z<4 Quasar pair 周囲の銀河密集度測定

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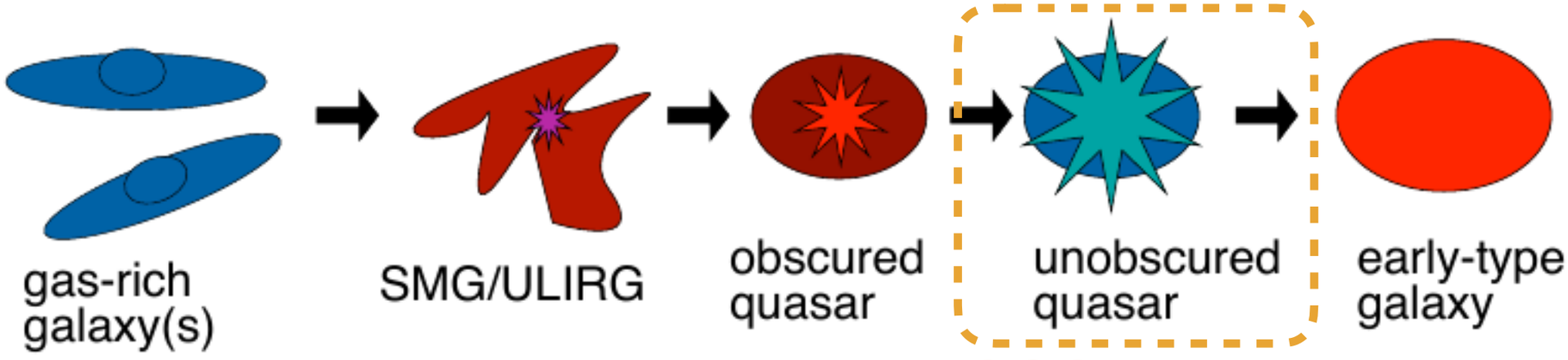
on behalf of HSC Project 168: "Galaxy Environment around Multiple QSO Systems"

2016/06/02 Galaxy Evolution Workshop @ Tohoku Univ.

Outline

- **Background**
  - Quasar environment studies (QSO 2PCF, LAE/LBG clustering around z>6 QSOs, semi-analytical simulation)
  - Low-z Multiple QSO System Studies
- **z<4 Multiple QSO System Study with HSC-SSP**
  - Sample & Method
  - Preliminary Result
    - z~4 QSO pair environments using g-dropout
    - z<2 QSO pair environments using photo-z
  - Future Prospects & Summary

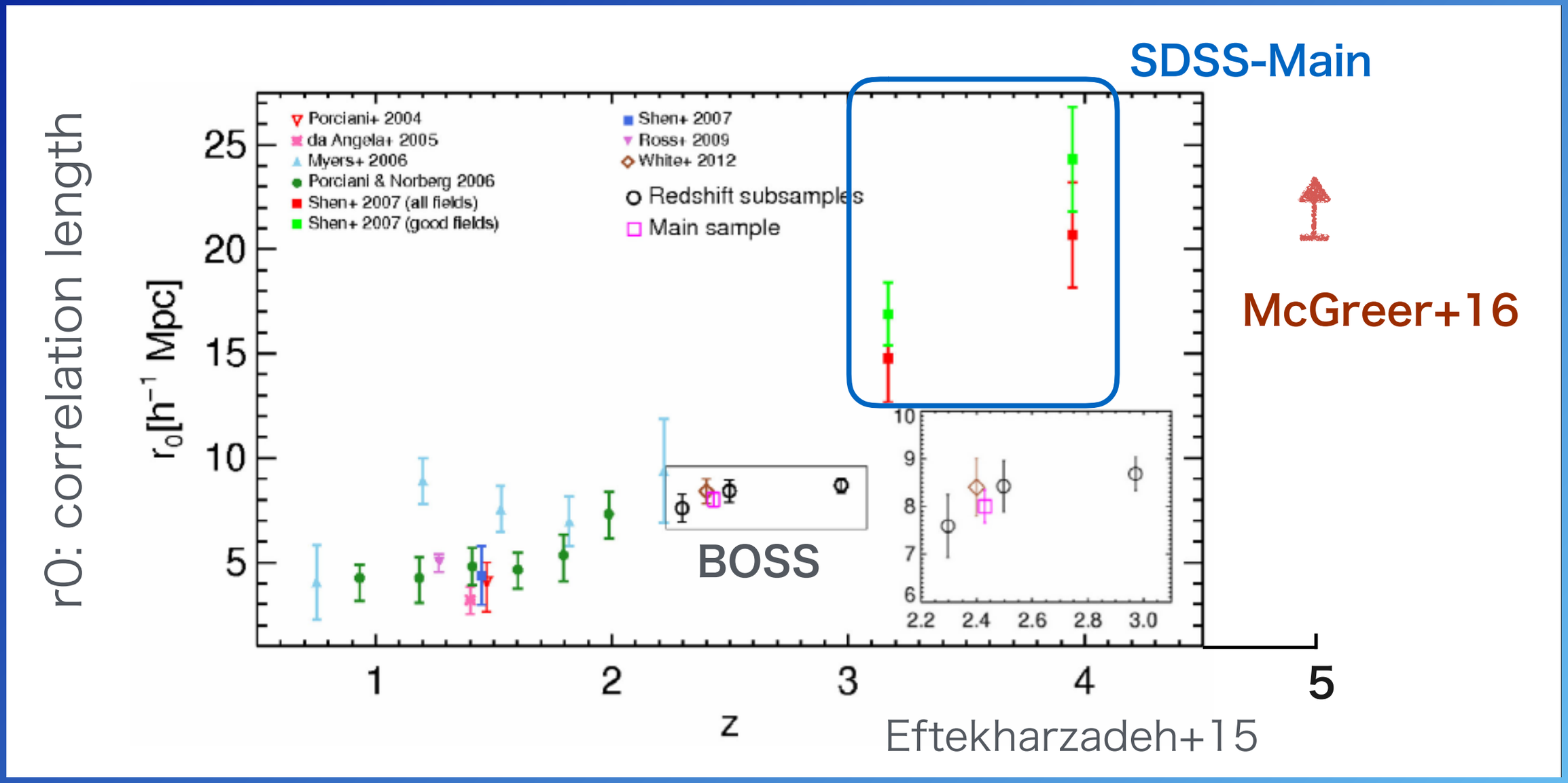
QSO Triggering Mechanism



Alexander&Hickox+12

- ✦ A well-accepted trigger of quasars: Major mergers of gas-rich galaxies
- ➡ Then, they should be good probes of rich environments inside massive dark matter haloes where such merger events frequently happen

Quasar Two-point Clustering



- Higher-z quasars more strongly cluster [Shen+07, McGreer+16]
  - Quasar environments are more biased at higher-z?
- The correlation gets flattened at z>2? [Eftekharzadeh+15]

Overdensity around z>6 Quasars

Object	z	FoV[pMpc2]	Technique	Overdense?	Ref
ULASJ0203+0012	5.72	5.6	LAE	0	Banados+13
SDSSJ1306+0356	5.99	1.4	LBG	no	Kim+09
SDSSJ1030+0524	6.28	3.7	LBG	0	Willott+05
SDSSJ0338+0021	6.43	83.3	LBG	yes	Utsumi+10
ULASJ1120+0641	7.08	1.4	LBG	0	Simpson+14

cf.) Kikuta-san's poster (at z~5)

