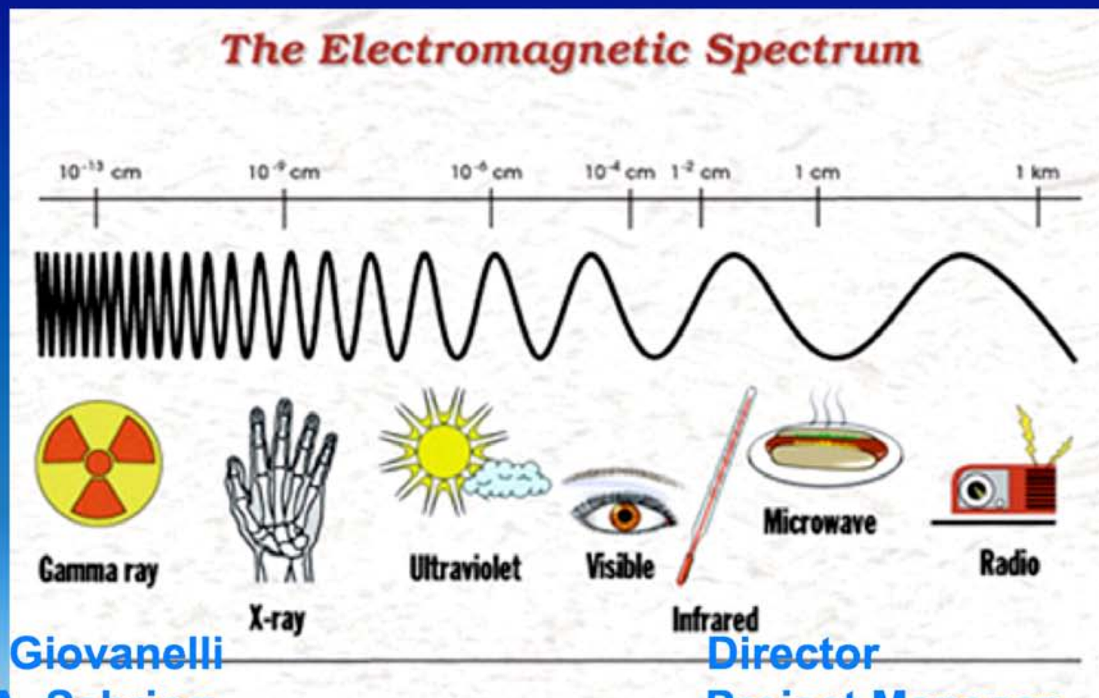
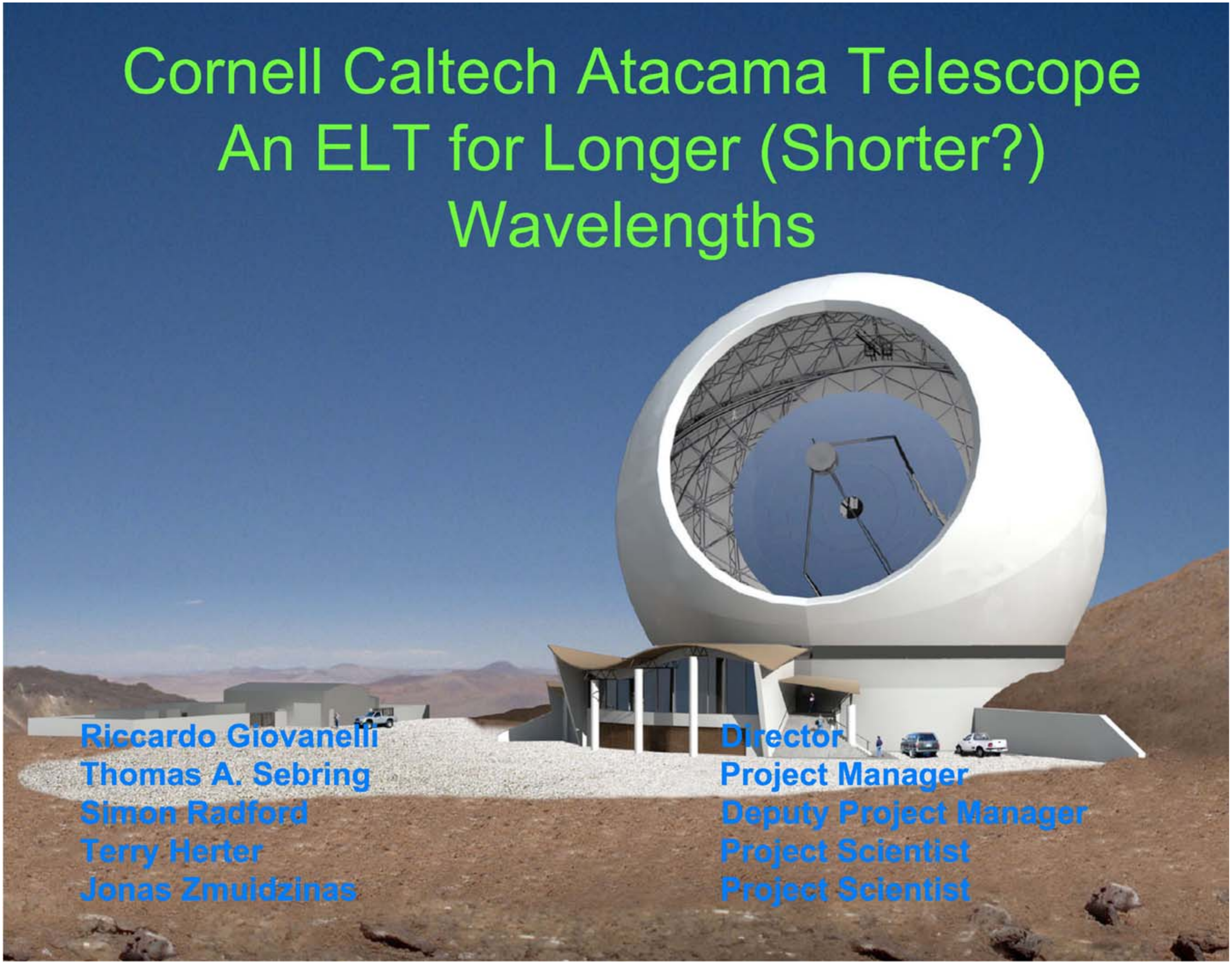
Cornell Caltech Atacama Telescope
An ELT for Longer (Shorter?) Wavelengths



Riccardo Giovanelli — Director
Thomas A. Sebring — Project Manager
Simon Radford — Deputy Project Manager
Terry Herter — Project Scientist
Jonas Zmuidzinas — Project Scientist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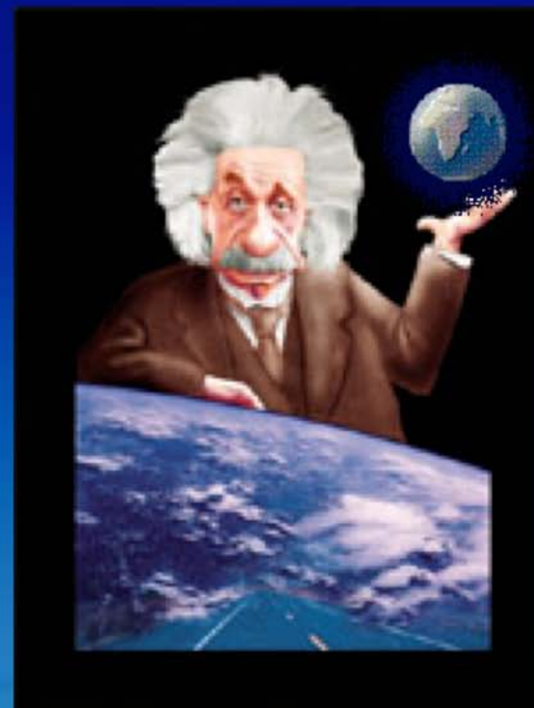
λ…Longer or Shorter??? It's all Relative Right?

- CCAT Operates λ=200μ to ????
- 350μ is the "Bread and Butter" Wavelength
- Why?
  - Science Historically Underdeveloped at Submm Wavelengths (Atmosphere & Detectors)
  - Now Seeing Incredible Recent Development of Large Area Submm Detector Arrays
  - Recent Availability of Superb Submm Sites as Atacama Science Preserve is Developed
  - Opportunity to Leverage the Large International Investment in and Spectacular Capabilities of ALMA



1.5 Terrahertz

That's a Frequency!

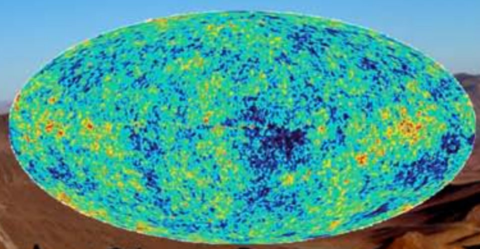
CCAT…The Big Picture

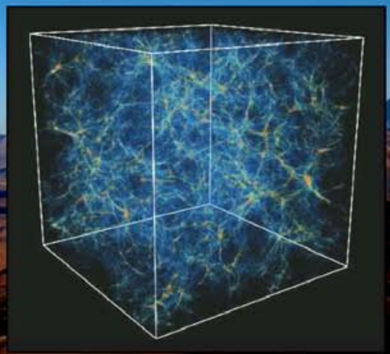
CCAT is a unique project geared towards the investigation of cosmic origins, from planets to galaxies, in the FIR/submm spectral region

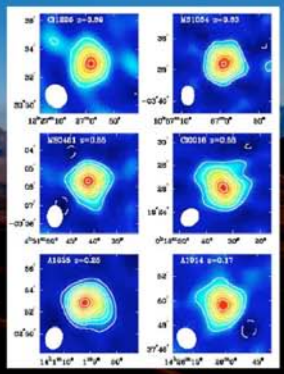
- Early Universe Cosmology
- Galaxy Formation & Evolution
- Disks, Star & Planet Forming Regions
- Cosmic Microwave Background, SZE
- Solar System Astrophysics

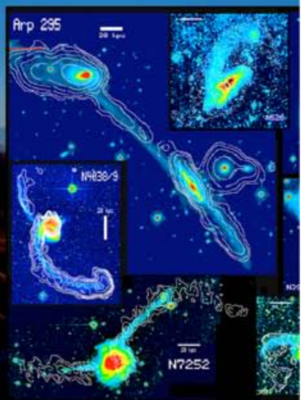
…to this?

How did we get from this







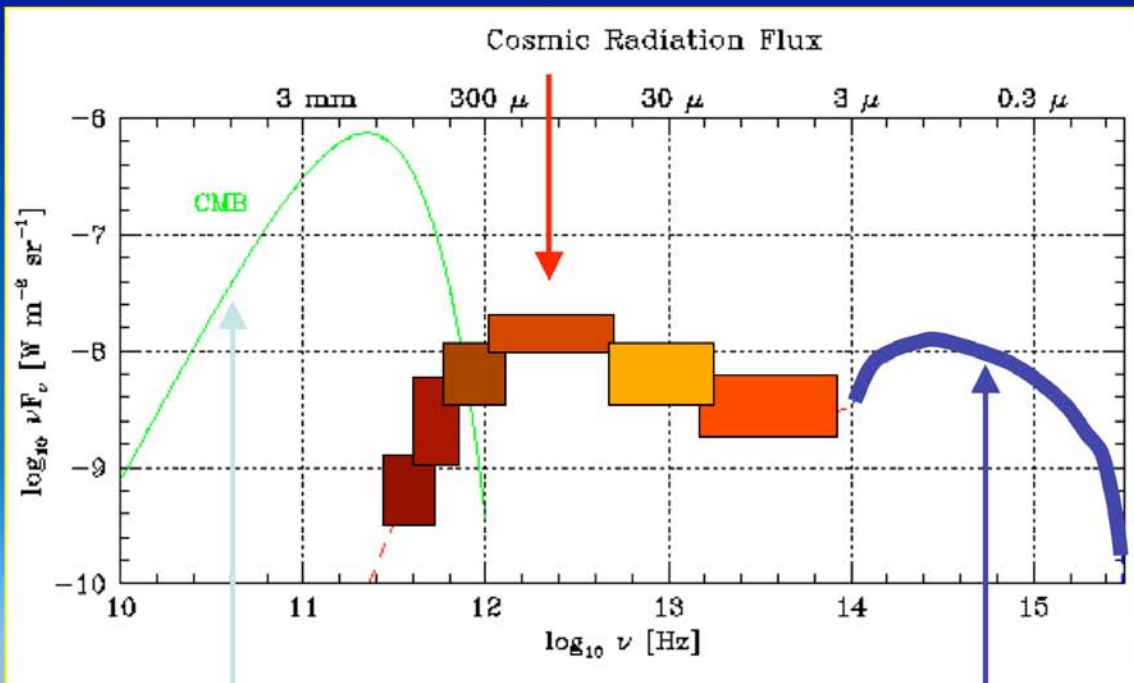


Why FIR/submm?

Photospheric light
Reprocessed by dust

That's the energy regime at which most of the Universe's early light produced after the recombination era reaches us.

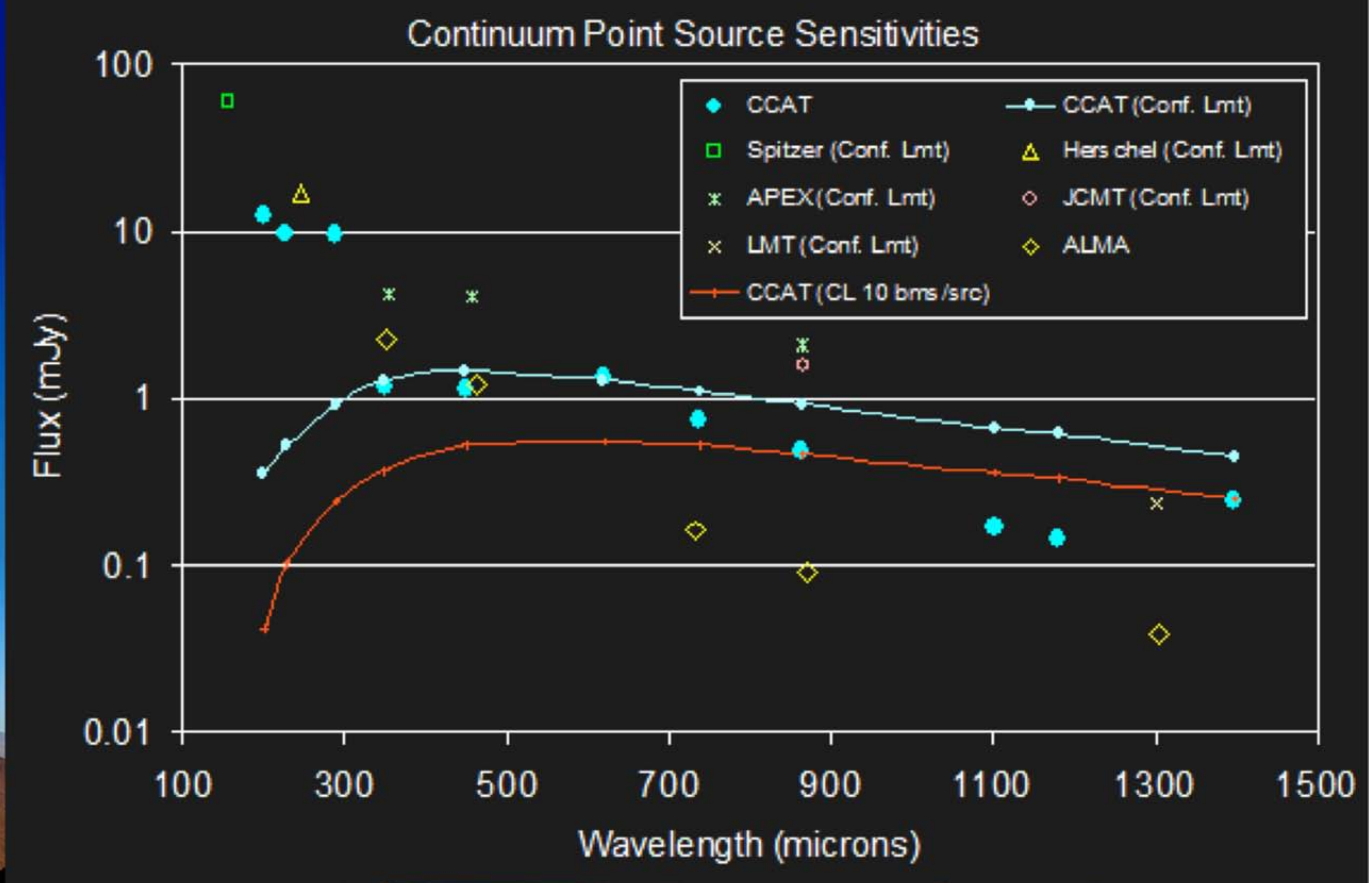
And at which radiation produced in star & planet forming regions emerges from the dust cocoons.



