# Telescope Project Development Seminar

## Session 5a: Science Instruments & Adaptive Optics
## Session 5b: Lessons Learned & Discussion

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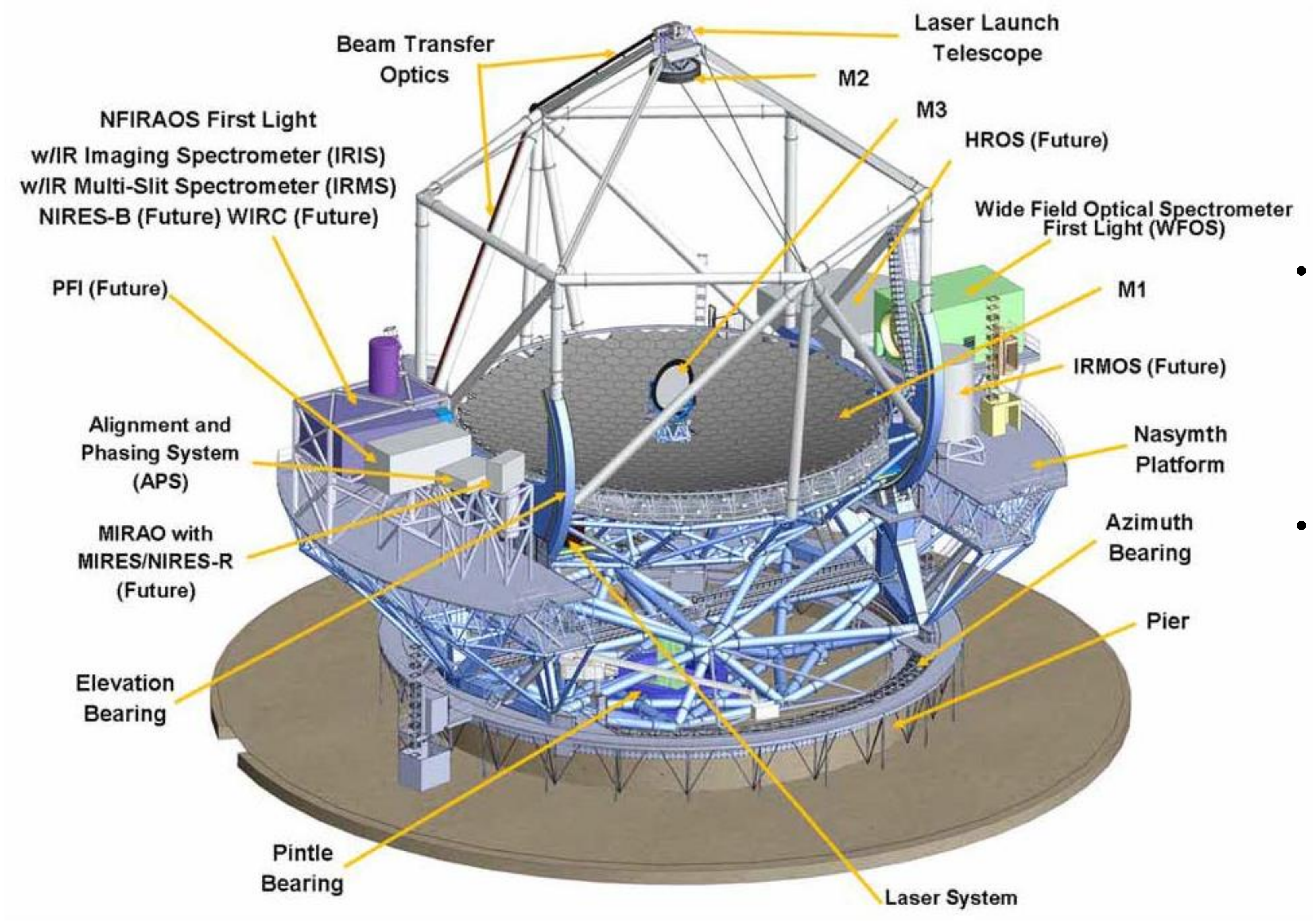
# Session Outline



- Science Instruments
- Adaptive Optics Overview (GMT perspective)
- Lessons Learned

# TMT Instrument & AO Systems Mounting



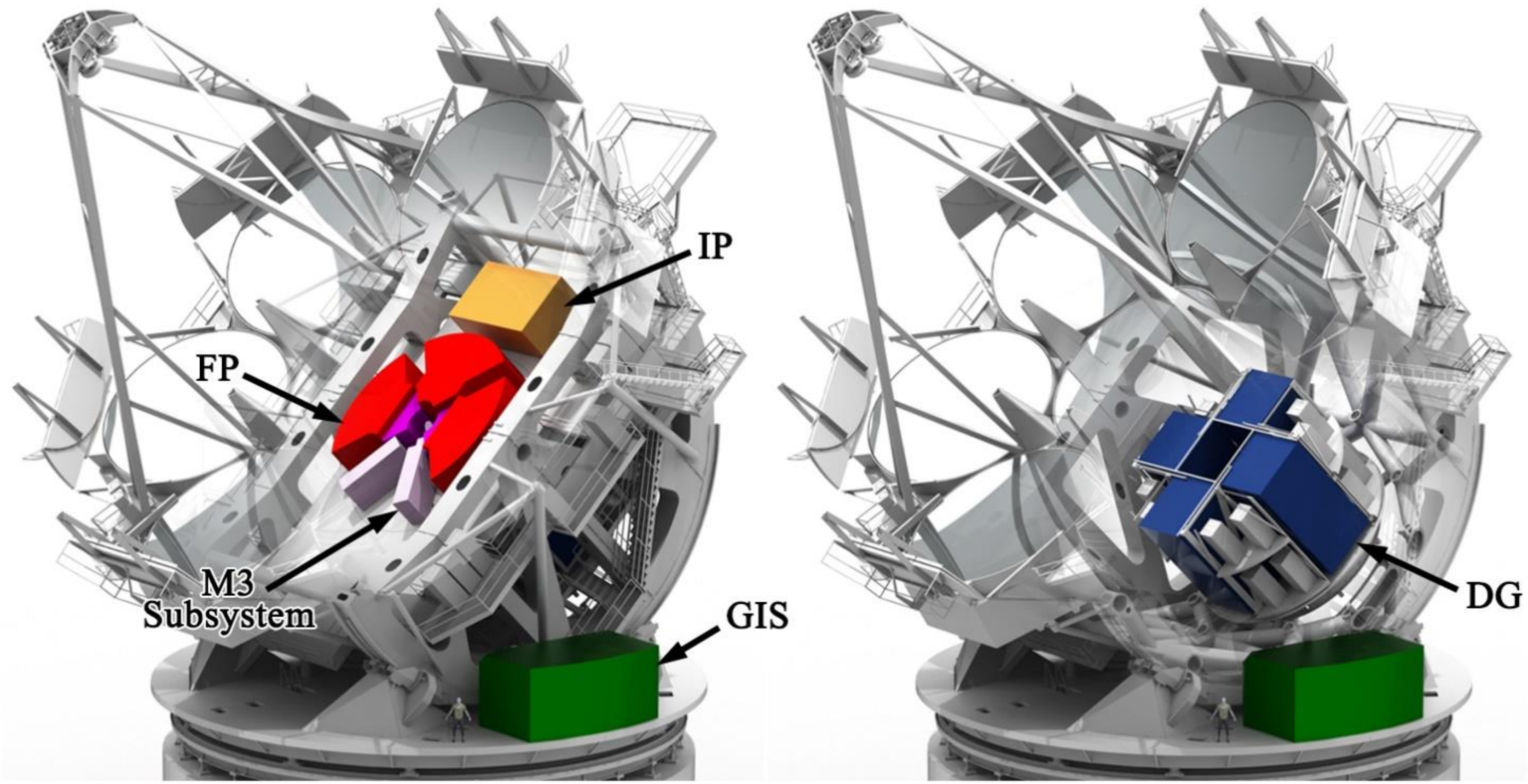



- Instruments are mounted on a gravity invariant Nasmyth platform that enables service access with the telescope at off-zenith elevation angles.
- Tertiary mirror directs the beam to instruments.

