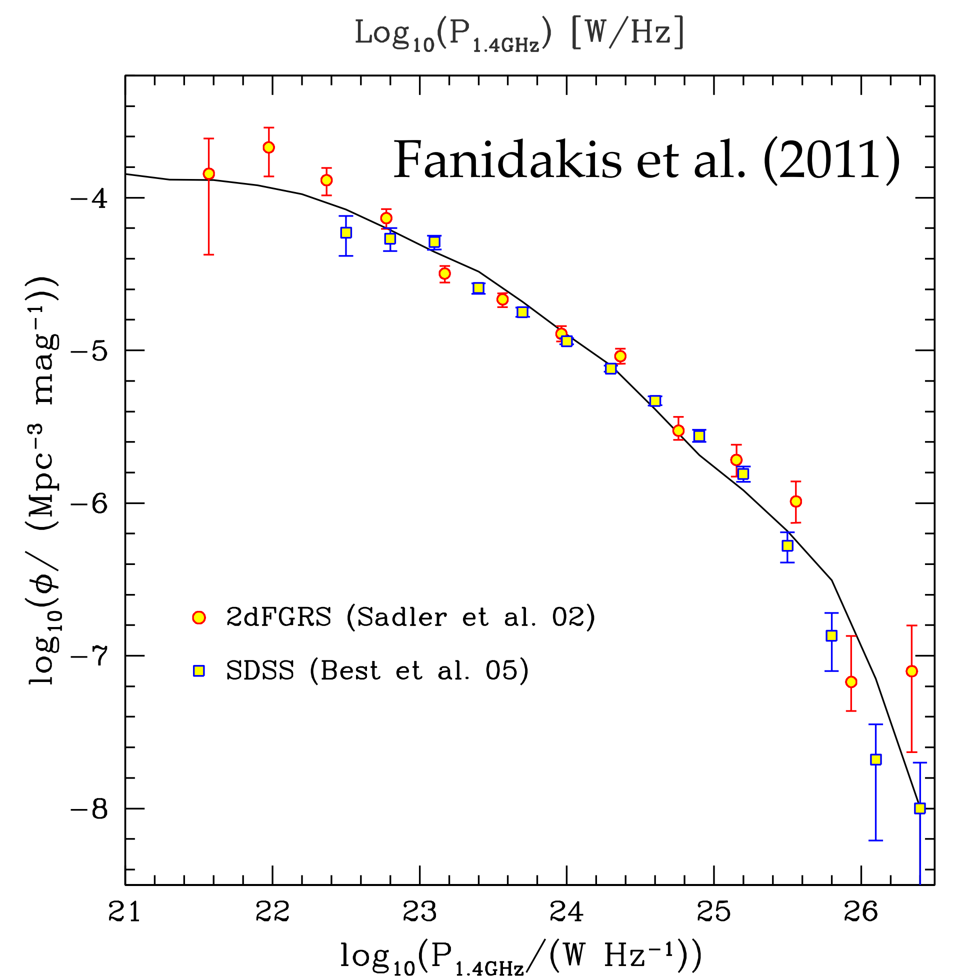
Fanidakis et al. (2013)



Modelling the central engine of AGN

Basic ingredients

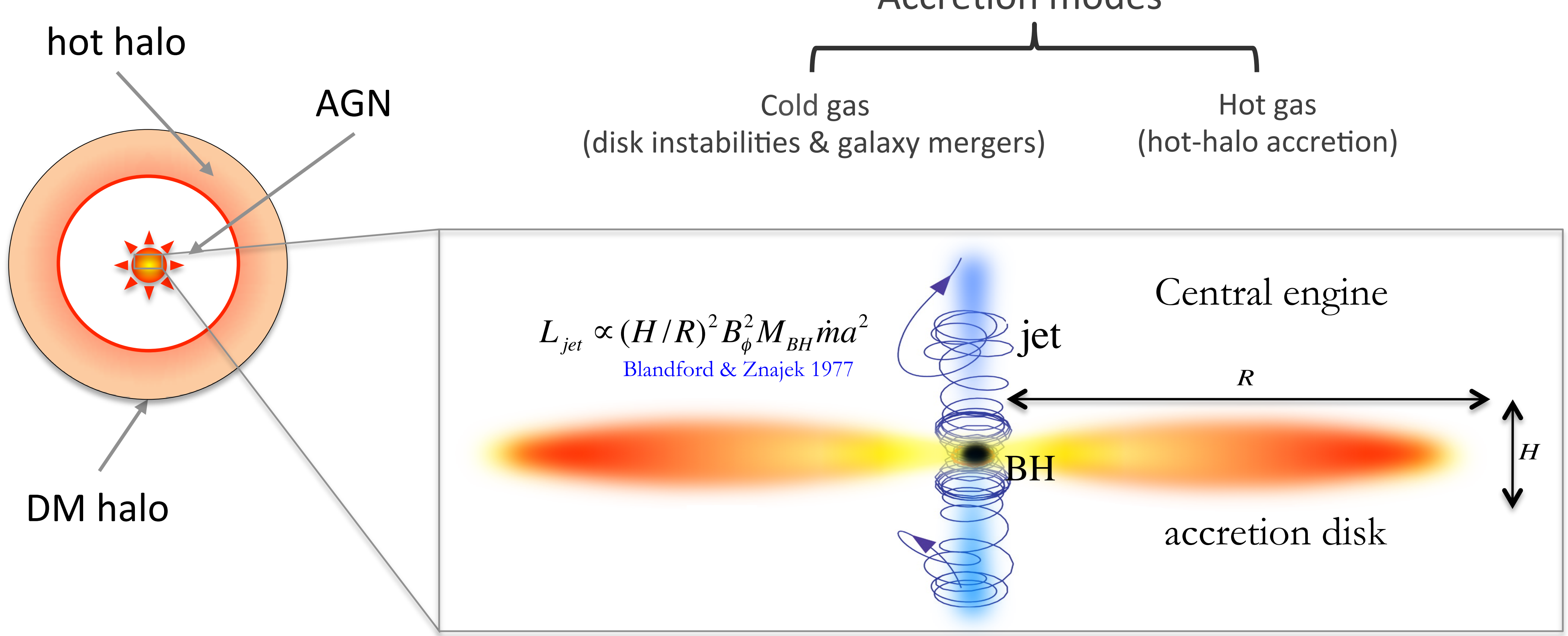
1) Accretion rate calculation
2) Disk structure (thin-disk/ADAF) Shakura & Sunyaev (1973); Mahadevan (1997)
3) BH spin evolution (accretion and BH-BH mergers) King et al. (2005)
4) Bolometric corrections for optical, x-ray, UV emission Marconi et al. 2005)
5) Empirical obscuration Hasinger (2008)
6) Jet total and radio luminosity Blandford & Znajek (1977)

