VAPoR Breadboard Development: First Pyrolysis Results

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What is VAPoR?

VAPoR:

Volatile Analysis by Pyrolysis of Regolith

suitcase sized pyrolysis mass spectrometer

keywords:

volatiles, Moon, regolith, atmosphere,
astrobiology, solid solar system bodies

Key Science Objectives

1) Determine the composition, abundance, spatial distribution, and source of lunar volatiles associated with polar hydrogen deposits.
2) Characterize the native lunar atmosphere at the poles.
3) Understand the processes by which terrestrial organics or volatiles are dispersed and/or destroyed on the Moon.
4) Evaluate the potential of the polar regolith for future in situ resource utilization (ISRU).
5) Identify potentially hazardous volatiles (e.g. radon)

Potential Sources of Lunar Volatiles

Earth
(contamination, possible terrestrial meteorites)

Solar wind
(implanted H,C,N, He, Ne)

Comets and Asteroids
(water-ice, organics?)

Interplanetary dust particles

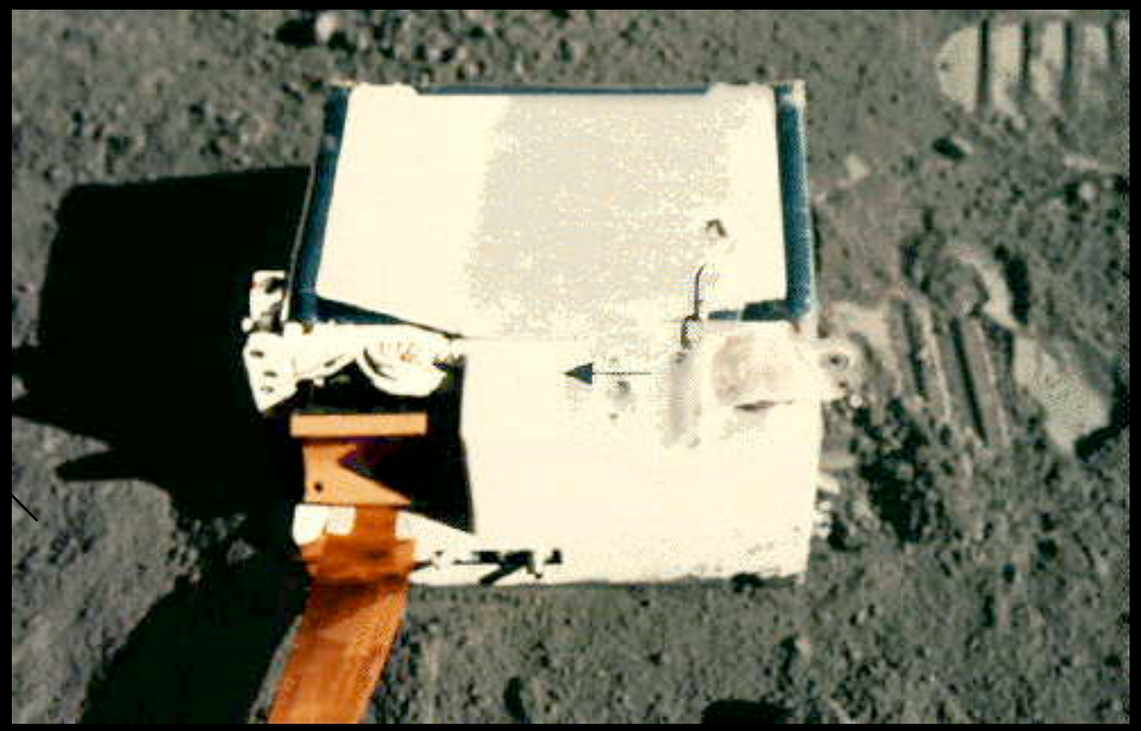
Lunar Atmospheric Composition Experiment (LACE)

Magnetic deflection mass spectrometer (1 to 110 amu)

Measured surface atmospheric composition during Apollo 17

Detected H_2, He, Ne, Ar and trace levels of CH_4, NH_3, H_2O and CO_2

Sources: chemical reactions with solar wind implanted ions, outgassing, and/or exchange with cold traps

