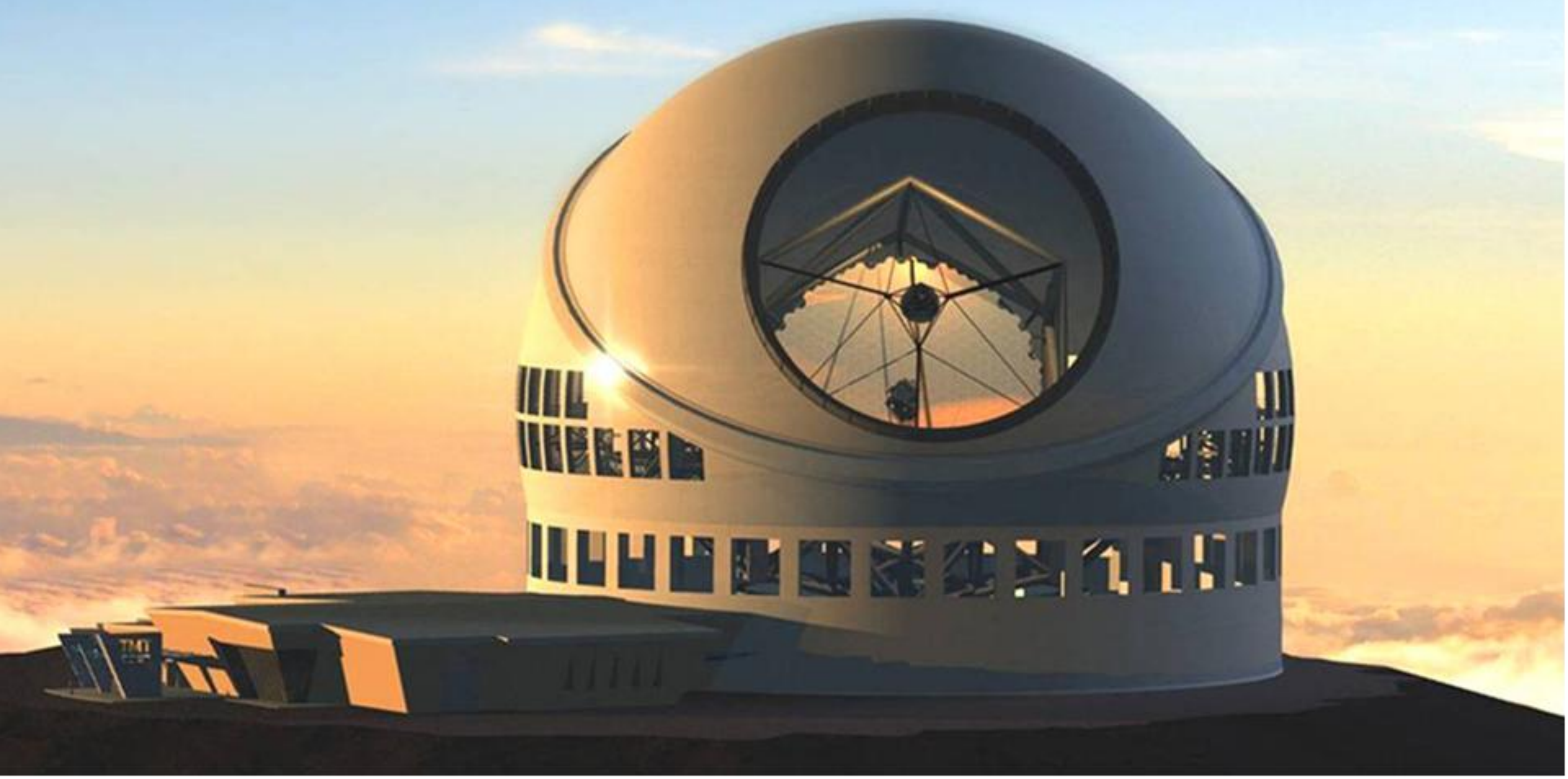
TMT

THIRTY METER TELESCOPE

Introduction to Thirty Meter Telescope (TMT) and Telescope Control System (TCS)



Purpose

- This presentation accompanies the proposal to request Expression of Interests (EoIs) for TMT-TCS

- The purpose of this presentation is to
  - Provide an overview of TMT and its partnerships
  - Provide an overview of the TMT-TCS
  - Introduce TMT Software Design and Software Development Process
  - Provide insight into the TCS Work Breakdown Structure
  - Highlight the considerations and challenges related to the TCS software development

Expression of Interest (EoI)

- The objective of this EoI is to identify vendors capable of carrying the entire development of TCS
- Although it is desired and intended to carry out the entire development of the TCS through a single contractor, the contracts for the subsequent phases will be awarded on the basis of past performance
- Only vendors shortlisted through the EoI process will be invited to submit technical and price bids for an initial phase of the project lasting 6 to 12 months
- IUCAA reserves the right to invite fresh EoIs at any stage of the process

Important Dates

Date of this announcement	**July, 22, 2015**
Pre-EoI submission meeting at IUCAA	**August, 07, 2015 (1500 hrs IST)**
Deadline for submission of EoI	**August, 20, 2015 (1500 hrs IST)**
Intimation of results of the EoI process	**October, 1, 2015**
Announcement of tendering process to invite technical and commercial bids	**October, 30, 2015**

Topics

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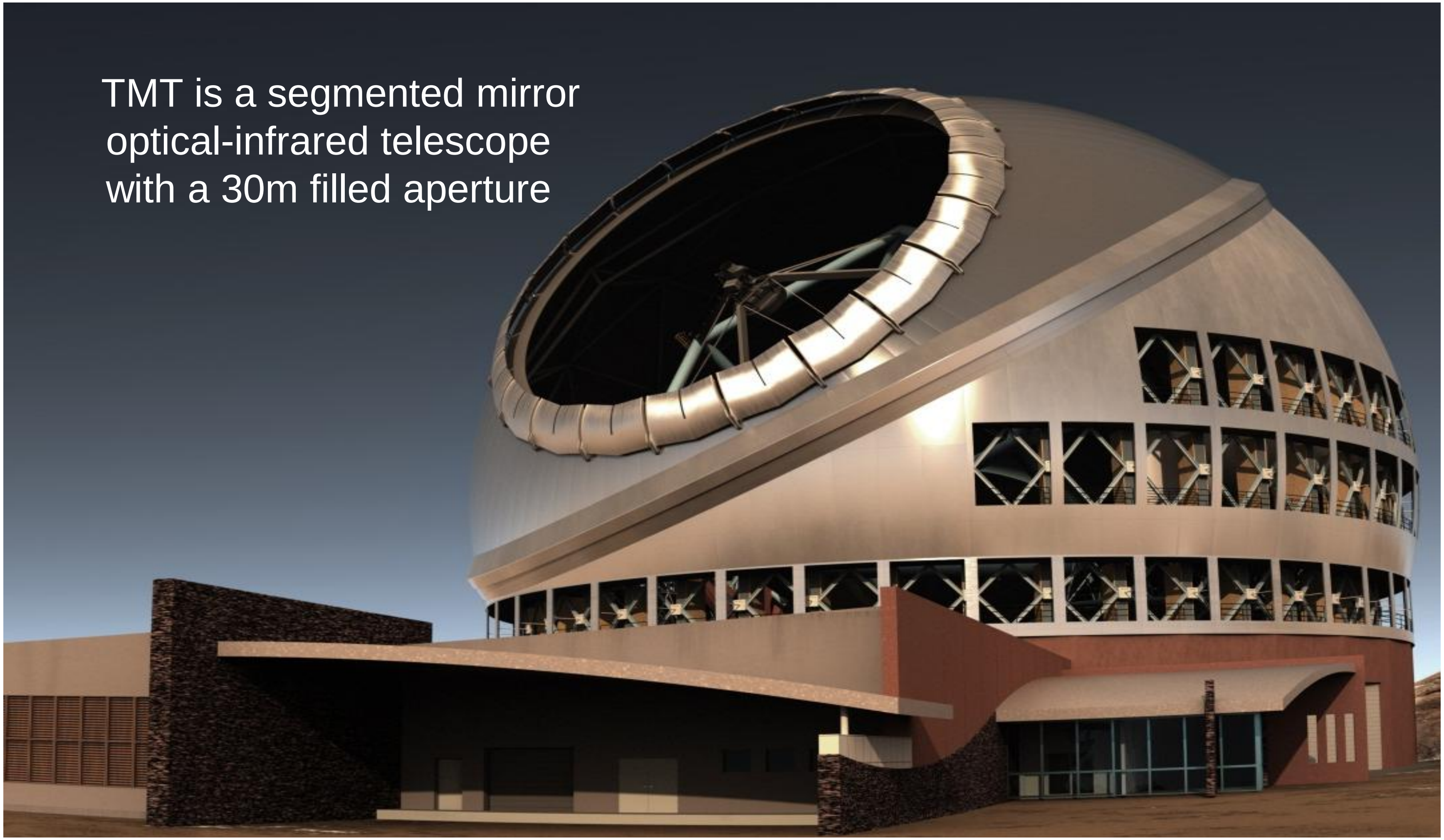
Thirty Meter Telescope (TMT) (Introduction)

Thirty Meter Telescope



www.tmt.org

Thirty Meter Telescope

- TMT will be world's most advanced and powerful ground-based telescope operating at optical and infrared wavelengths

- TMT will couple unprecedented light collection area with diffraction-limited spatial resolution

- TMT will enable astronomers to study objects in our own solar system and stars throughout our Milky Way and its neighbouring galaxies, and forming galaxies at the very edge of the observable universe, near the beginning of time

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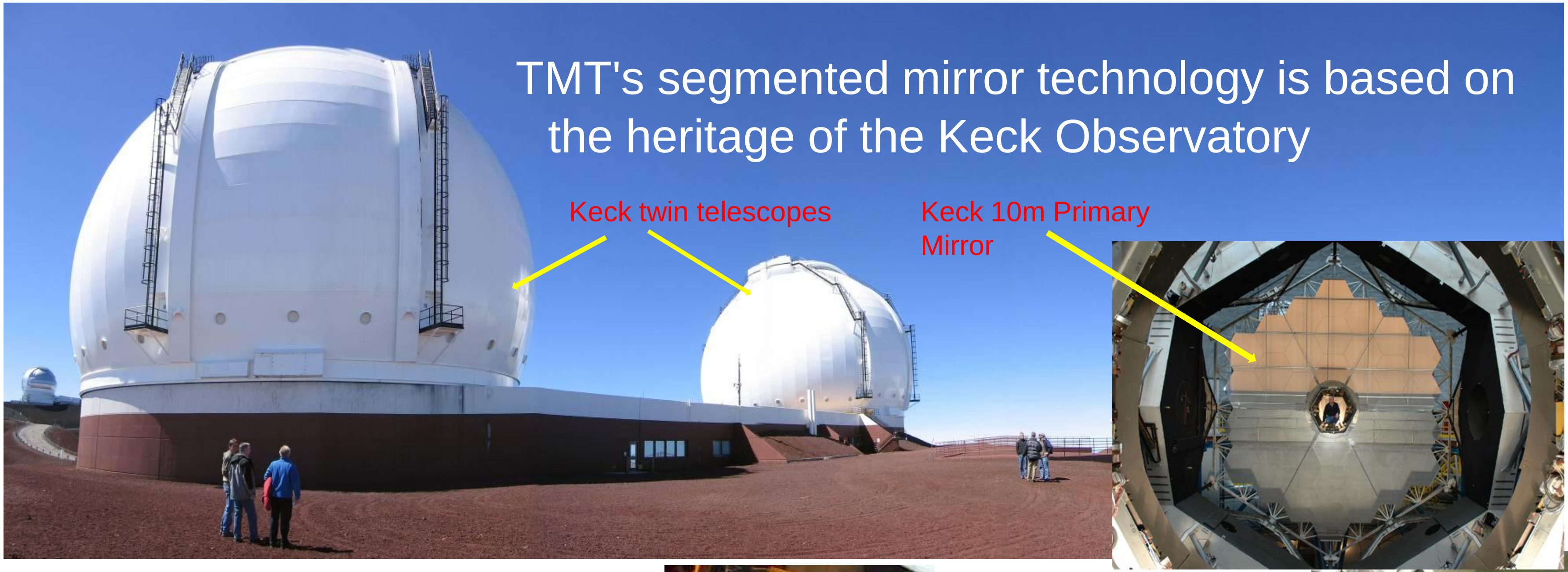
Thirty Meter Telescope

