TMT
Thirty Meter Telescope

Telescope Modeling Challenge Team Overview (TMT Perspective)

Jamie Nakawatase

INCOSE MBSE Leadership Meeting

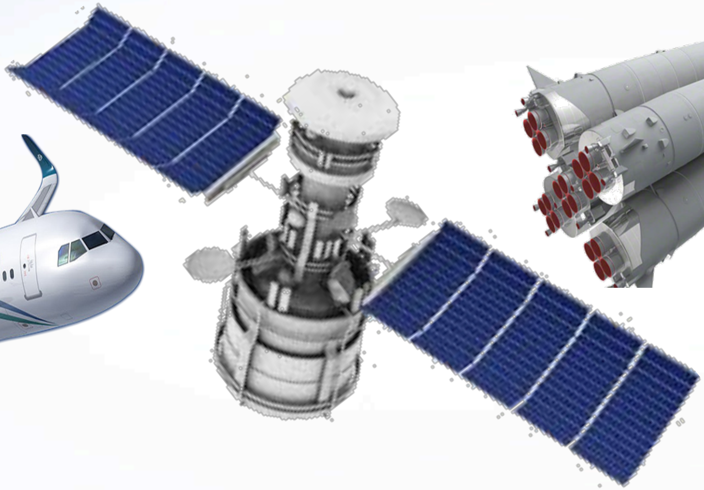
24 March 2017

Outline

- Thirty Meter Telescope (TMT)
  - Project overview
- Why MBSE?
  - TMT application
- Telescope Modeling Challenge Team
  - Organization and goals

Complexity of TMT

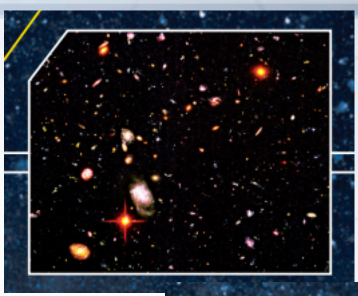
- The Thirty Meter Telescope (TMT) is no different than other complex systems of systems

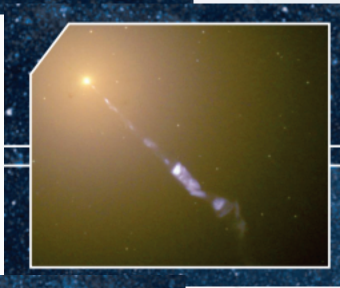



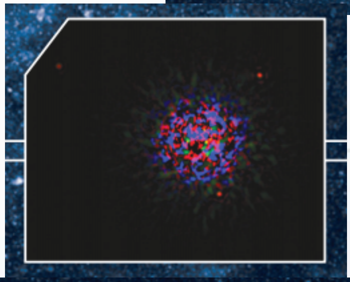
- We still need to apply core SE processes
- Difference: telescope community is historically unfamiliar with formal Systems Engineering

TMT Key Science

- Nature and composition of the Universe
- Formation of the first stars and galaxies
- Evolution of galaxies
- Relationship between black holes and their galaxies
- Formation of stars and planets
- Nature of extra-solar planets
- Potential of life elsewhere in the Universe
- Unforeseen discoveries…



