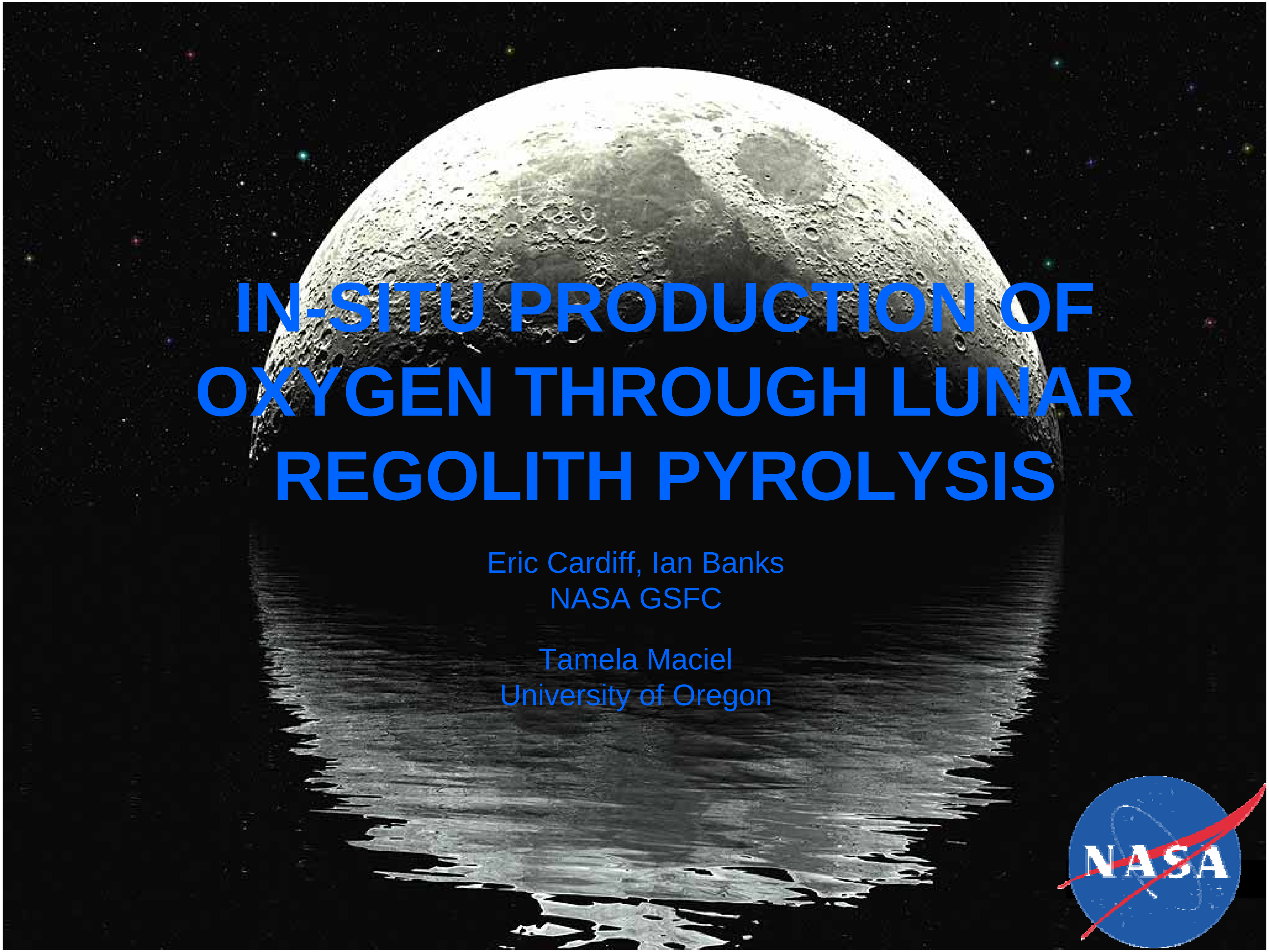
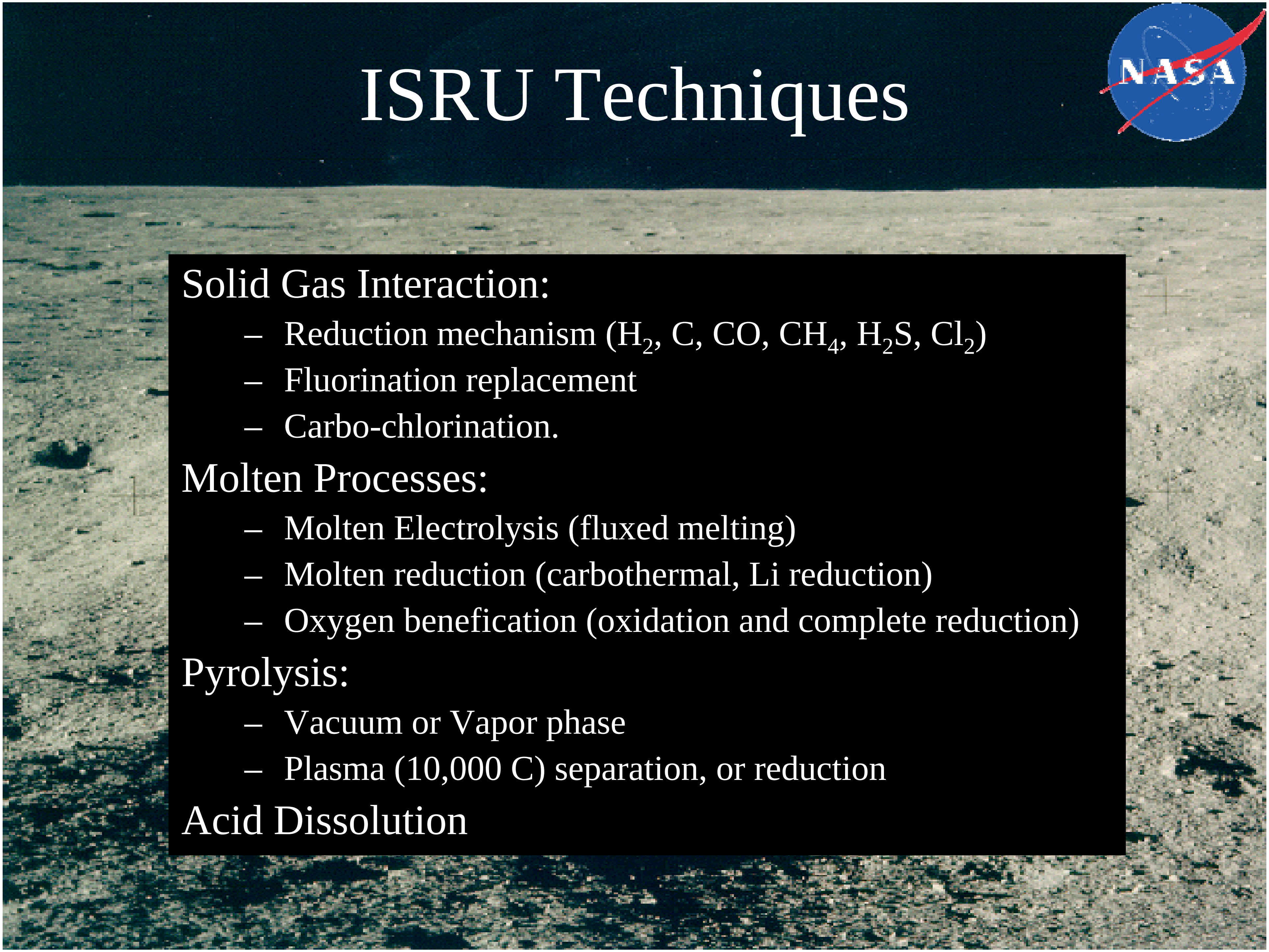


IN-SITU PRODUCTION OF OXYGEN THROUGH LUNAR REGOLITH PYROLYSIS

Eric Cardiff, Ian Banks
NASA GSFC

Tamela Maciel
University of Oregon



ISRU Techniques

Solid Gas Interaction:
  - Reduction mechanism (H_2, C, CO, CH_4, H_2S, Cl_2)
  - Fluorination replacement
  - Carbo-chlorination.

