Large Millimeter Telescope

Future of US Single Dish Radio Astronomy
May 17, 2017

Min S Yun
UMass-Amherst

Outline

- About the LMT...
  - Telescope
  - Site
  - Performance
  - Instruments
- Scientific Potential
  - Early Science with the LMT-32m
  - LMT and Focal Plane Arrays
- LMT in 2020s

- Bi-national project: INAOE (Mexico) & UMASS (USA)
- 50-m main reflector
- Active primary surface (~75 μm RMS)
  - 180 segments
  - Compensates for gravity & thermal deformations.
- Operational wavelengths 0.85 - 4 mm
- Beam resolution (FWHM) 4 -18 arcsec
- FOV ~ 4 arcmin diameter
- Site: Sierra Negra (4600m, 19º Latitude)
- LMT shared–risk Early Science >2013
  - Scientific operation as 32-m LMT
- Complete 50-m in 2017

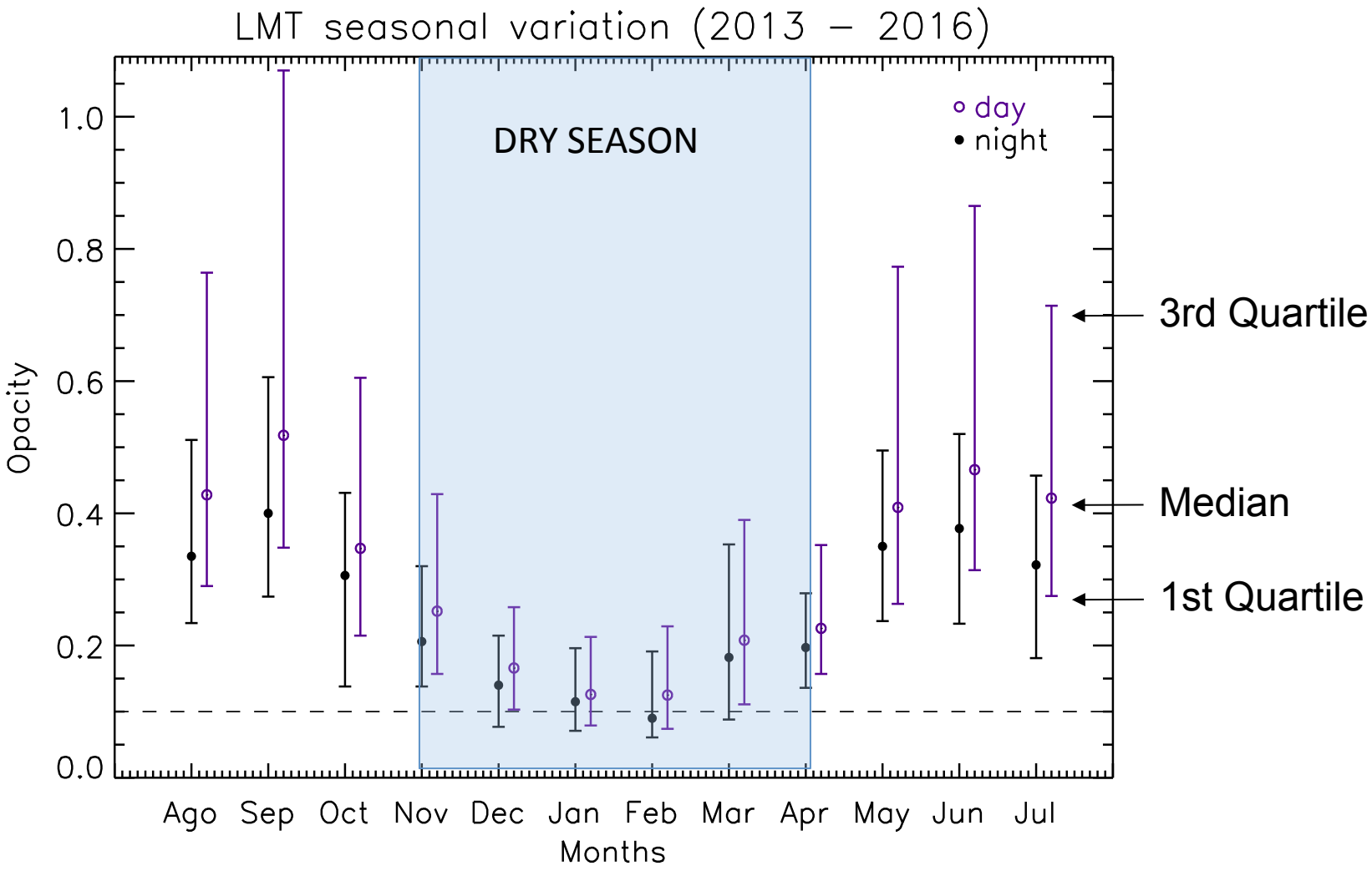
(Sub-)Millimeter Telescopes

telescope	Diameter (meters)	site	altitude (m)	freq. range (GHz)	Years of operation
GBT	100	Green Bank, West Virginia, USA	809	0.1 - 116	2001 -
LMT	50	Sierra Negra, Pue., Mexico	4582	70 - 345	2013 -
Nobeyama	45	Nobeyama, Japan	1350	20 - 230	1982 -
IRAM	30	Sierra Nevada, Granada, España	2850	70 - 345	1984 -
JCMT	15	Manua Kea, Hawaii, USA	4092	270 - 870	1987 -
APEX	12	Desierto de Atacama, Chile	5104	214 - 1390	2005 -
CSO	10	Manua Kea, Hawaii, USA	4092	177 - 900	1987 -
SMT	10	Mount Graham, Arizona, USA	3100	65 - 500	1993 -
ASTE	10	Desierto de Atacama, Chile	4860	270 - 500	2004 -


N
The Bahamas
Turks
Cuba
Mexico
Cayman Islands
Navass
Jamaica
Mexico City
LMT
Belize
Guatemala
Honduras
El Salvador
Nicaragua
US Dept of State Geographer
© 2011 INEGI
© 2011 Google
© 2011 Europa Technologies
©2010 Google
Clipperton Island
11°04'18.18" N 115°47'34.50" W elev -4073 m
Costa Rica
Eye alt 3419.82 km

Ciudad Serdan basecamp

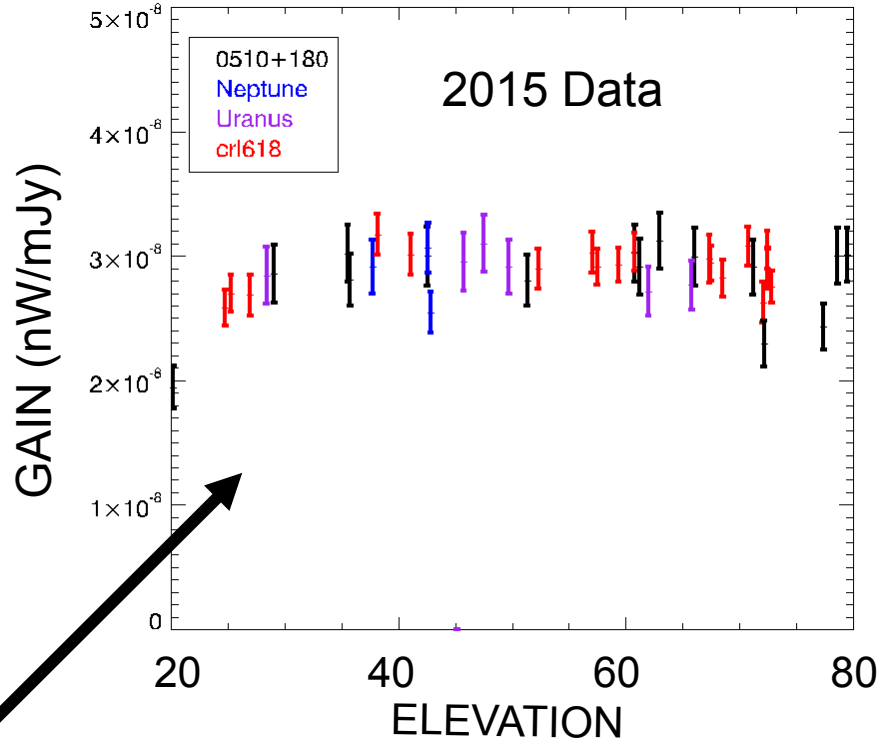
Seasonal Atmospheric 225GHz Opacity



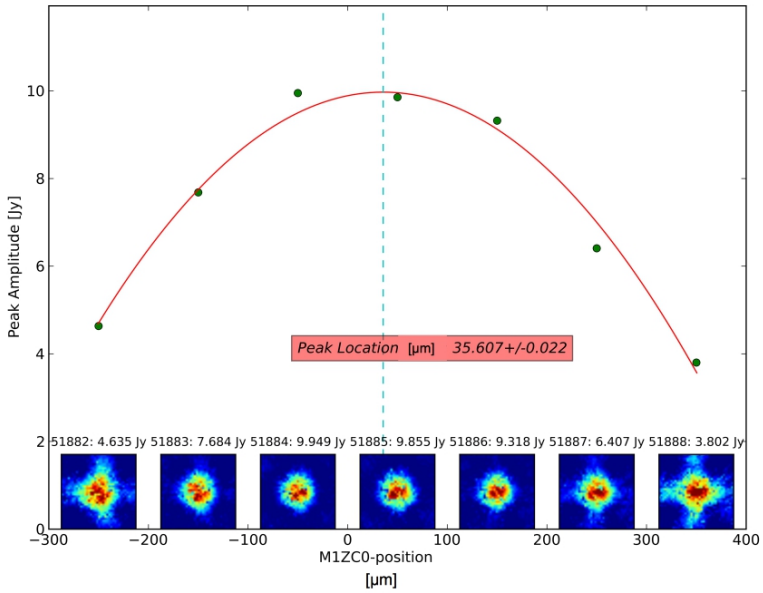
Reporting the first 3 years of 225GHz opacity measurements at the site of the LMT
Zeballos, M. et al. SPIE 9906-181 (2016).

LMT performance

- Primary Surface
  - LMT 32-m Current total optical r.m.s.: ~86 μm
  - Planned Upgrades and improvements: <75 μm
- Active Surface:
  - Maintains constant gain over full elevation range
  - Updates surface in response to thermal deformations.
- Pointing:
  - Good performance in wind
  - Absolute Pointing: 2.5”
  - Offset Pointing: <1”

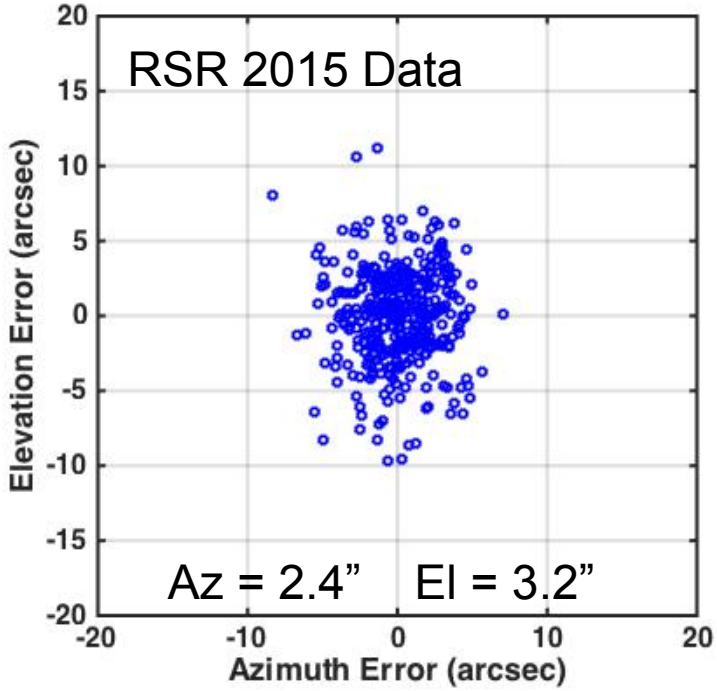


Real Time measurement of Surface Shape

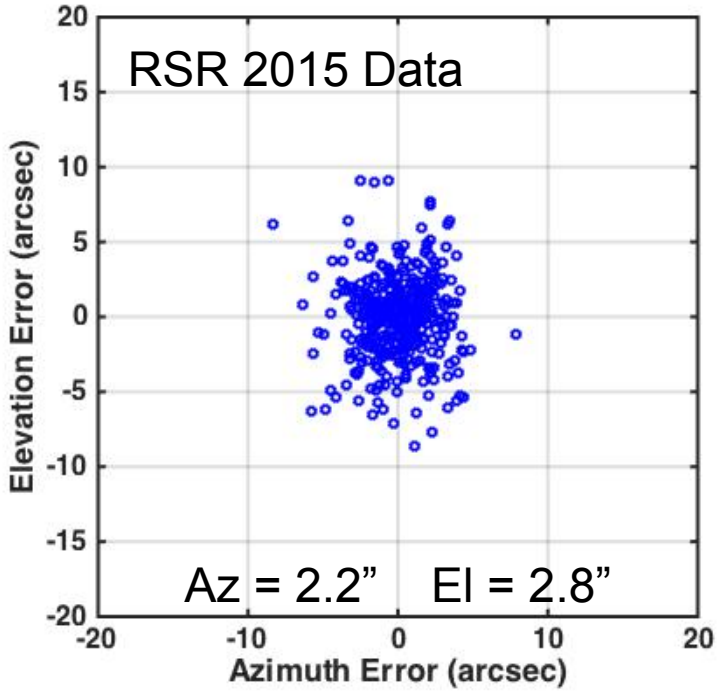


Calibration & Operation of the LMT Active Surface
F.P. Schloerb et al. SPIE 9906-245 (2016)

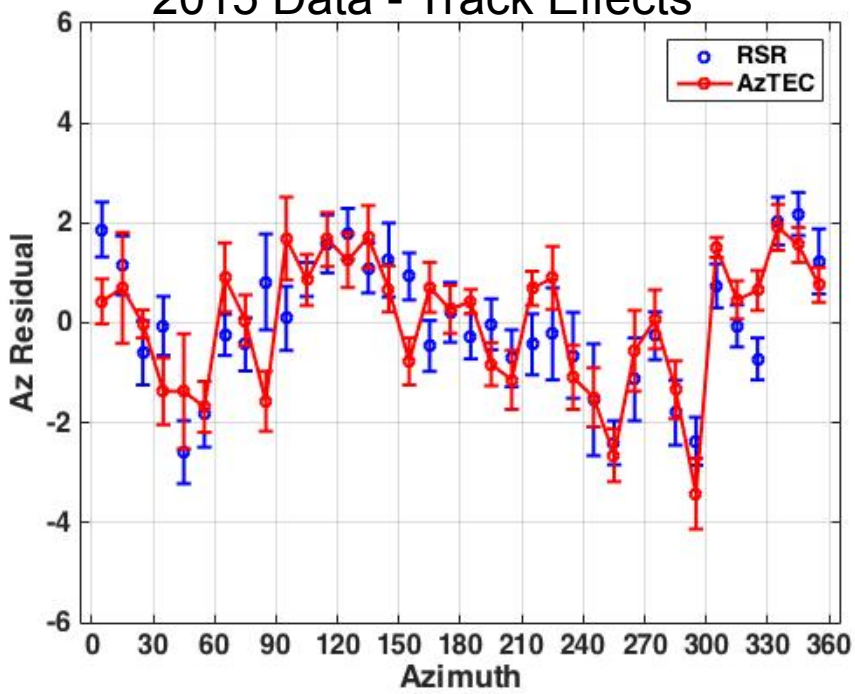
Nominal Model

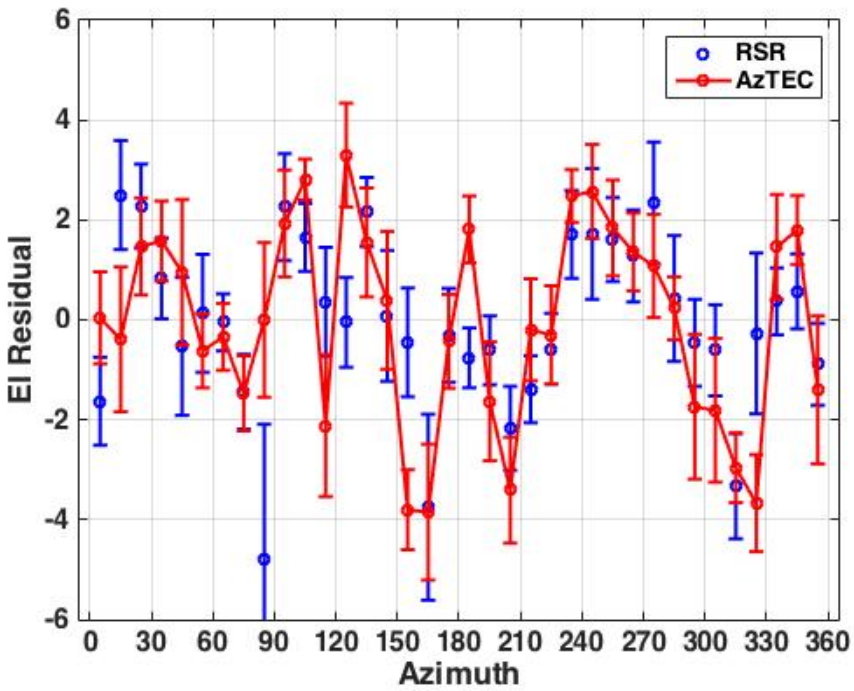


Enhanced Track Model



2015 Data - Track Effects





LMT Instruments

On Telescope

	AzTEC	1.1mm 144-element Continuum Array
	Redshift Receiver	Ultrawideband Spectrometer (73-111 GHz)

