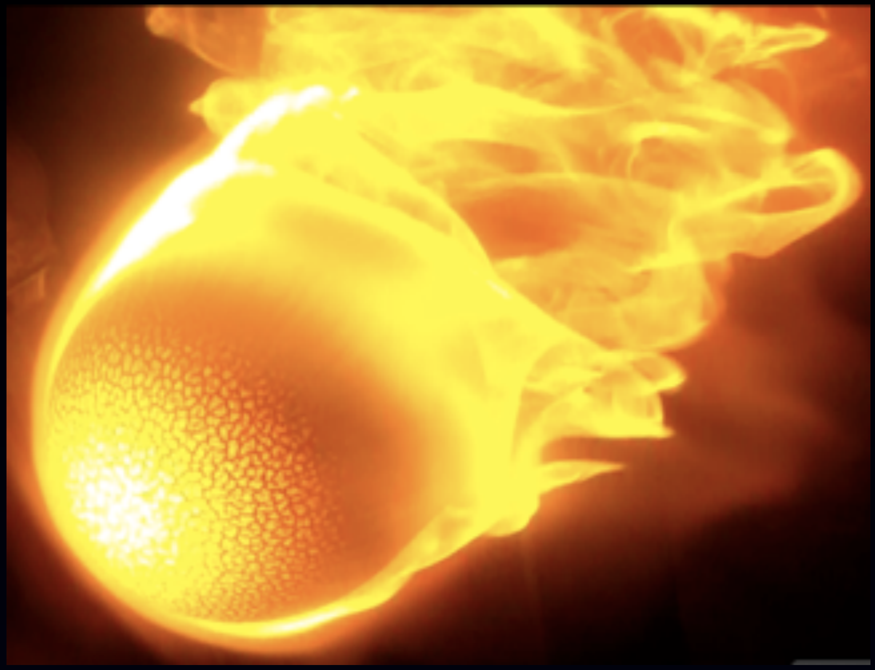
Material response characterization of new-class ablators in view of numerical model calibration



6th Ablation Workshop

April 10, 2014

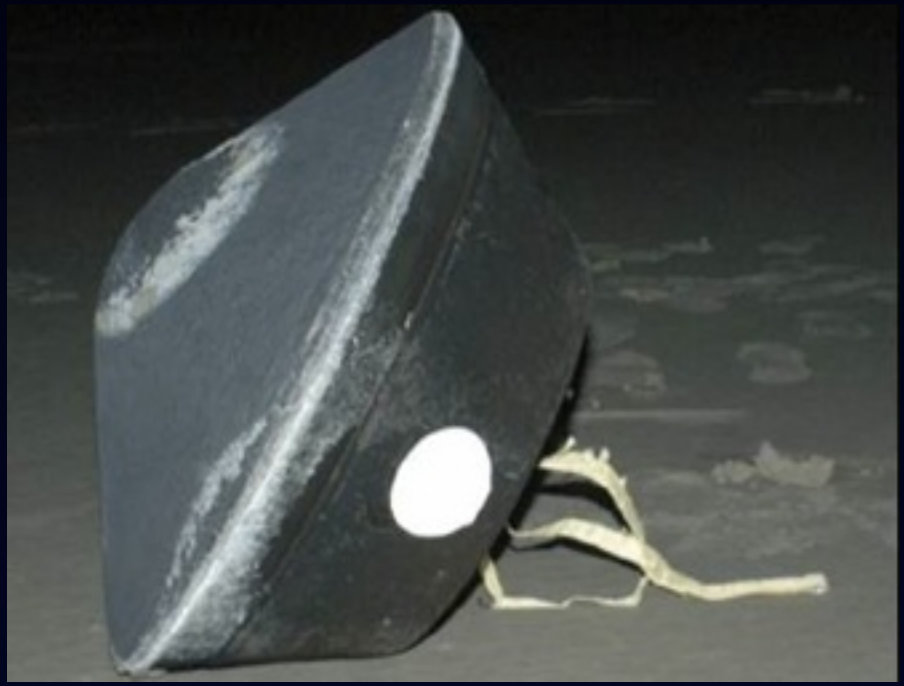
Urbana Champaign, Illinois

B. Helber[1,2], A. Turchi[1], T. E. Magin[1]

[1] *Aeronautics and Aerospace Department, von Karman Institute for Fluid Dynamics, Belgium*

[2] *Research Group Electrochemical and Surface Engineering, Vrije Universiteit Brussel*

TPM for Atmospheric Reentry



NASA Stardust probe, reentry: Jan. 15, 2006 (12.9 km/s) (AIAA 2008-1202)

Missions

Sample return, ISS serving (Dragon, ARV, ...), MPCV

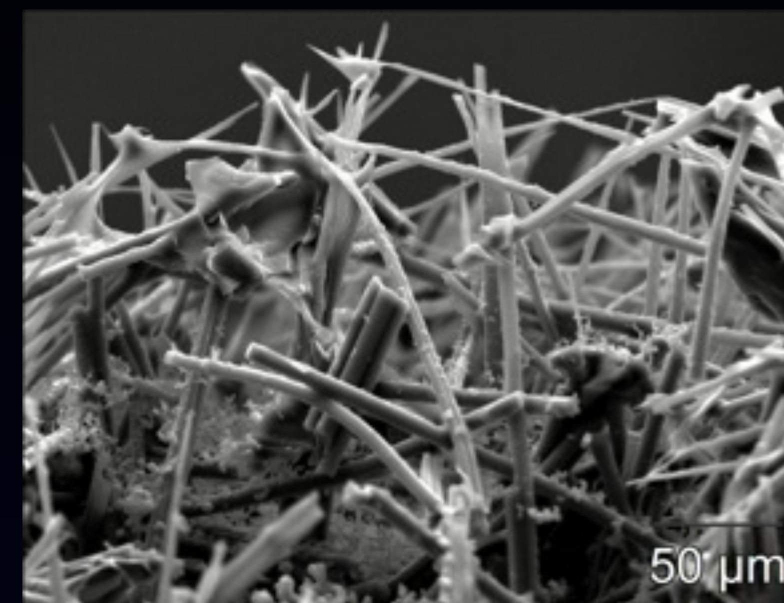
- Atm. reentry speeds > 10km/s
- Ablative materials
  - Mass loss and surface recession
  - Prediction of material response required
  - High margins decrease payload

New materials (1990's)

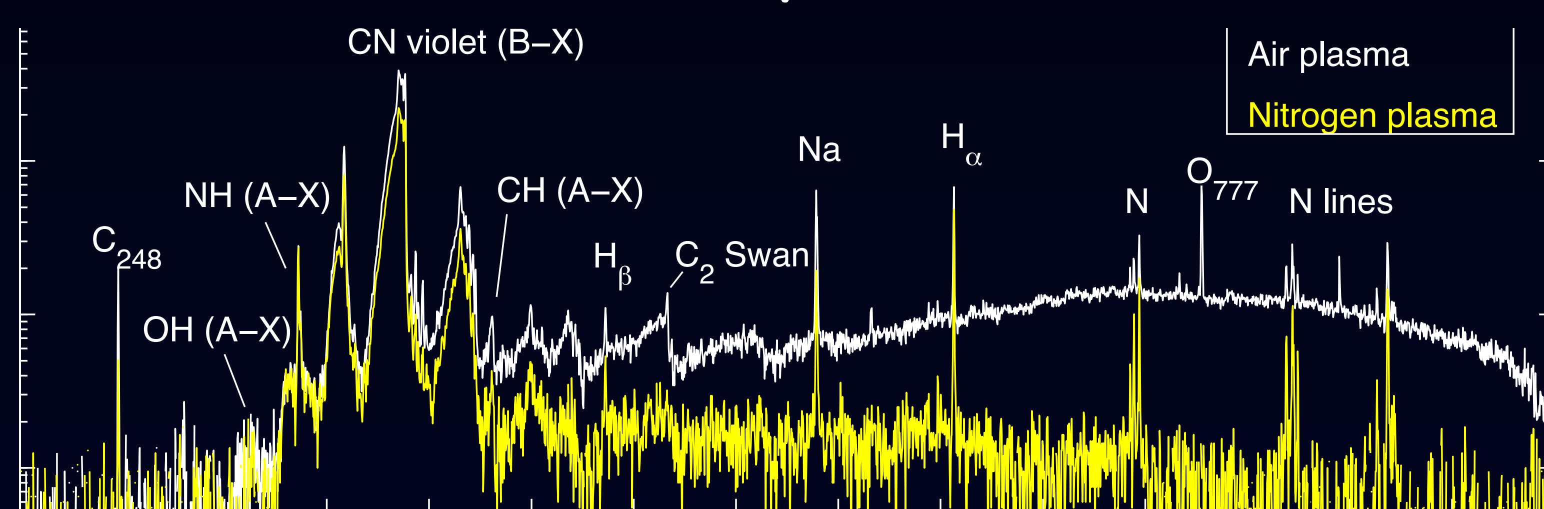
- Phenolic impregnated carbon fiber preform
- Very porous low density ablators

Complex Multiphysics - Multiscale problem
Coupled phenomena

Gas-Surface Interaction



Material



Radiation

We aim at improvement of

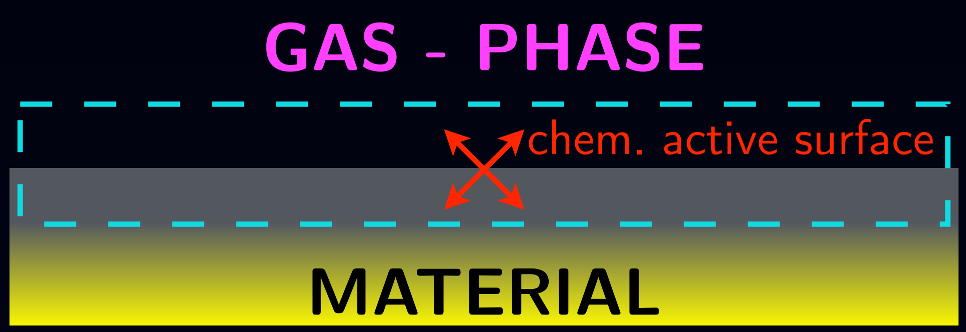
Experimental Methods (VKI) ⟷ TPS Design / Material (VUB, Astrium, ESA)

Material Response Modeling & Validation (VKI, collaborations)

Calibration (AIAA G-077-1998)

The process of adjusting numerical or physical modeling parameters in the computational model for the purpose of improving agreement with experimental data.

In the following



(1) Materials and Methods for Ablation Characterization

(2) Gas-phase ➪ BL emission & temp

(3) Surface ➪ Char blowing rates

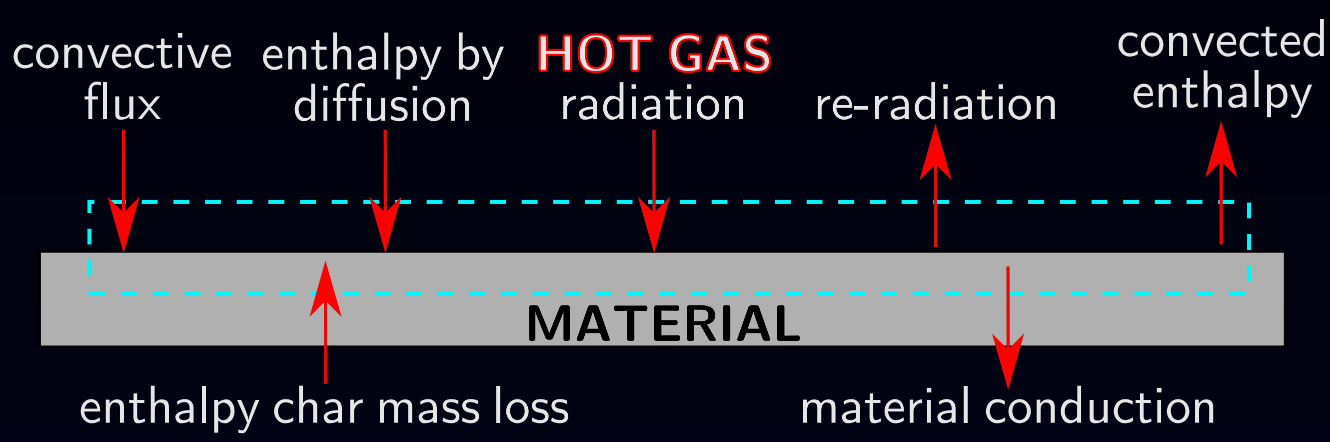
(4) Material ➪ Pyrolysis outgassing

Approach for ablation modeling (Kendall et al.[1])

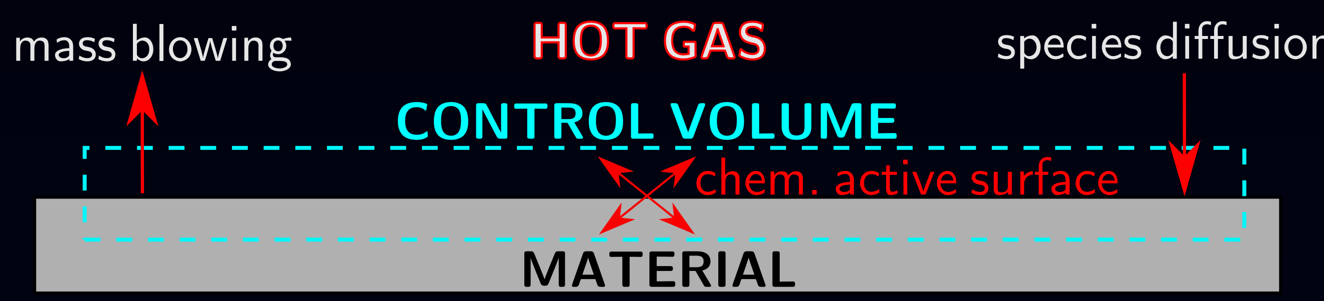
VKI: 1D Stagnation line description w/ surface ablation

(A. Munafo[2] / A. Turchi, VKI)

