EUV Mirror Coating that works for UVOIR applications

1. EUV optical constants of AlF_3

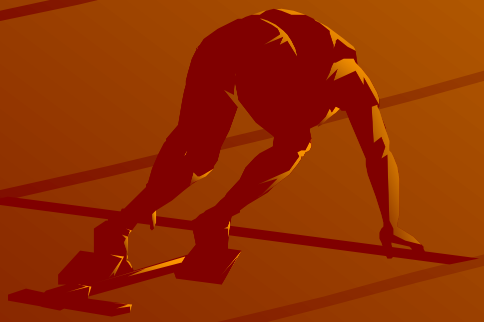
2. A Space-Mirror Coating with the Greatest Band Width

R. Steven Turley, Zoe Hughes, Michael Greenburg‡ & David Allred,

Brigham Young University

*Utah NASA Space Human Infrastructure Grant 2015
†NSF- BYU Physics REU/RET contract #PHY1461219 Summer 2016
‡BYU College of Physical and Mathematical Sciences Undergraduate RA support.

Part 1
Determining the Index of Refraction of AlF_3



Zoe Hughes- senior Drew University, NJ- summer ‘16
Mentor: Dr. R Steven Turley

Motivation

- Aluminum oxidizes when exposed to the atmosphere
- Why AlF_3?
  - One of three wide bandgap fluorides useful in protecting Al. The index of refraction of AlF_3 in EUV spectrum was unknown.
  - Some ML mirrors contain AlF_3 and in Kramers-Kronig analysis.

Sample Prep

- Evaporate AlF_3 on Si (100) pieces

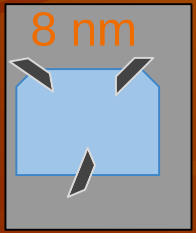
Methods: @ ALS 6.3.2

1. Measure reflectance vs Incidence Angle (Θ)
2. Fit Reflectance vs. Θ to find index of refraction for all wavelengths
   A) Thickness
   B) Index of refraction

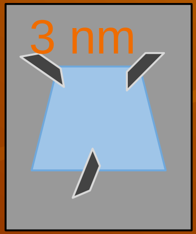
We tested three samples:

Sample A:

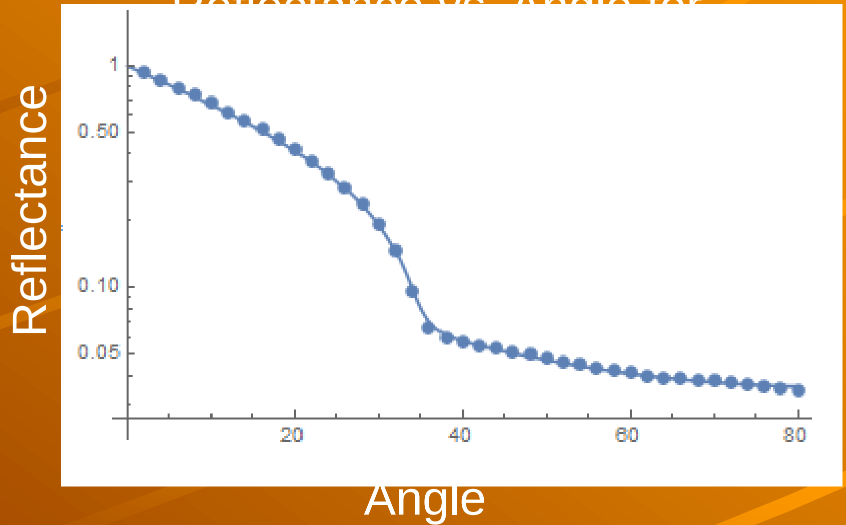
Sample C:



Sample D:

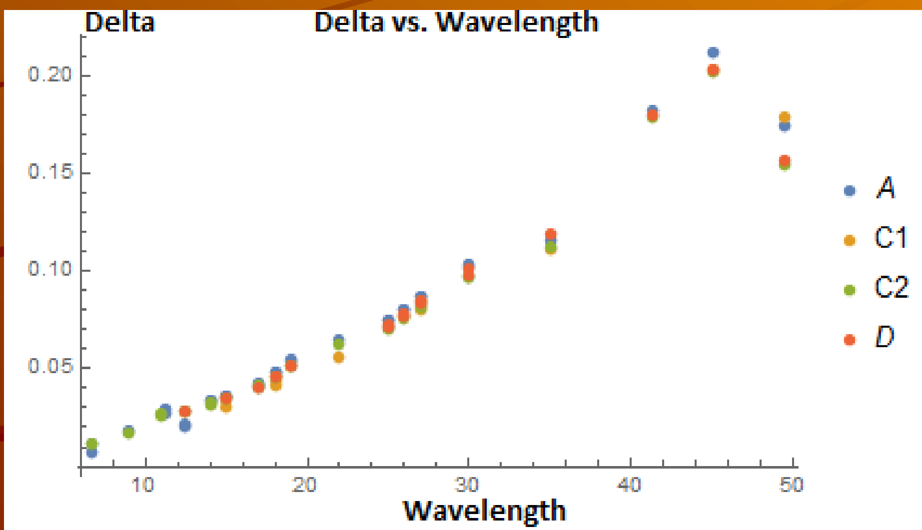


Θ-2Θ fit:

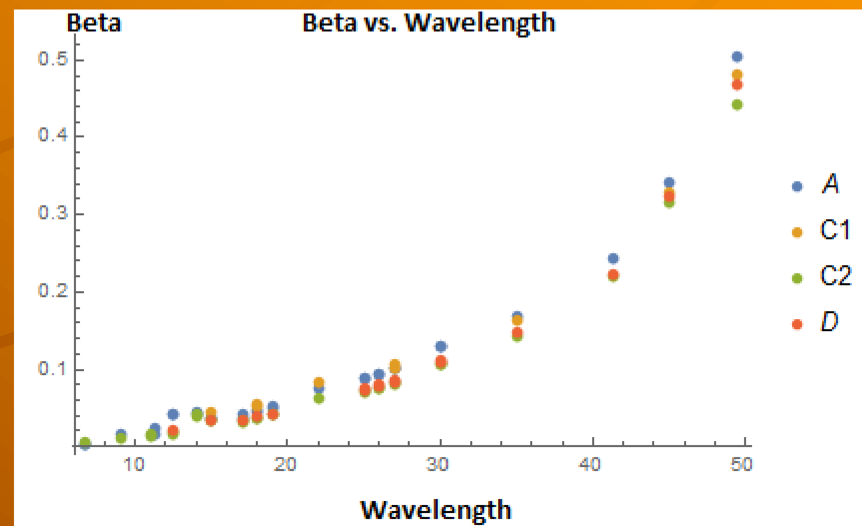


Initial Results:

Comparison of all samples index of refraction vs. wavelength



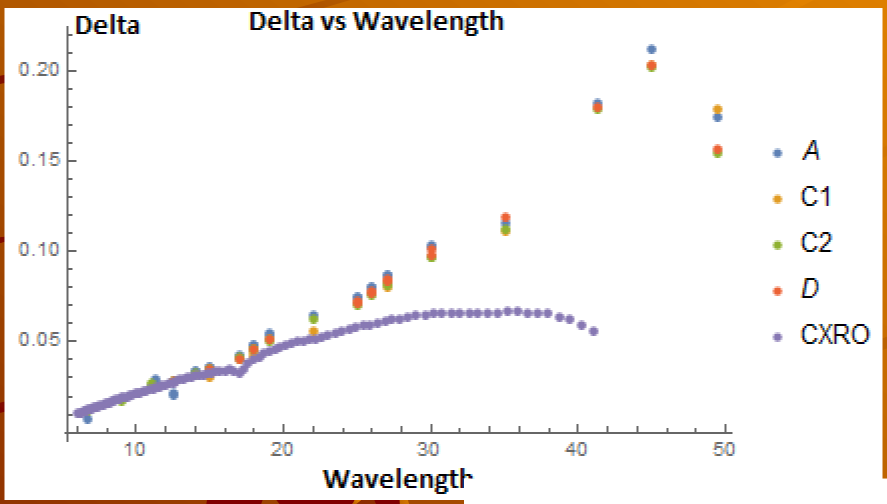
(nm)



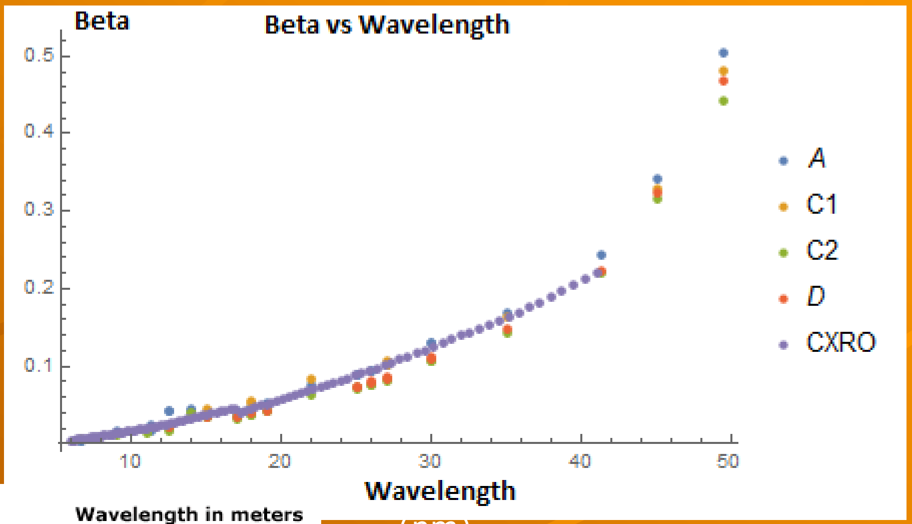
(nm)

$$n = 1 - \delta + i\beta$$

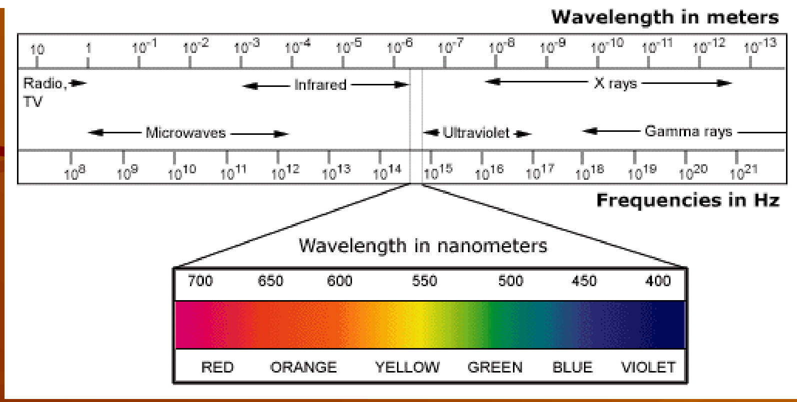
1. Compare with the CXRO data



(nm)



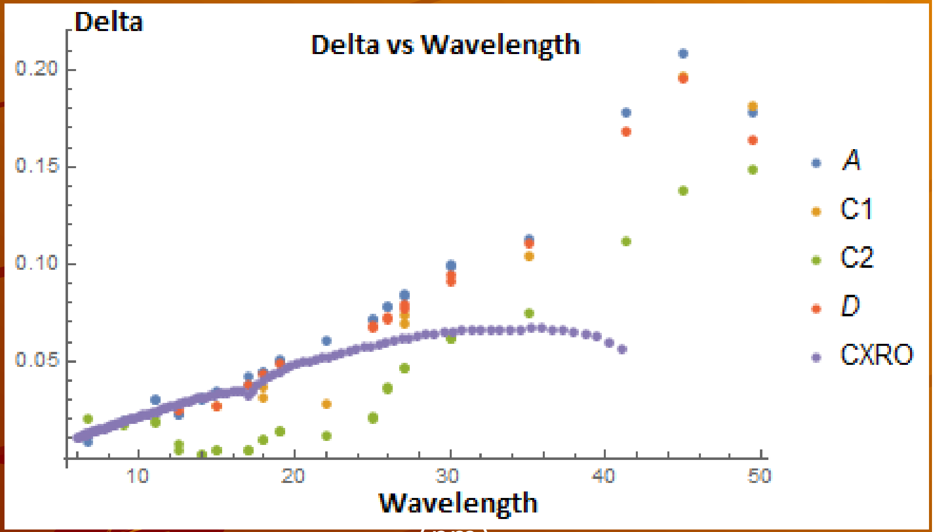
(nm)