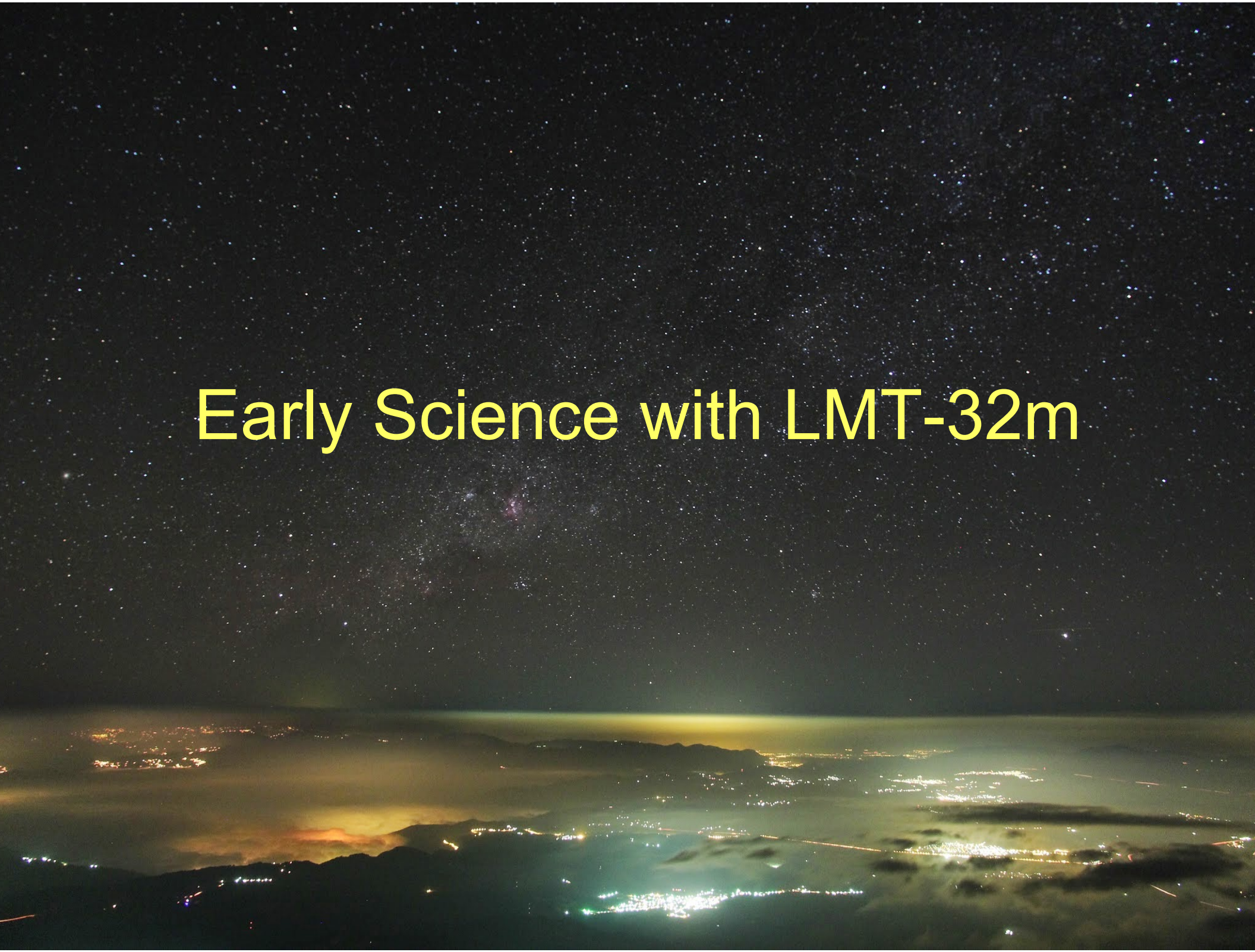
Near Term (funded commitments)

2017	SEQUOIA	16-element array (85-115 GHz)
2017	1mm SIS Receiver	200-280 GHz Receiver (VLBI)
2018	OMAR	16-element array (200-280 GHz)
2018	TolTEC	7000 element LEKID array; multicolor; with polarimeter

Long Term (seeking funding)

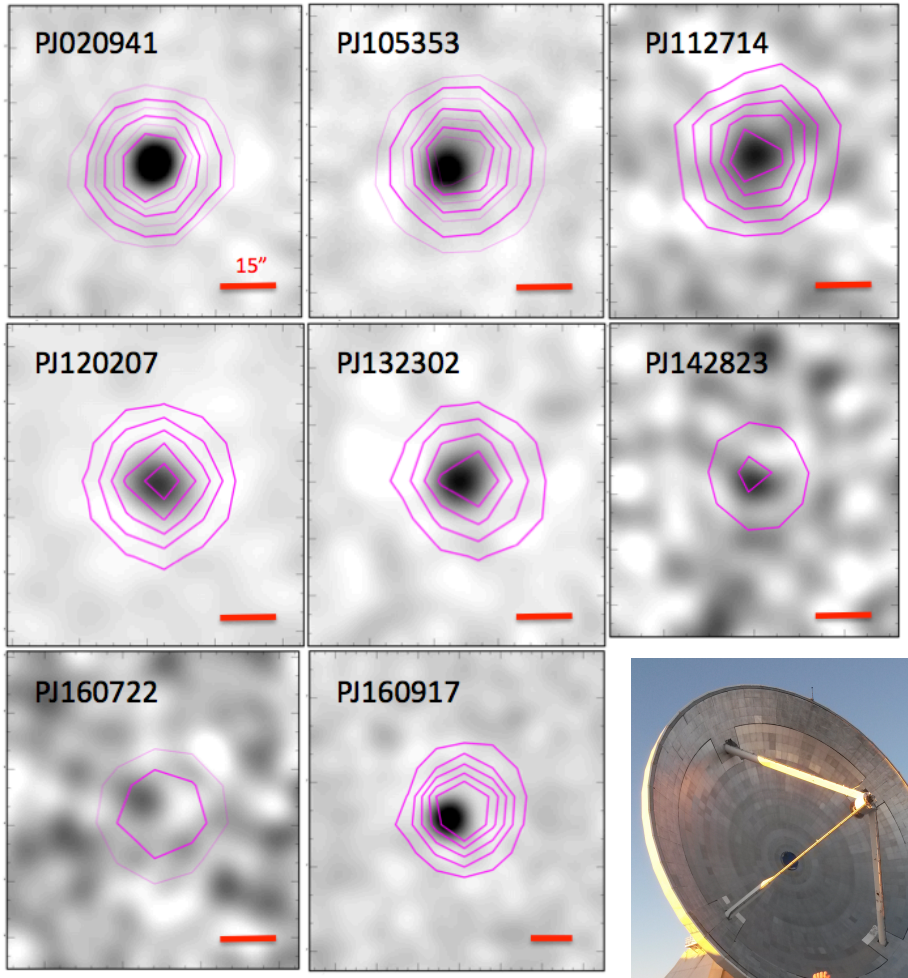
	Focal Plane Array Spectrometer	4 IF's per pixel for SEQUOIA and OMAR
	SubMM SIS Receiver	345 GHz window
	Phased Array Feed	100's of elements, phased array feed

Opportunities for Guest Instruments


Early Science with LMT-32m

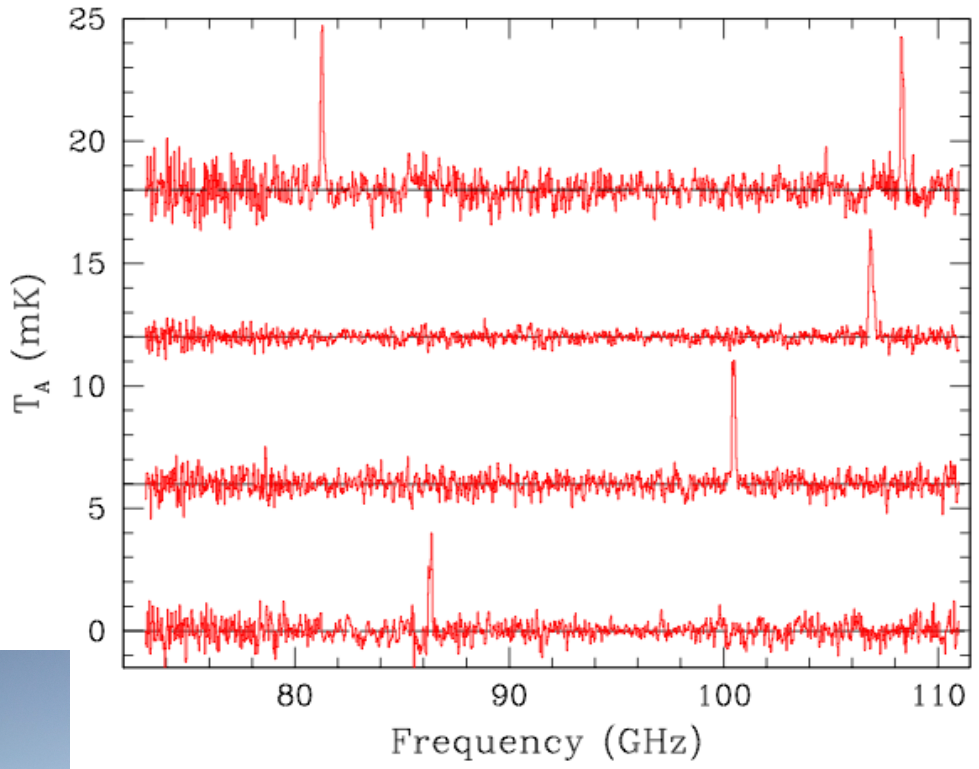
LMT Observations of Planck SMGs

SPIRE 350um on AzTEC



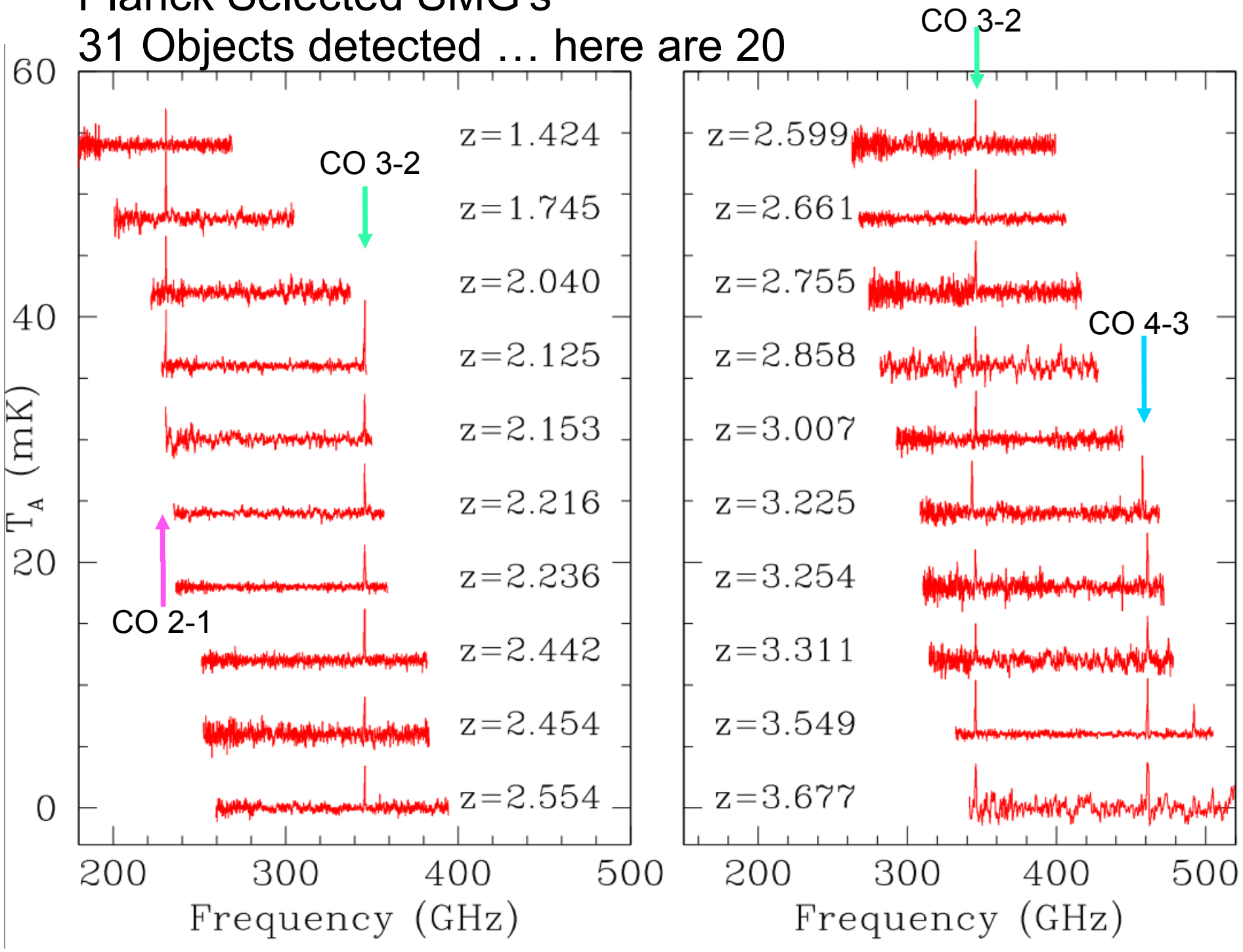
FWHM ~ 8” (3-20 minutes integration)

Harrington et al. (2016)



