Protoclusters traced by high-redshift quasars

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Protoclusters traced by high-z quasars

Based on Garcia-Vergara et al. 2017, 2019, 2021 in prep.

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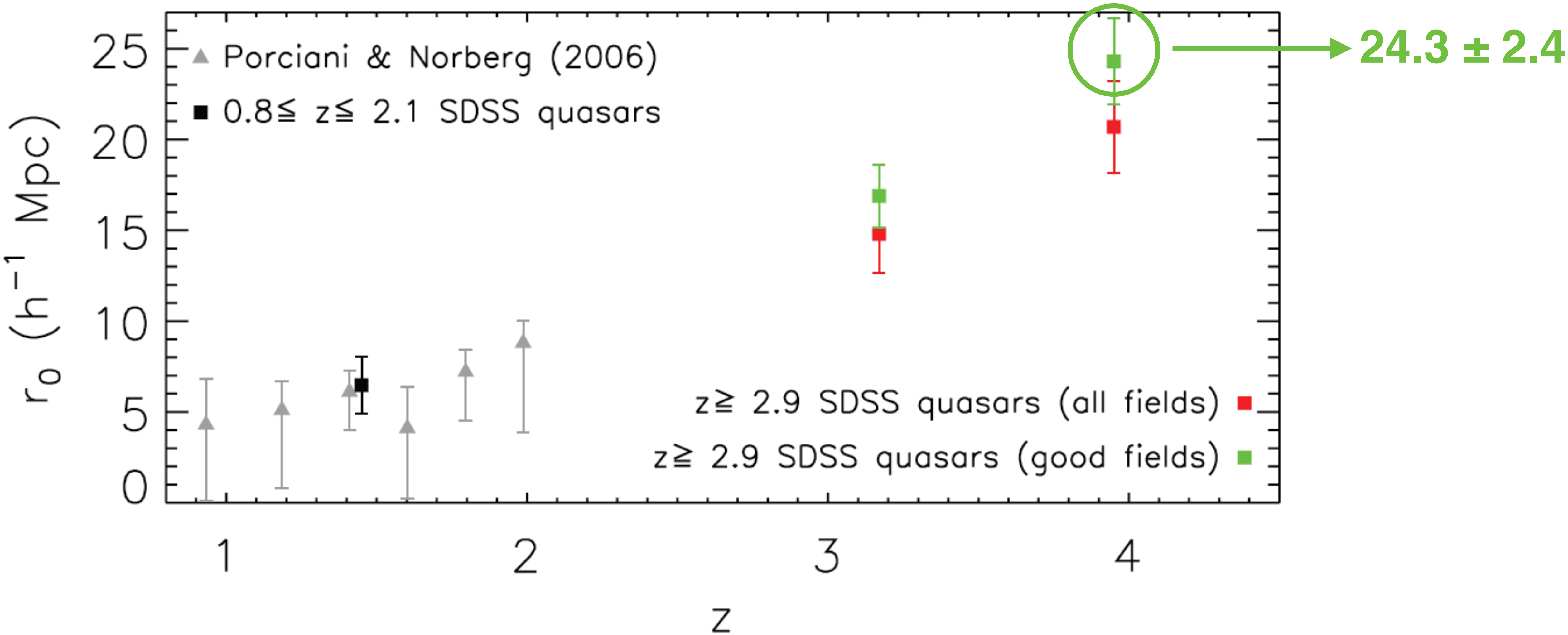
Quasars should trace massive dark matter halos in the early Universe

Shen et al. 2007



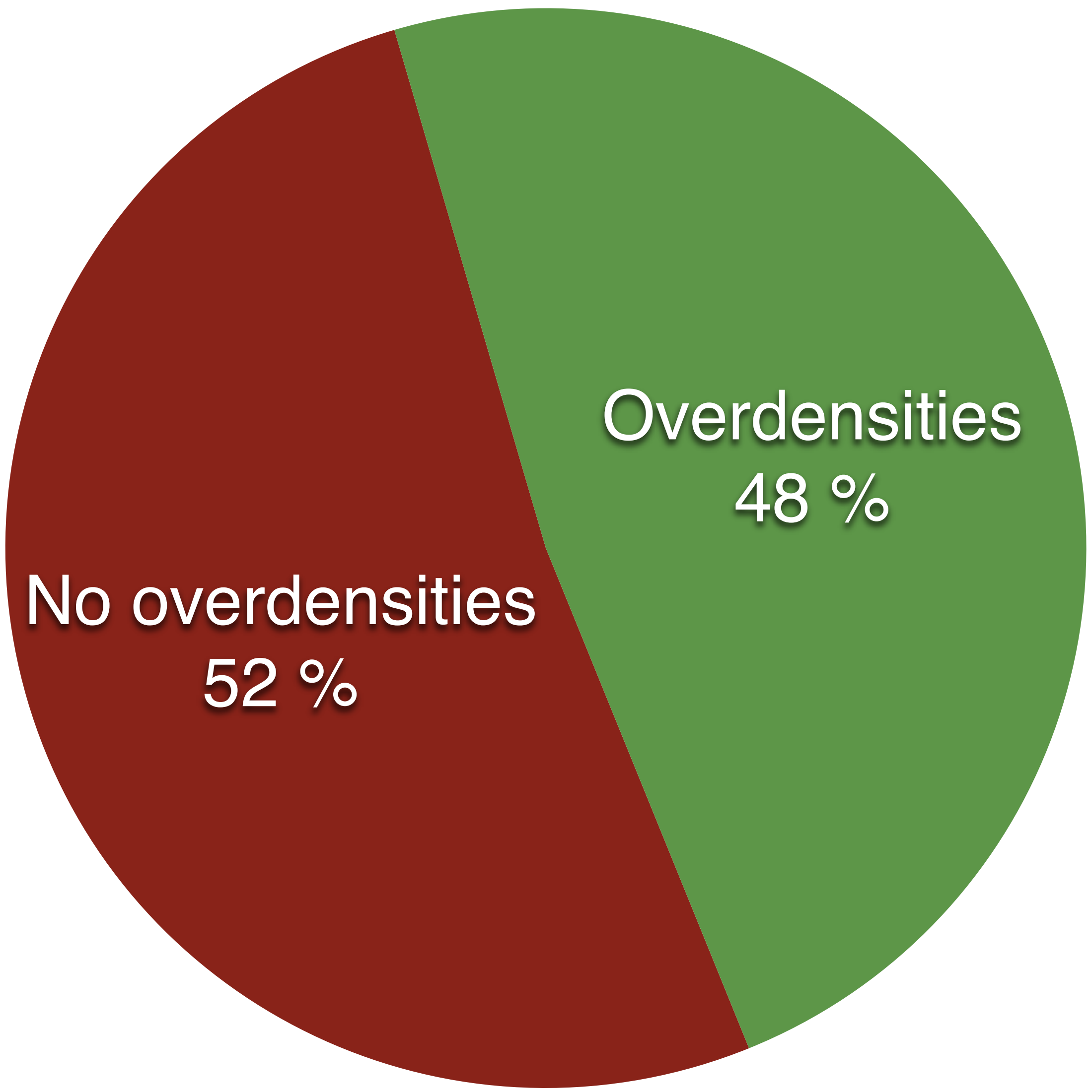
Extremely strong quasar clustering at $z > 3.5$