Molten Processes:
  - Molten Electrolysis (fluxed melting)
  - Molten reduction (carbothermal, Li reduction)
  - Oxygen benefication (oxidation and complete reduction)

Pyrolysis:
  - Vacuum or Vapor phase
  - Plasma (10,000 C) separation, or reduction

Acid Dissolution

Vacuum Pyrolysis

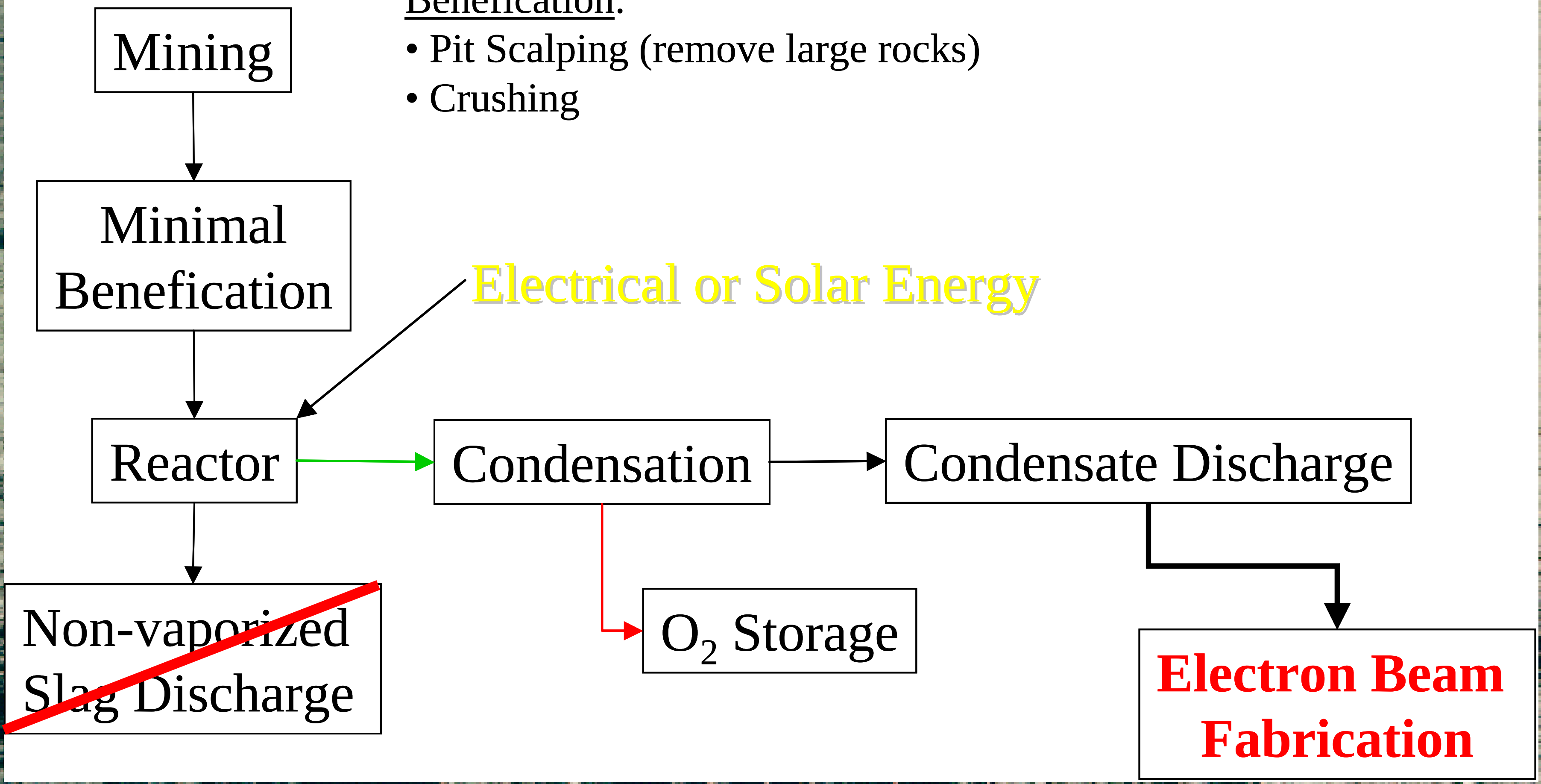
- Vacuum pyrolysis is based on the vaporization reaction of metal oxides that simultaneously reduces the oxide and produces O_2.

$$SiO_{2(s)} \rightarrow SiO_{(g)} + \tfrac{1}{2} O_{2(g)}$$

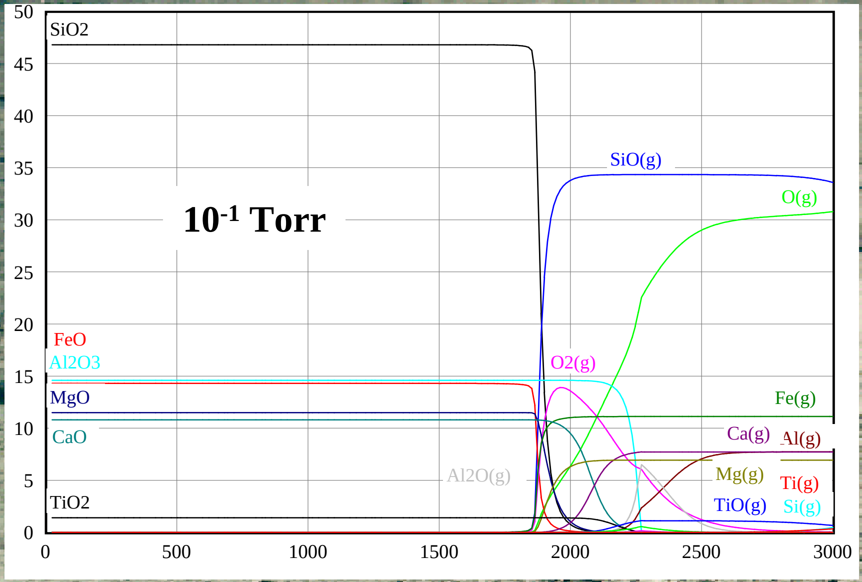
- The reduced oxide can be condensed out of the low-pressure gas as the gasses cool.
- Vacuum pyrolysis has a high potential efficiency (up to 0.2 g/g).
- The process requires no imported chemicals/consumables.
- Can produce metallic byproducts from the condensation.

Process Diagram

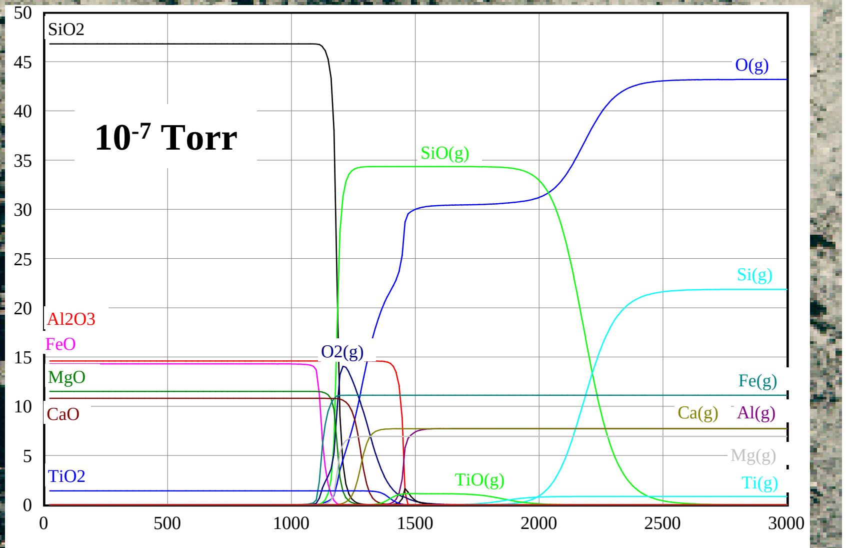
Benefication:
- Pit Scalping (remove large rocks)
- Crushing



