SRI International

Collecting Experimental Data for the Modeling of Reactive Gas and Pyrolysis Interactions with Hot Carbon Chars.

David Thorne: REU Program, SRI International

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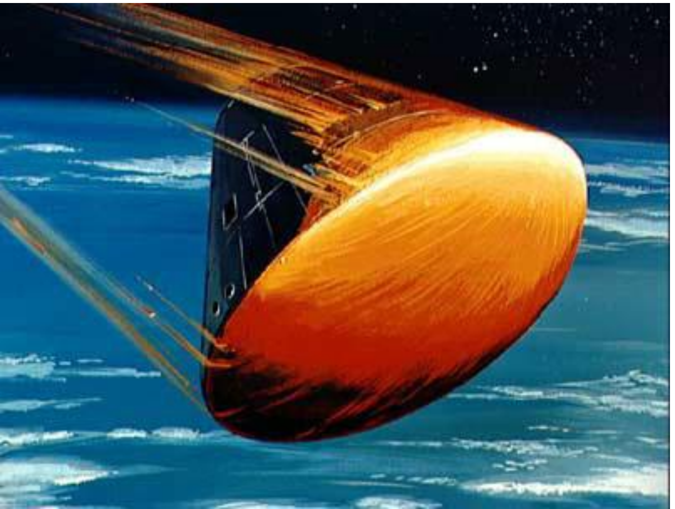
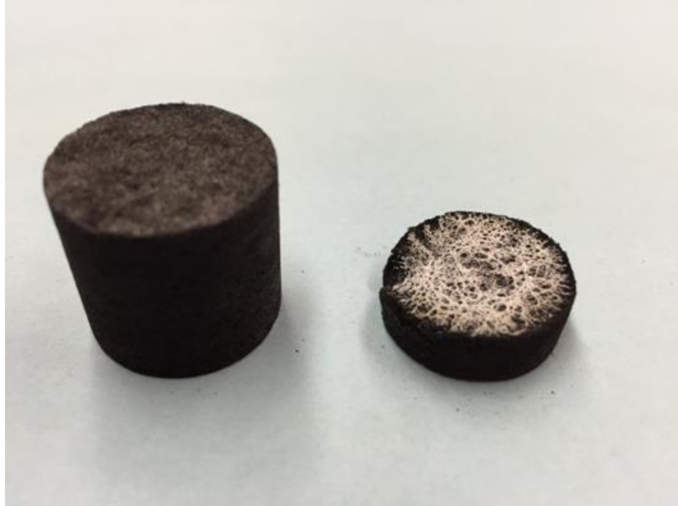
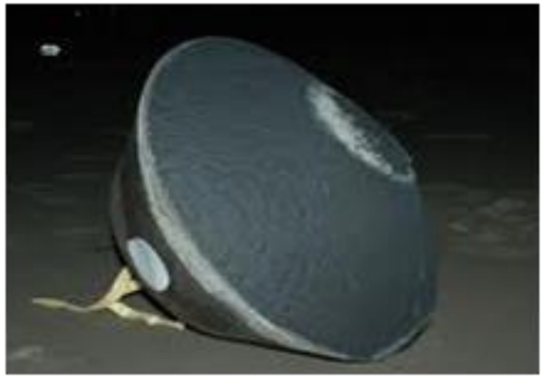




Ablative thermal protection system (TPS) materials are required for the extreme heating encountered during entry into planetary atmospheres.

Mars Science Laboratory (MSL), NASA



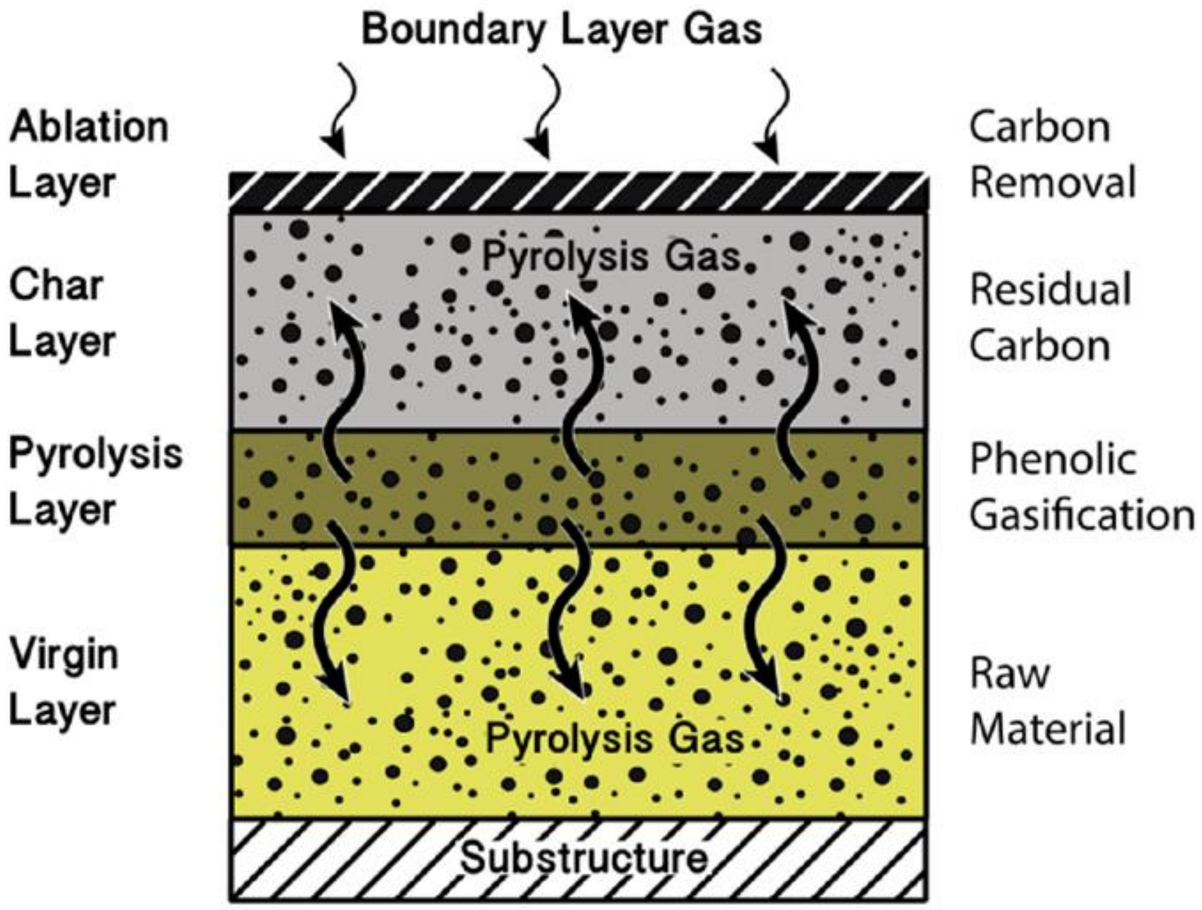
Stardust, NASA

Dragon Capsule, SpaceX

The Ablation Process

- A boundary layer is formed from gaseous reaction products within the heat shield material and provides protection against convective heat.

- The outer surface of the material chars, while the bulk of the TPS material undergoes pyrolysis and expels product gases.



Why is Research Involving Ablative Materials Desired?

- Modern design of heatshields is dependent on experiments performed in the 1960's;

- The physics and chemistry of ablation models are dependent on a limited set of measurements that were based on outdated techniques.

- Tend to overestimate ablation rates, calling for more material than necessary.

- The ablation community has expressed the need for modern data on the interactions between atmospheric gases, virgin carbon material, pyrolysis gases, and hot carbon char.

