Exploration of Mars by the European Space Agency

Alejandro Cardesín
ESA Science Operations
Mars Express, ExoMars 2016

IAC Winter School, November 2016
Mars Exploration nowadays...

2000-2010
- Mars Express (ESA)
- Odyssey
- MRO

2011
- Phobos-Grunt (RUSSIA)

2013/14
- MAVEN
- MOM

2016
- TGO (ESA-RUSSIA)

2018

2020
- ExoMars 2020 (ESA-RUSSIA)

Future ESA Studies...
- Mars Sample Return?

Spirit
- Opportunity

Phoenix

MSL Curiosity

Schiaparelli

ExoMars 2020 (ESA-RUSSIA)

Mars 2020

Future ESA Studies...
Mars Express 2003-2016 ... 

First European Mission to orbit another Planet! 
First mission of the “Rosetta family”
Up and running since 2003
First European Mission to orbit another Planet
First European attempt to land on another Planet

Original mission concept

Original mission layout... (Credit Astrium)
December 2003: Mars Express
Lander Release and Orbit Insertion

Bye bye Beagle 2!
Last picture after release, taken by VMC camera
19/12/2003 8:33
Beagle 2 was found in January 2015!

Only 6km away from landing site  OK
Open petals indicate soft landing  OK
Antenna remained covered  😞
Lessons learned: comms at all time!
Mars Express: so many missions at once

Mars Mission

Phobos Mission

Relay Mission
Mars Express science investigations

**Interior:**
Gravity field

**Sub-surface:**
physical properties and structures

**Surface:**
geology, composition, mineralogy, ...

**Atmosphere:**
composition, dynamics, temperature, climate, clouds, ...

**Martian Moons: Phobos & Deimos:**
surface, mass, volume, density, ...

**Ionosphere, Magnetosphere, Exosphere:**
Interaction with solar wind, auroraes

Comprehensive study of the planet and its history
Global coverage

145,000,000 km² total Martian Surface
98% 141,000,000 km² ≤ 100 m/pixel
70% 100,000,000 km² ≤ 20 m/pixel
Mars Express Payload: 8 Scientific Instruments

- **ASPERA:** Energetic Neutral Atoms Analyser
  PI: M. Holstroom, IRF Kiruna (SE)

- **HRSC:** High Resolution Stereo Camera
  PI: R. Jaumann, DLR Berlin (DE)

- **MaRS:** Mars Radio Science Experiment
  PI: M. Pätzold, RIU Köln (DE)

- **MARSIS:** Sub-Surface Radar
  PIs: R. Orosei, Univ. Rome (IT)
  J. Plaut, JPL (US)

- **OMEGA:** Visible and Infrared Mineralogical Mapping Spectrometer
  PI: J. P. Bibring, IAS Orsay (FR)

- **PFS:** Planetary Fourier Spectrometer
  PI: M. Giuranna, INAF Rome (IT)

- **SPICAM:** UV and IR Spectrometer
  PI: F. Montmessin, Latmos Paris (FR)

- **VMC Camera**
  A. Sanchez Lavega, UPV/EHU (ES)
  M. Almeida, DADP (CH)
  ESOC, ESAC, ESTEC

**Credit:** MEX/HRSC
Mars Express Science Highlights
Summary Video (~2min) https://youtu.be/hyWC_zPTLsI

Pioneering science
Life on Mars: Mars Express to ExoMars
Video (~4min) https://youtu.be/o52UR3CTJMQ
Methane (CH$_4$) on Mars shouldn’t be there

Methane molecules are destroyed by UV radiation within 100~300 years.
In 2004: three different groups reported observation of methane in Martian atmosphere:
  • Formisano et al. (Science 2004) 0~35ppbv
  • Krasnopolsky et al. (Icarus 2004) ~10ppbv
  • Mumma et al. (DPS meeting 2004) ~250ppbv

Methane existence has great geological/biological implications
Where is Methane on Earth coming from?

