

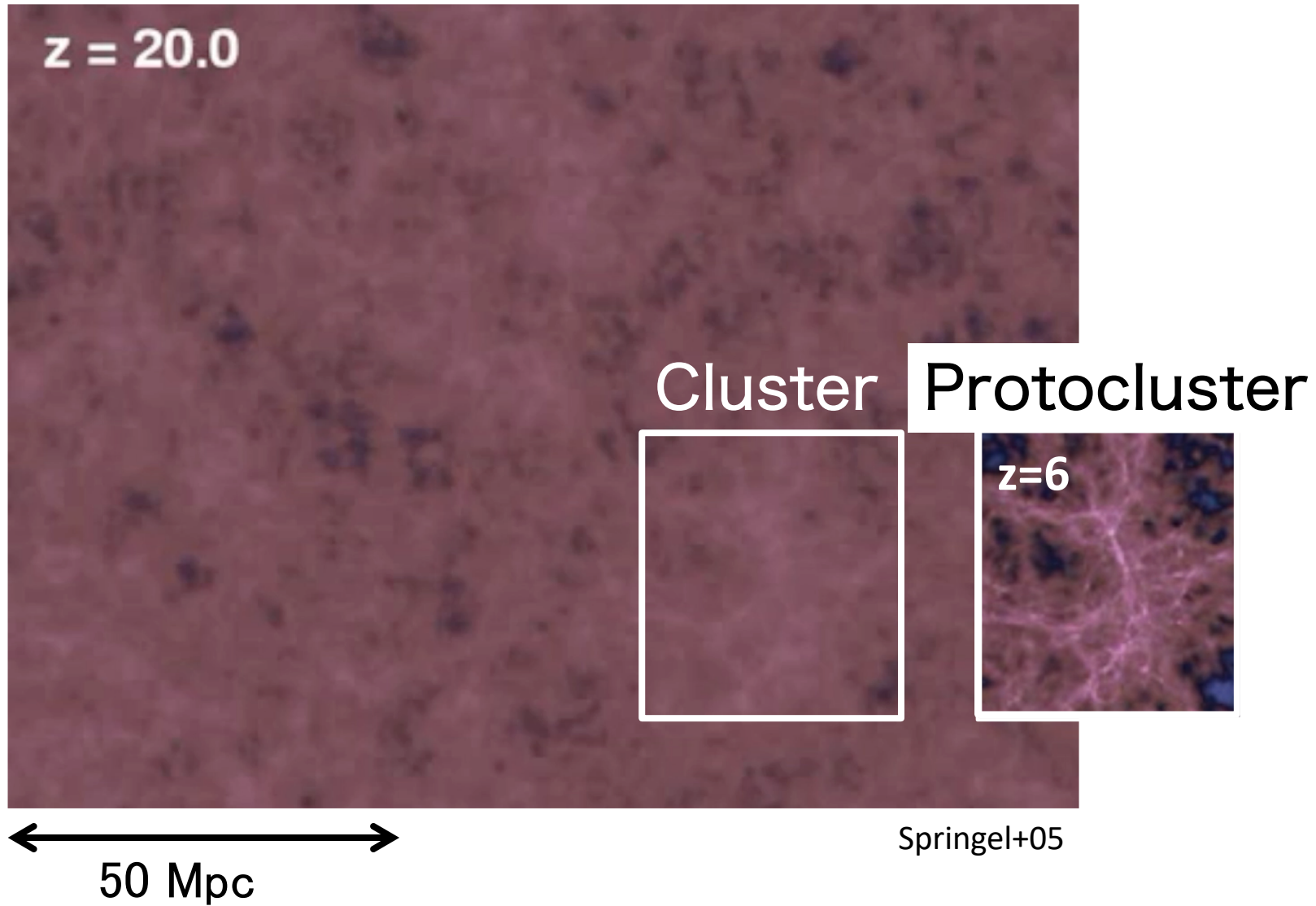
Spectroscopic Identifications of Early Large Scale Structures with Protoclusters Over 200 Mpc

Harikane+19 submitted to ApJ
arXiv:1902.09555

Yuichi Harikane (NAOJ)