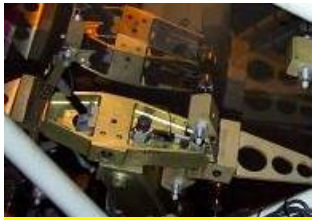
- TMT will make revolutionary discoveries in every field of astronomy, astrophysics and cosmology
- TMT Science Case
  - Nature and composition of the Universe
  - Formation of the first stars and galaxies
  - Evolution of galaxies and the intergalactic medium
  - Relationship between black holes and their galaxies
  - Formation of stars and planets
  - Nature of extra-solar planets
  - Presence of life elsewhere in the Universe
  - Investigation of Dark Matter and Dark Energy
- See http://www.tmt.org/science-case for details on TMT Science Case

Design Heritage of TMT



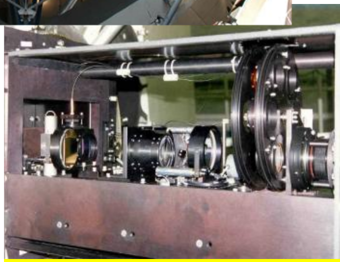
Handling

Supports



Warping harnesses

Edge sensors



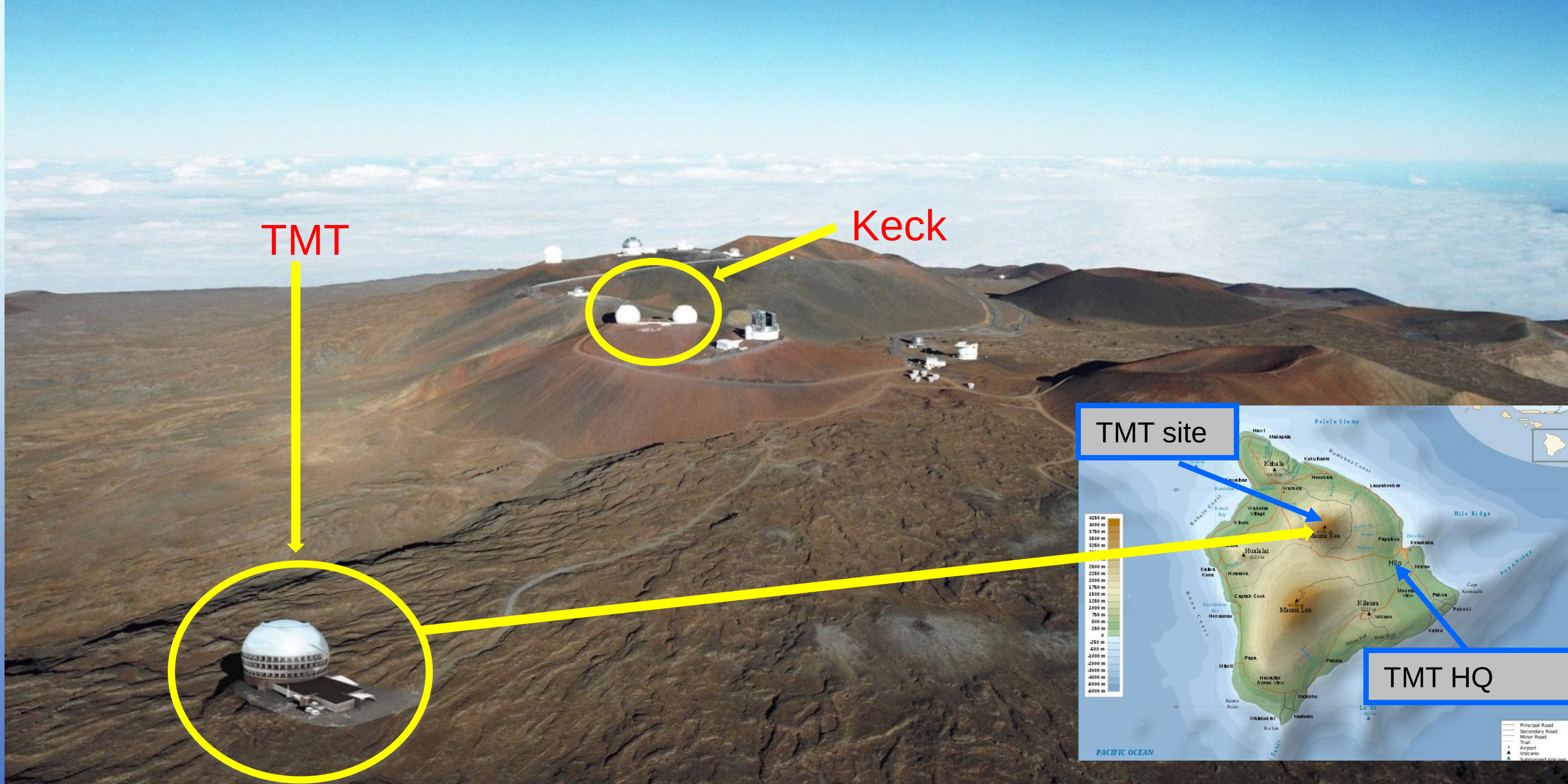
Alignment & phasing

www.keckobservatory.org

TMT Site Location

Introduction to TMT

TMT Site is on the northern plateau of Mauna Kea, Hawaii, at an elevation of 4050 meters



- TMT Headquarters will be based in Hilo, Hawaii

Introduction to TMT

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TMT is a Pacific Rim partnership centered around Hawaii

TMT Partnership

- TMT partner institutes will work together to construct the observatory
- Observing time at TMT will be shared by partner institutes
- Each partner institute is represented on the TMT Board of Directors
- Partnership is legal and business structures have been defined
- Work shares have been developed for each partner institute, based on the project work breakdown structure and a comprehensive cost estimate that was vetted in a formal cost review
- The design and build of the various telescope systems is distributed amongst the TMT partner institutes, collaborators, industry, and the TMT Project Office

Funding Commitments

Introduction to TMT

- Caltech/University of California(UC), USA, construction funding from the Gordon & Betty Moore Foundation has been in place for several years
- Construction funding commitments have also been made by the Canadian, Japanese, Chinese, and Indian governments
- National Science Foundation, USA, has also expressed considerable interest at joining TMT sometime in the latter half of the decade

TMT Telescope Concept Overview

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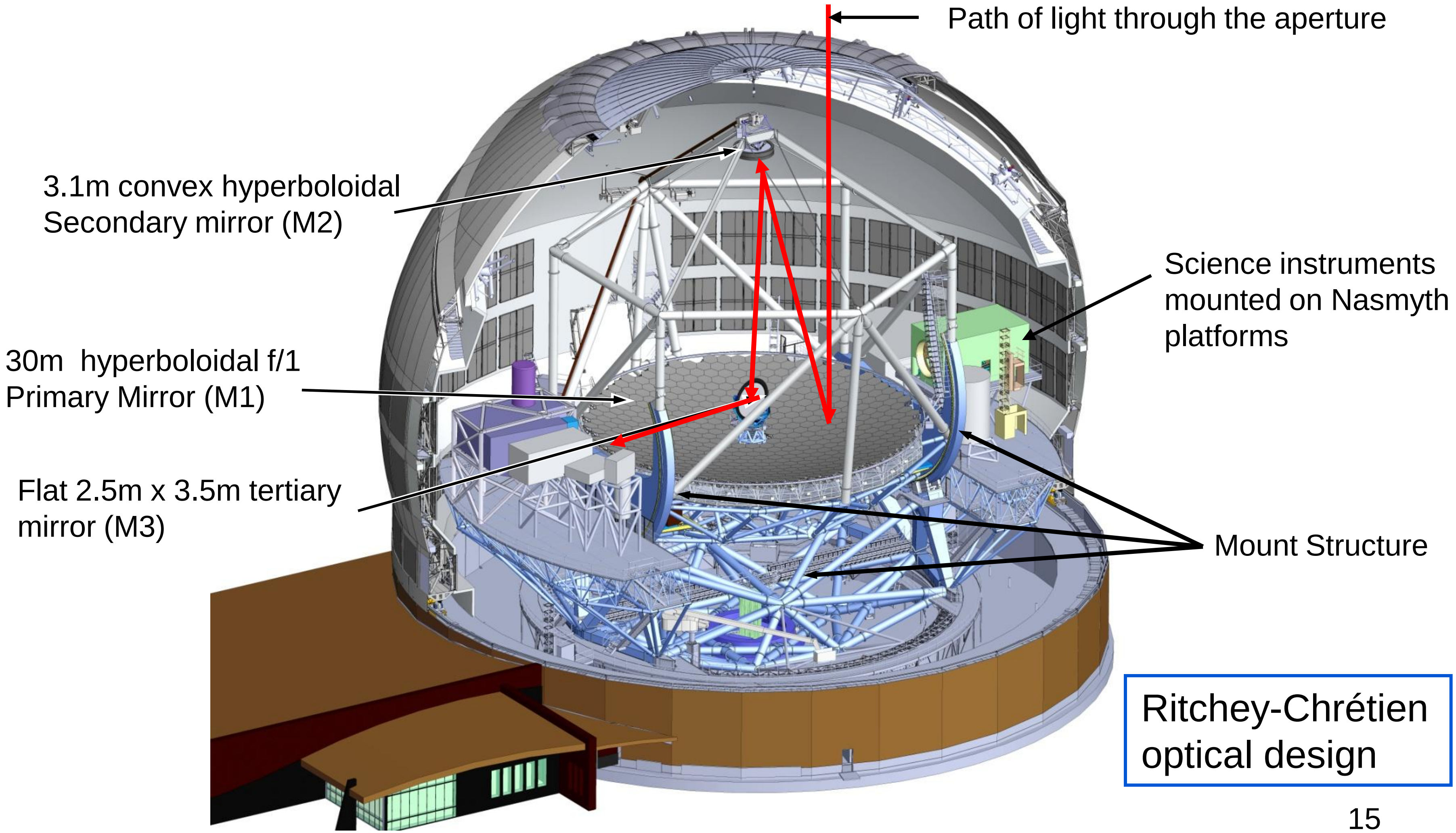

Ritchey-Chrétien optical design

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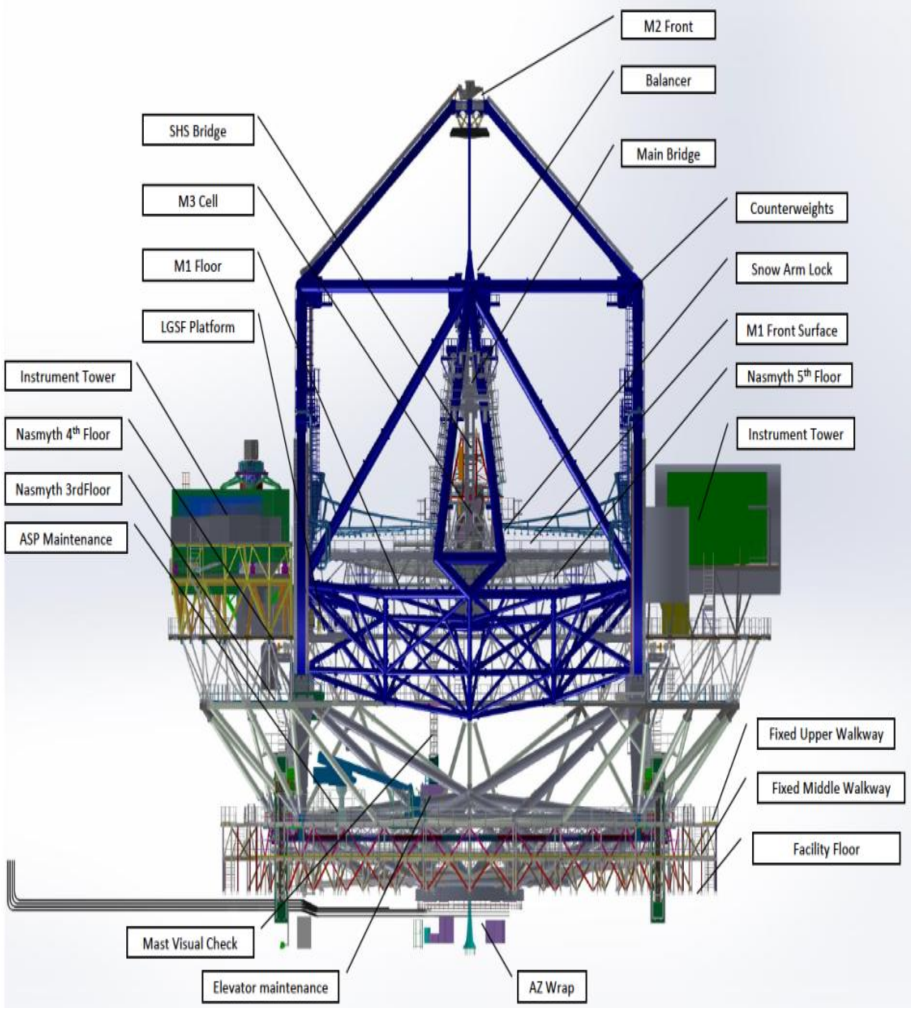
Telescope Structure