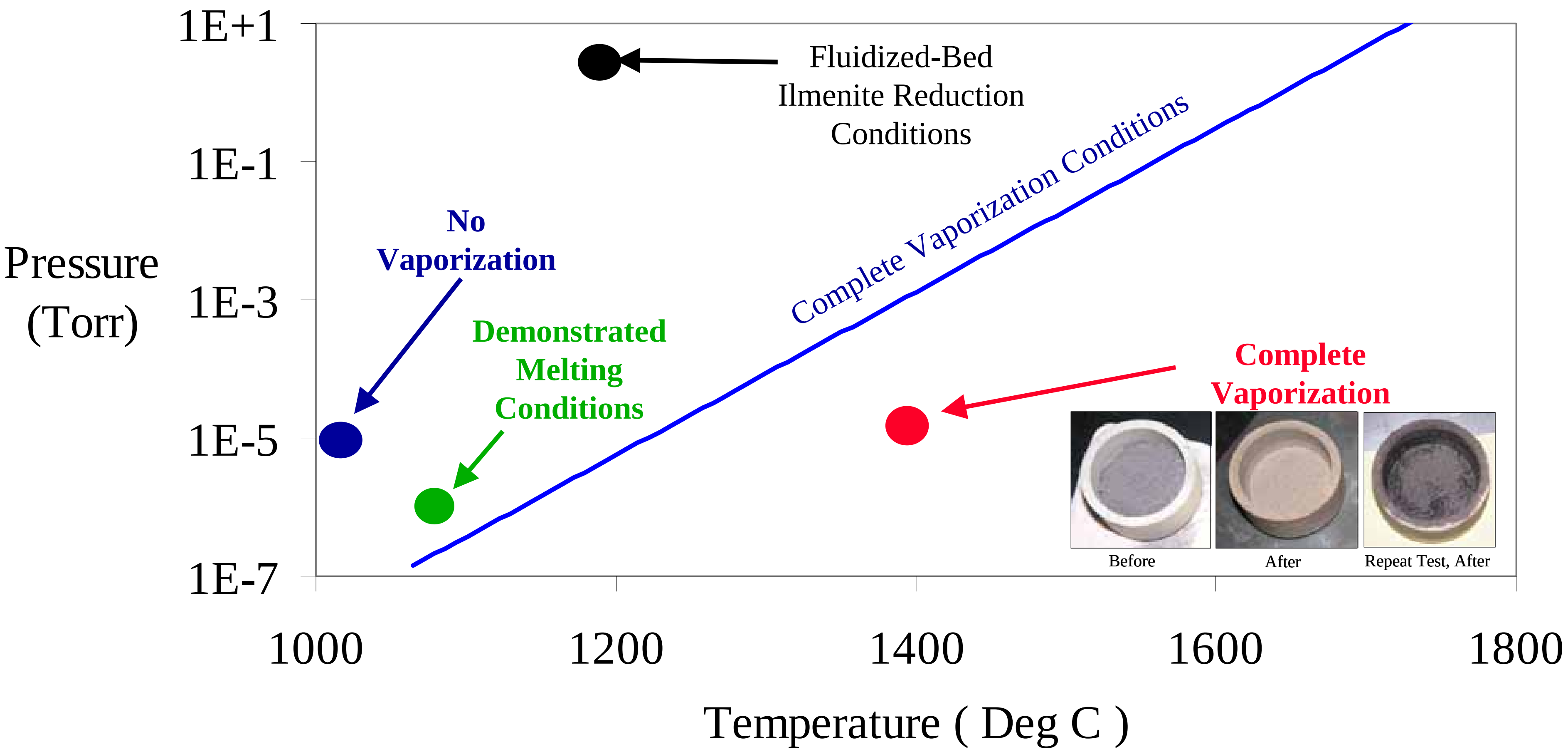
Pressure Effects



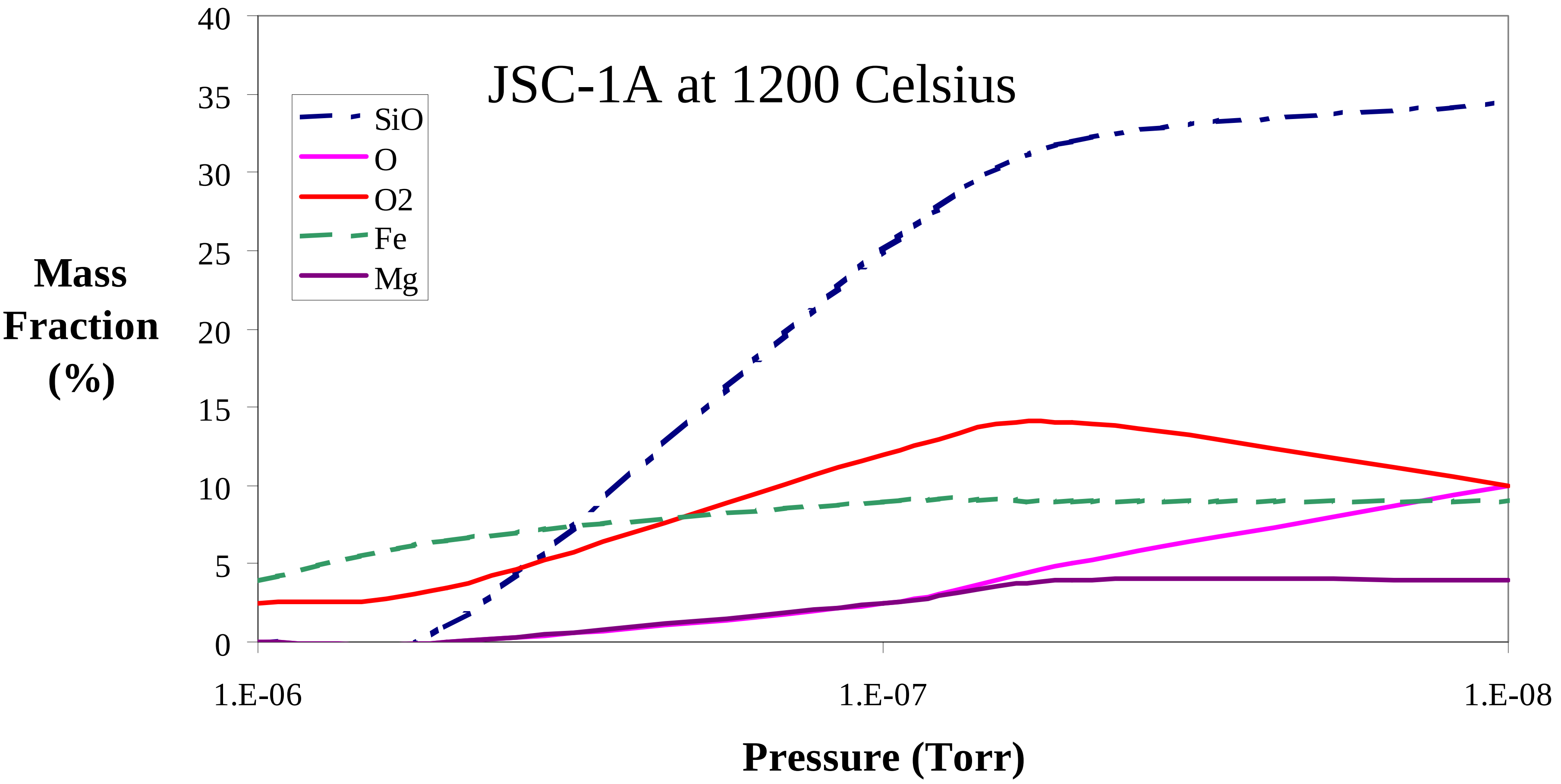
Reduced pressure Significantly reduces the vaporization temperature of MLS-1.