$M_{halo} > (4 - 6) \times 10^{12}\ M_{\odot}/h$

Therefore we expect a large ovedensity of galaxies around them

Search for galaxies at optical wavelengths show confusing and contradictory results

~30 z>~4 quasar fields studied so far:



No clear evidence of quasars tracing massive dark matter halos as suggested by the quasar clustering.

Some possible reasons:

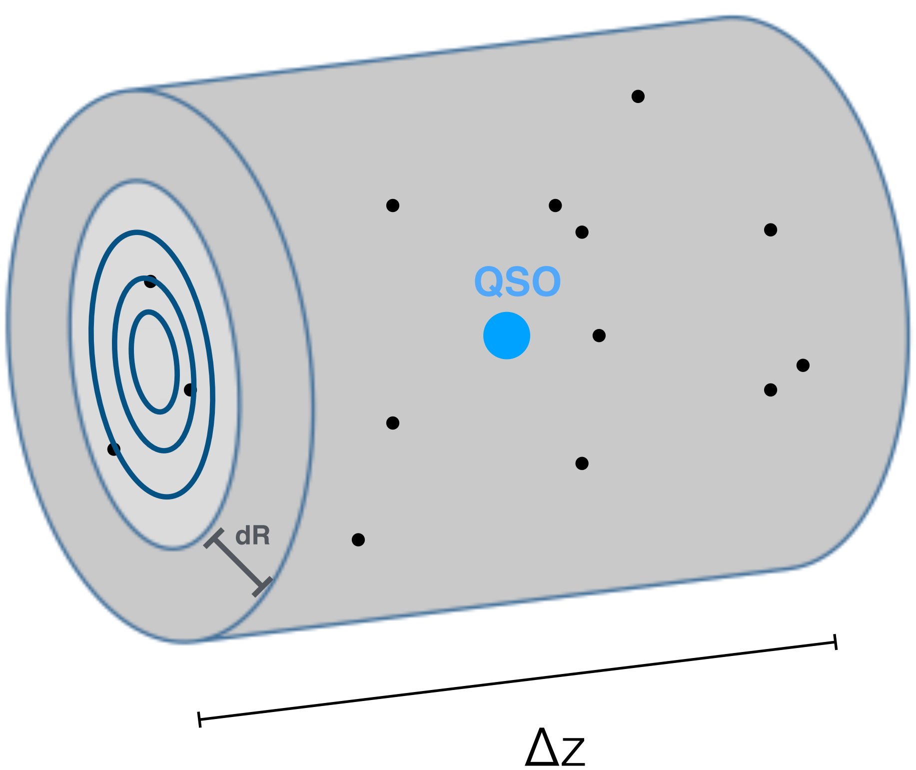
- Individual quasar fields, so affected by low number statistics and high cosmic variance.
- Incomplete galaxy population traced (indeed several serendipitous detections of dusty close companion around high-z quasars with ALMA has been reported (Decarli+2017, Trakhtenbrot+2017, Venemans+2020, Nguyen+2020).

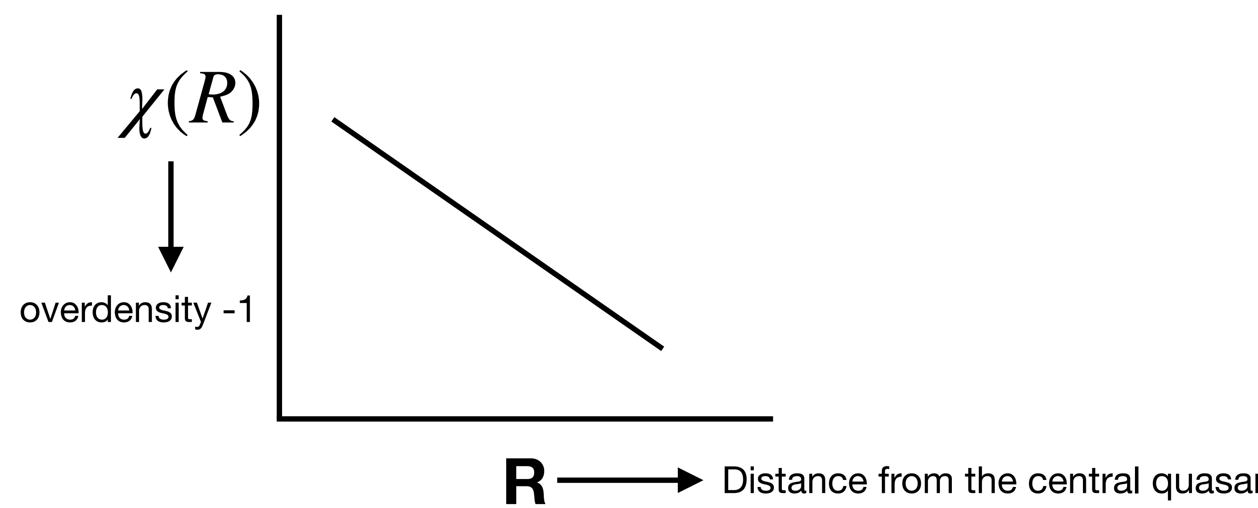
Willott+05, Kim+09, Bañados+13, Husband+13, Simpson+14, Mazzucchelli+17, Kikuta+17, Goto+17, Ota+18.

Adams+05, Stiavelli+05, Zheng+06, Kashikawa+07, Kim+09, Utsumi+10, Capak+11, Swinbank+12, Morselli+14, Balmaverde+17, Ota+18.

The quasar-galaxy cross-correlation function

A powerful technique to overcome high cosmic variance and low number statistic.





Expectation: Galaxies should be accumulated around quasar implying a large quasar-galaxy cross-correlation function.

