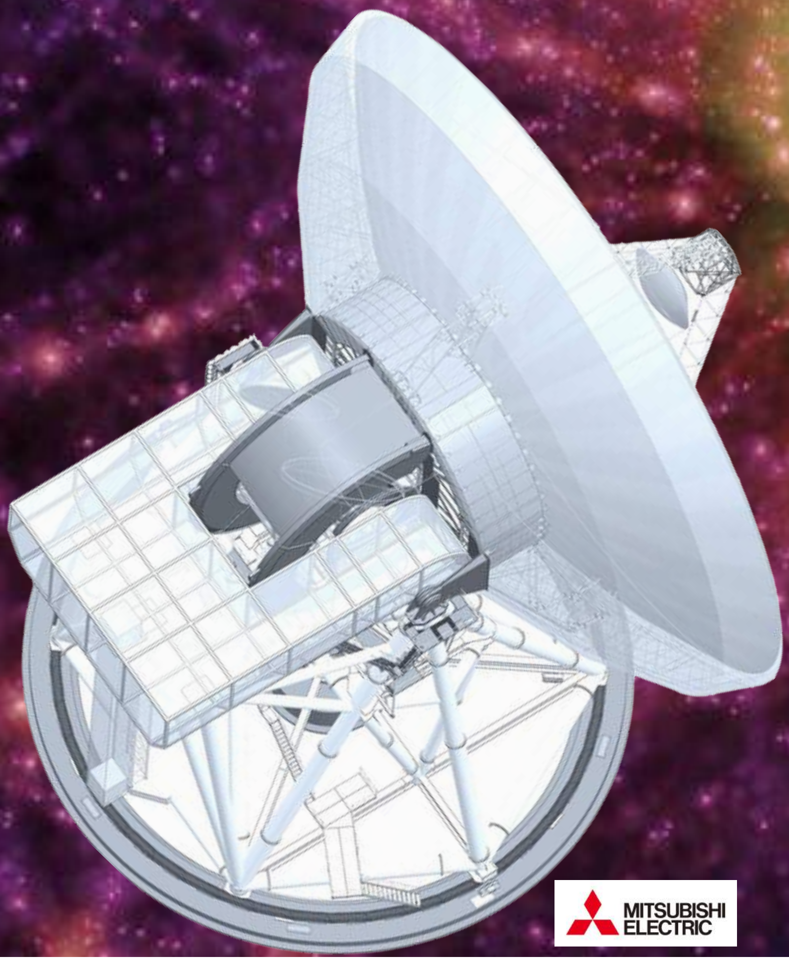
LST

LARGE SUBMILLIMETER TELESCOPE

New 50-m class single dish telescope

15.6 Mpc/h

# *Large Submillimeter Telescope (LST)*




Ryohei Kawabe, Tai Oshima, Shun Ishii (NAOJ)

Kotaro Kohno, Tatsuya Takekoshi (U. Tokyo),

Yoichi Tamura (Nagoya U.) and LST Working Group


MITSUBISHI ELECTRIC

# *Overview*

✦ The LST is a new telescope optimized for

- wide-area imaging and spectroscopic surveys in the freq. range of 70-420 GHz allowing exploration of universe in 2D and 3D
- also achieving high-cadence performance for transients

✦ LST targets observations at higher freq. up to 1THz, using an inner high-precision surface (under-illumination) to enhance science

✦ Through exploitation of its synergy with ALMA, the LST will contribute research on a wide range of topics in astronomy and astrophysics, e.g., chemistry, star formation, SZ, VLBI,..

✦ Basic Concept, Specs., Key Sci & Instrument, Recent Progress etc. introduced

# Chronology of LST

LARGE SUBMILLIMETER TELESCOPE


Natural Evolution

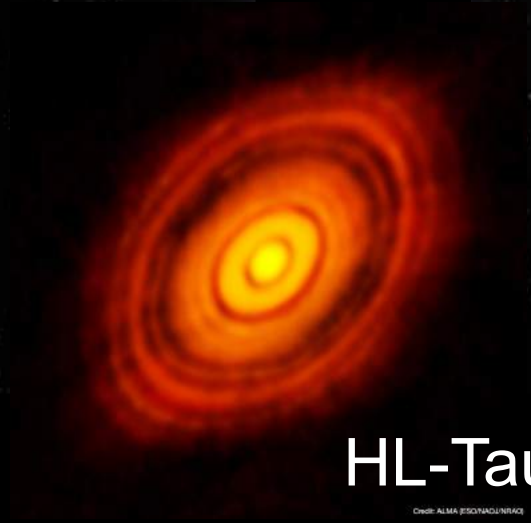
- Started as a future plan of NRO (45m/ASTE) in 2008/2009
- Exchanged basic idea with JP community and outside potential collaborators; science, spec., and instruments
- Science case has been investigated in WG since Jan. 2010
- Proposed a tentative plan as one of medium-scale plans to Science Council of Japan (SCJ) in 2011
- Concept and Science case updated in 2014/2015 based on Feedback from SCJ and further discussions
- (will be proposed to SCJ for Master Plan 2020)
- Discussion with AtLAST/EU started 2018

# *ALMA opens new era*

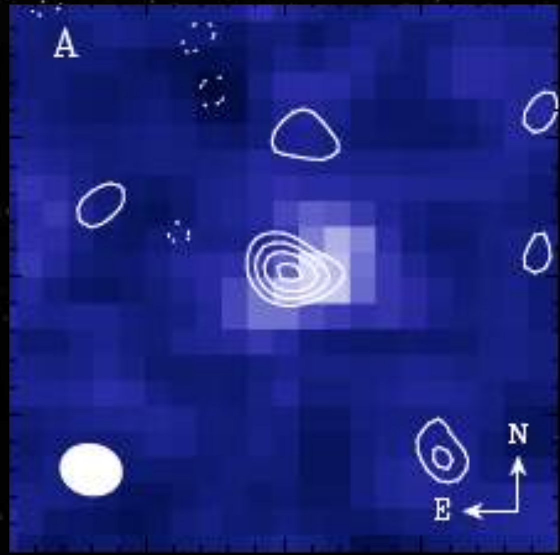
LST will facilitate new discovery space complementary to ALMA

High Angular resolution

High sensitivity




HL-Tau




[OIII] at z= 7.2

Time domain Science

Ultimate Wide Field Imaging

Instantaneous Wide Frequency Coverage

Pursue new “Dreams”

Incubate Future Science

> Spectroscopic Imaging in 3D of Early Universe

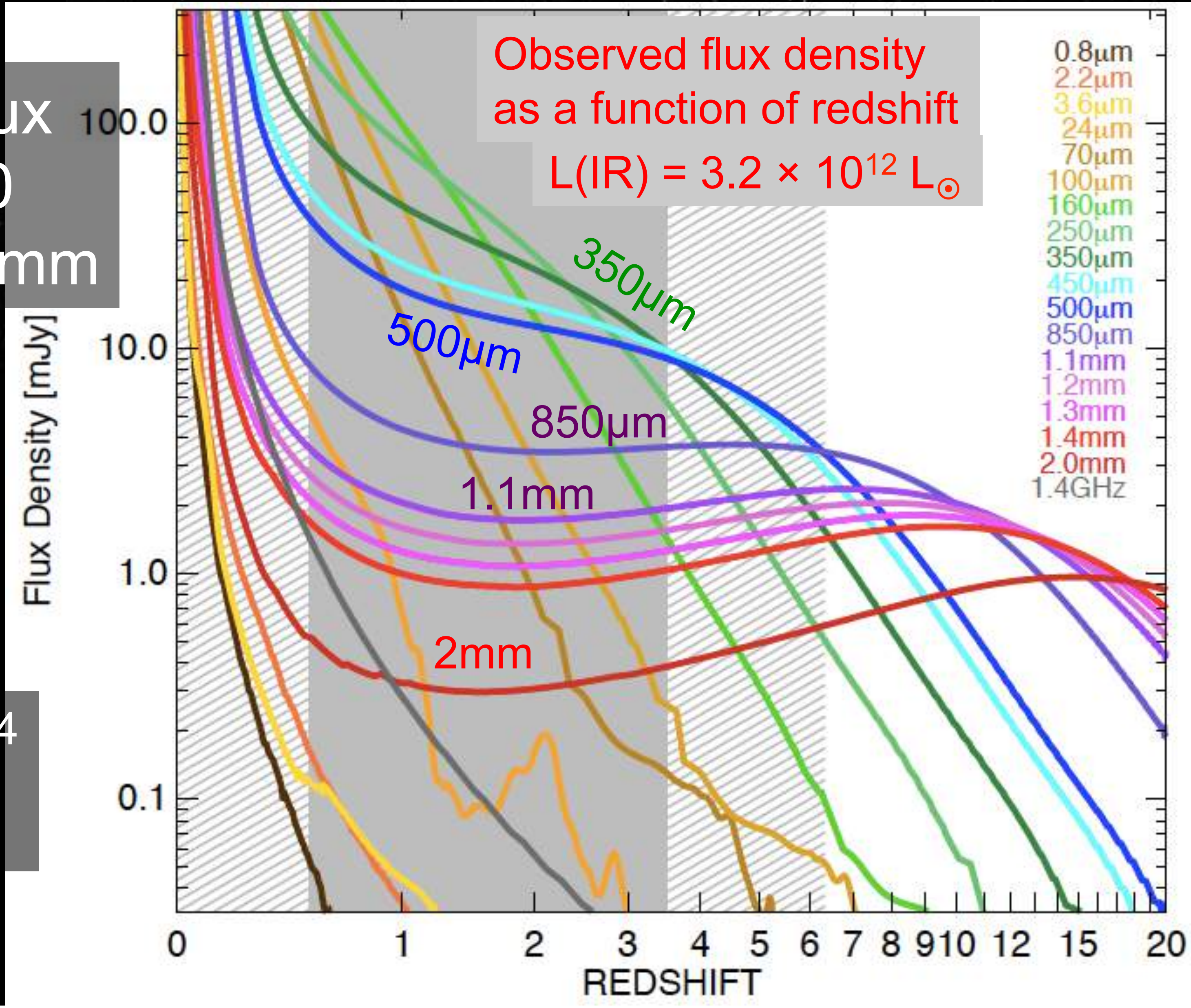
> Spectroscopic & Polarimetric Imaging: Dust Properties & B-field

# *Strong negative K-correction @mm/submm gives uniform selection function for high-z dusty galaxies*

Almost flat flux for 1 < z < 10 around λ ~ 1mm

λ = 850 μm
1.1 mm
1.3mm
(also 750μm)

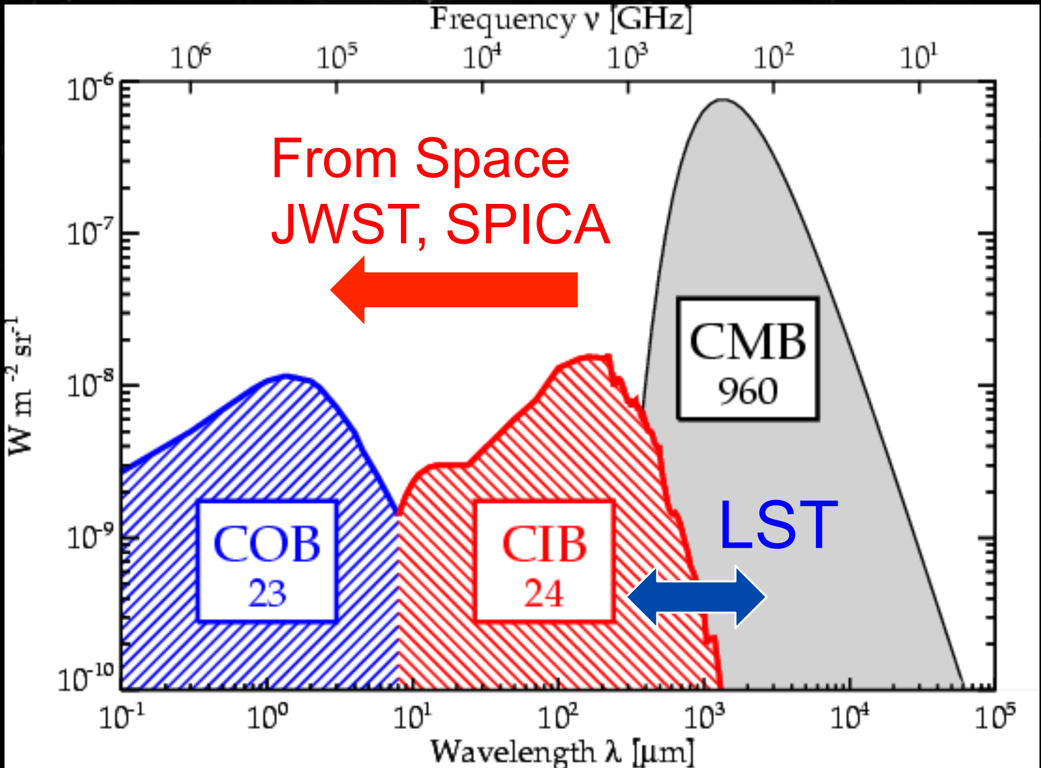
Casey et al. 2014
Physics Reports
541, 45



