

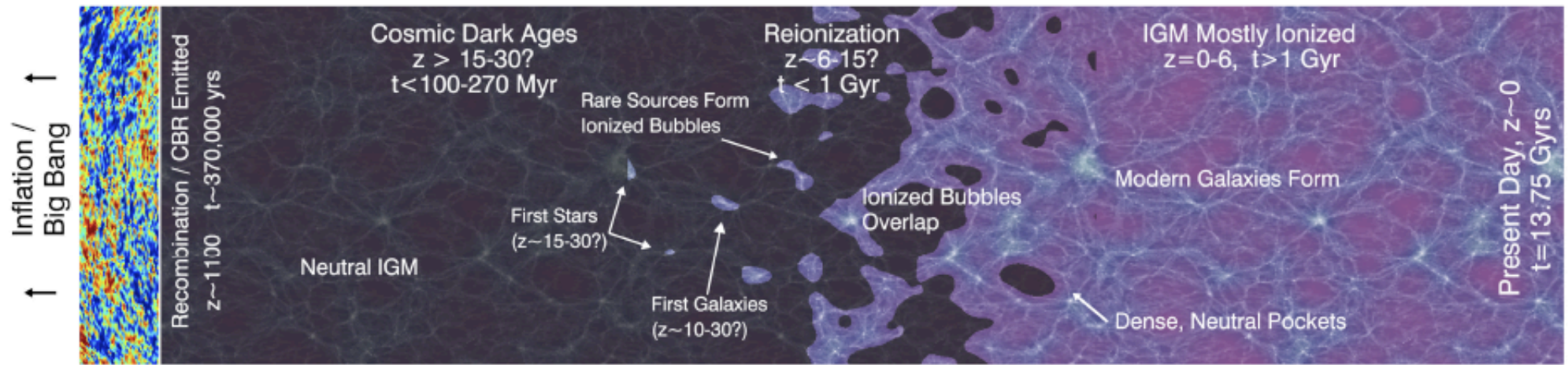
Observational Cosmology Group



Masami Ouchi
Associate Professor
ICRR, Univ. Tokyo

Credit: NASA, ESA and the HST
Frontier Fields team (STScI)

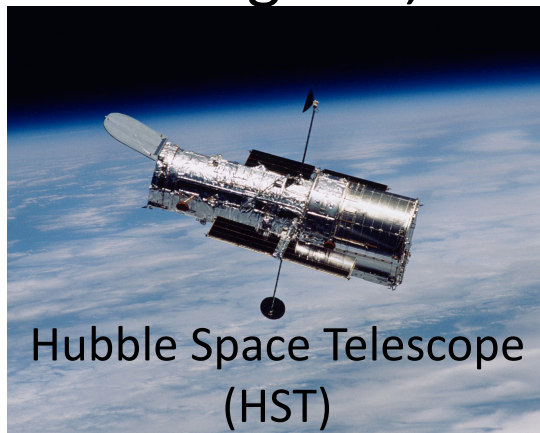
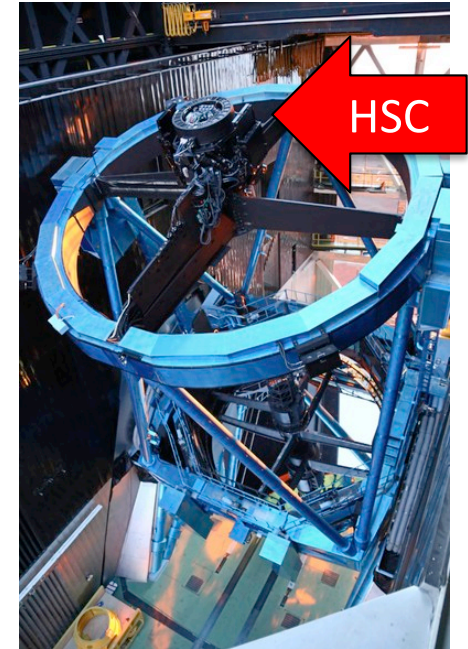
Scientific Goal



- Understanding the evolution of the universe including
 - Structure/galaxy formation, and
 - Cosmic reionizationby observations

Project Status (FY2012-2017)

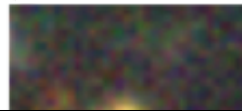
- Two projects
 - 1) Subaru Hyper Suprime-Cam (**HSC**) survey
 - HSC narrowband (NB) developments
 - HSC survey obs. started from 2014
 - 2) Complementary multi-wavelength prog. including HST, Keck, and ALMA obs (+SDSS).