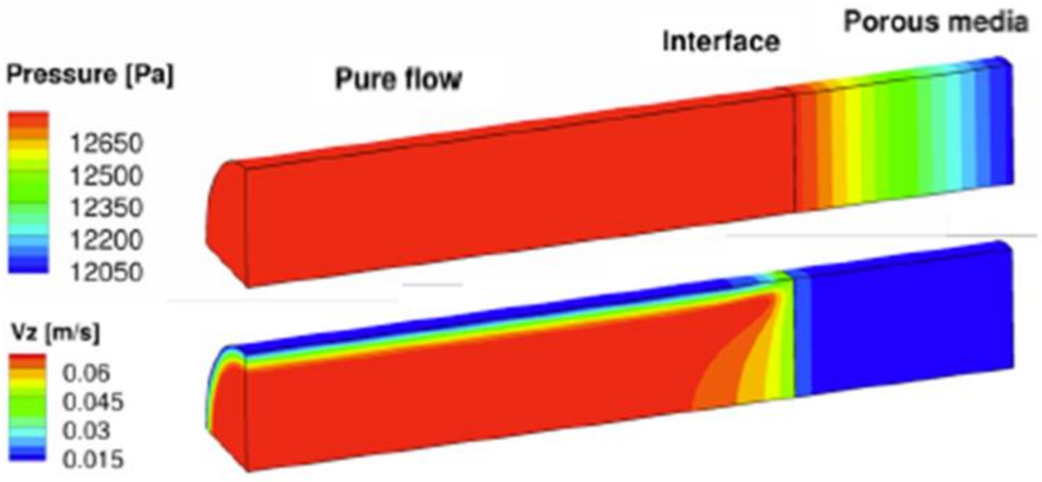
- Research pertaining to the ablative materials used for TPSs, remains one of the main focal points of NASA's technology development.

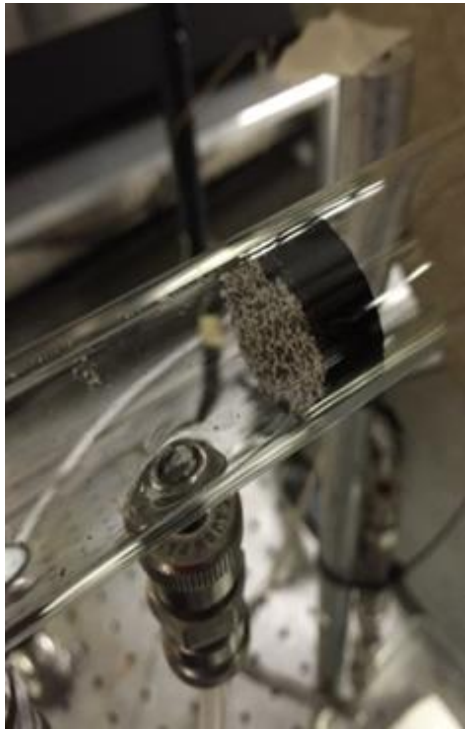
- Project Purpose: We are collecting modern experimental data, used to evaluate models currently used in ablation simulations, and develop new ones

Type of Data Collected

- Very simple experimental setup that can be easily simulated using fluid dynamics and material response codes

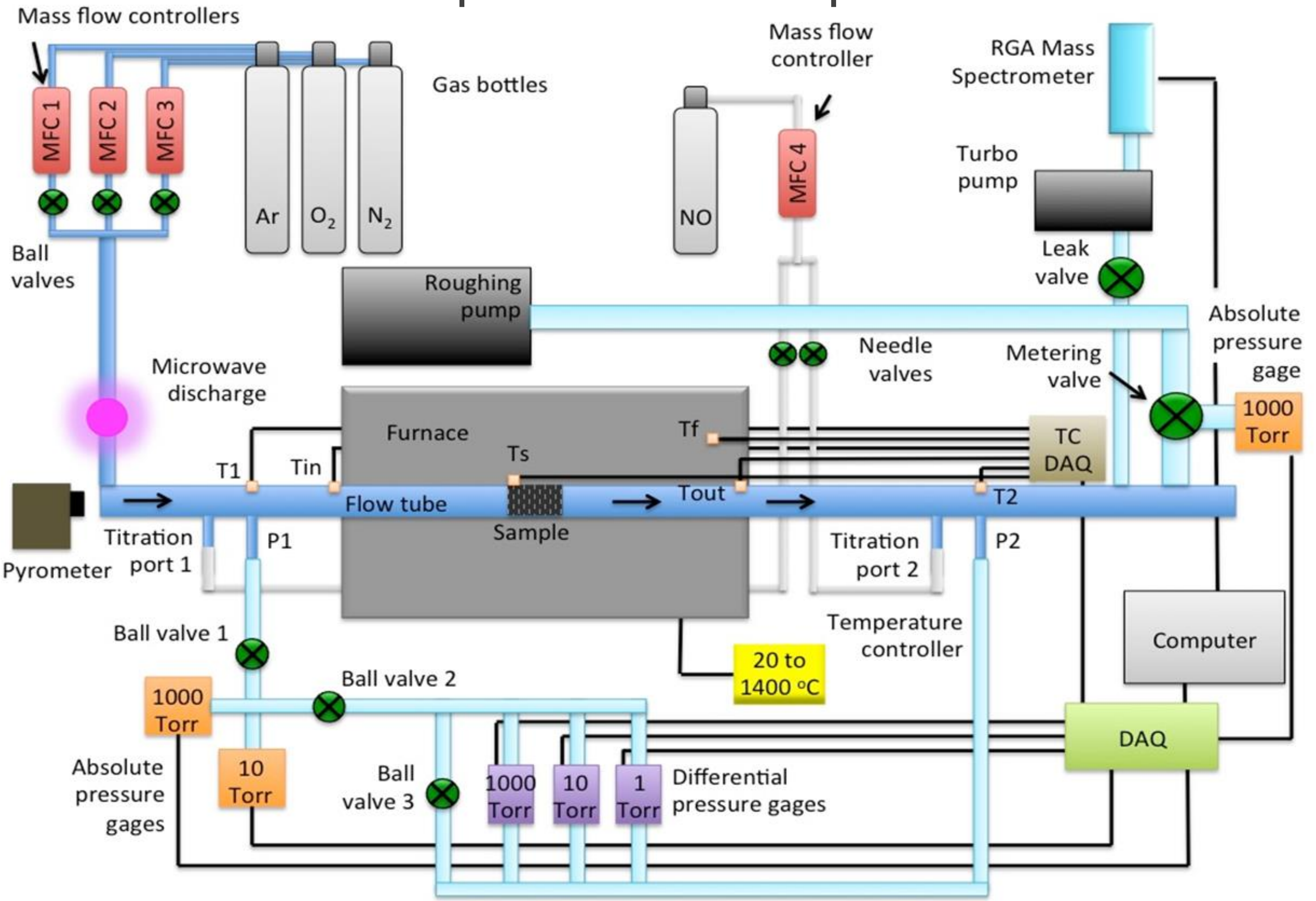
- Collect temperature, pressure, mass flow, and reaction product data





- KATS, Kentucky Aerothermodynamics and Thermal Response System, Combines fluid dynamics and material response codes in order to simulate chemical interactions with porous hot carbon chars.

