The California Extremely Large Telescope

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GSMT Science Working Group
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Desire for larger telescopes

- History shows largest telescope diameter doubles every 31 years
  - 2.5m 1917 Hooker
  - 5m 1948 Hale
  - 10m 1993 Keck

- 2001 NAS decadal astronomy and astrophysics survey committee (AASC) recommended a 30-m telescope (GSMT) as its highest ground based priority

- Other groups in the US and in Europe are thinking and talking about giant telescopes (up to 100-m) on the ground

- Advances in adaptive optics makes this particularly exciting
QuickTime™ and a Photo - JPEG decompressor are needed to see this picture.
Predicting the Future

- **The KPNO 25 m telescopes studies (~1980)**
  - Steerable Dish
  - Multiple telescope Telescope
  - Shoe
  - Mailbox
  - Singles Array (6 x 10 m, 100 x 2.5 m)

- **NGST (studies now, launch ~ 2010)**
  - 8 m from 2.5 m (*descoped to 5.6m*) very large increase in size
  - 50° vs 273° cryogenic telescope
  - L2 orbit vs low earth orbit distant, difficult orbit
  - Communications distant, high bandwidth
  - detector arrays very ambitious detectors
FOUR CONCEPTS
FOR A
NEXT GENERATION
TELESCOPE
Predicting the future

- **Proposed Future Ground Based Telescopes**
  - California Extremely Large Telescope (CELT) 30 m
  - 20/20 (University of Arizona study) 30 m equivalent
  - Euro 50 (Lund University study) 50m
  - OWL (ESO study) 100m

- **Major Issues (mainly cost)**
  - mass production of optics
  - active control
  - adaptive optics
  - science instruments
  - structural issues
  - enclosure/ weather protection
California Extremely Large Telescope

- CELT is a study to build a 30-m telescope
- UC and Caltech are partners
- Funding is not yet in hand
  - Proposal for phase 2 (technology development and preliminary design) being written
- Site is unknown (several candidates)
Brief History of CELT

- Feb 1999    Nelson describes possibilities of an extremely large telescope to Canadian survey committee
- June 1999   Nelson describes technical issues and ideas for making a 25-m telescope at the Backaskag meeting in Sweden
- June 1999   UC and Caltech strongly support a joint effort to design and build an ELT
- 2000        AASC decides to recommend a 30-m ground based telescope (GSMT)
- Sept 2000   Official start of CELT conceptual design effort
- April 2002  Completion of CELT conceptual design (publish “Greenbook”)
Brief History of CELT-2

• May 2002   External Review Committee for CELT (Moses committee)
  – Recommended to UC and Caltech that design was sound and they should support the next phase of development

• Fall 2002   political difficulties between UC and Caltech
  – UC and Caltech submit independent proposals to Moore Foundation for Phase 2 support

• Mar 2003   UC and Caltech agree to partner and form CELT corporation

• Mar 2003   CELT interested in partnering with AURA to develop a 30-m telescope
Key Assumptions for CELT Design

• **Historical experience (Keck +…)**
  – Prime focus in low demand
  – Cassegrain focus a servicing and maintenance complexity
  – Instruments prefer a large working area (also allows for future uncertainties)
  – Instrument exchanges are difficult and a maintenance issue
  – Demand for thermal IR science is modest
  – Interferometry is complex and demand is modest
  – Diffraction limited capability strongly desired

• **Simplifying assumptions for CELT**
  – Single aperture
  – No prime focus (reduces size, simplifies servicing)
  – No cassegrain focus (simplifies instrument exchanges, servicing)
  – Large Nasmyth platforms (carry multiple instruments, all accessible)
  – Thermal IR (emissivity) will be secondary design driver
  – AO system is important
CELT and Stonehenge
CELT Optical Design

- **Primary is 30m in diameter**
  - 1080 segments, 1m dia each
  - Shape actively controlled (segment piston, tip, tilt)
  - f/1.5 hyperbola

- **Final: f/15 Ritchey-Chretien**
  - Secondary 3.9m in diameter
  - 20 arc minute field of view with 0.5 arc second images
  - 1 arc minute FOV with 0.001 arc second images (design)