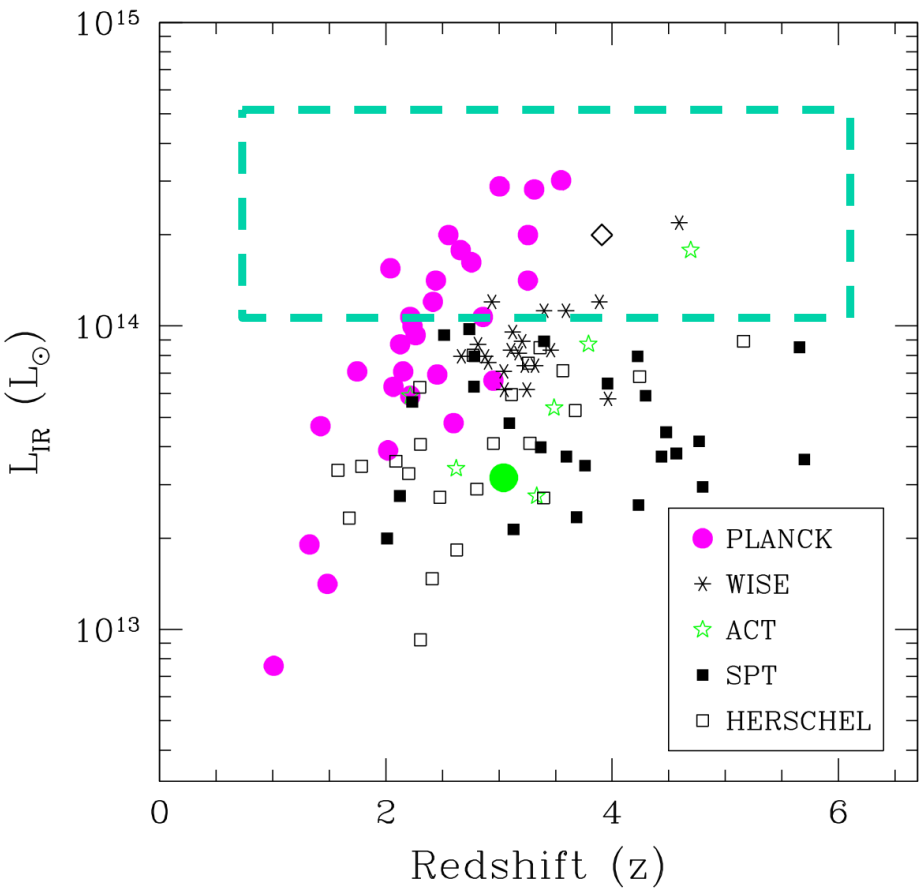
One or more CO line detected in 8/8 sources observed (15 to 30 minutes per source)

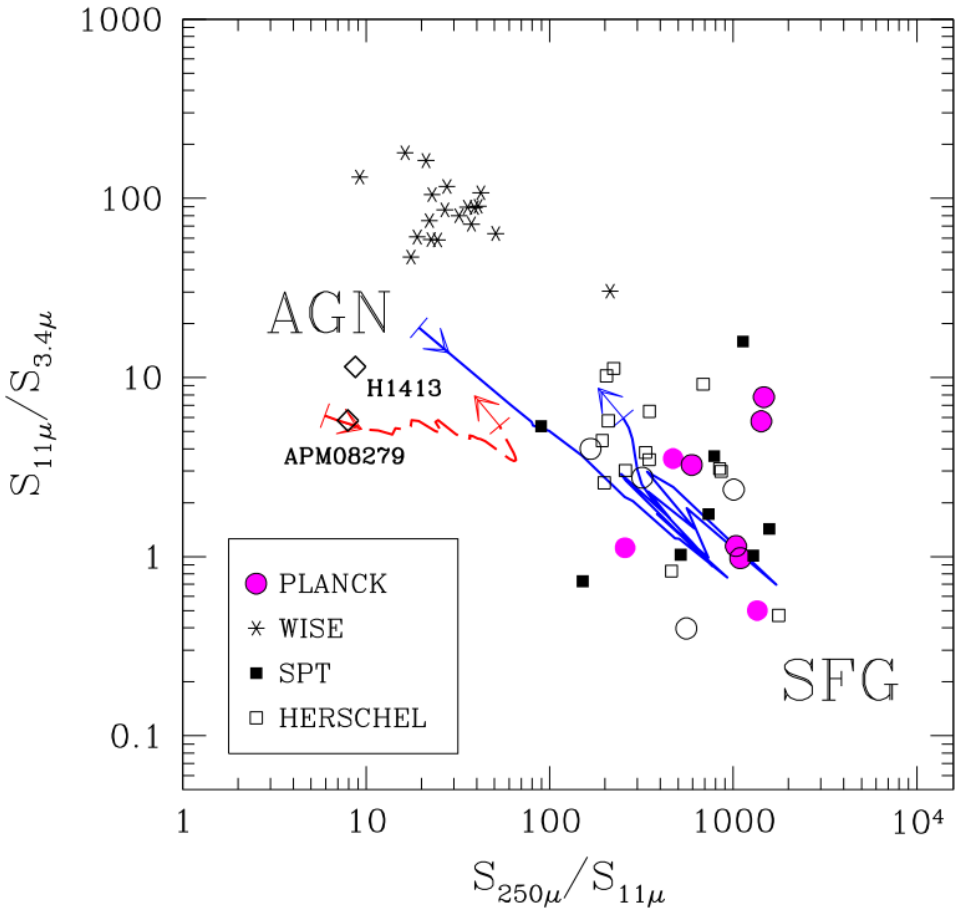
Planck Selected SMG's
31 Objects detected … here are 20

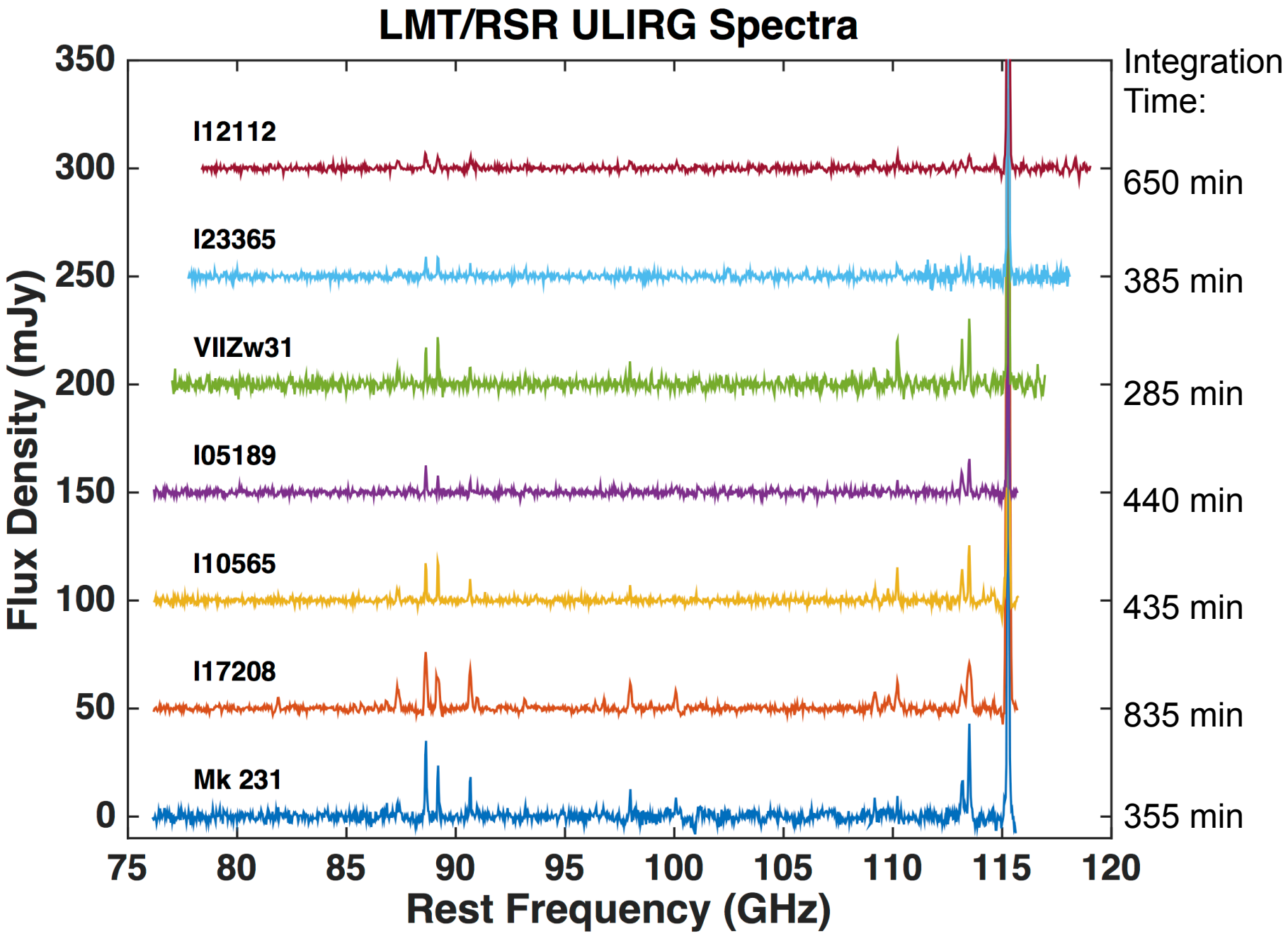


Planck Selected SMG's

Harrington et al. (2016), Yun+ in prep



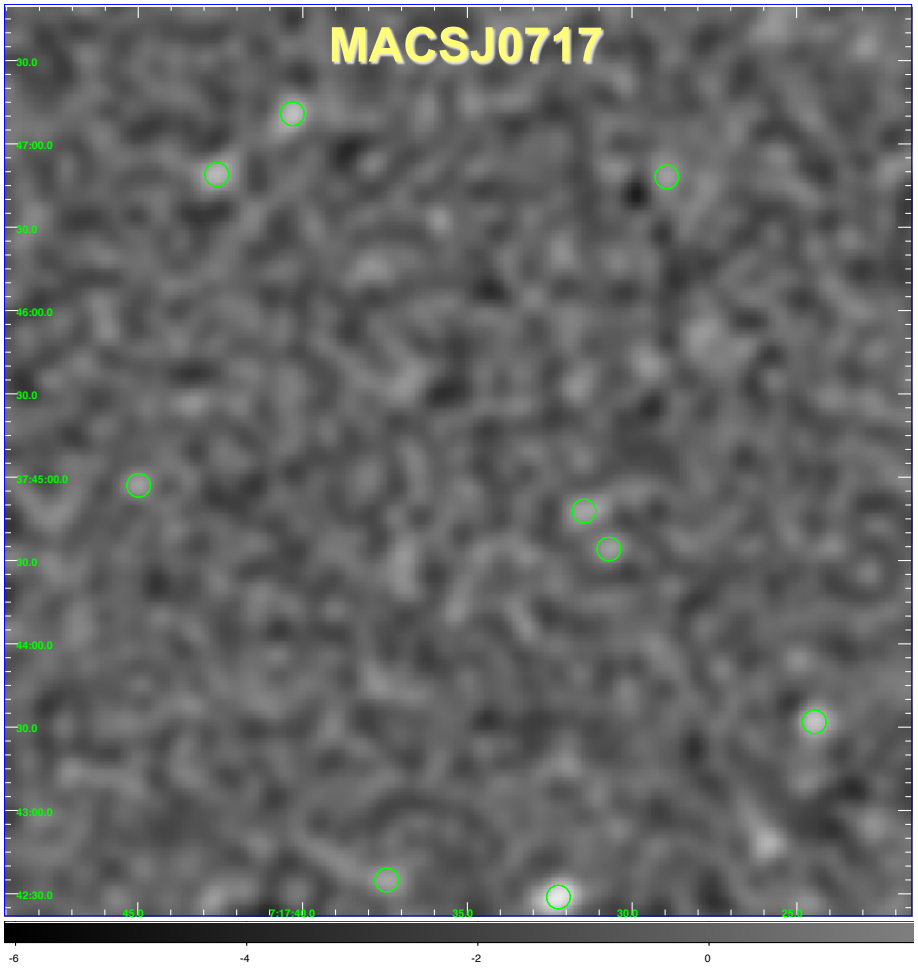


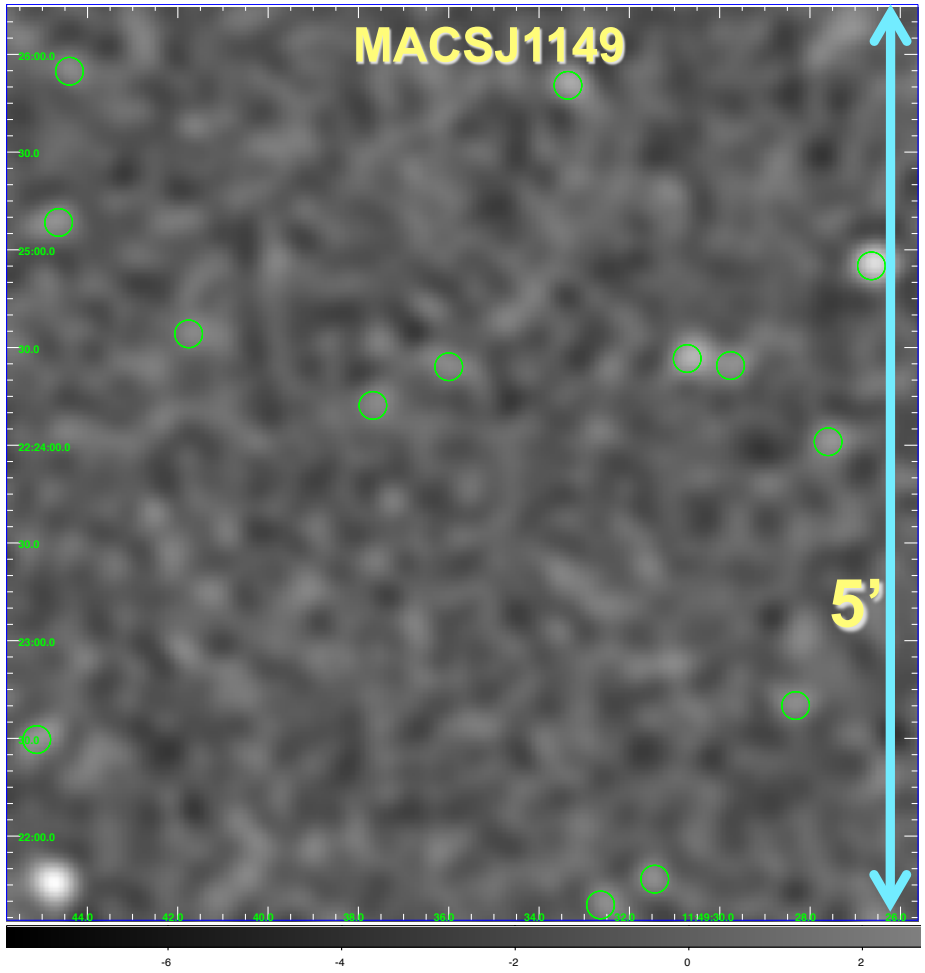

LMT/RSR ULIRG Spectra
Flux Density (mJy)
Rest Frequency (GHz)
Integration Time:
I12112
I23365
VIIZw31
I05189
I10565
I17208
Mk 231
650 min
385 min
285 min
440 min
435 min
835 min
355 min
350
300
250
200
150
100
50
0
75
80
85
90
95
100
105
110
115
120

