Advances in developing mirror coating technologies for enhancing the FUV reflectance of protected aluminum coatings

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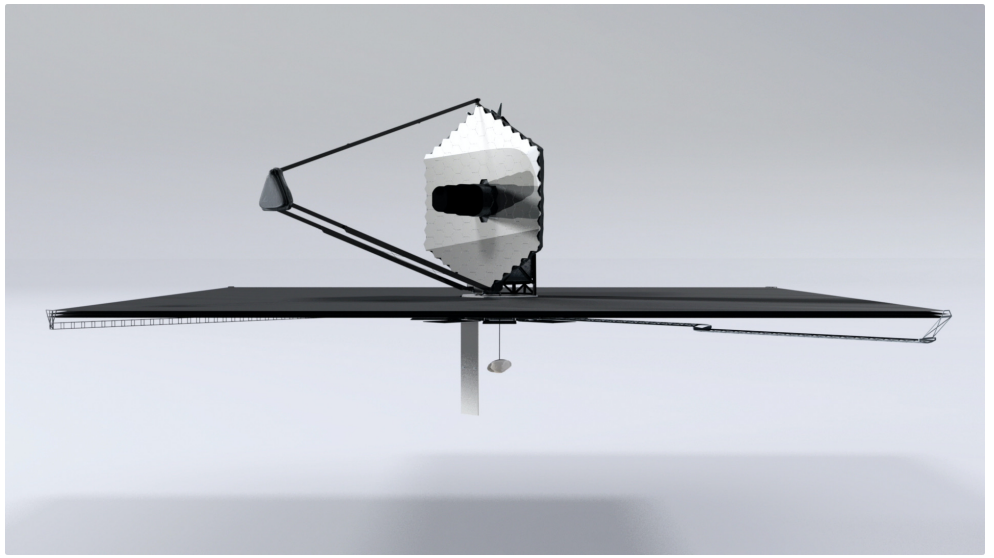
Outline

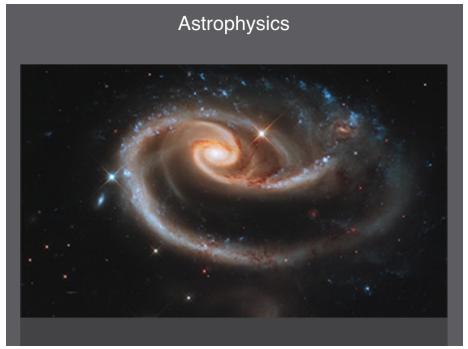
- Overview & Objectives
- Program Element Update
  - ✓ Research Chamber Fluorination
- Conclusions
- Acknowledgments

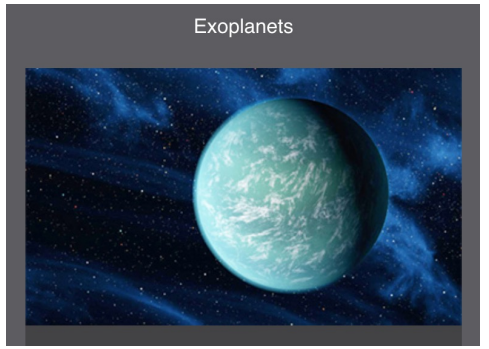
Overview and Objectives

- **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).

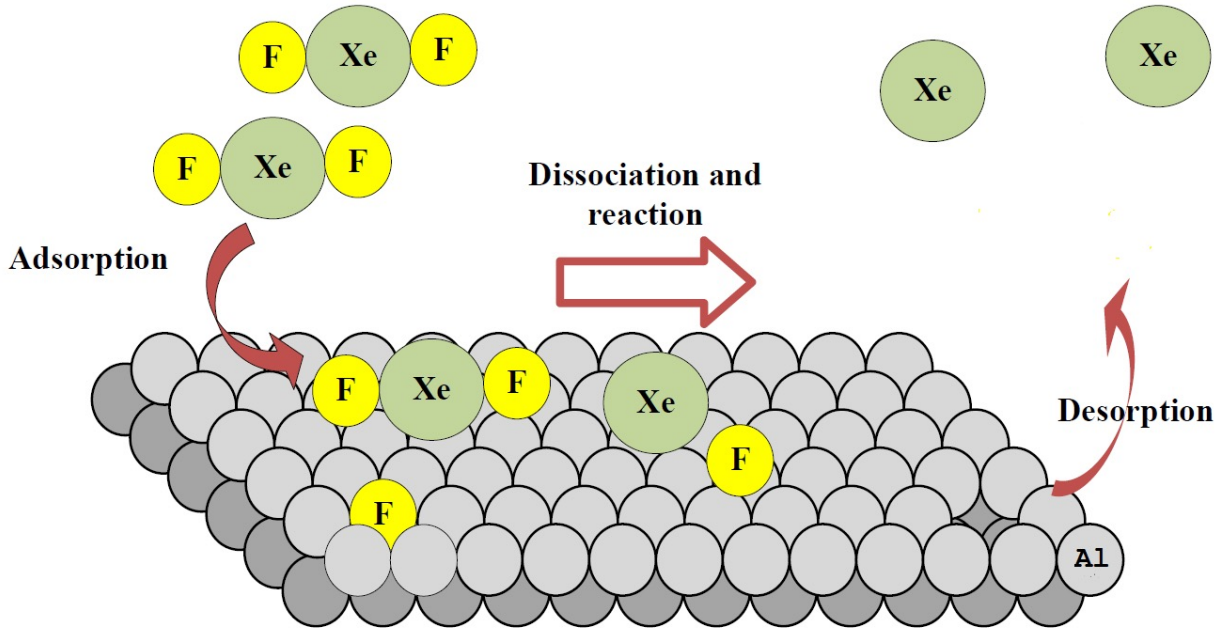
LUVOIR Concept Telescope







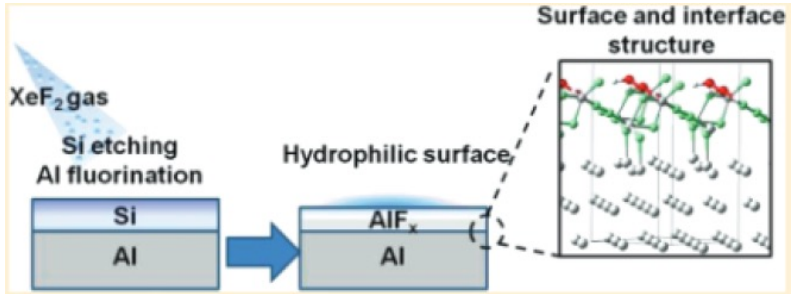
Hybrid PVD Passivation/Fluorination Chamber



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

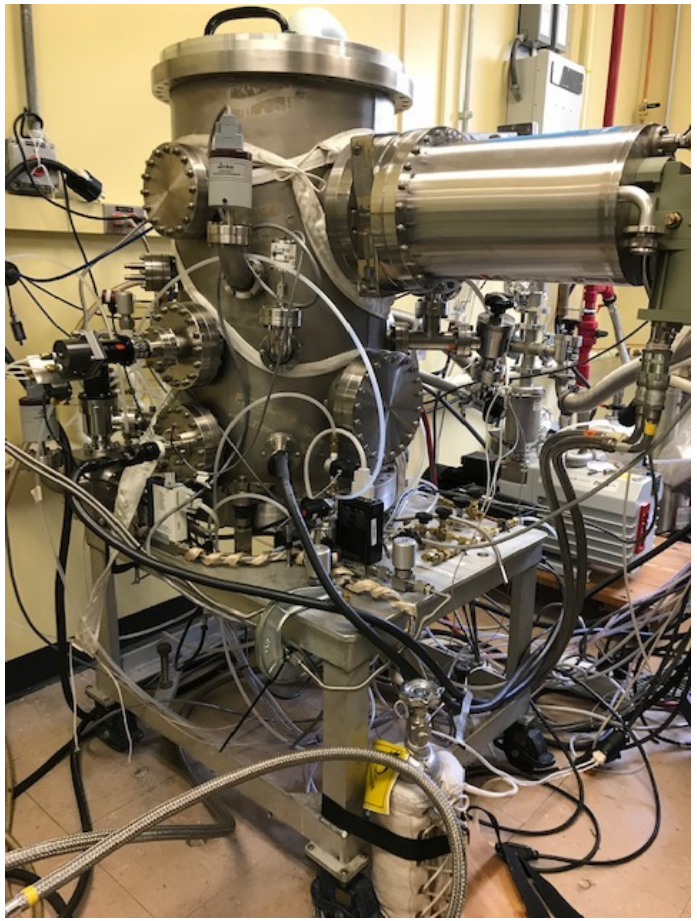
Heating of the XeF_2 may also be used if compound is not sufficiently reactive for increased selectivity.

