EUV and e-beam exposures of Ru-capped multilayer mirrors

S. B. Hill, C. Tarrio and T. B. Lucatorto
NIST

D. Buchenauer, L. E. Klebanoff and W. M. Clift
Sandia National Laboratories

S. Bajt†
Lawrence Livermore National Laboratory

O. Wood II, S. Wurm and N. V. Edwards
SEMATECH

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Outline

- Background on problem of developing an accelerated testing model for P.O. box mirrors
- New EUV 10-hour exposure data from scaling tests on Ru-capped multilayers: ΔR vs. p_{H_2O} and I
- Surprising results – damage *decreases* with increasing water vapor
- Conclusions (Caveats)

Degradation of EUV projection optics

Industry Problem

Lifetime of Mo-Si multi-layer mirrors (MLM) under anticipated projection-tool conditions *much* too short.

Required: $\Delta R<1\text{-}2\%$ over 30,000 hr lifetime

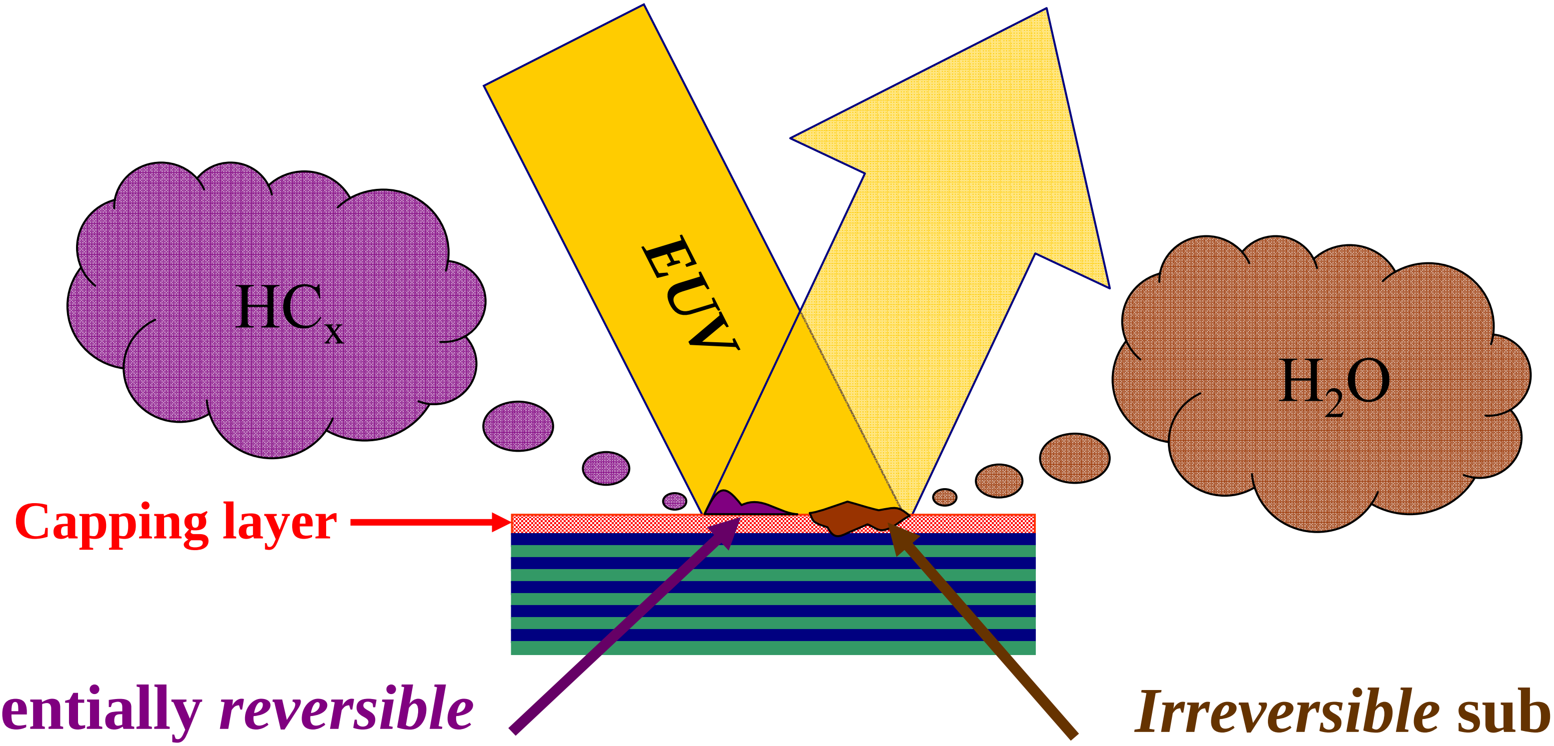
Conditions: EUV intensity, $I_{EUV} \leq 10\ \mathrm{mW/mm^2}$
Unbaked vacuum, $P_{H_2O} \sim 10^{-7}$ Torr, $P_{HC_x} \sim 10^{-10}$ Torr

Goal

Develop metrology techniques to estimate lifetime of new, more robust MLs under anticipated projection-tool conditions.

- Predict ML lifetime in tool ($\sim 10^4$ hrs) from $\sim 10^2$ hrs of accelerated testing at aggressive I_{EUV} and $P_{H_2O,\ HC_x}$ conditions

