SBIR: Polymer Based Starshade Contamination Control
Novel First Contact Polymers and Procedures

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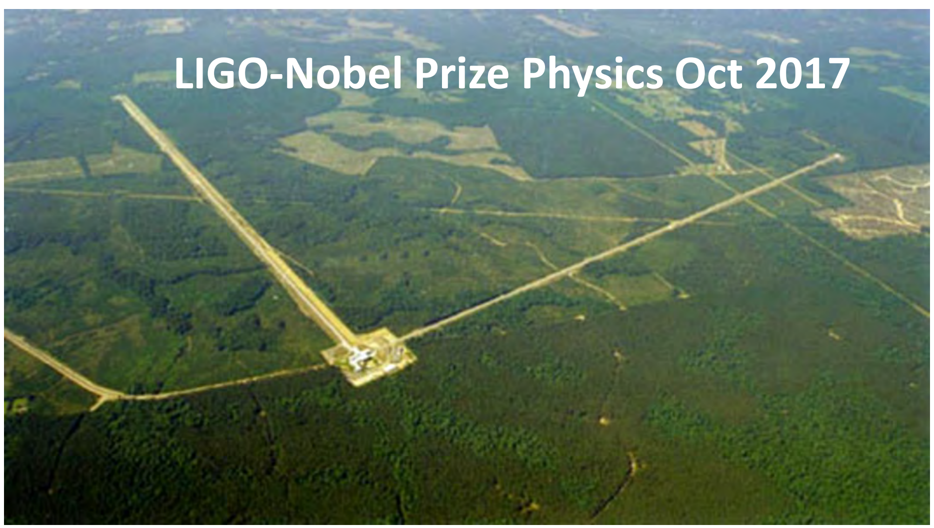


Laser Gravity Wave Interferometer

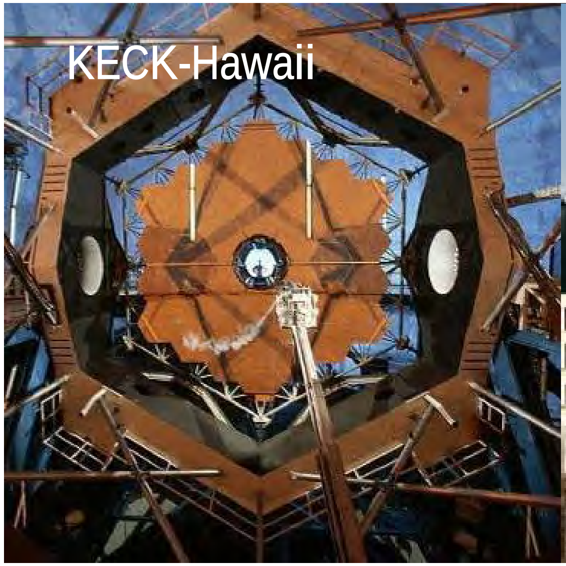
Seeker Window: Enabling US Ballistic Missile Defense System THAAD - Lockheed MAP Spec ZA10131

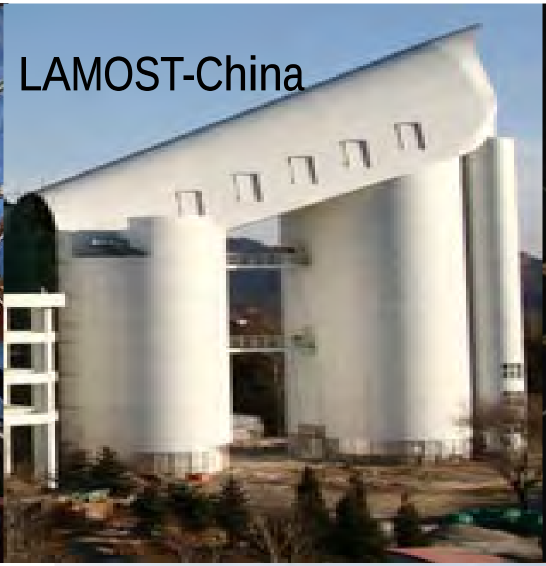
Protecting and Cleaning Precision Surfaces

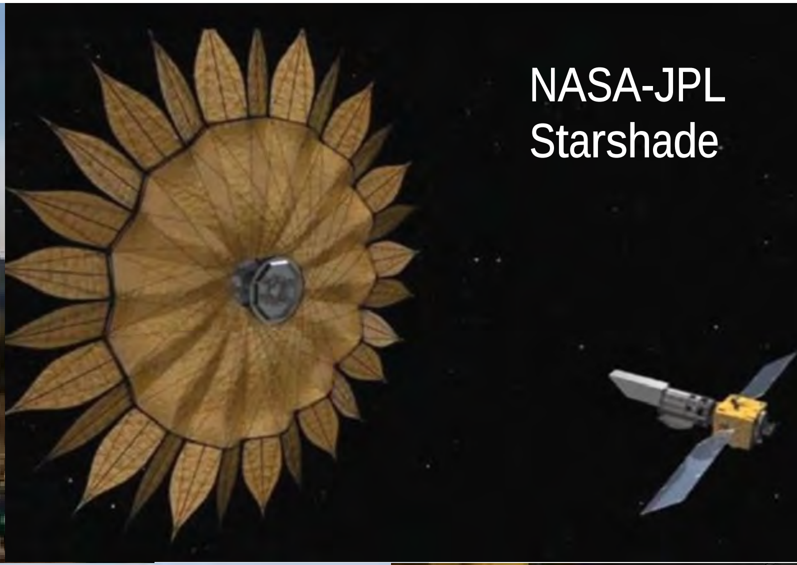
Outline of Presentation:

- Background: For Orientation
- Show (quickly) Examples in Use - Success
- We have the data:
  Mirrors, CCD's, Laser Optics, Space Surfaces
- SBIR Phase II Results so Far (1.25 Qtr's)
- 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.

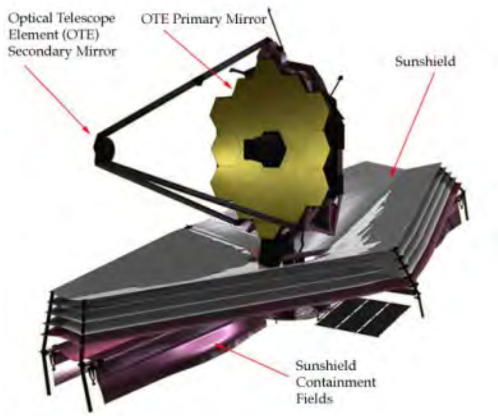






Keck, Gemini, CFHT – Hawaii
Chile - ESO
LAMOST- China
LIGO - Caltech/MIT
DES CAM – Fermilab/LBNL
CDMS – Stanford/Fermilab
GTC– Canary Islands
NASA GSFC
NASA JPL

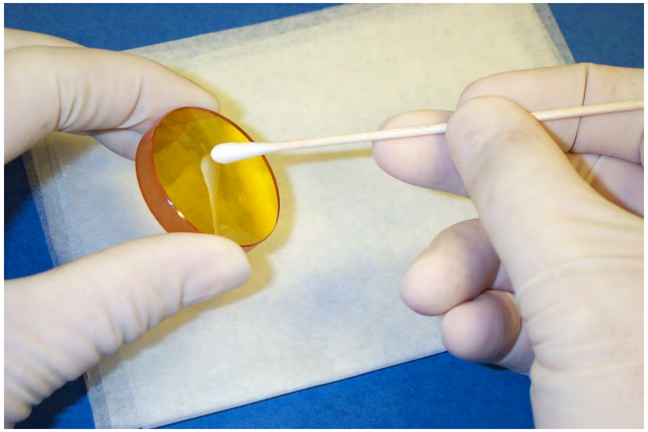
First Contact Polymer

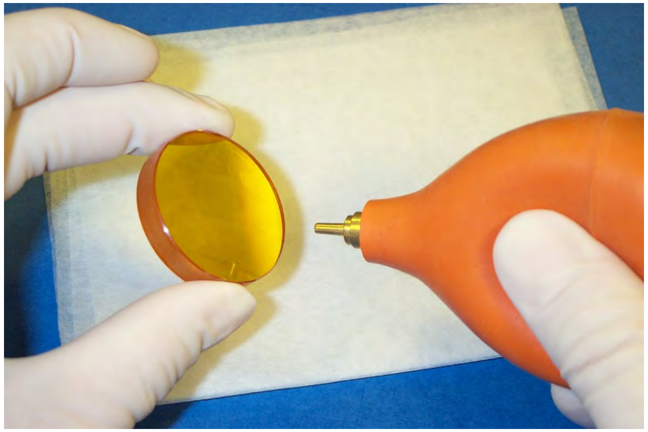


SPACELIFT RANGE SYSTEM CONTRACT

Engineered for space

Typical Methods of Cleaning Precision Surfaces like Optics


Cotton applicator Drag Wipe


Blowing Clean


Alcohol/Acetone Drag Wipe


CO_2 Snow Cleaning

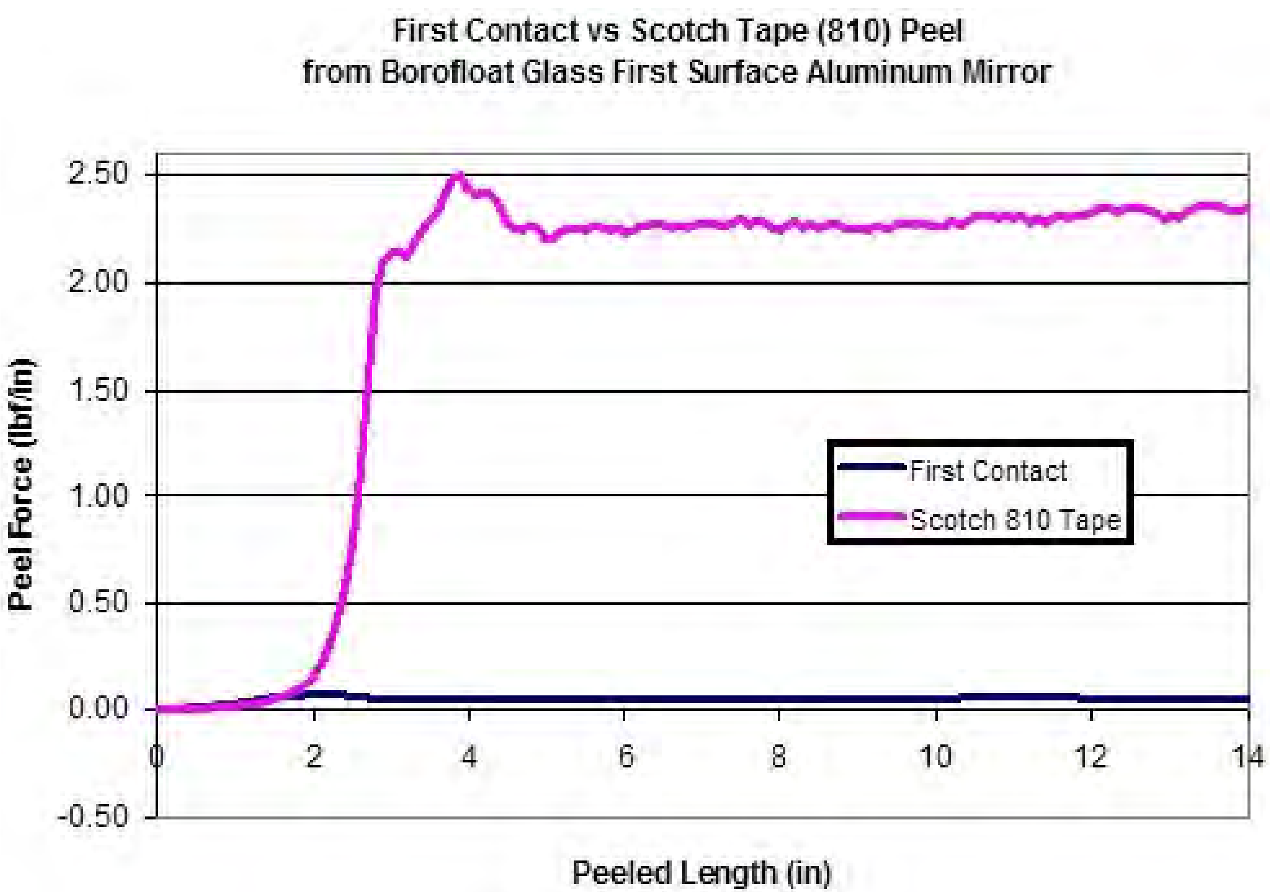
Historical Methods of Cleaning Optics. Welcome to the future.

First Contact® Polymer

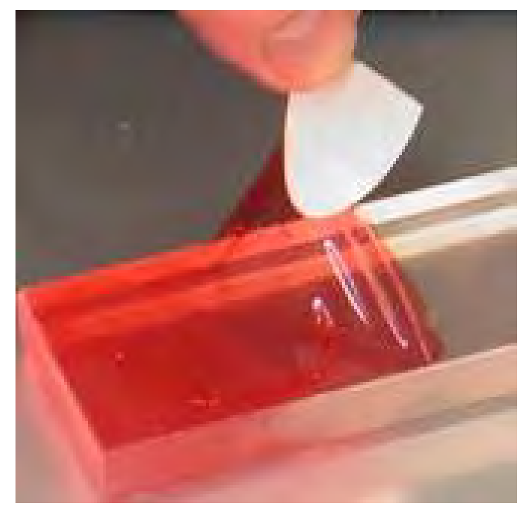

Laser Focus World
Photonics Technologies & Solutions for Technical Professionals Worldwide
First Contact Polymer
Our top 20 photonics stories of 2016—LIGO leads the list PAGE 27
Photonics guides remotely piloted aircraft PAGE 23
Galvo scanners support ultrafast laser micromachining PAGE 41

A No Residue Strip Coating
Protect & Clean

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



Cleaning & Protection



Sales in 72 Countries

“*THE* Protection and Cleaning Solution”

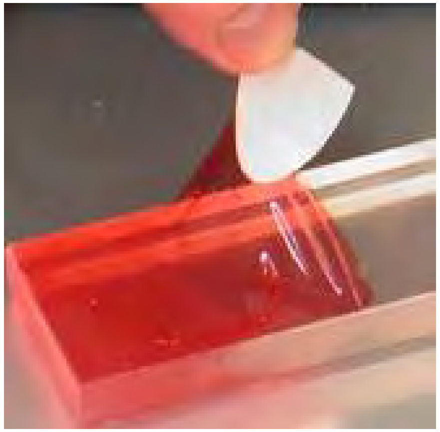
“Cleaning and Protecting Precision Surfaces in Manufacturing, Assembly, Shipping, Coating and Storage”

Value Propositions:

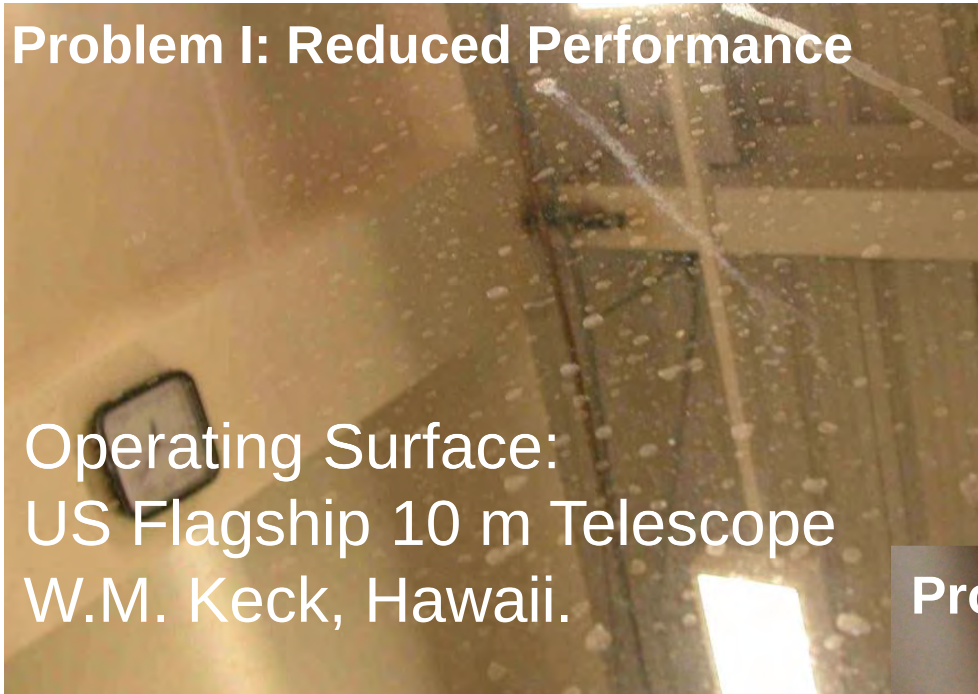
1. Asset is ready when it is needed.
2. Save time. Save Money. Quick clean. Space Ready.
3. Clean in situ – No Realignment
4. Cleanroom clean without the Cleanroom.
5. Clean the Uncleanable-Easily: Sensors, CCD’s, FPA’s, Gratings
6. Eliminate Diffraction Rings from Dust: Laser Patterning, Holography
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.