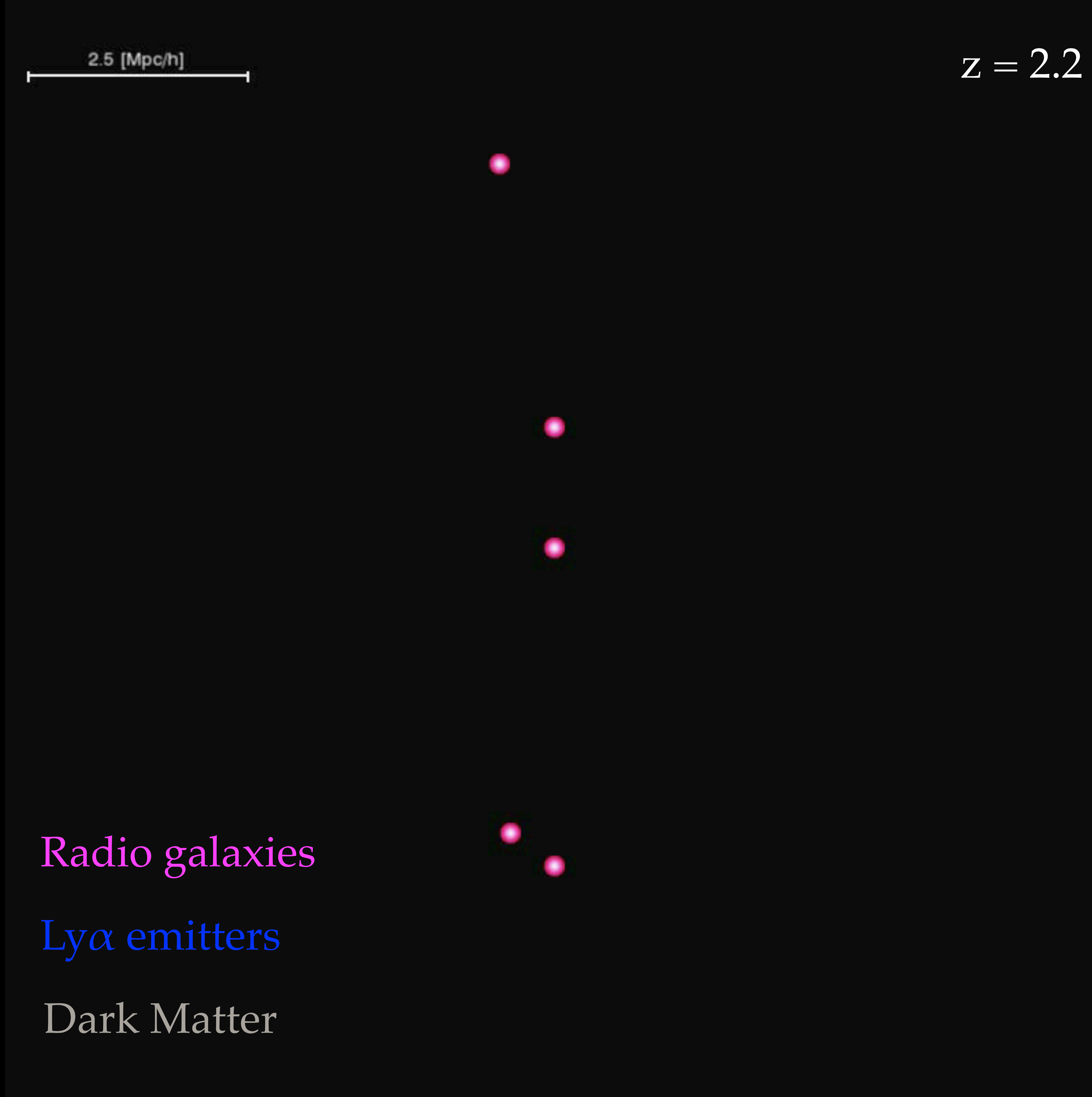


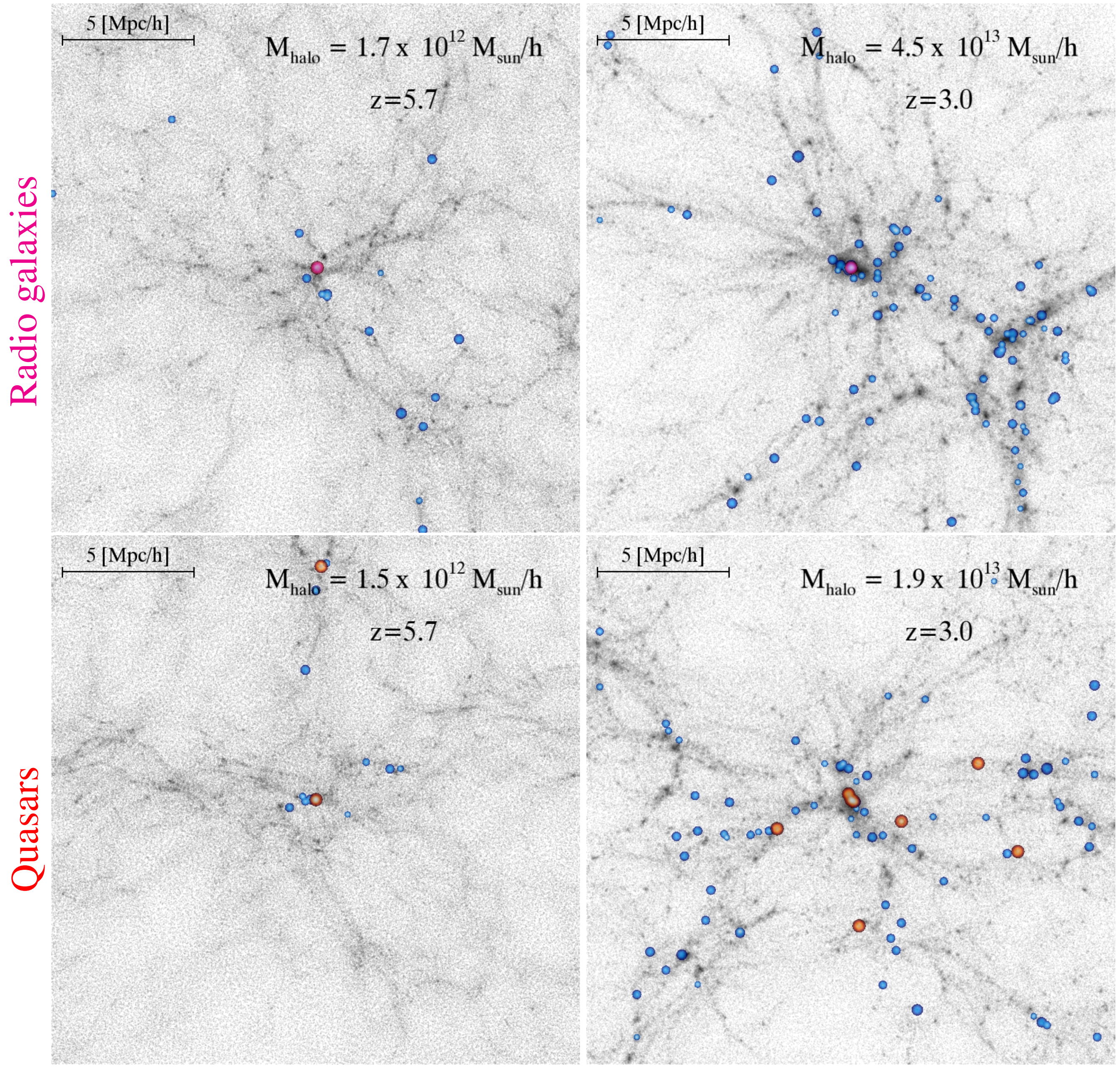
Accretion modes

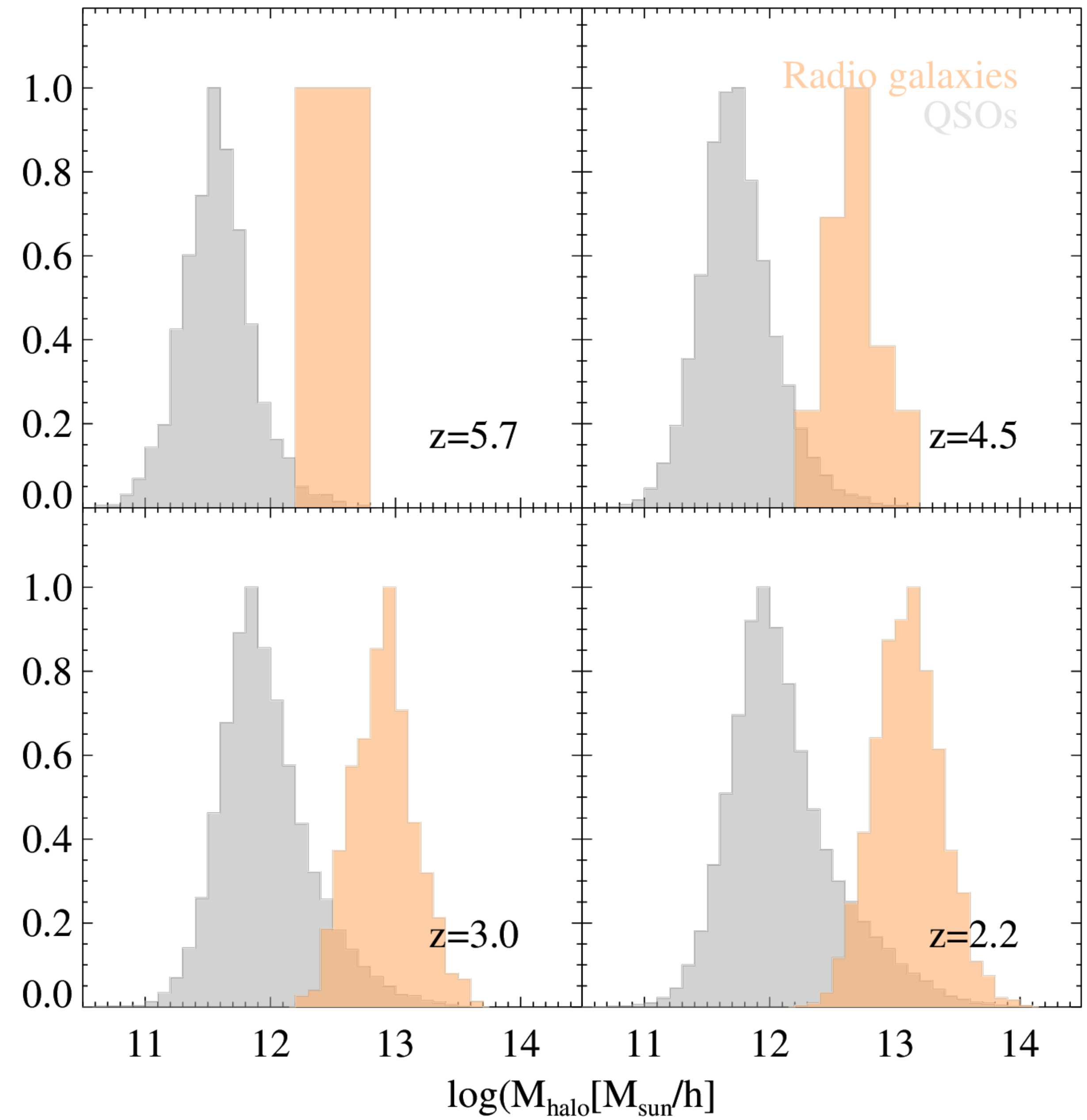
Cold gas
(disk instabilities & galaxy mergers)

Hot gas
(hot-halo accretion)




