Jet Propulsion Laboratory

ExoMars/TGO Science Orbit Design

Joseph Guinn, Rob Lock, Stacia Long, Dan Lyons
Jet Propulsion Laboratory
California Institute of Technology

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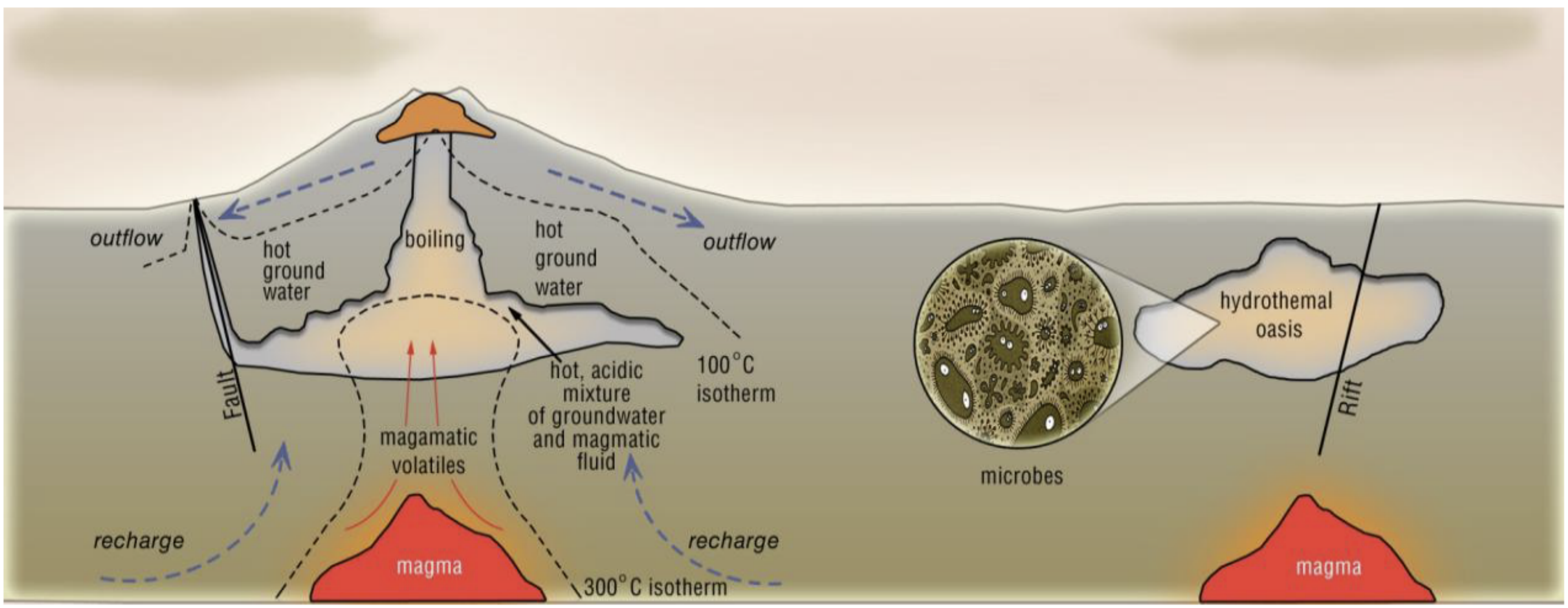
ExoMars Goals

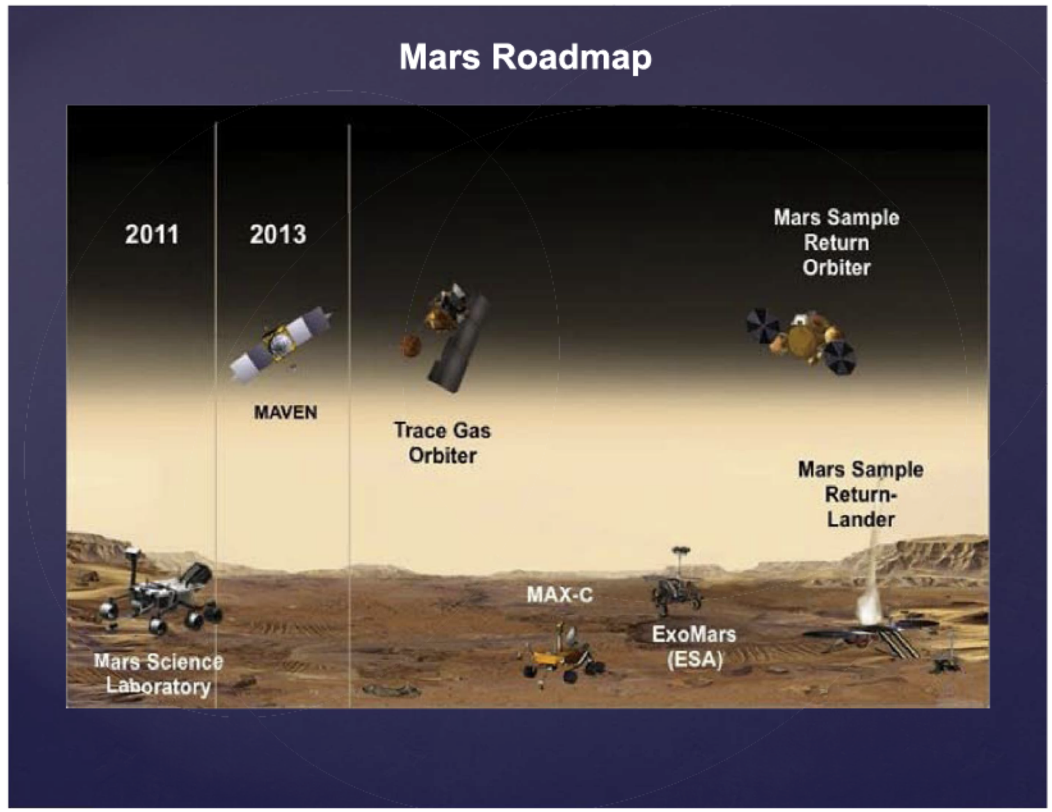
- **A goal of the European Space Agency's ExoMars Programme is to investigate the Martian environment and to demonstrate new technologies for future Mars sample return missions in the 2020's.**
- **A joint orbiter mission with NASA was proposed for 2016 called the Trace Gas Orbiter (TGO) to investigate the question:**

