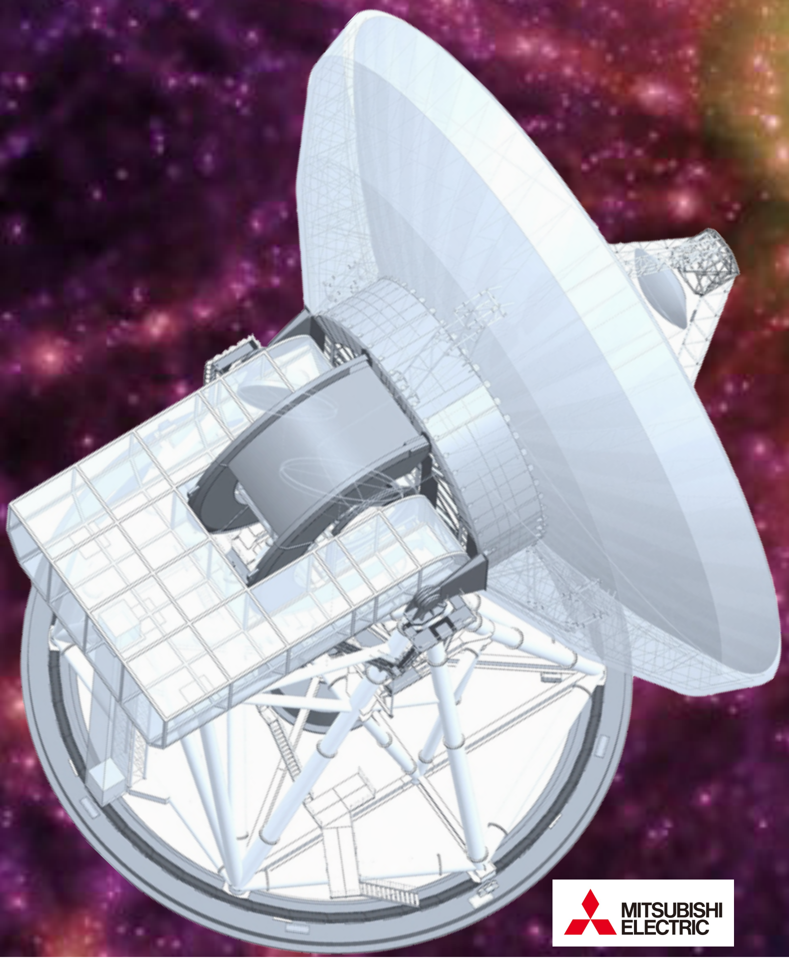
LST

LARGE SUBMILLIMETER TELESCOPE

Large Submillimeter Telescope (LST)

15.6 Mpc/h

Basic Concept

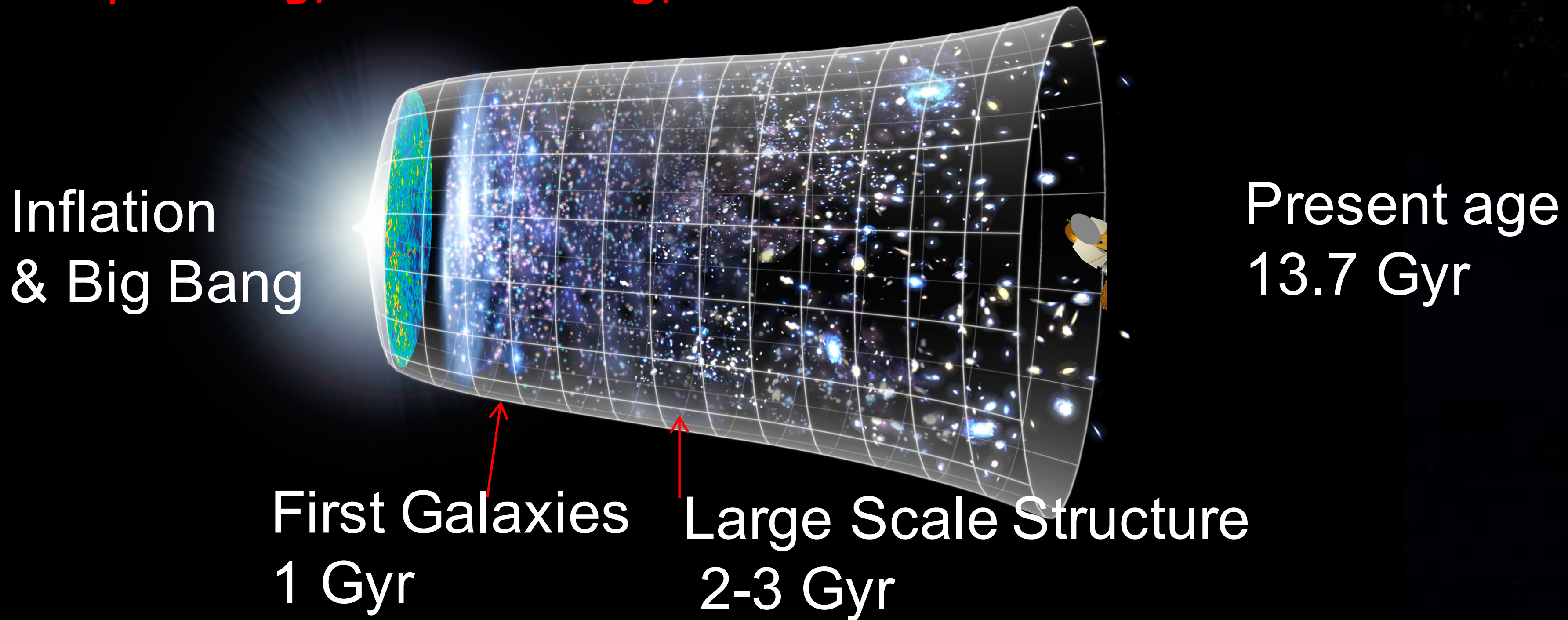


Ryohei Kawabe, Tai Oshima
(NAOJ)
Kotaro Kohno, Yoichi Tamura
(U. Tokyo)
LST Working Group

MITSUBISHI ELECTRIC

Mm & Submm Astronomy Science Goals

- Contributes over a wide variety of science: e.g., Cosmology, Early Universe, Active Galactic Nuclei, Star Formation, Interstellar Chemistry, Solar system and Planetary Science; challenges basic problems in the expanding, accelerating, and diverse universe

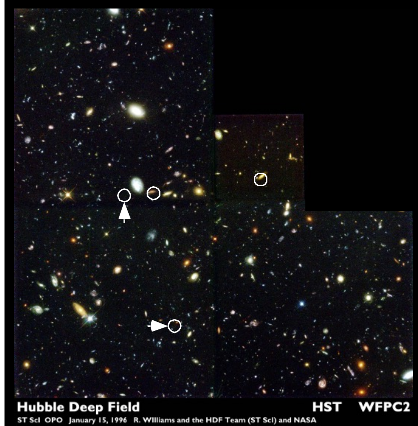


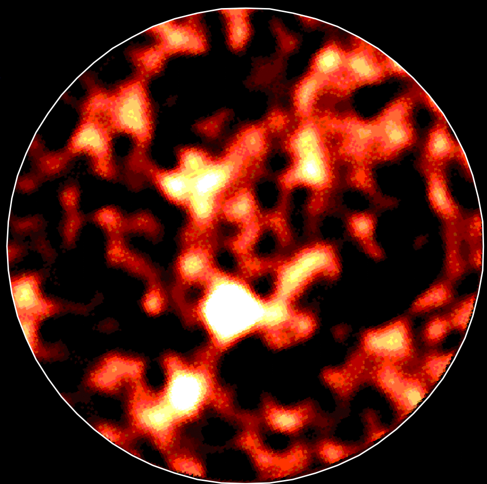
ALMA opens new era

✦ ALMA will contribute to elucidating galaxy formation and planet formation with exploiting extreme performance

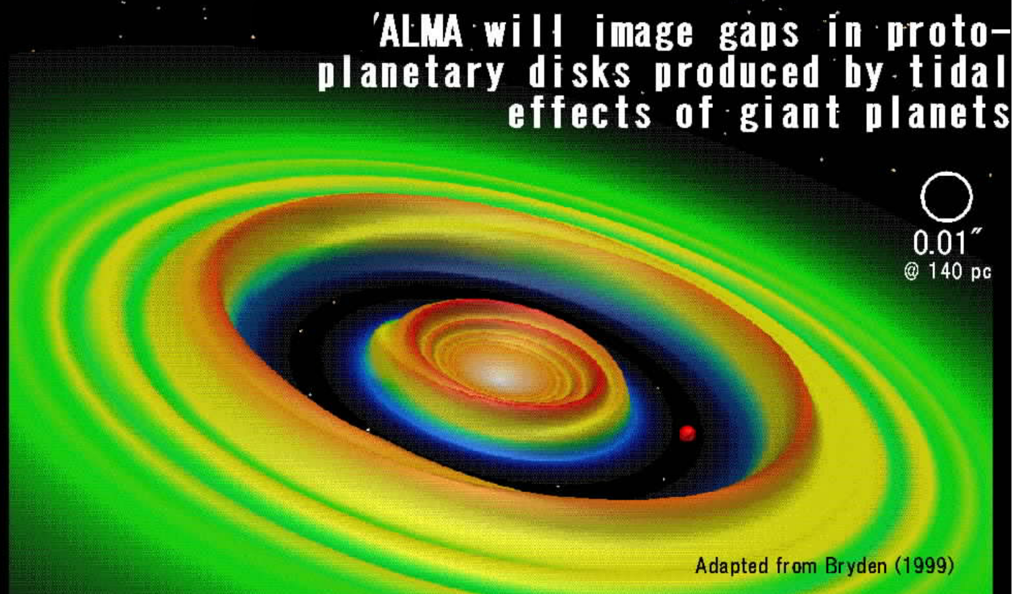
- High Angular Resolution, ~ 0.01 arcsec; sharp radio images
- High Sensitivity to reach the early universe (also thanks to very unique characteristic of submillimeter emission in SMG)

Hubble Deep Field and SCUBA map





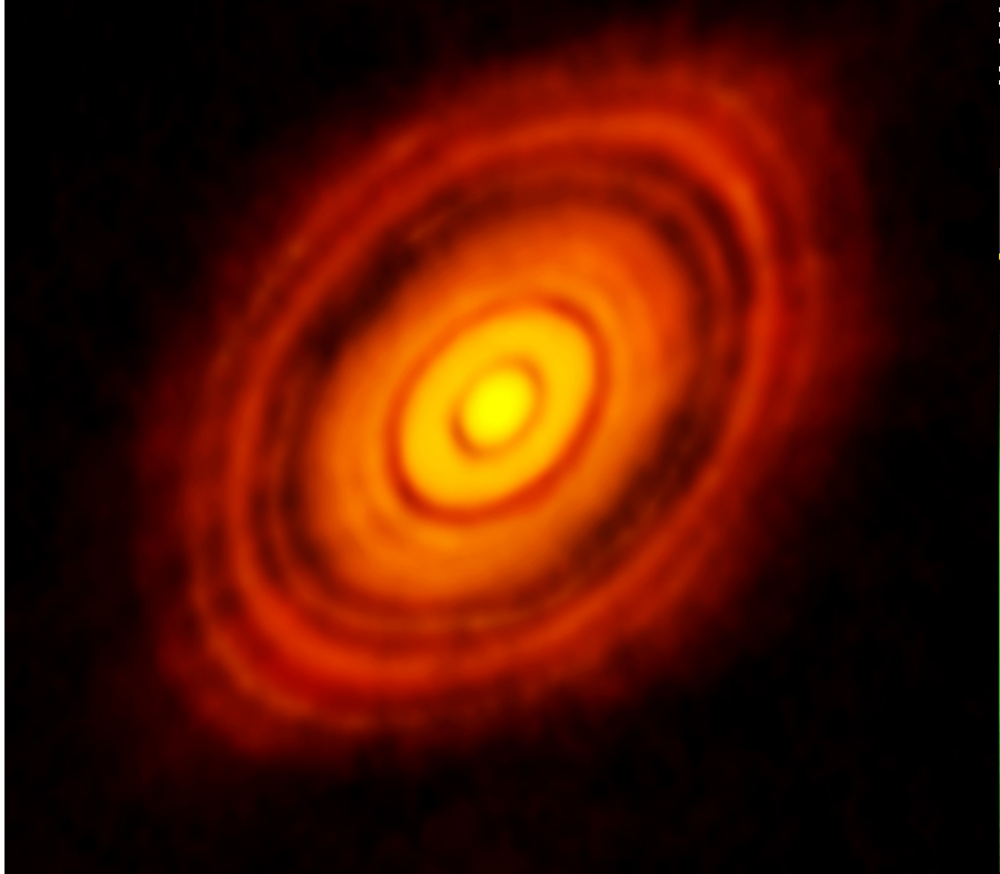
Gaps in Protoplanetary Disks



ALMA Science Goals

- ALMA will contribute to elucidating galaxy formation and planet formation with exploiting extreme performance

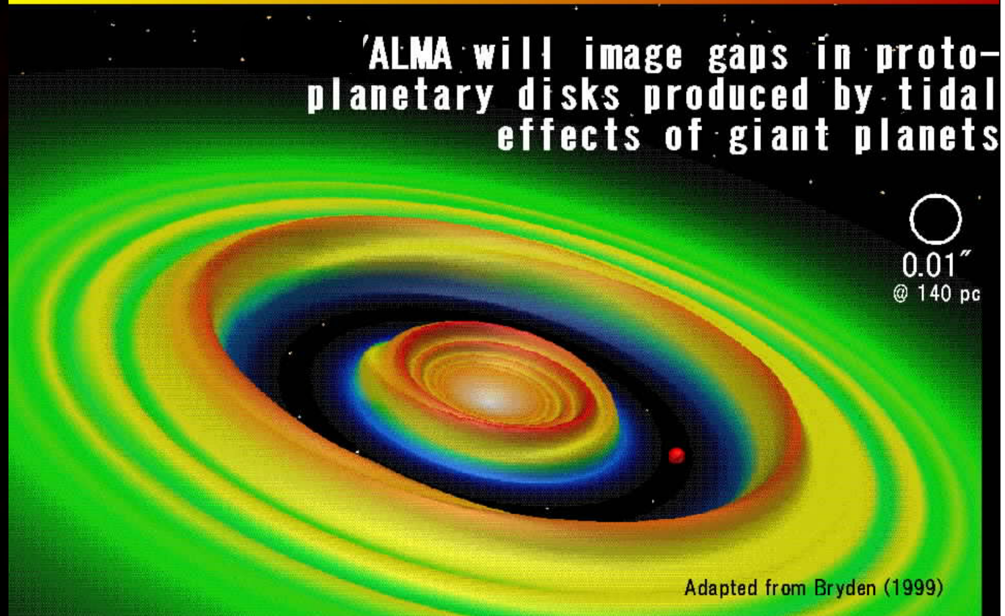
Dreams come true!