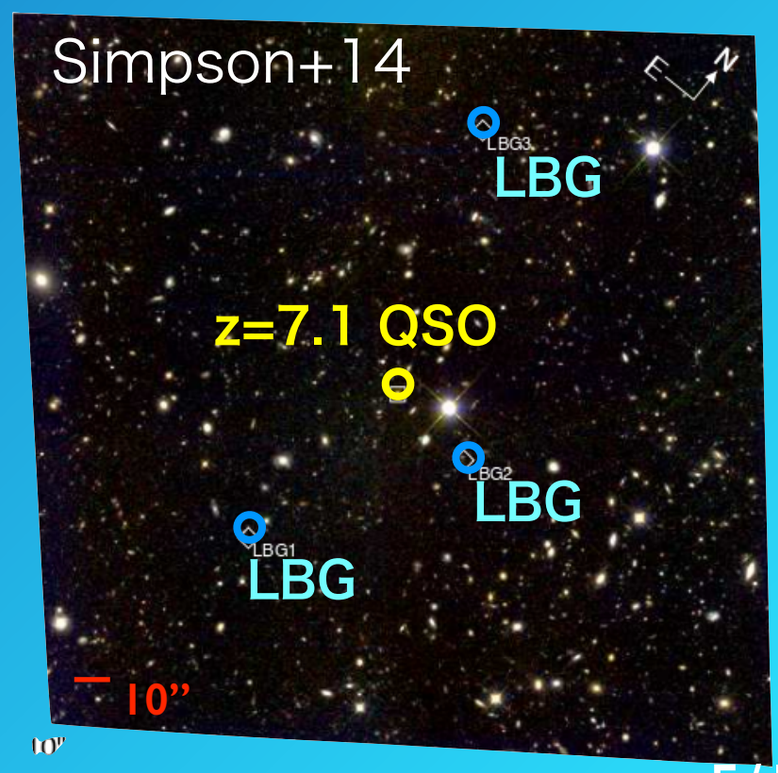
and more…

Courtesy of C.Mazzucchelli

Even at the highest-z, different results have been reported

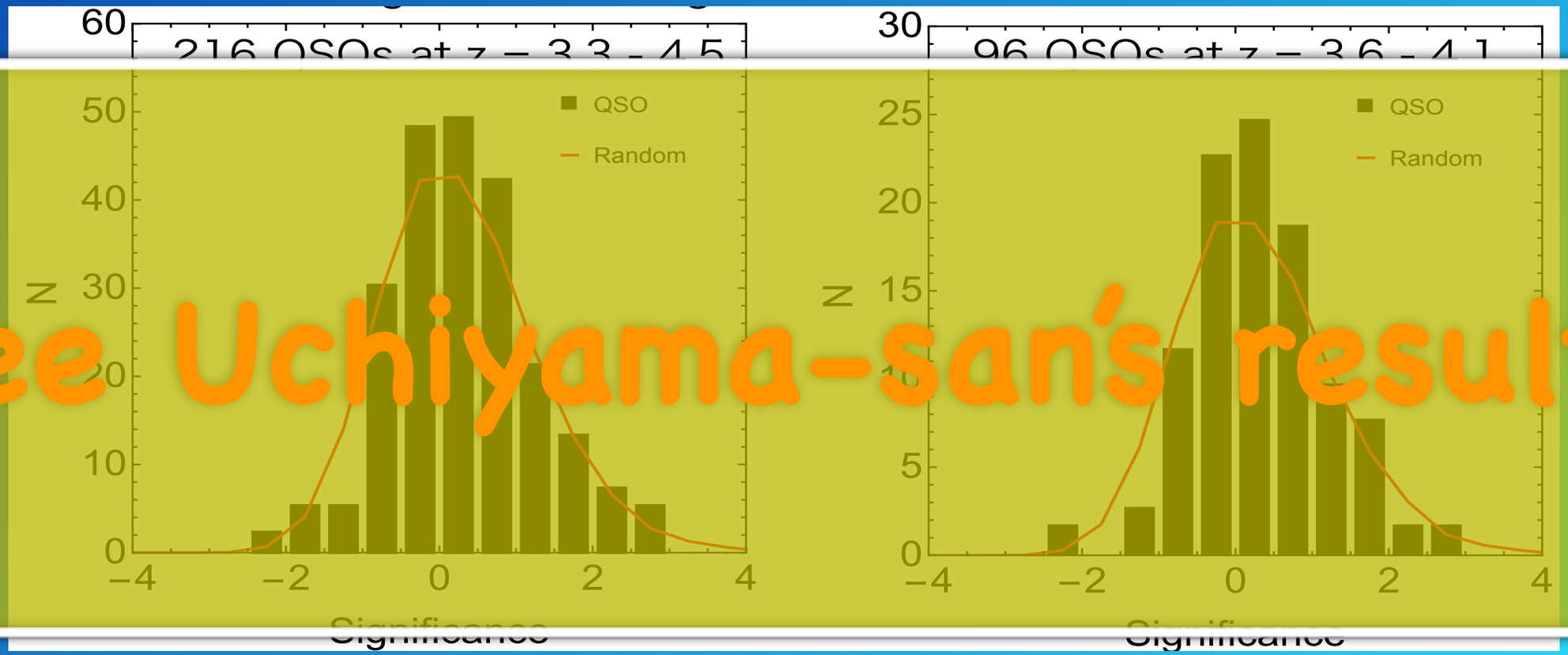
- Different technique, depth, FoV could be part of the reasons

➡Extremely luminous z>6 quasars emerge in both rich and normal environments?



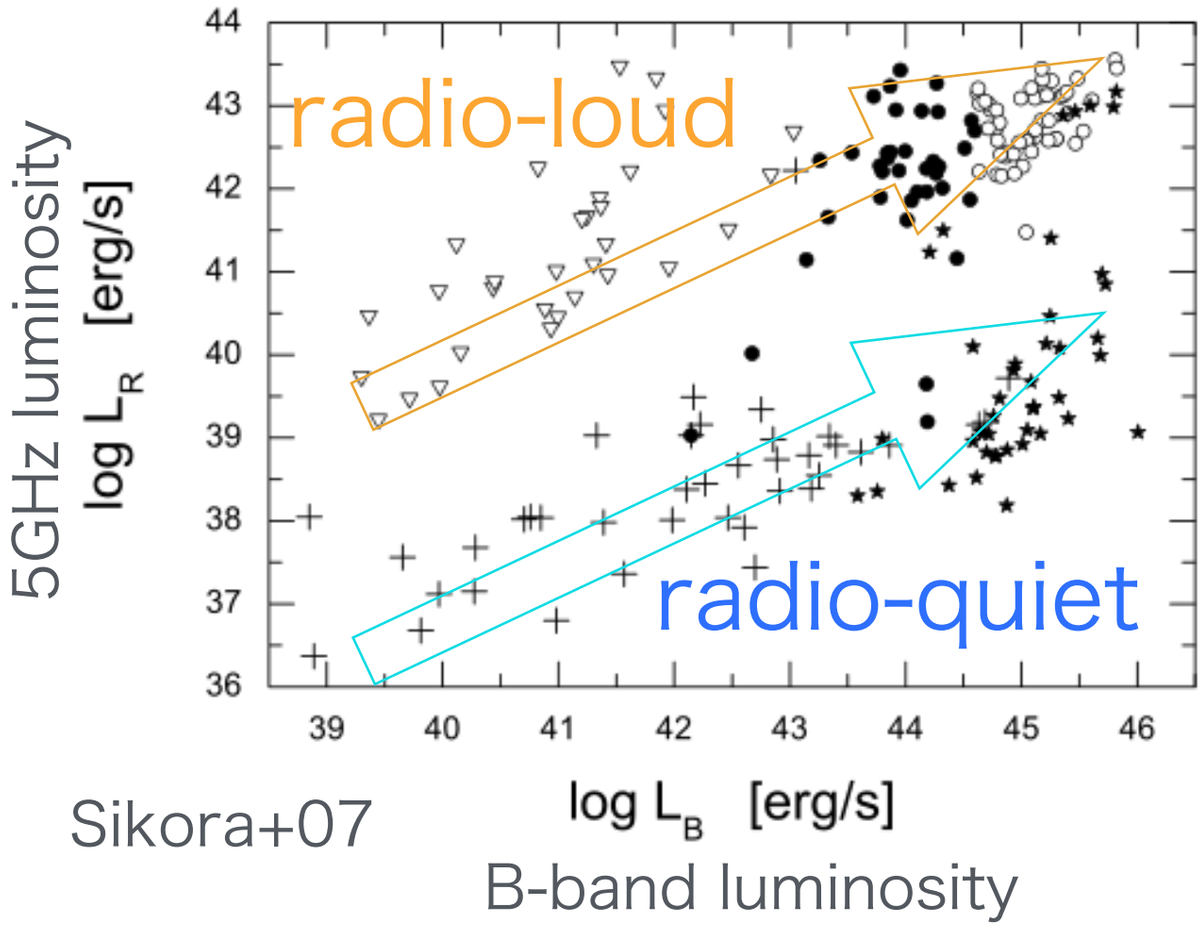
Why Is There No Clear Sign of Overdensity?

1. Quasar host haloes are not as massive as expected
2. Negative feedback suppresses galaxy formation in their proximities
3. Most galaxies are dusty and obscured
4. Overdense structure is very extended (>10pMpc?)