IS MARS ALIVE?



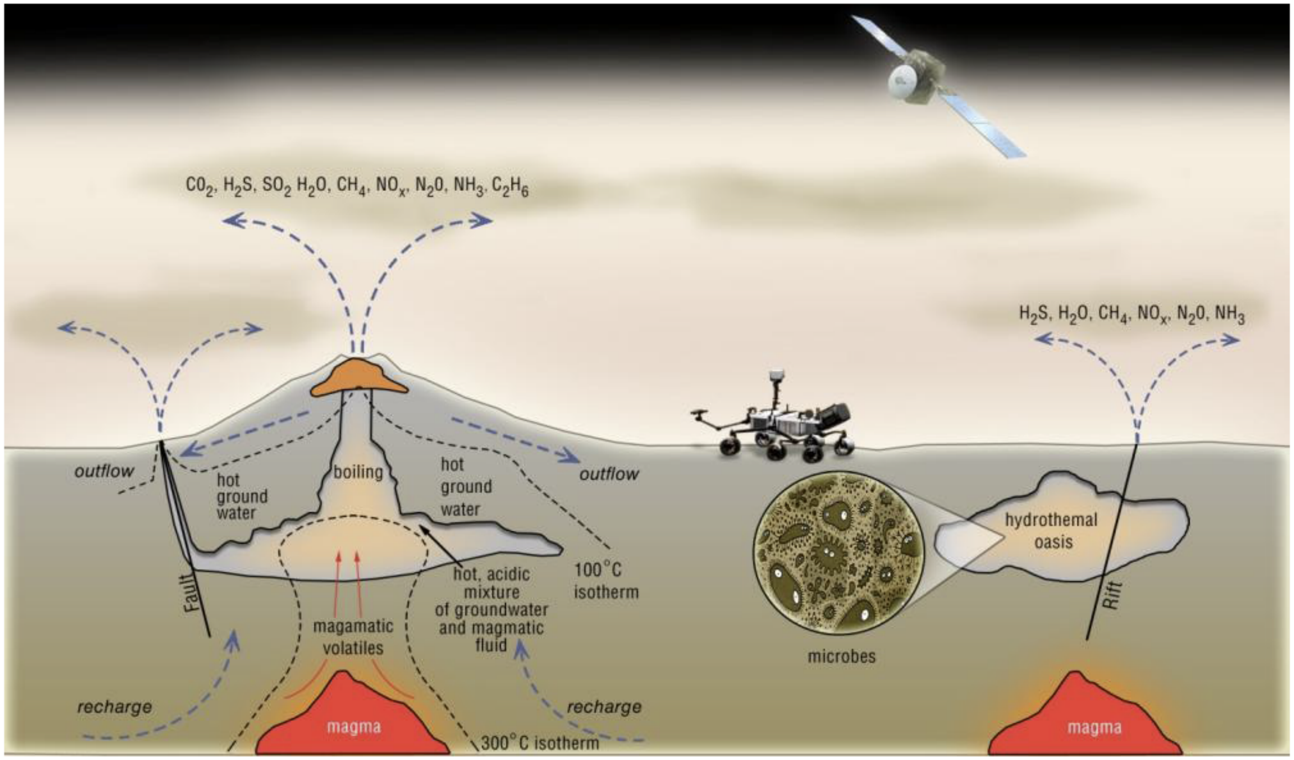
NASA Science Priorities

- **NASA's participation in the TGO mission was cancelled in 2011.**
- **Results from a mission like TGO are essential to landing site selection for a future Mars Sample Return mission.**
- **The TGO instruments and science orbit design can be leveraged for a future Mars orbiter mission - possibly as early as 2018.**



ExoMars/TGO Science

- As on Earth, subsurface processes may be revealed by gases released to the atmosphere. TGO would build upon reported discoveries of Methane.



