Filter degradation in long-term solar monitoring

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Outline

History of UV-induced carbonization studies at NIST

Data on filter degradation on the Solar Dynamics Observatory

Testing the carbonization hypothesis

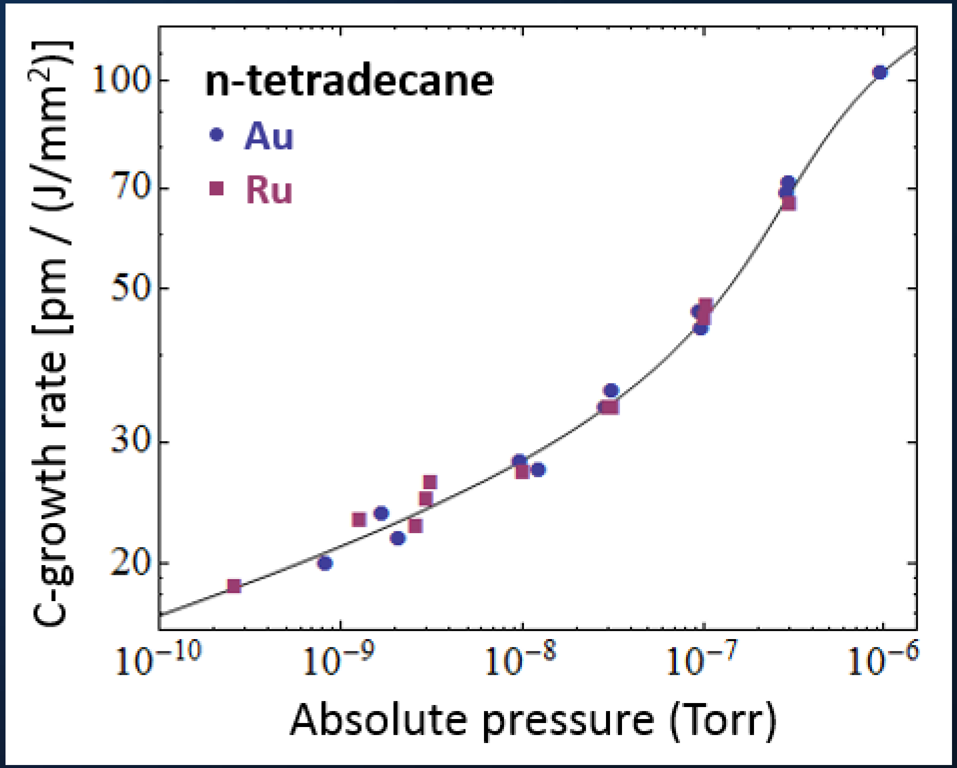
Oxidation studies

Summary

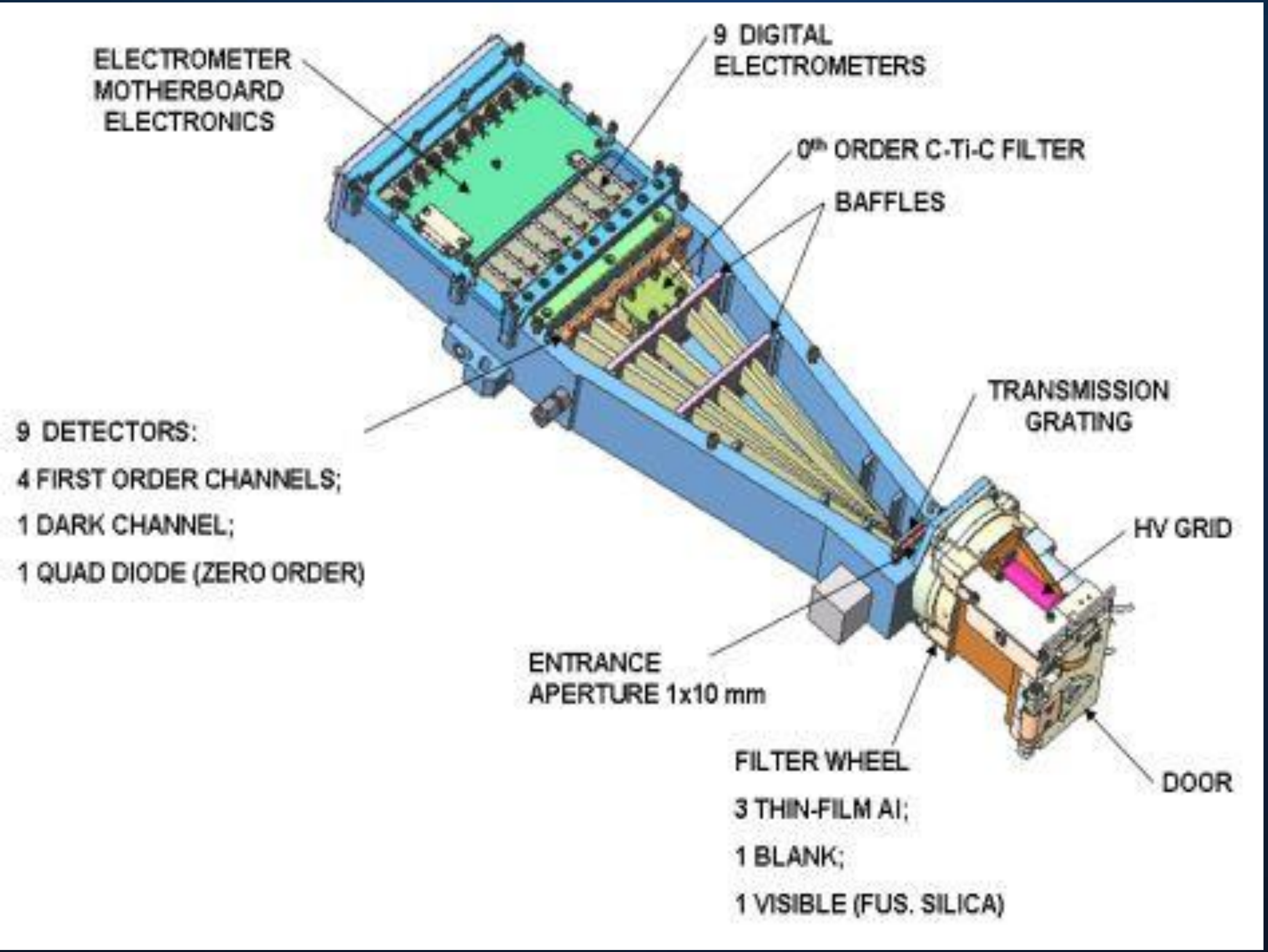
NIST has a long history of carbonization studies

Began working closely with microelectronics industry developers of EUV lithography at the very beginning with focus on optics lifetime testing

First in R&D community to develop realistic model to allow extrapolation of carbonization rates to very low pressures.



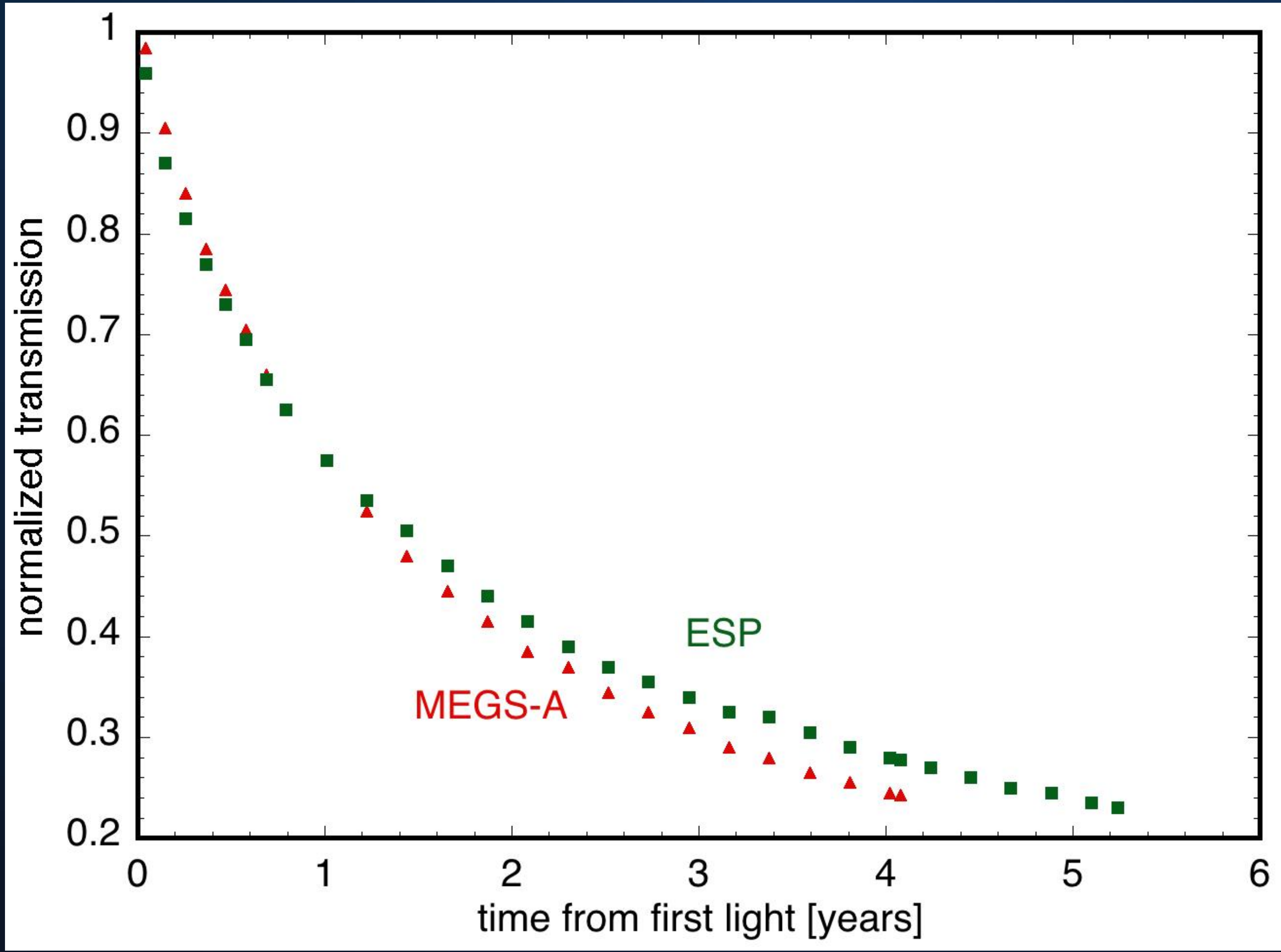
EUV spectrophotometer (ESP)