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

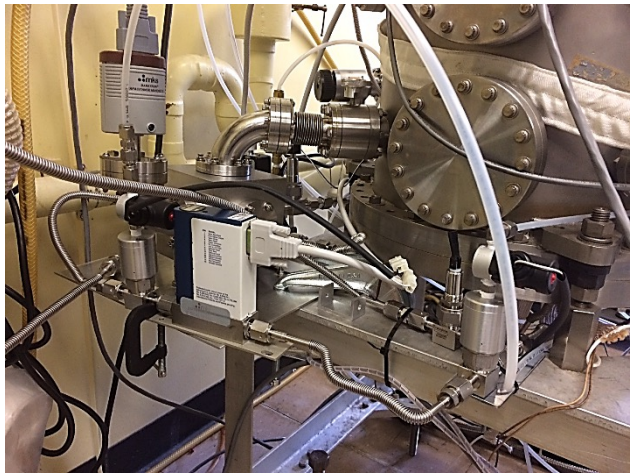


Roodenko *et.al.* J. Phys. Chem. C Vol. **115**, 21351, 2011

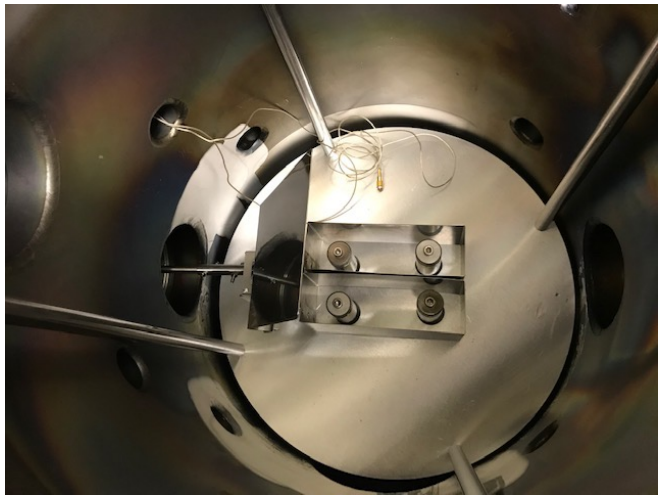
Research Coating Chamber Upgrades



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.

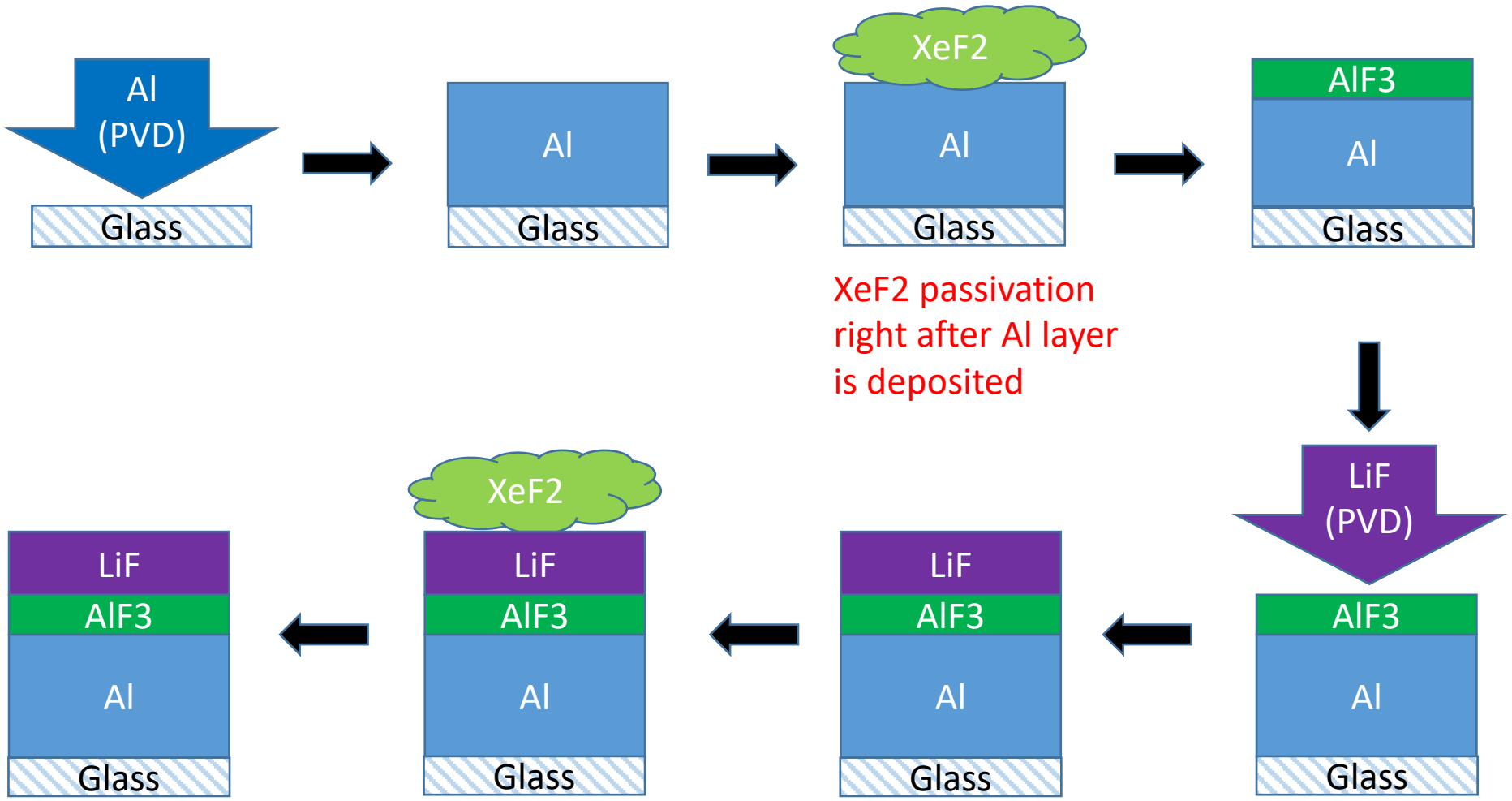


Inside view of RC with 2-materia PVD deposition system.

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

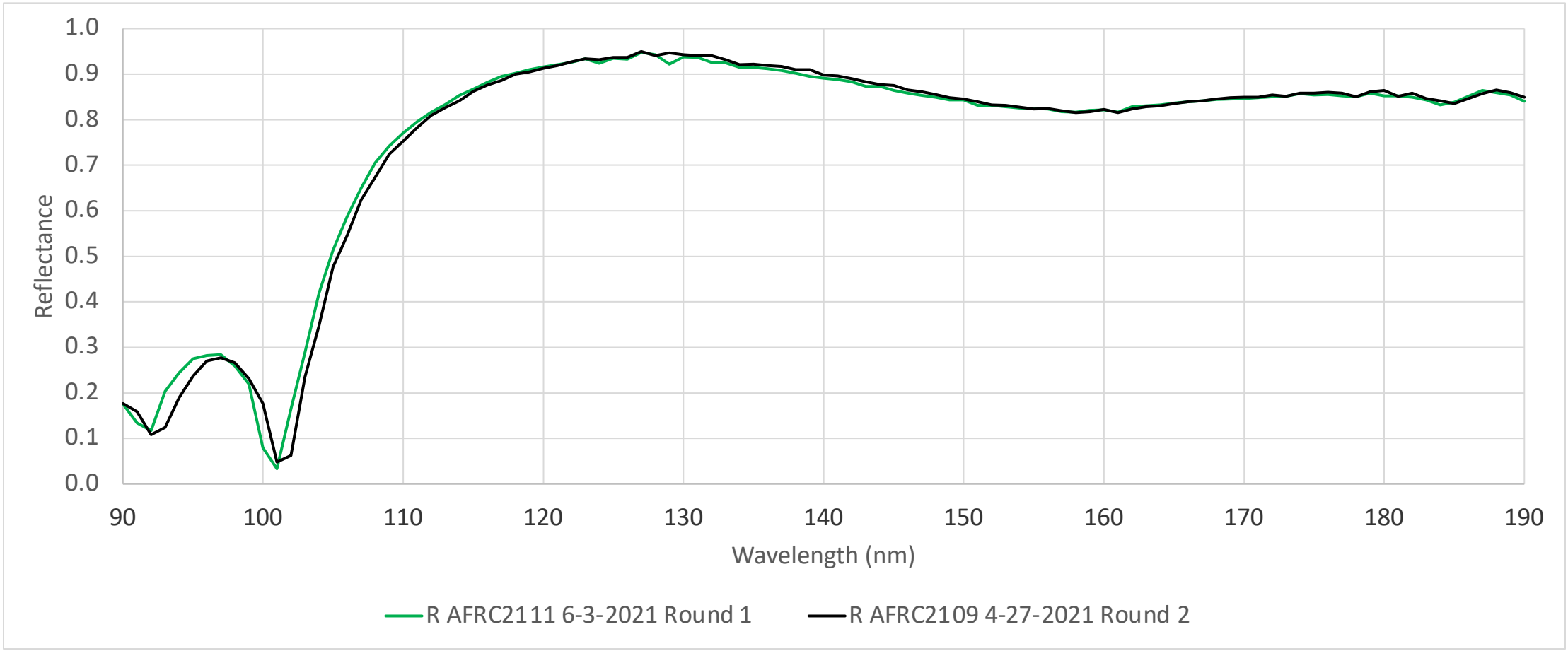
Chamber is in operation and experimentations on producing various schemes of fluorination are on-going

Reactive Physical Vapor Deposition (rPVD)