Contamination Control & Surface Protection

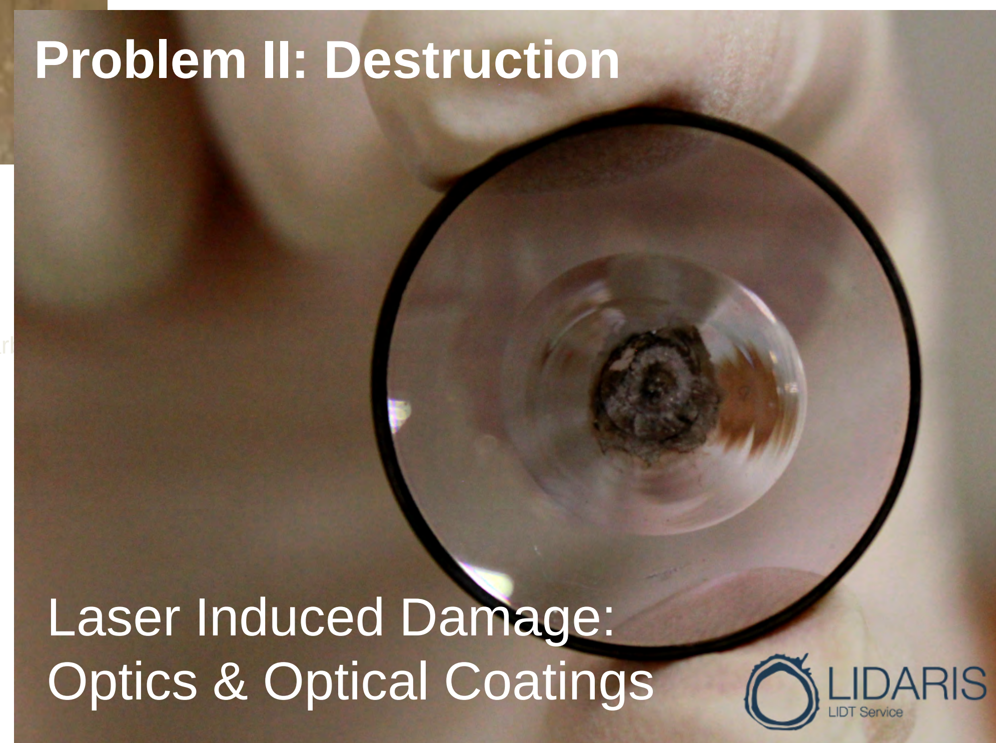


Some surfaces are “uncleanable”.

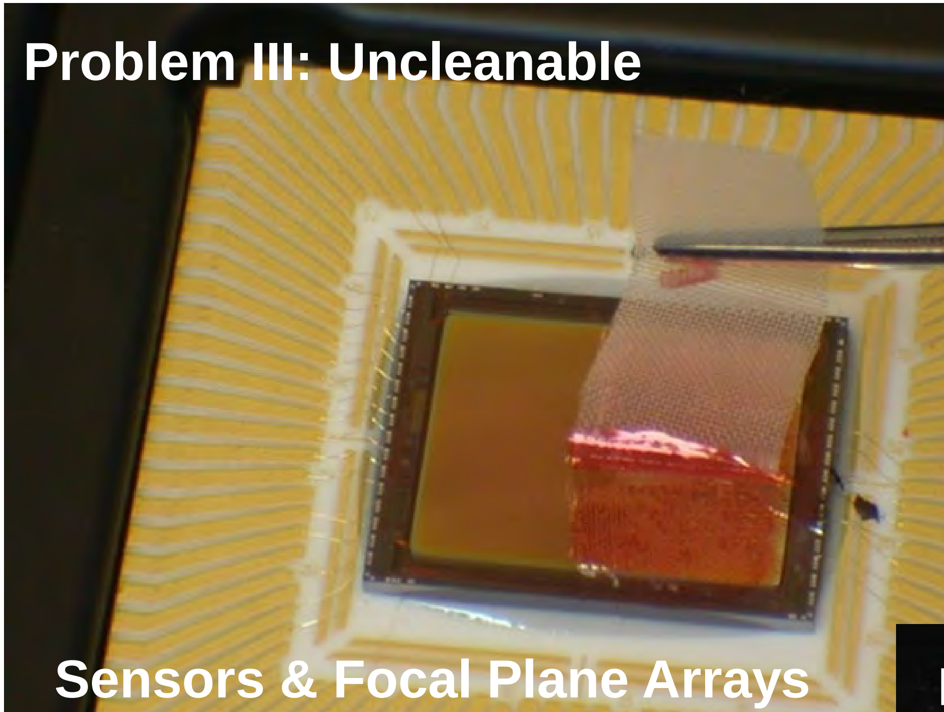
Nanoparticles & Residue ***very*** hard to remove.

Cleaning before coating.

Enabling Zero Defect Coatings.



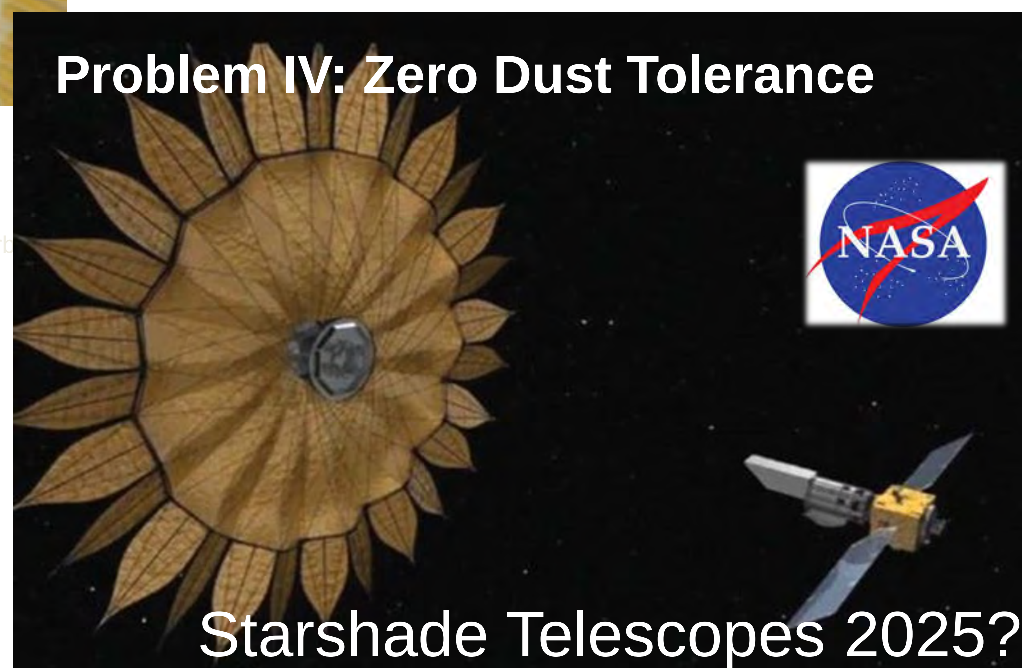
Contamination Control & Surface Protection

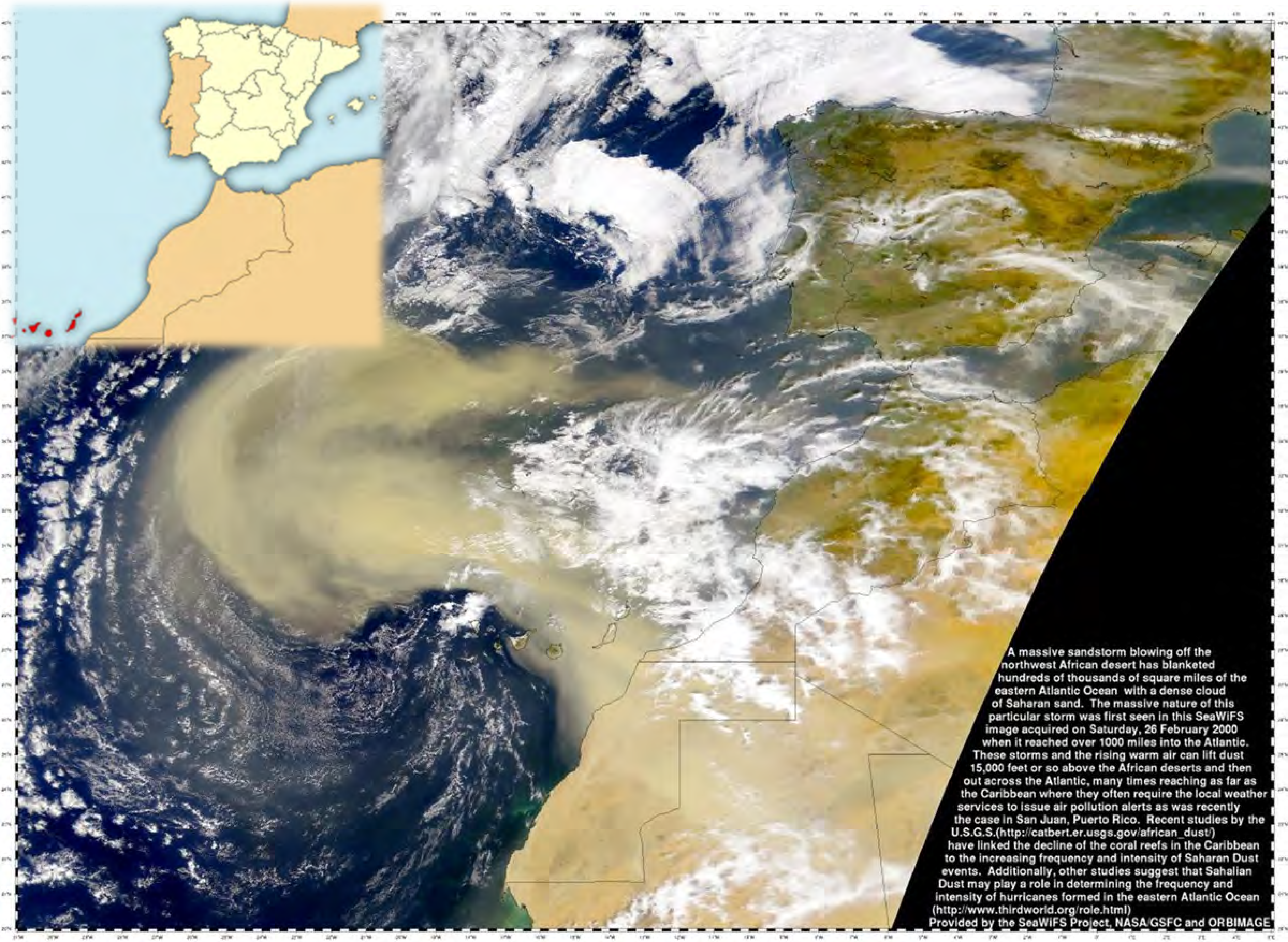


Zero Dust Tolerance - Literally.

> J. Coleman, TCD, Carb

Cleanroom Clean without the cleanroom.

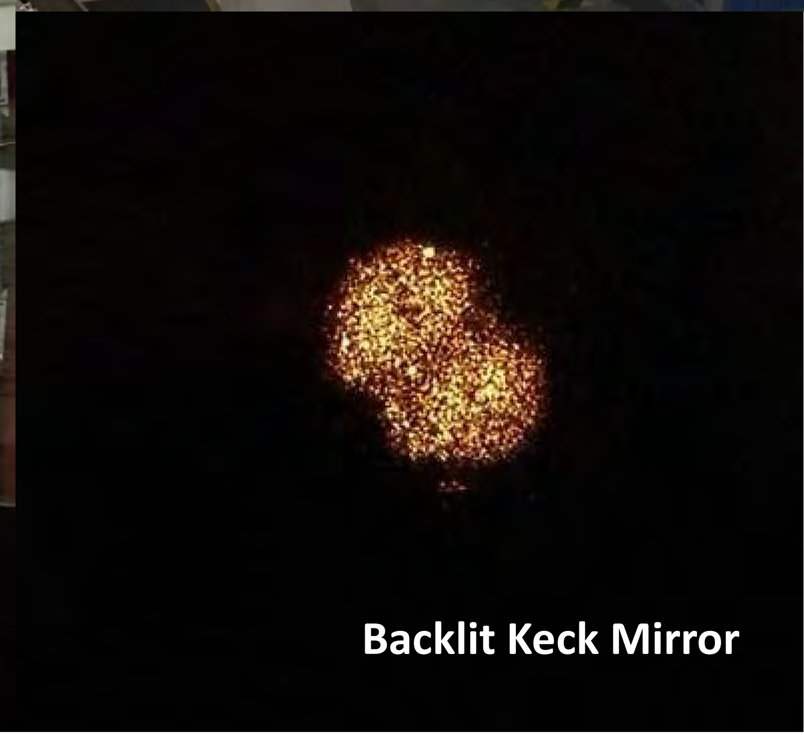



A massive sandstorm blowing off the
northwest African desert has blanketed
hundreds of thousands of square miles of the
eastern Atlantic Ocean with a dense cloud
of Saharan sand. The massive nature of this
particular storm was first seen in this SeaWiFS
image acquired on Saturday, 26 February 2000
when 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


Volcanic Dust on Keck


GTC


Sahara Dust on GTC


Backlit Keck Mirror

Acid Cleaning before washing.

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

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

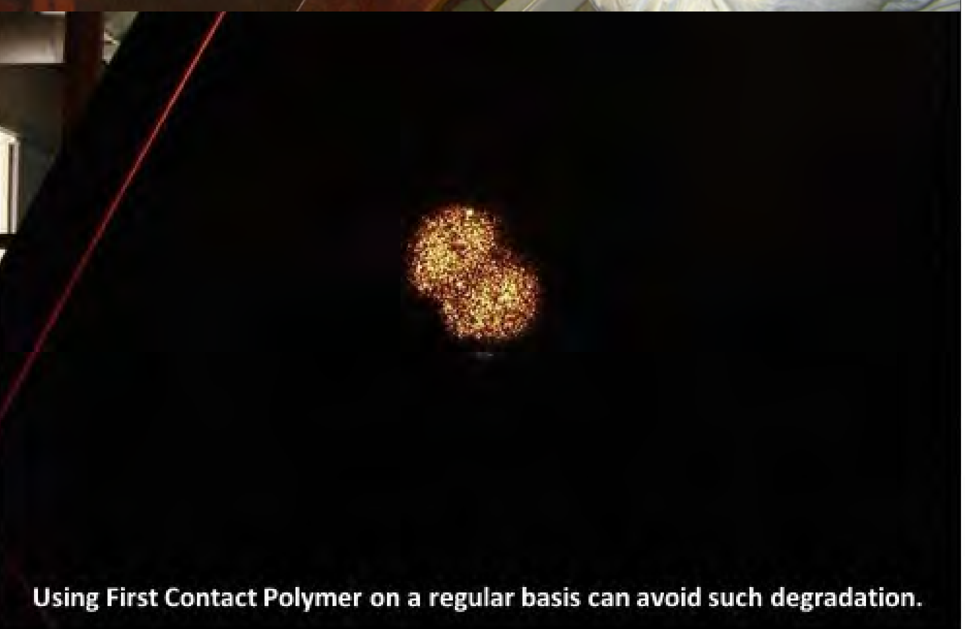

First Contact Polymer
Pour or Spray
Spread
Peel

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	
	7.63	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.

Cleaning aluminum coating on dirty, 3 year old mirror segment.

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.					

