

LST
LARGE SUBMILLIMETER TELESCOPE

New 50-m class
single dish telescope

15.6 Mpc/h

Large Submillimeter Telescope (LST)



Toshikazu Onishi (Osaka Pref. Univ.)

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Shun Ishii (U. Tokyo) and

LST Working Group



Overview



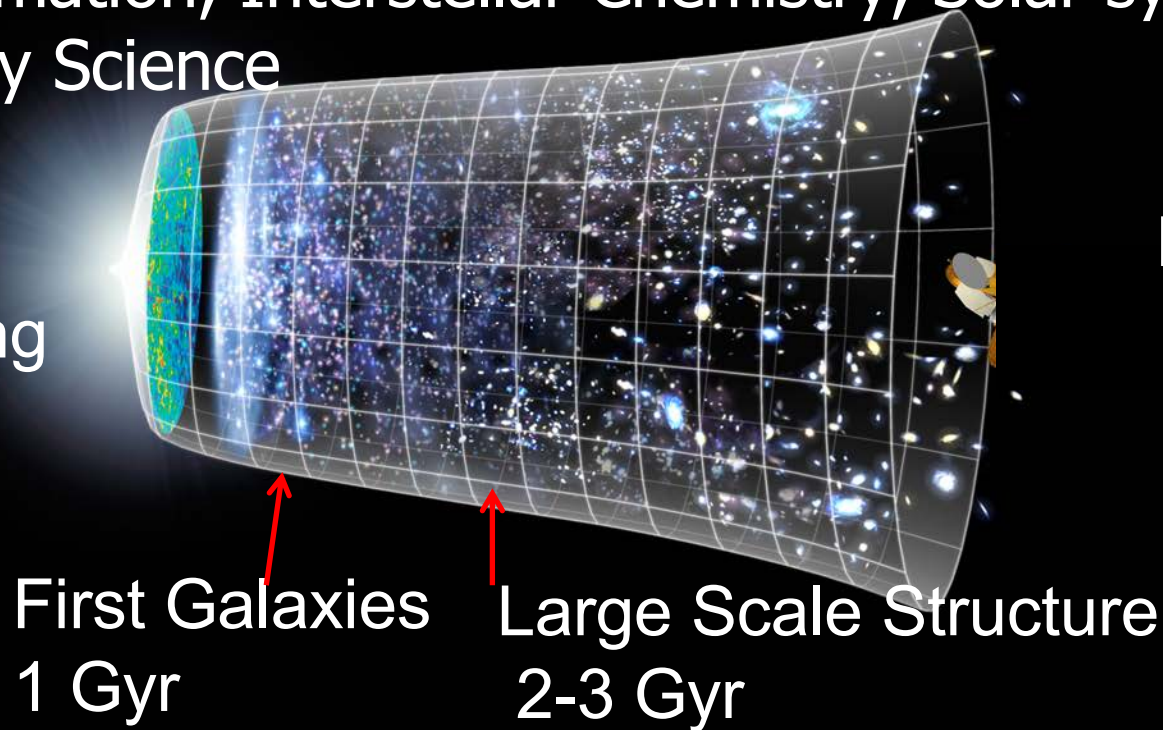
- ✦ Plan to construct a 50m-class single dish telescope, the Large Sub-millimeter Telescope (LST).
- ✦ The LST is optimized for
 - wide-area imaging and spectroscopic surveys in the freq. range of 70-420 GHz.
 - also achieving high-cadence performance for transients
- ✦ LST targets observations at higher freq. up to 1THz, using an inner high-precision surface (under-illumination)
- ✦ Active surface control is required to correct gravitational and thermal deformations of the surface.
- ✦ 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, SZ, VLBI,..
- ✦ Basic Concept, Specs., Key Sci & Instrument etc. introduced



Science Goals in Mm & Submm Astronomy

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

Inflation
& Big Bang

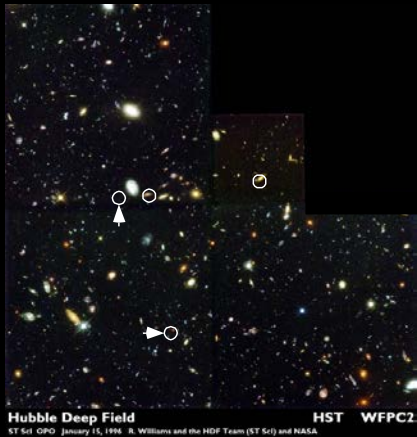




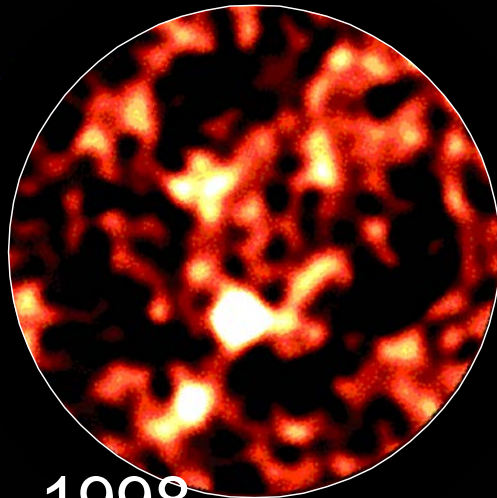
ALMA opens new era

- ◆ 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



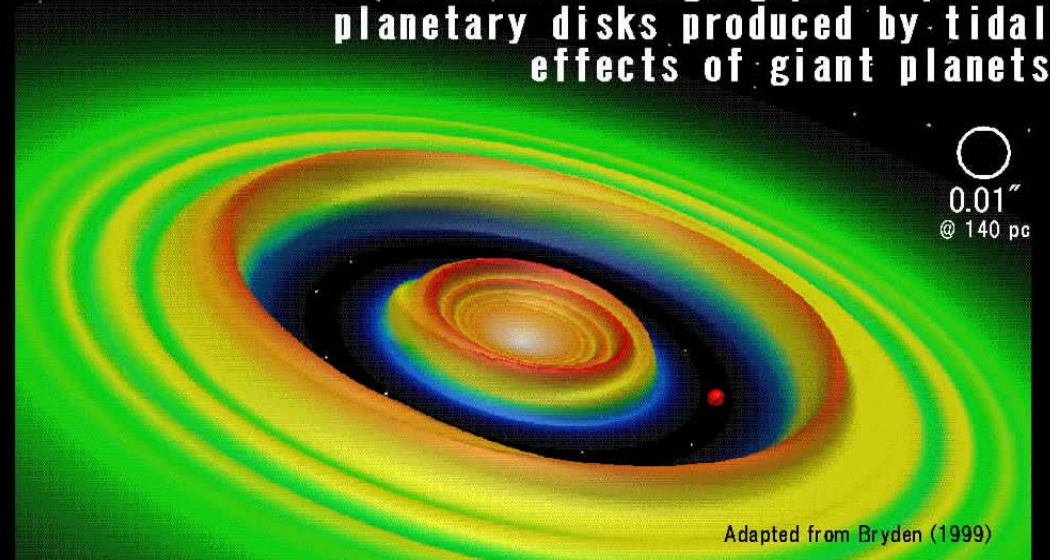
Hubble Deep Field
ST 51 OPO January 15, 1998. R. Williams and the HDF Team (ST 51) and NASA



Hughes et al. 1998

Gaps in Protoplanetary Disks

ALMA will image gaps in protoplanetary disks produced by tidal effects of giant planets



Adapted from Bryden (1999)



ALMA Science Goals

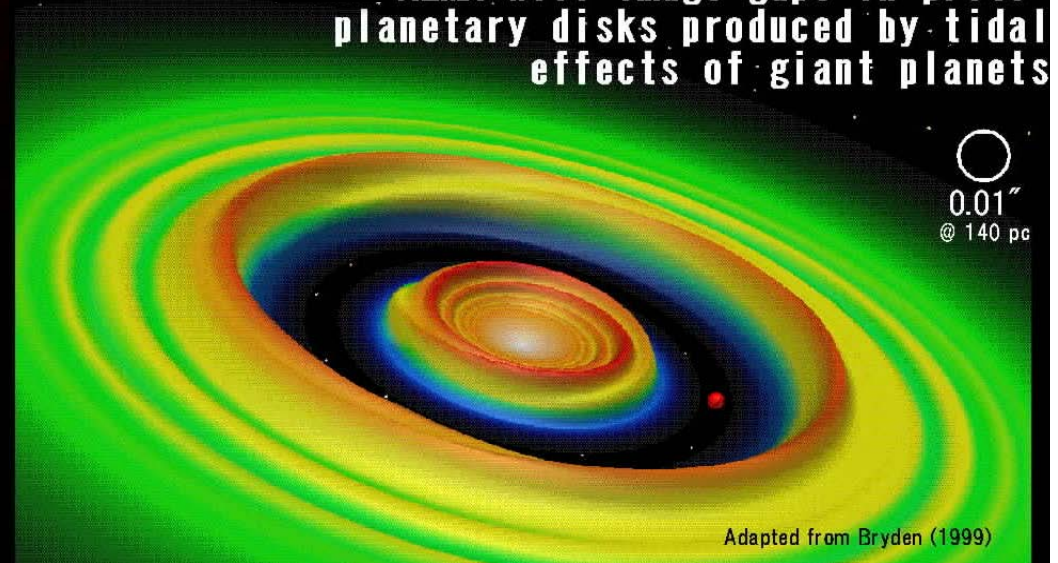
- ◆ ALMA will contribute to elucidating galaxy formation and planet formation with exploiting extreme performance

Dreams come true!

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

Gaps in Protoplanetary Disks

ALMA will image gaps in proto-planetary disks produced by tidal effects of giant planets



Adapted from Bryden (1999)

LST

LARGE SUBMILLIMETER TELESCOPE

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

LST will facilitate new discovery space complementary to ALMA

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

NRO 45m Telescope



Natural
Evolution



ASTE 10 m
Telescope
In Chie





Chronology of LST

Started as a future plan of Nobeyama Radio Observatory (45m/ASTE telescopes) in 2008/2009

Exchanged basic idea with JP 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

Concept and Science case been updated in 2014/2015 based on Feedback from SCJ and further discussions

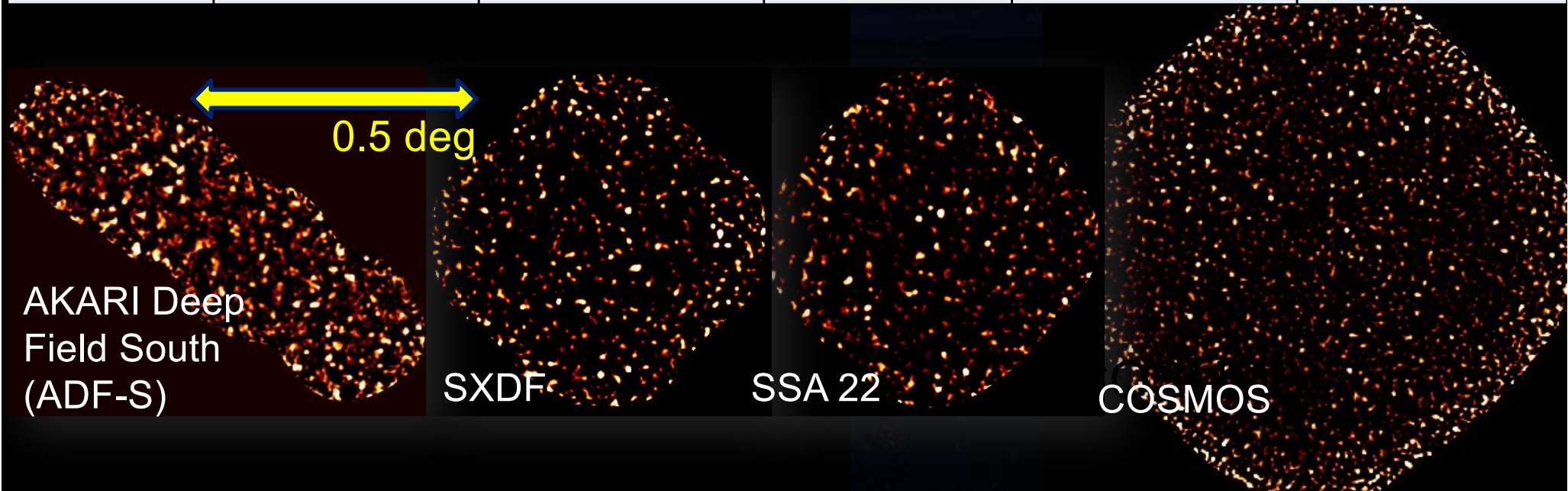
Basic Concept *: Tentative Specifications*