- Collection of atmospheric solar occultation measurements to detect many types of gases and their surface origin.
- A one Martian year mission spanning all seasons provides a comprehensive and global chemical survey of trace gases.

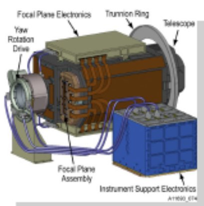
ExoMars/TGO Mission Elements

NASA / JPL

EMCS

MAGIE

Electra (UHF Radio)



HISCI

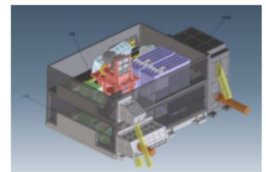
MATMOS

Atlas-V - 431 Class

JPL DSN

JPL SRA

ESA



NOMAD

EDM

Spacecraft / Orbiter

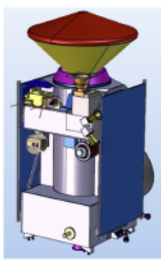
ESA ESTRACK

ESA ESOC

ExoMars/TGO Mission Events

LAUNCH

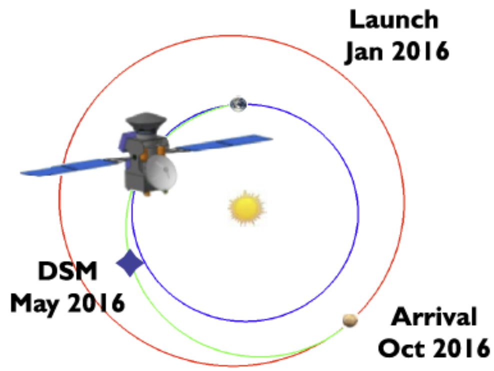
Jan 2016



EMTGO in launch configuration

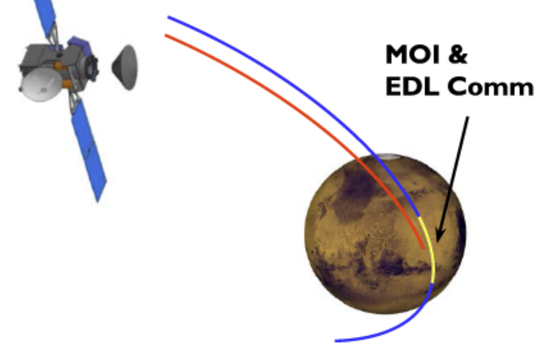
Atlas V 431

INTERPLANETARY CRUISE



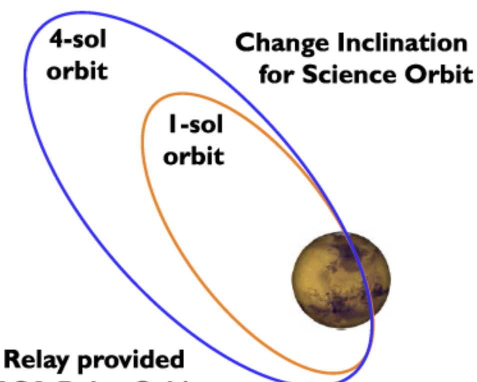
Type II Trajectory: C3 = 7.44 km²/s²

APPROACH, EDM RELEASE & MOI



- EDM release at MOI - 3 days
- Orbiter retargets to MOI altitude
- MOI captures to 4 sol orbit

