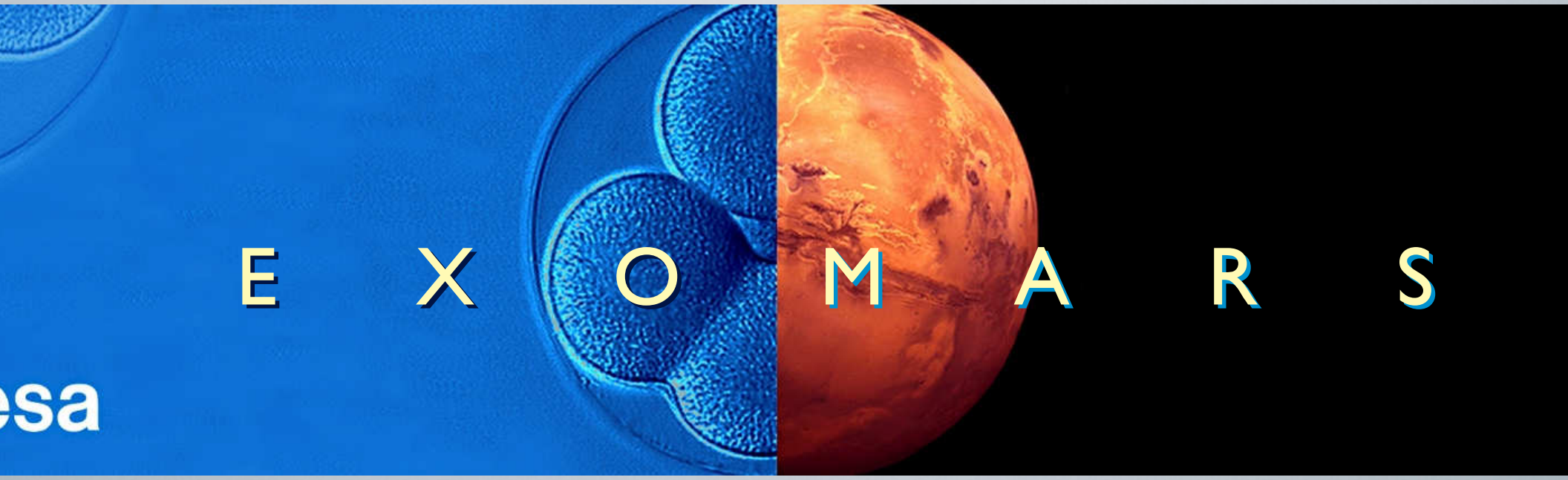

The ESA/NASA ExoMars Programme

MARCELLO CORADINI

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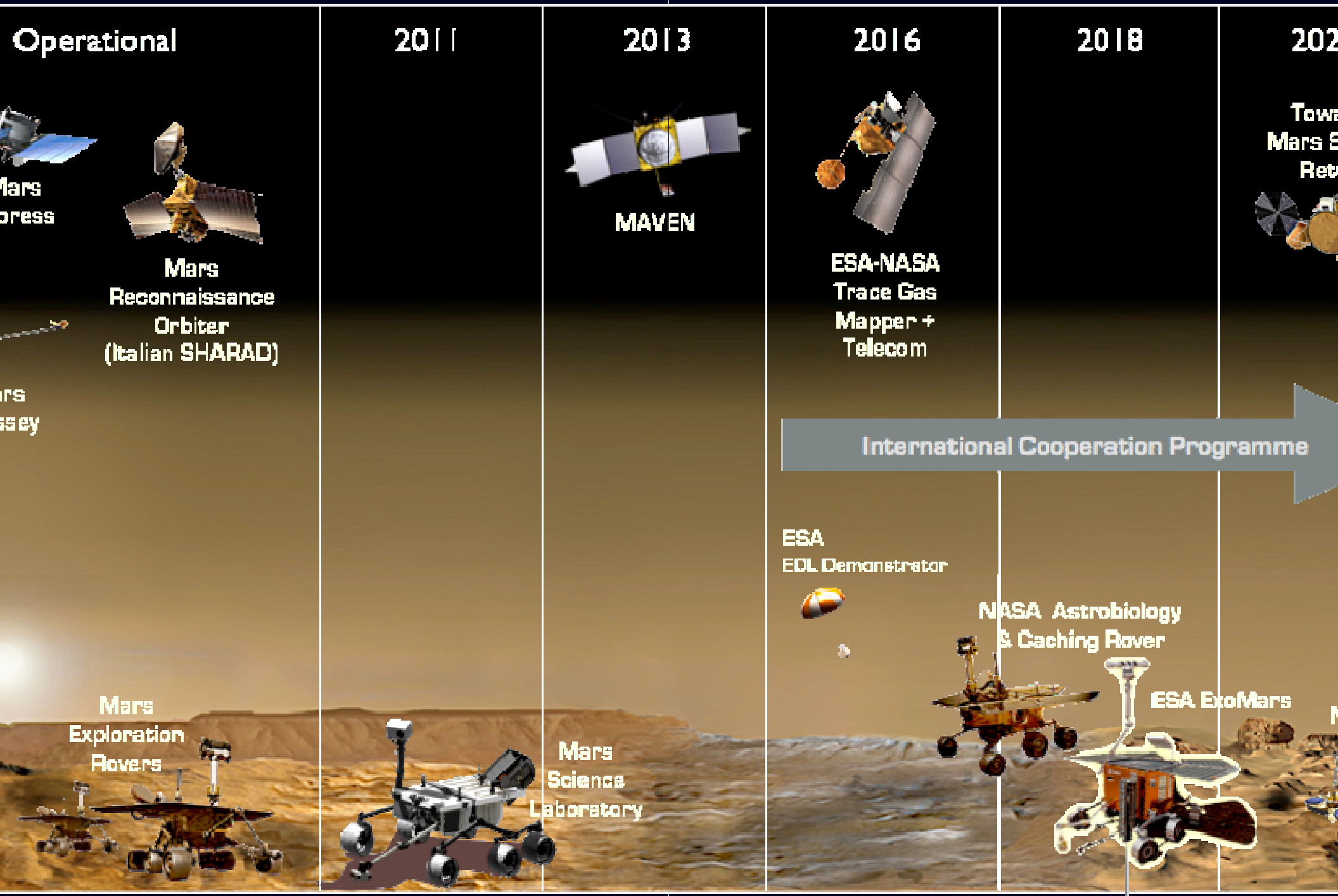
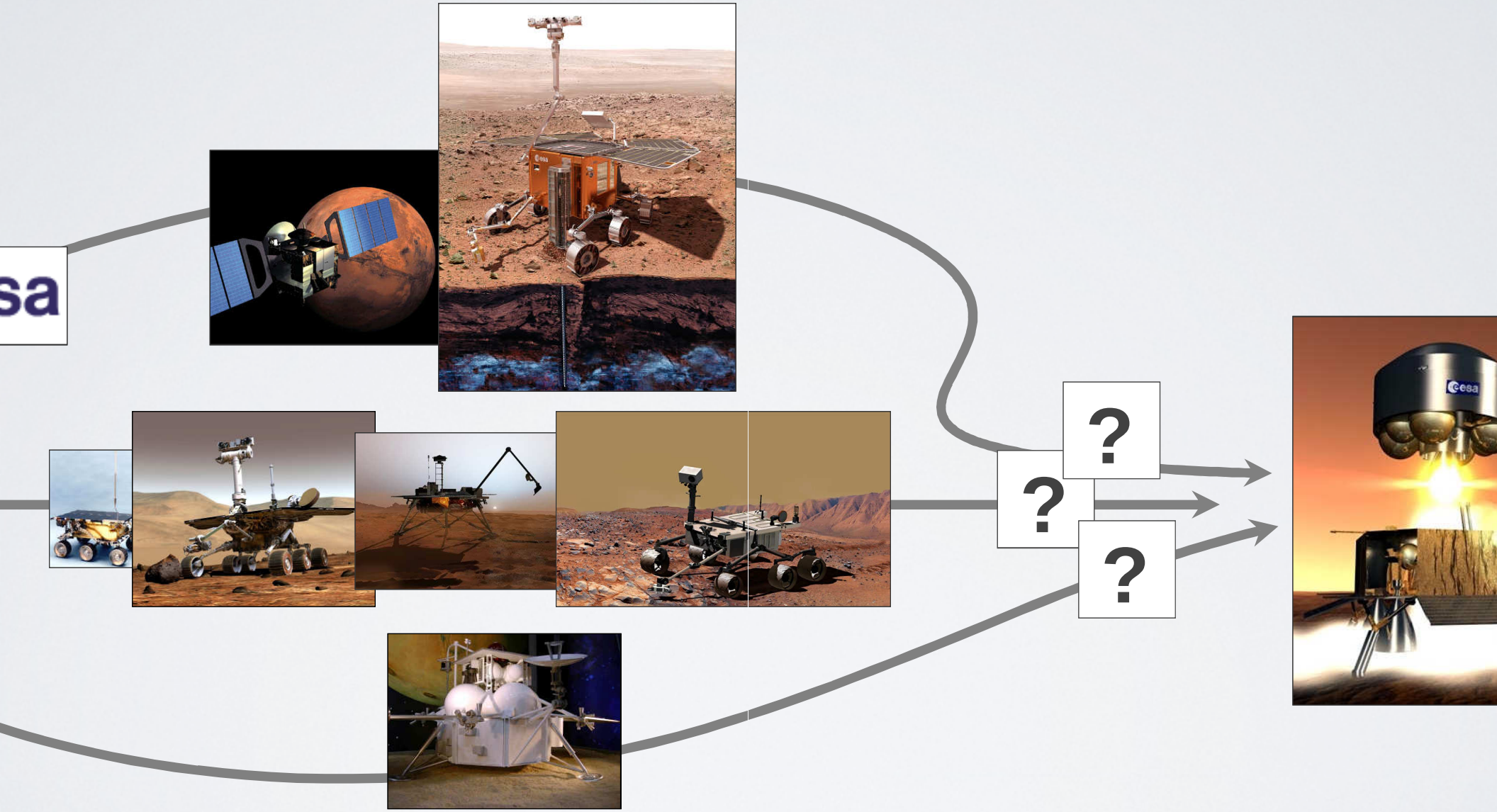


MSL: powerful rover; large 2-D mobility.

➢ **ExoMars:** next-generation instruments; 3-D access.

ecognising that a Mars Sample Return (MSR) mission is very challenging, and that
undertaking will likely exceed the financial capabilities of any one agency,

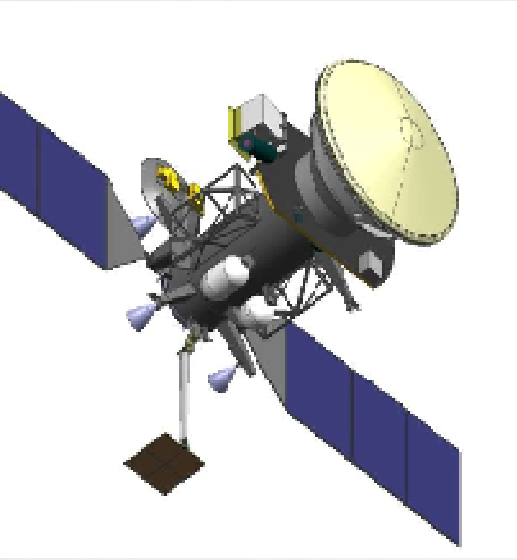


and NASA have agreed to embark on a joint Mars robotic exploration programme:

lly, seek agreement on mission configurations for 2016, 2018, and 2020 opportunities;

Mars becomes a key element of the 2016 and 2018 scenario;

Mars spreads its objectives over two opportunities.

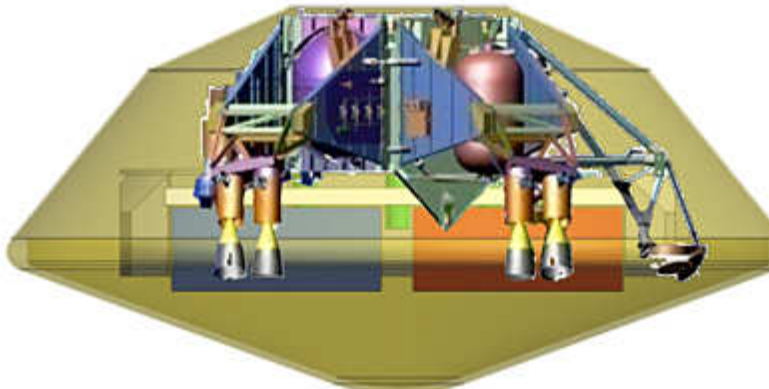


2016 — ESA-led mission

Launcher:	NASA – Atlas V 421
Orbiter:	ESA
Payload:	ESA-NASA
Lander:	ESA

2018 — NASA-led mission

Launcher:	NASA – Atlas V 531
Cruise & EDL:	NASA
Rover 1:	ESA
Rover 2:	NASA



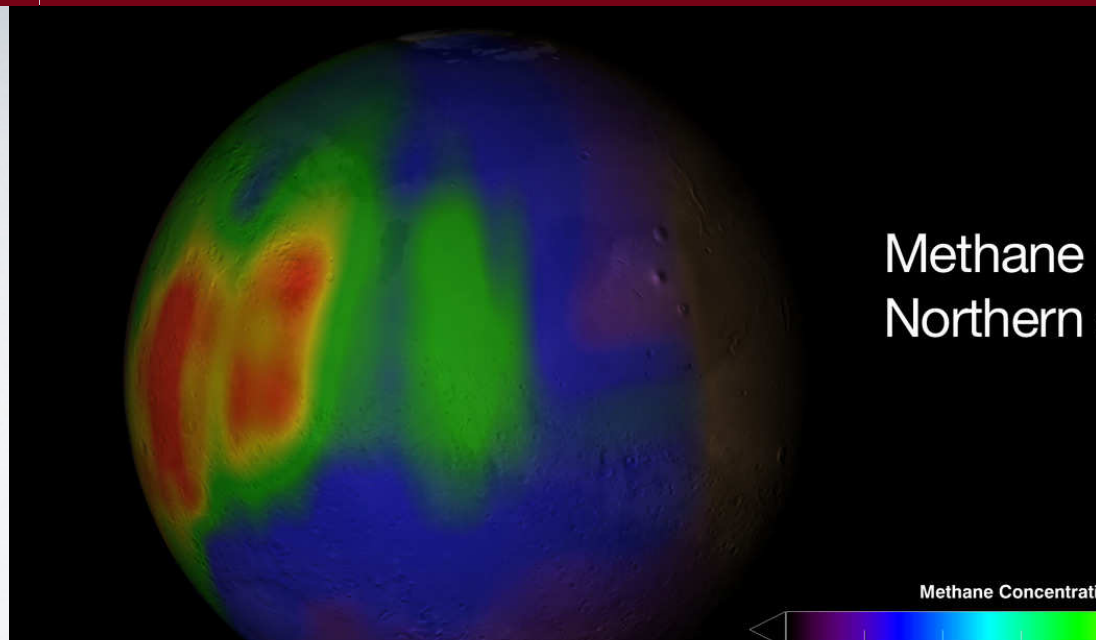
6

TECHNOLOGY OBJECTIVES

- Provide data relay services to landed missions until 2022;
- Entry, Descent, and Landing (EDL) of a payload on the surface of Mars

SCIENTIFIC OBJECTIVE

- To study Martian atmospheric trace gases and their sources.



Trace Gas (TG) Science Objectives

tion

Requires very high sensitivity to the following molecules and their isotopomers:
HO_2, NO_2, N_2O, CH_4, C_2H_2, C_2H_4, C_2H_6, H_2CO, HCN, H_2S, OCS, SO_2, HCl, CO, C
Detection sensitivities of 1-10 parts per trillion

acterization

Spatial and Temporal Variability: Latitude-longitude coverage multiple times in
year to determine regional sources and seasonal variations (reported to be large, l
controversial with present understanding of Mars gas-phase photochemistry)
Correlation of concentration observations with environmental parameters of temp
dust and ice aerosols (potential sites for heterogeneous chemistry)

ization

Inverse modeling to link observed concentration patterns to regional transformation
in dusty air) and to localized sources requires simulations using circulation
constrained by dust and temperature observations
Mapping of multiple tracers (e.g., aerosols, water vapor, CO, CH_4) with d
photochemical lifetimes and correlations helps constrain model simulations and p
source/sink regions

Mission Attributes

tion, characterization, localization are the goals in priority order

ce operations should last at least one Mars year

ine orbit:

proposed low-altitude (in the range 350 km to 420 km) nearly circular orbit

n orbital inclination of 74˚ with an acceptable science tolerance of +/- 10 deg

round-track should not precisely repeat but should be optimized for mapping coverage by the profiling in

n-pointed spacecraft:

rovides a good viewing geometry for solar occultation instruments and for instrument radiative coolers

ight require augmented viewing capabilities for profiling and low-resolution mapping instruments

ould require turn-tables or other devices for imaging instruments

fficult to accommodate high-resolution imaging

ad mass & (orbital average) power allocations of 125 kg and 190 W

nese allocations have been met by ESA

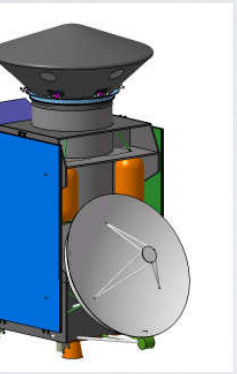
needed the available system margins (currently 20% above allocations) could be used in the near future fo
pproval with ESA and the spacecraft manufacturer

sary data volume requires two DSN ground station full passes per day for several months around max Ea
, given current design

16 Mission & System Summary

LAUNCH

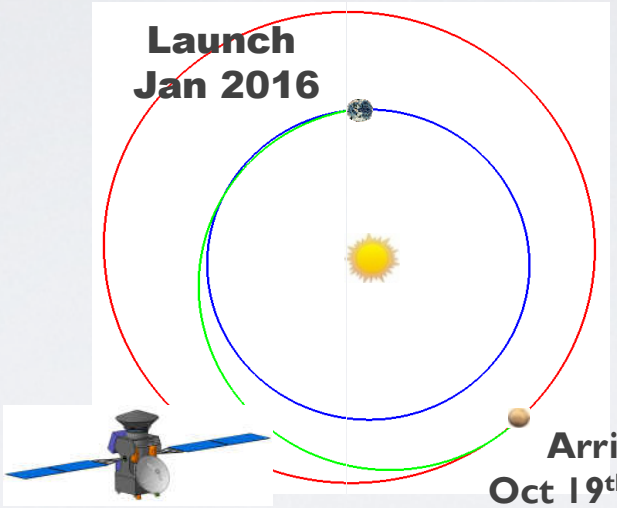
Jan 2016



s SCC in launch
nfiguration

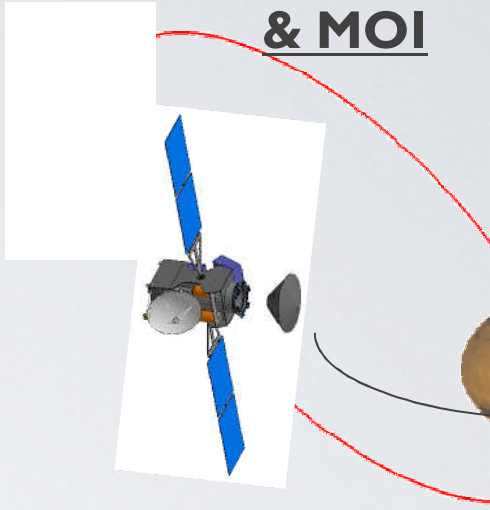
Atlas V 421

INTERPLANETARY CRUISE



Type II, C3 = 7.44 km²/s²

APPROACH, EDM R & MOI

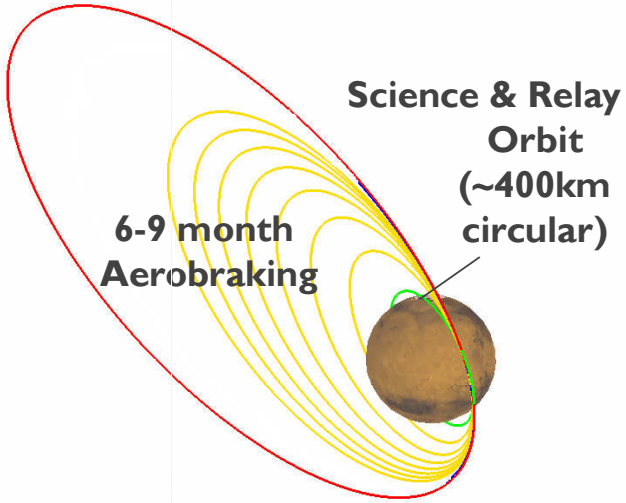


(1) EDM released from the hype
3 days before M
(2) Orbiter performs retargeting
sol orbit (inclination con
target landing s

ELAY & TRANSITION O 1-SOL ORBIT

lay for EDM during first 8 sols after landing

AEROBRAKING & SCIENCE PHASE



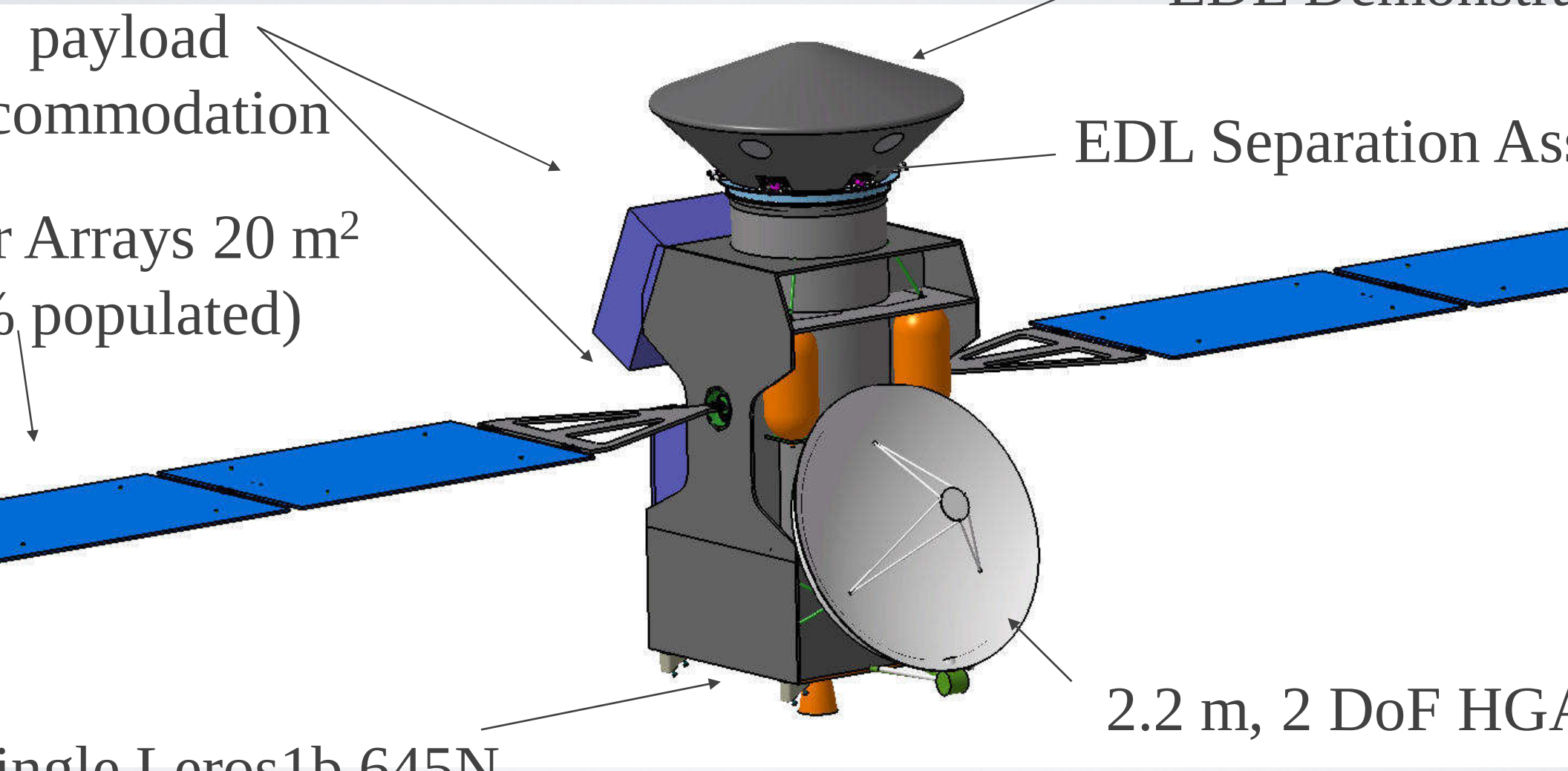
(1) Aerobrake to final orbit

DATA RELAY PHA

(1) Data relay for 2018 Rover
Jan 2019

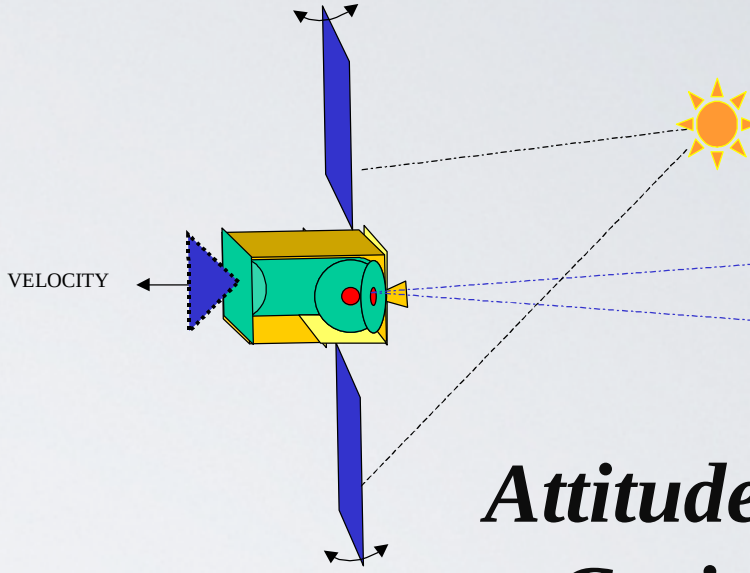
Spacecraft Composite - the Flight System

Spacecraft Composite (based on Orbiter Bus configuration 4AL)



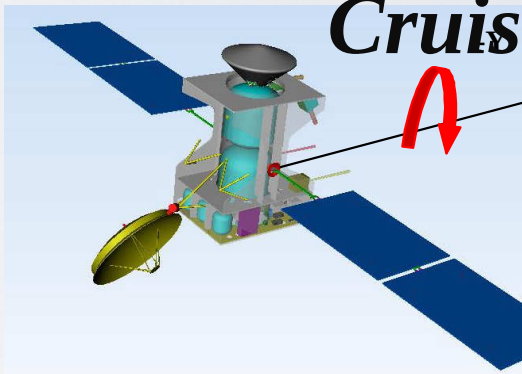
Orbiter Module (1/4)