- ◆ **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
cosmological deep and wide-field survey & high cadence
- ◆ **Main Frequency Range = 70 – 420 GHz**
well fit to Atm windows & “Major” Science Case
covers up to \sim THz with the limited use of surface
to maximize synergy with ALMA
- ◆ **total surface rms $\leq 45 \mu\text{m}$ (EI = 30-80 deg) with Active surface Control**
- ◆ **Possible site; ALMA site**



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 (1 σ , mJy)	0.4-0.80	0.5-0.9	0.7-1.3	1.2-2.2	0.5-0.7
N sources (>3.5 σ)	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



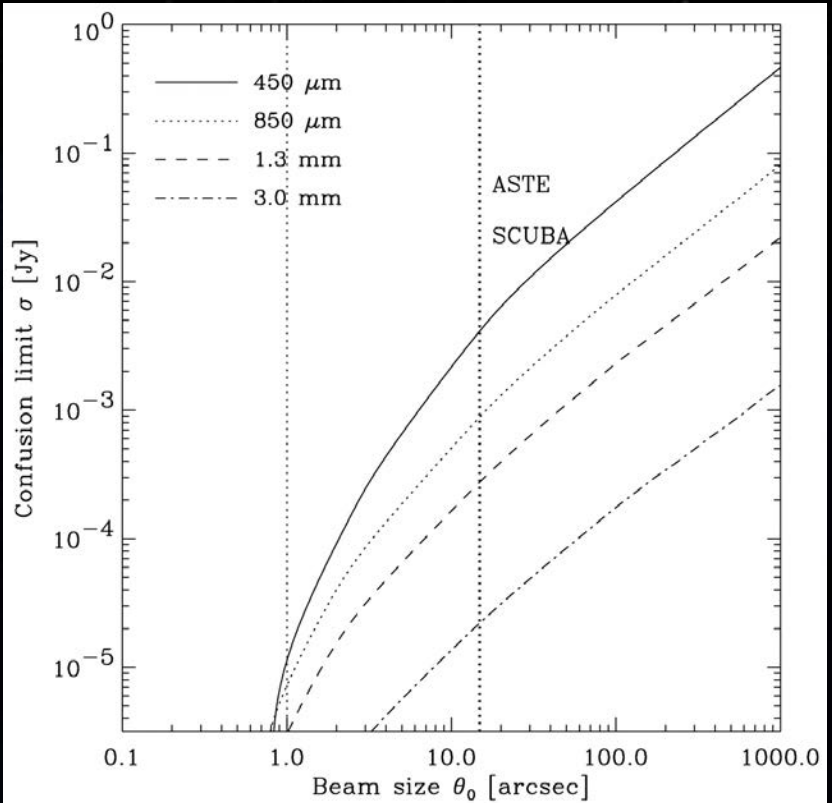


Merit of Large Dishes

		ASTE	CCAT	50m	50m/CCAT
Source Confusion	$\propto D^{-1.4}$	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 ^a	$\propto D^2$	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. Evaluated as survey area covered with fixed observing time and depth, e.g., in unit of deg²/hours

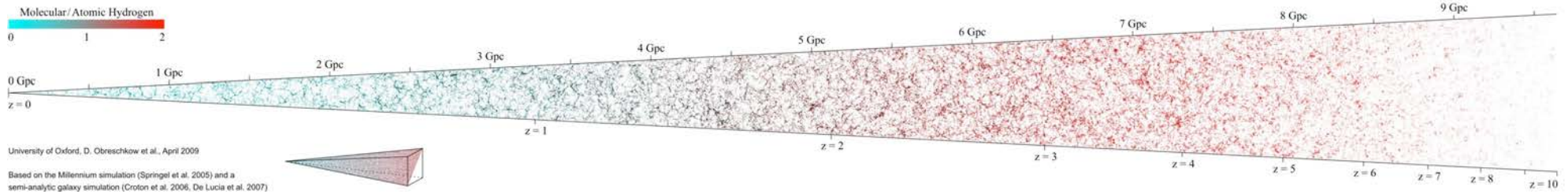




Key Science of LST

- ✦ Exploration of Cosmic Star Formation History and Large Scale Structures via two kinds of surveys
 - Multi-band Deep Continuum Survey over $\sim 10^3$ deg²
 - Blind CO/CII line emitter search (Tomography) up to $z \sim 7$, EoR, using imaging spectrograph
(Blind vs multi-target 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)
 - ✦ Time-domain science via high cadence performance
 - ✦ Covers wide range: SZ cosmology, VLBI, chemistry
- RK+ in SPIE proceedings; White paper by RK, Kohno, in prep

SKA Design Studies – Virtual Hydrogen Cone



CO/[CII] Tomography

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

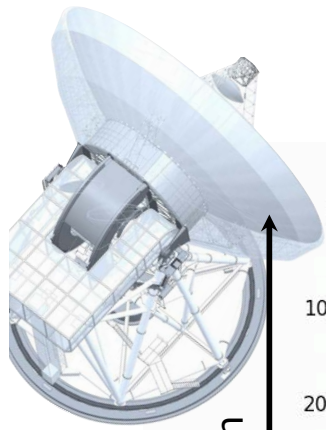
Cosmic evolution of galaxies proved through properties of interstellar medium

... and serendipitous discoveries

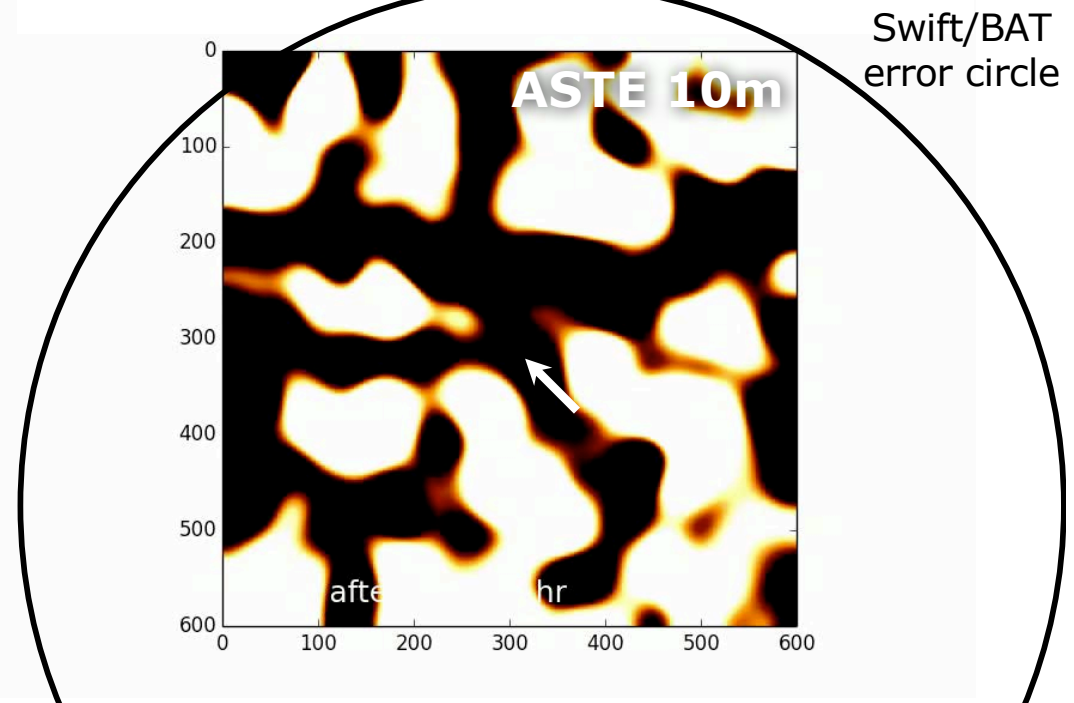
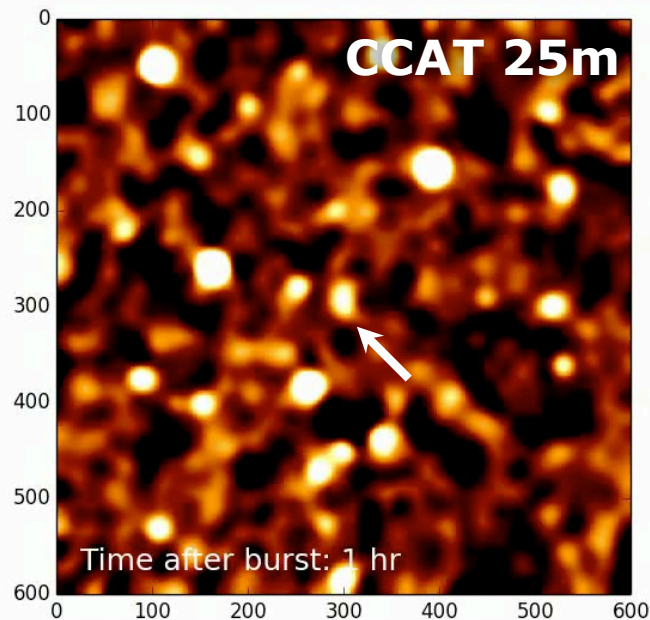
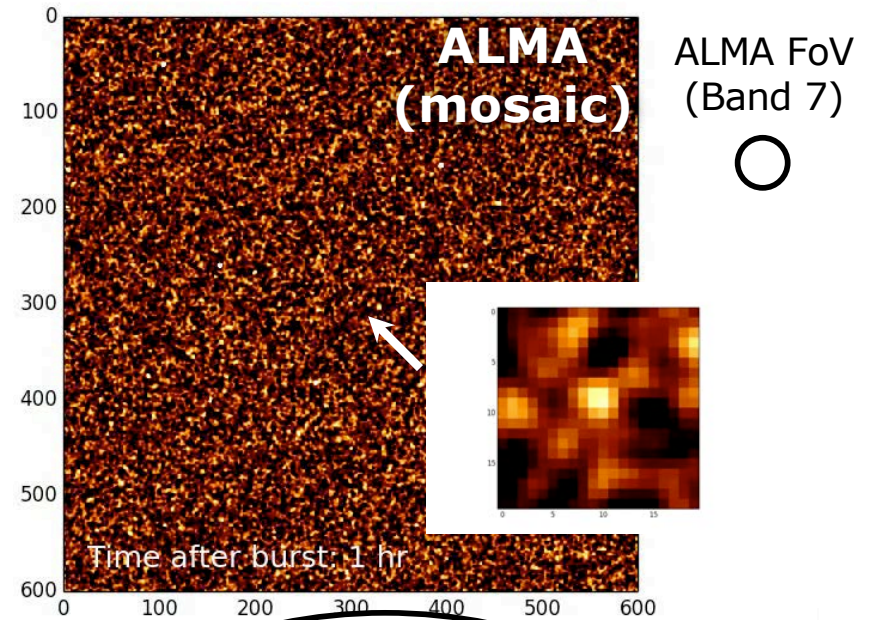
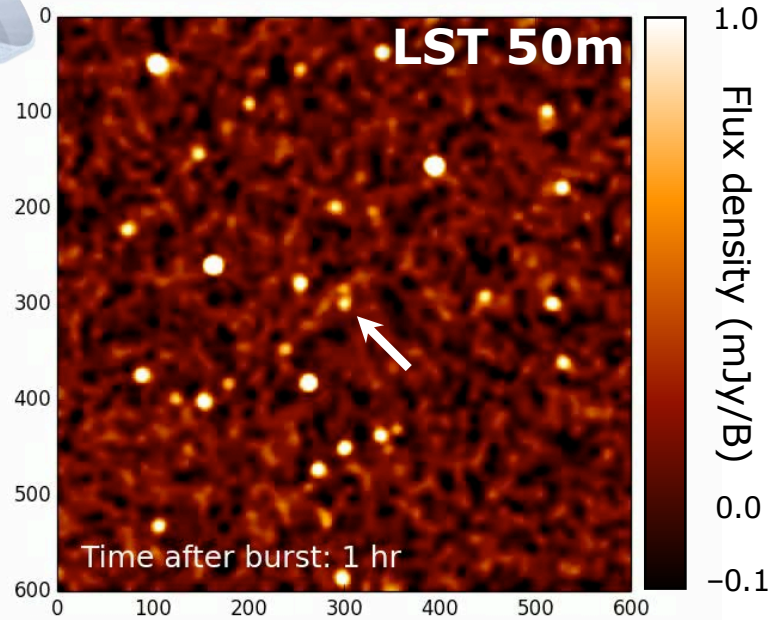
Line emitters, transient and variables, ...