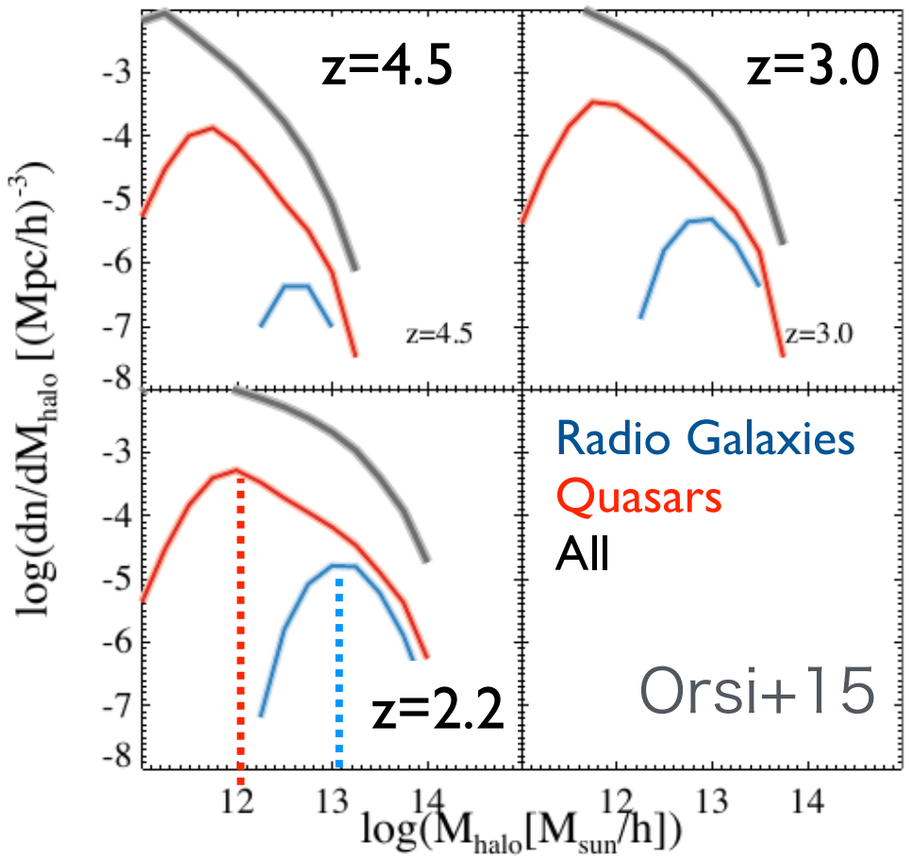
See Uchiyama-san's result!!

Radio-loudness is the key?



Sikora+07

B-band luminosity



Host halo mass

- **Radio-loud AGNs** trace overdense region quite well [e.g. Venemans+07, Hatch+14]
- Host mass range of radio-quiet AGNs seems wider than that of radio-loud AGNs.

  ➡ quasar can emerge in normal environments [e.g. Orsi+15]

Situation is Too Complicated

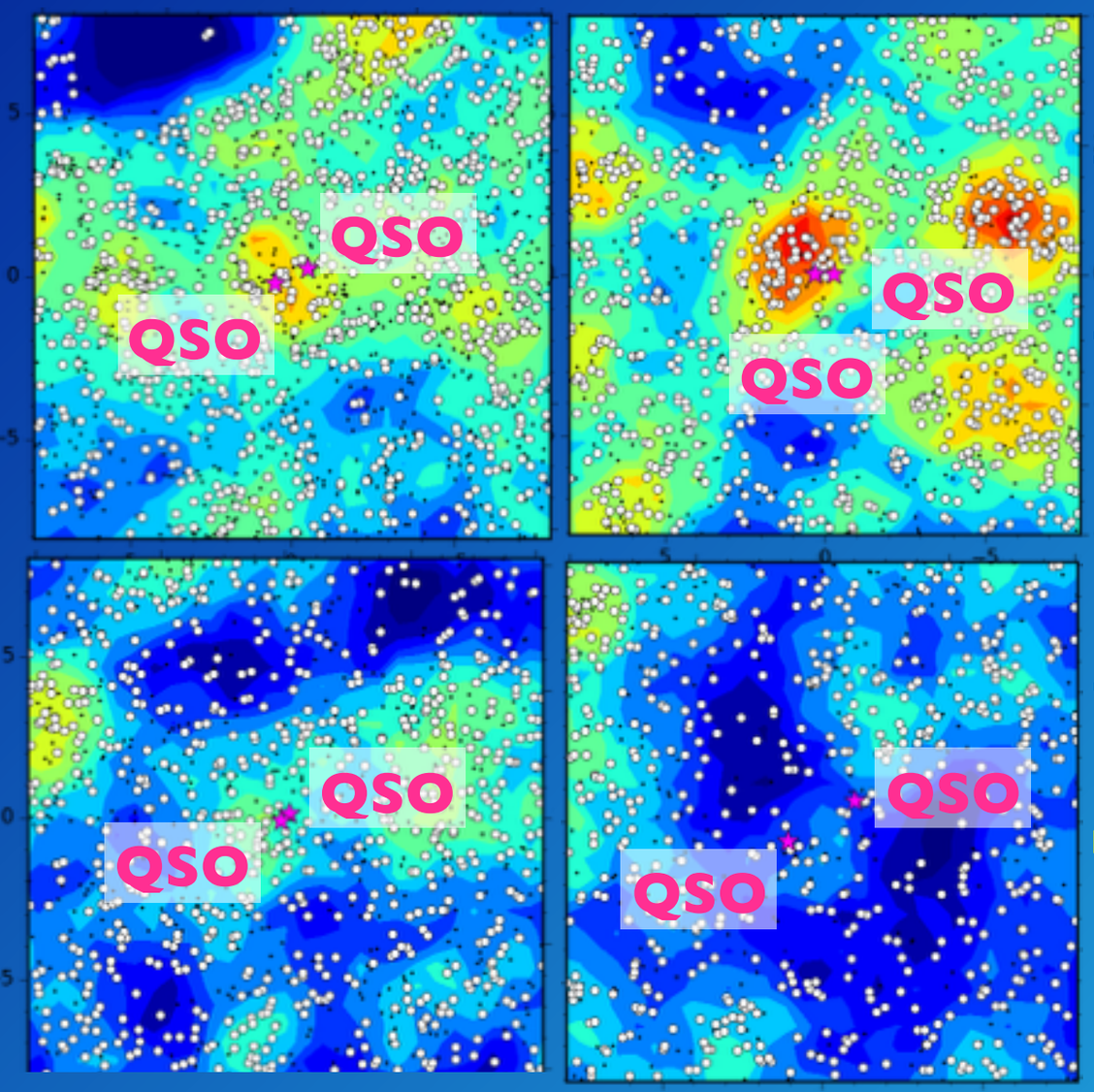
What we need is

- To observationally qualify quasar environment based on statistics (beyond case studies!)
- Sufficient sample size, FoV, depth

Wide and deep survey can overcome the current problems

➡ Subaru/HSC-SSP Survey !