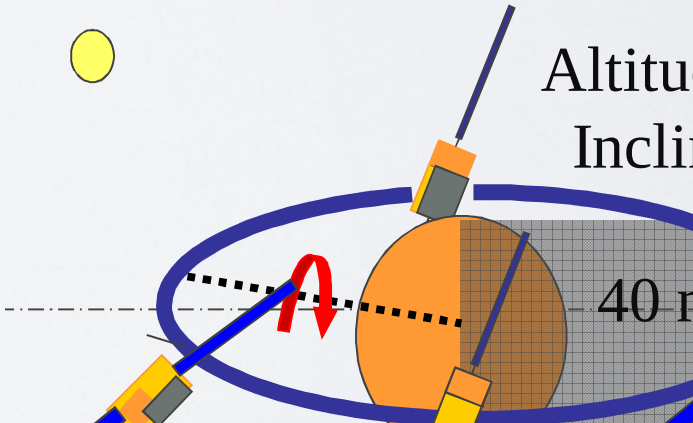
- **MARS Nadir Pointing – Yaw Steering strategy**
  - Allows for keeping – Y axis always Mars Nadir oriented with simultaneous Sun pointed Solar Arrays and Earth pointed High Gain Antenna
  - Max Yaw steering rate (around –Y axis) 1.5 mRad/s
  - *Yaw steering interrupted during Sun occultation measurements and during high resolution imaging slots*



Attitude

Cruis





Attitude during

Orbiter Module

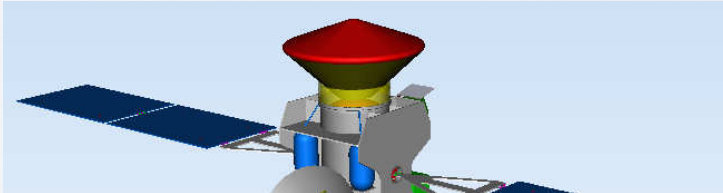
ionic/Electrical Systems

Steerable (1 DoF) Solar Arrays (2 x 10m^2 with 18.1 m^2 active) providing ~ 1800 W

Re-chargeable Lithium-Ion batteries with ~ 500 Wh to capacity

Unregulated voltage bus for instruments (22 V-34 V)

Centralised on-board computer: 1553 command/contro and Spacewire data I/F



Orbiter Module

o-Frequency Equipments

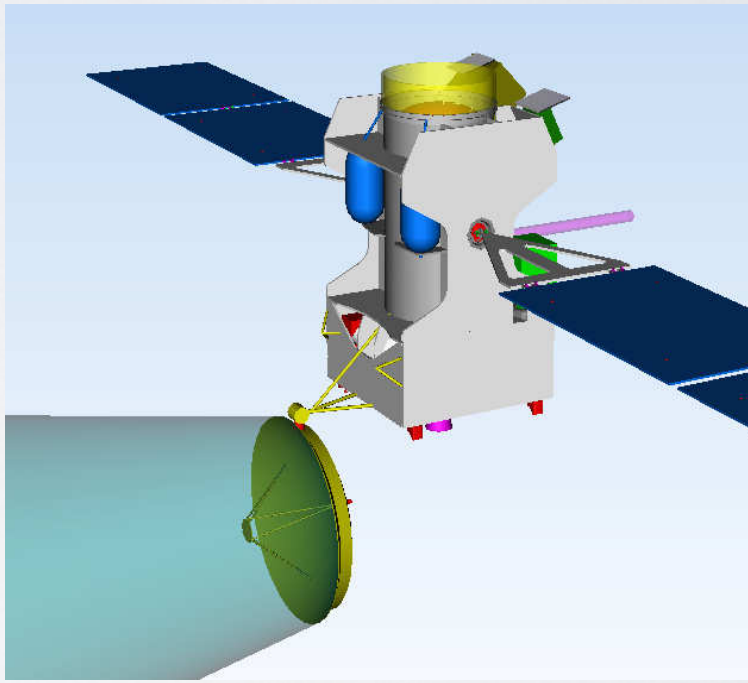
DoF HGA 2.2 m diameter (from Rosetta)
65 W TWTA

-band TM data rate (average)

- 150 kbps (max range) ~ 5 Gbits/day
- up to 900 kbps ~ 8 Gbits/day

HF-Band Electra transceiver and USO
NASA contribution)

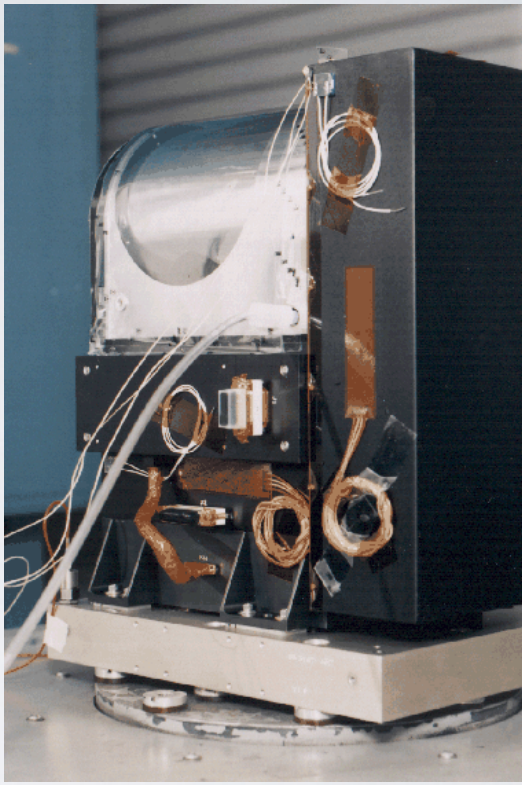
HF TM data rate: ~ 400 Mbits/sol average
om ExoMars and MAX-C Rovers

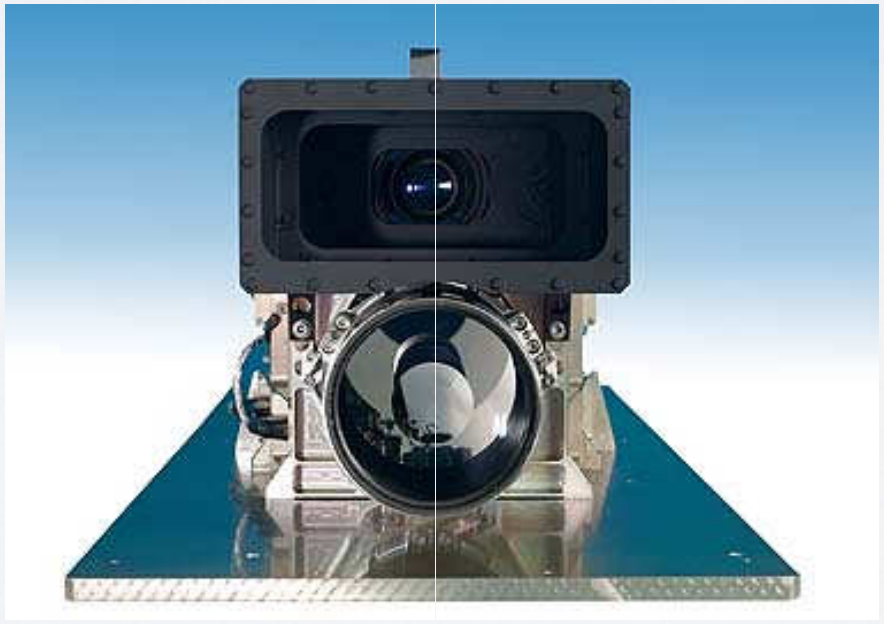


DT Strawman Measurement Approaches
ual Instrument Suite to be Selected thru AO)

R

SUB-MM





HRSC

WAC

ym	Description	View Modes	Observation Modes
	Solar Fourier Transform IR Spectrometer: **Broad survey** of trace gases with high precision	Solar Occultation only; passive radiative cooler	2 Solar Occultations per orbit (~24/d processing interferorgrams throughou
	Solar-Nadir IR Mapper: Detection and mapping of **specific** trace gases	Solar occultation; nadir and limb viewing; heat sink required (assumed to be provided by s/c)	2 solar occultations + dayside nadir/l (60 min) on each orbit
m	Sub-mm Spectrometer profiler/mapper **Atmospheric temperature & winds** plus **H2O and specific** trace gases	Nadir and limb, including away from velocity vector	Continuous operations switching betw nadir, space, different limb; observe l sides of ground track
	Thermal IR profiler/mapper spectrometer or radiometer for atmospheric **temperature and dust,** plus **H2O and some** trace gases	Nadir and limb views, including away from velocity vector	Continuous operations switching betw nadir, space, different limb; observe l sides of ground track
	Wide Angle Camera imaging **atmospheric phenomena** for discriminating between surface, dust clouds, & ice clouds	push-frame operation with .GE. 2 color bands; requires alignment with ground track motion	Cross-track (nearly orthogonal to vel vector) horizon-to-horizon
	High Resolution Color Stereo Camera: **Surface imaging**	~1 m/pixel ground sampling (at nadir) with TDI; fore/nadir/aft views	Designated targets of opportunity; re alignment with ground track motion (mitigation needed)

The EDLS Demonstrator

ximum Mass at launch 600Kg

mi-soft (almost soft) lander with liquid retro-propulsion

nding gears (TBD) crushable material, vented airbags, legs

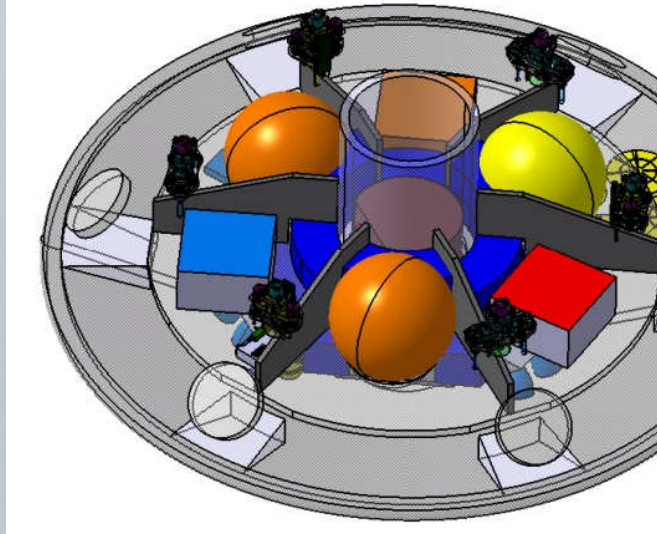
nimum Payload operated on primary battery (5-7 sol lifetime)

ss less than 5Kg and no deployment mechanisms

ence Goals: mostly environmental assessment

EDM CONFIGURATION

Internal View



Parachute

Antenna

HEPA filter

MSM

Sun Sensor

Access Door

Entry, Descent and Landing Demonstrator

- 2.4 m Φ Entry Shield

EDM Science

Science Sensors TBD

ubject to limitations of resources

TBD kg of sensors with accommodation hardware

Energy for operations limited to battery capacity on surfa
~8 sols

Data volume availability related to overflight of Orbiter

Back Cover Mould

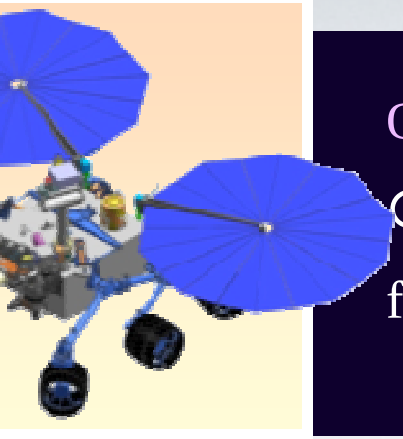
8

TECHNOLOGY OBJECTIVES

- Surface mobility with a rover (having several kilometres range);
- Access to the subsurface to acquire samples (with a drill, down to 2-m depth);
- Sample acquisition, preparation, distribution, and analysis.

SCIENTIFIC OBJECTIVES

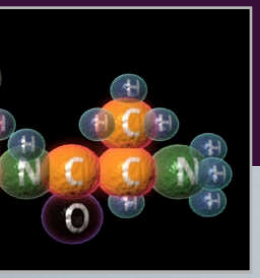
- To search for signs of past and present life on Mars;
- To characterise the water/subsurface environment as a function of depth in the sh subsurface.



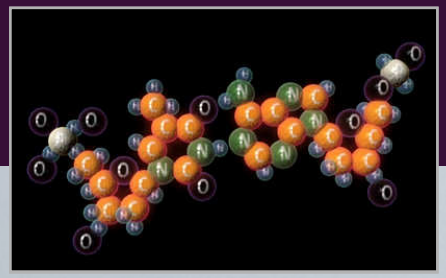
OBJECTIVE

- To identify, acquire, document, and cache “outstanding” samples in a manner s for collection by a future Mars Sample Return mission.

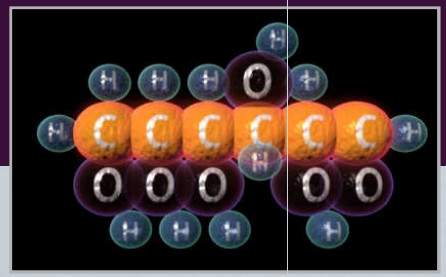
ENT LIFE: Biological markers, such as:



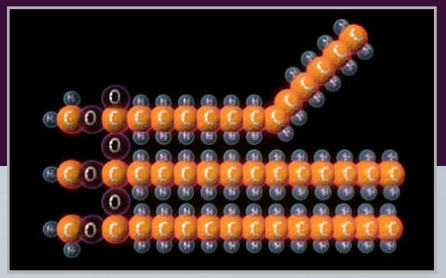
no acids



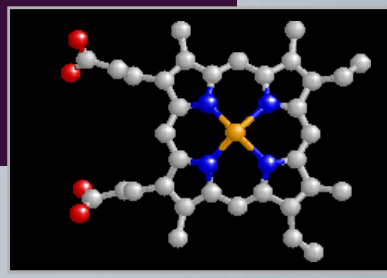
Nucleobases



Sugars



Phospholipids

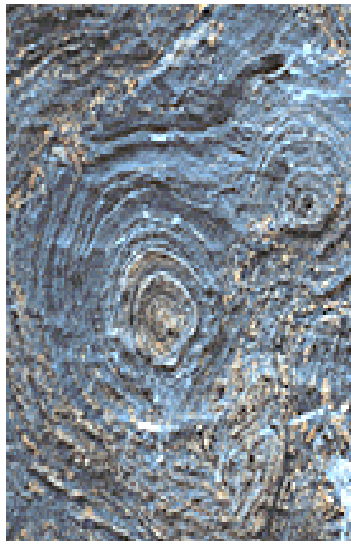


Pigments

- **PAST LIFE:** Organic residues of biological origin; (chemical, chiral, spectroscopic, and isotopic info)

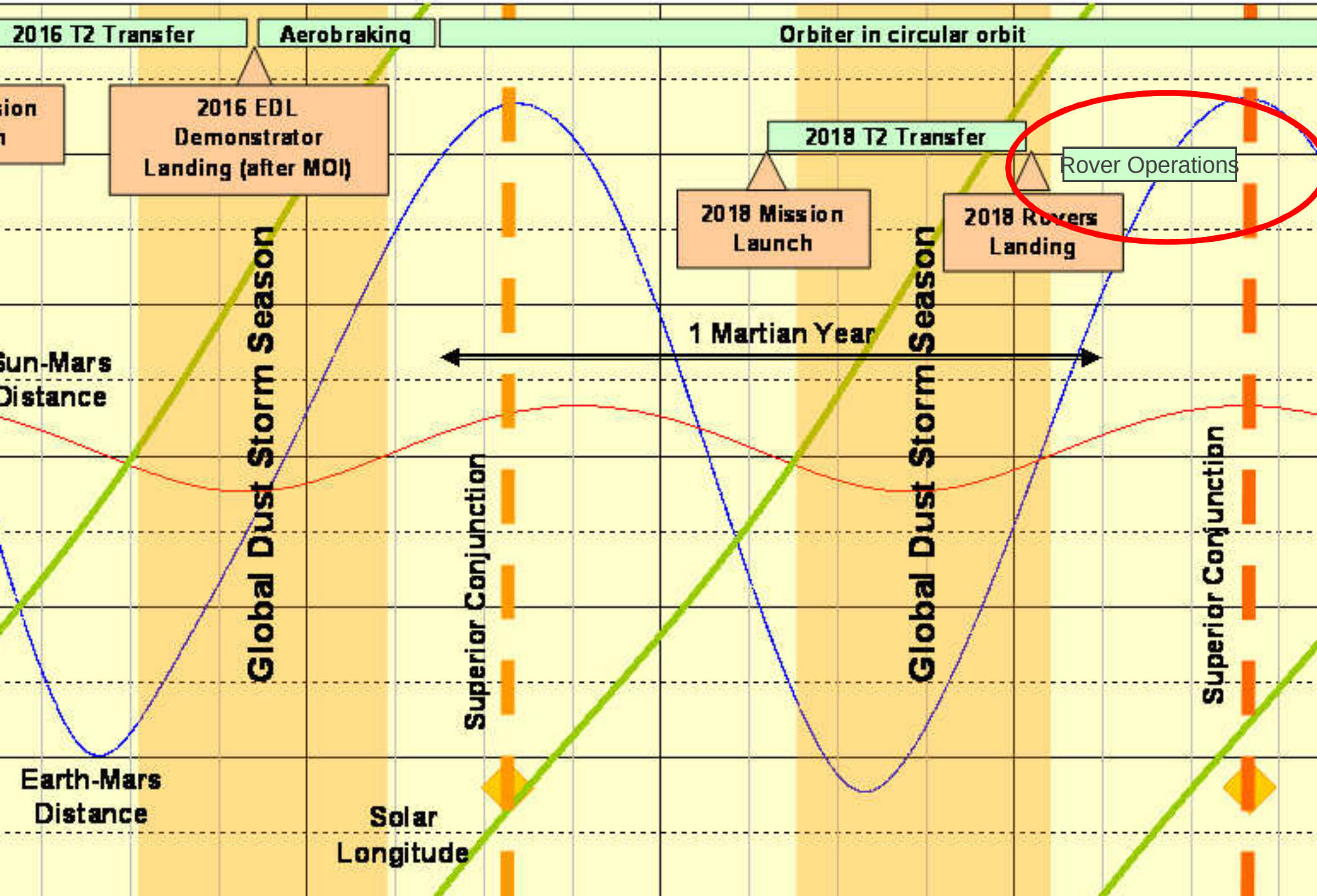
  Images of fossil organisms and their structures;

  (morphological evidence)