Surface Energy Balance (SEB)



Surface Mass Balance (SMB)



[1] Kendall et al., NASA CR 1060 (1968)

[2] A. Munafò, PhD Thesis, Ecole Central Paris, 2014

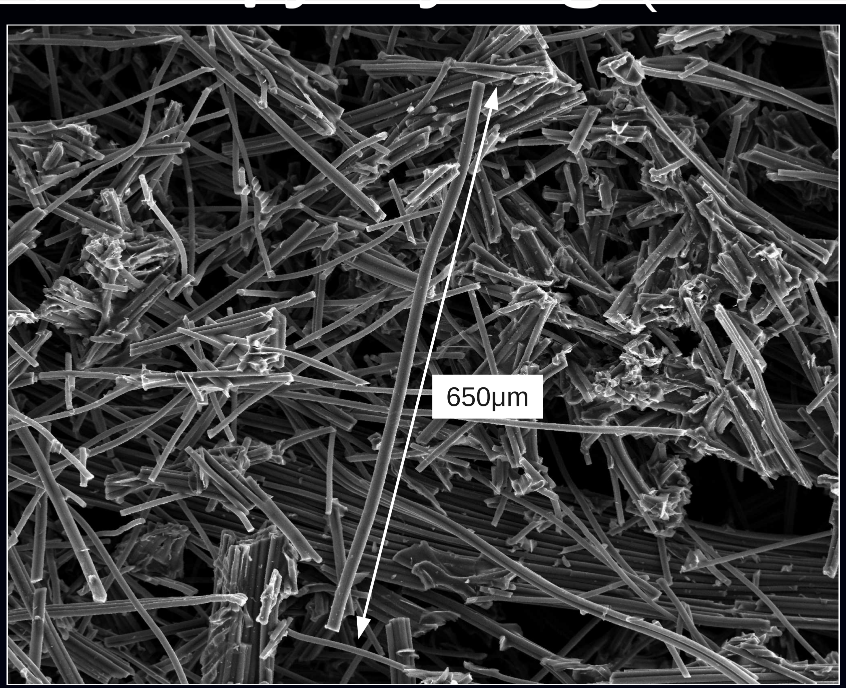
Boundary condition from experiments & plasma free-stream

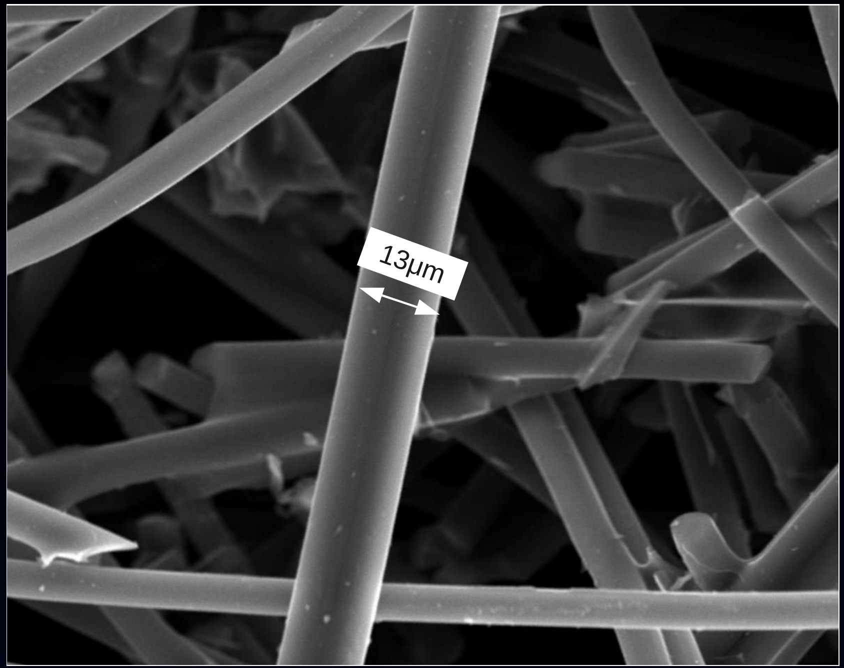
Experimental data for validation

GOAL: Coupling *1-D SL-code* *&* *material code* (P. Schrooyen)

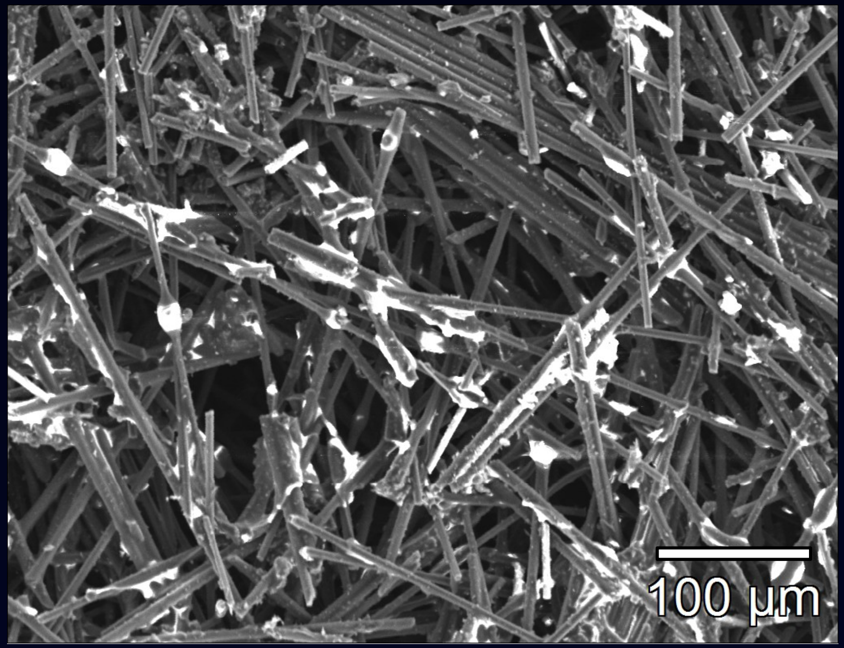
Materials of Investigation

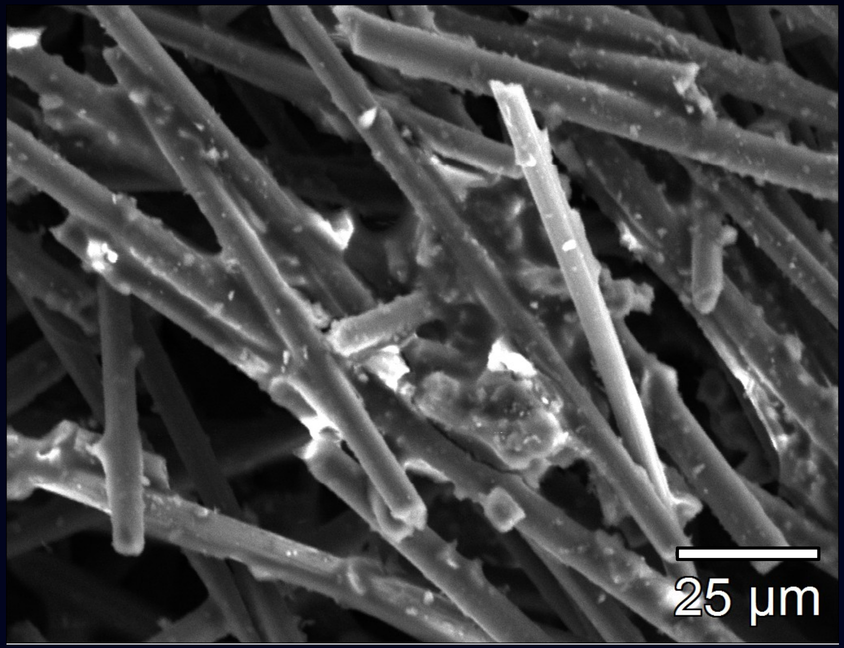
Carbon fiber preform, **non-pyrolyzing** (Mersen Scotland Holytown Ltd.)



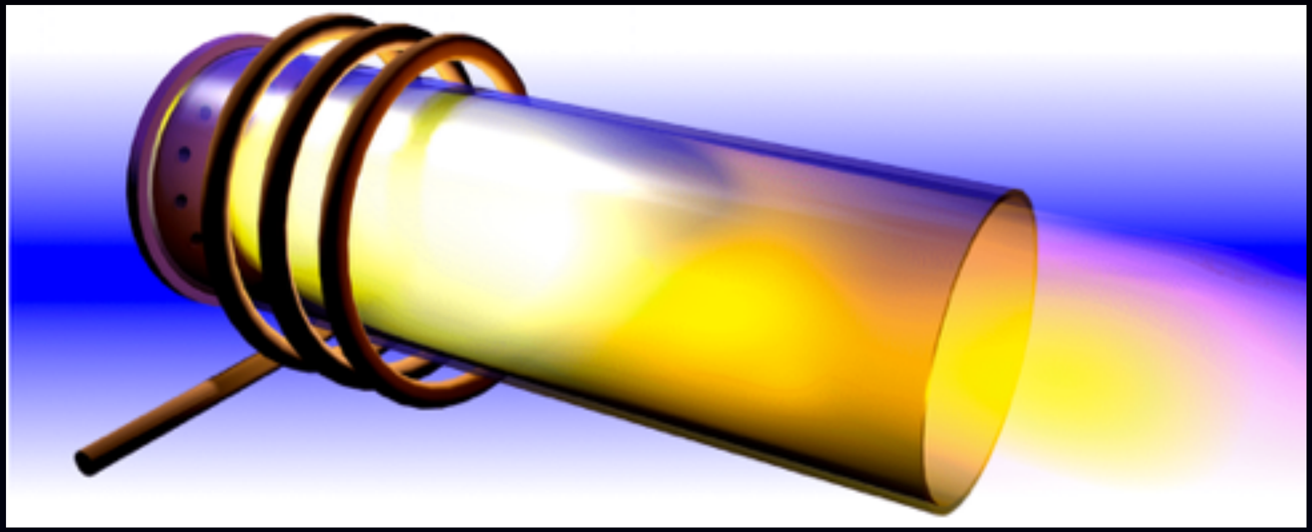


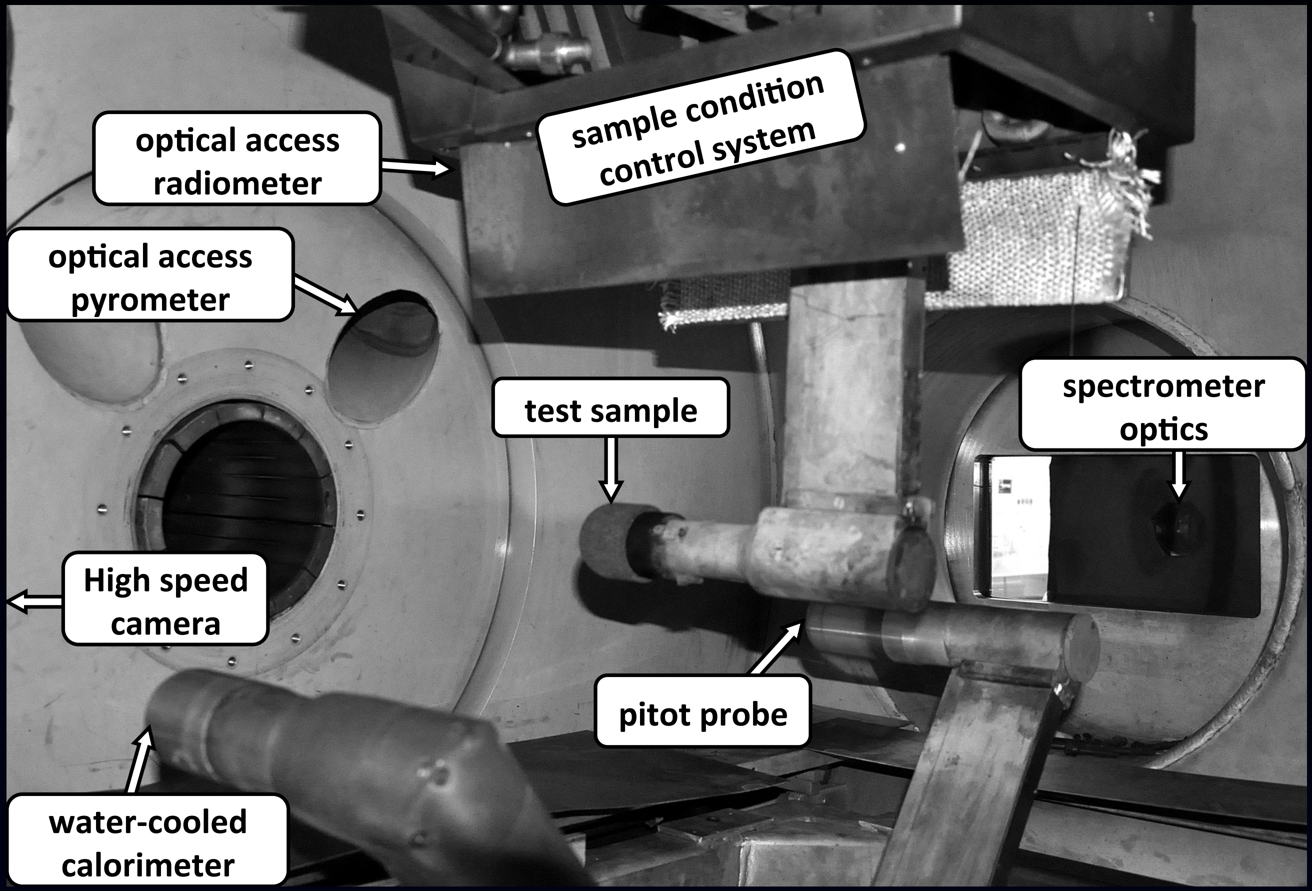
AQ61, **carbon-phenolic** (AIRBUS DS)