Advantages:

i) it quantifies not only the over/under density of galaxies but also their radial distribution about the QSO.
ii) it can be easily related to the respective auto-correlations of the QSO and galaxy samples.
iii) it provides an independent method to estimate QSO and galaxy host halo masses.

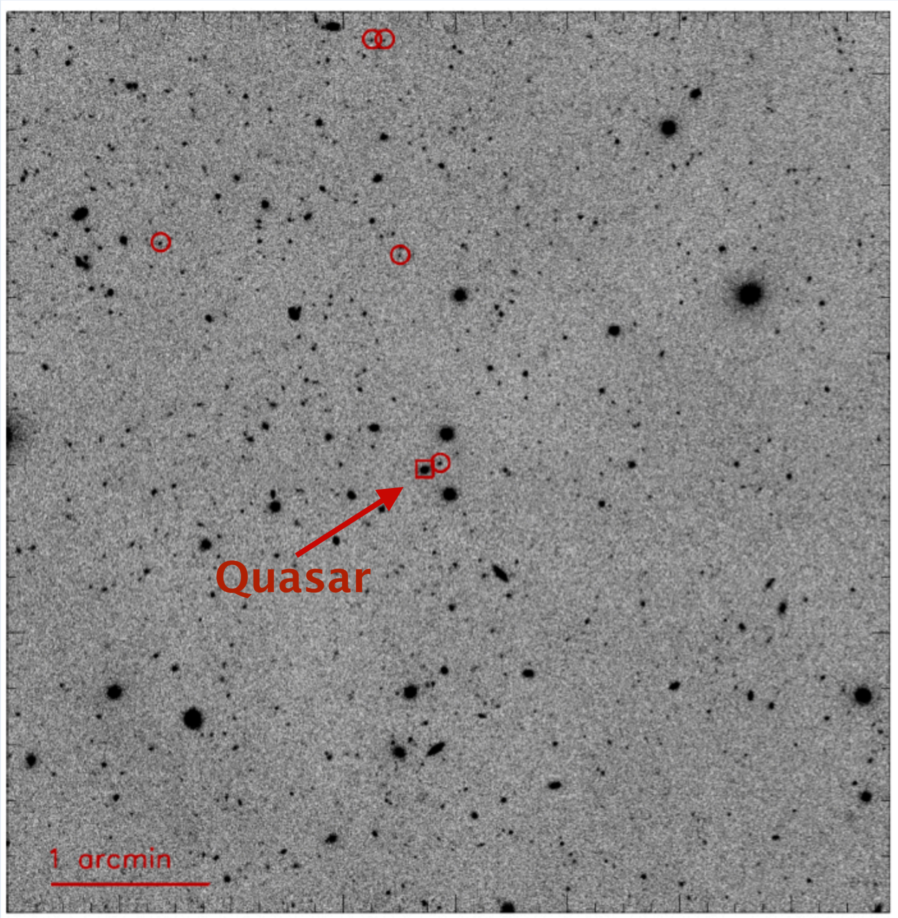
Survey of LAEs and CO emitters in the environments of 17 quasars at z~4

Tracing clustering of two populations simultaneously

OPTICAL

Observations of 17 QSO fields at z~4 with VLT/FORS2 (20hrs) to search for Lyman alpha emitters (NB_{5sigma}~24.5).

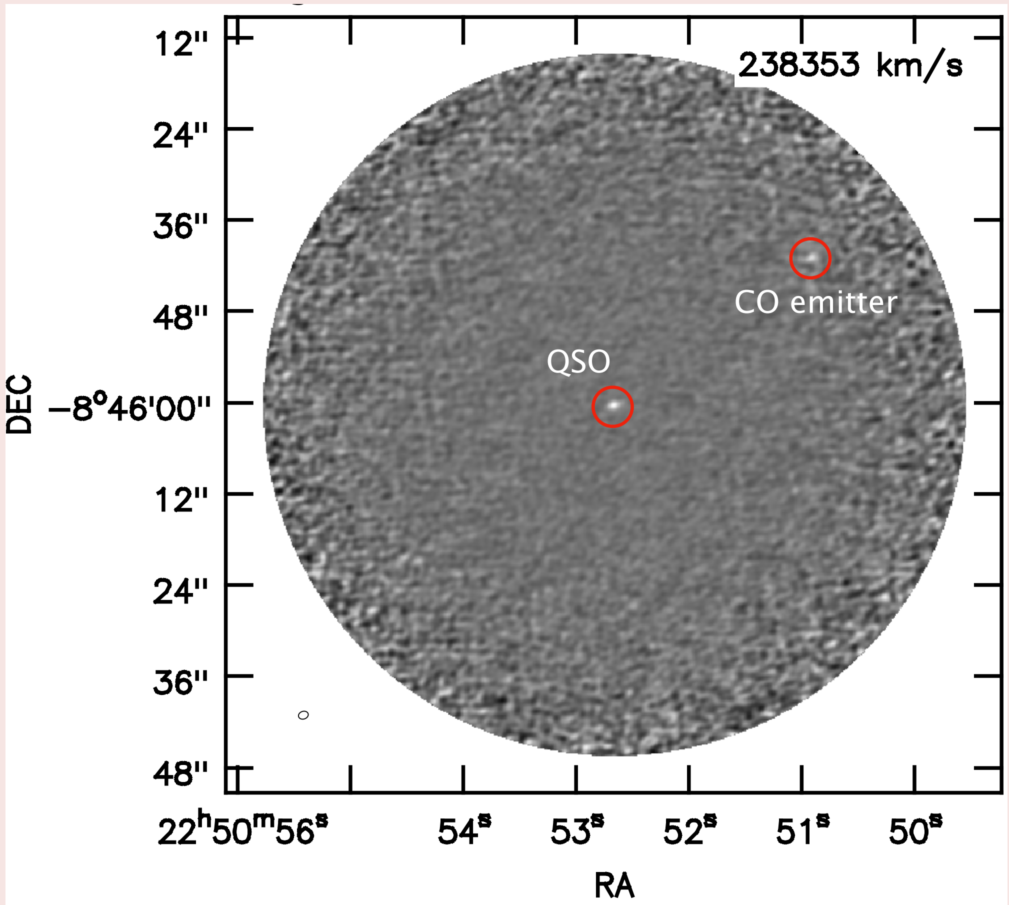
Example of one quasar field imaged with VLT/FORS2, and 5 LAEs around it

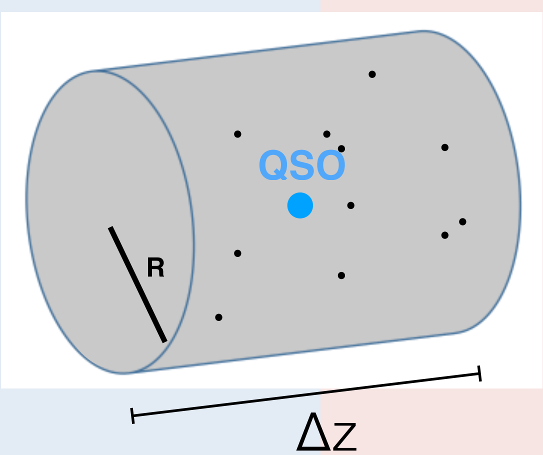


SUBMILIMETER

Observations of 17 QSO fields at z~4 with ALMA band 3 (20.5hrs) to search for CO(4-3) emitting galaxies (rms~0.25 mJy/beam).

