TMT First Light AO System Overview

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CfAO Fall Retreat, Nov. 2006, Yosemite

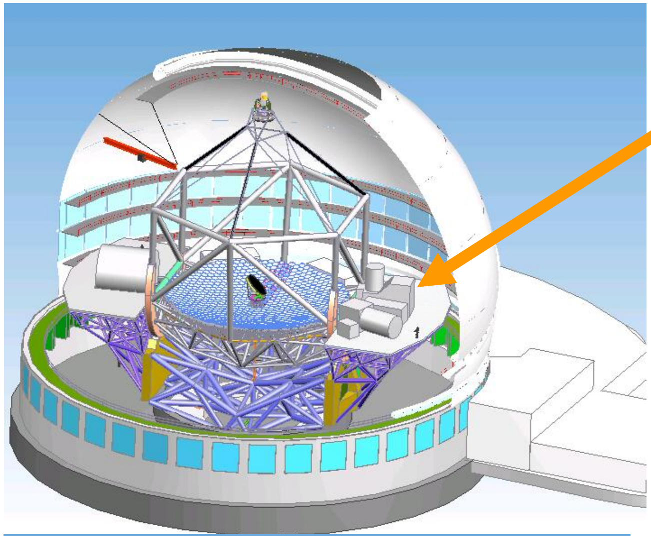
Overview

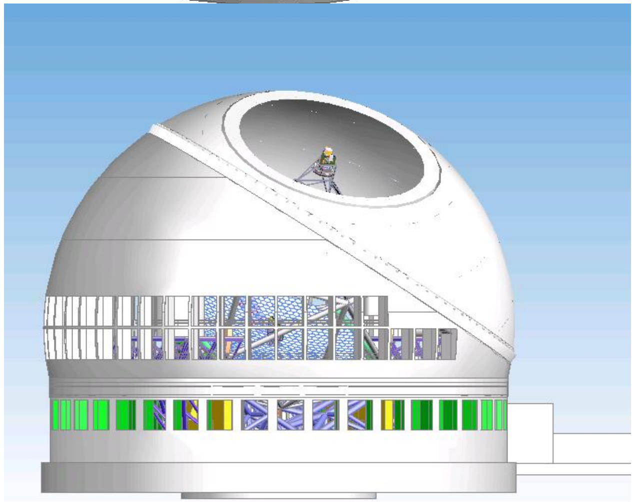
- TMT AO
  - Program history
  - AO & instrumentation modes
- NFIRAOS
  - Requirements
  - Design Concept
- Telescope Layout for instruments & AO
- NFIRAOS subsystem details
- Instrument Interfaces
- Upgrade plan
- Performance estimates and modeling plans

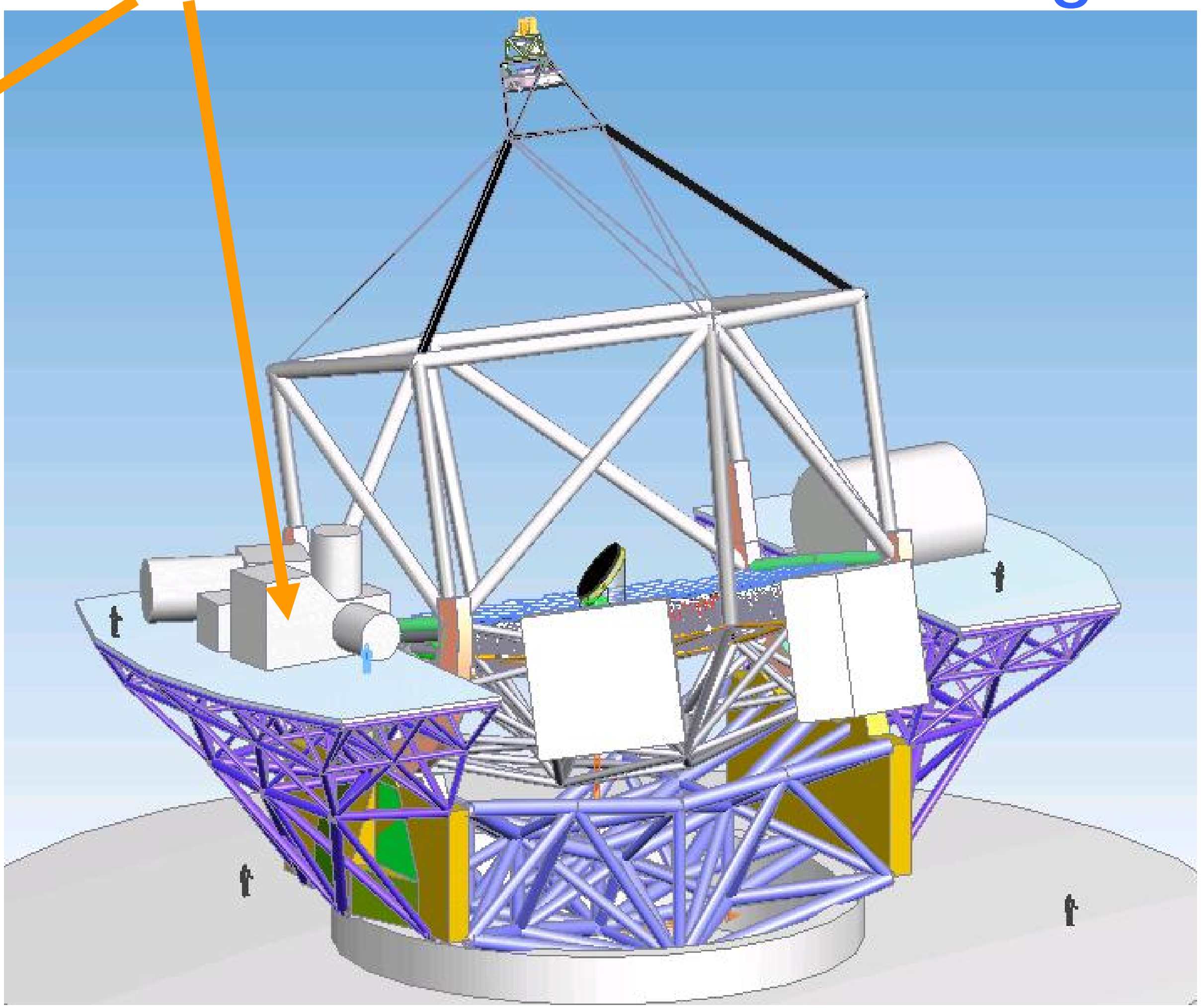
THIRTY METER TELESCOPE

Thirty Meter Telescope

NFIRAOS CoDR Design







TMT
THIRTY METER TELESCOPE

A Brief History of TMT AO

2003-4

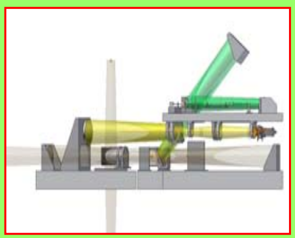
- **"Interim AOWG" Epoch: MCAO vs. MOAO. vs. AM2 vs. MEMS vs. ….**

11/2004

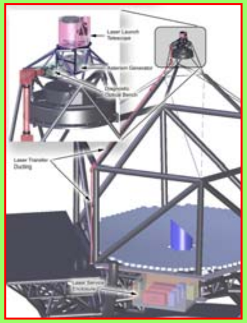
- **Reference AO Architecture formulated**
  - -- LGS MCAO system at TMT first light (NFIRAOS)
  - -- Adaptive Secondary (AM2) upgrade for ground-layer AO and mid IR AO
  - -- Follow-on MOAO and ExAO systems for IFU spectroscopy, planet finding

04/2005

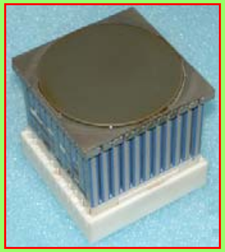
- **Conceptual Design and Feasibility Studies**



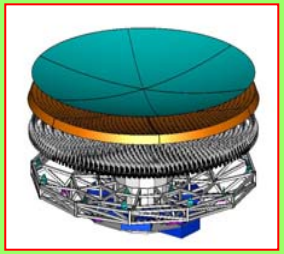
NFIRAOS



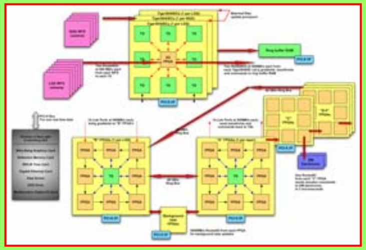
LGSF



Piezo DM



AM2



RTC

04/2006

05/2006

09/2006

- **TMT Conceptual Design and Cost Reviews**
  - -- Positive reviews of NFIRAOS and the Laser Guide Star Facility
  - --AM2 "walks the plank" due to high cost estimate
    (Deferred from TMT construction phase to early operations)

NRC

Older (and Poorer) but Wiser…

- **NFIRAOS design and performance estimates have held up pretty well**
  - 180-190 μm RMS WFE achievable with order 60^2 AO compensation
  - 50% sky coverage achievable with IR tip/tilt/focus sensing and MCAO
  - Large but workable opto-mechanical design
- **“Conventional” LGSF design is workable**
  - 3 50W, CW, solid state lasers with beam transport via mirrors
  - LGS elongation is acceptable with polar coordinate LGS WFS CCD arrays
- **Piezostack DM prospects encouraging**
  - Stroke and hysteresis requirements met at -35C
  - Acceptable cost estimates for 61^2 and 73^2 designs
  - Tip/tilt stage may be the greatest challenge
- **Real Time Controller (RTC) prospects encouraging**
  - FPGA- and DSP-based concepts for implementing conjugate gradient algorithms
- **AM2 cost estimates *discouraging***
  - Face-sheet dynamics and voice coil actuator design OK
  - Reference body, lateral support system designs are challenging
- **MOAO for IFU spectroscopy on a 5’ FoV is very challenging**
  - High order (~60^2) MEMS controlled in open loop
  - ~2’ FoV behind NFIRAOS is a reasonable alternative first step

(Rebaselined) Support for Scientific Capabilities by TMT AO Modes

First light AO mode	Enabled by AM2
Cash-flow-limited implementation	Enabled by MEMs and/or advanced components