1.2-MW Inductively Coupled Plasmatron





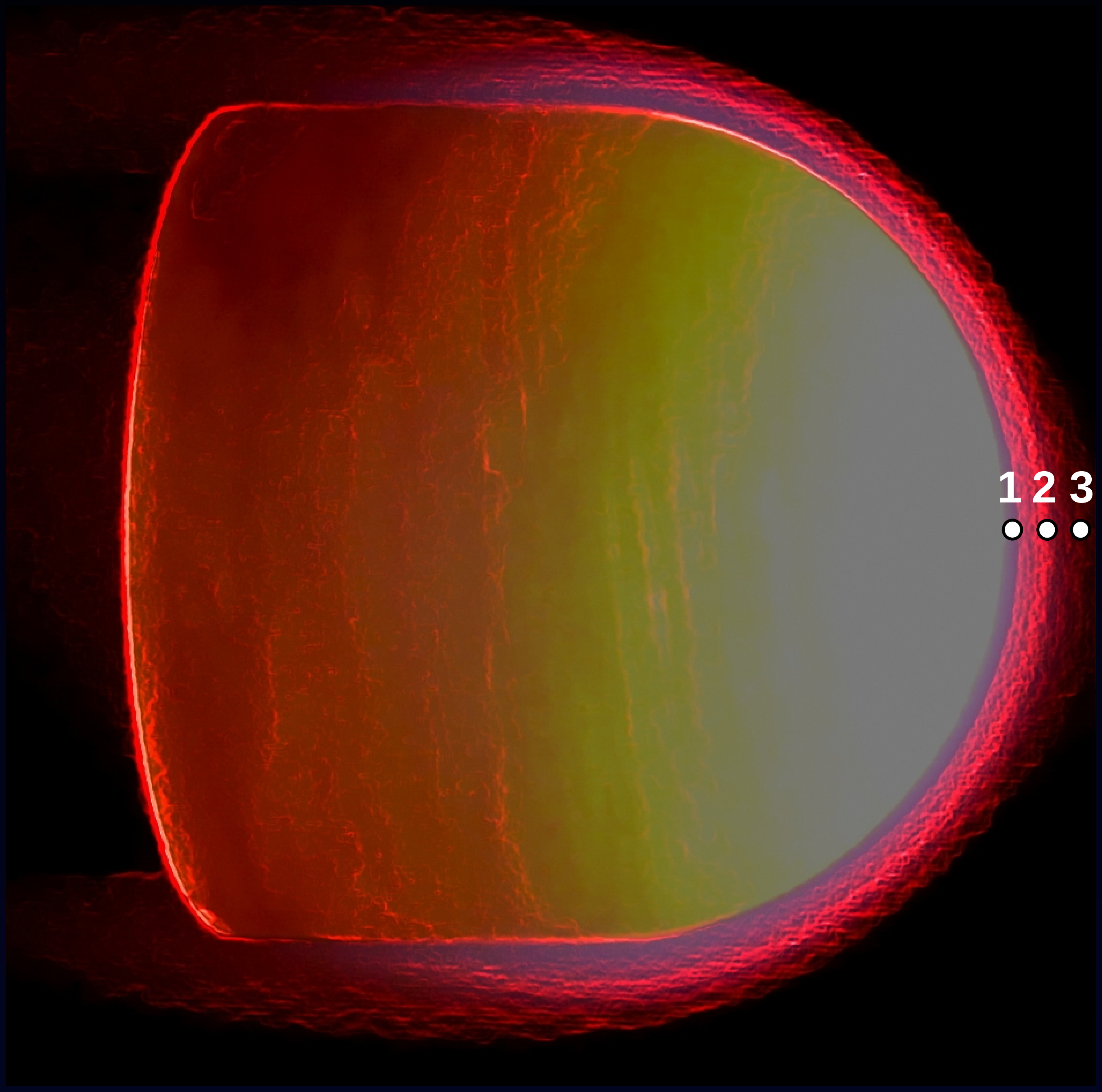
Gas: Air, N_2, CO_2, Ar

Power: 1.2-MW

Heat Flux: > 12 MW/m^2

Pressure: 10 mbar - 1 atm

Techniques for In-Situ Ablation Characterization



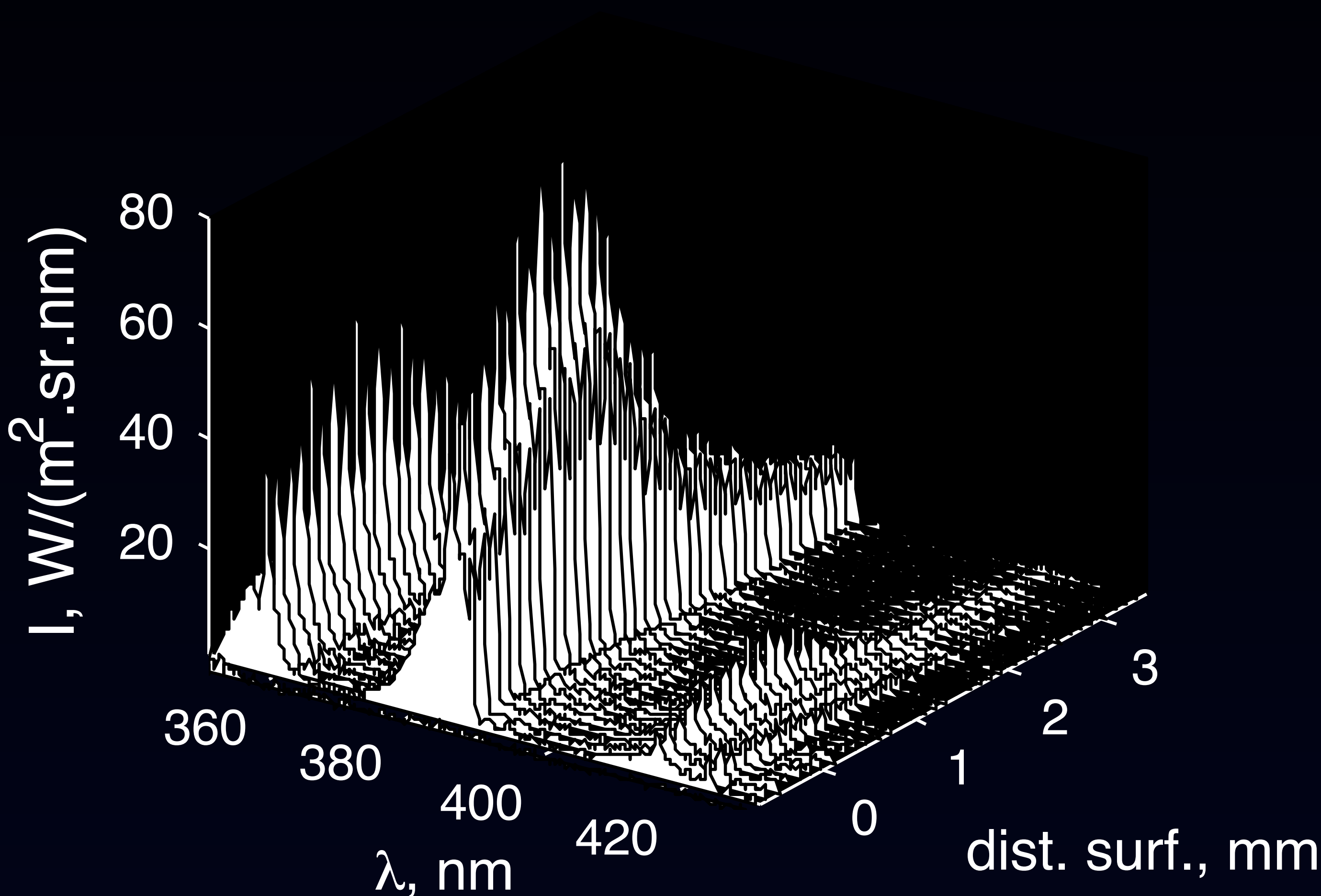
Our interest

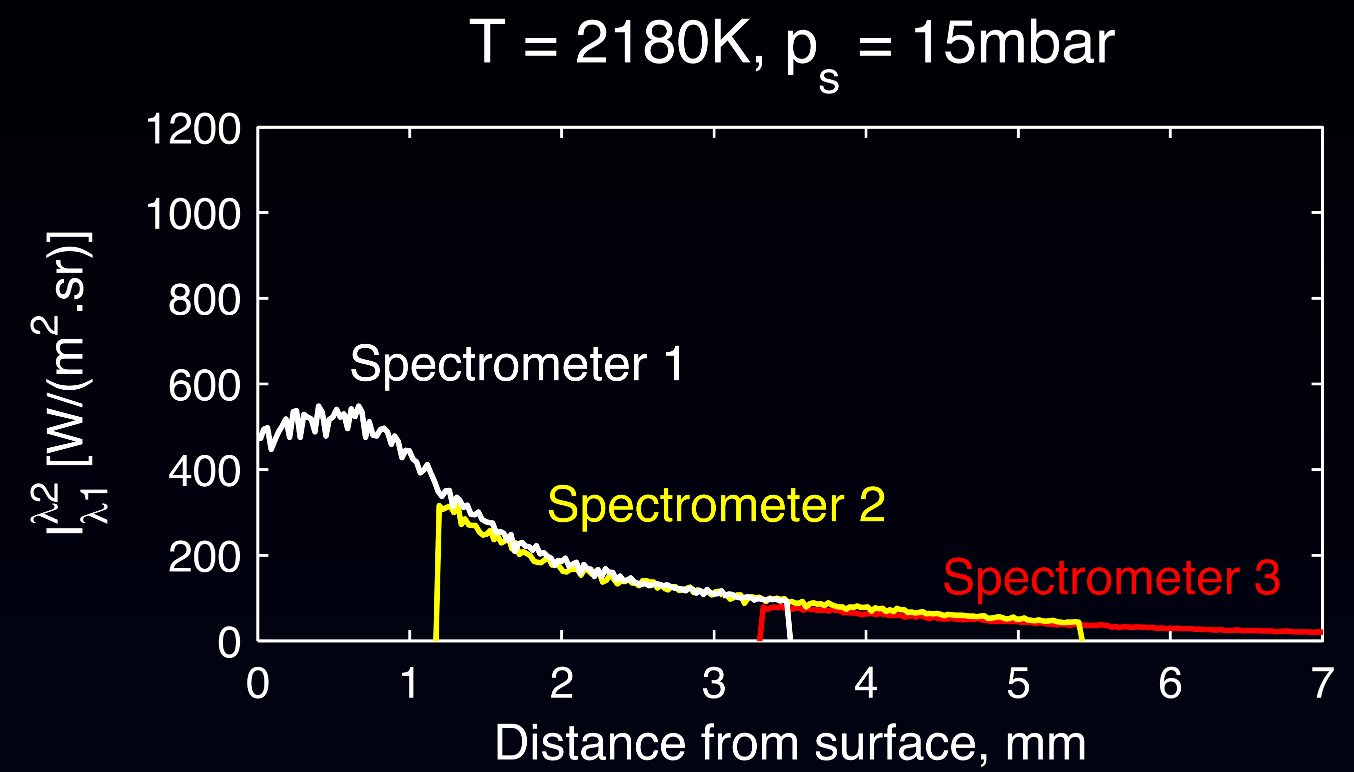
Surface temperature
Emissivity
Internal Temperature
In-situ recession analysis
Volumetric recession
Chemical composition
Temperature estimation

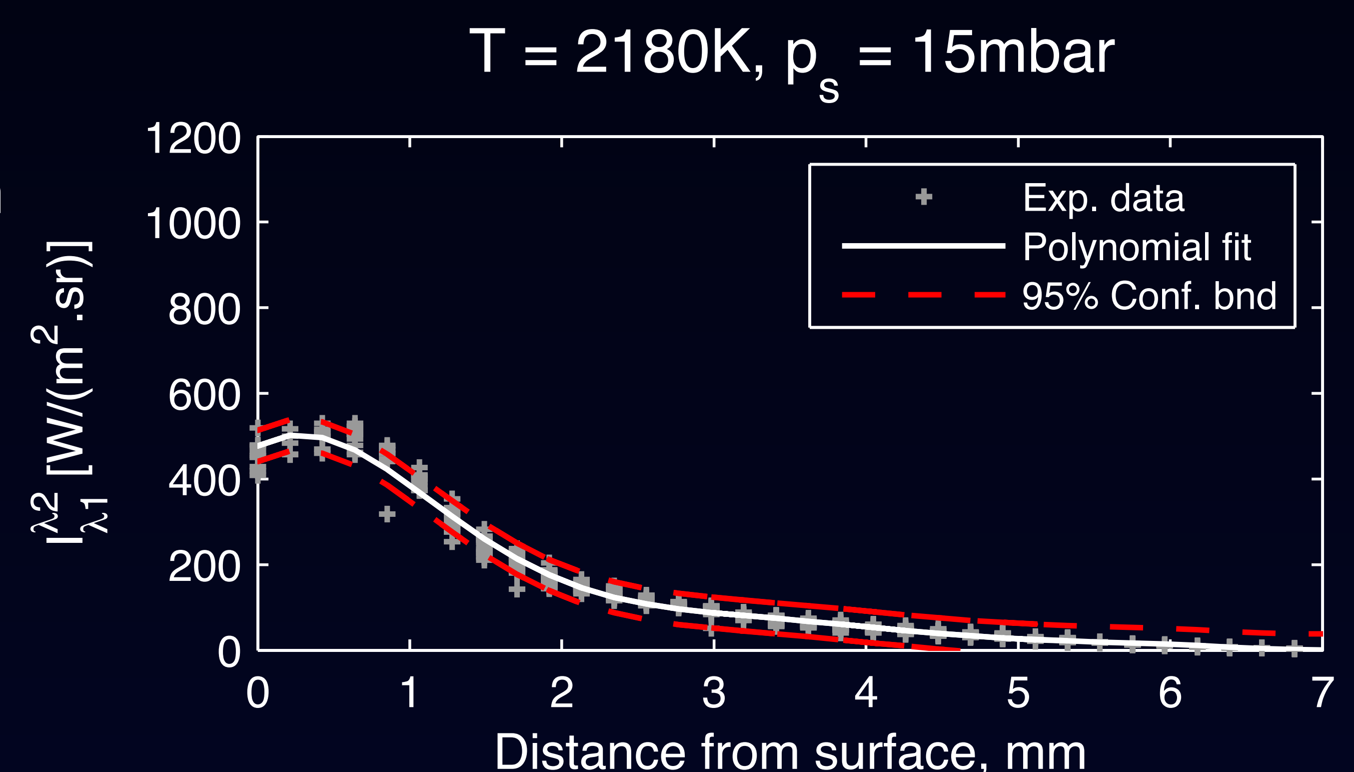
(AIAA 2013-2770)

