E X O M A R S

esa mars express

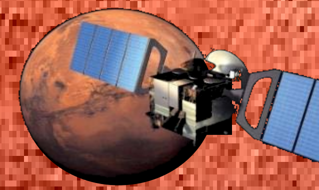
Re-use of science operations systems around Mars

From Mars Express to ExoMars

Alejandro Cardesín Moinelo
Mars Express and ExoMars
Science Operations Centres

SCIOPS Conference, ESAC, 19 Oct 2017

Mars Express 2003-2020…

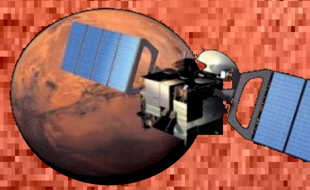


Up and running since 2003 (up to 2020 and beyond…)

First European Mission to orbit another Planet!

First & last mission of the successful “Rosetta family”

Mars Express science investigations



Martian Moons: Phobos & Deimos: surface, mass, volume, density, …

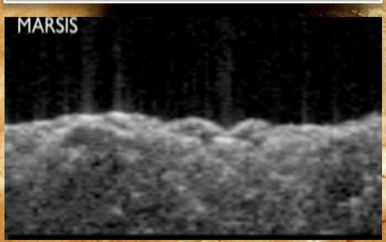
Atmosphere: composition, dynamics, temperature, climate, clouds, …

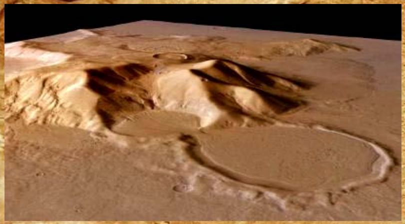
Ionosphere, Magnetosphere, Exosphere, Interaction with solar wind, auroraes

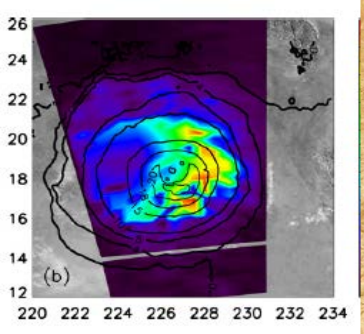
Surface: geology, composition, mineralogy, …

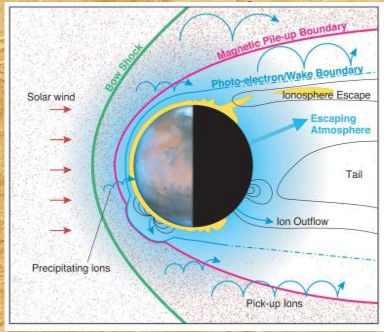
Sub-surface: physical properties and structures

Interior: Gravity field





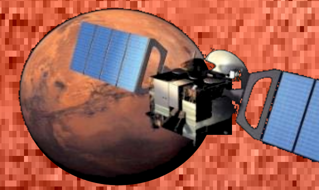


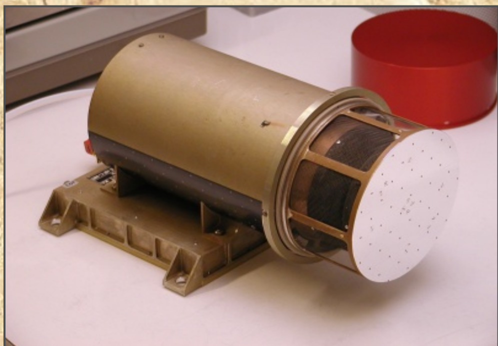


Comprehensive study of the planet and its history

MEX/HRSC

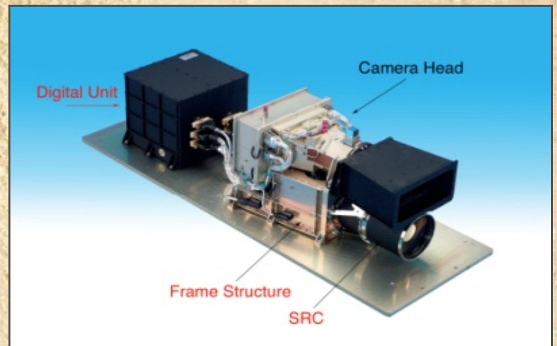
Mars Express Payload:
8 Scientific Instruments





ASPERA: Energetic Neutral Atoms Analyser

PI: M. Holstroom, IRF Kiruna (SE)



HRSC: High Resolution Stereo Camera

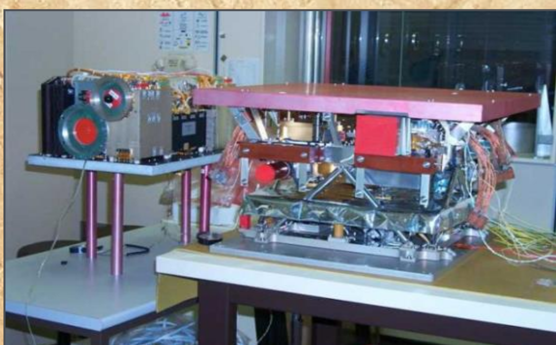
PI: R. Jaumann, DLR Berlin (DE)

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

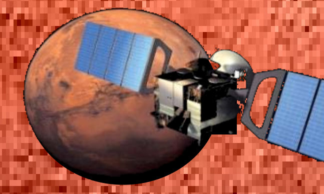
A.Sanchez Lavega, UPV/EHU (ES)

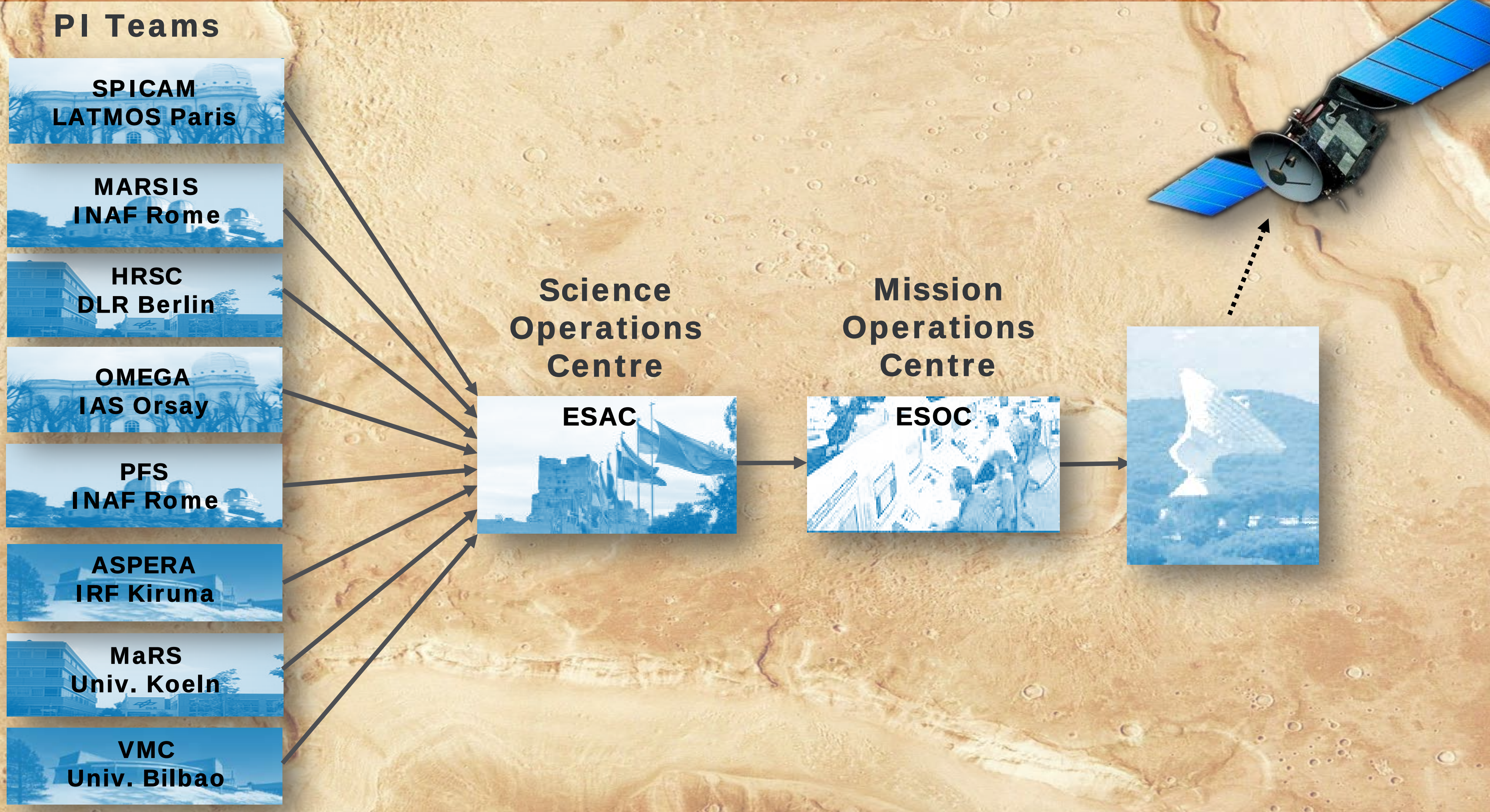
M. Almeida, DADPS (CH)

ESOC, ESAC, ESTEC

Credit: MEX/HRSC

Mars Express
Distributed Science Operations



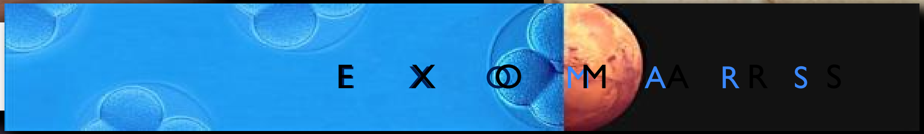


Credit: MEX/HRSC

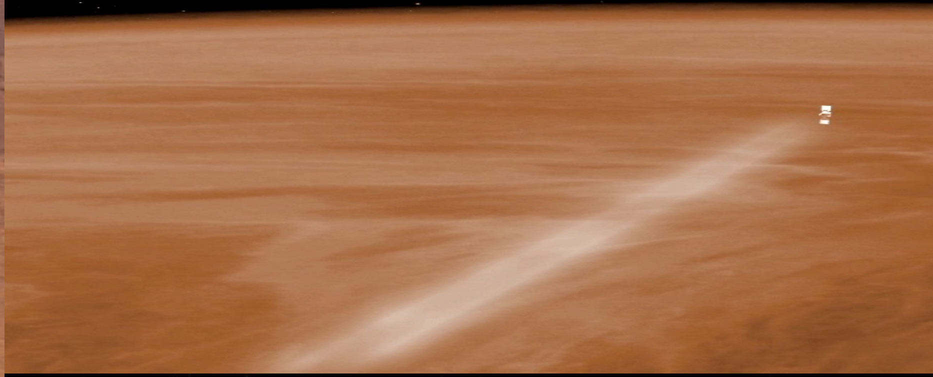
ExoMars 2016

Trace Gas Orbiter
Arrived at Mars
19 October 2016

SCIENCE OBJECTIVES
Martian atmosphere trace gases
Surface geology and ice content



Now: aerobraking until mid 2018
Orbit Circularization down to ~400km



TGO Payload

NOMAD

High-resolution occultation and nadir spectrometers

Atmospheric composition (CH_4, O_3, trace species, isotopes) dust, clouds, P&T profiles

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

CaSSIS

High-resolution, stereo camera

Mapping of sources
Landing site selection

ACS

Suite of 3 high-resolution spectrometers

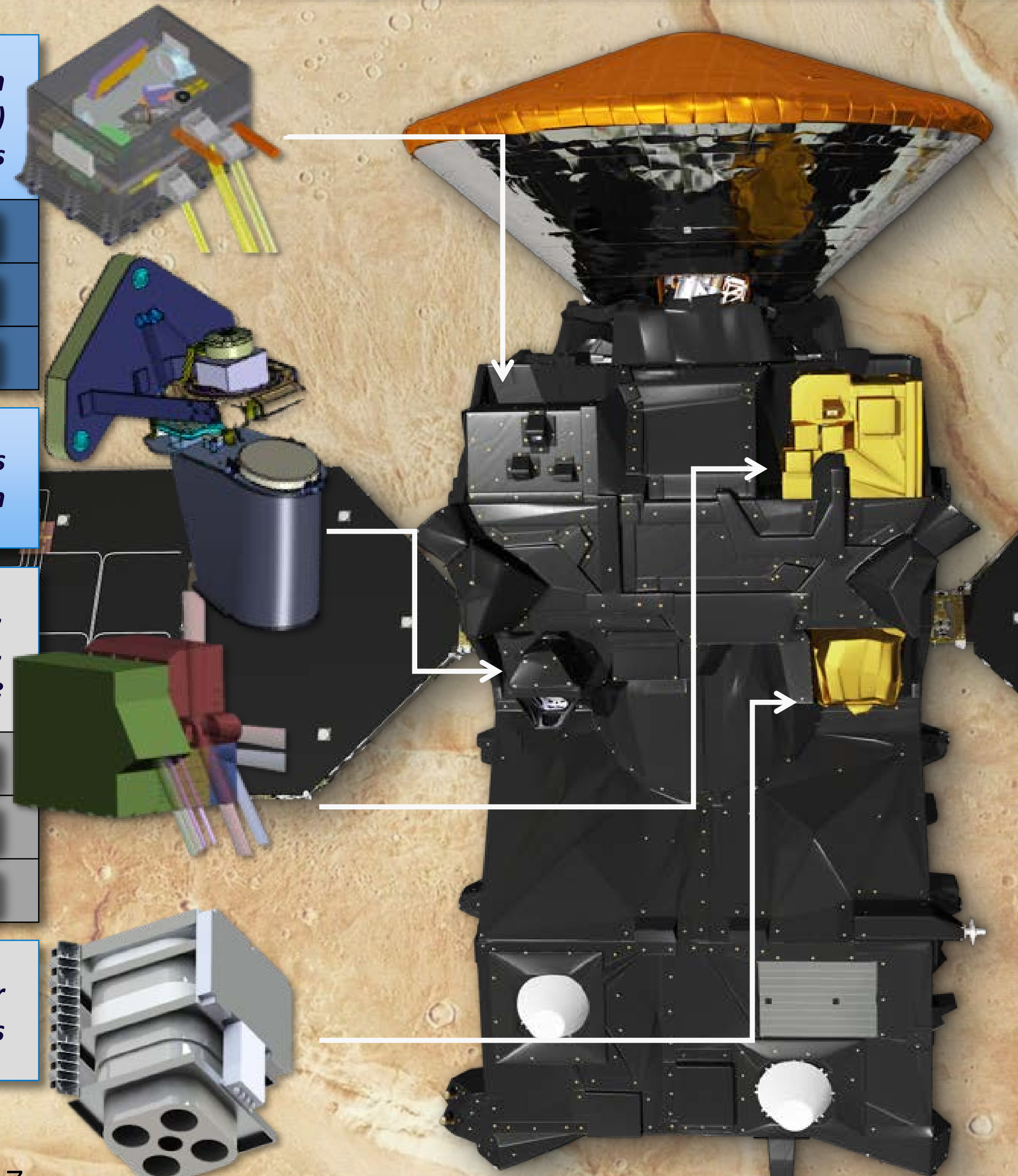
Atmospheric chemistry, aerosols, surface T, structure

