Conquering Frontiers: A New Era Contamination Control
Mirrors, First Contact Polymers, LIGO, Keck & NASA's Starshade Telescope

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Laser Gravity Wave Interferometer

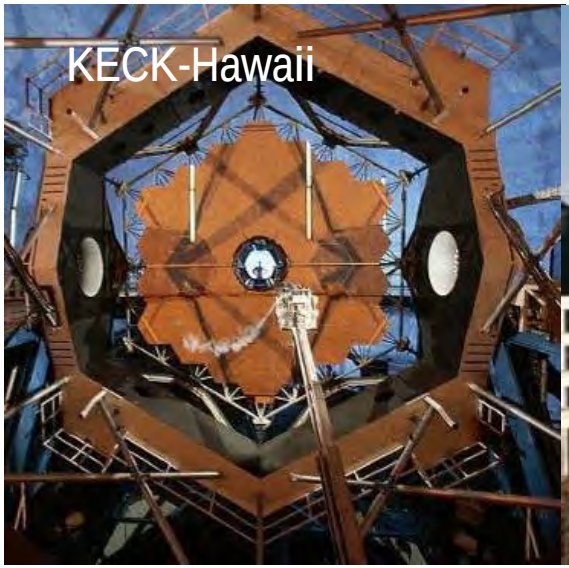
Largest Telescope - 10m Mirror

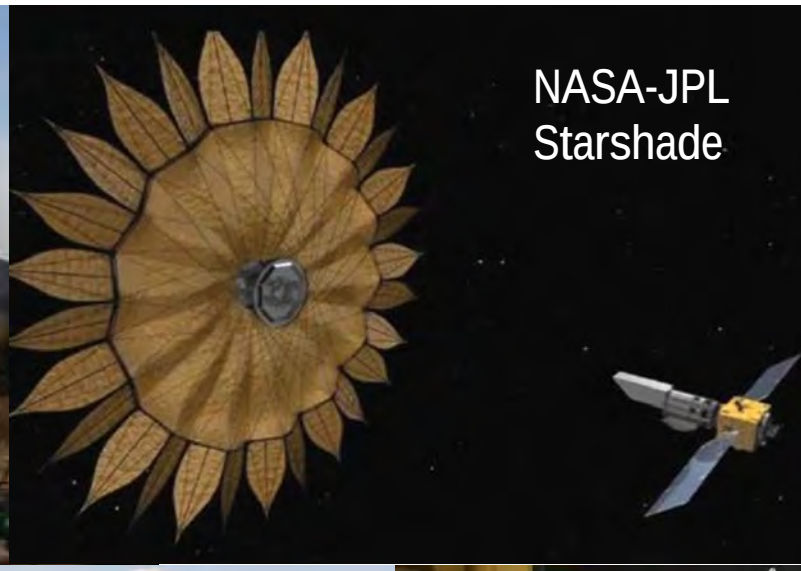
First Contact® Polymer

Outline of Presentation:

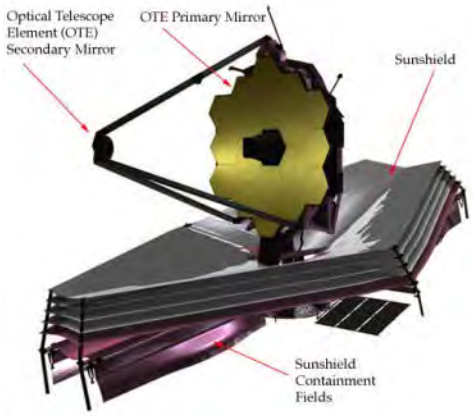
- Examples: Applications of some High Flyers
  - -Some surfaces are historically uncleanable
  - -Critical Surfaces can be damaged
- Background: For Orientation
- Data from projects that cared
- Conclusions and Future Work

First Contact Polymer End Game: Routinely Maintain Mirrors at Max Reflectivity, Extend Coating & Optic Lifetime, Eliminate Scatter, & make Zero Defect Coatings.





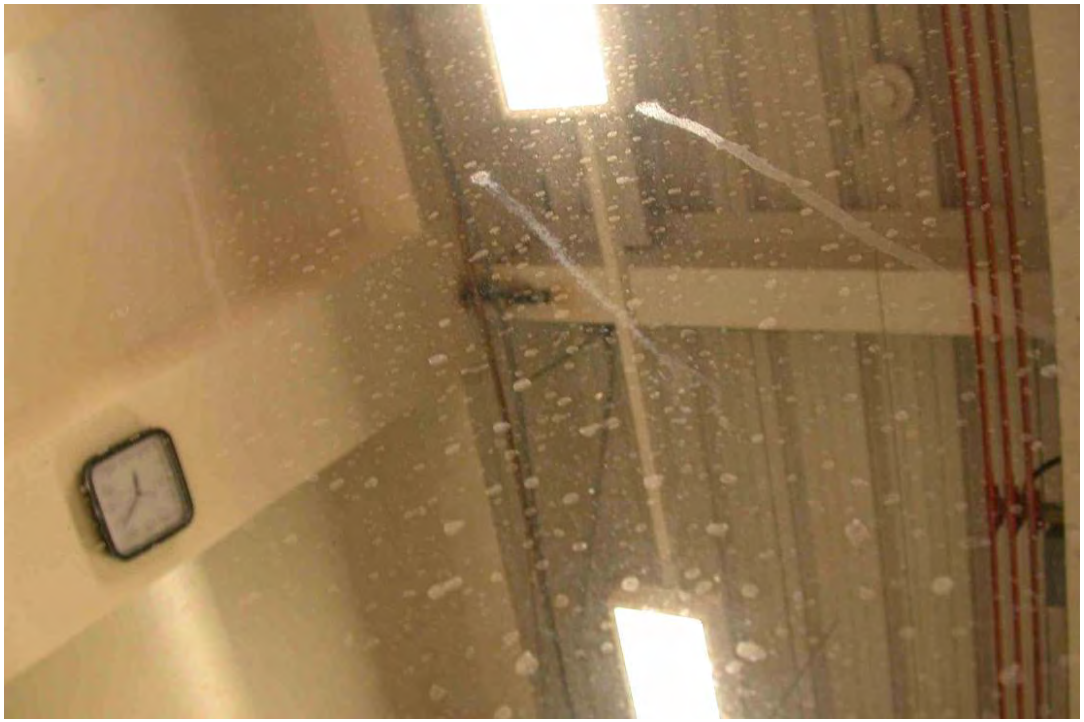
Keck, Gemini, CFHT – Hawaii
Chile - ESO
LAMOST- China
LIGO - Caltech/MIT
DES CAM – Fermilab/LBNL
CDMS – Stanford/Fermilab
GTC– Canary Islands
NASA GSFC
NASA JPL



SPACELIFT RANGE SYSTEM CONTRACT

Engineered for Space

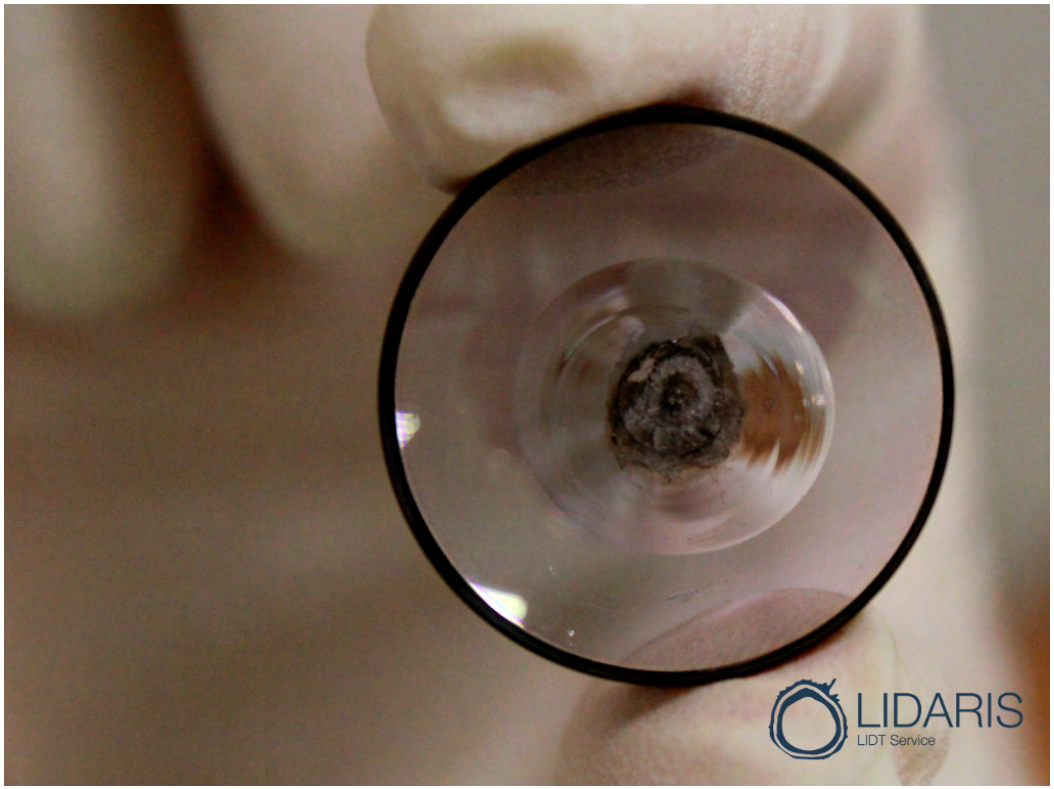
Problem: Contamination Control & Surface Protection



Operating Surface- 10 m Keck Telescope Hawaii.

Some surfaces are “uncleanable”.
Nanoparticles ***very*** hard to remove

Problem: Contamination Control & Surface Protection



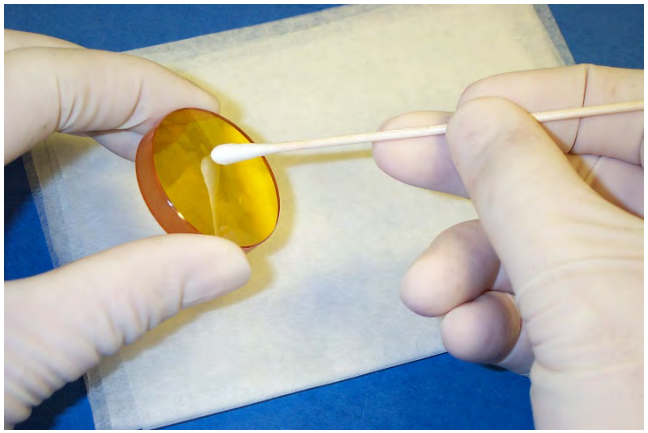
Laser Induced Damage: Optics & Optical Coatings

Some surfaces are “uncleanable”.
Nanoparticles ***very*** hard to remove.

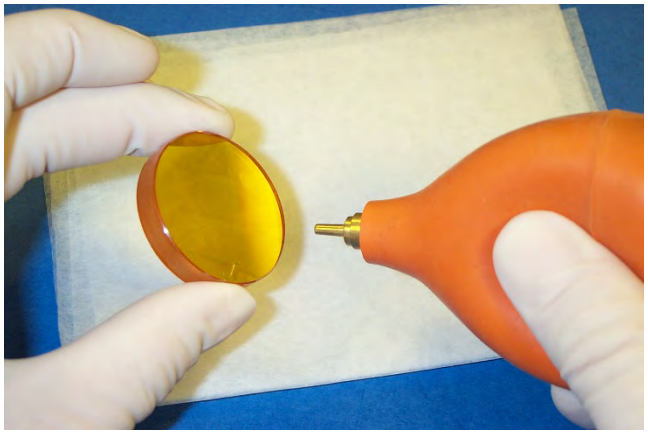
8.2m Mirror driven for cleaning & recoating: Atacama desert in Chile.

Acts of desperation: Use First Contact. Clean & Protect in situ?

Typical Methods of Cleaning Precision Surfaces like Optics



Cotton applicator Drag Wipe



Blowing Clean

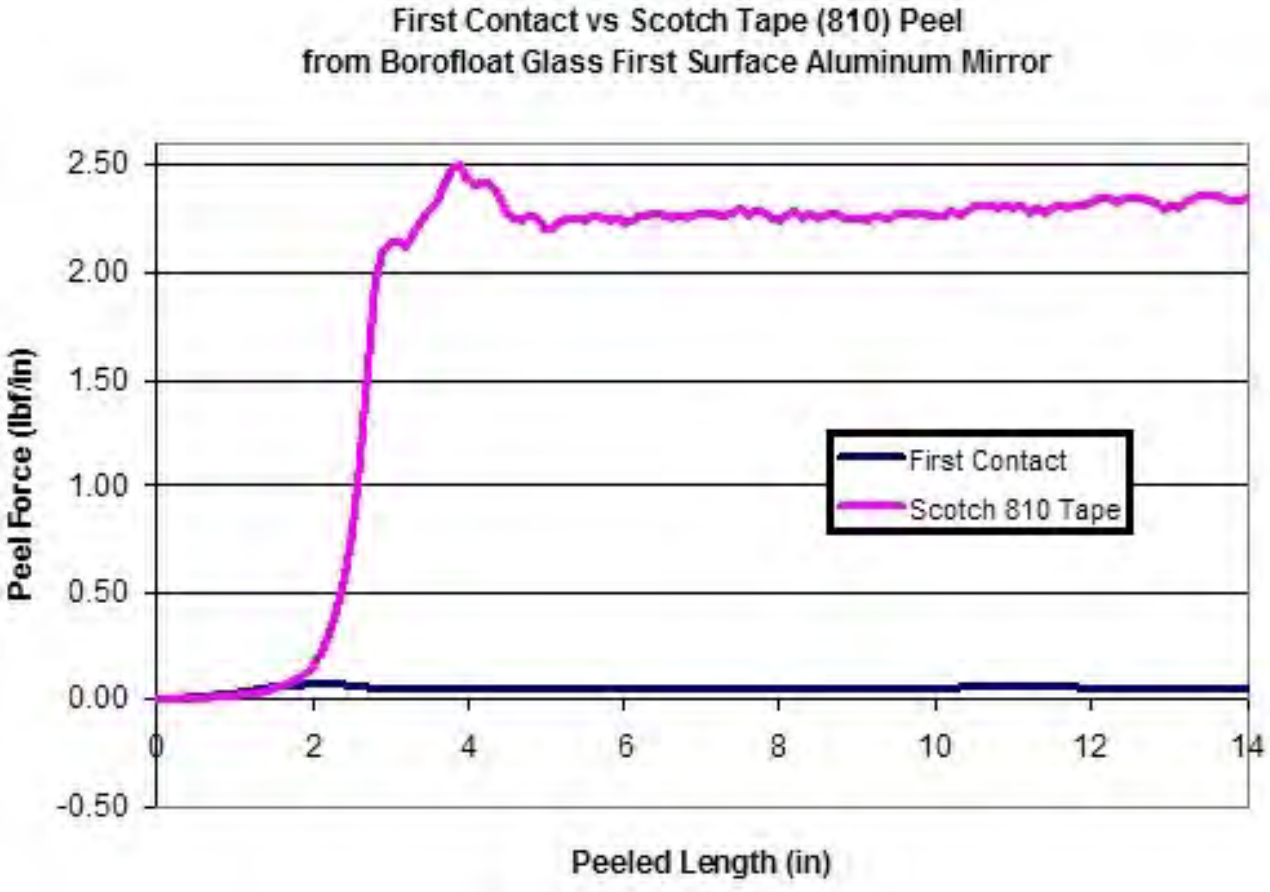
Alcohol/Acetone Drag Wipe

CO_2 Snow Cleaning

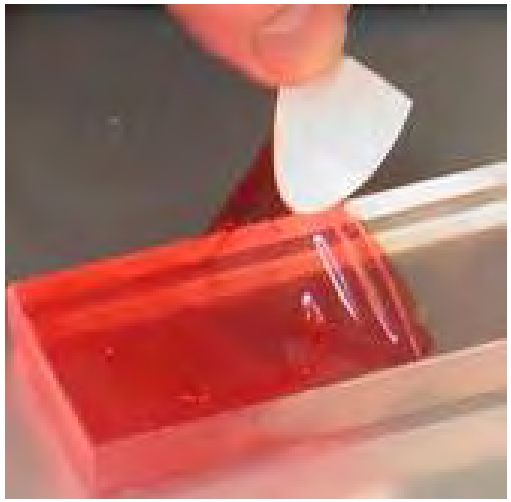
A No Residue Strip Coating
Protect & Clean

First Contact® Polymer

1/20th the adhesion of Scotch Tape on Al - SAFE



Cleaning & Protection



First Contact® Polymer

Sales in 71 Countries

"*THE* Protection and Cleaning Solution"

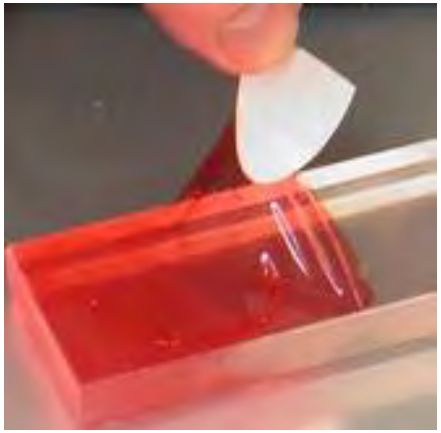
"Cleaning and Protecting Precision Surfaces in Manufacturing, Assembly, Shipping, Coating and Storage"

Value Propositions:

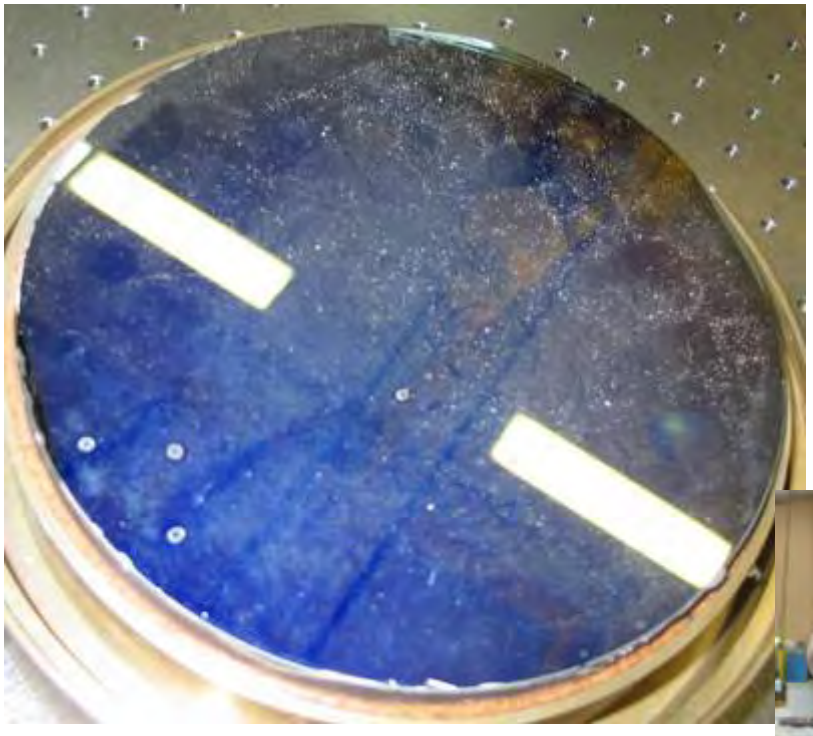
1. Asset is ready when it is needed.
2. Save time. Save Money. Quick clean. Space Ready.
3. Clean in situ – No Realignment
4. Cleanroom clean without the Cleanroom.
5. Clean the Uncleanable-Easily: Sensors, CCD's, FPA's, Gratings
6. Eliminate Diffraction Rings from Dust: Laser Patterning, Holography
7. Zero Defect Coatings: Cleaning before coating
8. No Residue, Vacuum compatible
9. Simple, Green, Easy, Reproducible

- Easy to use – No special training needed.

No mixing.	Doesn't tear.
No thinning.	Safe in Coating Chambers.
No Residue	Removes Fingerprints.



For USAF VAFB WR Depot Optics Group



Mirror Removed from Telescope for Recoating

Polymer Coat Removed

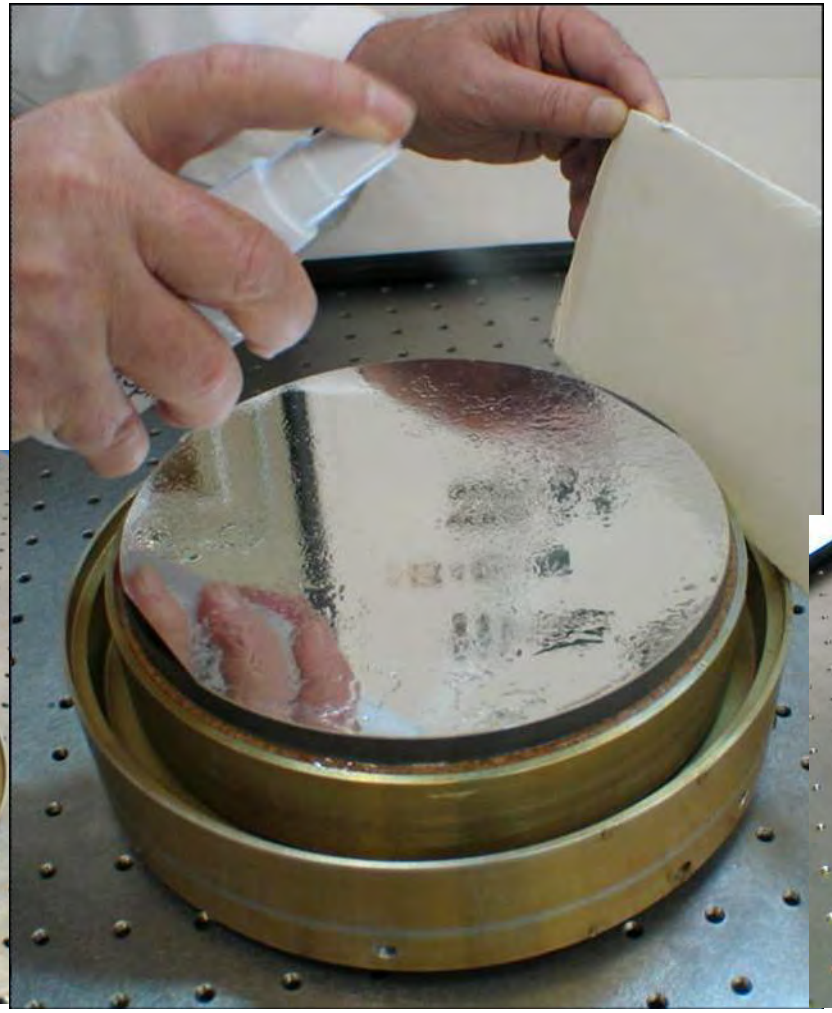
Sparkling Clean Mirror – *No* recoat Required.

