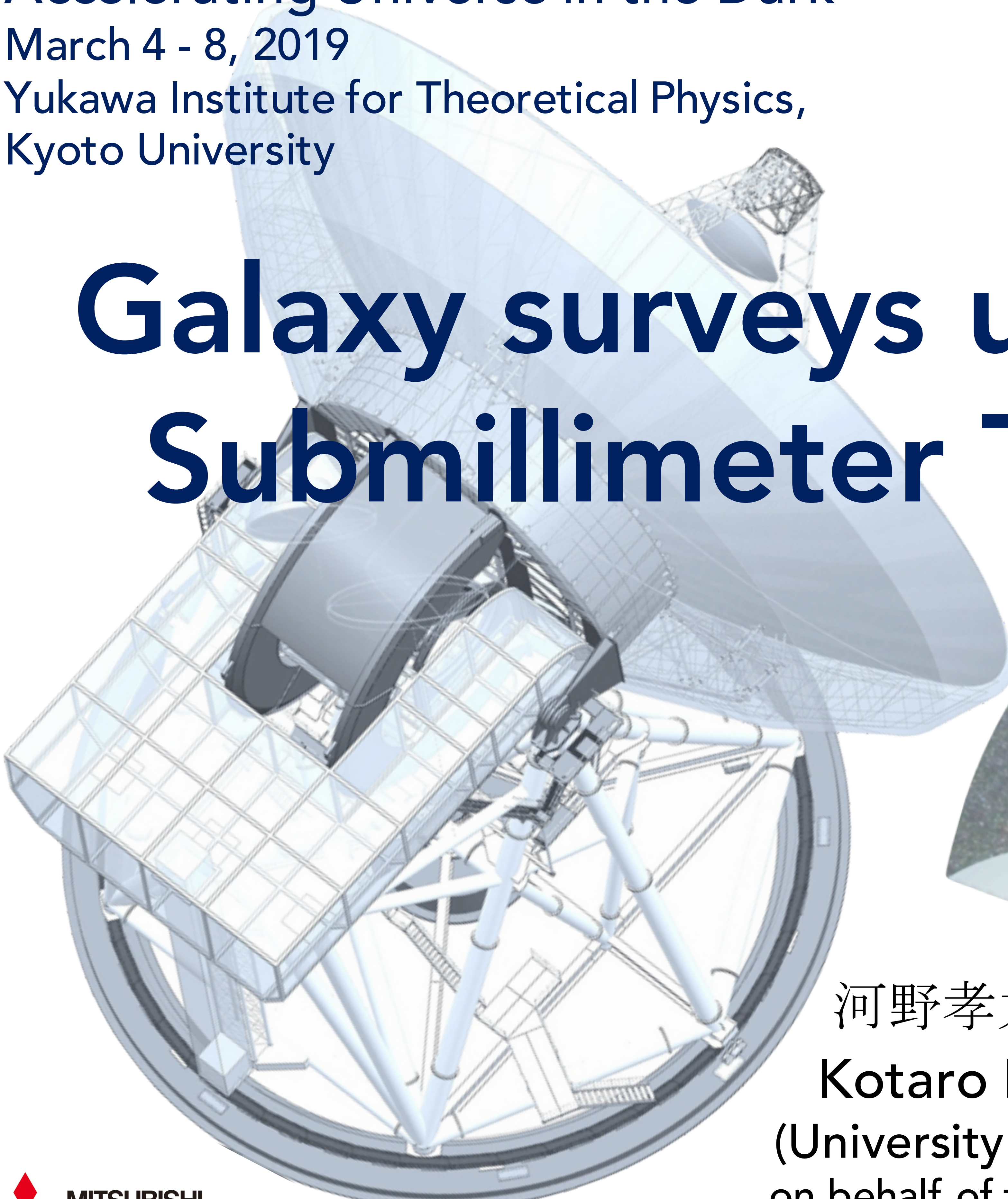
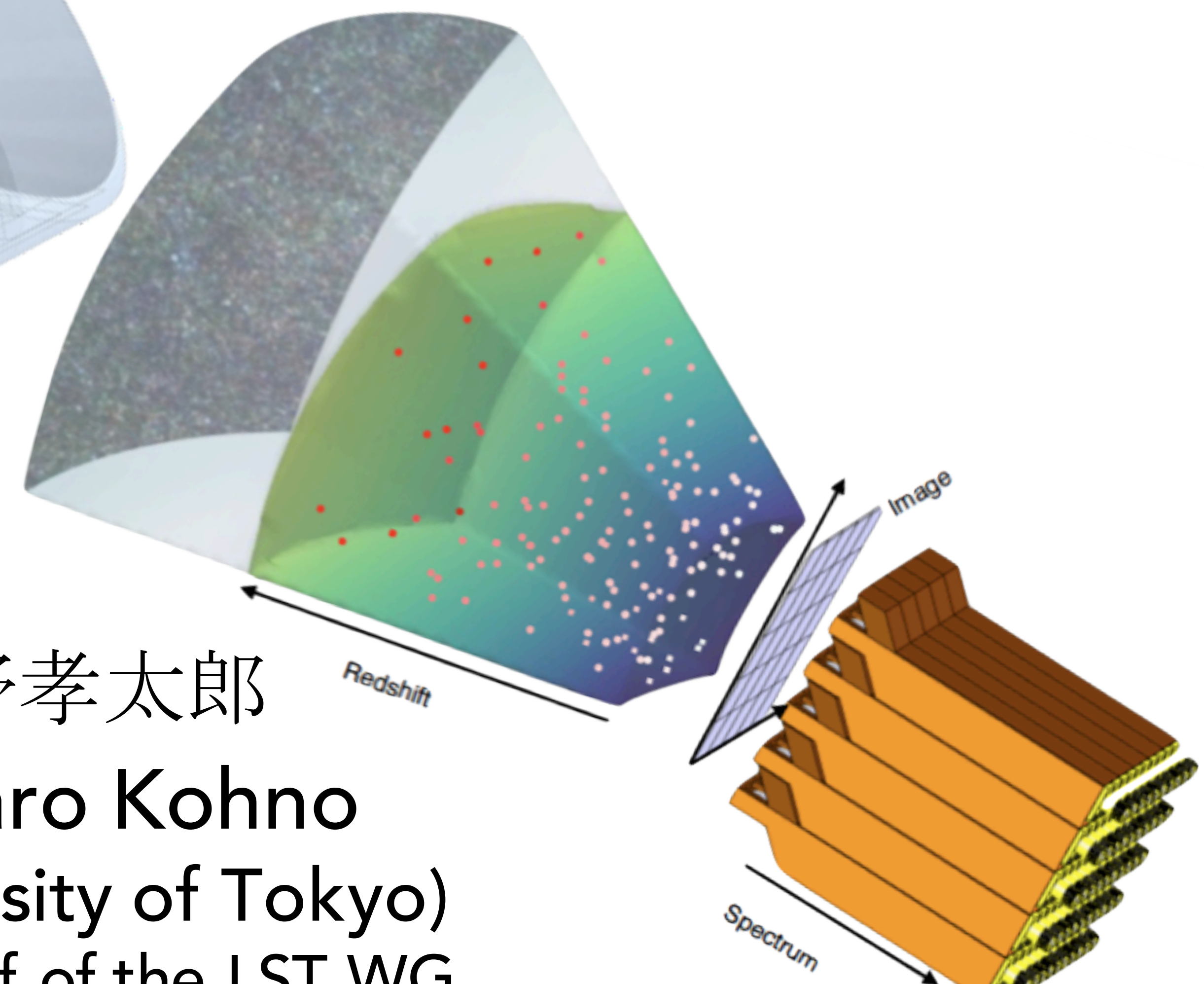
Accelerating Universe in the Dark
March 4 - 8, 2019
Yukawa Institute for Theoretical Physics, Kyoto University

LST
LARGE SUBMILLIMETER TELESCOPE

Galaxy surveys using Large Submillimeter Telescope





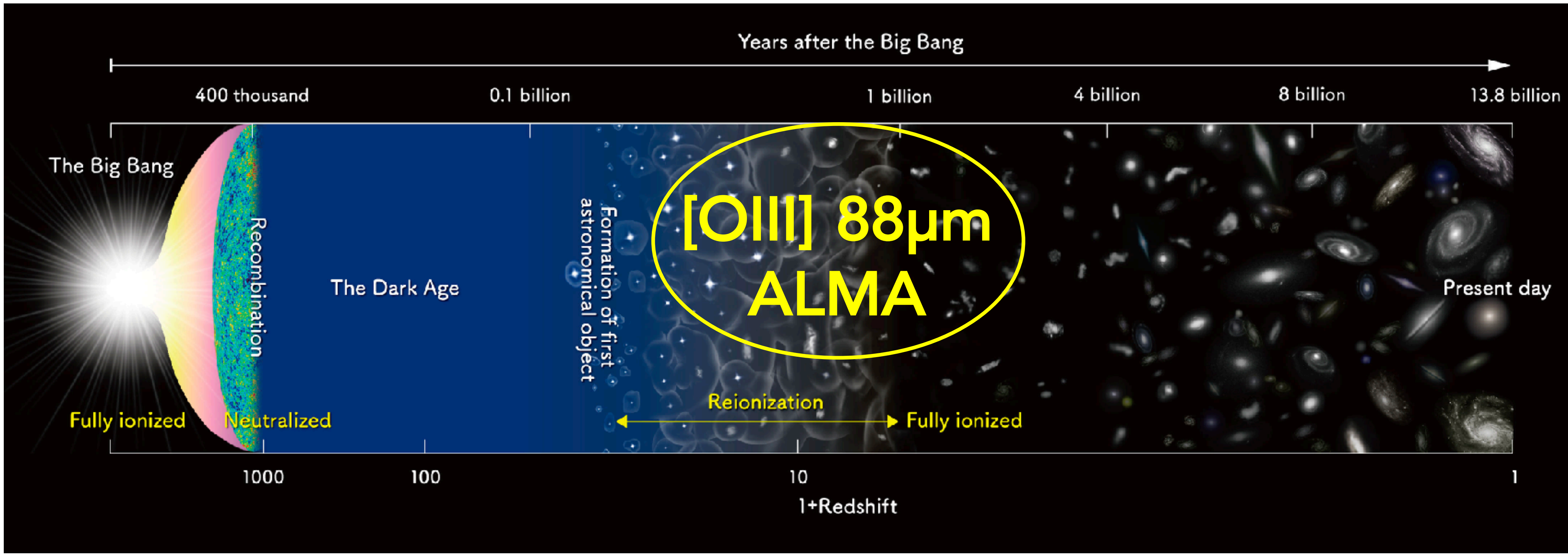
河野孝太郎
Kotaro Kohno
(University of Tokyo)
on behalf of the LST WG

