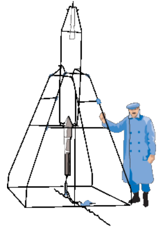

# Advanced Al Mirrors Protected with LiF Overcoat to Realize Stable Mirror Coatings for Astronomical Telescopes

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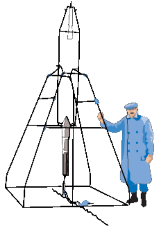
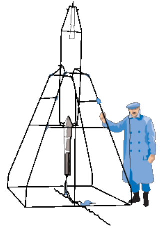


# Outline

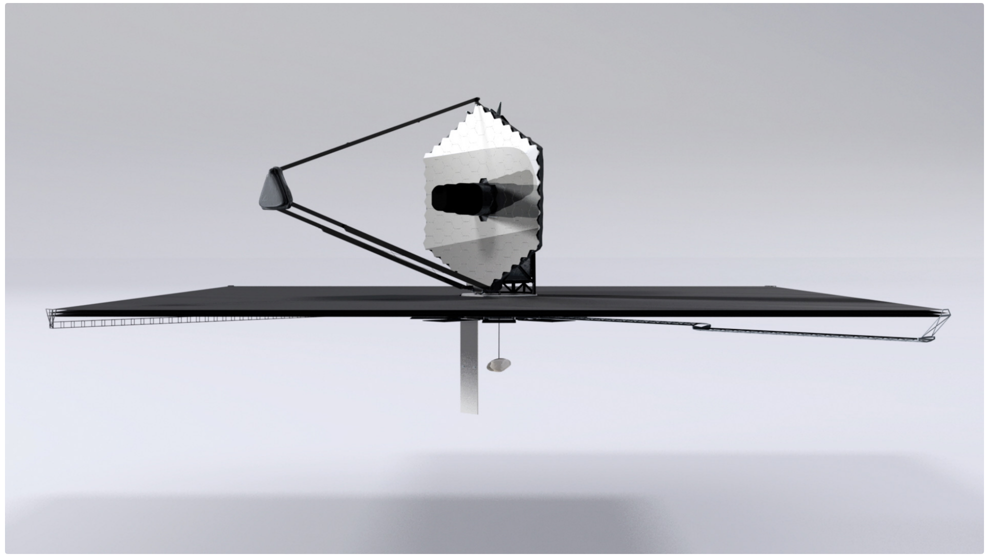
- Introduction
  - Overview & Objectives
  - Future IR/O/UV Telescope
  - UV Astronomy
  - Throughput vs. Mirror Reflectance
- FUV Coating Capabilities and activities at GSFC
  - Hot Physical Vapor Deposition
  - Reactive Physical Vapor Deposition
  - Environmental & other performance metrics
- Future Plans
  - Upgrade rPVD process to coat up to +1meter class mirrors
- Conclusions

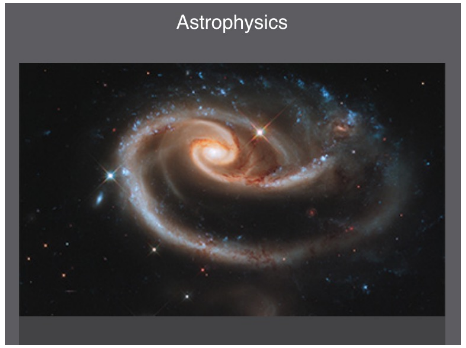


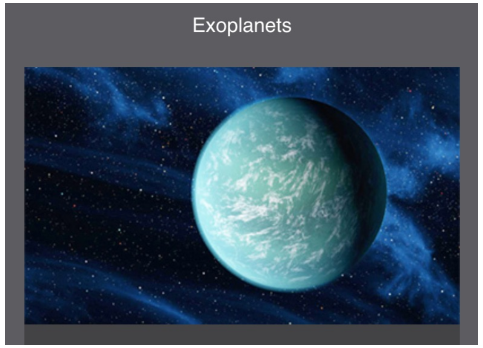
# Overview and Objectives

- **Task Description**
  - ✓ Deposit high performance optical broadband (FUV -> IR) mirror coatings:
    - ✓ Fluorination/passivation of Al-based coatings.
    - ✓ Atomic Layer Deposition (ALD) layers of $AlF_3$.
    - ✓ Ion assisted depositions for low-absorption metal-fluoride to protect Al mirrors.
- **Driver / Need**
  - ✓ Broadband coatings (90-2,500 nm) have been identified as an "Essential Goal" in the technology needs for a future Large-Aperture Ultraviolet-Optical-Infrared Space Telescope (LUVOIR and HabEx).
- **Benefits**
  - ✓ High throughput & high signal-to-noise ratio (SNR) over a broad spectral range.
  - ✓ Enabling technology for astrophysics and optical exoplanet sciences (in shared platform).

LUVOIR Concept Telescope

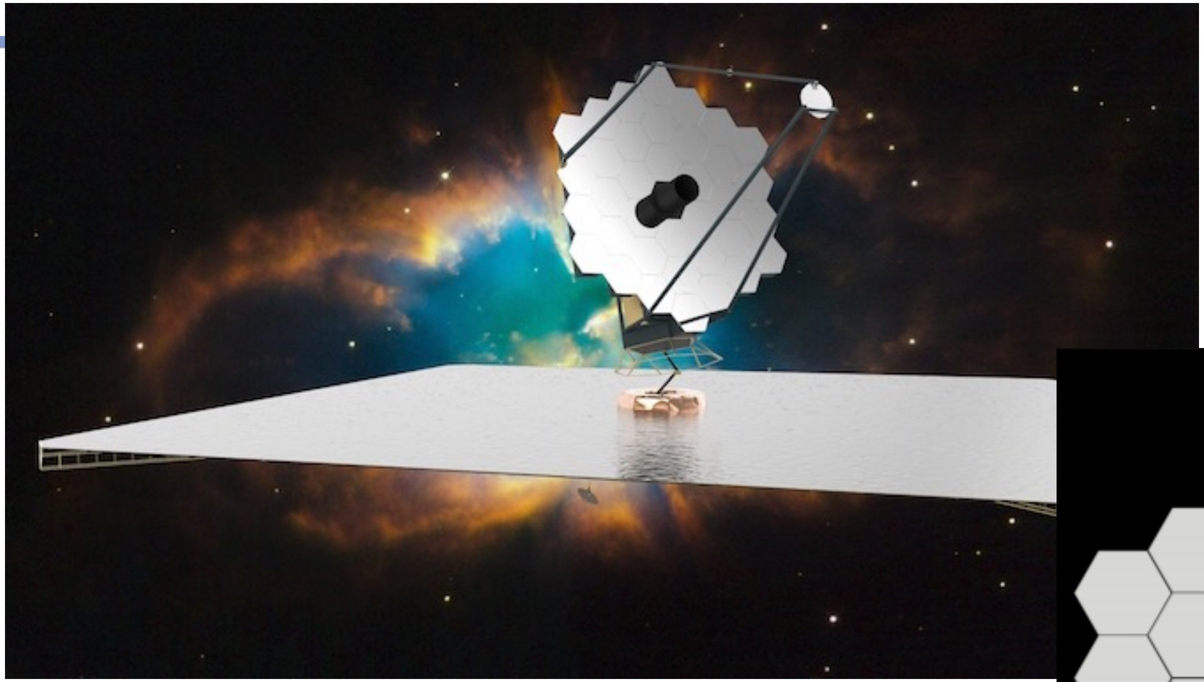


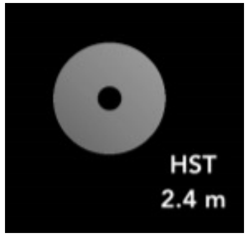


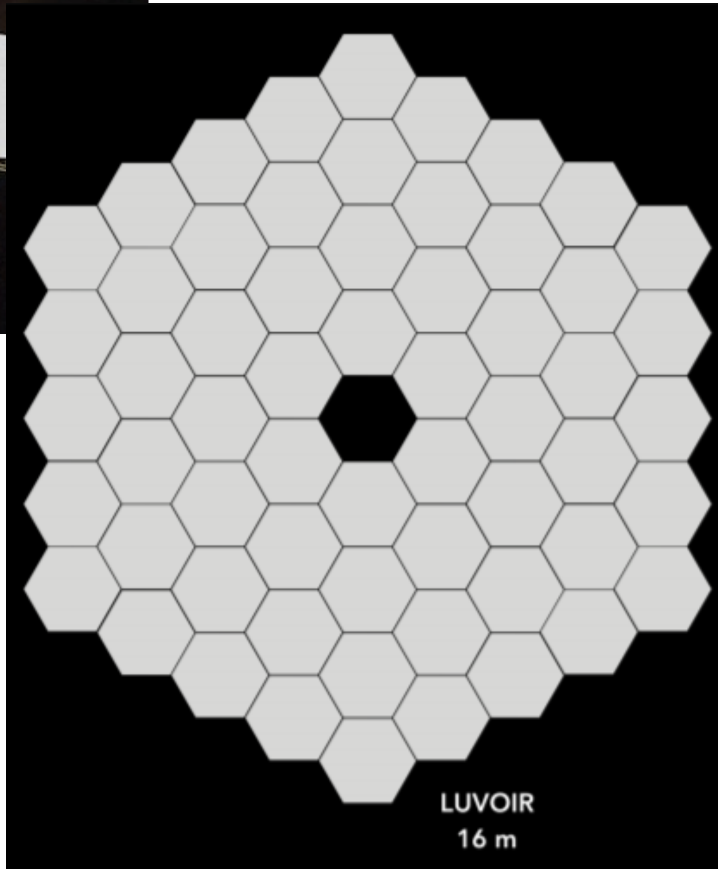
# Present and Future UV Telescopes

Existing: Hubble Space Telescope (HST)

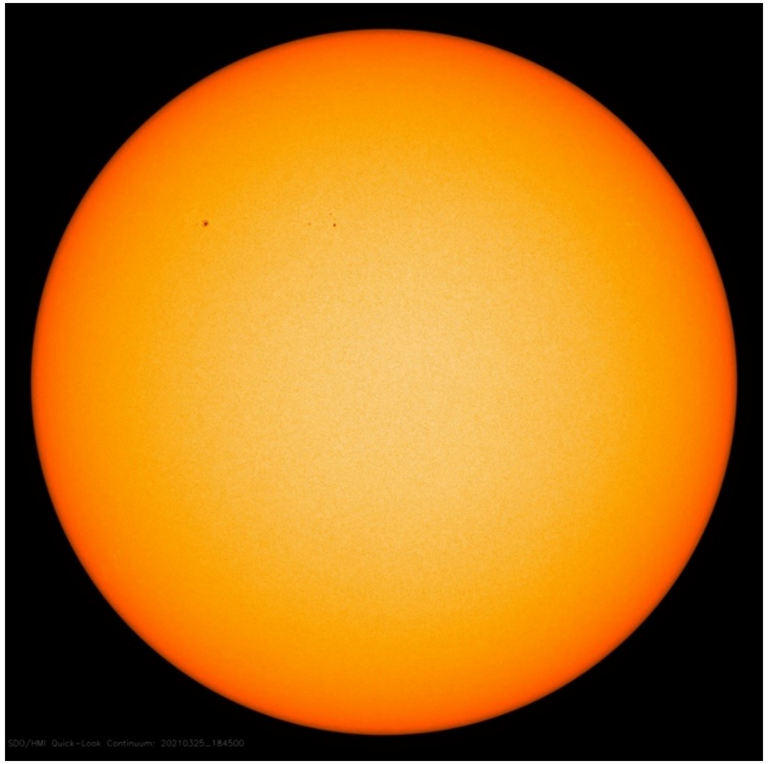





**Proposed: large infrared/optical/ultraviolet (IR/O/UV)**

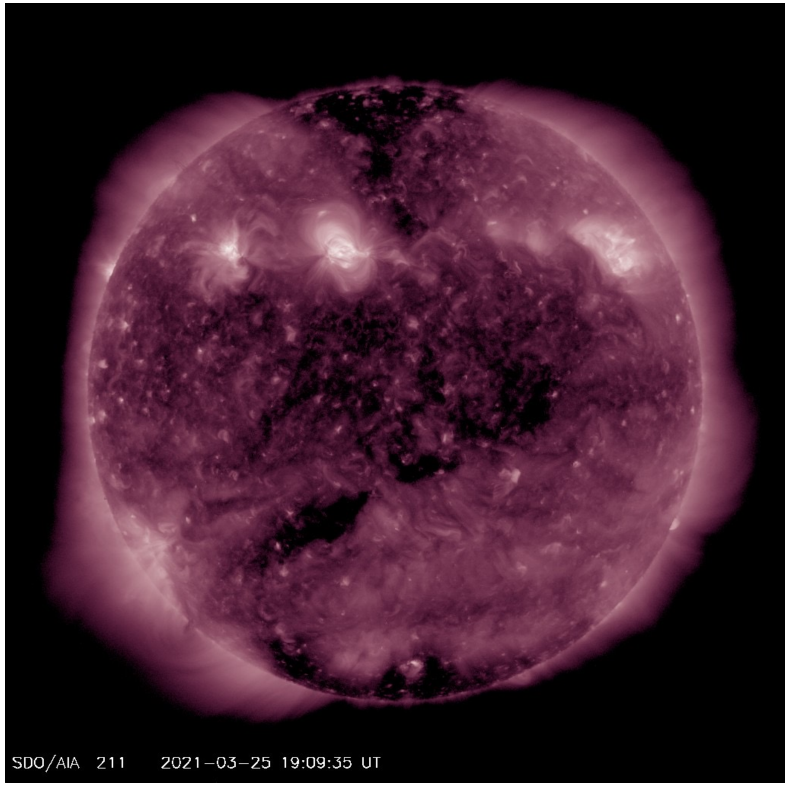


# Why UV Astronomy?



The Sun (in the visible)

