Overview and Testing of the Mars Organic Molecule Analyzer (MOMA), a Gas Chromatograph and Laser Desorption Mass Spectrometer

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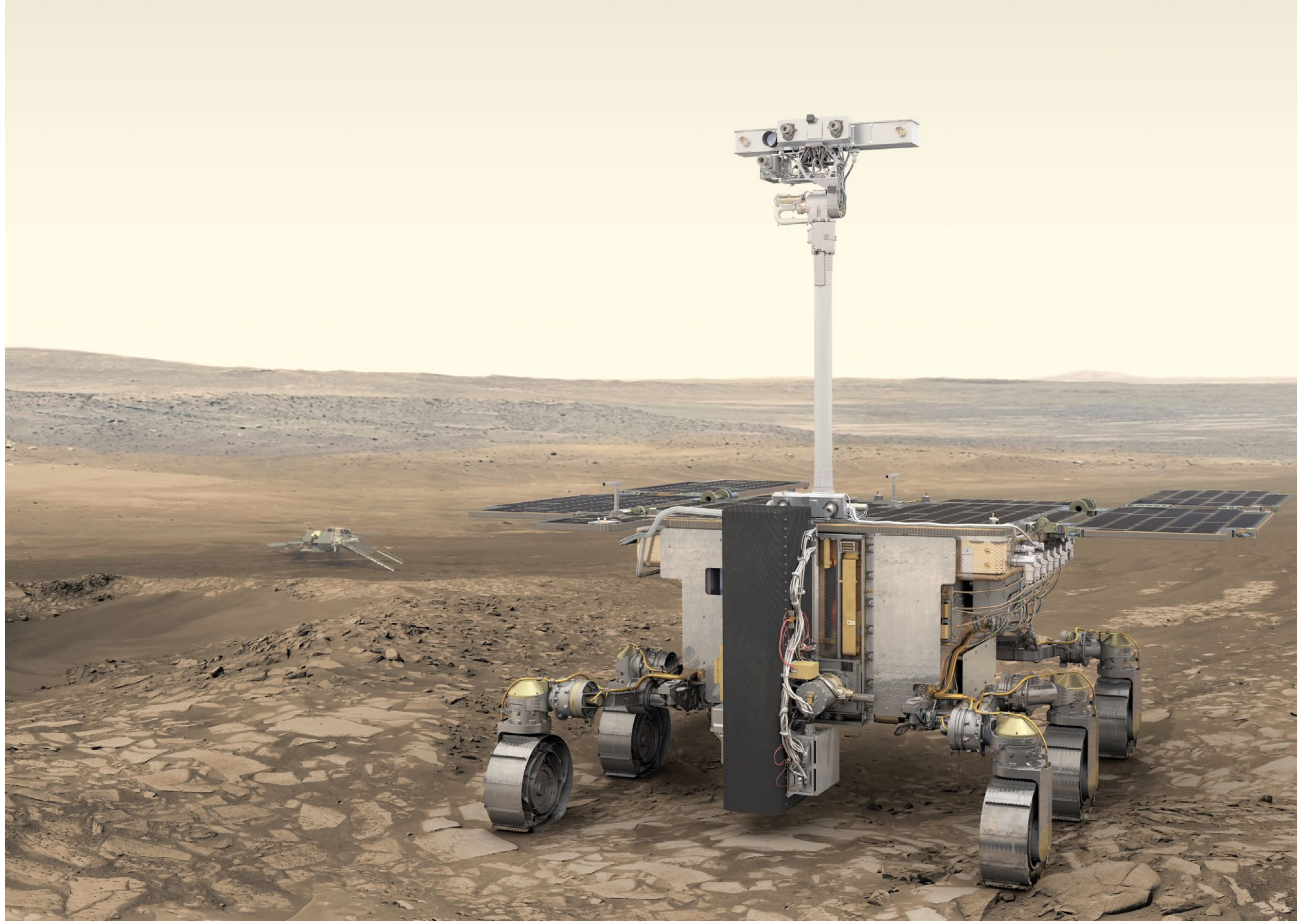
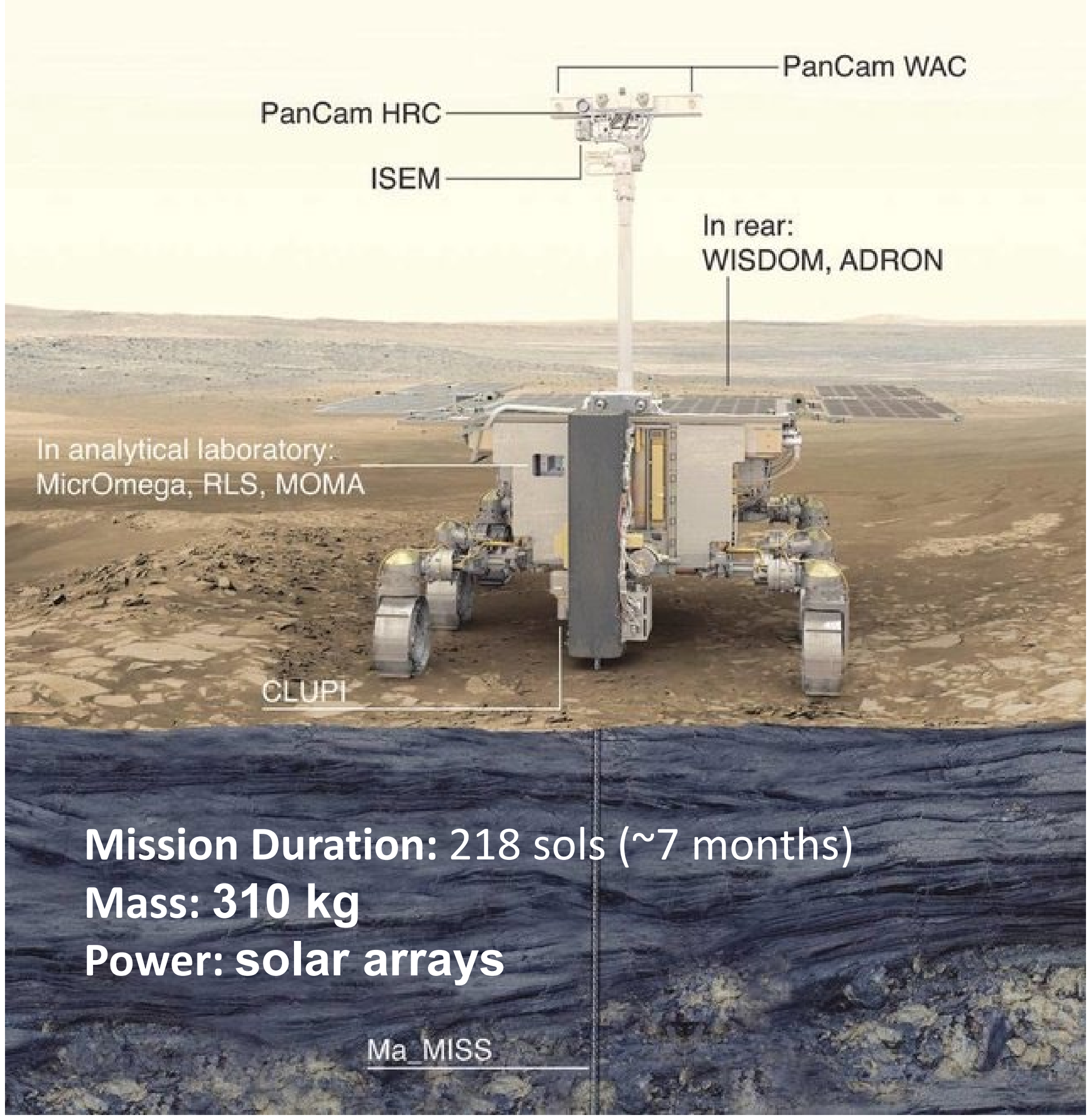
NASA, Mini-Mass Consulting, Inc.

HEMS Workshop 2022 Sept 26-29, Cocoa Beach



ExoMars rover mission



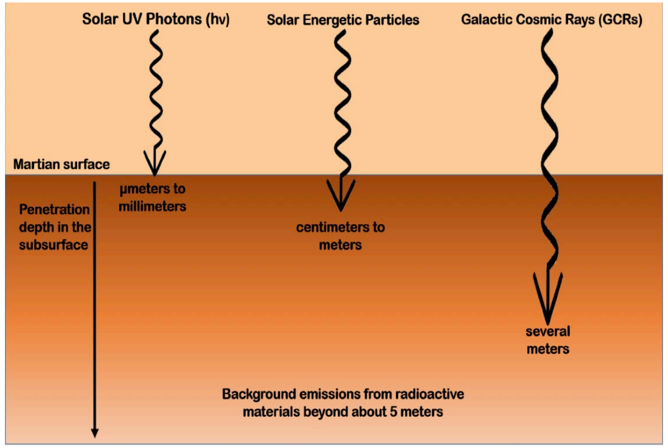
ExoMars Rover Science Goals:

1-Search for signs of past and present life in the Mars (sub)surface

2-Investigate the water/geochemical environment versus depth

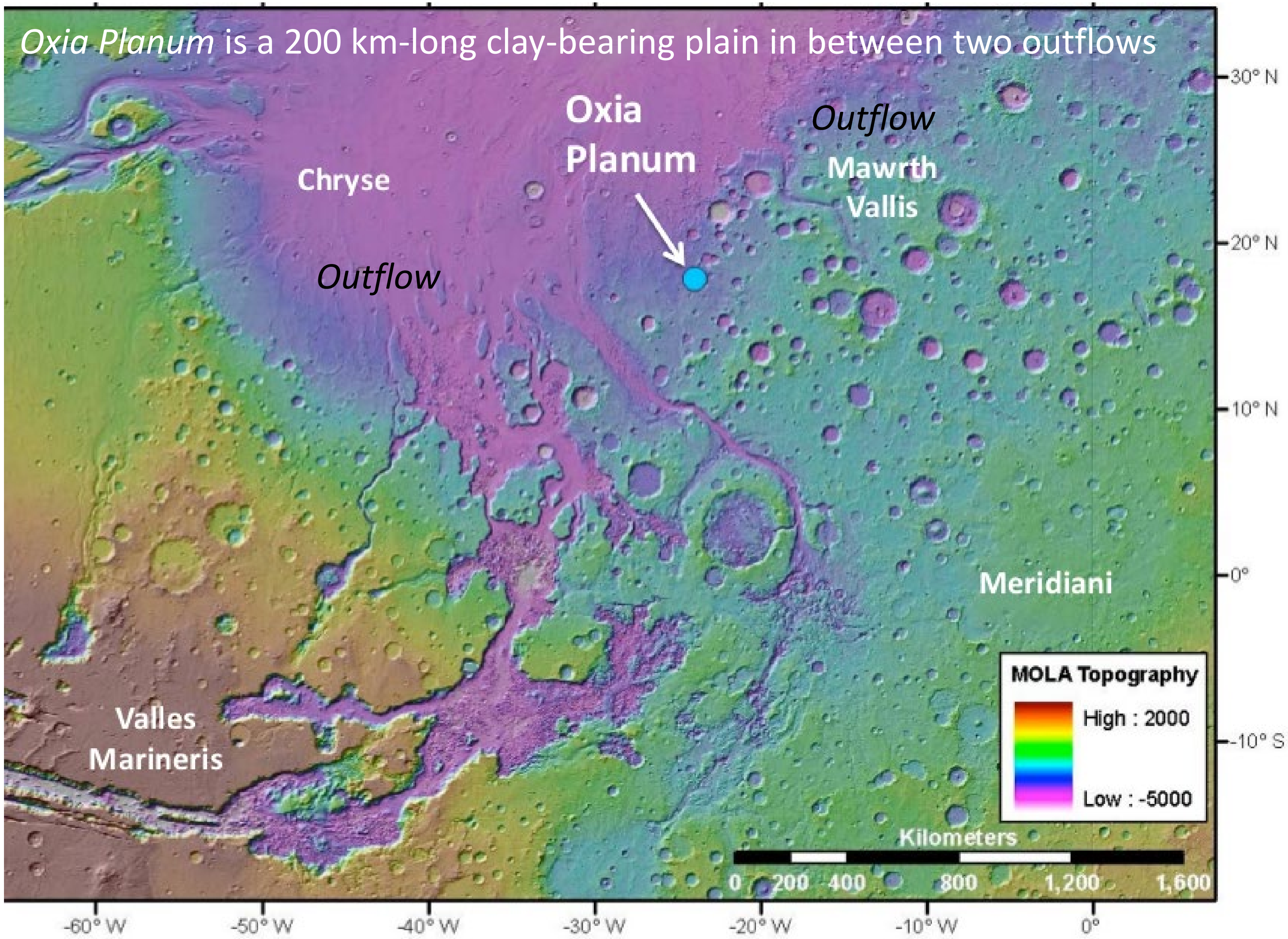
ExoMars Rover Instrumentation:

A drill (2 m) and a sampling preparation system PanCam, ISEM & CLUPI for the surface and drill bore context ADRON, WISDOM and MaMISS for subsurface information μMega, RLS and MOMA to analyze the collected samples

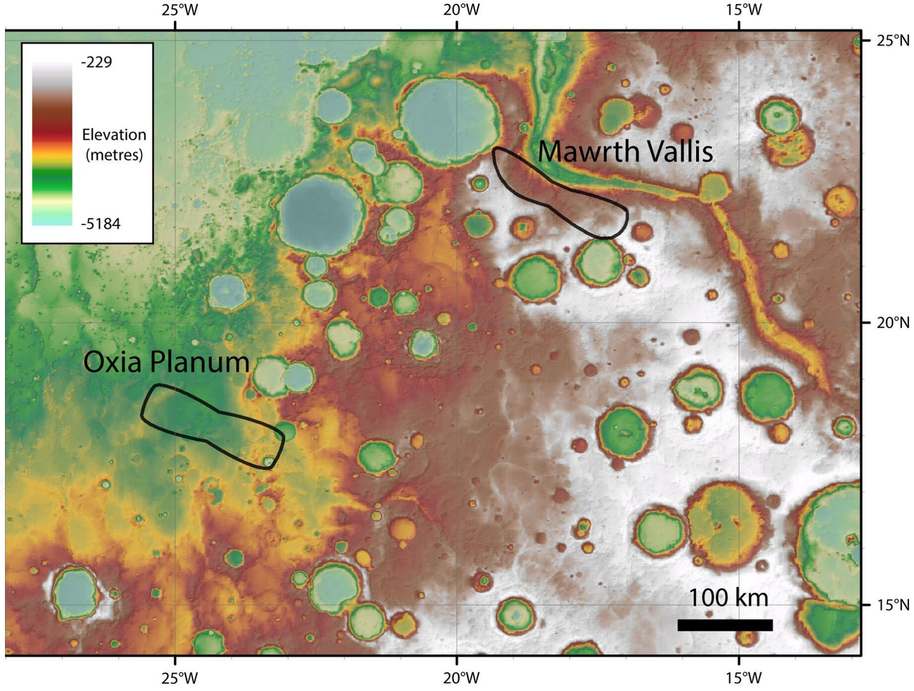


Cosmic radiation penetration. Organics can be broken down over millions of years.

Places to look for signs of life: Oxia Planum landing site



1. Search in a place where life could have developed.
2. Search in a place where life can or could have flourished.
3. Search in a place where life's remains may have collected.



Some facts about the ExoMars program

- ExoMars is an international collaboration
- Rocket and Lander are both Russian (until recent suspension)
- Given the current political climate the 2022 launch is delayed
- ESA is studying options on how to exchange the rocket and lander for a 2028 launch
- Science team will maintain the mass spectrometer and work on improved sample data interpretation

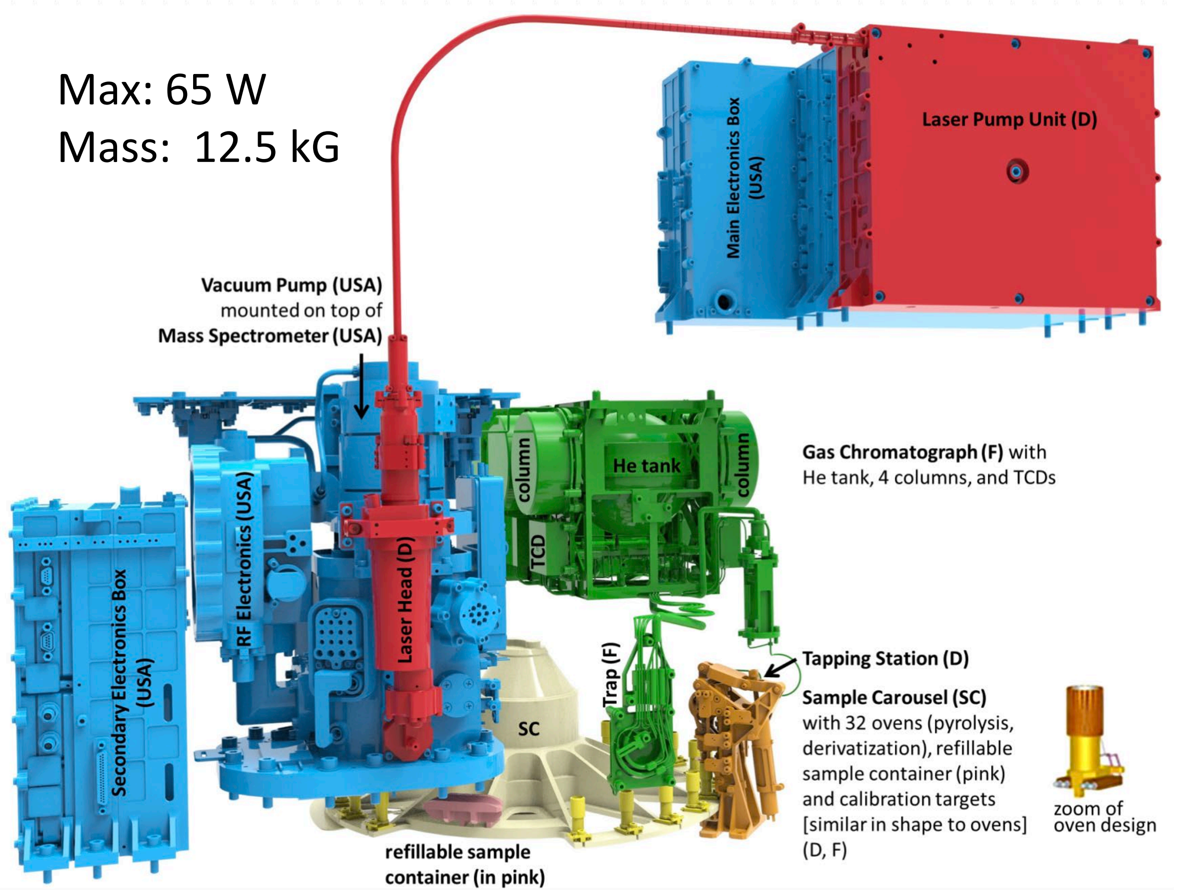
Travel distance about 300 million miles (480 million kilometers)

