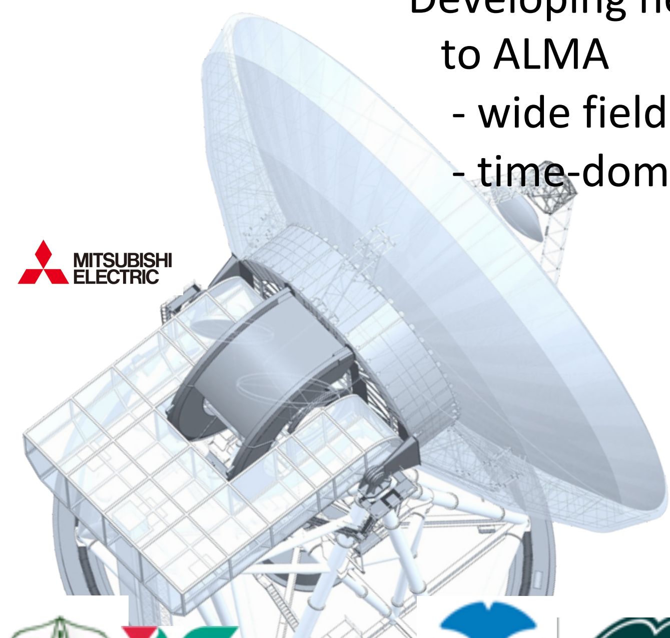
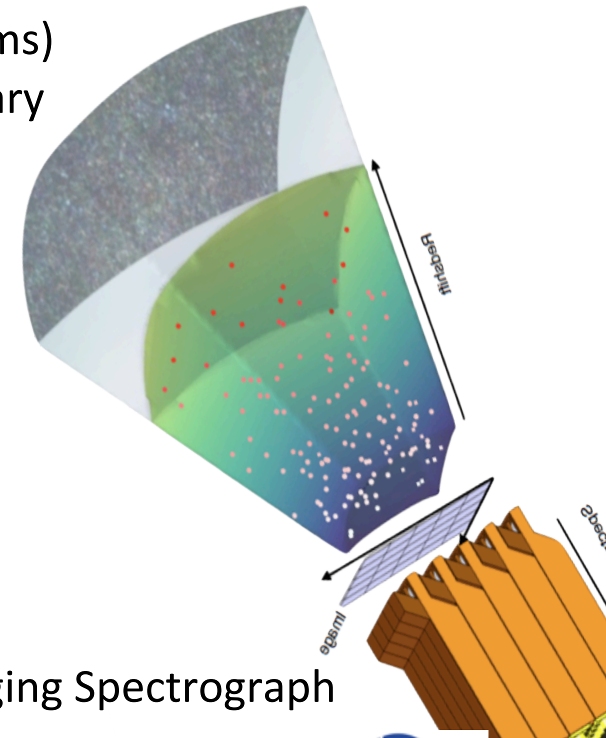
LST
Large Submillimeter Telescope as 3D Explorer of Universe

Large FOV Telescope



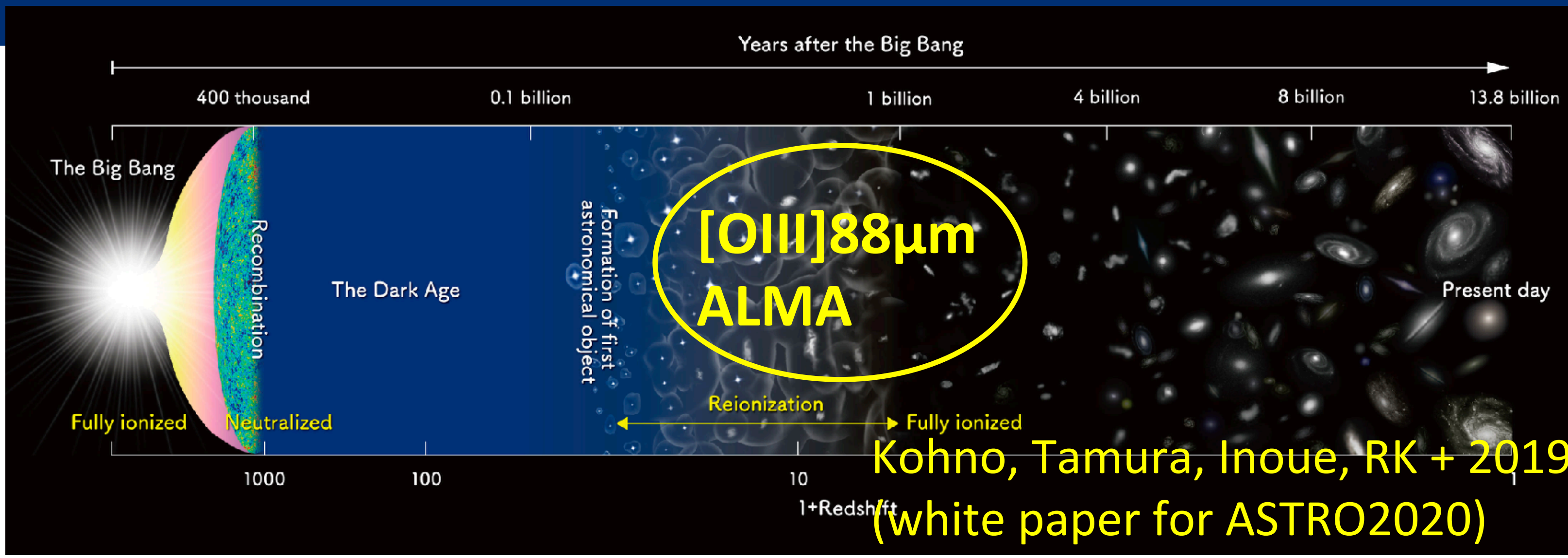
- D=50 m at ALMA plateau
- FOV > 0.5 deg diameter for 70-420 GHz
- Capability of obs up to 1 THz with under-illumination
- Active Surface control to achieve 45 micron (rms)
- Developing new discovery space complementary to ALMA
  - wide field imaging in line & continuum
  - time-domain science

Ryohei Kawabe (NAOJ)
Kotaro Kohno (U. Tokyo)
Yoichi Tamura (Nagoya U)
and LST working group



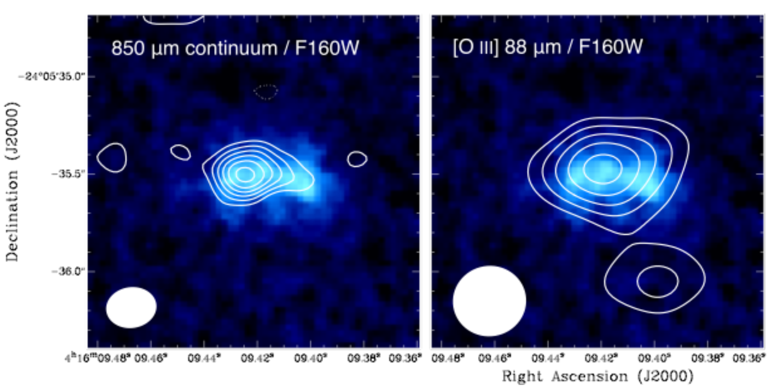
Large Imaging Spectrograph

Frontier of High-z Universe



"First Metal production" ➔ What is Origin ?

[OIII] & Dust @ z = 8.312

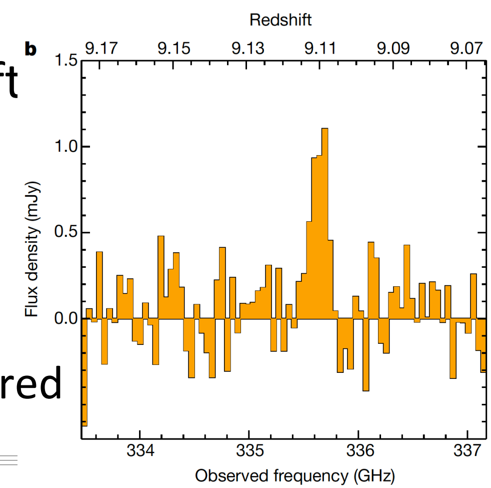


Tamura, Y., et al. (2018) ApJ

Spectroscopic redshift

z = 9.110

Hashimoto, YT et al. (2018) Nature



LETTER

First SF occurred @ z = 15 !

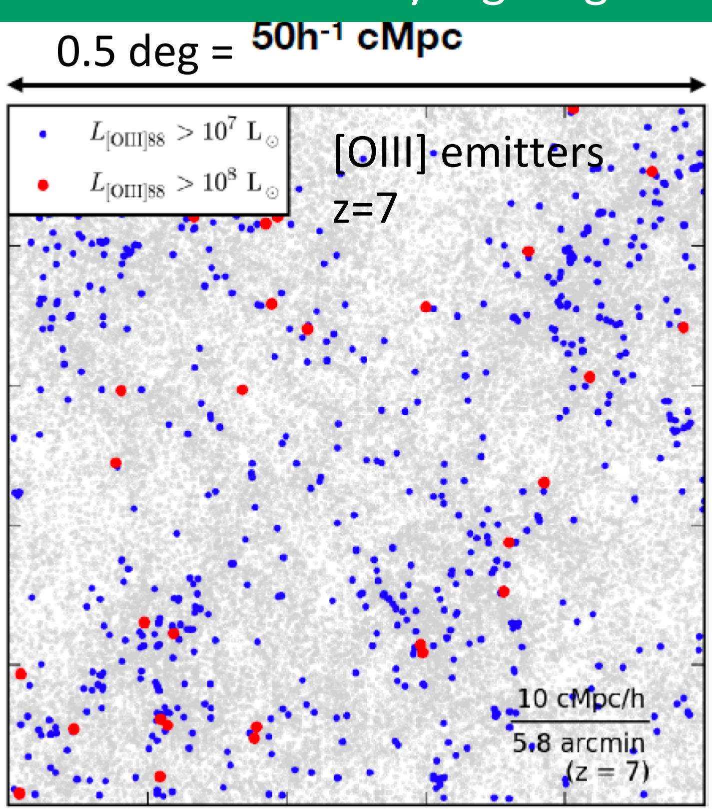
The onset of star formation 250 million years after the Big Bang

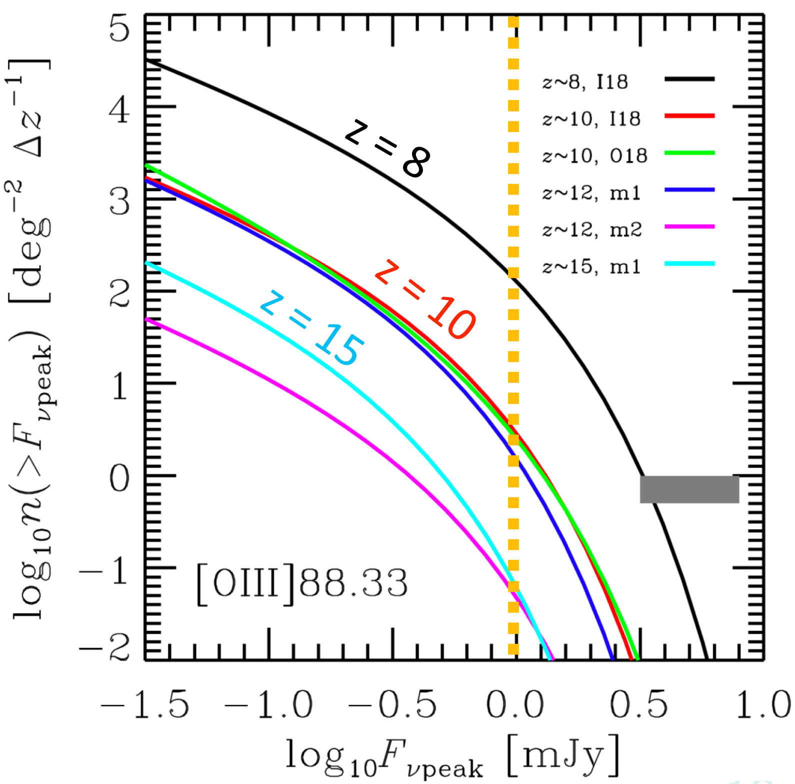
Galaxy Formation and Metal Production in Epoch of Re-ionization