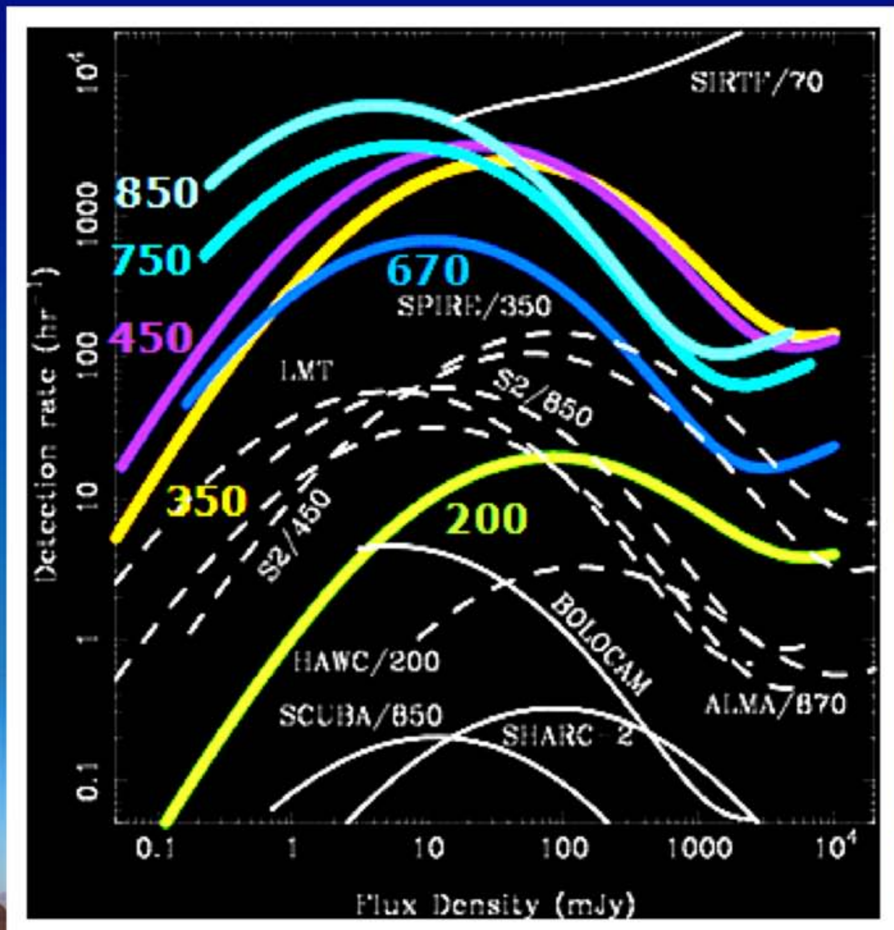
Microwave Background

Photospheric light
from stars

5σ, 1-hour CCAT and ALMA sensitivities



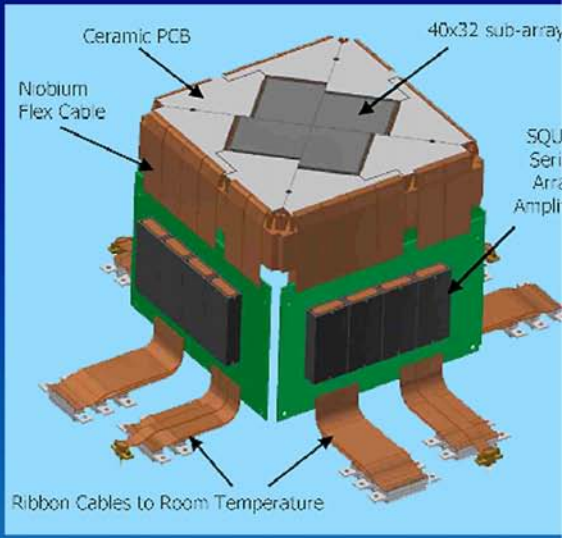
Mapping Speed Comparing Other Facilities



- CCAT Is An Ultrafast Mapper
- Assumptions
  - 10000 pixel detector, Nyquist sampled at all bands 0.2, 0.35 0.45, 0.67, 0.85,1.1mm (in order from violet-red)
  - Observationally verified counts (good to factor 2)
  - Confusion and all sky limits
- 1.2/0.85/0.35mm Imaging Speeds Are Compatible
  - To reach confusion at 0.35mm go several times deeper at 0.85mm
- Detection Rates Are
  - ~150×SCUBA-2; ~300×ALMA
  - About 100-6000 per hour
  - Lifetime detection of order 10^7 galaxies: ~1% of ALL galaxies
  - `1/3 sky survey': ~1000 deg^{-2} for 3 deg^{2}hr^{-1} gives 5000 hr

Two First Light Science Instruments

- Short Wavelength Camera: SWCam
  - λ=200-620 with Mesh Filters in Wheel for Selection
  - 20%-40% Throughput
  - 5' x 5' Field of View
  - 32,000 Directly Illuminated TES silicon bolometers
  - NIST SCUBA II Array Technology
- Long Wavelength Camera: LWCam
  - Slot Dipole Antenna Coupled Bolometers
  - Microstrip Bandpass Filters
  - Reflective Coupling Optics for Minimum Optical Loading
  - 20' x 20' Field of View (wavelength dependent)



SCUBA II Array

CCAT 1st Light Instrument Features 6x More Pixels than SCUBA II

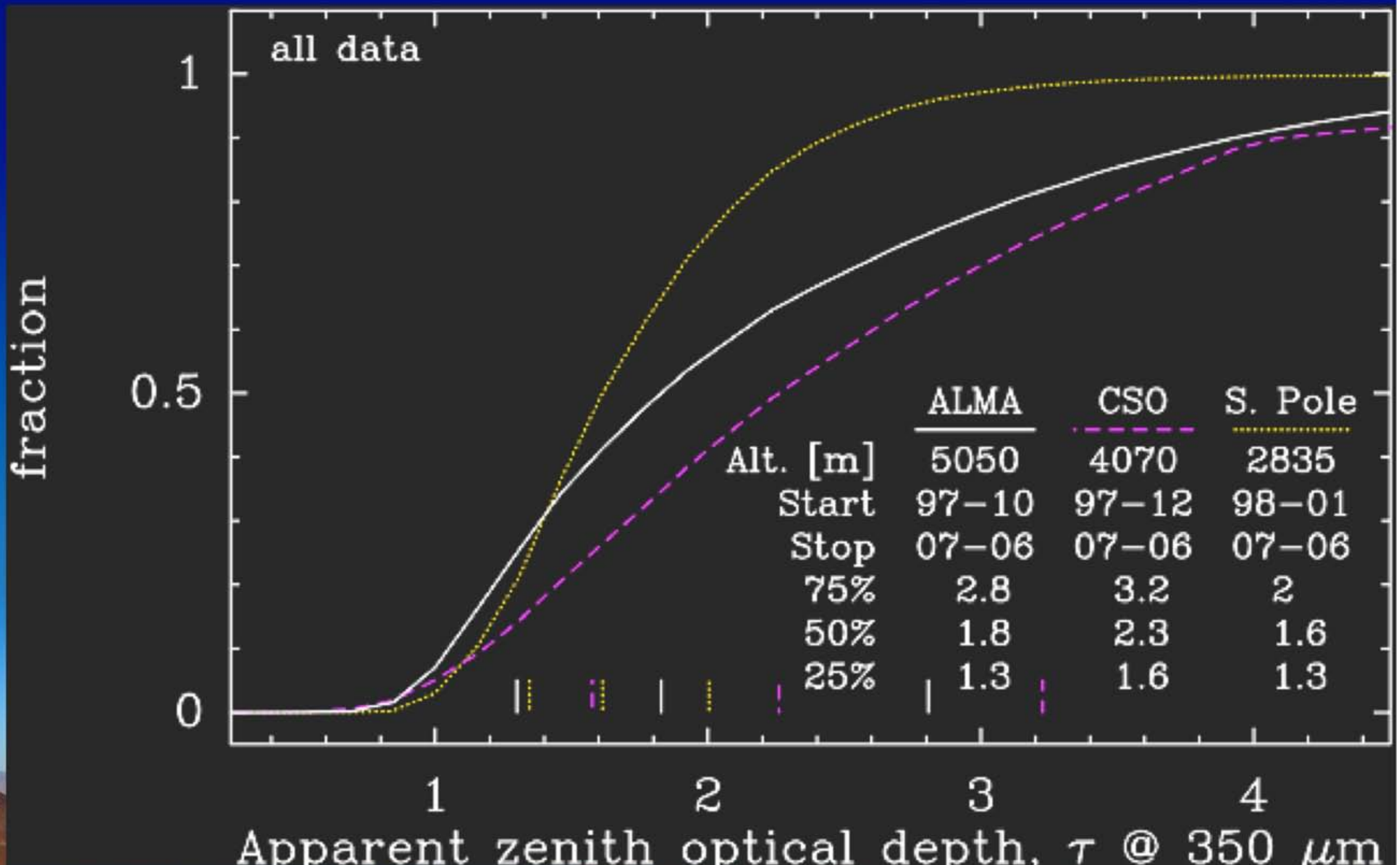
Advances in Submm Detectors

SCUBA II two arrays of 6,400 pixels each operating at λ=450 μ and 850 μ

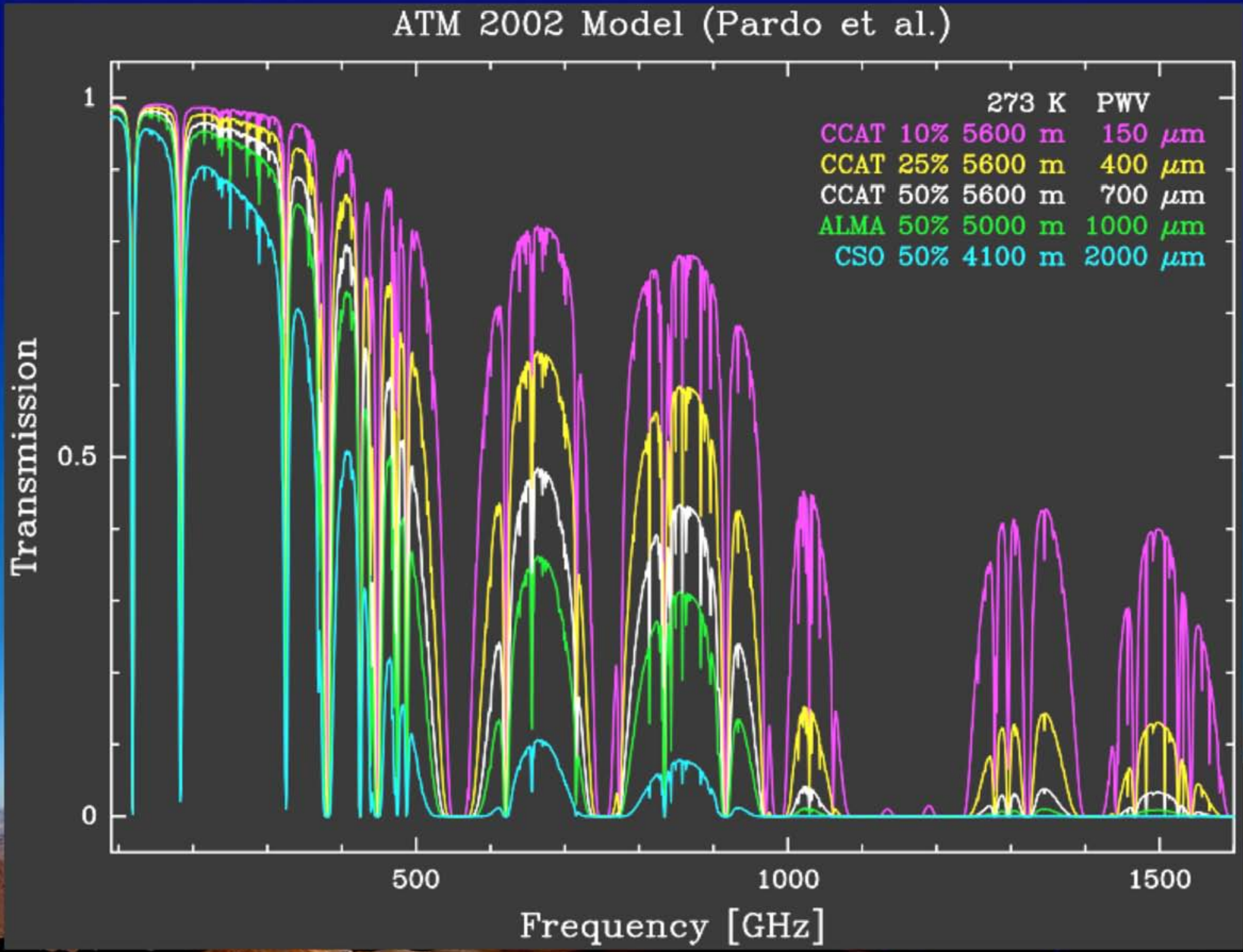
Likely 1st Light Instrument for CCAT

- Superconducting Transition Edge Sensors (TES)
- Micro Kinetic Inductance Detectors (MKIDS)
- Dipole Antenna Coupled Bolometer Arrays

Comparison of 3 Sites Over ~ 10 Years

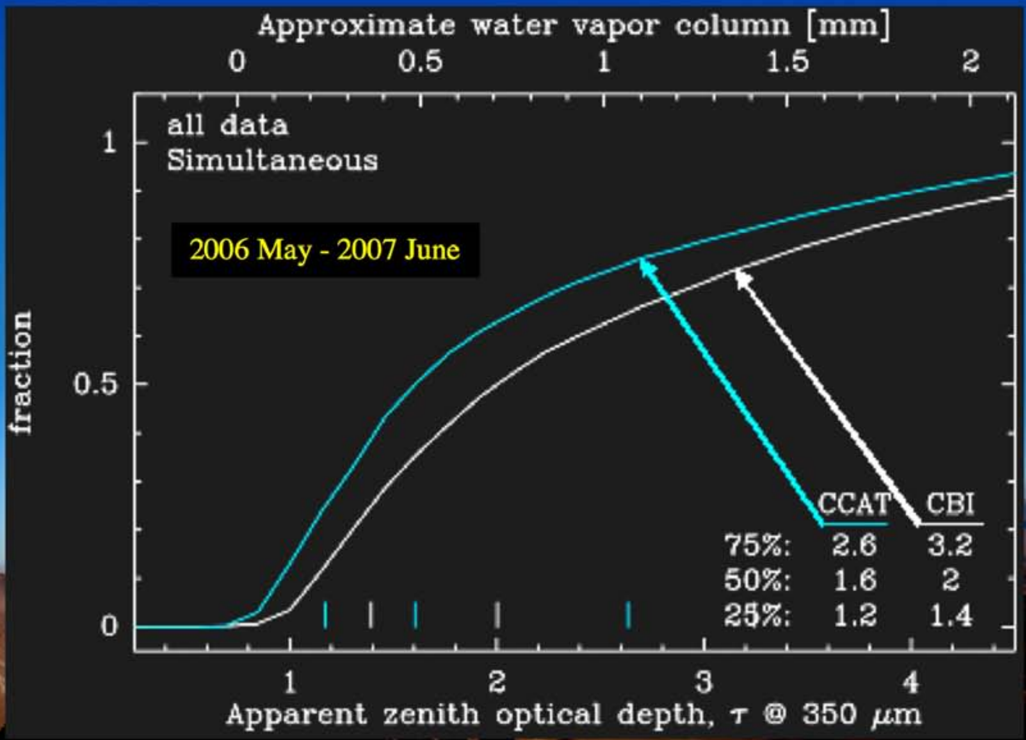


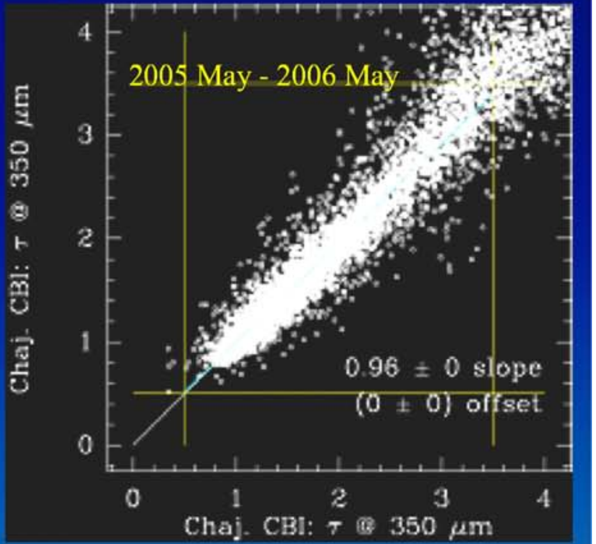
Modeled Atmospheric Transmission vs Frequency

