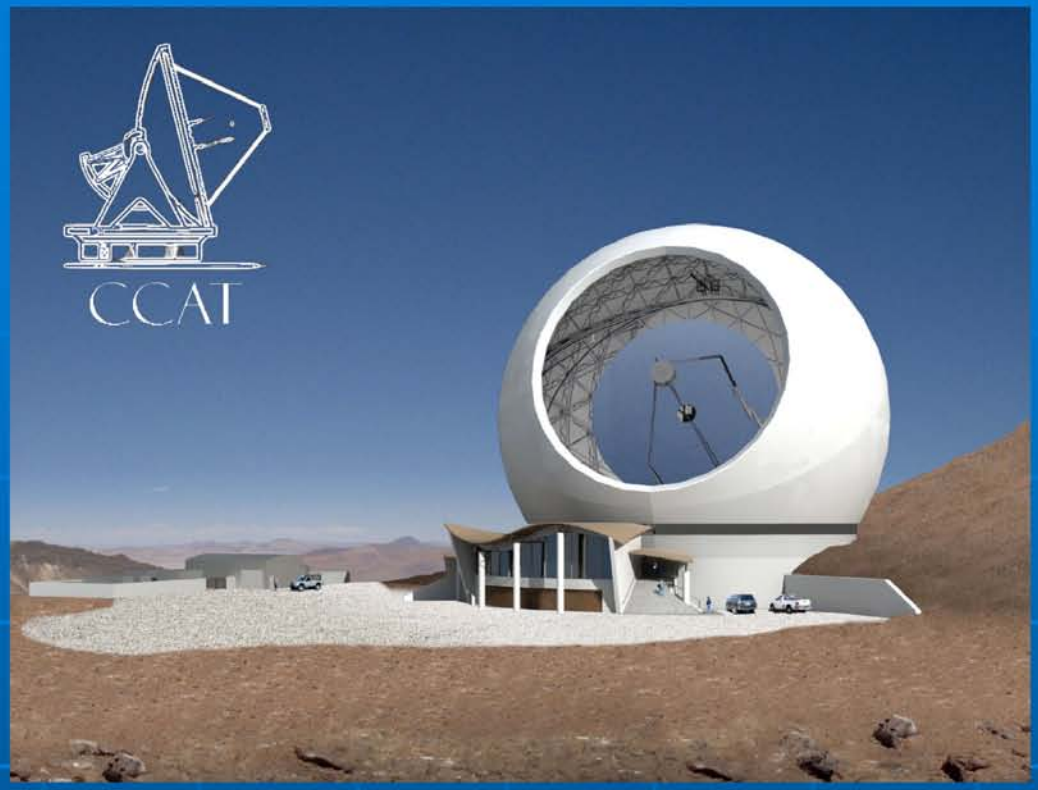
The Cornell Caltech Atacama Telescope

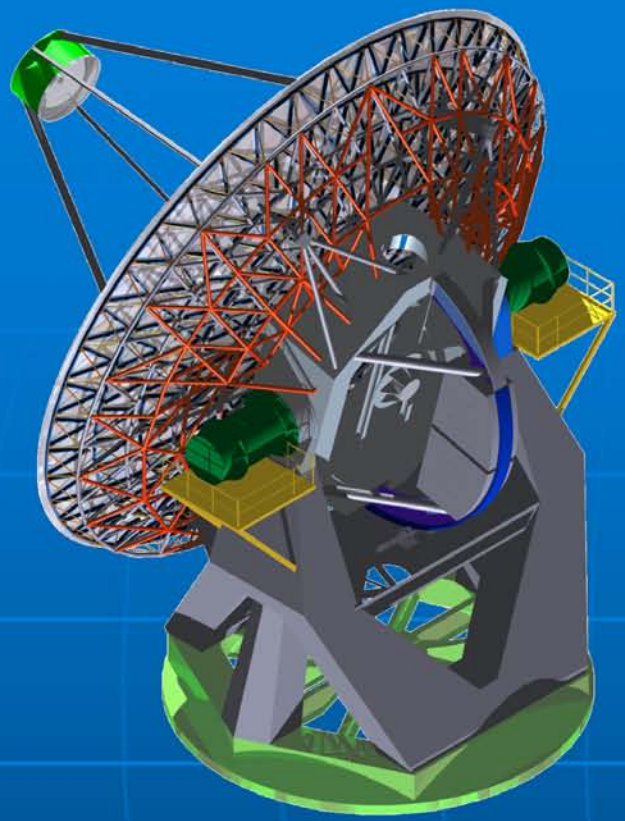
Overview, Progress & Status

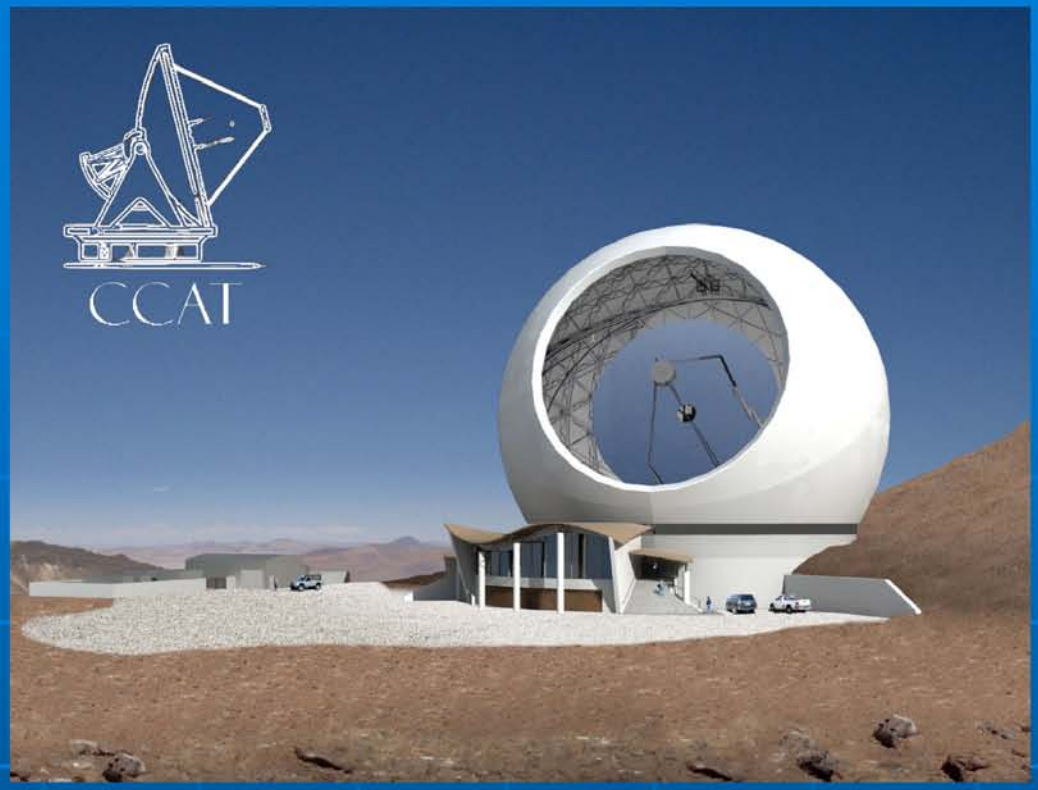
CCAT Board 18,19 July 07



Project Management

Riccardo Giovanelli	Director
Thomas A. Sebring	Project Manager
Simon Radford	Deputy Project Manager
Jonas Zmuidzinas	Project Scientist Caltech
Terry Herter	Project Scientist Cornell
Paul Goldsmith	Manages JPL CCAT Activities




CCAT

Currently Planned Project Phases and Schedule

- Feasibility/Concept Design Study
  - October 2005 – January 2006
  - Develop Baseline Concept, Assess Feasibility, Initial Cost Estimate

Complete

- Consortium Development Phase
  - June 2006 –2008
  - Interim Consortium Agreement Signed June 2007
  - Identify and Secure Funding
  - Complete Full Project Agreement Mid 2008

Current

- Technical Development Phase
  - Mid 2008 – Mid 2011
  - Detailed Design, Manufacture, Integration
- Commissioning Phase
  - 2011 – 2012
  - Optimize Performance & Handover to Operations

Consortium Status

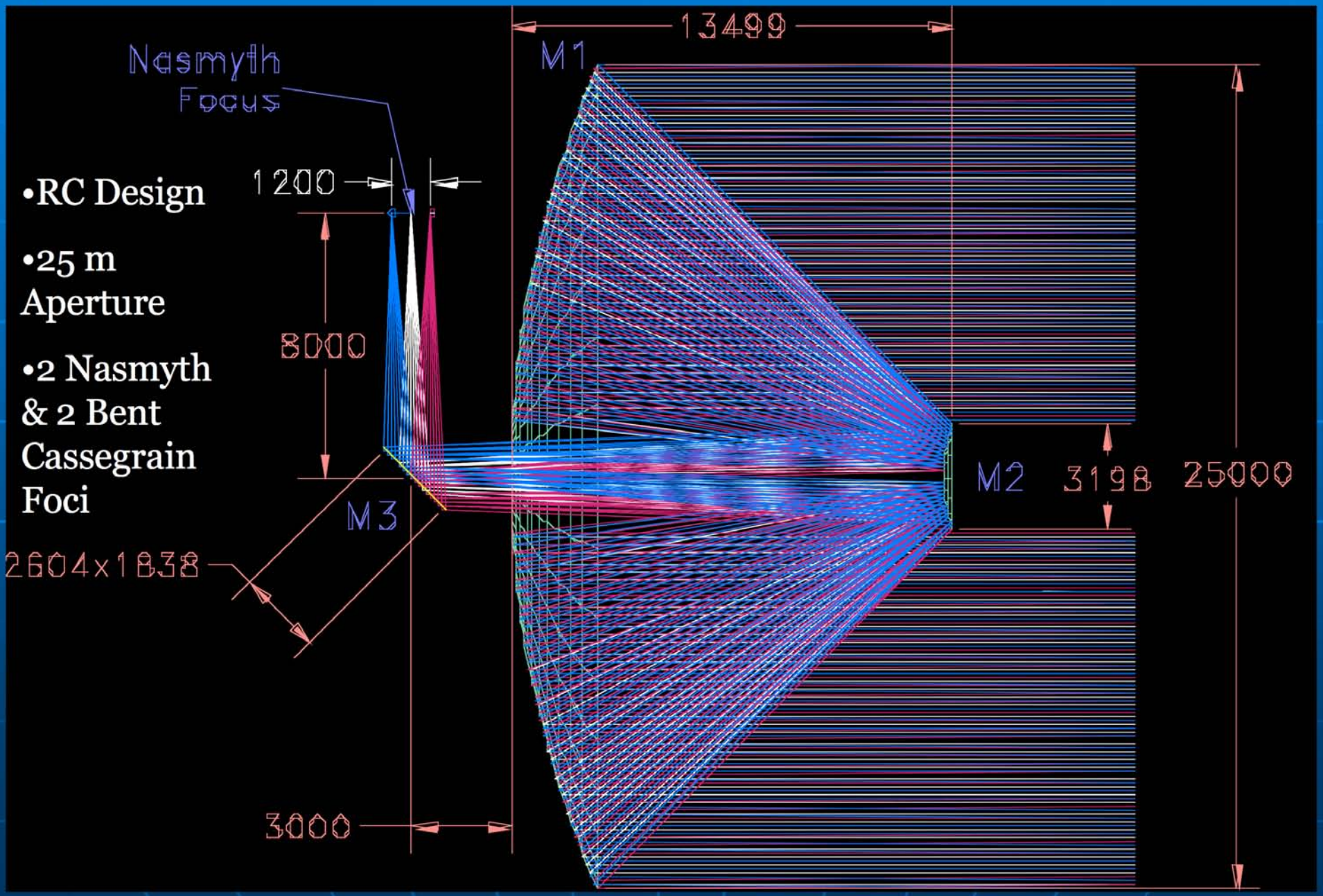
- ✓ Caltech 20%
  - $ 20M Proposal Prepared for Moore Foundation
  - Additional JPL involvement, i. e., instruments?
- ✓ Cornell University 25-30%
  - Major Donor Identified ~$ 10 M
  - Working to Find Support for Remainder
- ✓ University of Colorado Boulder 5-10%
  - Funding Under Development
- ✓ UK Astronomy Technology Centre 25%
  - Statement of Intent Submitted to STFC
- Canada (Univ of BC & Waterloo) 20%
  - Canadian Government Funding
- Strong Interest at Some Other Institutions

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

It is the Combination of These Features Along with Advanced Detector Arrays that Make CCAT a Revolutionary New Observatory

Optical Design…German Cortes Provided Updated Prescription for Faster M1…Smaller Telescope & M2



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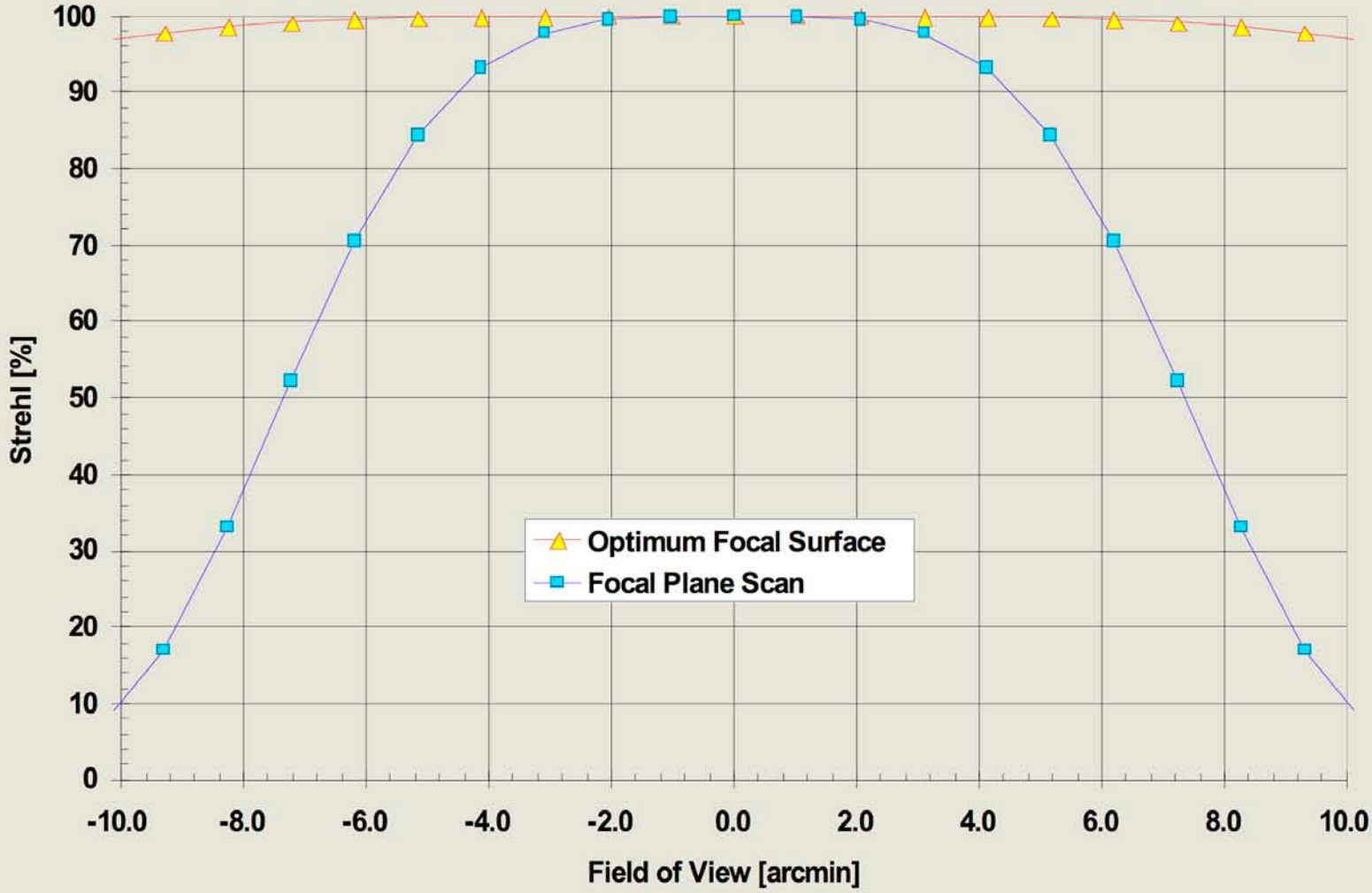
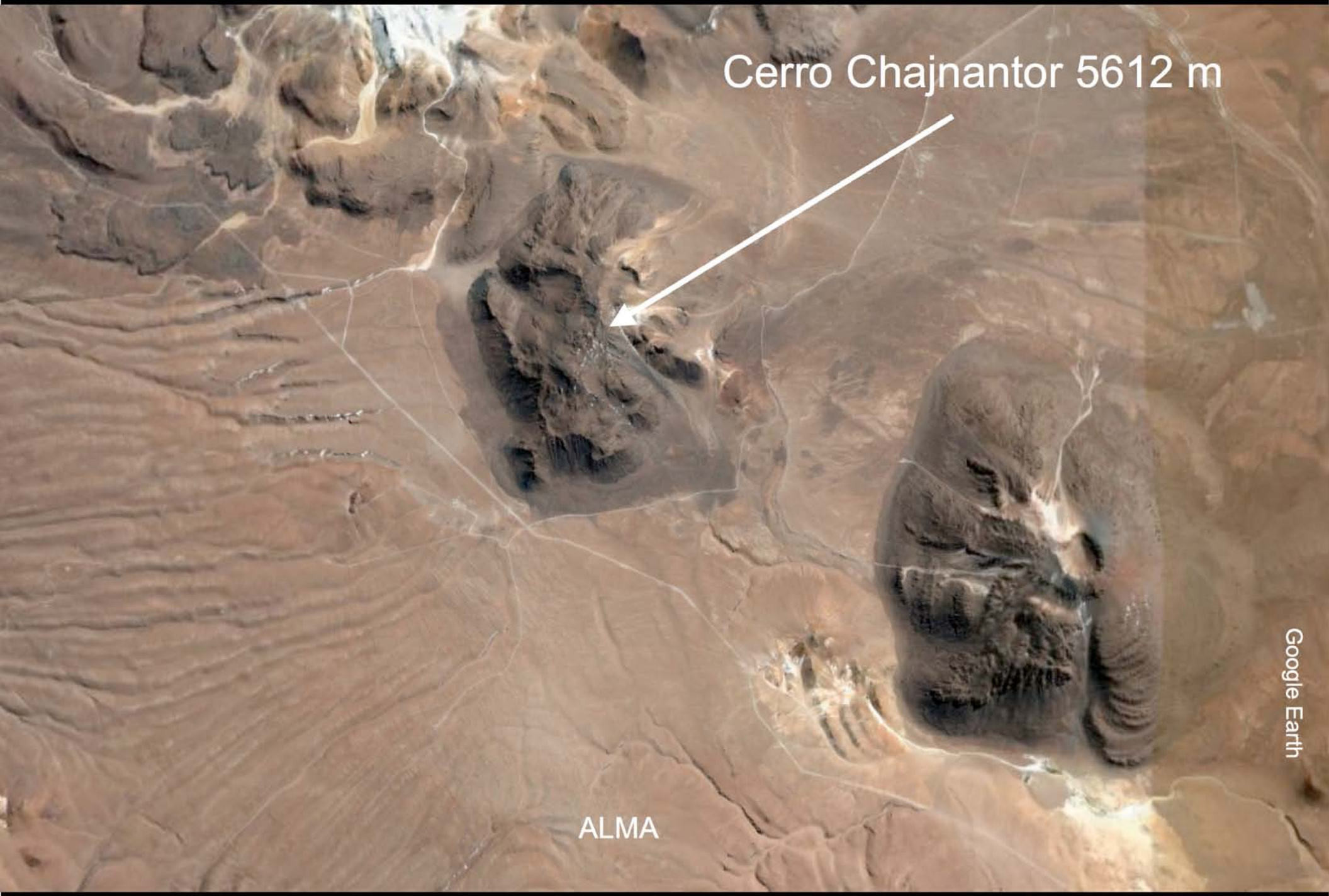