LST Large Submillimeter Telescope

- Still not well understood, sample for ALMA obs depends on candidates from HST
- Larger sample at z = 10- 15 available with HST? => No because does not catch Lyα
  FOVs of JWST, ALMA are too small for survey

Census of extremely high-z galaxies needs → **> 1 deg²** · peak flux **~1mJy in [OIII]**



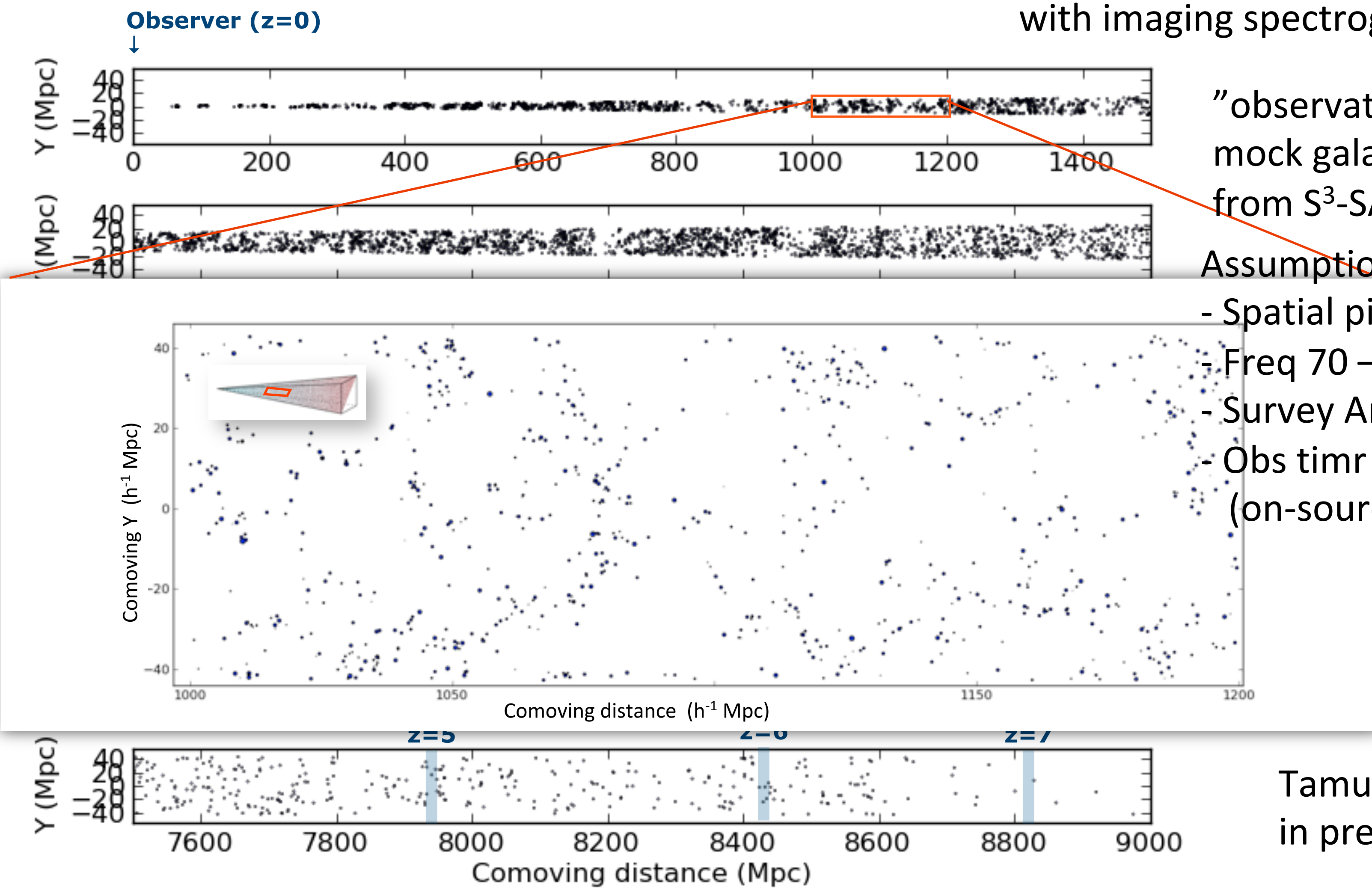


[OIII] emitter Luminosity Function (calculated)

Inoue et al.

Light cone from the LST 2-deg^2 Survey

with imaging spectrograph



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

Assumptions
- Spatial pix: 100
- Freq 70 – 370 GHz
- Survey Area 2 deg^2
- Obs timr 1,000 hours (on-source)

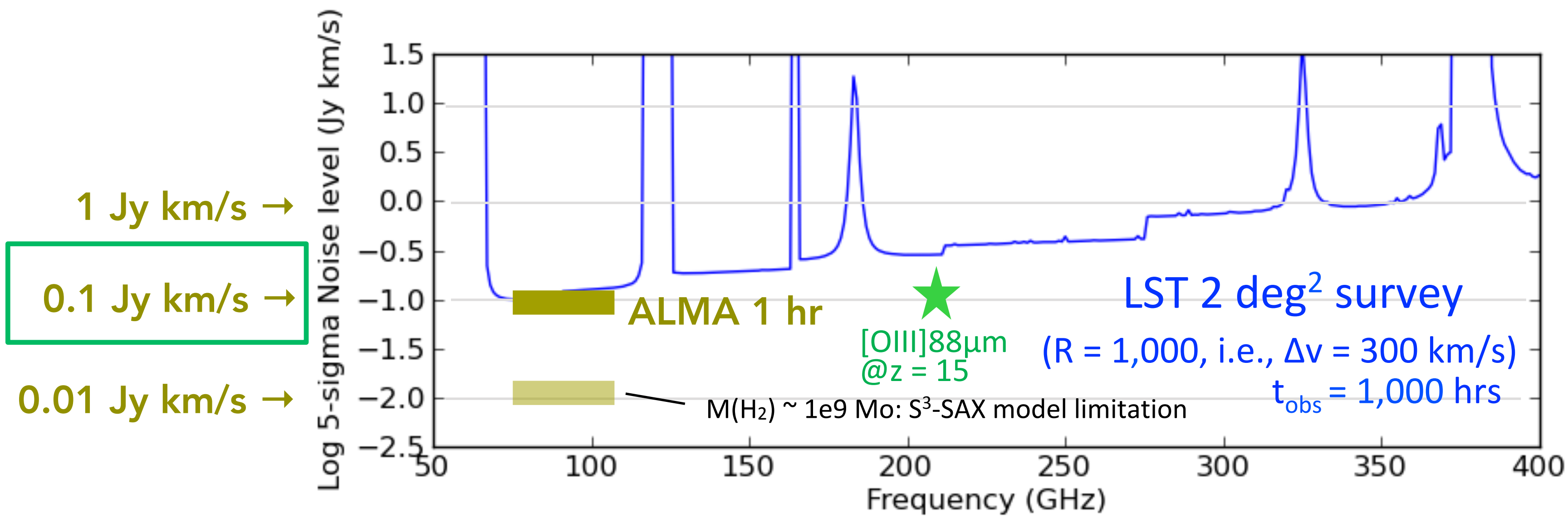
Tamura, Y., + in prep.

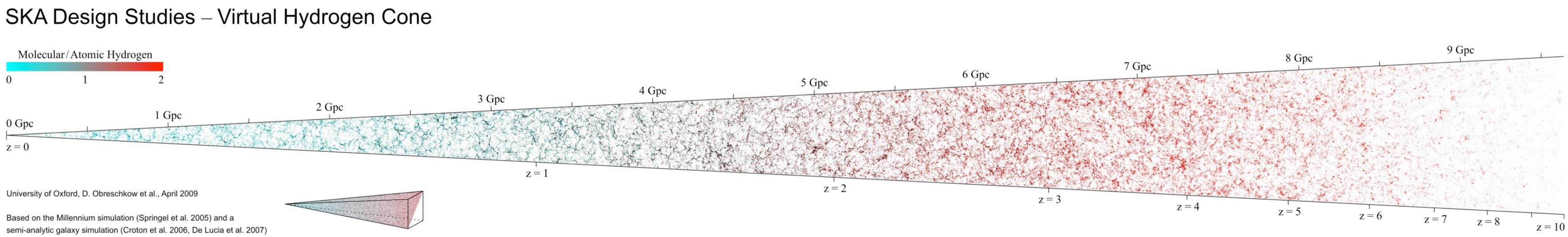
Kawabe, R., + 2016, SPIE

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

LST z = 8 – 15 galaxy survey

- 2 deg^2, but deeper t_{obs} = 9,000 hrs with LST 50m
  => Larger sample of z = 8 – 10 galaxies,
  => accessible to z = 12 – 15 galaxies
- Larger imaging spectrograph (spatial pix > 1000)
  => galaxy clustering/dark haro & luminosity function at z>10





CO/[CII] Tomography

+ [OIII] emitter

RSD Redshift Space Distortion

Verify GR by estimating the growth rate of structure, dark energy problem

LSS Cosmic Large-Scale Structure

Investigate the correlation between dark and baryonic matters from clustering analysis, dark matter problem

CSFH Cosmic Star-formation History

Investigate mass/luminosity function of molecular gas as a function of redshift, “hidden” history of baryonic matter

EoR Epoch of Reionization

Search for earliest “hidden” galaxies, first generation galaxies

Evolution of **Galaxies**

Cosmic evolution of galaxies proved through properties of interstellar medium

Tamura, Y., + in prep.

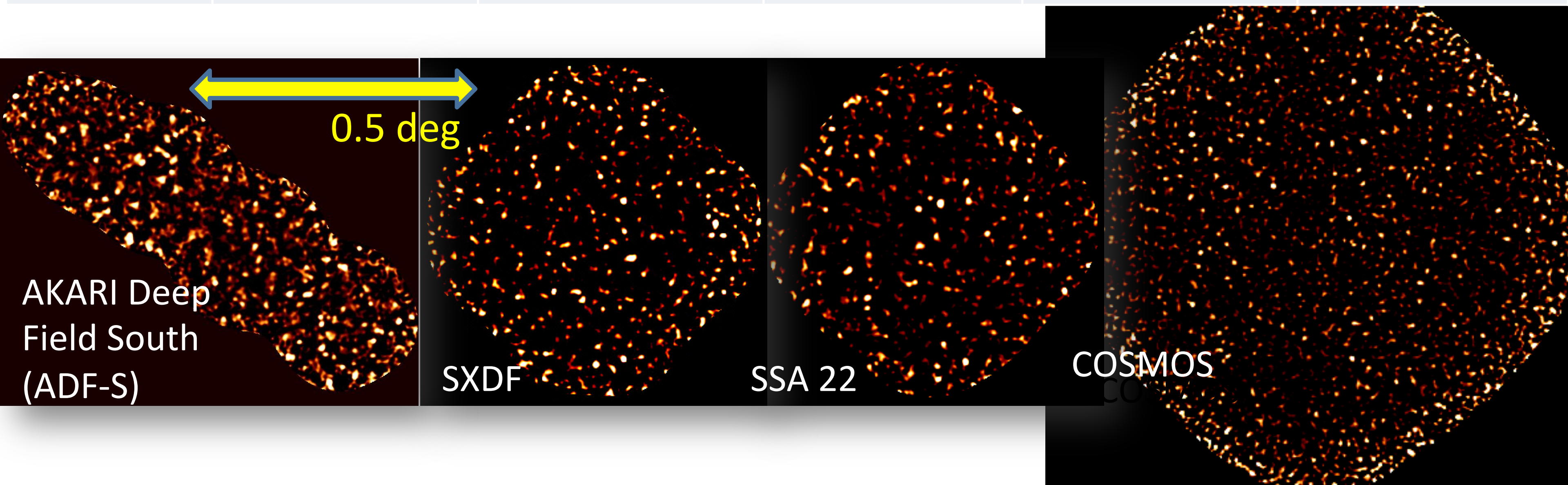
Kawabe, R., + 2016, SPIE

... and serendipitous discoveries

Line emitters, transient and variables, ...