Steve Ellieson, ITT Corp, VAFB

Cleaning 8” First Surface Mirror

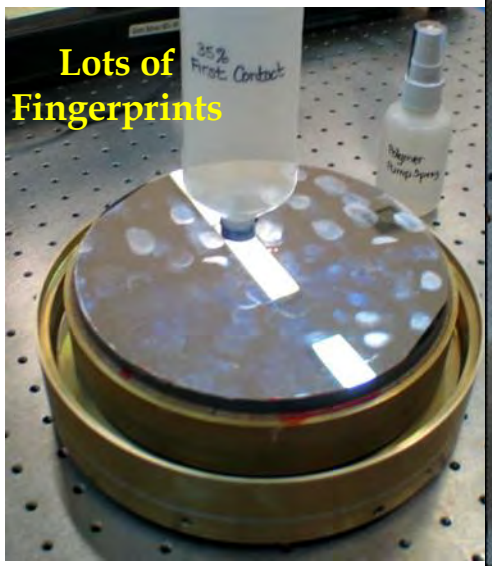
Fingerprints intentionally placed on mirror to demonstrate cleaning effectiveness

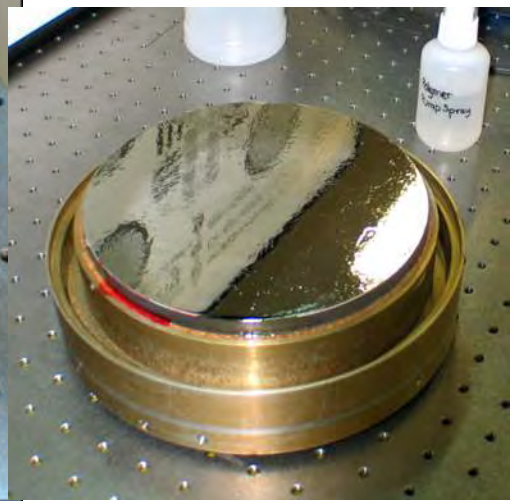
Polymer Applied with A Pump Spray Developed with the WR Optics Lab



A True Environmentally-Friendly process which leaves *no* hazardous waste

Next step: an air-brush application for precision spraying to reduce overspray!

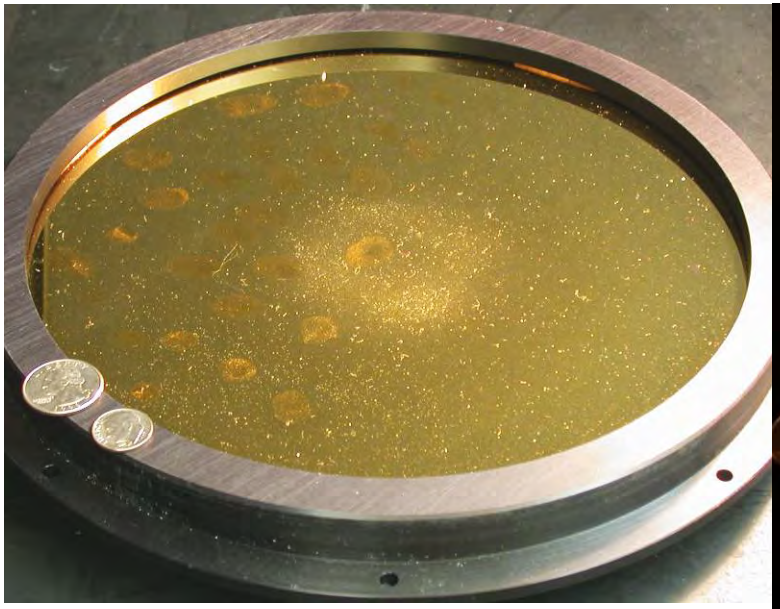




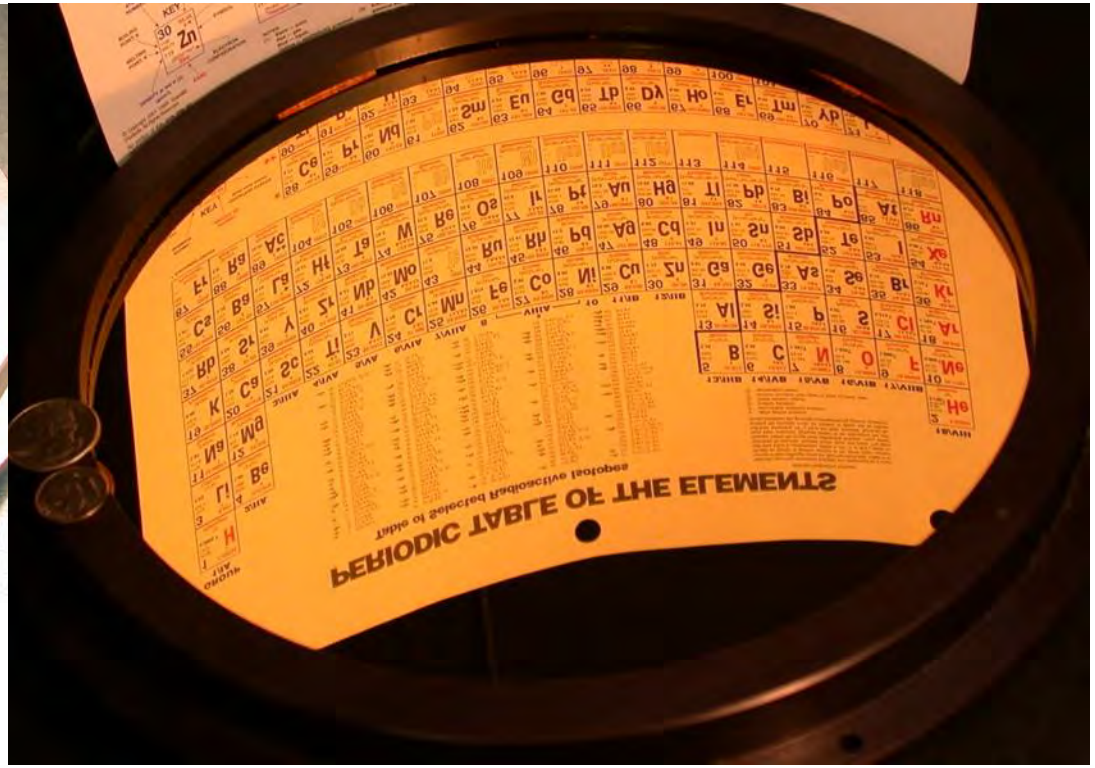
Spray Developed at WR OTF Lab For Use On Large Range Optics

First Contact™

Manual Spray Application to Large, Unprotected, Gold, First Surface Mirror



Unprotected Gold mirror. 400mm



After treatment with First Contact™

First Contact™

Before

After

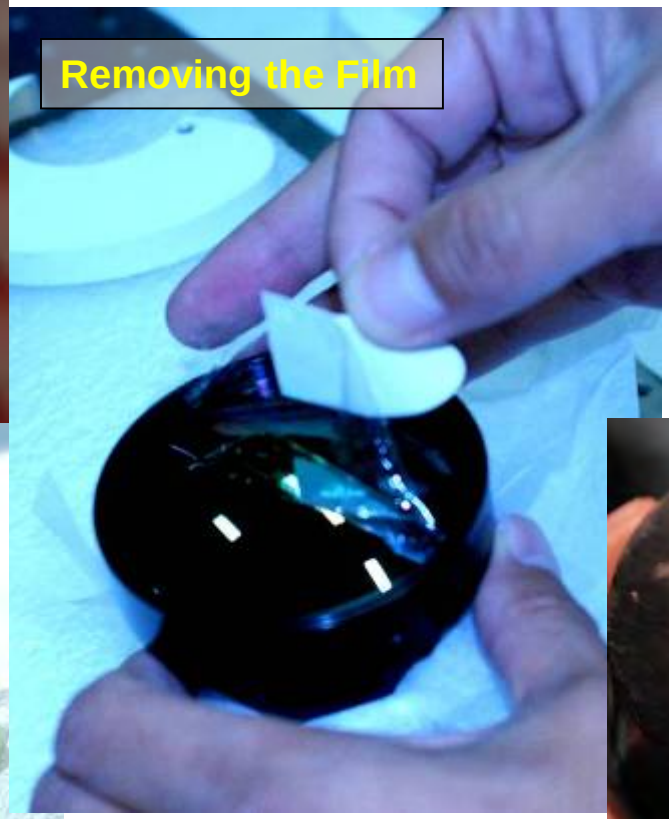
During

First Contact Polymer
"No touch, One step, Cleaning process"

Actual Customer Photos – Takahashi Coated CaF_2 Lense

First Contact™ Polymer Solution–Brush Application
Cleaning IR Telescope Optics

Applying First Contact Polymer with a Brush



Expensive Germanium Lenses are transparent to IR light

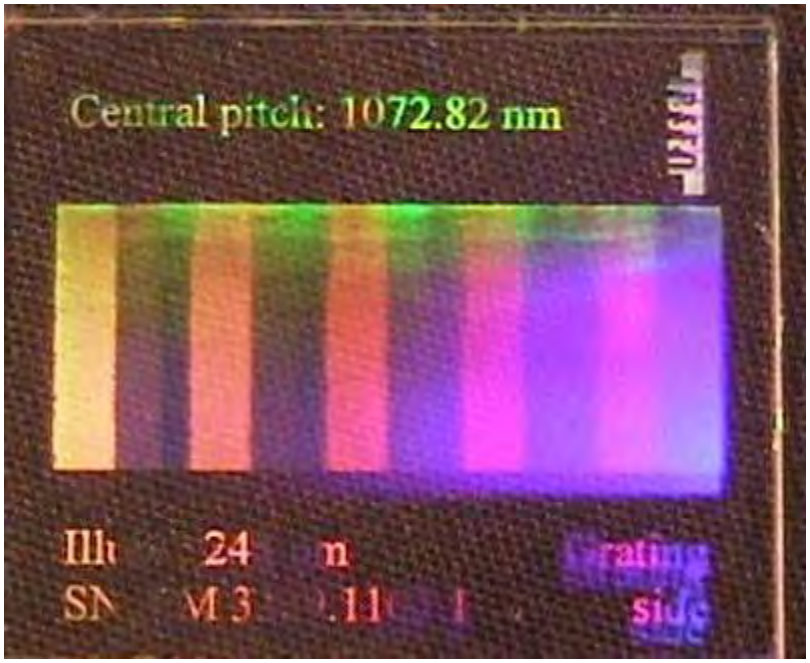
Sparkling Clean

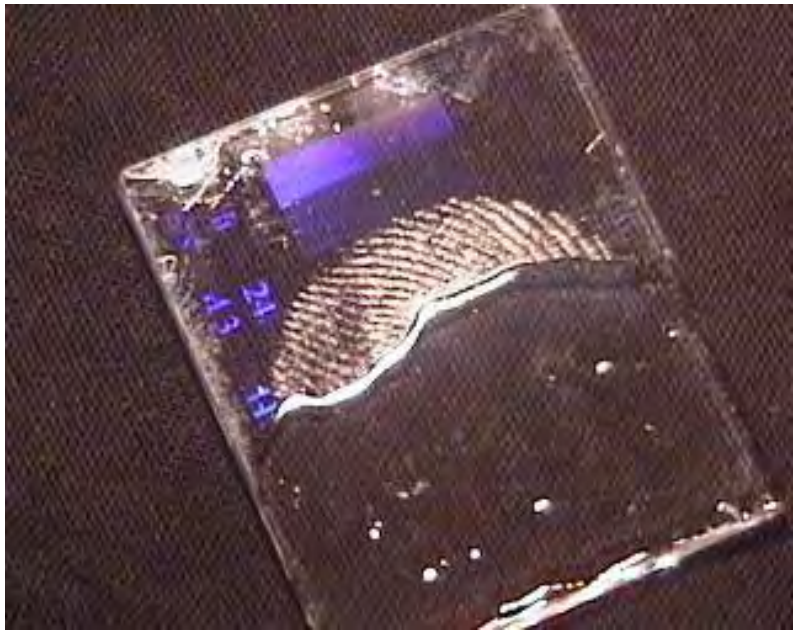
First Contact™

Ibsen Fused Silica Transmission Grating

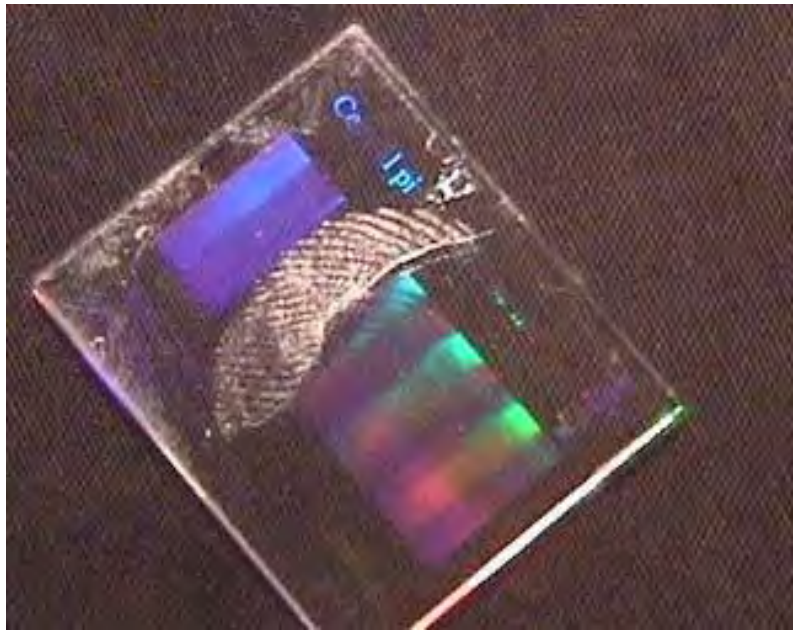
3000 lines/mm Phase Mask

Cleaned with First Contact



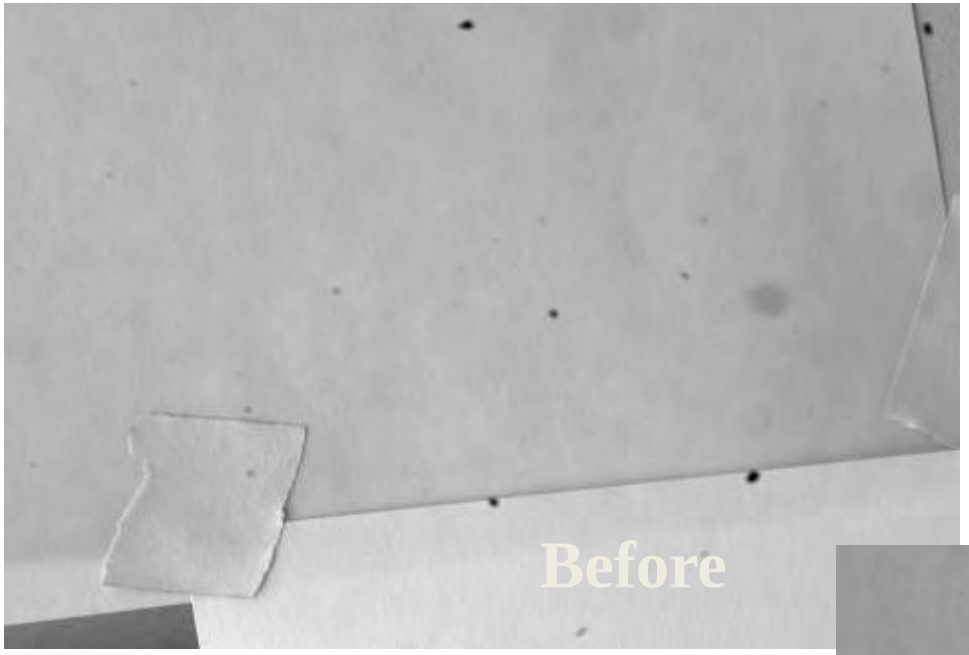


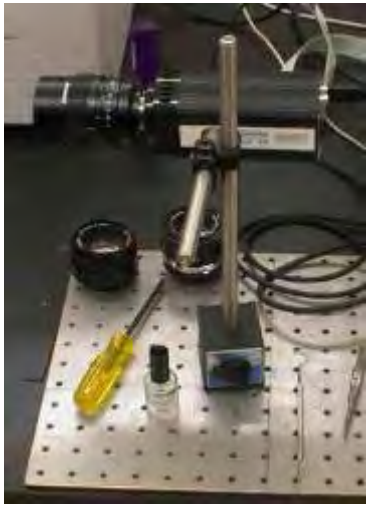
Polymer on half



Polymer removed-No residue

Cleaning Q-Imaging Retiga CCD Camera

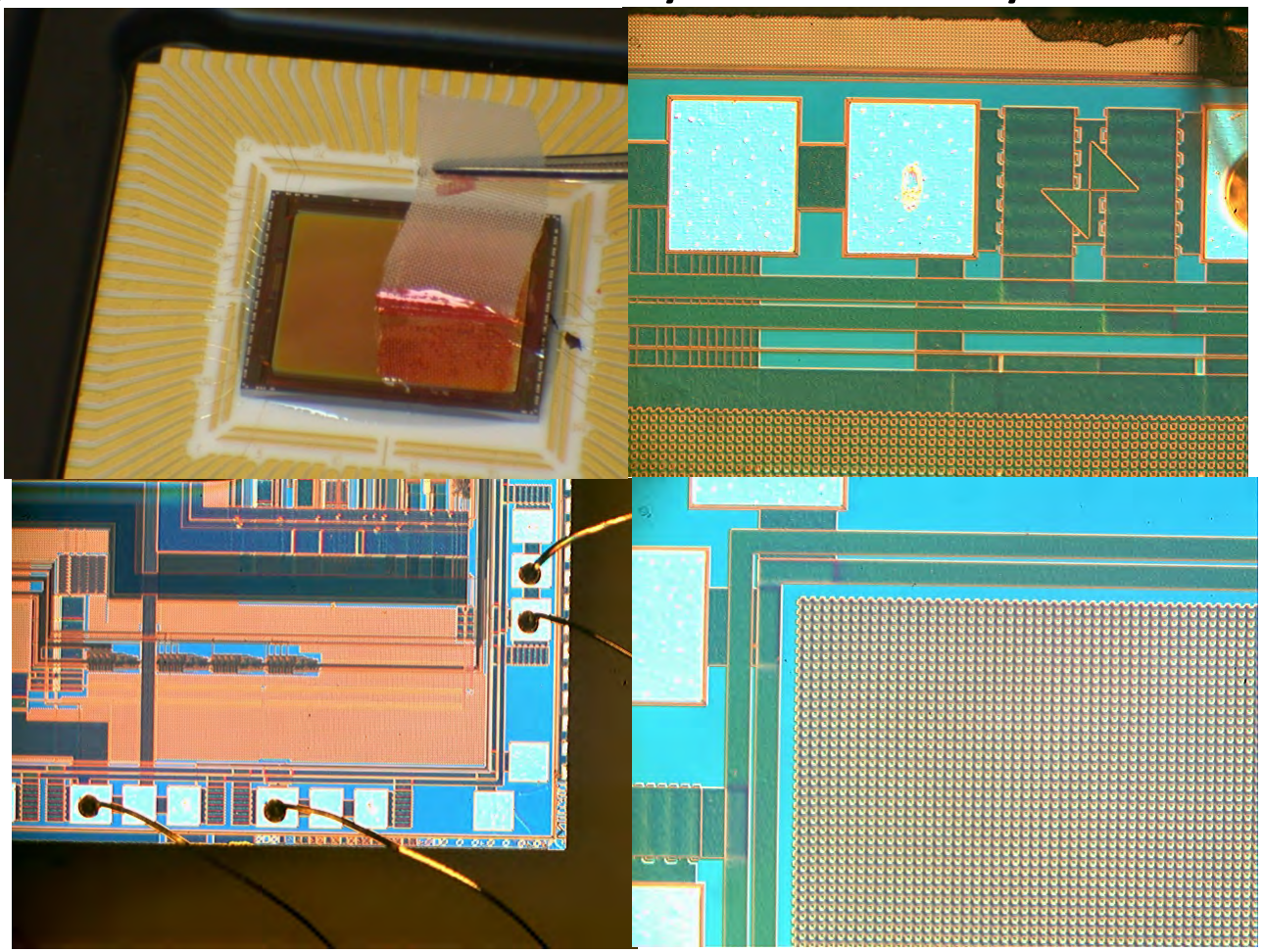




Images w/ IR Filter f 1.7 lens at f/16

- **Cleaned Sensor & IR Filter**
- **Cleaned Threads!! KEY!!**

~$200,000 IR Focal Plan Array- Previously Uncleanable



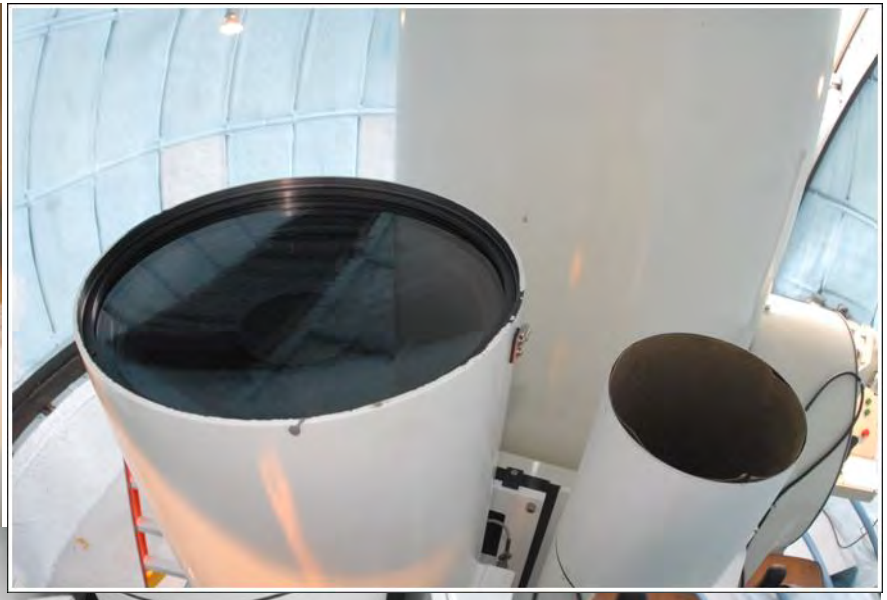
Cleaning the Uncleanable.