# GMT Science Instrument Locations



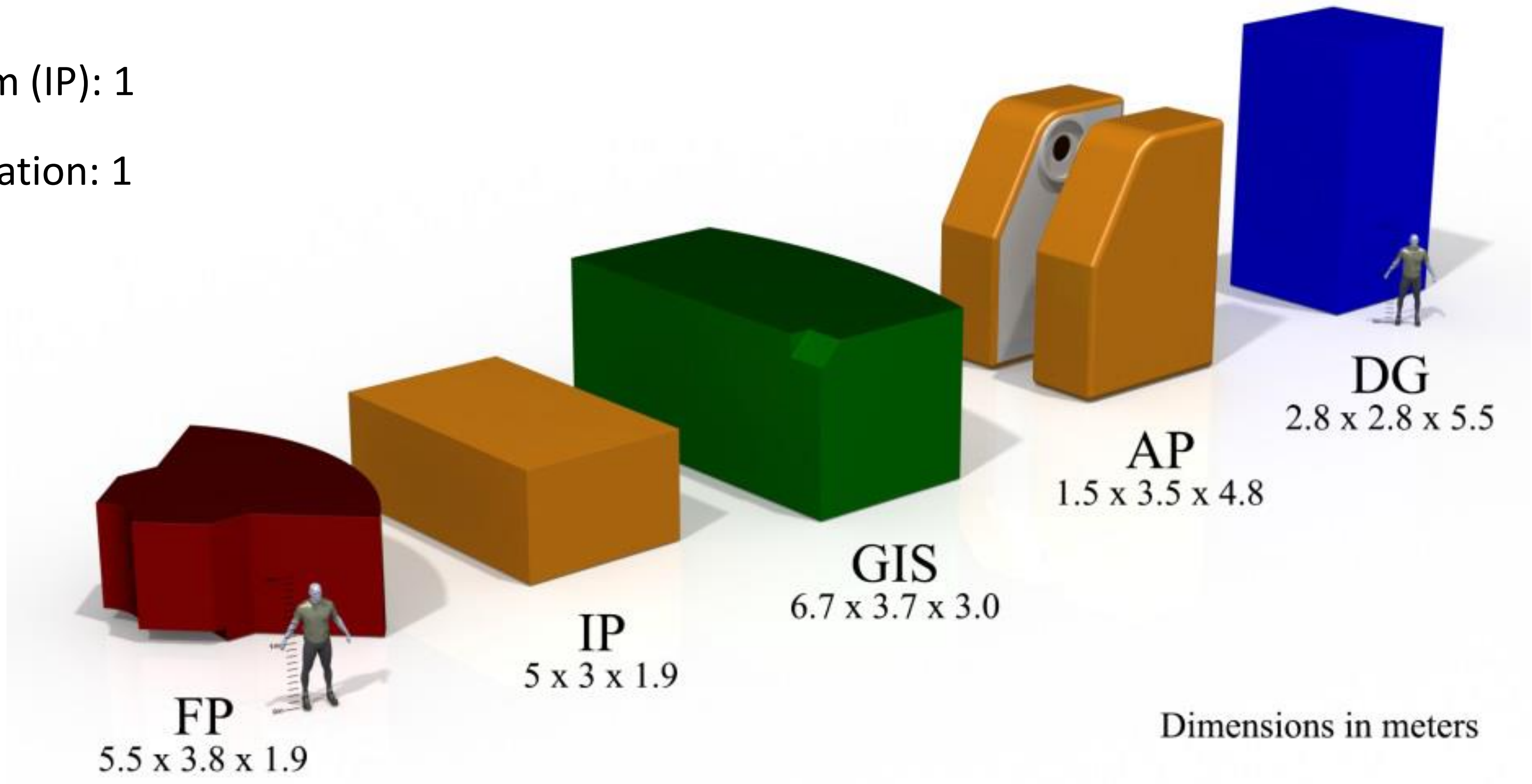
- Science instruments mount within the body of the OSS
- Field de-rotation for FP and DG stations
- Gravity invariant mounting location on azimuth structure
- Provisions for instrument handling



# Maximum Size GMT Instruments



- The maximum number of instruments:
  - Folded Port: 3
  - Instrument Platform (IP): 1
  - Gravity Invariant Station: 1
  - Auxiliary Ports: 2
  - Direct Gregorian: 4



# Development Process



- Science instruments are usually developed by teams separate from the telescope team.
- This is particularly true for general purpose facilities like the new generation ELTs.
- Instrument requirements are determined by the Project from the flow down of science requirements.
- The Project also manages instrument interface requirements based on the system architecture and other systems engineering procedures that apply to instrument development.
- The policies for funding instruments and conditions for their acceptance and use at the observatory are established by the governing Board.  This includes:
    - Granting of time for assembly and commissioning on the telescope.
    - Observer access (instrument team time, facility instrument, PI instrument, etc.)
    - Maintenance and servicing
    - Software support.
    - Instrument lifetime

# GMT Generation 1 Instrument Candidates



| Instrument | Function | λ Range, µm | Resolution | Field of View |
|---|---|---|---|---|
| G-CLEF | Optical High Resolution Spectrometer / PRV | 0.35 – 0.95 | 20 – 100 k | 7 x 1″ fibers |
| GMACS | Optical Multi-Object Spectrometer | 0.36 – 1.0 | 1500 – 4000, 10,000 | 40 – 80 $arcmin^2$ |
| GMTIFS | NIR AO-fed IFU / Imager | 0.9 – 2.5 | 4000 – 10,000 | 10 / 400 $arcsec^2$ |
| GMTNIRS | JHKLM AO-fed High Resolution Spectrometer | 1.2 – 5.0 | 50 – 100 k | Single Object |
| NIRMOS | Near-IR Multi-Object Spectrometer | 0.9 – 2.5 | 2700 – 5000 | 42 $arcmin^2$ |
| TIGER | Mid-IR AO-fed Imager and Spectrometer | 1.5 – 14 | 300 | 0.25 $arcmin^2$ |
| MANIFEST* | Facility Robotic Fiber Feed | 0.36 – 1.0 | | 300 $arcmin^2$ |

# GMT Instrument Modes & Deployment

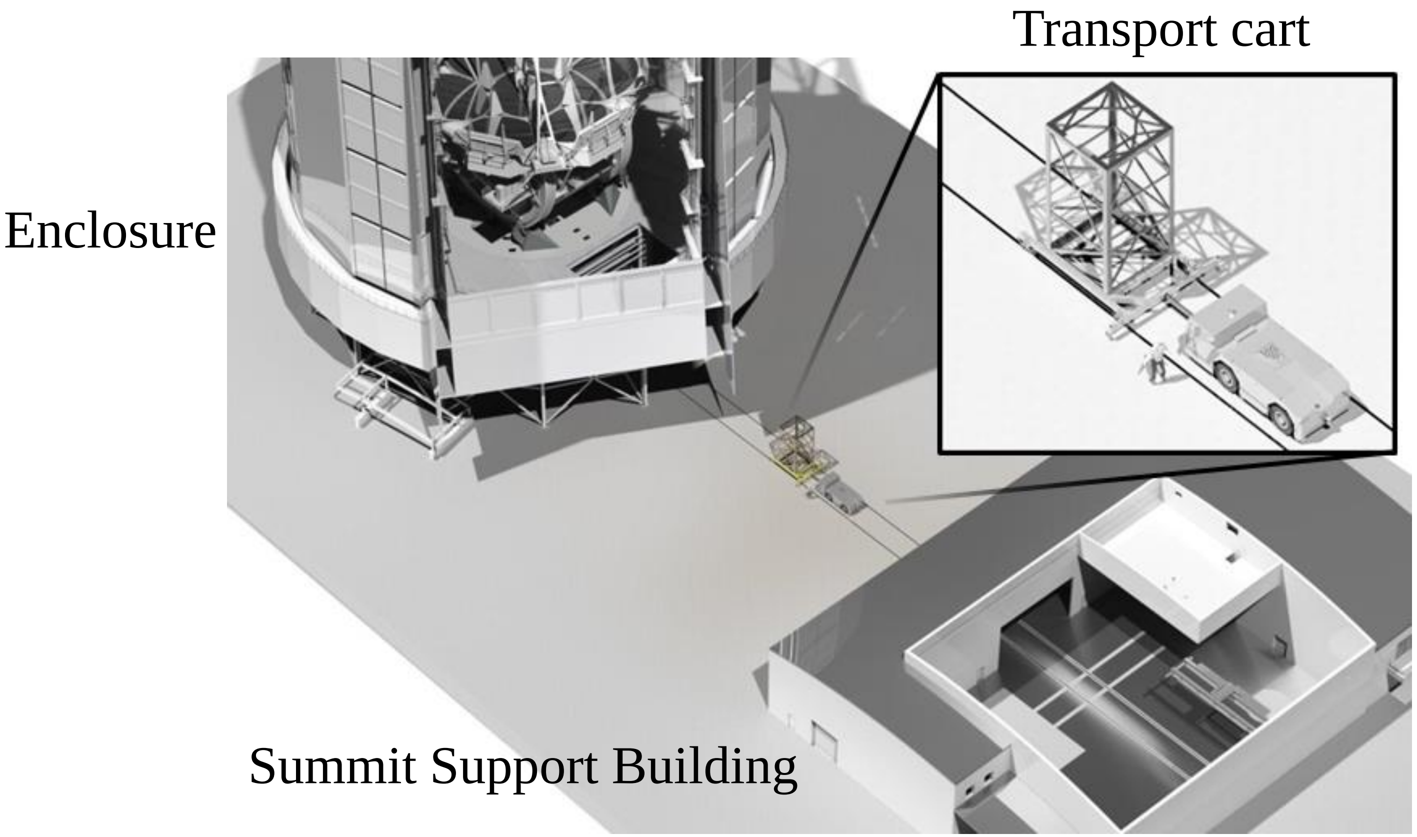


| Stage | GMT | Mode | Location on GMT |
|---|---|---|---|
| 1 | G-CLEF | Natural seeing, GLAO | Gravity Invariant Station |
| 1 | GMACS | Natural seeing, GLAO | Direct Gregorian |
| 2 | GMTIFS | LTAO/NGSAO | Folded Port |
| 3 | GMTNIRS | NGSAO | Folded Port |
| Future | NIRMOS | Natural seeing/GLAO | Direct Gregorian |
| Future | TIGER | AO (internal wfs) | Direct Gregorian * |
| 3 | MANIFEST | Natural seeing/GLAO | Direct Gregorian * |

* Possibe shared port.