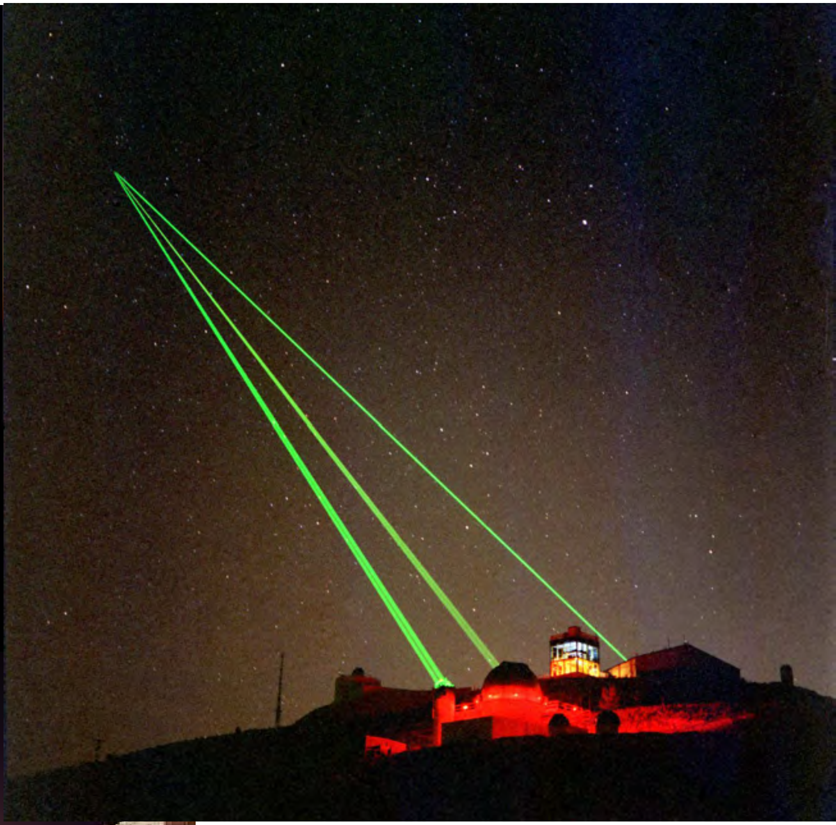


ashlight through 3 year old Al Mirror Coating on Keck Primary Mirror Segme

The End Game for Massive Telescopes:

Routinely Maintain Mirrors at Maximum Reflectivity

Dramatically (Indefinitely?) Extend Coating Lifetimes



First Contact®
Polymer

Photo Credit: James Hamilton

W.M. Keck Telescope Segments with First Contact Polymer

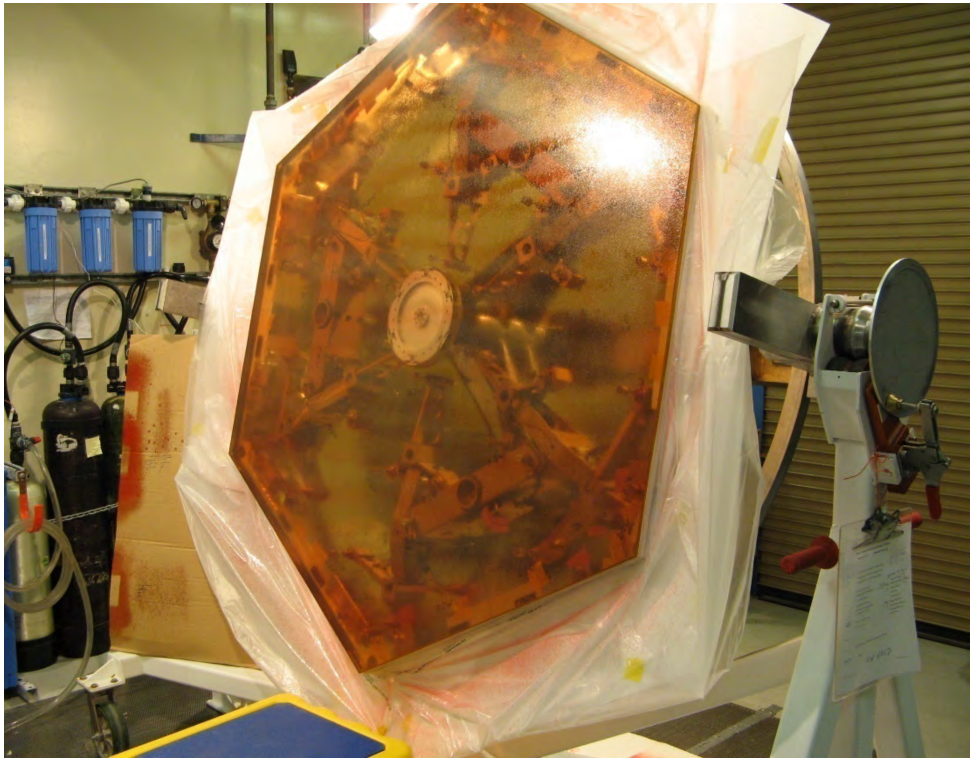
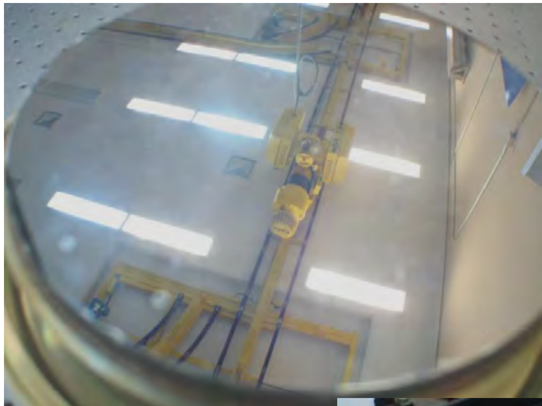


Photo Credit: Steve Doyle

Vandenberg AFB Western Range Depot Optics Group



Removing the Protective Polymer Coating

Worth Repeating: This **Environmentally-Friendly** process leaves _no_ hazardous waste!

SPACELIFT RANGE SYSTEM CONTRACT
Engineered for space

- Repeated applications can be used to remove difficult contamination.
- Polymer solution dissolves itself to remove any fragments.
- Multiple applications will create a strong, thick polymer film.
  Protect the optical surface indefinitely from salt fog, particulate contamination, fingerprints, and incidental contact.

First Contact Polymer

First Contact™

Before

After

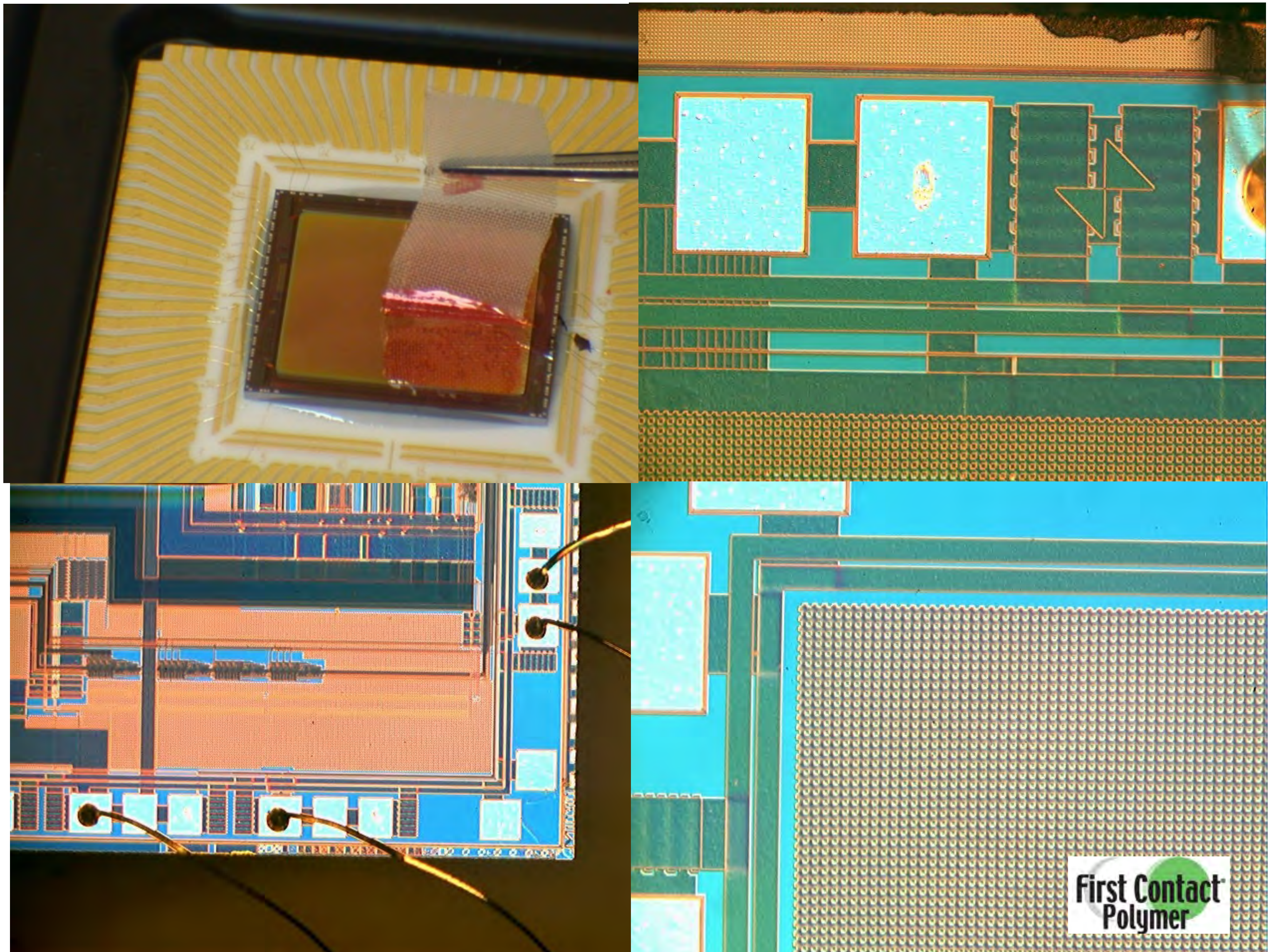
During

First Contact Polymer

"No touch, One step, Cleaning process"

Actual Customer Photos - Takahashi Coated CaF_2 Lense

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



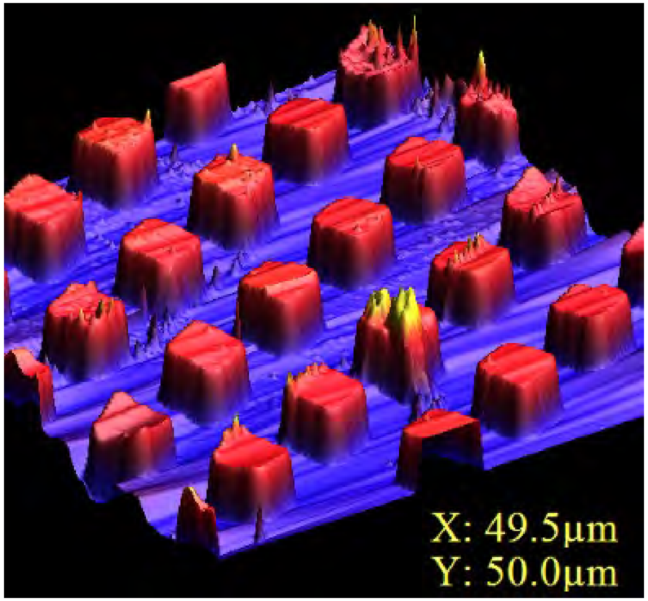
Cleaning the Uncleanable.

Nomarski Microscopy Images, PCT

How to determine Optical Surface Cleanliness

Metrology: Mechanical, Optical, Electron

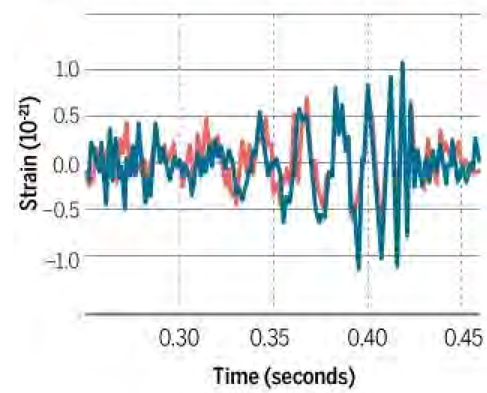
- Mass of Residue
- Differential Interference (DIC) Microscopy
- Scanning Electron Microscopy (SEM), Surfscan (KLA)
- Total Incident Scattering, Laser Induced Damage Testing
- Electron Spectroscopy (XPS, ESCA, Auger)
- Atomic Force Microscopy (AFM)
- Spectroscopy
- Polymer Properties

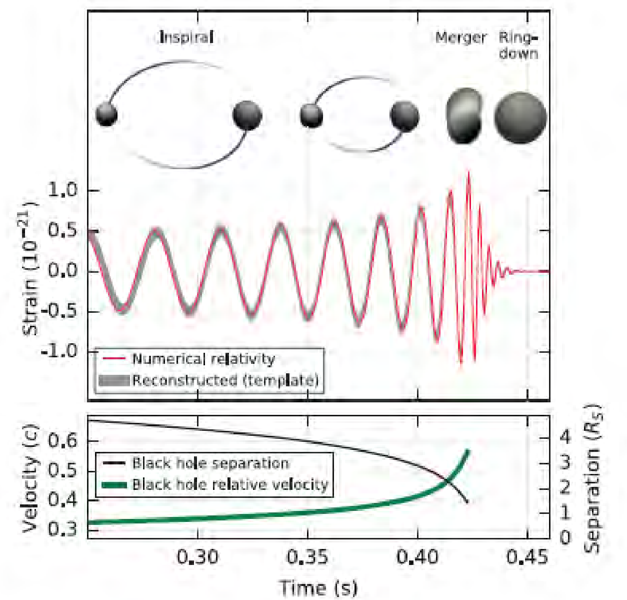


Our Surface Research:
A progression geared towards demonstrating atomic level cleanliness.

Signals in synchrony

When shifted by 0.007 seconds, the signal from LIGO's observatory in Washington (red) neatly matches the signal from the one in Louisiana (blue).





First Contact Polymer

LIGO PRL Feb 2016

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

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of the LIGO Laboratory.

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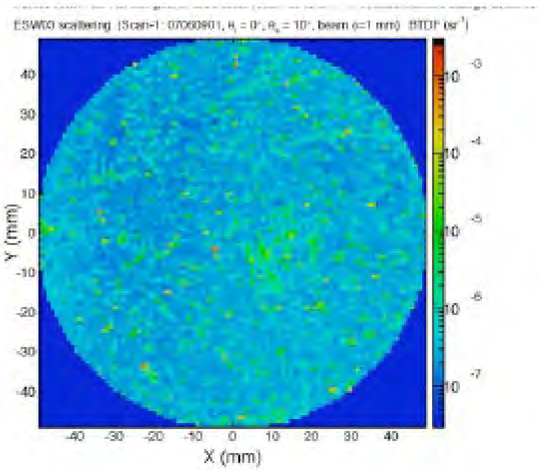
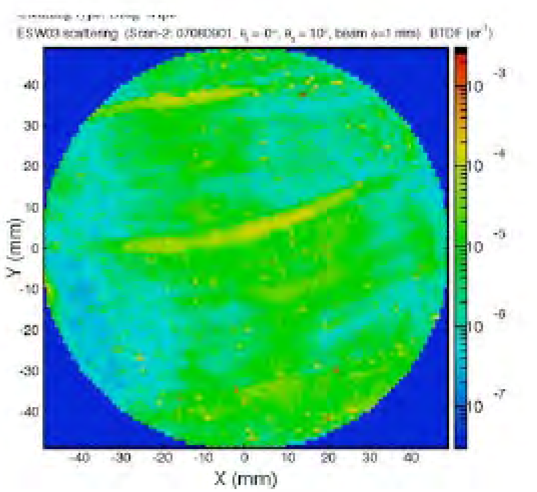
"Bidirectional Reflectance Distribution Function."



