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# TMT Adaptive Optics And Instruments Interface Definition

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## Abstract

This report describes TMT subsystem interfaces, particularly between instruments, adaptive optics (AO) and the telescope.

## Revision Sheet

The revision sheet should track all changes to the document and be consistent with project version control numbering.

| Release No. | Date | Revision Description |
|---|---|---|
| Rev. 0.1 | 01/01/05 | Initial draft |
| Rev 0.2 | 02/15/05 | Revisions based upon B.E. comments |
| Rev 0.3 | 02/18/05 | Revisions to add DHS, format drawings, prevent Word crashes |
| Rev 1.0 | 02/18/05 | Minor typos and an i/f from the TCS to the LGS WFS for LGS range |
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# 1 GENERAL

## 1.1 Acronyms and Names

| | |
|---|---|
| AO | Adaptive optics |
| AOGL | Adaptive optics group lead |
| CfAO | NSF Center for Adaptive Optics |
| DM | Deformable mirror |
| DHS | Data Handling System |
| ExAO | Extreme contrast adaptive optics |
| FoV | Field of view |
| GLAO | Ground-layer AO (also known as Wide-field AO, WFAO) |
| IFU | Integral field unit (type of spectrograph) |
| IPT | Integrated product team |
| IRIS | Infra-Red Imaging Spectrograph |
| IRMOS | Infra-Red Multi-Object Spectrograph |
| LAO | Laboratory for Adaptive Optics |
| LGS | Laser guide star |
| MEMS | Micro-electro-mechanical systems |
| MCAO | Multi-conjugate AO |
| MGSU | Multiple Guide Star Unit |
| MIRAO | Mid-infrared AO |
| MIRES | Mid-Infra-Red Echelle Spectrograph |
| MOAO | Multi-object AO |
| Na | Sodium |
| NIR | Near infrared (typically 1-2.5 microns wavelength) |
| NIRES | Near Infra-Red Echelle Spectrograph |
| OCS | Observatory Control System |
| PDR | Preliminary design review |
| PFI | Planet Formation Instrument |
| PSF | Point spread function |
| PM | Project manager |
| RMS | Root mean-squared |
| SAC | Science advisory committee |
| SEG | Systems engineering group |
| SOW | Statement of Work |
| SRD | Science requirements document |
| TBD | To be determined |
| TCS | Telescope Control System |
| TMT | Thirty-Meter Telescope Observatory |
| UVic | University of Victoria |
| WFE | Wavefront error |
| WIRC | Wide Field Infra-Red Camera |

## 1.2 Applicable Documents

1. TMT Science-Based Requirements Document v15.0, December 20, 2004 (TMT Report 52).
2. TMT Adaptive Optics Reference Design/Architecture Decision, December 6, 2004.
3. TMT ICD Template
4. Example NFIRAOS ICD.
5. NFIRAOS Reference Design: Final Report TMT.INS.AOAOS.WPKG2

## 1.3 Purpose

This report defines a set of instrumentation-relevant interfaces and subsystems of the TMT, in particular Instruments, AO Systems, and related telescope subsystems. It is intended as background for the TMT instrument studies, currently scheduled to begin in April, 2005.

The audience for this report is the Adaptive Optics Manager and Group, the Instrumentation Manager and Group, and external groups conducting feasibility and conceptual design studies of instruments and AO systems for TMT.

This interface definition document is a guide to filling in the Draft ICD Template (Reference 3) to create individual interface control documents, an example of which is Reference 4, NFIRAOS ICD.

## 1.4 Scope

The extent of this report is essentially a definition of those subsystems with some connection to TMT instruments or adaptive optics.

- AO: NFIRAOS, MCAO, LGS facility, and a (possible) facility wavefront reconstruction processor
- Instruments: IRIS, NIRES, WIRC, ExAO/PFI, MIRAO/MIRES, MOAO/IRMOS, and (possibly) GLAO/WFOS
- Telescope: Nasmyth Platforms, telescope optics (i.e. the optical interface), M2, AM2, A&G sensors, telescope control system(s), calibration sources, and observatory control system.