# Resolve CIB in 2D & 3D

LST
LARGE SUBMILLIMETER TELESCOPE

Cosmic IR Background (CIB) as 2nd Major component

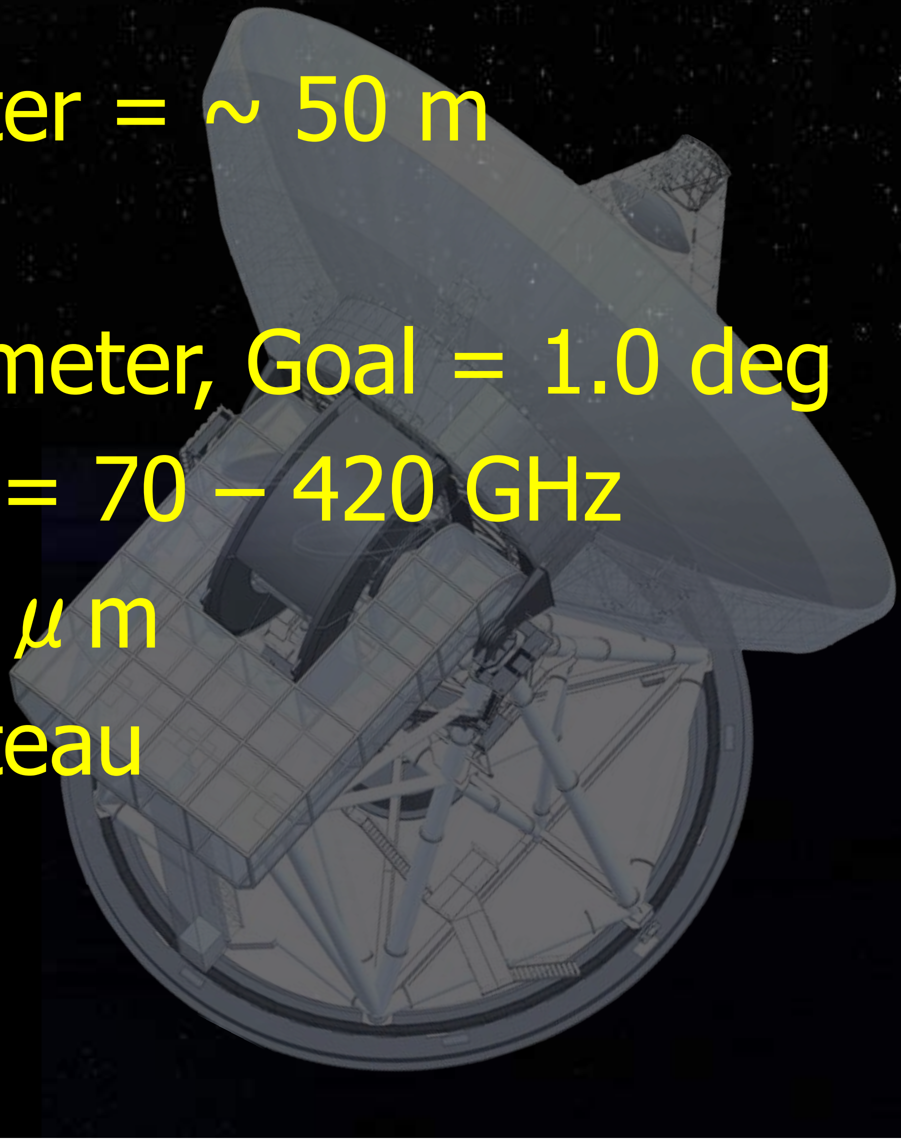



CMB or CMB-pol correlates with CIB discrete sources via ISW or gravitational lensing?

- Spatially Resolving CIB to DSFGs down to LIRGs
- Redshift Search of DSFGs and LSS study via CO/[CII] Tomography; can we find galaxies in EoR?
- Search for Dusty Sources (Proto-QSOs) powered by AGNs via CO-SLED
- Cosmic SF history together with History of SMHB formation/evolution can be investigated
- Dust/Metal Production

LARGE SUBMILLIMETER TELESCOPE

# Basic Concept
## :Tentative Specifications



- ✦ Large Aperture: Diameter = ~ 50 m
- ✦ Large FOV
  : F.O.V = 30 arcmin. diameter, Goal = 1.0 deg
- ✦ Main Frequency Range = 70 – 420 GHz
- ✦ Total surface rms ≤45 $\mu$ m
- ✦ Possible site; ALMA plateau

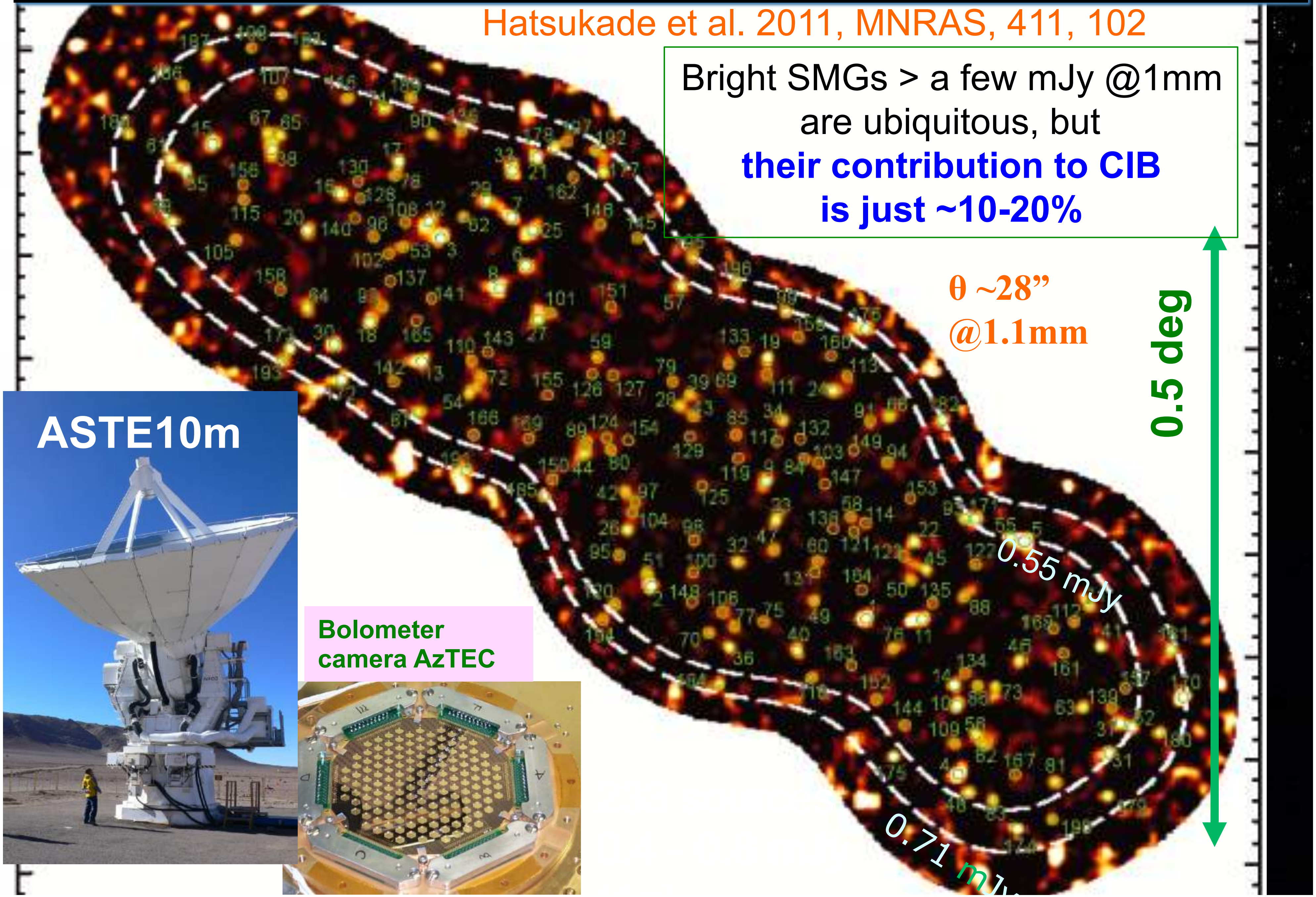
# *Why 50 m diameter?*

- ✦Larger dish, less confusion noise
- ✦Less confusion noise allows us to resolve majority (> 50 %) of CIB contributors at mm to submillimeter wavelength with uniform selection function
- ✦Make it easy to identify confident counterparts in Opt/IR images with ~ 4″ beam (850µm/350 GHz)
- ✦Better sensitivity for point-sources and transients

# “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%**

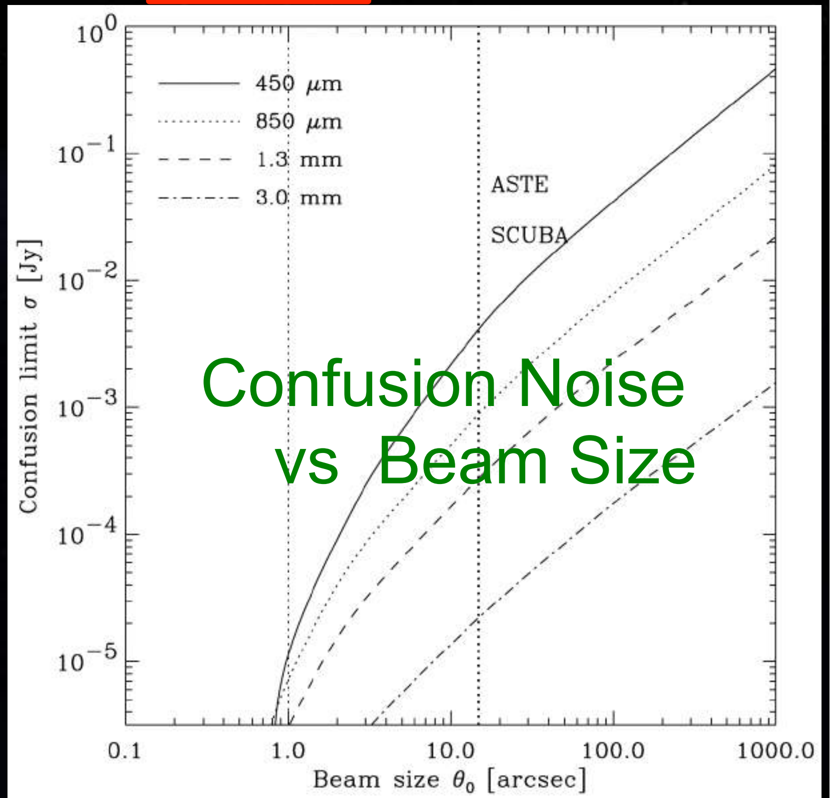


LARGE SUBMILLIMETER TELESCOPE

# *Merit of Large Dishes*

| | | ASTE | CCAT | 50m | 50m/CCAT |
|---|---|---|---|---|---|
| Source Confusion[a] | $\propto D^{-1.4}$ | 1 | 1/3.6 | 1/10 | (1/2.6) |
| Spatial Resolution | $\propto D^{-1.0}$ | 1 | 1/2.5 | 1/5 | (1/2) |
| Survey Speed[b] | $\propto D^2$ | 1 | 6 | 25 | (4) |
| Speed of pointed obs. (for point-like sources) | $\propto D^4$ | 1 | 36 | 600 | (16) |

LMT in Mexico can also improve source confusion by 10x!