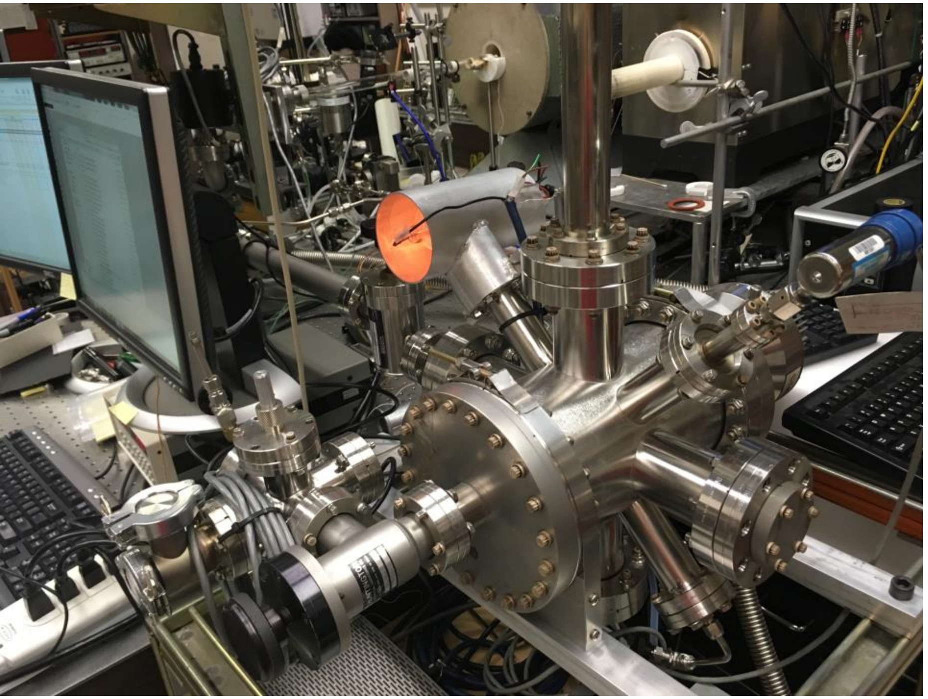
Experimental Setup

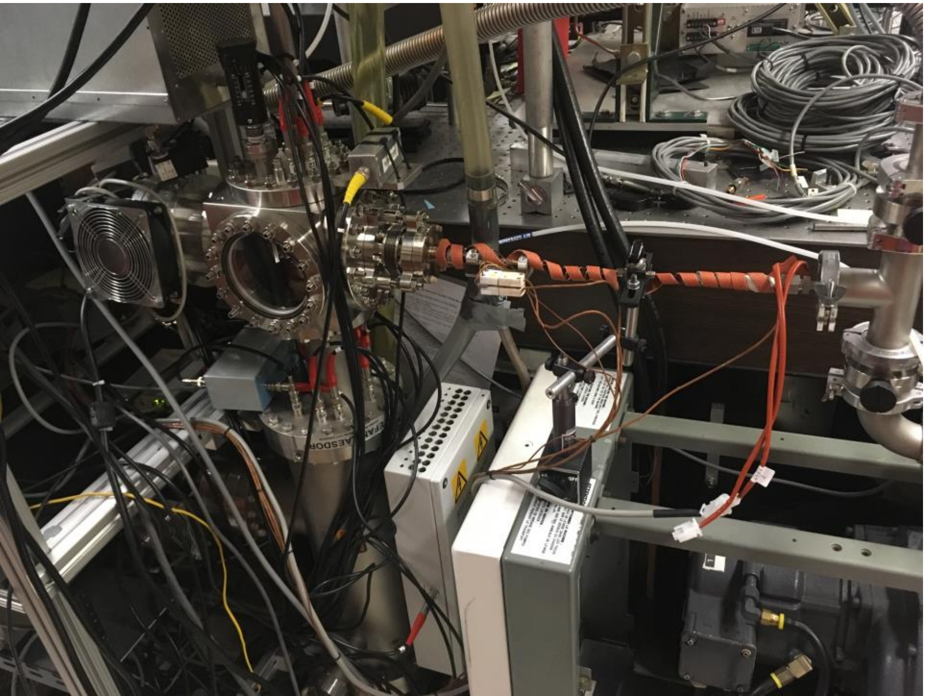


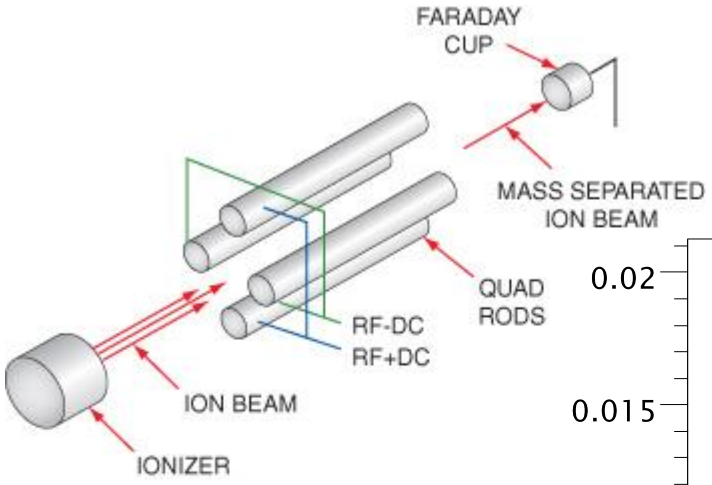
Lab Equipment

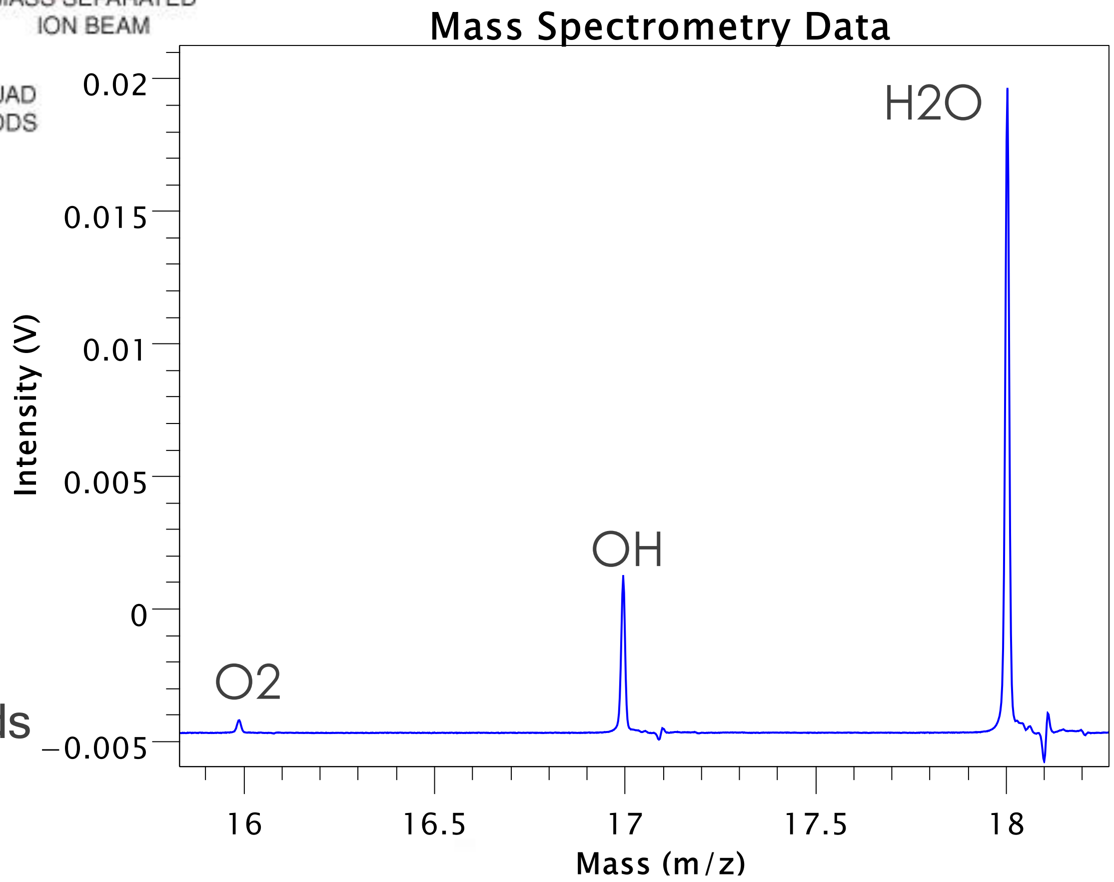
FiberForm, manufactured by Fiber Materials, Inc.

- A rigid carbon fiber composite used as preform for the carbon/phenolic ablator PICA

