communications

Integrated Optical Systems

New Era of Metal Optics for Visible Applications Bare Be, Bare Al and EN Cladding

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Focus on Metal Optics

Motivation: Customers require

- Off-Axis & Aspheric Mirrors
- Faster Delivery
- Lower Costs
- Visible Quality

Single Point Diamond Turning is not sufficient

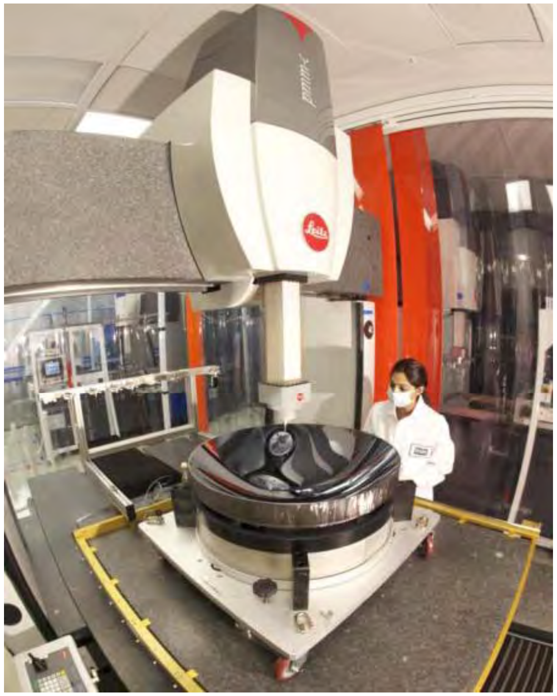
Integrated Optical Systems solves these challenges using Computer Controlled Optical Surfacing (CCOS)

Topics to be Discussed

- Bare Aluminum
- Electroless Nickel Plated Aluminum
- Bare Beryllium

Single-Point Diamond Turning (SPDT) Facility for Large Metal Optics

- Large optics are single-point diamond turned and post-polished
- Ideal environment for high precision machining
  - Floor is de-coupled from acoustic and seismic sources
  - <0.5°C temperature control
  - Existing large-optics handling equipment
- SPDT equipment uniquely modified to accept larger optics
  - Ultra-high precision SPDT up to 700mm Ø
- Metrology
  - Three 1.5m Leitz CMMs, numerous smaller

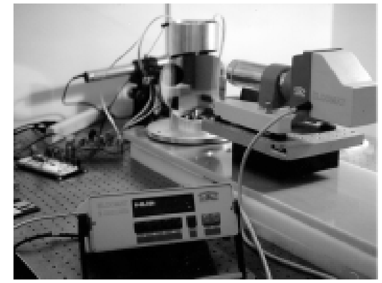


State-of-the-art Metrology and QA

Optical Assembly/Alignment with DMI

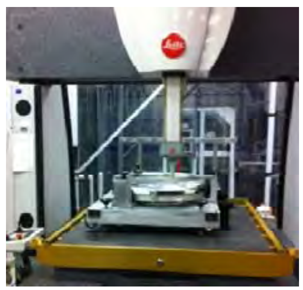
Cryo/VAC Optical Test Chambers

Computer Optimized Alignment Station



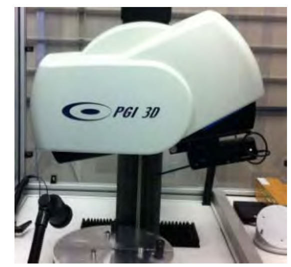
High Precision LOS Testing

Null Testing of Aspheric Components



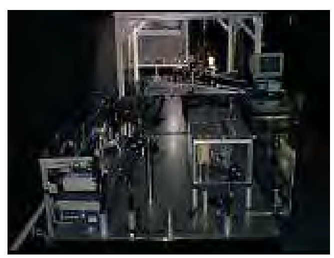
Large CMM Inspection Stations

Phase-shifting and white-light interferometric microscope



Stylus Profilometry

Visible & IR Phase Shift Interferometer



BRDF Measurement

PST

Atomic Force Microscope

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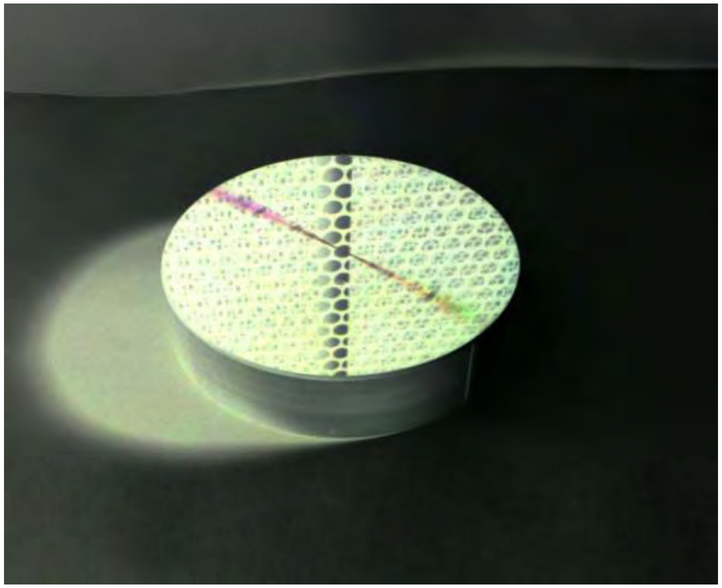
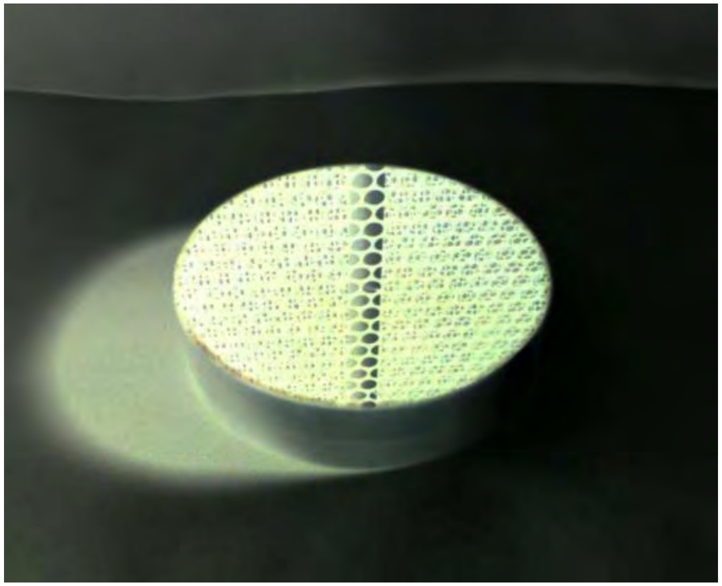
- Bare Beryllium