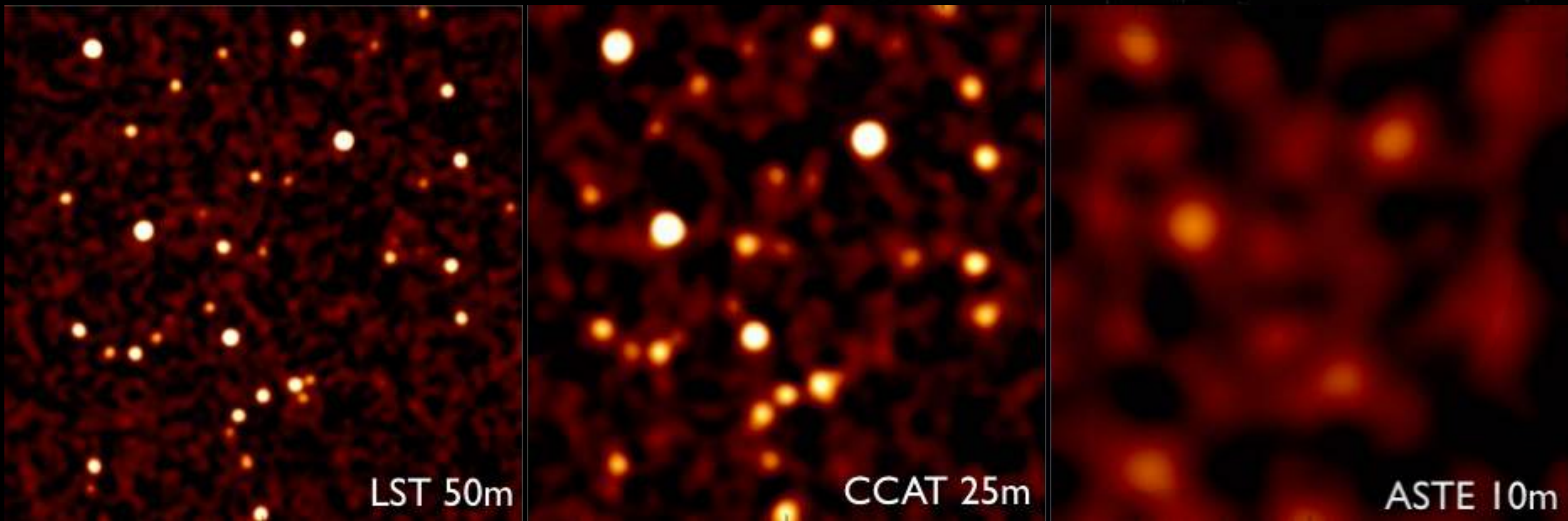



a. Takeuchi, RK, Kohno+ 2001

b. Evaluated as survey area covered with fixed observing time and depth, e.g., in unit of deg^2/hours

# *Confusion Noise: rough estimate*

- Confusion Noise $\propto D_{tel}^{-1.4}$
- 50m/LST: x 10 deeper than 10m/ASTE etc
- x 3 deeper than 25m/CCAT
- CIB resolved more with less confusion




LMT

# confusion limits (5σ) of mm/submm telescopes

Unit: mJy

| | LMT, LST, AtLAST | IRAM ,SST | CCAT | JCMT | APEX , GLT | CSO, ASTE, Tsukuba | SPT 1.2'@2mm 1.0'@1.4mm | Herschel |
|---|---|---|---|---|---|---|---|---|
| Dish D | 50m | 30m | 25m | 15m | 12m | 10m | 10m※ | 3.5m |
| 3.3mm | 0.052 | 0.084 | 0.098 | 0.15 | 0.17 | 0.20 | | 0.40 |
| 2.0mm | 0.13 | 0.23 | 0.28 | 0.44 | 0.53 | 0.61 | 1.4? | 1.22 |
| 1.3mm | 0.29 | 0.58 | 0.72 | 1.2 | 1.5 | 1.7 | 2 – 4? | 3.50 |
| 1.1mm | 0.36 | 0.78 | 0.97 | 1.7 | 2.0 | **2.0,** 2.4 | | 4.94 |
| 860μm | 0.42 | 1.02 | 1.3 | 2.3 | 2.9 | 3.4 | | 7.36 |
| 750μm | 0.53 | 1.37 | 1.8 | 3.2 | 4.0 | 4.8 | | 10.28 |
| 500μm | | | | | | | | **30.5**# |
| 450μm | 0.26 | 1.5 | 2.2 | 4.8 | 6.3 | 7.6 | | 18.0 |
| 350μm | 0.058 | 1.0 | 1.8 | 4.7 | 6.4 | 8.0 | | **27.5**# , 20.7 |
| 200μm | 0.0008 | 0.04 | 0.17 | 1.7 | 2.9 | 4.2 | | 17 |

**Bold font**: based on the measured number counts

#: Oliver et al. 2012, MNRAS, 424, 1614

Adopted number counts: Bethermin et al. (2012); definition of confusion: 30 beams per source

# *confusion limits (5σ) ➔ fraction of CIB resolved*

Note: CIB measured has an uncertainty of 10%

| | **LMT, LST AtLAST** | **IRAM, SST** | **CCAT** | **JCMT** | **APEX, GLT** | **CSO, ASTE** | **SPT** 1.2′@2mm, 1.0′@1.4mm | **Herschel** |
|---|---|---|---|---|---|---|---|---|
| Dish D | 50m | 30m | 25m | 15m | 12m | 10m | 10m※ | 3.5m |
| 3.3mm | 19.3% | 10.5% | 8.4% | 4.4% | 3.3% | 2.6% | | 0.7% |
| 2.0mm | 34.3% | 19.6% | 15.8% | 8.4% | 6.3% | 4.9% | 1.4%? | 1.2% |
| 1.3mm | 51.1% | 30.7% | 25.1% | 13.7% | 10.3% | 8.2% | 2 – 4%? | 2.0% |
| 1.1mm | 58.3% | 36.0% | 29.6% | 16.3% | 12.3% | 9.8% | | 2.4% |
| 860μm | 70.2% | 45.3% | 37.7% | 21.2% | 16.2% | 12.9% | | 3.2% |
| 750μm | 75.5% | 49.7% | 41.5% | 23.5% | 17.9% | 14.3% | | 3.5% |
| 500μm | | | | | | | | |
| 450μm | 95.4% | 73.8% | 64.1% | 39.2% | 30.6% | 24.7% | | 6.4% |
| 350μm | 99.2% | 86.3% | 77.6% | 50.9% | 40.6% | 33.3% | | 9.3% |
| 200μm | 99.9% | 99.6% | 98.2% | 83.0% | 72.6% | 63.6% | | 24.1% |

# *confusion limits (5σ) ➔ fraction of CIB resolved*

Note: CIB measured has an uncertainty of 10%

| | LMT, LST AtLAST | IRAM, SST | CCAT | JCMT | APEX, GLT | CSO, ASTE | SPT 1.2′@2mm, 1.0′@1.4mm | Herschel |
|---|---|---|---|---|---|---|---|---|
| Dish D | 50m | 30m | 25m | 15m | 12m | 10m | 10m※ | 3.5m |
| 3.3mm | 19.3% | 10.5% | 8.4% | 4.4% | 3.3% | 2.6% | | 0.7% |
| 2.0mm | 34.3% | 19.6% | 15.8% | 8.4% | 6.3% | 4.9% | 1.4%? | 1.2% |
| 1.3mm | 51.1% | 30.7% | 25.1% | 13.7% | 10.3% | 8.2% | 2 – 4%? | 2.0% |
| 1.1mm | 58.3% | | | | | | | 2.4% |
| 860µm | 70.2% | | | | | | | 3.2% |
| 750µm | 75.5% | | | | | | | 3.5% |
| 500µm | | | | | | | | |
| 450µm | 95.4% | | | | | | | 6.4% |
| 350µm | 99.2% | | | | | | | 9.3% |
| 200µm | 99.9% | 99.6% | 98.2% | 83.0% | 72.6% | 63.6% | | 24.1% |

50m-class submm telescope(s) captures majority of CIB contributors, dusty star-forming galaxies, up to epoch of reionization, EOR freely from cosmic variance also with multi-bands

# Why Large FOV?

- ✦ Higher Mapping Speed for Confusion-noise limited Wide-field Surveys; 100-1000 deg^2.
  - => census of star-forming galaxies
  - => various unbiased/biased fields covered
- ✦ Sampling large scale structure of Warm Intergalactic medium (WIM) in cluster of galaxies via SZ; as large as 1 deg^2 (~ 1 Mpc)
- ✦ Quick counter-part identification of GRBs or Gravitational-wave sources after X/γ-ray alert, and also high cadence for variable source search

# *Mapping Speed at 1.1 mm*

scaled to AzTEC/ASTE (conservative) value

- ✦MS ∝ D^2 x $N_{pix}$
- ✦$MS_{AzTEC, ASTE}$ ~ 15 amin^2/mJy^2/hr
  for $N_{pix}$ ~ 100
  (atmospheric noise limited)

Xcam
:future camera
for LST

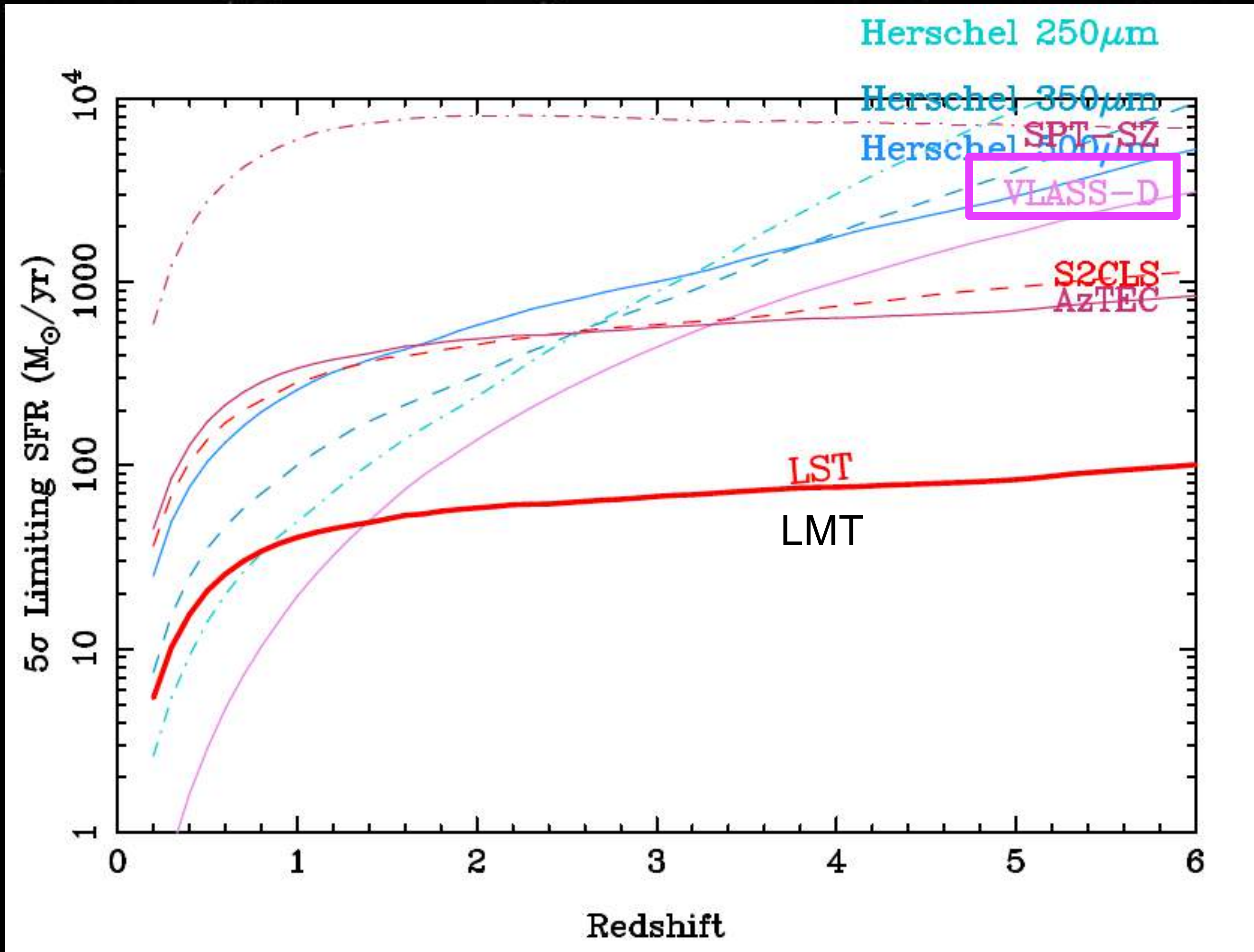
- ✦$MS_{Xcam,LST}$ ~ 10 deg^2/mJy^2/hr ($10^4$ pix)
  ~ 100 deg^2/mJy^2/hr ($10^5$ pix)
  $10^5$ pix => FOV~ 30 amin in diameter
- ✦$MS_{Xcam,LST}$ ~ 0.5 deg^2/$\sigma_{confusion}$^2/hr ($10^5$ pix)

=> 500 deg^2 with 1000 hrs (confusion-noise)

# Confusion-limited "Blank Field" Survey

LARGE SUBMILLIMETER TELESCOPE

LST-Deep : comparable to JVLA for z~ 1-2
> 10 times deeper for z > 3




VLASS-Deep; 0.8"
- S-band(2-4 GHz)
- 1.5 μJy (1σ)
- 10 deg^2
- 3391 hours
- N/deg^2 = 9200