The relevant topics are in the following areas:

- "Fast Guiding" with the Secondary Mirror
- Primary Mirror Segment Control
- Offloading Adaptive optics systems onto the above two
- Internal Adaptive Optics control systems for multiple sensors and correctors
- Calibration of primary mirror segment sensors
- Calibration of Instrument wavelength and flat field

- Multiplexing (sharing) of focal plane

Section 2 below summarizes relevant background material, including the TMT DDP schedule, the current reference design architecture and development schedule for the TMT AO systems. Section 3 begins with an $N^2$ diagram and description of the interfaces, and block diagrams illustrating controls interfaces. Section 4 continues with a list of interface parameters and their ranges currently under consideration.

# 2 BACKGROUND

## 2.1 TMT project schedule

The current schedule calls for a project conceptual design review in April 2006, followed by submission of the construction proposal in August 2006. The overall AO system architecture will be placed under configuration control at the time of the CoDR, and costs must be known accurately in time for the construction proposal. Further AO development during the remainder of the DDP will consist of parametric cost/performance trades (How many lasers can we afford? How many WFS subapertures?), and detailed component design work.

## 2.2 Reference AO architecture

The following figure illustrates the reference AO architecture for TMT as described in Reference 2. The earliest capabilities are indicated by solid lines (i.e., NFIRAOS and the laser guide star projection facility), with later instrumentation indicated by dashes. Several options that remain TBD are color-coded. The overall architecture is intended to avoid these uncertainties in the first light AO systems, while retaining as many options as possible for the follow-on systems.

A variety of uncertainties relate to future DM technologies, including the availability, cost, and performance of MEMS, adaptive secondary mirrors, cryogenic DMs, and high stroke DMs. The first light AO system NFIRAOS avoids the first three of these options (although DMs must still be cooled), and may also avoid (if necessary) the use of a high-stroke, high-order DM through the inclusion of a high-stroke, low-order “woofer” DM. The follow-on AO modes may use some combination of the more advanced DM technologies, as well as woofer/tweeter control.