MITSUBISHI ELECTRIC

Outline

- Frontiers of high-redshift galaxy study
  - exploring the earliest epoch of star and metal formations via [OIII] 88μm line and dust
- Overview of Large Submillimeter Telescope (LST) concept
- Galaxy surveys using LST
- Can we exploit LST galaxy surveys for cosmology ??
  - Redshift space distortion (RSD)
  - Intensity mapping (IM)
- Summary

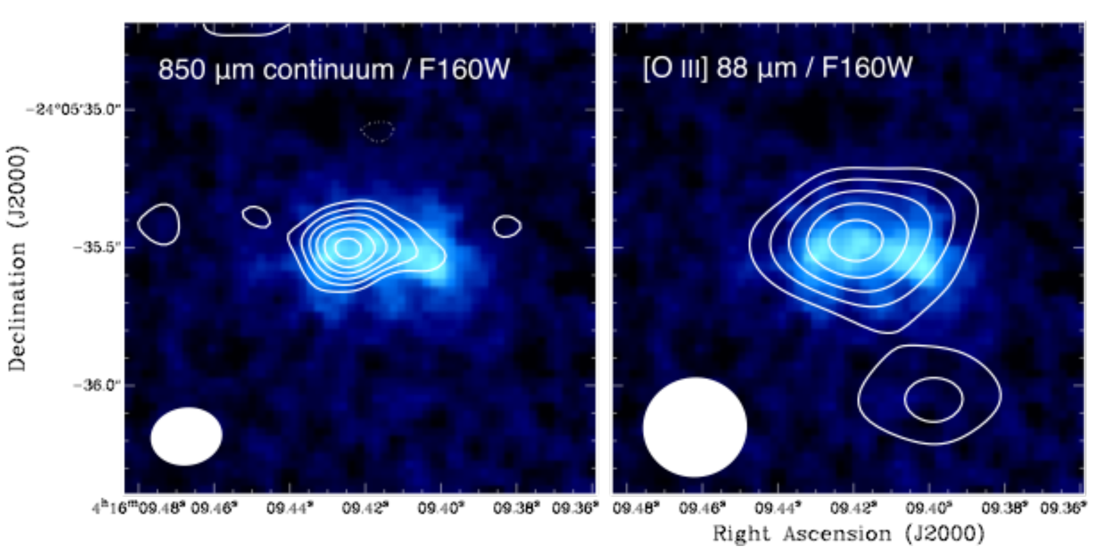
Exploring the earliest epoch of star and metal formations in galaxies



Credit: NAOJ

➔ what is the origin?

[OIII] & dust @ z = 8.312

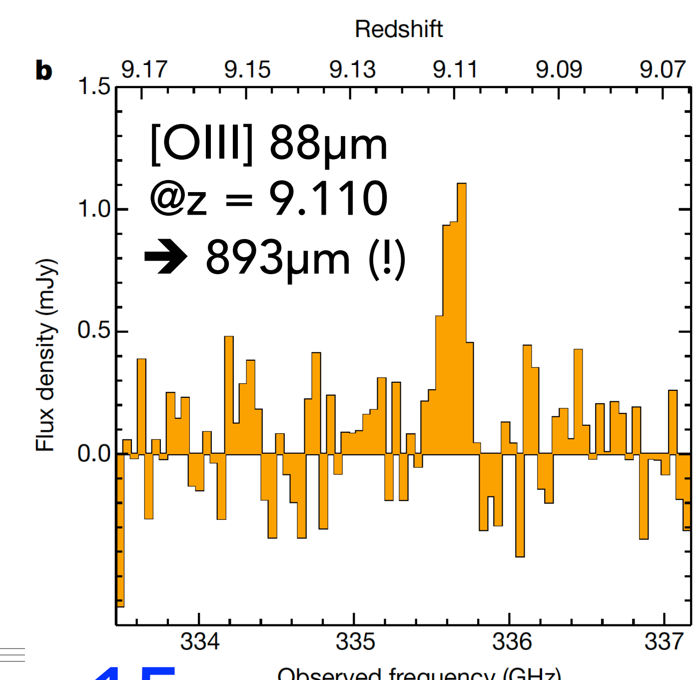


Tamura, Y., et al. (2019) ApJ, in press

the record high spectroscopic redshift

z = 9.110

Hashimoto, YT et al. (2018) Nature



LETTER

first star formation @z = 15 !

The onset of star formation 250 million years after the Big Bang

Redshift frontiers of spectroscopically detected galaxies

#	Redshift	Object	References	Telescope/Line
1	9.110	MACS J1149-JD	**Hashimoto+ (2018)***	**ALMA/[OIII]**
2	8.683	EGSY-2008532660	Zitrin+ (2015)*	Keck/Lyα
3	8.38	A2744_YD4	Laporte+ (2017)	**ALMA/[OIII]**
4	8.312	MACS0416_Y1	**Tamura+ (2018)**	**ALMA/[OIII]**
5	7.664	z7_GSD_3811	Song+ (2016)	Keck/Lyα
6	7.640	MACS1423-z7p64	Hoag+ (2017)	HST/Lyα & **ALMA/[CII]**
7	7.541	ULAS J1342+0928	Banados+(2017)	Magellan/Lyα
8	7.508	z8-GND-5296	Finkelstein+ (2013)*	Keck/Lyα
9	7.452	GS2_1406	Larson+ (2017)	HST/Lyα
10	7.212	SXDF-NB1006-2	Shibuya+(2012) **Inoue+ (2016)***	Subaru+Keck/Lya **ALMA/[OIII]**

Earliest star and metal formations
during the Epoch of Reionization (EoR) to "pre-EoR"

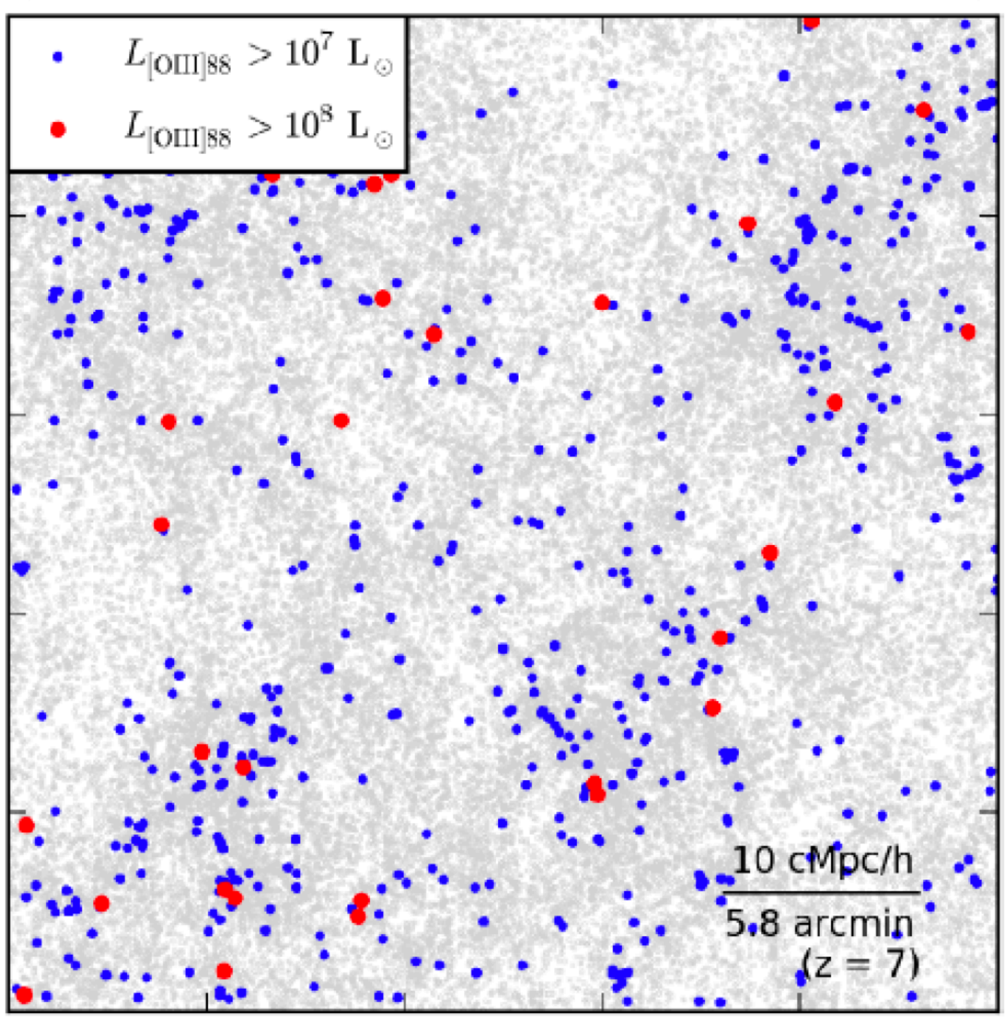
- An issue: how to find good target for ALMA observations ➔ HST (currently)
- statistically large sample? candidates for the first forming galaxies @z=15?