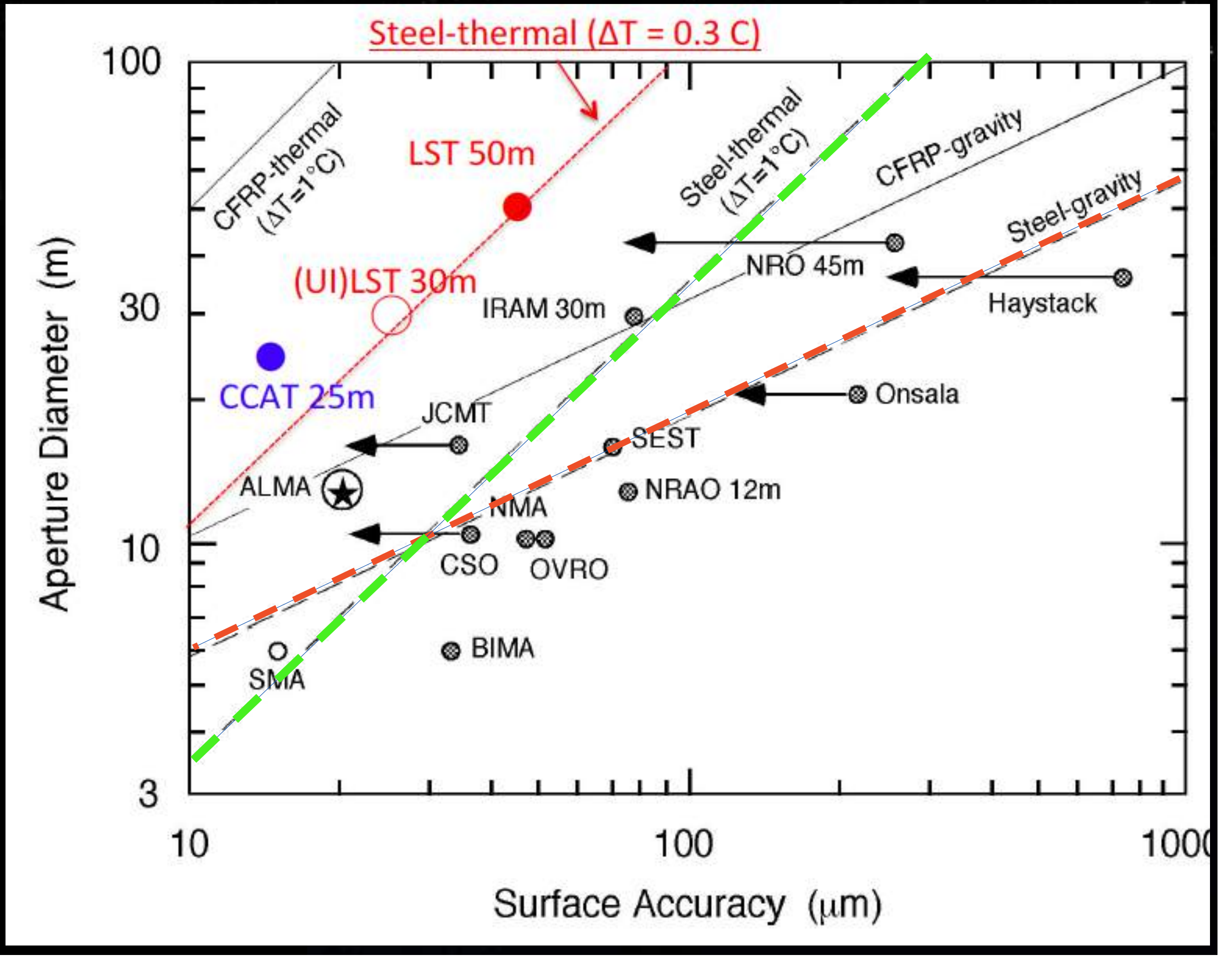
LST-Deep: 5" beam
- 1.1 mm
- 72 μJy (1σ)
- 500 deg^2
- 1000 hours
  (FOV=0.5 deg.)
- N/deg^2 ~ 20000

# *Why 70-420 GHz + up to 1THz?*

- ✦70-420 GHz is the best for unveiling CIB and Cosmic Star-formation history up to z~ 10 (Era of Reionization) in cont. & lines
- ✦Well-matched with other science cases and atmospheric windows in high-sites
- ✦Up to 1THz (with limited use of main dish、under-illumination) for enhancing science and synergy with ALMA

# *Why 45 μm rms?*

- ✦ High aperture efficiency up to 420 GHz (λ=715 μm) => $\varepsilon_{rms} = \lambda/16 = 45\ \mu m$
- ✦ Active surface control required for gravitational & thermal deform.
- ✦ Freq > 420 GHz needs $\varepsilon_{rms}$ ~ 30 μm? for D~30m (under-illumination)



# *Transformational Science Case*

✦ Exploration of Cosmic Star Formation History and Large Scale Structures via two kinds of surveys

- Multi-band Deep Continuum Survey over ~$10^3$ $deg^2$ ("2.5D" survey with using color of sources)
- Blind CO/CII line emitter search (Tomography) up to z~ 10, EoR, using imaging spectrograph ("3D") not severely affected by source confusion noise

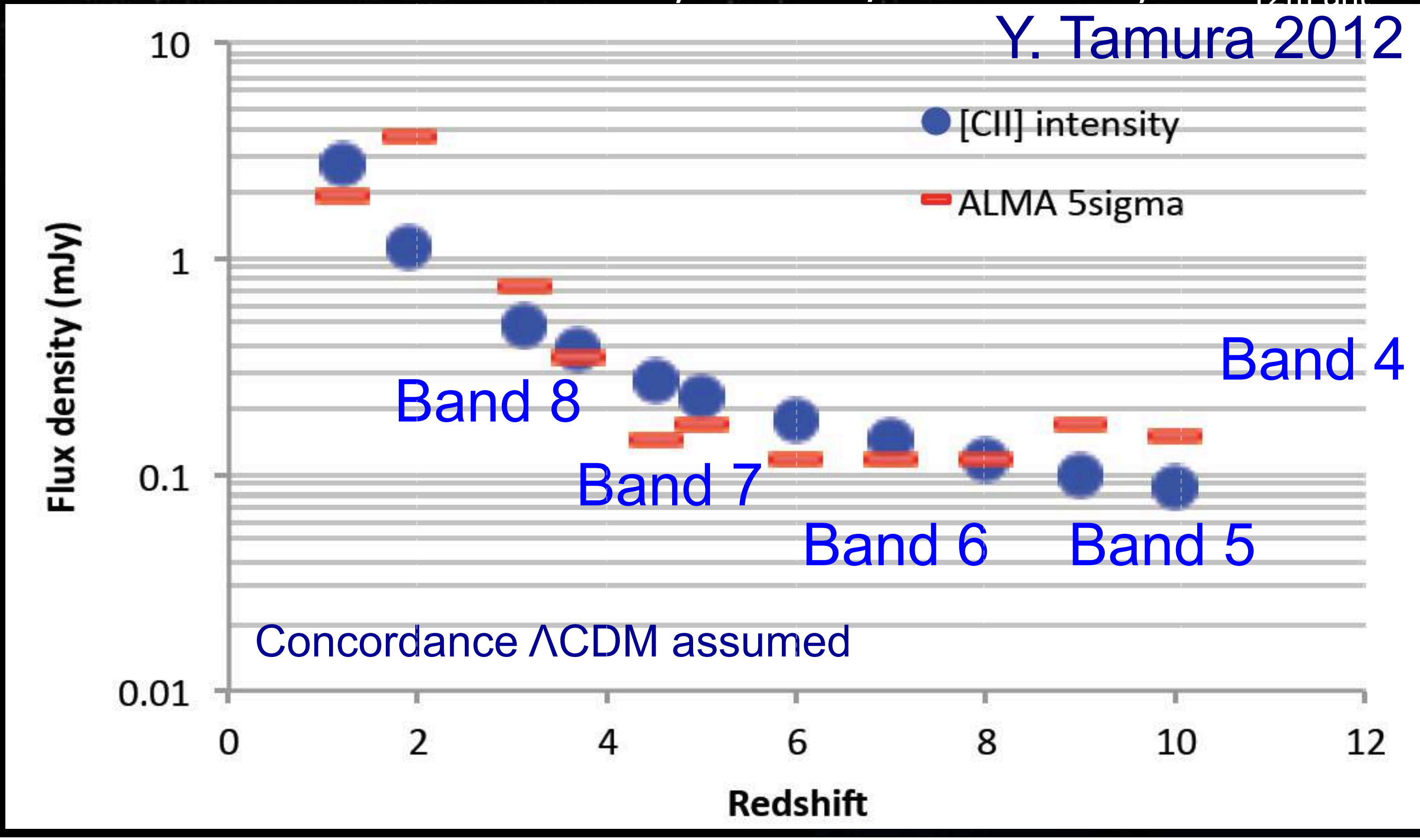
(Blind vs multi-object spectroscopy still needs to be investigated, but blind can provide us with census of "non-biased" line emitters, in which strong-line but continuum-weak emitters will be included)

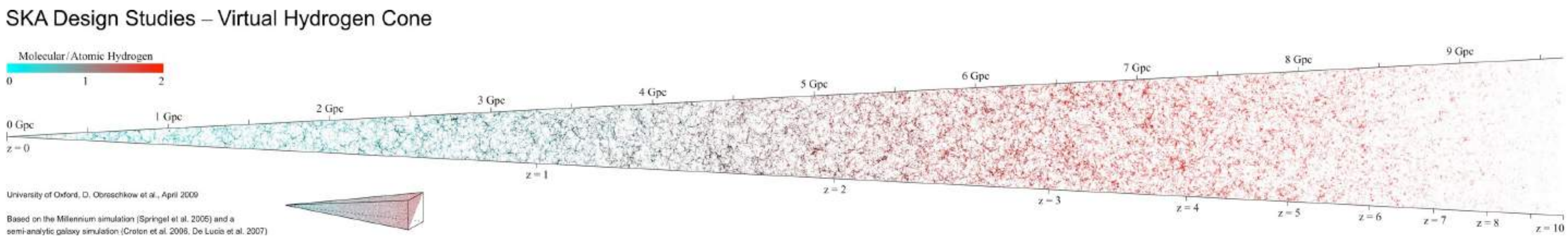
RK+ 2016 (SPIE proceedings paper)

# *Uniform "selection function" of [CII] expected in LST+ultra wide spectrometer*

Blind [CII] emitter search can reach up to z ~ 10, and will be a powerful tool to uncover CSFH and EoR

- ✦ L[CII] ~ 10^7.7 Lsun (our galaxy; COBE) assumed
- ✦ On-source 24 hours with ALMA; 100 km/s resolution, & $N_{12m\ ant}$ =50






# 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

## ... and serendipitous discoveries

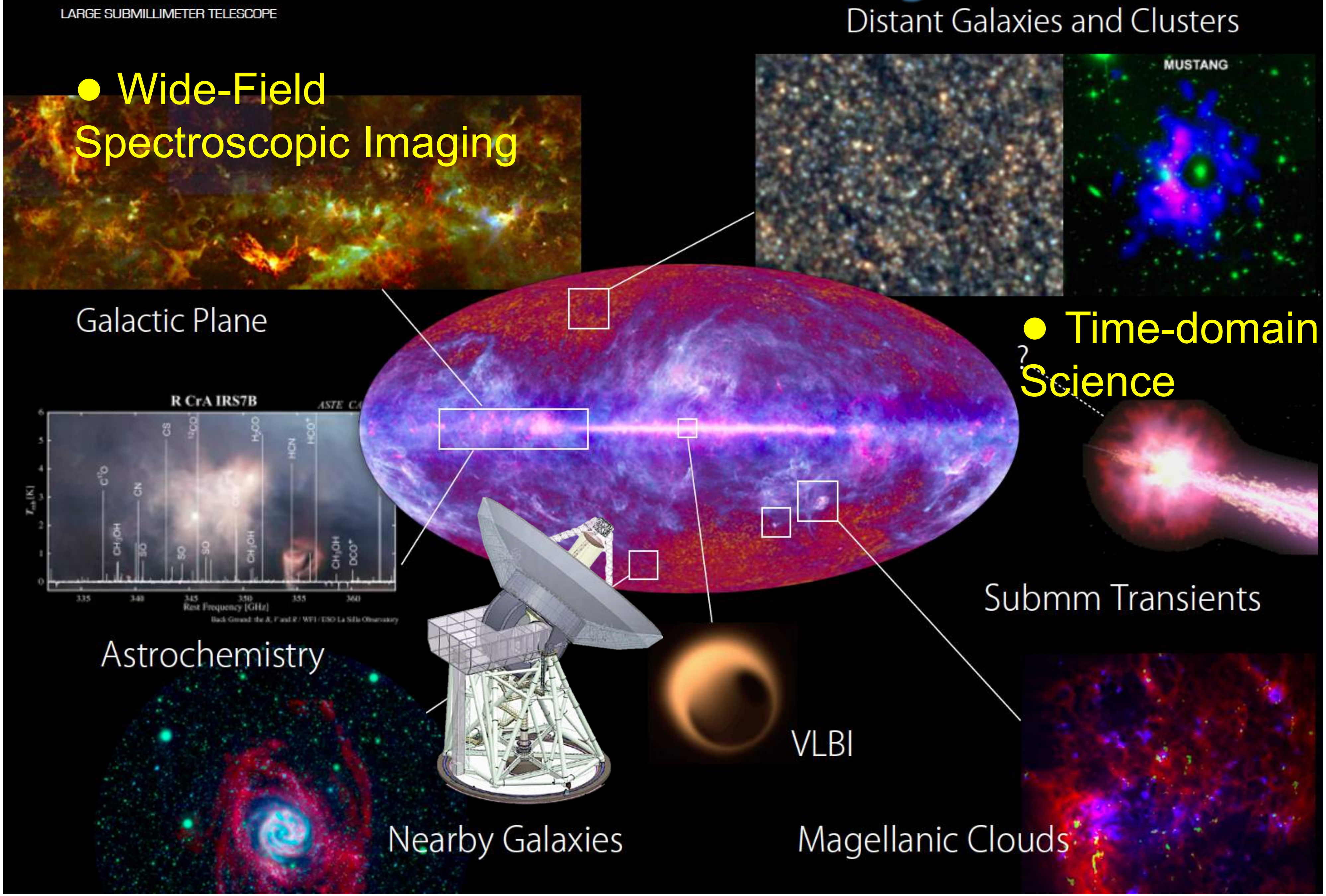
Line emitters, transient and variables, ...