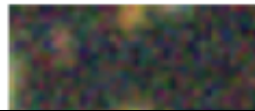
HSC Survey for High- z Galaxies

Examples

$z=4$



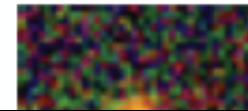
$z=5$



$z=6$

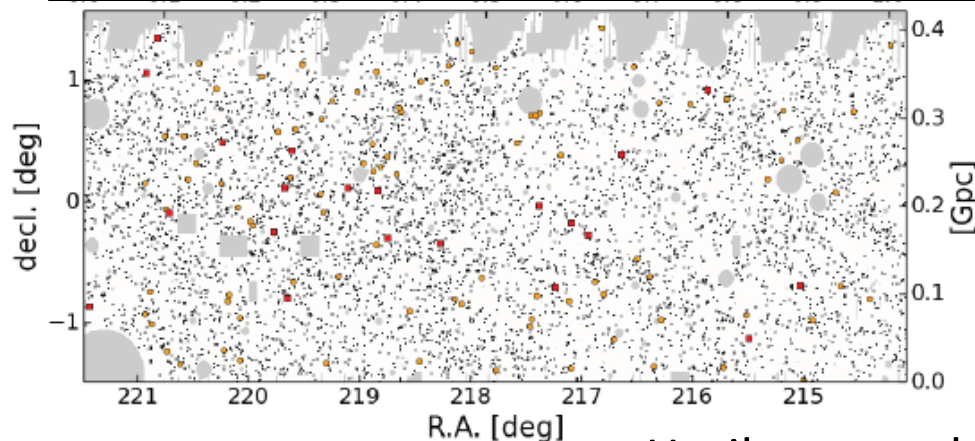


$z=7$

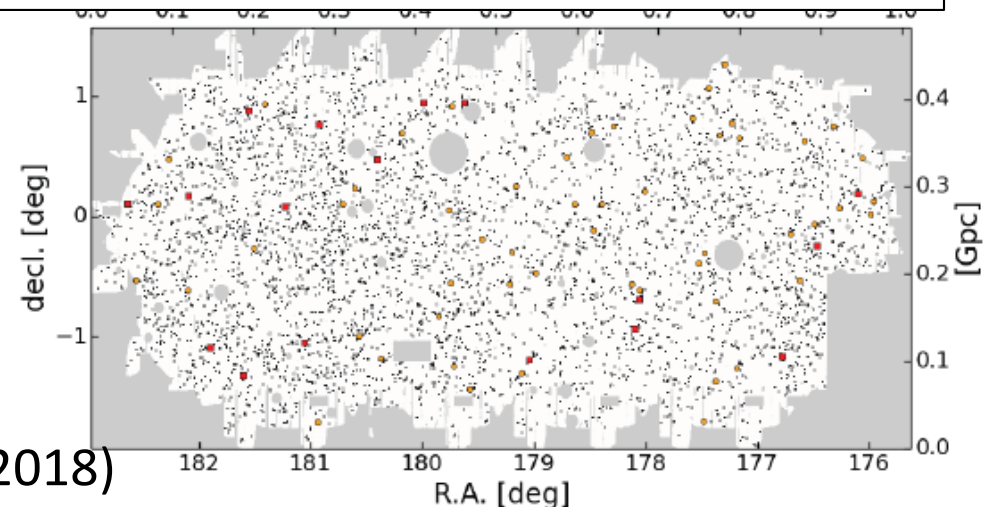


Ono et al. (2018)

~ 100 times larger than prev. samples
First cosmological probe of $z \gtrsim 4$ galaxies

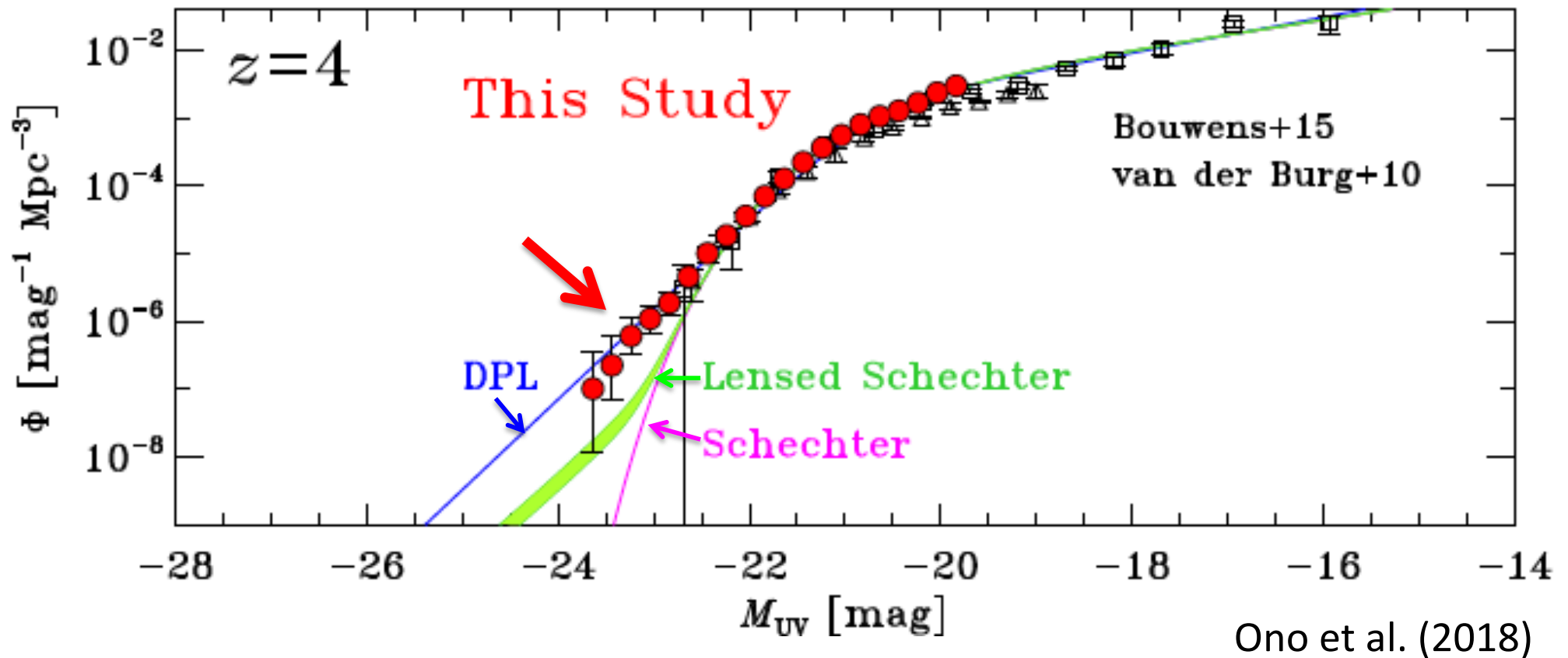


Harikane et al. (2018)