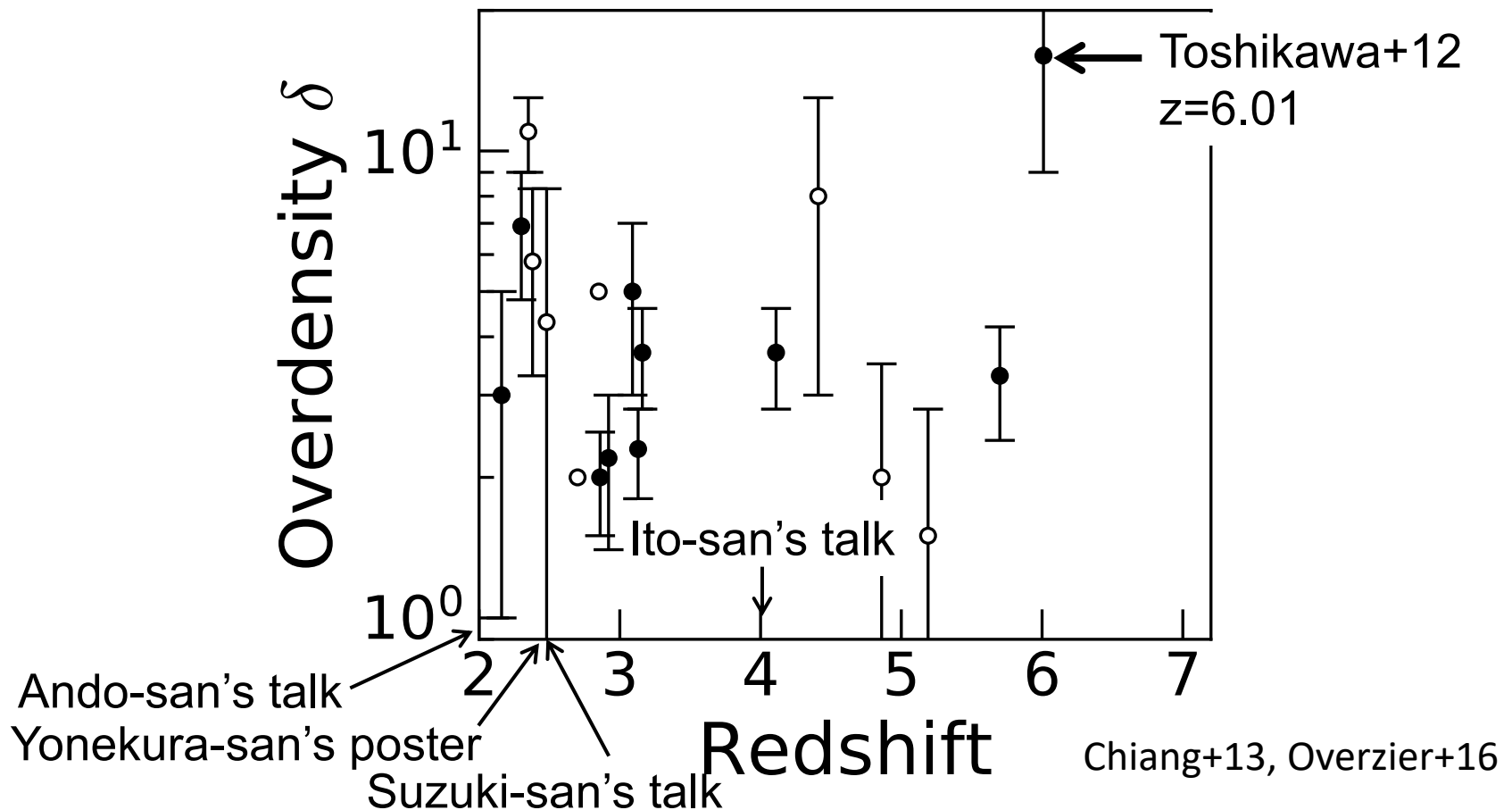
Masami Ouchi, Yoshiaki Ono, Seiji Fujimoto, Darko Donevski, Takatoshi Shibuya,
Andreas L. Faisst, Tomotsugu Goto, Bunyo Hatsukade, Nobunari Kashikawa,
Kotaro Kohno, Takuya Hashimoto, Ryo Higuchi, Akio K. Inoue, Yen-Ting Lin, Crystal
L. Martin, Roderik Overzier, Ian Smail, Jun Toshikawa, Hideki Umehata, Yiping Ao,
Scott Chapman, David L. Clements, Myungshin Im, Yipeng Jing, Toshihiro
Kawaguchi, Chien-Hsiu Lee, Minju M. Lee, Lihwai Lin, Yoshiki Matsuoka, Murilo
Marinello, Tohru Nagao, Masato Onodera, Sune Toft, Wei-Hao Wang