Simulation of GRB afterglow

$z = 30$ GRB afterglow (1-12hr, 300GHz)



5 arcmin



LST
LARGE SUBMILLIMETER TELESCOPE

LST covers wide range of Science

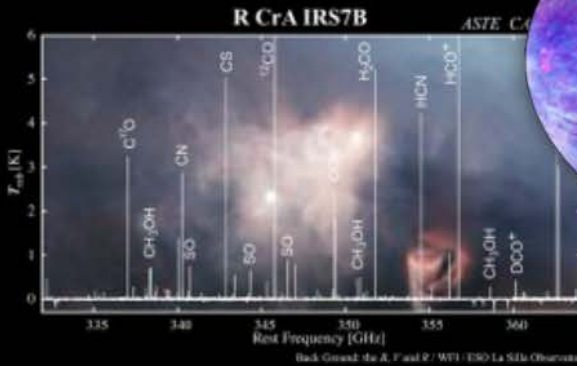
Develop new discovery space
complementary to ALMA

Distant Galaxies and Clusters

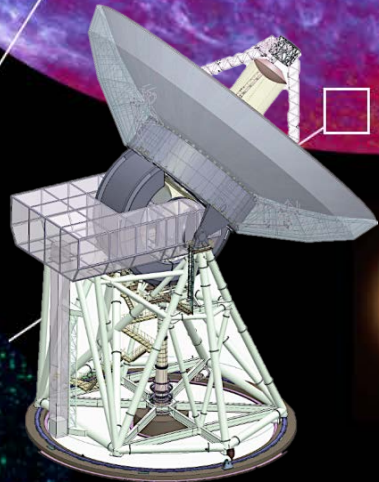
● Wide-Field
Spectroscopic Imaging

● Time-domain
Science

Galactic Plane



Astrochemistry

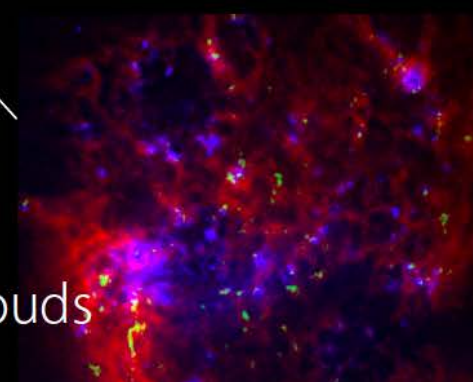
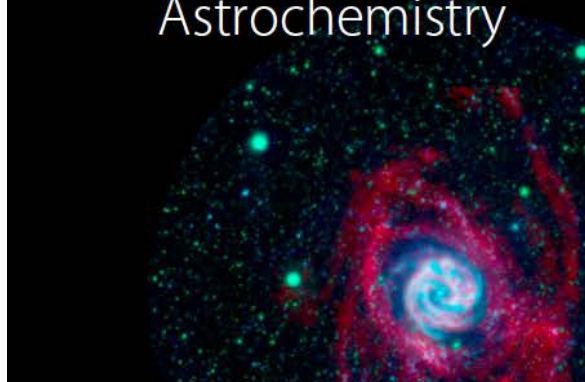
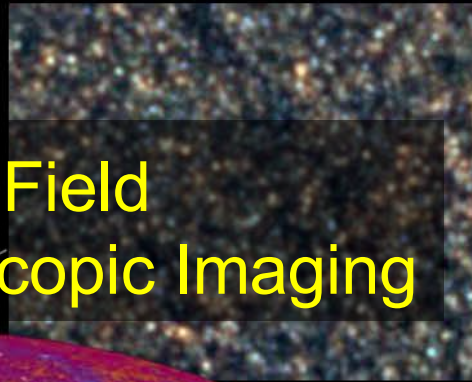
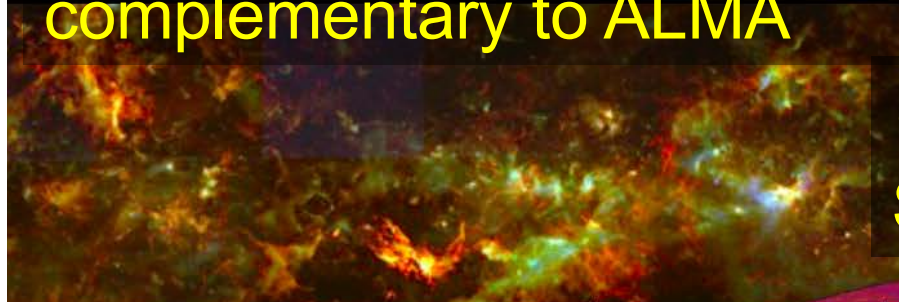


Nearby Galaxies

VLBI

Magellanic Clouds

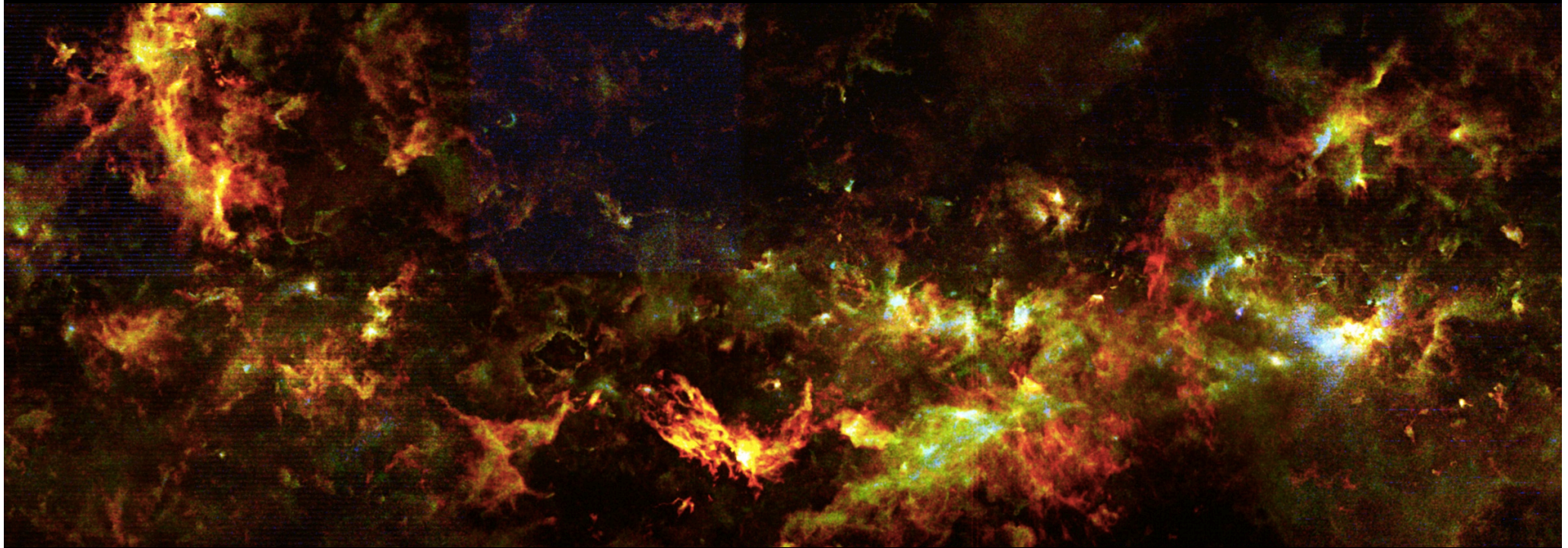
Submm Transients





NRO 45m GPS Pilot Observations

Filaments and Shells anywhere



$\Delta v \sim 1 \text{ km/s}$

rms $\sim 0.4 \text{ K}$ (in T_{a^*} : typical) for $\Delta v \sim 1 \text{ km/s}$

T_{a^*} peak maps were used

Red: $^{12}\text{CO}(1-0)$

Green: $^{13}\text{CO}(1-0)$

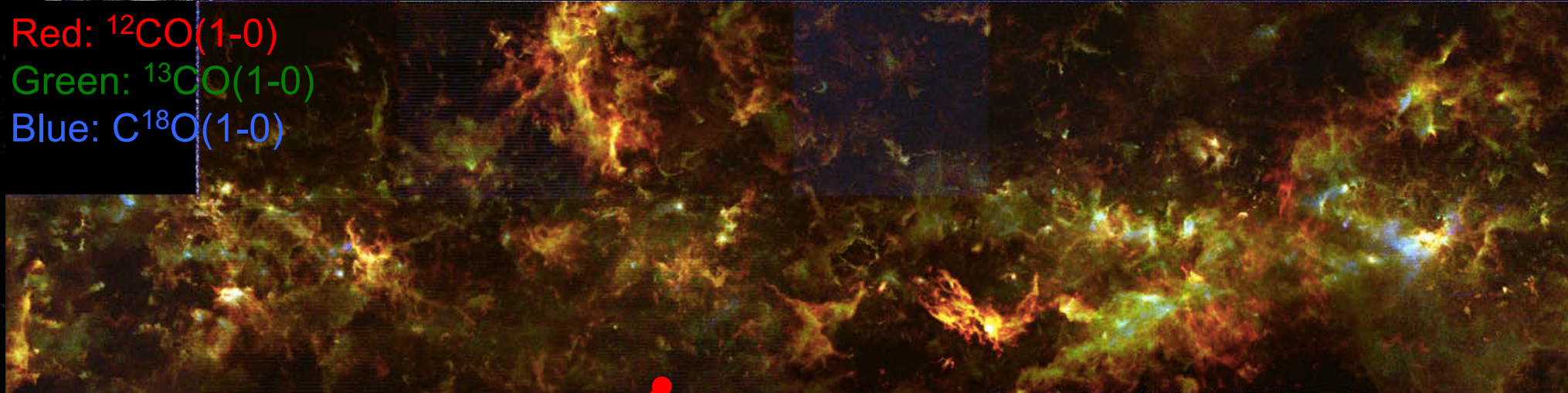
Blue: $\text{C}^{18}\text{O}(1-0)$

- Observed: $118 \text{ deg}^2 (76\%)$



LST is powerful for GPS in dust and gas

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



8 deg. X 2 deg

x 200

~ 360 deg. X 10 deg

LST GPS (Onishi+)
Dust polarization (Furuya)
Zeeman (Nakamura)