HSC Project 168 (PI: M.Onoue)
Galaxy Environment around Multiple QSO Systems



Star: z<2 QSO pairs, Circle&dot: galaxies
Contour: Galaxy Overdense Significance

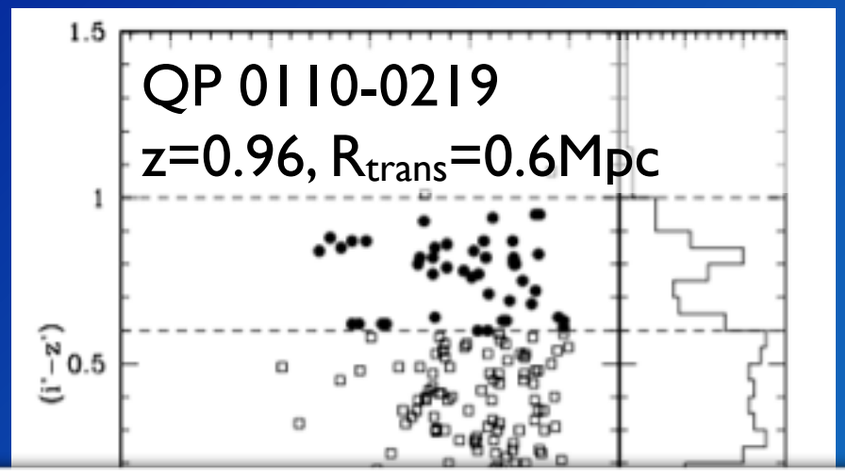
✦**Extreme system: Quasar Multiples**

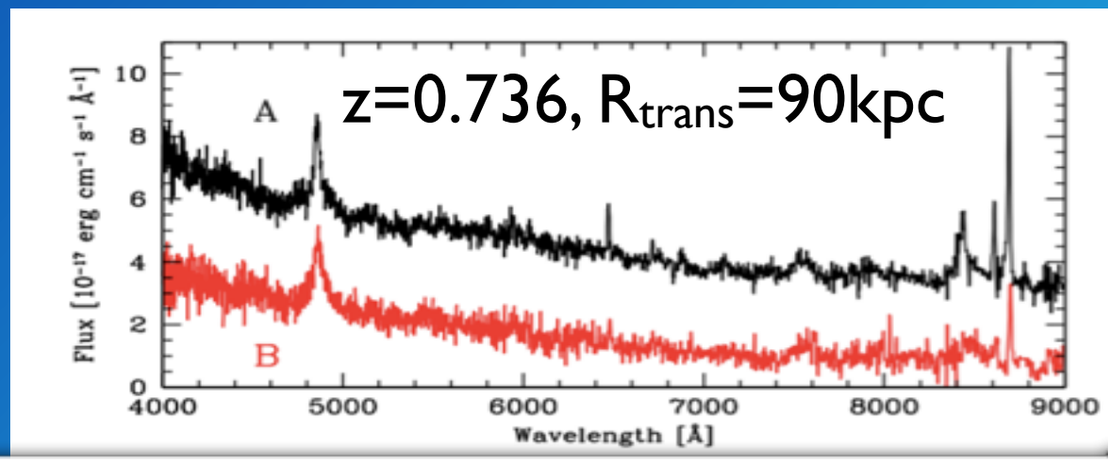
- In this study, we examine proto-clusters in a quasar point of view
- We examine the widely accepted yet not observationally confirmed assumption that quasars trace proto-clusters by focusing on extreme multiple environments
- Redshift: $0<z<4$

➡HSC survey is well-suited for this study!
(Wide: 1400 deg^2 , $r_{lim,5\sigma}$~26)

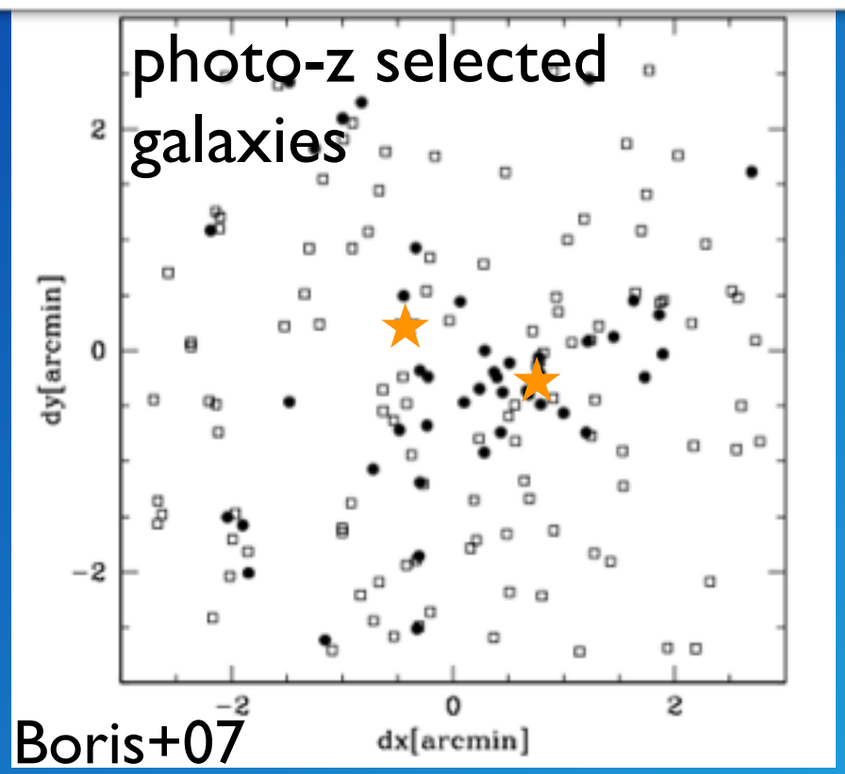
✦**First systematic study of quasar multiples at high redshift!**