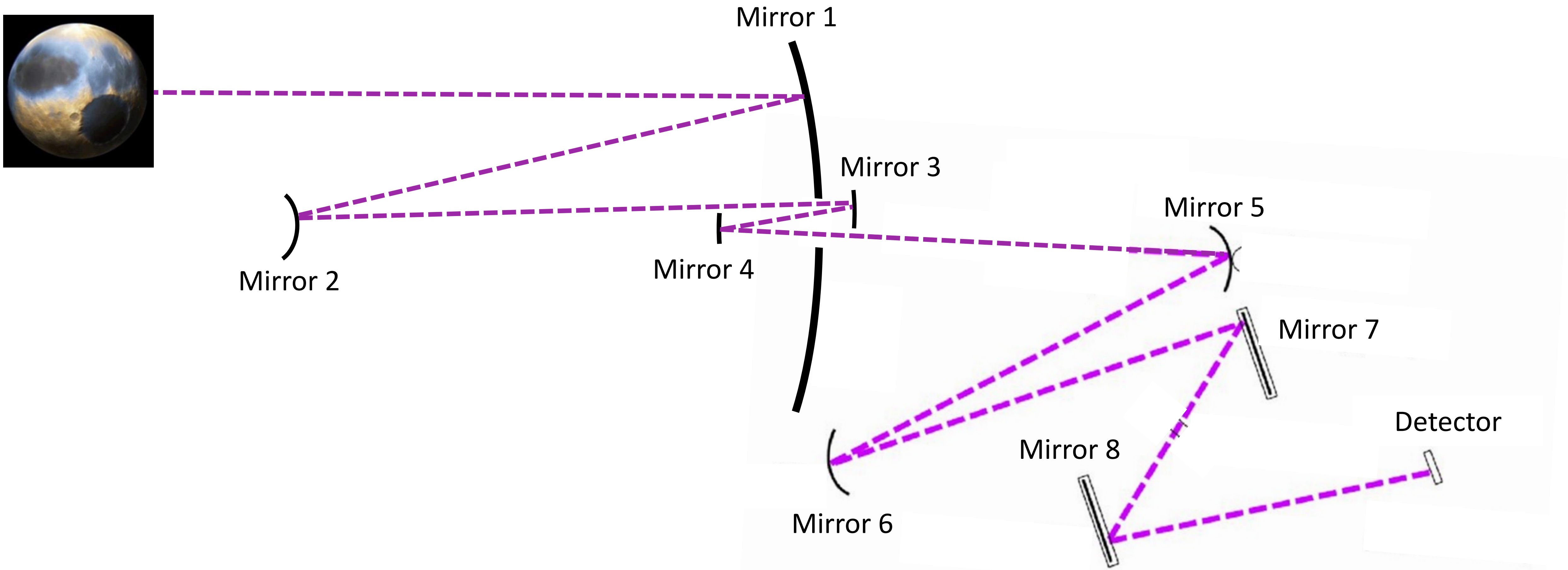
- Ultraviolet range: rich in physical information
- Example: Access to gas temperatures from $10^2$ K to $10^7$ K
- Others (resolution, diffraction, “darker sky”, etc)




The Sun (in the ultraviolet)

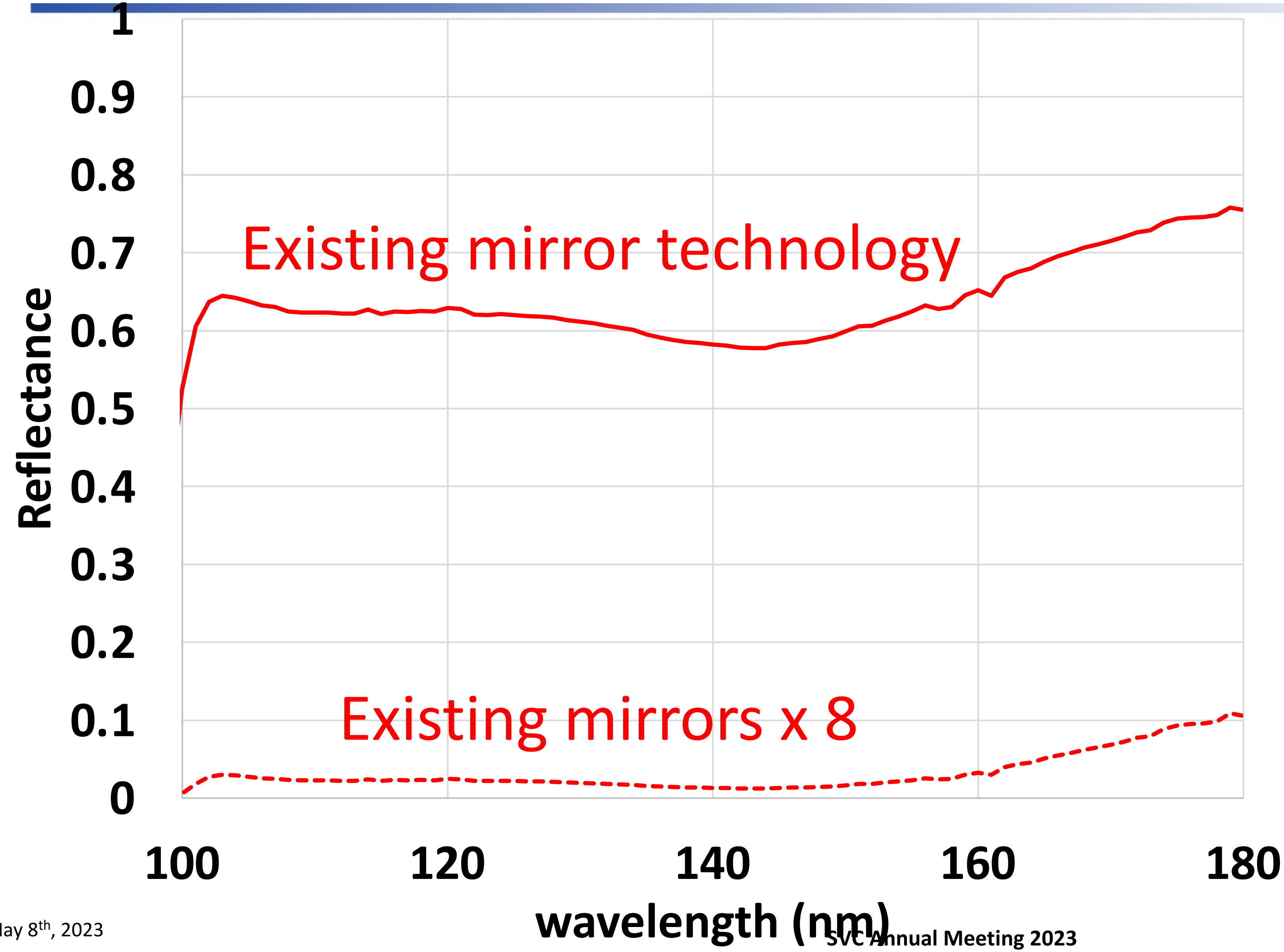
Pictures: NASA’s SDO, AIA

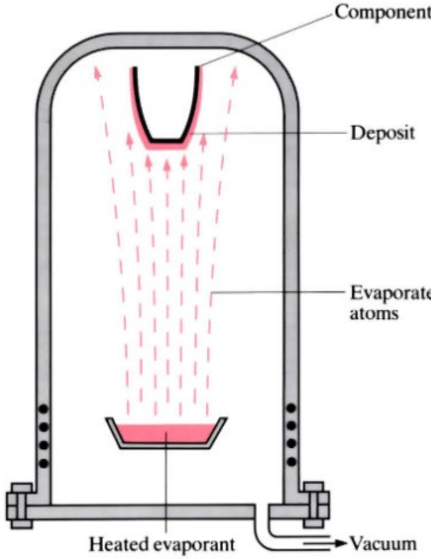
# Future UV Telescopes: Optical design




Future large UV telescope: Optical design.... with 8 mirrors!

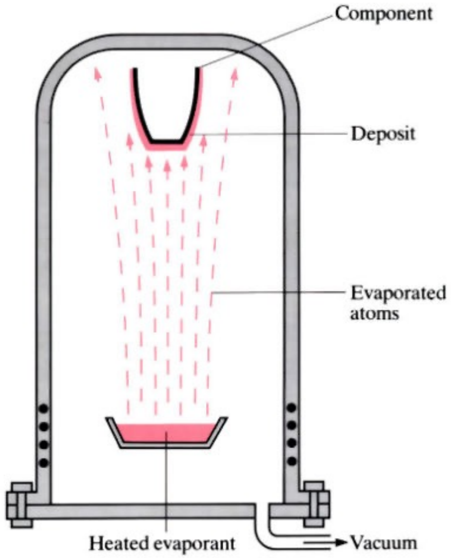
# New UV Coatings



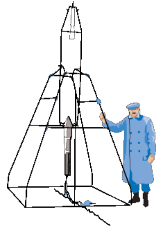




Physical vapor deposition (Al)