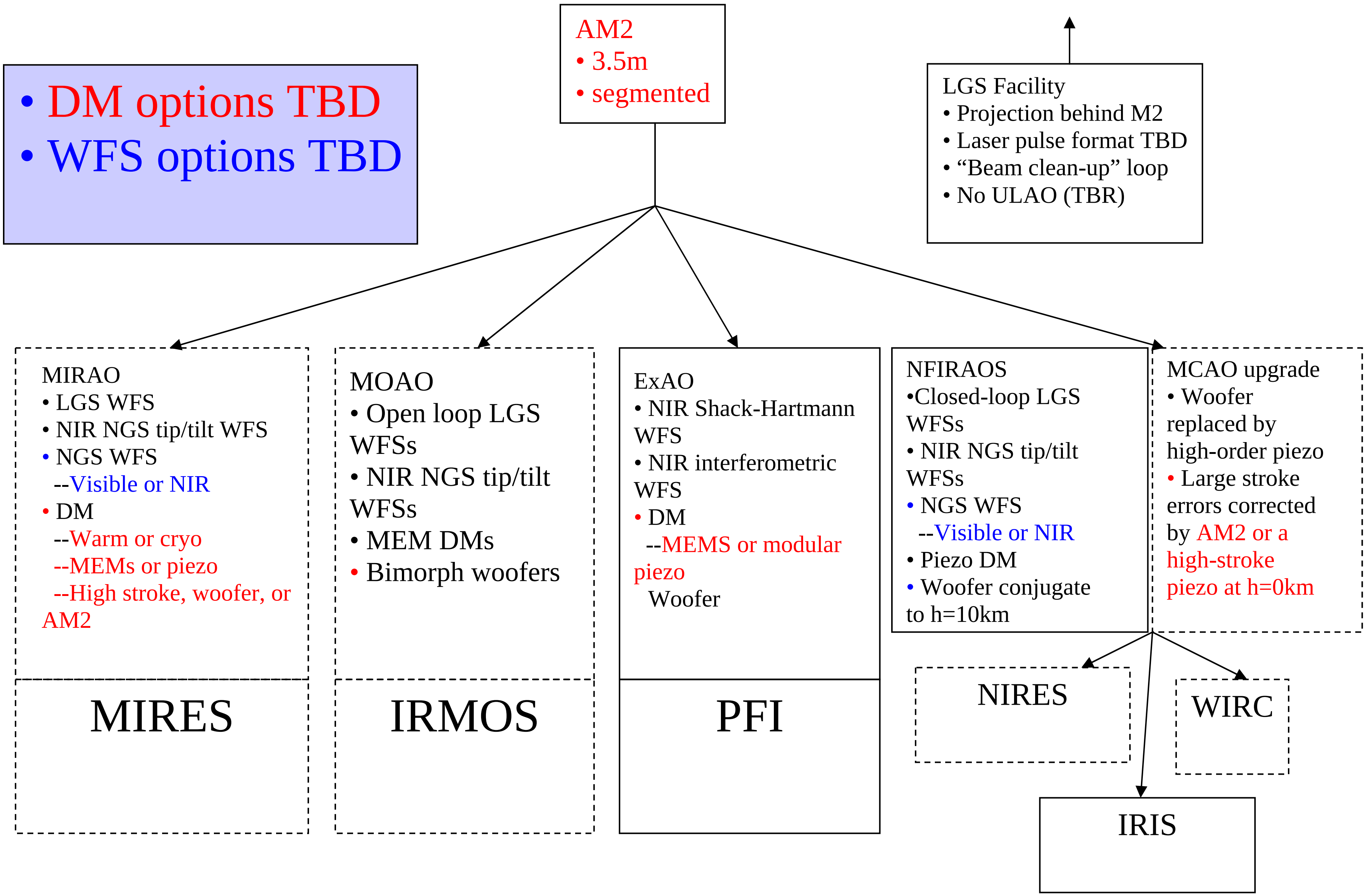


**Figure 1 AO Reference Design Architecture**

Beyond woofer/tweeter control, some additional advanced AO concepts (as opposed to components) implied by this AO architecture include:

- Atmospheric tomography, with wavefront measurements from multiple guide stars used to reconstruct the full three-dimensional atmospheric turbulence profile;
- NGS tip/tilt sensing in the infrared, where the LGS AO system "sharpens" the guide star image and improves tip/tilt measurement accuracy;
- Open-loop AO, requiring very accurate calibration of deformable mirrors and wavefront sensors;
- LGS wavefront sensing with elongated laser guide stars and/or non-uniform backgrounds induced by Rayleigh backscatter.

# 3 MAJOR INTERFACES

Table 1 on the next page is an N-squared diagram, so-called because with N subsystems there is a possibility of $N^2$ interfaces between subsystems. In a real telescope, many subsystems have no direct connection or interface with each other. This N-squared diagram indicates the major interfaces of interest here. It is meant to be read like a mileage chart on a map. An X at the intersection of a row and column indicates that some interface exists.

To better understand the $N^2$ diagram, please read it together with the signal flow diagrams presented in figures 2 and 3.

In preparing this table, we have to consider which of the following apply when choosing to place an X:

- Mechanical
  - Mounting face, space envelope, rotation, coordinate systems, handling
- Optical
  - Prescription, pupil, focal planes, atmospheric dispersion compensation
  - Calibration – flat fields, darks, wavelength
- Utilities
  - Power, cooling
  - Communications
  - Interlocks
- Software
  - Data flow to controls, displays, archives
- Environmental
  - Temperature
  - Heat Load

| **Telescope** | Nasmyth Platforms | Optics | M2/AM2 Control | M1 Control | Tel. Ctl. Sys | Obs. Control Sys. | Utilities | Data Handling System | **Instruments** | IRIS | NIRES | WIRC | PFI | MIRAO/MIRES | MOAO/IRMOS | GLAO/WFOS | HROS | **Adaptive Optics** | NFIRAOS | MCAO | LGS facility |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Telescope** | | | | | | | | | | | | | | | | | | | | | |
| Optics | x | | | | | | | | | | | | | | | | | | | | |
| M2/AM2 Control | | x | | | | | | | | | | | | | | | | | | | |
| M1 Control | x | x | | | | | | | | | | | | | | | | | | | |
| Tel. Ctl. Sys | | x | x | x | | | | | | | | | | | | | | | | | |
| Obs. Control Sys. | | x | x | | x | | | | | | | | | | | | | | | | |
| Utilities | x | x | x | | x | x | | | | | | | | | | | | | | | |
| Data Handling System | | | | x | x | x | | | | | | | | | | | | | | | |
| **Instruments** | | | | | | | | | | | | | | | | | | | | | |
| IRIS | x | | | | x | x | x | x | | | | | | | | | | | | | |
| NIRES | x | | | | x | x | x | x | | | | | | | | | | | | | |
| WIRC | x | | | | x | x | x | x | | | | | | | | | | | | | |
| PFI | x | x | x | | x | x | x | x | | | | | | | | | | | | | |
| MIRAO/MIRES | x | x | x | | x | x | x | x | | | | | | | | | | | | | |
| MOAO/IRMOS | x | x | x | | x | x | x | x | | | | | | | | | | | | | |
| GLAO/WFOS | x | x | x | | x | x | x | x | | | | | | | | | | | | | |
| HROS | x | x | x | | x | x | x | x | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| **Adaptive Optics** | | | | | | | | | | | | | | | | | | | | | |
| NFIRAOS | x | x | x | | x | x | x | x | | x | x | | | | | | | | | | |
| MCAO | x | x | x | | x | x | x | x | | x | x | x | | | | | | | | | |
| LGS Facility | | | | | | x | x | x | | | | | | | | | | | | | |
| (Tomography) | x | | | | x | | x | x | | | | | | x | x | x | | | x | x | x |