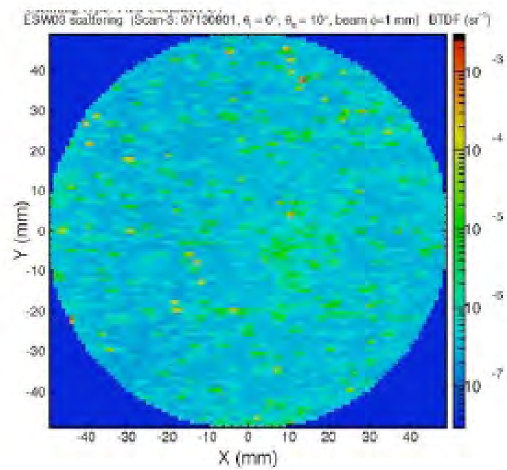
Before 2.05 ppm avg BRDF

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

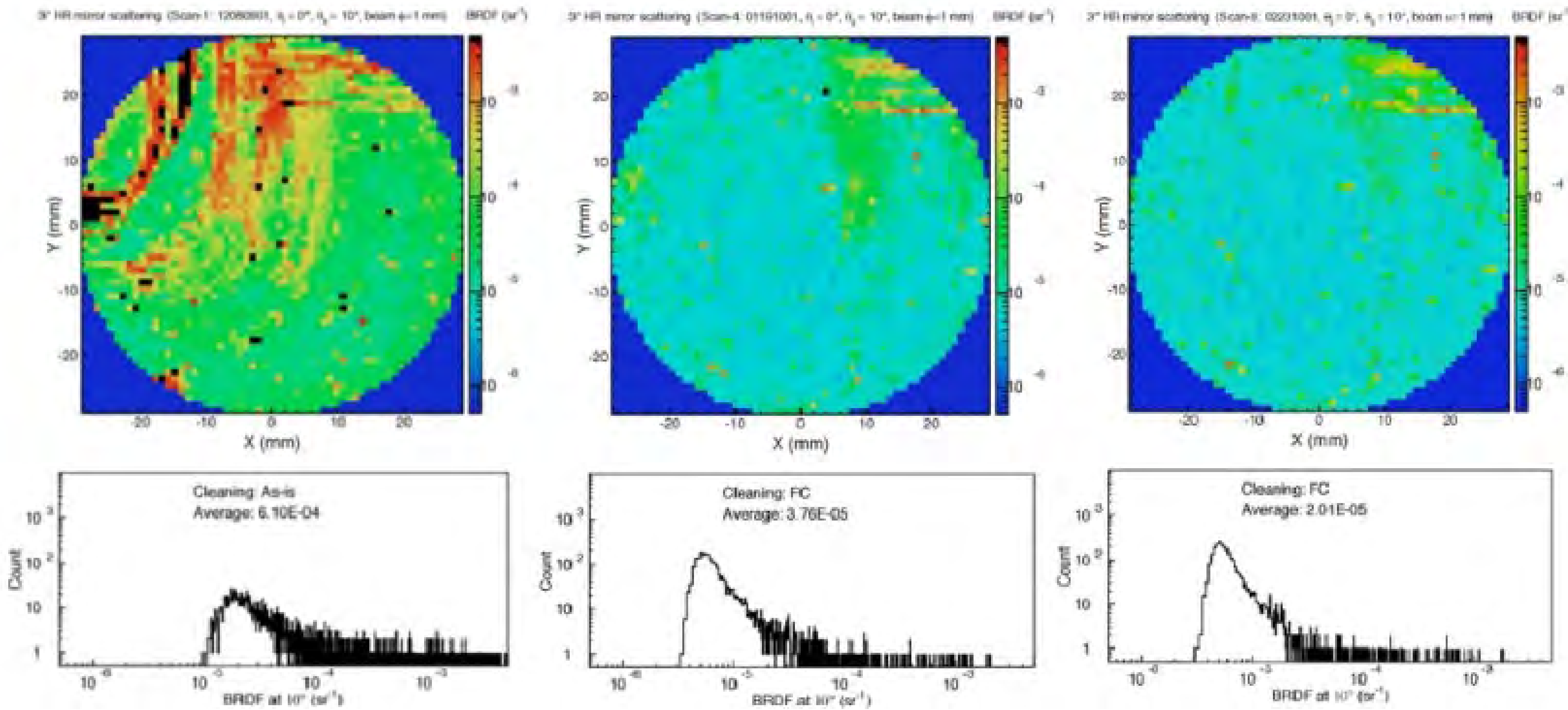


After MeOH Dragwipe
10.7 ppm avg BRDF



After First Contact 2.05 ppm avg BRDF

Sequential Progression First Contact BRDF Tests - LIGO Report



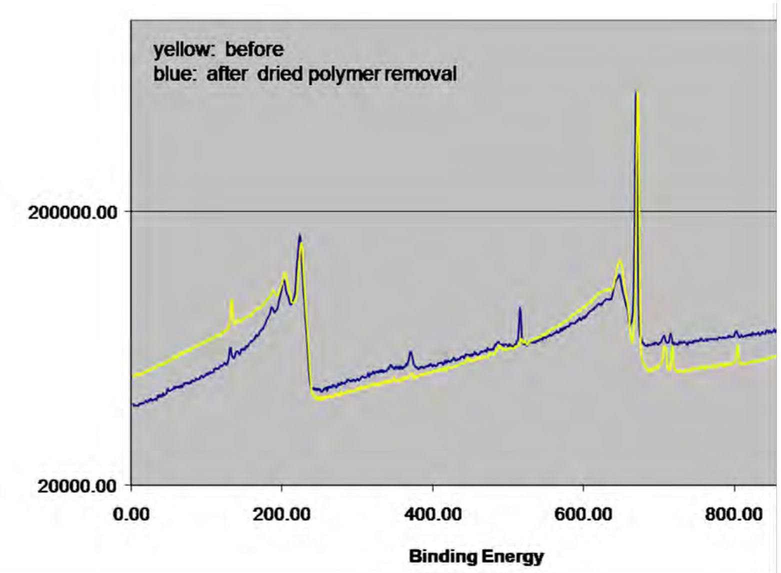
Apply. Peel. Repeat as/if needed.

“A highlight of the BRDF tests shows that repeated applications of FC only improves optical surfaces”

“Optical contamination control in the Advanced LIGO ultra-high vacuum system”, Margot H. Phelp, Kaitlin E. Gushwaa, and Calum I. Torriea, Proc. of SPIE Vol. 8885, 88852E · doi: 10.1117/12.2047327

-LIGO Laboratory, California Institute of Technology, 1200 E. California Blvd., Pasadena, CA

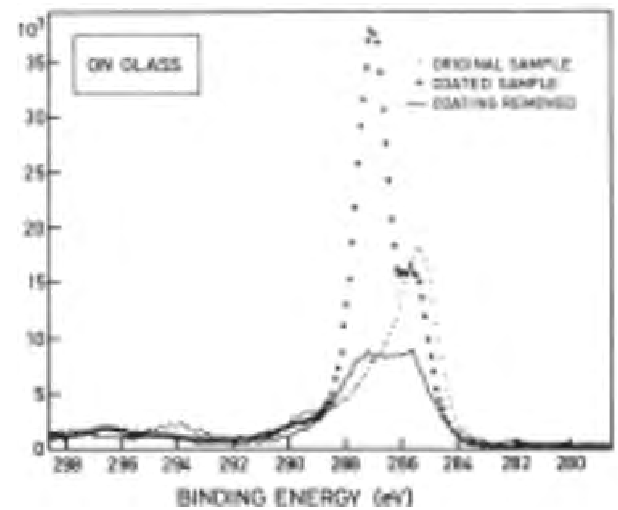
Atomically Clean after: Before and after XPS Spectra on Glass



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

No Residue.

Only First Contact™ didn't leave residue…



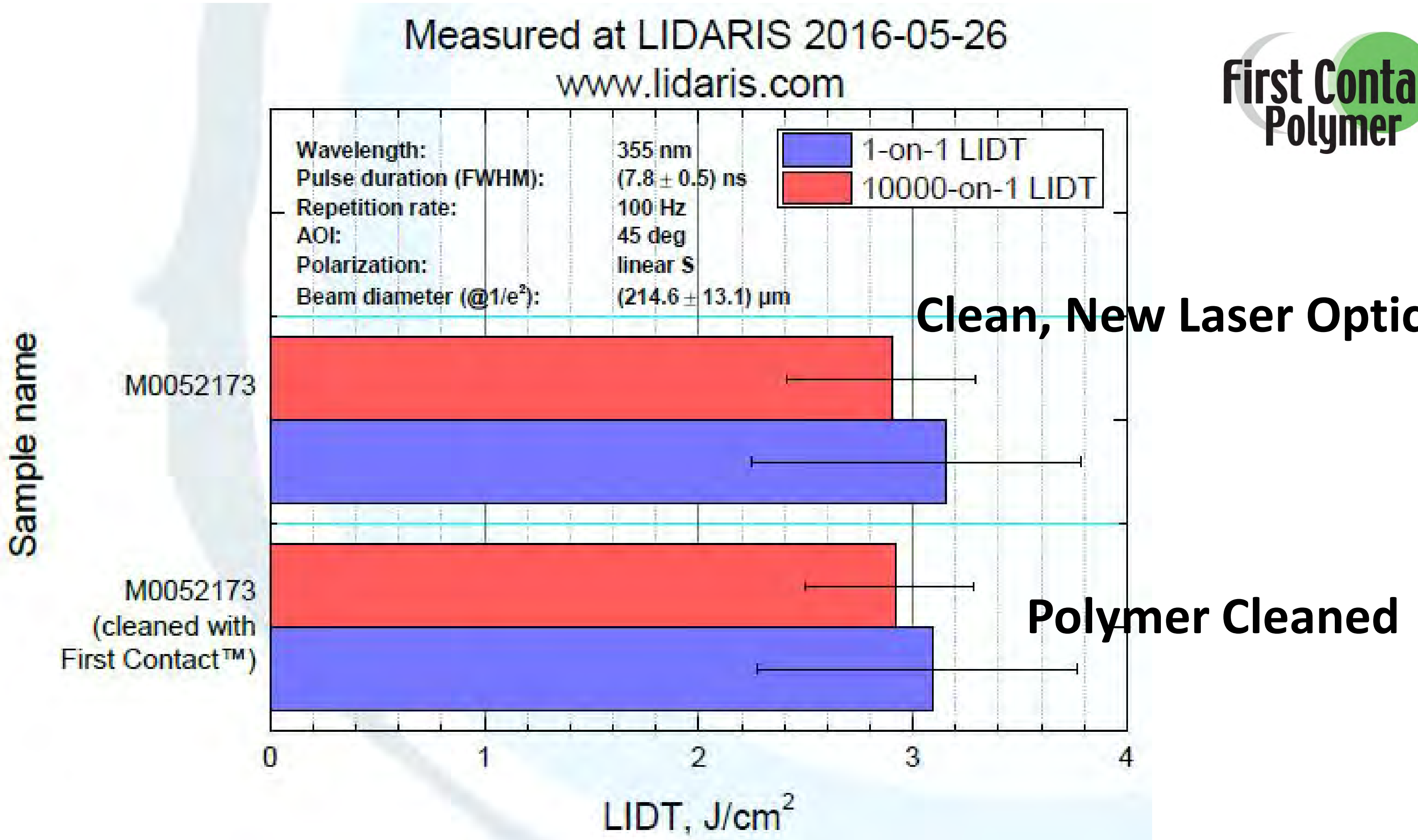
J. Bennett Applied Optics

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.

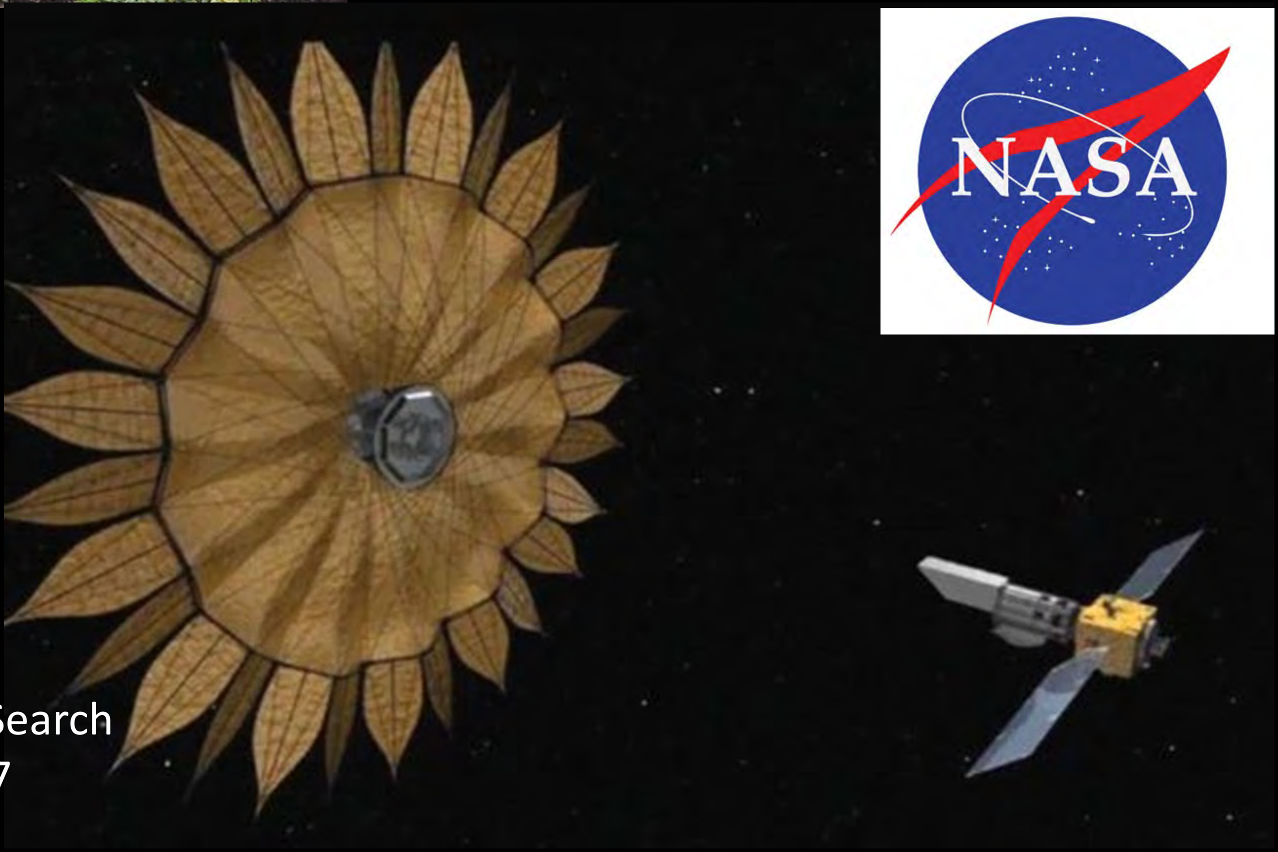
High Power Laser Damage Threshold (LIDT) – 355nm