Frontier Fields Survey

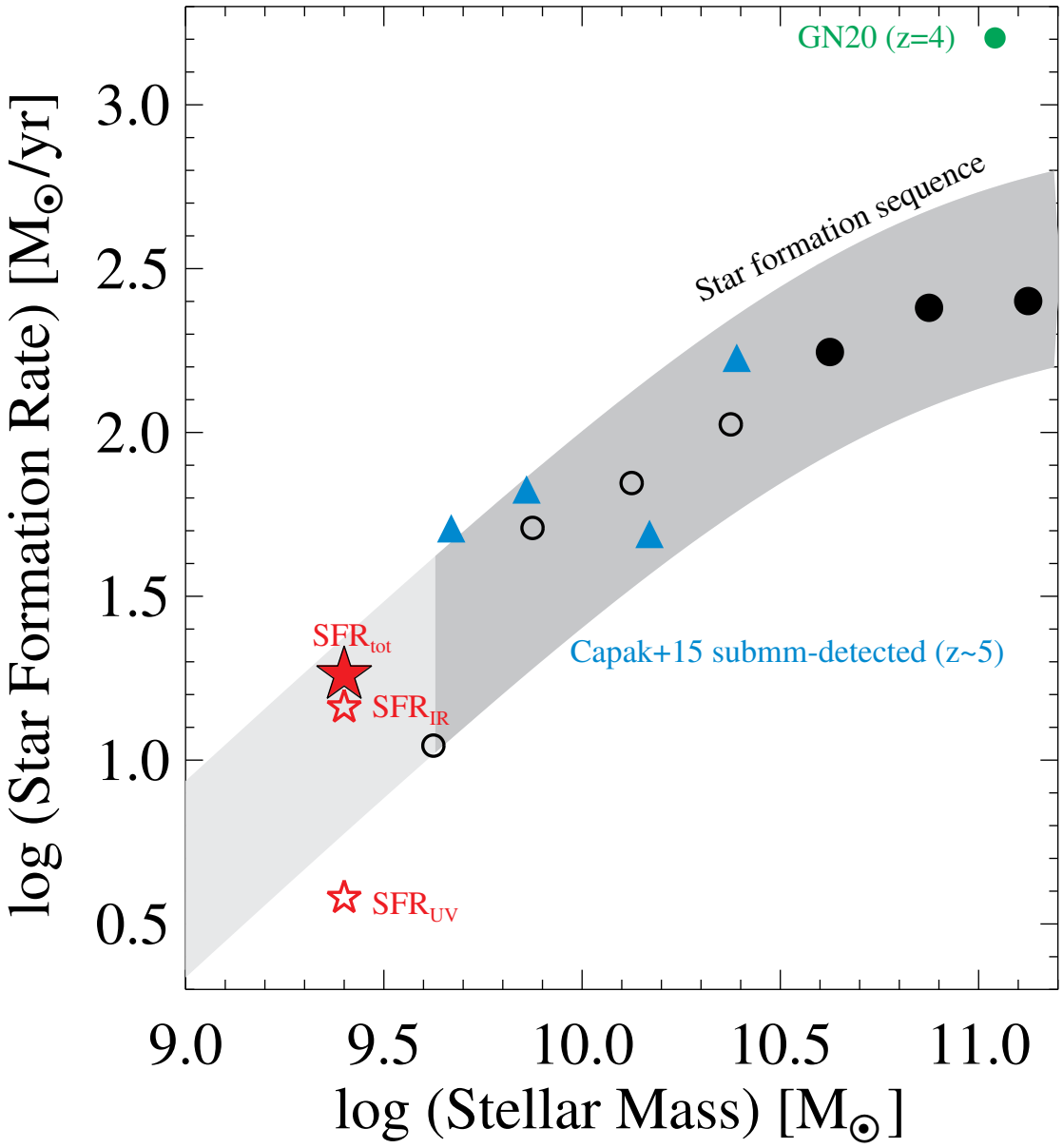
- Survey of 6 Clusters with HST (1000 h) and many other telescopes.
  - Magnification Maps are publicly available
- LMT has observed two of the fields (A. Pope, PI)
  - http://www.astro.umass.edu/~pope/FF/
  - *Pope at al (2016) submitted to ApJ.*
- 5' x 5' Fields Observed
  - MACSJ0717 21.1 hours 0.22 mJy rms (1 sigma)
  - MACSJ1149 25.4 hours 0.25 mJy rms (1 sigma)

LMT Frontier Fields: 1.1mm AzTEC maps





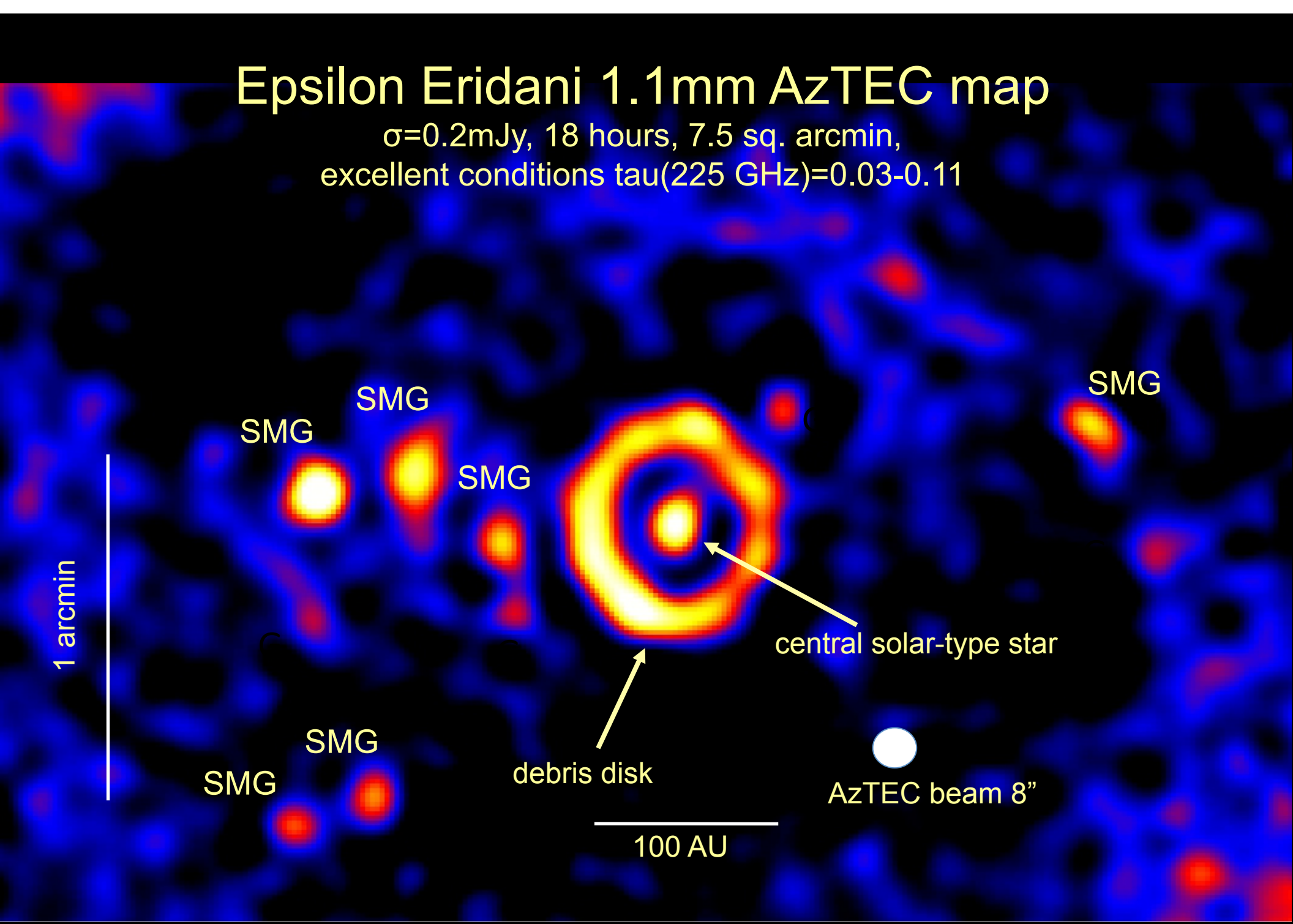
Alexandra Pope (UMass Amherst)



(Pope et al 2017)

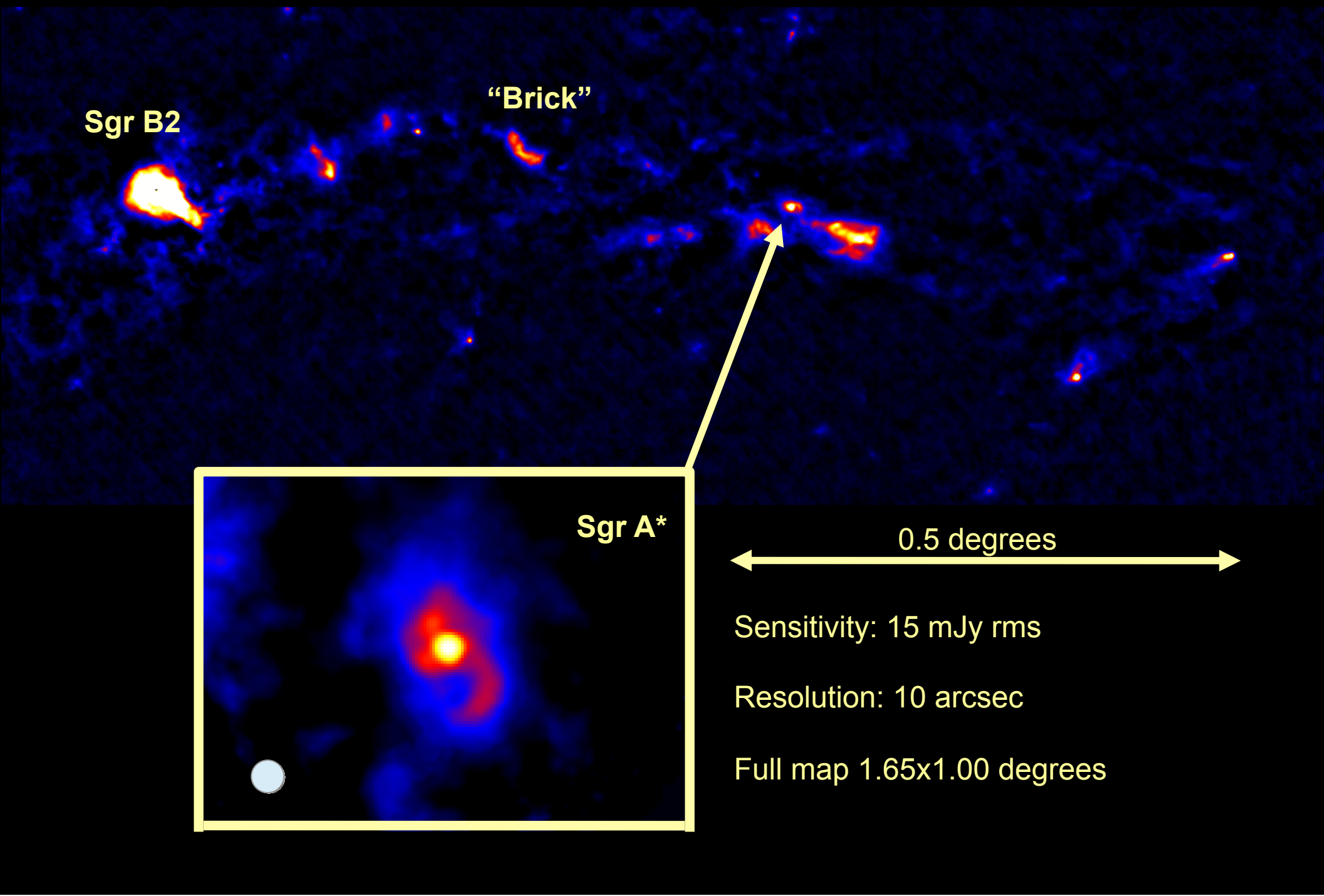
Epsilon Eridani 1.1mm AzTEC map

σ=0.2mJy, 18 hours, 7.5 sq. arcmin,
excellent conditions tau(225 GHz)=0.03-0.11



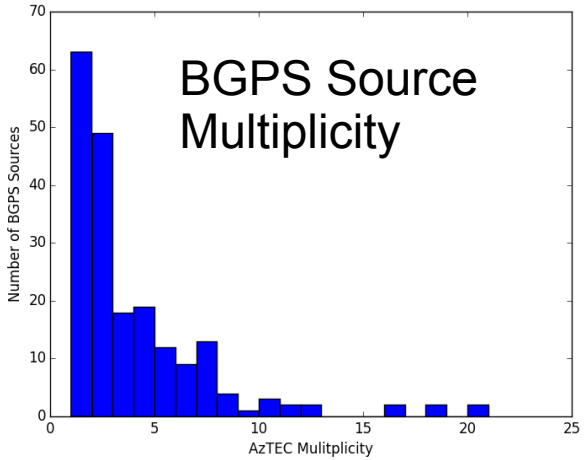
Chávez-Dagostino, M. et al 2016

LMT/AzTEC Milky Way Central Molecular Zone

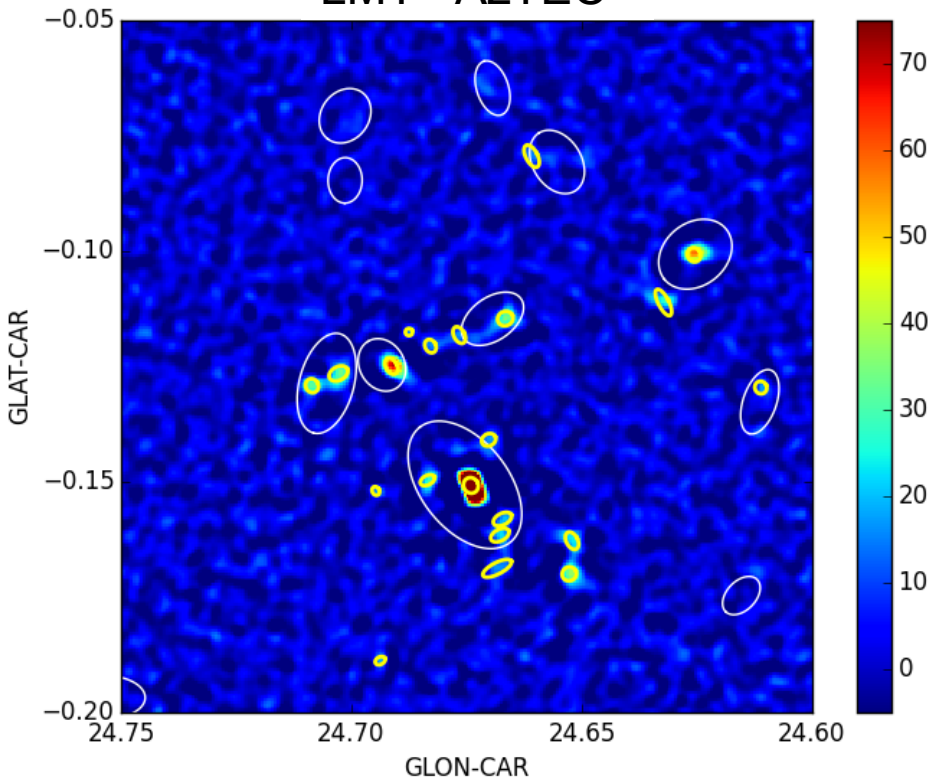


Continuum Galactic Plane Survey with LMT/AzTEC

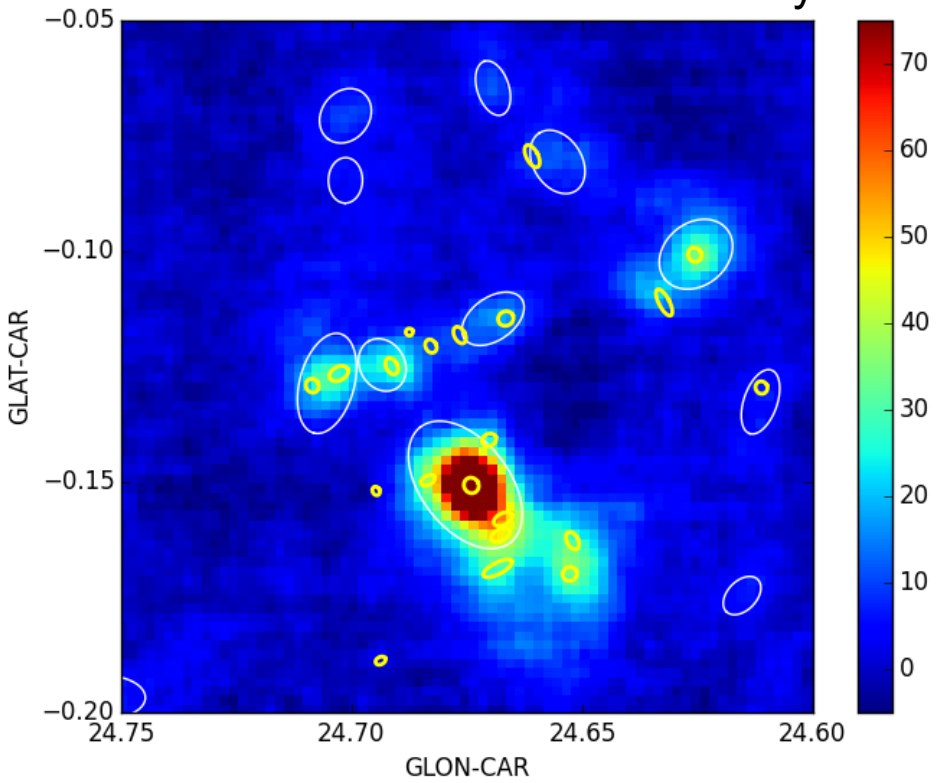
- G24.5 Prototype Field
- 8” resolution
- 5 mJy/beam sensitivity
- 1 square degree (9 h in τ=0.25 weather)