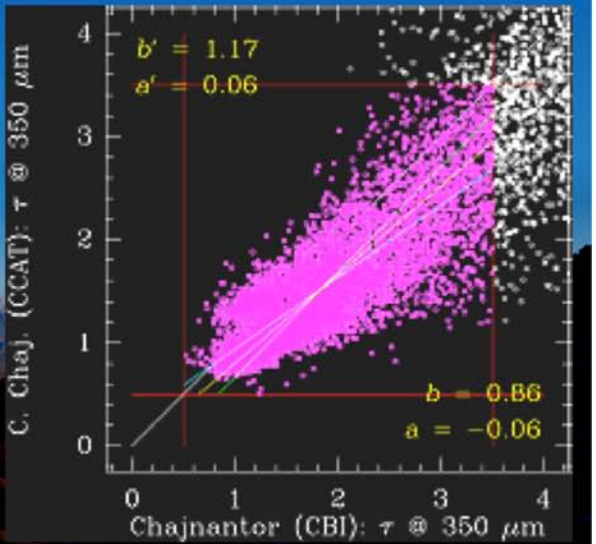


Better 350 µm Transparency

- Two Tippers: CCAT (5600 m) & CBI (5050 m)
- Side-by-Side at CBI: Same Values
- Better Transparency at CCAT
- Less Water Vapor at CCAT
  - $\tau_{off} \approx 0.5$
  - Slope ∝ PVW
  - PWV(CCAT) ≤ 70% PWV(CBI)







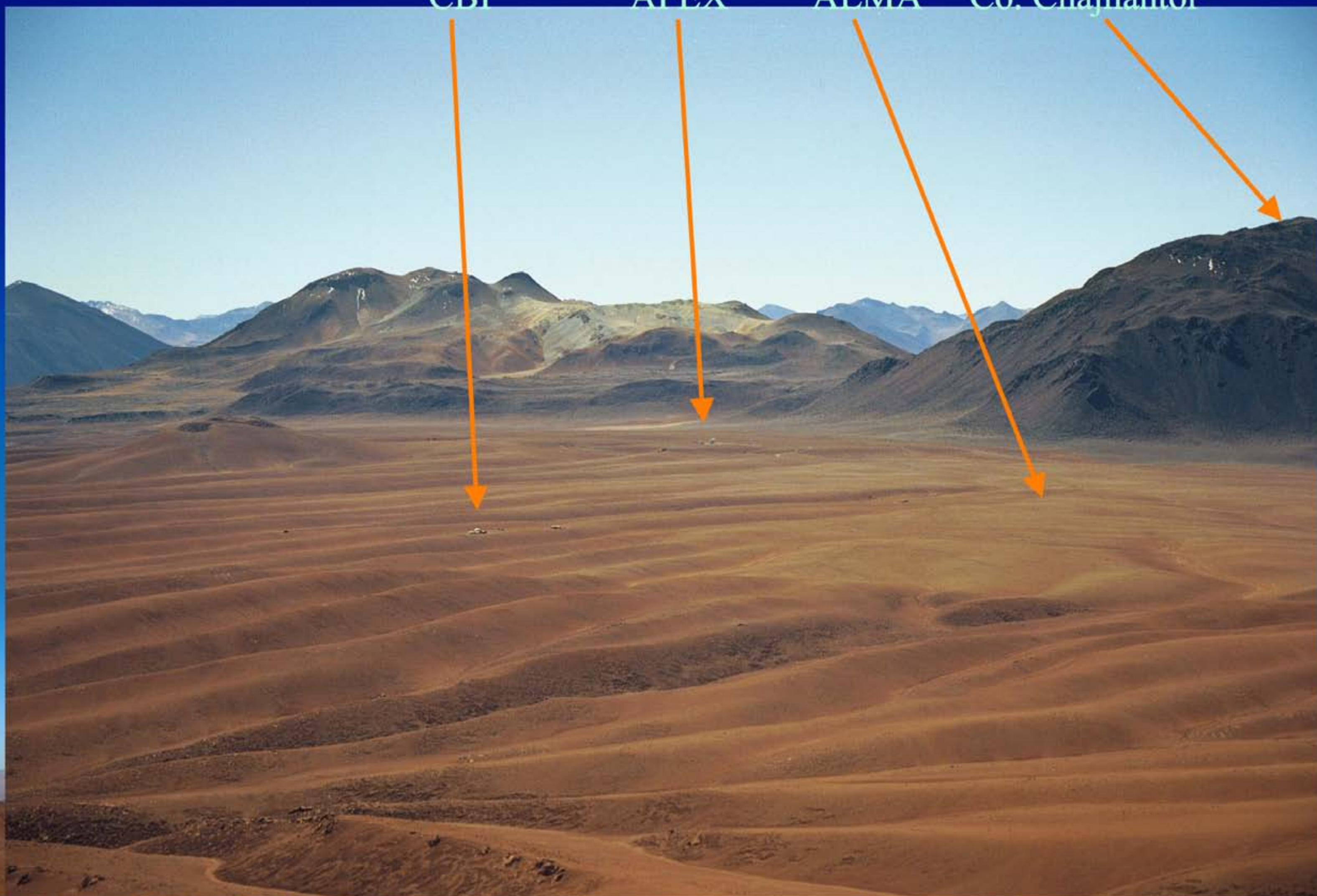

Cornell/Caltech Site Testing Equipment on the Telescope Site
Measures Water Vapor in Atmosphere and Weather
Results Transmitted to US via Satellite Phone

Newly Cut Road Visible on Cerro Chajnantor

The Atacama Desert

- Peaks at ~ 18,000 feet Altitude
- ~2 hours Flying Time from Santiago
- ~2 Hours Drive from Antofagasta, The Nearest Port
- ~ 1 Hour Drive from Calama, the Nearest Airport
- Scientific Preserve Set Aside for Astronomy
- Managed by CONICYT
- CCAT Altitude: 5612 meters

Chajnantor Plateau (5000 m)



Dietrich/Caltech

CCAT Requirements

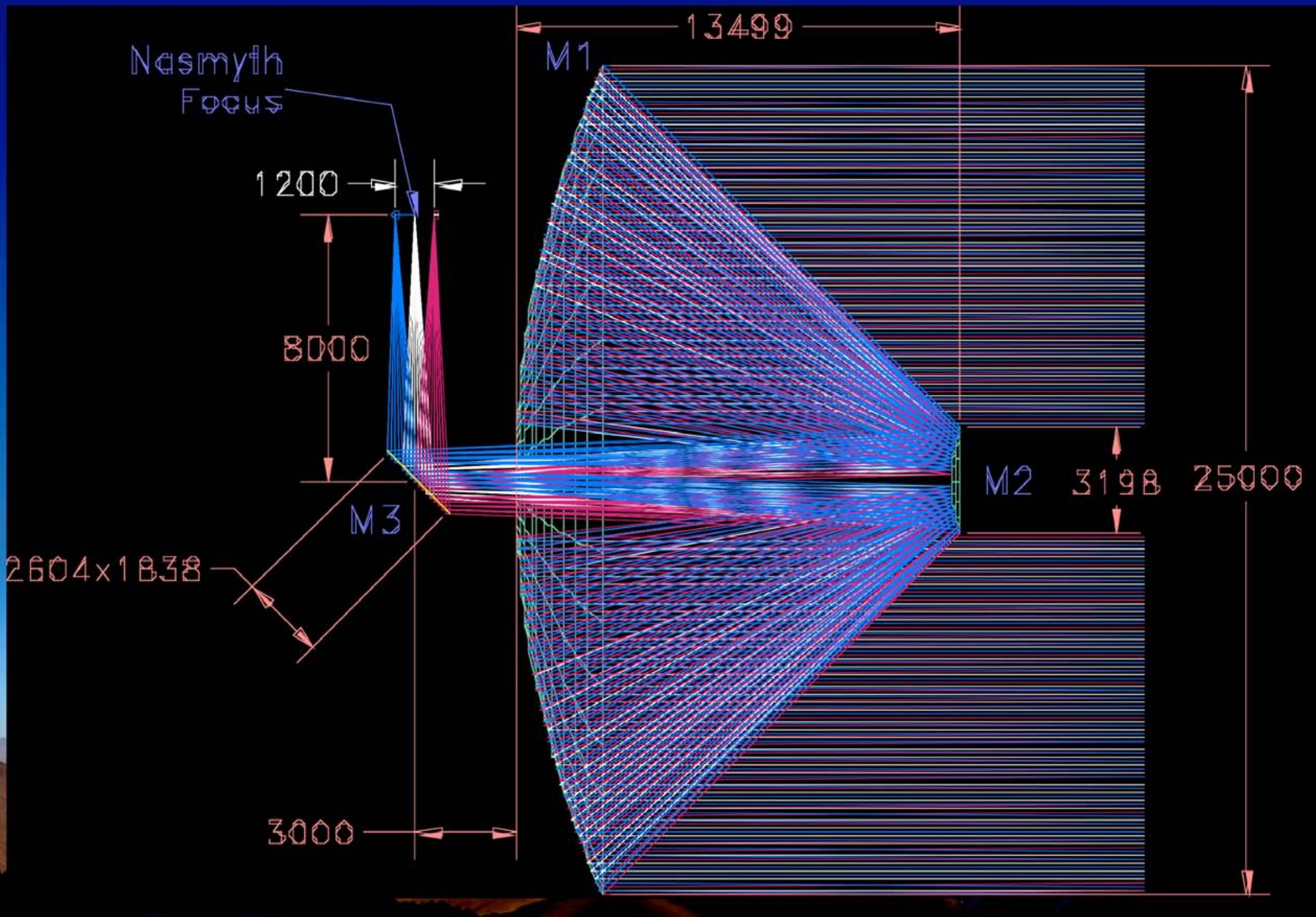
	Requirement	Goal	remark
Wavelength	350 – 1400	200 – 2500	µm
Aperture	25 m		
Field of view	10'	20'	
Half WFE	< 12.5 µm	< 9.5 µm	rms
Site condns.	< 1.0 mm	< 0.7 mm	median pwv
Polarization	0.2%	0.05%	after cal.
Emissivity	<10% @ >300 µm <20% @ 200 µm	< 5% @ >800 µm	

CCAT

Pointing and Scanning

	Requirement	Goal	remark
Pntg, blind	2"	0.5"	rms
Pntg, offset	0.3"	0.2"	within 1°
Pntg, repeat.	0.3"	0.2"	rms, 1 hour
Scanning rate	0.2° s^{-1}	1° s^{-1}	slow/fast
Scan. accel.	0.4° s^{-2}	2° s^{-2}	short/long λ
Pointing knowledge	0.2"	0.1"	rms
M2 nutation	±2.5' @ 1 Hz		azimuth only

Optical Design…German Cortes 6267-67 & 6267-82



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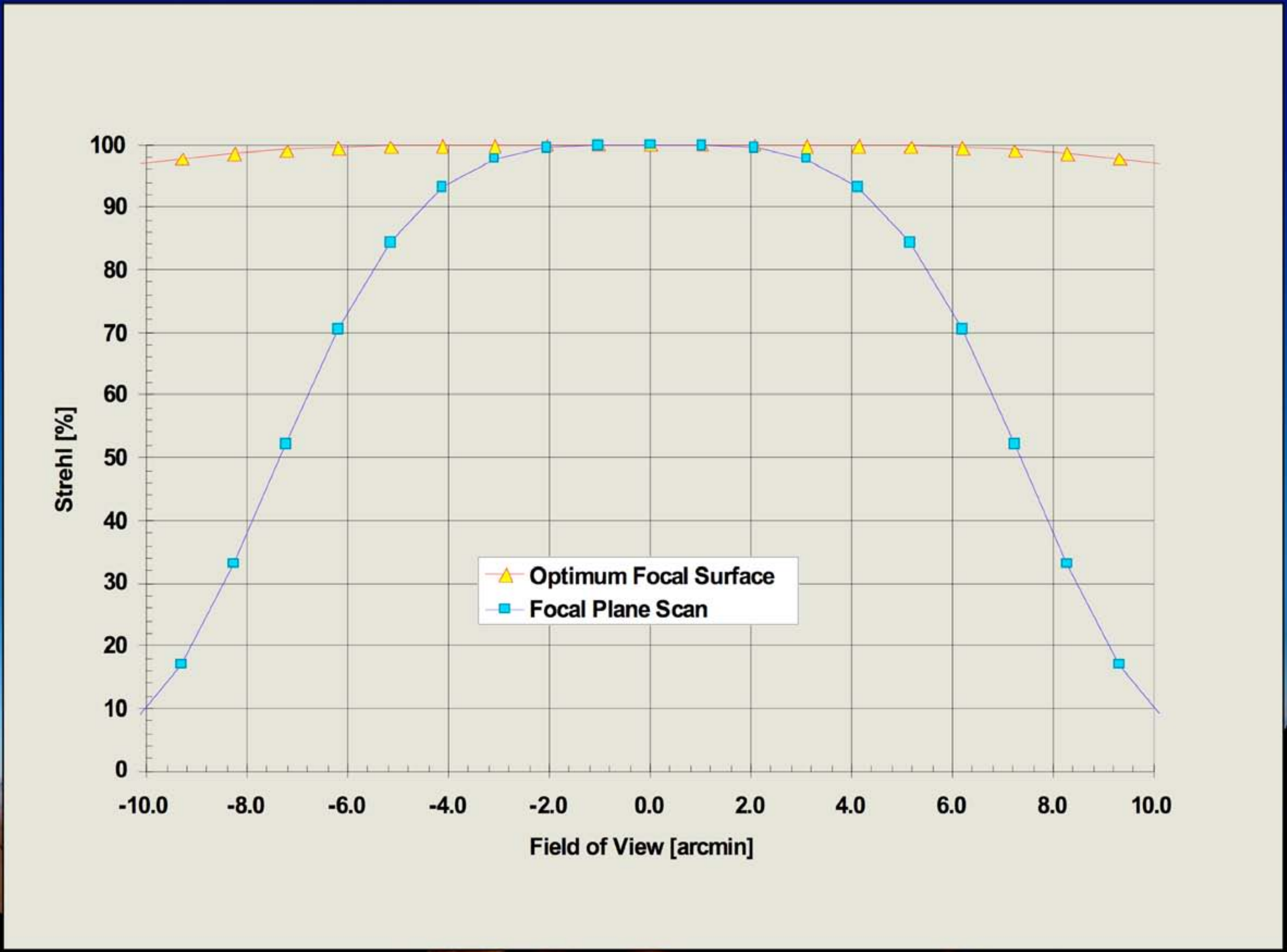
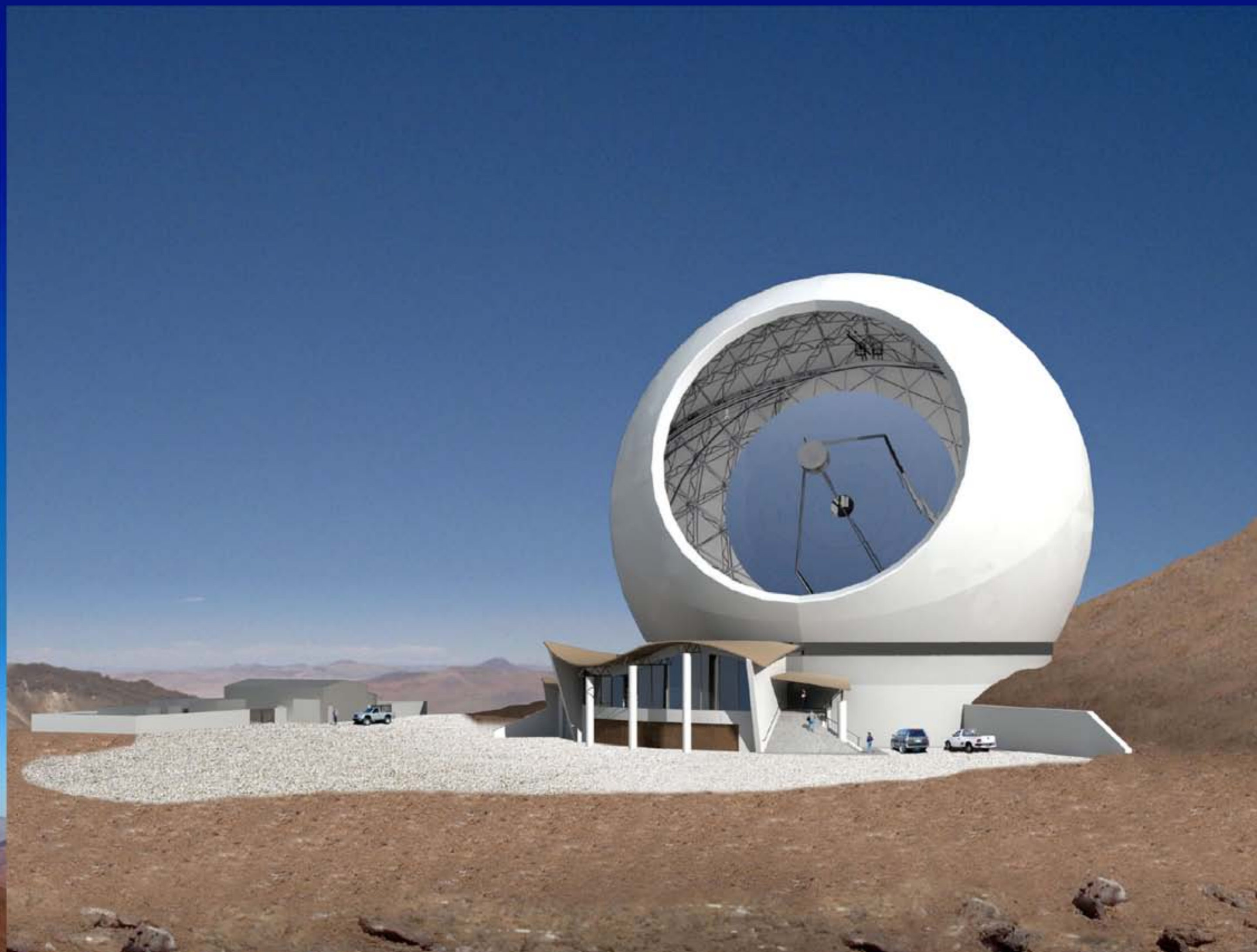


