Exploring Potential Habitats in our Solar System
The "Curiosity" Rover of
The Mars Science Laboratory (MSL)

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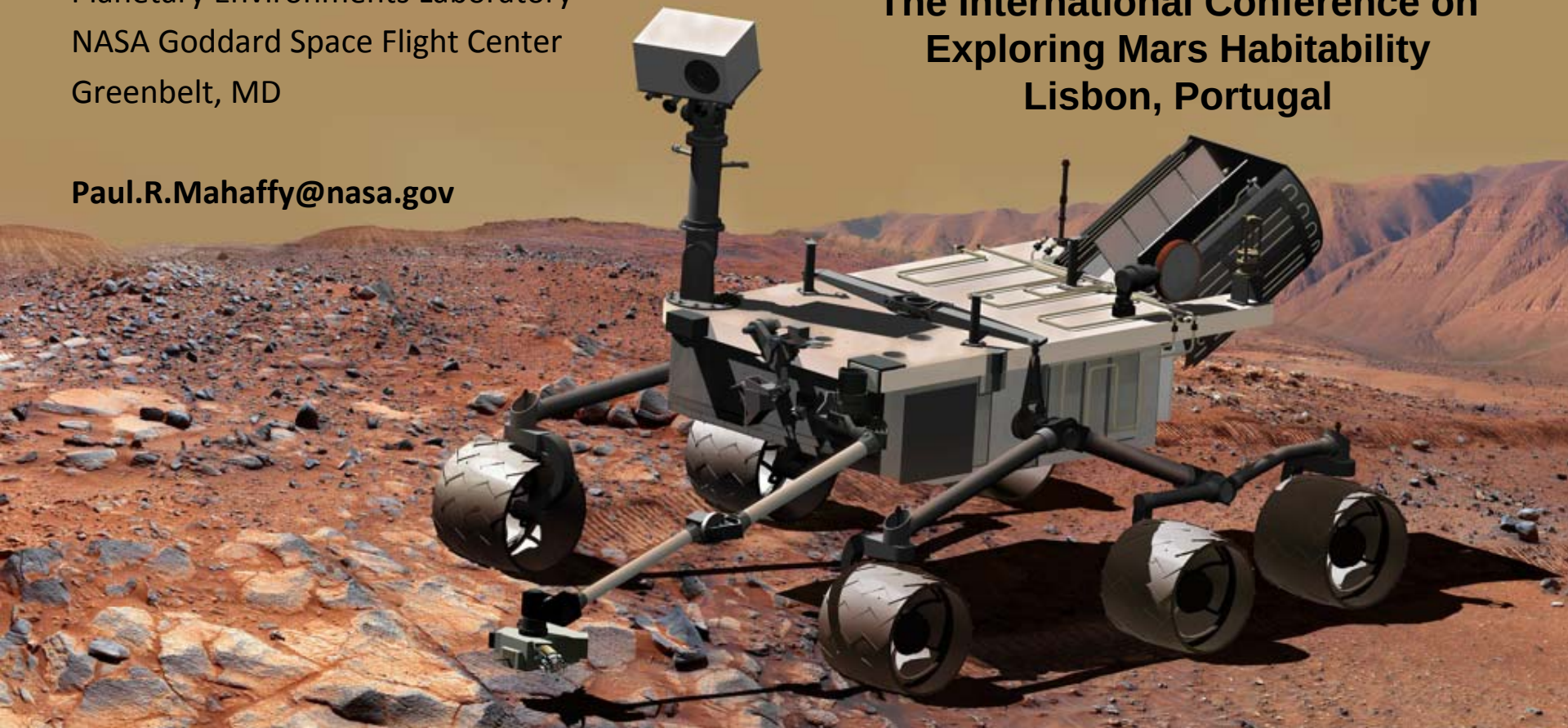


Curiosity's Capabilities

A Robotic Field Geologist

- Long life, ability to traverse many miles over rocky terrain
- Landscape and hand-lens imaging
- Ability to survey composition of bedrock and regolith

A Mobile Geochemical and Environmental Laboratory

- Ability to acquire and process dozens of rock and soil samples
- Instruments that analyze samples for chemistry, mineralogy, and organics
- Sensors to monitor water, weather, and natural high-energy radiation

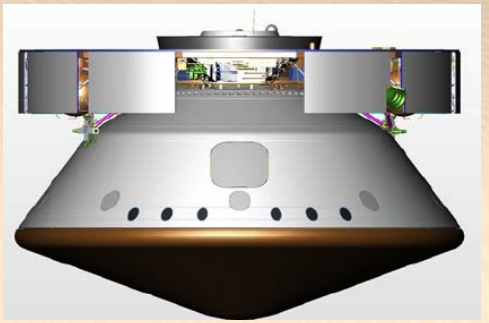
Curiosity's Science Goals

Curiosity's primary scientific goal is to explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present

Objectives include:

- Assessing the biological potential of the site by investigating any organic and inorganic compounds and the processes that might preserve them
- Characterizing geology and geochemistry, including chemical, mineralogical, and isotopic composition, and geological processes
- Investigating the role of water, atmospheric evolution, and modern weather/climate
- Characterizing the spectrum of surface radiation

Mission Overview



CRUISE/APPROACH

- 8 to 9-month cruise
- Arrive August 6-20, 2012

LAUNCH

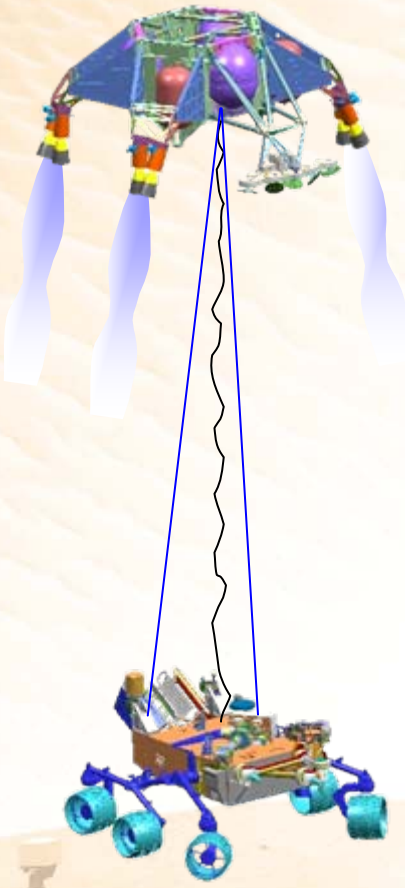
- Window is Nov. 25 to Dec. 18, 2011
- Atlas V (541)

ENTRY, DESCENT, LANDING

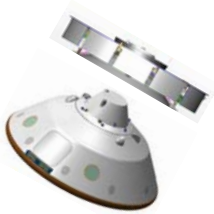
- Guided entry and powered "sky crane" descent
- 20×25-km landing ellipse
- Access to landing sites ±30° latitude, <0 km elevation
- 900-kg rover

SURFACE MISSION

- Prime mission is one Mars year (687 days)
- Latitude-independent and long-lived power source
- Ability to drive out of landing ellipse
- 84 kg of science payload
- Direct (uplink) and relayed (downlink) communication
- Fast CPU and large data storage



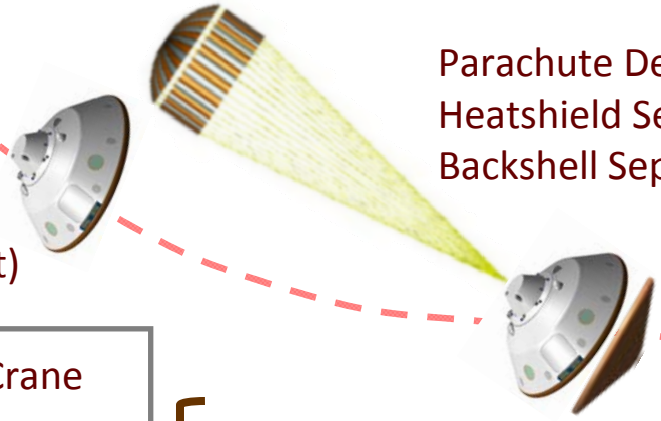
MSL Entry, Descent, and Landing



Cruise Stage Separation

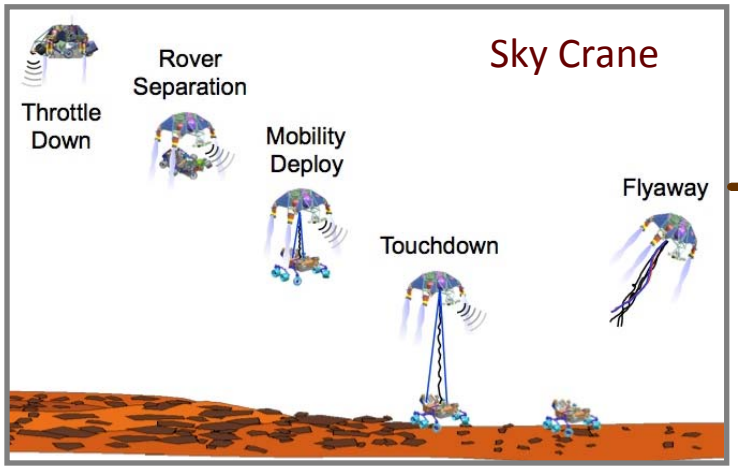
Max Heating and Deceleration

- **Guided entry corrects for atmospheric variability and improves landing accuracy**
- **"Sky Crane" design places the rover directly on Martian soil while keeping the rockets away from the ground**



Parachute Descent
Heatshield Separation
Backshell Separation

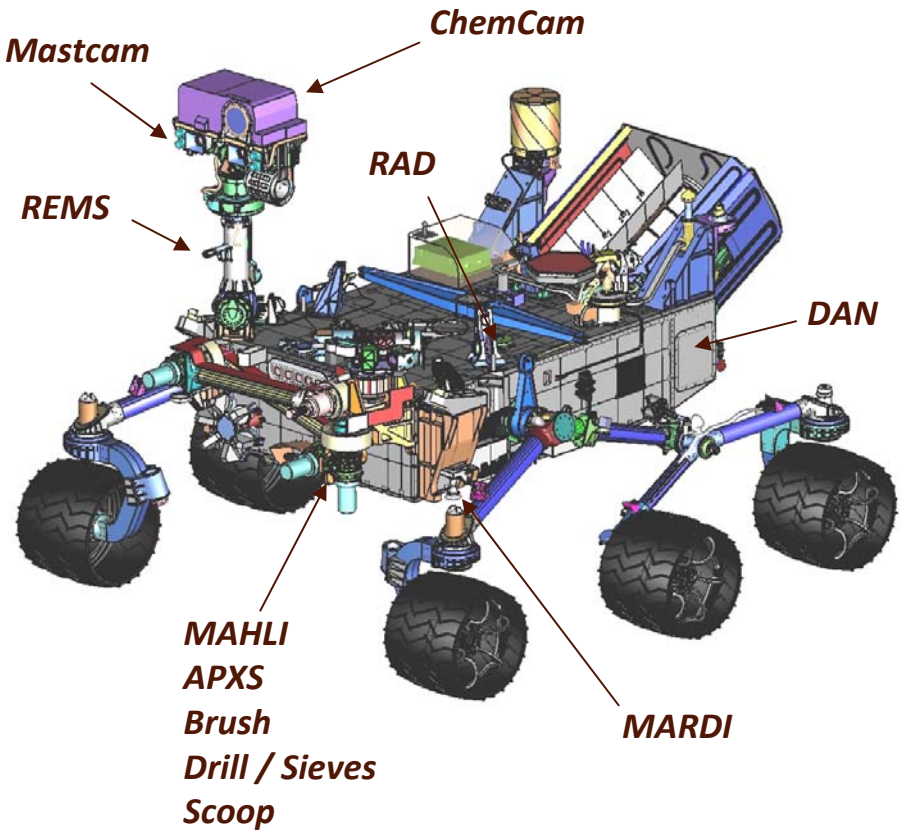
Guided Entry
(horizontal flight)



Powered Descent

Touchdown

MSL Science Payload



Rover Width:	**2.8 m**
Height of Deck:	**1.1 m**
Ground Clearance:	**0.66 m**
Height of Mast:	**2.2 m**

REMOTE SENSING

Mastcam (M. Malin, MSSS) - Color and telephoto imaging, video, atmospheric opacity

ChemCam (R. Wiens, LANL/CNES) – Chemical composition; remote micro-imaging

CONTACT INSTRUMENTS (ARM)

MAHLI (K. Edgett, MSSS) – Hand-lens color imaging

APXS (R. Gellert, U. Guelph, Canada) - Chemical composition

ANALYTICAL LABORATORY (ROVER BODY)

SAM (P. Mahaffy, GSFC/CNES) - Chemical and isotopic composition, including organics

CheMin (D. Blake, ARC) - Mineralogy

ENVIRONMENTAL CHARACTERIZATION

MARDI (M. Malin, MSSS) - Descent imaging

REMS (J. Gómez-Elvira, CAB, Spain) - Meteorology / UV

RAD (D. Hassler, SwRI) - High-energy radiation

DAN (I. Mitrofanov, IKI, Russia) - Subsurface hydrogen

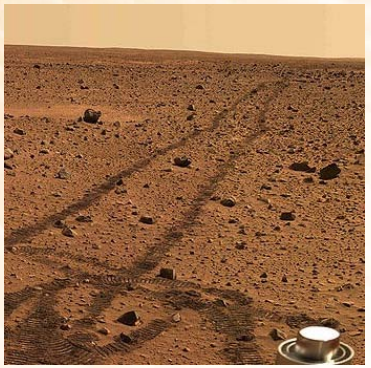
Science Operations

1. REMOTE SENSING

- Landscape imaging
- Sampling of rock and soil chemistry

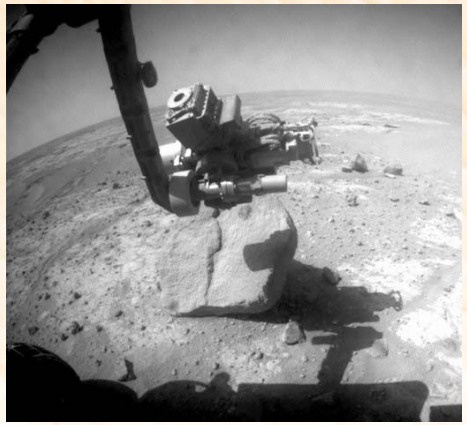
2. TRAVERSE/APPROACH

- Driving up to 100 m per sol
- Imaging and profiling chemistry along the drive
- Locating sampling targets



3. CONTACT SCIENCE

- Removal of surface dust
- Chemical and hand-lens observations of a specific target