**Table 1 N² Diagram – Interfaces between Instruments, Adaptive Optics and TMT telescope**

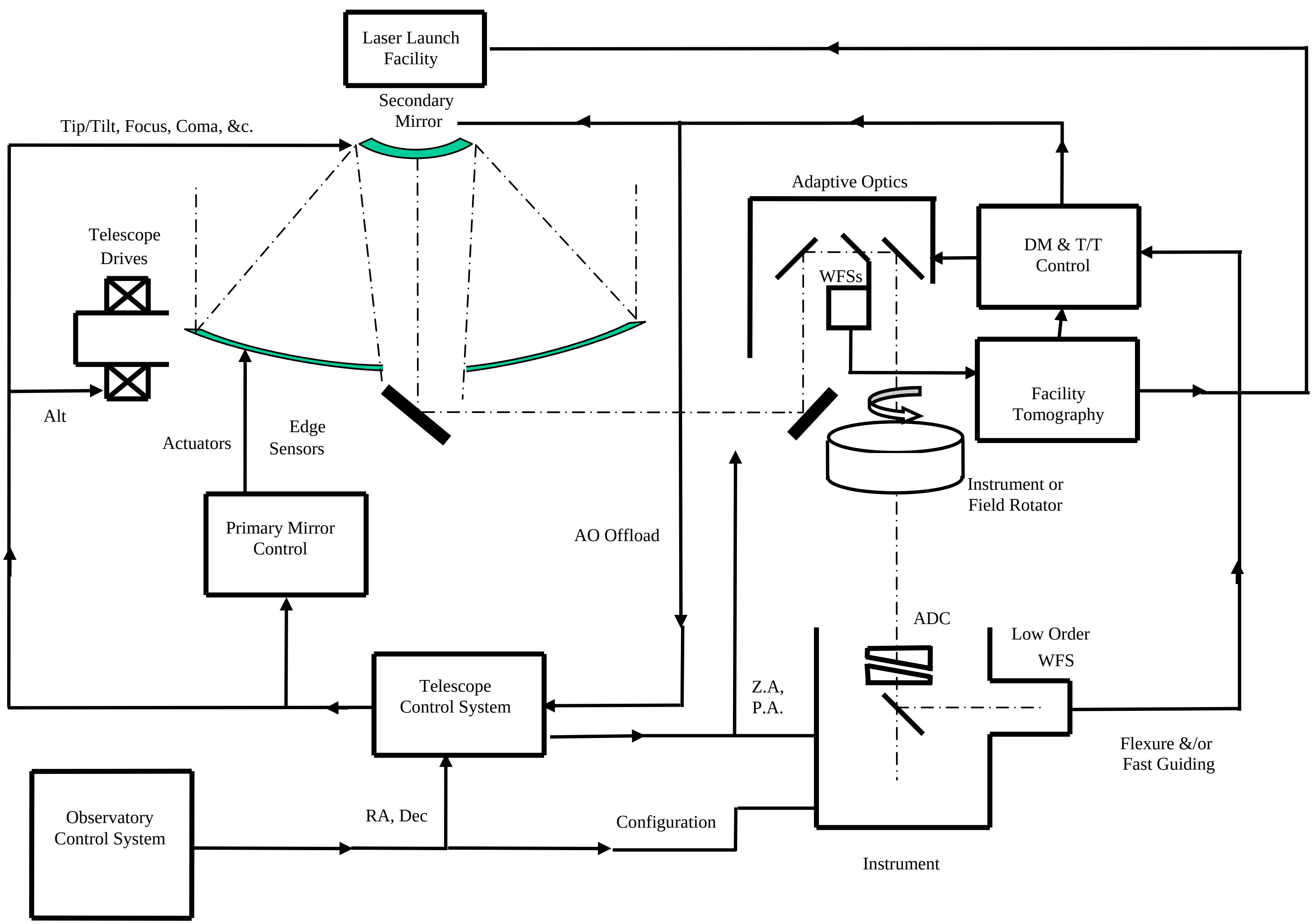


**Figure 2 Signal Interfaces to Adaptive Optics**

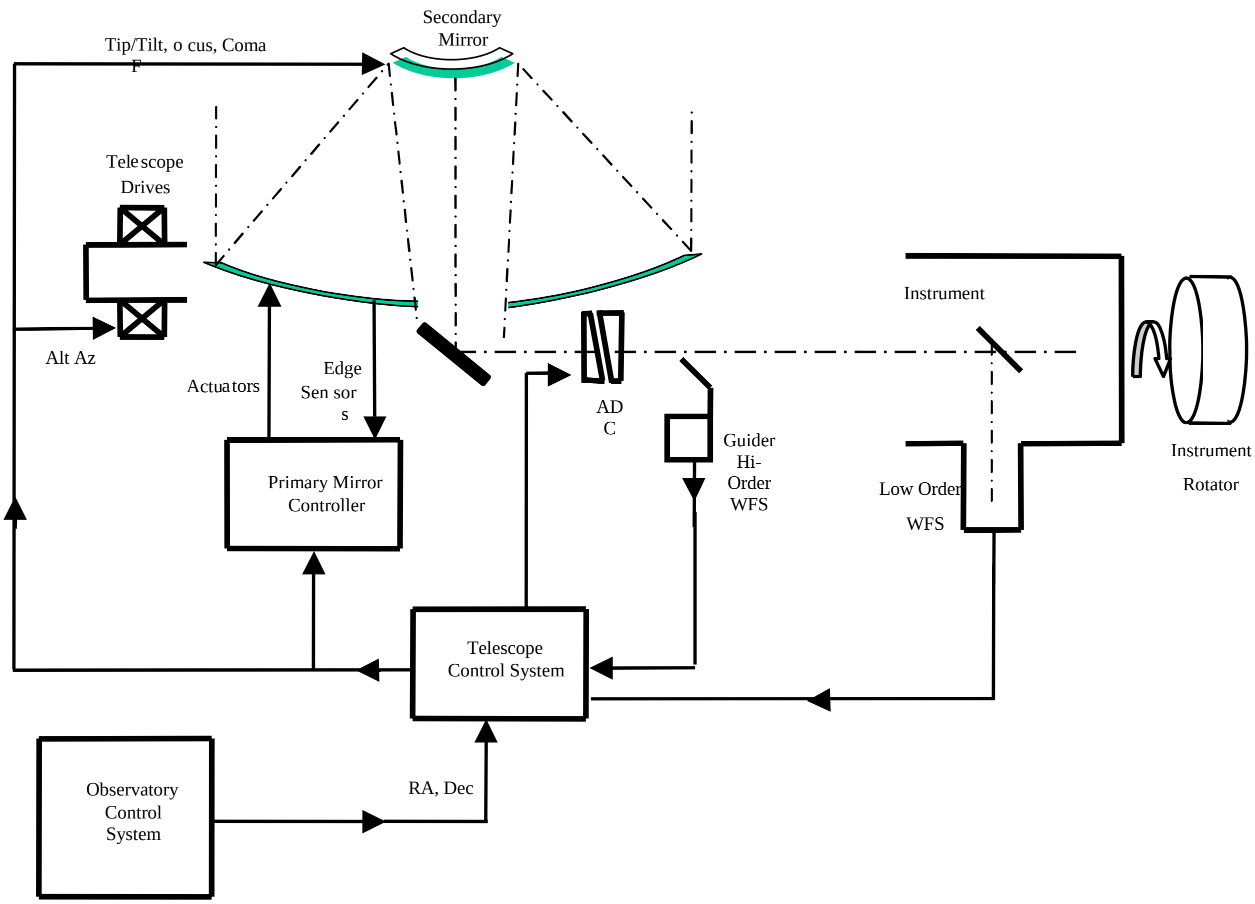


**Figure 3 Fast Guiding Natural Seeing Instruments**

## 3.1 Control Signal interfaces

Figures 2 and 3 show the major data flow paths within the observatory with and without adaptive optics in use. The purpose and type of data along with some indication of rate is described for each specific interface below.