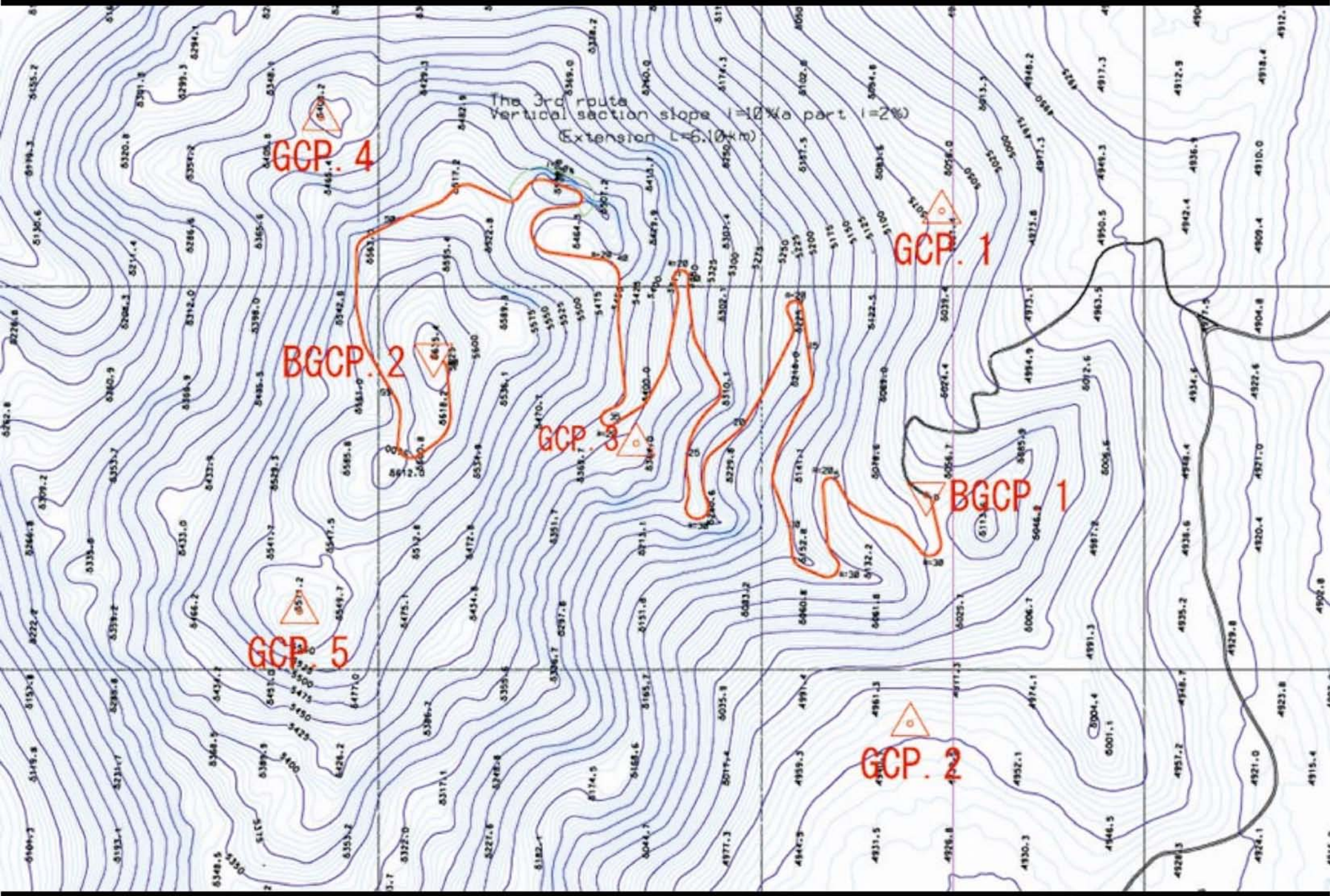
The Atacama Desert

- Site is 5612 m Altitude
- ~2 hours Flying Time from Santiago to Calama
- ~2 Hours Drive from Antofagasta, The Nearest Port
- Scientific Preserve Set Aside for Astronomy
- Managed by CONICYT
  - Comisión Nacional de Investigación Científica y Tecnológica de Chile

Chajnantor Plateau (5000 m)

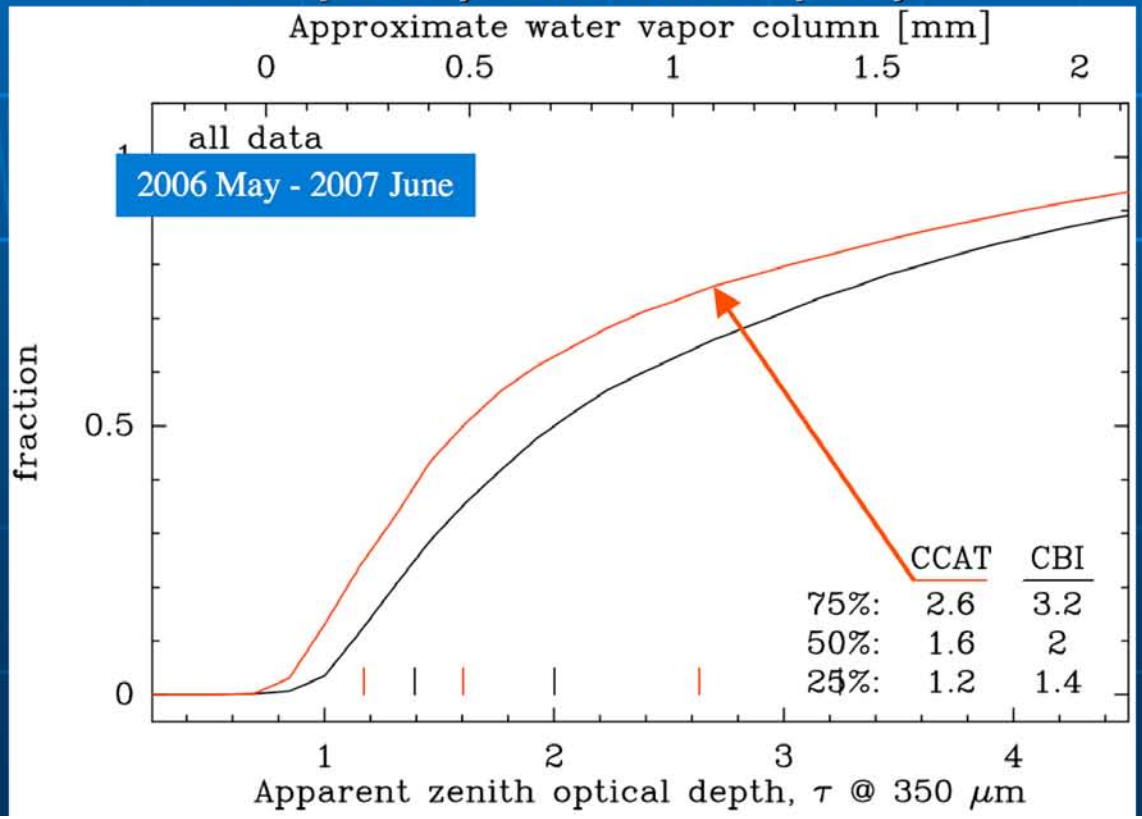
Dietrich/Caltech

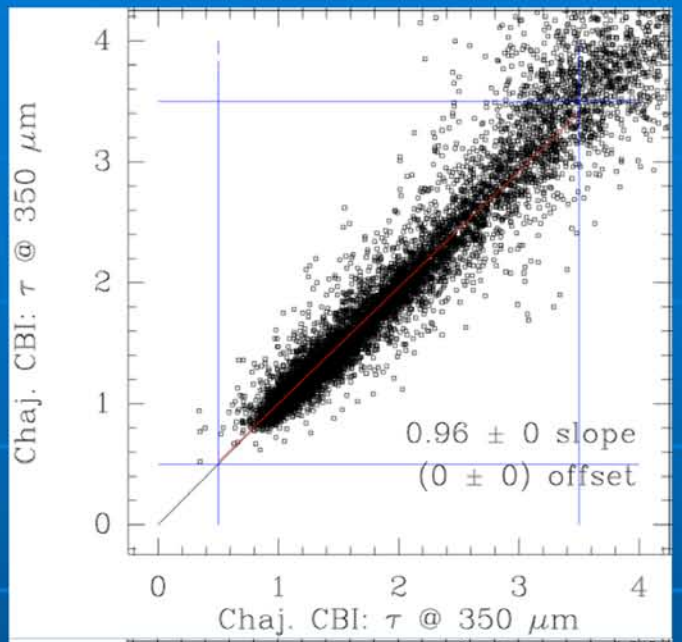

Cerro Chajnantor 5612 m
ALMA
Google Earth

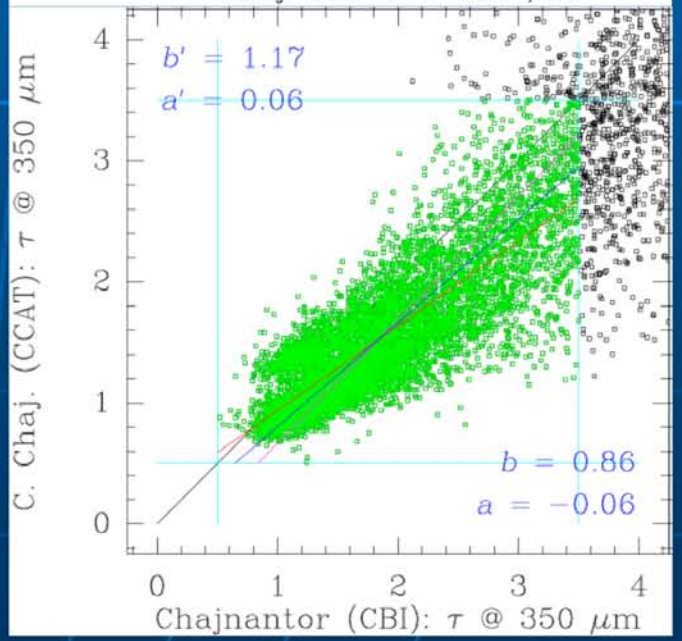

The 3rd route
Vertical section slope i=10%a part i=2%)
(Extension L=5.10km)
GCP. 4
GCP. 1
BGCP. 2
GCP. 3
BGCP. 1
GCP. 5
GCP. 2

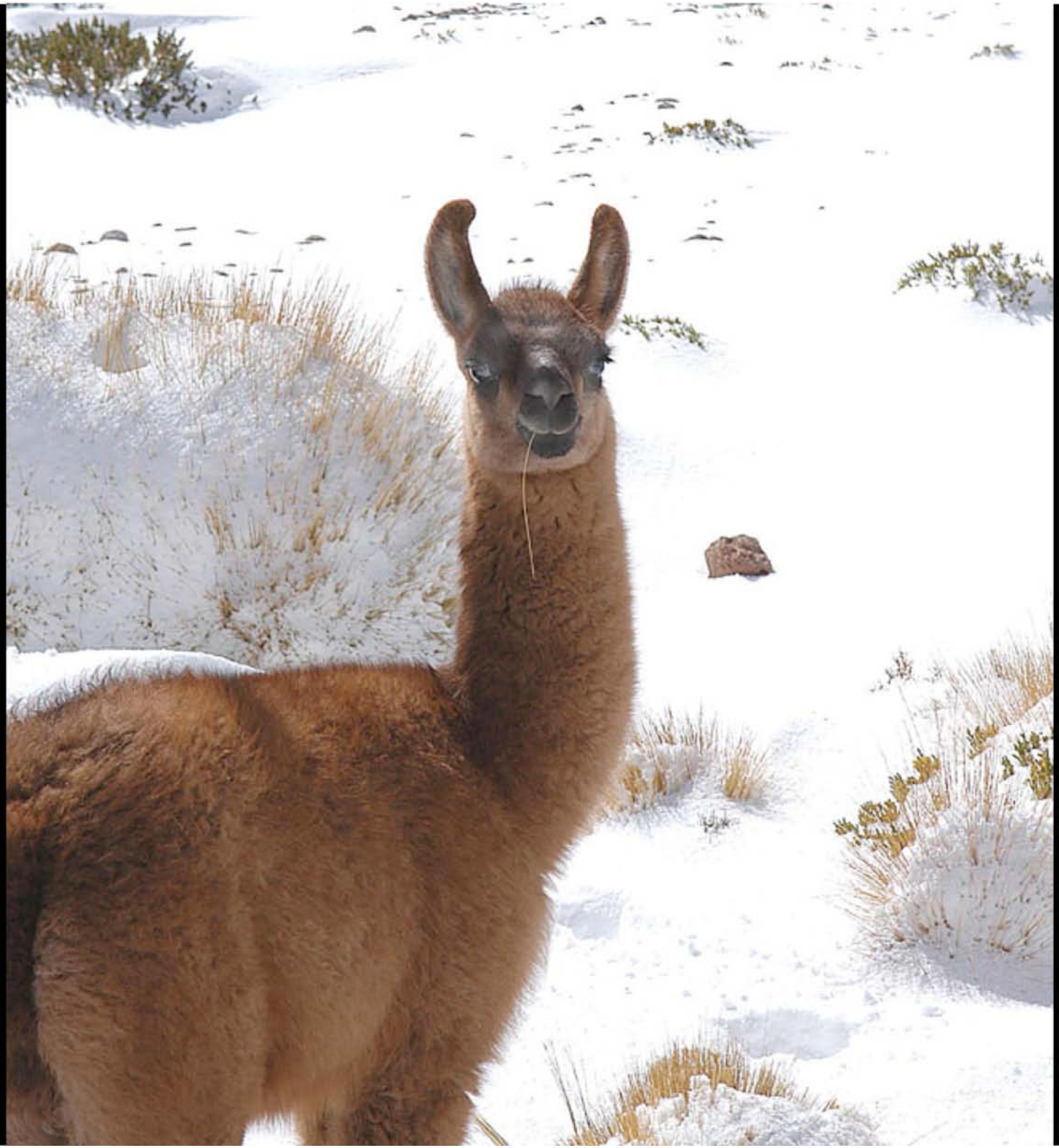
Better 350 μm Transparency @ CCAT Site

- 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)









Chajnanator Working Group Participants

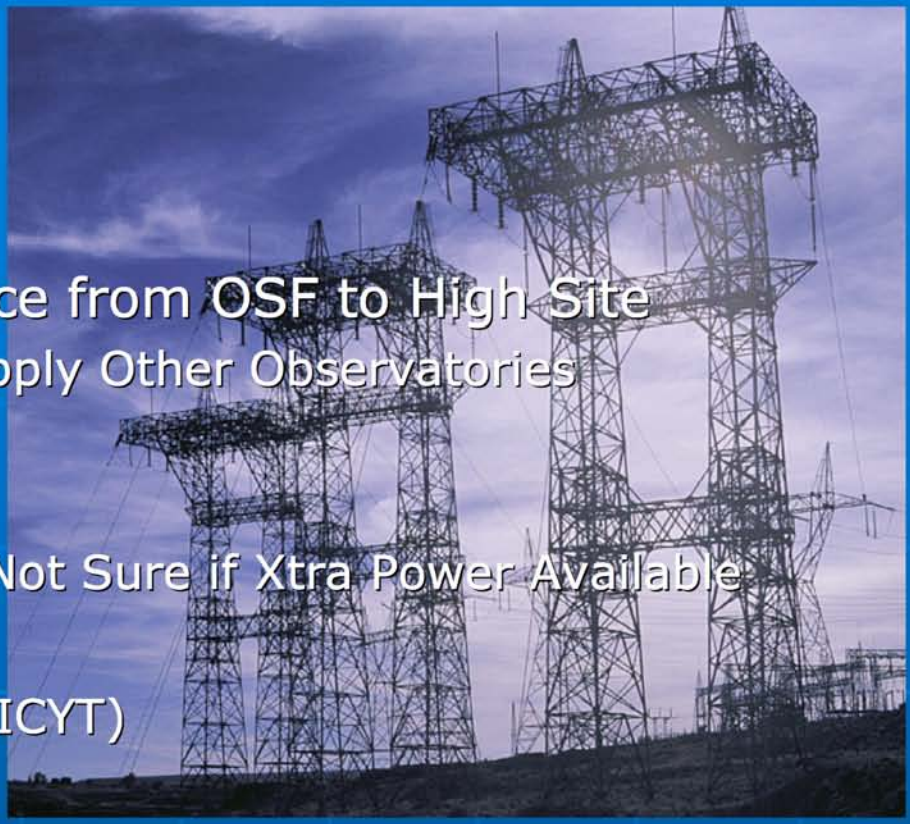
CHAJNANTOR WORKING GROUP (CWG)
April 26th and 27th '07

	Name	Organization
1	Limon, Michele	ACT
2	Hincks, Adam	ACT
3	Dunner, Rolando	ACT
4	Beasley, Tony	ALMA
5	Dierkxmeier, Claus	ALMA
6	Donoso, Eduardo	ALMA
7	Edmunds, Ann	ALMA
8	Muñoz, Karla	ALMA
9	Smeback, Russell	ALMA
10	Ikenoue, Bungo	ALMA-J
11	Nyman, Lars-Åke	APEX
12	Ezawa, Hajime	ASTE
13	Oshima, Tai	ASTE
14	Uehara, Masao	ASTE
15	Hardy, Eduardo	AUI
16	Ibañez, Roberto	AUI
17	Pilleux, Mauricio	AUI
18	Bustos, Ricardo	CALTECH
19	Oyarce, Norberto	CALTECH
20	Radford, Simon	CALTECH
21	Readhead, Anthony	CALTECH
22	Reeves, Rodrigo	CALTECH
23	Sebring, Thomas	CALTECH
24	Shepher, Martin	CALTECH
25	Weintraub, Larry	CALTECH
26	Campusano, Luis	CONICYT
27	Norambuena, Alicia	CONICYT
28	Lira, Felipe	ESO
29	Mizuno, Norikazu	NANTEN
30	Aoki, Tsutomu	TAO
31	Doi, Mamoru	TAO
32	Minezaki, Takeo	TAO
33	Mitani, Natsuko	TAO
34	Motohara, Kentaro	TAO
35	Tanabe, Toshihiko	TAO
36	Leonardo Bronfman	UCHILE

Power Status

- ALMA Must Decide Within <6 Months
  - Antennas Coming, Need to Complete Necessary Infrastructure
- ALMA Plans for Power
  - 3 Years Ago: Gas Turbine Generators Using Supply from Argentina
  - 1 Year Ago: Grid Power from Calama or Elsewhere
  - Currently: Either Grid Power or Diesel Generators
- Gas Supply is Vanishing
  - Argentina's Improving Economy Provides Internal Customers
  - Insufficient Supply to Use Directly for Power
  - Power Companies Finding Sources of Energy Very Difficult
- Power Companies Not Bullish
  - Have Major Contracts to Supply Power (e.g. for Mining)
  - Gas Supply is Vanishing, Other Sources Too Expensive
  - Lawsuits Over Failure to Supply Power Being Filed
- ALMA May Receive No Bids to Install Grid to Atacama
  - May Also be Out of Time (to Obtain Right of Way & Construct Lines)

Power (cont.)



- ALMA Wants $$$$ to Increase Service from OSF to High Site
  - If This Leg Needs to be Larger to Supply Other Observatories
  - Larger Wires, Transformers, etc.
  - "Guesstimated" Cost: $500k-$1.5M
  - Needs to be Done NOW…but…ALMA Not Sure if Xtra Power Available
- CCAT Studies Alternative Energy
  - Requested by Luis Campusano (CONICYT)
  - Two Levels of Interest
    - Alternatives Might Address Needs of Smaller Observatories
    - Science Preserve Might Serve as Demonstration Site for Chile
  - Previous Study by ALMA Showed Little Hope
- Results of Brief CCAT Alternative Energy Study
  - Brief Survey of Solar & Wind Approaches
  - Best System Probably Hybrid Solar/Diesel/Lead Acid Battery
  - Capital Cost More Than $1M More…Long Term Benefit Questionable
  - Report Submitted to CONICYT
  - Conclusion…Diesel Power Likely, Minimize Usage in Design of Observatory

CCAT Site Development Plans

- October 2007 Intend to Upgrade Site Testing Installation
  - Minor "Upgrade" to Road (~ 1 Pass with Bulldozer)
  - Level Small Area at CCAT Site
  - Install 20' Container
    - Pre-Manufactured with Insulation, Solar Power, Batteries, Workbenches, Generator, Radio, etc.
    - Painted w CCAT Logo
  - Relocate Site Testing Equipment Inside Container & Mount Existing Solar Cells, Antennas, etc.
  - Deploy Atmospheric Testing Interferometer
- Coordinating Plans with CONICYT
  - Hope to Scale Plans to Not Require "New" Permissions
  - May Need to Reduce Scope
- Objective: Better Base of Operations & Improved Safety; Equivalent Footprint on Mountain to TAO

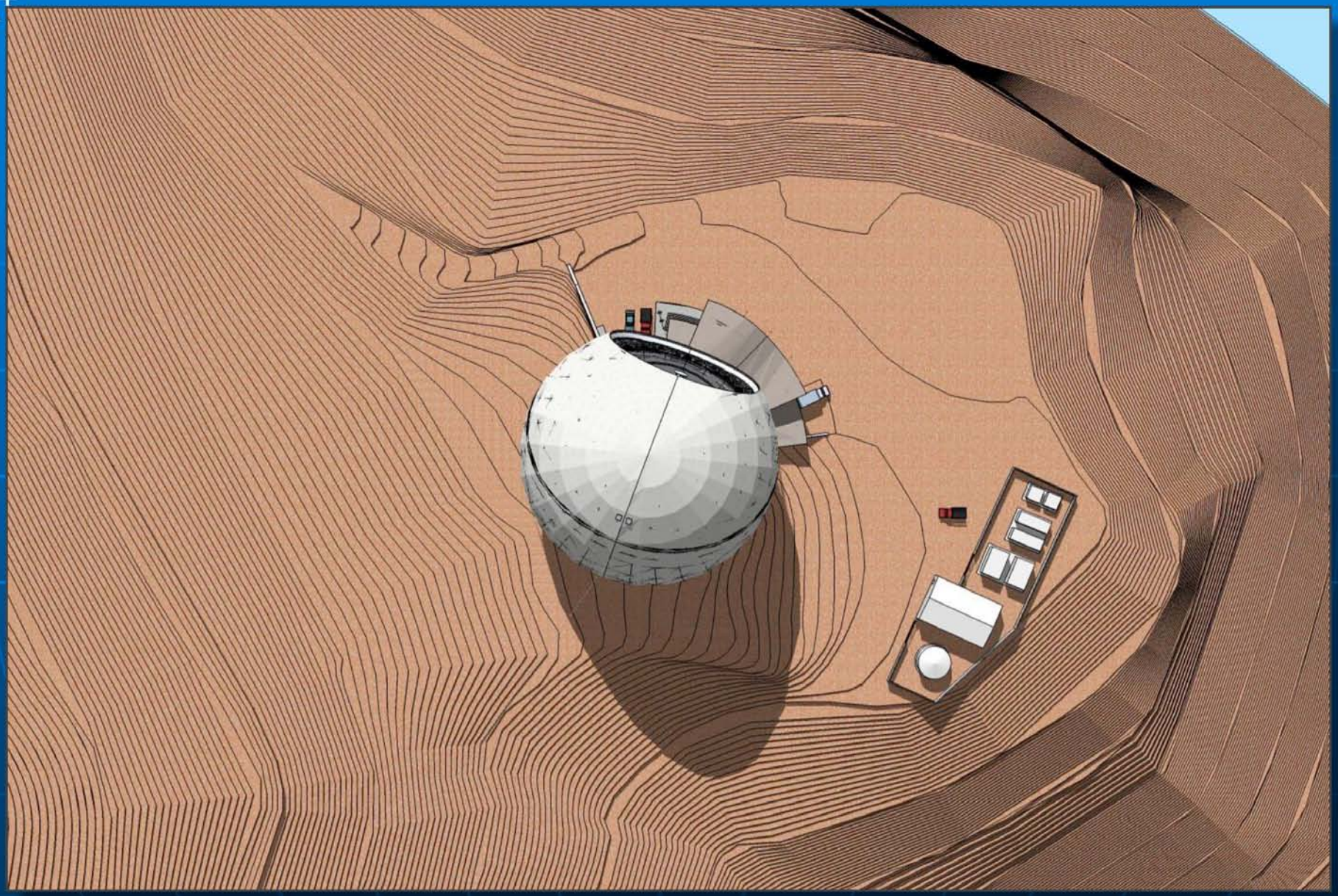
Facility Concept Design: M3 Engineering & Technology