Protocluster



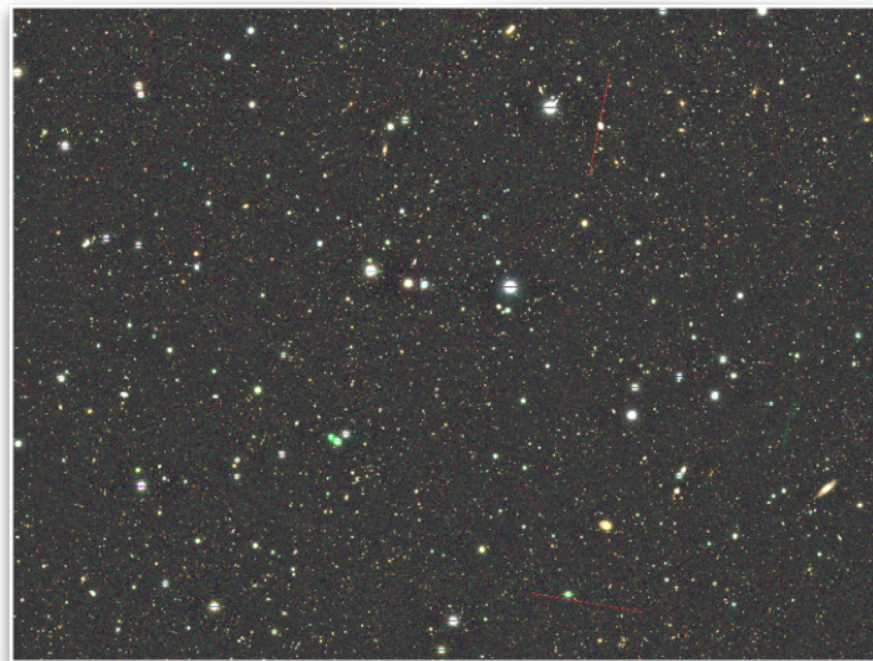
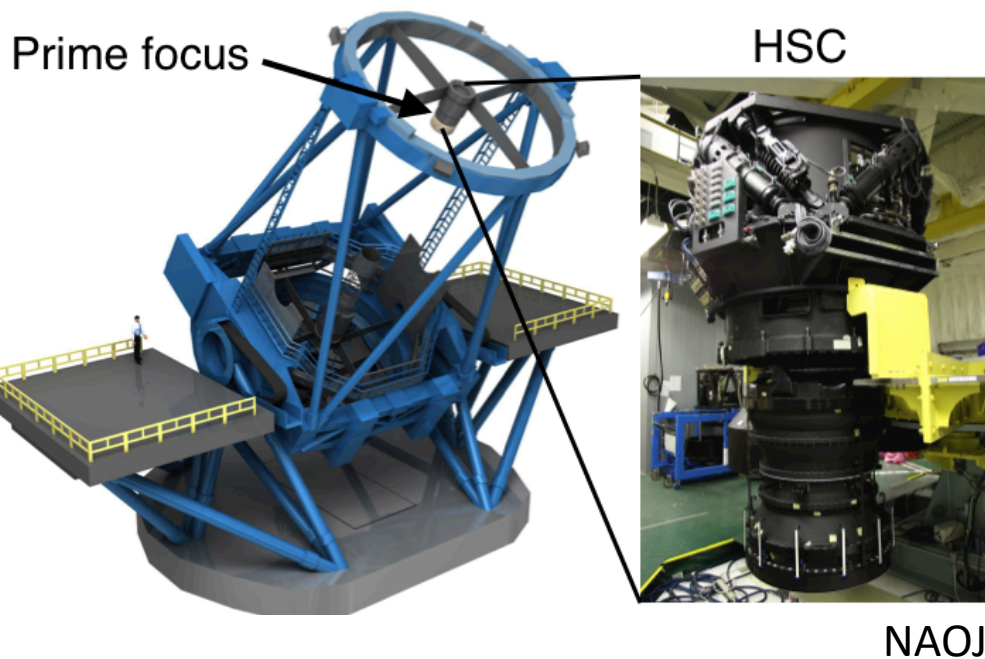
High Redshift Protoclusters

- Only a few protoclusters are identified at $z > 5$
- Large area deep survey is needed



Subaru/Hyper Suprime-Cam Survey

- Hyper Suprime-Cam (HSC) survey (PI: Miyazaki)
 - From 2014, 1400 deg² deep optical imaging ($r_{\text{lim}} \sim 26$ mag)



Subaru/Hyper Suprime-Cam Survey

Lyman break galaxies (LBGs; dropouts)