LMT - AzTEC



Bolocam Galactic Plane Survey



The New York Times

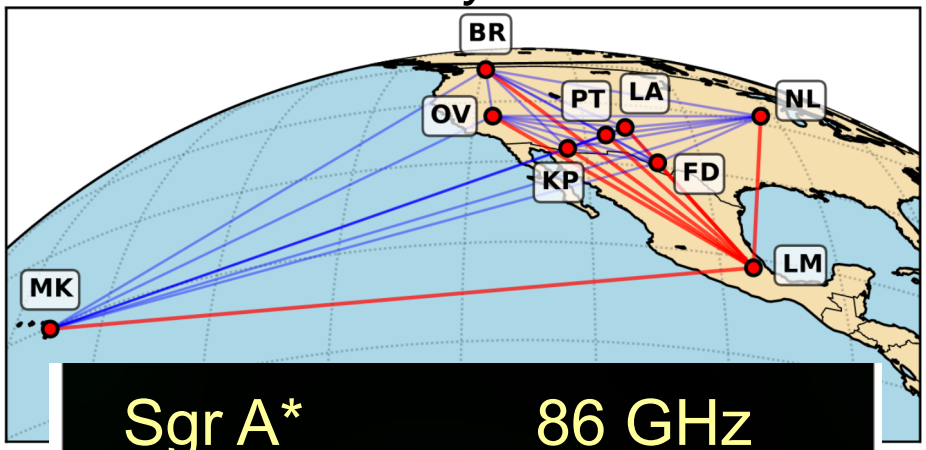
Black Hole Hunters

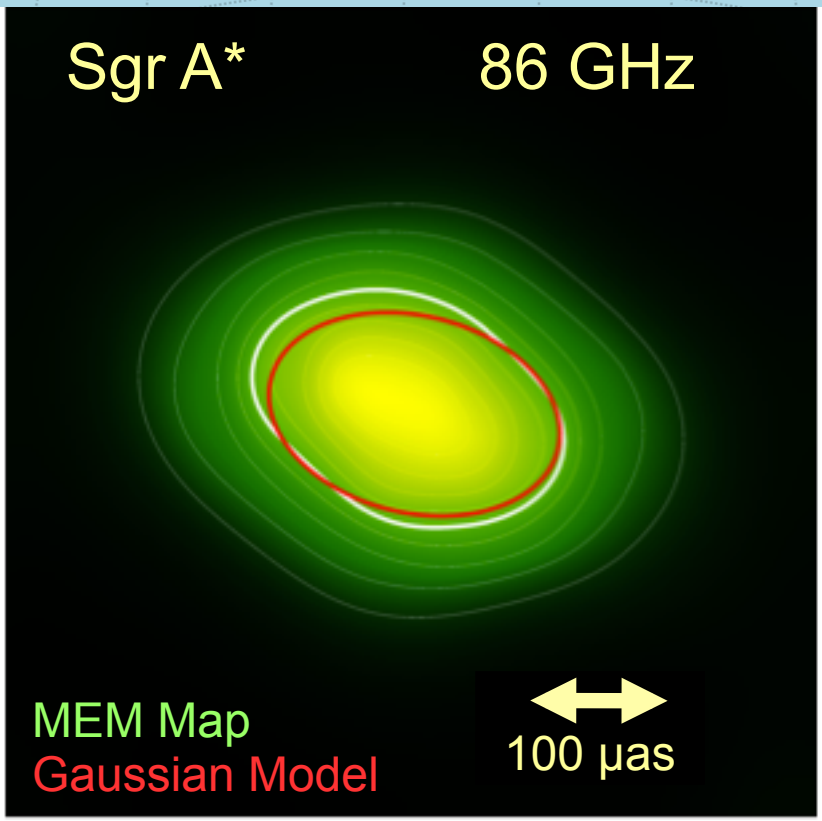
Aiming to make the first portrait of the hungry monster at the center of our galaxy, astronomers built “a telescope as big as the world.”

JUNE 8, 2015

LMT + VLBA

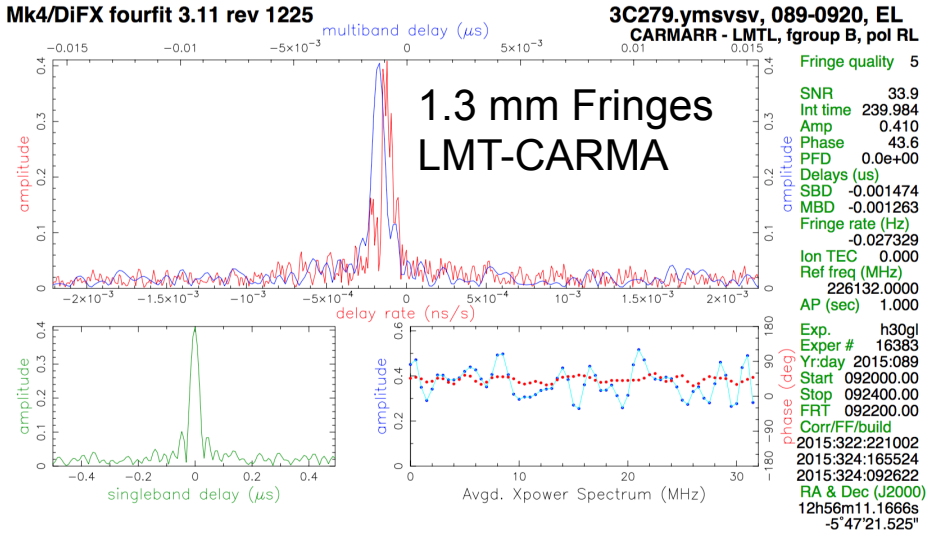
LMT Provides Key N-S Resolution

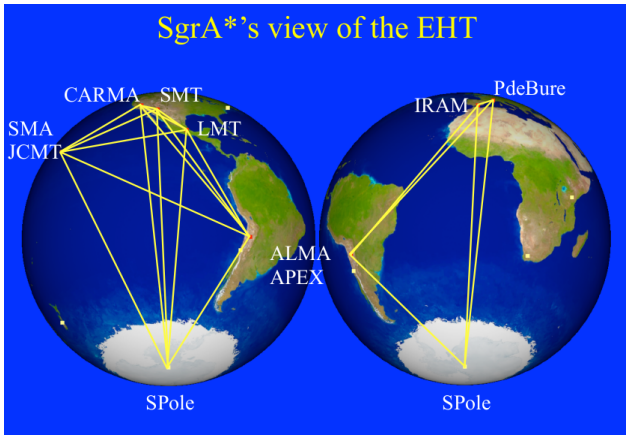




Ortiz et al. ApJ (2016)

VLBI





First LMT-ALMA EHT run
In April 2017


50-m Completion in 2017
GRAN TELESCOPIO MILIMETRICO
LARGE MILLIMETER TELESCOPE

50m Completion Plan

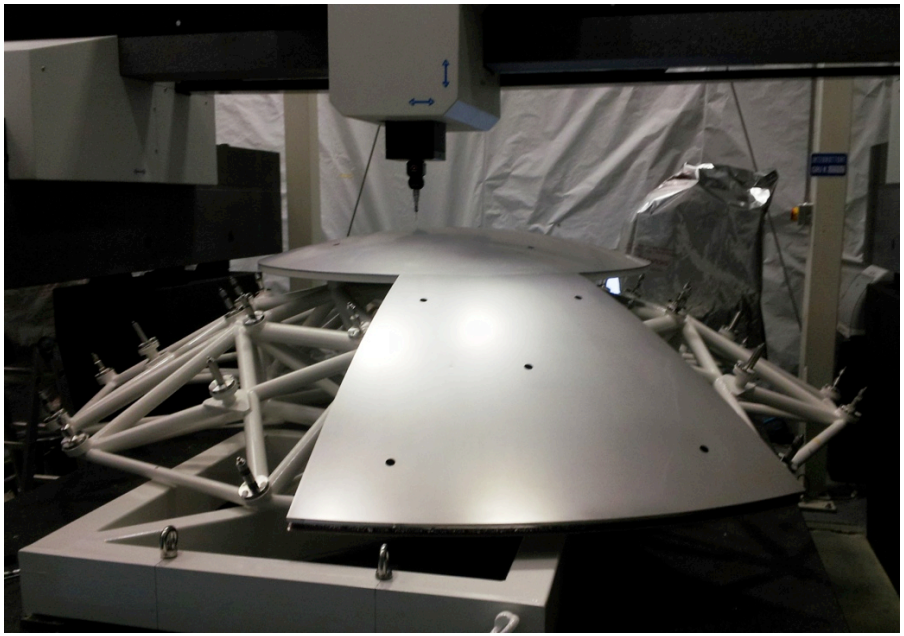
- Secondary Mirror
  - replace current machined aluminium M2; surface accuracy 36µm r.m.s. in inner 1.7m to illuminate inner 32-m diameter; outer mirror (1.7m < D < 2.6m) is unusable for 50-m LMT
- Secondary Mirror Hexapod
  - replace current hexapod; engineering problems (3 failures since 2013; self-interference; mechanical & electrical design flaws)
- Primary Reflector Surface Panels & Segments
  - complete 50-m diameter LMT primary surface.
- Active Surface Control System
  - complete 50-m active surface control system

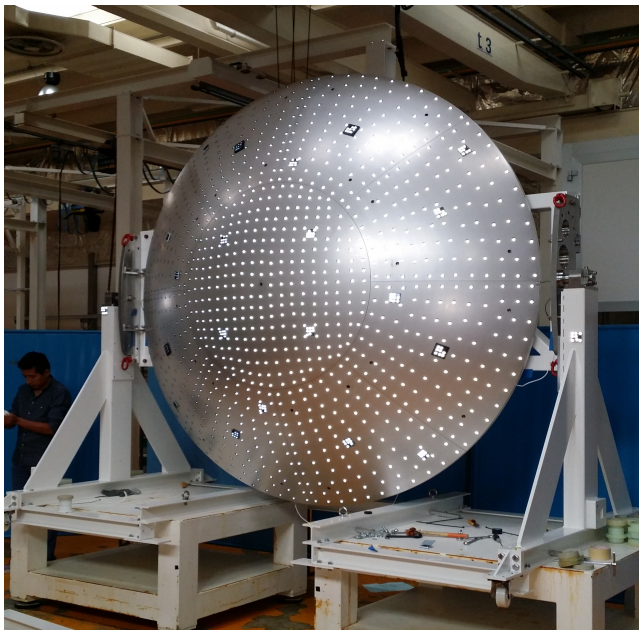
Replacement Secondary Mirror

2.6m diameter segmented reflector (Media Lario) constructed from 9 laminated composite panels (electroformed nickel, rhodium coating), stainless steel back-up structure, designed for operation with the full 50-m primary surface.

construction 20µm r.m.s. over full diameter,
with gravitational deformations ≤ 26µm r.m.s.

Final Acceptance Review - May 2016





Giuseppe Valsecchi (Media Lario), Segmented Subreflector with electroformed nickel panels for the LMT, SPIE 9912-128 (2016)

David Smith (MERLAB), Thermal testing results of an electroformed nickel M2 panel

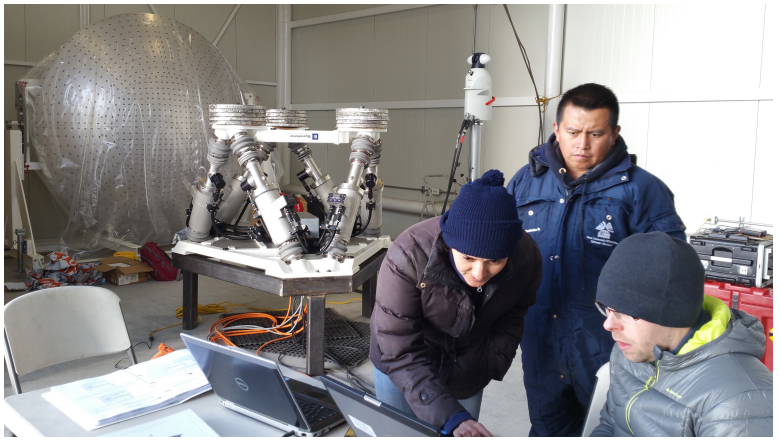
SPIE 9912-150 (2016)

Secondary Mirror Hexapod

Symetrie (France)

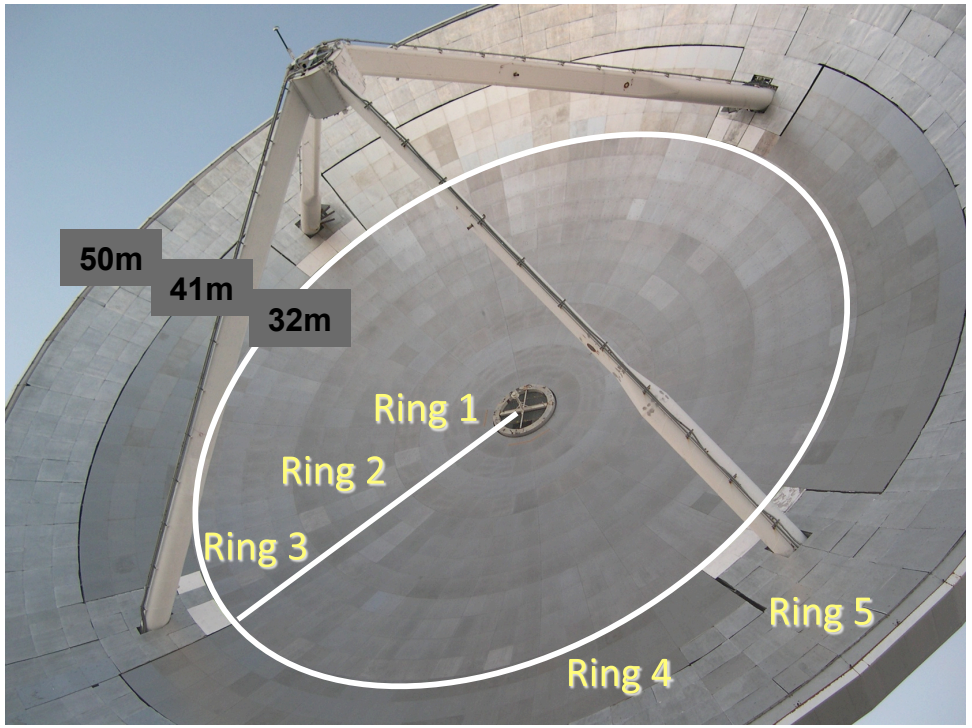
- Final Design Review December 2015
- Revised drawings accepted, & release for fabrication March 2016
- Standard mechanical parts machined; 80% electronics & control cabinet
- Mount actuators – July 2016
- Factory Acceptance Tests (hexapod & drive cabinet) at Symetrie, September 2016
- Site tests with M2 – January 2017
- Commissioning on LMT – April 2017