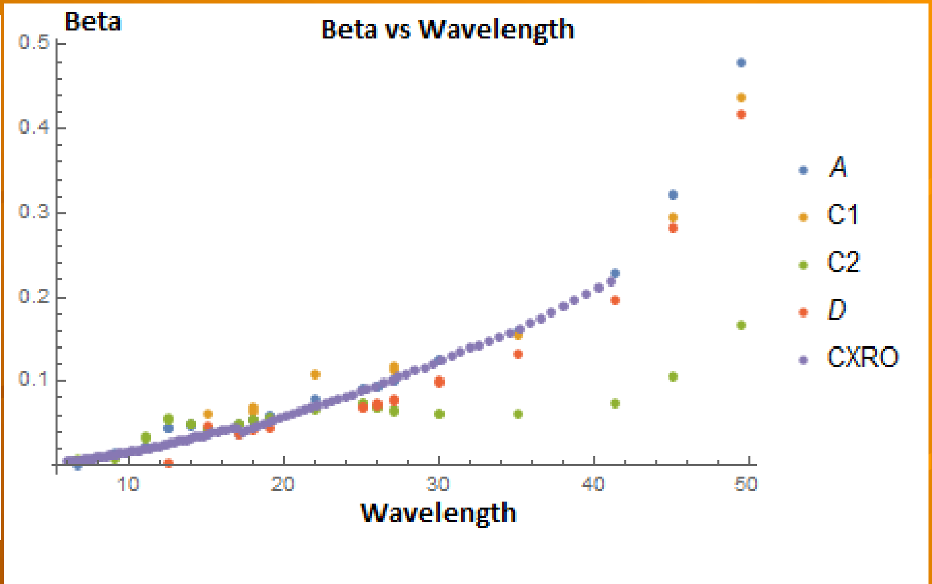
2. Adjust Model: Using Predicted Thicknesses

Sample	Experimental Avg (Ångstroms)	SE's Prediction (Ångstroms)	SE's 2nd Prediction (Ångstroms)
A	57.42	60.9	62.02
C	78.602(Day 1)	88.9	93.54
	31.3928(Day 2)		
D	32.4443	36.7	43.62

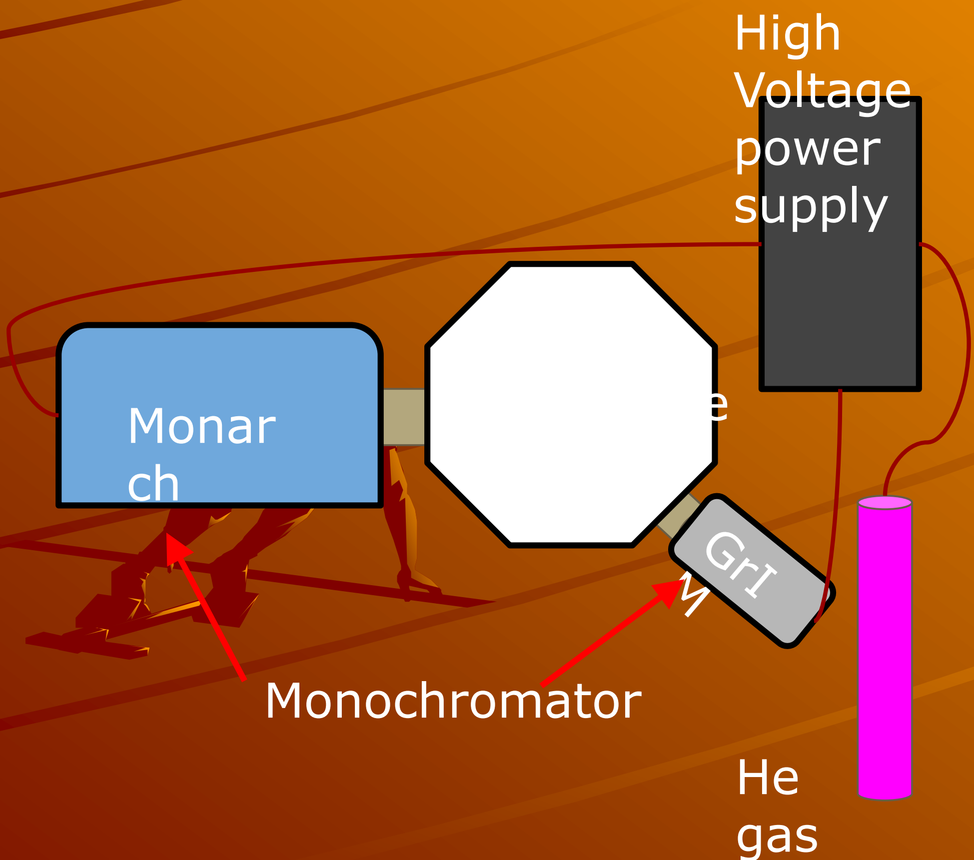
2. Adjust Model: Using Predicted Thicknesses

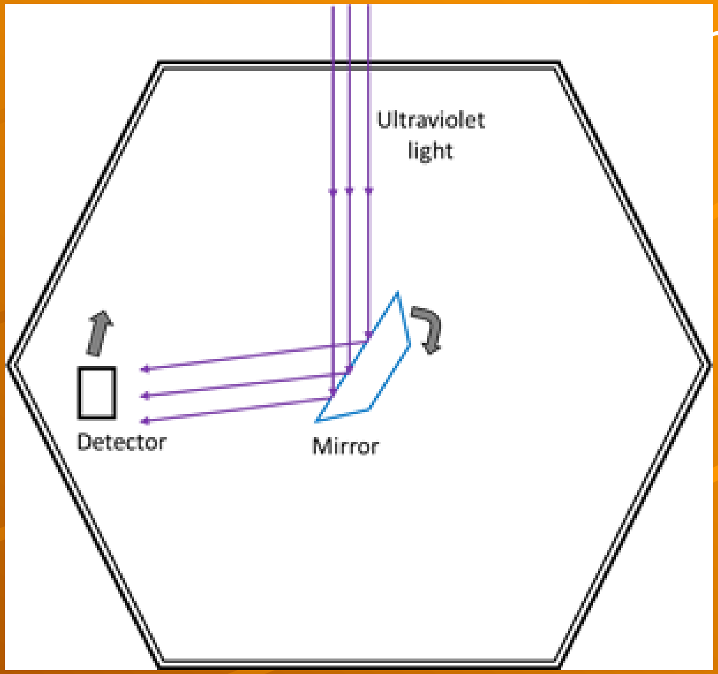


(nm)

