Mars Express Science Operations
Evolution after 10 Years

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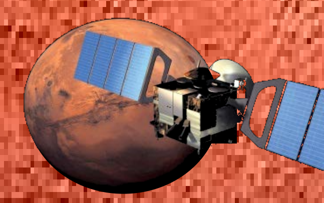
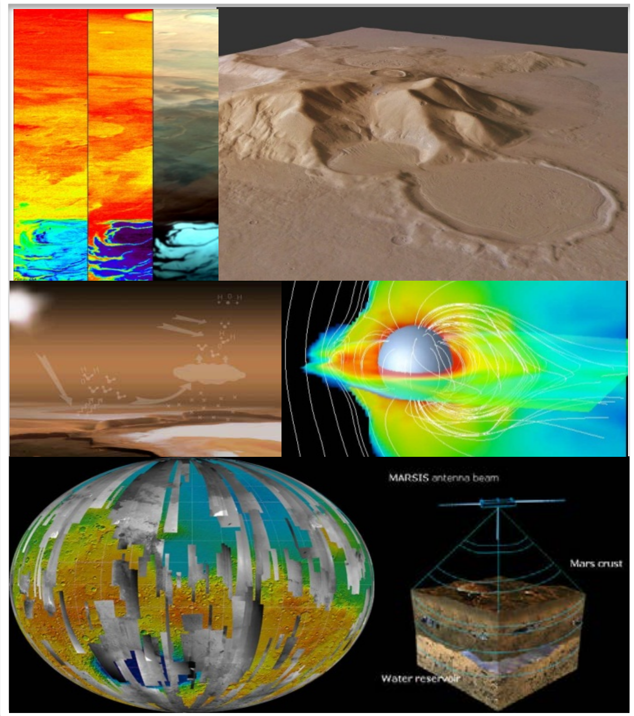
and the Science Ground Segment Team

SCIOPS 2013 Conference, ESAC 11th September 2013

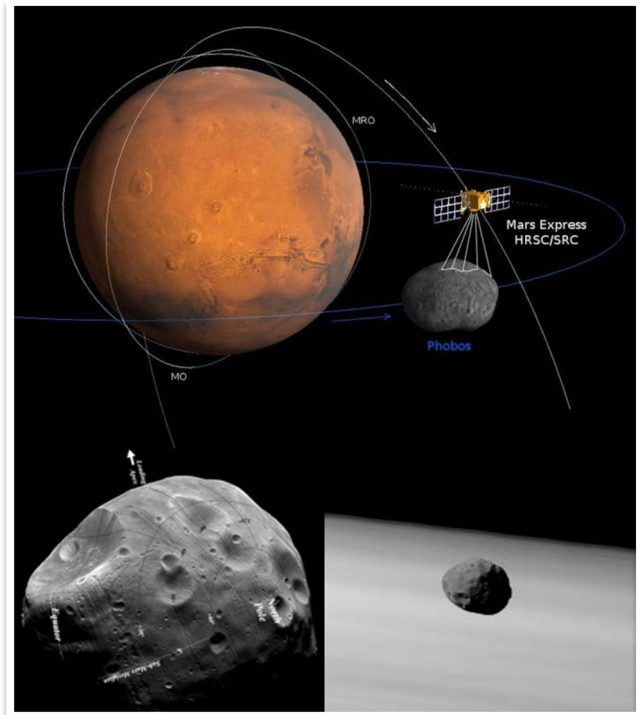
Mars Express: so many missions at once



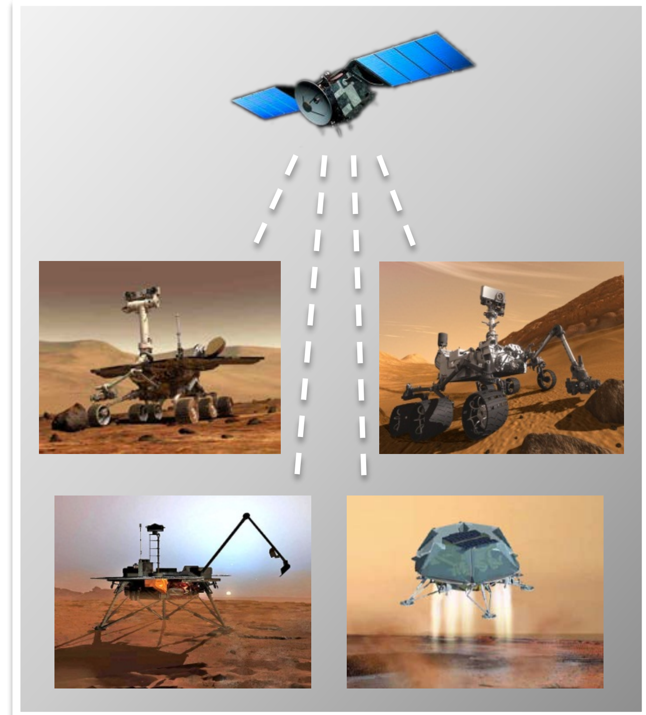
Mars Mission



Phobos Mission

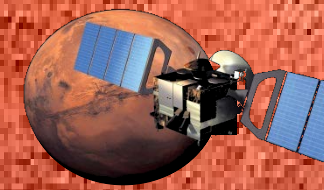


Relay Mission



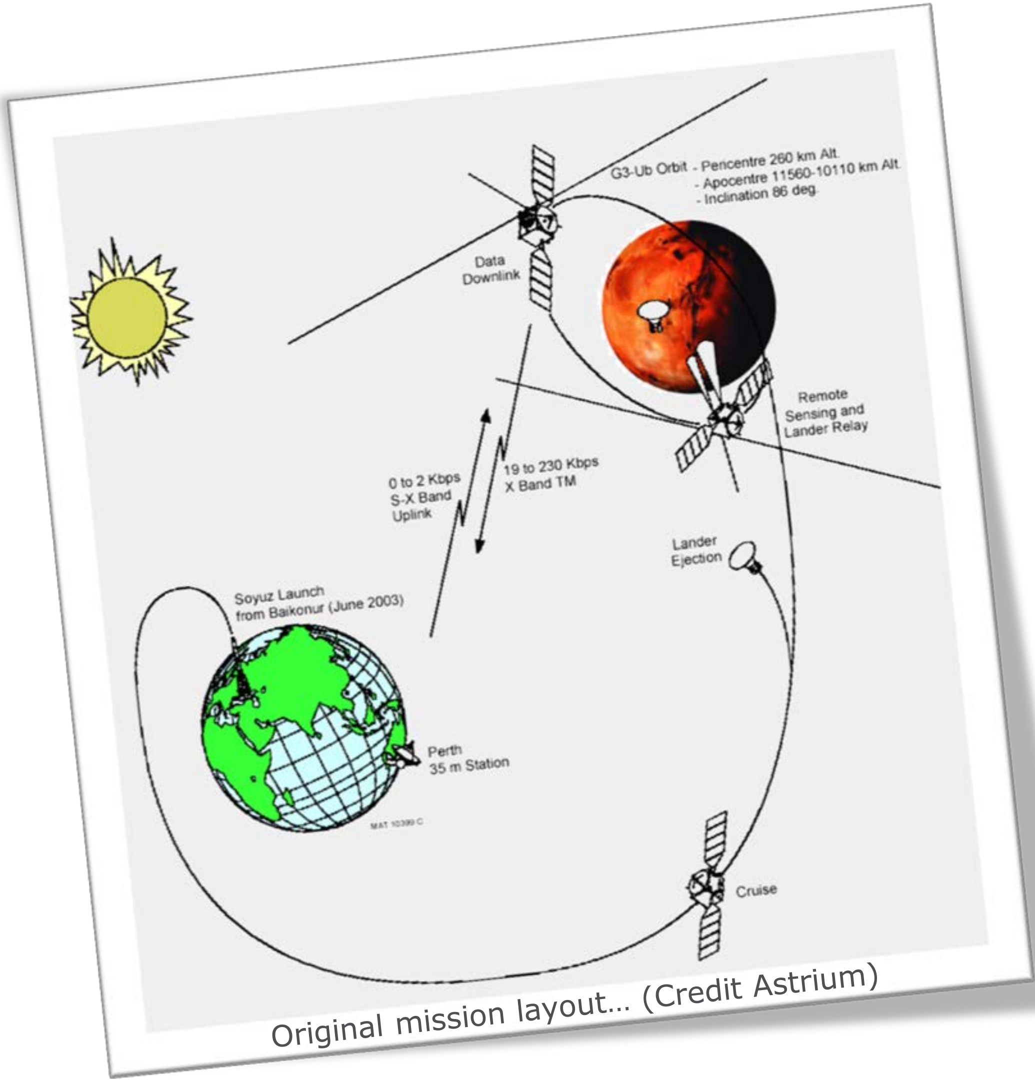
maybe also a
Comet Mission?

First European Mission to orbit another Planet!



First Planetary mission after Giotto (and Huygens)

First mission of the "Rosetta family"



Original mission layout... (Credit Astrium)

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

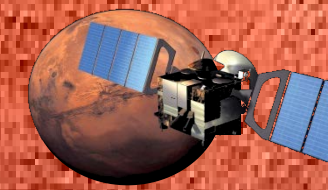
2013: 100% Science and Conjunction in 100 TCs

2014: A comet flies by Mars!

2015: MAVEN coordinated campaigns

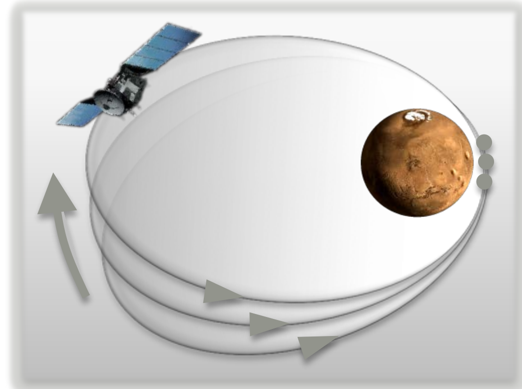
2016: ExoMars Trace Gas Orbiter ...