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

FREND

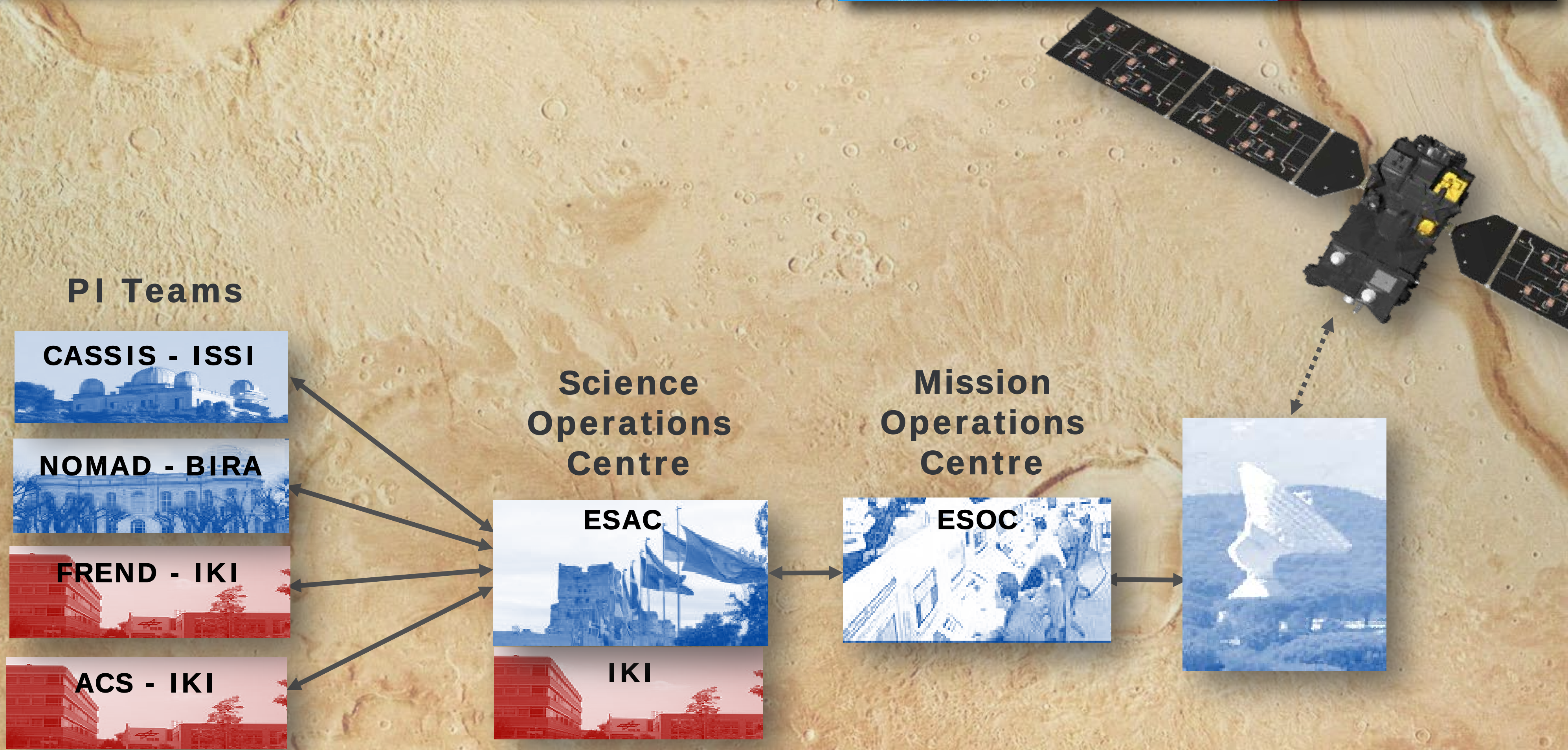
Collimated neutron detector

Mapping of subsurface water and hydrated minerals



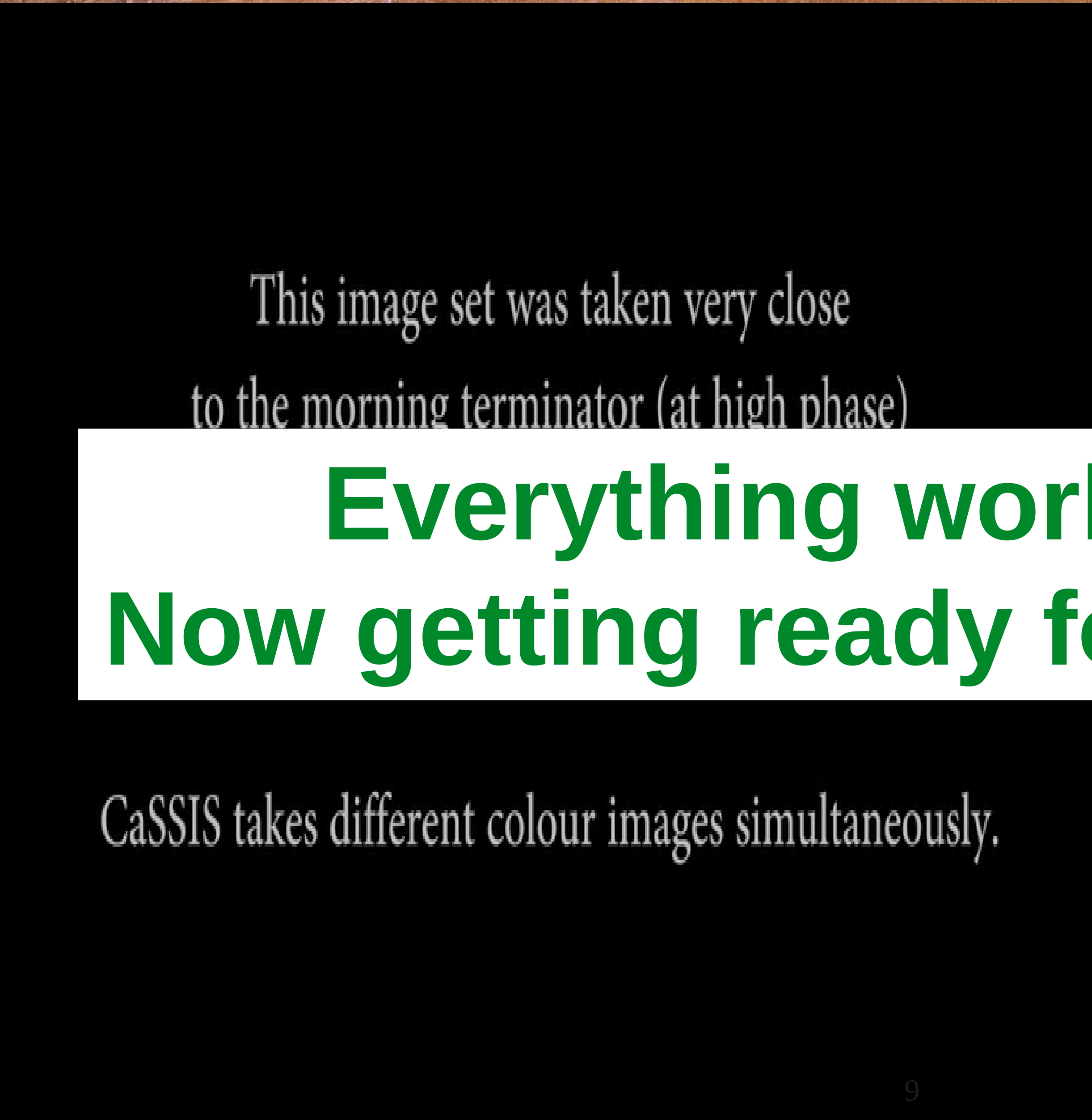
Credit: MEX/HRSC

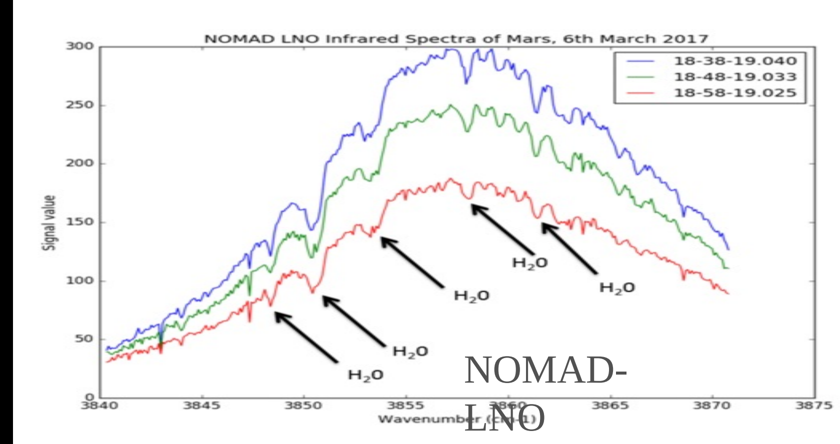
Distributed ExoMars Science Operations



Credit: MEX/HRSC

First in-orbit calibrations

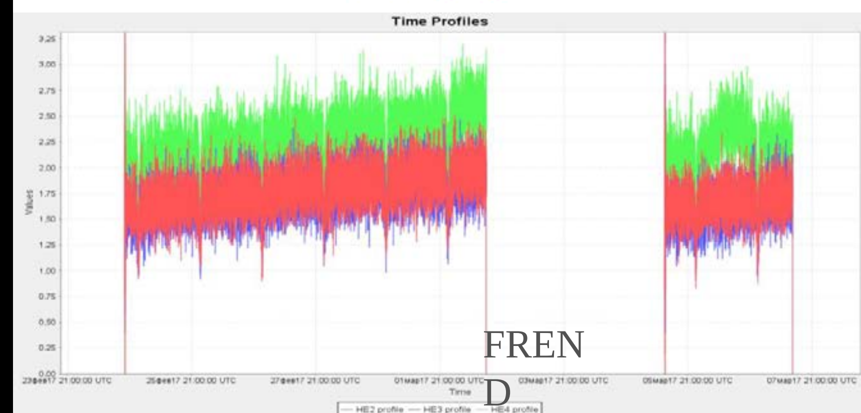




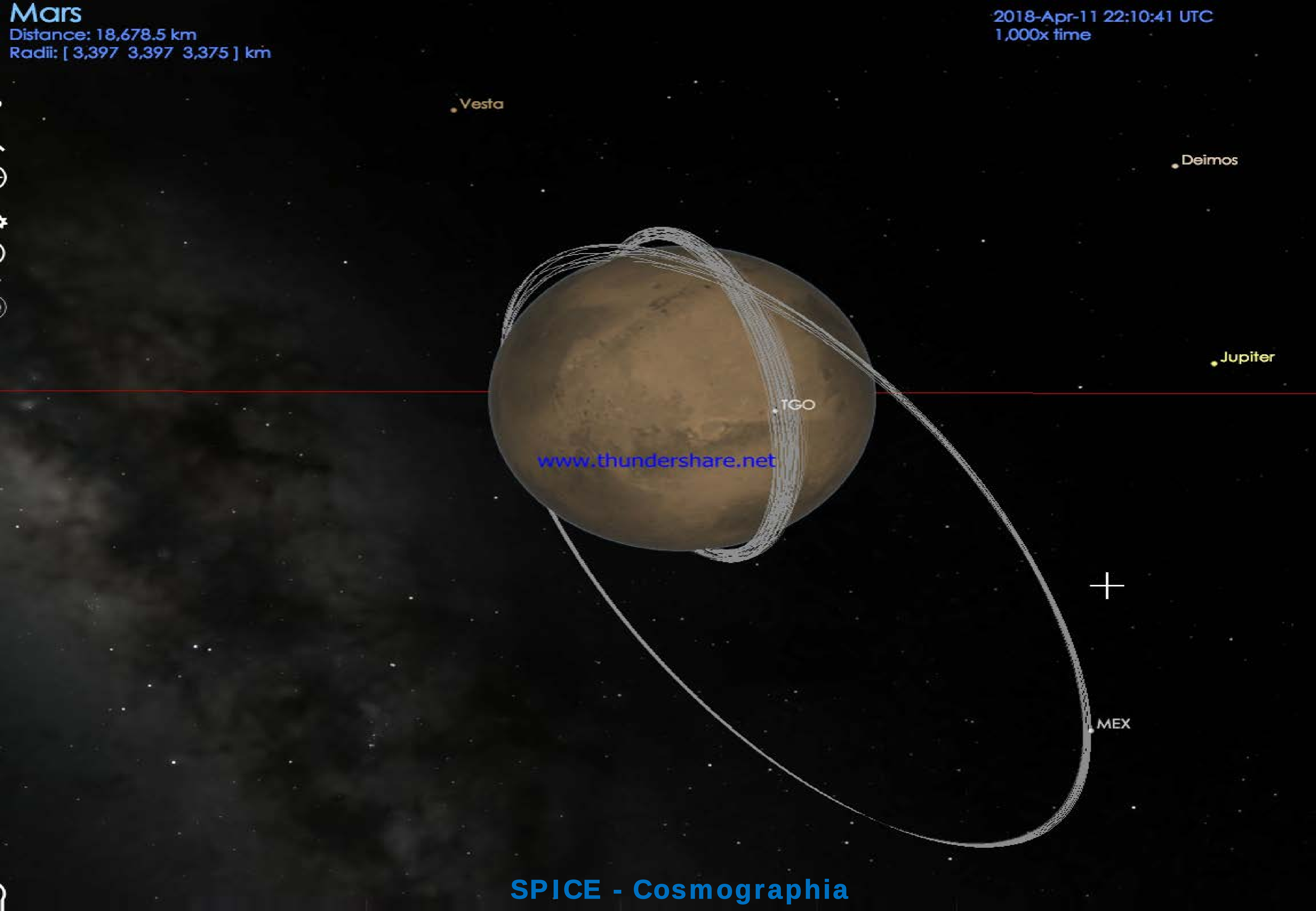
NOMAD-LNO

Everything working fine!
Now getting ready for mid 2018…

TIRVIM

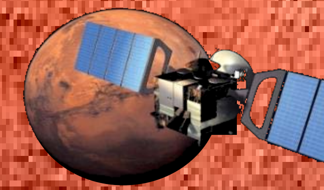


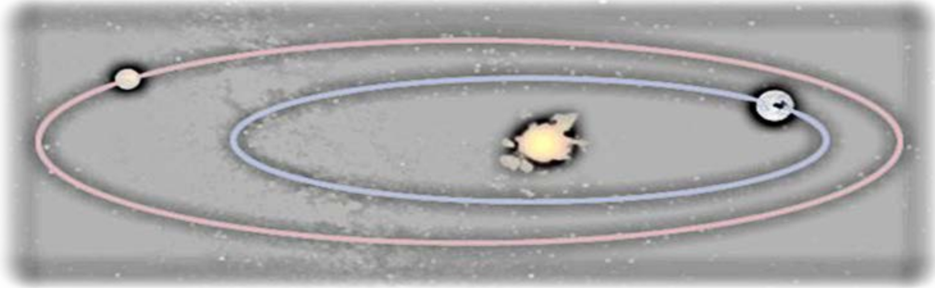
FREND



SPICE - Cosmographia

Mars Express: Mission Profile

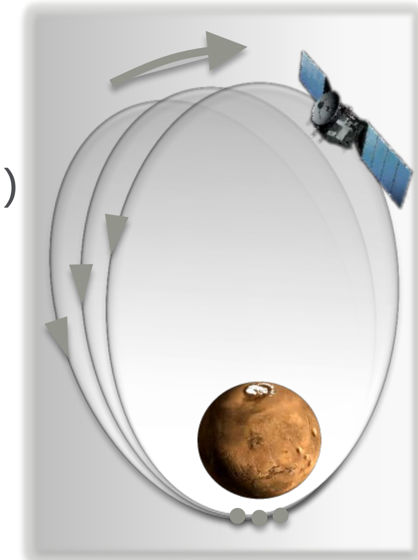




Mars Seasonal variability (both missions)

- Mars-Sun-Earth ephemeris:
  - Data rates 1 to 10, Solar power 1 to 1.5

Elliptical orbit of 7 hours around Mars

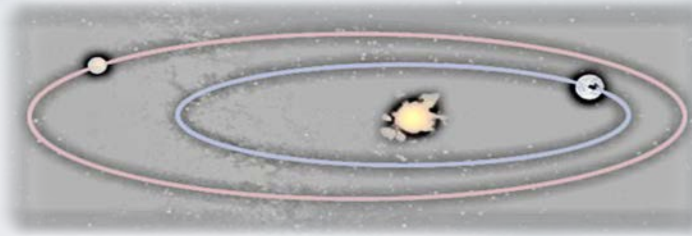


- Every month: ~100 orbits, ~200 science pointings, ~400 observations
- High pointing flexibility (nadir, earth, inertial, limb, phobos, tracking, ...)
- MEX orbit precession : changing latitude and illumination conditions
- Mars/Phobos resonances : Mars 11/3, 18/5, 25/7, ... (now Phobos)

Communications

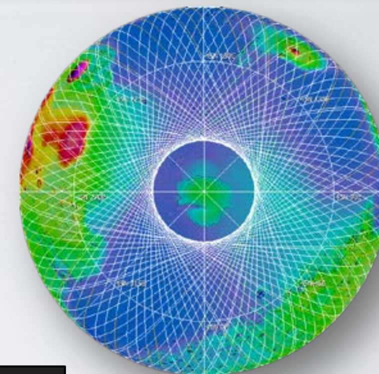
- Fixed antenna, cannot point during comms
- ~18 passes per week, ~10 ESA+DSN stations

TGO Science Mission Profile



Mars Seasonal variability (both missions)

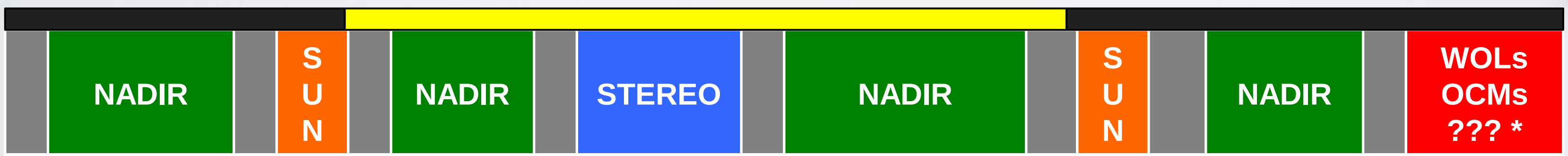
- Mars-Sun-Earth ephemeris:
  - variable data rates 1 to 10; sun power 1 to 1.5



Circular orbit ~2 hours

- Every month: **~350** orbits
- Orbital node regression cycles: every ~7weeks (wrt sun)
- Ground Track repeatability: ~ 30 days

Pointing baseline per orbit: Nadir + Sun + Stereo



+ No earth pointing (steerable antenna)
- Relay operations
- Orbit Control Maneuvers
- SC flips, etc …

* SC constraints under discussion
- Wheel-off loadings
- Slews
- Payload Calibrations

Every month: ~2000 science pointings, ~2000 observations

Need extra automation…

SCIENCE OPERATIONS

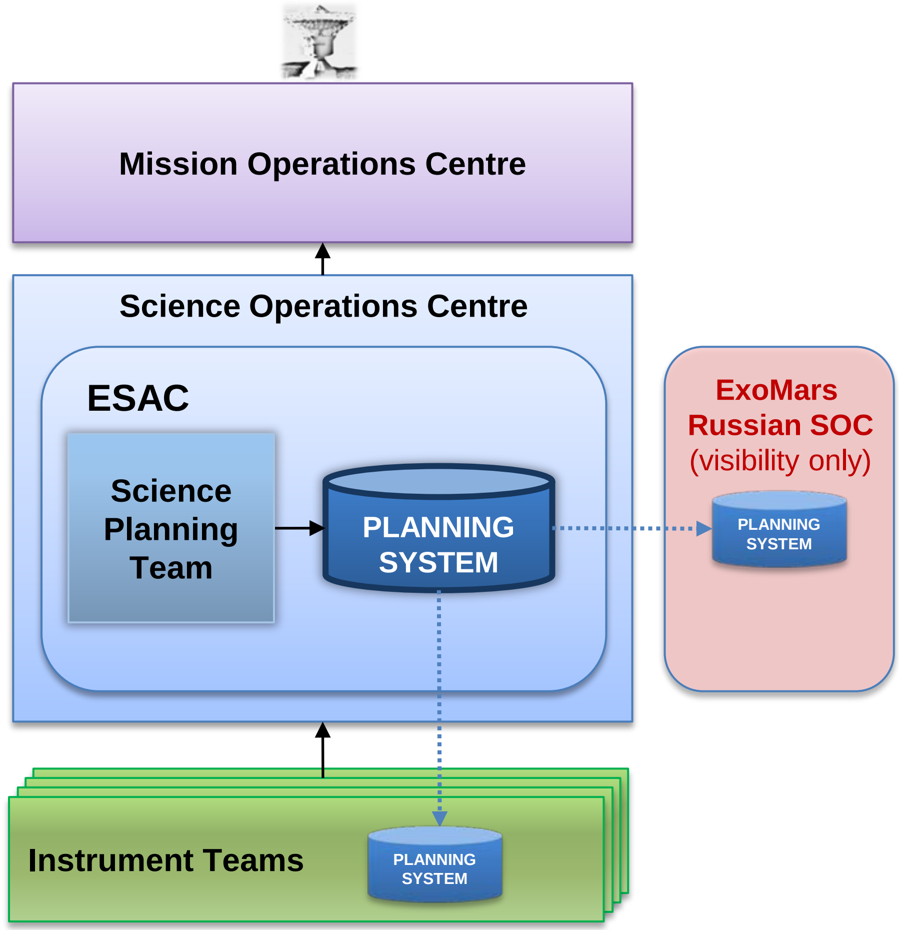
Uplink + Downlink

Uplink System (both missions)

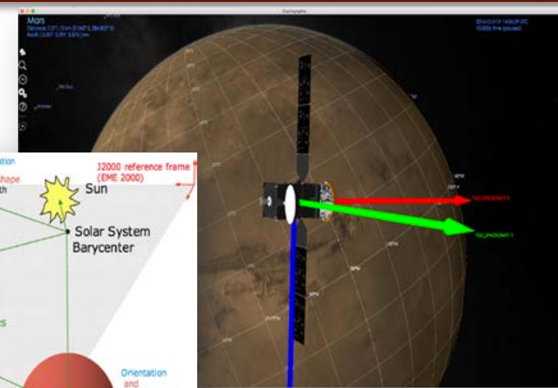
Planning System Centralized at ESAC

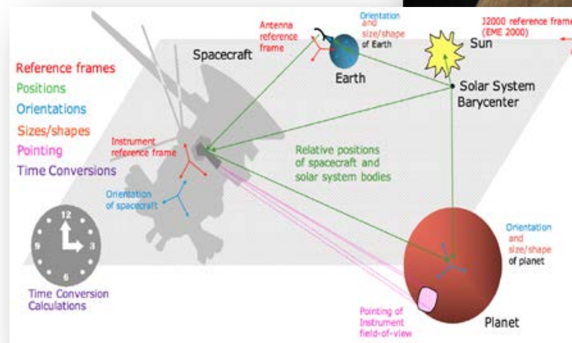
- ❑ Planning system <u>distributed</u> to all sites