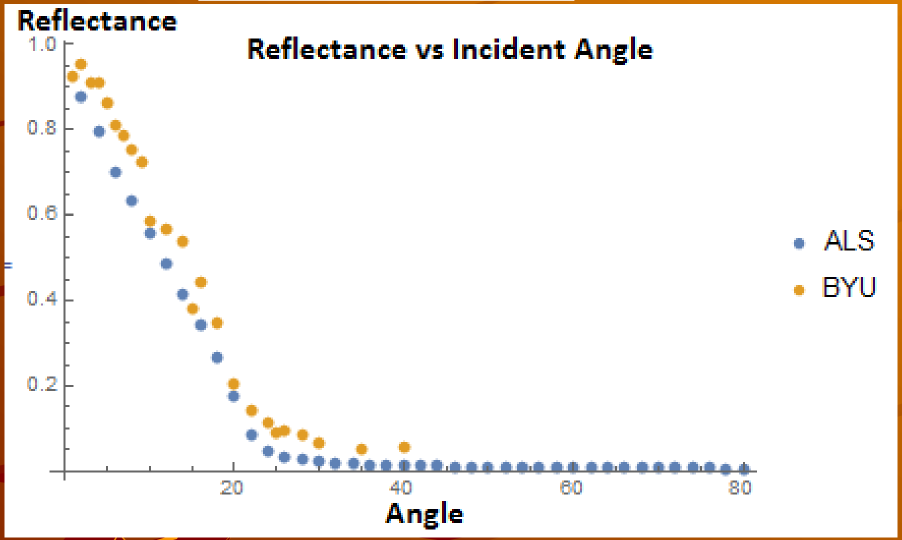


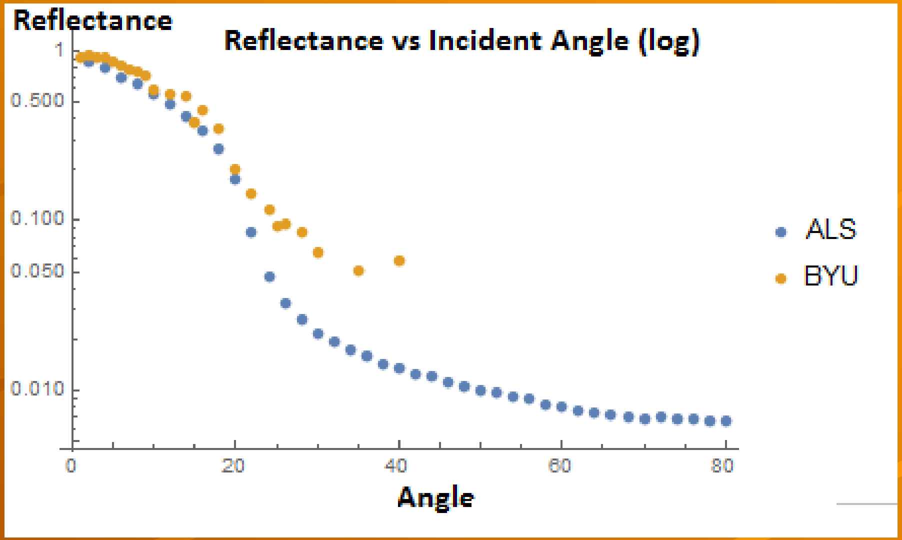
2. Check Data with ALS BYU Measurements





3. Check ALS Data with BYU Data- Why is BYU higher?



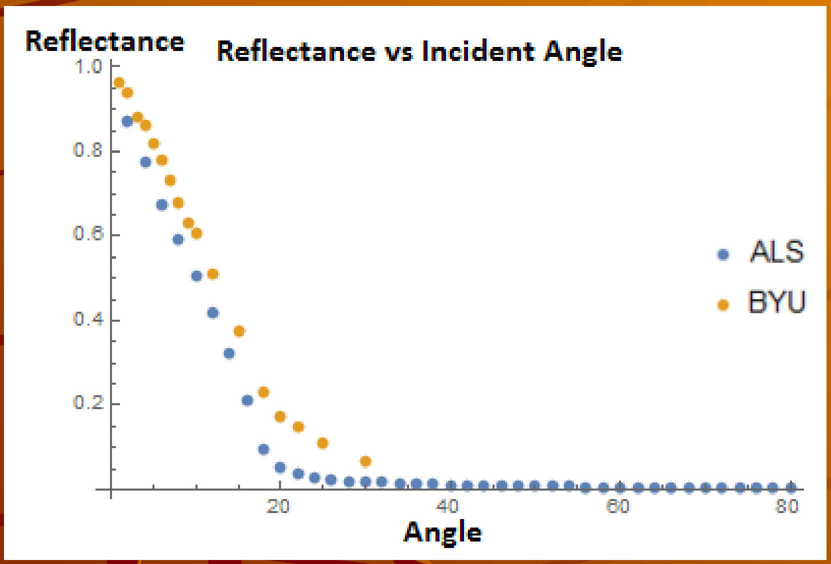


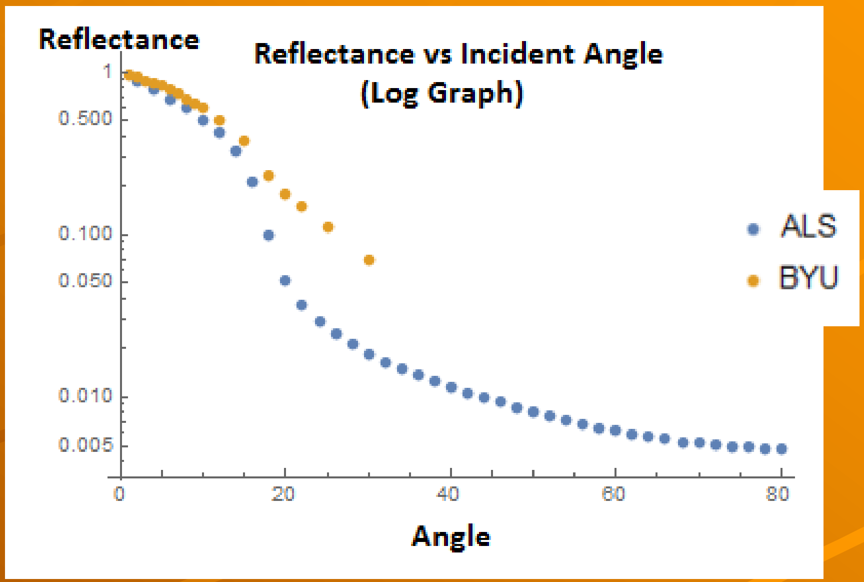
Sample D at Wavelength:
30.4 nm

	Estimate	Standard Error
ndx	0.901868	0.000416023
beta	0.108962	0.000961924

	Estimate	Standard Error
ndx	0.802581	0.0054152
beta	0.220945	0.0164399

3. Check ALS Data with BYU Data- Why is BYU higher?



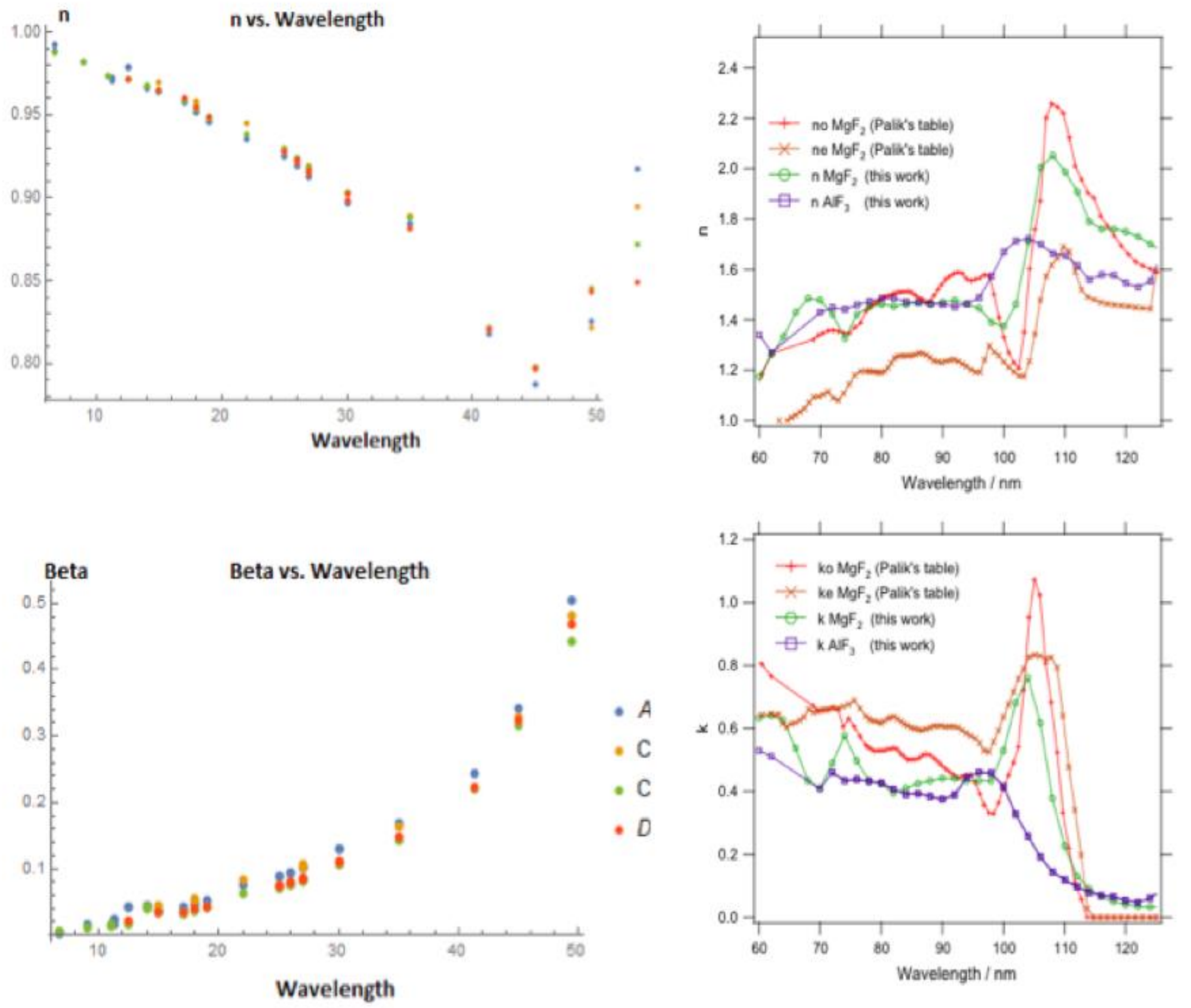


Sample D at Wavelength:
25.6 nm

	Estimate	Standard Error
ndx	0.928176	0.000223861
beta	0.0734126	0.000640469

	Estimate	Standard Error
ndx	0.830701	0.00993142
beta	0.291319	0.0248351

Our Experimental Data Compared to Bridou’s Data- There is a 10nm gap- can it really change that much?



Summary for this section

- Collected Data from ALS and BYU
- Investigated difference in results

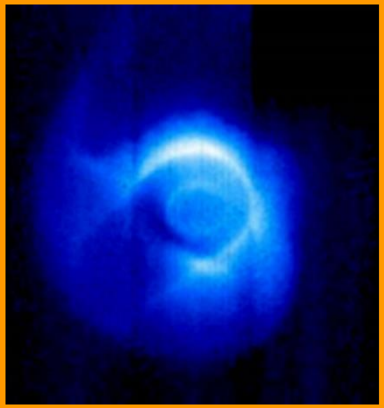
Turley-Allred Grou
EUV optics & Thin fil

Our group has made spaces mirrors for Far- Extreme Ultraviolet (EUV)

Thin Film U/Si Multilayer Mirrors

EUV Astronomy: IMAGE Mission

The Earth's magnetosphere is at UHV (<1E-8 torr) but we can see it with the right mirrors.



The Earth's magnetosphere in the EUV-30.4 nm

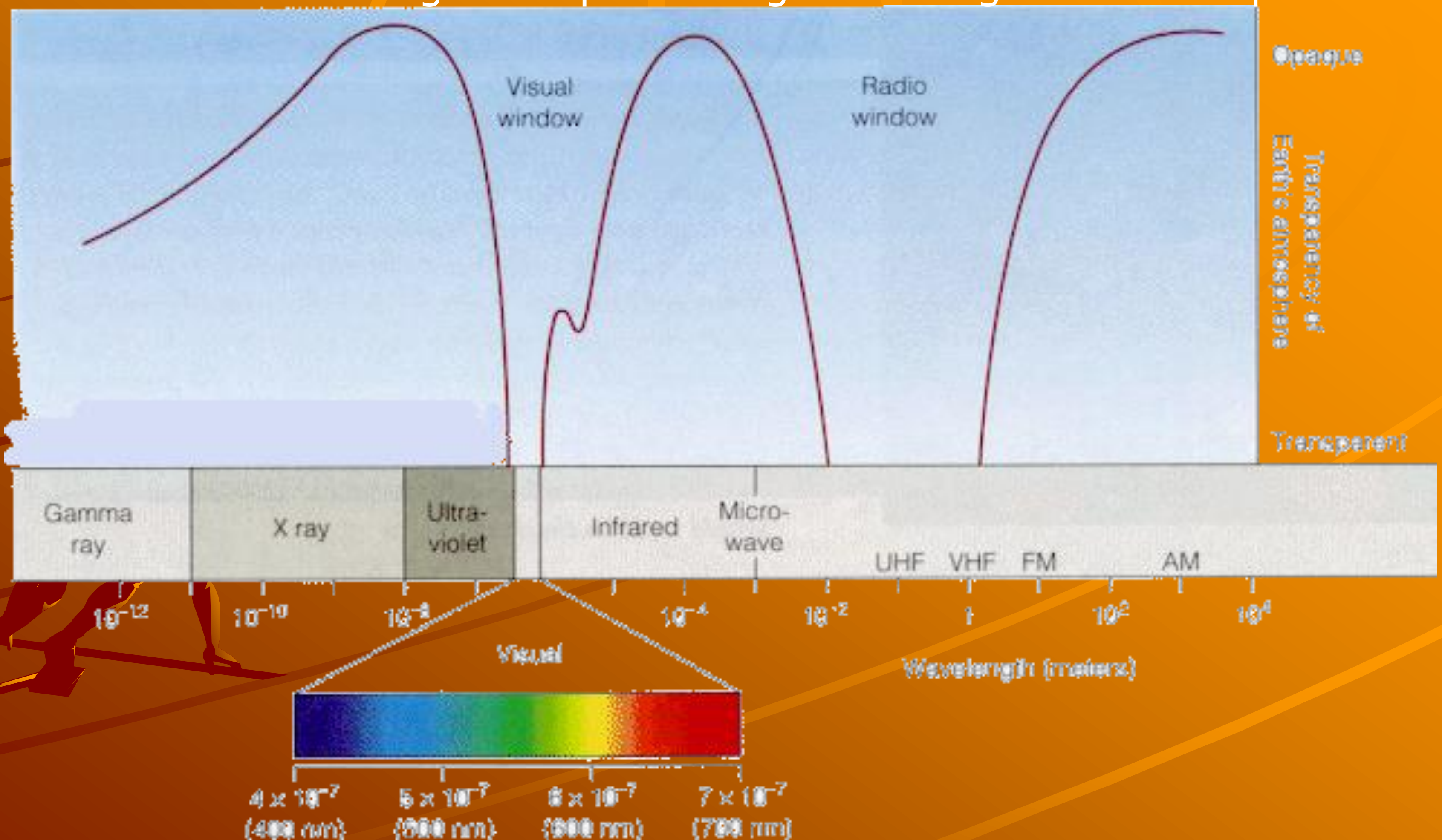
Tools to study EUV Multilayers

- Al is partially transparent <90 nm; particularly <60 nm
- Surfaces- Non Ideal
  - Roughness, Layers: Oxides, Contamination
- Bifunctional mirrors. Genetic algorithm.
- Compounds are often better.
- Optical Constants->40nm are needed.

Images from www.schott.com/magazine/english/info99/ and www.lbl.gov/Science-Articles/Archive/xray-inside-cells.html.

Space mirrors because:

Only part of the electromagnetic spectrum gets through the atmosphere.



EUV: 10 to 100 nm

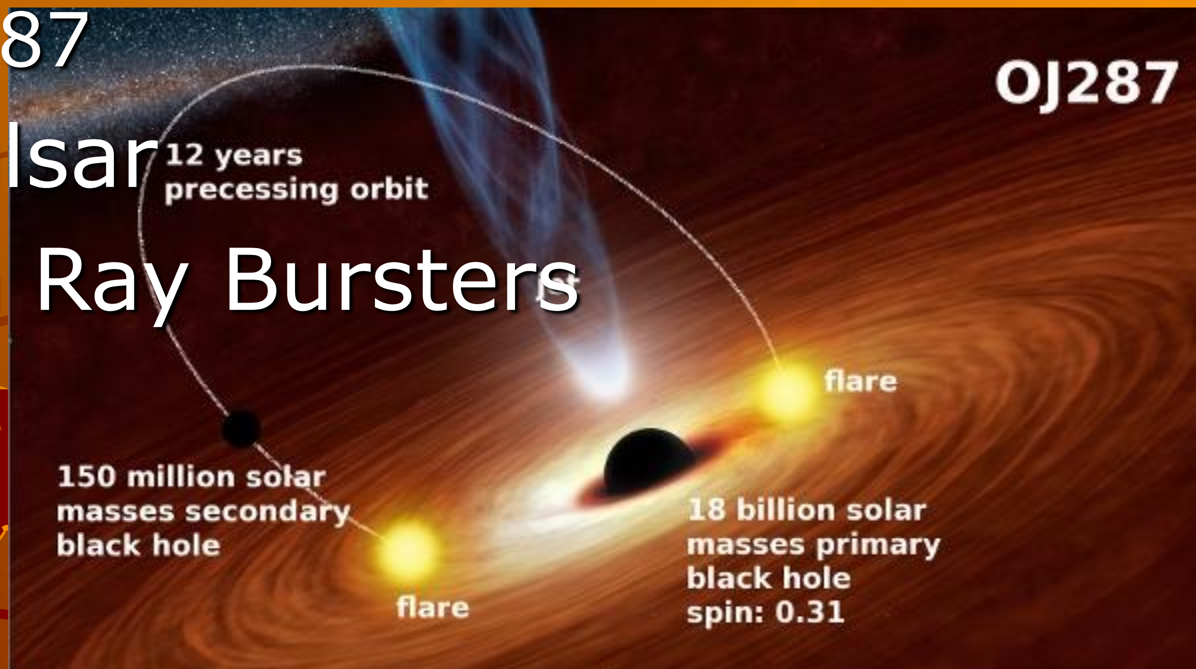
http://users.zoominternet.net/~matto/M.C.A.S/electromagnetic_spectrum.gif

Why EUV? Astrophysics

- AGN
  - OJ-287

Crab Pulsar

Gamma Ray Bursters



Thanks for Ben Taylor BYU Astronomy Faculty

Do we need the EUV?

- Planet characterization?
- Yes, Jupiter –Io flux tube

EUV Astronomy: IMAGE Mission

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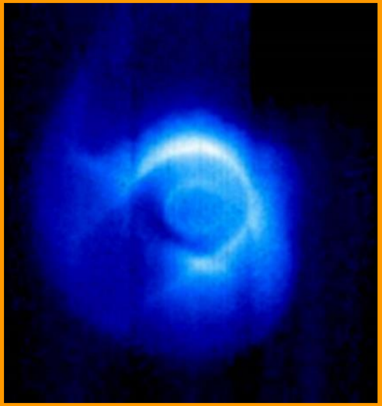


The Earth's magnetosphere in the EUV-30.4 nm

Proxima Centari b
may be a Ground Based will see it.
Magnetosphere?
Space Telescopes have an ESSENTIAL role
Why for M-Dwarf?
Flares & wind
UV can be brighter than rest of star output.
Light echos.