AzTEC/ASTE 1.1mm **confusion limited** deep survey

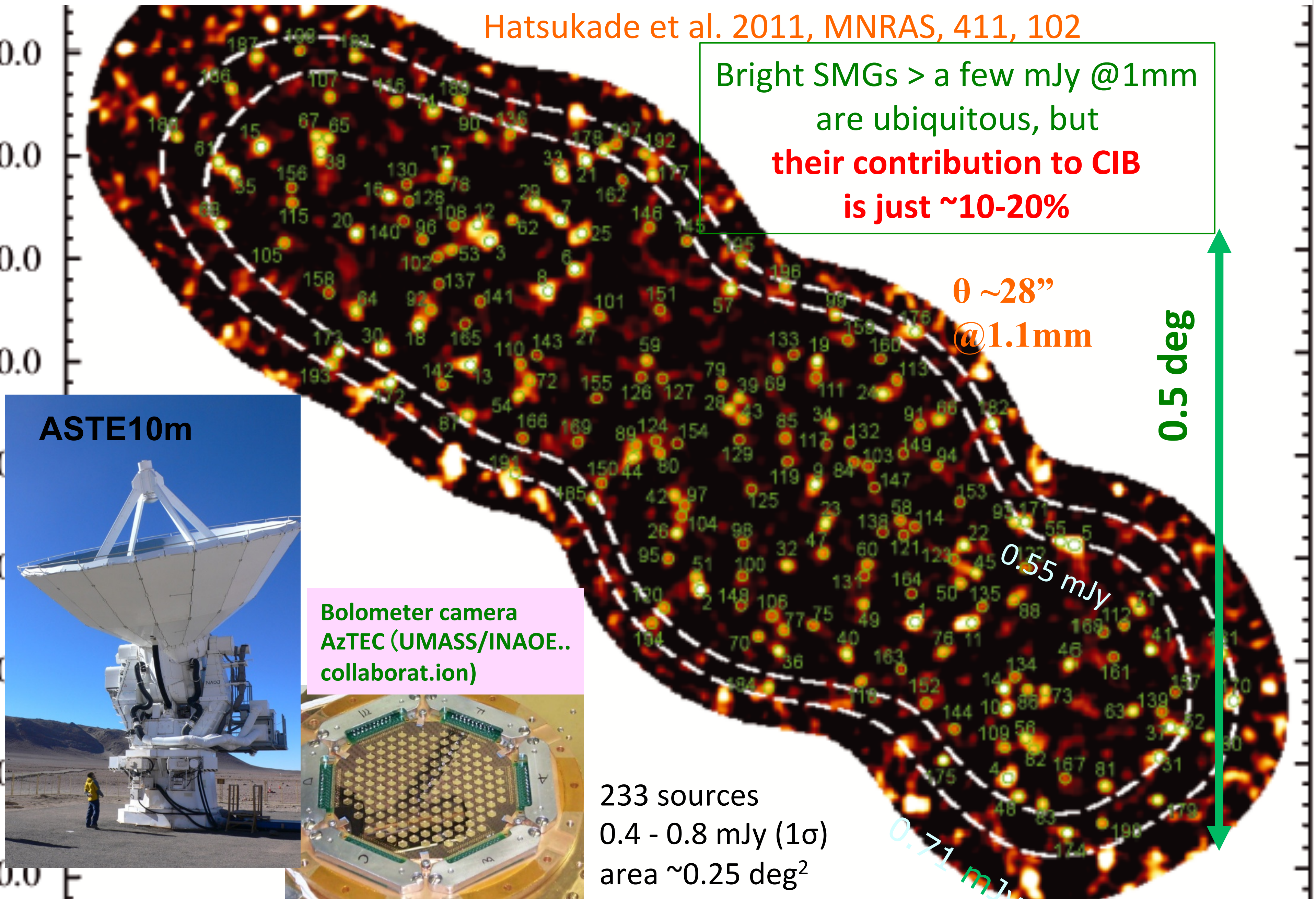
Field	ADF-S	SXDF	SSA22	COSMOS	GOODS-S
Coverage (arcmin^2)	909	954	973	2967	270
Depth (1σ, mJy)	0.4-0.80	0.5-0.9	0.7-1.3	1.2-2.2	0.5-0.7
N sources (>3.5σ)	**233**	**215**	**125**	**205**	**48**
references	Hatsukade+ 2011, MNRAS, 411, 102	Ikarashi+ 2011, MNRAS, 415, 3081	Tamura+ 2009, Nature, 459, 61	Aretxaga+ 2011, MNRAS, 415, 3831	Scott + 2010, MNRAS, 405, 2260



“Submm galaxies” are bright, but..

Hatsukade et al. 2011, MNRAS, 411, 102

Bright SMGs > a few mJy @1mm
are ubiquitous, but
their contribution to CIB
is just ~10-20%

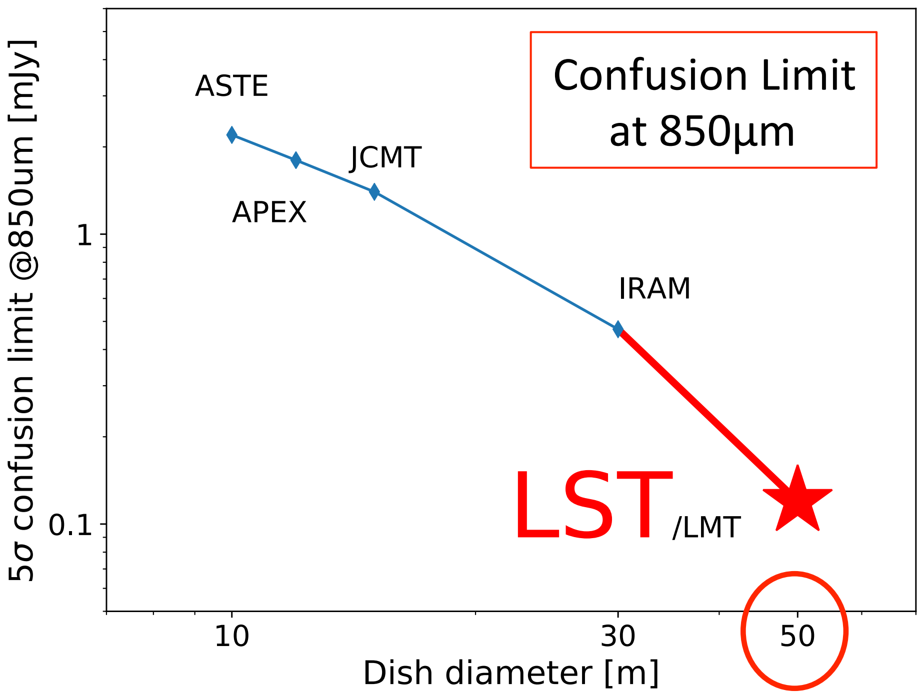


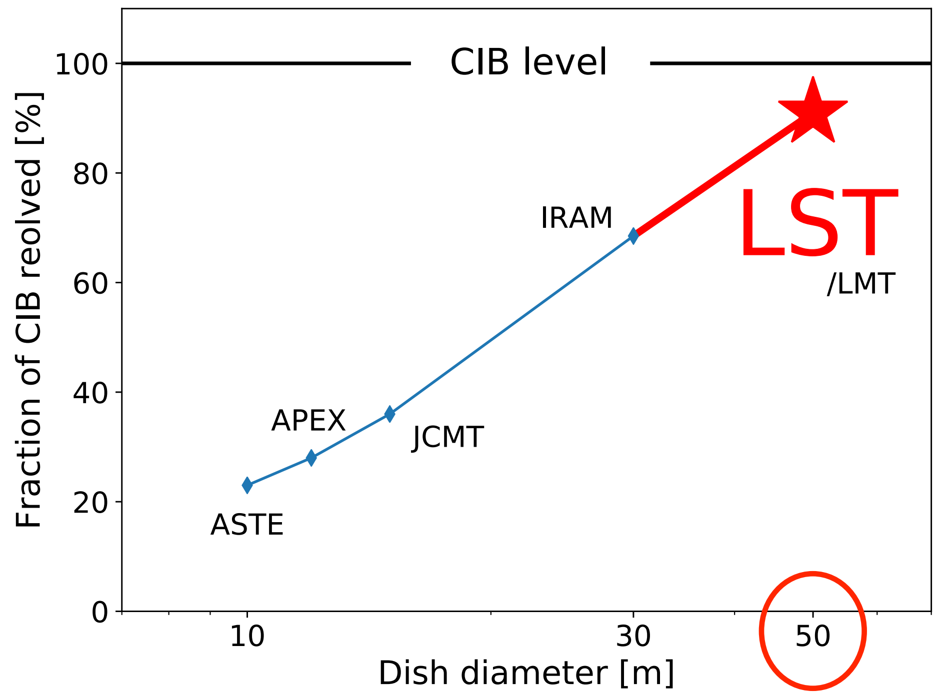
Bolometer camera
AzTEC (UMASS/INAOE..
collaborat.ion)