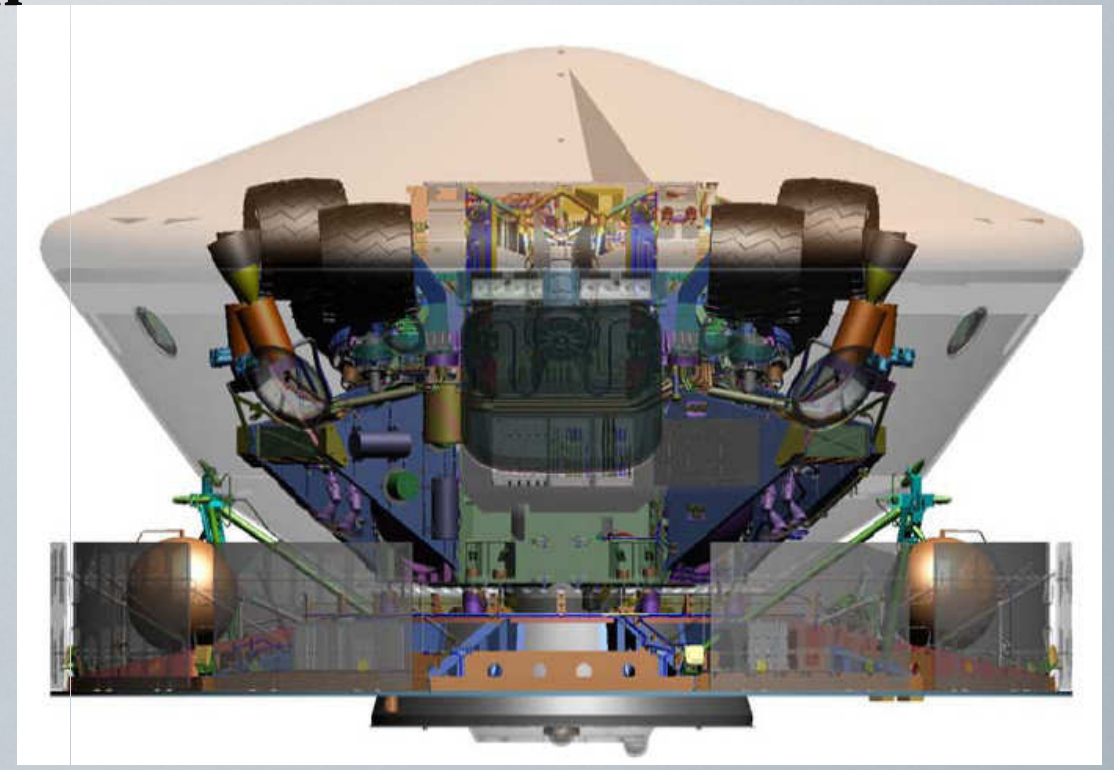


- **DELIVERED ORGANICS:** by meteoritic and cometary infall

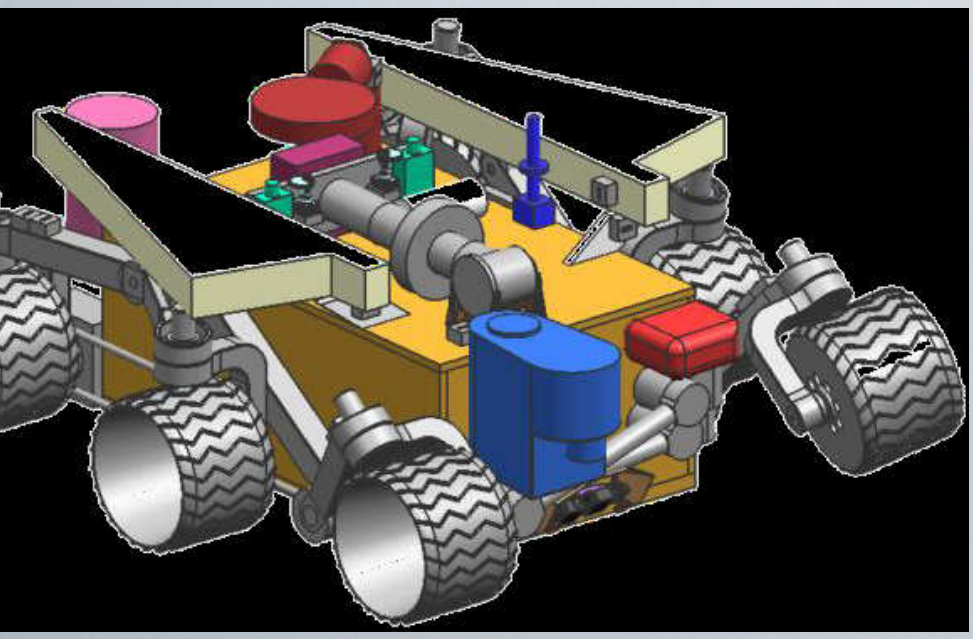
2018 Mission Context

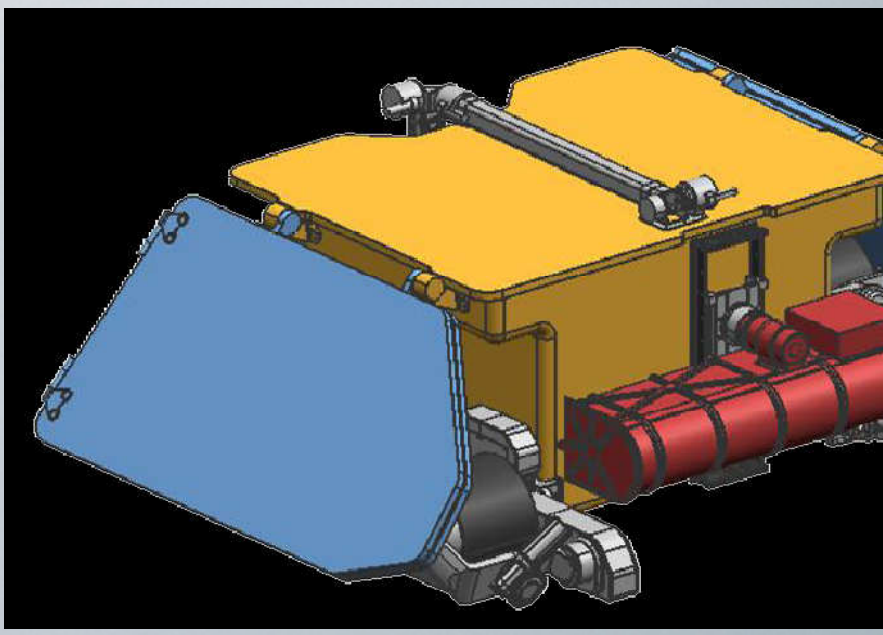


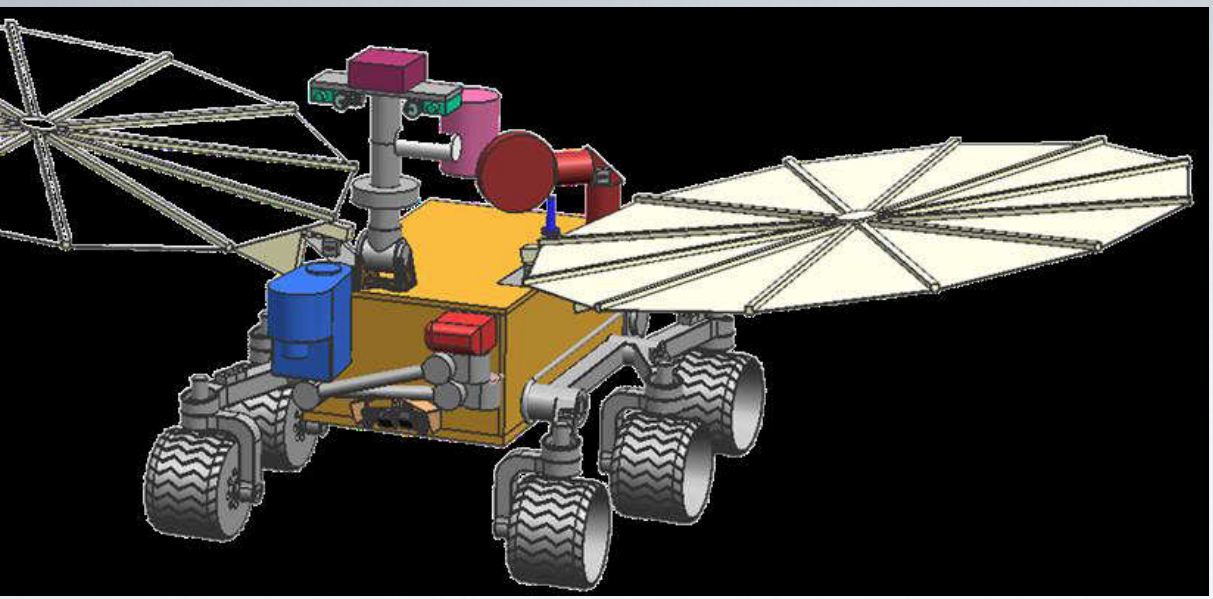
2011 MSL Configuration

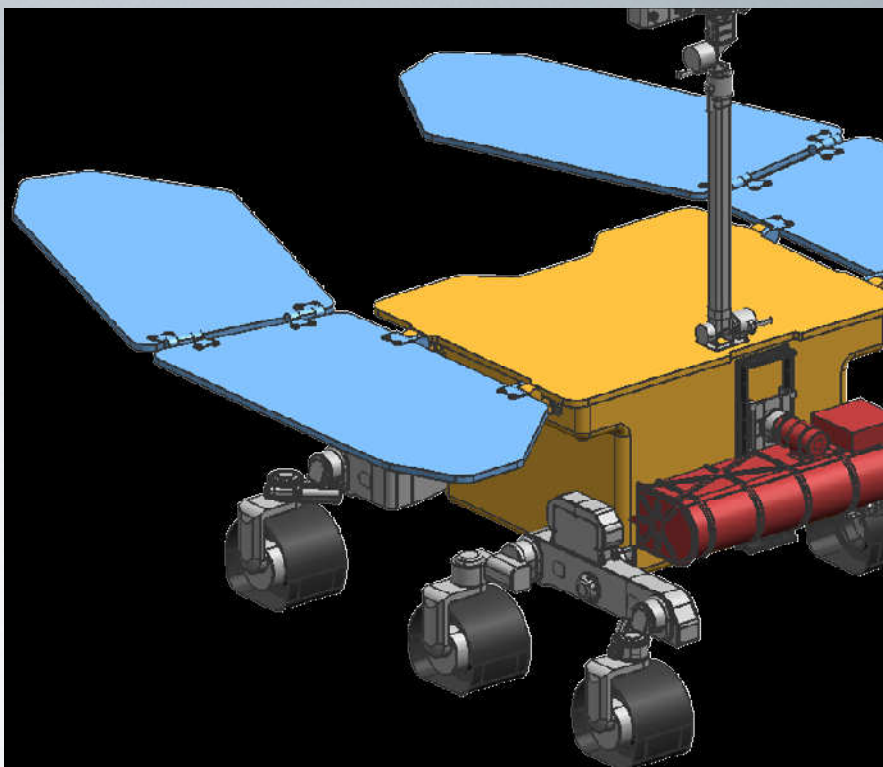


MAX-C & ExoMars-RM Configurations



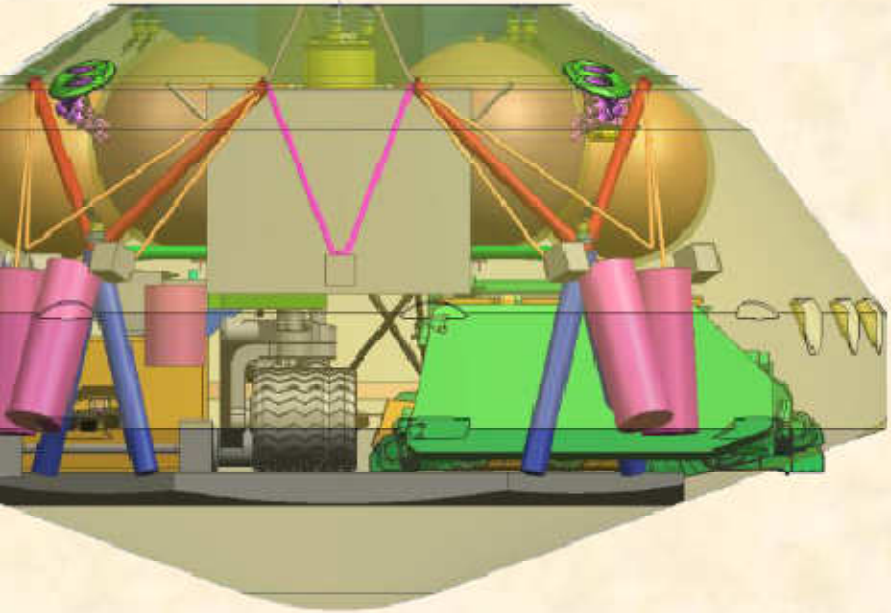




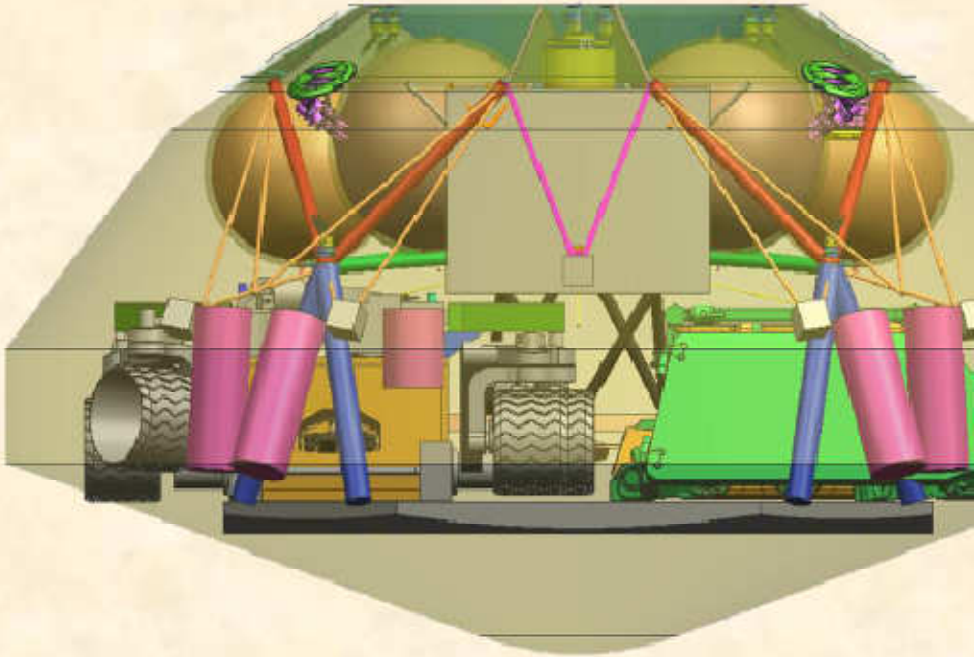


2018 EDL Configuration Trades

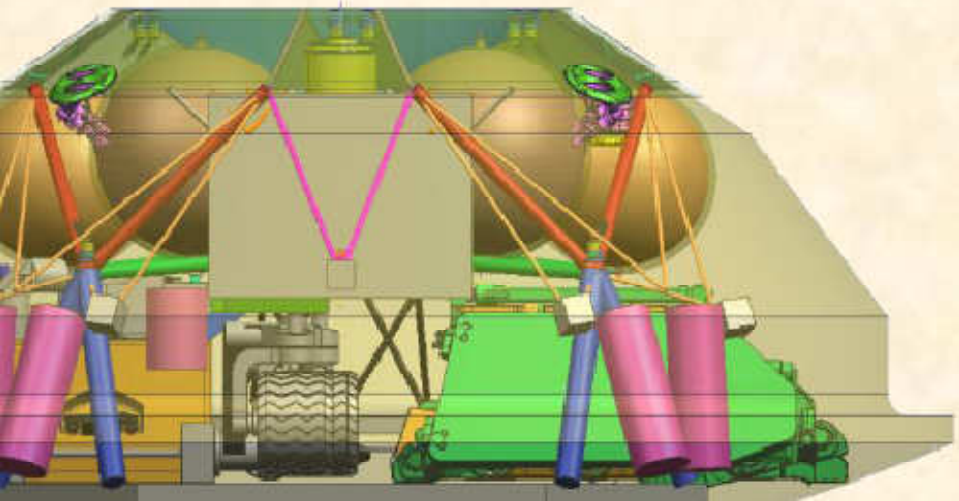
4.5 m Viking Envelope



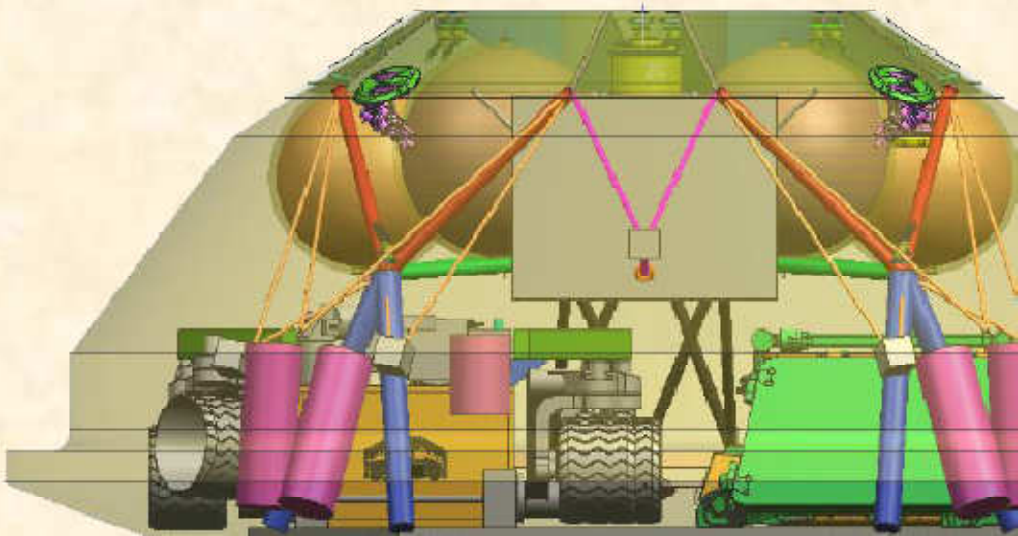
4.7 m Viking Envelope

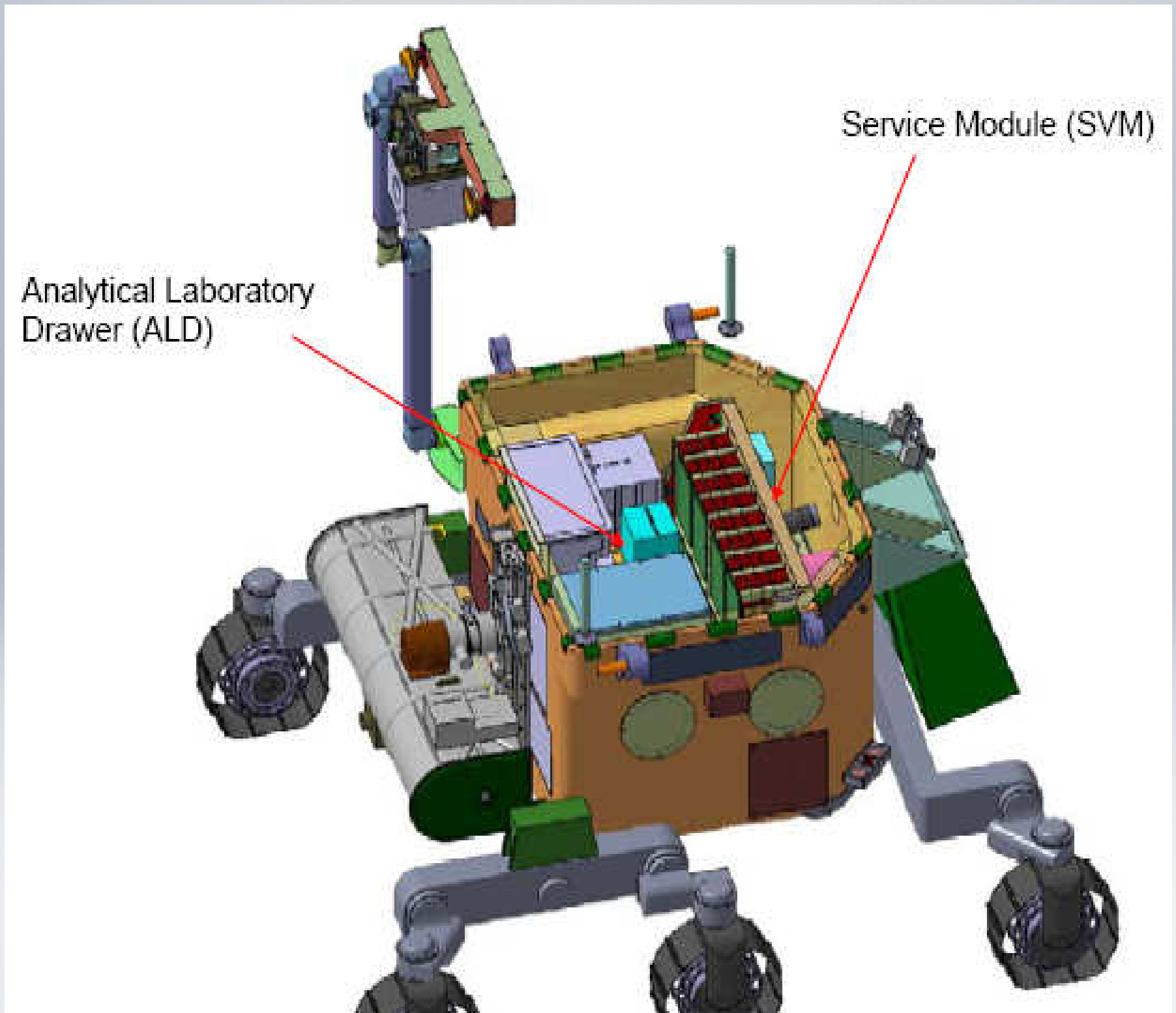


4.5 m Apollo/Orion Envelope

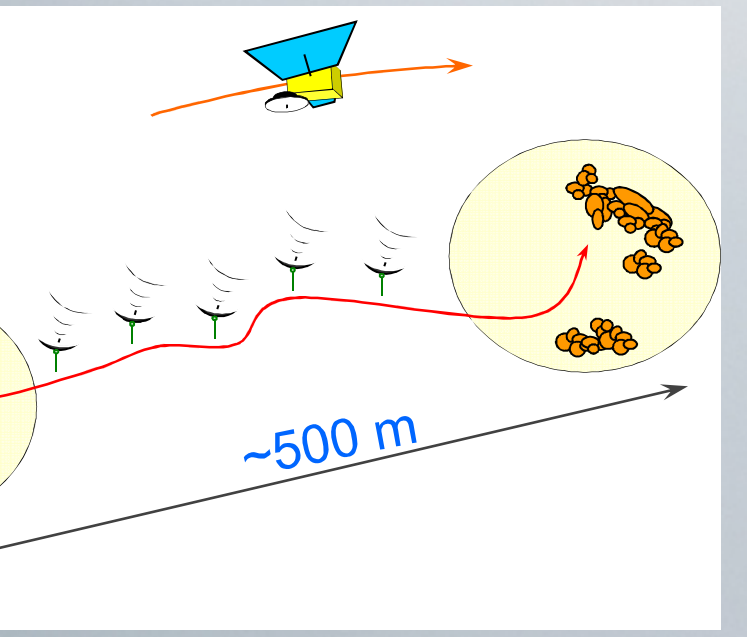


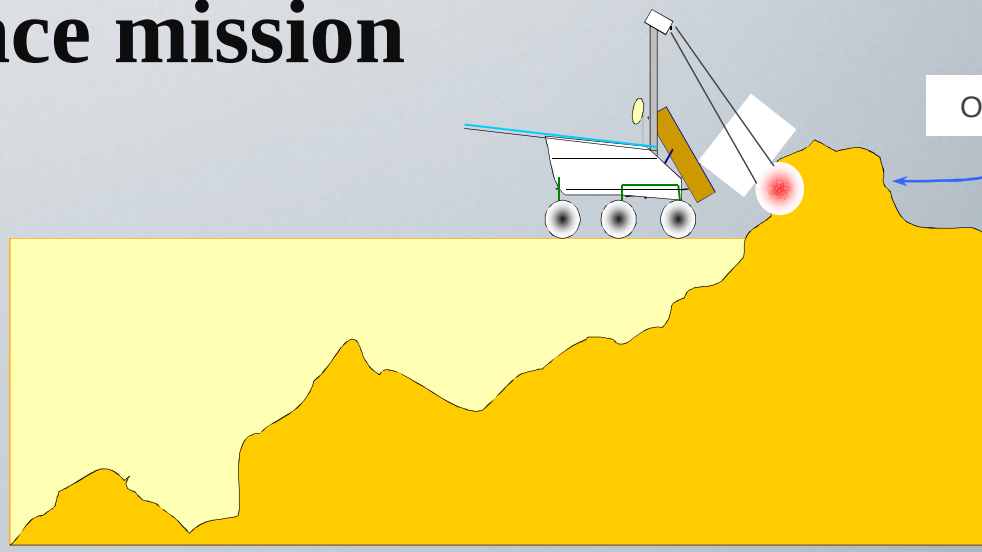
4.7 m Apollo/Orion Envel

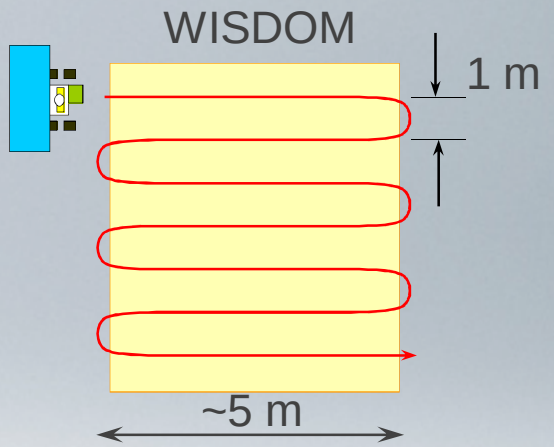



Service Module (SVM)
Analytical Laboratory
Drawer (ALD)

Rover reference mission

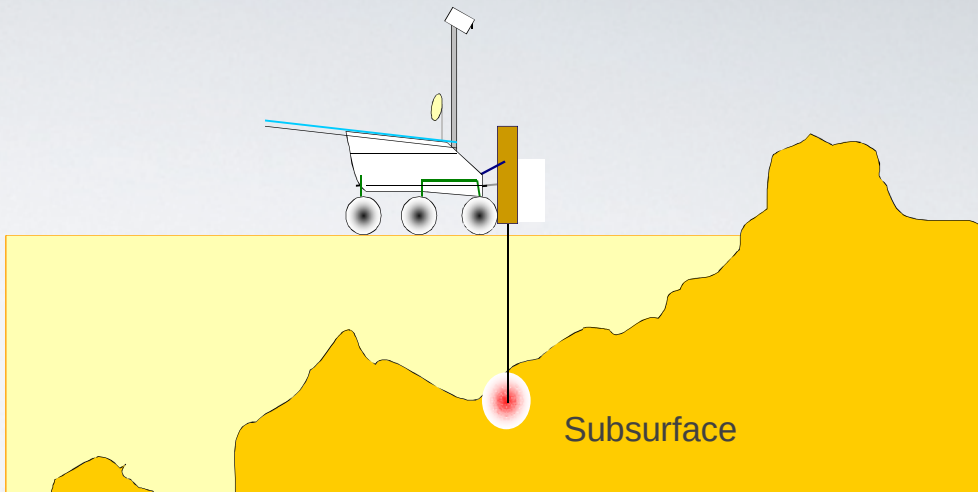






❑ 6 Experiment Cycles

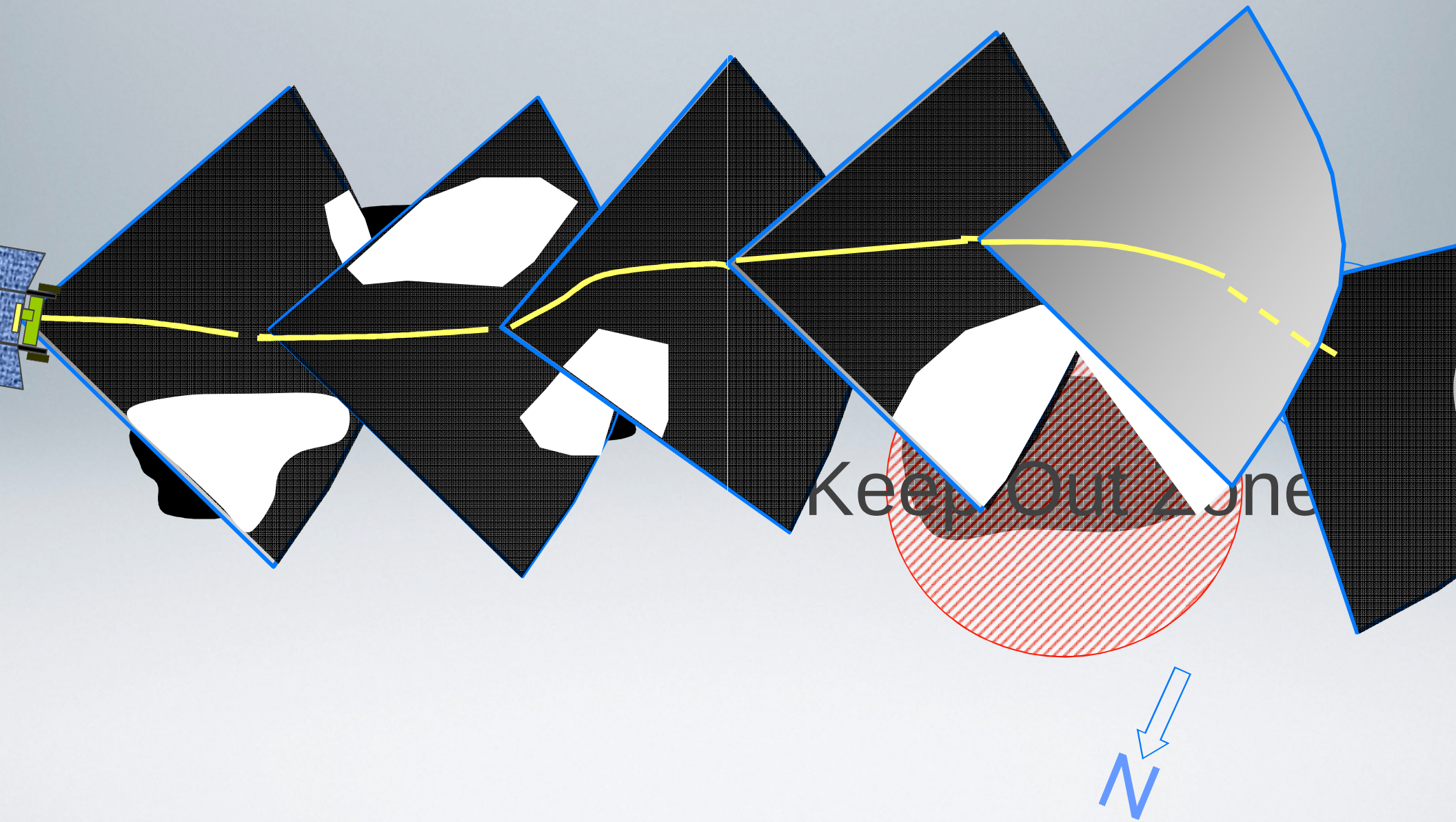
mental transverse distances 100m > 500 m
Visual & Ground radar within ~ Ø20 m
o close-up observation and surface sampling
- Ground radar mapping
rilling (~1.5 m) and sample acquisition
ample distribution and optical inspection
le crushing and analytical characterization



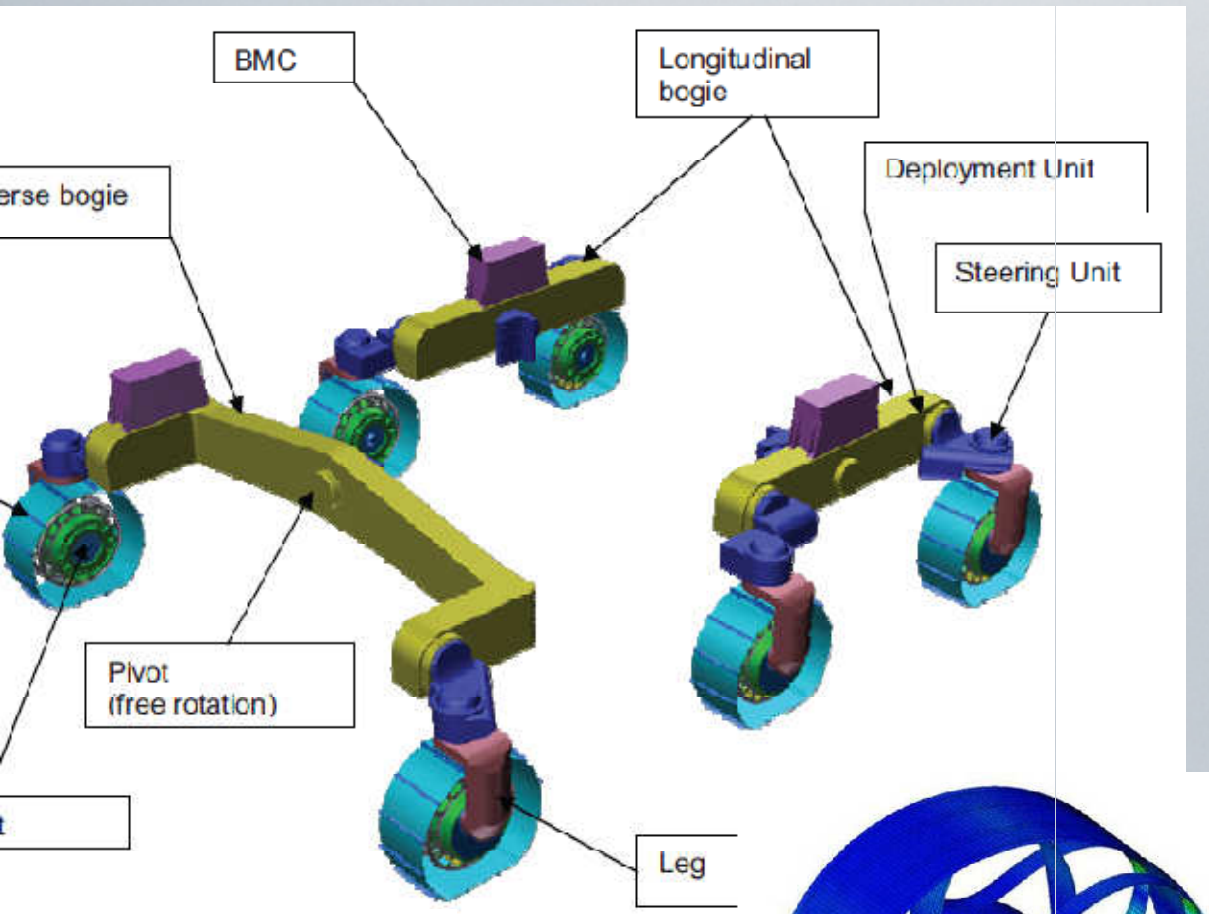
❑ 2 Vertical Surveys

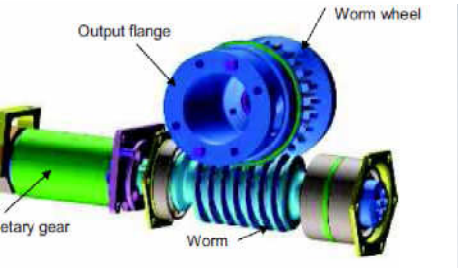
Drill and obtain sample from surface
- Sample distribution and analysis