LST
LARGE SUBMILLIMETER TELESCOPE

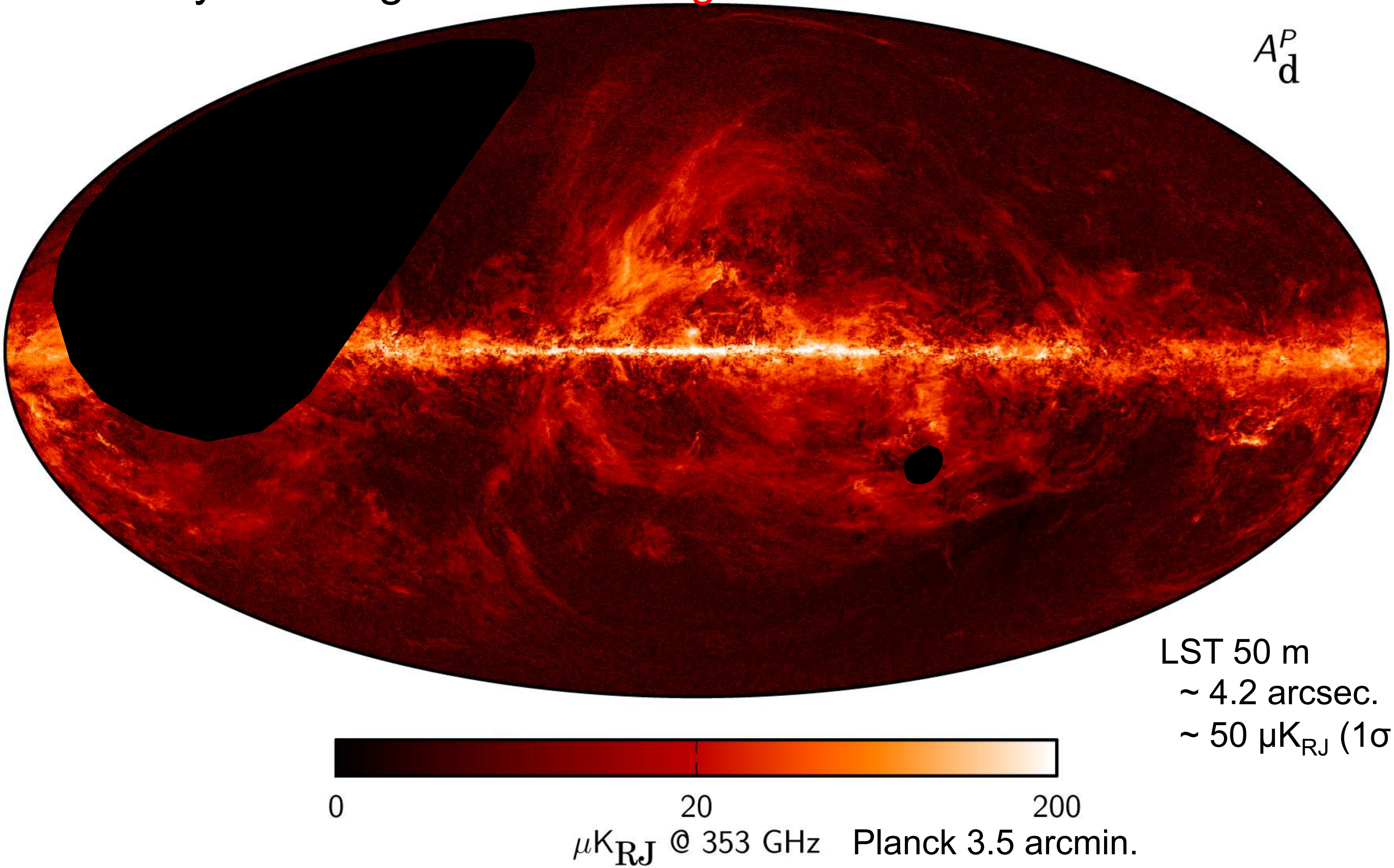
# *LST covers wide range of Science*

● Wide-Field Spectroscopic Imaging

● Time-domain Science



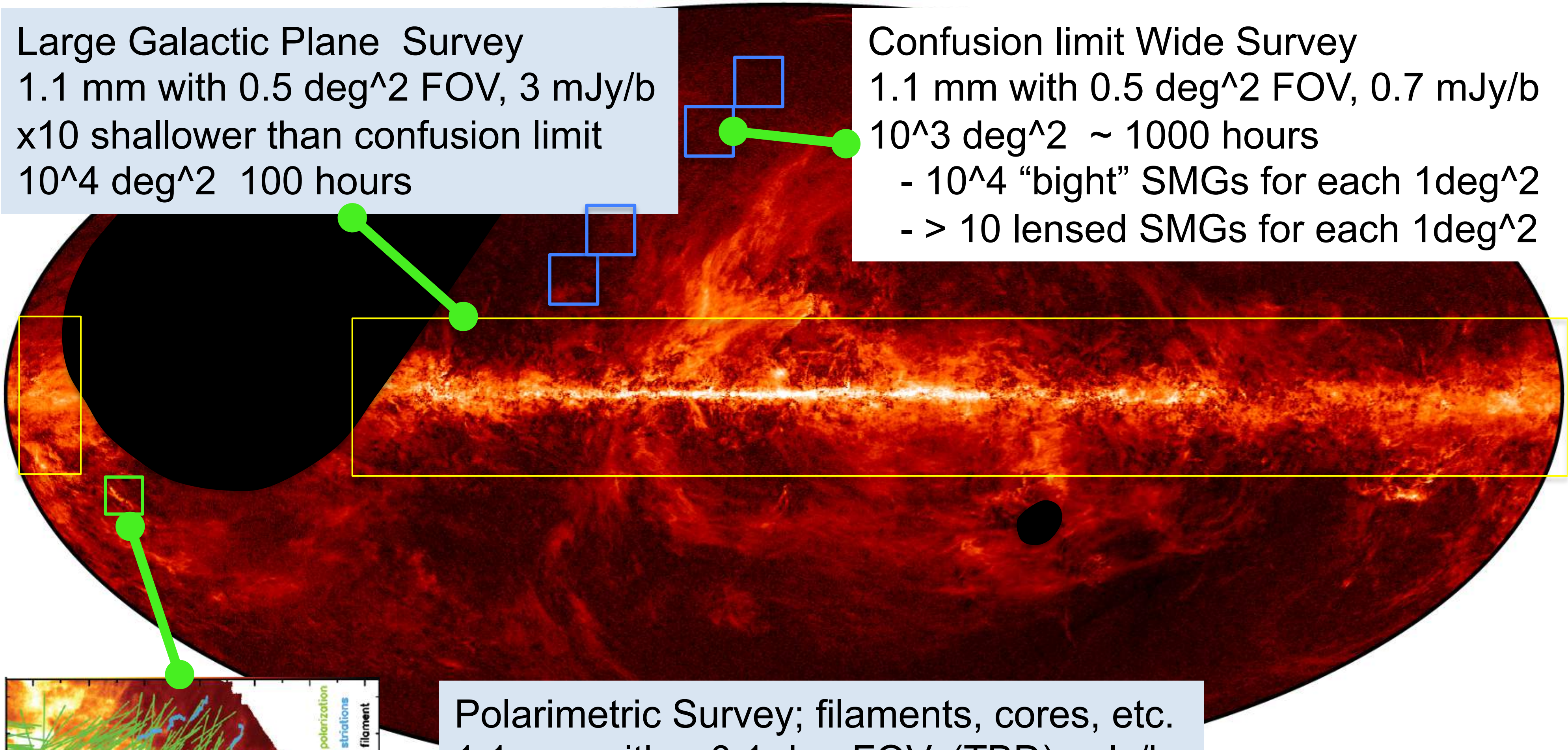
# LST Sky Coverage El > 25 deg

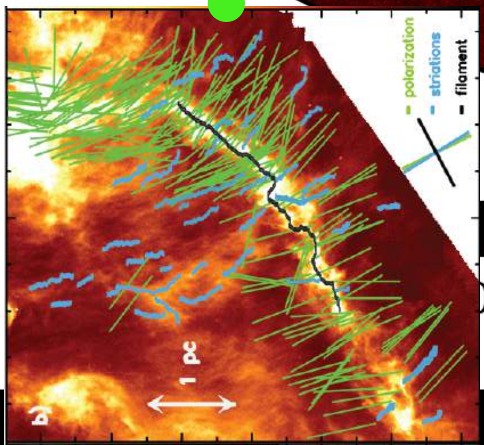


# LST Our Galaxy Survey Examples

Large Galactic Plane  Survey
1.1 mm with 0.5 deg^2 FOV, 3 mJy/b
x10 shallower than confusion limit
10^4 deg^2  100 hours

Confusion limit Wide Survey
1.1 mm with 0.5 deg^2 FOV, 0.7 mJy/b
10^3 deg^2  ~ 1000 hours
- 10^4 “bight” SMGs for each 1deg^2
- > 10 lensed SMGs for each 1deg^2




Polarimetric Survey; filaments, cores, etc.
1.1 mm with ~ 0.1 deg FOV, (TBD) mJy/b
X ? (TBD) shallower than confusion limit
(TBD)  deg^2   (TBD)  hours

# *Science Case Example for LST*

CO/CII Tomography (Tamura)
Redshift Space Distortion (Yoshimura)
CO/CII Intensity Mapping (Yoshimura/Kohno)
Resolving SZE (Komatsu, MPE)
Tracing Gas Physics in Galaxy Evolution (Takeuchi)
Environmental Effects in Nearby Galaxies (Sorai)
Orphan GRB Afterglow (Totani)
High Cadence sub-mm VLBI (Honma)
Multi-epoch Survey for Wondering-BH (Kawaguchi)

Chemical Evolution from Protostellar Cores to Disks (Yamamoto)
Galactic Plane Survey and Large-scale Mapping in Star Forming Regions (Onishi)
B-filed/Zeeman Mapping in Molecular Clouds (Hua Bai Lee, Furuya, Nakamura)
Monitoring of Planetary Atmosphere (Maezawa)
Chemistry in Planetary Atmosphere (Iino)

White Papers being updated

# *Chemical Evolution from Protostellar Cores to Protoplanetary Disks*

Yamamoto+

Strategy

(1) Unbiased Spectral Line Survey with a large single dish
(2) Discovery of Peculiar or Interesting Objects
(3) Detailed Study of Chemical and Physical Structure
with ALMA
(4) Modeling and Comparison with Observations
Global Fit of Spectrum

Requirements to new single dish

(1) High Sensitivity => Large Aperture and state-of-art RX
(2) Wide Freq. Coverage => mm to sub-mm, good atm.
(3) Large Instantaneous Bandwidth => Large Correlator sys.
(4) Reliable Observations = > Calibration, Pointing Accuracy

# SZ Cosmology; Two Major Goals

Kitamura & Komatsu

High Spatial Resolution Deep Imaging of SZ clusters

- resolve a core scale of 100 kpc and cover a cluster scale, 10 Mpc
- allow us to investigate the masses of clusters and structure (shock structure, energy..)

Blind Search for high-z SZ cluster up to z ~ 2

- provide a large sample of high-z SZ clusters, not well-understood
- allows to understand the high-mass end of LSS at z ~ 2, where Cosmic SF activity start to decrease sharply toward z~0.

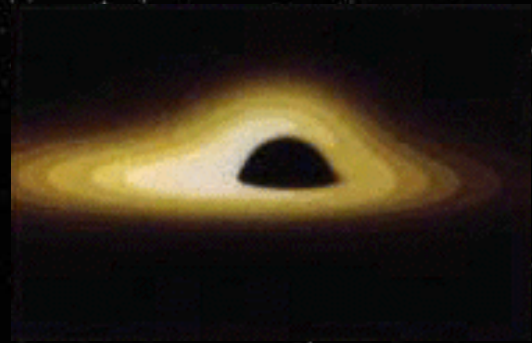
Requirements to new telescope

high spatial resolution => 10″ at z~2 & 150 GHz , and requires D ~ 50m

Wide Field of View => FOV of > 20 arcmin.

# *Mm/submm VLBI with LST*

Honma +



- BH shadow will be hopefully imaged with sub-mm VLBI including ALMA, so what's next ? => high cadence VLBI !
- Target : "To trace dynamic structure around black holes"

Time variability of accretion disks and jet roots around BHs will provide us the first and unique opportunity to directly test the theories of accretion disk / jet acceleration, and also general relativistic effects.