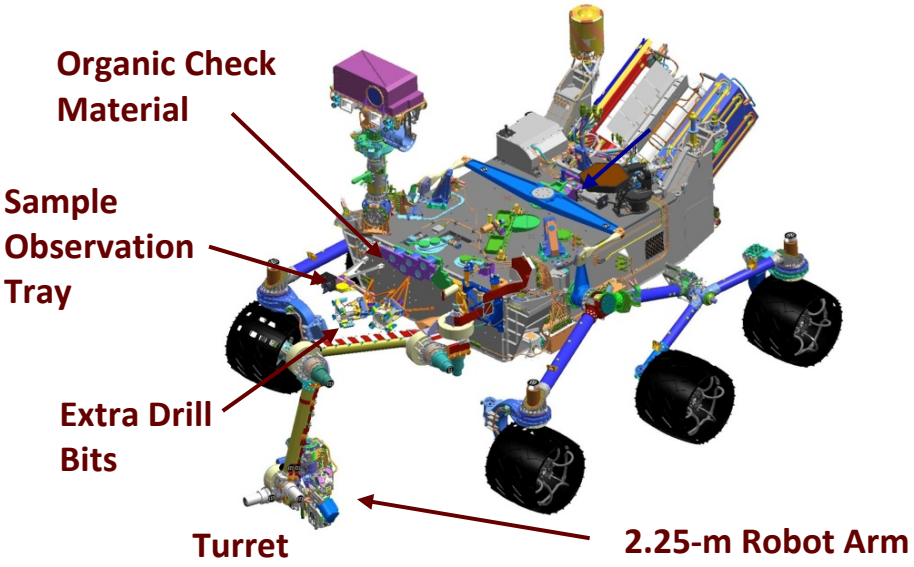


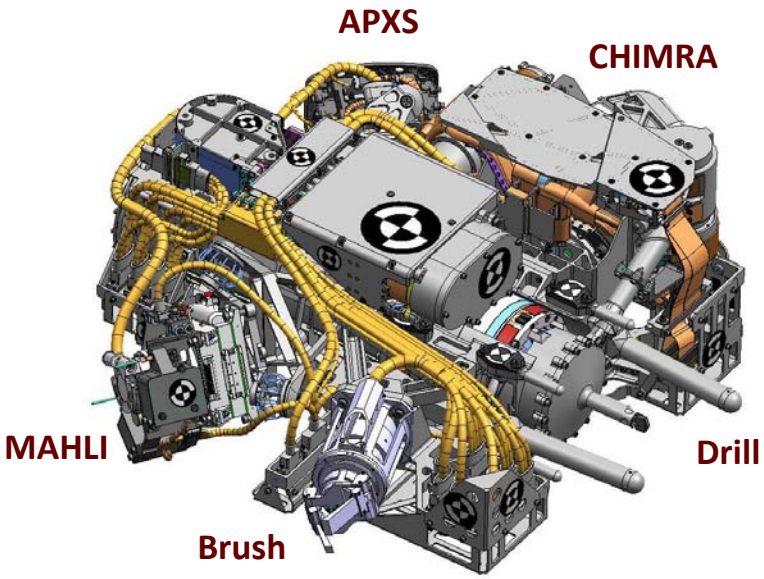
4. SAMPLE ACQUISITION/ANALYSIS

- Drilling, processing, and delivering sample material to the rover's lab instruments
- Analyzing for mineralogy, organics, elemental and isotopic chemistry

Each activity may require multiple sols. Results are reviewed on Earth before moving on to the next activity. Weather and radiation monitoring occur on all sols.

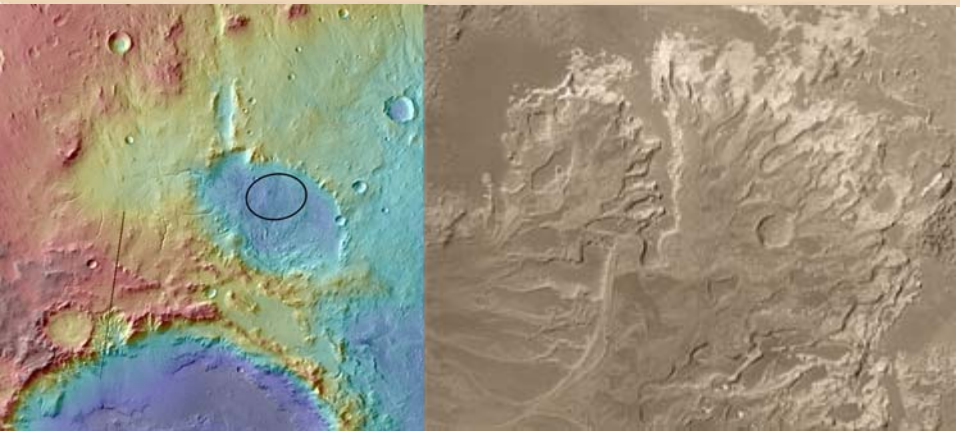
Sampling System



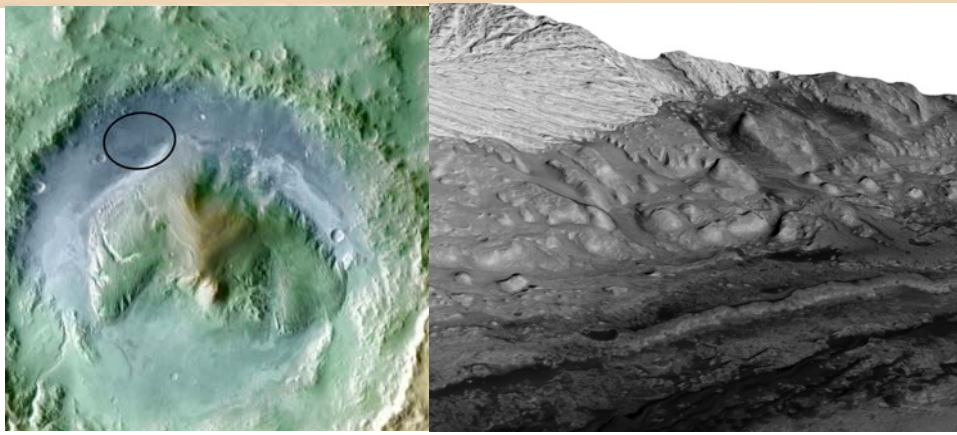


- Cleans rock surfaces with a brush
- Places and holds the APXS and MAHLI instruments
- Acquires samples of rock or soil with a powdering drill or scoop
- Sieves the samples (to 150 µm or 1 mm) and delivers them to instruments or an observation tray
- Exchanges spare drill bits

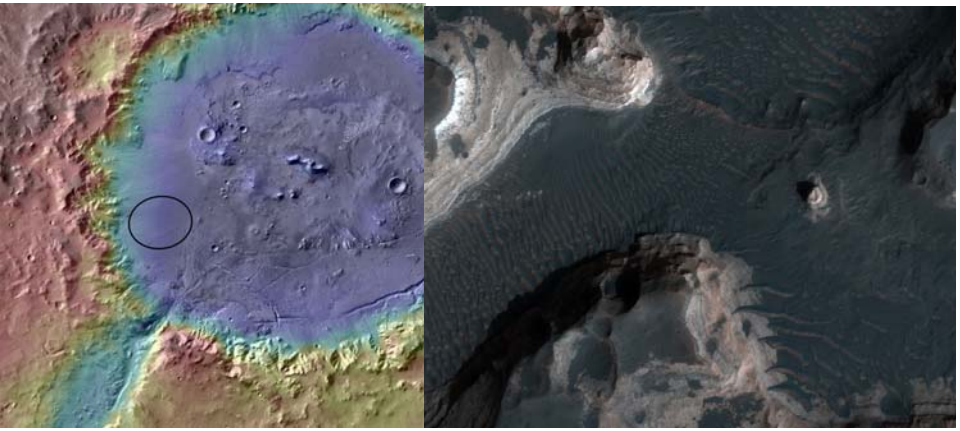
Candidate Landing Sites



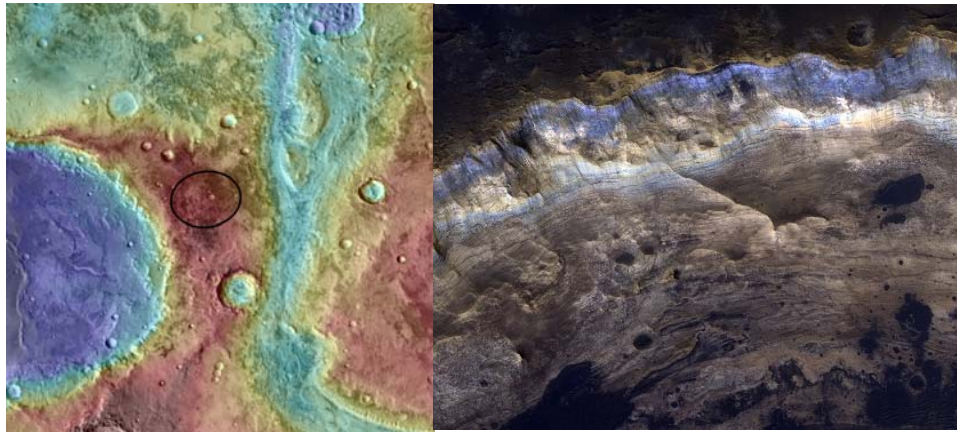
Eberswalde Crater (24°S, 327°E, -1.5 km) contains a clay-bearing delta formed when an ancient river deposited sediment, possibly into a lake.



Gale Crater (4.5°S, 137°E, -4.5 km) contains a 5-km sequence of layers that vary from clay-rich materials near the bottom to sulfates at higher elevation.

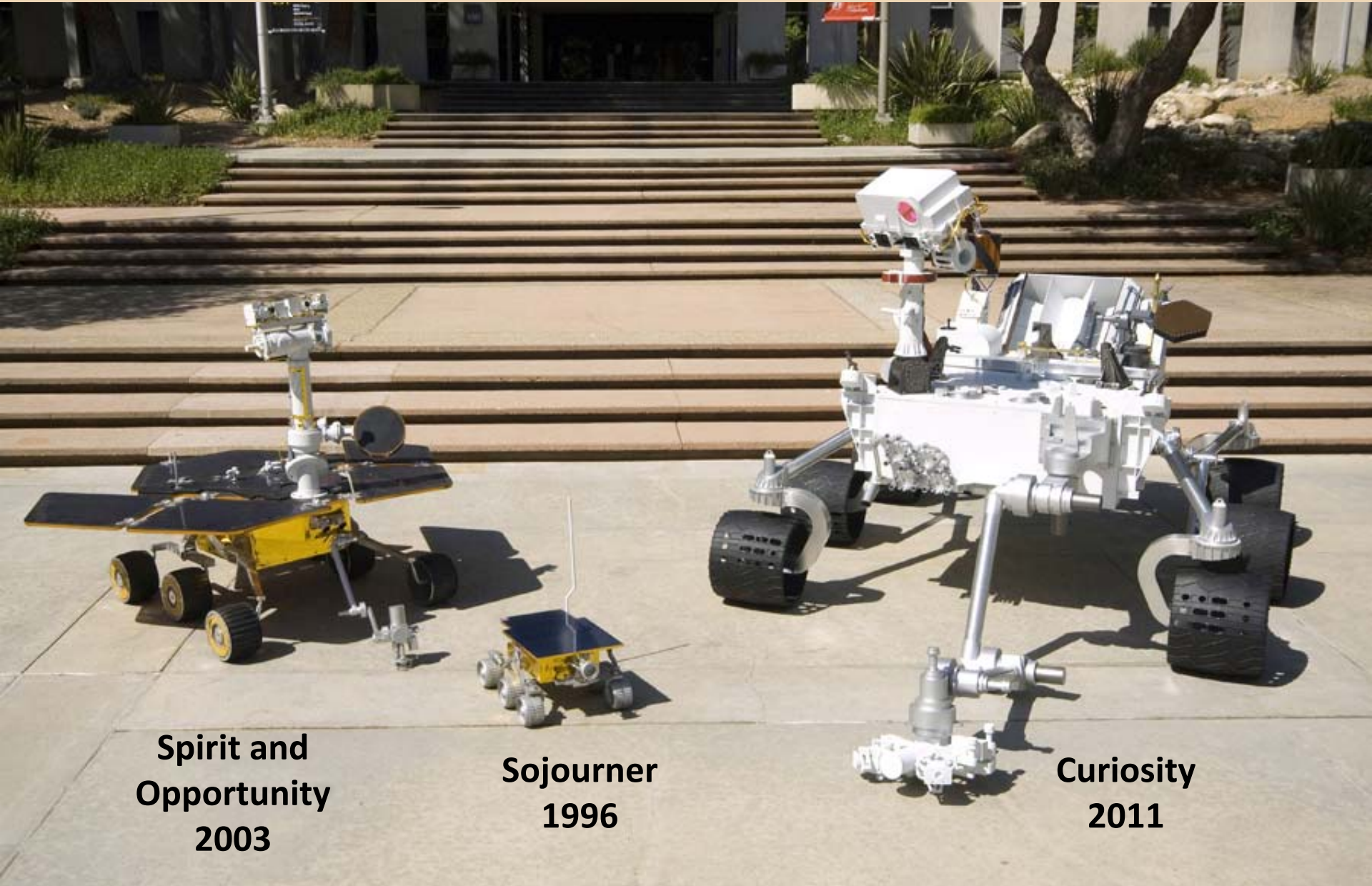


Holden Crater (26°S, 325°E, -1.9 km) has alluvial fans, flood deposits, possible lake beds, and clay-rich sediment.