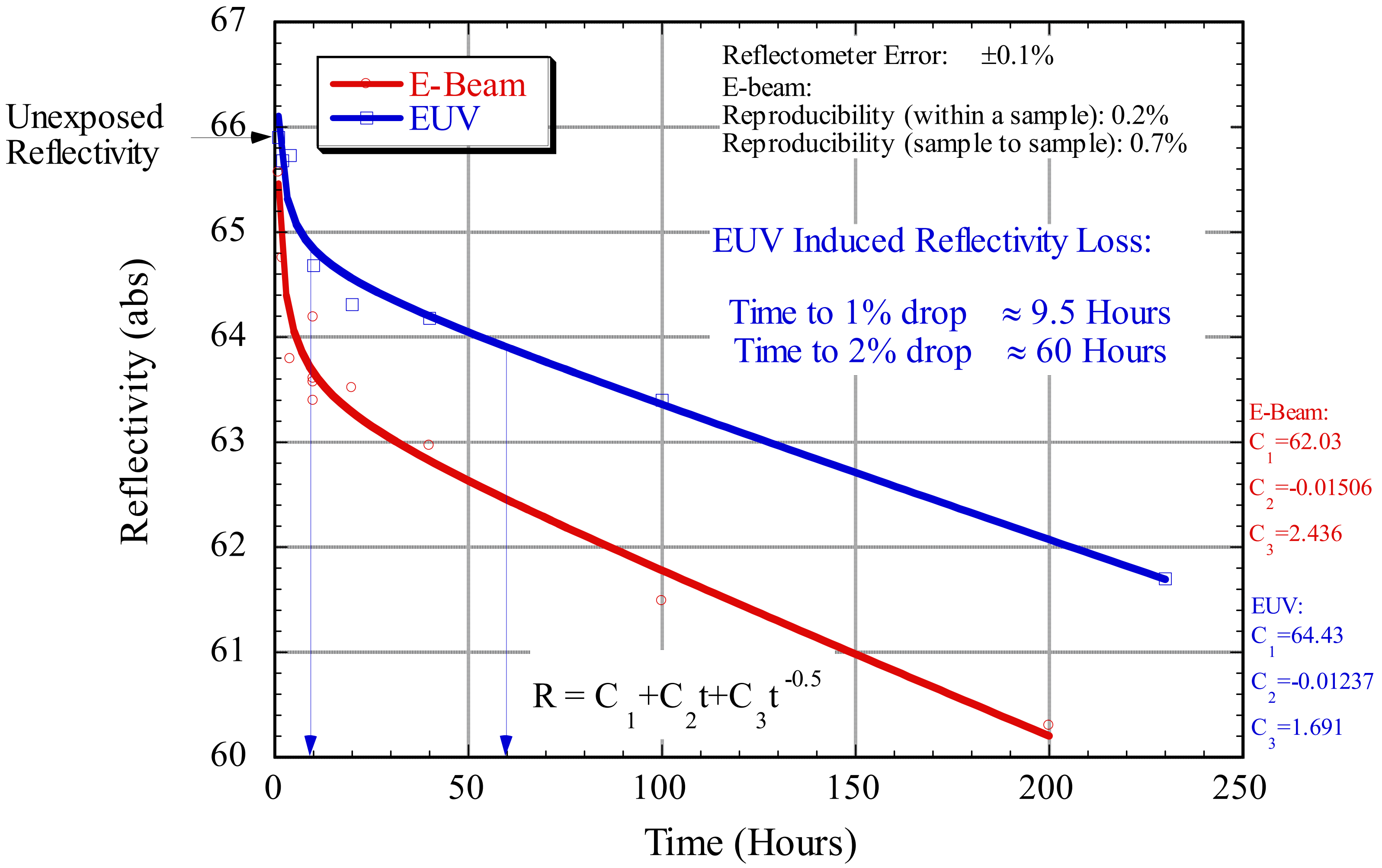
Present assumption: two dominant species



Potentially *reversible* surface carbon growth

***Irreversible* sub-surface oxidation**

E-Beam and EUV Induced Reflectivity Loss for Ru-capped MLM



Reflectometer Error: ±0.1%
E-beam:
Reproducibility (within a sample): 0.2%
Reproducibility (sample to sample): 0.7%

EUV Induced Reflectivity Loss:

Time to 1% drop ≈ 9.5 Hours
Time to 2% drop ≈ 60 Hours

$R = C_1 + C_2 t + C_3 t^{-0.5}$

E-Beam:
$C_1 = 62.03$
$C_2 = -0.01506$
$C_3 = 2.436$

EUV:
$C_1 = 64.43$
$C_2 = -0.01237$
$C_3 = 1.691$

Final Report for Lith 160, “Electron Beam and EUV Testing of Ru-Capped Multilayer Mirrors,” D. Buchenauer, W. Miles Clift, K. Williams, and L. Klebanoff

NIST approach for accelerated testing model

Phenomenological with two components:

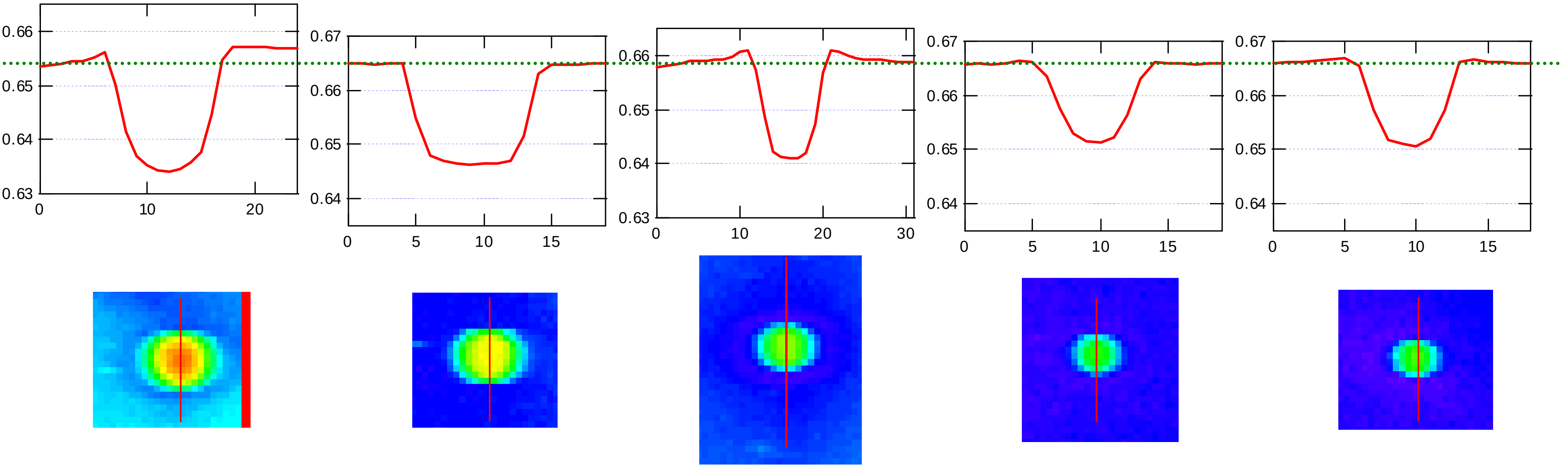
- determine if one can track the “reactivity” or “responsivity” of the mirror surface with an easily observed parameter such as the reflectivity R
- find scaling laws relating dR/dt to I_{EUV}, P_{H_2O}, and P_{HC} for a given reactivity

New series of tests: ΔR vs. p_{H_2O} and I

- All tests for 10 hours
- Two different intensities:
  - Low (~3 mW/mm^2)
  - High (~6 mW/mm^2)
- Five different pressures of H_2O:
  - 0.2, 0.5, 1, 2, and 5 x 10^{-6} Torr
- Trace contaminants in ambient background – measured only intermittently

10hr Exposures at Full Intensity (~6 mW/mm^2)

Reflectivity loss *decreases* with *increasing* water pressure



$2x10^{-7}$ Torr H_2O
6.2 ± 1.9 mW/mm^2
10 hrs (1A-S5)

$5x10^{-7}$ Torr H_2O
5.8 ± 2.1 mW/mm^2
10 hrs (2C-S5)

$1x10^{-6}$ Torr H_2O
5.8 ± 1.9 mW/mm^2
10 hrs (1A-S1)