Quasar Pair Studies at z<1

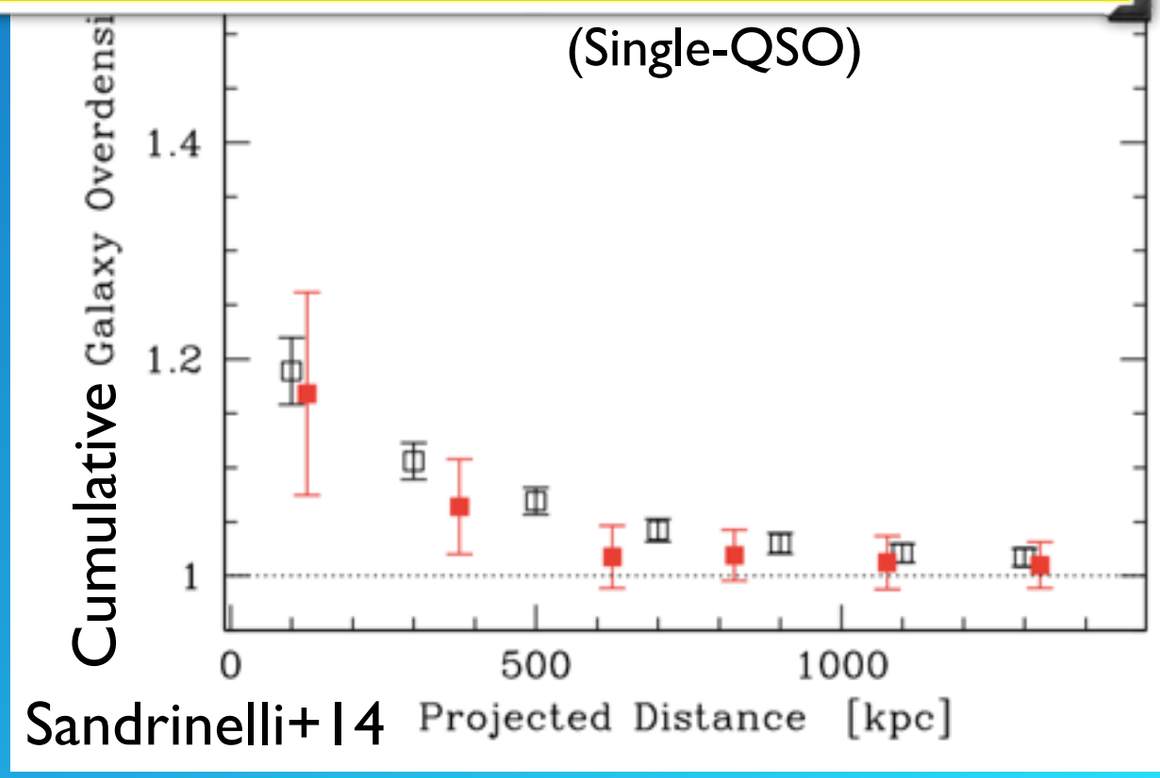




Low-z Quasar pairs do not necessarily reside in rich environments



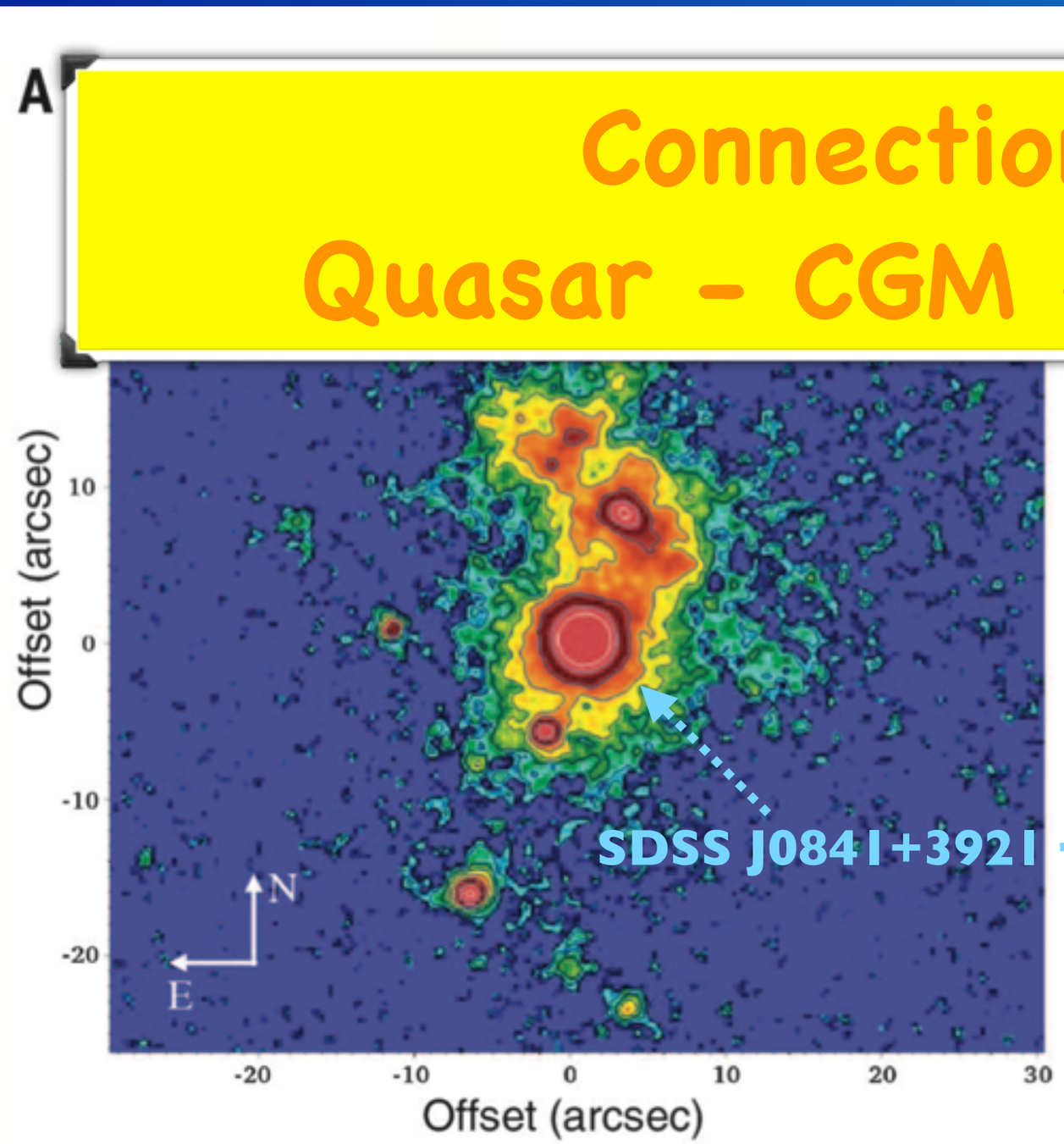
Boris+07

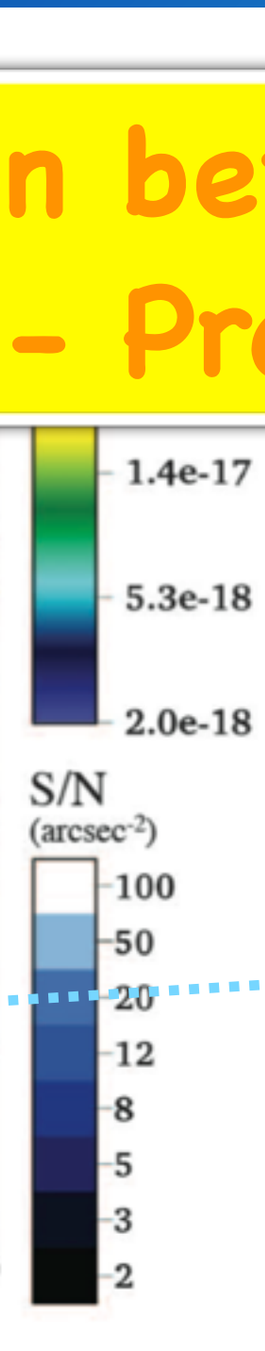


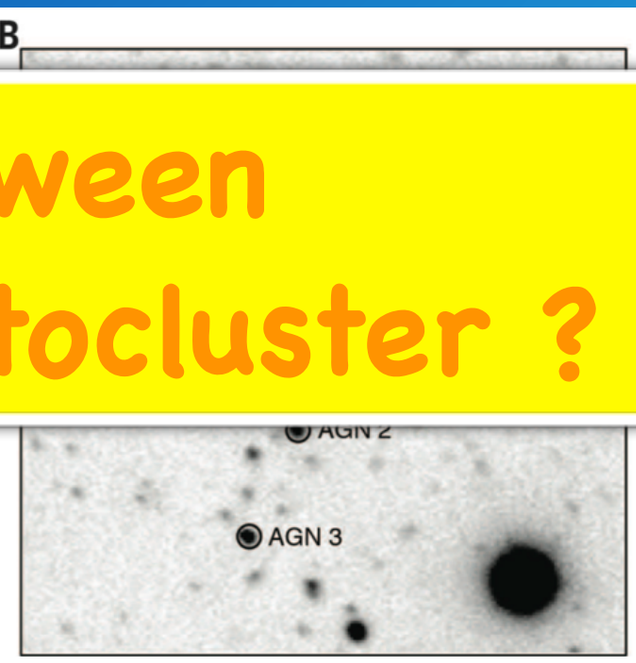
Sandrinelli+14

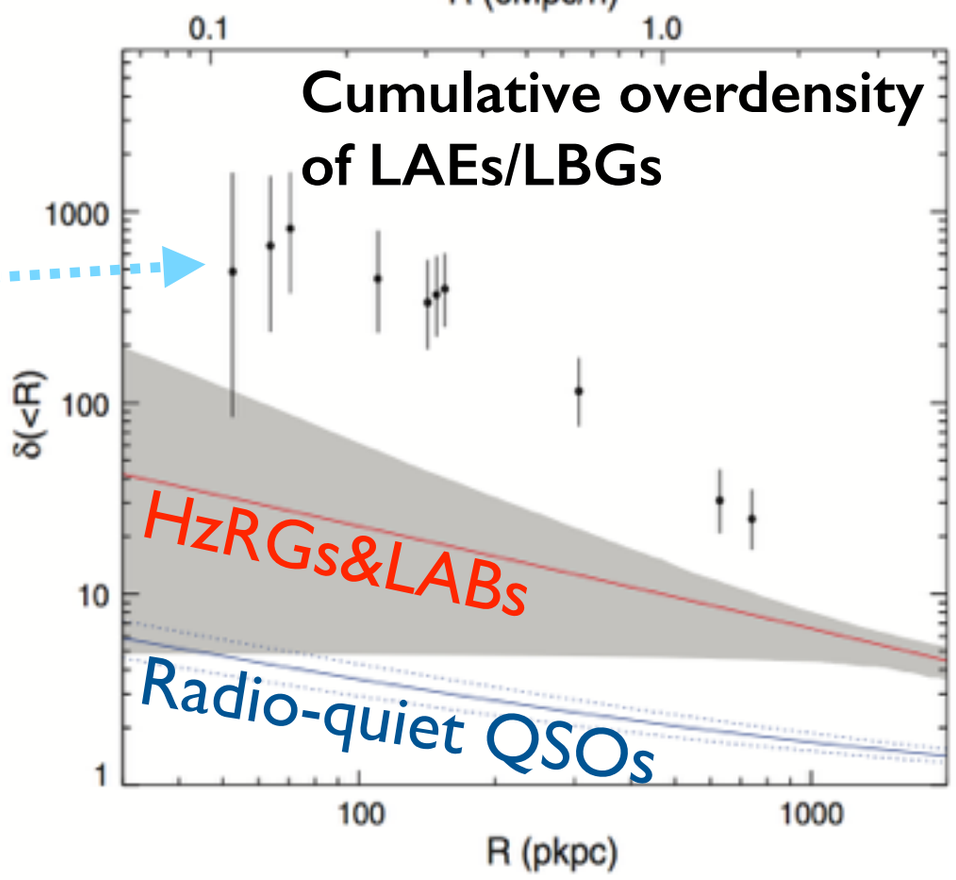
Quasar Quartet at z~2 [Hennawi+15, Science]

Connection between
Quasar - CGM - Protocluster ?