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)

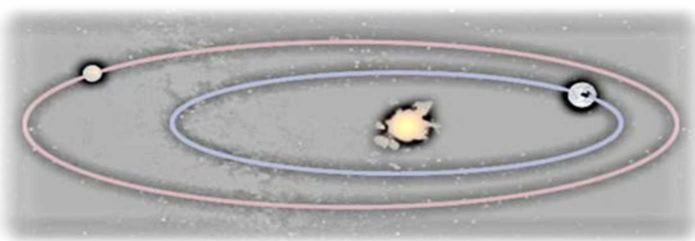


Variable Station passes

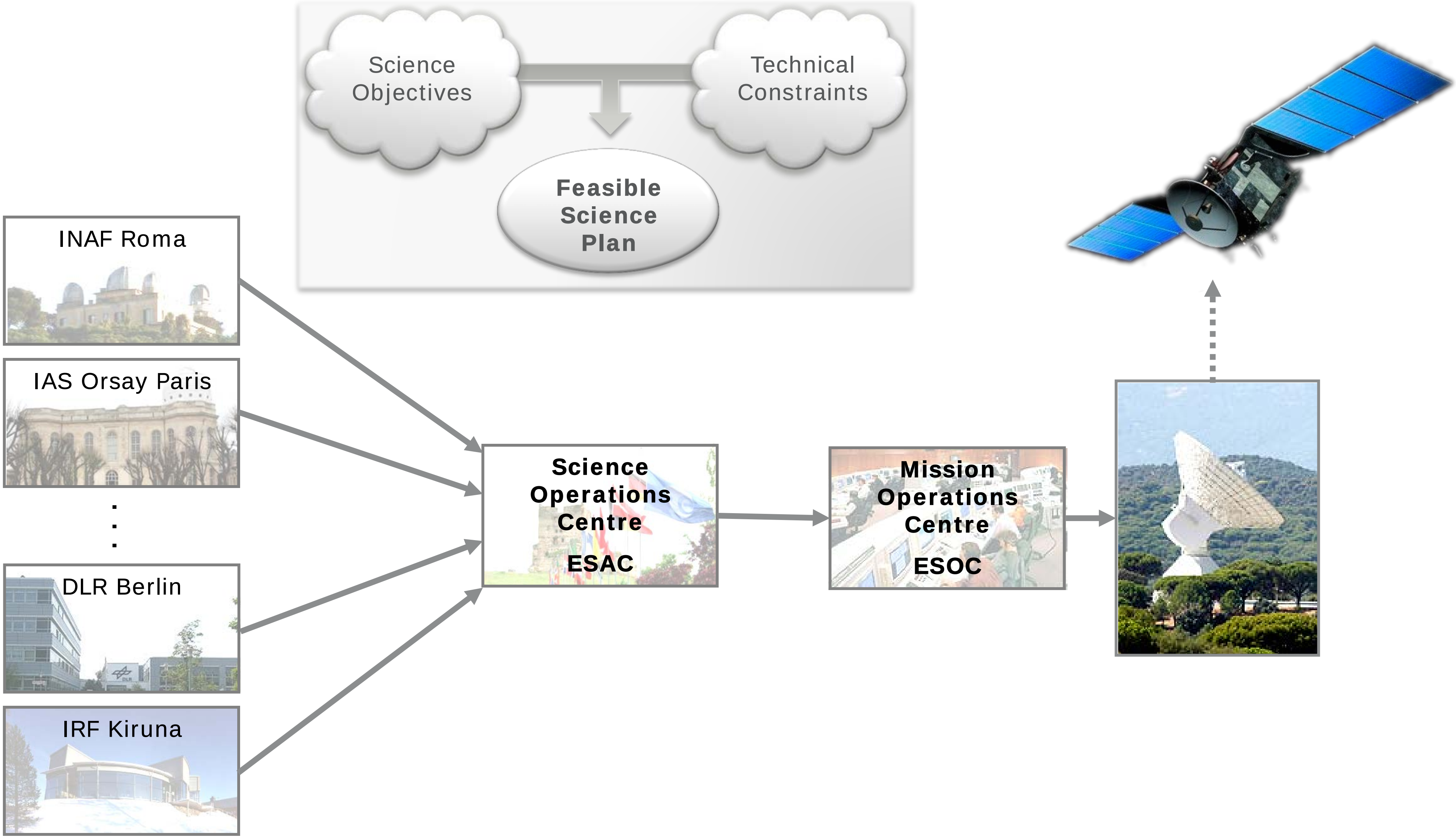
- 18 passes per week, 10 ESA+DSN stations
- 50-100 Gbit / month (requirement was 16Gbit/month)
- 98% data return (losses from downlink <0.5%, on-board <1%, planning <0.5%)

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

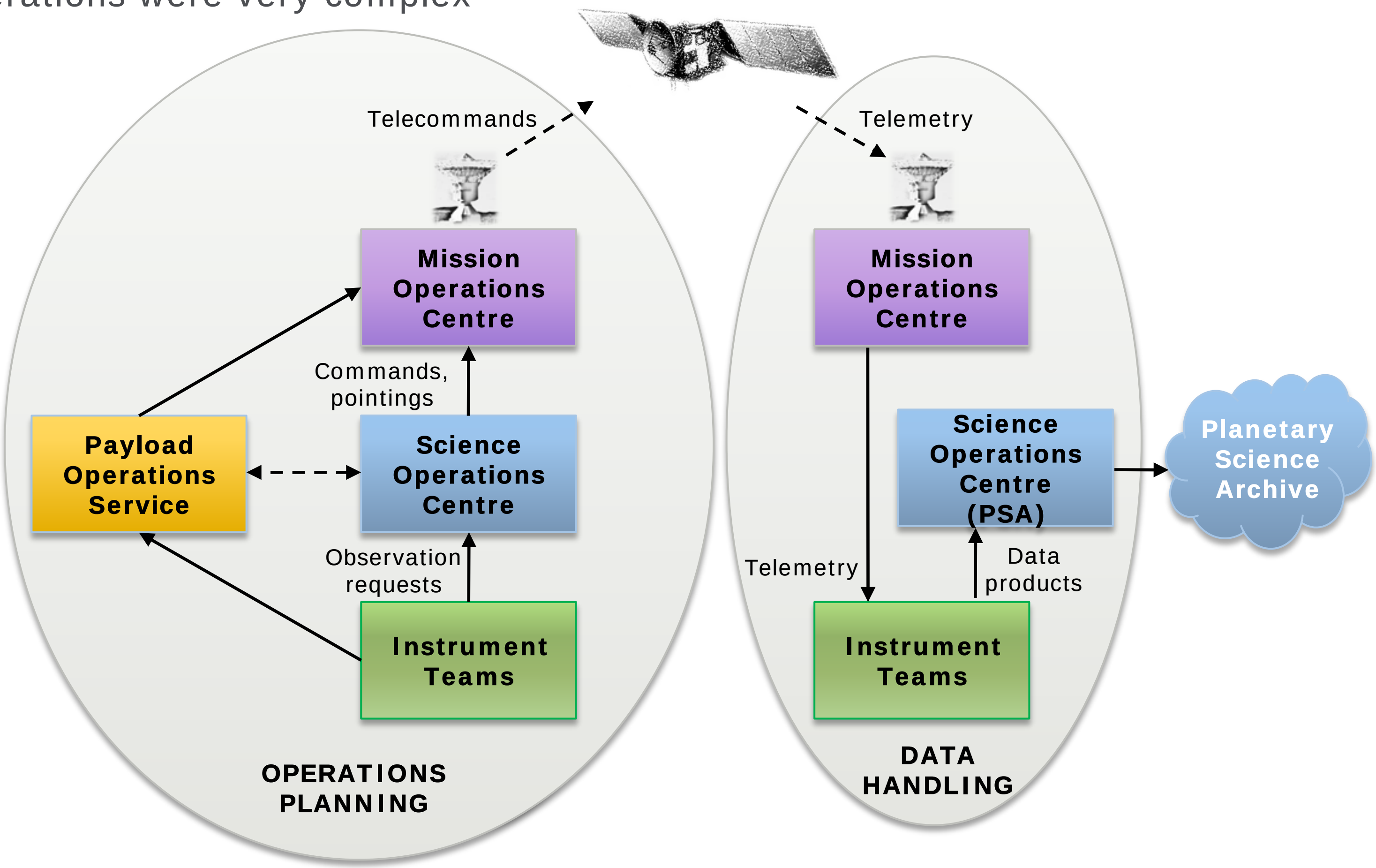


A bit of history:
Science Operations Original Diagramme

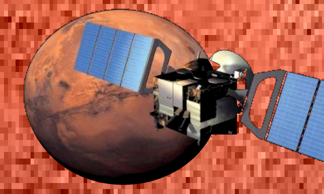
- Payload operations originally outsourced to the Payload Operations Service (POS) in UK
- POS was «service provider» for Commanding and Payload Modelling, Planning Interfaces and SW
- Responsability remained at Science Operations Center at ESTEC
- Interfaces and iterations were very complex