- Japan is responsible for the telescope structure
- Chosen contractor is Mitsubishi Electric Corp (MELCO)
    - Overseeing both the physical structure and the control systems
    - Provided the structure for Subaru on Mauna Kea
- TMT Structure passed its preliminary design review in November 2013 and is currently in the process of a multi stage final design review that will conclude in early 2016



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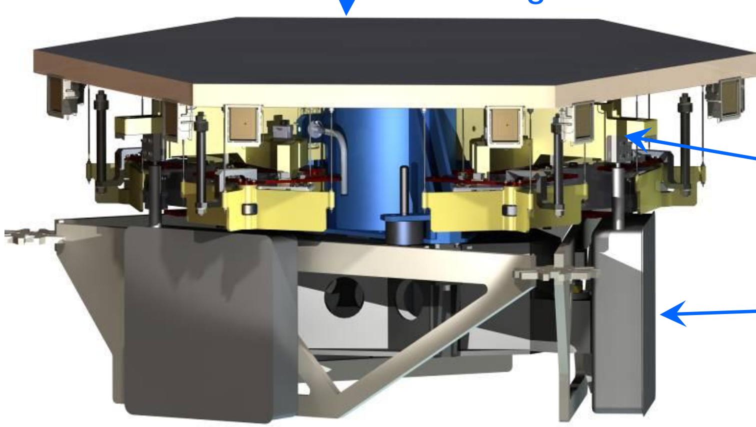
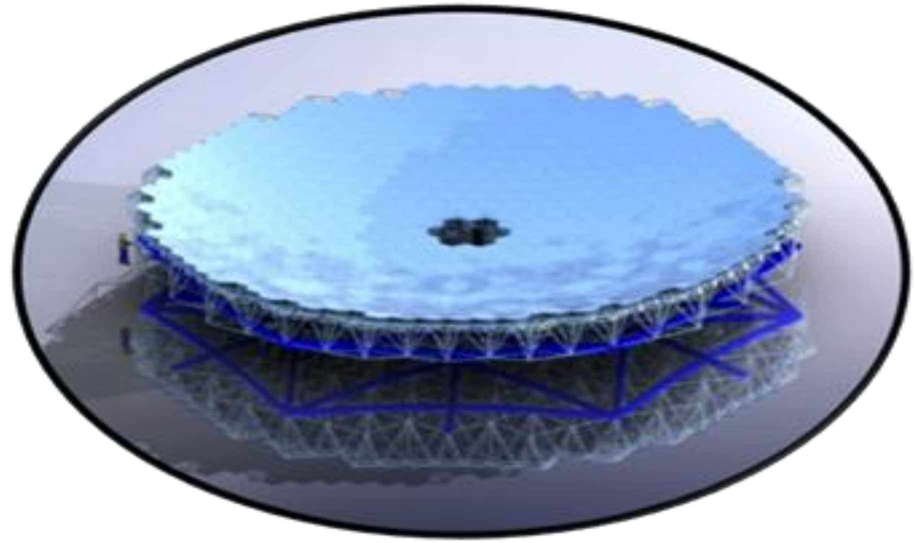
Primary Mirror (M1)

- 492 Segments
  - 574 including spares
- 82 different types
- 1.44m across corners
- 45mm thick glass ceramic
- 2.5mm gaps (0.6% lost area)

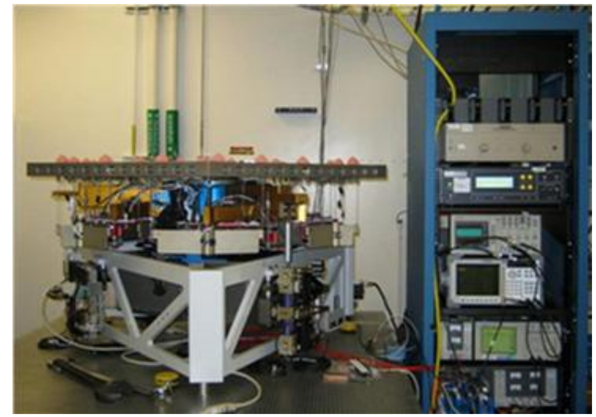




- Each of the 492 mirror segments forming the Primary Mirror (M1) will be mounted on such segment support and actuators assembly which is known as active adaptive optics to correct atmospheric turbulence

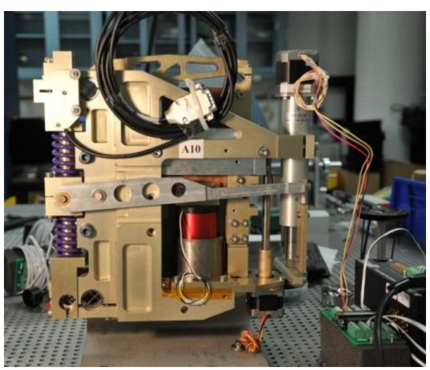
Alignment and Phasing System (APS) and M1 Control System (M1CS)

- APS aligns the telescope optics including segments and the M1CS maintains the overall shape of the primary mirror in the presence of disturbances
  - Gravity, temperature, wind, vibration
- M1CS
  - Control system for the primary mirror
  - 1476 position actuators
    - 5 mm measurement range, 5 nm resolution
  - 2772 capacitive edge sensors
    - 2 per segment edge



Mirror Segment Test Bed

Edge Sensors



Actuators

Drive Electronics Card

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M1 Control System and (M1CS) Alignment and Phasing System (APS)

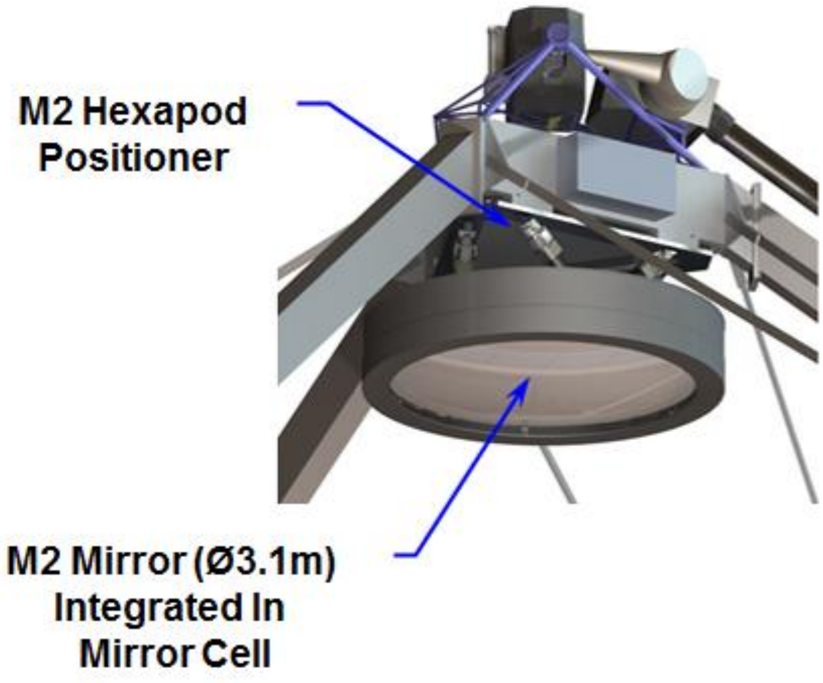
- Jet Propulsion Laboratory (JPL), USA and the UC Irvine, USA are responsible for the design and delivery of the APS (Caltech/UC work-share)

- JPL is responsible for the system design, software, and integration of the M1CS (Caltech/UC work-share)

- **India is responsible for production of actuators, sensors and electronics**

Secondary Mirror (M2)

- Description:
  - 3.1m Convex hyperboloid
  - 100 mm thick
  - Zero Expansion glass
  - Passive whiffletree support system
  - Positioned by hexapod
- M2 System is Caltech/University of California work-share



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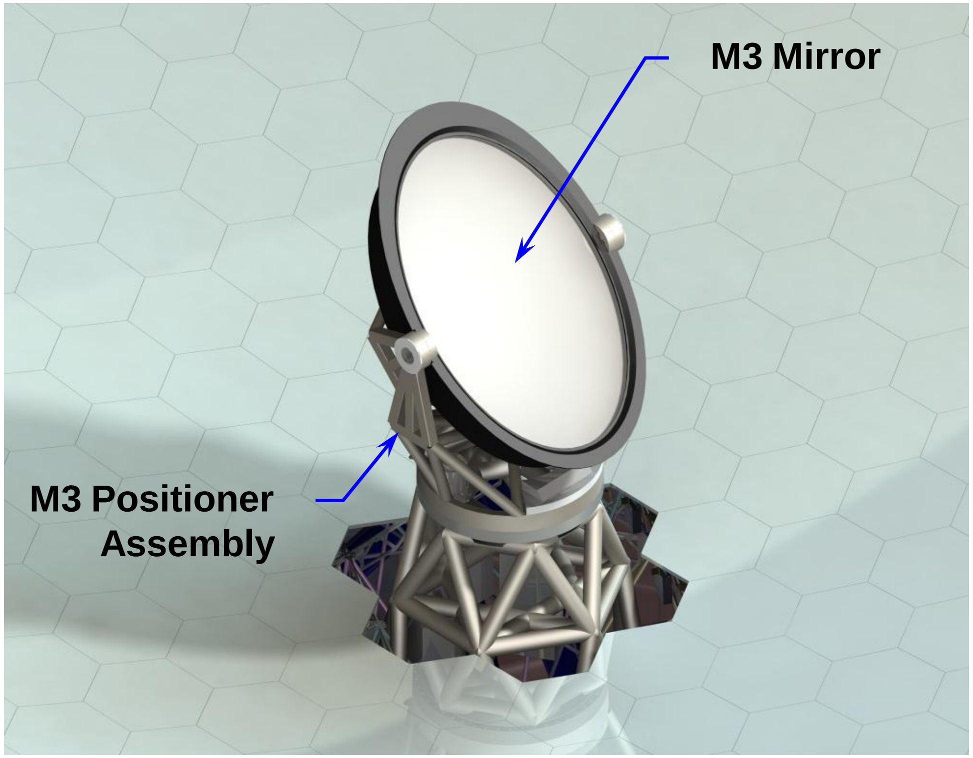
Giant Science Steering (Tertiary)Mirror (M3)

- Description:
  - 2.5 x 3.5m flat
  - 100 mm thick
  - Zero expansion glass
  - Passive whiffletree support system
  - 2-axis gimbal positioner
  - Stray light baffle around perimeter
- China is responsible for design and fabrication of the M3 System
  - Design is progressing at the Changchun Institute of Optics, Fine Mechanics and Physics (CIOMP), an institute of The Chinese Academy of Sciences (CAS)



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TMT Calotte Enclosure

- Pointing accomplished by two rotations
  - Azimuth rotation of enclosure on fixed base ring
  - Rotation of cap structure on tilted bearing ring
  - 32.5 degree tilt addresses objects from zenith to 65 degrees
- Minimal size round aperture protects telescope in high-wind conditions
- Shutter, vents and deployable flaps
  - 88 large (e.g., 4 x 5 m) vents can be individually controlled
- Enclosure is being designed by Dynamic Structures Limited of Canada

