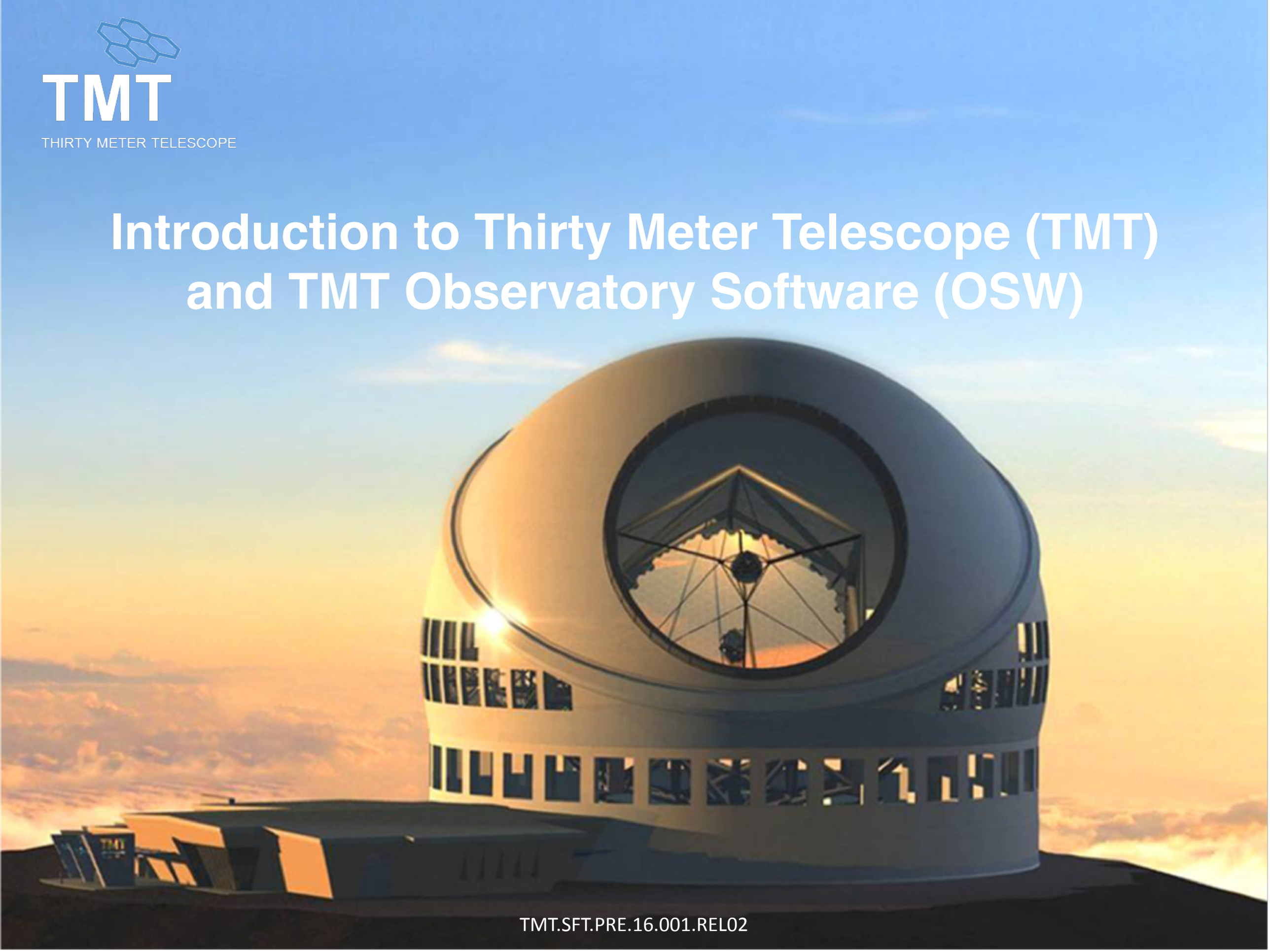
TMT

THIRTY METER TELESCOPE

Introduction to Thirty Meter Telescope (TMT) and TMT Observatory Software (OSW)



TMT.SFT.PRE.16.001.REL02

Purpose

- This presentation accompanies the proposal to request Expression of Interests (EoIs) for Observatory Software for Thirty Meter Telescope

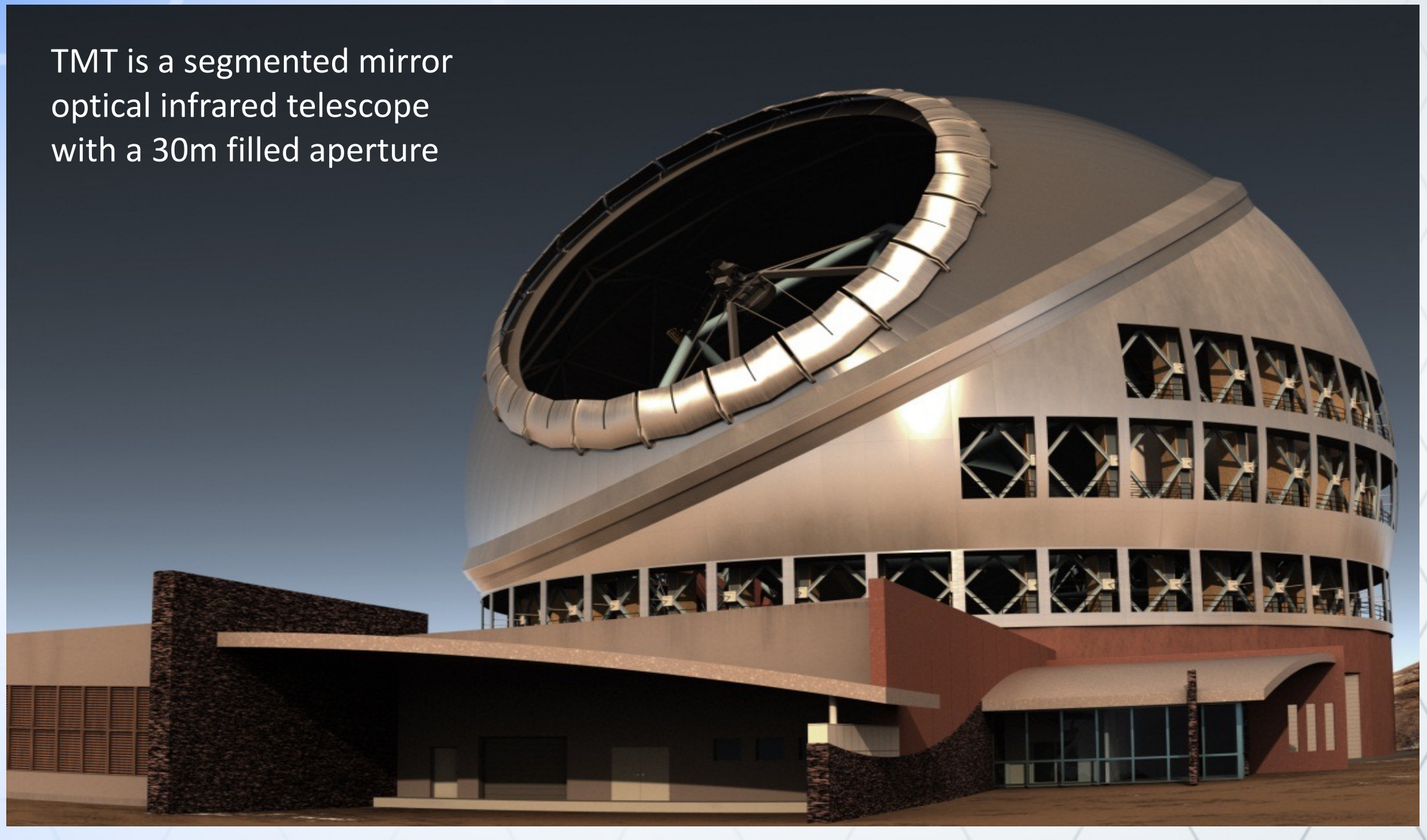
- The purpose of this presentation is to
  - Provide an overview of TMT and its partnerships
  - Provide an overview of the TMT OSW Software
  - Introduce TMT Software Design and Software Development Process
  - Provide insight into the OSW Work Breakdown Structure
  - Highlight the considerations and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

Topics

- Introduction to TMT
- TMT-India and its work share
- Introduction to OSW
- OSW Software Development Process
- OSW Subsystem Software Designs
  - OSW WBS
- Summary

Introduction to the Thirty Meter Telescope (TMT)

Thirty Meter Telescope



http://www.tmt.org

Thirty Meter Telescope

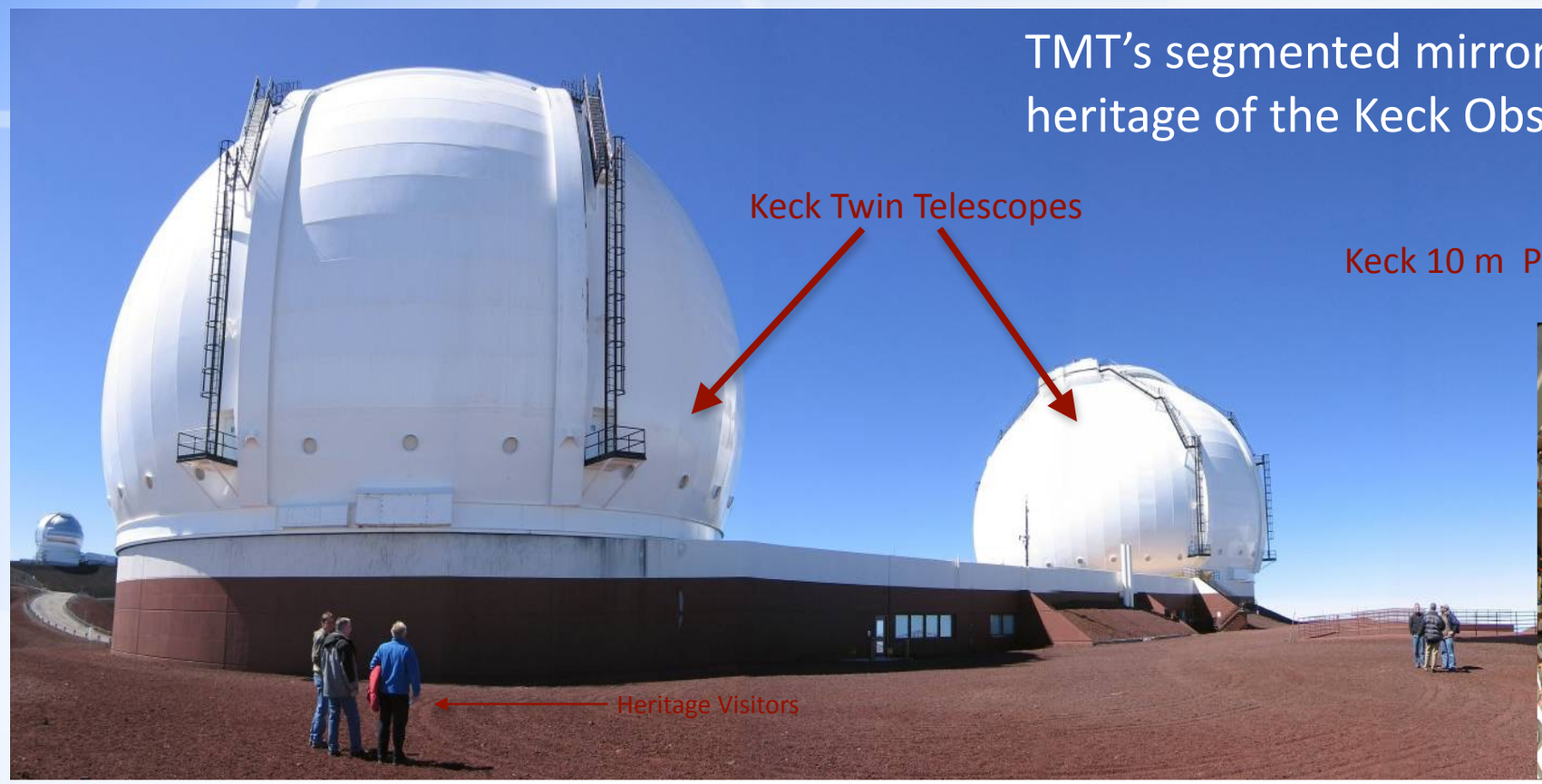
- TMT will be world's most advanced and powerful ground-based telescope operating at optical and infrared telescope wavelengths.
- TMT will enable astronomers to study objects in our own solar system and stars throughout our Milky Way and its neighboring galaxies, and forming galaxies at the very edge of the observable universe, near the beginning of time.
- TMT will couple unprecedented light collection area with diffraction-limited spatial resolution.

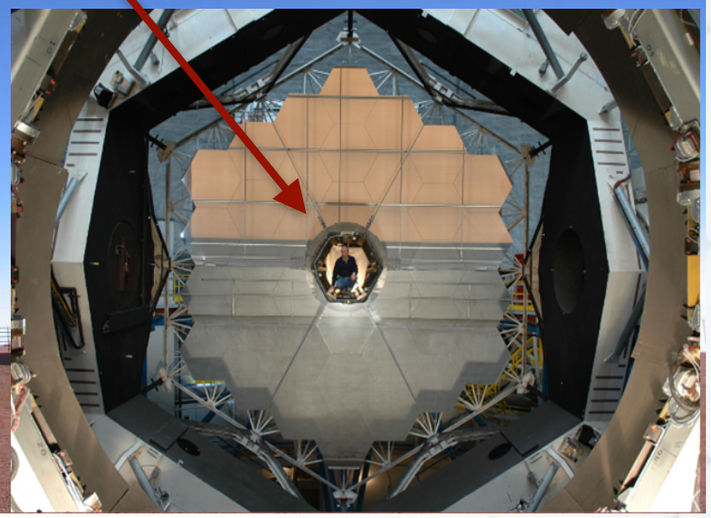
Thirty Meter Telescope

- 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

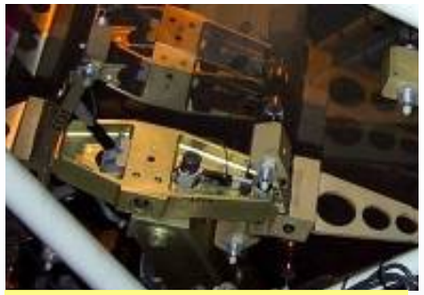
TMT's segmented mirror technology is based on the heritage of the Keck Observatory



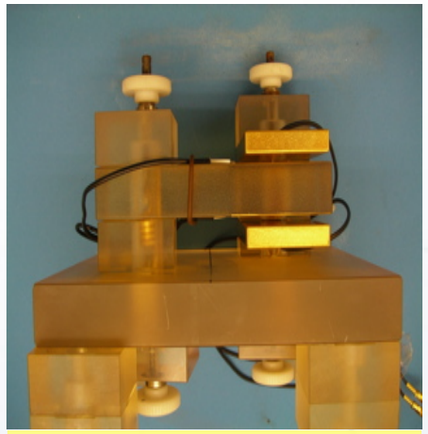


Handling

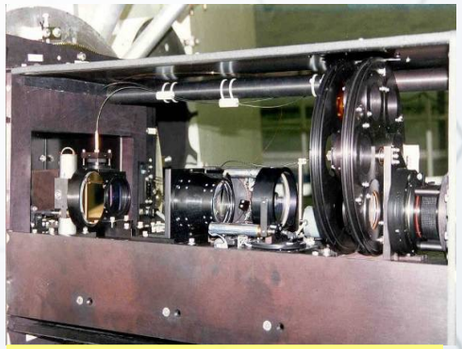
Supports



Warping Harnesses



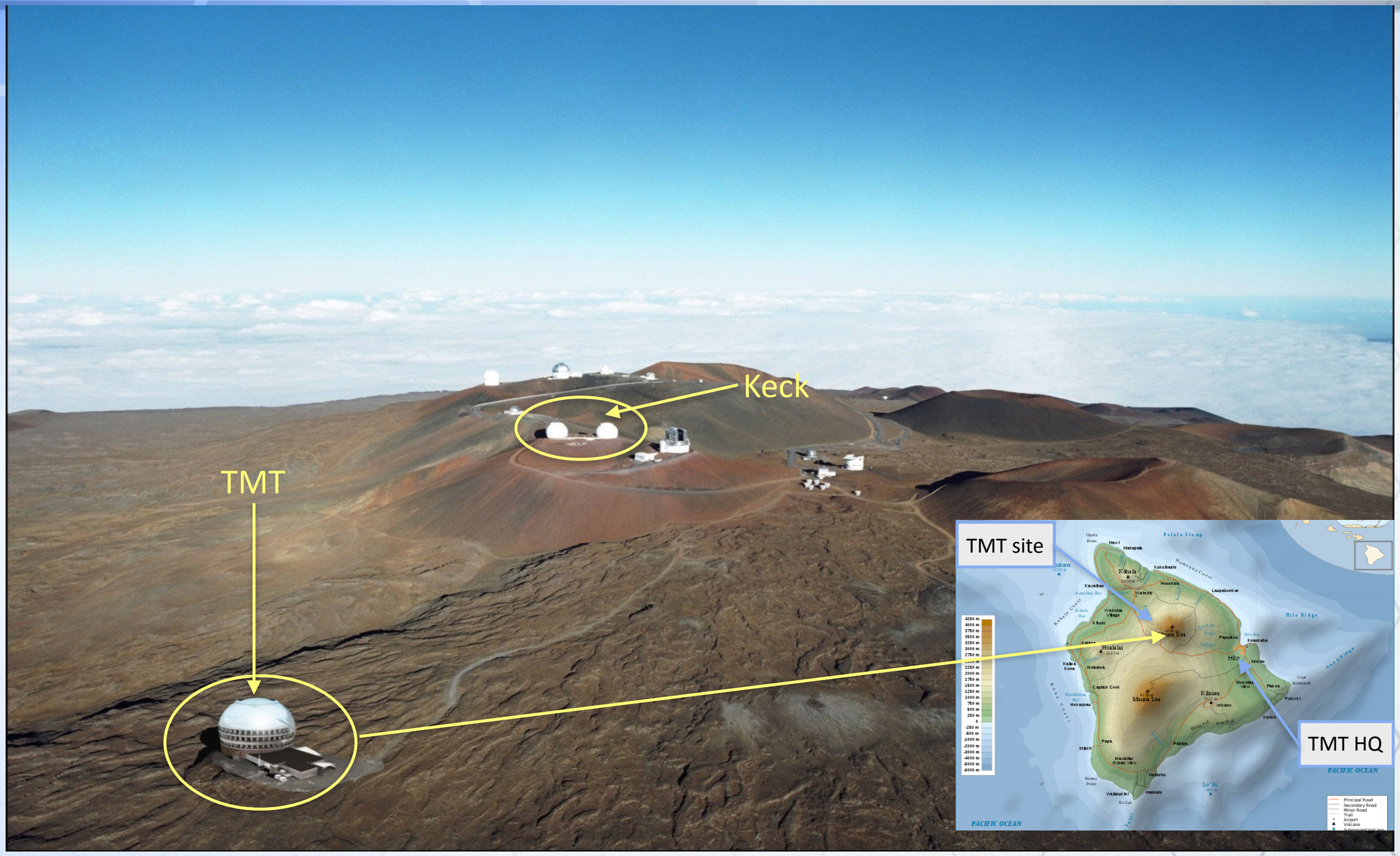
Edge Sensors



Alignment and Phasing

http://www.keckobservatory.org

TMT Site Location



TMT is a Pacific Rim Partnership Centered Around Hawaii

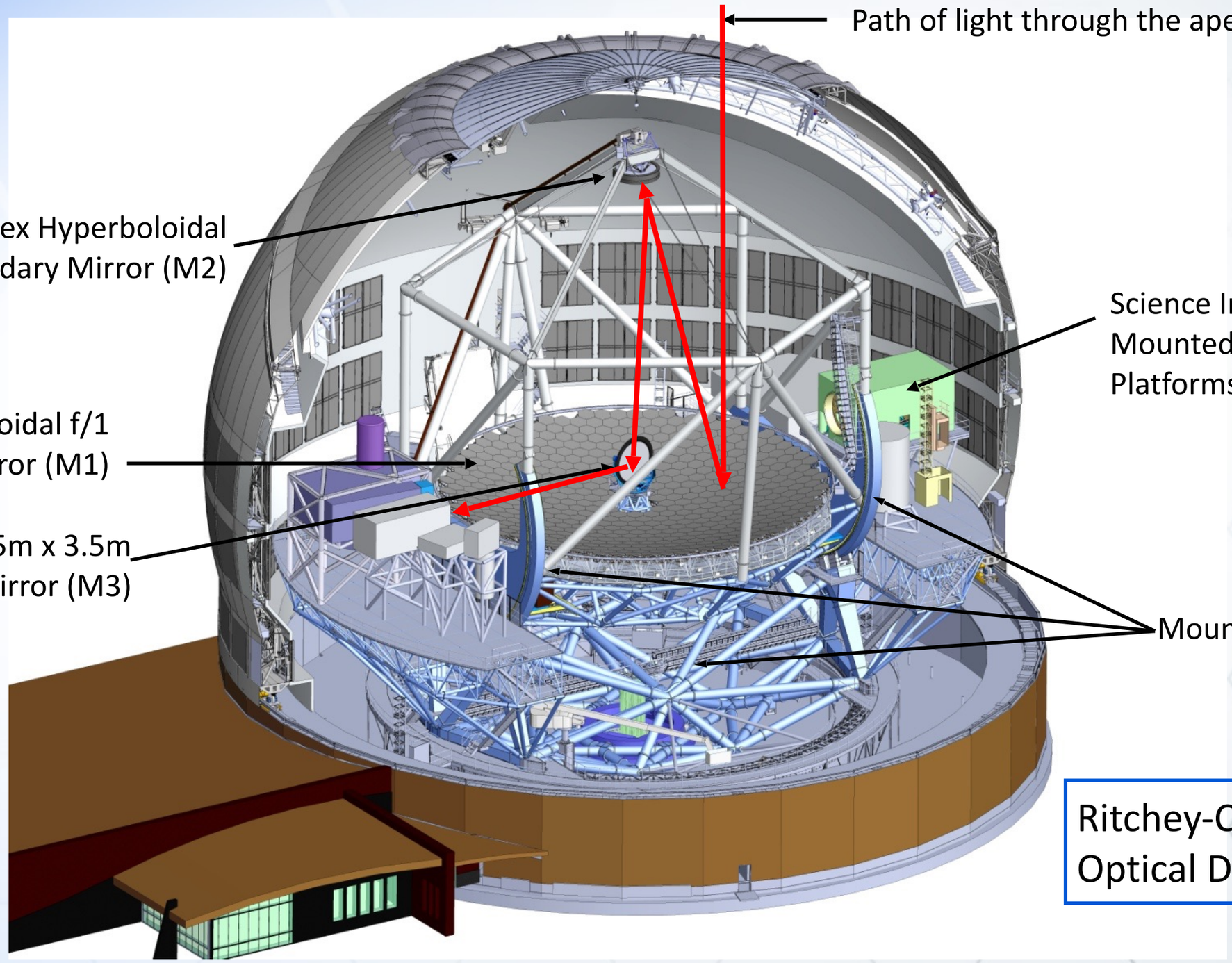
TMT Partnership

- 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 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

- Construction funding from Gordon & Betty Moore Foundation, California Institute of Technology, and University of California in the USA is in place.
- Construction funding commitments have also been made by the Canadian, Japanese, Chinese, and Indian governments.