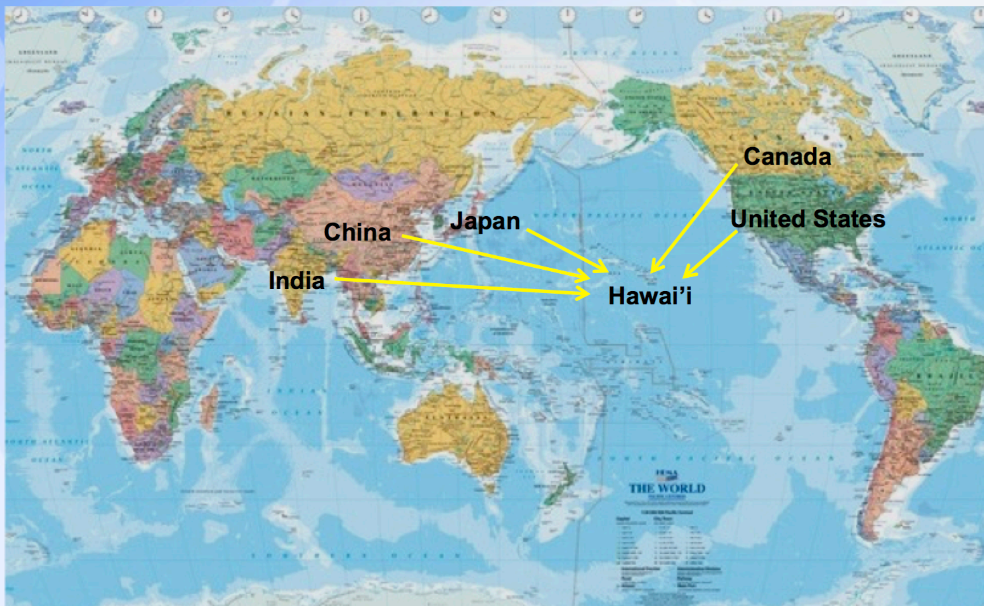




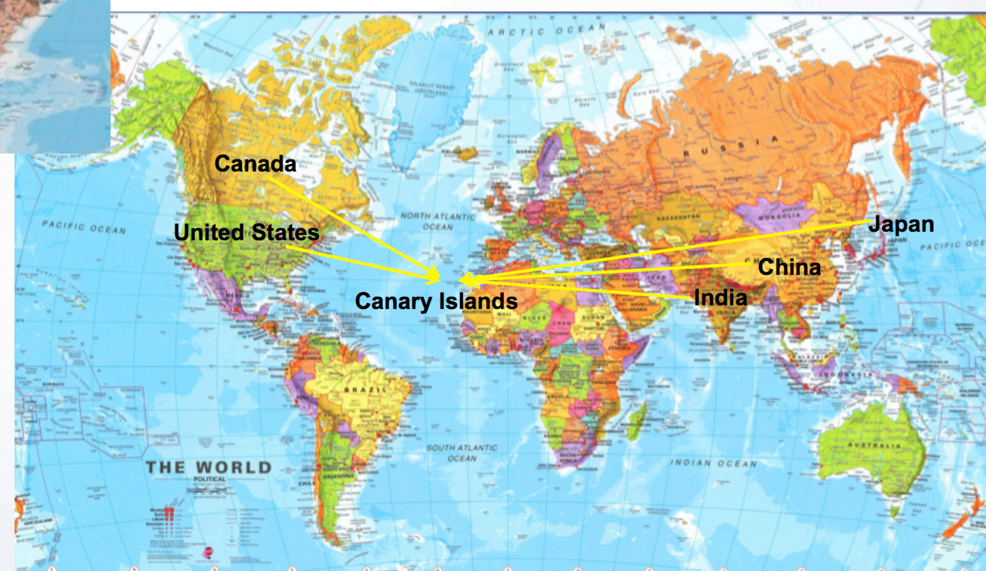
TMT Project

- TMT Project formed in 2004
- TMT international partnership grew
  - US (Caltech & UC), Canada, China, India, Japan
- 2004 – 2008 site studies
  - Chile, Mexico, Hawaii
- Mauna Kea, Hawaii selected in 2009
- 2014 start of TMT Construction Phase

TMT Site



- Preferred site:
  - Mauna Kea on the Big Island of Hawaii, United States



- Alternate site:
  - Observatorio del Roque de los Muchachos (ORM) on La Palma in the Canary Islands, Spain

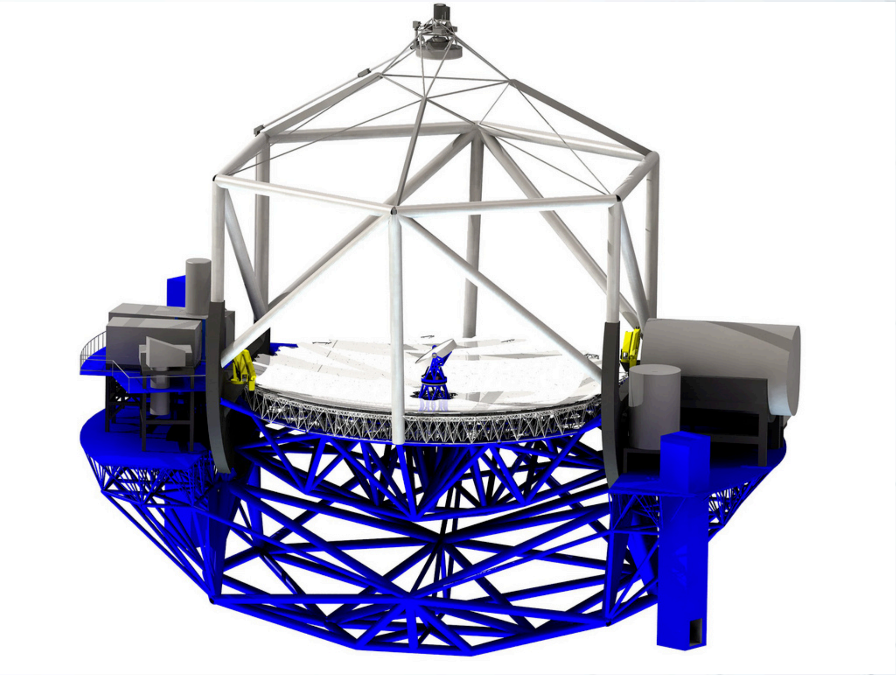
TMT Enclosure

- Calotte design
- Azimuth rotation on fixed base ring
- Rotation of cap structure on tilted bearing ring

- Aerodynamic design minimizes degradation image quality due to air turbulence and thermal influences
  - Smooth exterior
  - Minimal size aperture
  - Aperture flaps
  - Ventilation doors

TMT Structure

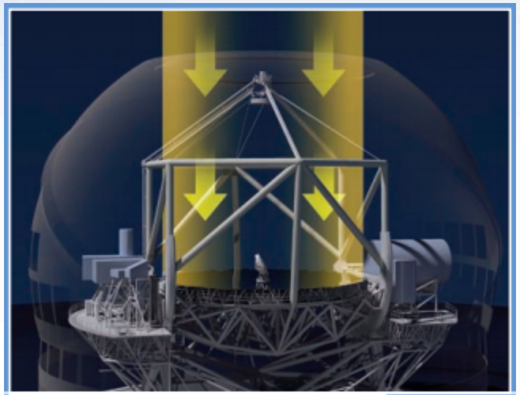
- Elevation structure
  - Mounting support for optics and laser guide star facility
- Azimuth structure
  - Supports elevation structure and 2 large Nasmyth platforms for instruments and AO systems
- Elevators, stairs, walkways, and all utility lines