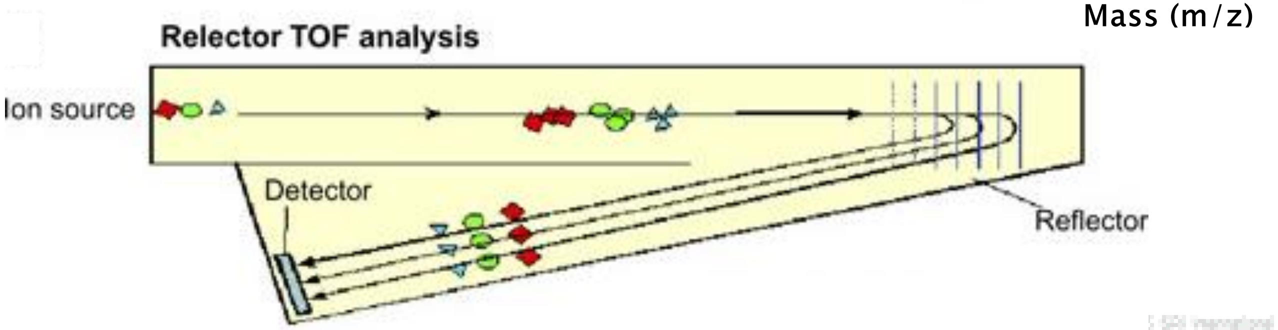




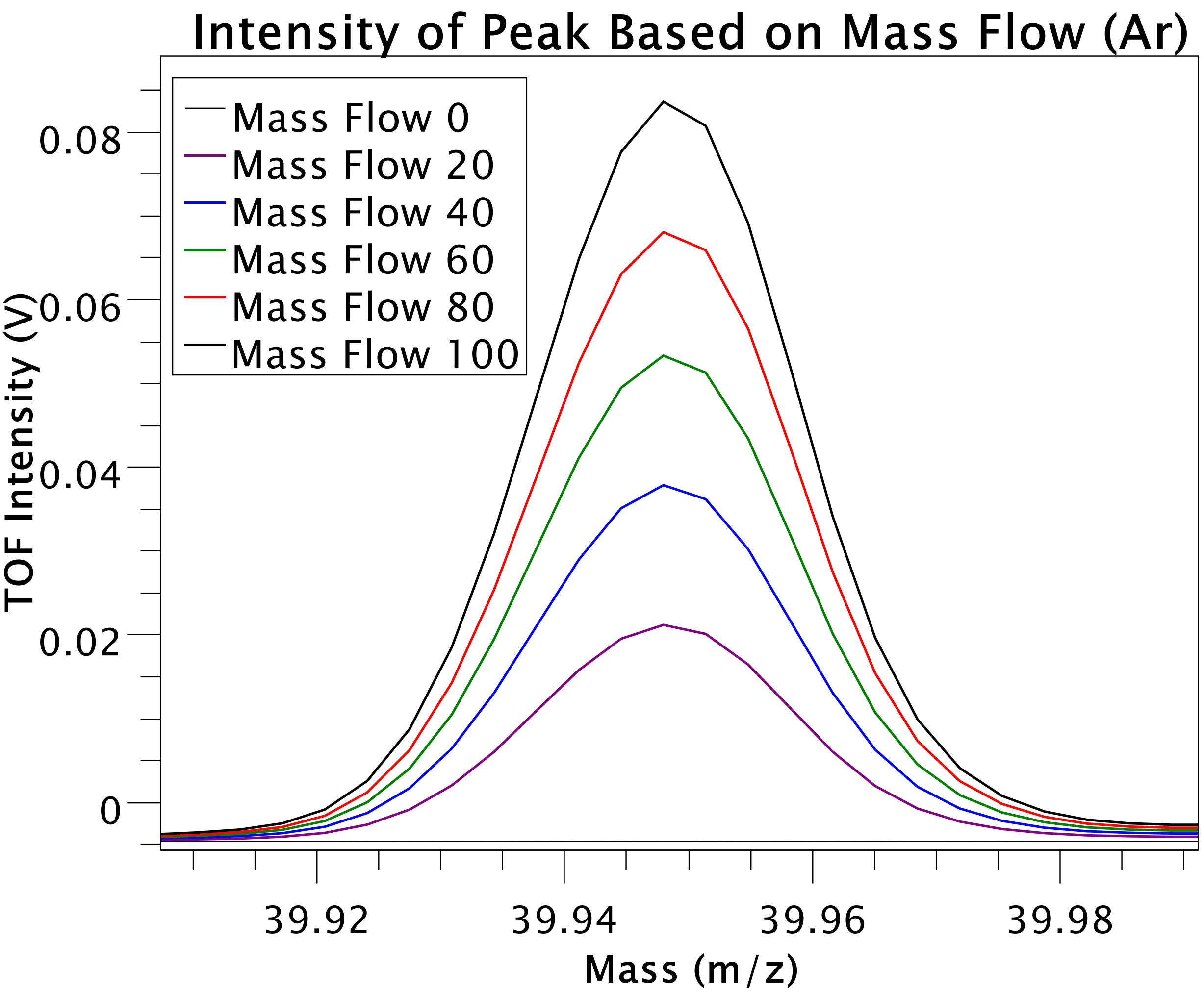


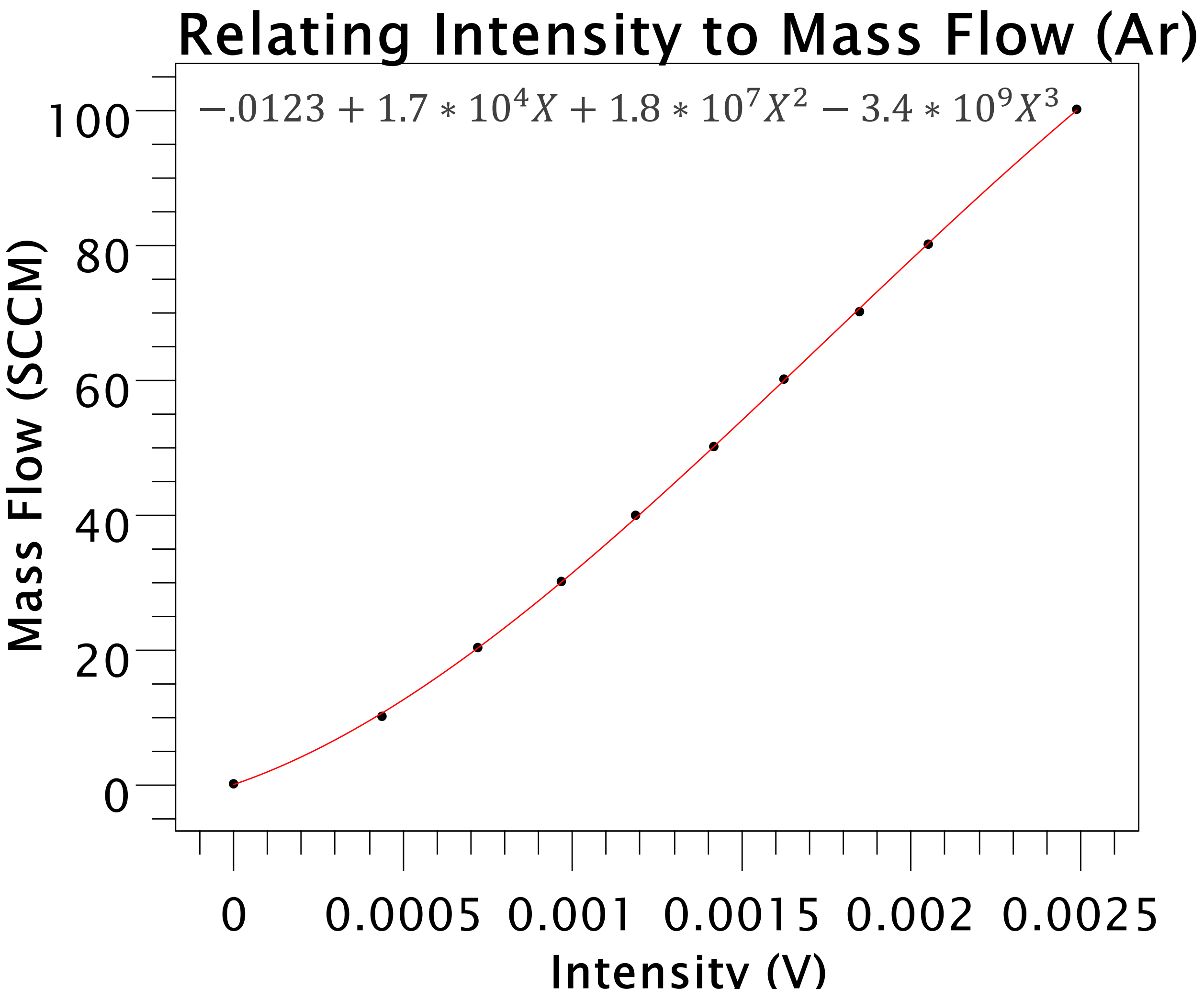


- Long flight path yields high resolution



Quantification

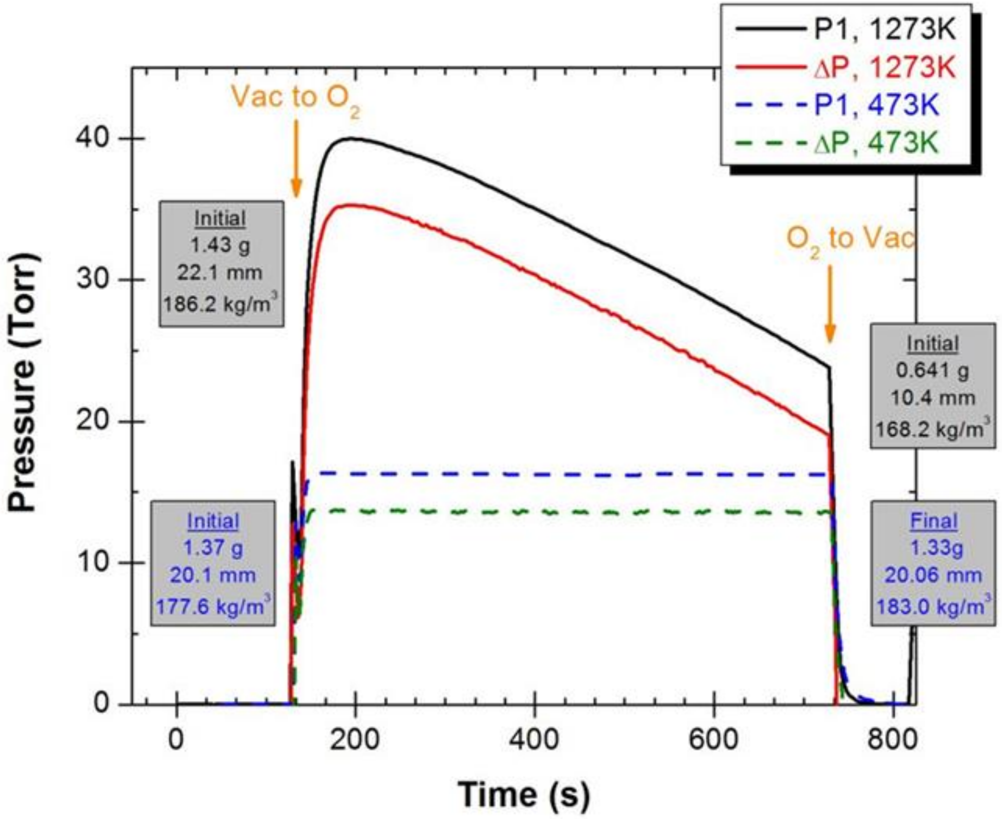




Overview of Experiments

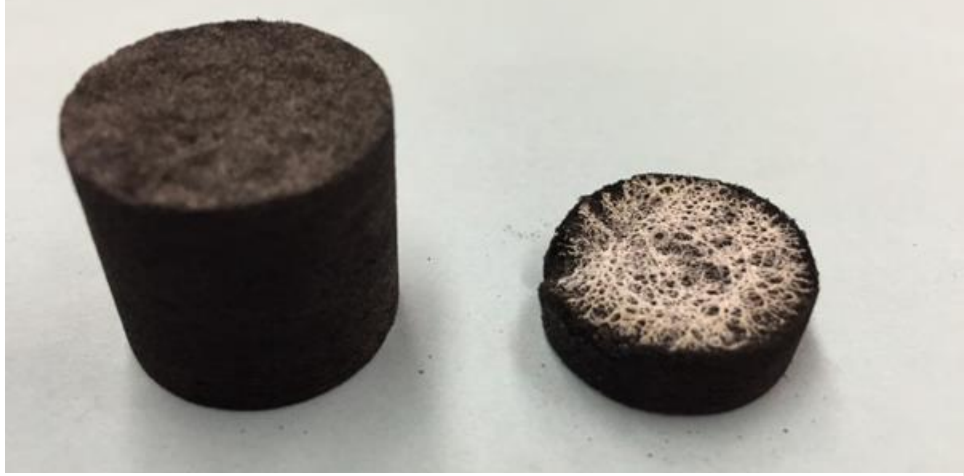
- Argon and Helium experiments were performed in order to obtain mass loss not associated with reactions.
- O_2 is very reactive with carbon, easy to model, and common in planetary atmospheres. O_2 and pyrolysis gasses are the core of the experiments.