2.5 [Mpc/h]
z = 2.2
Radio galaxies
Lyα emitters
Dark Matter

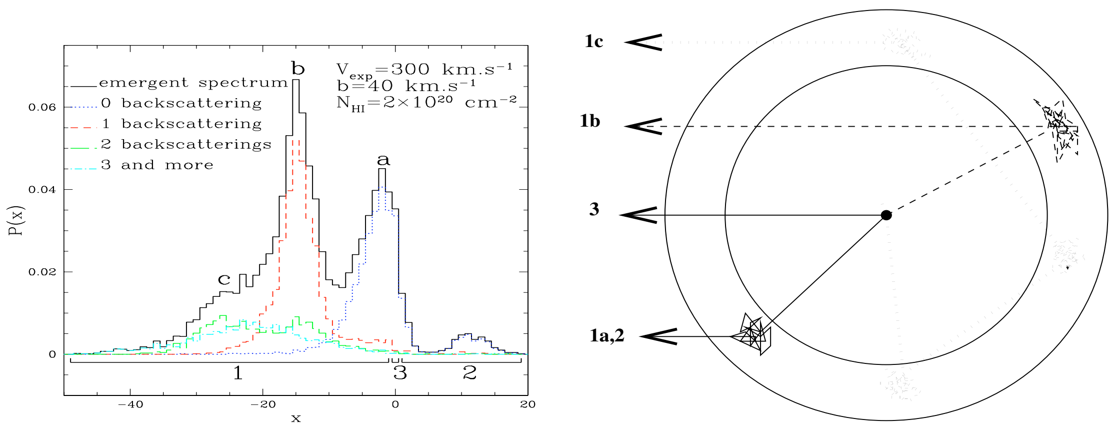




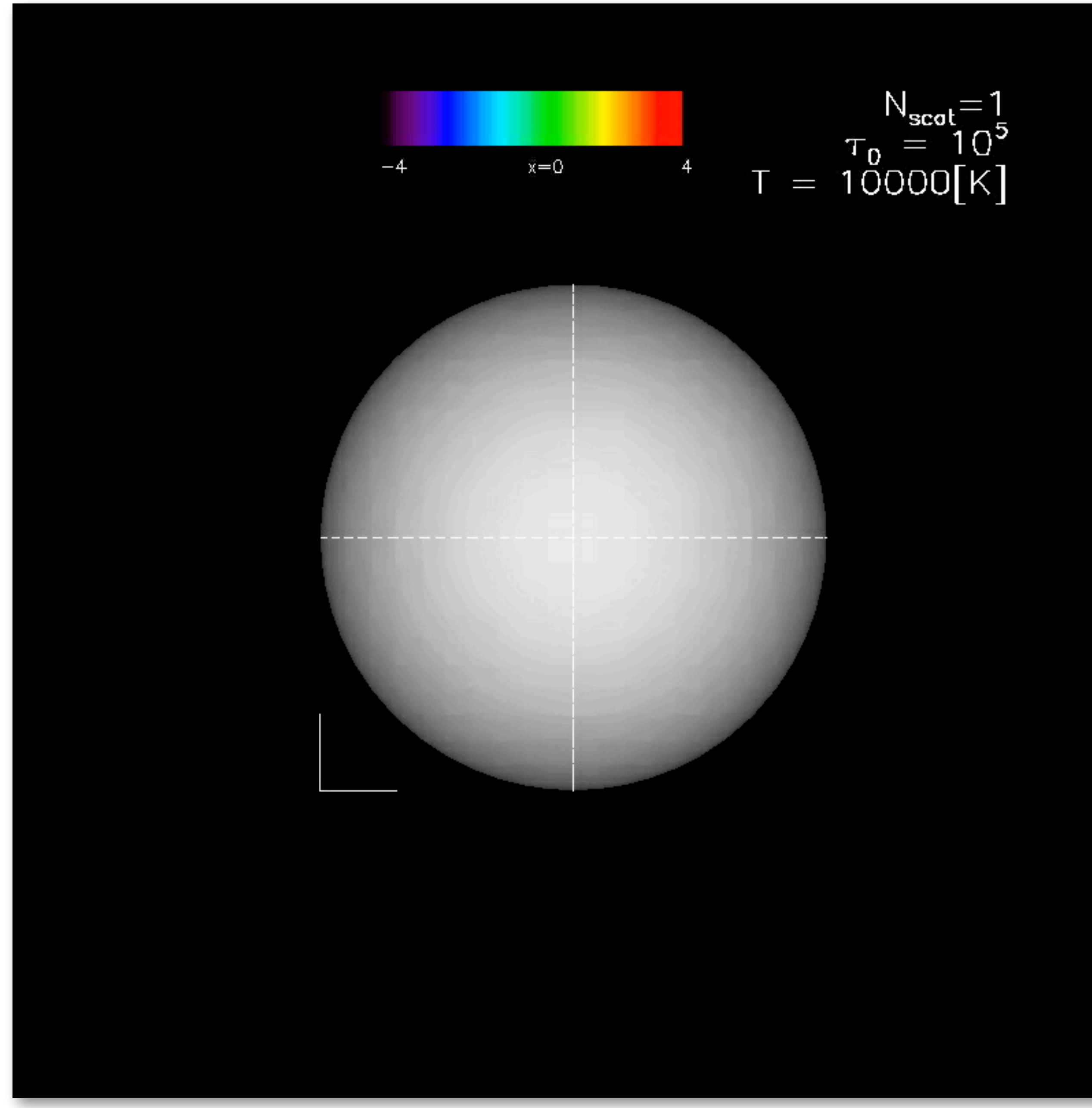
QSOs and radio galaxies appear to have similar galaxy environments

Radio galaxies are hosted by haloes significantly more massive than those hosting QSOs

Monte Carlo radiative transfer of Lyα photons

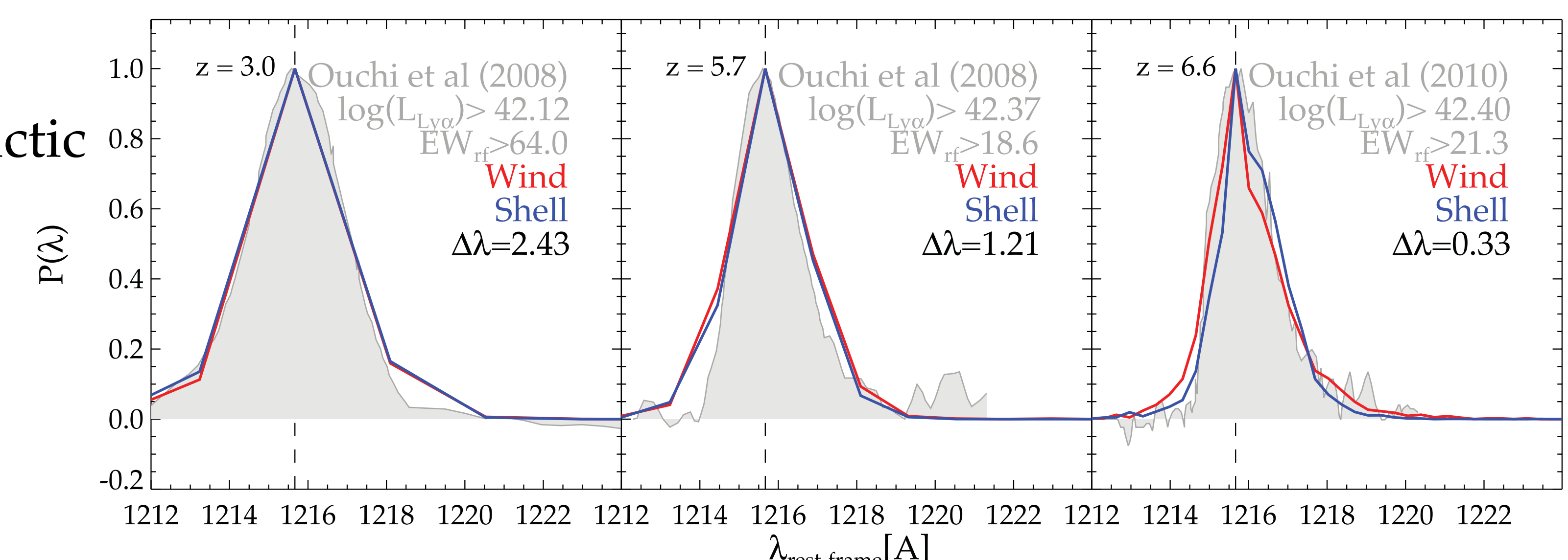


Verhamme et al. (2006)



- Follow the scattering histories of a large set of individual photons as they pass through a HI cloud
- Lyα photons escape through simple galactic outflow
- Semi-analytical model computes

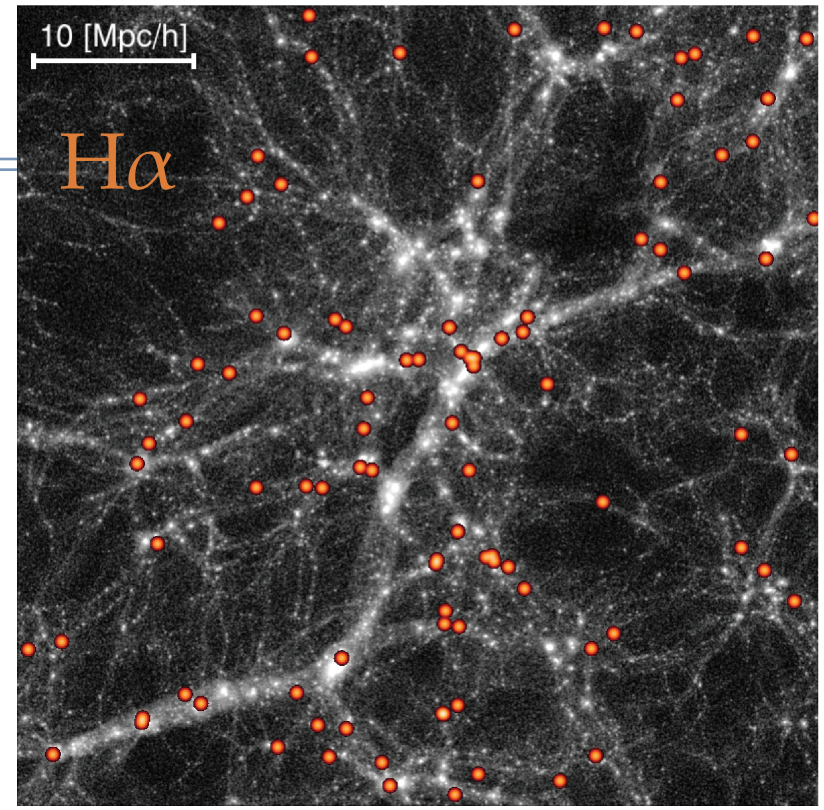
$$f_{\rm esc}(SFR, M_{\rm cold}, V_{\rm circ}, Z_{\rm cold}, r_{1/2})$$