Most of the degradation likely occurs at the entrance filter, a thin film that serves to reject out-of-band radiation

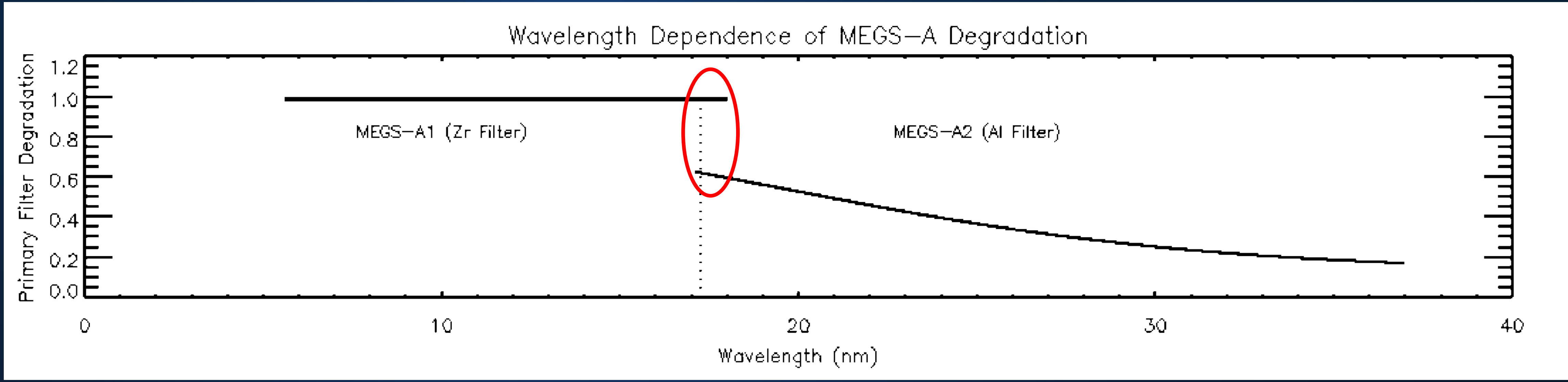
It's generally believed that the degradation is largely or entirely due to carbon growth

Degradation of aluminum channels of two instruments on SDO



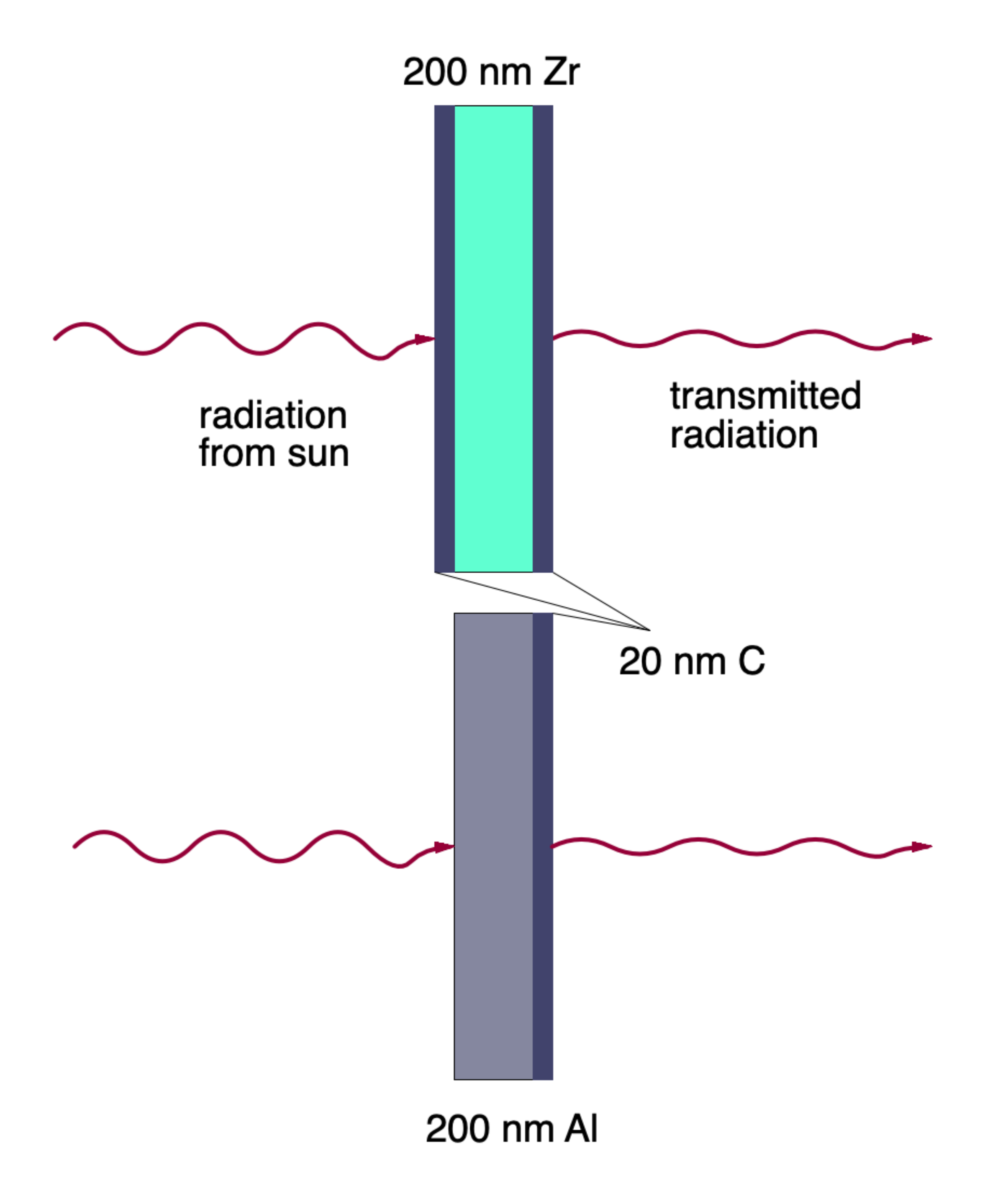
Instruments degraded about 40% in the first year at wavelengths around 30.4 nm

Wavelength dependence of degradation after four years



Even in the overlap region 17-18 nm, the Zr filters shows almost no degradation, while the Al shows around 40 %

Also: instruments have become considerably cleaner, but degradation hasn't been reduced as much as expected



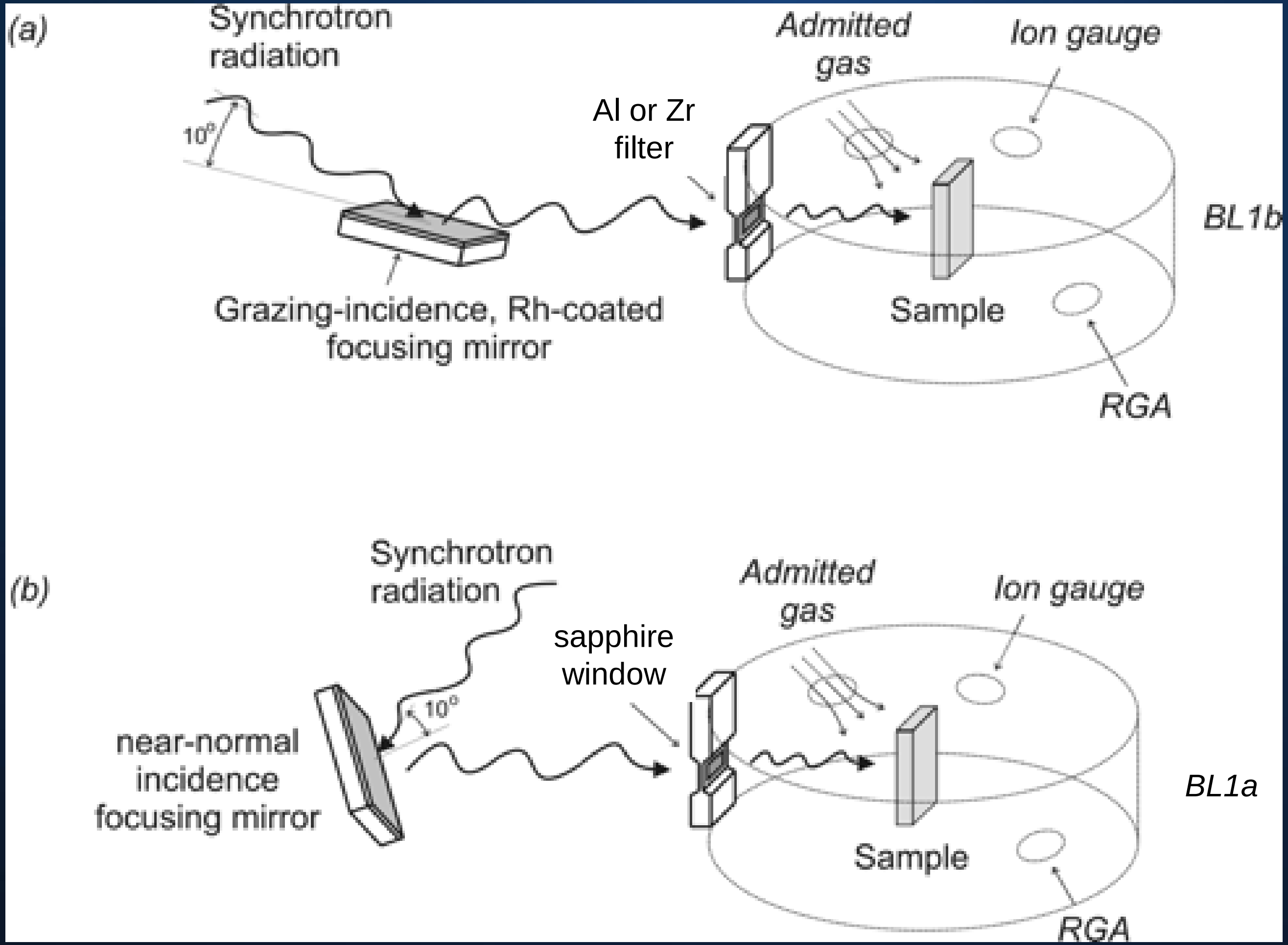
MEGS filters:

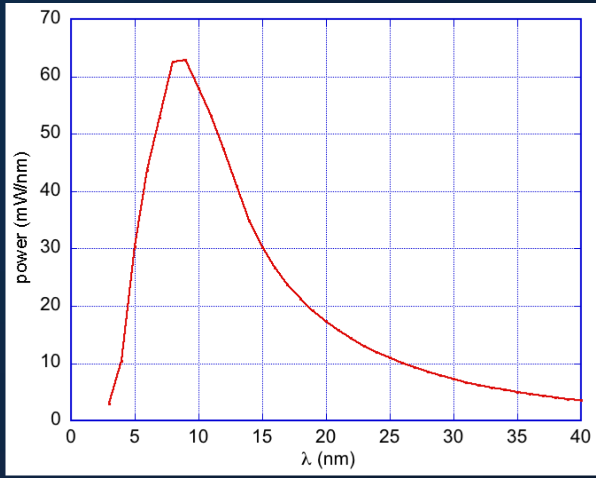
Zr filter has 20 nm C coating on both sides, which prevents oxidation but not carbon growth

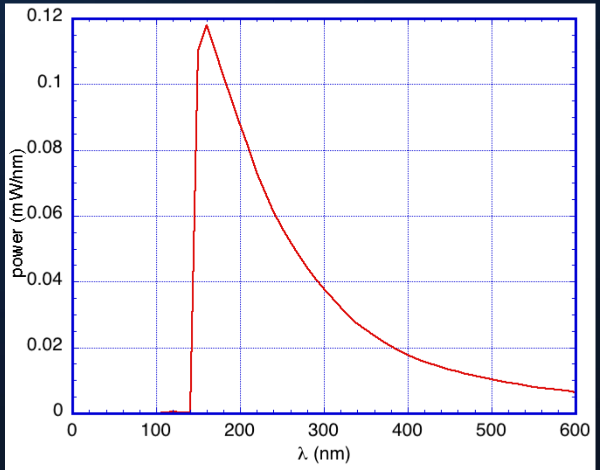
Due to high absorption in the Al bandpass, the Al filter has protective C on only the downstream side

ESP Al filter has no protective carbon coating

Beamline 1 – Laboratory tests







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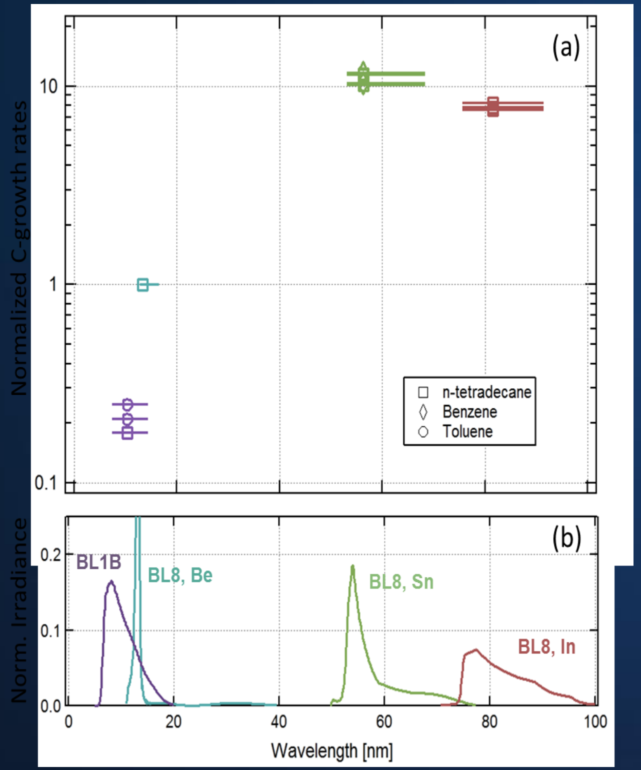
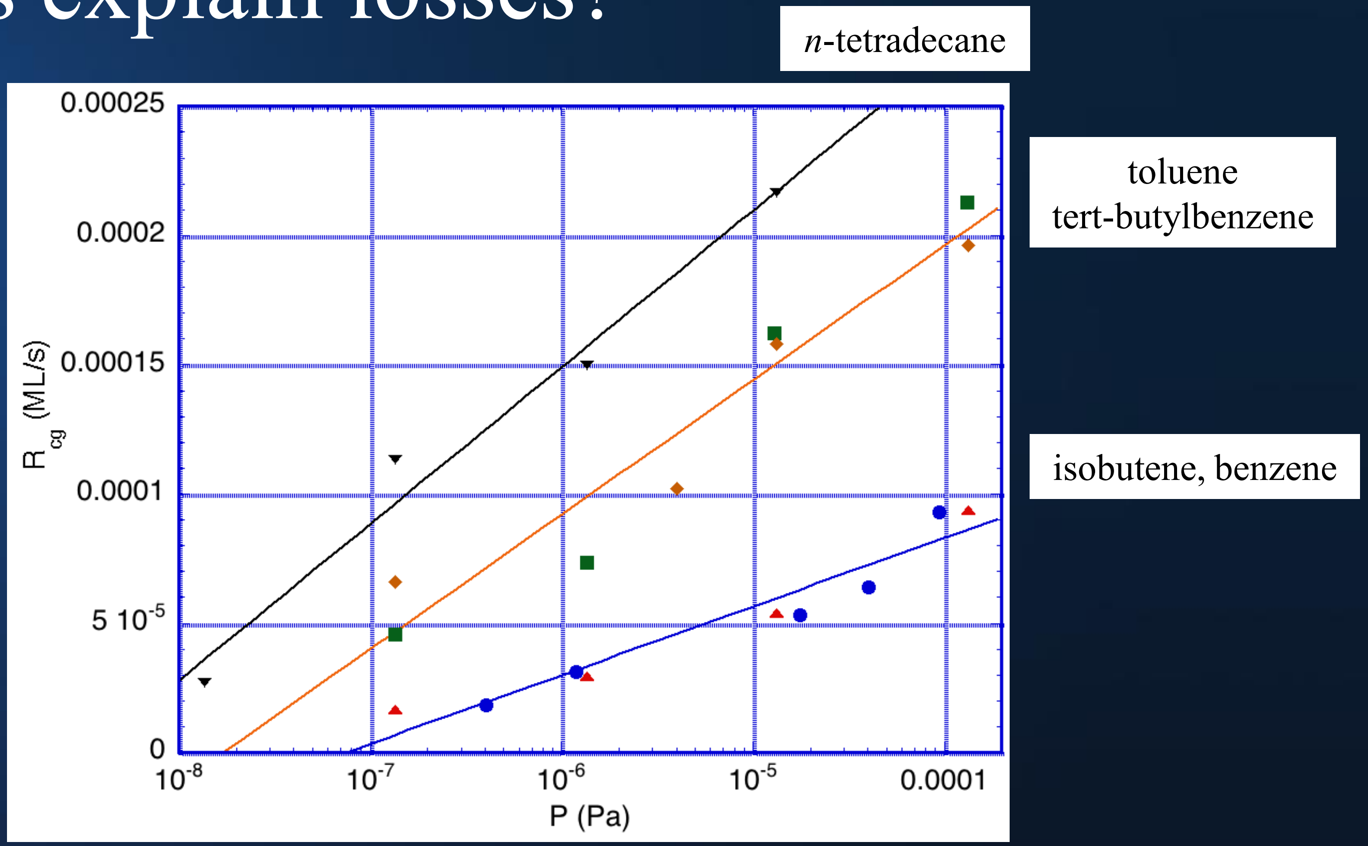
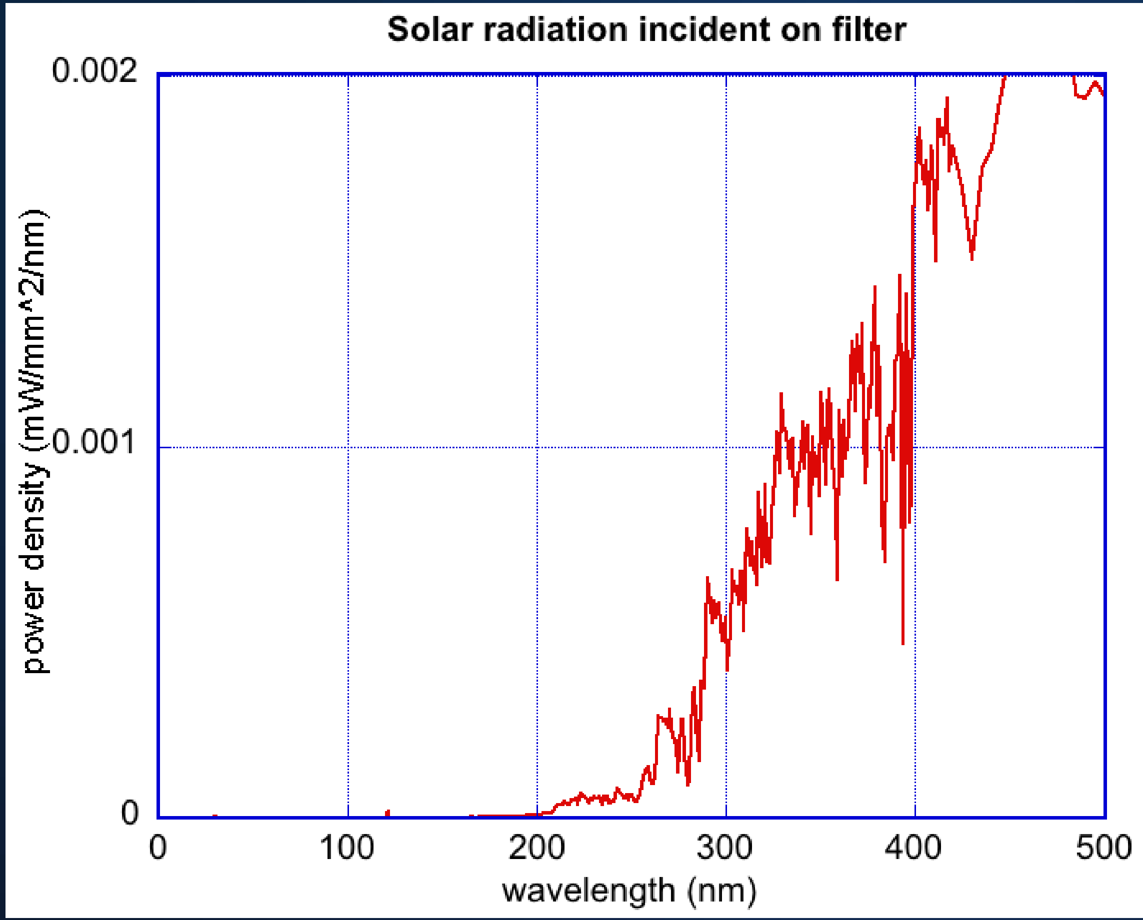
Lab test I: Can carbonization on the downstream sides of filters explain losses?