Aluminum Polishing Results: Surface Quality
2011 Results, RSP RSA 6061-T6

Single-point diamond turning (SPDT) followed by post-polish

4" 6061-T6 Aluminum sample SPDT on Tinsley's Nanotech 350FG





- SPDT Result
  - Surface errors of ~0.250λ PV & 0.060λ RMS @ 632.8nm
  - Surface roughness of ~30Å RMS
  - Surface quality of 40/20
    Color is apparent in the surface

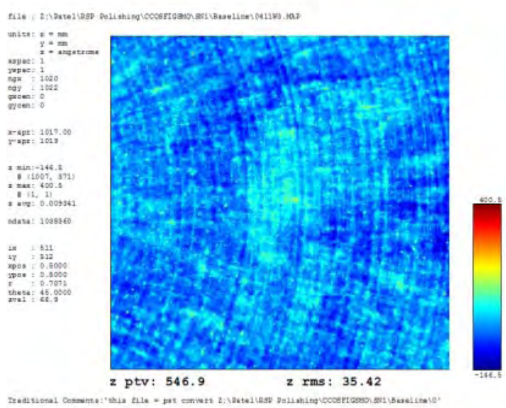
- Post-Polish Result
  - Surface error deterministically polished to specification
  - Surface roughness of <20Å
  - Surface quality of 40/20 or better
    No-color remains in the surface

Aluminum Polishing Results: Surface Roughness

2011 Results, RSP RSA 6061-T6

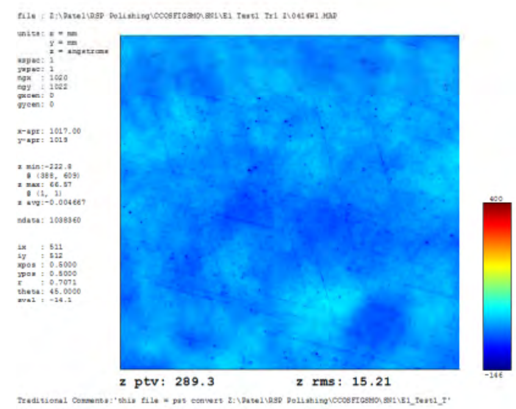
Single-point diamond turning (SPDT) followed by post-polish

4" 6061-T6 Aluminum sample SPDT'd on Tinsley's Nanotech 350FG

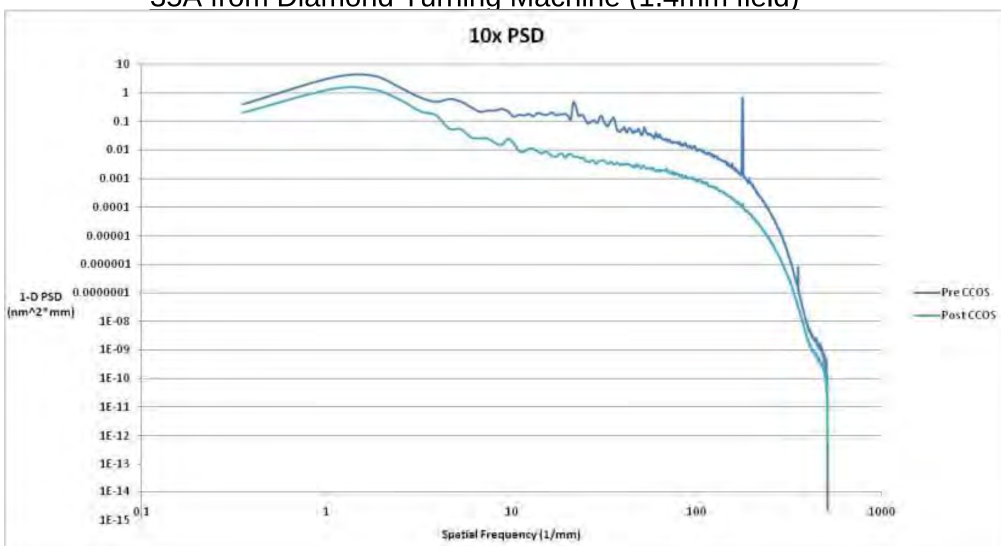


35Å from Diamond Turning Machine (1.4mm field)

Tinsley - CCOS Surfacing →



15Å rms after Tinsley Surfacing (1.4mm field)



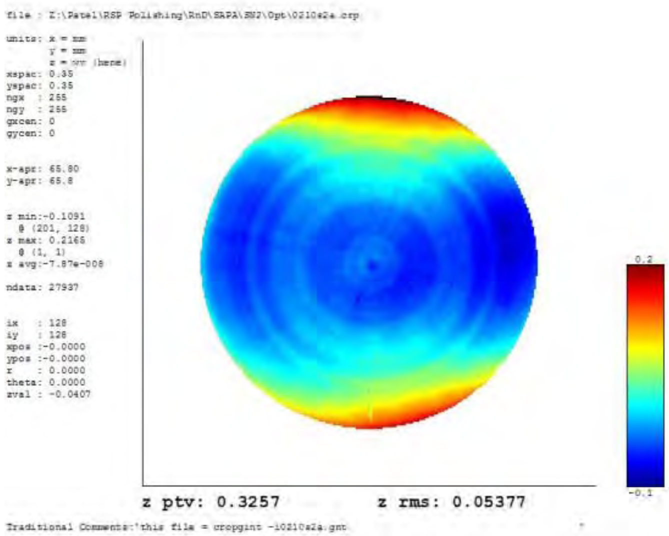
- Polish process is 100% CCOS machine based and highly repeatable
- Polish times are very low, making the process viable on low-cost optics
- Post-polish removes little material, compatible with off-axis mirrors, and maintains SPDT datum to optical surface integrity