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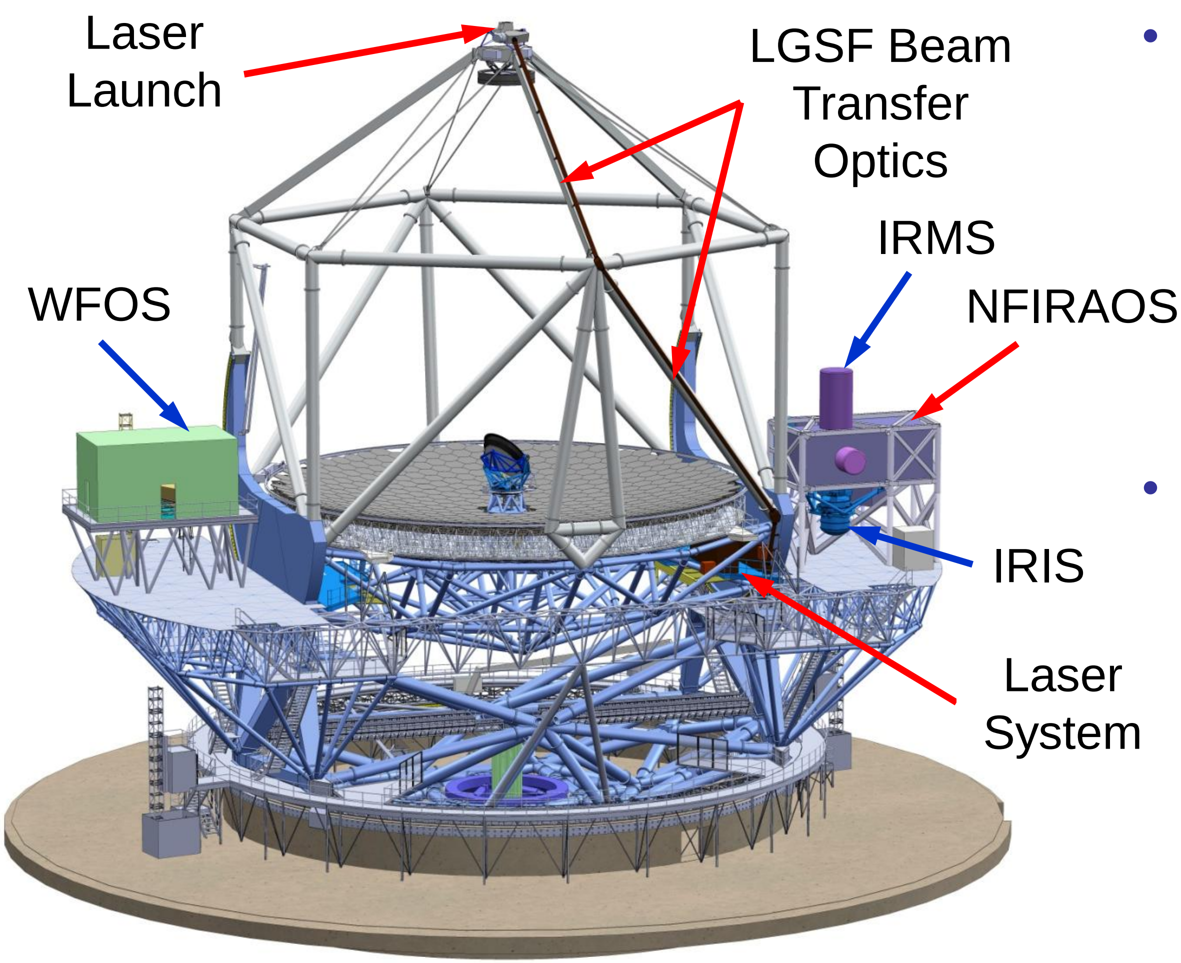
First Light Instruments

- The first light instrument suite that will be delivered as part of the construction project are
  - Near Field InfraRed Adaptive Optics System (NFIRAOS)
    - a laser guide star supported, multi-conjugate adaptive optics (MCAO) system being built by Canada
  - InfraRed Multi-Slit Spectrometer (IRMS)
    - IRMS, a multi-partner collaboration, is a close copy of the very successful and versatile Keck/MOSFIRE instrument, and it leverages the MCAO capability provided by NFIRAOS to boost the amount of light falling within its slitlets
  - InfraRed Imaging Spectrometer (IRIS)
    - IRIS, a multi-partner collaboration, is a combined high-resolution imager and integral-field unit (IFU) spectrometer
  - Wide Field Optical Spectrometer (WFOS)
    - WFOS, a multi-partner collaboration, is a seeing limited instrument that will cover a total spectral range from 0.31 to 1.1 μm using separate red and blue color channels
  - Laser Guide Star Facility (LGSF)
    - The LGSF, being built by China, will create an asterism of stars, each asterism specifically chosen according to the particular adaptive optics system being used and the science program being conducted

First Light Adaptive Optics Systems and Science Instruments



- Adaptive Optics Systems
  - Narrow Field InfraRed Adaptive Optics System (NFIRAOS)
  - Laser Guide Star Facility (LGSF)
- Science instruments
  - InfraRed Imaging Spectrograph (IRIS)
  - InfraRed Multi-slit Spectrometer (IRMS)
  - Wide Field Optical Spectrometer (WFOS)

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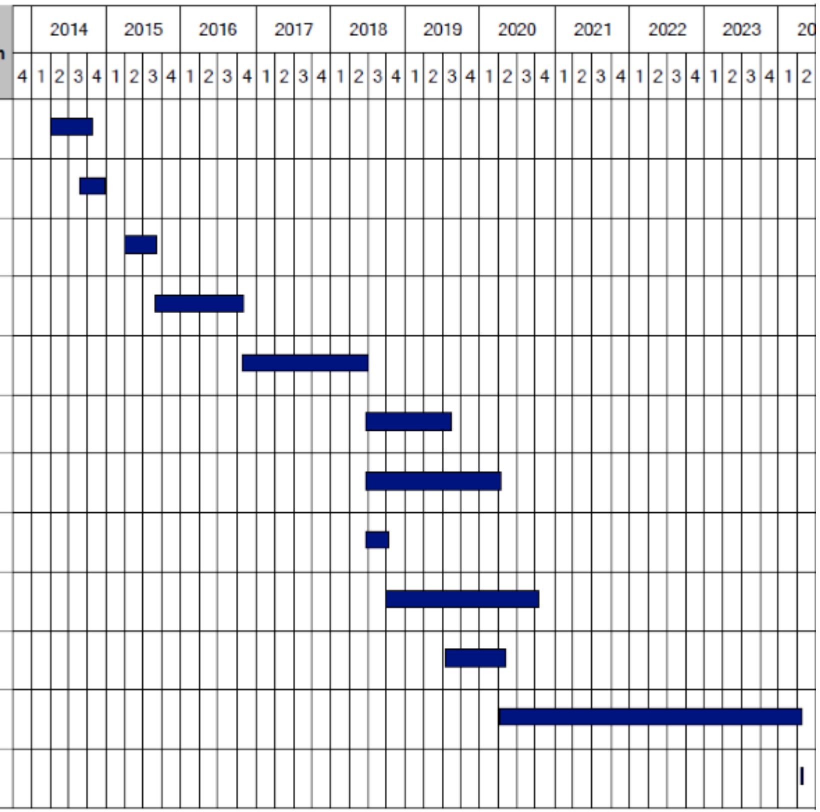
Project Status and Schedule

- The project has officially entered the construction phase
- First light is targeted for 2024

Activity ID	Early Start	Early Finish
01 -- Access Road	04/01/2014	10/16/2014
02 -- Site Grading	08/21/2014	12/15/2014
03 -- Fixed Enclosure Base Foundations & Trenches	04/02/2015	08/27/2015
04 -- Fixed Enclosure Base Structure	08/28/2015	10/24/2016
05 -- Enclosure Shell	10/25/2016	06/27/2018
06 -- Enclosure Completion	06/28/2018	08/05/2019
07 -- Summit Facilities Completion	06/28/2018	04/03/2020
08 -- Cladding on Fixed Enclosure Base	06/28/2018	09/28/2018
09 -- Telescope Structure Erection & Integration	10/01/2018	10/05/2020
10 -- Fixed Enclosure Base Completion	07/15/2019	05/01/2020
11 -- Assembly, Integration, and Verification (AIV)	04/06/2020	04/15/2024
12 -- First Light	04/15/2024	04/15/2024



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TMT-India and its Work Share (Introduction)

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TMT-India

- India officially joined TMT project in September 2014 with the approval of the Indian government (Press Release)

India signs membership documents

- **02 December, 2014**

Signing of TIO partnership agreements by *Dr. Vijay Raghavan, Secretary, DST* in the presence of *Dr. Harsh Vardhan, Hon'ble Union Minister of Science and Technology and Earth Sciences, Govt. Of India*

- Members from various embassies of partner countries, TMT-India, and media attended the event

- TMT-India will be jointly funded by the Departments of Science and Technology and Atomic Energy

TMT-India

- The Aryabhatta Research Institute for Observational Sciences (ARIES), *Nainital*, the Indian Institute of Astrophysics (IIA), *Bengaluru* and the Inter-University Centre for Astronomy and Astrophysics (IUCAA), *Pune* are the three main institutes constituting TMT-India
- The activities of TMT-India will be coordinated by the India TMT Coordination Committee (ITCC), located at IIA, Bengaluru, and set up by the Department of Science and Technology

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TMT-India Work Share

- Software
  - **Telescope Control System (Subject of this EOI)**
  - Observatory Software (~ 50%)

- Hardware
  - 86 Mirror Segments
  - Mirror Segment Support Assemblies
  - M1 Control System Actuators
  - M1 Control System Sensors
  - M1 Control System Distributed Control Electronics (SCC)
  - Science Instruments

Telescope Control System (TCS) (Introduction)

TCS

- Context within TMT
- Responsibilities
- External interfaces
- Work Breakdown Structure (Overall)
- TCS schedule and current status
- Software Design and Development
- TCS WBS elements

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TMT Principal Systems

- A software system can be viewed in multiple ways which is shown in next 2 subsequent slides
- At the highest level the TMT software system consists of 5 principal systems
- Each principal system is focused on a specific, easily identifiable functionality
- Each principal system is itself a complex collection of software subsystems
- Command communication between other systems is limited
- Command communication between principal systems is relatively low-bandwidth by design
- All high speed communication occurs within a single principal system
- Observatory Controls is in charge of coordinating and commanding the other principal systems