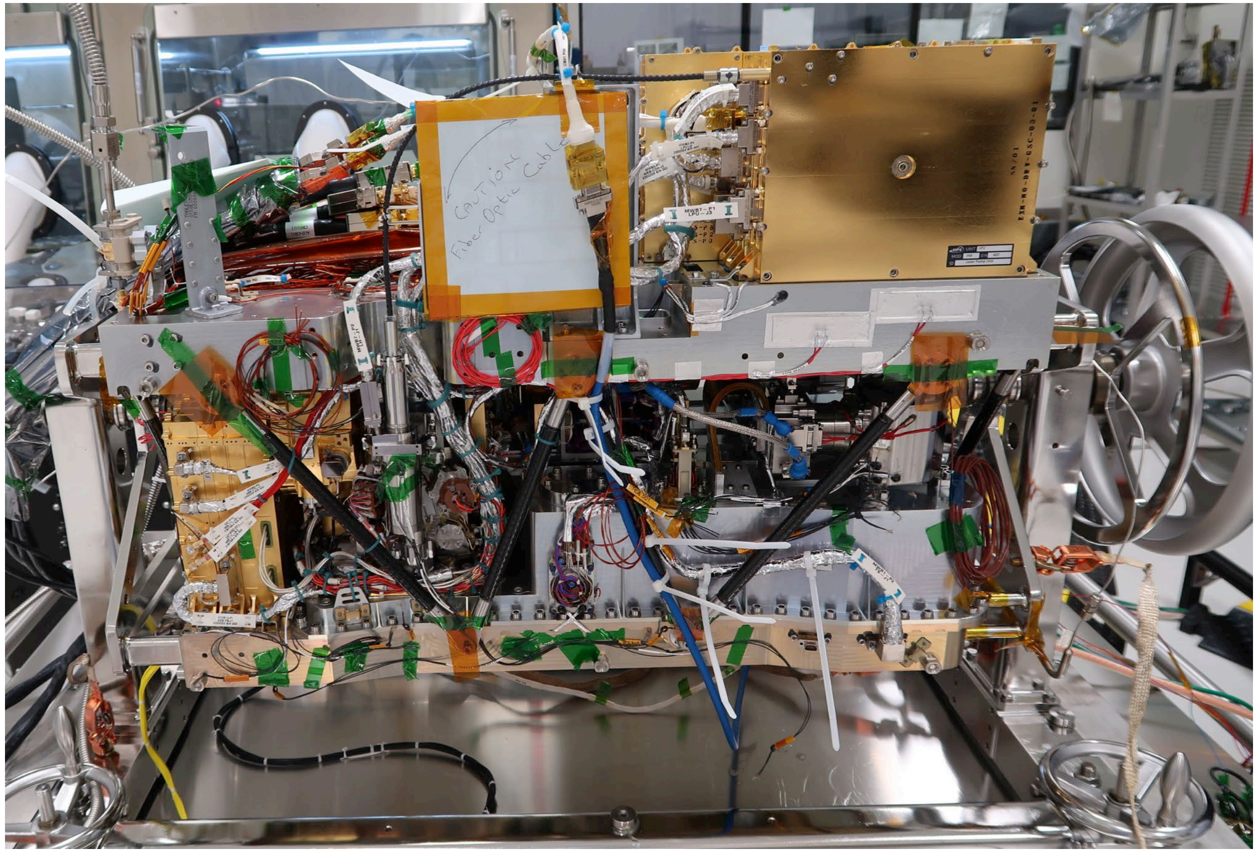
Mars atmosphere:

Carbon dioxide	95%
Nitrogen	2.8%
Argon	2%
Oxygen	0.174%
Carbon monoxide	0.0747%
Water vapor	0.03% (variable)

Overview of the Mars Organic Molecule Analyzer (MOMA)

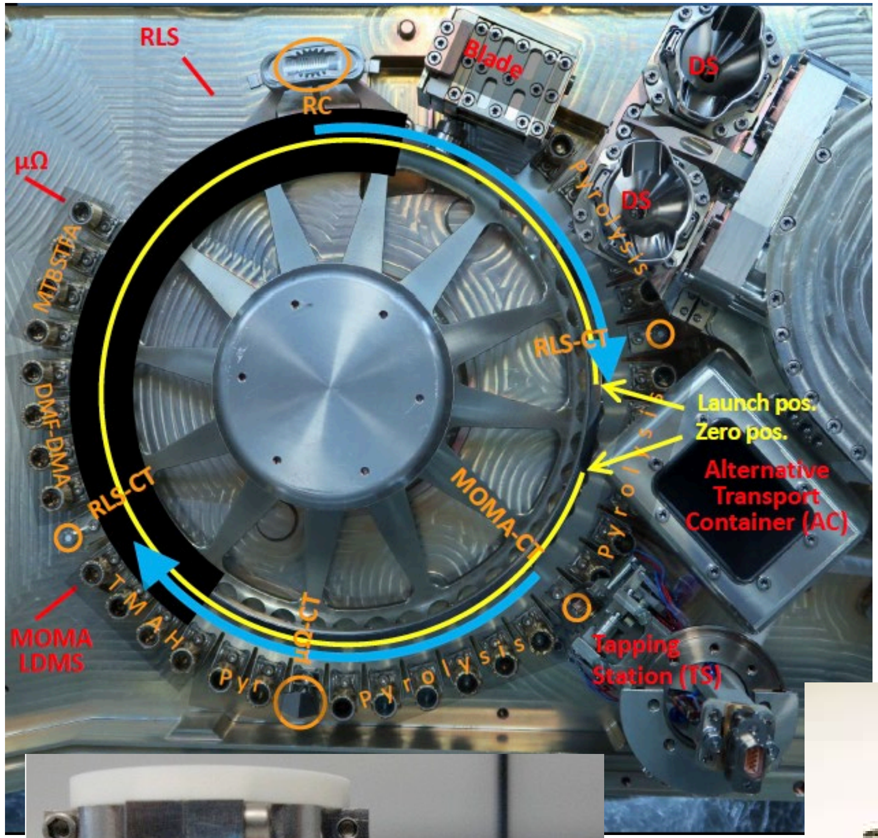
Max: 65 W
Mass: 12.5 kG

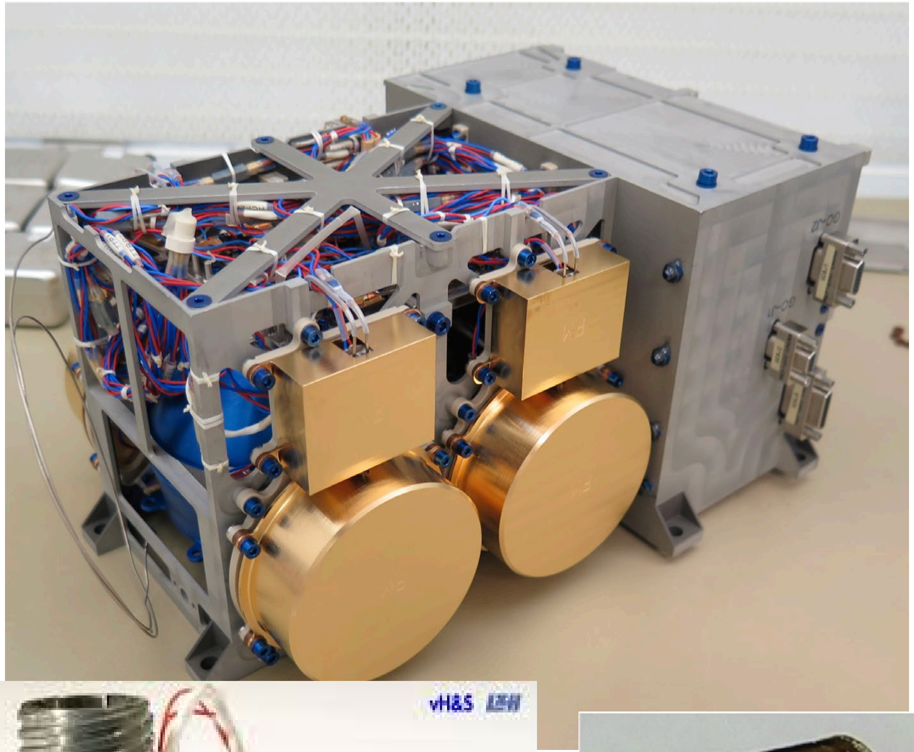


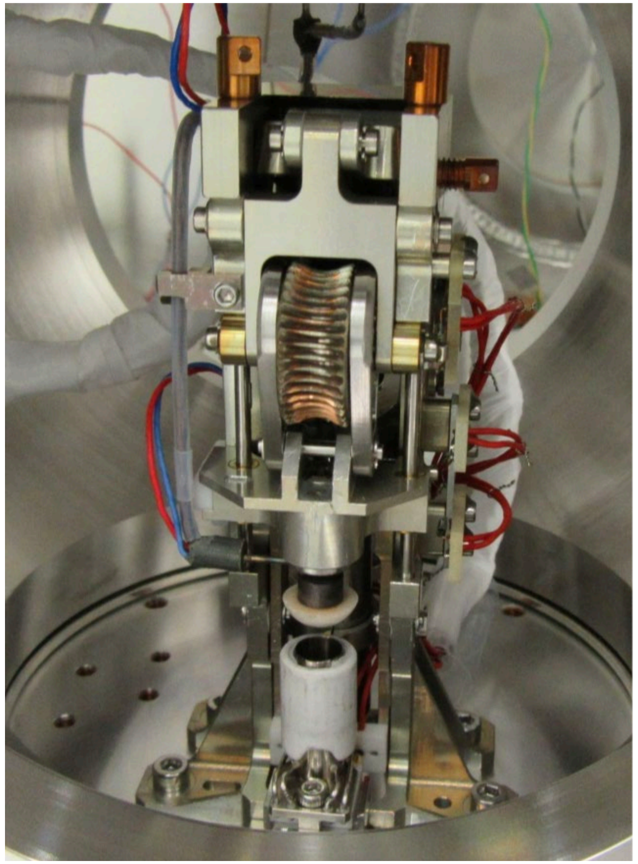


Two ionization methods. 1: Laser desorption Ionization 2: Electron impact ionization