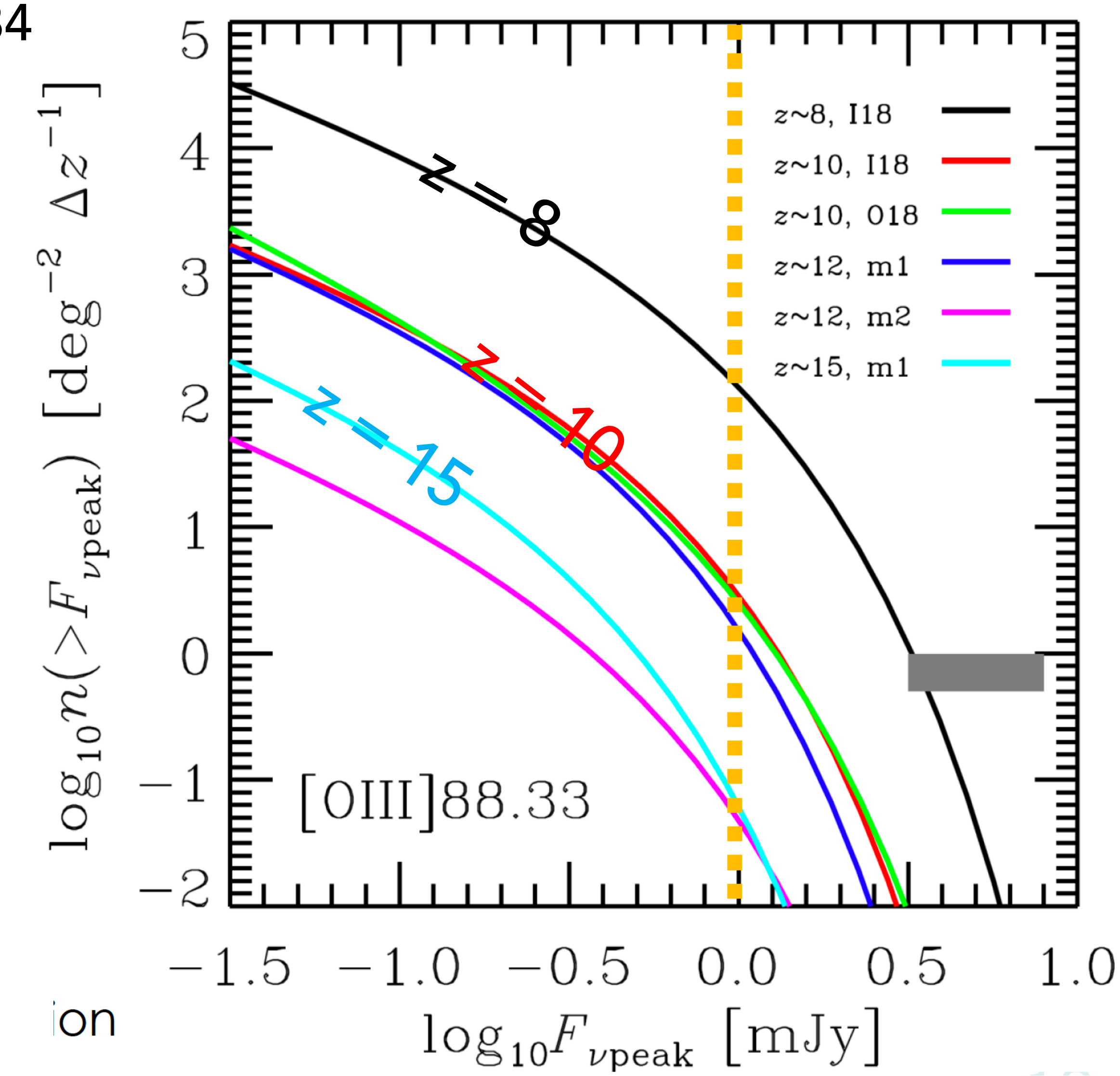
HST no longer works; JWST and ALMA sensitivities are good but not optimized for survey

Required survey area and depth predicted ➔ > 1 deg^2 · peak flux ~1mJy

0.5 deg = 50h^{-1} cMpc

Moriwaki, K., Yoshida, N., et al. (2018)
MNRAS, 481, L84





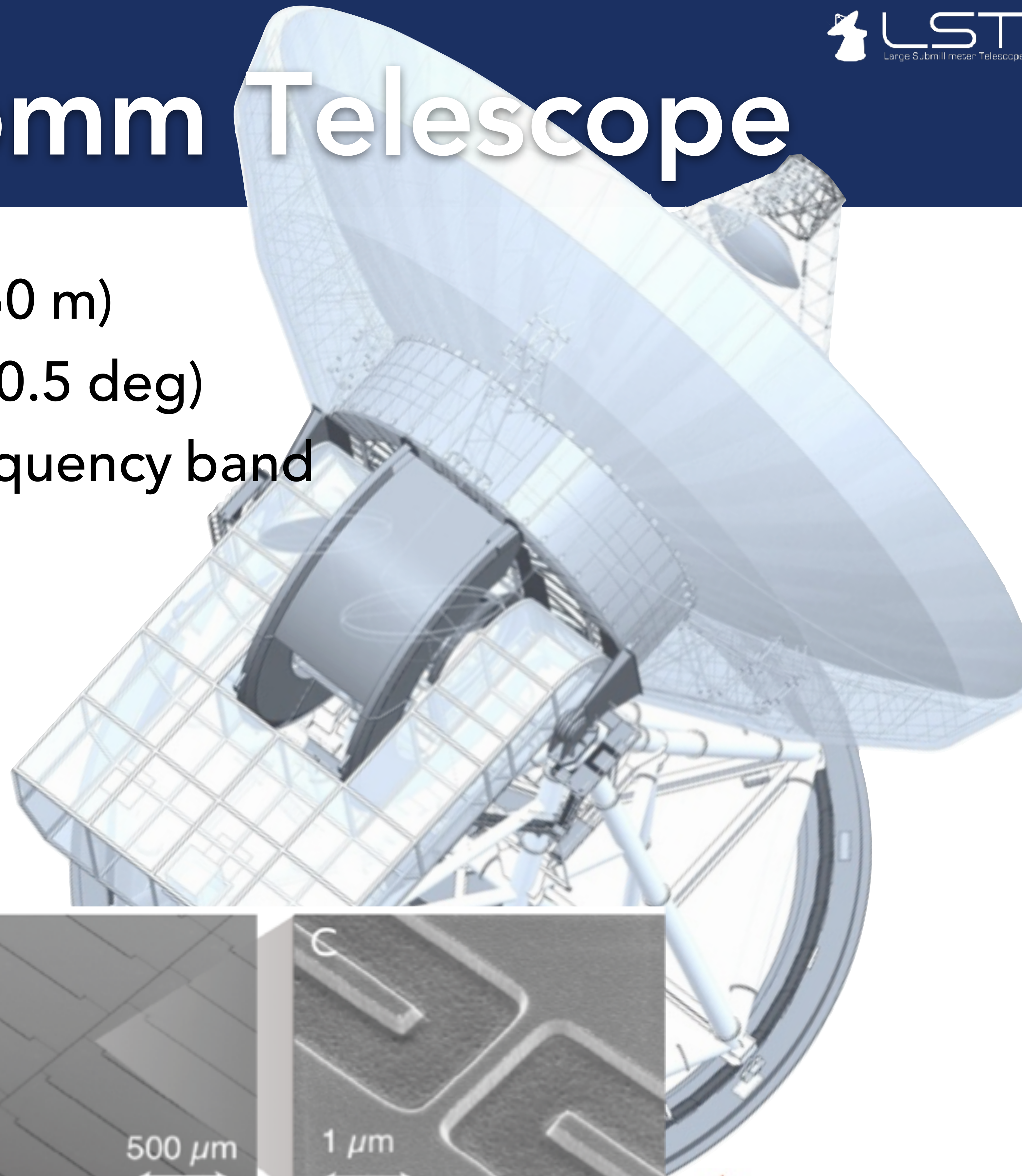
ion

[OIII]88μm luminosity functions

Inoue, A., et al.

Large Submm Telescope

- Large aperture (D = 50 m)
- Wide field of view (> 0.5 deg)
- Long-submm/mm frequency band
- Survey-oriented