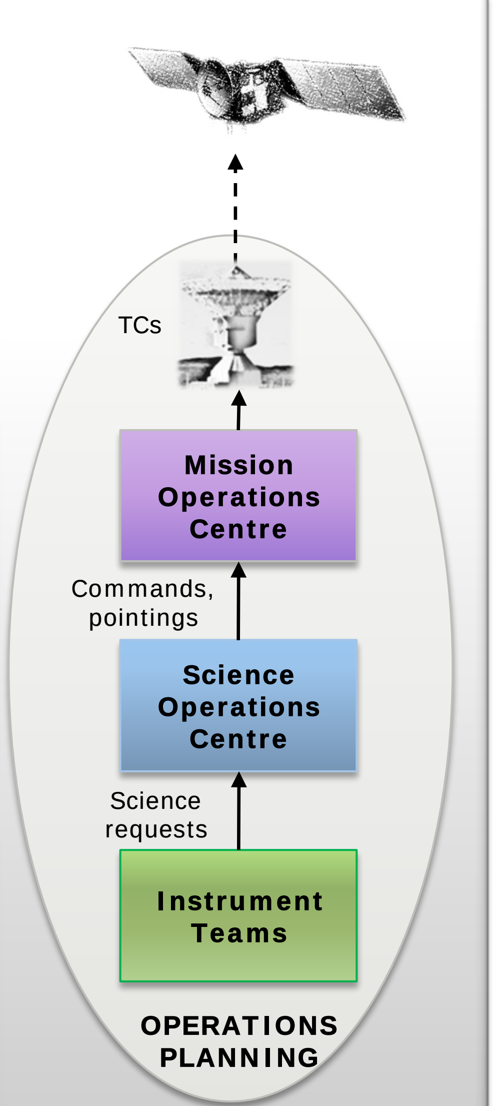
After 5 years: 2009

POS and SOC merged and moved to ESAC



Science Operations Transition:
ESAC-based Science Ground Segment

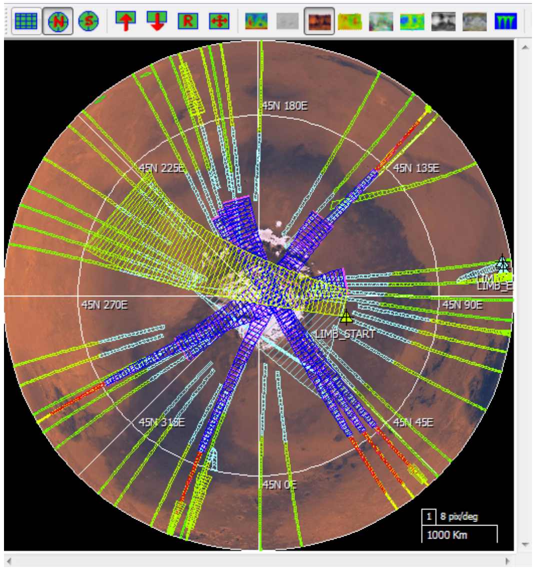


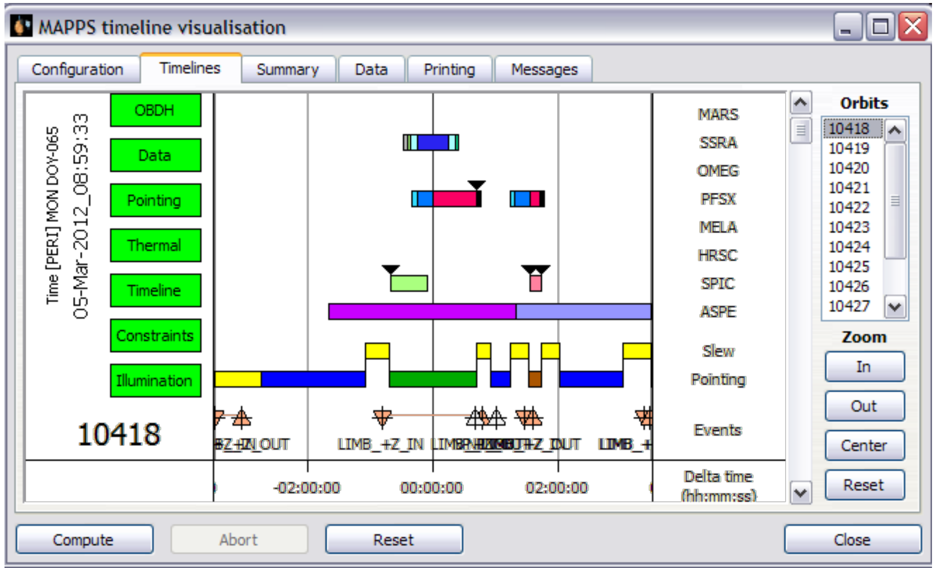


GOAL: **replace POS to reduce interfaces, cost and optimize planning procedures**

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**





Science Operations Planning Cycles

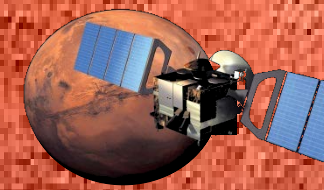
Summary of Planning Cycles and Lessons Learned

Long Term Planning : >6 months before execution

Medium Term Planning : 12 weeks before execution

Short Term Planning : 4 weeks before execution

Long Term Planning

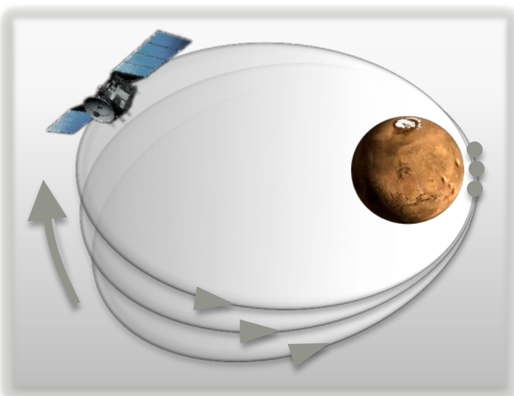


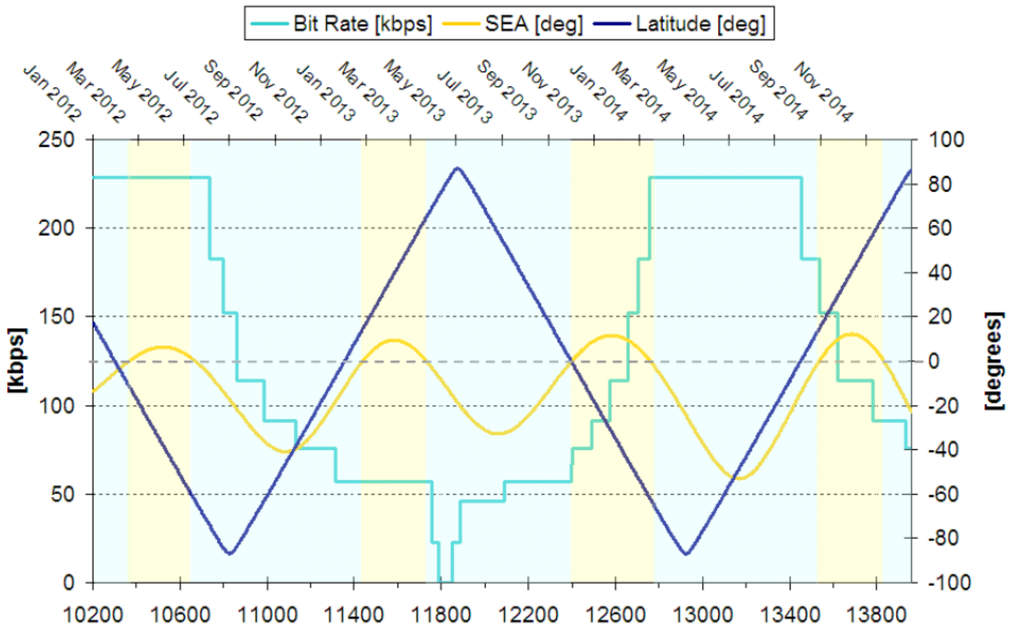
PRINCIPLE: **All geometry and observation conditions are known well in advance**

- 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

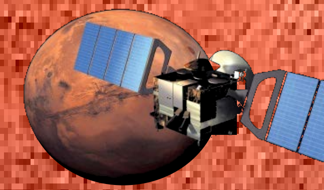
- Study of all geometry aspects (illumination, data rate, eclipses, occultations, etc)
- Definition of long term observation priorities and campaigns
- Identify and prevent critical seasons: limited data rate, solar eclipses, conjunction, etc