- CO and CO_2 are products of the carbon-oxygen reaction, and O is present in O_2, so individual experiments are required for each.
- A titration is required to produce O atoms ($N+NO \rightarrow N_2+O$). So N and NO must all have individual experiments.

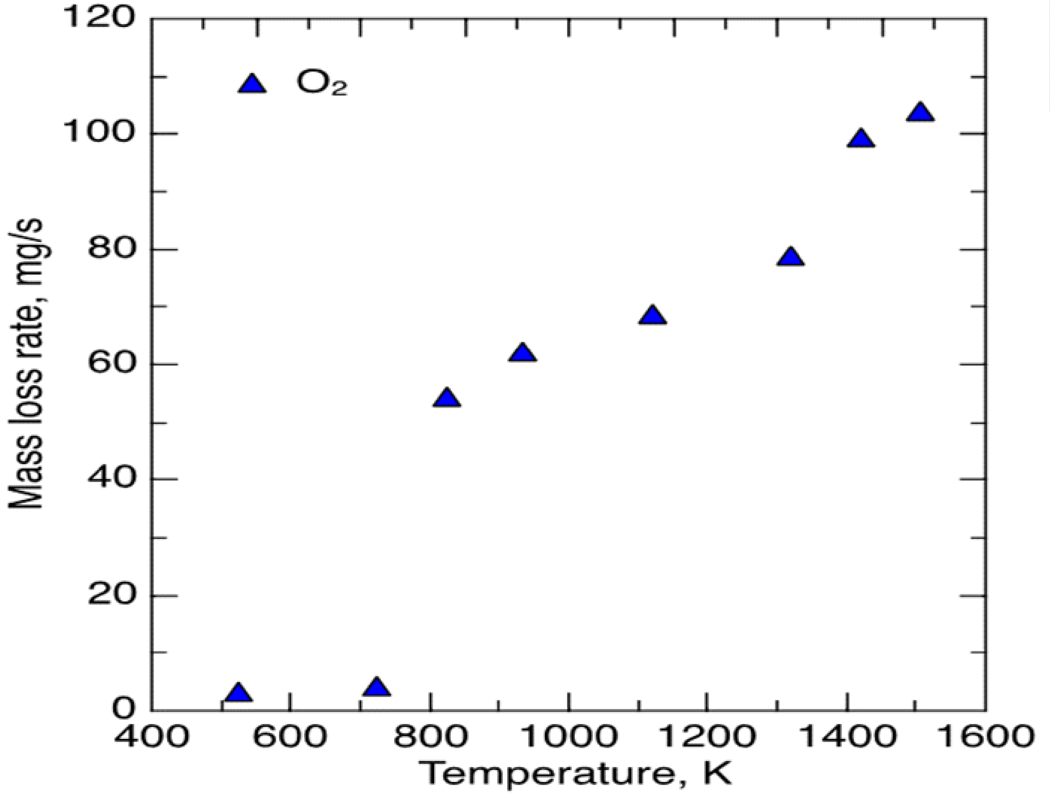
O2 Experiments



Upstream Pressure drop
due to recession of plug

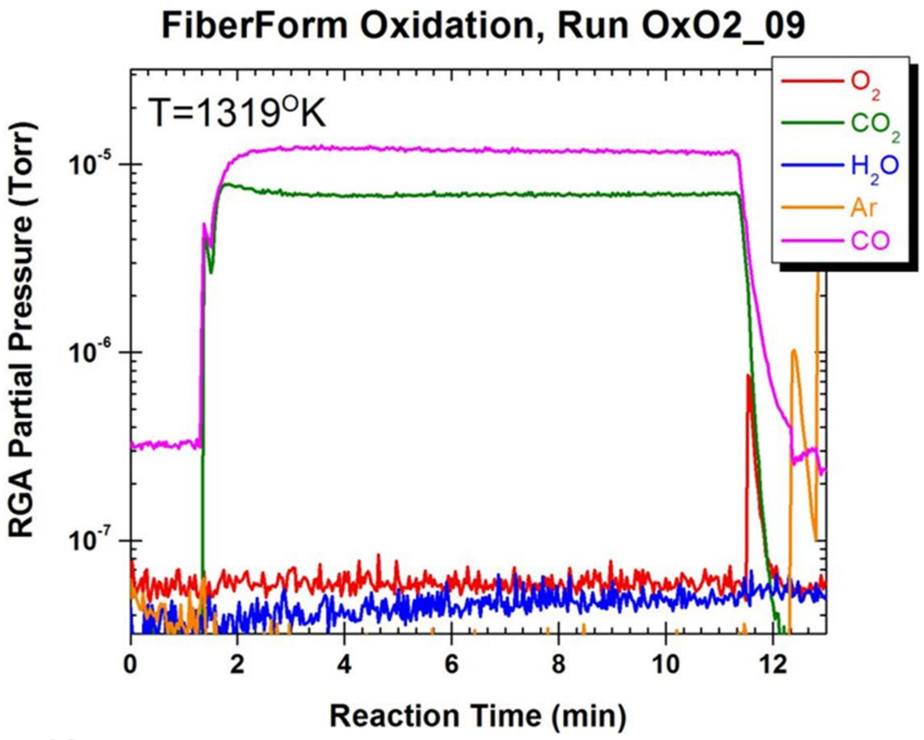
Whitish material attributed to Ca residue