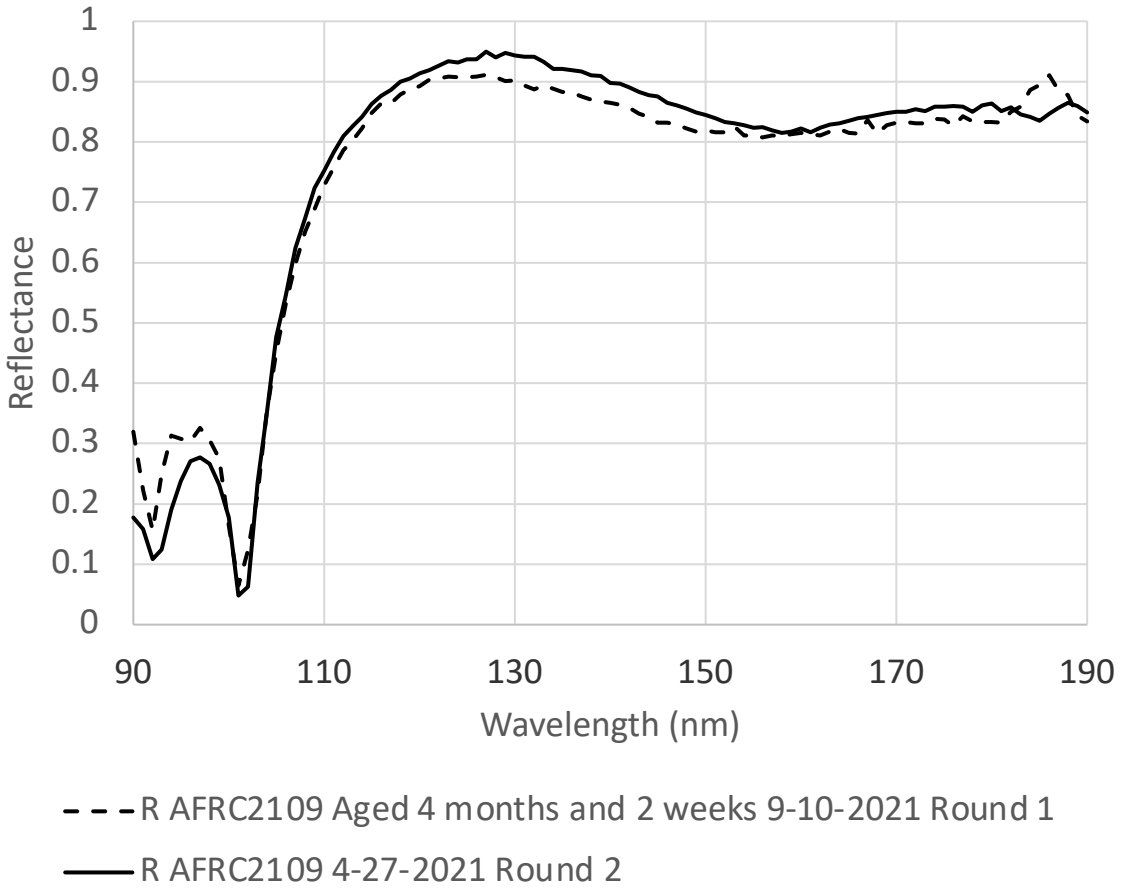
Reflectance Result rPVD: Al+LiF

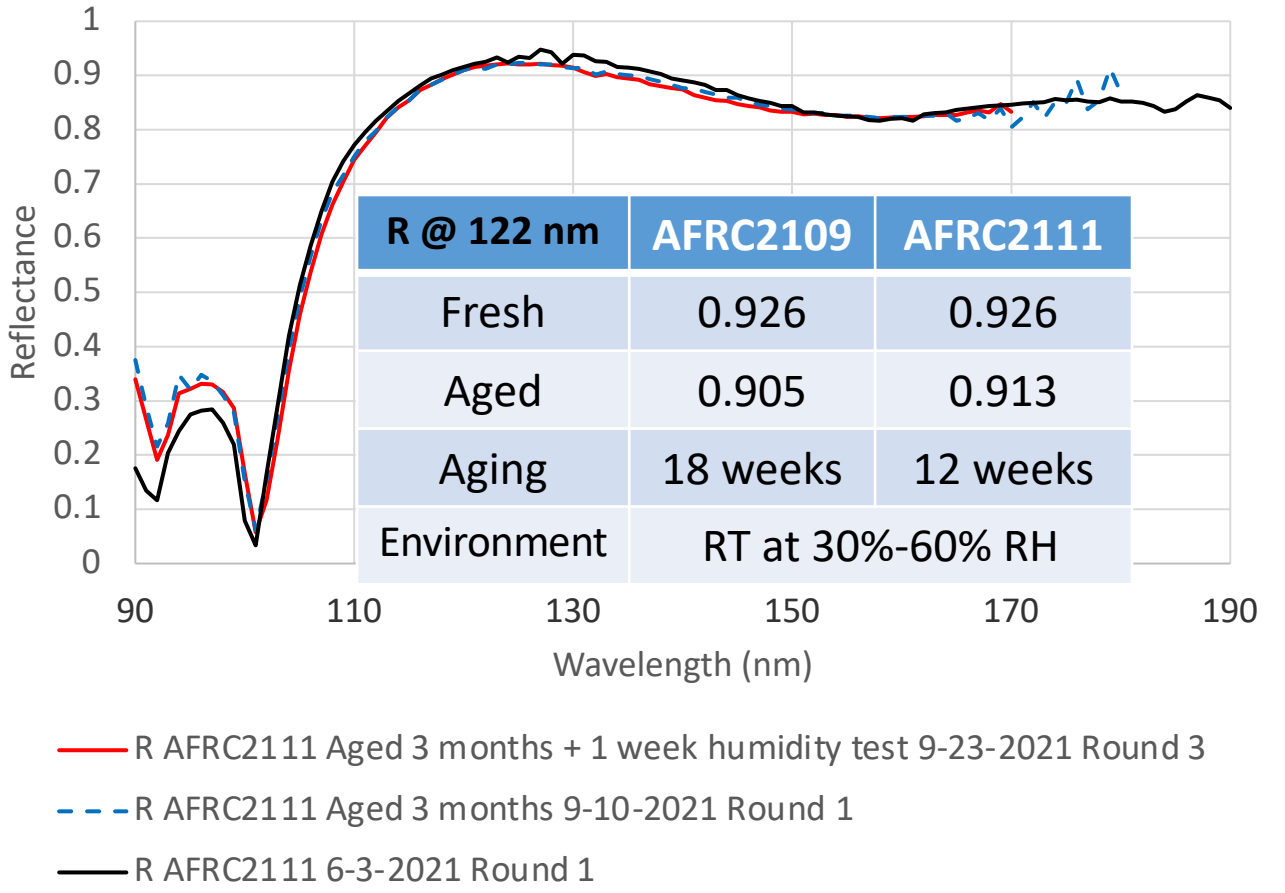
Highest R at H Lyman-alpha **ever reported** ☺, obtained twice ☺