Credit: ALMA (ESO/NAOJ/NRAO)

01 arcsec; sharp radio images
early universe (also thanks to
submillimeter emission in SMG)

Gaps in Protoplanetary Disks



New Era of Astronomy will come in the decade of 2020!

- ✦ Advent of ALMA
- ✦ TMT, EELT will start observations in 2020
- ✦ JWST, SPICA, Millimetron will be launched
- ✦ SKA, low radio frequency array
- ✦ What is the roles of ground-based mm/sub-mm single dish telescope(s)?

- Develop new discovery space complementary to ALMA
- Incubate New Ideas for cutting–edge science with ALMA and other big telescopes

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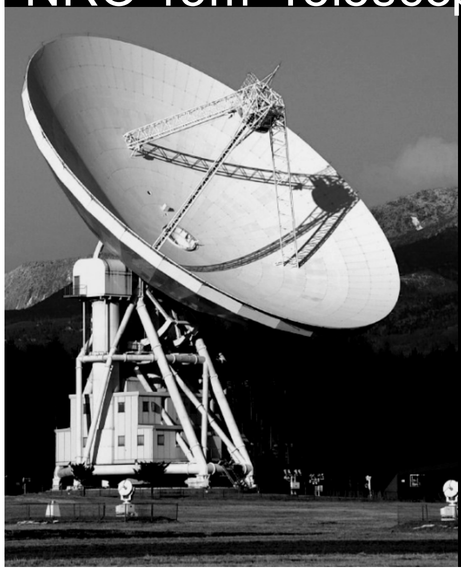
Future Plan to built a new 50 m class mm/sub-mm single dish telescope (at ALMA plateau, Chile)

Major Roles

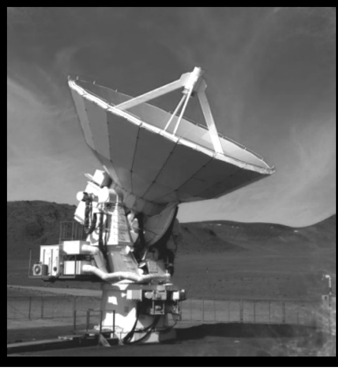
- Develop new discovery space complementary to ALMA
- Operation for ~30 years to exploit synergies with ALMA, SPICA and other telescopes

- Ultimate Wide-field Survey (in Cont. & Spectral Lines)
- Time-domain Science
- Incubate New Ideas

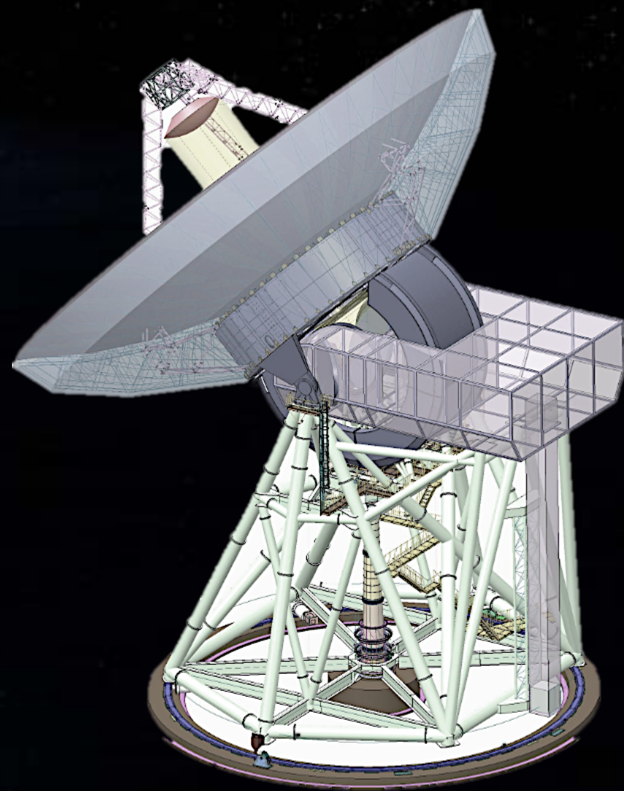
NRO 45m Telescope



Natural Evolution



ASTE 10 m Telescope In Chie



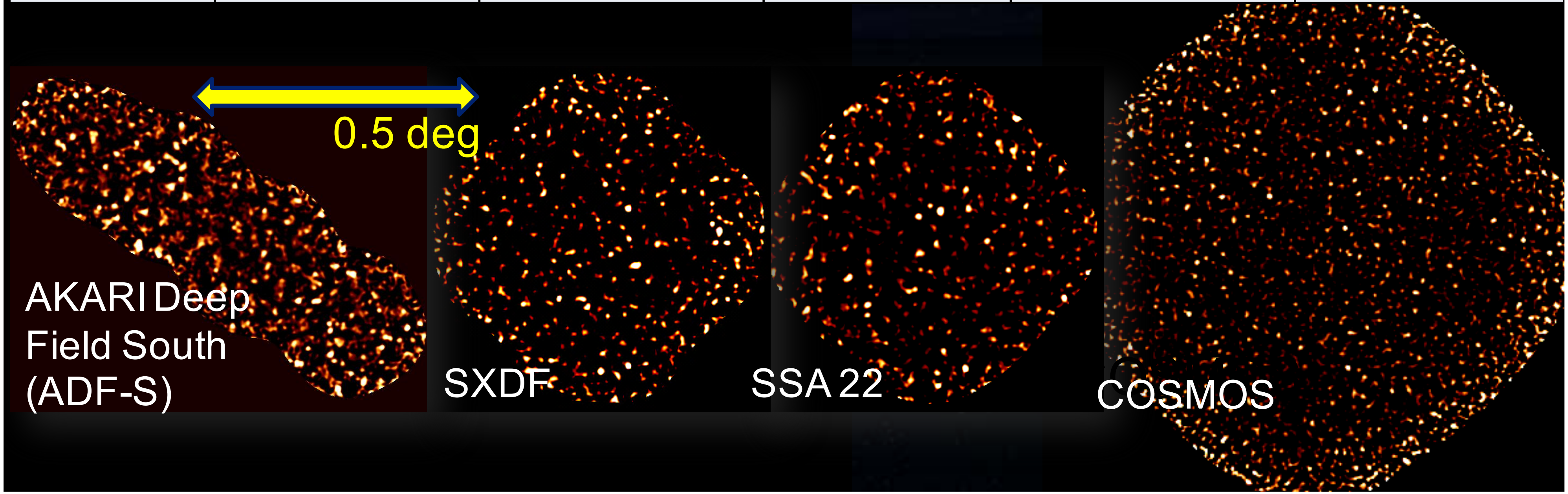
LARGE SUBMILLIMETER TELESCOPE

Basic Concept
:Tentative Specifications

- ✦ Large Aperture: Diameter = 50 m
  less confusion, confident counterpart ID,
  high sensitivity for line emitter search and
  point-like sources & transients such as GRB
- ✦ Large FOV
  : F.O.V = 30 arcmin. diameter, Goal = 1.0 deg
  very high cont. survey speed
- ✦ Main Frequency Range = 70 – 420 GHz
  well fit to Atm windows & "Major" Science Case
  covers up to ~ THz with the limited use of surface
  to maximize synergy with ALMA)
- ✦ total surface rms ≤45 μm (El = 30-80 deg) with Active surface Control

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



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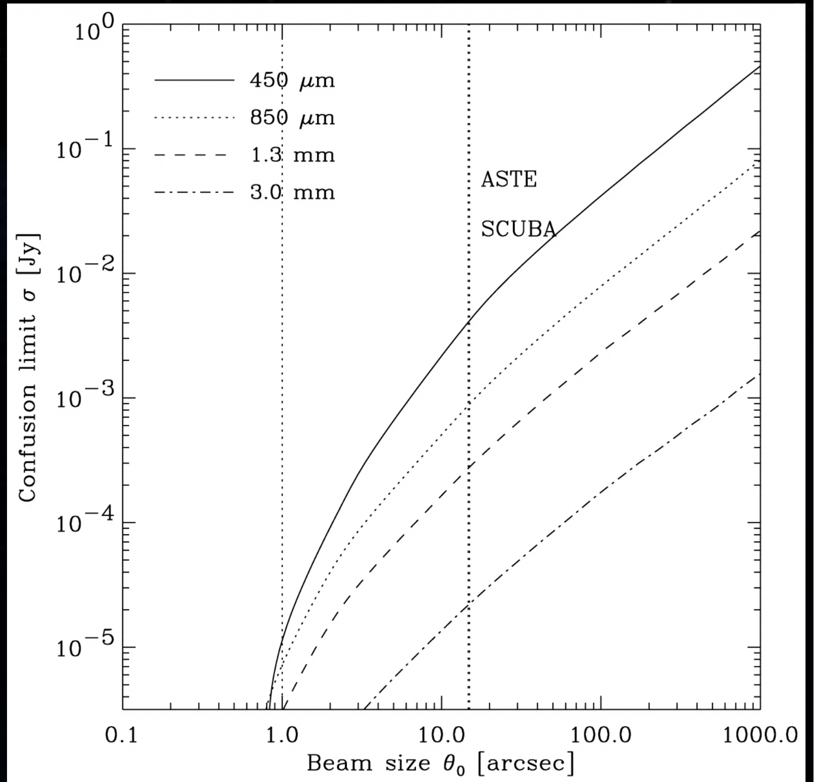
Merit of Large Dishes

		ASTE	CCAT	new (50m)	new/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)

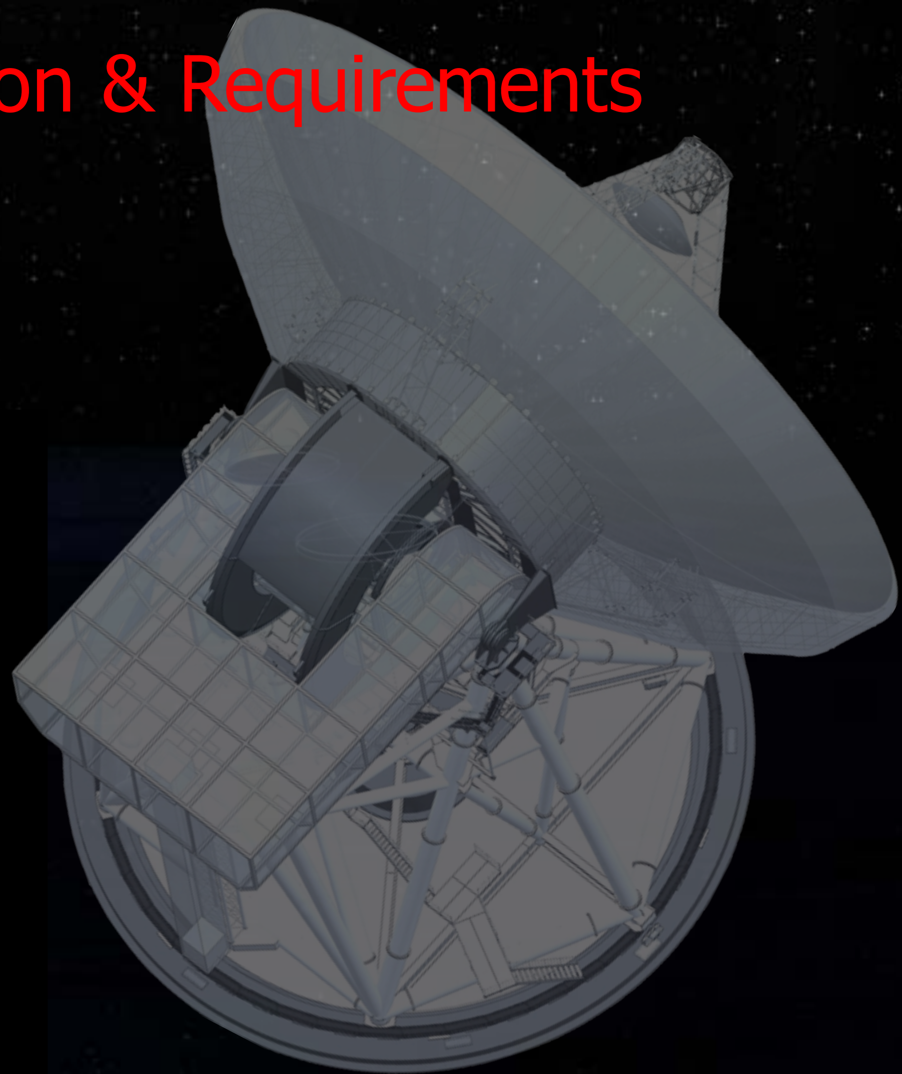


a. See Takeuchi, RK, Kohno+ 2001

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

Basic Concept

:Tentative Specifications



✦ Other Detailed Specification & Requirements

Sub-mm observations
at λ< ~ 1 mm
available for ~ a half in
10 months
(Feb. & Mar. are excluded)