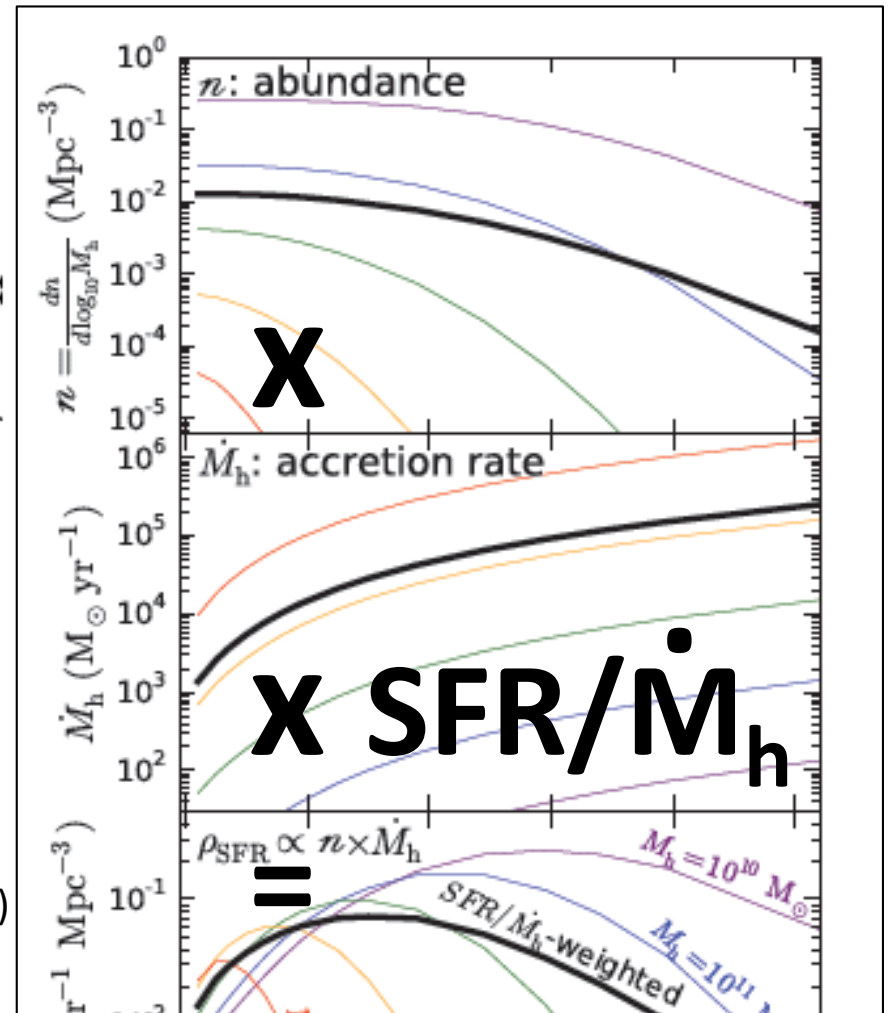
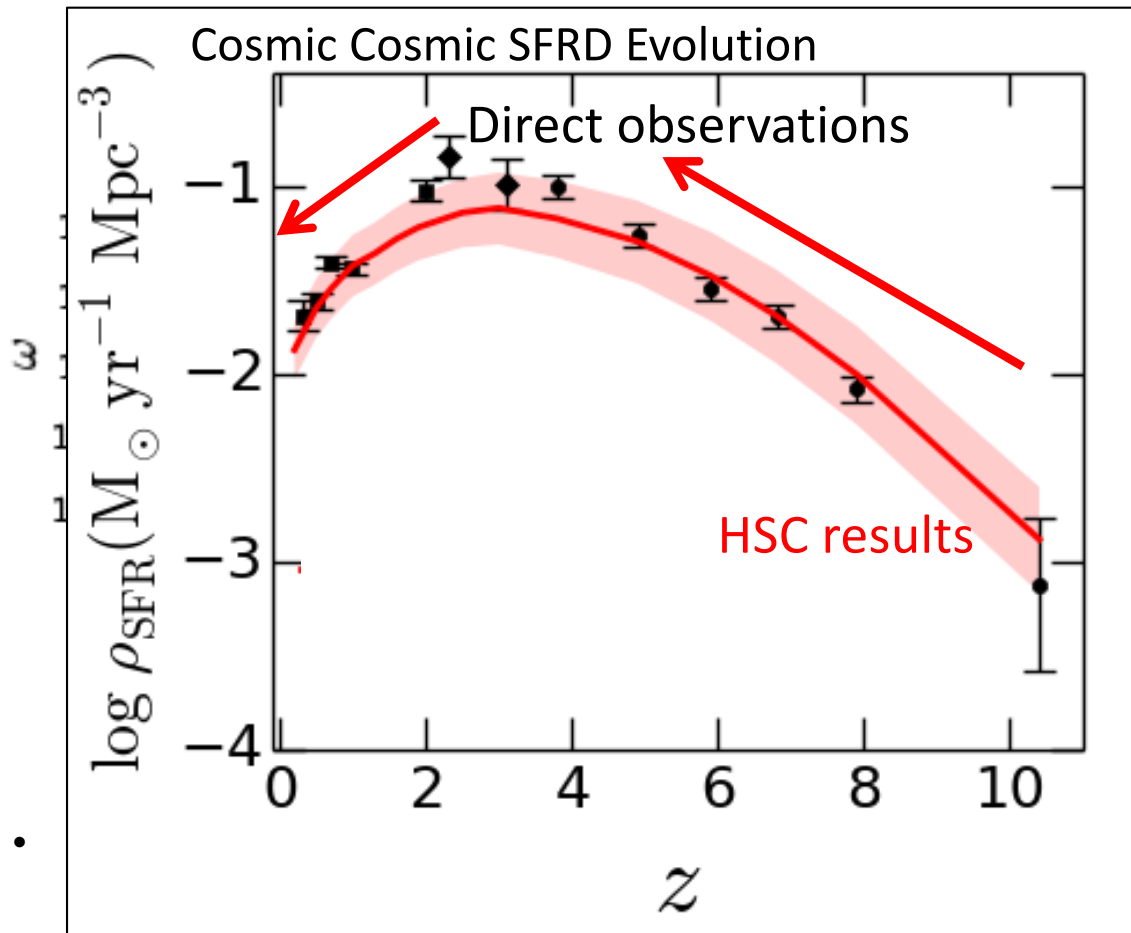
- **579,555 galaxies** (by dropout technique)
over $100 \text{ deg}^2 \rightarrow 1.4 \text{ Gpc}^3$ (cosmology scale)

UV Luminosity Function (LF)



- Precision UV luminosity function (LF) → Bridging the LFs of galaxies and SDSS QSOs.
 - Rycharde Bouwens (Leiden U.) e-mailed us, saying “Your figures showing the transition between the galaxy and quasar LF regimes will likely appear in many textbooks and reviews for many years to come.”
- Subtraction of the AGN LFs
 - LF excess: Not Schechter+Lensing, but double powerlaw. (Bowler+15,+17)
 - Evidence of weak feedback?

Clustering and Fundamental Relation

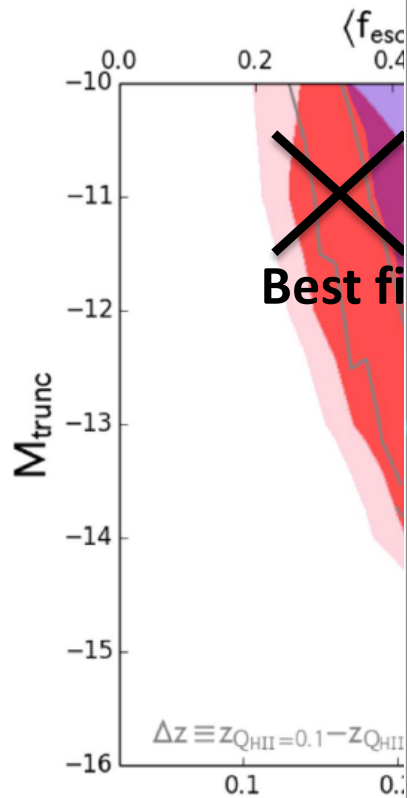


SFRD evolution = Structure Form. x Cosmic Ex.