Environmental Stability: Al+LiF Coatings

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

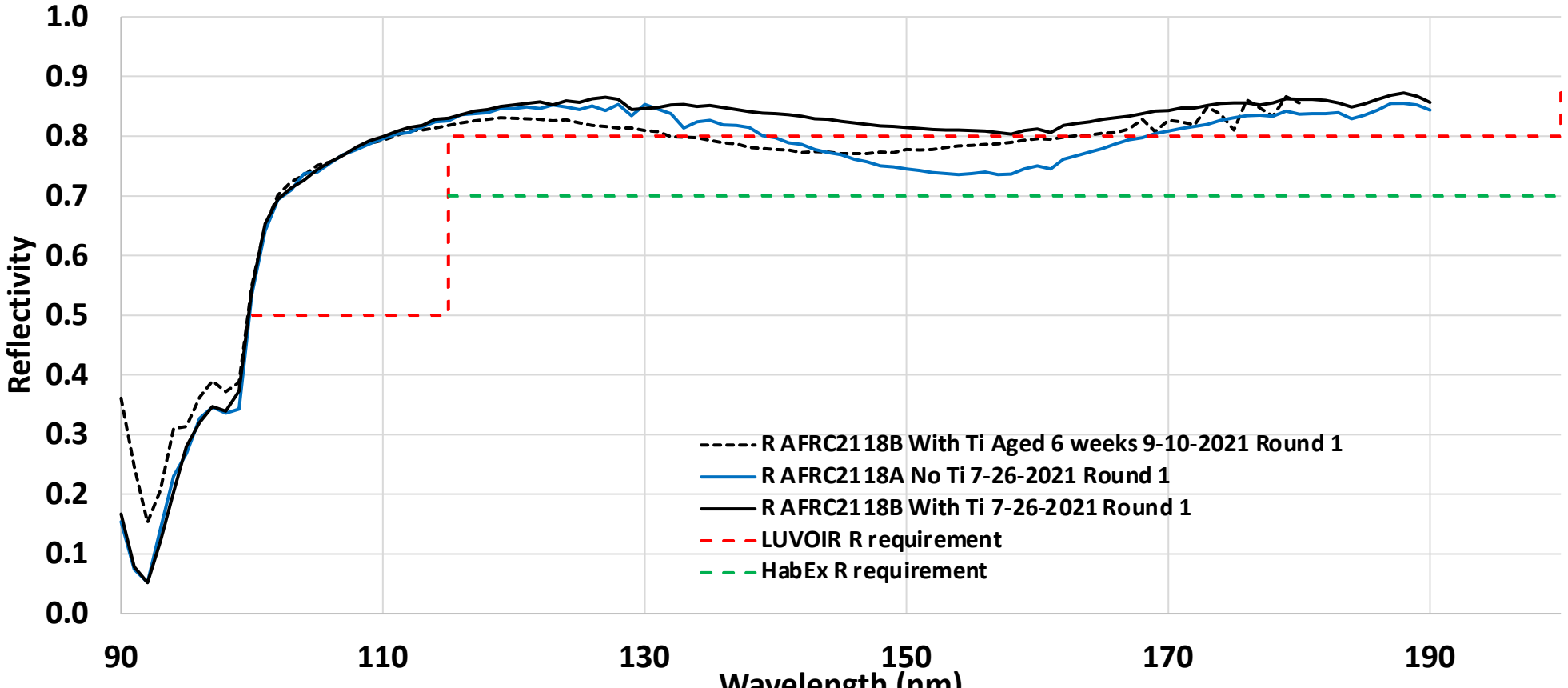




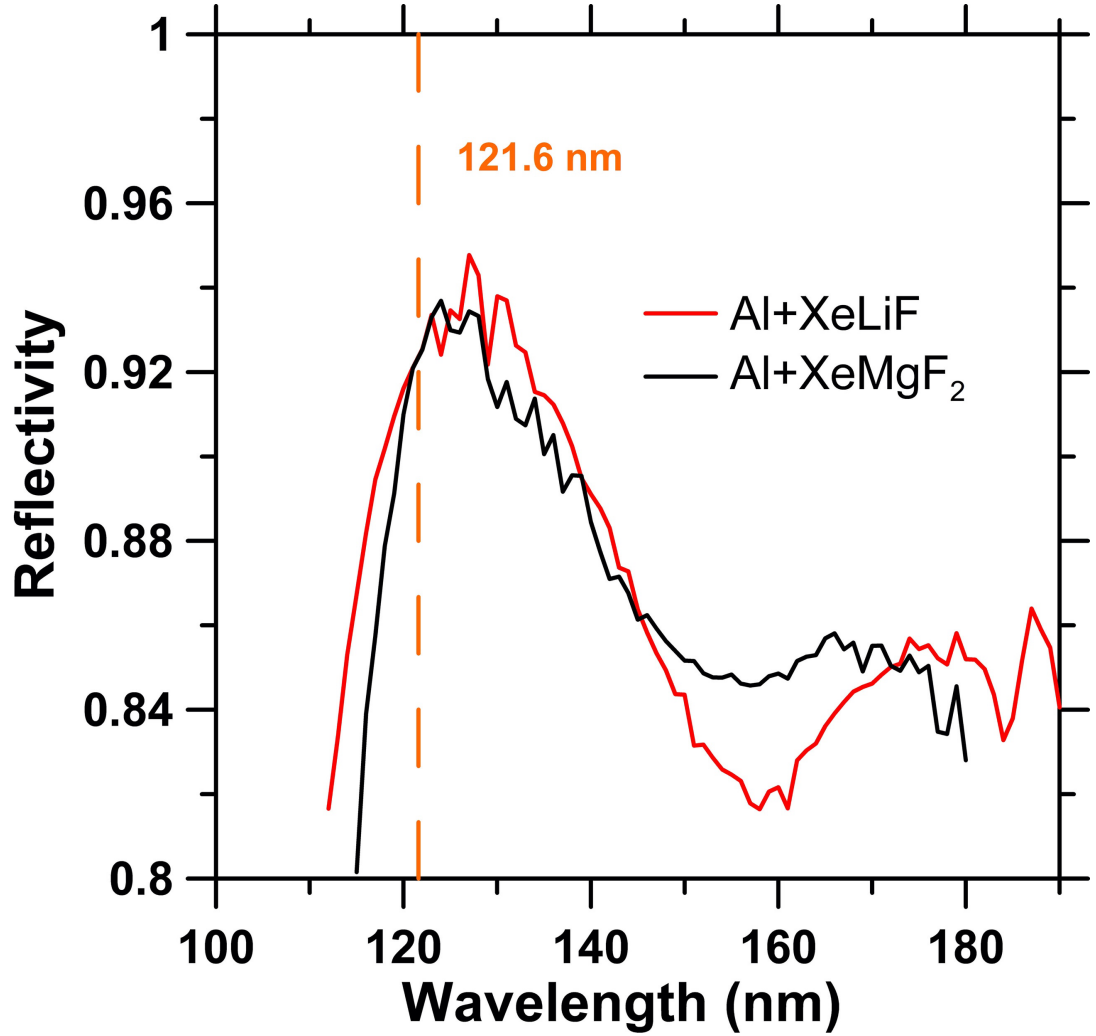
R @ 122 nm	AFRC2109	AFRC2111
Fresh	0.926	0.926
Aged	0.905	0.913
Aging	18 weeks	12 weeks
Environment	RT at 30%-60% RH	

Reflectance with Ti Seed Layer

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



FUV Reflectance Al+XeMgF$_2$



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) >80% reflectivity (115-200nm) >88% reflectivity (200-850nm) >96% refelctivity (> 850nm) <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

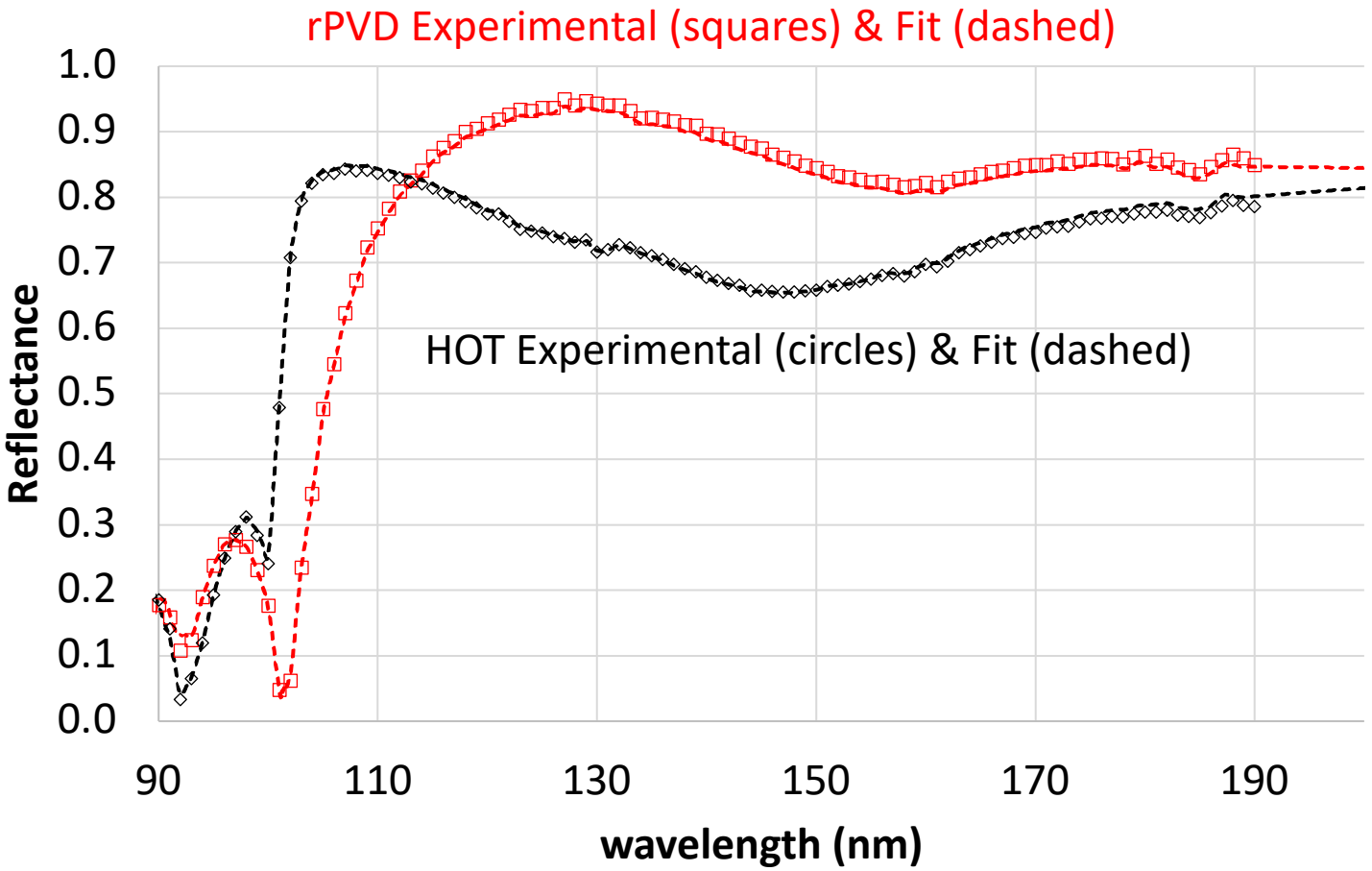
- *NASA Astrophysics Research Analysis grant # 15-APRA15-0103*
- *NASA Strategic Astrophysics Technology grant # 17-SAT17-0017*
- *GSFC FY21 & FY22 Internal Research & Development (IRAD) Program*