Instruments will be developed and deployed in 3 stages with possible future instruments identified.

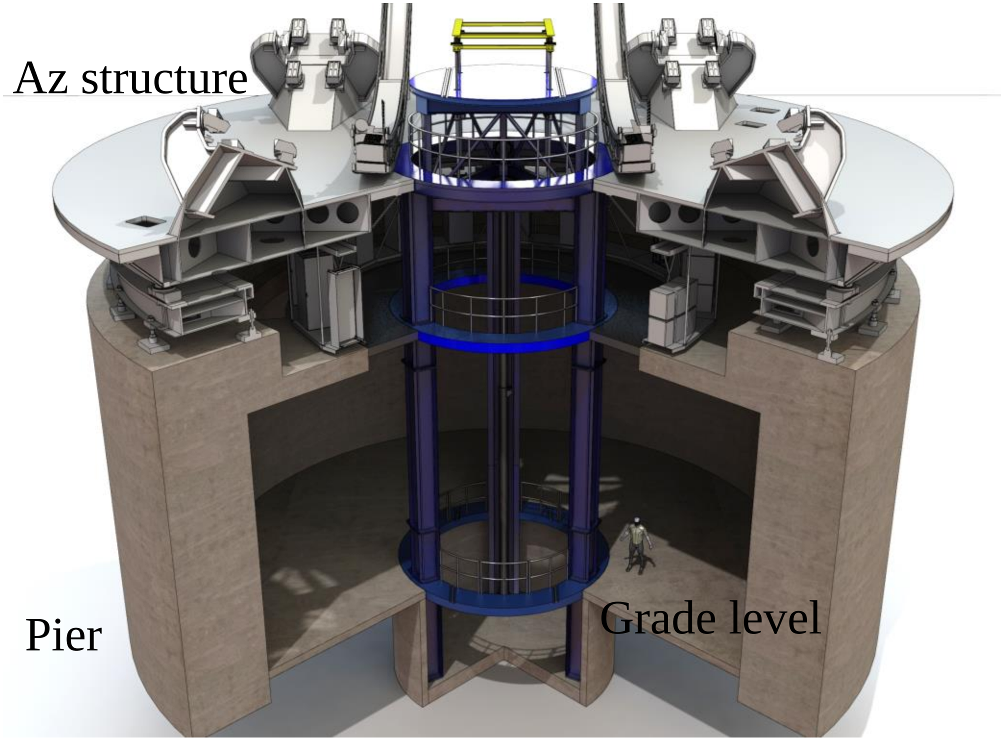
# Instrument Transfer

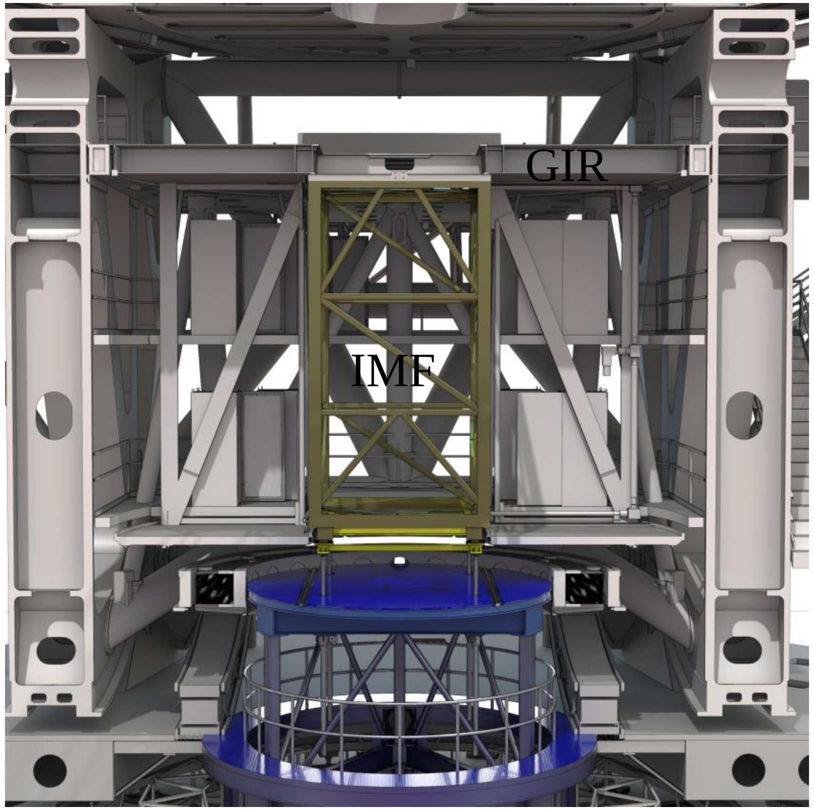



- Bridge crane in Auxiliary Building loads instruments on carts
- Instruments are transported on rails to the enclosure
- Enclosure crane or pier lift inserts instruments in telescope

# Installing DG Instruments



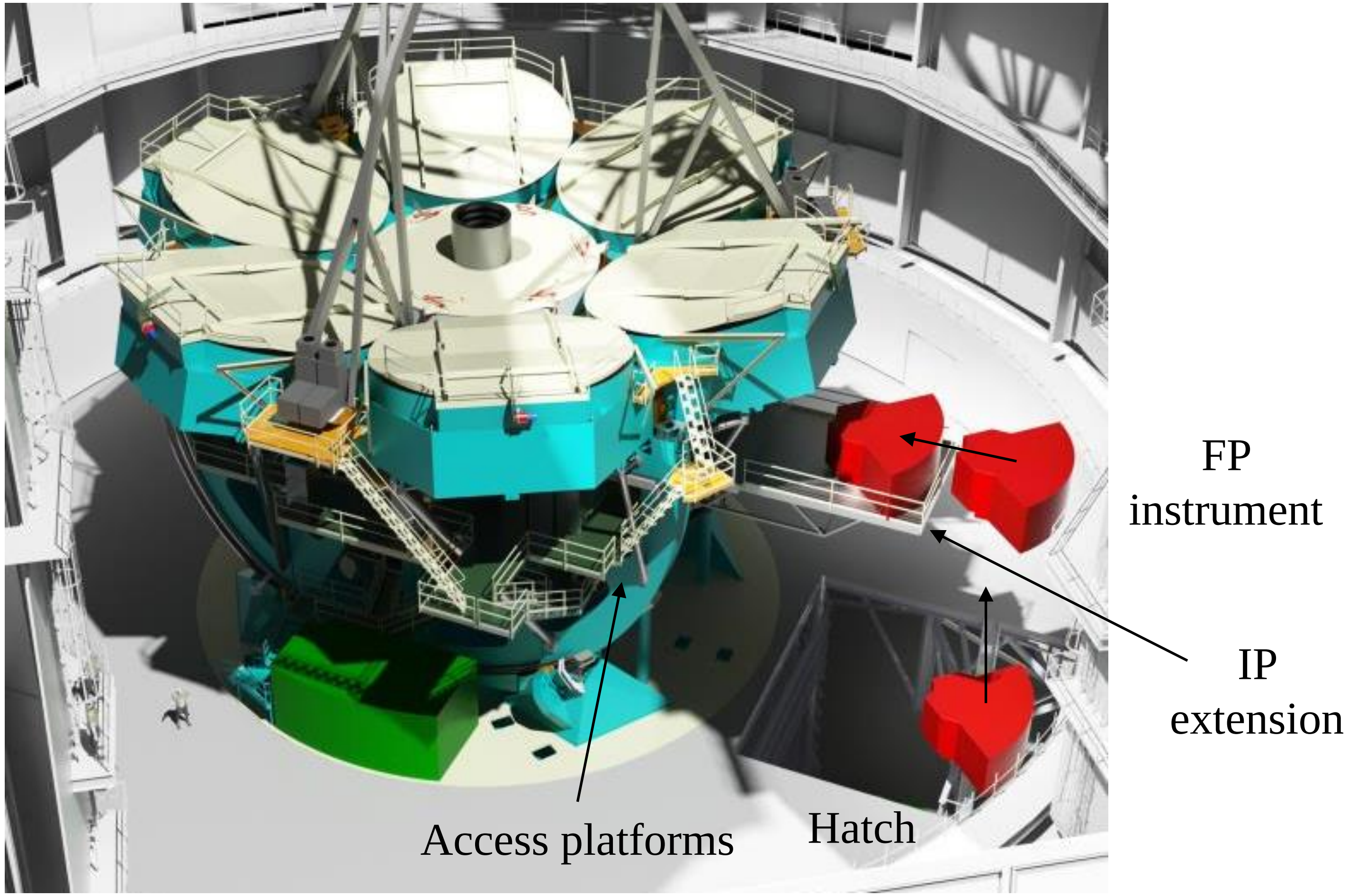



- DG instruments are raised with a lift and inserted into the GIR from below.
- Platforms in the OSS provide service access to installed instruments