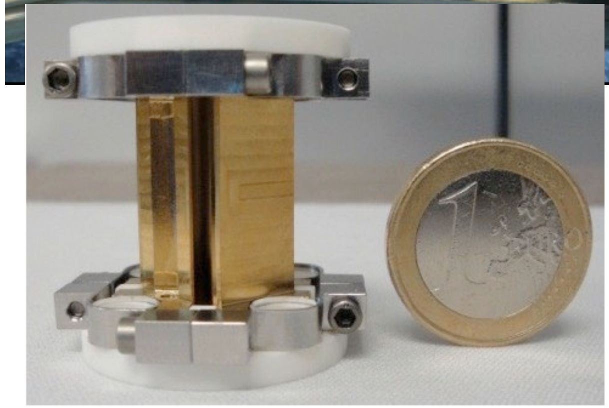
Some parts of the MOMA ms





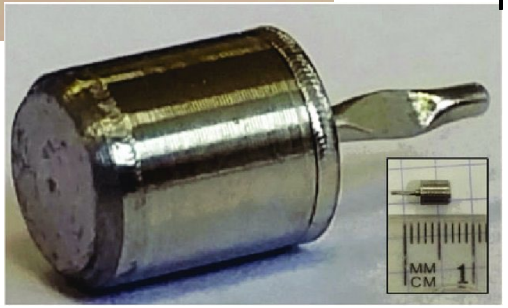


Tapping station/oven



LIT ion trap

UV-laser for LDI (266 nm)



Derivatization capsule

Linear ion trap mass spectrometer: A dual source mass spectrometer.

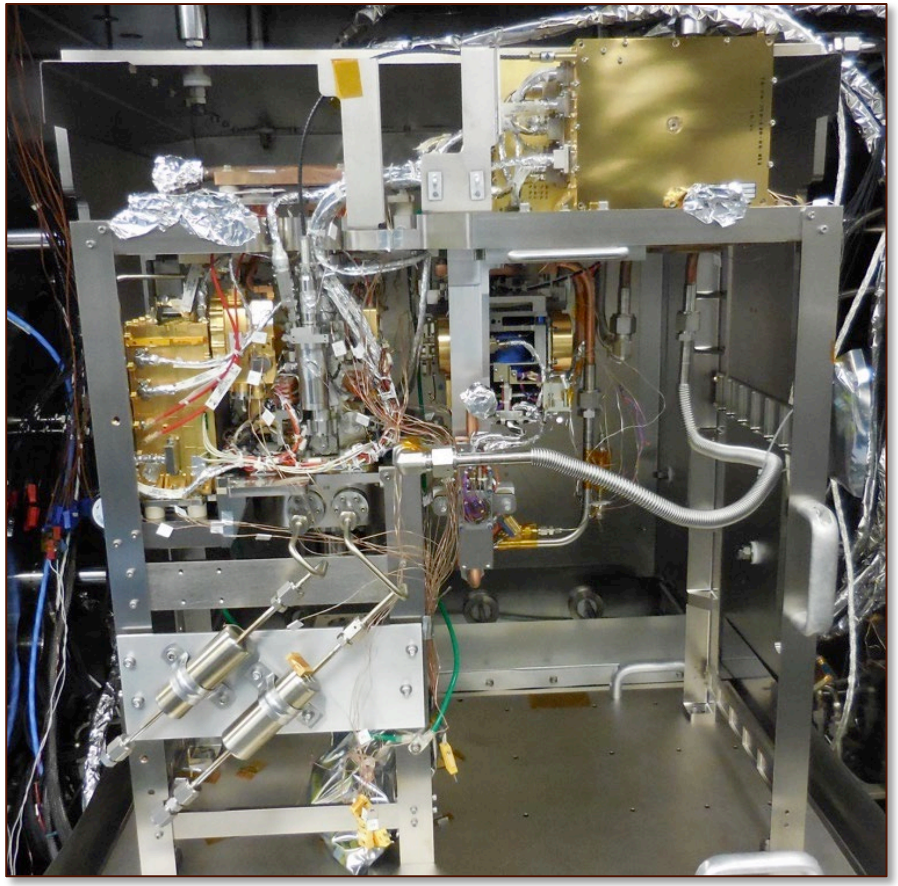
- The MOMA Mass Spectrometer centers on a miniaturized linear ion trap mass analyzer
- Laser: Nd:YAG, 266 nm, 1 ns pulse width;
- GC: two injection traps, four columns, all but one with TCD;
- Ovens: pyrolysis to 800 °C
- Derivatization via eutectic-sealed capsules that open/melt with heating

Based on Thermo LXQ trap design

Size:	x0, y0 = 3 mm,
RF frequency ~	1 MHz, RF Vmax = 1200 Vpp
Helium pressure	3 mTorr max
Temperature	50 degC to 200 degC (cleaning)

Dual dynode (-5000 V)
Detector with pulse counting
Dual electron ionization filament

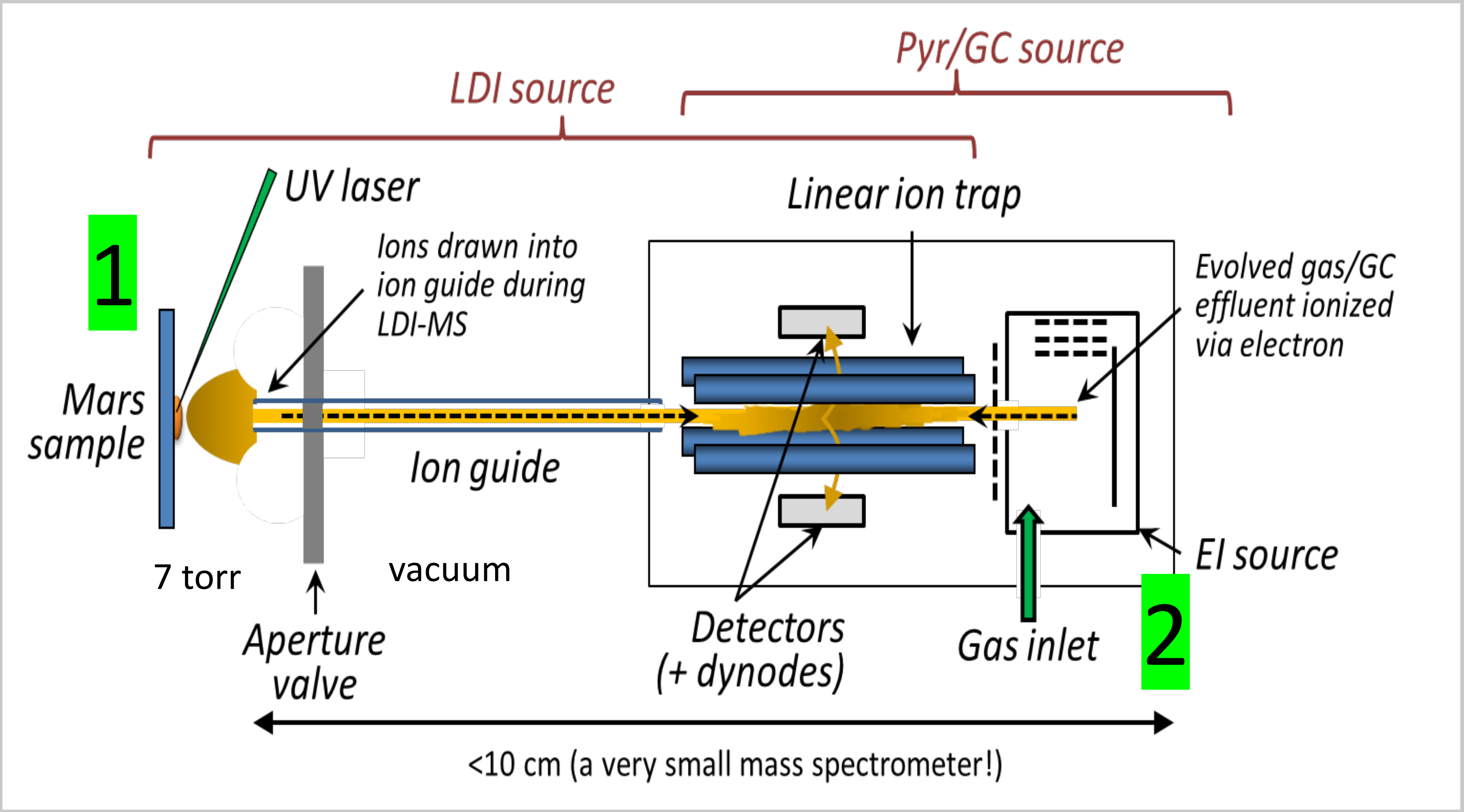
ms/ms, SWIFT capability



Testbed is positioned in aTVAC chamber as they would be on the Rosalind Franklin rover to accurately simulate the thermal environment

Flight system is packed and ready for launch. Testbed almost ready for TVAC testing

MOMA features a dual-source linear ion trap mass spectrometer.



