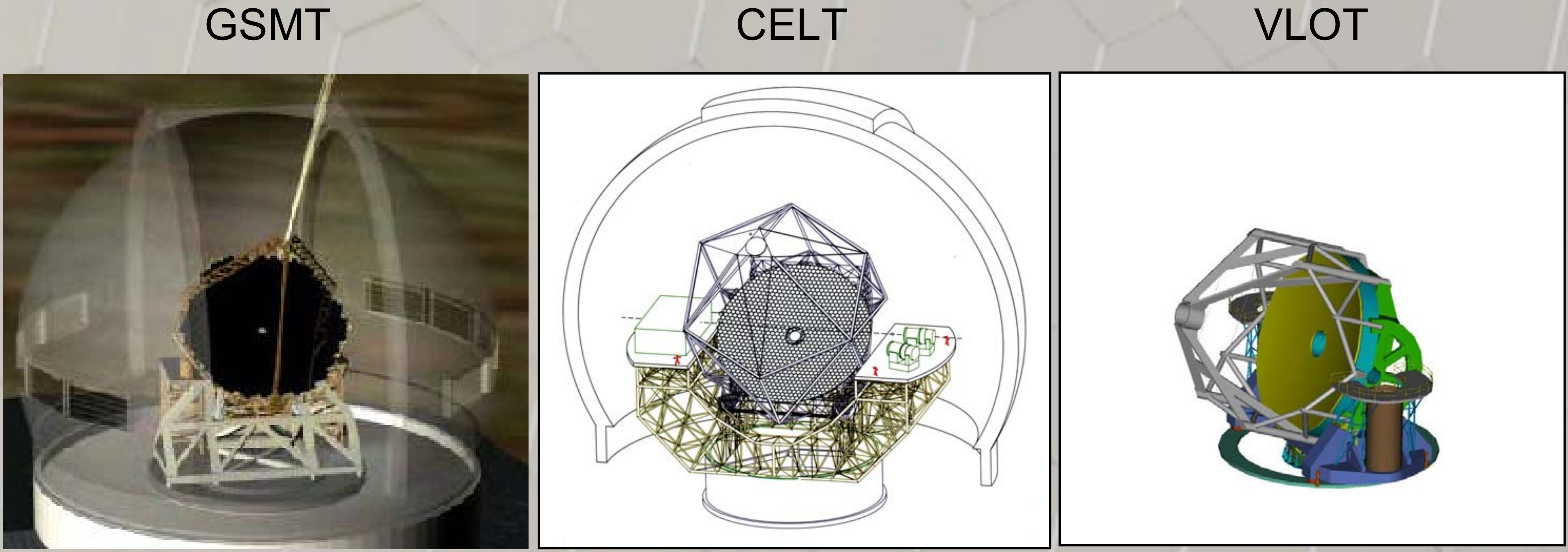
Adaptive Optics Development Plans for the Thirty-Meter Telescope Project



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AURA New Initiatives Office

Outline

- The TMT Partnership
- Science requirements and AO modes
- AO architecture options
- Scope of AO component requirements
- AO development process
  - System designs
  - Component development
  - Lab and field testing
- Summary

The TMT Project…

- Is a partnership of
  - ACURA (Assoc. of Canadian Univ.'s for Research in Astro.)
  - AURA (Assoc. of Univ.'s for Research in Astro.)
  - CELT (California Extremely Large Telescope project)
- Will combine the strengths of public and private observatories to create a 30-m diffraction-limited telescope
  - Adaptive optics is fundamental to achieving science goals
- Will work with other ELT programs to maximize community benefit from available AO development funds

Science Objectives Define Five AO Modes

AO mode	Enables	Baseline concept	Potential upgrades / alternative concepts
Mid-IR NGS (MIRAO)	Diffraction-limited resolution beyond 5 μm	Classical AO system	Infrared WFS Cyrogenic DM's
Multi-Conjugate (MCAO)	Diffraction limited resolution from 1.0 to 2.5 μm over 1-2' FOV	Multiple DM's, WFS's, and LGS's	Higher-order correction, More DM's and WFS's, Advanced guidestar constellations
Extreme (ExAO)	High dynamic range imaging	High- to very-high-order DM and WFS	Focal plane WFS Predictive reconstructors
Ground-layer AO (GLAO)	0.2-0.3" resolution over 5-10' FOV	Multiple LGS's, one moderate order DM	Pyramid-sensor-based NGS concepts
Multi-Object (MOAO)	0.1" resolution over multiple integral field units	Multiple LGS's, one DM per IFU	Pyramid-sensor-based NGS concepts