Expected time-scale

| | |
|---|---|
| Sgr A* | hours |
| M87 | a few days |
| Blazar jets | days to months |

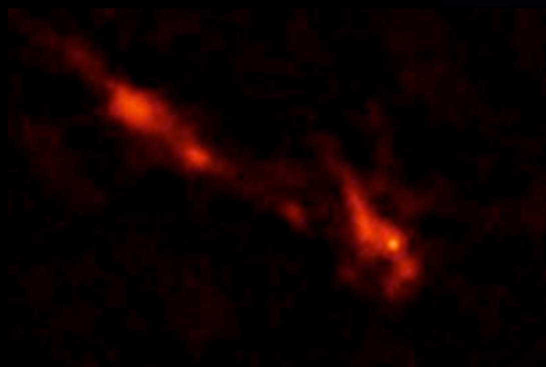
# Core to Brown Dwarf/Planet

Nakamura, RK etc.

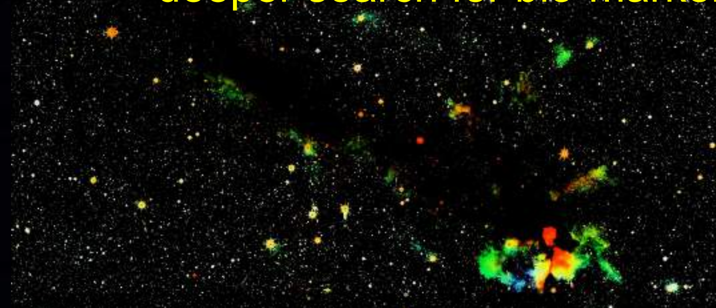
- Formation mechanism of Brown Dwarfs (BDs) and Planetary-mass objects (PMOs or free-floating planets(*)) is still not–well understood: one possible mechanism is formation in isolated cores similar to low-mass stars, and another is ejection from unstable proto-stellar disks.
- Core mass functions down to planetary mass and comparison with IMF is one of keys
- It is also desired to identify forming sites of BDs or PMOs in order to test the forming scenarios

=> Large Survey with a large single dish needed

(*) free floating planets allow deeper search for bio-markers



AzTEC/ASTE 1.1 mm



JHK Composite (25' x 40')
Oasa+ 2015 in prep.

# *Technical Feasibility Study*

- ✦Science Requirement & Technical Specification
- ✦Operation condition & Operation Planning
- ✦Optics Design
- ✦Conceptual Design of Telescope Structure
- ✦Surface Accuracy Budget Analysis
- ✦Developments of Key Instruments
- ✦Millimetric Adaptive Optics (MAO) concept under development: started R&D and plan to demo

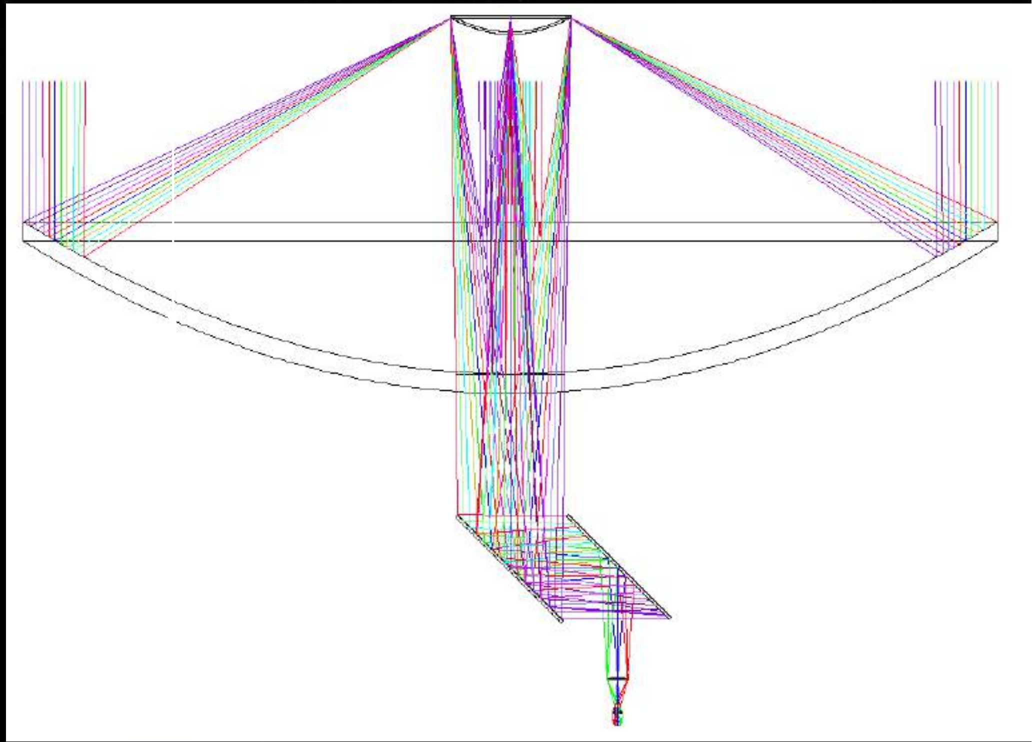
LARGE SUBMILLIMETER TELESCOPE

# Optics Design for wide FOV

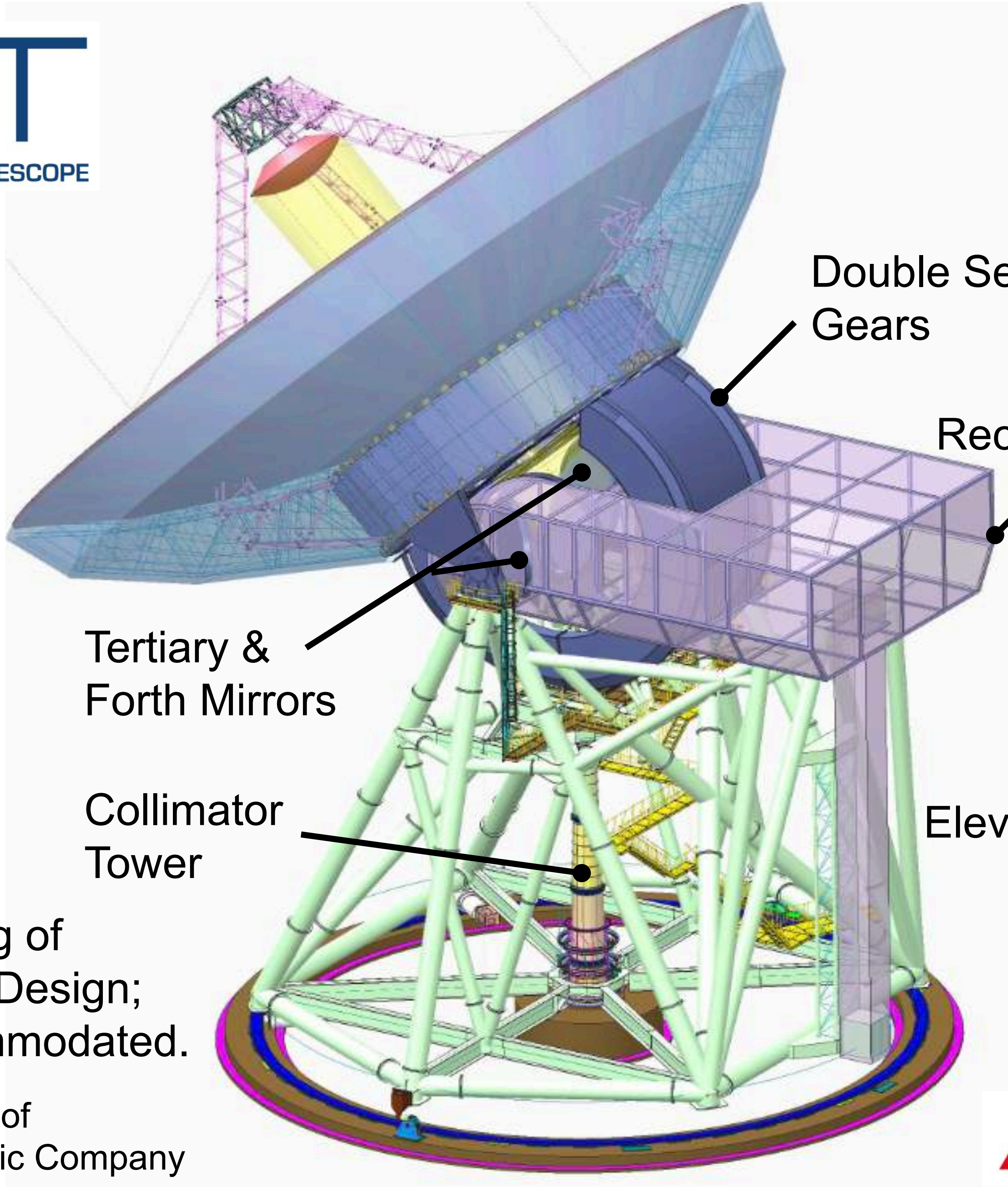
very preliminary

Richey-Chretien Optics for D= 50 m main reflector
Lyot-Stop at Sub-refrector: $D_{effective}$ ~ 46.7 m
FOV ~ 0.66 deg. in diameter at 850 micron achievable

But…
- large mirrors
  $D_{sub\text{-}ref}$ ~ 6.2 m
  #3 mirror ~ 7 m diameter
- huge RX cabin needed
- big impact on telescope mechanical structure?
- being investigating better optics design



Takekoshi, Oshima + in prep.

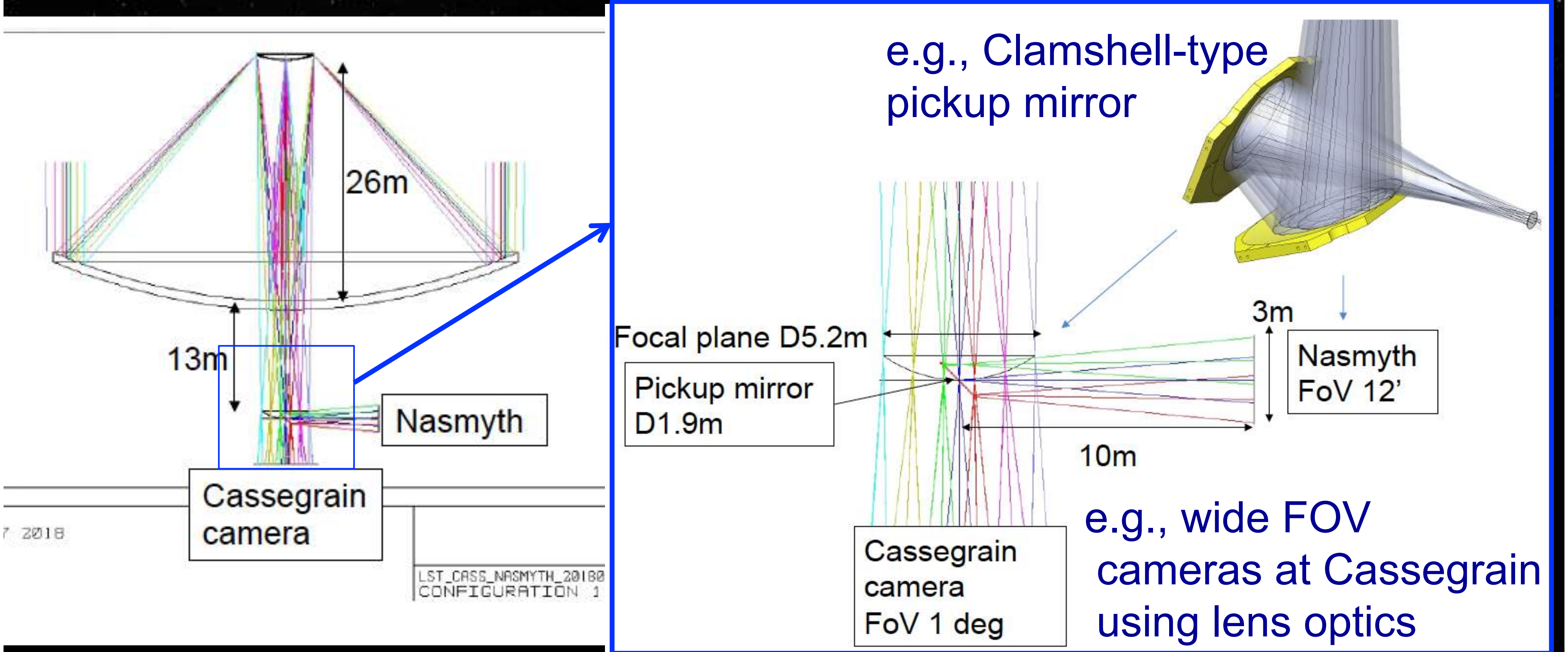



The First Drawing of
LST Conceptual Design;
Major req. accommodated.

Image Courtesy of
Mitsubishi Electric Company

# Hybrid of Nasmyth and Cassegrain

- $D_1$=50m, $D_2$=6.6m, F/6 keeed, but M=15→10
- FoV = 0.76 deg @850 micron; a little improved
- Primary focal ratio=0.6➔secondary is a bit far?