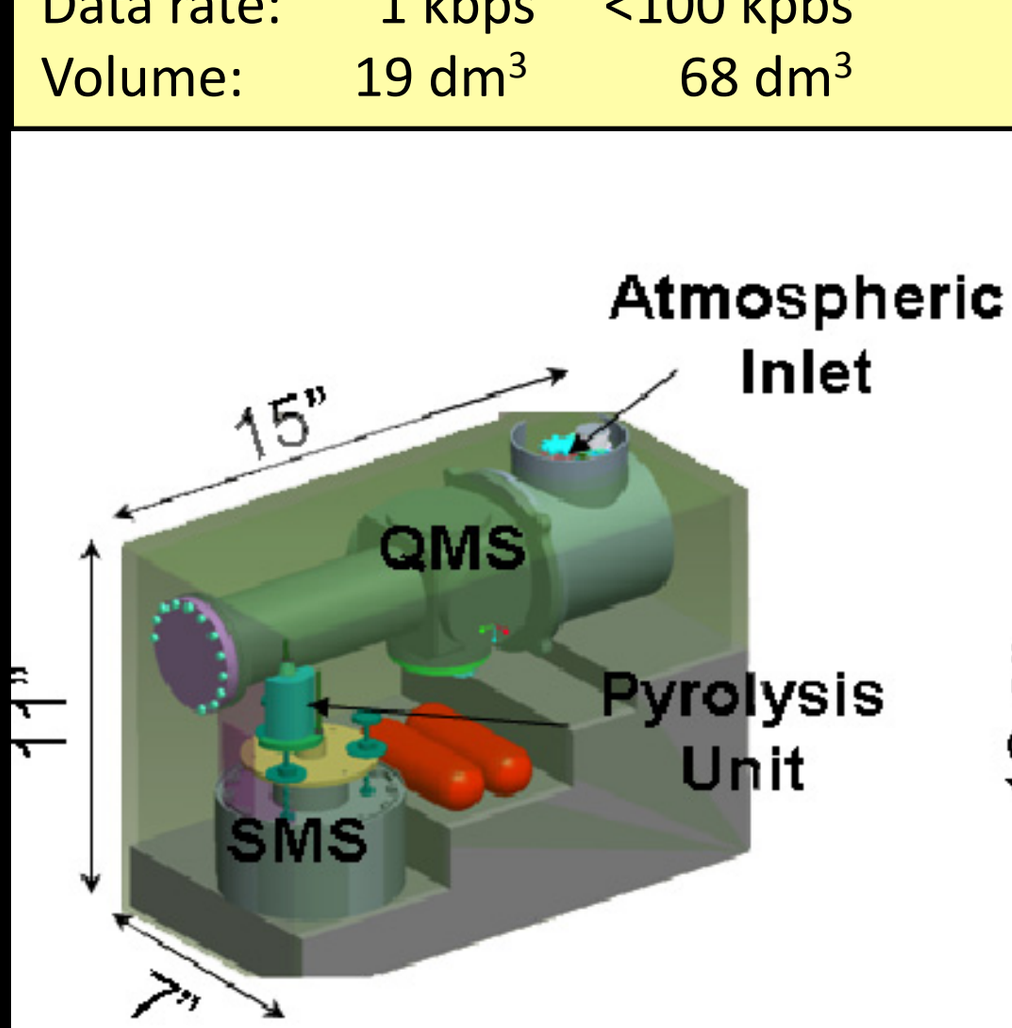


LACE PI: John Hoffman

Surface regolith samples not analyzed by LACE

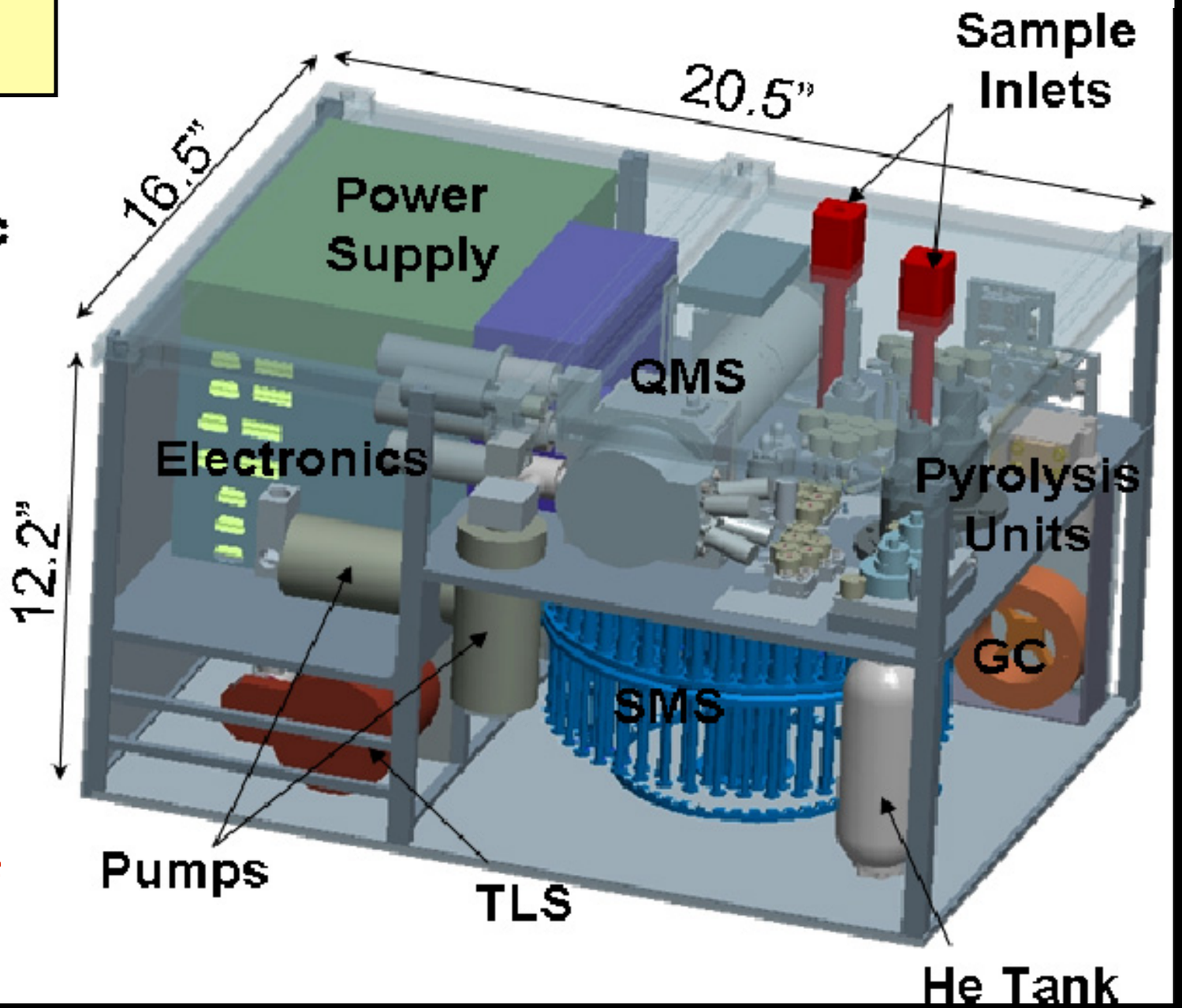
VAPoR is a Miniature Version of SAM

	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)

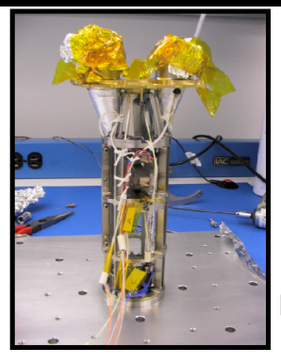
Sample Analysis at Mars (SAM)



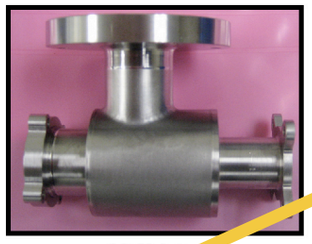
VAPoR

solid sample inlet

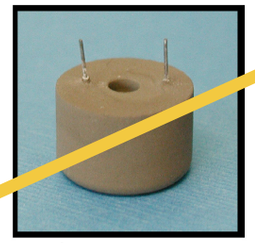
atmospheric inlet



Solid Sample Inlet Tube (SSIT)



HCV 2



Active Gas Getter (Noble Gas Enrichment)

Microvalve

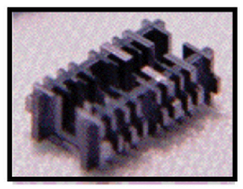
Atomospheric Inlet

HCV 1

Exhaust Vent

In Line High Conductance Valve (HCV)

Ion Extractor Optics



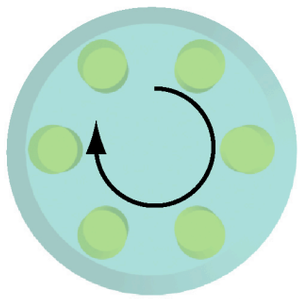
Top ASIC Electronics Board

Vacuum Housing

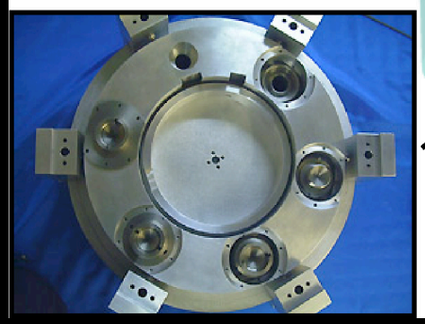
Honeybee Interface Seal To Mass Spectrometer

MCP Detectors

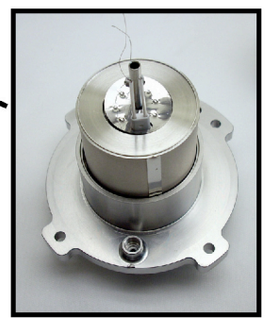
Reflectron Time of Flight Mass Spectrometer



Top View of Honeybee Sample Carousel



Honeybee Sample Carousel (6 Cup)