Boundary Layer Radiation Profiles

Experimental: Spatial CN violet emission







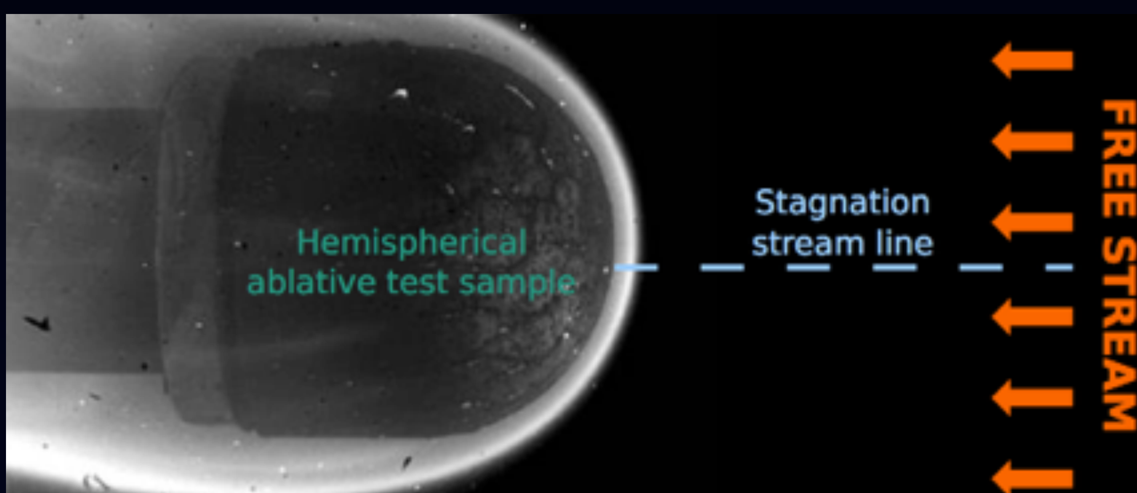
CN Production:

gas phase: $CO + N \rightleftharpoons CN + O$

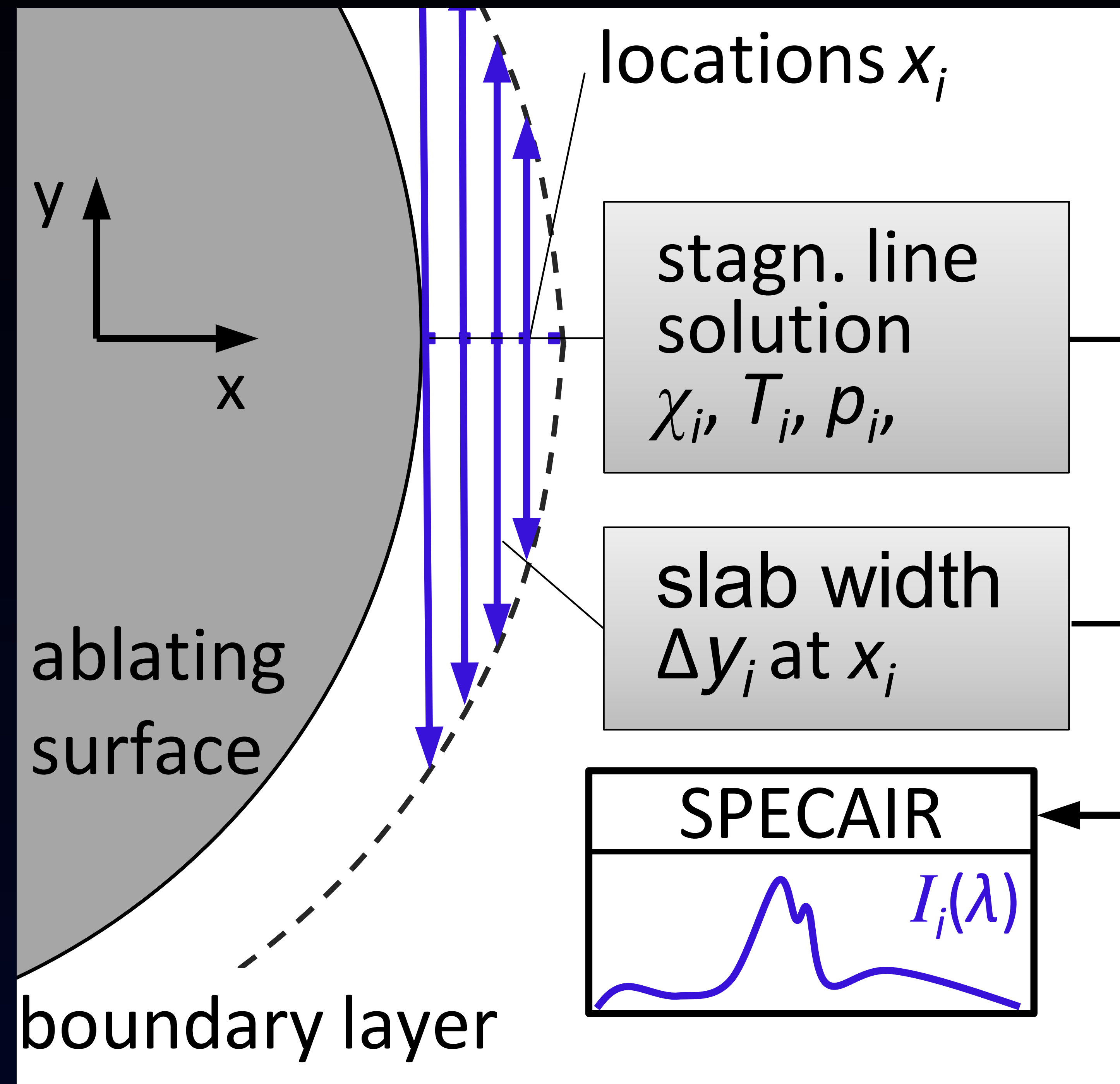
wall: $C_w + N_w \longrightarrow CN$

Boundary Layer Radiation Profiles

Numerical: Simplified approach using Specair slab



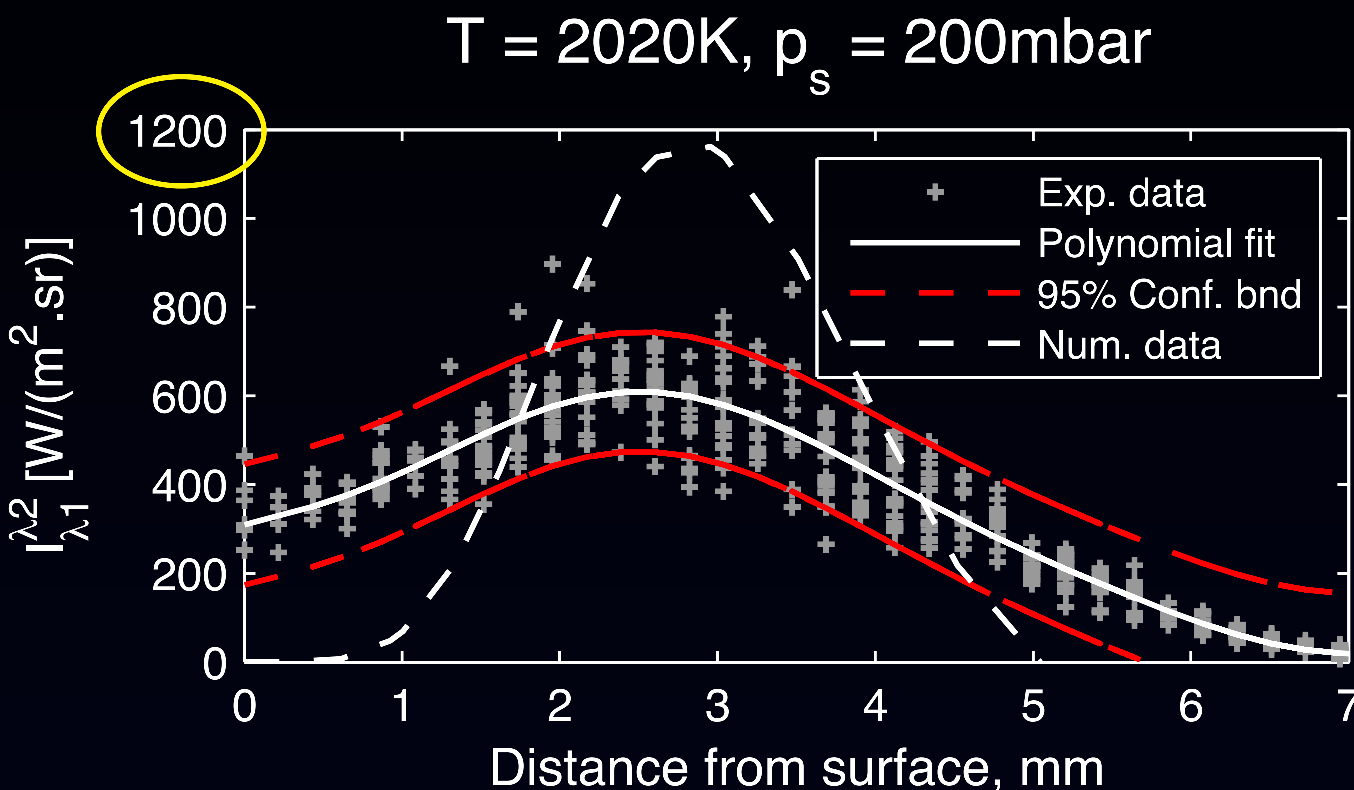
Simulate line-of-sight measurement

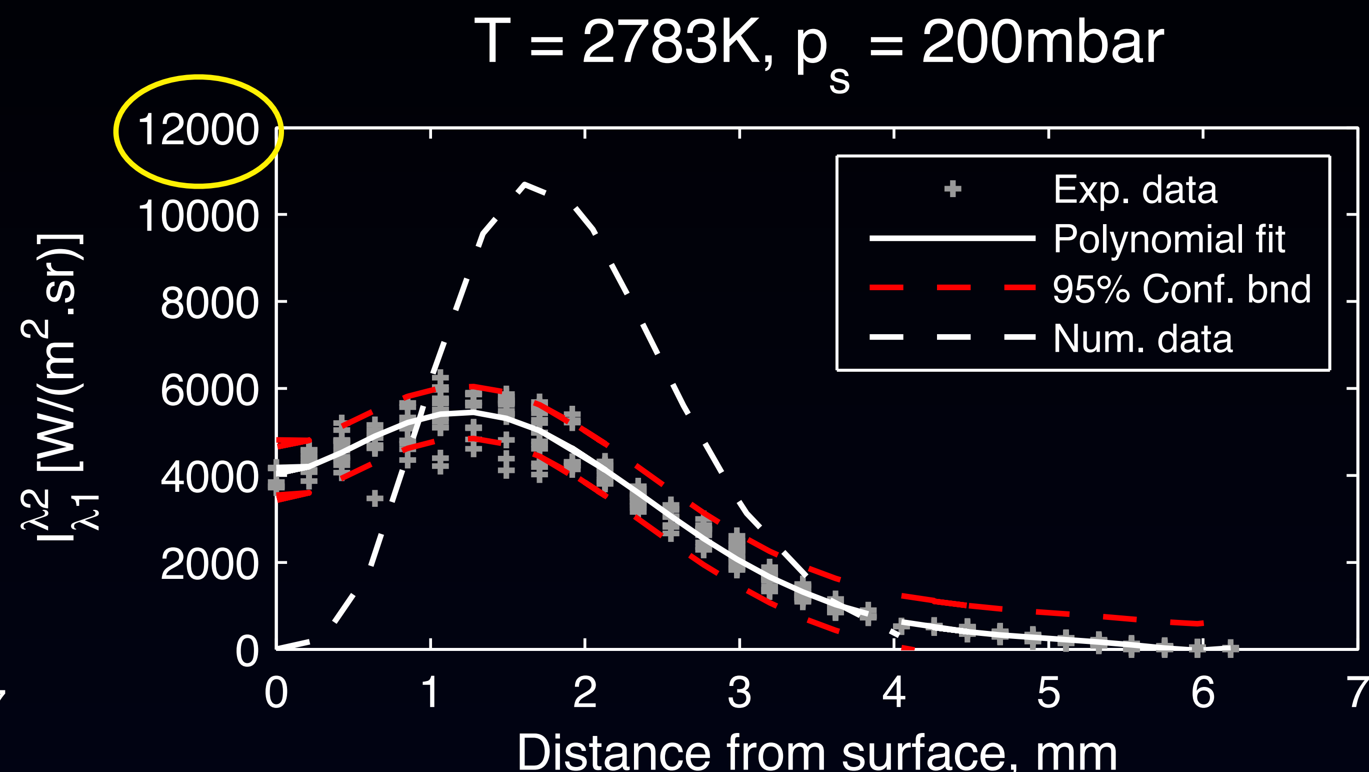


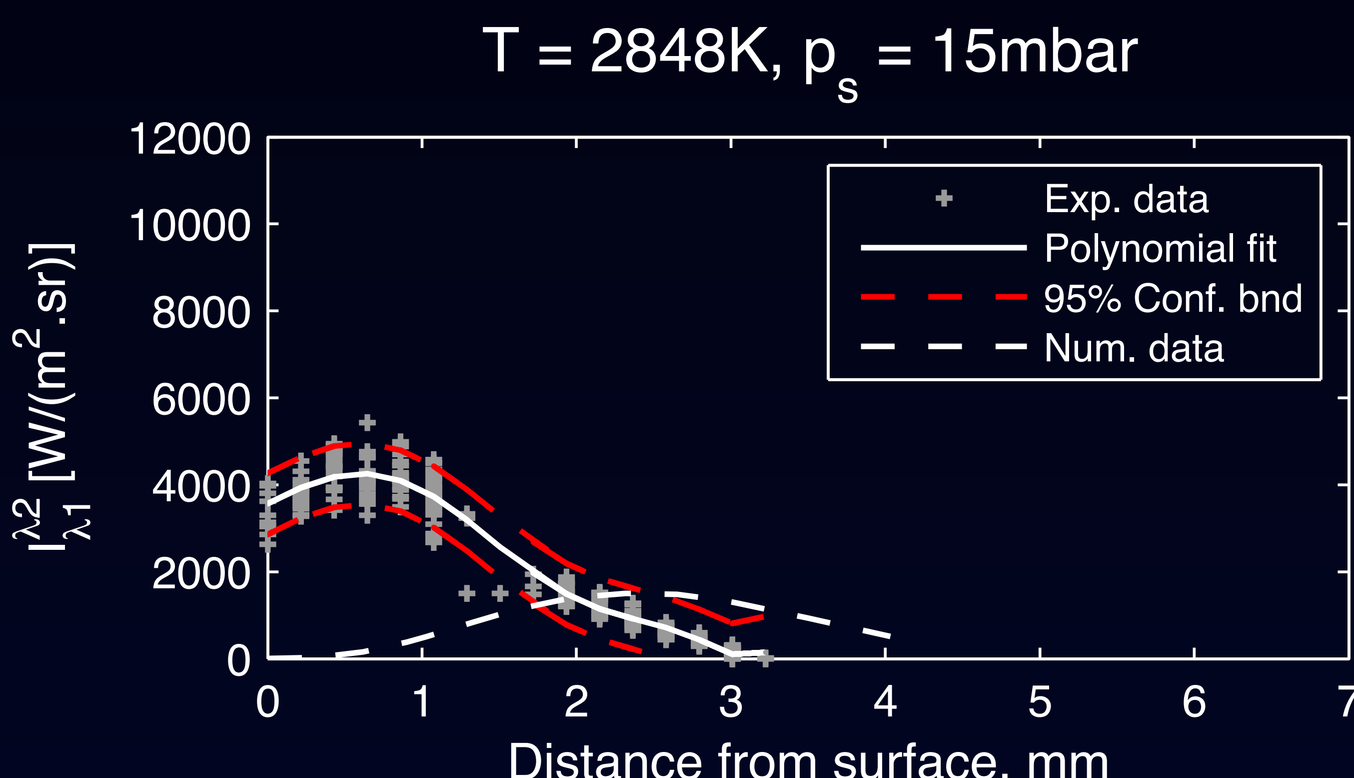
Perspective:
Radiation Coupling (J.B. Scoggins)

Comparison of Boundary Layer Radiation Profiles

Very preliminary approach but promising comparison



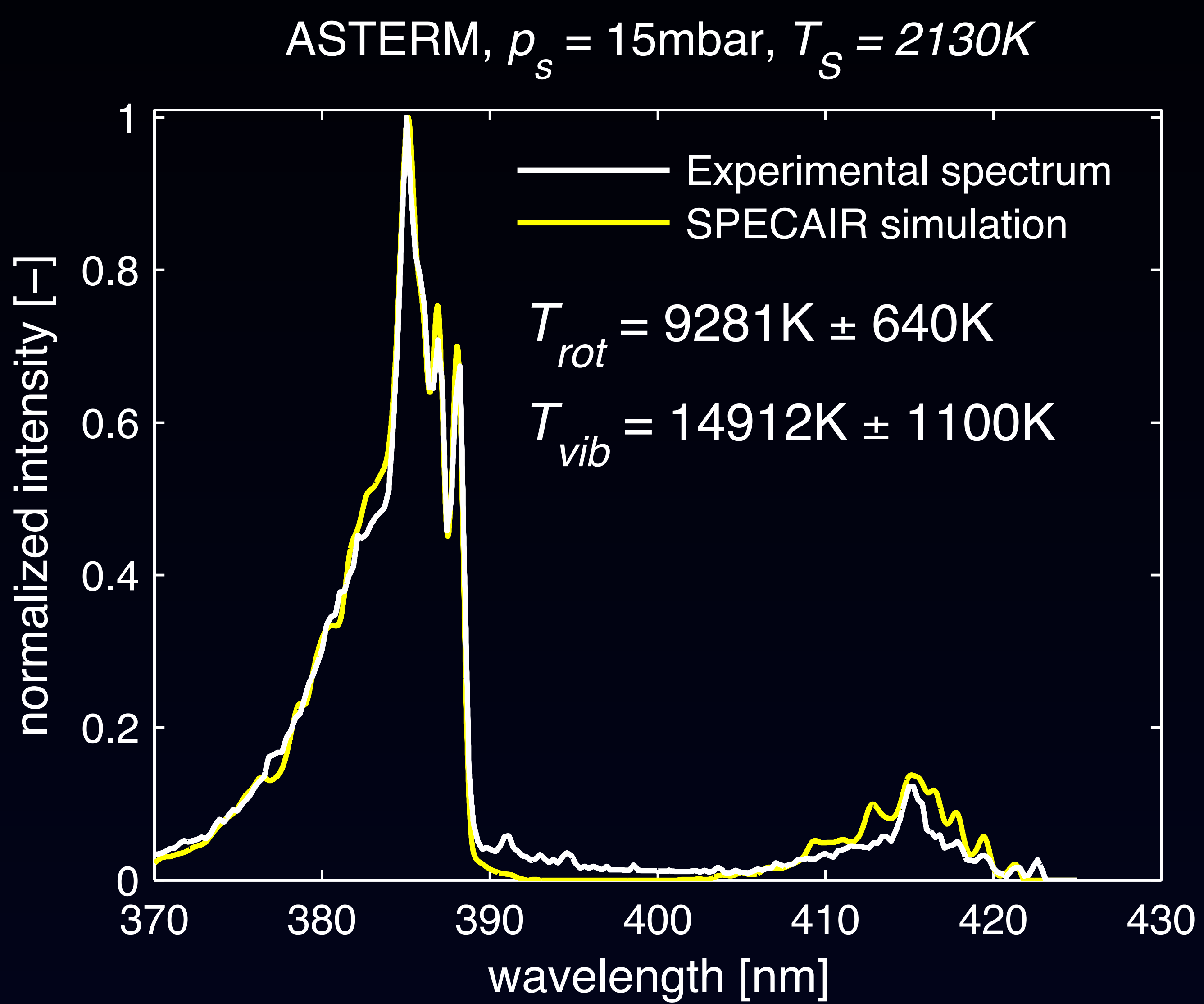


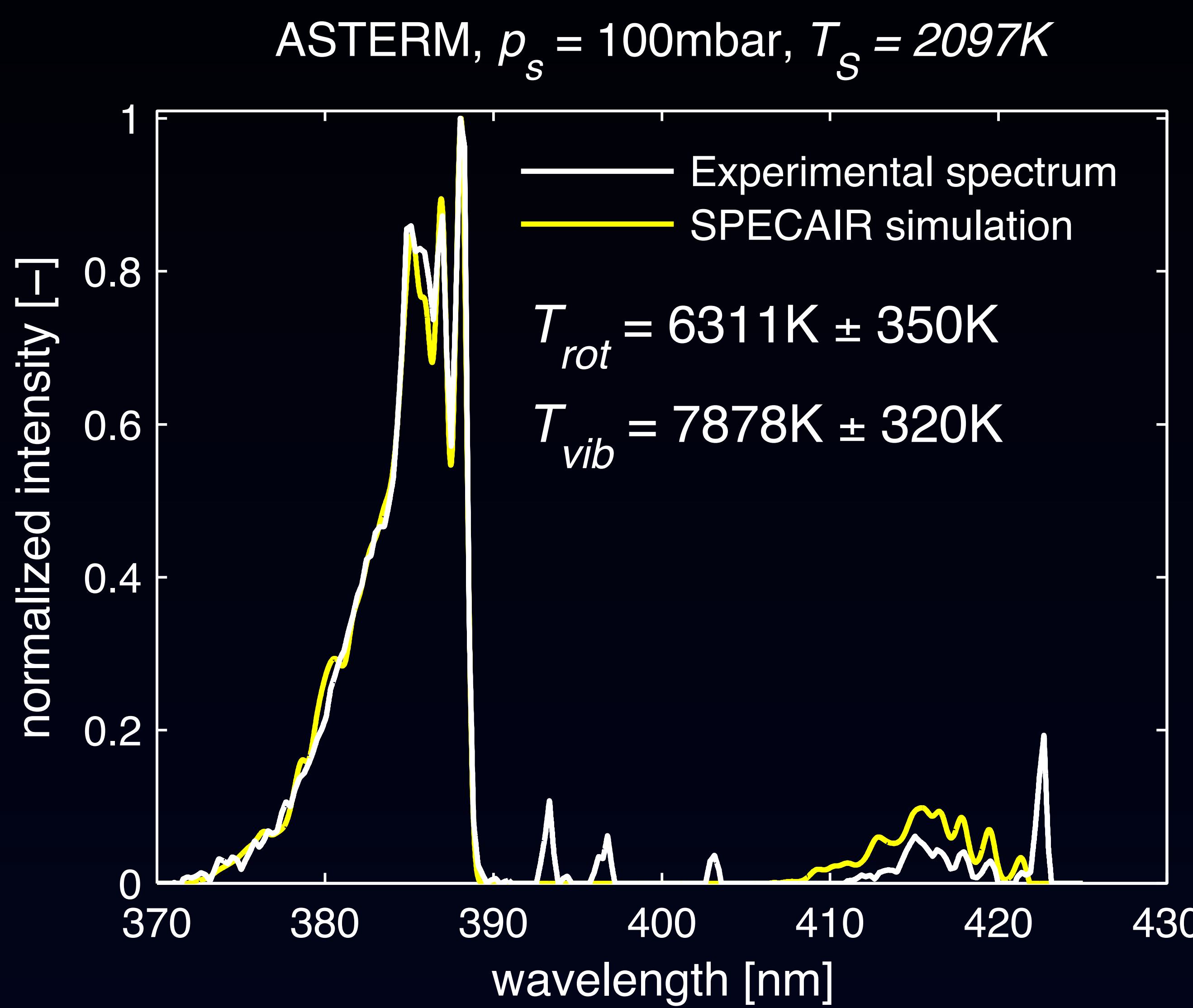


- ✓ Locations of maxima
- ✓ BL thickness
- ✓ Order of magnitude

CN Radiation Simulation for Temperature Estimation

Non-equilibrium?





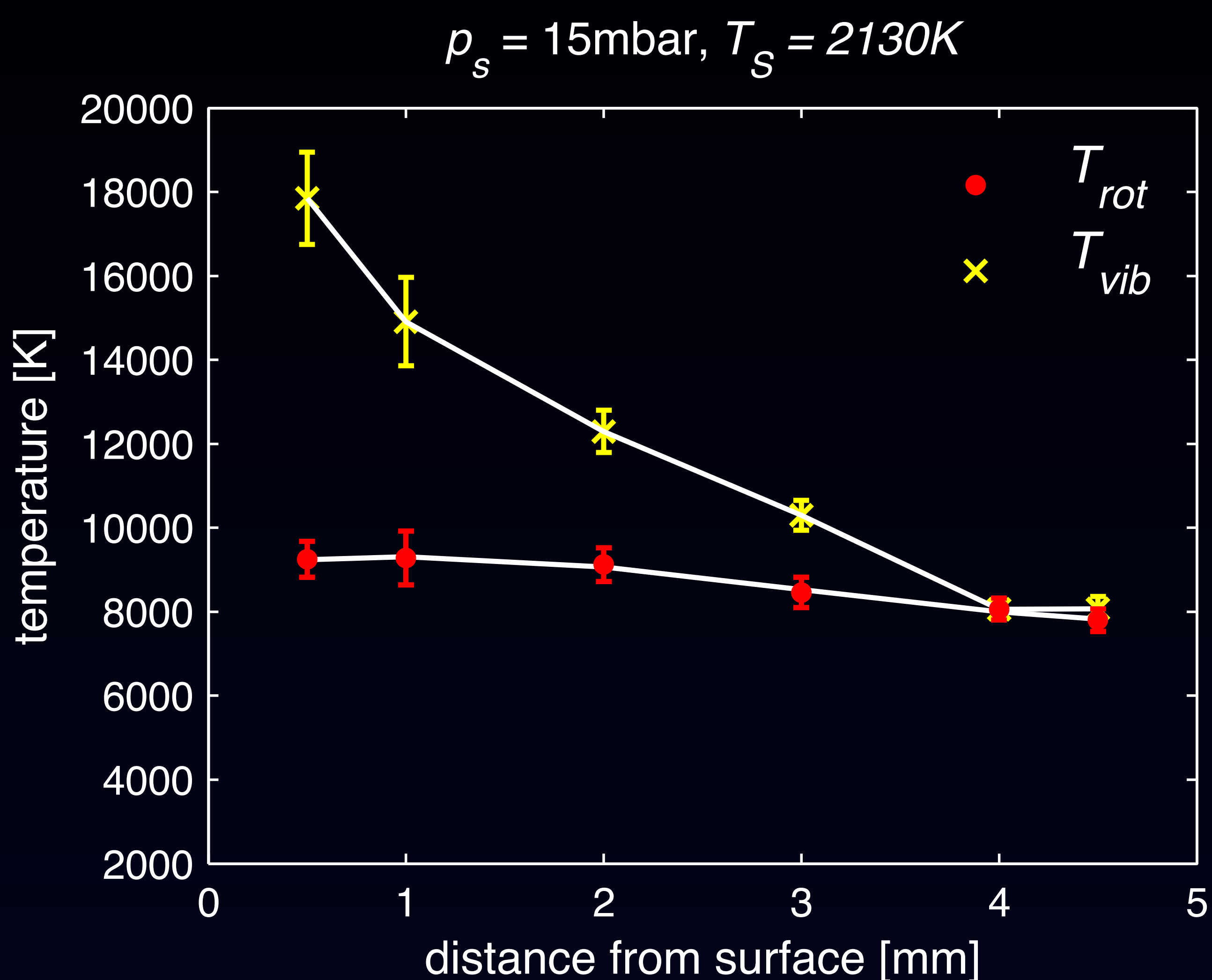
Non-thermal vibrational level distribution at low pressure (AIAA 2013-2770)