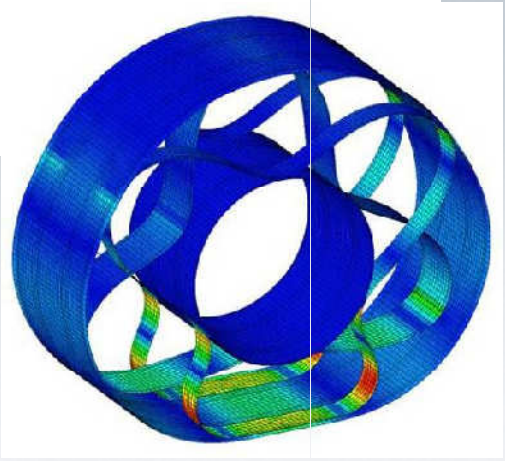
Autonomous Navigation Animated Example

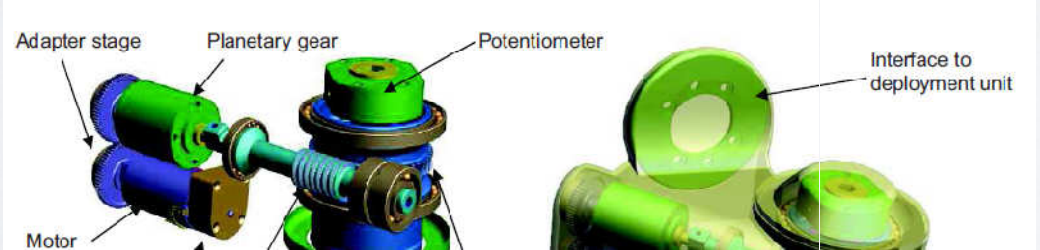


ocomotion System





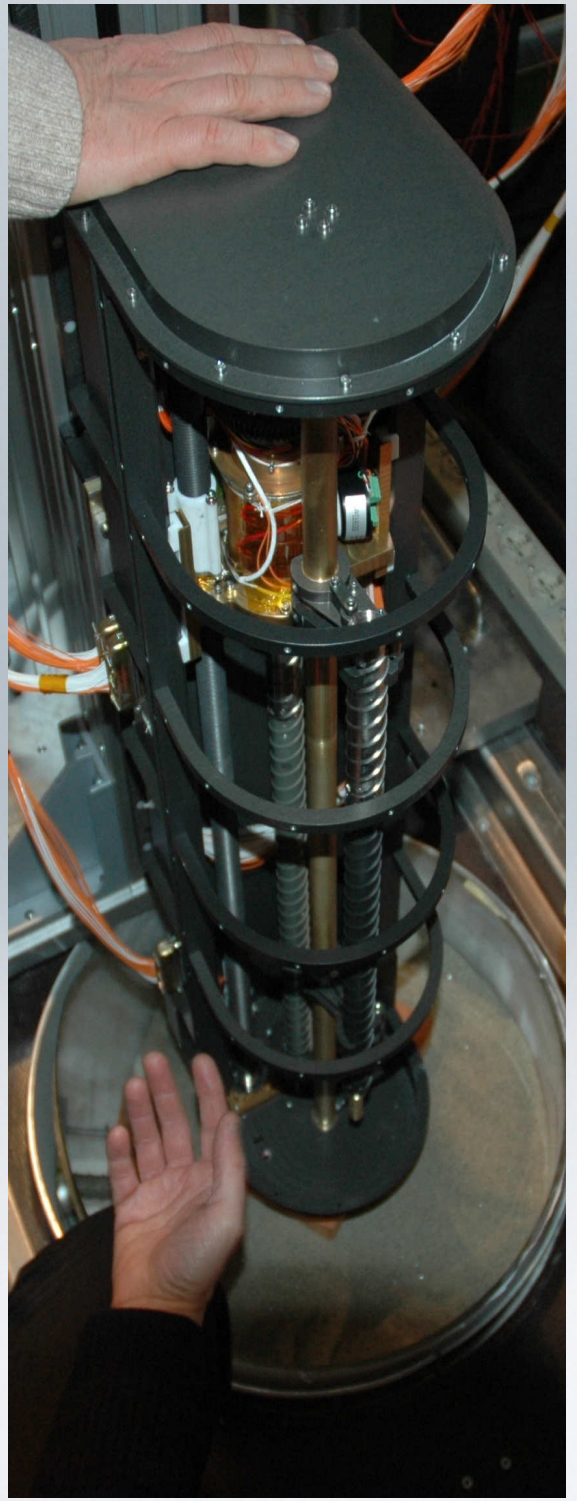


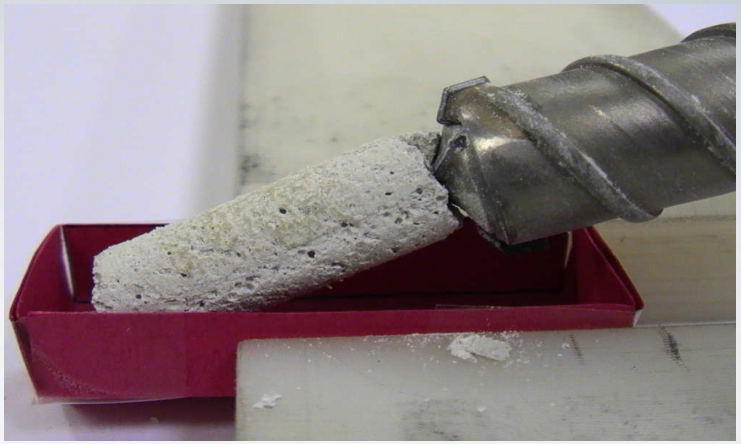


- 21 DoF system
  - 6 Drive
  - 6 Steer
  - 6 Deploy/Wheel Walking
  - 3 Bogey rotation

- Sub-system consists of
  - Mechanical Assembly
    - Bogeys
    - Actuators
    - Flexible Wheels
  - Control Electronics and Motor C Algorithms (BMC)

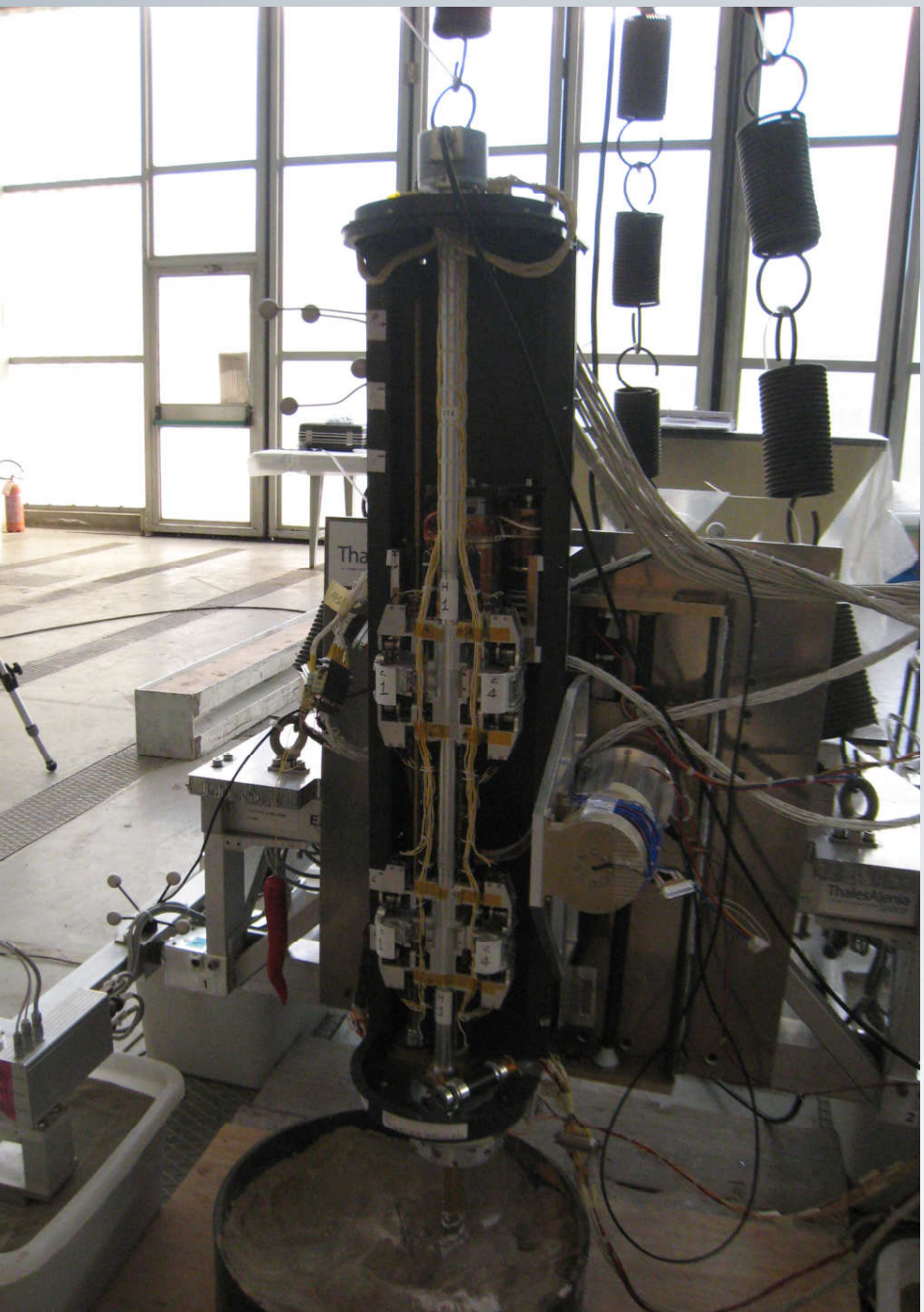
Drill

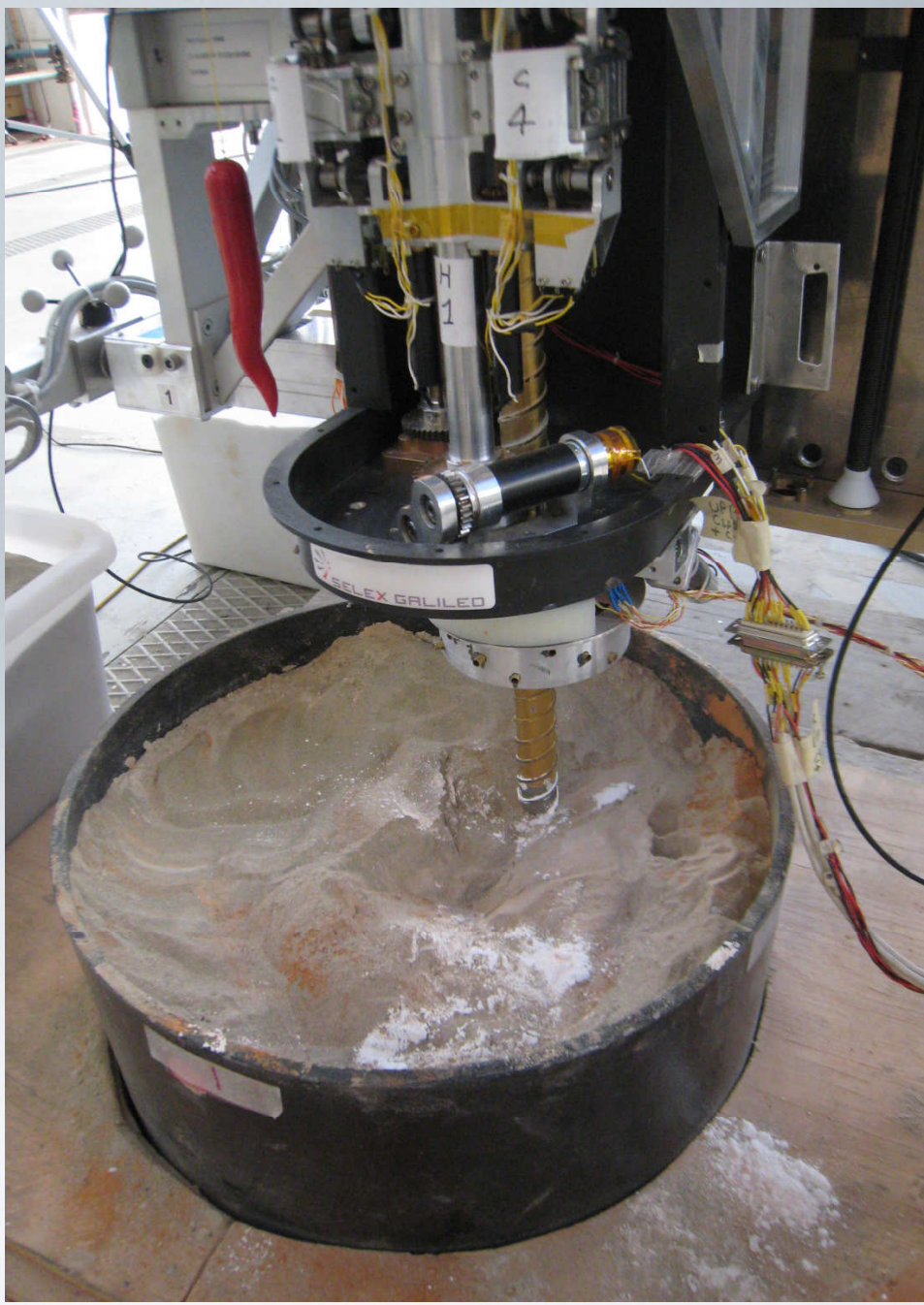




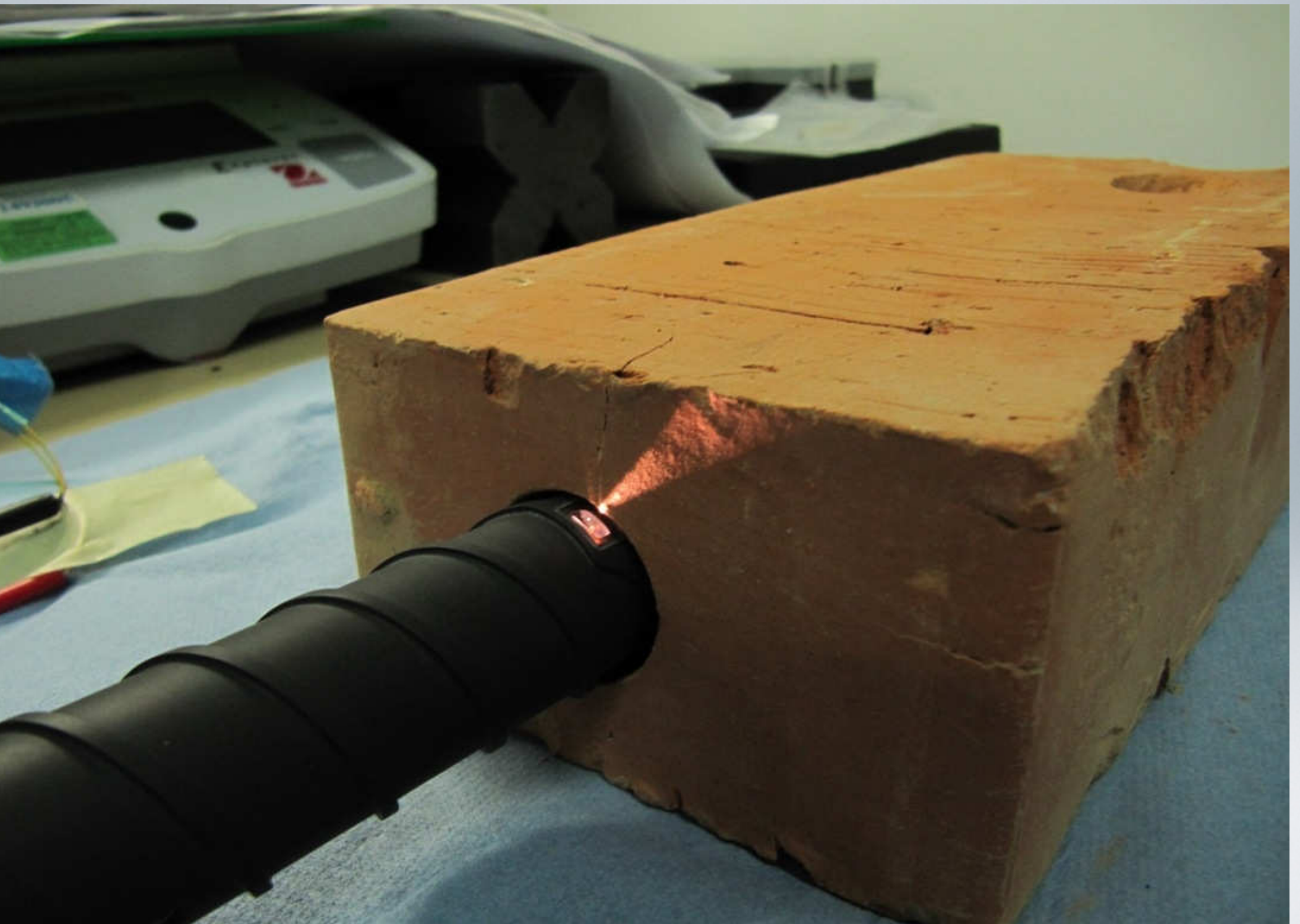
Drill Tool with sample

Drill Tests on going at TAS-I

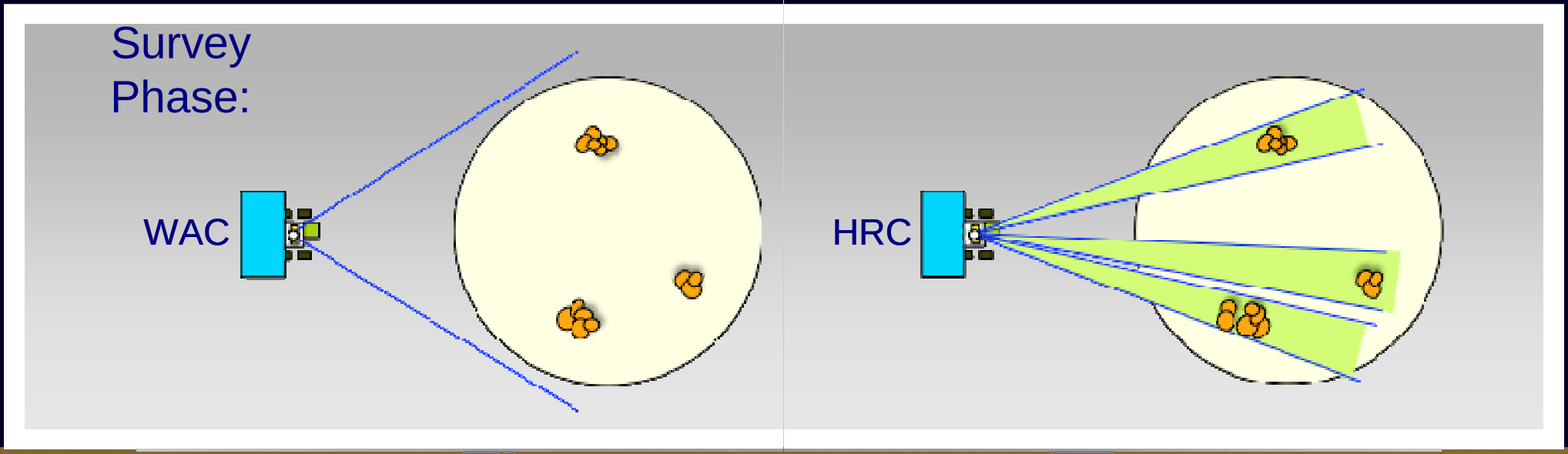


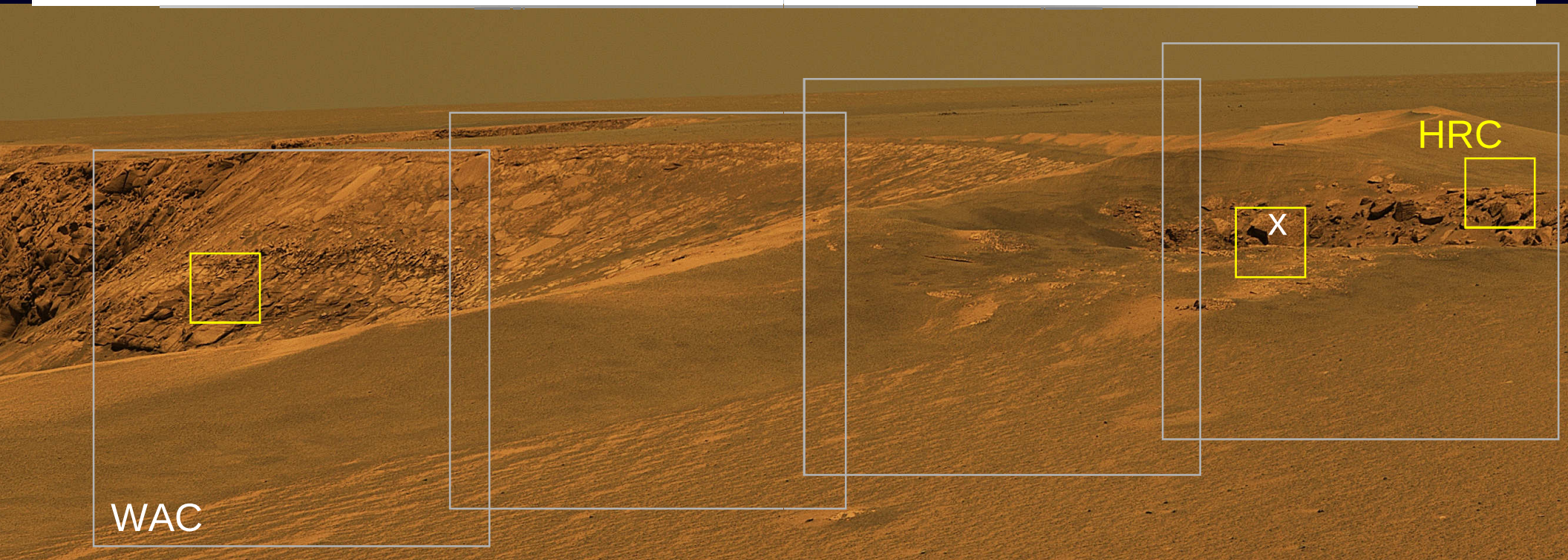


Ma_Miss Accommodation



PANORAMIC SCALE: To establish the geological context





ROCK SCALE: To ascertain the past presence of water
For a more detailed morphological examination

High-Resolution Camera

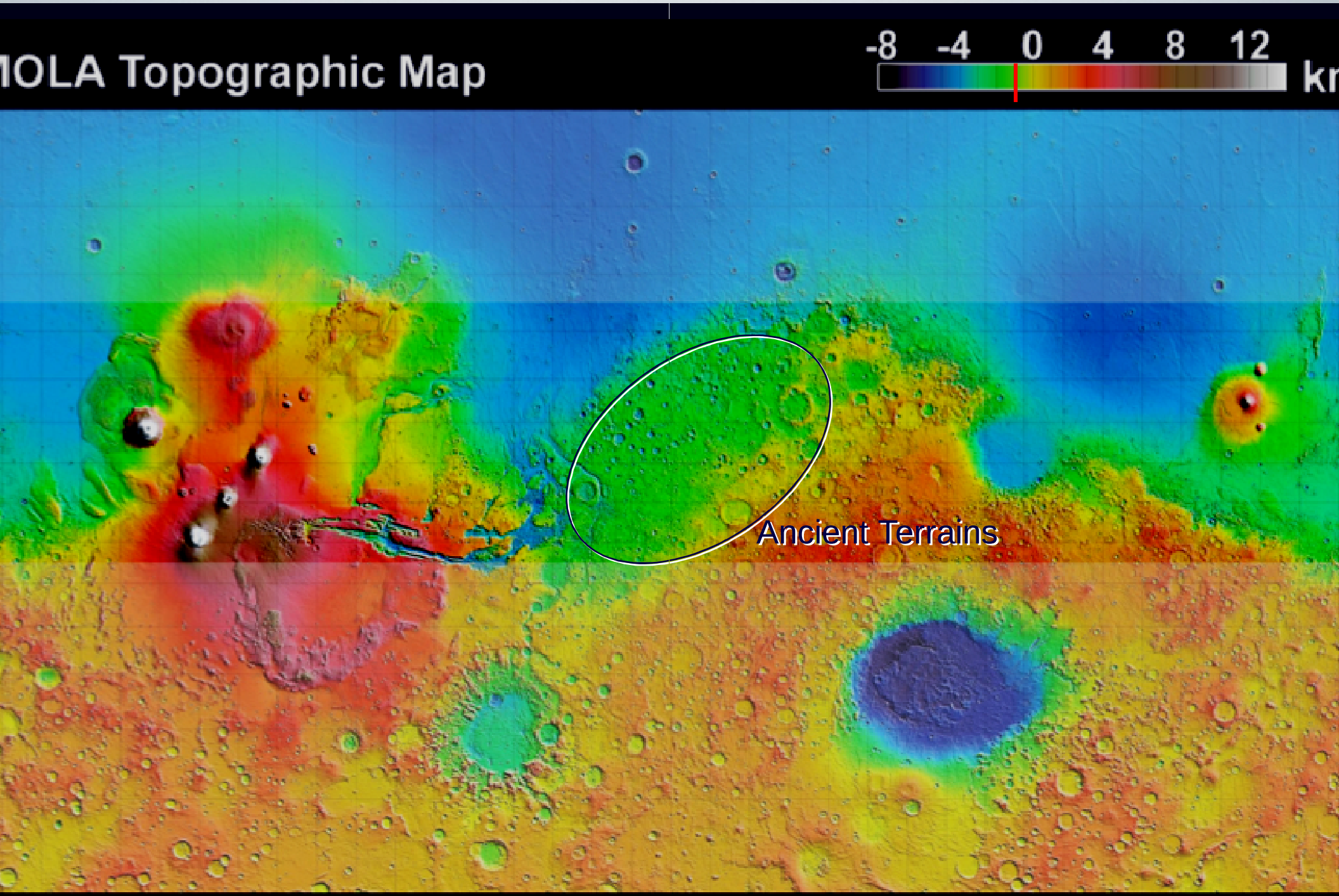
Close-Up Imager

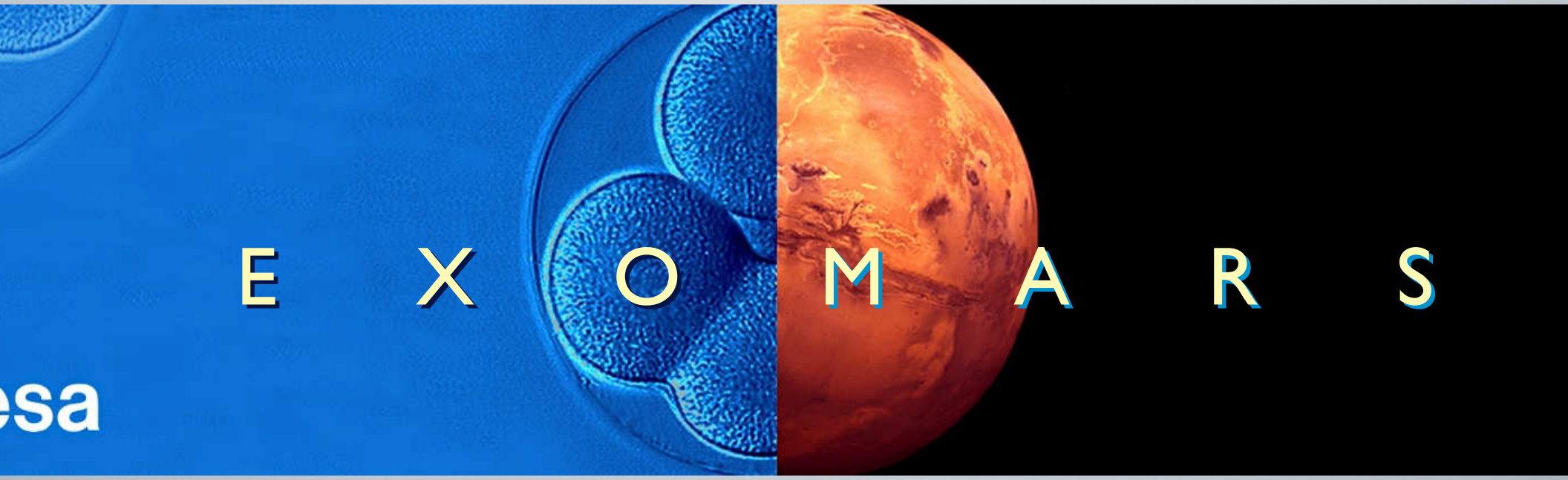
Next step: **ANALYSIS**

Use the drill to collect a sample
- From an outcrop
- From the subsurface

Instrument Name	Description	Mass (kg) including maturity margi
PanCam (WAC + HRC)	Panoramic camera system	1.560
MOMA	LD-MS + Pyr GC-MS for organic molecule characterisation	6.100
MicrOmega IR	IR imaging spectrometer	0.960
Mars-XRD	X-ray diffractometer + X-ray fluorescence	1.480
Raman (internal)	Raman spectrometer	2.260
WISDOM	Shallow ground-penetrating radar	1.380
a_Miss included in 2.0-m drill	IR borehole spectrometer	0.650