# FP Instrument Exchange

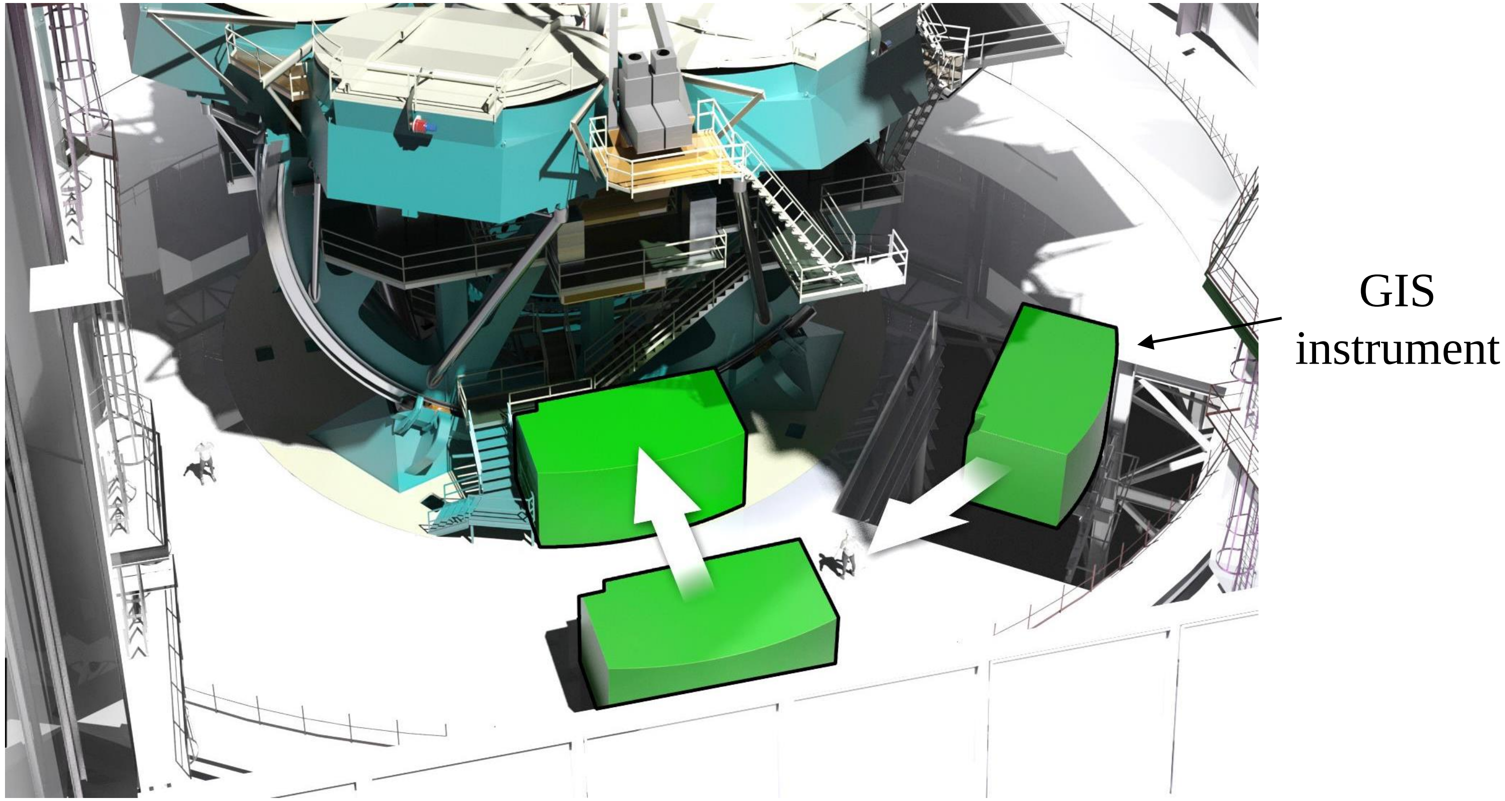





- Enclosure crane lifts FP instruments through the observing floor hatch and sets them on the IP extension.
- Instruments are rolled onto the GIR with guides.

# GIS Handling



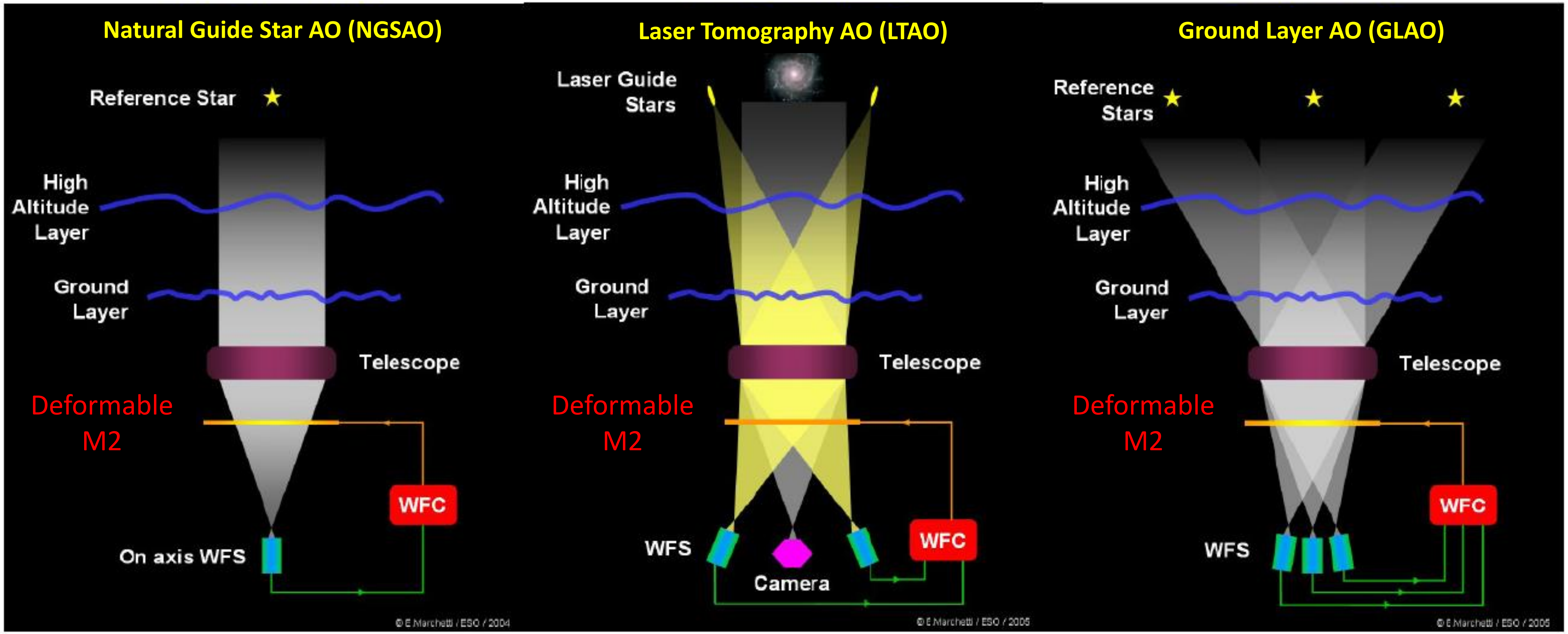



- GIS instruments are lifted through the observing floor hatch with the overhead crane and set on the observing floor.
- They are then moved into place on temporary rails/cribbing or fork lift.

# Adaptive Optics

# GMT Adaptive Optics Modes






- Adaptive optics are required in order to achieve the diffraction limit of an ELT.
- Adaptive optics techniques have been developed on the current generation of large telescopes but a scale-up of the hardware and algorithms including subaperture phasing will be required for ELTs.

# GMT Observing Modes



The GMT is designed to operate in a variety of observing modes over a wavelength range starting at the atmospheric cut-off around 320 nm in the UV and extending up to 25 µm in the IR.