Nomarski Microscopy Images, PCT

DOAMS Deactivation: Protecting the Optics

Preparing to Apply the *First Contact* Polymer Protective Coating

All Exposed Optical Surfaces Receive a Generous Polymer Coating



Applying a protective coating of the *First Contact* Polymer to the Visible Wavelength Dahl-Kirkham Telescope

First Contact Polymer Protection Applied with a Spray

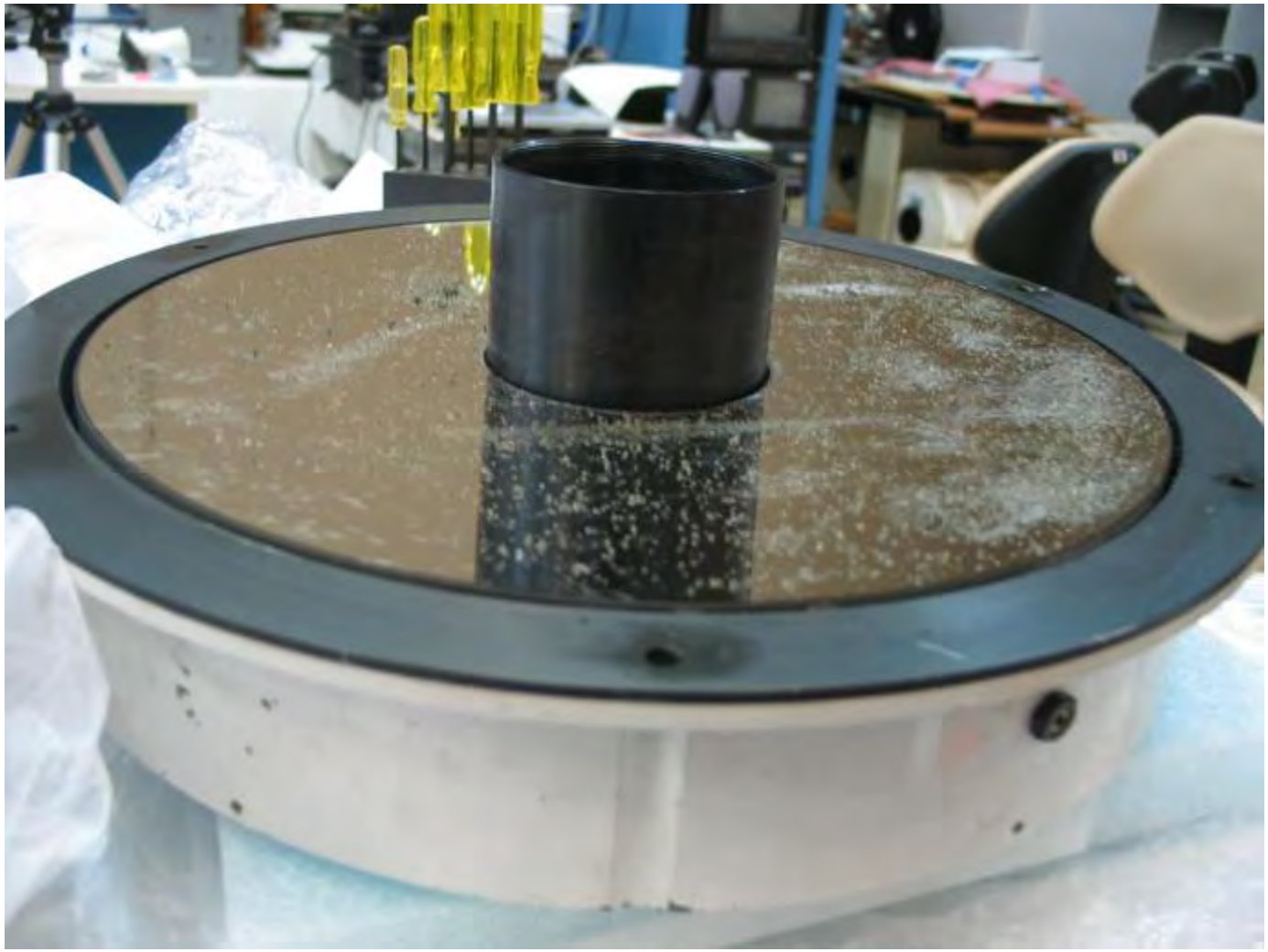
Minutes to Apply – Seconds to Remove – Years of Protection

Western Range Depot Optics Group and *First Contact* Polymer

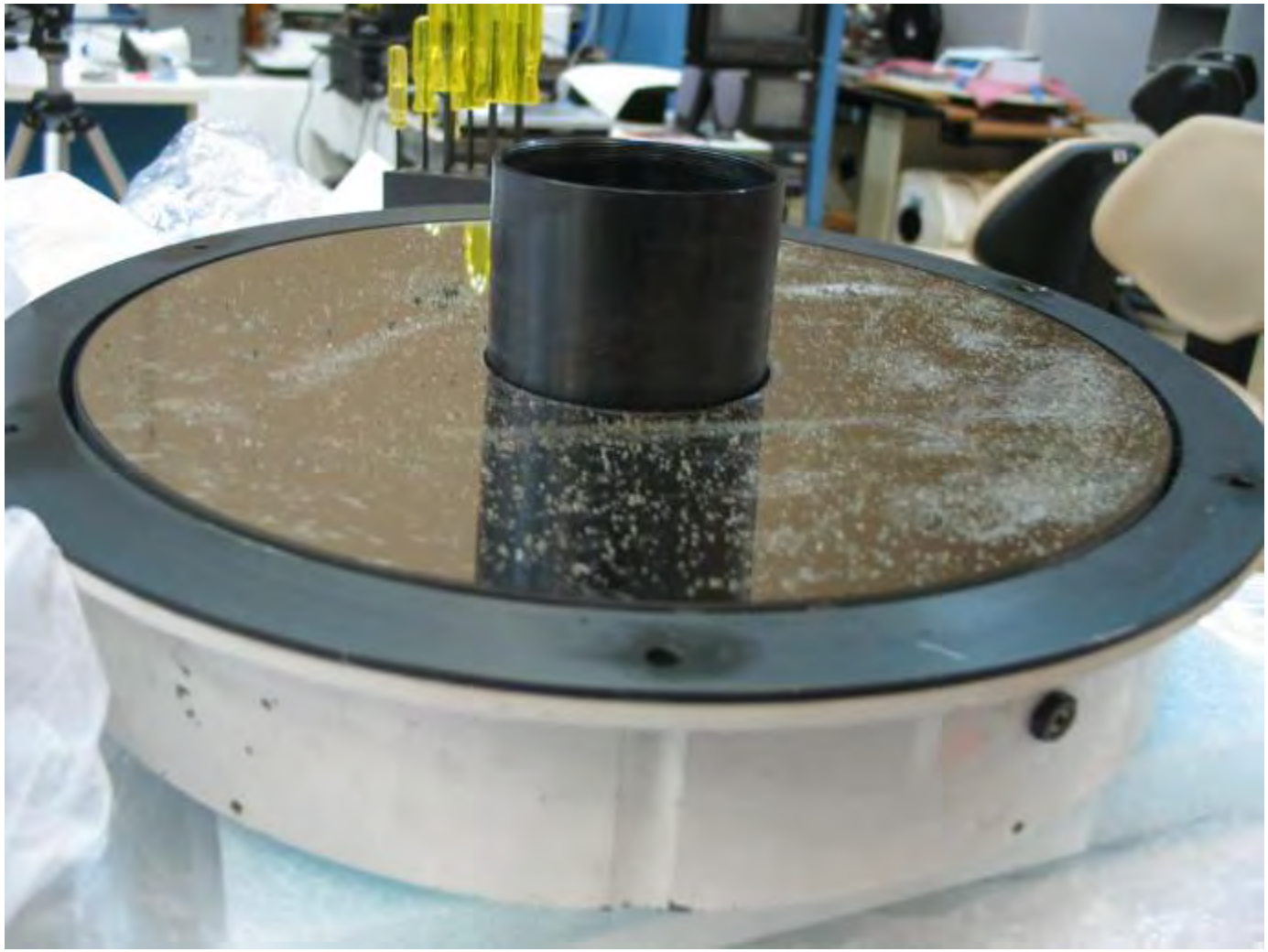
Note: As can be seen, the salt fog encountered on this day is a reminder of how vulnerable the telescope is to the corrosive effects of the Pacific Ocean environment …

The Optical Team Protecting a Valuable Air Force Asset and a Huge Taxpayer Investment.

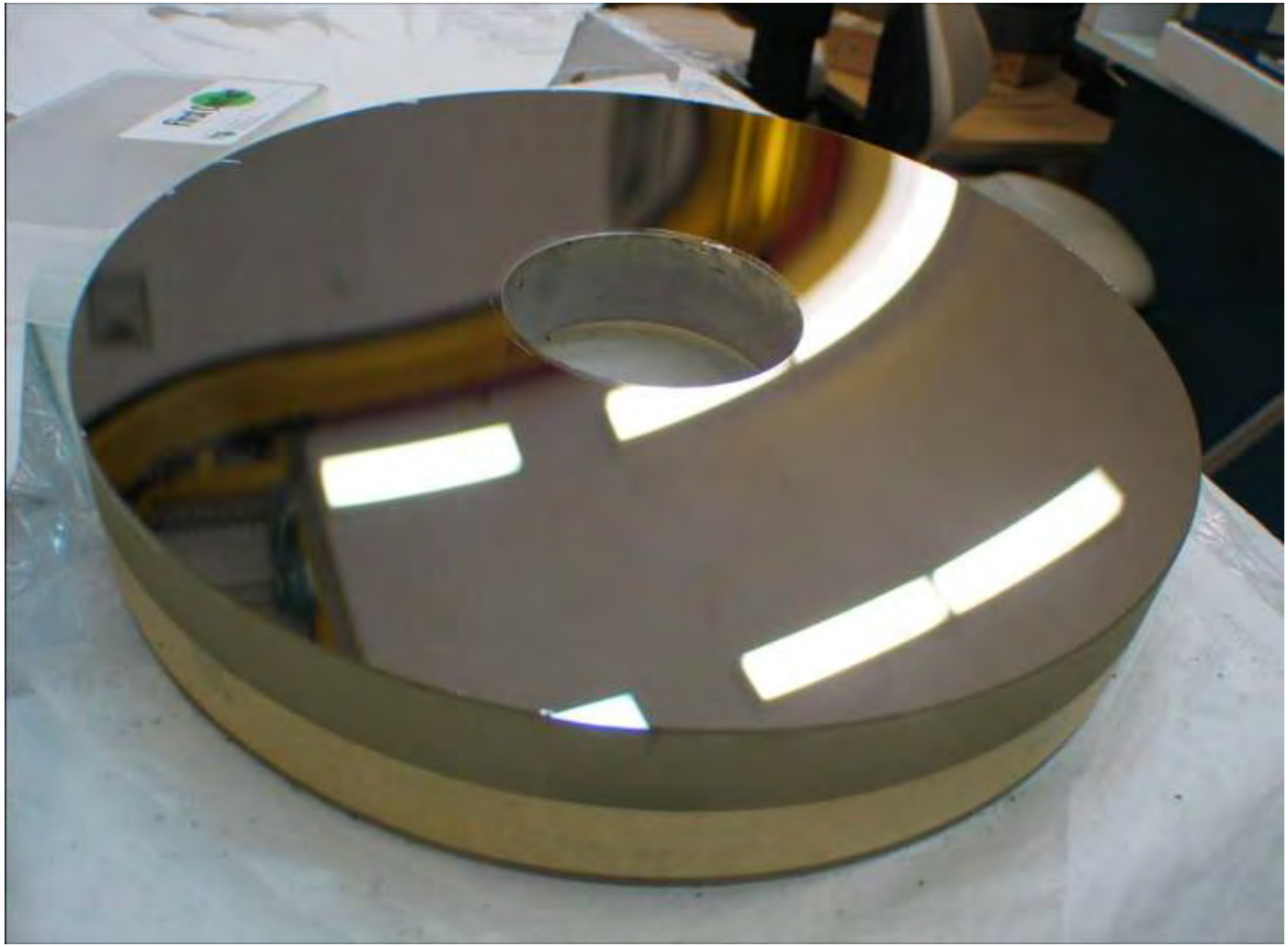
The Heavily Contaminated Primary Mirror - An Optical Engineer's Nightmare …



The Heavily Contaminated Primary Mirror - An Optical Engineer's Nightmare …



Restored to Pristine Condition - An Optical Engineer’s Dream …



First Contact® Polymer

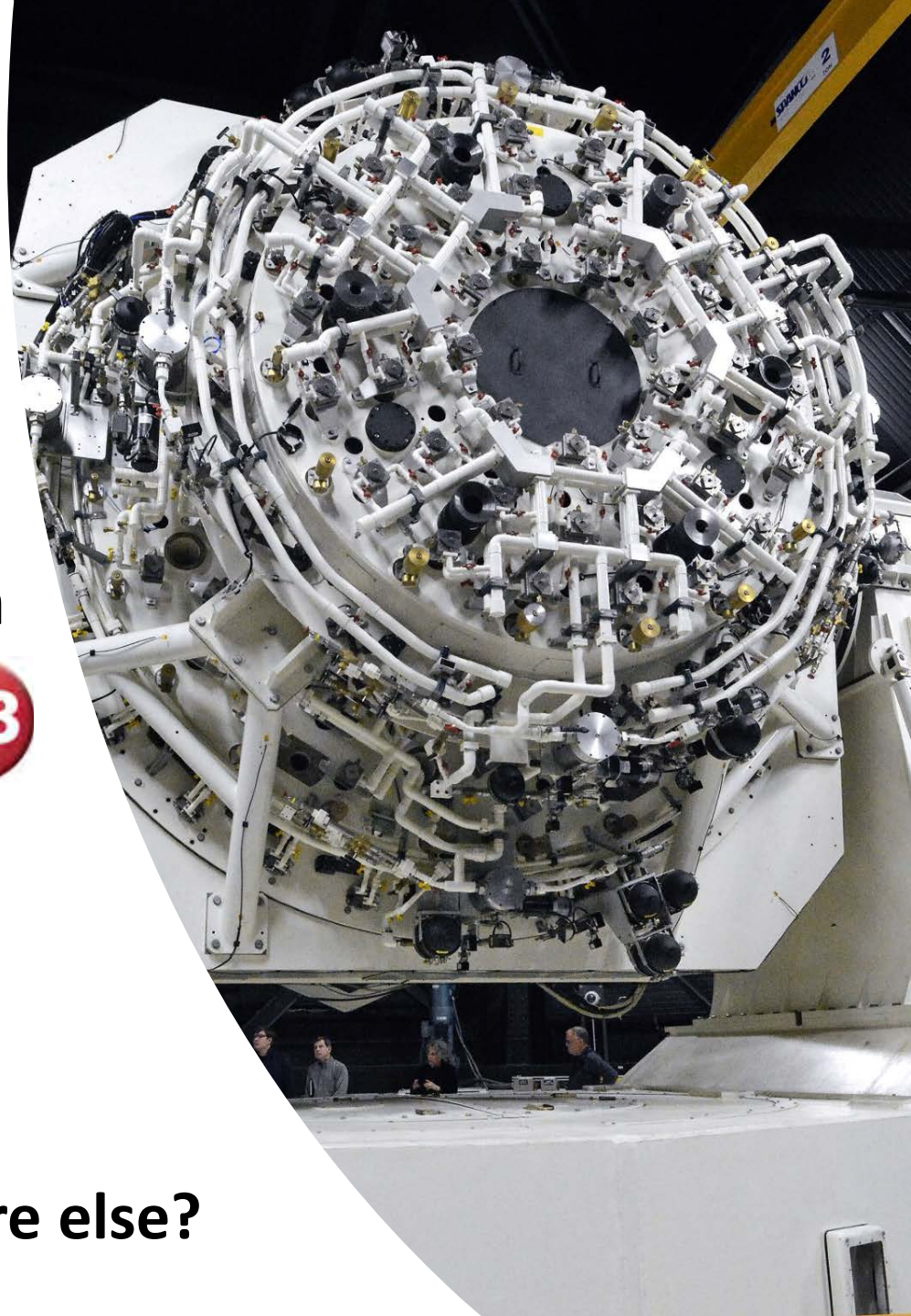
Space Surveillance Network

Cleans & Protects

SST - Space Surveillance Telescope

Space Surveillance Telescope Moving from White Sands to Australia.

Mirrors are protected with First Contact Polymer for shipping by boat.



First Contact® Polymer

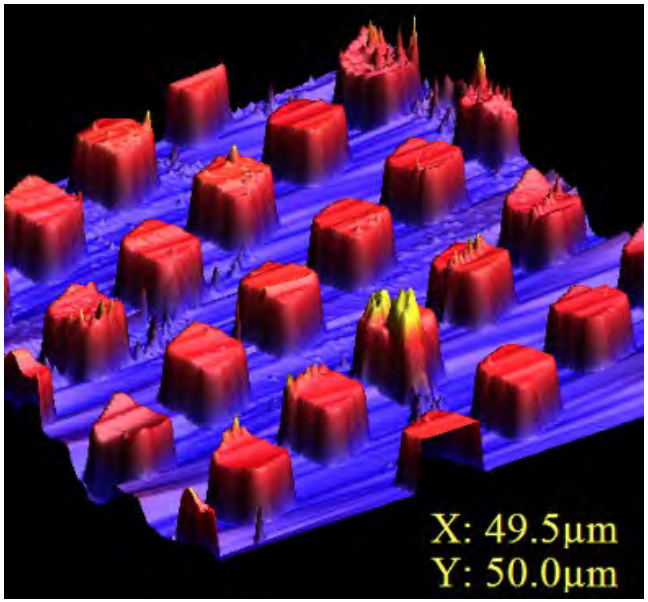
Where else?

How to determine Optical Surface Cleanliness

Metrology: Mechanical, Optical, Electron

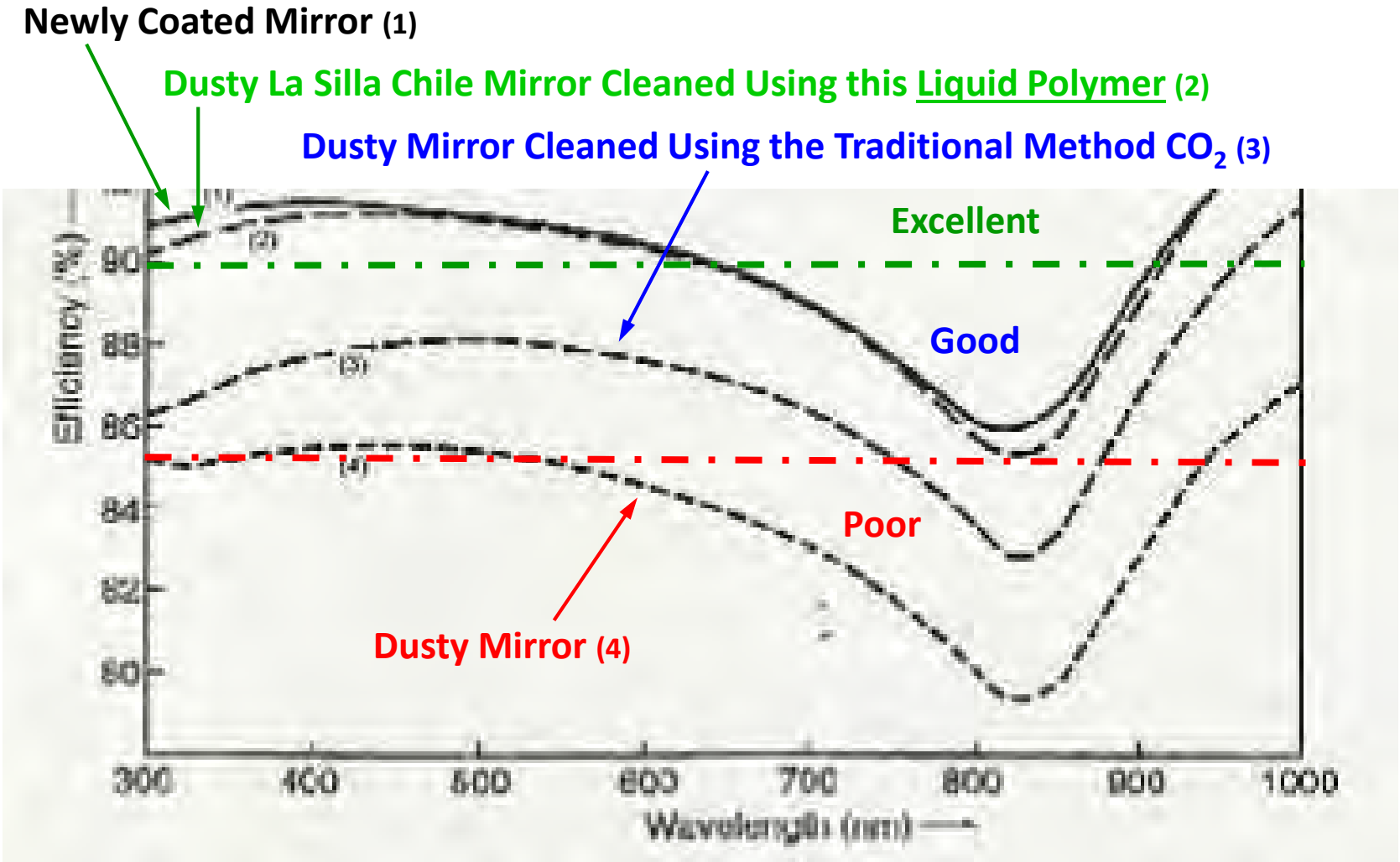
- Mass of Residue
- Differential Interference (DIC) Microscopy
- Scanning Electron Microscopy (SEM), Surfscan (KLA)
- Total Incident Scattering, Laser Induced Damage Testing
- Electron Spectroscopy (XPS, ESCA, Auger)
- Atomic Force Microscopy (AFM)
- Spectroscopy
- Polymer Properties

Our Surface Research:
A progression geared towards demonstrating atomic level cleanliness.