Example of one channel (25km/s width) of a cube showing CO for the quasar and a companion





R ~ 300" R ~ 60"

dv= ±1,600 km/s dv= ±1,000 km/s

Effective Survey volume: 40,254 $(cMpc/h)^3$ Effective Survey volume: 1752 $(cMpc/h)^3$

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Mild LAE overdensity around quasars

We detected 25 LAEs with S/N>5.0 and with EW_{RF} > 28 Angstroms

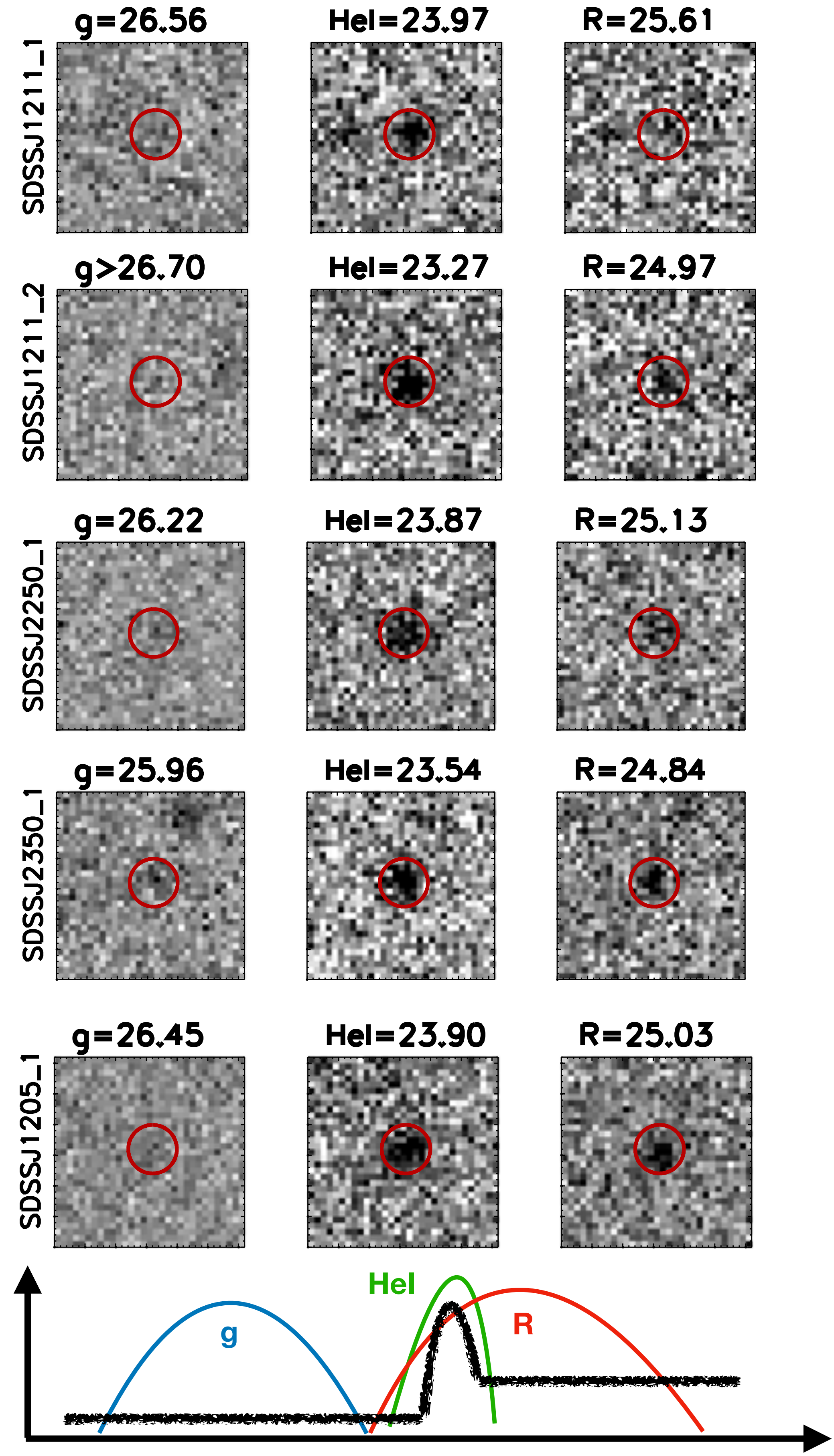
Only 18.4 LAEs are expected in blank fields over the same volume (computed based on the luminosity function of LAEs at z~4; Ouchi+08).

We detected a total overdensity of LAEs in QSO fields of 1.4

García-Vergara+19

…so on average quasars trace massive structures at the early universe

Example of 5 LAEs in our survey



Quasar-LAE cross-correlation function

Volume averaged cross-correlation function:

$$\chi = \frac{\langle QG \rangle}{\langle QR \rangle} - 1$$

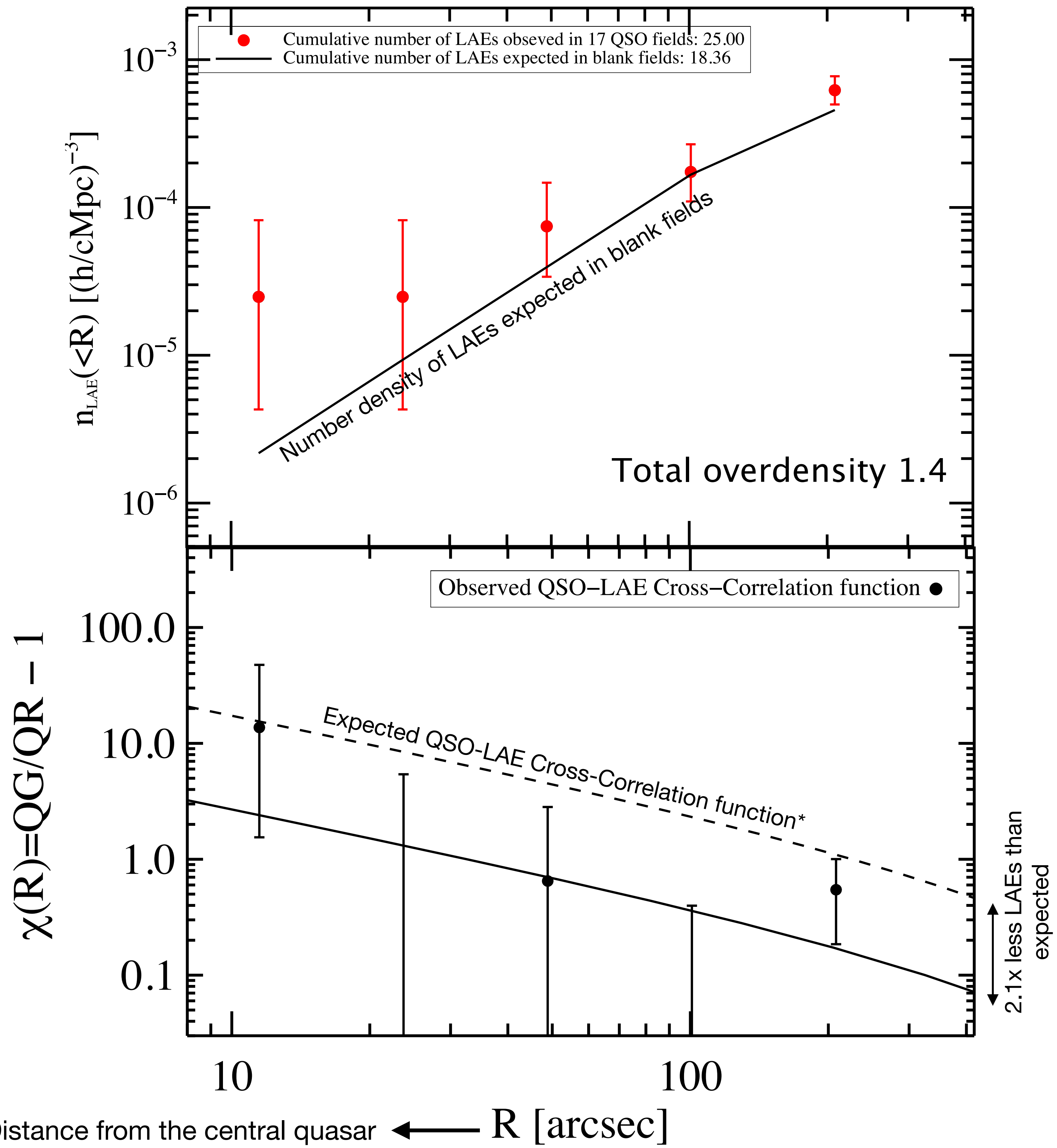
⟨QG⟩: Observed number of galaxies in quasar fields.

⟨QR⟩: Expected number of galaxies in blank fields:

We detected a positive QSO-LAEs cross-correlation function, indicative of a concentration of LAEs centered on QSOs.

However, our measurement fall short of the predicted overdensities by a factor of 2.1.

García-Vergara+19



*Based on a deterministic bias model, and assuming $\xi^2_{QG} = \xi_{QQ}\xi_{GG}$

Large CO overdensity around quasars

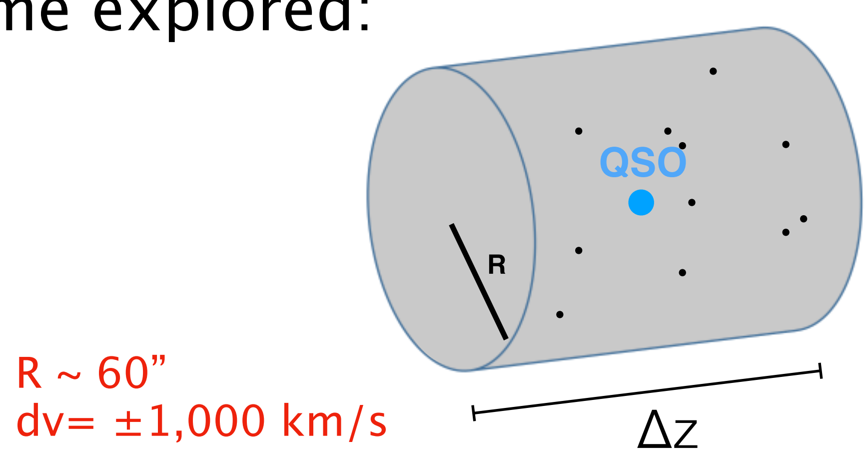
We detected 5 CO emitters with S/N>5.6 (Fidelity>80%).