CCAT

The Facility: M3 Engineering & Technology



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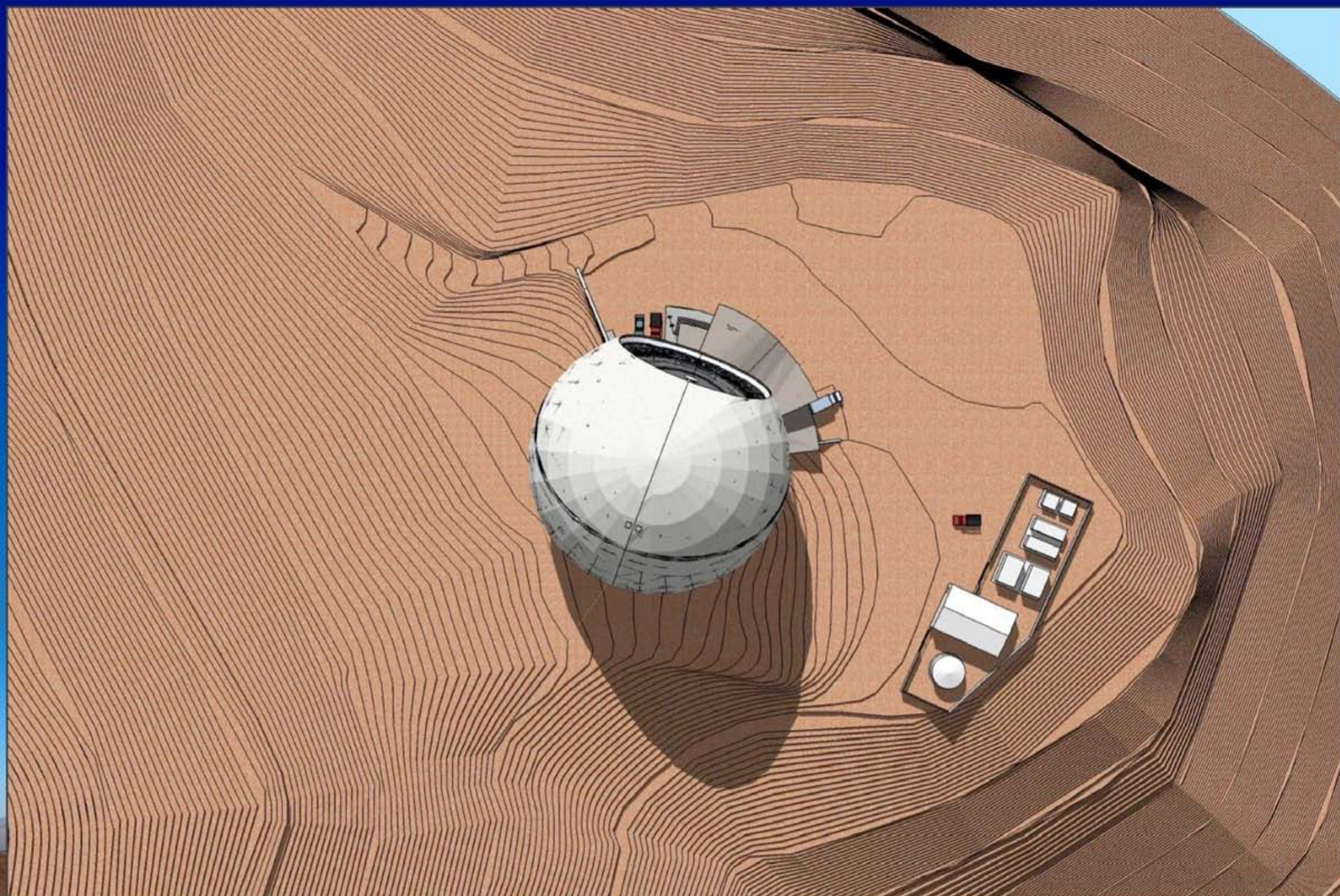

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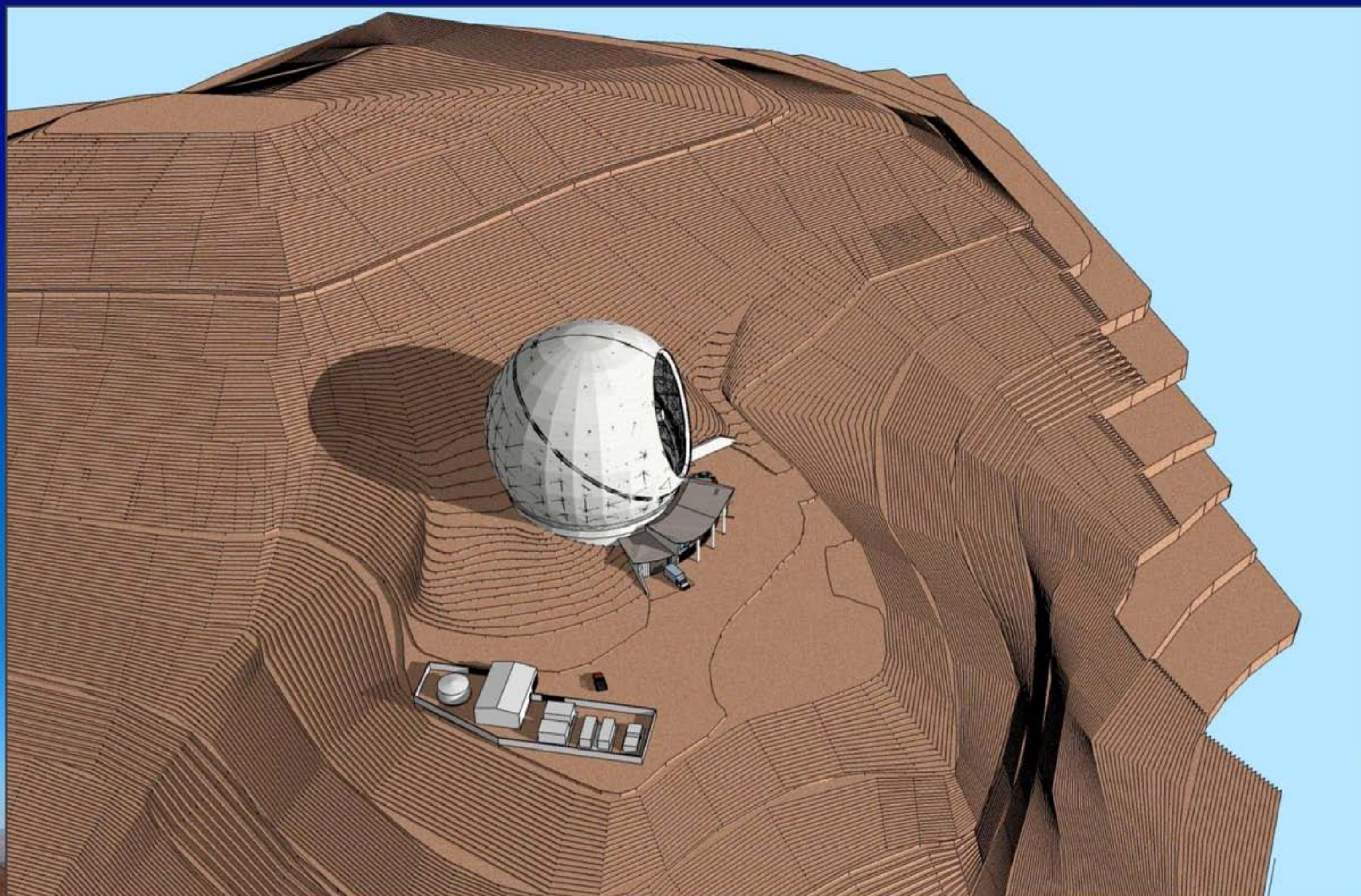

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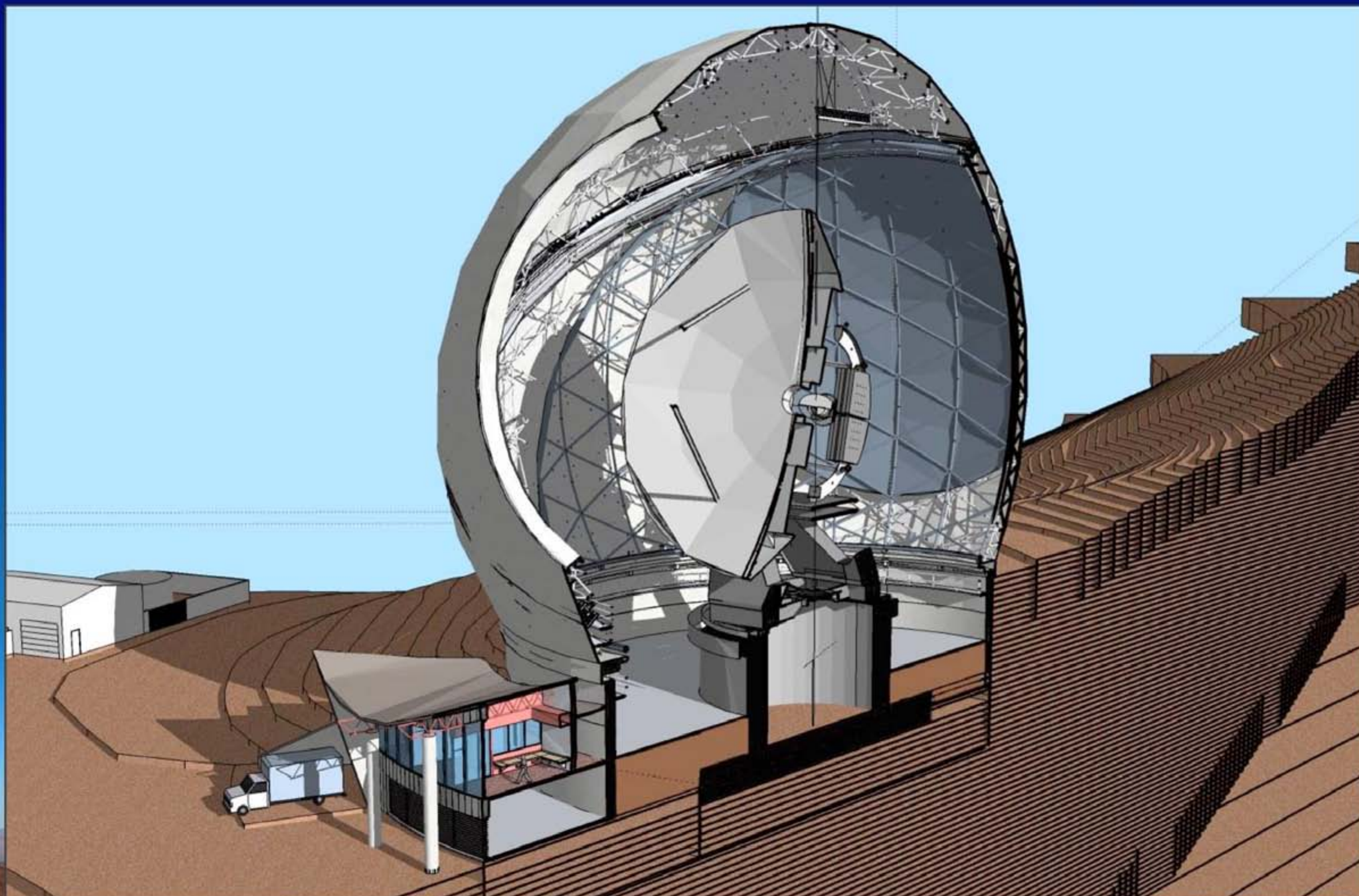