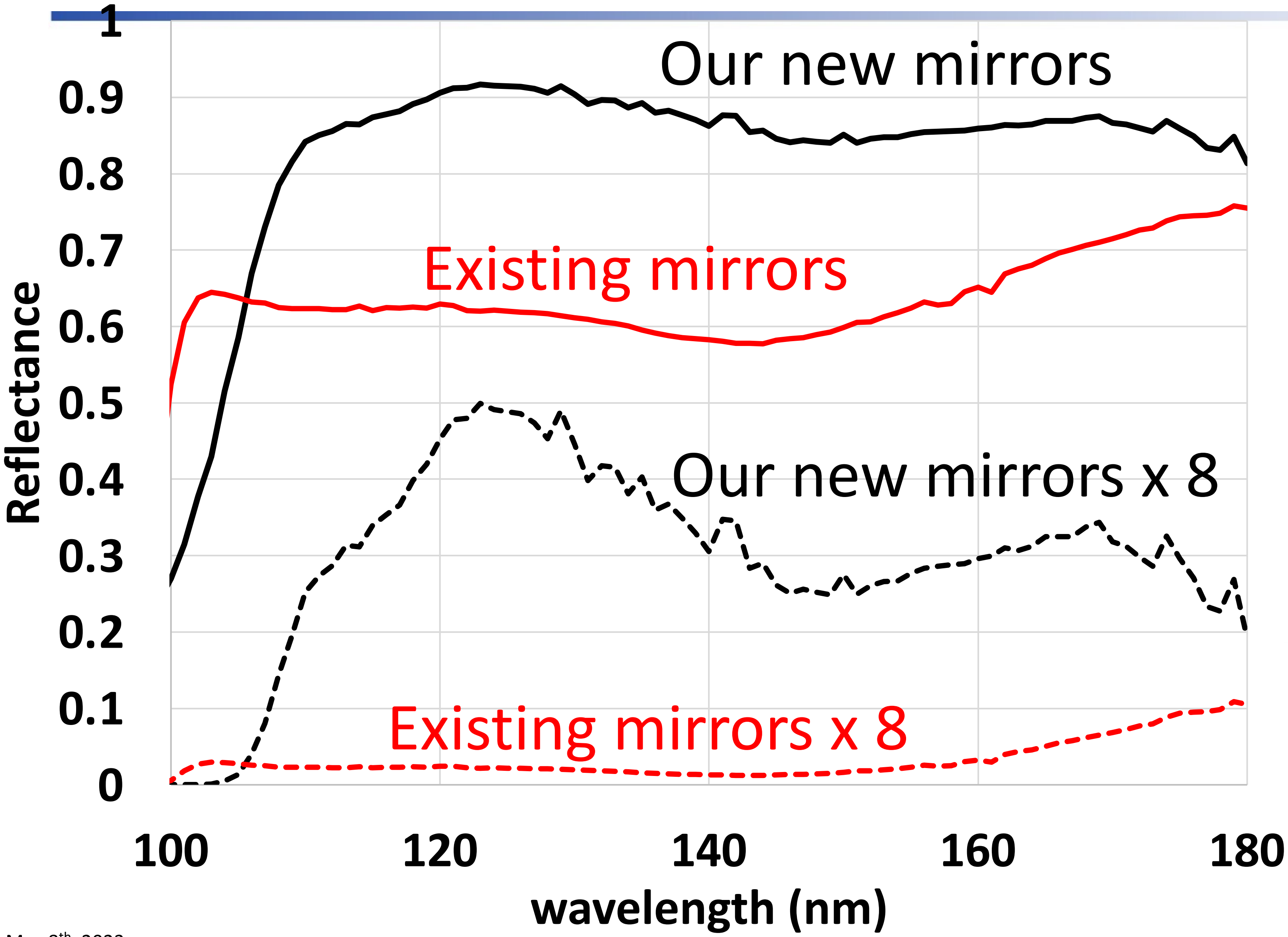
+

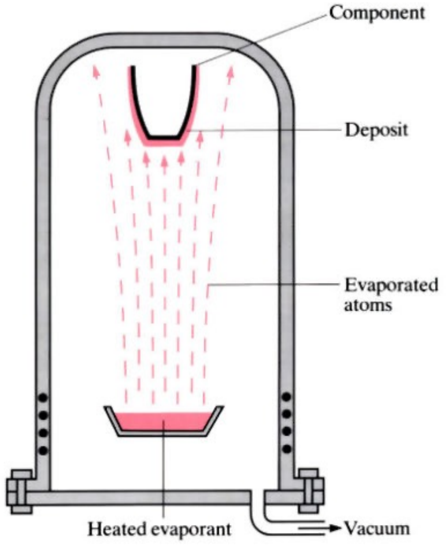


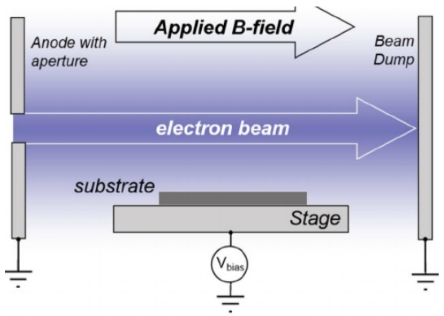

Physical vapor deposition (LiF)

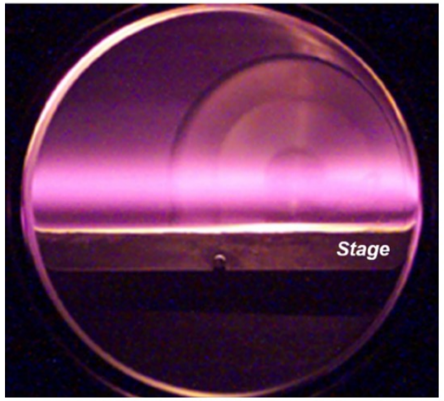


# New UV Coatings



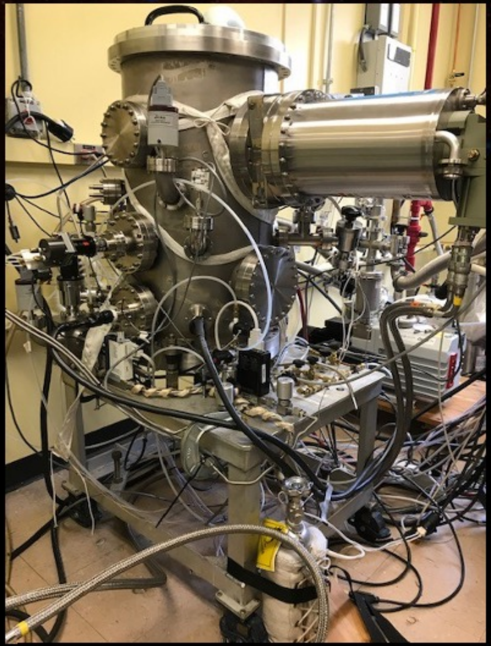




Physical vapor deposition (Al) + Plasma passivation process ($AlF_3$)

# UV fabrication and characterization tools at 551

## Fabrication:

- 2-m deposition chamber (IBS, PVD, IAPVD & e-gun) with H-Lyman α in-situ optical monitor
- 3 x 1-m deposition chambers (PVD and DC & RF Sputtering)
- 0.5-m UHV deposition chamber (PVD, rPVD)
- Clean room class ISO-6



UHV chamber for PVD thin-film deposition with $XeF_2$ fluorination.

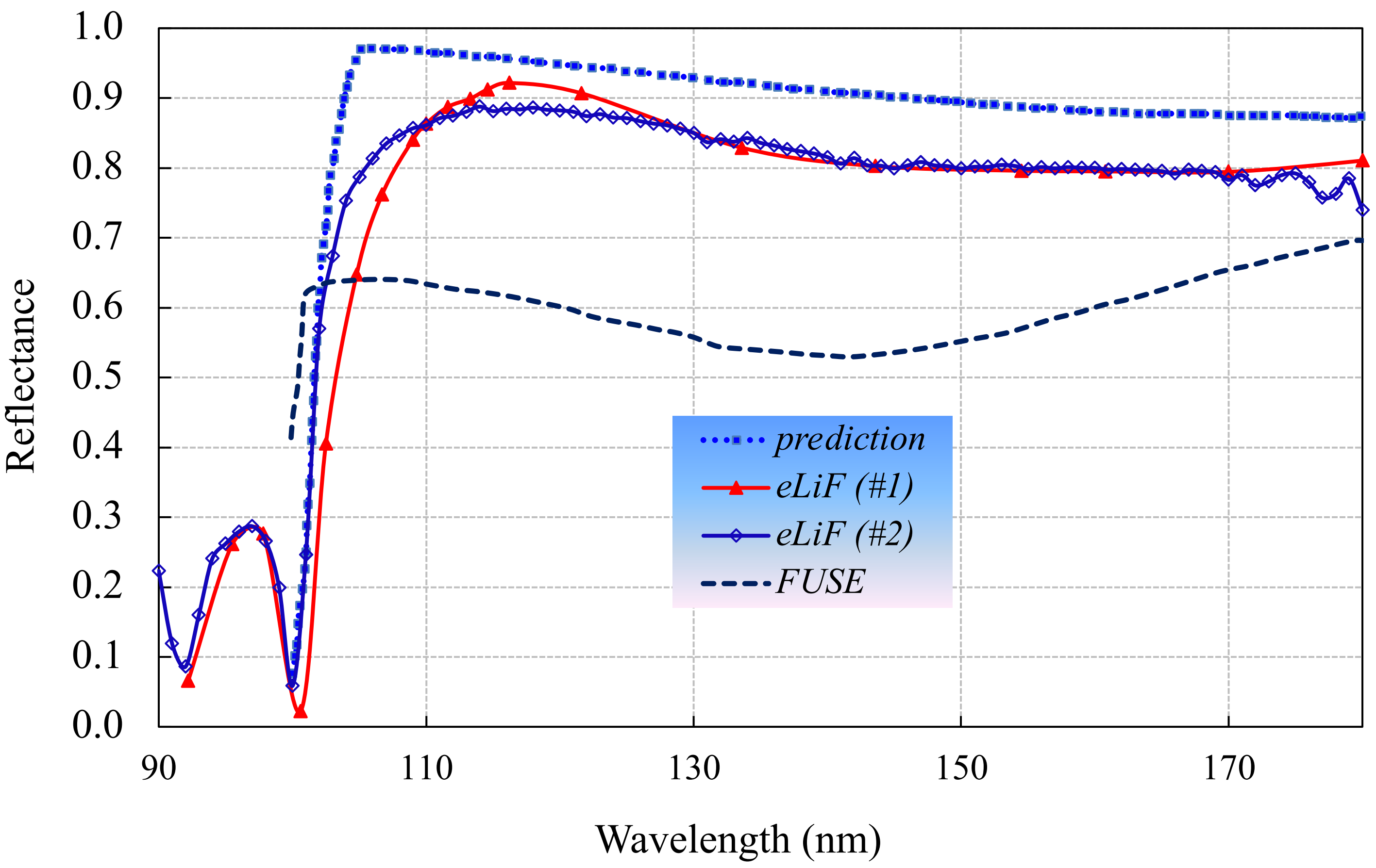
## Characterization:

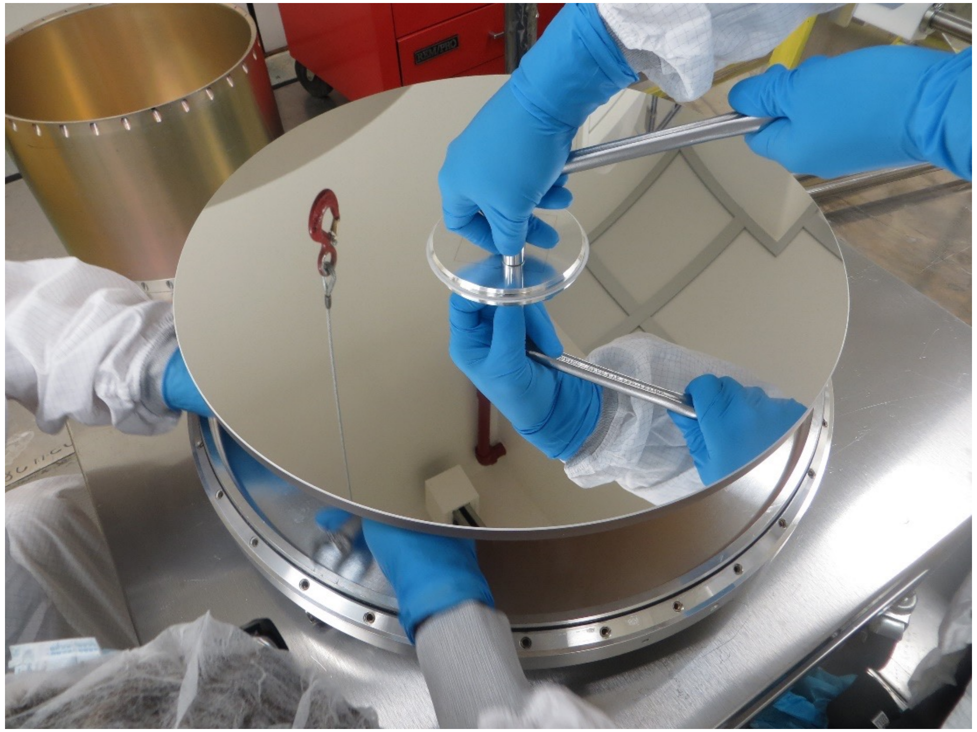
- 2x VUV reflectometers (McPherson 225 and old Acton) covering 30-230 nm
- 2x NUV-NIR Spectrometers (PE 950 and Cary), covering 200-3300 nm
- Variable angle spectroscopic ellipsometer Horiba UVISEL (190-2500 nm)
- 2x KLA stylus profilometer and optical profilometer.
- Atomic Force Microscope (Park Systems)
- Interferometers, microscopes, and more


The McPherson 225 spectrometer for transmittance and reflectance measurements in the 30-230 spectral range