First Surface Mirror Efficiency Curve

Adapted from textbook: R.N. Wilson, Reflecting Telescope Optics II, Springer, 2002

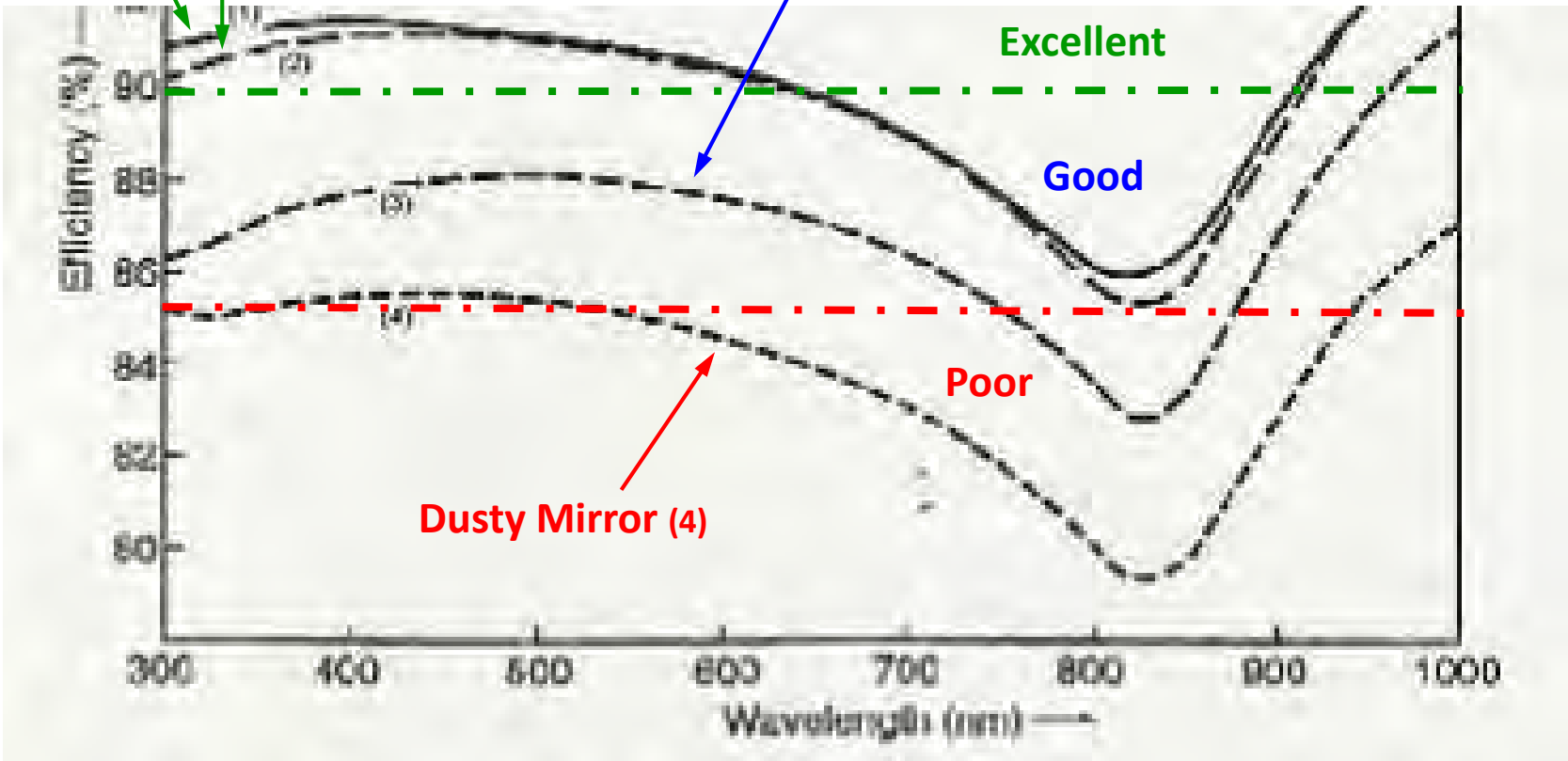


"Cleaning of large telescope surfaces has entered a period of active development after half a century of stagnation - clearly one of the most important trends in modern telescope optics" **- R.N. Wilson, Reflecting Telescope Optics II**

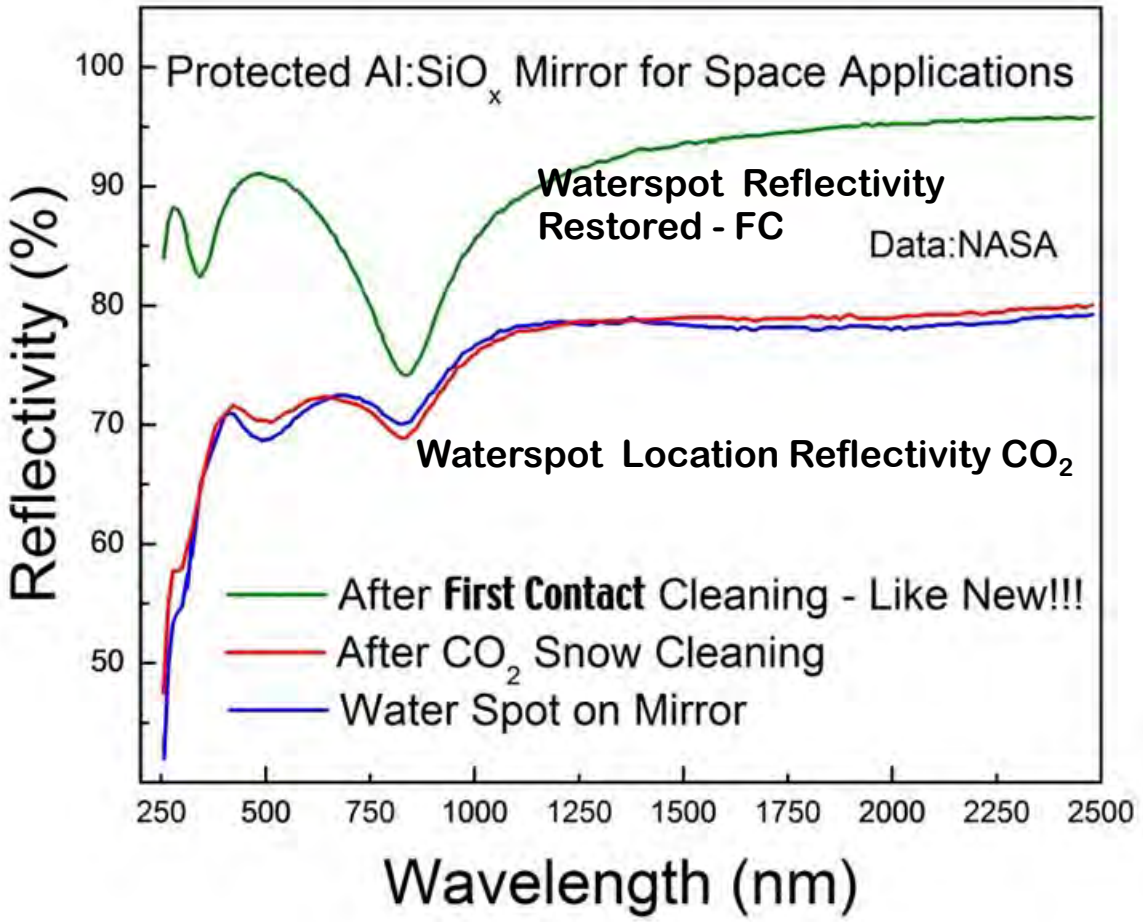
Newly Coated Mirror (1)

Mirror Cleaned Using this Liquid Polymer (2)

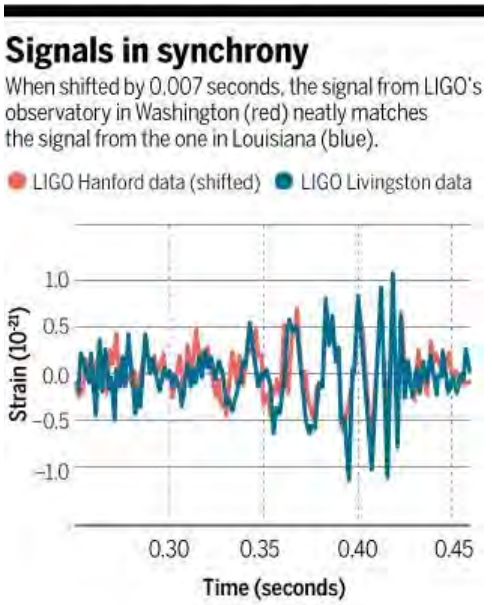
Dusty Mirror Cleaned Using the Traditional Method CO_2 (3)

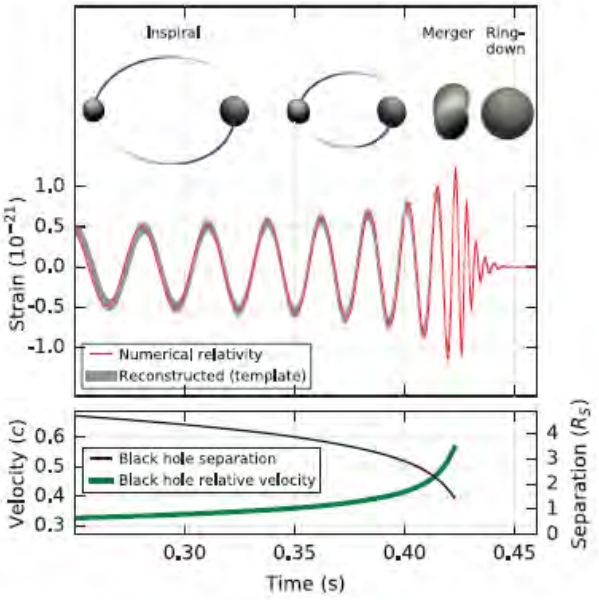


First Contact™ - Cleans Waterspots CO_2 can't - NASA



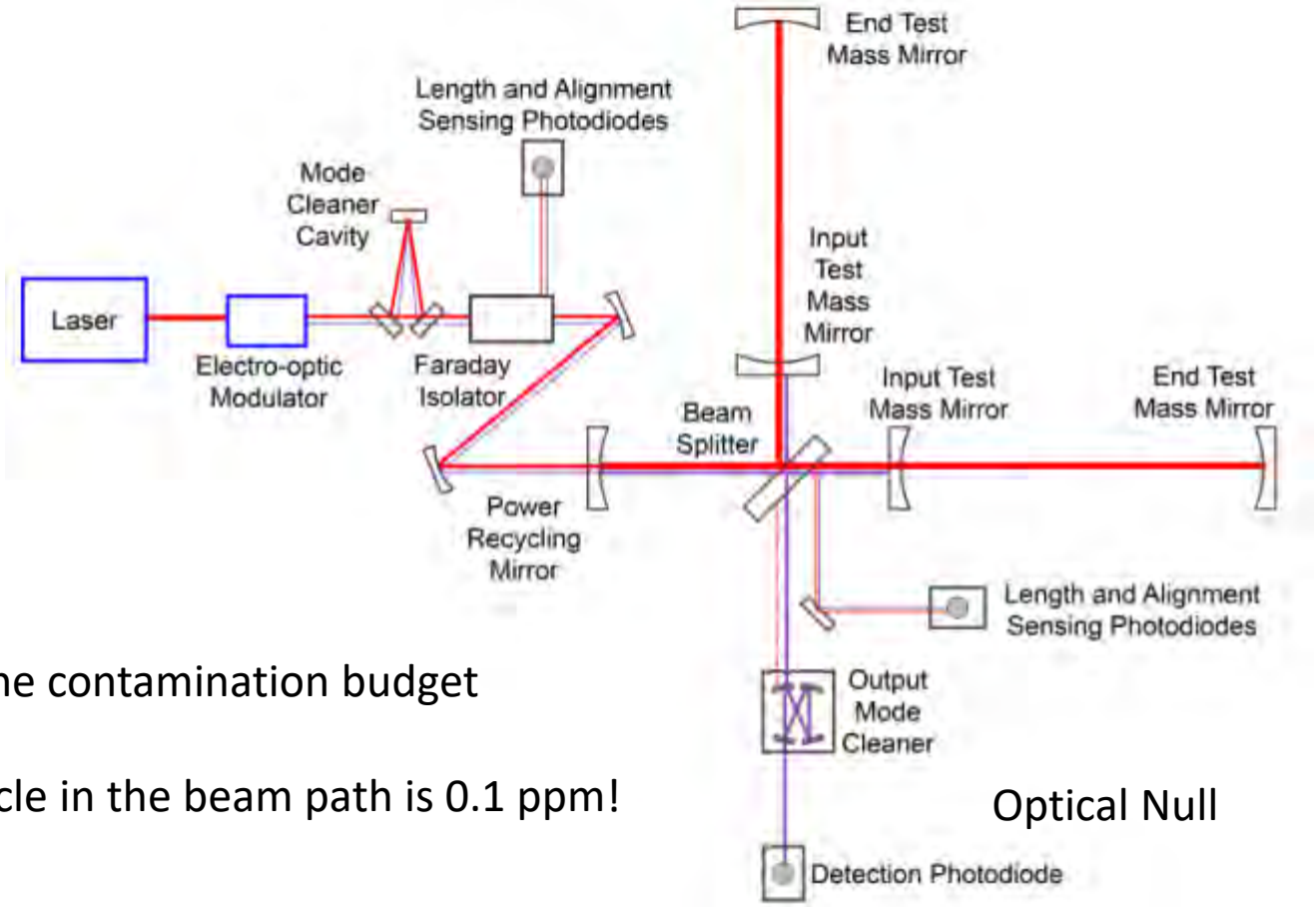
Data: **NASA/Goddard, Greenbelt, MD**





LIGO PRL Feb 2016

LIGO Laser Intensities at optical surface: 200 kW/cm2,
Absorption specification 0.1ppm on optics & coatings
Total cavity loss budget in operation= 70 ppm
Allowable each cavity surface = strict at 0.5 ppm per surface



0.1 ppm set aside for the contamination budget

One single 30 µm particle in the beam path is 0.1 ppm!

Optical Null

(Images and Diagrams Credit: Caltech/MIT/LIGO Lab)

LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO- T1000434-v1 *LIGO* Date 7/22/10

Advantages of cleaning optics with Red First Contact

Garilynn Billingsley, Margot Phelps

Distribution of this document:
LIGO Scientific Collaboration

This is an internal working note
of the LIGO Laboratory.

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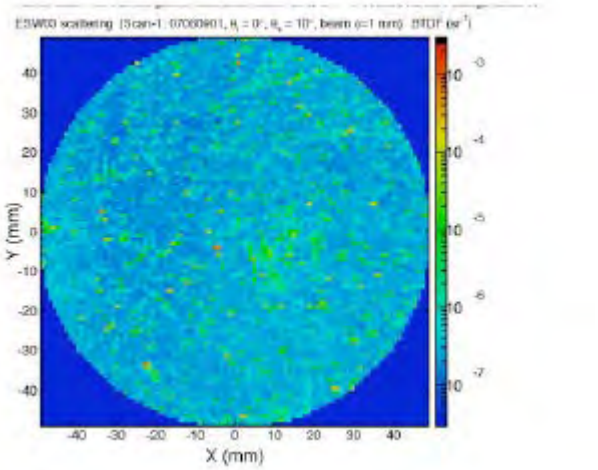
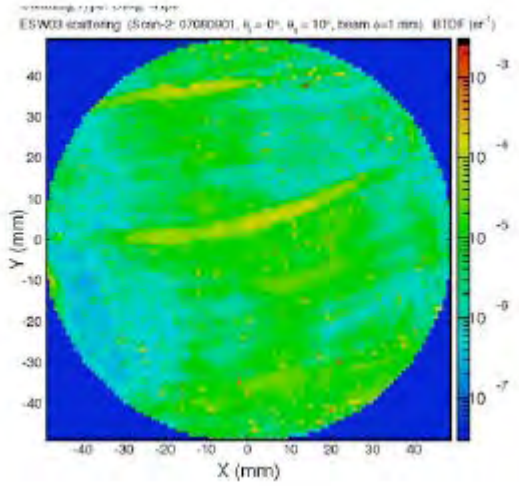
"Bidirectional Reflectance Distribution Function."



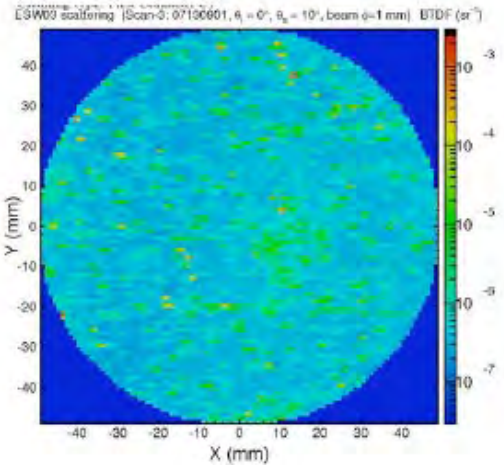
Before 2.05 ppm avg BRDF

BRDF = Reflectance of a target as a function of illumination geometry and viewing geometry.

“Not only did cleaning with First Contact leave no residue, it also removed nearly all the residue left by the methanol. -LIGO Internal Report T1000137-v3

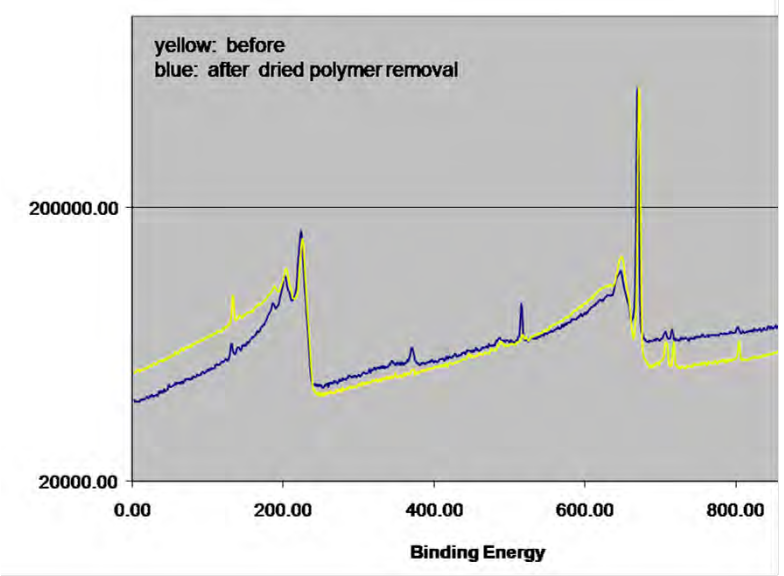


After MeOH Dragwipe
10.7 ppm avg BRDF



After FCP 2.05 ppm avg BRDF

Atomically Clean after: Before and after XPS Spectra on Glass



LOCKHEED MARTIN

NASA

XPS	C 1s %	O 1s %	Si 2p %
After	17.8	57.4	20.6
Before	48.1	33.3	16.0

First Contact® Polymer

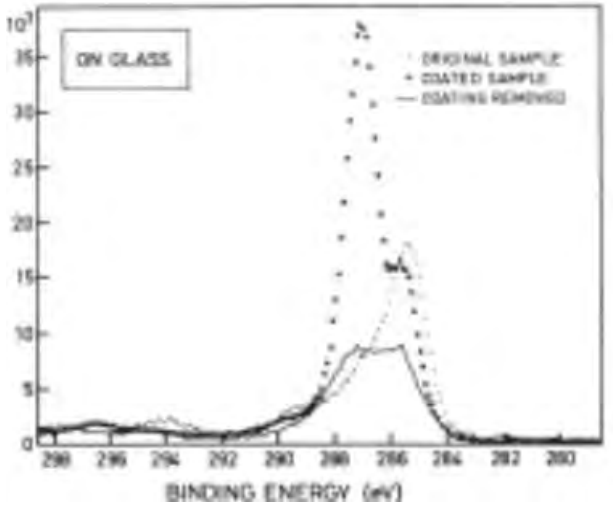
No Residue.

In fact, First Contact™ polymers actually removed previously existing carbon contamination present on the Si & glass surfaces.

Integrated peak area: 4 monolayers removed.

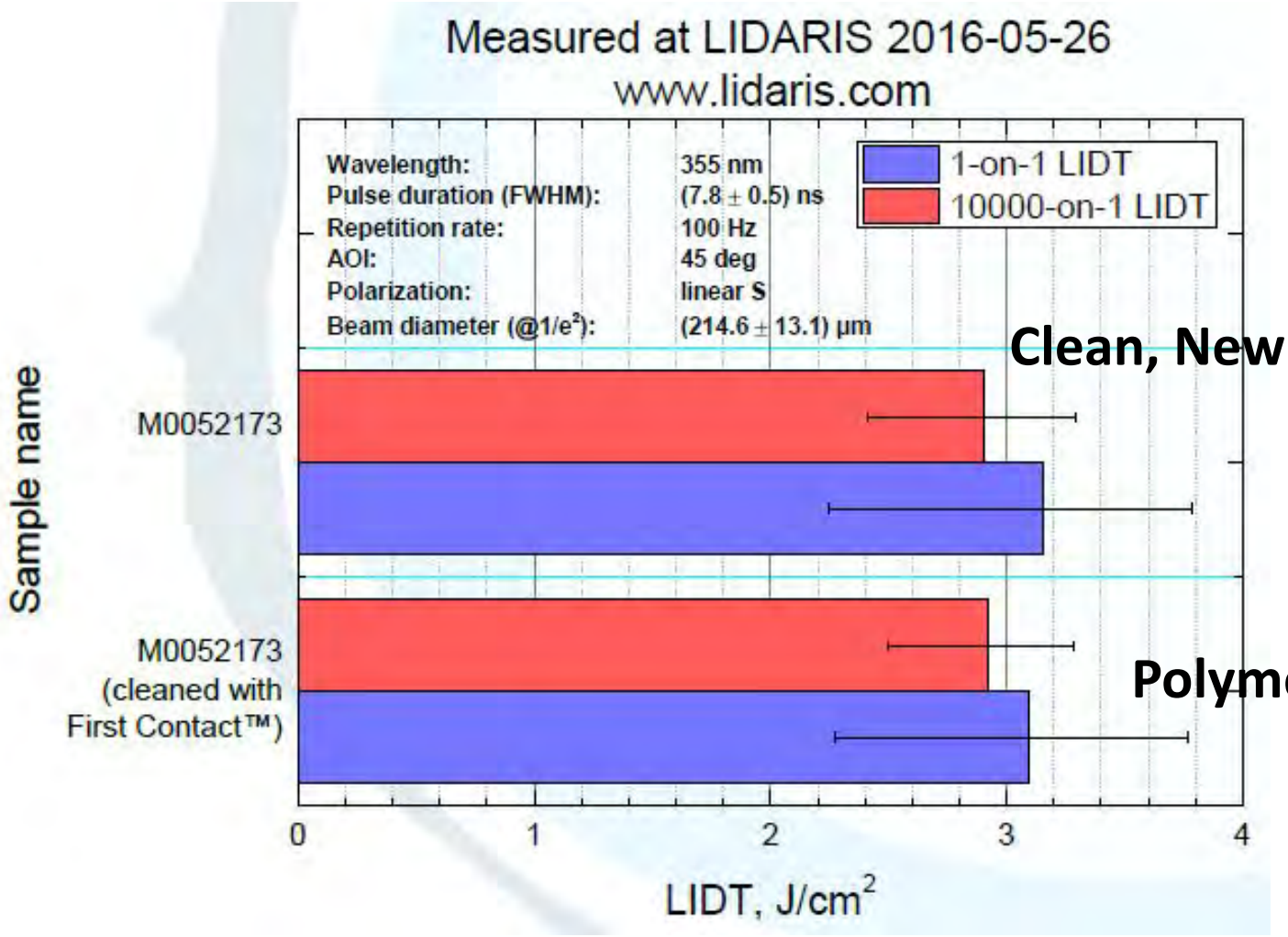
Prep for vacuum. Remove water, organics.