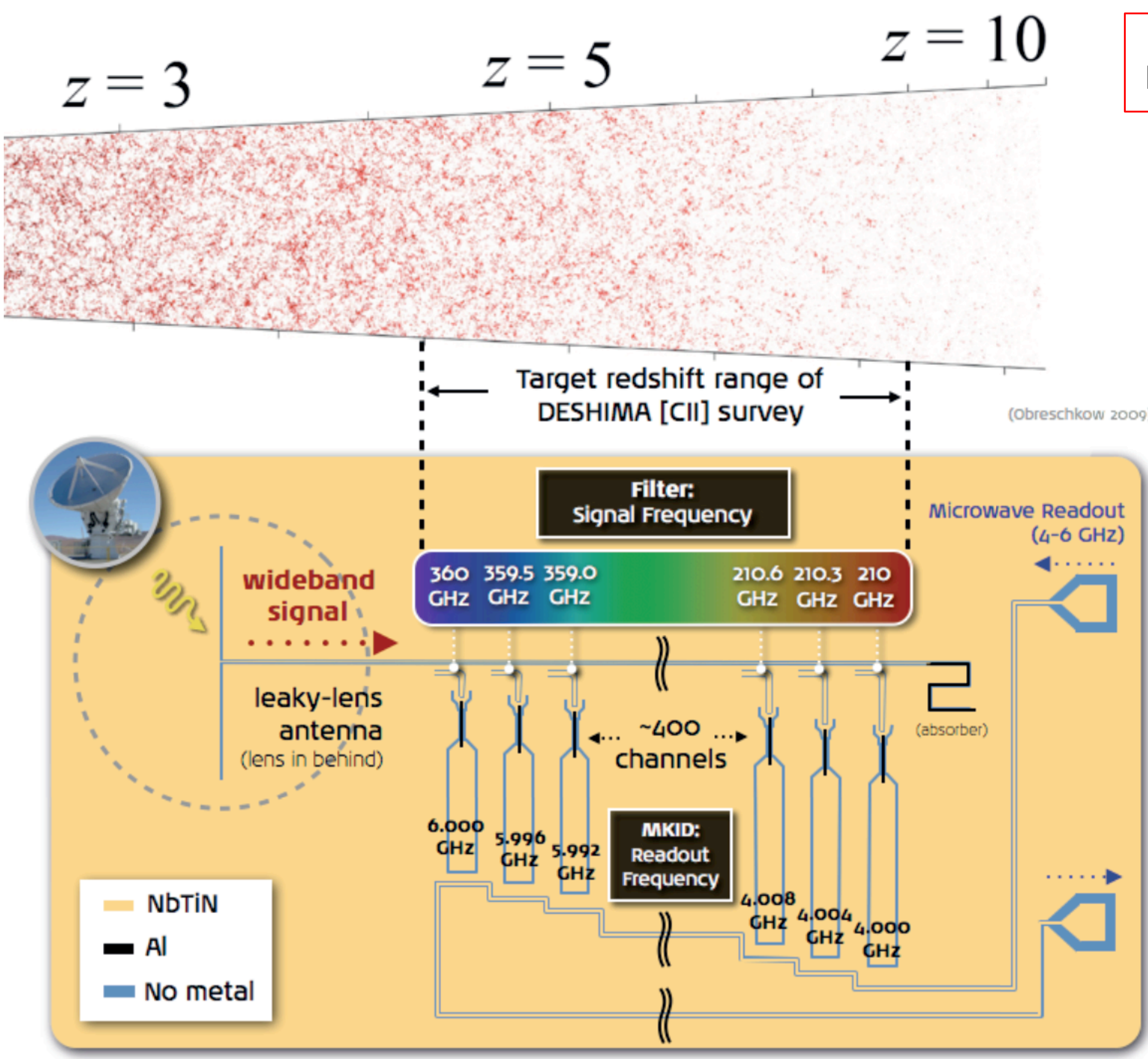


DESHIMA

Deep Spectroscopic High-z Mapper

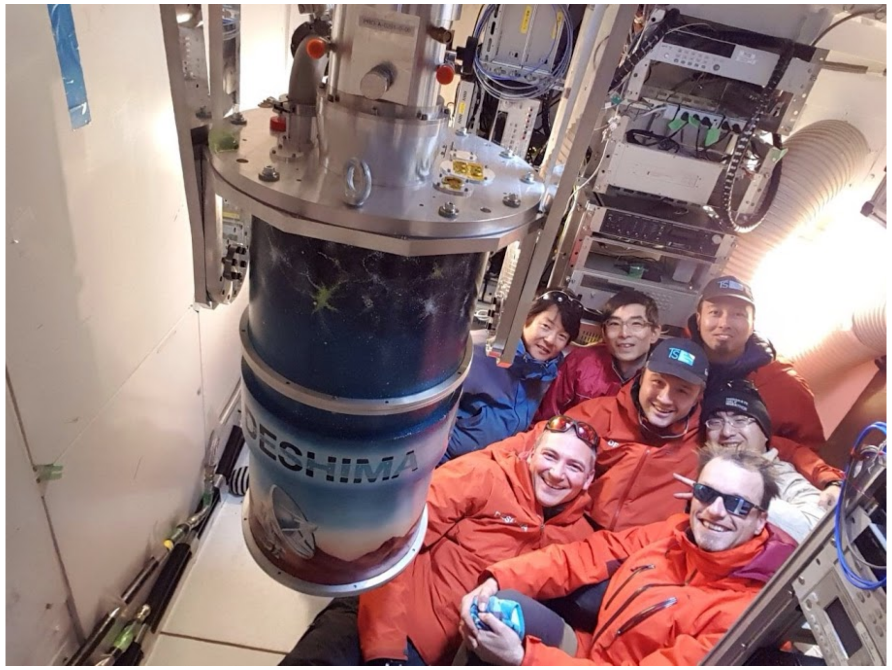
(Endo et al. 2011)

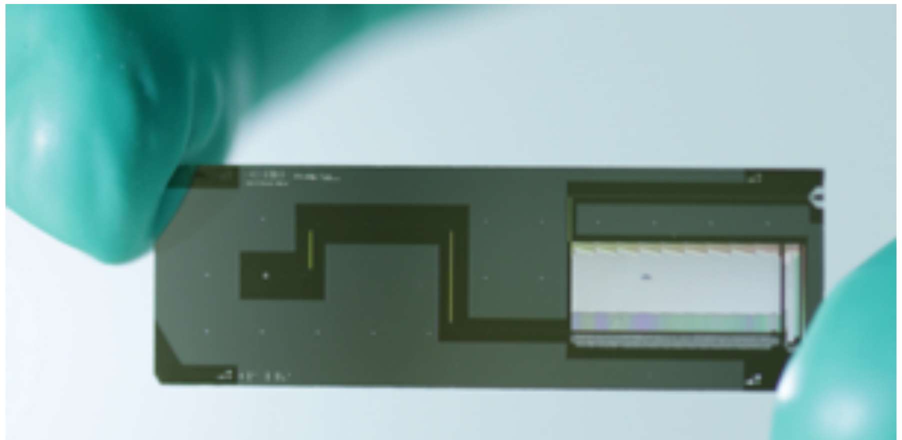
On-chip superconducting spectrograph DESHIMA does exist



Endo et al. 2012, JLTP, 167, 341
Endo et al., submitted to Nature Astronomy

DESHIMA on ASTE 10m in Atacama



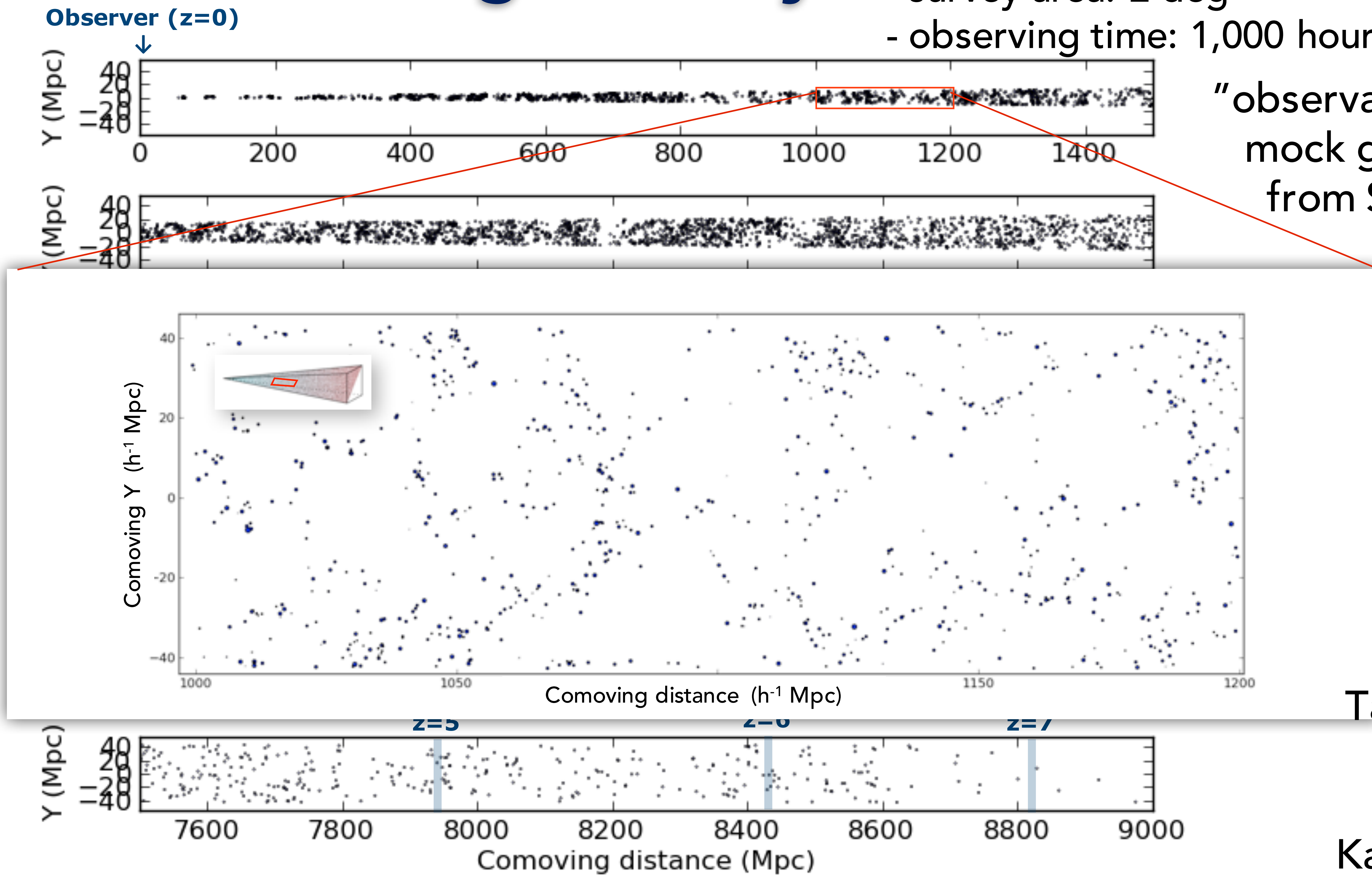


Small !! ➔ large format multi-beam

Galaxy surveys using LST

Light cone from the LST 2-deg^2 Survey

Imaging-Spectrograph "super-MOSAIC"
- number of pix: 100
- freq. coverage: 70 – 370 GHz
- survey area: 2 deg^2
- observing time: 1,000 hours (on-source)