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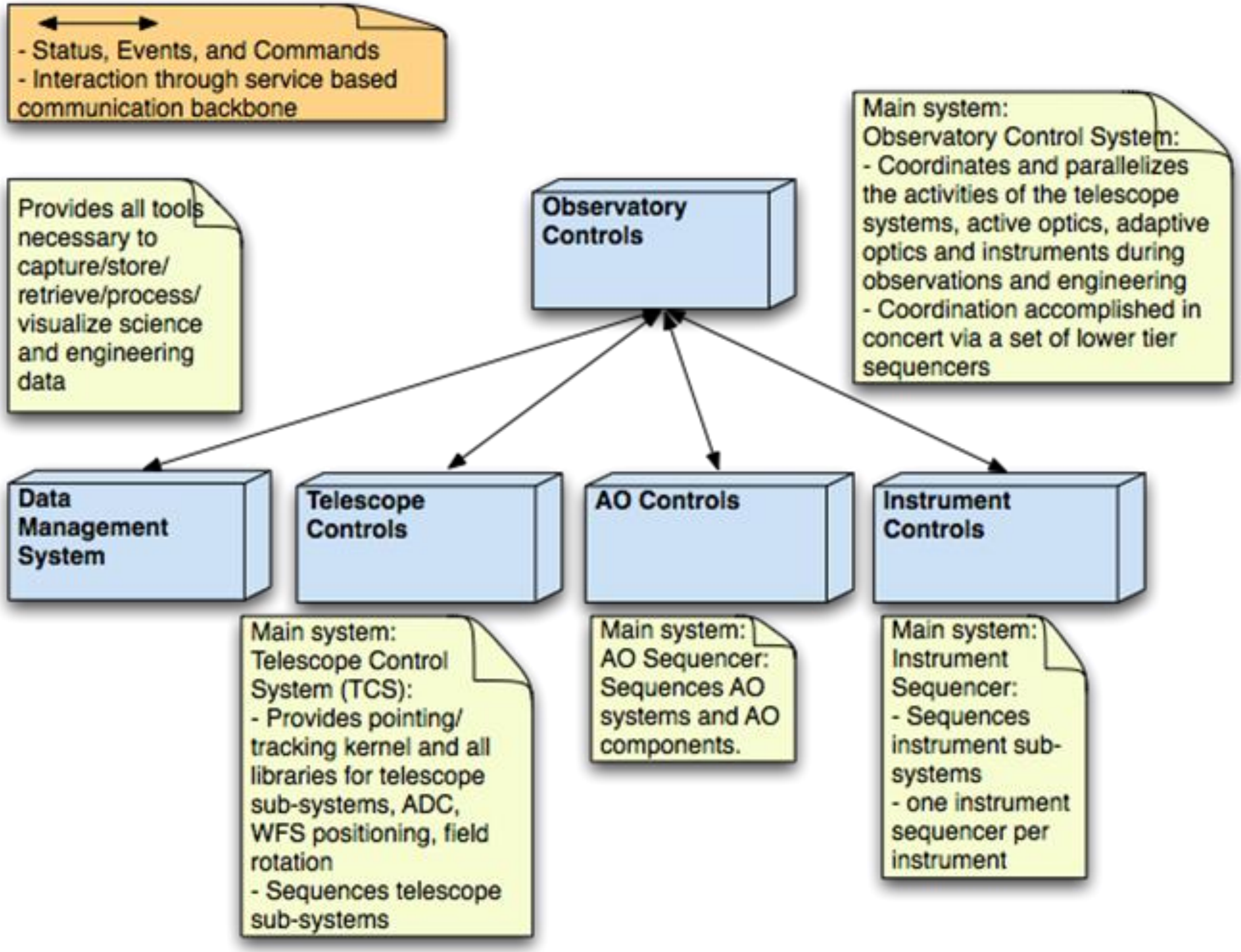
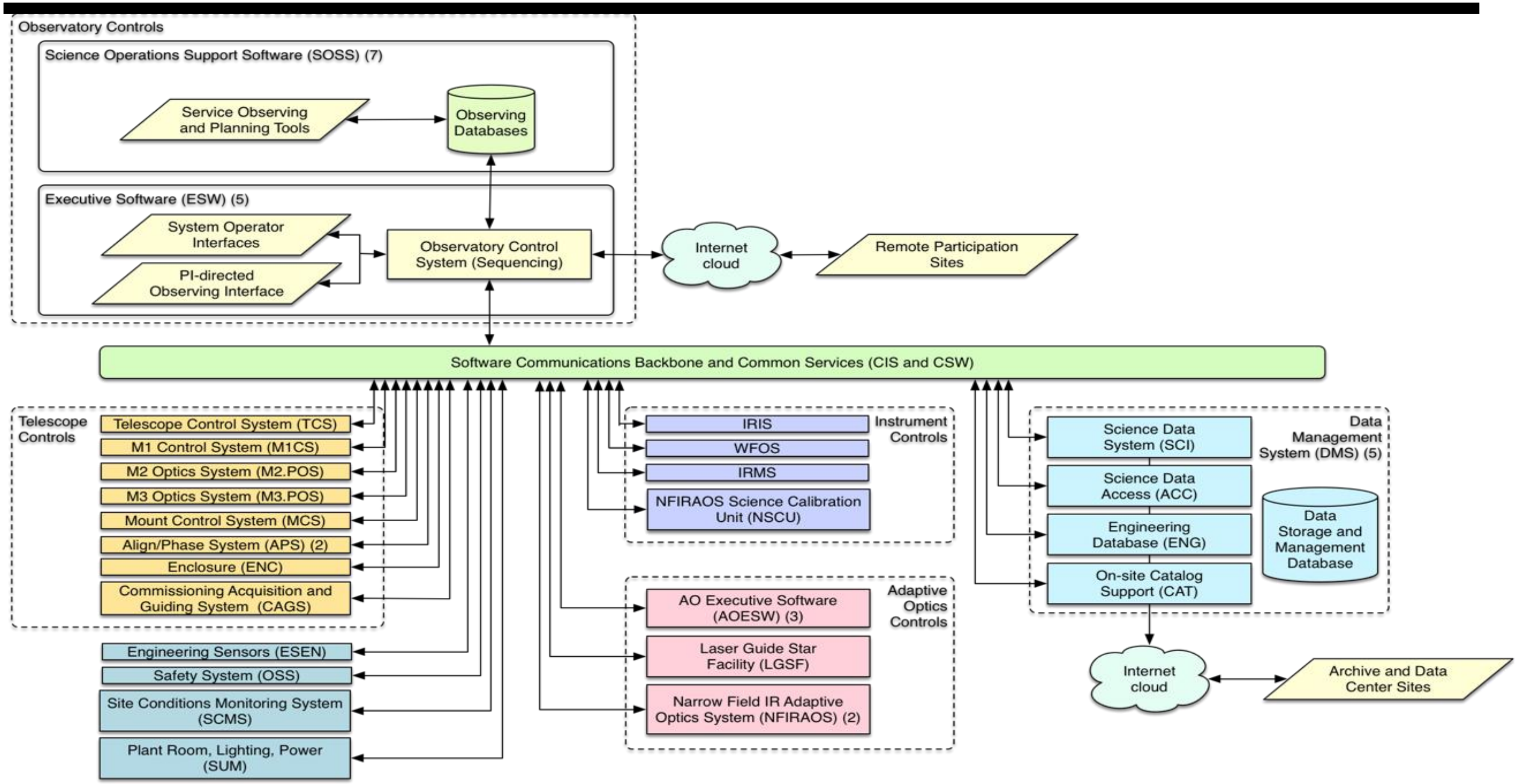
TMT Principal Systems View 1



TMT Principle Systems View 2



All principle systems communicate to each other via TMT provided software communications backbone and common services, together called as Common Software (CSW)

What is TCS? (Summary)

- Telescope controls is one of the 5 TMT principal systems
- TCS is not just the pointing kernel
- It includes the non-vendor supplied parts of the Mount, Enclosure, Secondary Mirror (M2) and Tertiary mirror (M3) control systems etc.
- TCS includes the control and coordination of optics corrections
- TCS will utilize TMT Observatory Software (OSW) and TMT Common Software (CSW)

What is TCS? (Details)

- TCS is responsible for the coordination and control of the various subsystems that make up the telescope
  - responding to commands received from the observatory control system and from expert user interfaces
- TCS primarily consists of software and the associated off the shelf computer hardware necessary to perform its responsibilities
- TCS consists of a sequencer and status/alarm monitor, a pointing kernel, a corrections module, and several adaptors
  - The Sequencer and Status/Alarm monitor provide high level control of the mount, the primary, secondary and tertiary mirrors, and the enclosure
  - The Pointing Kernel converts target positions (right ascension and declination) into pointing and tracking demands in the appropriate coordinate systems for the telescope mount
  - Corrections Module is responsible for adjustments to be made in concerned systems like primary, secondary and tertiary mirrors and relevant instruments during an observation
  - Adapters will handle differences between vendor and commercially supplied software systems and core observatory software systems

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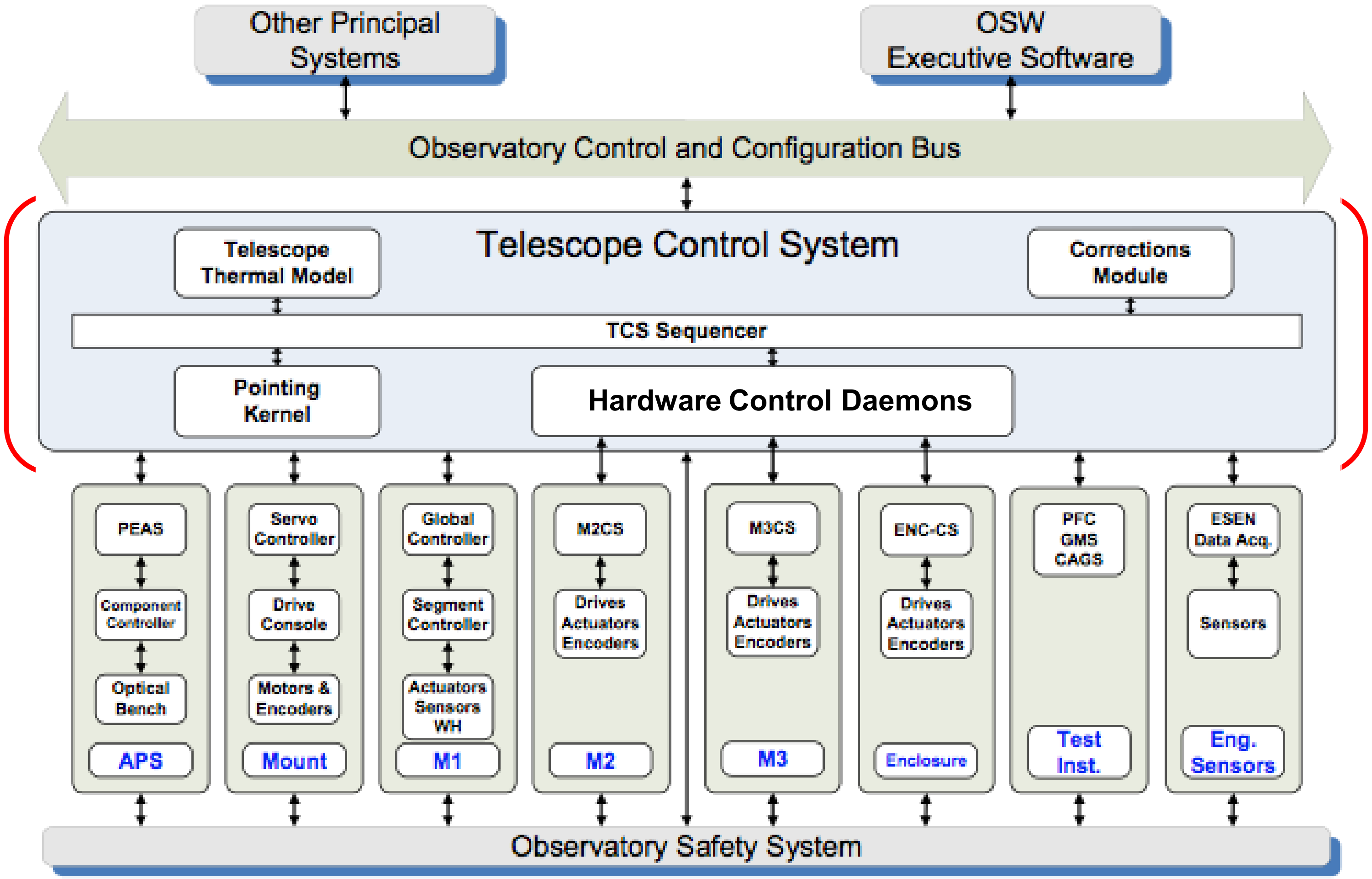
Control Hierarchy



TCS Responsibilities

- Pointing & Tracking
- Sequencing and Coordination
- Optics Control
- User Interaction
- Subsystem control

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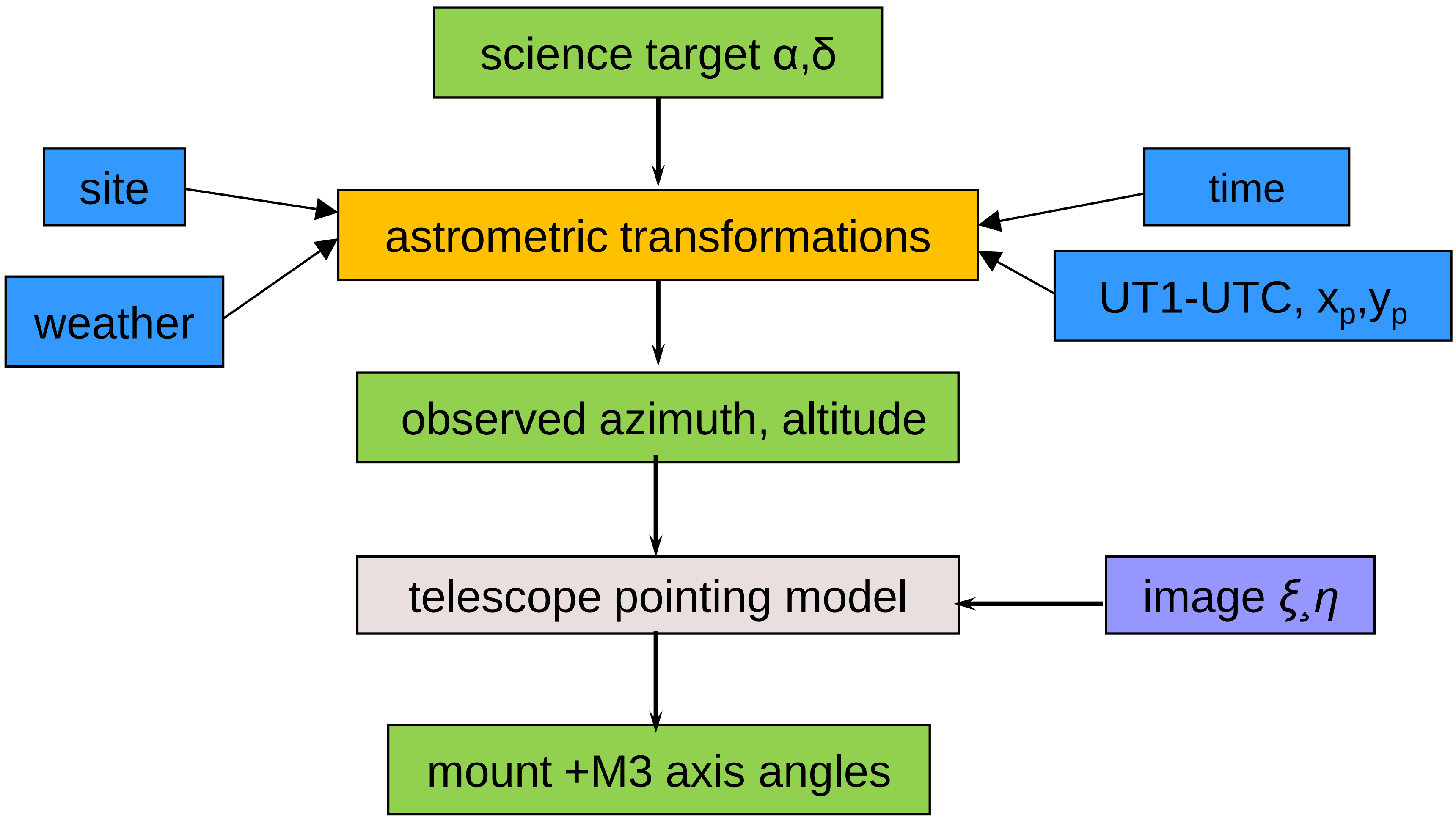
TCS Responsibilities