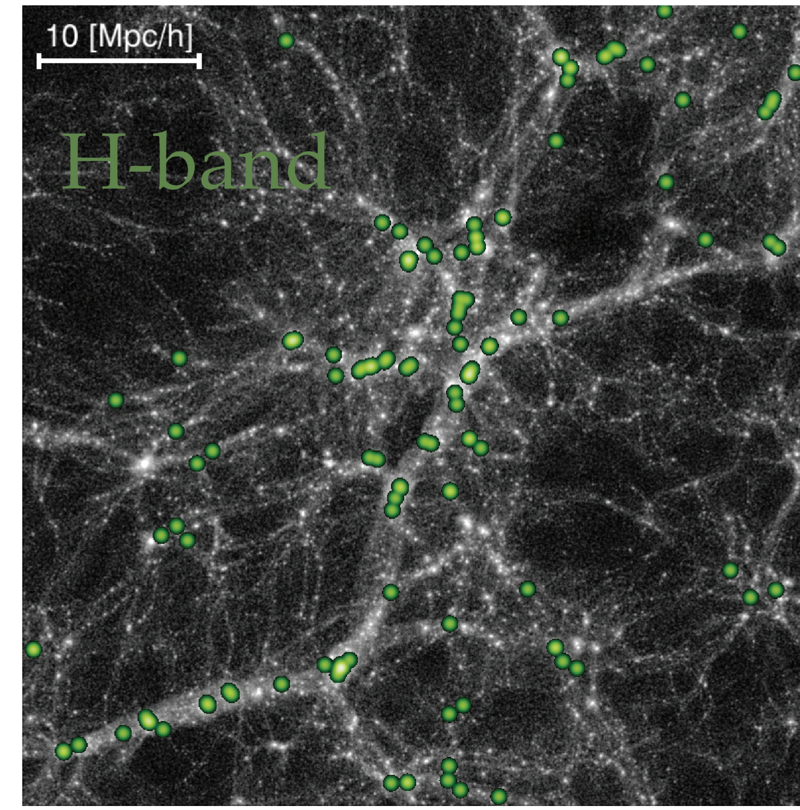


Orsi et al. (2012)

Emission-line galaxies tend to avoid massive haloes!

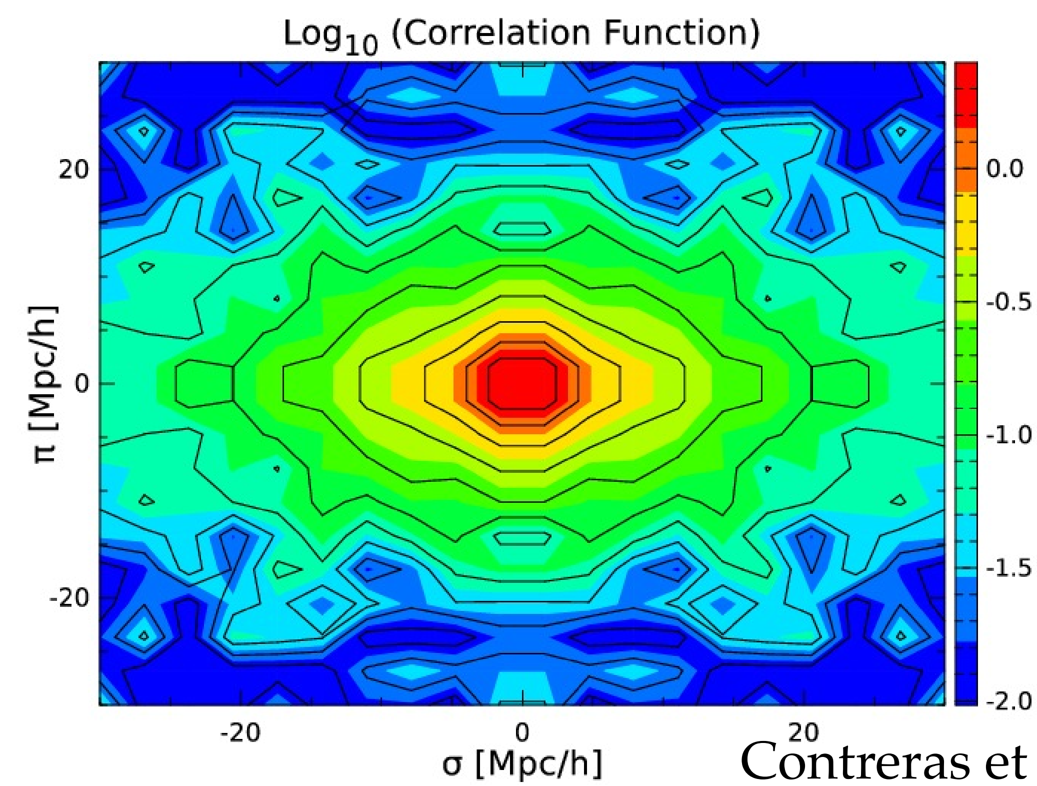
Orsi et al. (2010)





- Nebular emission traces recent star-formation events (~10 Myr). Star-formation quenching shuts off line luminosities

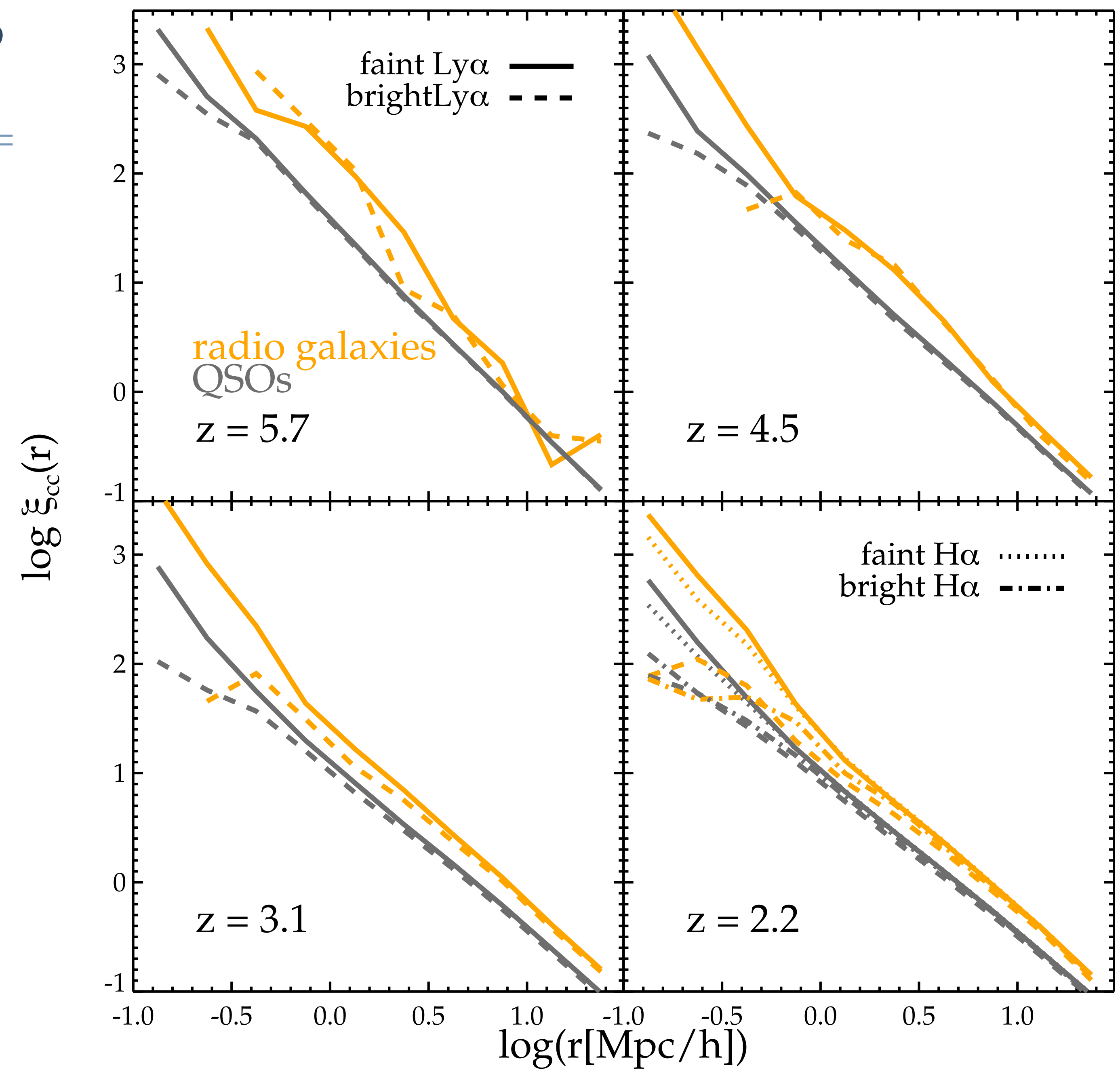
- Clustering bias is low (b~2-3) compared to other galaxy populations (e.g. LRGs, LBGs, SMGs)