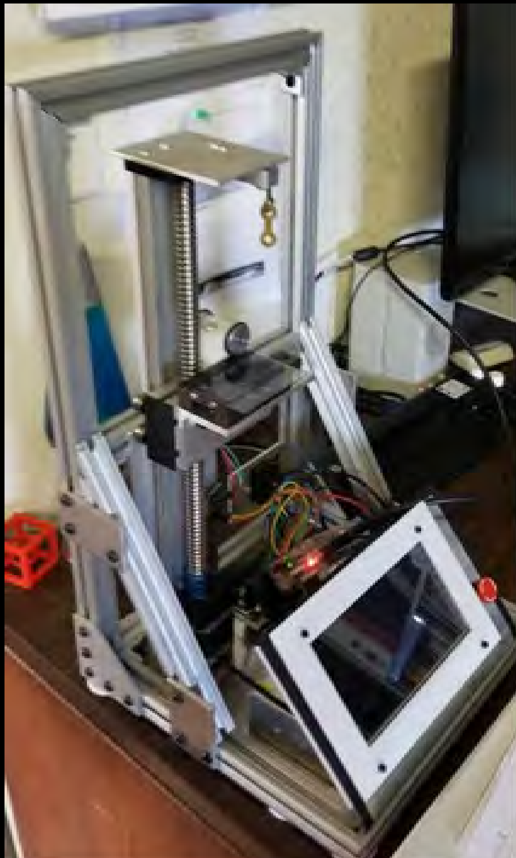
First Contact® Polymer

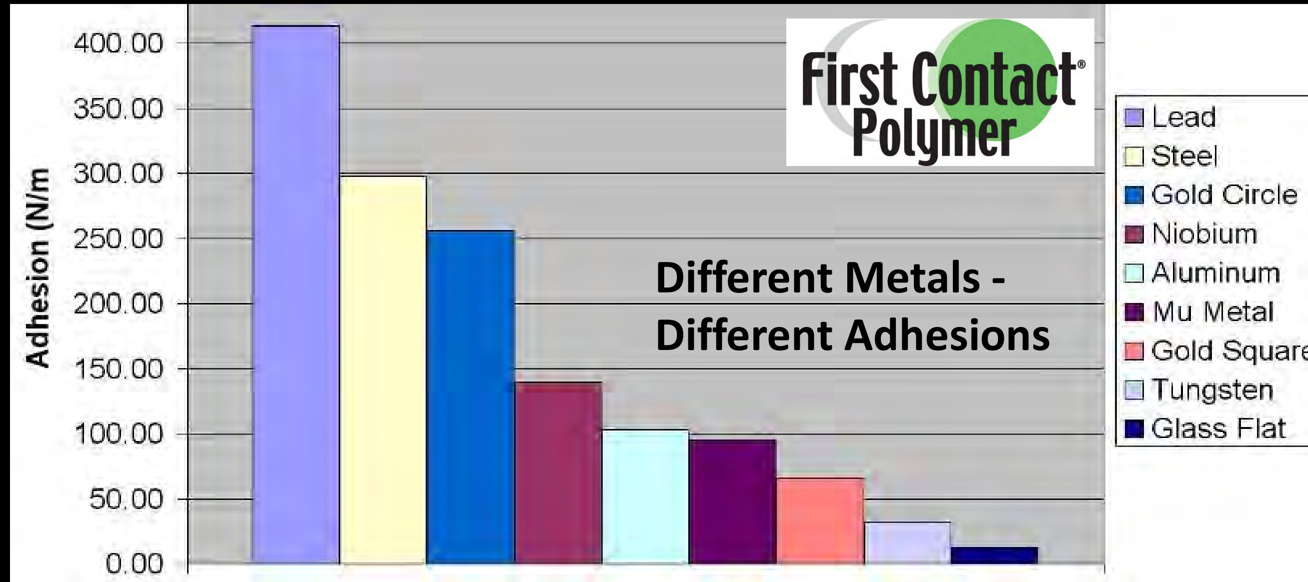
No Change in LIDT = No residue = No Damage

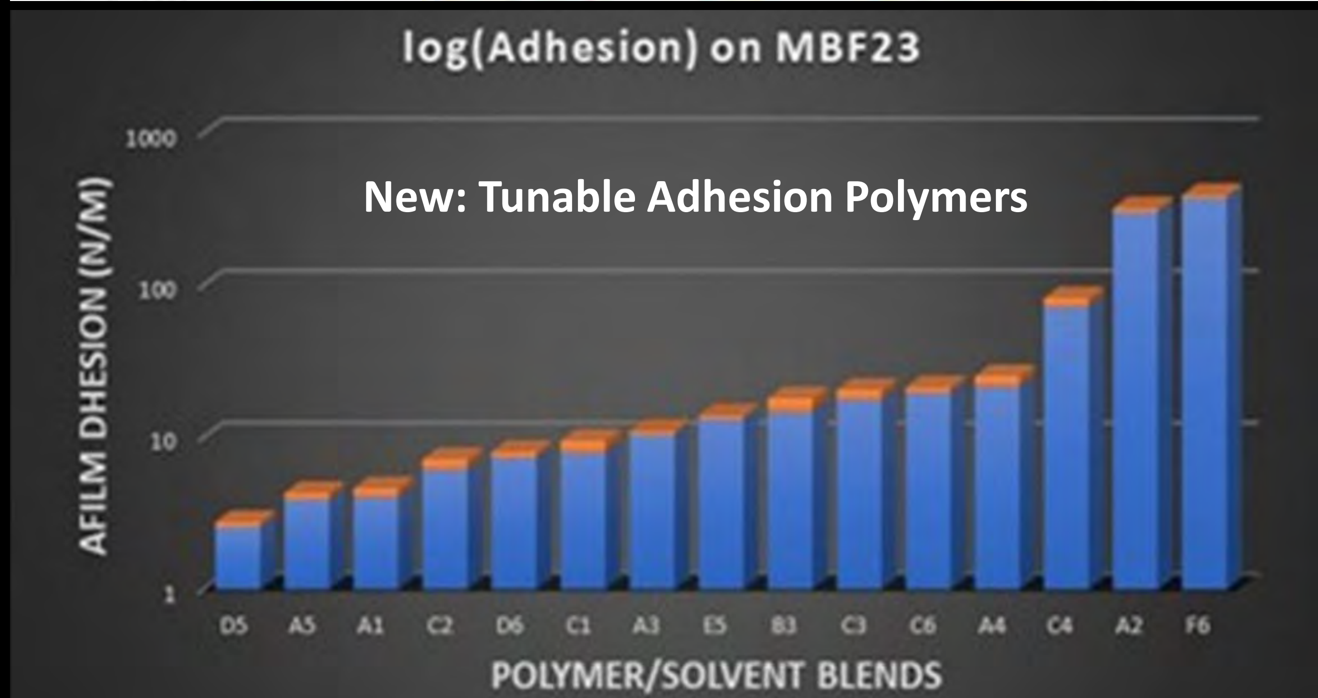
First Contact Polymer



NASA's Starshade Exoplanet Search
Jet Propulsion Lab   SBIR 2017

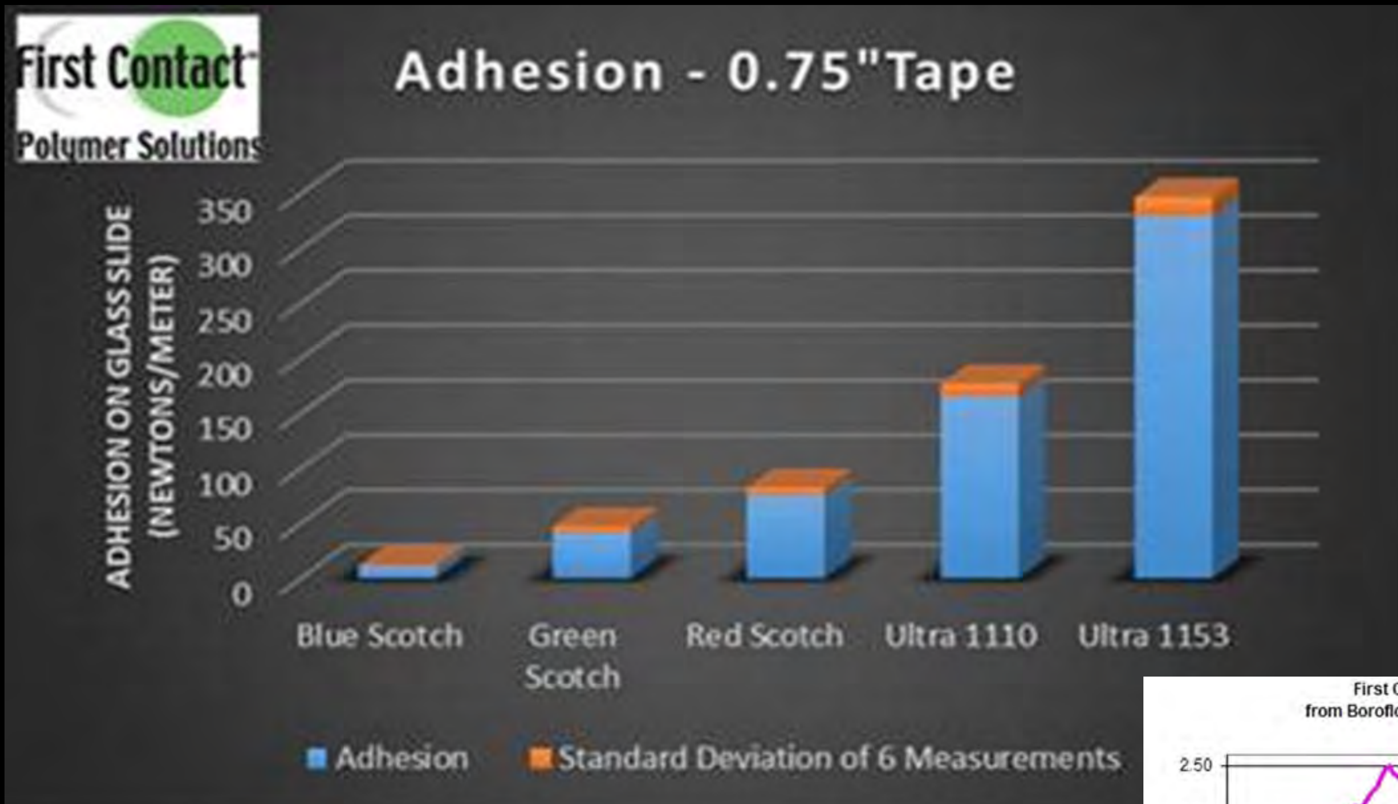


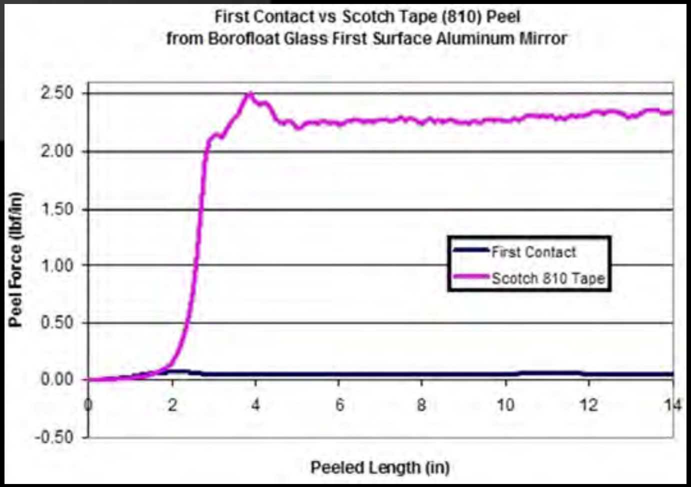




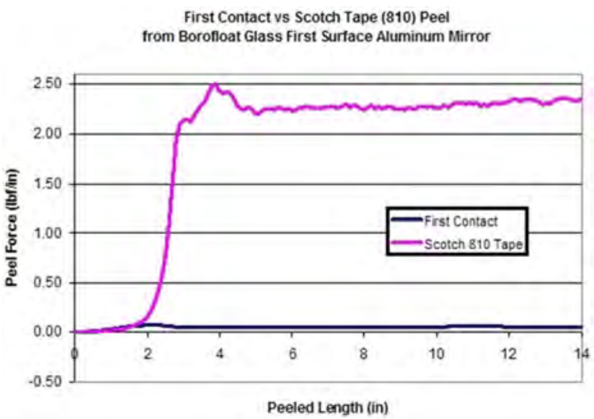
Cleaning & Protecting is a Balance of Adhesion and Release