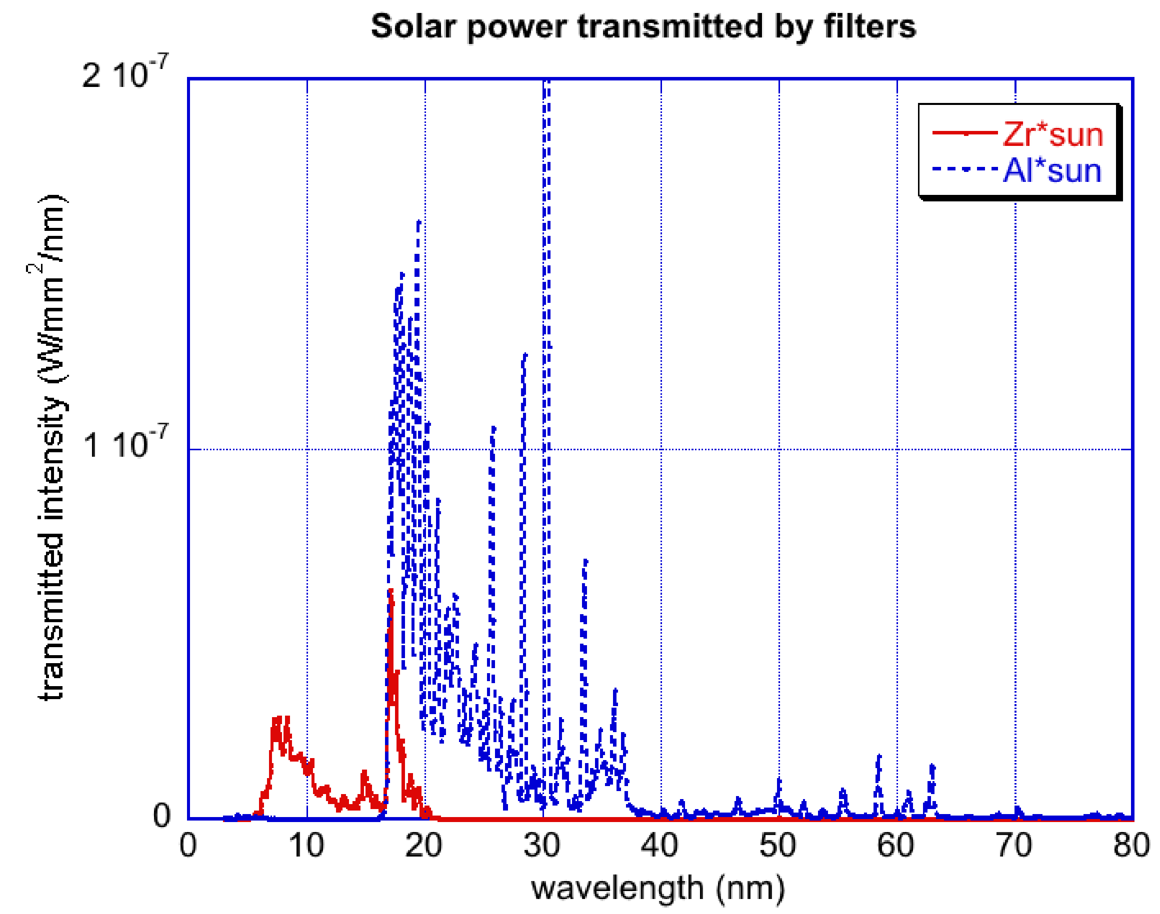




Contamination rate increases with wavelength

Contamination rate varies slowly with pressure
Molecules group into low, medium, and high contamination rates
We've selected toluene as a representative organic contaminant





Radiation incident on satellite filters (left) is orders of magnitude greater than that transmitted.
Away from saturation, we have demonstrated that carbon growth is linear with intensity, so it would be expected that contamination would be greater on the sun-facing surface of the filter.