Scientific Capability	Initial AO Mode	Upgraded AO Mode
Narrow field, near IR spectroscopy and imaging (**IRIS**, **NIRES-b**, **WIRC**)	Multi Conjugate AO (**MCAO**): NFIRAOS	**MCAO** with higher order components; DLIRAOS
Moderate field, near IR multi-object IFU spectroscopy (**IRMOS**)	2' FOV behind **MCAO**	5' FOV **MCAO** N-shooter or Multi-Object AO (**MOAO**)
Narrow field mid IR spectroscopy and imaging (**MIRES**, **NIRES-r**)	Laser Tomography AO (**LTAO**) with a conventional DM	**LTAO** with an adaptive secondary mirror (AM2)
High resolution optical spectroscopy (**HROS**)	None (Seeing-limited observations)	**LTAO** with AM2
Wide field optical spectroscopy (**WFOS**)	None (Seeing-limited observations)	Ground-layer AO (**GLAO**) with AM2
High contrast imaging and spectroscopy (**PFI**)	None at TMT first light	Extreme AO (**ExAO**)

NFIRAOS purposes

- Science Requirement Document specifications:
  - Facility Laser Guide star AO system feeding three near infrared instruments 1.0 – 2.5 μm (goal 0.6 – 2.5 μm)
  - 50% sky coverage at galactic pole …
    with RMS tip/tilt jitter < 0.1 λ/D; relaxed to 0.002” at first light
  - 133 nm rms high-order wavefront error over 30 arcsecond field
    …now relaxed to 180 nm RMS over 10” Field of View at first light
  - 85% throughput (goal 90%)
  - NFIRAOS must not increase inter-OH background by more than 15% of sky + telescope background
- *Ready for commissioning at first light with low risk, reasonable cost*

Implications for NFIRAOS *Design Concept*

- Excellent sky coverage
  - Laser guide star Adaptive Optics (AO) + tip/tilt/focus natural guide star wavefront sensors
  - MCAO Multi-conjugate AO (multiple Deformable mirrors) with a technical FoV of at least 2 arc minutes for tip/tilt guidestars
  - Tip/tilt sensing in the infra-red with “sharpened” guidestars
- Excellent image quality on a moderate science FoV
  - Very high order system with multiple laser guidestars and MCAO
- Very good throughput and emissivity
  - Minimum surface count
  - Systems cooled to approximately -30 Celsius
- Commission system shortly following telescope first light
  - Use existing and near-term components/concepts when possible
  - Utilize closed-loop MCAO for wide-field compensation
  - Utilize Piezostack DM technology
    - Interactuator spacing of at least 5 mm → mechanically large system
  - Utilizing CW guidestar laser technology
    - Guidestar elongation → bright beacons

NFIRAOS design characteristics

- Laser guide star AO; 6 wavefront sensors
- 2 Deformable Mirrors - Order-60 MCAO system
  - DM0 with 2900 actuators;   DM12 with 4200 actuators
- 175 GigaOps Real Time Computer
- 2 arc minute technical field
- Design for, and operation at, -30 C
- Calibration (“perfect”) internal sources
- External turbulence simulator and High-Res’n. WFS
- Upgradeable to Order-120 system (high optical quality)
- IR acquisition camera
- Separated electronics cabinets

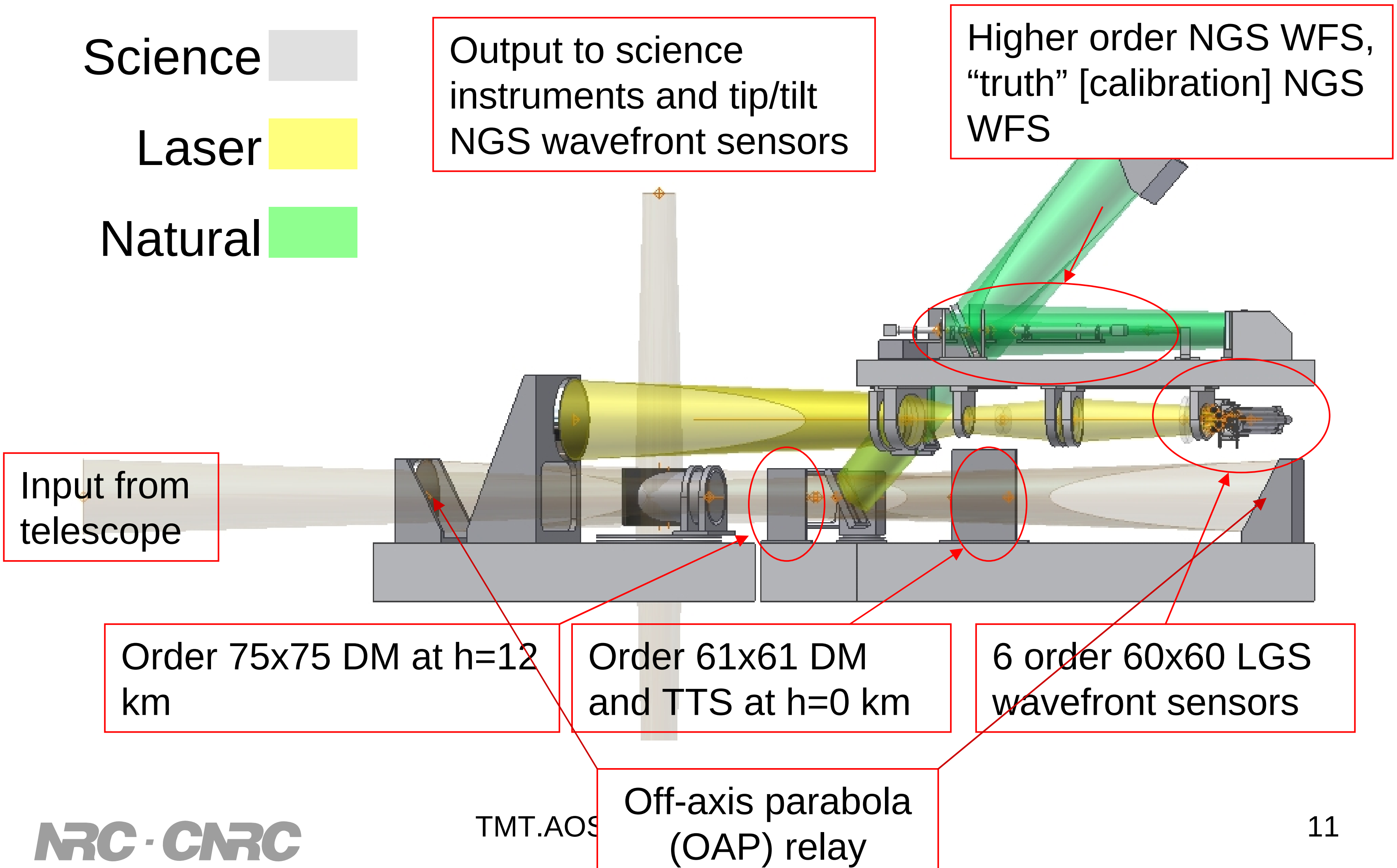
NFIRAOS Feeds Three Instruments

1. IRIS Integral Field Near IR Spectrograph 1 – 2.5 *μ*m, specified to have 2” IFU and 10”x10” imager

2. NIRES Near infrared Echelle Spectrograph 1 – 2.5 *μ*m, high spectral resolution, narrow field

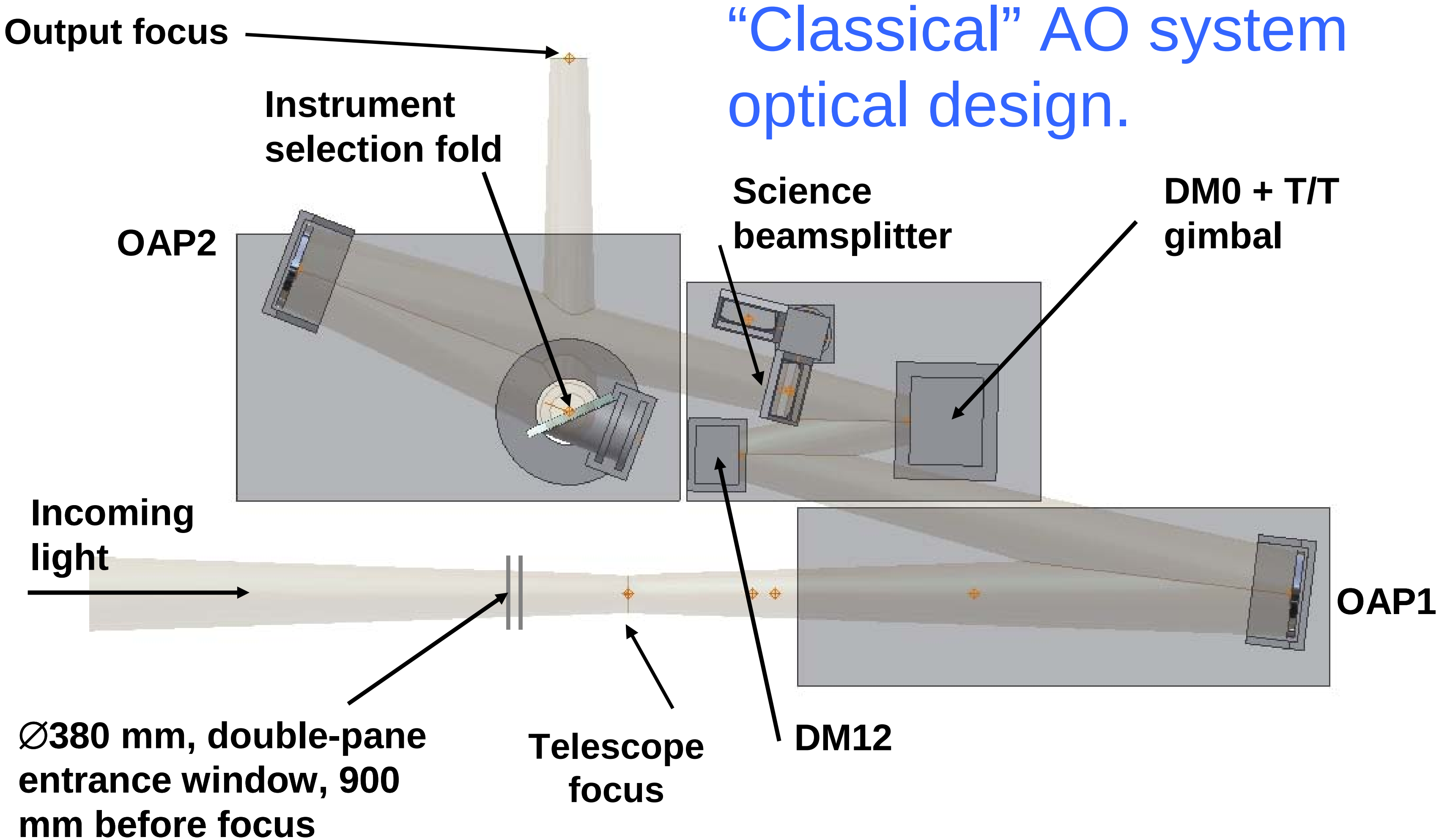
3. WIRC Wide field (30”) infrared camera, 1 – 2.5 *μ*m