233 sources
0.4 - 0.8 mJy (1σ)
area ~0.25 deg^2

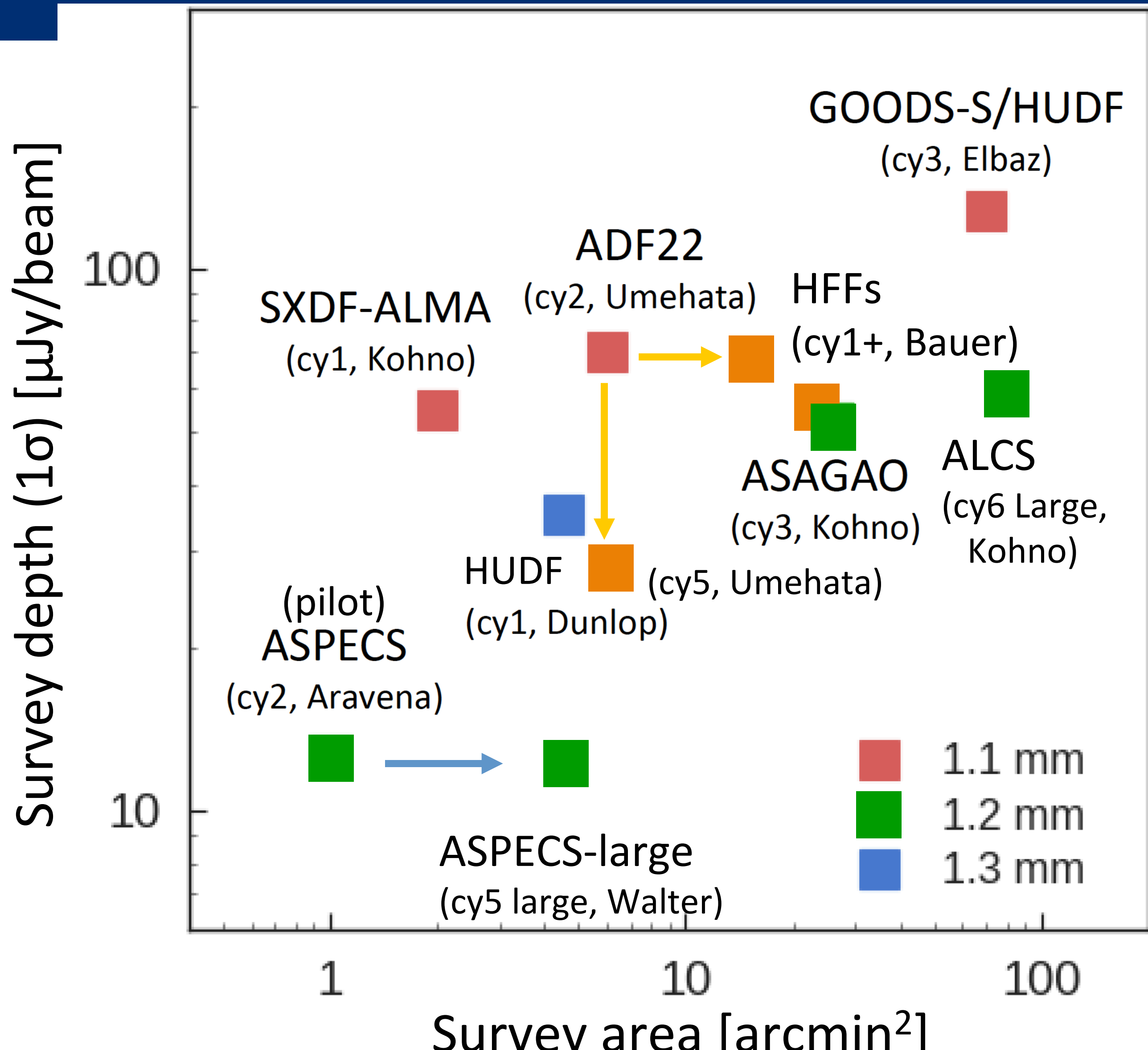
50m LST allows 100% resolving CIB

- Complete Understanding of CIB, i.e., obscured star formation in the universe.





ALMA Deep Fields



z>7のダストを持つ銀河は稀
➔ 大規模探査

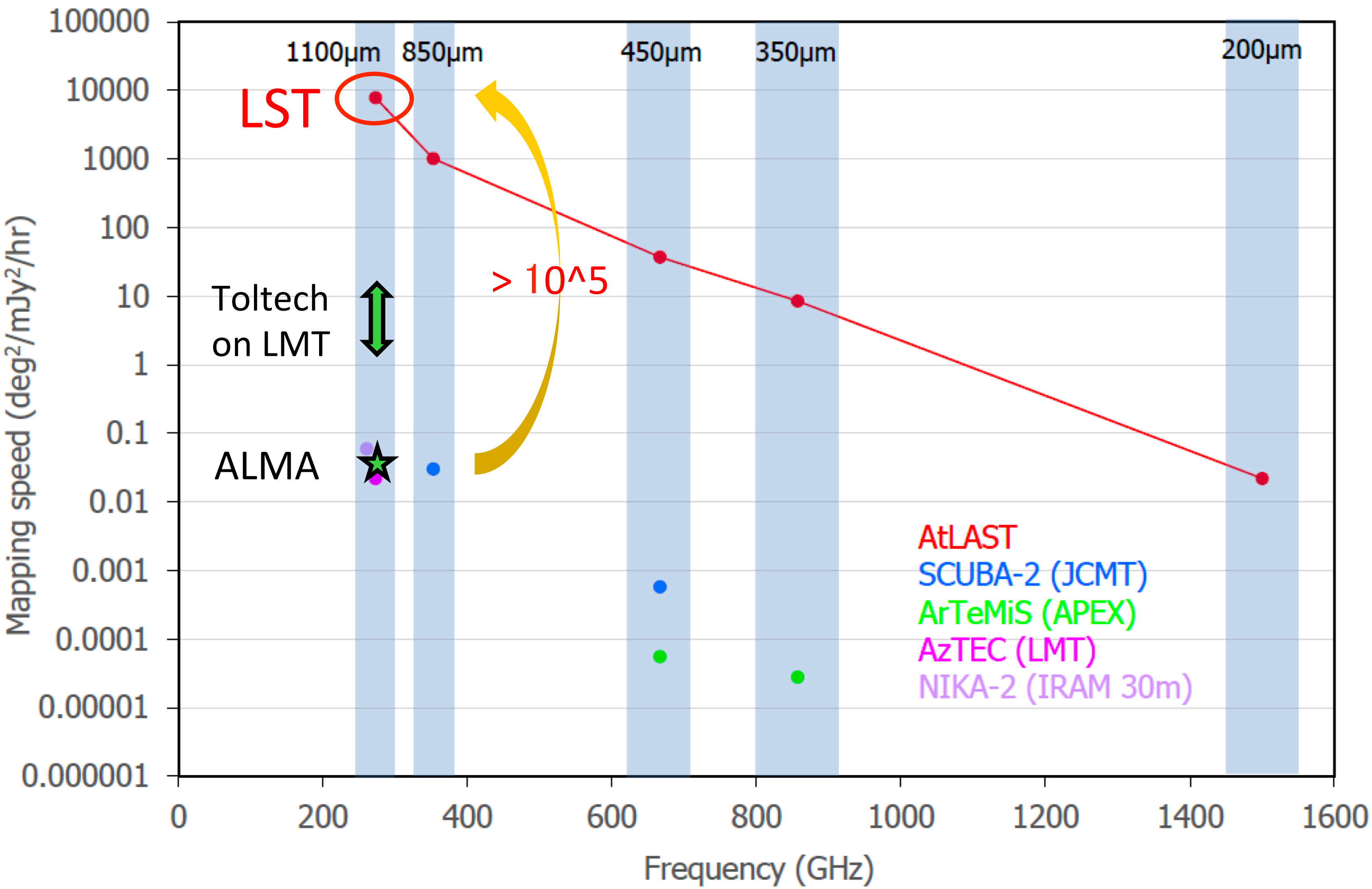
ALMA Cy6 Large Program

ALCS

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

Mapping Speed in Continuum Survey

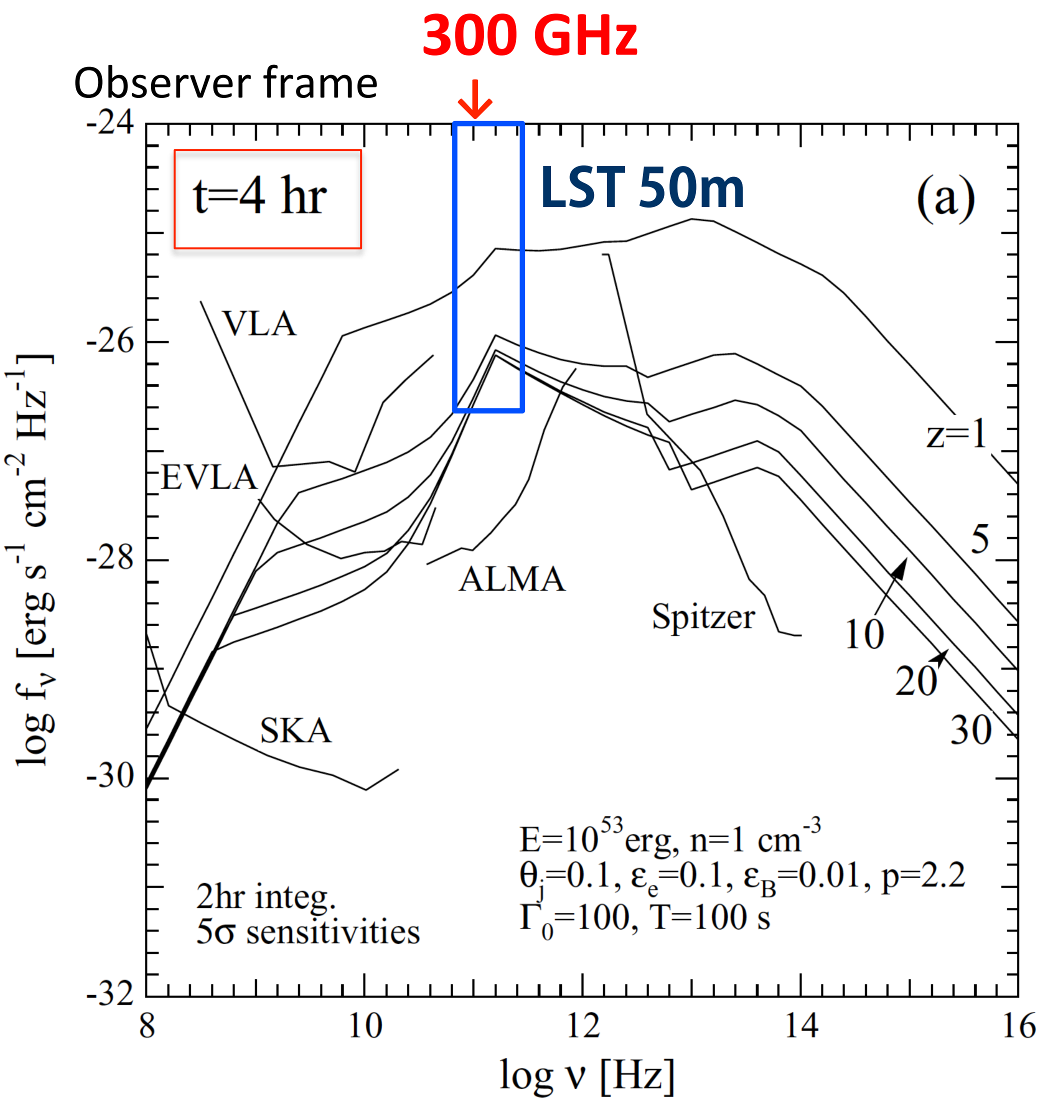
単位時間あたり、ある深さで掃くことのできる面積



Open up Time-domain Science : Detection reverse shock from Long-GRB@z=5-30

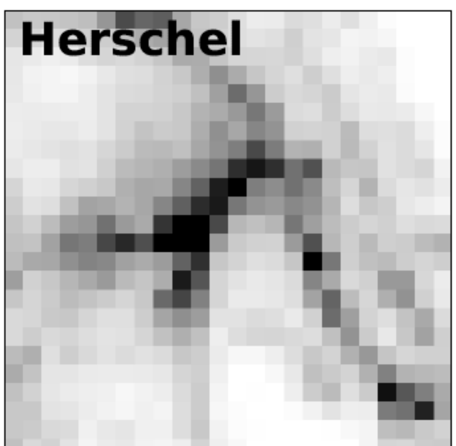
- high-z long-GRBs host reverse shock for several hours to 1 days
- Reverse shock has a SED with peak at submm – to FIR
- Peak ~ mJy
- Possible Sign Post of EoR, most distant objects, first stars etc

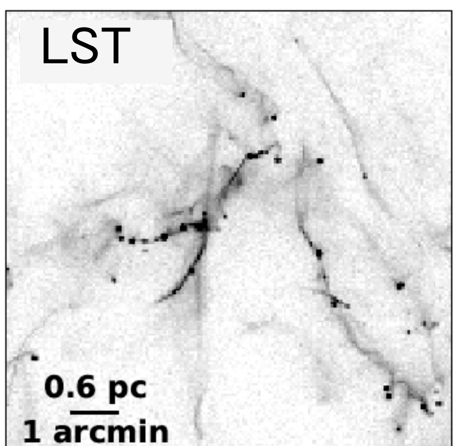
Inoue et al., 2007, MNRAS, 380, 1715

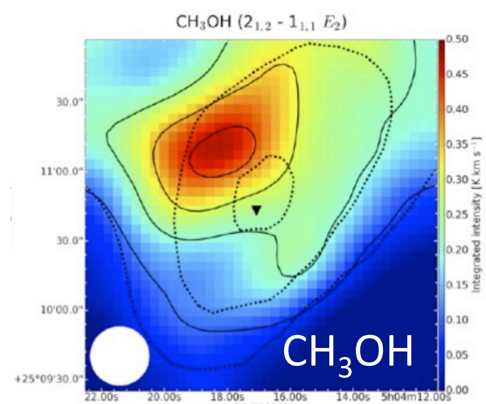


LST Science; Galactic case

1. Continuum (+pol) /Spectral Line Mapping survey
   - IMF vs CMF for various Star forming regions
   - Origin of Brown Dwarfs and Planetary mass objects
2. Spectral Line Mapping survey from starless cores to PPDs
   - Study of chemical evolution and chemical diversity; e.g, formation of COMs and CCMs.