DAPI = Discontinuous Atmospheric Pressure Inlet

Source 1:

A DAPI style valve inlet system with laser desorption capability. Ions can be formed with a UV laser. Larger compounds up to at least 1000 u.

Source 2:

An electron ionization source for gases from GC and pyrolysis oven. Up to 500 u.

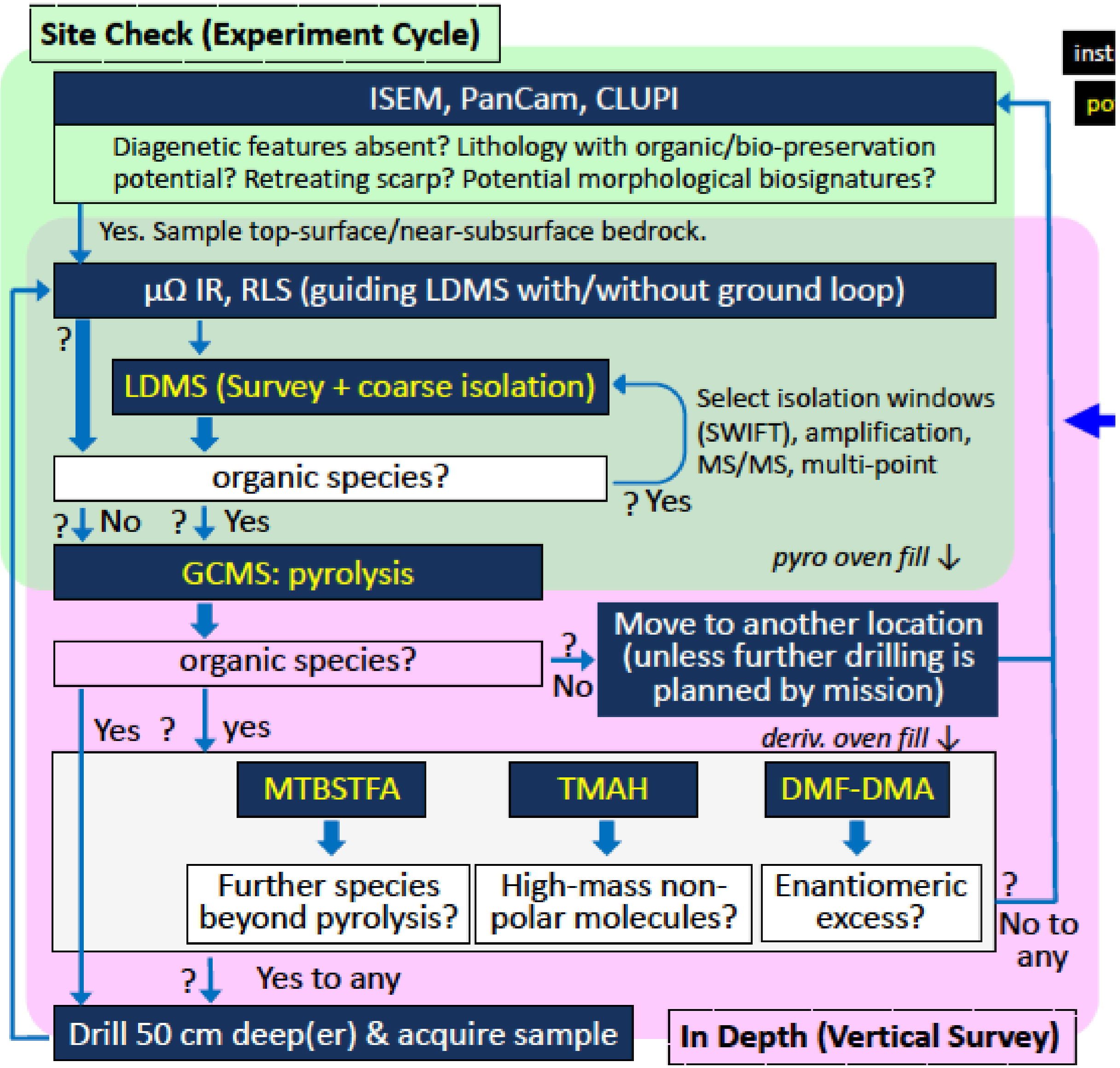
Systems available for sample measurements. Database preparation

System	Description	Sample quality	Database	Operation time
LITMS	A lab study instrument build from spare part breadboards	Can use 'dirty' samples	Not yet connected	~ 150 h estimated
ETU	Engineering test unit (first flight like system)	Can use samples deemed to be not or slightly contaminating	Connected to database	1429 h ✔
Flight system	Final flight system	Ultra clean	Connected	127 h
Testbed	Simulation and planning system in Mars environment	Ultra clean initially, for diagnostics; later more like ETU	Connected	53 h

- Online database
- All mass spectrometer consumables recorded
- All recorded spectra stored from ETU, FLT and Testbed
- Capability of searching for mass spectra and mass peaks
- Machine learning is being added

Sample analysis flowchart. Operations planning/training

- **Planning and training for operational roles at the mission level**
- **Involvement in decision making processes**
- **Science analysis at the Rover (mainly ALD) level (e.g. common samples to test rover instruments)**
- **Science scenario development and instrument contingency planning**



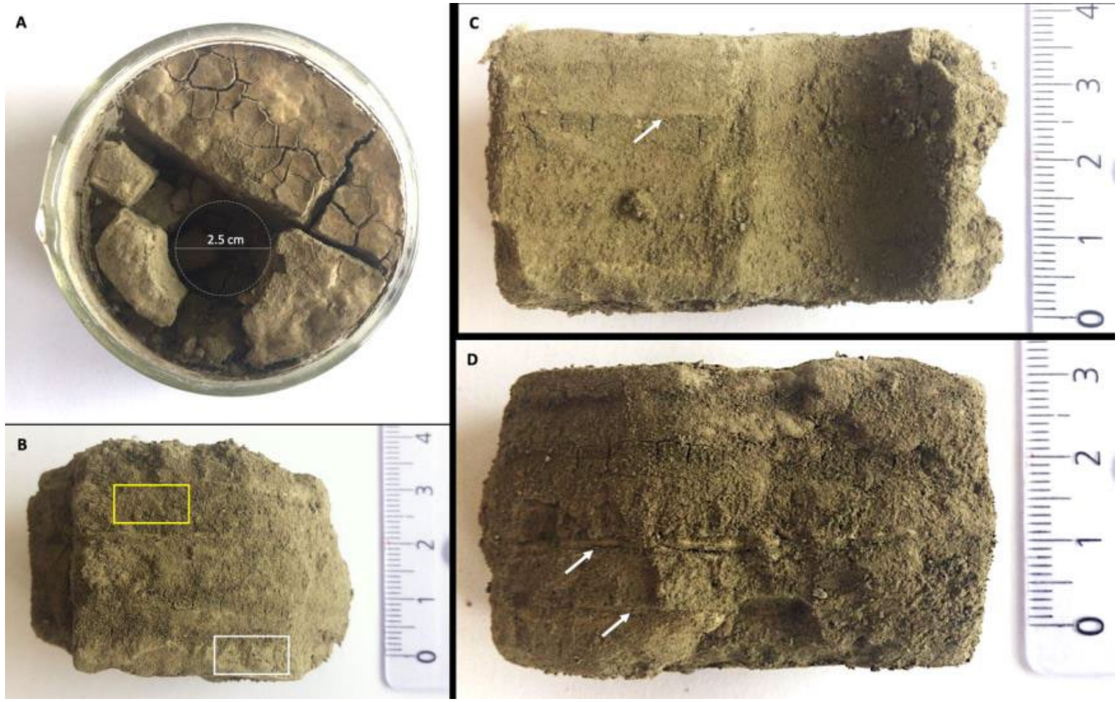
Realistic simulation of martian samples
(T. Fornaro, J. Brucato et al.)

Which are the possible geochemical settings in Oxia Planum and how can we simulate processes of molecule-mineral complexes formation?

- Equilibrium Adsorption method (more homogeneous samples)
- Mixing of organics into mineral matrices (heterogenous samples)

Organics mixed with different Mars- relevant synthetic standards (including include magnesium sulfate, halite and jarosite) as they precipitated out of aqueous solution.

At GSFC we test both homogenous (difficult to make) and heterogenous samples (easier to prepare).