# Tentative Surface Error Budget for LST

& comparison with IRAM 30m Telescope

Error budgets for Gravity and Thermal Deformation can be smaller
Wind-Load is current headache, some correction etc. needed

Table 3. Tentative surface error budget for LST and comparison with IRAM 30-m telescope (Baars et al. 1987[14]). All unit is $\mu$m in rms.

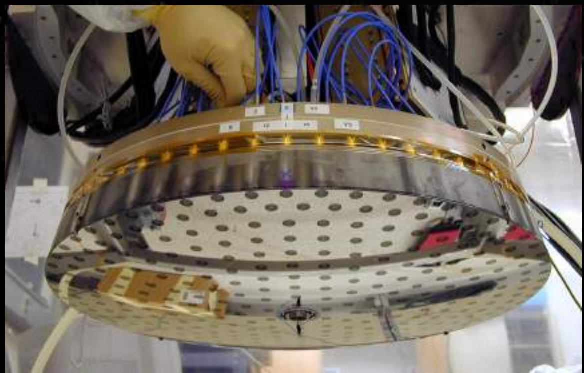
| Telescope | IRAM 30-m | LST 50-m | Note |
|---|---|---|---|
| Gravity (residual) | 40 | 15 | FEM modelling + active surface control |
| Thermal (residual) | 20 | 15 | FEM modelling + active surface control |
| Wind (residual) | 30 | 25 | IRAM spec is for wind velocity $\leq$ 12 m/s<br>Wind load correction using pressure sensors |
| Surface panel | 26 | 20 | |
| Subreflector (residual) | 20 | 15 | Correction with active surface control |
| #3, 4 mirrors (residual) | 10 | 15 | Correction with active surface control |
| Measurements and setting errors | 35 | 15 | Holography using astronomical sources |
| Total (RSS) | 70 | 44.1 | |

RK+ in SPIE proceedings; White paper by RK, Kohno

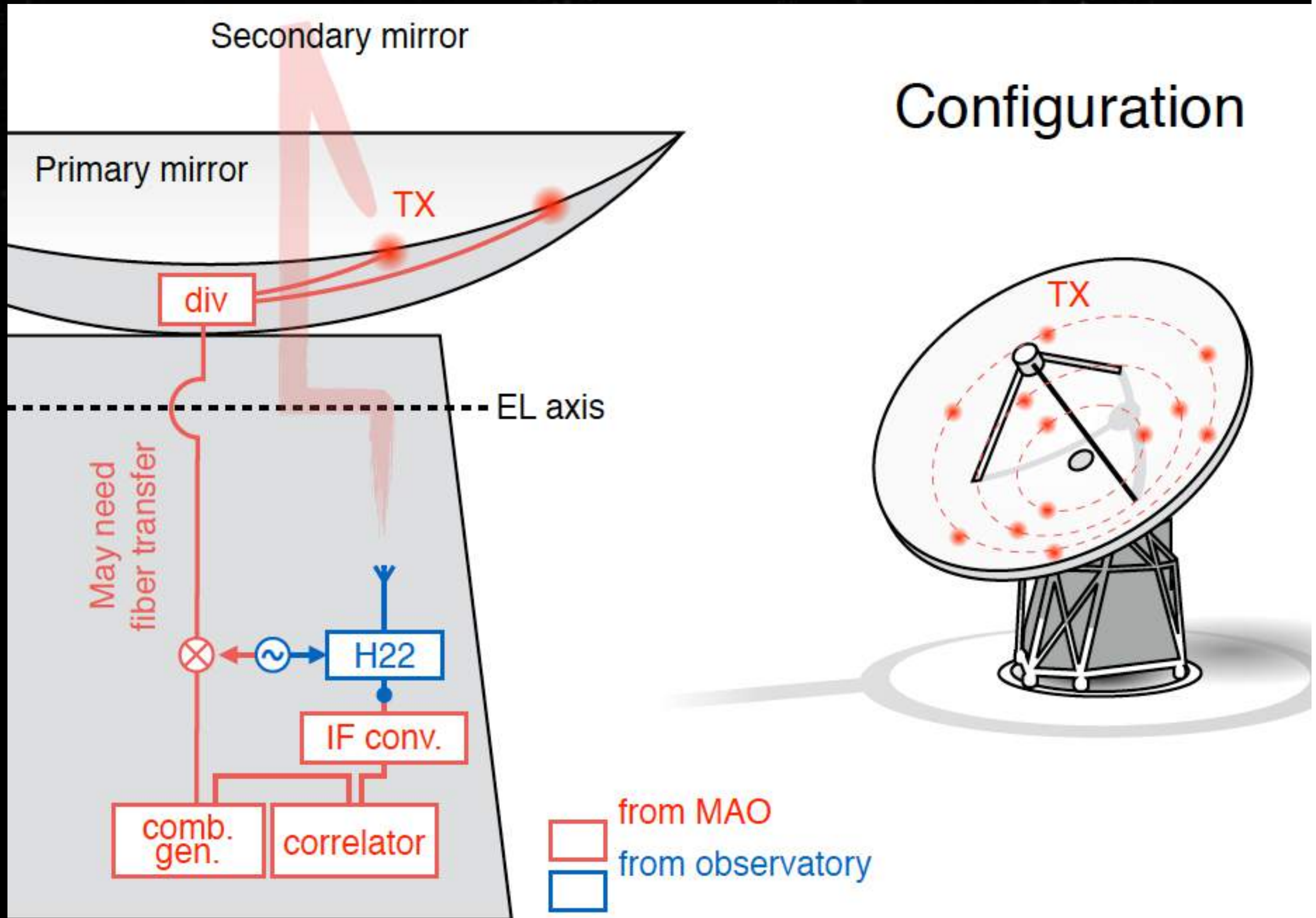
# *Millimetric Adaptive Optics (MAO)*

Yoichi Tamura, RK et al.

Transmitters on Dish (ToD) to measure short-timescale deform.
Correction with adaptive secondary or other optics

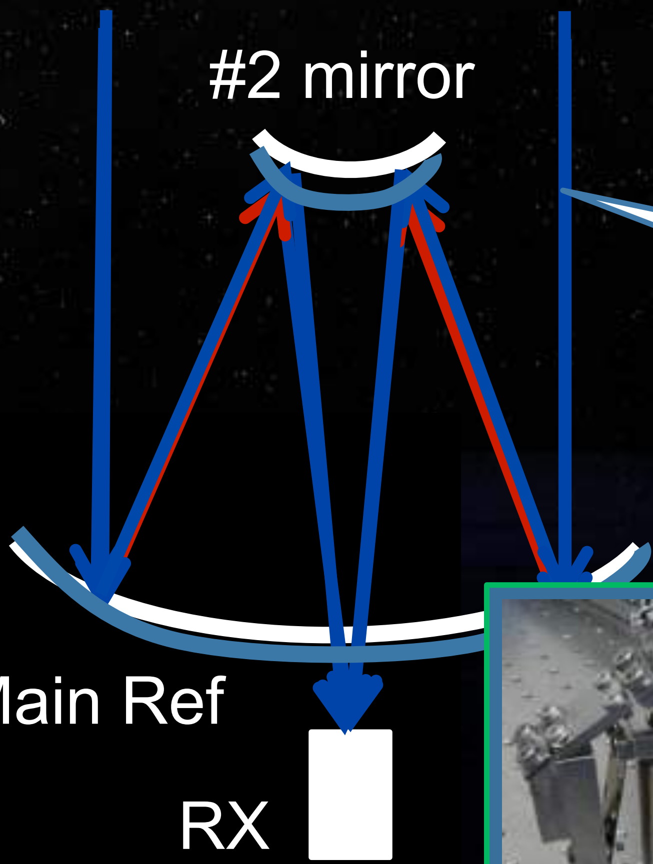


The MMT adaptive secondary built by the U. Arizona and Arcetri : 336 voice coils equipped at the back



# Deformable Mirror Development

Radio Telescope
Prototype
for balloon/space




Deformable Secondary

actuators
at back side

actuator unit

Seki, Kogiso+

# *Key Focal Plane Instruments*

- ✦ Ultra-Wideband Medium-spectral Resolution Imaging Spectrometer Array: Blind CO/[CII] Tomography

  Freq= 150 GHz - 420 GHz & $N_{pix}$ of > 300 (~ 1000)
- ✦ Multi-Chroic Wide–Field Camera

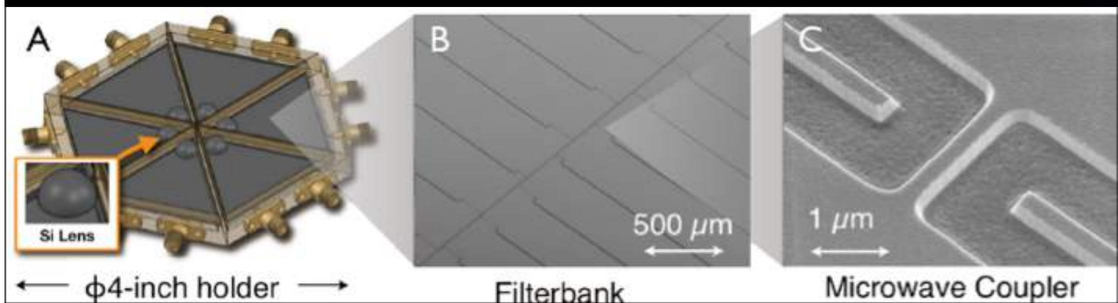
  covering 3, 2, 1.1, 0.85 mm, (+0.45, 0.35 mm)
- ✦ Multiple-band Heterodyne Array Receivers (~ 100 beams)

  + Ultra-wideband Spectrometers (for line survey)

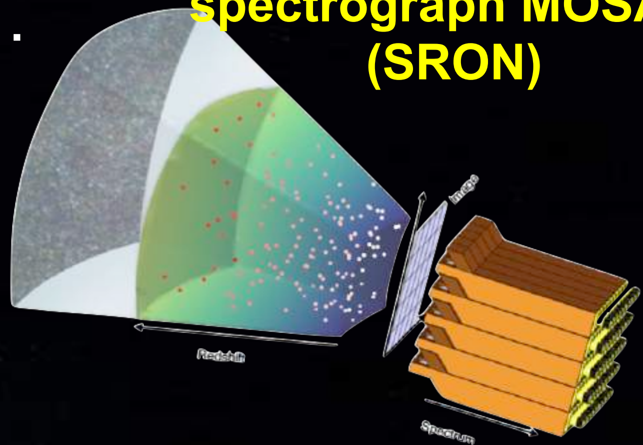
DESHIMA
Deep Spectroscopic High-z Mapper

=> "Super DESHIMA" <=
or "Super MOSAIC"…

**Mm/submm multi-object spectrograph MOSAIC (SRON)**



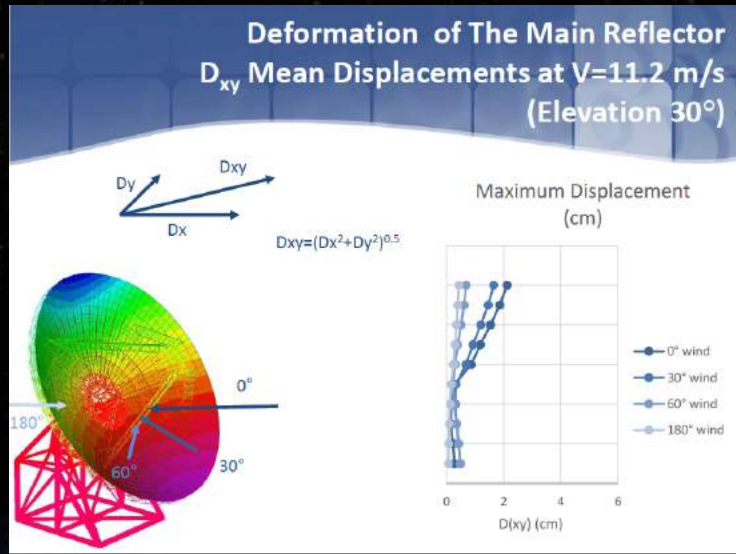

Deep Spectroscopic High-Z Mapper



# *R&D plan in the next 3 yrs*

- ✦ MAO concept demonstration on NRO45m or LMT; accelerometers also used to investigate wind effects
- ✦ Simulation of dynamical effects of 50m dish due to wind and comparison with measurements with accelerometers; needs FEM
- ✦ Wind measurement with LIDER from MELCO
- ✦ DESHIMA science run on ASTE, & development of its array/MOSAIC for LMT50m => A. Endo's Talk
- ✦ Multichroic KID or TES camera

; 2 mm, 1.3mm, 1.1mm, 850um,..