Backup Slides

Degradation of Al+LiF Mirrors Over Time

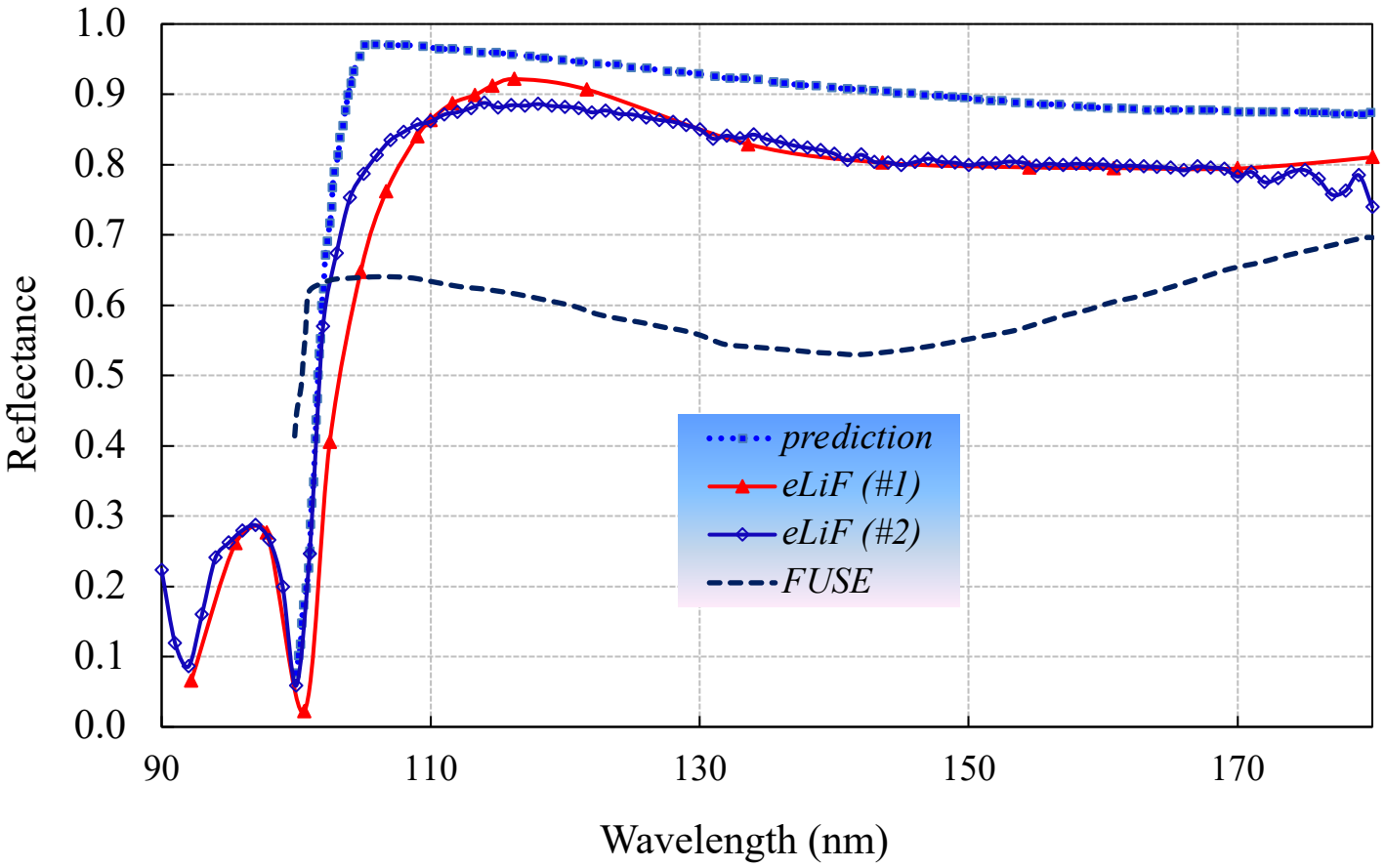
Storage in dry box
(Humidity ≈ 35%)

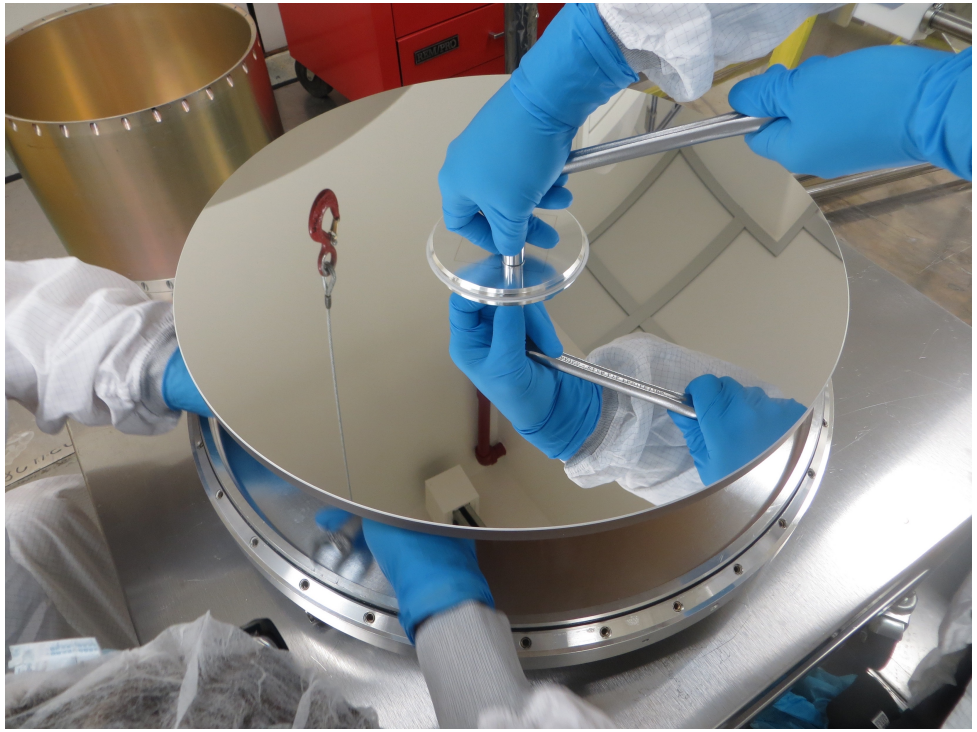
‘Hot’ *vs.* ‘rPVD’