Aluminum Polishing Results: Surface Error

2012 Results, Standard 6061-T651

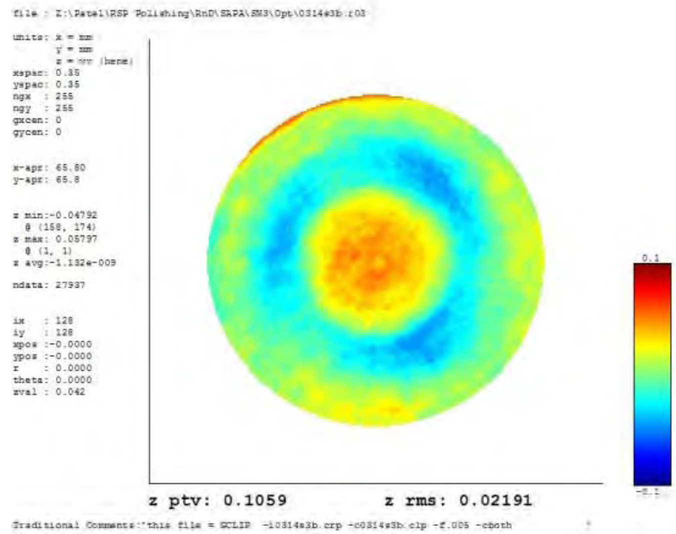
Single-point diamond turning (SPDT) followed by post-polish

4" 6061-T651 Aluminum sample SPDT'd on Tinsley's Nanotech 450UPL



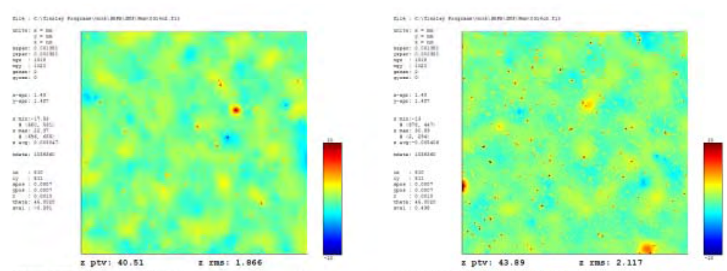
Surface Error: λ/3 PV & λ/18 RMS (@632.8nm)

Tinsley Surfacing →



Surface Error: λ/9 PV & λ/45 RMS (@632.8nm)

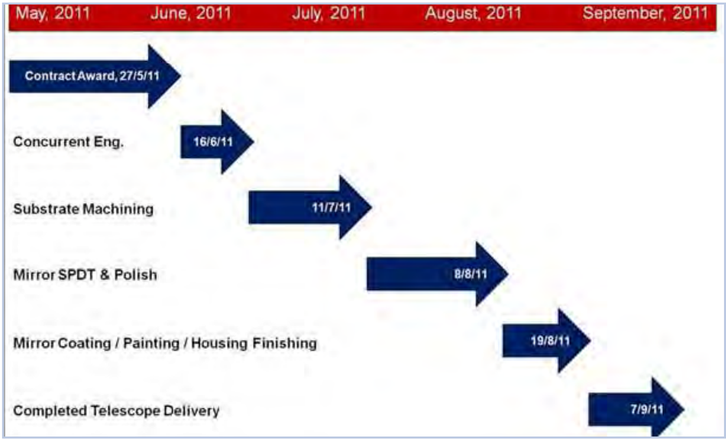
- Demonstration of highly deterministic polish
- 60% convergence on SPDT surface error residual, done in a matter of hours
- Surface roughness of 20Å after processing.



~20Å after smoothing (1.4mm field)

Application of Bare Al: Telescope Overview

- In April of 2011, Tinsley was solicited for the manufacture of a very short lead-time Aluminum telescope
- Scope of Work:
  - Concurrent Engineering
  - Substrate Manufacture and Testing
  - Finishing of CFM Housing
  - Assembly
  - Final Telescope WF Over Field Testing

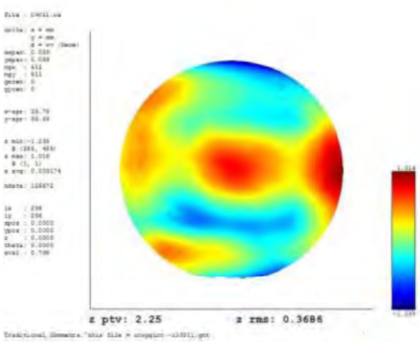


- A finished telescope was delivered just 15 weeks from start of order.

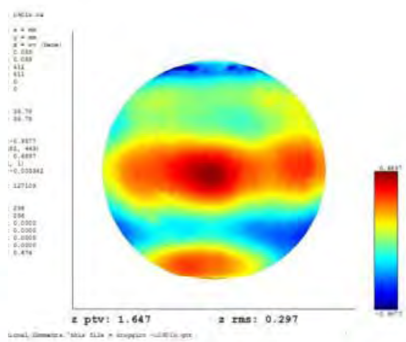
Bare Al: Proven Visible Quality Performance

Telescope Wavefront

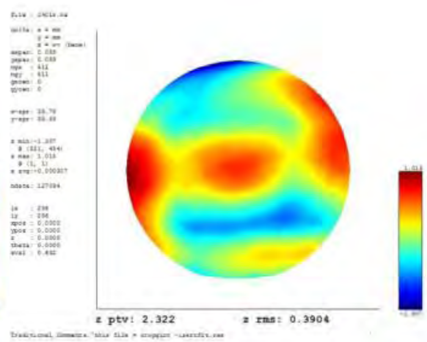
Focus Plane Within 65µm of Nominal Position



Field Angle = -4.31 deg
RMS = 0.36 wv He-Ne



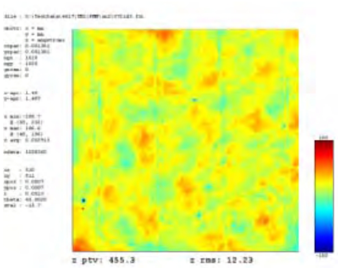
Field Angle = 0 deg
RMS = 0.30 wv He-Ne



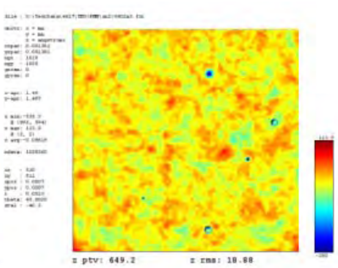
Field Angle = 4.43 deg
RMS = 0.39 wv He-Ne