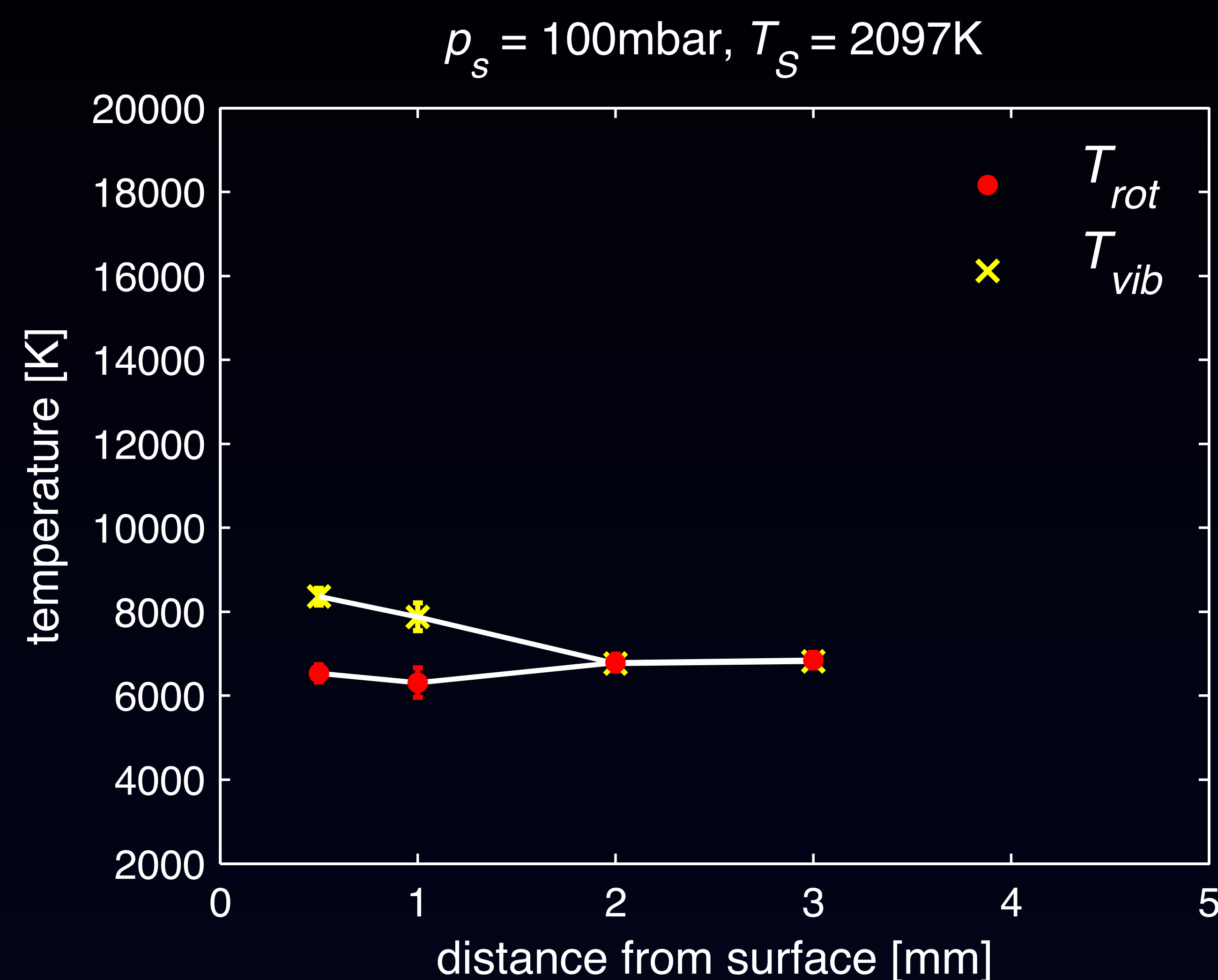
➟ Thermal non-equilibrium?

➟ Deviation from Boltzmann distribution?

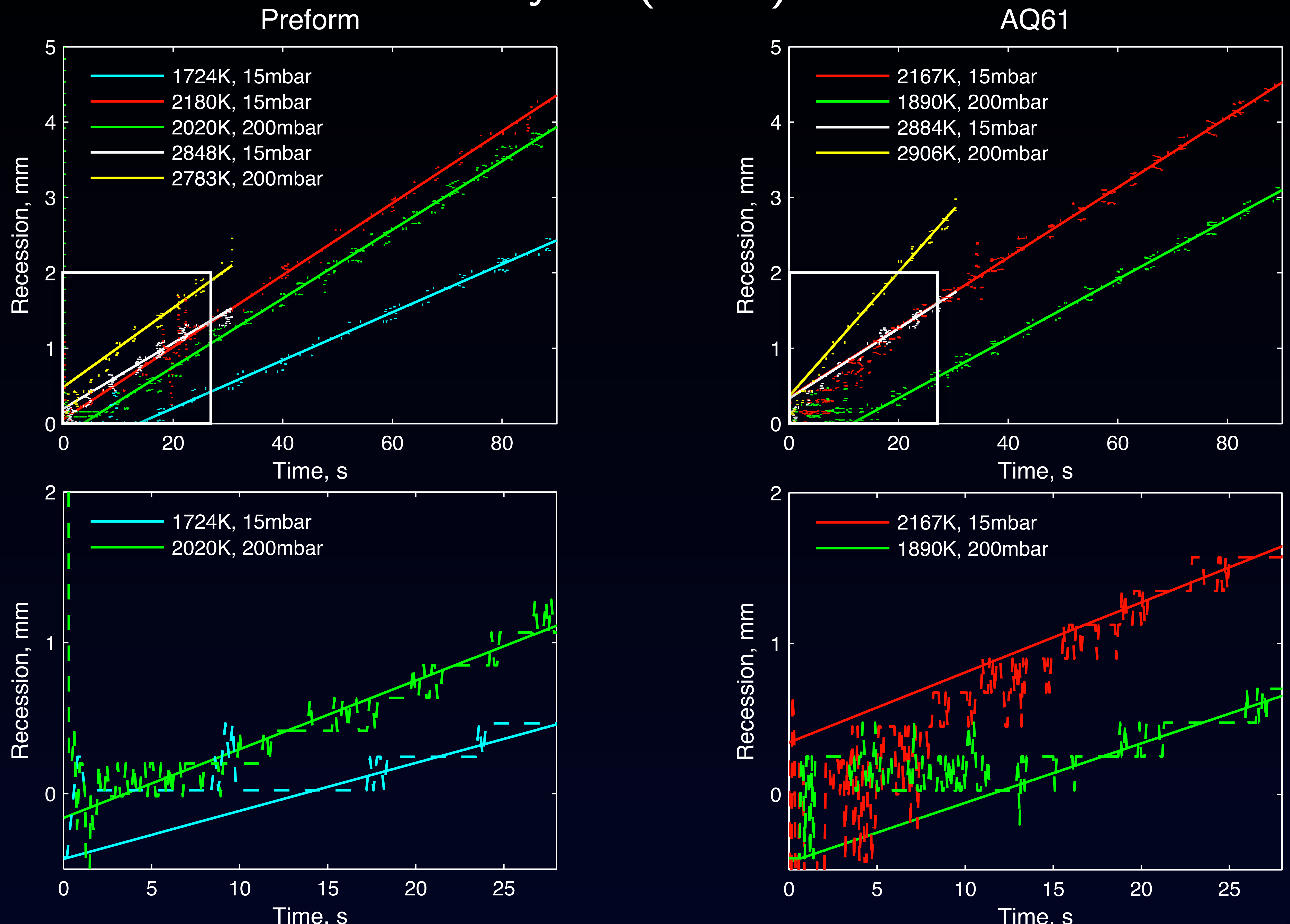
Boundary Layer Temperature Profile

Non-equilibrium at the wall?

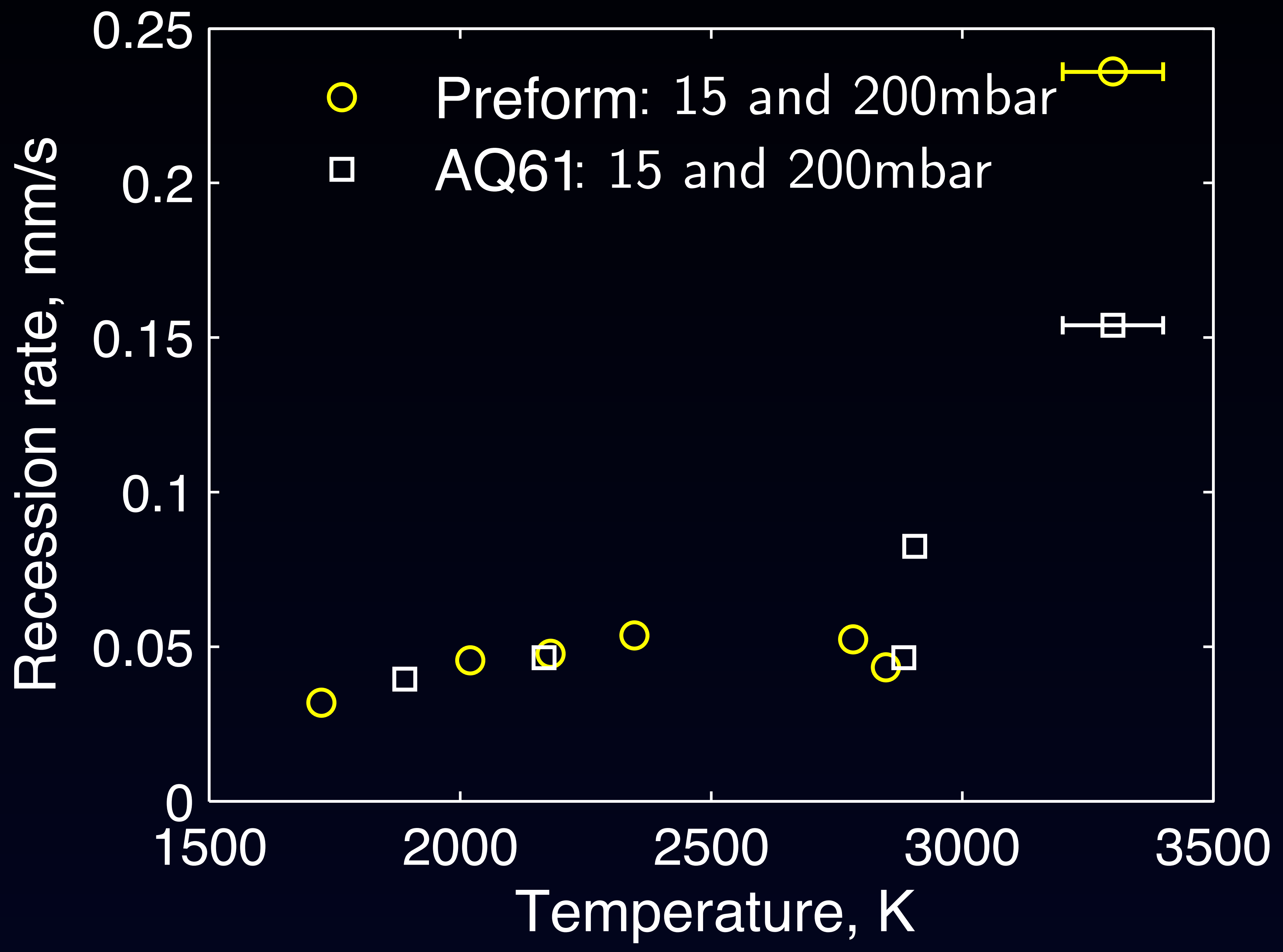




In-situ Recession Analysis (HSC)