→ SFR regulated by mass accretion (i.e. gas accretion from LSS)
 → explaining the evolution of cosmic SF history



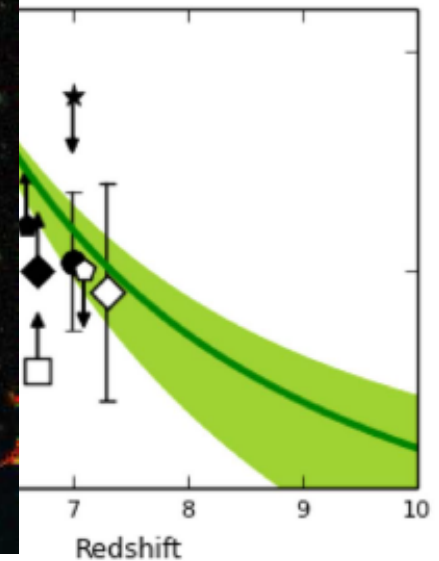
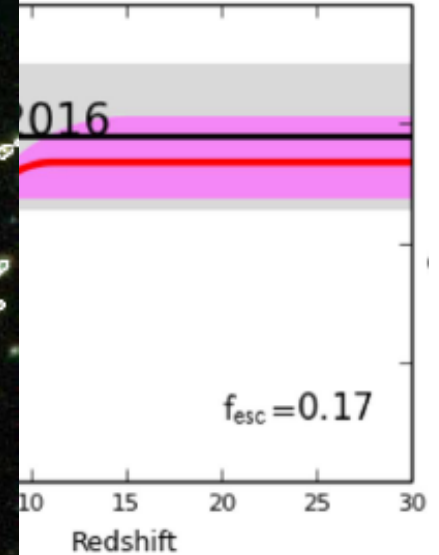
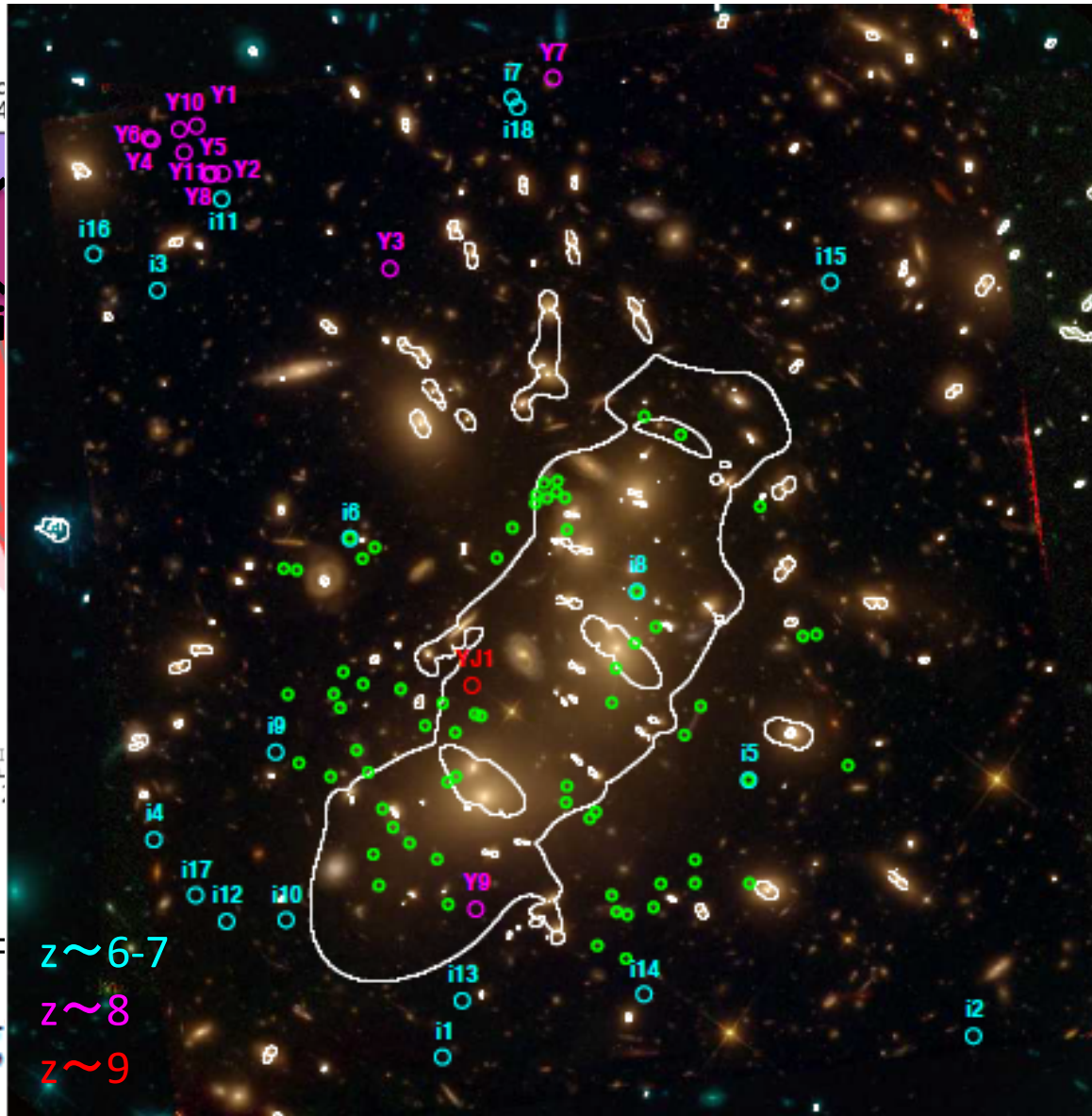
Cosmic Reionization