Methane may mean either life or geology: both with liquid water!
Subsurface Methane Sources

Volcanic or hydrothermal processes produce gases like SO$_2$, CO$_2$, .. and hydrocarbons like CH$_4$ and C$_2$H$_6$.

Biological activity produces gases like CH$_4$, H$_2$S ...
Volcanic or hydrothermal processes produce gases like SO₂, CO₂, and hydrocarbons like CH₄ and C₂H₆.

Biological activity produces gases like CH₄, H₂S, ...
By all rights, Mars should have zero methane. The gas is quickly cleansed from the air by chemical reactions driven by sunlight or weather patterns, and known geologic and astronomical processes cannot replenish it fast enough. Thus, the methane hints at unseen activity, such as black smokers or methane-creating microbes swimming in underground bodies of water.

**SPACE**

- **Ultraviolet photon**
  - Methane → Ethane

**CONVENTIONAL METHANE SOURCES**

- **Meteoritic dust** contributes a negligible amount of methane
  - Winds should mix methane uniformly throughout the atmosphere, so observed variations remain puzzling

**ATMOSPHERE**

- **Photochemical reactions** occur mainly above 60 kilometers
  - Water + Methane → Formaldehyde

- **Oxidation** occurs in lower atmosphere
  - Hydrogen peroxide + Methane → Formaldehyde

**SURFACE**

- **Electrochemical reactions** are driven by dust devils and wind
  - Methane clathrate could form methane produced by microbes or smokes and gradually release it to the surface through cracks

**POSSIBLE METHANE SOURCES**

- **Volcanoes** could vent methane if they erupted but currently appear to be dormant or extinct

**UQUIFER**

- **Methane clathrate** produced by microbes or smokers and gradually released to the surface through cracks

**DEEP CRUST/MANTLE**

- **Microbes** may produce methane by combining water with carbon-bearing molecules

- **Hydrothermal vents** may produce methane in a two-stage process involving water and rock
Methane detection over time
further measurements, but still controversial

Mumma, 2005-2009

Geminale et al., JGR, 2007

Workshop on Methane on Mars
Current observations, interpretation and future plans
25-27 November 2009, ESRIN, Frascati, Italy

Methane has been detected in the Martian atmosphere by ground-based telescopes and from orbit. This discovery indicates that the planet is either biologically or geologically active. The goal of the workshop is to review the available measurements, the potential reservoirs and release mechanisms of Methane and its circulation in the atmosphere, and to discuss all possible origins of this constituent.

Deadline for abstracts: 1st September 2009
http://www.congress.nl/09c28/
Possible Methane Sources

Atreya et al, 2009
MSL Curiosity 2013: no Methane???

NASA Curiosity Rover Detects No Methane on Mars

This picture shows a lab demonstration of the measurement chamber inside the Tunable Laser Spectrometer, an instrument that is part of the Sample Analysis at Mars investigation on NASA’s Curiosity rover.

Credit: NASA/JPL-Caltech

PASADENA, Calif. -- Data from NASA’s Curiosity rover has revealed the Martian environment lacks methane. This is a surprise to researchers because previous data reported by U.S. and international scientists indicated positive detections.

Credit: MEX/HRSC
MSL Curiosity 2014: actually... Methane is there! (but it comes and goes?)

Methane appears and disappears within months

Now we need sources and sinks!
Possible Methane Sources and Sinks

- UV
- Cosmic Dust
- Surface Organics
- Winds
- Photochemistry
- Methane
- Formaldehyde
- Methanol
- Carbon Dioxide
- Subsurface
- Methane Clathrate Storage
- Microbes
- Methane
- Olivine (rock)
- Water
ExoMars TGO science instruments may give us the answer soon...