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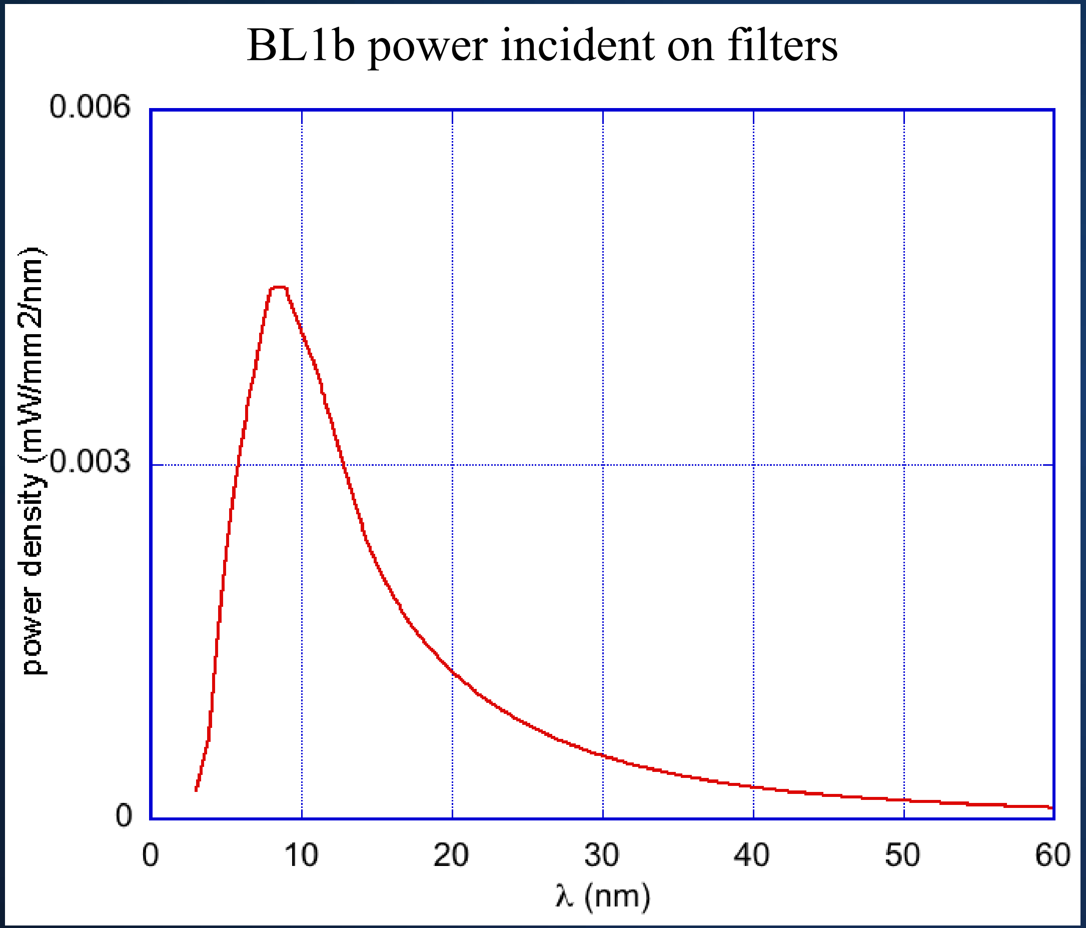
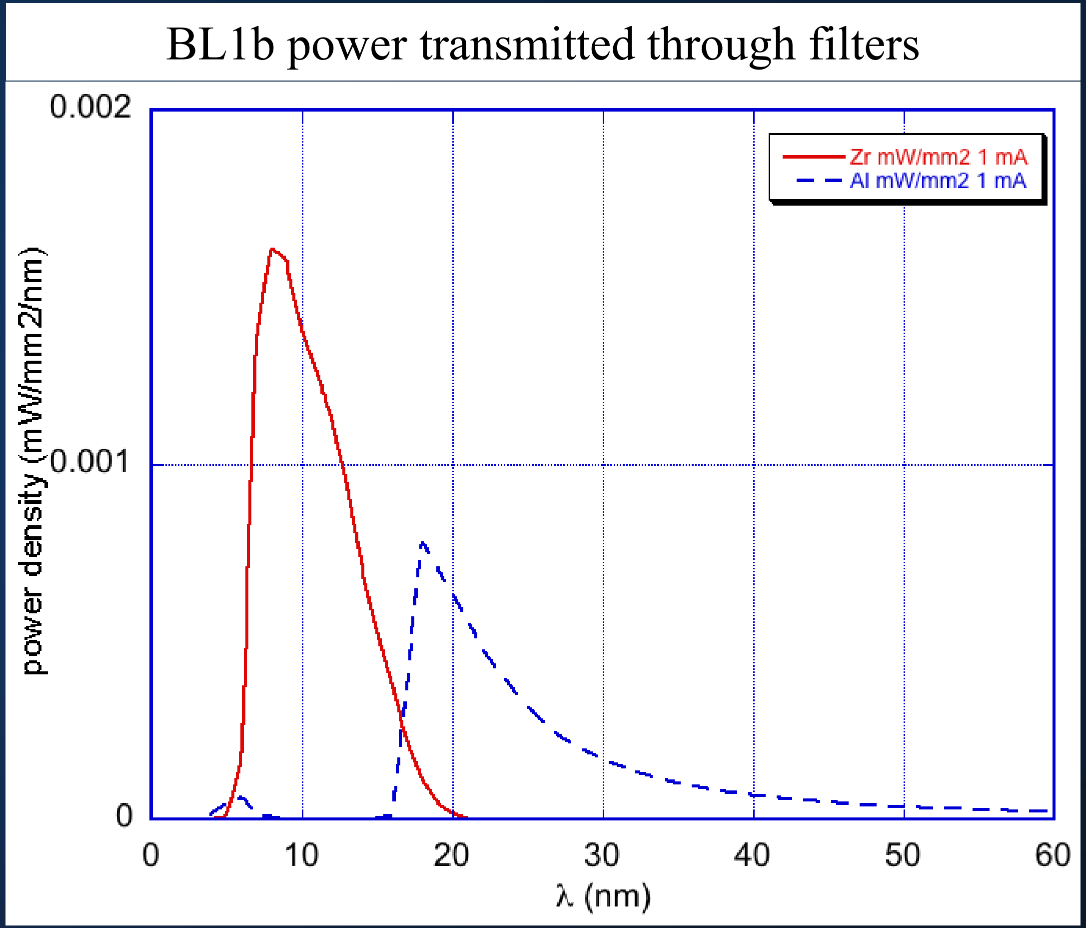
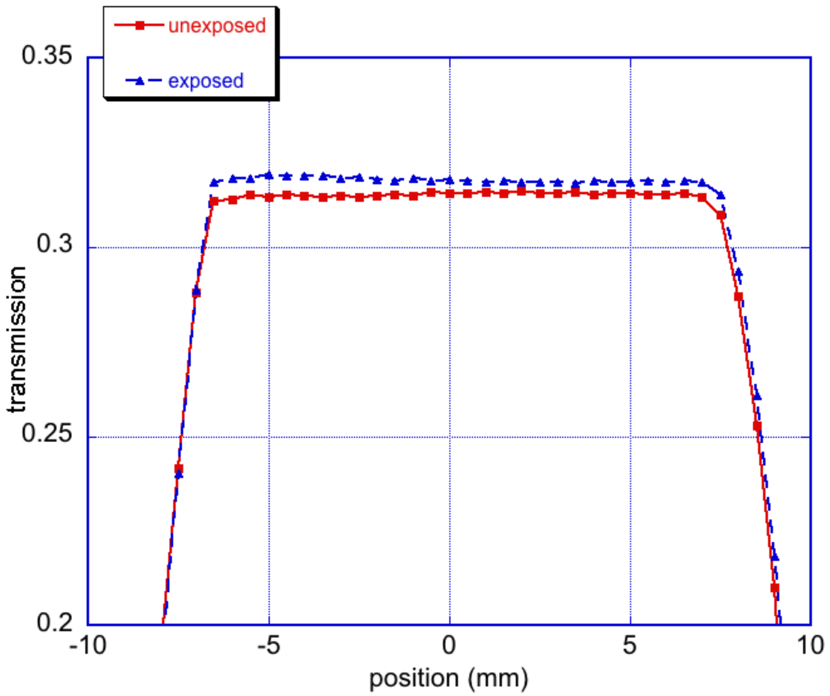




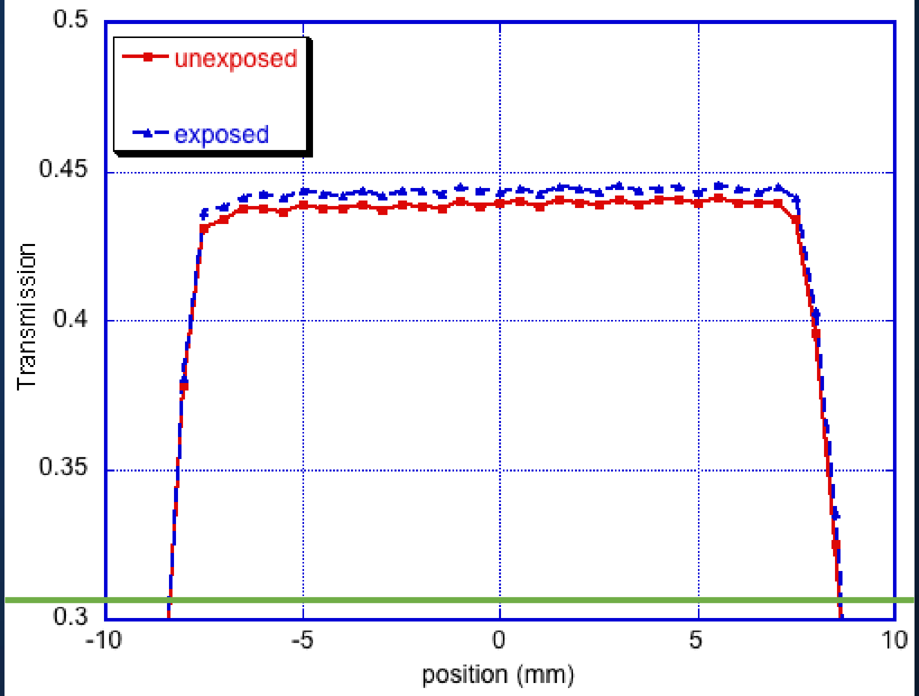
Radiation incident (left) on filters on BL1b. Right is transmitted, which is still orders of magnitude greater than that seen by filters on satellites. Since longer wavelengths cause more contamination growtn, we've given more weight to longer wavelengths when comparing SURF to solar damage rates. We estimate that 5 years of solar exposure on the downstream sides of filters can be achieved on BL1b in 1 hr for Zr and 5 hr for Al at reduced beam currents

Results indicate carbon growth is unlikely the culprit

Zr filter transmission 13.5 nm



Al filter transmission 17.5 nm



Green line indicates Al transmission loss equivalent to five years solar exposure

The small increase in transmittance after illumination is likely photon-stimulated desorption of adventitious organics and possibly water vapor

1 nm of grown graphitic carbon corresponds to a 0.7% relative decrease at 13.5 nm and 1.1% at 17.5 nm

Based on these results, growth of 40 nm of C on the backside of a filter is exceedingly unlikely