NFIRAOS Optics Paths and Key Components



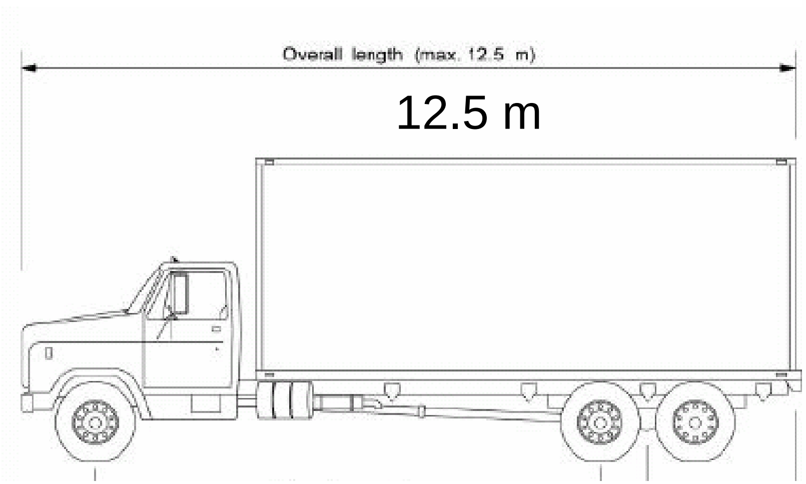
Top view of science path optics

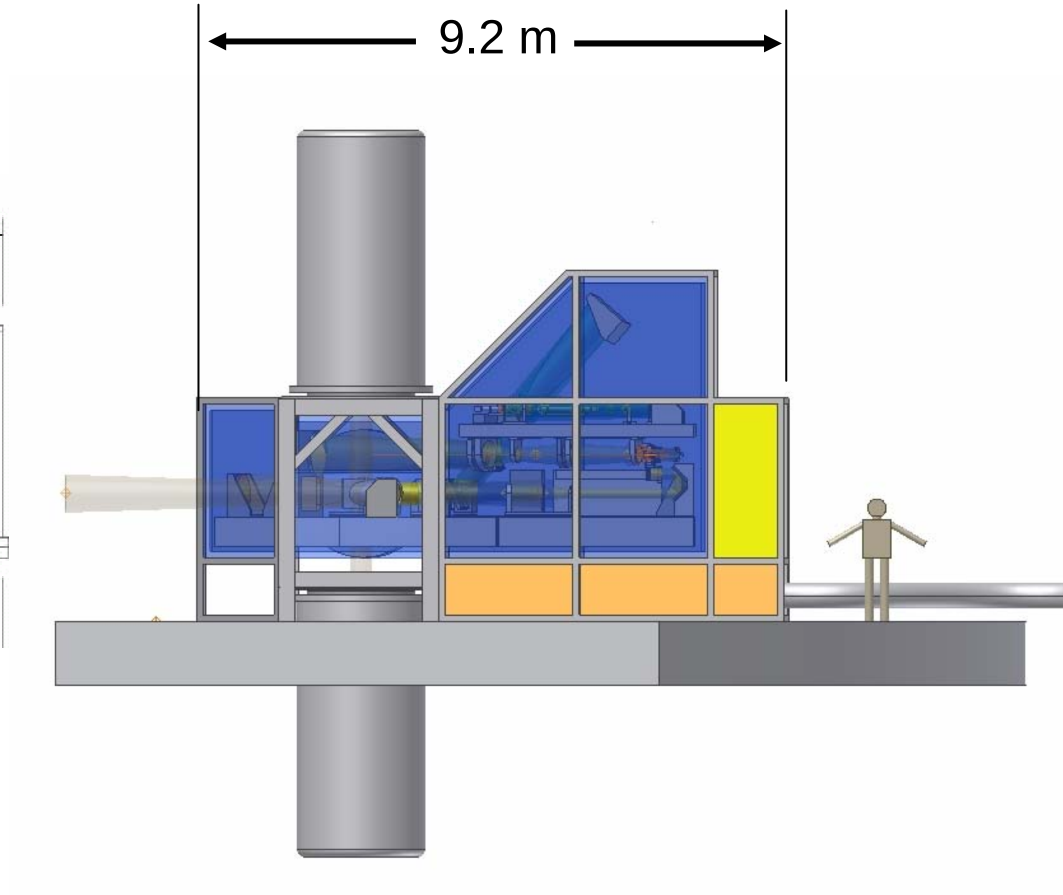
"Classical" AO system optical design.



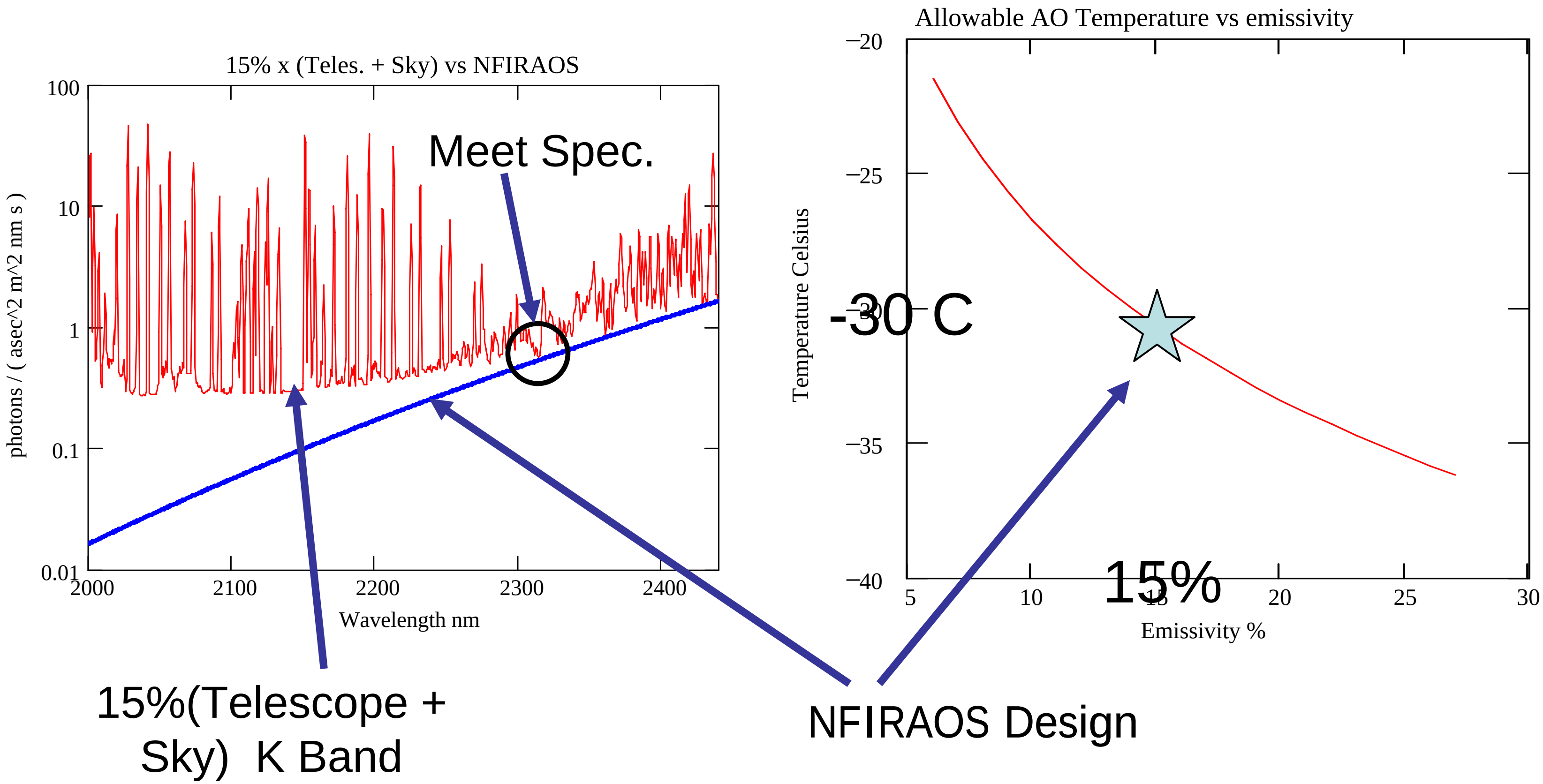
NFIRAOS size is appropriate for a 30-m telescope

Largest regulation rigid-chassis truck size (to scale)