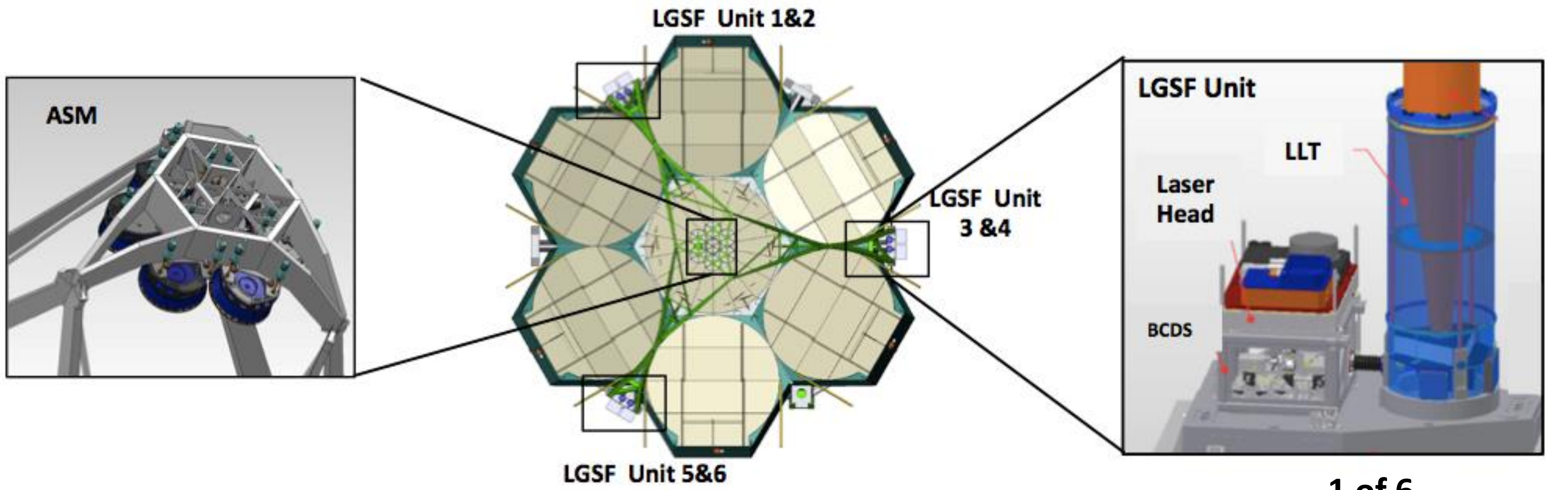
Five observing modes are supported:

| Mode | Features | FOV (arc-min) | Wavelength (microns) | Image size |
|---|---|---|---|---|
| Narrow-field (NF) Natural Seeing | • Non-AO mode<br>• No corrector | 7 | 0.32 – 25 | Atmospheric seeing |
| Wide-field (WF) Natural Seeing | • Non-AO mode<br>• Uses the WF corrector at direct Gregorian | 20 | 0.37 – 1.0 | Atmospheric seeing<br>WFC/ADC optical design |
| Ground Layer AO (GLAO) | • All focal stations<br>• Natural guide stars | $\geq$ 10 | Optical to K-band | Ground-layer correction<br>~10-30% FWHM reduction |
| Natural Guide Star AO (NGSAO) | • Folded instrument ports<br>• Bright on-axis guide star | limited by natural anisoplanatism | NIR/IR | High Strehl (>75% K band) |
| Laser Tomography AO (LTAO) | • Multi-laser guide stars<br>• Tip/tilt focus ref. star | limited by natural anisoplanatism | IR | Strehl ratio (>30% H band) |

AO modes proposed for other telescopes include Multi-conjugate AO (MCAO) and Multi-object AO (MOAO).

# GMT AO System Architecture



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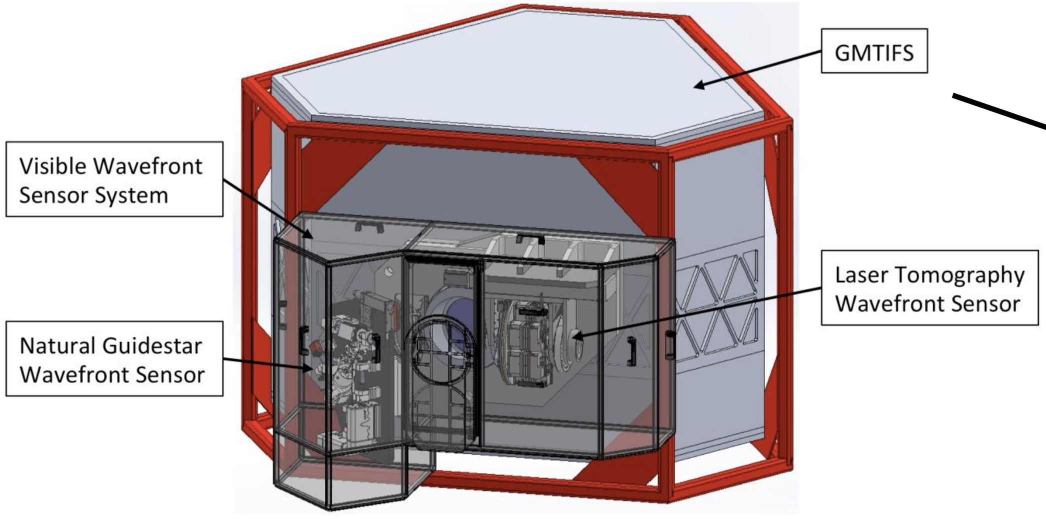
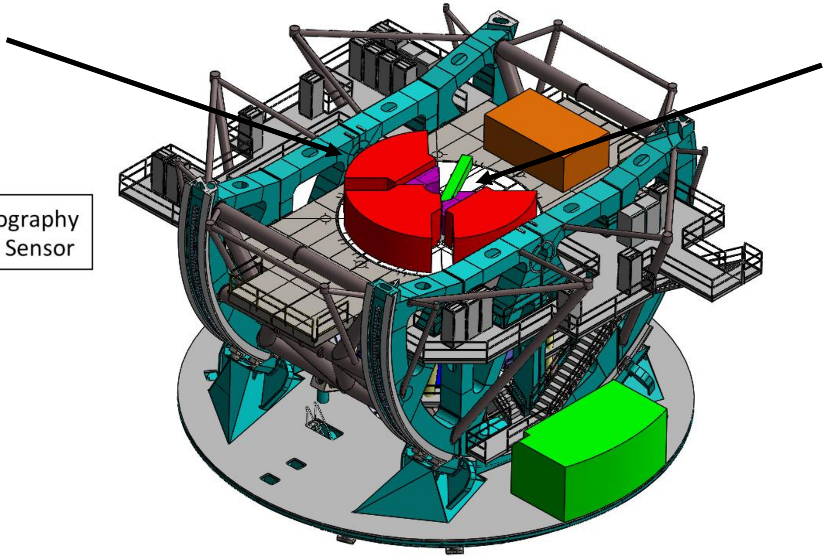
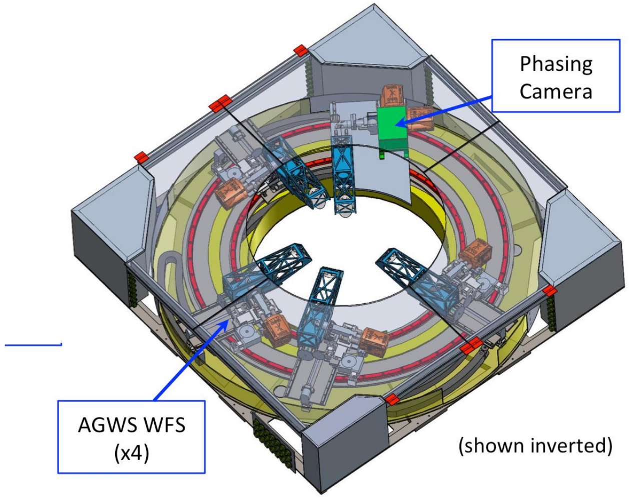