Contreras et al. (2013)

Clustering of ELGs around protoclusters

- 2 samples of LAEs:
  - Shallow (bright): $L_{Ly\alpha} > 10^{42}[\mathrm{ergs}^{-1}\mathrm{h}^{-2}]$
  - Deep (faint): $L_{Ly\alpha} > 10^{41}[\mathrm{ergs}^{-1}\mathrm{h}^{-2}]$
- Cross-correlation functions reflect that radio galaxies are hosted by more massive haloes than QSOs
- Faint Lyα emitters are more clustered at small scales
- The same result is found for Hα emitters @ z=2.2

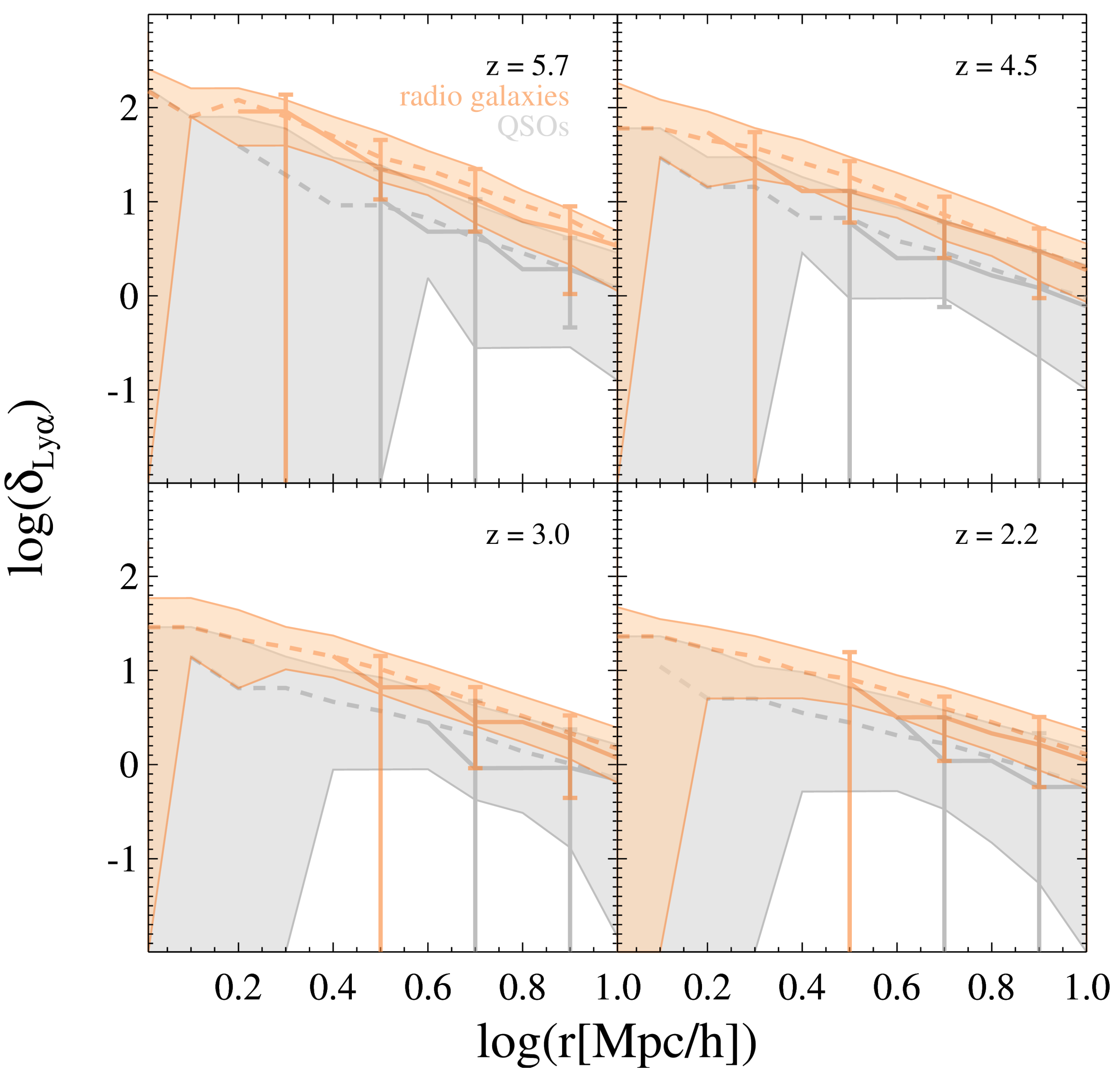


Clustering of ELGs around protoclusters

- Overdensity δ(r) is related to ξ(r) but is easier to measure

$$\xi_{cc}(r) = \frac{1}{3r^2}\frac{d\delta(r)}{\mathrm{d}r}$$

- Radio galaxy environments are denser and have less scatter
- Significant scatter in the overdensity around QSOs
- Non-negligible fraction of QSOs with an under-dense environment



Tracing the dark matter mass in a protocluster

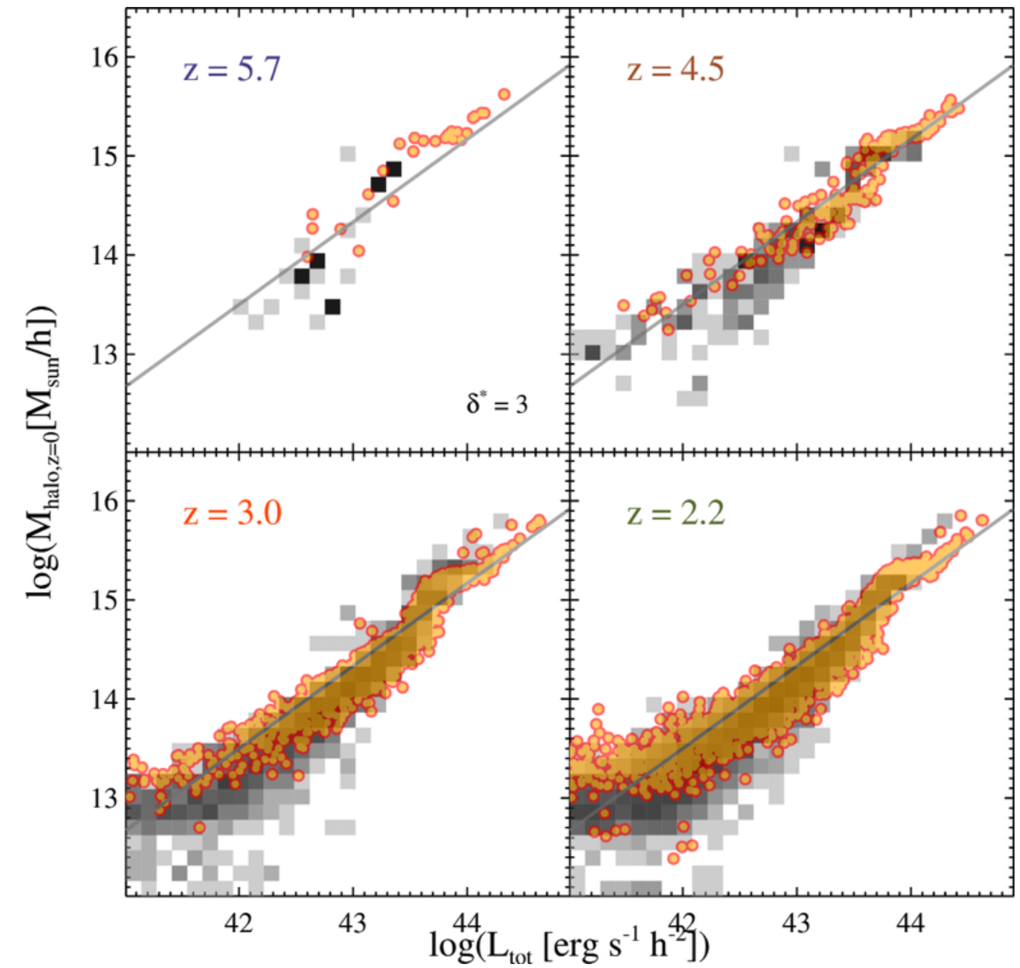
- Typically, the DM mass is estimated by using