### NOMAD

**High-resolution occultation and nadir spectrometers**

- **Atmospheric composition**
  - $(CH_4, O_3, \text{trace species, isotopes})$
  - dust, clouds, P&T profiles

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelength Range ($\mu m$)</th>
<th>$\lambda/\Delta\lambda$</th>
<th>SO</th>
<th>Lim</th>
<th>Nad</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVIS</td>
<td>(0.20 – 0.65)</td>
<td>250</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IR</td>
<td>(2.3 – 3.8)</td>
<td>10,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IR</td>
<td>(2.3 – 4.3)</td>
<td>20,000</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

### ACS

**Suite of 3 high-resolution spectrometers**

- **Atmospheric chemistry, aerosols, surface $T_s$, structure**

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<th>SO</th>
<th>Lim</th>
<th>Nad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near IR</td>
<td>(0.7 – 1.7)</td>
<td>20,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IR (Fourier)</td>
<td>(2.5 – 25)</td>
<td>4,000 (SO)/500 (N)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mid-IR</td>
<td>(2.3 – 4.5)</td>
<td>50,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Mars History of liquid water... (and life???)
Water Phase: Temperature & Pressure

- Solid
- Liquid
- Critical point: 647 K, 22.064 MPa
- Freezing point at 1 atm: 273.15 K, 101.325 kPa
- Boiling point at 1 atm: 373.15 K, 101.325 kPa
- Solid/Liquid/Vapour triple point: 273.16 K, 611.657 Pa
- Vapour
Habitability zone in the Solar System

MARS 1.52

EARTH 1 AU

VENUS 0.72

MERCURY 0.39

Global fridge

“Paradise”

Greenhouse oven

Thin atmosphere frying pan
Water balance on an Earth-like planet
(Greenhouse effect and atmospheric escape)

$T_s < 0 \, ^\circ\text{C}$

$T_s \sim 22 \, ^\circ\text{C}$

$T_s \sim 100 \, ^\circ\text{C}$

$T_s >> 100 \, ^\circ\text{C}$

Solar flux, W/m$^2$

Earth now 300

Venus now 625

Moist greenhouse

Runaway greenhouse
Possible evolution of Mars???
Mars today: surface elevation map
History based on other Physical Properties: dielectric constant measurement by MARSIS

- Dense volcanic rocks have high dielectric constants (basalt ~10)
- Low density porous sediments are lower (sedimentary <10)
- Pure water ice also has low dielectric constant (ice ~3)
- Maps of low dielectric constant are consistent with topography and with paleo-ocean shoreline around Mars' northern plains
- Episodic fluvial evolution of the northern plains resulting in massive ice deposits with layers of sediment and volcanic materials maybe before the underlying ice had sublimed away.

Credit: MEX/HRSC
Río Tinto, Spain

J. Mouginot et al. 2012
Topography
History based on Geologic Analysis: Glacial and Fluvial features by HRSC

Oldest fluvial features >100My ago
In line with oldest volcanic features

Glacial structures are more recent (<1My)
**History based on chemical analysis:**

hydrated minerals detected by OMEGA

- Mars surface mainly **ferric oxide red dust in northern young areas** and **Mafic minerals in older terrains** (olivine and pyroxene)

- **Liquid water is not responsible for Mars red color:** red dust (ferric oxydes) in younger Northern Lowlands do not show presence of water in its mineral structure; (oxidized without water/dehydrated, so no water?)

- **Hydrated minerals found, but not in obvious “wet” places,** river floors or deposits from outflow channels. (wet events too sudden to alter minerals?)

- **Hydrated Phyllosilicates (clays) are in very ancient locations,** Noachian era, buried rocks that only exposed by erosion. (Wet ancient Mars?)

- **Hydrated Sulfates require very acid water,** detected in Meridiani, Valles Marineris, and northern dark dunes.
Science Highlight 1: History of liquid water

- Start of conditions compatible with life
- Surface conditions becoming less habitable

Mars:
- Pre-Noachian
- Noachian
- Hesperian
- Early heavy bombardment
- Late heavy bombardment

Earth:
- Hadean
- Archaean
- Oldest preserved traces of life

Ga: 4.568 4.4 3.9 3.5
Beginning of terrestrial planet accretion
Martian History revisited based on hydrated mineral detection

- **Phyllosian era**: Phyllosilicates found in oldest terrains formed by aqueous alteration very early in the planet’s history;
- **Theiikian era**: Sulfates formed later in acidic environment.
- **Siderikian era**: since 3.5 Gyears, dominated by the formation of anhydrous ferric oxides in a slow superficial weathering, without liquid water playing a major role across the planet.