see a poster by Tamura-san
or the LST website

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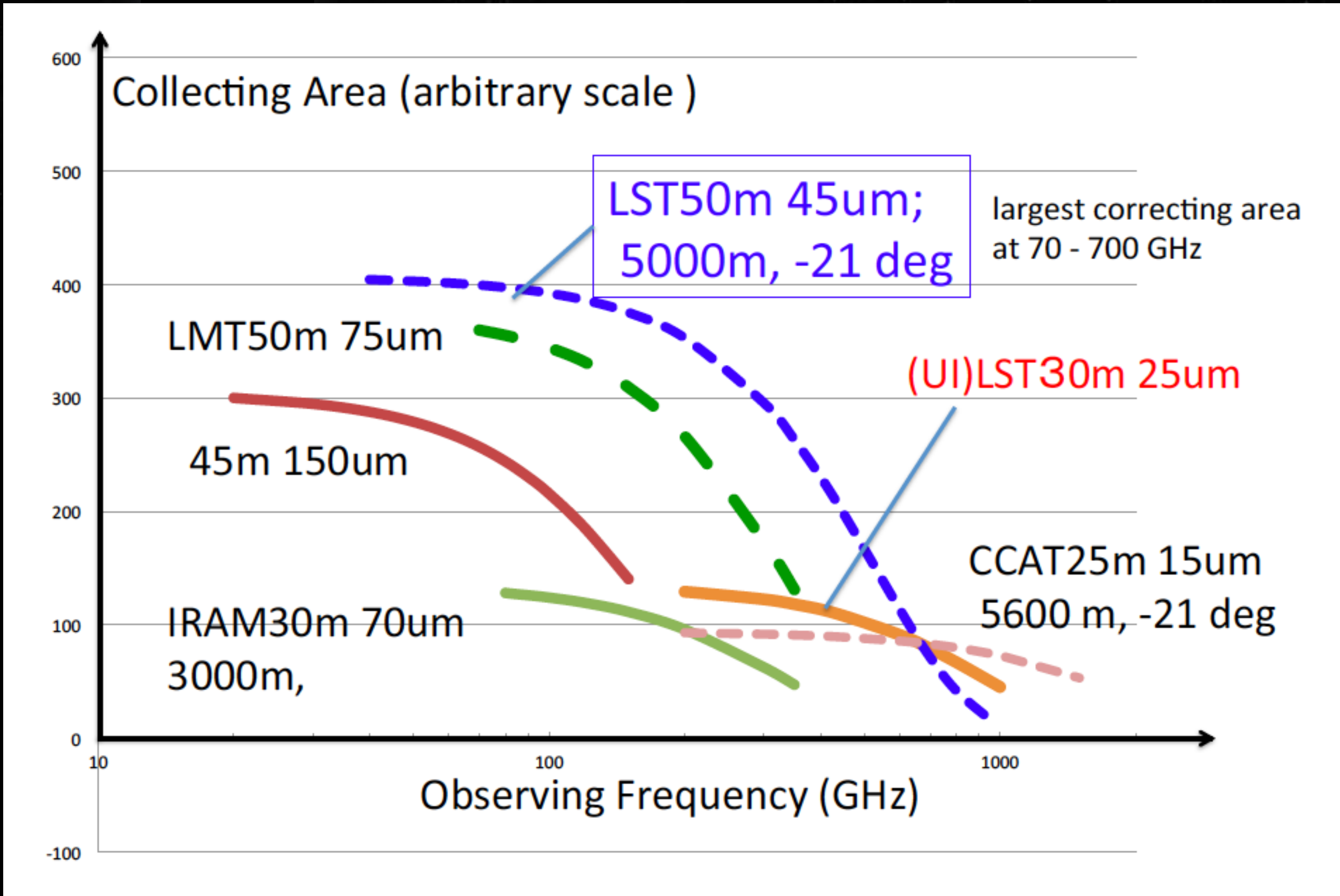
Collecting Area



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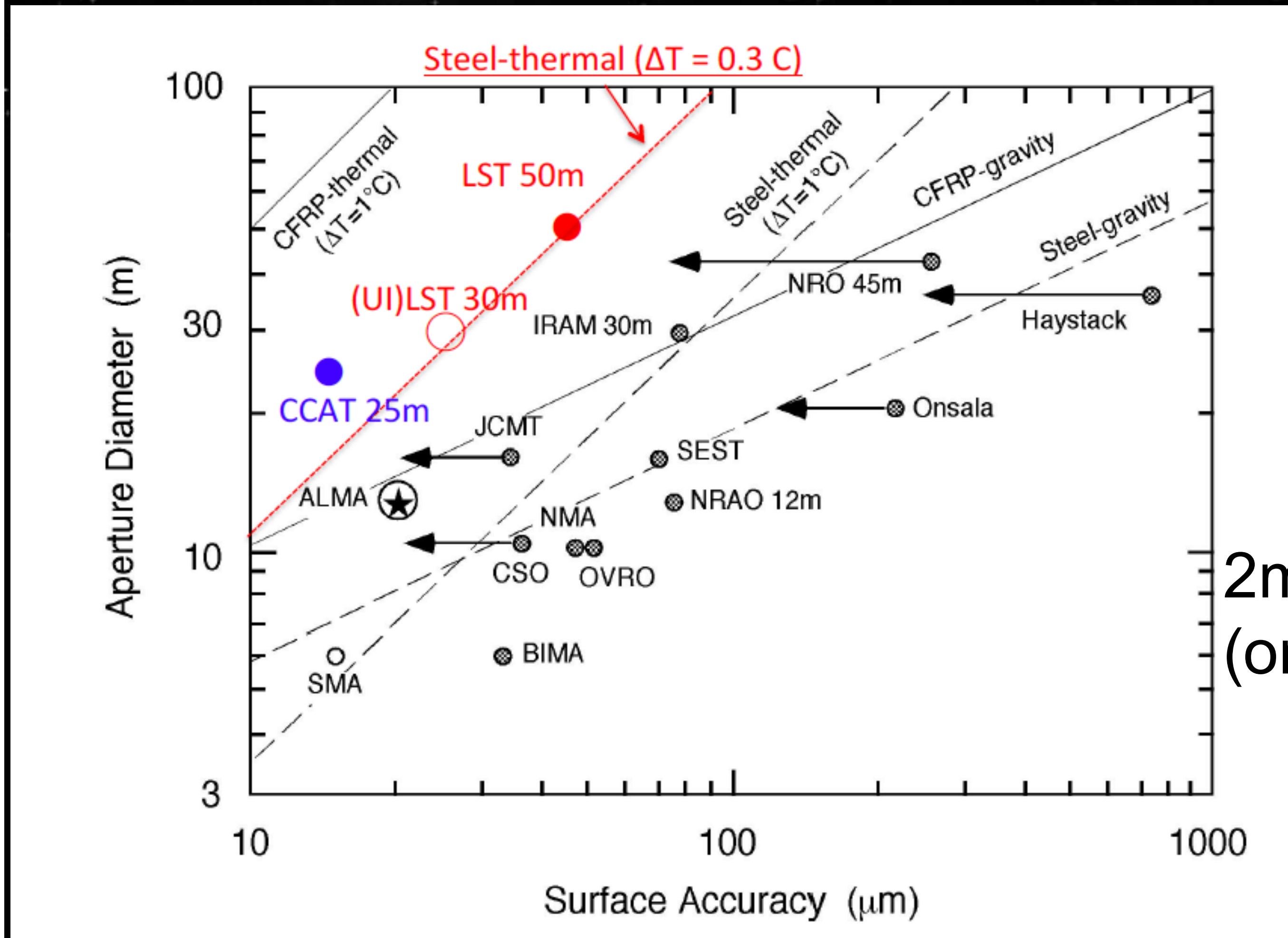
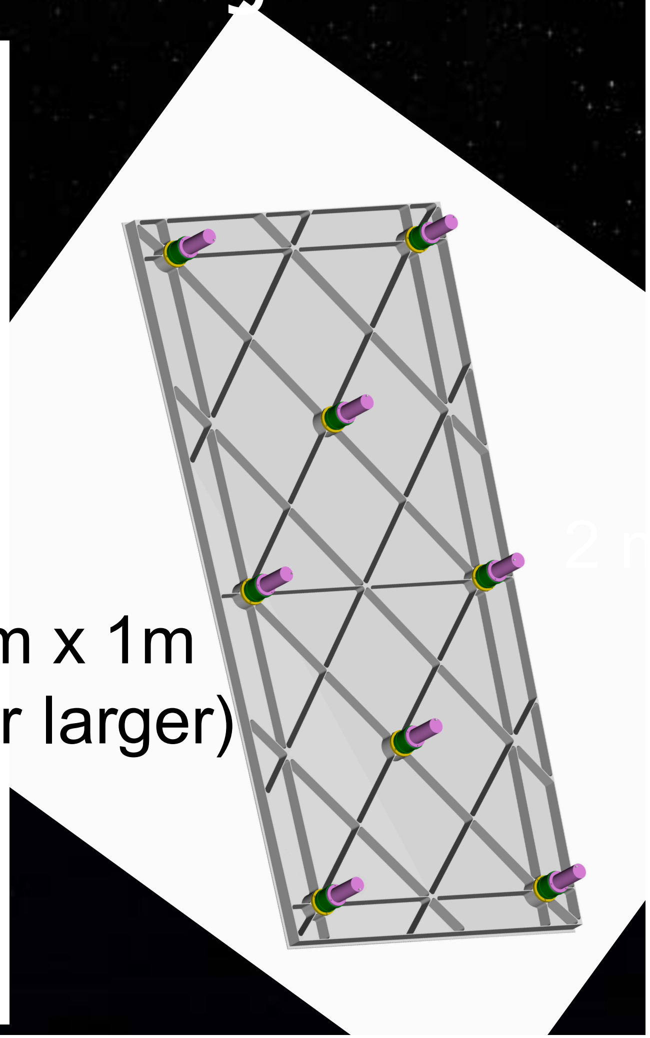
Active Surface Control Required

45 μm rms needs careful thermal design



2m x 1m
(or larger)



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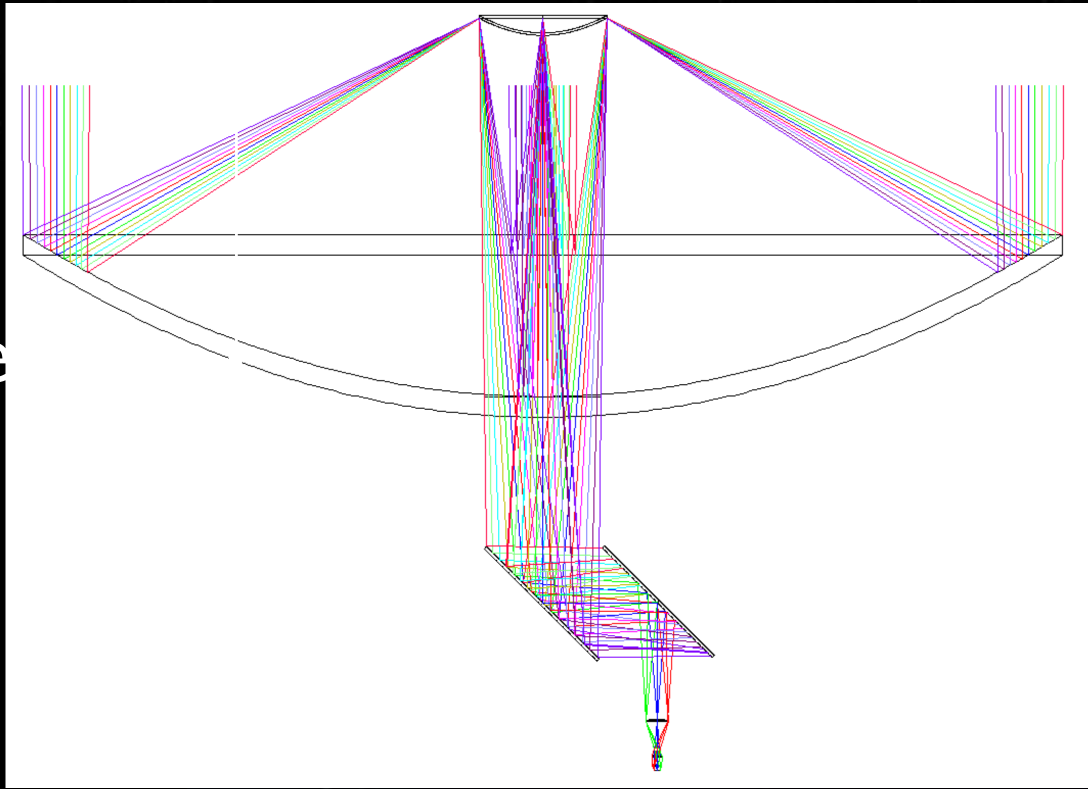
Optical Design for wide FOV

very preliminary

Richey-Chretien Optics for D= 50 m main reflector
Lyot-Stop at Sub-refrector: $D_{effective}$ ~ 46.7 m
FOV ~ 0.7 deg. in diameter at 850 micron achievable