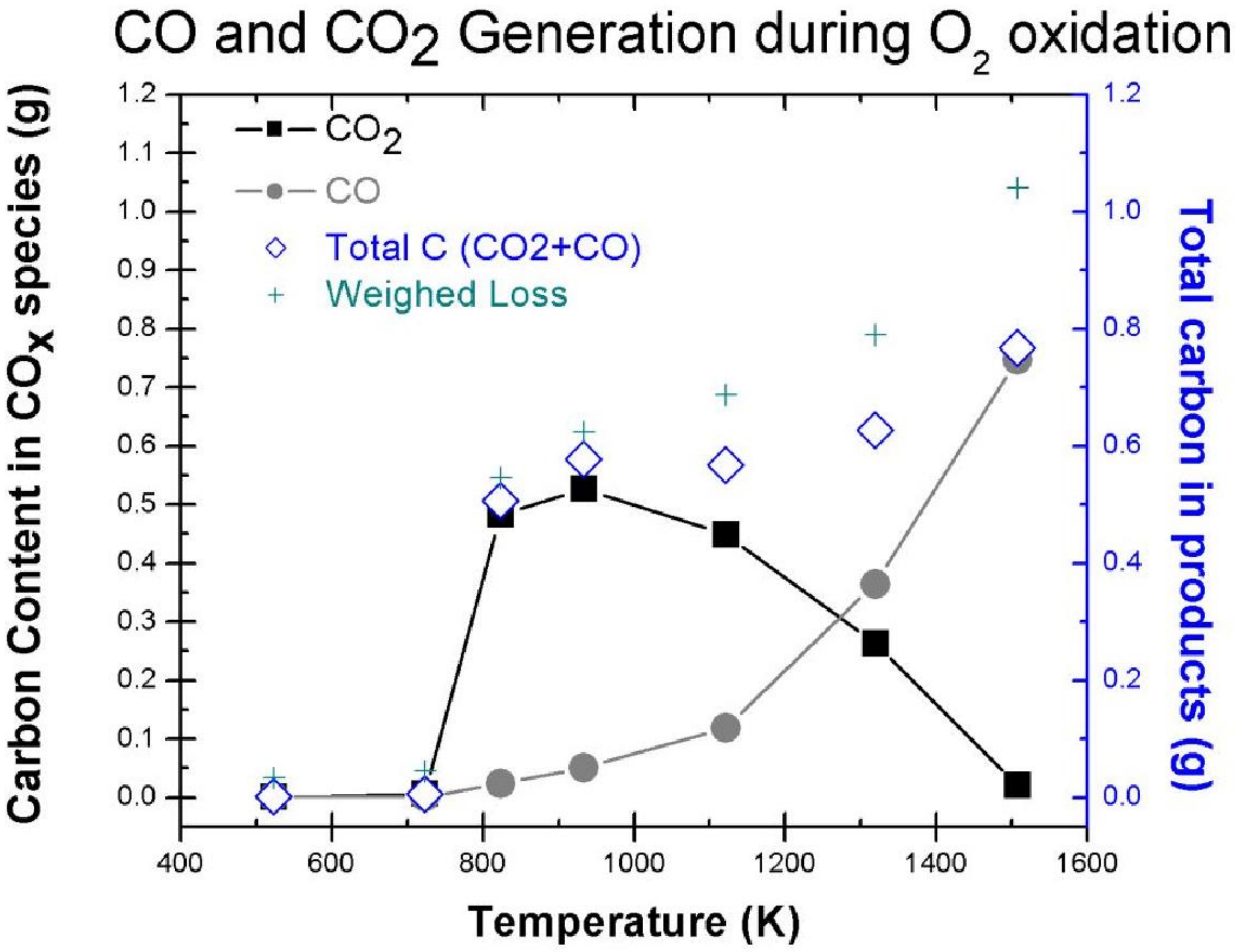


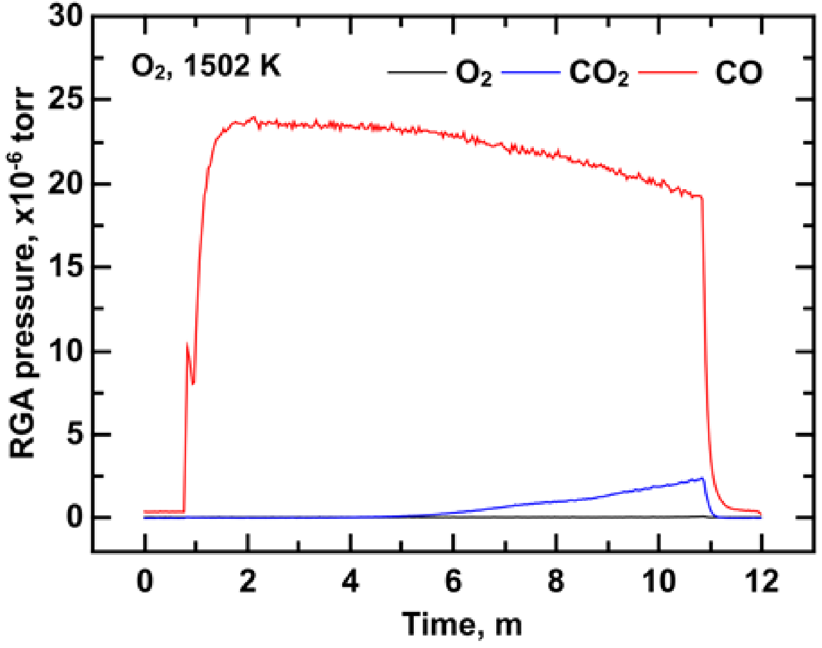


Mass loss is temperature dependent

O2 Experiments







Boudouard Reaction

$$2CO \rightleftharpoons CO_2 + C$$

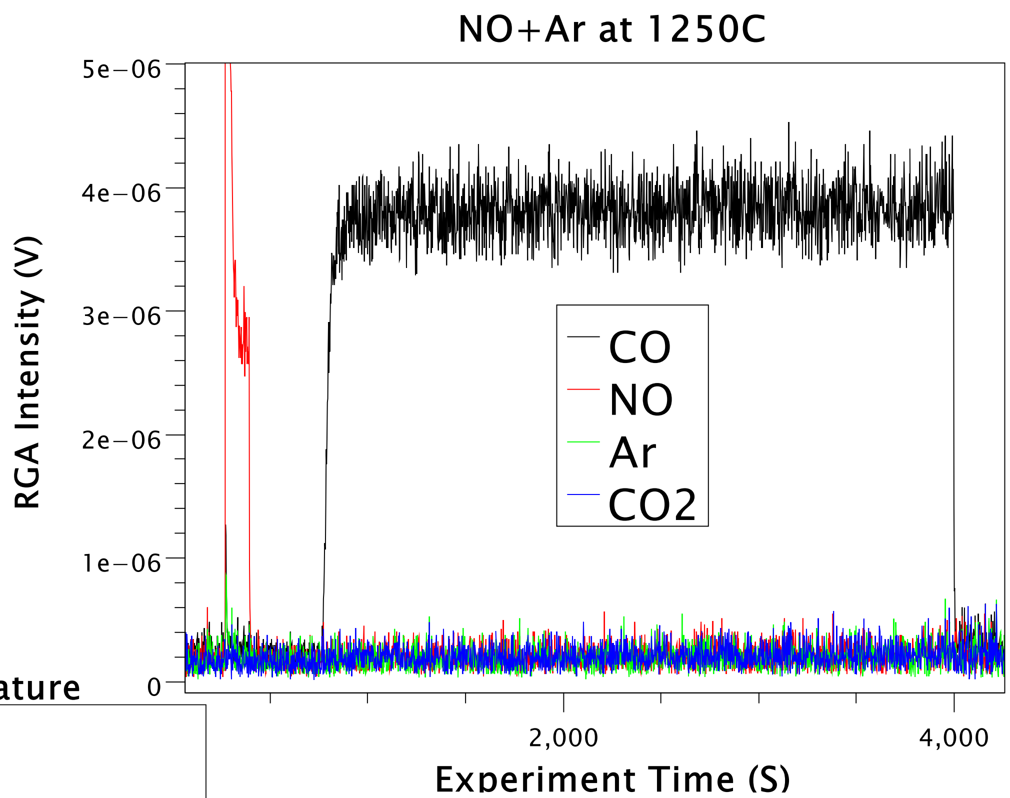
NO Experiments

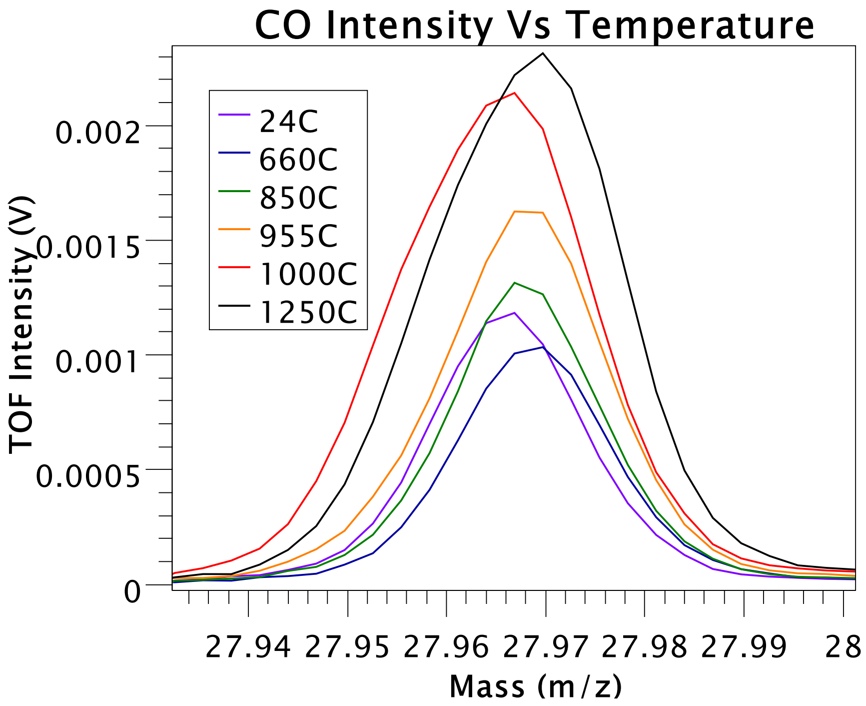
- Titration: N+NO→N2+O
- Products due to O must be distinguished from those due to NO; NO's chemical interaction with the plug must be determined