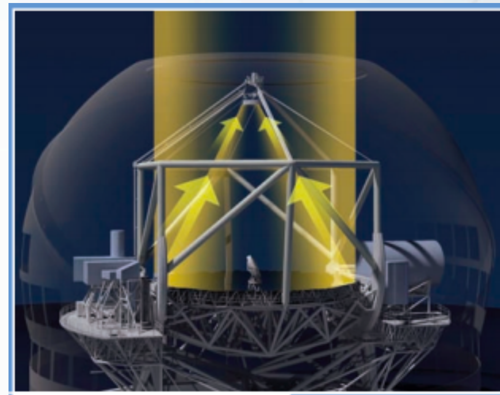
TMT Optics

TMT
Thirty Meter Telescope

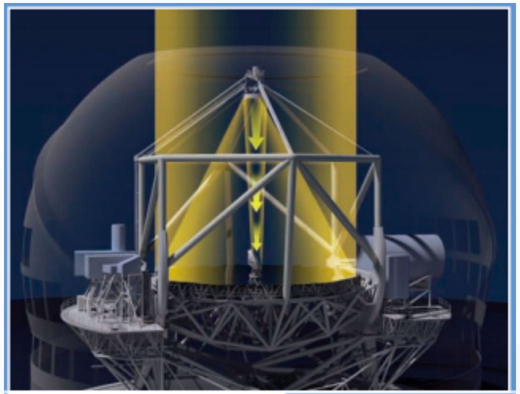
- 3x larger, 9x more powerful than today's best telescopes
- Ritchey-Chrétien design
- Segmented primary mirror (M1)
  - 492 segments, < 2 m across
  - Collects/concentrates light
- Secondary mirror (M2)
  - Works with M1 to form well-corrected focus
- Tertiary mirror (M3)
  - Steers light to adaptive optics system and science instruments on Nasmyth platforms