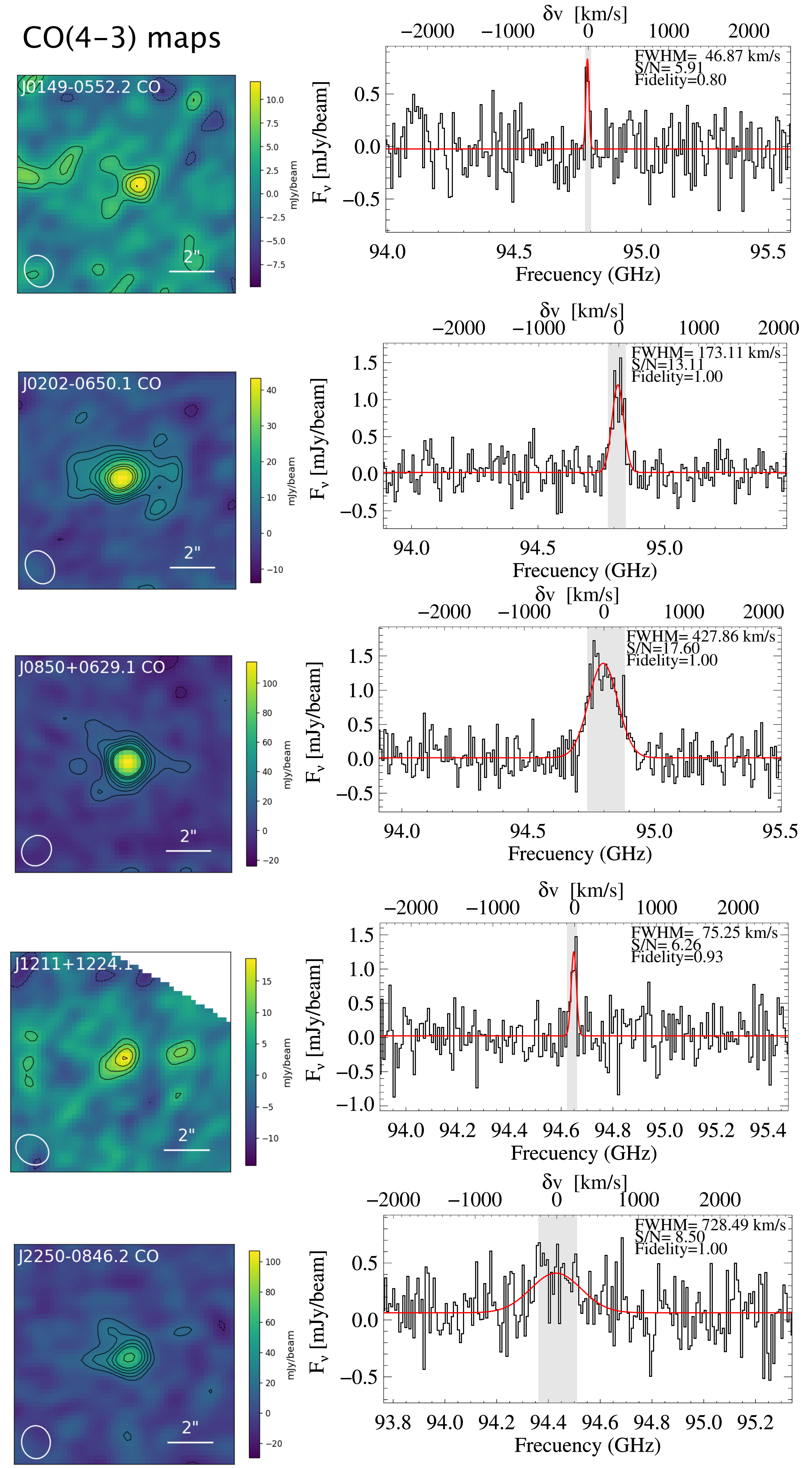
Only 0.28 COs are expected in blank fields over the same volume (computed based on the luminosity function of CO(4-3) at z~4; Decarli+19).

We detected a total overdensity of CO lines in QSO fields of $17^{+11.9}_{-7.6}$

García-Vergara+in prep.

Volume explored:

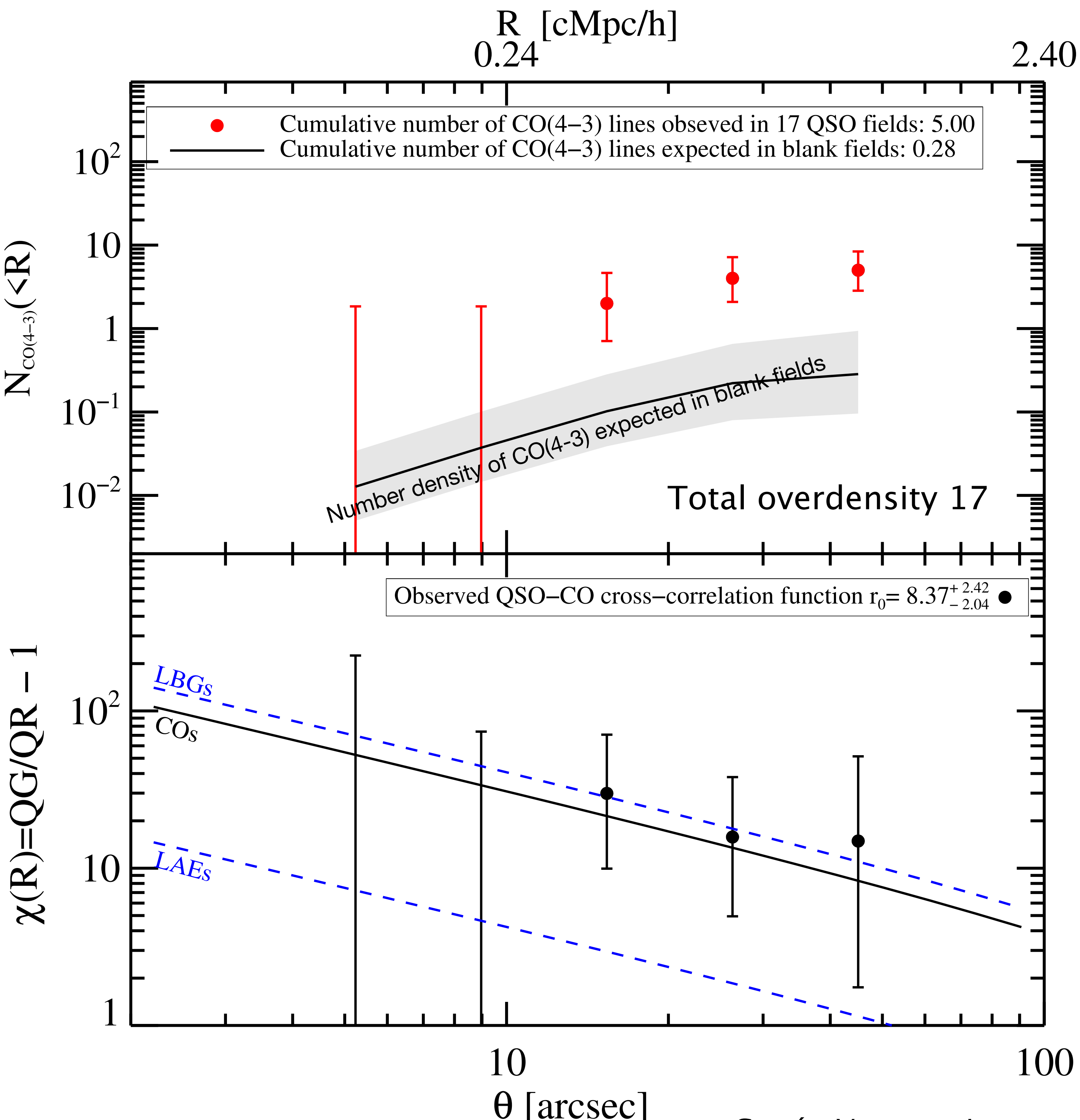




Quasar-CO cross-correlation function

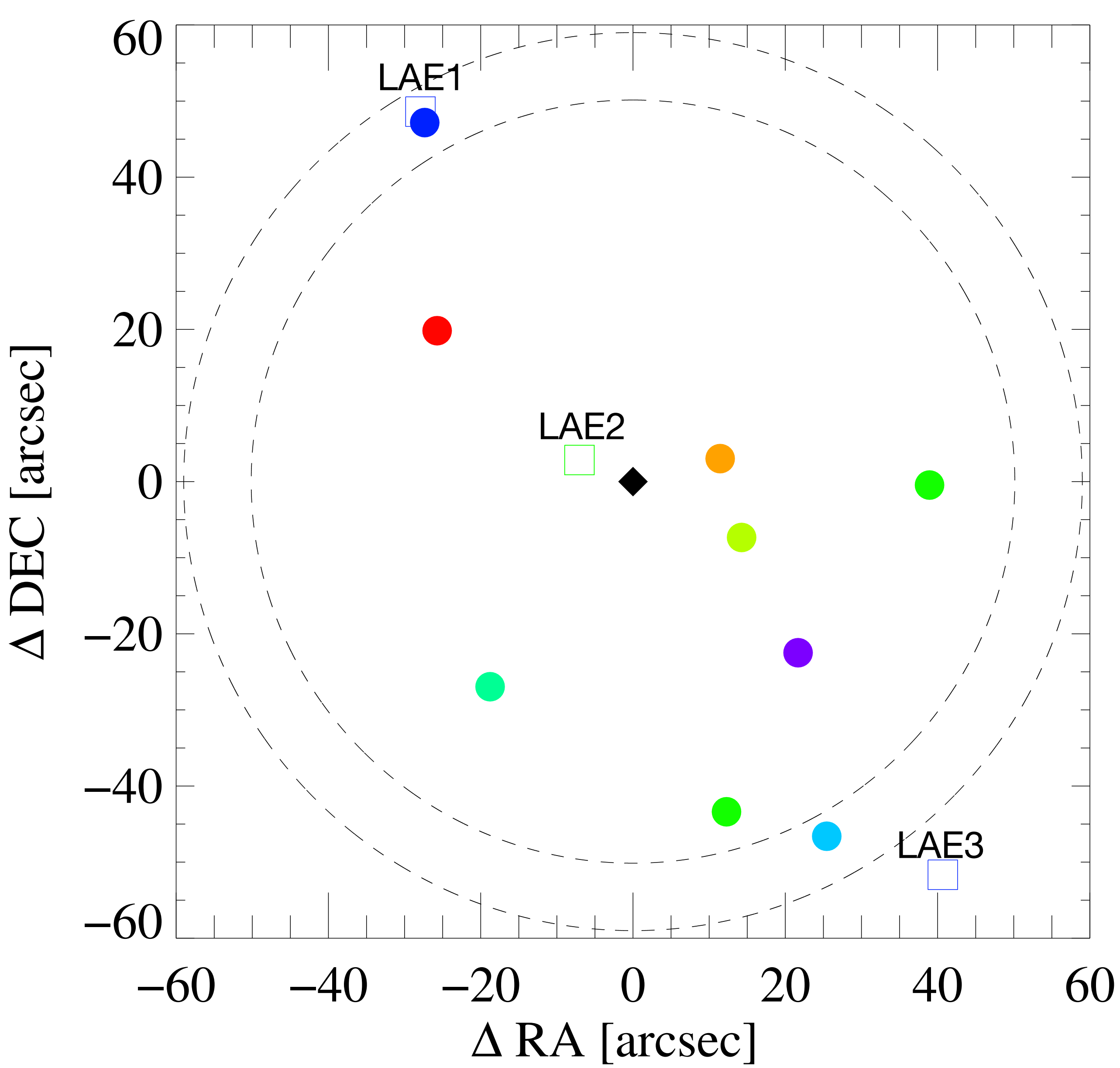
We detected a strong QSO-CO cross-correlation function.

Clustering of CO(4-3) lines around quasars is comparable with that measured for LBGs, and significantly higher than the one measured for LAEs.



García-Vergara+in prep.

Optical counterparts of the CO(4–3) emitting galaxies



Expanding the search of CO lines up to 3000 km/s from the quasar, we detect 9 galaxies in total.

Only 1/9 CO lines match with the position of a LAE. The others do not show Lyalpha emission, even when relaxing the S/N of the LAEs down to S/N=3.

One additional source shows the Lyalpha break, so it could be an LBG.

All the others are not detected in either UV continuum and Lyalpha emission.

The CO emitting galaxies around quasar seem to be invisible at optical wavelengths.

Possible explanations for the lack of LAEs and the large CO overdensity

CO(4–3) ⟶ traces the molecular gas in a galaxy.

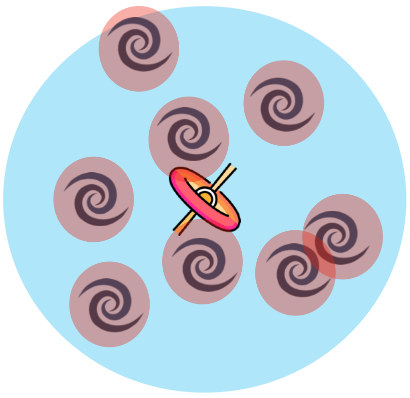
Ly alpha ⟶ traces instantaneous star formation (but also depend on CGM and IGM properties).

i) A relatively **small star formation efficiency** in galaxies around quasars could explain the lack of LAEs in these fields.

What is needed: JWST observations could provide information for a more accurate estimation of SFR. This is also possible to compute from CII observations.