Mirror Surface Roughness

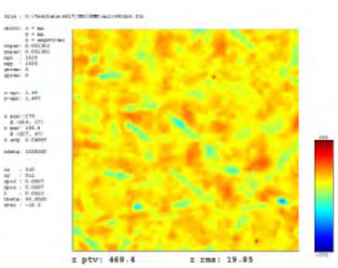
All optics <20Å, 1.4 x 1.4mm Field Nyquist Filtered



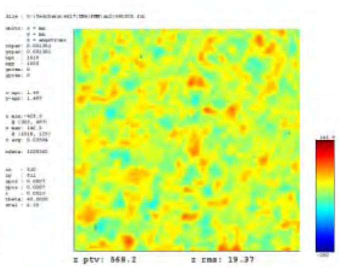
Fold Mirror
12.2Å RMS



Primary Mirror
19.9Å RMS



Secondary Mirror
18.9Å RMS



Tertiary Mirror
19.4Å RMS

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Topics to be Discussed

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- Bare Beryllium

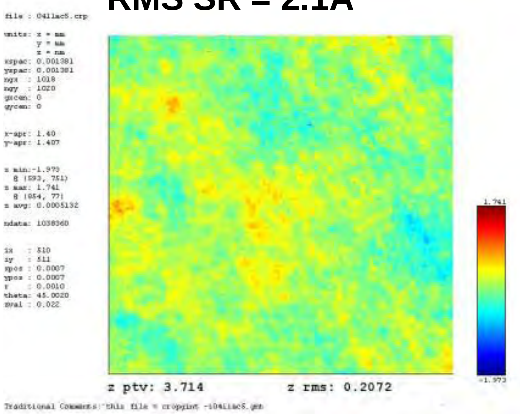
Super Polish of Nickel Results:

Single-Point Diamond Turning followed by CCOS

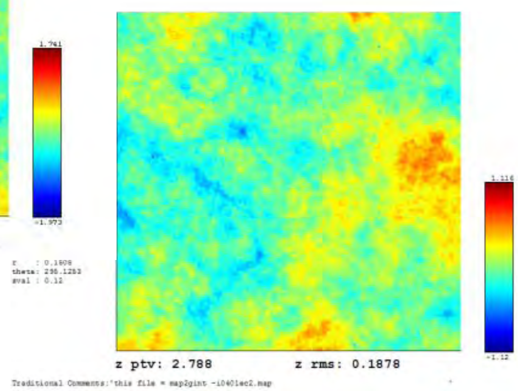
1/ mm → 10/ mm → 100/ mm → Spatial Frequency → 1000/ mm → 10k/ mm