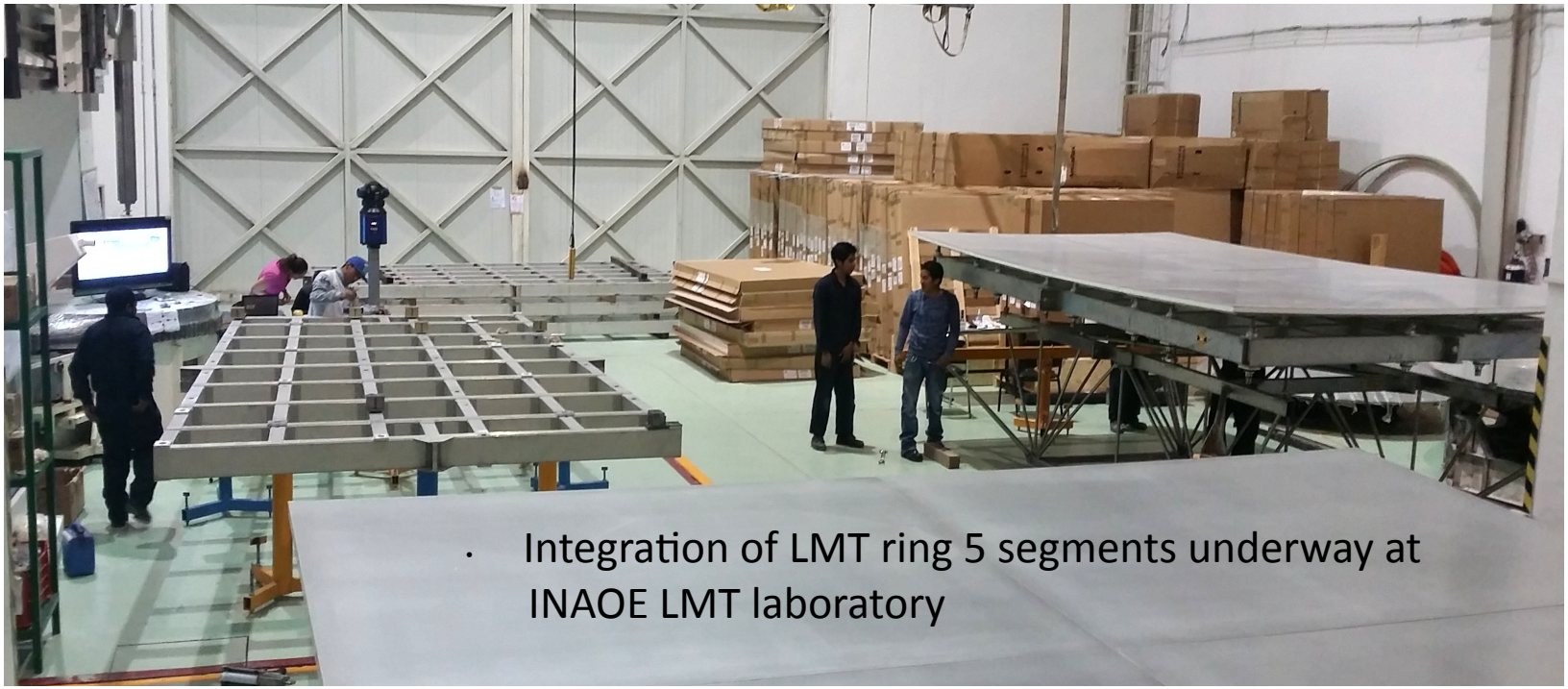
Testing at LMT Site



Primary Surface

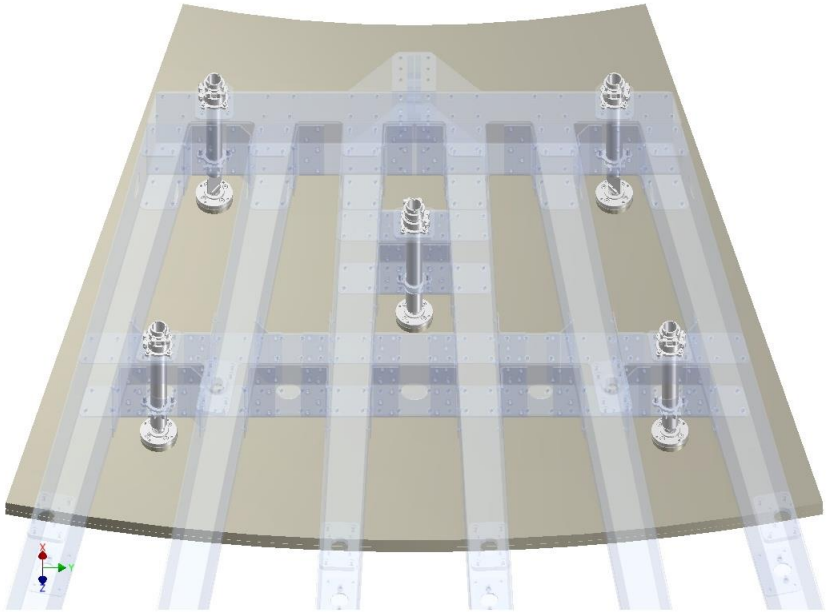
- 180 primary surface segments (~5m x 2m) in 5 concentric rings
- Inner 32-m used for current scientific operation

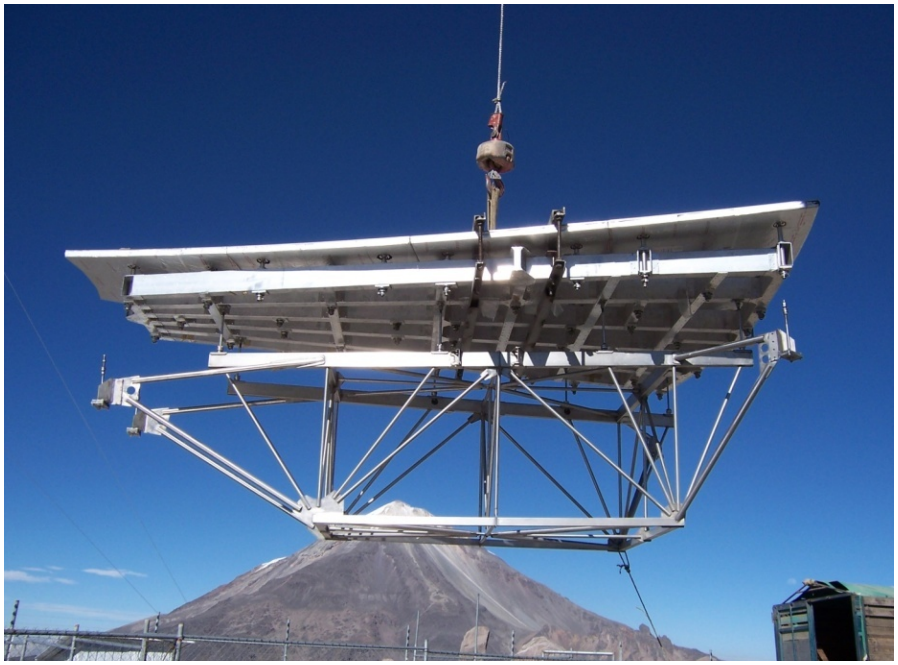




- Integration of LMT ring 5 segments underway at INAOE LMT laboratory

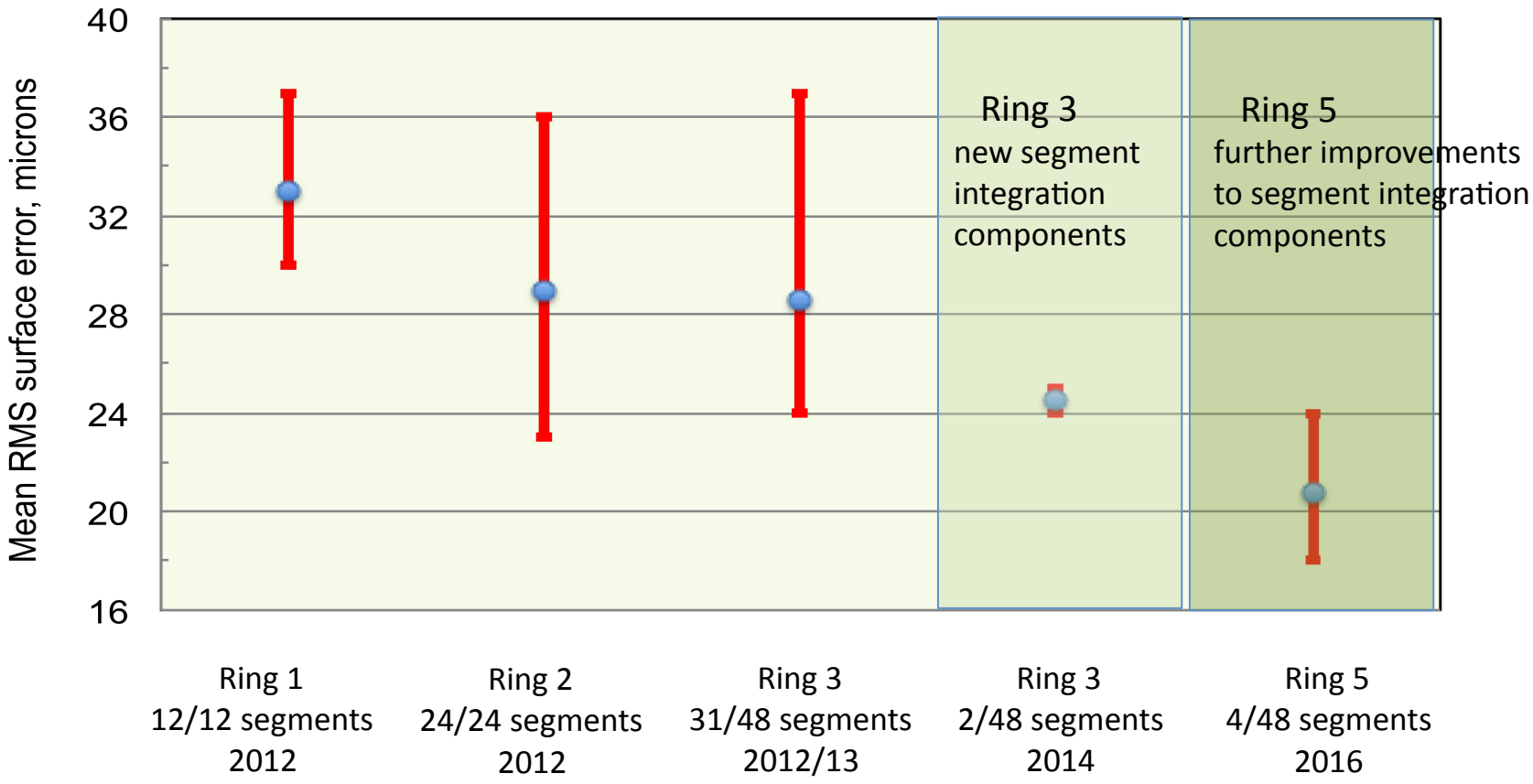
LMT primary reflector (M1)





- 8 composite panels per segment (<9 μm r.m.s.), electro-formed nickel with rhodium coating, aluminum honeycomb
- panels fabricated by Media Lario Technologies (MLT), Italy
- MLT contract complete - rings 1,2, 3 (2005-2006); rings 4, 5 (2014-2015)

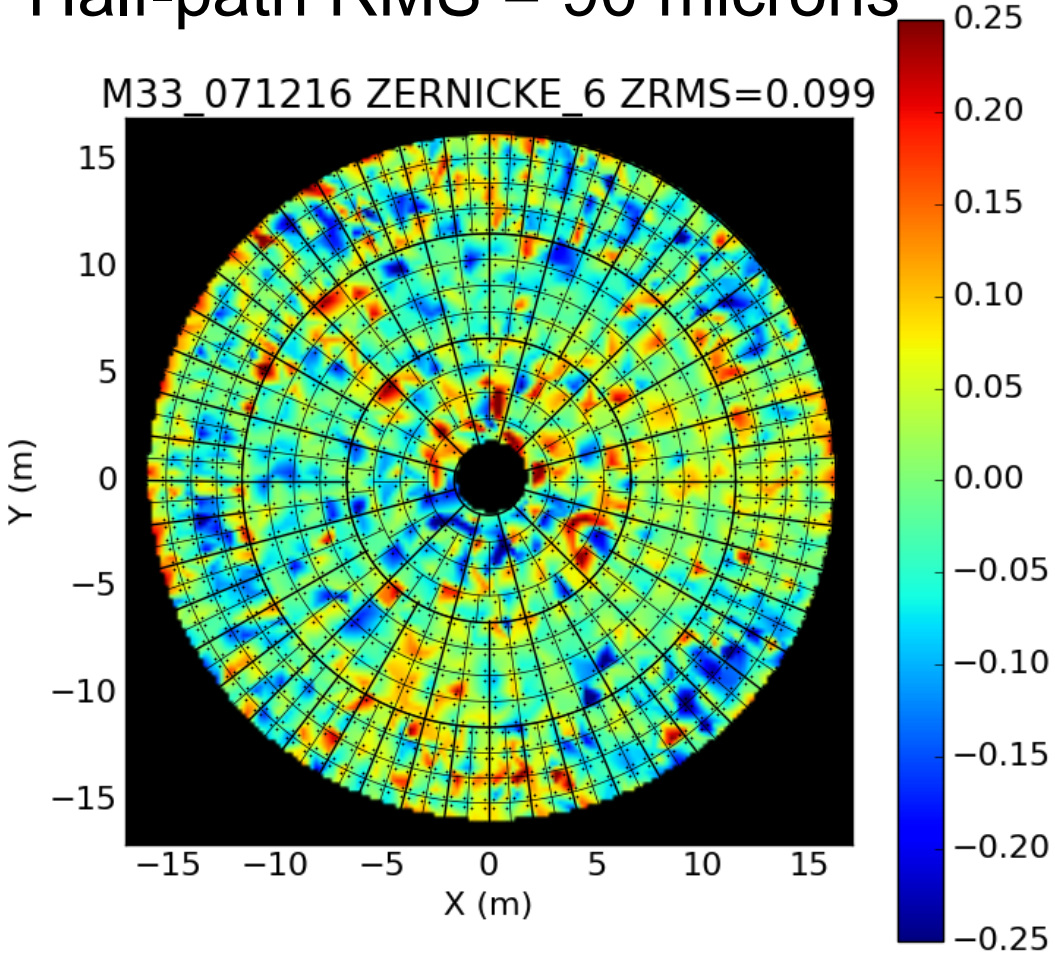
Evolution of refurbished M1 segment surface errors (on-site)



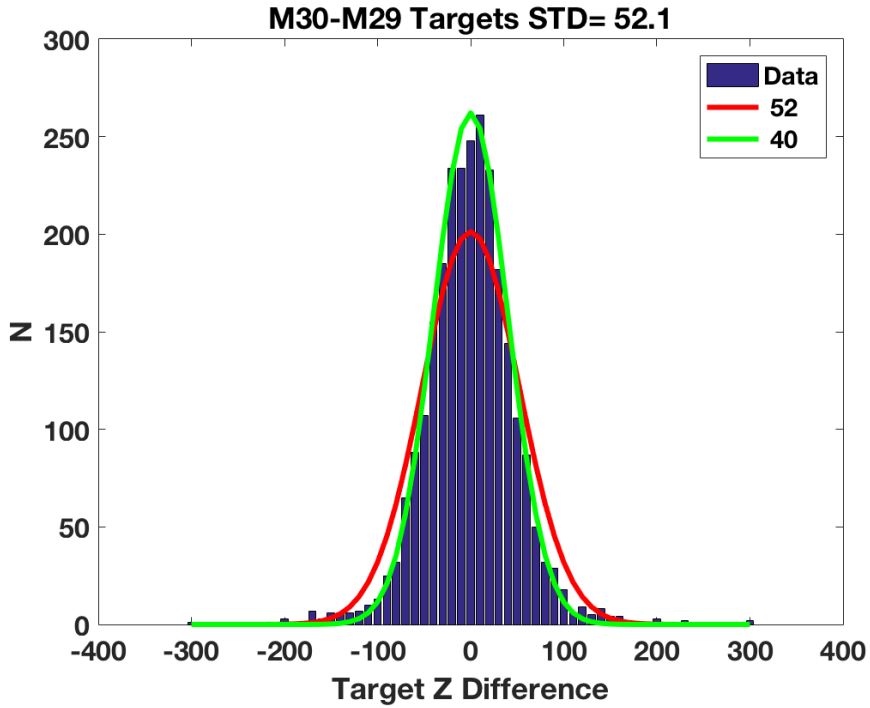
David Gale (INAOE): Metrology of LMT primary surface panel: SPIE 9912-36 (2016)