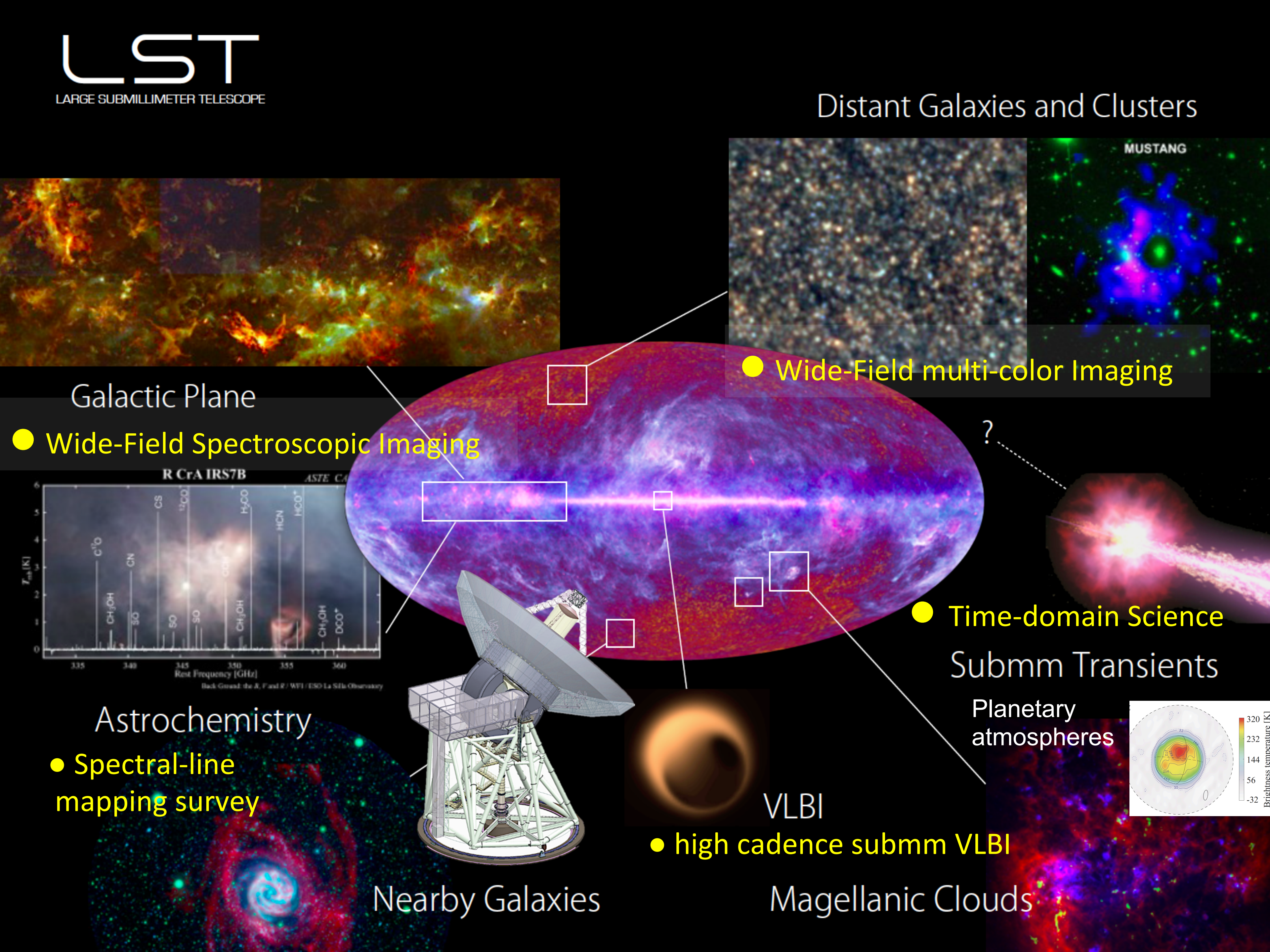






1 arcmin.

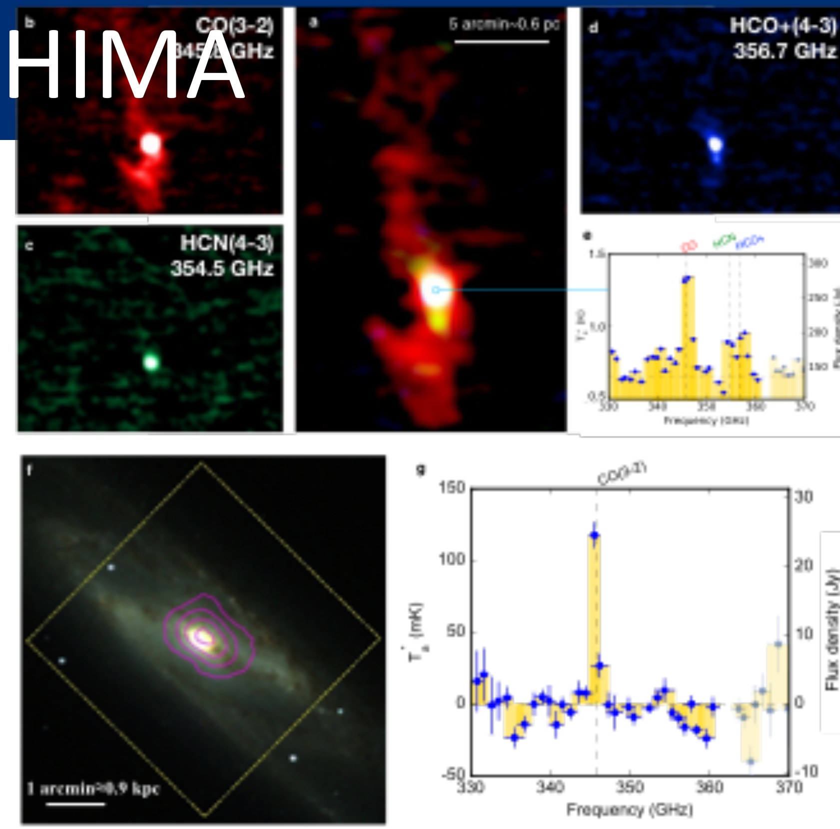
Spezzano et al. 2017, A&A, 606, 82

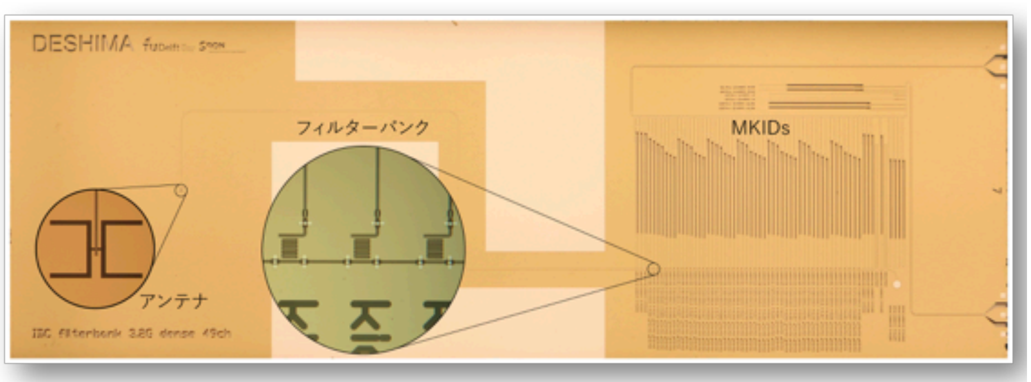


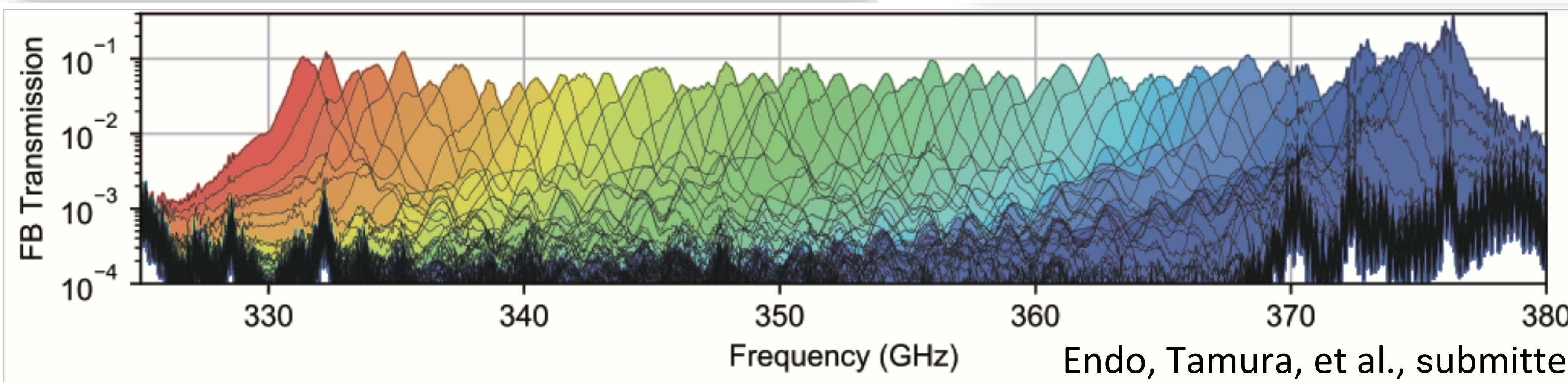
LST
LARGE SUBMILLIMETER TELESCOPE
Distant Galaxies and Clusters
MUSTANG
Wide-Field multi-color Imaging
Galactic Plane
Wide-Field Spectroscopic Imaging
R CrA IRS7B
Rest Frequency [GHz]
?
Time-domain Science
Submm Transients
Planetary
atmospheres
Astrochemistry
Spectral-line
mapping survey
VLBI
high cadence submm VLBI
Nearby Galaxies
Magellanic Clouds

Superconducting On-chip filterbank Spectrometer DESHIMA

- One of keys technologies for 3D exploration/ Tomography; other are SperSpec, MicroSpec
- Demonstrated for the first time on ASTE（Nov., 2017）