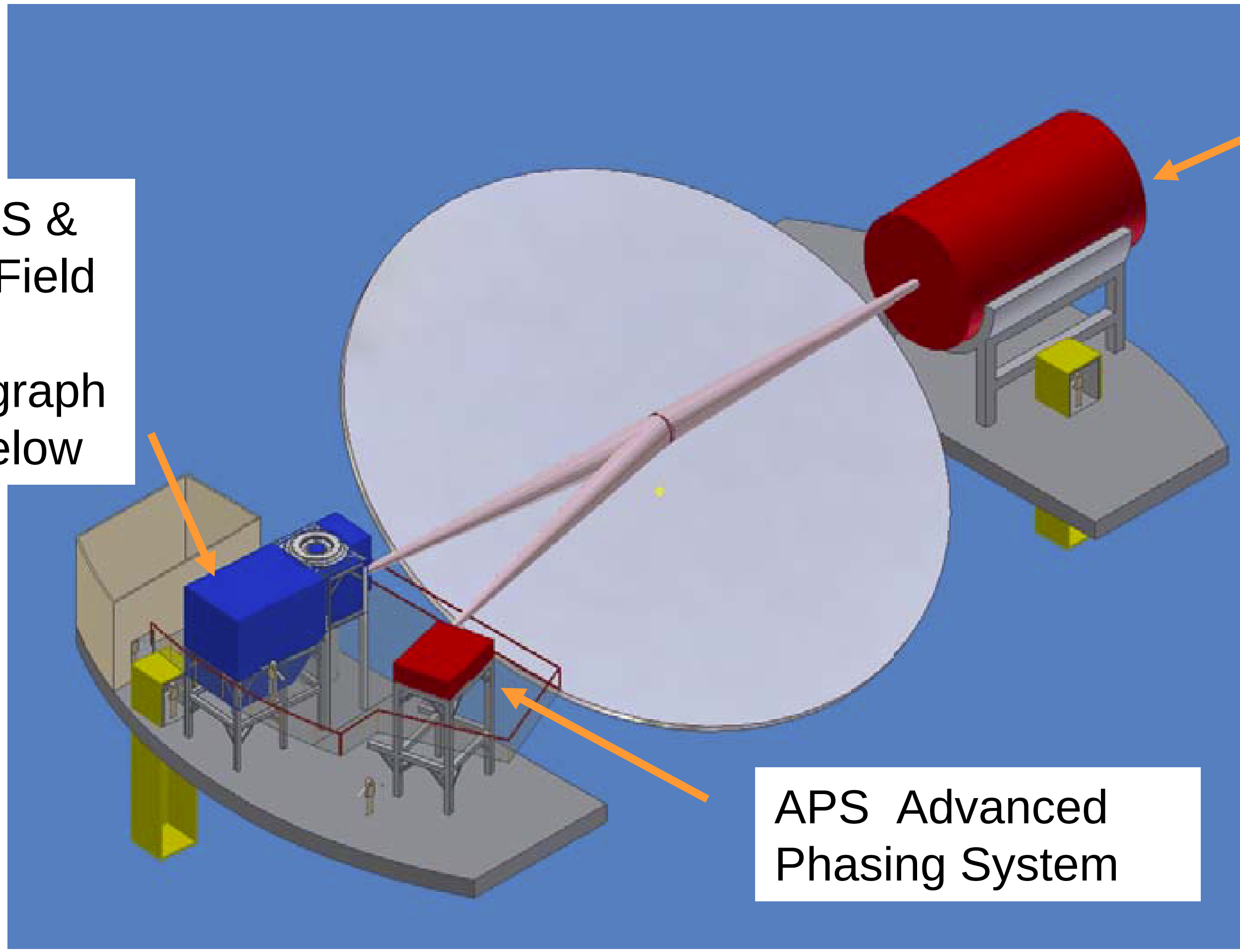




NFIRAOS is frosty!



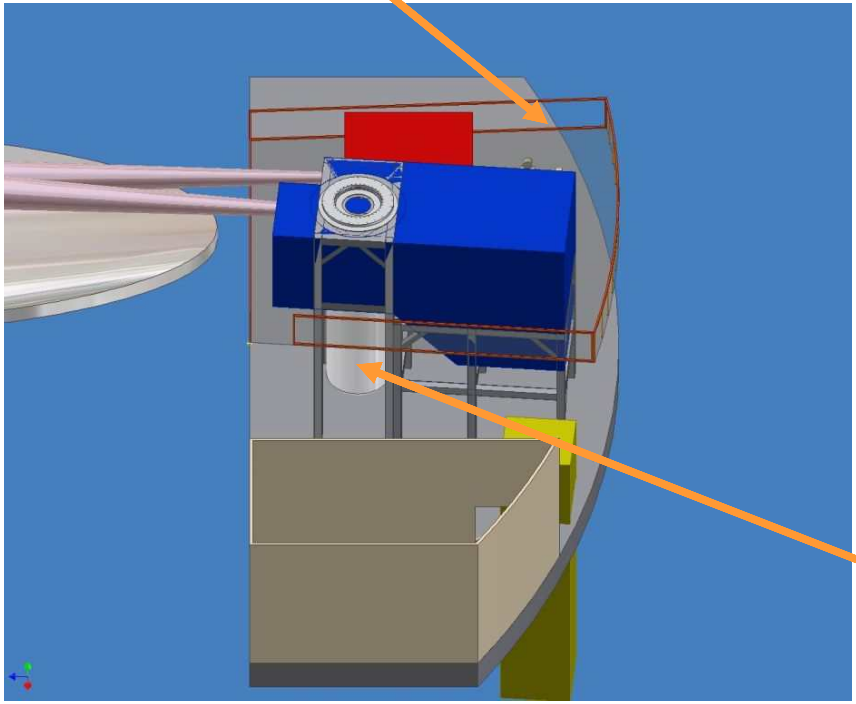
First Light at TMT

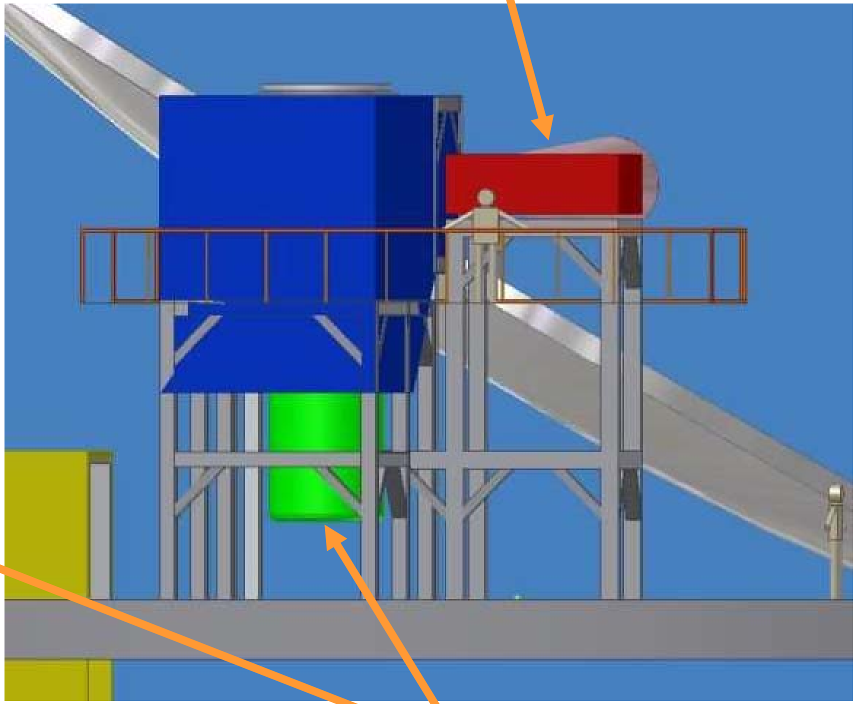


NFIRAOS upside-down for low wind cross-section to help flush M1

Removable walkways for servicing

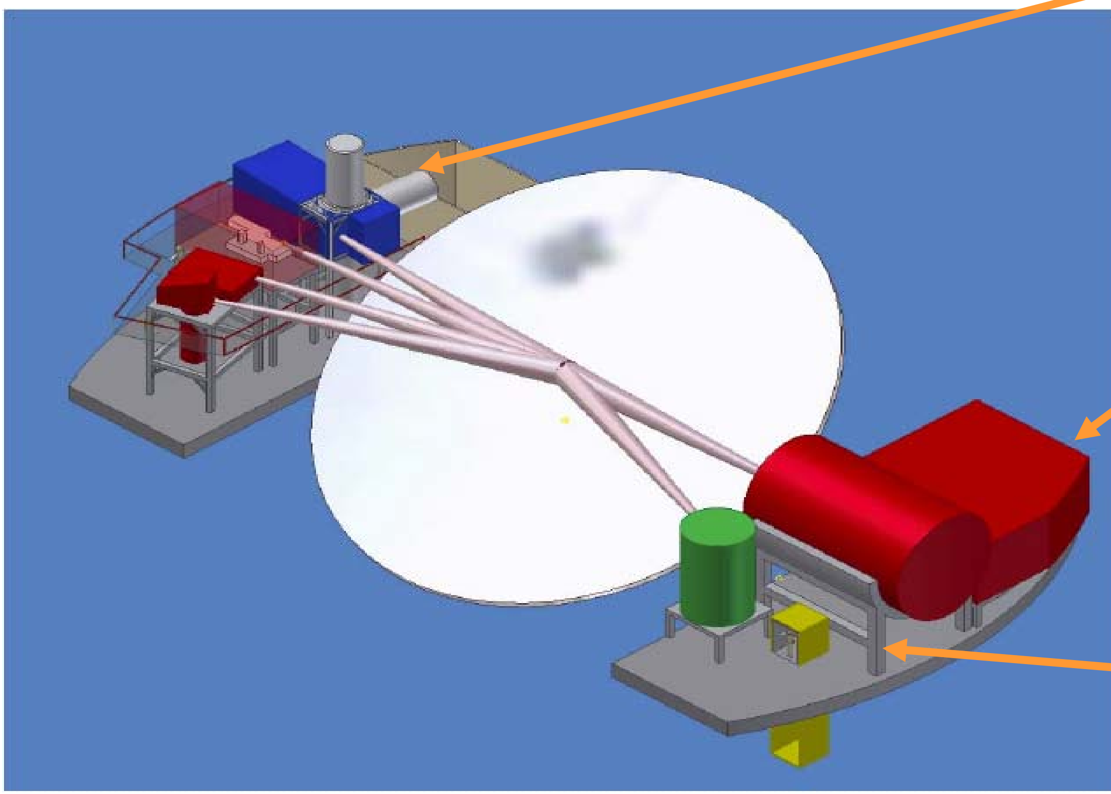
APS initially on elevation axis during early segment alignment