As discussed in section 3.2.2, the option for a facility tomography system is under continued study.

Note that Figure 2 does not apply to PFI if it is self-contained with its own AO system. In that case, the facility tomography system is not used, and PFI's real time computer takes in pixel data from its own WFS and drives its own DM. The connection to offload persistent aberrations to the telescope is still used by PFI.

## 3.2 Interfaces identified in $N^2$ Diagram

Since the $N^2$ diagram is broadest at the bottom, and has the most relevant AO interfaces there, this section 3.2 describes table 1, row by row, starting at the bottom. For each X (or group of highly related Xs) there is a summary of the interfaces.

### 3.2.1 Tomography / Laser Launch

- Services
  - High Speed Data communications

- Data
  - Tip/Tilt steering error signals to laser launch system to keep 7-9 artificial guide stars centered on the laser wavefront sensors within AO systems.
    - Bandwidth high
    - Range: a few arcseconds (depends on telescope windshake)
  - Asterism rotation error signal to keep pattern of artificial stars at constant rotation as seen from LGS WFSs. The Alt/Az/Tertiary telescope will cause the field of view seen by a fixed array of LGS WFS to rotate. A least squares fit of the best rotation correction to all of the LGS tip/tilt errors will be sent to the launch system. Low bandwidth.

### 3.2.2 Tomography / AO systems

Applicable to all AO systems with laser guide star WFS:

- GLAO/WFOS
- MOAO/IRMOS
- NFIRAOS/MCAO
- MIRAO/MIRES

It is still to be determined, but one strong possibility is that the real time computing for AO systems will be split into two:

1. a facility tomography system (one for the entire TMT)
2. a specialized DM and Tip/Tilt controller, possibly unique for each instrument

**Data from tomography to AO DMs controller**
The data flow between these two components is a 3D representation of the atmospheric turbulence in front of the telescope, held in a large array of numbers. The AO DM controller is responsible for projecting onto various DMs and implementing a servo controller for each. (Under review - see below)

**Data from AO wavefront sensors to tomography**

- Data
  - WFS Pixels at a 0.5 to 2.5 kHz frame rate from 7-9 LGS WFS and 3-4 NGS T/T stars. Both types of data are needed to resolve quadratic modes in the atmosphere. The number of WFS pixels per wavefront sensor is likely to be in the range from 100 to 800k.

The existence of facility tomography, and indeed the boundary between it and the DM controller is still under study. Perhaps more of the DM projection process will reside in the tomography unit. Other possibilities include making all instruments self-contained, or providing a standardized tomograph processor as a component for each AO system.

In the event that an AO system does not use the facility Tomography system, then these two interfaces in section 3.2.2 become internal interfaces within the AO system, and are the responsibility of the instrument builders.

During the feasibility studies for instruments, teams should comment on the practicality of a facility tomography system for their particular application.

### 3.2.3 Tomography / Observatory Control System

The observatory control system (OCS) is responsible for sequencing the observations, by coordinating the telescope and the instruments. At the beginning of an observation, setup information flows from the OCS to the Tomography system:

- Which instrument to select WFS data from
- Configuration of guide stars and elevation angle

### 3.2.4 Tomography / Telescope Control System

During an observation, the shadow of the secondary mirror support vanes rotates on DMs and WFSs as a function of the Altitude axis and tertiary mirror axes. The TCS reports this pupil rotation to the Tomography system, so that it can drop and add subapertures from the atmospheric reconstruction as these become available.

Based on 10% vignetting change allowed at an outer subaperture of a 100x100 WFS before it crosses a threshold and becomes unusable, this pupil rotation measurement must be updated often enough that it is accurate to one part in 500 of a radian.

### 3.2.5 Tomography / Nasmyth Platform

- Space Envelope available
  - TBD Mount above NFIROAS, or provide space on Nasmyth platform

### 3.2.6 Laser Facility / Utilities

- Utilities
    - Power
    - Cooling
    - Communications

### 3.2.7 Laser Facility / Observatory Control System

At the beginning of an observation, setup information flows from the OCS to the laser launch system:

- Configuration of guide stars. The geometry of the asterism, tailored to the specific instrument or AO system, together with the initial rotation of the asterism.