- Design by M3, Tucson
- Summit Facility
- Road and Site Design
- Oxygen Enriched Working Areas
- Minimum Scope to Support Long-Term Operations

Facility Concept Design: M3 Engineering & Technology

- 2 Meetings with M3 Over Past Year
- ~$300k to Develop Concept Further & Bid Documents for Site Development
- Discussion of Revisions in Design to Lower Cost
- M3 Recent Experience with ALMA Helps Accurate Cost Estimation

Site & Facility Design



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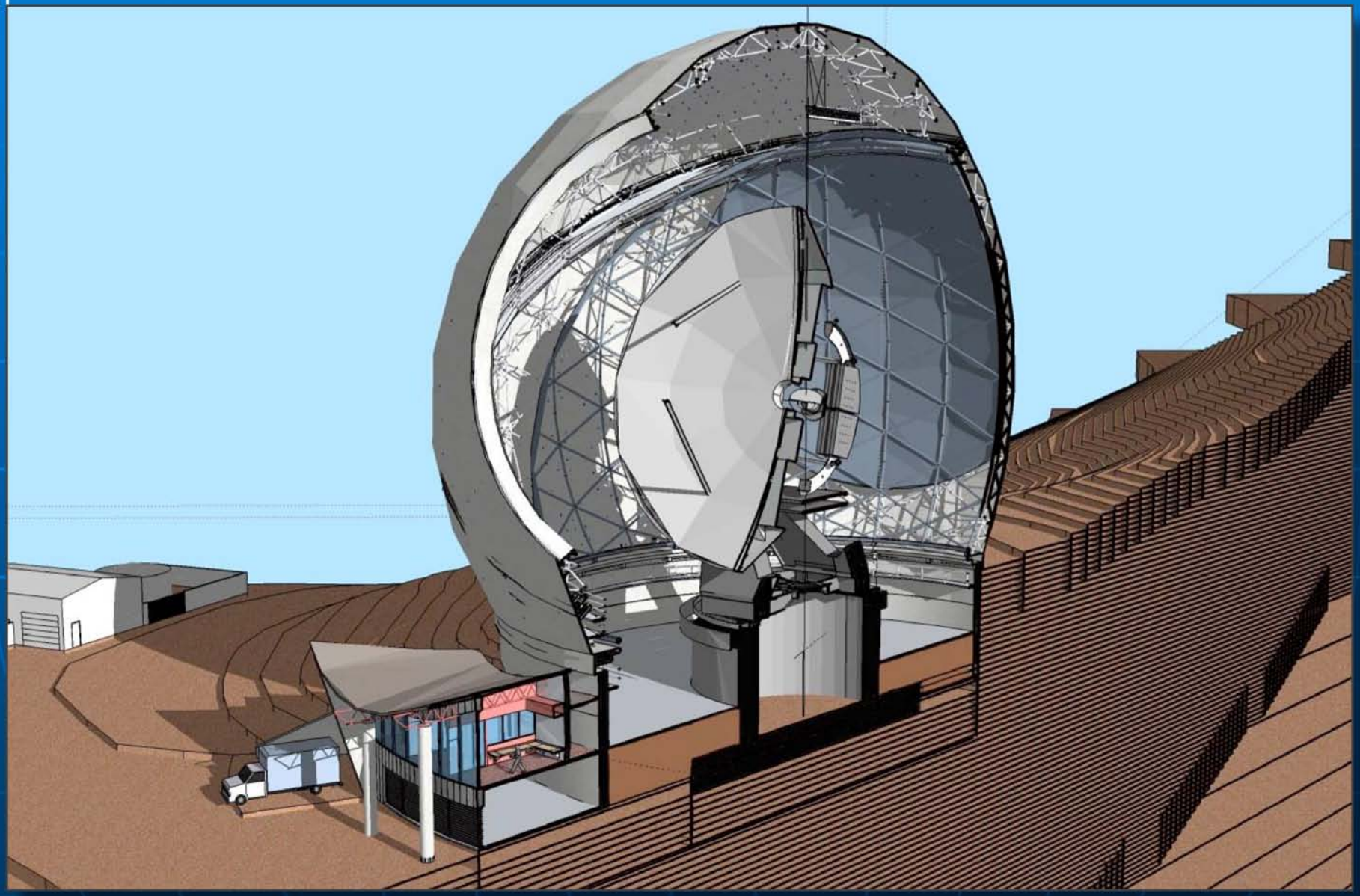

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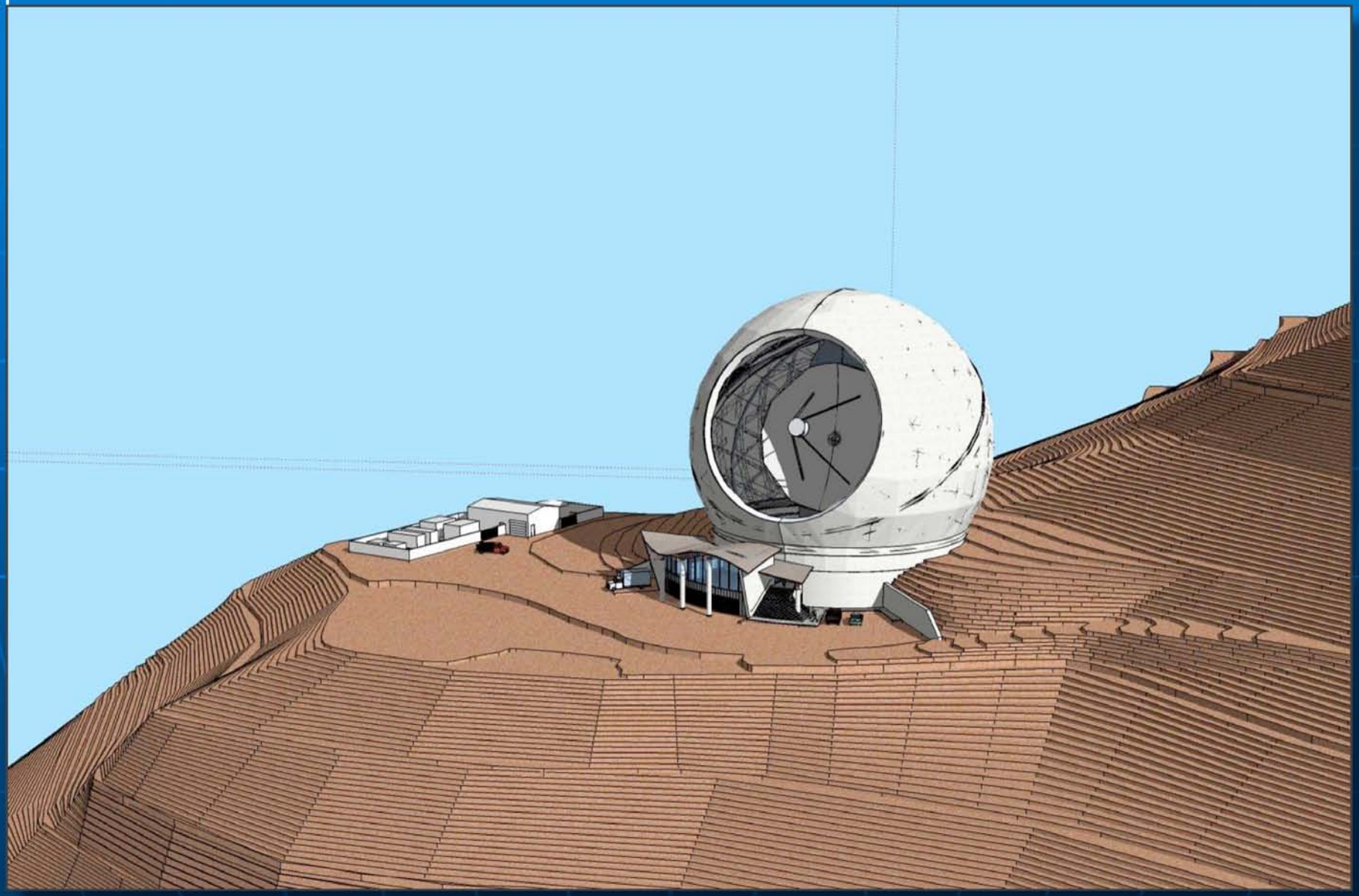
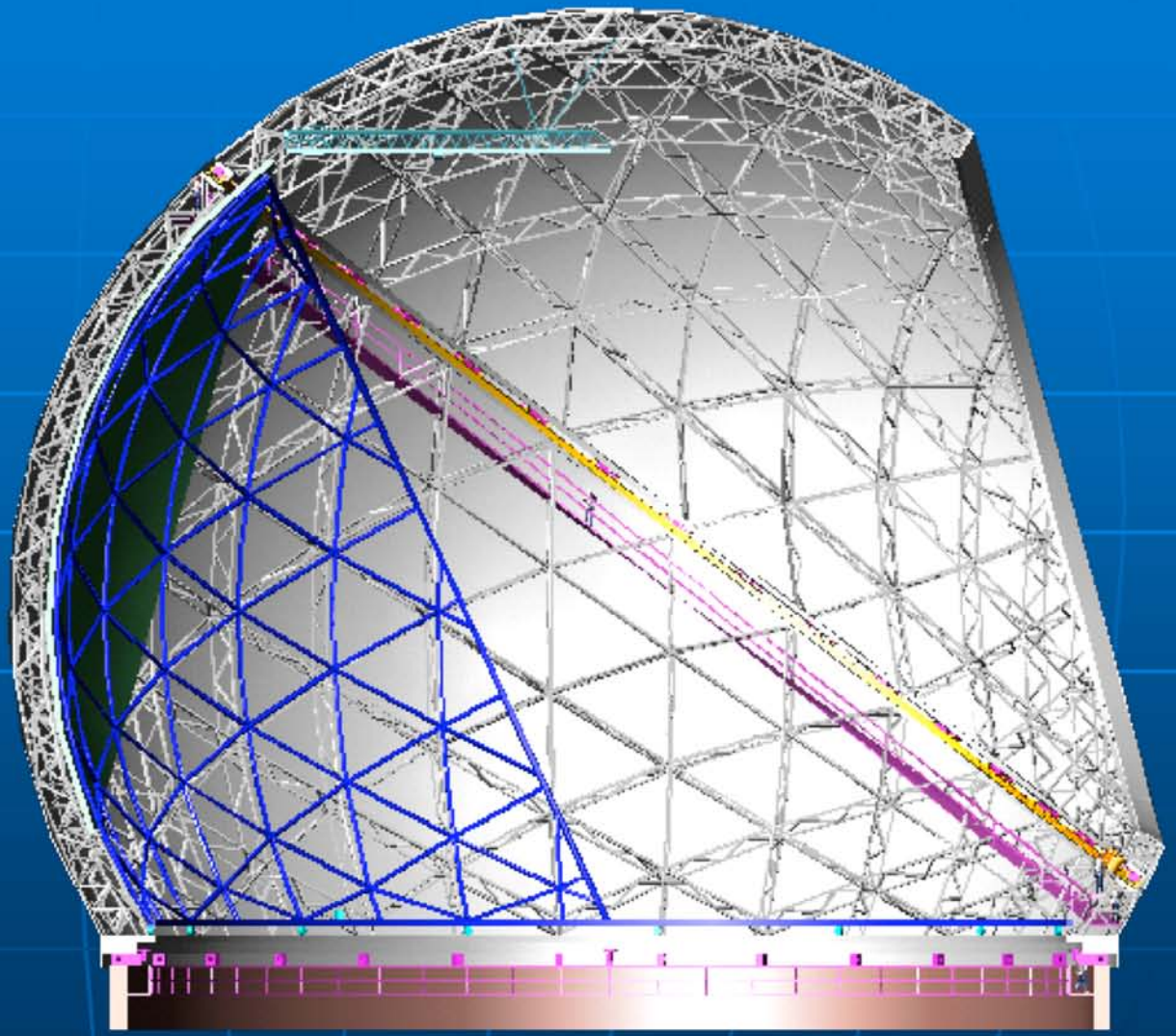


Site & Facility Design

Telescope Dome Concept

- 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



Calotte Uses 6x Less Power

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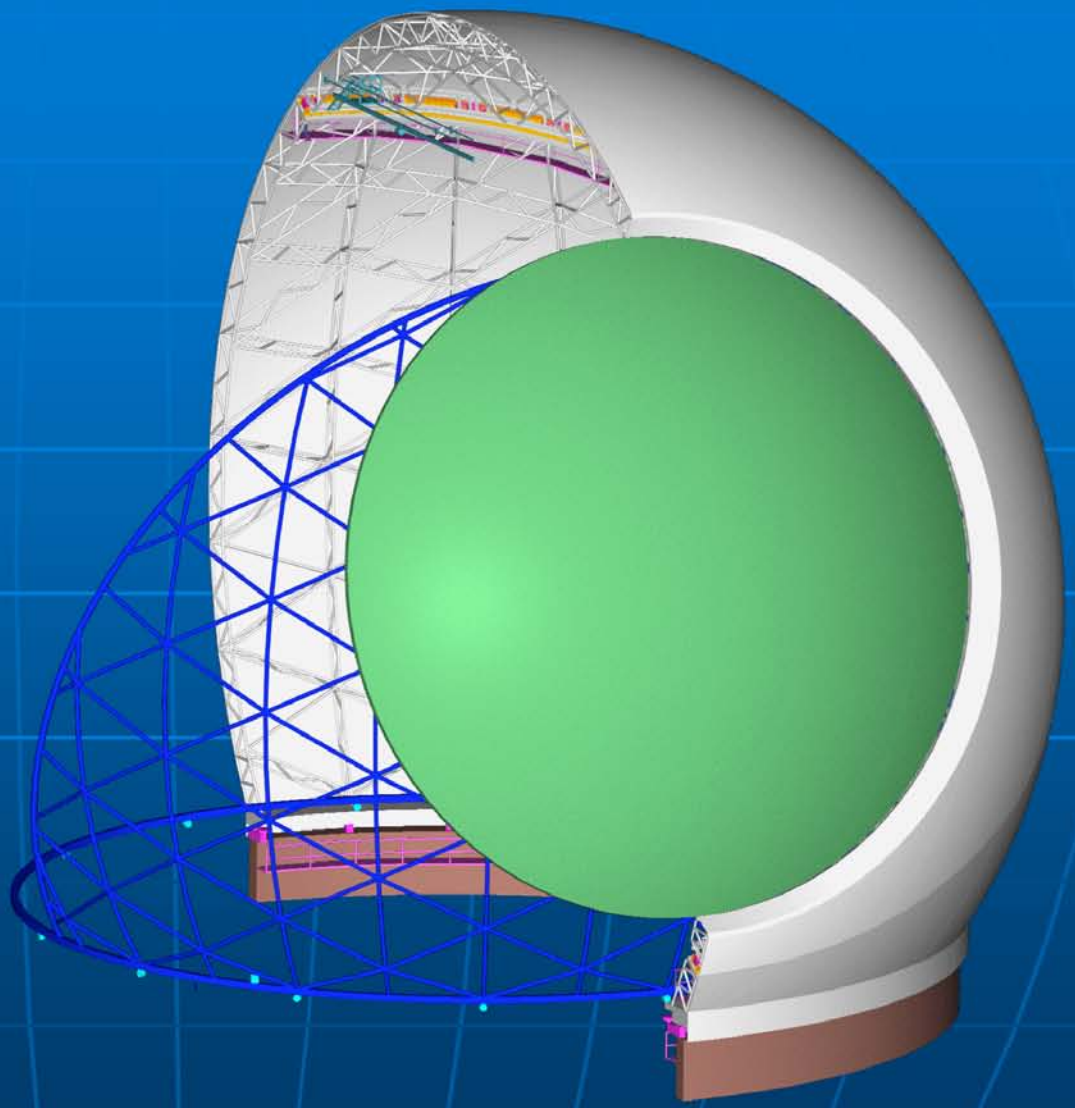

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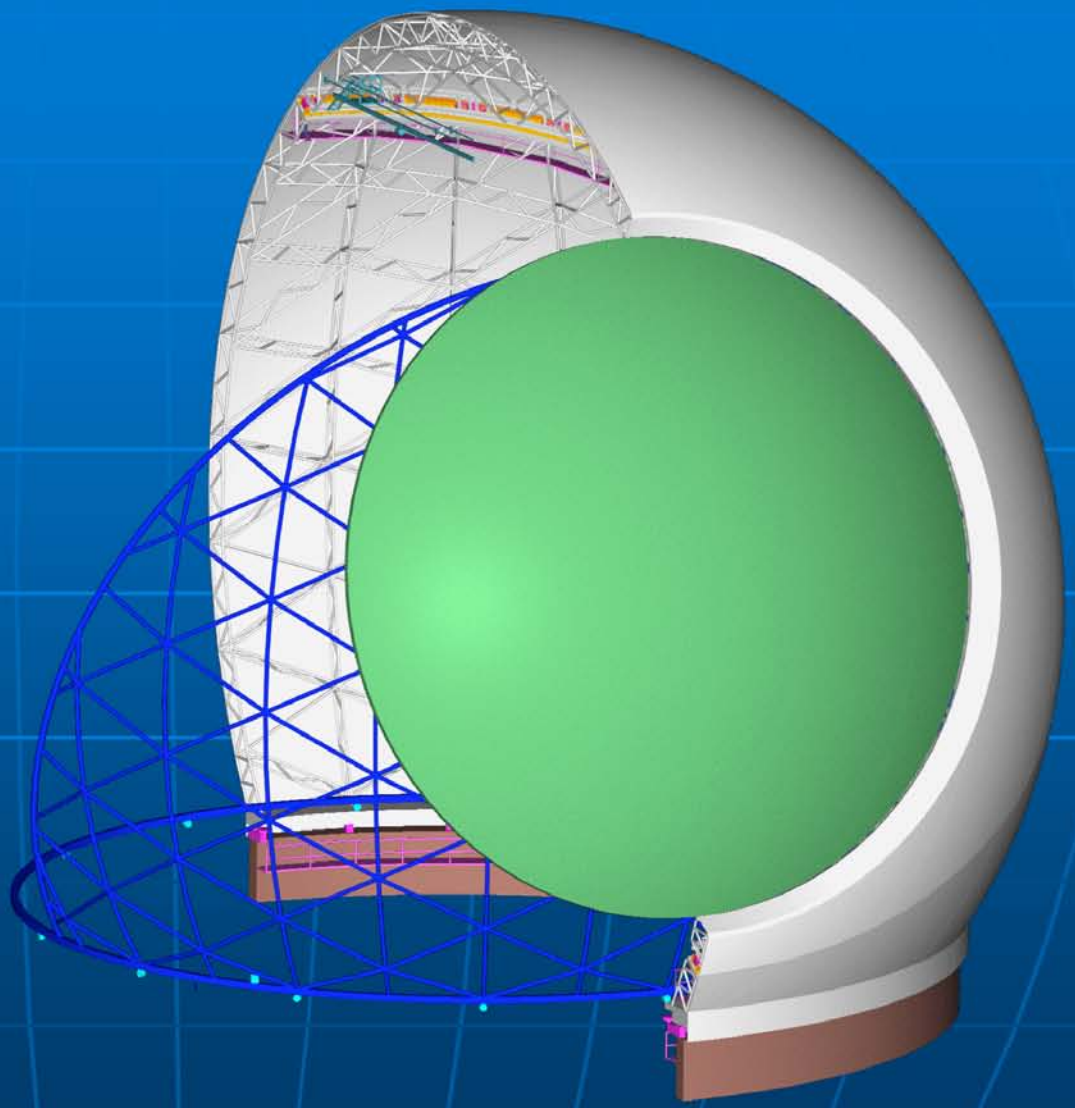
Telescope Dome Concept

- 3 Meetings with AMEC in the Past Year
- Much Funded Work by TMT Project
- Tilted Rotation Stage Major Technical Challenge
- 2 Meetings with MERO TSK, Germany
- Lower Cost/Weight Structural Concept by MERO, Germany