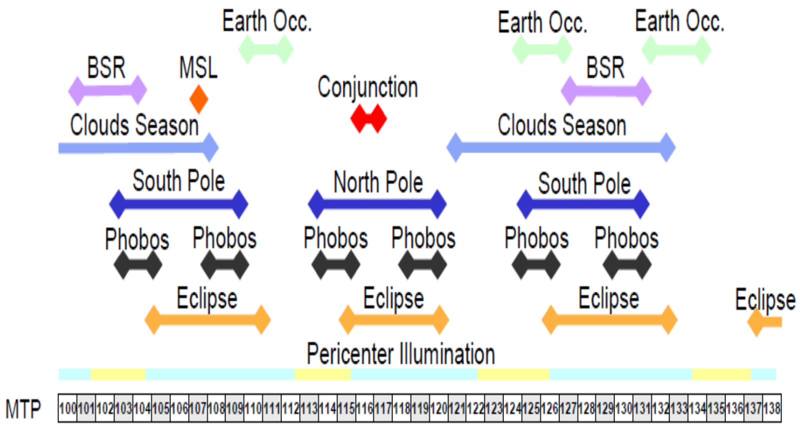


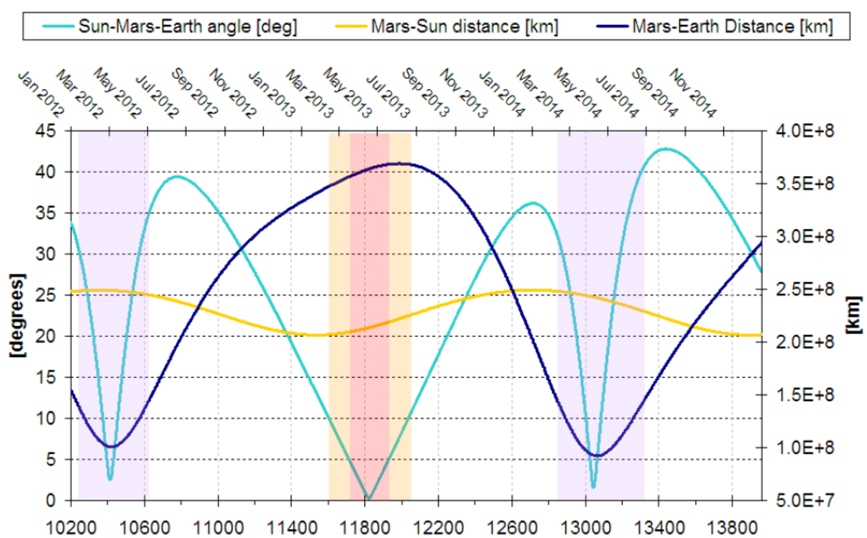


Bit Rate, Solar Elevation and Latitude at pericenter

Basic Long Term Planning: Definition of seasons and campaigns

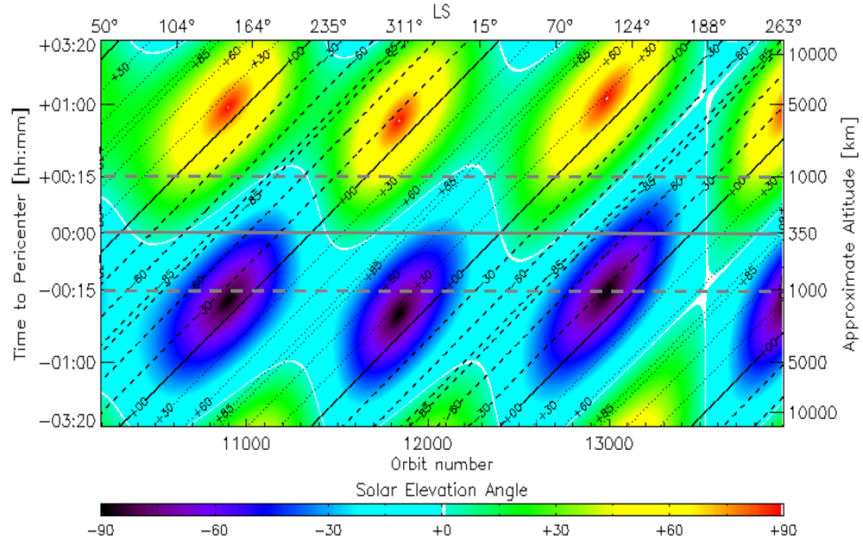




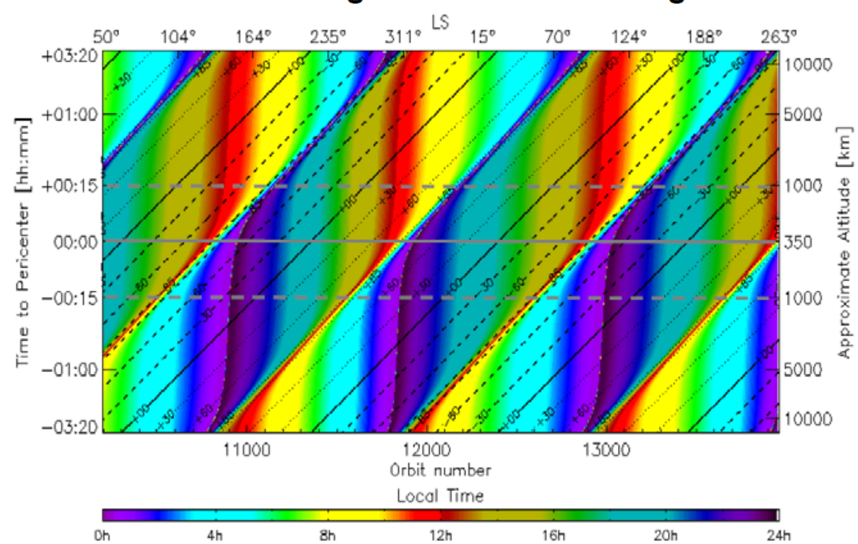


Sun-Mars-Earth angle and relative distances

(Solar Conjunction in red, RS Solar Corona in orange, BSR in violet)

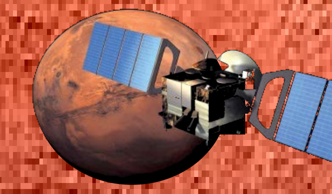


Solar Elevation Angle and Latitude along the orbit



Local Solar Time and Latitude along the orbit

Advanced Long Term Planning: Science Opportunity Analysis



Observation opportunities defined based on scientific criteria:

- Occultations: Stars, Sun, Earth, ...
- Phobos fly-bys
- Target visibility windows, ...

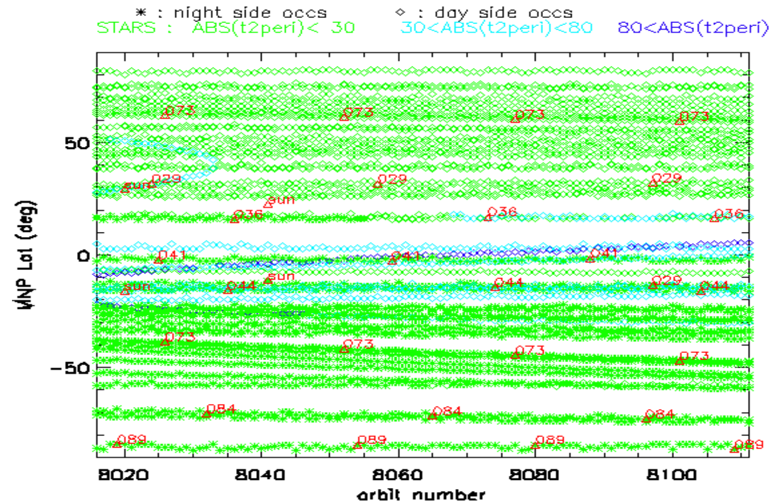
Opportunity windows pre-computed and stored in a database.

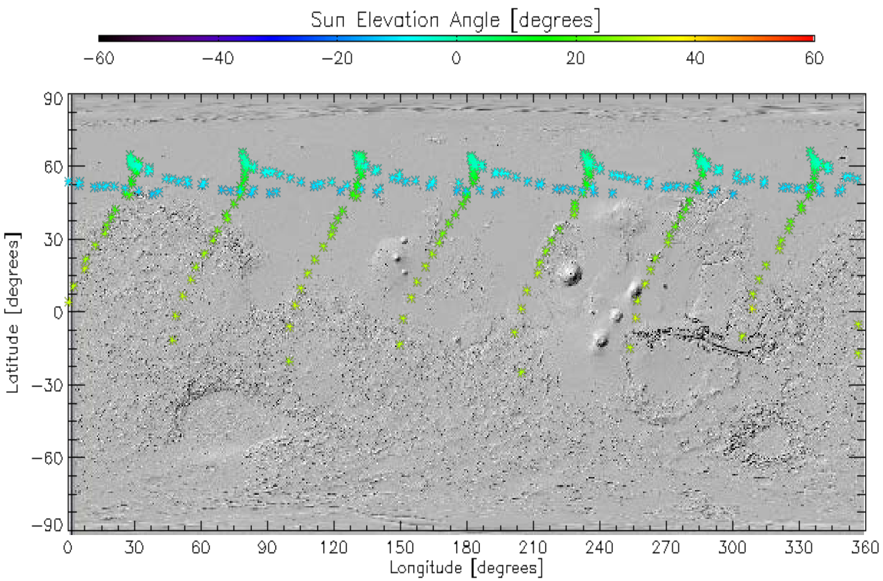
Events are analyzed, filtered and processed to build a skeleton plan.

LESSON LEARNED:

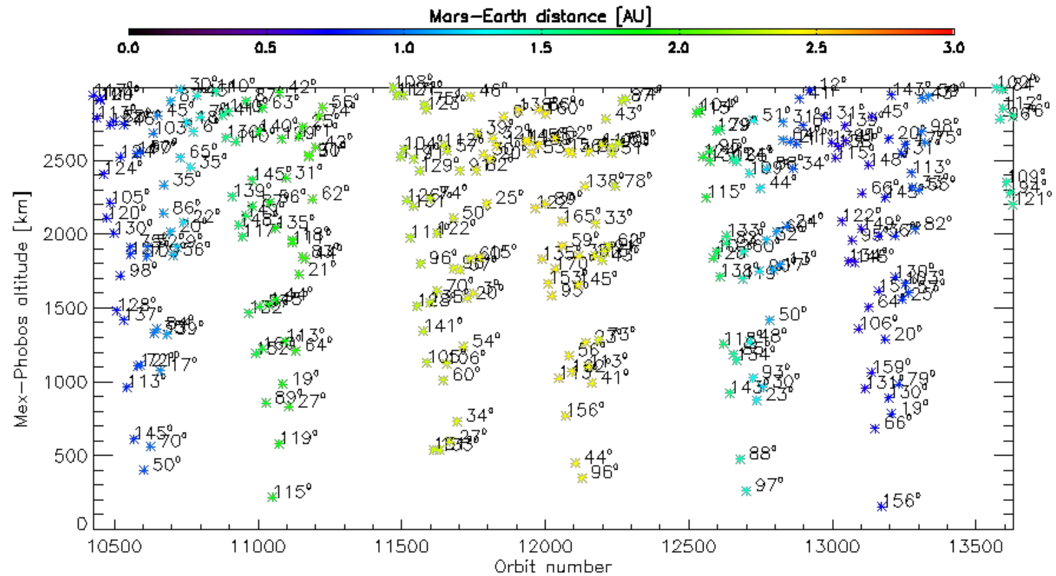
Science Opportunity Analysis is a must to assure science return

Stellar Occultation Opportunities



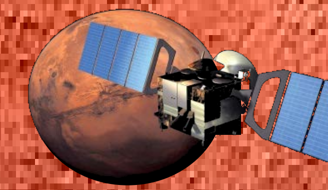


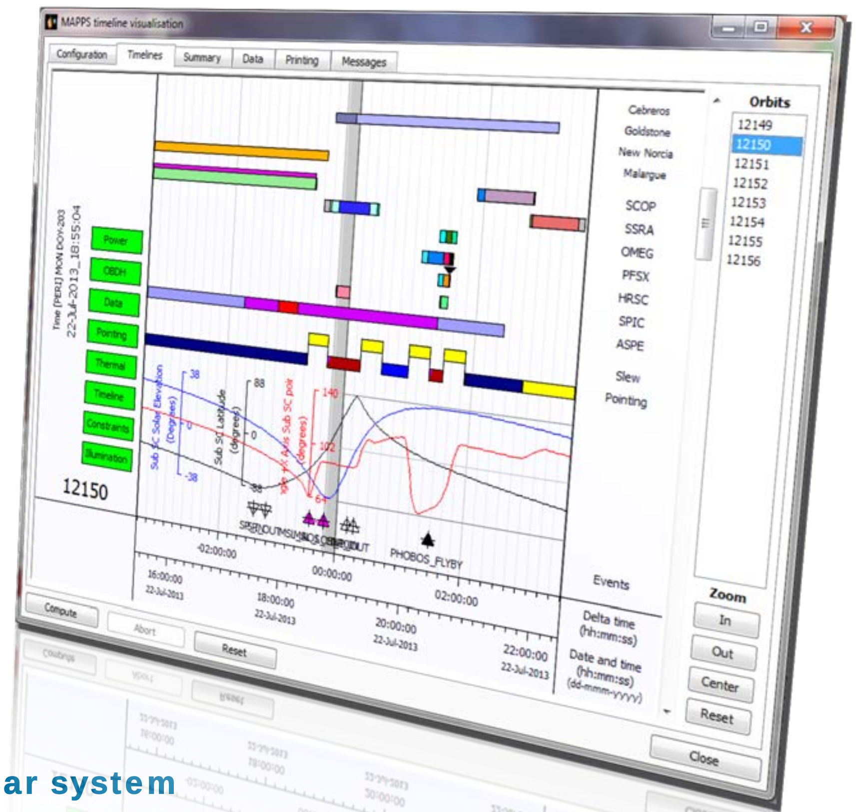
Radio Science Earth Occultation Opportunities