"observations" of mock galaxies from S^3-SAX

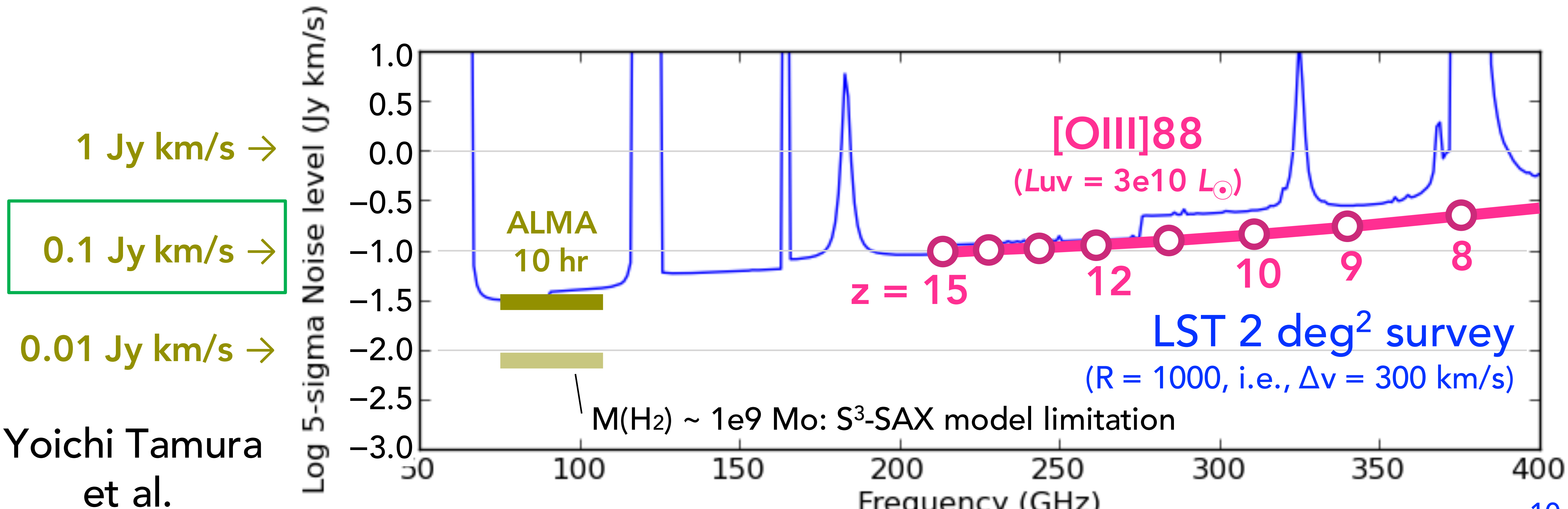
Tamura, Y., + in prep.

Kawabe, R., + 2016, SPIE

10^5 galaxies across the cosmic time
10^3 galaxies in the epoch of reionization

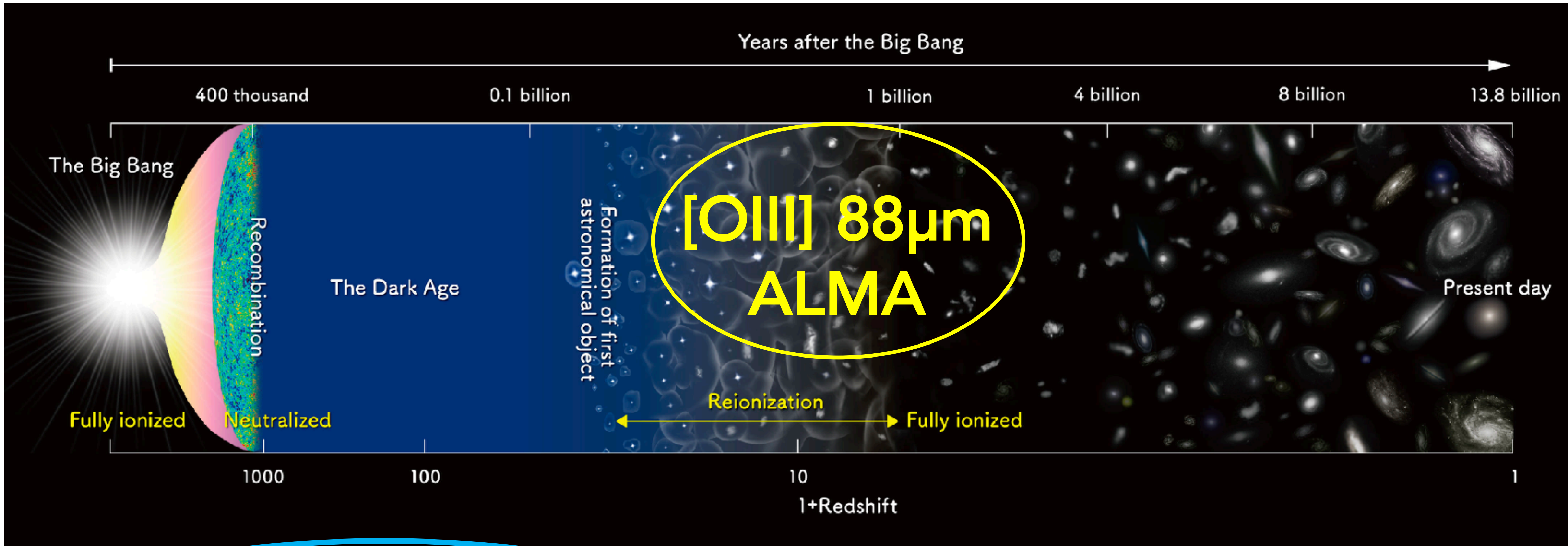
Search for z = 8 – 15 galaxies using the LST ultra-deep 2-deg² imaging-spectroscopy survey

- An unbiased imaging-spectroscopy survey using LST 50m + multi-pixel (100 pix), medium-resolution (R=1000), ultra-wideband (70 – 370 GHz) imaging spectrograph
- ➔ Statistically large sample @z = 8 – 10, significant number of candidates @z = 12 – 15
  - 2 deg², t_{obs} = 9,000 hrs
    - more sample ➔ clustering analysis @z>10 ➔ first measurements of dark halo mass, evolution of [OIII] luminosity functions up to z>10



Yoichi Tamura et al.

Exploring the earliest epoch of star and metal formations in galaxies



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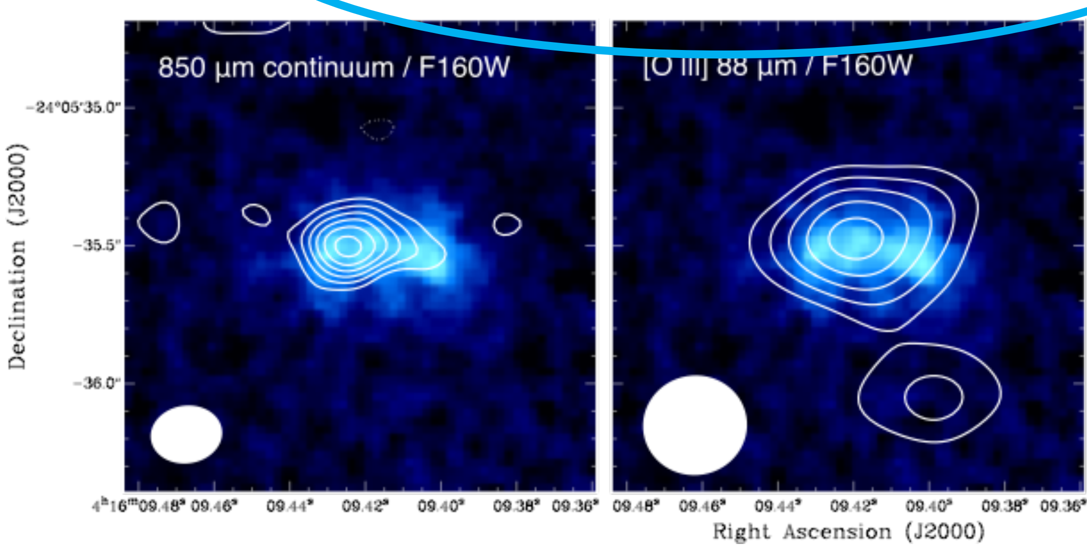