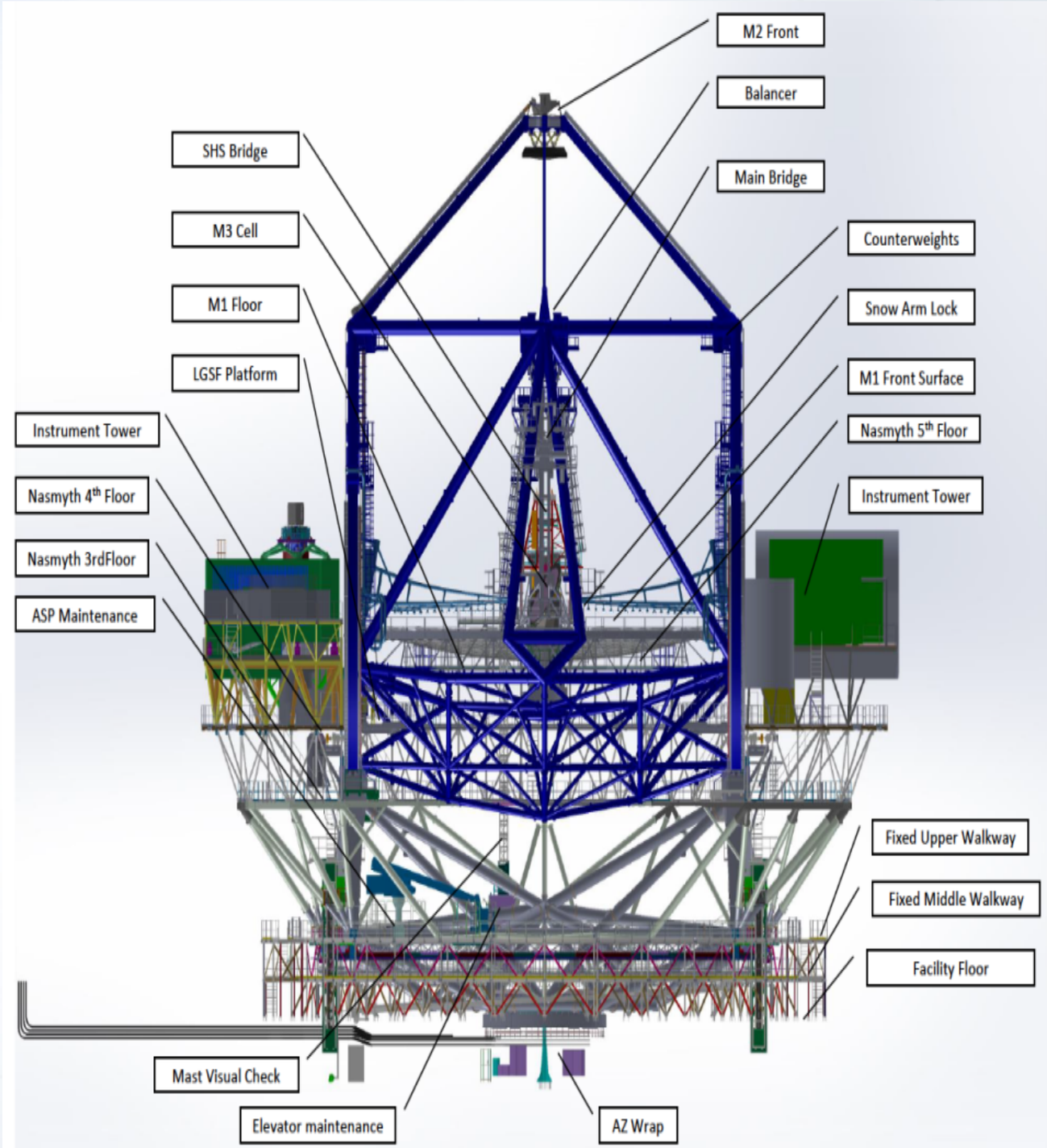
TMT Telescope Concept Overview



Ritchey-Chrétien Optical Design

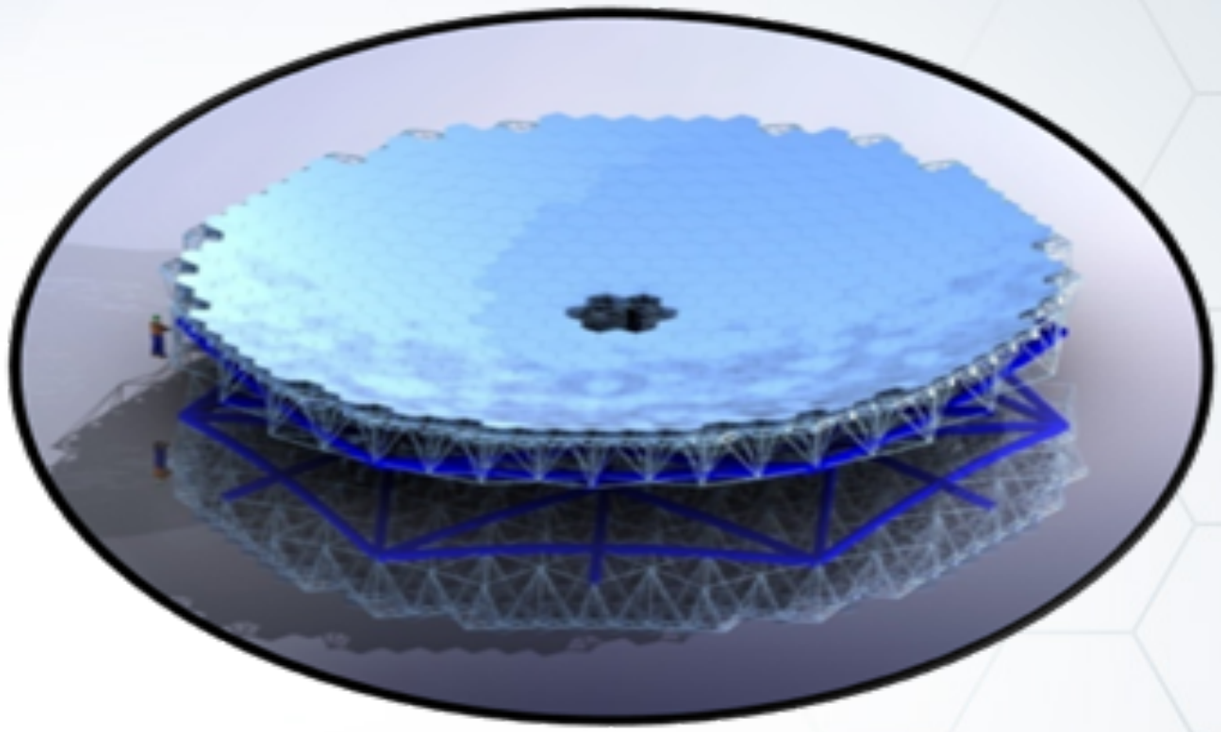
Telescope Structure

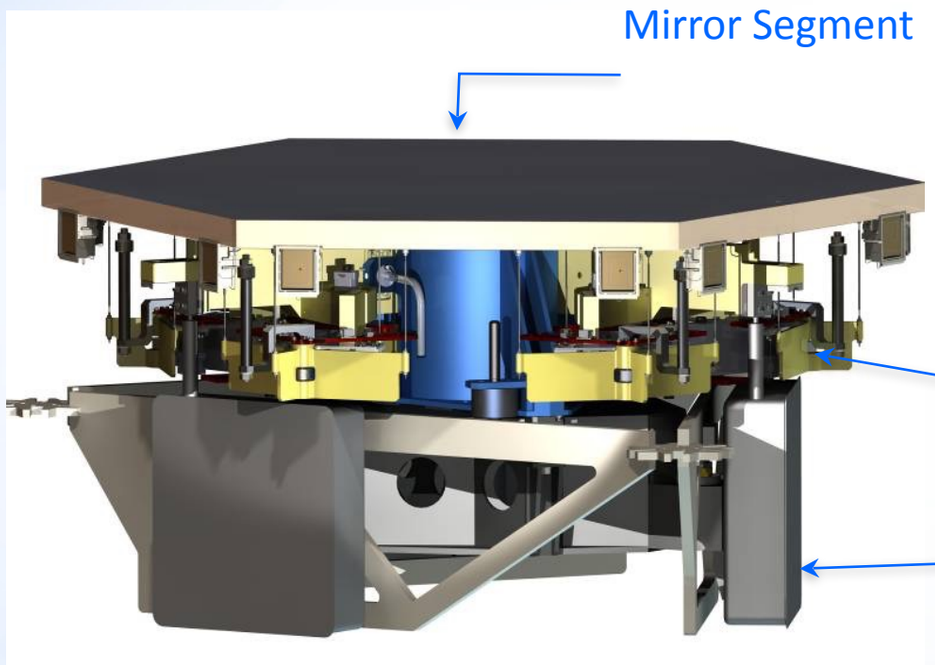
- Japan is responsible for the telescope structure.
- Chosen contractor is Mitsubishi Electric Corp (MELCO)
  - Overseeing both the physical structure and the control systems.
  - Provided the structure for Subaru on Mauna Kea.
- TMT Structure passed its preliminary design review in November 2013 and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



Primary Mirror (M1)

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

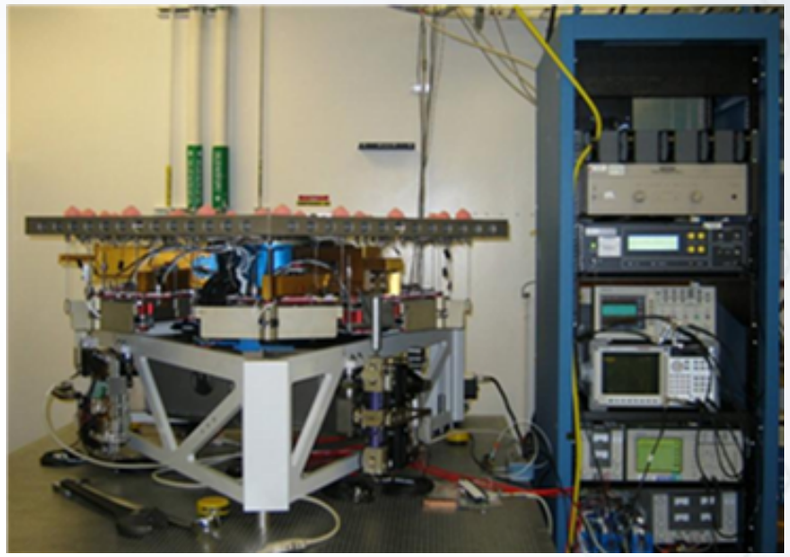


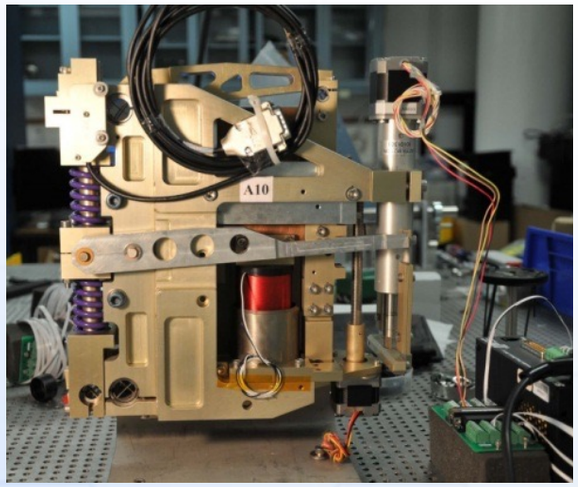


- Each of the 492 mirror segments forming the Primary Mirror (M1) will be mounted on such segment support and actuators assembly which is known as active adaptive optics to correct atmospheric turbulence.

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





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

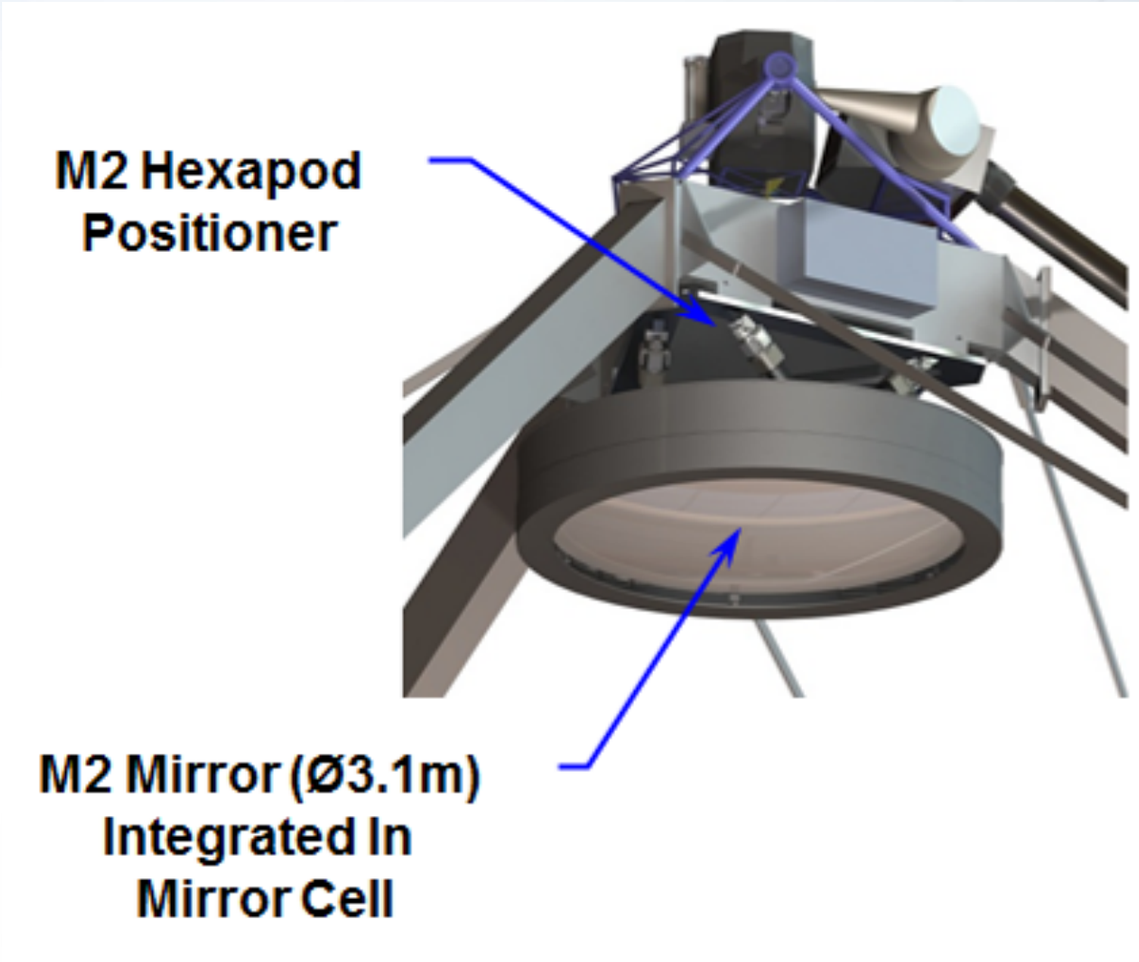
- Jet Propulsion Laboratory (JPL), USA and the UC Irvine, USA are responsible for the design and delivery of the APS (Caltech/UC work-share) with input from ITCC.

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

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

Secondary Mirror (M2)

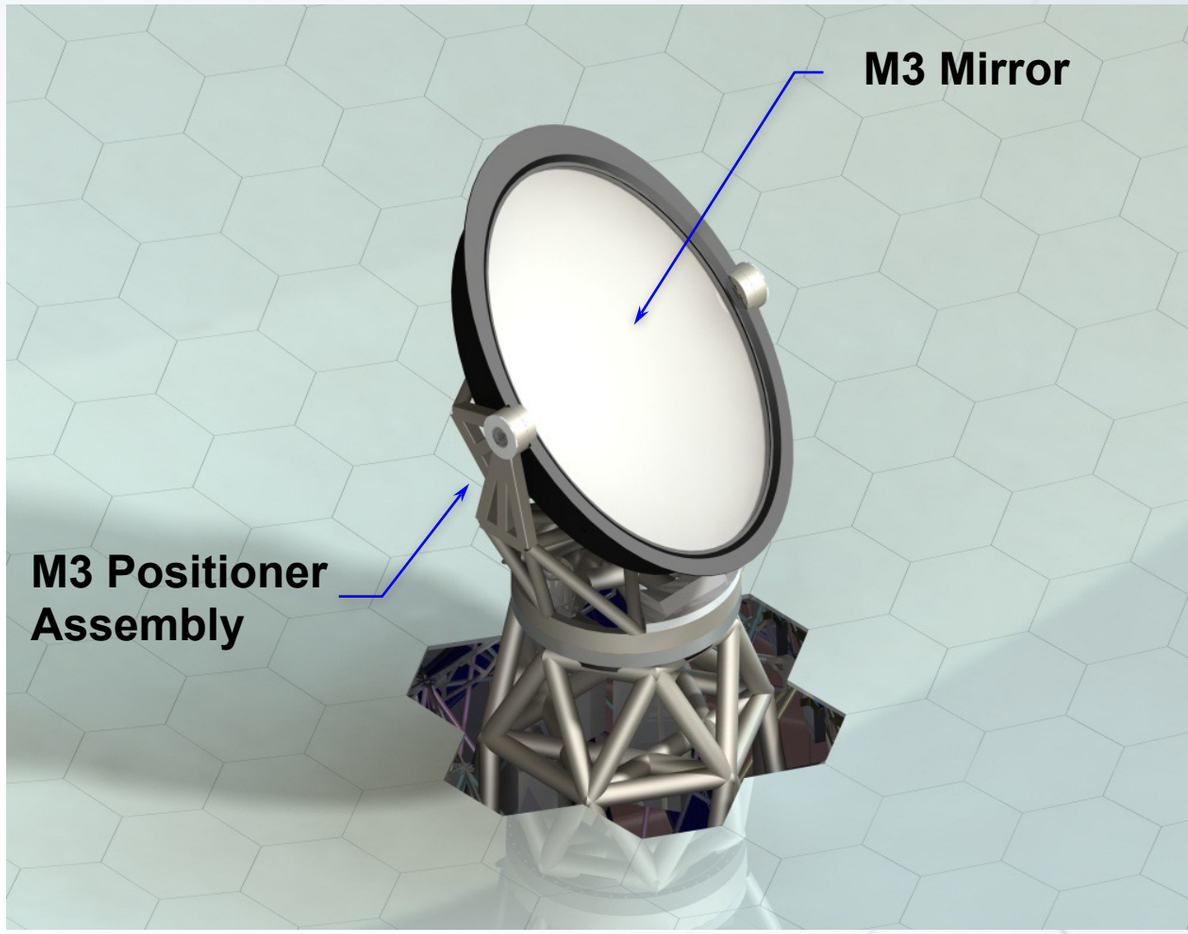
- Description:
  - 3.1m Convex hyperboloid
  - 100 mm thick
  - Zero Expansion glass
  - Passive whiffletree support system
  - Positioned by hexapod



- M2 System is Caltech/University of California work-share.