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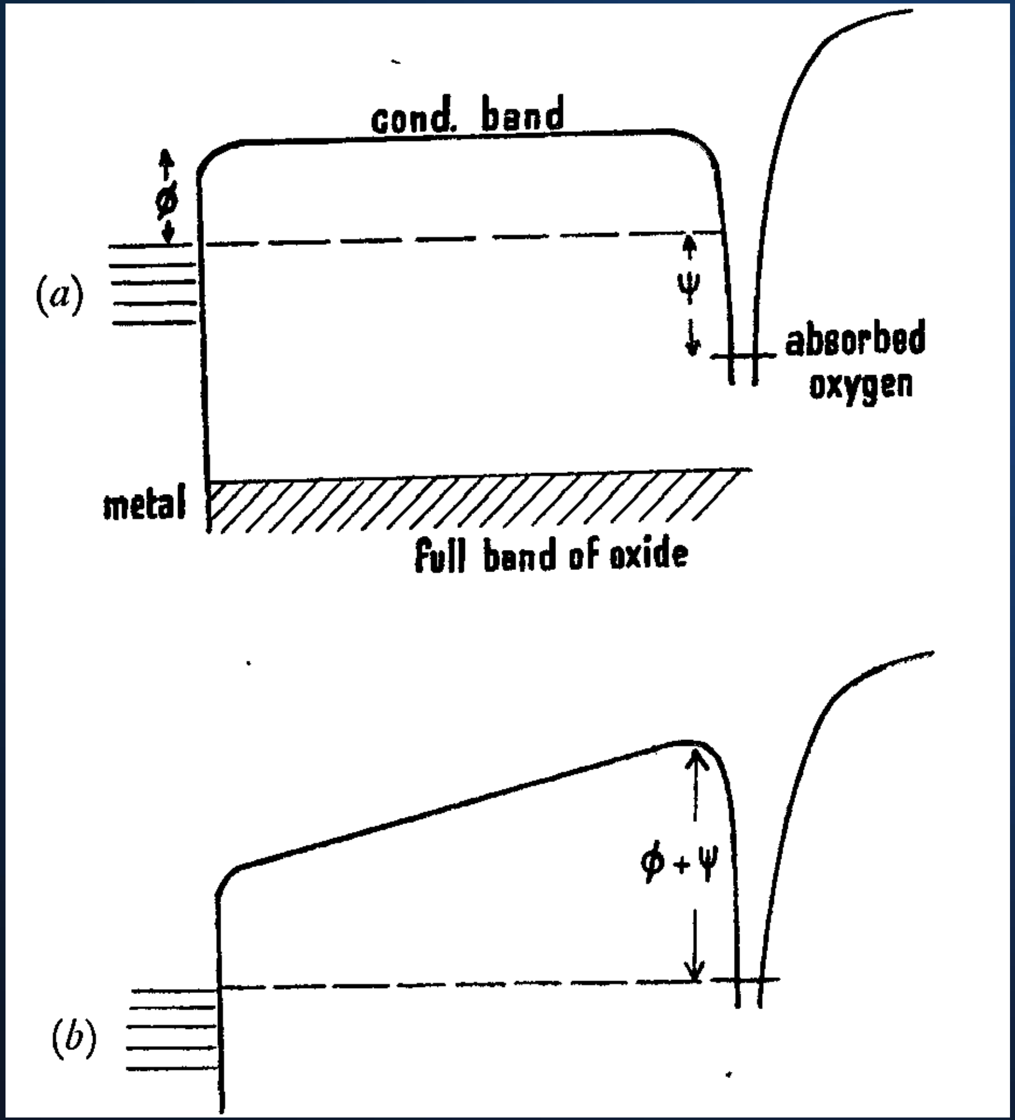
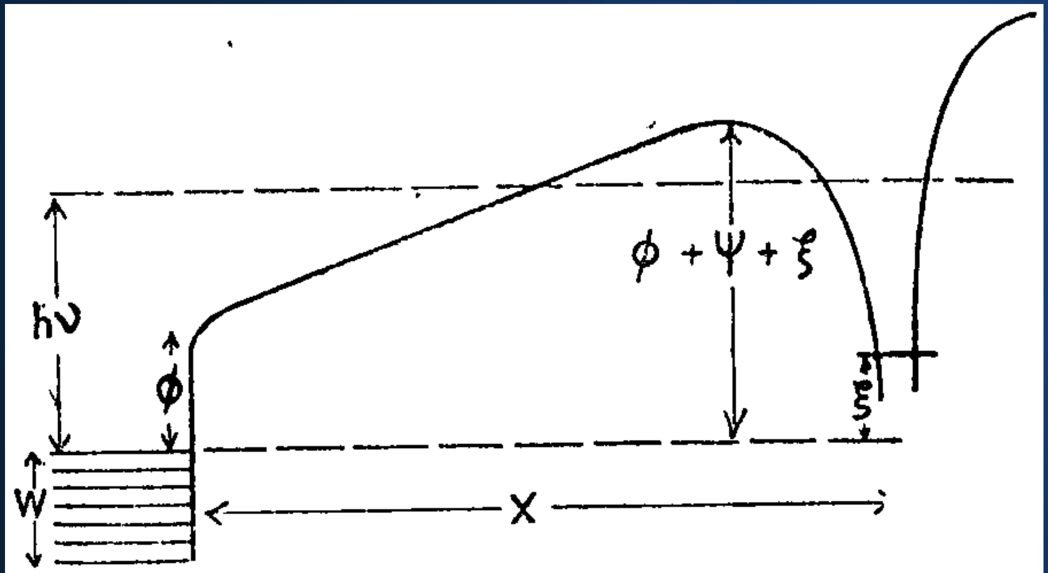
The case against oxidation



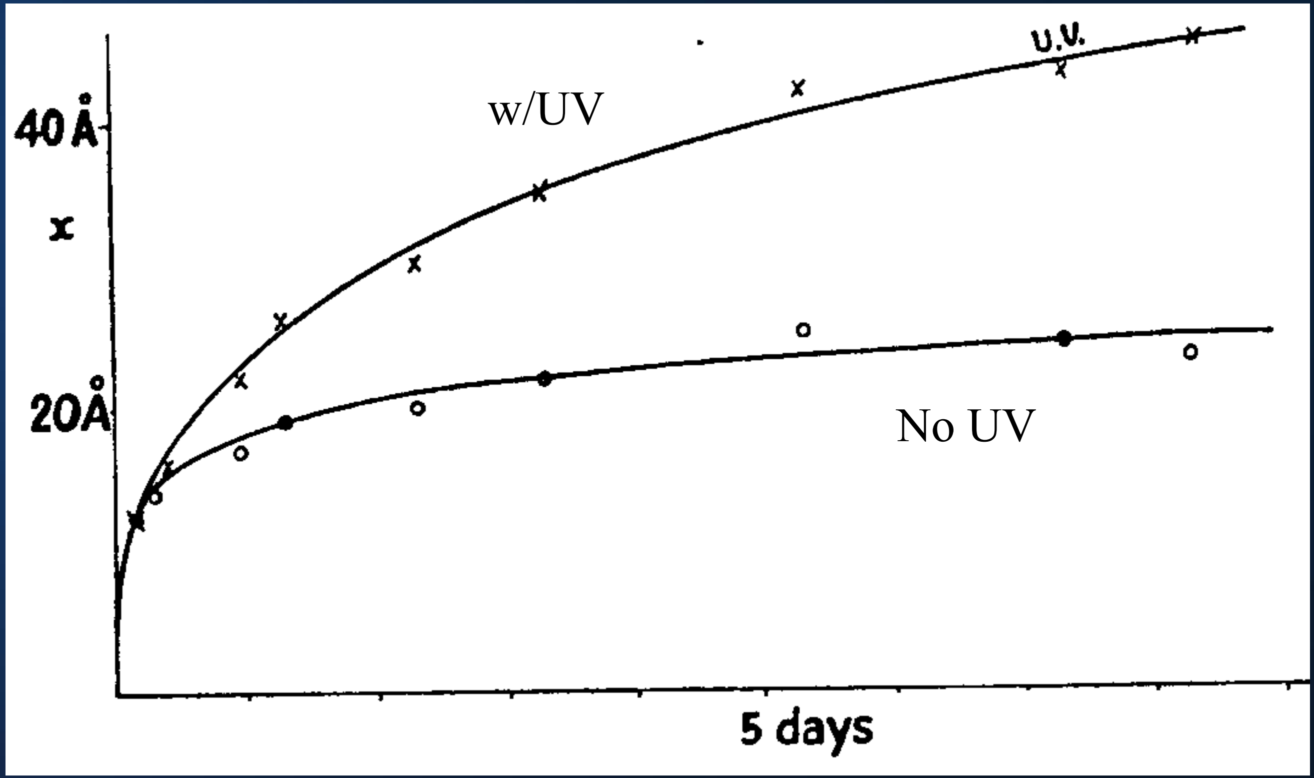
Cabrera and Mott, Rep. Prog. Phys 12, 163-184 (1949): Many metals, including Al, develop a ~2 nm self-limiting oxide layer

Adsorbed oxygen ions cause a large electric field, which draws aluminum ions from the metal causing oxide formation. Limit arises from electric field weakening with oxide thickness.

But UV changes that



Cabrera, Phil. Mag. 40, 175-188 (1949): added energy from UV can lead to greater oxide thickness

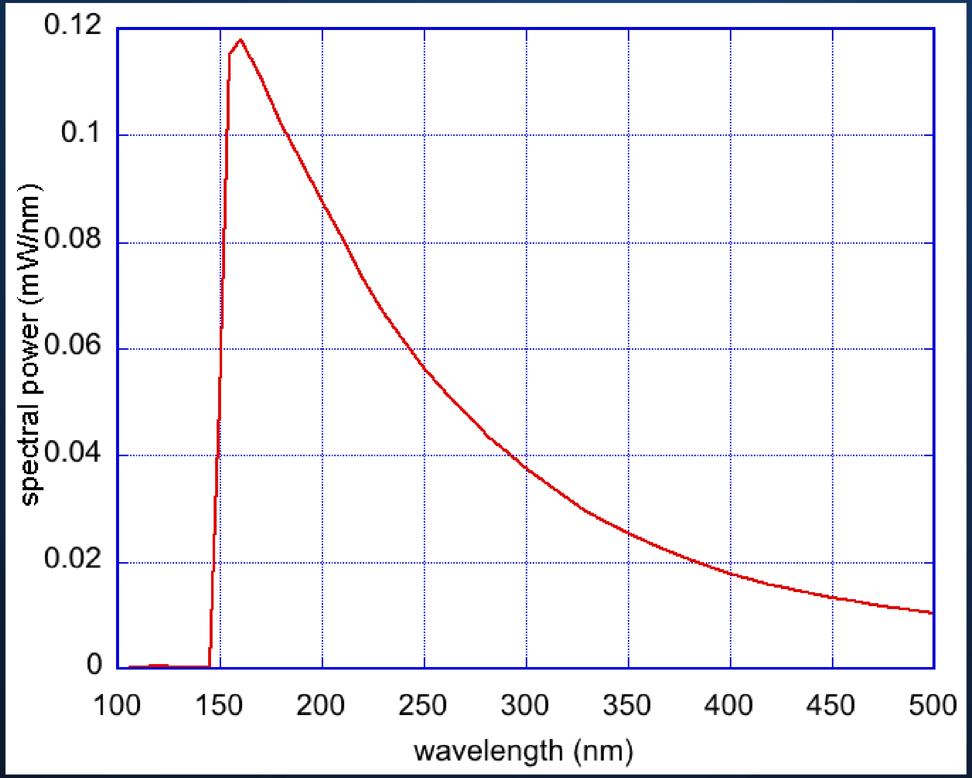


Cabrera, Terrien, and Hamon, Comptes Rendus 224, 1558 (1947). Aluminum exposed to mercury lamp (254 nm) in moist air.