Best-fit results

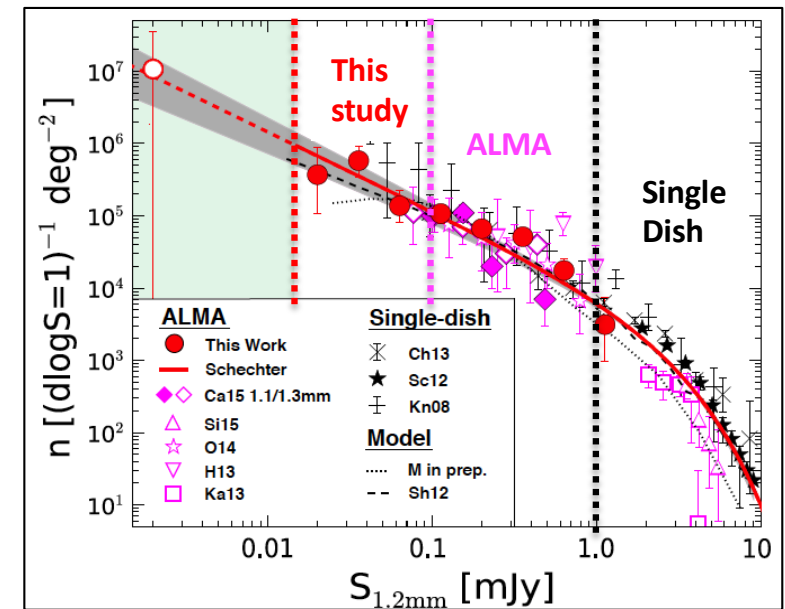
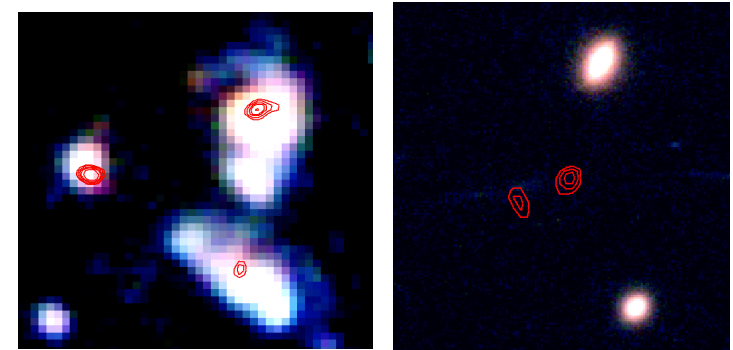
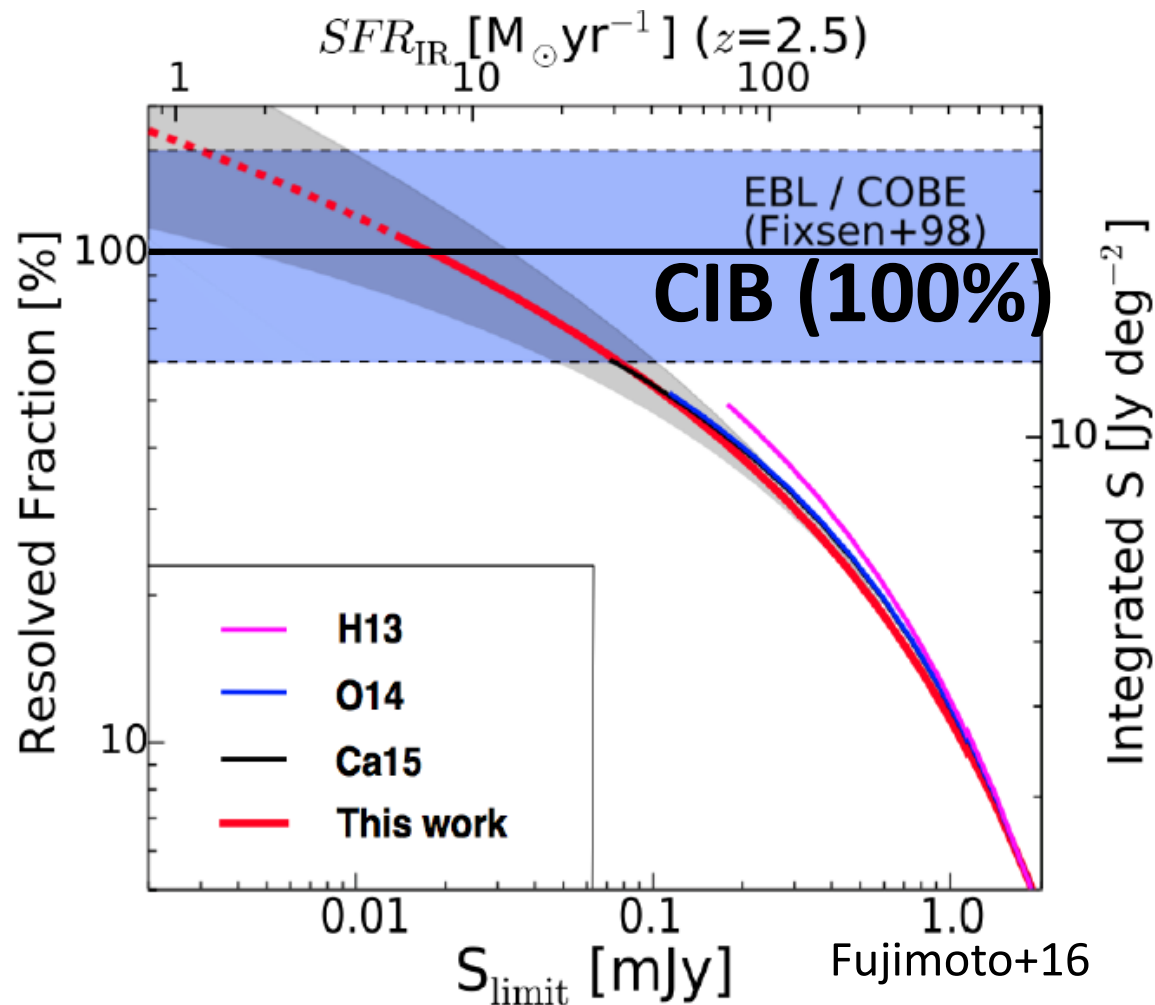
$$\langle \log f_{\text{esc}} \xi_{\text{ion}} \rangle =$$

$$\log \xi_{\text{ion}} / [\text{erg s}^{-1} \text{Mpc}^{-3}]$$



- All measurements are explained, if star-forming **galaxies are major reionization sources**
 $\rightarrow \Delta z = 3.9 (-2.0/+1.6)$ [for $Q_{\text{HII}} = 10\% - 99\%$]: Consistent w kSZ res. of Planck2016 ($\Delta z < 2.8$)
 --- M. Ishigaki : U. Tokyo School of Science award in 2015 ---

Origin of Cosmic Infrared Background (CIB)



- Intensive survey for mm sources: $104 \pm 30\%$ of CIB is resolved by ALMA obs (Fujimoto+16).
→ CIB is originated from dust in galaxies (no diffuse emission in the DM halos and IGM)
- ~40% has no clear optical-NIR counterparts (down to ~27 mag) → Physical origin?

Scientific Results

(2012 Apr – 2018 Mar)

- All papers (incl. collaboration papers)
 - A total of 120 refereed papers
 - A total of 5251 citations
- ICRR-led papers
 - 33 refereed papers, 1784 citations

Example,

- Ouchi et al. (2018), “Systematic Identification of LAEs for Visible Exploration and Reionization Research Using Subaru HSC (SILVERRUSH). I. Program strategy and clustering properties of ~2000 Ly α emitters at $z = 6-7$ over the 0.3-0.5 Gpc² survey area” (59 citations)

Size of Group, and Manpower

- Faculty
 - Masami Ouchi, Associate Professor, 2010 to the present
 - Yoshiaki Ono, Assistant Professor, 2012 to the present
- Postdoctoral Fellows
 - Masao Hayashi, 2013-2014
 - Rieko Momose, 2012-2015
 - Suraphong Yuma, 2012-2015
 - Tomoki Saito, 2014-2015
 - Mariko Kubo, 2014-2016
 - Florent Duval, 2015-2016
 - Yi-Kuan Chiang, 2016-2016
 - Takatoshi Shibuya, 2013-2018
 - Jun Toshikawa, 2017 to the present
 - Ken Mawatari, 2018 to the present
 - Seiji Fujimoto, 2019 to the present

Education

- Students
 - Resuming education activities after the arrival of Ouchi
 - Students from Physics/Astronomy departments of U. Tokyo
 - First 2 students in 2012
 - Accepting a total of 16 students incl. students in school (2012-2018)
 - Master (Ph.D) degrees for 13 (3) students
- Fellowships
 - JSPS DC fellowships: 8 students
- Strong demands on our study subject from young students.