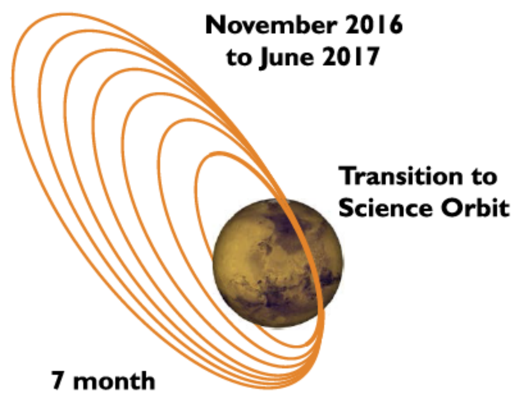
EDM RELAY & TRANSITION TO 1-SOL ORBIT



EDM Relay provided by NASA Relay Orbiters

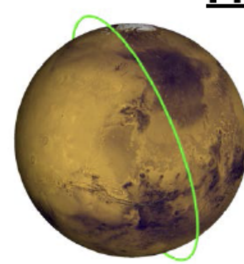
AEROBRAKING PHASE

November 2016 to June 2017



7 month Aerobraking

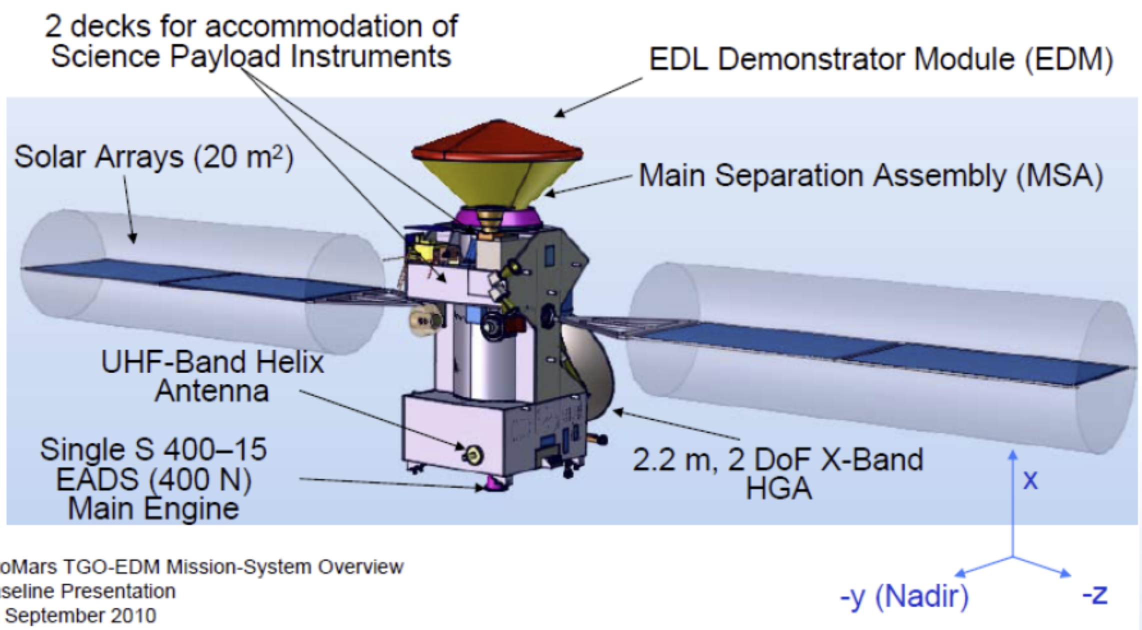
SCIENCE & DATA RELAY PHASE



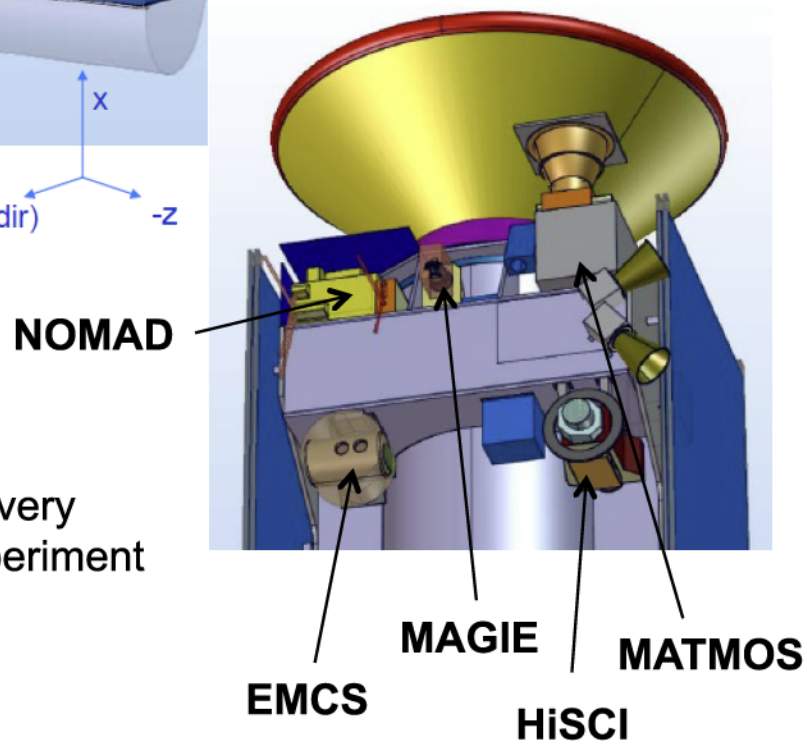
Science & Relay Orbit
- 400 km Frozen
- Rotates every 4 months
- Phased for 2018 Relay

- Science Phase: 1 Mars Year 6-2017 to 6-2019
- Relay Phase: 2018 Rovers Jan 2019
- Relay Phase: Future Missions through 2022

ExoMars/TGO Spacecraft Overview



ExoMars TGO-EDM Mission-System Overview
Baseline Presentation
13 September 2010



<u>Science Instruments:</u>

MATMOS – Mars Atmosphere Trace Molecule Occultation Spectrometer
NOMAD – Nadir and Occultation for Mars Discovery
MAGIE – Mars Atmospheric Global Imaging Experiment
EMCS – ExoMars Climate Sounder
HiSCI – High-resolution Stereo Color Imager

ExoMars/TGO Science Orbit Description

- Science orbit assumptions initially provided by ESA
- Science phase from late May 2017 through June 2017 (717 days)
- Orbit is circular, inclined 74±10 degrees with a mean altitude between 350 and 420 km
- 3 to 5 sol repeating groundtrack. Three orbit options proposed:
  - 37:3 with a mean altitude = 413km
  - 62:5 with a mean altitude = 399km
  - 63:5 with a mean altitude = 358km
- Orbit maintenance strategy: monthly maneuvers to correct back to a pre-determined reference trajectory.