- Pointing & tracking
  - Traditional role of a TCS to generate azimuth, altitude demands
  - Handle all astrometric transformations
  - Provide a pointing model for the structure
  - Allow positioning of target in focal plane
  - Calculations of guide target positions
  - Demands to M3 including a pointing model
  - Calculation of instrument rotator angles
  - Calculations to allow setting of ADCs
  - Calculations of enclosure base and cap

TCS Responsibilities



TCS Responsibilities

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- Sequencing and Coordination
  - Aim is to simplify system for user/operator/observatory controls
  - Provide a high level view of system
  - Manage TCS sub-systems
  - Reject invalid configurations
  - Provide a Command Action Model
  - Provide health & alarm tree for subsystems
  - Simulation

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TCS Responsibilities

Sequence Execution Component

- A Sequence Execution Component is the application or component that is used to coordinate and synchronize Assemblies (i.e. sequence the system).
- Each observing mode to be executed using a unique set of Assemblies (see slides 61-62) and Sequence Execution Components as needed
- A Sequence Execution Component executes a “script”
  - Can load a script from a file as well as from Configuration Service
- A Sequence Execution Component is the supervisor for all actions it starts
  - It represents those actions to the higher-level Sequence Execution Components
- Allows standalone operation for testing
- Same component and specialized scripts are used for testing
- Is a reusable TMT delivered component

TCS Responsibilites

- Optics Control
  - Manage Primary Mirror (M1) open loop models
  - Manage Secondary Mirror (M2) open loop models
  - Coordinate data from seeing limited sensors to provide guiding corrections, M2 displacements, low order M1 modes
  - Accept off loads from Adaptive Optics (AO) system to provide guiding corrections, M2 displacements and M1 modes

TCS Responsibilites

- User interaction
  - Support engineering & commissioning work
  - Support classical observing
  - Support remote observing

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TCS Responsibilites

- Subsystem Control
  - Hardware Control Daemons and Assemblies
    - Standard interface to Cameras
    - Telescope Structure (STR)
      - MELCO Mount Control System
      - Hydrostatic Bearing System
      - Segment Handling System
    - Enclosure
      - Base, cap, shutter, vents
    - Secondary Mirror (M2) Positioner
    - Tertiary Mirror (M3)
    - Commissioning and Guiding Wavefront Sensor (WFS)
    - Prime Focus Camera (PFC)

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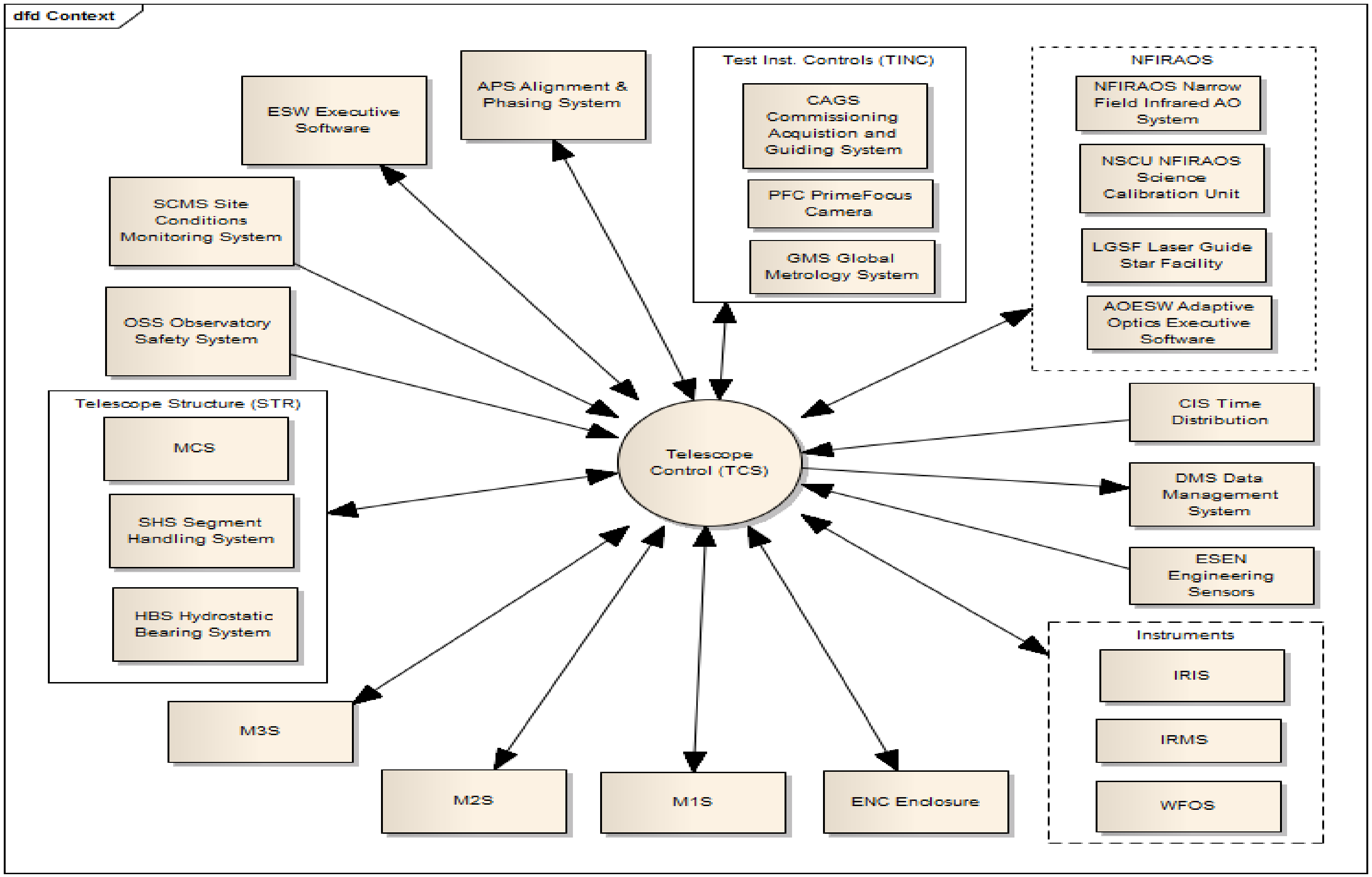
TCS External Interfaces

15 systems in total which TCS needs to interface with

- Structure (STR)
- Primary Mirror System (M1S)
- Secondary Mirror System (M2S)
- Tertiary Mirror System (M3S)
- Enclosure (ENC)
- Alignment and Phasing System (APS)
- Near Field InfraRed Adaptive Optics System (NFIRAOS)
- Test INstrument Control (TINC)
- Engineering Sensors (ESEN)
- NFIRAOS Science Calibration Unit (NSCU)
- Laser Guide Star Facility (LGSF)
- InfraRed Imaging Spectrometer (IRIS)
- InfraRed Multi-Slit Spectrometer (IRMS)
- Wide Field Optical Spectrometer (WFOS)

TCS External Interfaces



Interface Control Documents (ICDs) for each of these 15 external interfaces will contain interaction details between TCS and respective external systems

Work related to TCS (Overall)

- Covers all effort associated with the architecture, design, development, documentation, integration and commissioning of the Telescope Control System
- Computer hardware required for operation of the TCS plus development tools and licenses
- The development of Design Requirements, Design Documents, Interface Control Documents (ICDs), User Manuals, Troubleshooting guides etc.
- Hardware Control Daemons (HCDs) (see slides 59-60) to interface turn-key systems delivered by third party suppliers to the standard TMT communication layer
- Offline processes for building calibration look up tables for the mount, M1, M2 and M3
- An expert GUI
- A TCS simulator, adequate to support basic testing, for other subsystems under development that have interfaces to the TCS

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Work Breakdown Structure

- A detailed product oriented breakdown of every piece of work that must be performed to deliver the project and every subsystem and component
- Each subsystem is defined by the Work Breakdown Structure (WBS) elements that it encompasses
- TCS currently has 14 top level (L2) WBS elements (see slides 73 - 86)
  - TCS
  - Sequencer (SEQ)
  - Pointing Kernel (TPK)
  - Status Alarm Monitor (SAM)
  - CAMERA
  - Wave Front Sensor (WFS)
  - Corrections Module (CM)
  - Commissioning Acquisition and Guiding System (CAGS)
  - Enclosure (SEQ)
  - Structure (STR)
  - Secondary Mirror (M2)
  - Tertiary Mirror (M3)
  - Prime Focus Camera (PFC)
  - ANALYSIS

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TCS WBS Phases

The work associated with each element in the TCS WBS will be performed in a series of phases

- PDP - Preliminary Design Phase
  - Development of design to show that requirements and interfaces are met, enabling technologies developed, major risks retired, bottom-up cost estimate, fabrication and construction schedule developed
- FDP - Final Design Phase
  - Production ready design, work scopes for subcontracts and procurements, key technologies industrialized, show compliance with requirements and interfaces and plans for test and verification, quality, safety, hazard/risk assessment, operations and maintenance plans, refined cost and schedule

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TCS WBS Phases

- Code and Test
  - Development of the software based on the architectural, functional and operational inputs derived from the Final Design phase, unit and acceptance testing done at the software vendor's location
- INT - Integration and Test
  - Integration and testing of independently testable software modules shipped by the vendor done at the TMT Project Office. The Software Test and Integration Lab (STIL) support staff in TMT Project Office will be a resource available to the software vendor during this phase and will provide the necessary standards, tools, support, and testing fixtures
- AIV - Assembly, Integration and Verification
  - On-site Integration and testing of software in the telescope environment on real observatory equipment and hardware. The software vendor personnel will assist TMT personnel in the integration and verification activities at the site during this phase

TCS Schedule

Project Phase	Period
Design Phase • **Preliminary Design Phase** • **Final Design Phase**	 **Q4 2015 – March, 2018** **April, 2018 – May, 2019**
Code and Test	**June, 2019 – January, 2021**
Integration	**February, 2021 – February, 2022**
Assembly, Integration and Verification	**March, 2022 – April, 2022**

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TCS Current Status

- Conceptual Design Review held in Pasadena, USA during April, 1-3, 2014 with the following deliverables
  - Design Requirements Document
  - Software Design Document
  - Configuration Index Document
  - Risk Register
  - Work Breakdown Structure
  - Management Plan
- Currently TMT-India team is seeking contractors within India to carry out subsequent phases of TCS, namely, PD, FD, Code and Test, INT and AIV