Opportunity for dynamic measurements- a flare will generate a time delayed reflectance echo-

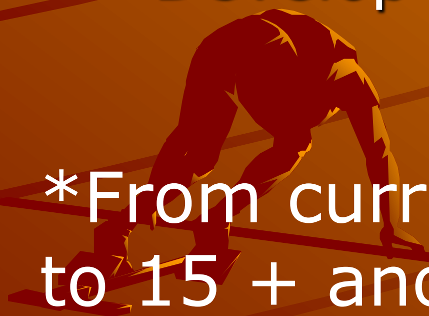
Do we have far UV (FUV) and EUV deep space, solar-observing, and planetary space-based telescopes?

1. **Hubble** – COS in 6-11 eV (115 to 205nm) range (far UV) it uses an MCP. 2009-21?
2. **GALEX**- , 2003 until 2012, was an Explorer class mission with a 50cm diameter aperture primary, the near UV- to FUV making observations from 4.4 -9.2 eV (135-280nm).
3. Far Ultraviolet Spectroscopic Explorer (**FUSE**) 1999 to 2007-10.4-13.7eV (90.5-119.5nm)
4. **EUVE** (1992-2001) one of the most successful spacecraft to fly. 7 to 76 nm (16-177eV). Glancing-angle optics (Wolters) optics.

BETWEEN 76nm & 90 nm NOTHING ever!
After Hubble NOTHING in VUV-EUV

Our Goals:

- Pathway to doubling* the effective bandwidth of traditional Al mirrors- used way traditional mirrors used (near normal)
  - Tradeoffs.
  - Educate students.
  - Develop computational tools.



*From current 0 to ~10 eV to 0 to ~20 eV or 0 to 15 + another 5eV further on in EUV
124nm to 62nm or e.g., 124 to 83 & 62-56 nm

Summary: What the mirror coating might be.

A Multilayer (ML) VUV-EUV Mirror Coated with as Thin as Possible Aluminum Film- without oxide

- Processed in Space -
  - Point of use.
  - far from Earth.
- It is helpful to devise and perfect tools.

Our group has made spaces mirrors for Far- Extreme Ultraviolet (EUV)

Thin Film U/Si Multilayer Mirrors

EUV Astronomy: IMAGE Mission

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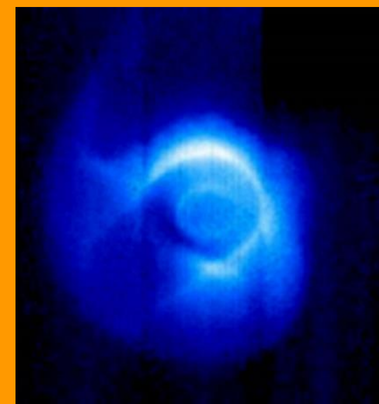

The Earth's magnetosphere in the EUV-30.4 nm

Tools to study EUV Multilayers

- ❖ Al is partially transparent <90 nm; particularly <60 nm
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  - ❖ Roughness, Layers: Oxides, Contamination
- ❖ Bifunctional mirrors. Genetic algorithm.
- ❖ Compounds are often better.
- ❖ Optical Constants->40nm are needed.

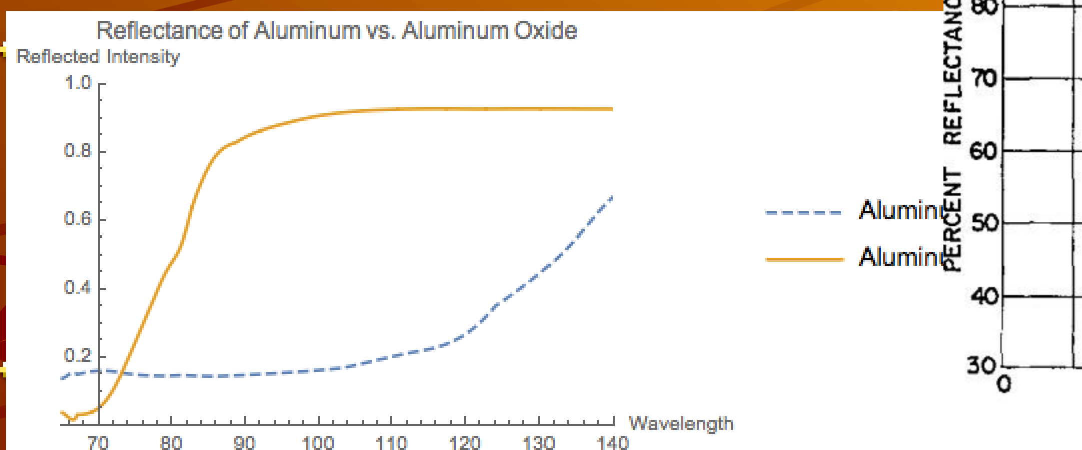
Images from www.schott.com/magazine/english/info99/ and www.lbl.gov/Science-Articles/Archive/xray-inside-cells.html.

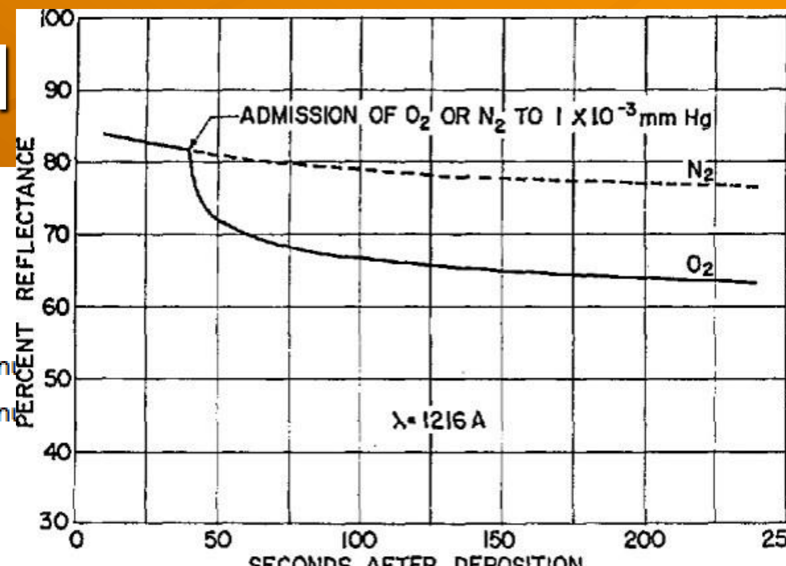
OUTLINE

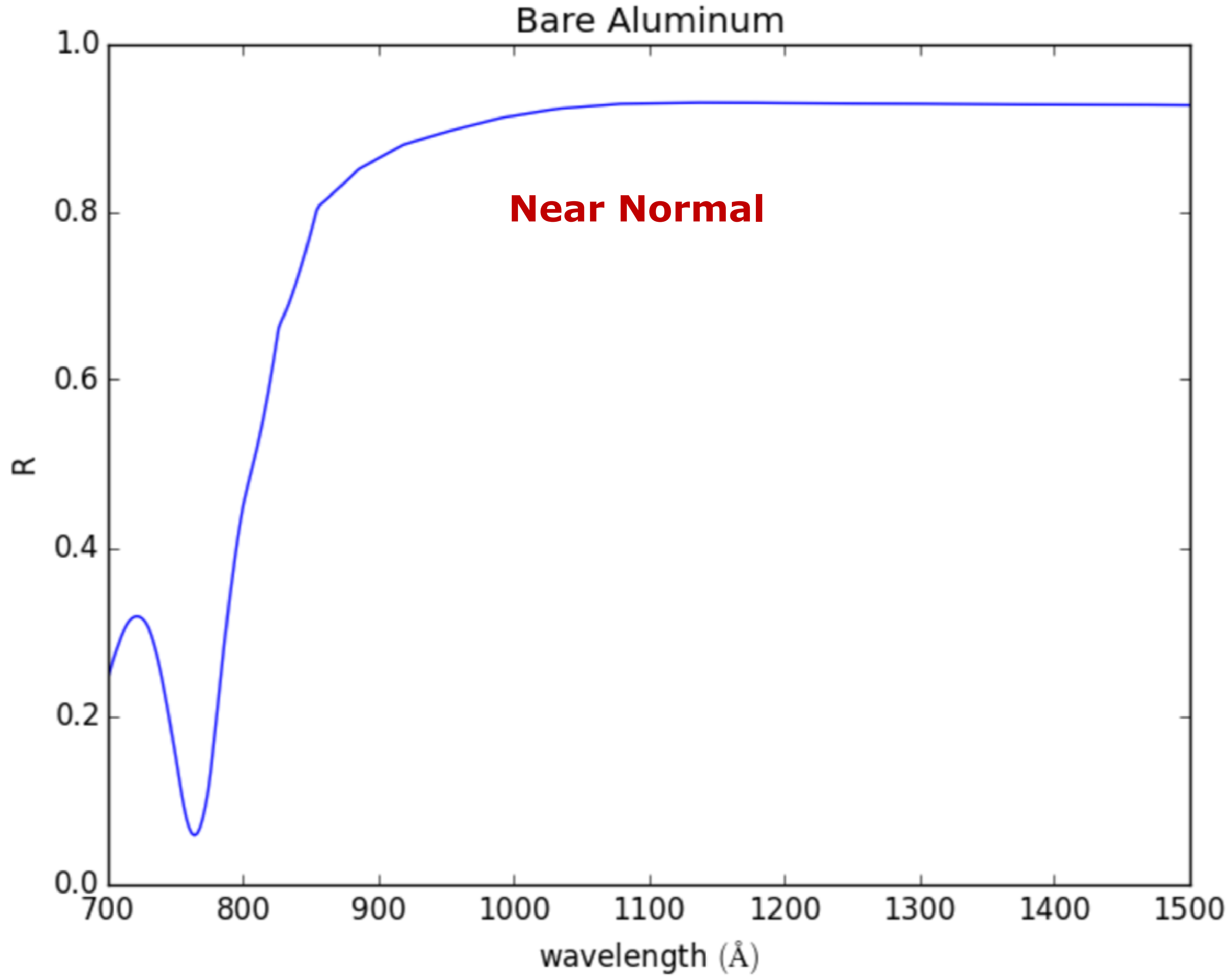
- Introduction:
- Tool development: What do to once we get bare aluminum in space
- Computational GA
- Optical constants required. An example.

Optimizing Reflectance with Aluminum

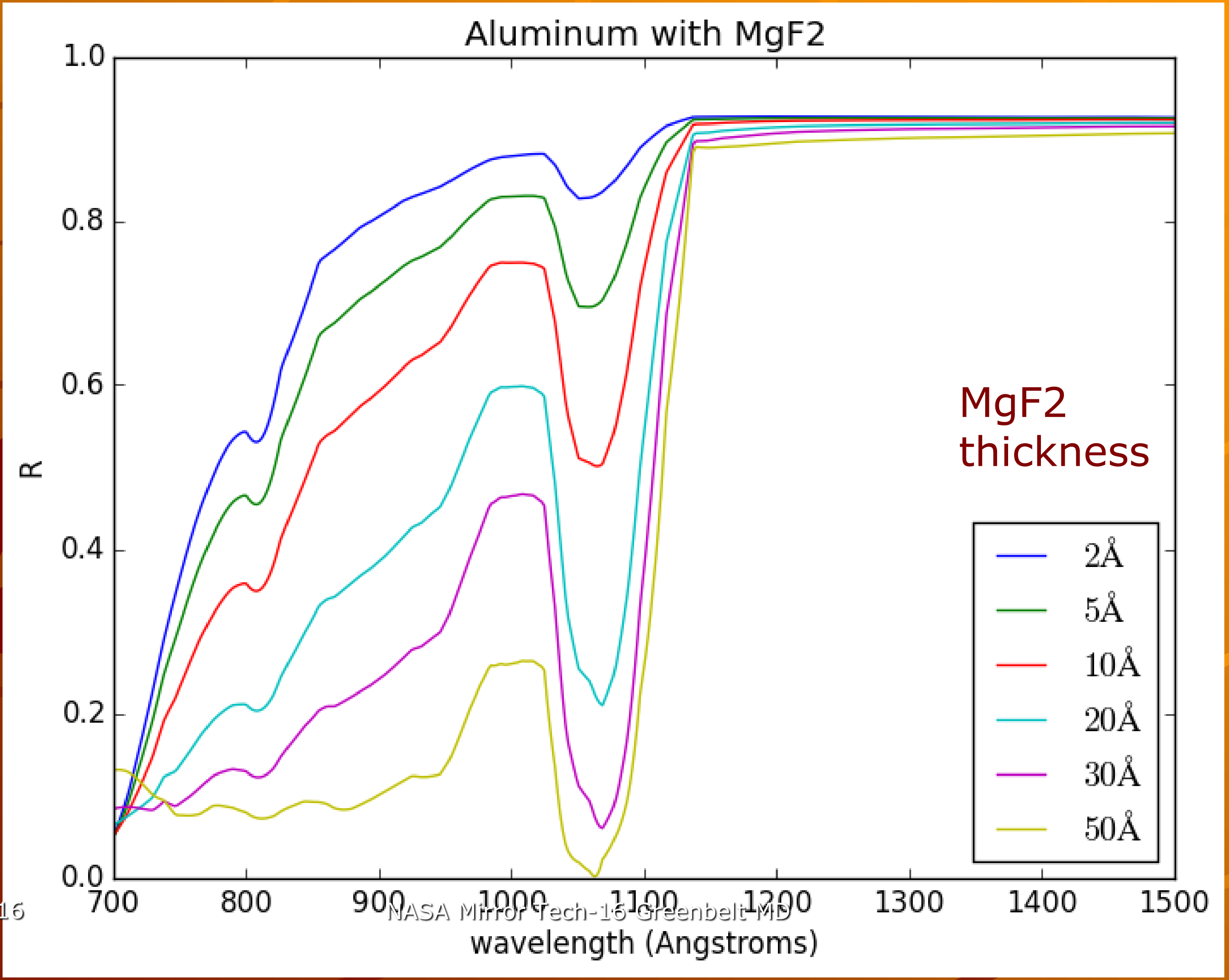
- Extends range of UV to ~83 nm (15 eV)
- Transparent at small