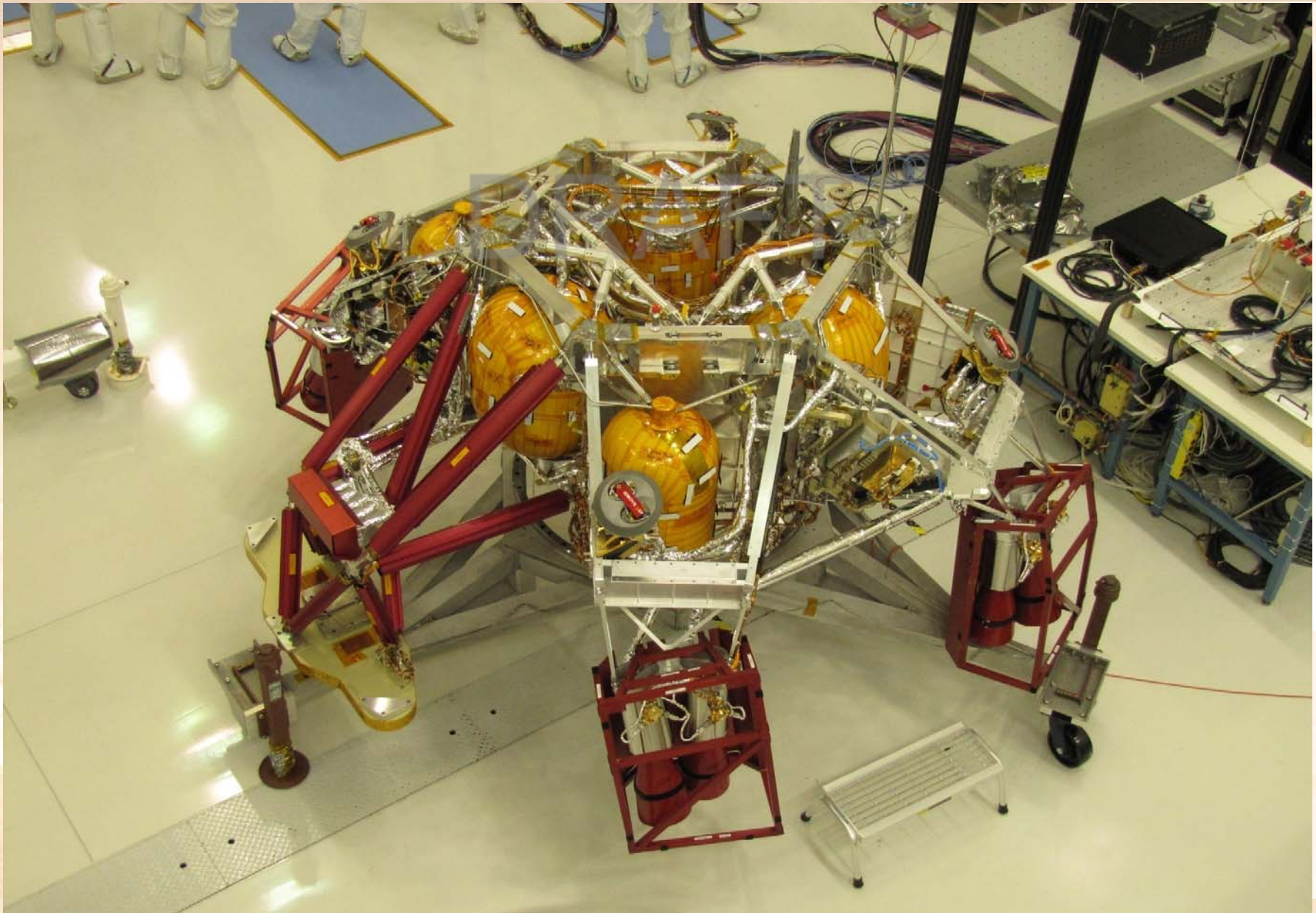
Mawrth Vallis (24°N, 341°E, -2.2 km) exposes layers within Mars' surface with differing mineralogy, including at least two kinds of clays.

Rover Family Portrait

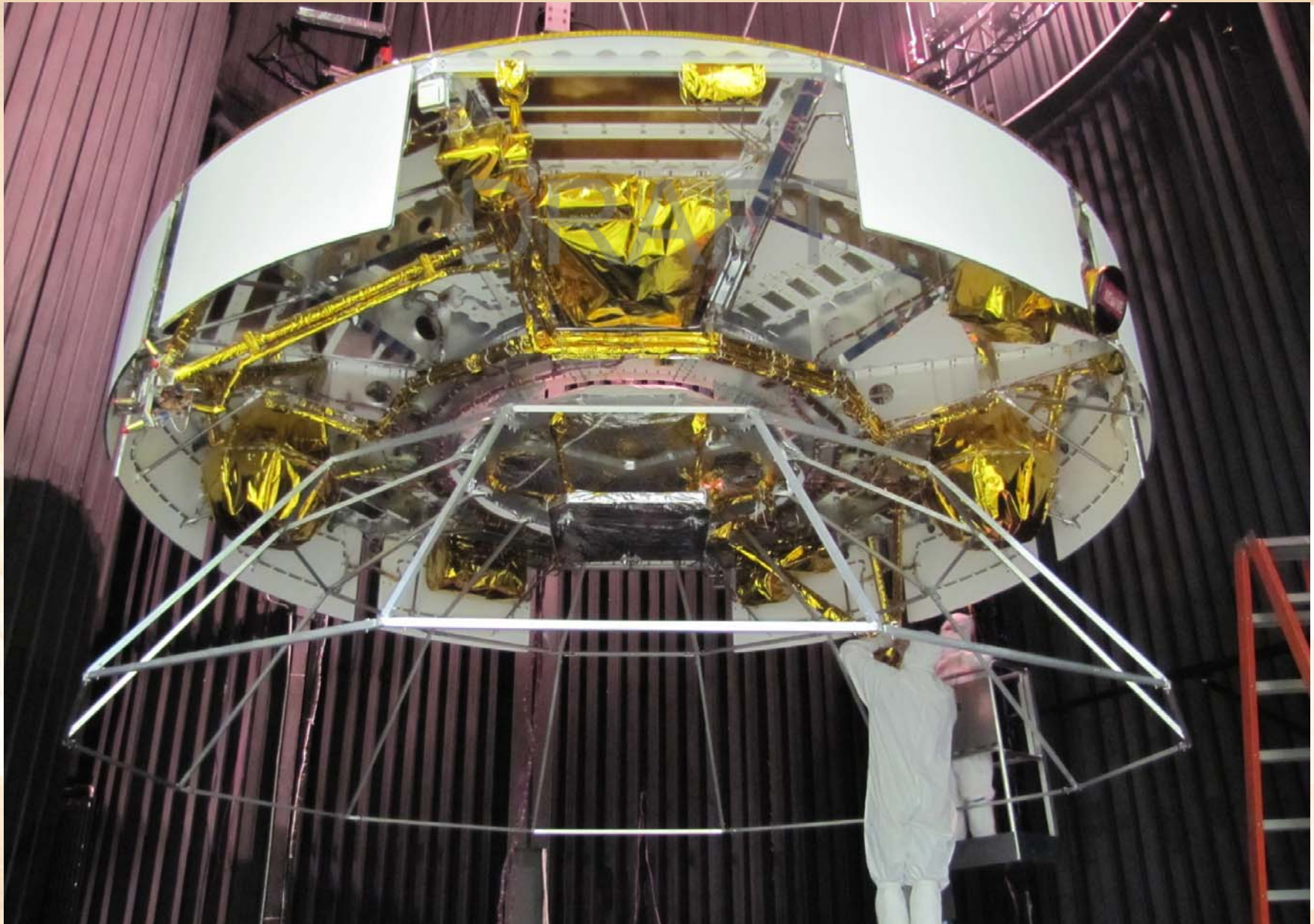


Rover Driving Test

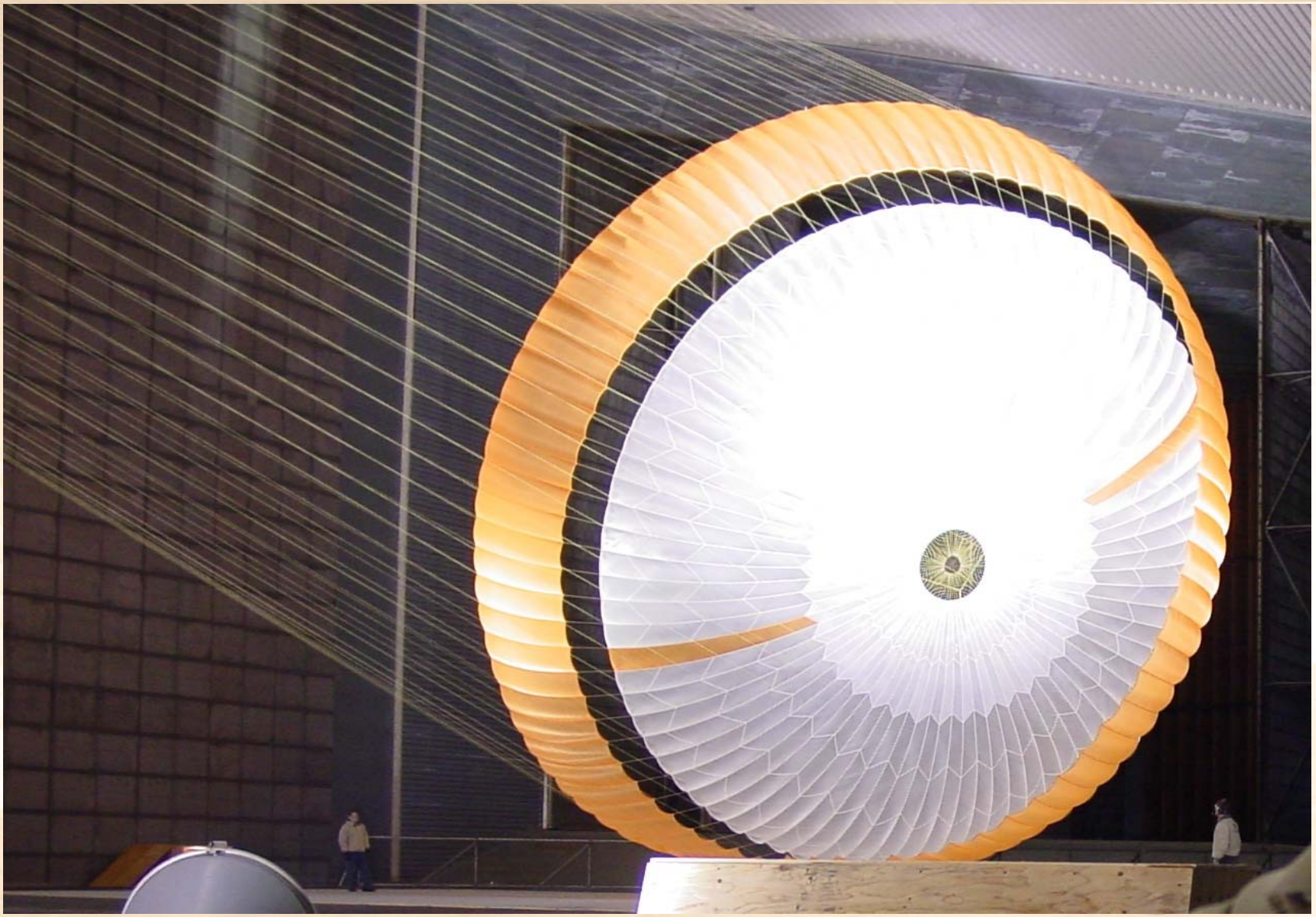
Descent Stage



Cruise Stage



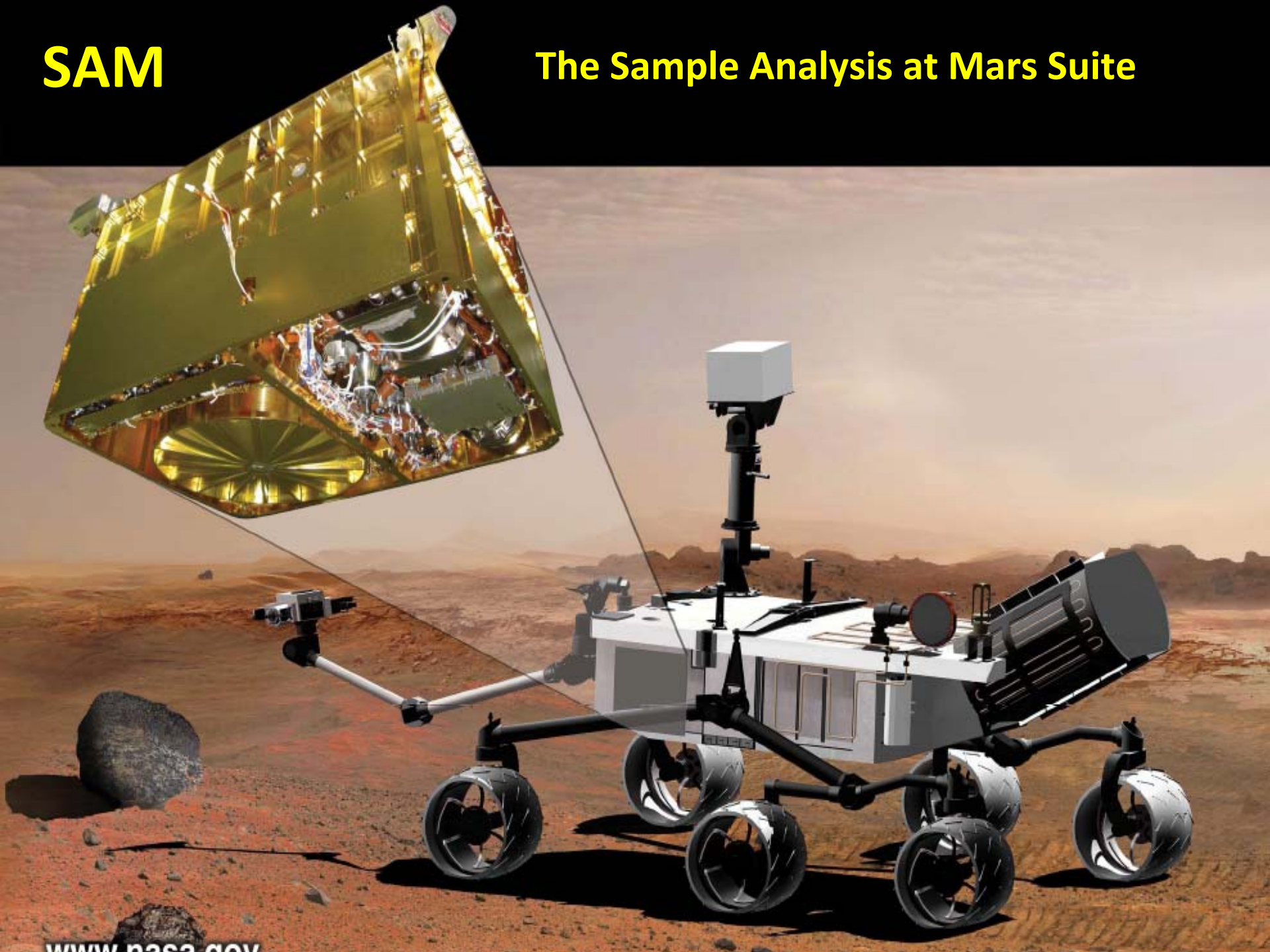
Parachute Test



Assembled Spacecraft

SAM

The Sample Analysis at Mars Suite



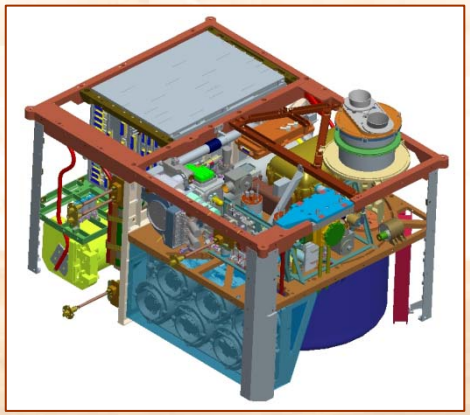
SAM – The Sample Analysis at Mars Suite

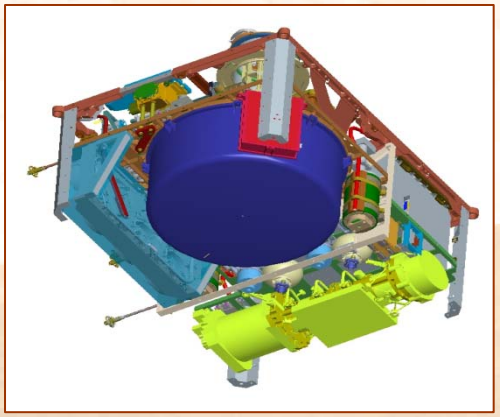
SAM is a Suite of 3 Instruments

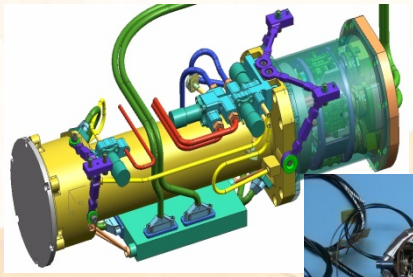
- **Quadrupole Mass Spectrometer (QMS) – Goddard Space Flight Center**
  - Molecular and isotopic composition in the 2-535 Dalton mass range for atmospheric and evolved gas samples
- **Gas Chromatograph (GC) - University of Paris, CNES**
  - Resolves complex mixtures of organics into separate components
- **Tunable Laser Spectrometer (TLS) – Jet Propulsion Laboratory**
  - Abundance and precision isotopic composition of CH_4, H_2O, and CO_2