Pyrolysis Heater

time-of-flight mass spectrometer

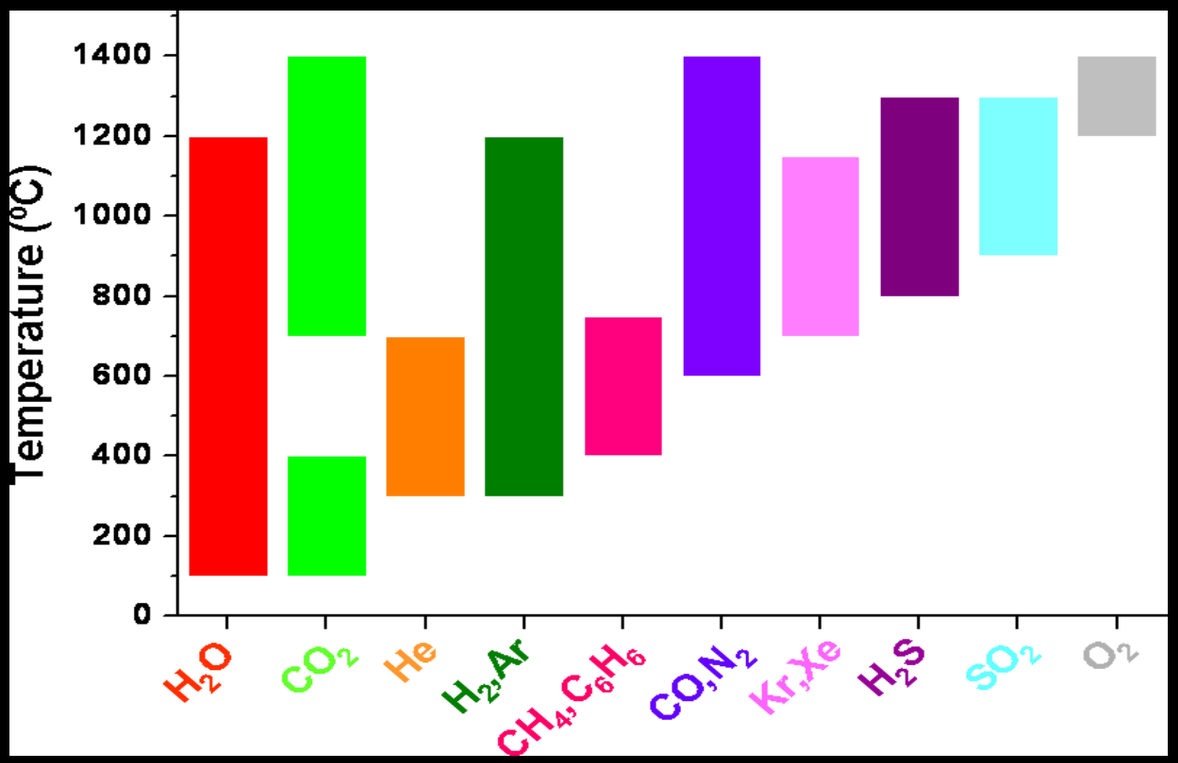
pyrolysis oven with 6 individually heated cups

Instrument requirements

Objective		Requirements	Capability
Origin of Volatiles (Isotopes)	*C,H,O,N-Volatiles*	Measure D/H in water	~10‰ (per mil)
		Measure $^{13}C/^{12}C$ ratio in CO_2 from regolith	~5‰
		Measure $^{16}O/^{18}O$ in CO_2	5‰
		Measure $^{14}N/^{15}N$ in N_2	5‰
	Noble Gases	Measure Ne abundance and isotopes	10‰
		Measure Ar abundance and isotopes	5‰
		Measure Kr and Xe abundance and isotopes	5-20‰
	Organics	Detect volatile hydrocarbons and measure abundance at ppb to ppm level	Mass range: 1-250 amu, LOD: sub ppm
		Measure $^{13}C/^{12}C$ ratio of CO_2 from organics combustion	~5‰
Resources (ISRU)		Measure abundance of H_2O, H_2, CO_2, CO/N_2, SO_2 in atmosphere and regolith	~ 1 ppm
		Measure He abundance	$^3He/^4He$ (TBD)
		Measure abundance of O_2	>1200ºC, 5% low conductance leak
		Measure reduced inorganic gases (e.g. H_2S)	< 20 ppb

Vacuum Pyrolysis

Highly efficient way to extract volatiles from regolith

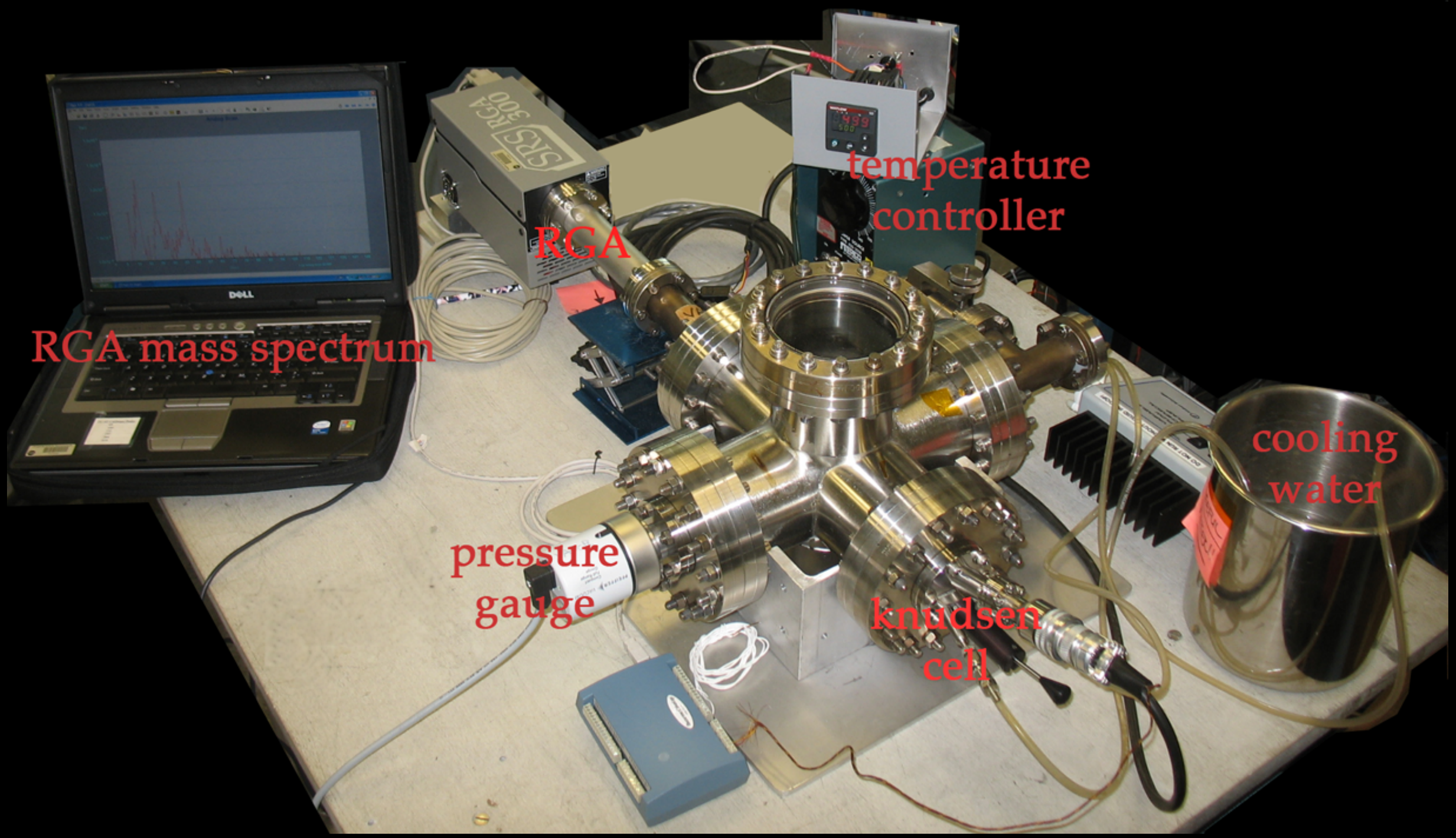


adapted from Gibson&Johnson, 1971

Species	Temperature Range(s) [° C]	Species	Temperature Range(s) [° C]
Volatiles			
H_2	200-600[4]	C O	600-1300[3]
H e	200-500[4] -800[5]	CO_2	100-1200[3]
H_2O	0-1200[1] -800[3]	N O	200-700[1]
N_2	600-1200[3]	NH_3	100-850[3]
Sulfurous Species			
SO_2	200-400[1] 900-1400[5]	H_2S	1000-1300[1] 700-1300[5]
Noble Gases			
N e	300-1250[3]	K r	300-1650[7]
A r	300-1250[3] -1700[7,8]	X e	300-1700[7,8]
R n			
Organics & Contaminants			
CH_4	300-1000[3]	H C N	100-900[3]
C_6H_6	300-1000[3]		
KREEP Volatiles			
K	900-1200[2]	N a	800-1200[2]
Pyrolysis Reaction Products			
F e	1100-1400[2]	O_2	1100-1300[2]