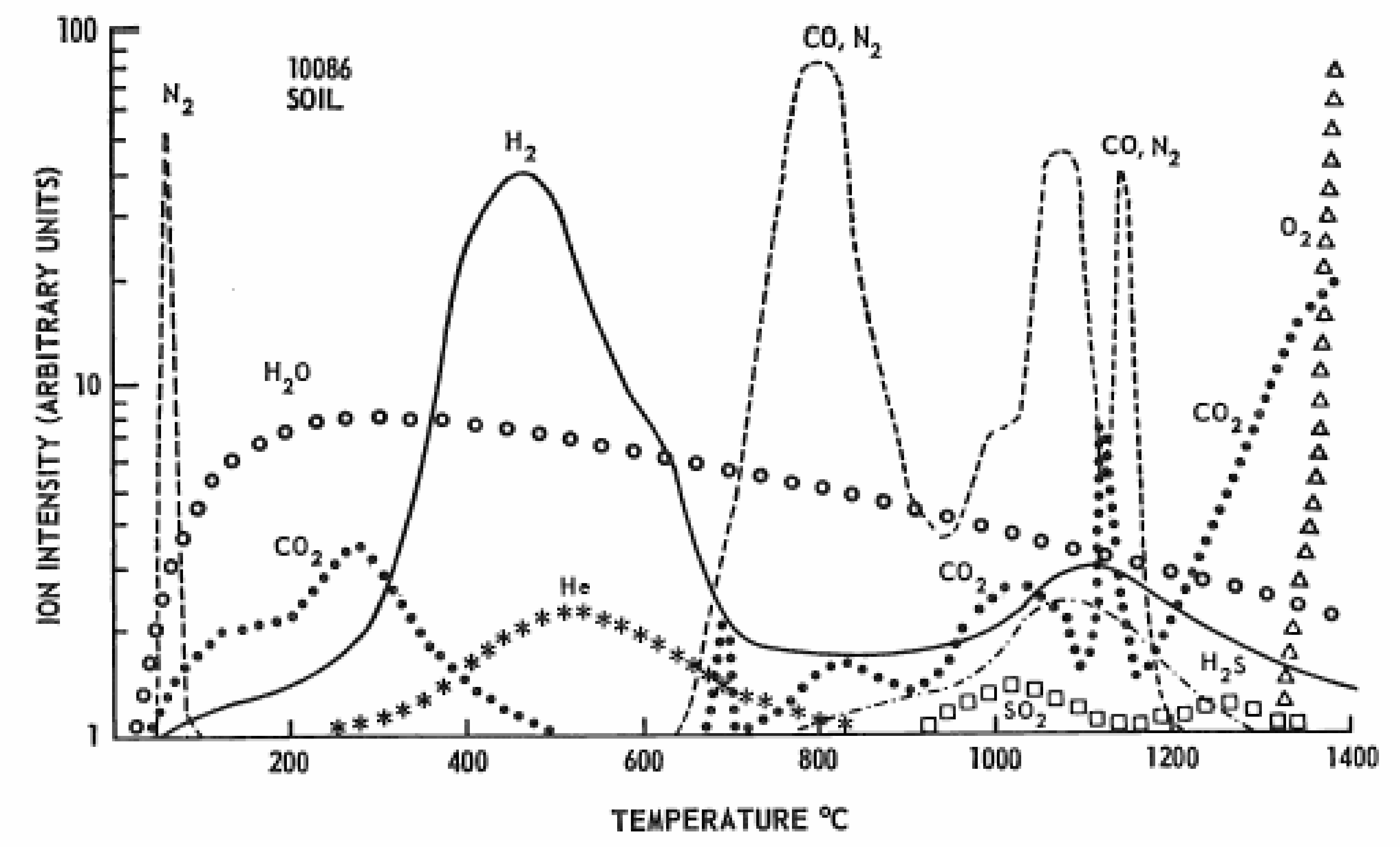
Operating Conditions



Expected Yields



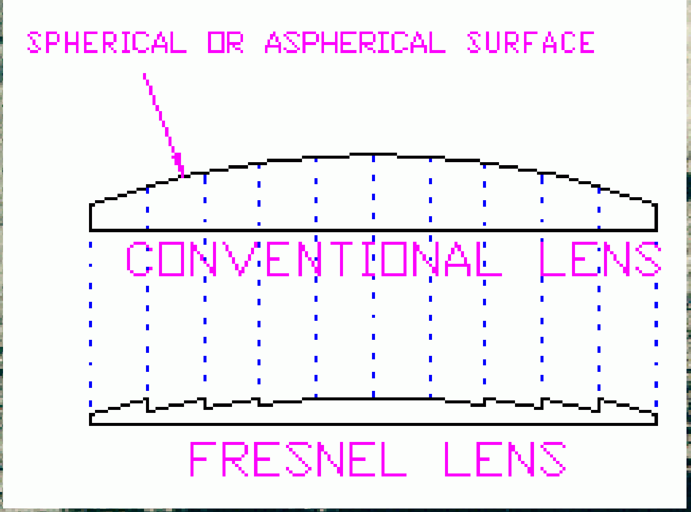
Vacuum Pyrolysis of Apollo 11 Sample 10086



Systems Designed

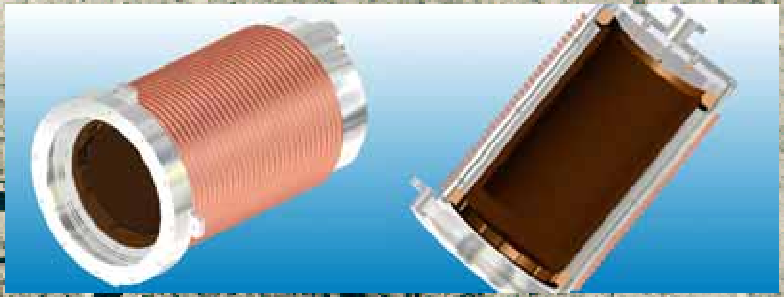
	Solar Prototype	Solar Reflector	VAPoR	High Temperature	2nd Generation
Power (W)	650	10,000	60	500	210
Max Temp (C)	1870	1500+	1300	1100	1300
Chamber Mass (kg)	35	300	18	12	30
Sample Size (g)	20	2000	0.15	20	20