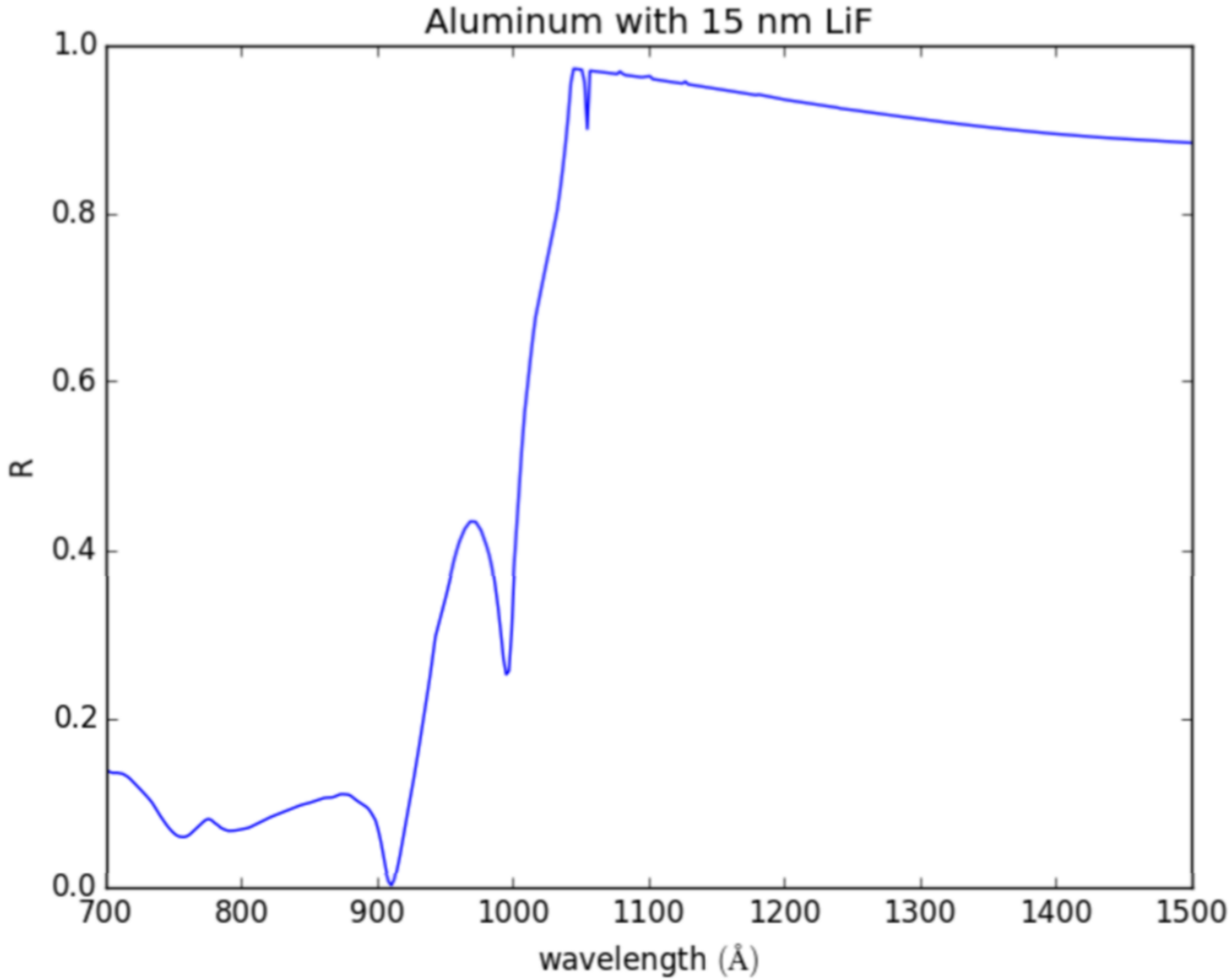


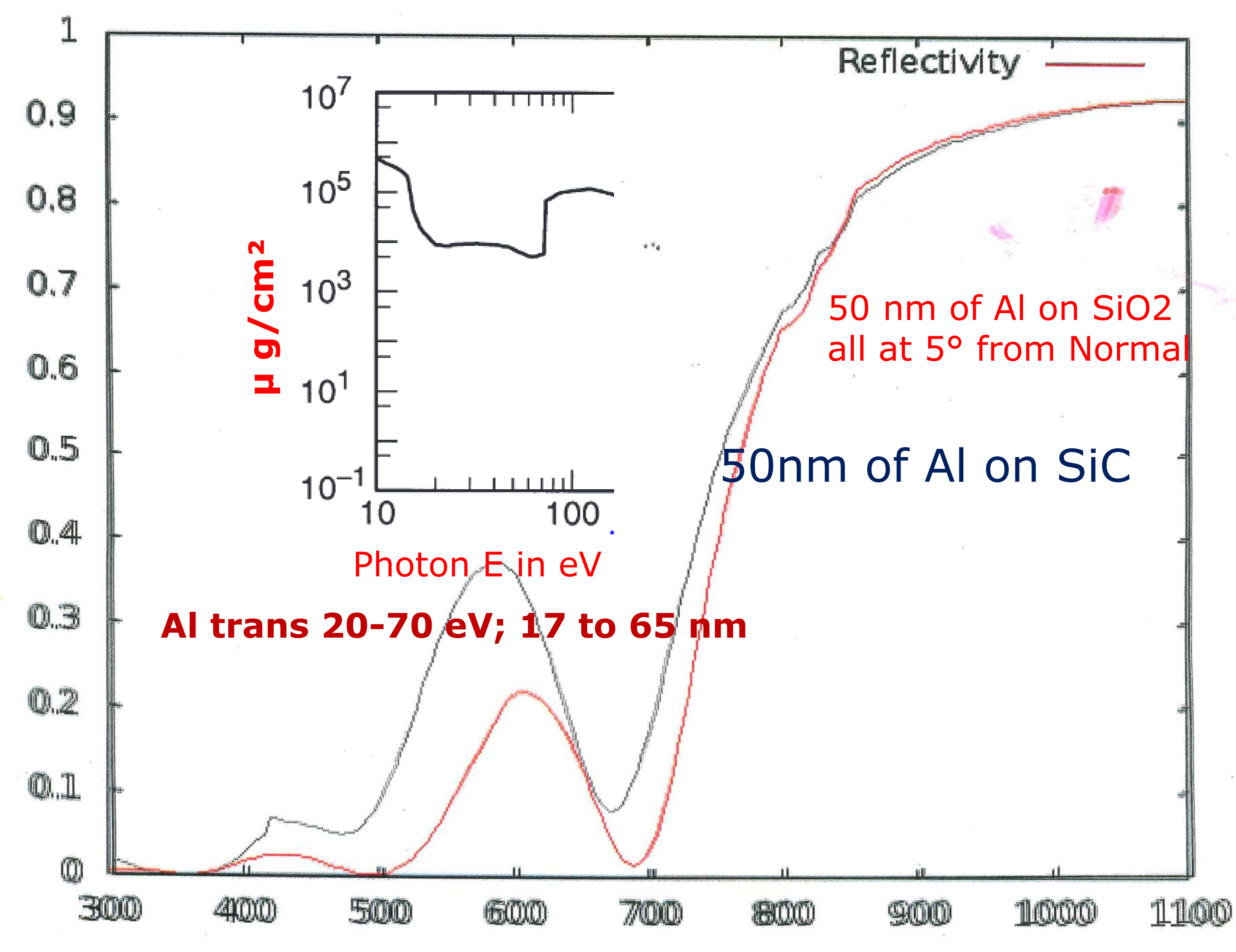



Bare Aluminum
Near Normal
R
1.0
0.8
0.6
0.4
0.2
0.0
700
800
900
1000
1100
1200
1300
1400
1500
wavelength (Å)

Why we need barrier layers to go away if we want to go below ~100 nm ?