1. Simoneit et al., 1973.
2. de Maria et al.,1971.
3. Holland et al., 1972.
4. Lord, 1968.
5. Gibson & Johnson, 1971.
6. Friesen et al., 1972.
7. Bogard et al., 1975.
8. Lightner et al., 1974.

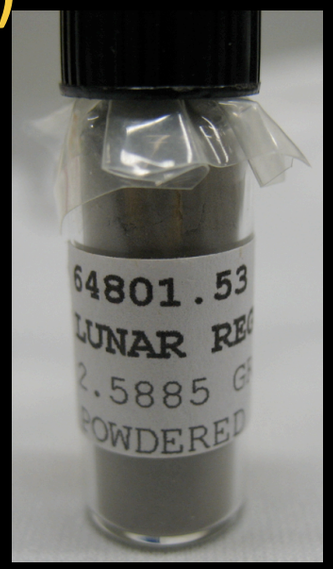
VAPoR Breadboard

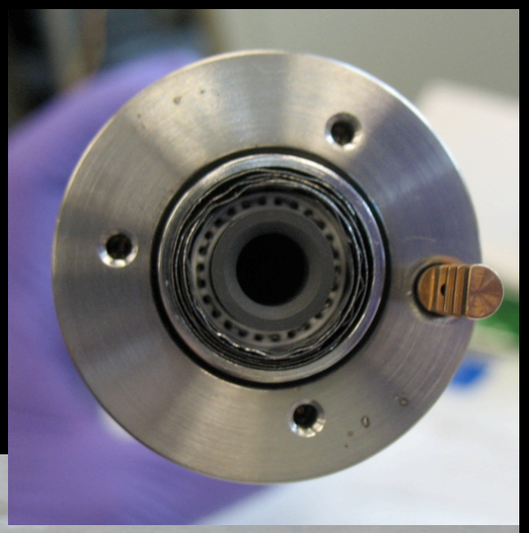


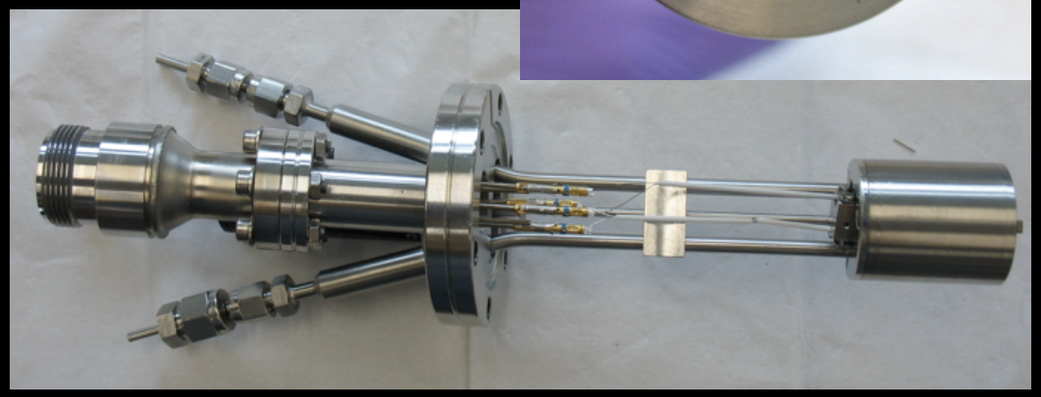
VAPoR Breadboard - first tests

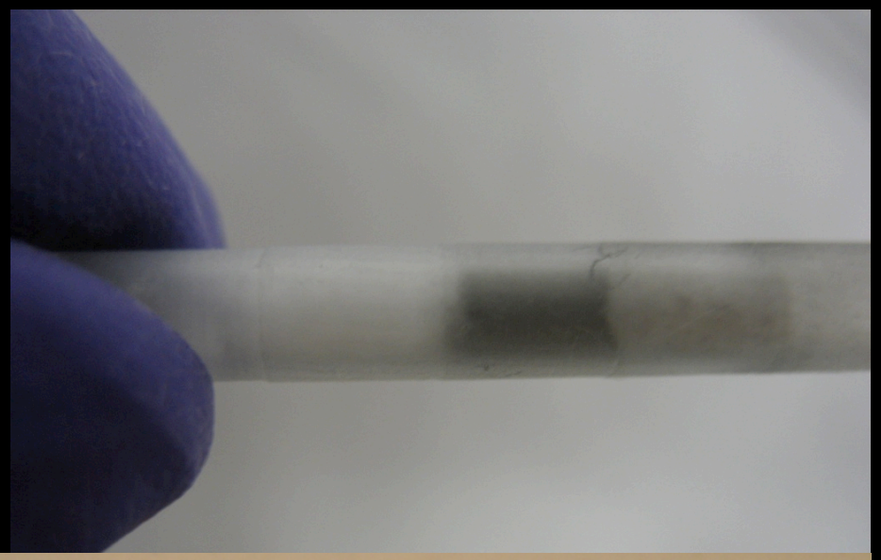
4 samples:

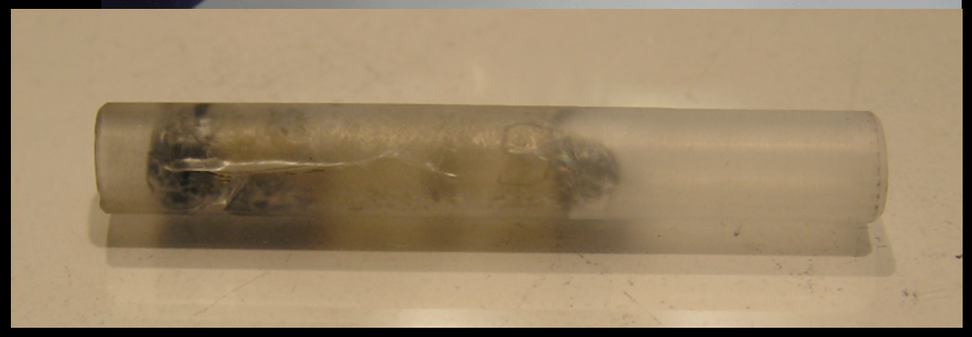
JSC1A (current standard)
GSC1 (Va, Paul Lowman)
Murchison meteorite
Apollo 16 - 64801.53











2 temperature profiles:

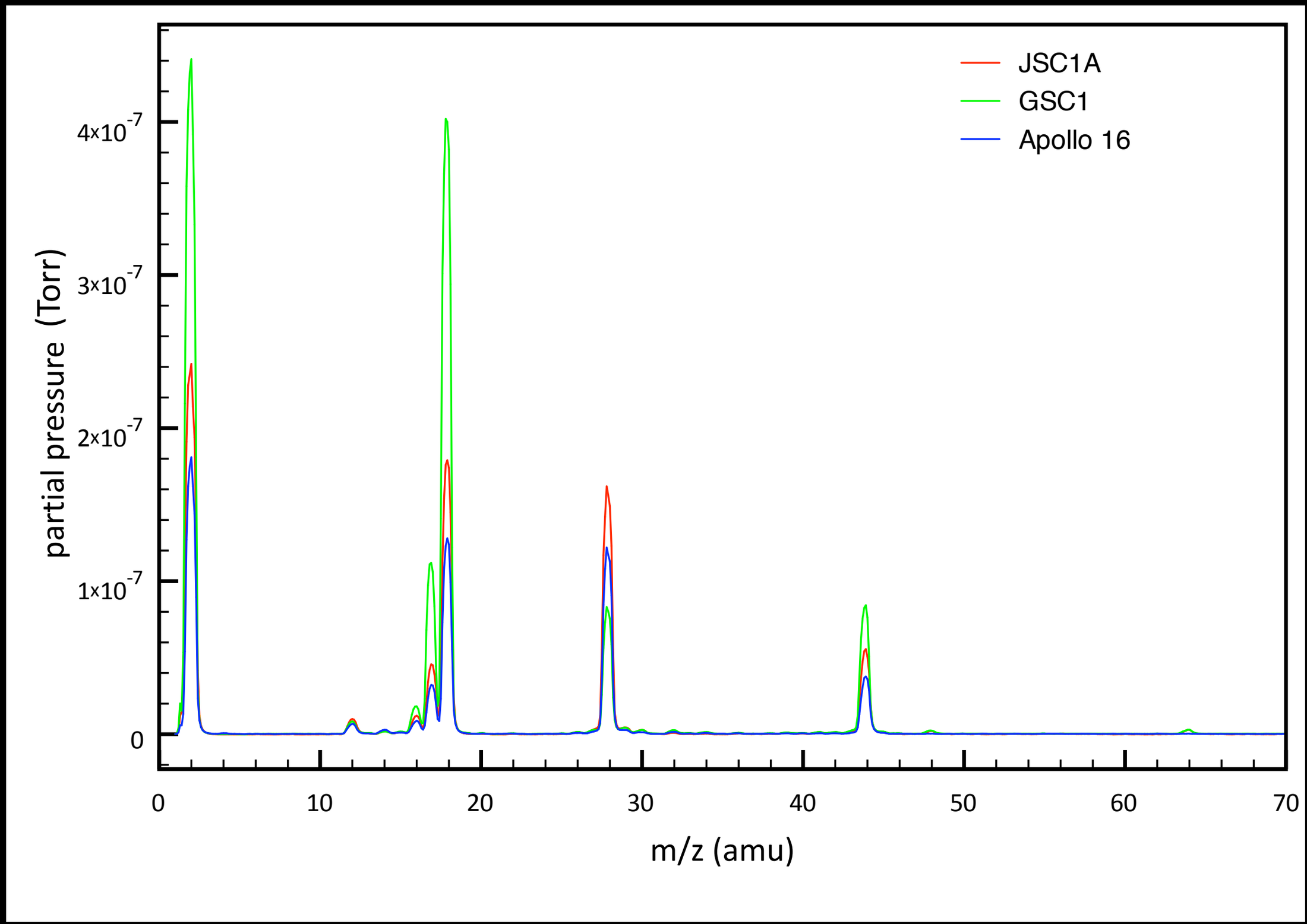
constant ramp:

4 ºC /min to 1200 ºC

stepped:

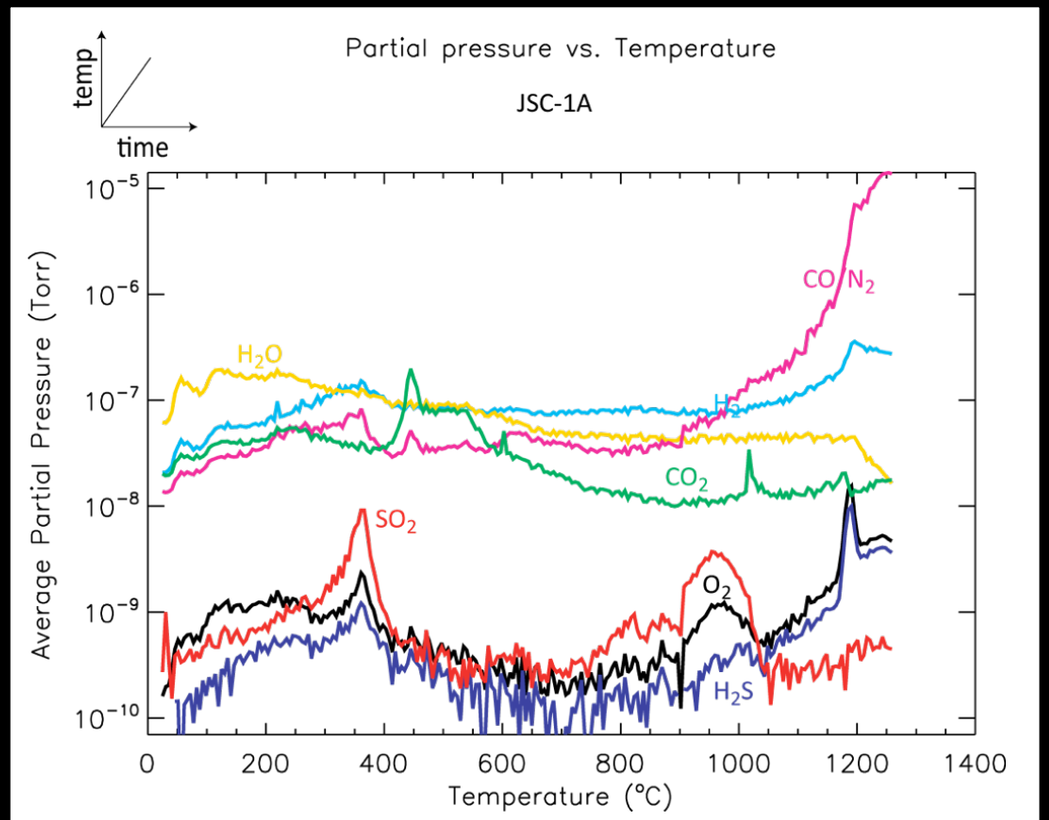
20 ºC /min for 5 min, 15 min constant, to 1200 ºC