Prototype System

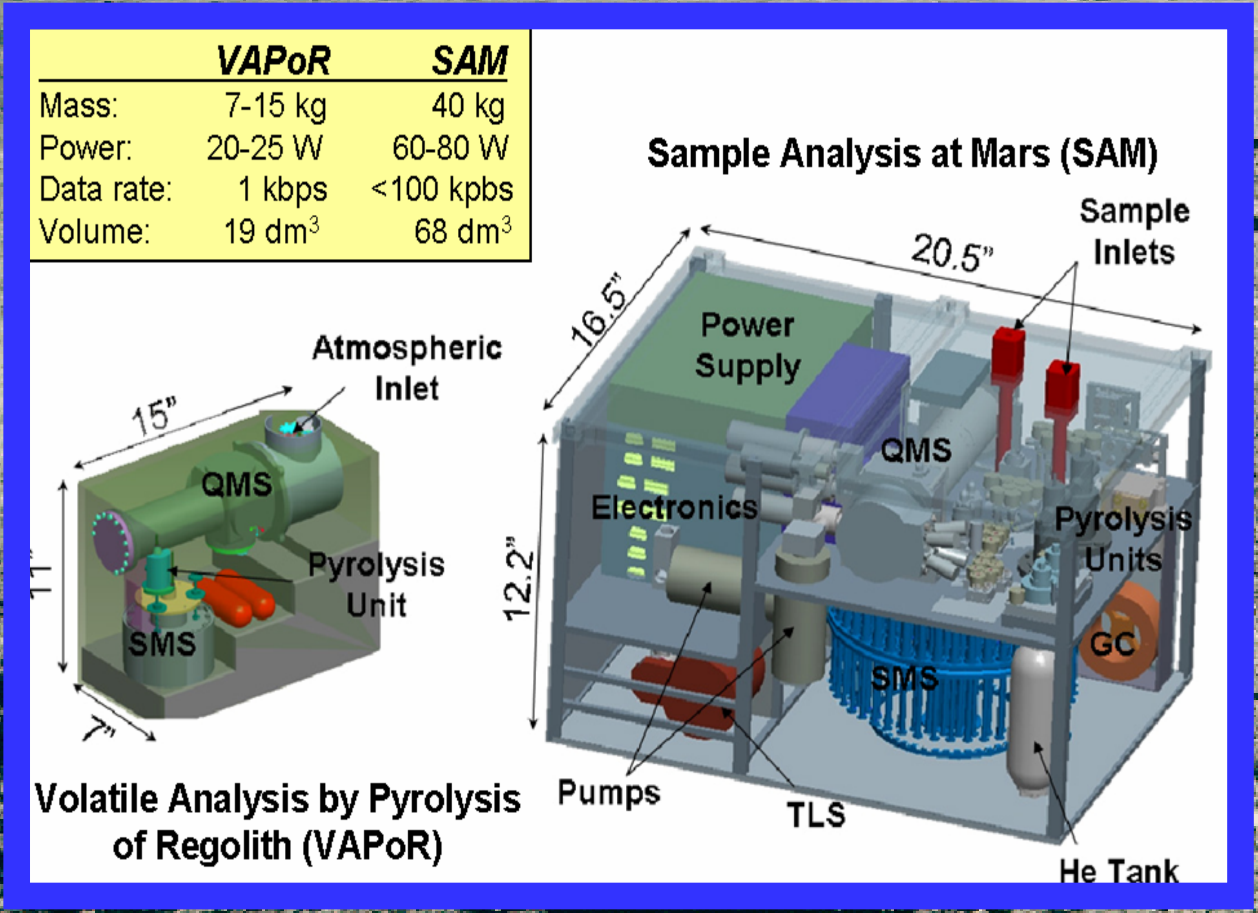


Indirect Solar

3.8 m solar reflector



VAPoR

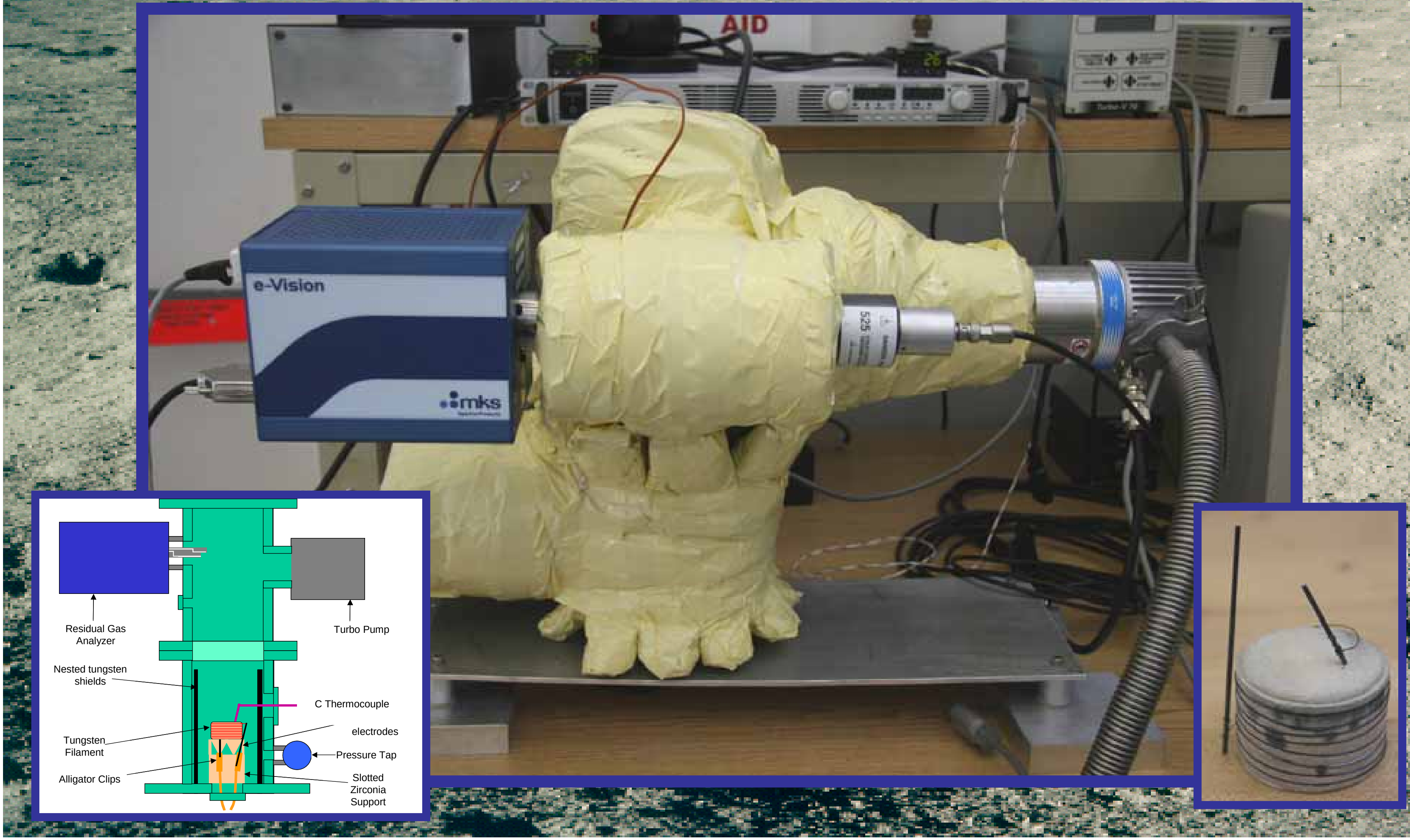


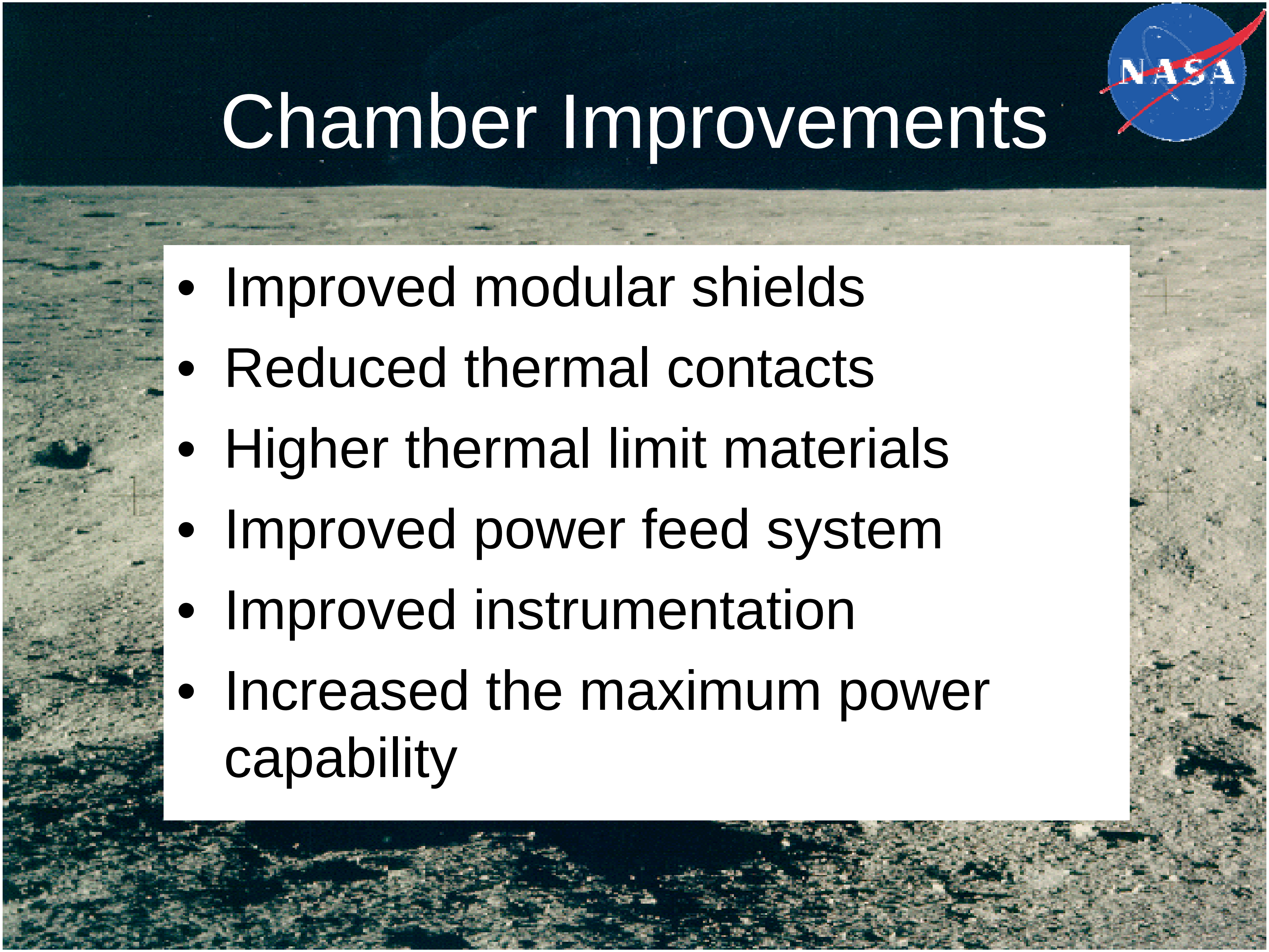
	VAPoR	*SAM*
Mass:	7-15 kg	40 kg
Power:	20-25 W	60-80 W
Data rate:	1 kbps	<100 kpbs
Volume:	19 dm^3	68 dm^3