Technical Feasibility Study

- ✦ Science Requirement & Technical Specification
- ✦ Operation condition & Operation Planning
- ✦ Optics Design
- ✦ Conceptual Design of Telescope Structure
- ✦ Surface Accuracy Budget Analysis
- ✦ (Very Preliminary) Cost Estimate
- ✦ AO application or Radio AO (??) under discussion

LST

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Optical Design for wide FOV

very preliminary

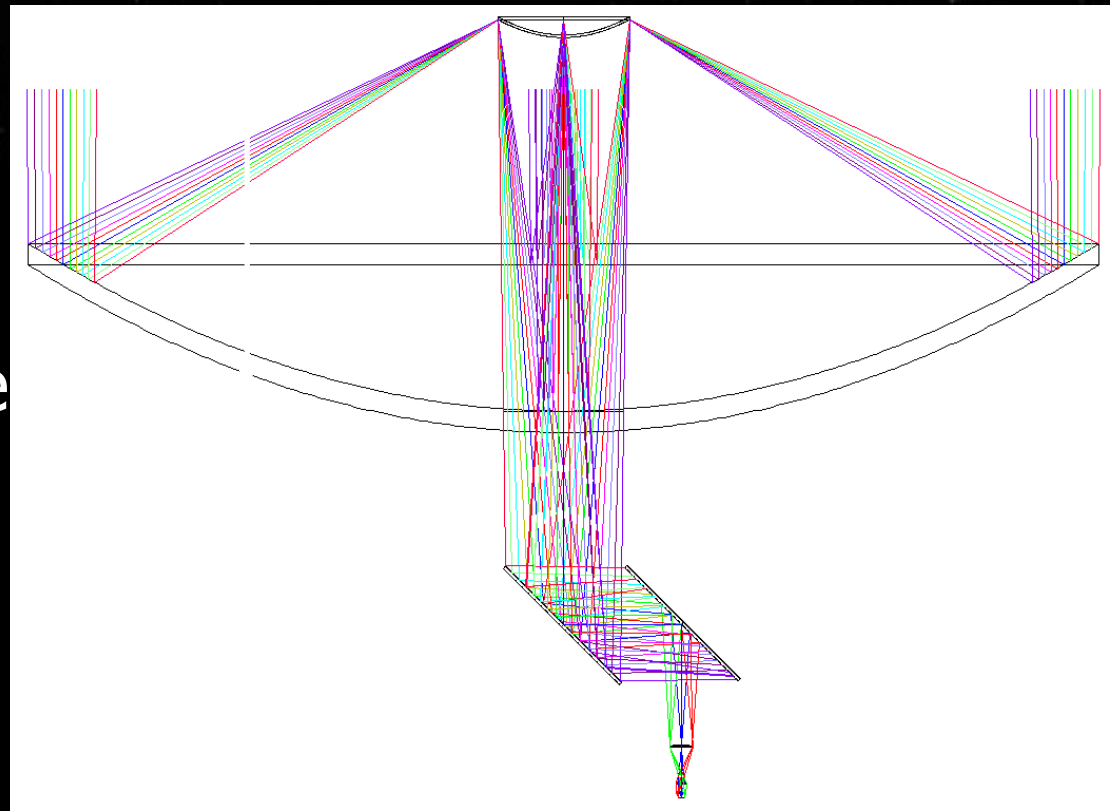
Richey-Chretien Optics for $D = 50$ m main reflector

Lyot-Stop at Sub-reflector: $D_{\text{effective}} \sim 46.7$ m

FOV ~ 0.7 deg. in diameter at 850 micron achievable

But...

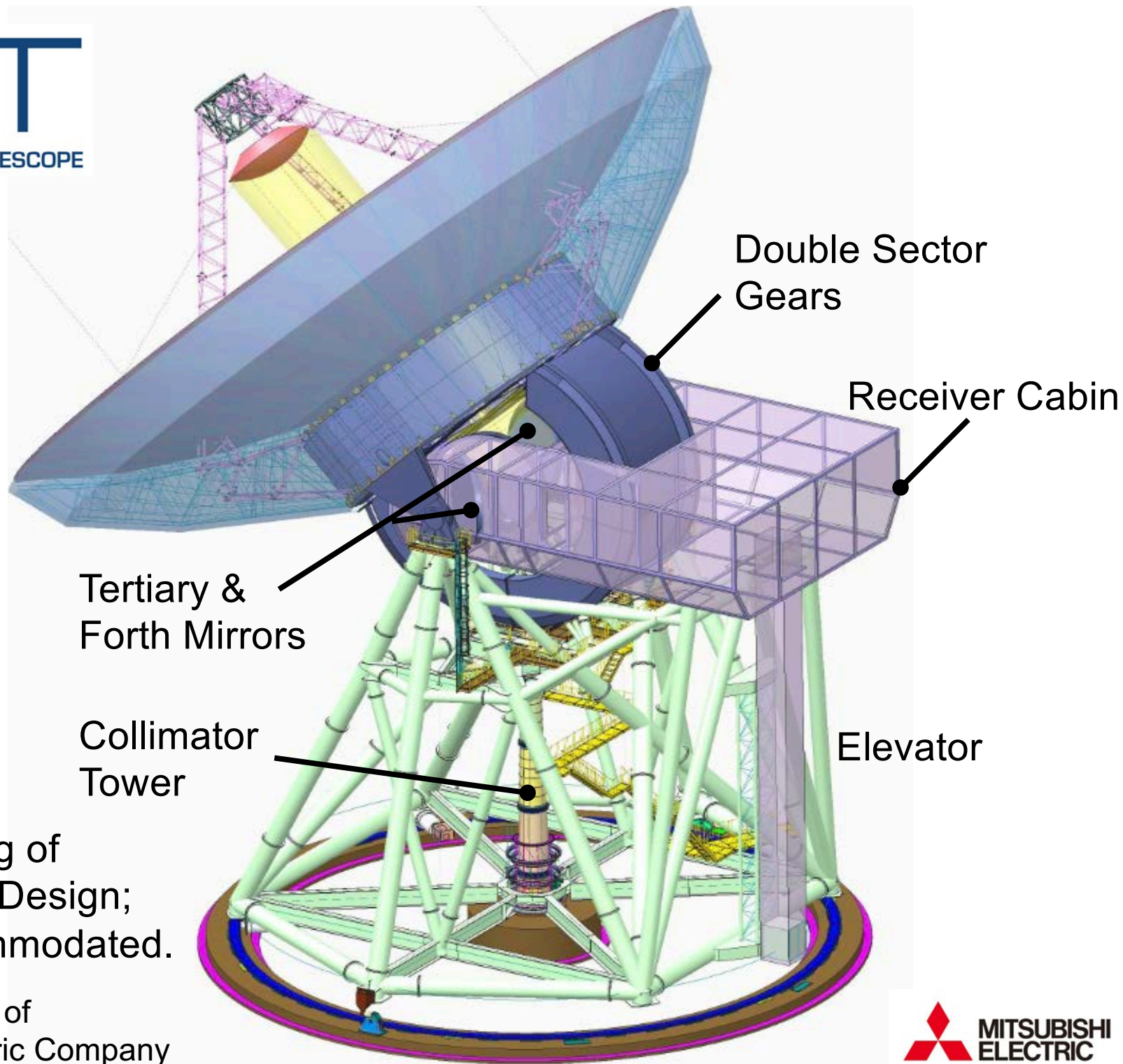
- large mirrors
 $D_{\text{sub-ref}} \sim 6.2$ m
#3 mirror ~ 7 m diameter
- huge RX cabin needed
(big impact on telescope
mechanical structure?)
- No aperture plane
@main reflector



Takekoshi, Oshima + in prep.

LST

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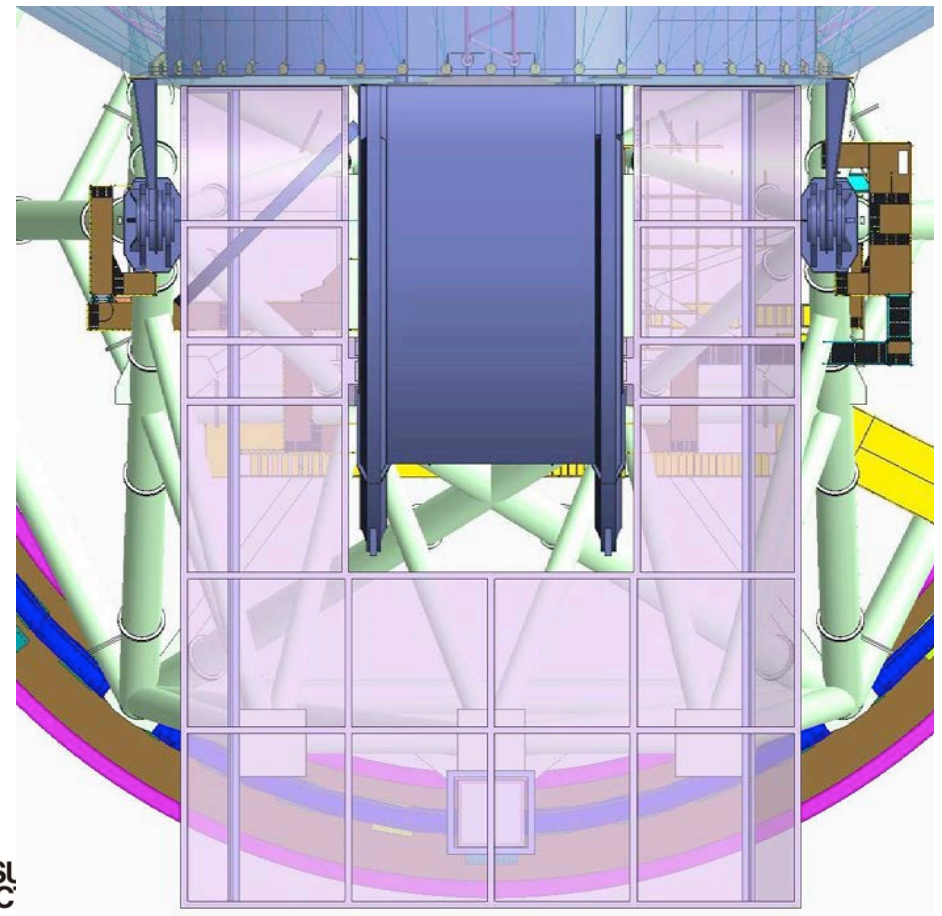
The First Drawing of
LST Conceptual Design;
Major req. accommodated.