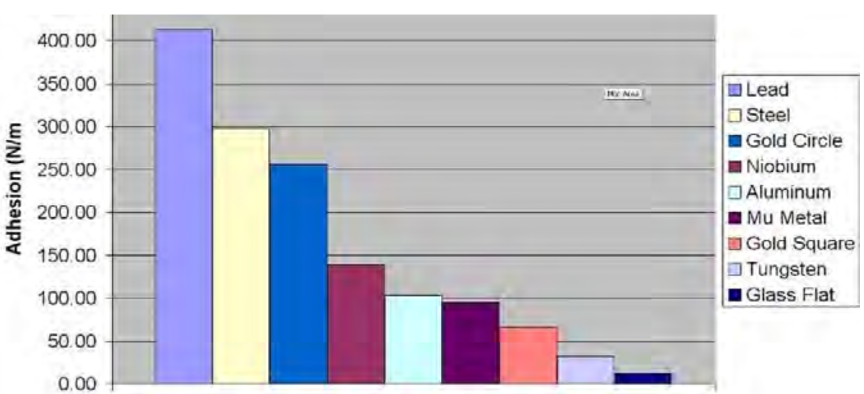
Calibration, Precision & Accuracy



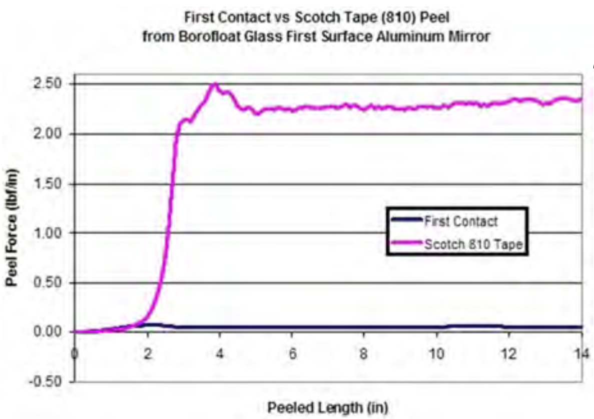


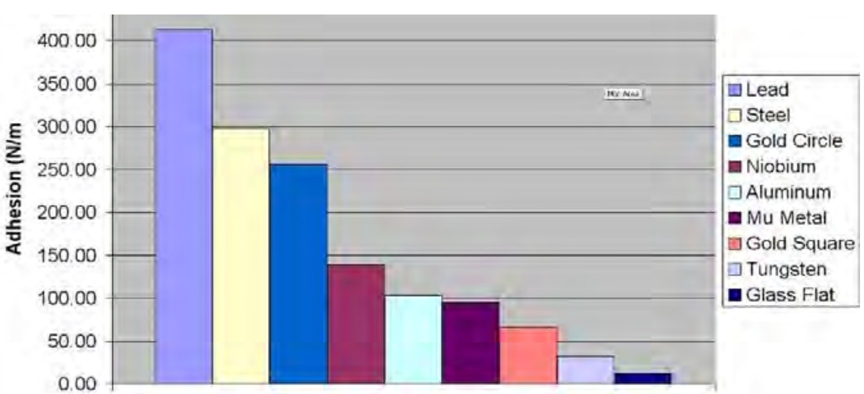
Before Phase II SBIR

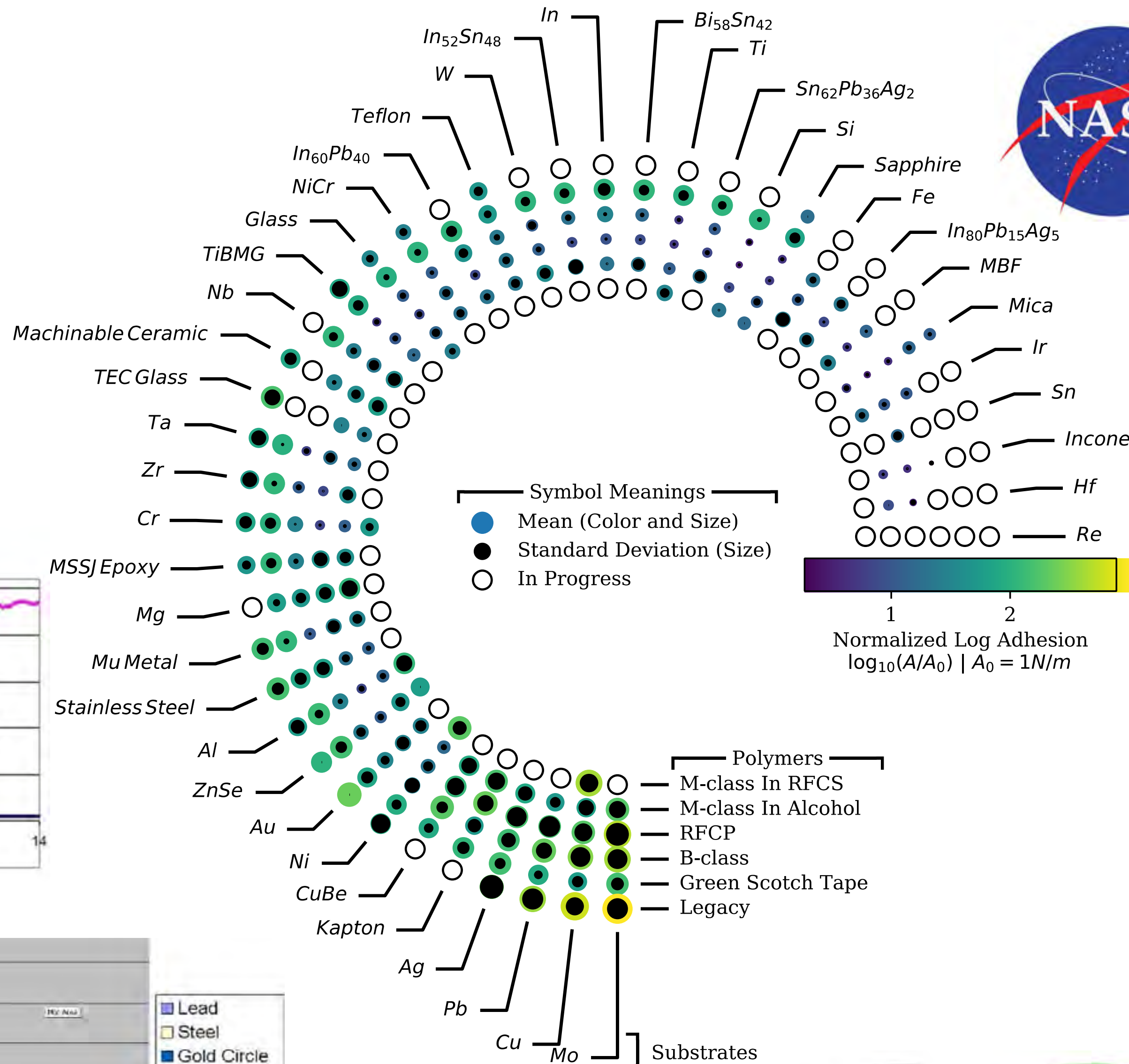




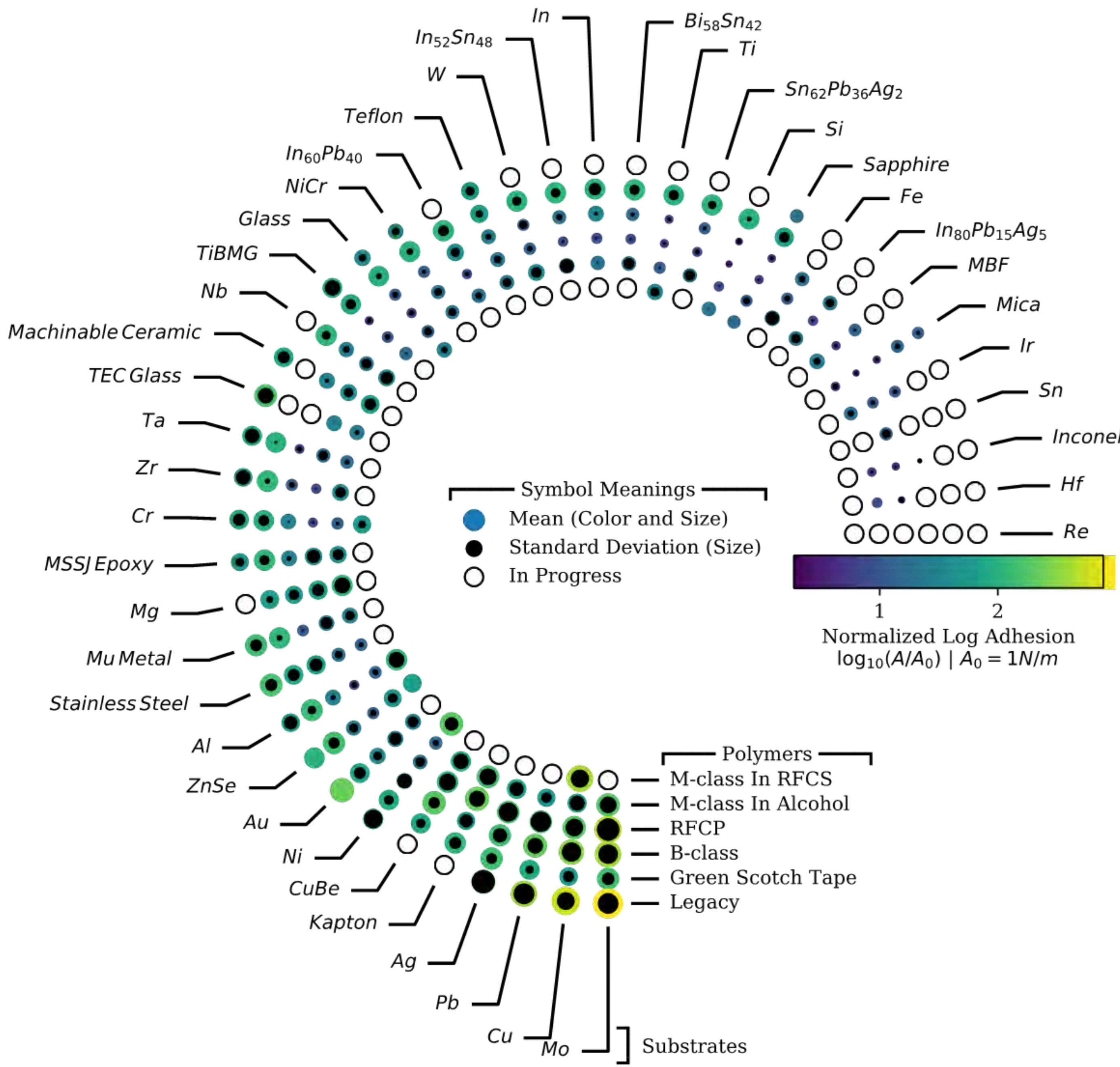
Before Phase II SBIR



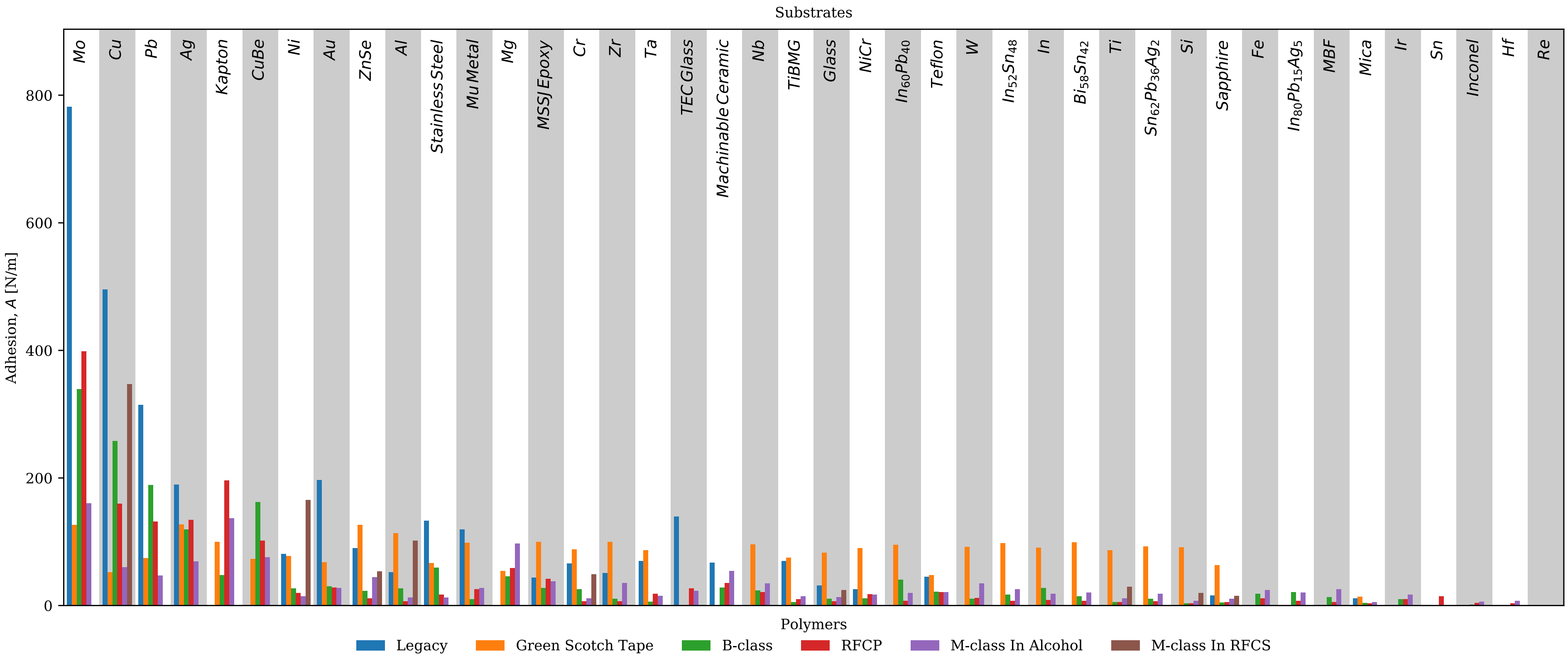


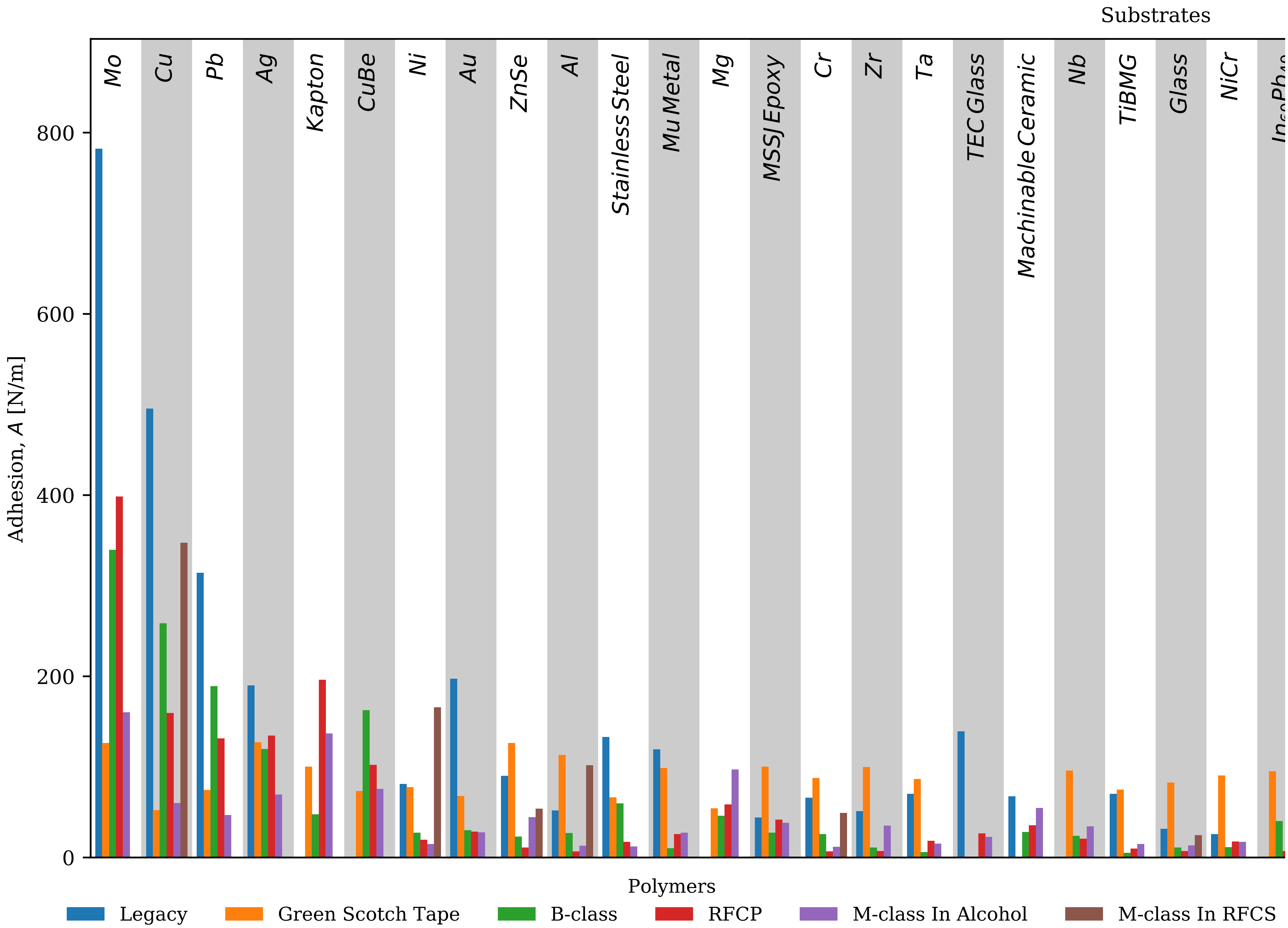


First Contact® Polymer

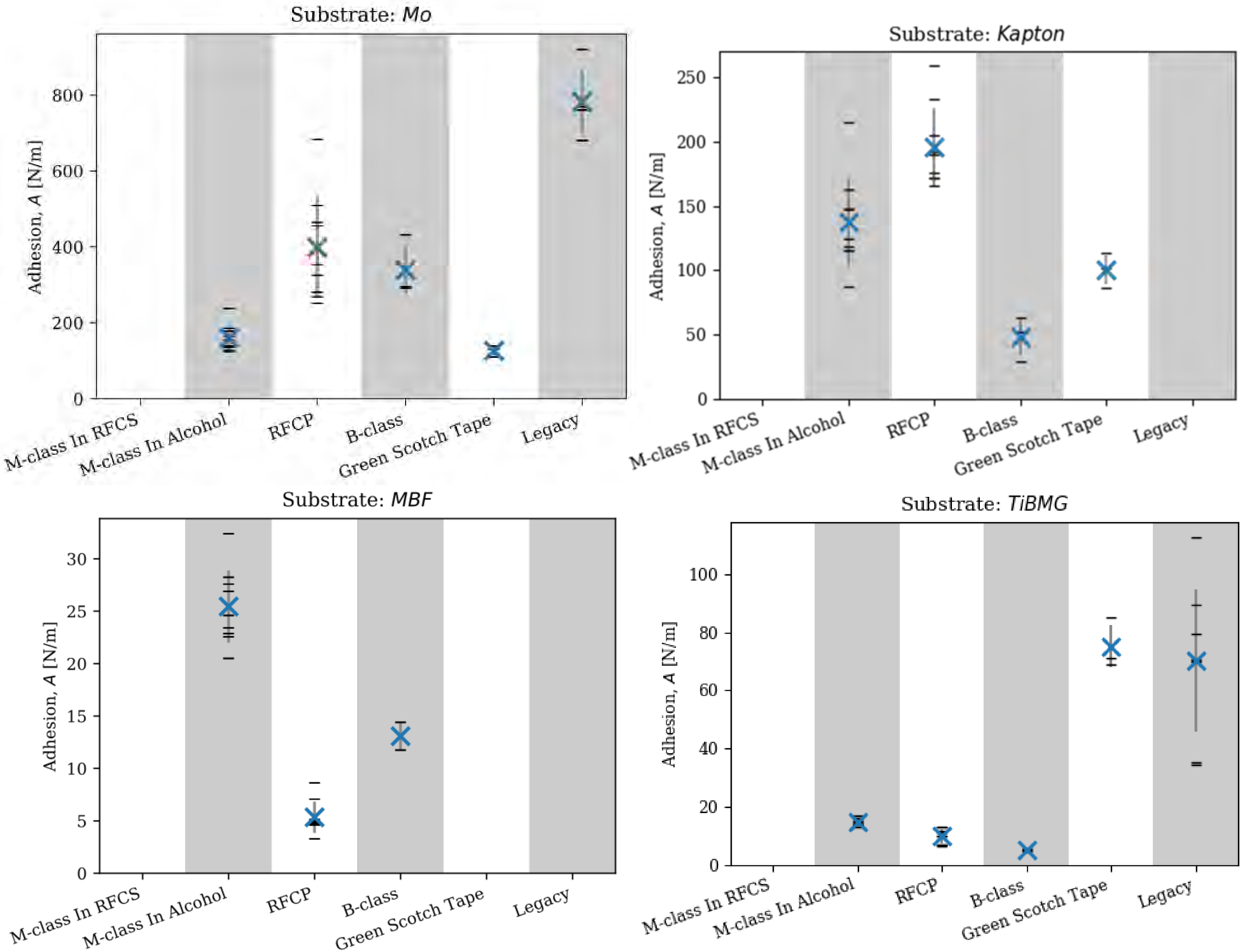


In
$Bi_{58}Sn_{42}$
$In_{52}Sn_{48}$
Ti
W
$Sn_{62}Pb_{36}Ag_2$
Teflon
Si
$In_{60}Pb_{40}$
Sapphire
NiCr
Fe
Glass
$In_{80}Pb_{15}Ag_5$
TiBMG
MBF
Nb
Mica
Machinable Ceramic
Ir
TEC Glass
Sn
Ta
Inconel
Zr
Hf
Cr
Re
MSSJ Epoxy
Mg
Mu Metal
Stainless Steel
Al
ZnSe
Au
Ni
CuBe
Kapton
Ag
Pb
Cu
Mo
Substrates
Symbol Meanings
Mean (Color and Size)
Standard Deviation (Size)
In Progress
1
2
Normalized Log Adhesion
$\log_{10}(A/A_0)$ | $A_0 = 1N/m$
Polymers
M-class In RFCS
M-class In Alcohol
RFCP
B-class
Green Scotch Tape
Legacy