SAM supporting subsystems

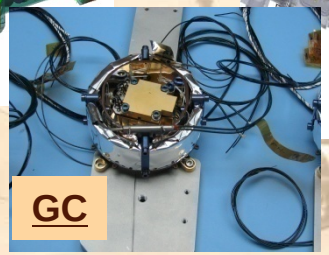
- **Gas Processing System (GPS) – Goddard Space Flight Center**
  - Includes valves, manifolds, carrier gas, enrichment cells, Wide Range Pump (WRP), and Pyrolysis Ovens
- **Sample Manipulation System (SMS) – Honeybee Robotics**
  - Positions 74 sample cups to below a sample inlet tube or into SAM pyrolysis ovens
  - 59 quartz cups, 9 derivatization cups, 6 cal cups
- **Common Infrastructure Systems – Goddard Space Flight – engineering, software etc**



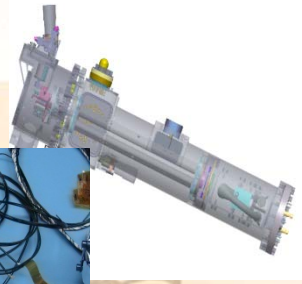




TLS



GC



QMS

SAM – Core science goals

- **GOAL #1: Explore sources and destruction paths for carbon compounds**

  → Met by measurements of the identity and abundance of **organic molecules** and their distribution of oxidation states, molecular weights, and chemical structures

- **GOAL #2: Search for organic compounds of biotic and prebiotic relevance including methane**

  → Met by measurements of:
  - **amino acids, nucleobases, carboxylic acids** by solvent extraction and chemical derivatization
  - **methane abundance** in the atmosphere & its **$^{13}C/^{12}C$ ratio** with TLS.

- **GOAL #3: Reveal chemical and isotopic state of other light elements that are important for life as we know it on Earth**

  → Met by measurement of **inorganic gases** such as SO_2, H_2O, and CO_2 evolved from solid samples

- **GOAL #4: Study habitability of Mars by atmospheric/surface interactions expressed in trace species compositions**

  → Met by measurement of
  - abundance of multiple minor and **trace atmospheric species** including those with short photochemical atmospheric lifetimes
  - **diurnal and seasonal variation of atmospheric species** such as H_2O, O_2, N_2, Ar, O_3, H_2, and CH_4

- **GOAL #5: Understand atmosphere & climate evolution through isotope measurements of noble gases & light elements**

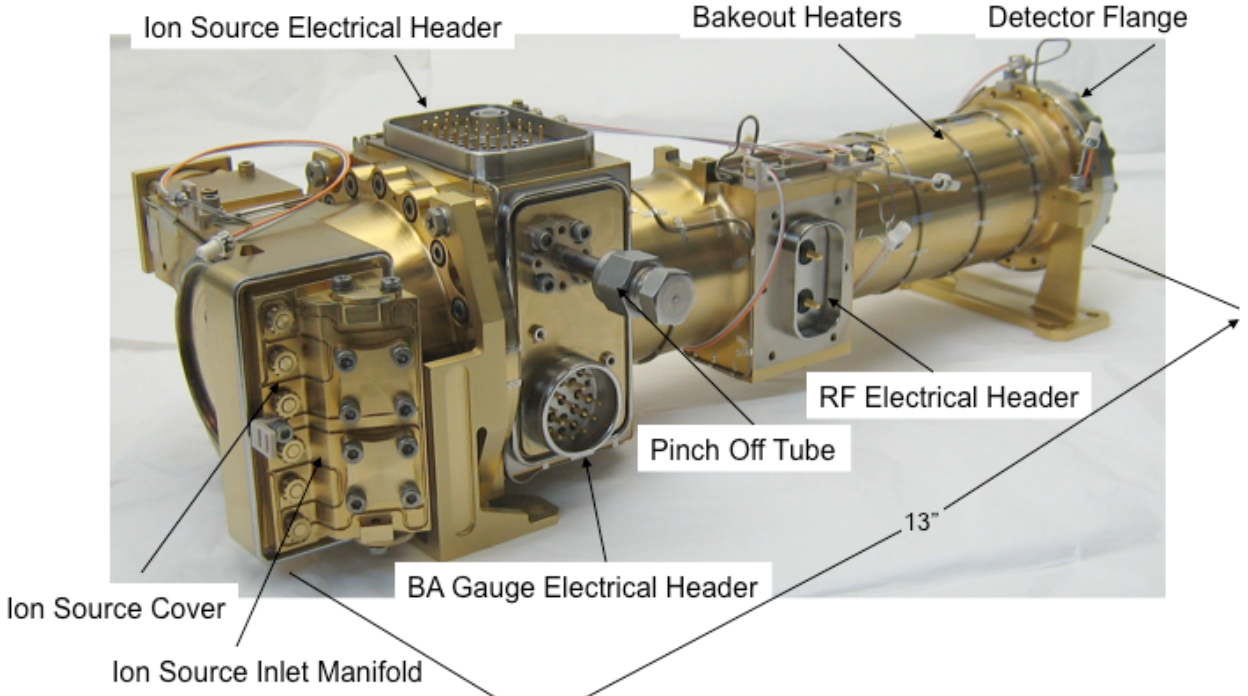
  → Met by measurement in the atmosphere and in gas evolved from fines and powdered rocks
  - **isotope ratios for noble gases**
  - **$^{13}C/^{12}C$, $^{15}N/^{14}N$, $^{18}O/^{16}O$, $^{17}O/^{16}O$, and D/H** in simple compounds

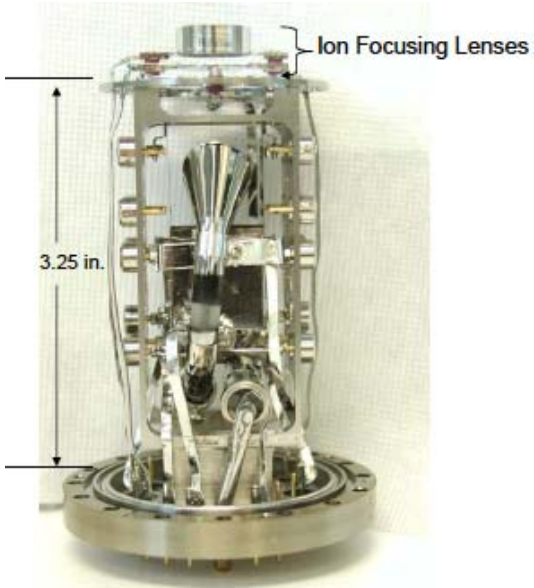
  provides a database that constrains models of atmospheric evolution and identifies reservoirs of the light elements that contribute to the present atmosphere.

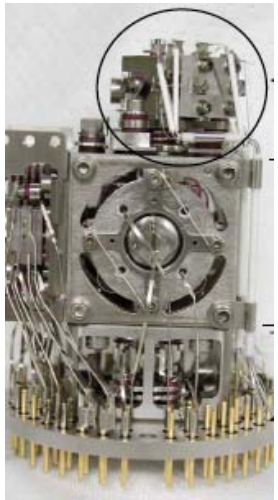
SAM Quadrupole Mass Spectrometer (QMS)

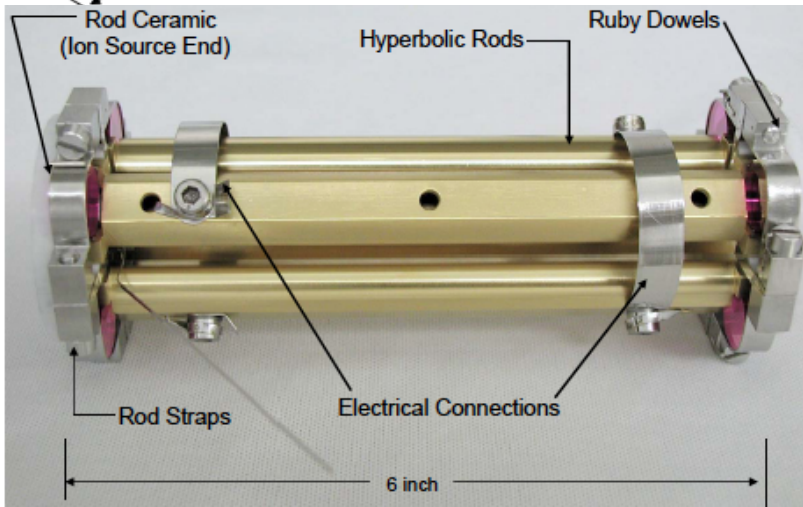
QMS characteristics

- precision assembly hyperbolic rods
- titanium alloy housing
- in situ bakeout
- 3 frequency RF
- pressurized enclosure for RF electronics
- 2-535 Da
- dual electron guns
- dual detectors
- 2 direct atmosphere inlets
- 6 gas chromatograph inlets







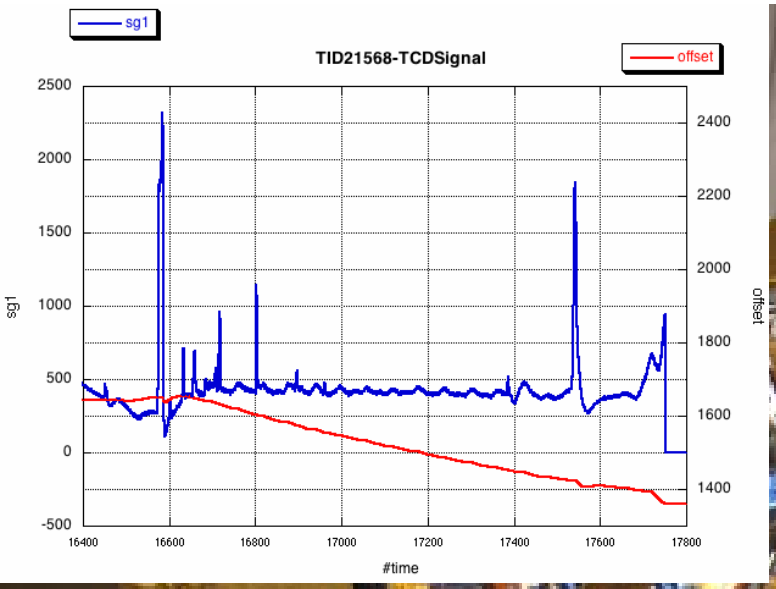


SAM Gas Chromatograph (GC)

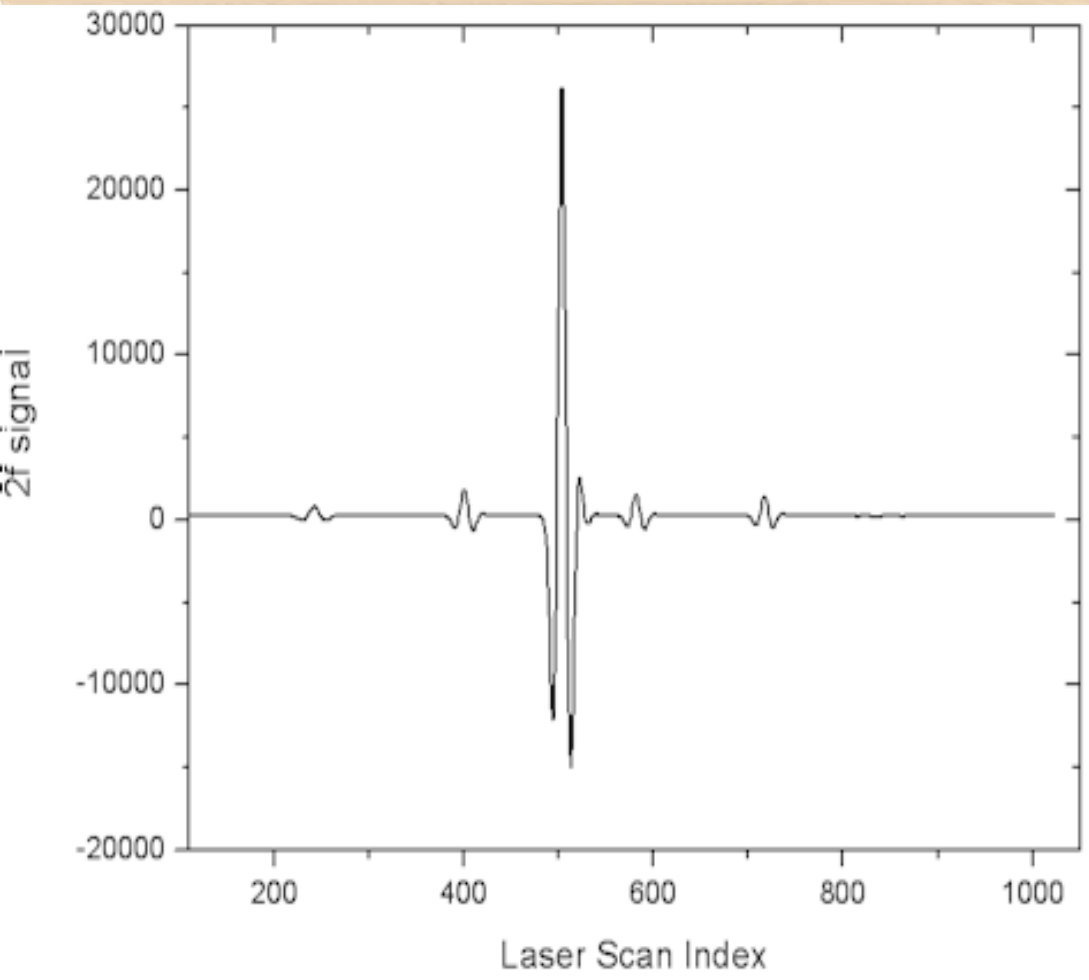
EM columns	Stationary phase	Species targeted	Stationary phase	FM columns
Carbobond (PLOT)	Carbon molecular sieve	Permanent gases C_1-C_2 HCs	Carbon molecular sieve	Carbobond (PLOT)
MXT U (PLOT)	Divinylbensene	C_1-C_4 organics NH3, S containing compounds	Divinylbenzene or substituted divinylbenzene	MXT U or Q (PLOT)
MXT 20 (WCOT)	polydimethylsiloxane with 20% of phenyl	Medium molecular weight organics (C_5-C_{15} organics)	polydimethylsiloxane with 20% of phenyl	MXT 20 (WCOT)
MXT CLP (WCOT)	polydimethylsiloxane with phenyl and cyanopropyle	Medium molecular weight organics (C_5-C_{15} organics)	polydimethylsiloxane with phenyl and cyanopropyle	MXT CLP (WCOT)
MXT 5 (WCOT)	polydimethylsiloxane with 5% of phenyl	High molecular weight VOCs including derivatives (>C_{15} organics)	polydimethylsiloxane with 5% of phenyl	MXT 5 (WCOT)
Chirasil-β Dex CB	β cyclodextrin	Enantiomers of VOCs	β cyclodextrin	Chirasil-β Dex CB