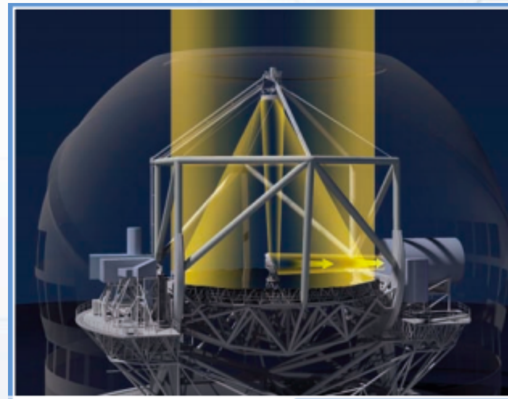
Mirror Path 1



Mirror Path 2



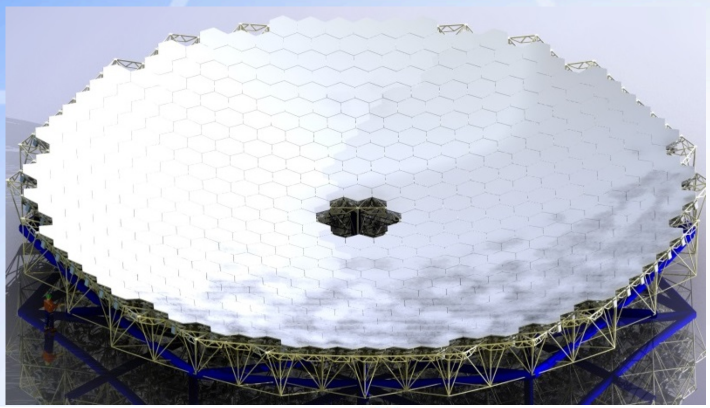
Mirror Path 3

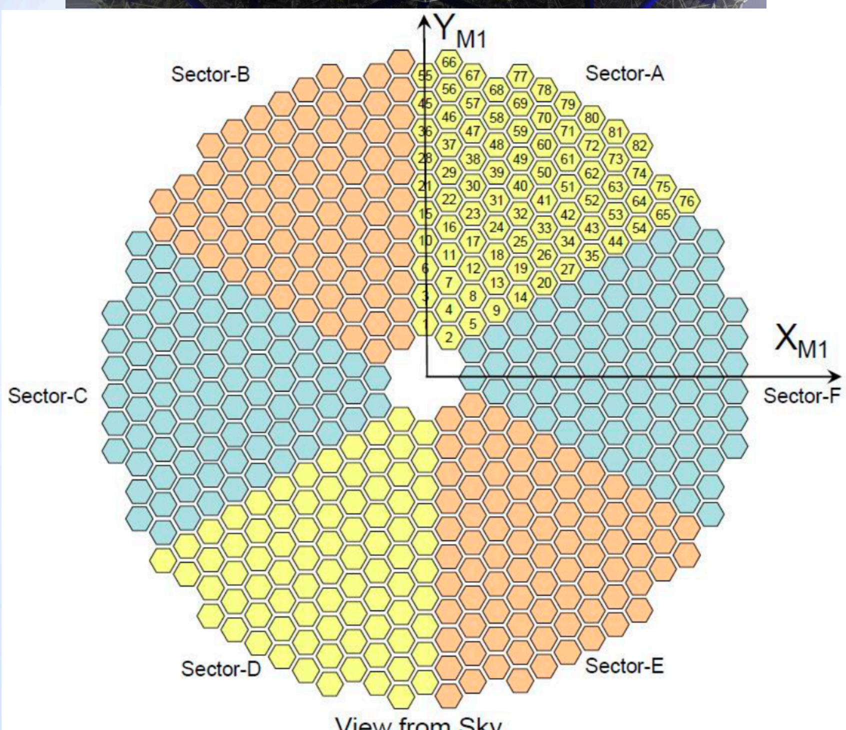


Mirror Path 4

TMT
Thirty Meter Telescope

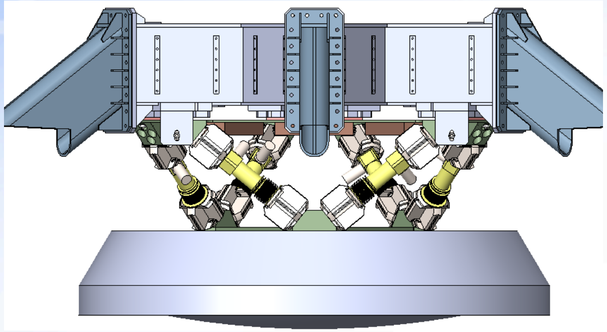
Primary Mirror (M1)





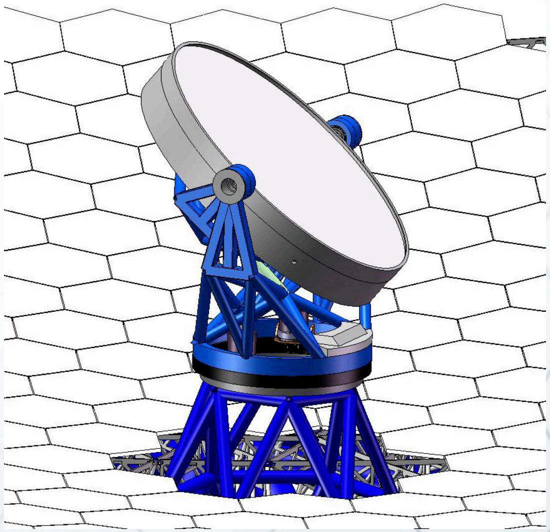
- Segmented primary mirror
  - 492 hexagonal segments
  - 1.44 m across corners
  - 2.5 mm gaps (0.1 in, 0.6% lost area)
  - Thin glass (~2 in) reduces mass and thermal inertia
- Reduces difficulties:
  - Fabrication
  - Testing
  - Transportation
- Reduces risks:
  - Breakage of single segment is less catastrophic
- Moderate cost and complexity

Secondary and Tertiary Mirrors (M2 and M3)



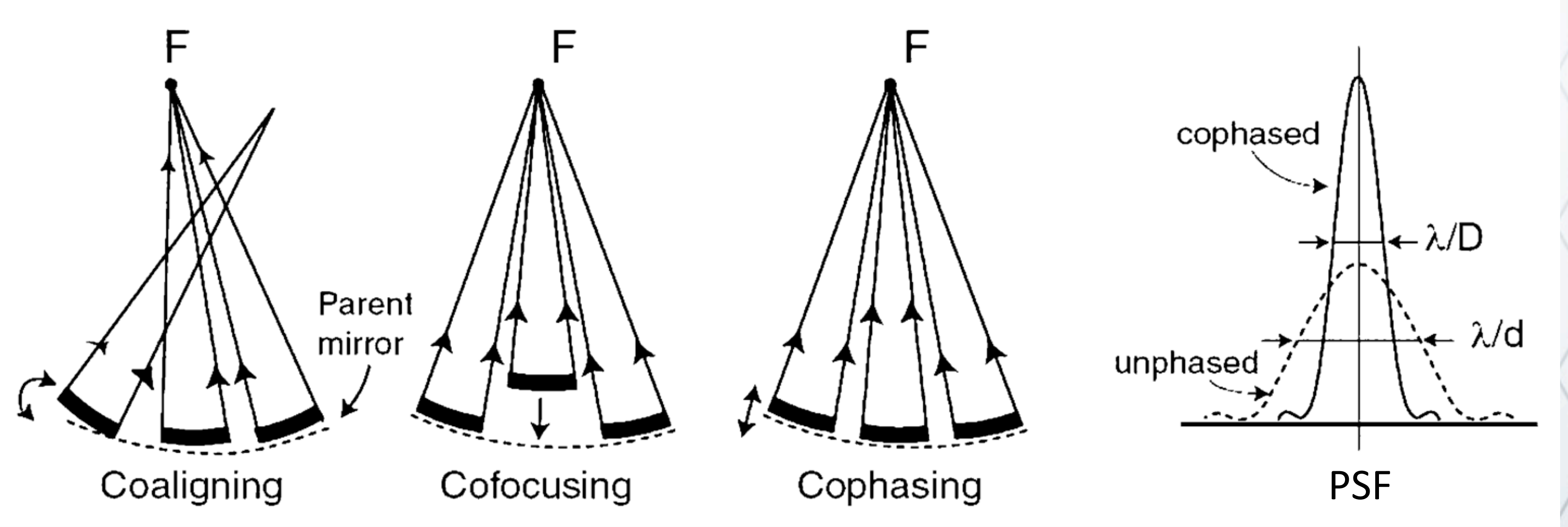
- Secondary Mirror (M2)
  - 3.1 m convex hyperboloid mirror
  - Mounted to telescope top end

- Tertiary Mirror (M3)
  - 2.5 m x 3.5 m flat steerable mirror
  - Rotates and tilts to deliver image to instruments on Nasmyth platforms
  - China (CIOMP) is responsible for design and fabrication