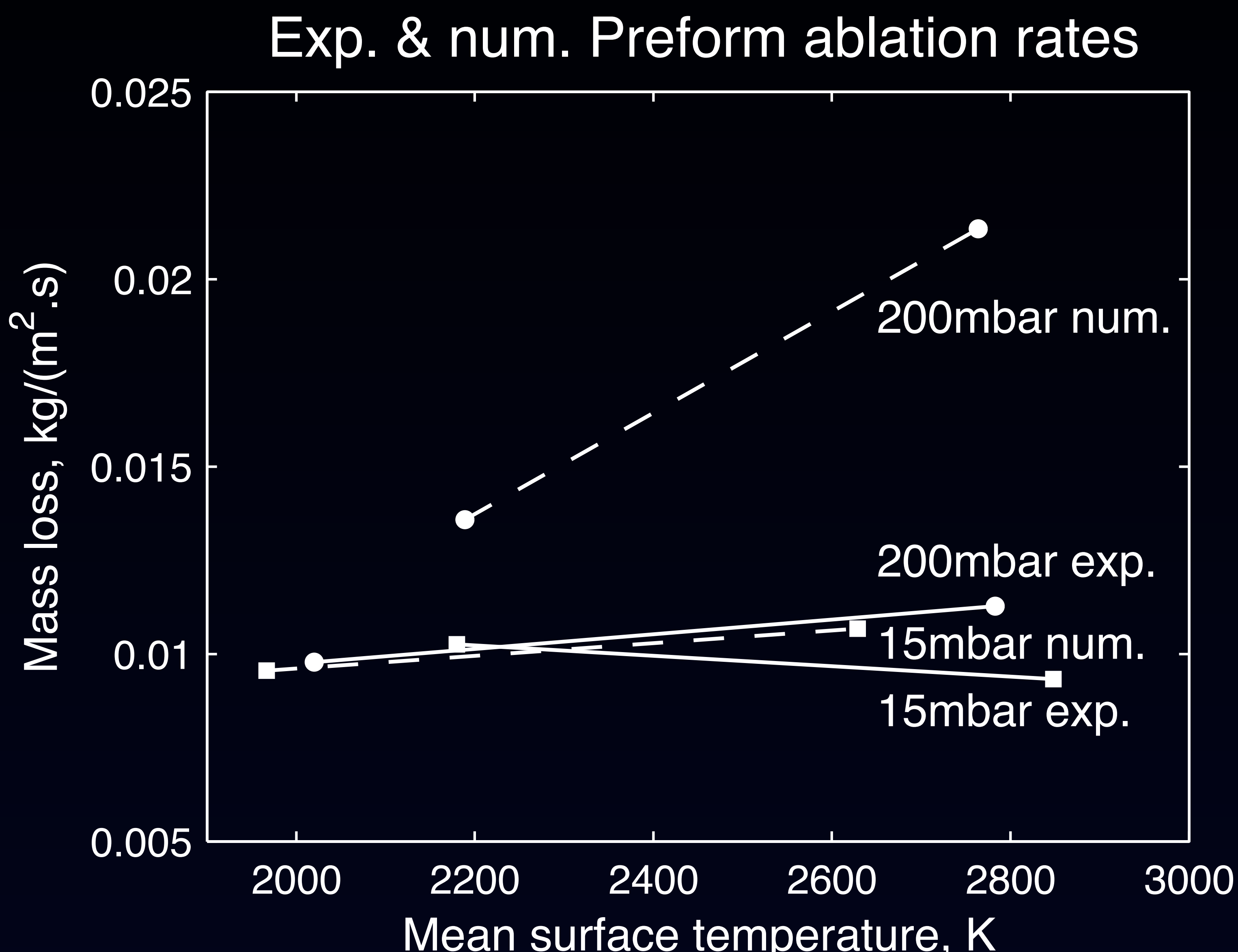


Ablation Regimes of Preform and AQ61



- ➠ diffusion limited ablation and sublimation regime
- ➠ recession not much influenced by pressure!

Diffusion Limited Ablation and Code Comparison



Surface temperature driven by catalytic reactions:

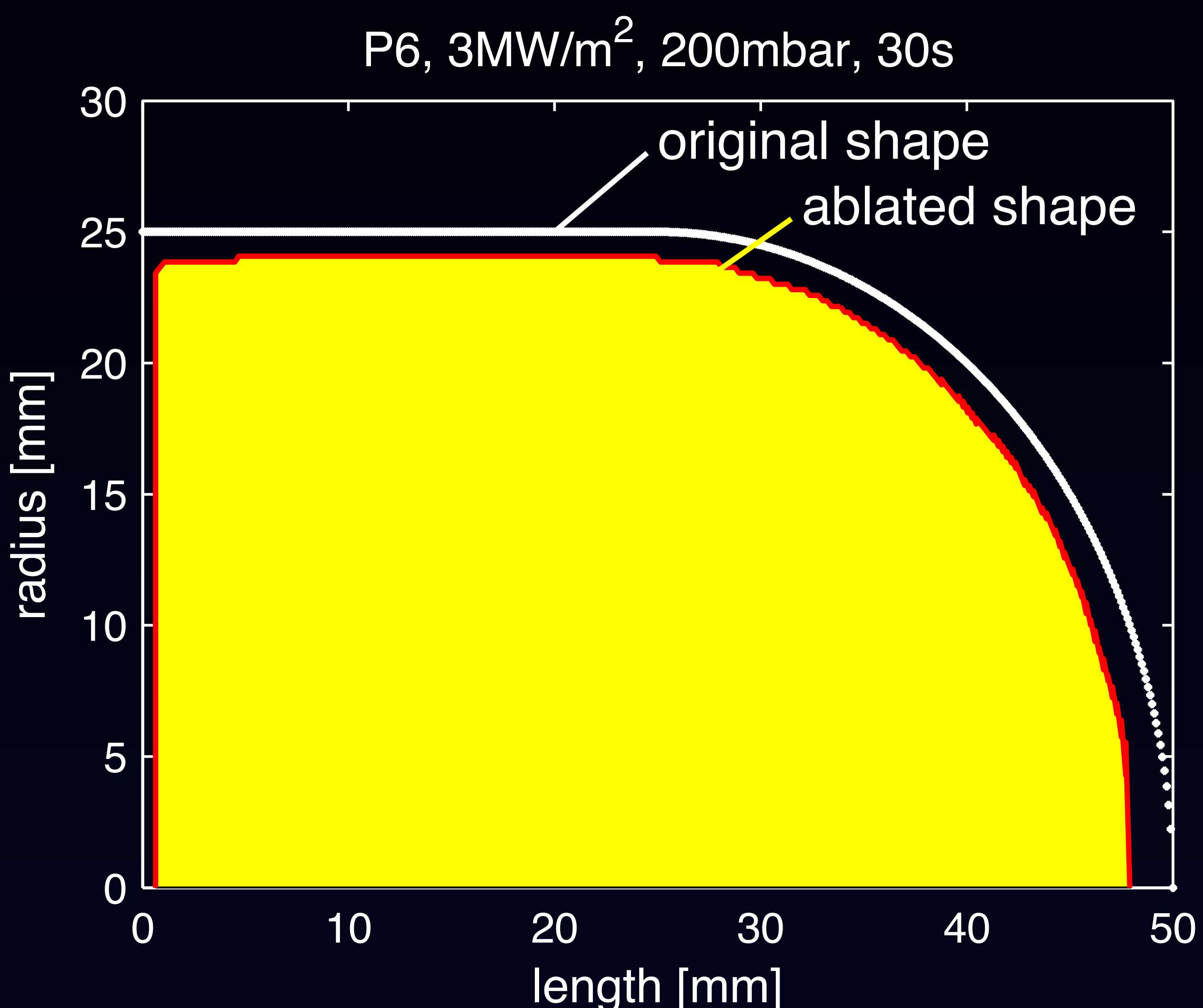
$$N + N \longrightarrow N_2$$

➟ Modeling of tests in nitrogen

15mbar: good agreement, possibly misleading measurement? (AIAA 2012-2876)

Pyrolysis-Gas Blowing Rate Determination

Non-pyrolyzing carbon-preform



$$\dot{m}_{pg} + \dot{m}_c = (\rho V)_w$$

$$\dot{m}_{pg} = \dot{m}_{pg} - \frac{(V_{abl} \cdot \rho_c)}{t_{exp}}$$

Carbon Preform (non-pyrol.):

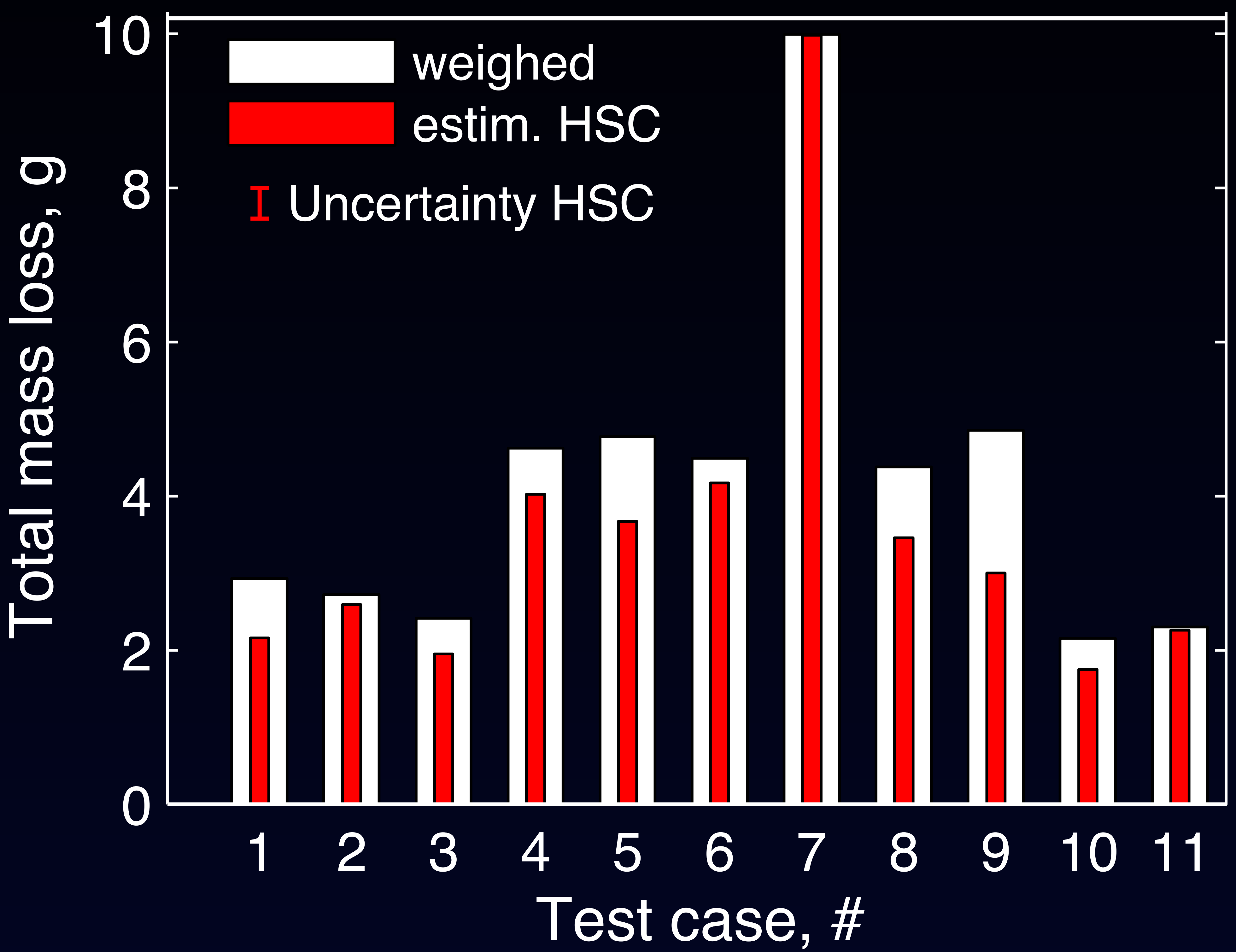
➡ $\dot{m}_c = \dot{m}_{tot} = V_{abl} \cdot \rho_c$

Pyrolyzing Ablators:

➡ char density required

Pyrolysis-Gas Blowing Rate Determination

Non-pyrolyzing carbon-preform

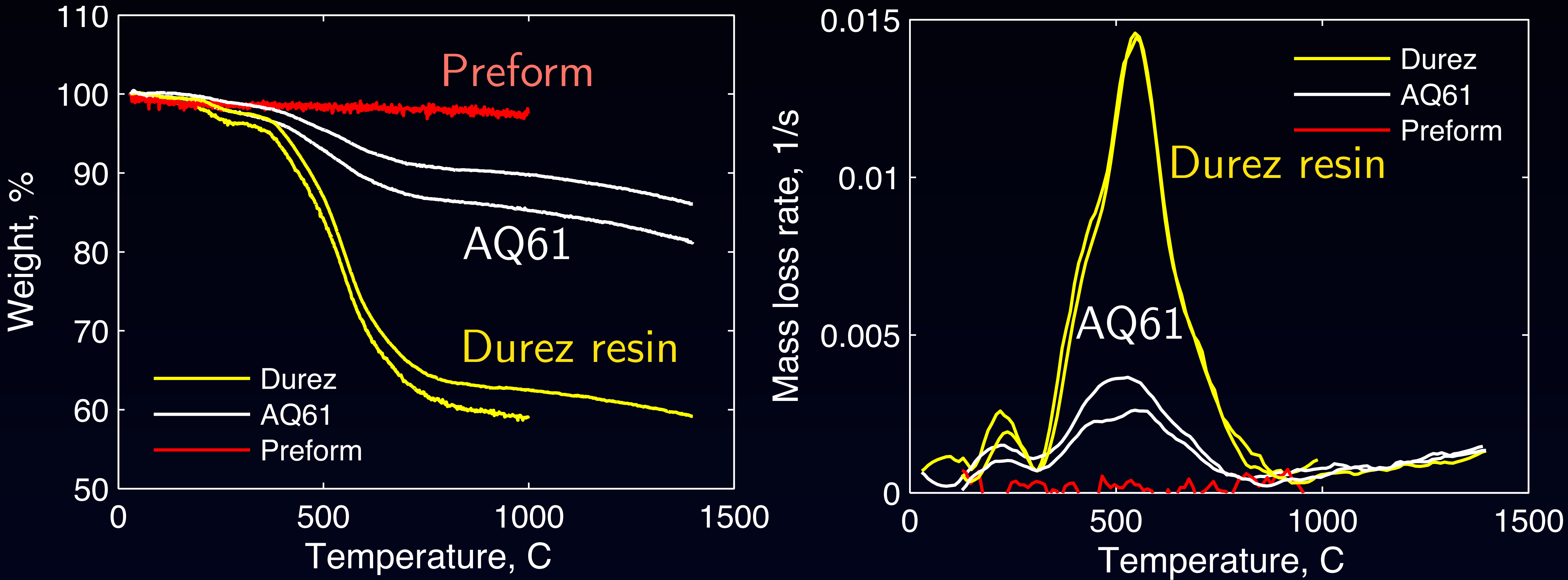


discrepancy:

- water
- initial density
- damage by deinstallation

Pyrolysis-Gas Blowing Rate Determination
Thermogravimetric Analysis (TGA)