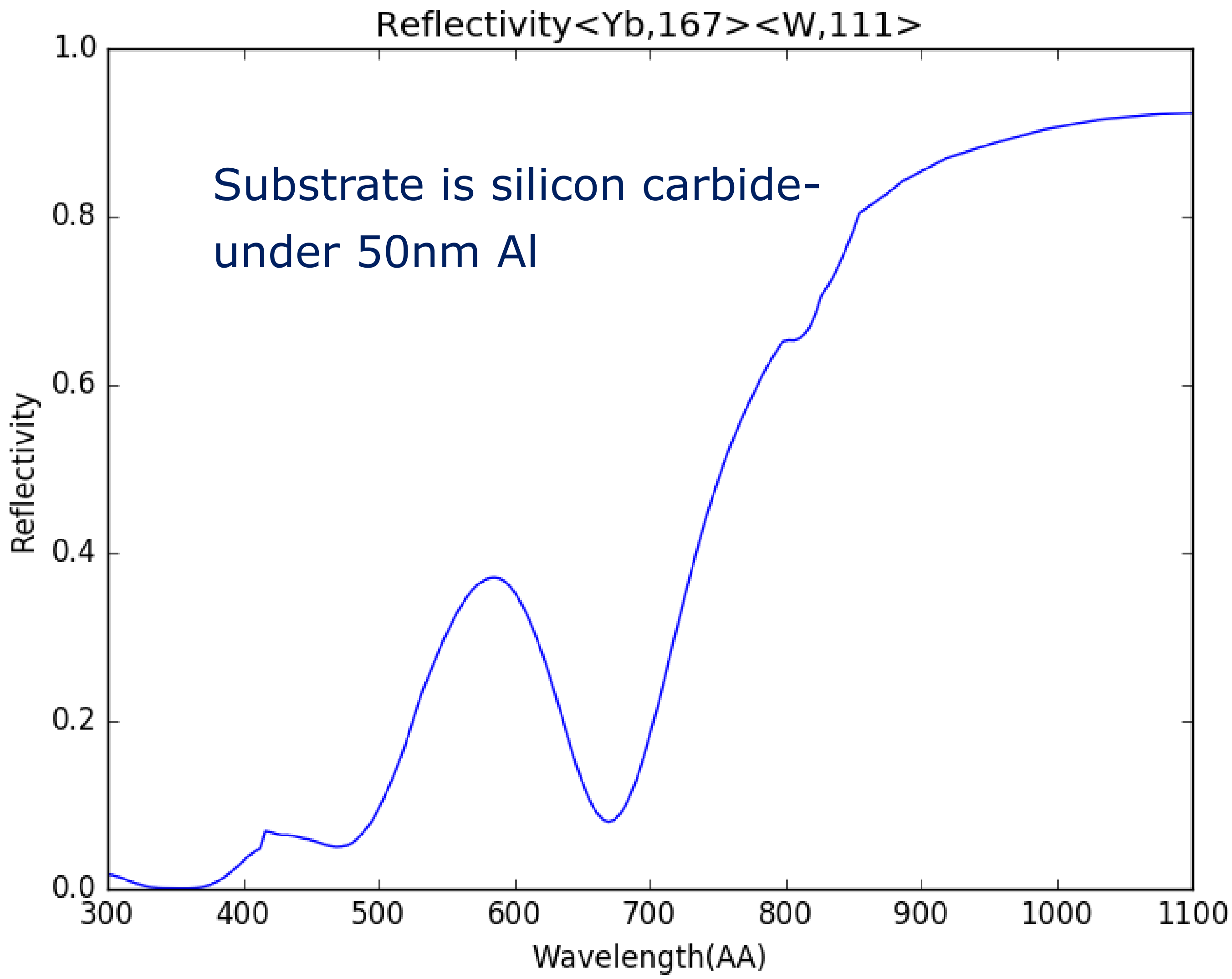


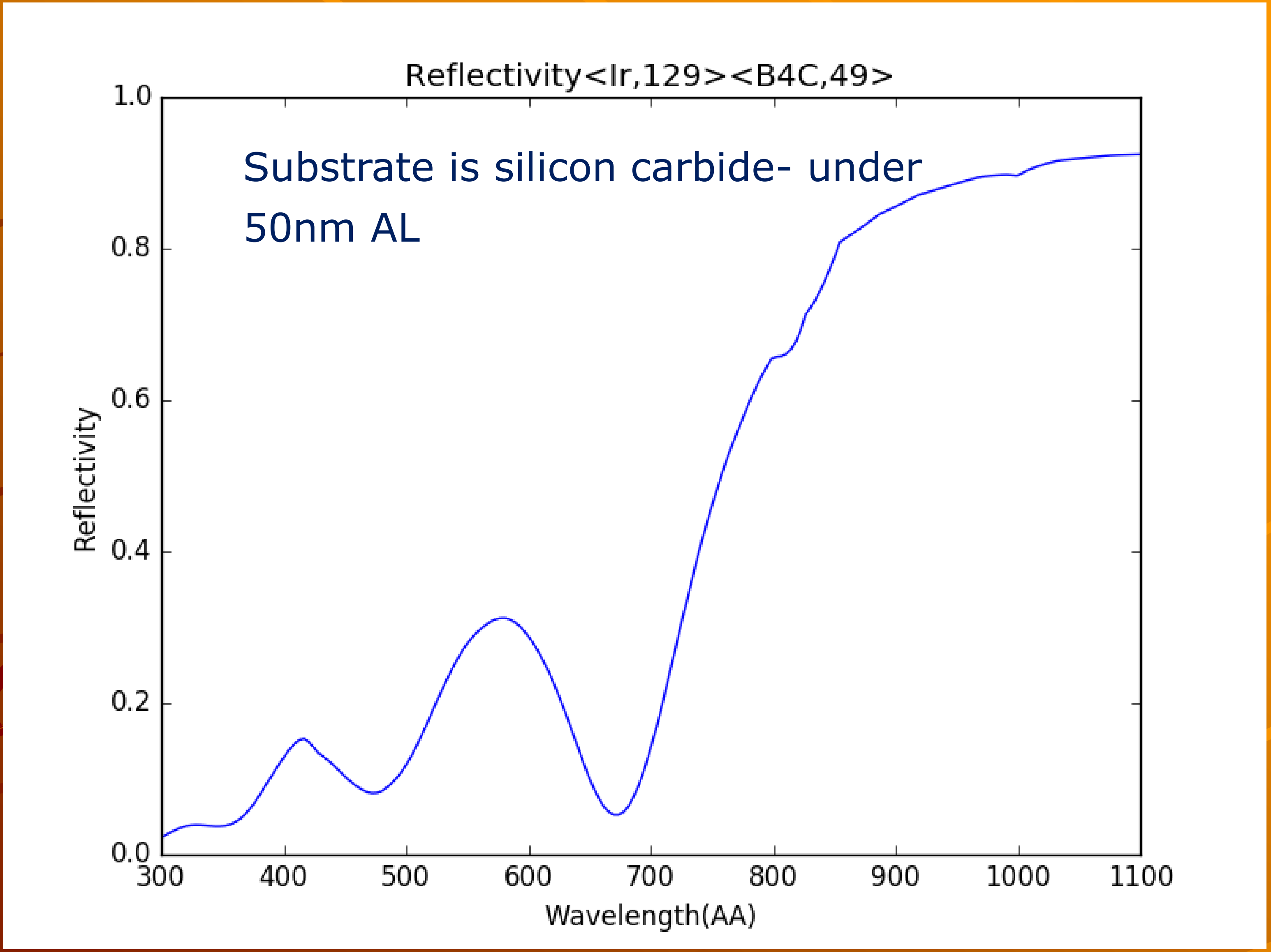

Aluminum with 15 nm LiF
R
0.0
0.2
0.4
0.6
0.8
1.0
700
800
900
1000
1100
1200
1300
1400
1500
wavelength (Å)

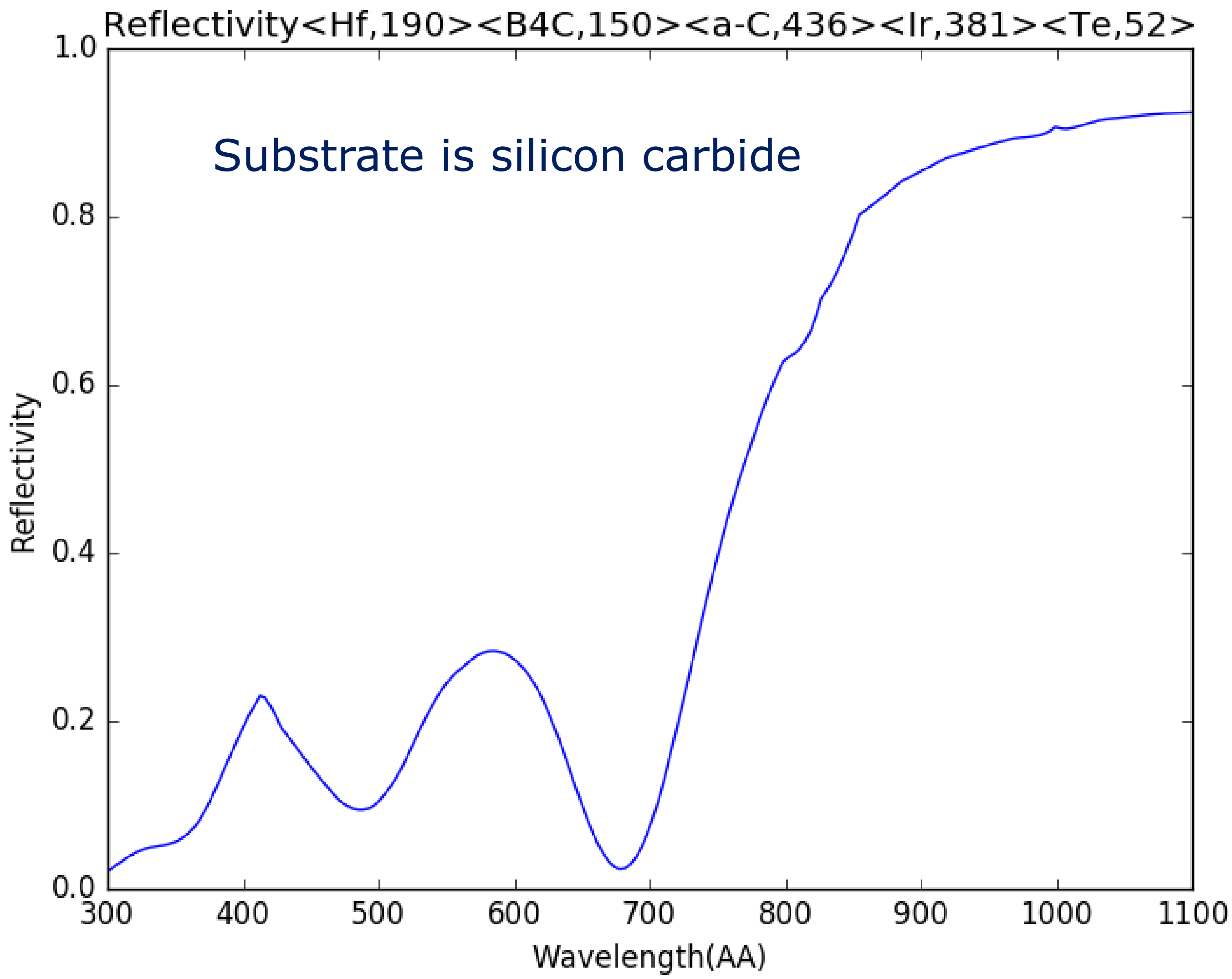


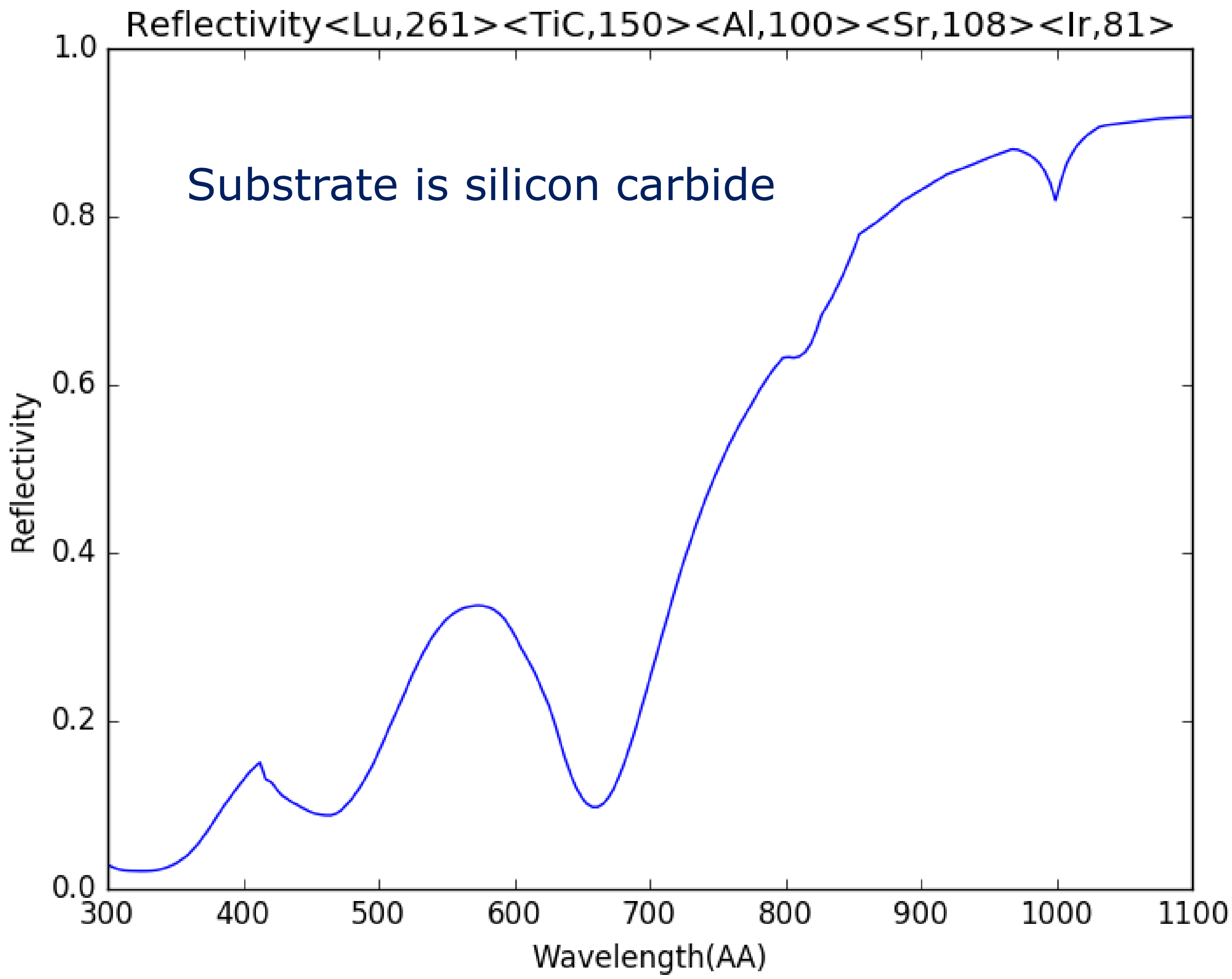
Reflectivity
50 nm of Al on SiO2
all at 5° from Normal
50nm of Al on SiC
μ g/cm²
Photon E in eV
Al trans 20-70 eV; 17 to 65 nm