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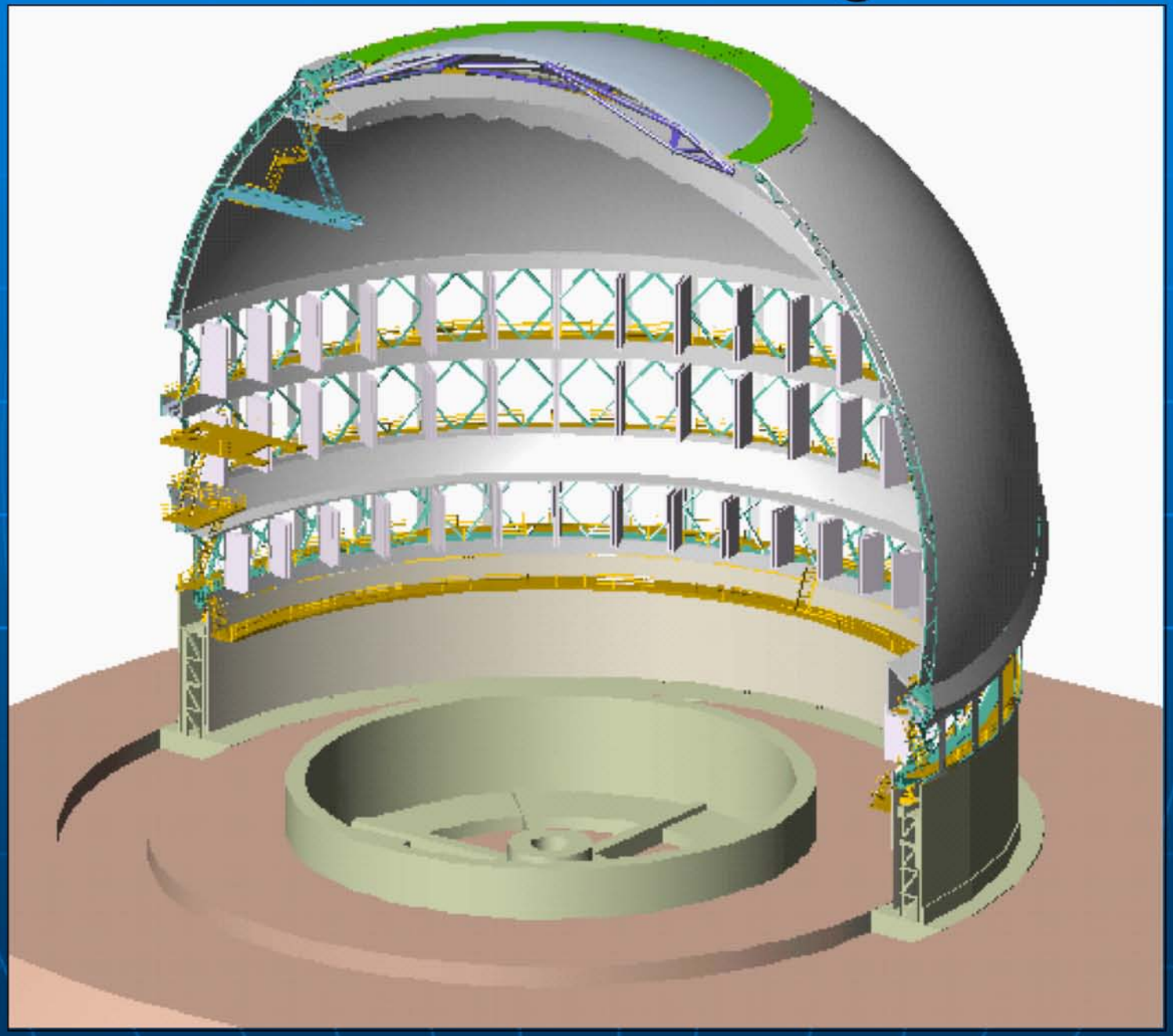
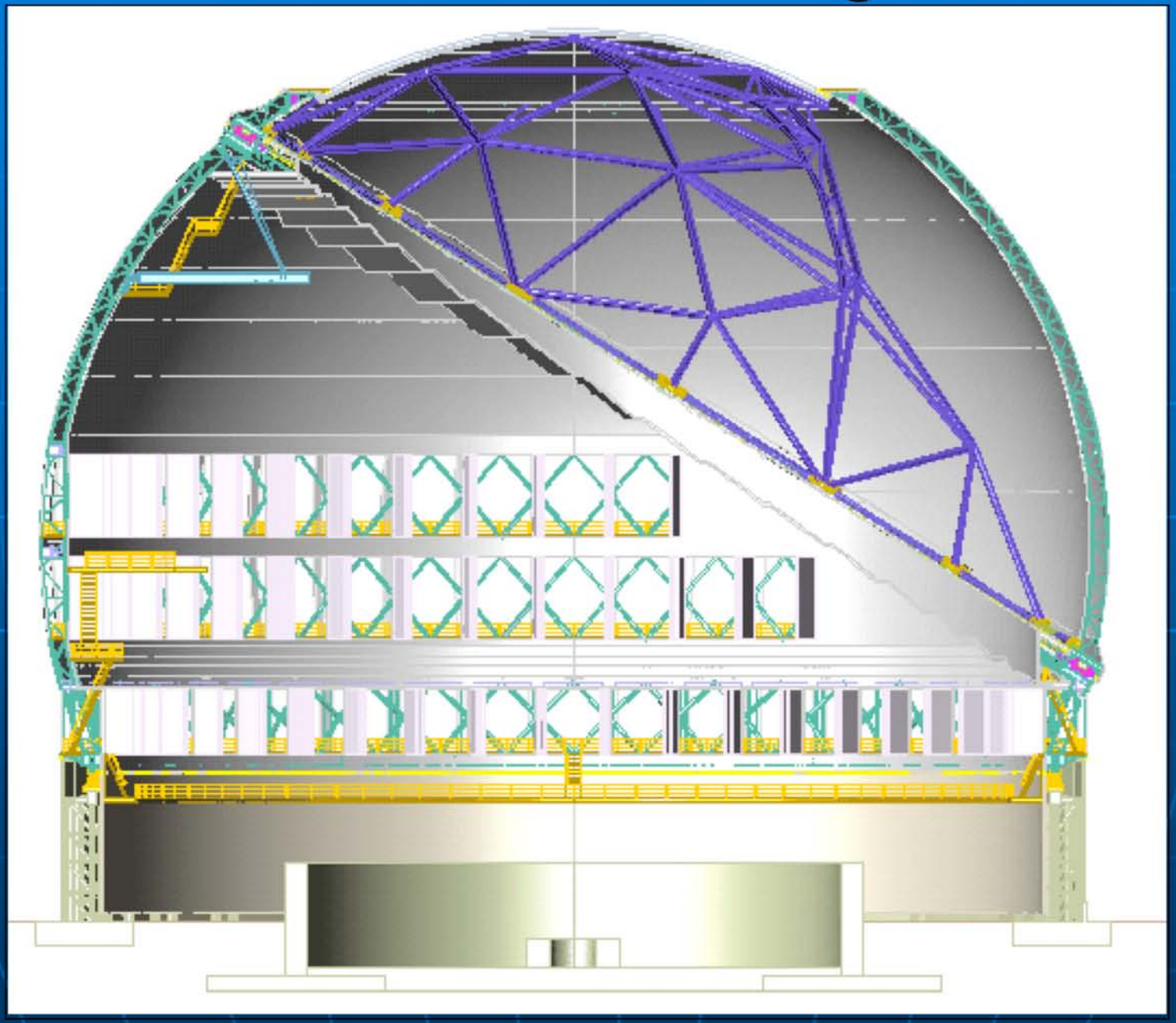
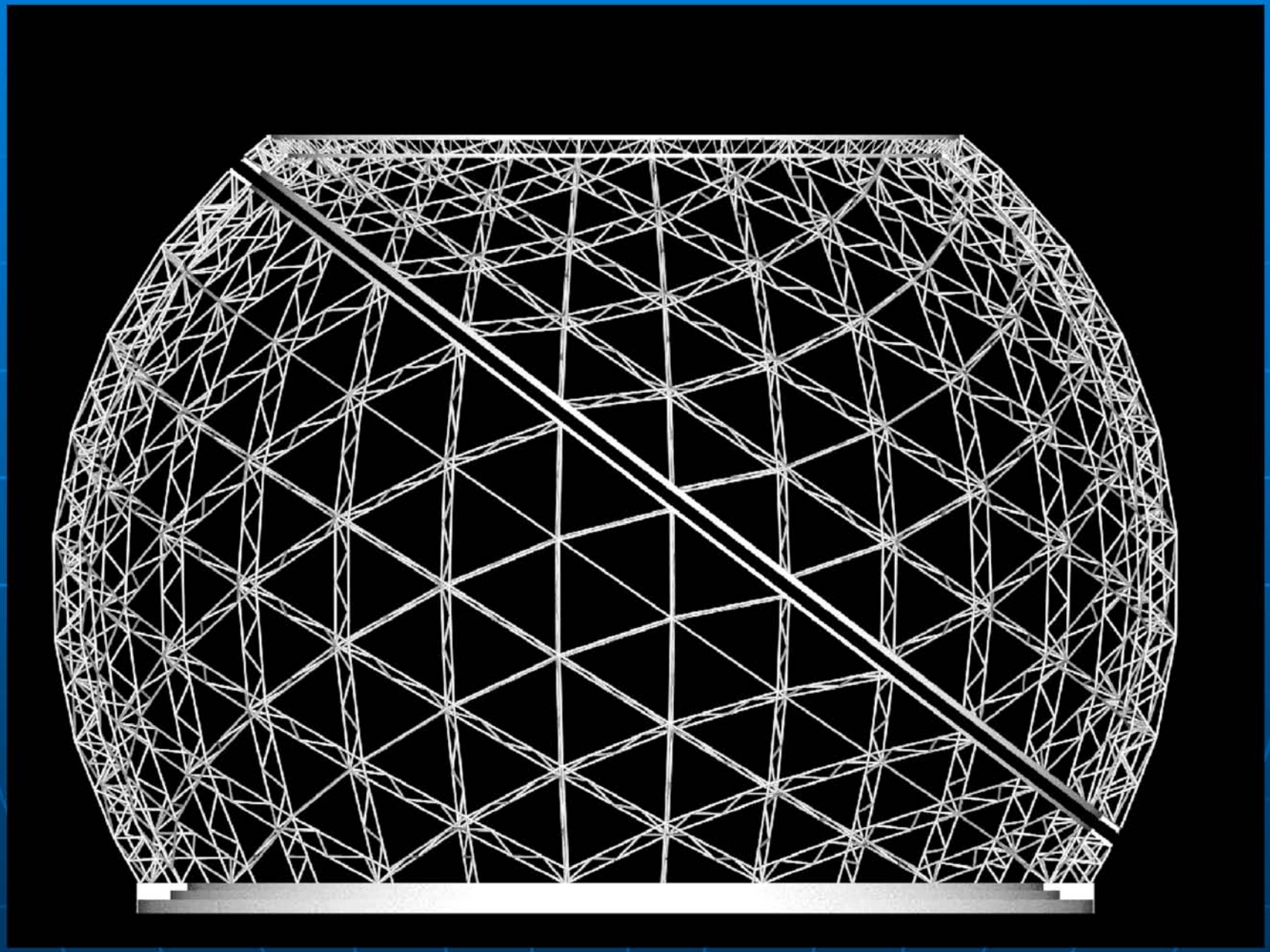
TMT Design



TMT Design



AMEC and Mero TSK Designs



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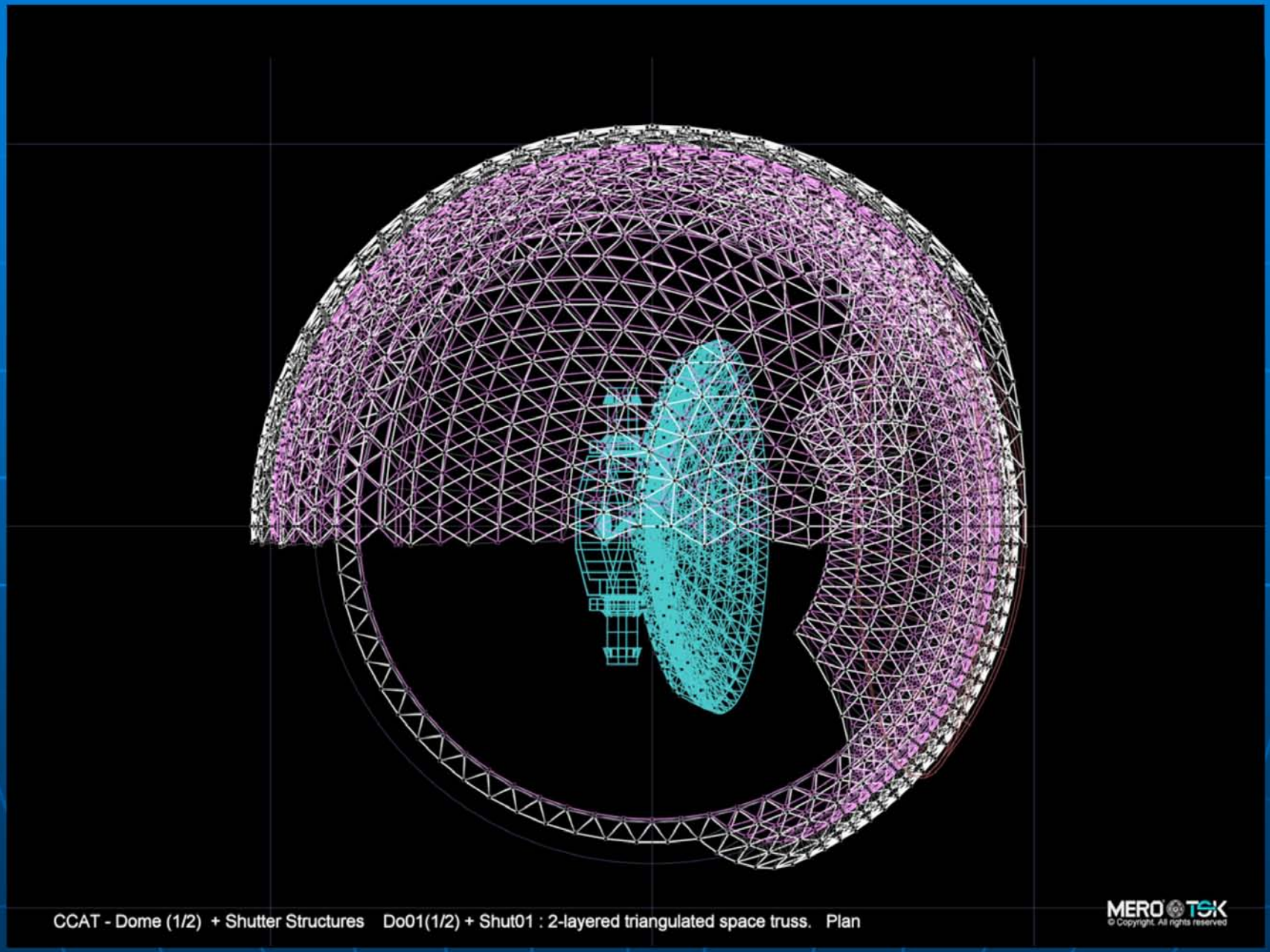

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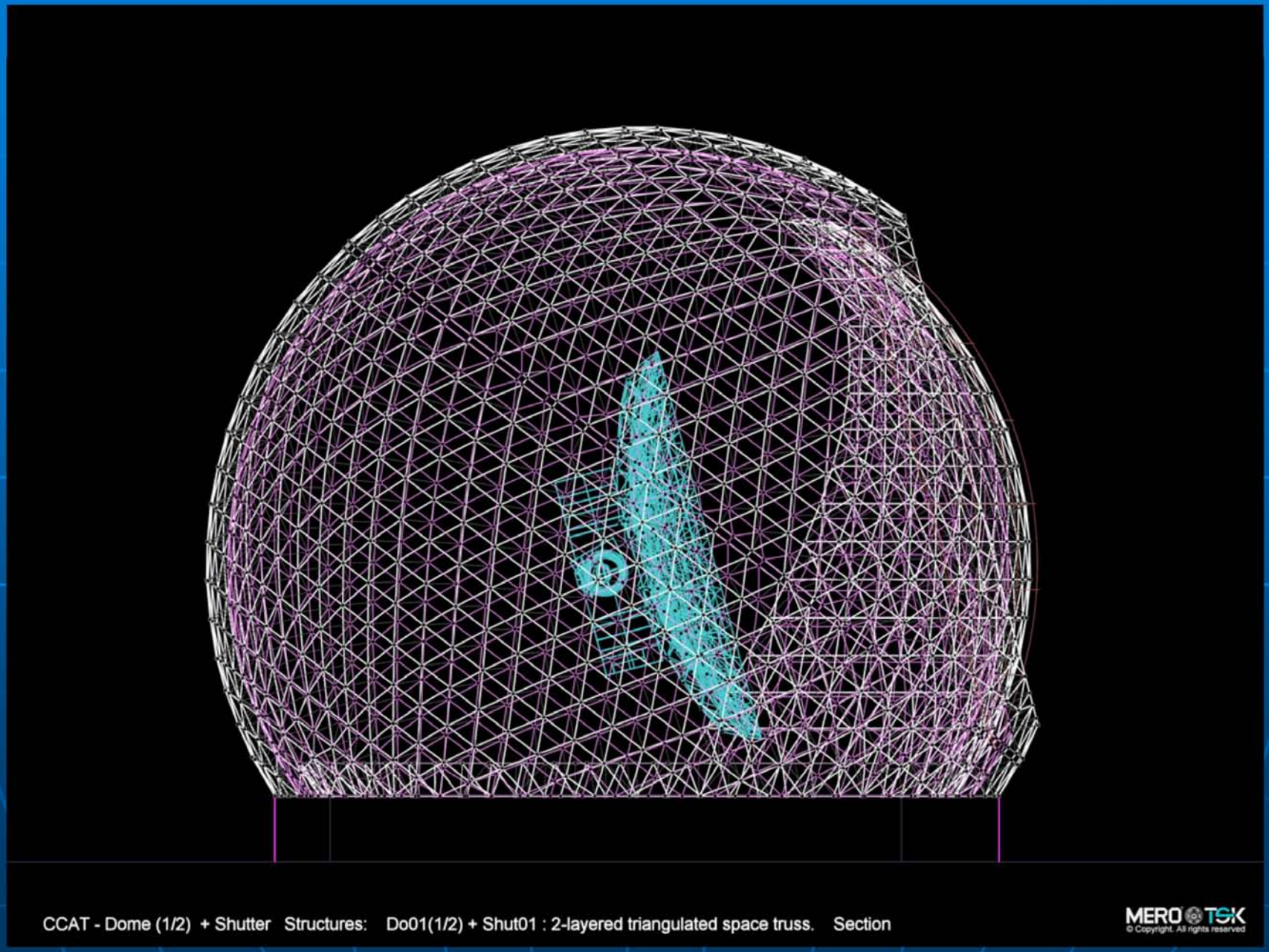

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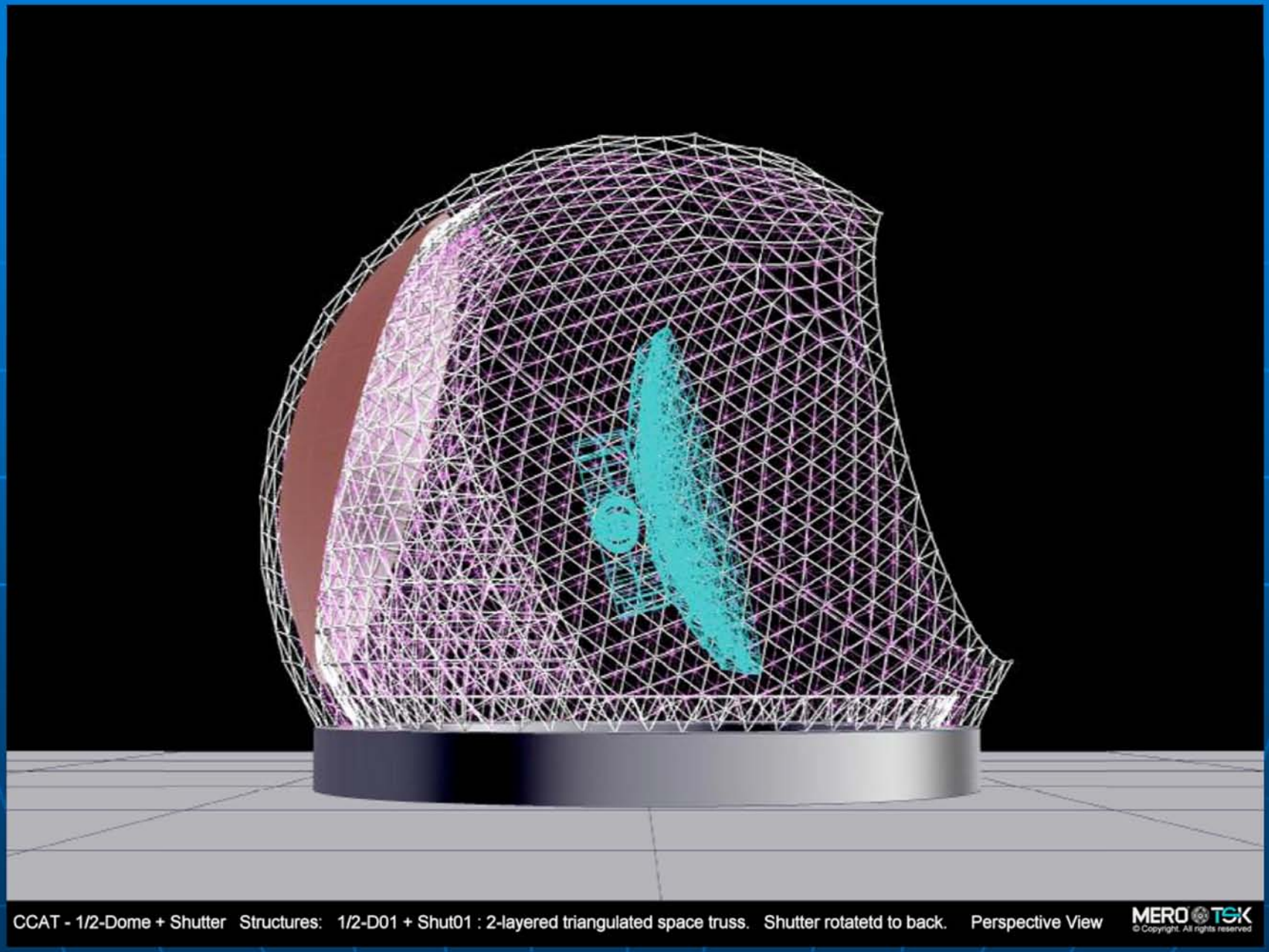