Volatile Analysis by Pyrolysis of Regolith (VAPoR)

Sample Analysis at Mars (SAM)

High Temperature Chamber



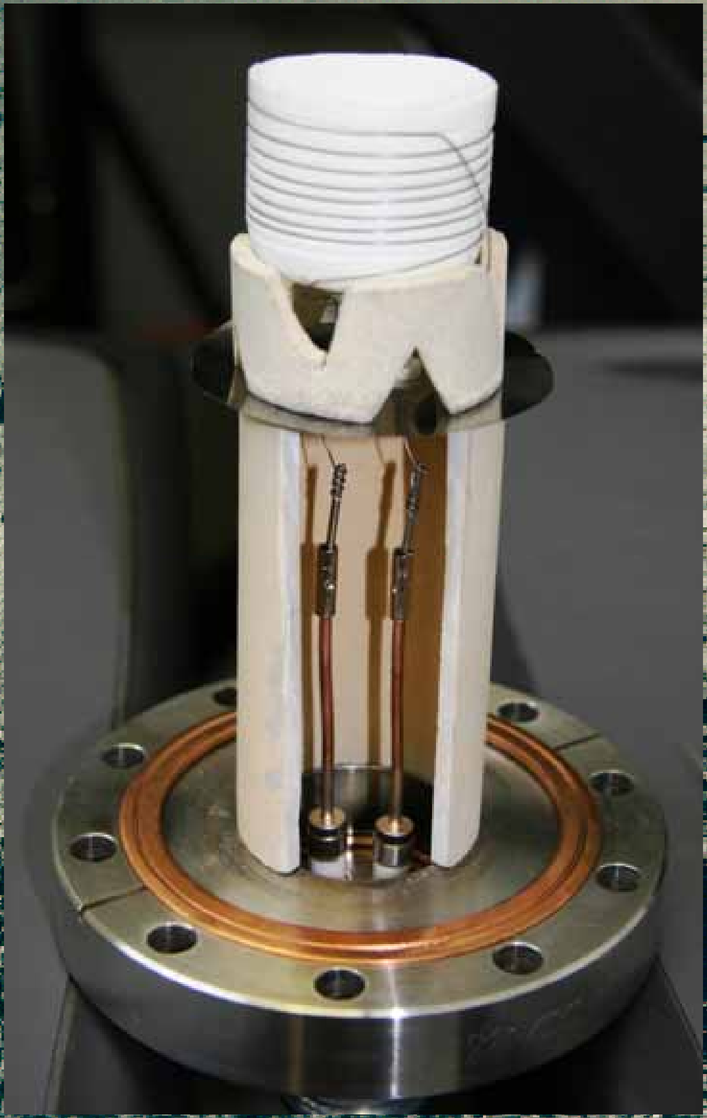


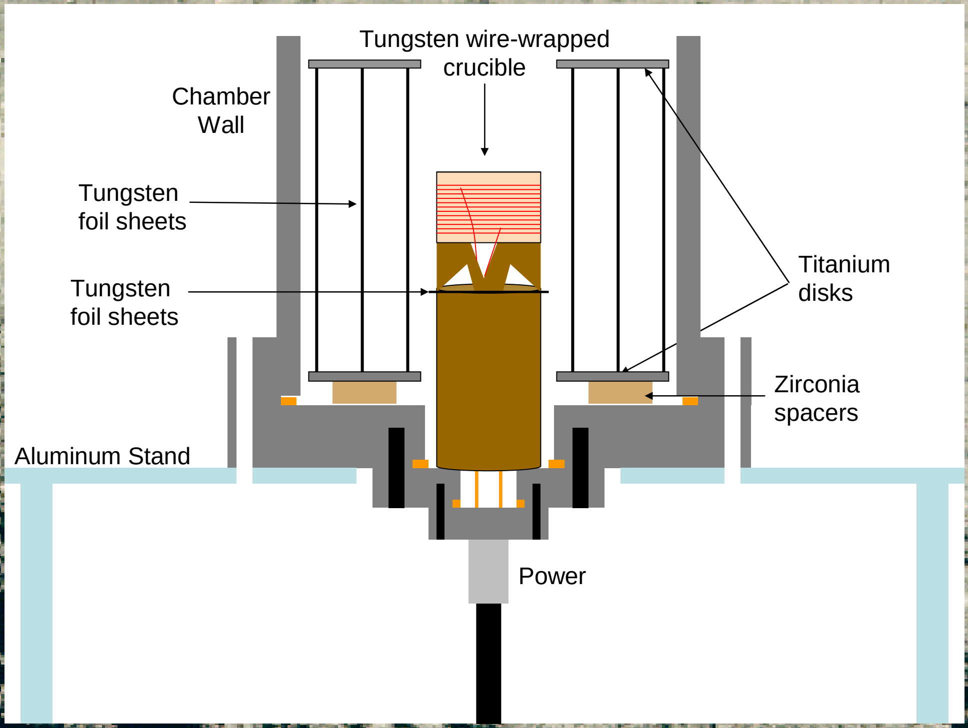
Chamber Improvements

- Improved modular shields
- Reduced thermal contacts
- Higher thermal limit materials
- Improved power feed system
- Improved instrumentation
- Increased the maximum power capability