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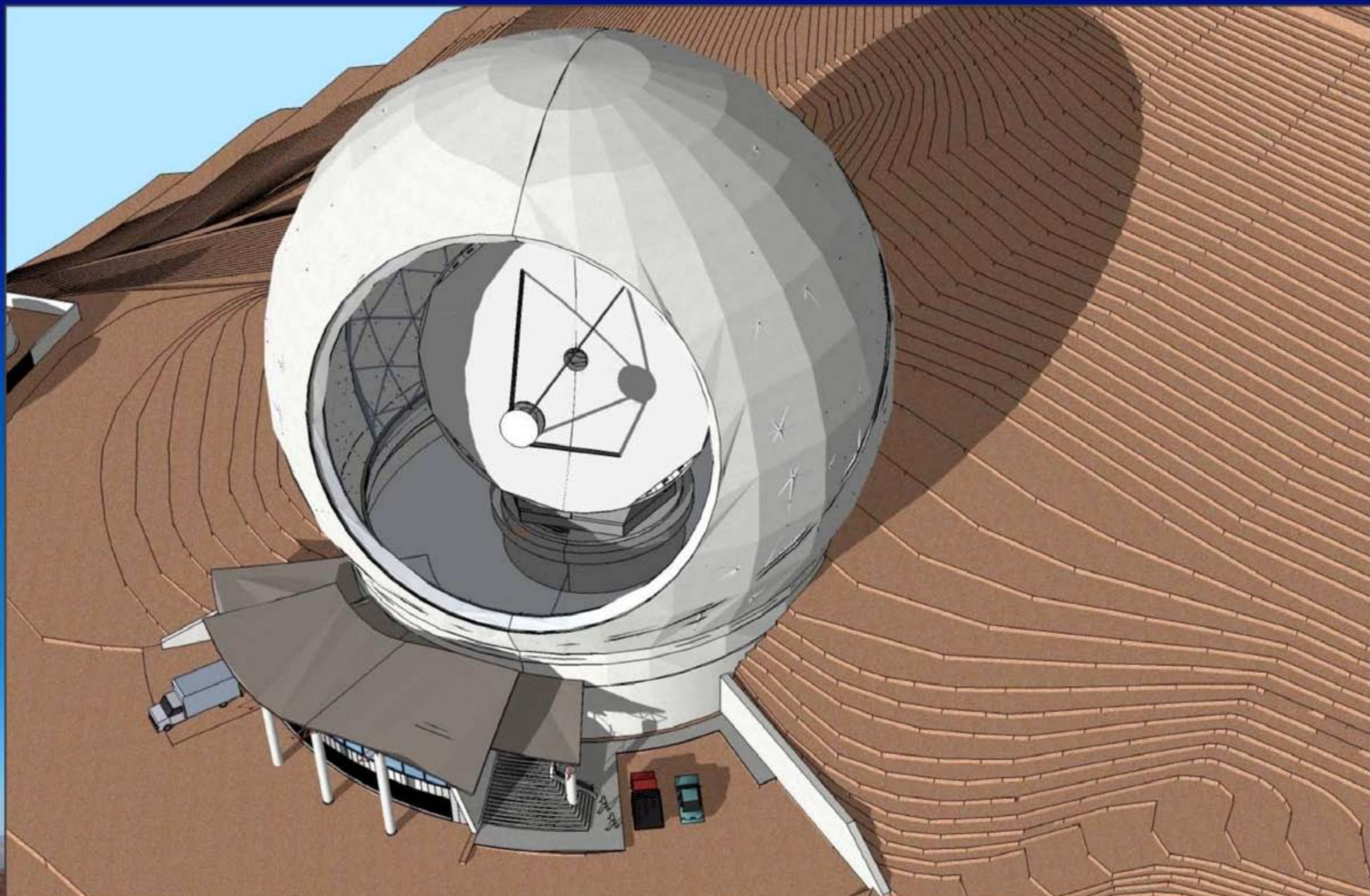
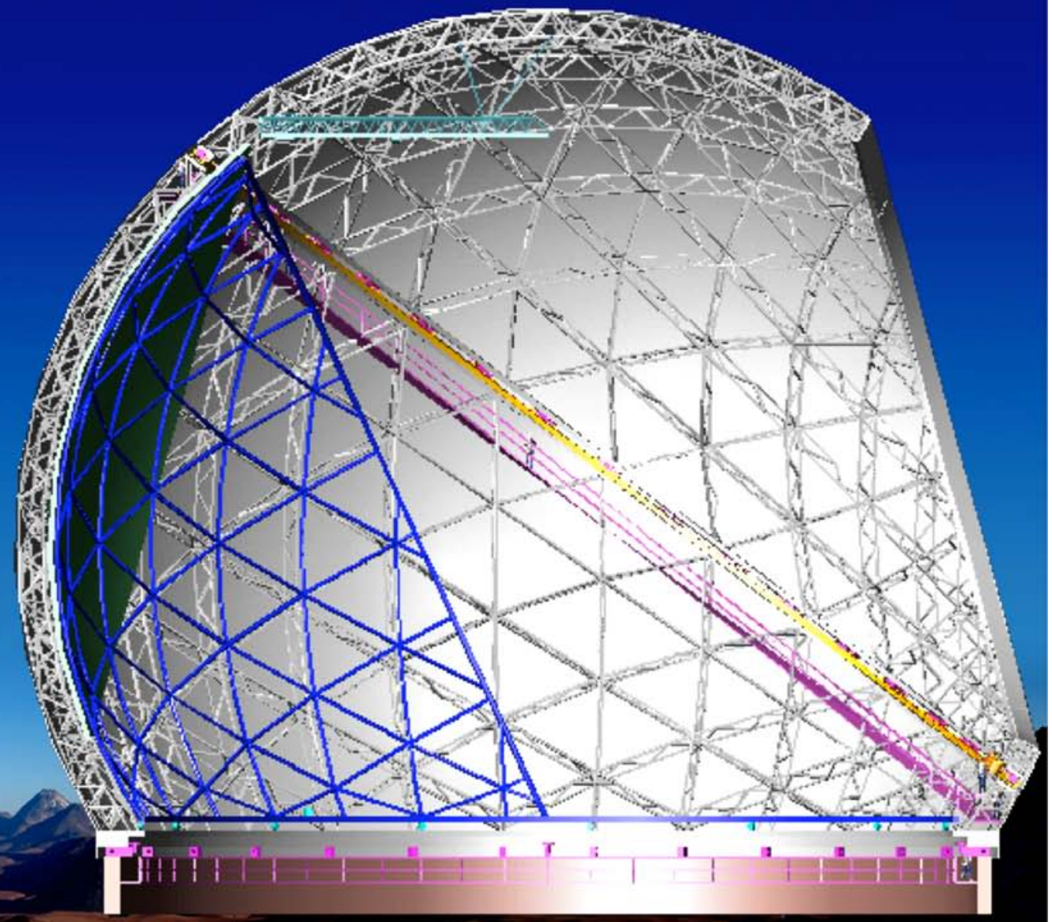


Telescope Dome Concept
AMEC Dynamic Structures

- 40 m Diameter at Equator
- 30 m Aperture
- Rib & Tie Structure is Highly Repetitive
- Operation via Two Similar Rotation Stages
- Aperture Sized to Keep M2 2 meters Inside Dome



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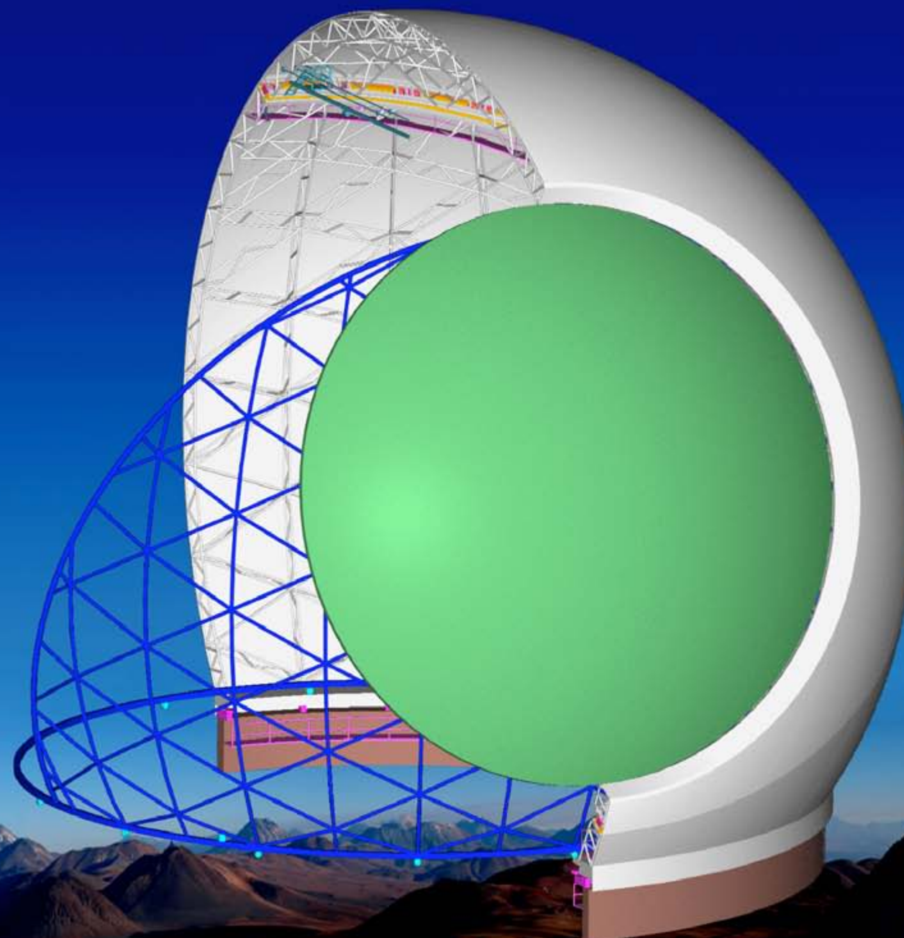
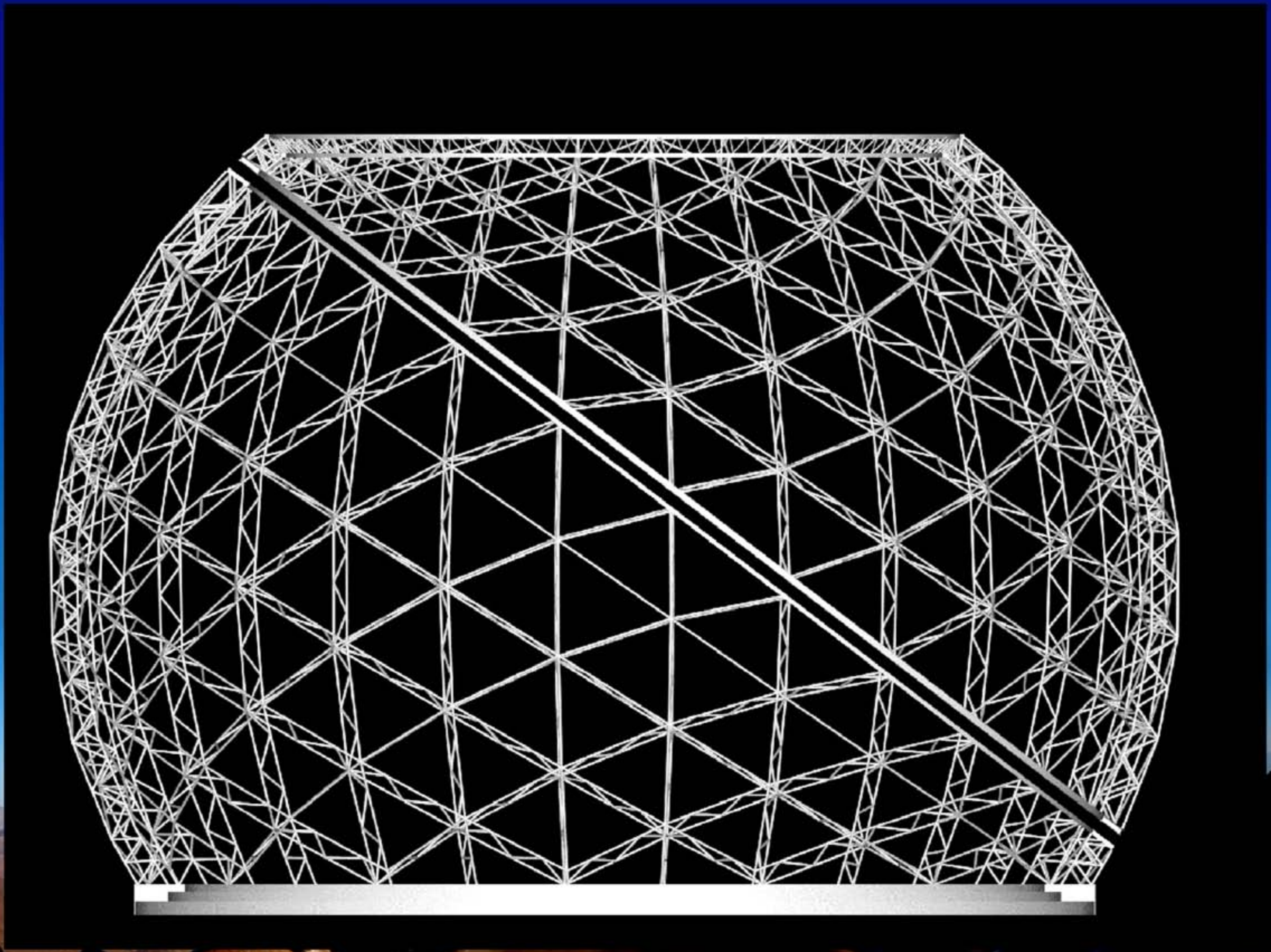


CCAT

Mero TSK Designs



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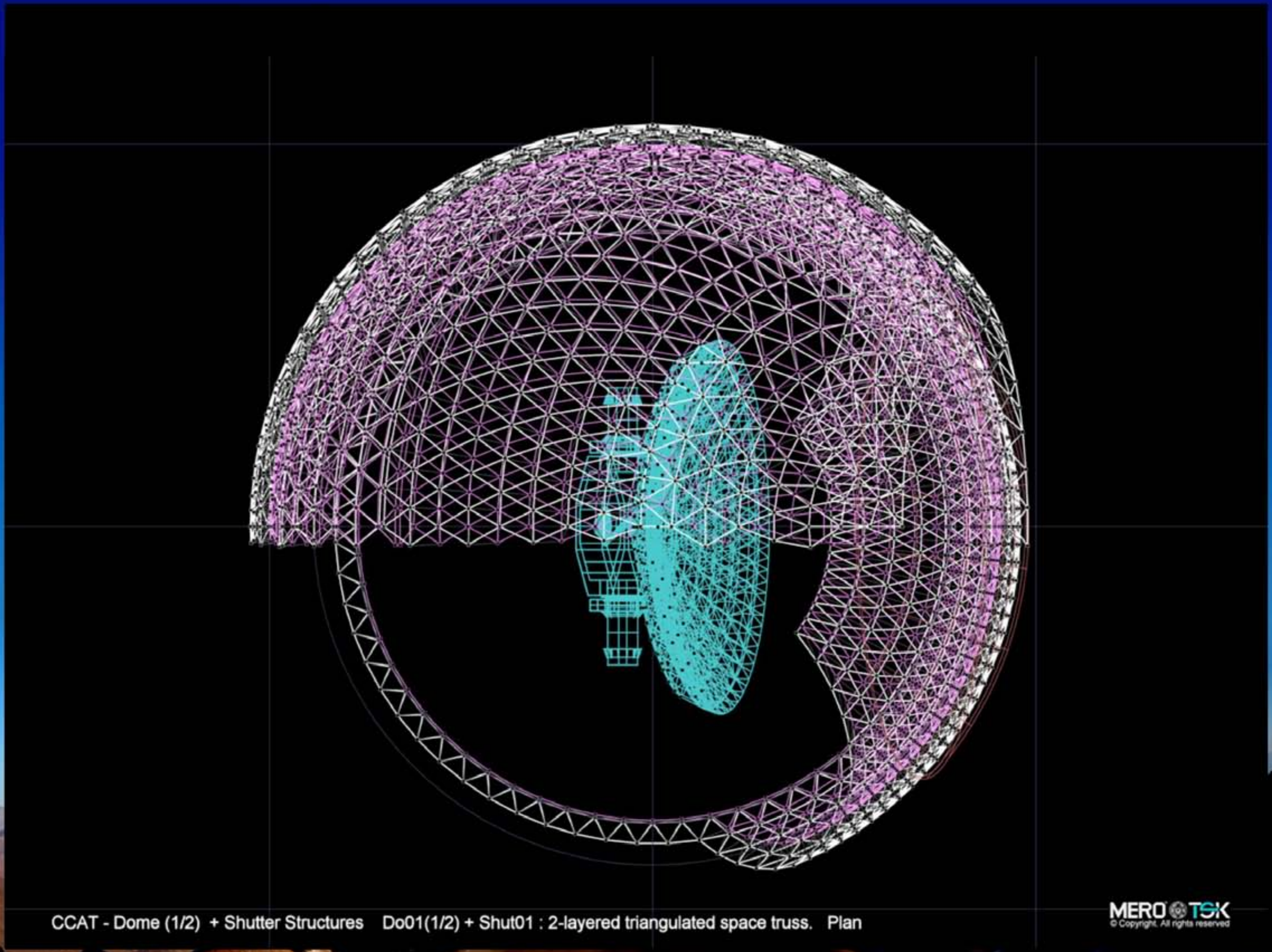