- ❑ Input: Science Obs. Requests from PIs
- ❑ Output: Pointing/TCs to Mission Ops. Centre



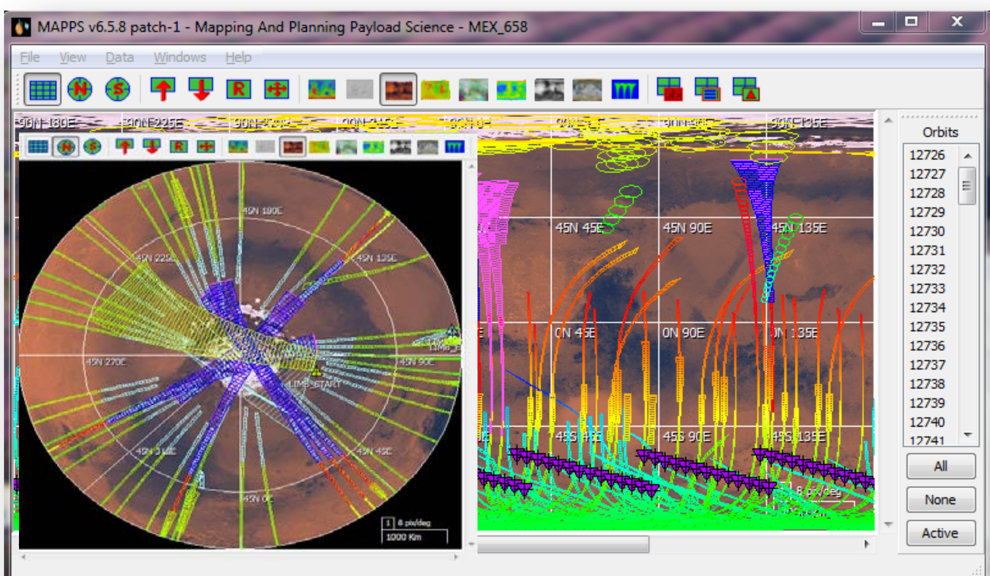
System Legacy

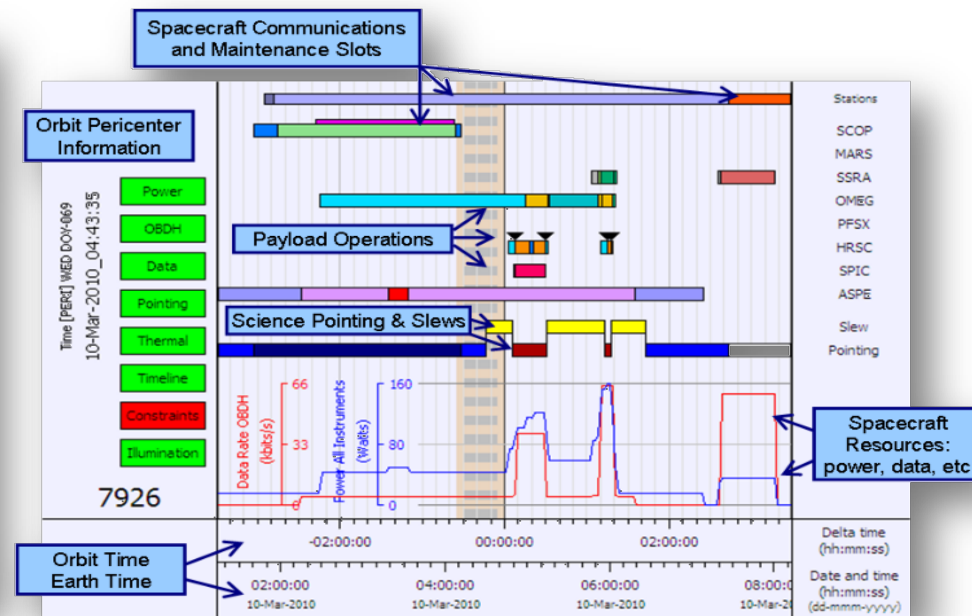




- **SPICE** :
  Geometry/Auxiliary Information System

- **MAPPS / EPS** :
  Mapping and Planning Payload Science, Experiment Planning System



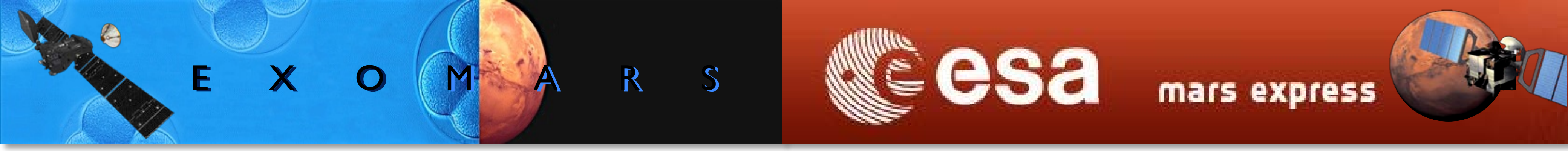


Planning Cycles

Long Term Planning (6 months) : Baseline Science Plan

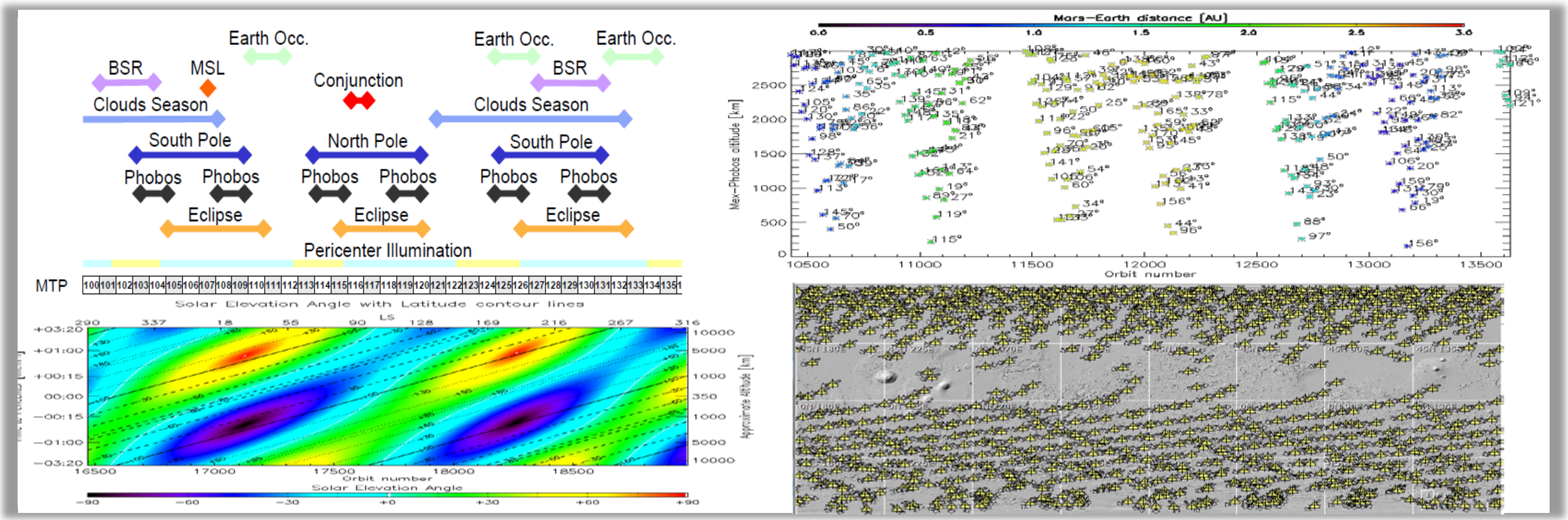
Medium Term Planning (4 weeks) : Confirm Pointing & Resource Allocation

Short Term Planning (1 week) : Detailed Commanding



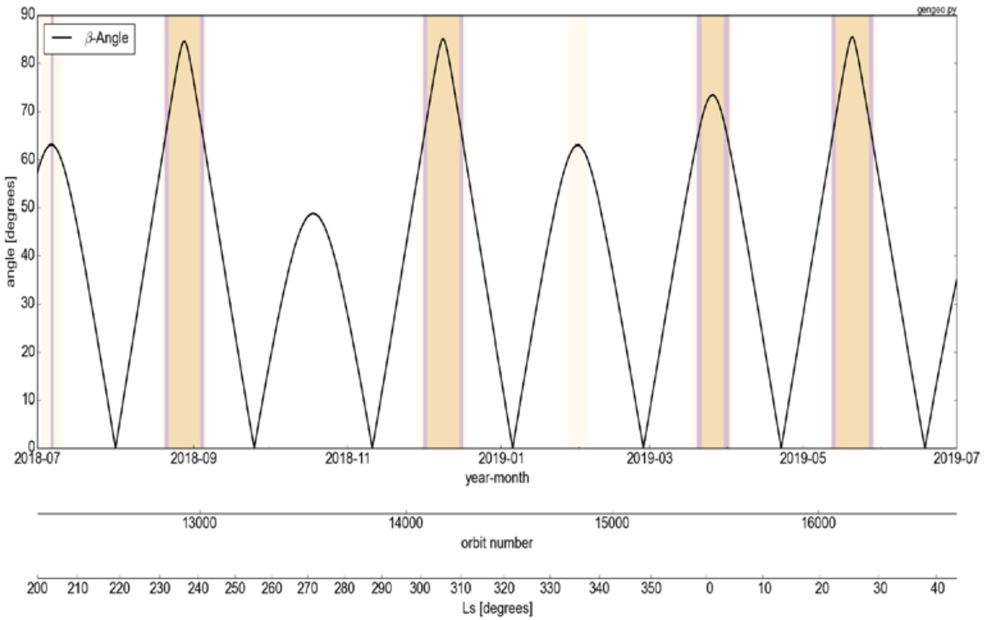
Long Term Planning

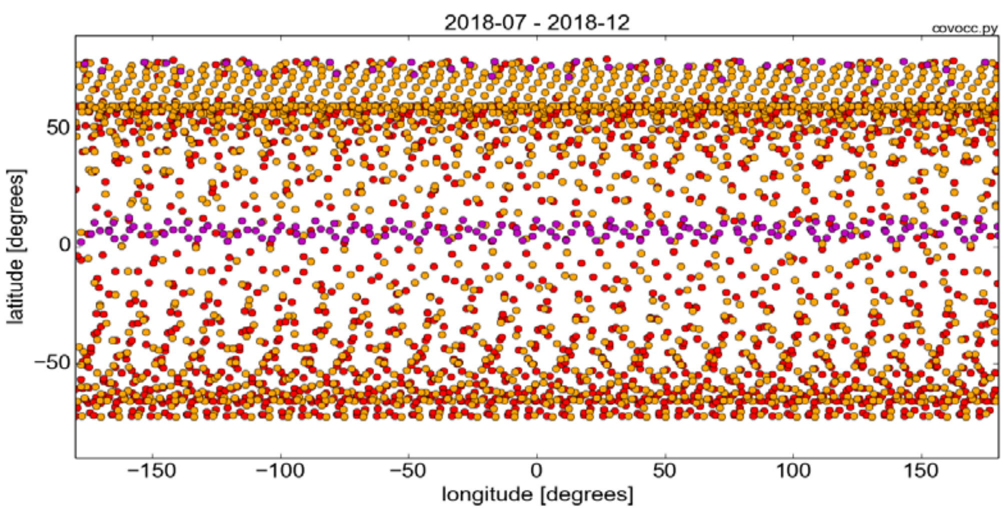
- **Long term analysis of all input geometry and operational events**
  - Illumination, occultations, eclipses, data rate, ground station coverage, etc
- **Definition of long term seasons, campaigns, priorities**
  - Scientific and Operational seasons: definition of priorities, share, limited data rate, eclipses, etc
- **Science Opportunity analysis**
  - Calculation of specific science events (occultations, fly-bys, …)



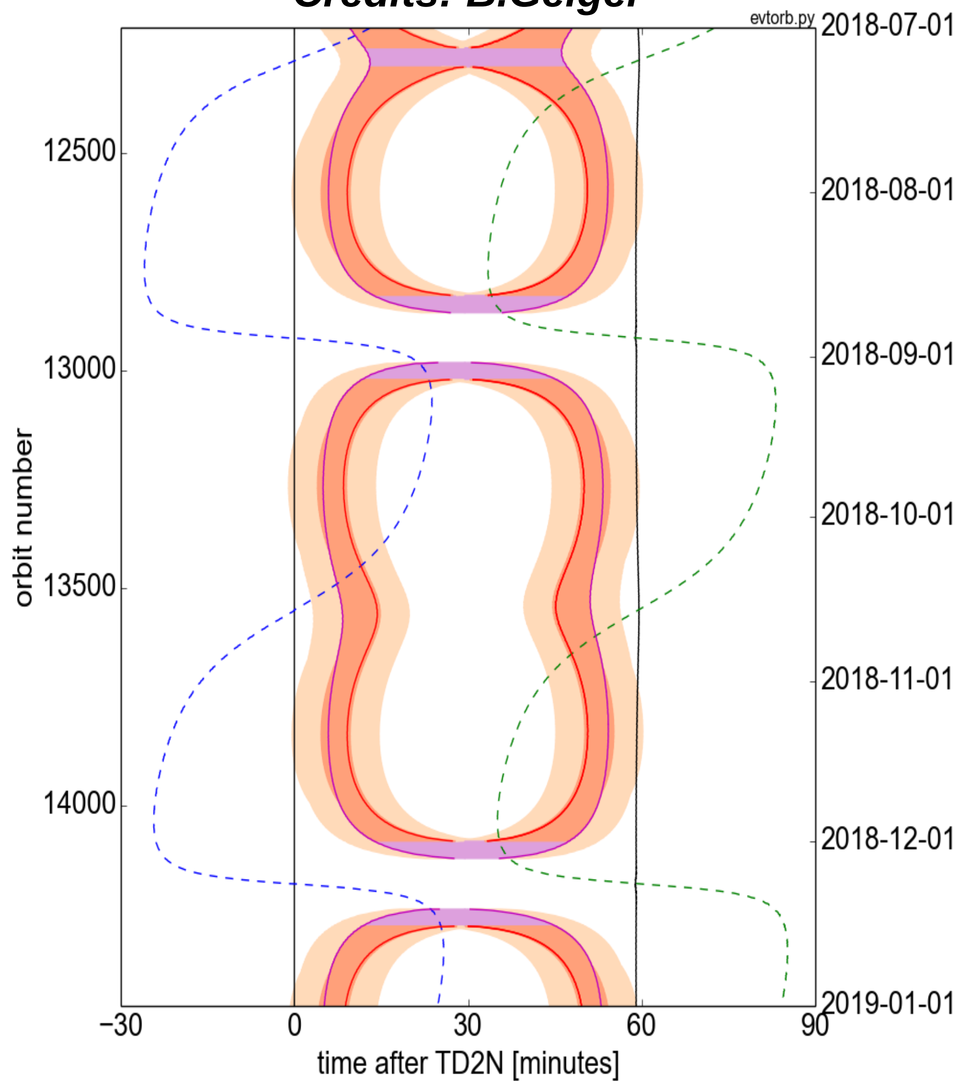
MEX Examples: seasons, illumination, phobos flybys, earth occs, …

ExoMars LTP analysis: Seasons + Opportunities





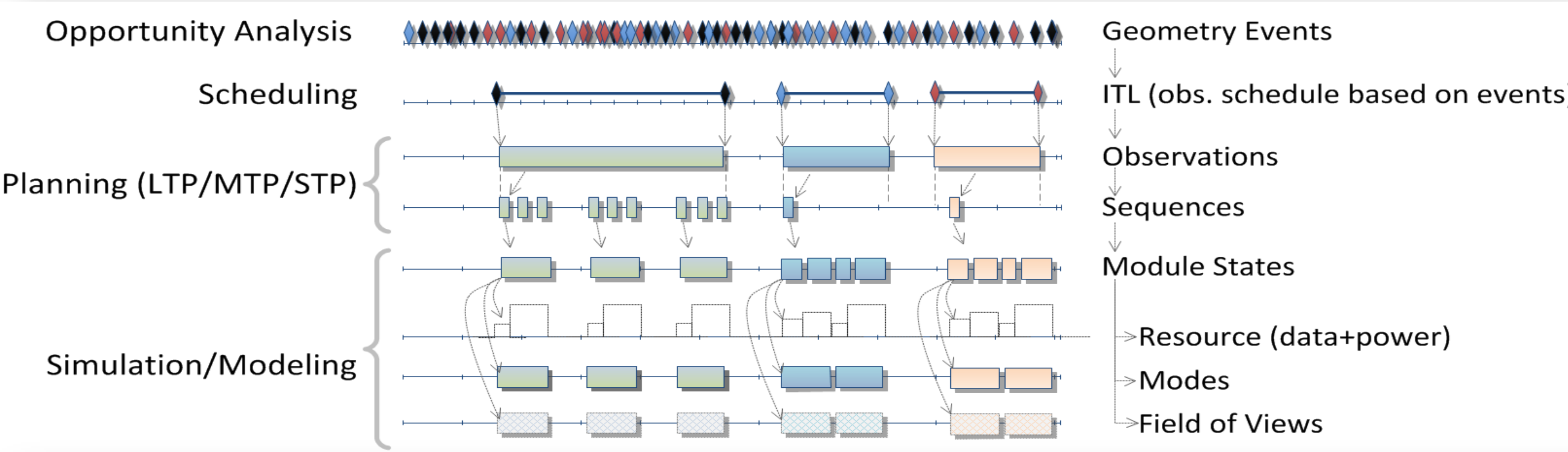
Credits: B.Geiger

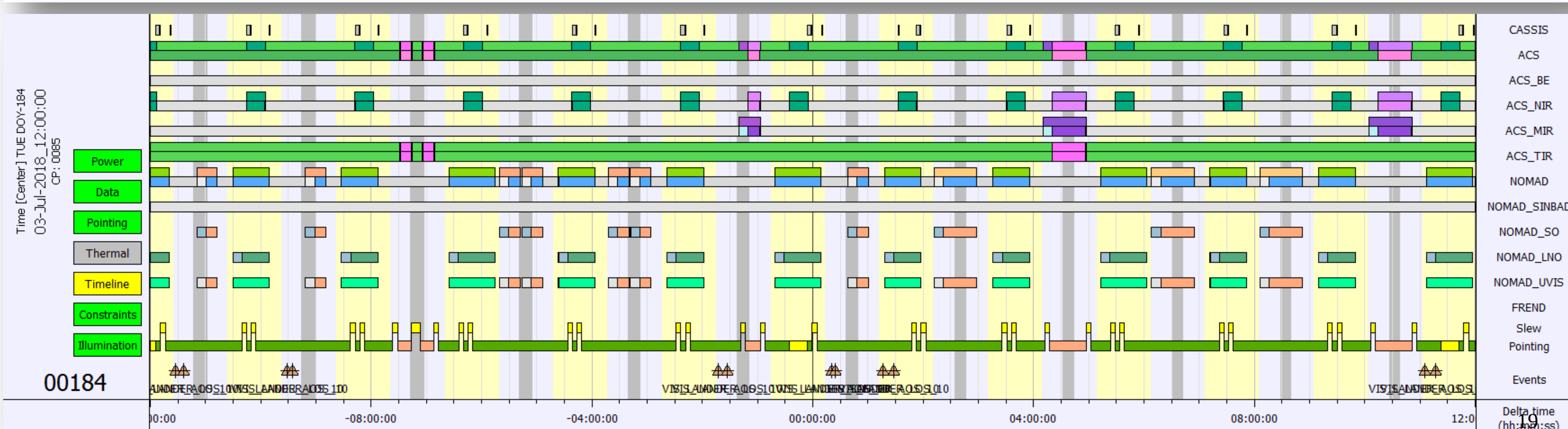


ExoMars LTP Extra Automation:

Opportunity Analysis → Scheduling → Observation expansion → Timeline

Credits: B.Geiger, SOC





Medium Term Planning (same for both missions)

Confirm a feasible fully detailed schedule of payload science operations

Input : **Science Observation requests and priorities**

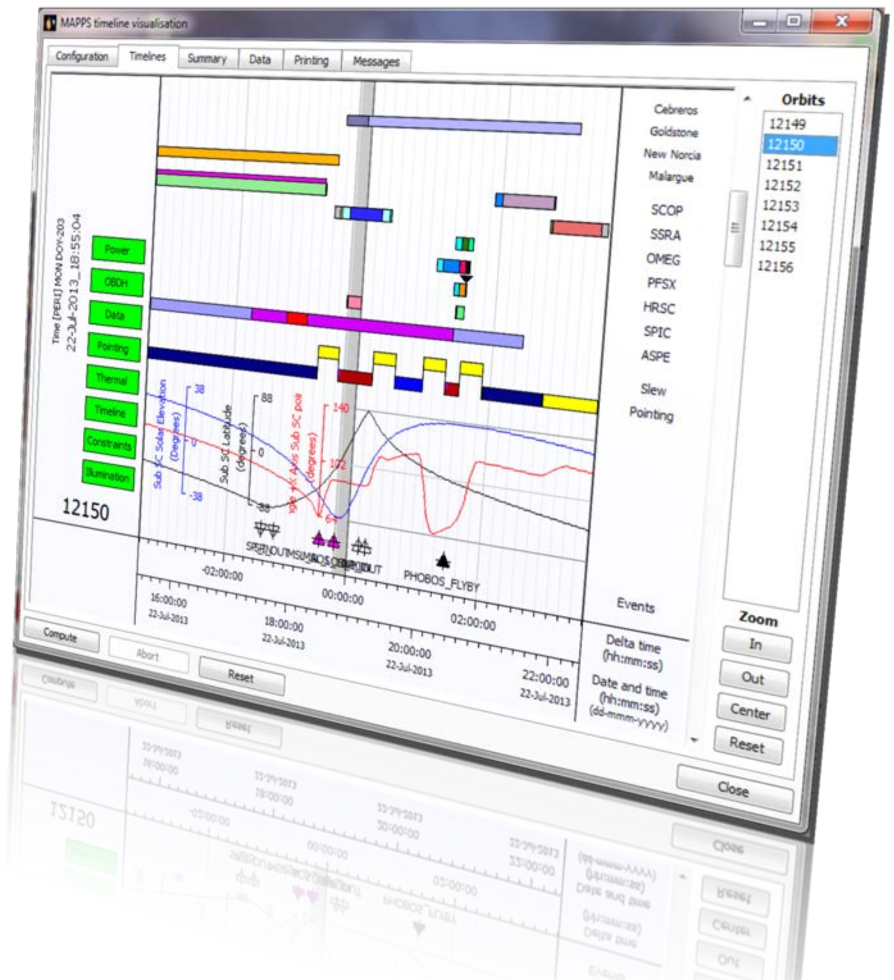
***ExoMars: input timeline baseline from LTP**

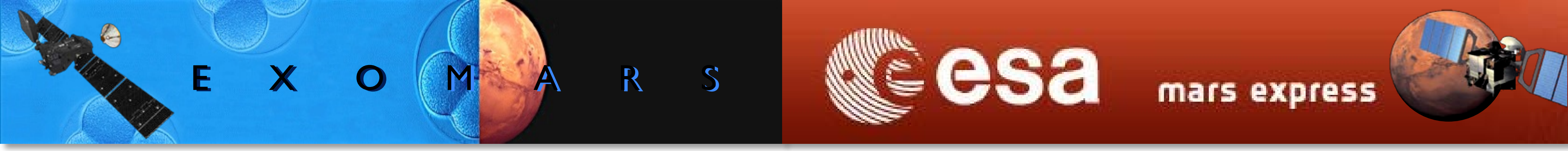
SC contraints and events from ESOC

Output: **Fully harmonized feasible plan**

Spacecraft Pointing and Attitude

Payload Command Sequences + Resources





Short Term Planning (same for both missions)

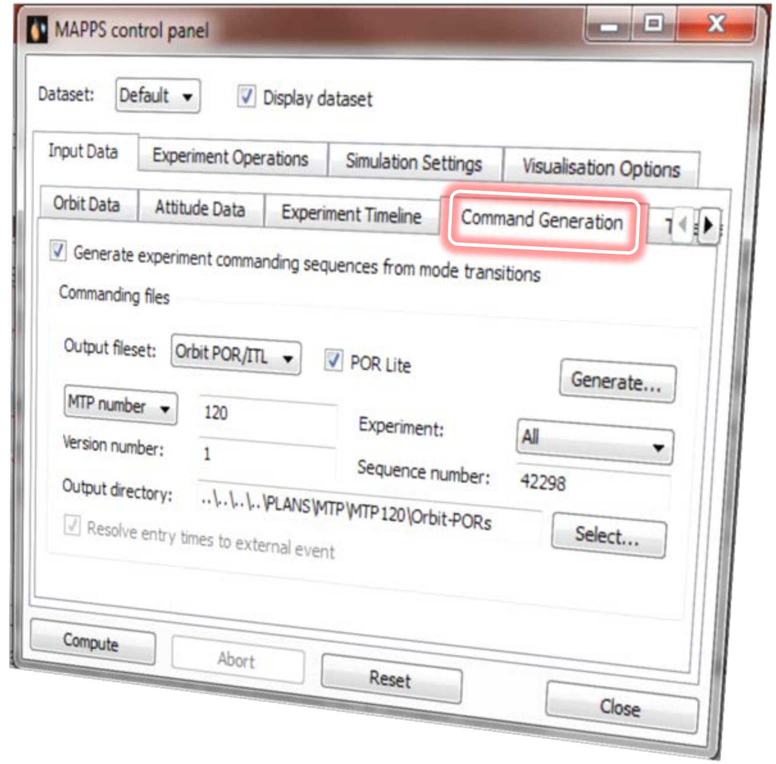
Confirm payload commanding and fine tune parameters

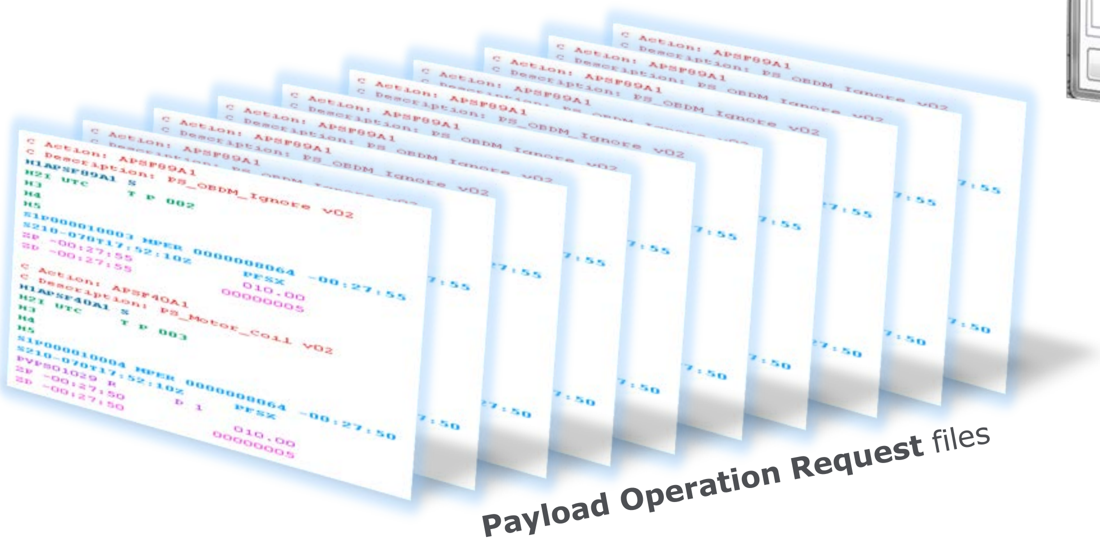
Input : **Commanding files from MTP baseline**

Updated by Pis with latest configuration

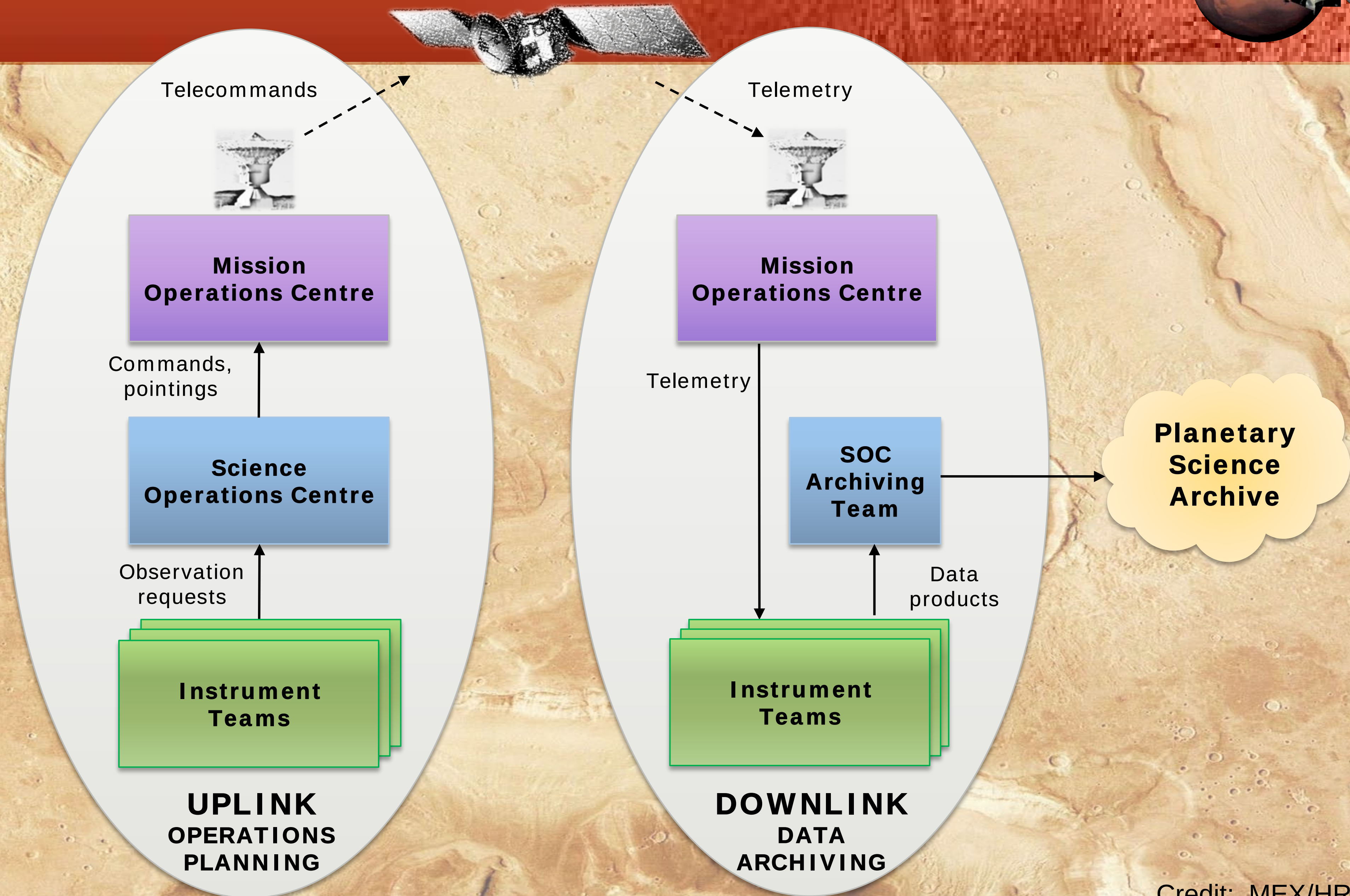
Output: **Fully detailed commanding files**

Command sequences and Resources (Data/Power)



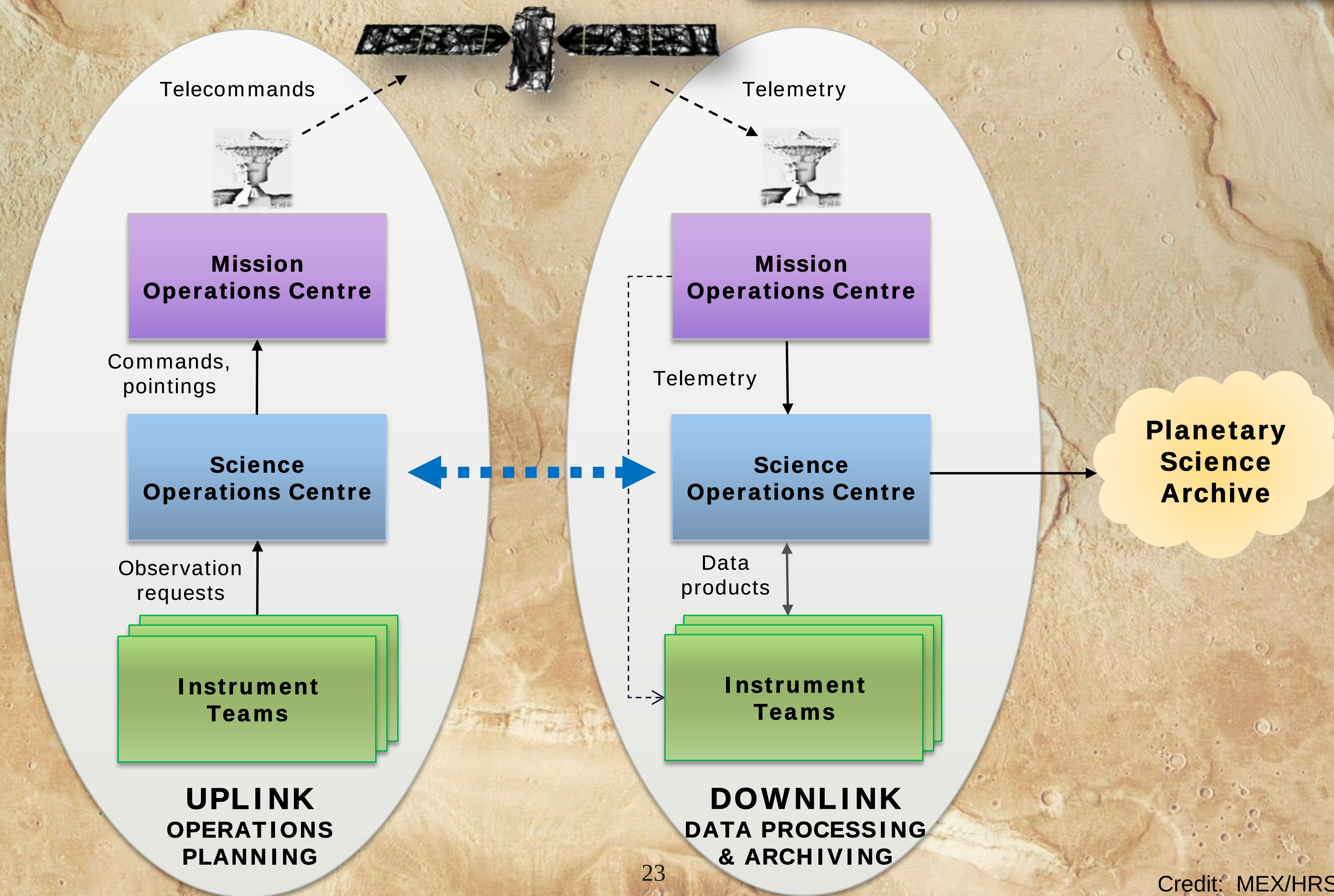


Mars Express PI-SOC-MOC Diagram
(similar to VEX/Rosetta)