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)

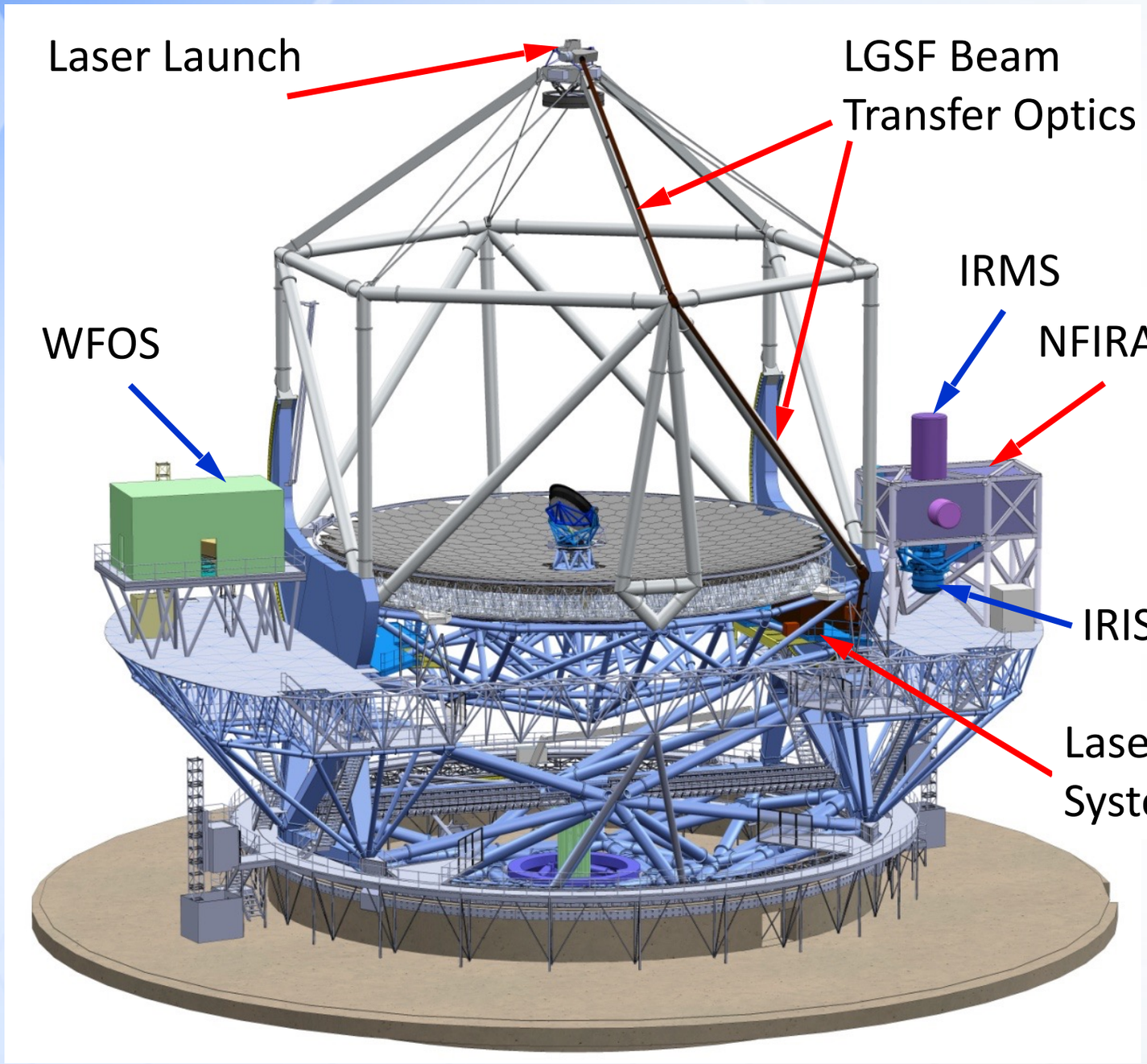
TMT Calotte Enclosure

- 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

First Light Instruments

- The plan for the first light instruments to be delivered as part of the construction project is being reconsidered, but the current plan is the following:
  - 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)

Introduction to TMT-India

TMT-India

- India joined TMT as an Observer to the TMT Collaborative Board in 2010 and officially joined the 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.*

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

TMT-India Work Share

- Software
  - Observatory Software (Subject of this EOI)
  - Telescope Control System
- Hardware
  - 86 Mirror Segments
  - Mirror Segment Support Assemblies
  - M1 Control System Actuators
  - M1 Control System Sensors
  - M1 Control System Distributed Control Electronics (SCC)
  - Mirror Coating Chambers
  - Science Instruments

Introduction to Observatory Software

Introduction to OSW

- Context within TMT
- Responsibilities
- External interfaces
- Work Breakdown Structure
- OSW schedule and current status
- Software Design and Development

Opening Comments

- Observatory Software is a large project with many different areas of work.
- The TMT software work is designed, developed, and managed within a traditional, waterfall-like Systems Engineering process that may not be familiar to software teams, but must be followed.
- In the following the term “construction” is used to indicate the phase of TMT OSW work that is being executed within India.

What is Observatory Software?

- Observatory Software is three things:
  - Architecture and design of the entire TMT Software System, AND
  - The software infrastructure that implements the architecture, AND
  - User-oriented software that supports the observing process.

Prior to construction

Included in construction

Why Early Design?

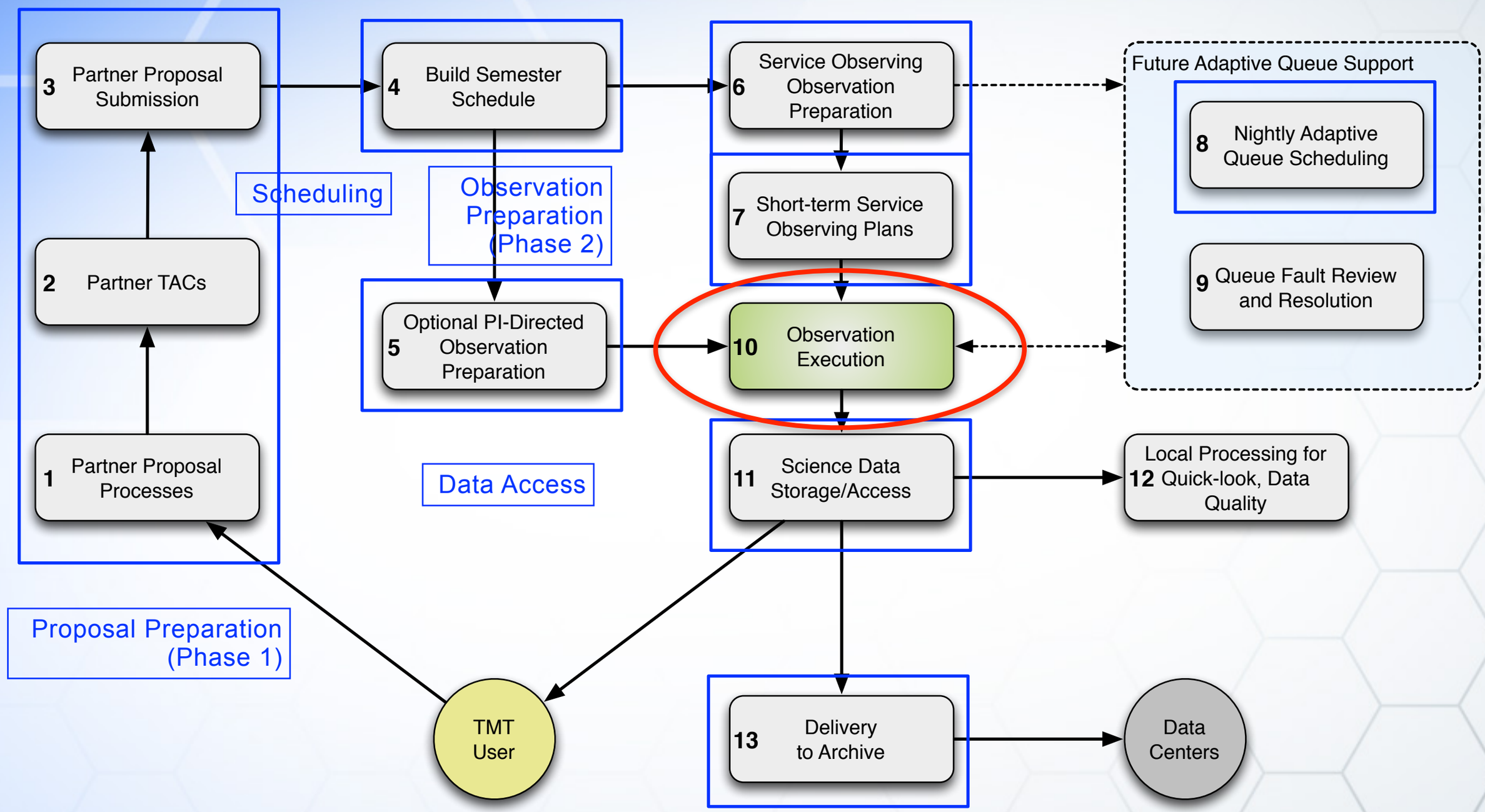
- The overall architecture and design of the TMT Software System is being completed prior to the start of construction.
  - To allow the design of software that is not part of OSW, it is necessary to know how the software system will work.
  - Other groups need to estimate the cost of their work based on the system architecture and design.
  - The domain experience is within the project office.
  - Desire to standardize shared solutions across the project.
- Final design of some parts of the OSW will occur with the participation of India vendor teams.

OSW Software Architecture

Operations Plan and OSW

- TMT has an Operations Plan that describes how the scientists and staff will observe with operate the telescope.
- The Operations Plan describes an “end to end” system that supports the entire operations/observing work flow. (See next slide.)
- The TMT operations work flow follows the work flow used in current large telescope facilities and uses domain terminology.
- OSW provides the software that supports and implements the operations/observing workflow.

Operations Plan and Software System



Workflow Points

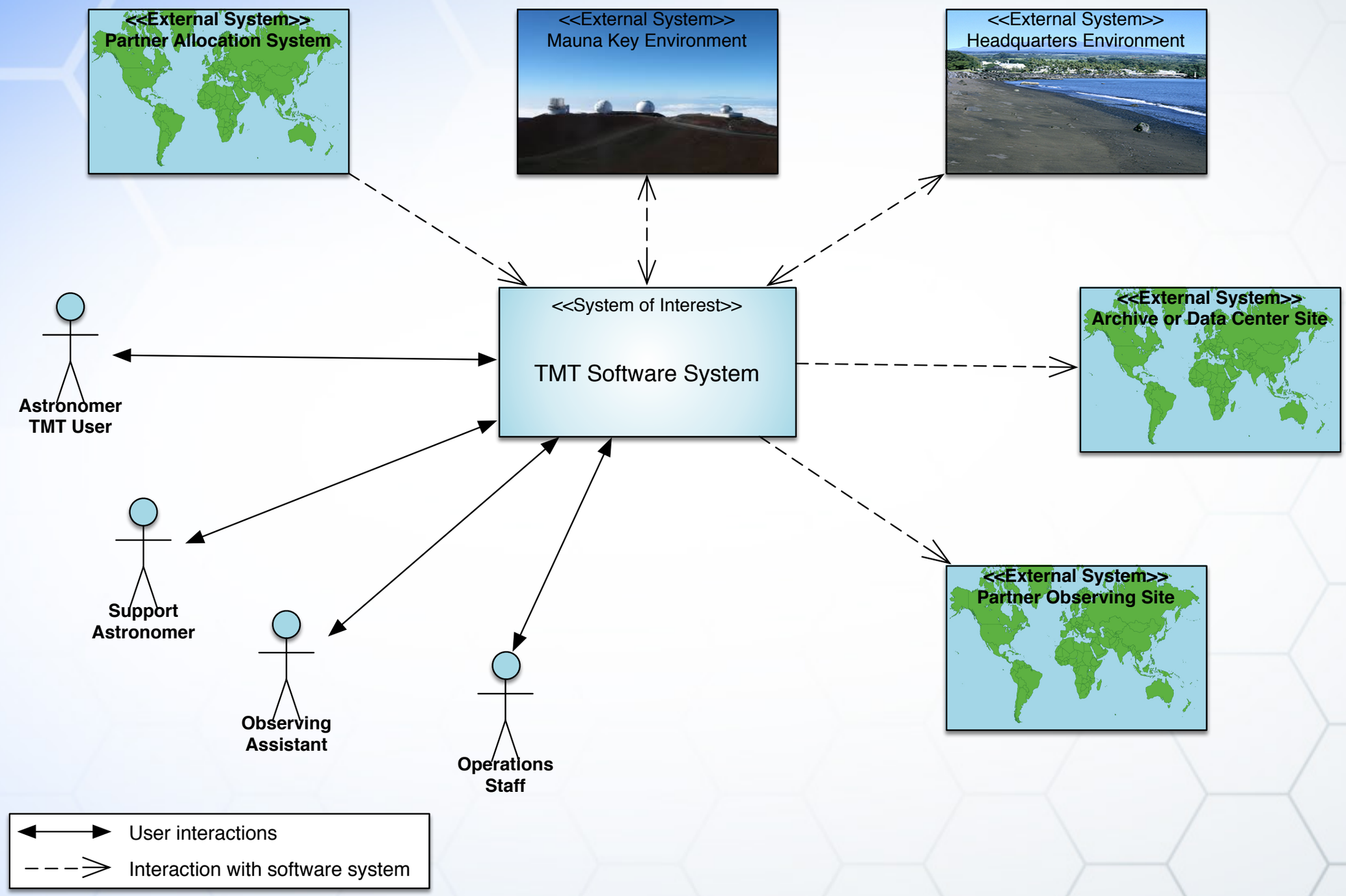
- Not all the OSW software executes at the telescope site. Only box 10, “Observation Execution” interacts directly with the telescope.
- Some software executes at the support facility (Hilo) and some off site (observer site).
- Some of the parts of the operations work flow are not currently implemented during construction. They are deferred to the first 5 years of operations (although the design exists).

Technical and Functional Architecture

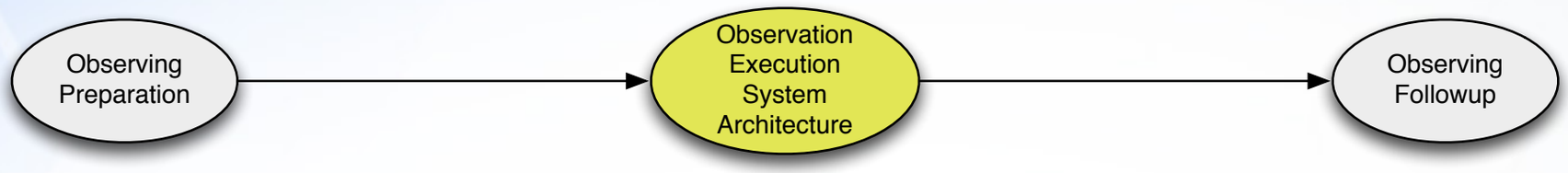
Technical Architecture and Design → Software concepts and infrastructure that provide the foundation for the software system and enables the functional architecture

Functional Architecture and Design → Software concepts, components, and applications that enable the activities of the Observatory from the ***point of view of the users***.

Mauna Kea Observatory Context

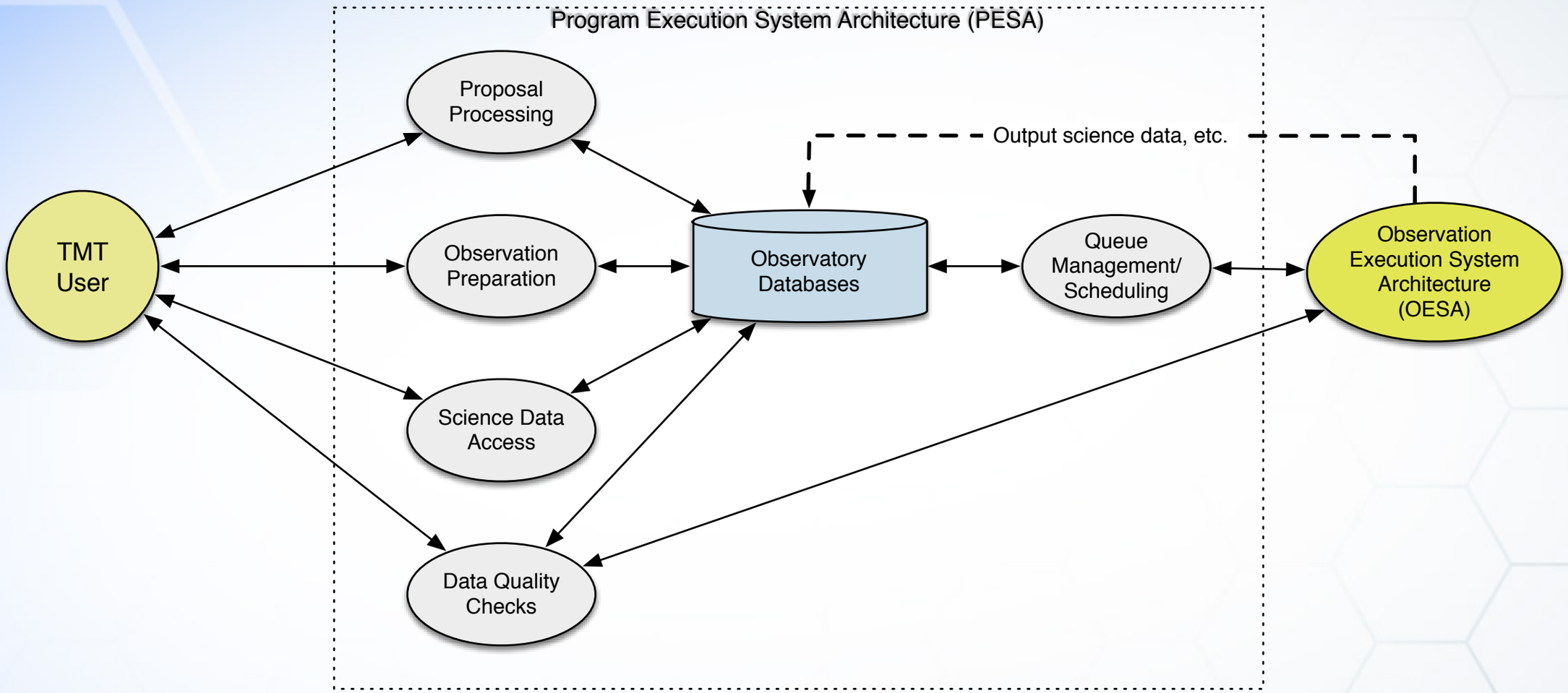


Software Architecture Decomposition



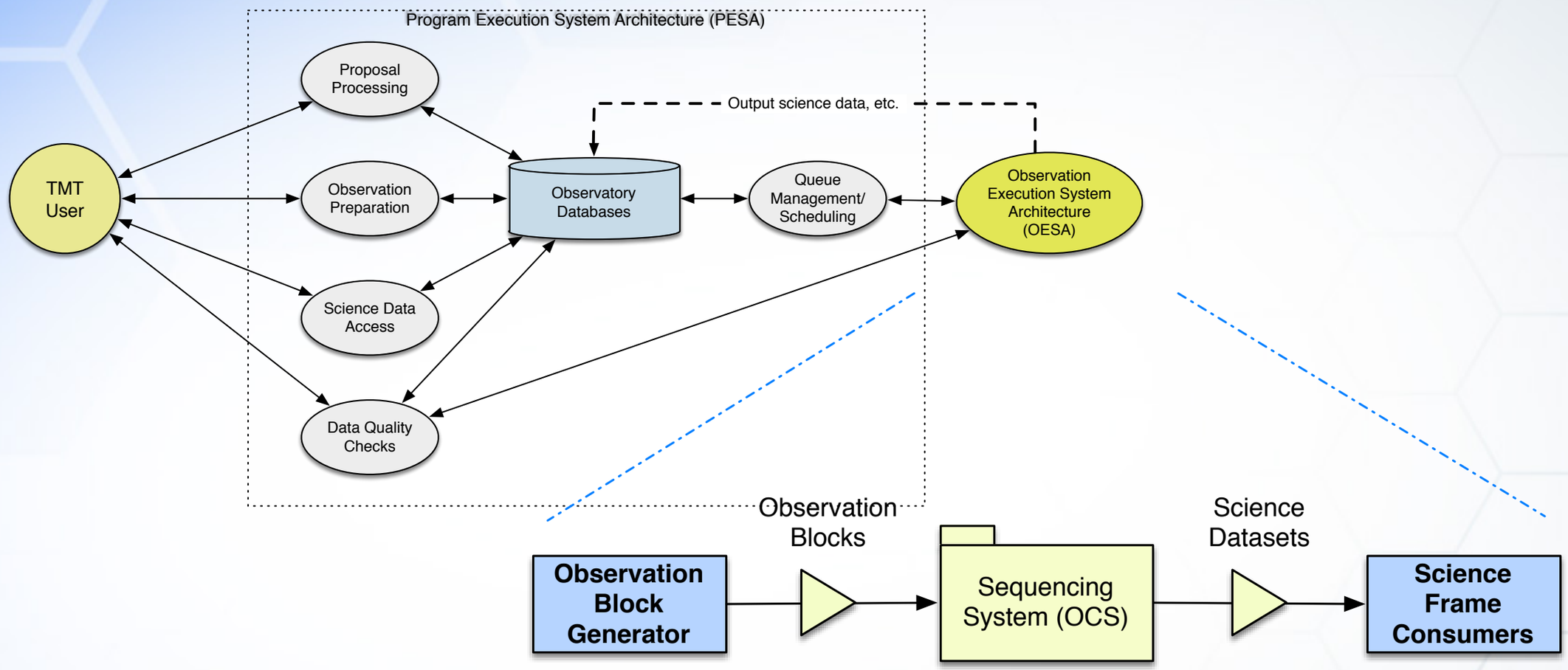
- Observing preparation and followup generally happen away from the telescope.
  - Program Execution System Architecture
- Observation Execution contains all software activities that occur at the telescope to acquire science data.
  - Observation Execution System Architecture

Software Architecture: PESA and OESA



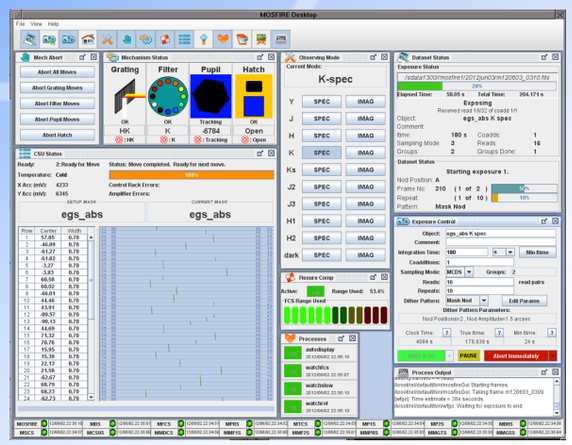
TMT.DEOPS.OSW.SOSS
TMT.DEOPS.OSW.DMS.SCI
TMT.DEOPS.OSW.DMS.ACC

Software Architecture: PESA and OESA

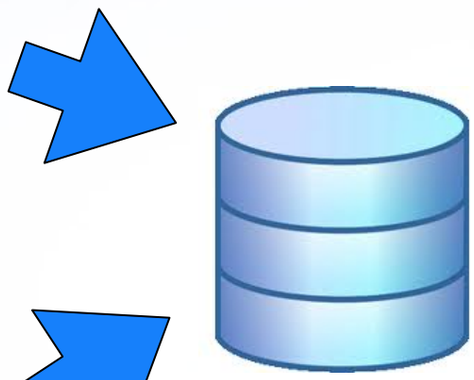


TMT.DEOPS.OSW.ESW.OCS

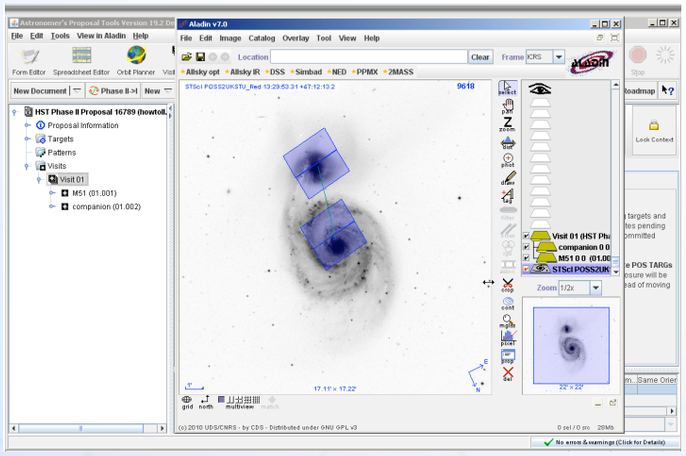
Observation Block Generators



PI-Directed Instrument UI



Science Program/
Observation Database



Pre-planned Instrument UI

- *Observation Description* is all the stored information about an observation.
- An *Observing Block* is part of an Observation Description that contains a sequence of steps that when executed will result in the creation of science datasets.
- A PI-Directed UI will create an Observing Block on the fly and store it prior to execution.
- An Observing Block created with a Pre-planned UI stores was stored in the database system during observation preparation.