IRIS

Full SAC suite of Instruments



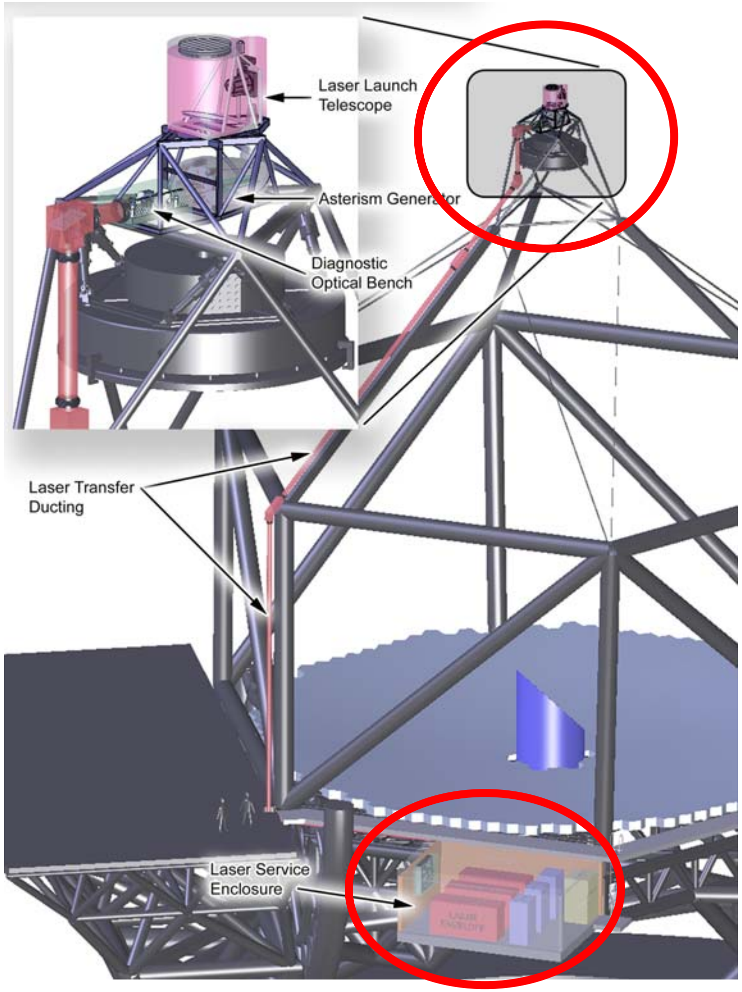
NFIRAOS & IRIS,
NIRES-b, WIRC

Nasmyth platform
proposed 7m below
elevation axis

Low wind cross-section structures added as instruments installed.

LGSF Design Concept and Issues

- Concept derived from existing LGSF designs, and components
  - CW, solid-state lasers
  - Launch telescope behind TMT M2
  - Mirror-based beam transport
  - Existing safety and control system concepts
- Reference design includes 3 current-generation 50W laser systems to produce 6 25W beacons for NFIRAOS
- Opportunities for advanced technology design upgrades will be monitored
  - Pulsed lasers (Rayleigh backscatter suppression and/or dynamic refocusing)
  - Fiber optic beam transport (Lasers moved to Nasmyth platform)



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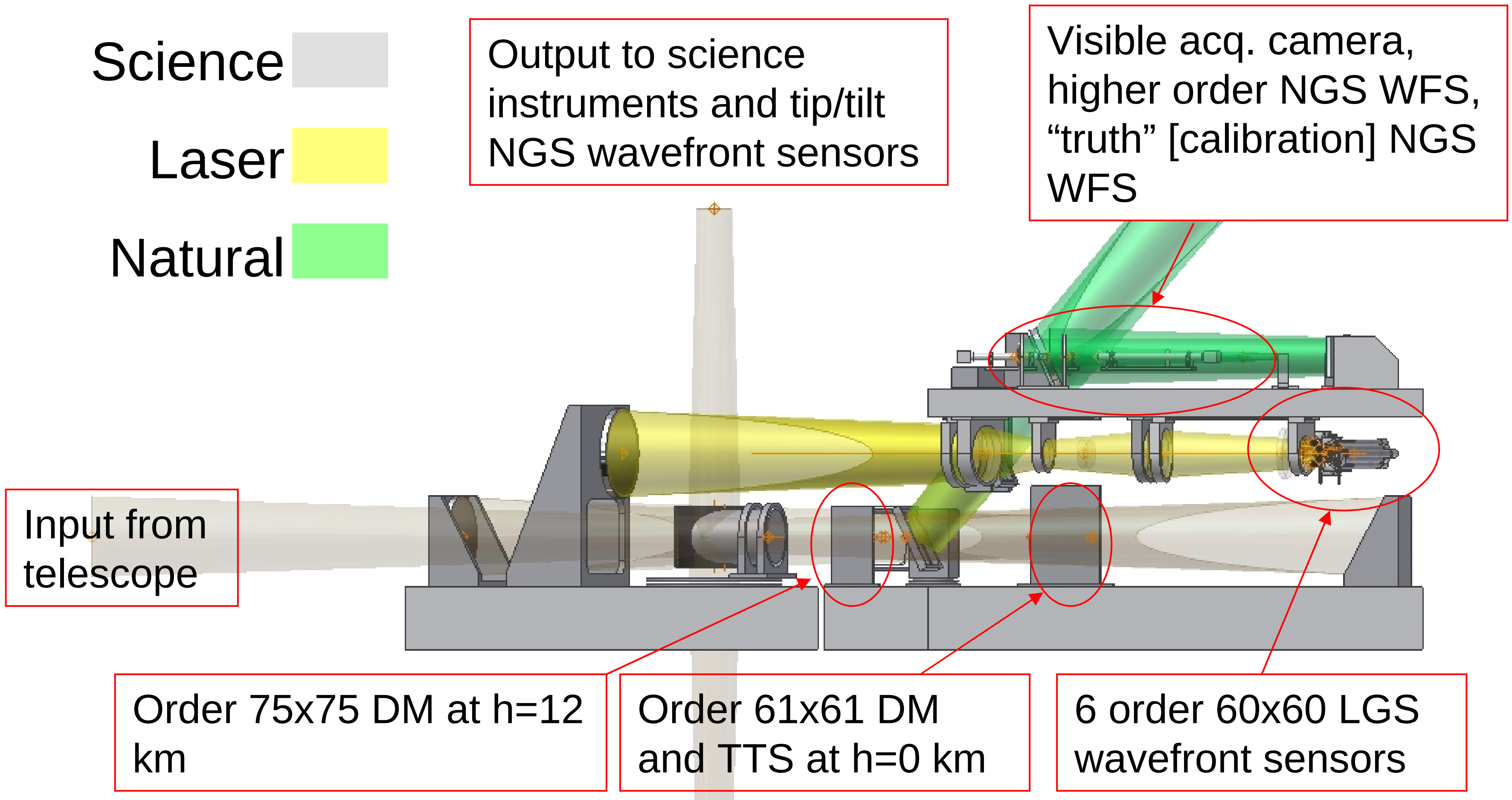
NFIRAOS Optics Paths and Key Components