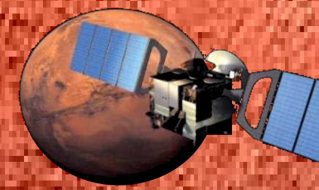
Credit: MEX/HRSC

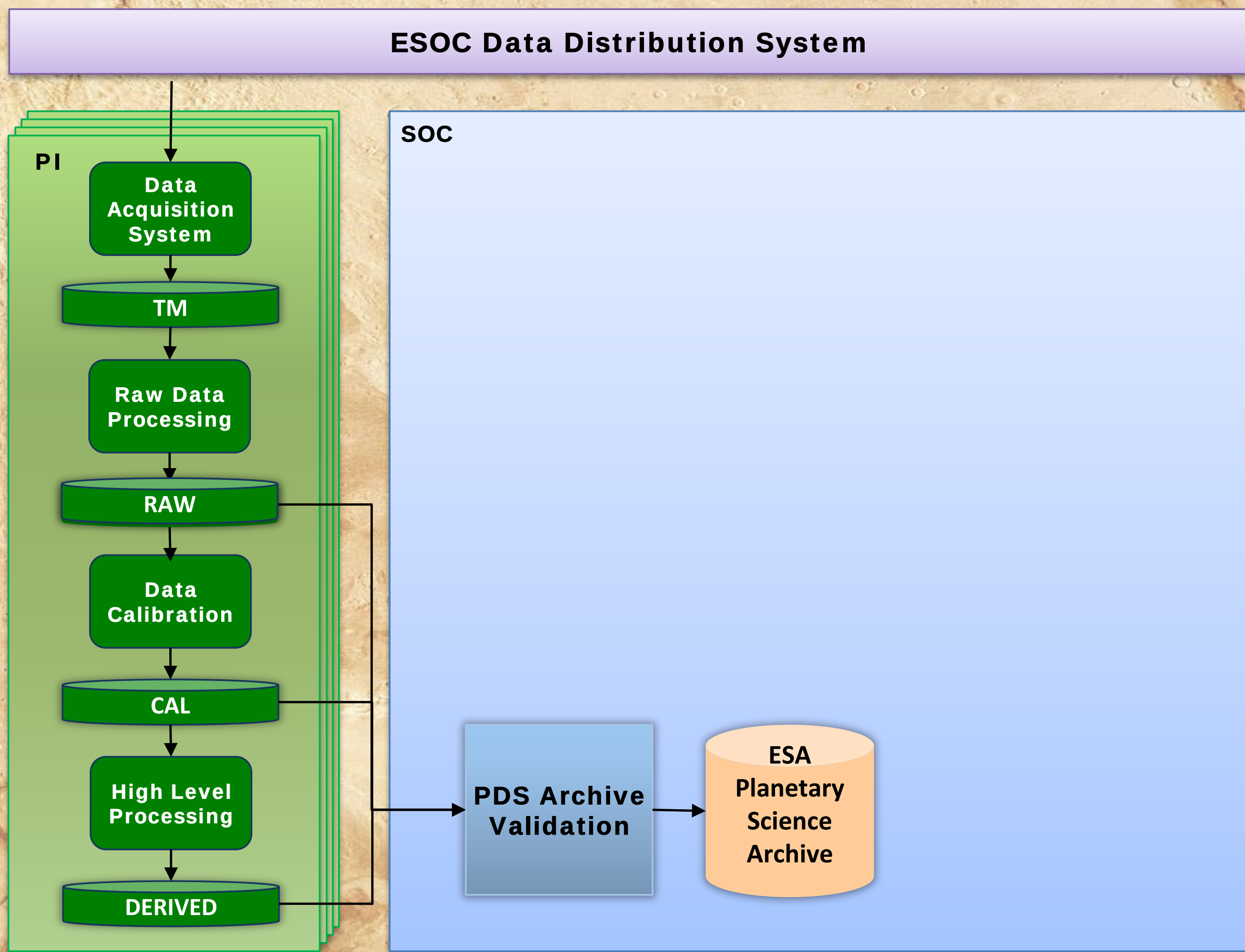
ExoMars PI-SOC-MOC Diagram



Credit: MEX/HRSC

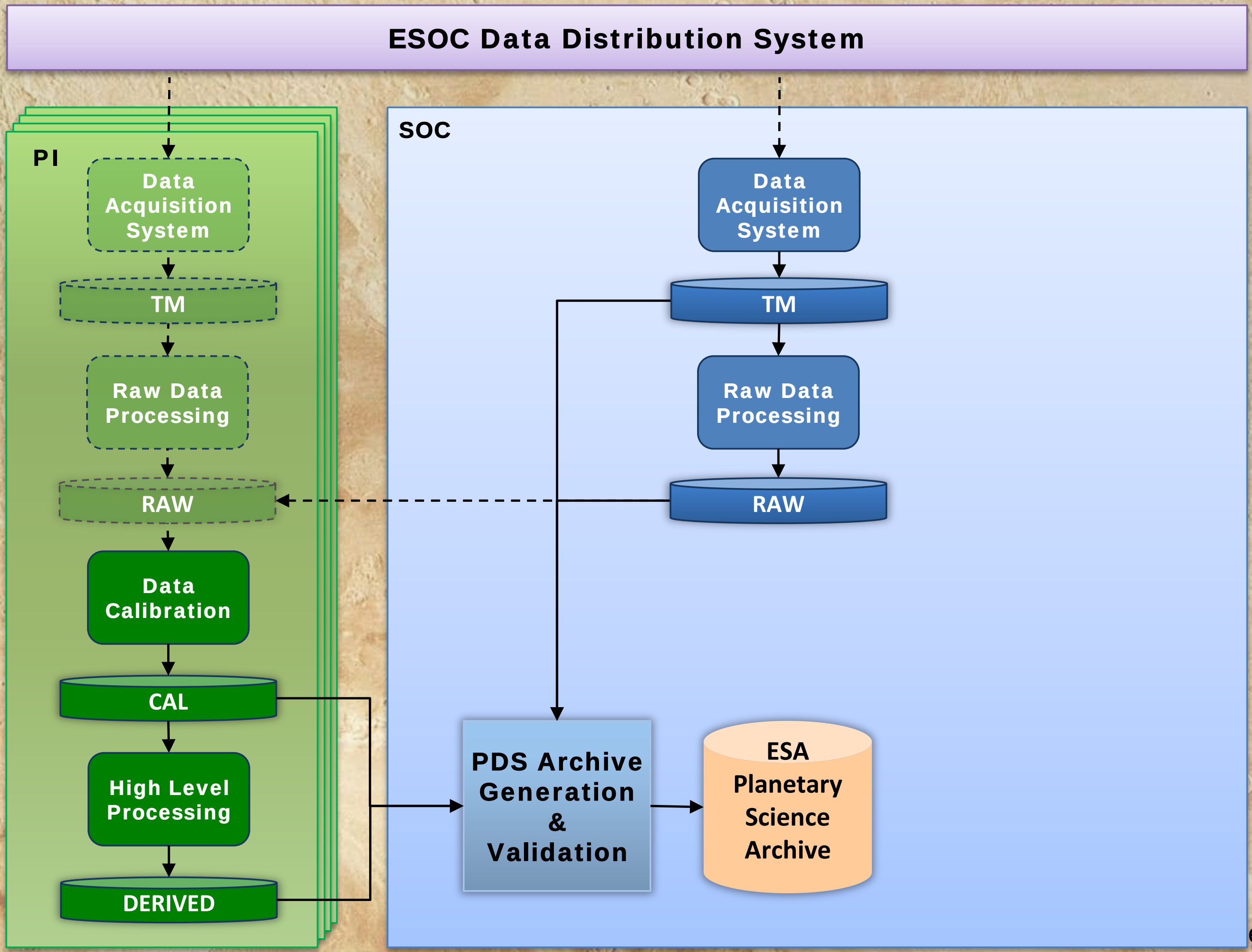
MEX (Traditional)
Data processing fully at PI institute





Credit: MEX/HRSC

ExoMars: First ESA planetary mission to use centralized data processing operationally



Credit: MEX/HRSC

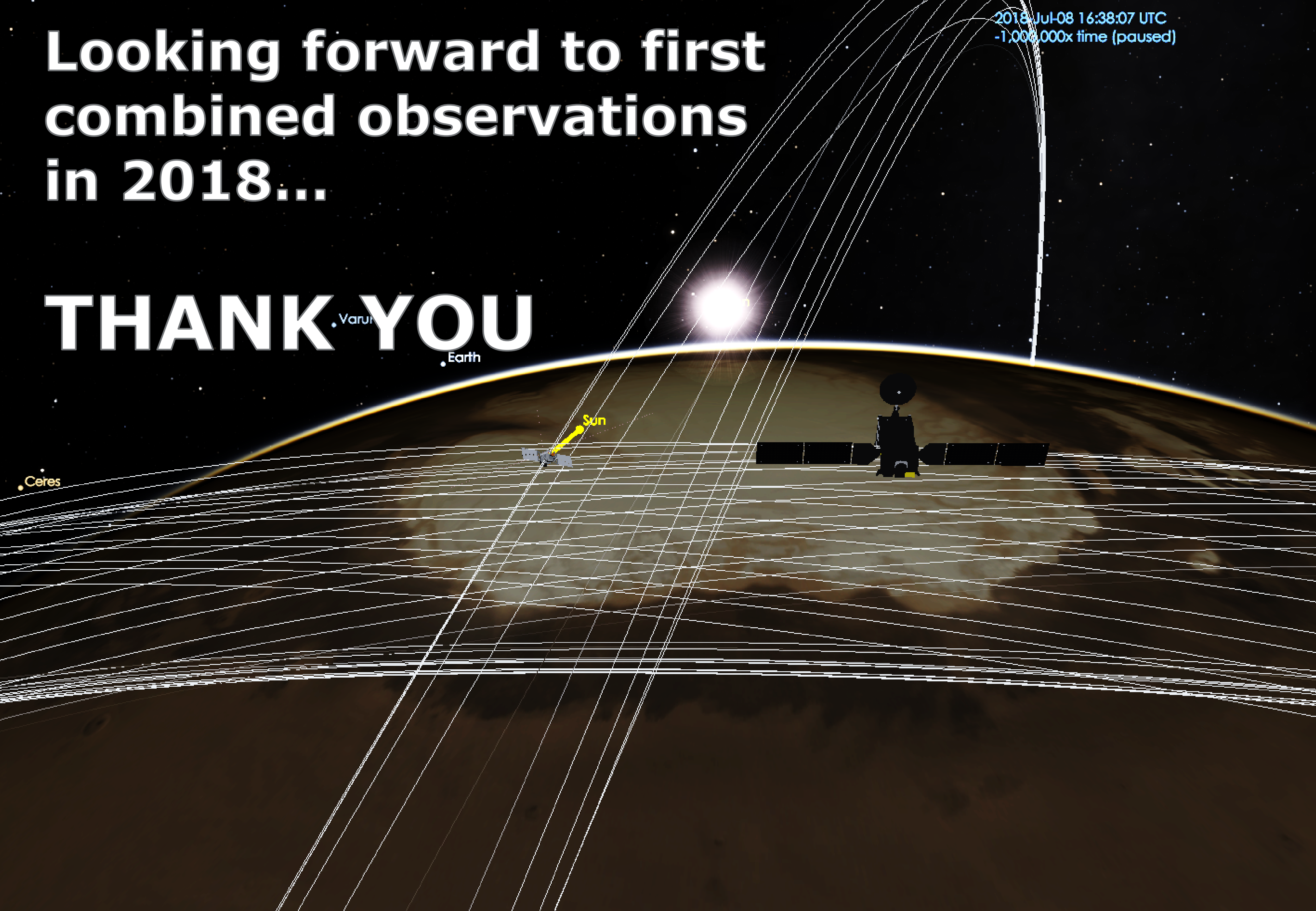
Drivers for Centralized Data Processing

- **ARCHIVE**
  - Ensure completeness of the data
  - Ensure timely availability of data
  - Ensure redundancy
  - Facilitate PDS compliance
- **FEEDBACK**
  - May perform Science Quality Quick-Look
  - Engineering Housekeeping Performance
- **RESOURCES**
  - PI can focus more on scientific activities (engineering centralized)
  - Collaborative effort ESAC/NNK
  - Commonalities with other missions (Rosetta, VEX, Bepi, JUICE, …)
- **RESPONSIBILITY**
  - PI remains responsible for all science data
  - Restricted permissions to PI's and SOCs

Credit: MEX/HRSC

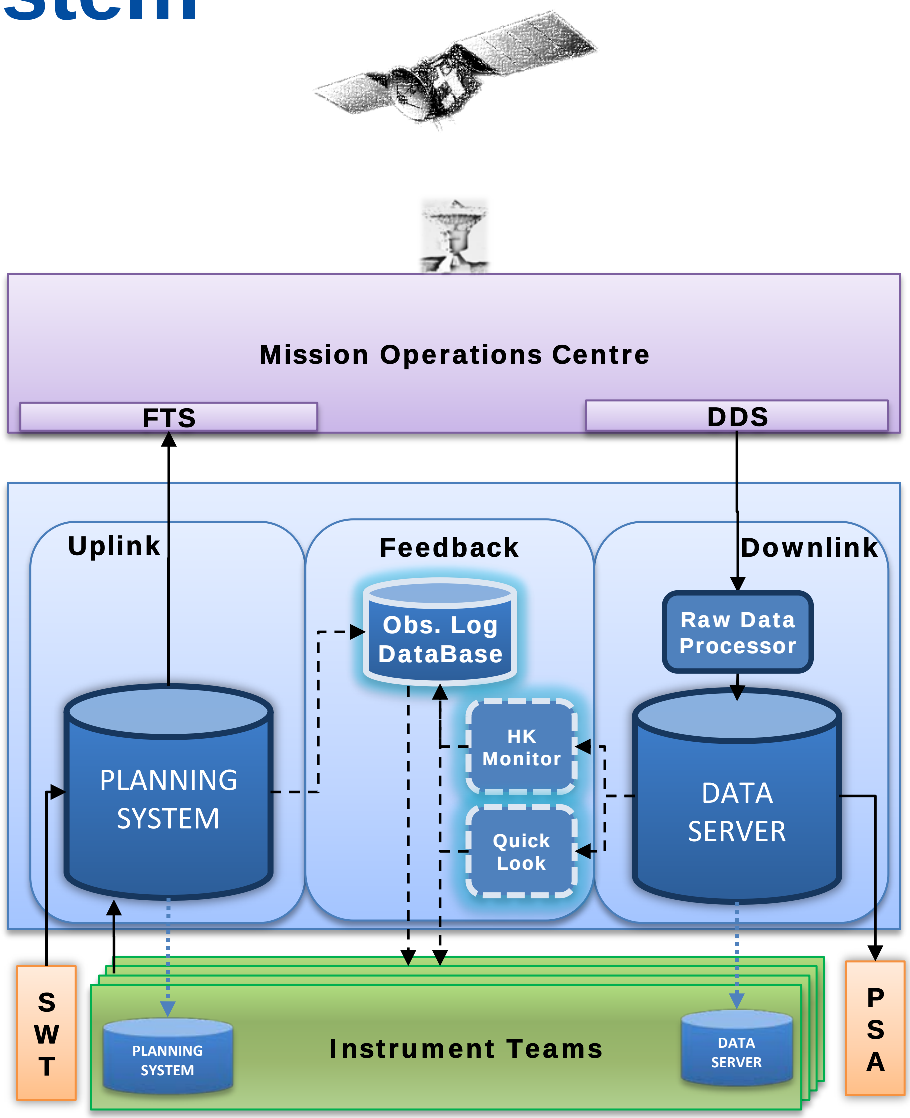
Looking forward to first combined observations in 2018...

THANK YOU



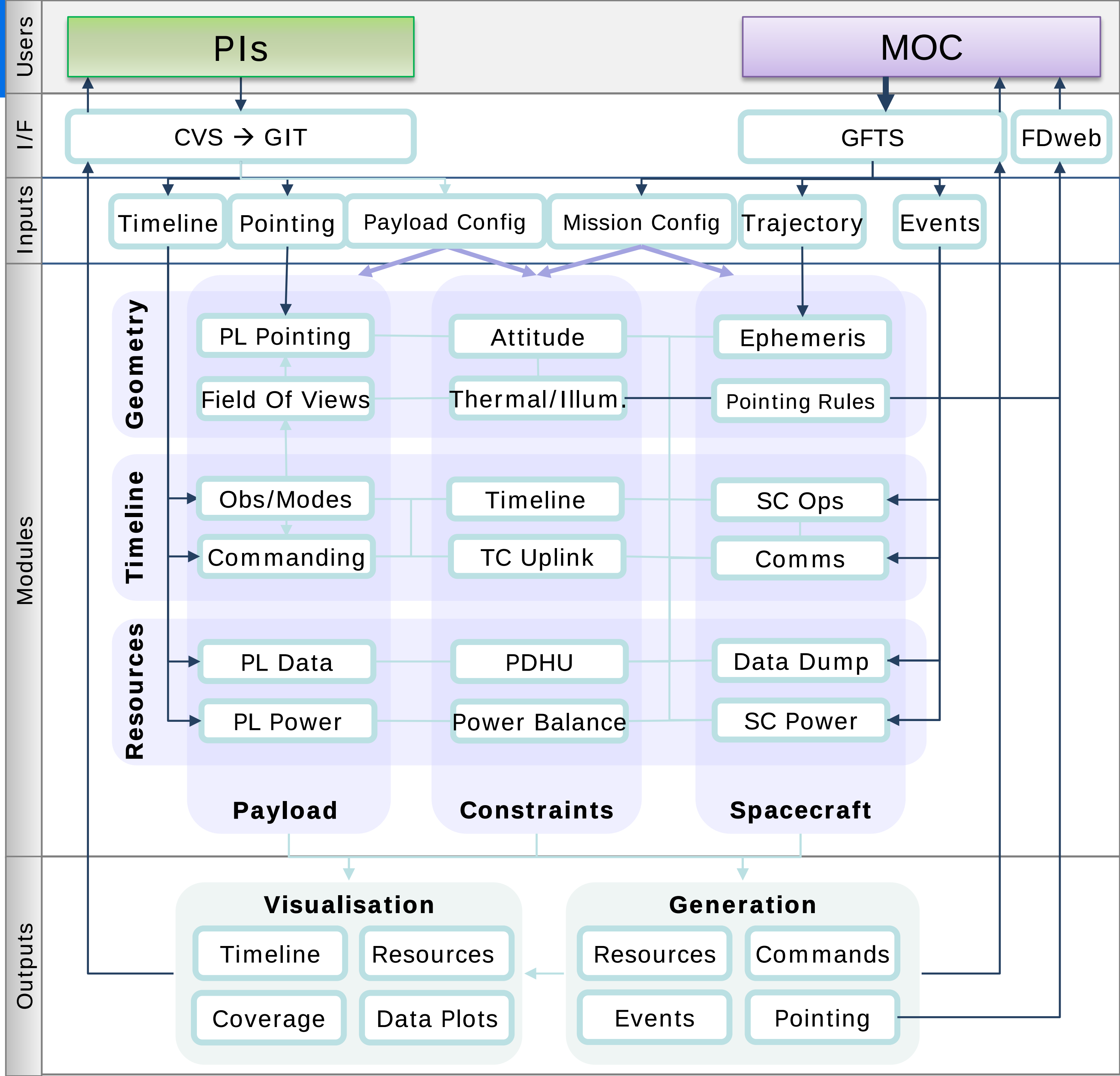
ExoMars 2016 Top Level System Design

- **Uplink System:**
  - Science Operations Planning and Commanding
  - First Level – Core Design Specifications
    - Critical Functionalities Demonstrable by launch
- **Downlink System:**
  - Data Handling and Archiving
  - Second Level - Core Design Specifications
    - Critical Functionalities Demonstrable by launch
- **Feedback System:**
  - Traceability of Uplink-Downlink Systems
  - Third Level - "Additional" Design Specifications
    - Non critical specifications
    - Enhancement of SGS capabilities
    - Taken into account now, implemented later