Substrates
Mo
Cu
Pb
Ag
Kapton
CuBe
Ni
Au
ZnSe
Al
Stainless Steel
Mu Metal
Mg
MSSJ Epoxy
Cr
Zr
Ta
TEC Glass
Machinable Ceramic
Nb
TiBMG
Glass
NiCr
$In_{60}Pb_{40}$
Teflon
W
$In_{52}Sn_{48}$
In
$Bi_{58}Sn_{42}$
Ti
$Sn_{62}Pb_{36}Ag_2$
Si
Sapphire
Fe
$In_{80}Pb_{15}Ag_5$
MBF
Mica
Ir
Sn
Inconel
Hf
Re
Adhesion, A [N/m]
0
200
400
600
800
Polymers
Legacy
Green Scotch Tape
B-class
RFCP
M-class In Alcohol
M-class In RFCS



Substrates
Mo
Cu
Pb
Ag
Kapton
CuBe
Ni
Au
ZnSe
Al
Stainless Steel
Mu Metal
Mg
MSSJ Epoxy
Cr
Zr
Ta
TEC Glass
Machinable Ceramic
Nb
TiBMG
Glass
NiCr
Adhesion, A [N/m]
800
600
400
200
0
Polymers
Legacy
Green Scotch Tape
B-class
RFCP
M-class In Alcohol
M-class In RFCS


Substrate: Mo
Substrate: Kapton
Substrate: MBF
Substrate: TiBMG
Adhesion, A [N/m]
M-class In RFCS
M-class In Alcohol
RFCP
B-class
Green Scotch Tape
Legacy

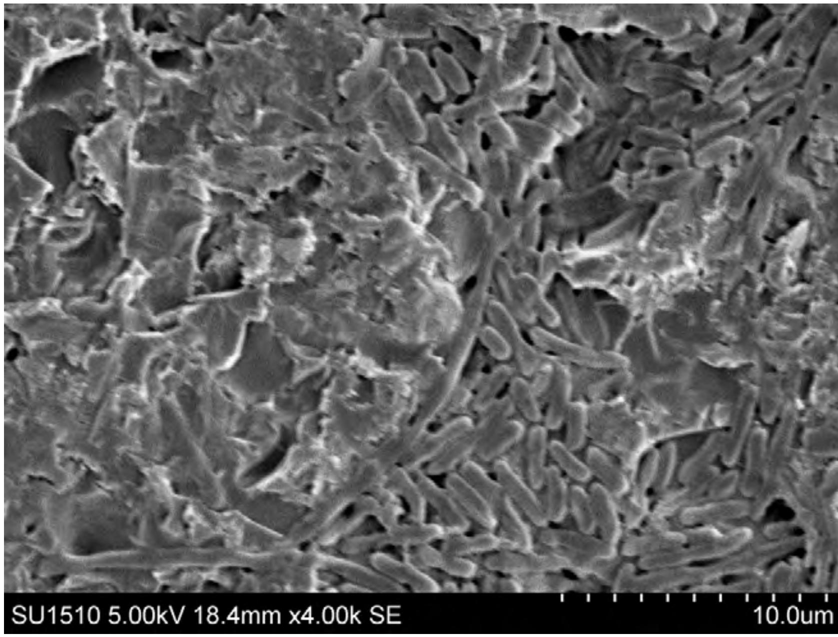
Spores, Bacteria, RNA, DNA, Prions?

Mars Viking Lander:
Heat Sterilization 1976

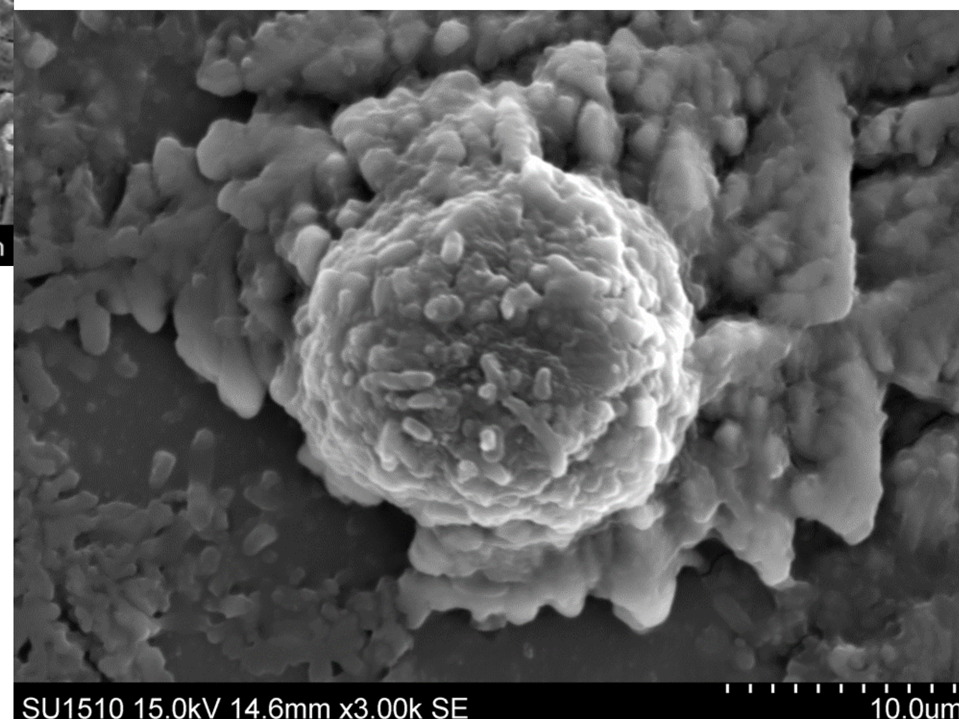
Compliance with Planetary Protection requirements is mandatory for NASA missions per

NASA Policy Directive (NPD) 8020.7G: Biological Contamination Control for Outbound and Inbound Planetary Spacecraft.

SEM Images of E. Coli and Substrates



E. coli rods in Luria Broth

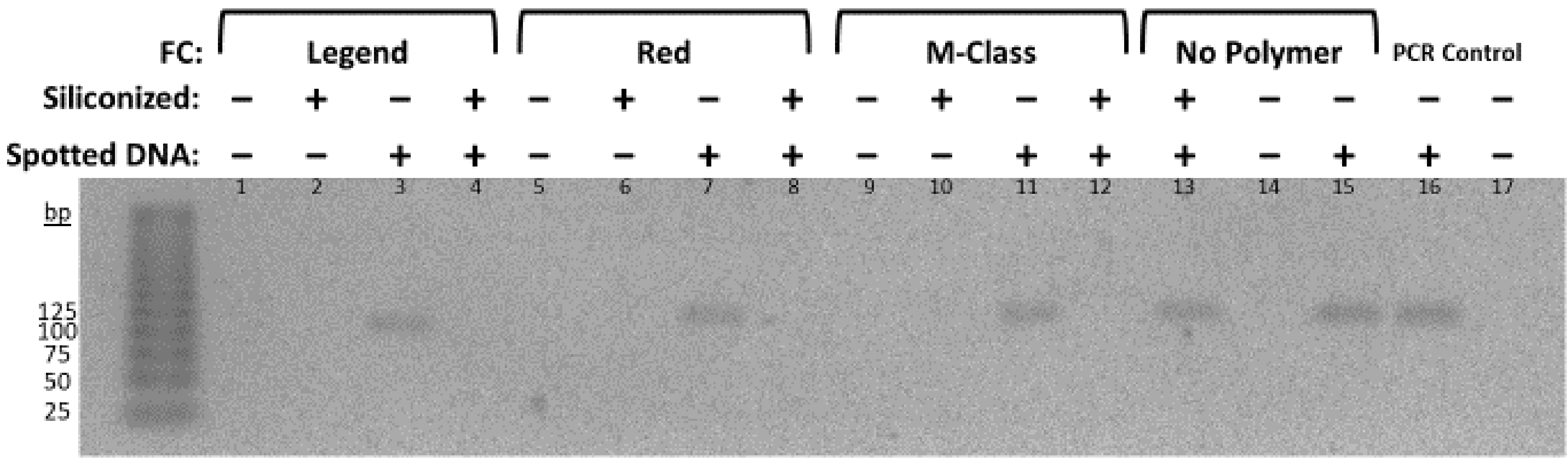


E. coli pooling in a drop of Luria Broth

First Contact Removes *E. coli* from Brass Surface

First Contact Formulation	Growth		
	Aluminum	Brass	Silicone
None	+	+	+
L Class	+	-	+
R Class	+	-	+

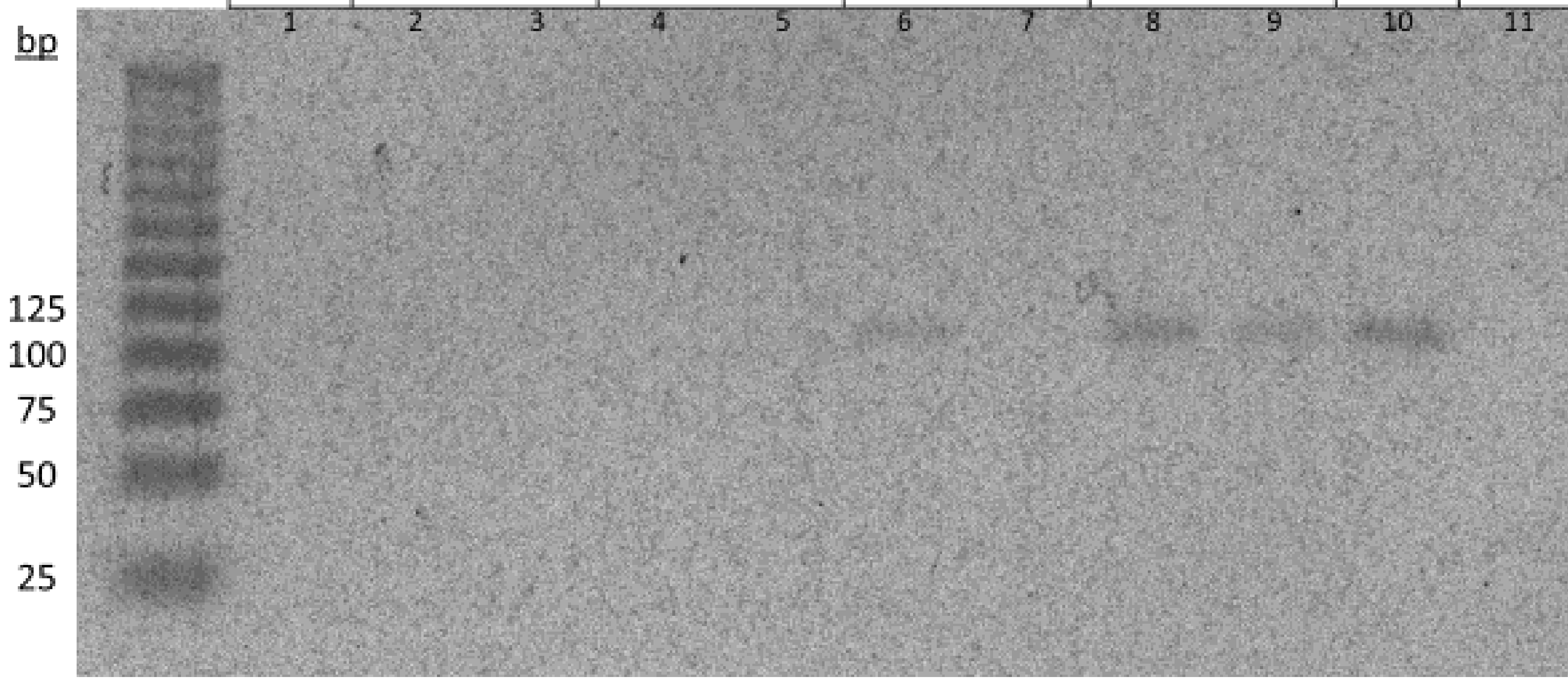
Siliconizing Glass Improves First Contact:DNA Binding on Glass



- Siliconized Glass does not degrade DNA (Lane 13)
- All polymers adhere to DNA on siliconized glass (Lanes 2, 6, 10)
- Additional formulations may remove DNA from untreated glass (to be tested)
- PCR controls confirm no contamination (Lanes 16, 17)

Cumulative DNA Removal: First Contact on Brass

Rounds of Removal:	1x	1x	2x	1x	2x	1x	2x	1x	2x	PCR Controls	
DNA :	-	10 ng		50 ng		100 ng		500 ng		+	-

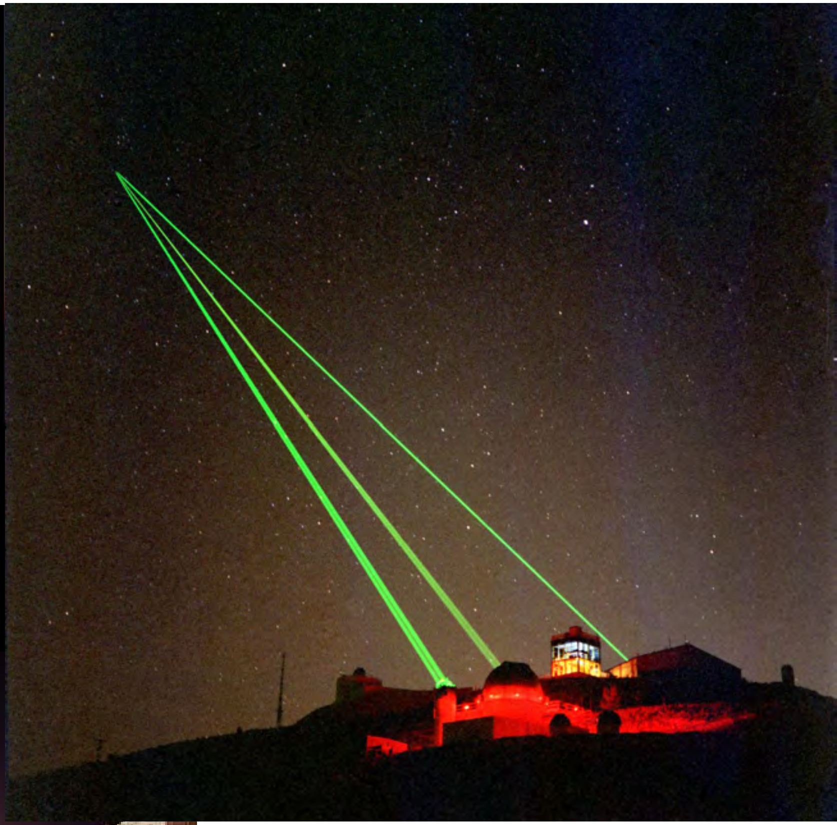


- Polymer removes DNA completely from untreated Brass (Lanes 2-5, 7)
- Additional rounds of polymer treatment remove additional DNA (Lanes 6/7, 8/9)

The End Game for Massive Telescopes:

Routinely Maintain Mirrors at Maximum Reflectivity

Dramatically (Indefinitely?) Extend Coating Lifetimes

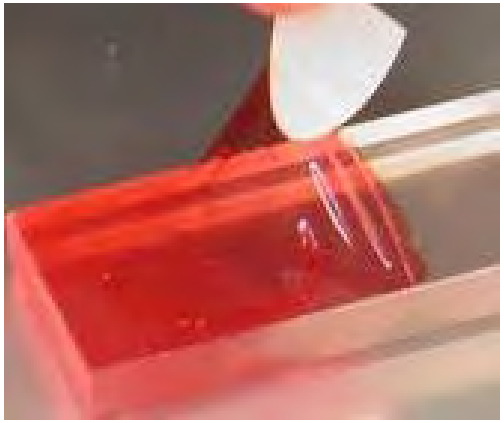


First Contact Polymer

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



Dark Energy Survey Camera

Total DOE cost $24M

Plan first light Oct. 2010

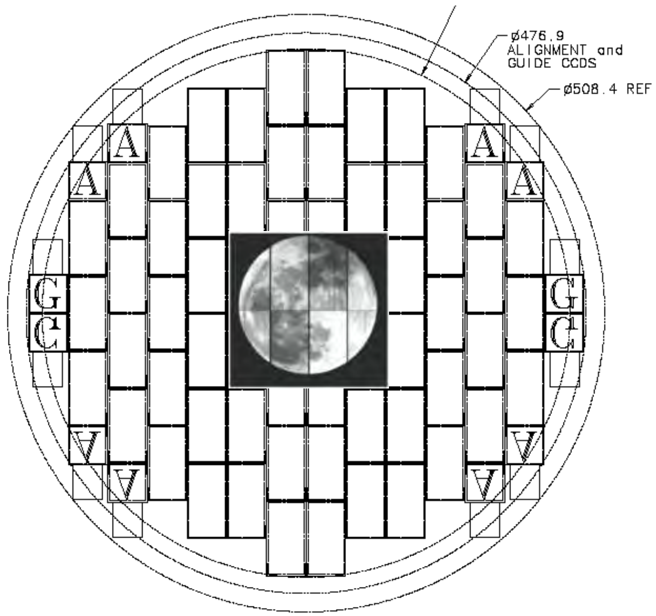
3 sq. deg. Field of View

Each image will contain:

- ~ 20 Galaxy clusters
- ~ 200,000 Galaxies

Each night ~ 300 GB

Entire survey ~ 1 PB



DES Focal Plane

520 Mpixel!!

El Blanco
Chile

62 2kx4k Image CCDs

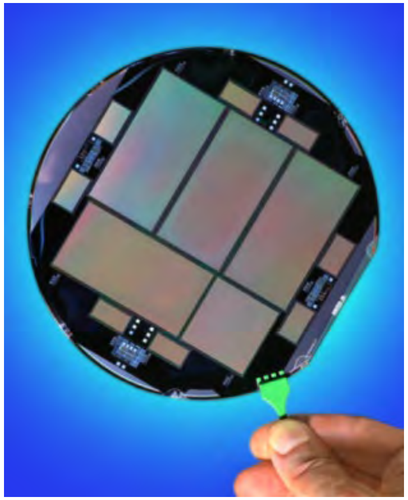
82kx2k focus, alignment CCDs

4 2kx2k guide CCDs

The Dark Energy Survey Camera: DECam

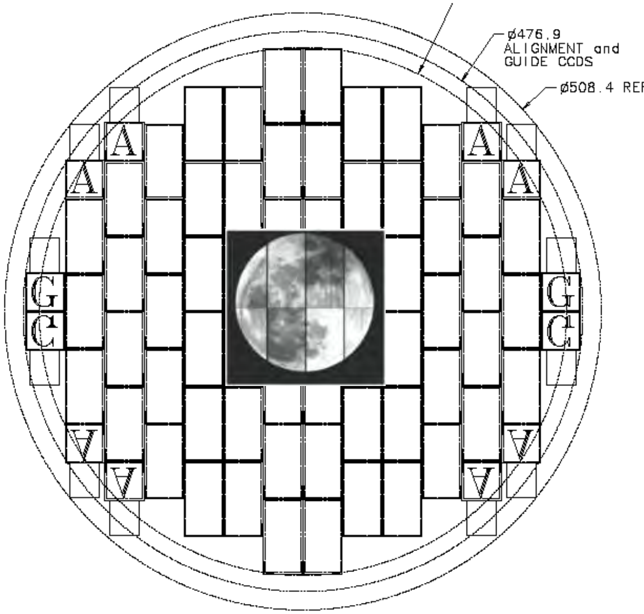
3 sq. deg. Field of View
Each image contains:
- ~ 20 Galaxy clusters
- ~ 200,000 Galaxies

Each night ~ 300 GB
Entire survey ~ 1 PB
El Blanco - Chile



Static Sensitive!!!

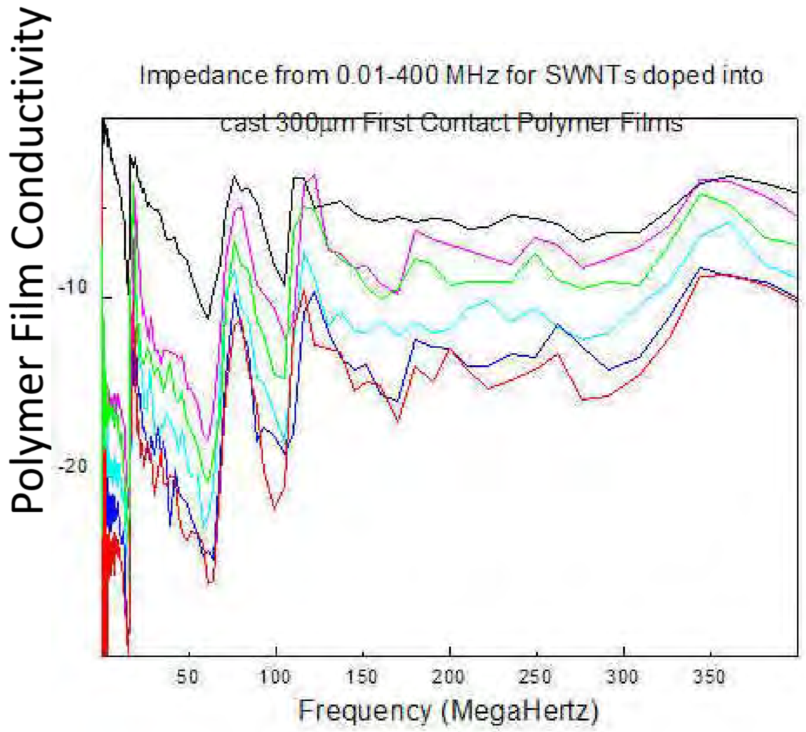
DES Focal Plane

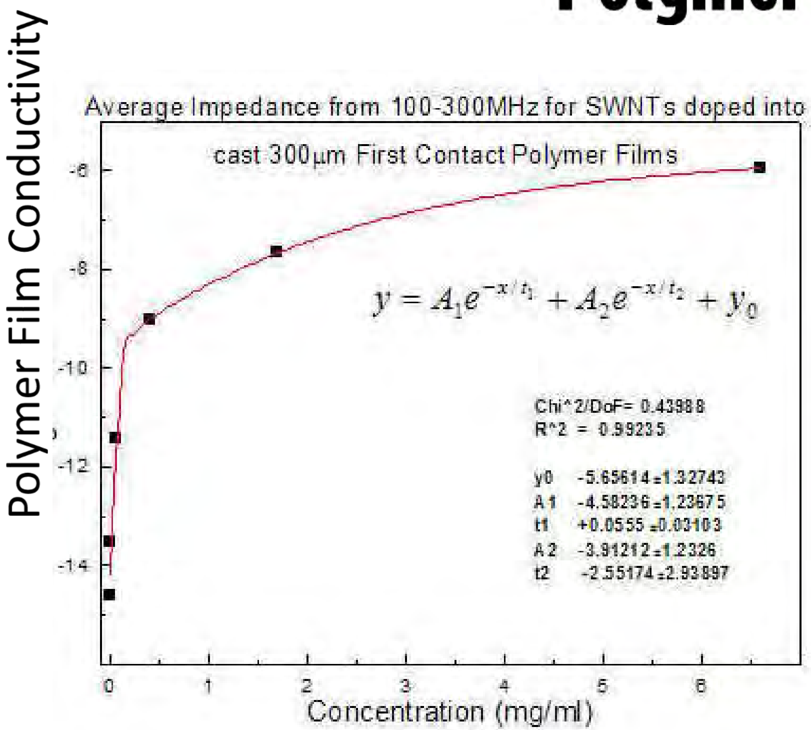


520 Mpixel!!

62 2kx4k Image CCDs
4 2kx2k guide CCDs
82kx2k focus, alignment CCDs

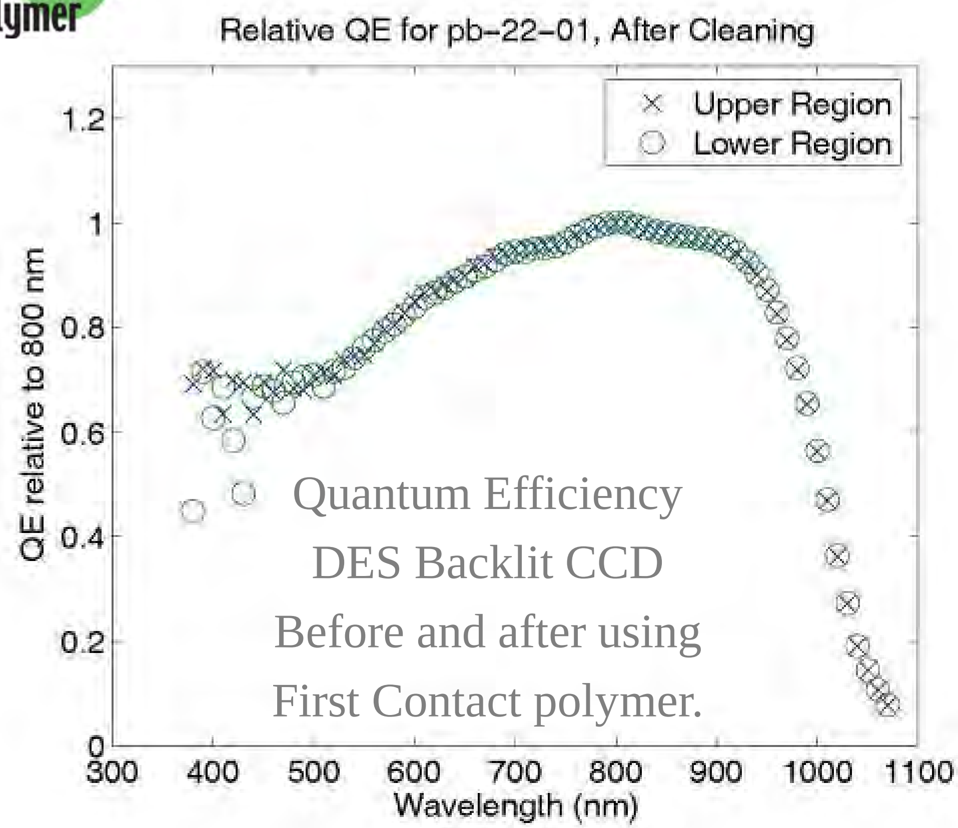
Removable Polymer Films with Controlled ESD Conduction



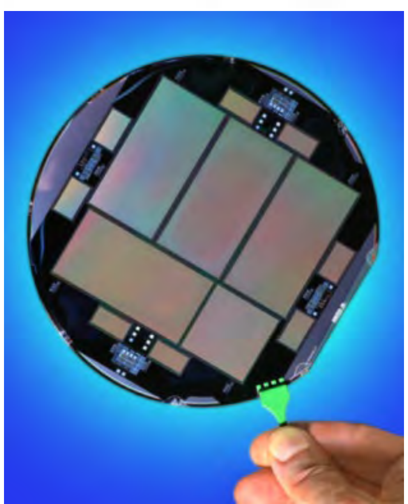


Average of Impedance between 100-300 MHz for SWNT doped films. These films were used to protect and clean Dark Matter sensors and astronomical CCD detectors on DESCAM built at Fermilab on the following slides.

"Surface cleaning of CCD imagers using a electrostatic dissipative nanotube doped formulation of First Contact", G.Derylo, J.Estrada, B.Flaugher, J.Hamilton, D.Kubik, K.Kuk, V.Sparpine,), Proc. SPIE 7018, 701858 (2008); doi:10.1117/12.789654



Quantum Efficiency
DES Backlit CCD
Before and after using
First Contact polymer.



520 Mpixel!!

Dark Energy

Survey Camera

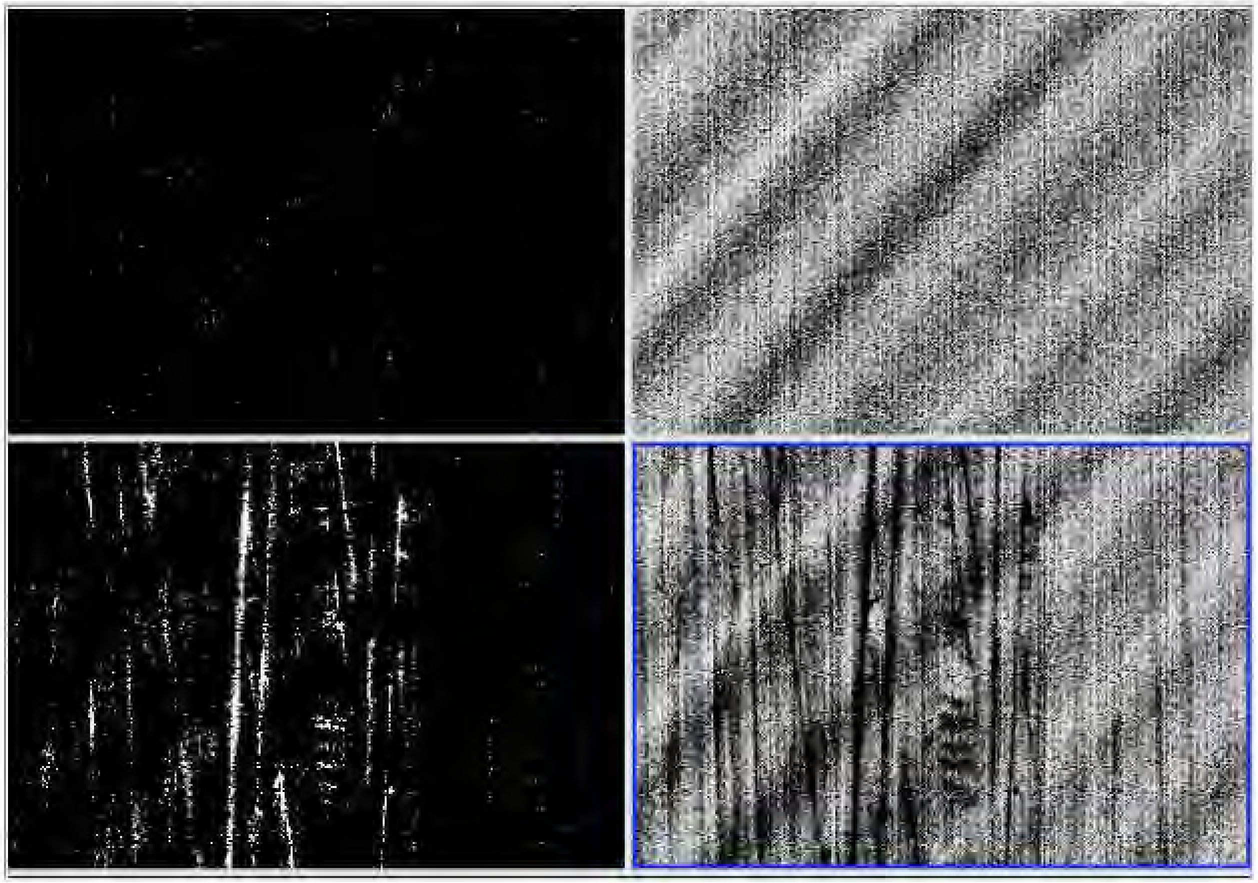
First contact test

Flag 3% below background

This was a BRAND NEW CCD fabbed at LBL and sent direct to the Fermilab Cleanroom.

Mask of flagged pixels

20 second flat image



After cleaning with First Contact

Before cleaning with First Contact

“Surface cleaning of CCD imagers using a electrostatic dissipative nanotube doped formulation of First Contact”
G.Derylo, J.Estrada, B.Flaugher, J.Hamilton, D.Kubik, K.Kuk, V.Sparpine,), Proc. SPIE 7018, 701858 (2008)
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