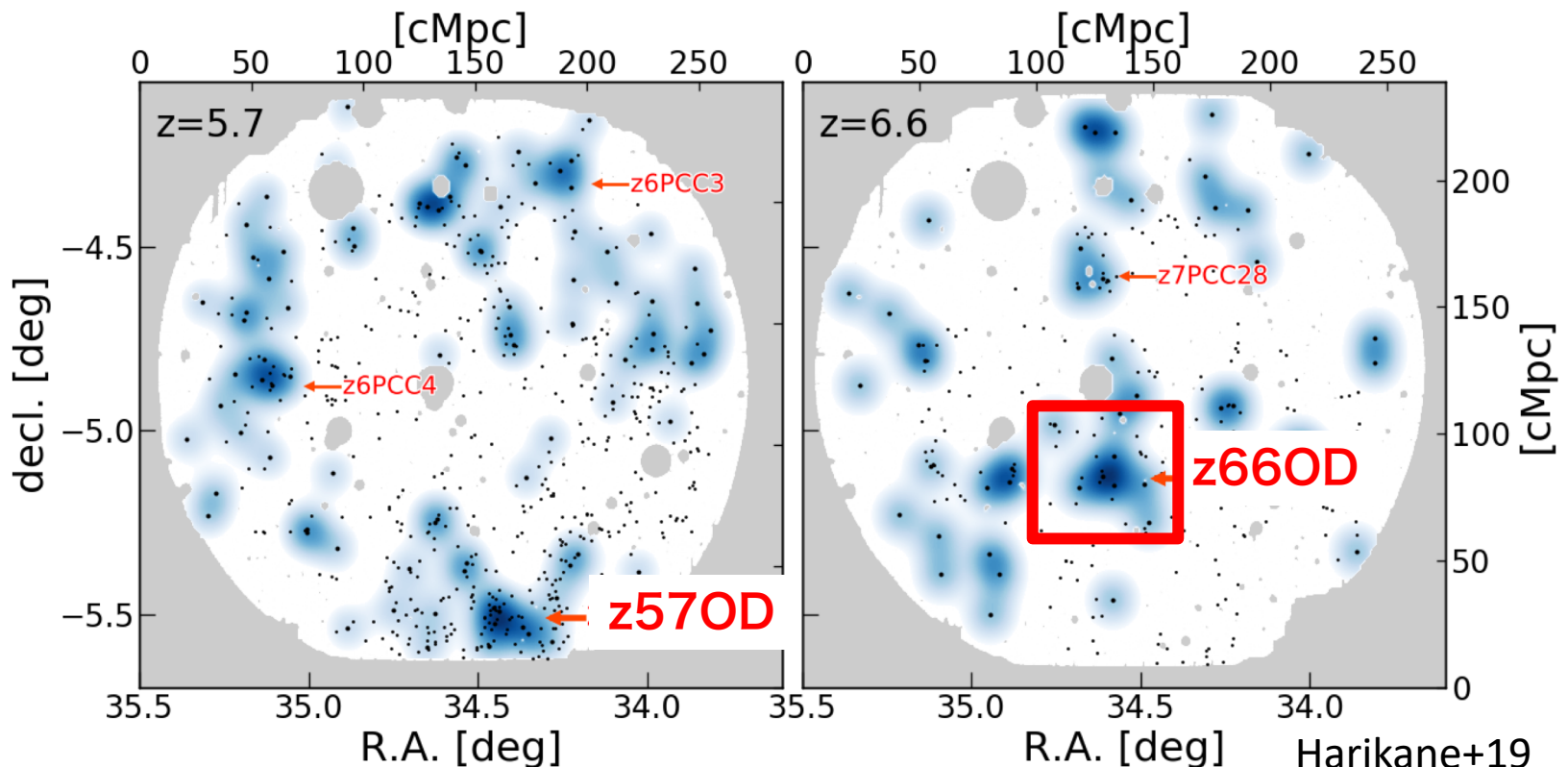
(Protocluster search in GOLDRUSH: Toshikawa+18)

Lyman alpha emitters (LAEs)



Lyman alpha Emitters (LAEs)

- 810 LAEs at $z \sim 5.7, 6.6$ with NB816 & NB921
- Overdensity δ in 10cMpc
$$\delta = \frac{n - \bar{n}}{\bar{n}}$$

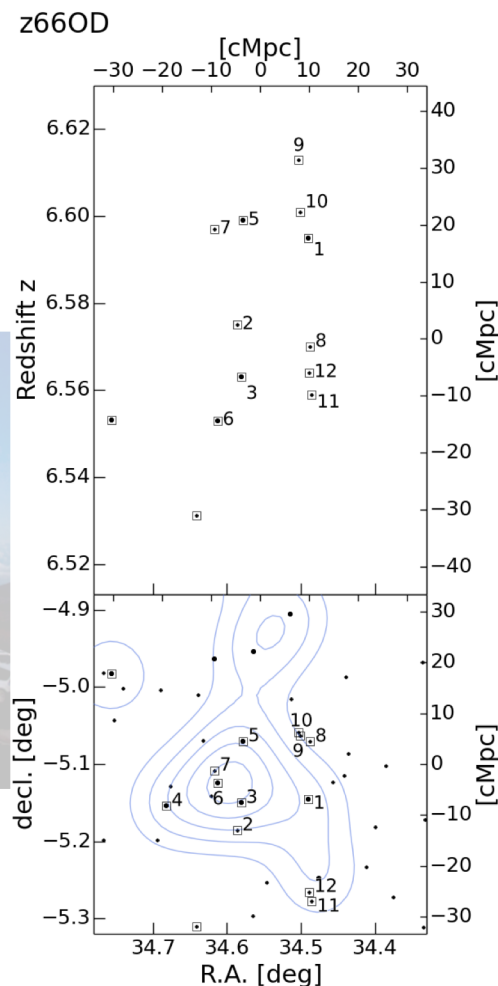
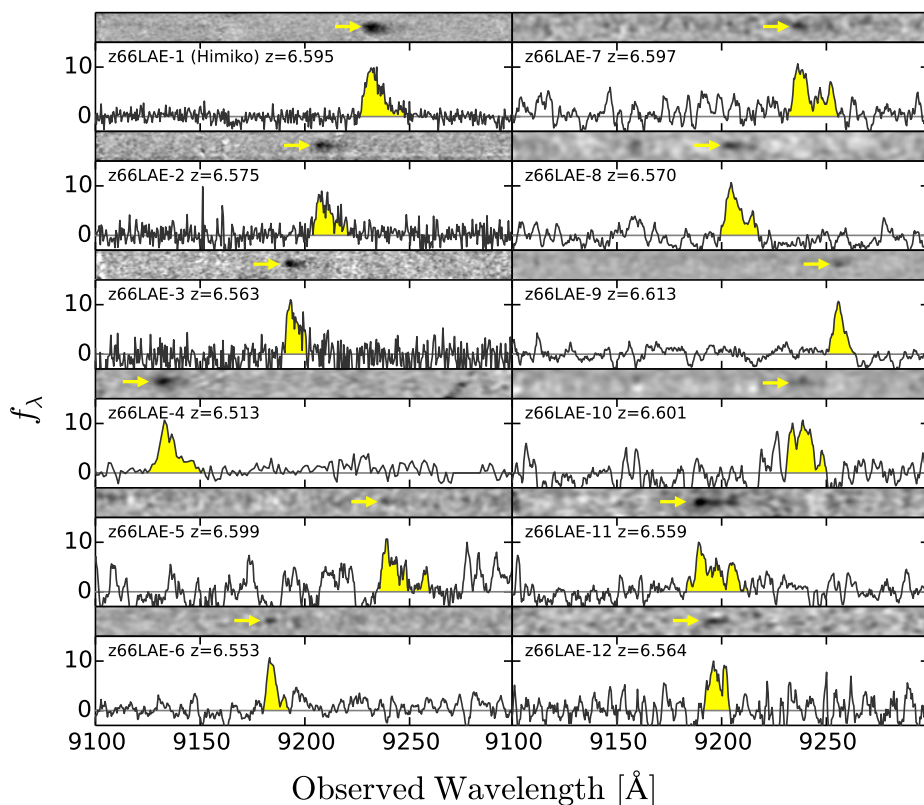