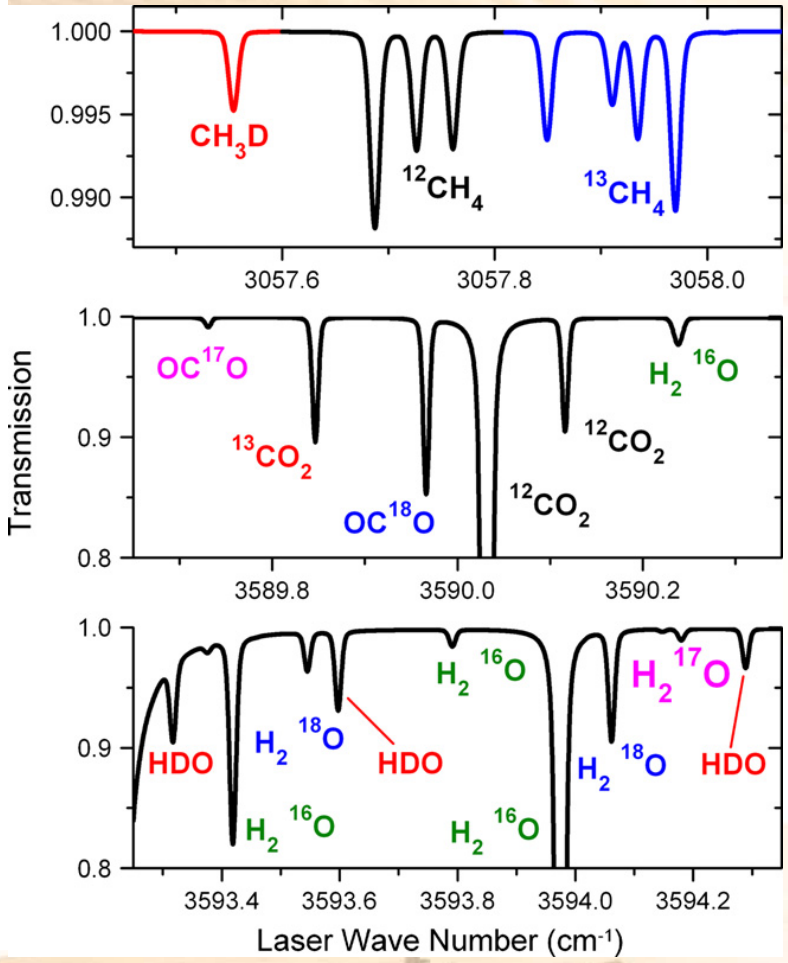
All the columns have the same dimensions (L=30 m, ID=0.25 mm and d_f=0.25 for the WCOT and 10 µm for the PLOTs)

SAM Gas Chromatograph (GC)



TLS samples 3 spectral regions



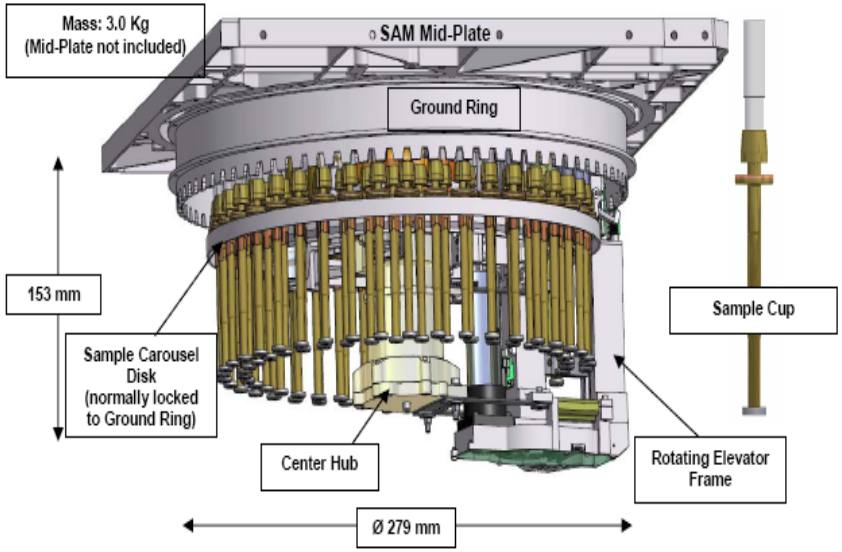


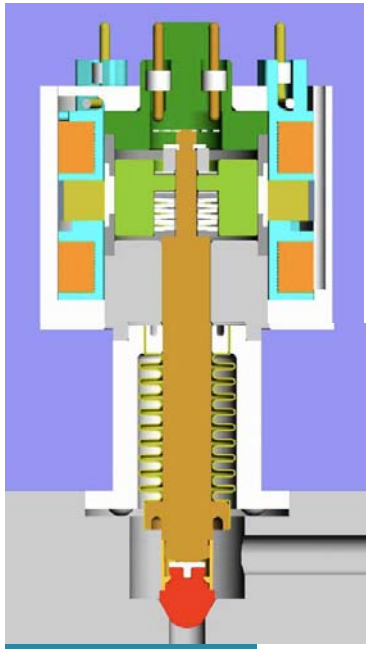
TLS spectra for CO_2 show SNR's of tens of thousands for main line

Multiple isotopes secured with two TLS IR lasers

SAM INSTRUMENT SUITE OVERVIEW

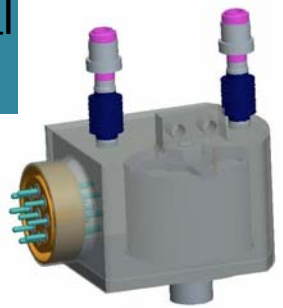
Gas and solid sample manipulation

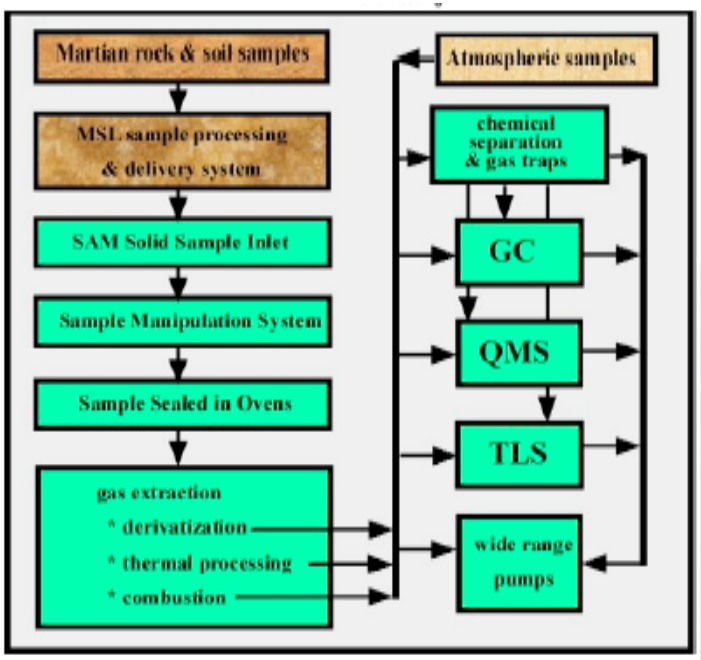




microvalve

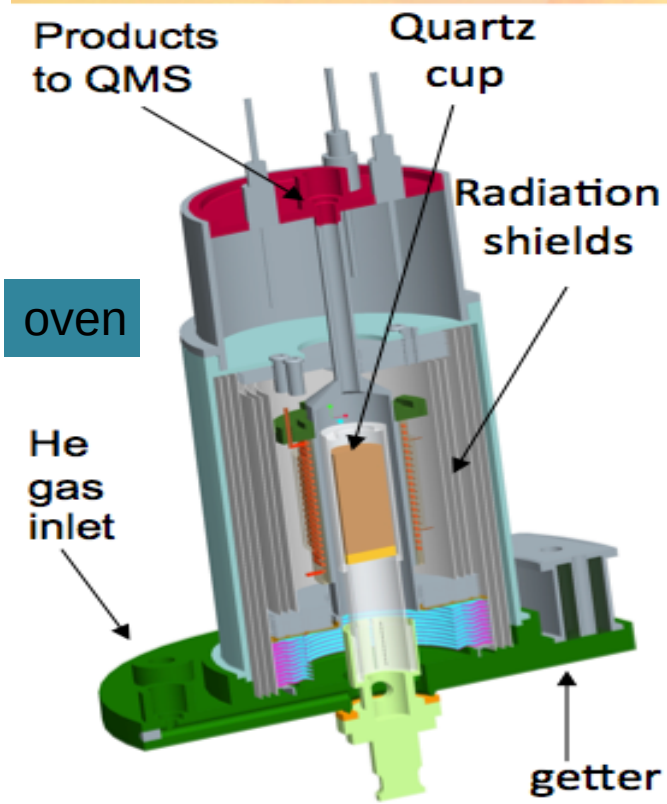
chemical getter





Sample manipulation

oven



SAM Integration

Integrated onto SAM frame and main deck

- Quadrupole Mass Spectrometer
- Tunable Laser Spectrometer
- 6 GC columns
- Sample Manipulation System
- 2 pyrolysis cells
- 16 Gas Processing System manifolds
- 2 high conductance valves
- 52 microvalves
- 51 gas line heaters
- combustion & cal gases
- 2 scrubbers and 2 getters
- hydrocarbon trap
- 2 turbomolecular pumps
- 2 He tanks pressurized to ~2000 psi
- 4 heat pipes
- electronics stack
- ~ 600 m of harness wire
- Solid Sample Inlet Tubes
- thermal shields

Sequences for surface operations

Experiment	Instruments	Frequency
Pyrolysis with preconditioning	QMS, GC, TLS	Science driven
Derivatization	QMS, GC (SMS)	Science driven
Combustion	QMS, TLS	Science driven
Atmospheric Sampling (direct)	QMS, TLS	Once per month
Atmospheric Sampling w/ Enrichment	QMS, TLS	Once per month
Atmospheric Methane Enrichment	TLS	Science driven
Atmospheric Noble Gas Enrichment	QMS	Multiple times during mission
Solid Sample Calibration	QMS, GC, TLS	6 month intervals or as needed
Calibration Gas Sampling	QMS, TLS, GC	Once a month or as needed
Clean-up	QMS, TLS	As needed

Calibration expts Solid Sample expts Gas expts

Core sequences exercised during environmental tests

- pyrolysis with preconditioning
- atmospheric sampling

SAM post-integration calibration

Post-integration calibration data

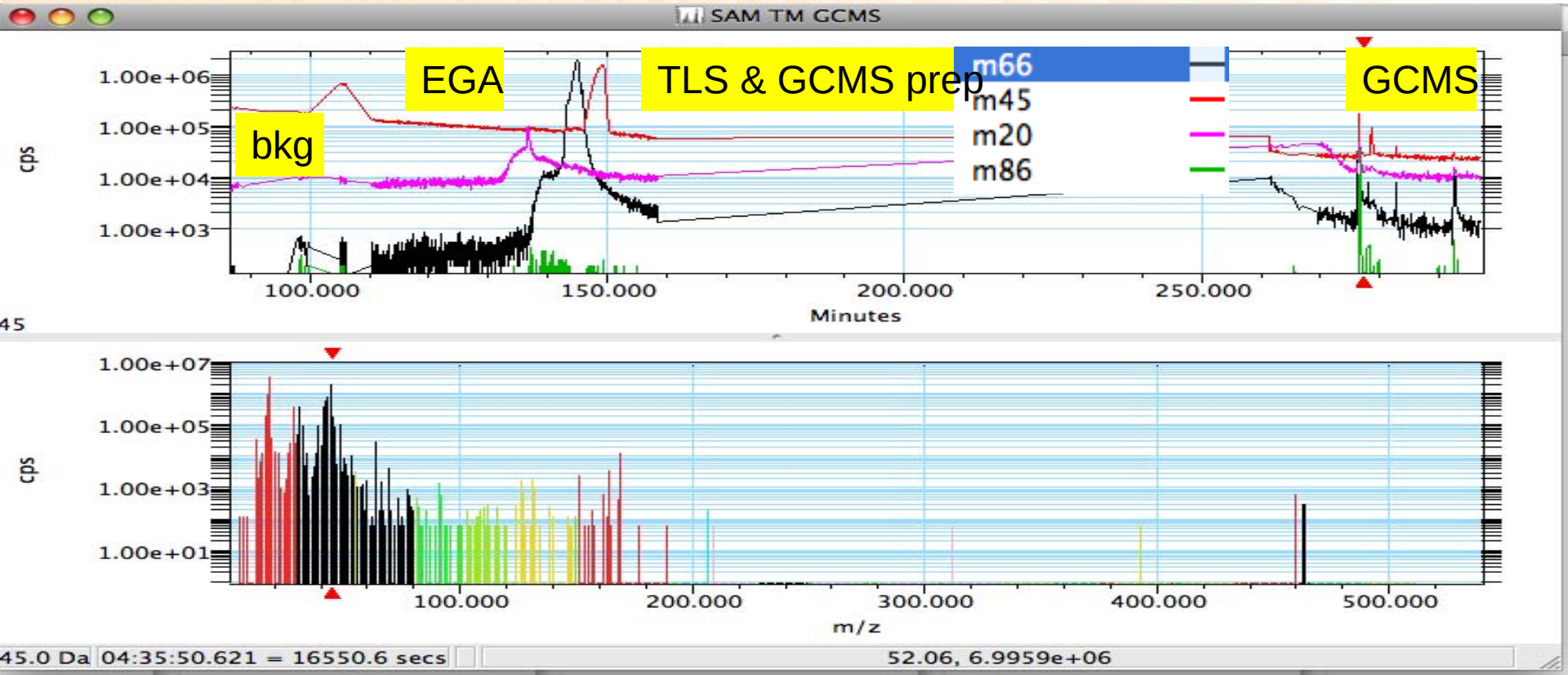
- calibration carried out in conjunction with environmental tests
- SAM in environmental chamber at Mars P CO_2
- over range of SAM temperatures in Mars environment repeated
  - ✓ direct atmospheric sequence
  - ✓ pyrolysis, GCMS, TLS sequence

