Mars Express Science Operations
Evolution after 10 Years

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Mars Express: so many missions at once

Mars Mission

Phobos Mission

Relay Mission

maybe also a Comet Mission?
First European Mission to orbit another Planet!

First Planetary mission after Giotto (and Huygens)
First mission of the “Rosetta family”

Operational challenges appear every year...
2003: Launch, Orbit Insertion, Beagle-2, ...
2004: 0 to 100% science
2005: Marsis boom deployment
2006: Energy Survival
2007: Mars Webcam
2008: NASA Phoenix Relay
2009: SGS system transition
2010: Phobos flybys
2011: Mass Memory major anomaly 😊
2012: Recovery and NASA MSL Relay
2013: 100% Science and Conjunction in 100 TCs
2014: A comet flies by Mars!
2015: MAVEN coordinated campaigns
2016: ExoMars Trace Gas Orbiter ...
Mars Express: Mission Profile Complexity

Elliptical orbit of 7 hours around Mars
- Every month: ~100 orbits, ~200 science pointings, ~400 observations
- Various Mars resonances: 11/3, 18/5, 25/7, 88/25... (now random)
- Non Earth-synchronous (randomly distributed passes/shifts)

Variable Station passes
- 18 passes per week, 10 ESA+DSN stations
- 50-100 Gbit / month (requirement was 16Gbit/month)
- 98% data return (losses from downlink <0.5%, on-board <1%, planning <0.5%)

Seasonal variability
- MEX orbit precession: changes latitude and illumination conditions
- Mars-Sun-Earth orbits: critical variations in data rates 1 to 10; sun power 1 to 1.5
Science Operations Concept

Feasible Science Plan

Science Objectives

Technical Constraints

INAF Roma

IAS Orsay Paris

DLR Berlin

IRF Kiruna

Science Operations Centre

ESAC

Mission Operations Centre

ESOC
A bit of history: Science Operations Original Diagramme

- Payload operations originally outsourced to the Payload Operations Service (POS) in UK
- POS was «service provider» for Commanding and Payload Modelling, Planning Interfaces and SW
- Responsibility remained at Science Operations Center at ESTEC
- Interfaces and iterations were very complex

After 5 years: 2009
POS and SOC merged and moved to ESAC
Science Operations Transition:
ESAC-based Science Ground Segment

**GOAL:** replace POS to reduce interfaces, cost and optimize planning procedures

**Successful Multi-Mission Development Effort** re-using expertise across projects
- Optimized interfaces and configuration control (ORFA, FTS, CVS...)
- Introduced Science Opportunity Analysis
- Centralized planning tool for simulation and command generation: MAPPS
Summary of Planning Cycles and Lessons Learned

**Long Term Planning**: >6 months before execution
**Medium Term Planning**: 12 weeks before execution
**Short Term Planning**: 4 weeks before execution
**Long Term Planning**

**PRINCIPLE:** All geometry and observation conditions are known well in advance
- Based on Long Term Reference Trajectory (within 10s, updated by Flight Dynamics every few months/years)
- ESTRACK is also allocated for a full year, only DSN availability is unknown until -10 weeks.

**LONG TERM ANALYSIS**
- Study of all geometry aspects (illumination, data rate, eclipses, occultations, etc)
- Definition of long term observation priorities and campaigns
- Identify and prevent critical seasons: limited data rate, solar eclipses, conjunction, etc

![Graph of Bit Rate, Solar Elevation, and Latitude at Pericenter](image)
Basic Long Term Planning: Definition of seasons and campaigns

- Sun-Mars-Earth angle and relative distances
  (Solar Conjunction in red, RS Solar Corona in orange, BSR in violet)

- Solar Elevation Angle and Latitude along the orbit

- Time to Pericenter [h:mm]
  - Approximate Altitude [km]

- Orbit number
  - Mars-Sun distance [km]
  - Mars-Earth Distance [km]
Observation opportunities defined based on scientific criteria:
- Occultations: Stars, Sun, Earth, …
- Phobos fly-bys
- Target visibility windows, …

Opportunity windows pre-computed and stored in a database. Events are analyzed, filtered and processed to build a skeleton plan.

LESSON LEARNED:
Science Opportunity Analysis is a must to assure science return
Medium Term Planning

PRINCIPLE:
Build a feasible fully detailed schedule of payload science operations

**Input:**  
- **Payload Science Observation requests (MREQs)**
- Ground Station allocation from ESTRACK/DSN
- Specific spacecraft contraints and events from ESOC

**Output:**  
- **Fully harmonized feasible plan**
  - Spacecraft Pointing and Predicted Attitude
  - Detailed Payload Command Sequences
  - Payload and Spacecraft Resources (Data/Power)

LESSONS LEARNED:
- **Centralize** all operational/technical procedures in a single **modular system**
- **Simplify** interfaces and procedures as much as possible
- **Minimize manual work:** automatized all routine technical/scientific processes
- **Model all** payload and spacecraft subsystems as much as possible
- Trade-off Robustness vs. Flexibility: system **fully configurable** with time-dependent constraints
- Focus PI iterations in **scientific terms:** pure scientific request and flexibility
- PIs and ESOC need to gain **confidence in the centralized approach** to science planning
Short Term Planning

PRINCIPLE:
Confirm full payload commanding and fine tune parameters

Input: **PI updated commanding files (CP-PORs)**
Mode level schedule and resource allocation (from MTP)
Latest updates on stations, contraints, etc

Output: **Fully detailed commanding files (Orbit-PORs)**
Command sequences and Resources (Data/Power)
One file per instrument per orbit (~80 per week)