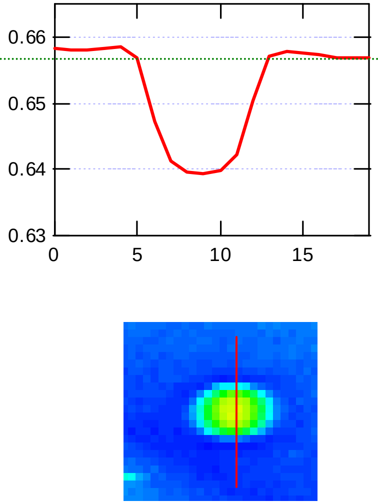
$2x10^{-6}$ Torr H_2O
4.6 ± 1.5 mW/mm^2
10 hrs (2C-S3)

$5x10^{-6}$ Torr H_2O
5.5 ± 1.8 mW/mm^2
10 hrs (2C-S4)

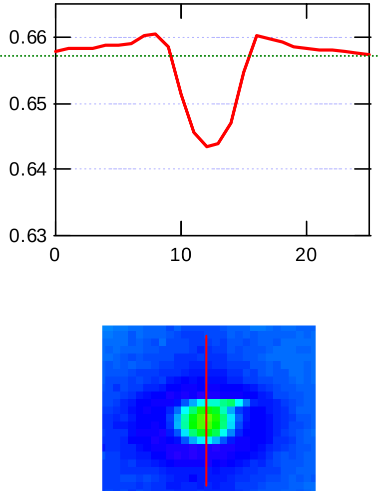
Increasing water vapor pressure

10hr Exposures at Half Intensity (~3 mW/mm^2)

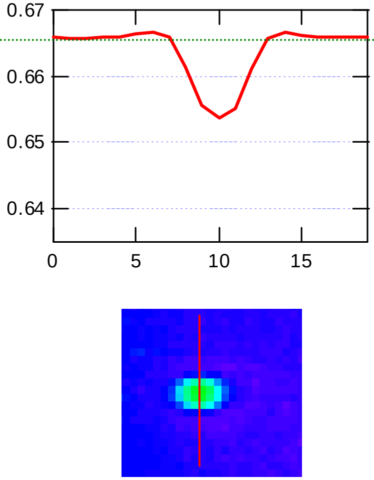
Reflectivity loss *decreases* with *increasing* water pressure



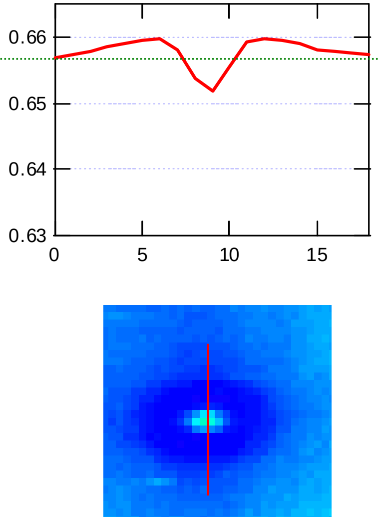
5x10^{-7} Torr H_2O
3.0±0.9 mW/mm^2
10 hrs (1A-S4)



1x10^{-6} Torr H_2O
3.0±0.9 mW/mm^2
10 hrs (1A-S2)



2x10^{-6} Torr H_2O
2.9±1.0 mW/mm^2
10 hrs (2C-S2)



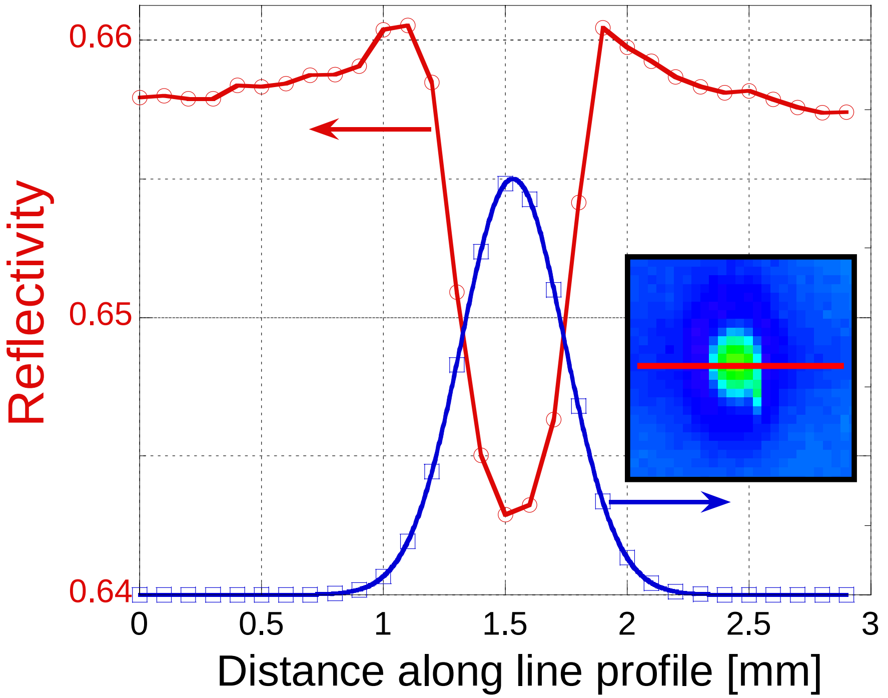
5x10^{-6} Torr H_2O
2.8±0.9 mW/mm^2
10 hrs (1A-S3)

Increasing water vapor pressure

Sample line profiles of ALS reflectivity maps and calculated incident intensity distributions

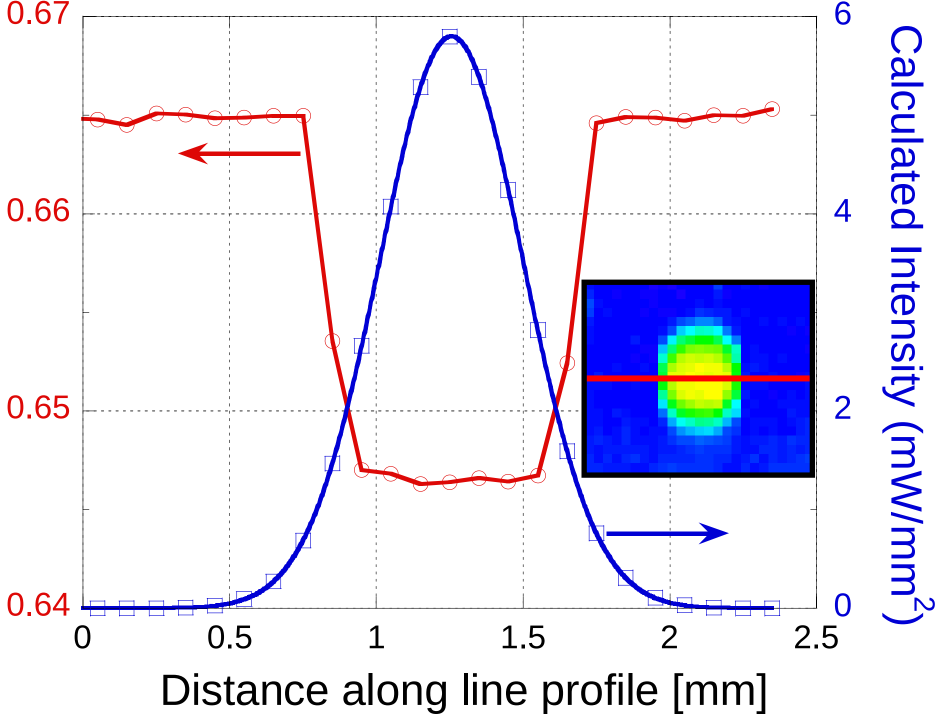
10 hrs @ 1x10^{-6} Torr H_2O

3.0±0.9 mW/mm^2 (1A-S2)