But…

- large mirrors
  $D_{sub\text{-}ref}$ ~ 6.2 m
  #3 mirror ~ 7 m diamete
- huge RX cabin needed (big impact on telescope mechanical structure?)
- No aperture plane @main reflector



Takekoshi, Oshima +

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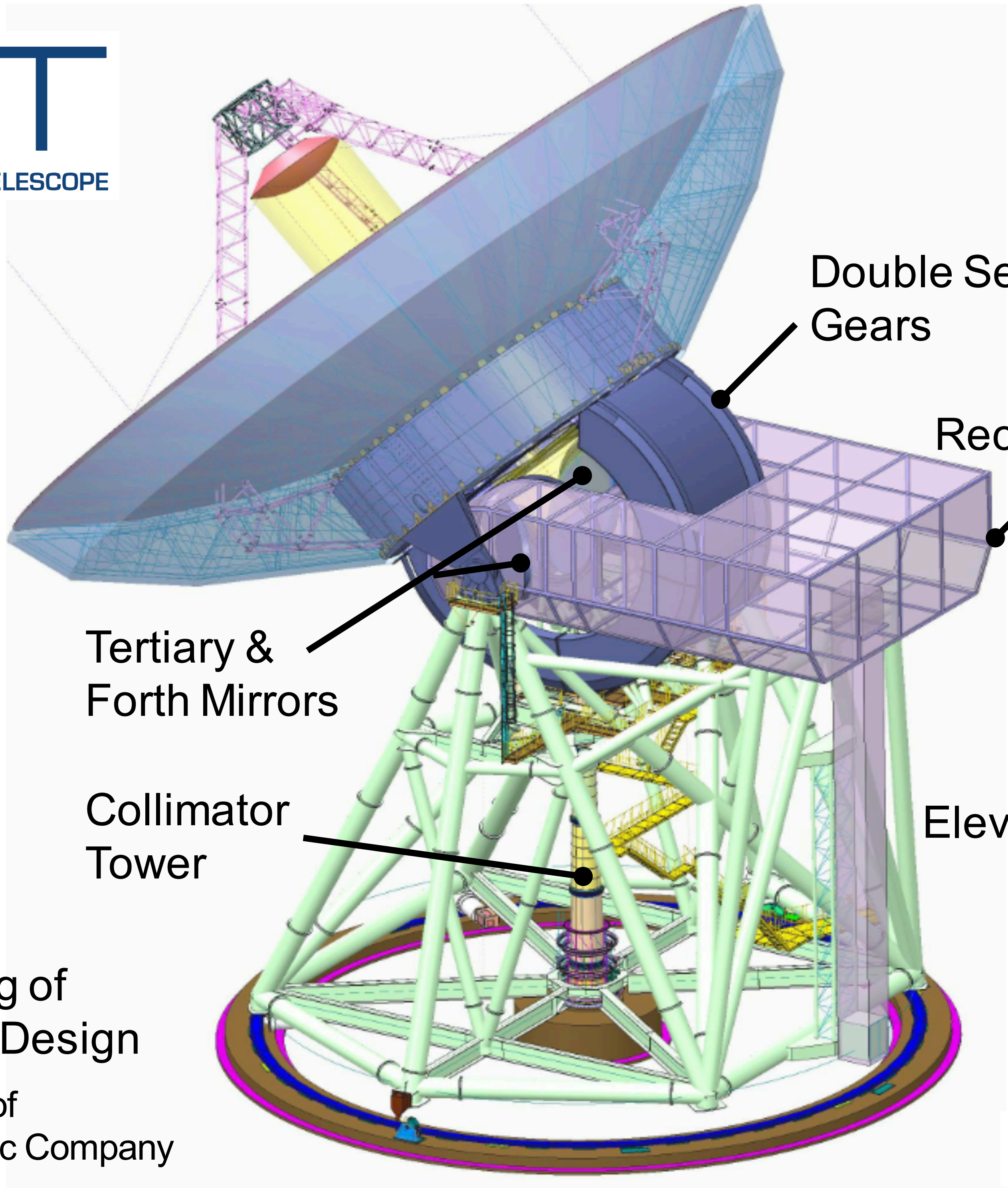

The First Drawing of LST Conceptual Design

Image Courtesy of
Mitsubishi Electric Company

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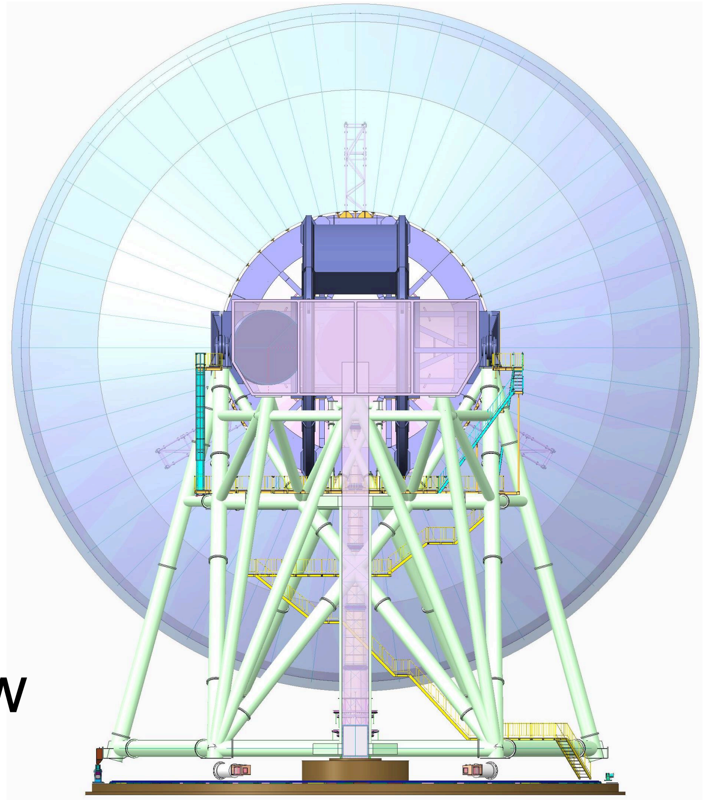
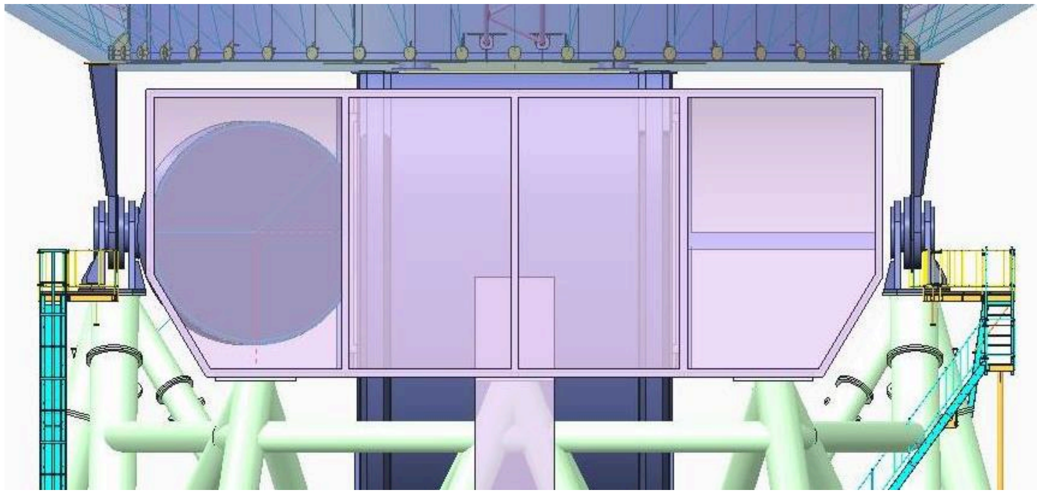
#3, & #4 mirrors limit the minimal size of receiver cabin..

Back View





Top View

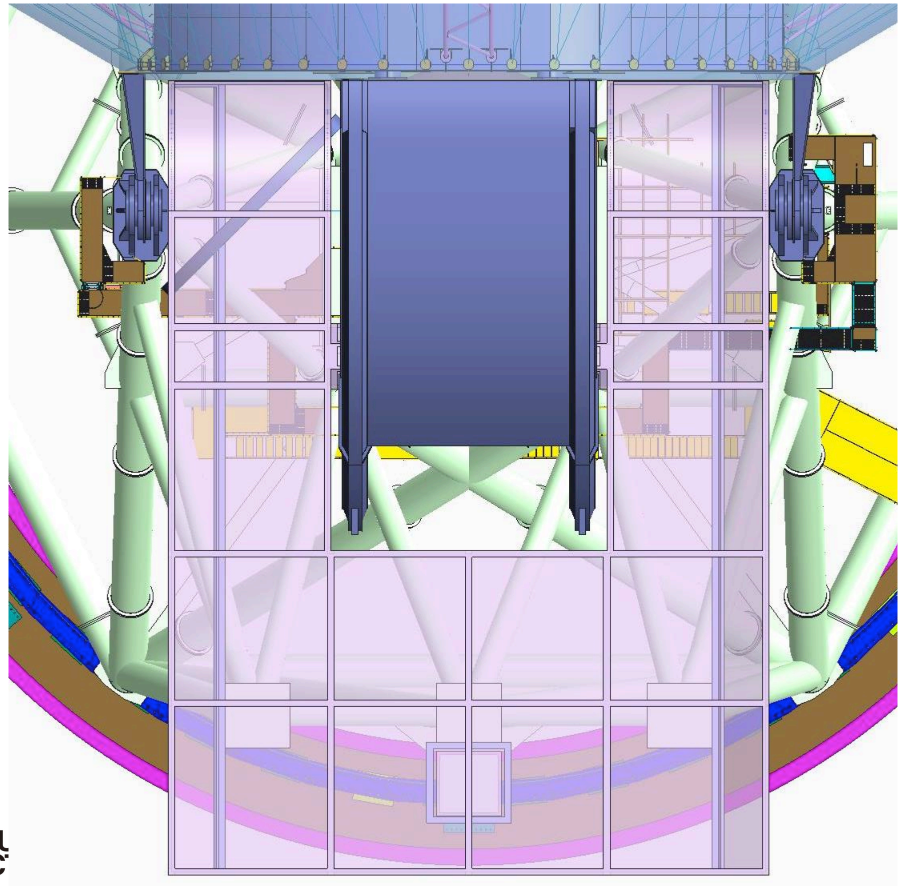


Image Courtesy of
Mitsubishi Electric Company

Chronology of LST (or "ASTE-II")

- Started as a medium-scale future plan of Nobeyama Radio Observatory (45m/ASTE telescopes) in 2008/2009
- Exchanged basic idea with JP astronomy community and outside potential future collaborators in terms of science, telescope specification and instruments
- Science case has been investigated in working group since Jan. in 2010
- Proposed the tentative plan as one of medium-scale plans to Science Council of Japan (SCJ) in 2011
- Discussed in/Feedback from SCJ and NAOJ steering committee of Radio Astronomy etc.
- Concept and Science case been updated in 2014

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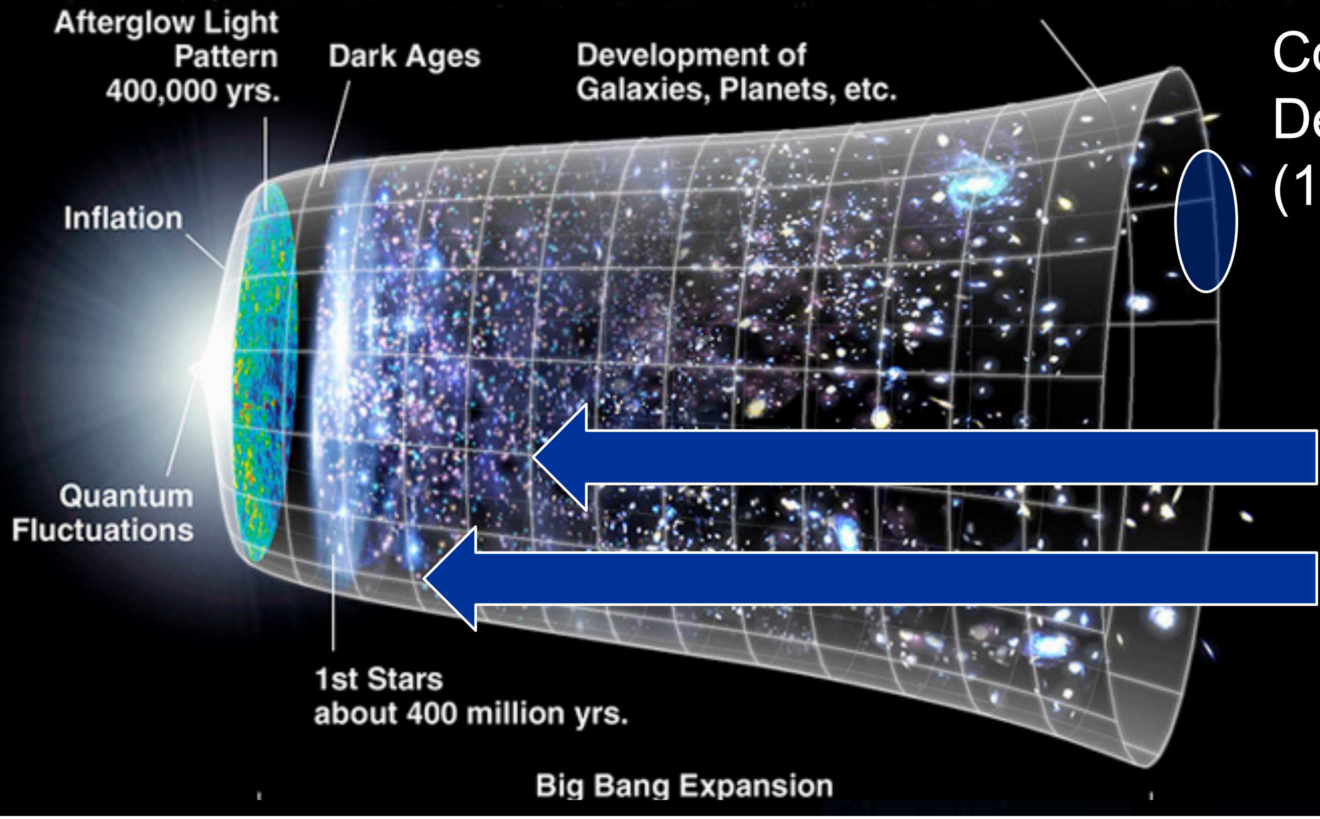
Science Goals

Exploring Obscured Star Formation/Evolution and also SMBH in the Early Universe, and also Large Scale Structure(LSS)
Exploring Star and Planet Formation & Chemistry in our Galaxy
Challenging Time-Domain Science via GRB/Transient Search



Confusion-limited Deep Survey (10-100 deg^2)

Dusty Star Forming Gals/ Proto-QSOs z~ 7-8

GRB Up to z~ 10 (30?)