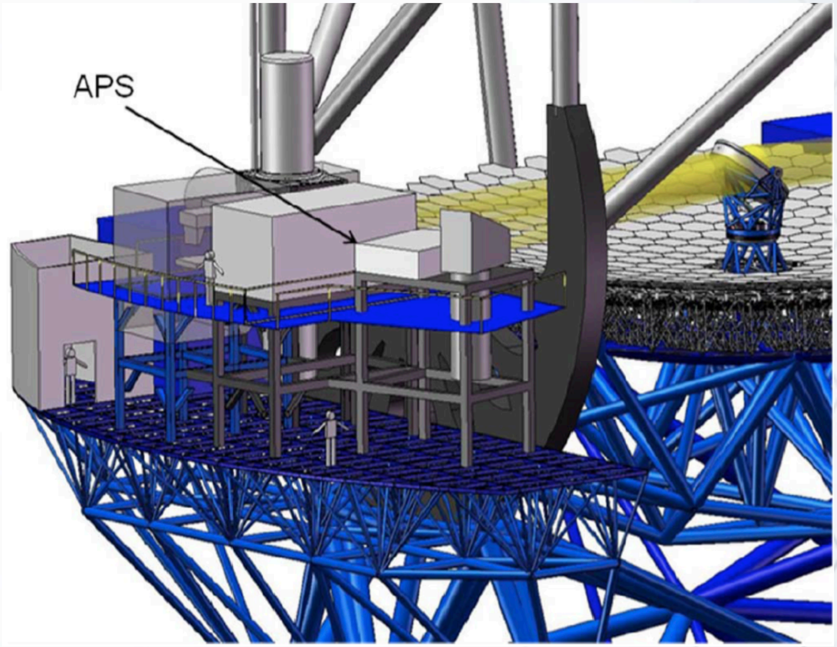
Segmented Mirror Control

- Segmented M1 must perform like a single, smooth mirror to provide optimal image quality
  - **Coaligning**: stacking images produced by each segment to form single image
  - **Cofocusing**: focal lengths of individual segments are equal
  - **Cophasing**: no discontinuities between edges of neighboring segments
- If not phased, image quality = that of individual segment



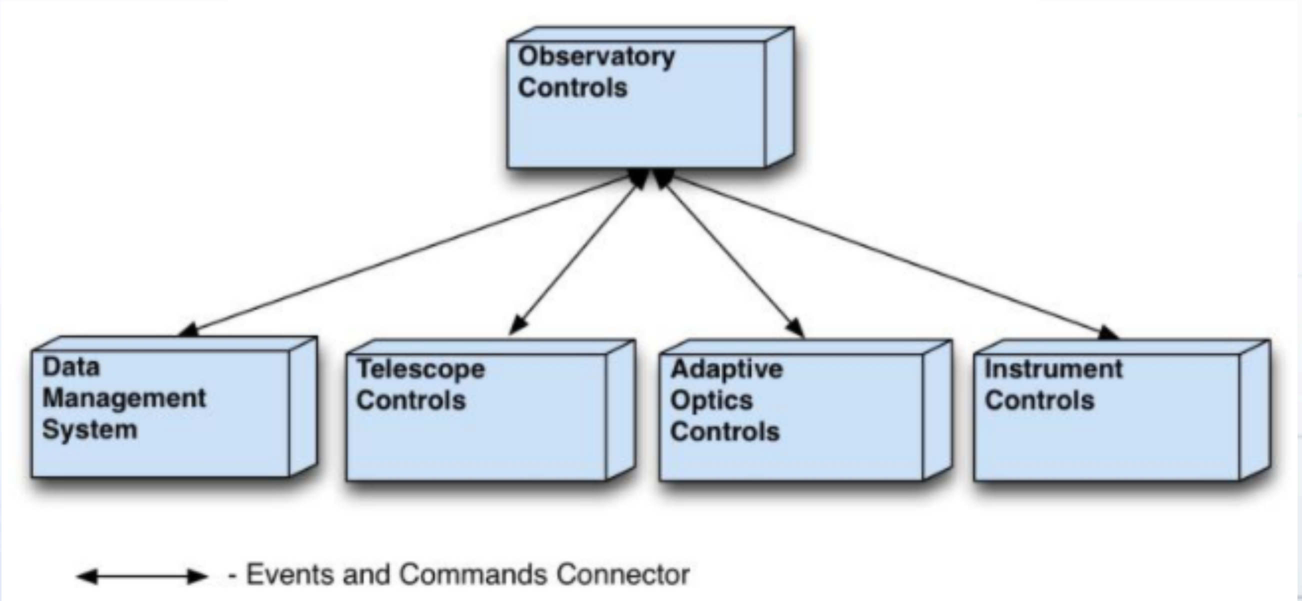
Alignment and Phasing System (APS)

- Alignment and diagnostic instrument located on a Nasmyth platform
- Modified Shack-Hartmann wavefront sensor
- Responsible for pre-adaptive optics wavefront quality
- Uses starlight to measure wavefront errors and determine commands to send for aligning optics

