CCAT: Overview & Status

Large Aperture Millimeter/Submillimeter Telescopes in the ALMA Era
Osaka Prefecture University
12-13 Sept, 2011
Guiding Principles

- Scientific excellence
- Designed to take advantage of fast-moving detector technology
  ➤ Fast surveyor
- At the best possible, easily serviceable Earth location with full coverage of Equatorial skies
- High synergy with (and enabler to) ALMA
- Synergy among partner institutions
  ➤ Nimble, University-led facility, with top instrument-building groups

A joint project of Cornell University, the California Institute of Technology, the University of Colorado, the Universities of Bonn & Cologne, a consortium of 9 Canadian Universities and Associated Universities, Inc.
Telescope concept

HWFE<10μm rms, PE<0.35” rms

- Active surface with 0.5m Al tiles on 2m CFRP subframes
- CFRP truss
- Steel EL structure
- Tertiary
- Direct EL drive
- Direct AZ drive
- Pintle bearing
- CFRP tripod
- Segmented secondary
- 3m diameter Nasmyth tube holds 1° FoV instruments
- Hydrostatic EL bearing
- Hydrostatic AZ bearing
- Steel alidade

AcKve	
  surface with
0.5m Al Kles on 2m
CFRP subframes

CFRP	
  tripod

Segmented
  secondary

3m diameter
Nasmyth tube
holds 1° FoV
instruments

Hydrostatic
  EL bearing

Hydrostatic
  AZ bearing

Steel alidade
All CCAT instruments will be on line all the time. Select instruments by changing pointing.
Can support 2 large instruments, or many smaller instruments, e.g., a wide field spectrometer in one tube & cameras in the other tube (maybe a submm camera on axis, surrounded by mm cameras).

3m dia for 1° FoV

0.8° FoV available on Nasmyth platform.
# CCAT Performance Requirements

<table>
<thead>
<tr>
<th>Contribution</th>
<th>HWFE (µm rms)</th>
<th>PE (arcsec rms)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aberrations</td>
<td>3.65</td>
<td>0.00</td>
<td>Ritchey-Chretien design</td>
</tr>
<tr>
<td>Primary open-loop</td>
<td>7.21</td>
<td>0.03</td>
<td>CFRP truss</td>
</tr>
<tr>
<td>Primary closed-loop</td>
<td>7.48</td>
<td>0.52</td>
<td>Steel truss</td>
</tr>
<tr>
<td>Secondary</td>
<td>6.28</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Tertiary</td>
<td>4.45</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Instrument</td>
<td>0.05</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Mount</td>
<td>0.00</td>
<td>0.09</td>
<td>No HWFE from mount</td>
</tr>
<tr>
<td>Alignment</td>
<td>2.19</td>
<td>0.10</td>
<td>Regular pointing with science camera,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>occasional wavefront measurements with WFS</td>
</tr>
<tr>
<td>Telescope RSS open loop</td>
<td>11.37</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>Telescope RSS closed-loop</td>
<td>11.55</td>
<td>0.58</td>
<td></td>
</tr>
<tr>
<td>Telescope requirement</td>
<td>10.00</td>
<td>0.35</td>
<td>&lt;50% increase in integration time, PE&lt;1/10th beam, from CCAT-TM-48</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>5.74</td>
<td>0.23</td>
<td>1st quartile</td>
</tr>
</tbody>
</table>

## Observatory parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>350</td>
<td>µm</td>
<td>3rd quartile</td>
</tr>
<tr>
<td>Mean outside wind speed</td>
<td>6</td>
<td>m/s</td>
<td>3rd quartile</td>
</tr>
<tr>
<td>Wind speed for pressure</td>
<td>8.484</td>
<td>m/s</td>
<td>$2^{1/2}v_{outside}$ see CCAT-TM-56</td>
</tr>
<tr>
<td>Density of air</td>
<td>0.7</td>
<td>kg m$^{-3}$</td>
<td>At 5600 m altitude</td>
</tr>
<tr>
<td>Scan acceleration</td>
<td>0.4</td>
<td>deg s$^{-2}$</td>
<td>0.4 deg s$^{-2}$ if $\lambda$&lt;620µm, else 2 deg s$^{-2}$, from CCAT-TM-48</td>
</tr>
<tr>
<td>rms temp gradient in dome</td>
<td></td>
<td>K</td>
<td>From TMT CFD</td>
</tr>
<tr>
<td>Soak temp change</td>
<td>20</td>
<td>K</td>
<td>Diurnal &amp; longer</td>
</tr>
<tr>
<td>Flux density of pointing source</td>
<td>0.1</td>
<td>Jy</td>
<td>For &gt;1 source/deg$^2$, $S&lt;0.3$Jy at $\lambda$=350µm and $S&lt;40$mJy at $\lambda$=850µm, see Fig. 4.9 in feasibility study</td>
</tr>
<tr>
<td>Pointing integration time</td>
<td>120</td>
<td>s</td>
<td>&lt; a few min for reasonable observing efficiency</td>
</tr>
<tr>
<td>Field angle</td>
<td>0.08</td>
<td>deg</td>
<td></td>
</tr>
</tbody>
</table>
CCAT truss designs