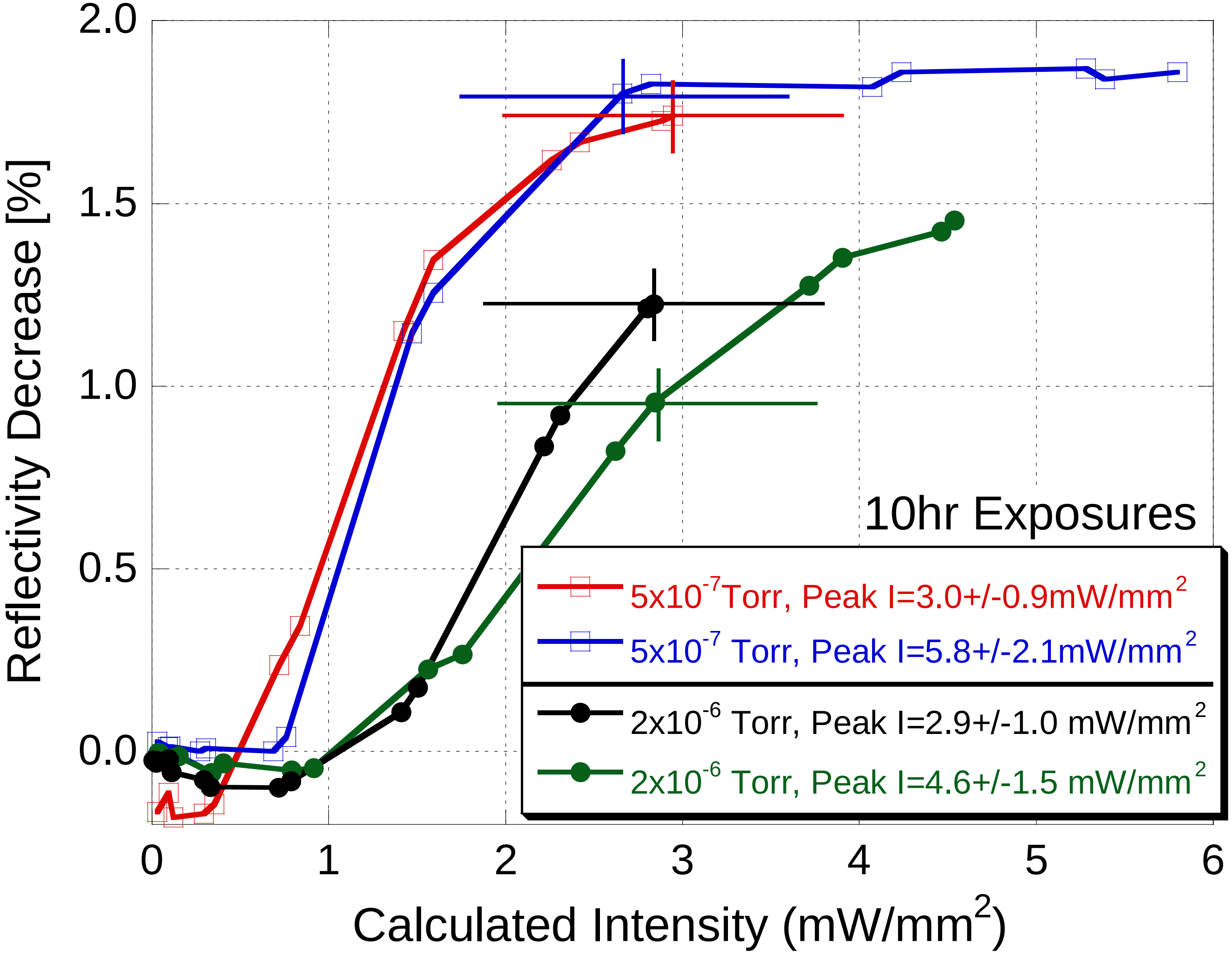


10 hrs @ 5x10^{-7} Torr H_2O

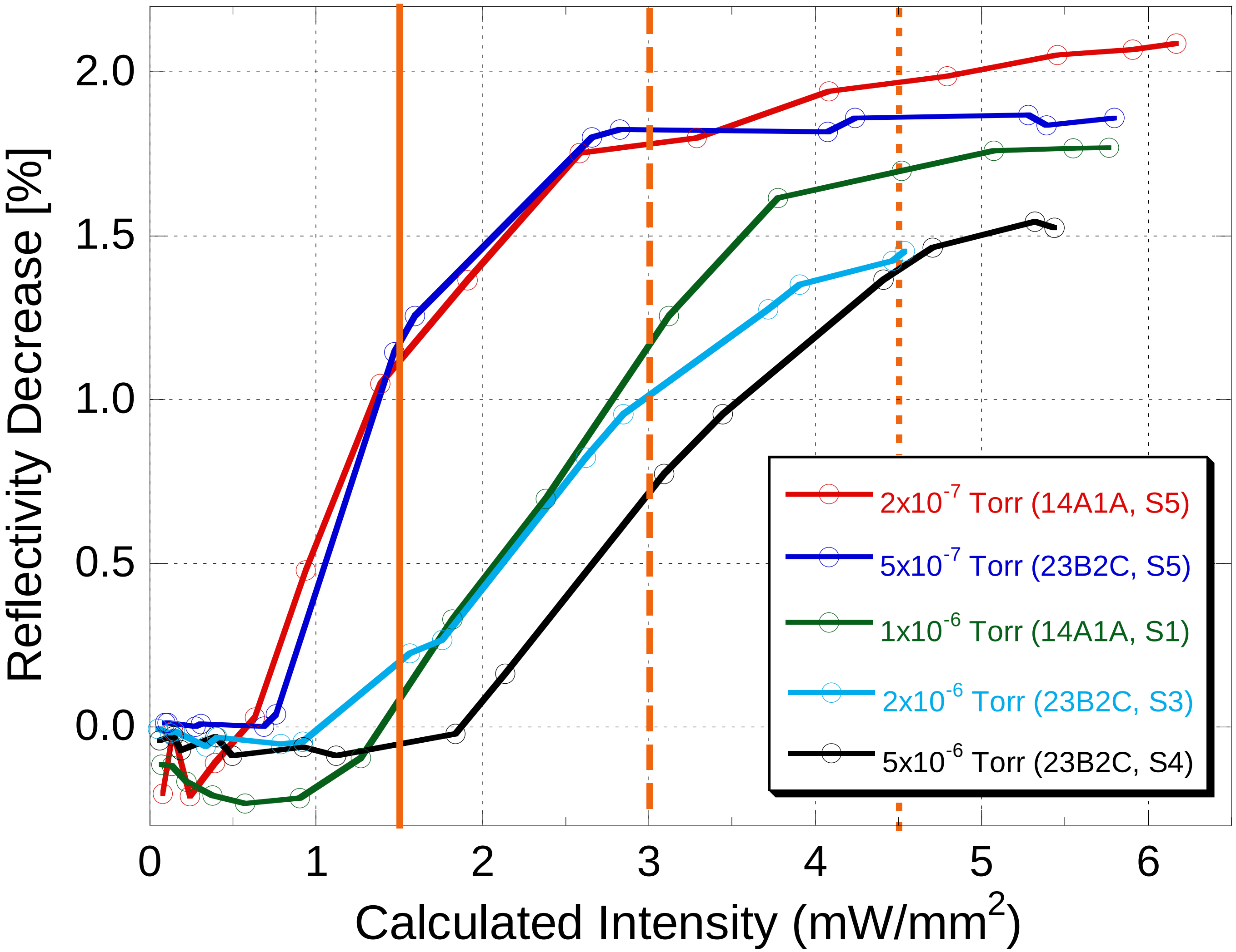
5.8±2.1 mW/mm^2 (2C-S5)