Phobos Fly-by Events

Medium Term Planning





PRINCIPLE:

Build a feasible fully detailed schedule of payload science operations

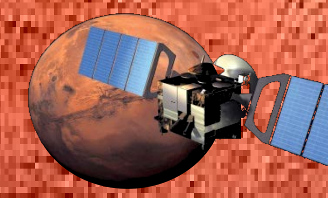
Input : **Payload Science Observation requests (MREQs)**
Ground Station allocation from ESTRACK/DSN
Specific spacecraft contraints and events from ESOC

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)**

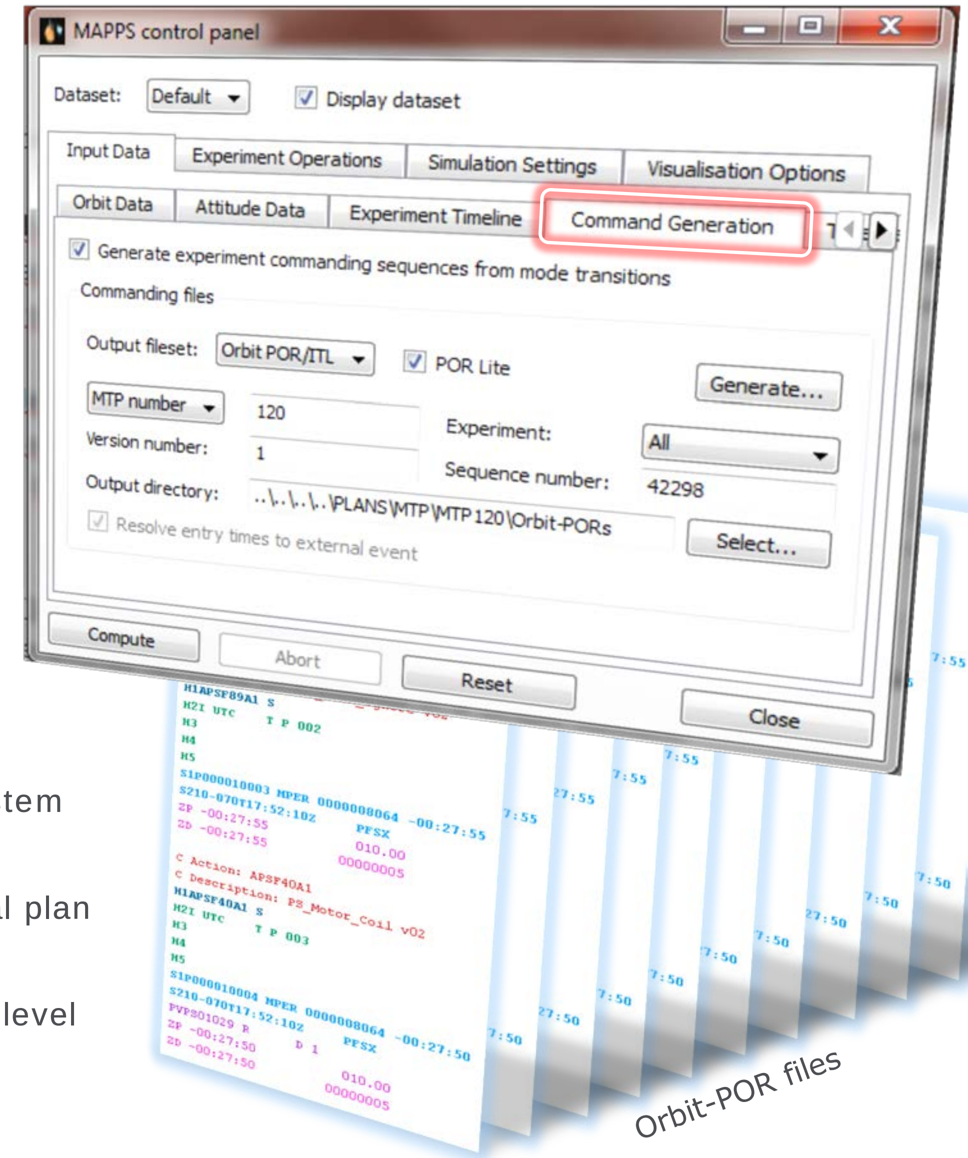
Mode level schedule and resource allocation (from MTP)

Latest updates on stations, contraints, etc

Output: **Fully detailed commanding files (Orbit-PORs)**

Command sequences and Resources (Data/Power)

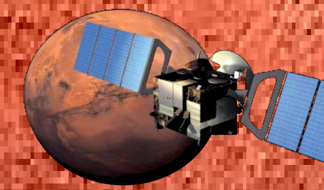
One file per instrument per orbit (~80 per week)



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)

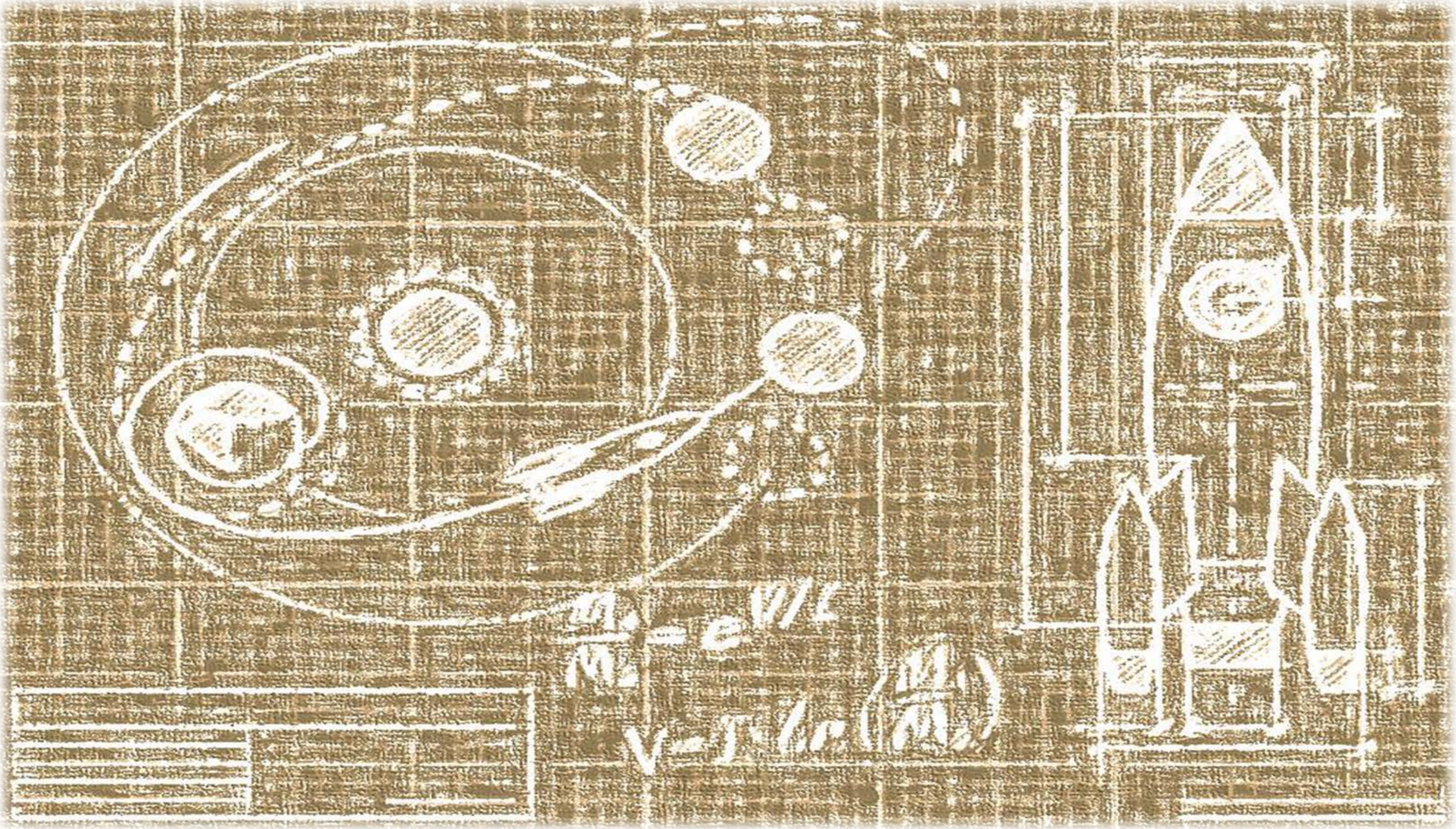
Cooperation and team spirit between PIs-SGS-ESOC-MM-PS and other missions
➔ Key for the outcome of the mission ⇐