Only First Contact™ didn't leave residue…



J. Bennett Applied Optics

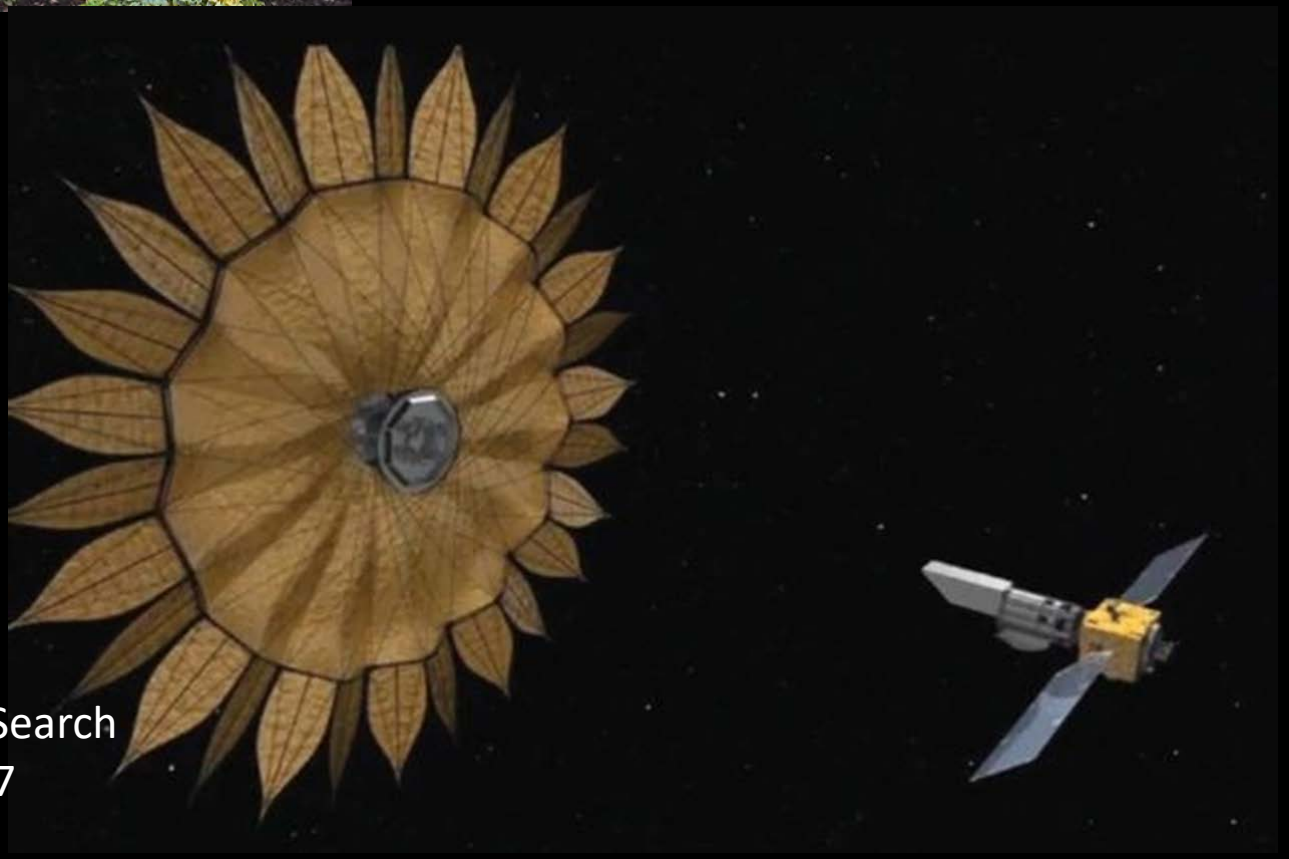
High Power Laser Damage Threshold (LIDT) – 355nm



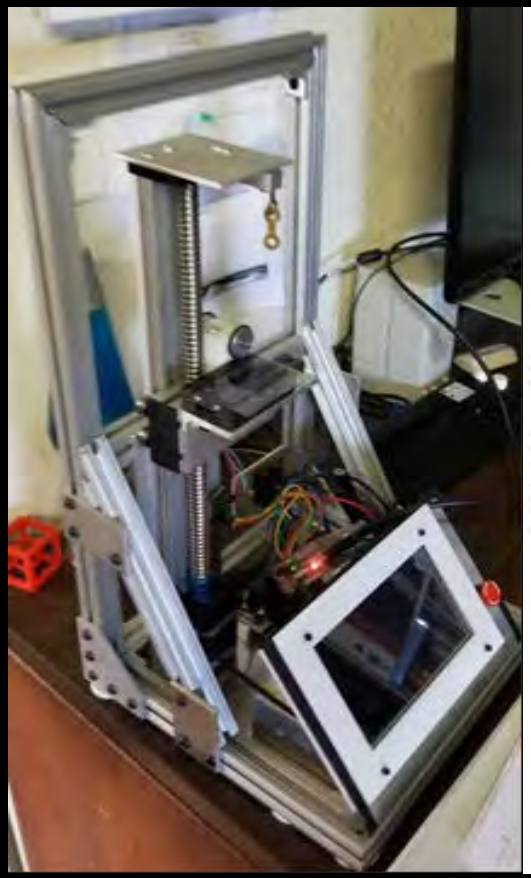
Clean, New Laser Optic

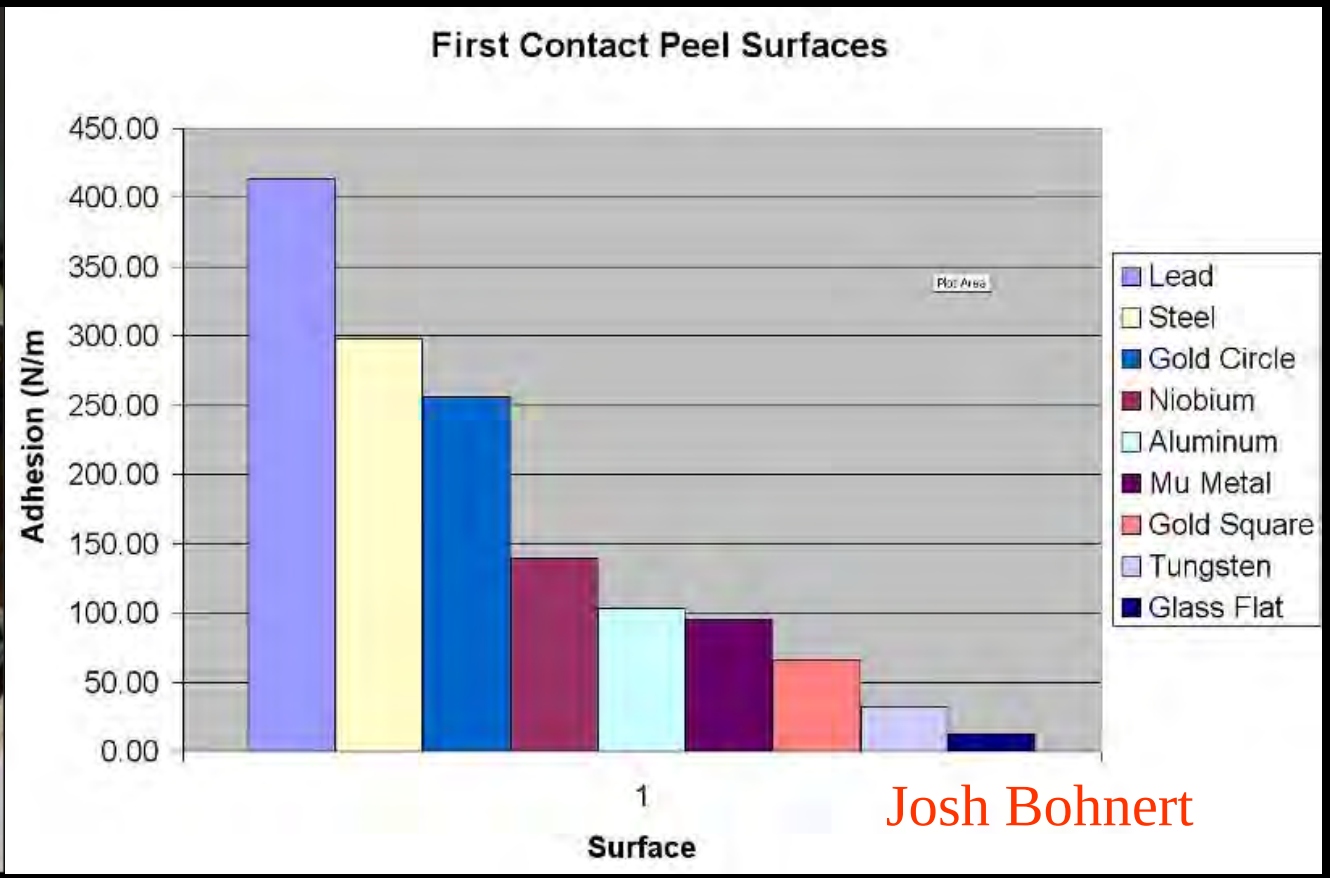
Polymer Cleaned

No Change in LIDT = No residue = No Damage



NASA's Starshade Exoplanet Search
Jet Propulsion Lab SBIR 2017

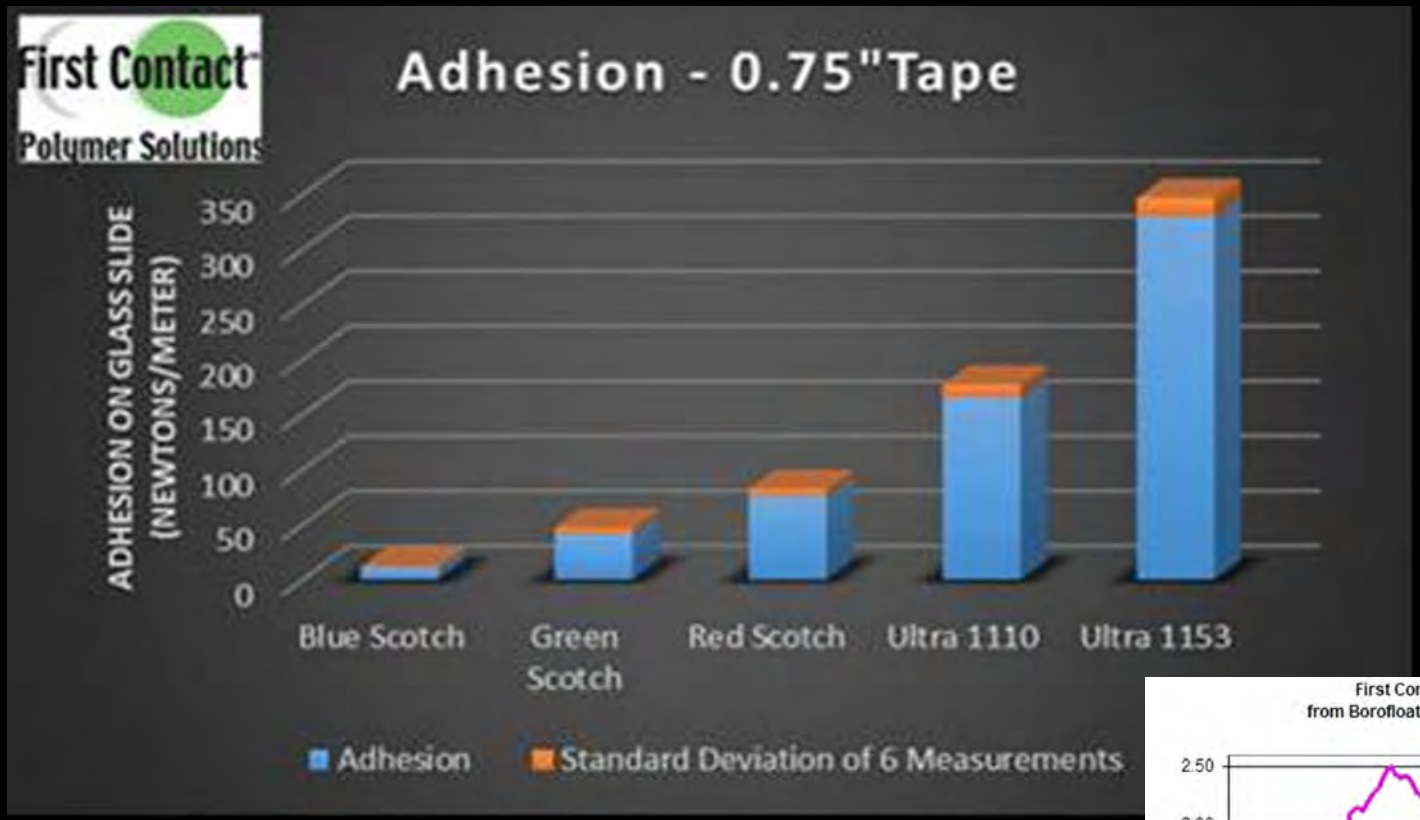


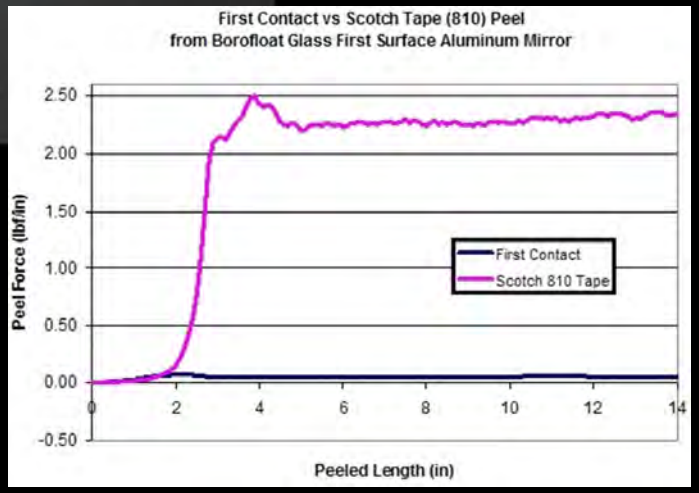


Josh Bohnert

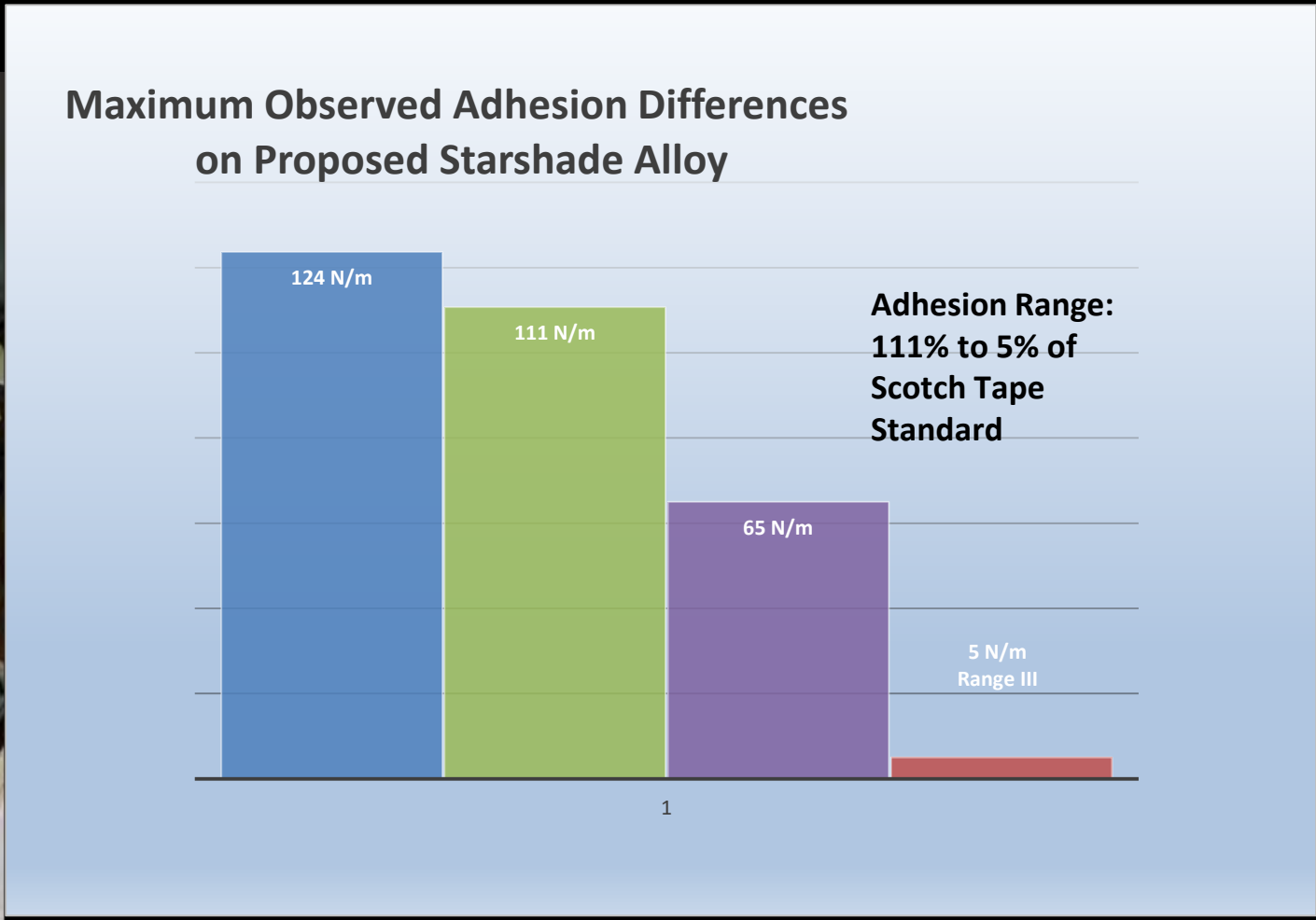
Cleaning & Protecting is a Balance of Adhesion and Release

Calibration, Precision & Accuracy





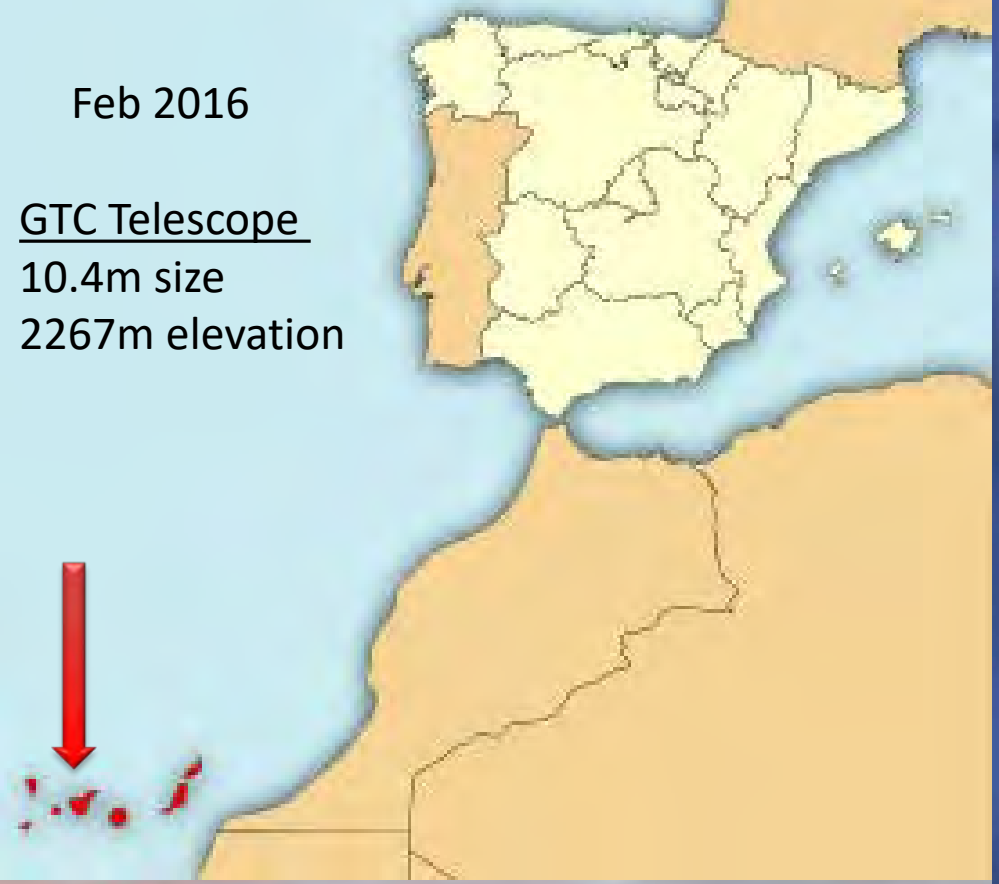
A Result of Phase I SBIR

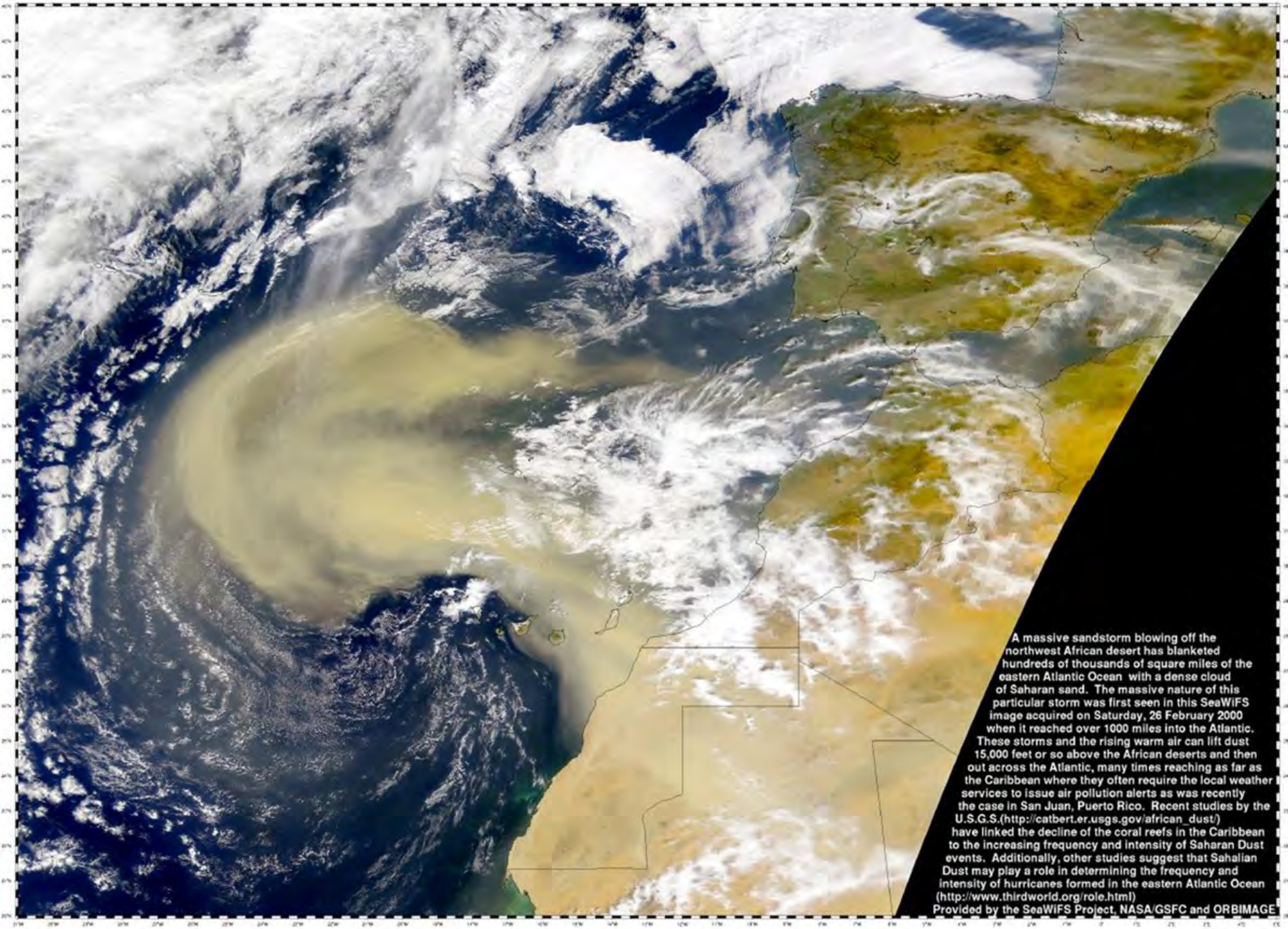


Now, Phase II …

Feb 2016

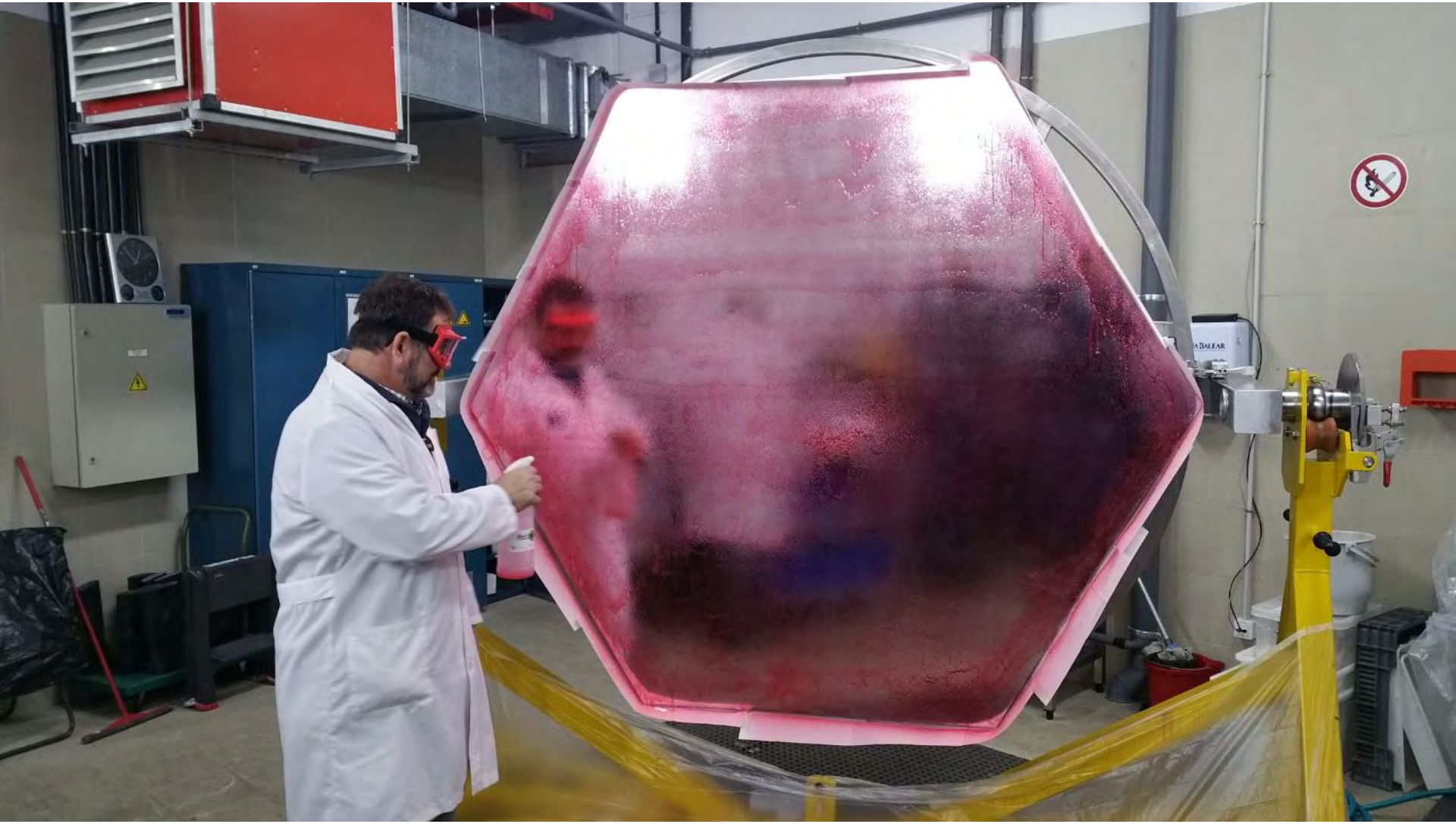
GTC Telescope
10.4m size
2267m elevation