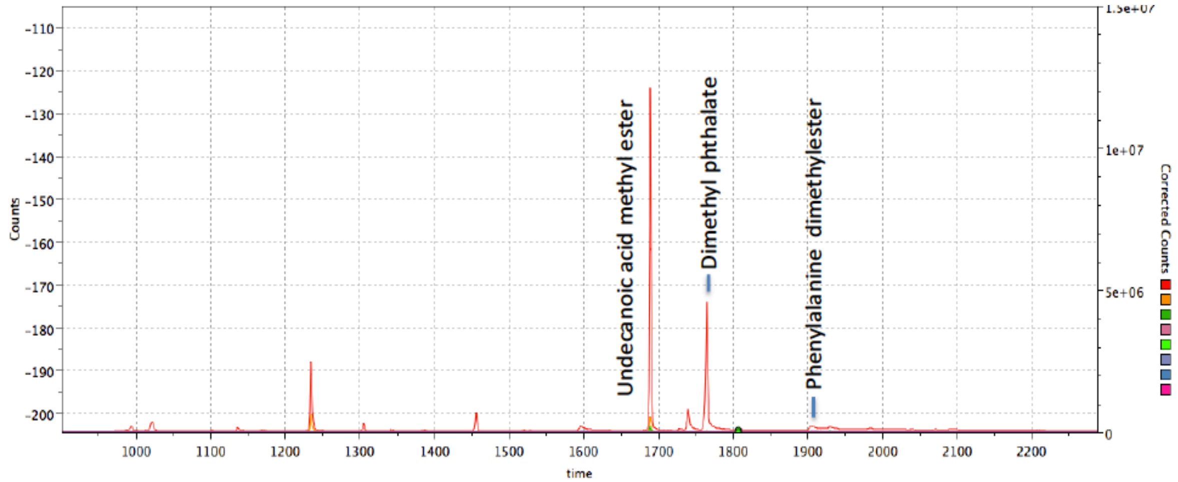


Sedimentation method: **Artificial sediments built up from deposition of aqueous slurry of basalt of varying granulometry mixed with other components.**

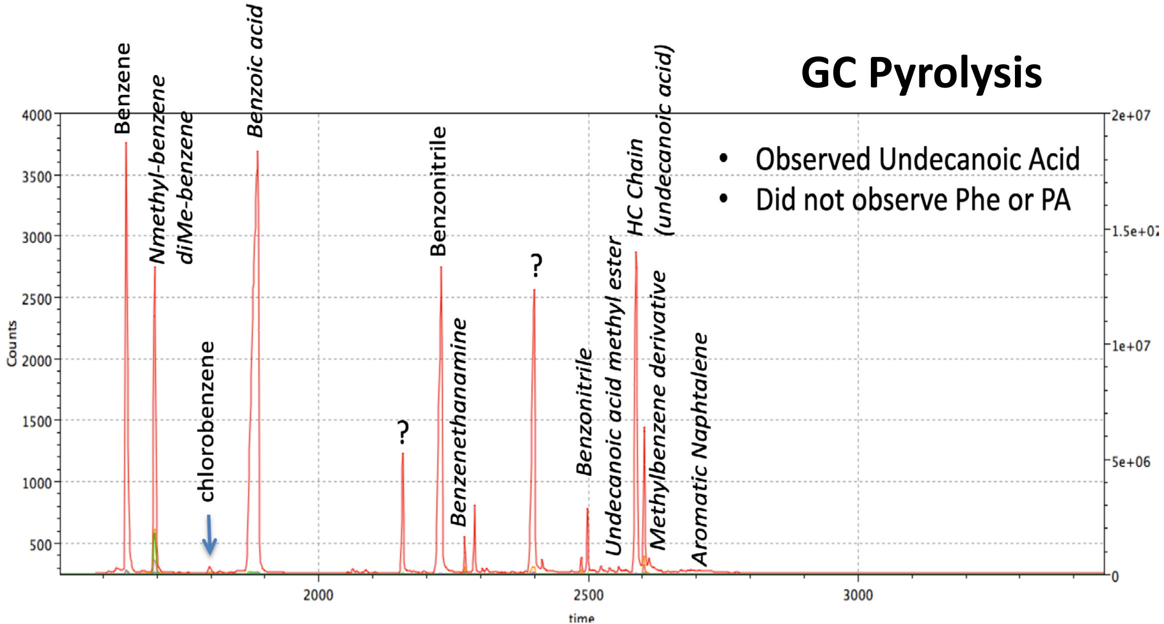
Minerals mixed with organics: **Massed organic samples are mixed mechanically with a mineral of choice**

Gas chromatography data (derivatization functional)

Analysis of organic acids (3% doped in vermiculite) derivatized with DMF-DMA

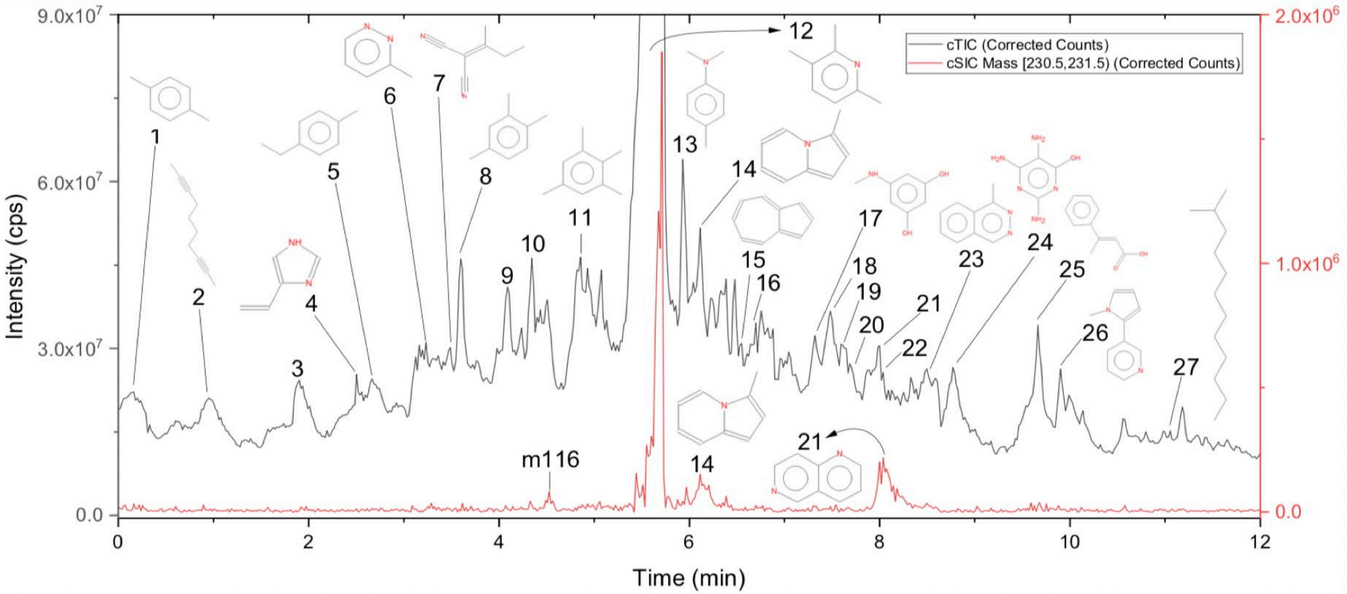


GC Pyrolysis

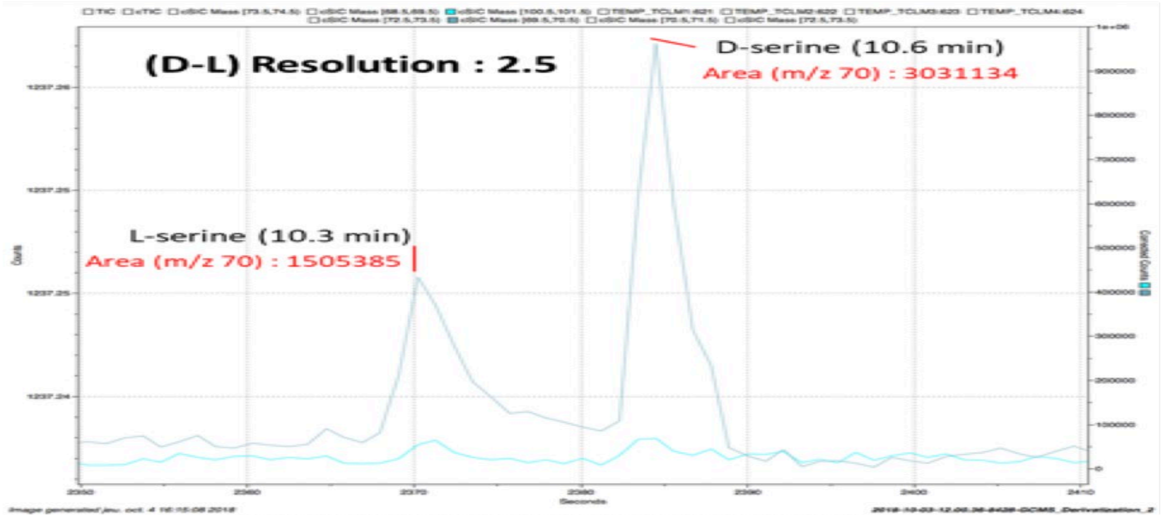


- Observed Undecanoic Acid
- Did not observe Phe or PA

Analysis of complex samples (JSC Mars-1)