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	

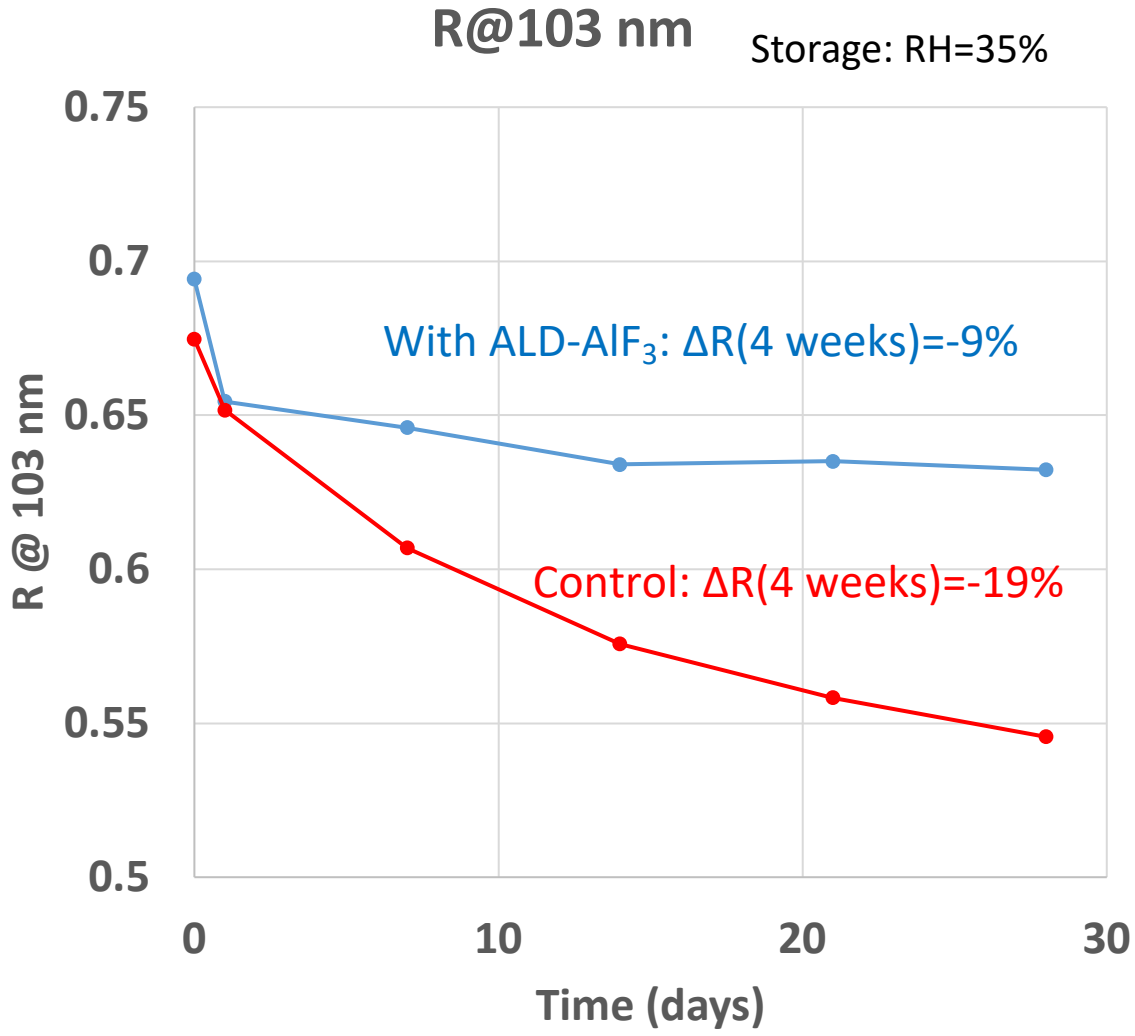
Optimization Al+LiF (eLiF) Hot Coatings

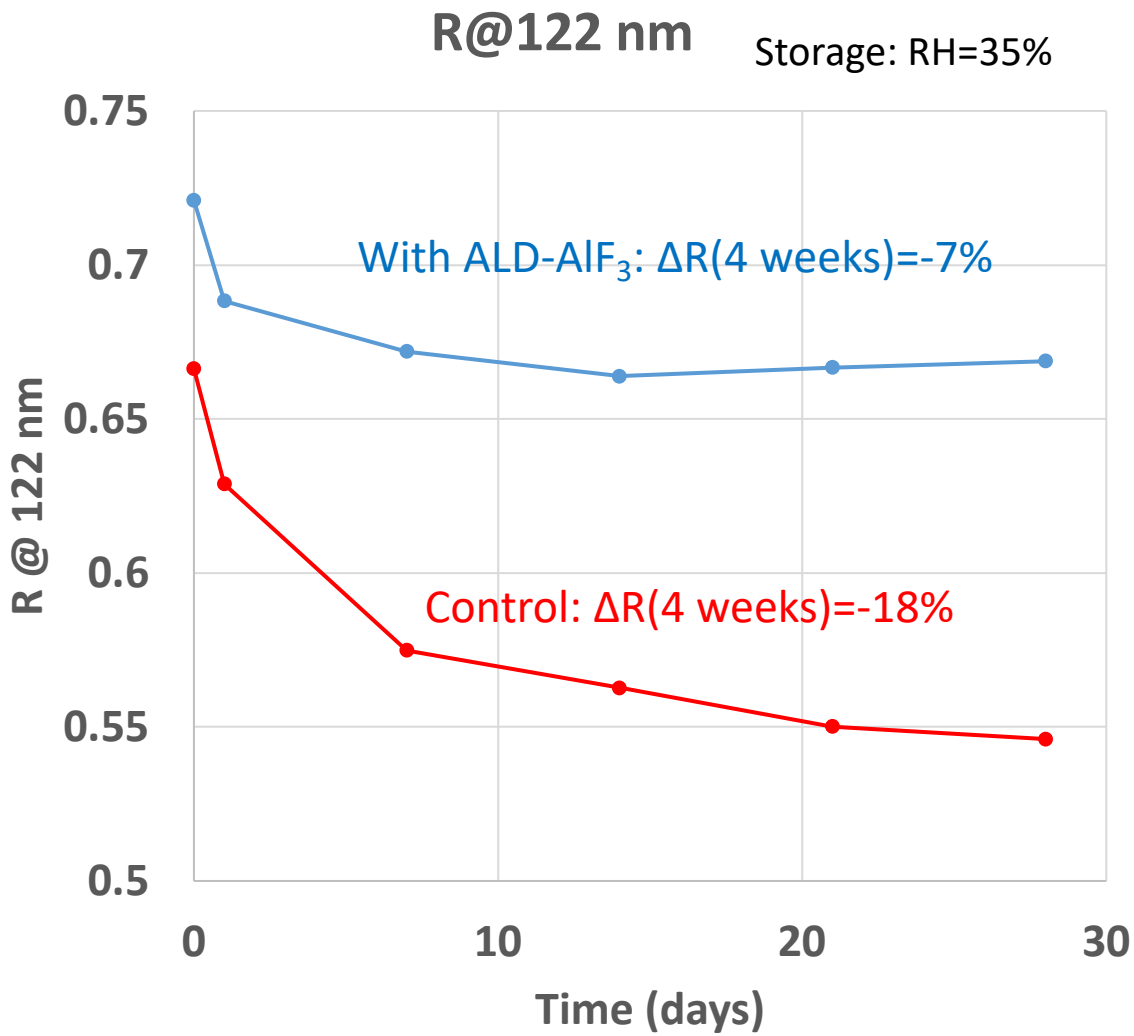




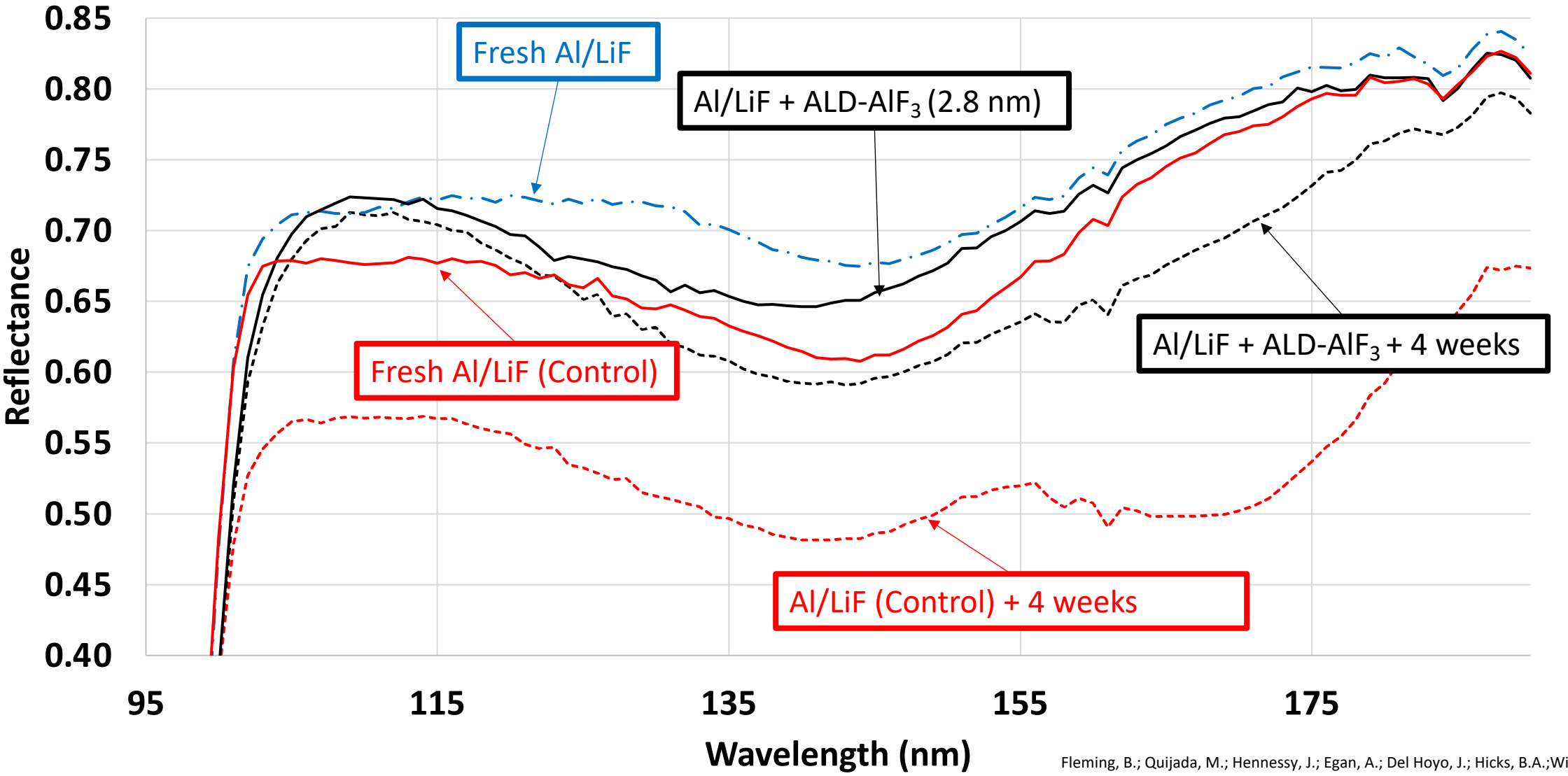
The SISTINE primary mirror after coating with Al+LiF in 2-meter chamber at GSFC.