### 3.2.8 NFIRAOS (or MCAO) / IRIS

See references 4 & 5 for more details.

**Optics:**

Entrance window is part of IRIS. Clear porthole at exit of NFIRAOS, blocked by a purged and insulated cover from inside NFIRAOS during instrument mounting.

F/15 beam, with entrance window 1.05 m beyond focus. However, we expect instrument developers to comment on this, and at the same time, the NFIRAOS conceptual design team will be asked to study the tradeoffs with other designs that may minimize the focal distance, possibly at the expense of more reflections or fewer output ports.

Field of view, circular, 10 arcseconds diameter.

Field rotation by K-mirror within NFIRAOS

Atmospheric Dispersion compensation, if needed will be inside IRIS

**Data Flow:**
A low bandwidth tip/tilt/focus sensor tracking a natural guide star, within IRIS, sends T/T/F data to NFIRAOS which will treat this signal as the truth reference, and compensate for thermal expansion.

**Mechanics**
Mounting face

Sealing exit port on NFIRAOS during mounting of instruments
Temperature of interior of NFIRAOS will be –35 C.

Orientation: Horizontal

Space Envelope

Access clearance

There are several open issues surrounding the IRIS-NFIRAOS interface, including the location of the opto-mechanical interface, precision, flexure compensation, a possible WFS within IRIS, calibration, etc.

### 3.2.9 NFIRAOS (or MCAO) / NIRES

See references 4 & 5 for more details.

Similar to NFIRAOS/IRIS interfaces

### 3.2.10 NFIRAOS (or MCAO) / WIRC

See references 4 & 5 for more details.

Similar to NFIRAOS/IRIS interfaces, except:

Downward looking, vertical optical axis, resting on a rotator bearing, which is part of NFIRAOS. Interface is mounting surface on top of bearing.

Cable wrap is responsibility of WIRC

Field of view 30 arcseconds.

### 3.2.11 NFIRAOS (MCAO) / Utilities

Perhaps as much as 20 kW for DM driver electronics electrical consumption, and equivalent cooling required to remain with specification in section 4.5

Cooling of the interior to –35 C may require power and refrigeration with a liquid-to-air heat exchanger within NFIRAOS.

Cryogens for cooling the Near-Infrared natural guide star wavefront sensors.

### 3.2.12 NFIRAOS (MCAO) / Observatory Control System

At the start of an observation with a new observing mode, the OCS sets up NFIRAOS with configuration commands. For example, of the output instrument will be selected via the perforated mirror and output steering mirrors.

The configuration of the integration time of the NGS WFS will be based on the stars' brightness and location in the field of view. The OCS will report expected magnitude in one of JHK bands for each guide star.

### 3.2.13 NFIRAOS (MCAO) / Optics

The telescope f/15 beam and location as per the reference design. 1.8 m clearance between the nominal edge of a 30 m primary mirror and the entrance window for NFIRAOS.

### 3.2.14 NFIRAOS (MCAO) / Nasmyth Platform

Footprint on Nasmyth platform as per reference 5.

### 3.2.15 Instruments & AO / Data Handling System

- **Services**
  - High Speed Data communications
- **Data**
  - Astronomical Images
  - Engineering and diagnostic data

The data handling system accepts and stores both images and spectra as well as time series and snapshot engineering data. Examples might be temperature monitoring or telemetry data from Adaptive optics systems.

Diagnostic images from the "Truth WFS" within NFIRAOS are stored on the DHS for calibrating the telescope primary mirror control system. See section 3.2.21.

### 3.2.16 Tomography / Data Handling System

Telemetry data will be passed to the data handling system for storage, analysis and display as described in the previous section.

### 3.2.17 LGS Facility / Data handling System

Diagnostic Data will be sent to the data handling system for storage, analysis and display. See section 3.2.15

### 3.2.18 Instruments / Utilities

Applicable to all instruments and AO systems:

- GLAO/WFOS
- MOAO/IRMOS

- NFIRAOS/MCAO
- MIRAO/MIRES
- IRIS
- NIRES
- WIRC
- PFI

See section 4.3

### 3.2.19 Instruments / Observatory Control System

Applicable to all instruments and AO systems:

- GLAO/WFOS
- MOAO/IRMOS
- NFIRAOS/MCAO
- MIRAO/MIRES
- IRIS
- NIRES
- WIRC
- PFI

Configuration commands for filters, gratings, etc. delivered at start of observation.