FOVAST v0.5

File View Tabs Interop Help

GSC2 2MASS USNO

New Visualization

Resolve Source: ngc1204 Simbad NED

RA: 46.1664542 J2000/FK5

DEC: -12.3413222 J2000/FK5

Set as science target

Capture guide stars

Show target marker

Drag

OIWFS focus correction probe2

Element Name	Catalog Name	RA	DEC
base position	null	3:4:39.949	-12:20:28.75
iris.oiwfs.probe1....	GSC2(SearchRa...	3:4:39.622	-12:19:45.79
iris.oiwfs.probe2....	GSC2(SearchRa...	3:4:40.954	-12:20:53.51
iris.oiwfs.probe3....	GSC2(SearchRa...	3:4:37.257	-12:20:53.78

- IRIS
  - Imaging Mode
  - IFU Mode
    - Lenslet
    - Slicer
    - Dragger
  - OIWFS Probes
- NFIRAOS
  - Show Limits
  - Show Laser Guide Star Asterism
  - TWFS
    - Show TWFS detector
  - Show Acquisition Camera
- Mobile

NFIRAOS Acquisition FOV

TWFS

IRIS OIWFS Probes (3)

Probe selected for focus

Imaging detector and IFU (slicer)

NFIRAOS FOV

Laser Guide Star Asterism

N

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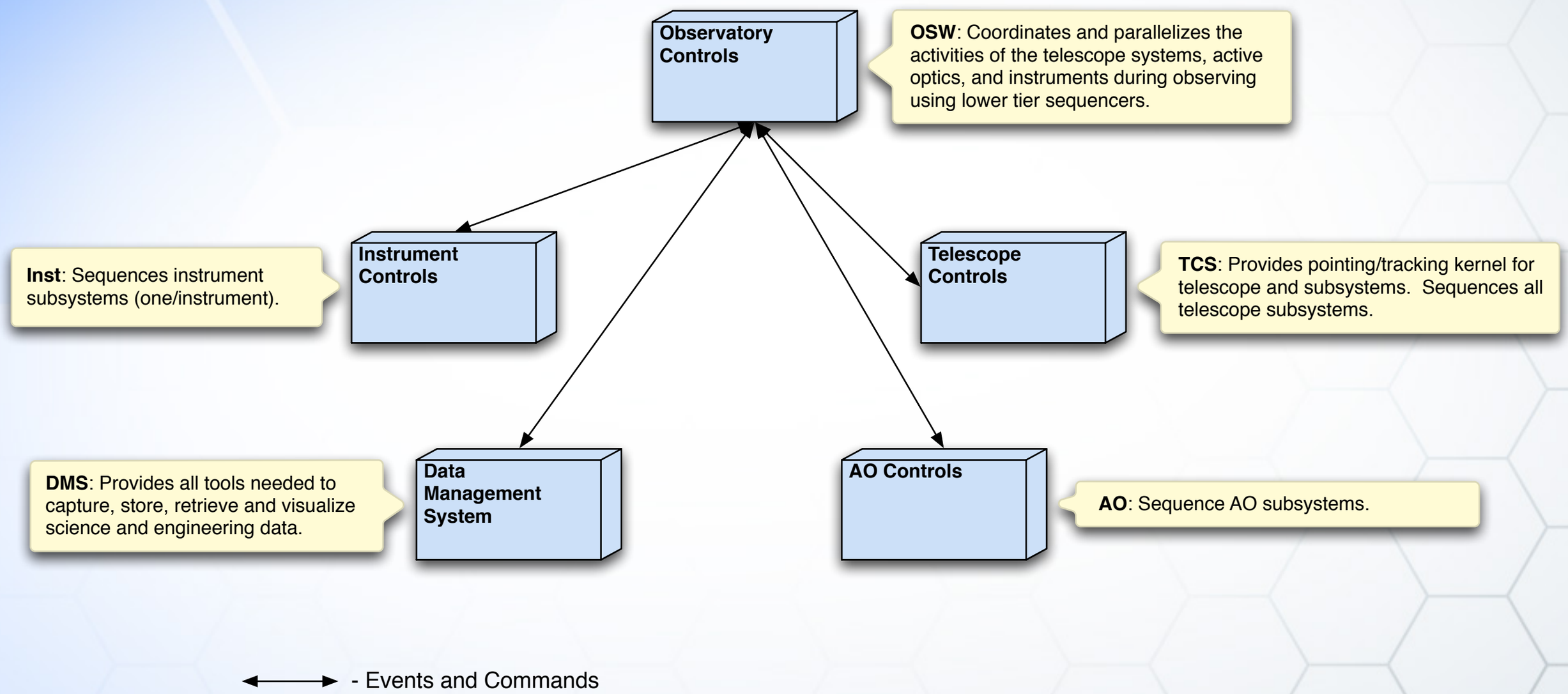
4x 443.8, 627.2 5457.0 03:04:52.849, -12:17:35.26 (J2000)

Observation Execution System Architecture: Principal Software Systems



Principal System Notes

- At the highest level the 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.
- Observatory Controls is in charge of coordinating and commanding the other systems.
- Observatory Software includes the Observatory Controls and Data Management System principal systems.

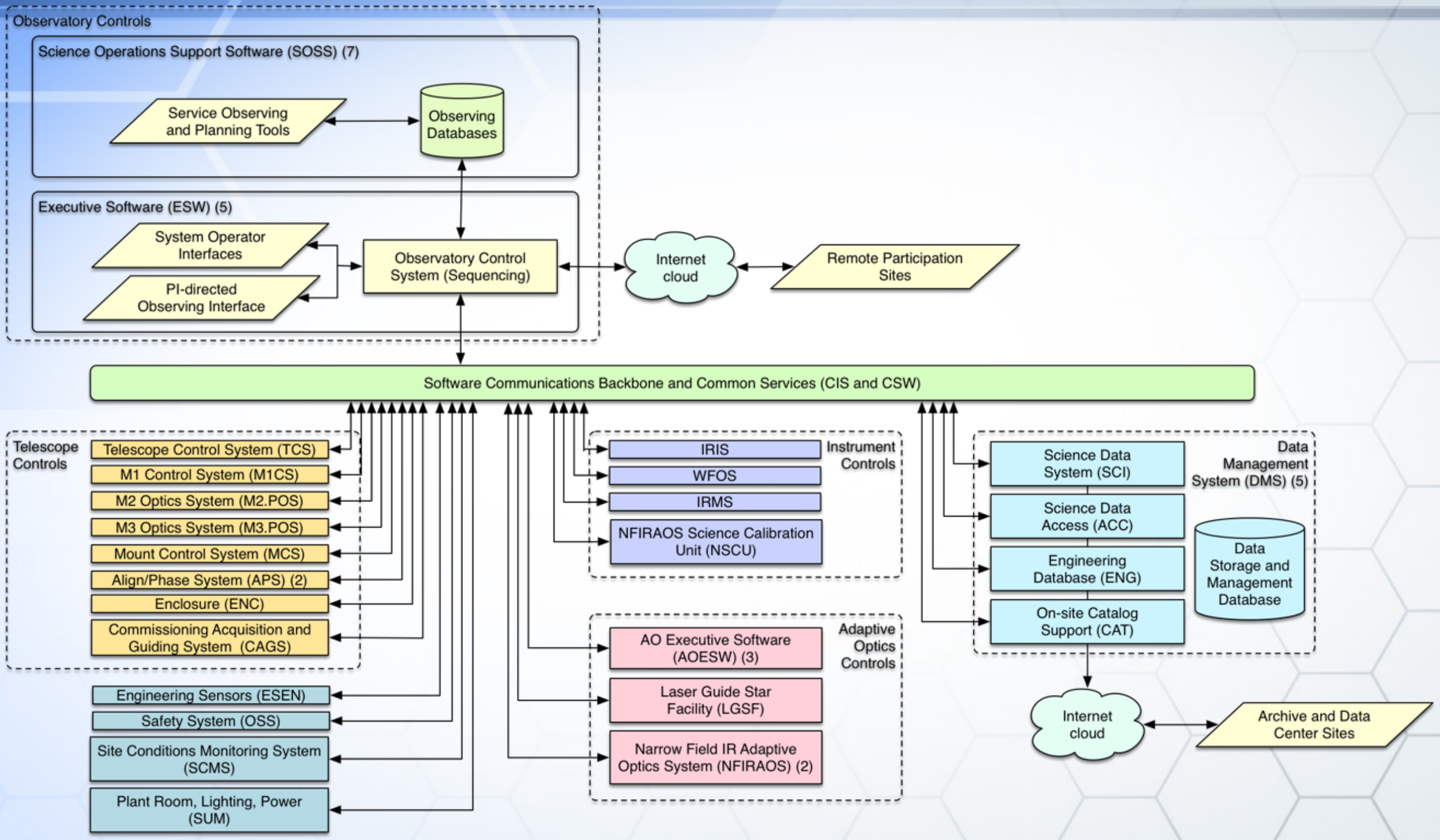
Observation Execution System: Conceptual Architecture Notes

- Command communication is hierarchical flowing down from the Observatory Controls to the other principal systems.
  - Command communication between other principal systems is limited
- Command communication between principal systems is relatively low-bandwidth by design.
  - All high-speed communication occurs within a single principal system.
- Systems distribute status, alarms, events to one another over high-speed publish-subscribe communications backbone.
- System built on Common Software, a set of services constructed on top of COTS or open-source middleware product(s) similar to all modern observatory software systems.

Subsystem Decomposition (following slide)

- The following slides shows the decomposition of the principal systems into subsystems that exist in the TMT WBS.
- The green bar is the Common Software, an OSW subsystem that provides communication services to all other software components in the TMT Software System.
- OSW includes Common Software, Data Management System, and Observatory Controls.
- Each of these subsystems is described later in this presentation.

Observation Execution System: Principle Systems WBS Decomposition



Technical and Functional Architecture Package Distribution

Technical Architecture and Design → TMT.DEOPS.OSW.CSW

Functional Architecture and Design →
TMT.DEOPS.OSW.ESW
TMT.DEOPS.OSW.DMS
TMT.DEOPS.OSW.SOSS
TMT.DEOPS.OSW.DPS

Common Software provides the implementation of the Technical Architecture

Note: This slide shows OSW subsystems involved in technical and functional architecture.

OSW Subsystems Descriptions

OSW Level-2 Subsystems

- Executive Software (ESW)
  - The Executive Software subsystem provides the core functionality needed to enable classical observing and other future observing modes at the telescope site. The ESW enables synchronized operation of all the TMT sub-systems from user interfaces or other programs. The Observatory Control System (OCS) is the Executive Software central engine providing this functionality. Other Executive Software deliverables include user interfaces for system operators and observers as well as user interfaces for monitoring of system status and overall environmental monitoring.
- Data Management System (DMS)
  - The Data Management System provides the mechanisms and interfaces needed to capture, time-stamp, describe, store, transmit, and access all science data flowing through the TMT software system (Science Data System). The first light Data Management System also provides the mechanisms and interfaces needed to capture, time-stamp, store, transmit, access, and visualize engineering information flowing through the TMT system (Engineering Database).
- Science Operations Support System (SOSS)
  - Science Operations Support Systems are a tightly coupled set of applications to manage high-level science operations workflow from proposal preparation to observation execution.
- Data Processing System (DPS)
  - The Data Processing System (DPS) enables the removal of atmospheric and instrument signatures from data produced by TMT science instruments. It also enables a quick-look and long-term trending data quality assurance process.
- Common Software (CSW)
  - CSW includes the software required to integrate the TMT sub-systems and establish the software communication backbone and interfaces necessary for observatory-wide configuration, command, control, and status reporting. CSW is layered on top of the IT infrastructure ("network"). However, the Common Software does not include the IT infrastructure, which is provided by the WBS element TMT.DEOPS.CIS.

ESW
Level-3 Subsystems

- ESW.OCS - Observatory Control System
  - Software concepts and infrastructure required to sequence the actions of all the TMT sub-systems during an observation such that science data is acquired correctly and efficiently.
- ESW.UISTD - User Interface Standards
  - UI standards, remote observing support, example code.
- ESW.HCMS - High level Control and Monitoring
  - Observing interfaces for control and monitoring of telescope, AO, instruments.
- ESW.VIZ – Data Visualization
  - Infrastructure and tools needed for quick-look and acquisition.
- ESW.ACQ – Acquisition Tools
  - Coordinating observing sequences for observing and acquisition.

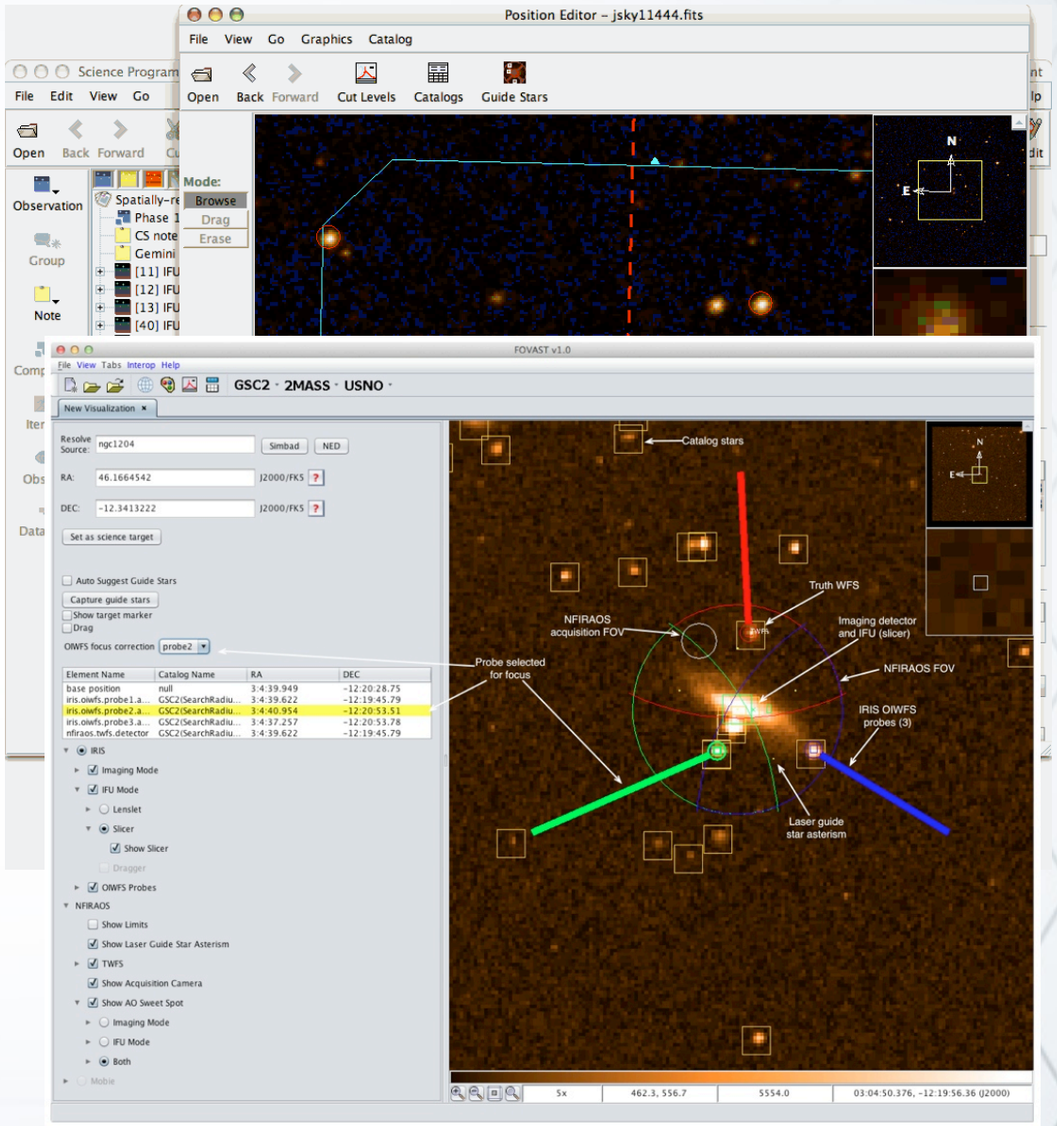
DMS
Level-3 Subsystems

- DMS.SCI - Science Data System
  - Software and hardware infrastructure for storing, copying, and transporting science data. Managing science metadata. Ensuring data integrity, security and proprietary data policies.
- DMS.ACC - Science Data Access
  - Provide access to science data for software components and users including the local searchable data store.
- DMS.ENG - Engineering Database
  - Software, hardware, and interfaces needed to capture, time-stamp, store, transmit, access, and visualize technical data flowing through the TMT system.
- DMS.CAT – Image and Object Catalogs
  - Minimal set of catalogs needed on site to support observing.
  - Creation of any TMT-specific catalogs and and search algorithms.

SOSS
Level-3 Construction Subsystems

- SOSS.ODB - Observatory Databases
  - Models for storing observing-related information.
  - Software interfaces for access and querying databases, reports.
  - Database hardware and software technology choices.
- SOSS.FLP1 - First Light Phase 1
  - A minimal Phase 1 implementation based on an existing system in use by TMT partners or within the astronomy community with modifications for TMT-specific requirements. .
- SOSS.FLP2 - First Light Phase 2
  - Tools supporting minimal amount of planning required to enable classical observing during early light observing as needed specifically for AO observing.

Example observation preparation tool



Software Development Process

- Observatory Software will be developed according to TMT Software Development Process described in the next several slides.
- The SDP is based on common agile practices and should be familiar to most experienced programmers.

Purpose of a Software Quality Assurance Plan

- From *Requirements for TMT Software Quality Plans* (TMT.SFT.TEC.14.011)

> *The purpose of software and software-based systems testing is to help the development organization build quality into the software and system during the life cycle processes and to validate that the quality was achieved.* ***The test process determines whether the products of a given life cycle activity conform to the requirements of that activity, and whether the product satisfies its intended use and user needs.*** *This determination can include inspection, demonstration, analysis, and testing of software and software-based system products.*

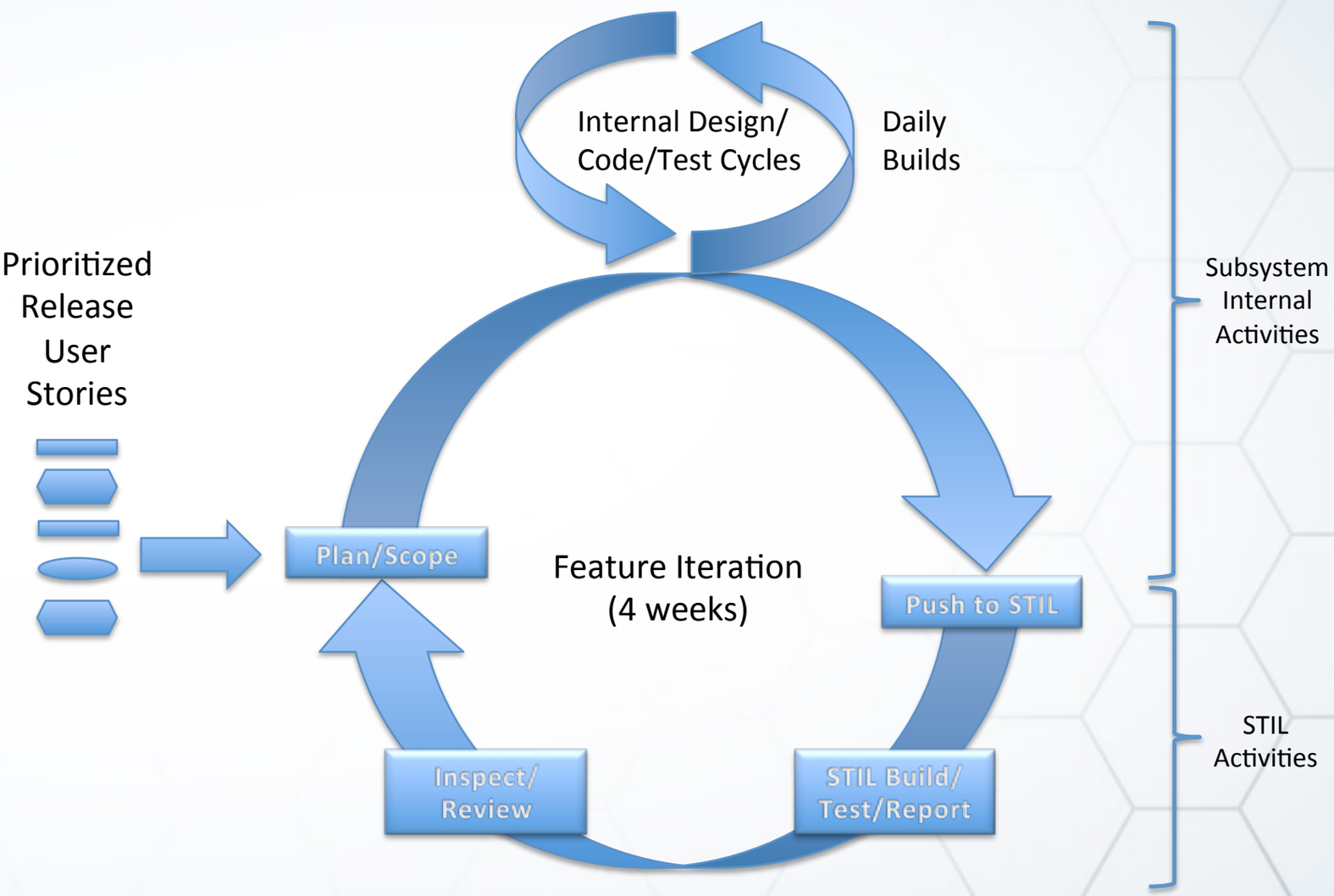
- By following the TMT Software Development Process, software teams satisfy the requirements of TMT Software Quality Assurance Plans

TMT Software Development Plan Overview

- The SDP includes the following aspects of agile development processes focused on producing quality software:
  - Frequent releases of software and iterative development. Each release includes design, coding, testing, and documentation.
  - Deliver finished, user-oriented features as vertical code slices rather than horizontal “layers”.
  - Each release is a working system albeit of limited functionality.
  - Project requirements and standards for unit testing, functional/ acceptance testing, component testing, system testing.
  - All testing of code is automated, Project Office creates automated nightly builds of the entire TMT software system.