AO Architecture Options

- Adaptive secondary mirror
  - Enables low-emissivity NGS AO
  - First stage of correction for ExAO and MCAO
  - Constrains secondary mirror diameter and output focal ratio
  - Gregorian vs. Cassegrain?
  - Backup option: low-order, large stroke, more conventional DM
- Nasmyth or Cassegrain mounting for AO systems
  - Impacts mass and volume constraints
  - Fixed vs. changing gravity vector
- Options for defeating sodium LGS elongation
  1. Innovative pulse formats and dynamic refocusing
  2. Multiple launch telescope locations per guide star
  3. Higher power lasers (factor of 1.5-2.0), radial CCD arrays, extended scene wavefront sensing

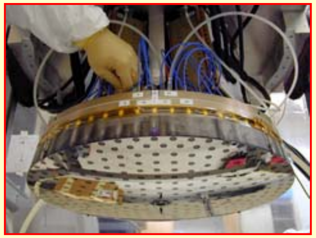
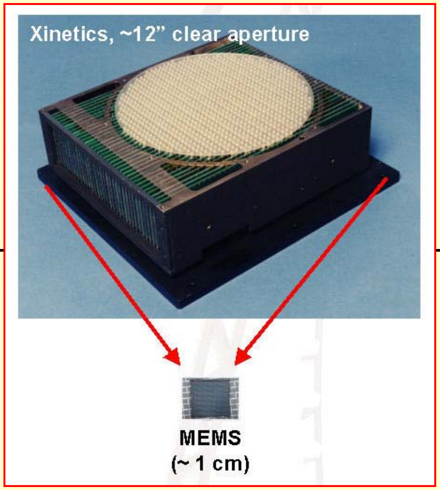
Key AO Technology Developments

🟩 Required Development

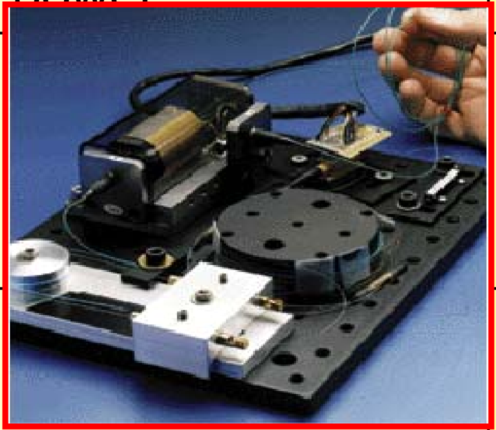
🟧 Possibly Required

	MIRAO	MCAO	GLAO	ExAO	MOAO
Improved analysis & simulation methods		🟩	🟩	🟩	🟩
Adaptive secondary mirrors	🟧	🟧	🟧	🟧	🟧
Other large adaptive mirrors		🟩	🟩	🟧	🟧
MEMS deformable mirrors				🟧	🟧
Laser guidestar beacons		🟩	🟩		🟩
Large-format, fast, low noise detectors		🟩	🟩	🟩	🟩
(Site testing of C_N^2 distribution)		🟩	🟩	🟩	🟩
Cryogenic deformable mirrors	🟧				🟧
Focal plane wavefront sensing				🟧	
Wavefront rec. & fast signal processors		🟩	🟩	🟩	🟩

Component Requirements: Deformable Mirrors

Category	Current Performance	Required Upgrade
	0.6m clear aperture, 336 actuators, 10 μm stroke 50 Hz bandwidth	2m clear aperture, 2-3k actuators, 10 μm stroke 100 Hz bandwidth
	941 actuators, 5-7 mm actuator pitch, ~4 μm stroke High bandwidth	3-10k actuators, 2-5mm actuator pitch, ~1μm stroke High bandwidth
	~100 actuators, < 1 mm pitch, ~1 μm stroke	3-10k actuators (or more), < 1 mm pitch, ~1μm stroke High bandwidth
Cryogenic DM	To be reviewed	1000+ actuators, ~1μm stoke ~100 Hz bandwidth

Component Requirements: Guidestar Lasers

Category	Current Performance	Desirable Upgrades
Sodium laser power	10-20 W equivalent CW	Up to 50W
	CW Mode locked CW	~200 μsec at ~800 Hz (to avoid Rayleigh interference) ~1-2 μsec at ~10-20 kHz (to eliminate spot elongation)
	Dye Solid-State	Fiber lasers
Rayleigh lasers	High power, short pulses, dirt cheap	None required
Beam relay systems	Mirrors and lenses	Optical fibers