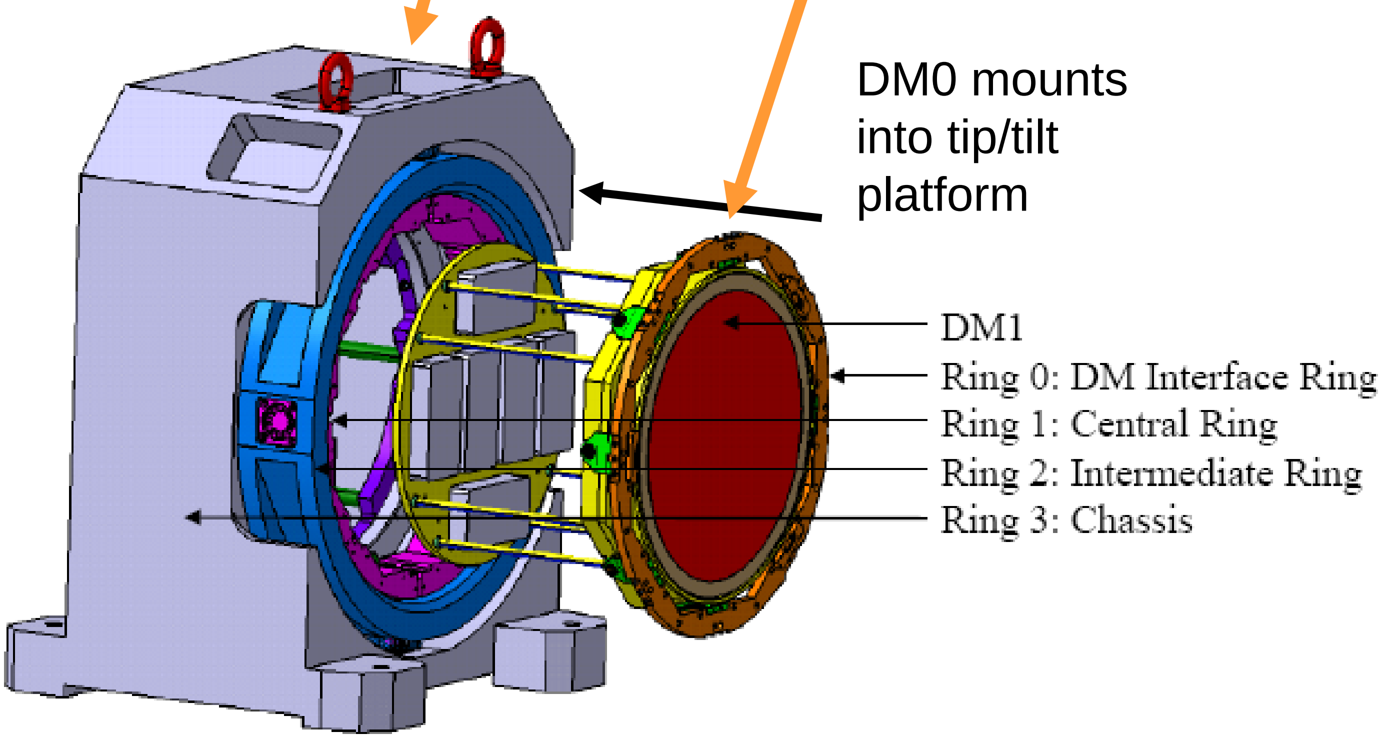


Wavefront Correctors

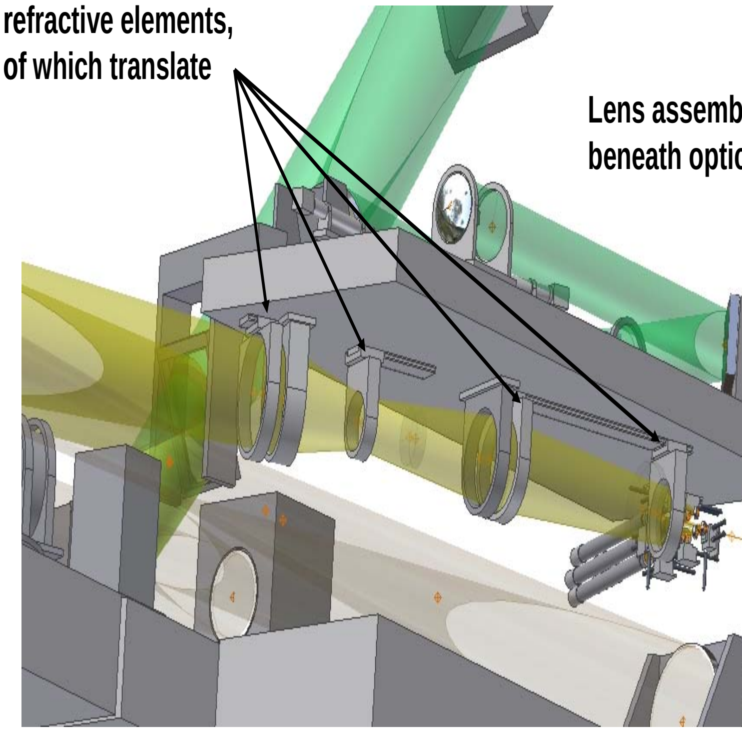
Tip/tilt Platform

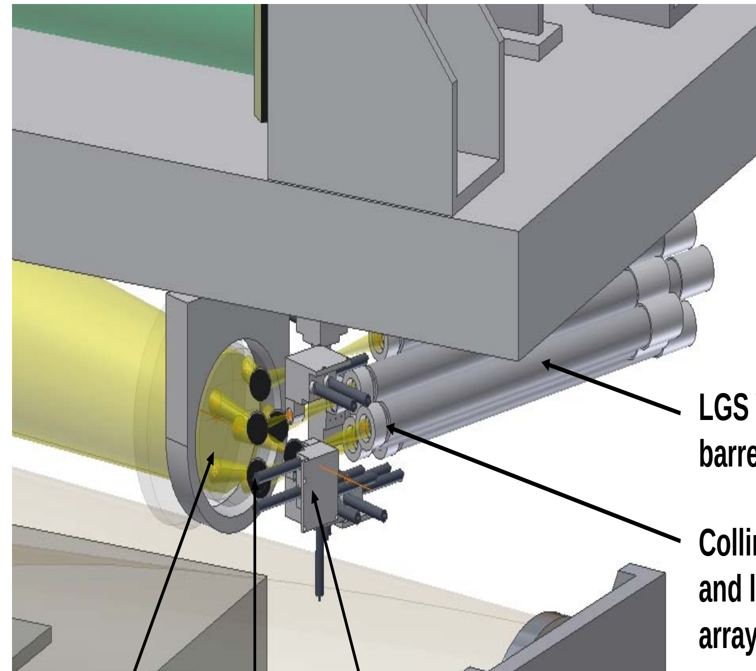
Deformable Mirror
.   @ 0 km

DM0 mounts into tip/tilt platform



Laser Wavefront Sensors (CoDR)



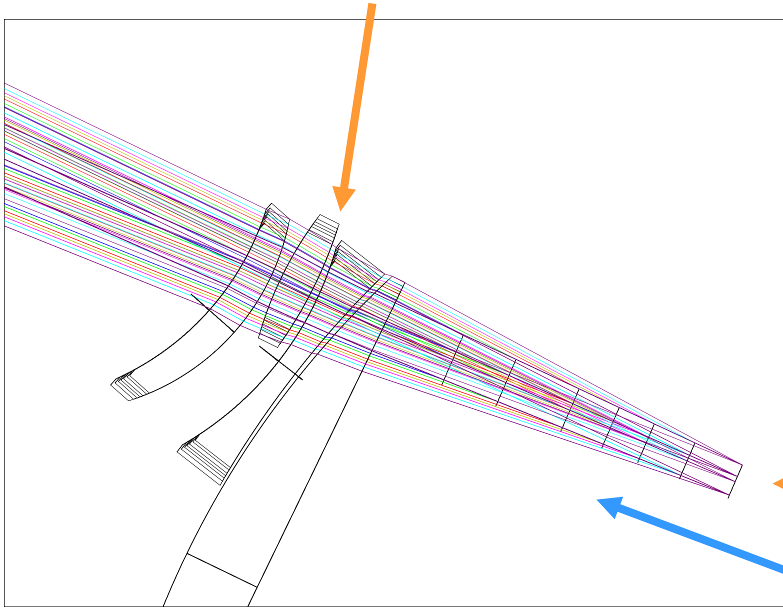


Zoom Optics: refocus on 85-235 km Sodium Layer range; reimage DM0 accurately onto WFSs; compensate aberrations caused by imaging objects at finite distance through a telescope designed for objects at infinity

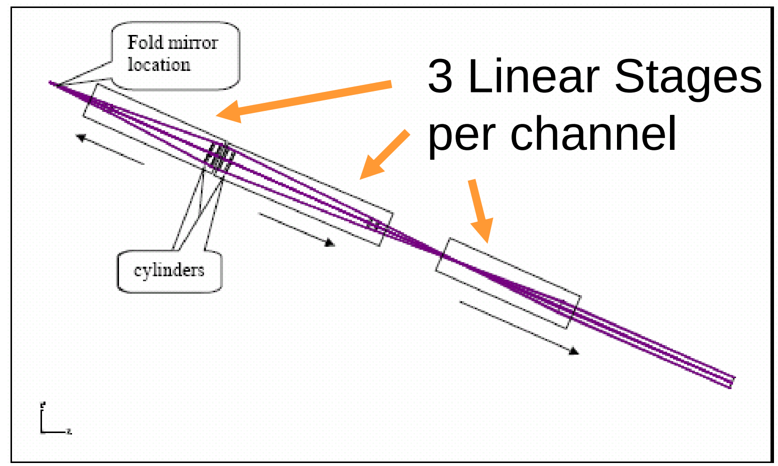
Promising new LGS WFS Concept

- Small spherical lenses, may save ~$1M in optics cost compared with the 8th order aspheres in the CoDR design that cost ~$2.4M

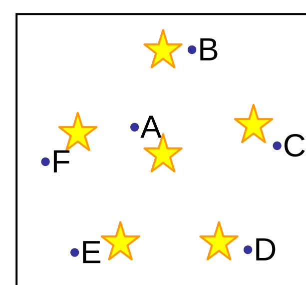
1. All 6 Laser beams first pass through four stationary, spherical Lenses



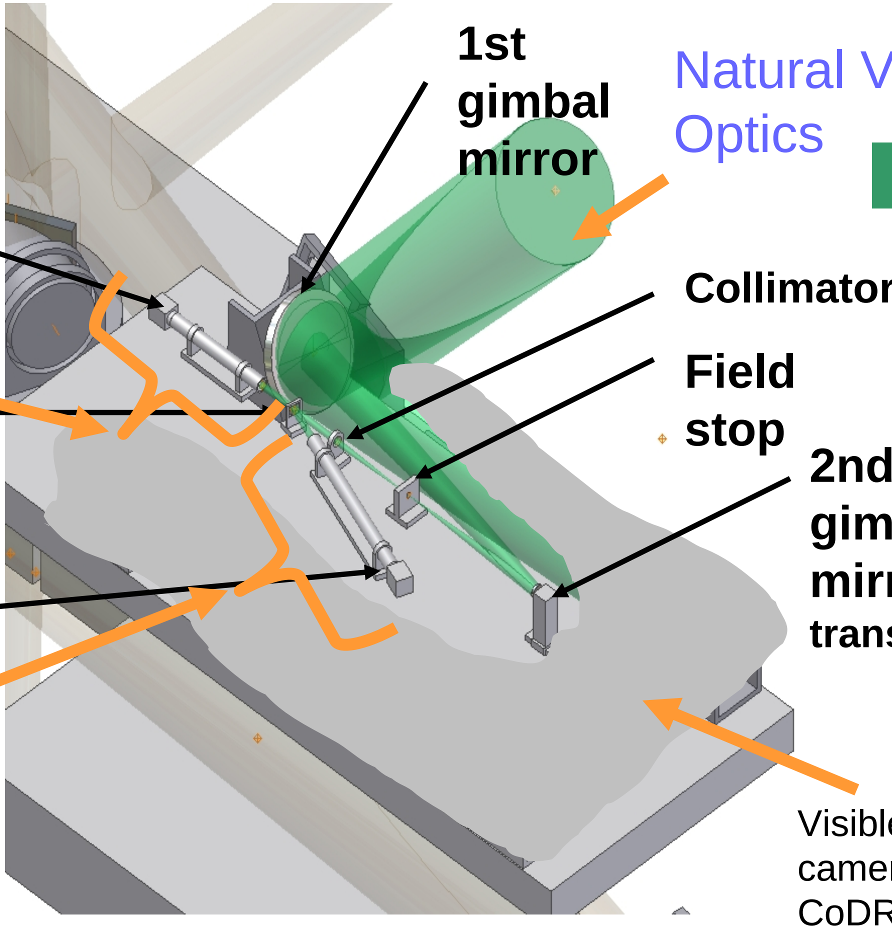
2. Followed by 6 individual zoom channels