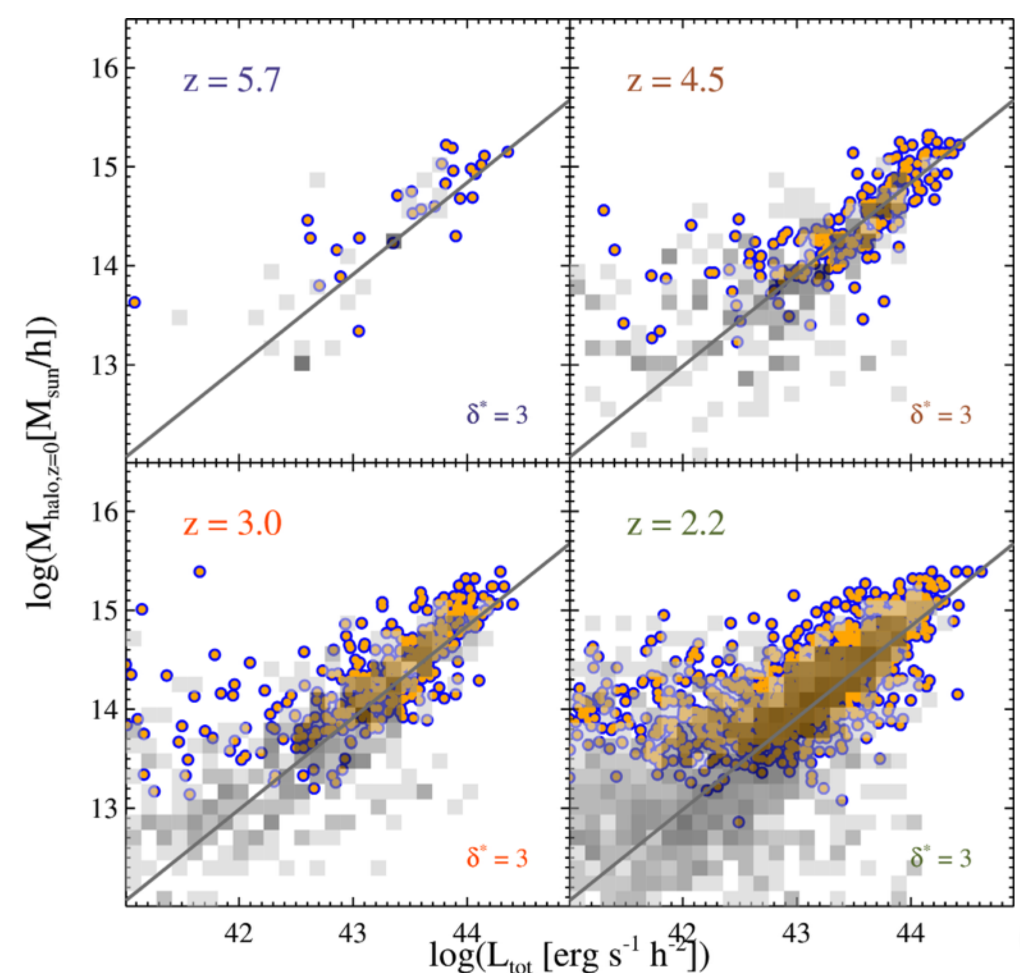
$$M_{\rm DM} = \rho V (1 + \frac{\delta_g}{b})$$

Our model predicts a correlation using simple observables:
- Integrated luminosity:

$$M_{\rm DM} = 3.6 \times 10^{11} \delta^{0.5} \left(\frac{L^{\rm tot}_{\rm Ly\alpha}}{10^{40}} \right)^{0.9-0.03\delta}$$

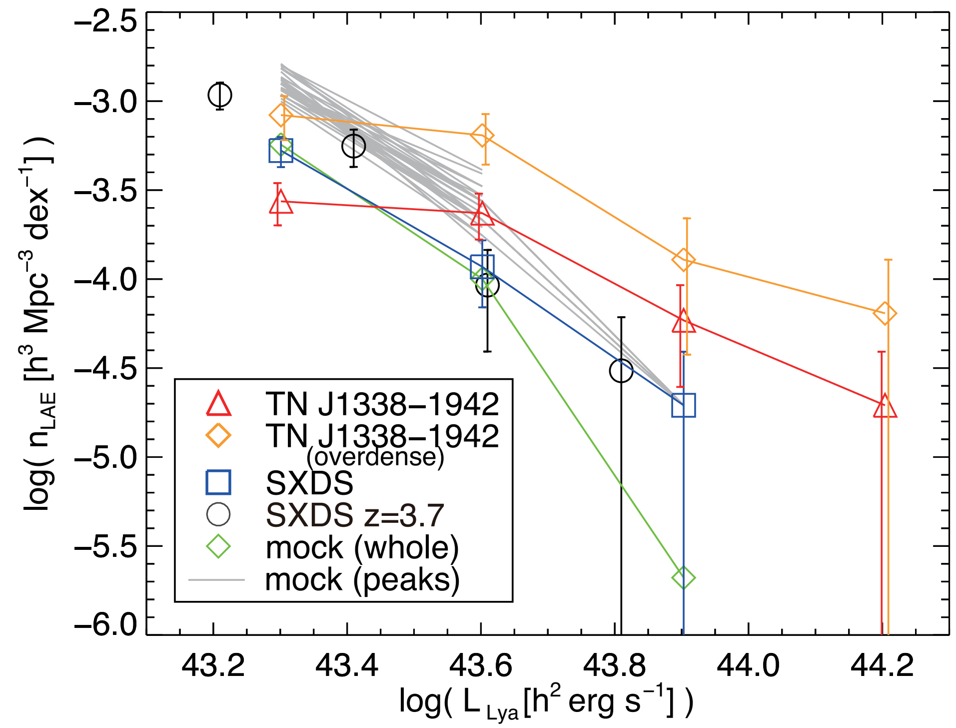
- **z=0 descendant mass can also be related with the integrated luminosity**



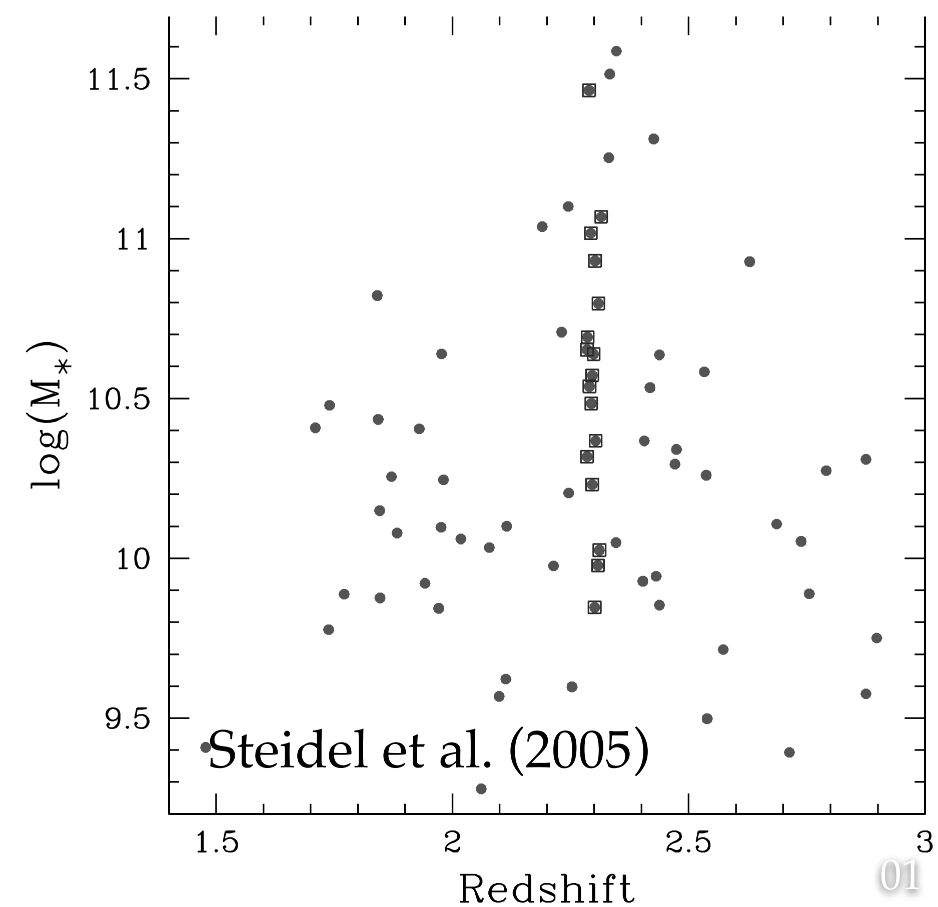


Impact of dense environments at high redshifts

- Star-formation enhancement at z=4.5?
- More massive galaxies in denser environments at high redshifts