### 3.2.20 Instruments / Telescope Control System

Applicable to all instruments and AO systems:

- GLAO/WFOS
- MOAO/IRMOS
- NFIRAOS/MCAO
- MIRAO/MIRES
- IRIS
- NIRES
- WIRC
- PFI

Since the TCS takes in Right Ascension and Declination from the observatory control system and adjusts the drives in Altitude, Azimuth together with the articulation of the tertiary mirror, it is responsible for the pointing of the telescope. It also communicates the results of these real time pointing models to control:

**Data from TCS to Instrument/AO**

- instrument (image) rotators
- NGS WFS probe stages ( especially during Dithering and nodding)
- LGS WFS focus range set via zenith angle
- ADC rotation set via paralactic angle and zenith angle.

**Data from AO to TCS**

- Communication
  - High Speed Data communications
- Data:
  - AO offload – Persistent aberrations (on timescales of tens of milliseconds to seconds) corrected by the AO system will be reported to the TCS which will report them to the Primary mirror controller, the drives, and the secondary mirror control system as appropriate.

For the first-light rigid-body secondary mirror, tip/tilt/focus errors will reposition the secondary at a few Hz closed loop bandwidth. Persistent coma will cause lateral translation of the secondary mirror.

For an adaptive secondary, a greater number of modes (possibly 300-800) at much higher update rate (possibly 100-200 Hz) will be sent to the secondary mirror. The interface should support this upgrade.

Note that this latter data, and/or the tip/tilt/focus data may be broadcast to both the TCS and the secondary mirror control system, on some form of high-speed bus to avoid the middleman of the TCS. This path is shown as a branch leading directly to the secondary mirror in Figure 2.

### 3.2.21 NFIRAOS / Primary Mirror Control

The "Truth WFS" within NFIRAOS shall act as an off-line phasing camera to calibrate the zero points of the edge sensors in the primary mirror control system.

There is no direct connection between the two. The interface for this calibration shall be via the data handling system. NFIRAOS will take an image and deposit it in the DHS for the M1 calibration procedure to use. The command to take this data will arrive on the control interface used by the observatory control system to set up NFIRAOS.

### 3.2.22 Primary Mirror Control / Data Handling System

As described in the previous section, calibration of the primary mirror control system is done with WFS images passed from NFIRAOS via the DHS.

### 3.2.23 Data Handling System / Telescope Control System

The DHS will store diagnostic data from the telescope control system, for example to help calibrate telescope pointing models.

### 3.2.24 Data Handling System / Observatory Control System

The Observatory control system will set up and instruct instruments and AO systems to deposit data into the DHS, with astronomical data associated with appropriate AO telemetry data. The intent of linking this telemetry with astronomical images and spectra is to provide point-spread function estimates, and astrometric image distortion models for each observation.

# 4 GENERAL INTERFACE SPECIFICATIONS

## 4.1 Mechanics

Mounting face

- Sealing exit port during mounting of instruments
- Temperature of interior of NFIRAOS

Orientation

Space Envelope

Access clearance

Handling – feet, clevises

## 4.2 Optics

Location of input beam

Field Rotation

## 4.3 Utilities

Communications
Time
Power
Cooling
pumping, cooling/heating/compression, and distribution for the following subsystems

- Electronics cooling - glycol at or near ambient temperature
- hydraulic oil for hydraulic pads
- ambient air - circulation for dome ventilation
- ambient air-heating for support building
- ambient air – compression for dome and support building
- cryogens instruments / AO systems
- oxygen for the control room (if selected)

Archive

## 4.4 Software

Development standards
Communications protocols

## 4.5 Environment

Shipping

Operating to Spec

Vibration power spectrum XYZ
Temperature range, slew rate

Functional

Seismic

**Heat Load in Enclosure**

Under lightly ventilated conditions, (air speed a few m per second), resulting in a forced convective heat transfer coefficient h= 1 W/(m^2 . K), and constant air temperature, instrument surfaces shall remain within 1 Kelvin of ambient temperature.
I.e., assuming 1 Kelvin temperature difference between cabinet surfaces and the air, the heat load shall be less than +/- 1 W/m^2.
Provenance: while delta T of 1 Kelvin at the primary mirror would completely dominate the telescope budget under these conditions, instruments are not directly in the beam, and have a more generous allowance.