Stability of AlF_3- protected Al/LiF mirrors



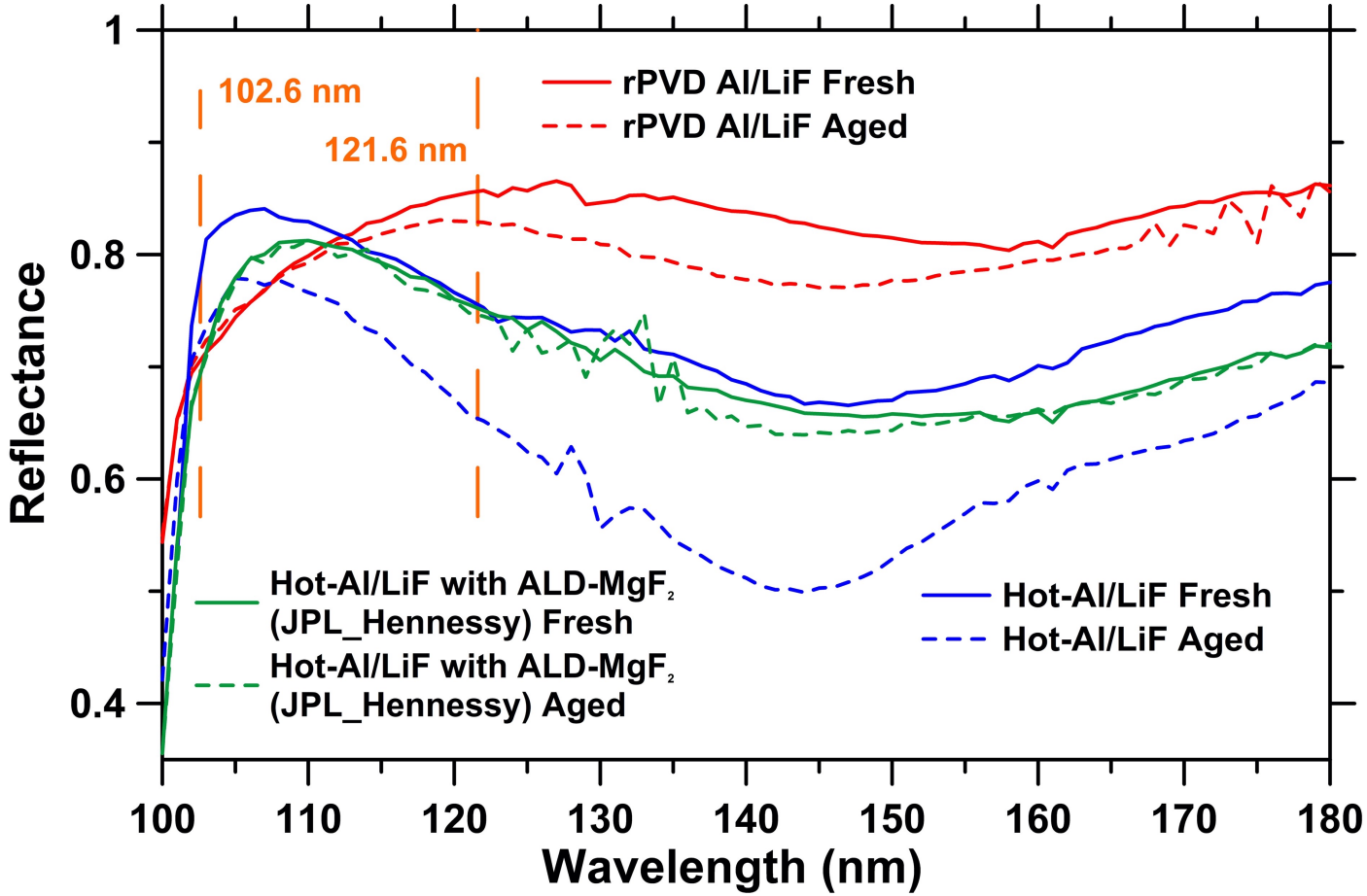


Protection Al+LiF with ALD-AlF_3 Deposition



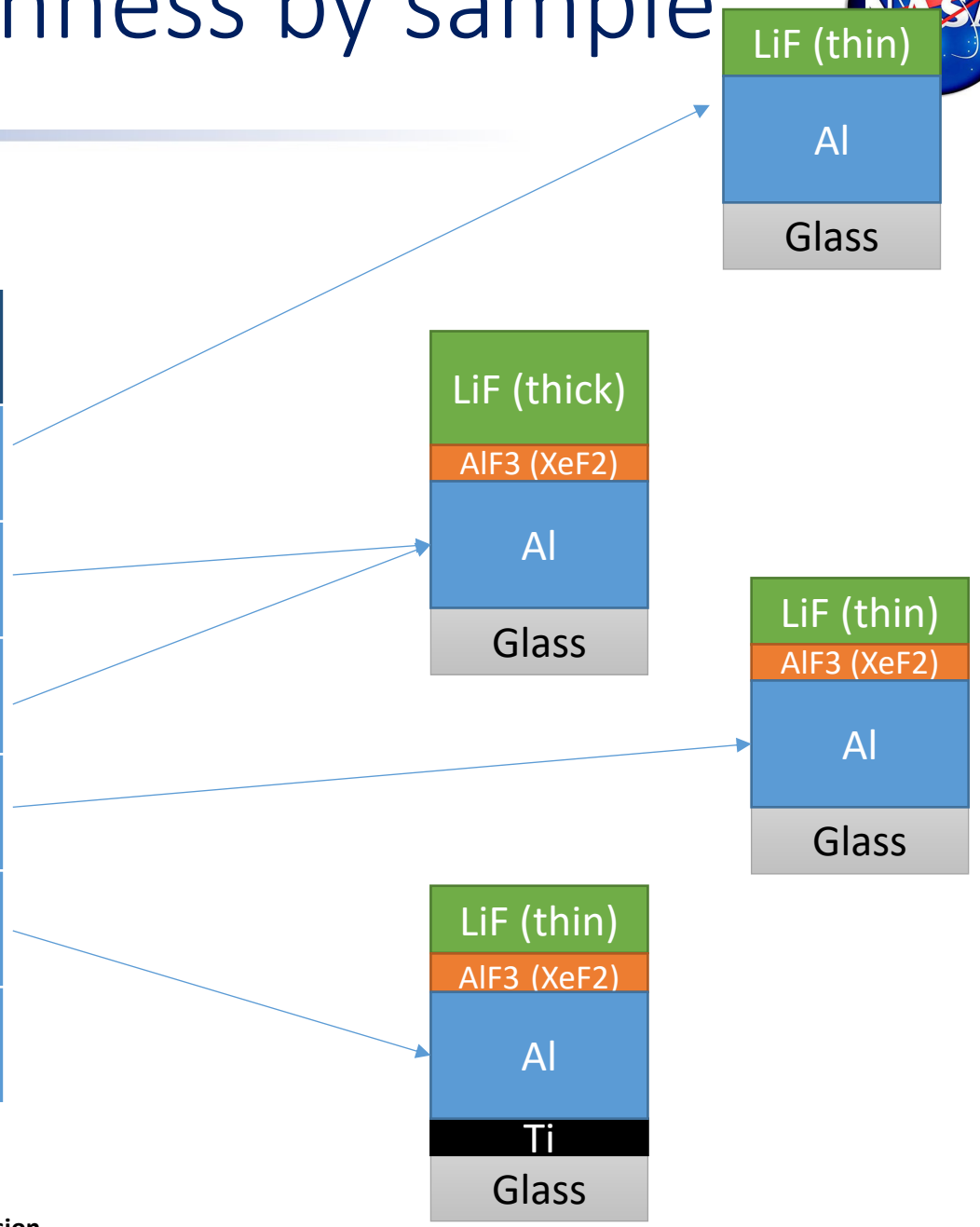
Fleming, B.; Quijada, M.; Hennessy, J.; Egan, A.; Del Hoyo, J.; Hicks, B.A.;Wiley, J.; Kruczek, N.; Erickson, N.; France, K.; Appl. Opt. 2017, 56, 9941–9950.