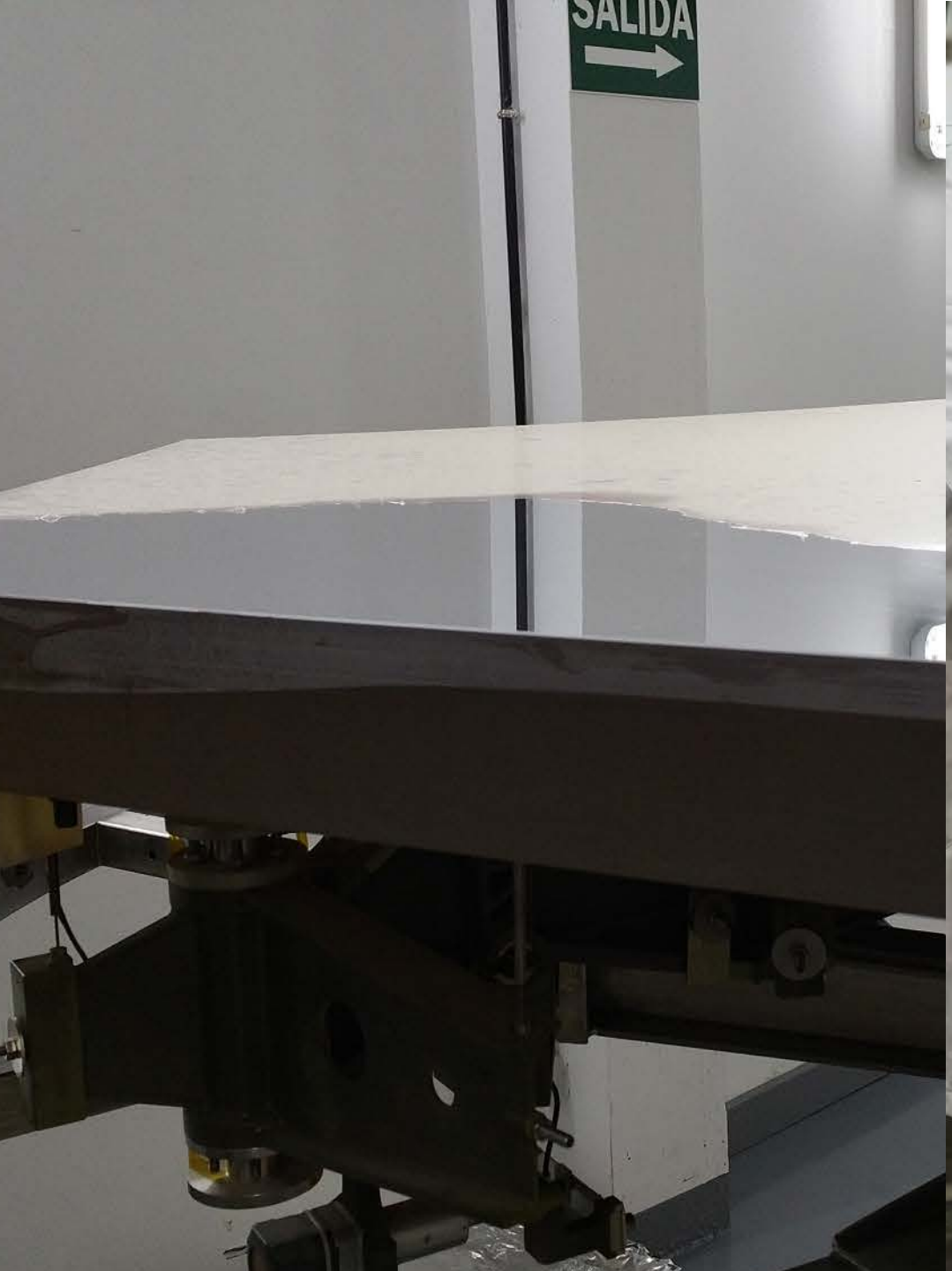




A massive sandstorm blowing off the northwest African desert has blanketed hundreds of thousands of square miles of the eastern Atlantic Ocean with a dense cloud of Saharan sand. The massive nature of this particular storm was first seen in this SeaWiFS image acquired on Saturday, 26 February 2000 when it reached over 1000 miles into the Atlantic. These storms and the rising warm air can lift dust 15,000 feet or so above the African deserts and then out across the Atlantic, many times reaching as far as the Caribbean where they often require the local weather services to issue air pollution alerts as was recently the case in San Juan, Puerto Rico. Recent studies by the U.S.G.S.(http://catbert.er.usgs.gov/african_dust/) have linked the decline of the coral reefs in the Caribbean to the increasing frequency and intensity of Saharan Dust events. Additionally, other studies suggest that Sahalian Dust may play a role in determining the frequency and intensity of hurricanes formed in the eastern Atlantic Ocean (http://www.thirdworld.org/role.html)

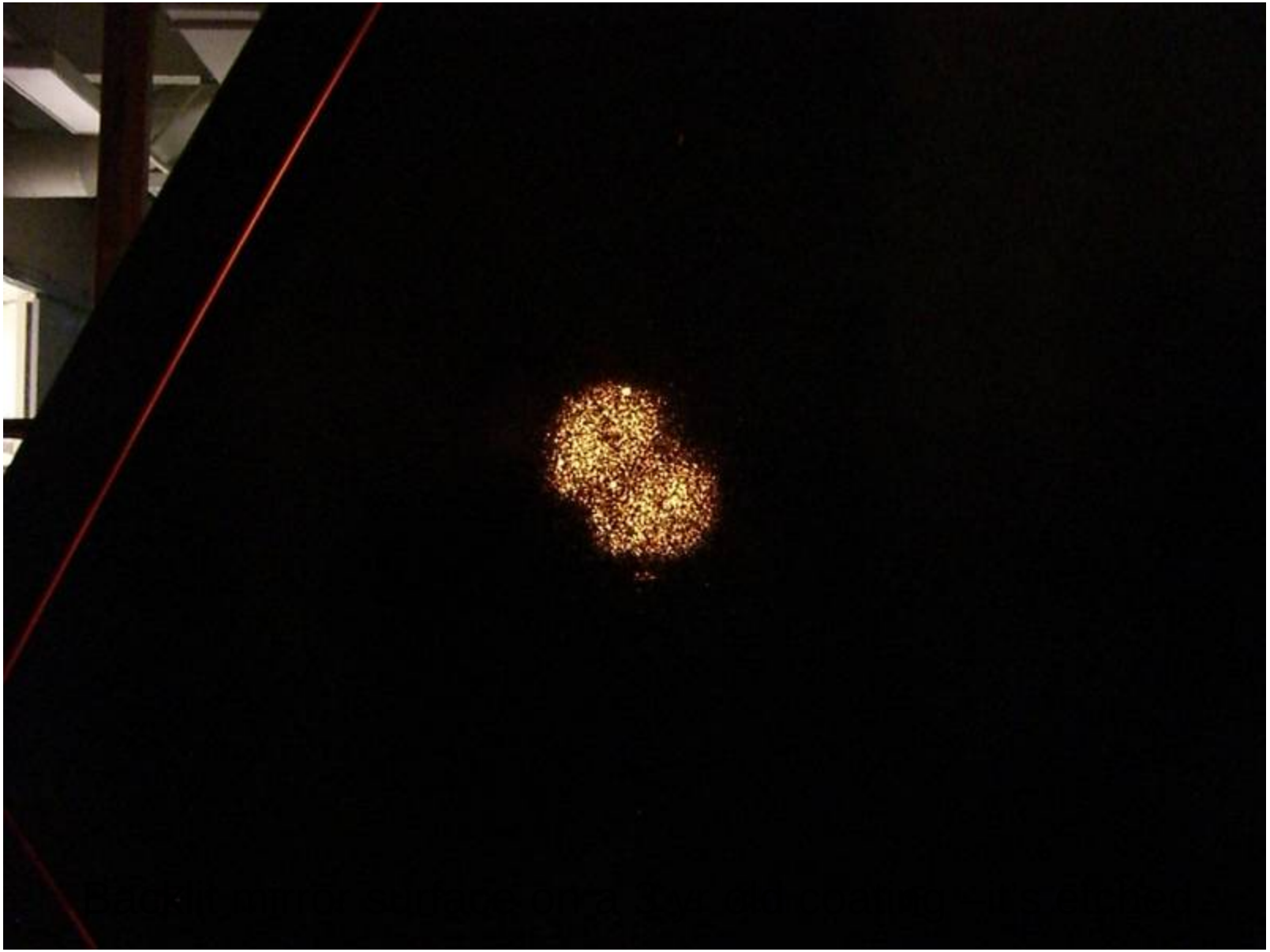
Provided by the SeaWiFS Project, NASA/GSFC and ORBIMAGE




SALIDA

First Contact Polymer Trials- Gran Canarias Telescopio: 2/2/16					
Mirror Name: La Palma		**Reflectivity %**			
Color	**λ nm**	**Before**	**After**	**Orig. %**	**% Gain**
Blue	470	81	90	92	9
Green	530	81	90	91	9
Red	650	79	89	90	9
Near IR	880	77	87	88	10
	Total Integrated Scattering, 670 nm				
	Before	**After**	**Improv.**	**Original**	
	2.71	0.88	6.75	0.2‡	
This mirror had light dust, water marks, some pinholes, insects marks, bugs & some microscratches.					
Primary Mirror Segment Installed 3/27/2015, removed January 2016					

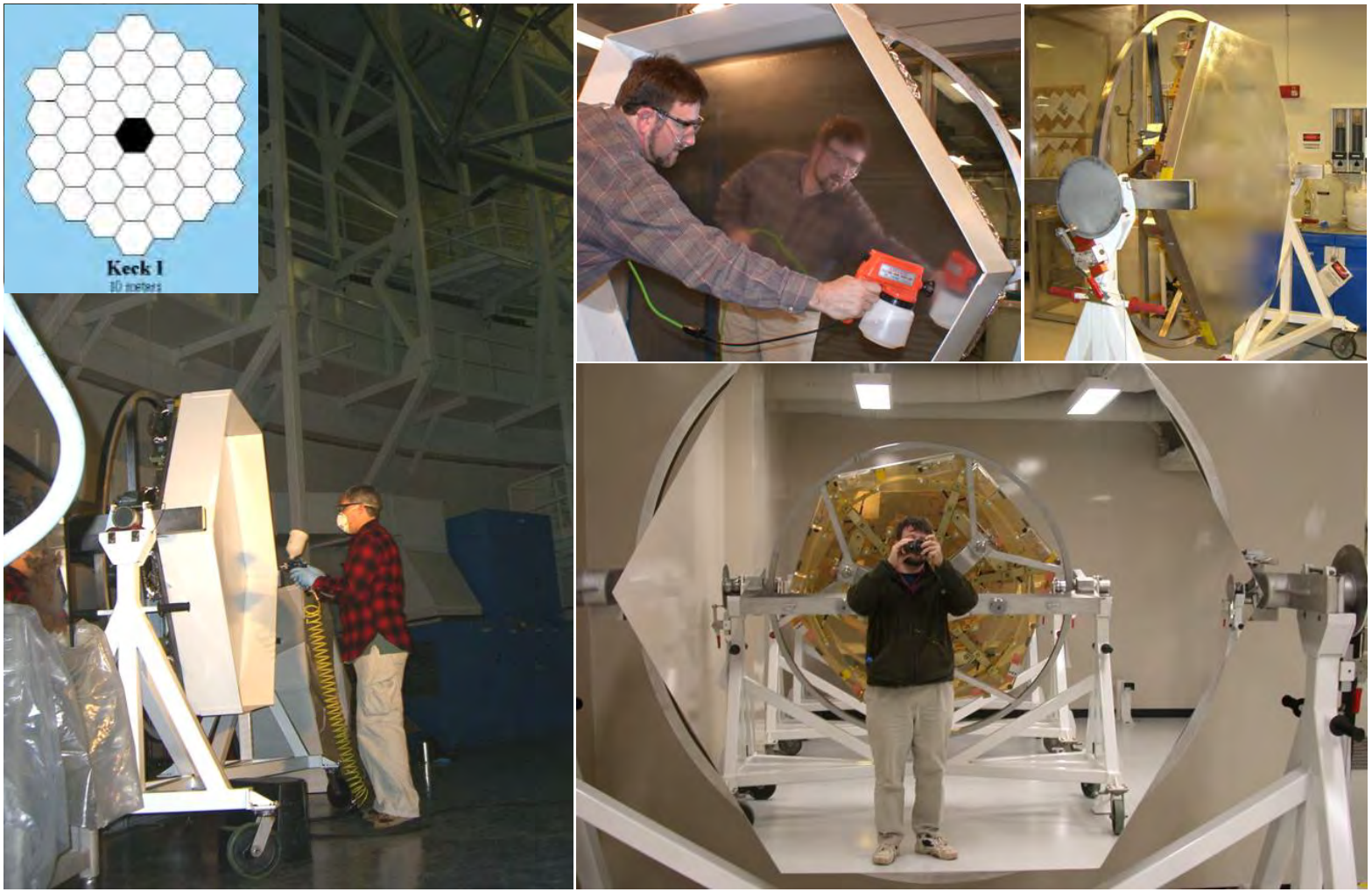
What this data proves, is that regular maintenance of mirror surfaces with First Contact Polymer can maintain reflectivity indefinitely and prevent damage.



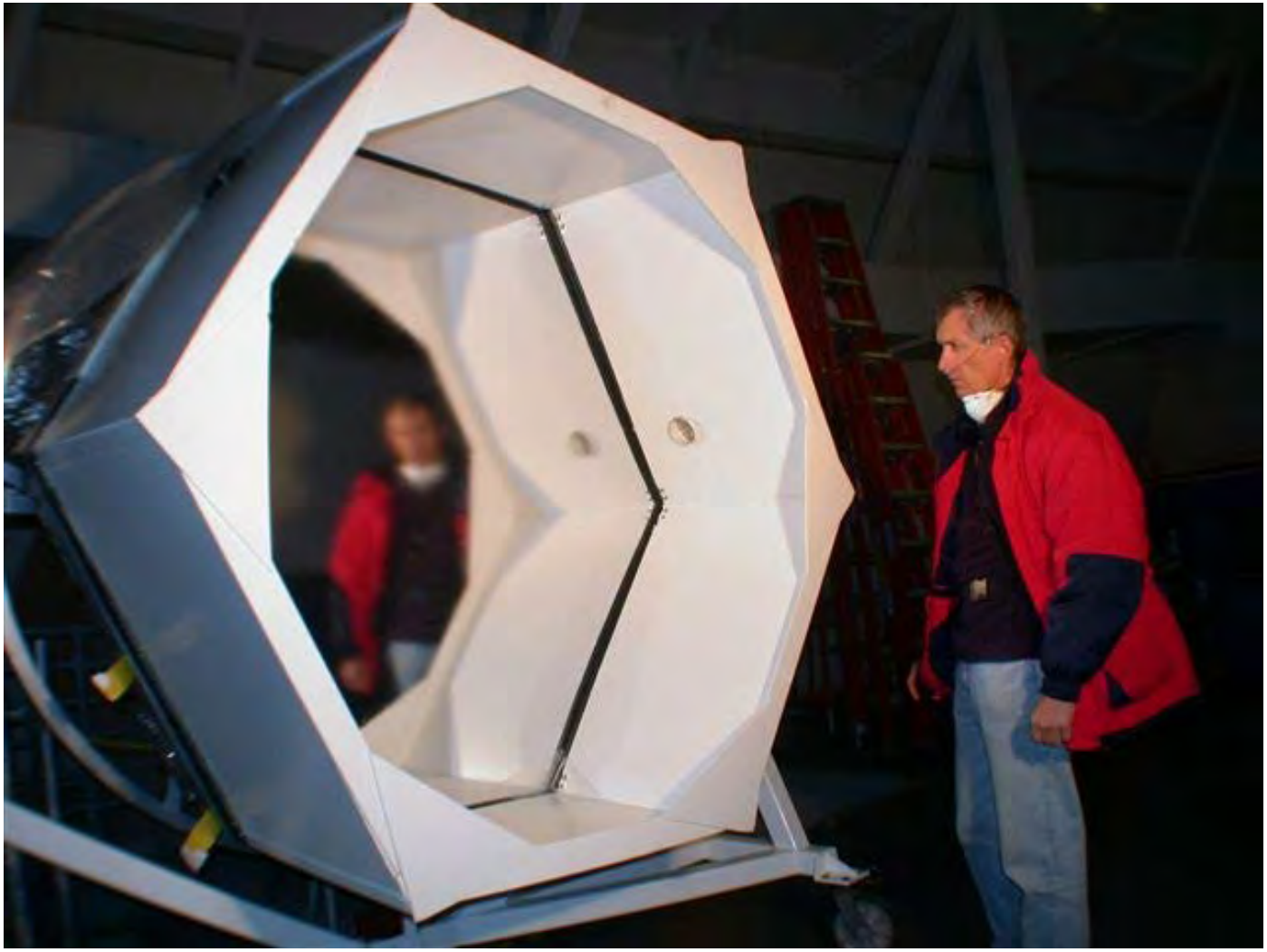
Flashlight Shining through Keck Primary Mirror

First Contact Polymer Trials- Gran Canarias Telescopio: 2/2/16					
Mirror Name: Cardone		**Reflectivity %**			
Color	**λ nm**	**Before**	**After**	**Orig. %**	**% Gain**
Blue	470	72	88	91	16
Green	530	71	88	91	17
Red	650	69	87	90	18
Near IR	880	67	86	87	19
	Total Integrated Scattering, 670 nm				
	Before	**After**	**Improv.**	**Original**	
	10.29*	2.38	7.92	0.2‡	
This mirror had thick Saharan dust, water marks, pinholes, insects marks, bugs & microscratches from CO_2 cleaning due to dust.					
Primary Mirror Segment Installed 3/27/2012, removed January 2016					
*essentially offscale reading on TIS instrument. ‡Regular cleaning over the years resulted in roughness causing 0.1 TIS moving to 0.2 baseline.					

Cleaning one of the 36 segments of the Keck Telescope with Liquid Polymer. When implemented by Keck Observatory management, this polymer cleaning process will open the window on a revolutionary method for cleaning astronomical telescopes.



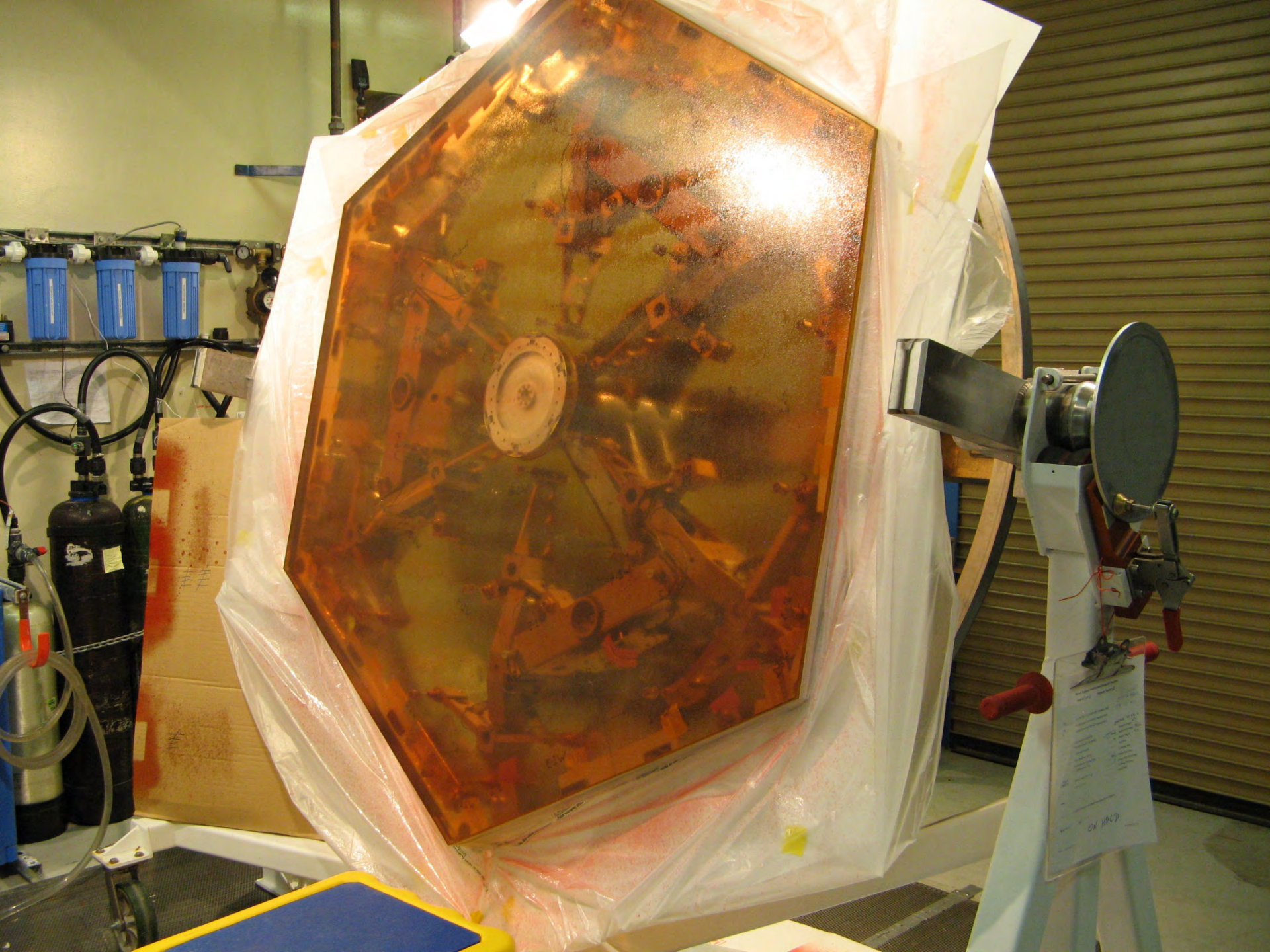
Cleaning a First Surface Mirror



Sergey Panteleev Inspecting his work

Spray Application of First Contact Polymer to Keck 6ft hexagonal mirror.