Science Orbit Trade #1

Goal: Select an Inclination value from a trade space of 64 to 84 deg

- Assume:
  - Frozen eccentricity and argument of periapsis
  - Average altitude around 400km
  - Note: No sun synchronous constraints (i.e. no fixed LMST)
- Used JPL mean element propagation tool called Morbiter to generate one year trajectories with inclinations between 64 and 84 deg at 1 deg steps.
- Orbiter Science Working Team (OSWT) concluded that 74 deg inclination best balanced the desire for:
  - 4-6 Time-of-Day (TOD)* cycles per Mars year
  - Good global occultation distribution at the poles and the equator

*A TOD cycle is the amount of time required for the orbit plane to rotate about the Mars pole back to the same local solar time.

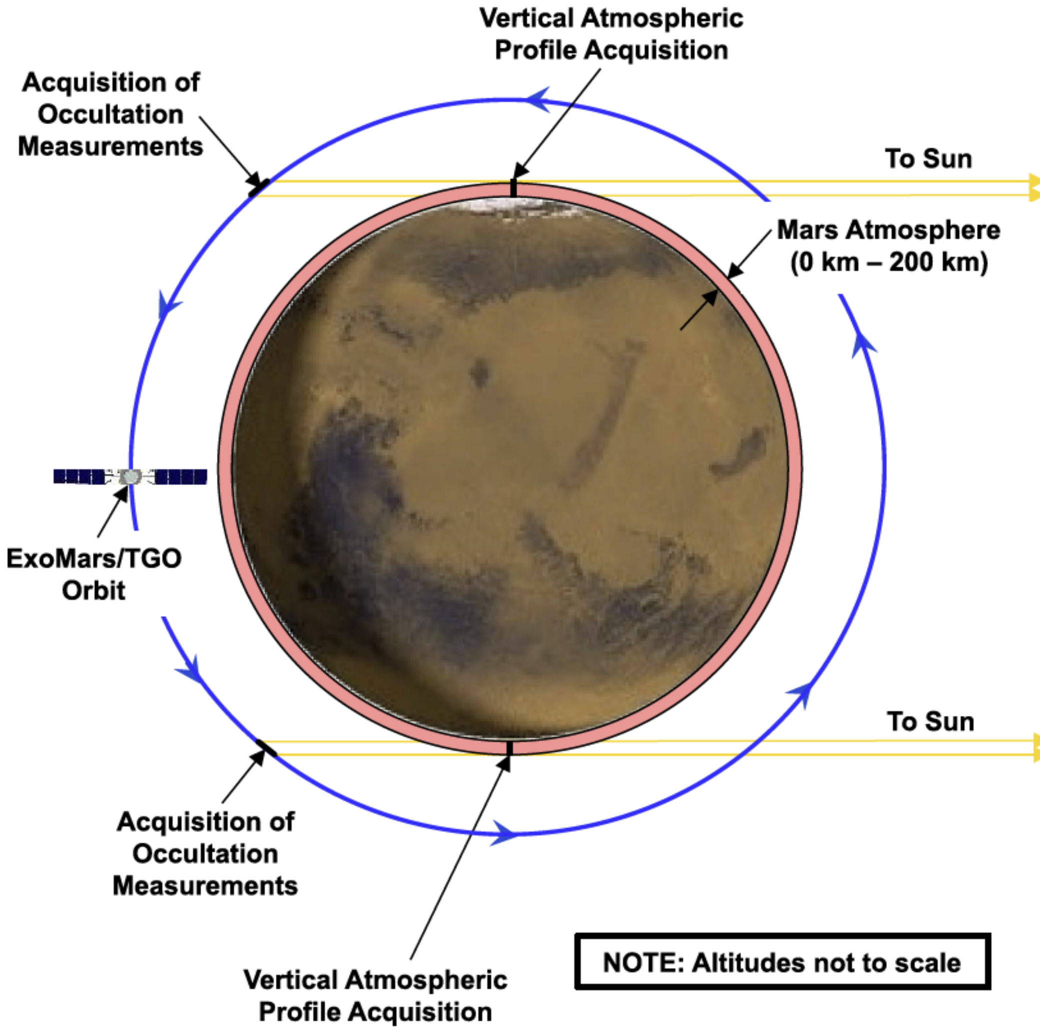
Inclination Trade Space Analysis

Science instruments gather data throughout the occultation events.