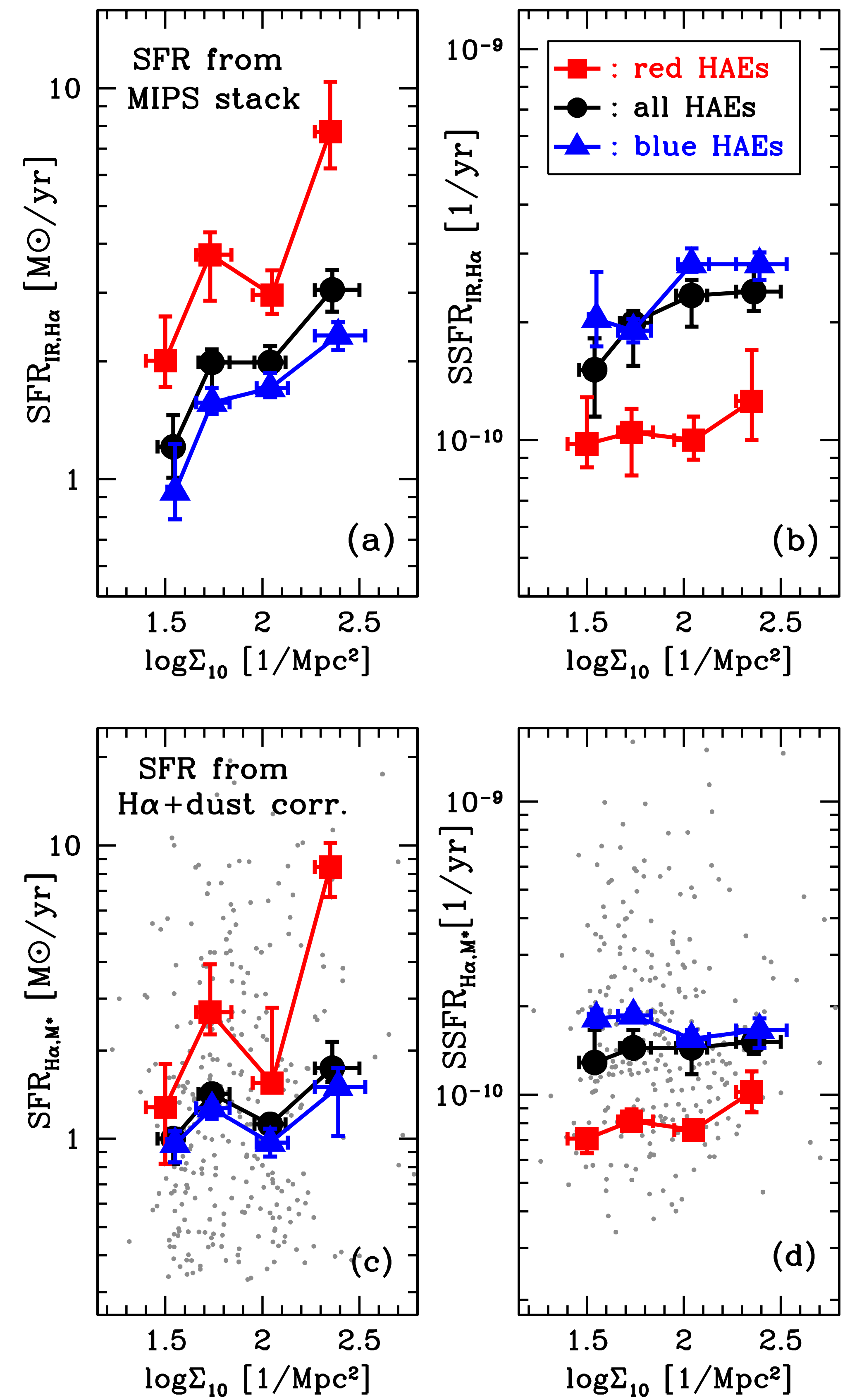


Saito et al. (2014)



Impact of dense environments at high redshifts

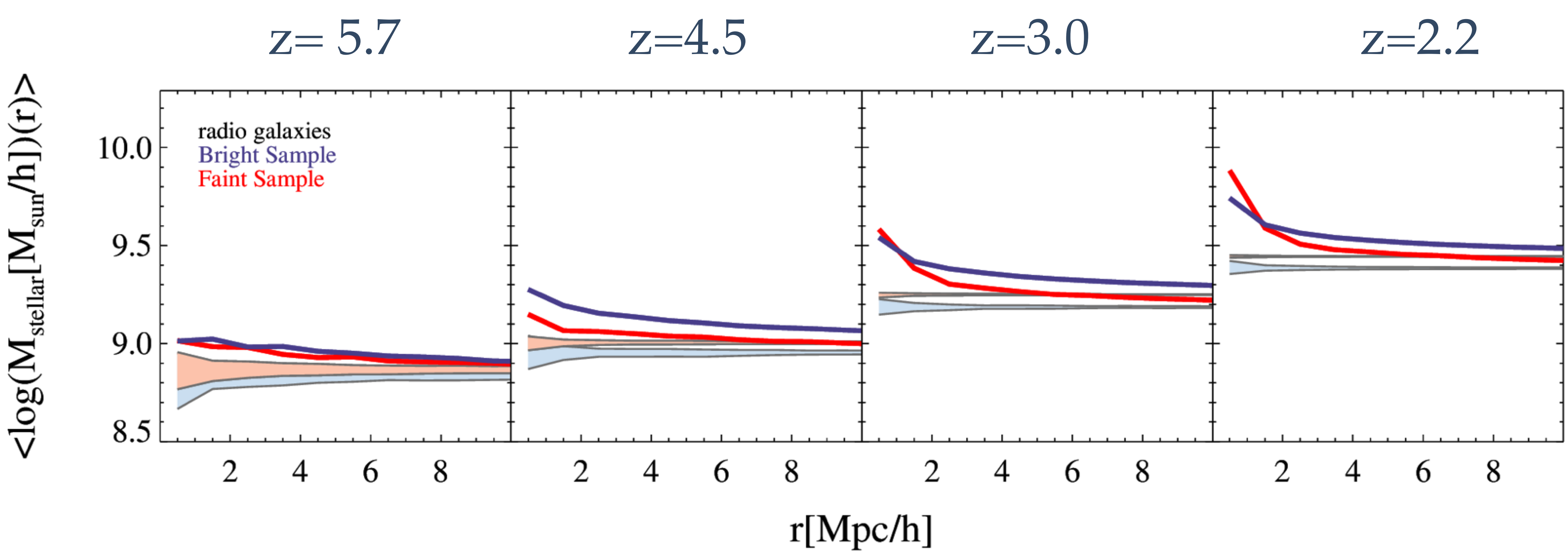
- Star-formation enhancement at z=4.5?
- More massive galaxies in denser environments at high redshifts
- sSFR increase not visible when inferring the SFR from Hα alone
    - Dustier galaxies in overdense environments?



Koyama et al. (2013)

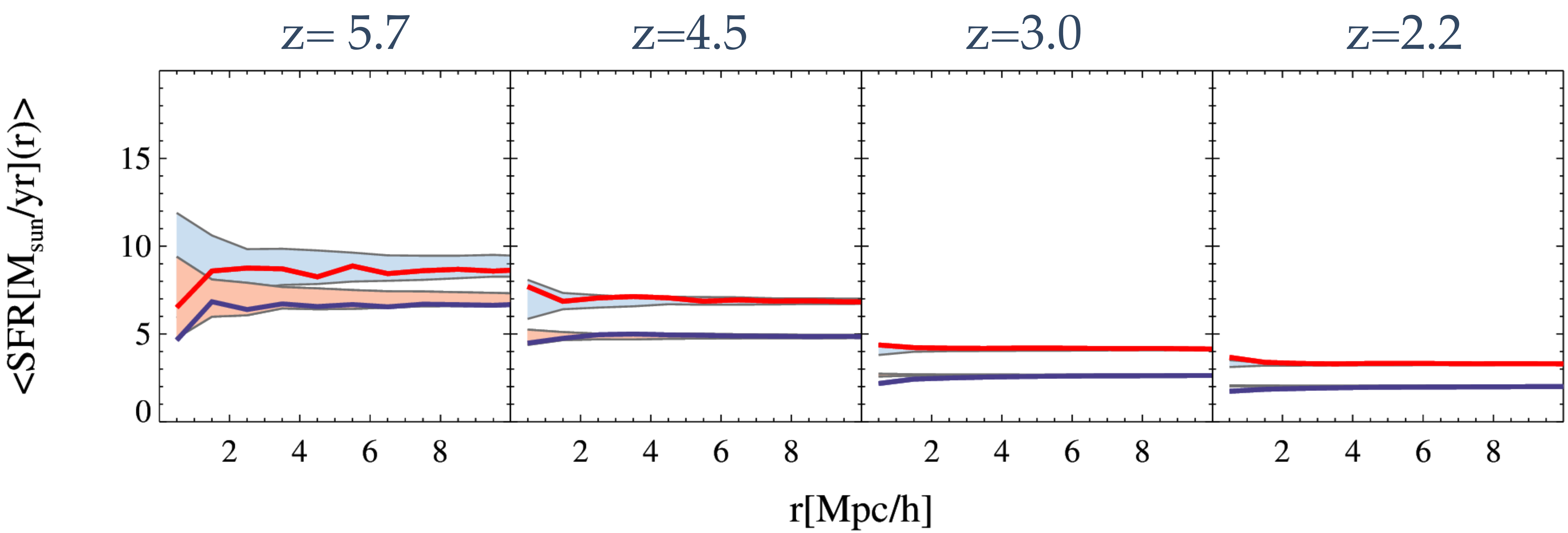
Impact of dense environments at high redshifts