- **Instruments at Nasmyth platforms**
  - Articulated tertiary allows direct feed to multiple instruments with no additional optics (3 mirrors total)
  - 2 platforms: 15x30 m
  - Possible lower or upper platforms
Cluster geometry

Most circular layout
CELT structural design

- Main structural design by S. Medwadowski
- Space frame concept
- Upper truss uses tension and compression members
- Hydrostatic bearings
- Lowest natural frequency ~ 2Hz (hoping to improve)
Segment Fabrication

• **Segments are off axis sections of hyperbola**
  
  – Requirements: ~ 20 nm rms surface (better than Keck)
  – ~ 20 µm deviation from sphere (Keck was ~ 100µm)
  – Stressed mirror polishing (oap to sphere)
  – Planetary polishing to increase efficiency (simultaneous polishing)
  – Low expansion material
  – Final corrections with ion figuring

  – In telescope warping harnesses (hopefully not)
  – In telescope AO will correct low order errors
Planetary polishing to produce 1000 segments
Proposed CELT Stressed Mirror Polishing Set-up

Arrows indicate force direction and magnitude required to create / remove astigmatism.
asphericity vs focal length, segment radius

segment radius (m)

primary focal ratio

asphericity ~ \( \frac{a_2}{k_3} \)

10\( \mu \)m

20\( \mu \)m

50\( \mu \)m

100\( \mu \)m

200\( \mu \)m

harder

GSMT

CELT
Active Control

- **Active control algorithm (details by G. Chanan)**
  - Same idea as Keck: edge sensors, actuators, least squares fitting
  - Error propagation calculated to be acceptable: ~ 20x sensor noise

- **Edge sensors**
  - Need low cost
  - Need no mechanical interlock
  - Solution is edge sensors on edge faces of segments
  - Much less expensive, also measures edge tilt

- **Actuators**
  - Keck actuators expensive, used roller screw
  - Present CELT idea is voice coil actuator
  - Much less expensive
Active Control Summary

Selected $a = 0.5 \text{ m}$ for segment size

<table>
<thead>
<tr>
<th>Item</th>
<th>Keck</th>
<th>CELT</th>
</tr>
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<tbody>
<tr>
<td>segment size</td>
<td>0.9m</td>
<td>0.5m</td>
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<tr>
<td># segments</td>
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<td>1080</td>
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<tr>
<td># edge sensors</td>
<td>168</td>
<td>6204</td>
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<tr>
<td># actuators</td>
<td>108</td>
<td>3240</td>
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</table>
Principle of active control with edge sensors

- Actuator (piston)
- Sensor (measures height difference)

Sensor signal depends only on motion of two neighbor segments

\[ s = a_1 P_1 + a_2 P_2 + a_3 P_3 + a_4 P_4 + a_5 P_5 + a_6 P_6 \]

\( a \) are constant coefficients that depend only on geometry
Mode Noise Multipliers for Keck-Like Sensors

![Graph showing Mode Noise Multipliers for Keck-Like Sensors with different modes and sensor configurations. The graph plots Mode Noise Multiplier against Mode Number. The sensors include Keck, 7 Rings, and CELT.](image-url)
Keck Sensor Geometry

Mirror Segment

Sensor Paddle

Sensor Body

Sensor Mount

Conducting Surfaces

R = 35 m

7.5 cm

2 mm

L

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Proposed CELT Sensor Geometry

Non-Interlocking Sensors
Voice coil actuator
Enclosures

Design options under study (from NIO)
CELT Issues

- Want greatest science yield for lowest practical cost
- Issues
  - Review elimination of prime and cassegrain foci
  - Determine optimal location of elevation axis
  - Determine optimal f-ratio of primary
  - Determine optimal segment size
  - The above depend critically on segment fabrication and active control
  - Understand impact of wind disturbance on performance
  - Review importance of thermal IR
  - Select site
  - Assess feasibility and costs of science instruments
  - Develop needed AO designs and components
End of Talk