Harikane+19

See also Higuchi+19

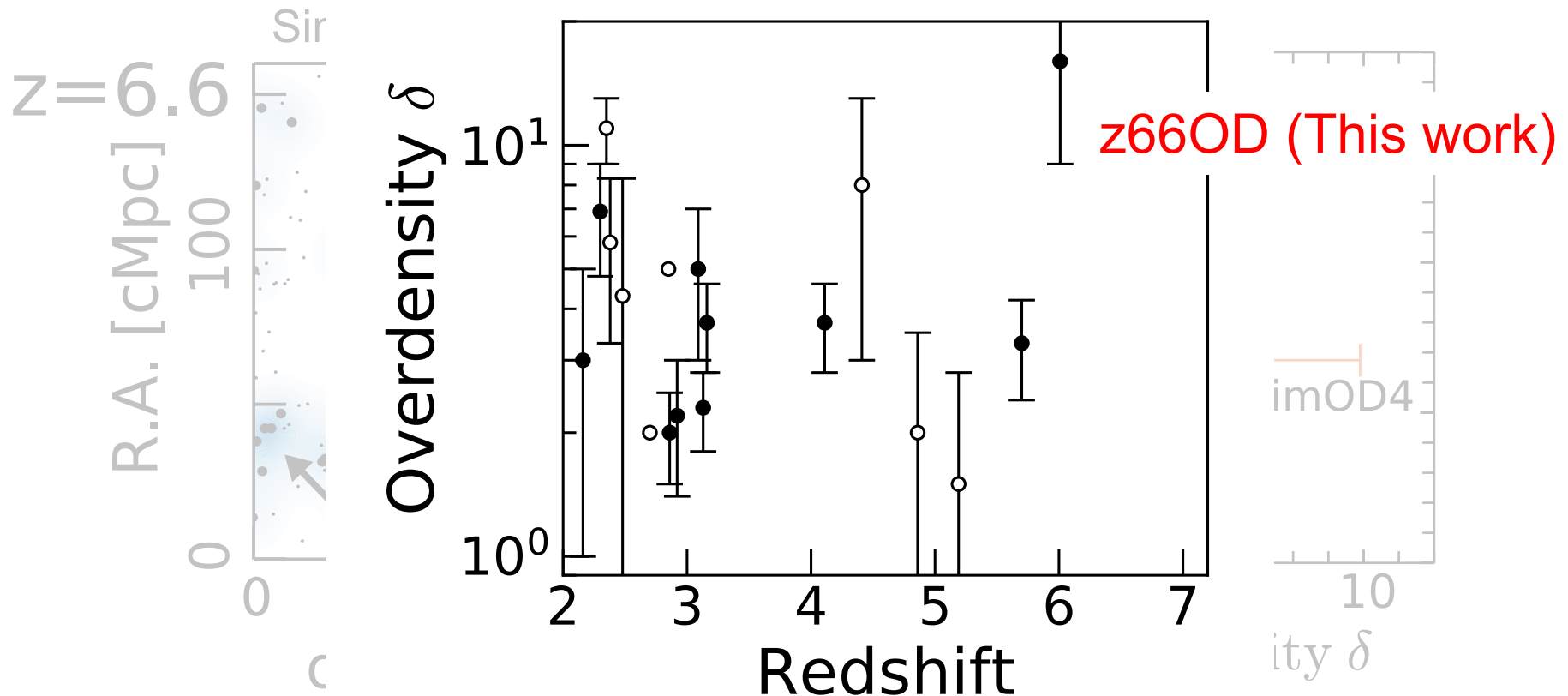
Spectroscopy for z66OD

- Spectroscopic confirmation of z66OD at $\langle z \rangle = 6.585$ with $N_{\text{spec}} = 12$