Super polish of Nickel that effectively addresses all spatial period ranges

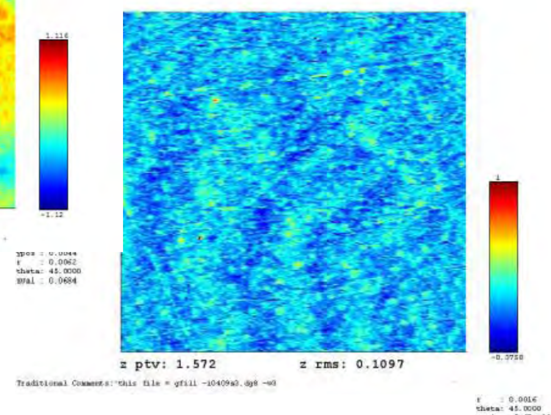
1.4mm x 1.4mm Field
RMS SR = 2.1Å



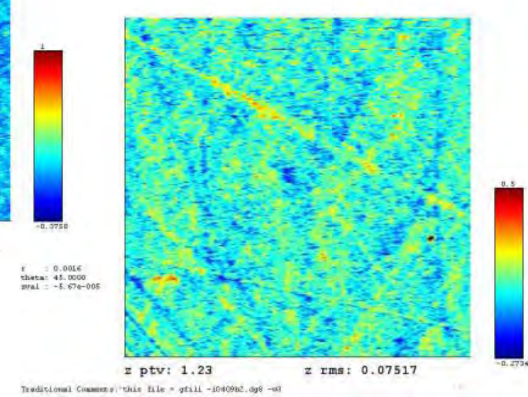
0.28mm x 0.28mm Field
RMS SR = 1.9Å

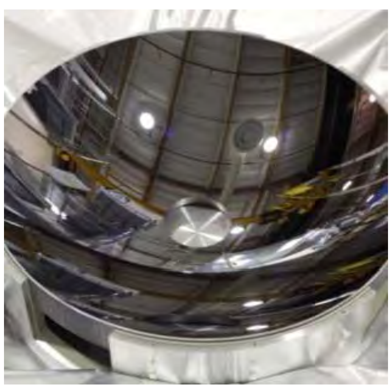


8.7µm x 8.7µm Field
RMS SR = 1.1Å



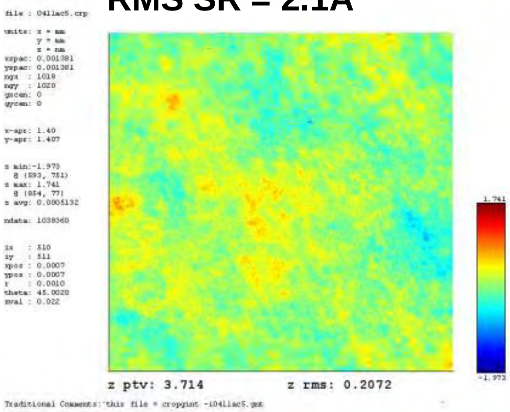
2.2µm x 2.2µm Field
RMS SR = 0.8Å



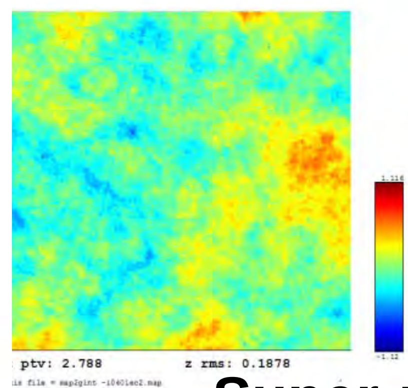


Super Polish of Nickel Results:
Versus Silicon

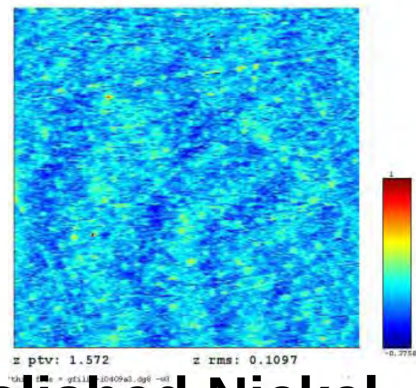
1.4mm x 1.4mm Field
RMS SR = 2.1Å



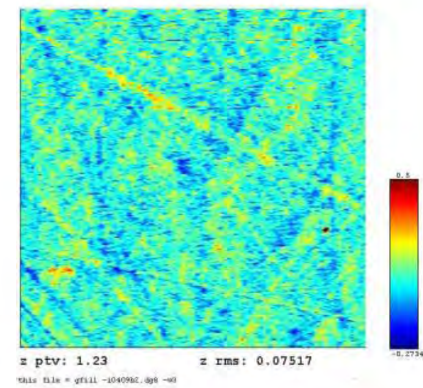
0.28mm x 0.28mm Field
RMS SR = 1.9Å



8.7µm x 8.7µm Field
RMS SR = 1.1Å



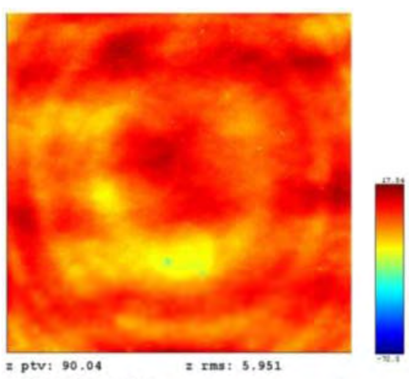
2.2µm x 2.2µm Field
RMS SR = 0.8Å



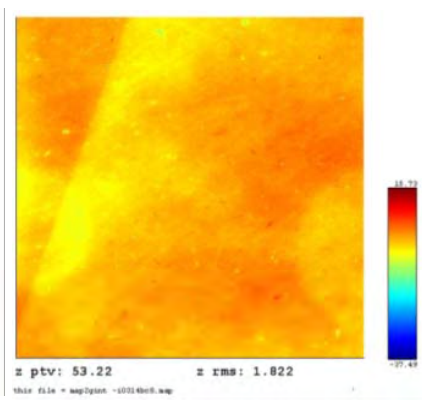
Super-polished Nickel

Super-polished Silicon

