CCAT Primary Mirror Overview

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Recent Examples Radio/Optical

Telescope	Panel Shape	Material	Fabrication	Mounting	Figure (RMS μm)
Caltech Submm Obs	Hexagonal	Aluminum	Machined as Parent	Active, Open Loop. Kinematic	~15
H. Hertz Telescope	Radial	CFRP/Al Sandwich	Replication & Bonding	Passive & Overconstrained	~15
ALMA/APEX (VRSI)	Radial	Aluminum	Machined as Panels	Passive & Overconstrained	~20
ALMA Alcatel/EIE	Radial	Electro-Ni/AL Sand.	Replication & Bonding	Passive & Overconstrained	~20
Keck Telescopes	Hexagonal	Zerodur	Stressed Lap & Ion	Active, Closed, Kinematic	~0.03
Hobby Ebberly	Hexagonal	Zerodur	Planetary & Ion Figuring	Active, Closed, Kinematic	~0.045
SALT	Hexagonal	Sittal (Fused Qz)	Planetary & Ion Figuring	Active, Closed, Kinematic	~0.045

We Have Assumed that CCAT Must be Segmented…okay?

ALMA Approach: Not Adequate

- Initial Error Budget Allocations
  - ALMA 2x Worse ½ Wavefront Error Than Required
  - ALMA 12 m Diameter vs. CCAT 25 m Diameter
- Mirror Mounting Strategy
  - ALMA: Panels Mounted on 5 Points to Structurally Rigid CFRP Support Structure
  - 25 Meter Structure Would Not be Sufficiently Rigid
  - Cost of CFRP PM Truss 5x Greater than Steel ($10m)*
- Opinion of Vertex ALMA Telescope Builders
  - "ALMA Technology Unlikely to Meet Requirements."

* Independent Estimates of MERO and ATK

Conclusions on General Approach

- Active Panel Positioning Would be Required
  - Gravity Driven Deflection of Even CFRP Truss Too Large
  - Success of Optical Segmented Telescopes Illustrates Feasibility
- Use of Steel Truss Prohibits Overconstrained Mounting
  - Local Truss Deformations Would Degrade Panel Figure
  - Hence Panels Should Self-Determine Figure Like the Optical Telescopes
- Kinematic Panel Mounting via Bipod Flexures
  - Multi-Point Whiffle Tree Mounts a Challenge
  - Expense, Hysterisis, Part Count
  - Separate Axial/Lateral Load Bearing Difficult
  - Problems with Keck, HET, SALT Mounts

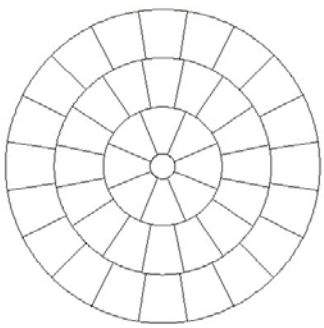
Panel Shape

- Hexagonal Segments
  - Less Deflection for Kinematic 3 Point Mounting
  - Only 6 Identical of Each Type: (~35 Different Types)
  - Don't Regularly Tile Surface of Revolution
  - Don't Form Smooth Inner/Outer Edges (Wasted Area)
- Radial Segments
  - Not a Favorable Shape for 3 Point Support
  - Only 6-7 Different Types of Panels
  - Identical Perimeter Shapes for Each Type
  - Full Area of Panels Useable to Inner/Outer Edges

Conclusion: If Radial Panels Would Exhibit Acceptable Deformation on 3 Point Mounts Then Better In Other Regards