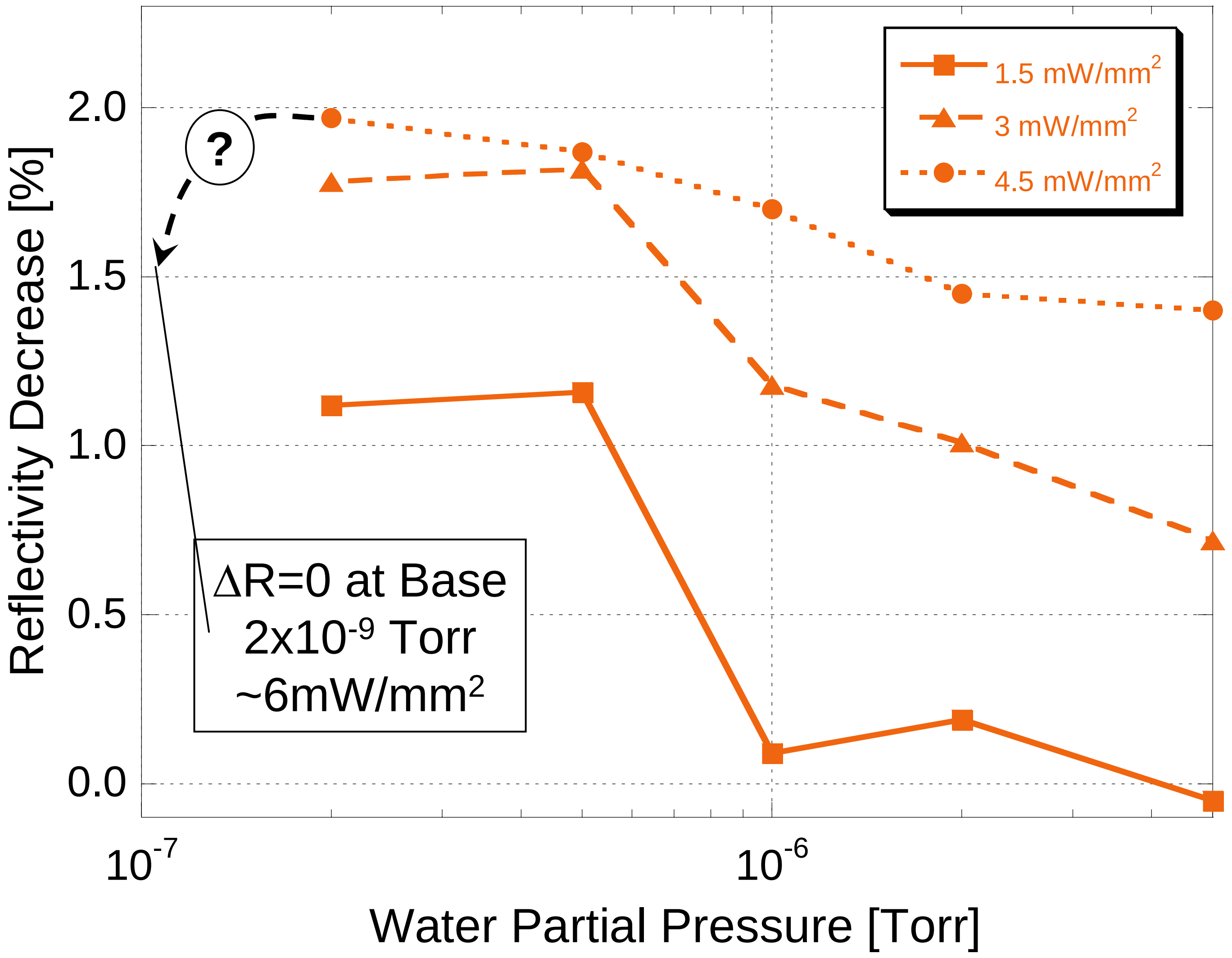
Consistency Check of Intensity Distribution Analysis