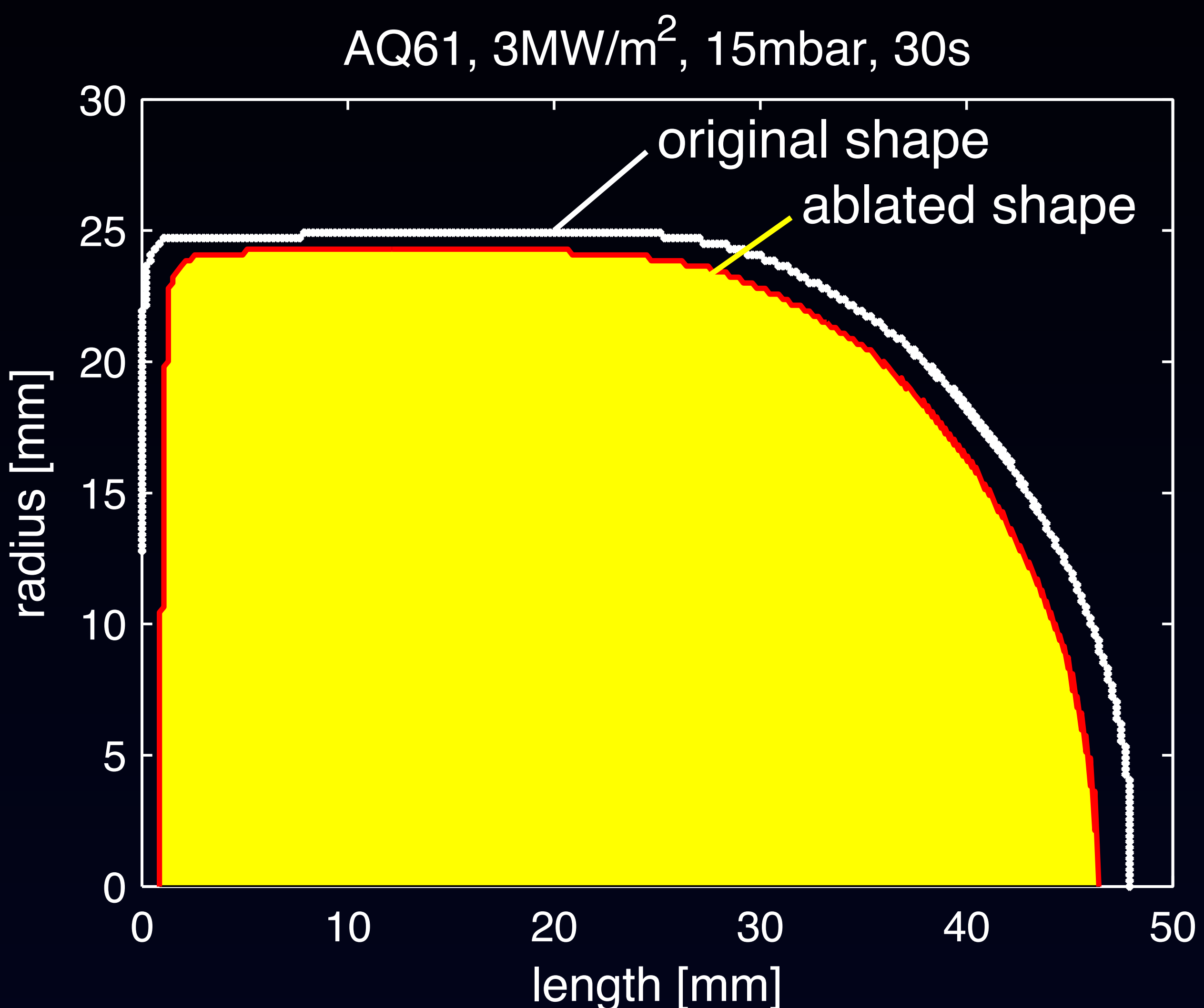
Argon (20-200 ml/min), 10 K/min, 1 atm



charred AQ61: $\rho_c = 80\text{-}85\% \ \rho_v$

Pyrolysis-Gas Blowing Rate Determination

Carbon - phenolic: AQ61



$$m_{pg} + m_c = (\rho V)_w$$

$$m_{pg} = m_{pg} - \frac{(V_{abl} \cdot \rho_c)}{t_{exp}}$$

<u>AQ61 (carbon-phenolic)</u>:

$m_{meas} = 4.03$ g

$m_{c,HSC} = 2.26 \pm 0.4$ g

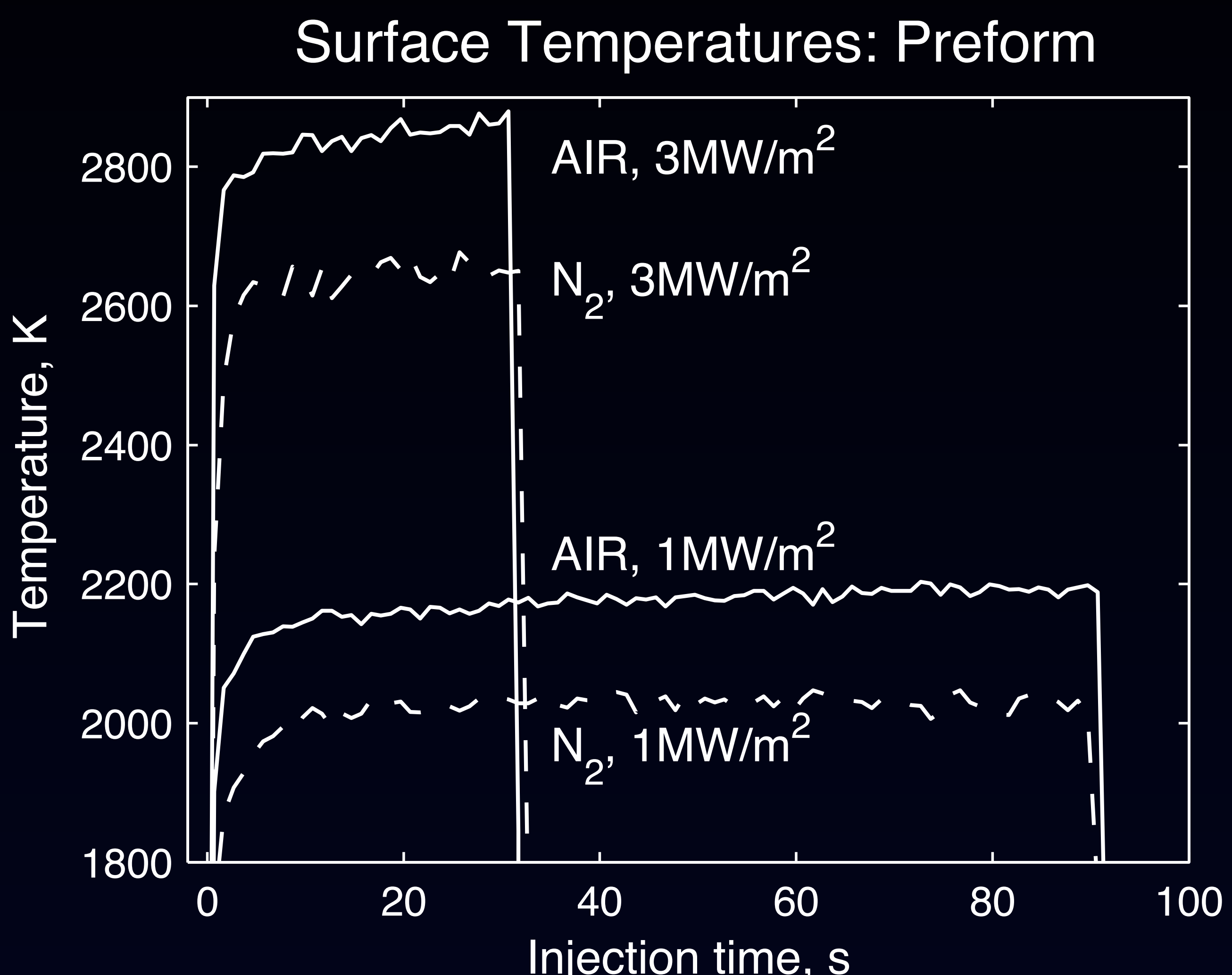
➡ $m_{pg} = 1.77$ g $\pm\ 0.4$ g

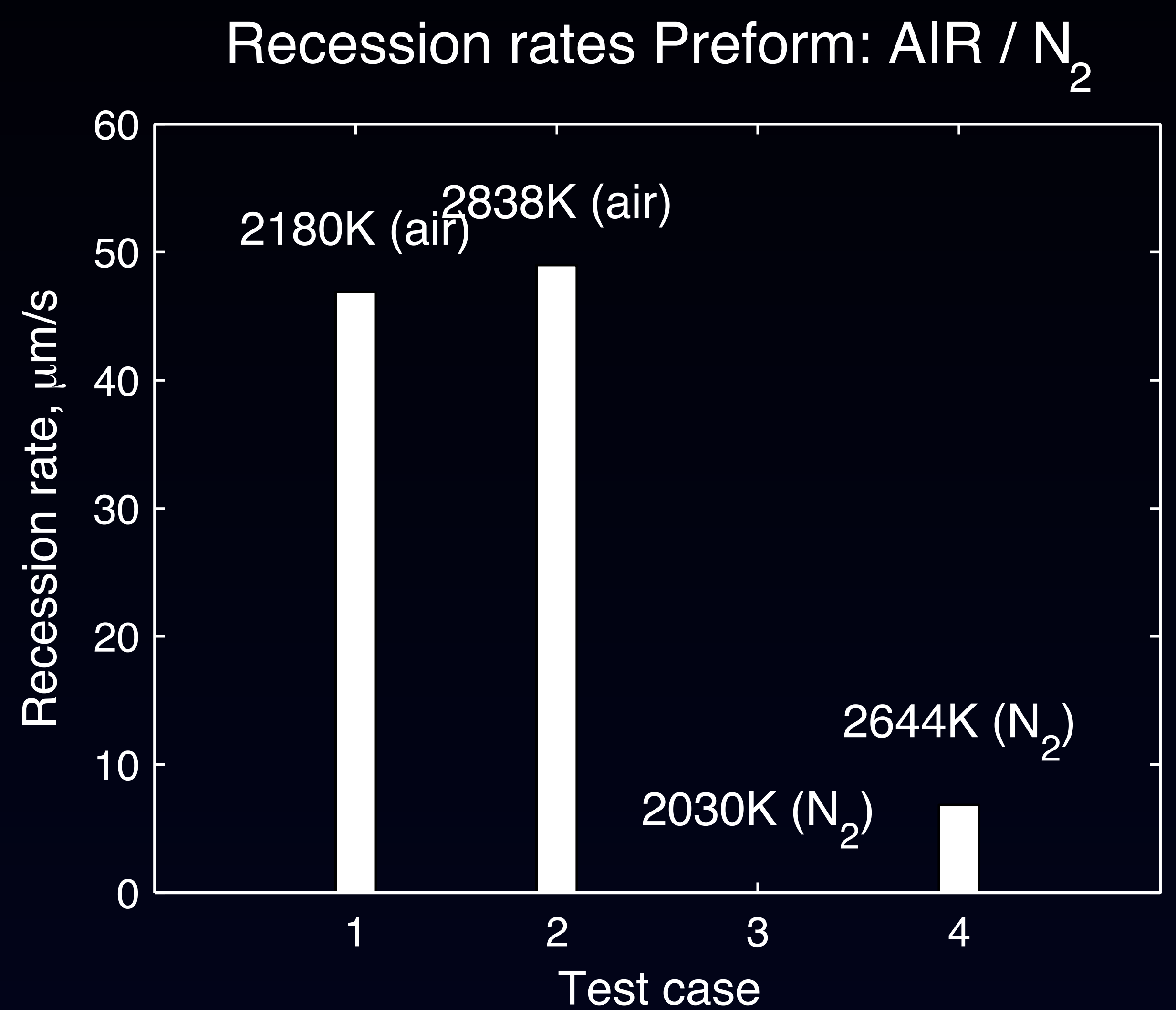
<u>Main challenges</u>:

Side-wall outgassing, non-1D effects, too-long test times

Ongoing Work

Rebuilding of ablation tests in nitrogen plasmas → γ_N

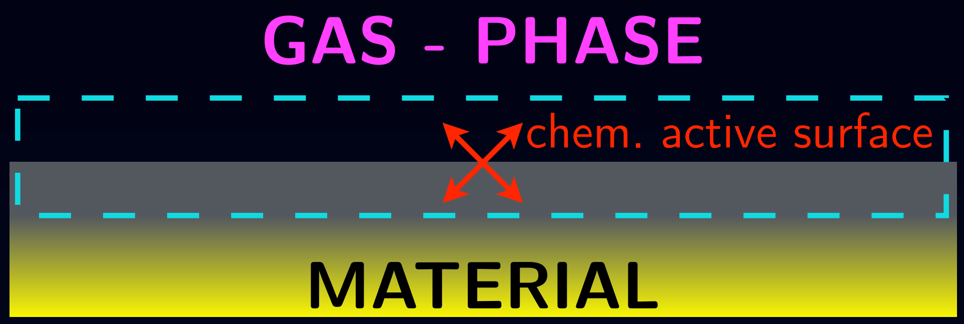




Nitridation negligible for recession

➟ Match of T_s for γ_N

Conclusions



(1) Materials and Methods
- hemispherical samples
- HSC imaging
- coupled w/ 3 Spectrometers

(2) BL emission
- steady ablation process
- preliminary comparison num/exp radiation profiles

(3) Char blowing rates
- diffusion limited ablation and sublimation
- deviation from num. model

(4) Pyrolysis outgassing
- Vol. ablation + TGA → $\dot{m}_{pg}$

Which chemical and physical phenomena matter?

ACKNOWLEDGEMENTS

Funding and materials supply:

AIRBUS DEFENCE & SPACE

MERSEN

IWT agency for Innovation by Science and Technology

In particular:

- Jean-Marc Bouilly & Gregory Pinaud (Airbus Defence & Space)
- N.N. Mansour (NASA ARC), J. Lachaud (UC Santa Cruz), F. Panerai (University of Kentucky) for informative support
- VKI Plasmatron & Ablation Team
- VUB SURF research team