Award and Scholarship

- Students
 - Masafumi Ishigaki: The School of Science Encouragement Award (M.S.) in 2015
 - Seiji Fujimoto: The School of Science Encouragement Award (M.S.) in 2016
 - Yuichi Harikane: The School of Science Encouragement Award (Ph.D.) in 2019
 - Seiji Fujimoto: The School of Science Encouragement Award (Ph.D.) in 2019
- Post-docs
 - Takatoshi Shibuya: Astronomical Society of Japan Young Astronomer Award in 2019 (for 2014-2015 papers)
- Staff
 - Yoshiaki Ono: Astronomical Society of Japan Young Astronomer Award in 2015
 - Masami Ouchi: Beatrice M. Tinsley Research Scholar in 2013
 - Masami Ouchi: The Young Scientists' Prize (Japan's Minister of Edu.) in 2014
 - Masami Ouchi: JSPS Prize in 2019
 - Masami Ouchi: Japan Academy Medal Prize in 2019

Budget

- Grant for staff members

1) "Matter Exchange in the Cosmological Scale Probed with the Subaru/HSC and SDSS data", JSPS Grant-in-Aid for Scientific Research (A): 2015-2019

PI: M. Ouchi, ¥32,200,000

2) "Pionnering Cosmic Reionization and Magnetism Investigated by Long Wavelength Radio Observations", JSPS Grant-in-Aid for Scientific Research (A): 2017-2019

PI: N. Sugiyama (M. Ouchi as a Col) ¥33,900,000 (¥1,500,000)

3) "Cosmic Reionization Revealed by the Subaru/HSC NB Survey: CHORUS Project", JSPS Grant-in-Aid for Scientific Research (A): 2017-2020

PI: A. Inoue (M. Ouchi as a Col) ¥24,100,000 (¥2,728,000)

4) "Cosmic Reionization Investigated by the Next Generation Observations and Simulations", JSPS Grant-in-Aid for Scientific Research (A): 2011-2014

PI: M. Ouchi, ¥39,960,000

5) "Determining the Physical Nature of a Unique Giant Lyman Alpha Emitter at $z=6.595$ ", Hubble Space Telescope Grant (AURA for NASA): 2010-2013

PI: M. Ouchi, \$61,219

6) "Galaxy overdensities and their contribution to the cosmic reionization around distant QSOs based on the wide field millimeter and optical observations", Grant-in-Aid for Young Scientists: 2019-2022,

PI: Y. Ono, ¥3,300,000

7) "Cosmic Reionization Revealed by the Subaru/HSC NB Survey: CHORUS Project", JSPS Grant-in-Aid for Scientific Research (A): 2017-2020

PI: A. Inoue (Y. Ono as a Col) ¥34,100,000 (¥1,364,000)

8) "Observational study on galaxy formation history based on the Subaru HSC survey", Grant-in-Aid for Young Scientists (B): 2015-2019

PI: Y. Ono, ¥2,900,000

9) "Properties of Galaxies in the Reionization Epoch Revealed by the 2012 Hubble Ultra Deep Field Campaign", Grant-in-Aid for Research Activity Start-up: 2012-2014

PI: Y. Ono, ¥2,000,000

*** ICRR joint usage/research center grant --- PI: M. Ouchi ¥500,000 (2012-2018)

- Grant for students

– JSPS DC fellowship grants for 8 students

Relation with other universities/community

1) HSC program

- HSC survey consortium ~>100 scientists (Opt-NIR obs. society in [Japan](#), [Princeton](#), [Taiwanese institutes](#))
- Narrow-band development w scientists from [Tokyo](#), [NAOJ](#), [Ehime](#), [Osaka-sangyo](#), [Tsukuba](#) etc.

2) HST, ALMA program

- Hubble Ultra Deep Field 2012 (UDF12): [Caltech](#), [Arizona](#), [Edinburgh](#) etc.
- HST/RELICS survey: [STScI](#), [UC Davis/Riverside](#), [Michigan](#) etc.
- ALMA Lensing Cluster Survey (ALCS): [NAOJ](#), [Arizona](#), [Lyon](#), [LAM](#), [UCL](#), [Catolica](#) etc.

Accepting (sending) post-docs from (to) Opt-NIR obs. and ALMA communities.

• On-going and forthcoming program

- Subaru Prime Focus Spectrograph (PFS) survey: Tokyo, NAOJ, Osaka, Princeton, LAM etc.
- Murchison Widefield Array (MWA): Nagoya, Kumamoto, ANU, Curtin, MIT etc.
- Subaru-NASA Wide Field Infrared Survey Telescope (WFIRST): NAOJ, Caltech/IPAC, JPL+