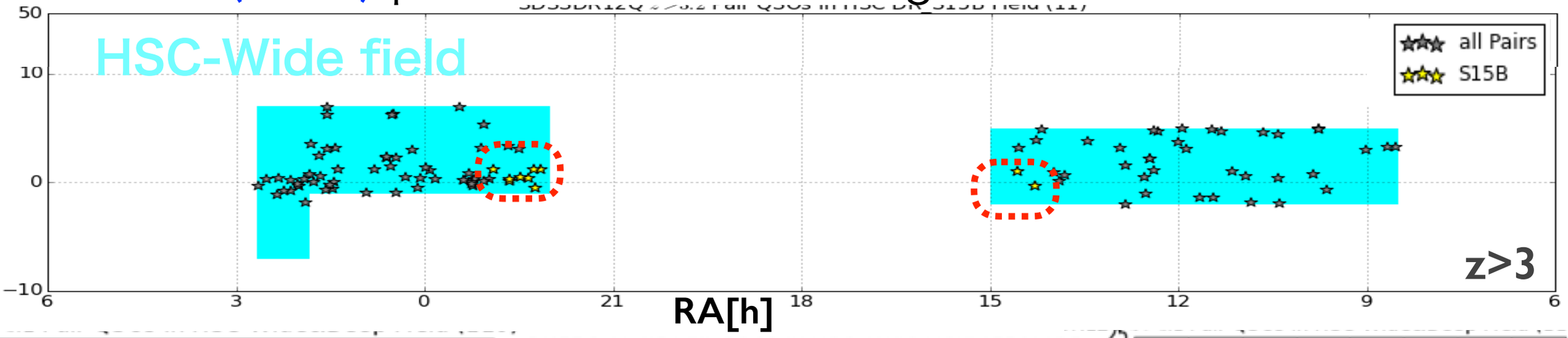


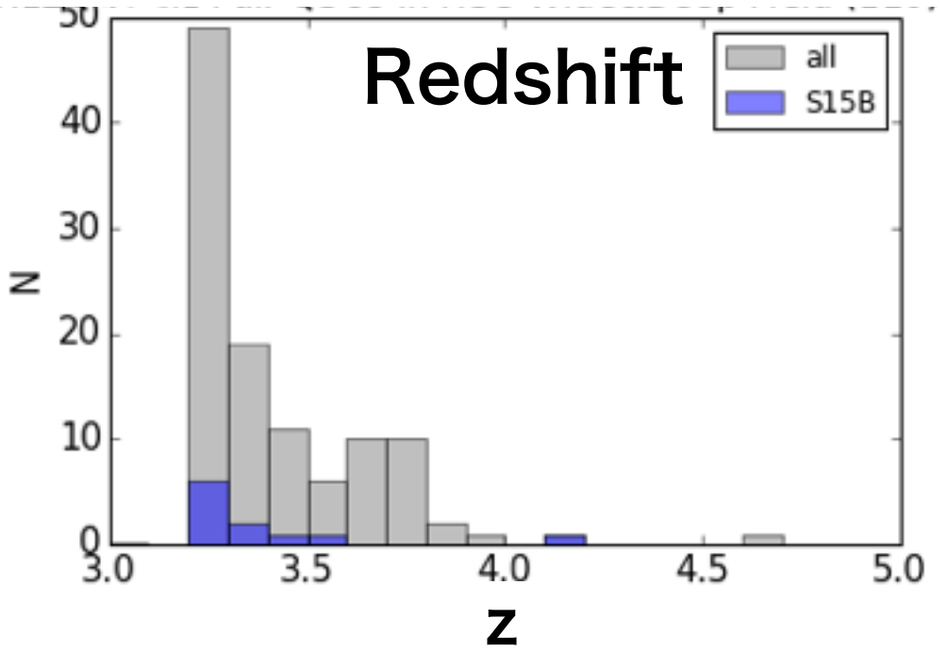


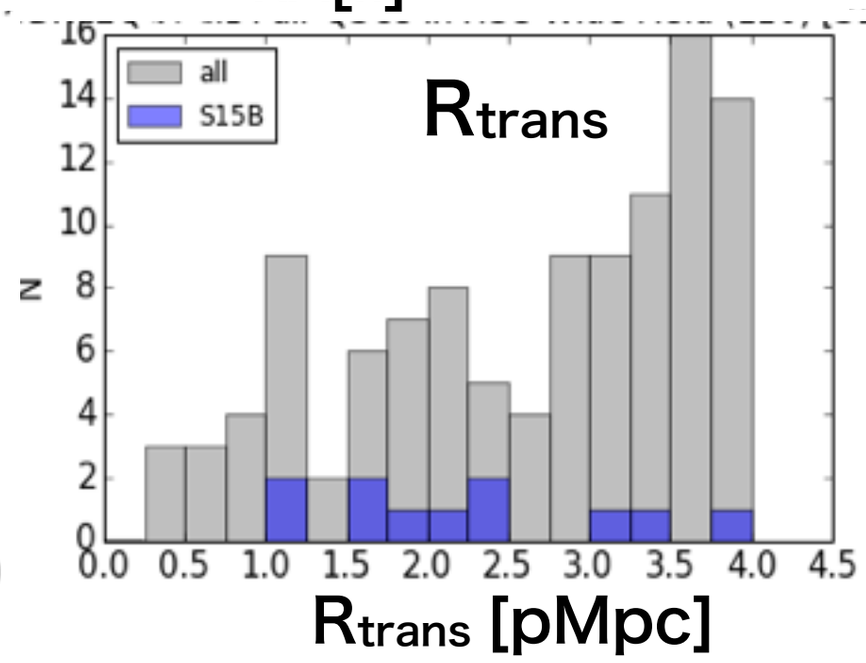


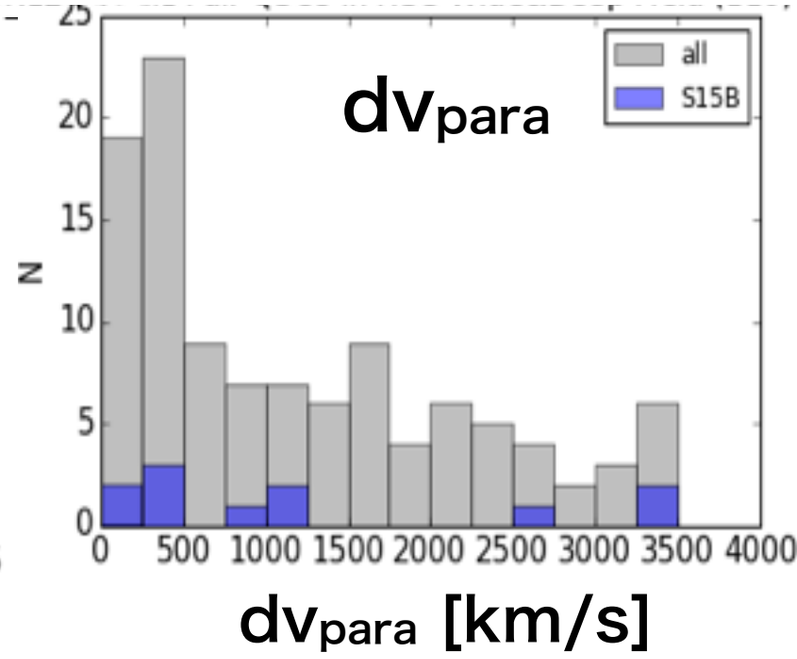
Quasar Multiple Sample Selection

- SDSS DR12 QSO Catalog & Hennawi+06,+10 & McGreer+16
- R_{trans}<4pMpc (typical massive cluster size, Chiang+13)
- dv_{para}<3500km/s (at z>3)
- 110(11) z>3.2 pairs in all (S15B) HSC-Wide&Deep field
- ~4000 (~900) pairs in all redshift range