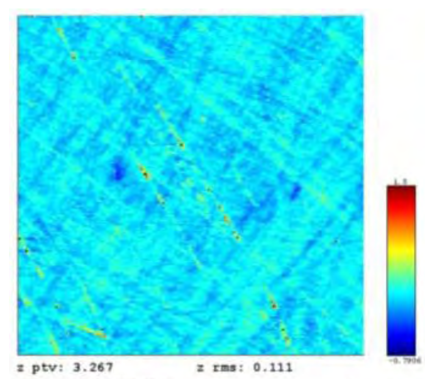
1.4mm x 1.4mm Field
RMS SR = 5.9Å



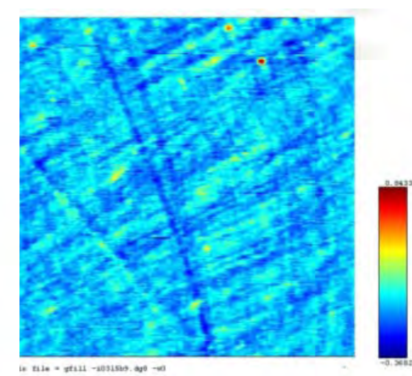
0.28mm x 0.28mm Field
RMS SR = 1.8Å



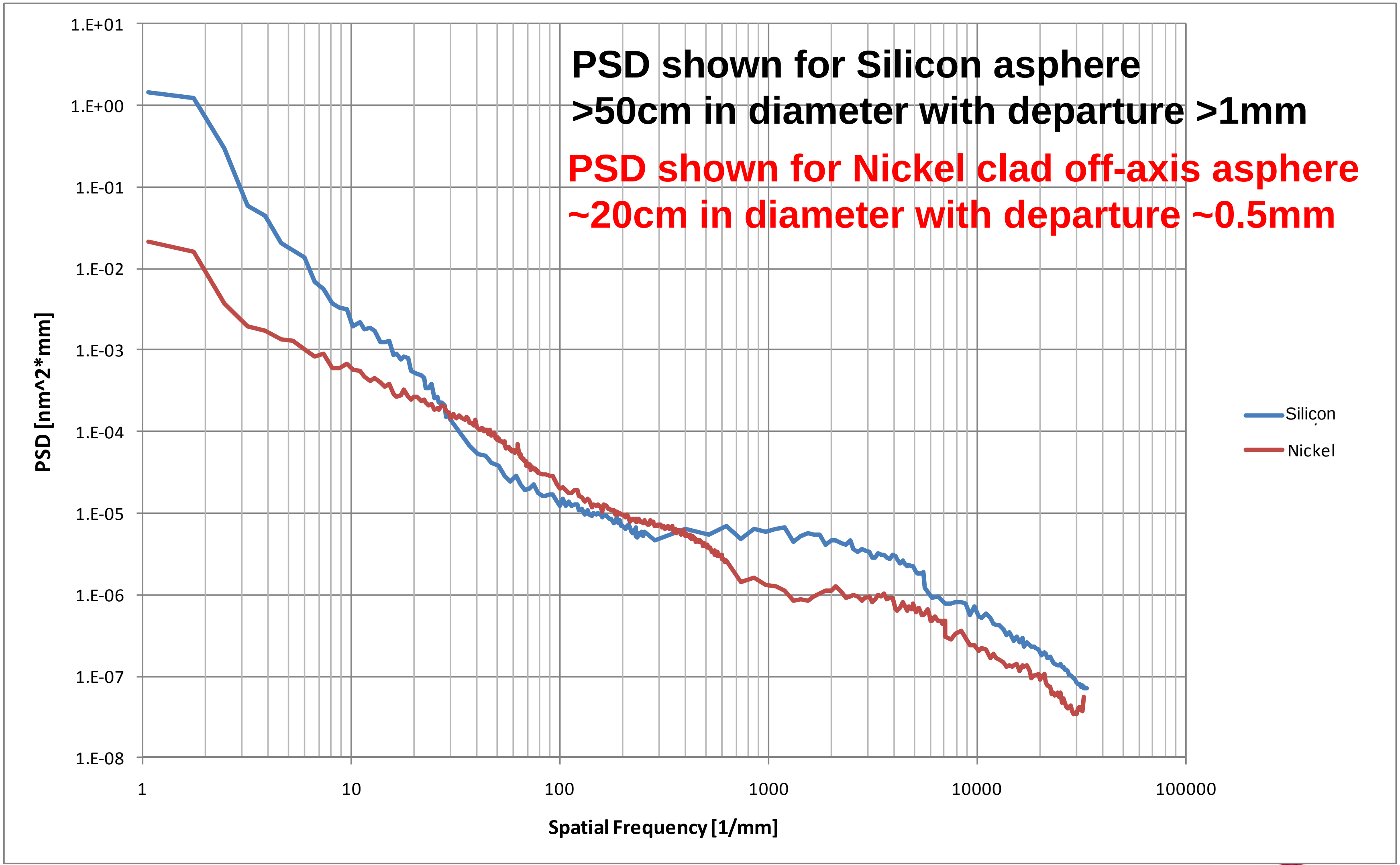
8.7µm x 8.7µm Field
RMS SR = 1.1Å



2.2µm x 2.2µm Field
RMS SR = 0.9Å



Super Polish of Nickel Results:
PSD Comparison to Silicon



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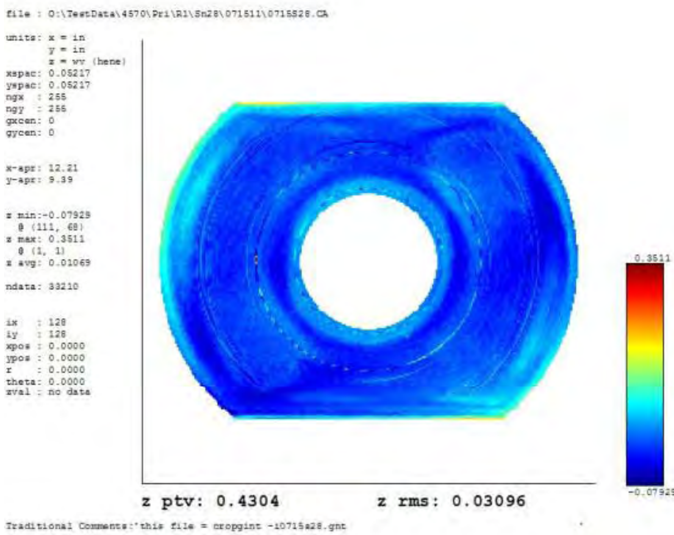
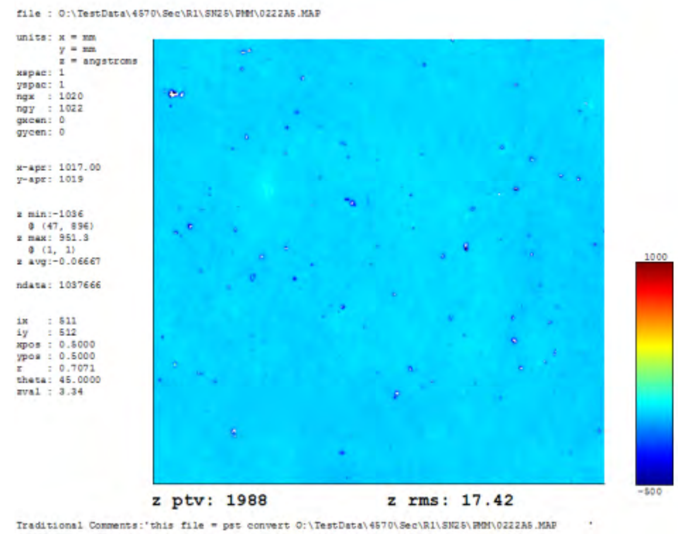
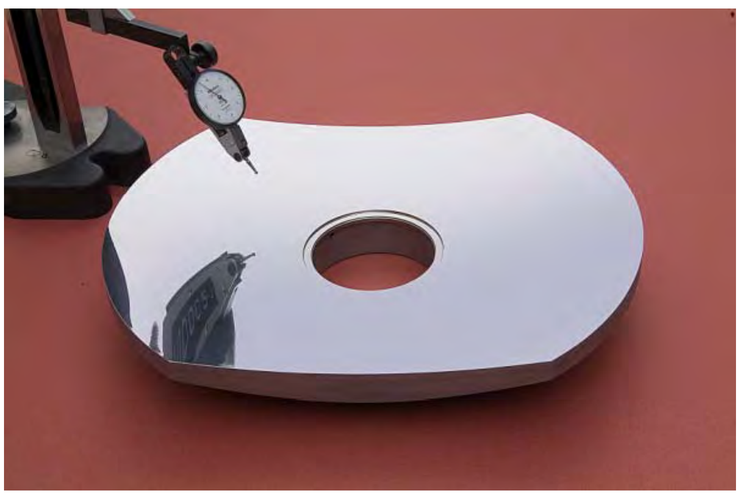
Bare Beryllium: I-70 Production Aspheres



Primary Mirror Surface Error: 0.031λ RMS (@632.8nm)



Primary Mirror Surface Roughness: 17.5Å RMS (1.0mm Field)



- I-70 Beryllium provides a more readily available and economical alternative to O-30
- IOS has made more than eighty (80) production aspheres in I-70 over the past 5 years