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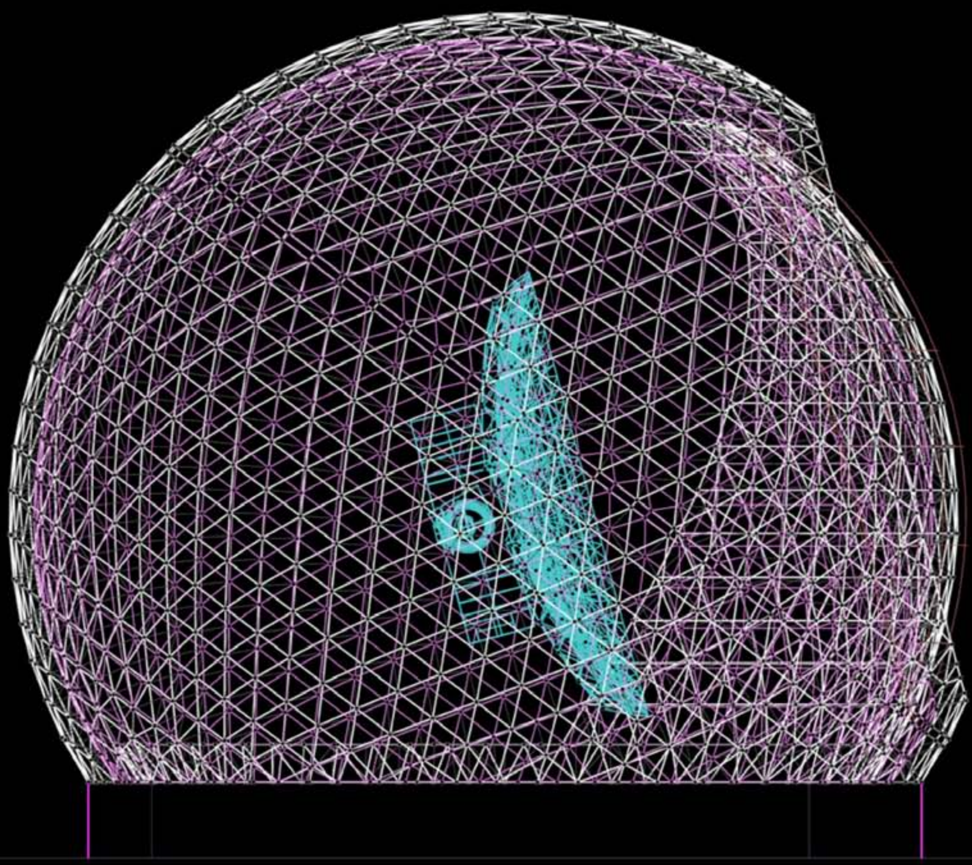
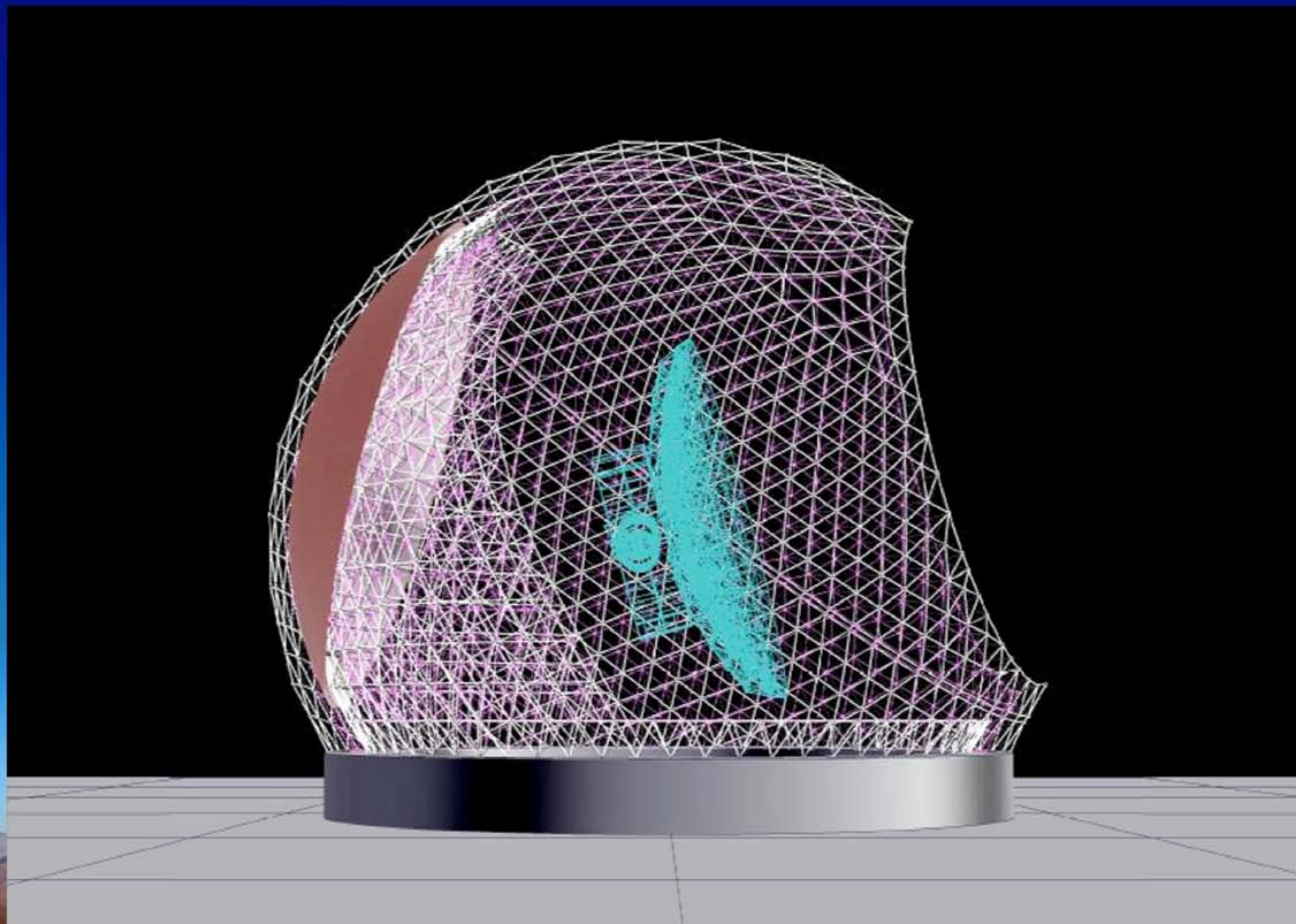


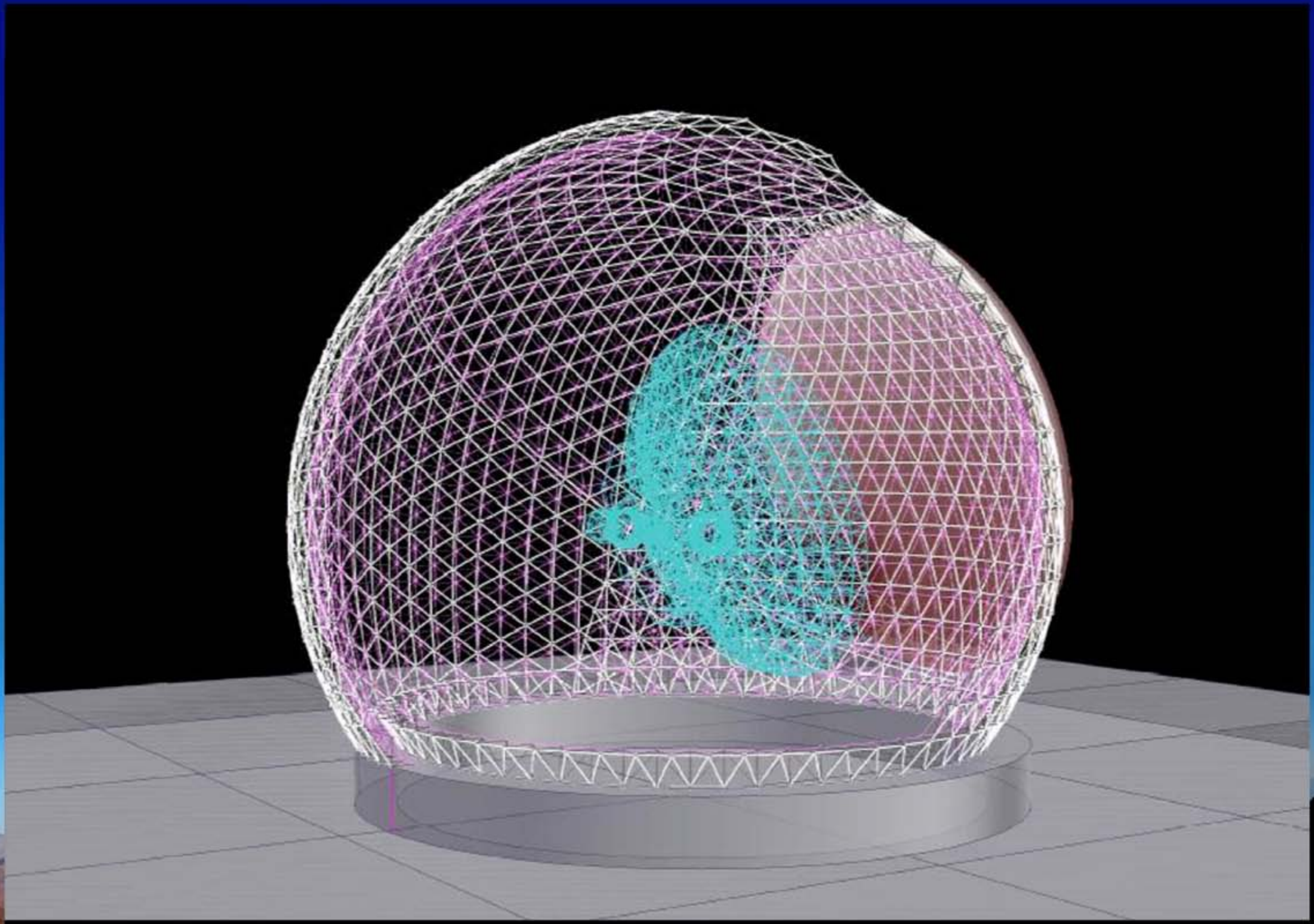
CCAT - Dome (1/2) + Shutter Structures: Do01(1/2) + Shut01 : 2-layered triangulated space truss. Section

Mero TSK Designs



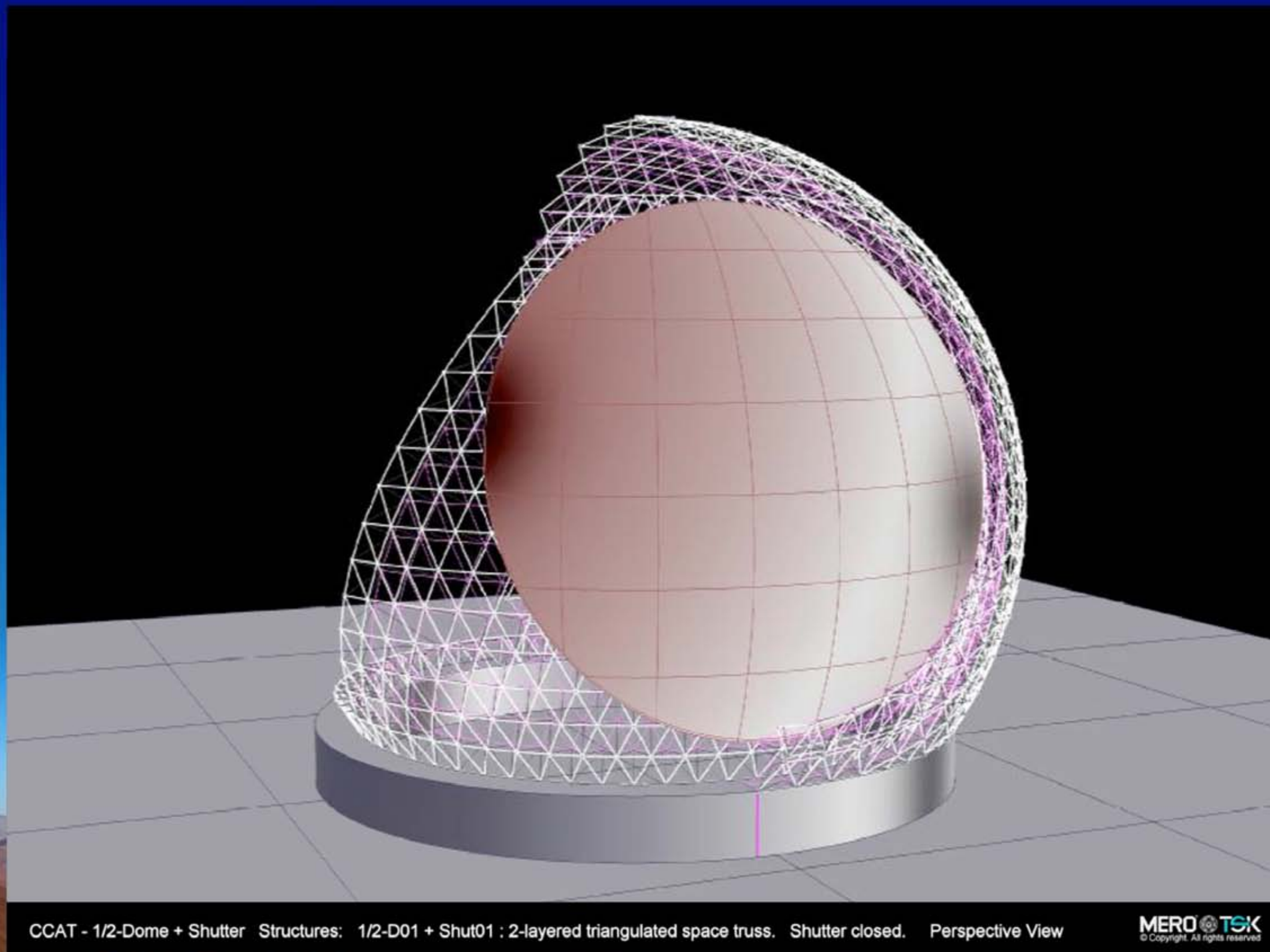
CCAT - 1/2-Dome + Shutter Structures: 1/2-D01 + Shut01 : 2-layered triangulated space truss. Shutter rotatetd to back. Perspective View MERO TSK

Mero TSK Designs



CCAT - 1/2-Dome + Shutter Structures: 1/2-D01 + Shut01 : 2-layered triangulated space truss. Shutter closed. Perspective View

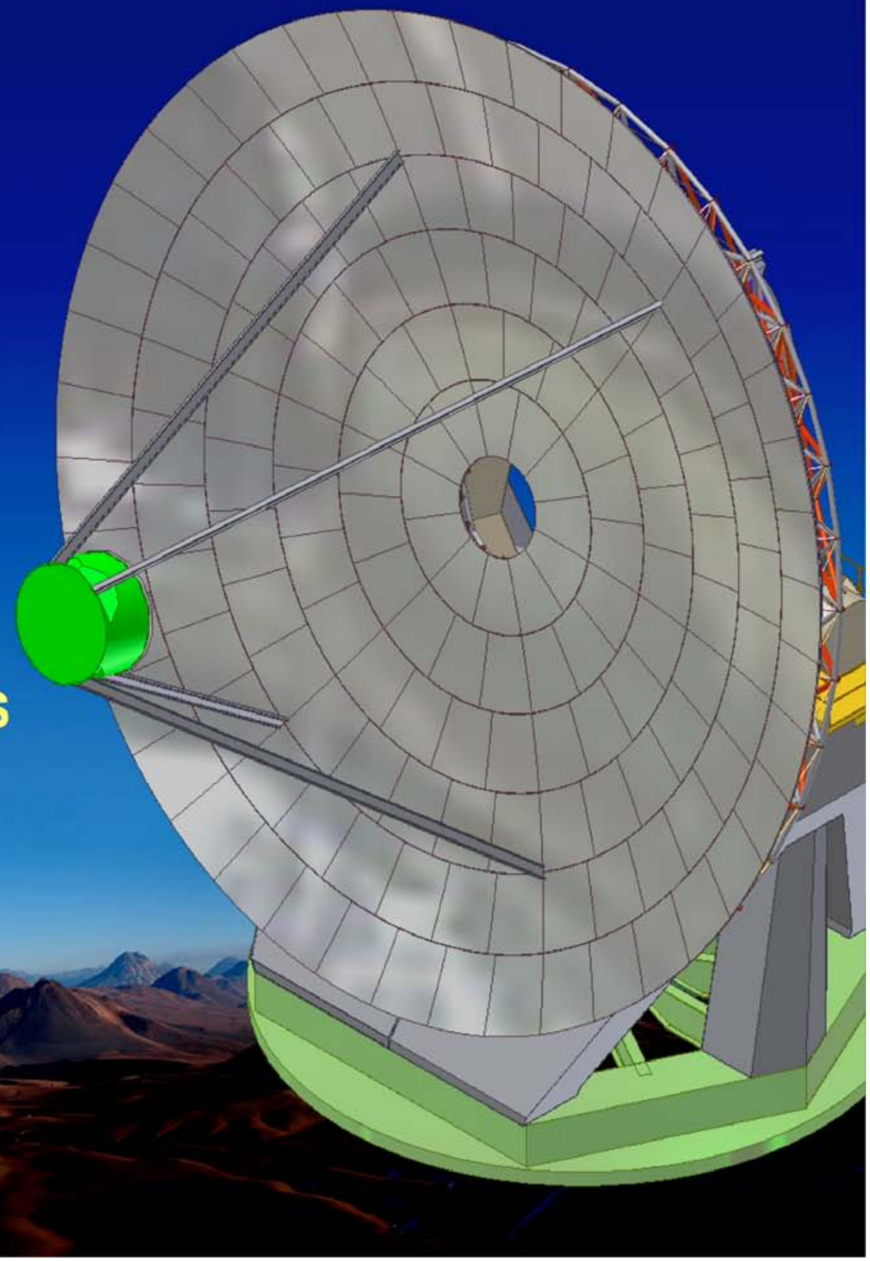
Mero TSK Designs



CCAT Mount

- Design by Vertex RSI
- Uses Approaches from Radio and Optical Telescopes
- Hydrostatic & Rolling Element Bearings