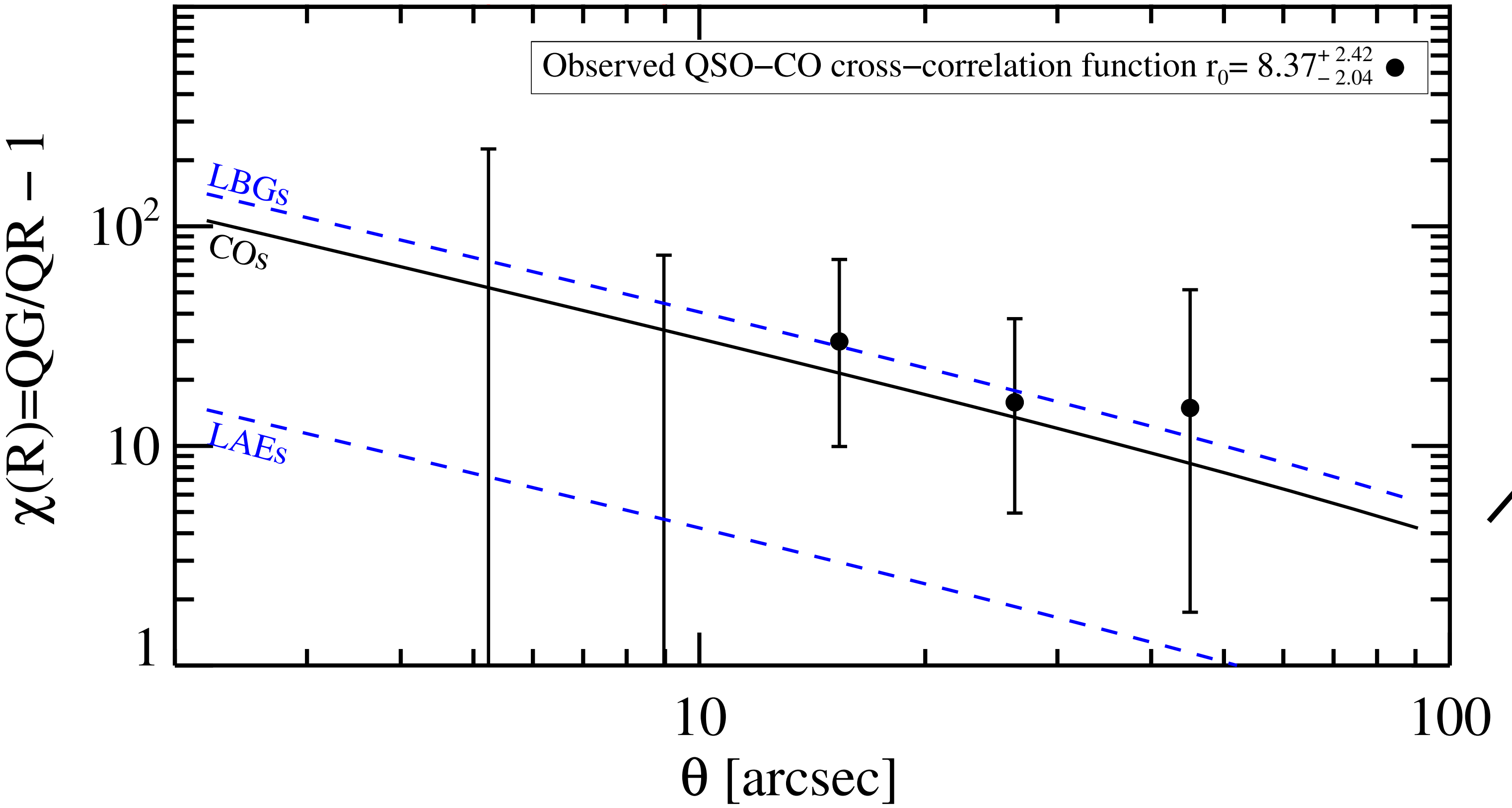
ii) Galaxies around quasars could be **more dusty**, suppressing or attenuating the Lyα emission line.

What is needed: Deeper optical observations, and additional ALMA continuum observations to constrain the amount of gas.



Characterization of the properties of galaxies in dense environments, and specifically in quasar environments is crucial to understand the lack of LAEs around quasars.

Bonus science: First estimation of the clustering of CO emitters at z~4



i) Assuming that the small-scale correlation function is extrapolated to larger scales following a power-law shape

ii) Assuming a deterministic bias model

$$r_{0,\mathrm{QG}} = \sqrt{r_{0,\mathrm{QQ}} r_{0,\mathrm{GG}}}$$

$r_{0,QQ}$ well constrained in the literature

$$r_{0,\mathrm{GG}} = 3.14 \pm 1.71\, h^{-1}\mathrm{cMpc}$$

correlation length CO emitters at z~4

CO emitting galaxies would inhabit dark matter halos of $3 \times 10^{11} M_{\odot} \lesssim M_{\mathrm{halo}} \lesssim 1 \times 10^{12} M_{\odot}$,

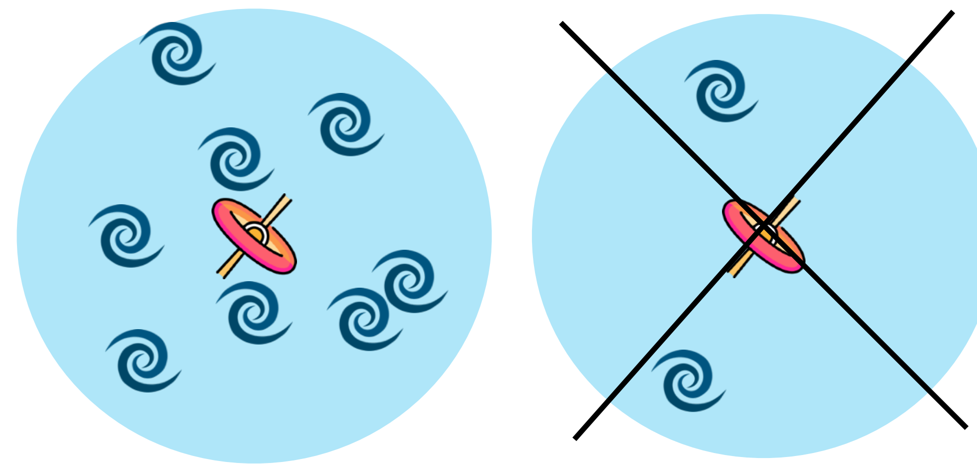
CO emitters would inhabit halos:

- with similar mass as LBG
- slightly more massive than LAEs (but consistent within error bars)
- >2.4 times less massive than bright (S>4mJy) SMGs at 1<z<3 (even after correcting by blending effects, Garcia-Vergara+2020). So, CO emitters tracing a different population than SMGs?

Summarizing

- We detect an enhancement of galaxies (LAEs and COs) in quasar fields, and they are clustered around the quasar, so **quasars trace massive structures in the early universe.**

(high cosmic variance and incomplete sampling of galaxy populations may be the explanation for the contradictory results so far)



- The clustering of CO emitters around quasar is strong and comparable with the clustering of LBG around quasars, but it is significantly higher than the LAE clustering around quasars.

- **LAEs seem to be missed:** low SF efficiency in these galaxies or possibly an excess of dust in galaxies around quasars.

- **Multi-wavelength observations** would allow us to perform a more complete characterization of the properties of galaxies around quasars.