Search for:
- Eclipse entry/exit events
- Tang. Pt for 0km and 200km atm
- Grazing cases use min alt

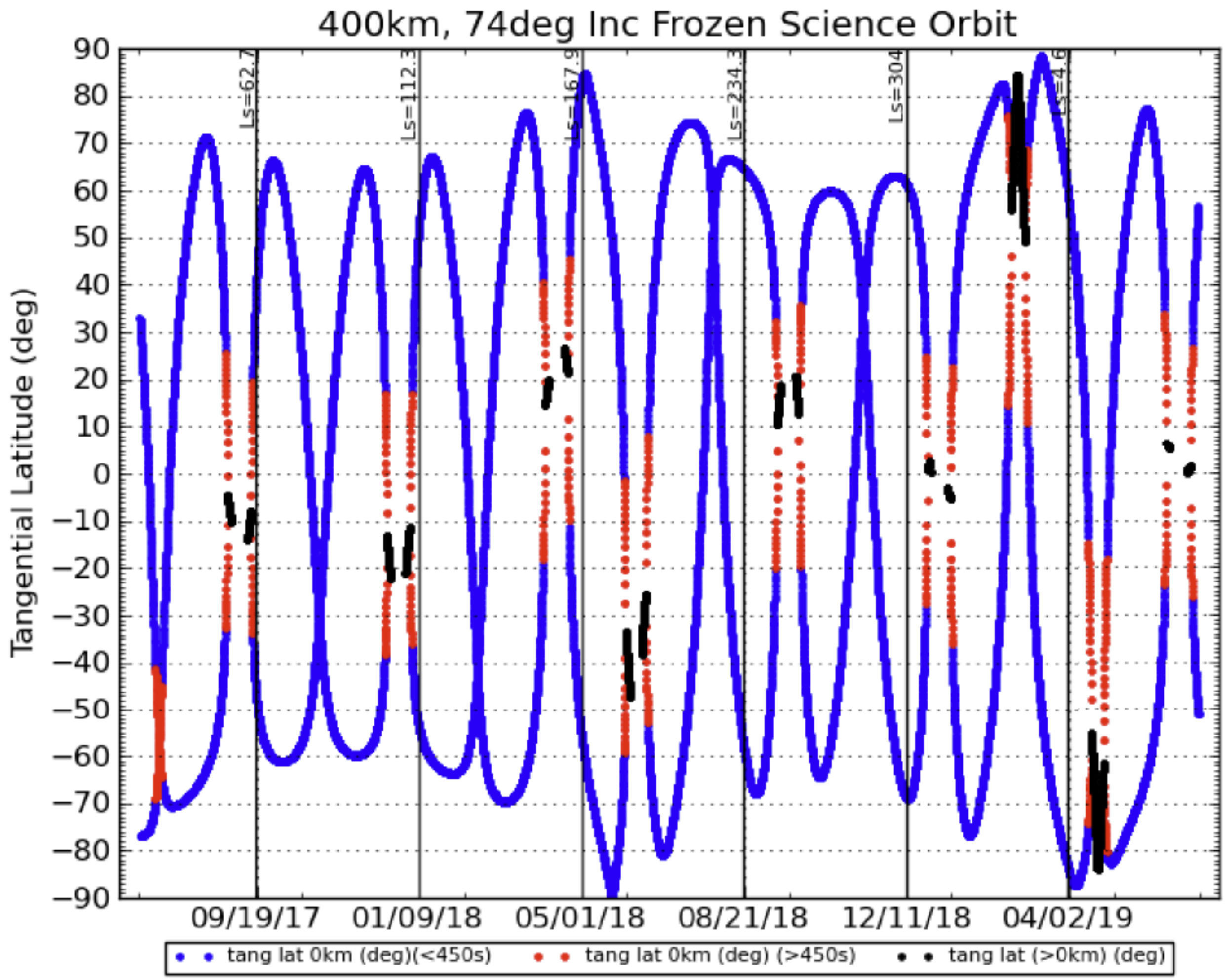
Determine:
- Event times, Tang Lat, Tang Long, Range to tang pt., Occ Duration, Occ Ground Distance

Segment data into:
- Occultation durations <450s
- Occultation durations >450s
- Grazing cases



Occultation Distribution (1 Mars Year)

Sample of occultation plot shows tangent latitude at eclipse enter and exit points.



Science Orbit Design Trade #2

- The next step was to refine the orbit altitude requirement and establish the associated desired ground track repeat pattern.