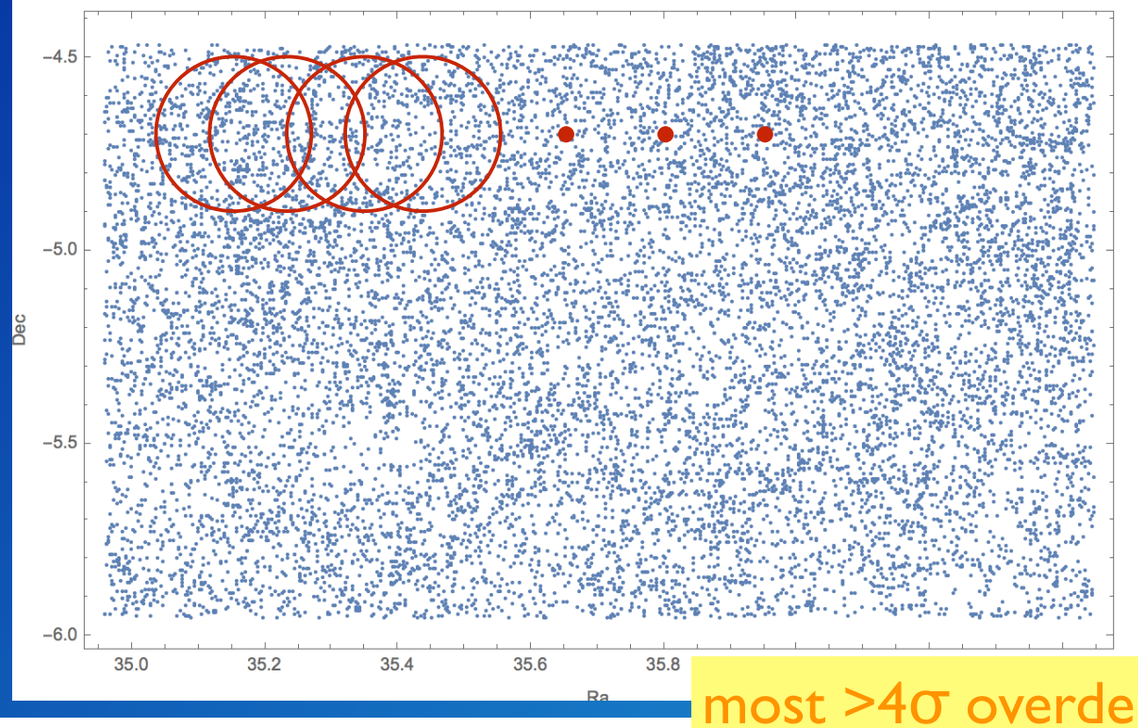






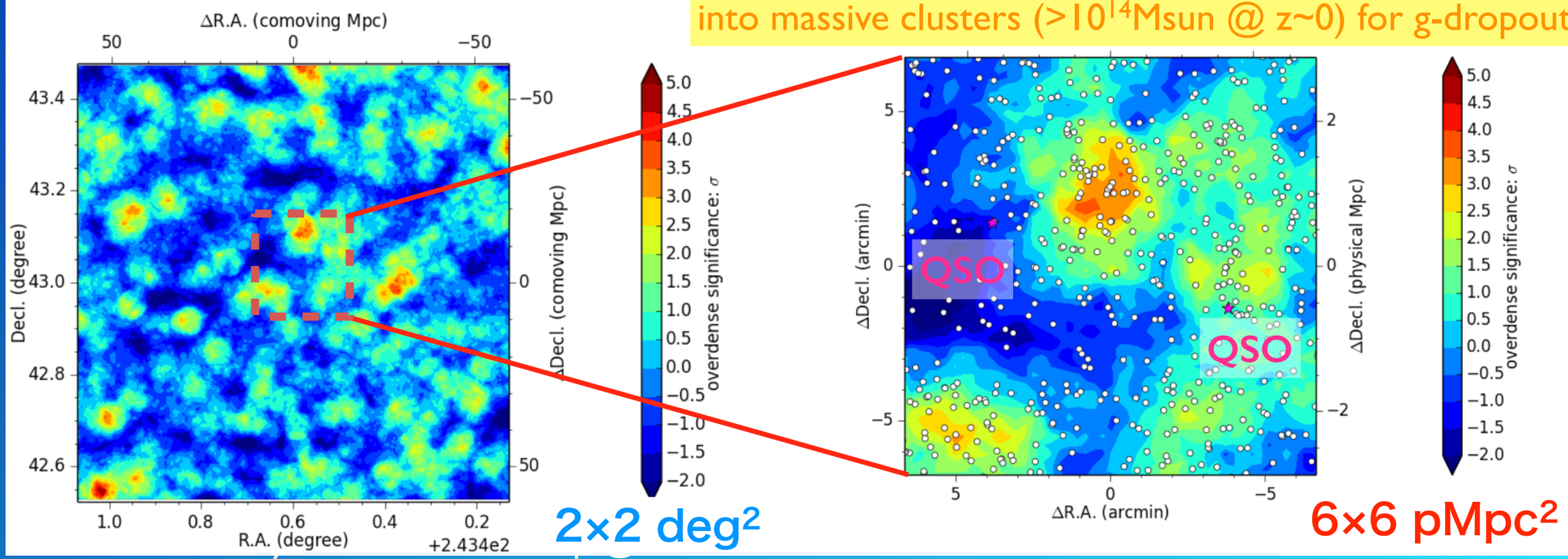
Method

- **Overdensity measurement:** fixed aperture method (cf. Toshikawa+16)



1. distribute apertures
   r =1.8' (~0.8pMpc @z~4)
2. count **dropout/photo-z selected galaxies**
3. estimate ave and std
4. determine significance
5. zoom up the pair field

most >4σ overdense regions are expected to evolve into massive clusters (>10^{14}Msun @ z~0) for g-dropouts



2×2 deg²

6×6 pMpc²

Preliminary Result

1.z~4 (radio-quiet) quasar pairs (N=2, g-dropout)

2. z<2 pairs (N=250, photo-z)

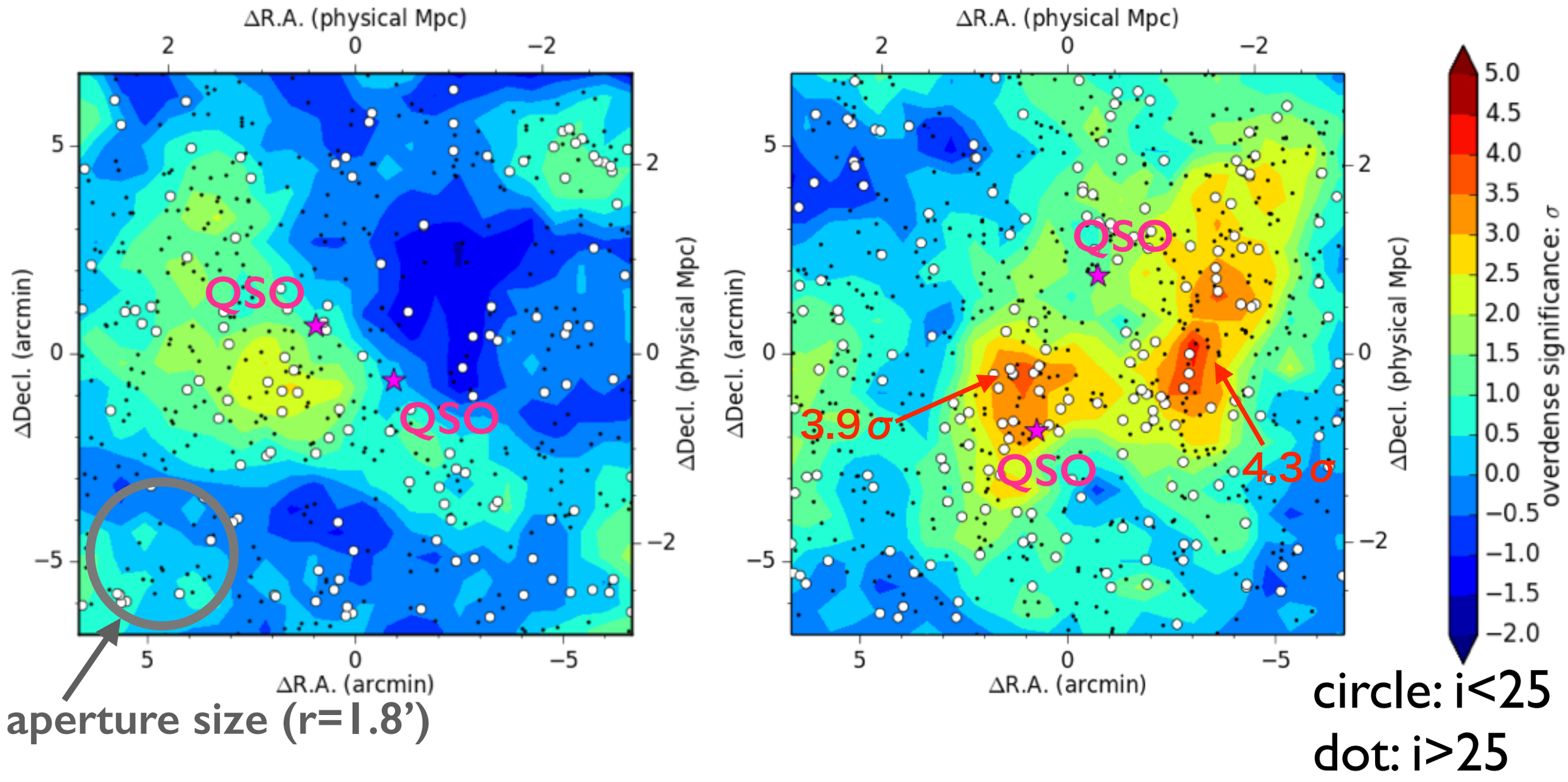
G-dropout Density Map

QSOP J2209+0111 (z_1=3.45, z_2=3.75)

R_{trans}=1.04 pMpc, dv_{para}=3369 km/s

QSOP J2214+0109 (z_1=3.59, z_2=3.57)