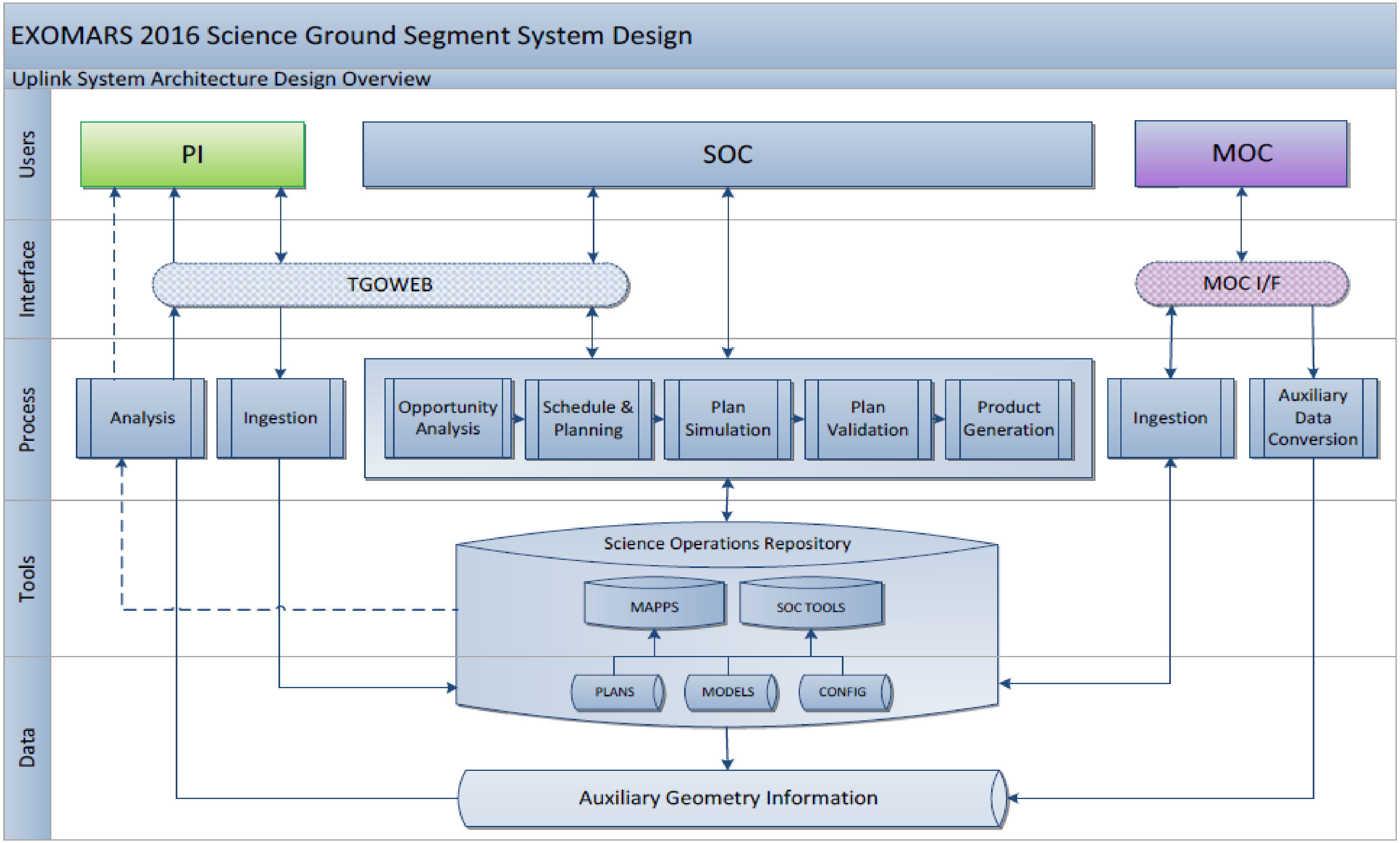
Uplink

Simulation & Validation SubSystem Status



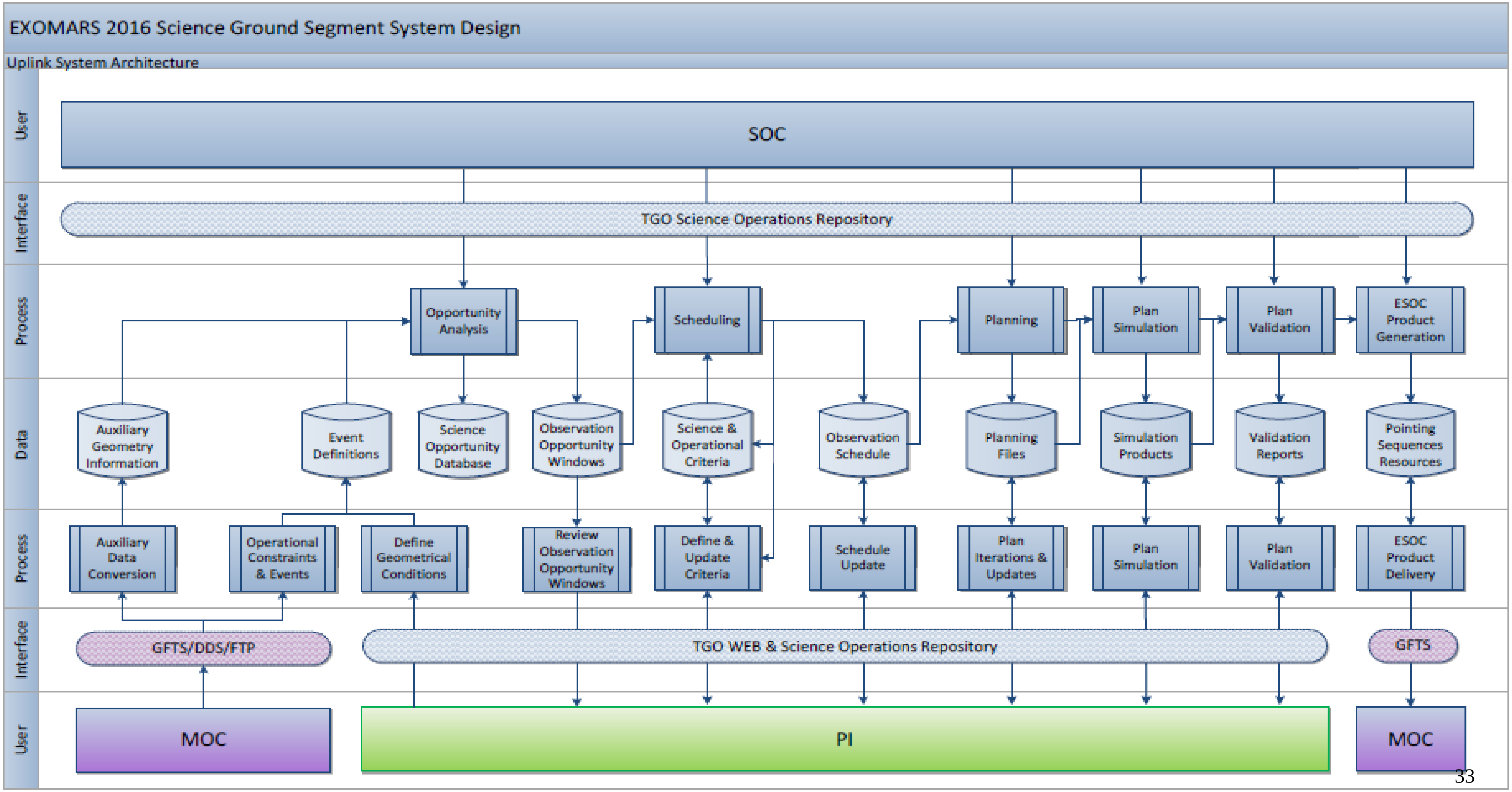
Uplink System Design Overview

SGS System Design Document (SDD)
Architectural Design Description (ADD)



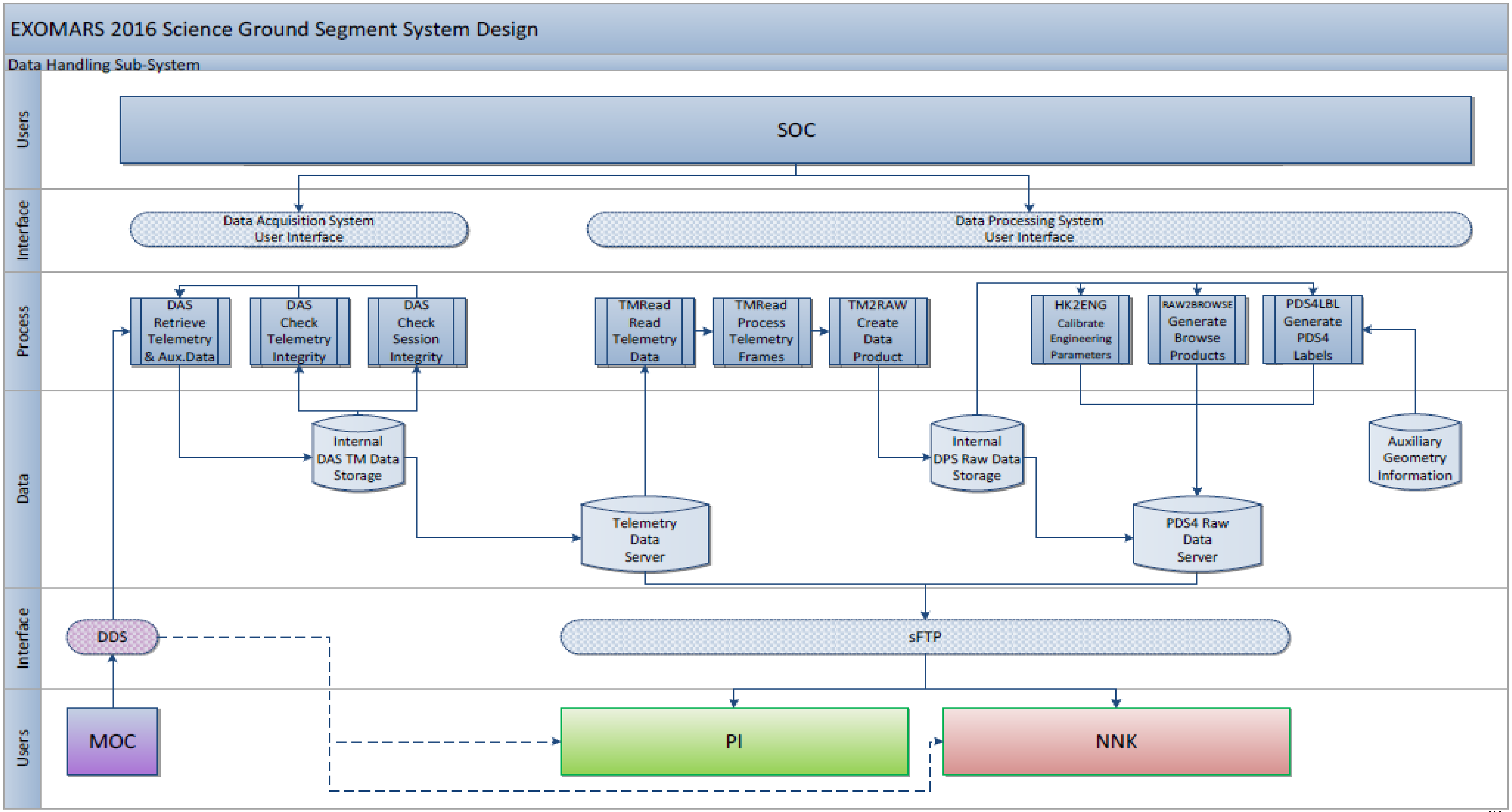
Uplink System Design Architecture

SGS System Design Document (SDD)
Architectural Design Description (ADD)



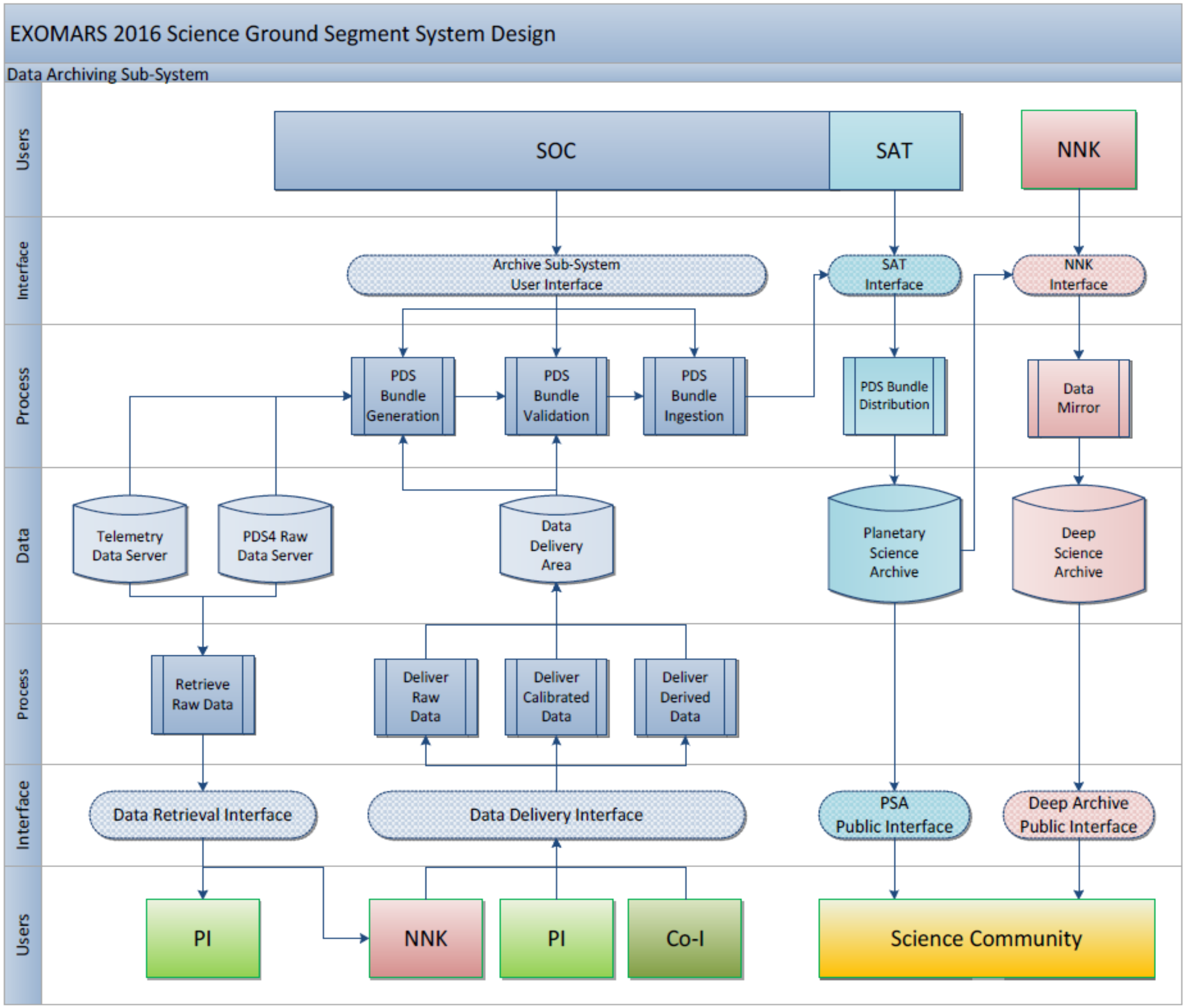
Data Handling System Design Overview

SGS System Design Document (SDD)
Architectural Design Description (ADD)



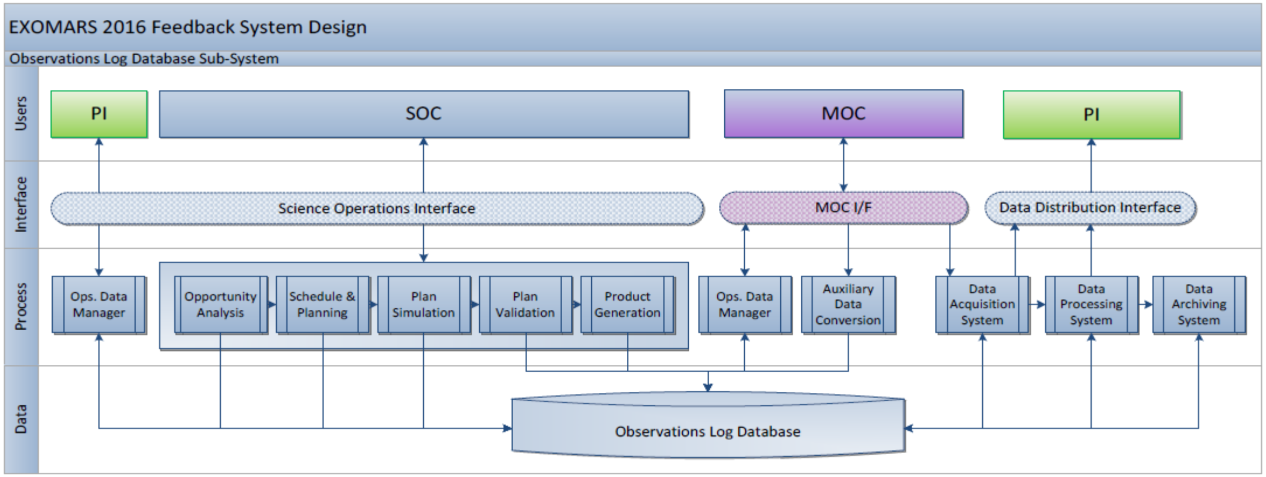
Data Archiving System Design Overview

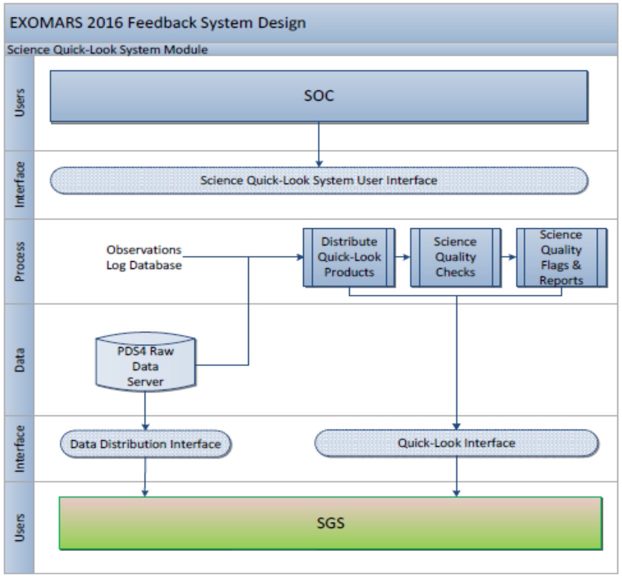
SGS System Design Document (SDD)
Architectural Design Description (ADD)

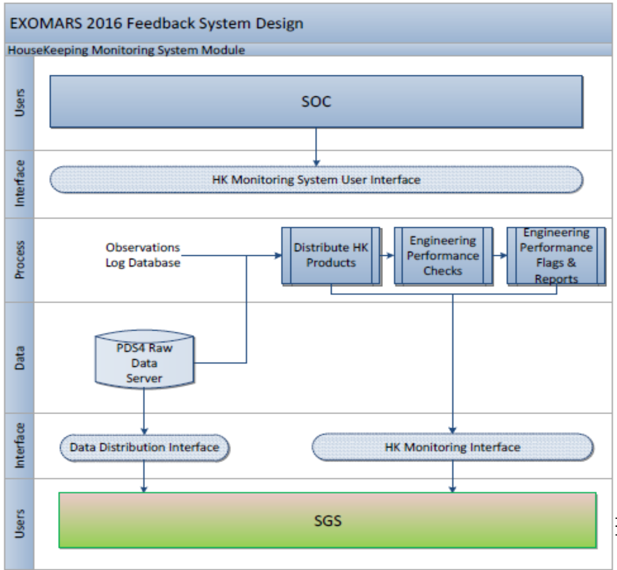


Feedback System Design Overview

SGS System Design Document (SDD)
Architectural Design Description (ADD)







Centralized Data Processing Concept Drivers

- **ARCHIVE**
  - Ensure completeness of the data
  - Ensure timely availability of data
  - Ensure redundancy
  - Facilitate PDS compliance

- **FEEDBACK**
  - May perform Science Quality Quick-Look
  - Engineering Housekeeping Performance

- **RESOURCES**
  - Commonalities with new missions (Bepi, JUICE, …)
  - Experience in previous missions (MEX/VEX, Smart-1, Chandrayaan)
  - Collaborative effort ESAC/NNK
  - PI can focus more on scientific activities (engineering centralized)

Centralized Data Processing
Key Points

- **PROPRIETARY DATA**
  - Restricted access to PI's and SOCs
  - Permissions will be handled following agreements
  - Only Raw data will be centralized

- **RESPONSIBILITY**
  - Pipeline development done TOGETHER between PI and SOC
  - Full visibility and access to all data and the pipeline
  - PI remains responsible for all data
  - PI remains responsible for scientific quality assessment
  - PI remains responsible for the configuration of the pipeline
  - PI remains responsible for the design of the data products