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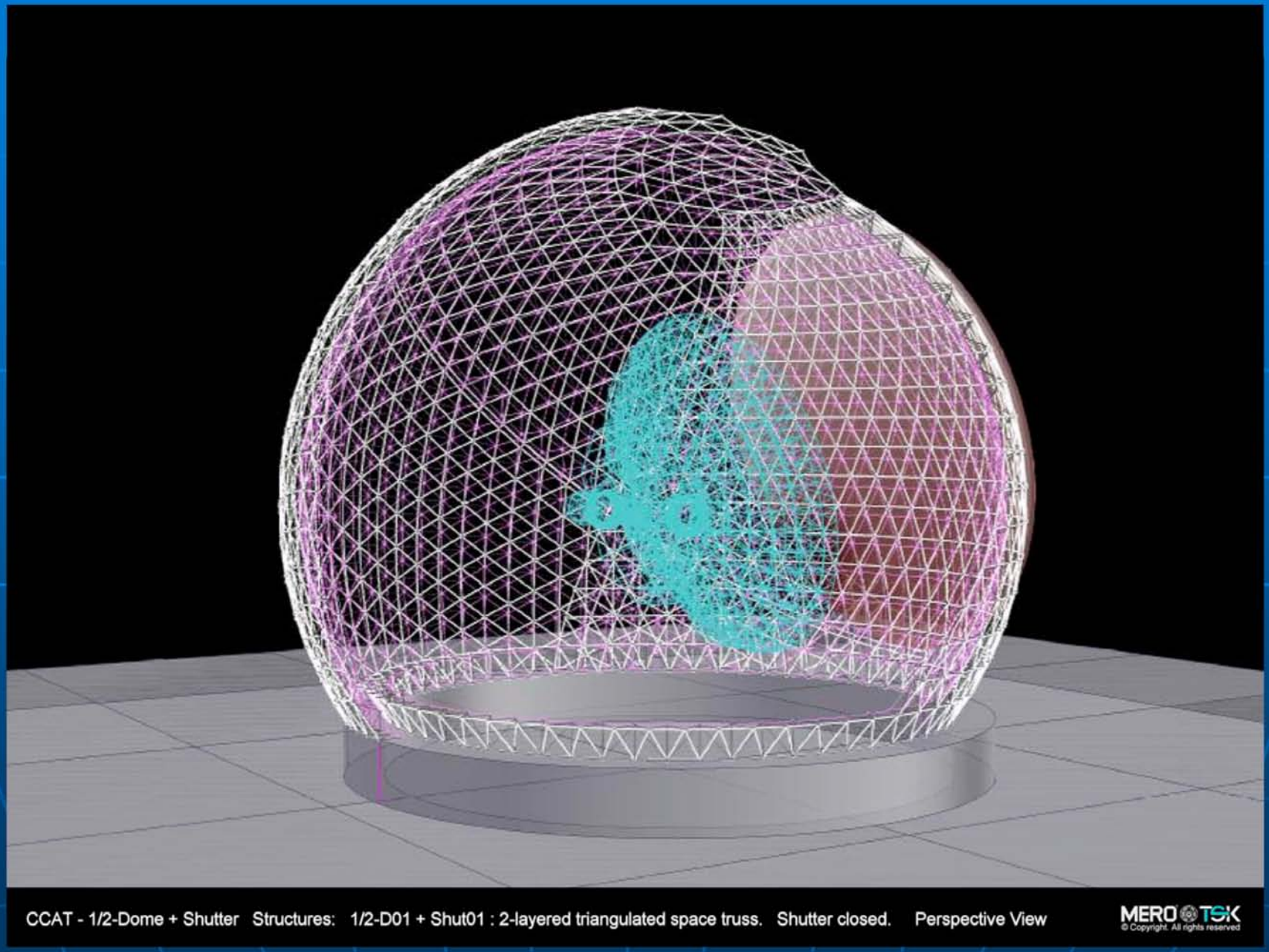

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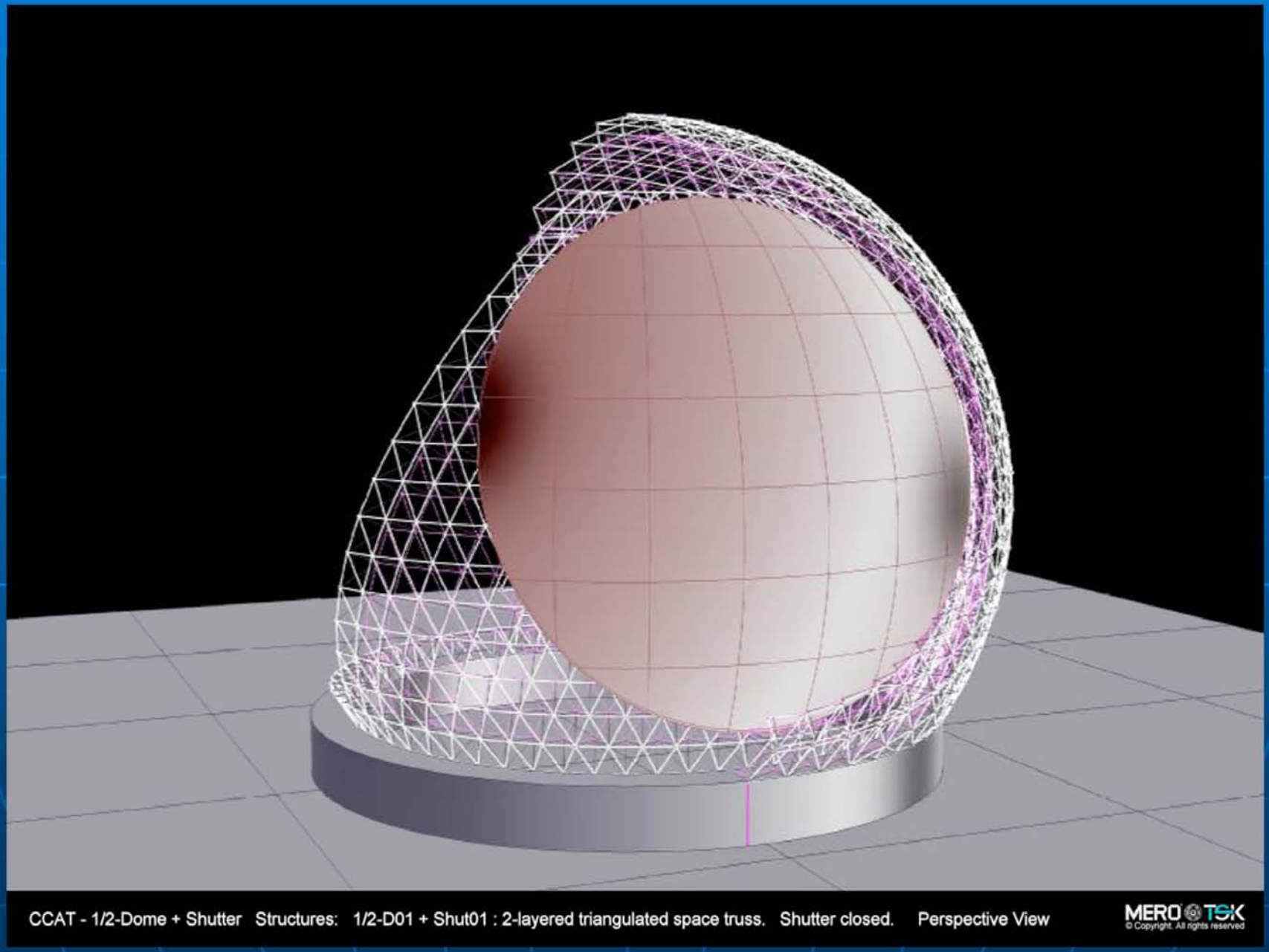
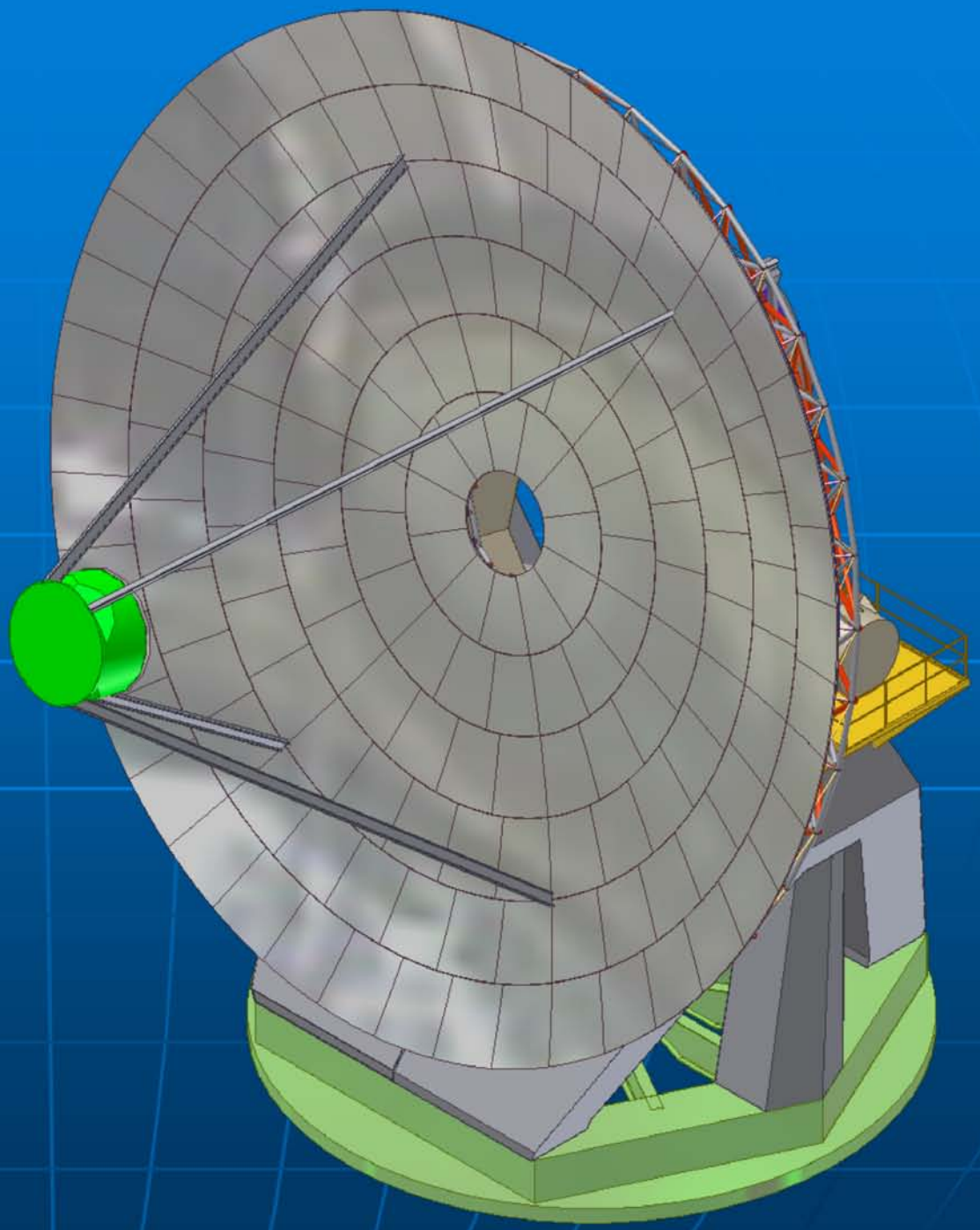


CCAT Mount

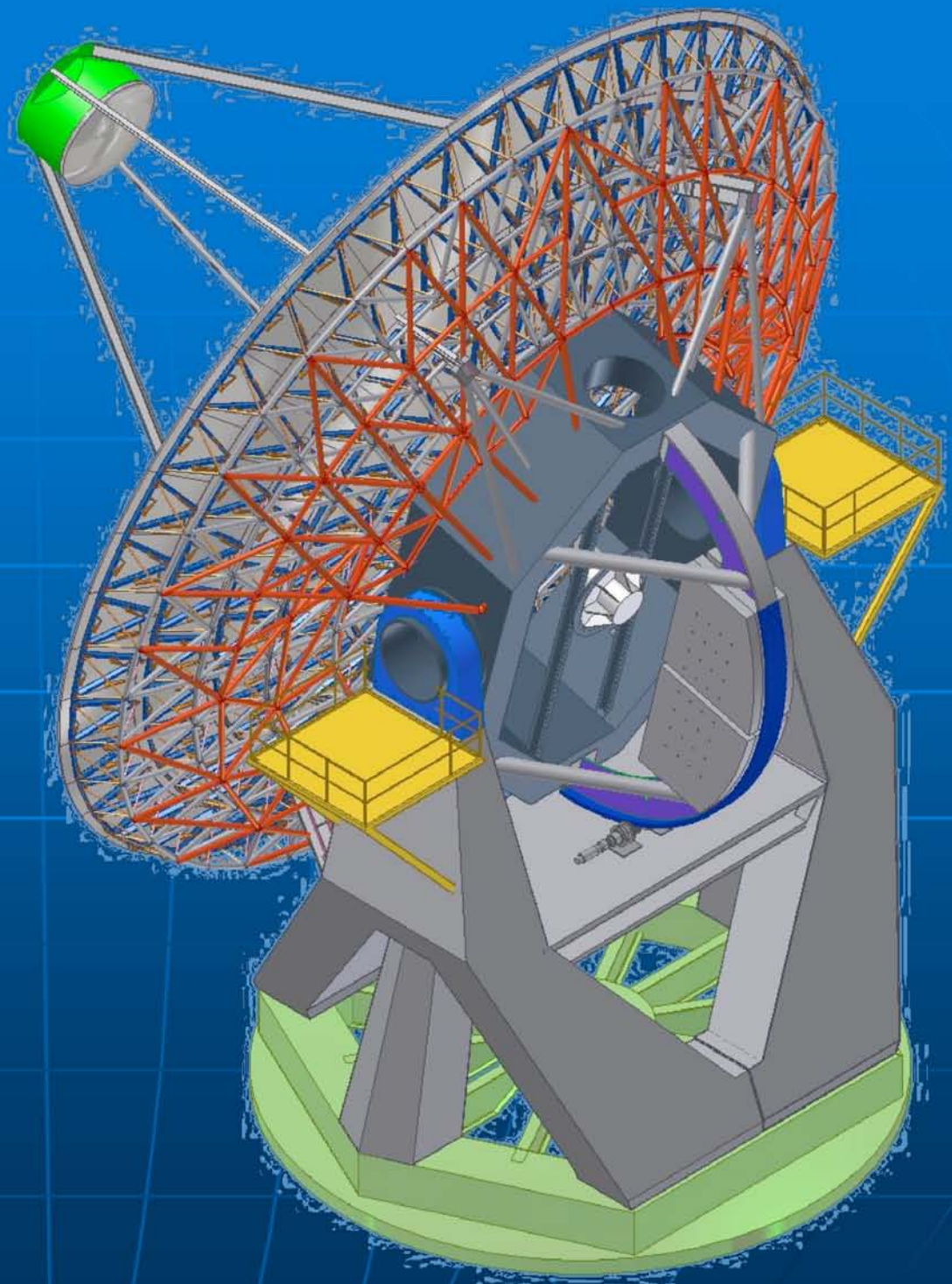
- Design by Vertex RSI
- Uses Approaches from Radio and Optical Telescopes
- Hydrostatic & Rolling Element Bearings

Pointing	2 arcsec RMS
Offset Pointing RMS	<0.5 arcsec
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



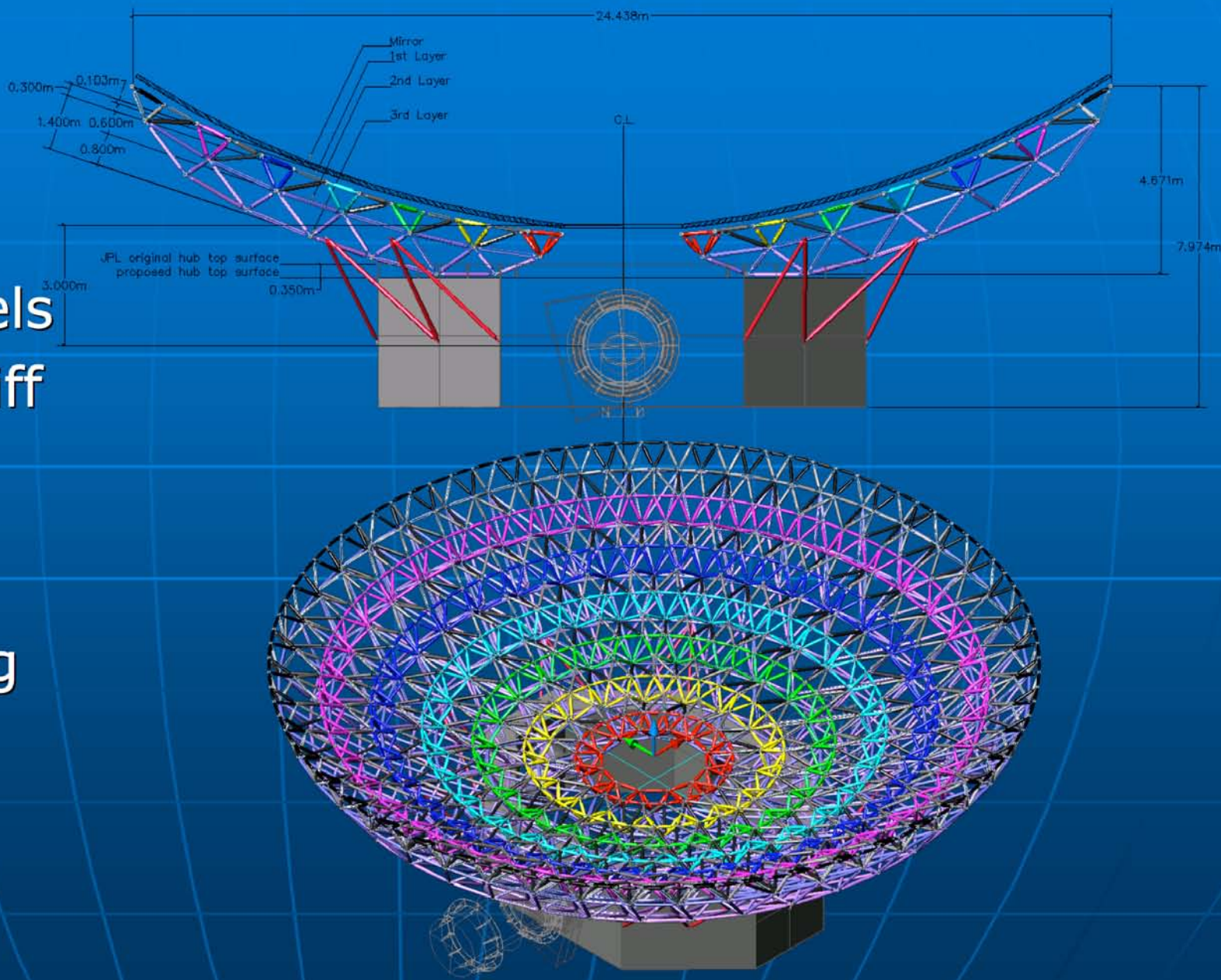
CCAT Mount

- 2 Meetings with VRSI in the Past Year
- Discussions of Design Changes to Lower Weight and Cost
- Brokered Meeting with Vertex Antennentechnik in Duisburg, Germany
  - Provider of ALMA Antennas
  - Same Company, Different Branch
  - Vow to Work Together to Apply Best Knowledge and Skills



Primary Mirror Truss Design

- Truss Supports Primary Mirror Panels
- Must be Stiff and Light
- Design by Stutzki Engineering
- Funded by JPL



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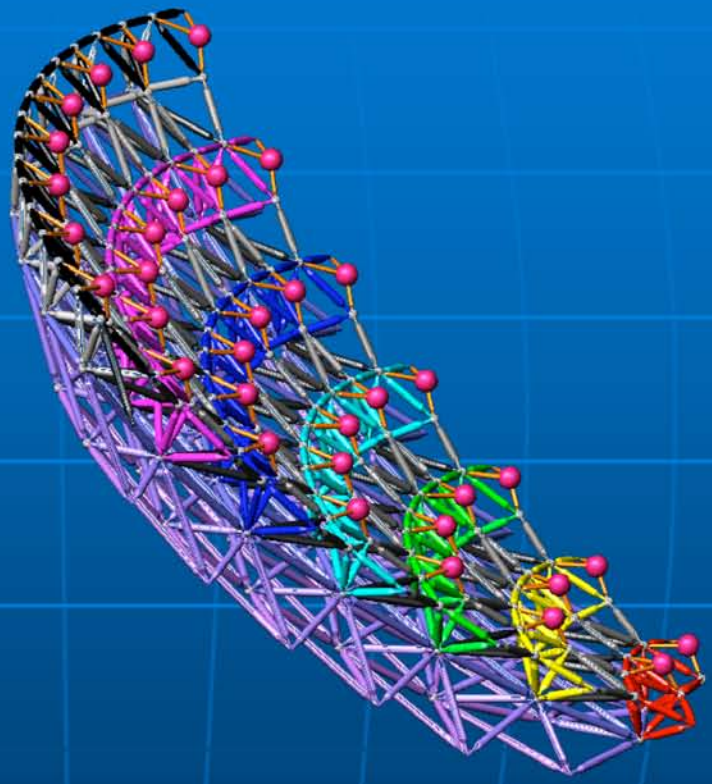