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**

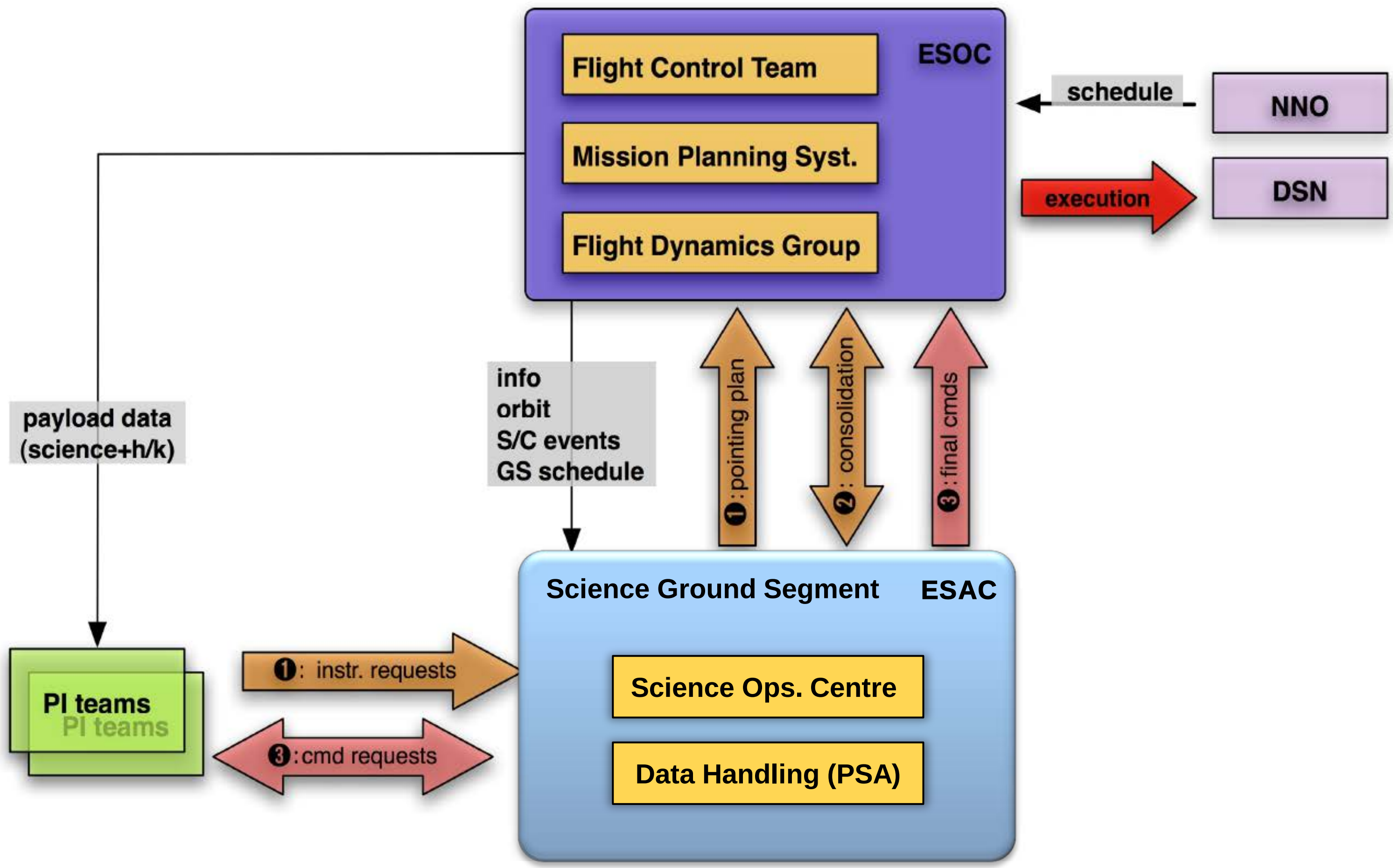
Complexity and Variability require Automatization and Flexibility
➔ Robust Highly Configurable System for Efficient Operations ⇐

THANK YOU!