Endo, Tamura, et al., submitted

Millimetric Adaptive Optics (MAO) Concept

PI: Yoichi Tamura

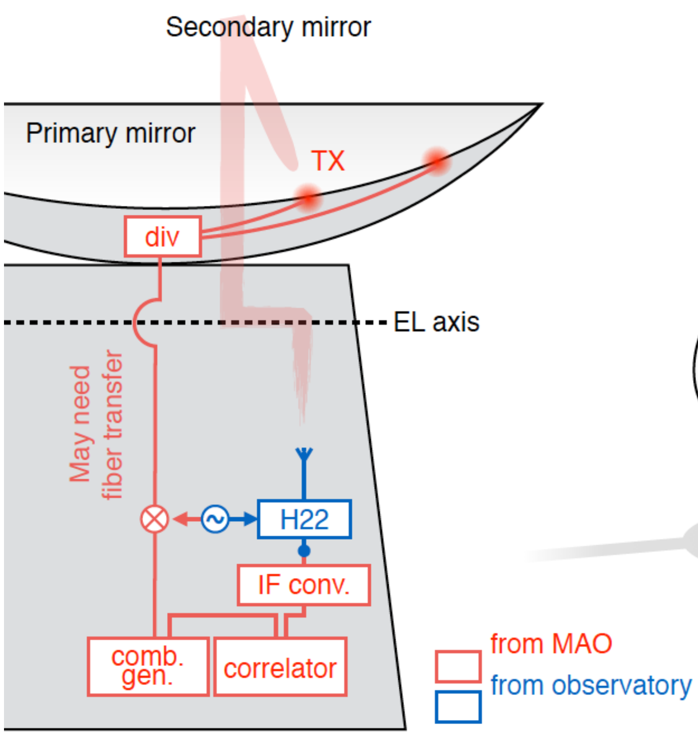
Wave-front Sensor for Large Submillimeter Telescopes

- Transmitters on Dish (ToD) to measure short-timescale deformation of surface
- Correlation with reference signal provides phase change, converted to deformation

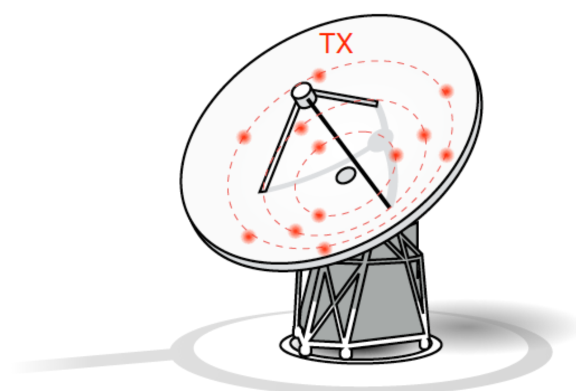
Correction with adaptive primary surface or other optics

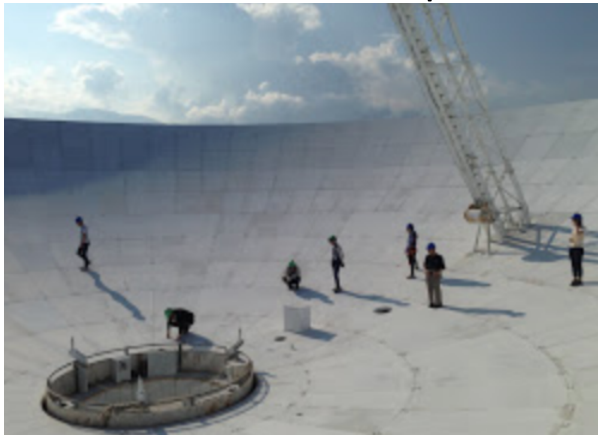
Demonstration on NRO 45m planned

Concept of Wave-front Sensor



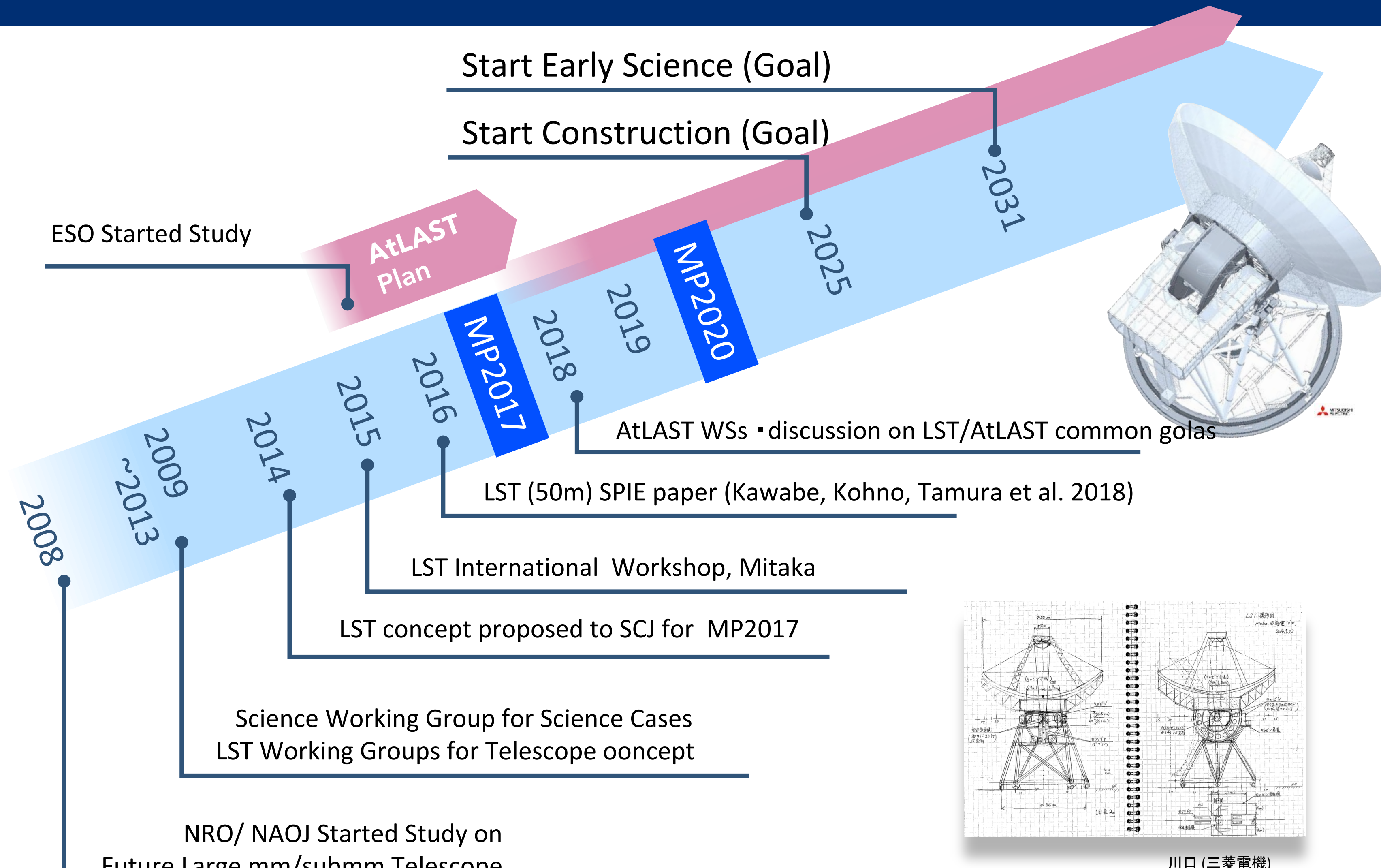
Configuration





Correlator for Wave-front Sensor

Timeline of LST (+AtLAST)



International Collaboration: Support Letter from AtLAST

Tony Mroczkowski
Subm/mm Instrument Scientist/Astronomer
European Southern Observatory (ESO)
Karl-Schwarzschild-Str. 2
Garching, Germany 857
(+49) 89-32006174
amroczko@eso.org

9th January 2019

Ryohei Kawabe
National Astronomical Observatory of Japan
Mitaka, Tokyo 181-8588, Japan

Kotaro Kohno
Institute of Astronomy,
School of Science,
The University of Tokyo,
Mitaka, Tokyo, 181-0015, Japan

Dear Dr. Kawabe and Dr. Kohno,

We write in strong support of your initiative to merge the Large Submillimeter Telescope (LST) and the Atacama Large Aperture Submm/mm Telescope (AtLAST) into one unified project. The participation of the LST experts such as yourselves during the AtLAST workshops in 2018 showed a large overlap in the science goals of the two projects, and has already influenced our design. As a result, we are strongly convinced that the only way forward is to join forces as an ambitious multinational project. We understand this aligns directly with your proposal to the Science Council of Japan for the Master Plan 2020.

Many members of the submillimeter and millimeter community worldwide recognise the unique value that a 50-meter class single dish with a large (> 1 square degree) field of view would bring. The mapping speed attainable with a fully-instrumented large single dish would be over 1 million times that of the full ALMA observatory, and even since the beginnings of ALMA many have argued for the inclusion of a widefield, large single dish. This facility would give us unprecedented access to large-scale, low surface brightness structures, and so would place AtLAST (and the overall mm/submm community) in a privileged position to complement future astronomical facilities working in different wavelength ranges (the SKA, Athena, Lynx, DES, LSST, SDSS V, JWST, LiteBIRD, SPICA, OST, etc.) and multi-messenger astronomy.

As we look forward to the 2020's, and having seen the progress of mm/submm instrumentation over the last decade, it is clear now is the optimal time to move forward, and that the best and only way to succeed is through a multinational partnership.

Our recent workshops at the European Southern Observatory (ESO) and the Royal Observatory Edinburgh (ROE) have shown there is much enthusiasm for the AtLAST project not only inside Europe and the United Kingdom, but worldwide, including members of the Chilean, East Asian, and North American communities.

We thank you very much for leading this crucial effort of proposing to the Science Council of Japan to unify the LST and AtLAST projects, and we look forward to a strong partnership.

Sincerely, on behalf of the AtLAST community,

Frank Bertoldi (Bonn), Claudia Cicone (INAF), Carlos De Breuck (ESO), Simon Dicker (U. Pennsylvania), James Geach (Hertfordshire), Diah Gunawan (U. Valparaíso), Eduardo Ibar (U. Valparaíso), Rob Ivison (ESO), Pamela Klaassen (UK Astronomy Technology Centre), Tony Mroczkowski (ESO), Omid Noroozian (NRAO), Leonardo Testi (ESO), Alwyn Wootten (NRAO)

Strong Support form EU, NA ALMA Community

Sincerely, on behalf of the AtLAST community,

Frank Bertoldi (Bonn), Claudia Cicone (INAF), Carlos De Breuck (ESO), Simon Dicker (U. Pennsylvania), James Geach (Hertfordshire), Diah Gunawan (U. Valparaíso), Eduardo Ibar (U. Valparaíso), Rob Ivison (ESO), Pamela Klaassen (UK Astronomy Technology Centre), Tony Mroczkowski (ESO), Omid Noroozian (NRAO), Leonardo Testi (ESO), Alwyn Wootten (NRAO)

Astronomy and Astrophysics Panel in SCJ (Science Council of Japan) reviewed LST together with other large scale future projects, and finally recommended LST for MS2020 (Master Plan 2020) this year.