Image Courtesy of
Mitsubishi Electric Company



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

Top View



Back View

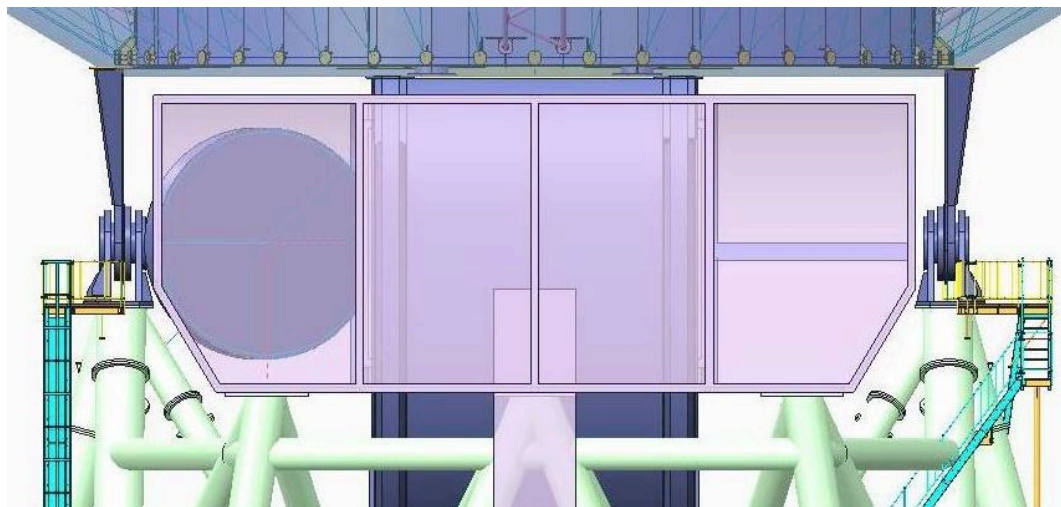
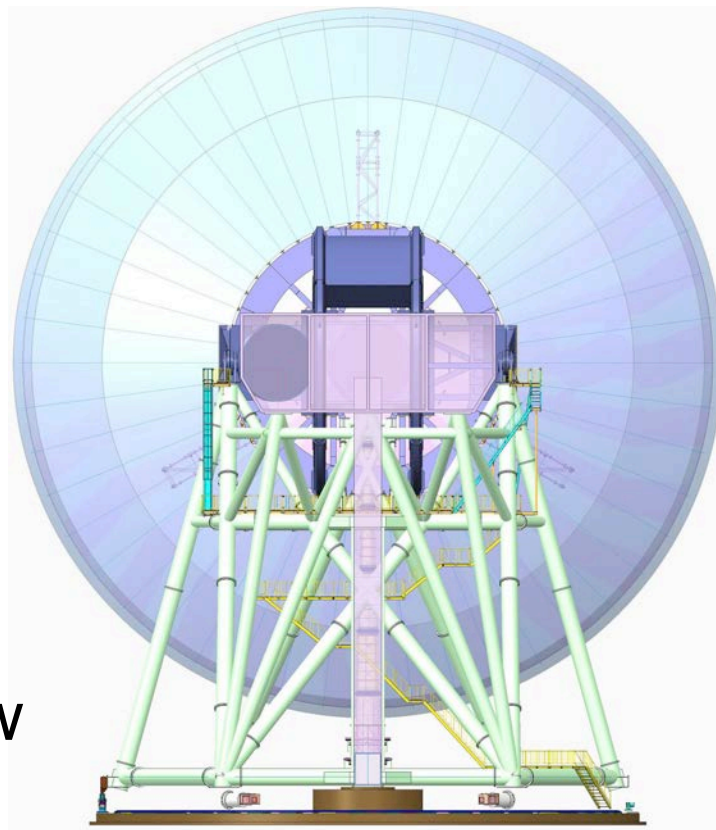
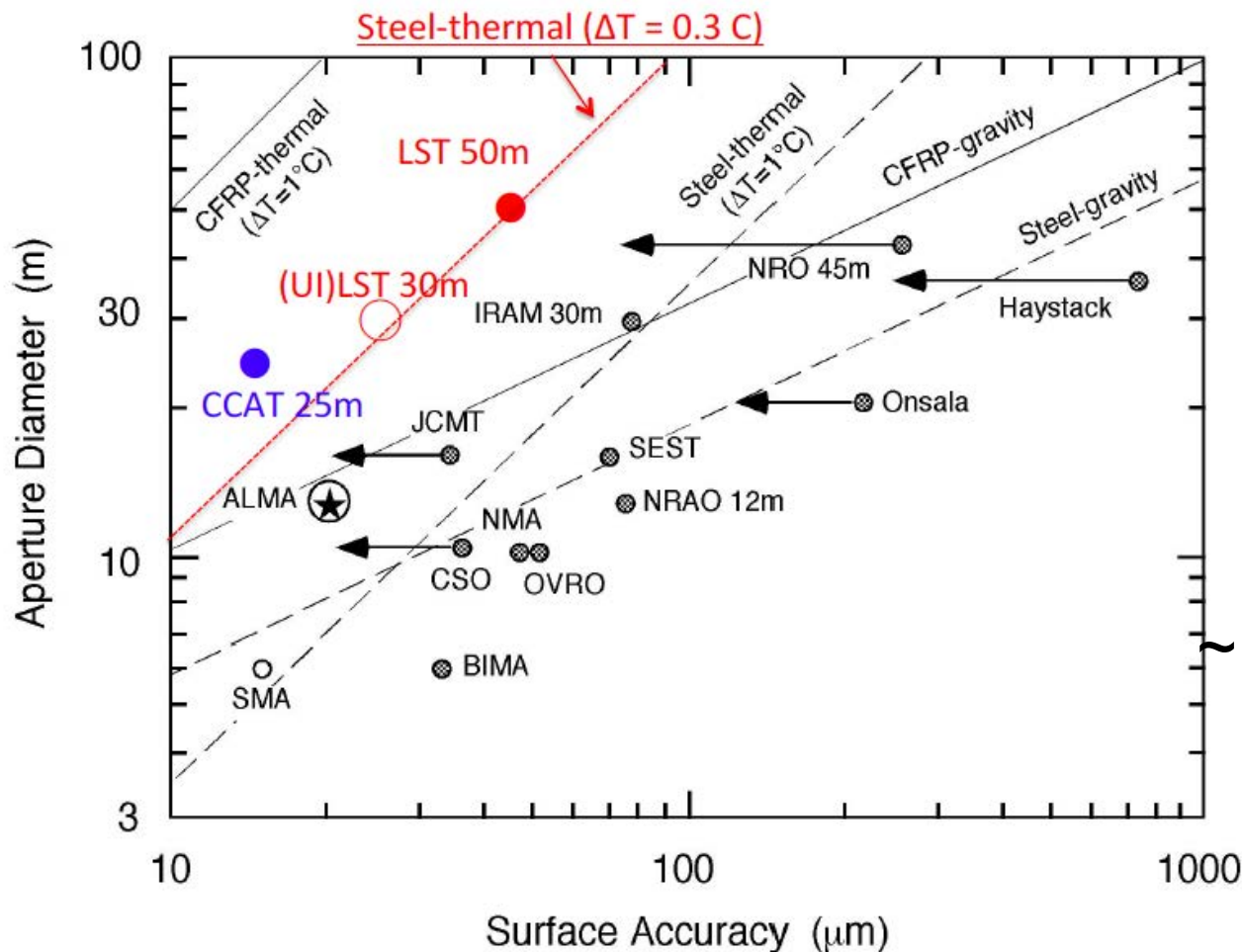


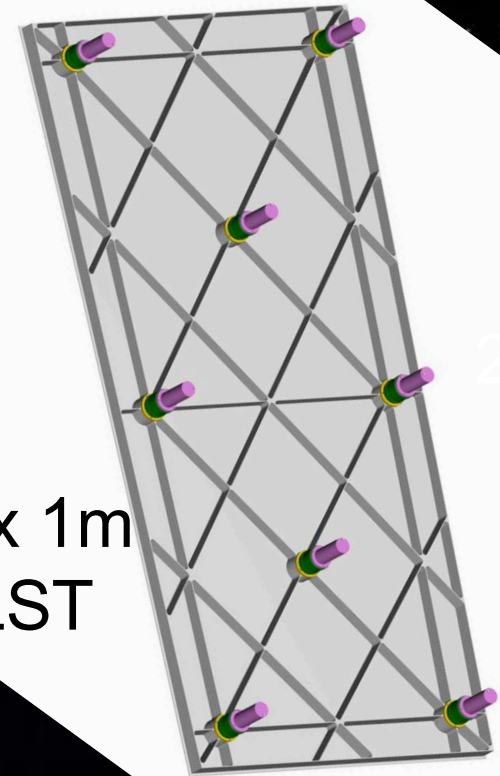
Image Courtesy of
Mitsubishi Electric Company

Active Surface Control Required

45 μm rms needs careful mech/thermal design as well



~ 2m x 1m
for LST





ASTE 10m and Panel Adjustment

- ◆ 10m Surface
 - 204 Aluminum panels
 - 3 motorized actuators per panel (612 actuators in total)
 - “quick” automatic panel adjustments after Holography measurements
- ◆ Current Surface
 - Accuracy ~ 20 micron rms

ASTE 10m Telescope
(Pampa la Bola 4860m)



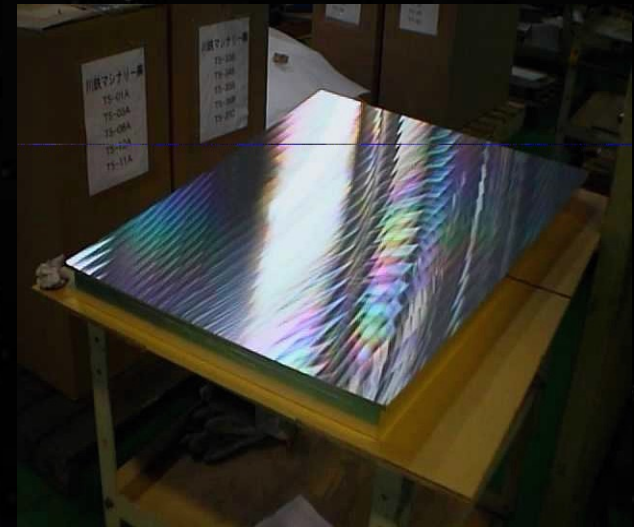


Machined Aluminum Panel for ASTE

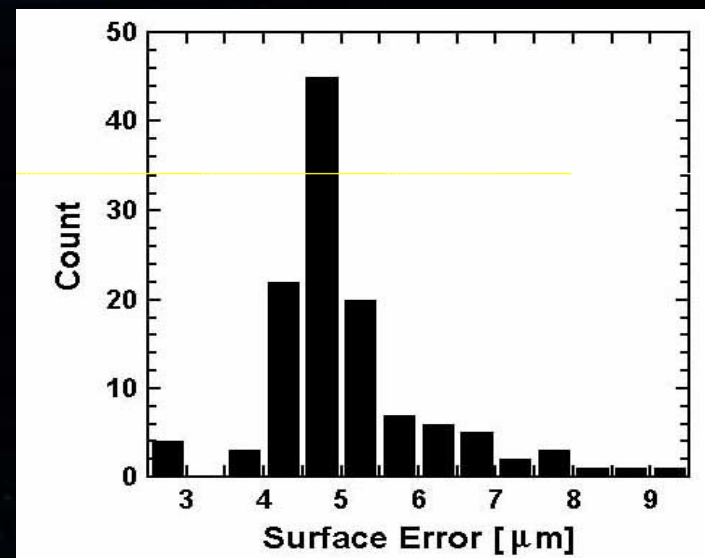
Surface Panel

- Machined from Aluminum mono-block
- Size: $\sim 80 \text{ cm} \times 80 \text{ cm}$ (average)
- Weight: $\sim 12\text{-}15 \text{ kg/m}^2$
- Accuracy: $\sim 5 \mu\text{m}$ (rms)
- three motorized actuators at back side