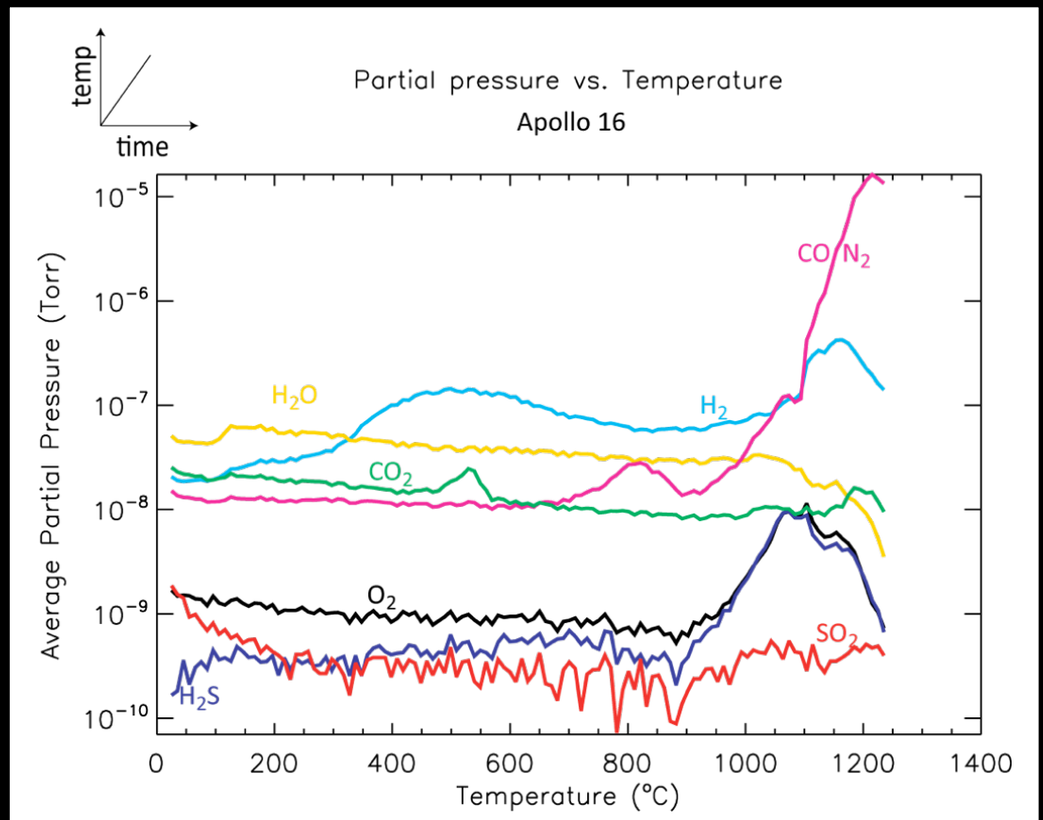
Ramped heating - 800 ºC

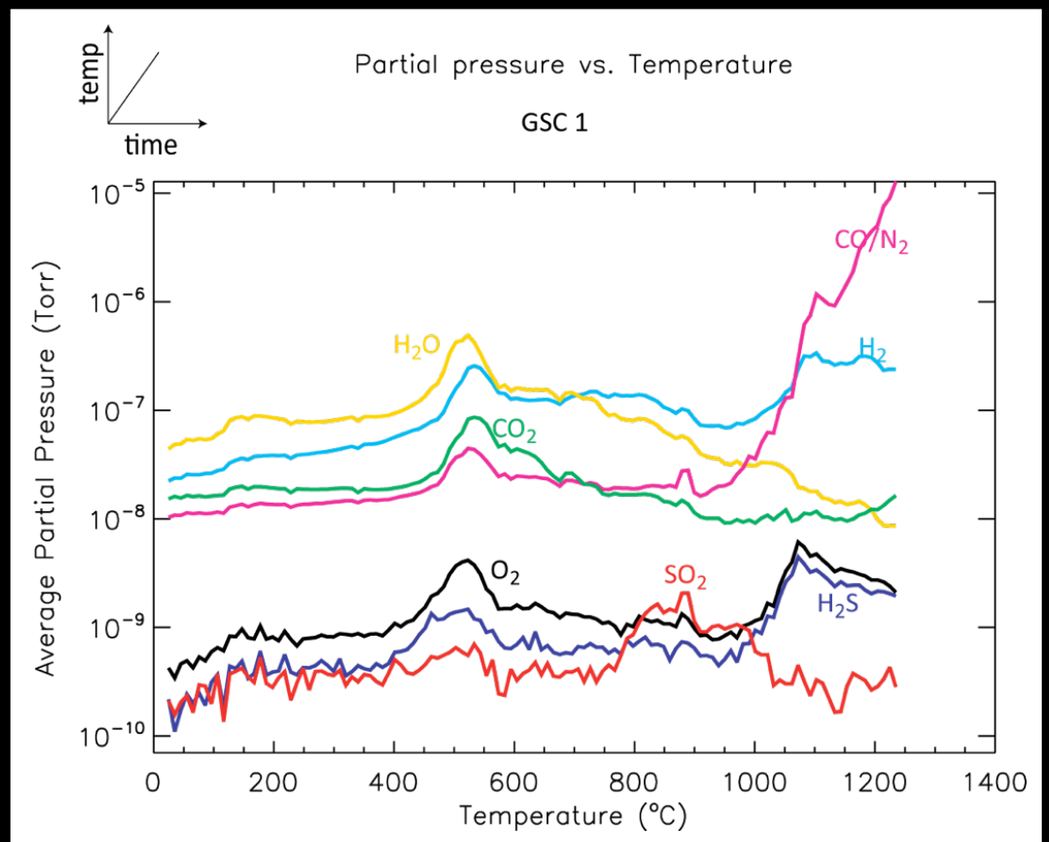


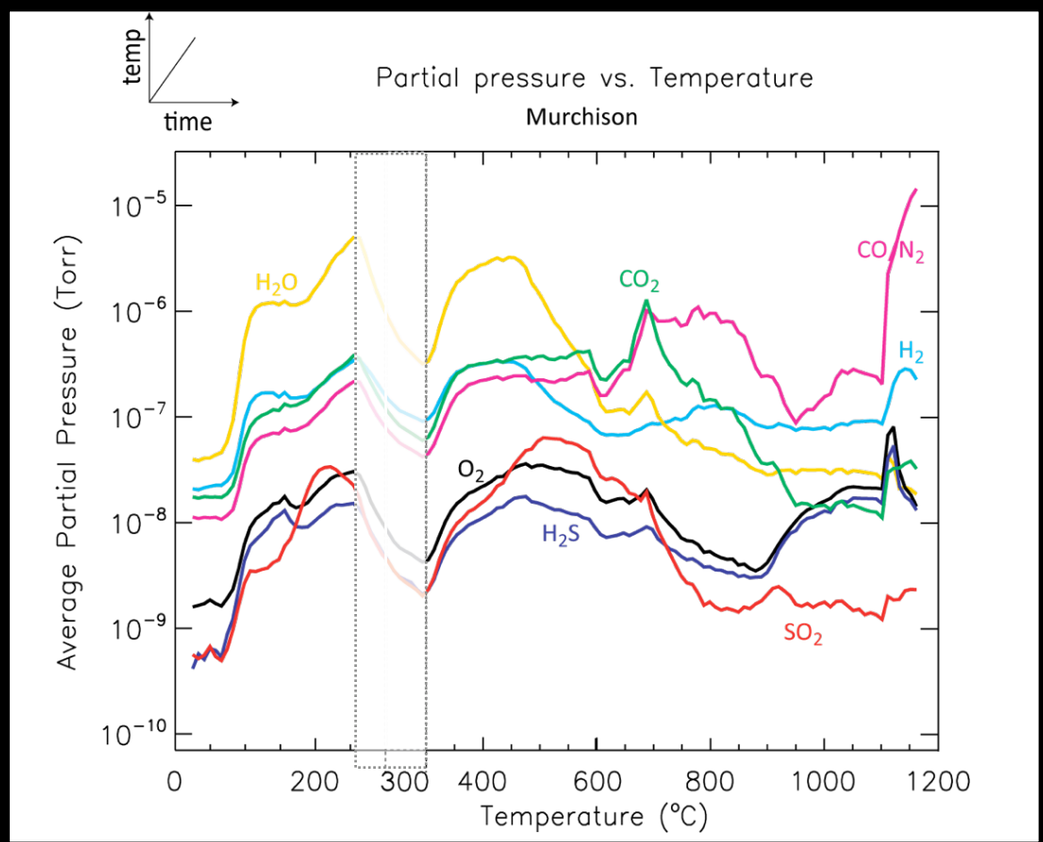
5 ºC per minute to 1200 ºC

Ramped heating - evolved gases

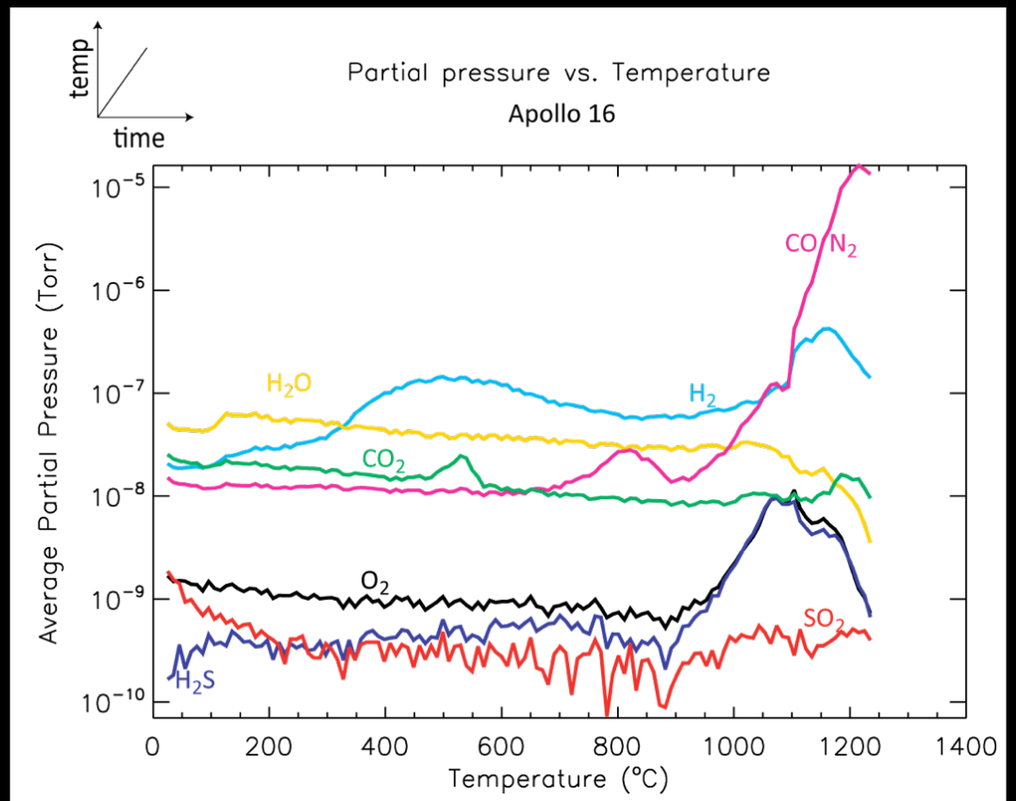