Development Using Iterations

- Fixed length 4-week iteration /release
- Each release provides end-to-end features including testing code.
- Provides a mechanism to review progress and quality metrics and enables management to respond to problems early.

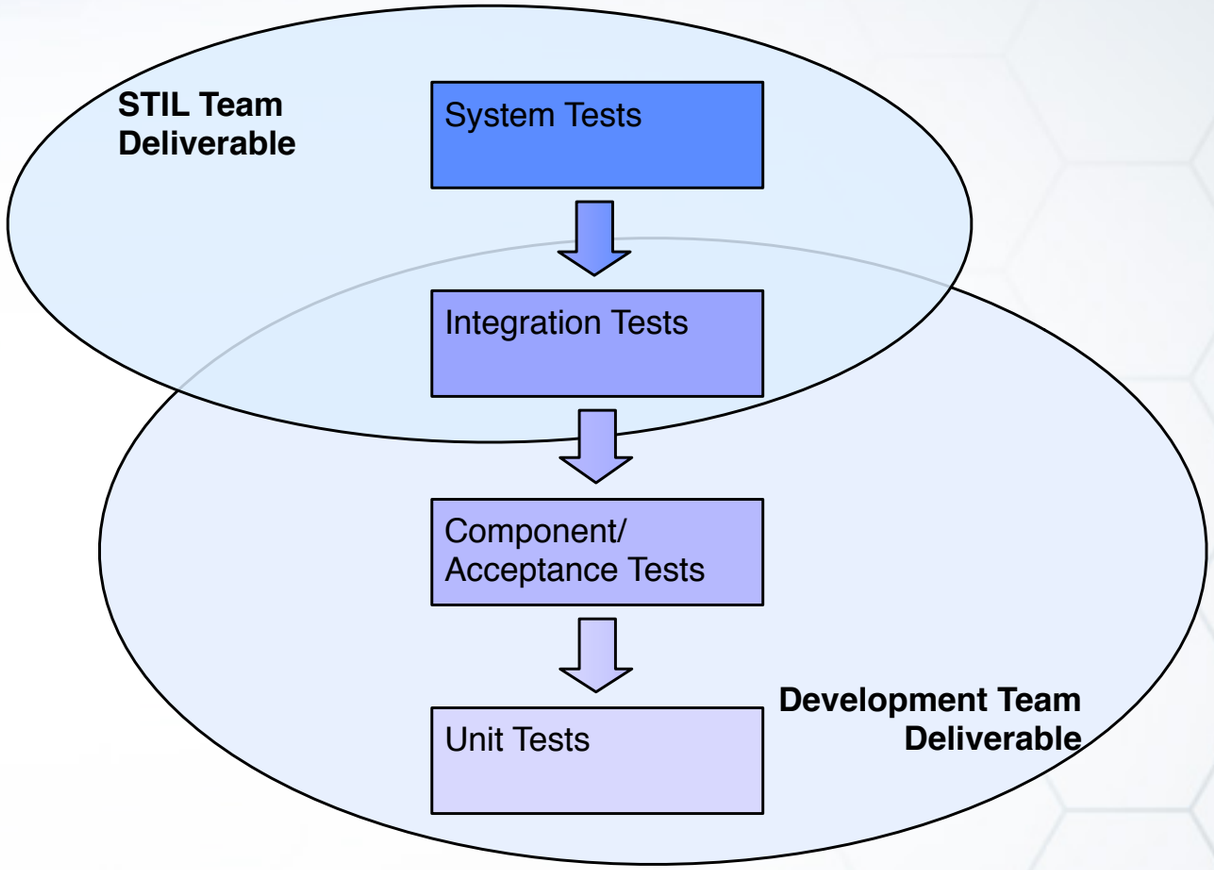


Software Test and Integration Lab

- The TMT plan includes a Software Test and Integration Laboratory (STIL) and staff at the TMT project office during construction to support software testing and the integration of software from the SSTs across the project.
- The STIL staff will be a resource for all development teams 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.

Software Testing Plan

- Automated testing is the core of TMT quality assurance.
- Frequent testable releases distribute AIV across the development cycle and mitigate the chances of discovering integration problems at the worst time—when products are delivered.
- The development process includes required testing at multiple levels.
- Unit Tests and Component/ Acceptances Tests are the responsibility of the SSTs. Integration Tests and System Tests are the responsibility of STIL.

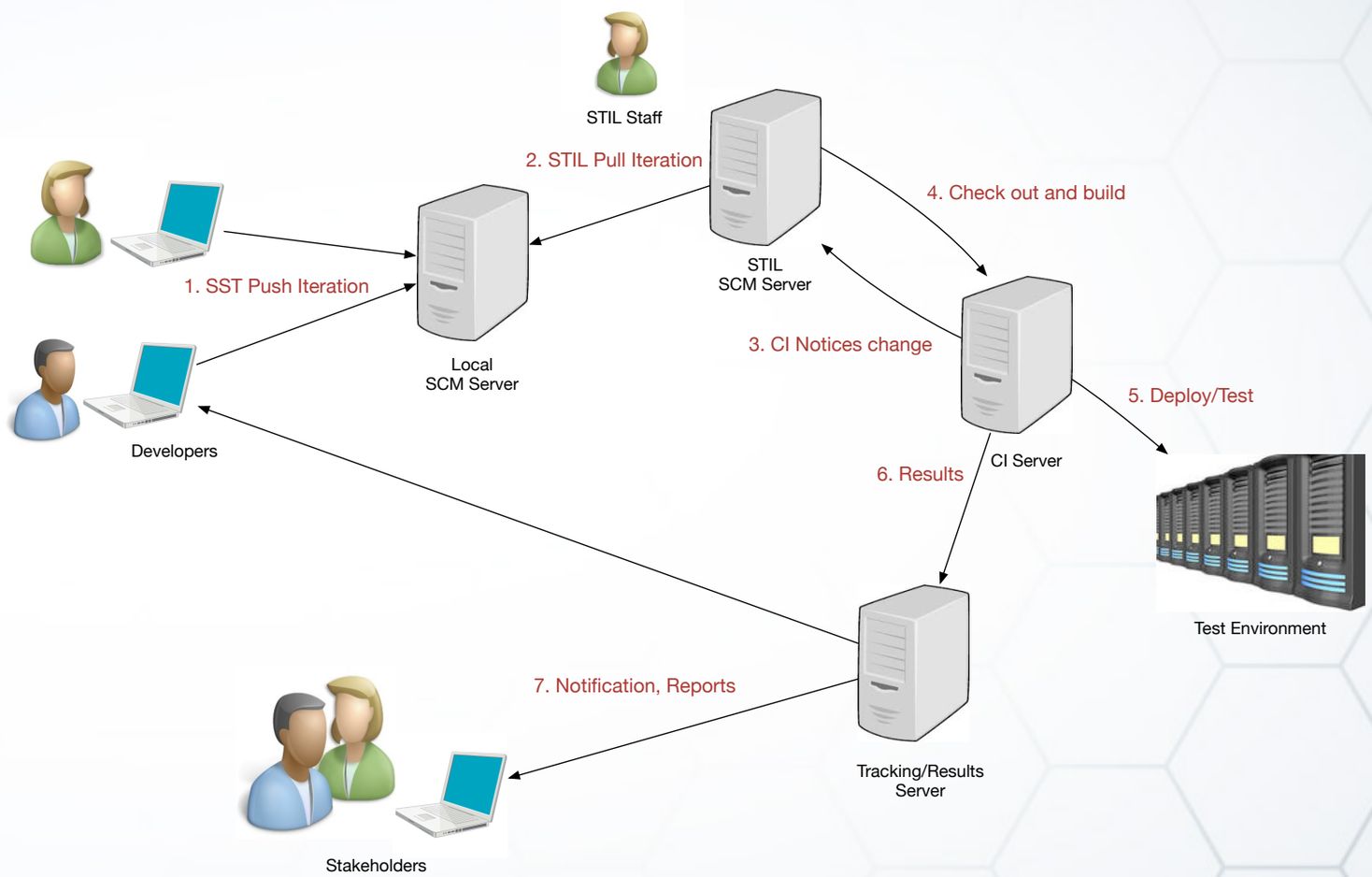


Verification and Validation

- The iterative process allows validation throughout the development of the software with potential for increasing quality.
- Requirements flow to features/user stories and tasks that result in software deliverables, which are tested and can be demonstrated for the product owner. Immediate feedback increases quality.
- Structuring the software as end-to-end features deliverable over the course of the subsystem construction period allows continuous validation.
- Systems Engineering has documented a process for requirements verification that must be followed.
- The conclusion of each iteration is a Verification Milestone. The Iteration Review meeting is an opportunity to review requirements and verification of requirements
- The SE PSR and FAR reviews are Verification Milestones that serve as an opportunity for a final verification of all incrementally delivered features/ requirements from the iterations.

Configuration Management

- The Configuration Management Plan is built on popular, well-understood distributed configuration management processes and tools.
- The SCMP documents what configuration management activities are to be accomplished, how they are accomplished, who is responsible for specific tasks, the schedule of events, and what resources will be utilized.
- Part of the plan includes documenting how the release and delivery of the product software is managed.



Common Software Overview and Standards

TMT Common Software (CSW)

- TMT Common Software is a collection of software, services and standards.
- CSW Includes:
  - Library code for constructing Observing Mode Oriented Architecture components (explained in following slides).
  - Library code that helps developers create components including code and deployment support.
  - Integration and communication services each with a simple application programming interface.
  - Examples, best practices, documentation, etc.

TMT Common Software (CSW)

- Common Software is the first TMT subsystem to be constructed in India.
- Common Software is prototyped in Scala with Java interface as well.
- Vendor will “productize” the prototype code that has been developed during preliminary and final design phases.
- CSW is based on technical choices made during PD and FD.

Common Software Integration Services

Current Common Software Services (Nov, 2015)

Name	Task
Connection and Command Service	Support for subscribing to, receiving, sending, and completing commands in the form of configurations
Location Service	Locate and connect to components within the distributed system
Event Service	Enable event publishing/subscription
Alarm Service	Support component alarms and health
Telemetry Service	Store status values/structured data with history, publish/subscribe
Configuration Service	Manage system and component configuration file changes
Authentication and Authorization Service	Centrally manage user authentication/access control
Logging Service	Capture/store local and distributed logging information
Database Service	Common access to centralized, relational database
Time Service	Standards-based, precision time access

Preliminary Design Prototyping

- Preliminary design phase has been about refining the Akka +Services approach.
- Focus during preliminary design is prototyping services, component construction, and testing performance.

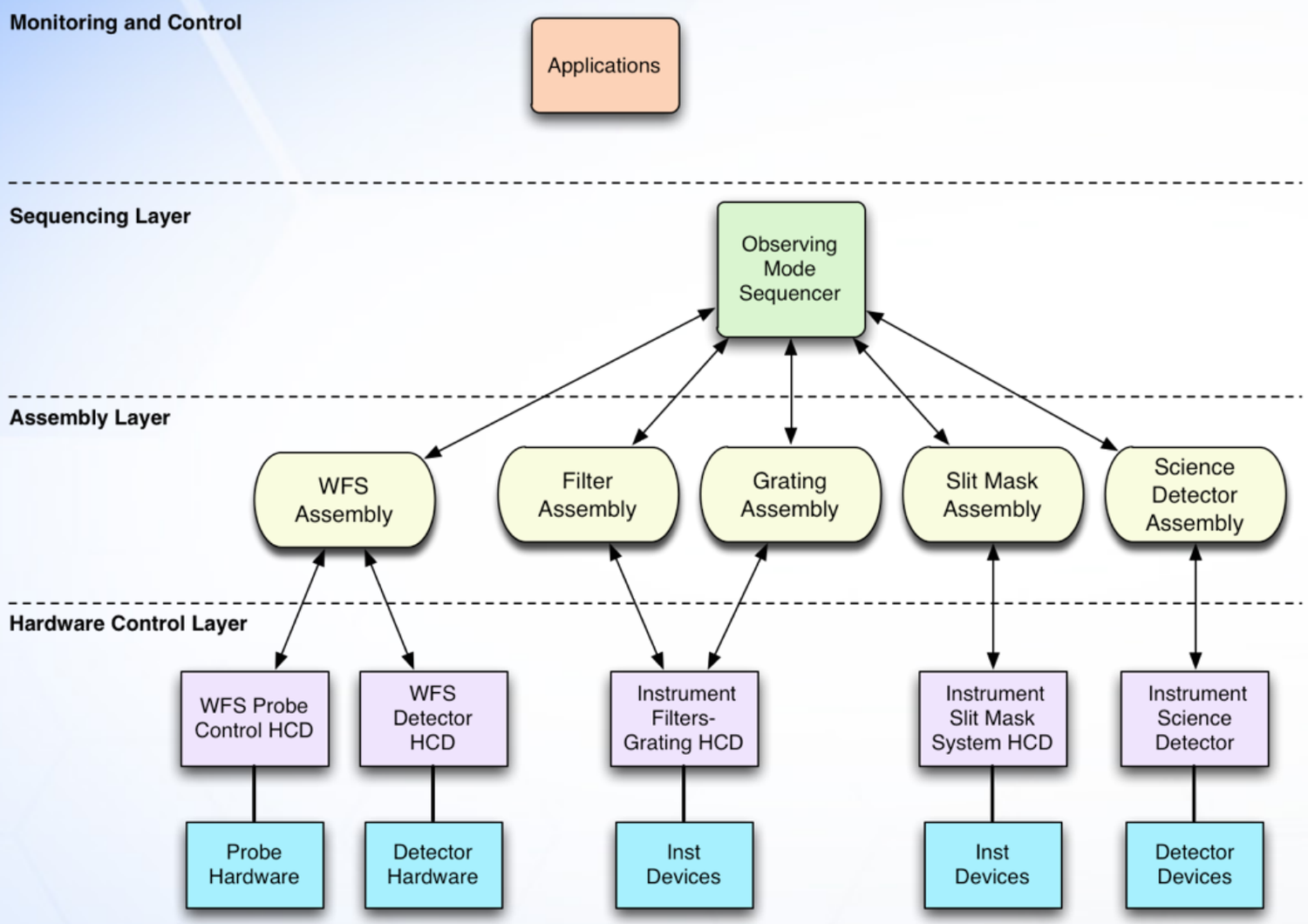
Choice	Description	Prototype?	Reference
Time Service	**Primary**: IEEE-1588 TMT Provides GrandMaster	Yes	Section 12.9
Event Service	**Primary**: HornetQ	Yes	Section 12.4
Location Service	**Primary**: ZeroConf	Yes	Section 12.1
Telemetry Service	**Primary:** Redis	Yes	Section 12.5
Connection and Command Service	**Primary**: Akka and Spray12.2	Yes	Section 12.2
Database Service	**Primary**: PostgreSQL	No	Section 12.10
Configuration Service	**Primary**: jGit + git-annex	Yes	Section 12.7
Authentication and Authorization Service	**Primary**: Atlassian Crowd, Apache Directory	No	Section 12.11
Logging Service	**Primary**: logstash+elasticsearch+kibana	Yes	Section 12.8
Framework	**Primary**: Akka, TMT code	Yes	Section 10.2
GUI Technology	**Primary:** Browser-based applications using JavaScript and TBD set of supporting libraries. **Primary**: Angular JS, D3	Continuing to Test	Section 13.2
Remote Observing	**Primary**: VPN-based Keck Remote Observing Solution and Browser-based GUIs	No	Section 13.2.2.1

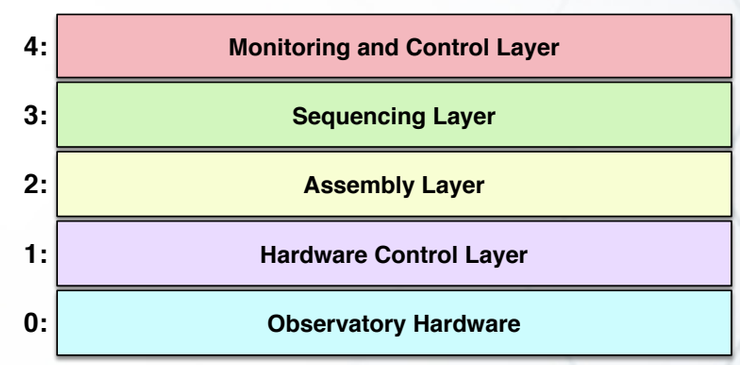
Table 6: TMT CSW PDR service product choices (Oct, 2015).

Observing Mode Oriented Architecture (OMOA)

- Common Software includes standard components for structuring the software at the telescope site. This is the software that interacts with hardware and is sequenced by the Observatory Control System.
- All subsystems for instruments and telescope that control hardware follow this TMT standard.
- Common Software supports this structuring standard.
- The defined OMOA components are shown in the next slide.

OMOA
Software Components in Control System





Hardware Control Daemon (HCD) Functions and Uses

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

Assembly Functions and Uses

- **Assemblies represent "user-oriented" devices or high-level functionality.**
- An Assembly can group, coordinate, and synchronize one or more HCDs.
- An Assembly can perform computations or use events as needed to control HCDs.
- Provides a uniform interface to the Sequencing Layer for device control.
- Assemblies use TMT CSW for services:
  - Command Service to receive configurations, completion,
  - Event Services for alarms, telemetry, and events,
  - Location Service to locate/connect to HCDs as needed,
  - Time Service for precise time and to synchronize HCDs as needed,
  - Configuration Service for default values, other configuration info,
- An Assembly provides a testable unit of user-oriented functionality with minimal dependencies.

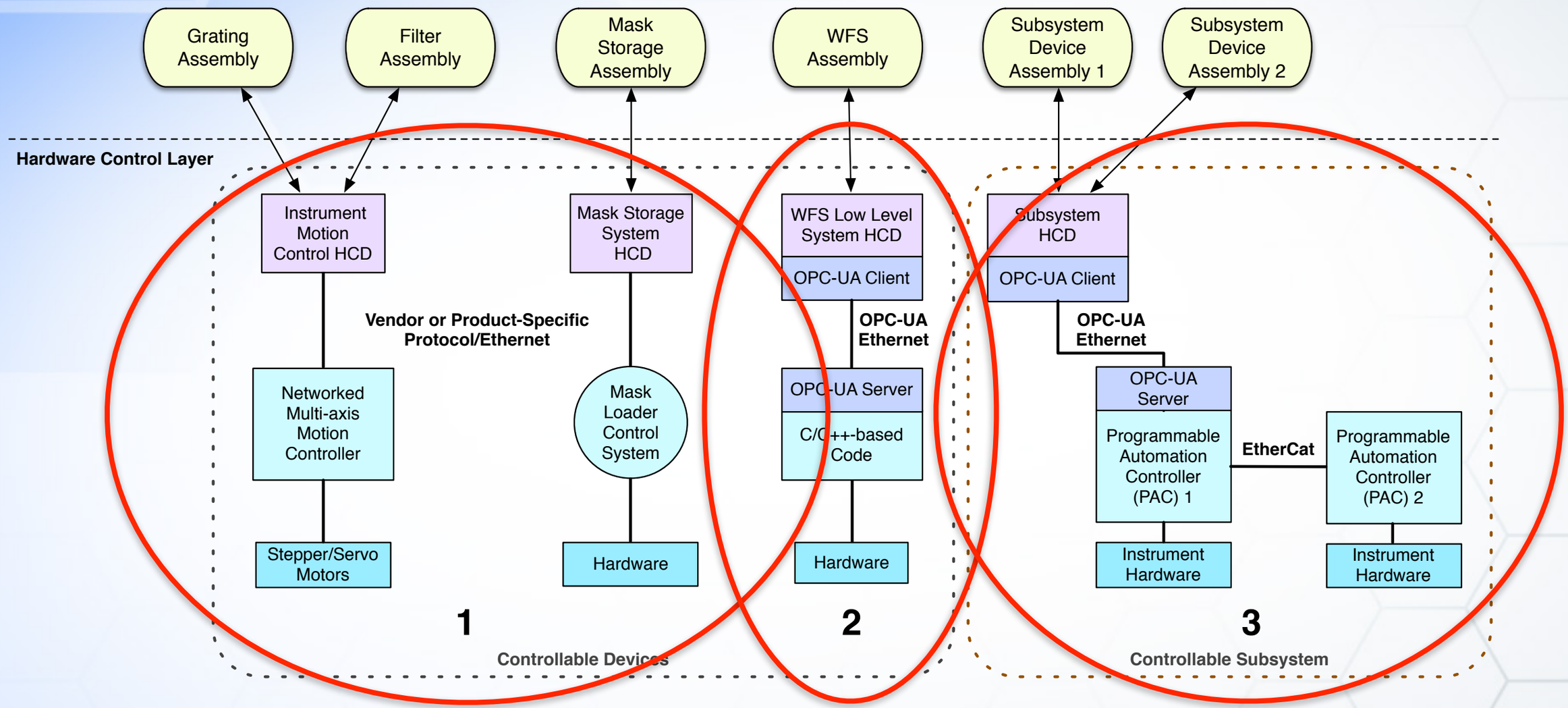
Sequence Execution Component

- **A Sequence Execution Component is the application or component that is used to coordinate and synchronize Assemblies (i.e. sequence the system).**
- A Sequence Execution Component executes a “script”.
  - Can load a script from a file as well as from Configuration Service.
  - Can be used interactively like a shell.
- Can use a unique set of Assemblies and Sequence Execution Components for a specific observing mode.
- 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.