Resolve CIB in 3D

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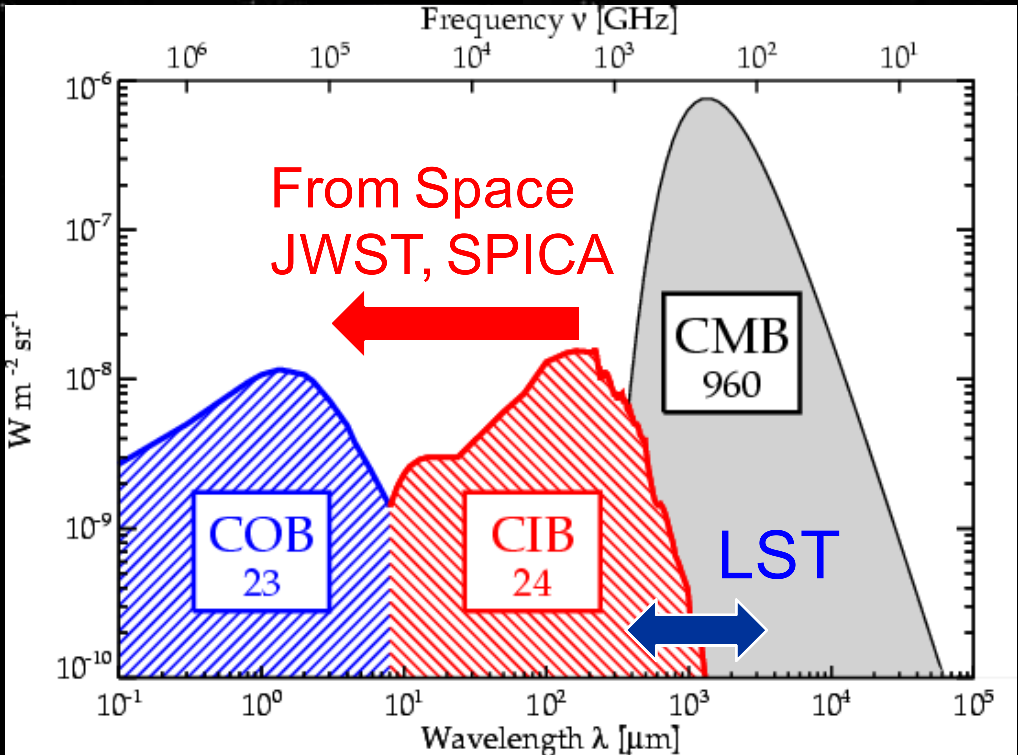

CMB or CMB-pol correlates with CIB discrete sources via ISW or gravitational lensing?

- 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

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Beam Properties for Continuum camera: D= 50 m

Band center	90 GHz 3.3 mm	150 GHz 2.0 mm	225 GHz 1.3 mm	275 GHz 1.1 mm	350 GHz 0.86 mm	405 GHz 0.74 mm
Coverage [GHz]	70-110	125-175	200-250	250-300	335-365	390-420
[mm]	4.3-2.7	2.4-1.7	1.5-1.2	1.2-1.0	0.90-0.82	0.77-0.71
Beam size [arcsec]	**16.5**	**9.9**	**6.6**	**5.4**	**4.2**	**3.7**

Beam size: $1.2 \times \lambda/D$

Confusion-limited "Blank Field" Survey

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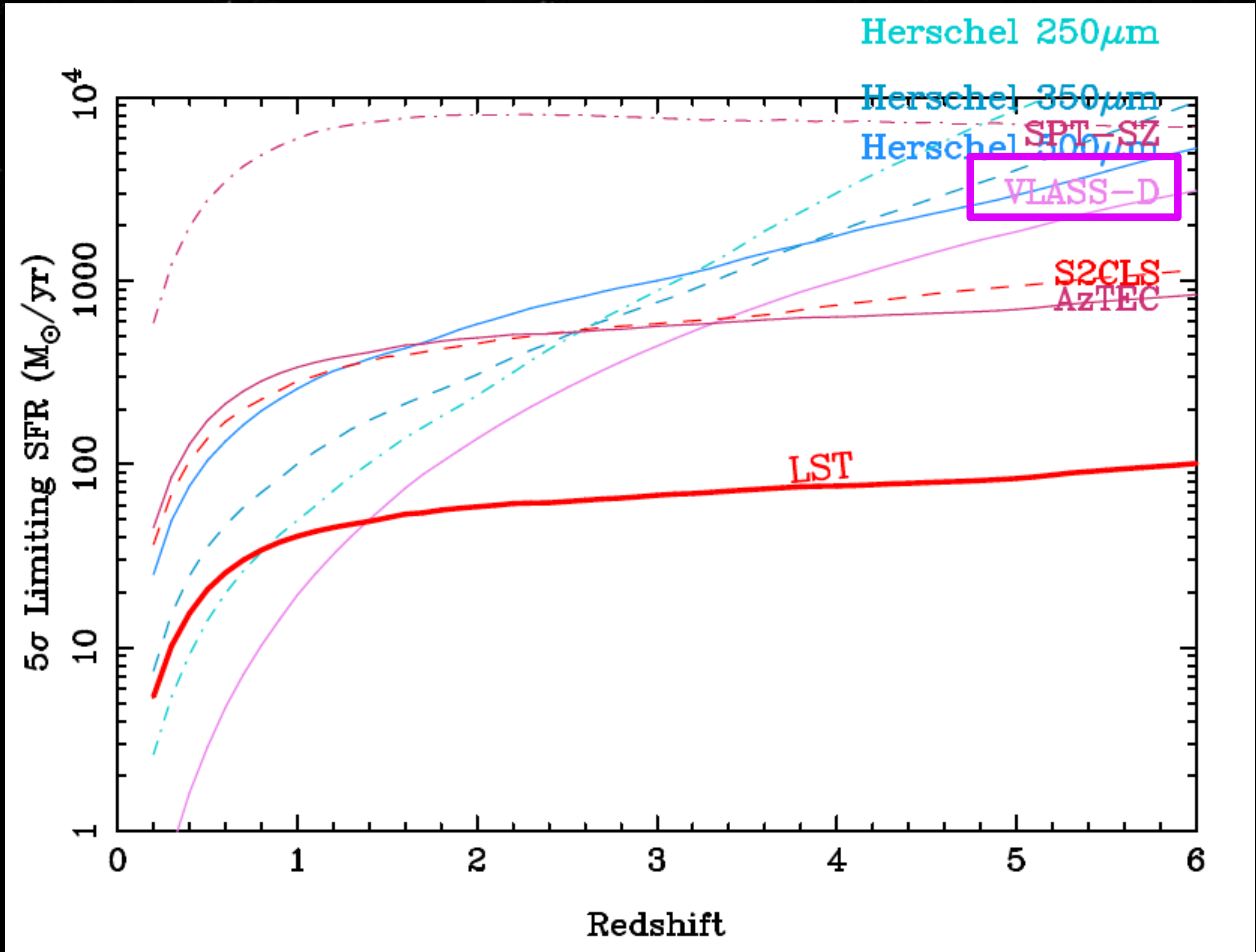
LST-Deep : comparable for z~ 1-2
> 10 times deeper for z > 3



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)
- 10 deg^2
- 870 hours (FOV=0.5 deg.)
- N/deg^2 ~ 20000

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Case 1: simultaneous 3 color observations

1 deg diameter FoV is shared by 3 bands (30' FoV each)
→ equivalent to ~52' FoV)

	2mm (150GHz)	1.1mm (275GHz)	860μm (350GHz)
Beam size	9.9"	5.4"	4.2"
FoV (diameter)	30'	30'	30'
Mapping speed	65,100 arcmin^2/mJy^2/hr	8,000 arcmin^2/mJy^2/hr	1,730 arcmin^2/mJy^2/hr
	18 deg^2/mJy^2/hr	2.2 deg^2/mJy^2/hr	0.48 deg^2/mJy^2/hr
Sensitivity (5σ) for 1 deg^2 map, 1 hour	1.2 mJy	3.4 mJy	7.2 mJy
Sensitivity (5σ) for 1 deg^2 map, 1 min.	9.1 mJy	26 mJy	56 mJy
Confusion limit (5σ)#	0.13 mJy	0.36 mJy	0.42 mJy
Time to a confusion-limited 1 deg^2 map	81 hours	87 hours (1.9×10^4 sources expected)	295 hours (3.0×10^4 sources expected)

based on the number counts by Bethermin et al. (2012) model, 30 beams per source.

Case 2: Single color observations (but 4× higher mapping speed)

Only one band can be operational, but 1 deg diameter FoV

	2mm (150GHz)	1.1mm (275GHz)	860μm (350GHz)
Beam size	9.9″	5.4″	4.2″
FoV (diameter)	60′	60′	60′
Mapping speed	260,400 $arcmin^2/mJy^2/hr$	32,000 $arcmin^2/mJy^2/hr$	6,920 $arcmin^2/mJy^2/hr$
	72 $deg^2/mJy^2/hr$	8.9 $deg^2/mJy^2/hr$	1.9 $deg^2/mJy^2/hr$
Sensitivity (5σ) for 1 deg^2 map, 1 hour	0.6 mJy	1.7 mJy (~400 sources expected)	3.6 mJy
Sensitivity (5σ) for 1 deg^2 map, 1 min.	4.6 mJy	13 mJy	28 mJy
Confusion limit (5σ)#	0.13 mJy	0.36 mJy	0.42 mJy
Time to a confusion-limited 1 deg^2 map	20 hours	22 hours (1.9×10^4 sources expected)	74 hours (3.0×10^4 sources expected)

based on the number counts by Bethermin et al. (2012) model, 30 beams per source.

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Galactic Plane Survey

LST-Wide & Shallow
- 1.1 mm
- 720 μJy (1σ)
- 1000 deg^2
- 870 hours (FOV=0.5 deg.)
- 5σ M(H2) mass sensitivity ~ 10 $M_{jupiter}$ for d~ 150 pc

10x shallower than Deep

Continuum

- "Contamination" cared

N_{tot} ~ 10^6 (SMG)

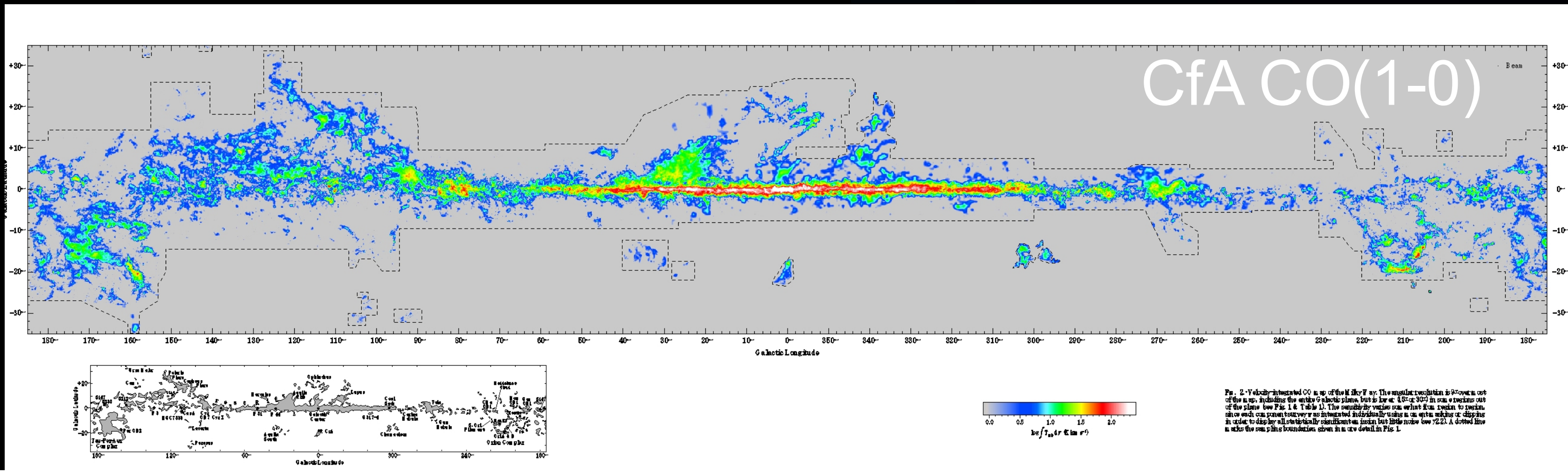
N > 1000 (lensed SMGs)