Pointing	<2 arcsec RMS
Offset Pointing	<0.5 arcsec RMS
Dynamics	0.25 deg/sec
	0.01 deg/sec^2
Unguided Jitter	<0.1 arcsec
Open Loop Drift	0.1 arcsec/min
Max Accel.	2 deg/sec^2
Axis Velocity	1 deg/sec



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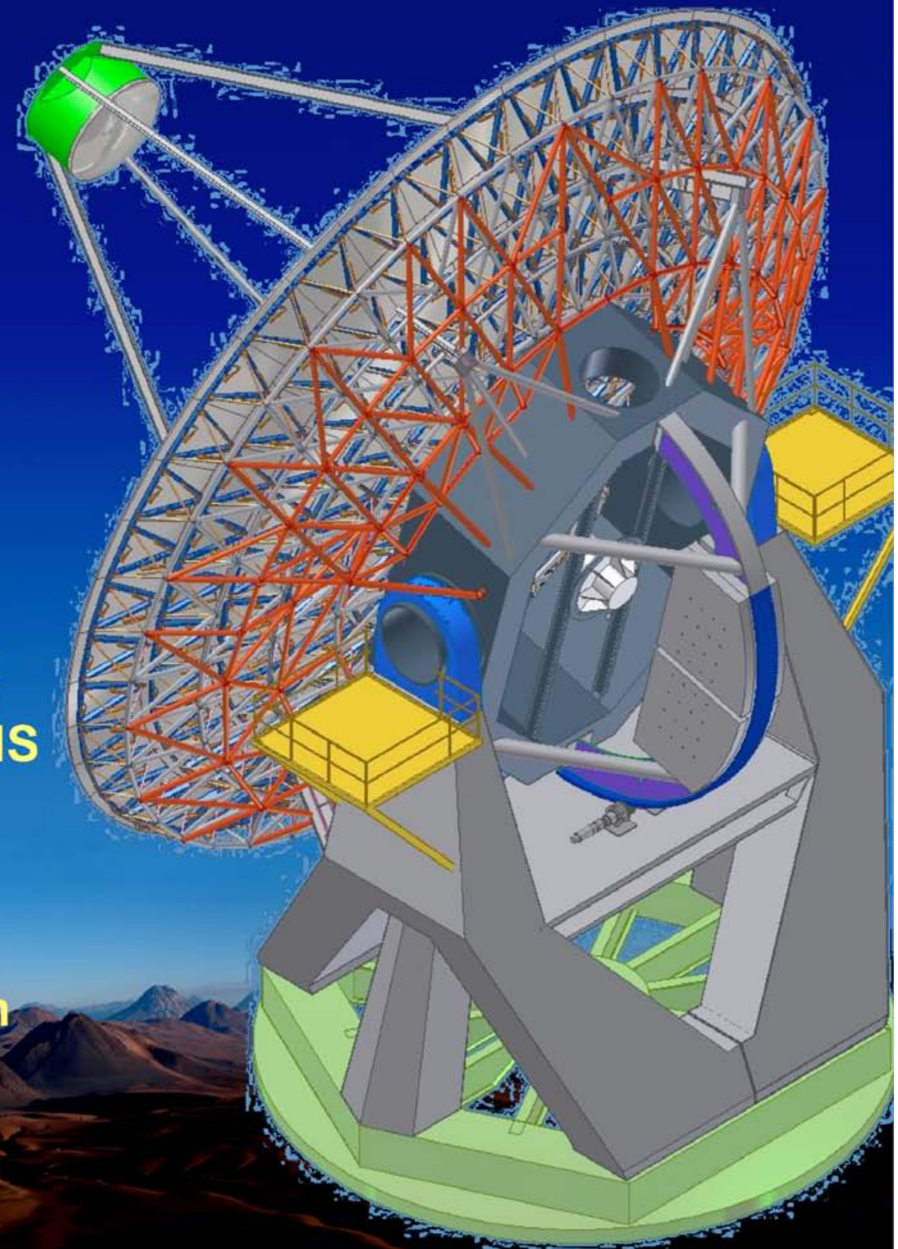
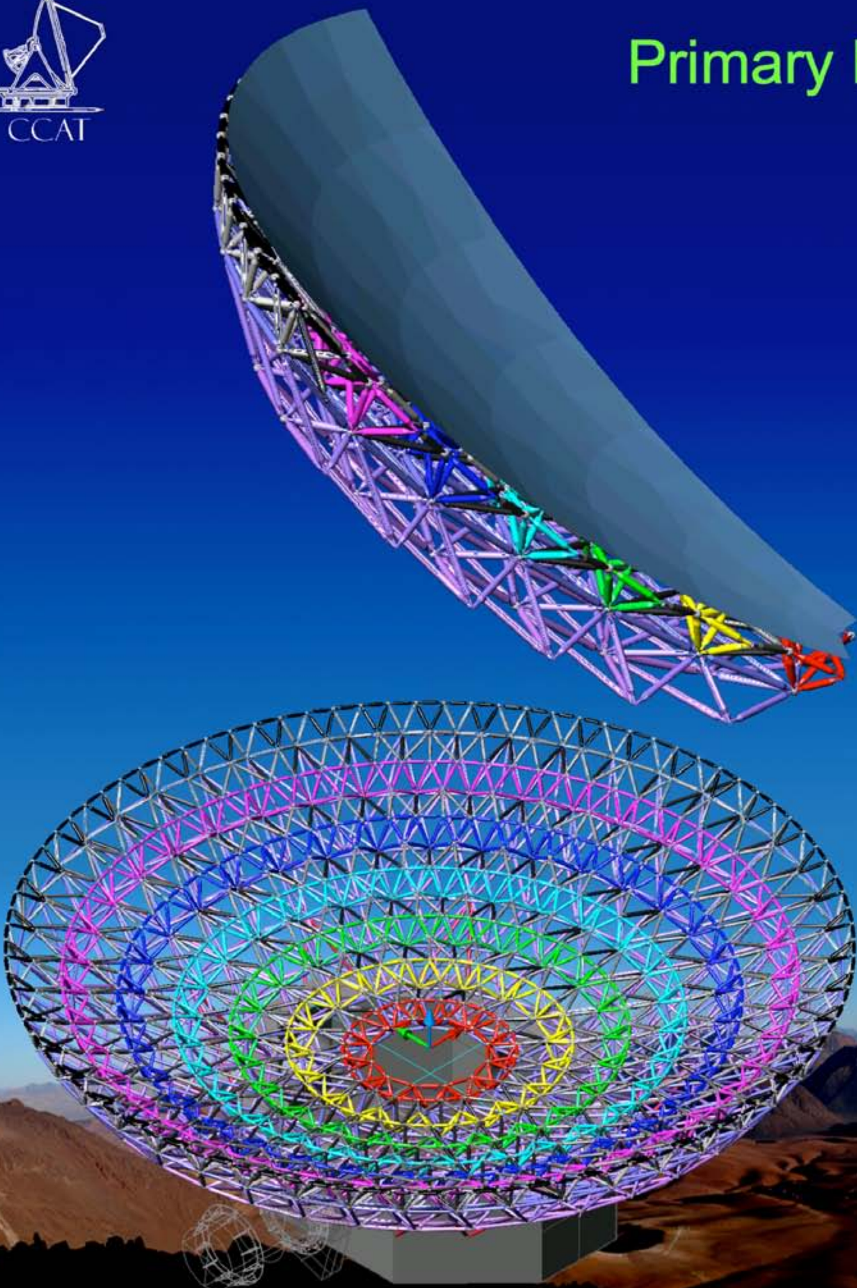
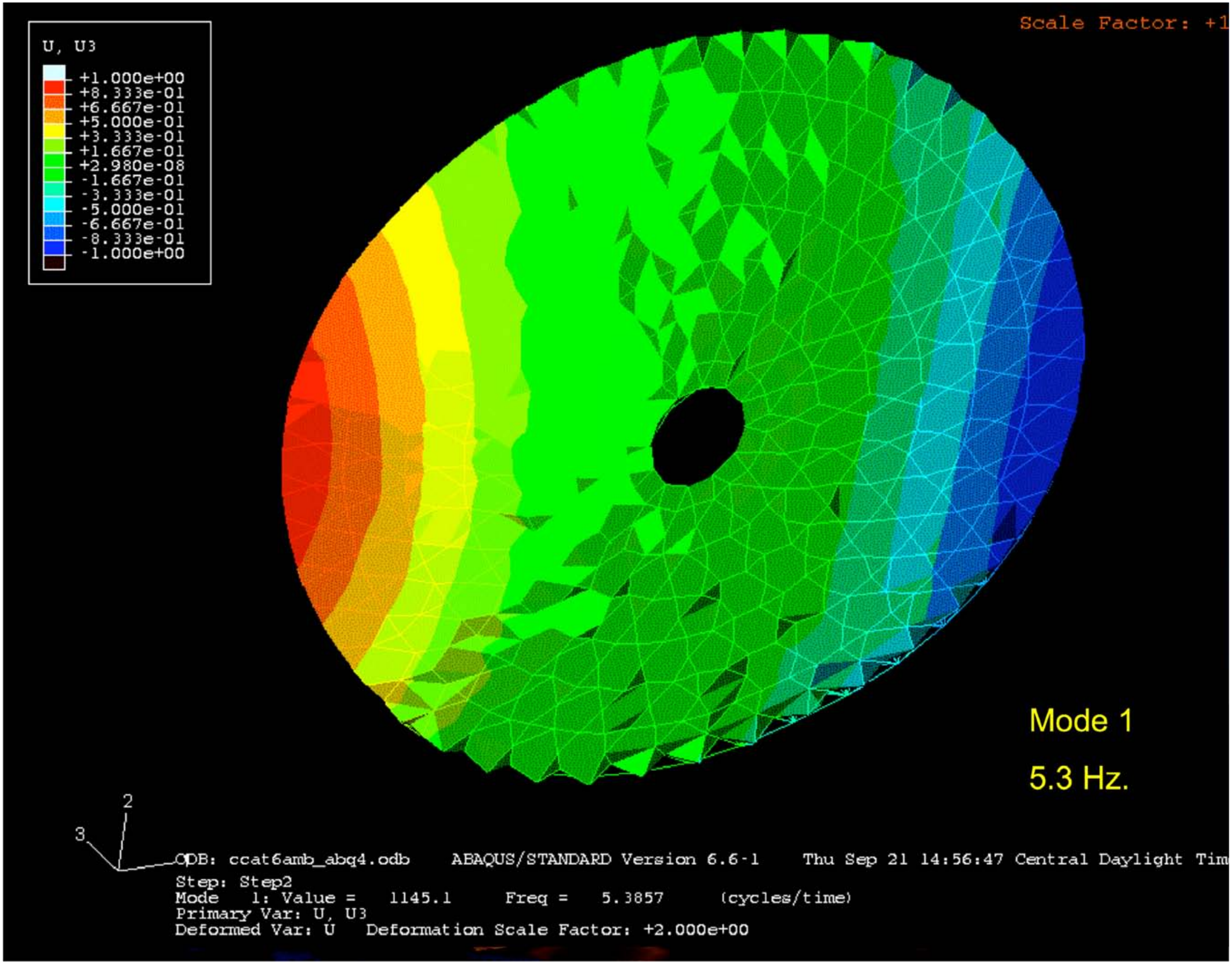


CCAT

Primary Mirror Design



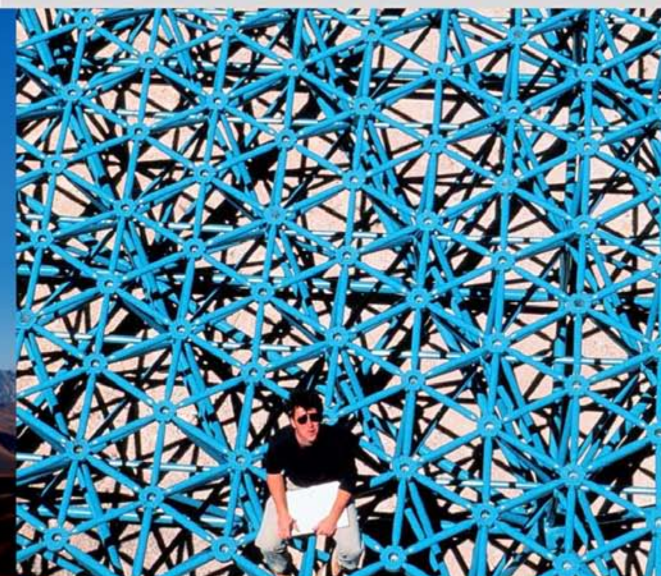
- Bolted Steel PM Truss
- One Front Surface Node per Actuator
- 3 Actuators per Panel
- Mounted via 3 Bipod Flexures
- Provides Tip/Tilt/Piston Motion for Panels


U, U3
+1.000e+00
+8.333e-01
+6.667e-01
+5.000e-01
+3.333e-01
+1.667e-01
+2.980e-08
-1.667e-01
-3.333e-01
-5.000e-01
-6.667e-01
-8.333e-01
-1.000e+00
Scale Factor: +1
Mode 1
5.3 Hz.
2
3
ODB: ccat6amb_abq4.odb ABAQUS/STANDARD Version 6.6-1 Thu Sep 21 14:56:47 Central Daylight Tim
Step: Step2
Mode 1: Value = 1145.1 Freq = 5.3857 (cycles/time)
Primary Var: U, U3
Deformed Var: U Deformation Scale Factor: +2.000e+00

CCAT

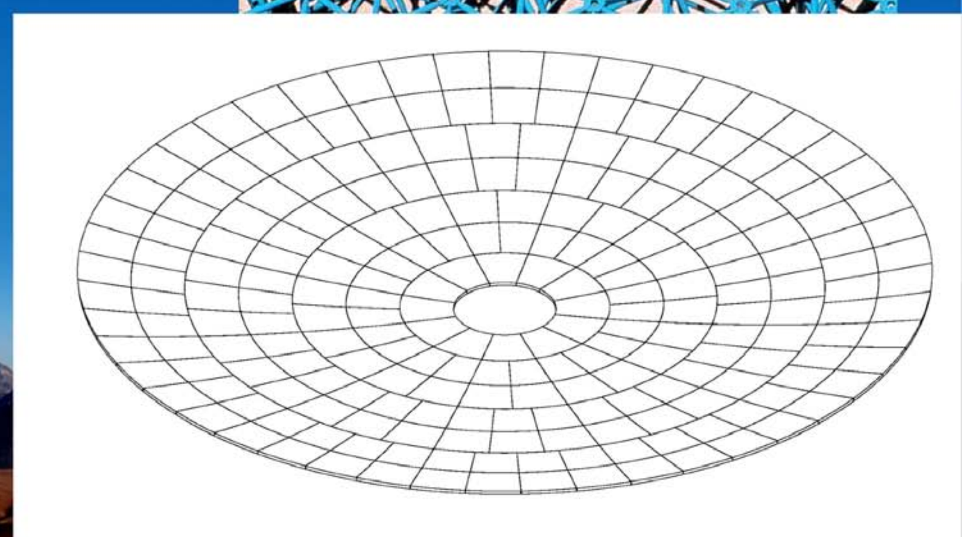
Primary Mirror Concept

- Steel Truss: ~5x Lower Cost than CFRP
- Commercial Actuators Support Axial and Lateral Loads



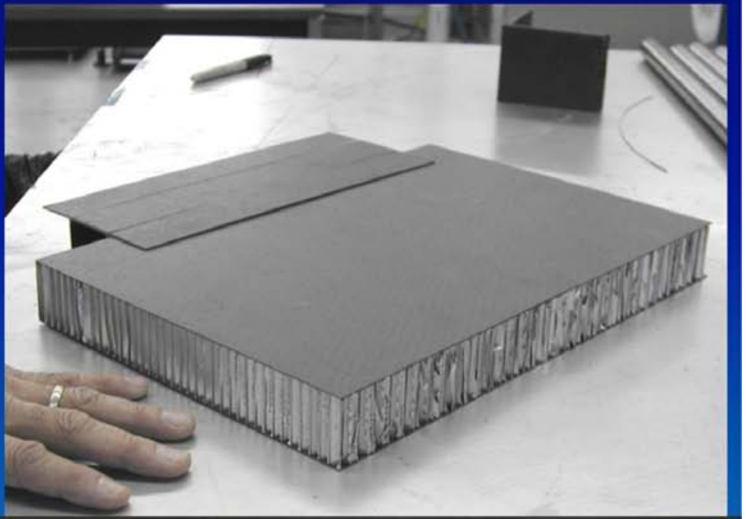
Primary Mirror Concept

- Steel Truss: ~5x Lower Cost than CFRP
- Commercial Actuators Support Axial and Lateral Loads
- 7 Ring Panel Layout
- 7 Sets of Identical Panels
- Total ~ 210 Panels @ ~1.7m Major Dimension