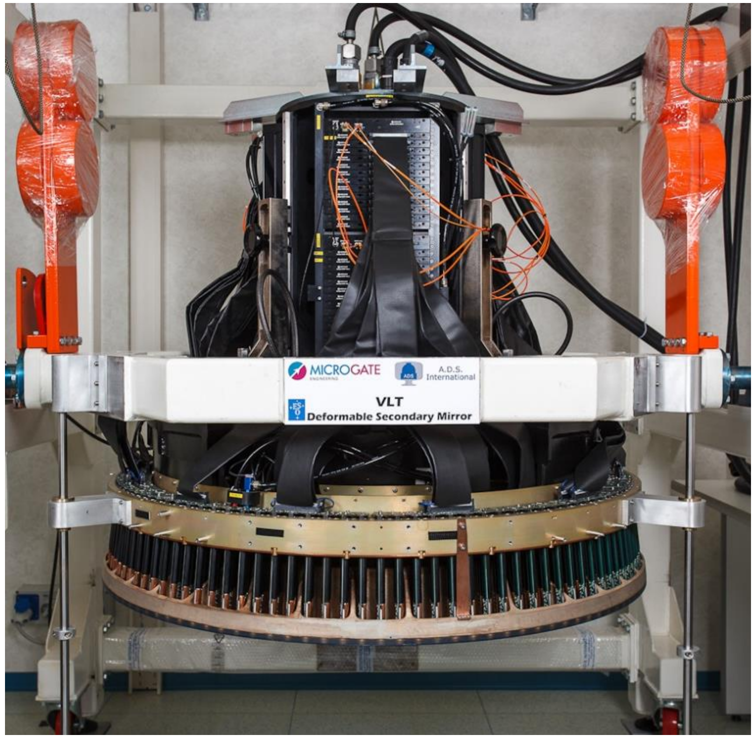



Acquisition, Guiding, and Wavefront Sensing System



# Adaptive Telescope Mirrors

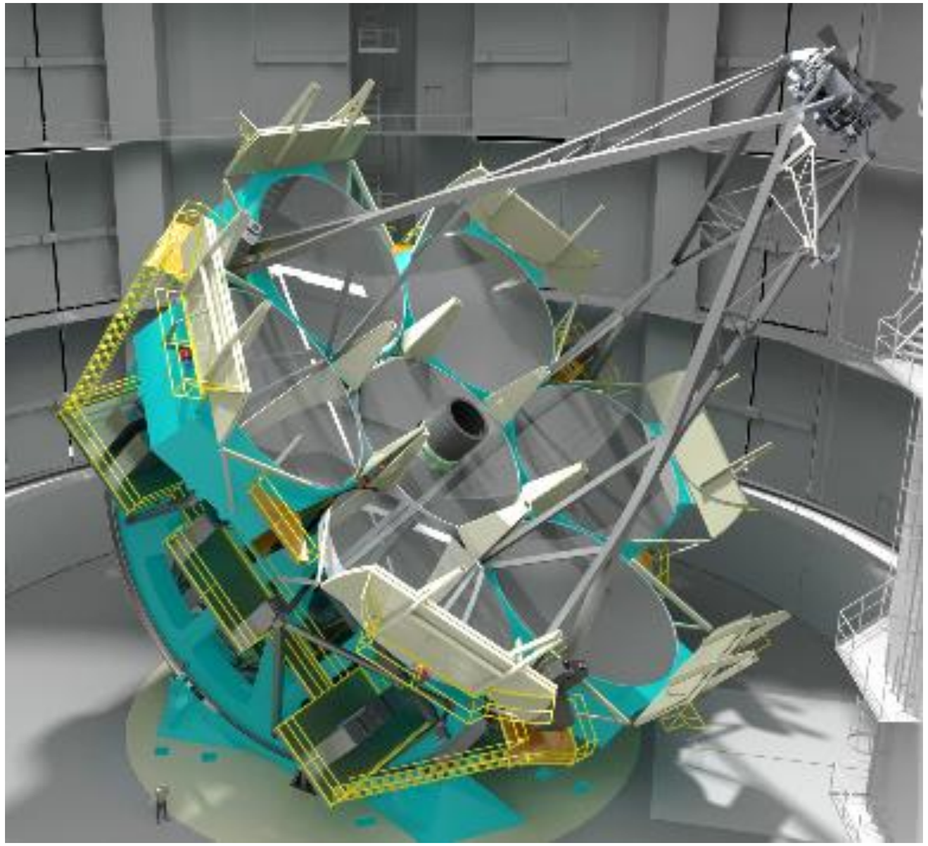
- An essential component of AO systems is a deformable mirror.
- The adaptive secondary mirror was first developed for the Multiple Mirror Telescope (MMT) on Mt. Hopkins in collaboration with Arcetri Observatory, Italy.
- Subsequent versions have been employed on a number of other telescopes including the LBT, Magellan, and VLT (right).
- Electromagnets suspend a ~2 mm thick Zerodur facesheet from a support structure.
- A figured rigid Zerodur blank in close proximity above the facesheet provides a reference for the optical surface.
- The gaps between the face sheet and the reference body are measured by capacitance sensors at each electromagnet.
- The controller adjusts the gaps to change the mirror figure hundreds a times a second to achieve wavefront correction.
- These complex assemblies are very challenging devices to build and maintain.
- Both GMT and EELT plan to use deformable telescope mirrors.




VLT 642mm diameter convex secondary mirror with 336 actuators. Manufactured by the AdOptica Consortium.

# GMT Adaptive Secondary Mirror Assembly





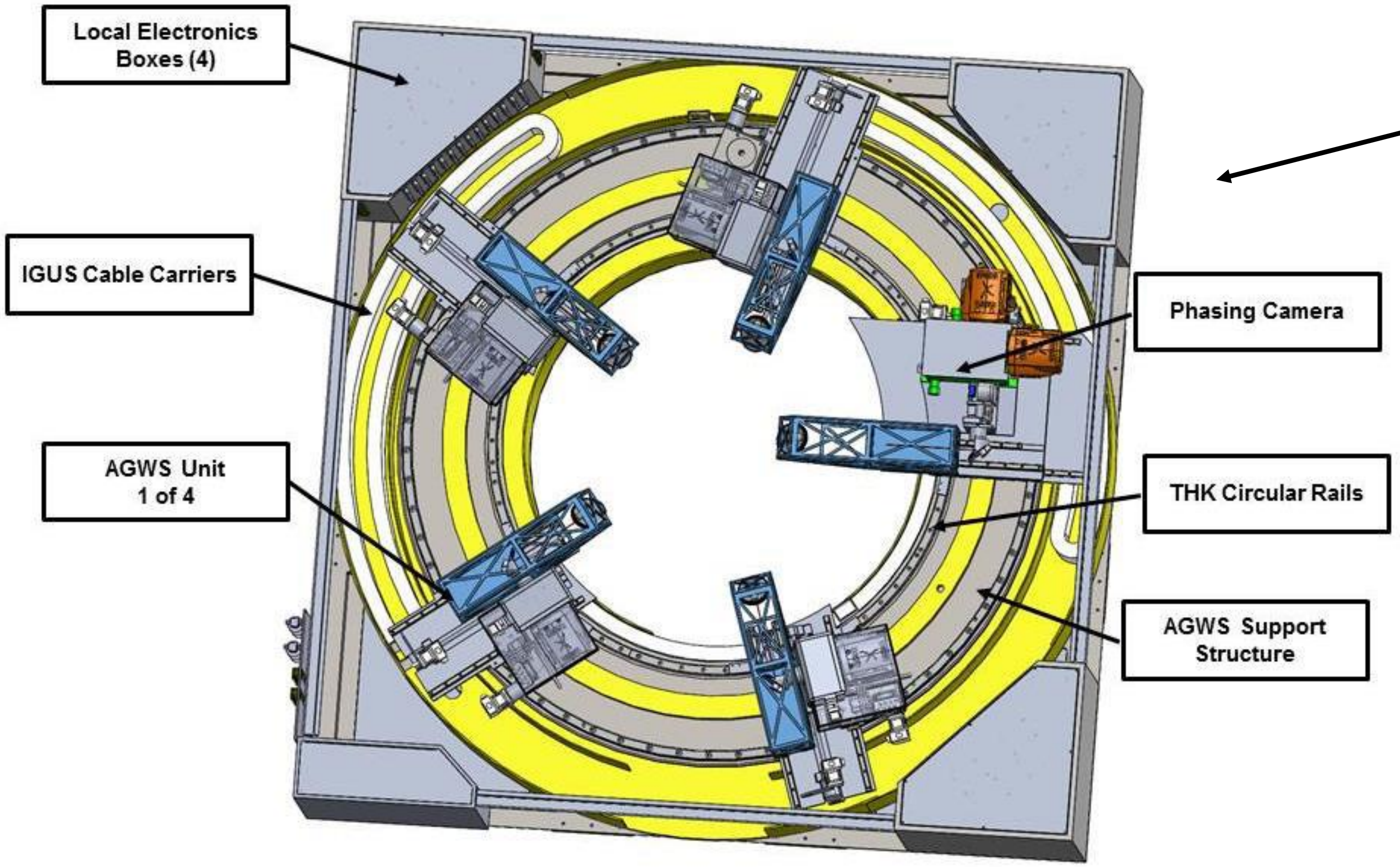
<ins>GMT Adaptive Secondary Mirror</ins>