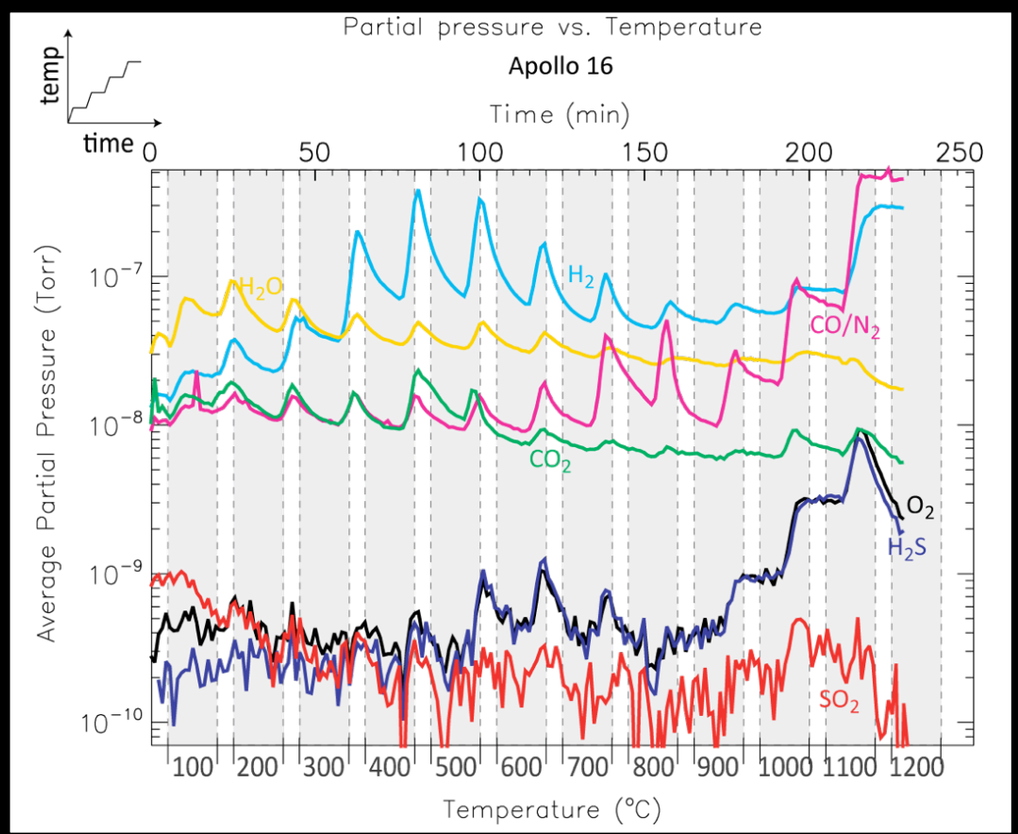






Stepped heating - evolved gases





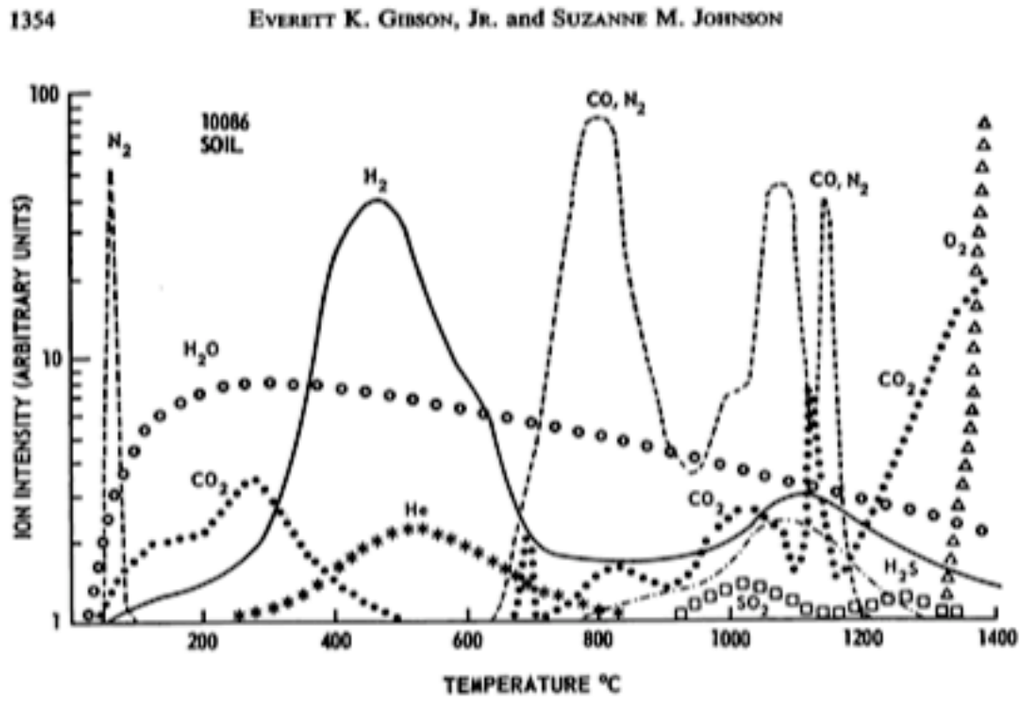


Fig. 1. Gas release pattern for Apollo 11 soil 10086,16. Sample weight 242.94 mg. Heating rate 4°C/minute.