Primary Mirror

- Two Current Panel Approaches Considered
  - Replicated CFRP/Al Sandwich (Composite Mirror Applications)
  - Precision Molded Lightweight Borosilicate (ITT Govt. Sys. Division)
- Panels Kinematically Supported on 3 Points by Bipod Flexures
- ~8 kg/m^2 Areal Density



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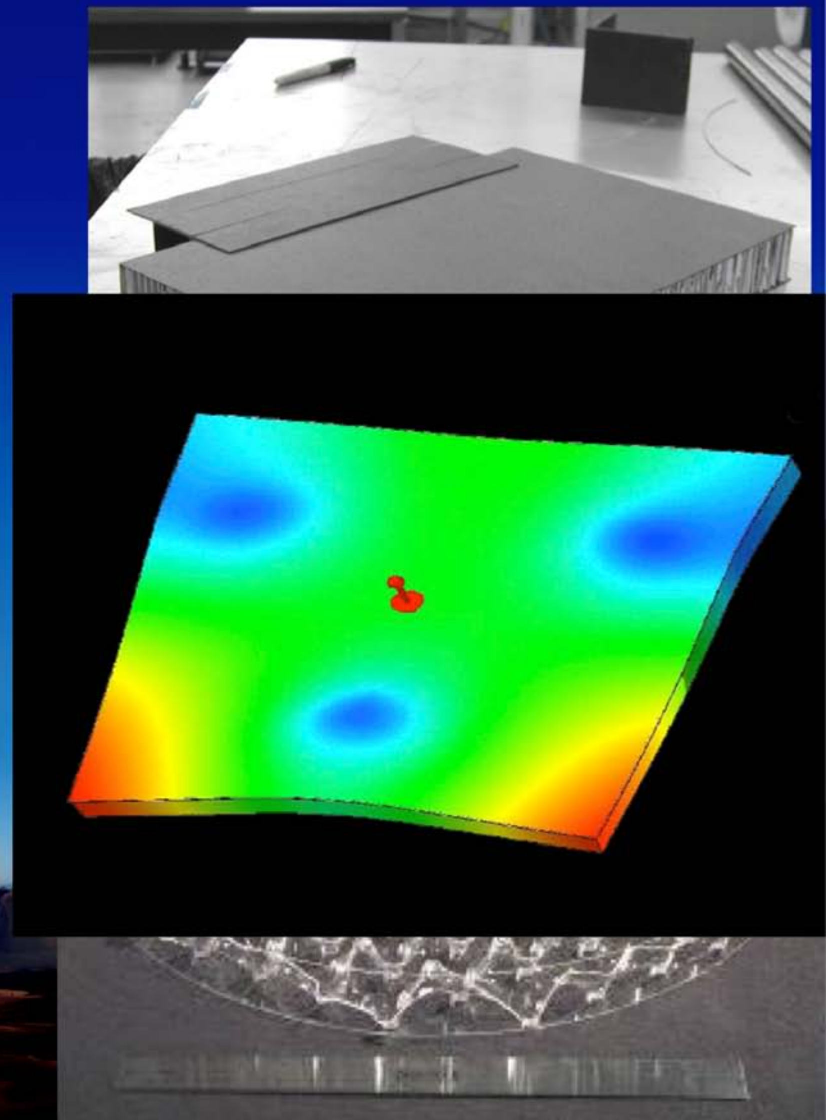
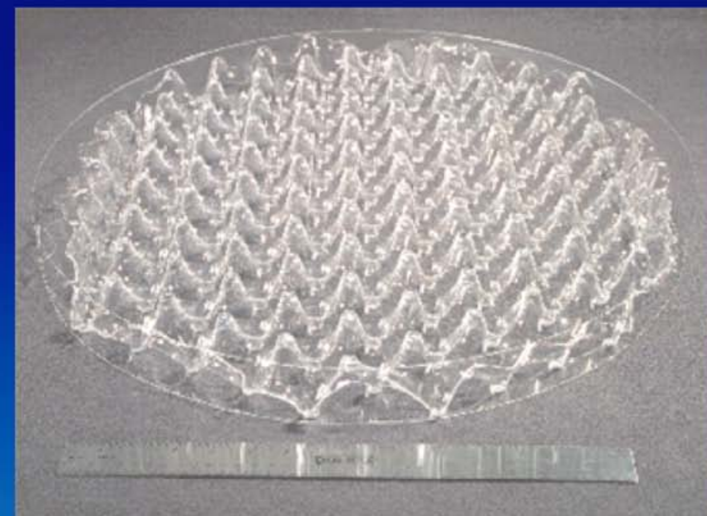
  - Precision Molded Lightweight Borosilicate (ITT Govt. Sys. Division)
- Panels Kinematically Supported on 3 Points by Bipod Flexures
- ~8 kg/m^2 Areal Density
- ~5 μm rms Panel Figure Total Error



Precision Molded Borosilicate Lightweight: ITT Industries, Rochester, NY

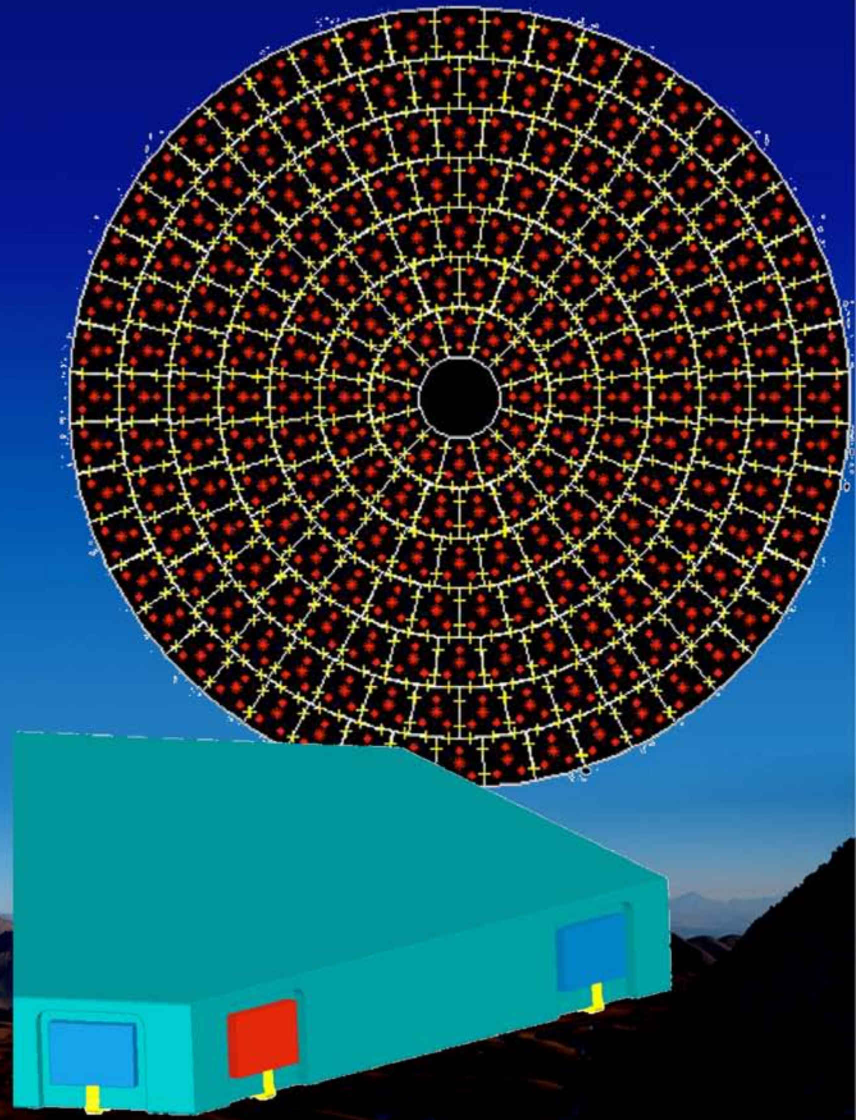
- What are they?
  - Borosilicate glass
  - Corrugated “egg crate” Core
  - Thin Facesheet Fused to Core
  - Precision Molded



  - Meets Figure Requirements
  - Inert Material Stable Over Time

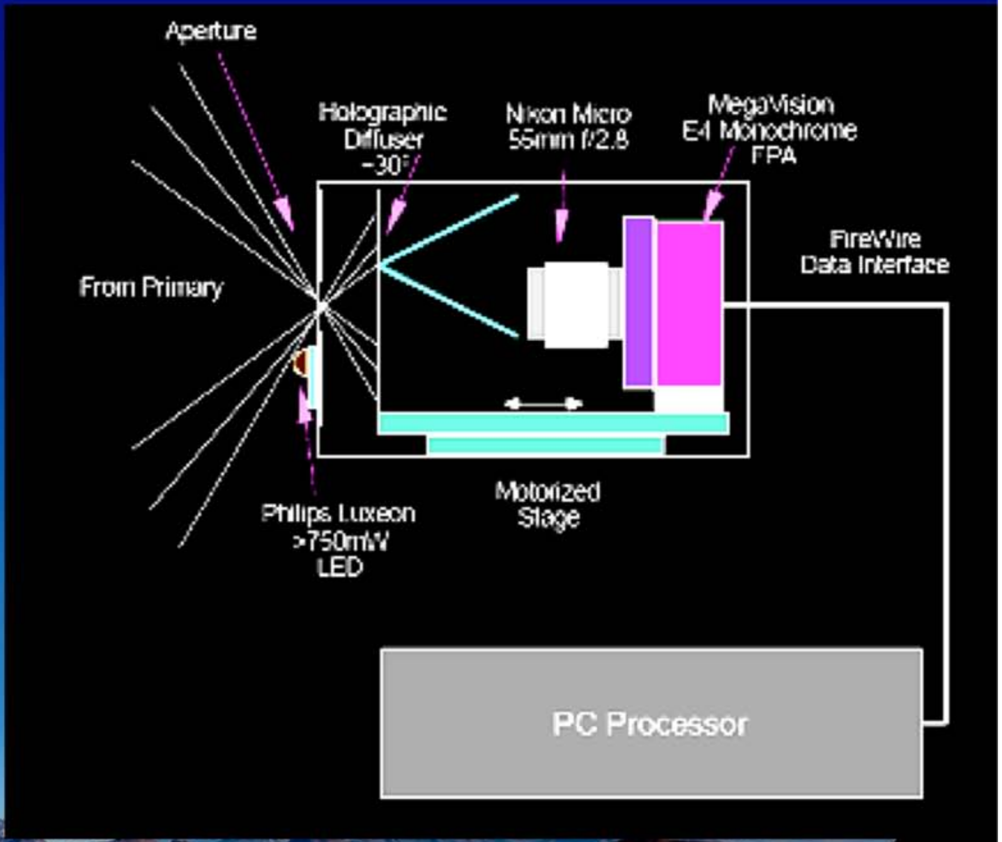
Primary Mirror Segments

- JPL Developed Segmentation Pattern
- Edge Sensors on Segment Interstices
  - Sense Piston and Dihedral Angle
  - Based on Inductance
  - New Fogale Nanotech Product
  - Unaffected by Humidity or Dust



Supplementary Panel Alignment Sensor: AOA

- Operates in Visible Wavelengths
- Point Source at M2
- Small (~20mm) Spherical Mirrors on Segments
- Focused Spots on Holographic Diffuser
- Imaging of Diffuser Provides Spot Pattern for Analysis



Sensor Provides Robust Control of RoC and Other Low Order Aberrations

CCAT

The Partners:

- Cornell University
  - Ithaca, NY
- Caltech (and JPL)
  - Pasadena, CA
- UK ROE ATC
  - Division of STFC
- Canada
  - U. Waterloo & B.C.
- U. Colorado
  - Boulder, CO

CCAT

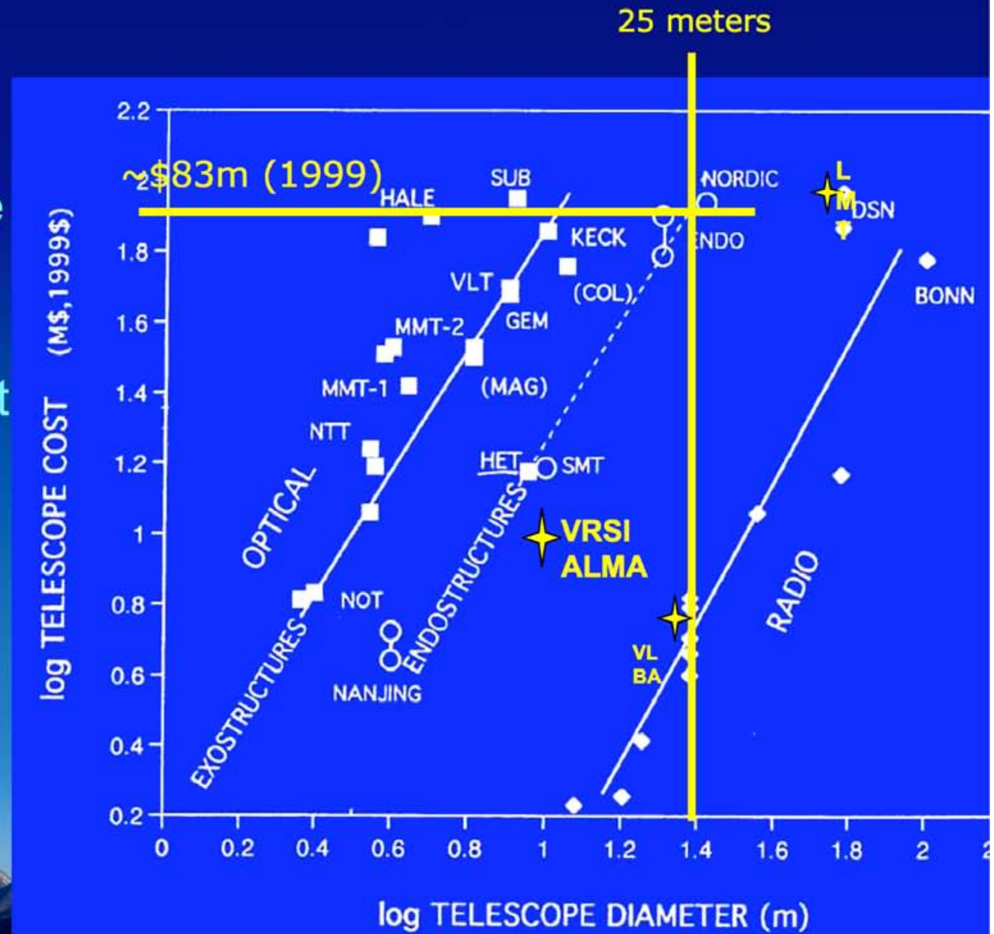
The Schedule:

- 1st Cornell Caltech MOU Signed Feb '04
- Feasibility/Concept Design Study Completed Jan '06
- Interim Consortium Agreement Signed Jul '07

- Full Consortium Agreement to be Completed Sep '08
- Development Begins Jan '09
- First Light 2012
- Full Science Operations 2013

The Budget

- Total Budget: $100 M
- 2006 Dollars
- Includes $20 M Set Aside for Astronomical Instruments
- Consistent Historical Cost vs Wavelength & Size
- Validated by Detailed Study
  - Costs from Contractors
  - Catalogue Costs
  - Extrapolation
  - Benchmarked by ALMA Experience



CCAT Moves Ahead!

- The CCAT Project is Progressing Very Well
- Signing of an Interim Consortium Agreement Marks an Important Step
- Current Partners Would be Sufficient to Build Telescope if All Desired Funding Were Found
- Additional Partners Have Expressed Strong Interest
- Good Progress Has Been Made in the Most Critical Technical Areas
- We Expect to Begin Construction in About 1 Year


CCAT Moves Ahead!
HAMM