- Initial experiments were the standard 10 minutes long
- Mass loss was very small, increase sensitivity to measurement by increasing experiment time

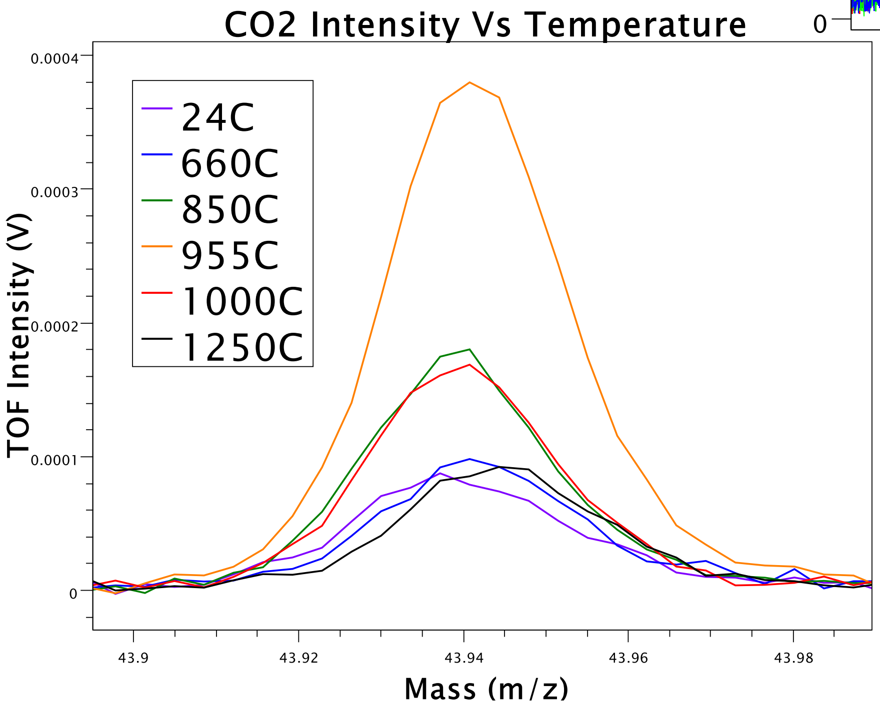
	Temperature (C)	Mass Loss (%)
NO	1250	2.8
O2	1200	58.5
Ar/N2	1200	~1.9

NO hour series

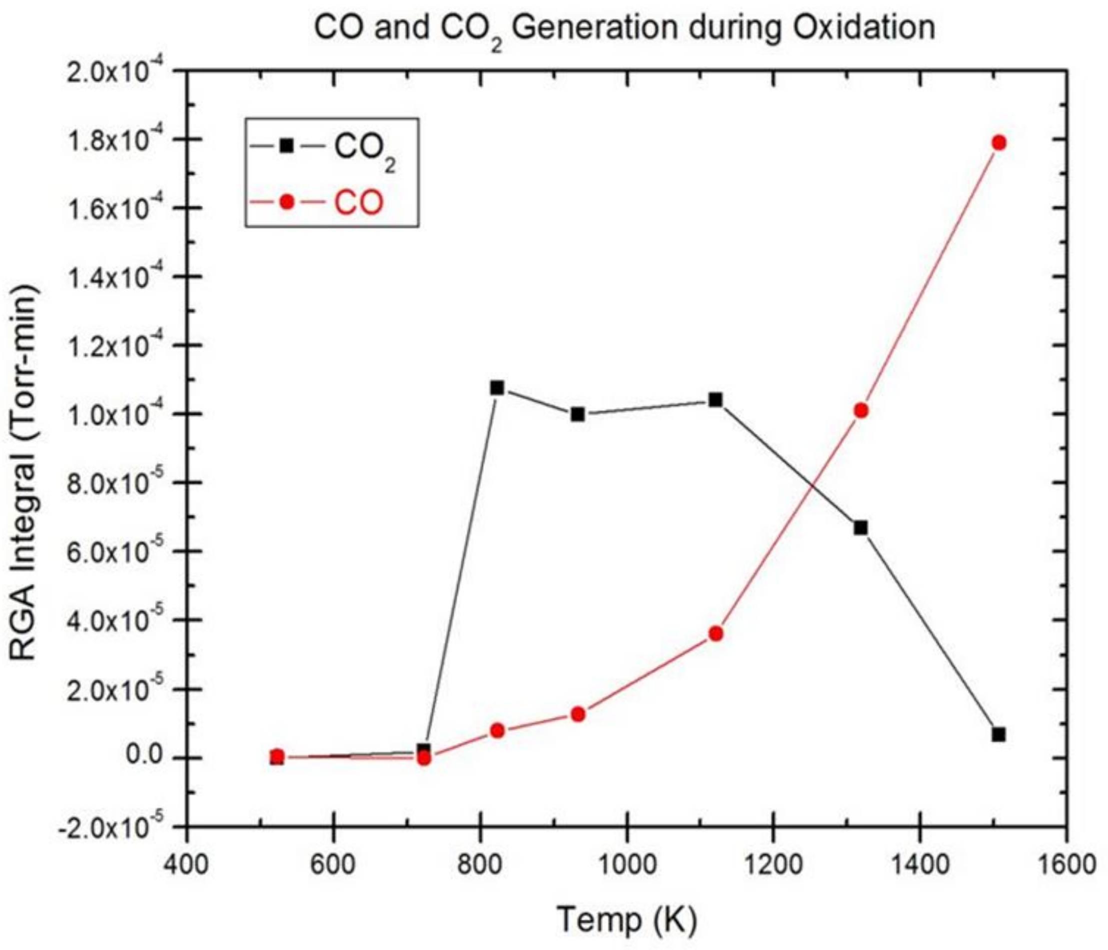
- Received 12% mass loss at highest temperature
- Products were not detected until above 800C, mostly CO, and a small amount of CO2
- $C + NO \rightarrow CO + \frac{1}{2}N_2$