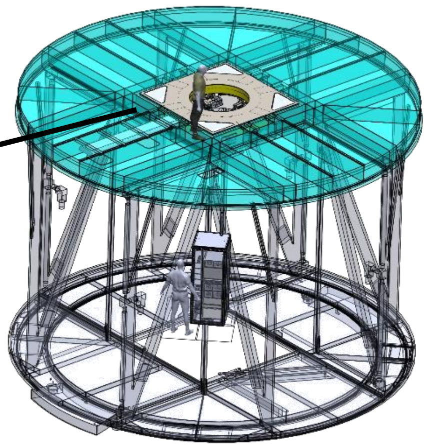
Six 1.05 m diameter segments

672 actuators per segment

4704 total actuators

# AGWS Assembly

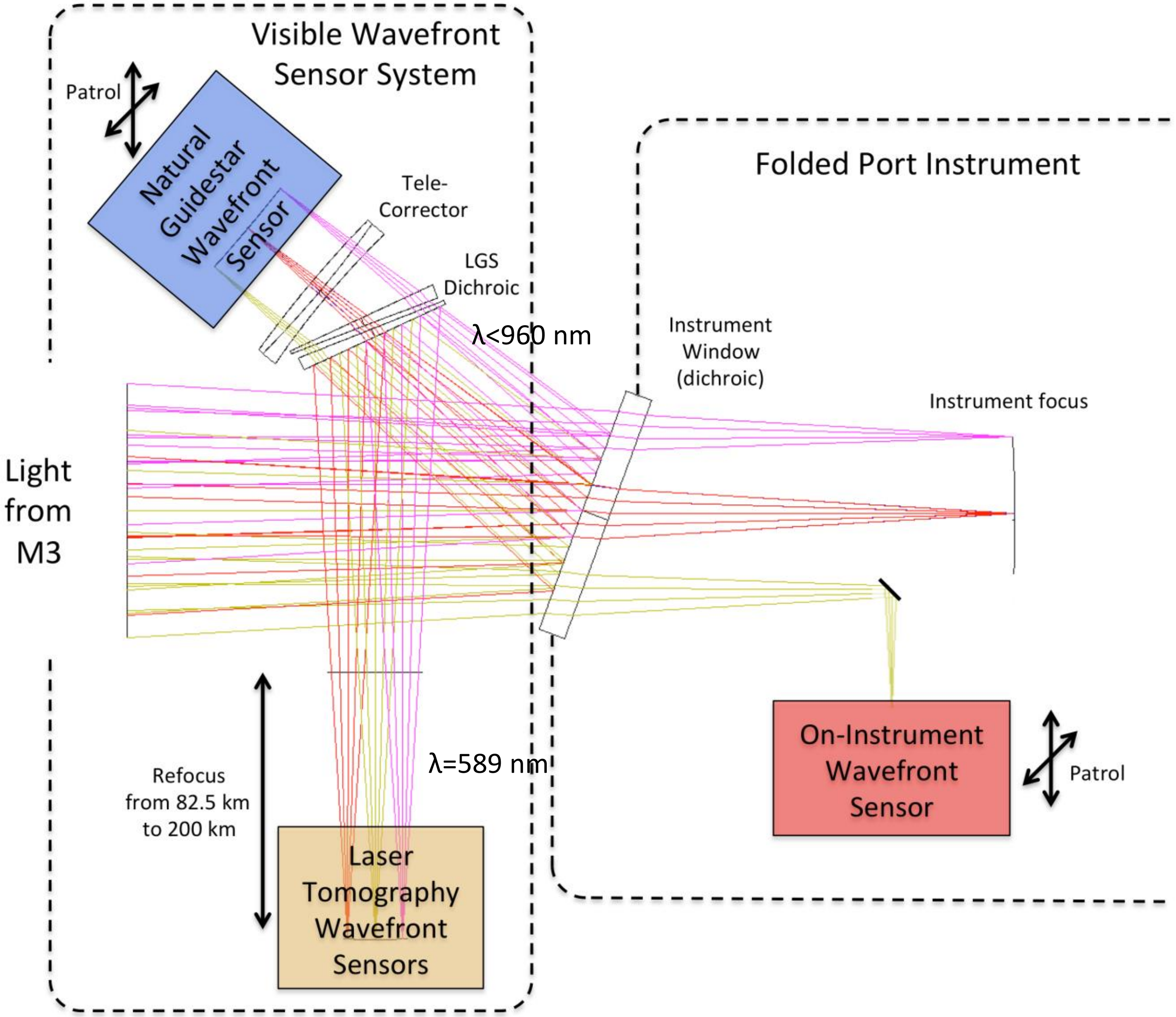


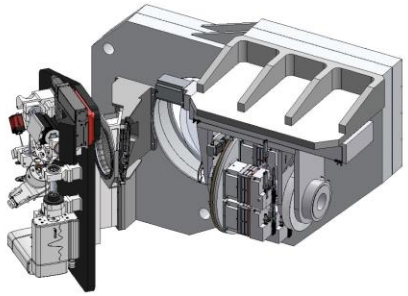
- The Acquisition, Guide and Wavefront Sensor (AGWS) assembly contains the sensors for acquiring guide and wavefront reference stars.
- AGWS probes mount on R-theta stages and patrol an annulus around the axis.
- Four probes contain the sensors for guiding, active optics, and GLAO.
- One stage carries the camera for phasing the 7 telescope subapertures.

# NGSAO/LTAO Focal Plane Sensors

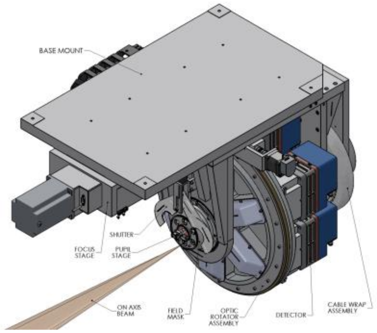





Visible Wavefront
Sensor Assy.



Laser Tomography
Wavefront Sensor Assy.



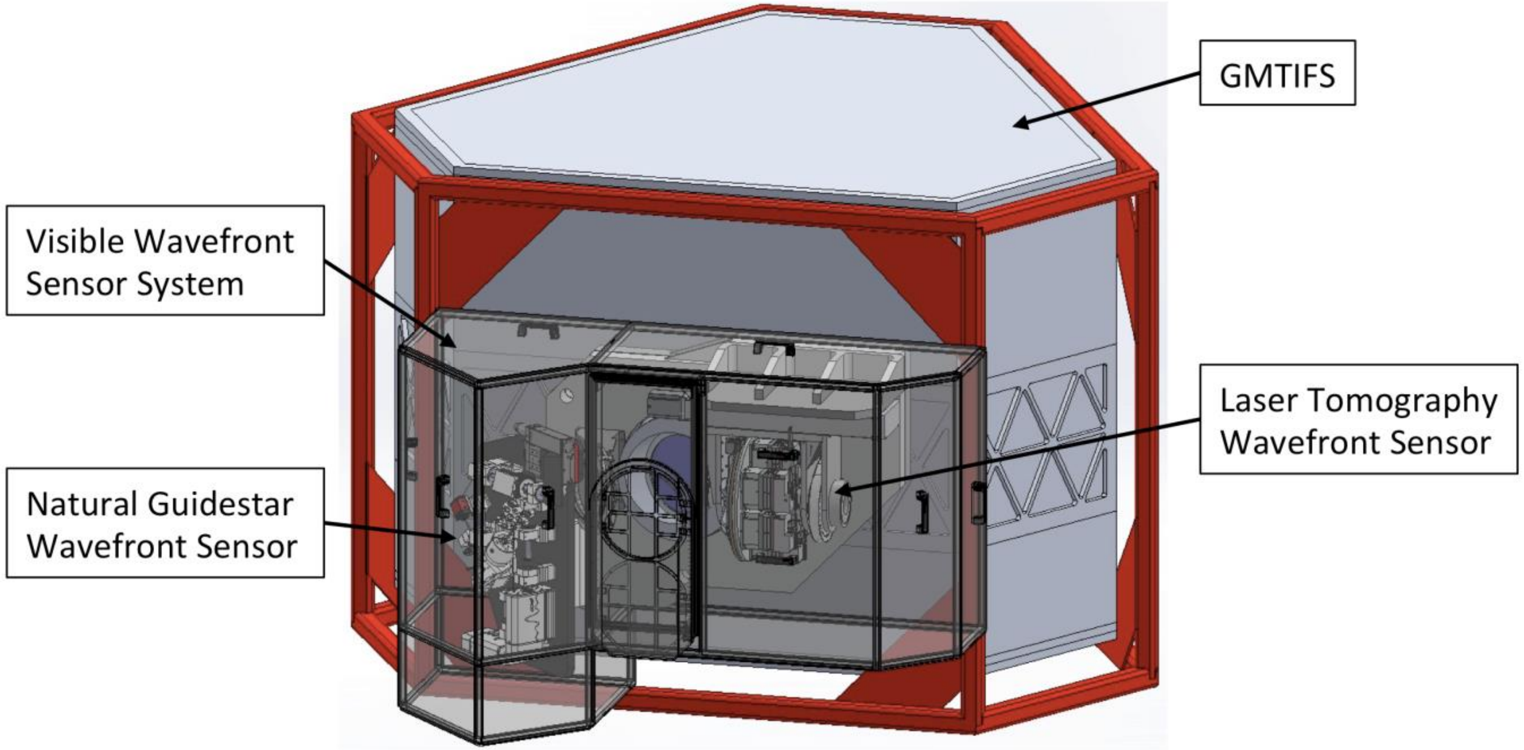
## Features:

- Visible light (λ<960 nm) is reflected from a tilted instrument window back to the Visible Wavefront Sensor System.
- Notch dichroic sends sodium line (λ=589 nm) light to the Laser Tomography wavefront sensors.
- A patrolling wavefront sensor in the science instrument provides tip/tilt/focus signals for LTAO.