Summary of Lessons Learned

Team

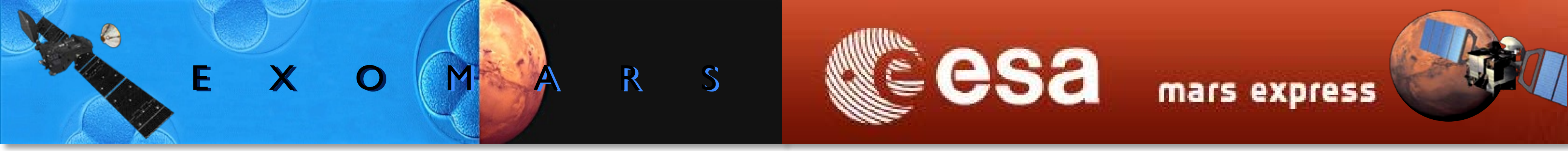
- Reinforce **PI iterations in terms of science** (need understanding of scientific requirements)
- Exchange **all technical details with ESOC** (need understanding of engineering requirements)
- Ensure **in-house knowledge** (not enough if technical/scientific know-how is in ESTEC/ESOC/PIs)
- PI's and ESOC need to gain **confidence in centralized approach** of scientific/technical processes

Promote cooperation and team spirit between PIs-SGS-ESOC-MM-PS
➔ Key for the outcome of the mission 🡐

System

- **Centralize** all operational/technical procedures in a single system
- **Get rid of manual procedures**: automatize all 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 🡐



Advanced Long Term Planning: Science Opportunity Analysis

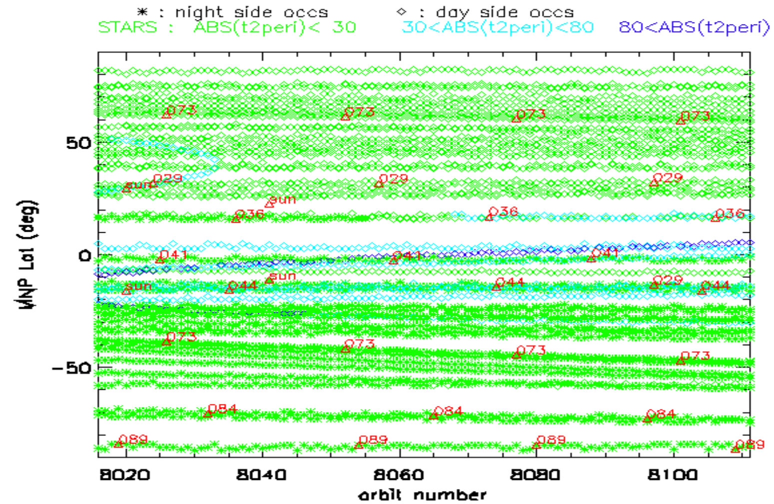
MAJOR IMPROVEMENT:

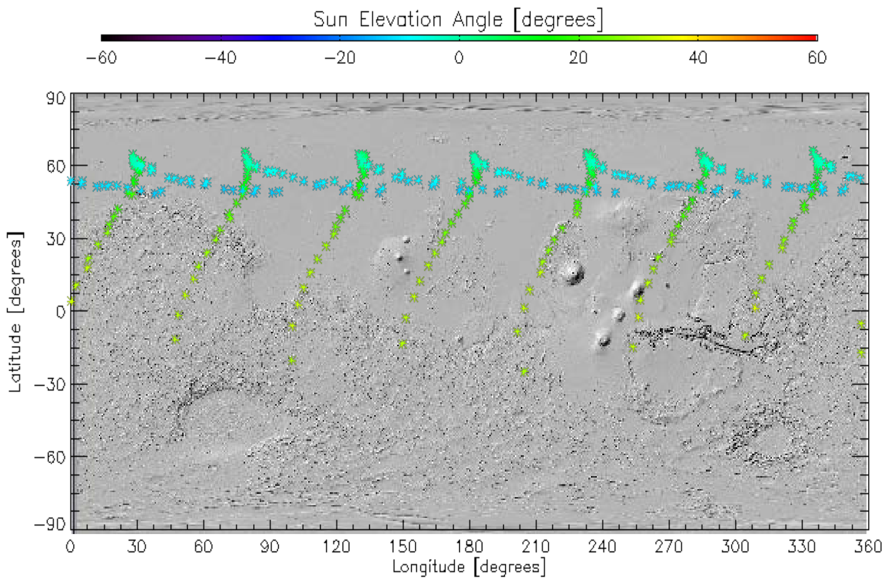
Definition of observation opportunities based on scientific criteria:

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

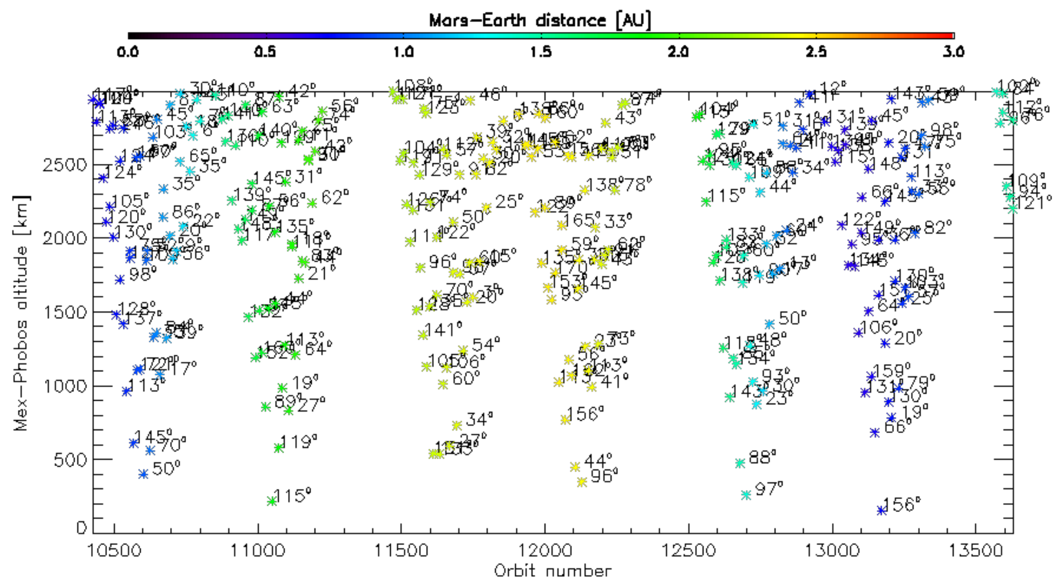
Opportunity windows pre-computed and stored in a data base.
Events can be analyzed, filtered and processed to build a skeleton plan.
Long term scheduling is a must for global coverage monitoring.

Stellar Occultation Opportunities





Radio Science Earth Occultation Opportunities



Phobos Fly-by Events

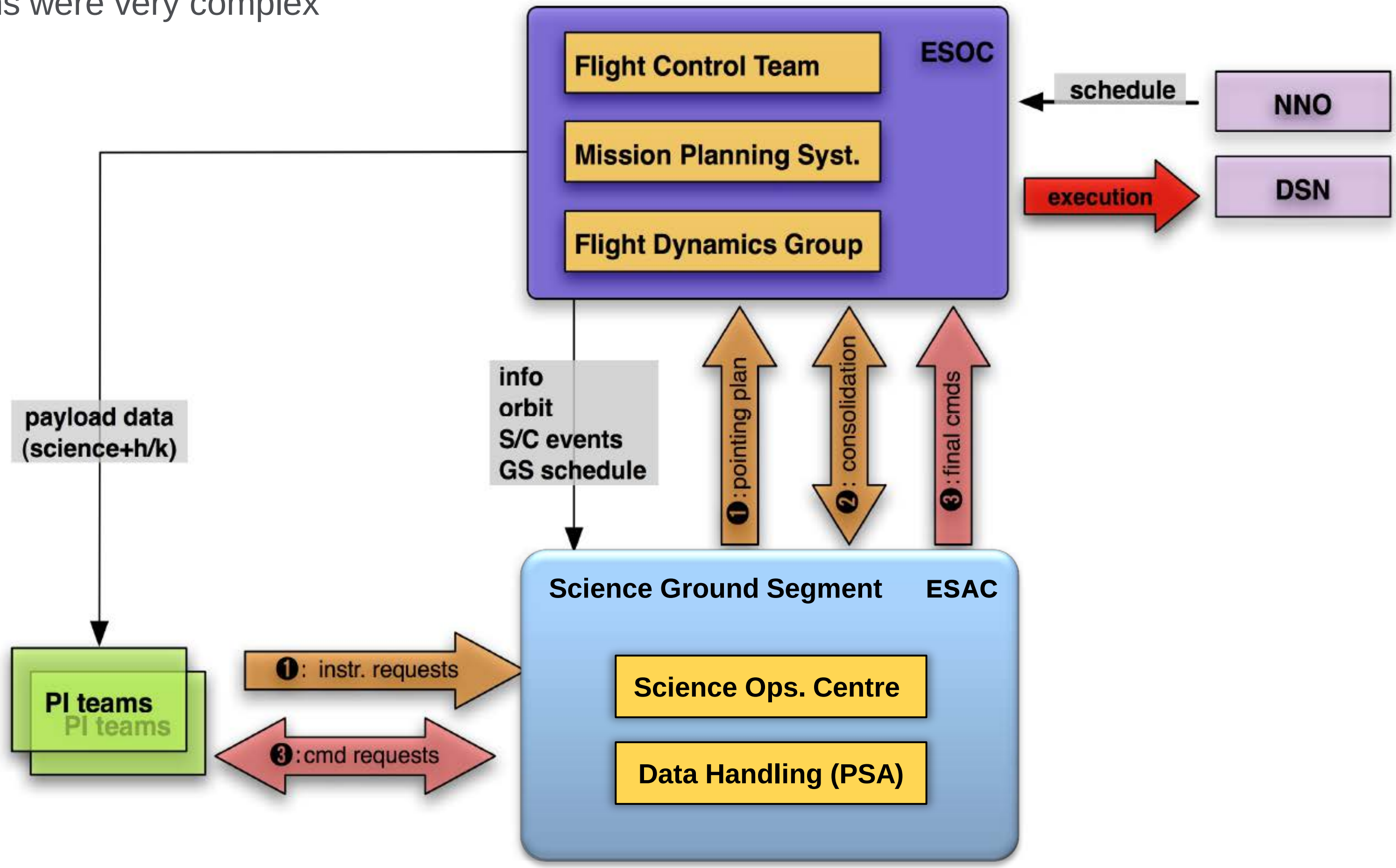
A bit of history:

Science Operations Original Diagramme

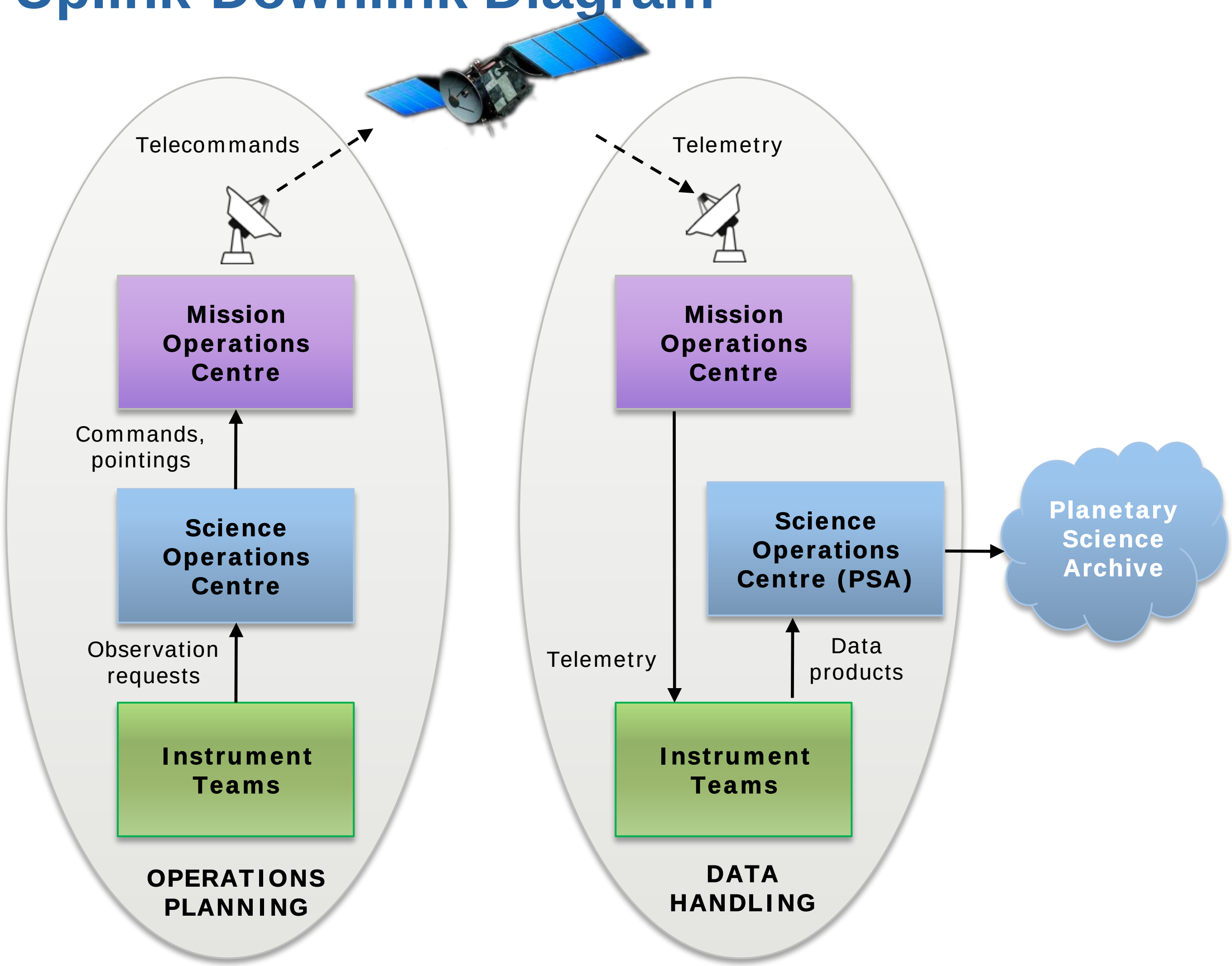
- Payload operations originally outsourced to the Payload Operations Service (POS) in UK
- POS was «service provider» for Commanding and Payload Modelling, Planning Interfaces and SW
- Responsability remained at Payload Science Team (PST) at ESTEC
- Interfaces and iterations were very complex

After 5 years :