In SMS cup

- calcite
- heptahydrate melanterite

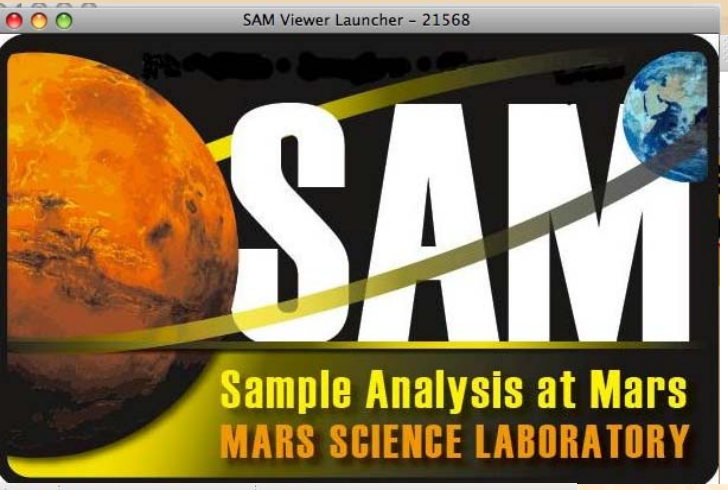
In SAM trap

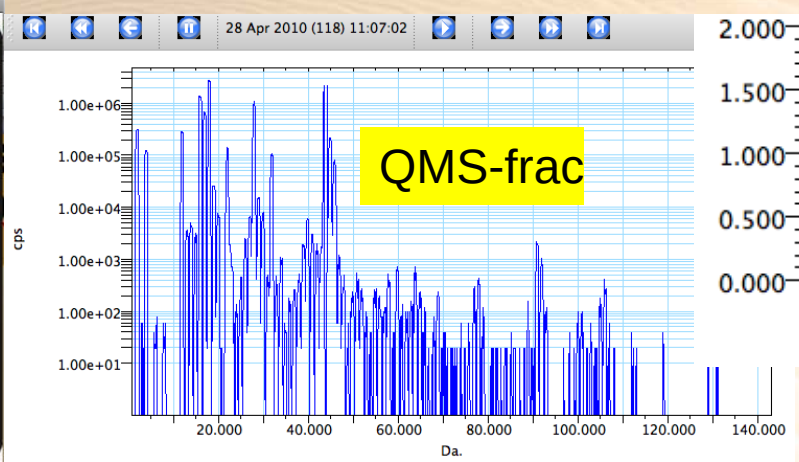
- perfluorotributlyamine
- 4 simple hydrocarbons (butane, pentane, hexane, benzene)

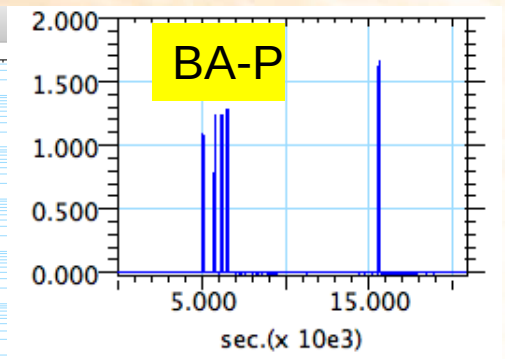


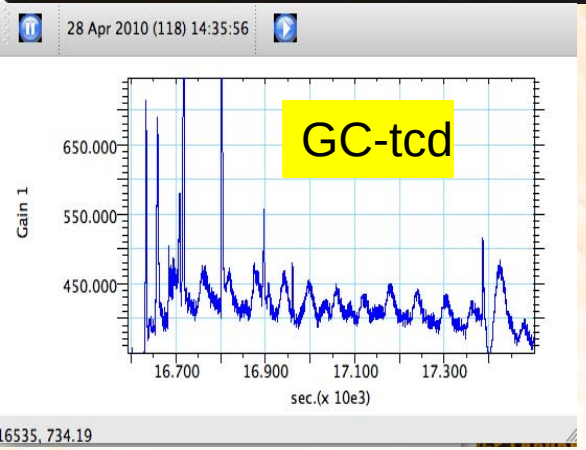
SAM calibration in Mars chamber

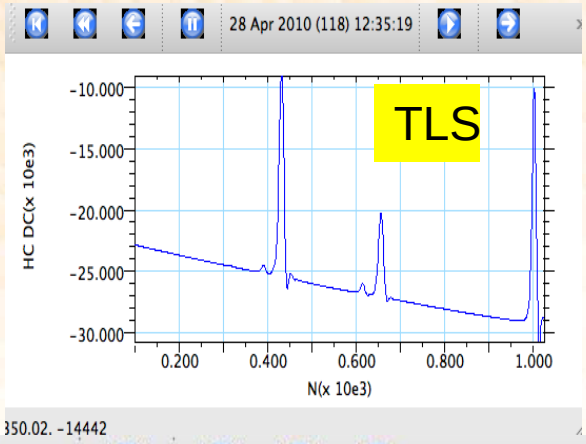
SAM calibration Dataviewer for all HK & science data

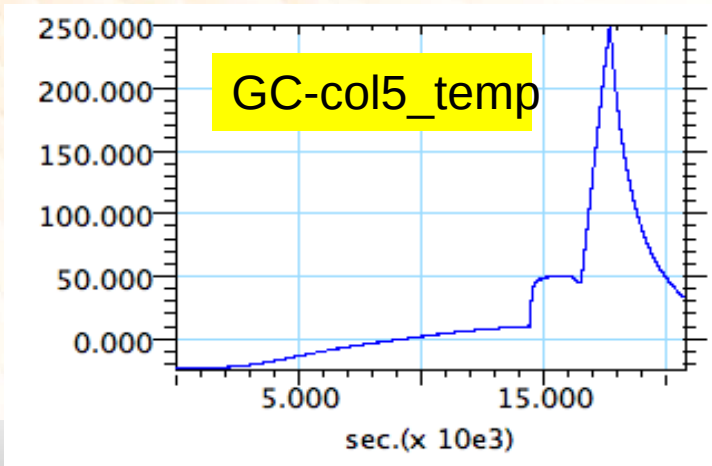










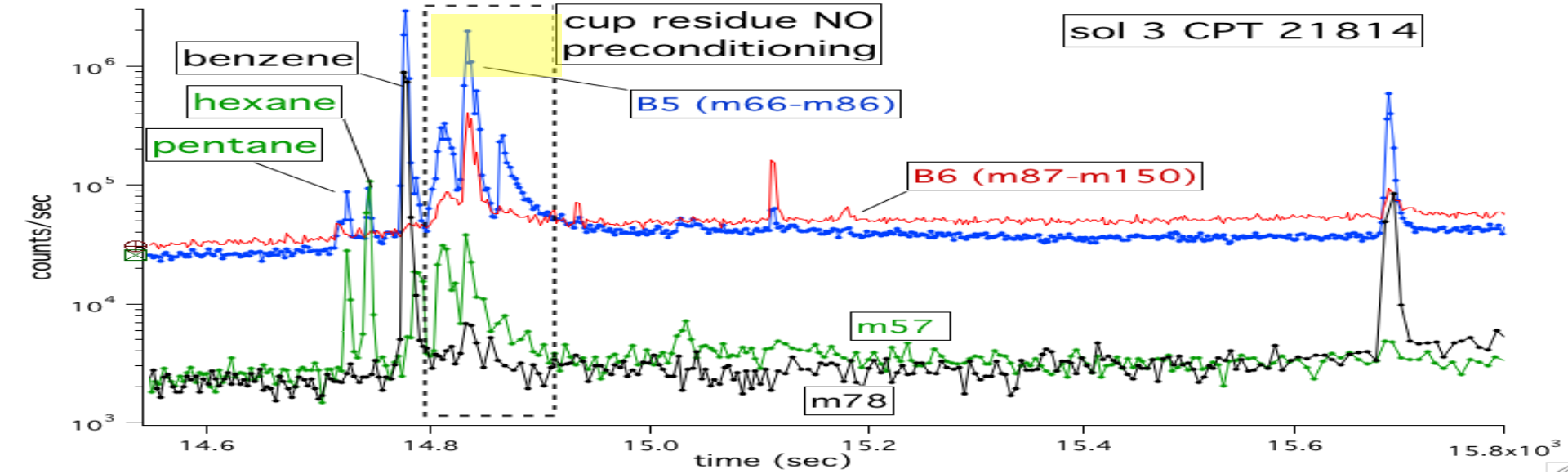


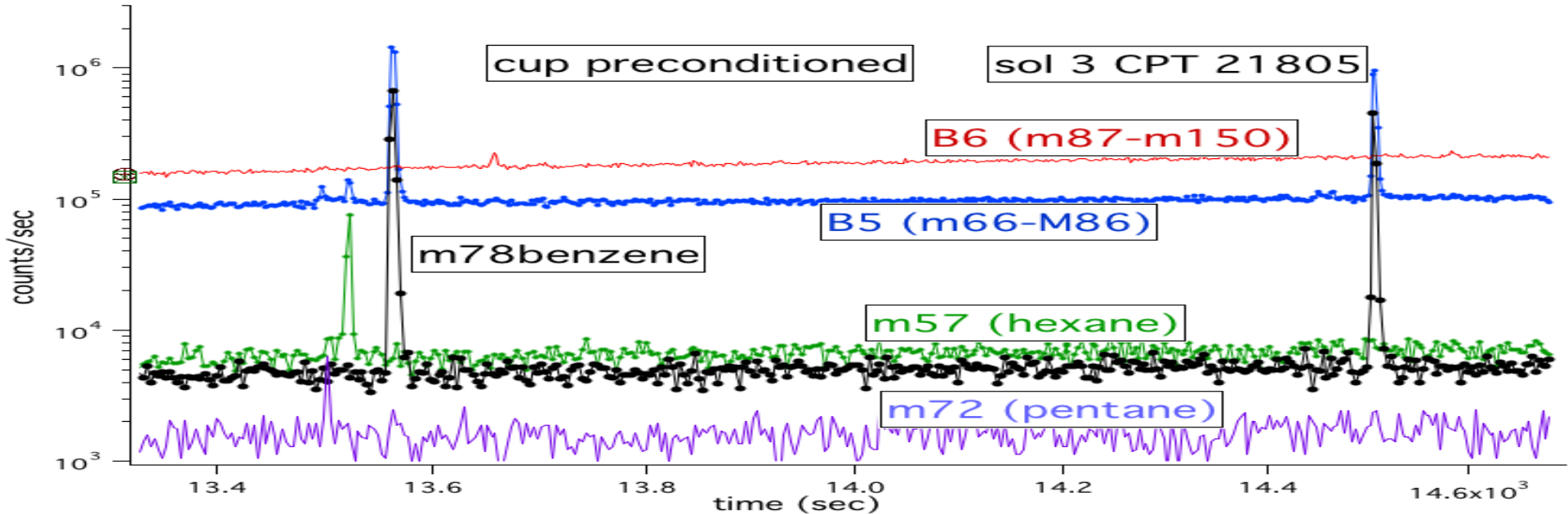
28 Apr 2010 (118) 15:24:52

ANODE1_Imon_-7	0.0023	ANODE2_Imon_14	0.0093	BA_Grid_Imon	-0.0624	BS_Lens_(RF-9)	-0.3622	EA_1_Imon_AF-6	0.0107	EF1A_Imon_AF-2	-0.0150
EF1B_Imon_AF-3	0.0027	EF1C_Imon_AF-4	-0.0027	EF1D_Imon_AF-5	0.0006	EF2A_Imon_AF-9	-0.0003	EF2B_Imon_AF10	0.0003	EF2C_Imon_AF11	0.0026
EF2D_Imon_AF12	0.0069	EL_(R_Fix-8)	-0.0195	FIL1_Emon	0.0006	FIL2_EMON	0.0006	FIL_BA_Emon	0.0012	FS_1_Imon_AF-1	-0.0044
FS_2_Imon_AF-8	0.0034	GND_Ref	0.0003	I_ACC_Imon	-0.2206	IFA_Imon	-0.8575	IFB_(R_Fix-2)	-0.3329	IFC_(R_Fix-1)	-0.2966
Ion_Rep_Imon	0.0784	MASK_II_(RF-7)	-0.0455	MASK_I__(RF-6)	0.0009	WINDOW_Vmon	0.2382	Nozzle_Vmon	0.0044		

SAM test, qualification, and calibration

SOL 3 run with and without cup preconditioning gives residual contamination level in SMS

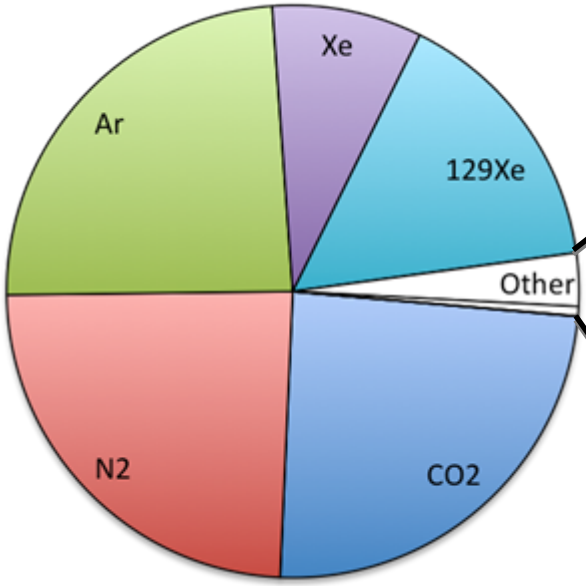




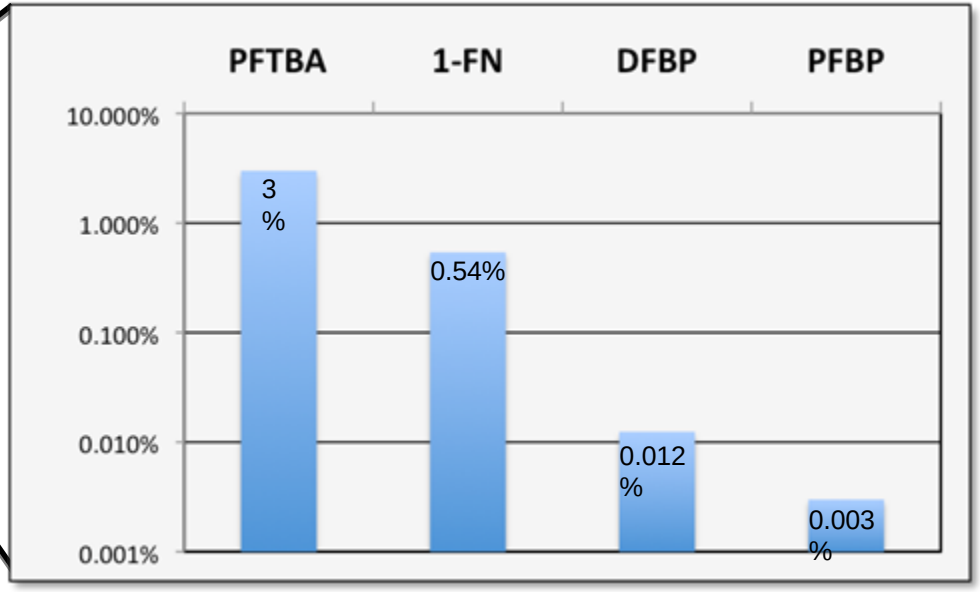
SAM Gas Calibration Cell - Composition

- Strong contrast to Mars composition
- Xe strongly enriched in ^{129}Xe to contrast with Mars Xe
- Mole fraction of calibration fluoro compounds in gas phase in cell set by cell temperature