More information:
manuel.a.quijada@nasa.gov

# Optimization Al+LiF (eLiF) Hot Coatings



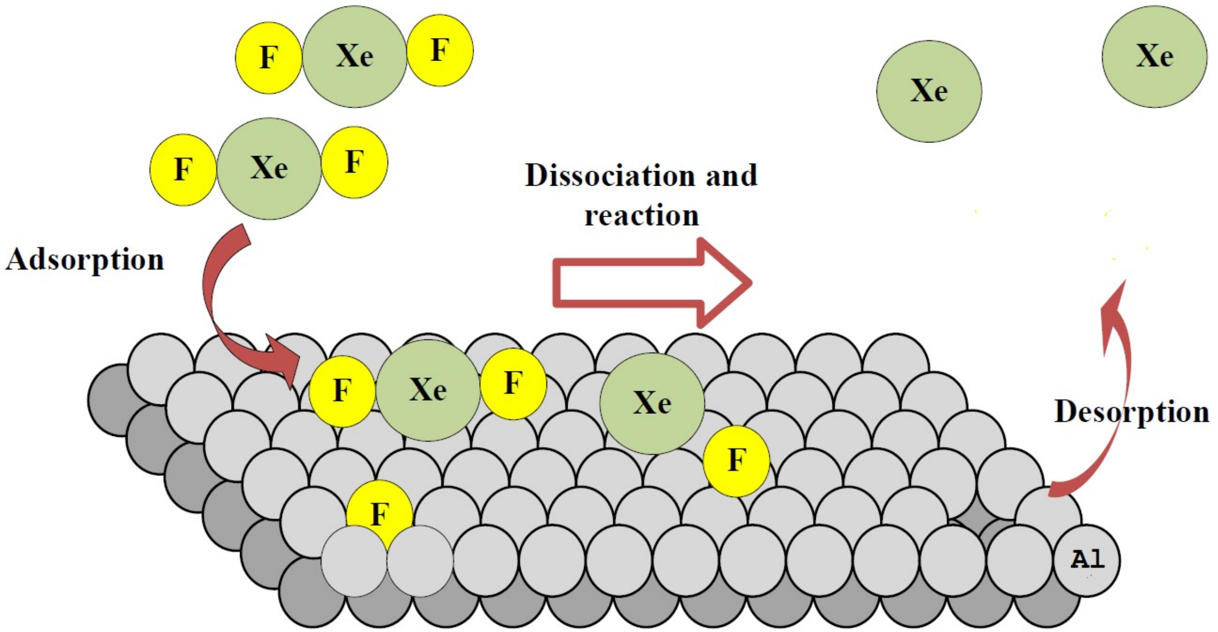



The SISTINE primary mirror (PI: Kevin France/U of C) after coating with Al+LiF in 2-meter chamber at GSFC.

# Degradation of Al+LiF Mirrors Over Time

Storage in dry box
(Humidity ≈ 35%)

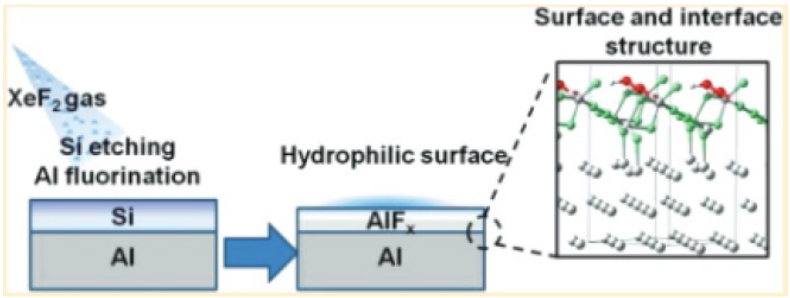
# Hybrid PVD Passivation/Fluorination




Reactive fluorine compound with low bond energy used (e.g. $XeF_2$ with 133.9 kJ/Mole).

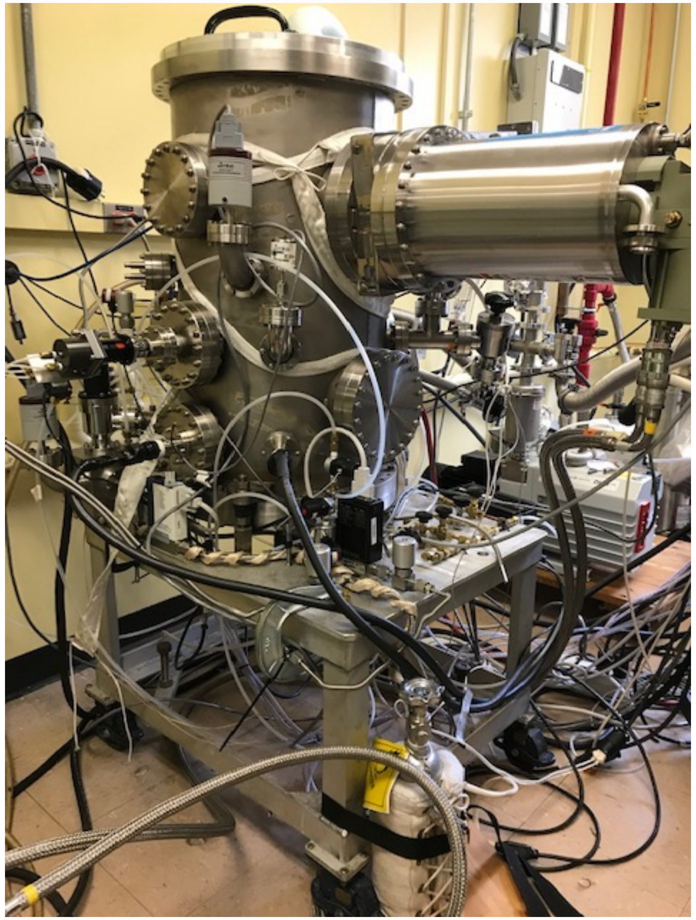
Heating of the $XeF_2$ may also be used if compound is not sufficiently reactive for increased selectivity.

$XeF_2$ is a dry-vacuum based method of reaction and requires no plasma or other activation minimizing damage to substrate.

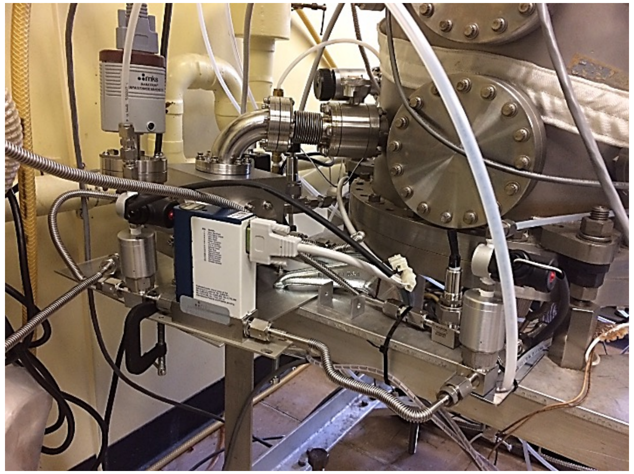



Roodenko *et.al.* J. Phys. Chem. C Vol. **115**, 21351, 2011

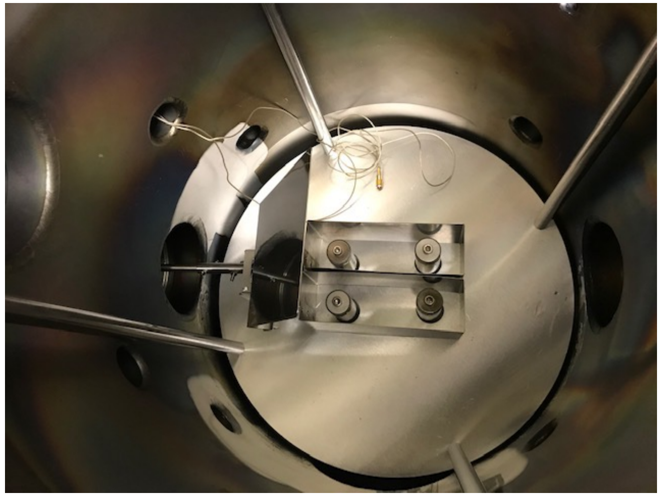
# Research Coating Chamber Capabilities



UHV Research Chamber capable of thin film physical vapor deposition (PVD) and passivation.



$XeF_2$ Gas feed components capable of continuous flow or pulsed flow.

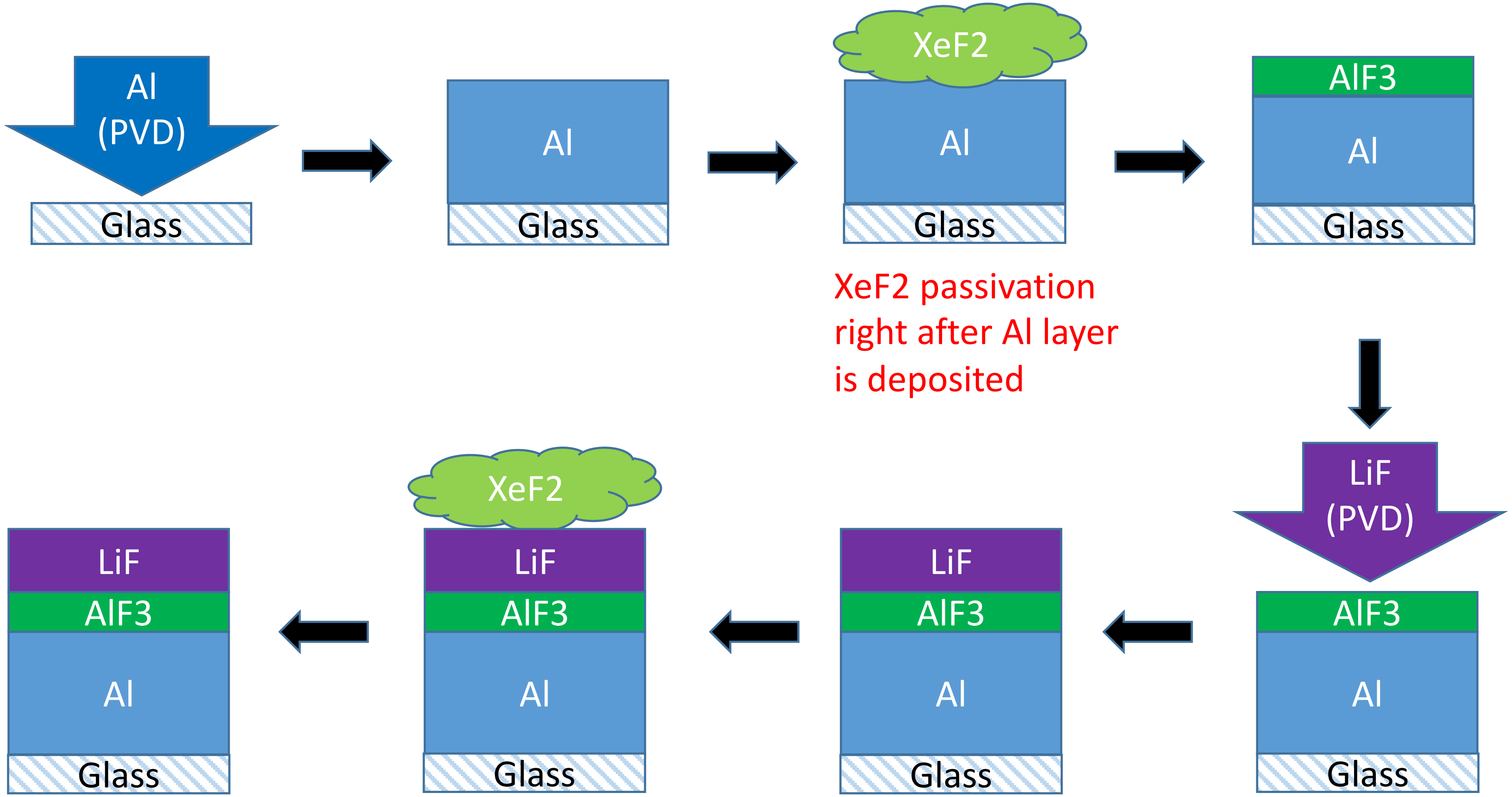


Inside view of RC with 2-materia PVD deposition system.