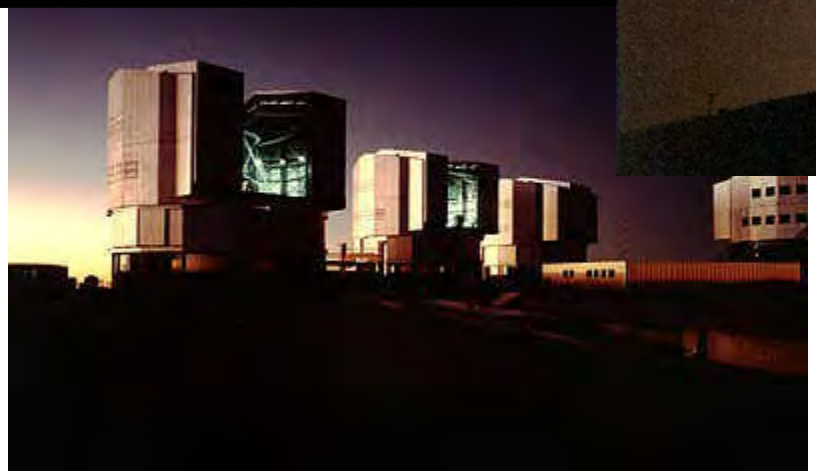
In the Dome: 0° C and 13,800 ft.



The End Game for Massive Telescopes:

Routinely Maintain Mirrors at Maximum Reflectivity

Dramatically (Indefinitely?) Extend Coating Lifetimes

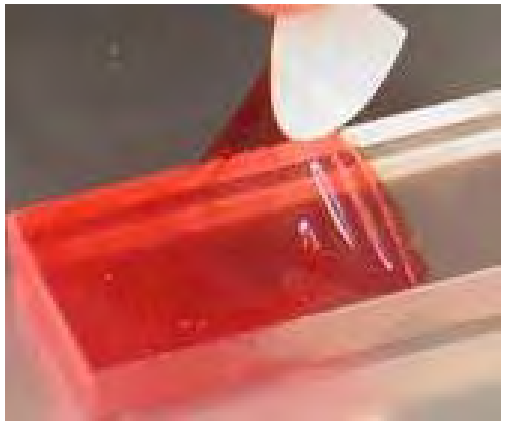


First Contact® Polymer

Summary

- Cleanroom Clean without a Cleanroom
- Assets will be Mission Ready: Just Peel
- UHV & Space Compatible
- Extend life of Coatings and Laser Optics
- Create Zero Defect High Power Laser Optics (R&D)
- Critical Surfaces Protected & Clean after peel.
- Decontaminate Critical Surfaces
- Clean the Uncleanable
- Reduce Downtime

hamiltonj@photoniccleaning.com




CLEANING LIGO OPTICS
with GariLynn Billingsley
Senior Optical Engineer
Advanced LIGO, Caltech

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- University of Wisconsin - Platteville Students
  - Austin Rickertson, Cole Orlebeke, Jorge Camacho, Lester Lambert, Robinson Flaig
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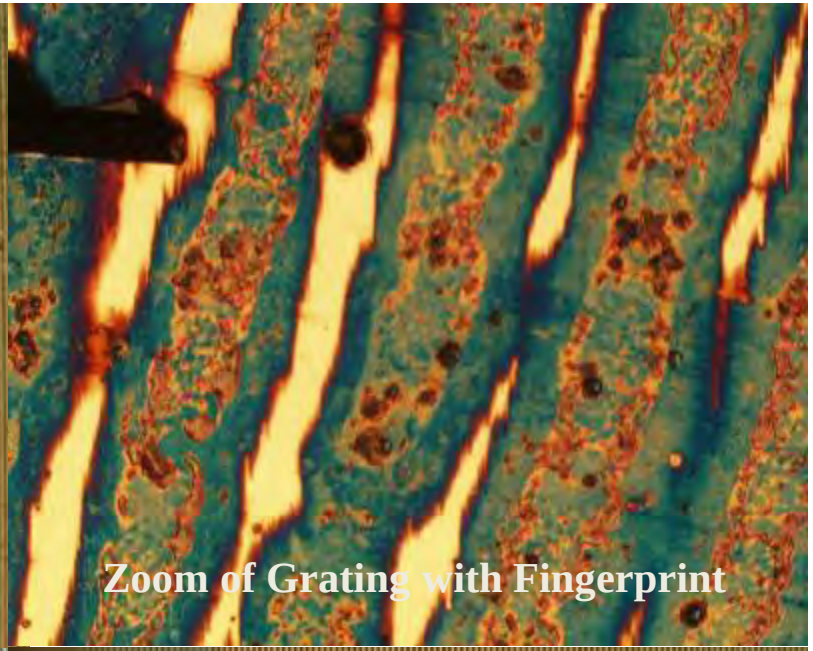
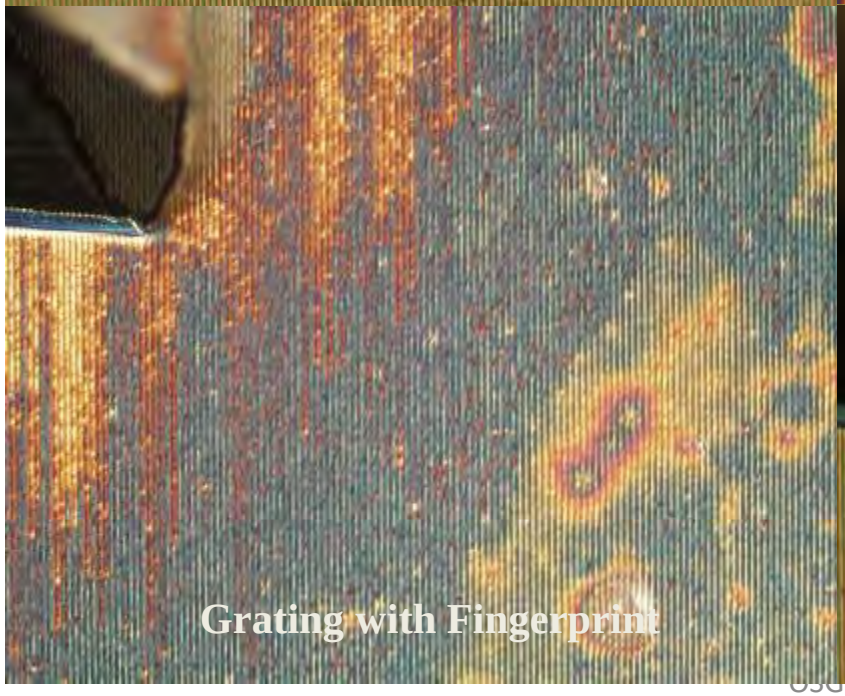
- NASA Phase I SBIR 2017 S2: Advanced Telescope Systems S02.03– Starshade
- *This work was supported in part by the U.S. Department of Energy, Basic Energy Sciences-Materials Sciences, under contract no. W-31-109-ENG-38. The authors acknowledge the support and facilities provided by the Advanced Photon Source and the Electron Microscopy Center at Argonne National Laboratory
- State of Wisconsin 2002-05,2014-16 Applied Research Grants, WITAG Funding '08-'11
- U.S. Department of Energy, ERLE Grants, e.g. DOE Grant # DE-FG26-03NT41687
- Wisconsin Distinguished Professor established under Wisconsin State Statute 36.14
- WiSys Technology Foundation, Madison, Wisconsin USA

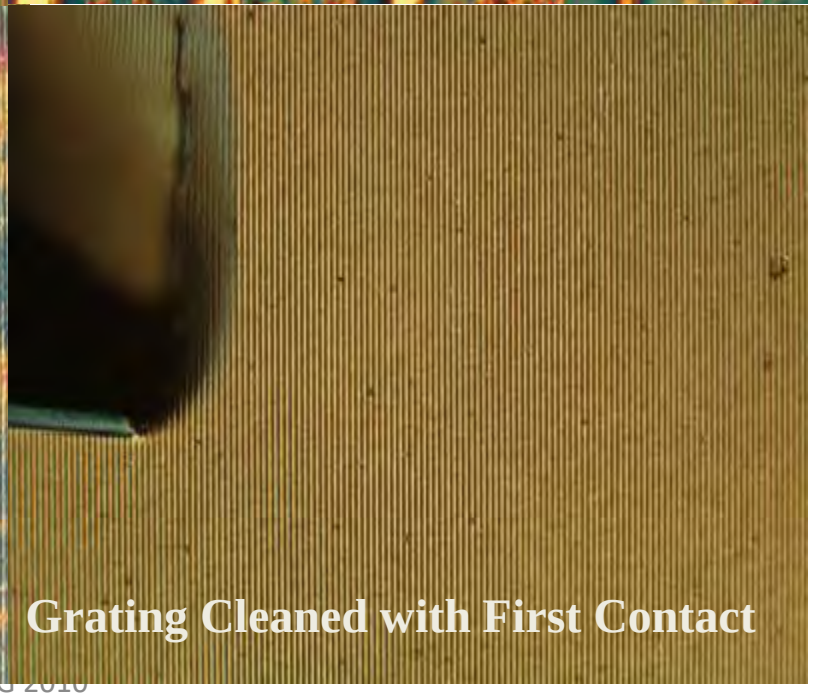
Hawaii, 14,000 ft: W.M. Keck Telescope - Bandpass Filter and Diffraction Grating cleaned with First Contact

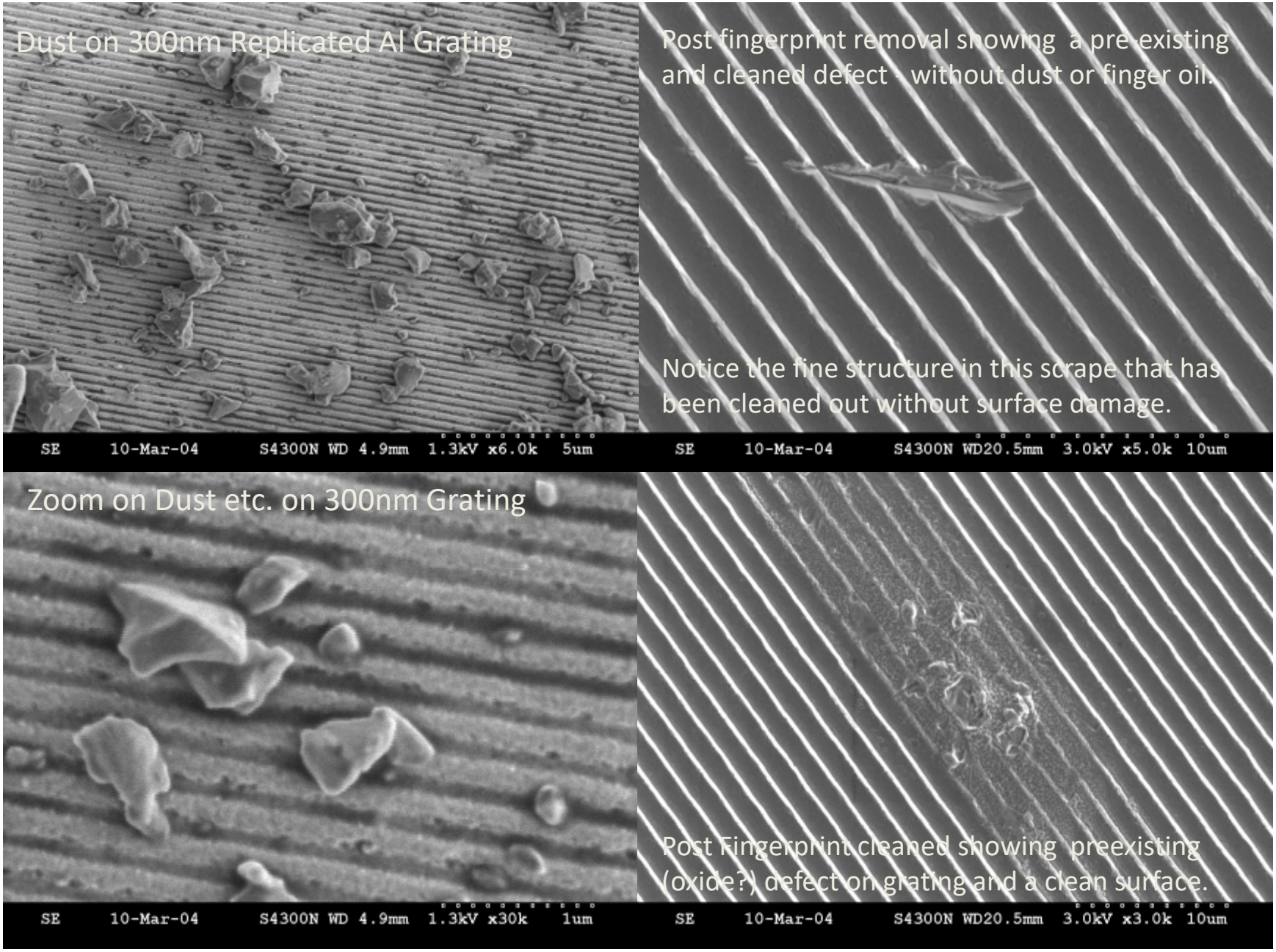
New 1200 line per mm Grating with Fingerprint


Brand New Grating
Hole made from Diamond tip.

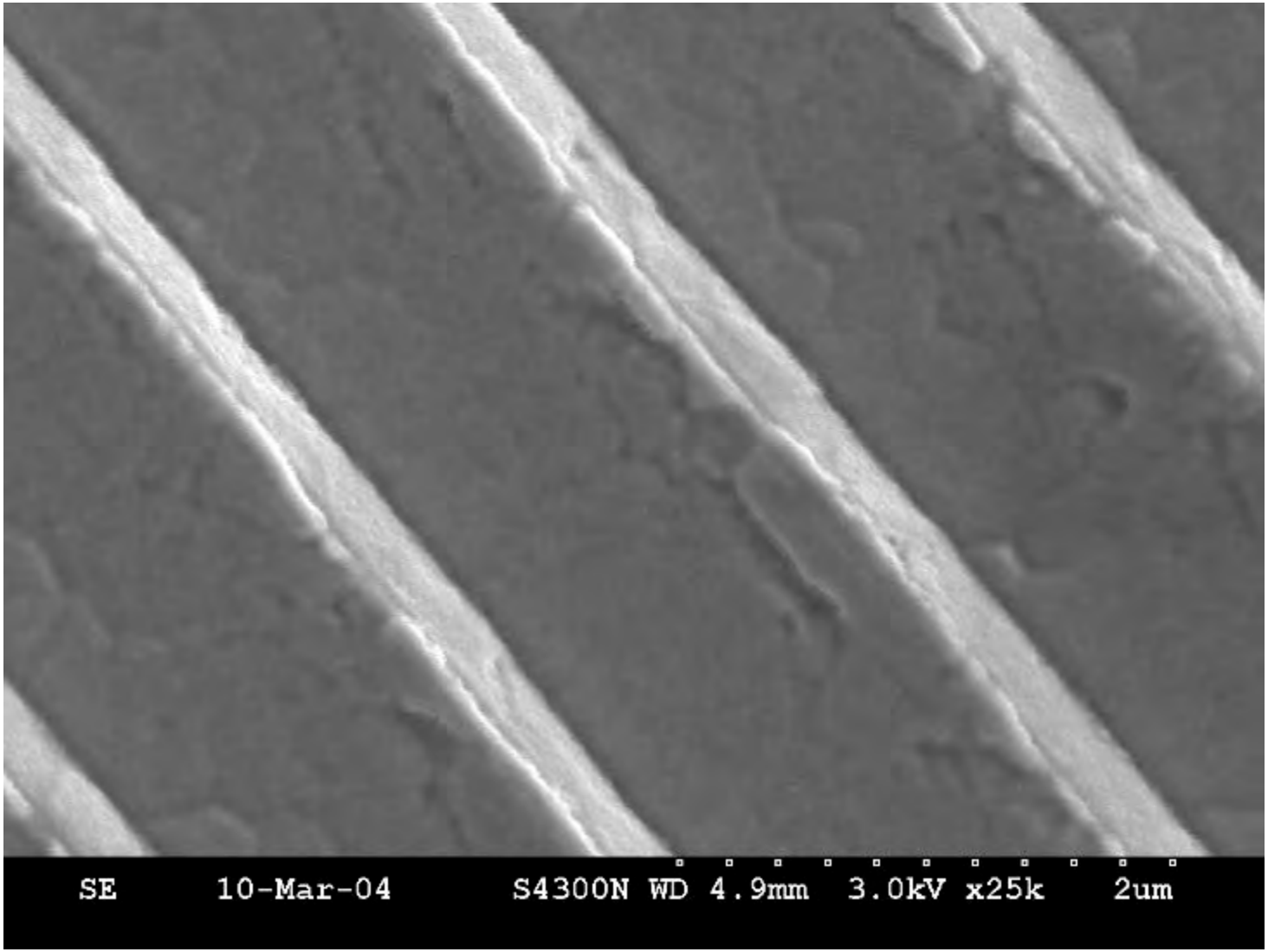

Zoom of Grating with Fingerprint


Grating with Fingerprint


Grating Cleaned with First Contact

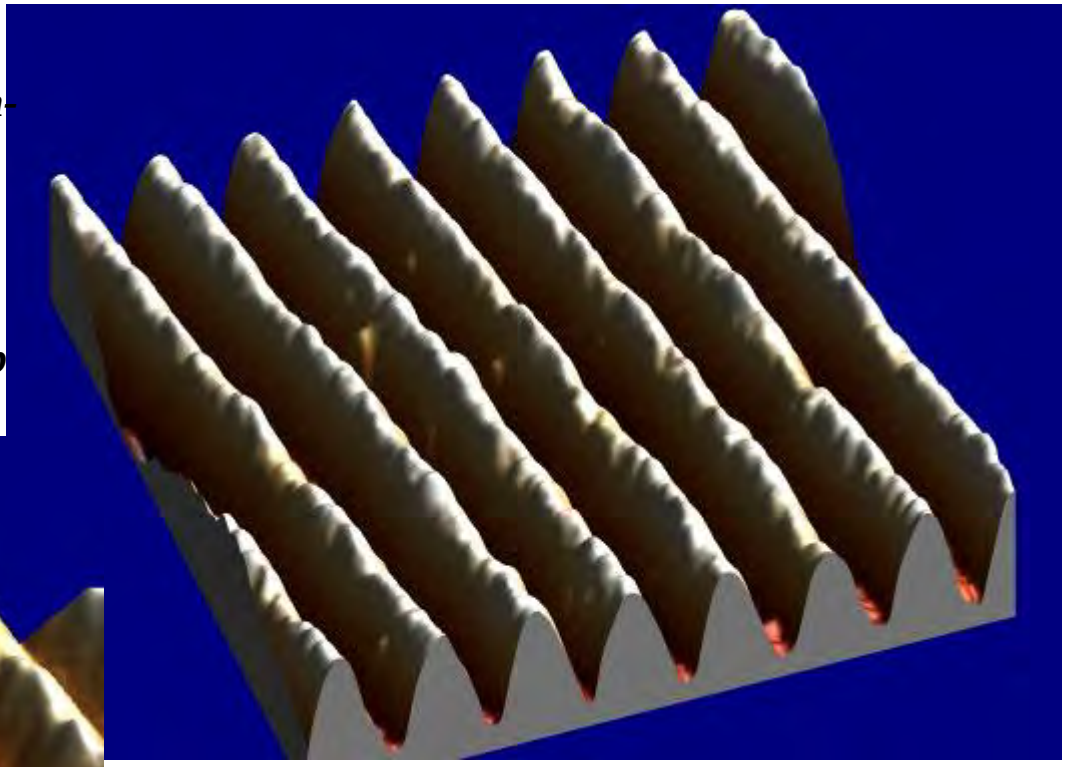


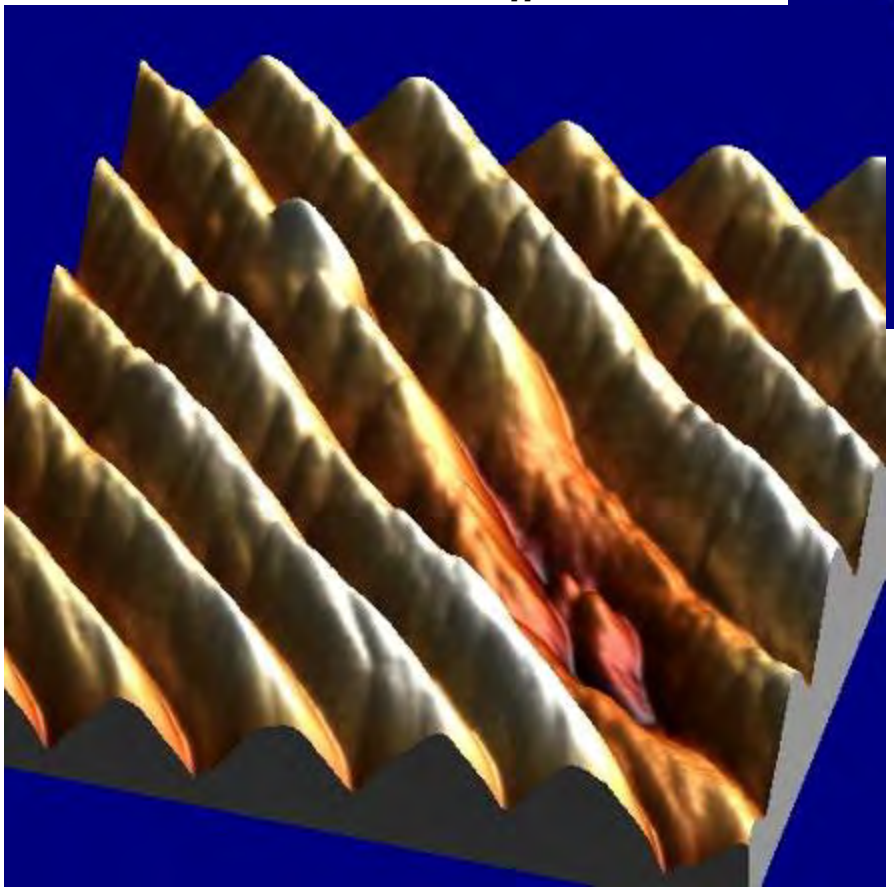
Precleaning and Post Fingerprinting, Cleaned Surface on Hitachi S-4300 Cold FE-SEM



Post Fingerprint, Cleaned Surface on Hitachi S-4300 Cold FE-SEM

Images on this poster are from a TopoMetrix Explorer AFM operated in non-contact mode using high resonance frequency cantilever (Si cantilever Model 1650, resonance frequency ~229.6 kHz, Scan size 2.5x2.5 μm, scan rate 2.5 μm/sec. Images taken with high aspect ratio FIB tip did not show a noticeable difference.