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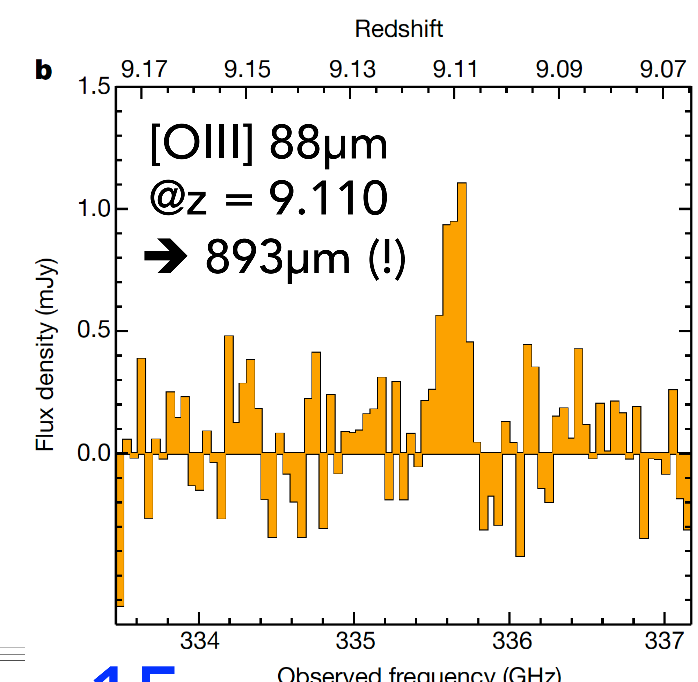
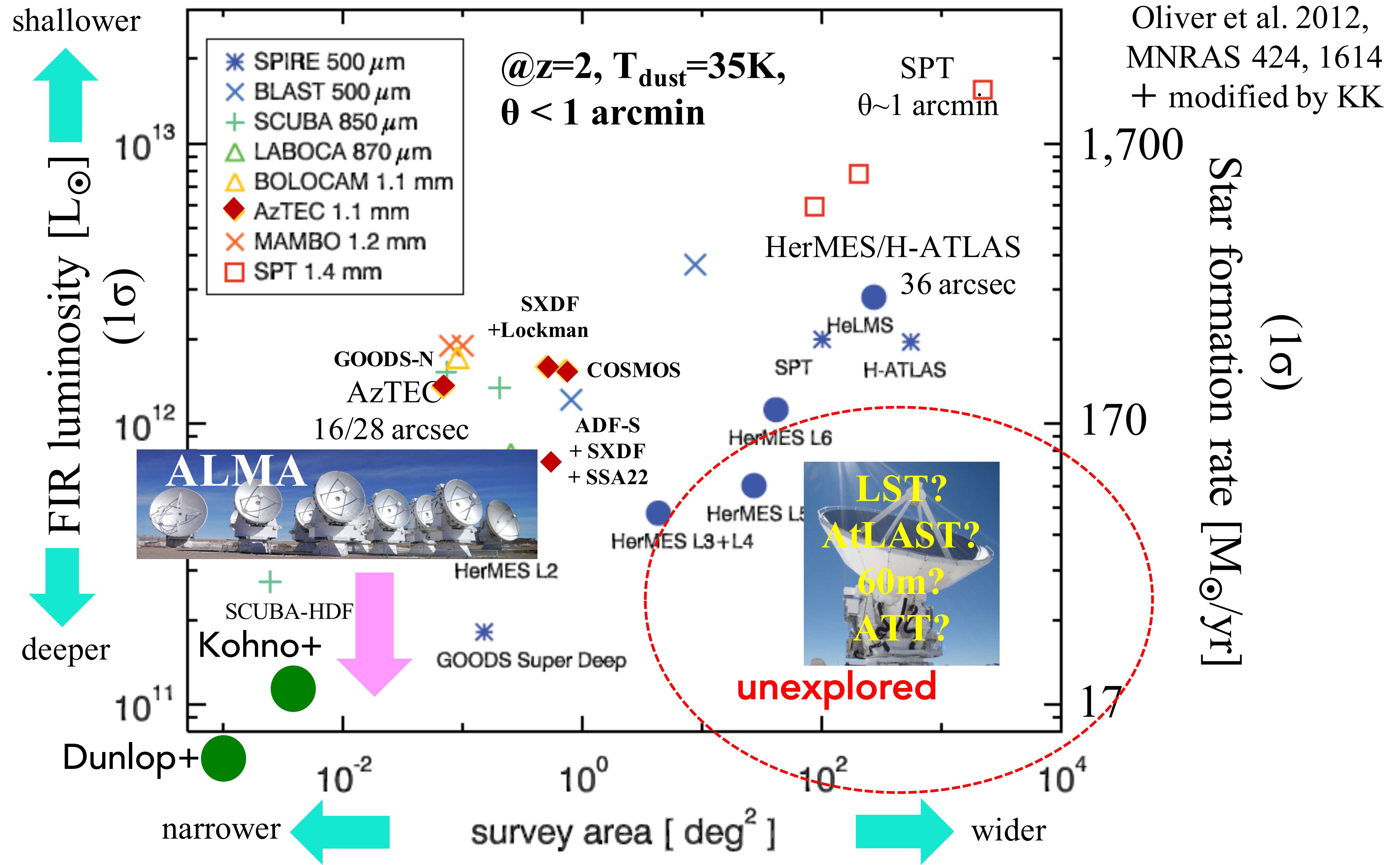


LETTER

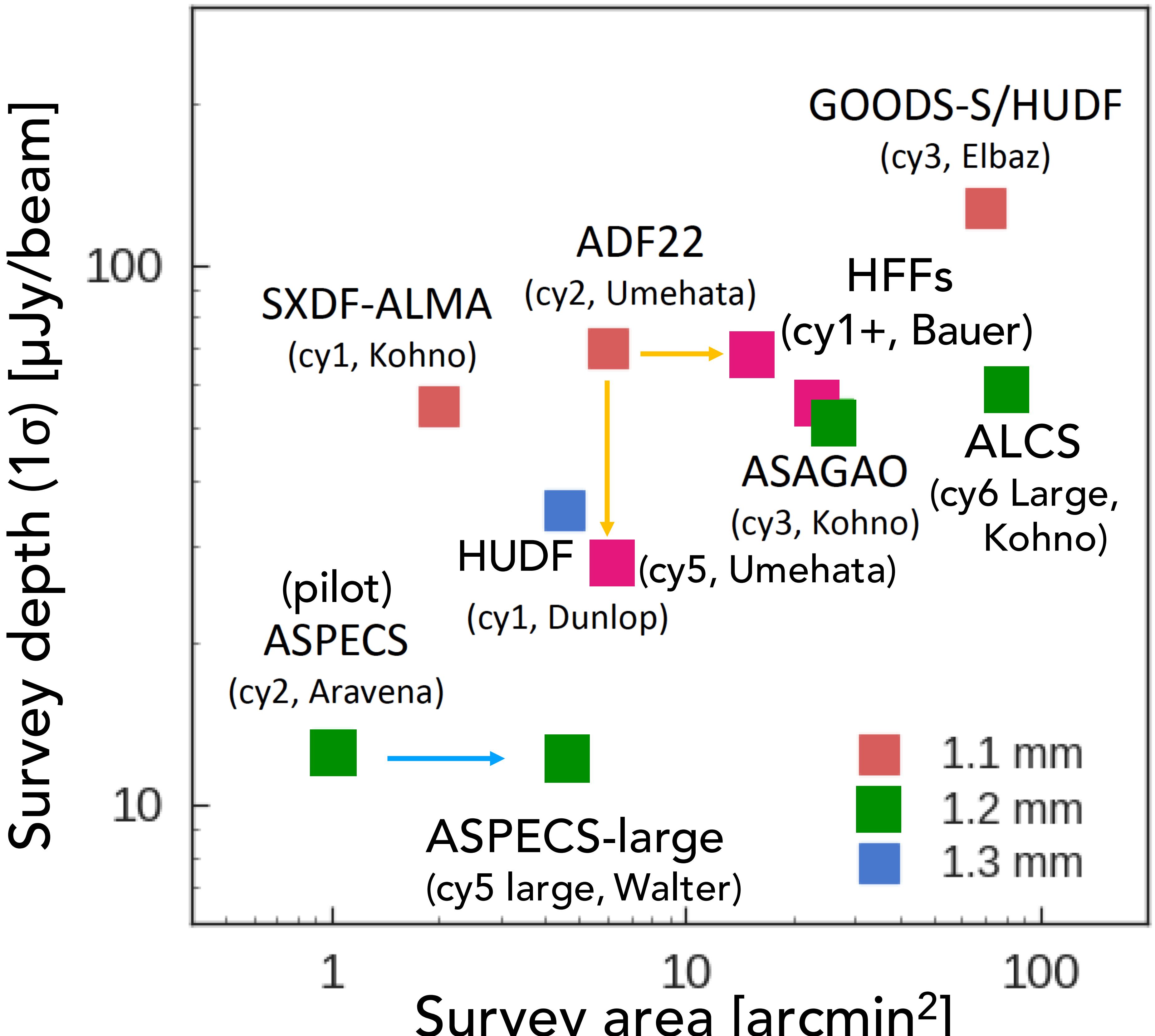
first star formation @z = 15 !

The onset of star formation 250 million years after the Big Bang

Millimeter/submillimeter imaging surveys



ALMA deep surveys at λ = 1.1-1.3 mm



dusty z>7 galaxies are rare
➔ need a wide area survey

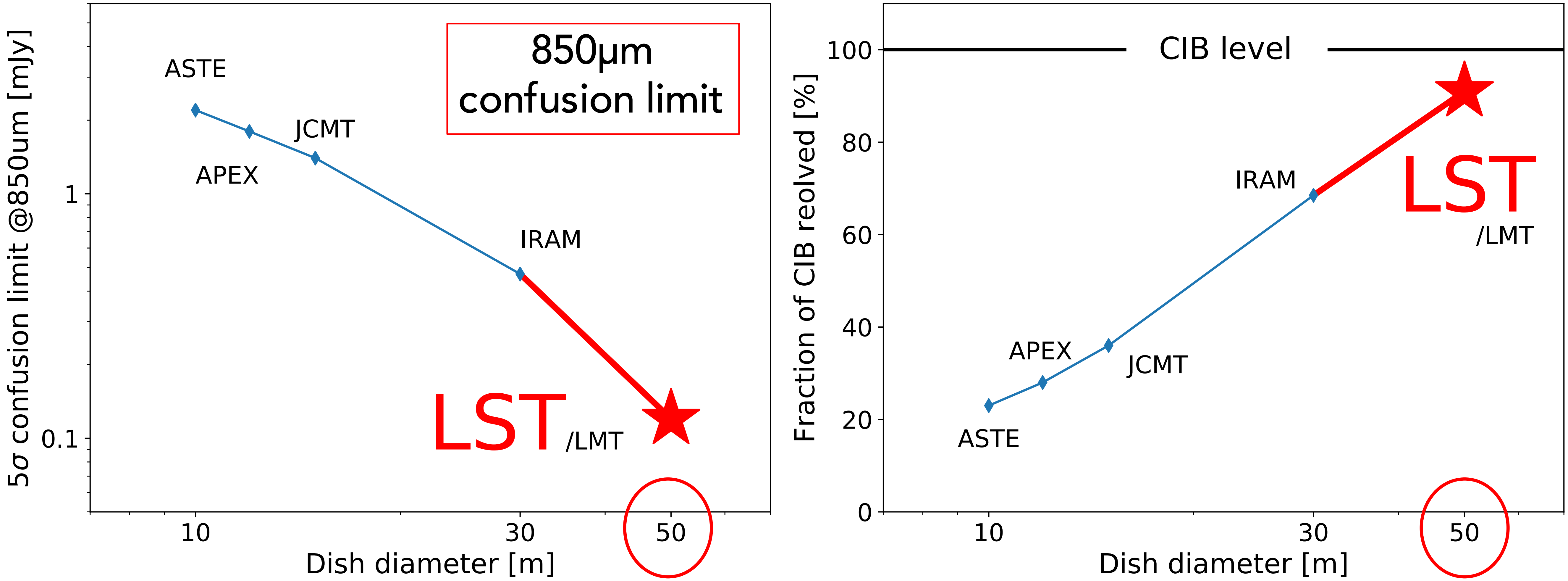
ALMA Cy6 Large Program

ALCS

PI: K. Kohno
33 clusters
88 $arcmin^2$
80 μJy (1σ)