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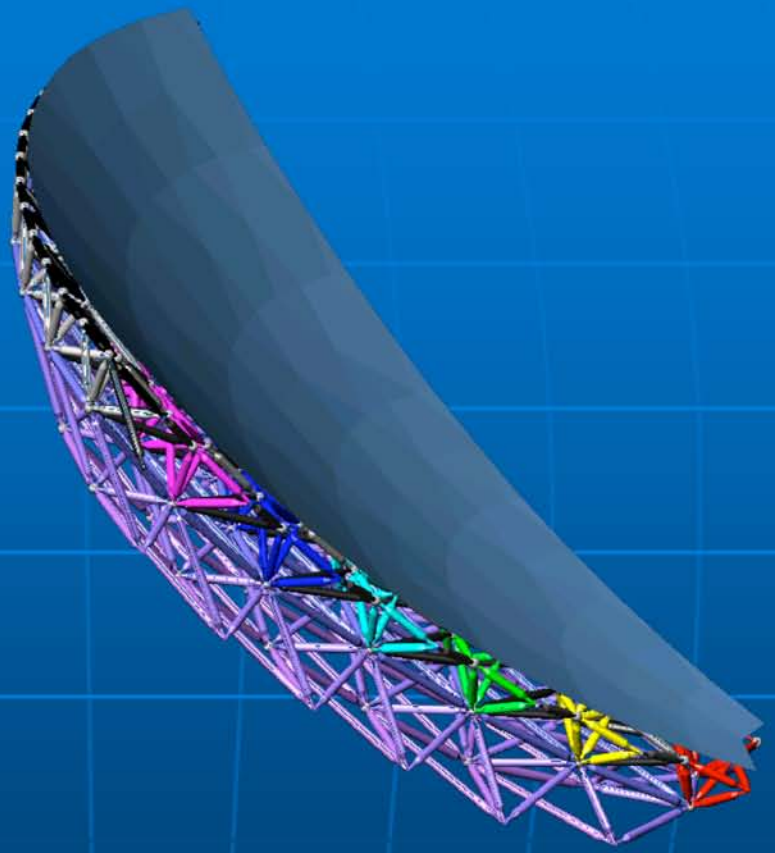
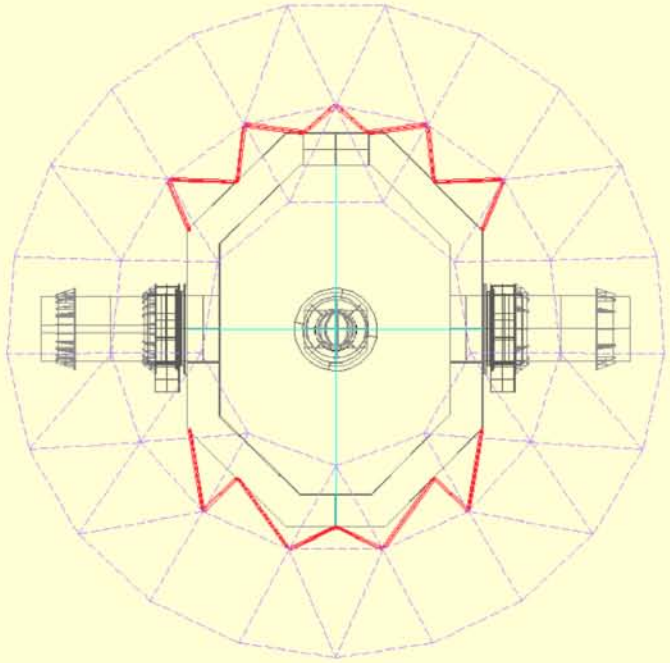


PM Truss Design

- Initial Geometric Concepts
- Determines Gravity Deformation
- Explores Mode Frequencies and Shapes
- Layered Design
- Uses MERO Type Bolted Nodes
- Packs Small Assembles Easily
- Accuracy Built In Not Adjusted



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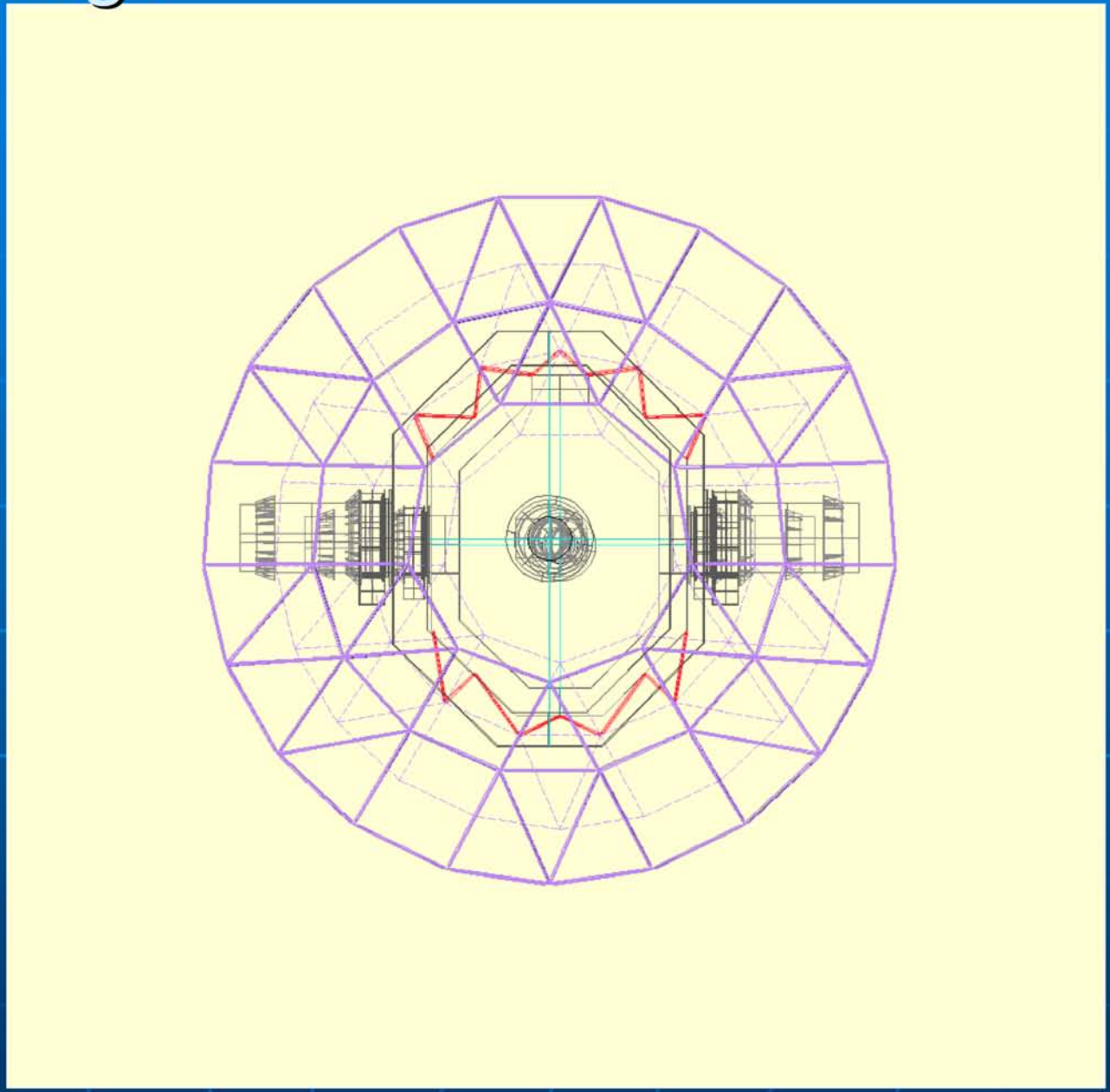

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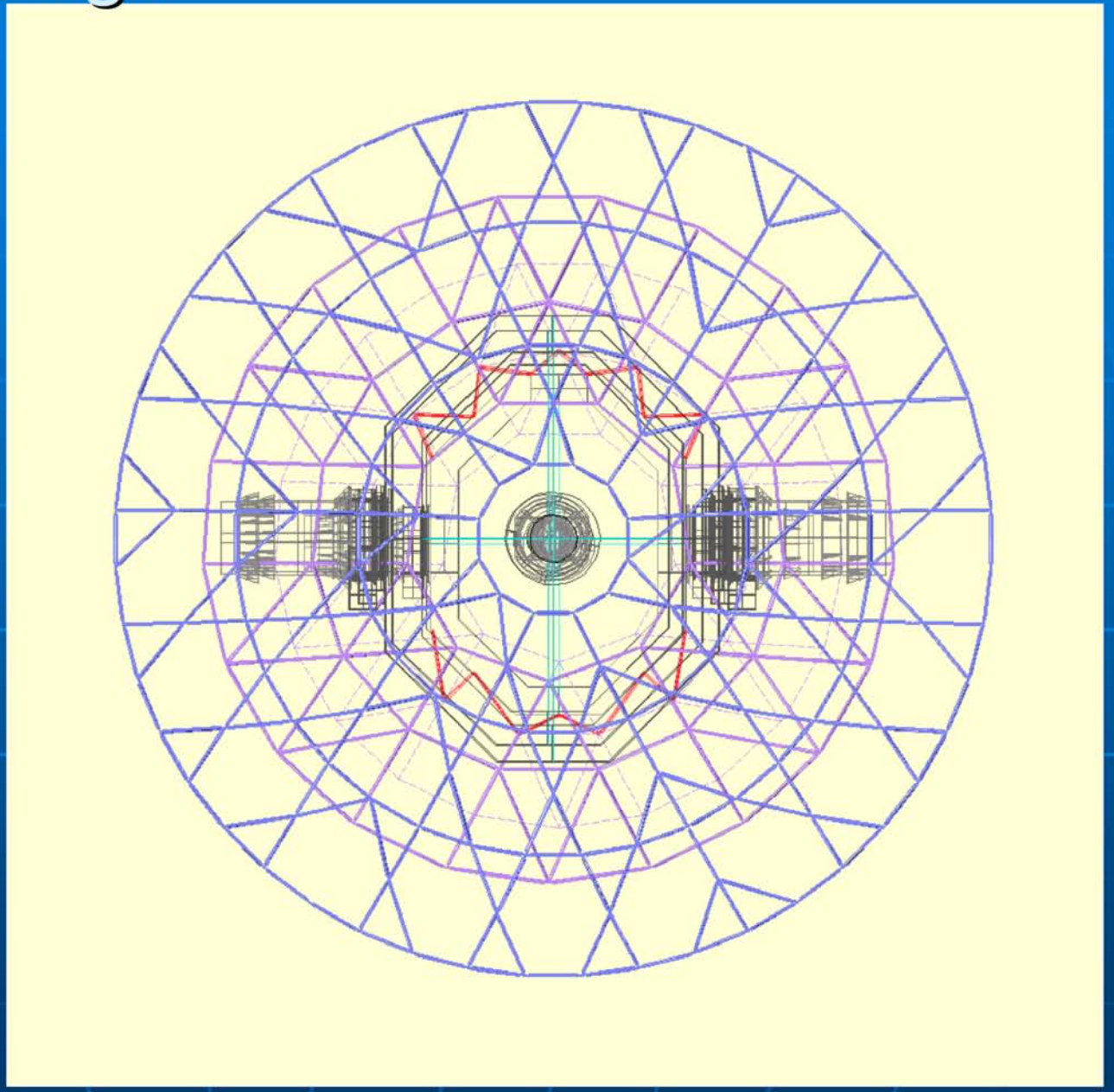

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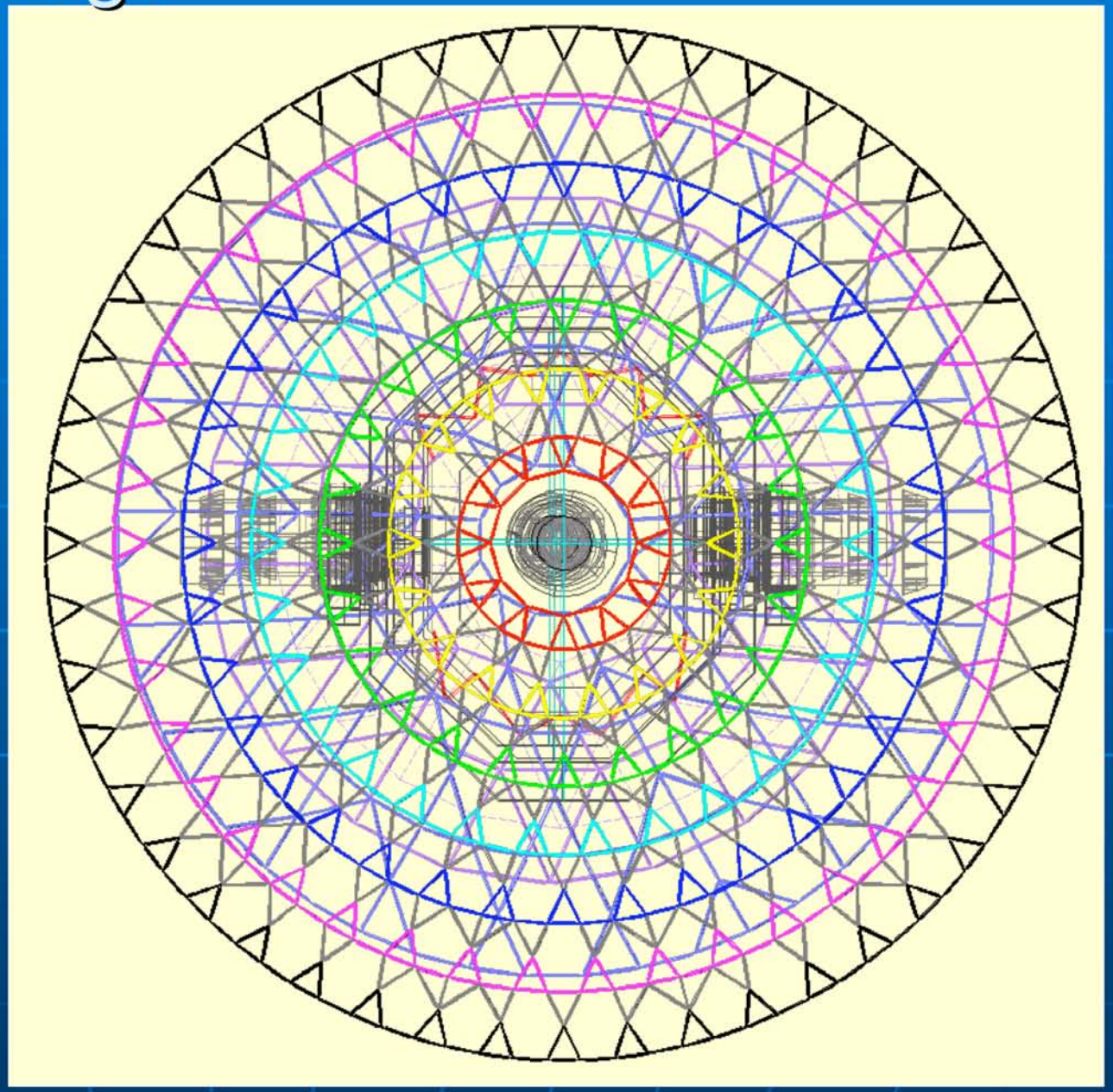
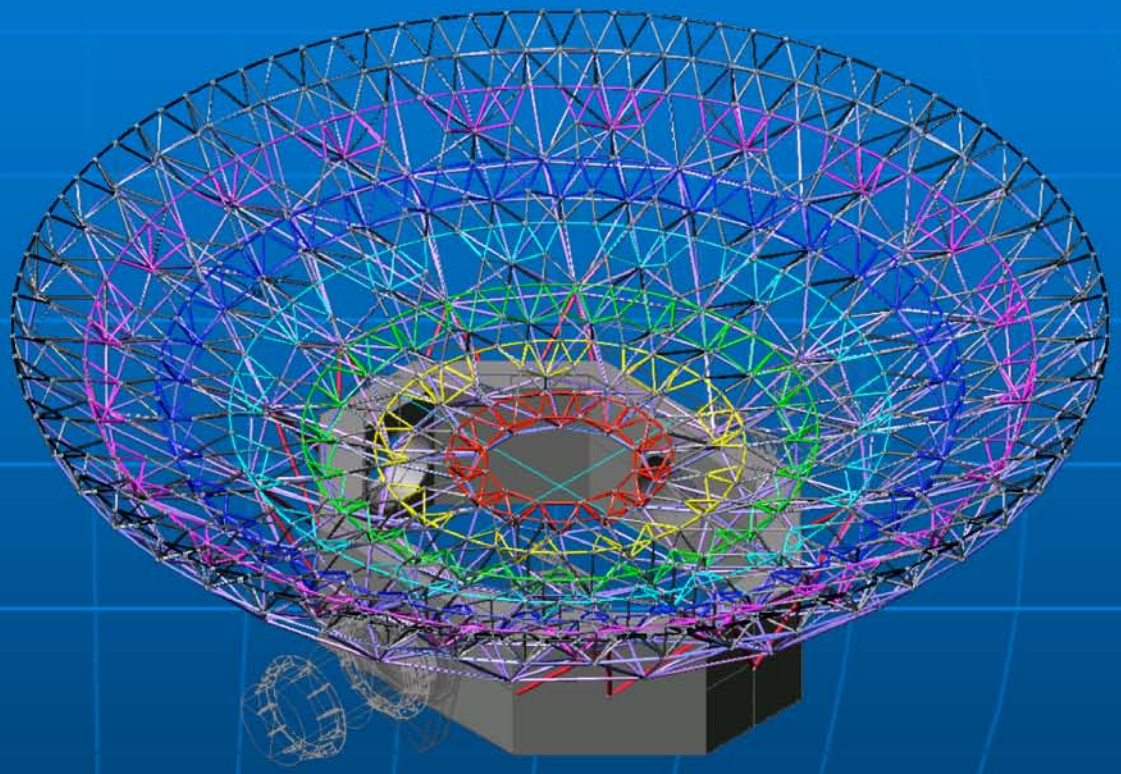


PM Truss Concept

- Mass (Metric Tons)
  - Struts 12.5
  - Nodes 4.7
  - Mirrors 5
  - Actuators & Sensors 1.5
  - Total Dead Load 23.7
- Number of Members
  - 2892
  - 30% Fewer than 1st Design
- Gravity Deformation
  - ~ 5 mm Maximum
  - <1/4 Actuator Range
- 1st Natural Frequency
  - 5.3 Hz



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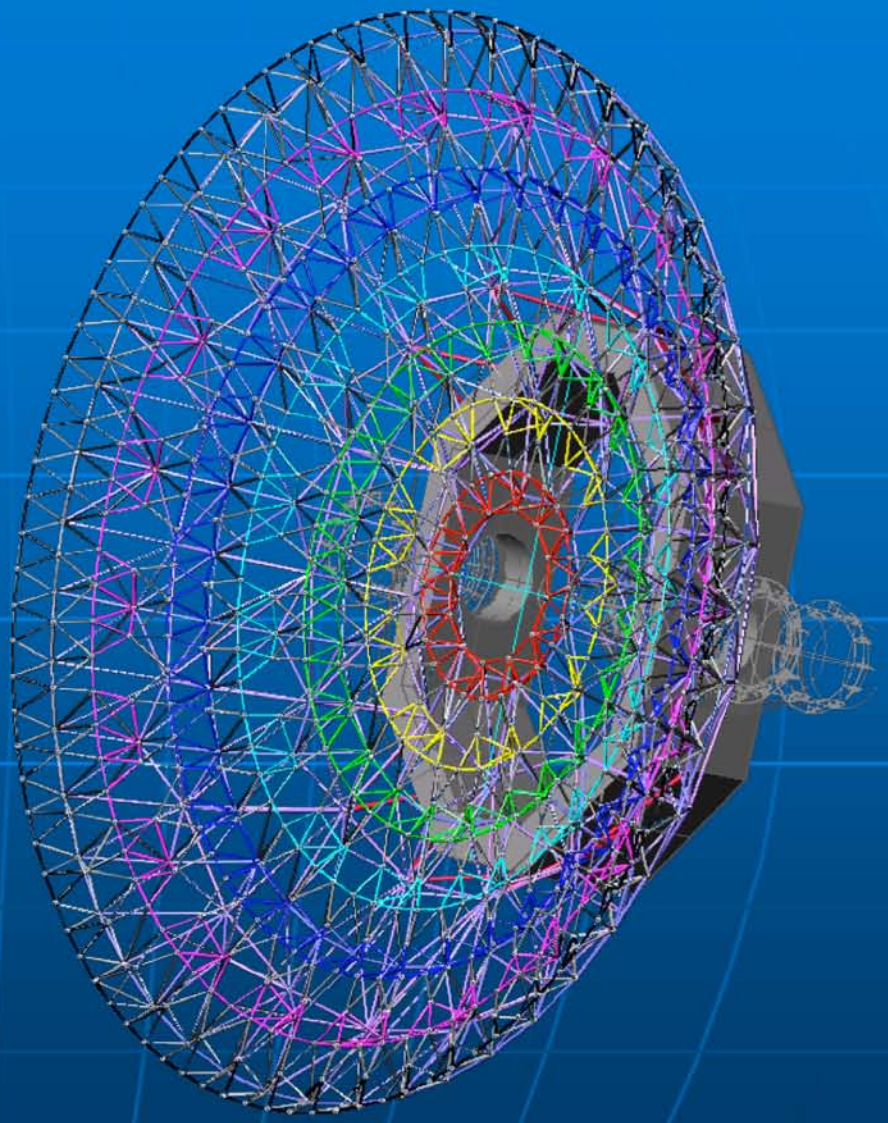
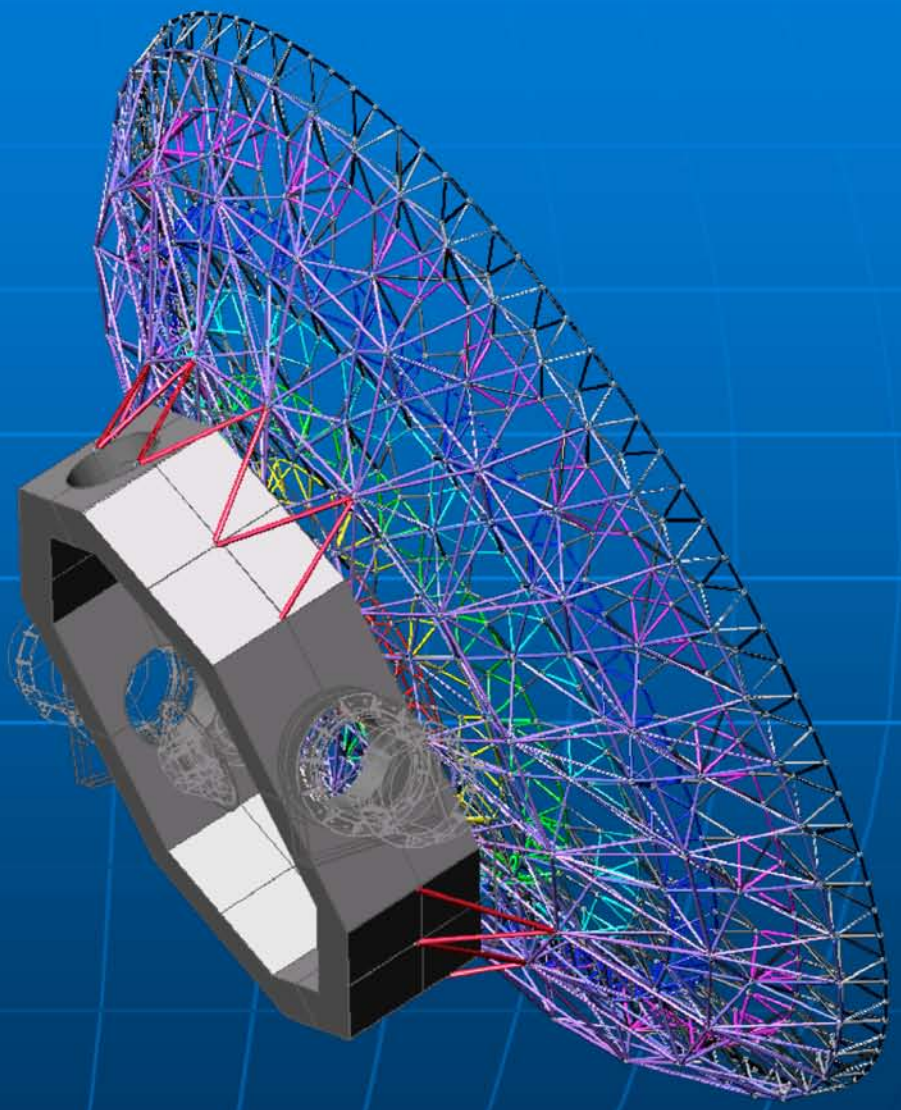
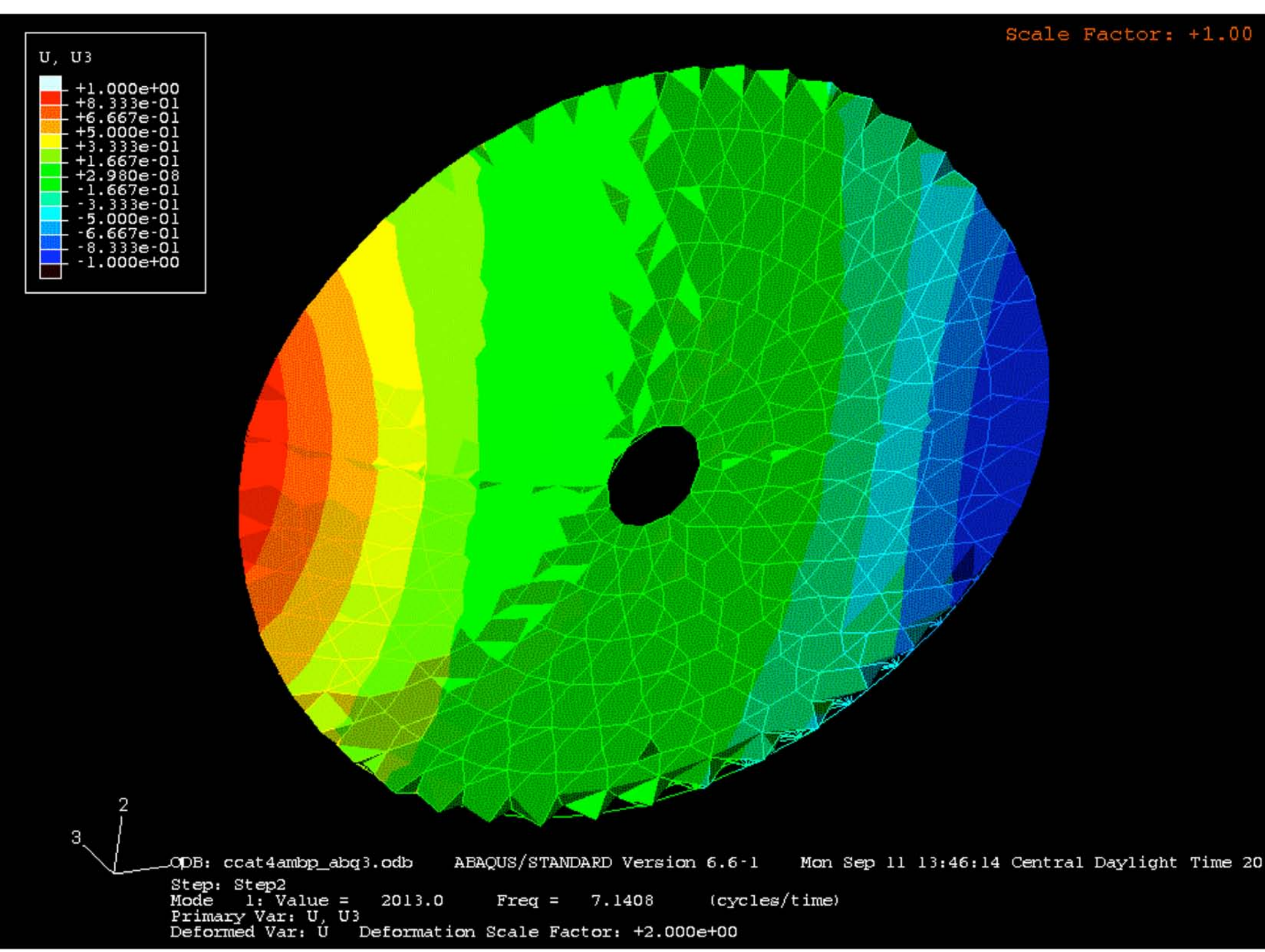