Ring & pillar
30,000 kg truss
12,000 kg segments
(25 kg m\(^{-2}\))
7-8 Hz

Stutzki Engineering
CCAT bearing & truss options

Ring & pillar

3d

Hydrostatic bearings

Rolling element bearings

General Dynamics
Finite element models

Ring & pillar

3d
### FEA results

<table>
<thead>
<tr>
<th>Load case</th>
<th>zenith</th>
<th>EL=20°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>μm rms</td>
<td>μm rms</td>
</tr>
<tr>
<td>Gravity</td>
<td>287</td>
<td>276</td>
</tr>
<tr>
<td>0.4°s^{-2} acceleration</td>
<td>1.7</td>
<td>1.3</td>
</tr>
<tr>
<td>20K soak</td>
<td>3.8</td>
<td>5.0</td>
</tr>
<tr>
<td>1K vertical</td>
<td>0.2</td>
<td>0.7</td>
</tr>
<tr>
<td>1K horizontal</td>
<td>0.9</td>
<td>0.9</td>
</tr>
</tbody>
</table>

### Analytical model

<table>
<thead>
<tr>
<th>Load case</th>
<th>zenith</th>
<th>EL=20°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>μm rms</td>
<td>μm rms</td>
</tr>
<tr>
<td>gravity</td>
<td>360</td>
<td>187</td>
</tr>
<tr>
<td>0.4°s^{-2} acceleration</td>
<td>2.3</td>
<td>1.5</td>
</tr>
<tr>
<td>20K soak</td>
<td>69.2</td>
<td>69.2</td>
</tr>
<tr>
<td>1K vertical</td>
<td>0.7</td>
<td>1.7</td>
</tr>
<tr>
<td>1K horizontal</td>
<td>1.8</td>
<td>1.8</td>
</tr>
</tbody>
</table>
# Bearing Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Wheel</th>
<th>Hydrostatic</th>
<th>Rolling</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>m</td>
<td>18</td>
<td>18</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Friction torque</td>
<td>kNm</td>
<td>99.9</td>
<td>9.0</td>
<td>123.9</td>
<td>3kNm for wrap + 4kNm for pindle</td>
</tr>
<tr>
<td>Axis stiffness (3d)</td>
<td>kNm/arcsec</td>
<td>360</td>
<td>360</td>
<td>612</td>
<td></td>
</tr>
<tr>
<td>Axis stiffness (ring)</td>
<td>kNm/arcsec</td>
<td>599</td>
<td>599</td>
<td>659</td>
<td></td>
</tr>
<tr>
<td>PE due to friction (3d)</td>
<td>arcsec</td>
<td>0.28</td>
<td>0.03</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>PE due to friction (ring)</td>
<td>arcsec</td>
<td>0.17</td>
<td>0.02</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>Repeatable PE</td>
<td>arcsec rms</td>
<td>3.0</td>
<td>3.0</td>
<td>1.25</td>
<td>0.25mm track error, rolling bearing PE seems small (cf 2” in SPT)</td>
</tr>
<tr>
<td>Non-repeatable PE</td>
<td>arcsec rms</td>
<td>1.3</td>
<td>0.2</td>
<td>0.12</td>
<td>10μm rms oil film variation, 10% of repeatable for rolling</td>
</tr>
</tbody>
</table>

Baseline hydrostatic bearings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Hydrostatic</th>
<th>Rolling</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friction torque</td>
<td>kNm</td>
<td>2.0</td>
<td>55.5</td>
<td>3kNm for wrap + 4kNm for pindle</td>
</tr>
<tr>
<td>Axis stiffness (3d)</td>
<td>kNm/arcsec</td>
<td>43.7</td>
<td>63.0</td>
<td>From finite element model</td>
</tr>
<tr>
<td>Axis stiffness (ring)</td>
<td>kNm/arcsec</td>
<td>167</td>
<td>261</td>
<td></td>
</tr>
<tr>
<td>PE due to friction (3d)</td>
<td>arcsec</td>
<td>0.05</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td>PE due to friction (ring)</td>
<td>arcsec</td>
<td>0.01</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td>Repeatable PE</td>
<td>arcsec rms</td>
<td>4.4</td>
<td>7.4</td>
<td>4.4” shaft runout, 3” bearing runout</td>
</tr>
<tr>
<td>Non-repeatable PE</td>
<td>arcsec rms</td>
<td>0.3</td>
<td>0.3</td>
<td>10μm rms oil film variation, runout across 14m for rolling bearings</td>
</tr>
</tbody>
</table>
Primary surface control

EL=45°, 1μm rms edge sensor noise, no secondary position sensor noise

Perturbed wavefront

Controlled wavefront

1g

20K soak

1K vertical gradient
Keystone-shaped segments were originally chosen to give the option of replicating tiles.