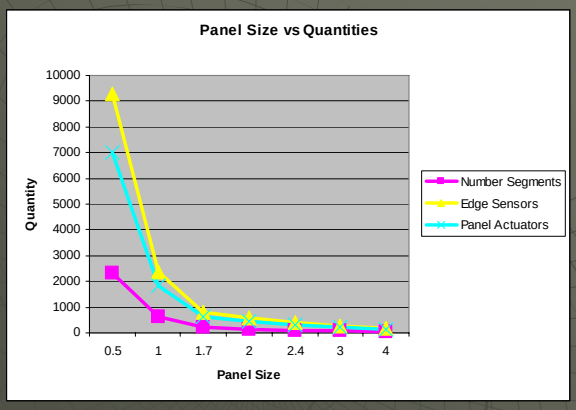
Segmentation

To 4 meter Panels



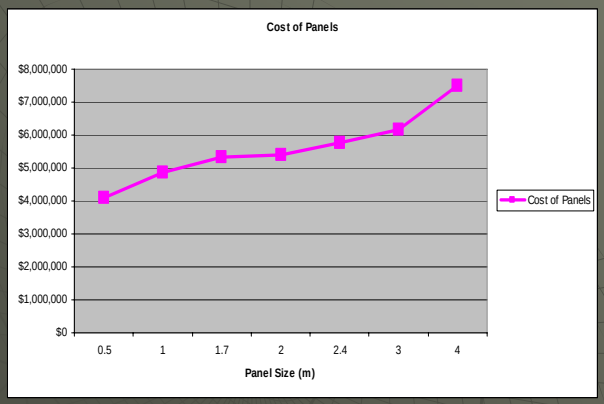
We Looked at Various Segmentation Schemes

Assessment of Number of Panels, Edge Sensors, and Actuators



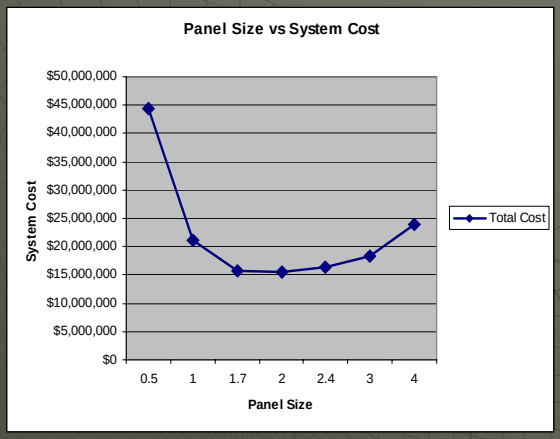
- Total Number of Panels Grows Rapidly as Panels Get Smaller
- Number of Edge Sensors and Actuators Required Grow Even Faster

Total Panel Cost Scaled by Size



- Using Estimated Cost for Replication of 1.7 m Panels as Baseline
- Panel Costs Scaled with Size $(D1/D2)^{2.2}$

When Adding Other Costs



- Includes:
  - Mandrel's Cost Scaled by Size (Ratio of Panel Size)$^{2.5}$
  - Edge Sensors
  - Actuator's Cost Scaled (Ratio of Panel Size)$^{0.75}$

Supports Usual Contention that There is a Range of Panel Sizes Over Which Number/Size/Infrastructure Roughly Cancel

Other Considerations in Panel Size

- Mandrels are Convex and Need to be Accurate to <1 µm RMS
- In Sizes Larger than 2m Only a Couple of US Fabricators Could Bid…Probably Very Expensive
- Initial Study Specified 2m Panel Sizes
- Based on Panel Study Results We Anticipate ~1.7m Panels

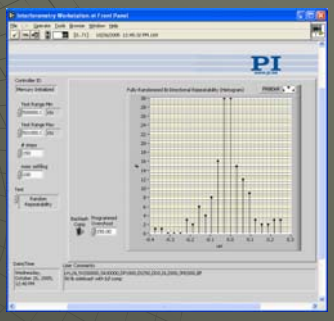
Panel Approaches Considered

- Machined Aluminum
  - Large Thermal Errors & Warping Require Overconstrained Mounting…Not Compatible
- Ni/Al Sandwich (Media Lario)
  - Early Info from Media Lario Indicated Large Thermal Errors if Panels Were Made Thicker than ALMA's
  - Now Considered "In the Mix" Until Resolved
- CFRP/Al Sandwich (Several Possible Vendors)
  - Good Structural and Thermal Performance
  - "Easily" Replicated
  - Questions of Long Term Stability, Coating, Cost
- Precision Molded LW Borosilicate Glass (ITT)
  - Emerging Technology
  - "Inert" Material, One Stop Shopping wrt Mandrels
- SiC/Nanolaminate: Proven Too Costly