Necessity of >50m-class dishes: to fully resolve the cosmic infrared background

- 850μm band continuum imaging surveys using a 50-m telescope
- ➔ majority (>90%) of the cosmic infrared background light (CIB) can be resolved into discrete sources

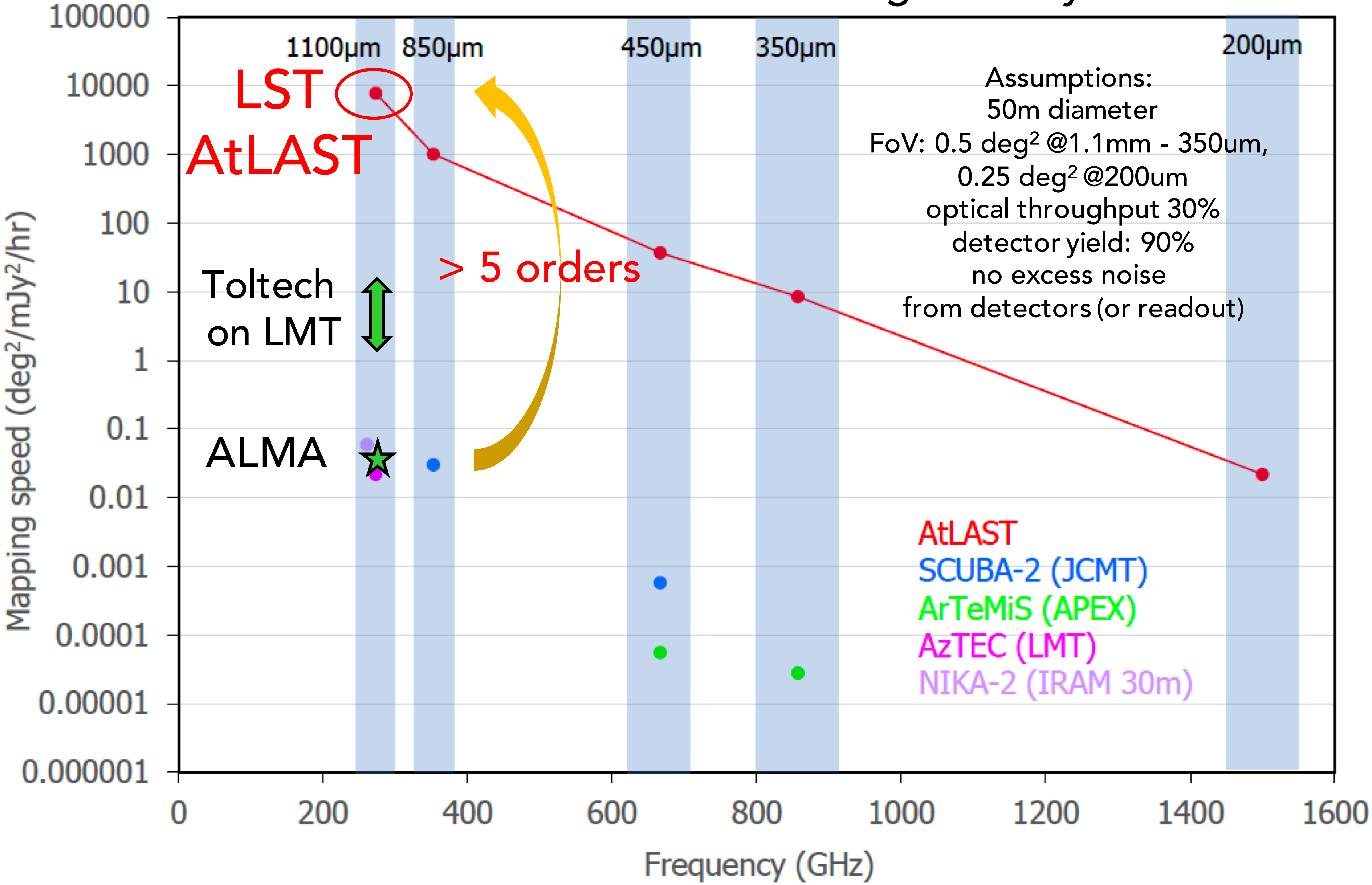


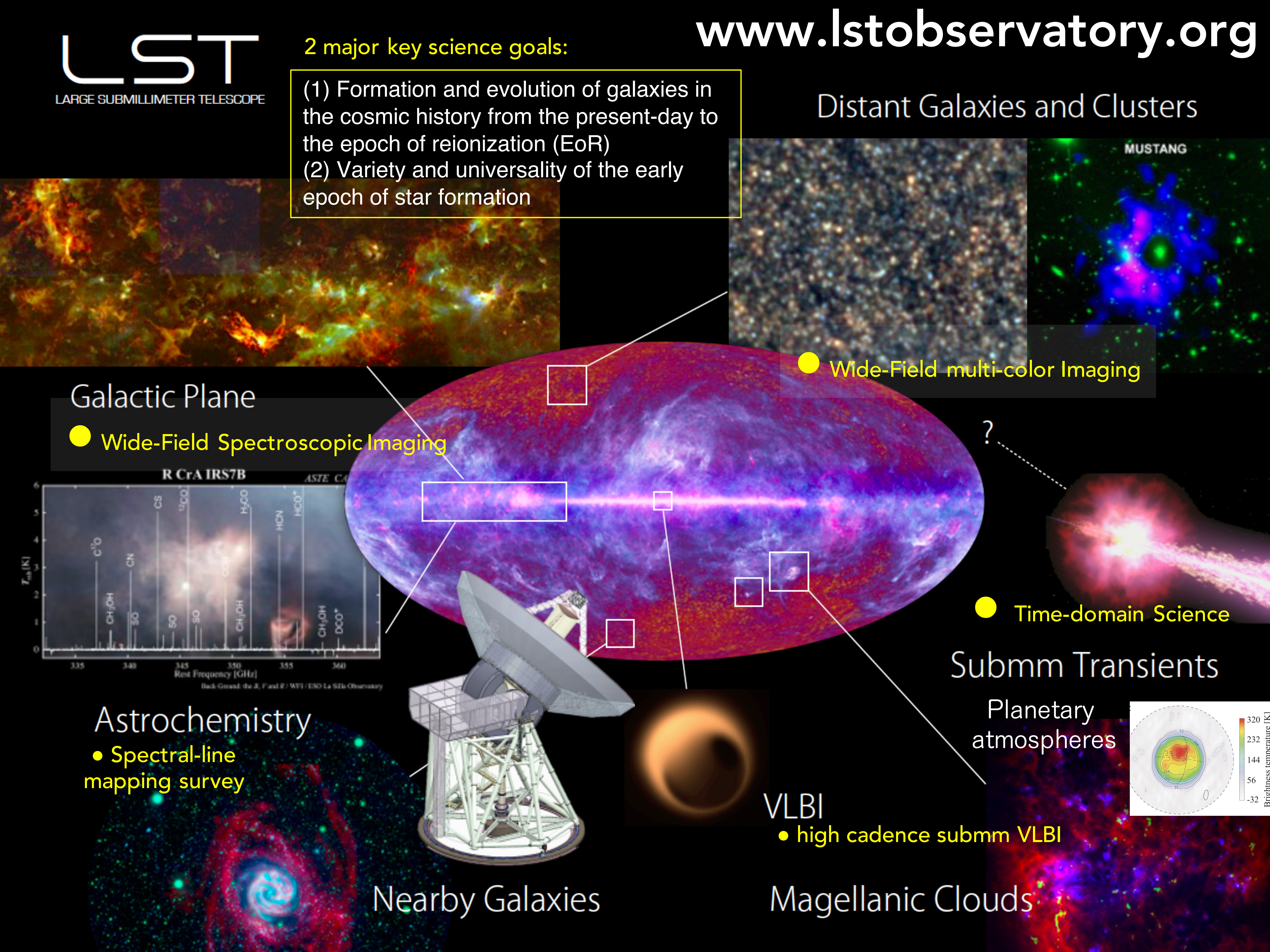
Adopted number counts: Bethermin et al. ApJ, 757, L23 (2012) Definition of confusion: 12 beams per source