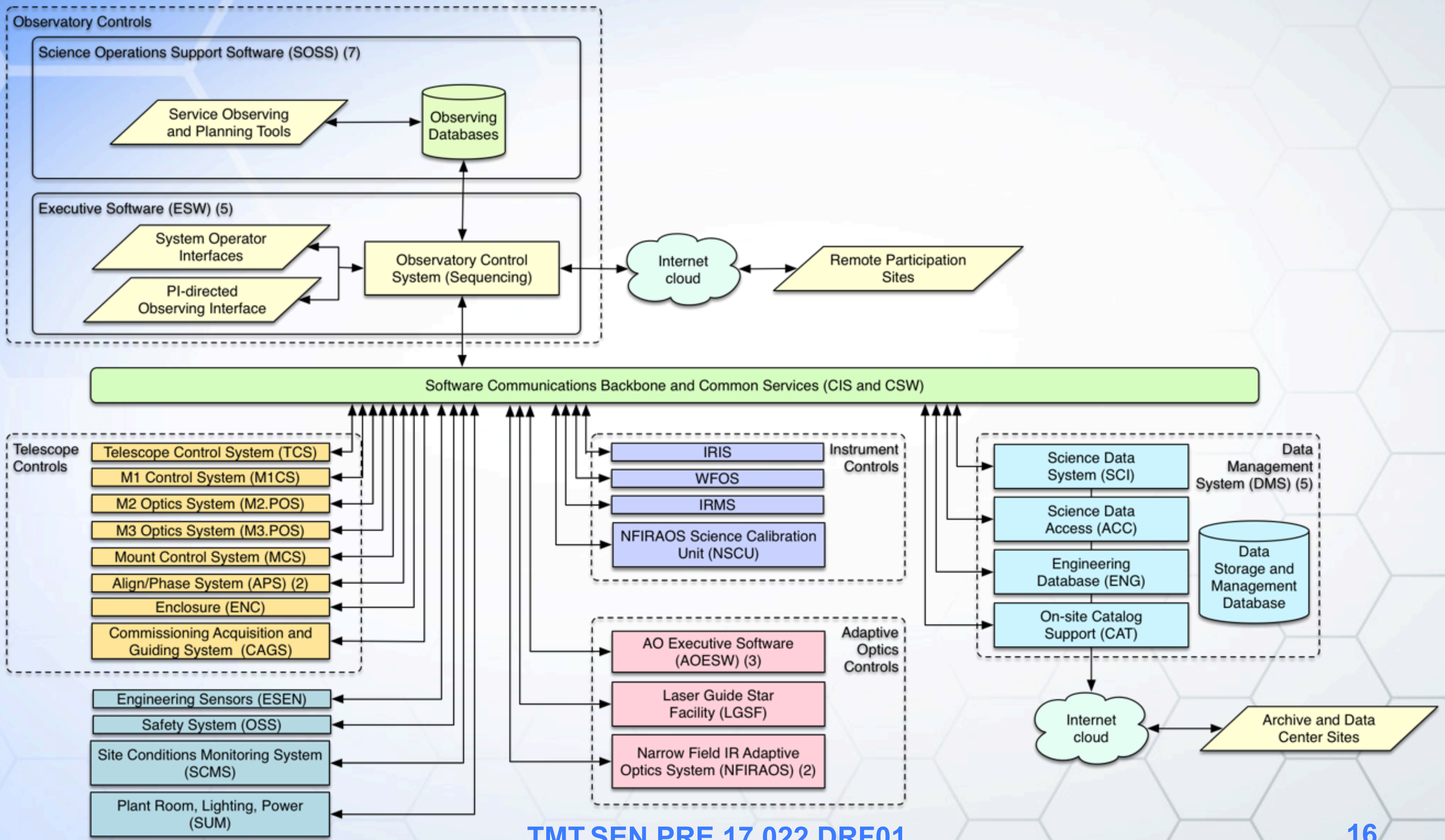


TMT Controls/Software

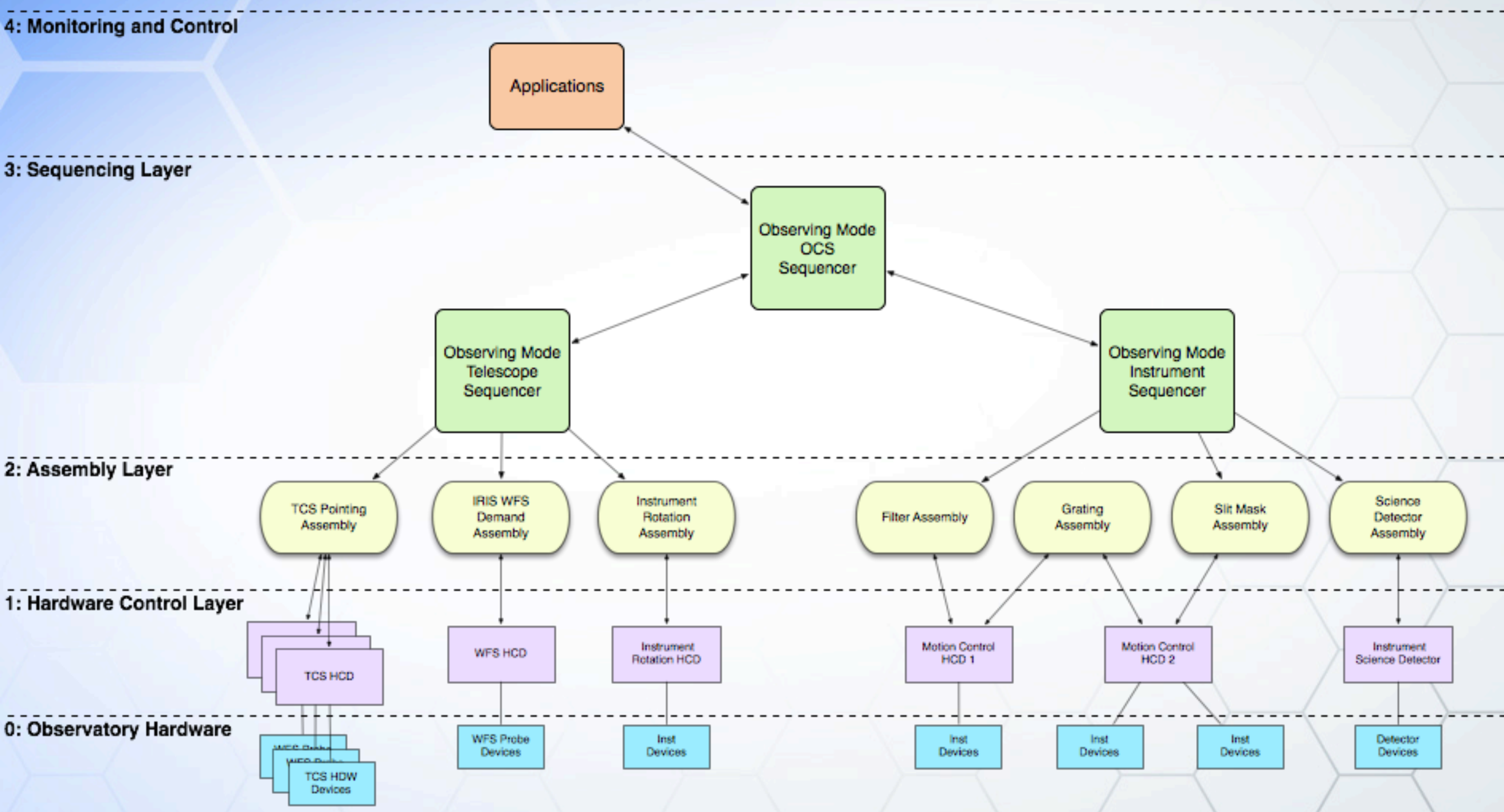
- Responsible for 30,000 I/O channels, 12,000 controlled DOF
- Telescope Control System
  - Synchronization of subsystems comprising wavefront control capability