Surface Alignment with Photogrammetry

Rings 1-3
Half-path RMS = 90 microns



Target differences
between two maps

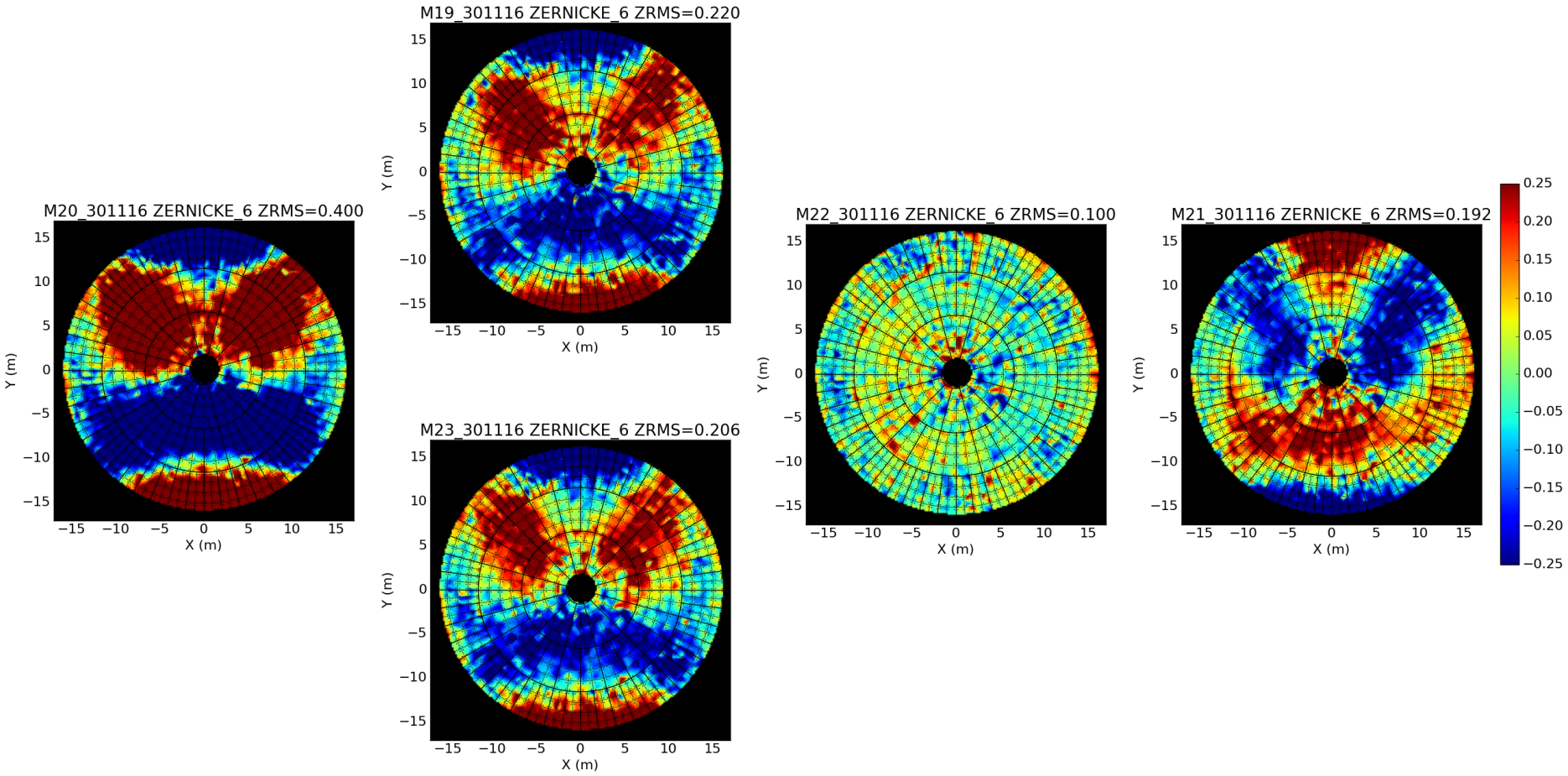


We think 30-40 microns is realistic for measurement error.

Nov 30 Maps

Actuator Positions Held Fixed at 43 degree settings

Zernicke 6 parameter fit to Surface

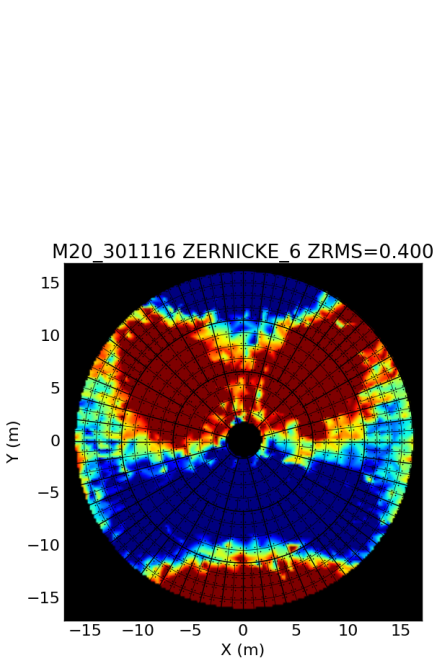


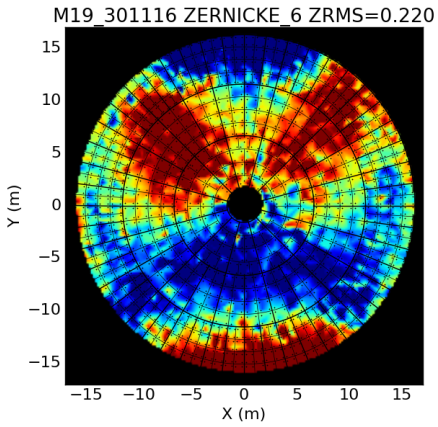
80 62 43 20

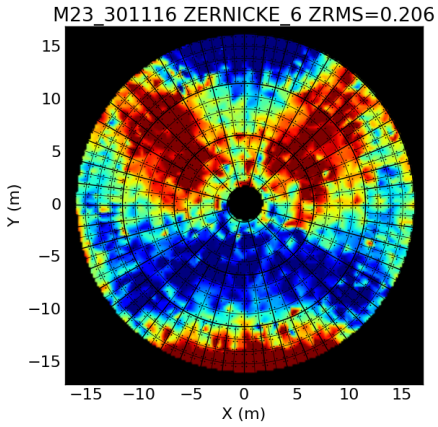
Nov 30 Maps

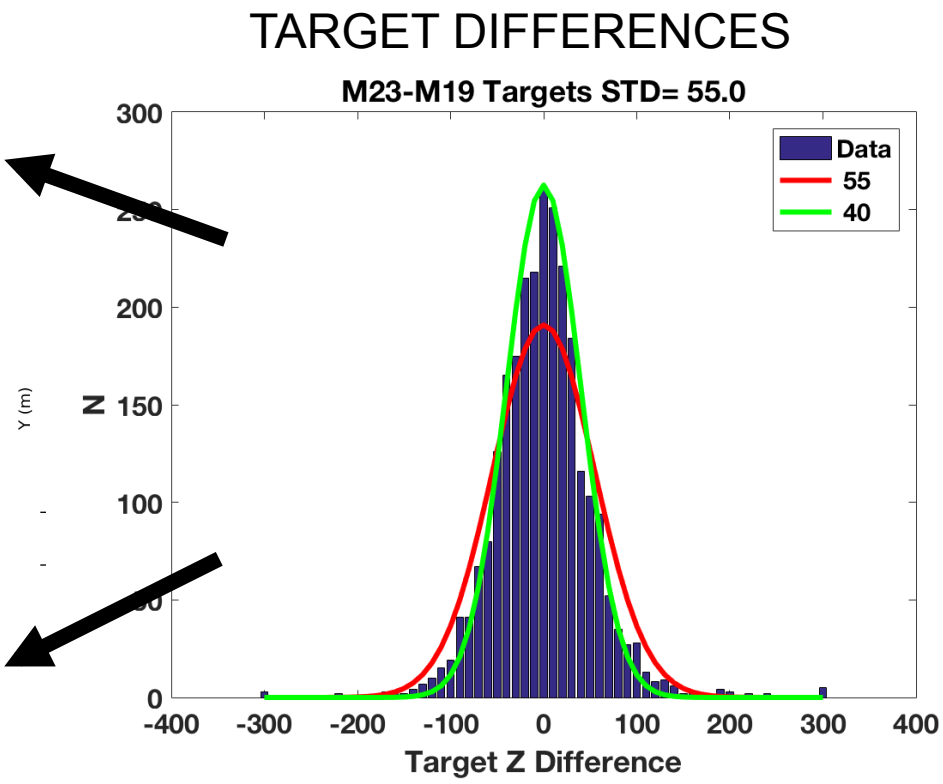
Actuator Positions Held Fixed at 43 degree settings

Zernicke 6 parameter fit to Surface









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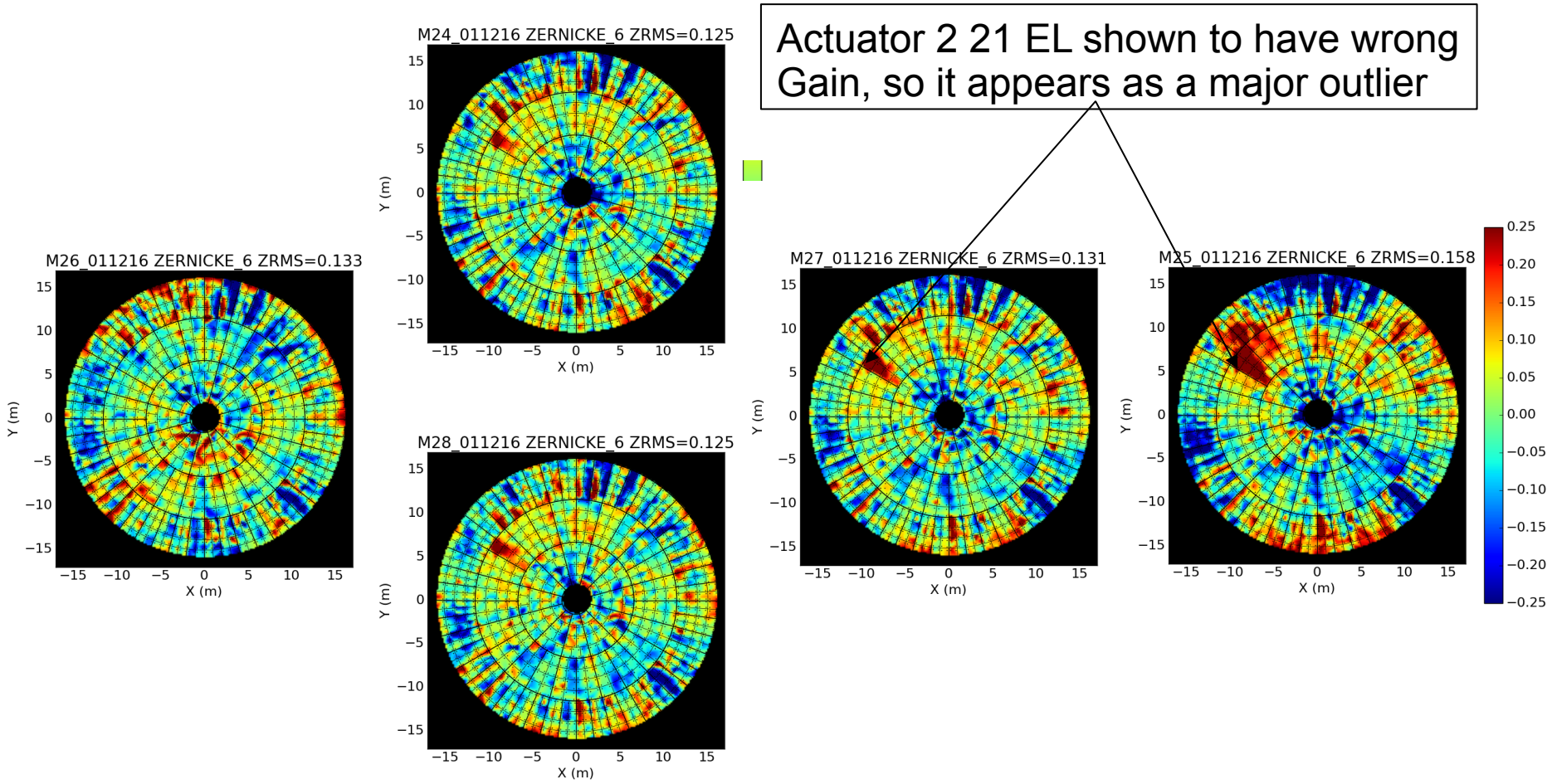
Dec 1 Maps