Machined Aluminum panel



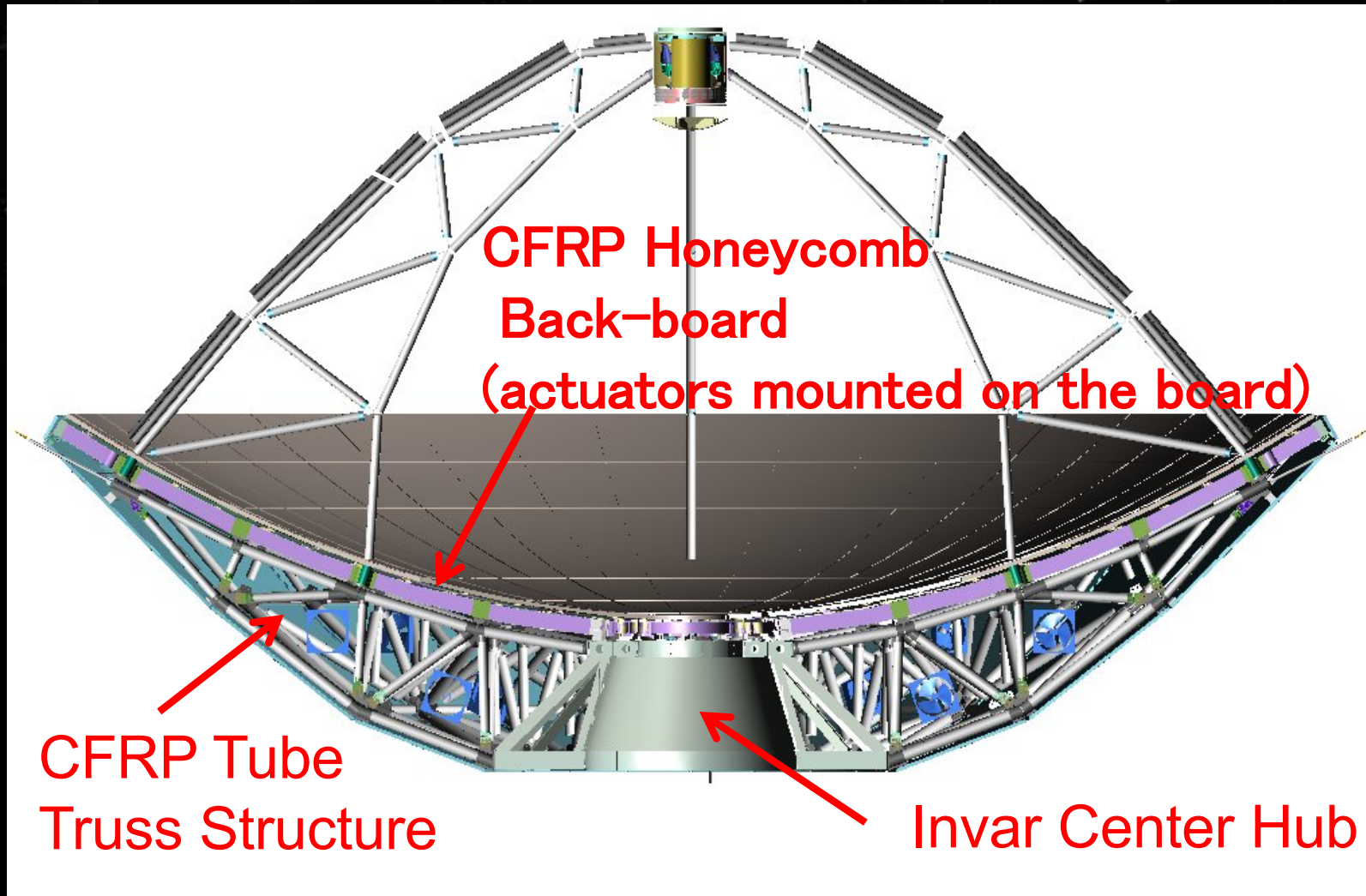
Surface Errors of panels





Structure of Main-reflector

Note: ASTE 10m has a different quad pot structure





Holography and Panel Adjustment

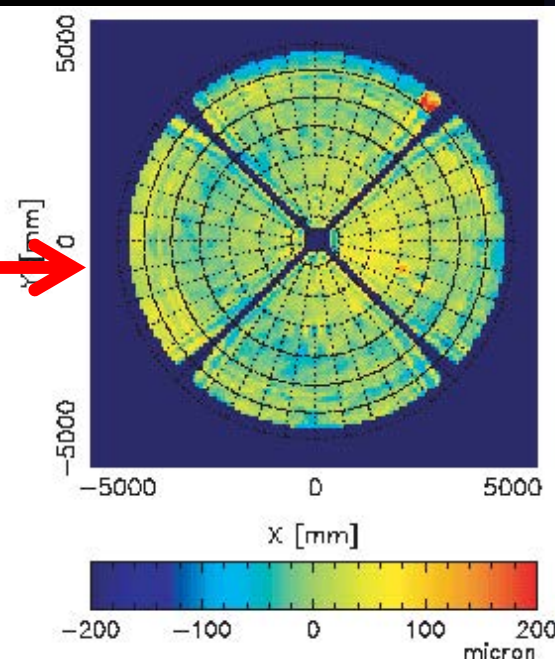
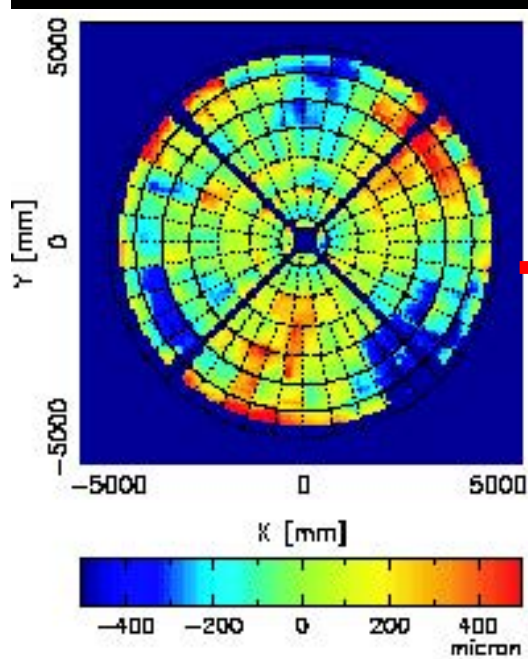
Holography using
Transmitter signal @ 100 GHz
Surface Adjustment
optimizing for El ~ 45 deg
setting 612 actuators in 1 hour



Holography Receiver at top of secondary

Before

After



Holography Transmitter
~3 km from ASTE 10m



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. 1987¹⁴). All unit is μm 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 ≤ 12 m/s 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, in prep

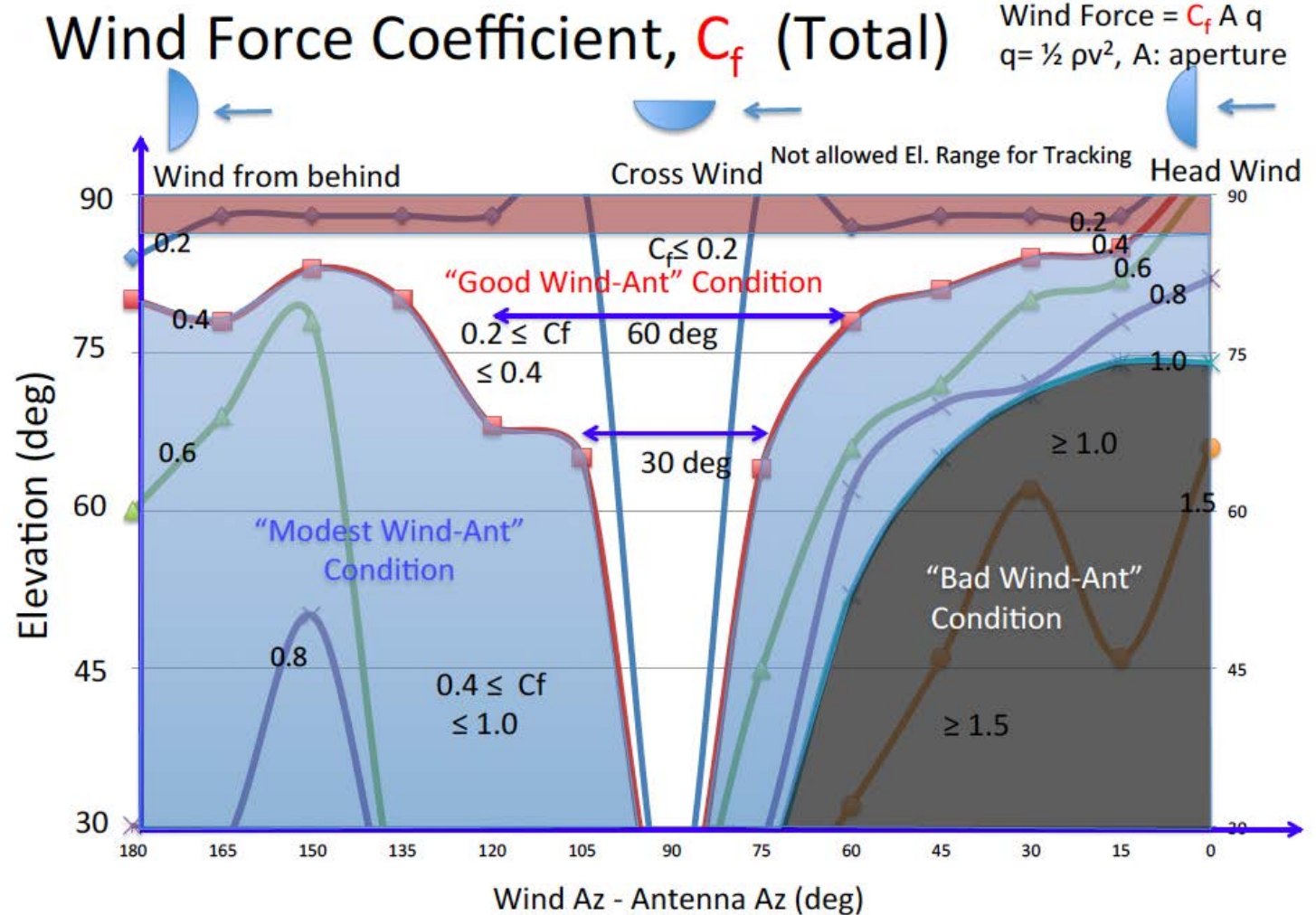


Wind Effect on the Telescope

Head wind is the worst case, should be avoided
 Cross wind is much better, and should be exploited

C_f distribution
 On
 EI- Δ Az plane

Δ Az:
 differential
 Az angle btw.
 Wind&Ant.



Data from R. Levy, "Structural Engineering of Microwave Antennas: For Electrical, Mechanical, and Civil Engineering"