=> Shallower Survey favorable

3 times shallower

10 times wider; ~10000 deg^2

(core mass function vs IMF)



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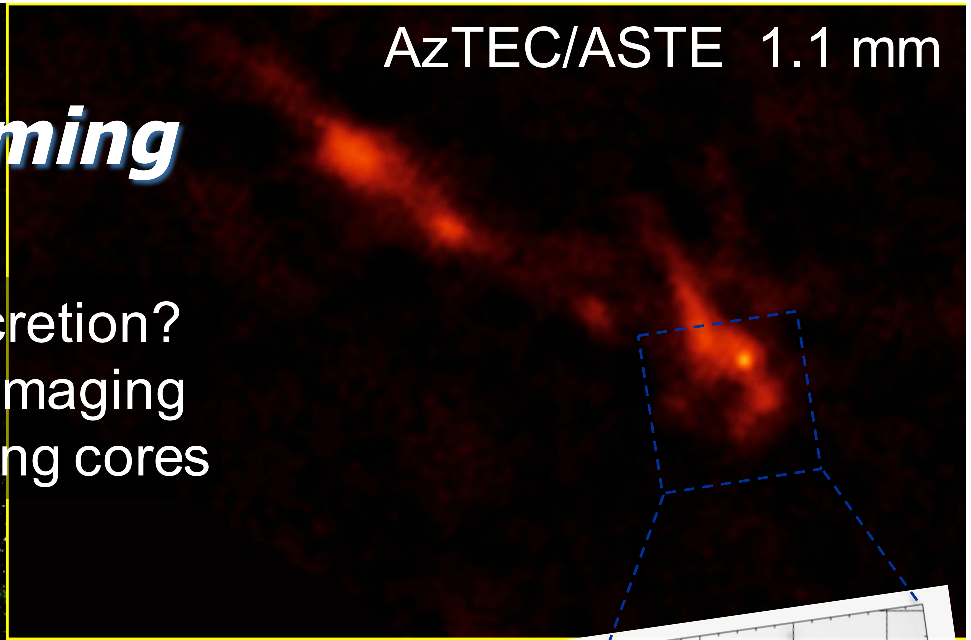
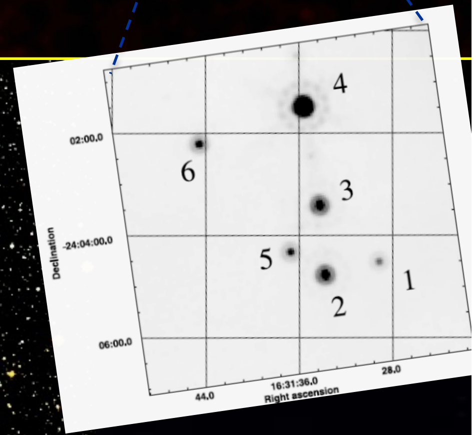
Survey: Star Forming Region

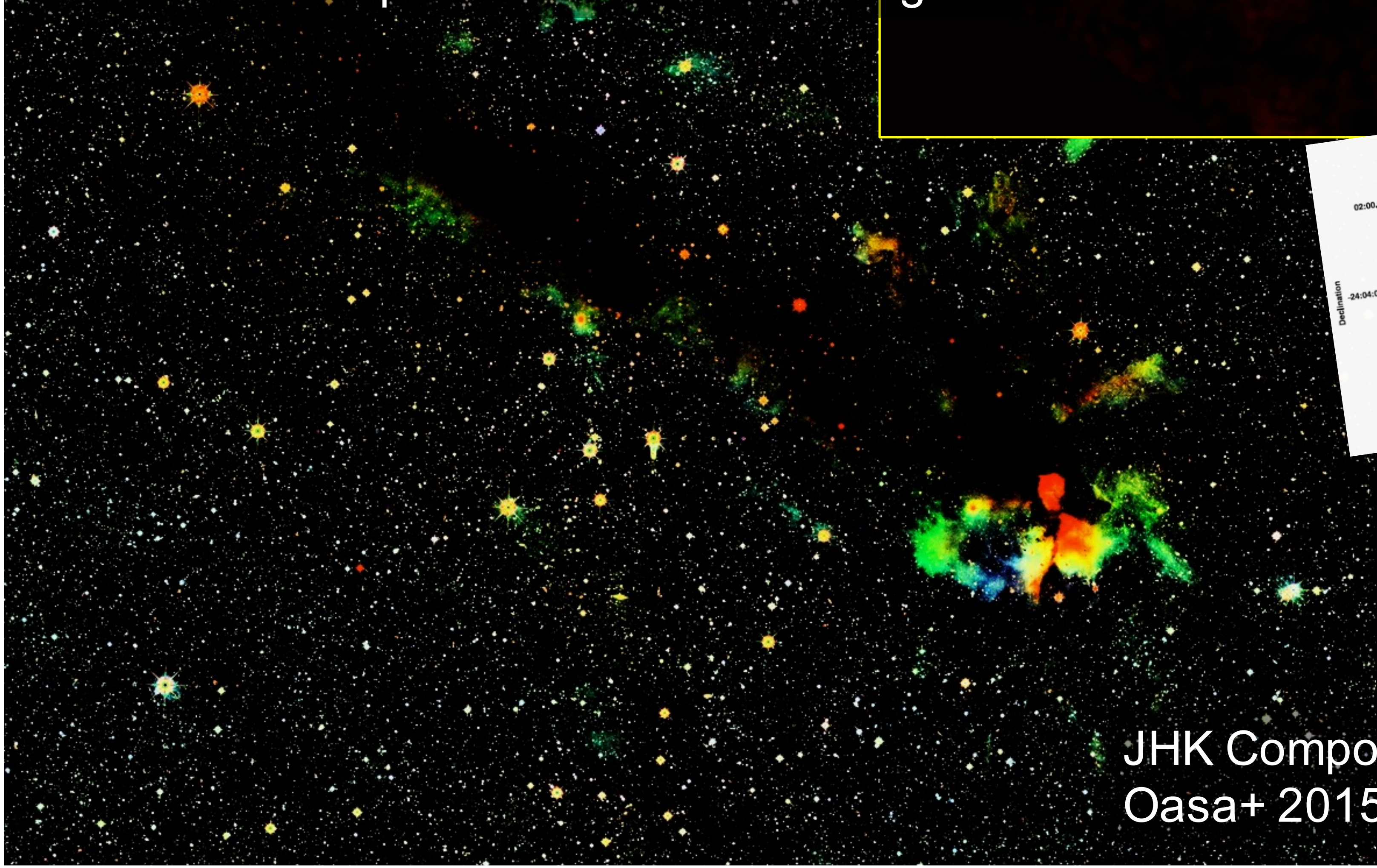
BD and PMO formed via (MC) Core Accretion?
LST 5"-resolution (600 AU d=120 pc) imaging can search for possible BD/PMO forming cores



AzTEC/ASTE 1.1 mm



Spitzer 24micron : six YSOs including a VeLLO (#5)



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

Galactic Plane Survey

spectral line case

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Next Generation Heterodyne Array needed

✦ LST GPS Survey: Scaled to NRO 45m GPS

- the same line set - 10x larger number of beams
- 3x more sensitive RX/Telesc (x 6 possibly realistic)

=> 1600 deg^2 with 120 hours (same rms)

✦ NRO 45m GPS; 15 ”beam

- CO(1-0), 13CO(1-0), & C18O(1-0) simultaneously
- FOREST 4 beam receiver
- Planning 160 deg^2 area with 1200 hours

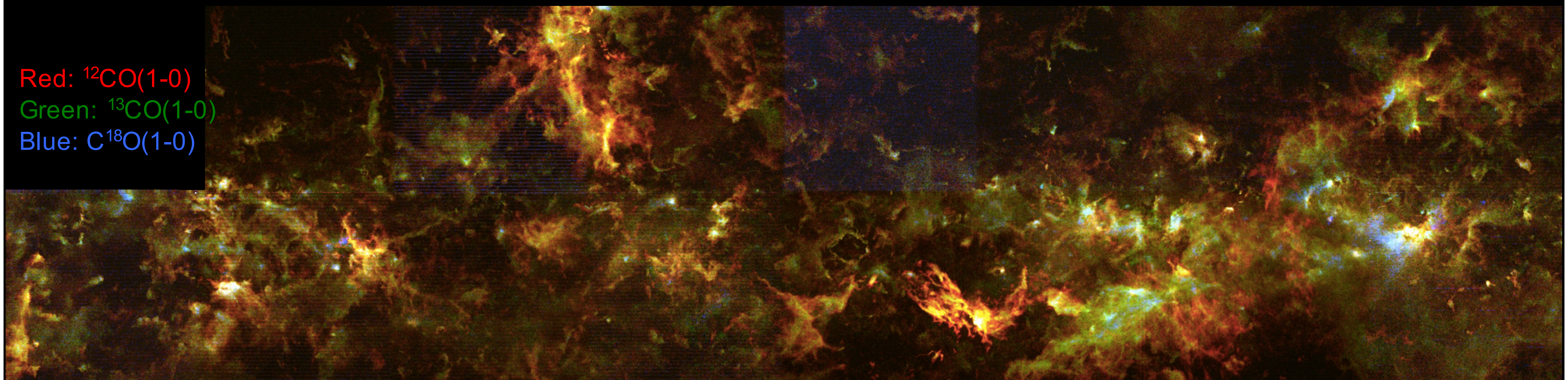
Pilot Observations in 2013-2014

- NRO Galactic Plane Survey
  - One of the NRO 45m Legacy Project
  - Revealing the missing links between the Galactic structures and giant molecular clouds through the observation of interstellar
    - L=10° -- 50° , 198° -- 236° ; B=±1° (~ 160 deg^2)
    - ^{12}CO, ^{13}CO, $C^{18}O$ (J=1-0)
    - NRO 45m Telescope
    - Angular resolution: 15″ @ 115GHz
    - Three-year Legacy Project @ NRO : 2014 -- 2016
    - Total: 1200 hours

Minamidani (NRO) +

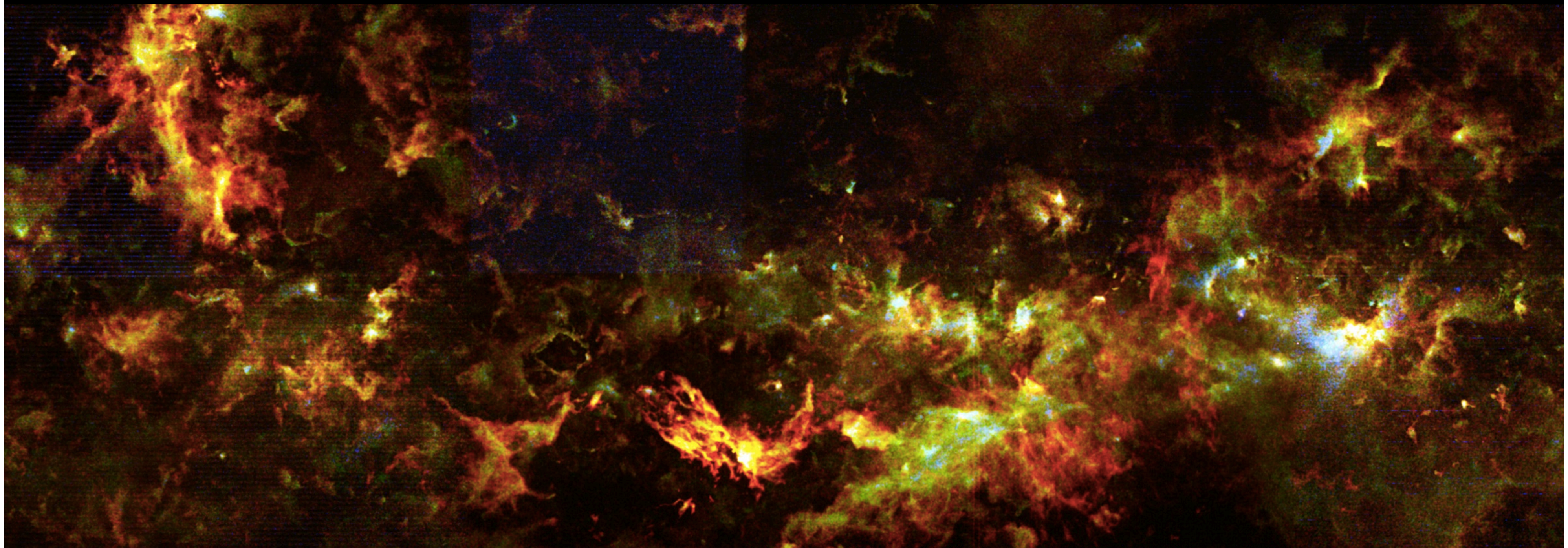
Pilot Observations in 2013-2014

8 deg. X 2 deg



Red: ^{12}CO(1-0)
Green: ^{13}CO(1-0)
Blue: $C^{18}O$(1-0)

NRO 45m GPS Pilot Observations
Filaments and Shells anywhere



Red: $^{12}CO(1-0)$
Green: $^{13}CO(1-0)$
Blue: $C^{18}O(1-0)$

Δv ~ 1 km/s
rms ~ 0.4 K (in Ta*: typical) for Δv ~ 1 km/s
Ta* peak maps were used

LST

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Spectral Line Survey Speed (100 beams, 1 deg², 0.3K@0.3km/s)