International Workshop on Submillimeter Astronomy

February 21-23, 2019
Nanjing China

Focus on Single Dishes

Chinese (PMO) 60-m submm
Telescope at Tibet?
- up to 500 GHz?
- covered by Astro-dome for wind
- site testing at Ali (5800m, 北緯32°)

China-JP collaboration on R&D
planned (btw. PMO/CAS & NAOJ/JSPS)

LMT collaboration

Large Submillimeter Telescope

B4R (2mm): NAOJ/Japanese Univ. collaboration (Installation and commissioning last year)

FINER(2mm-800um): Nagoya-U led Japanese Univ/NAOJ collaboration
- R&D of new spectrometer funded
- preparing a proposal to JSPS (Japan Society of Promotion of Science)

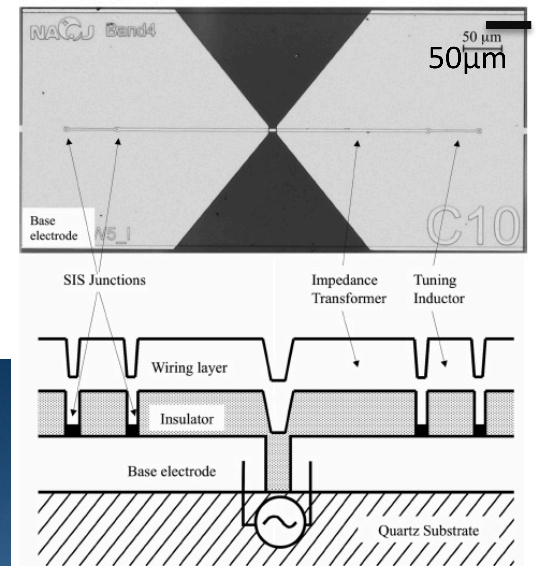
B1R (40 GHz) for LMT: AISAA-NAOJ collaboration for Zeeman etc.
- plan to install on the 45m telescope and test this winter
- move to LMT two or three years later

MOSAIC : SRON/Delft-UTokyo/NAOJ/NagoyaU collaboration (fully funded and under development)
- 5 x 5 spatial array of upgraded-DESHIMA
- covering 185 to 365 GHz in one shot, ~ 500 MHz freq resolution.
- Beam-steering mechanism is optional

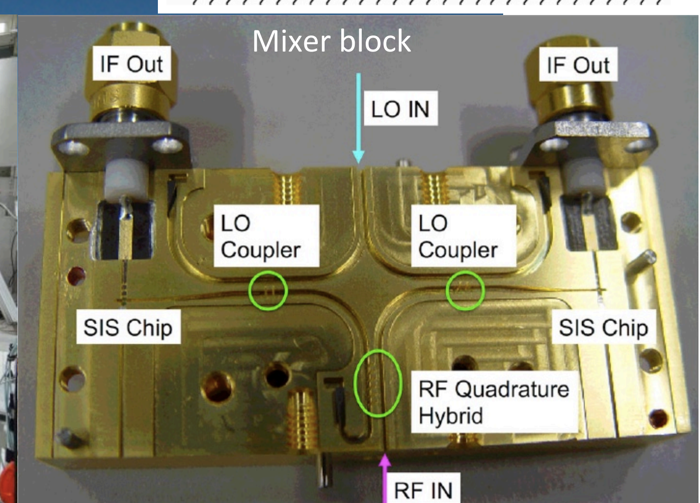
LMT collaboration: Band-4 Receiver (B4R)

- Single beam, dual-polarization, side-band-separating mixer receiver for 2-mm and + spectrometer system
  for redshift determination via CO detection, CO-SLED study
- Frequency (RF) range: 125 − 163 GHz
- Instantaneous bandwidth for spectrometer: 10 GHz in total ➔ 15 GHz ➔ 20 GHz ? (depending on funding..)
- Spectral resolution: df = 88.5 kHz or dv = 0.18 km/s @2mm

SIS junctions for ALMA Band-4
Asayama et al. 2014, PASJ, 66, 57



B4R inside LMT RX cabin



FINER for LMT

Far-Infrared Nebular Emission Receiver

PI: Yoichi Tamura

LST Large Submillimeter Telescope

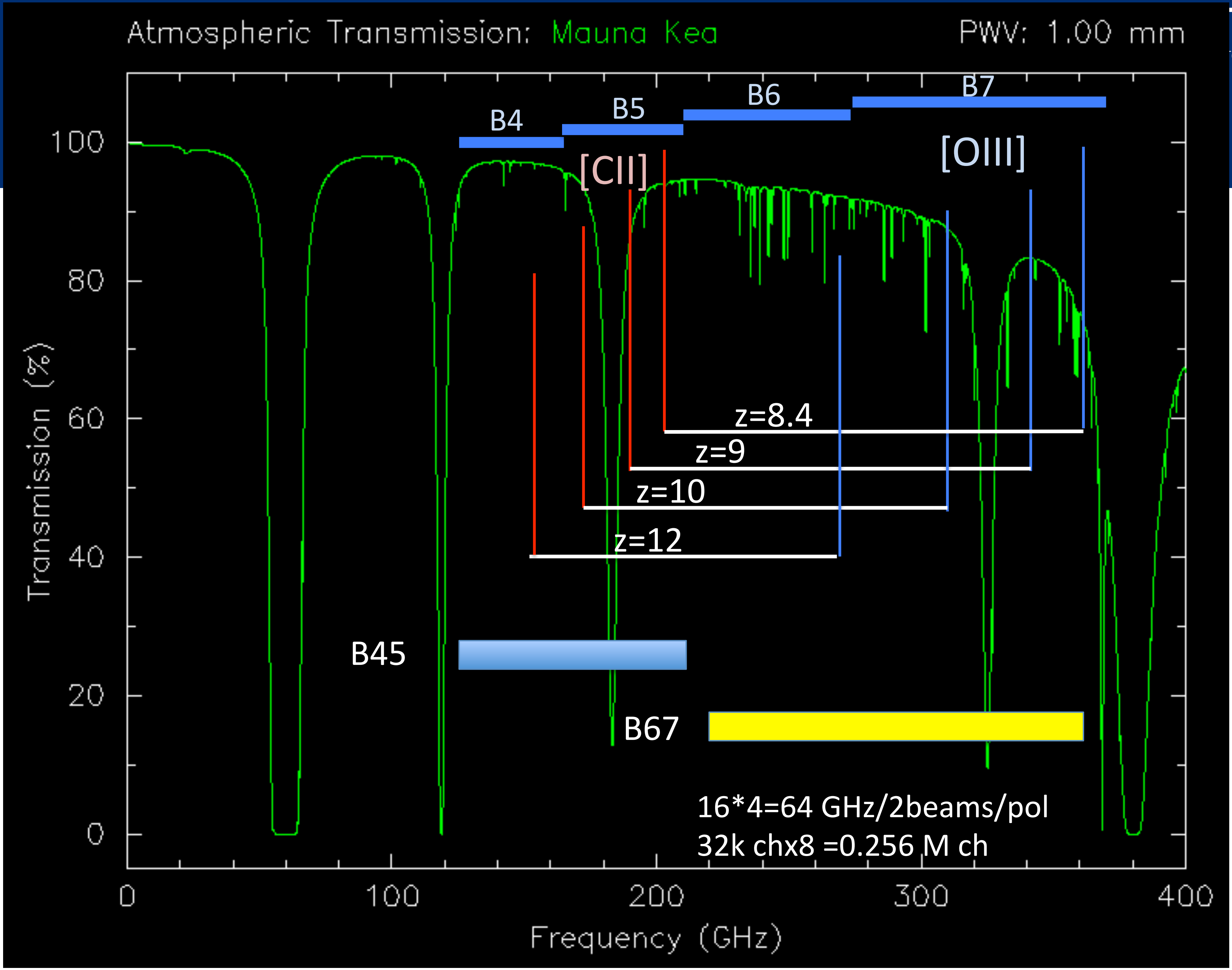
- 125-365 GHz Heterodyne receiver (B4 - B7) for LMT: combination of two new SIS mixers, B4+5, B6+7
- Aiming at pioneering EoR (z~10) with [OIII] 88 μm and [CII] 158 μm in the northern sky with many candidates
- LMT (~ 40% of ALMA in correcting area) can compete with NOEMA (also ~40 % of ALMA)
  - the LMT site is better than the NOEMA site
  - Correcting area are comparable, but LMT surface worse a bit: achieving ≤ 75 μm (rms) in LMT is desired
- (Optional) Millimetric Adaptive Optics is needed for the LMT together with Acitive Surface?

Ultra-Wideband Spectrometer for FINER: OCTAD-S

LST
Large Submillimeter Telescope

ELECS (JP company)

- Hittite ADC
- > 16 Gsps, 3 bits
- FFT with FPGAs
- 4 ADCs, 32k-point FFT outputs for each ADC
  (> 8 GHz Bandwidth and 16 k freq. channels)
- Flexible spectral data outputs with FPGAs
- (digital or LO offset) sideband separation capability will be implemented for IRR < - 30 dB
- R&D funded recently

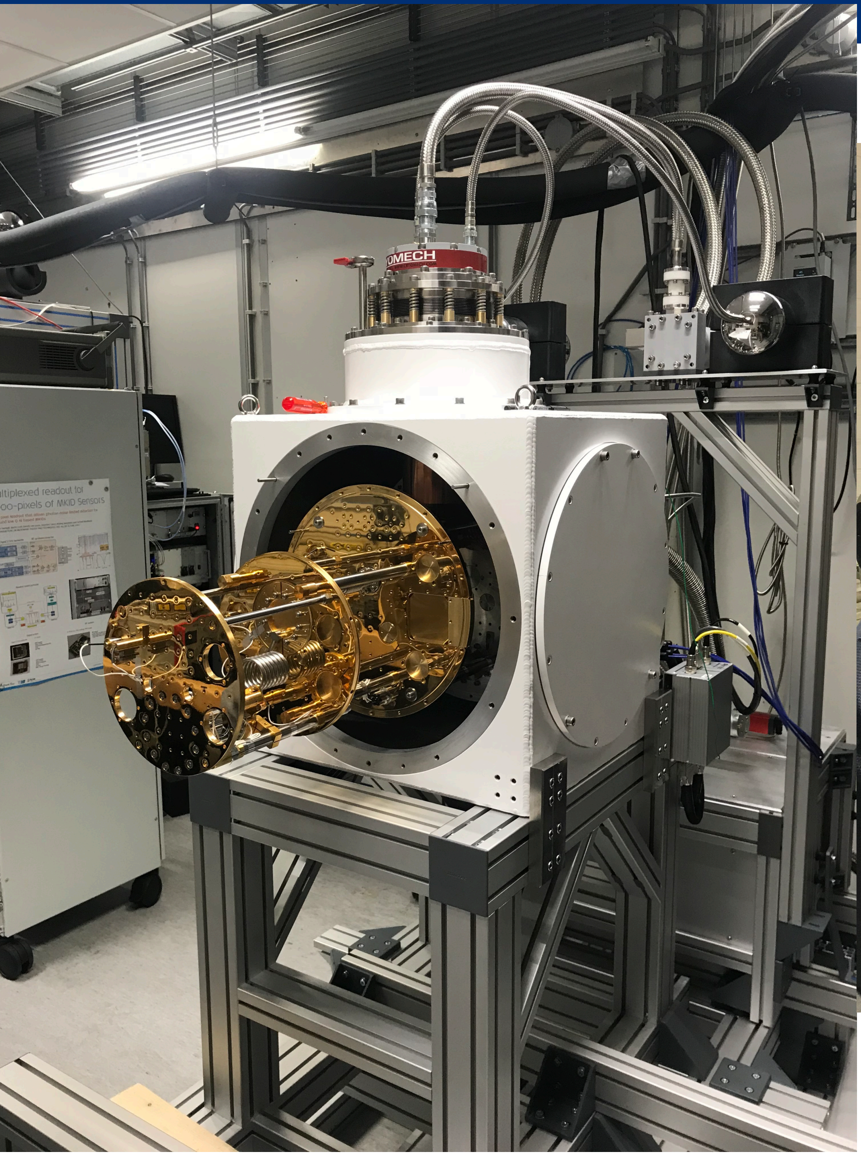


Atmospheric Transmission: Mauna Kea
PWV: 1.00 mm
B4
B5
B6
B7
[CII]
[OIII]
z=8.4
z=9
z=10
z=12
B45
B67
16*4=64 GHz/2beams/pol
32k chx8 =0.256 M ch
Transmission (%)
Frequency (GHz)
0
20
40
60
80
100
0
100
200
300
400