+ CLUPI


MOLA Topographic Map
-8 -4 0 4 8 12
km
Ancient Terrains



The ESA/NASA ExoMars Programme

MARCELLO CORADINI

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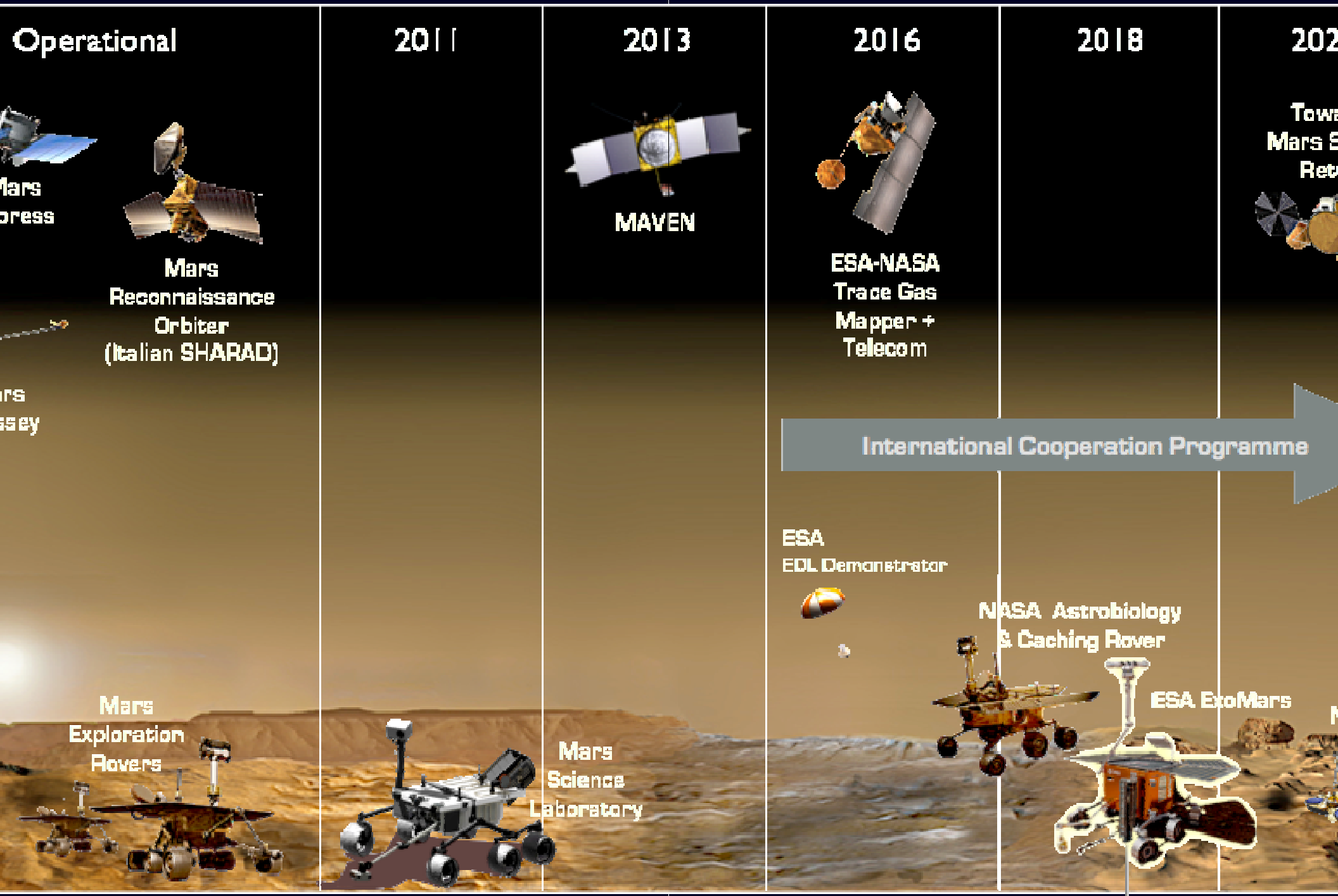
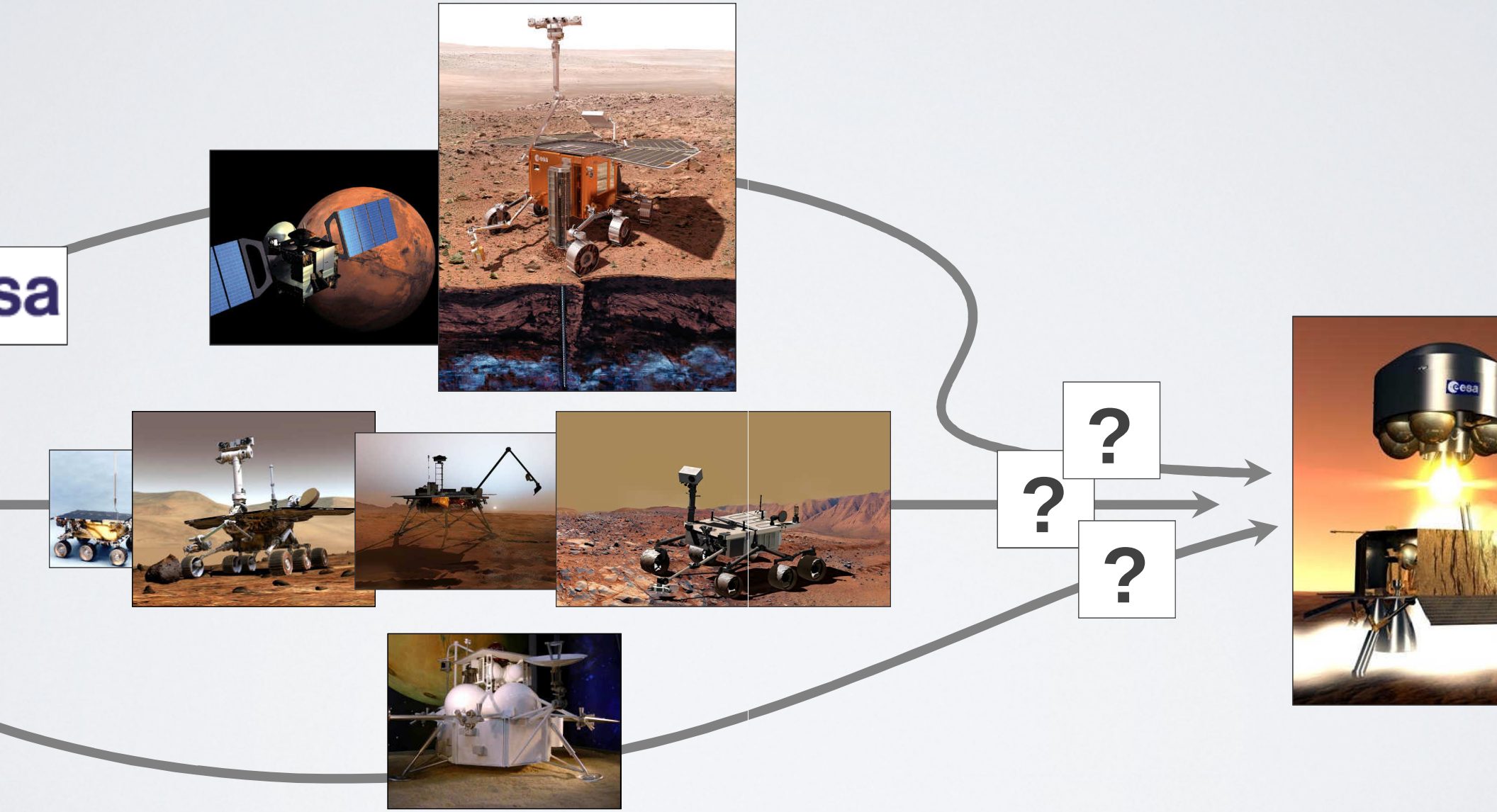


MSL: powerful rover; large 2-D mobility.

➢ **ExoMars:** next-generation instruments; 3-D access.

ecognising that a Mars Sample Return (MSR) mission is very challenging, and that
undertaking will likely exceed the financial capabilities of any one agency,

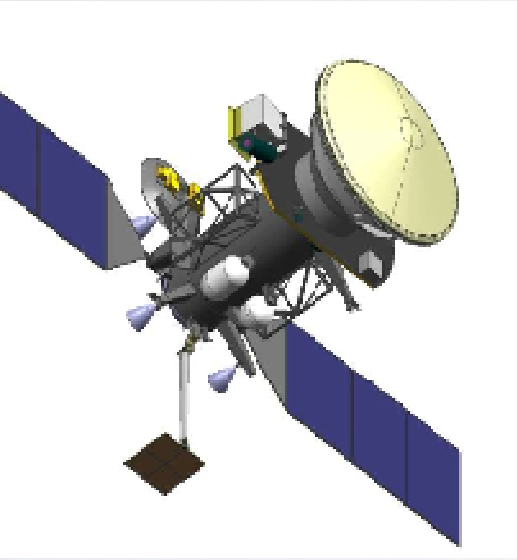


and NASA have agreed to embark on a joint Mars robotic exploration programme:

lly, seek agreement on mission configurations for 2016, 2018, and 2020 opportunities;

Mars becomes a key element of the 2016 and 2018 scenario;

Mars spreads its objectives over two opportunities.

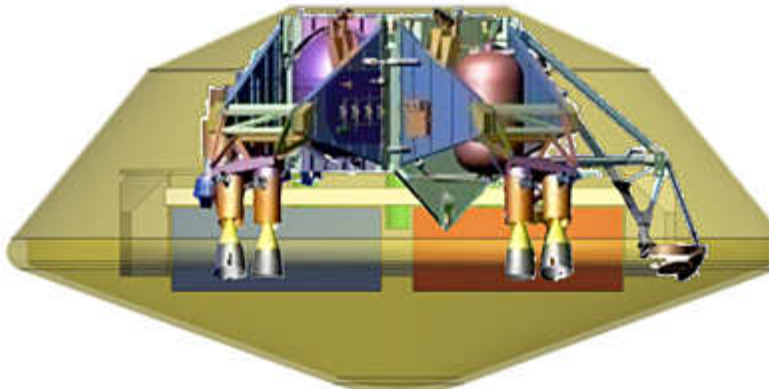


2016 — ESA-led mission

Launcher:	NASA – Atlas V 421
Orbiter:	ESA
Payload:	ESA-NASA
Lander:	ESA

2018 — NASA-led mission

Launcher:	NASA – Atlas V 531
Cruise & EDL:	NASA
Rover 1:	ESA
Rover 2:	NASA



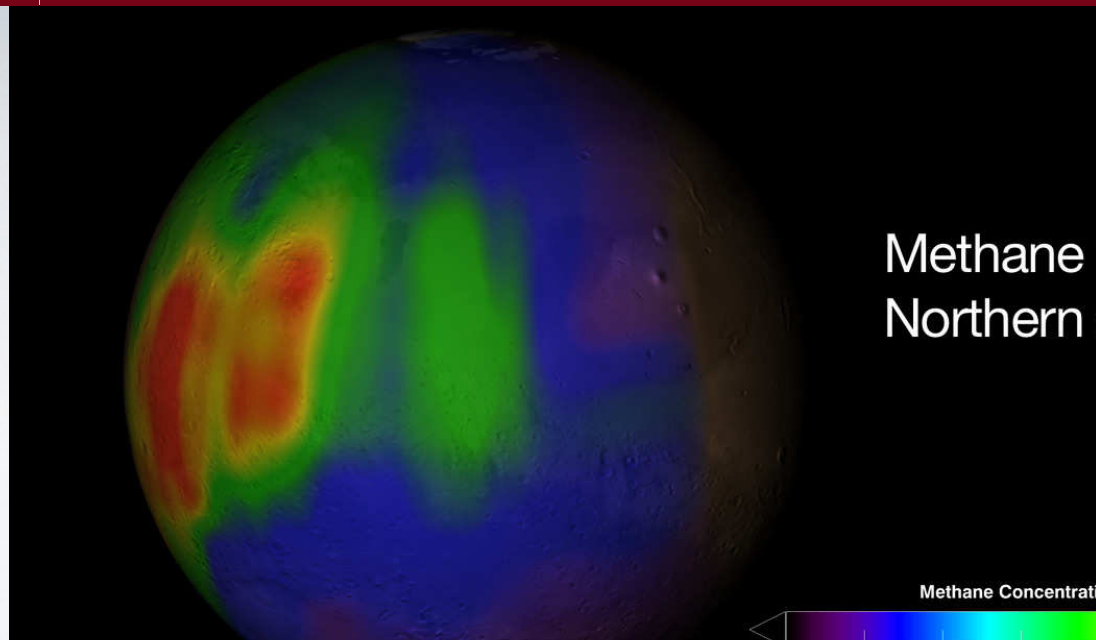
6

TECHNOLOGY OBJECTIVES

- Provide data relay services to landed missions until 2022;
- Entry, Descent, and Landing (EDL) of a payload on the surface of Mars

SCIENTIFIC OBJECTIVE

- To study Martian atmospheric trace gases and their sources.



Trace Gas (TG) Science Objectives

tion

Requires very high sensitivity to the following molecules and their isotopomers:
HO_2, NO_2, N_2O, CH_4, C_2H_2, C_2H_4, C_2H_6, H_2CO, HCN, H_2S, OCS, SO_2, HCl, CO, C
Detection sensitivities of 1-10 parts per trillion

acterization

Spatial and Temporal Variability: Latitude-longitude coverage multiple times in
year to determine regional sources and seasonal variations (reported to be large, l
controversial with present understanding of Mars gas-phase photochemistry)
Correlation of concentration observations with environmental parameters of temp
dust and ice aerosols (potential sites for heterogeneous chemistry)

ization

Inverse modeling to link observed concentration patterns to regional transformation
in dusty air) and to localized sources requires simulations using circulation
constrained by dust and temperature observations
Mapping of multiple tracers (e.g., aerosols, water vapor, CO, CH_4) with d
photochemical lifetimes and correlations helps constrain model simulations and p
source/sink regions

Mission Attributes

tion, characterization, localization are the goals in priority order

ce operations should last at least one Mars year

ine orbit:

proposed low-altitude (in the range 350 km to 420 km) nearly circular orbit

n orbital inclination of 74˚ with an acceptable science tolerance of +/- 10 deg

round-track should not precisely repeat but should be optimized for mapping coverage by the profiling in

n-pointed spacecraft:

rovides a good viewing geometry for solar occultation instruments and for instrument radiative coolers

ight require augmented viewing capabilities for profiling and low-resolution mapping instruments

ould require turn-tables or other devices for imaging instruments

fficult to accommodate high-resolution imaging

ad mass & (orbital average) power allocations of 125 kg and 190 W

nese allocations have been met by ESA

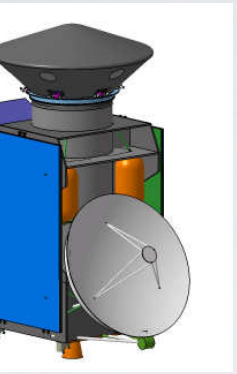
needed the available system margins (currently 20% above allocations) could be used in the near future fo
pproval with ESA and the spacecraft manufacturer

sary data volume requires two DSN ground station full passes per day for several months around max Ea
, given current design

16 Mission & System Summary

LAUNCH

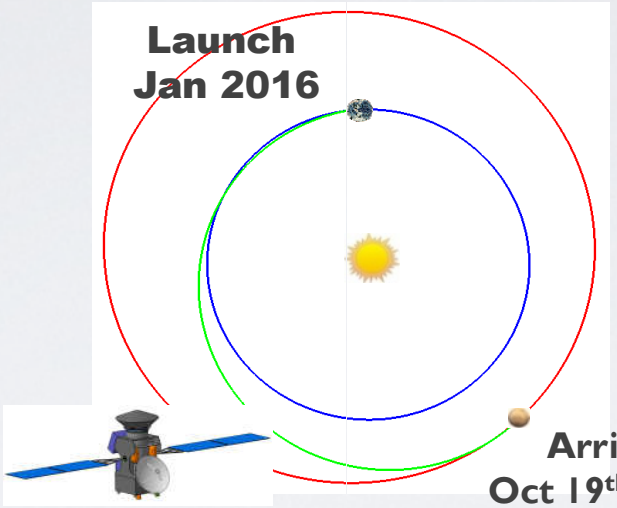
Jan 2016



s SCC in launch
nfiguration

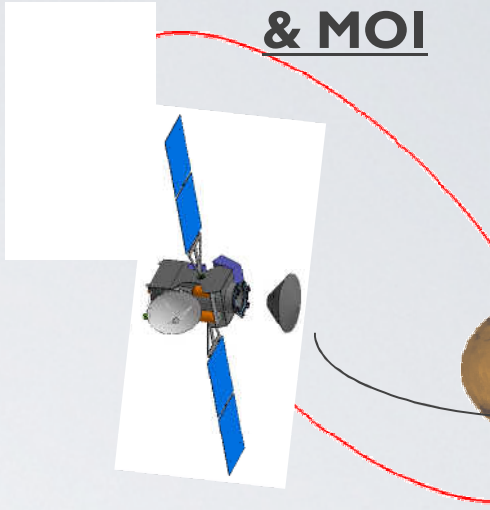
Atlas V 421

INTERPLANETARY CRUISE



Type II, C3 = 7.44 km²/s²

APPROACH, EDM R & MOI

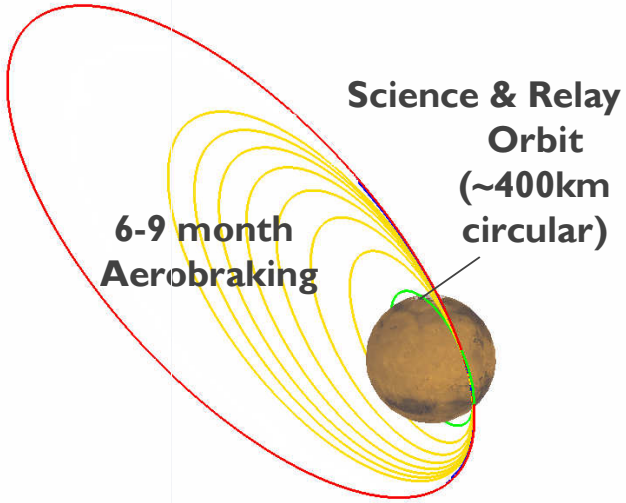


(1) EDM released from the hype
3 days before M
(2) Orbiter performs retargeting
sol orbit (inclination con
target landing s

ELAY & TRANSITION O 1-SOL ORBIT

lay for EDM during first 8 sols after landing

AEROBRAKING & SCIENCE PHASE



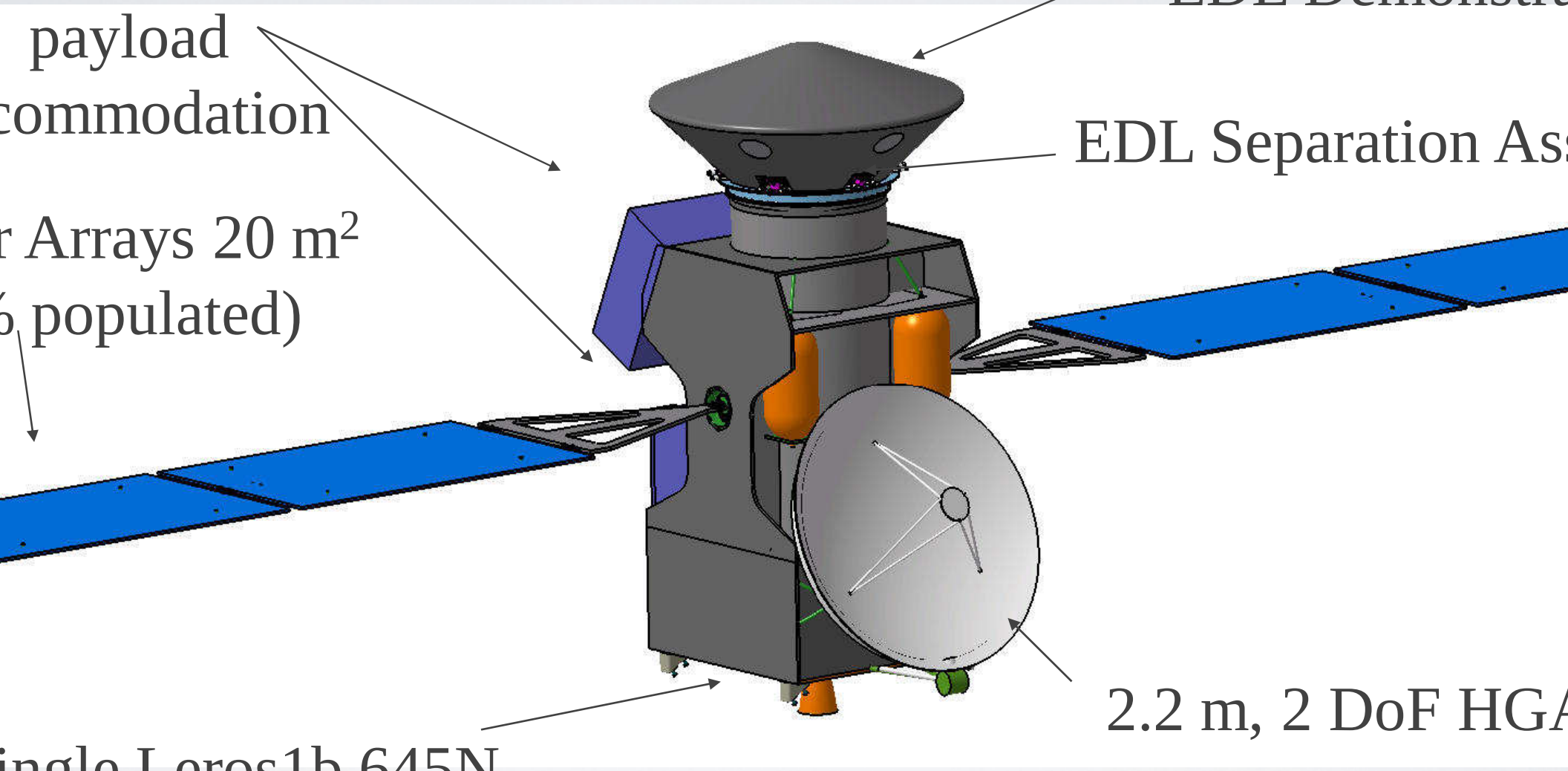
(1) Aerobrake to final orbit

DATA RELAY PHA

(1) Data relay for 2018 Rover
Jan 2019

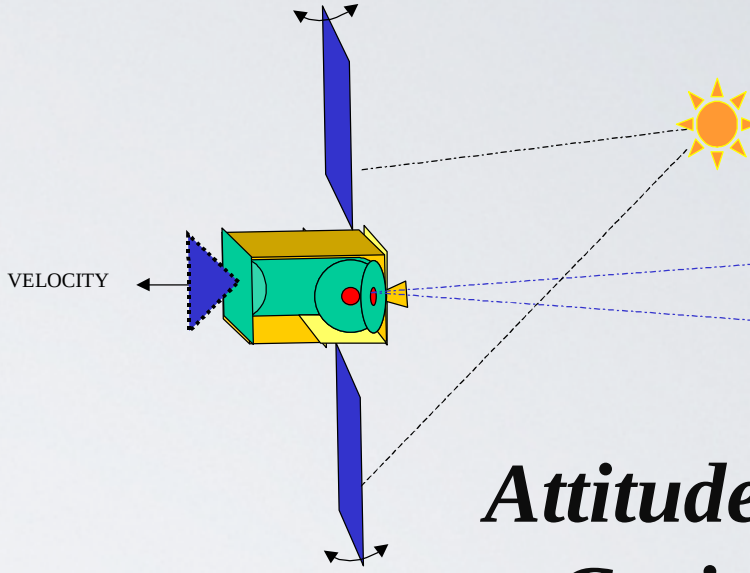
Spacecraft Composite - the Flight System

Spacecraft Composite (based on Orbiter Bus configuration 4AL)



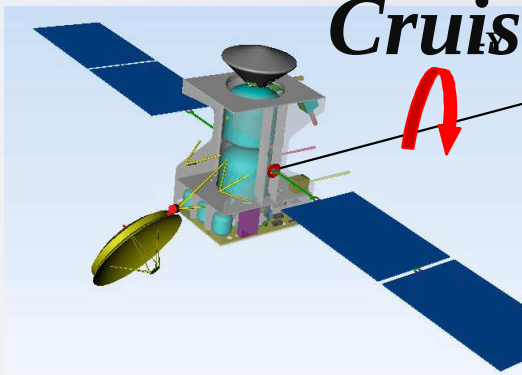
Orbiter Module (1/4)