  - Software architecture with 5 functionalities
  - Communication flow by events/commands between systems



Software Block Diagram

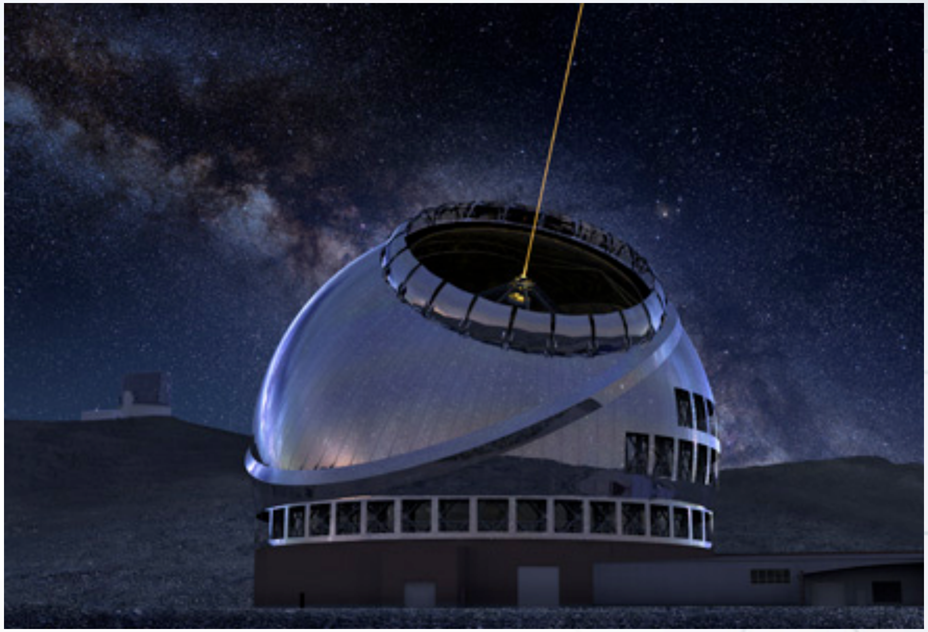


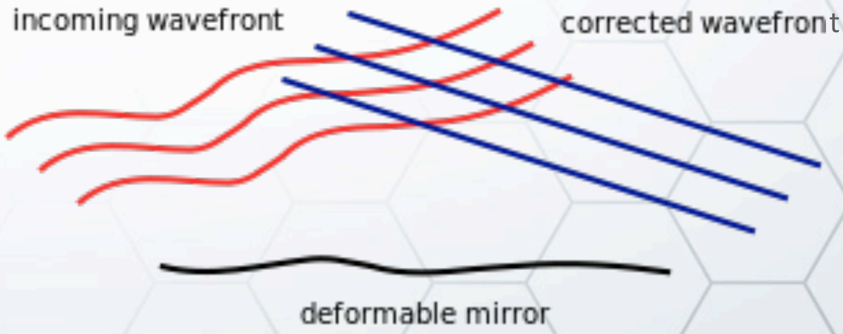
Observing Mode Oriented Architecture (Control System Structure View)



TMT Adaptive Optics (AO)