Revisited history of Mars, based on the detection of hydrated minerals (Bibring et al., 2006), in Mawrth Vallis (top left)
Where did the water and the atmosphere go?

Mars Express ASPERA analysis of ion composition & escape.

**Escape dominated by hydrogen & oxygen ions (WATER!)**

~1 ton per day → ~1 m of Global Ocean loss in 3~4 Gyear

Ion escape is not enough to remove the martian atmosphere. Some other mechanism is required: loss of neutral atoms?

**Water may be stored below planet’s surface or polar caps**

Also escape rate of carbon dioxide (CO2) is extremely slow, insufficient to for most planet’s assumed atmospheric loss.
Polar Ice Subsurface structures by MARSIS

MARSIS analysis of Water ice in polar caps down to a few kms

Equivalent to global ocean of 10~50m

More ice can be trapped deeper, also more distributed along the whole planet subsurface

3D reconstruction of ice polar caps
Global Monitoring of Climate variability

Global Climate Model
F. Forget et al.

Glacial Forms
HRSC
OMEGA

CO₂ Clouds

Montmessin et al., Icarus, 2015

Global Monitoring
Characterisation of Phobos and Deimos
Origin of Phobos and Deimos

captured asteroid? surviving planetesimals?
remnant of a giant impact of a large object on Mars?
Present and Future European Missions to Mars
ExoMars International Programme

2 missions: orbiter in 2016, surface rover in 2020
- Cooperation between ESA and Roscosmos
- Includes contribution from NASA.

Credit: MEX/HRSC
ExoMars 2016

Trace Gas Orbiter

Schiaparelli
Mission Profile

Nominal
Launch date: March 2016
Mars Arrival: October 2016
EDM landing: Meridiani, –1 km MOLA
Ellipse: 100 km x 15 km
TGO Aerobraking: 10 month duration
TGO Orbit: 74°, 400-km alt
ExoMars 2016: Objectives

TECHNOLOGY OBJECTIVES
- Entry, Descent and Landing with science instrumentation
- Relay Communications until 2022

SCIENCE OBJECTIVES
- Study of martian atmosphere: minor gases and sources
- Detailed surface analyses
Schiaparelli: Demonstration Module

- Demonstration of technology for Entry, Descent and Landing on Mars
- Platform for environmental measurements during descent and on surface

PAYLOAD

- Integrated mass: 5 kg;
- Surface lifetime: 2–3 sols;
- Measurements:
  - Descent atmospheric science;
  - Pressure, Temperature, wind speed and direction;
  - Optical depth;
  - Atmospheric charging;
  - Descent camera.
EDM: Schiaparelli
Landing Ellipse on Meridiani

Legend
mola128_oc180

Value
High : 0
Low : -3000

Copyright: IRSPS/TAS-
Schiaparelli Entry Descent and Landing
19 Oct 2016 16:43-16:49 CEST

- **Schiaparelli enters atmosphere**
  - Time: 0 sec
  - Altitude: 121 km
  - Speed: 21,000 km/h

- **Heatshield protection during atmospheric deceleration**
  - Time of maximum heating: 1 min 12 sec
  - Altitude: 45 km
  - Speed: 1700 km/h

- **Parachute deploys**
  - Time: 3 min 2 sec
  - Altitude: 11 km
  - Speed: 19,000 km/h

- **Front shield separate, radar turns on**
  - Time: 4 min 3 sec
  - Altitude: 7 km
  - Speed: 120 km/h