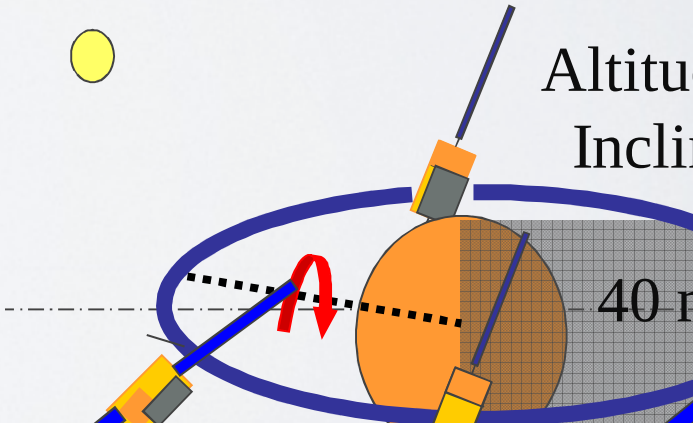
- **MARS Nadir Pointing – Yaw Steering strategy**
  - Allows for keeping – Y axis always Mars Nadir oriented with simultaneous Sun pointed Solar Arrays and Earth pointed High Gain Antenna
  - Max Yaw steering rate (around –Y axis) 1.5 mRad/s
  - *Yaw steering interrupted during Sun occultation measurements and during high resolution imaging slots*



Attitude

Cruis





Attitude during

Orbiter Module

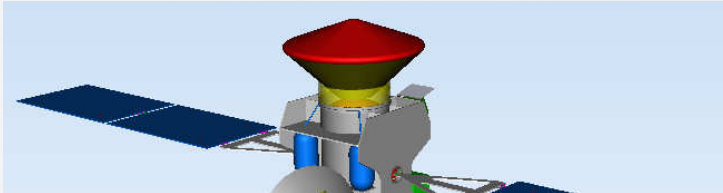
ionic/Electrical Systems

Steerable (1 DoF) Solar Arrays (2 x 10m^2 with 18.1 m^2 active) providing ~ 1800 W

Re-chargeable Lithium-Ion batteries with ~ 500 Wh to capacity

Unregulated voltage bus for instruments (22 V-34 V)

Centralised on-board computer: 1553 command/contro and Spacewire data I/F



Orbiter Module

o-Frequency Equipments

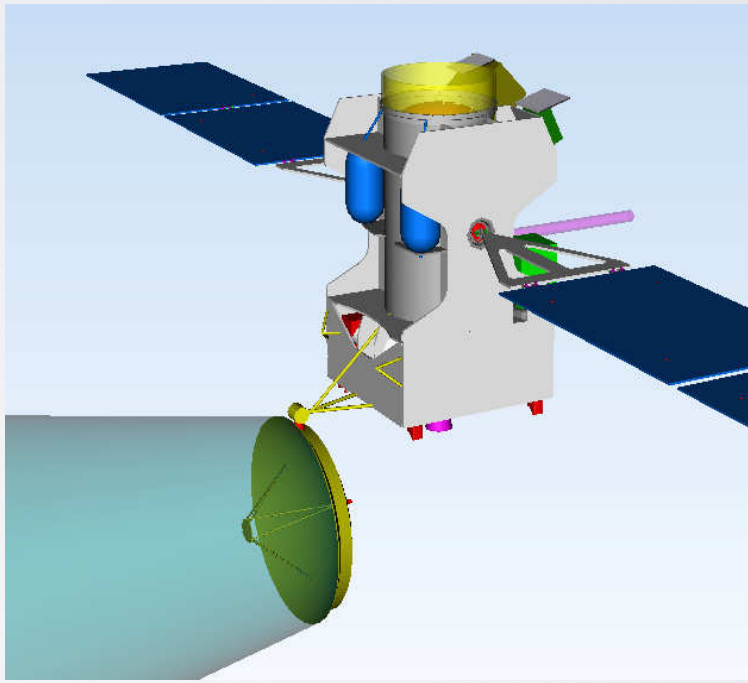
DoF HGA 2.2 m diameter (from Rosetta)
65 W TWTA

-band TM data rate (average)

- 150 kbps (max range) ~ 5 Gbits/day
- up to 900 kbps ~ 8 Gbits/day

HF-Band Electra transceiver and USO
NASA contribution)

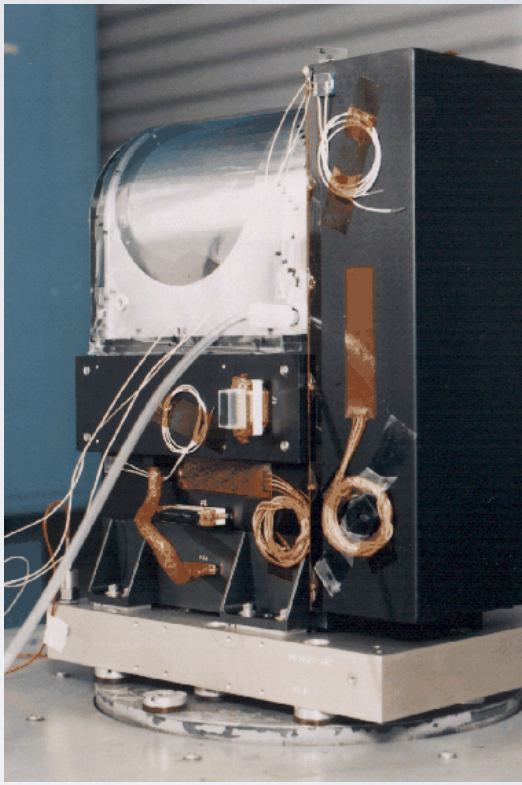
HF TM data rate: ~ 400 Mbits/sol average
om ExoMars and MAX-C Rovers

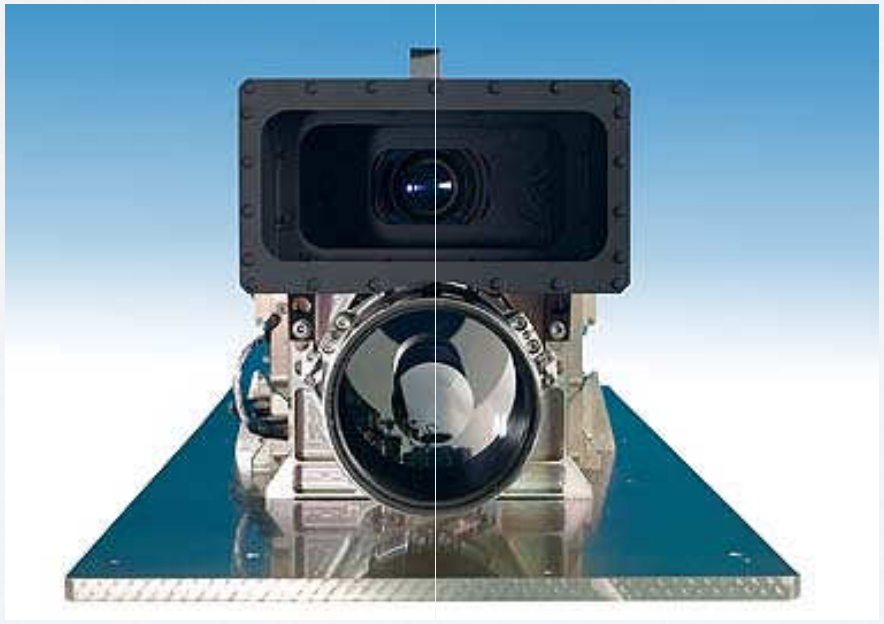


DT Strawman Measurement Approaches
ual Instrument Suite to be Selected thru AO)

R

SUB-MM





HRSC

WAC

ym	Description	View Modes	Observation Modes
	Solar Fourier Transform IR Spectrometer: **Broad survey** of trace gases with high precision	Solar Occultation only; passive radiative cooler	2 Solar Occultations per orbit (~24/d processing interferorgrams throughou
	Solar-Nadir IR Mapper: Detection and mapping of **specific** trace gases	Solar occultation; nadir and limb viewing; heat sink required (assumed to be provided by s/c)	2 solar occultations + dayside nadir/l (60 min) on each orbit
m	Sub-mm Spectrometer profiler/mapper **Atmospheric temperature & winds** plus **H2O and specific** trace gases	Nadir and limb, including away from velocity vector	Continuous operations switching betw nadir, space, different limb; observe l sides of ground track
	Thermal IR profiler/mapper spectrometer or radiometer for atmospheric **temperature and dust,** plus **H2O and some** trace gases	Nadir and limb views, including away from velocity vector	Continuous operations switching betw nadir, space, different limb; observe l sides of ground track
	Wide Angle Camera imaging **atmospheric phenomena** for discriminating between surface, dust clouds, & ice clouds	push-frame operation with .GE. 2 color bands; requires alignment with ground track motion	Cross-track (nearly orthogonal to vel vector) horizon-to-horizon
	High Resolution Color Stereo Camera: **Surface imaging**	~1 m/pixel ground sampling (at nadir) with TDI; fore/nadir/aft views	Designated targets of opportunity; re alignment with ground track motion (mitigation needed)

The EDLS Demonstrator

ximum Mass at launch 600Kg

mi-soft (almost soft) lander with liquid retro-propulsion

nding gears (TBD) crushable material, vented airbags, legs

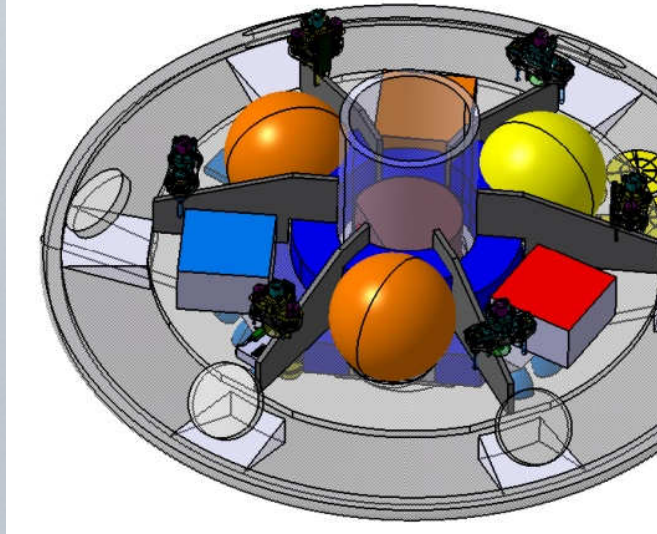
nimum Payload operated on primary battery (5-7 sol lifetime)

ss less than 5Kg and no deployment mechanisms

ence Goals: mostly environmental assessment

EDM CONFIGURATION

Internal View



Parachute

Antenna

HEPA filter

MSM

Sun Sensor

Access Door

Entry, Descent and Landing Demonstrator

- 2.4 m Φ Entry Shield

EDM Science

Science Sensors TBD

ubject to limitations of resources

TBD kg of sensors with accommodation hardware

Energy for operations limited to battery capacity on surfa
~8 sols

Data volume availability related to overflight of Orbiter

Back Cover Mould

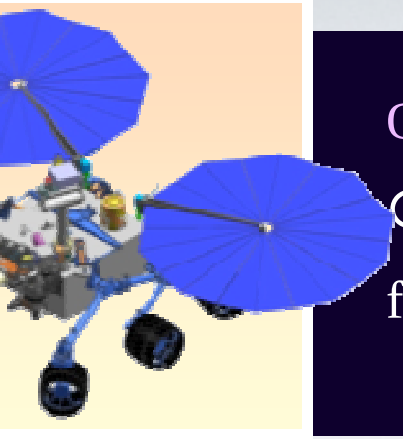
8

TECHNOLOGY OBJECTIVES

- Surface mobility with a rover (having several kilometres range);
- Access to the subsurface to acquire samples (with a drill, down to 2-m depth);
- Sample acquisition, preparation, distribution, and analysis.

SCIENTIFIC OBJECTIVES

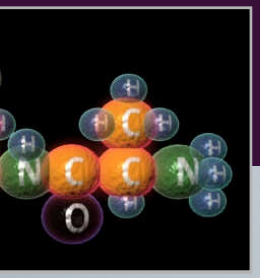
- To search for signs of past and present life on Mars;
- To characterise the water/subsurface environment as a function of depth in the sh subsurface.



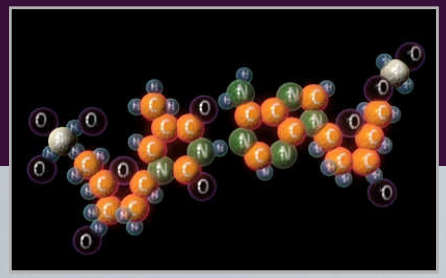
OBJECTIVE

- To identify, acquire, document, and cache “outstanding” samples in a manner s for collection by a future Mars Sample Return mission.

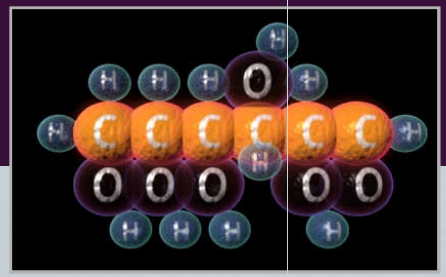
ENT LIFE: Biological markers, such as:



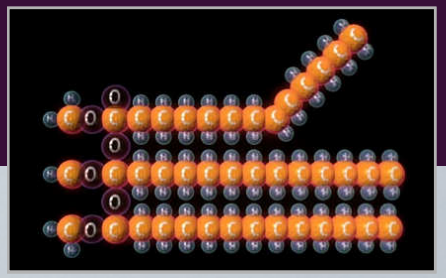
no acids



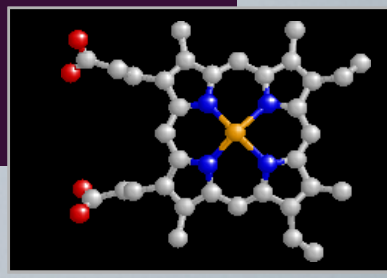
Nucleobases



Sugars



Phospholipids

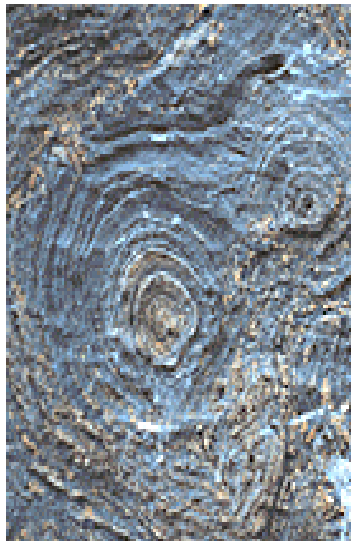


Pigments

- **PAST LIFE:** Organic residues of biological origin; (chemical, chiral, spectroscopic, and isotopic info)

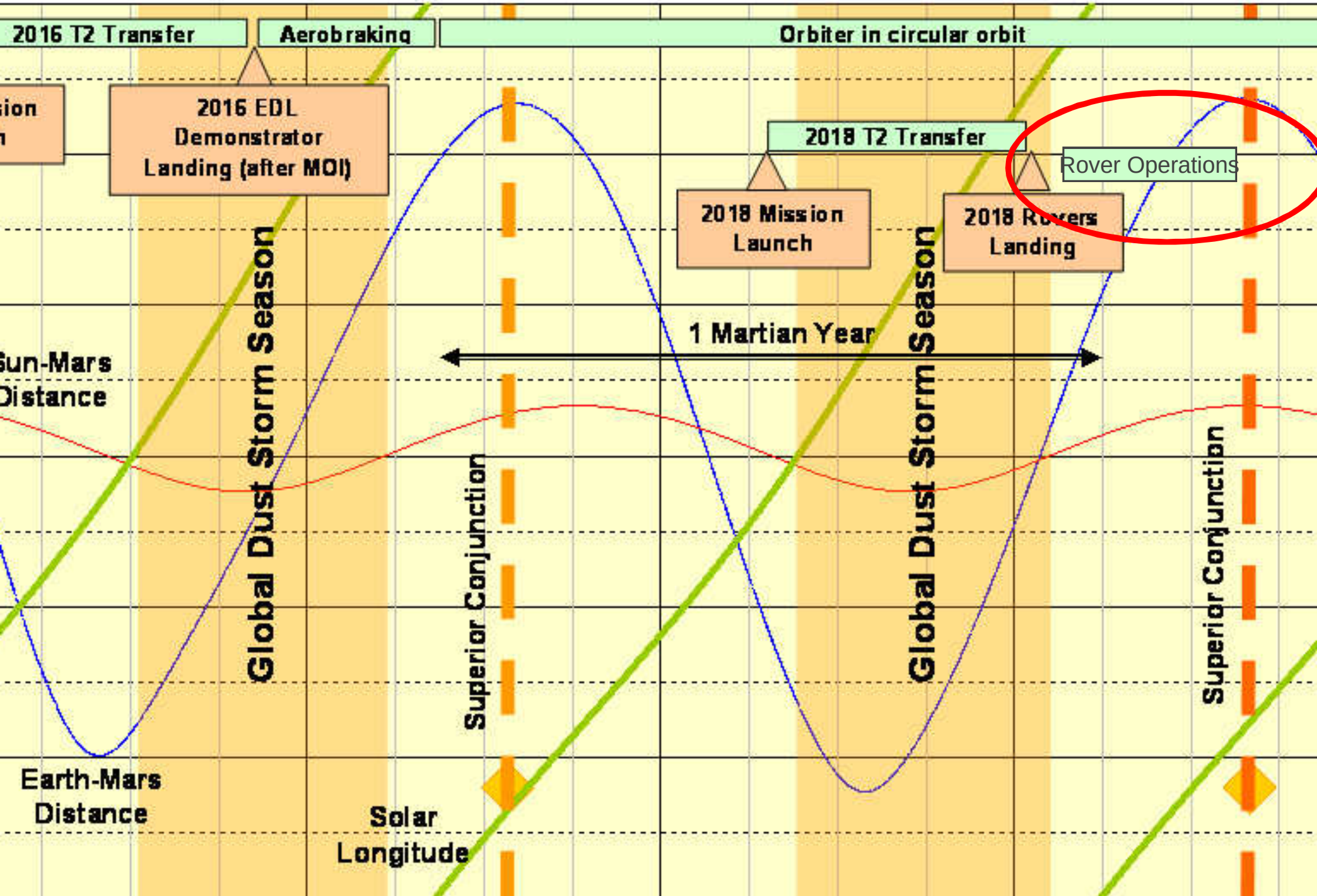
  Images of fossil organisms and their structures;

  (morphological evidence)