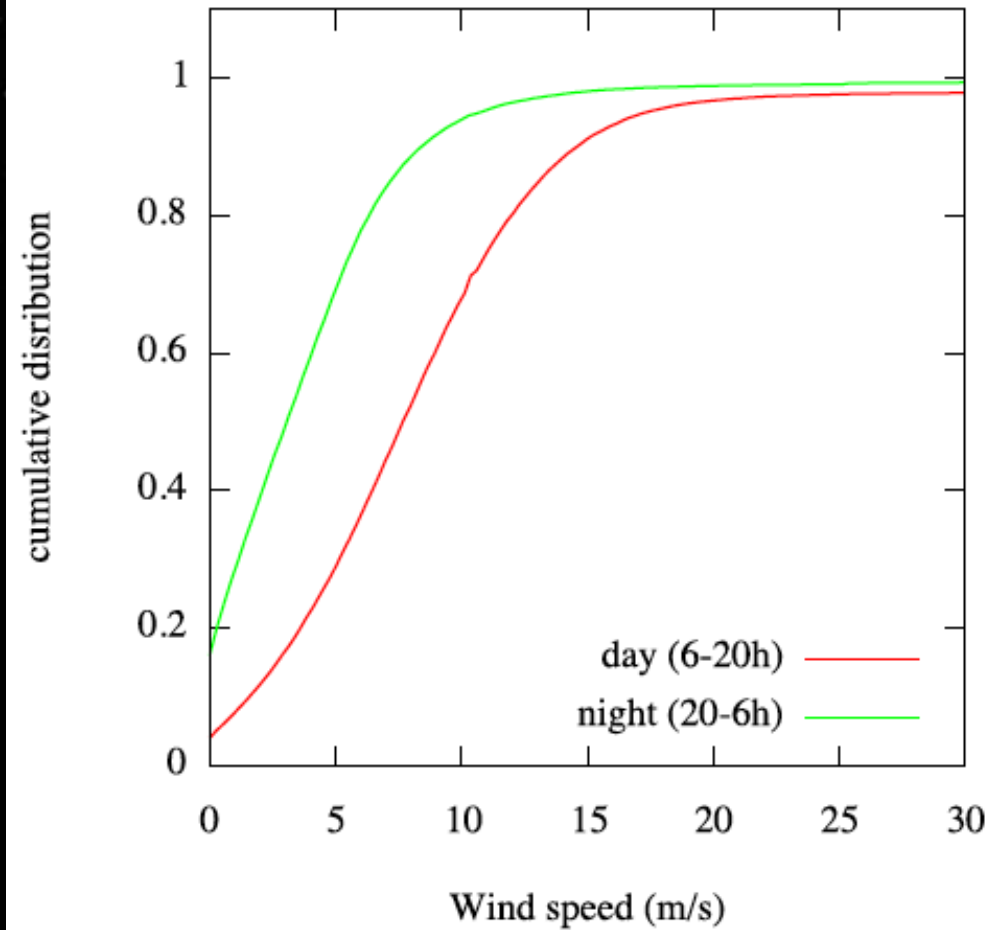
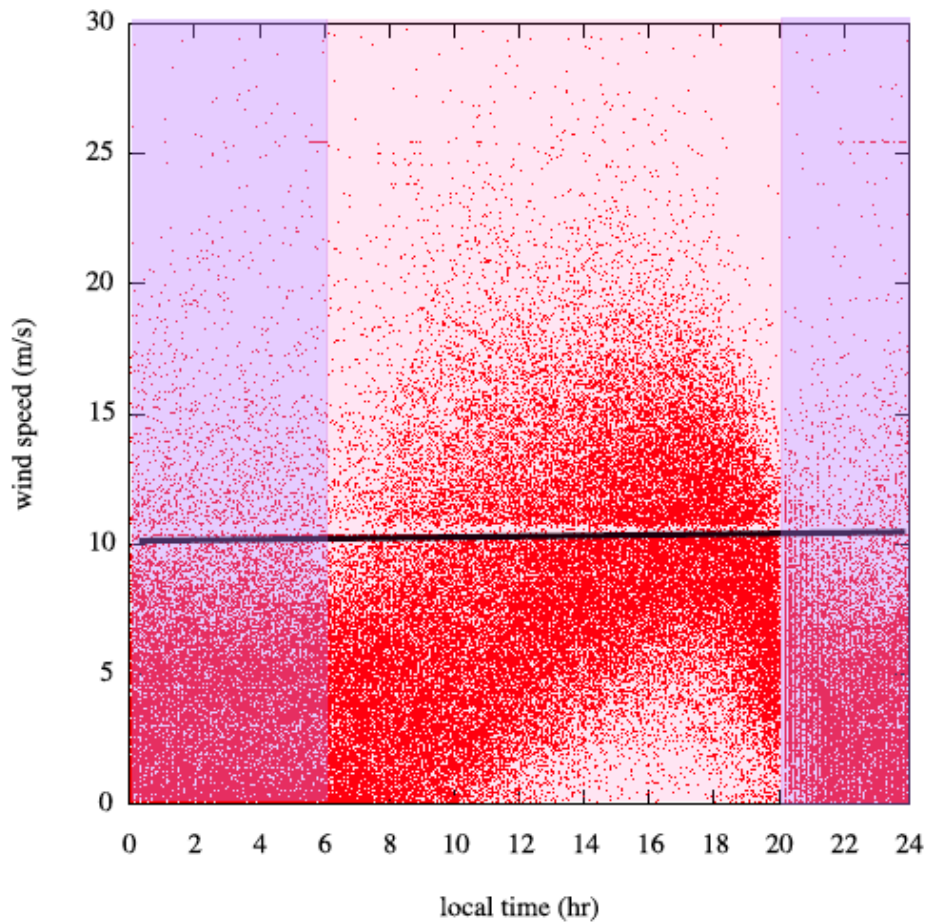


Wind Statistics at ALMA site Pampa la Bola

Diurnal Variation

Cumulative

2000-2004





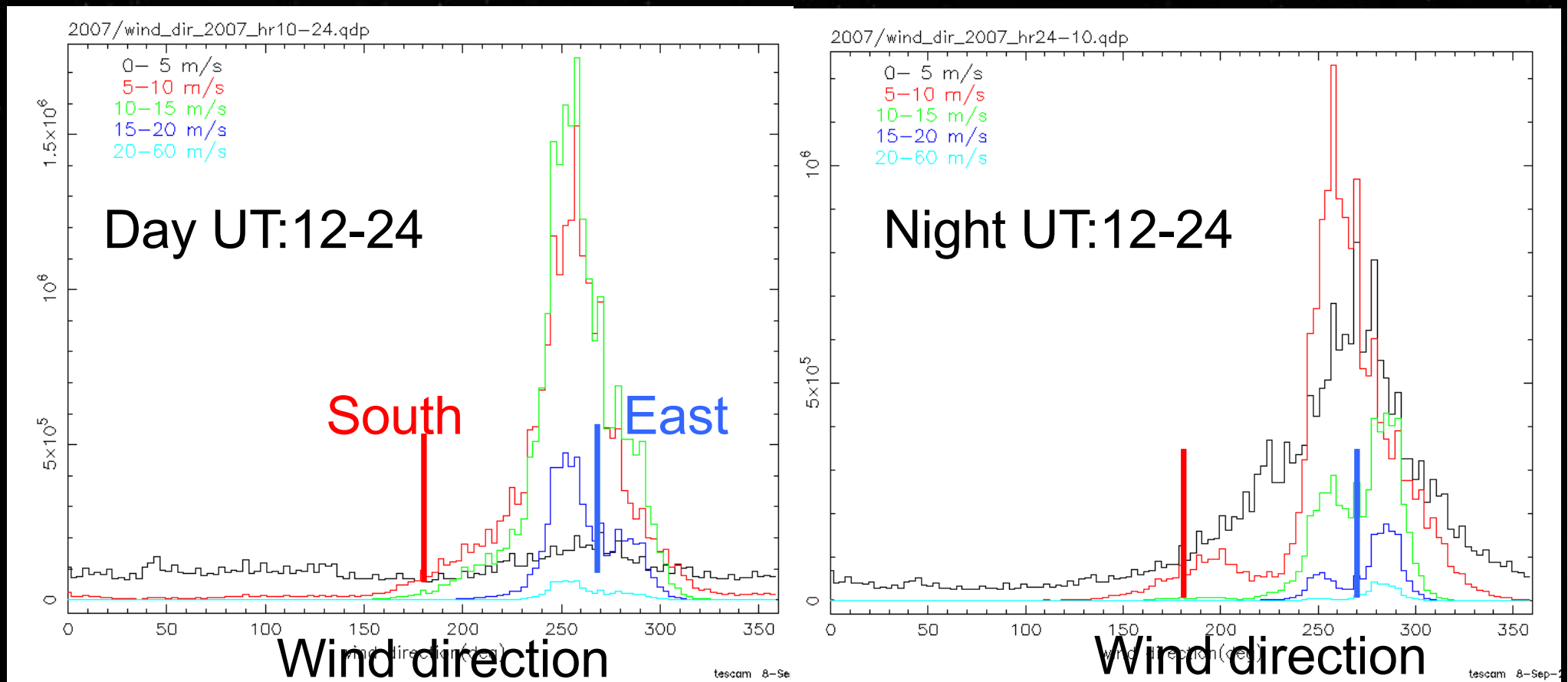
Wind Statistics at ALMA site

Pampa la Bola

Wind Azimuth Distribution:

Wind usually from East with narrow angle range: $v_{\text{wind}} \leq 10$ m/s

Observing ~ South/North directions can minimize wind effects
(also can relax error budget of surface error for wind)





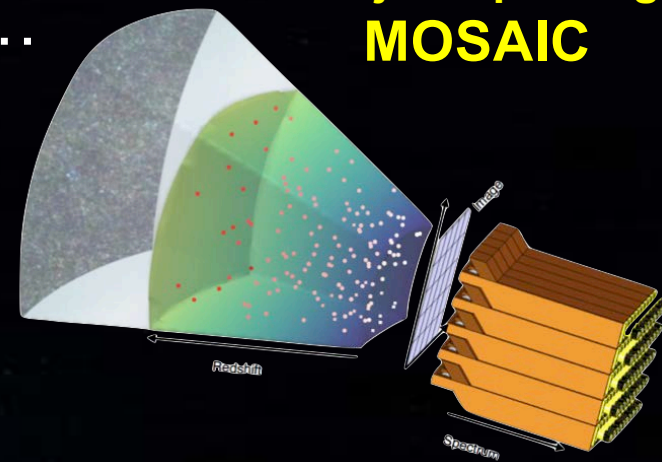
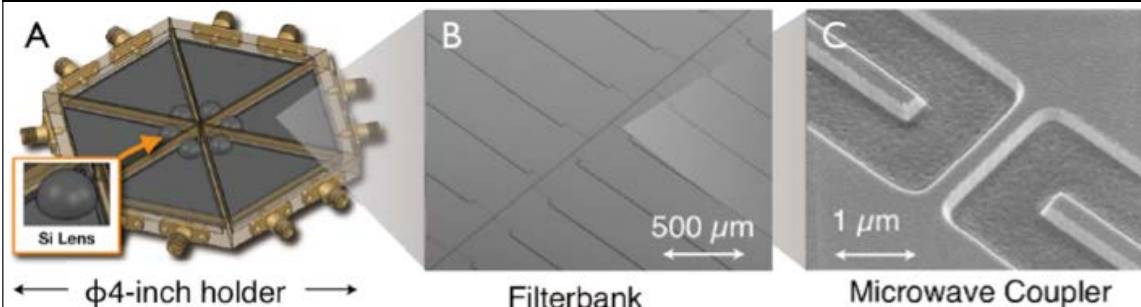
Key Instruments

- ◆ Ultra-Wideband Medium-Resolution Imaging Spectrometer Array: Blind CO/[CII] Tomography
Freq= 200 (70) -420 GHz & N_{pix} of > 300 (\sim 1000)
- ◆ Multi-Chroic Wide-Field Camera covering 2, 1.1, 0.85 mm, (+0.45, 0.35 mm)
- ◆ Multiple-band Heterodyne Array Receivers (\sim 100 beams) + Ultra-wideband Spectrometers (for line survey)



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

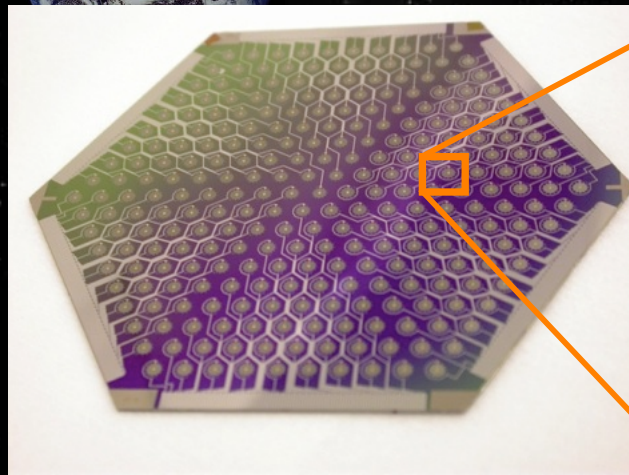
Mm/submm
multi-object spectrograph
MOSAIC