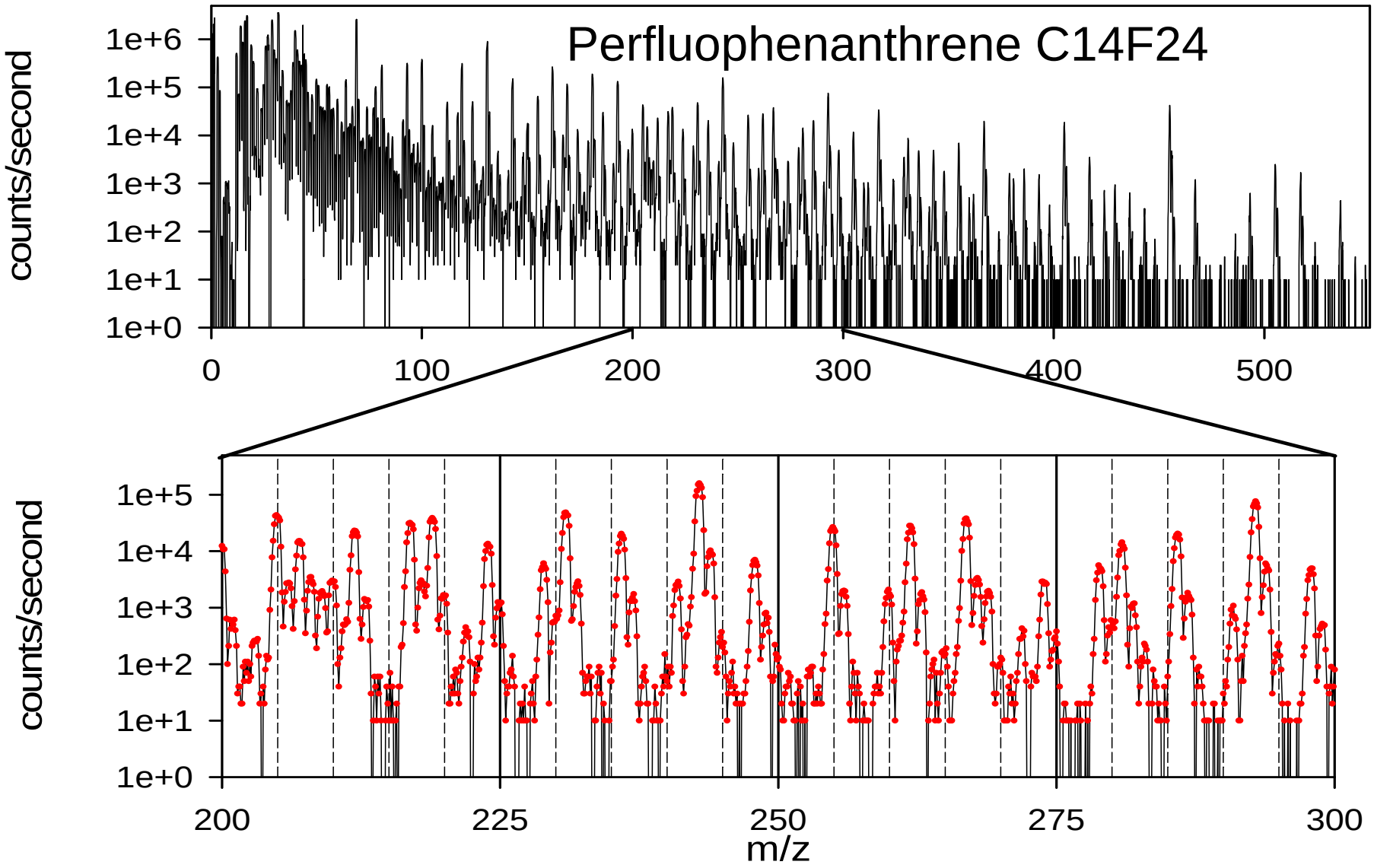
Total Composition
(Mole Fraction)



Mole fractions for higher-molecular-weight, calibration compounds

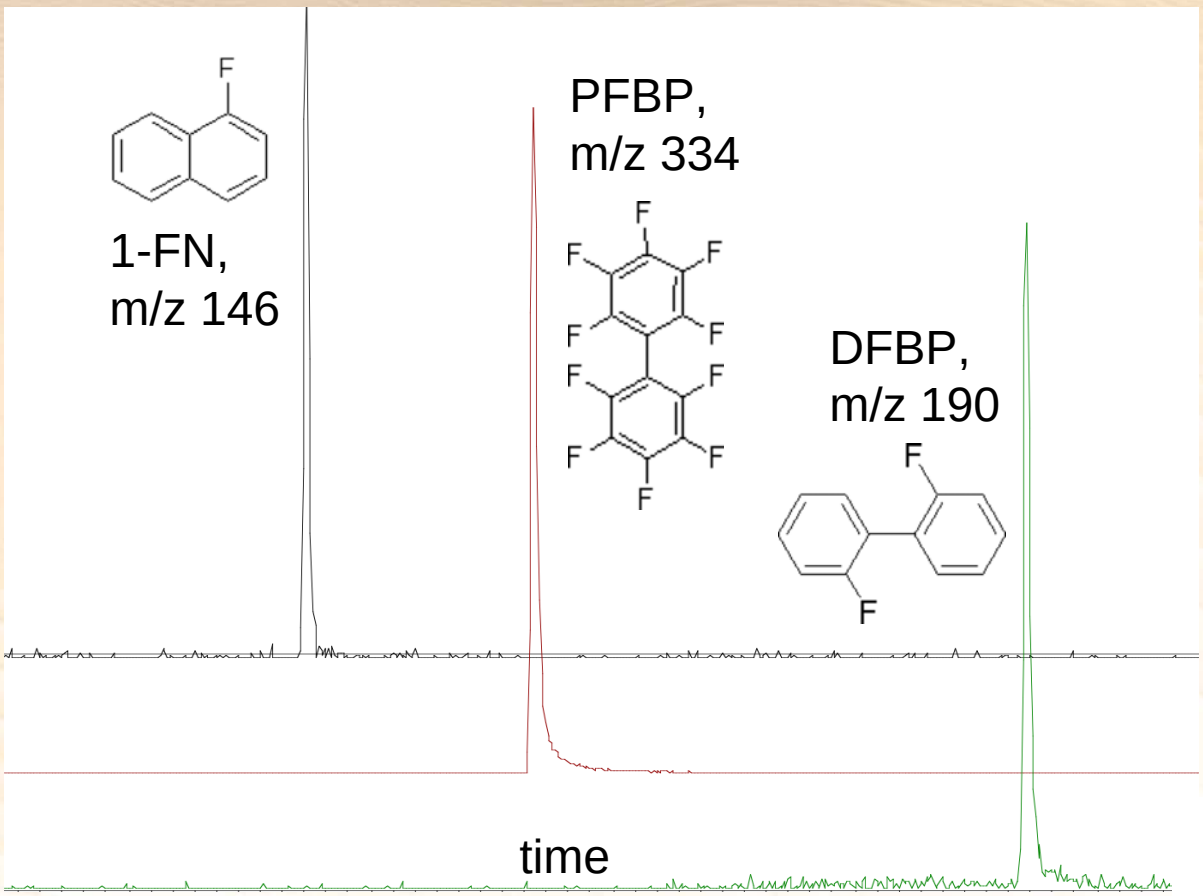


SAM QMS performance



SAM test, qualification, and calibration

During calibration in the Mars chamber a simple hydrocarbon mixture was utilized in addition to heavier fluorocarbons that we would never mistake as Martian



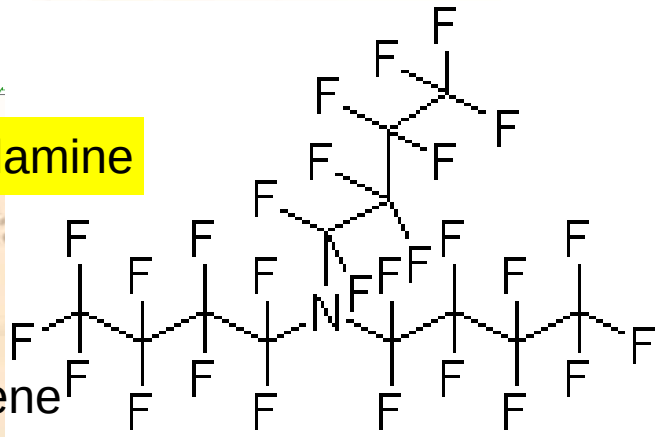
1-FN: 1- fluoronaphthalene
PFBP: perfluorobiphenyl
DFBP: 2,2-difluorobiphenyl

The four fluorocarbons shown are included together with CO_2, Ar, and a ^{129}Xe spiked xenon mix in the SAM flight calibration cell.

Use of these gases on Mars can serve as an internal check on SAM performance.

The organic check material will include 2 fluorocarbons adsorbed on an inert silica glass that is sampled by the

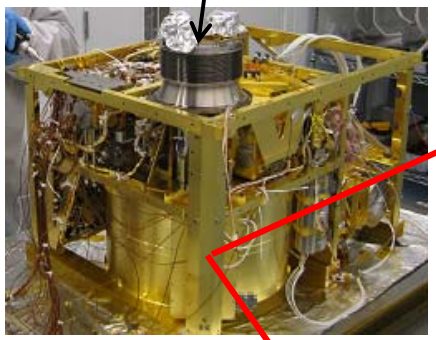
perfluorotributylamine



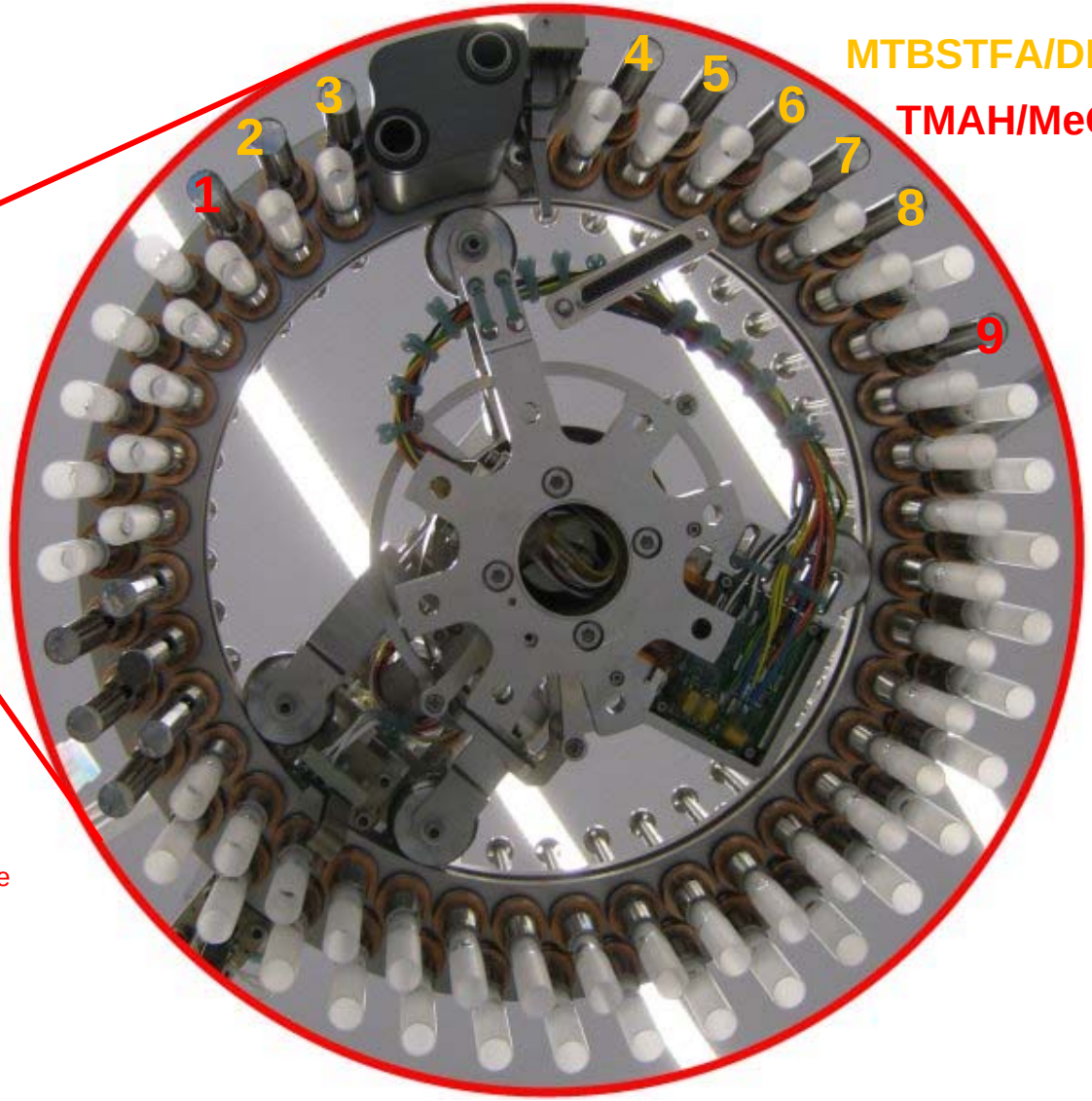
Simple HC mix = ppt butane, pentane, hexane, & benzene

SAM Derivatization Experiment

Solid Sample Inlet Tube
(~ 0.5 g soil dropped to cup)



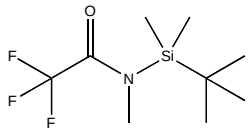
Sample Carousel (74 cups total, 9 derivatization)