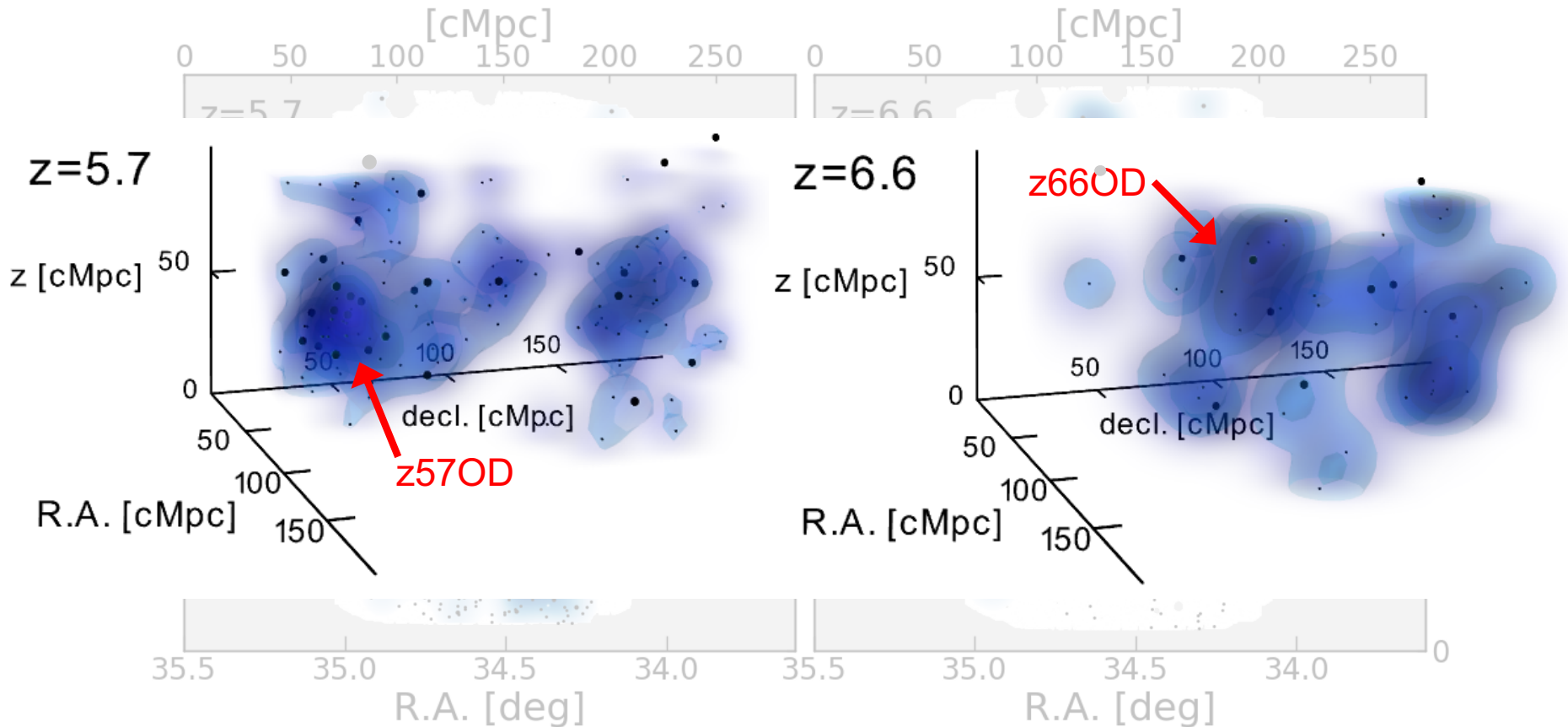
Comparison with Simulation

- simOD4: similar overdensity to z66OD
 - Halo mass $M_h \sim 10^{12} M_\odot \rightarrow > 10^{14} M_\odot$ at $z=0$