POS and PST transition into SGS at ESAC



EXTRA: Uplink-Downlink Diagram

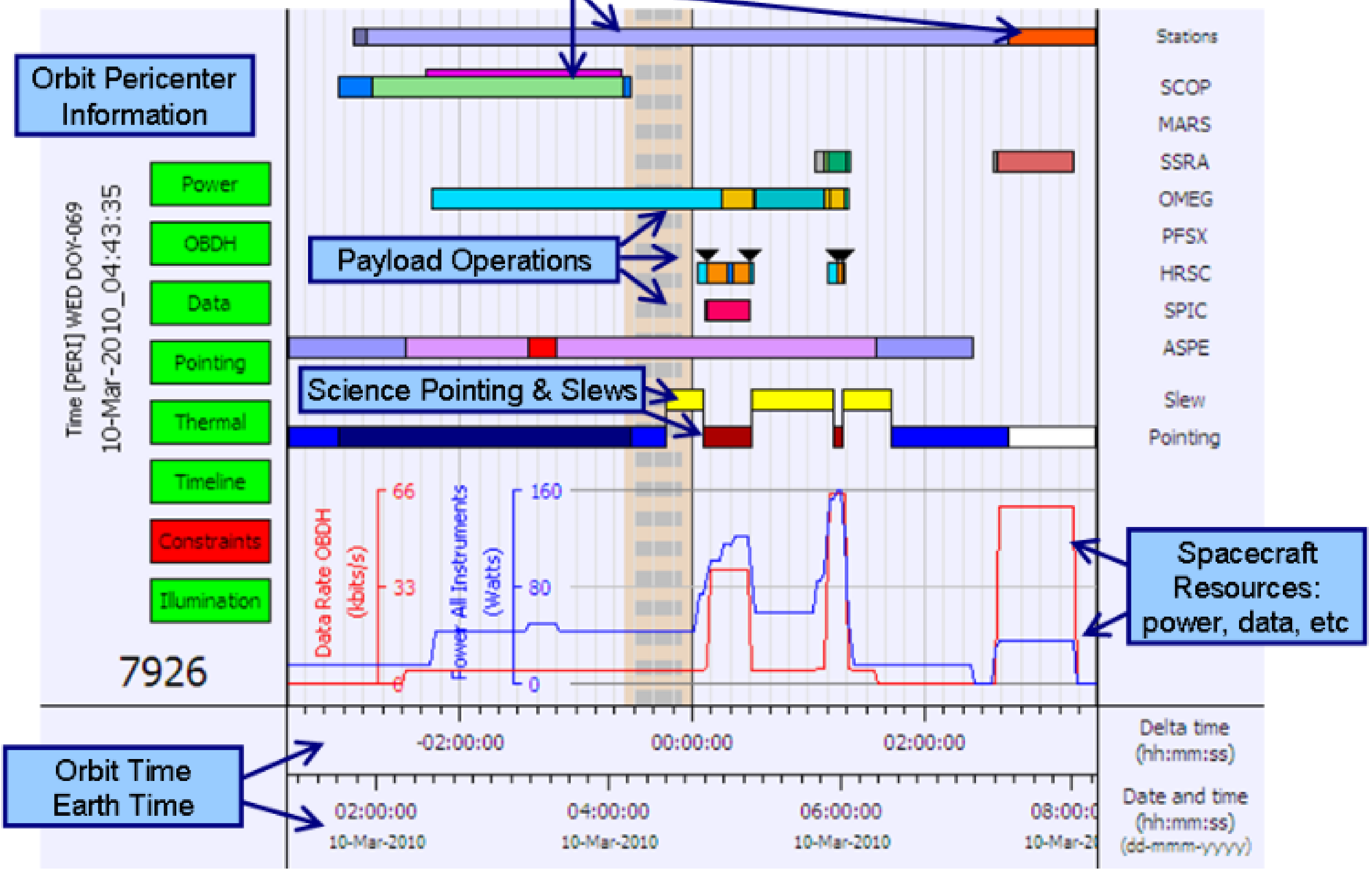


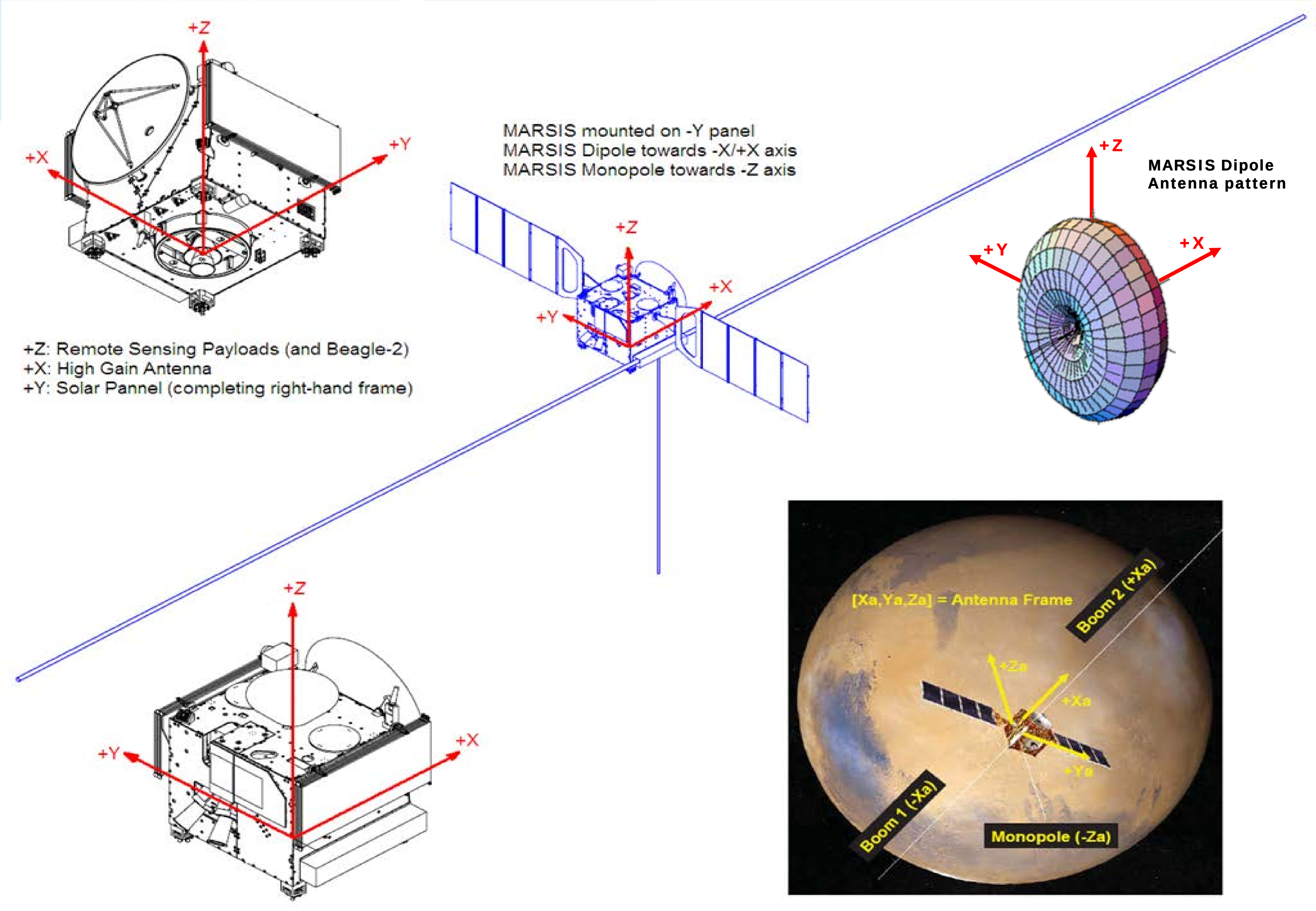
EXTRA: Spacecraft drivers

- 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

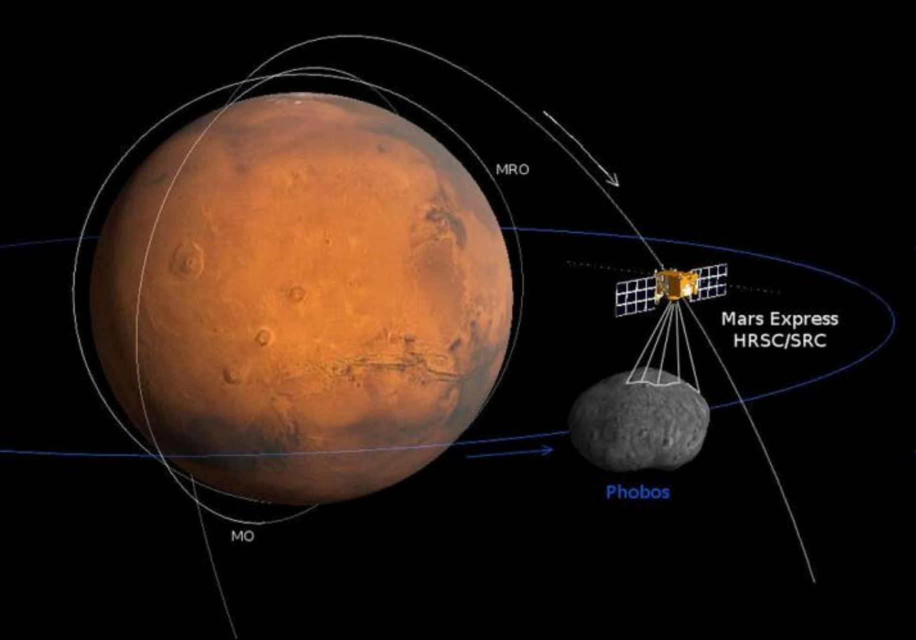
- Add a note on interfaces and conventions (lack of conventions causes backward incompatibility and no history tracking)

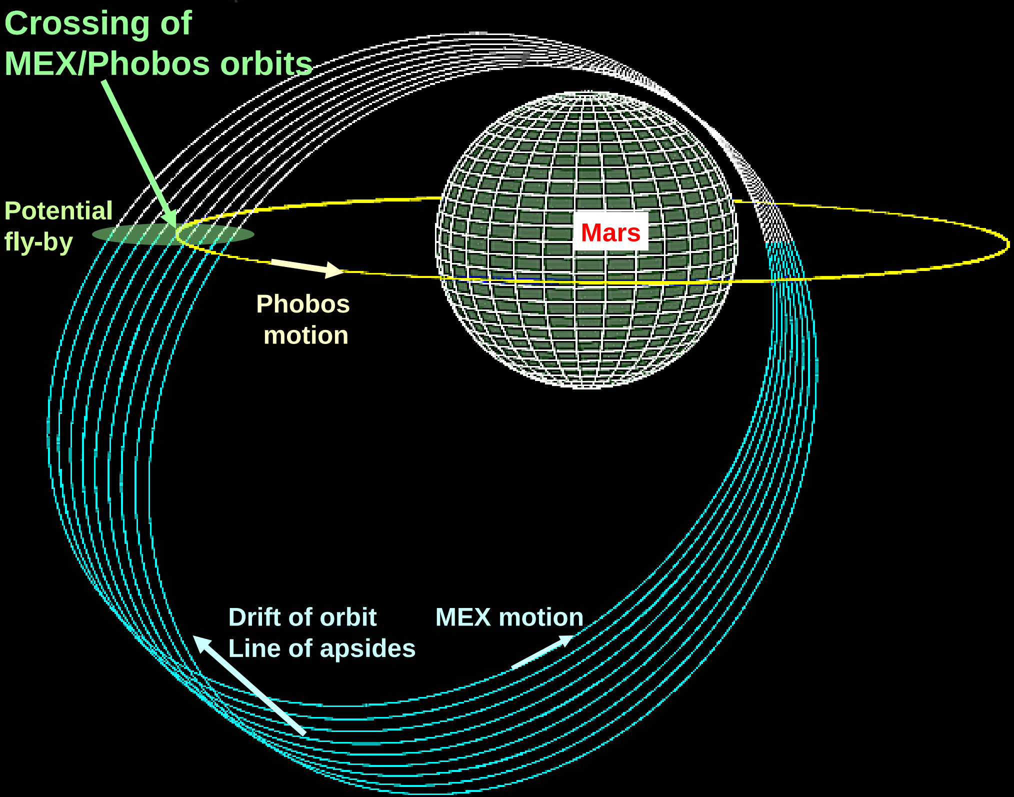
EXTRA... ne detail

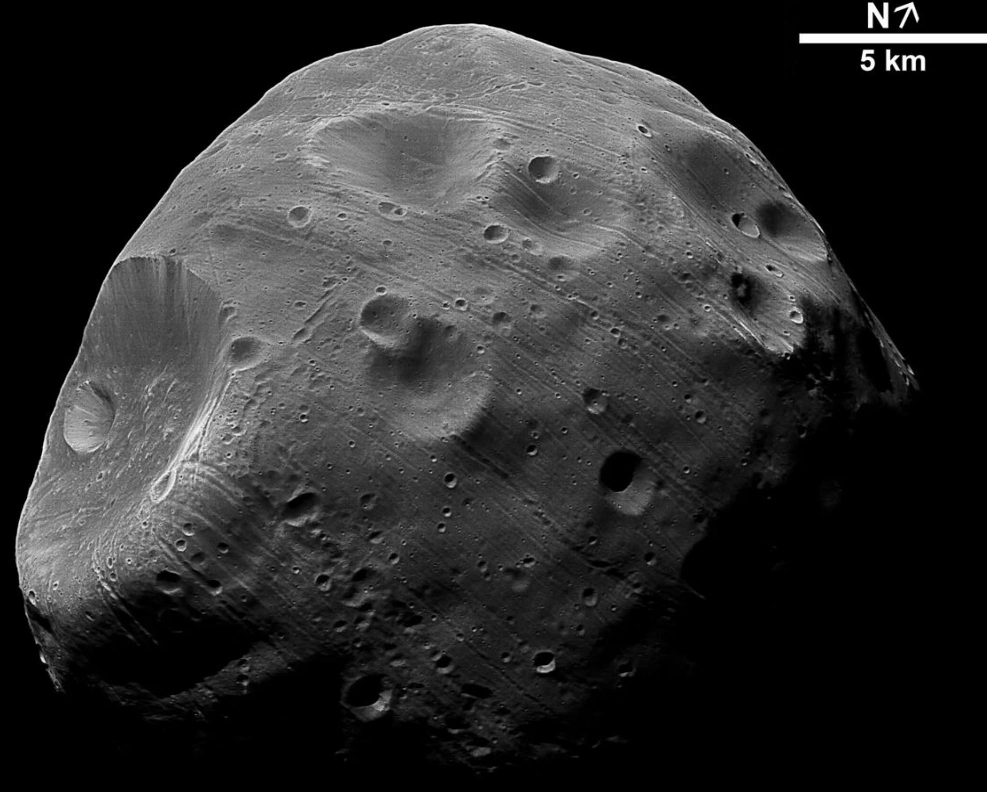


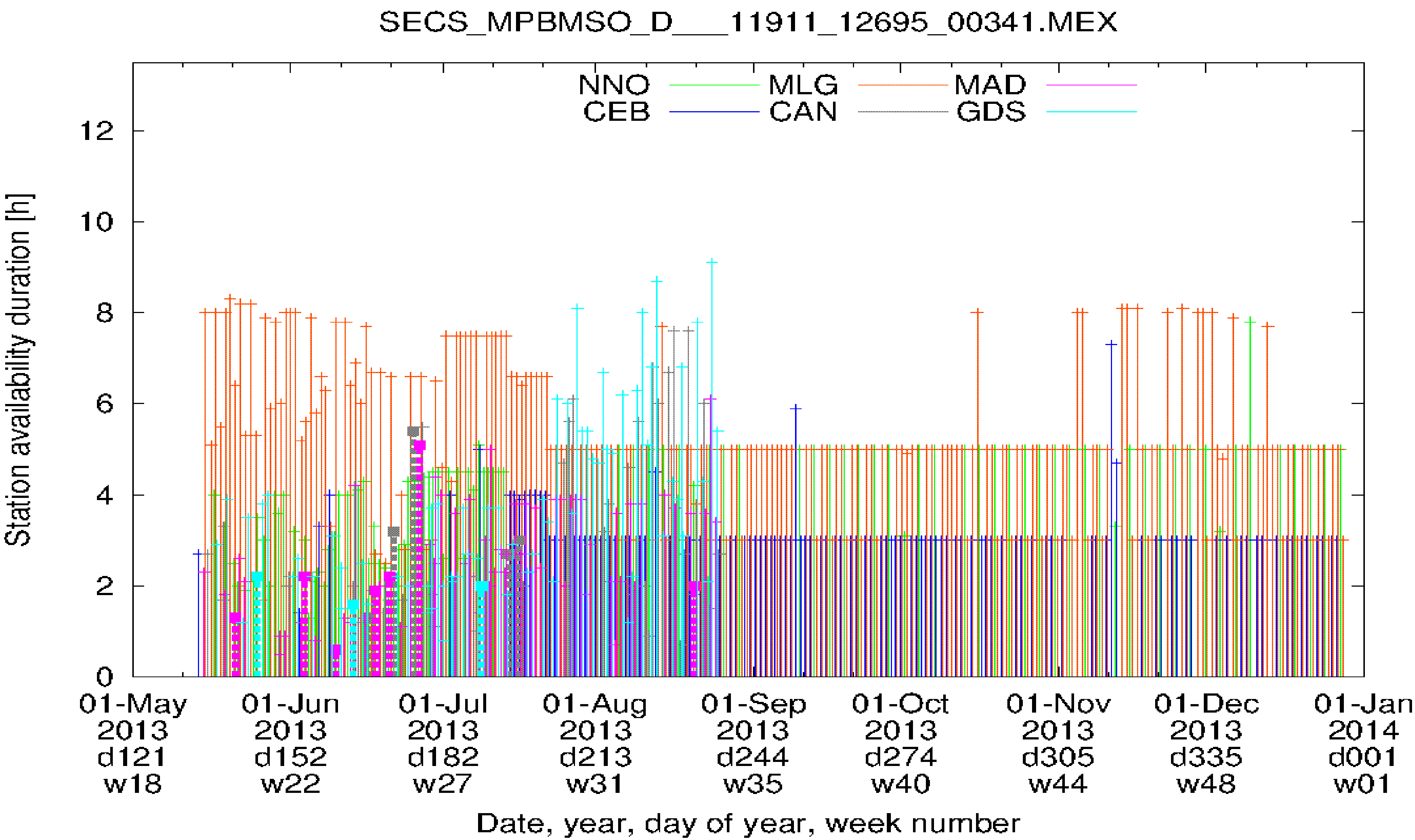


+Z
+X
+Y
+Z: Remote Sensing Payloads (and Beagle-2)
+X: High Gain Antenna
+Y: Solar Pannel (completing right-hand frame)
MARSIS mounted on -Y panel
MARSIS Dipole towards -X/+X axis
MARSIS Monopole towards -Z axis
MARSIS Dipole
Antenna pattern
[Xa,Ya,Za] = Antenna Frame
Boom 2 (+Xa)
+Za
+Xa
+Ya
Boom 1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


SECS_MPBMSO_D___11911_12695_00341.MEX
NNO
MLG
MAD
CEB
CAN
GDS
Station availability duration [h]
0
2
4
6
8
10
12
01-May 2013 d121 w18
01-Jun 2013 d152 w22
01-Jul 2013 d182 w27
01-Aug 2013 d213 w31
01-Sep 2013 d244 w35
01-Oct 2013 d274 w40
01-Nov 2013 d305 w44
01-Dec 2013 d335 w48
01-Jan 2014 d001 w01
Date, year, day of year, week number

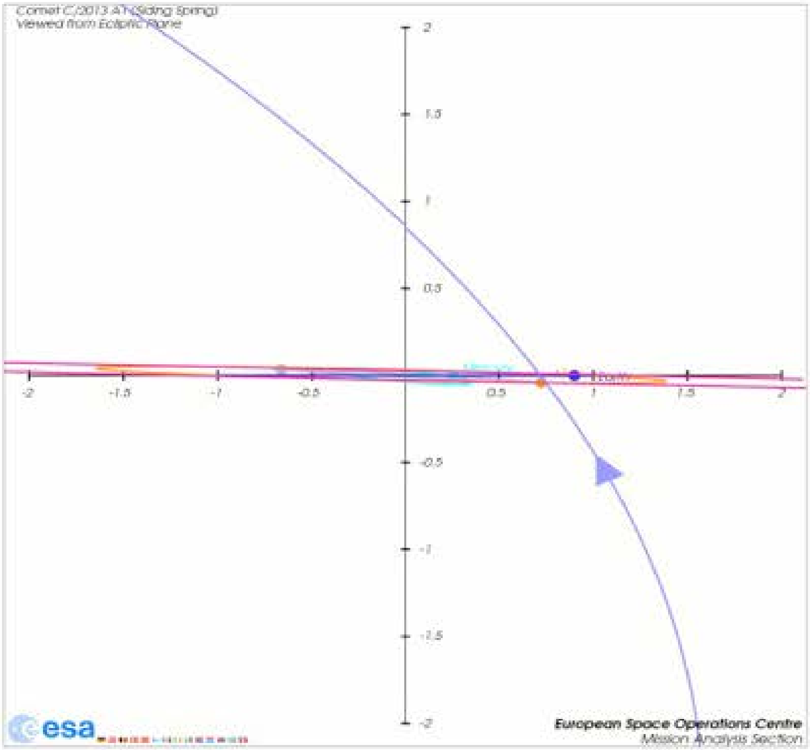
EXTRA: (FAST)

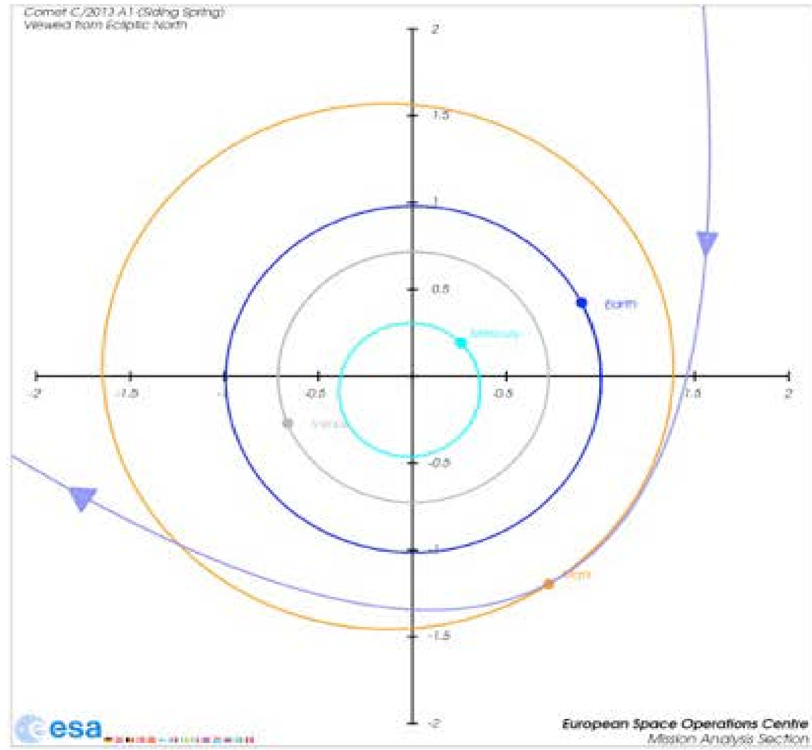
Instrument	TCs without OBCP	TCs with OBCP	OBCP implemented
MARSIS (AIS/SS/FM)	20~34	6/11/9	Switch ON/OFF (might need cleanup)
HRSC/SRC	35 (+8 heating)	23/26	Switch ON/OFF and initialization
SPICAM	13	3	Switch ON/OFF
PFS	70	7 +4	Switch ON/OFF (might need cleanup) Parameter updates (configurable)
OMEGA (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!**