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TMT Software Design

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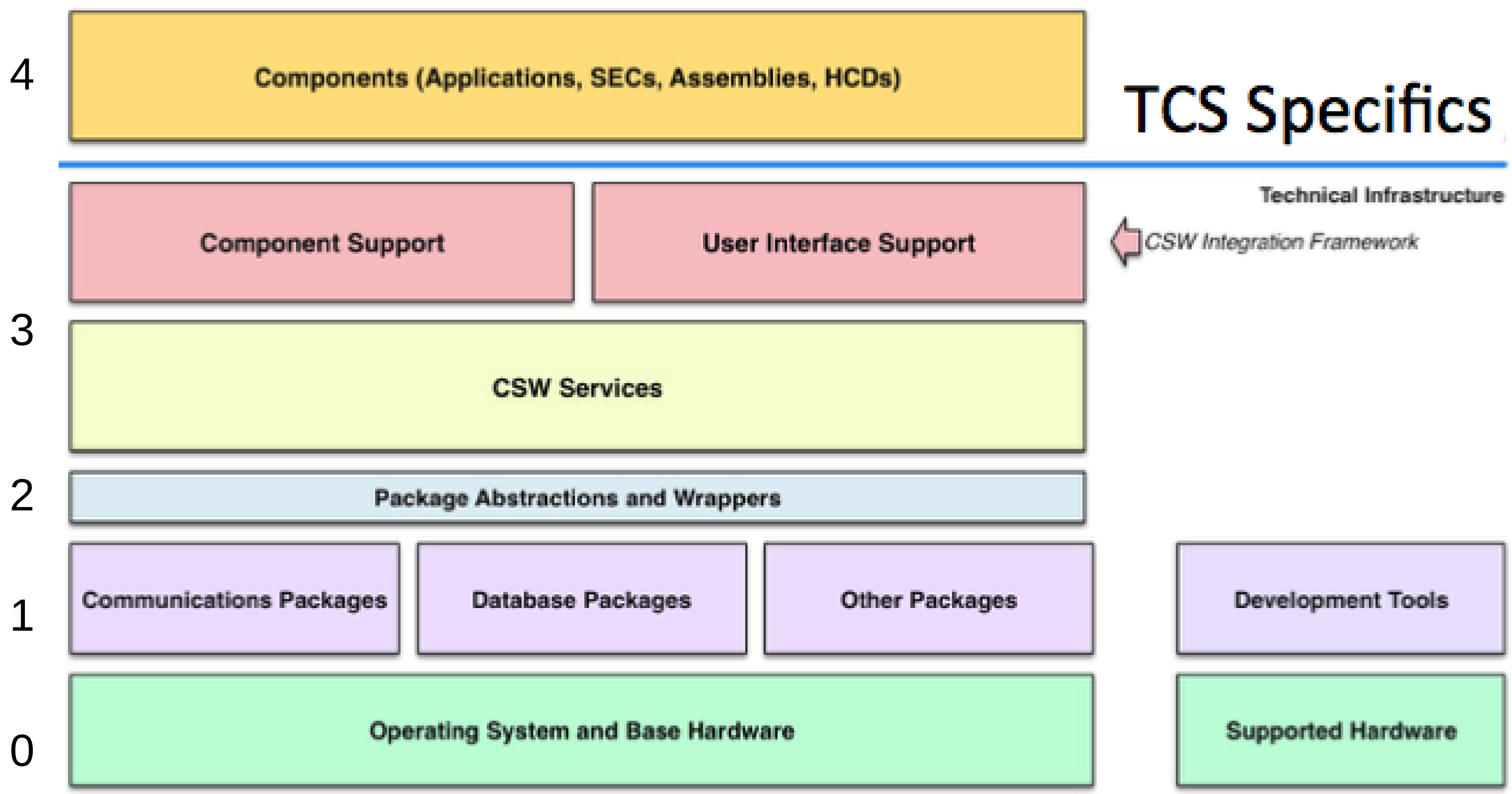
TMT Software Layers



TCS software will be built on these TMT Software Layers

TMT Software Layers

- Layer 0: Operating system and base hardware (eg: disk drives, network interfaces, etc.). Compliance with TMT specification and provided by operating system and hardware vendors

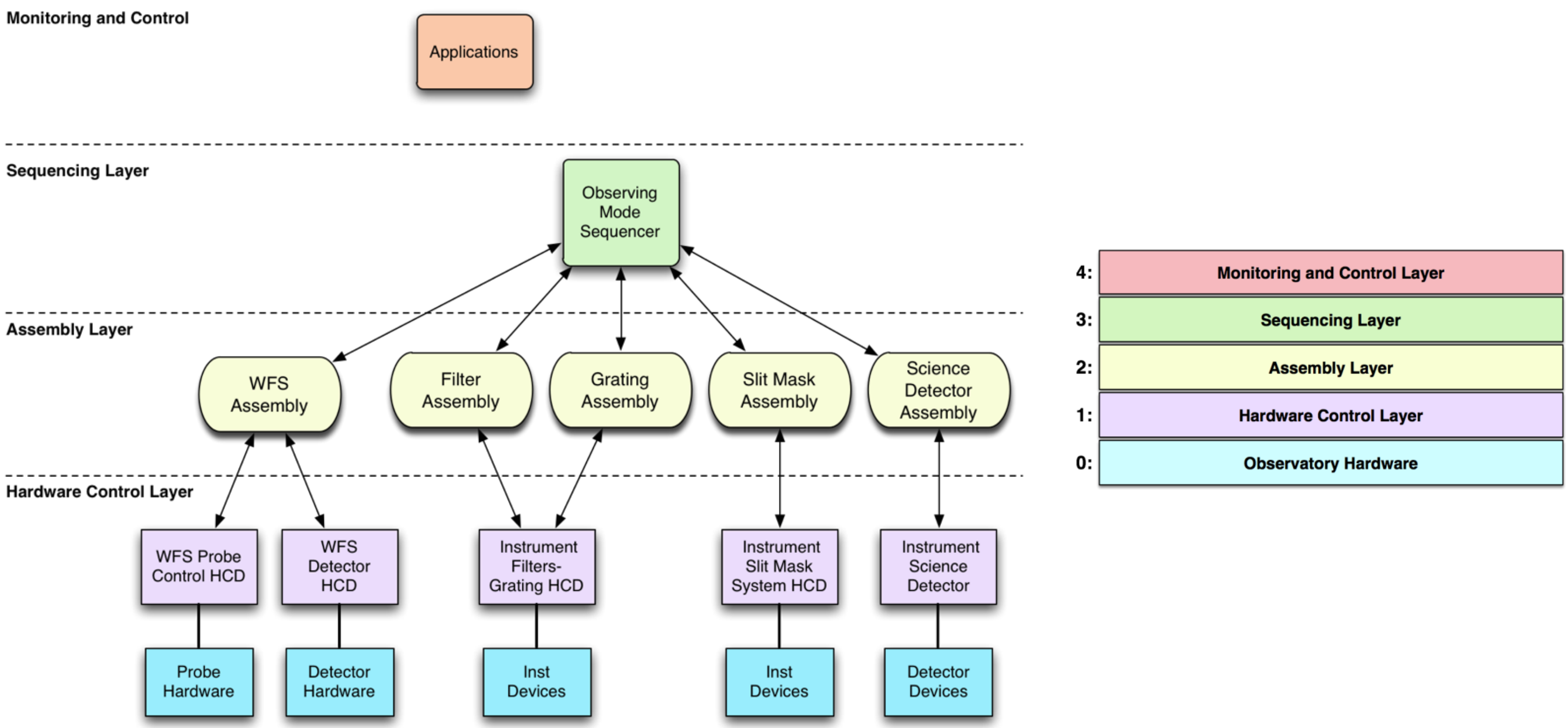
- Layer 1-3: Common Software (CSW) specific providing infrastructure integration services

- Layer 4: Astronomy applications or components which use CSW and any other libraries to ease service usage

TMT Common Services

- Time Service
- Event Service
- Location Service
- Connection & Command Service
- Database Service
- Configuration Service
- Single Sign-On Service
- Logging Service
- Container & Components

Software Component Hierarchy



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Hardware Control Layer

- This layer is above physical hardware and will handle all communications related to disparate hardware
- Consists of all the controllable hardware that is available for use by higher levels of software
- At this layer in the software each HCD and hardware controller is independent; any required synchronization with other hardware is handled in a higher layer
- Provides hardware abstraction to the upper layers by means of Hardware Control Daemons

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Hardware Control Daemon (HCD)

- HCDs are **adapters** that provide a uniform interface to hardware controllers
- Each HCD controls 1 hardware controller
- HCD encapsulates the controller protocol
- Converts configuration into native commands, etc.
    - HCD encapsulates the hardware controller proprietary protocol, transport, and physical connection
    - HCD monitors the state and status of hardware controller
- Can multiplex requests and responses for multi-axis hardware controllers or PLC/PACs
- Allows direct control for low-level testing
- Provides one location for device simulation allowing end-to-end system testing or can communicate with remote device simulator
- HCDs use CSW for communication and services as needed
    - Command Service and Configuration Service for initialization
    - Event Service for events, alarms, health

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Assembly Layer

- The Assembly Layer is above the Hardware Control Layer
- Assemblies control Hardware Control Daemons (HCDs), not hardware controllers
- The Assembly Layer allows HCDs to be grouped to provide:
    - Coordinated hardware functionality
    - Enhanced capabilities
    - More complex user-oriented devices
- Allows for higher level coordination and synchronization of HCDs
- Assemblies allow addition of new capabilities
- Assemblies can be transient or long-lived

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Assembly Functions and Uses

- An Assembly is the supervisor and is responsible for all actions it starts
- Provides a uniform interface to the Sequencing Layer to control devices
- An Assembly can be an adapter for a code library needed for computations
- Assemblies use TMT Common Software (CSW) for services
  - Command Service to receive configurations, completion
  - Event Service for alarms, health, events
  - Time Service for precise time and to synchronize HCDs as needed
  - Configuration Service for default values, other configuration info
  - Assembly and HCD lifecycle, initialization handled by CSW
- An Assembly provides a testable unit of user-oriented functionality with minimal dependencies

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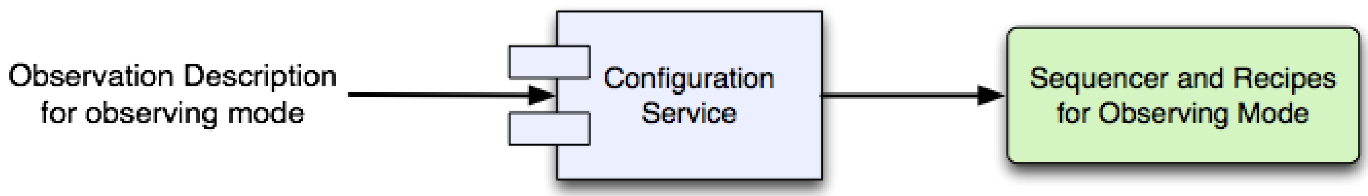
Sequencing Layer

- Components in the Sequencing Layer control, coordinate and synchronize Assemblies



- Sequencer can be dynamically created for each observing mode
- Overall sequencer consists of multiple focused component or subsystem sequencers
- Software and hardware can be optimally grouped and controlled for each observing mode

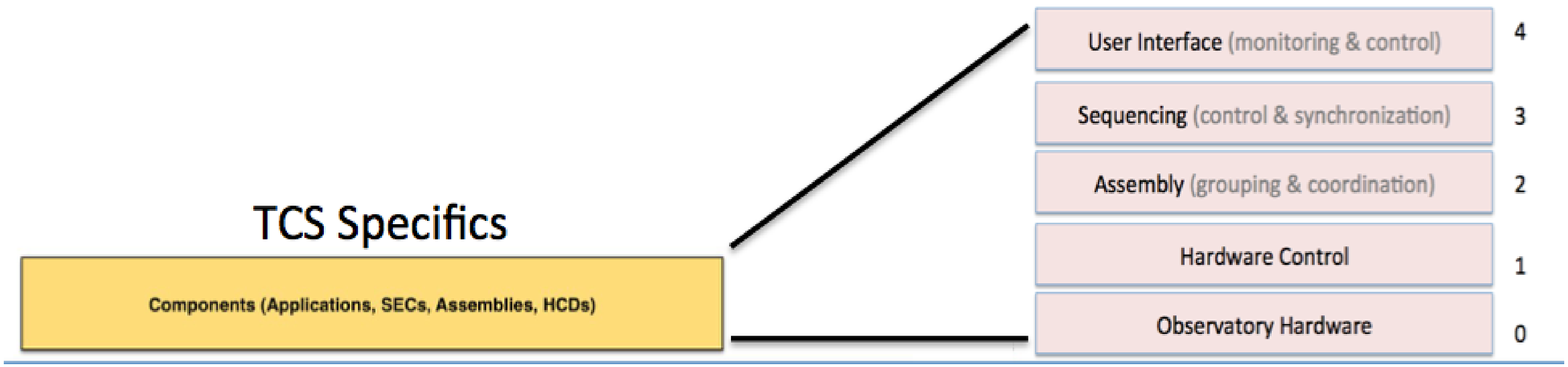
TMT Software Design

Monitoring and Control Layer

- Applications are the visible programs astronomers use during observation

- Applications need access to all system features
  - May need to interact with WFS or science data images during acquisition or science data acquisition
  - May need to provide a complex UI for controlling the system (TCS)
  - May need to display or use Event Service information
  - May need to control and synchronize Assemblies actions in an observing or engineering mode
  - May need to execute complex scriptable tasks
  - May need to do all these things within a single application