A huge leap in continuum sensitivity

mapping speed: survey area observed within a given depth and observing time

Figure: Wayne Holland



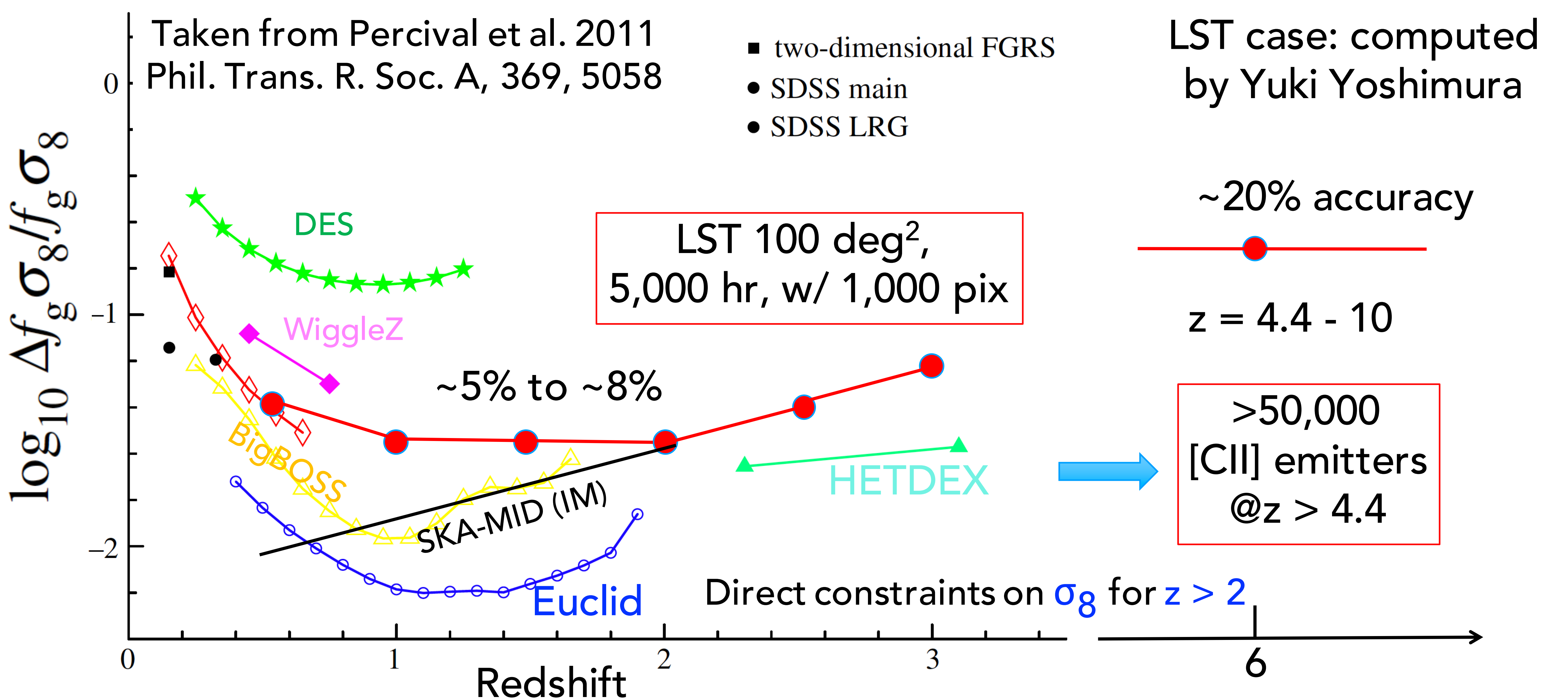

LST
LARGE SUBMILLIMETER TELESCOPE
2 major key science goals:
(1) Formation and evolution of galaxies in the cosmic history from the present-day to the epoch of reionization (EoR)
(2) Variety and universality of the early epoch of star formation
www.lstobservatory.org
Distant Galaxies and Clusters
MUSTANG
Wide-Field multi-color Imaging
Galactic Plane
Wide-Field Spectroscopic Imaging
R CrA IRS7B
Rest Frequency [GHz]
?
Time-domain Science
Submm Transients
Planetary atmospheres
Brightness temperature [K]
Astrochemistry
• Spectral-line mapping survey
VLBI
• high cadence submm VLBI
Nearby Galaxies
Magellanic Clouds

Large Submillimeter Telescope

Can the LST galaxy surveys also be useful for cosmology??

Redshift Space Distortion via CO and [CII]

σ_8: The rms amplitude of density fluctuation with a comoving radius of 8/h Mpc



- A LST 100 deg^2 survey using super-DESHIMA (1,000 spatial pixel) can put constraints on RSD at z = 2 – 3 using CO ⇔ HETDEX (Lyα-based) and z = 4.4 – 8 using [CII] 158μm ⇔ SPHEREx (Lyα-based) S. Saito-san's talk
- Can we say that these LST constraints are useful as "multi-tracer" to mitigate cosmic variance (e.g., Seljak+09) ??

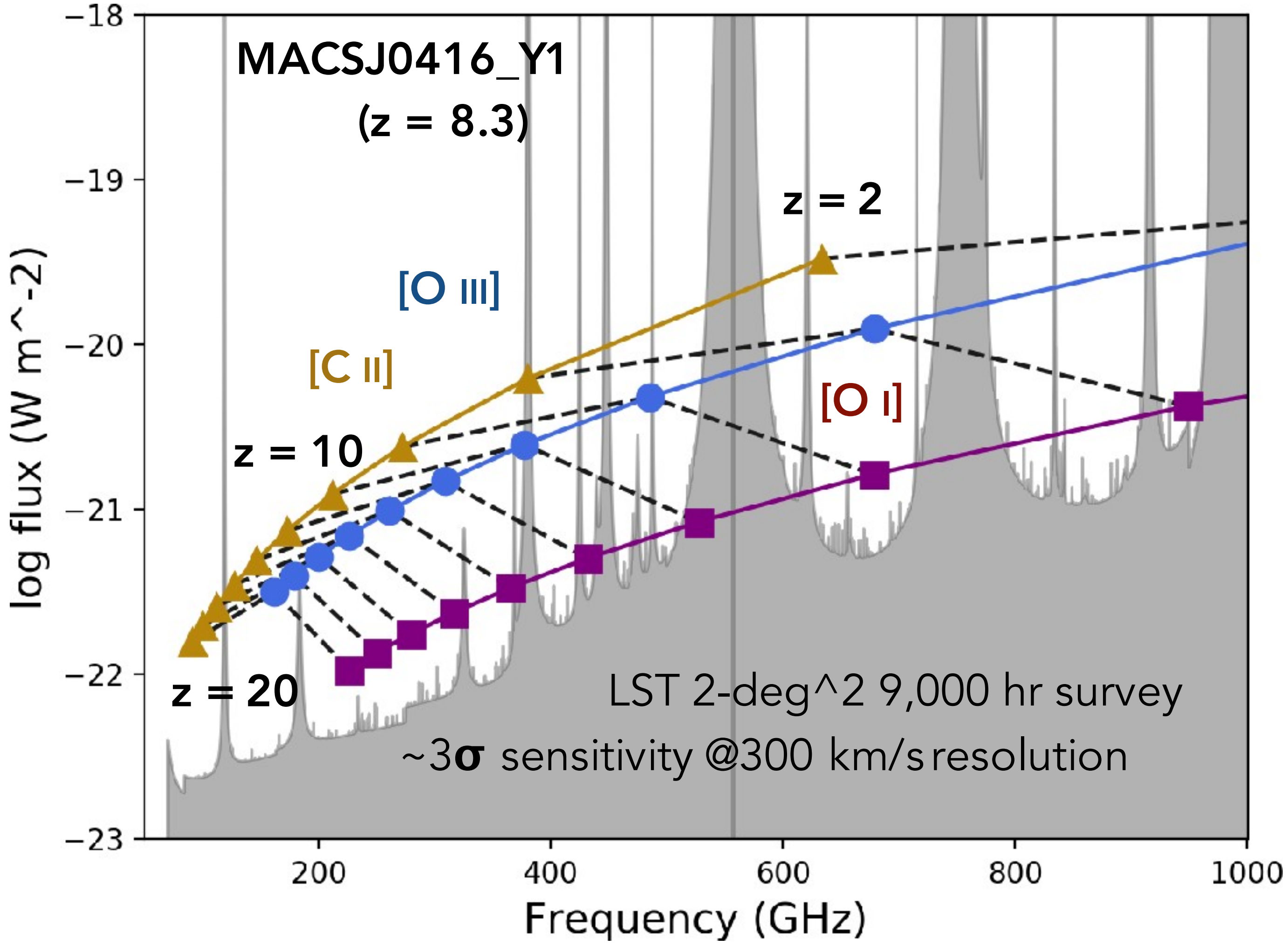
[OIII] 88μm + [CII] 158μm Intensity Mapping

- [OIII] 88μm intensity mapping: a new probe of LSS beyond z>8
  - beyond the redshift range of SPHEREx (z = 5.2 – 8, Lyα)
  - cross-correlation with [CII] 158μm ➔ eliminating foreground contaminations

- "sweet spot" redshift ranges
  - z = 8.4 – 9.0
  - z = 12 – 15

➔"Narrow band filter"- like instruments for some specific redshift ranges can be another promising way to go?

example: [CII] 158μm Intensity Mapping using CCAT-p



Summary

- Redshift frontiers of galaxy study via [OIII] 88μm lines and submm continuum to explore the earliest formation of metal and dust in galaxies: now [OIII] 88μm line + ALMA starts to outperform Lyα + optical/near-infrared telescopes
  - O^{++} and dsut @z = 9.110 ➔ star formation @z ~ 12 – 15
- How to uncover candidate z~12-15 star-forming galaxies? [OIII] 88 μm with ALMA, CIII] 1909 A with JWST can be feasible but FoVs are too small
- Large Submillimeter Telescope (LST), D=50m survey optimized, equipped with medium-resolution (R=500-1000) imaging spectrograph (super-DESHIMA/MOSAIC), covering 70 – 370 GHz with 100 spatial pixels, can be unique for this purpose!
- galaxy survey 1: a 2-deg^2 drilling survey (9,000 hrs) ➔ a statistically large [OIII] emitters at z = 8 – 10, and a significant number of [OIII] candidates at z = 12 – 15
- galaxy survey 2: a 100-deg^2 wide survey (5,000 hrs) having 1,000 spatial pixels ➔ ~10^6 CO emitters and ~50,000 [CII] emitters (z>4.4)
  - Put unique constraints on the bright-end of CO and [CII] luminosity functions, which is inaccessible with ALMA (good for galaxy studies)
  - Put unique constraints (~5%) on the growth rate of the universe (RSD) at z = 2-3 and a purely new constraint (~20%) on RSD at z = 4 – 6 and beyond ➔ synergies with Lyα-based surveys HETDEX and SPHEREx ??
- [OIII] 88μm & [CII] 158μm dual-line intensity mapping may be more promising ? ➔ need more collaborations with cosmology colleagues