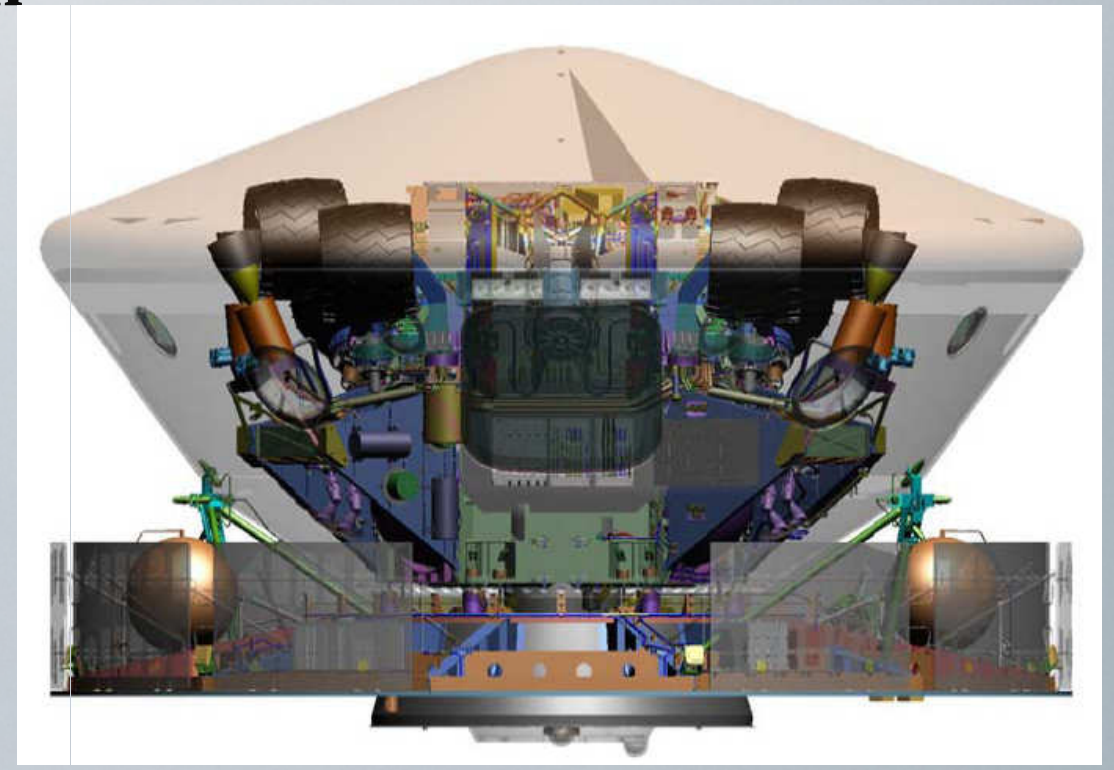


- **DELIVERED ORGANICS:** by meteoritic and cometary infall

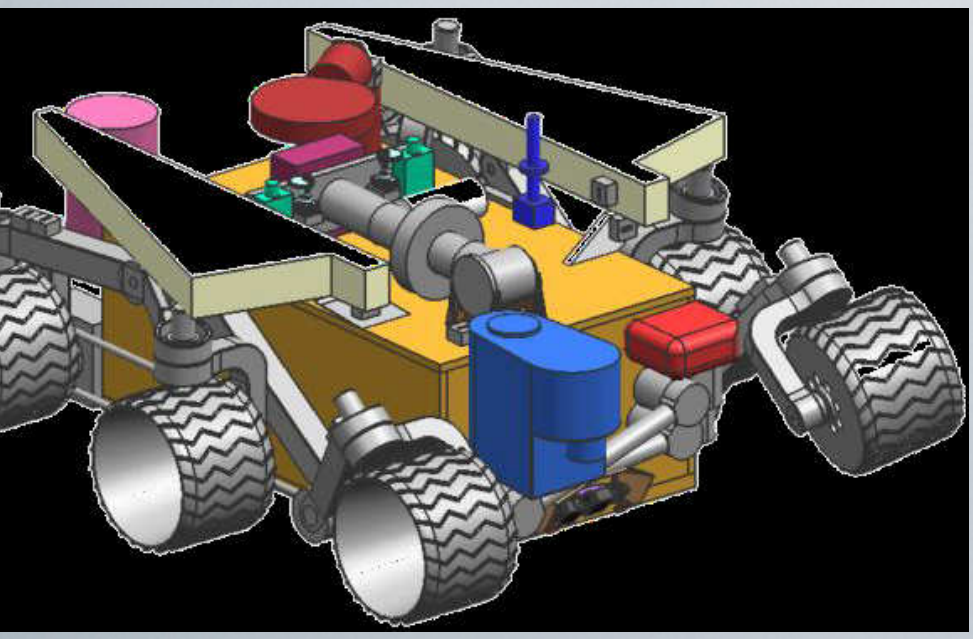
2018 Mission Context

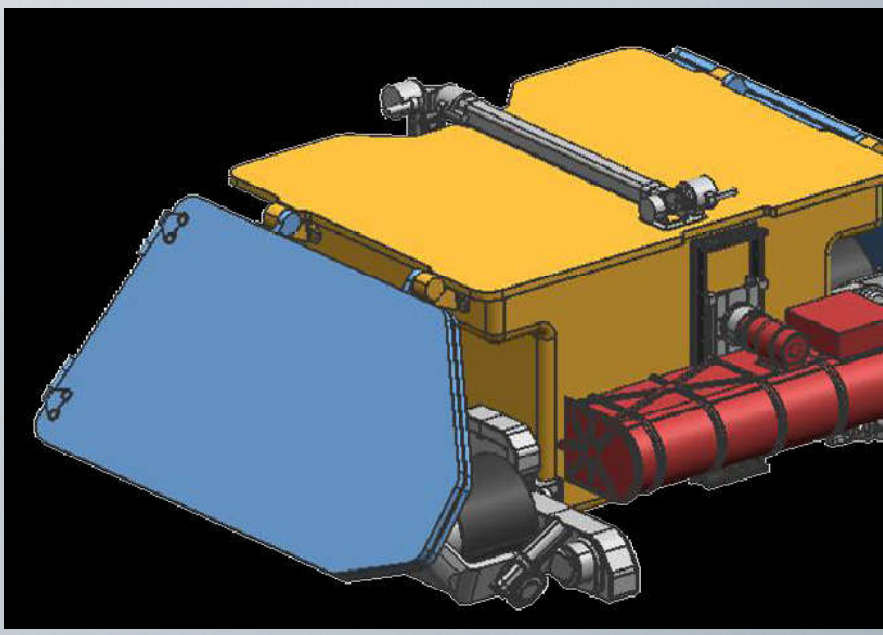


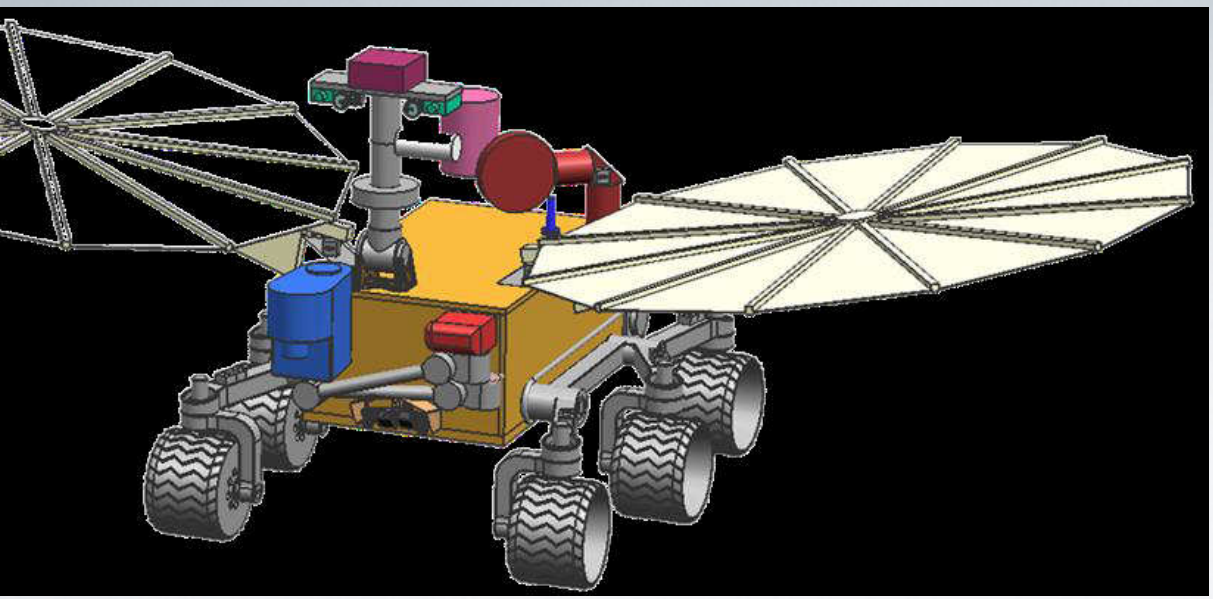
2011 MSL Configuration

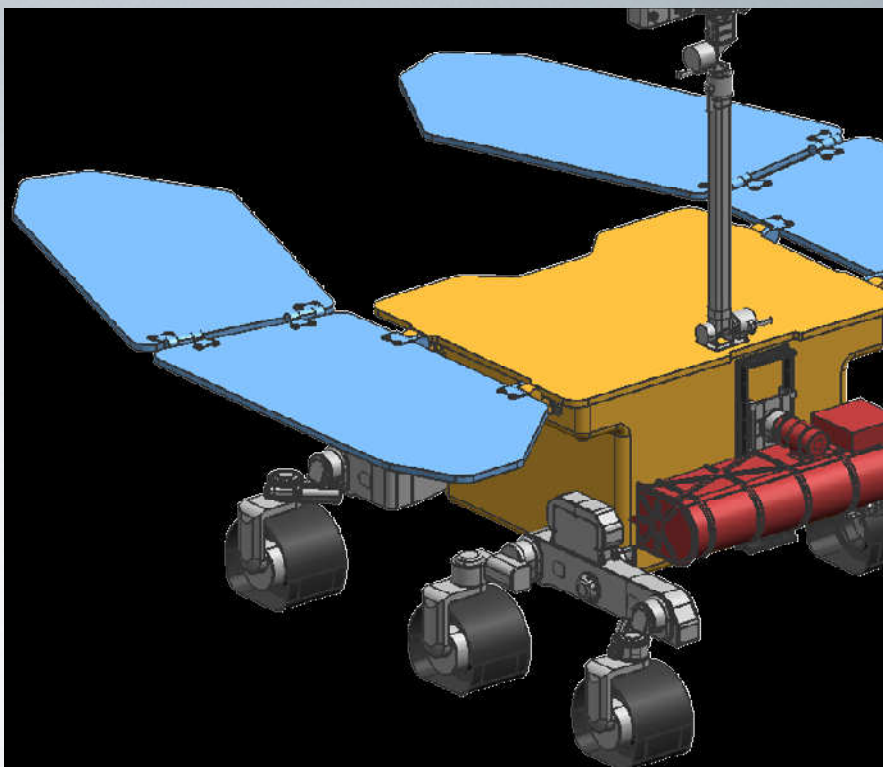


MAX-C & ExoMars-RM Configurations



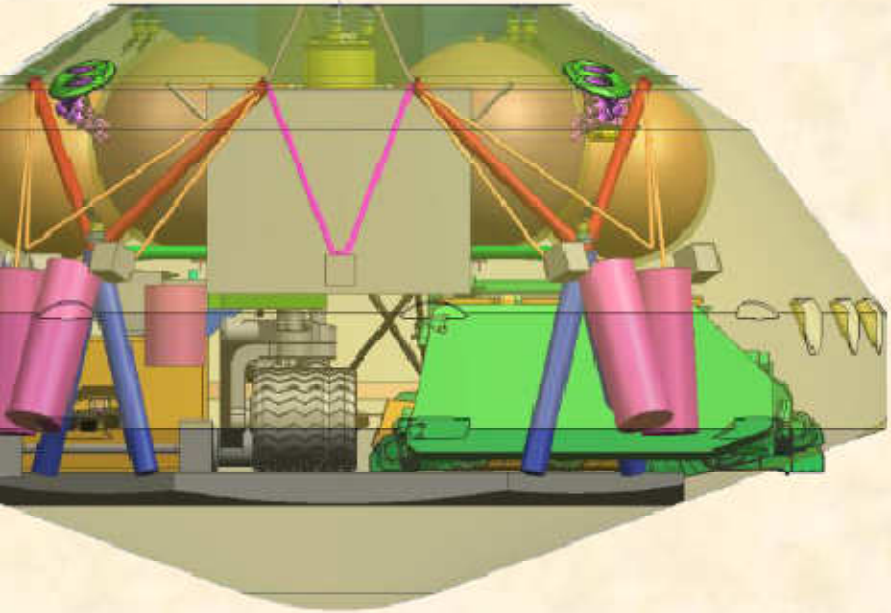




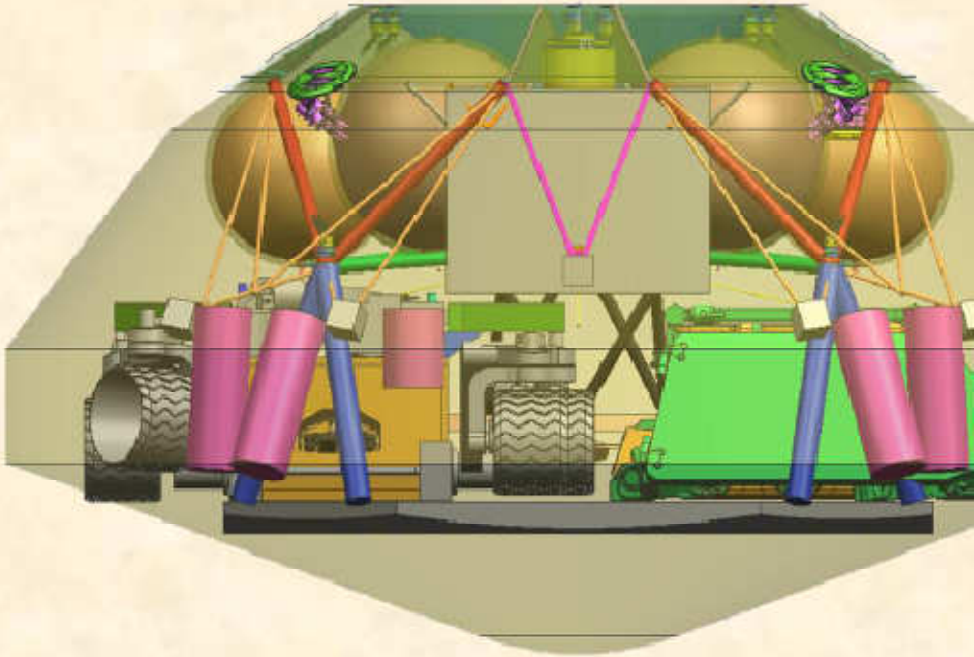


2018 EDL Configuration Trades

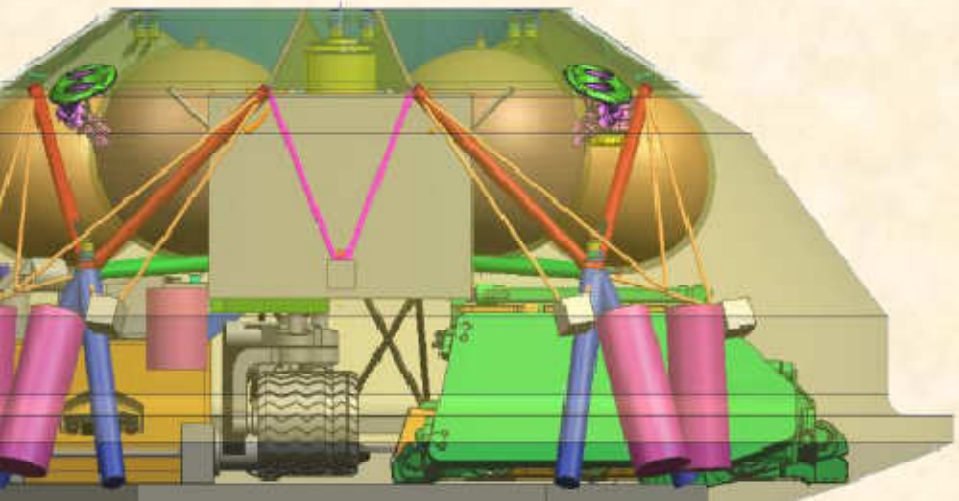
4.5 m Viking Envelope



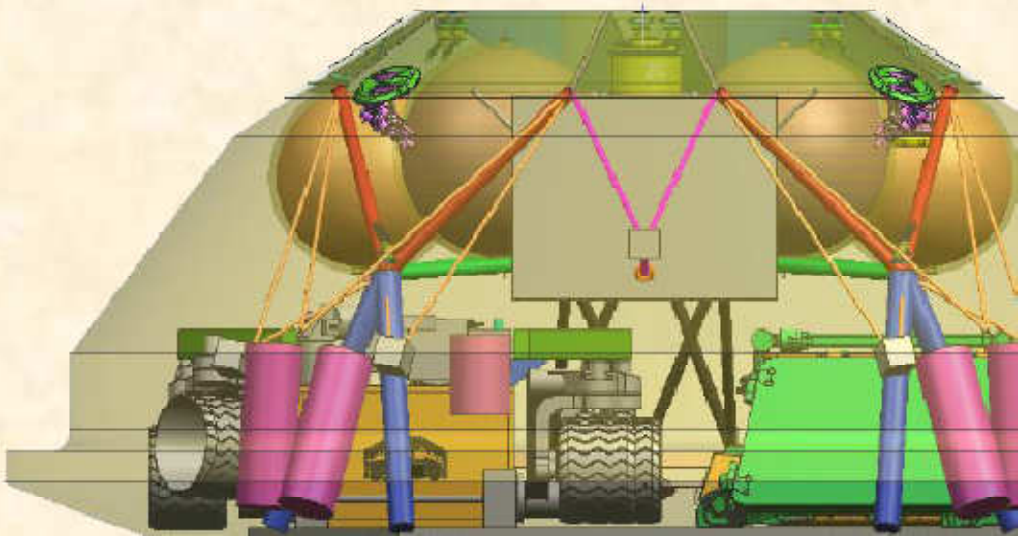
4.7 m Viking Envelope

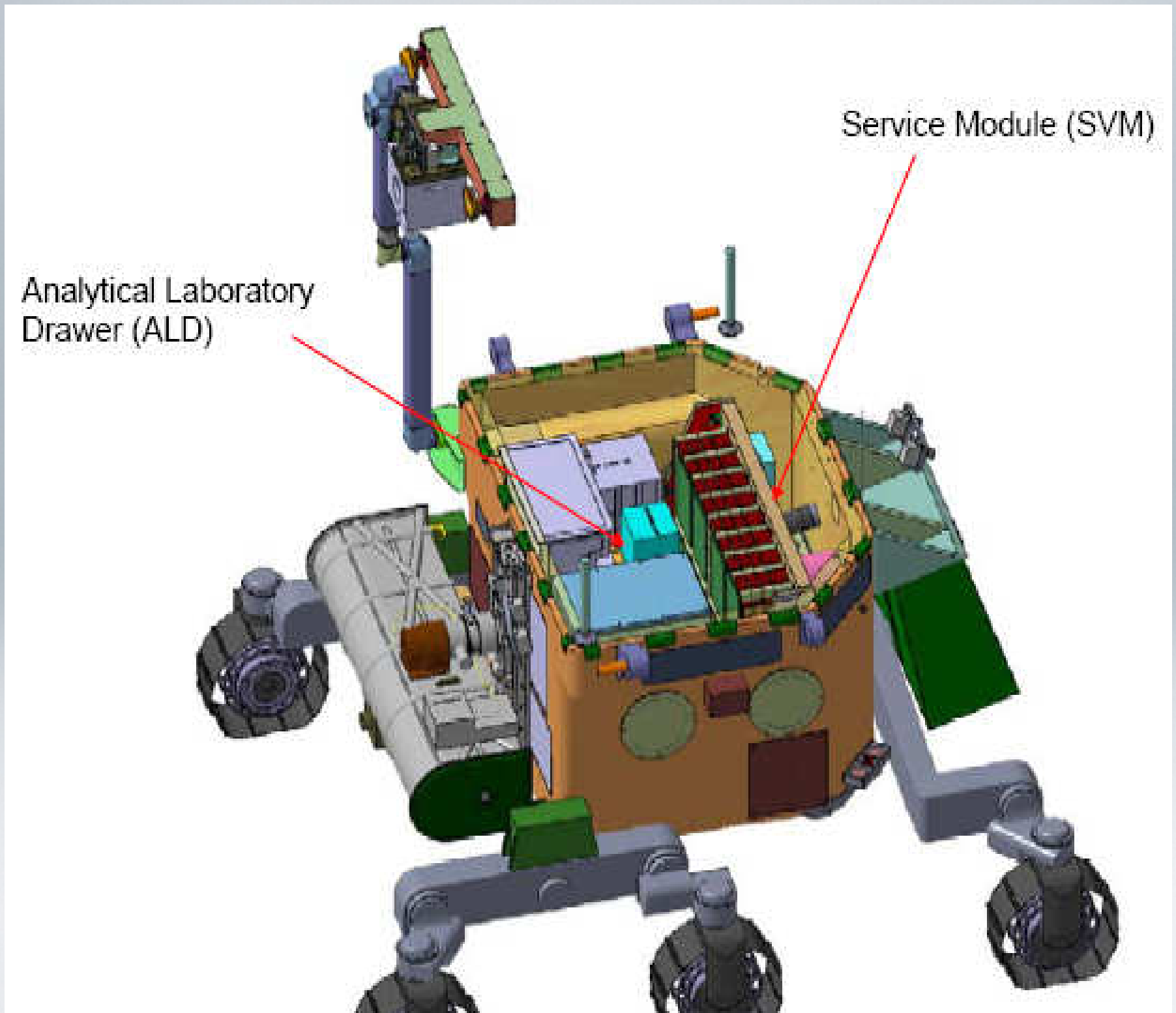


4.5 m Apollo/Orion Envelope

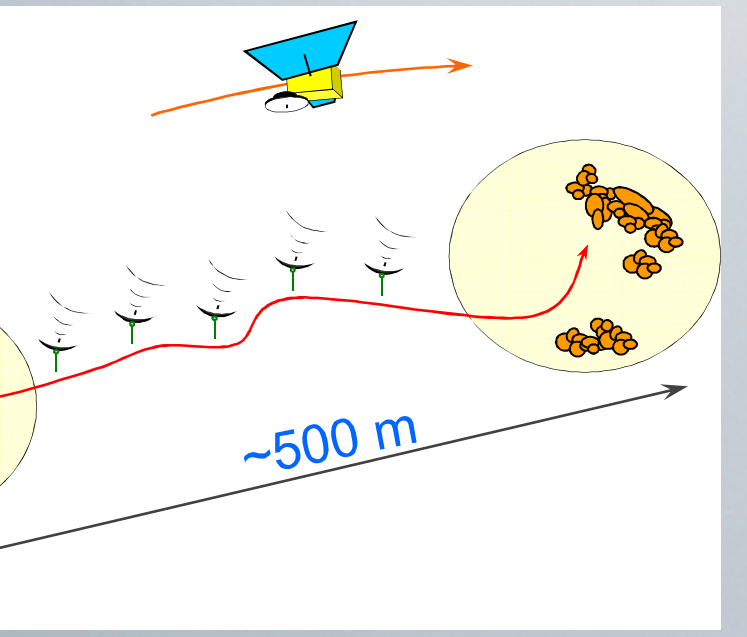


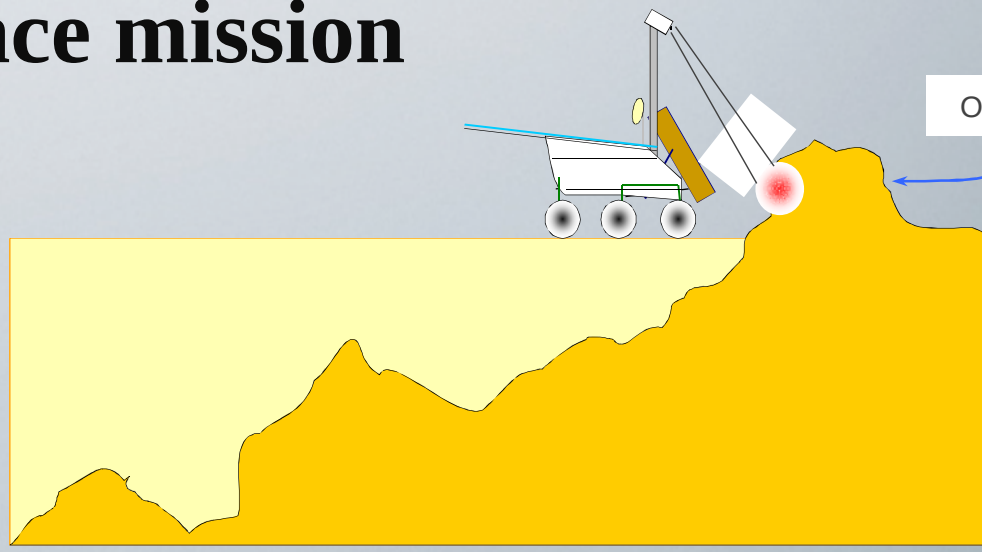
4.7 m Apollo/Orion Envel

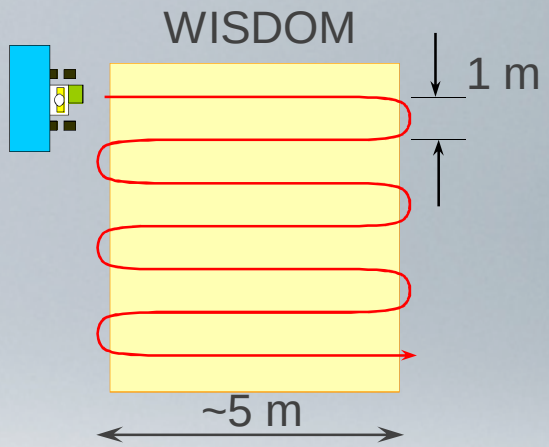



Service Module (SVM)
Analytical Laboratory
Drawer (ALD)

Rover reference mission

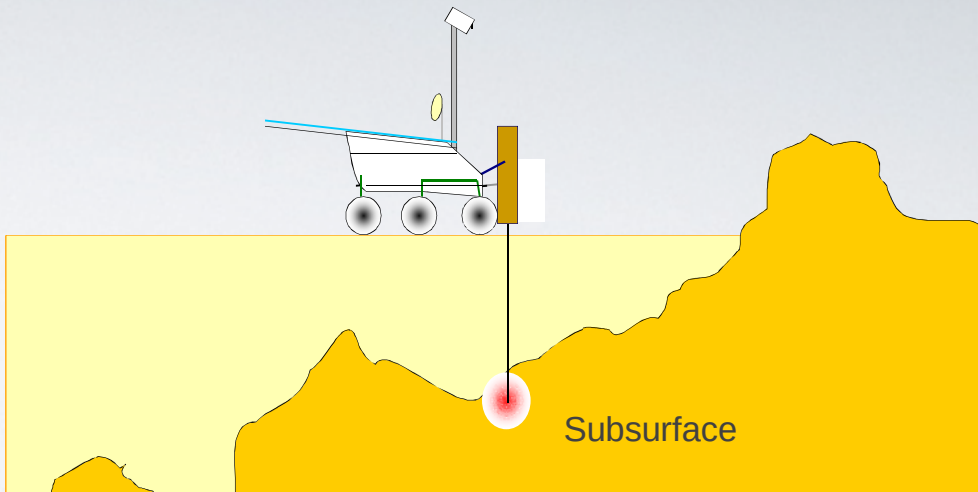






❑ 6 Experiment Cycles

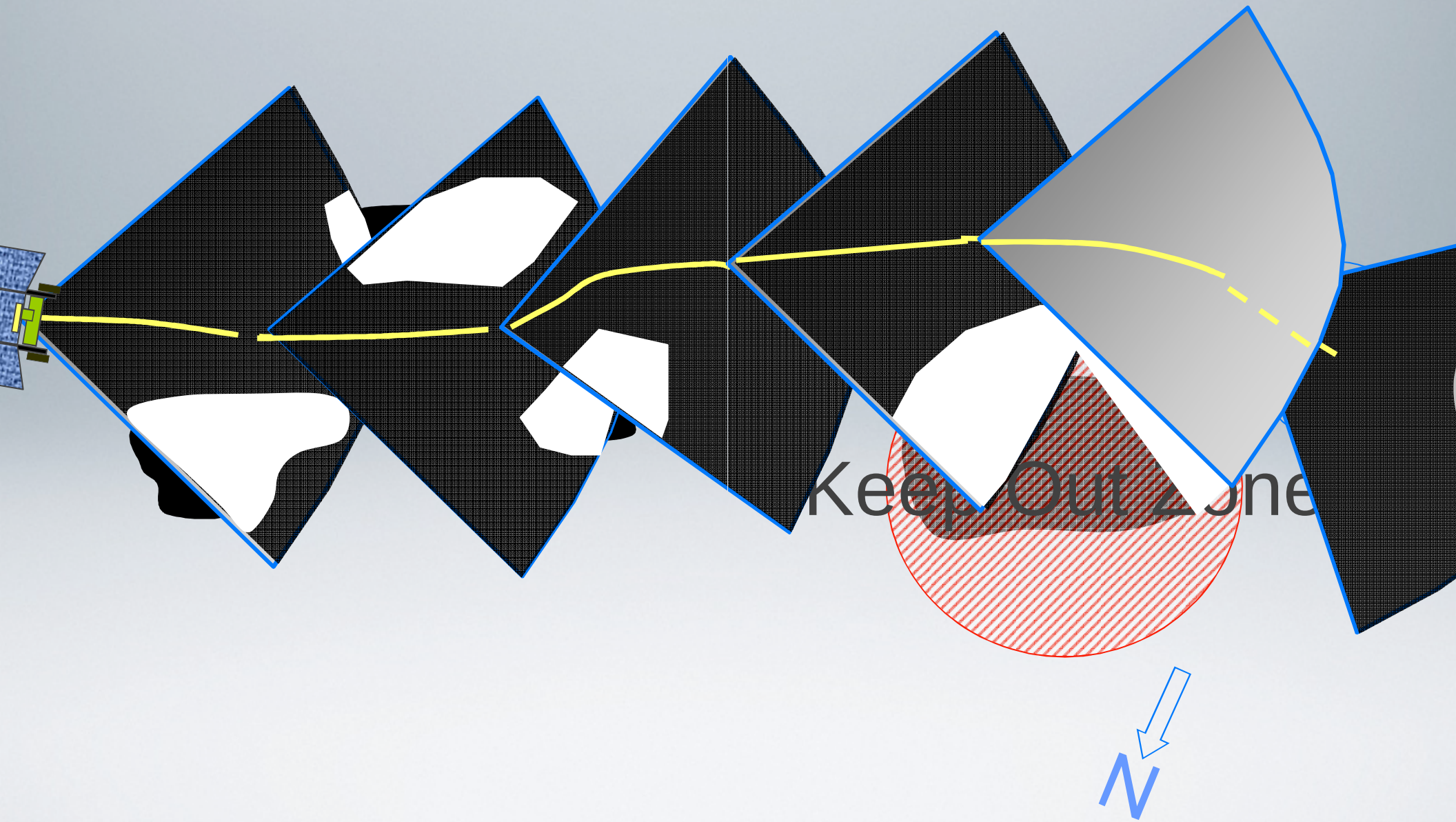
mental transverse distances 100m > 500 m
Visual & Ground radar within ~ Ø20 m
o close-up observation and surface sampling
- Ground radar mapping
rilling (~1.5 m) and sample acquisition
ample distribution and optical inspection
ple crushing and analytical characterization



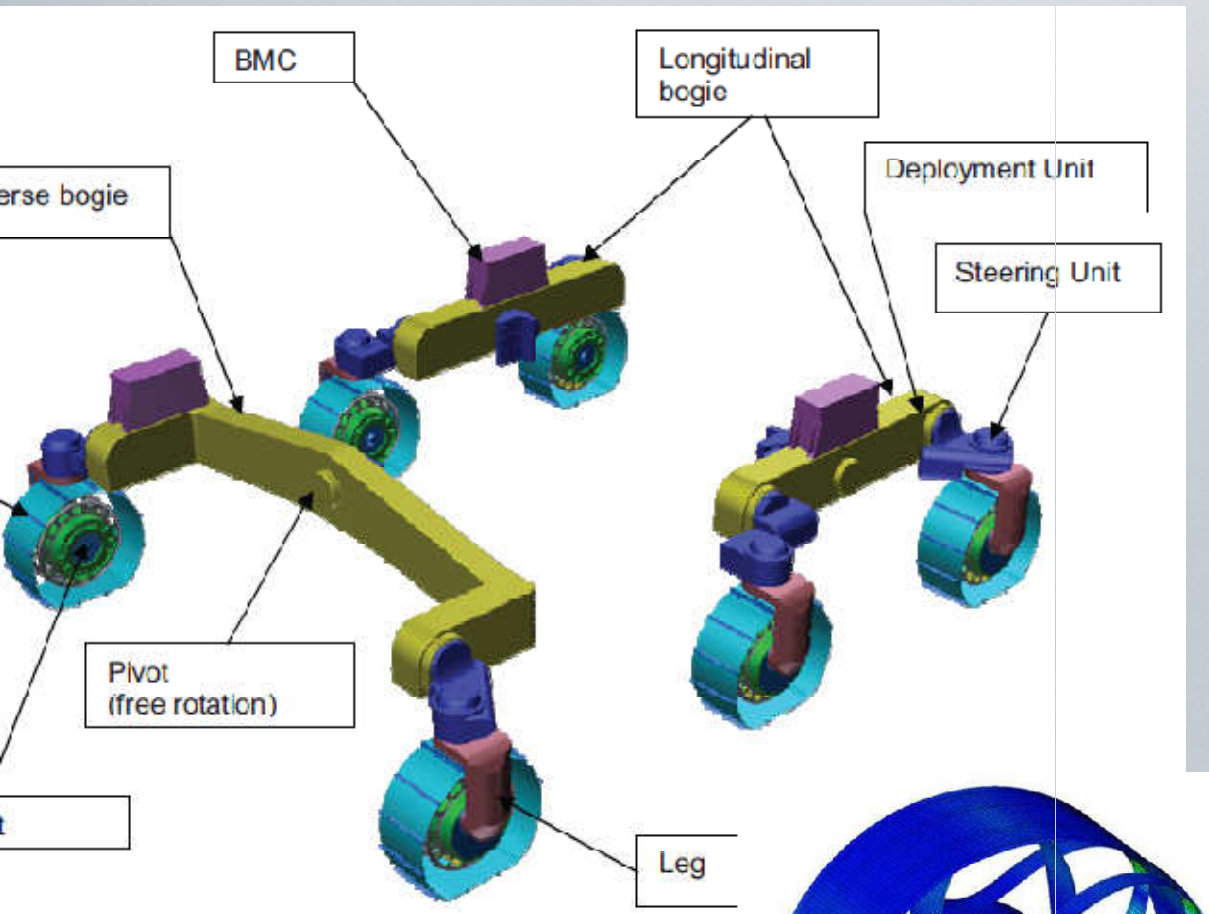
❑ 2 Vertical Surveys

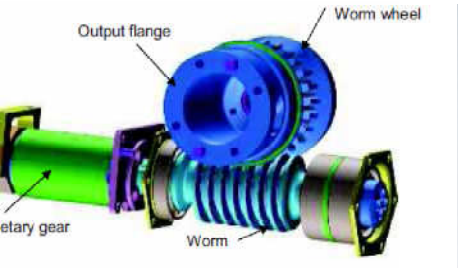
Drill and obtain sample from surface
- Sample distribution and analysis