Line	Freq.	Tsys	Beam (") (50m)	Time [hr] (50m)
CO(3–2)	345.796	140	4.4	10.5
^{13}CO(3–2)	330.588	199	4.6	20.2
C^{18}O(3–2)	329.331	239	4.6	28.5
CO(2–1)	230.538	91	6.6	2.6
^{13}CO(2–1)	220.399	89	6.9	2.4
C^{18}O(2–1)	219.56	89	6.9	2.3
CO(1–0)	115.271	130	13.1	3.2
^{13}CO(1–0)	110.201	77	13.7	0.8
C^{18}O(1–0)	109.782	76	13.8	0.8

Source Elevation: 68° , PWV = 0.913mm, Dual polarization

Rich Science of LST

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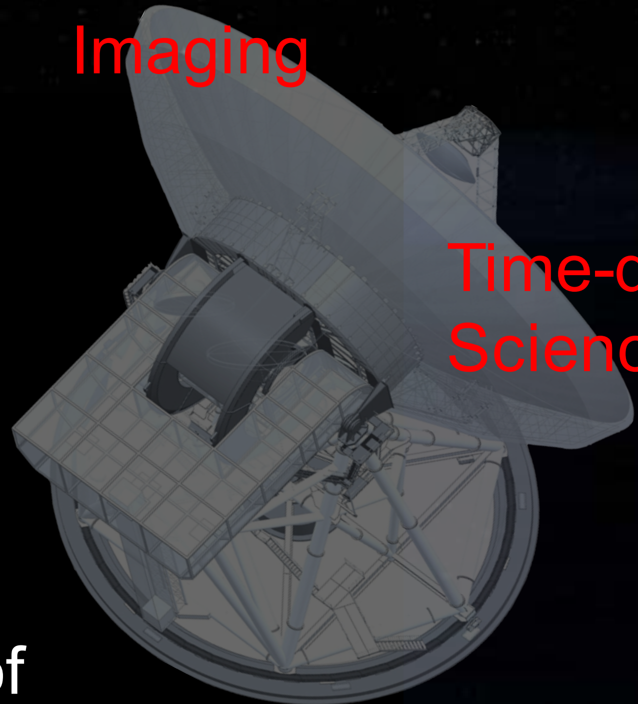
SZ Cosmology
- blind search for high-z SZ cluster

Galaxy Formation & Evolution, LSS:
CO & [CII] emitter Search

Chemical Evolution
From core to disk via
Spectral line survey

Wide-Field Imaging



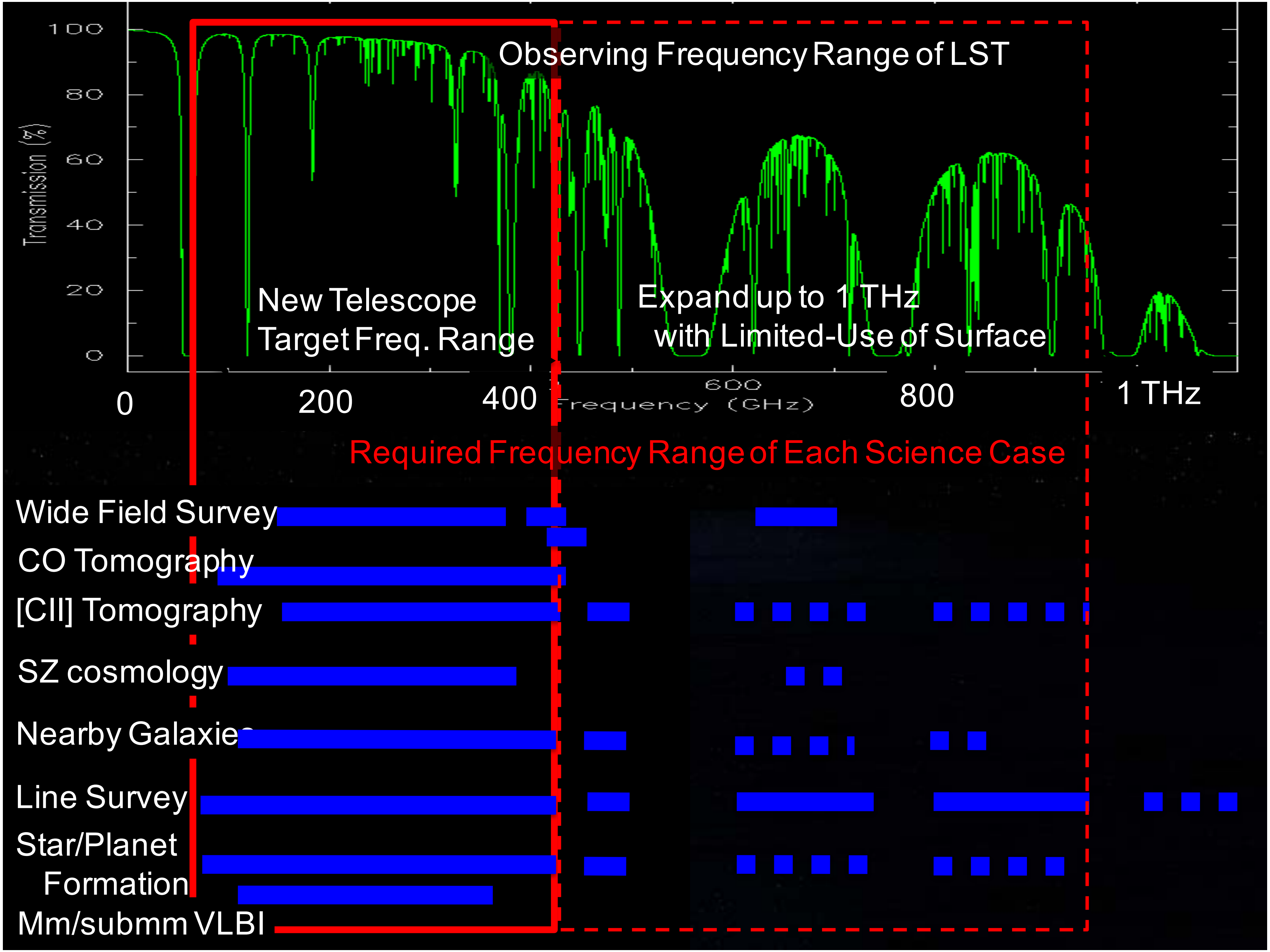
Nearby galaxies

Time-domain Science

Large Survey of Milky Way/SFRs
-e.g., CMF vs IMF

GRB & Transient
- GRB physics
- diagnostic of EoR
- unknown physics
(NS merger as GW)

Mm/sub-mm VLBI
- time-variability of accretion disk/jet structure



Observing Frequency Range of LST
100
80
60
40
20
0
Transmission (%)
New Telescope
Target Freq. Range
Expand up to 1 THz
with Limited-Use of Surface
0
200
400
600
Frequency (GHz)
800
1 THz
Required Frequency Range of Each Science Case
Wide Field Survey
CO Tomography
[CII] Tomography
SZ cosmology
Nearby Galaxies
Line Survey
Star/Planet
Formation
Mm/submm VLBI

Key Instruments

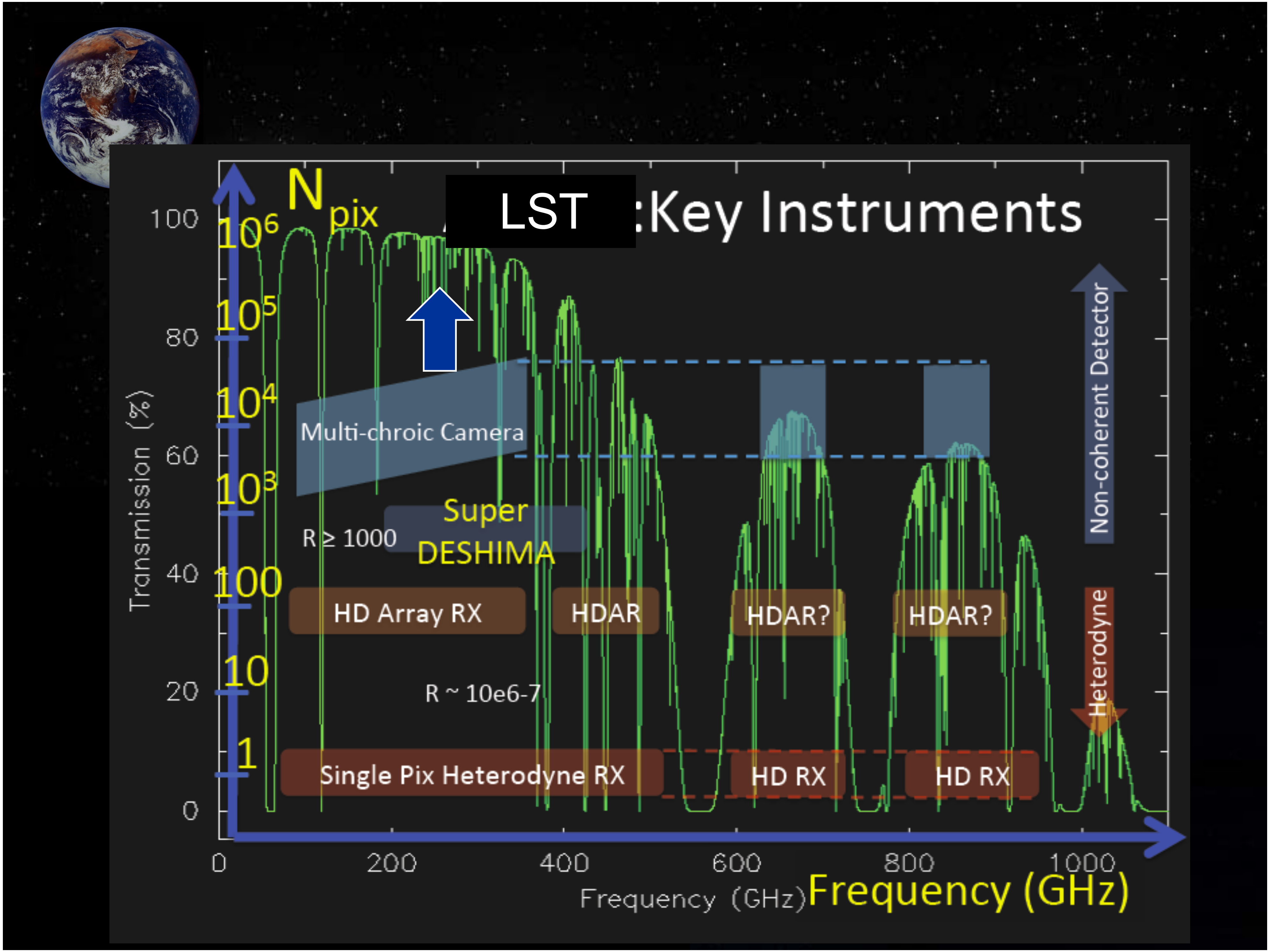
Wide-Field Instruments as keys for Science Goals

Multi-chroic (or single color) wide-field Camera(s)
covering 2, 1.1, 0.85, (+0.45, 0.35 mm)

Multi-pix Imaging Spectrometer; e.g., “Super(Hyper) -DESHIMA” with 200 (70) -420 GHz & Npix (# of beams) of > 300 (~ 1000) for [CII]/CO Tomography

Multi-band Heterodyne Receiver
+ Ultra-wideband Spectrometers (for line survey)

Heterodyne Arrays; e.g., 100, 230, 350, 490 GHz
25 - ~ 100 beams?


LST :Key Instruments
N pix
10^6
10^5
10^4
10^3
100
10
1
Transmission (%)
100
80
60
40
20
0
Multi-chroic Camera
Super DESHIMA
R ≥ 1000
HD Array RX
HDAR
HDAR?
HDAR?
R ~ 10e6-7
Single Pix Heterodyne RX
HD RX
HD RX
Non-coherent Detector
Heterodyne
0
200
400
600
800
1000
Frequency (GHz)
Frequency (GHz)

LARGE SUBMILLIMETER TELESCOPE

LST from now

Tentative Goal in coming 3-4 years

- Propose LST as one of big-scale plans to Science Council of Japan in ~ 2017

Preparation for the new proposal

- Killer science should be more sharpened, also wide variety of science case will be planned:

  Feedback to Telescope Spec & Requirements
- Planning telescope design study & R&D :

  planning in 2015, R&D starts in 2016
- Continue to exchange ideas: collaboration in e.g., detector developments, ..