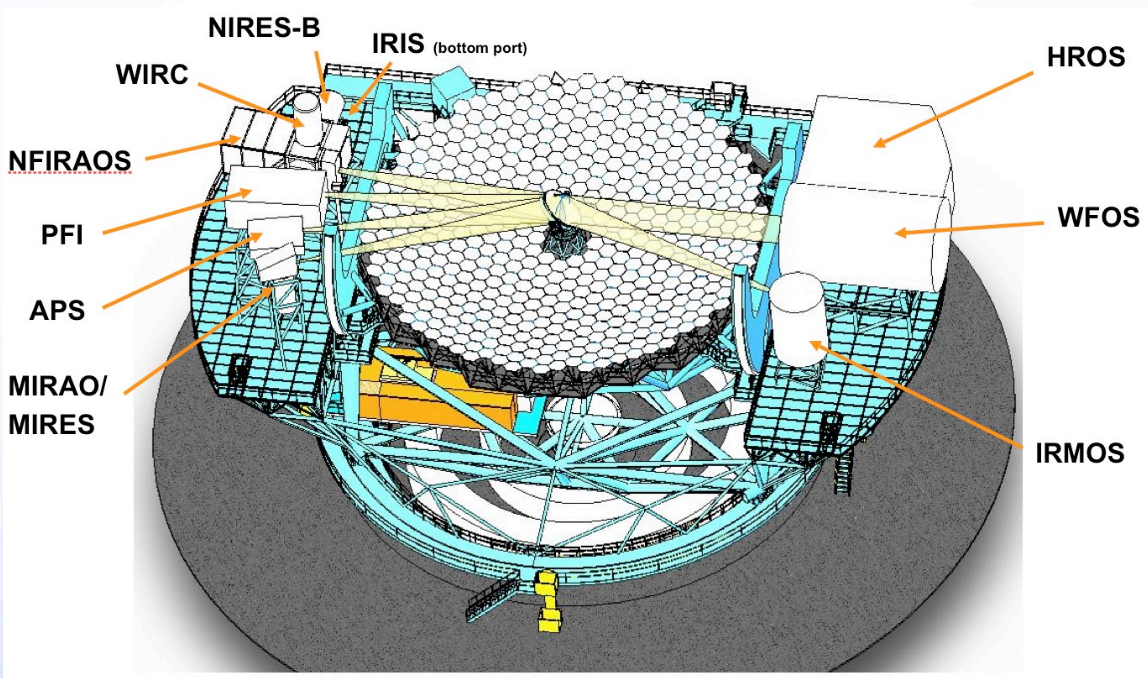
- Cancel blurring effects of atmosphere to obtain optimal image quality
- Wavefront sensing and correction
  - Measures distortions to be nulled
  - Requires a bright “guide star” or point source near science target
  - Laser system to generate artificial guide stars
  - 2 deformable mirrors correct wavefront errors
  - Corrected wavefront is directed to science instruments





TMT Instruments

- Powerful suite of 8 instruments to solve key science objectives by exploring wide astronomical terrain
- 3 first light instruments
  - Wide Field Optical Spectrometer (WFOS)
  - InfraRed Imaging Spectrometer (IRIS)
  - InfraRed Multi-object Spectrometer (IRMS)



MBSE: TMT Application

- Why MBSE?
  - Emphasizes rigor and precision, best practices
  - Helps manage complexity
  - Horizontal (life cycle) and vertical (multiple domain) integration
- TMT SysML model
  - Created to better understand and communicate complex system behavior
  - Executable SysML model to **capture** requirements, use cases, system decomposition, subsystem relationships
  - **Analyze** system design against power, mass, duration requirements
  - **Produce** engineering documents (ICDs, etc.)
  - Use standard language and techniques (**communication**)

TMT
Thirty Meter Telescope

Solution: Hybrid Approach

- Traditional SE
  - Clear, defined deliverables
  - Easily accessible
  - Shallow learning curve
  - Simple traceability
- MBSE
  - Understanding behaviors of a system
  - "Rich" capability to represent complex systems

Exploit the advantages of each approach

MBSE: TMT Application

- TMT SysML Model does not model the entire telescope
- Main objective is to model operational scenarios and demonstrate that requirements are satisfied by the design
- Motivator for TMT MBSE = optimization
- Ex: JPL modeling of APS subsystem
  - Use Case: Post segment-exchange alignment, 2h requirement
  - Component characteristics (power, mass)
  - Relationships (TCS, M1CS)
- Ex: Monte Carlo simulations for acquisition and slew time
  - To minimize loss of observing time, TMT should be able to move from one target to another and acquire it in 3 min or less

Telescope Modeling Challenge Team

- Formalized SE practices are “new” to the telescope community
- Challenge team will be investigating applicability of MBSE to specify, design, analyze, and verify telescope systems
- New revision of Cookbook for MBSE with SysML
    - Best practices to support common SE tasks
    - Lessons learned
- SEBoK TMT Case Study for Fall 2017 publication
- Collaboration in telescope community
    - MBSE Telescope Workshop II, April 2017

Acknowledgments

The TMT Project gratefully acknowledges the support of the TMT collaborating institutions. They are the Association of Canadian Universities for Research in Astronomy (ACURA), the California Institute of Technology, the University of California, the National Astronomical Observatory of Japan, the National Astronomical Observatories of China and their consortium partners, and the Department of Science and Technology of India and their supported institutes. This work was supported as well by the Gordon and Betty Moore Foundation, the Canada Foundation for Innovation, the Ontario Ministry of Research and Innovation, the National Research Council of Canada, the Natural Sciences and Engineering Research Council of Canada, the British Columbia Knowledge Development Fund, the Association of Universities for Research in Astronomy (AURA) and the U.S. National Science Foundation.