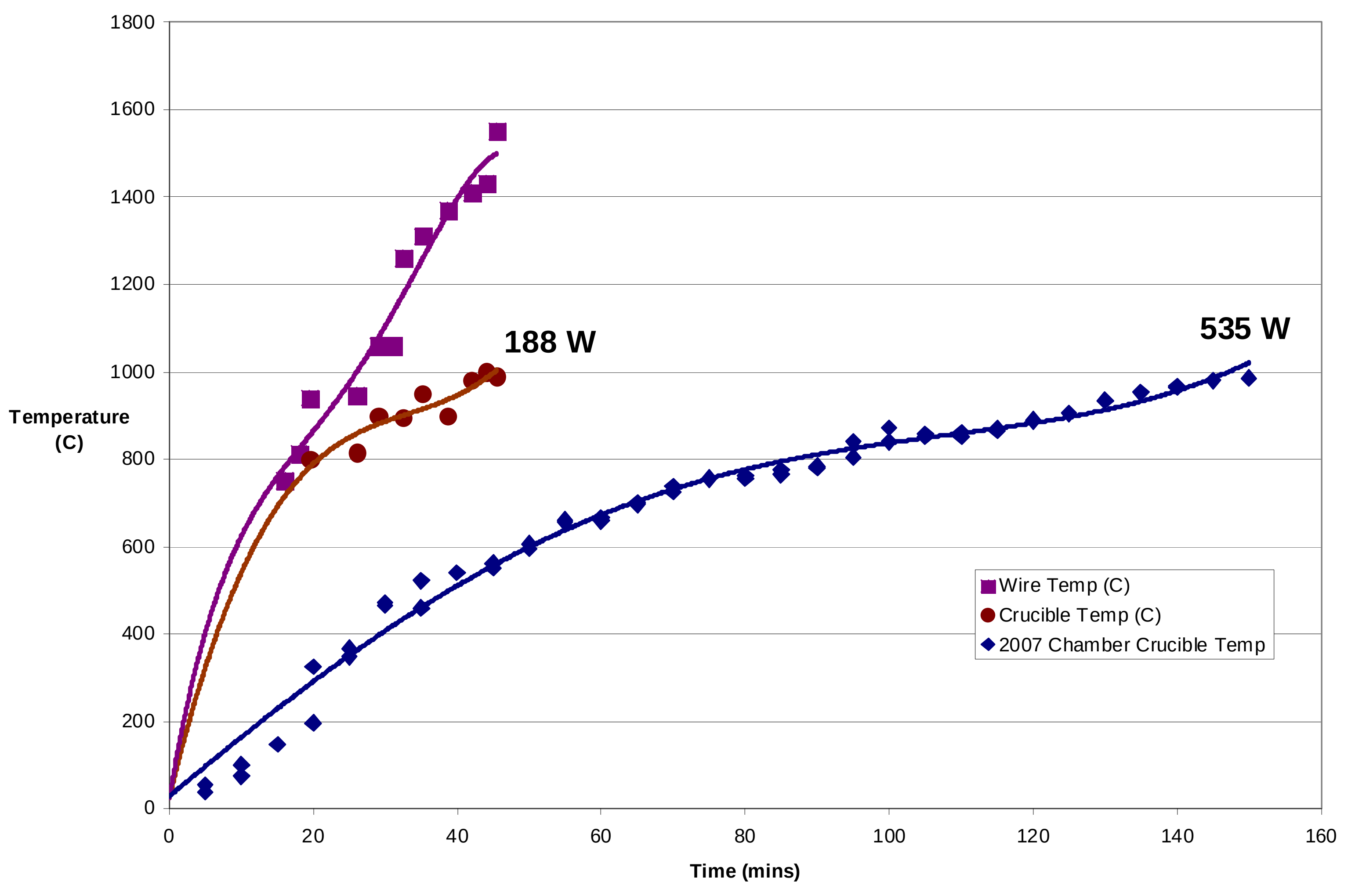
2nd Generation Chamber

Chamber Details

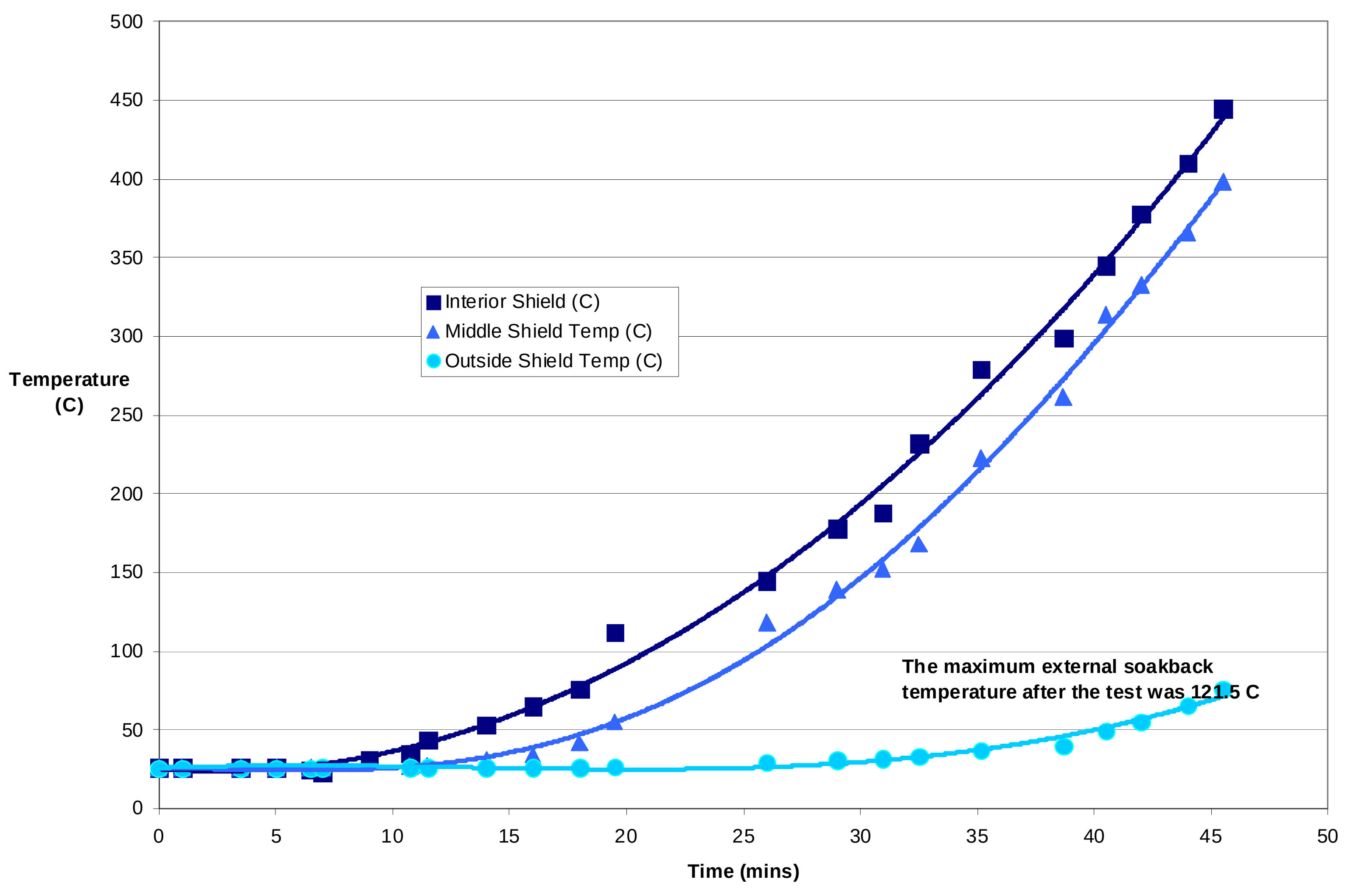




Heating Profiles



Shield Temperatures



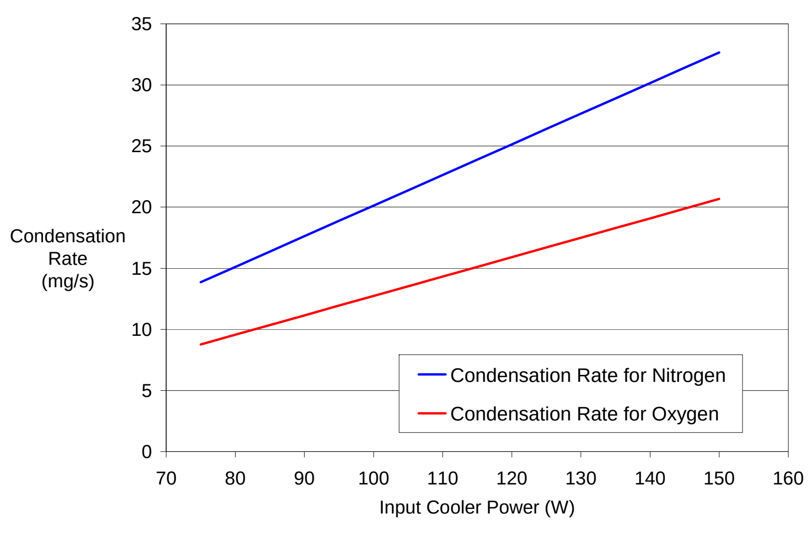
The maximum external soakback temperature after the test was 121.5 C

Scaling Calculations

- We calculated an effective thermal capacitance of the crucible + regolith:

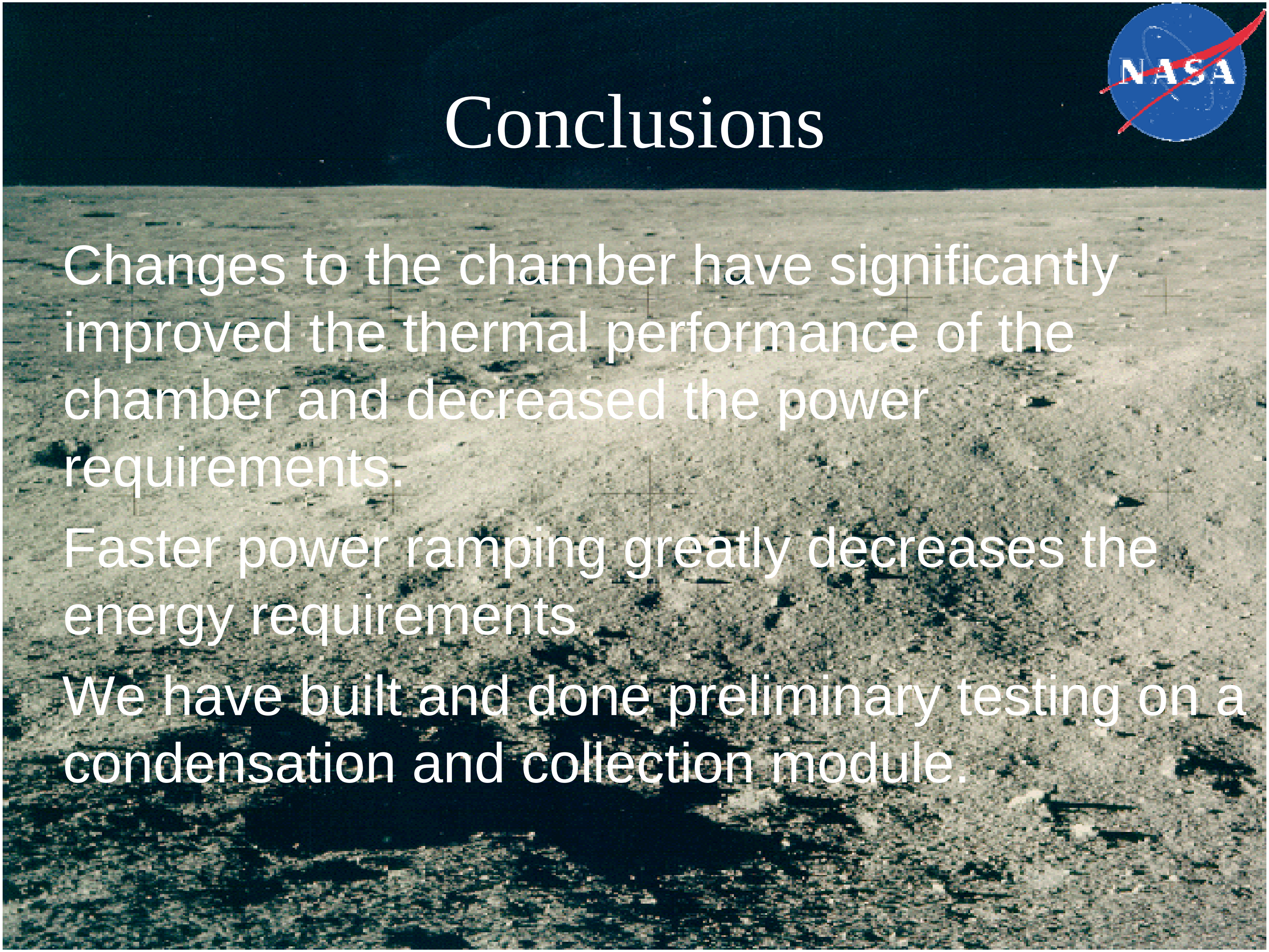
  0.41 W.hr/kg.C
- Scaling assumptions:
  - 1500 C
  - 2 hour process time
  - Sample mass of 12 kg
  - 50% on-time
- The power required is ~15 kW.
  - This produces ~4 mT of O_2 / year (ASSUMES 15% efficiency); Reactor mass is ~60 kg
  - Extraction at 1100 C drops the power requirement to ~11 kW

Condensation and Collection Module



An additional ~13 kW of cryocooler power to produce 4 mT of O_2 per year

Conclusions

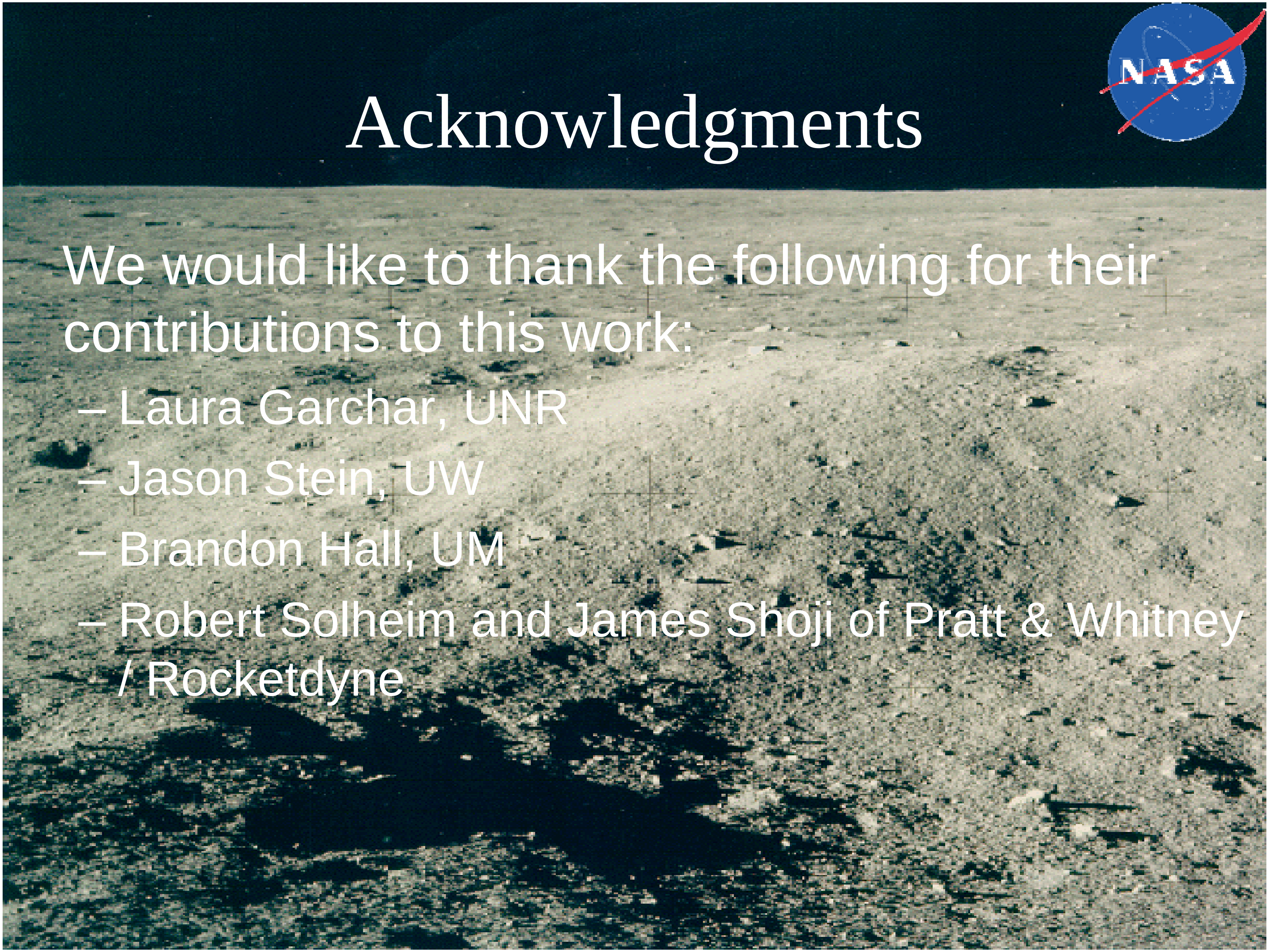


Changes to the chamber have significantly improved the thermal performance of the chamber and decreased the power requirements.

Faster power ramping greatly decreases the energy requirements.

We have built and done preliminary testing on a condensation and collection module.

Acknowledgments



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