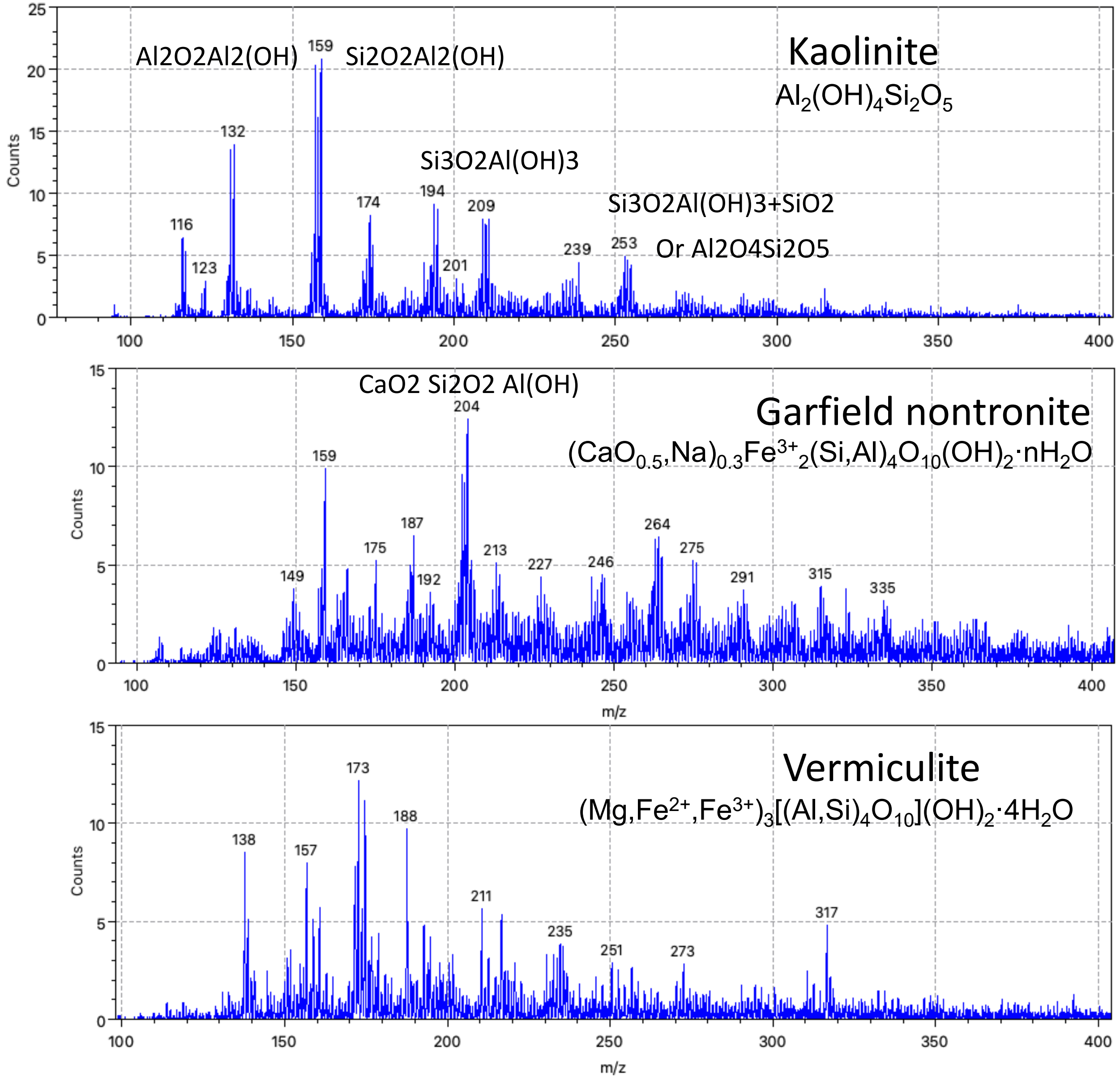


Separation of amino acids enantiomers

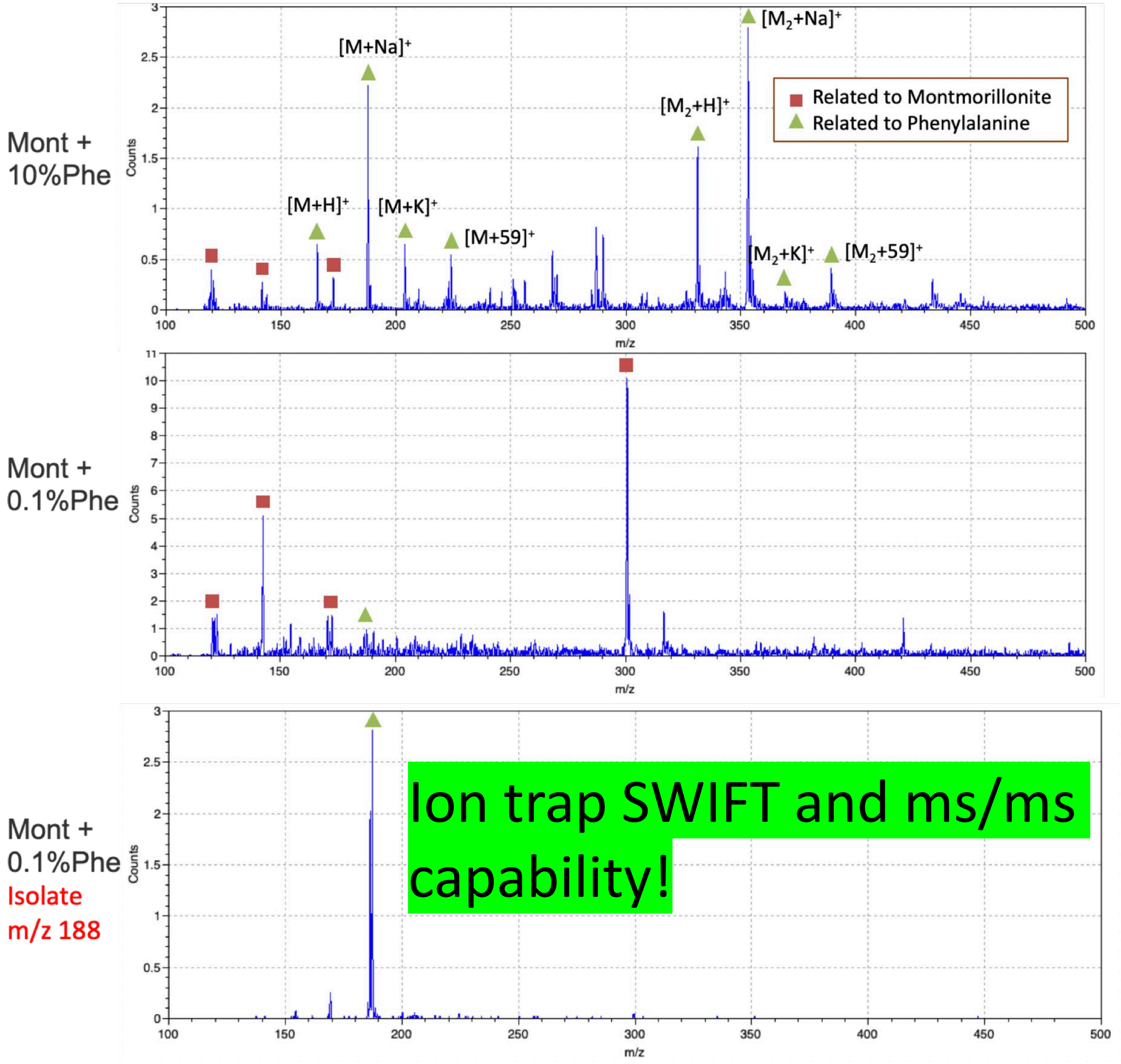


Typical laser desorption ionization data

Phyllosilicates



Analytical capabilities concentration mixes of organics in a matrix



Hematite measurements

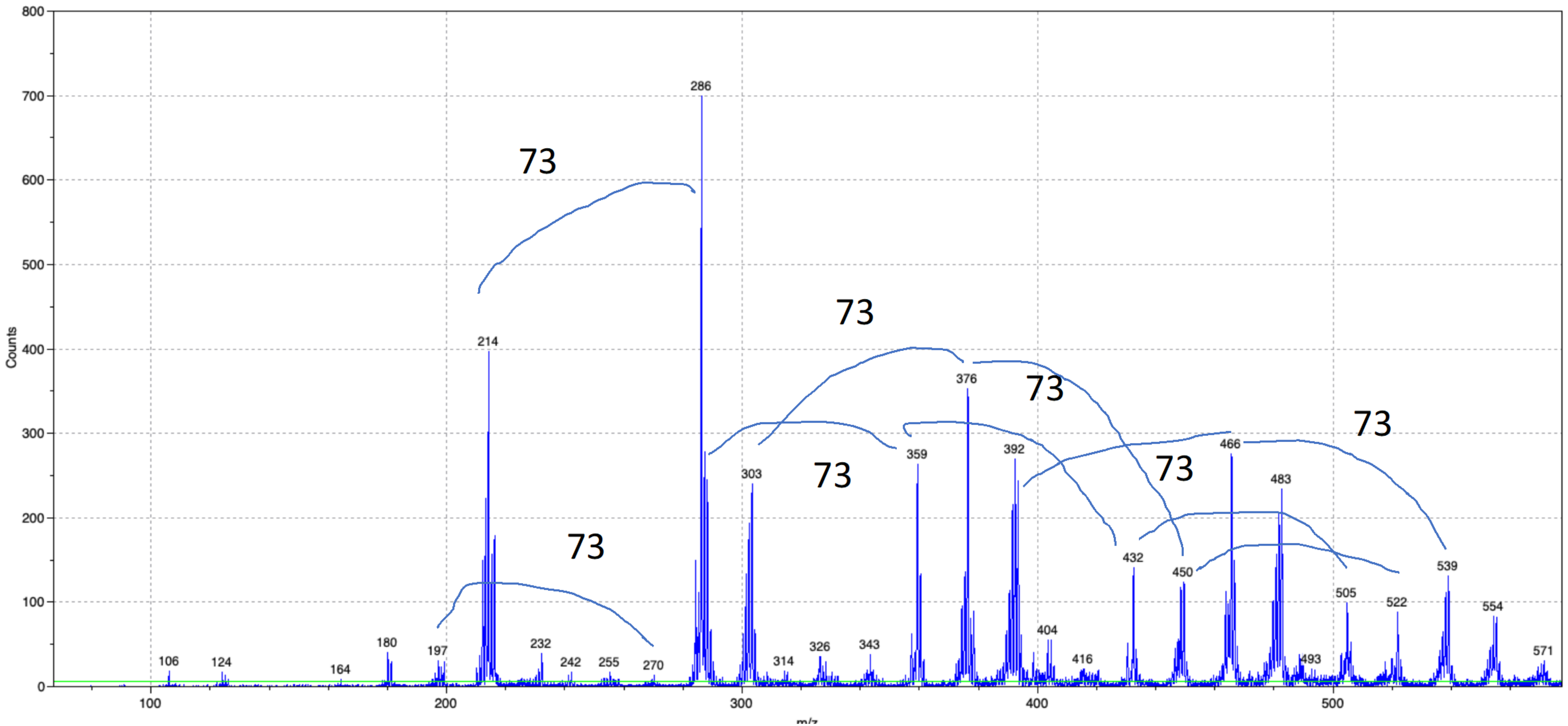
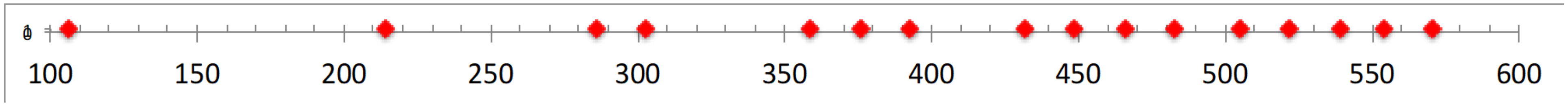