Application and Monitoring Layer

- Applications are the visible programs astronomers use to observe.
- Applications need access to all system features:
  - May need to interact with wavefront sensor or science data images during acquisition or science data acquisition.
  - May need to provide a complex user interface for controlling the systems such as telescope operator user interface.
  - 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 using sequence components.
  - May need to do all these things within a single application.

Hardware Integration (Reference Architecture)



Hardware is integrated in one of three ways including networked devices, OPC-UA servers or PLC/PACs hosting OPC-UA servers.

OMO Architecture Summary

- OMO architecture defines the components that are in the software system and their responsibilities.
- The reference architecture defines the ways hardware are integrated into the system.
- Common Software provides the code to build and integrate OMOA components.
- There are no reported cases where this approach does not meet the needs of the software system.

Tool and Standard Choices

Operating System Choice

- Primary Choice: CentOS - (http://www.centos.org)
- Requirements state “Unix-like” operating system (OAD-9715).
- CentOS is a Redhat derived Linux distributions (with possible hardware support advantages).
- Real-time Applications:
  - Adopt an “official” real-time kernel.
  - Choice is Redhat MRG
    - Is supported in CentOS distribution through Scientific Linux: https://linux.web.cern.ch/linux/mrg/
- No windows except when required for specific development tasks (e.g., PLC dev).

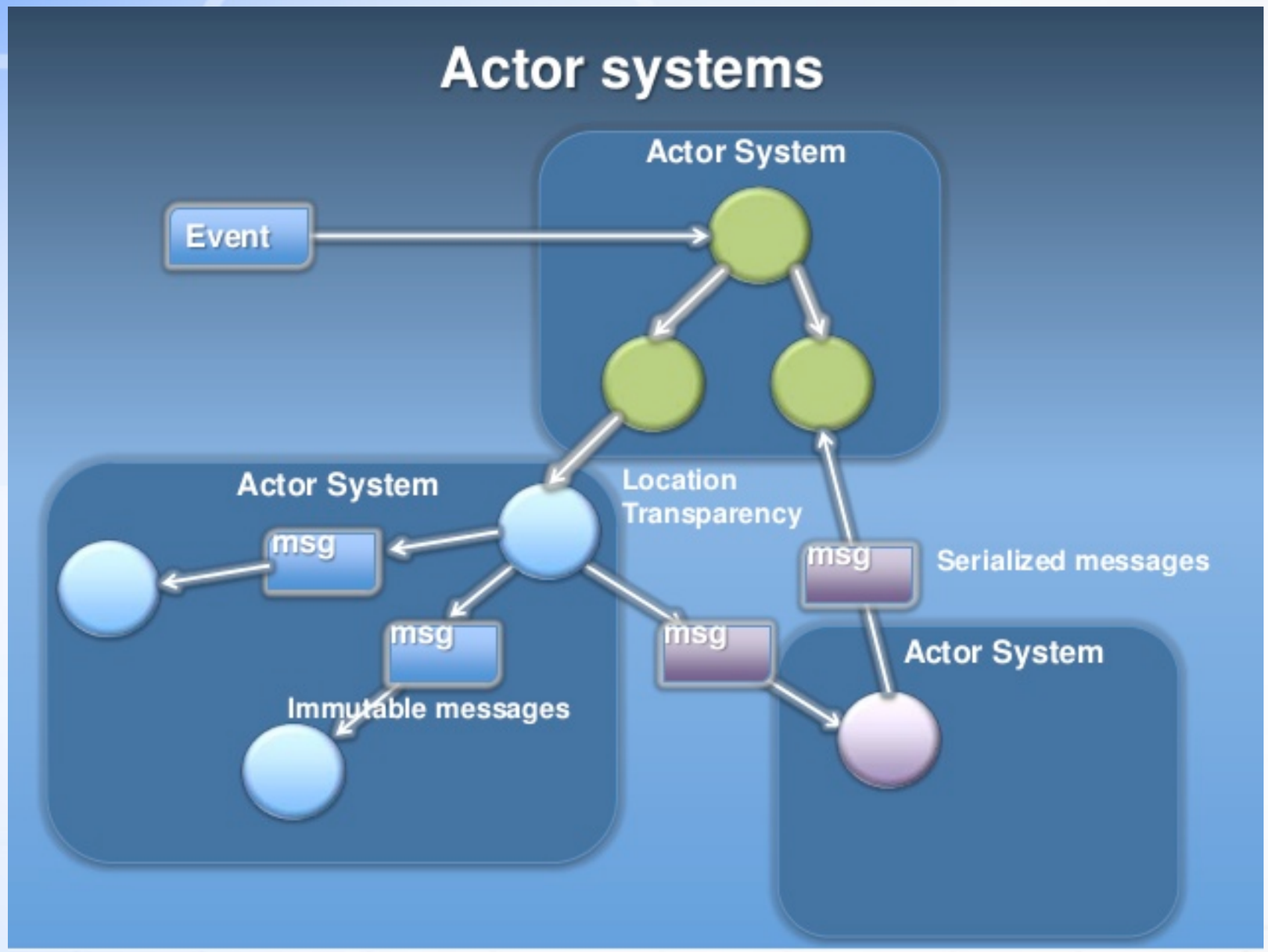
Programming Languages

- Infrastructure code is based on Java Virtual Machine.
  - Cost of creating and maintaining CSW and APIs for multiple computer languages can be large and limits infrastructure choices.
- Choice is JVM-based languages for ESW, DMS, SOSS
  include Scala and Java.
- Scripting for SEC also based on JVM
  - Choices: Scala and JPython.
- Python agreed choice for data processing side due to popularity in astronomical data processing.

Akka Advantages for Components

- Akka is designed to be asynchronous, non-blocking, and distributed like the TMT software system. Akka exactly matches our control scenarios and Command Action Model.
- Akka is based on actors, a programming model that removes the programming challenges around concurrency and locking that introduce so many hard to find bugs in other systems and languages. The Akka model allows safe code to be written without worrying about synchronization and locks.
- Akka is very high performance and has a small memory footprint supporting millions of messages/sec on a single machine and allows 2.5 million actors/GB of memory allowing our framework to be lightweight.
- Akka is available with interfaces in Scala and Java. It is our intention to support Java during construction, but prototype PDR code is only in Scala.
- Akka is a safe choice. Akka is supported by the TypeSafe company, the same company that supports Scala. Akka and all related tools are open source on Github.

Akka: Scala and Java Actors



- Simple abstraction
- Concurrent
- Asynchronous
- Non-blocking
- Lightweight
- Event-driven
- Fault-tolerant
- Message based
- Distributed
- Use Clusters

User Interfaces

- The CoDR plan for the web browser as the platform for user interfaces continues to be the decision.
- User interfaces are based on JavaScript and selected libraries.
- CSW must provide the software infrastructure that allows an application written in the browser to access the services.
- The TMT.DEOPS.OSW.ESW.UISTD work package will finalize the UI tool choices, look and feel templates, and examples.

Executive Software System

Sub-system Requirements

- The ESW packages provide the core functionality needed to enable PI-Directed observing, Pre-planned Queue and future support for Conditions-based Queue scheduling/observing.
- The ESW enables synchronized operation of all the TMT sub-systems from user interfaces or other programs. The Observatory Control System (OCS) is the Executive Software central engine providing this functionality.
- Provide user interfaces for system operators and observers as well as user interfaces for monitoring of system status and overall environmental monitoring.
- Build the system based on the overall system design using the technical architecture developed during preliminary design phase.

ESW: Observatory Control System

- ESW is critical infrastructure for the observatory.
- Observatory Control System (OCS) is the part of ESW that coordinates the activities of the telescope subsystems to take science observations as directed by the observer.
- OCS has interfaces with planning tools (SOSS), the Observing Database, and telescope and instruments at the site.

ESW Subsystems

- The Observatory Control System (TMT.DEOPS.OSW.ESW.OCS) functionality is an infrastructure package that includes:
  - The software concepts and infrastructure required to sequence the actions of all the TMT sub-systems during an observation such that science data is acquired correctly and efficiently.
  - The creation of script libraries or other software that systems within instruments and telescope control system use to allow participate in sequencing by OCS and to create sequencers or implement sequencing of systems.
  - Software that integrates ESW.OCS with the DMS.SCI infrastructure to ensure information for dataset headers is gathered or made available at the appropriate times.

The Observatory Control System provides the software needed to support classical observing workflow and provides the hooks needed to enable an end-to-end observatory workflow. Libraries produced by the Observatory Control System package will be used in the ESW.HCMS package to build observing user interfaces and the ESW.ACQ package that develops the target acquisition capability and other basic observing functionality. The sequence libraries will be used by and allow integration of sequencing capabilities developed elsewhere in the project such as TMT.INS.AO.AOESW.

ESW Subsystems

- The User Interface Standards (TMT.DEOPS.OSW.ESW.UISTD) provides infrastructure that includes:
  - Standards for user interfaces as required by the overall design that will be used to develop observing user interfaces.
  - Final determination, specification and refinement of the user interface toolkit(s).
  - Creation of reusable Graphical User Interface templates, frameworks, libraries, or tools as needed.
  - Refine or define a solution for remote observing and provide any standardized support as appropriate.
  - Provide standardized solutions for integrating with TMT.DEOPS.OSW.ESW.OCS and use of Common Software services.
  - Provide demonstration applications showing typical user interface scenarios and solutions.

ESW.UISTD does not include the user interfaces or acquisition tools themselves. User interfaces are part of the ESW.HCMS WBS element. The acquisition tools and observing sequences are defined within ESW.ACQ.

ESW Subsystems

- The High-level Control and Monitoring System (TMT.DEOPS.OSW.ESW.HCMS) provides the software tools used during observing to control the TMT sub-systems. The ESW.HCMS system includes the following:
  - User interfaces required for operation of the telescope and its sub-systems integrated with adaptive optics control.
  - User interfaces for observing including control of instruments.
  - User interfaces providing observatory status, alarms and monitoring of environmental conditions.
  - Other operations-focused user interfaces required by the observatory design.

The software tools in this ESW.HCMS are science and operations-focused and are optimized to make observing as efficient as possible. The user interfaces are planned to be Graphical User Interfaces (GUI) and are built upon the infrastructure provided by the User Interface Standards defined in the TMT.DEOPS.OSW.ESW.UISTD WBS element, the Observatory Control System defined in TMT.DEOPS.OSW.ESW.OCS the WBS element, and the Common Software defined in the TMT.DEOPS.OSW.CSW WBS element.

ESW Subsystems

- The Data Visualization system (TMT.DEOPS.OSW.ESW.VIZ) provides the infrastructure and tools needed for visualizing science data during observing and includes the following:
  - Infrastructure that allows distributed visualization tools to integrate with the TMT science data distribution system.
  - Creation and/or modifications of current visualization tools to integrate tools with the visualization infrastructure.
  - Modifications or extensions of visualization tools required to visualize TMT science data in the ways required by the operations model and observing modes.

The Data Visualization sub-system is an application package built upon the products of the Observatory Control System defined in the TMT.DEOPS.OSW.ESW.OCS WBS element, the TMT User Interface standards developed in the TMT.DEOPS.OSW.ESW.UISTD WBS element, the Data Management System Access Services defined in the TMT.DEOPS.OSW.DMS.ACC WBS element, and possibly products from the Science Data System defined in TMT.DEOPS.OSW.DMS.SCI.

ESW Subsystems

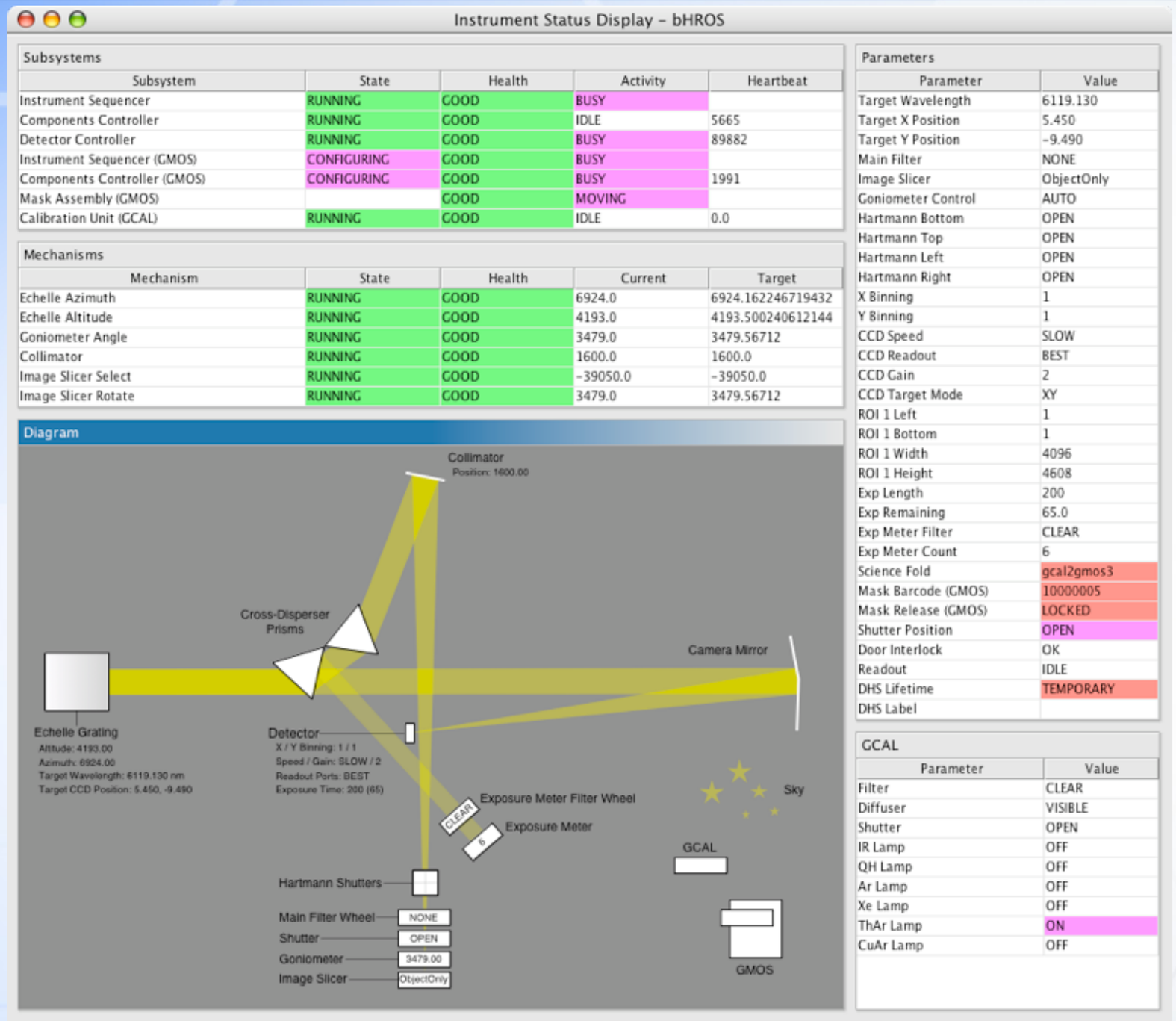
- The Acquisition Tools sub-system (TMT.DEOPS.OSW.ESW.ACQ) is an application package that provides:
  - The operational sequences that allow execution of observations using the TMT instruments, telescope, and AO systems
  - The sequences for execution of critical acquisition processes that occur at the beginning of each science observation.

TMT.DEOPS.OSW.ESW.ACQ builds either directly or indirectly upon the products delivered the Common Software work-package defined in the TMT.TMT.DEOPS.OSW.CSW WBS element, the Observatory Control System work-package defined in the TMT.DEOPS.OSW.ESW.OCS WBS element, the TMT User Interface standards developed in the TMT.DEOPS.OSW.ESW.UISTD WBS element, the Data Visualization Tools developed in the TMT.DEOPS.OSW.ESW.VIZ WBS element. the Data Management Science Data System defined in the TMT.DEOPS.OSW.DMS.SCI WBS element, and the Data Management System Access Services described in the TMT.DEOPS.OSW.DMS.ACC WBS element.

ESW: High Level Control and Monitoring (HCMS)

- ESW provides all operations/observing user interfaces.
- Team will need to be experts in current user interface technologies.
- User Interfaces include:
  - Observing Associate UI - All user interfaces that are used to move the telescope and its subsystems and to verify and monitor proper operation.
  - Status screens showing images and diagnostic data.
  - Observer UIs - All instrument user interfaces for observing with TMT instruments.

HCMS:Example Interactive Instrument UI



- Simple
- Repeatable UI themes
- No popup windows/hidden information
- Optical path visible, animated, interactive

Data Management System

DMS Subsystem Requirements Summary

- Provides secure, reliable storage infrastructure for science data.
- Provides the infrastructure for moving and tracking science data from instruments to support facility and eventually to the TMT archive(s) or partner data centers.
- Provides science data standards and metadata standards for instruments.
- Provides the infrastructure, hardware storage systems, and interfaces for access and analysis of the technical data stream.
- Build the system based on the overall system design using the technical and functional architecture developed from design documents.

DMS Subsystems

- DMS.SCI - Science Data System
  - Software and hardware infrastructure for storing, copying, and transporting science data. Managing science metadata. Ensuring data integrity, security and proprietary data policies.
- DMS.ACC - Science Data Access
  - Provide access to science data for software components and users including the local searchable data store.
- DMS.ENG - Engineering Database
  - Software, hardware, and interfaces needed to capture, time-stamp, store, transmit, access, and visualize technical data flowing through the TMT system.
- DMS.CAT – Image and Object Catalogs
  - Minimal set of catalogs needed on site to support observing.
  - Creation of any TMT-specific catalogs and and search algorithms.

DMS Subsystems

- The Science Data System (TMT.DEOPS.OSW.DMS.SCI) includes:
  - The standards and requirements for science data formats.
  - The software and hardware infrastructure for storing, moving, and ensuring the integrity and security of the science data (including any required back-up) acquired at the site by instruments, AO systems, and any other systems generating information that is associated with science data.
  - The standards and requirements for science data metadata.
  - The infrastructure required to manage science metadata and associate metadata with science data.
  - The model for securing science data including any required authentication and authorization services.
  - A model for uniquely identifying science datasets, associated files, and associations.
  - A persistent science data location service.

WBS Dictionary Entries

- The Science Data Access system (TMT.DEOPS.OSW.DMS.ACC) includes the following:
  - Design and implement science data access services for use by observing software as well as infrastructure components that must access science data during observing.
  - Provide web access site for users to access their science data and related files.
  - Provide basic form-based queries considering roles and authorization of users.
  - Any data-oriented software services for querying science data metadata from the on-site science data collection or updating the science data metadata including IVOA cone and TAP services.
  - Any other tools or services required for integrating data access with other observatory software tools are implemented in the DMS.ACC sub-system.

WBS Dictionary Entries

- The Engineering Database (TMT.DEOPS.OSW.DMS.ENG) system functionality includes the following:
  - System allows for periodic sampling of a configurable set of telemetry items.
  - Provides time-based storage and access of telemetry.
  - Provides format and metadata standards for long-term storage of engineering data.
  - Provide software interfaces for storage of long-term engineering data other than telemetry.
  - Provides a basic user interface for querying, retrieving, viewing and plotting engineering data from the archive of values.

The Engineering Database provides storage and an archive for engineering telemetry collected at the site. This package is an application built on the infrastructure provided by the common software infrastructure provided by the TMT.DEOPS.OSW.CSW WBS element. The package includes required infrastructure such as hardware, database software, software services, and user interfaces for access and basic analysis of data such as plotting of values versus time.

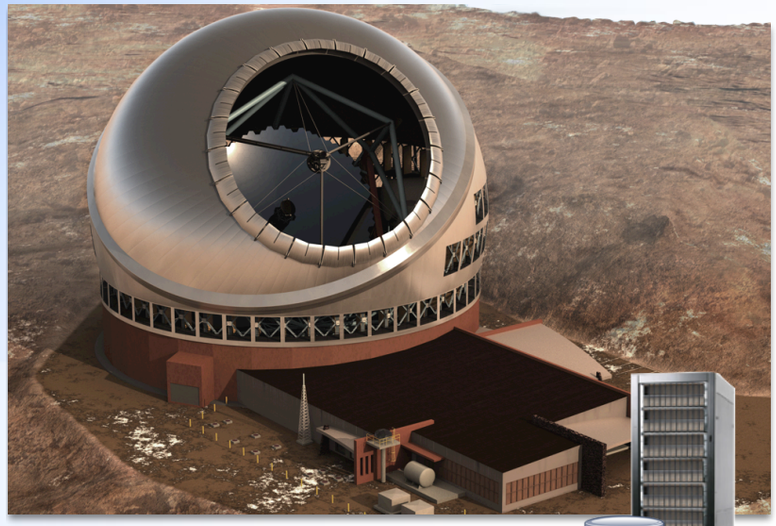
WBS Dictionary Entries

- The Image and Object Catalogs (TMT.DEOPS.OSW.DMS.CAT) system includes the following:
  - Determining which observing resources are required and which must be provided on-site based on instruments and operations observing modes.
  - Creation of any TMT-specific object catalogs needed to support wavefront sensor target selection if no adequate catalogs exist based on requirements provided by the instrument, telescope, and AO teams.
  - Development of any TMT-specific catalog search algorithms needed to support wavefront sensor target selection.
  - Provide the software services to that provide access to observing resources on site based on current astronomy standards.
  - Provide any hardware or database systems required to support the observing resource access implementation.