Primary Mirror Truss

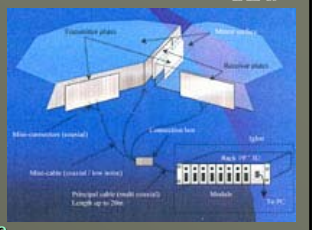
Actuators

- 3 Actuators/Segment
- Intended to Take Lateral as Well as Axial Loads
- Studied by Polytec PI Pro Bono
- Actual Tests Validate Performance
  - ***Histogram still shows FWHM <0.2µm,***
  - ***And >70% better than 0.1um***
  - ***Tested with high radial load of 50lbs***

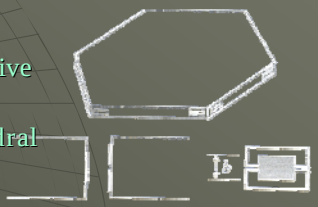


Panel Alignment & Control

- Edge Sensors: Several Approaches Possible
  - Fogale Nanotech (SALT) and Blue Line Engineering (HET) Commercial Solutions…~$1000-1500/sensor
  - TMT Developing Mark II Keck Edge Sensor
  - JPL to Investigate Lateral Effect Photodiode Approach
- Supplementary Sensors
  - Un-sensed or Low Sensitivity Modes Drive Need for Supplemental Sensors
  - Some Edge Sensors May Measure Dihedral Angle
  - Other Supplementary Sensors Under Consideration



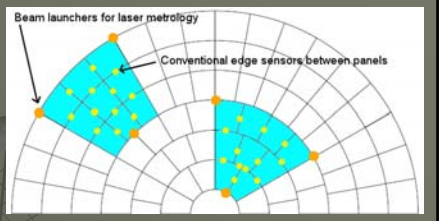
Fogale SALT Sensor

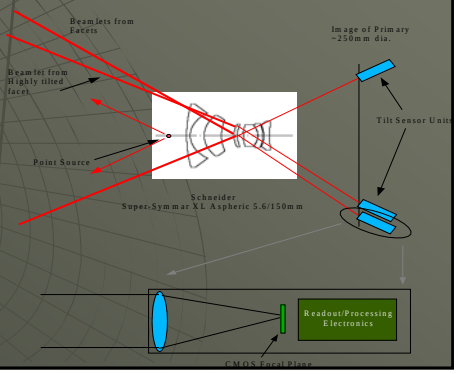


Proposed TMT Edge Sensor

Supplementary Sensors

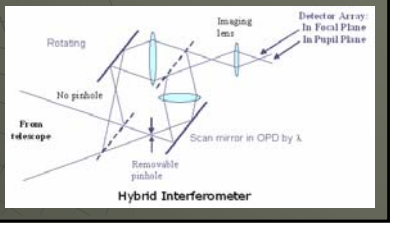
- Laser Absolute Distance Meas. Interferometry: JPL
  - Distributed as Required
  - Provide Absolute Start-Up Data
  - Provide M1/M2 Alignment
- Hartman Type Sensor: AOA
  - Senses Angles via Facets on Facesheets
  - Size Dictates 1 Sensor per Panel
  - Analysis Validates Precision
  - Low Cost ~$750k
- Wavefront Sensing Guider
  - Requires IR Panel Quality
  - May Yet Work





Initial Alignment via Interferometry

- Initial Alignment via Mechanical and Optical Gauging
  - Spherometer at Adjacent Panel Surfaces (~5 µm precision)
  - Hamar Laser & Probe Over Larger Areas (~5 µm precision)
- G. Serabyn JPL Has Identified Three Possible Interferometric Approaches Based on CSO Type Sensors
  - Shearing Interferometer
  - Point-Diffraction Interferometer
  - Pupil Plane Point-Diffraction Interferometer
  - Large and Expensive Instrument
  - Depends on Science Instrument for Camera



PM Issues for Next Phase

- Panel Analyses, Tests, Qualification
- Calibration Alignment Development
- Alignment Maintenance Development
- Optimize Segmentation/Sensors/Deployment

The CCAT Primary Mirror Appears Feasible and of Acceptable Risk…Further Definition of Concept and Cost Reduction Work Planned