**R&D for combined PVD & fluorination of Al-based high performance FUV coatings.**

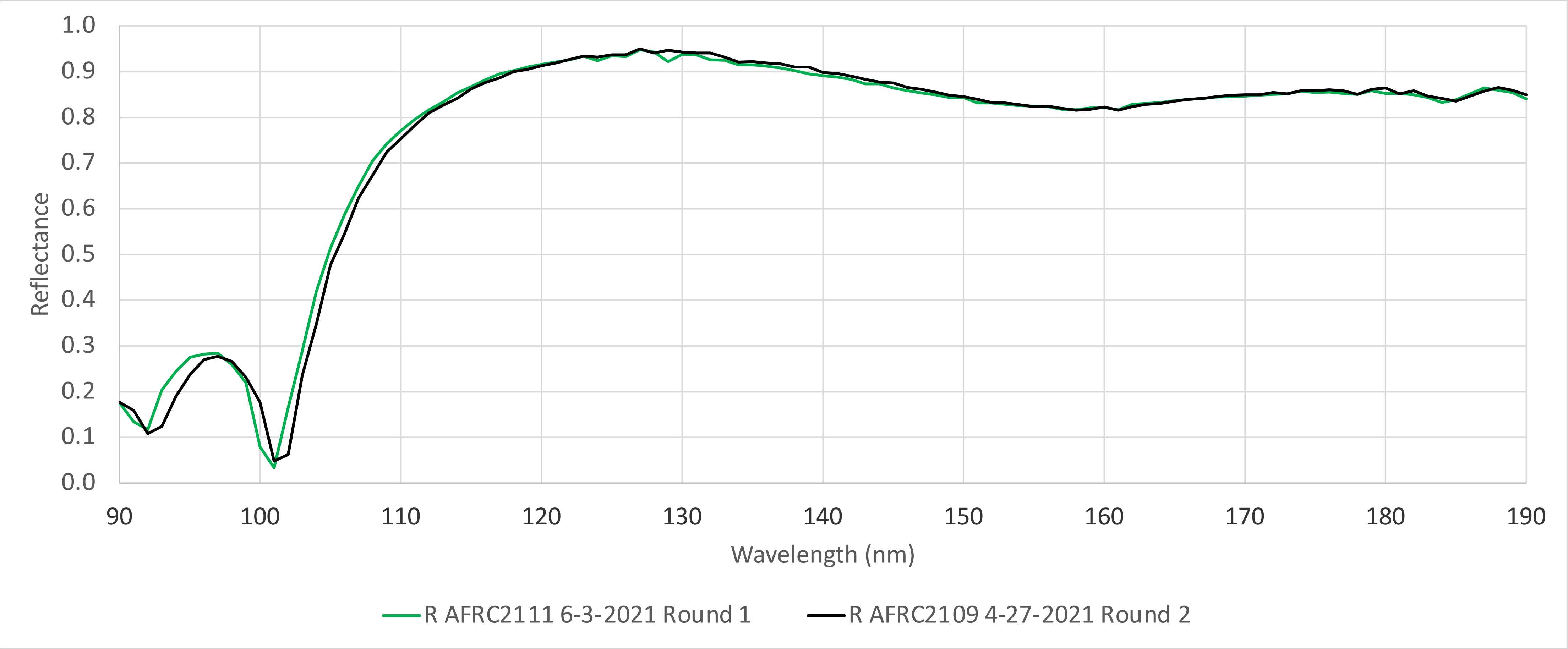
**Chamber is in operation and experimentations on producing various schemes of fluorination are on-going**

# Reactive Physical Vapor Deposition (rPVD)



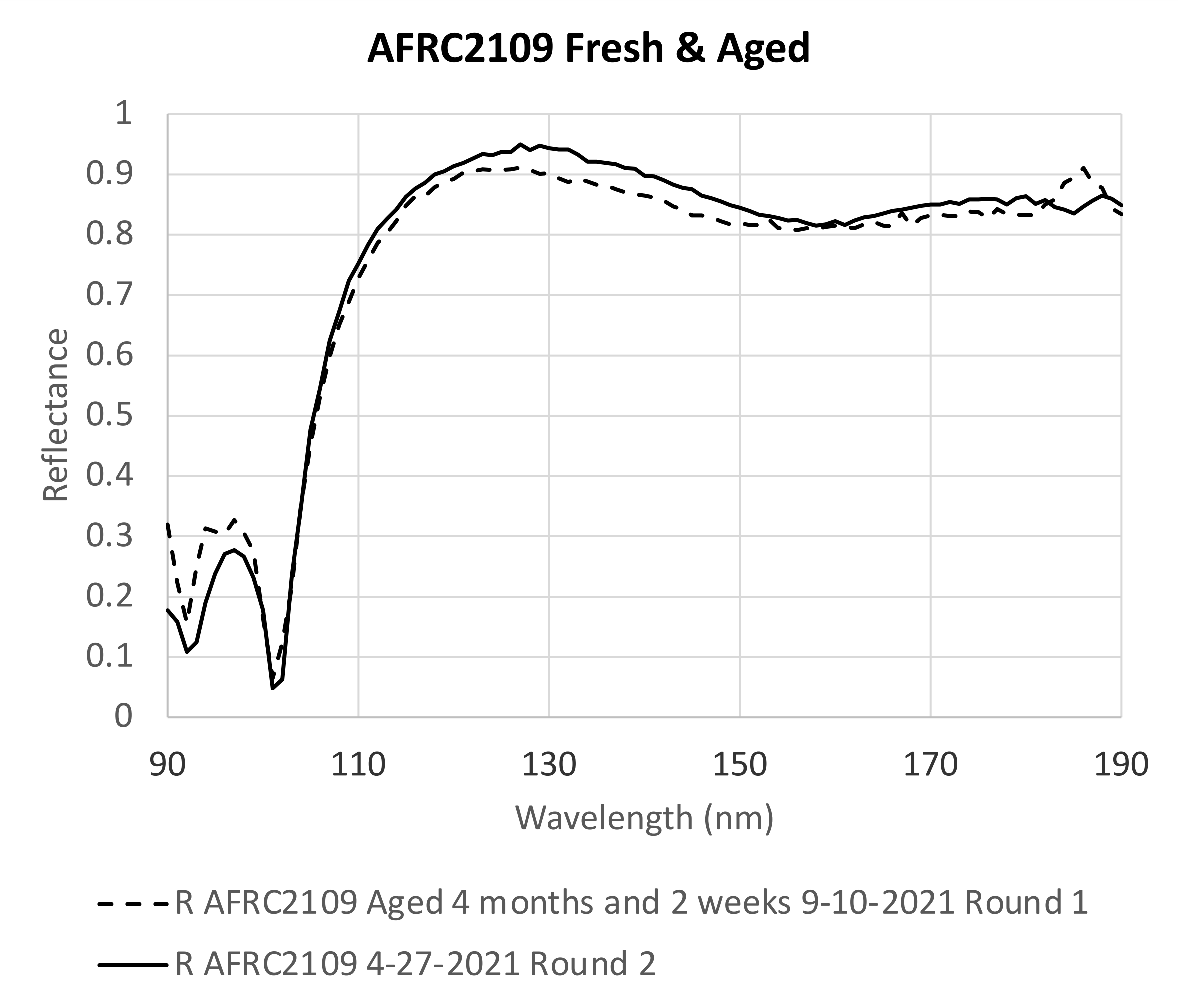
# Reflectance Result rPVD: Al+LiF

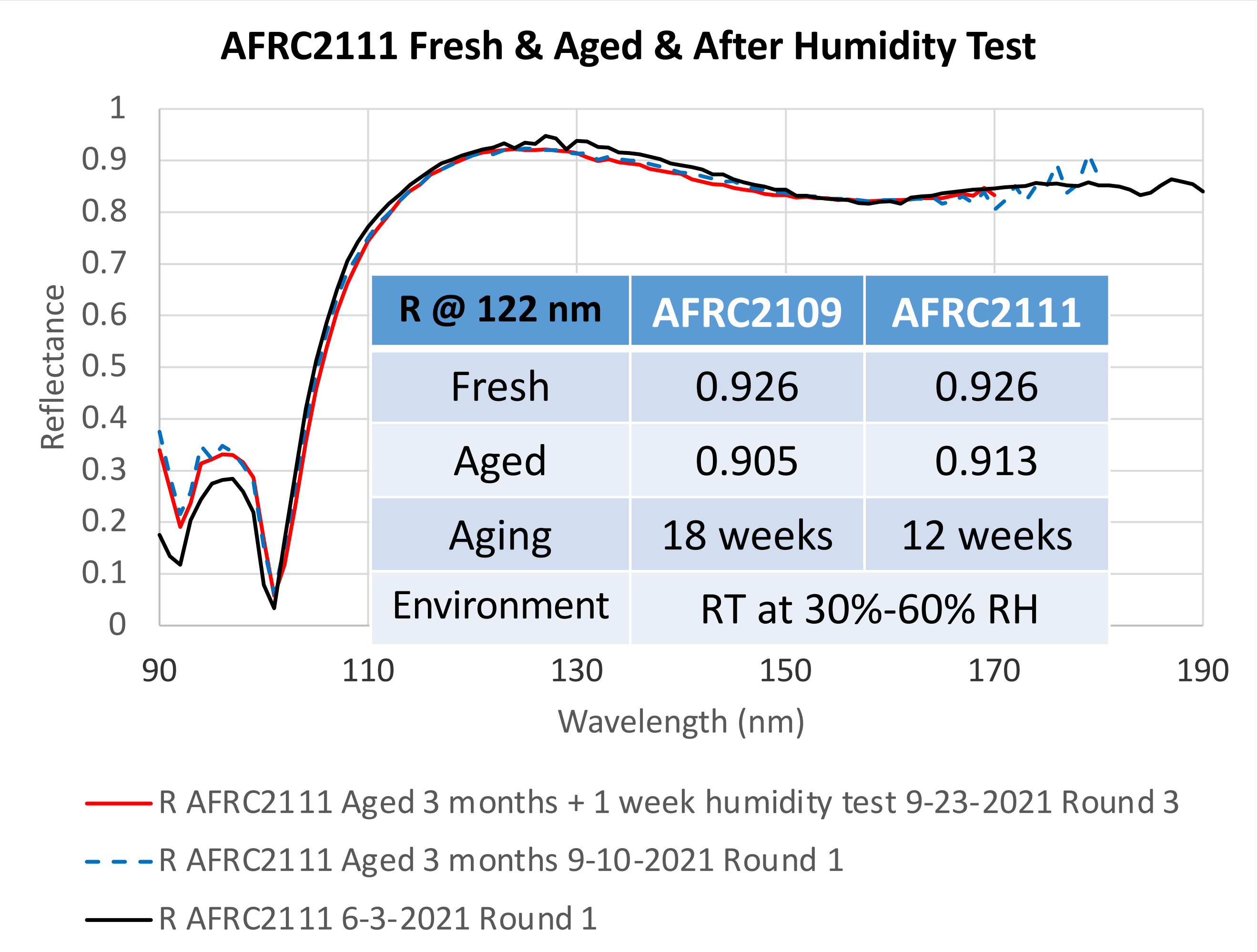
## Highest R at H Lyman-alpha **ever reported** ☺