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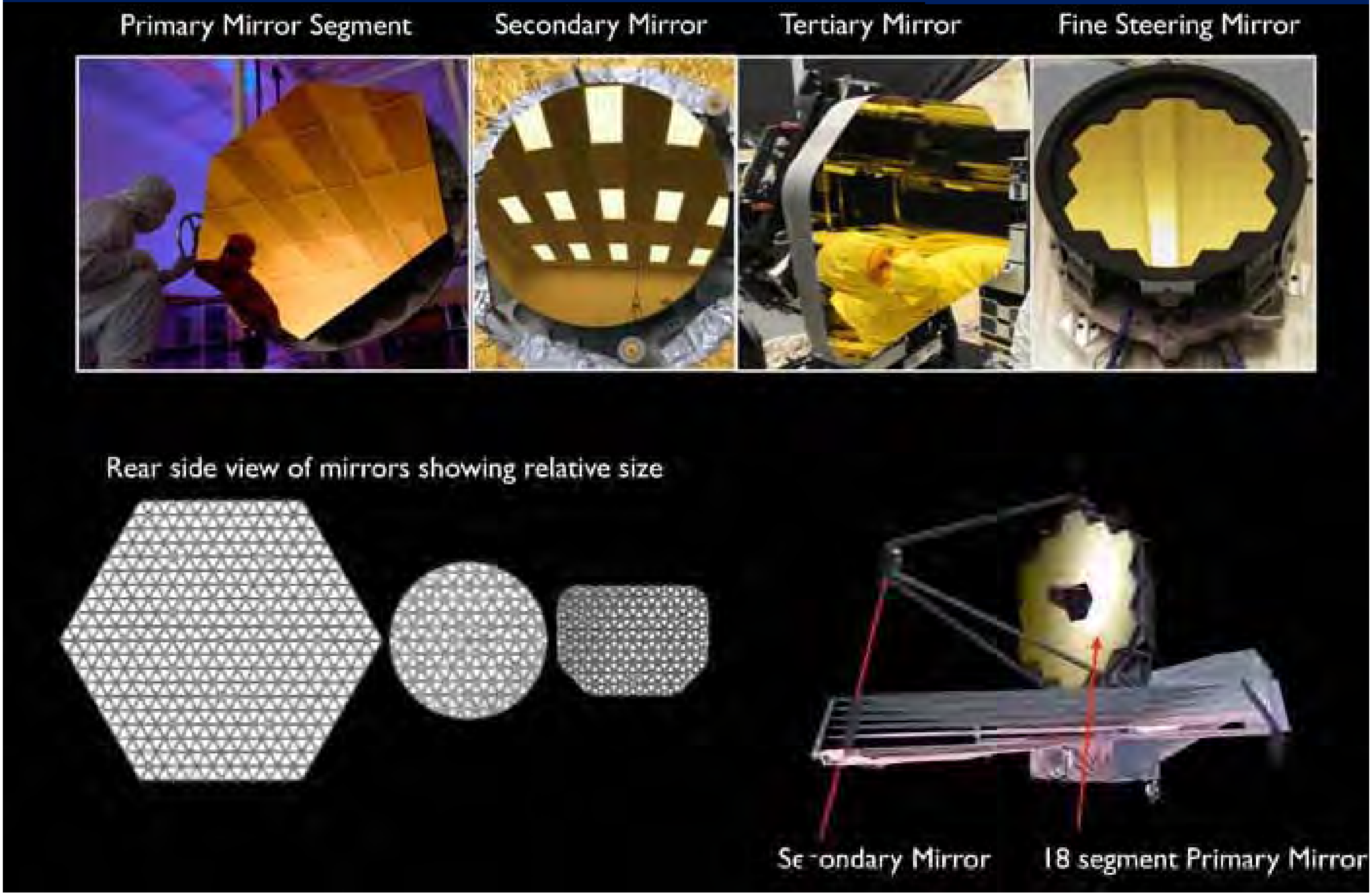
James Webb Space Telescope