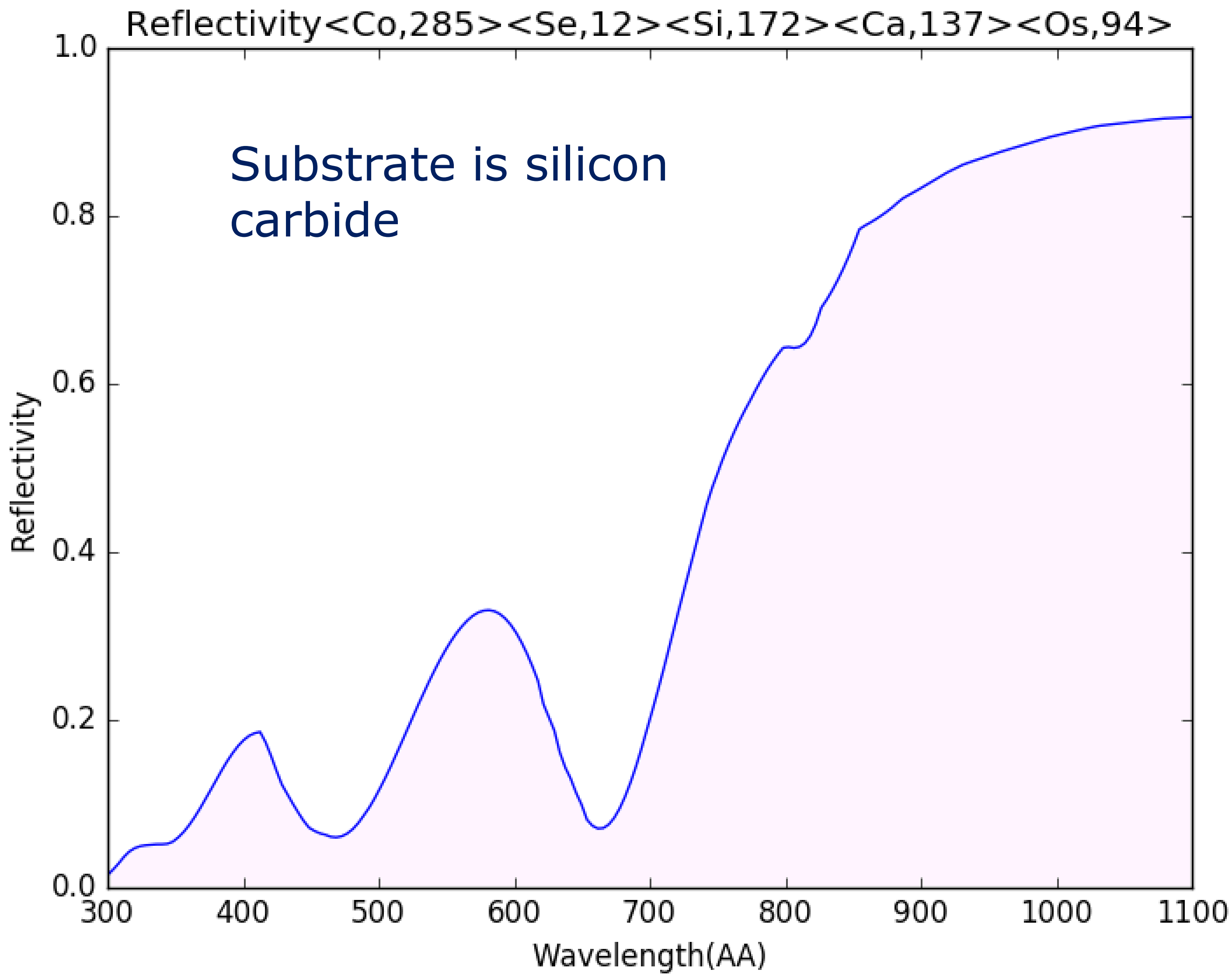
Preliminary results from GA approach to finding EUV mirrors with full UVOIR function.

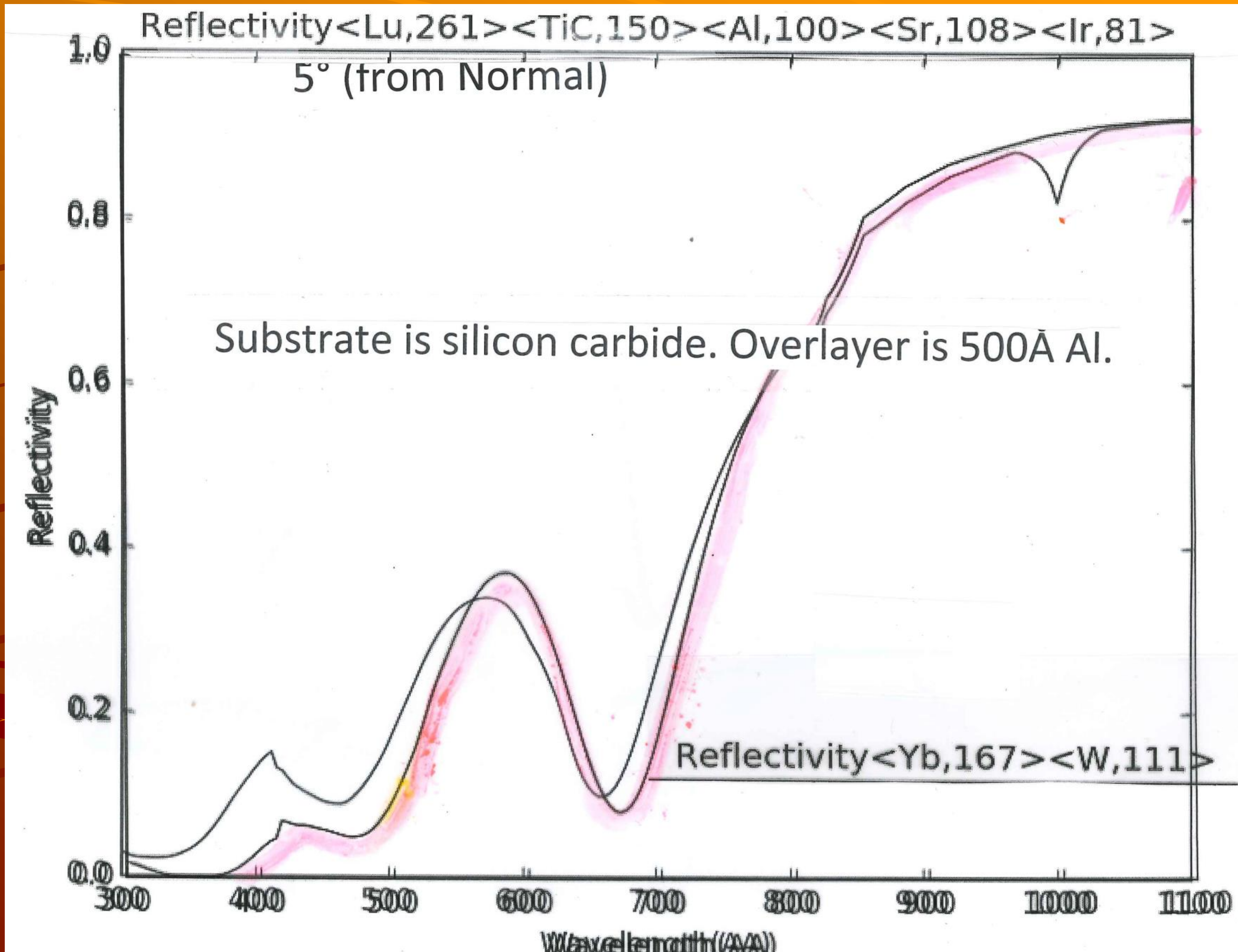

Reflectivity<Yb,167><W,111>
Substrate is silicon carbide-
under 50nm Al
Reflectivity
Wavelength(AA)
1.0
0.8
0.6
0.4
0.2
0.0
300
400
500
600
700
800
900
1000
1100


Reflectivity<Ir,129><B4C,49>
Substrate is silicon carbide- under
50nm AL
Reflectivity
1.0
0.8
0.6
0.4
0.2
0.0
300
400
500
600
700
800
900
1000
1100
Wavelength(AA)


Reflectivity<Hf,190><B4C,150><a-C,436><Ir,381><Te,52>
Substrate is silicon carbide
Reflectivity
Wavelength(AA)
0.0
0.2
0.4
0.6
0.8
1.0
300
400
500
600
700
800
900
1000
1100

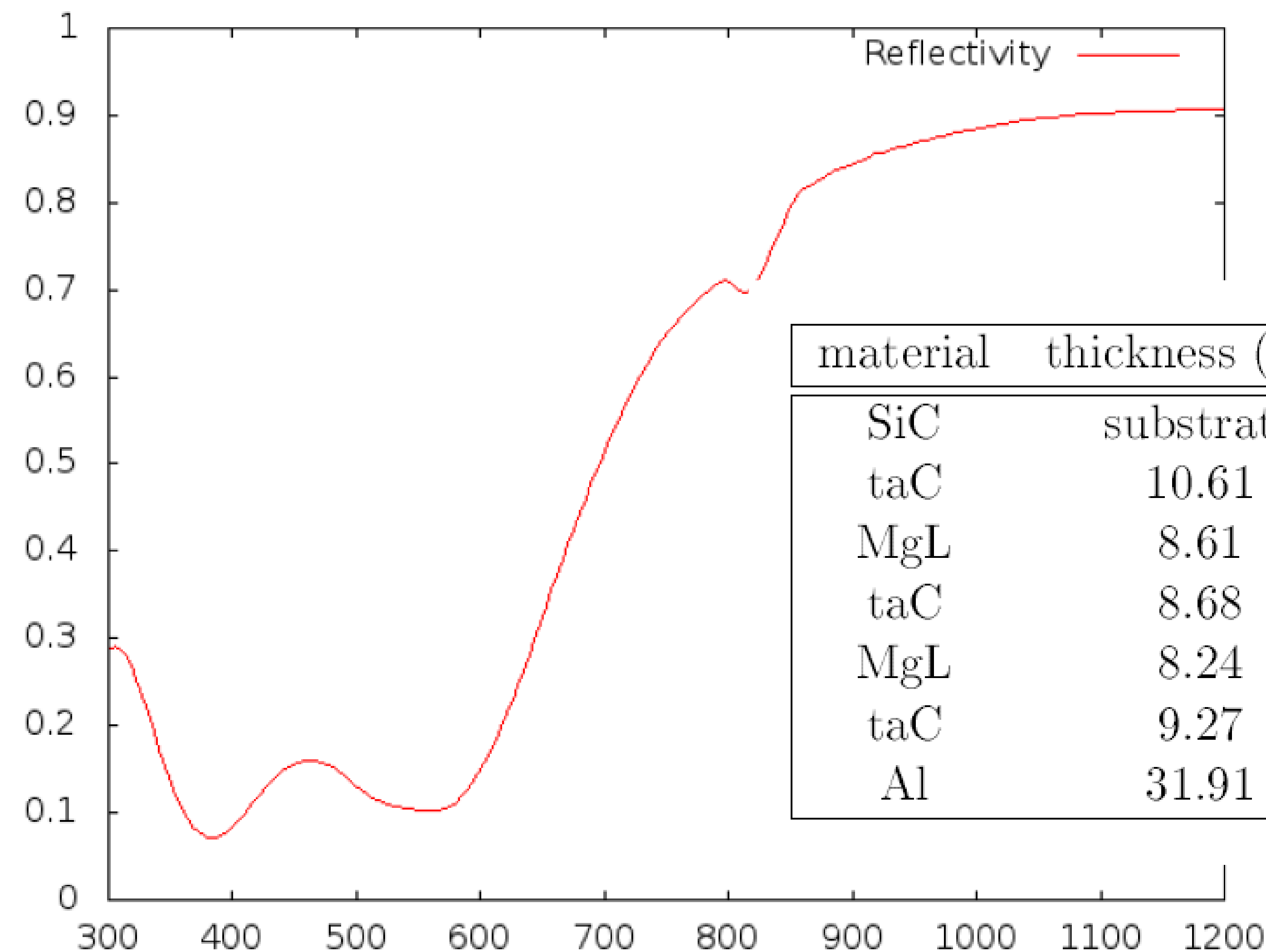

Reflectivity<Lu,261><TiC,150><Al,100><Sr,108><Ir,81>
Substrate is silicon carbide
Reflectivity
1.0
0.8
0.6
0.4
0.2
0.0
300
400
500
600
700
800
900
1000
1100
Wavelength(AA)


Reflectivity<Co,285><Se,12><Si,172><Ca,137><Os,94>
Substrate is silicon carbide
Reflectivity
1.0
0.8
0.6
0.4
0.2
0.0
300
400
500
600
700
800
900
1000
1100
Wavelength(AA)