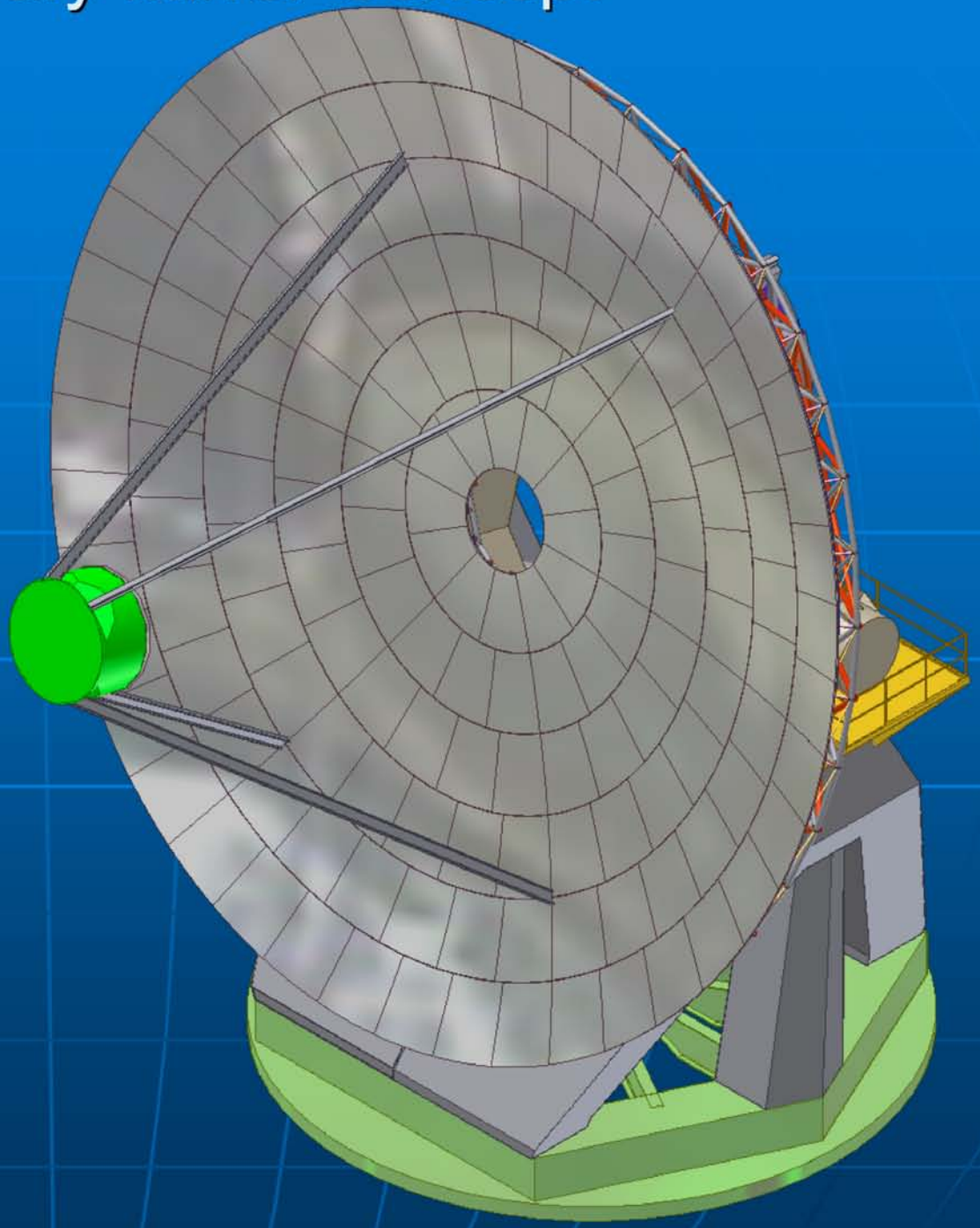
PM Truss Concept

- Mass (Metric Tons)
  - Struts 12.5
  - Nodes 4.7
  - Mirrors 5
  - Actuators & Sensors 1.5
  - Total Dead Load 23.7
- Number of Members
  - 2892
  - 30% Fewer than 1st Design
- Gravity Deformation
  - ~ 5 mm Maximum
  - <1/4 Actuator Range
- 1st Natural Frequency
  - 5.3 Hz



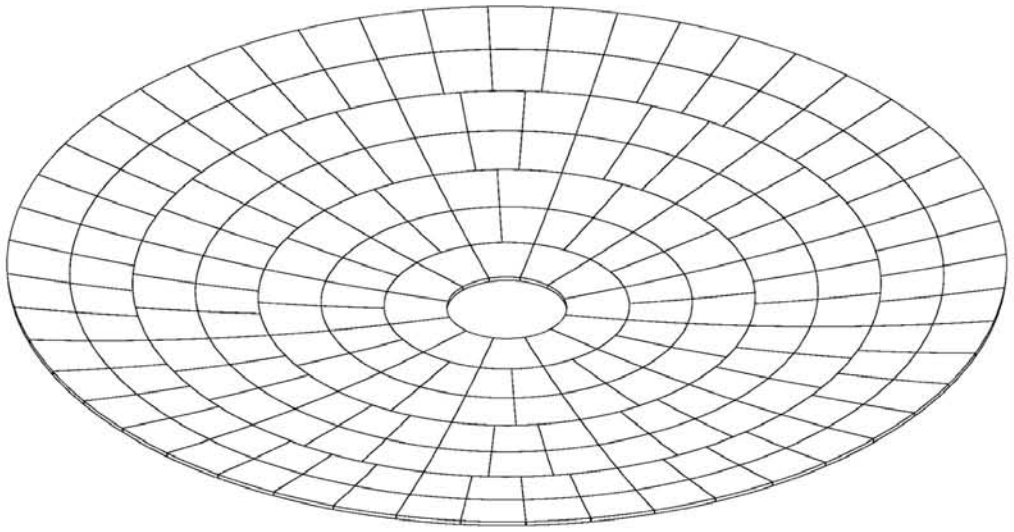

Scale Factor: +1.00
U, U3
+1.000e+00
+8.333e-01
+6.667e-01
+5.000e-01
+3.333e-01
+1.667e-01
+2.980e-08
-1.667e-01
-3.333e-01
-5.000e-01
-6.667e-01
-8.333e-01
-1.000e+00
2
3
ODB: ccat4ambp_abq3.odb ABAQUS/STANDARD Version 6.6-1 Mon Sep 11 13:46:14 Central Daylight Time 20
Step: Step2
Mode 1: Value = 2013.0 Freq = 7.1408 (cycles/time)
Primary Var: U, U3
Deformed Var: U Deformation Scale Factor: +2.000e+00

Primary Mirror Concept



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

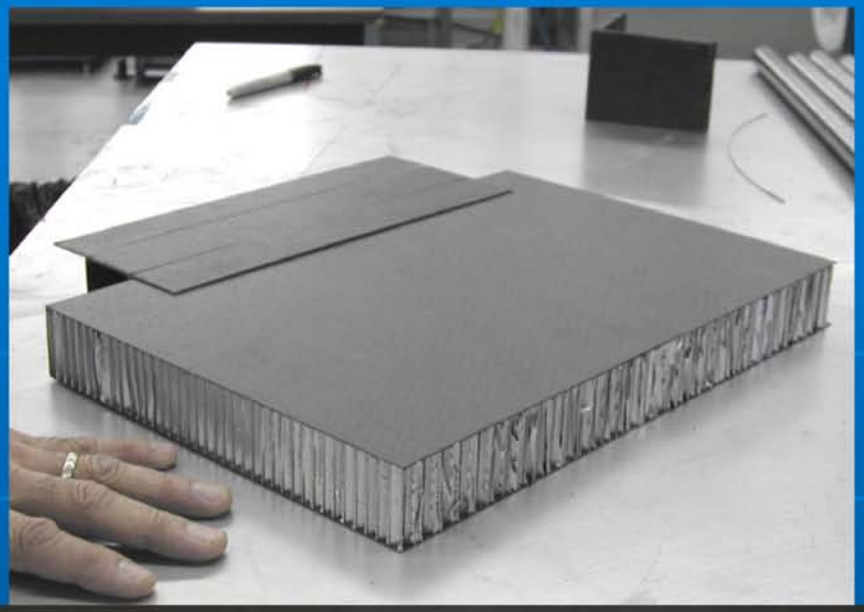


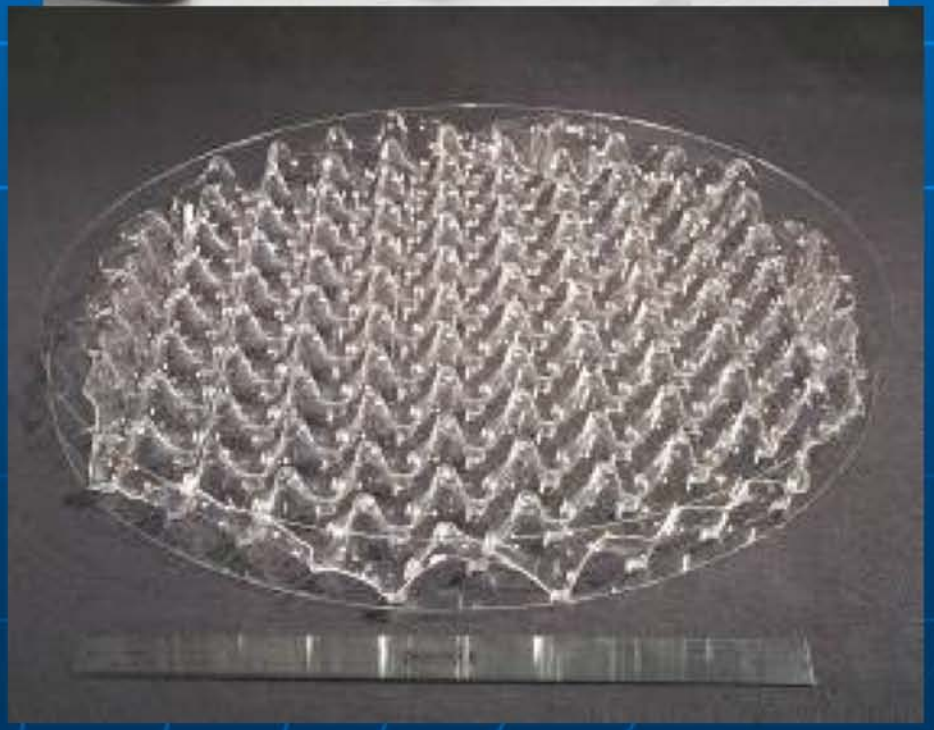
Primary Mirror Concept

- CFRP Truss May be Affordable After All
- Polytec Has New Lower Cost Actuator
- JPL Segment Modeling Effort Optimized Segmentation Pattern
- D. Woody Performed Initial Control and Segment Support Analysis

Primary Mirror Panels

- Four Current Panel Approaches Considered
  - Carbon Fiber Epoxy and Aluminum Honeycomb
  - Precision Molded Lightweight Borosilicate
  - Ni/Al Sandwich
  - Al/Al Sandwich
- Panels Kinematically Supported on 3 Points by Bipod Flexures
- ~8 kg/m^2 Areal Density





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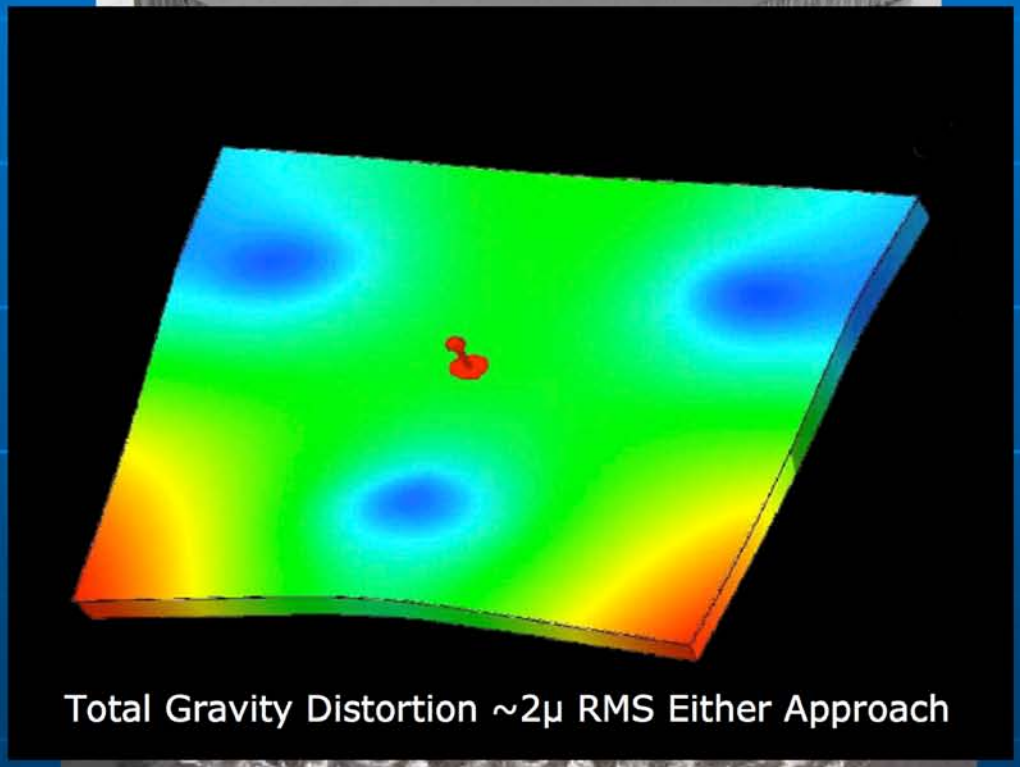
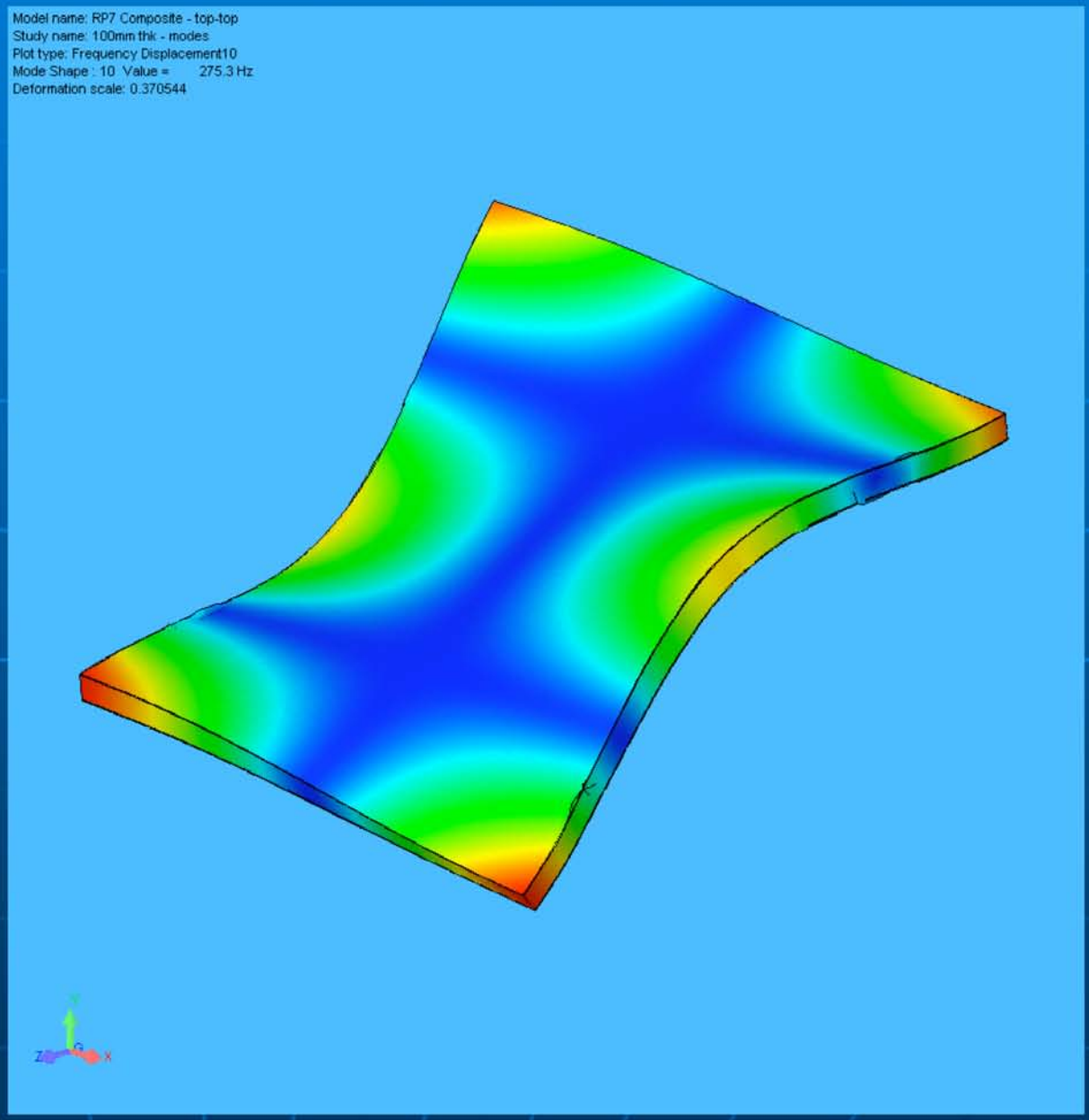
- ~5 μm rms Panel Figure Total Error



