CCAT Panels
Corrugated Mirror Solution

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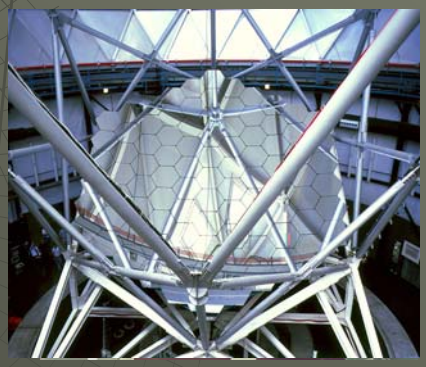
ITT Corporate Heritage

- Large segmented terrestrial telescopes
  - SALT, HET
    - Spherical primary mirror
    - 11.1 x 9.8 m
    - 91 1.0 m segments
    - ITT delivered:
      - PM segments + spares
      - Mounted, 1g corrected
  - KECK I & II
    - 10 m aspheric PM
    - 36 1.8 m segments
    - ITT final figured 81 PM segments

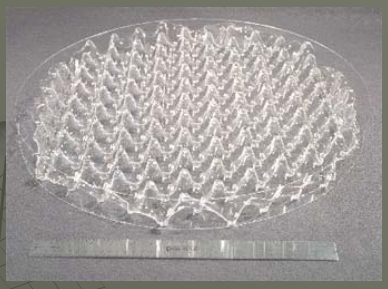


IIT Study Scope

- Primary Mirror Panel Manufacturing
  - Cost
  - Performance
    - Stiffness / 1 g sag
    - Thermal stability
    - Robustness
    - Segmentation
  - Manufacturability
    - Panels
      - material availability, design trades, process trades
    - Mandrels
      - process, metrology, material trades

ITT Corrugated Mirrors

- What are they?
  - Borosilicate glass
  - Stable, no hysteresis, no outgassing, no cure

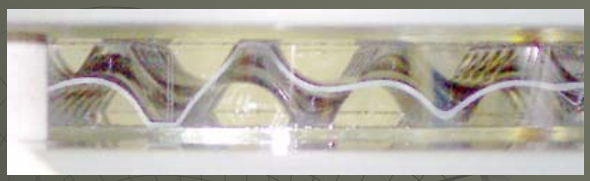


- Formed core
- Fused facesheets

ITT Corrugated Mirrors

- Strong
  - 4.7 Kg/m^2 mirror
  - 72 Kg load

Visible Systems: 60 nm Mirror in 5 Days

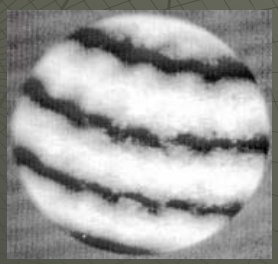


Quality: 58 nm RMS / 310 nm P-V

Specs: <10 kg/m², 150mm diam, plano surface, borosilicate

Replicated surface ± 2um – minimal post processing

Ready for ion figuring



Sheet stock

↓

Corrugate core

↓

Fuse assembly

↓

Replicate surface

↓

Grind / Polish
(for visible systems)

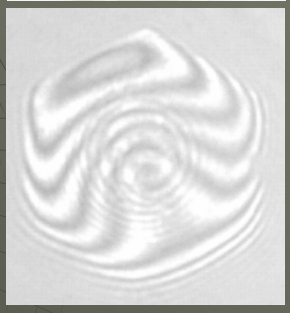
↓

Final figure
(for visible systems)

ITT Corrugated Mirrors

- Replicated
  - Geometry
    - 235 mm hexagonal part
    - 20 mm thick borosilicate glass
    - Replicated 5 m radius sphere
  - Figure:
    - <1.5 µm P-V surface error
    - Interferogram shown is at normal incidence, 632.8 nm wavelength

Rings are an interferometer artifact



Panel Requirements

- Materials and properties
  - Specific stiffness and areal density
  - Panel gravity deflection
  - Replication
  - CTE and thermal conductivity
  - Reflectivity and coatings
- Panel front surface requirements
  - RMS figure accuracy
  - Peak to valley
  - Surface roughness

Key Design Parameters

- Panel design parameters
  - Glass thickness
    - Robustness
    - Use existing LCD glass industry base
  - Corrugation spacing
    - Robustness
    - 3 vs 5 layer
  - Panel depth
    - 1 g sag
    - Manufacturability

Panel Design

- Specific stiffness and areal density
  - Trade
    - Glass thickness, corrugation spacing, panel depth
  - Changes
    - 1 g sag, robustness, manufacturability
- Point design – 1.8 m panels
  - 2 mm thick glass
  - ~85 mm deep panel
  - ~75 mm corrugation spacing
- 2 µm RMS gravity sag on 3 points
- Acceptable robustness, manufacturability

Panel Thermal Design

- CTE and thermal conductivity
  - First order analysis, recommend FEA
  - Thermal flow
    - Panels lose heat by radiating into the sky and dome
    - Panels gain heat from radiation from the ground
    - Heat moves within the panel by
      - Conduction (very inefficient)
      - Convection (efficient)
      - Radiation (efficient)
    - Convection to environment would decrease gradients
  - Full model shows 17 µm P-V / 3.5 µm RMS sag
  - Can be corrected by measuring temperatures or by insulating the back of the PM
  - 60% correction meets specification

Panel Design

- Reflectivity and coatings
  - SiO_2 protected aluminum
    - 95^{+}% reflectivity
    - 250µm to 3mm wavelengths
  - Borosilicate glass can be coated and stripped without surface degradation

Panel Design

- Panel front surface requirements
  - Error budget – total 5 µm RMS
    - Metrology – 2 µm RMS
      - OAGM <1 µm RMS accuracy
    - Surface error – 3.5 µm RMS
      - Mandrel as generated 2 µm RMS, grinding improves at small marginal cost increase
      - Replication demonstrated to 0.3 µm RMS in small scale
      - Balance scale-up
    - Gravity sag – 2 µm RMS
      - Designs meet this requirement
    - Thermal – 1.5 µm RMS
      - Panels meet this requirement with correction
    - Contingency – 1.5 µm RMS

Panel Front Surface Requirements

- Replicated panels will meet requirements
  - Roughness
    - 25-30 nm requirement (increases cost)
    - 1-2 nm demonstrated
  - RMS figure accuracy
    - 5 µm RMS total
    - 3.5 µm RMS allocated to the surface
      - 2 µm RMS mandrel - easy to fabricate
      - 2.75 µm RMS allocated replication
      - 0.3 µm RMS replication demonstrated in small scale, scale up risk should be addressed in follow-on work
  - Peak to valley
    - 15 µm P-V requirement, 1.5 µm P-V demonstrated
      - Scale-up to size, light weight must be demonstrated

Critical Risks Assessment

- Scale up to larger sizes
  - Glass material availability
    - Design for existing glass product lines
    - Some sizes require a custom glass run
  - Mandrel material availability
    - Demonstrate alternate, lower cost mandrel materials
  - Release from the mandrel
    - Size
    - Change in roughness requirements

Recommended next steps

- Additional analysis, design
  - Full panel design
    - Finalized segmentation, FEA (mechanical, thermal), mount locations, edge sensors, drawings, tooling quotes
- Subscale testing
  - 0.25 – 0.5 m solid parts
    - Verifies mandrel materials, assembly
    - Confirms release, surface figure and roughness
- Large scale demonstration
  - >1 m lightweight
    - Demonstrates full system
    - Lower NRE than full size demo piece
    - Confirms figure, roughness, release, scaling