R_{trans}=1.79 pMpc, dv_{para}=120 km/s



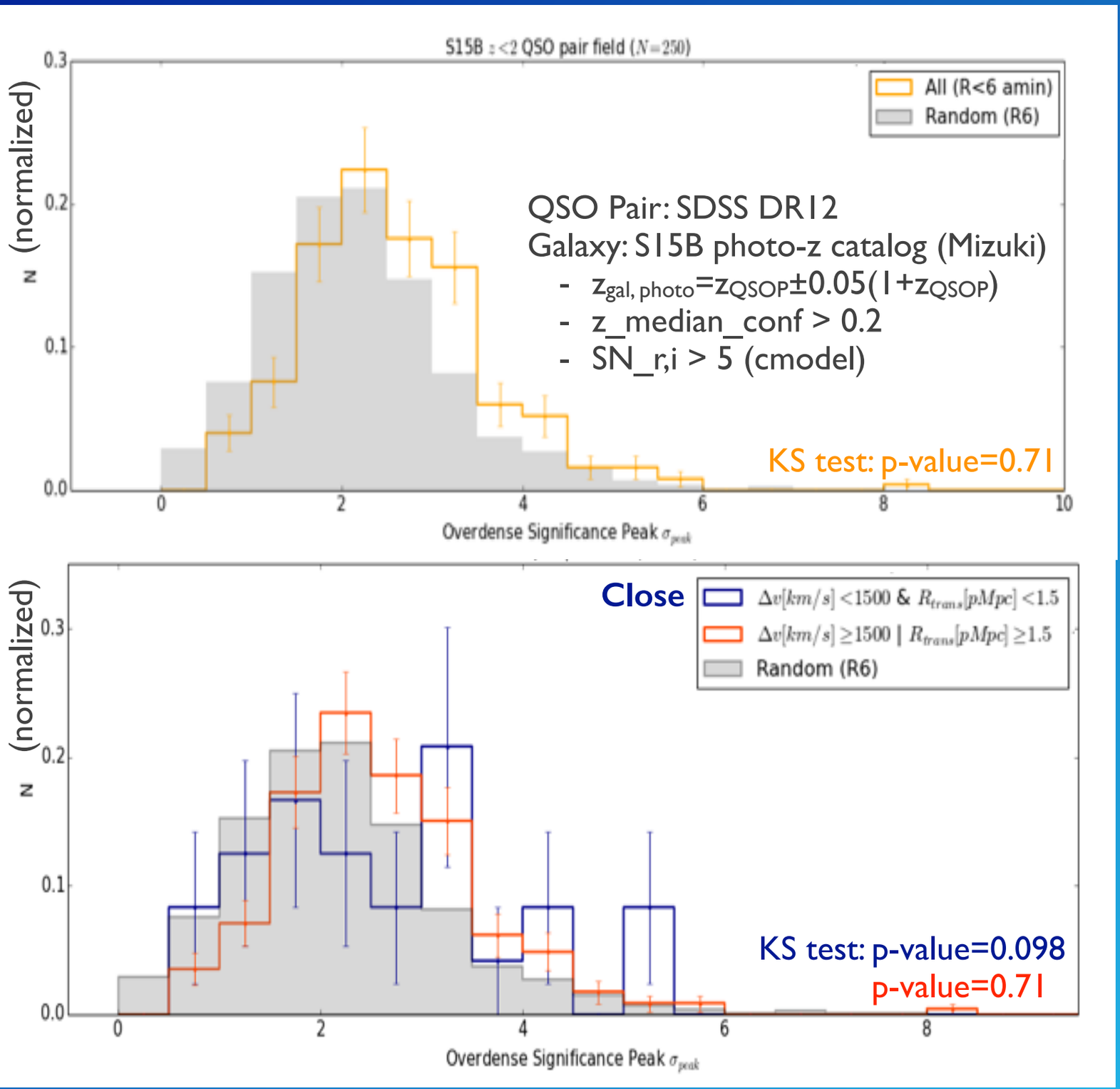
aperture size (r=1.8')

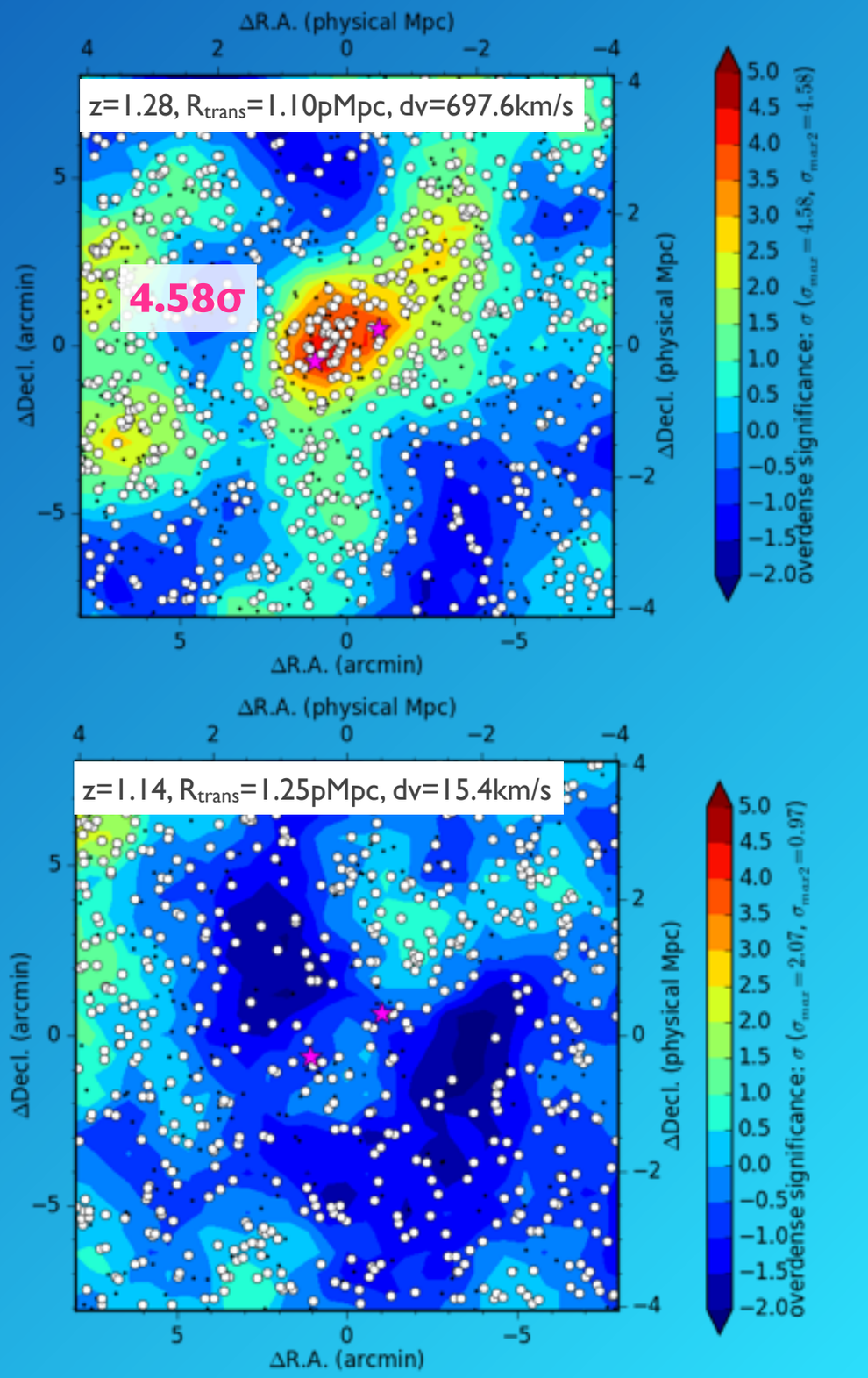
circle: i<25

dot: i>25

A giant protocluster candidate found

z<2 QSO Pair Field (N=250)





Not all, but close pairs prefer dense regions at low-z

Future Prospects

- VLT/VIMOS Follow-up observation of the promising proto-cluster candidate at z~4
  (spec-z determination, Lyα emission properties)

- Extend this study to **all redshift range** using photo-z

- It would be interesting to check the presence of other objects such as highly obscure galaxies (DOGs) and radio-loud AGNs in the pair fields

- Compare pair fields with single-QSO fields

- Constructing fainter quasar pair sample using HSC photometry catalog

We aim to investigate the role of quasars in the galaxy evolution from a unique point of view

Summary

- We have started z<4 quasar multiple environment study with the HSC-SSP survey to investigate whether quasars really trace overdense regions
- From the current sample for which g-dropout technique is applicable (only 2), we have already found a promising giant proto-cluster traced by a close quasar pair. Its follow-up observation will be in near future.
- Based on photo-z, we find z<2 close quasar pairs are likely to reside in overdense regions, which suggests they are better proto-cluster tracers than single quasars
- We aim to derive a unique constraint on how quasars relate to their host haloes and surrounding galaxy formation