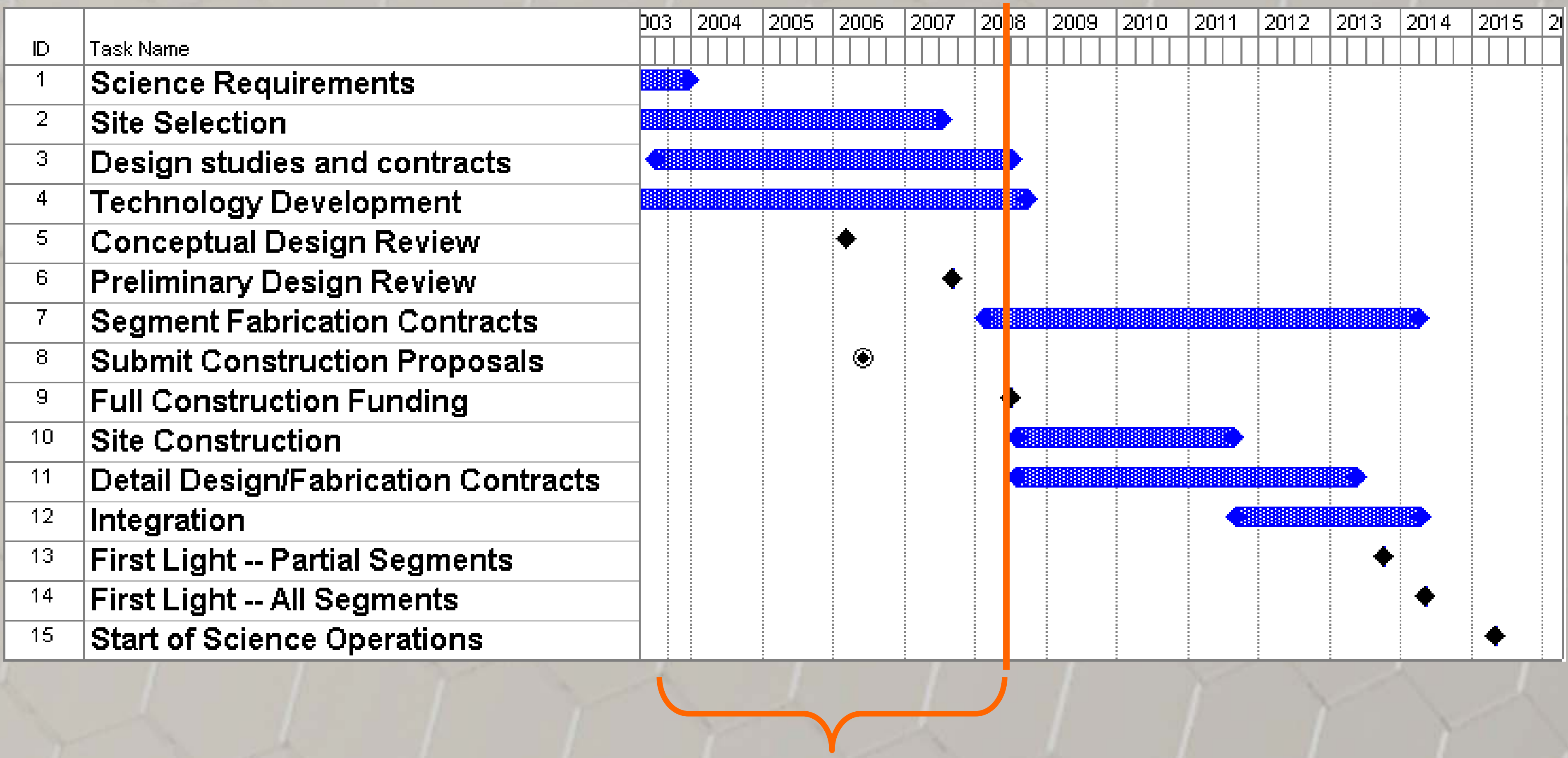
Component Requirements: Wavefront Sensors

Category	Current Performance	Potential Upgrades
Low noise CCD arrays	128^2 arrays < 1 electron	256^2 arrays <1 electron at 500-1000 Hz
Large format, high speed CCD arrays	128^2 arrays 5-7 electrons at 2500 Hz	256^2 to 512^2 arrays 5-7 electrons at 1000-2500 Hz
Special format detectors (MCAO)		"Radial" pixel geometries 60^2 to 100^2 subapertures ~2 by 6 pixels/subaperture
IR detectors for MIRAO	To be reviewed	To be determined as designs mature
Pyramid sensors for GLAO, MOAO	Proof of concept demonstrations	To be determined as designs mature
Focal plane sensors for ExAO	Concepts	To be determined as designs mature