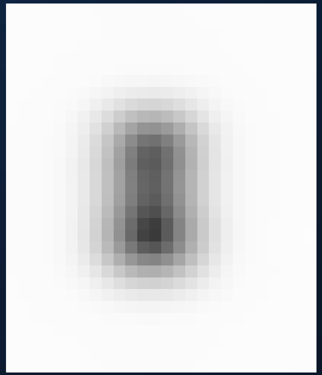
Oxidation studies

expose freestanding filters in the presence of 10^{-6} mbar water vapor

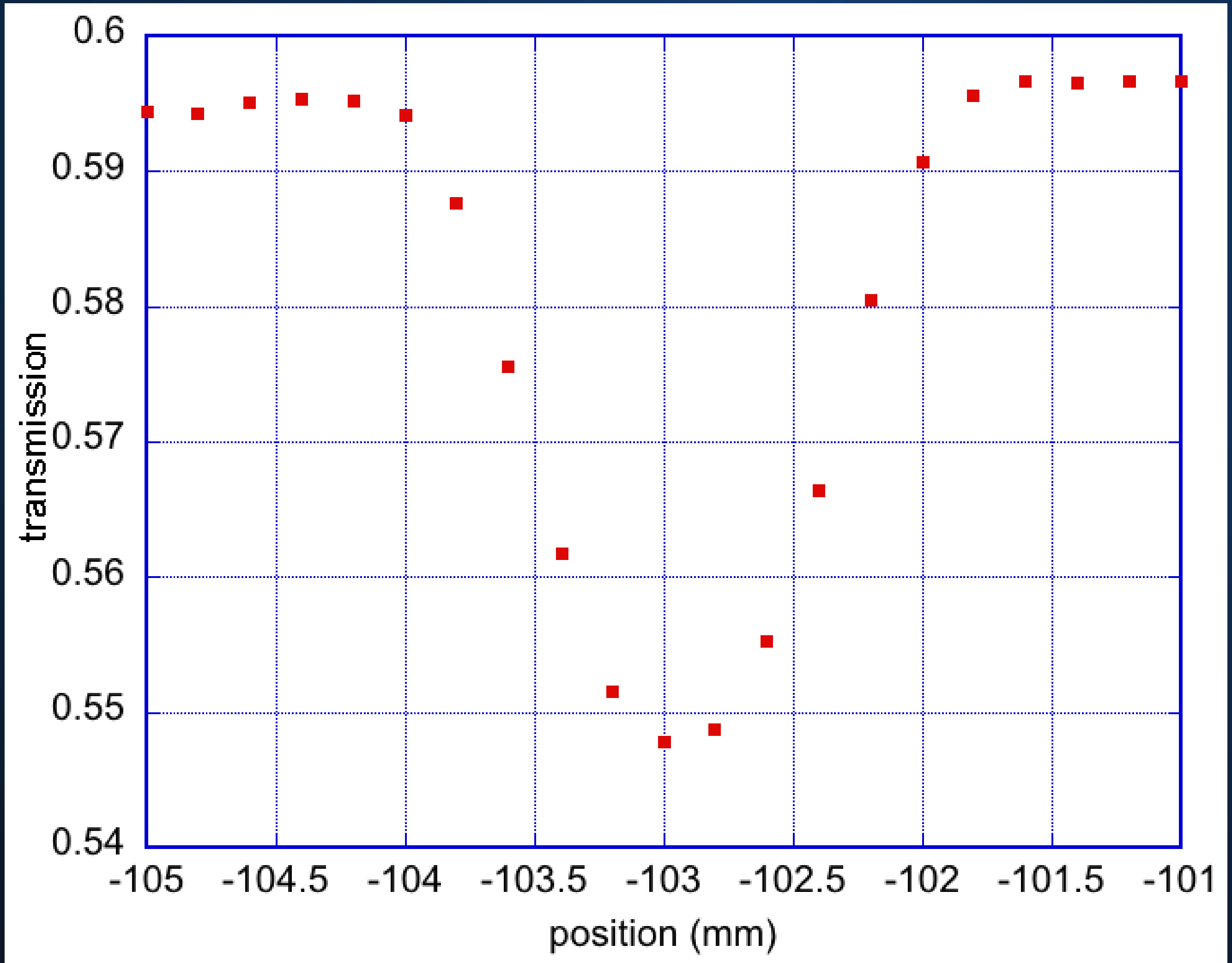
BL1a spectrum with sapphire window



Spot profile



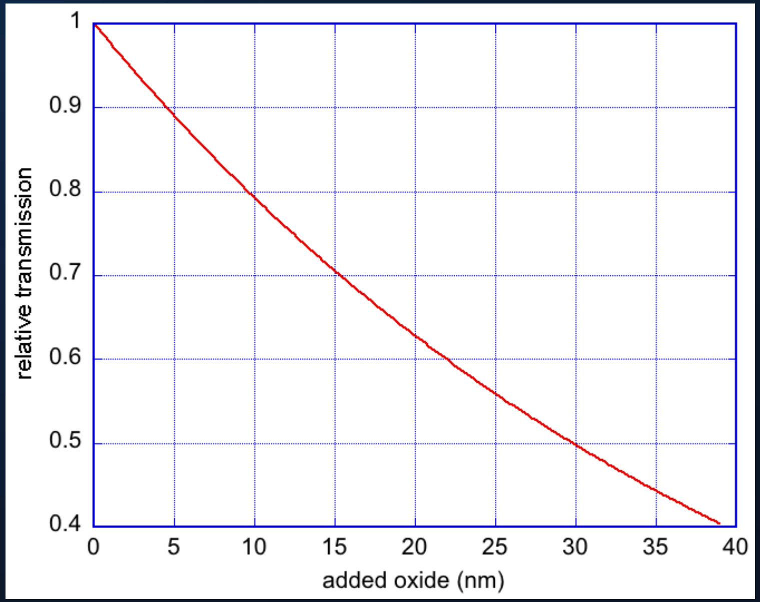
Measurement of oxide thickness



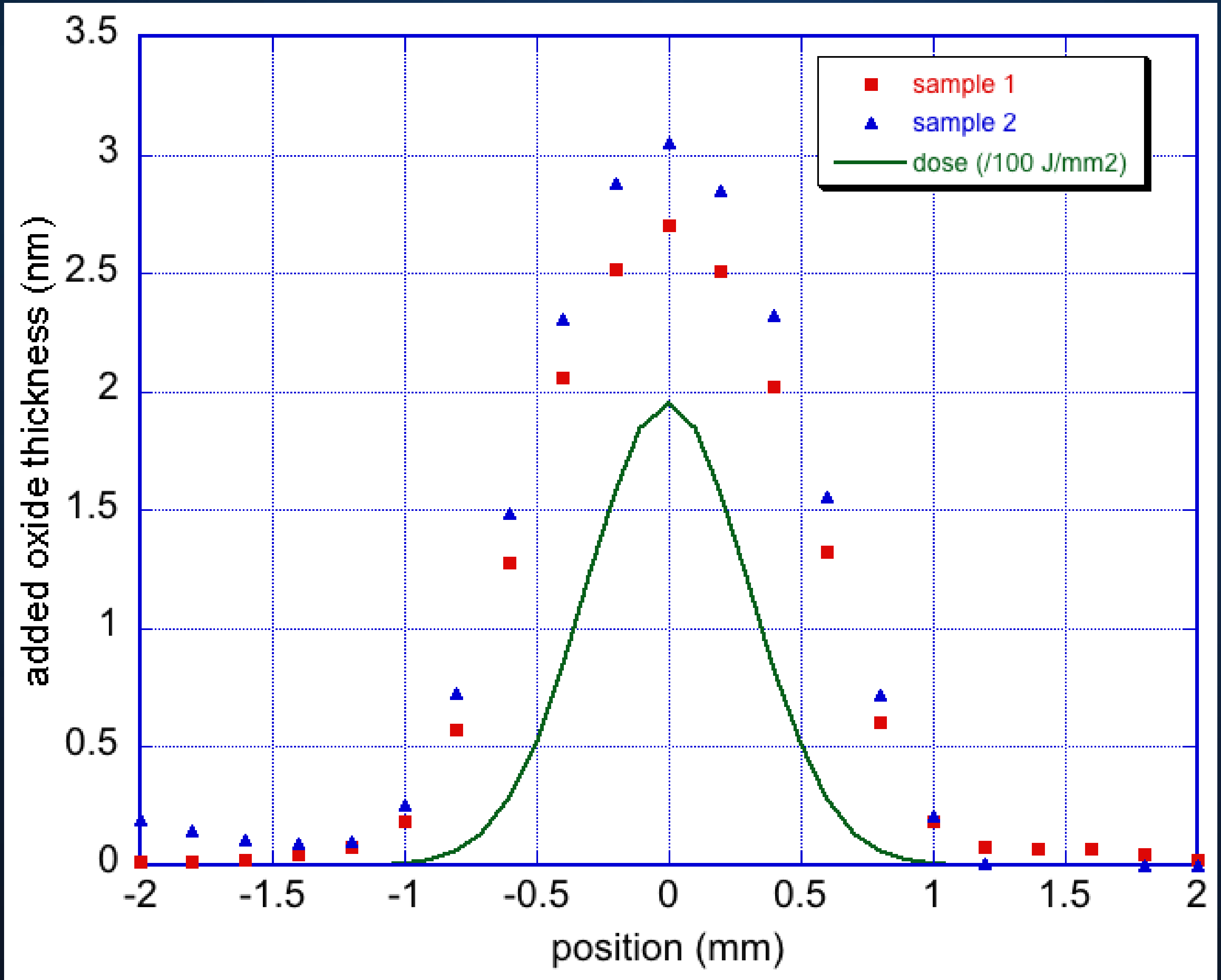
Measure EUV transmission at 17.5 nm as a function of position