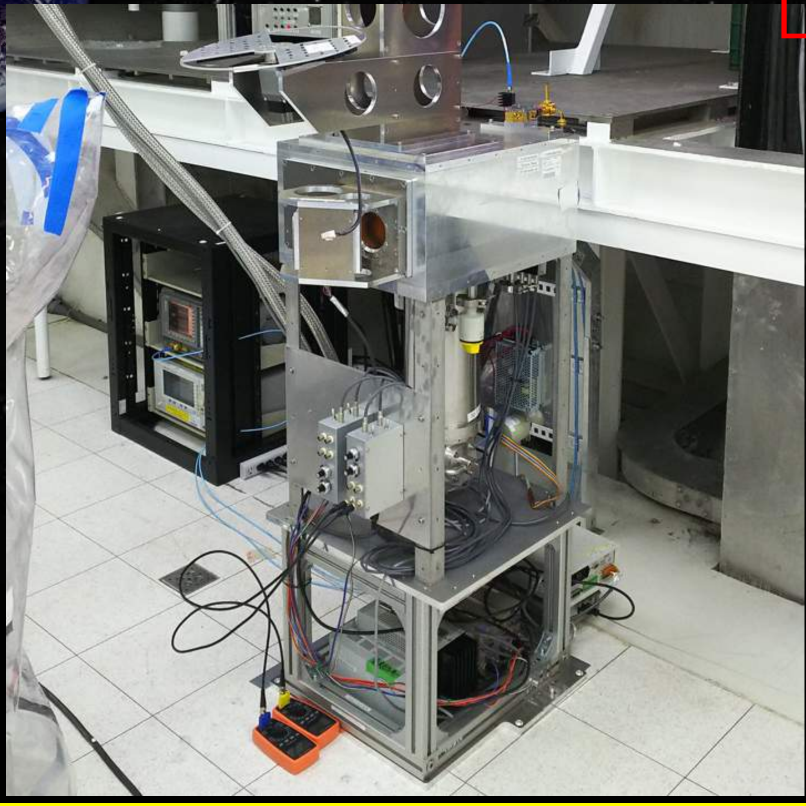




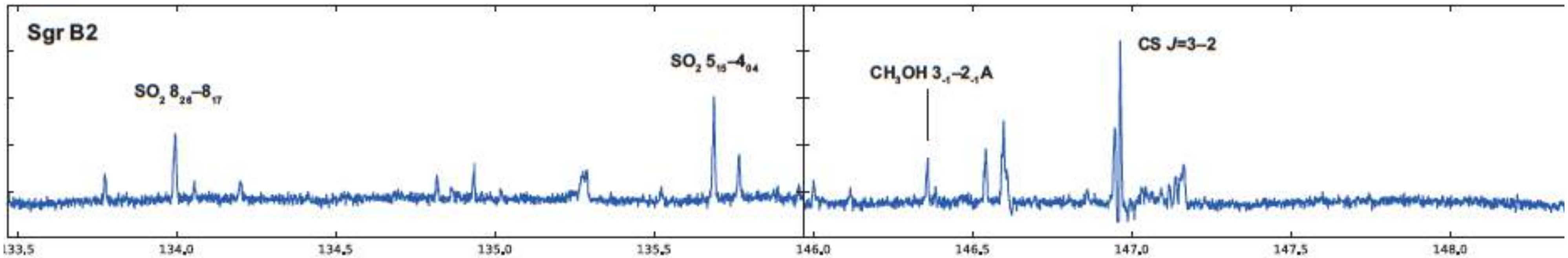
LMT 50m (altitude = 4600m)
- 75 um rms with Active Surface
- FOV ~ 3.5 min. in diameter
- latitude = 19 deg.
=>Valuable experience toward future large submm single dishes
March, 2017
Tau(230 GHz)
~ 0.04-0.05
David Hughes
Hatsukade
RK
Tamura
Tanaka
Sakai

# 2mm Rx:B4R installed on LMT

Last Week



Spectroscopic First Light (on-source ~1 sec. with B4R & XFFTS (> 30000 ch/2.5 GHz)



# *International Collaboration?*

Yes, we are positive. Need close cooperation.

✦ Discussion via workshops

- e.g., LSTWS2015: "Large millimeter/submillimeter telescope in the ALMA era", Mitaka/Japan

- Status of Other Telescopes updated

e.g., Caltech ~ 30m survey telescope (CCST)

✦ Recent Progress in Europe: "AtLAST"

- European perspective: ~ 40m class similar to LST

: A good-sign toward a future "40-50 m class" sub-mm single disk telescope in ALMA plateau as a single international project, although it will be hard to project and secure construction budget

# Scope of WS (Bertoldi)

様々な望遠鏡がある
何ができて、検討され、できていない？

## Inventory

AtLAST Workshop, Jan.2018
(ESO Garching)

GBT 100m, LMT 50m, NRO 45m, IRAM 30m, JCMT 15m, APEX 12m, ASTE 10m, SOFIA + CMB telescopes (SPT 10m, ATC 6m, ...)
under construction: LLAMA 12m, Greenland Telescope 12m, CCAT-prime 6m

### Why another submm-telescope?

1. We could do it.
2. Excellent science case.
3. It is affordable.

### Has it been tried?

1. CCAT (2004-15)
2. LST (2008-)
3. CSST (2014-)

### Why has it not been done yet?

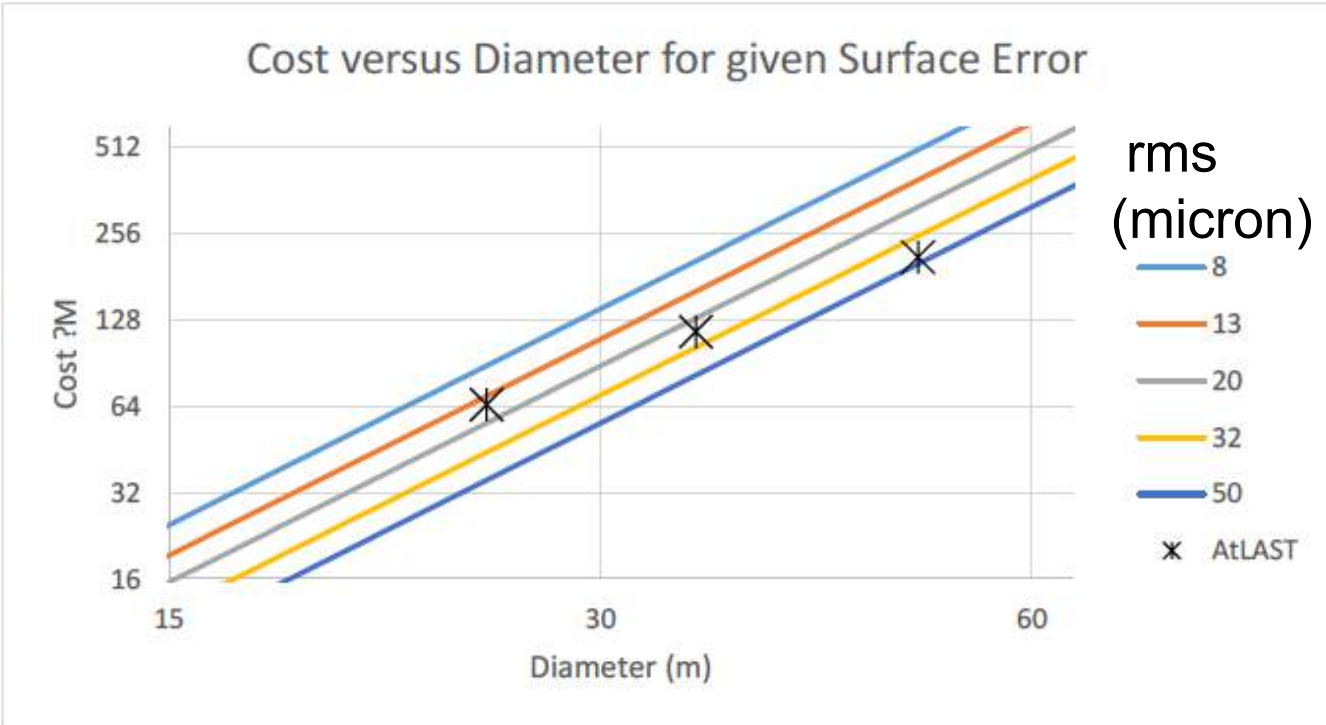
1. ?
2. ?
3. ?

# Cost of Single Dish

By R. Hills

Plots of the historic cost equation - not to be taken seriously!

- Cost $\propto D^{2.5} / \lambda_{min}^{0.5}$
- Telescope ONLY perhaps 50% of project? (25% for instruments, 25% for infrastructure, management, etc)
- Ignores added costs for higher sites.
- Assumes "non-political" procurement process.




- Normalized by assuming that a 25m diameter with a 25um surface costs 50?M.

# *LST unified with AtLAST?*

✦AtLAST workshop in Jun, 2018

- Many options of sub-mm telescopes & sites are discussed in the workshop, but original plan of AtLAST or LST confirmed to be more realistic and compelling; we will pursue a unified way
- Science Case should be more elaborated; Science Case developed for LST will be merged with AtLAST

✦Future Activity

- Science Workshop in Edinburgh in Sep/Oct, 2018

# *Cooperation among East Asia*

- ✦Interests from Asian Institutes/Universities
  - ASIAA, KASI, Shanghai Observatory, …
  - C.U. Hong Kong
- ✦Discussion on Potential Future Planes of EAO (East Asian Observatory) under planning

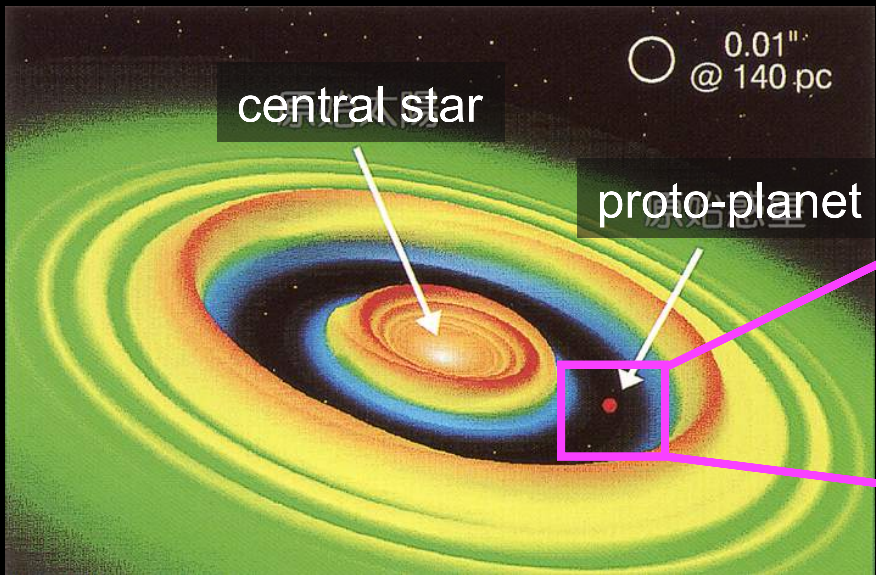
# *Impact on ALMA*

- ✦Development of new discovery spaces complementary ALMA:
- ✦Improvement of Total Power Data needed for ALMA
- ✦Enhancing Collecting Area (x 1.4) and Sensitivity: beneficial for achieving higher sensitivity in spectral lines, and also longer baselines of ALMA

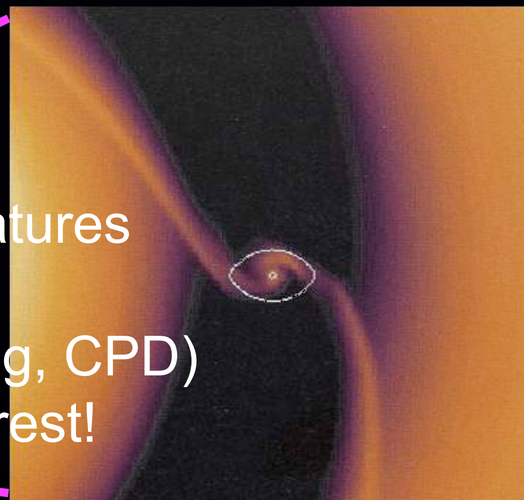
From RK's presentation
for "ALMA Long Baseline WS"

# *Beyond ALMA*

- ✦ What can be done by ALMA, what new needed future?
- ✦ Going back to 20 years ago at Nobeyama to learn about the NMA-45m combined array, Rainbow
- ✦ Introduce future Large Submillimeter Telescope (LST)
- ✦ How beneficial large single dish + ALMA combined array is for ALMA?




Next Dream!



Detecting signatures of putative proto-planet (eg, CPD) is of great interest!

# *LST outreach/website Issue etc.*

- ✦LST website cannot be accessed from community due to some our mistake(?)
- ✦Outreach should be improved
  - Information on LST and LST Working Group activity will be updated via “Ryunet”
- ✦Preparation study should be more enhanced

# *Summary*

- ✦LST/AtLAST Unification will be projected for single international project
- ✦Key Science & Science case for LST/AtLAST more elaborated
- ✦Breakthrough in Technologies for Key Instruments and High-precision Telescope

desired; e.g., Imaging spectrograph (R~ 1000, >$10^3$ pix), Heterodyne Array (> 100 beams) , and MAO

Please join us with new science/technology!