TCS Software Structure Layers



- Another view of slide 50
- The TCS must be designed and developed so that it adheres to the TMT Observatory Software Architecture and Common Software Services Framework
- Common Software (CSW) is a set of services constructed on top of Commercial of the Shelf (COTS) or open-source middleware product(s) similar to all modern observatory software systems

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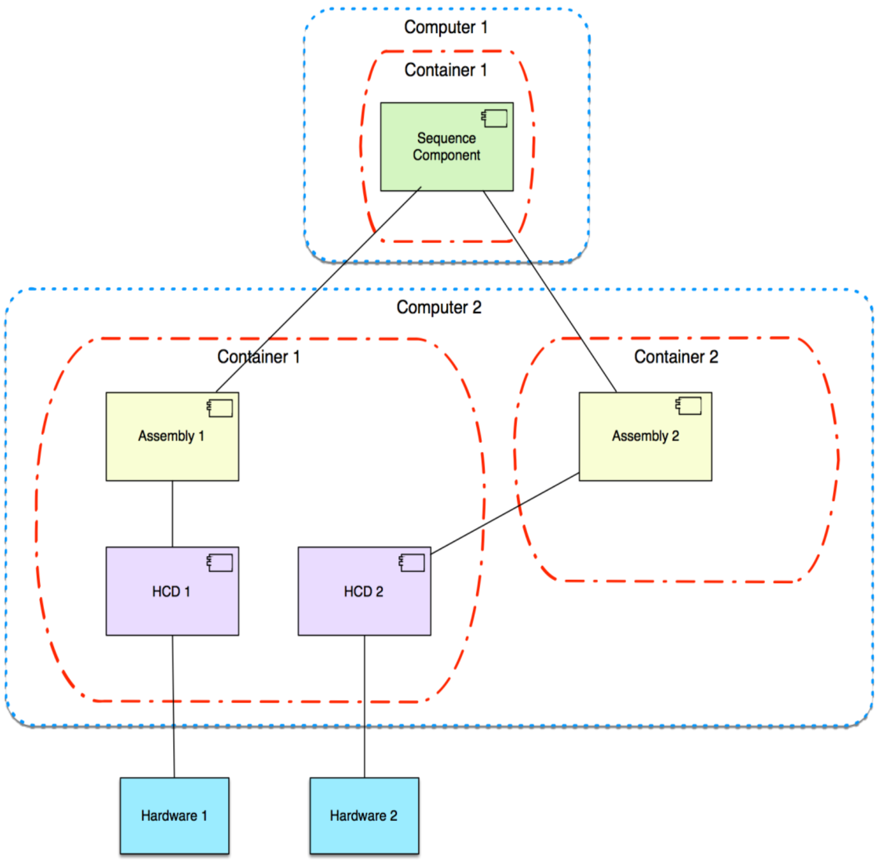
Deployment Support

- CSW provides a *container* that can host one or more components
- Each container is a single JVM process
- A single computer can host multiple containers
- Between containers, communication is remote
- Container provides lifecycle support for components



Operating System Choice

- TMT Requirements state "Unix-like" operating system
- Plan to choose Redhat derived Linux distributions (possible hardware support).
- **Primary Choice:** CentOS (http://www.centos.org)
- **Secondary Choice**: Scientific Linux (http://www.scientificlinux.org)
  - Maintained by Fermilab and CERN
- **Real-time Applications**:
  - Required in only a few places.
  - Adopt an "official" real-time kernel.
  - Preliminary choice is Redhat MRG
    - Appears to be supported in CentOS distribution
- No windows except when required for specific development tasks (e.g., PLC dev).

CentOS

Scientific Linux

RED HAT ENTERPRISE MRG
MESSAGING, REALTIME, GRID

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Programming Languages

- TMT plan is to use JVM-based languages including Scala and Java
- Scripting for SEC also based on JVM
    - Preliminary choices: JPython and Scala
- Python probable choice for data processing side due to popularity

Scala

Java

python™

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TCS Software Development Process

TCS Software Development Process

- To be consistent with TMT software development process
- Inspired by Agile development methodology
- Iterative development with frequent releases for risk mitigation
- Automated testing and Continuous Integration
- Distributed revision control and source code management (eg: Git) for distributed software development
- Frequent releases of software modules by vendor will be integrated and tested at Software Test and Integration Lab (STIL) located at TMT Project Office

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Software Test and Integration Lab (STIL)

- Provide infrastructure support for software testing and the integration of software from the software vendors at TMT Project Office during Integration (INT) phase and on-site during Assembly, Integration, and Verification (AIV) phase
- The STIL staff will be a resource for the software vendor and will provide standards, tools, support, and testing fixtures to help the software teams do their jobs
- The STIL will have computing equipment to allow the integration and testing of the software throughout construction prior to delivery at the site. The STIL will maintain the project source code repository and other software tools to monitor and coordinate progress
- All software-related deliverables will be delivered to the project through the STIL. The STIL will create the TMT project software releases and will be responsible for ensuring the software system builds as a single system

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TCS WBS elements

WBS Element (1/14)

- TMT.TCS

Objective

- Implement top level controller tmt.tcs

Requirements

- Handle configurations, basic checking of attributes, monitor successful completion
- Includes TCS GUI
- Produce external TCS ICD
- TCS User Manual

Skills

- Good understanding of sub-system interfaces and functionality
- Good understanding of OSW infra-structure
- UI design

WBS Element (2/14)

- Sequencer (SEQ)

Objective

- Implement all TCS level sequences

Requirements

- Provide standard observing sequences that can be called by OSW e.g. Acquire MOBIE WFS
- Provide commissioning and calibration sequences e.g. For APS data taking

Skills

- Understanding of OSW scripting support
- Understanding of system wide capabilities of engineering groups, instruments etc.

WBS Element (3/14)

- Pointing Kernel (TPK)

  Objectives
  - Produce main pointing engine of TMT

  Requirements
  - Handle all possible target frames e.g. FK4, FK5, ICRS etc.
  - Generate demands for mount, enclosure, M3, rotators, guide probes, ADC etc.
  - Support offsets, guider feedback
  - Tools for pointing model derivation

  Skills
  - Understanding of astrometric conversions
  - Understanding of telescope modelling
  - Overview of engineering & operational requirements to achieve science goals

WBS Element (4/14)

- Status Alarm Monitor (SAM)

  Objectives
  - Provide user feedback on operational state of TCS and its subsystems

  Requirements
  - Integrate with observatory wide status & alarm handler
  - Provide feedback on any status that may affect observing
  - Interface to SCMS
  - Monitoring that TCS sub-systems are on-line
  - Compute times to limits for tracking mechanisms

  Skills
  - Good understanding of sub-system interfaces and functionality
  - Good understanding of OSW infra-structure

WBS Element (5/14)

- CAMERA

  Objective
  - Provide standardized interface to all camera systems used by TCS

  Requirements
  - Standard interface to start/stop integrations, set integration times, set ROI
  - Cameras to handle are at least PFC, APS APT, Instrument OIWFS

  Skills
  - Understanding of capabilities and requirements of full range of TMT adopted cameras
  - Understanding of CSW to make cameras TMT compliant

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WBS Element (6/14)

- Wave Front Sensor(WFS)

Objective

- Create library to take raw images and produce Zernike modes

Requirements

- Handle both simple and SH images
- Flat field, bias subtract etc.
- Extract centroids
- For SH images use reference image to deduce slopes and then perform a modal reconstruction

Skills

- Image analysis
- Wave front reconstruction

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WBS Element (7/14)

- Corrections Module (CM)

Objective

– Handle all incoming wave front data and route appropriately to TPK (for guiding), M3 (pupil adjustment), M2 (coma, focus), M1 (higher modes)

Requirements

– Manage all sub-controllers
– Manage LUTS for M1, M2
– Switch between and possibly blend signals from multiple WFS

Skills

– Good understanding of OSW infra-structure
– Understanding of optical consequences of M1, M2 and M3 adjustments

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WBS Element (8/14)

- Commissioning Acquisition and Guiding System (CAGS)

  Objective
  - Provide an integrated TMT compliant commissioning, acquisition and guiding facility

  Requirements
  - Control LOWFS hosted by APS plus any associated hardware
  - Handle guiding functionality of APS APT camera
  - Liaise with APS on control split between APS and CAGS using the APT camera

  Skills
  - Good understanding of OSW infra-structure
  - Good understanding of functionality provided by CAMERA and WFS packages

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WBS Element (9/14)

- Enclosure (ENC)

Objective

- Produce a TMT compliant subsystem that encapsulates all the functionality of the Enclosure hardware

Requirements

- Coordinate and sequence where necessary all enclosure mechanisms
- Provide and manage configurations of vent gates
- Provide HCDs for interfacing to hardware
- Produce ICD describing public interface
- Produce enclosure engineering GUI

Skills

- Full understanding of enclosure hardware interface
- Good understanding of OSW infra-structure

WBS Element (10/14)

- Structure (STR)

  Objective
  - Provide TMT compliant system to control mount hardware

  Requirements
  - Provide HCD to interface to MELCO hardware
  - Implement motion profiling
  - Produce engineering GUI
  - Produce STR ICD of public interface

  Skills
  - Good understanding of OSW infra-structure
  - Understanding of mount hardware performance / servo to optimize profiling
  - Understanding of MELCO public interface capabilities

WBS Element (11/14)

- Secondary Mirror (M2)

  Objective
  - Produce a TMT compliant sub-system to control M2

  Requirements
  - Produce a HCD that exposes all functionality of M2 hardware to CSW
  - Write ICD for M2 public interface
  - Implement open loop positioning models
  - Accept closed loop correction signals

  Skills
  - Good understanding of OSW infra-structure
  - Understanding of third party supplied M2 control system

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WBS Element (12/14)

- Tertiary Mirror (M3)

Objective

– Provide TMT compliant subsystem to control M3

Requirements

– Provide a calibration control system that understands astrometric conversion to tilt and rotation
– Generate tilt and rotation demands from TPK provided data
– Produce ICD of M3 public interface
– Produce HCD to expose all functionality of M3 supplied control system
– Accept tilt/rotation feedback for pupil adjustment

Skills

– May need to provide a pointing kernel

WBS Element (13/14)

- Prime Focus Camera (PFC)

  Objective

  - Produce a commissioning test facility prior to the installation of M2

  Requirements

  - Control of PFC camera
  - Control of X, Y, Z stage
  - Development of open loop LUT for positioning

  Skills

  - Understanding and use of CAMERA package
  - Understanding of OSW infrstructure

TCS WBS

WBS Element (14/14)

- Analysis

Objective

- Produce software to generate Look Up Table (LUT) for Primary Mirror (M1), Secondary Mirror (M2) etc.

Requirements

- Generate LUT for M1 global tip/tilt piston
- Generate LUTs for M1 sensor calibrations from APS raw data

Skills

- Database interface / design
- Fitting/visualization of large data sets

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Summary

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Important Considerations

Summary

- An overall architecture and common software layer is already in place
- A software development process/plan is in place
- System engineering supports requirements, Interface Control Documents, reviews, risk registers
- Lots of integration
- Extensive use of JVM and scripting
- Use of 3rd party C/C++ libraries and integration of C/C++ code into a JVM
- Possible use of Ethercat, BACnet and OPC UA
- Technical competence needed in Java & Scala and C++
- Domain expertise needed for pointing kernel and HCDs
- Early software vendor engagement is critical

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Important Considerations

- Disparate systems need to be integrated
- Distributed development to be carried out with various suppliers and stakeholders
- There are some Observation Execution Sequence applications where a JVM language may not be appropriate/necessary and porting not practical
    - Case 1: Existing C/C++ Libraries
        - Some applications may rely on libraries of such value or complexity that porting isn't practical or possible
    - Case 2: Hardware Control
        - Some hardware devices may require proprietary vendor code that is written in C/C++. Assume this will be necessary in some cases

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