# Environmental Stability: XeLiF Coatings

- Awesome stability of the mirrors with the highest R at Ly alpha

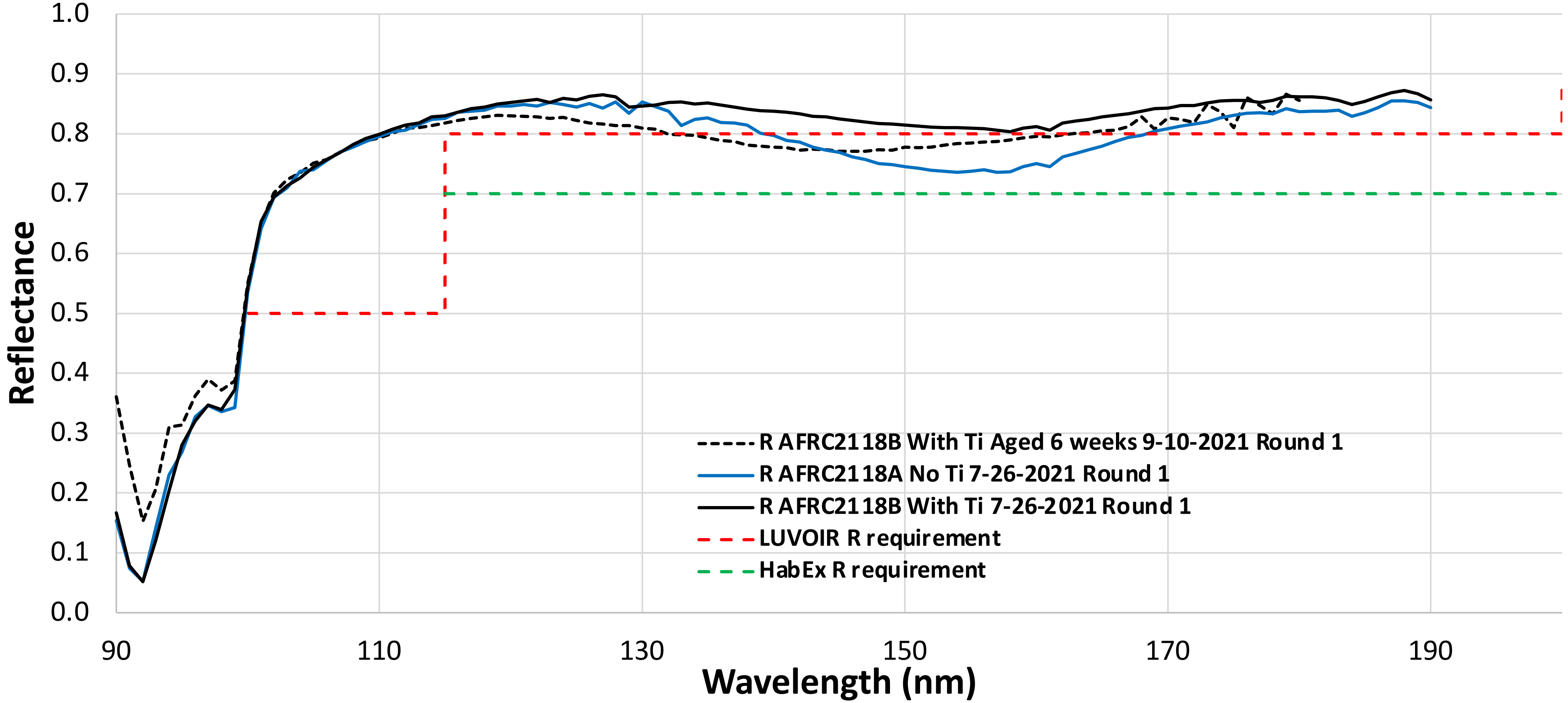


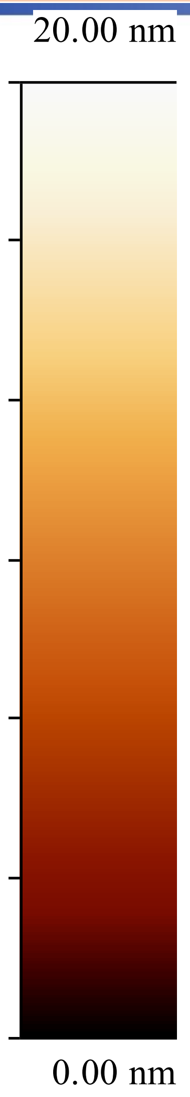

| R @ 122 nm | AFRC2109 | AFRC2111 |
|---|---|---|
| Fresh | 0.926 | 0.926 |
| Aged | 0.905 | 0.913 |
| Aging | 18 weeks | 12 weeks |
| Environment | RT at 30%-60% RH | |

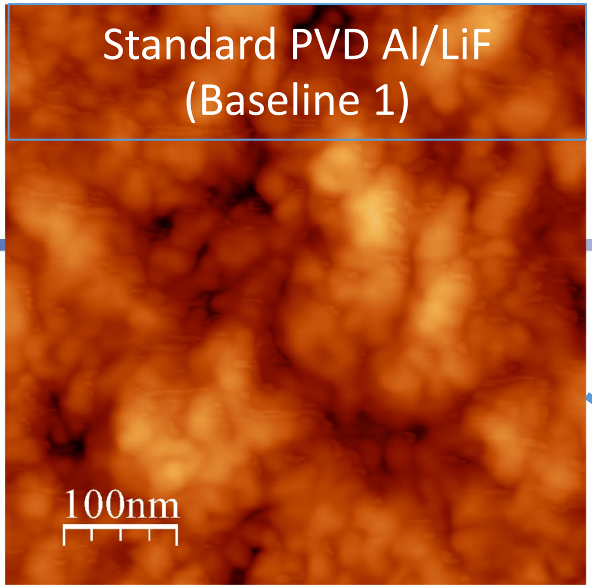
# Reflectance with Ti Seed Layer

- R data of mirrors with and without Ti seed layer meeting HabEx and LUVOIR R requirements