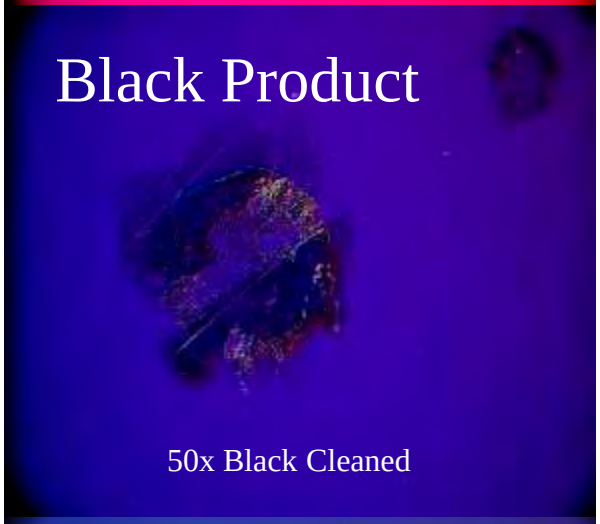


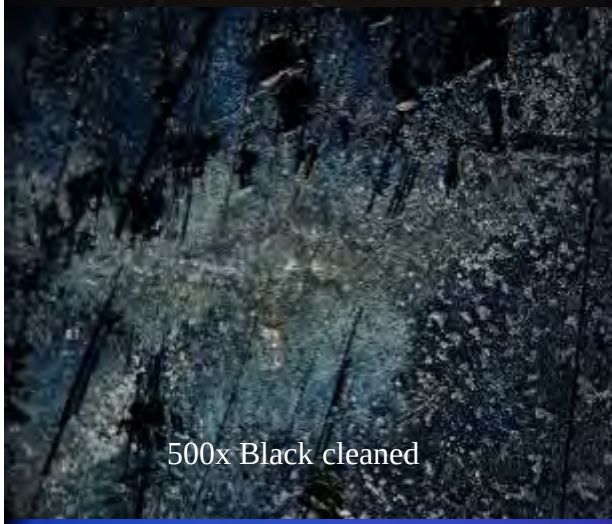


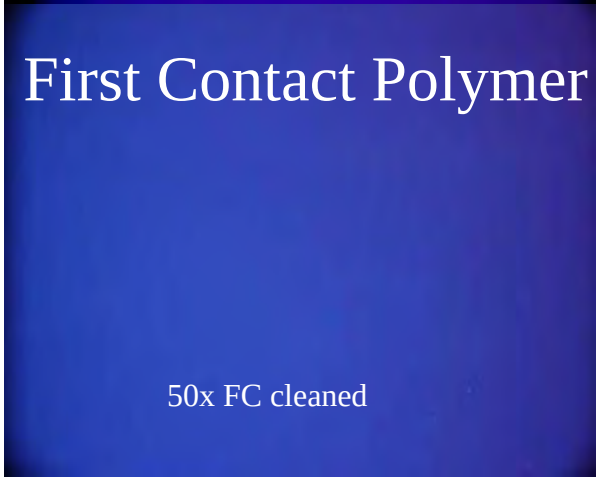
False color images obtained after applying a fingerprint to the 300nm grating, applying polymer & removing the film after allowing it to dry. Notice preexisting defect at left. Some of these gratings were "seconds" from the manufacture.

Comparison of some Commercial Strip Coatings

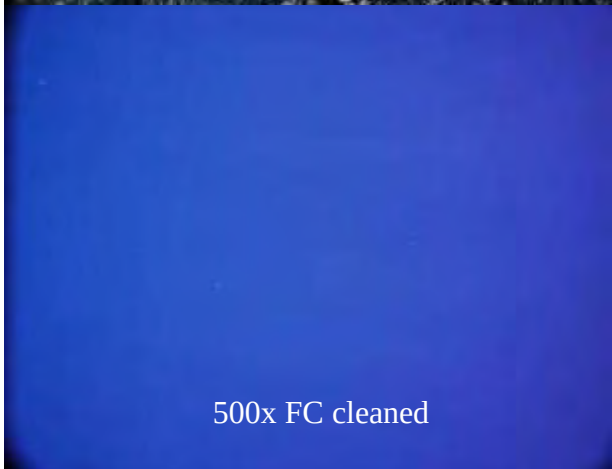
Protection while grinding. <u>Not</u> Cleaning.



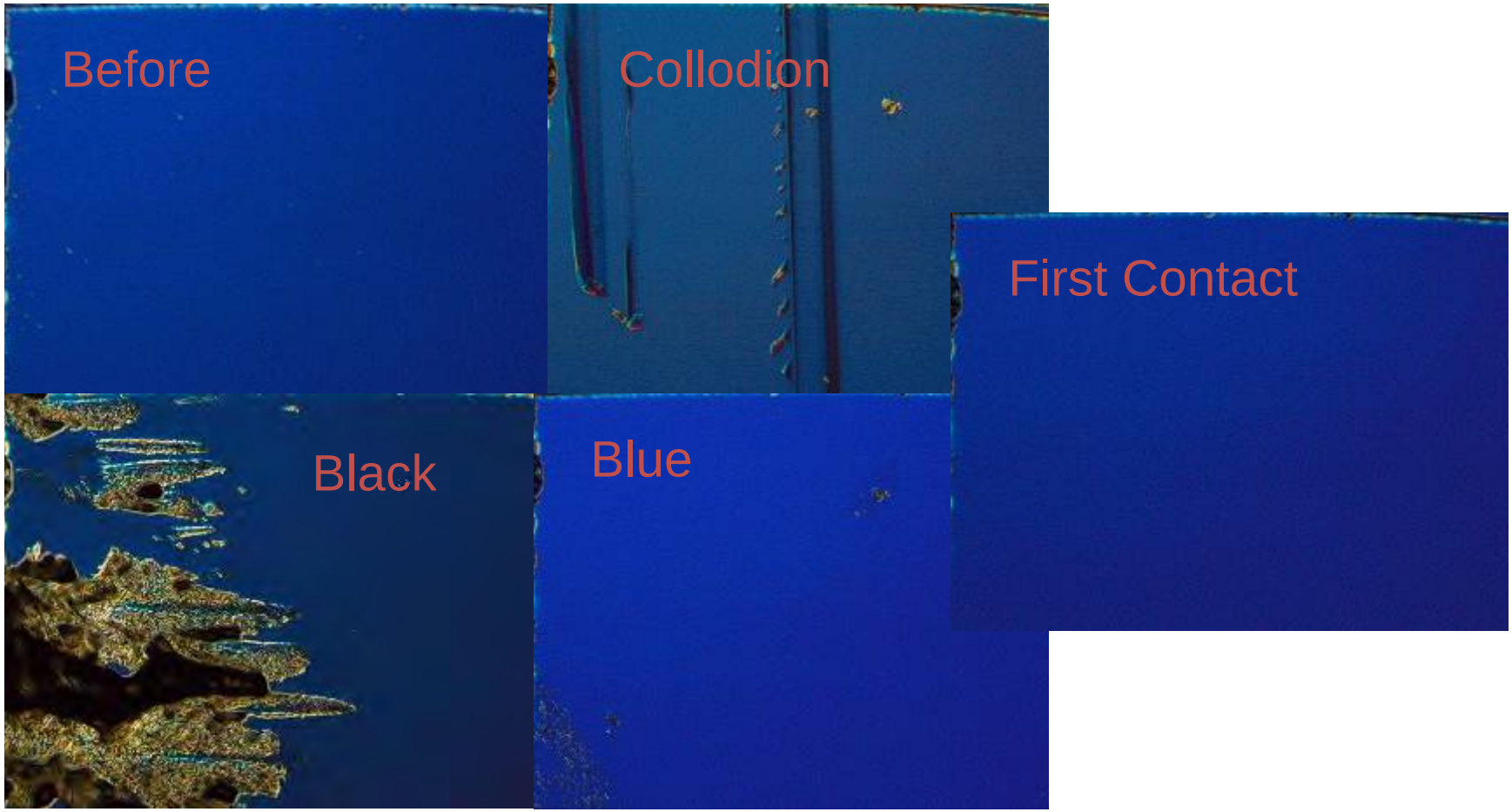




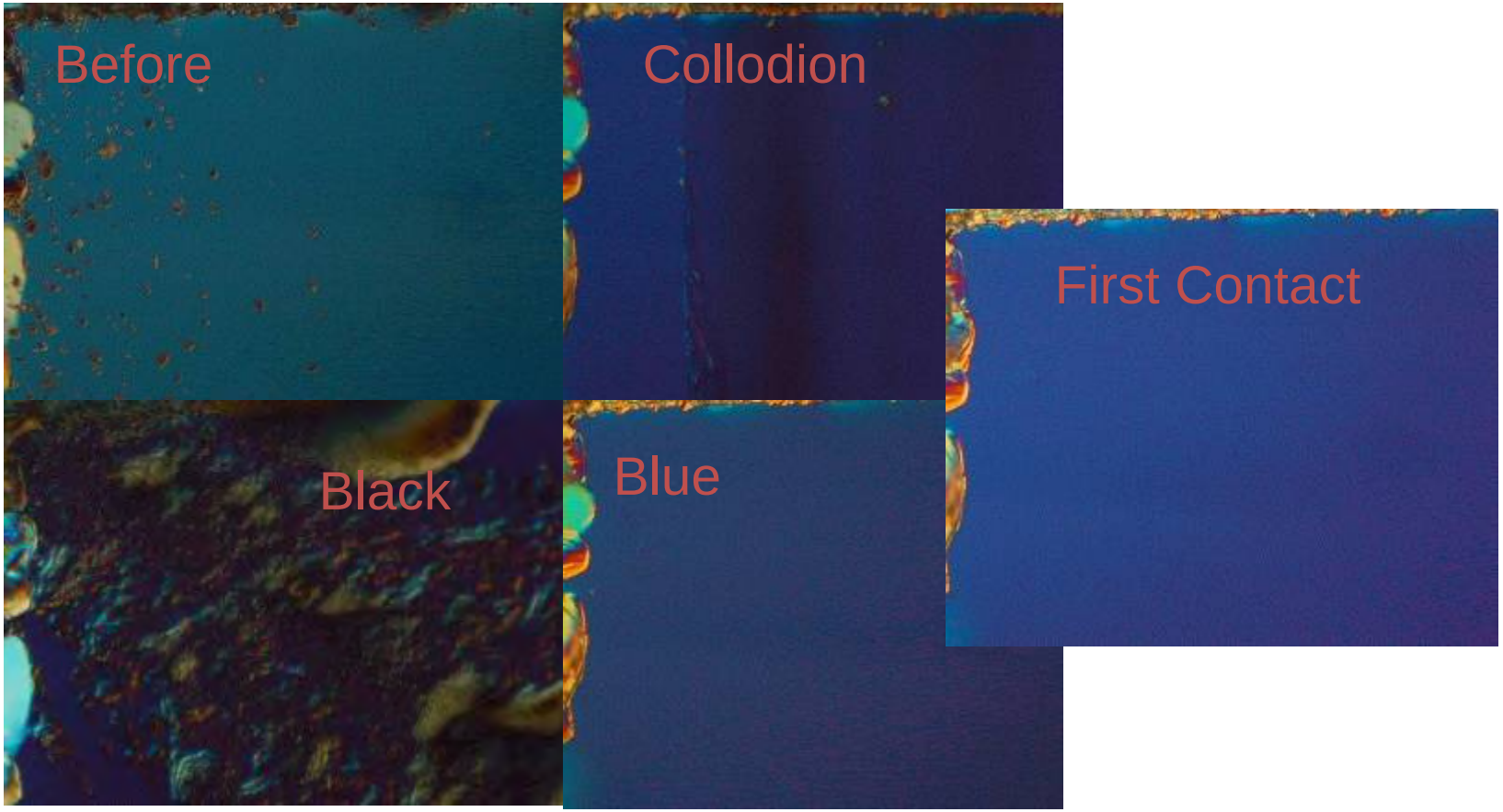
First Contact Polymer: Completely Clean using Nomarksi Interference Microscopy



50X Nomarksi Images

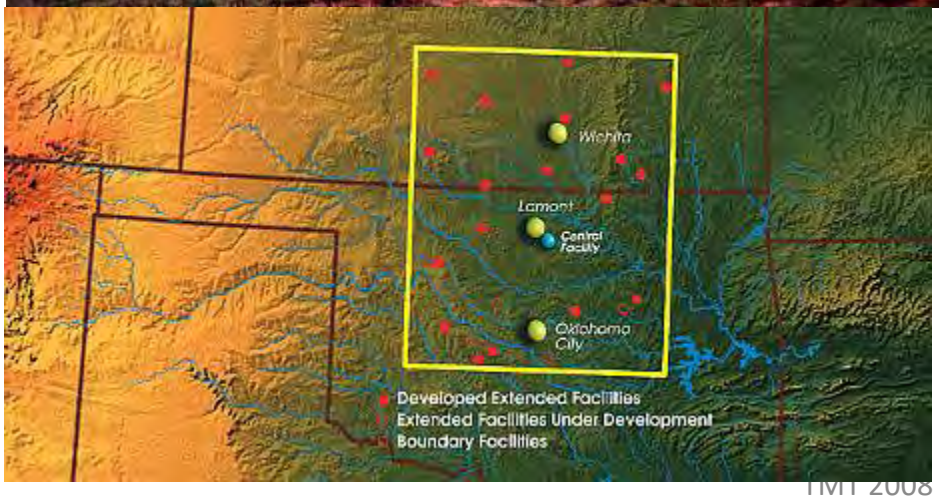


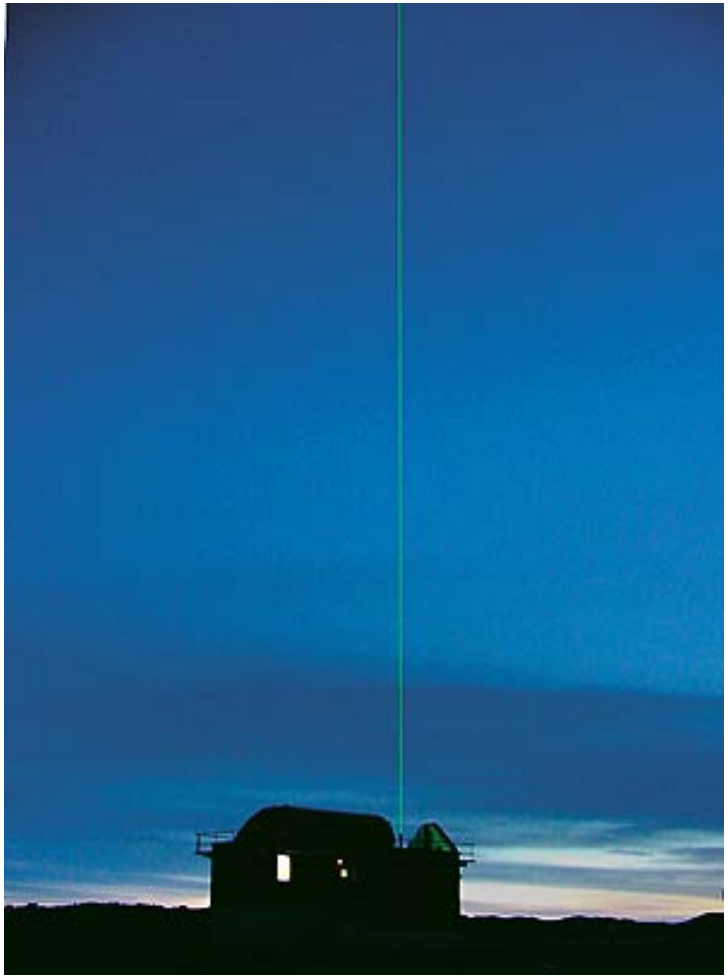
500X Nomarski Images

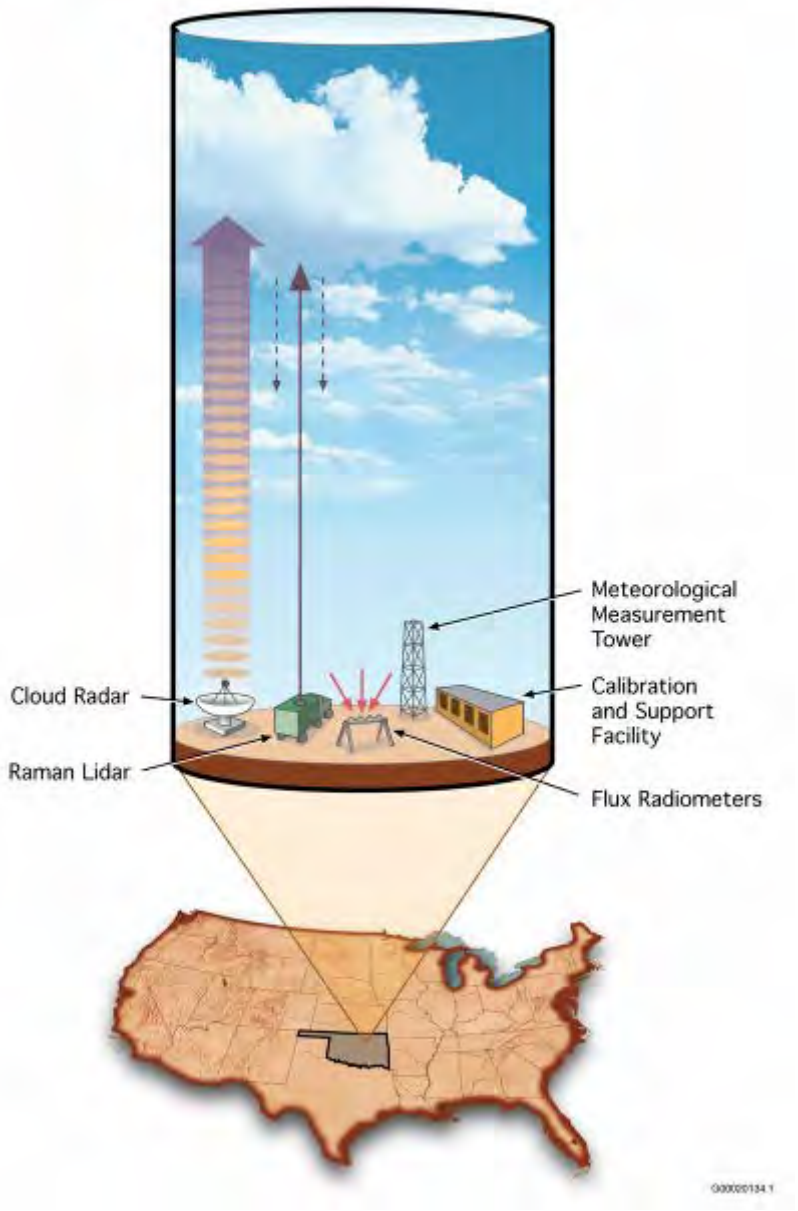


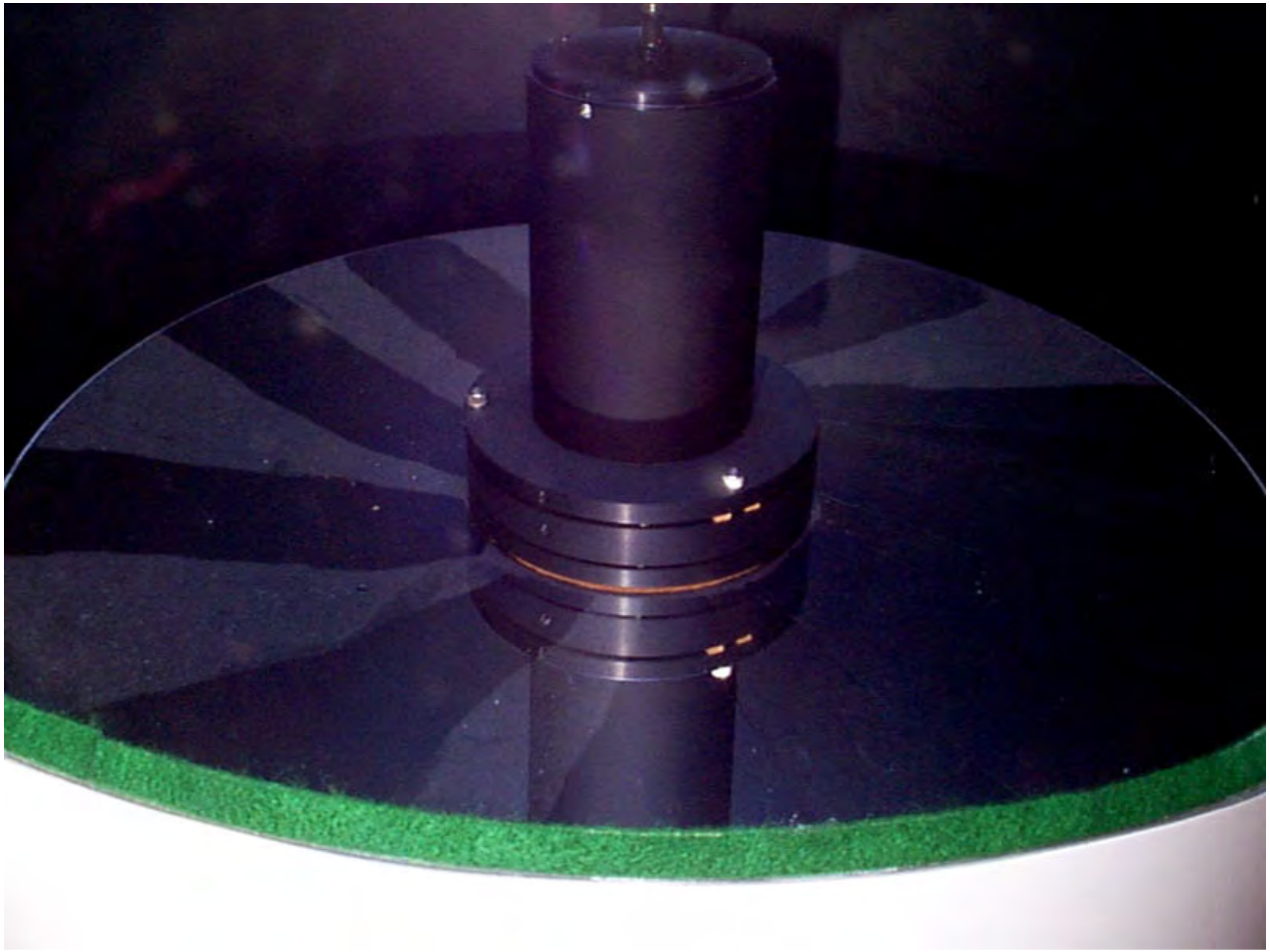
DOE's ARM LIDAR Field in OK

Atmospheric Radiation Measurement






Meteorological
Measurement
Tower
Cloud Radar
Calibration
and Support
Facility
Raman Lidar
Flux Radiometers



TMT 2008