- **Parachute jettisoned with rear cover**
  - Time: 5 min 22 sec
  - Altitude: 1.2 km
  - Speed: 240 km/h

- **Thruster ignition**
  - Time: 5 min 23 sec
  - Altitude: 1.1 km
  - Speed: 250 km/h

- **Thrusters off, free fall**
  - Time: 5 min 52 sec
  - Altitude: 0 m
  - Speed: 4 km/h

- **Touchdown**
  - Time: 5 min 53 sec
  - Altitude: 0 m
  - Speed: 10 km/h
MRO Low Resolution Camera
TGO Orbit Insertion: 19 Oct 2016

Capture Orbit 100,000~500km

Orbit Circularization down to ~400km

Aerobraking ~9 months in 2017

~2h20min burn

~1.3 Tons of Fuel!
NOMAD
High-resolution occultation and nadir spectrometers

Atmospheric composition (CH₄, O₃, trace species, isotopes) dust, clouds, P&T profiles

- UVIS (0.20 – 0.65 μm) λ/Δλ ~250
- IR (2.3 – 3.8 μm) λ/Δλ ~10,000
- IR (2.3 – 4.3 μm) λ/Δλ ~20,000

CaSSIS
High-resolution, stereo camera

Mapping of sources Landing site selection

ACS
Suite of 3 high-resolution spectrometers

Atmospheric chemistry, aerosols, surface T, structure

- Near IR (0.7 – 1.7 μm) λ/Δλ ~20,000
- IR (Fourier, 2.5 – 25 μm) λ/Δλ ~4,000 (SO)/500 (N)
- Mid-IR (2.3 – 4.5 μm) λ/Δλ ~50,000

FREND
Collimated neutron detector

Mapping of subsurface water and hydrated minerals
Methane detection can be confirmed by many absorption bands.

TGO methane sensitivity is 100 ppt (~1000 times better than Mars Express).

The ability to also measure other hydrocarbons will help establish its origin.

**Infrared:**
- \( \text{CO}_2 \) (and \( ^{13}\text{CO}_2, ^{17}\text{OCO}, ^{18}\text{OCO}, C^{18}O_2 \)),
- \( \text{CO} \) (and \( ^{13}\text{CO}, C^{18}O \)), \( \text{H}_2\text{O} \) (and HDO),
- \( \text{NO}_2, \text{N}_2\text{O}, \text{CH}_4 \) (and \( ^{13}\text{CH}_4, \text{CH}_3\text{D} \)), \( C_2\text{H}_2, \text{C}_2\text{H}_4, C_2\text{H}_6, \text{H}_2\text{CO}, \text{HCN}, \text{OCS}, \text{HCl}, \text{HO}_2, \text{H}_2\text{S} \), aerosols/ice

**Ultraviolet:**
- \( \text{O}_3 \) and \( \text{SO}_2 \)

Credit:
MEX/HRSC
- Stereo and colour camera (4 filters)
- Resolution \( \leq 5 \) m/pixel
- Imaging swath is 9-km wide
Detection of Sub-surface Water

**FRIEND**
Collimated neutron detector

*Mapping of subsurface water and hydrated minerals*

**HEND/Odyssey data**, 300-km resolution!

**Simulation of FREND/TGO data based on HEND/Odyssey**, 40-km resolution!

**Gale Crater!**

**300 km pixel!**

**40 km pixel!**

**Gale Crater!**
ExoMars 2020 Objectives

**TECHNOLOGY OBJECTIVES**

- Movility on Marsurface (up to a few kilometers);
- Direct access to martian subsurface (2m depth drill);
- Sample acquisition and analysis from surface and subsurface

**SCIENCE OBJECTIVES**

- Search for signs of present and past life on Mars
- Research for water in subsurface and environment

**TECHNOLOGY OBJECTIVES**

- Descent and landing platform
- Communications with European and Russian stations

**SCIENCE OBJECTIVES**

- Characterisation of Surface environment.
**Nominal**
- Launch date: 2018
- Mars Arrival: 15 Jan 2019
- Transfer: 233–253 days
- Arrival LS: 324°