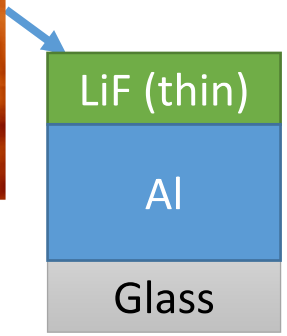


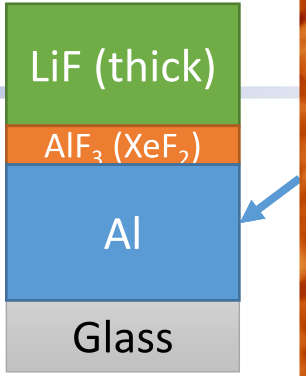
All samples:
Similar z-scale

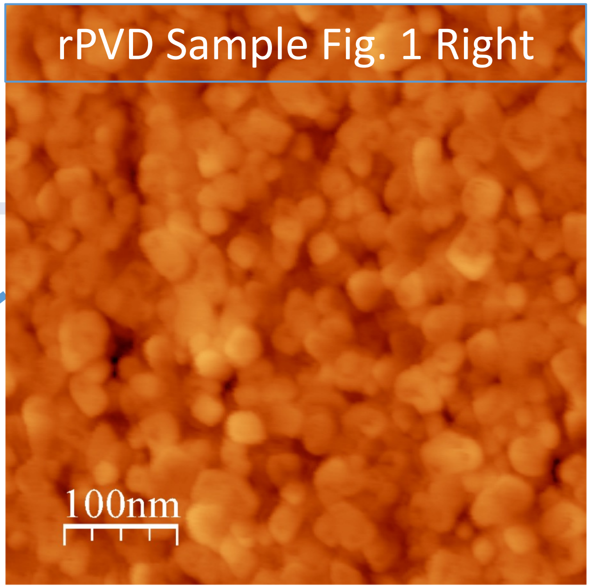


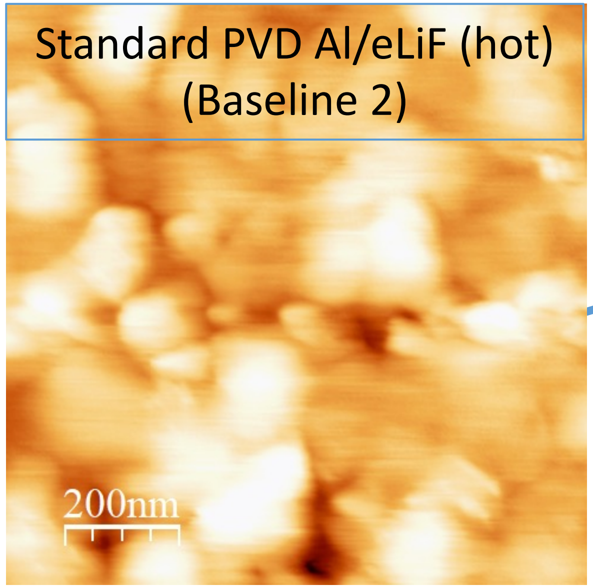

**Standard Al/LiF σ=2.34 nm**
**(ALSC2111)**



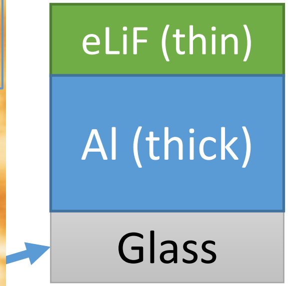



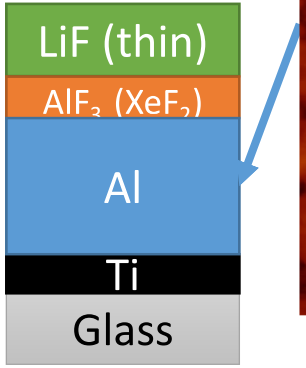



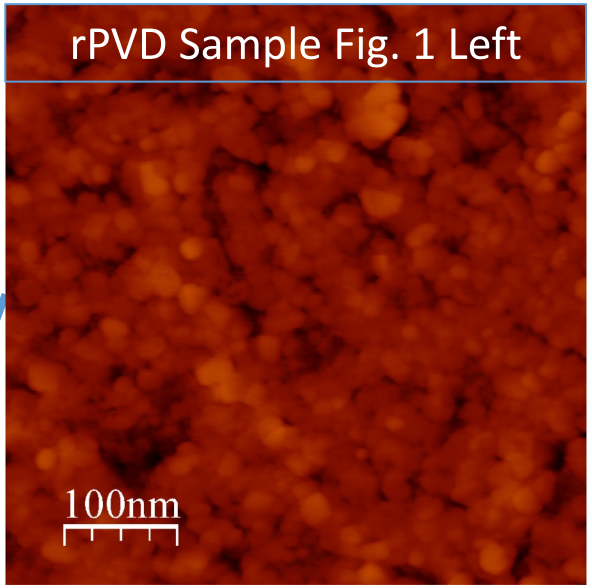

**Sample 09, σ=1.56 nm**
**(AFRC2111)**




**Standard Al/eLiF σ=2.81 nm**
**(ALSC2201 W1)**



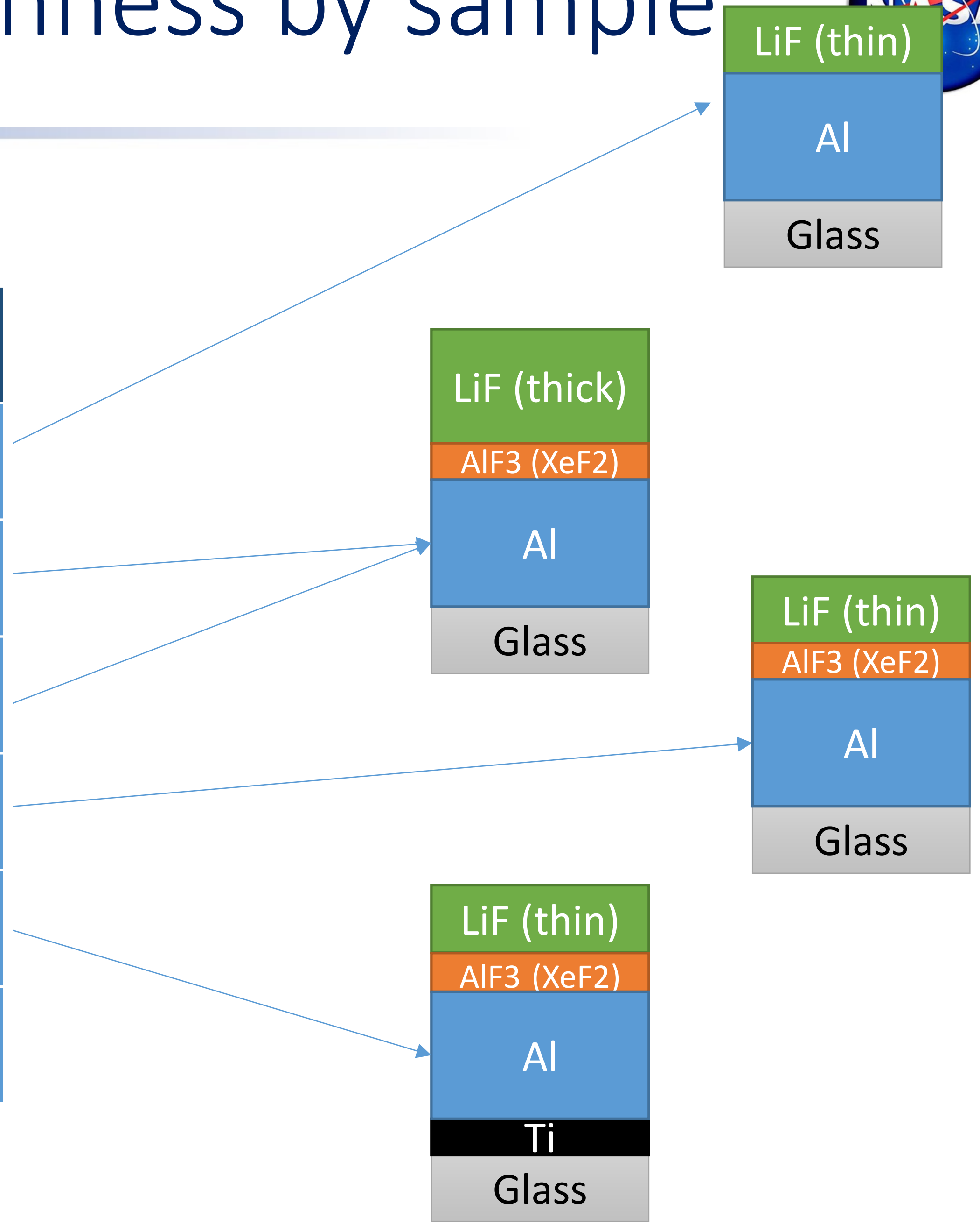




**Sample 18B, σ=1.02 nm**
**(AFRC2118B)**

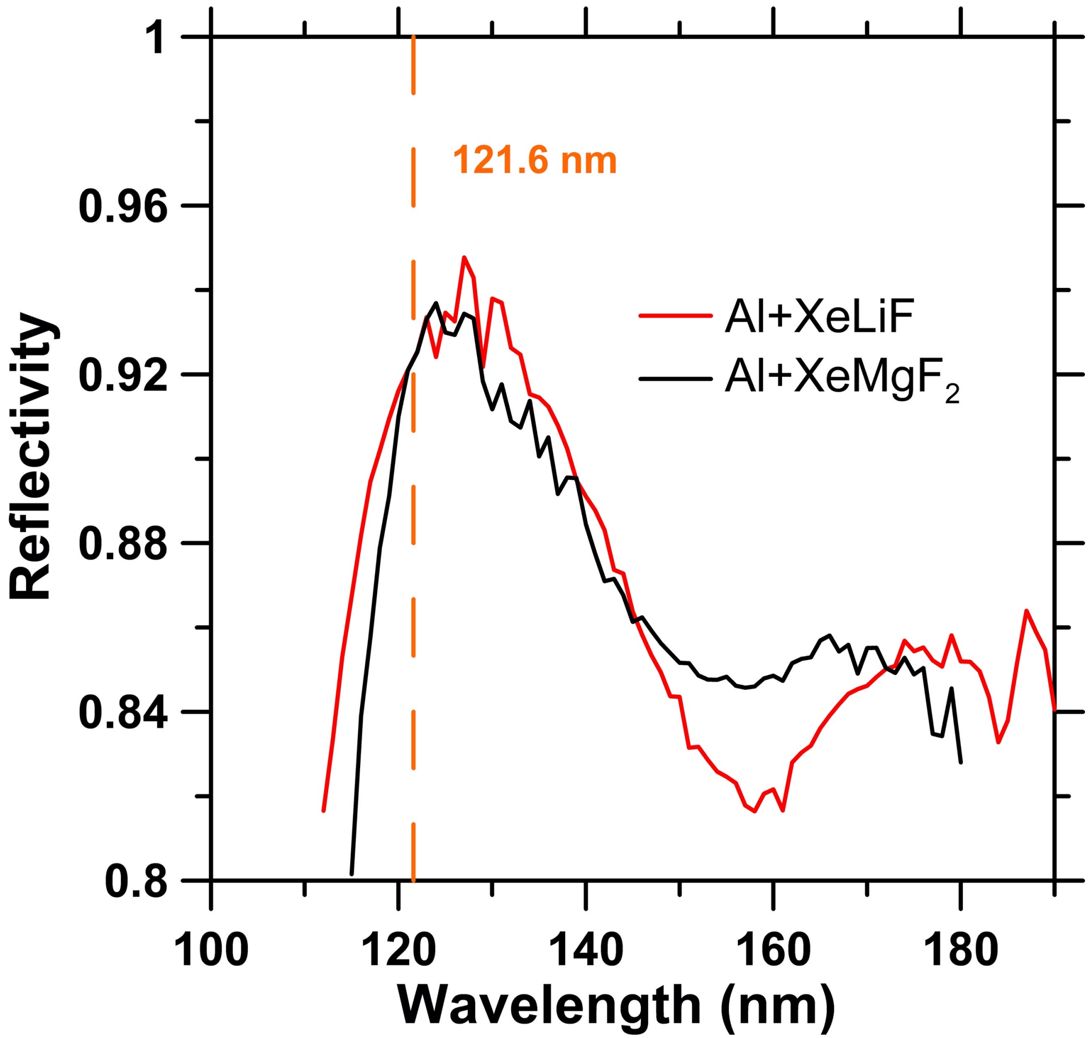
# Summary – Surface roughness by sample

| Sample Name | + info | Rq [nm] (500x500 nm^2) | Rq [nm] (5x5 um^2) |
|---|---|---|---|
| ALSC2111 | Standard Al/LiF (baseline) | 2.13 | 2.24 |
| AFRC2109 | Optimized @ 122 nm w/o Ti | 1.49 | 1.47 |
| AFRC2111 | Optimized @ 122 nm w/o Ti | 1.80 | 1.53 |
| AFRC2118A | Optimized @ 103 nm w/o Ti | 2.98 | 3.01 |
| AFRC2118B | Optimized @ 103 nm w/ Ti | 1.00 | 1.03 |
| ALSC2126 | Optimized @ 103, Hot | 1.34 | 12.48 |

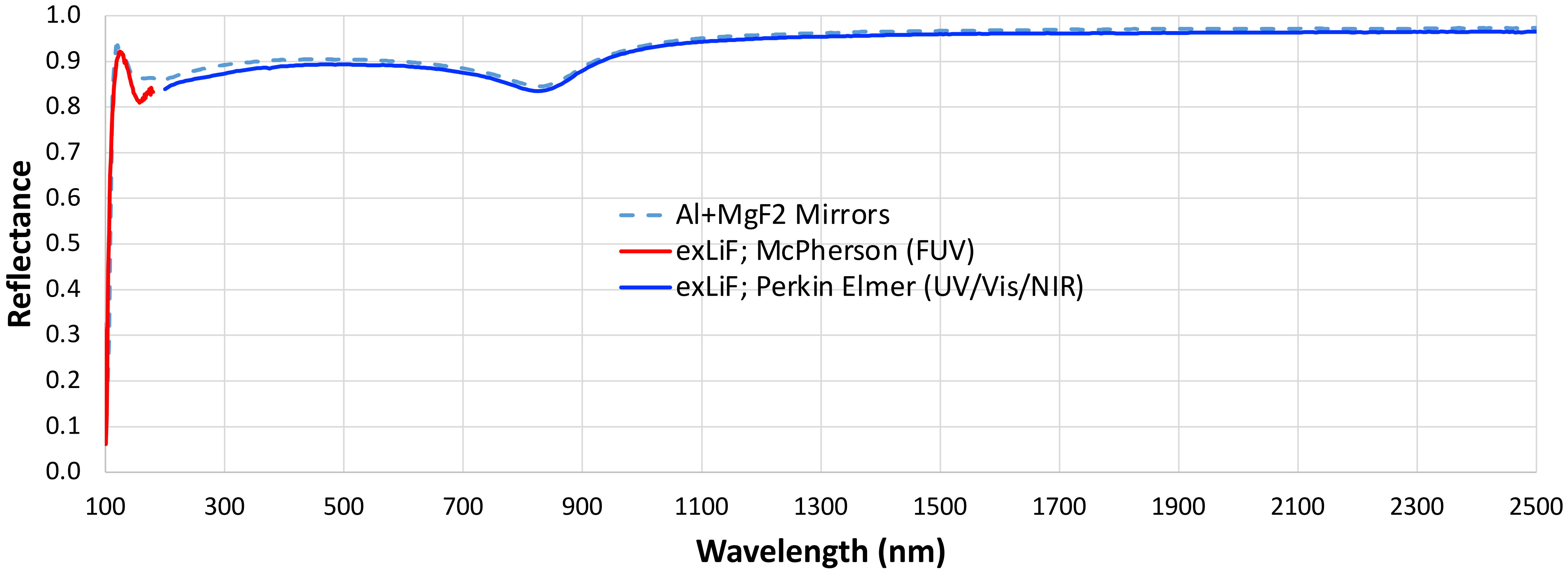
Accidentally sprayed with water



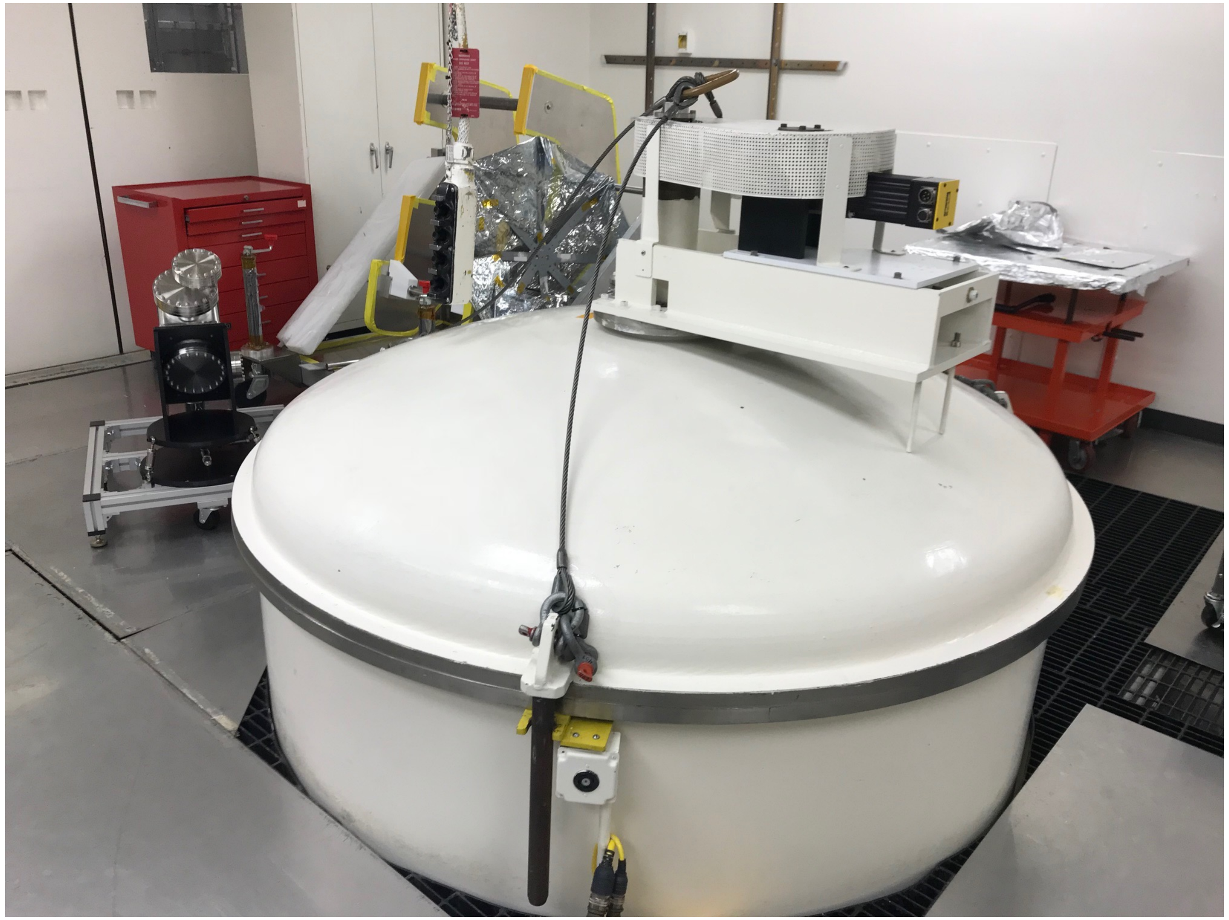
# FUV Reflectance Al+$XeMgF_2$



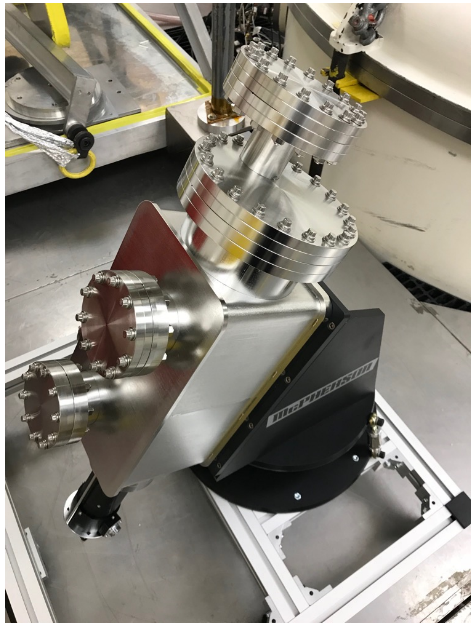
# Broadband Reflectance



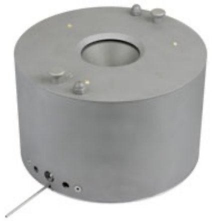
# Future Plans: 2-Meter Chamber Upgrades



Deposition of a ion-assisted physical vapor deposition (IAPVD) of FUV-optimized Al+metal fluoride overcoats (LiF, MgF2, and Al+$AlF_3$) in the large 2-meter coating chamber.