DMS: Science Data System

- Science Data System (SCI) is one subsystem of the Data Management System.
- The SCI subsystem is focused on reliably storing, maintaining, and moving science data and metadata.
- Metadata is the information from the telescope that is collected and associated with each science data set collected from an instrument.

DMS: Science Data Flow



TMT Observatory on Mauna Kea

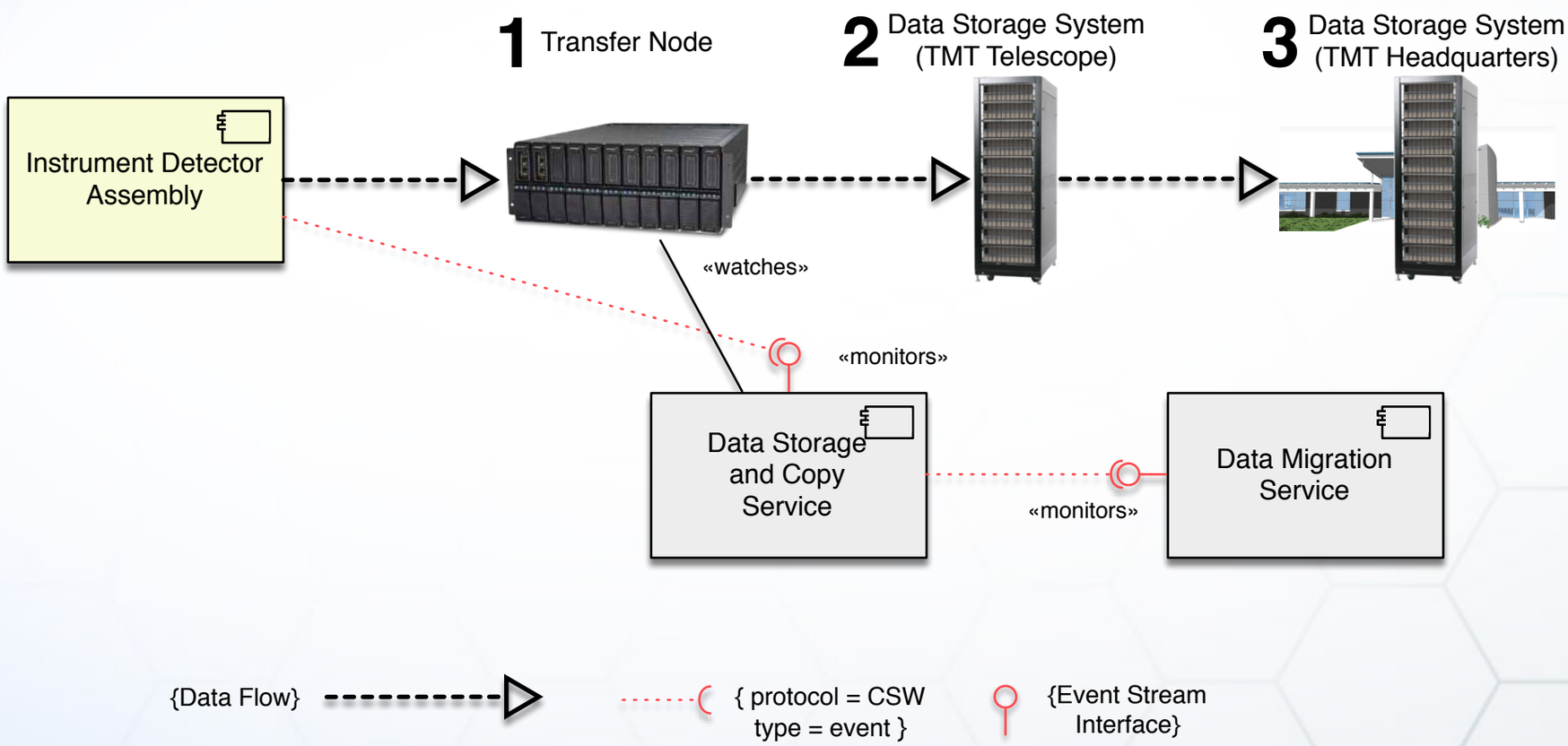
TMT Hilo Support Facility

Image Data Flow

Science data is collected at the summit site, travels to the Hilo Support Facility and in some cases to the remove observing sites.

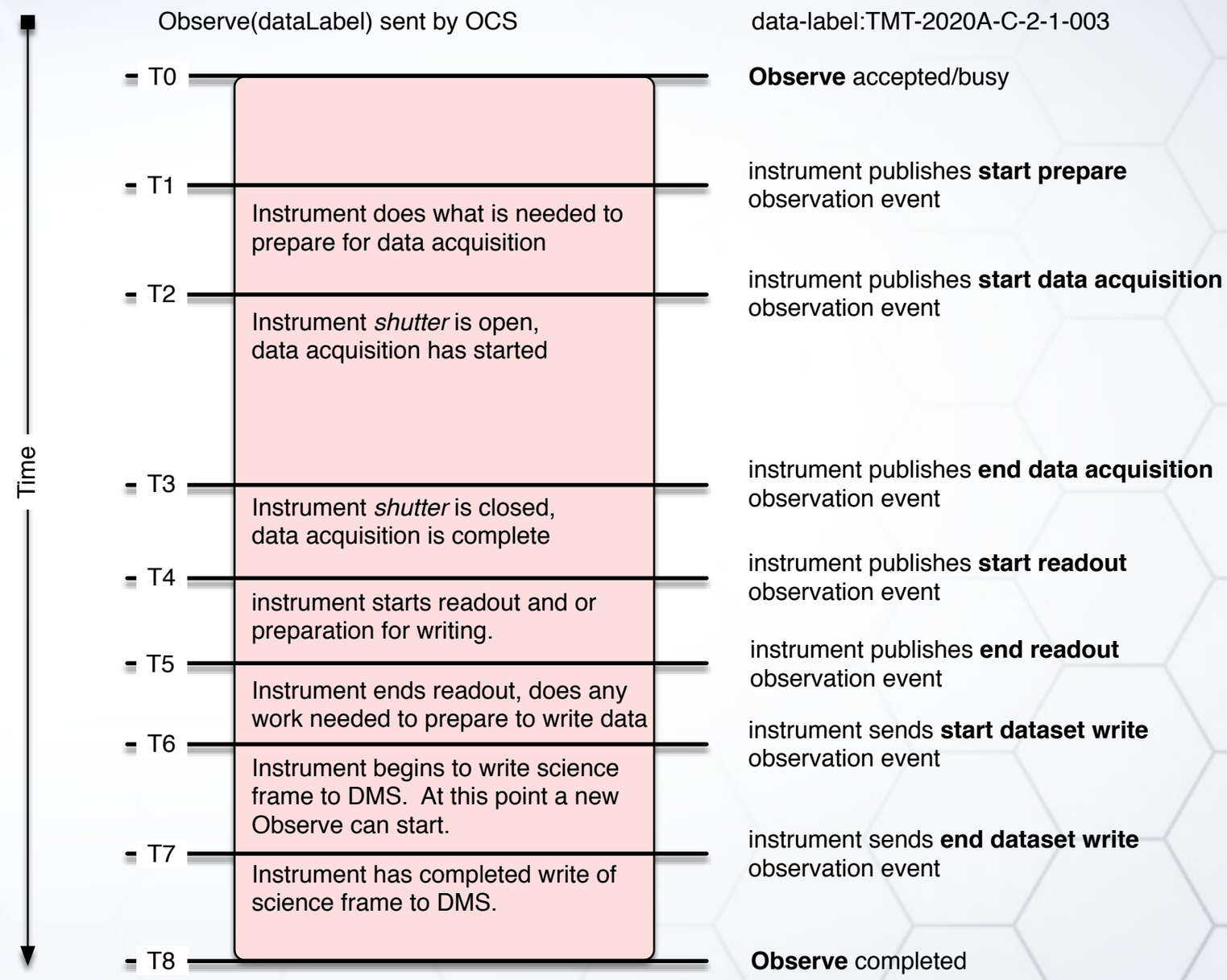
DMS: Science Data System (SCI)

- Instruments write science data to a high-speed disk storage system. SCI software monitors storage for arrival, stores a backup, and migrates the science data to the support facility.



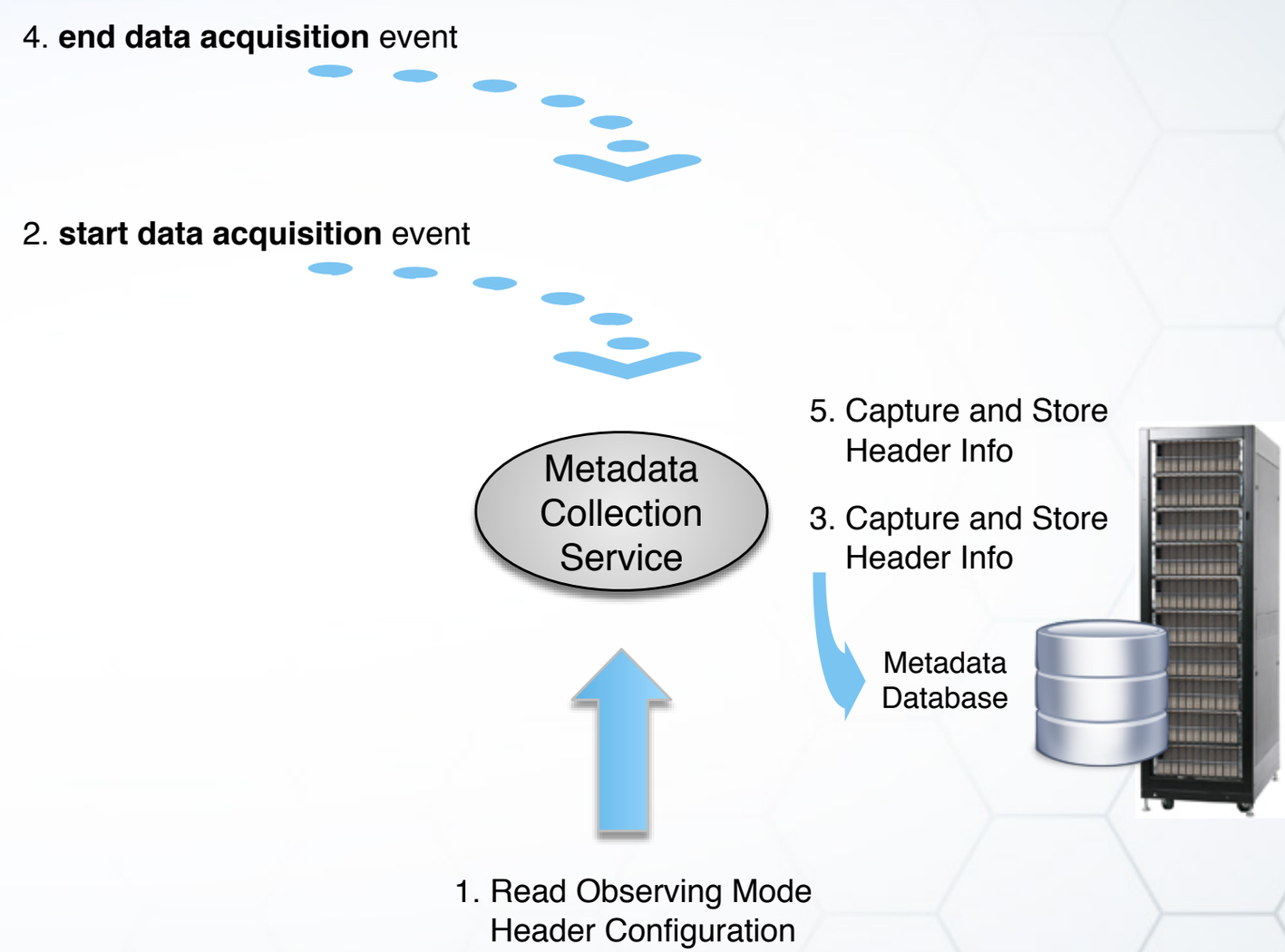
DMS: Metadata Collection

- Metadata for science images is collected based on events sent by science detector systems.
- Observe Events use the CSW Event Service.



DMS: Metadata Collection

- DMS SCI provides a service that samples the observatory status information based on the events published by the detector systems.

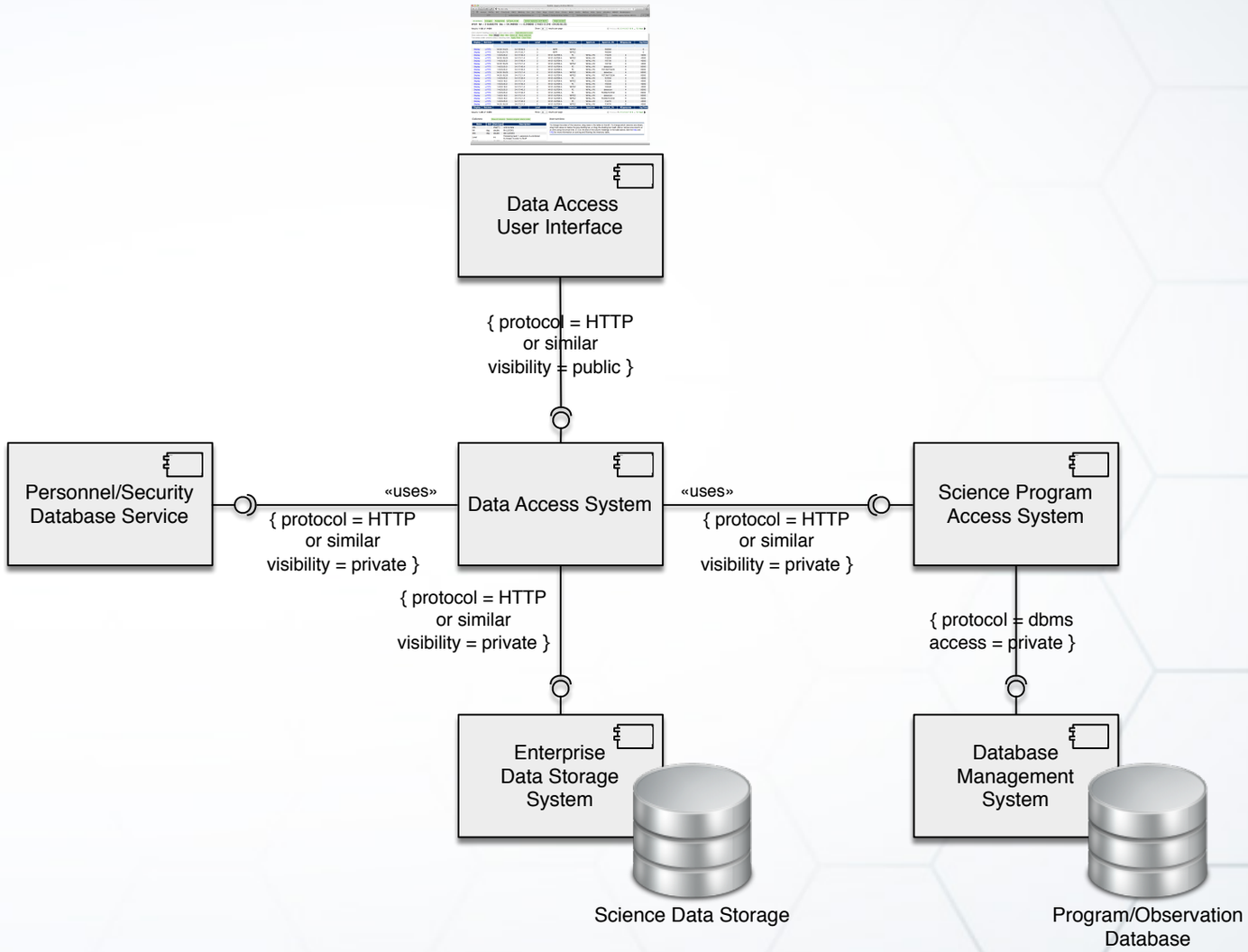


DMS: Science Data Access

- Science Data Access (ACC) is one of the subsystems of the Data Management System.
- The ACC provides access to the observatory data for observers and staff as well as for parts of the software system.
- ACC must enforce the data access restrictions and proprietary data policies of the observatory.
- ACC provides a web based user interface to allow observers to access their science data and all related information.
- ACC provides simple VO access to TMT data for the public once the data is no longer proprietary.

DMS: Science Data Access

- DMS ACC provides services that allow a PI to access their data that has been collected in the software system at an earlier time.

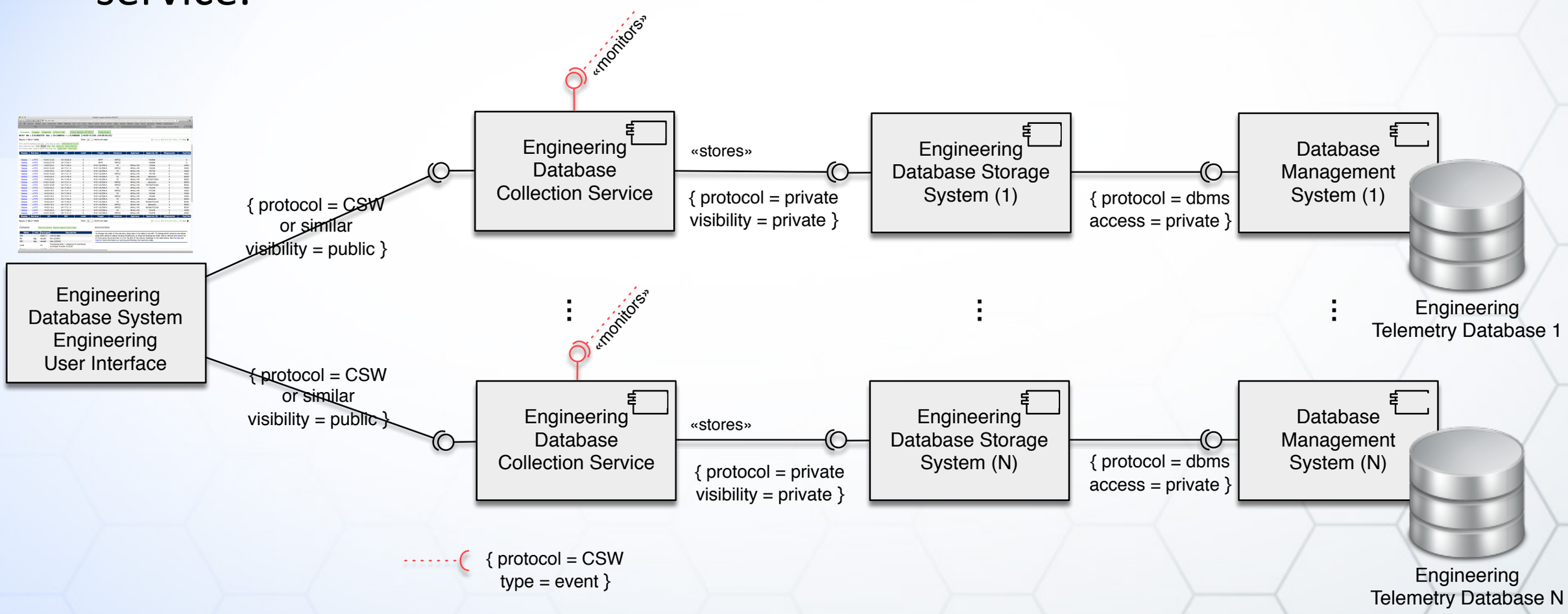


DMS: Engineering Database

- The Engineering Database (ENG) is one of the subsystems of the Data Management System.
- It provides a centralized service for collecting various kinds of technical engineering data in order to monitor the long-term behavior of the telescope system.
- ENG provides a scalable collection service for collecting various types of data.
- ENG provides a web-based user interface that allows querying the technical data and downloading data to local tools.