Actuator Positions from Fit to Nov 30 Data

Zernicke 6 parameter fit

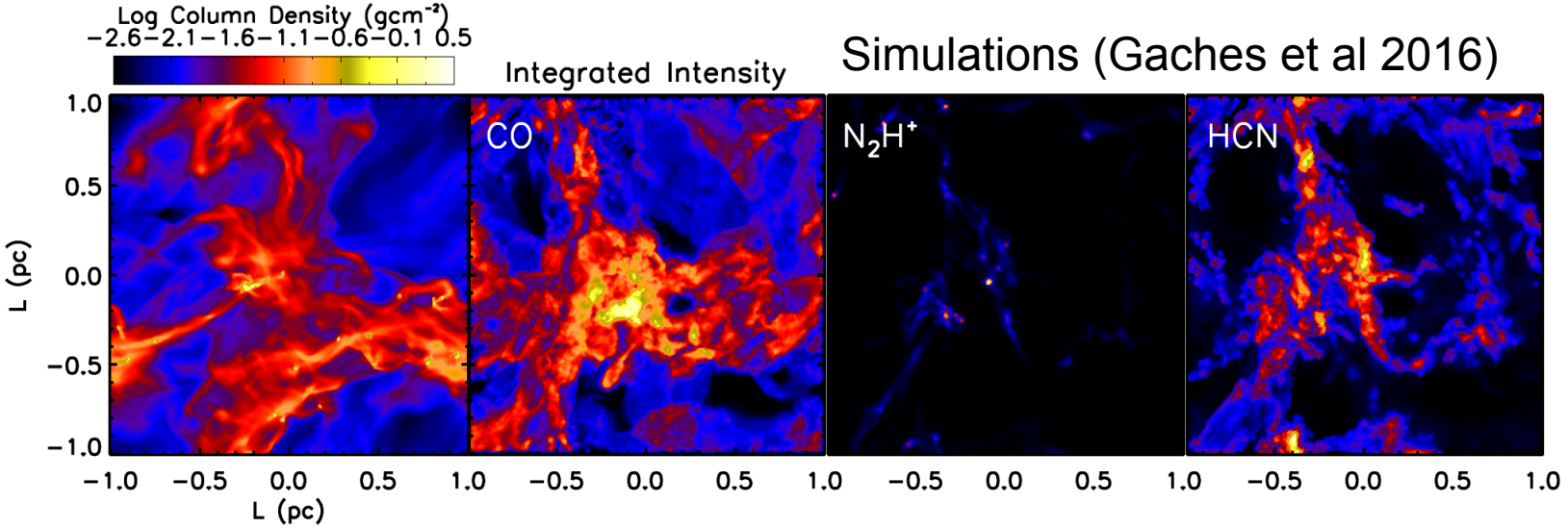


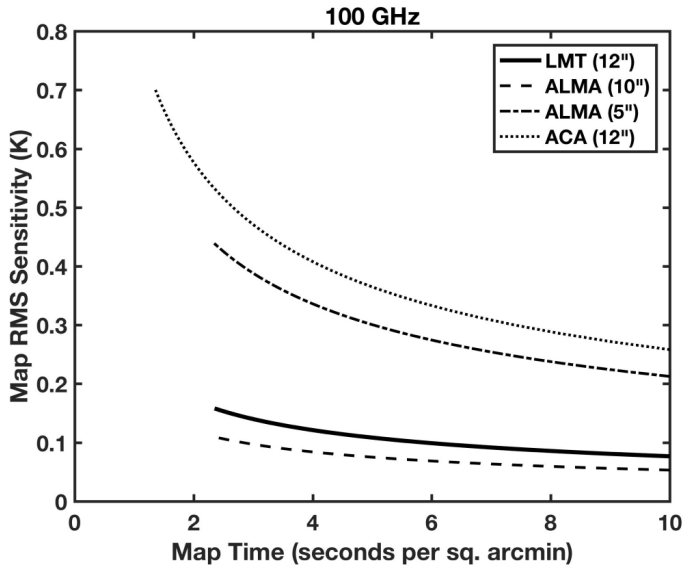
80 62 43 20

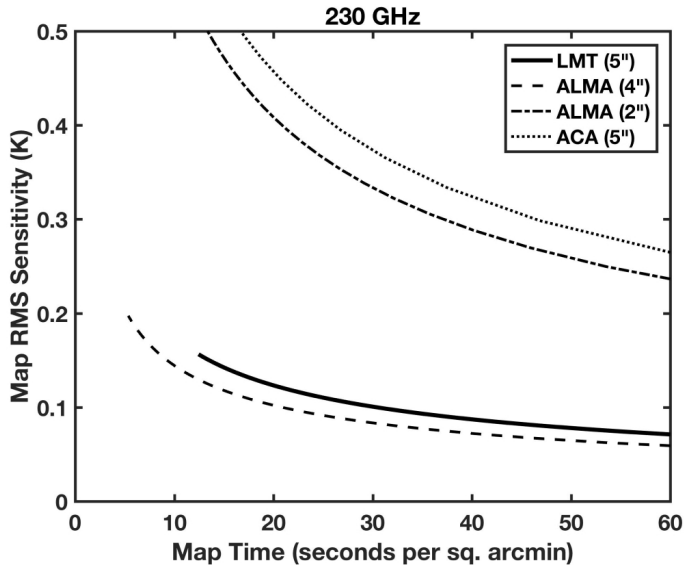
LMT's Near Term Instrument Plans

- “Single Pixel” (VLBI and spectroscopy)
  - 230 GHz SIS Receiver (Funded - 2017)
  - 345 GHz SiS Receiver (TBD)
- Heterodyne Focal Plane Arrays
  - SEQUOIA 16-element 3mm array (Funded – 2017)
  - OMAR 16-element 1.3mm array (Funded – 2018)
  - Focal Plane Array Spectrometer (Seeking funding to augment development system to allow 4 lines to be observed simultaneously.)
- TolTEC Project for Continuum Observations
  - Fill LMT 4' FOV with 7000 pixels covering 3 wavelengths; polarimetry (Funded - 2018)

LMT's Focal Plane Arrays can compete with ALMA







LMT Mapping Speed is comparable to ALMA

SEQUOIA (3mm) Projects

- GMC Map – 1.5 h observing time:
  - 1 square degree – 12” resolution
  - 70 m/s spectral resolution
  - 0.3 K RMS
- Large External Galaxy – 5.2 h observing time
  - 100 square arcmin – 12” resolution
  - 5.9 km/s spectral resolution
  - 4 mK RMS
- Above projects could be done with 4 lines simultaneously (e.g. HCN, HCO^+,N_2H^+,CS)

NSF-MSIP: TolTEC Project

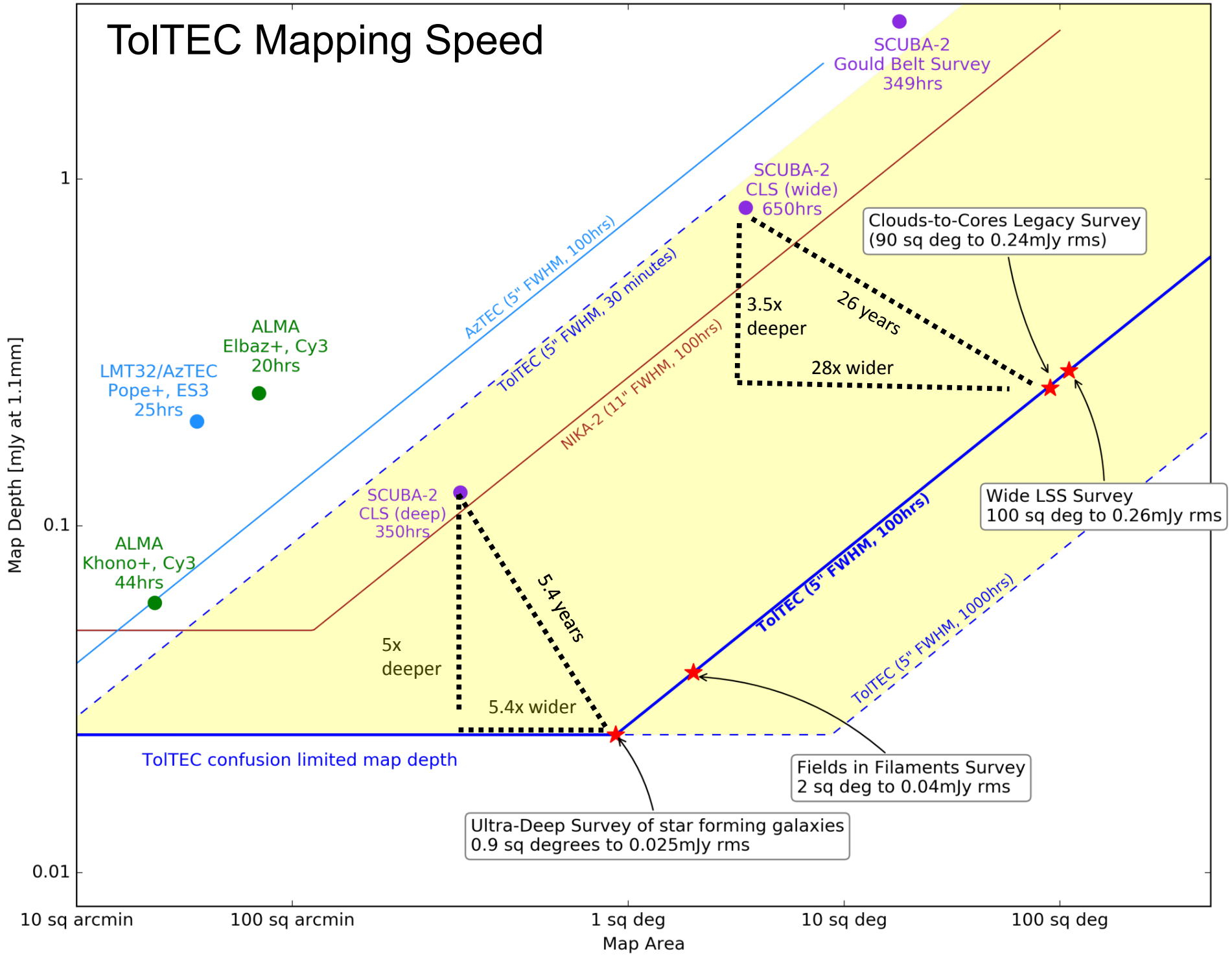
- Build/Commission TolTEC for LMT
  - 3 color imaging polarimeter (2.1mm, 1.4mm, 1.1mm)
  - 4’ diameter field of view
  - mapping speeds > 10 deg2/mJy2/hr
  - UMass, ASU, NIST, Northwestern, U. Michigan, INAOE, Cardiff

http://toltec.astro.umass.edu/

see “Get Involved”

TolTEC Properties

	2.1mm	1.4mm	1.1mm	Units
Beam Size	9.5	6.3	5.0	arcseconds
NEFD	0.3	0.3	0.4	mJy sqrt(s)
# Detectors	900	1800	3600	
Map Speed	26	15	13	Deg2/mJy2/hr


TolTEC Mapping Speed
SCUBA-2
Gould Belt Survey
349hrs
SCUBA-2
CLS (wide)
650hrs
Clouds-to-Cores Legacy Survey
(90 sq deg to 0.24mJy rms)
3.5x
deeper
26 years
28x wider
AzTEC (5" FWHM, 100hrs)
TolTEC (5" FWHM, 30 minutes)
NIKA-2 (11" FWHM, 100hrs)
ALMA
Elbaz+, Cy3
20hrs
LMT32/AzTEC
Pope+, ES3
25hrs
SCUBA-2
CLS (deep)
350hrs
ALMA
Khono+, Cy3
44hrs
5x
deeper
5.4 years
5.4x wider
TolTEC (5" FWHM, 100hrs)
TolTEC (5" FWHM, 1000hrs)
Wide LSS Survey
100 sq deg to 0.26mJy rms
TolTEC confusion limited map depth
Fields in Filaments Survey
2 sq deg to 0.04mJy rms
Ultra-Deep Survey of star forming galaxies
0.9 sq degrees to 0.025mJy rms
Map Depth [mJy at 1.1mm]
1
0.1
0.01
10 sq arcmin
100 sq arcmin
1 sq deg
10 sq deg
100 sq deg
Map Area

NSF-MSIP: TolTEC Project

- Build/Commission TolTEC for LMT
  - 3 color imaging polarimeter (2.1mm, 1.4mm, 1.1mm)
  - 4’ diameter field of view
  - mapping speeds > 10 deg2/mJy2/hr
  - UMass, ASU, NIST, Northwestern, U. Michigan, INAOE, Cardiff
- Perform series of 10-100 hour surveys with LMT
  - The Clouds-to-Cores Legacy Survey (C2C)
  - The Fields in Filaments Legacy Survey (FiF)
  - The Ultra-deep Survey of Star-forming Galaxies
  - The Large Scale Structure Survey
  - 6 more surveys in 2022-2025 timeframe
- All data (and survey definition process) public

TolTEC Properties

	2.1mm	1.4mm	1.1mm	Units
Beam Size	9.5	6.3	5.0	arcseconds
NEFD	0.3	0.3	0.4	mJy sqrt(s)
# Detectors	900	1800	3600	
Map Speed	26	15	13	Deg2/mJy2/hr

LMT in 2020s

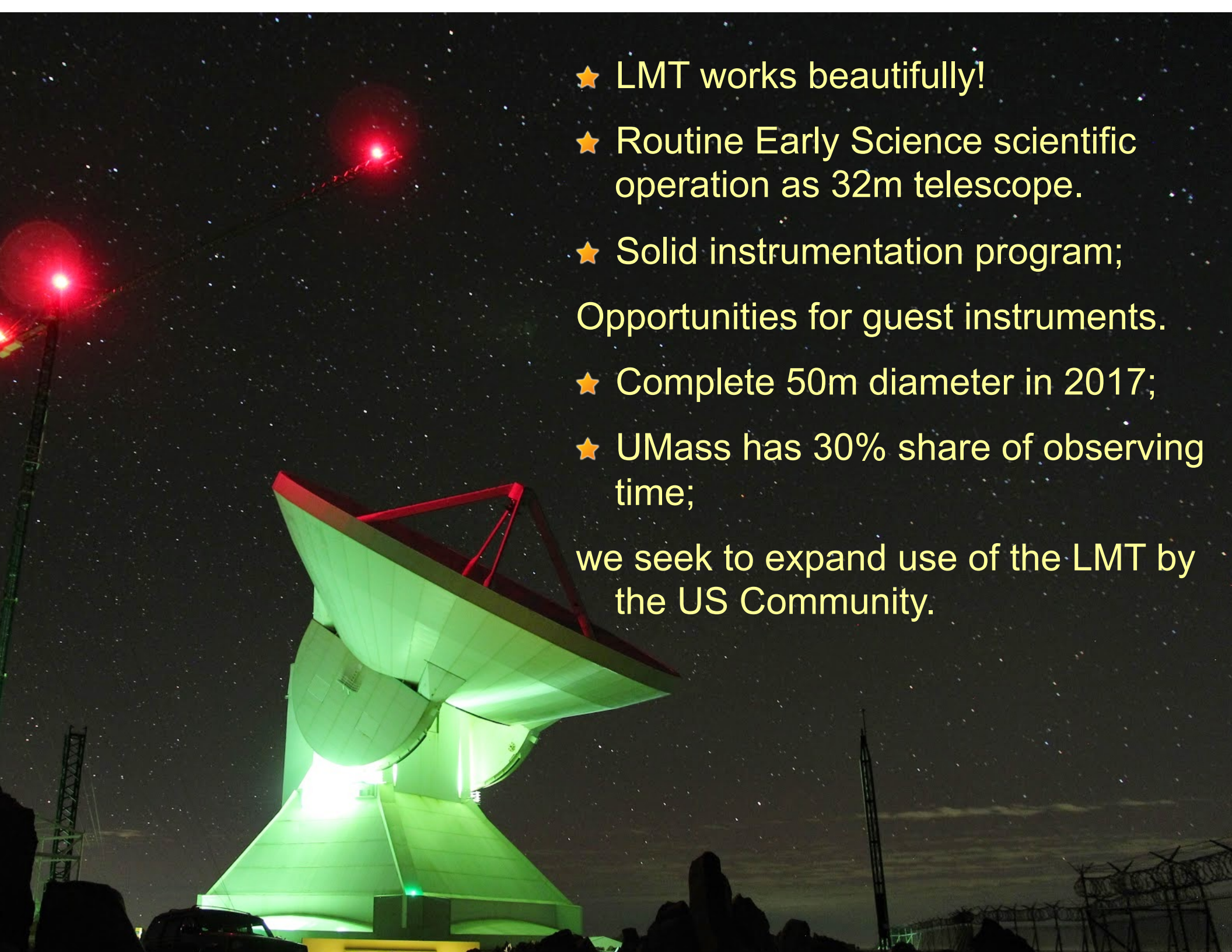

GRAN TELESCOPIO MILIMETRICO
LARGE MILLIMETER TELESCOPE
INAOE

LMT is the "Big Single Dish Complement" to ALMA

- LMT's Complementary Roles:
  - Large Scale Mapping and Surveys.
  - Exploit large collecting area to develop special purpose instrumentation.
  - "Hands-on" opportunities for young scientists.
- Large Scale Maps/Mapping Speed is critical to establishing a case for complementarity.
  - Do everything you can to improve mapping metrics.
  - Focal Plane Arrays are essential for Continuum and Spectral Line observations.

How will US Astronomers use the LMT?

- UMass has access to 30% of the Observing Time on LMT.
- UMass required to pay our proportional share of the annual costs of the LMT operation and development in order to access that time …
  … there is no free lunch for UMass.
- We seek to find ways to make LMT accessible:
  - Formation of US Consortium to share expenses
  - Public Surveys (TolTEC)
  - Bring in NSF as a “partner” (e.g., MSIP)?



- LMT works beautifully!
- Routine Early Science scientific operation as 32m telescope.
- Solid instrumentation program;

Opportunities for guest instruments.

- Complete 50m diameter in 2017;
- UMass has 30% share of observing time;

we seek to expand use of the LMT by the US Community.