Aging of rPVD and Protected Al+LiF+MgF_2 Samples



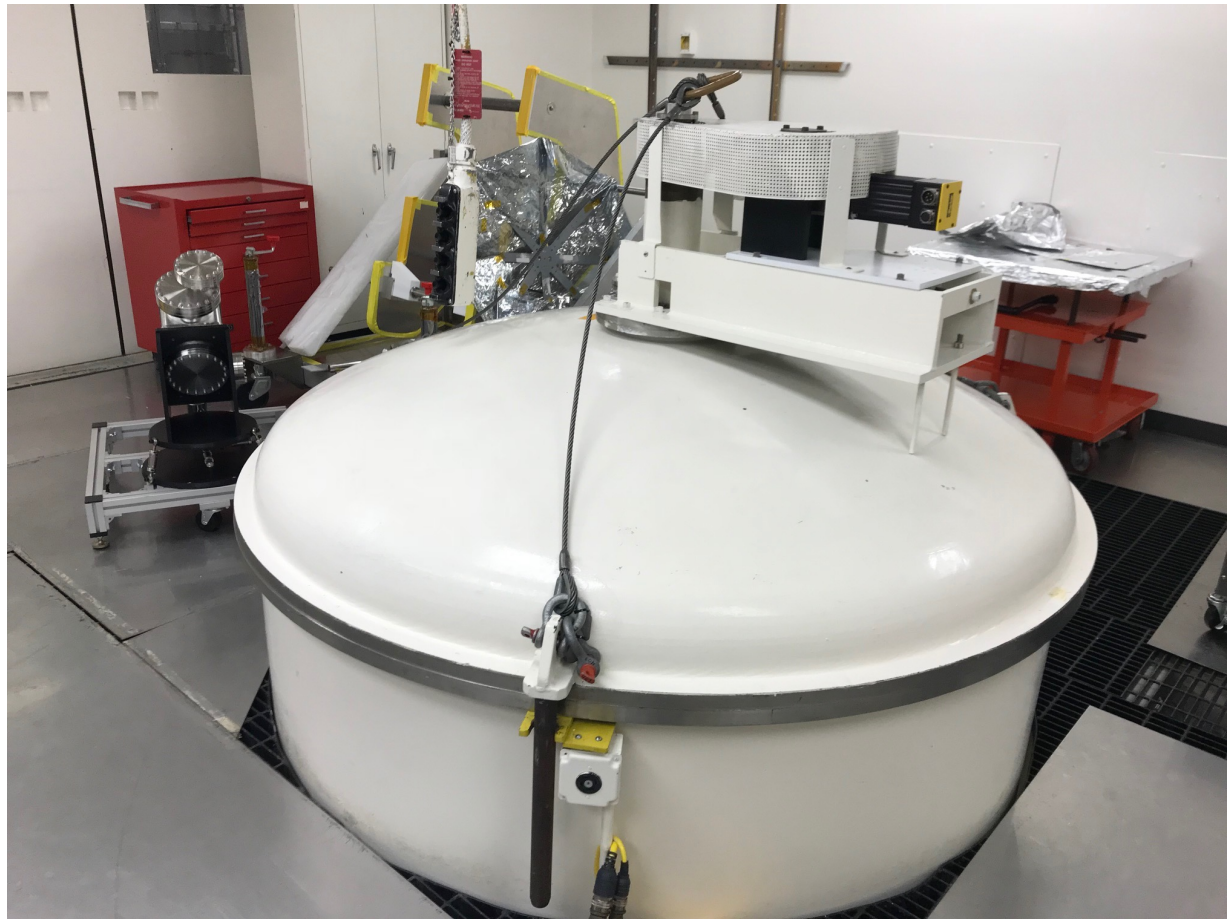
Summary – Surface roughness by sample

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

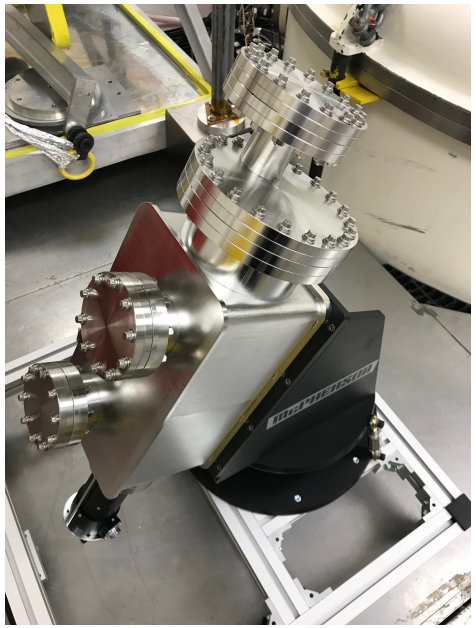


Accidentally sprayed with water

2-Meter Chamber Upgrades

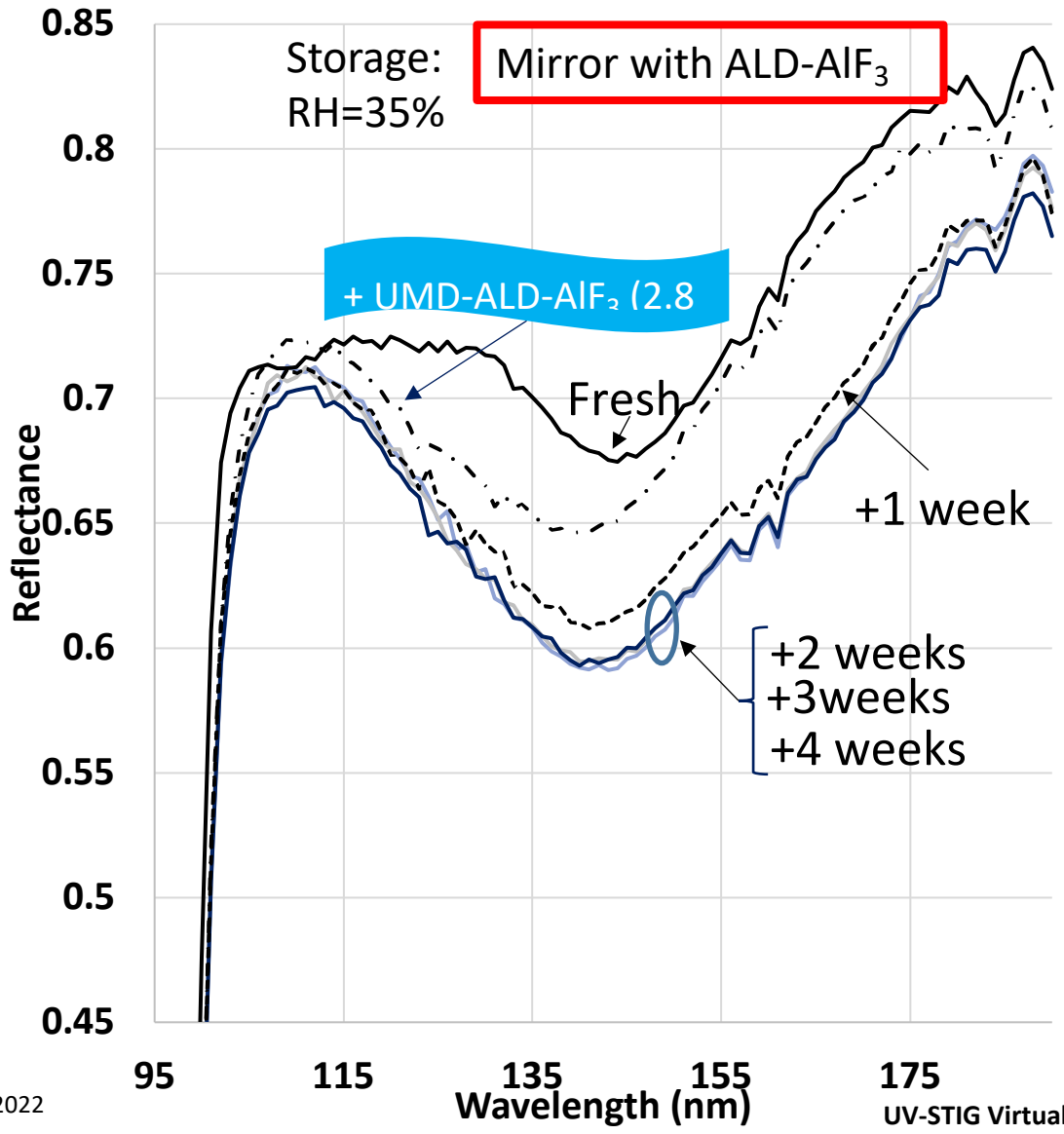


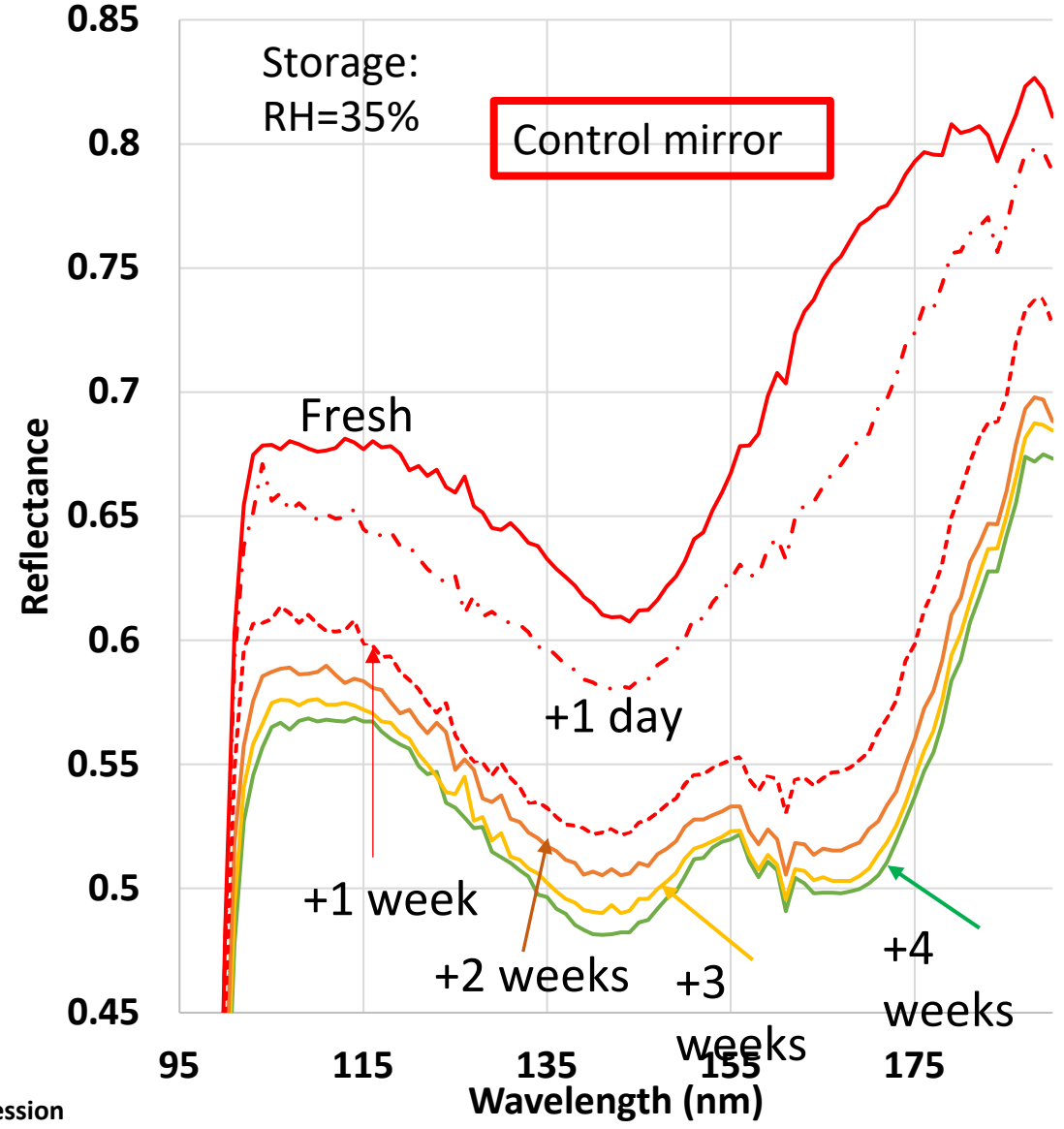
Deposition of a ion-assisted physical vapor deposition (IAPVD) of FUV-optimized Al+metal fluoride overcoats (LiF, MgF2, and Al+AlF_3) in the large 2-meter coating chamber.

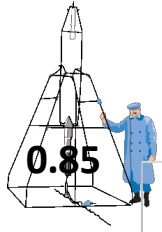


Lyman-Alpha Optical Monitor

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


Storage:
RH=35%
Mirror with ALD-AlF3
+ UMD-ALD-AlF3 (2.8
Fresh
+1 week
+2 weeks
+3weeks
+4 weeks
Reflectance
Wavelength (nm)
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
95
115
135
155
175


Storage:
RH=35%
Control mirror
Fresh
+1 day
+1 week
+2 weeks
+3 weeks
+4 weeks
Reflectance
Wavelength (nm)
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
95
115
135
155
175



Protection Al+LiF with ALD-AlF_3 Deposition

Storage in dry box (R. Humidity ≈ 35%)

This is the most valuable portion in the FUV

Sample A: Al/LiF overcoated with ALD AlF3 aged 1 week

Control sample aged 1 week (without protection

Reflectance

0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45

95 105 115 125 135 145 155 165 175 185

Wavelength (nm)