Component Requirements: Processors and Algorithms

Category	Current Performance	Potential Upgrades
Processor Throughput	~2k inputs by ~1k outputs at ~1 kHz	MCAO: ~40k inputs by ~10k outputs at ~1 kHz ExAO: TBD
Processor Architectures	General purpose CPUs DSPs	DSPs FPGAs
Control Algorithms	Matrix vector multiplies Classical temporal filters	FFT, sparse, iterative algorithms Predictive filtering
Parallel I/O	16-port WFS CCDs	To be determined as designs mature

Proposed Program Schedule



ID	Task Name
1	Science Requirements
2	Site Selection
3	Design studies and contracts
4	Technology Development
5	Conceptual Design Review
6	Preliminary Design Review
7	Segment Fabrication Contracts
8	Submit Construction Proposals
9	Full Construction Funding
10	Site Construction
11	Detail Design/Fabrication Contracts
12	Integration
13	First Light -- Partial Segments
14	First Light -- All Segments
15	Start of Science Operations

D&D Phase

AO Development Process

- Mid IR AO and MCAO are “first light” facility capabilities
  - Design concepts and impact on telescope architecture defined by CoDR
  - Cost/performance trades well understood by PDR
  - Designs and trade studies performed by project team supported by consultants and industry
- Remaining AO modes are follow-on capabilities
  - R & D aspects mandate more extended schedule
  - Conceptual designs developed by competing teams from observatories, universities, or industry
- Component technology development will support design process
  - Must demonstrate feasibility of Mid IR AO and MCAO components by PDR
  - Phased development contracts awarded competitively
- Lab and field testing will validate system designs and performance estimates

Component Development Activities

- Near-term (commencing in 6-12 months)
  - Design and feasibility studies for adaptive secondary mirrors
  - Sodium guidestar laser technology
  - MCAO deformable mirror technology
- Likely near-to-mid-term (commencing in 6-18 months)
  - High speed, low noise, and/or special format WFS detector arrays
  - Signal processor architectures
- Will take cognizance of ongoing related activities
  - NSF Adaptive Optics Development Program
  - NSF- and Gemini- supported laser development
    - Keck I laser system
    - Gemini South laser system
    - R & D in ELT laser technologies
  - CfAO supported development of MEMS DMs
  - ESO AO R & D

Design validation

- Successful AO is essential for meeting TMT science goals
  - Analysis and simulations are the primary systems engineering tools
  - However, experience indicates that innovative AO systems miss their initial performance specifications
  - Prototyping major architectural and component advances reduces cost and risk
- For many observations, loss of Strehl is equivalent to reducing telescope diameter
- TMT will aggressively pursue laboratory and field demonstrations to mitigate risks for new architectures and components

Lab and Field Tests

- **Architectural elements to be demonstrated**
  - Wavefront sensing
    - 4-channel tomography sensor (Palomar, Gemini South)
    - Pyramid sensor prototype (LAO)
    - High-contrast testbed (LAO)
    - Segmentation and antialiasing (Keck)
  - DM configuration
    - MCAO (LAO, U Vic, Gemini South)
    - Woofer/tweeter DM operation (Palomar)
    - High-incidence angle DM operation (Palomar)
  - LGS configuration
    - Off-axis projection (Keck, Palomar)
    - Range gating bandwidth improvement (Palomar)
    - Uplink compensation (Gemini, Palomar)

- **Components to be lab / field tested (current, partial list)**
  - MEMS DMs (LAO, Keck)
  - Macro DMs (LAO,Palomar)
  - Sodium lasers
    - Micropulse/macropulse (Palomar)
    - LLNL fiber laser (TBD)
    - New Gemini South and Keck I lasers
  - Low-noise infrared wavefront sensors (Caltech, UCLA)
  - New visible wavefront sensor
  - detectors (TBD)
  - Dispersion correctors (TBD)
  - Efficient reconstructors (Palomar, LAO, Gemini South)

Summary

- ACURA, AURA, and CELT have formed the TMT partnership to design and build a diffraction-limited 30-meter telescope
- AO is central to meeting science requirements
  - Dramatic advances required in all component technologies
  - Mid IR NGS AO and MCAO as first light facility capabilities
  - ExAO, GLAO, and MOAO are next generation options
- TMT system PDR is scheduled in 48 months
  - Evaluate design options and costs
  - Aggressively develop necessary component technologies
  - Demonstrate system concepts and performance via lab and field tests