Intensity Dependence of 10hr Exposure Reflectivity Drop



Pressure Dependence of 10hr Exposure Reflectivity Drop

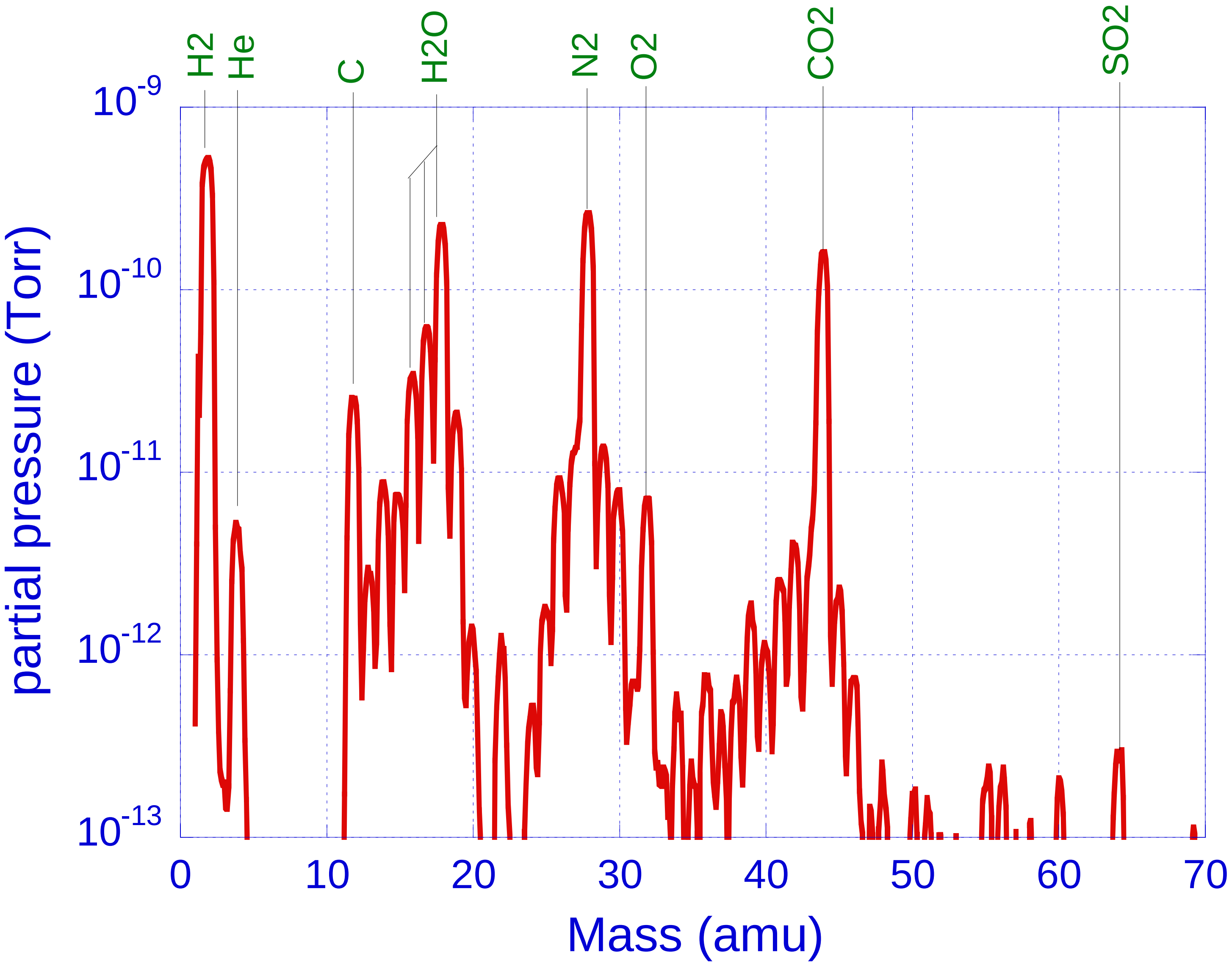


ΔR=0 at Base

2×10^{-9} Torr

~6mW/mm²

Exposure chamber base pressure RGA scan



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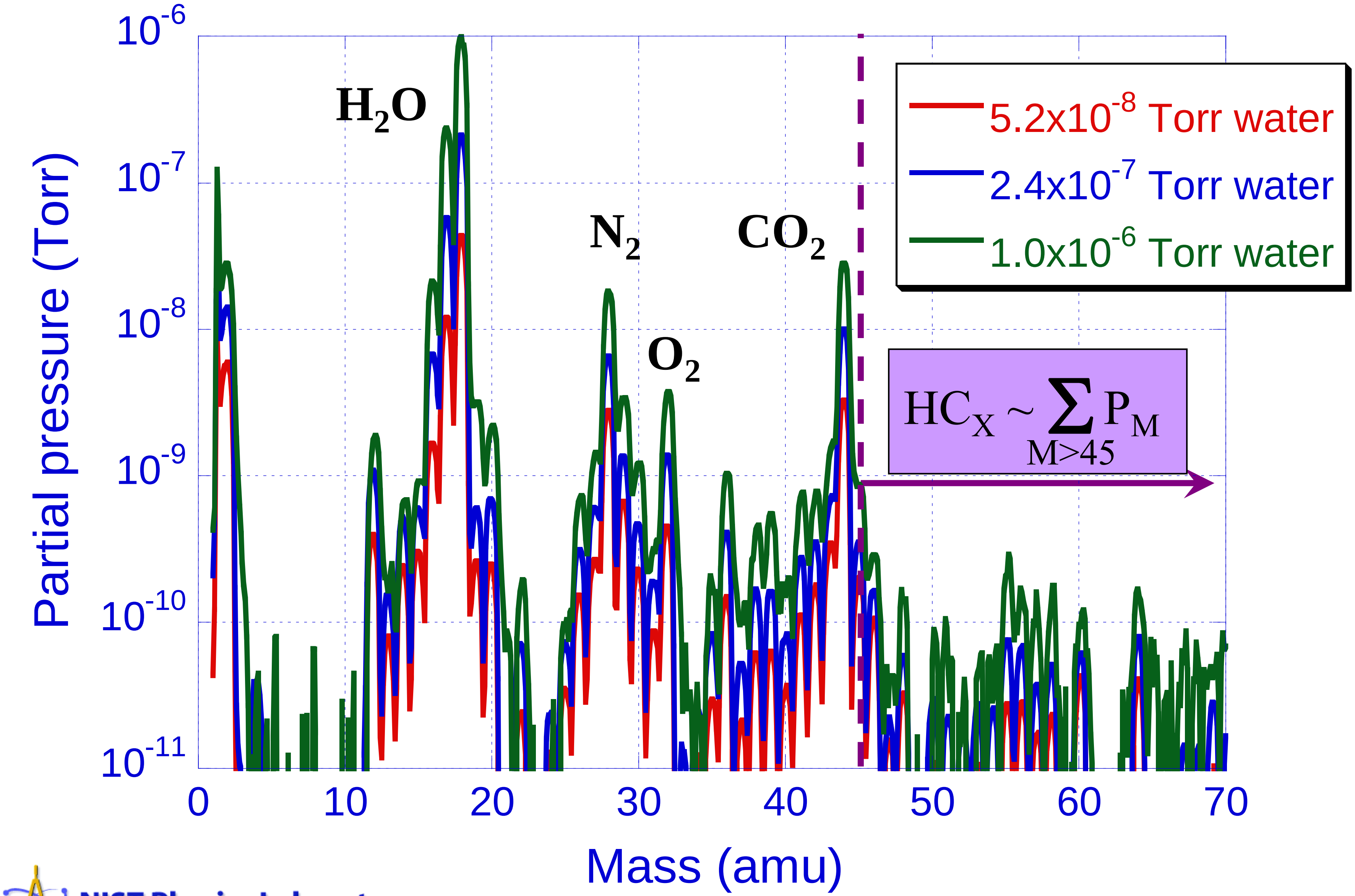