**Backup**
- Launch date: 5 Aug 2020
- Mars Arrival: 19 Apr 2021
- Transfer: 237–257 days
- Arrival LS: 34°
Entry, Descent and Landing

Credit: MEX/HRSC
Surface Platform
Nominal mission: 218 sols
Nominal science: 6 Experiment Cycles + 2 Vertical Surveys
EC length: 16–20 sols
Rover mass: 300-kg class
Mobility range: Several km
Pasteur Science Payload

**PanCam**
- Wide-angle stereo camera pair
- High-resolution camera
- Geological context
- Rover traverse planning
- Atmospheric studies
- WAC: 35° FOV, HRC: 5° FOV

**ISEM**
- IR spectrometer on mast
- Bulk mineralogy of outcrops
- Target selection
- $\lambda = 1.15 – 3.3 \mu m$, 1° FOV

**CLUPI**
- Close-up imager
- Geological deposition environment
- Microtexture of rocks
- Morphological biomarkers
- 20-μm resolution at 50-cm distance, focus: 20 cm to $\infty$

**WISDOM**
- Ground-penetrating radar
- Mapping of subsurface stratigraphy
- 3 – 5-m penetration, 2-cm resolution

**ADRON**
- Passive neutron detector
- Mapping of subsurface water and hydrated minerals

**Drill + Ma_MISS**
- IR borehole spectrometer
- In-situ mineralogy information
- $\lambda = 0.4 – 2.2 \mu m$

**Analytical Laboratory Drawer**

**MicrOmega**
- VIS + IR spectrometer
- Mineralogy characterisation of crushed sample material
- Pointing for other instruments
- $\lambda = 0.9 – 3.5 \mu m$, 256 x 256, 20-μm/pixel, 500 steps

**RLS**
- Raman spectrometer
- Geochemical composition
- Detection of organic pigments
- spectral shift range 200–3800 cm$^{-1}$, resolution $\leq 6$ cm$^{-1}$

**MOMA**
- LDMS + Pyr-Dev GCMS
- Broad-range organic molecules with high sensitivity (ppb)
- Chirality determination
- Laser desorption extraction and mass spectroscopy
- Pyrolysis extraction in the presence of derivatisation agents, coupled with chiral gas chromatography, and mass spectroscopy

Credit: MEX/HRSV
The rover reference surface mission includes:

a) EXIT LANDING AREA:
Scientifically it serves the purpose to get away from any rocket organic contamination before opening the analytical laboratory to the Martian environment.

b) BLANK ANALYSIS RUNS:
To demonstrate that the rover’s sample pathway is free from organic contamination.

c) 6 EXPERIMENT CYCLES:
Combined surface and subsurface exploration, resulting in 6 surface and 6 subsurface samples.

d) 2 VERTICAL SURVEYS:
At one location, collect and analyse samples at depths of 0, 50, 100, 150, and 200-cm. Results in 10 additional subsurface samples.
Landing site selection process is critical to cover mission objectives:

- Must be old (≥ 3.6 Gaños), and have a humid “past” environment.
- Must have great capacity for conservation of bio-markers.
- Must fulfill requirements for descent trajectory and landing risks.
Conclusions

2016: ExoMars Trace Gas Orbiter
- Improve our understanding of Mars and atmospheric processes of exo-biological relevance.
- Example of international cooperation.
- Technology demonstration for future exploration.

2018: ExoMars Rover and Surface Platform
- Mission with great exo-biological importance.
- First attempt to combine mobility and sub-surface sounding.
- Rover with state-of-the-art scientific instrumentation.
- Pasteur Module will study for the first time:
  - Organic molecules and bio-markers for present and past life;
  - Vertical characterisation of geochemistry and water.
- Surface platform will measure environmental properties.

One more step in the roadmap for exploration towards the Mars Sample Return challenge.
THANKS!

Questions...