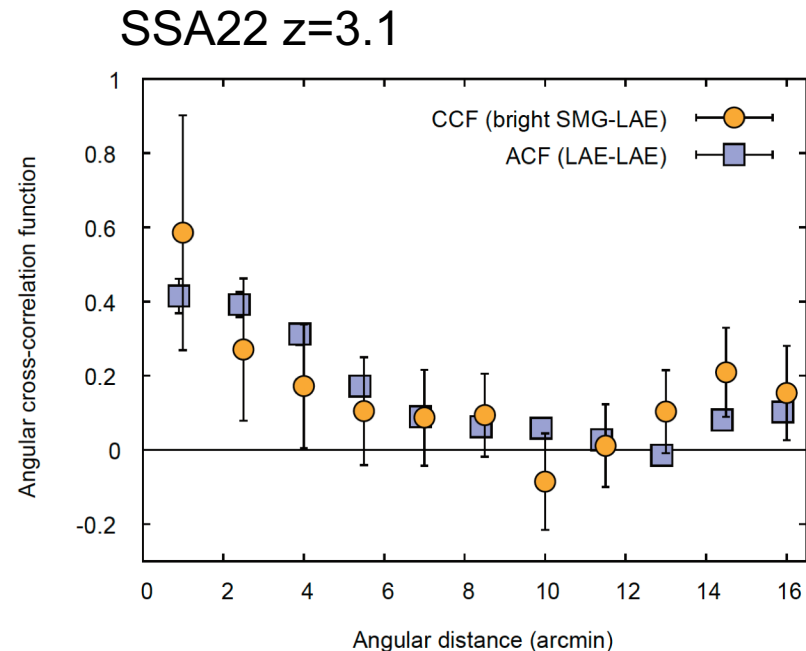
3D Map at $z=5.7, 6.6$

- 174 spec- z LAEs ($>80\%$ at $L_{\text{Ly}\alpha} > 10^{43}$ erg/s)



LAE-SMG Correlation

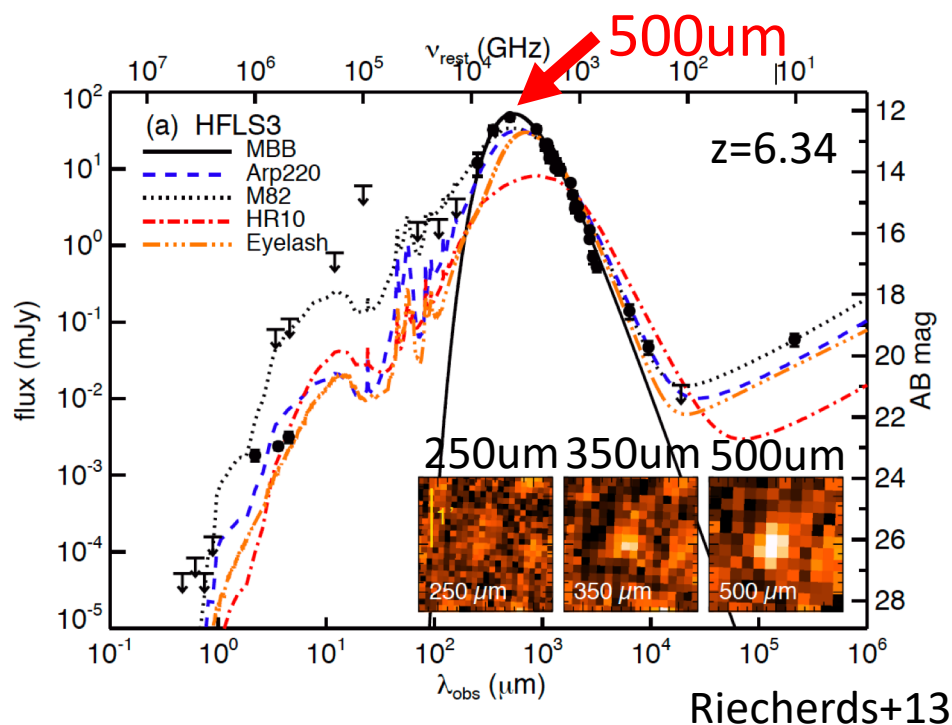
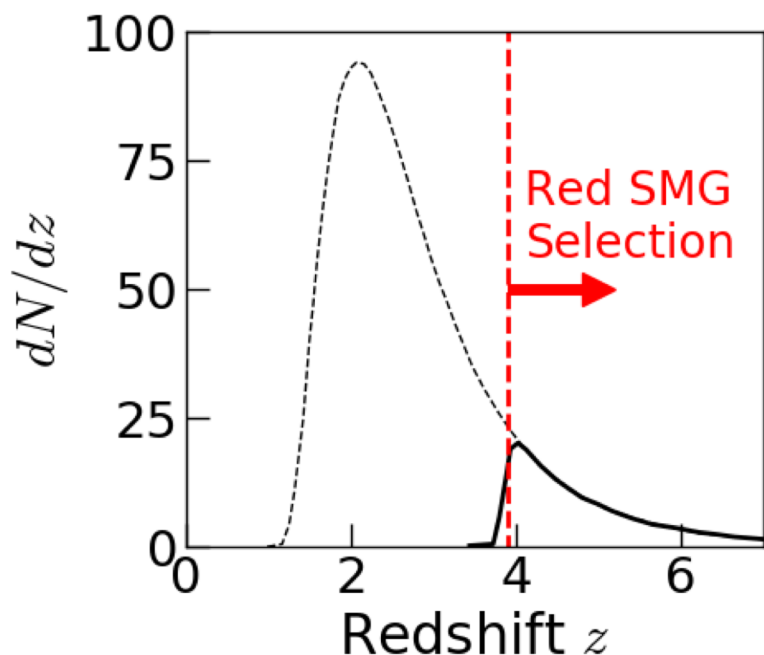
- LAE: dust-poor star-forming galaxies
- Submillimeter galaxies (SMGs): dusty star-forming
 - Cross-correlation reported at $z=3.1$ in SSA22 protocluster