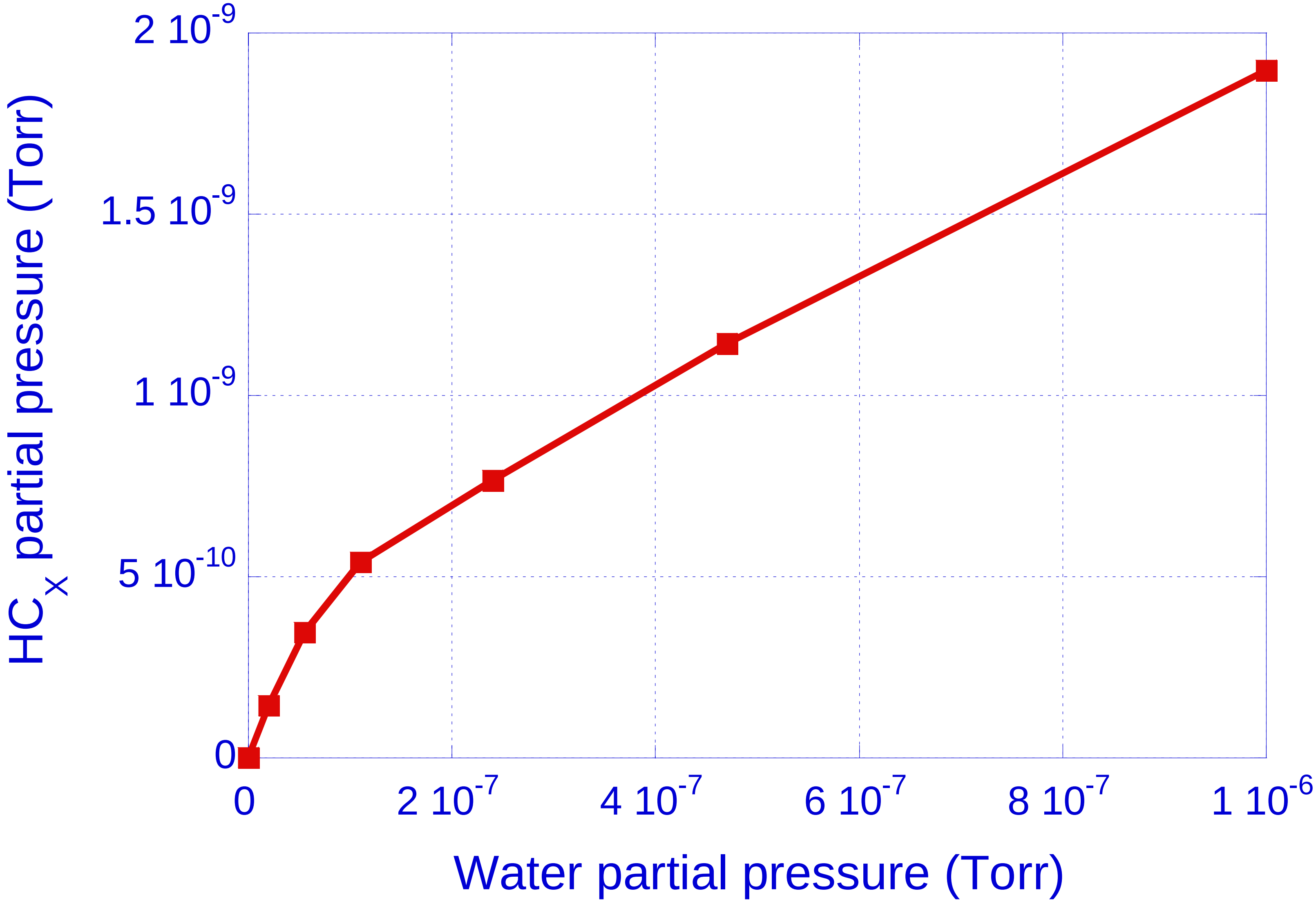
Exposure chamber RGA scan



Estimated HC_X content with water pressure



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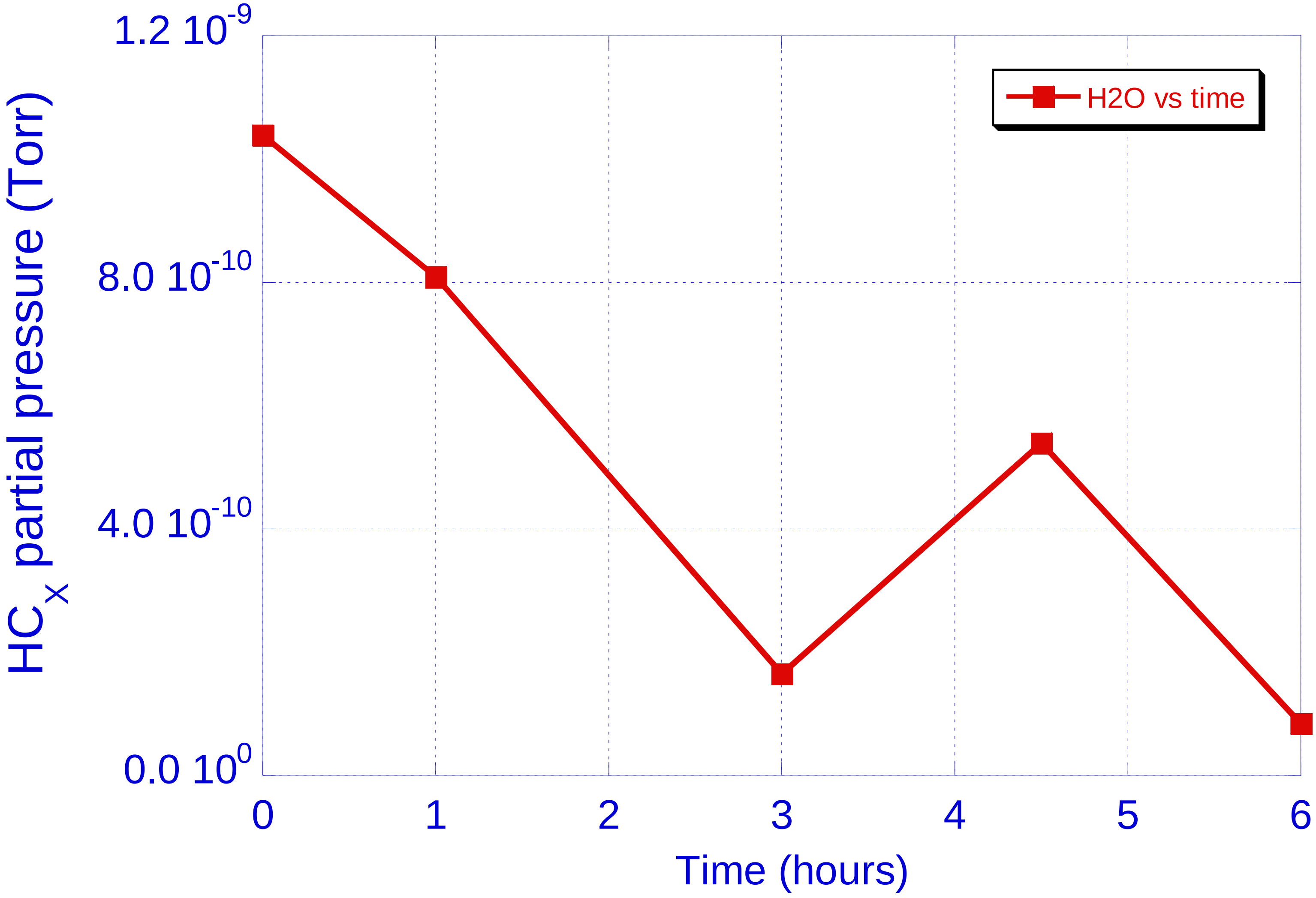
Time dependence of estimated HC_X content