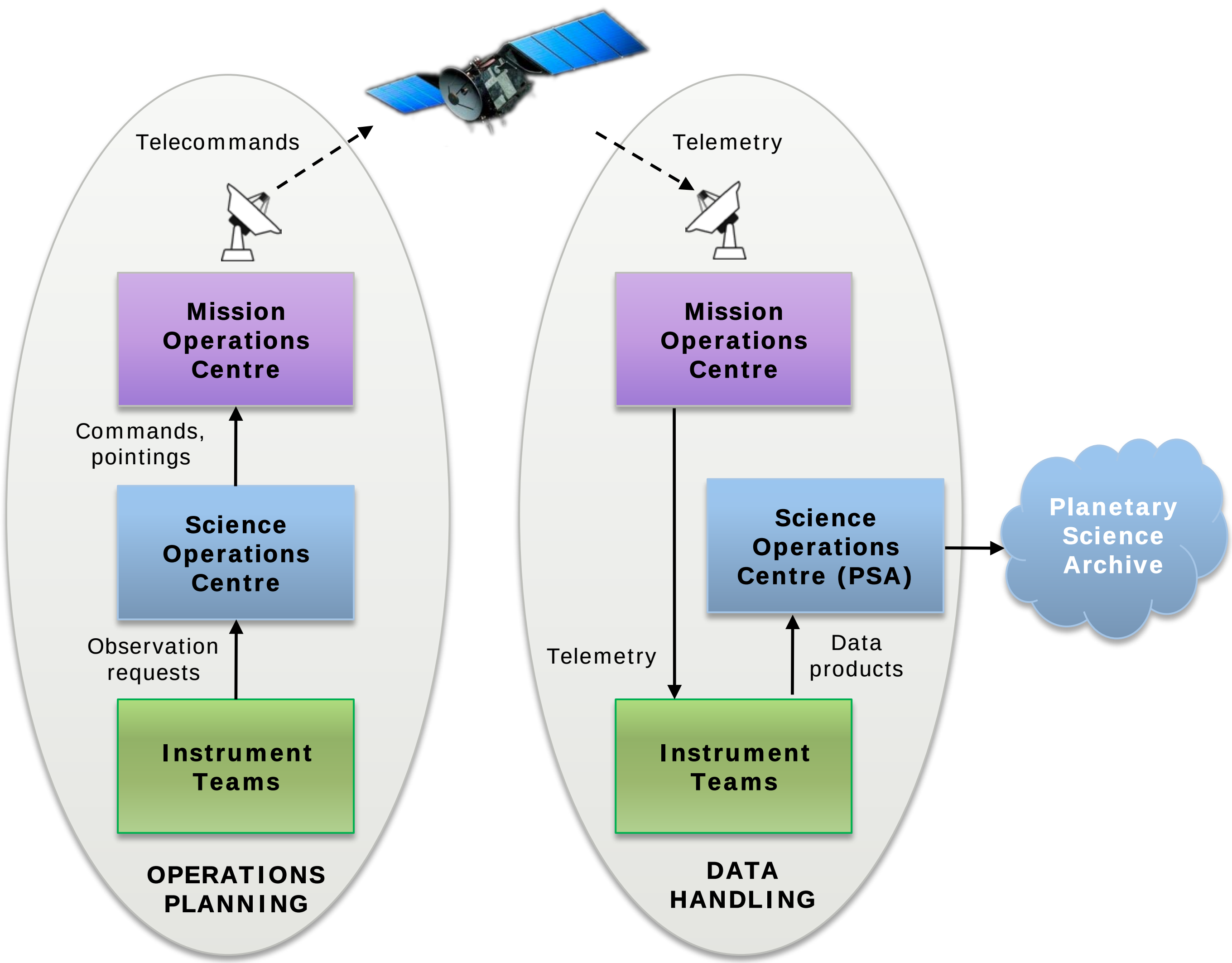


EXTRA SLIDES

EXTRA: POS Original Diagramme



EXTRA: Uplink-Downlink Diagram

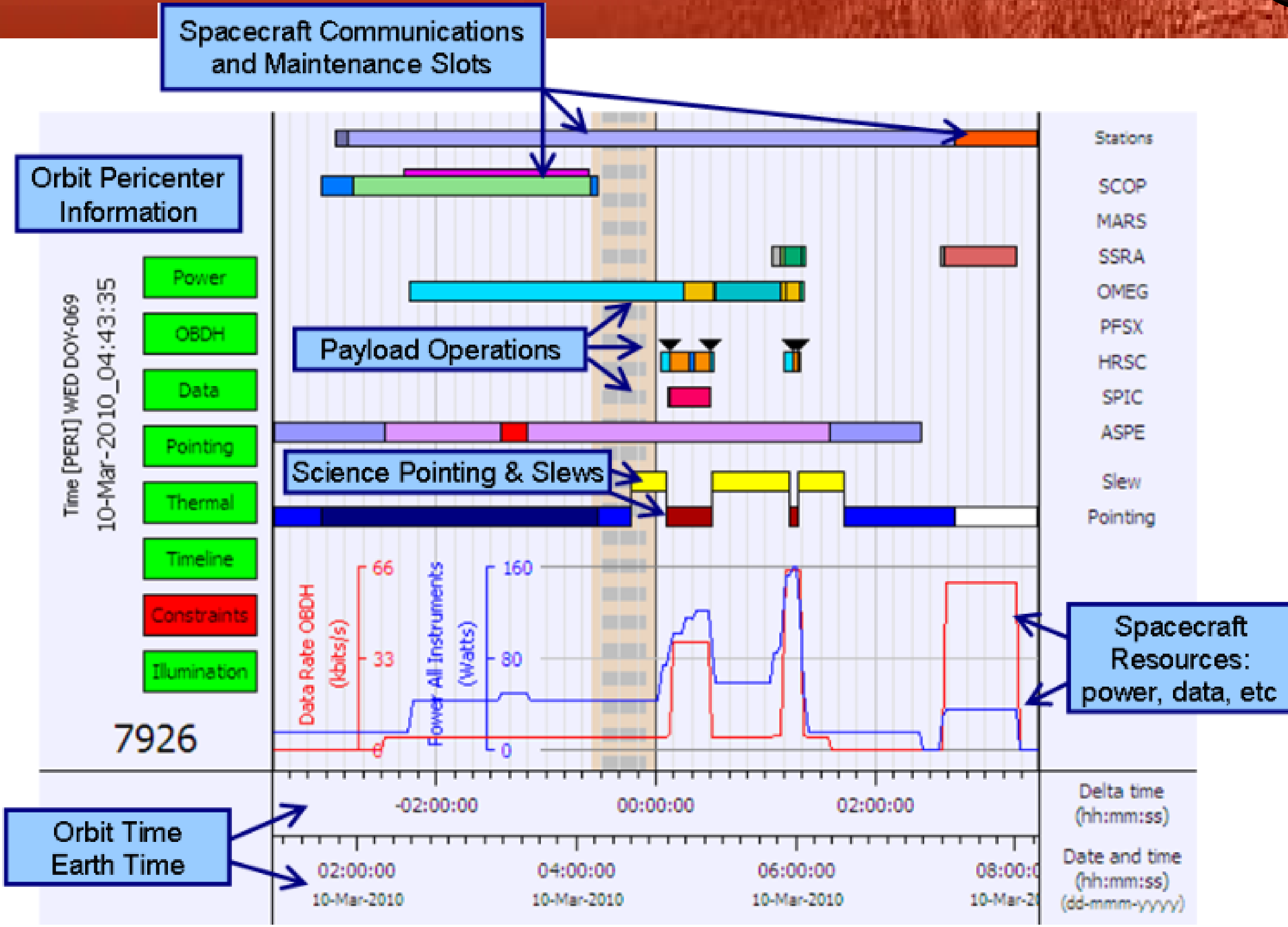


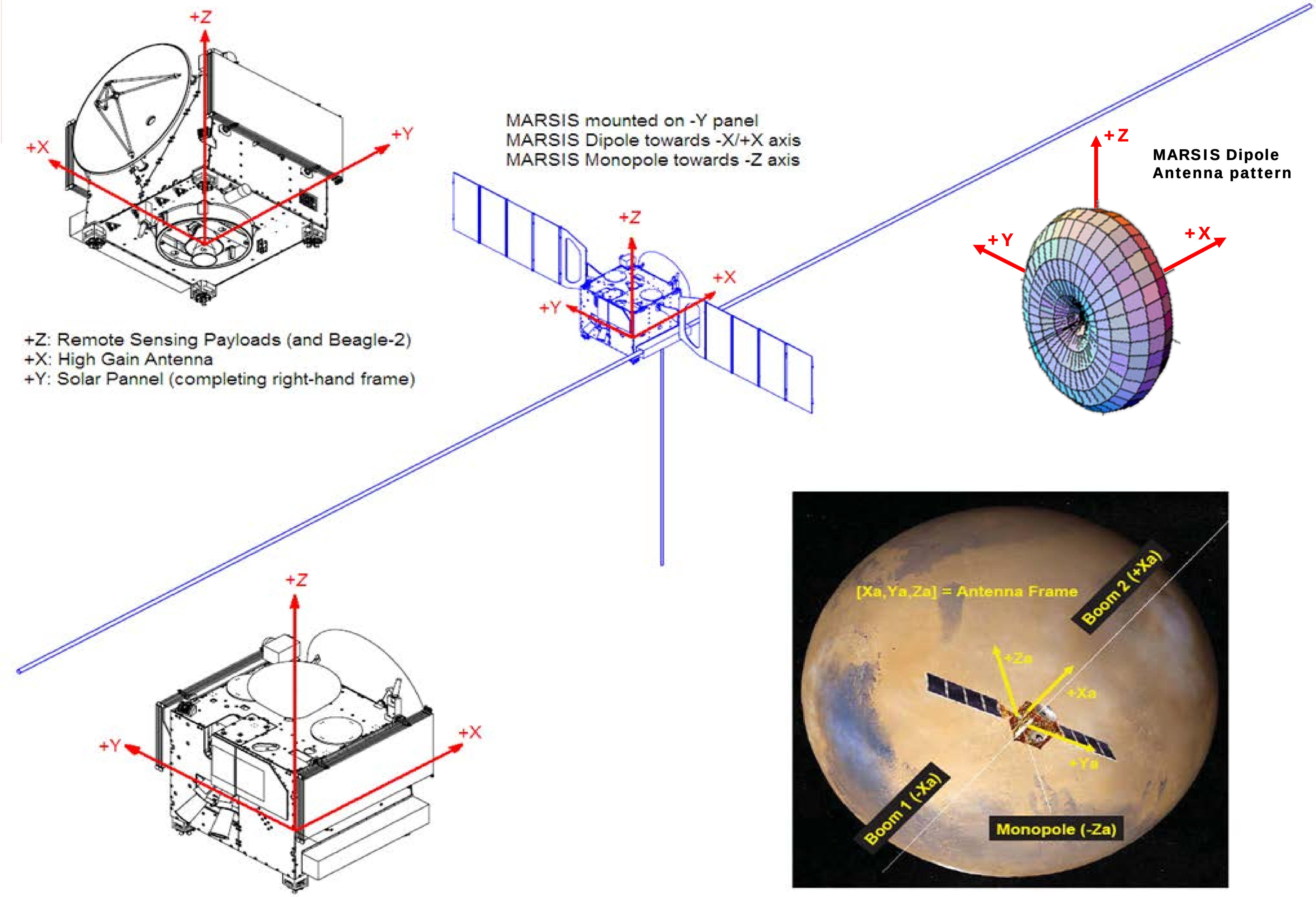
EXTRA: Spacecraft drivers

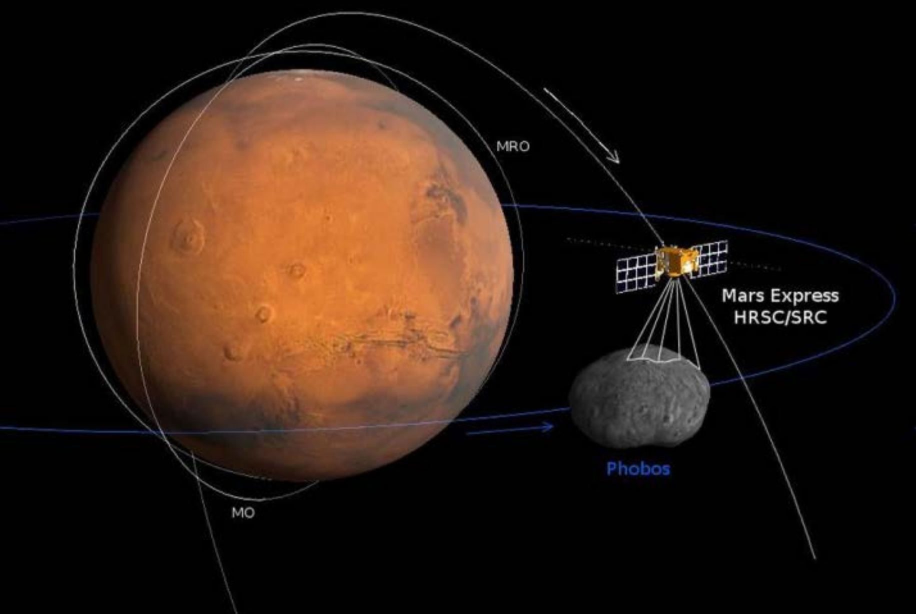
- Science pointing capabilities (duration, rates, RW momentum, etc)
- Fixed antenna
- Only 70% power available from solar panels
- Battery degradation 40%
- SSMM data handling over OBDH bus (<100kbps)
- Uplink windows (daily, now weekly)
- Payload constraints (AS scanner, etc)
- Illumination
- Thermal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

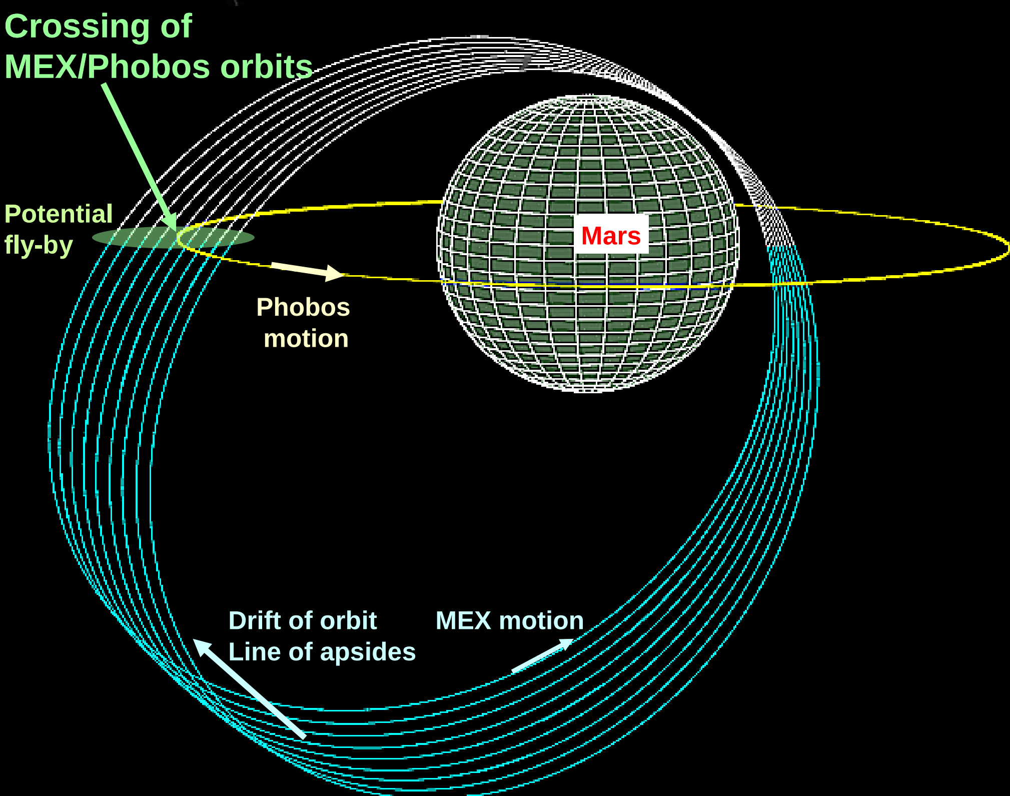
- Add a note on interfaces and conventions (lack of conventions causes backward incompatibility and no history tracking)