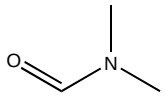
MTBSTFA/DMF (7 cups)

TMAH/MeOH (2 cups)

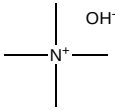
MTBSTFA: N-(*tert*-butyldimethylsilyl)-N-methyltrifluoroacetamide



DMF: Dimethylformamide



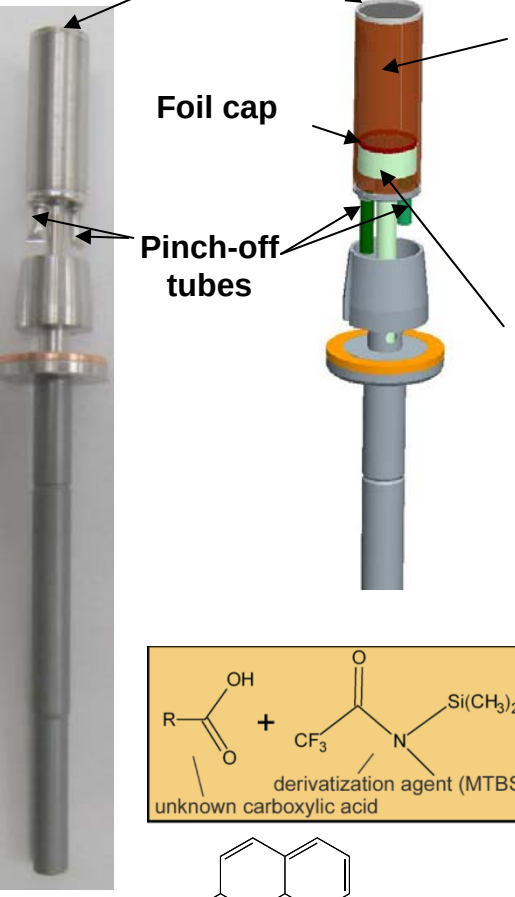
TMAH: Tetramethylammonium hydroxide



MeOH: Methanol

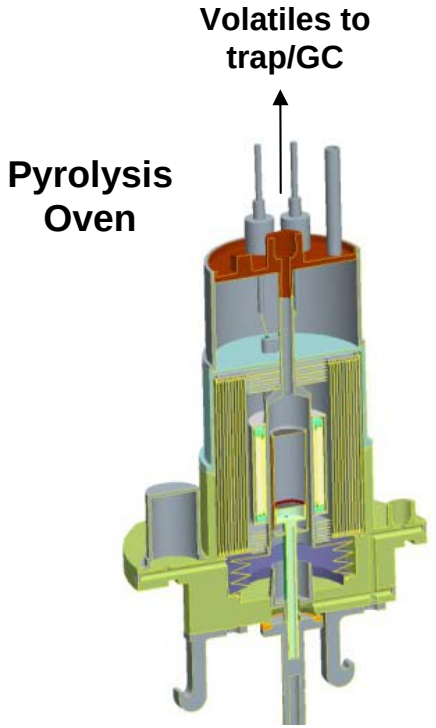
Derivatization Chemistry

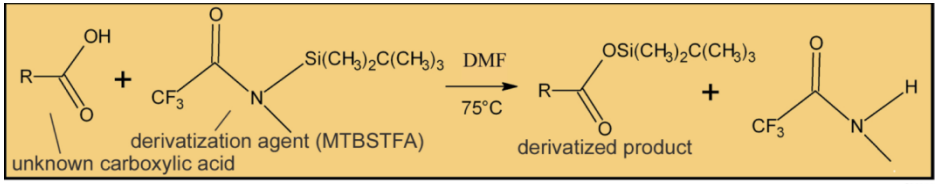
Contents of Derivatization Cups:

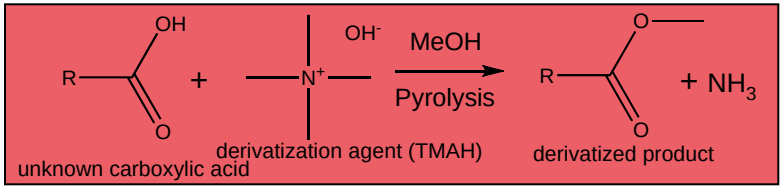


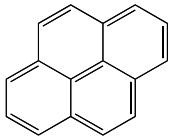
Outer volume:
0.5 ml MTBSTFA/DMF (4:1) or TMAH/MeOH (1:3)
25 nmol pyrene (in solution)
Solvent degassed by 3 freeze-pump-thaw cycles

Inner volume (Internal standard):
40 nmol 3-Fluoro-DL-valine (MTBSTFA) or 13 nmol Nonanoic acid (TMAH)

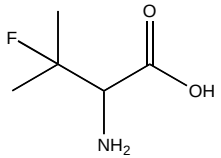




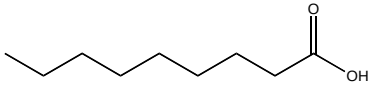




pyrene



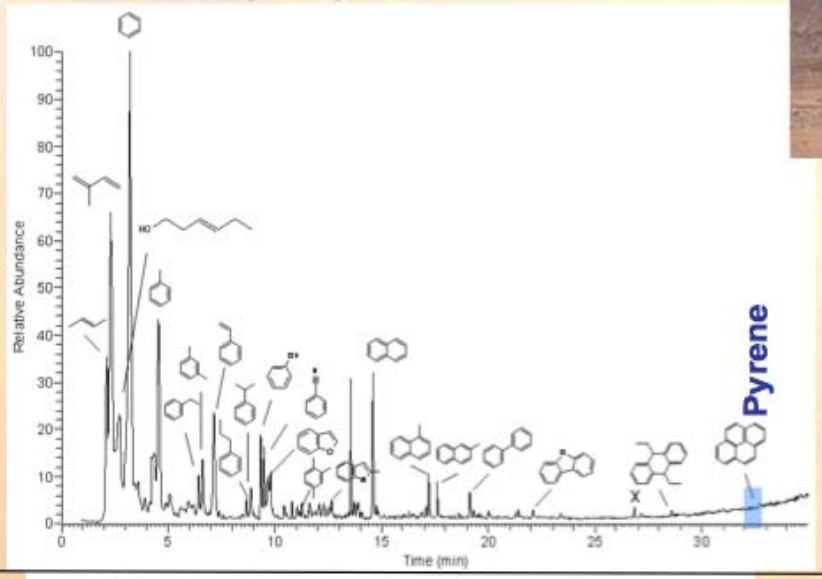
3-Fluoro-DL-valine



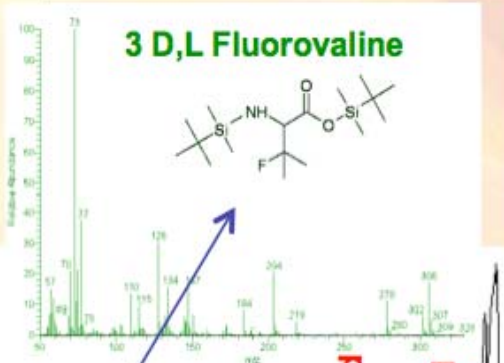
Nonanoic acid

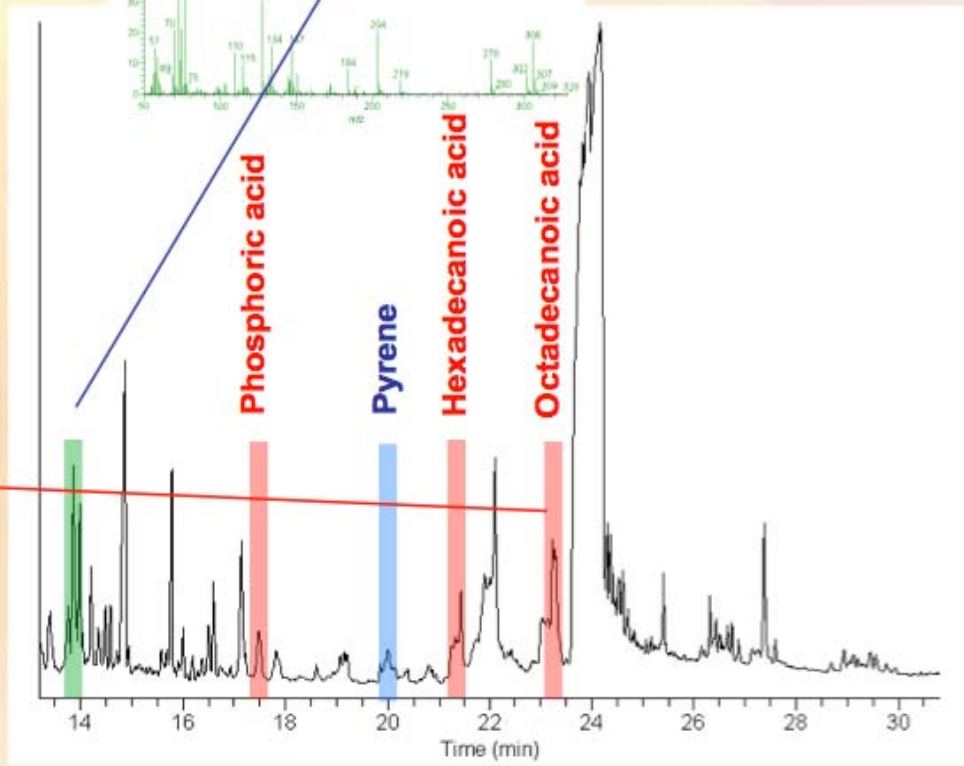
Analog derivatization sample – Atacama soil

Inert Pyrolysis

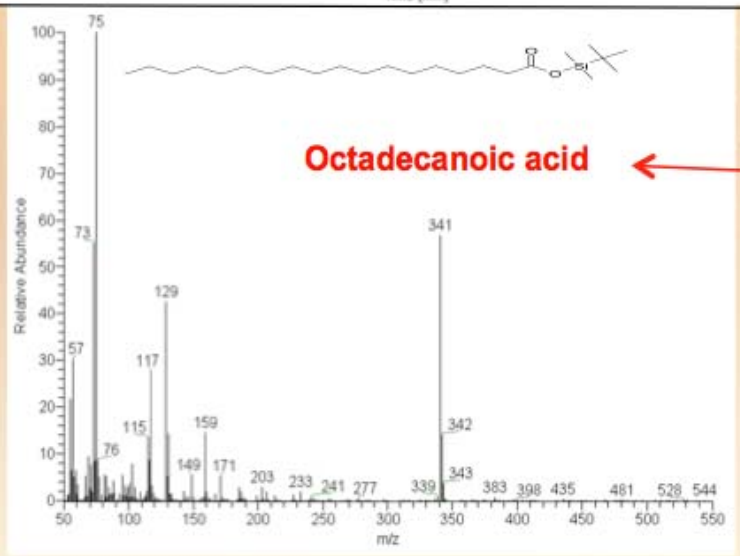


MTBSTFA Derivatization





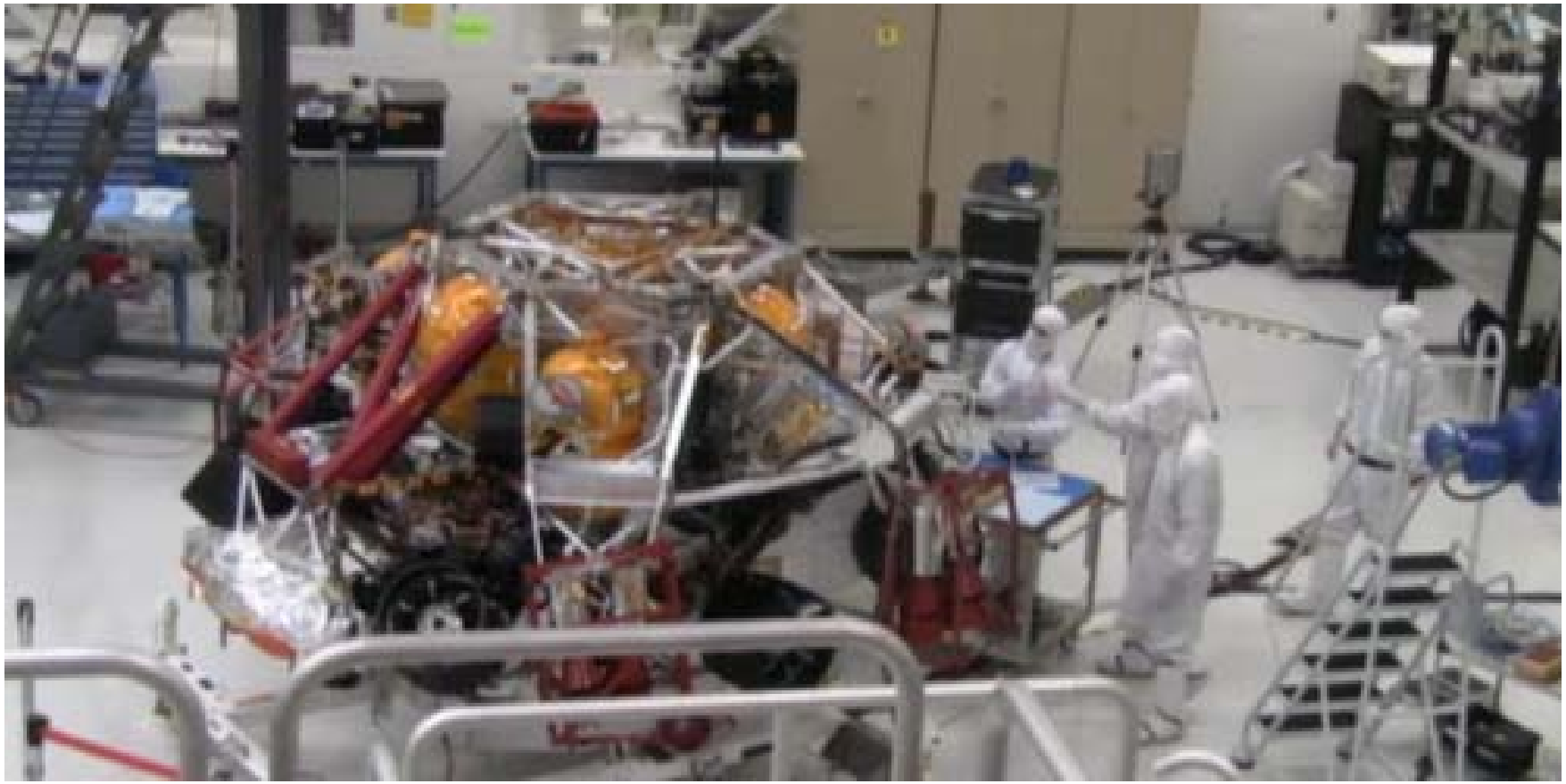
Octadecanoic acid



Fast Motion Field Test – June/July 2011

Follow Curiosity on its way to Mars

http://www.ustream.tv/nasajpl live webcam



http://mars.jpl.nasa.gov/msl