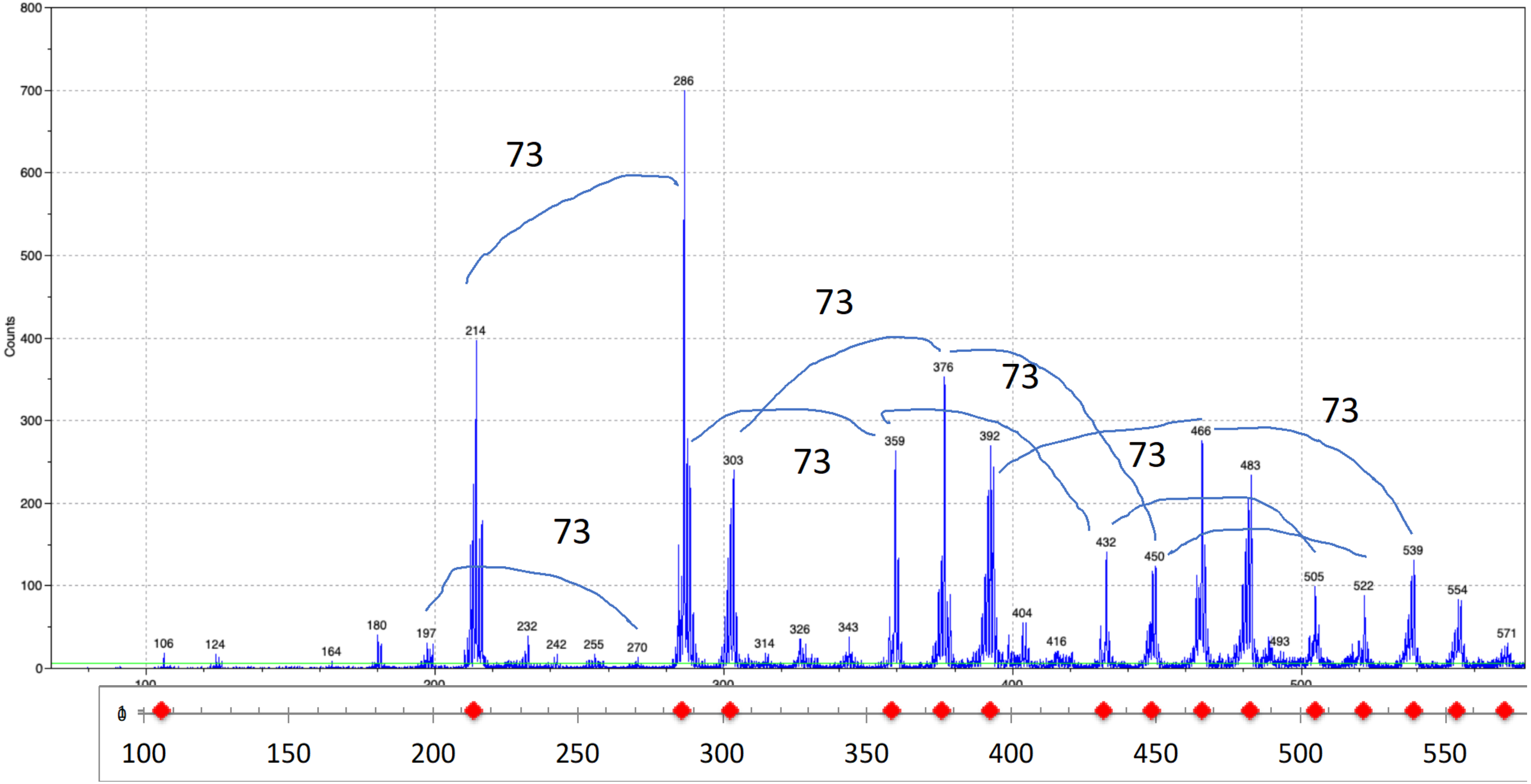
Table of estimated hematite fragment with water addition/reactions

		Fe	FeOH	Fe	O	H2O	OH	H		
		54	73	56	16	18	17	1		
FeO2	H2O			1	2	1			106	1
									0	
									0	
Fe2O2	(H2O)2			2	2	2			180	
	OH			2	1	1	2		180	
	OH			2	1	1	3		197	
									0	
Fe2O3	(H2O)3			2	3	3			214	1
									0	
									0	
Fe3O4	(H2O)3			3	4	3			286	1
Fe3O4(OH)	OH			3	4	3	1		303	1
									0	
									0	
Fe3O4(FeOH)1	(H2O)3		1	3	4	3			359	1
Fe3O4(FeOH)1(OH)	OH		1	3	4	3	1		376	1
Fe3O4(FeOH)1(OH)2	OH		1	3	4	3	2		393	1
									0	
									0	
Fe3O4(FeOH)2	(H2O)3		2	3	4	3			432	1
Fe3O4(FeOH)2(OH)	OH		2	3	4	3	1		449	1
Fe3O4(FeOH)2(OH)2	OH		2	3	4	3	2		466	1
Fe3O4(FeOH)2(OH)3	OH		2	3	4	3	3		483	1
									0	
									0	
Fe3O4(FeOH)3	(H2O)3		3	3	4	3			505	1
Fe3O4(FeOH)3(OH)	OH		3	3	4	3	1		522	1
Fe3O4(FeOH)3(OH)2	OH		3	3	4	3	2		539	1
Fe3O4(FeOH)3(OH)3	OH		3	3	4	3	3		556	1
Fe3O4(FeOH)3(OH)4	OH		3	3	4	3	4		573	1

Estimated chemical formula



Hematite measurements

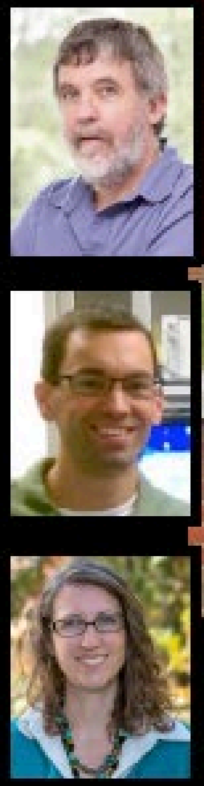


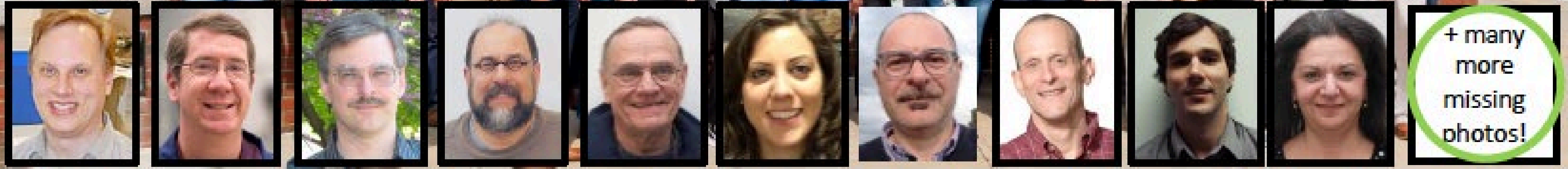
Different mass spectrometers will give different results.

Mineral analysis not standard with mass spectrometers.

Red dots are from table with ‘estimated’ hematite fragments with water additions

MOMA - A Serious Team Effort!





THANKS to everyone who put in such an amazing effort to envision, design, debate, model, calculate, machine, weld, bolt, assemble, align, clean, bake, leak check, wire, mate, heat, cool, code, control, test, analyze, manage, and review this incredible instrument every step of the way to a successful delivery of MOMA to ESA!