Future prospects

1) HSC

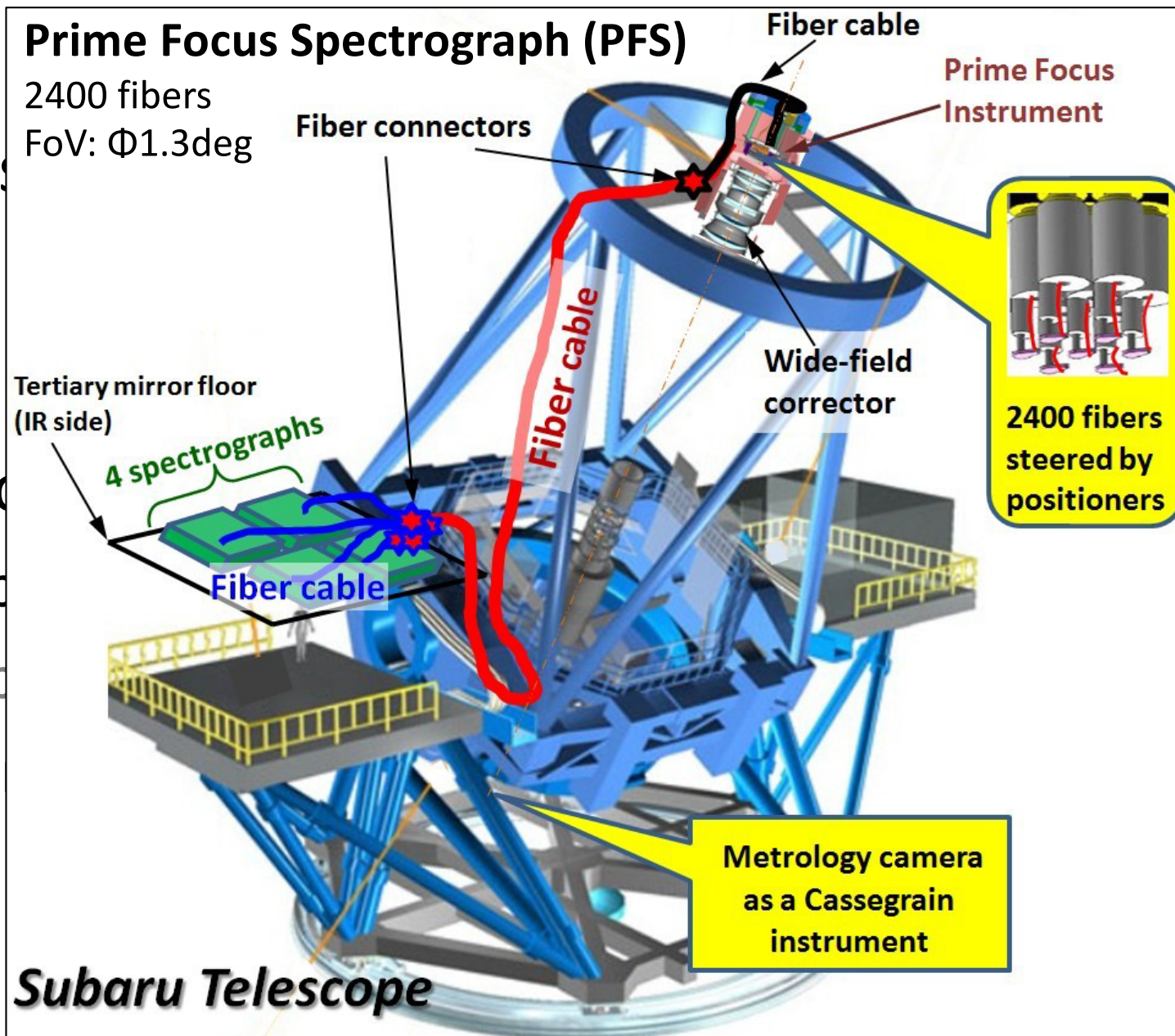
2) HST,

• On-going

– Sub

– Sub

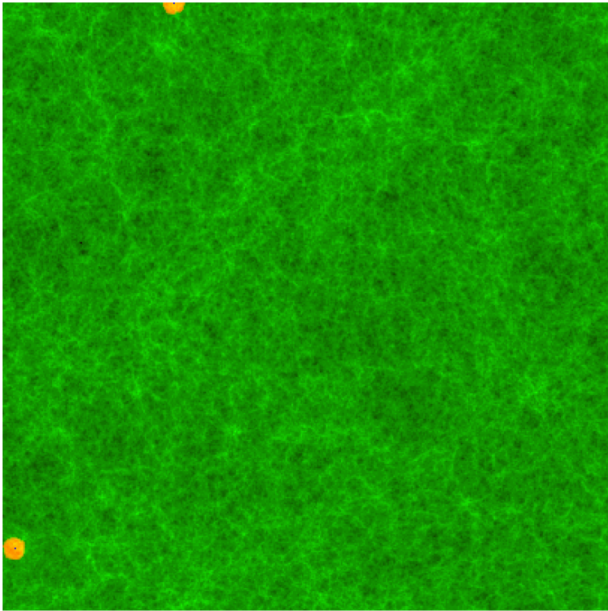
– Thi



020s

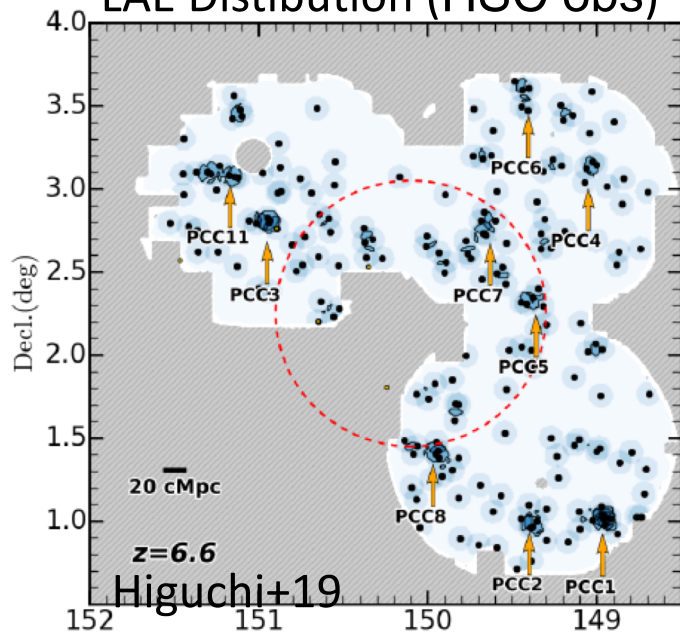
PFS Program for Reionization Physics

RT simulations

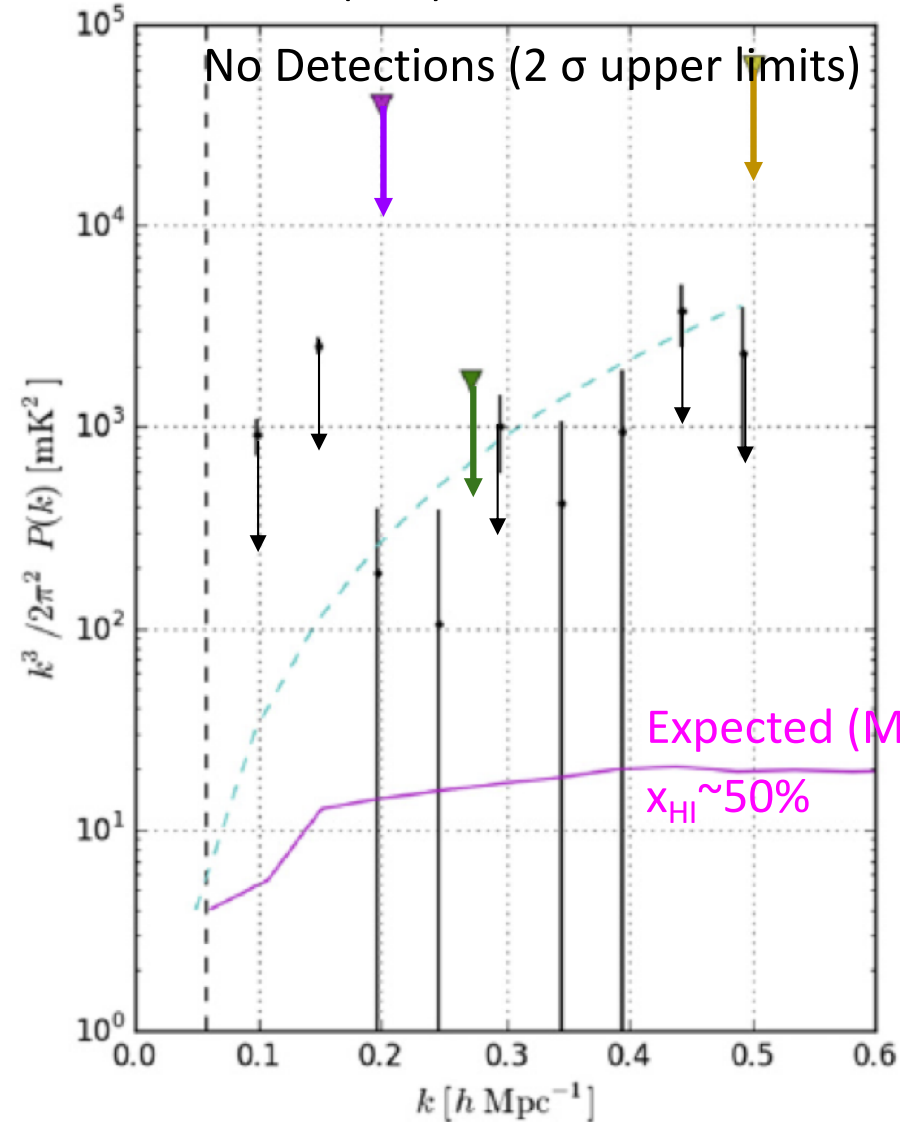


Galaxies (blue dots), ionized bubbles (orange) (Iliev+06)

LAE Distribution (HSC obs)

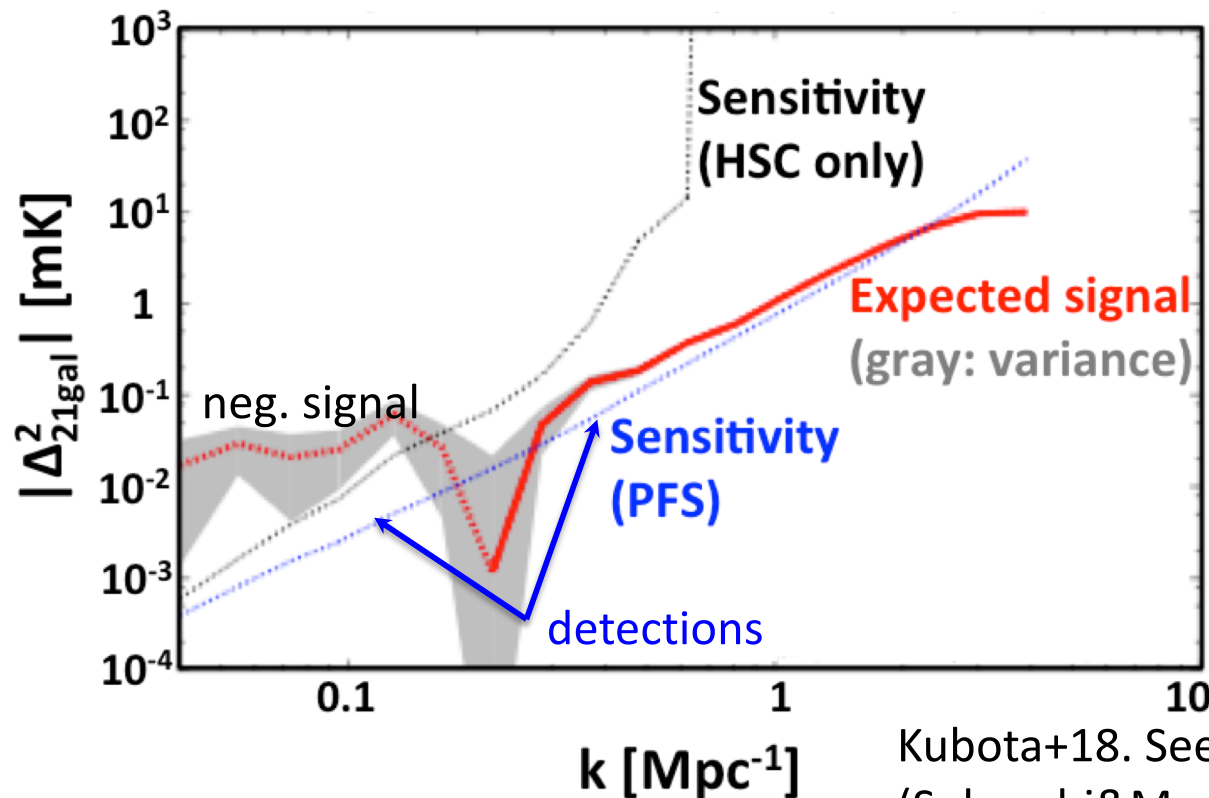


Epoch of Reionization (EoR) HI 21cm Auto Power Spectrum



- No detections, due to foreground systematics
- Cross Correlation with real signal of HSC+PFS galaxies (LAEs)

First Detection of EoR HI 21cm Signal by LAE-21cm Cross Correlation



21cm: MWA,SKA

Kubota+18. See similar predictions (Sobacchi&Mesinger+16, Hutter+18)

- Goal-1: Detection of the cross-correlation signals -> Evidence of early cosmic HI struc.
 - Positive cross-correlation at $k \sim 0.4 \text{ Mpc}^{-1}$ at ~ 5 sigma
 - Negative cross-correlation at $k \sim 0.1 \text{ Mpc}^{-1}$ at ~ 3 sigma
- Goal-2: Determination of the CPST scale at $z=6.6$ with $\Delta k \sim 0.1$ accuracy
 - First definitive evidence of cosmic ionized bubbles

No competing studies exist in the existing/planned projects.

Summary

- **Science goal**
 - Evolution of the universe (Structure/galaxy formation, Cosmic reionization)
- **Project status**
 - HSC Survey (2014-) and multi-wavelength prog (+SDSS)
- **Scientific results**
 - 120 refereed papers, 33 out of which are led by ICRR
- **Size of Group, manpower, and education**
 - 2 faculty. 9 post-doc. 16 students (+in school). 13/3 degrees. 8 JSPS fellowships
- **Award and Scholarship**
 - 2 School of Science Awards, 1 ASJ Young Astronomer Award, 1 MEXT Prize
- **Budget**
 - 9 grants, 2 of which are ~30-40 million yen programs led by Ouchi
- **Future prospect**
 - HST to PFS (for WFIRST/TMT). HI-galaxy corr. for reionization phys