Tamura+09 Nature

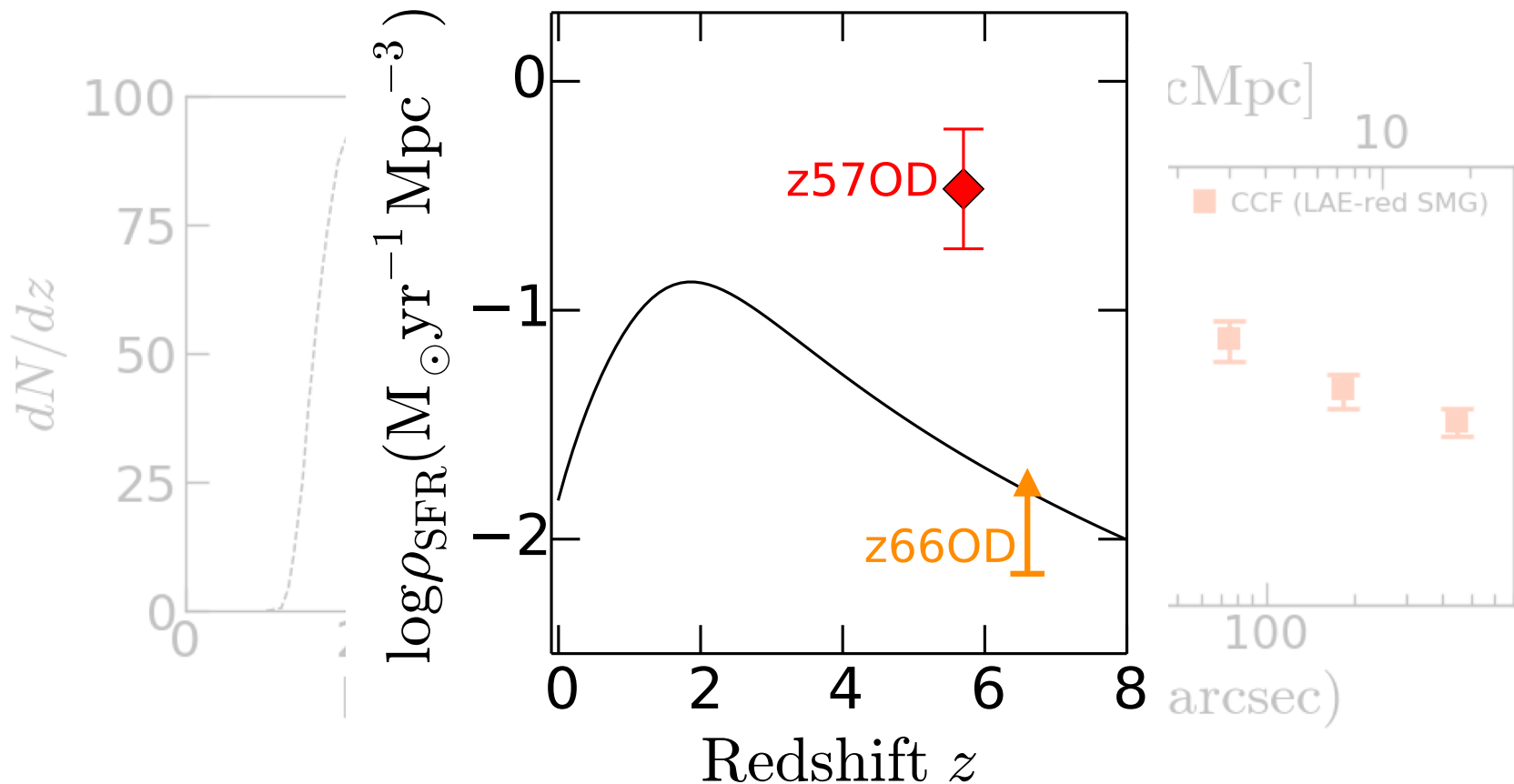
Red SMG Selection

- SCUBA-2 Cosmology Legacy Survey (Geach+17)
- Select "Red SMG" ($z > 4$) using Herschel color
 - $S_{250} < S_{350} < S_{500}$ (Donevski+18) $\rightarrow$ 42 red SMGs



LAE-SMG Correlation at $z=5.7$

- 99.97% cross correlation
 - z57OD: overdensity with both LAE and SMG



Summary

- Spectroscopic confirmation of the most distant protocluster ($z=6.585$, $N_{\text{spec}}=12$)
- 99.97% correlation between SMGs & LAEs ($z=5.7$)