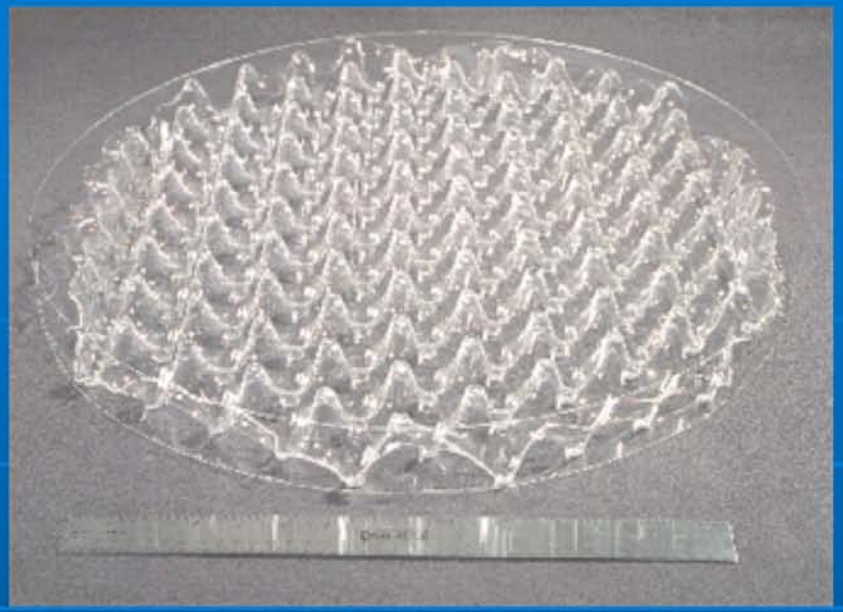
Work on Panel Design

- Investigation of Panel Reinforcement Geometry
- Optimization of Mounting Points
- Stiffness for Future Wind Deformation Analysis
- Performed by S. Parshley at Cornell

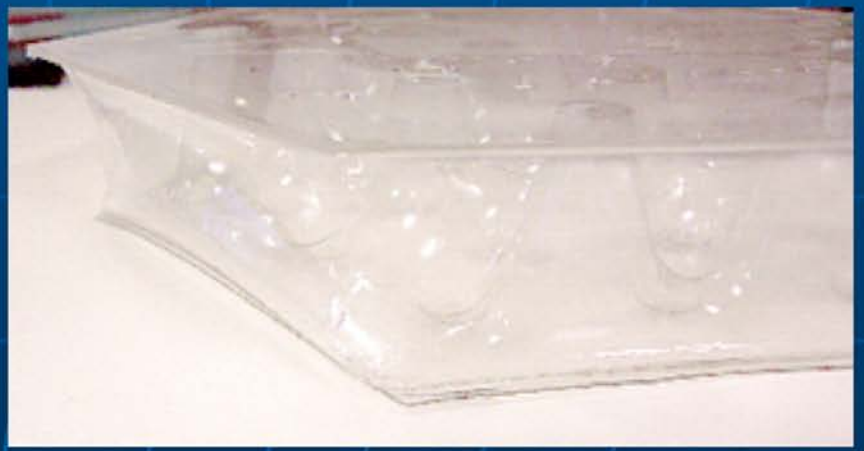


Precision Molded Borosilicate Lightweight: ITT Industries, Rochester, NY

- What are they?
  - Borosilicate glass
  - Corrugated "egg crate" Core
  - Thin Facesheet Fused to Core
  - Precision Molded
  - Can be Ion Figured



- Development Continues Under Other Funding
- .6 m Demonstration Underway



Optics Working Group Formed

- Members
  - Eli Atad Edgui — UK ATC
  - Eri Cohen — JPL
  - Simon Radford — Caltech
  - Thomas Sebring — Cornell
  - David Woody — OVRO/Caltech
- Objective: To investigate and develop approaches to manufacture of optics for CCAT.
- Meetings:
  - Jan 07 Kickoff Meeting at Caltech
  - Feb 07 Visits to CFRP Optics Vendors and Mold Makers
  - Mar 07 Visits to CMM Manufacturers
- Progress: Identification of 3 qualified vendors for CFRP panels. Identification of mold materials and processes. Identification of metrology approach. Identification of critical risk areas and areas of required process development.

JPL Precision Segmented Reflector Program~1989-1992

- Fabricated Several CFRP Sandwich Panels (Al and CFRP core)
- Manufactured at JPL, Hextek, Composite Optics Inc.
- Attempt to Make Cryo Temp Mirror for Space
- Eri Cohen Directly Involved in Effort
- **~ 1 meter Diameter Panels Achieved ~2-5 microns rms Surface**

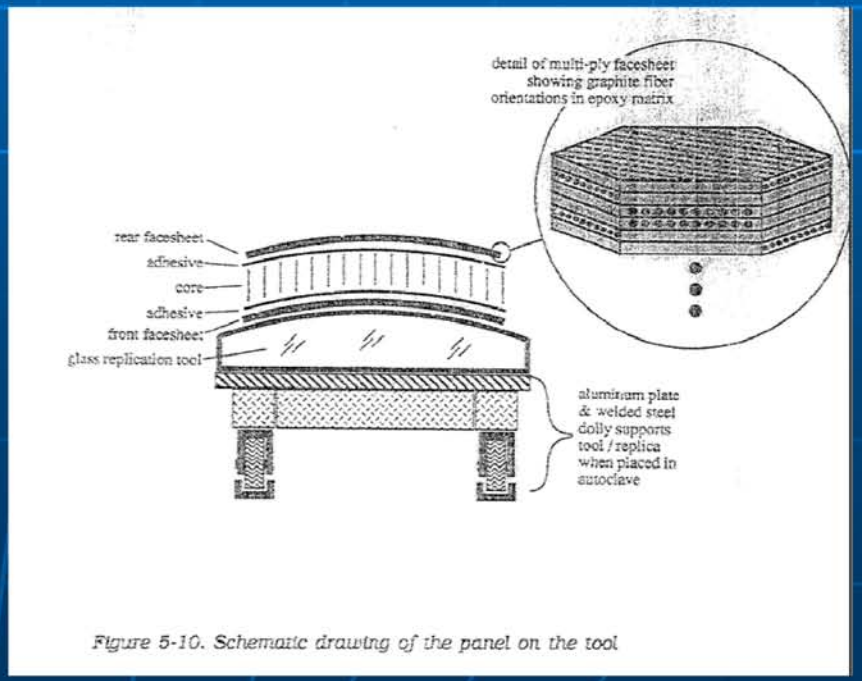


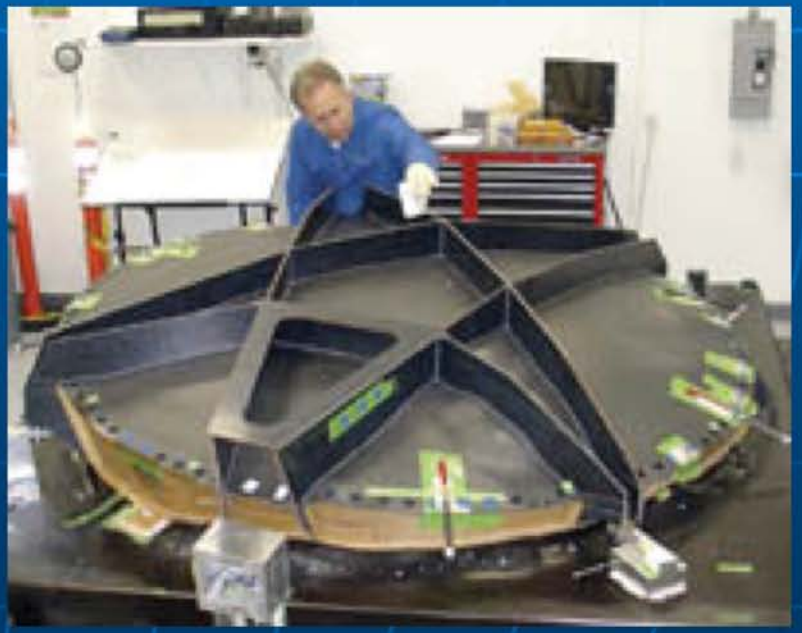
Figure 5-10. Schematic drawing of the panel on the tool

Vendors of CFRP Reflectors

- ATK (formerly Composite Optics Inc, San Diego, CA
  - Most Technically Advanced, Very Interested in our Program
  - Would Like to be Exclusive Vendor, Prepared to do R & D
  - Purchased CMM Which Could Accommodate Panels
- Vanguard Composites: San Diego, CA
  - Manufacture Longer Wavelength Reflectors for Space
  - Strong on Composite Technology but Not With The Required Precision
- Applied Aerospace Structures Corp., Stockton, CA
  - High Volume, High Precision Space & Flight Structures
  - Good Understanding of Technology, But No Equivalent Products
- Other Vendors
  - Several Other US Vendors Possible, e.g. ITT Aerospace
  - Multiple Potential European Contractors Working in Composites Also
  - Basis for a Good Cost Competition but….
  - Stages of Development for Technology Validation More Complicated

Similar Products

- Ku/Ka Band Satellite Reflectors
  - "Volume" Production
  - ~.001 Inch PV Precision
  - ~2 m Diameter
- 3.0 Meter Parabolic Antenna
  - ~5 kg/m^2
  - 400 gHz
  - About 2.5x Worse Surface Quality Than Required for CCAT
  - Right Size for M2 & M3 for CCAT
- Metrology Limits Precision for Companies Making Reflectors
  - Laser Trackers Only Permit ~0.001 inch Measurement



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3.0-meter High Gain Antenna
with 0.5-meter Sub Reflector

Mold Manufactures

- STADCO, Los Angeles, CA
  - 115 Employees
  - Complex Invar Tooling
  - Able to Make Most Shapes
  - Limited to ~25 μ PV
  - Mold Costs Acceptable
- Coast Composites, San Diego
  - Experience in Graphite Molds & Invar, Same Size Company
  - ~ Same Tolerances

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Metrology

- Optical Tests of Panels Not Feasible
- Contacted NIST wrt Coordinate Measuring Machines
- 3 Potential Vendors ID'd
- Visited 2 in Germany
  - Zeiss: Oberkochen
  - Leitz: Wetzlar
- Either Could Provide CMM
- Standard OTS Machines
- Accuracy of <1 μ Within Standard Capabilities
- CCAT Panels Use Only ~ 17 mm of "Z" Travel
- Machines Cost ~$350-500k
- Might Make Customer Furnished Equipment for Panel Fab Effort

ATK Has Purchased a Machine Already!!!

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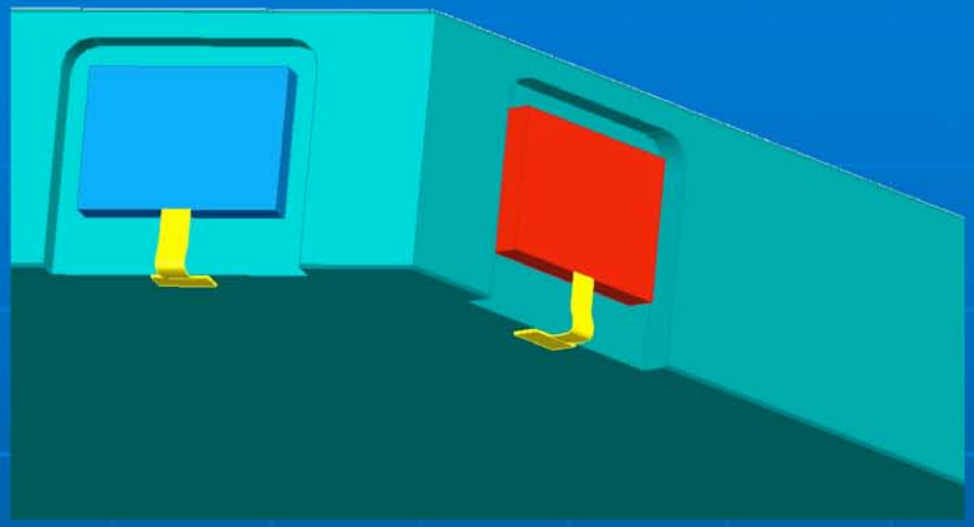
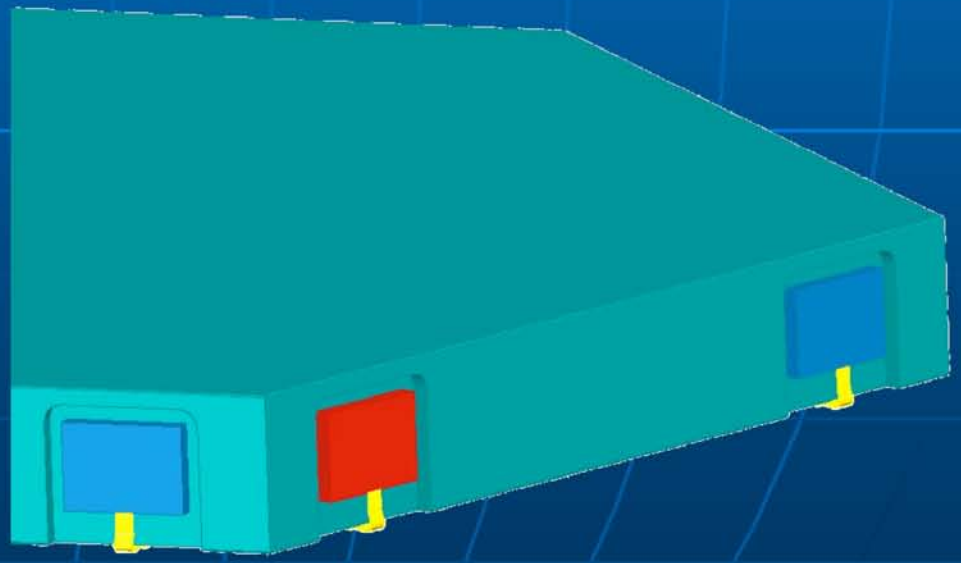
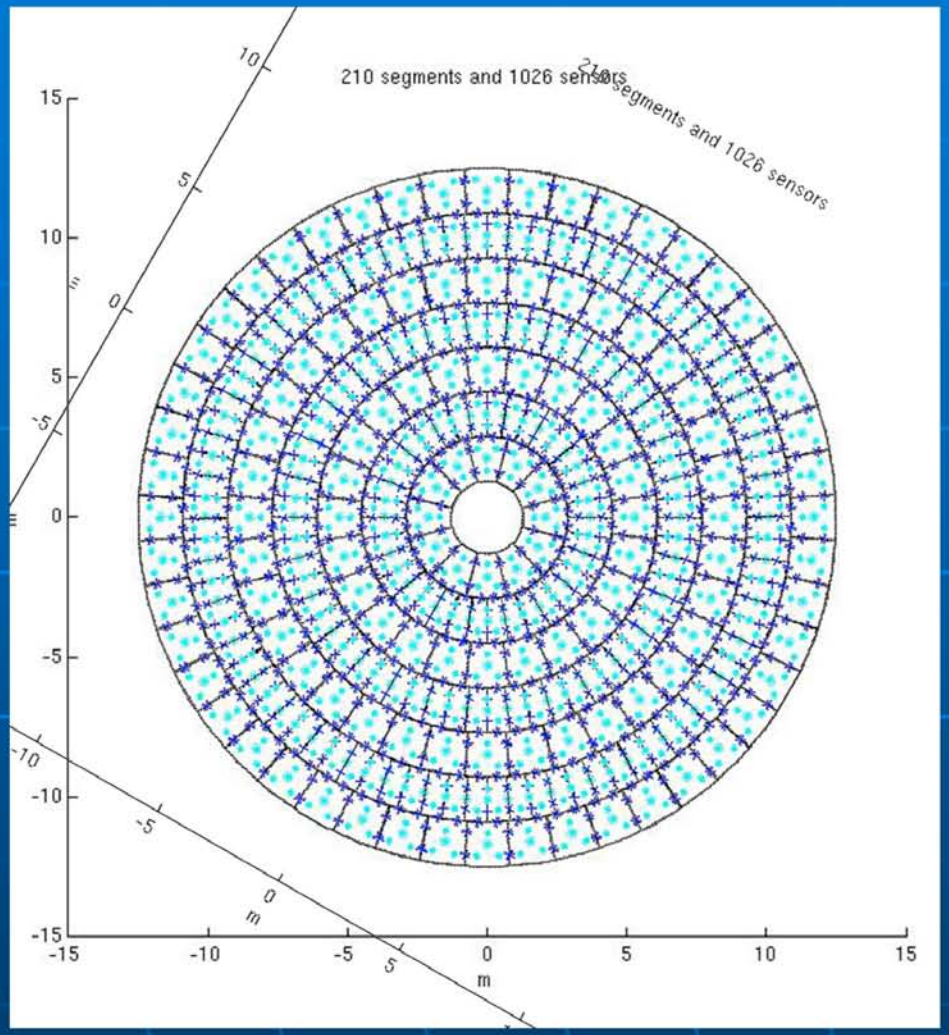
Edge Sensors

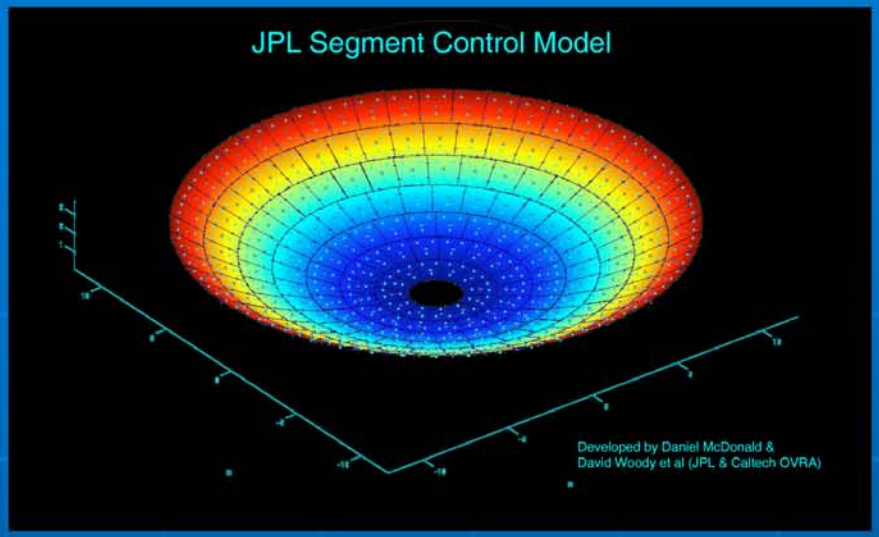
- Mount Between Primary Mirror Panels
- Sense Segment Positions With Respect to Each Other
- Several Discussions with Fogale Nanotech
- New Fogale Product Operates by Electrical Induction Rather than Capacitance
- Can Measure Piston, Tip, and Space Between Panels
- Measure Only Changes in Position
- Allow Control of Segment Positions





Current CCAT Efforts : Segmented Mirror Control Modeling





- Model Developed by D. MacDonald et al
- Incorporates
  - Segmentation
  - Edge Sensor Distribution
  - Error Propagation
  - Control Law

Co Aligned IR Guider Telescope

- Mounted Behind M2 or Behind M1 Looking Through Hole
- T. Herter Analysis Indicates Sufficient Objects and Resolution from 12 inch Telescope
- One Option: RC System Telescope
- All CFRP Structures
- 12 inch Primary, 1 Degree FOV
- Enhanced Aluminum (SiO2/TiO2) overcoat - 96.9% reflectivity.
- Near Zero Expansion, Carbon Fiber Truss
- CNC Machined Rear Cell and Truss Base bolts directly to mount or mounting plate.
- Base Price $9,400

Contractors Worked With and Visited in the Past Year; 34 In Person Meetings

- Vertex RSI Richardson, TX & Duisburg, Germany (2x) (Telescope Mount)
- Amec Dynamic Structures Vancouver, BC (2X) (Dome)
- Temcor Los Angeles, CA (Dome)
- M3 Engineering & Technology Tucson, AZ (2X) (Facility Architecture)
- Steward Observatory Mirror Lab, Tucson, AZ (Manufacture of Panel Molds)
- Composite Mirror Applications, Tucson AZ (2X) (Composite Mirror Panels)
- Composite Optics (ATK) San Diego, CA (2X) (Composite Mirror Panels)
- Applied Aerospace Structures Stockton, CA (2X) (Composite Mirror Panels)
- Adaptive Optics Associates Cambridge, MA (2X) (Optical Panel Alignment System)
- Coast Composites Irvine, CA (Invar and Graphite Mirror Panel Molds)
- ITT Aerospace, Rochester, NY (3X) (Composite and Glass Mirror Panels)
- Corning Glass, Corning, NY (Borosilicate and ULE for Panels and Molds)
- Fogale, Nanotech Nimes, France (Edge Sensors)
- Geotechnical Consultores Santiago, Chile (Geotech Survey)
- Zeiss Oberkochen, Germany (Coordinate Measuring Machines)
- Leitz (Hexagon) Wetzlar, Germany (Coordinate Measuring Machines)
- Media Lario Bosisio Parini, Italy (Ni/Al Mirror Panels)
- MERO TSK Wurzburg, Germany (Truss and Dome Structure)
- Polytec PI Auburn, MA (Actuators)
- Stadco Inc. Los Angeles, CA (Invar Molds for Mirror Panels)
- Vanguard Composites San Diego, CA (2X) (Composite Mirror Panels)
- TNO Science and Industry, Delft, The Netherlands (Al Composite Panels)

Astronomical Institutions Met With to Discuss CCAT

- Max Planck Institute, Bonn & Garching, Germany
- ESO, Garching, Germany
- Harvard Smithsonian Center for Astronomy
- University of Arizona, Tucson, AZ
- University of Virginia, Charlottesville, VA
- NRAO, Charlottesville, VA
- University of Chile (4X in past year)
- NRAO, Soccoro, NM (Review ALMA Antennas)
- SMT (H.Hertz Telescope, Mt. Graham, AZ
- LBT, Mt. Graham, AZ
- Rochester Institute of Technology, Rochester, NY
- TMT Project Pasadena, CA
- Tokyo Astronomical Observatory San Pedro de Atacama

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!