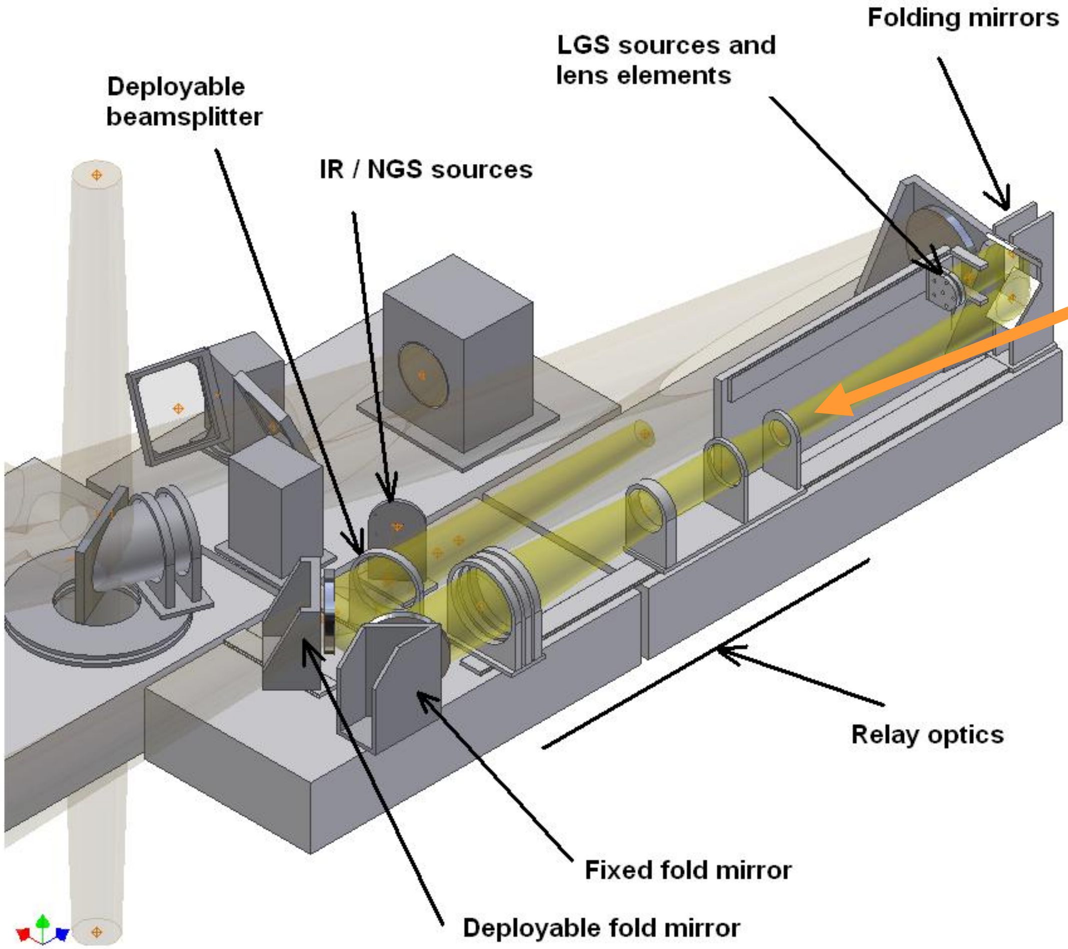
Focal Plane moves with Na Range



Visible/NGS Path WFSs



Source Simulators

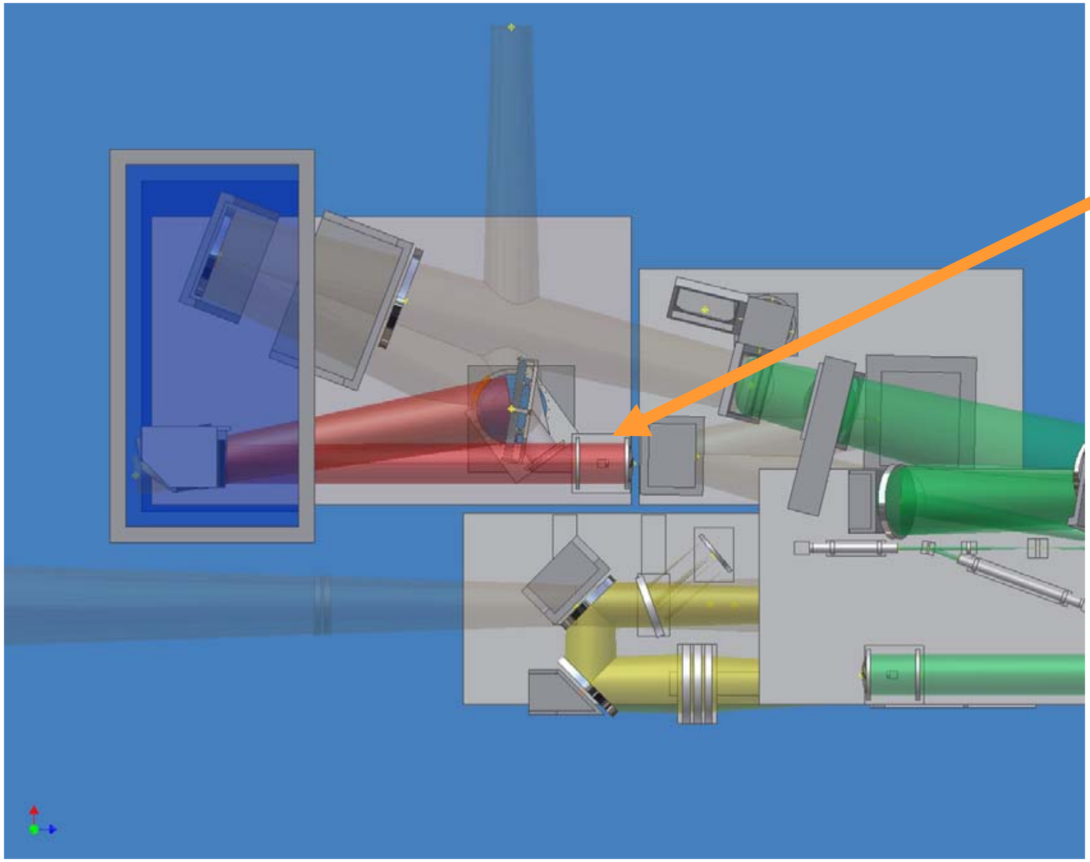


Source simulators

(Calibration Unit)

IR Acquisition Camera

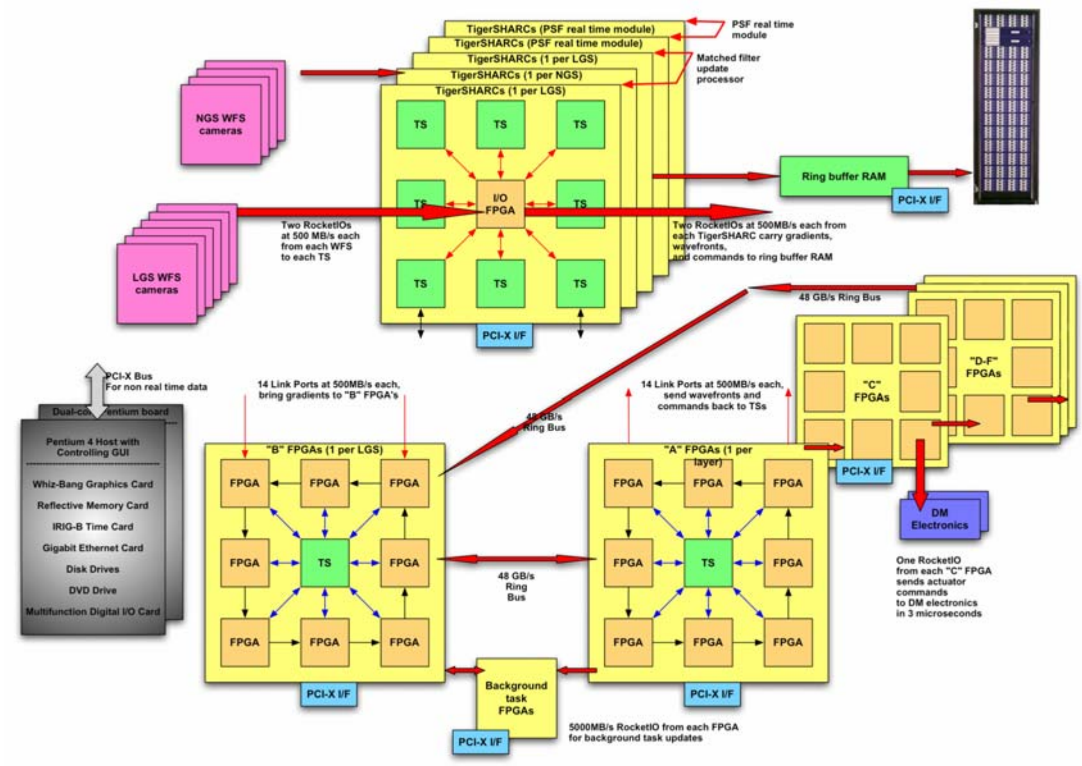
- Top view



Infrared Acquisition Camera

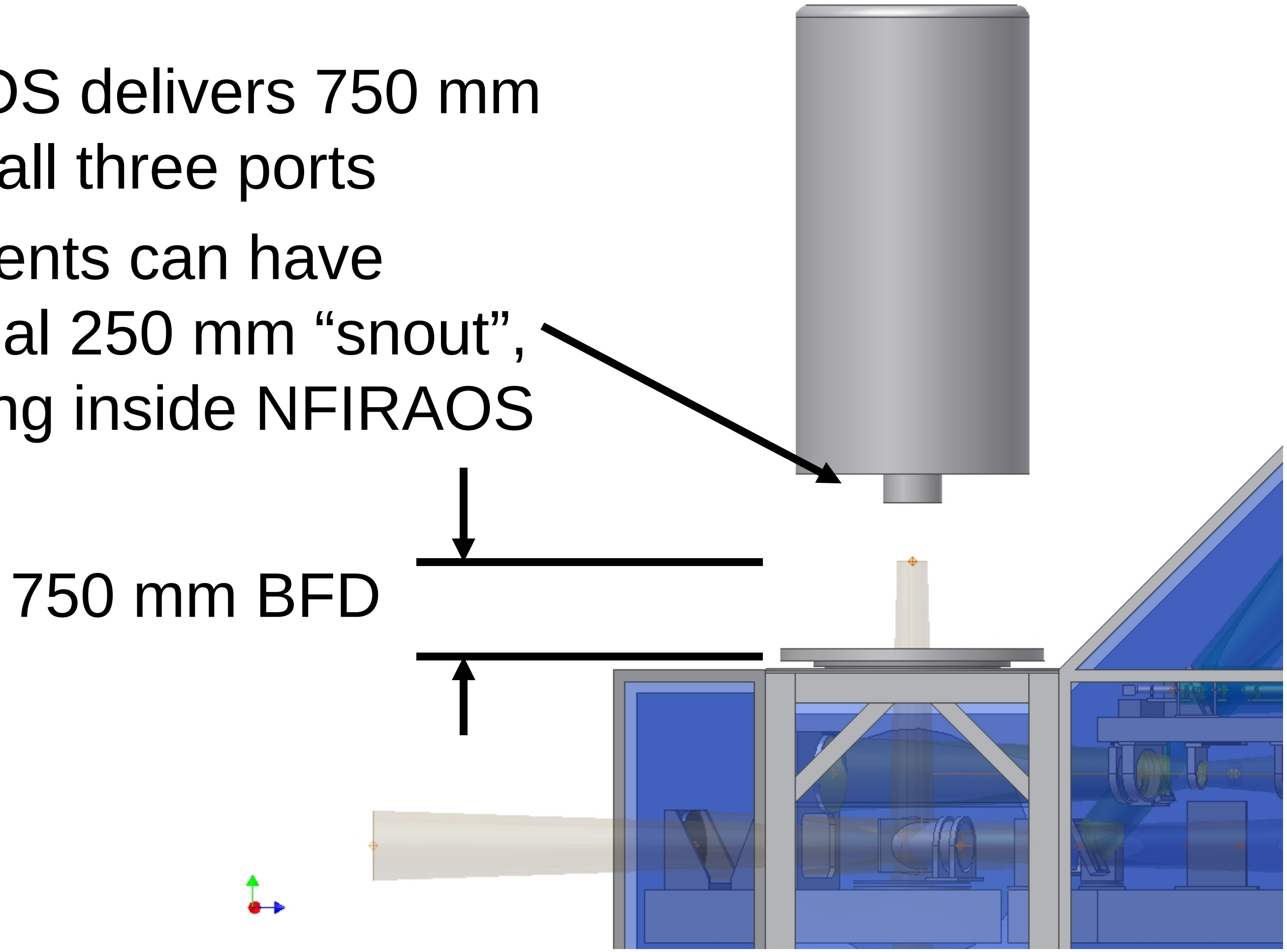
NFIRAOS.RTC
Real Time Computer

- Current matrix-vector-multiply methods not scalable to very high order TMT AO systems
- tOSC design study has demonstrated feasibility of new approaches using existing components and algorithms
  - COTS FPGA and DSP processors
  - Preconditioned conjugate gradient algorithms