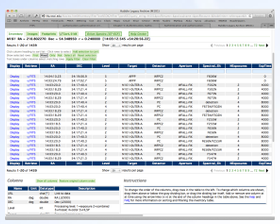
DMS: Engineering Database Technical Data Collection

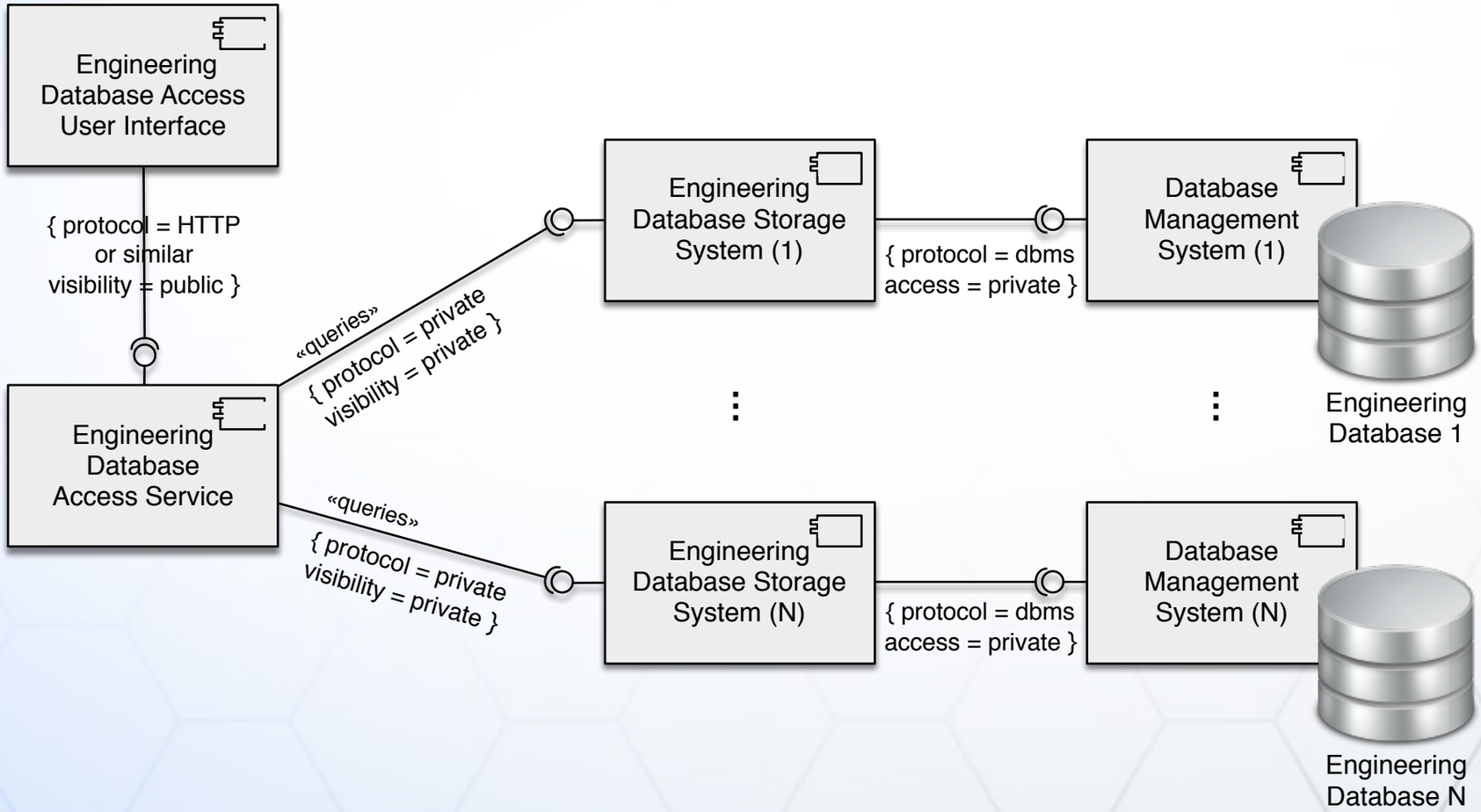
- ENG provides collection of different types of engineering data with scalable collection infrastructure and database.
- One example is collection of telemetry data using CSW telemetry service.



DMS: Engineering Database Technical Data Access

- ENG provides a user interface and access system for querying the databases of stored engineering data.
- Users issue time-based queries and other types of queries.



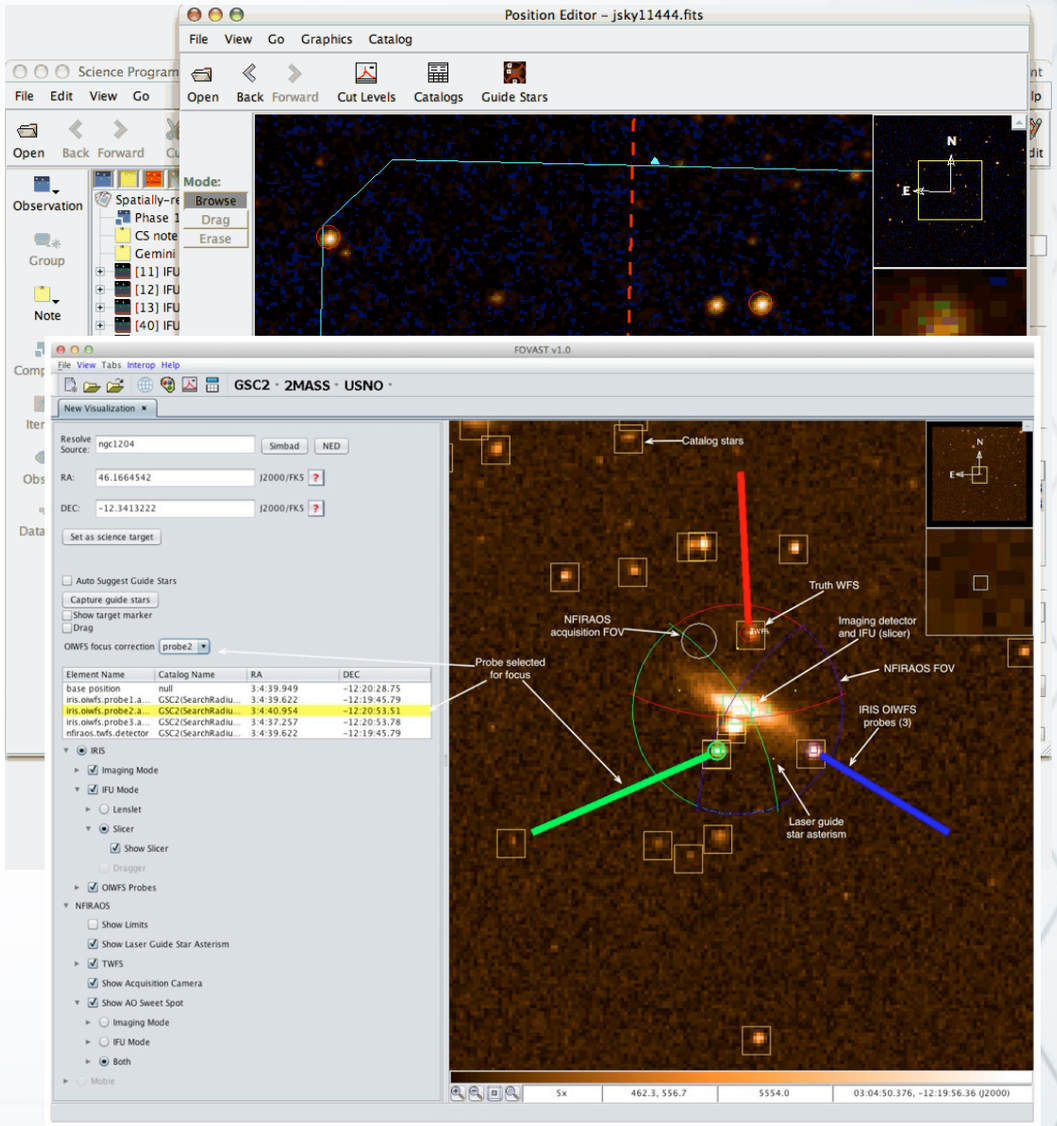


Science Operations Support System

TMT.DEOPS.OSW.SOSS
Level-3 Construction Subsystems

- SOSS.ODB - Observatory Databases
  - Models for storing observing-related information.
  - Software interfaces for access and querying databases, reports.
  - Database hardware and software technology choices.
- SOSS.FLP1 - First Light Phase 1
  - A minimal Phase 1 implementation based on an existing system in use by TMT partners or within the astronomy community with modifications for TMT-specific requirements. .
- SOSS.FLP2 - First Light Phase 2
  - Tools supporting minimal amount of planning required to enable classical observing during early light observing as needed specifically for AO observing.

Example observation preparation tool



SOSS Sub-system Requirements

- Provide proposal preparation, handling, review, and time allocation ("Phase 1").
- Support observation preparation, planning, handling, review, and queuing ("Phase 2").
- Provide observation scheduling as needed by the TMT operations model.
- Integrate observation planning and observation execution.

SOSS Subsystems

- The Observatory Database (TMT.DEOPS.OSW.SOSS.ODB) system includes the following:
  - Evaluation of TMT database requirements for persisting and querying observing-related information.
  - Creation of models representing the observing-related information.
  - Evaluation and selection of a database technology that supports the observatory data model.
  - Implementation of the data model in the chosen database technology.
  - Creation of software interfaces and/or services to access the Observatory Database.
  - Procurement of appropriate hardware for the on-site SOSS.ODB system.

- The Observatory Database System must provide support for the construction system, but also provide the infrastructure and interfaces to support the completion of the operations system in the TMT.DEOPS.OSW.SOSS.P1, TMT.DEOPS.OSW.SOSS.P2, TMT.DEOPS.OSW.SOSS.SCH, and TMT.DEOPS.OSW.SOSS.ISSP packages. These other packages are not part of the construction plan. These other work packages are planned for the first 5 years of operations.

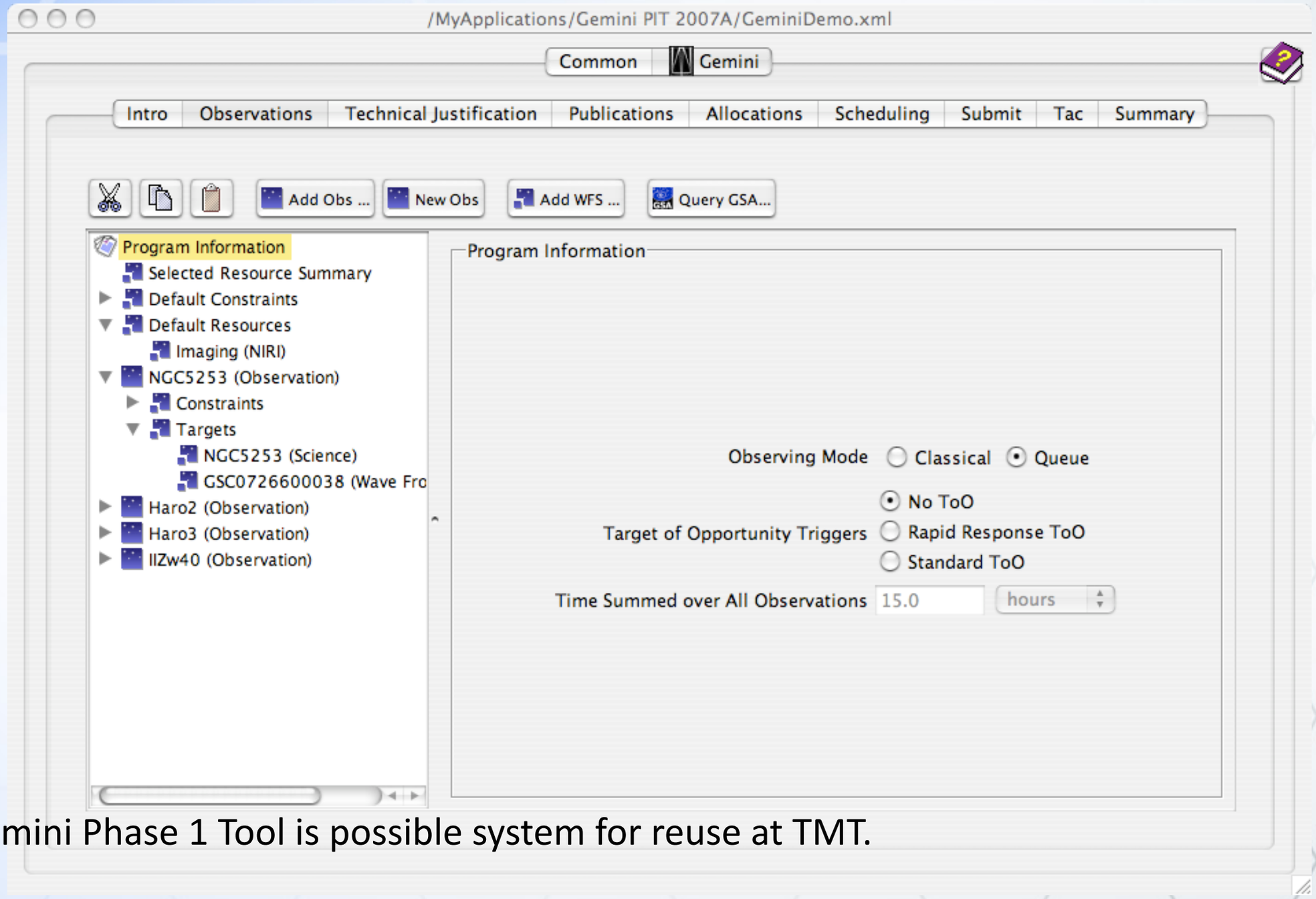
SOSS Subsystems

- The First Light Phase 1 Tool (TMT.DEOPS.OSW.SOSS.FLP1) is part of the construction phase of the Science Operations Support Systems (SOSS) work.
- The TMT Observatory requires a system at first light for accepting proposals from potential observers. The OSW SOSS First Light Phase 1 Tool is meant to be a minimal implementation based on an existing system in use by TMT partners or within the astronomy community with modifications for TMT-specific requirements.
- It is assumed that the First Light Phase 1 Tool and any associated infrastructure will be a standalone system with minimal or no integration with the remaining operations software system in OSW.SOSS and OSW.ESW. The Phase 1 System will use the data models and software interfaces that are part of the software of SOSS.ODB if possible.

SOSS Subsystems

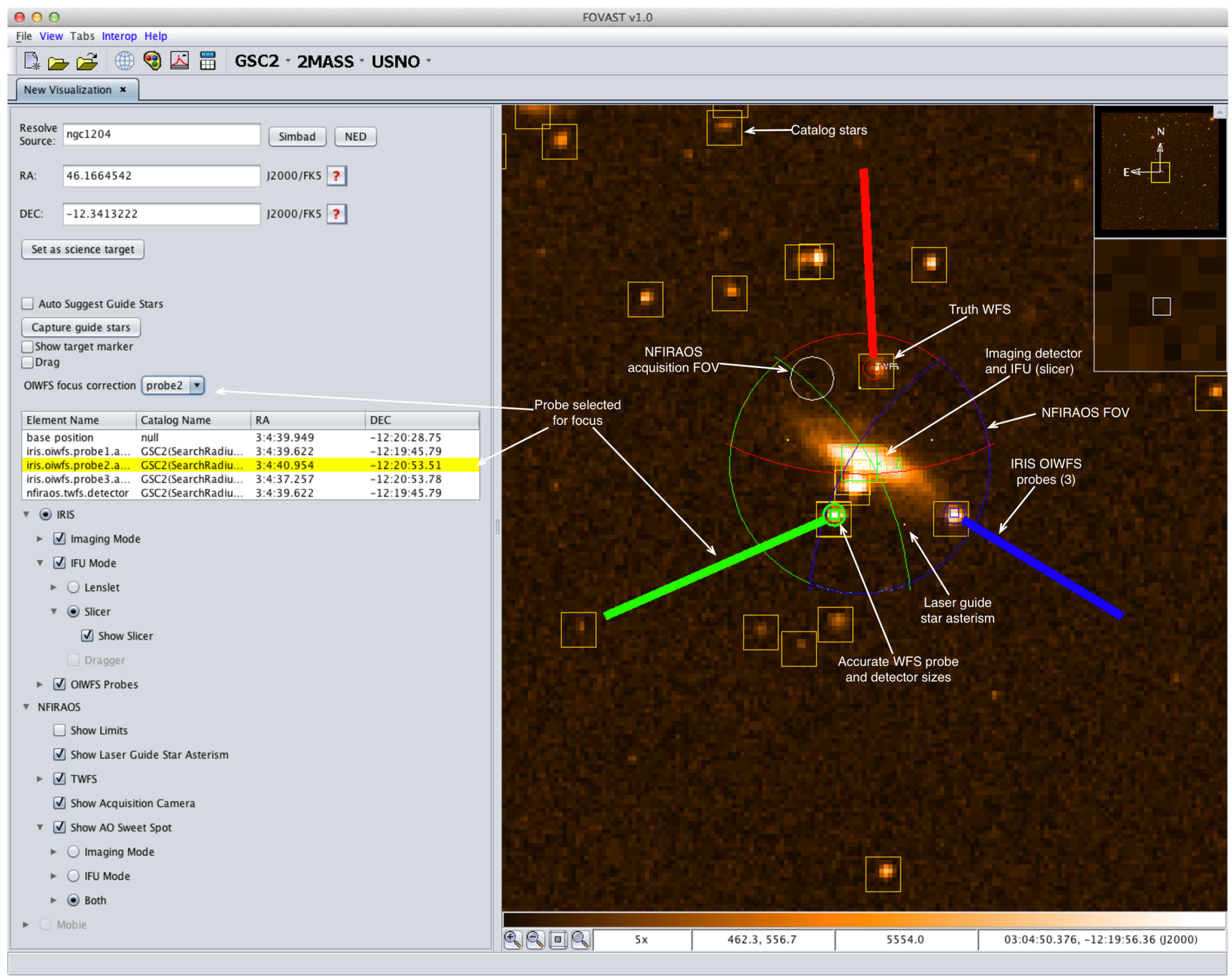
- The SOSS.FLP2 First Light P2 System is part of the construction phase of the Science Operations Support Systems (SOSS) work.
- The TMT Observatory requires a system that allows observers to do the minimal amount of planning that is required to enable them to do classical observing during early light observing. As an example, observers should choose guide stars for wave front sensors before arriving at the telescope. The FLP2 system will support this kind of activity as required by the TMT operations model. The inclusion of other planning information is possible, but adding information during Phase 2 is not required at this time by the TMT operations plan.
- The OSW SOSS First Light Phase 2 Tool is planned to be a lightweight implementation based on an existing system in use by TMT partners or within the astronomy community but with modifications for TMT requirements and operations models. It is assumed that the First Light Phase 2 Tool and any associated infrastructure will be a standalone system with minimal or no integration with the remaining operations software system in OSW.SOSS and OSW.ESW. The First Light Phase 2 System will use the data models and software interfaces that are part of the software of SOSS.ODB if possible, but creation of the operations proposal workflow is part of the deferred OSW.SOSS work.

Gemini Phase 1 Tool (PIT)

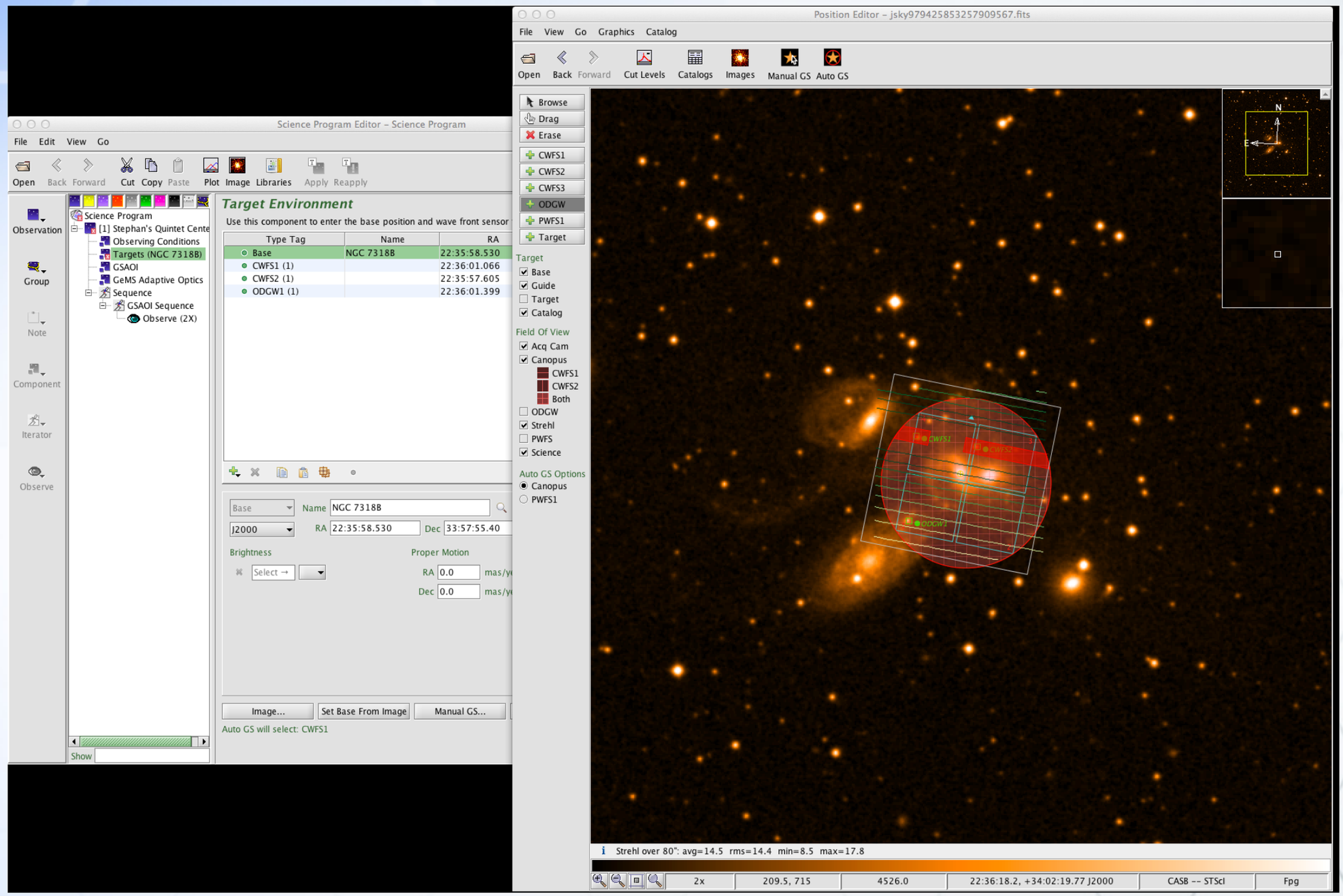


The Gemini Phase 1 Tool is possible system for reuse at TMT.

Prototype Phase 2 Tool for IRIS



Gemini Observing Tool (P2)



Gemini Observing Tool is available for reuse with TMT: https://github.com/gemini-hlsw/ocs

Summary

- The overall architecture and design of the TMT Software System and Observatory Software is in place.
- A software development process and quality assurance plan is in place.
- The vendor will participate in the latter design phases of the software and the construction, testing, and integration of the software at the telescope site.
- There are many systems and the software is complex, but it is a great opportunity to be involved in a telescope that will shape our knowledge of the universe for years to come.

Acknowledgments

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