Intrinsic oxide on these evaporated films is about 4 nm

Transmission loss is related to added oxide thickness



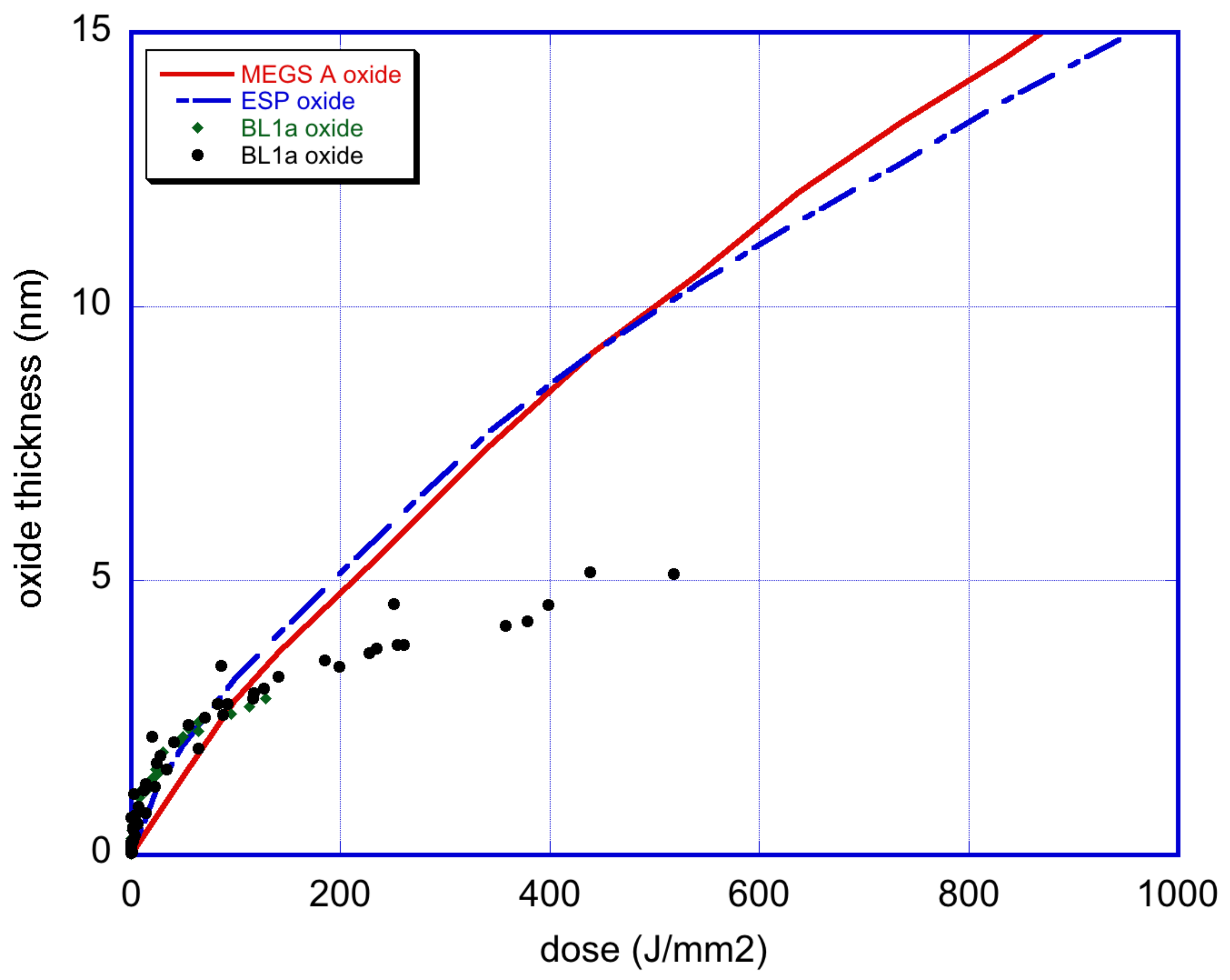
Oxide thickness, two different 200J/mm^2 exposures



Oxide thickness can be mapped onto the known exposure dose

Note that exposure spot has smaller FWHM than the grown oxide spots, showing sub-linear growth

Comparison of lab results to satellite data



Initial results match well, but there's a falloff in oxide growth at larger doses

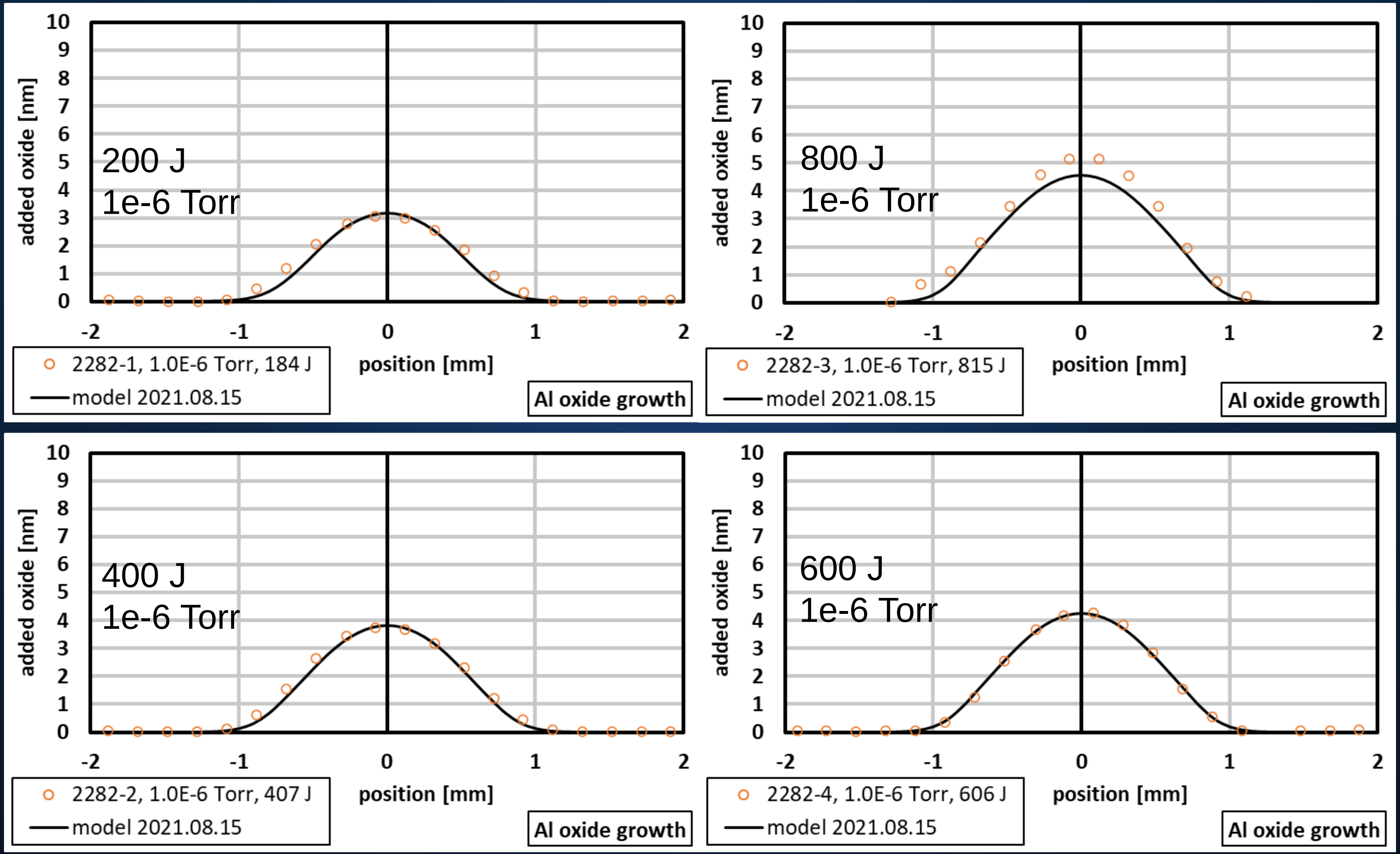
Not due to incorrect dose-matching – functional dependence is different

Roughly square-root dependence in spacecraft, roughly cube-root in lab experiments

Experiments indicate no temperature dependence

Time- (or intensity-) dependence? Need a model

Modeling beginning to shed light on growth process



Initial modeling indicates this is probably due to the very low irradiance in the spacecraft

Reduced field in oxide allows more electrons to reach surface in thicker oxide

Summary and future work

Carbon growth is unlikely the dominant cause of instrument degradation on SDO

VUV radiation can grow oxide well beyond the Cabrera-Mott limit

Continue modeling and pursue the possibility of exposures for very long periods of time at very low intensities

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