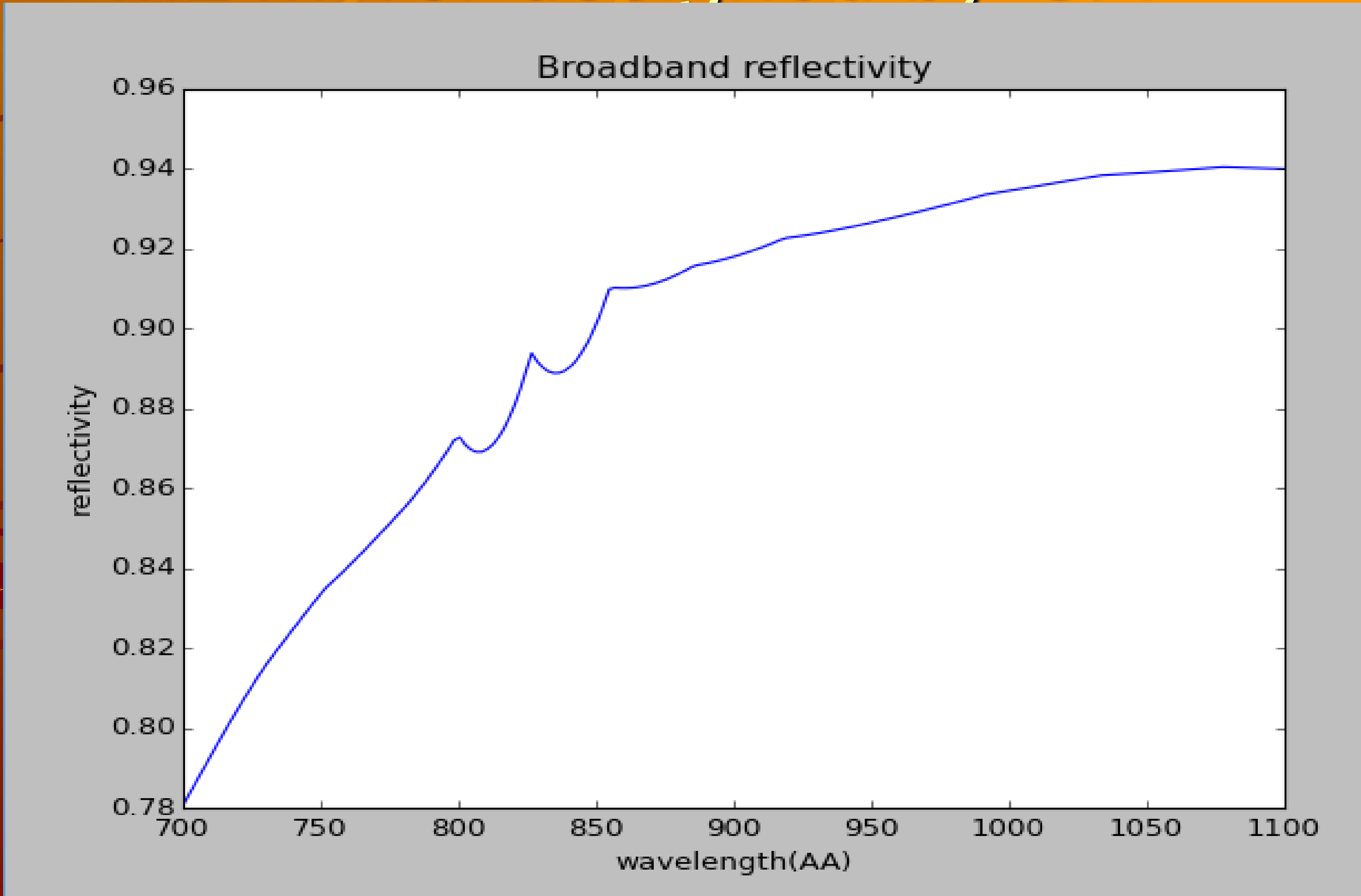
Reflectivity<Lu,261><TiC,150><Al,100><Sr,108><Ir,81>
5° (from Normal)
Substrate is silicon carbide. Overlayer is 500Å Al.
Reflectivity<Yb,167><W,111>
Reflectivity
1.0
0.8
0.6
0.4
0.2
0.0
300
400
500
600
700
800
900
1000
1100
Wavelength (AA)

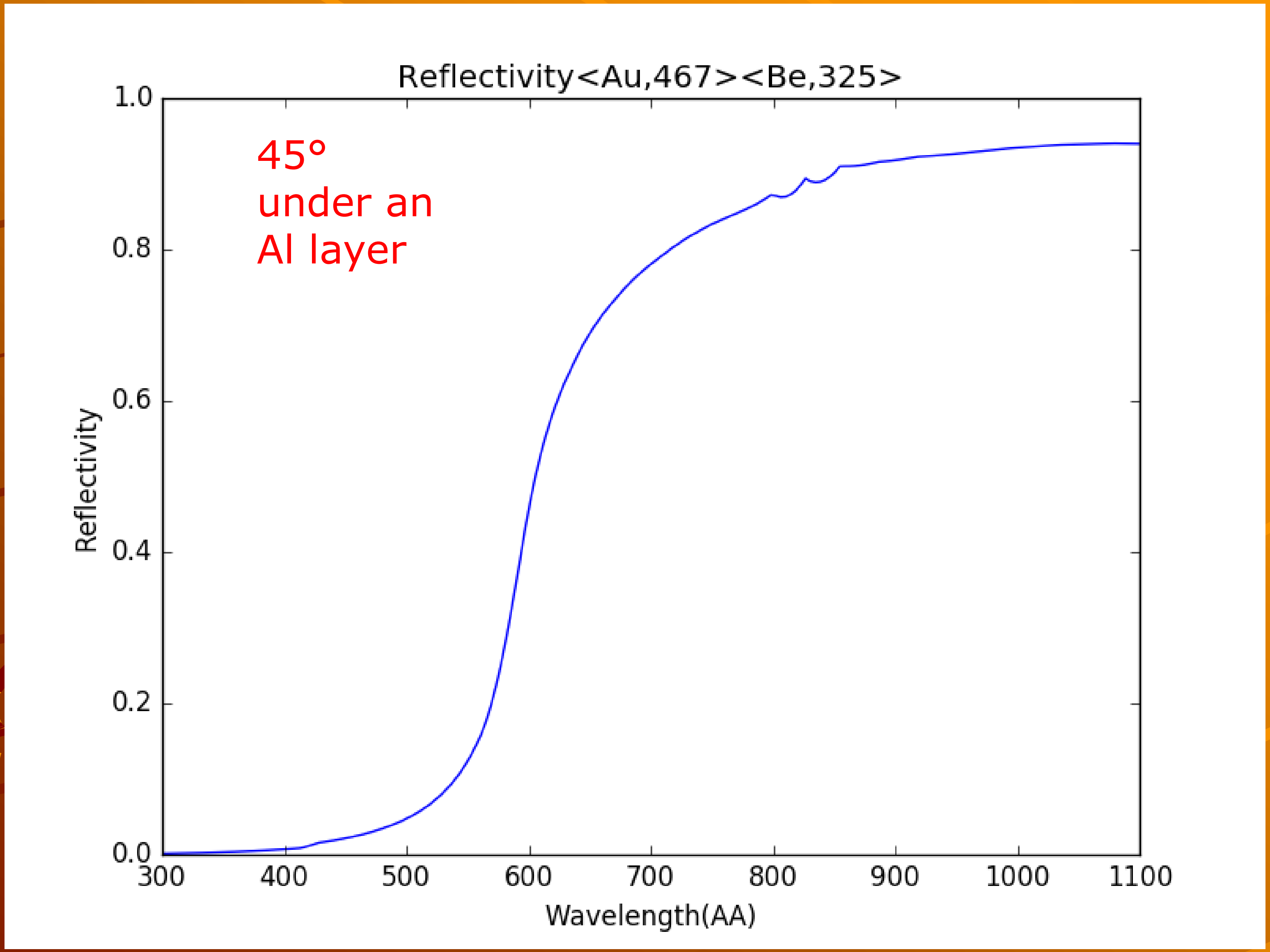
An exploratory design of wide VUV-EUV & 30 nm



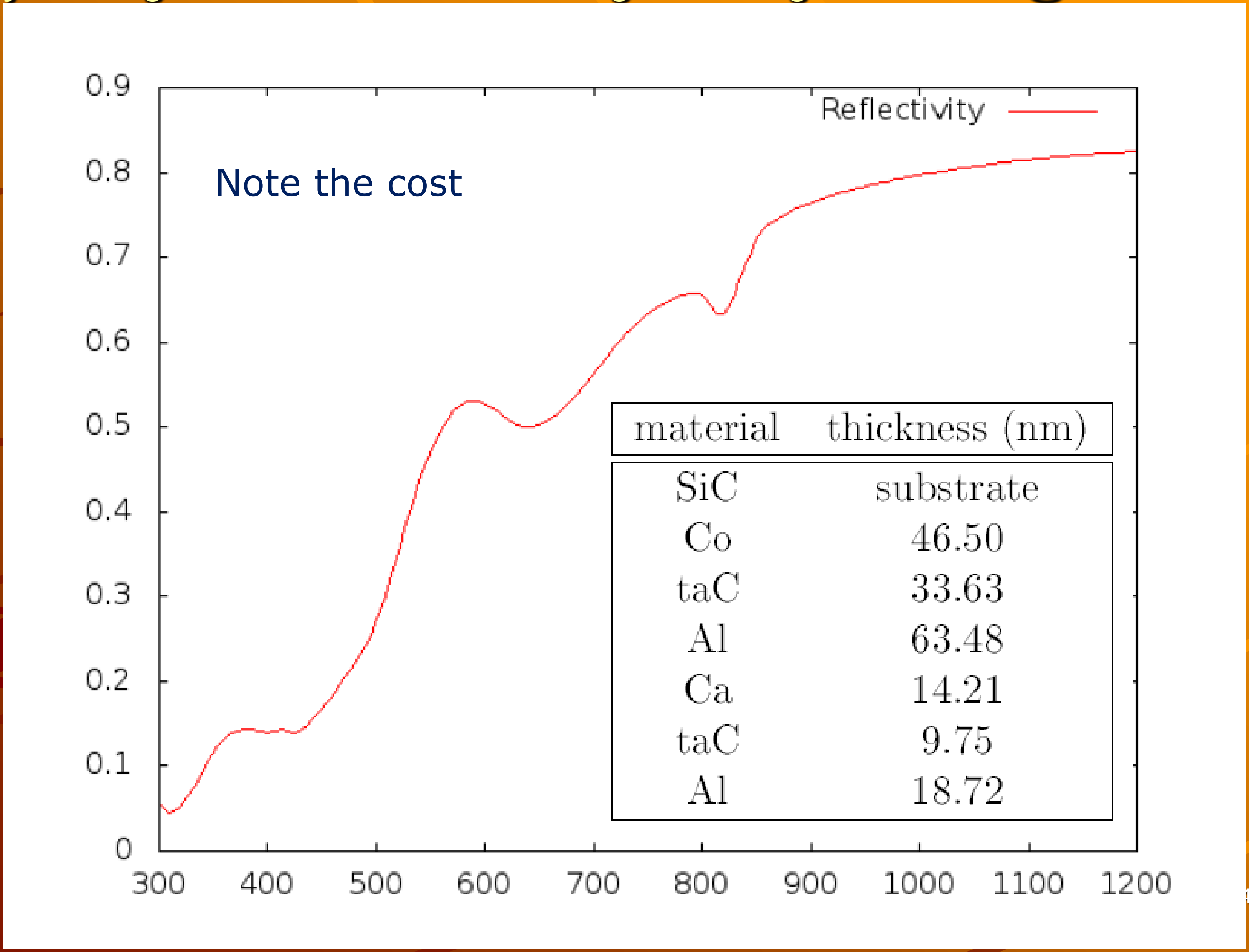
material	thickness (nm)
SiC	substrate
taC	10.61
MgL	8.61
taC	8.68
MgL	8.24
taC	9.27
Al	31.91

At 45° reflectance 78 to 94% for ML mirror designed by GA




Reflectivity<Au,467><Be,325>
45°
under an
Al layer
Reflectivity
1.0
0.8
0.6
0.4
0.2
0.0
300
400
500
600
700
800
900
1000
1100
Wavelength(AA)

6 layer to get above 50% for largest range <80nm @ 5° normal



Take home-Part 2

- The mirror with the largest bandwidth will be a Multilayer (ML) VUV-EUV Mirror Coated with as Thin as Possible Aluminum Film-
  - without oxide/ fluoride overlayers. Space Processing
- We need the EUV ASAP. Definitely for LUVOIR
- Let’s do it

& Acknowledgements

Ben Smith.
Joel Fuentes (summer NSF REU student)
Paul Allred- helpful conversations
Western Alliance to expand Student opportunities.
An NSF Louis Stokes Alliances for Minority Participation
NSF REU #PHY1461219
NASA-Utah space grant consortium grant 2015-16

50 questions about next-generation broadband mirrors for space-based observatories

- 1 Broadband mirror coatings & aluminum:
- 2 Understand oxidization of aluminum mirrors
  - characterization tools
- 3 Barrier layers against oxidation
  - 3.1 Those that stay on-
  - 3.2 Those that come off:
    - Role of Vacuum deposited/ Vacuum removable barriers-
  - 3.3 point-of-use processing
- 4 Applications
  - 4.1 Beyond 15 eV: Aluminum becomes (partially) transparent below its plasma edge at about 85 nm 4.2 Space observatory applications
- 5 Practicalities: How raise TRL.