MOSAIC on LMT proposed

- Proposing to the on-chip imaging-spectrograph MOSAIC on LMT 50m.
- Instantaneous frequency coverage: 185 – 365 GHz (covering 180 GHz width in one shot!)
- With a coarse resolution R = f/df ~500 (dv ~600 km/s)
- 5 x 5 = 25 spatial pixels (350 detectors per pixel, 8,750 detectors in total)
- The proposed target year of installation: 2021/22
- **Suited for follow-up of AzTEC & Toltec (and other bright submm) sources** Note: beam steering will be in the 2nd generation MOSAIC
- 25-beam DESHIMA/MOSAIC on LMT is >10 times more efficient than ALMA in blind search for line emitters
- Fully funded by Dutch & Japanese grants (ERC and JSPS grants, > 1 M Euro each)

MOSAIC cryostat@TU Delft



Jochem Baselmans (MOSAIC-PI)

Akira Endo (DESHIMA-PI)

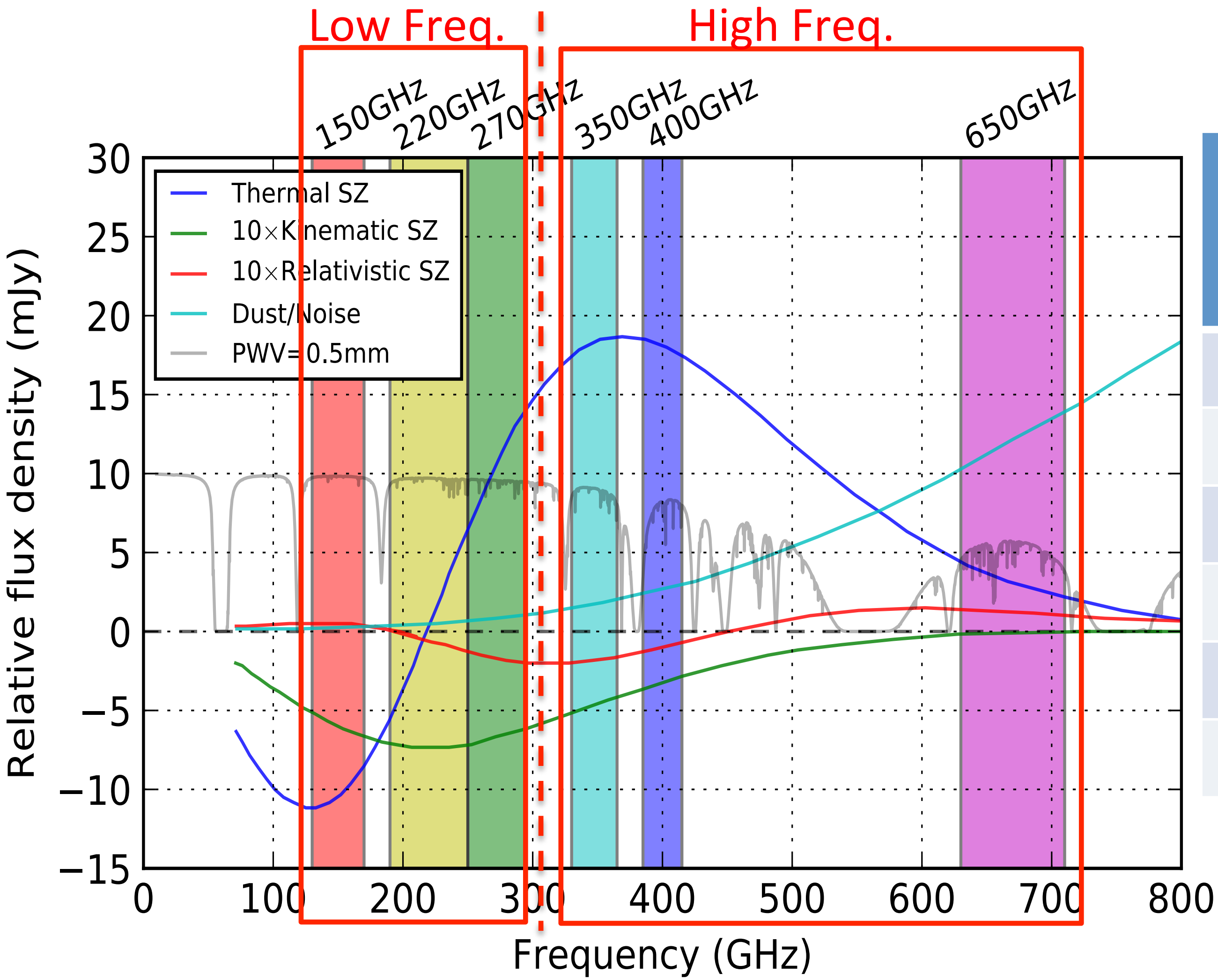
Oct. 2018

Multi color camera

3 color multichroic x 2 focal planes ➔ 6 colors

- SZE of groups, clusters, WHIM, +...

PI: Tai Oshima (ATC, NAOJ)

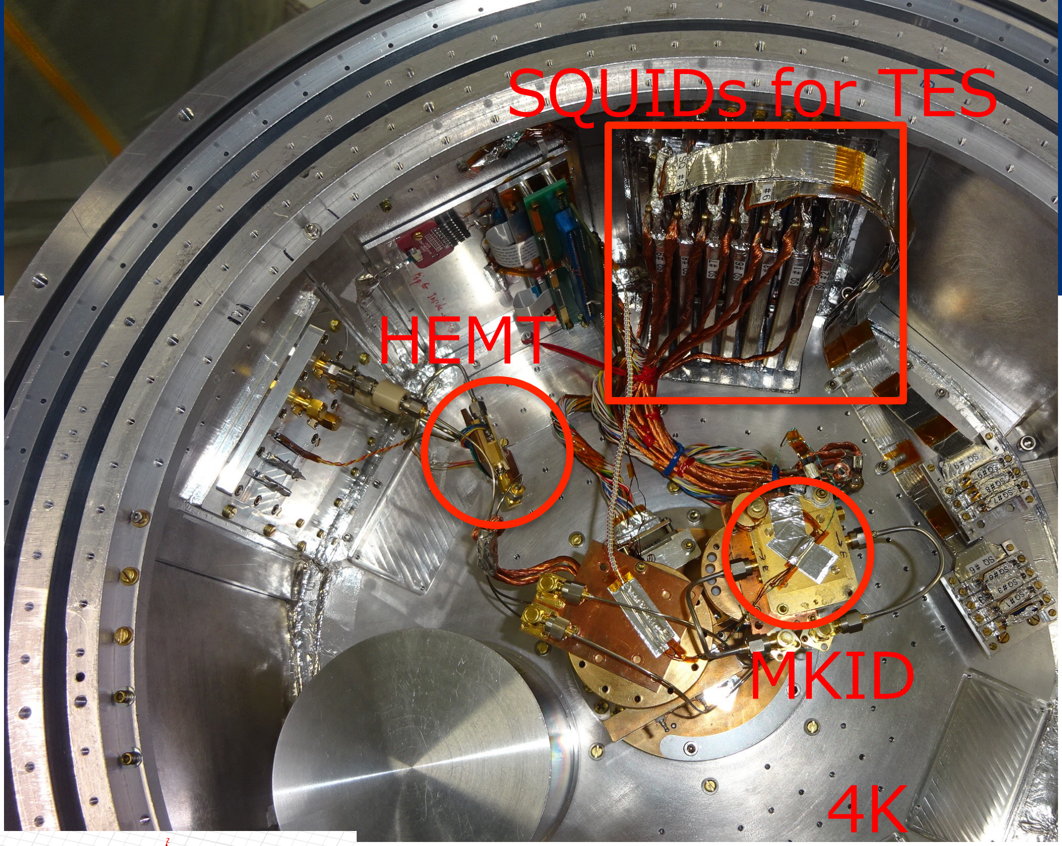


Band (GHz)	FWHM @10mϕ (")	N_{beam}
135-160	51	91
180-245	36	91
251-294	28	91
330-365	22	271
390-420	19	271
630-700	11	271

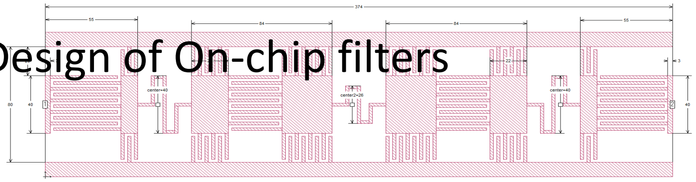
Development items for Broader & Multi bands

2019
- Vacuum window (NAOJ
- Horn array (NAOJ)
- Planar OMT (NAOJ)
- On-chip filters (NAOJ)
- MKID Detector (RIKEN/NAOJ)

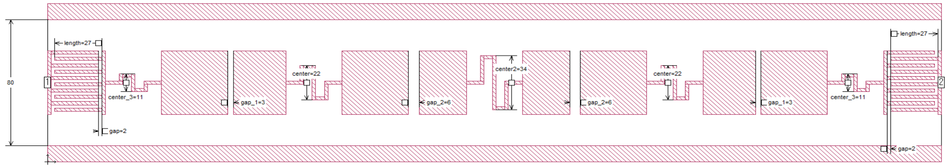
2020
- Test of Integrated OMT + on-chip filters + MKIDs (NAOJ)



Design of On-chip filters

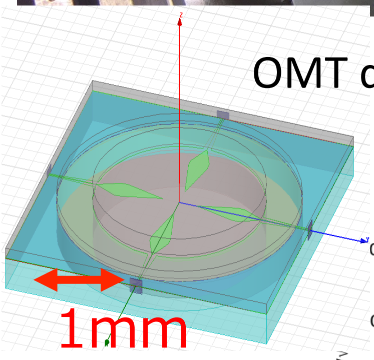


150GHz: 80µm x 374µm

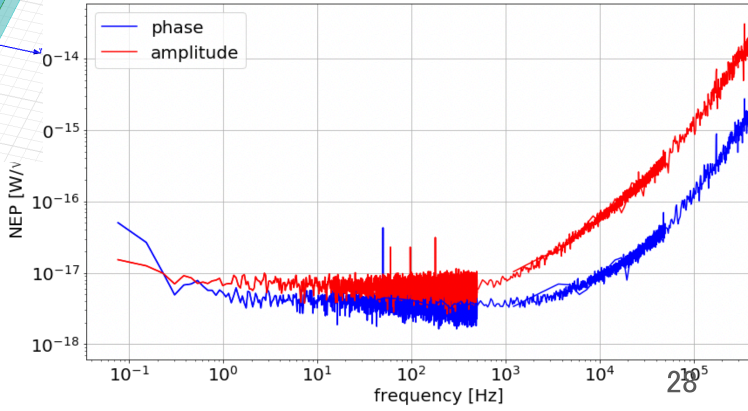


270GHz: 80µm x 510µm

OMT design



Read-out Test of MKIDS



Summary

- Future large submillimeter telescopes very much desired in the mm/submm community world wide
- Integrated efforts in Asian regions necessary to realize one or two large telescopes as well as world wide collaboration

  - developing science cases; i.e., key science
  - developing key technologies, 3D-cam, MAO, etc
- JCMT/ASTE and LMT/45m can enhance single dish science and keep our community active, and would lead us to the future