LESSONS LEARNED:
- **Centralize** all commanding procedures in the operational system
- **Minimize manual work**: all files automatically generated
- Resource constraints **automatically checked** against original plan
- Most instruments **delegate** full commanding pipeline to SGS
- All commanding details **available in advance**, ready at MTP level
Summary of Lessons Learned

Team
- Focus **PI iterations towards science** (implies understanding of scientific requirements)
- Exchange **all technical details with ESOC** (implies understanding of engineering requirements)
- Ensure **in-house knowledge** (not enough if technical/scientific know-how is in ESTEC/ESOC/PIs)
- PI’s and ESOC need to gain **confidence in centralized approach** of scientific/technical processes
- Promote **exchange of Multi-Mission expertise** (especially during development)

System
- **Centralize** all operational/technical procedures in a single system
- **Minimize manual procedures**: automation of routine technical/scientific processes and interfaces
- **Model all** payload and spacecraft subsystems to the maximum detail (basic resources at least)
- **Long Term Science Opportunity Analysis** is a must to assure science return
- Equilibrium in Robustness-Flexibility: **fully configurable system**

Cooperation and team spirit between PIs-SGS-ESOC-MM-PS and other missions

- **Key for the outcome of the mission**

Complexity and Variability require Automatization and Flexibility
- **Robust Highly Configurable System for Efficient Operations**
THANK YOU!
EXTRA SLIDES
EXTRA: POS Original Diagramme
EXTRA: Uplink-Downlink Diagram

- **Telecommands**
- **Telemetry**

**Mission Operations Centre**
- **Science Operations Centre**
- **Instrument Teams**

**OPERATIONS PLANNING**
- Commands, pointings
- Observation requests

**DATA HANDLING**
- Telemetry
- Data products

**Science Operations Centre (PSA)**

**Planetary Science Archive**
EXTRA: Spacecraft drivers

- Science pointing capabilities (duration, rates, RW momentum, etc)
- Fixed antenna
- Only 70% power available from solar panels
- Battery degradation 40%
- SSMM data handling over OBDH bus (<100kbps)
- Uplink windows (daily, now weekly)
- Payload constraints (AS scanner, etc)
- Illumination
- Thermal model
- FD slew code

- Add a note on interfaces and conventions (lack of conventions causes backward incompatibility and no history tracking)
MARSIS mounted on -Y panel
MARSIS Dipole towards -X/+X axis
MARSIS Monopole towards -Z axis

+Z: Remote Sensing Payloads (and Beagle-2)
+X: High Gain Antenna
+Y: Solar Panel (completing right-hand frame)
EXTRA: Phobos Fly-by detail

MEX motion

Phobos motion

Drift of orbit

Line of apsides

Mars Crossing of MEX/Phobos orbits

Potential fly-by

Phobos motion

Drift of orbit

Line of apsides

MEX motion

N

5 km
# Table of TCs per Instrument

<table>
<thead>
<tr>
<th>Instrument</th>
<th>TCs without OBCP</th>
<th>TCs with OBCP</th>
<th>OBCP implemented</th>
</tr>
</thead>
<tbody>
<tr>
<td>MARSIS (AIS/SS/FM)</td>
<td>20~34</td>
<td>6/11/9</td>
<td>Switch ON/OFF (might need cleanup)</td>
</tr>
<tr>
<td>HRSC/SRC</td>
<td>35 (+8 heating)</td>
<td>23/26</td>
<td>Switch ON/OFF and initialization</td>
</tr>
<tr>
<td>SPICAM</td>
<td>13</td>
<td>3</td>
<td>Switch ON/OFF</td>
</tr>
<tr>
<td>PFS</td>
<td>70</td>
<td>7</td>
<td>Switch ON/OFF (might need cleanup)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+4</td>
<td>Parameter updates (configurable)</td>
</tr>
<tr>
<td>OMEGA (VIS/IR)</td>
<td>30~40</td>
<td>10~18</td>
<td>Switch ON/OFF and initialization</td>
</tr>
<tr>
<td>ASPERA</td>
<td>245 TCs</td>
<td>4</td>
<td>ON/OFF + HV Up/Down</td>
</tr>
<tr>
<td></td>
<td>for 3-4 orbits</td>
<td>2,2,1,1,1,1</td>
<td>NPI On/Off, NPD On/Off, Scan, ELS Calib, IMA Pacc</td>
</tr>
<tr>
<td>Radio Science</td>
<td>2/10/2</td>
<td>-</td>
<td>No OBCPs needed</td>
</tr>
<tr>
<td>VMC</td>
<td>60~90TCs</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2 TC/min)</td>
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</table>
Comet C/2013 A1 (Siding Spring)

Discovered in January 3rd, 2013
Hyperbolic orbit = Oort Cloud comet

Close approach on October 19th, 2014
119,000 km - relative speed = 56 km/s
Collision with Mars has been ruled out,
but Mars will pass through the coma and tail
EXTRA: SSMM Anomaly → FAST Approach

PAST: Daily uplink passes (~3000 TCs available at SSMM, can be executed directly)

SUMMER 2011: SSMM anomaly
- Solar Flare Event: readout errors become very frequent
- MEX in Safe Mode everytime there is an error during a TC execution
- Safe Modes cause important fuel consumption and reduce lifetime

RECOVERY PHASE: FAST (File Activity from Short Timeline)
- New Commanding Scheme: execute from short Mission TimeLine, only 117 TCs available!
- Reduction: group Telecommands into OBCPs (OnBoard Control Procedures)
- All operations grouped into “FAST Activities” of 117 TCs each

SUCCESSFUL RECOVERY:
- 90% science recovered in 2012, 100% recovered in 2013
- No daily uplink needed any more (less pointing constraints)
- No need for DSN Uplink → DSN Downlink availability increased → MORE DATA VOLUME!