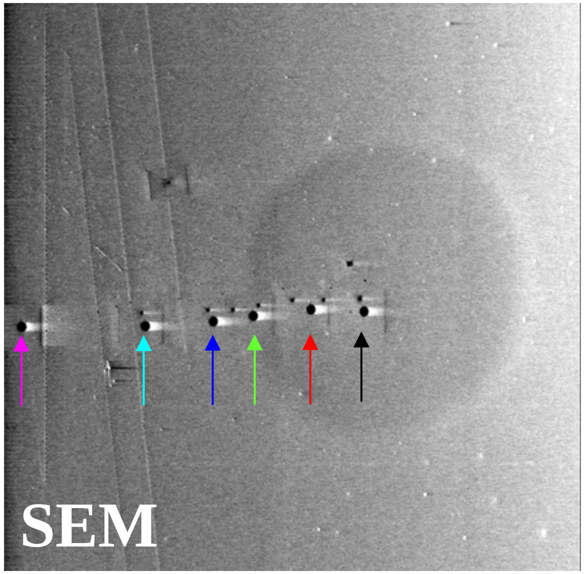


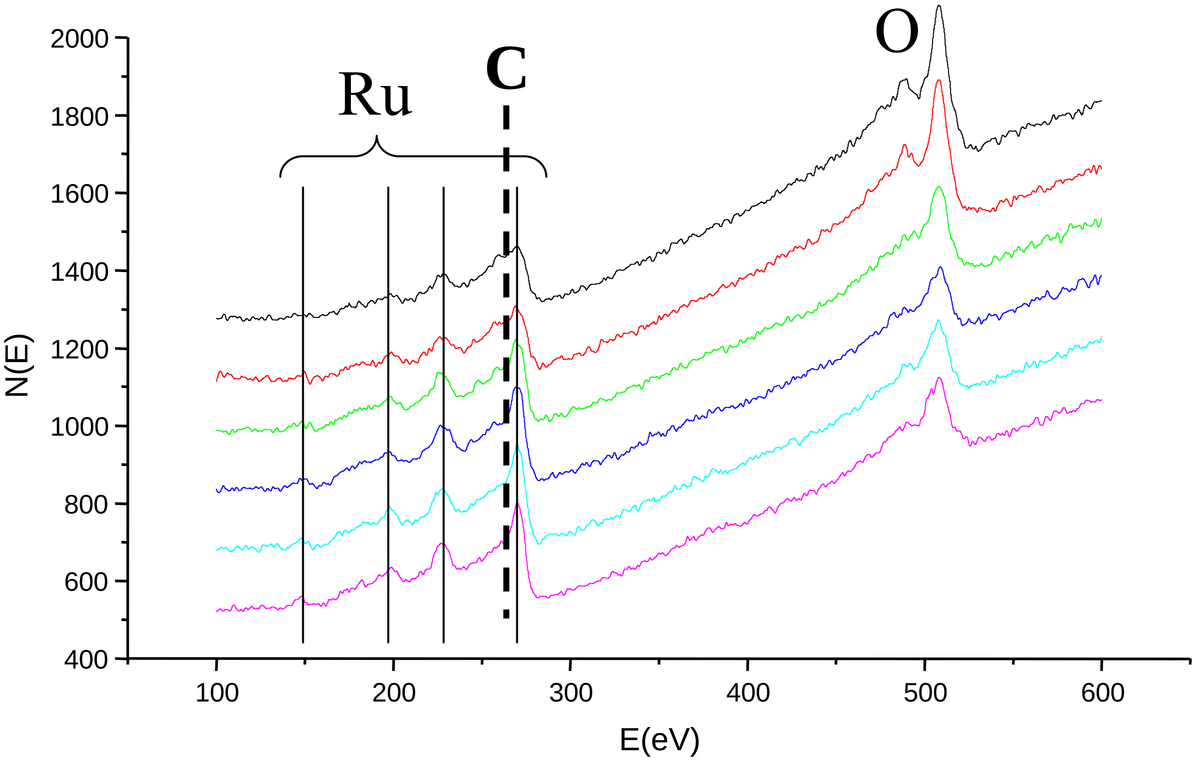
Characteristics of ambient background

- Ambient background changes with amount of water vapor introduced and duration of exposure
- Material desorbed from walls is probably the major source; typically unbaked walls contain ~10^4 more molecules than gas phase
- Spectrum containing all species with masses greater than 45 amu provides some measure of HC contamination

Auger Spectra of Exposed Spot and Surrounding Area

10 hrs, 2x10^{-7} Torr Water
6.2 mW/mm^2





- •Increased O in exposed areas
- •O signal grows with ΔR (as with Sandia results)
- •C masked by Ru peaks

Conclusions: 10-Hour Exposures

- Photochemistry of mirror surface seems to be strongly dependent on trace contaminants in ambient background; this chemistry must be better understood before one can develop reliable scaling laws that will apply to the stepper environments or explore the possibility of using R to characterize surface “responsivity.”

- The cause of damage still not fully understood: Auger analysis shows damage correlates to increased oxide; however, no excess of carbon seen to the limits of sensitivity in Auger analysis (carbon masked by Ru).

Conclusions on Damage Rates

- Decreases with increasing p_{H2O} in our system
- Increases with intensity at all pressures, but less so for the lowest pressures
- Mirrors become more damage resistant for $\Delta R < -0.02$, both for 10-hour and for longer exposures
- dR/dt smaller but not zero at longer times

Conclusions for Metrology

- Intensity profiles superimposed on reflectivity maps can be used to provide parallel data at many intensities from a single exposure.
- Strongly non-linear variation of damage with intensity prevents straightforward application of in-situ reflectivity measurement.
- Much of trace contaminants in ambient background desorbed from surfaces in chamber; all partial pressures vary with time and should be continuously monitored during test exposures.