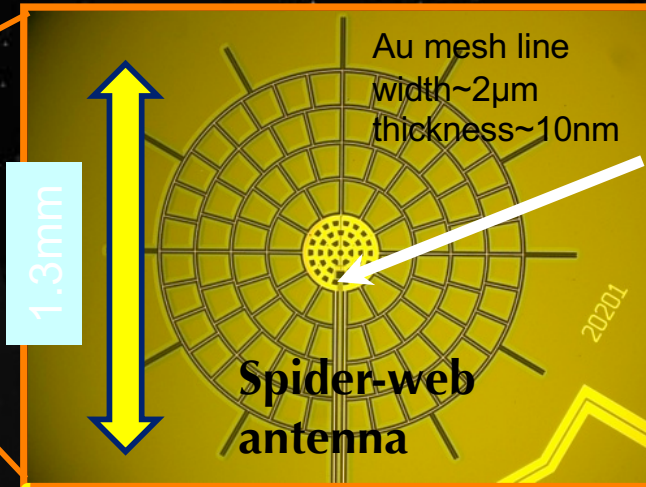
Delft SRON High-Z Mapper



The Multi-color TESCAM for ASTE



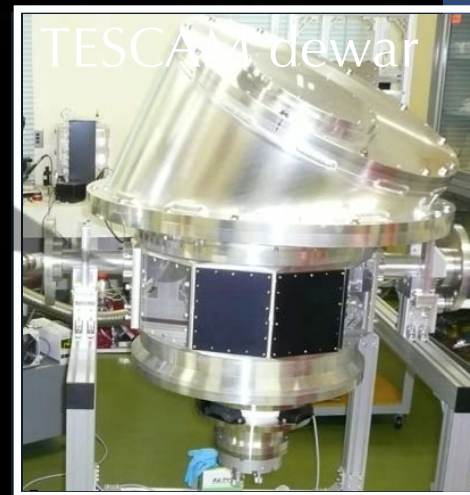
270 GHz TESCAM wafer fabricated at UC Berkley



Transition-edge sensor (TES)



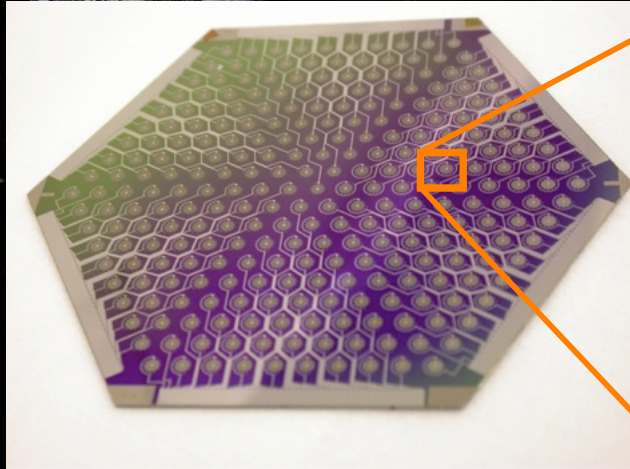
- ◆ First on-site commissioning of TESCAM April - June 2012 was very tough but successful (using engineering-grade arrays) !!!



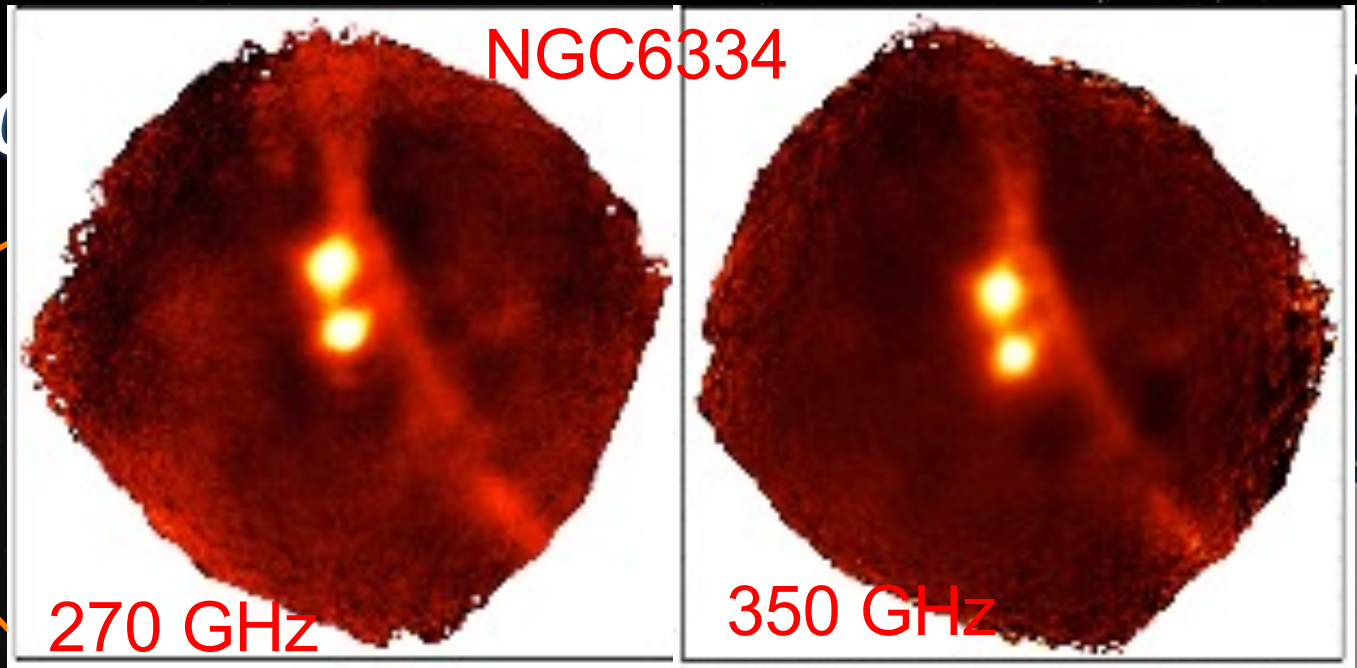
Oshima et al. 2013, IEEE T. App. Supercond.
Hirota et al. 2013, IEEE T. App. Supercond.
Takekoshi et al. 2013, IEEE T. THz Sci. Tech.



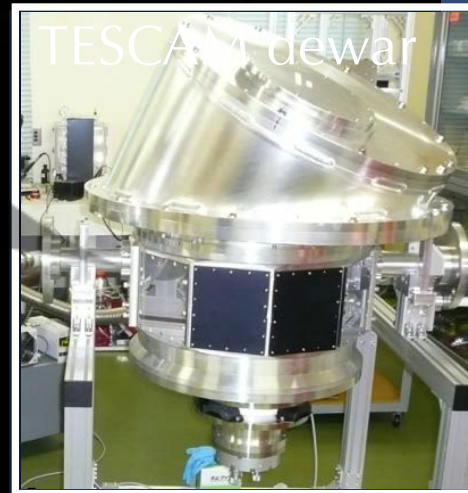
The Multi-



270 GHz TESCAM wafer
fabricated at UC Berkley



- ✦ First on-site commissioning of TESCAM April - June 2012 was very tough but successful (using engineering-grade arrays) !!!



Oshima et al. 2013, IEEE T. App. Supercond.
 Hirota et al. 2013, IEEE T. App. Supercond.
 Takekoshi et al. 2013, IEEE T. THz Sci. Tech.



Future Directions

- ◆ Study of Detailed Telescope Design
- ◆ Developing Future Key Instruments
- ◆ Propose as a future plan to Science Council of Japan (next survey & issuing recommendation planned in 2020)
- ◆ **International Cooperation**

LSTWS2015

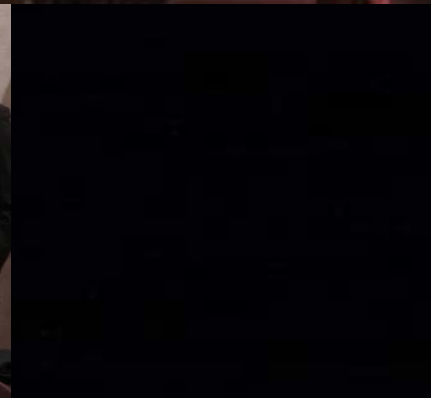
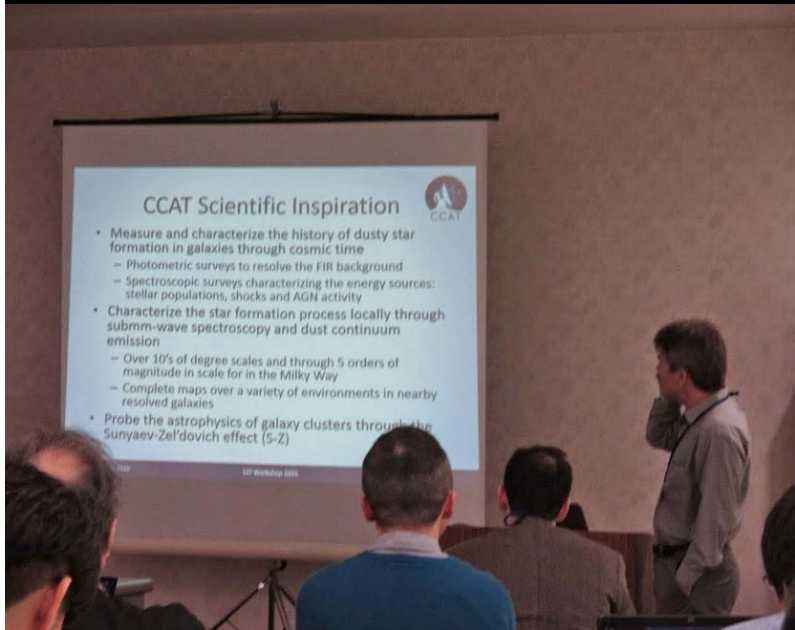
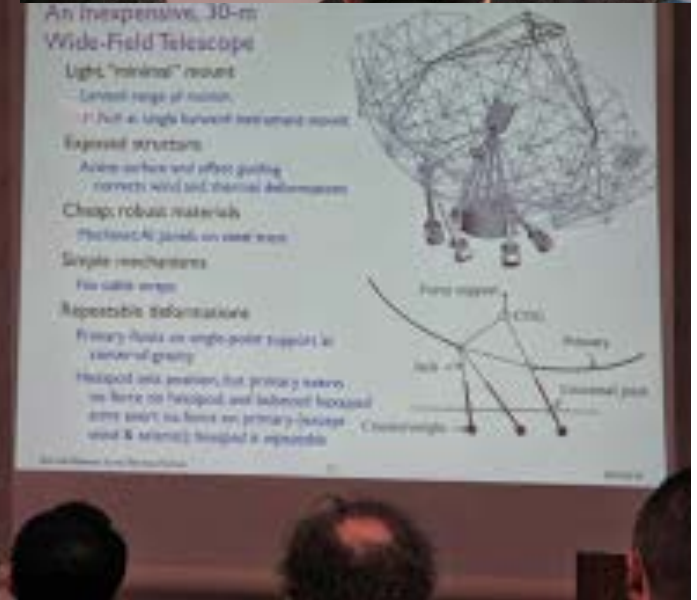
The 3rd Workshop on Large Aperture Sub/mm Telescope in the ALMA Era

NAOJ, Tokyo
March 10 – 11, 2015

More information on **LST** available

<http://www.ioa.s.u-tokyo.ac.jp/~ytamura/WS/LSTWS2015/Welcome.html>

LMT, SPT, CCAT
Caltech 30m,...





Summary

- ◆ 50m class submillimeter single dish telescope
- ◆ Covers 70 – 420 GHz (full aperture)
- ◆ Targets up to ~ 1 THz (central ~ 30 m)
- ◆ Wide-Field Survey in cont. & lines
- ◆ Key Instruments
 - Imaging spectrograph ($R \sim 1000$)
 - large format camera ($\sim 10^6$ pixels)
 - Heterodyn Array (> 100 beams) lines
- ◆ Construction complete no later than CY2030