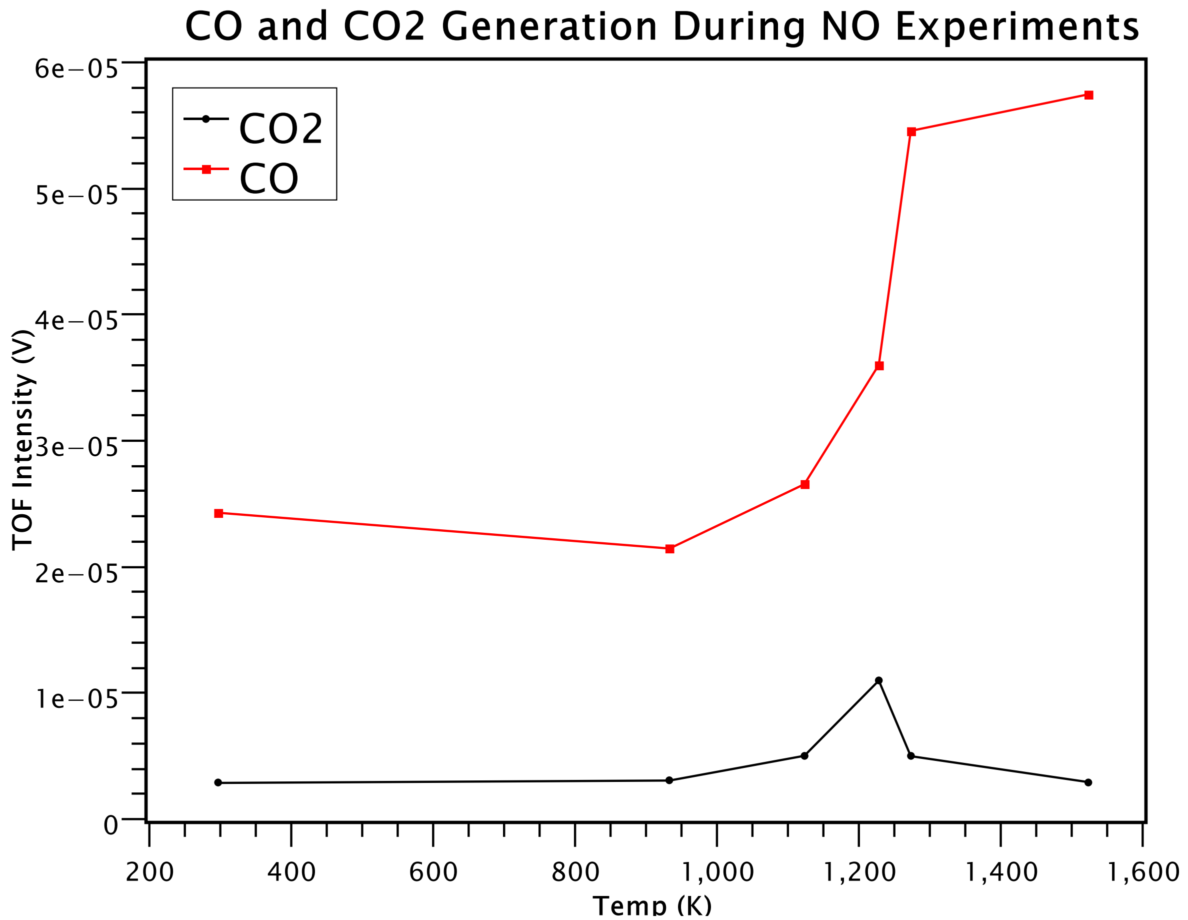






NO hour series

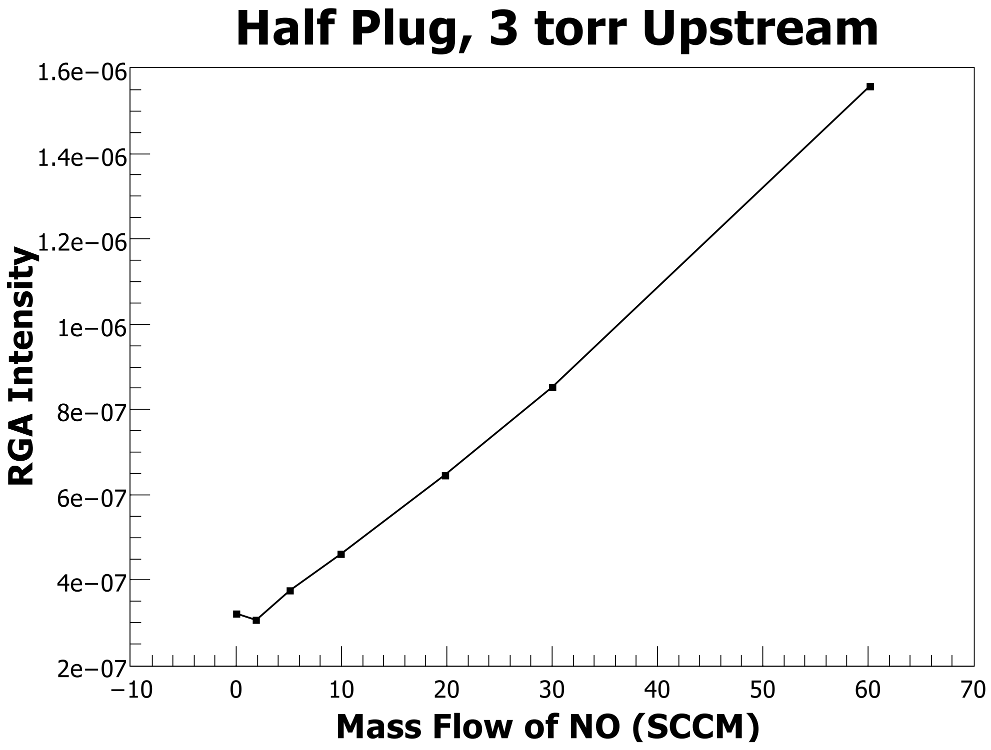




O Experiments

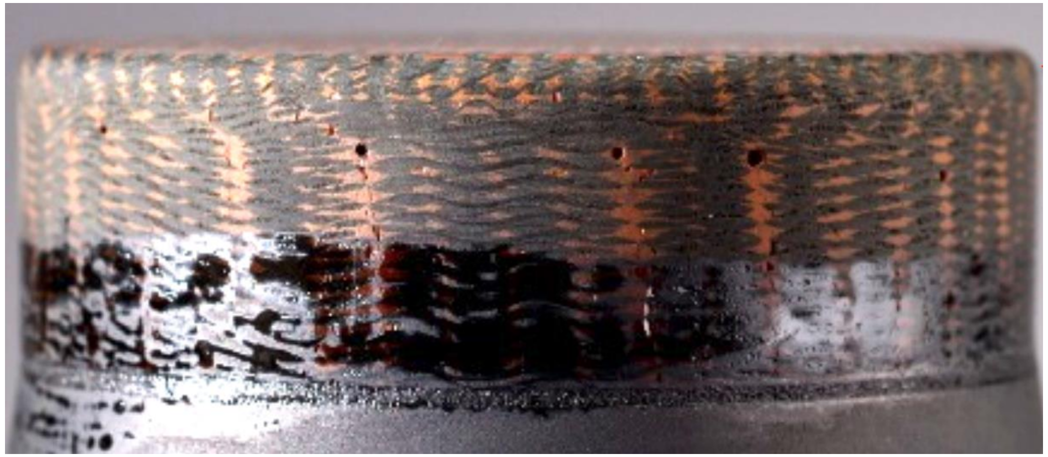
- No reaction with the plug was observed during discharge experiments
- High pressures may cause recombination O atoms before reaching plug surface
- Upstream pressure was lowered using a half plug/in-plane plug, still no reaction

- It was shown that at 10 torr, no plug, NO intensity remained constant during titration
- At 3 torr, no plug, N was shown to combine with NO (no increase in NO signal) during titration
- Titration still showed no reaction at 3 torr.



Future Experiments

- Improve O experiments
- Experiment with pyrolysis gases (phenol, benzene, alcohols, hydrogen, were all produced during pyrolysis experiments of carbon/phenolic material here at SRI)
- Perform experiments with PICA instead of Fiberform, as well as with conformal ablative materials.



←Woven Ablative Material

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Thank you

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