- The OWST provided the following inputs for this analysis:
  - Altitude trade space should be confined to a mean altitude of 400km-420km +/-10%
    - Results in altitude trade space of 360km to 462km
  - Space ground tracks less than 8 km apart at the equator over a long period of time (~2700 orbits).
    - Based on HiSci cross-track footprint of 8km
    - Altitude constraints result in range from 7.5km to 8.15km

- Used two excel spreadsheet from MRO to estimate orbit options
  - Altitude and ground track requirements result in Q (#Orbits/#Sols) trade space of 12.52 to 12.275
    - Approximately 600 orbit options in this trade space

Science Orbit Design Trade #3

- The OWST provided additional inputs on Mid-Term ground track spacing to help narrow down the orbit options
  - 16 km ground track spacing after 100 – 120 sols (~1400 orbits)

- The OWST provided additional inputs on short-term ground track spacing to help narrow down the orbit options
  - 1760 km ground track spacing on first sol (orbit 2)
  - 880 km ground track spacing on second sol (orbit 14)
  - 440 km ground track spacing on fourth sol (orbit 38)

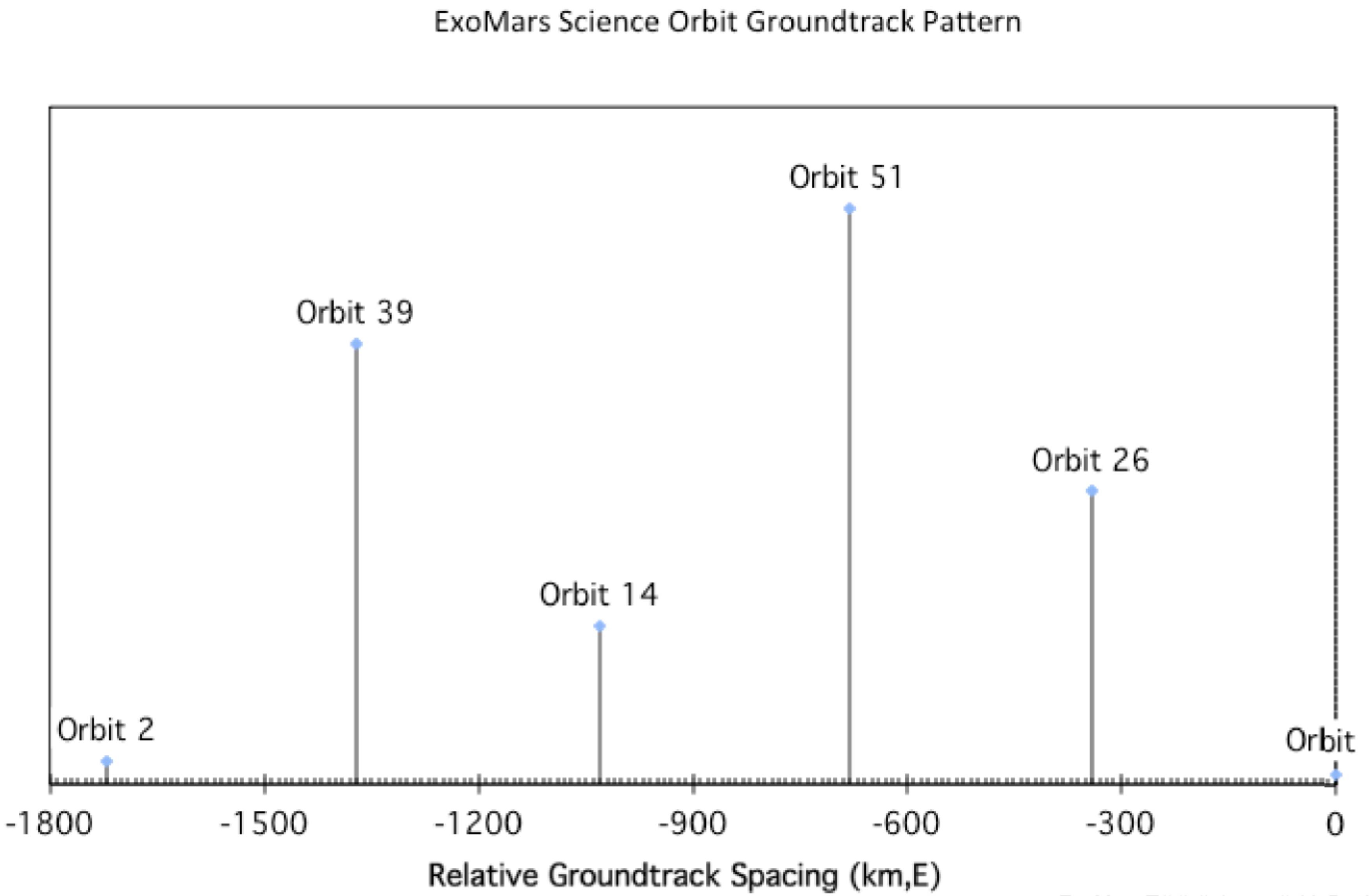
Short-Term Requirements

Short-Term Design Results:

- 1760 km ground track spacing on first sol can be met
- 880 km ground track spacing on second sol can be met
- 440km ground track spacing on fourth sol (Orbit 38) was not possible with current Q trade space
  - At min Q=12.275, ground track spacing on fourth sol at 480km
  - For 440km spacing, would need Q of ~12.25 which requires max altitude of ~467km
  - OWST did not want to exceed the 462km max alt already specified.