Start construction from ~ decade of 2020

(possibly immediately after completion of TMT)

Summary

LARGE SUBMILLIMETER TELESCOPE

✦ The Advent of New Decade of Discovery

2016- start full ALMA; 0.01 arcsec resol

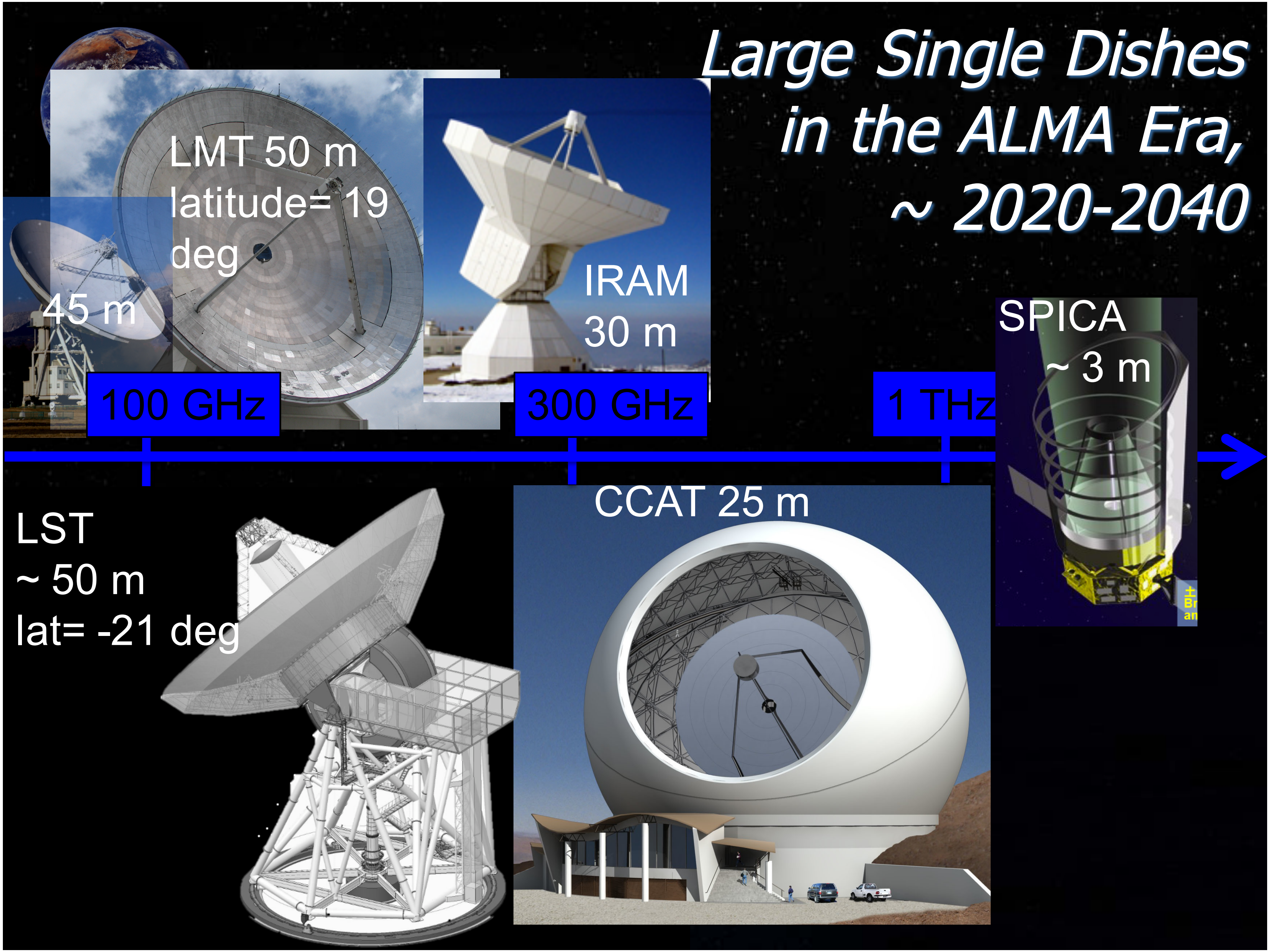
2020- TMT, EELT, JWST, SPICA ..

2020- CCAT, SKA..

2025(?)- LST

✦ LST can open wide-filed and time-domain science in mm/sub-mm wavelengths, and can allow cutting-edge science via census of universe

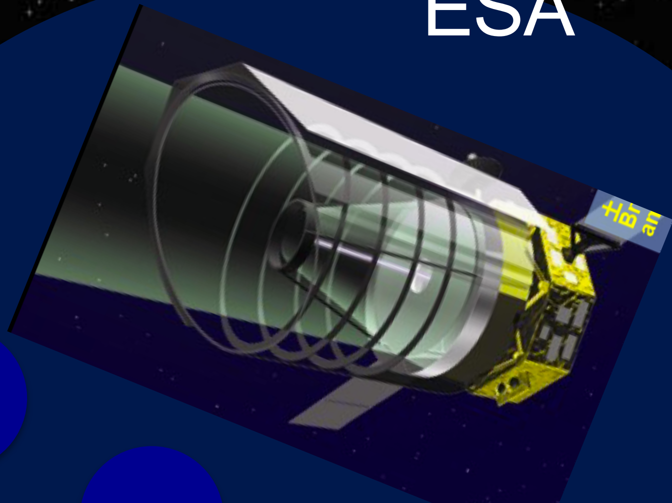
✦ Also can pick up very interesting/extraordinary sources for ALMA (+TMT/EELT etc.) high-spatial resolution imaging, and can enhance ALMA science



Large Single Dishes
in the ALMA Era,
~ 2020-2040
LMT 50 m
latitude= 19
deg
45 m
IRAM
30 m
SPICA
~ 3 m
100 GHz
300 GHz
1 THz
LST
~ 50 m
lat= -21 deg
CCAT 25 m

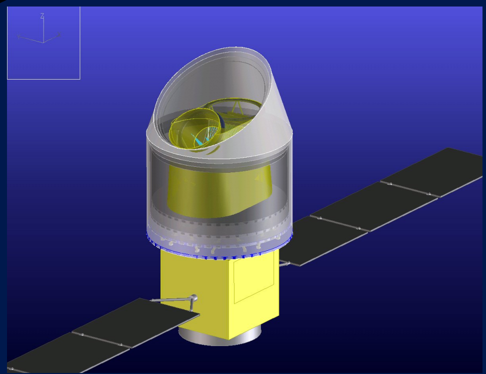
Synergies with telescopes in space

SPICA/ISAS/JAXA, ESA



LiteBIRD/KEK, ISAS/JAXA

Inflation to Dark Age



Satellite Technology

Origin of Life
Cosmic SF

Mm to FIR Camera/Detectors

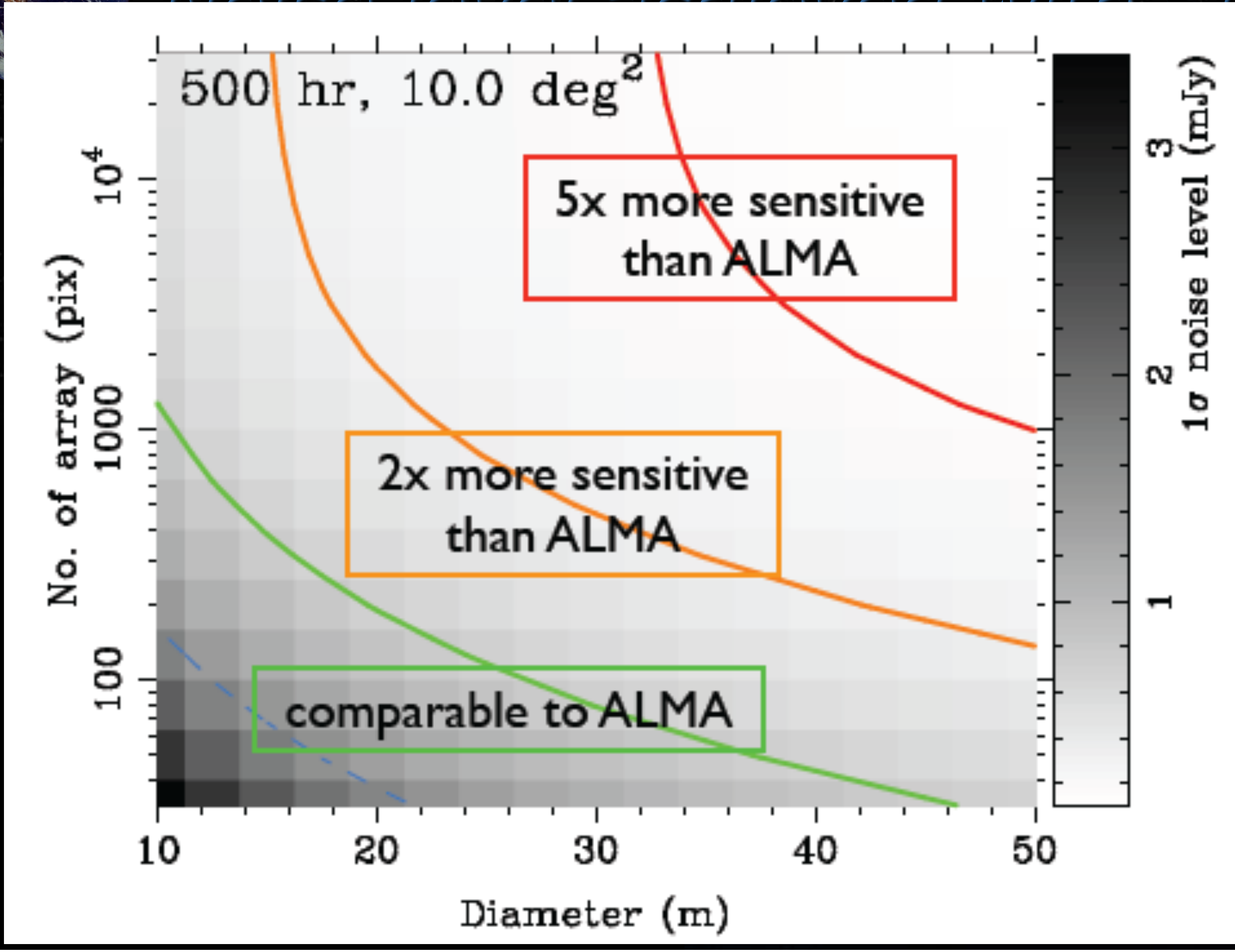
Imaging Spectroscopy

CMB Secondary
CMB and LSS/Dark matter

LST/JP Univ. &NAOJ & ALMA

Back-up

Advantage of Singe Disk + Cont. Camera



Science Goals of LST: examples

Census of SMGs; Obscured Star Formation-part 1

- Establishing a large sample of dusty forming galaxies (SMGs) at z=1-5 (peak of cosmic star formation) down to SMGs with “lower” SFR~ 100 Msun/yr

CO + [CII] Tomography; Obscured Star Formation-part 2

- Large Scale Structure (LSS) up to z ~ 5 (or 7?)
- CO Luminosity Functions & CO SLEDs for various sources (SBs & AGNs)

Census of high-z SZ clusters as high-mass end of LSS

Census of Cores and Clumps in our galaxy

Spectral Line Survey for varisou kinds of object; disk..

Dynamical Structure of Jets and Accretion disks (VLBI)

CO/[CII] Tomography

Science Goals

Y.Tamura, K. Kohno+

- LSS (Large Scale Structure) up to z~7
- CO Luminosity Function at each redshift shell; $L_{CO3\text{-}2}{}^{*}$
- CO SEDs & Diagnostics of Power sources
- Redshift Space Distortion (RSD) at z~2 with 10^4 galaxies
- Byproduct; galaxies in EoR might be detected in [CII]

Survey Example; 6 deg^2 Survey with D~50m & 1000 hours

- Feasibility study based on S-cubed SAX by Obreschkow + 2009
- assuming use of future Imaging Spectrometer ("Super-DESHIMA") with 300 pix & Freq. coverage of 70 – 400 GHz
- Estimated Number Count; # of detectable gals > 10^4 at z~2
- [CII] can be detected at z ~ 4 to 7 (EoR) at 200-400 GHz

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.

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

Large Surveys of Milky Way Galaxy

Onishi +

Wide-filed Survey or nearby Star forming regions

Survey of Galactic Plane

Requirements

high spatial resolution for

- identifying clumps at d~ 10 kpc => needs 30-50m class telescope (0.3pc ~ 6")
- investigating structure of envelopes from 0.1 pc down to 1000 AU => (1000 AU ~ 6" at d~ 150 pc)

Large Surveys of Milky Way Galaxy

Onishi +

- AzTEC/ASTE 1.1 mm Survey of nearby SF regions
  - ~20 deg^2 with 5-20 mJy with 100 hours
  - 4 σ H2 mass sensitivity ~ 0.05 Msun for d=150 pc
- Survey Speed (deg^2/hour with a fixed depth) $\propto n_{pix}D^2$

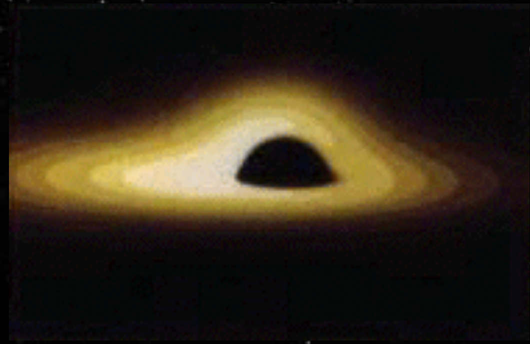
	D=10 m(ASTE)	=> D= 35m
n_{pix} = 100 (AzTEC)	1	10
1000	10	100
10^4	100	1000

- Example of Deeper Survey with new telescope

Depth & # of Pixels	Observing time	Survey Area
σ= 1 mJy Npix = 10^4	1000 hours	2000 deg2; Nearby SF Regions with 4σ mass ~ 0.01 Msun => includes >10^{5-6} SMGs => includes >10^3 lensed SMGs like SPT SMGs

Mm/submm VLBI with LST

Honma +



- BH shadow will be hopefully imaged with sub-mm VLBI including ALMA, so what's next ?
- 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

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ALMA Receiver Bands

	RF (GHz)	Region	
Band 1	35 – 50	EA (ASIAA)	
Band 2	67 – 90	(EU/NA)	?
Band 3	84 – 116	NA (HIA)	
Band 4	125 – 163	EA (NAOJ)	Cyc-II
Band 5	163 – 211	EU (NOVA)	Cyc-?
Band 6	211 – 275	NA (NRAO)	
Band 7	275 – 373	EU (IRAM)	
Band 8	385 – 500	EA (NAOJ)	Cyc-II
Band 9	602 – 720	EU (SRON)	
Band 10	787 – 950	EA (NAOJ)	Cyc-?

ASTE-II also covers the same frequency range (except b-1)