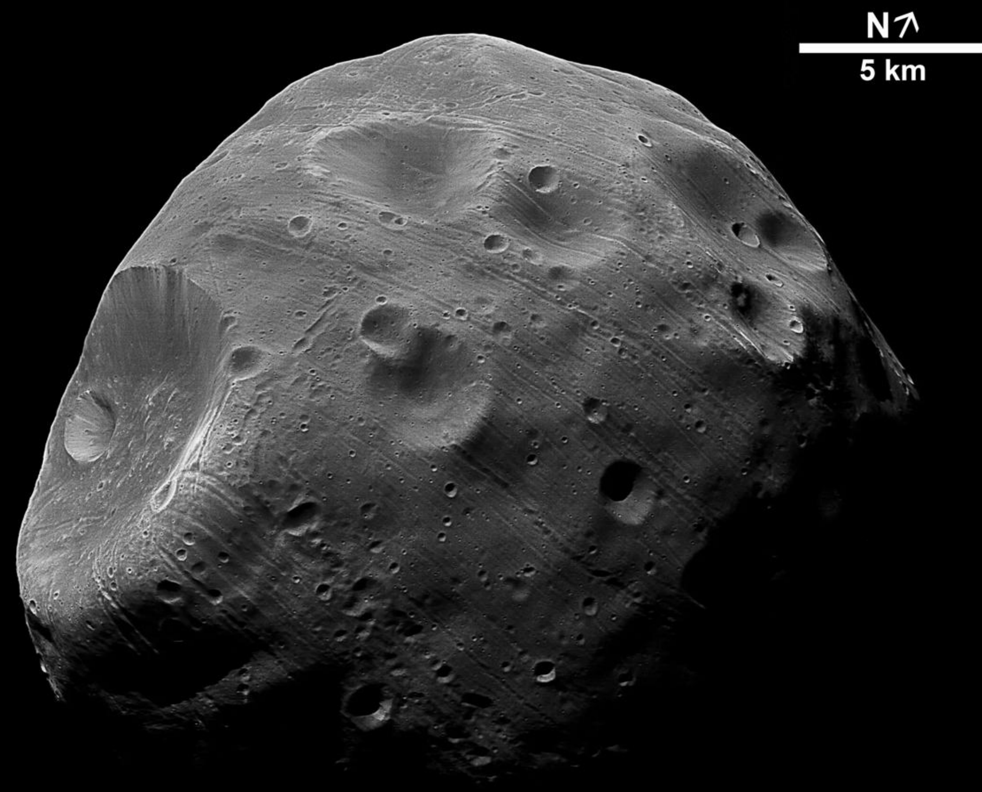
EXTRA : MAPPS Timeline detail



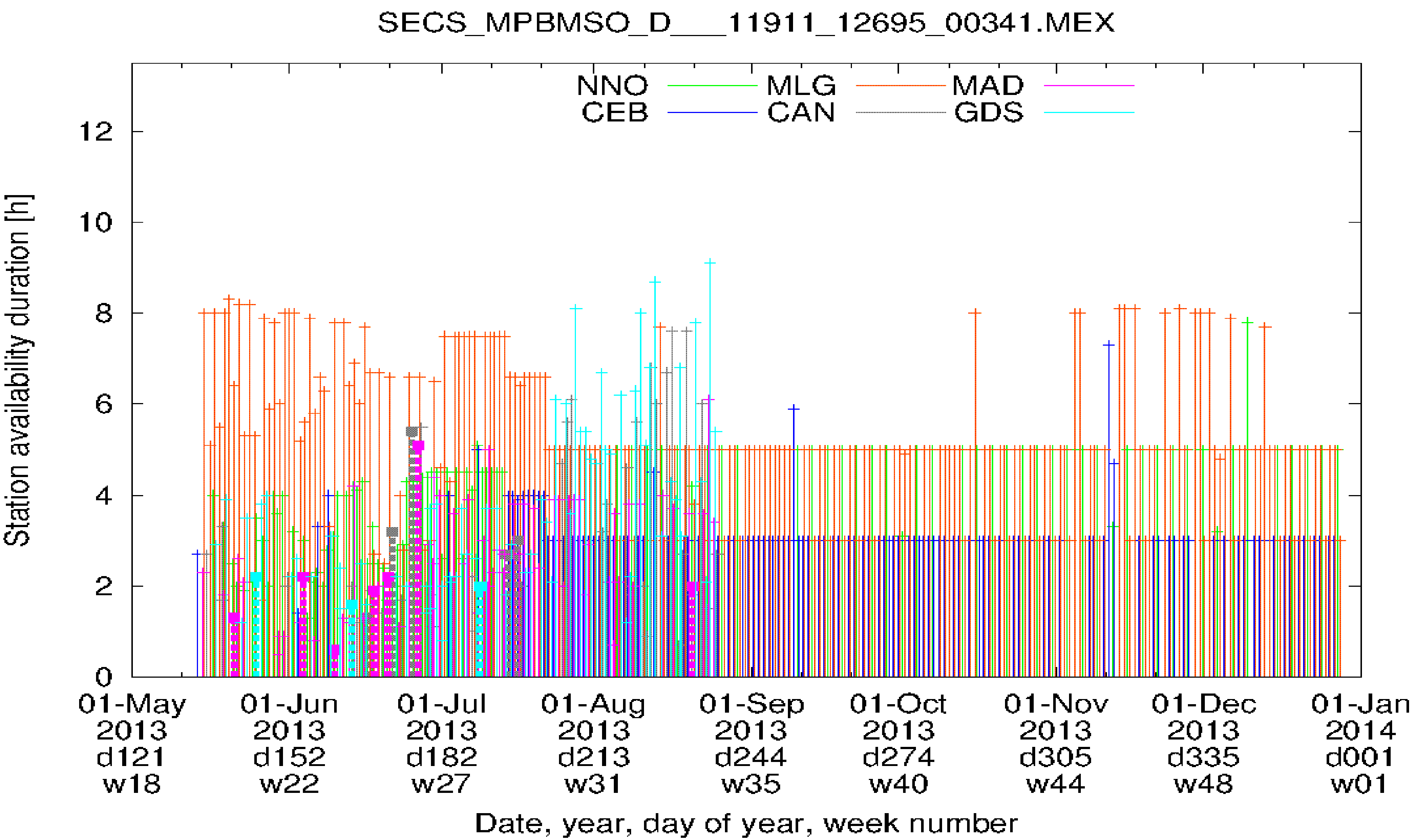

+Z
+X
+Y
+Z: Remote Sensing Payloads (and Beagle-2)
+X: High Gain Antenna
+Y: Solar Pannel (completing right-hand frame)
MARSIS mounted on -Y panel
MARSIS Dipole towards -X/+X axis
MARSIS Monopole towards -Z axis
+Z
+X
+Y
+Z
MARSIS Dipole
Antenna pattern
+Y
+X
+Z
+Y
+X
[Xa,Ya,Za] = Antenna Frame
Boom 2 (+Xa)
+Za
+Xa
+Ya
Boom 1 (-Xa)
Monopole (-Za)


MRO
Mars Express
HRSC/SRC
Phobos
MO

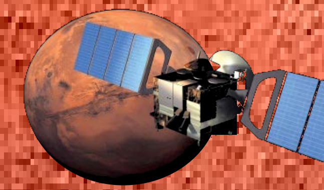

Crossing of
MEX/Phobos orbits
Potential
fly-by
Mars
Phobos
motion
Drift of orbit
Line of apsides
MEX motion


N
5 km

EXTRA : SECS
Station Events Communications Skeleton



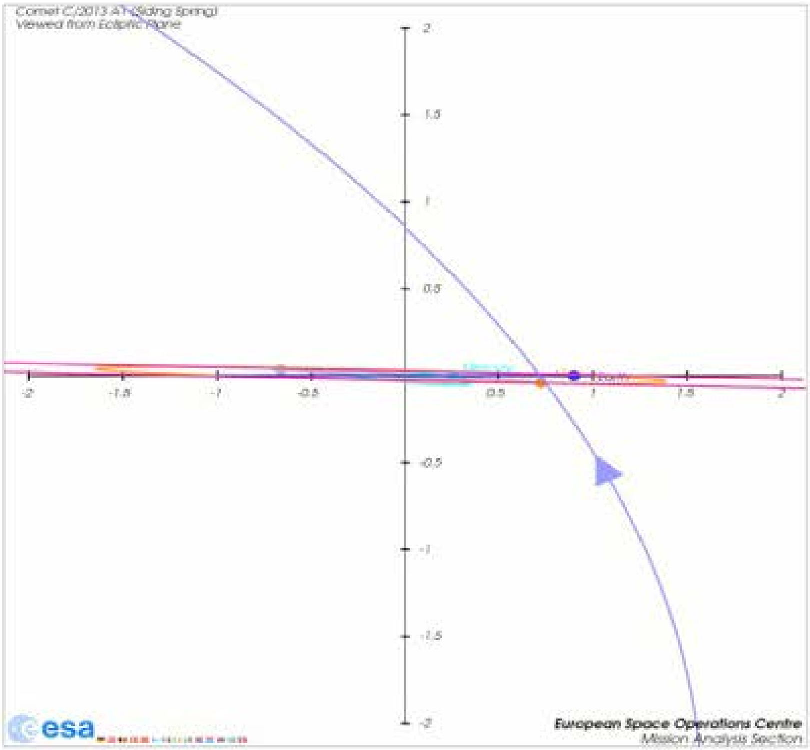
EXTRA: (FAST)
Table of TCs per Instrument

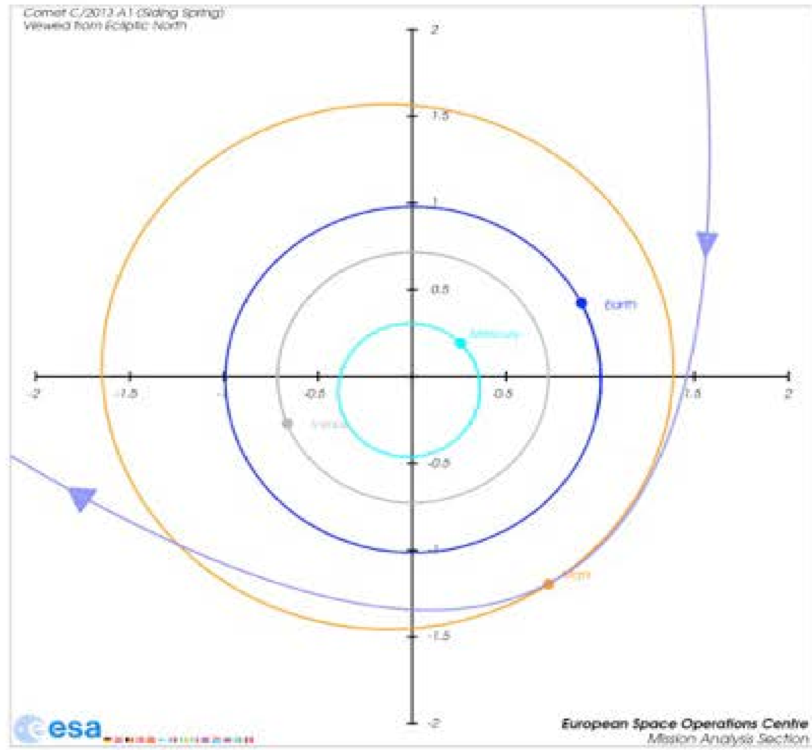


Instrument	TCs without OBCP	TCs with OBCP	OBCP implemented
MARSIS (AIS/SS/FM)	20~34	6/11/9	Switch ON/OFF (might need cleanup)
HRSC/SRC	35 (+8 heating)	23/26	Switch ON/OFF and initialization
SPICAM	13	3	Switch ON/OFF
PFS	70	7 +4	Switch ON/OFF (might need cleanup) Parameter updates (configurable)
OMEGA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

Comet C/2013 A1 (Siding Spring)

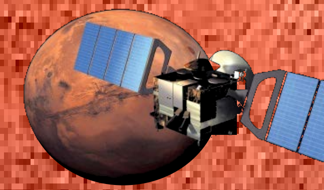
Discovered in January 3rd, 2013
Hyperbolic orbit = Oort Cloud comet





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 (~3000TCs 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

SUCCESFUL 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!**