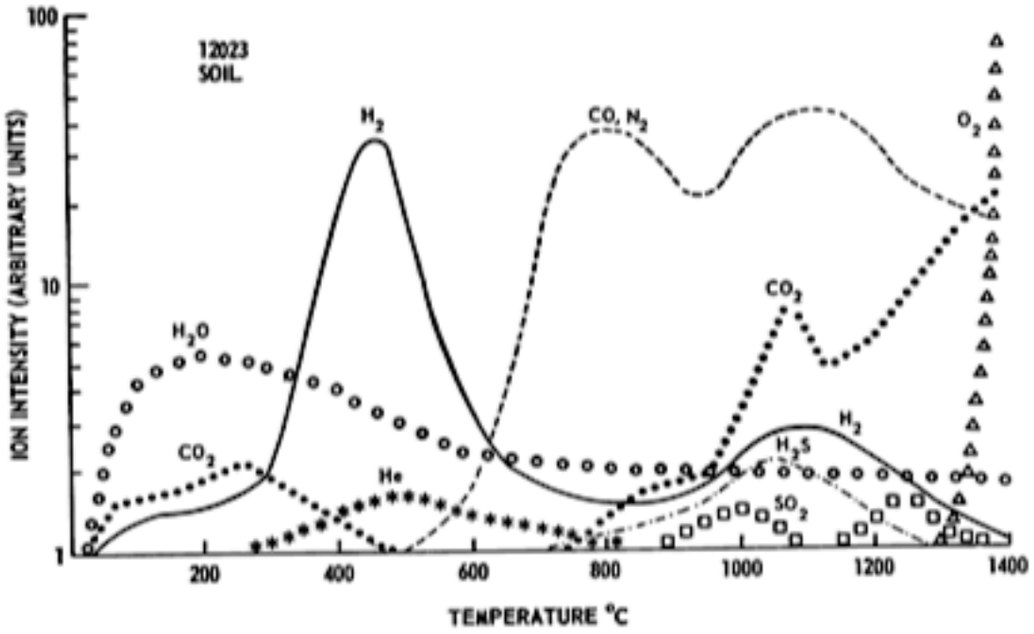


Fig. 2. Gas release pattern for Apollo 12 soil 12023,9. Sample weight 208.50 mg. Heating rate 4°C/minute.

Future Work

*) minimal sample size

*) power necessary for heating sample to 1200ºC

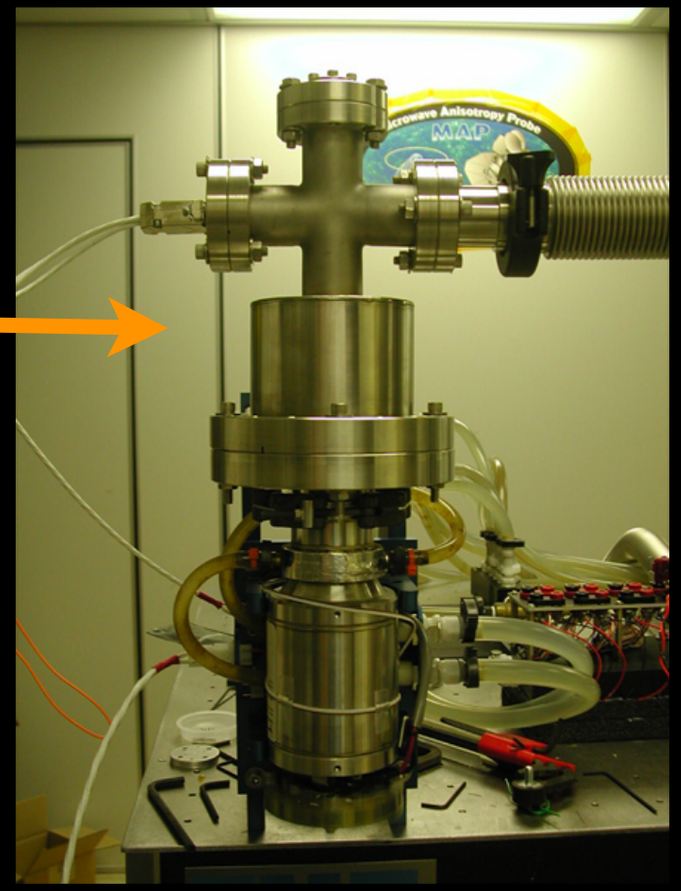
*) different pyrolysis temperature profiles

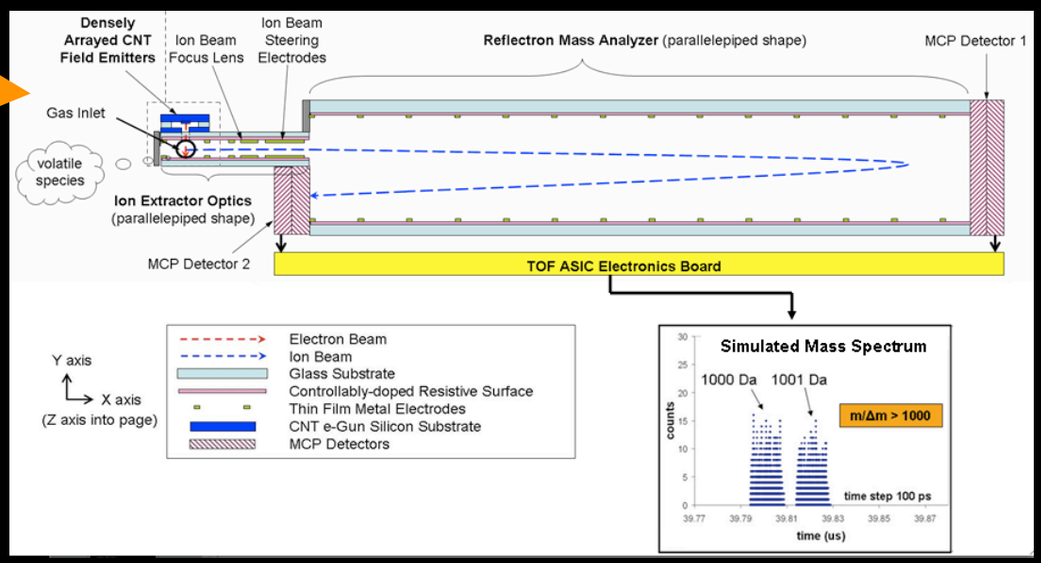
*) optimal oven configuration

*) condensation module

*) SMS

*) TOF-MS





Acknowledgments

- NASA Lunar Sortie Science Opportunites (LSSO) and NASA Goddard Internal Research and Development (IRAD) Programs for supporting the VAPoR instrument concept study (2007-2008).
- NASA Astrobiology Science and Technology Instrument Development (ASTID) Program for miniature time-of-flight mass spectrometer and VAPoR prototype development support (2004-2012).