Lyman-Alpha Optical Monitor



Acquisition of Ion Gun, optical monitor, deposition controller and PVD power supplies upgraded.

# Conclusions

- A fluorination with $XeF_2$ combined with PVD  of Al+LiF coatings (rPVD) further improves durability of Al+LiF mirror coatings.
- These rPVD Al+LiF (**XeLiF**) samples have shown:
  - ✓ The highest ever reported reflectance for Al+LiF at Lyman-Alpha  of 92%
  - ✓ Sample reflectance (@ Lyman-Alpha) only degraded  91% after 6 months of storage in the lab and going through 50% (1 week) and 60% (1 week) relative humidity tests.
  - ✓ AFM surface characterization indicates a 25% reduction in surface roughness for these samples when compared to conventional Al+LiF samples.
- ✓ This more stable (**Al+XeLiF**) mirror coating could be a viable option to the current baseline for LUVOIR ($Al+LiF+MgF_2$)

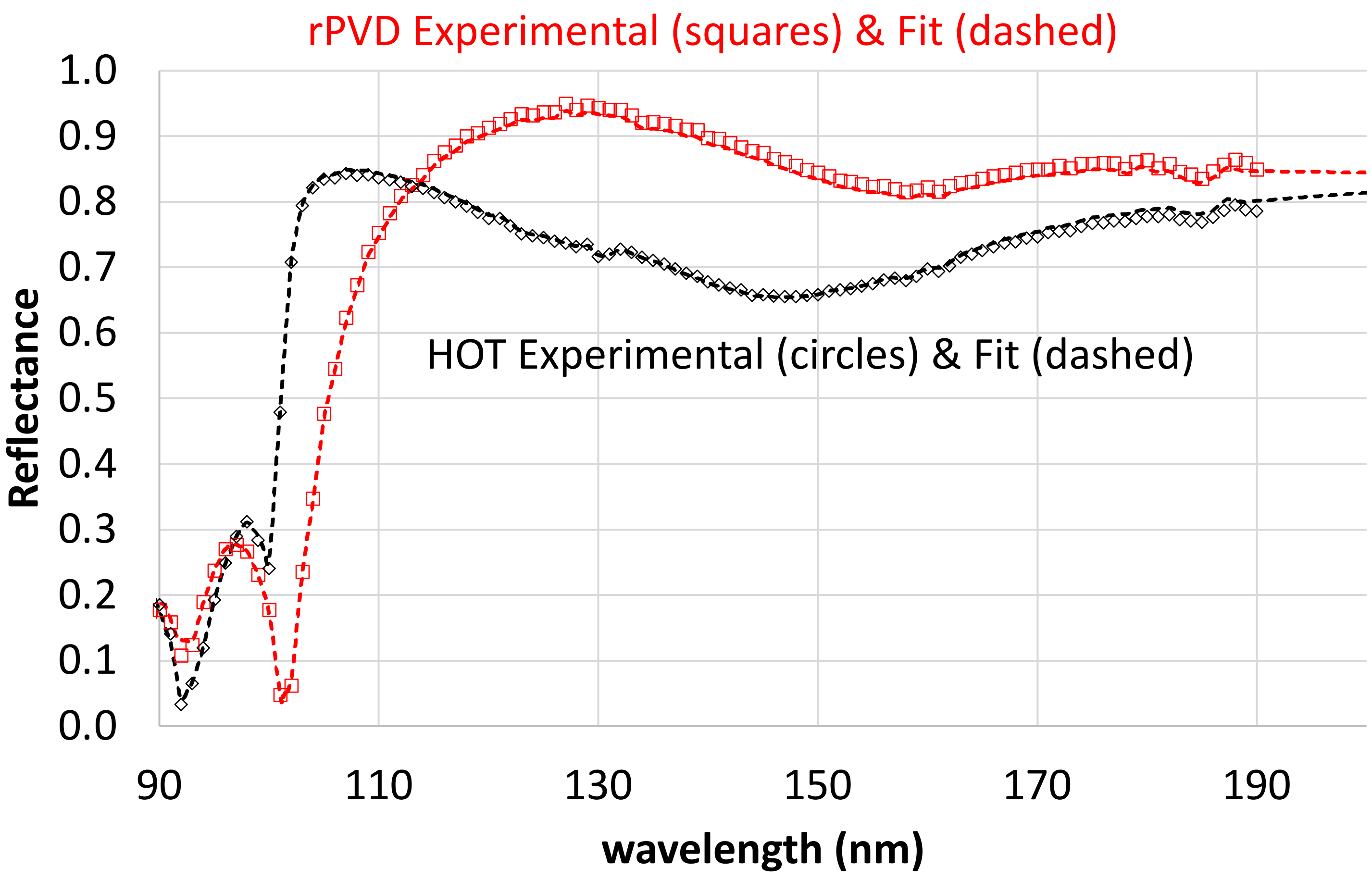
| Technology Component | Implementation Options | State of the Art | Capability Needed | FY19 TRL | In LUVOIR Baseline? |
|---|---|---|---|---|---|
| Far-UV Broadband Coating | Al + eLiF + $MgF_2$ | Meets performance requirements, but requires demonstration on meter-class optics; requires validation of uniformity, repeatability, environmental stability | >50% reflectivity (100-115nm)<br>>80% reflectivity (115-200nm)<br>>88% reflectivity (200-850nm)<br>>96% refelctivity (> 850nm)<br><br><1% reflectance nonuniformity (over entire primary mirror) over corongraph bandpass (200 - 2000 nm) | 3 | ✓ |
| | Al + eLiF + $AlF_3$ | | | 3 | |
| | Al + eLiF | Meets performance requirements, but is environmentally unstable | | 5 | |

# Funding


- *NASA Astrophysics Research Analysis  grant # 20-APRA20-0093*
- *NASA Strategic Astrophysics Technology grant # 21-SAT21-0027*
- *GSFC FY21 & FY22  Internal Research & Development (IRAD) Program*

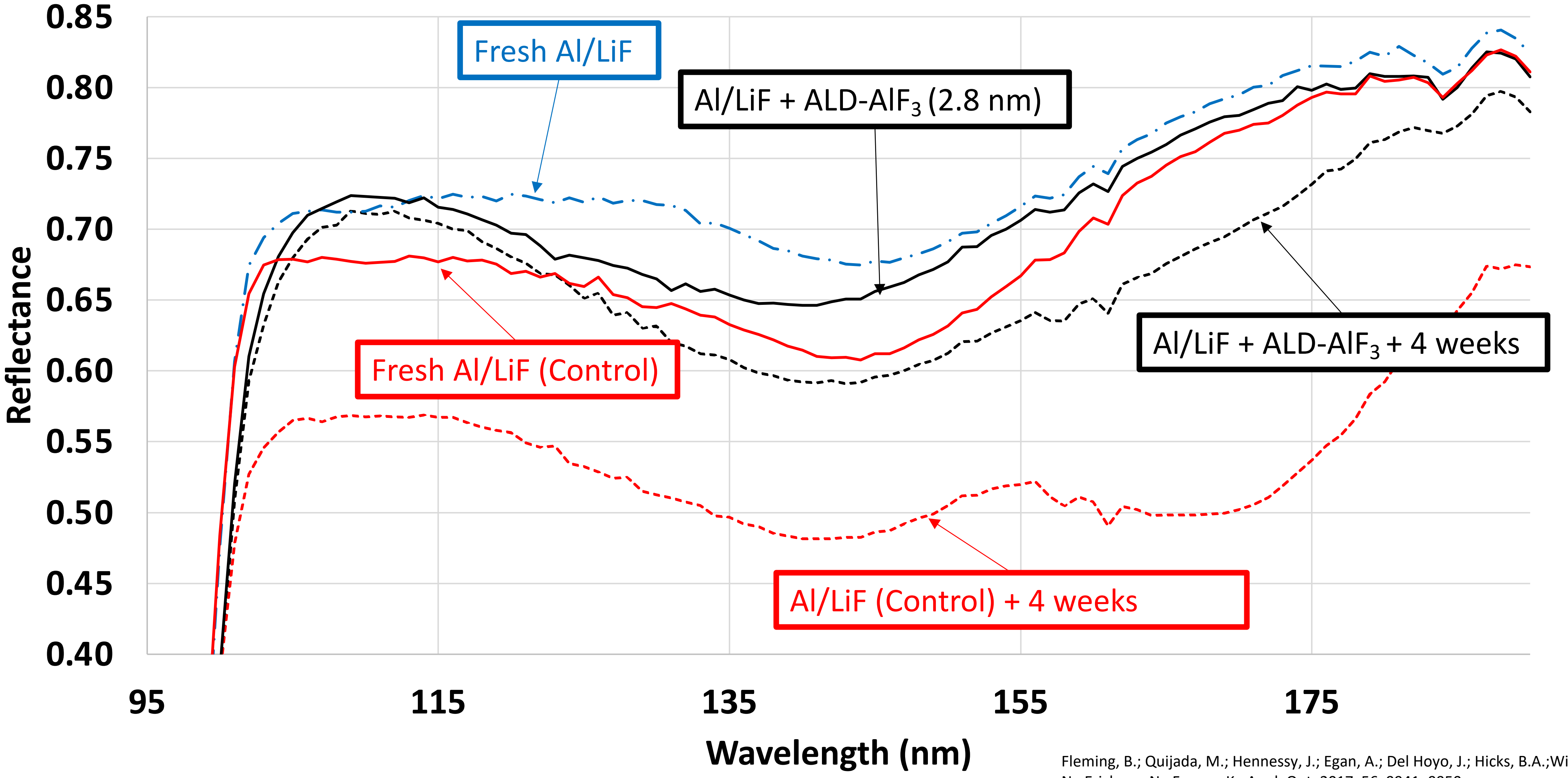
# Backup Slides

# ‘Hot’ *vs.* ‘rPVD’




| Sample | Composition | Thickness | Fabrication Temp. |
|---|---|---|---|
| rPVD | LiF | 22.9 nm | Ambient |
| | Al+XeF2 → AlF3 | 2 nm | |
| | Al | 65 nm | |
| Hot | LiF | 17.5 nm | 266 C for 1h |
| | Al | 100 nm | |

# Protection Al+LiF with ALD-$AlF_3$ Deposition




Fleming, B.; Quijada, M.; Hennessy, J.; Egan, A.; Del Hoyo, J.; Hicks, B.A.;Wiley, J.; Kruczek, N.; Erickson, N.; France, K.; Appl. Opt. 2017, 56, 9941–9950.

# Aging of rPVD and Protected Al+LiF+$MgF_2$ Samples