# GMT AO Instrument (GMTIFS)

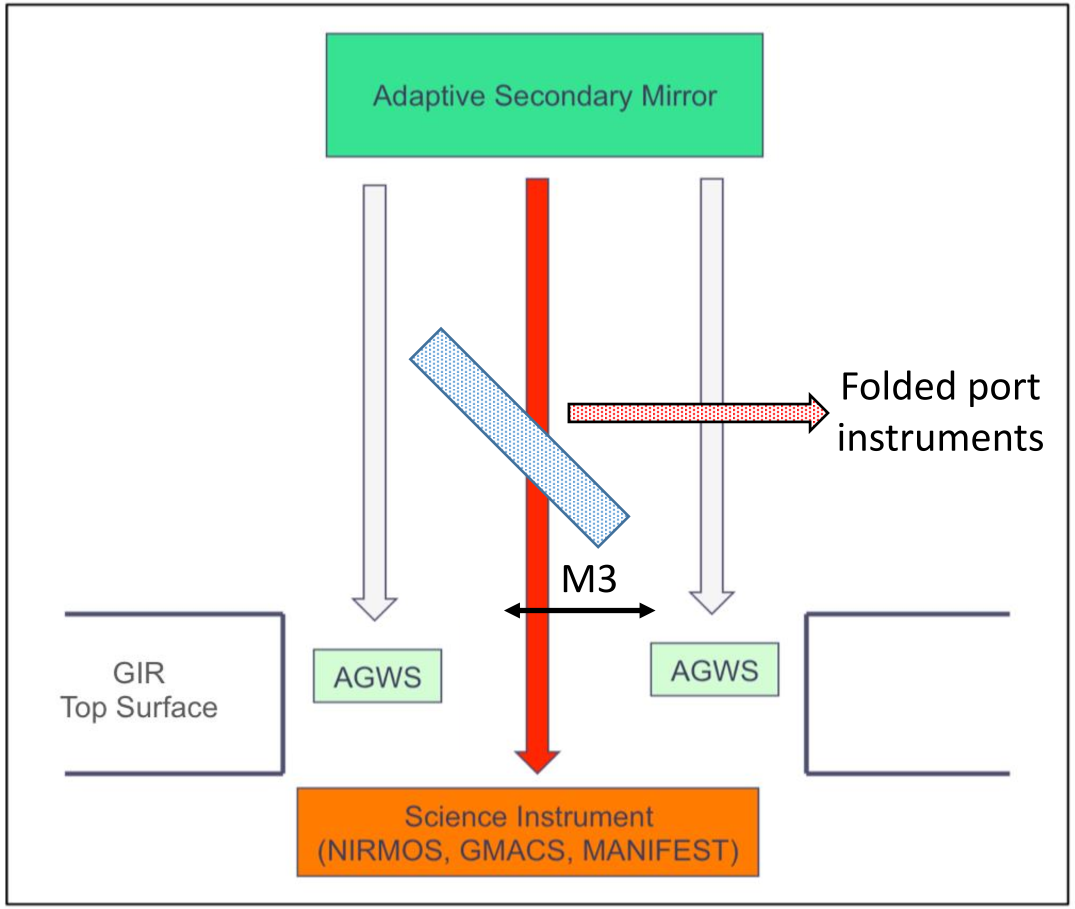


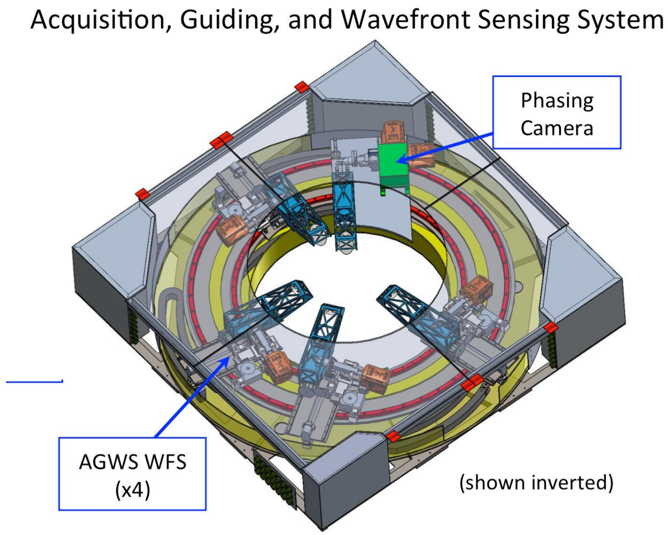
- The Visible Wavefront Sensor Assembly contains the Natural Guidestar Wavefront Sensor (NGWS) and, for instruments that require it, the Laser Tomography Wavefront Sensor (LTWS).
- The assembly provides the front end for NGSAO and LTAO instruments.
- NGSAO instruments have only the NGWS.
- LTAO instruments have both the NGWS and the LTWS.



# GLAO Wavefront Sensing






- GLAO wavefront sensing relies on the four wavefront sensors in the AGWS assembly.
- The light not picked-off by the AGWS probes passes uninterrupted to the Direct Gregorian instruments with the tertiary mirror (M3) retracted from the beam.
- Inserting M3 enables GLAO operation in Folded Port instruments.
  - Reference beams to the AGWS probes pass around the sides of M3.

# Subaperture Phasing



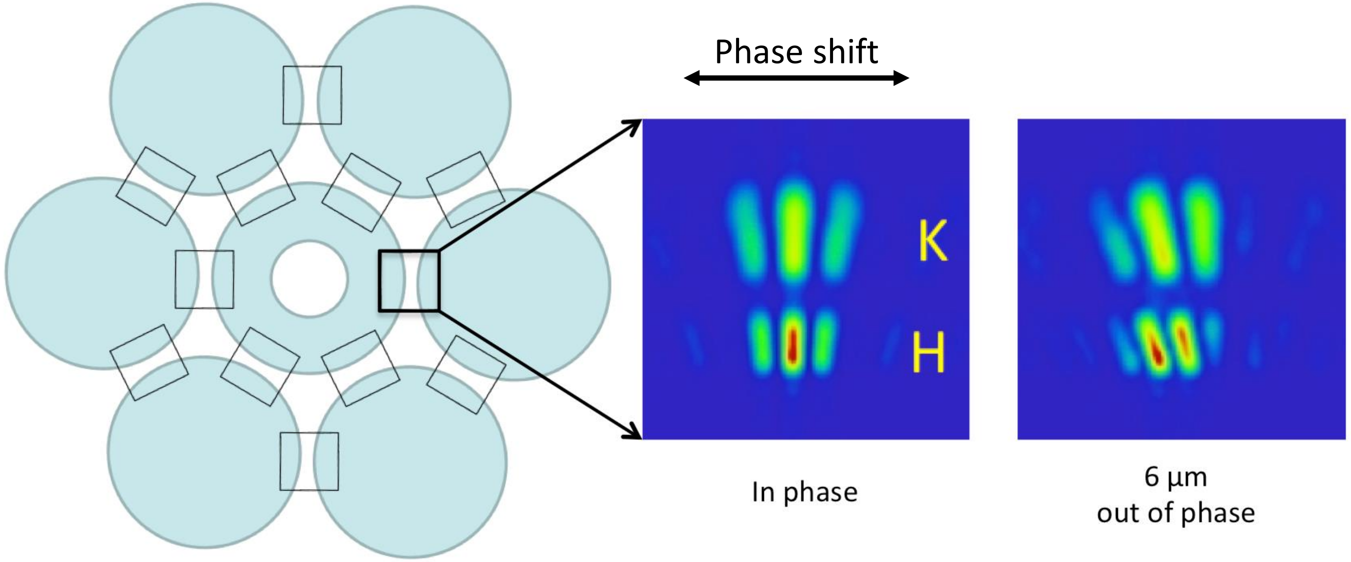
To deliver diffraction-limited images in the NGSAO and LTAO observing modes, the GMT subapertures must be phased to a small fraction of the observing wavelength. This is done using a combination of wavefront sensors in the phasing camera and mechanical displacement sensors along the edges of the mirror segments.

In LTAO mode, the edge sensors are used to detect high-frequency disturbances in the mirror arrays, while the wavefront sensors compensate any long-term drifts in these measurements.

In NGSAO mode the wavefront sensors compensate for all phasing errors. The adaptive secondary mirrors, being more agile than the large primary mirror segments, provide the means to keep the telescope phased.

Phasing Camera operation:

- Camera interferes K-band images across the segment gaps.
- The position of the (false-color) fringes gives the relative piston of the adjacent segments modulo one wavelength.
- The tilt of the dispersed fringes resolves the 2π-lambda ambiguity.



# An Alternative Approach



Instead of making one of the telescope mirrors (M2 for GMT, M4 for EELT) the adaptive mirror for AO operation, relay optics can be added after the telescope focus with a deformable mirror for wavefront correction. This approach trades the difficulty of producing and maintaining a large and complex adaptive mirror in the telescope for a smaller one in the relay but with the added complication of more reflective and/or refractive elements for each AO station. The AO secondary mirror is particularly well suited for wide-field GLAO that can feed multiple instruments.

# ELT AO System Challenges



## AO development challenges

- Production of large and robust adaptive mirrors
- Wavefront sensor development
- Phasing of the primary mirror segments
- Dealing with telescope windshake and mechanical vibrations
- Lasers for Laser Tomography AO (LTAO)
- Control algorithms

# Final Thoughts & Discussion

# Lessons Learned



- A good early systems engineering approach helps avoid problems later in the project.
- Establish the top-level design requirements at the start.
- Conduct and document trade-studies to arrive at a system architecture.
- Anticipate future science and technological trends and provide for future expansion.
- Over the lifetime of an observatory certain components will become obsolete and will have to be replaced (e.g. computer systems and science instruments). Design accordingly.
- Resist adding marginal capabilities that add little to critical functionality and compromise overall performance, and/or boost project cost and distract from the core effort.
- Design for compactness and stiffness to maximize modal and thermal performance.
- Capitalize on existing experience, technology and expertise but critically judge heritage designs against new technology that might offer better performance and/or lower cost.
- Factor in maintenance requirements at each step in the design process.
- Identify high technical risk subsystems. Analyze and prototype those components as early as possible.
- Look for cost efficient solutions but don’t be afraid to spend where the gains are justified.
- Enabling exciting science is the reason we build telescopes. Focus on getting there promptly.

This concludes the Telescope Project Development lectures.

Thank you for attending.