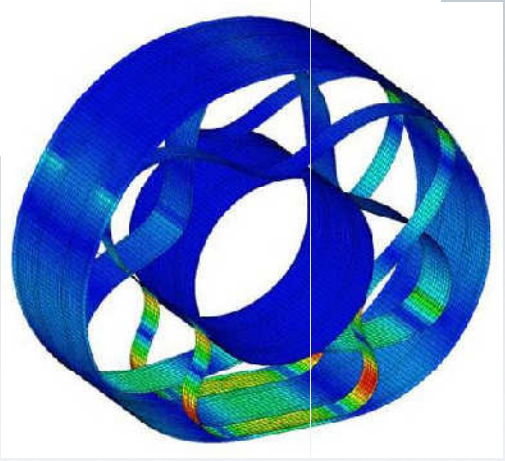
Autonomous Navigation Animated Example

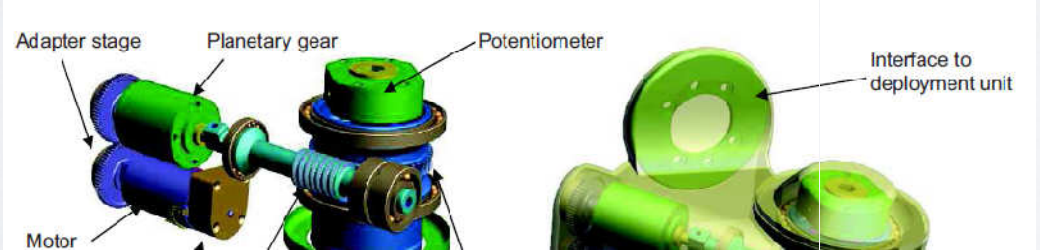


ocomotion System





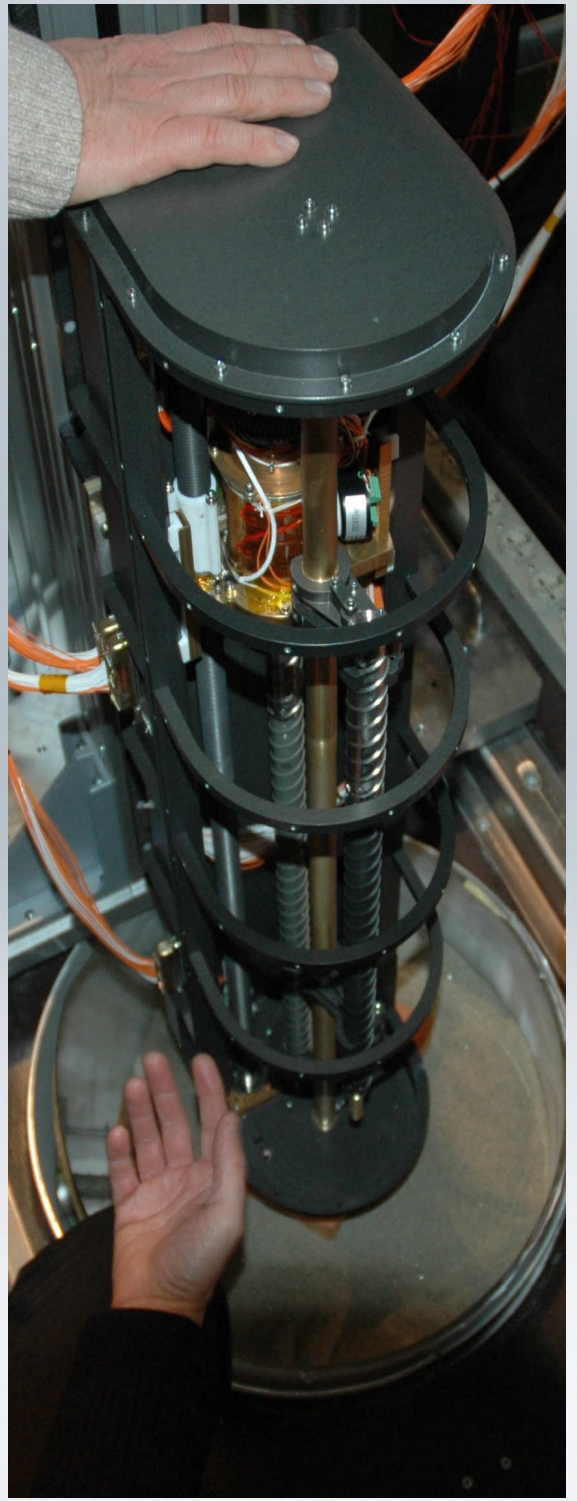


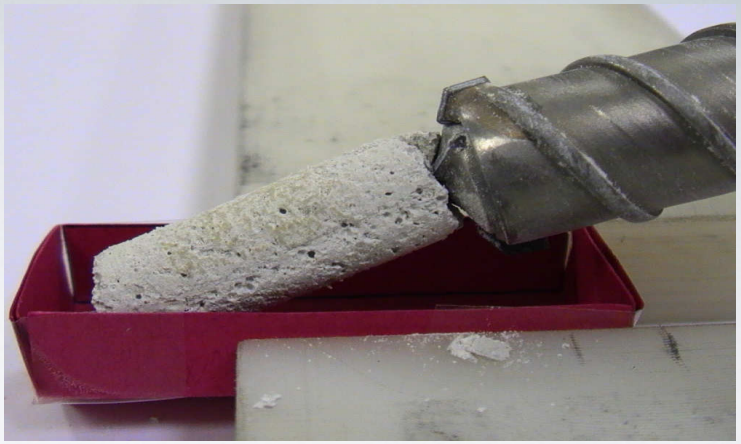


- 21 DoF system
  - 6 Drive
  - 6 Steer
  - 6 Deploy/Wheel Walking
  - 3 Bogey rotation

- Sub-system consists of
  - Mechanical Assembly
    - Bogeys
    - Actuators
    - Flexible Wheels
  - Control Electronics and Motor C Algorithms (BMC)

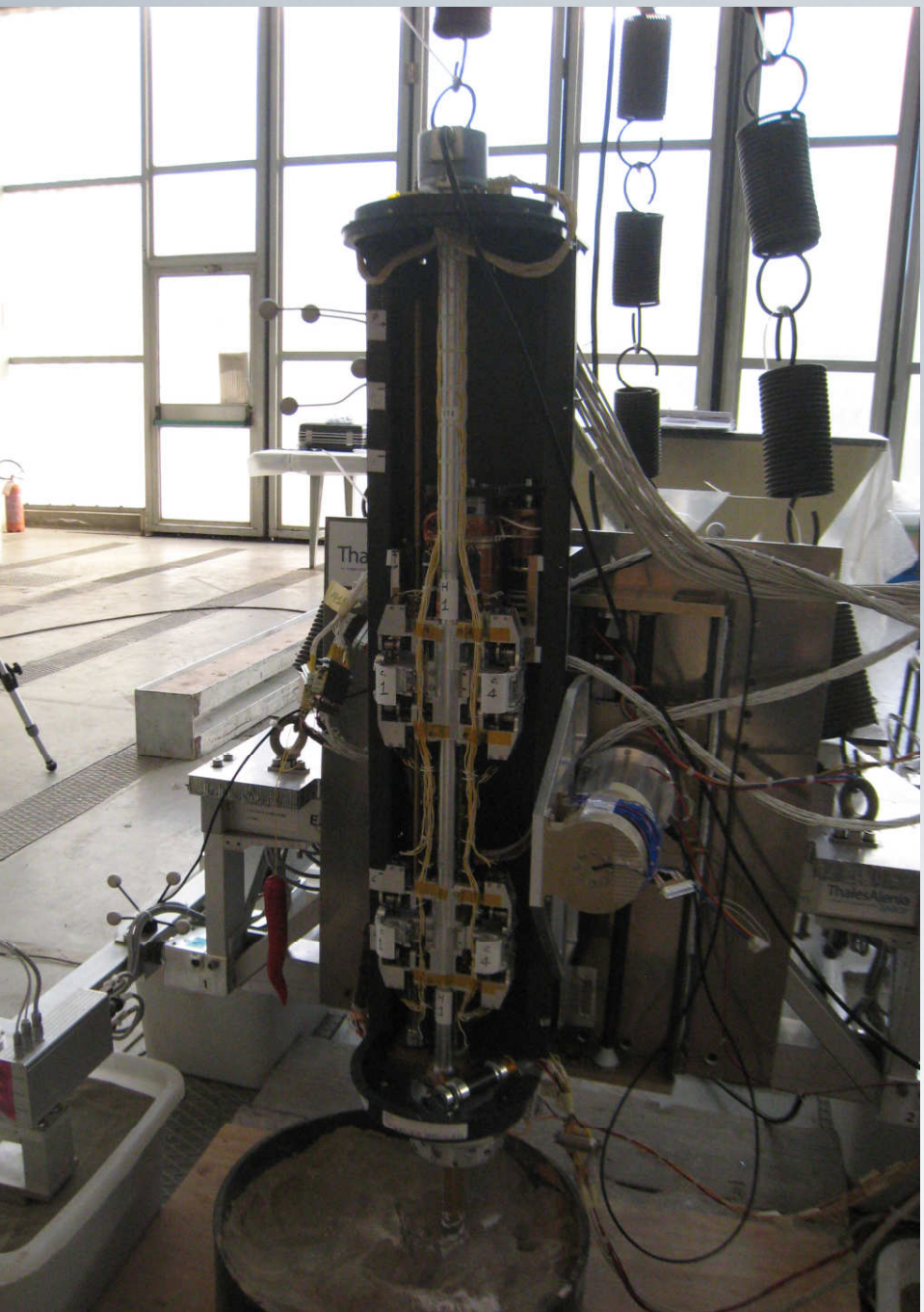
Drill

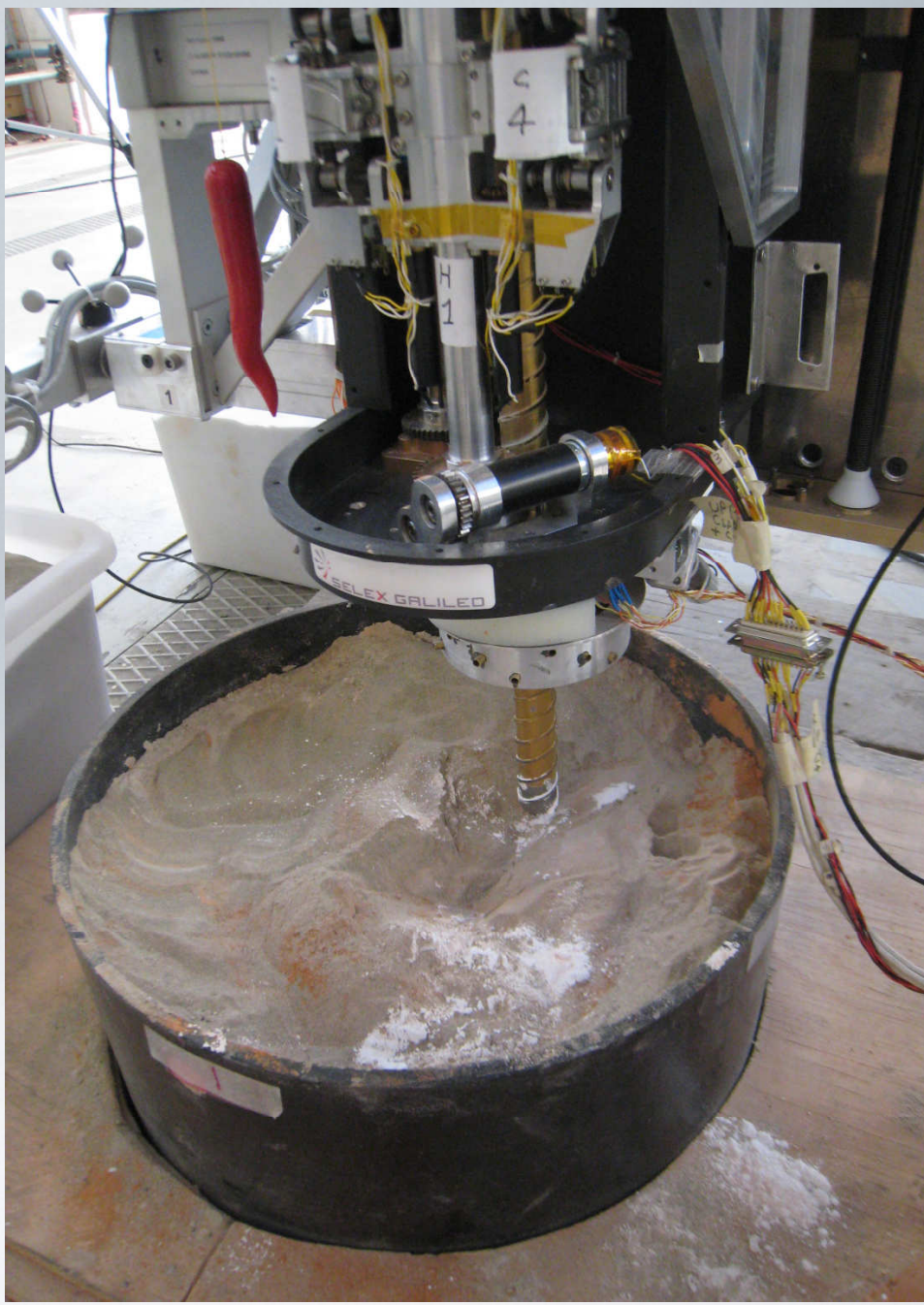




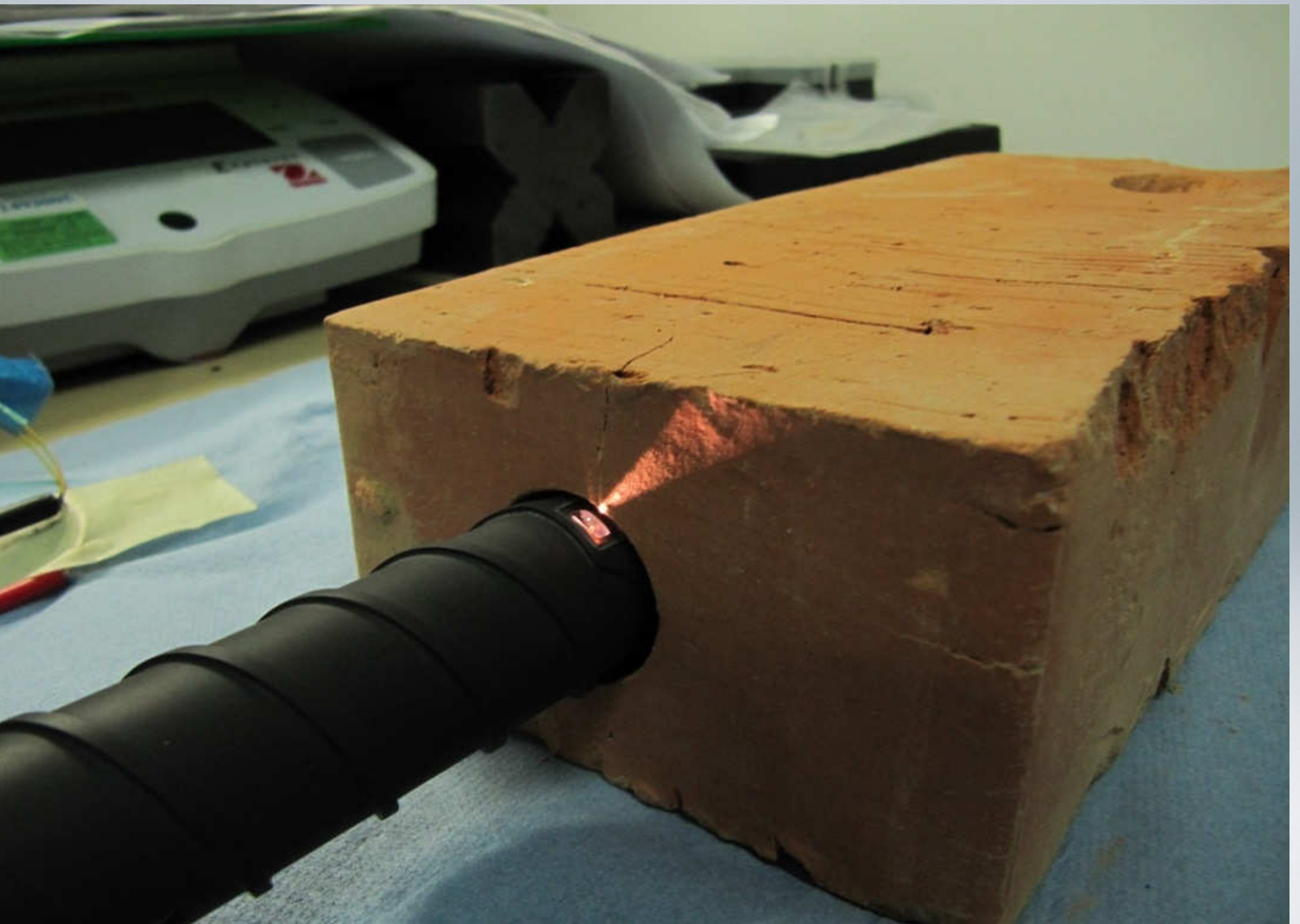
Drill Tool with sample

Drill Tests on going at TAS-I

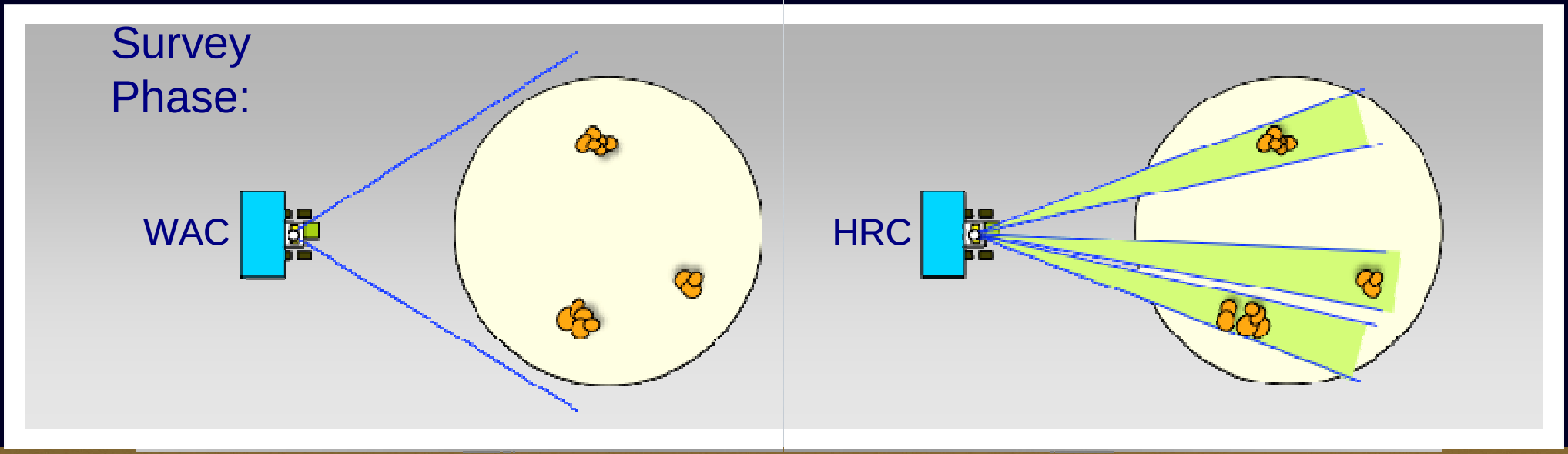


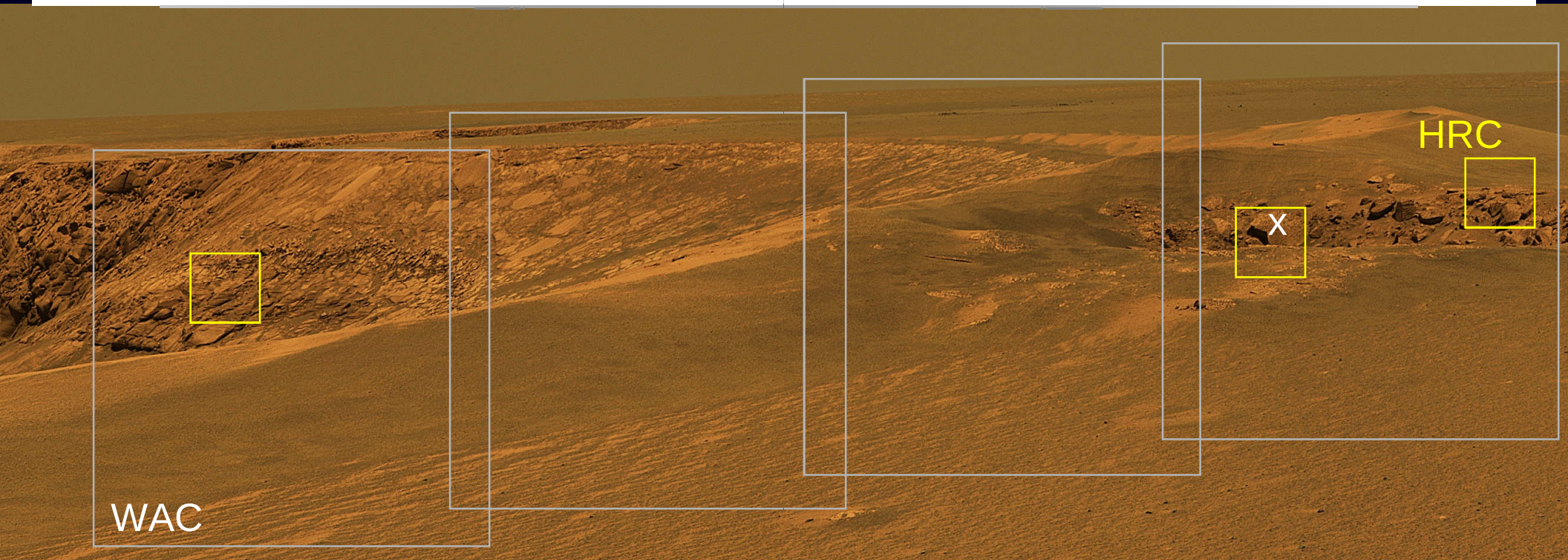


Ma_Miss Accommodation



PANORAMIC SCALE: To establish the geological context





ROCK SCALE: To ascertain the past presence of water
For a more detailed morphological examination

High-Resolution Camera

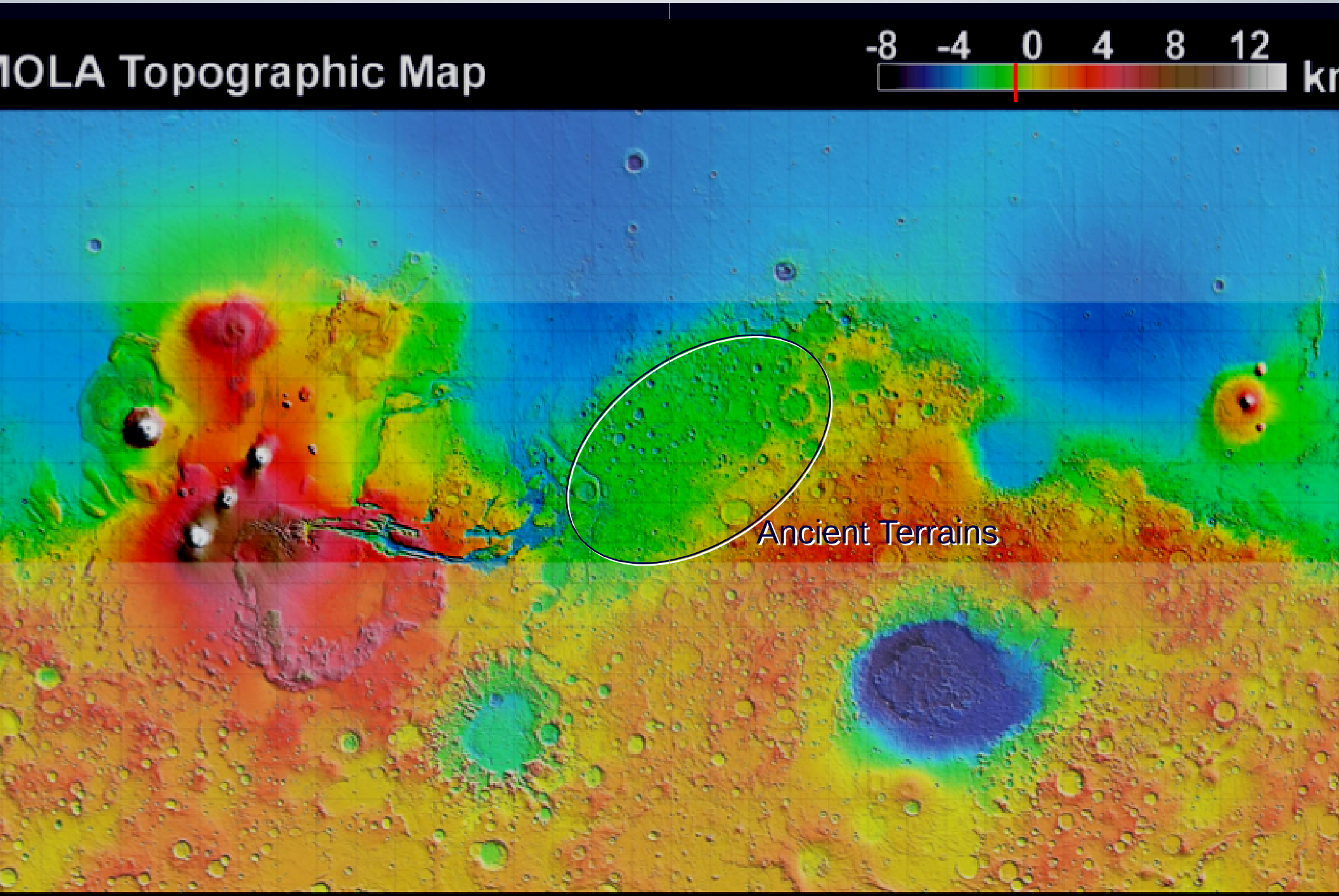
Close-Up Imager

Next step: **ANALYSIS**

Use the drill to collect a sample
- From an outcrop
- From the subsurface

Instrument Name	Description	Mass (kg) including maturity margi
PanCam (WAC + HRC)	Panoramic camera system	1.560
MOMA	LD-MS + Pyr GC-MS for organic molecule characterisation	6.100
MicrOmega IR	IR imaging spectrometer	0.960
Mars-XRD	X-ray diffractometer + X-ray fluorescence	1.480
Raman (internal)	Raman spectrometer	2.260
WISDOM	Shallow ground-penetrating radar	1.380
a_Miss included in 2.0-m drill	IR borehole spectrometer	0.650

+ CLUPI


MOLA Topographic Map
-8 -4 0 4 8 12
km
Ancient Terrains