For a simple 3-point support, segment size is limited to ~2m, so 6 rings, for a total of 162 segments.
Actuator concept

Stepper + 80:1 gearbox + nut
Linear encoder on screw between output bearings
Linear bearings to support the output shaft
Current CCAT Organization

CCAT Engineering Design Phase Organization Chart

CCAT Corporation
Board of Directors

Project Director
Riccardo Giovanelli

Project Manager
Jeff Zivick

Chief Engineer
Steve Padin

CCAT Science Group
Project Scientist: Jason Glenn
Gordon Stacey
Frank Bertoldi
Tom Phillips
Peter Schilke
Rene Plume

Science Software Architect

Instrument Manager

Instrument Engineer

Instrument Common SW

Administrative Assistant

Business Manager

Chilean Activities
AUI

Systems Engineer

Scripts & User I/F

Telescope Engineer

Truss Engineer

Mount Engineer

Telescope Control S/W
CCAT Historical Perspective

2003: Cornell proposes concept to Caltech; Collaboration workshop in Pasadena

2004: MOU signed by Caltech and Cornell; Project Office established at Cornell; Feasibility study initiated.

2005: Feasibility study executed

2006: Feasibility study review

2006-2010: Expand partnership (U Colo, U Cologne, U Bonn, Canada); Finalize site selection; Review high risk issues; Initiate preliminary engineering trade-off analyses; Astro2010; Step up fundraising.
CCAT Feasibility Review

Review Panel:

Robert Wilson (Harvard-Smithsonian, Chair)
Mark Devlin (Penn)
Fred Lo (NRAO)
Matt Mountain (STScI)
Peter Napier (NRAO)
Jerry Nelson (UCSC)
Adrian Russell (ALMA, NA)

“CCAT is an important and timely project that will make fundamental contributions to our understanding of the processes of galaxy, star and planetary formation, both on its own and through its connection with ALMA. It should not wait.”
New Worlds, New Horizons in Astronomy and Astrophysics

Committee for a Decadal Survey of Astronomy and Astrophysics

National Research Council

“Only one medium project is called out, because it is ranked most highly. Other projects in this category should be submitted to the Mid-Scale Innovations Program for competitive review.” pg 7-37

The one project is CCAT.

“CCAT is called out to progress promptly [...] because of its strong science case, its importance to ALMA and its readiness.” pg 1-12 & 7-38

Recommends that US National Science Foundation participate in CCAT with funding 1/3 of construction costs.
CCAT Looking Ahead

2011-2013: NSF proposal review;
   Engineering design phase (telescope, instruments, enclosure, site);
   Assemble project staff;
   Prototype development of key components;
   Demonstration testing of essential functionality (control algorithms, wavefront sensing technique, instrument detectors);
   Construction of improved access road and site infrastructure;
   Establish CCAT Corporation.

2013: Critical Design Review.

2013-2017: Construction ➔ First light
CCAT Budget

CCAT was asked to provide Astro2010 detailed information to be used for the CATE process carried out by the Aerospace Corp.

Their estimates of the cost and time to completion of construction were higher than the project team’s:

- $140M vs. $110M
- 2020 vs. 2017

(Construction costs include $20M towards first-light instrumentation)

Over last 5.5 yr the CCAT project $ burn rate has been $1-2M/yr, adding up to $8.0M to date, fully funded by partners.
CCAT Support at U.S. national level

Nov 2010: Proposal submitted to US NSF asking $4.85M (~45% of total estimated cost) to complete EDP by early 2013

May 2011: NSF communicates that an award of $4M will be made

June 2011: NSF communicates that the award will be $4.5M

1 Aug 2011: award for first year ($2.5M) transferred to Cornell

…while at the private level…
$11M gift for Atacama telescope will help astronomers answer fundamental questions about galaxy, star formation

By Lauren Gold

Retired businessman Fred Young ’64, M.Eng. ’66, MBA ’66, has committed $11 million to CCAT, the Cerro Chajnantor Atacama Telescope, a proposed 25-meter aperture telescope that will be the largest, most precise and highest astronomical facility in the world.

The Department of Astronomy announced the gift Nov. 12 at a workshop for CCAT scientists. Vice Provost for Research Robert Buhrman called it "a beautiful day in Ithaca, a great day for astronomy and a great day for Cornell."

Provost Kent Fuchs, left, introduces benefactor Fred Young ’64, who committed $11 million to support the CCAT telescope, at a workshop for CCAT scientists.