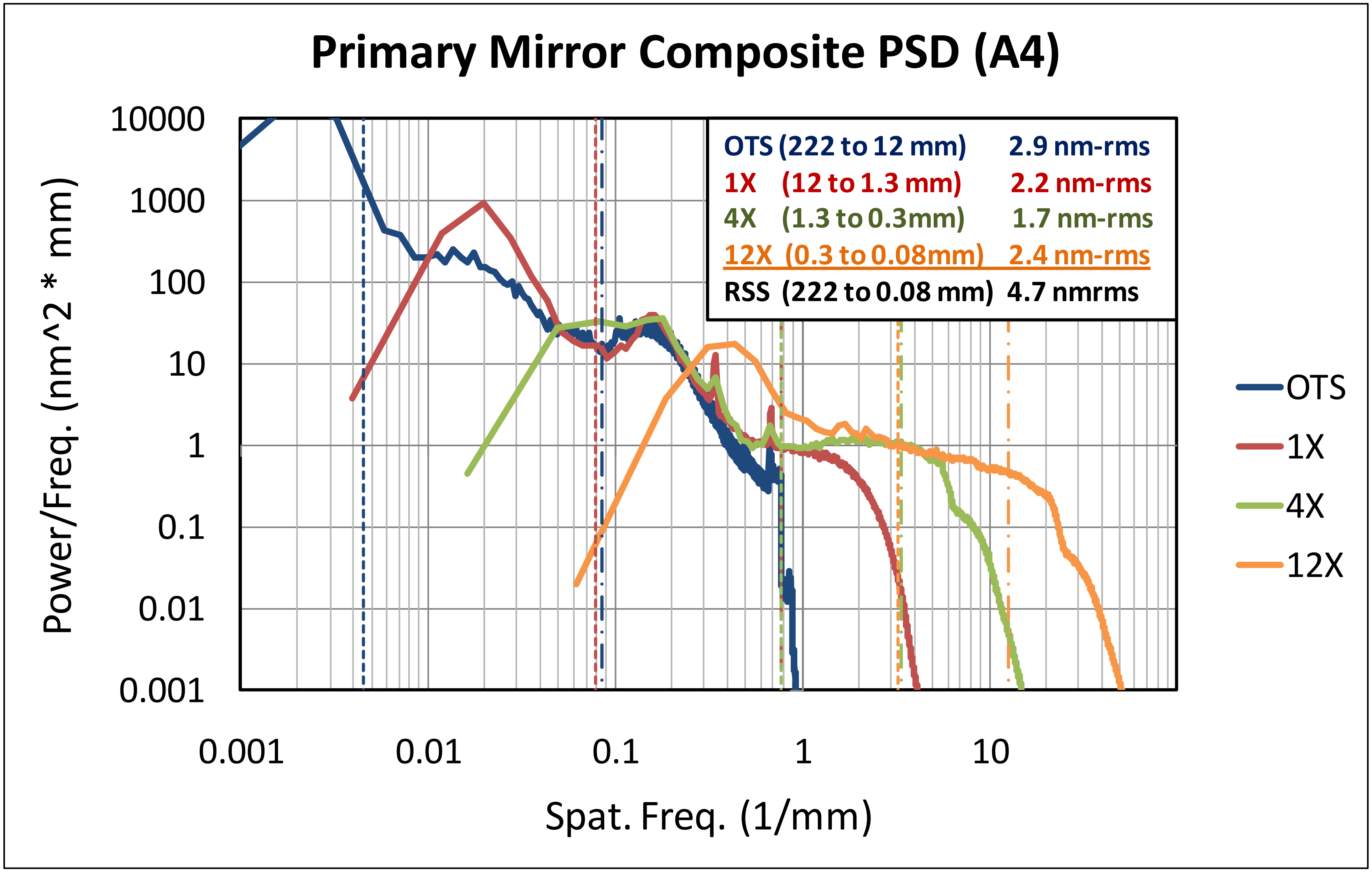


Cryo-null figuring: Requirements and Results

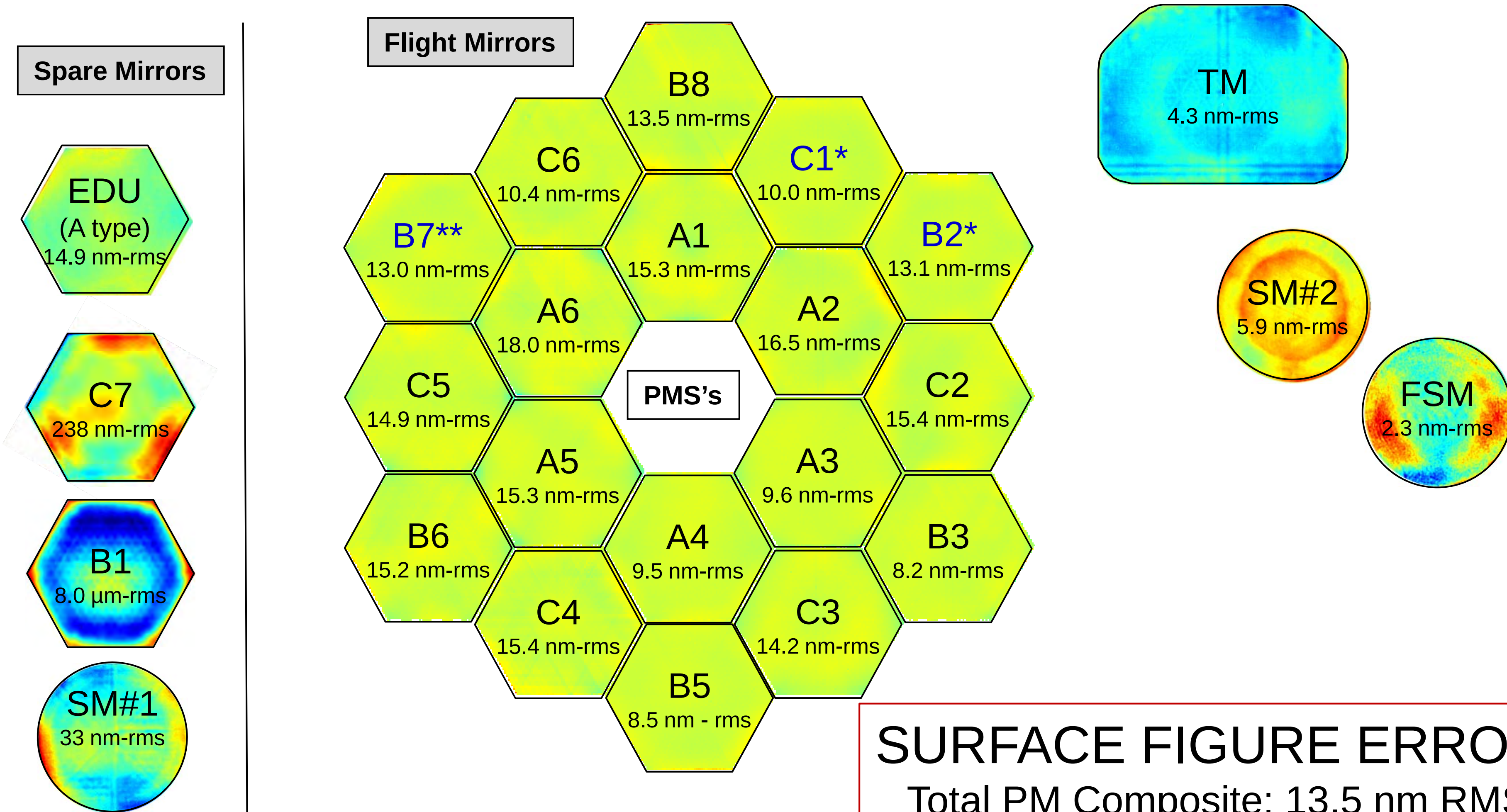
Mirror Performance Parameter	Specification	Tolerance	Average Final Performance	Average Margin %
Clear Aperture (CA) Area	1.47 m^2	Minimum	1.47 m^2	**0%**
Mid. Frequency SFE (spatial period range: CA to 222 mm)	20 nm RMS	Maximum	12.3 nm RMS	**38%**
High Frequency SFE (spatial period range: 222 mm to 0.080mm)	7 nm RMS	Maximum	6.1 nm RMS	**13%**
Surface Roughness	4 nm RMS	Maximum	3.2 nm RMS	**20%**

IOS polished 30m^2 of bare beryllium mirrors for JWST – twice !

Power Spectral Density (PSD)
Sample PM (Overlapping Curves)



Optical Performance of deliverable mirrors

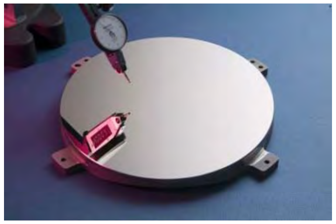


SURFACE FIGURE ERROR

Total PM Composite: 13.5 nm RMS

Telescope PM Target: 21.2 nm RMS

Conclusion – Visible Quality Metal Mirrors = Reality





- L-3 IOS has made Visible Quality Metal Mirrors a reality using Computer Controlled Optical Surfacing
- CCOS is fast and deterministic, without loosing the benefits of SPDT
  - Visible quality finish & figure
  - Snap-Together tolerances for fast, precision assembly
- Demonstrated CCOS on wide variety of metals
  - Visible quality, passively athermal imaging achieved
  - bare Aluminum
  - bare Beryllium
  - Nickel-plated super-polish allows a variety of substrate materials to be used
  - Aluminum, Beryllium, AlSiC, AlSi, AlBeMet, Stainless Steel, etc.