Interface to Instruments

- NFIRAOS delivers 750 mm BFD at all three ports
- Instruments can have additional 250 mm “snout”, extending inside NFIRAOS



Natural Guide Star IR WFSs in instruments

- All client instruments will have choice of Near-Infrared Natural star WFSs
  - Either 2 tip/tilt NIR sensors and one 2x2 SH NIR WFS (best performance, but less convenient)
  - Or a single 2x2 tip/tilt/focus/astigmatism sensor (may confuse variable Sodium Altitude with plate scale)
- Fed by a 2 arcminute “technical field”, image sharpened by MCAO operation giving J-band Strehl 0.1 – 0.5 over technical field.

Baseline & Upgrade

- At first light, 133 nm wavefront error over a 30 arcsecond field is judged to be too ambitious and risky.
- Baseline NFIRAOS has 61x61 actuators (pitches across beamprint of a point source) on each of 2 DMs, 5 mm pitch, 9 micron stroke, correcting a 10 arcsecond field of view, with relaxed error budget.
- NFIRAOS will later be upgraded to DLIRAOS with
  - More actuators on DM conjugate to 0 km (120x120)
    - 2.5 mm pitch, but reduced stroke.
  - 4x More subapertures on LGS WFS
  - 2x Flux, and Pulsed Laser vs. baseline ~150 W CW (3 lasers, but note that baseline NFIRAOS works well with 2 lasers)
  - Adaptive Secondary mirror as “woofer” giving more stroke.

Baseline & Upgrade configurations

AO parameter		NFIRAOS Baseline	DLIRAOS Upgrade
Optimized field		10"x10" square	30"x30" square
Number of DMs		2	2
Altitude conjugate	DM0 DM12	0 km 12 km	0 km 12 km
Actuator spacing	DM0 DM12	0.5 m 0.5 m	0.25 m 0.5 m
NGS, Truth WFS, Acquis. Cam.		1 each	1 each
Number of LGS		6	6
LGS asterism		R=35" circle	R=35" circle
Frame rate		800 Hz	800 Hz
Laser power		6 beacons x 25 W =150 W CW	6 beacons, 2x flux, from pulsed lasers
AO Controller		Integrator g=0.5	Integrator g=0.5

THIRTY METER TELESCOPE

Estimated NFIRAOS+LGSF Performance at First Light

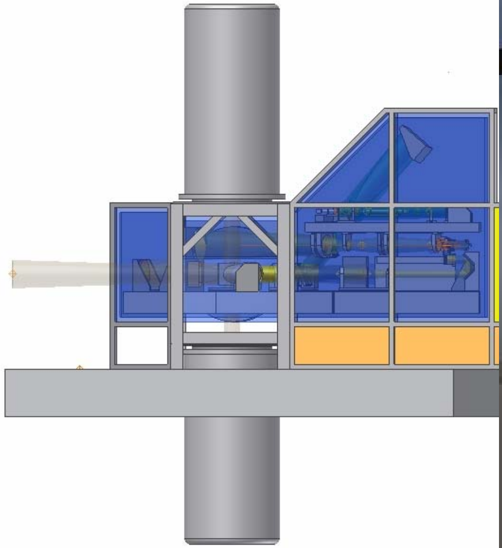
Error Budget Element, RMS nm	Field-of-View	
	On-axis	Average over 10”
Ideal AO	130	136
AO imple-mentation	89	8
Telescope	45	45
Instrument	30	30
RSS higher-order total	166	170
Two-axis Tip/tilt	85	86
RSS total	187	191

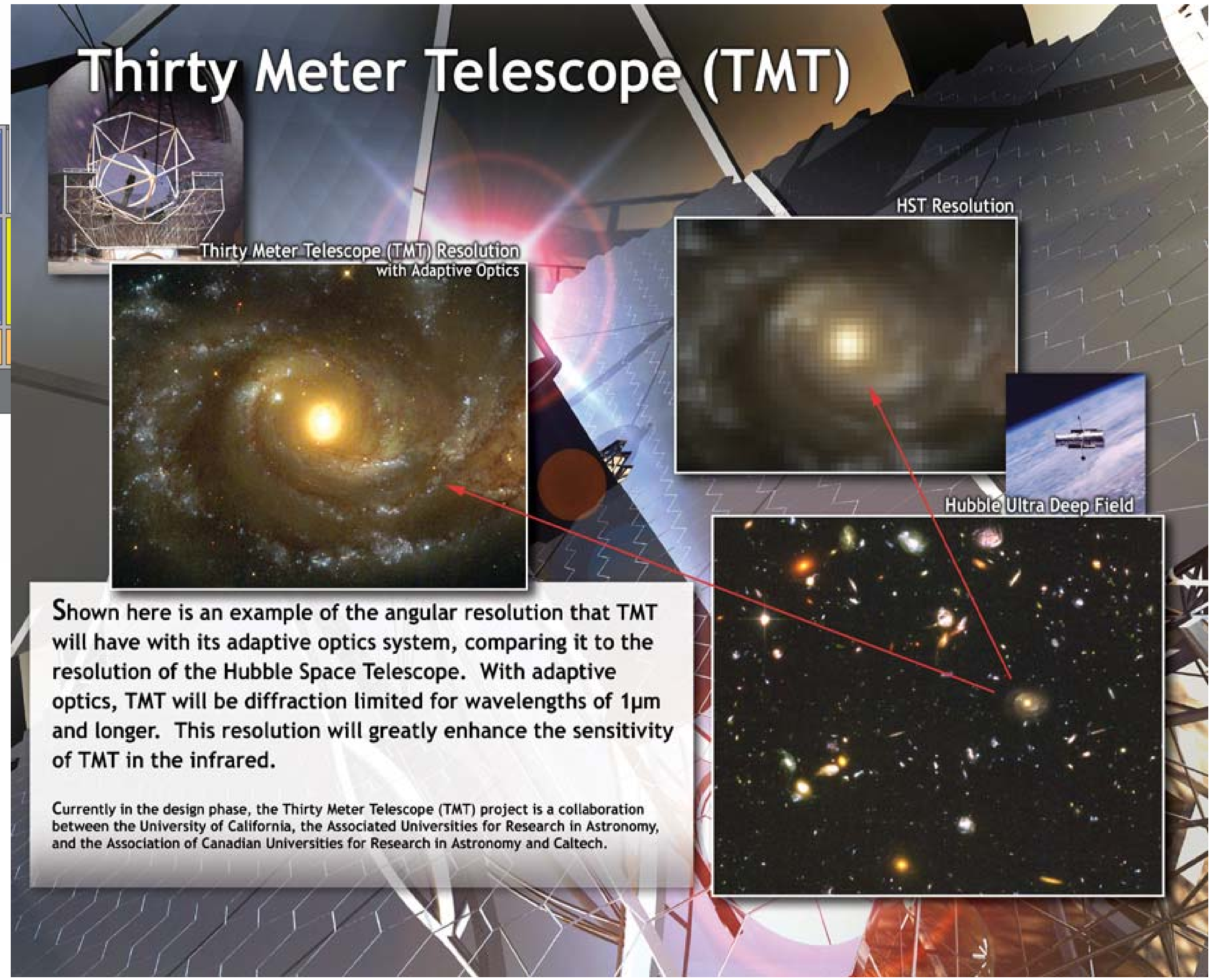
- TMT SRD atmosphere, r_0=15cm
- Two DMs conjugate to h=0 and 12 km, order 61x61 compensation
- 6 25 W LGS produced with CW lasers
- Telescope and instrument error budgets from the TMT Science Requirements Document (SRD)
- Results of extensive modeling and simulation
- Compares favorably with performance of existing AO systems on 8- to 10-m class telescopes (240-380 nm RMS)

Important Issues for PDR-Phase Modeling and Analysis

- Impact of elongated LGS
  - Improved 3-D modeling for both pulsed and CW lasers
  - Linearity and noise sensitivity of gradient estimation algorithms
- Impact of telescope amplitude/phase nonuniformities
  - Static and dynamic M1/M2/M3 aberrations
  - M1 aperture geometry and M2 supports
- Misregistration effects
  - DM actuators, WFS subapertures, telescope pupil
- Real-time wavefront reconstruction
  - Robust, efficient implementation of Fourier Domain PCG
- Impact of sodium layer variability
  - Range (focus) tracking
  - Adaptive gain/bias estimation for gradient estimation algorithms
- PSF reconstruction (estimation) in LGS MCAO systems

TMT NFIRAOS





Thirty Meter Telescope (TMT)
Thirty Meter Telescope (TMT) Resolution
with Adaptive Optics
HST Resolution
Hubble Ultra Deep Field
Shown here is an example of the angular resolution that TMT will have with its adaptive optics system, comparing it to the resolution of the Hubble Space Telescope. With adaptive optics, TMT will be diffraction limited for wavelengths of 1μm and longer. This resolution will greatly enhance the sensitivity of TMT in the infrared.
Currently in the design phase, the Thirty Meter Telescope (TMT) project is a collaboration between the University of California, the Associated Universities for Research in Astronomy, and the Association of Canadian Universities for Research in Astronomy and Caltech.