- Stellar mass of LAEs around radio galaxies is larger



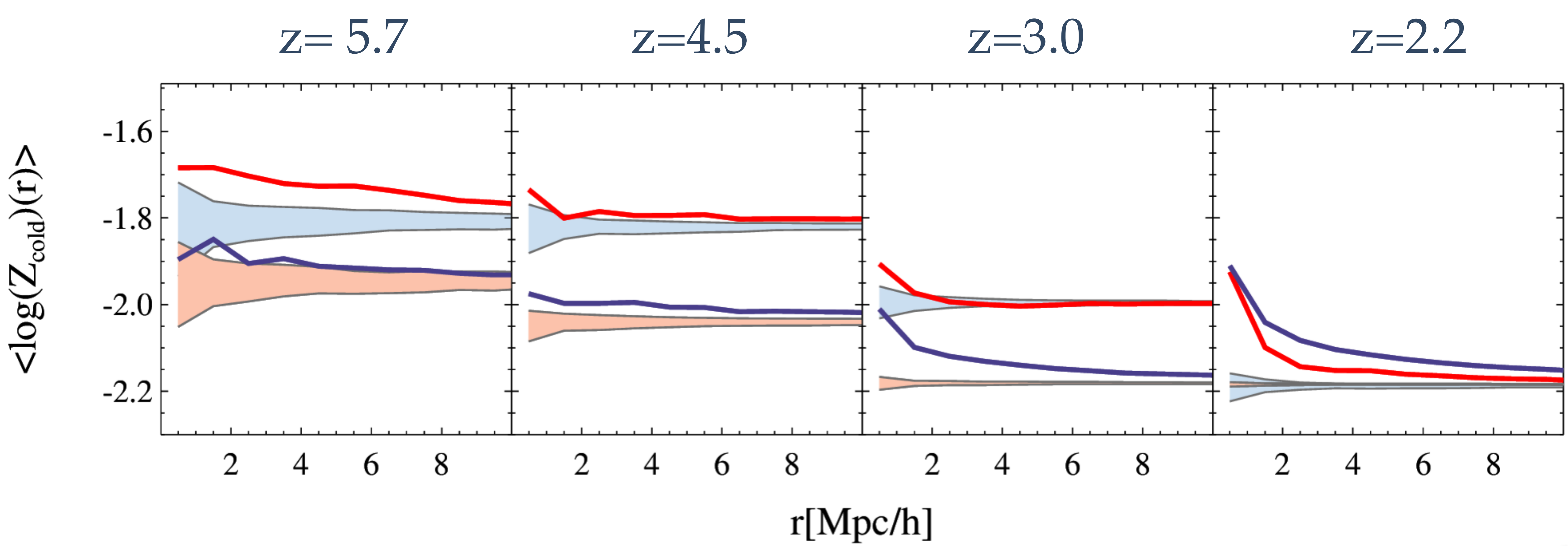
Impact of dense environments at high redshifts

- Stellar mass of LAEs around radio galaxies is larger
- SFR of observed LAEs has no significant environmental dependence



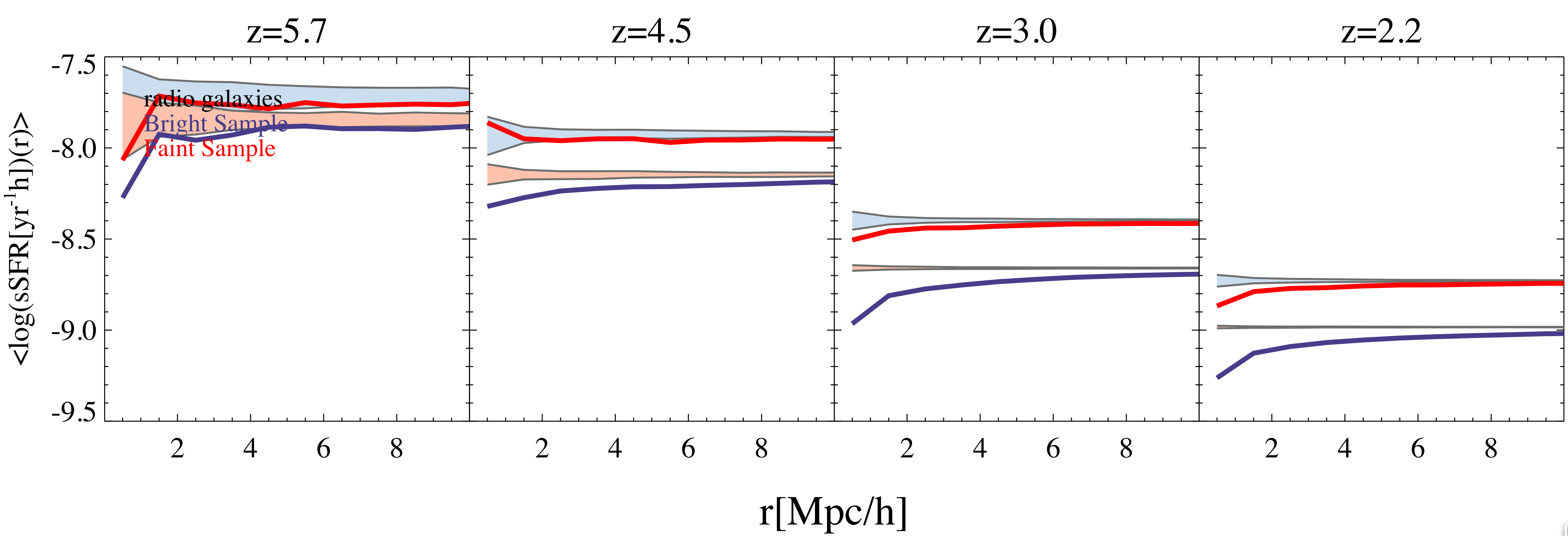
Impact of dense environments at high redshifts

- Stellar mass of LAEs around radio galaxies is larger
- SFR of observed LAEs has no significant environmental dependence
- Gas metallicities are higher towards denser environments



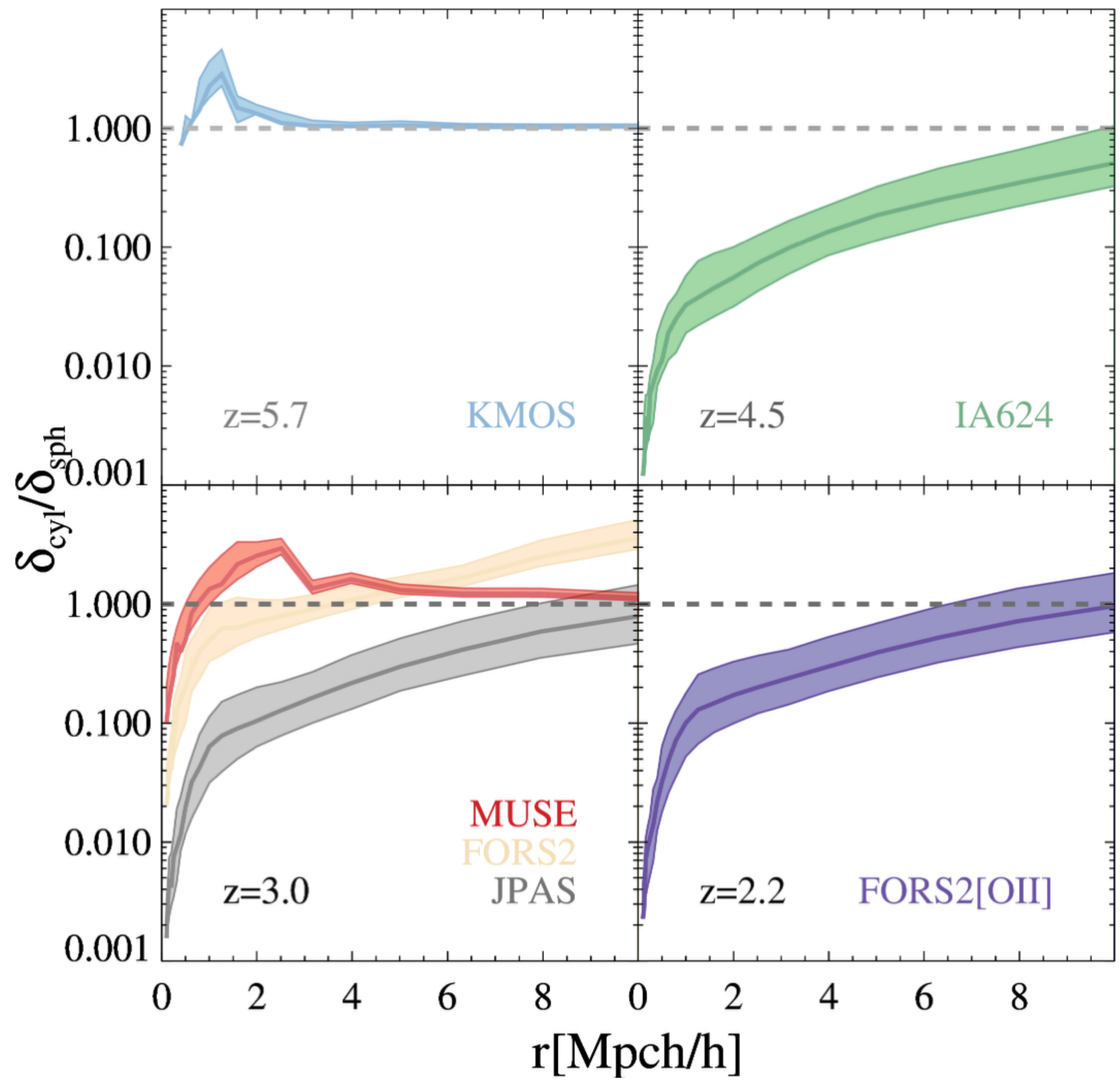
Impact of dense environments at high redshifts

- Stellar mass of LAEs around radio galaxies is larger
- SFR of observed LAEs has no significant environmental dependence
- Gas metallicities are higher towards denser environments
- sSFRs of LAEs show some environmental dependence



Projected δ(r) at high redshift

- Redshift uncertainties can lead to significantly different values of δ(r)
- New spectrographs have the ability to map the environments of high redshift protoclusters with high accuracy!
- Narrow-band surveys are suitable to study larger scales (r~10 Mpc/h)



Conclusions

- Characterising high redshift protoclusters is a challenging task
- High redshift radio galaxies are predicted to be tracers of the most massive protoclusters
- Environmental effects at high redshifts offer new probes of galaxy formation physics
- New multi-object spectrographs and IFUs (e.g. MUSE, KMOS, MOSFIRE, MOONS) can study the environments of high redshift galaxies with great accuracy