- Can achieve less than 440km spacing by fifth sol (orbit 51) with current Q value trade space and altitude requirements
  - Evenly spaced ground tracks at 344km after 5 sols with a Q=12.4.
  - At Q=12.400, get exact repeating ground tracks. Open up selection to Q=12.395 to 12.405
  - Selected Q = 12.405. Ground track spacing after 5 sols has min=326km, max=371km.

Short-Term Distribution



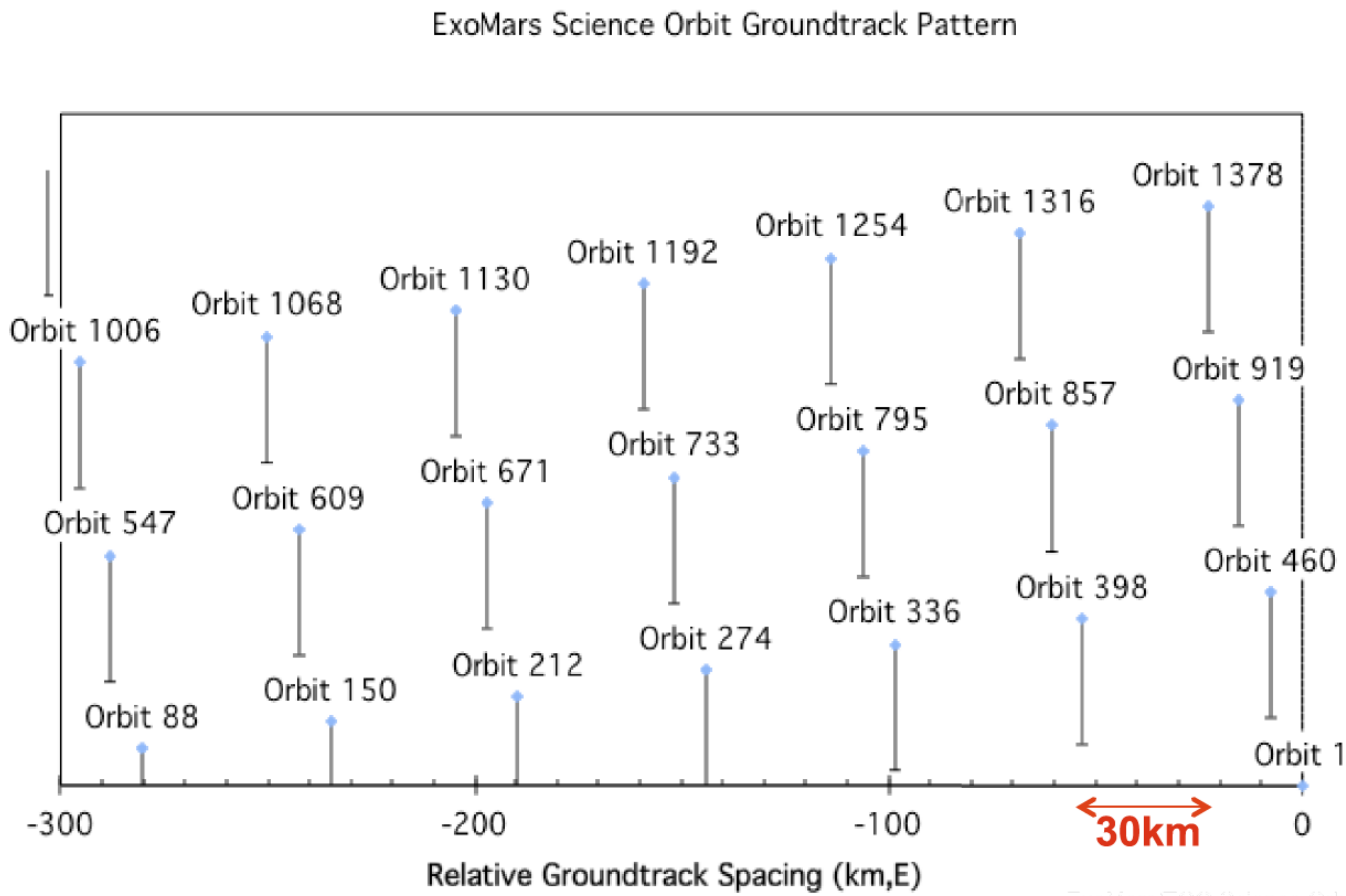
Mid-Term Requirements

Mid-Term Design Requirement:

- 16 km ground track spacing after 100 – 120 sols (~1400 orbits)
    - For Q=12.405, the ground track spacing after 111 sols (1378 orbits) is 30km
    - Would take 185 sols (2295 orbits) to get down to 15 km gap spacing
        - Gap closes at rate of 7.5km every 459 orbits (37 days)
    - OWST was OK with this

Mid-Term Distribution

- For Q=12.405, the ground track spacing after 111 sols (1378 orbits) is 30km.

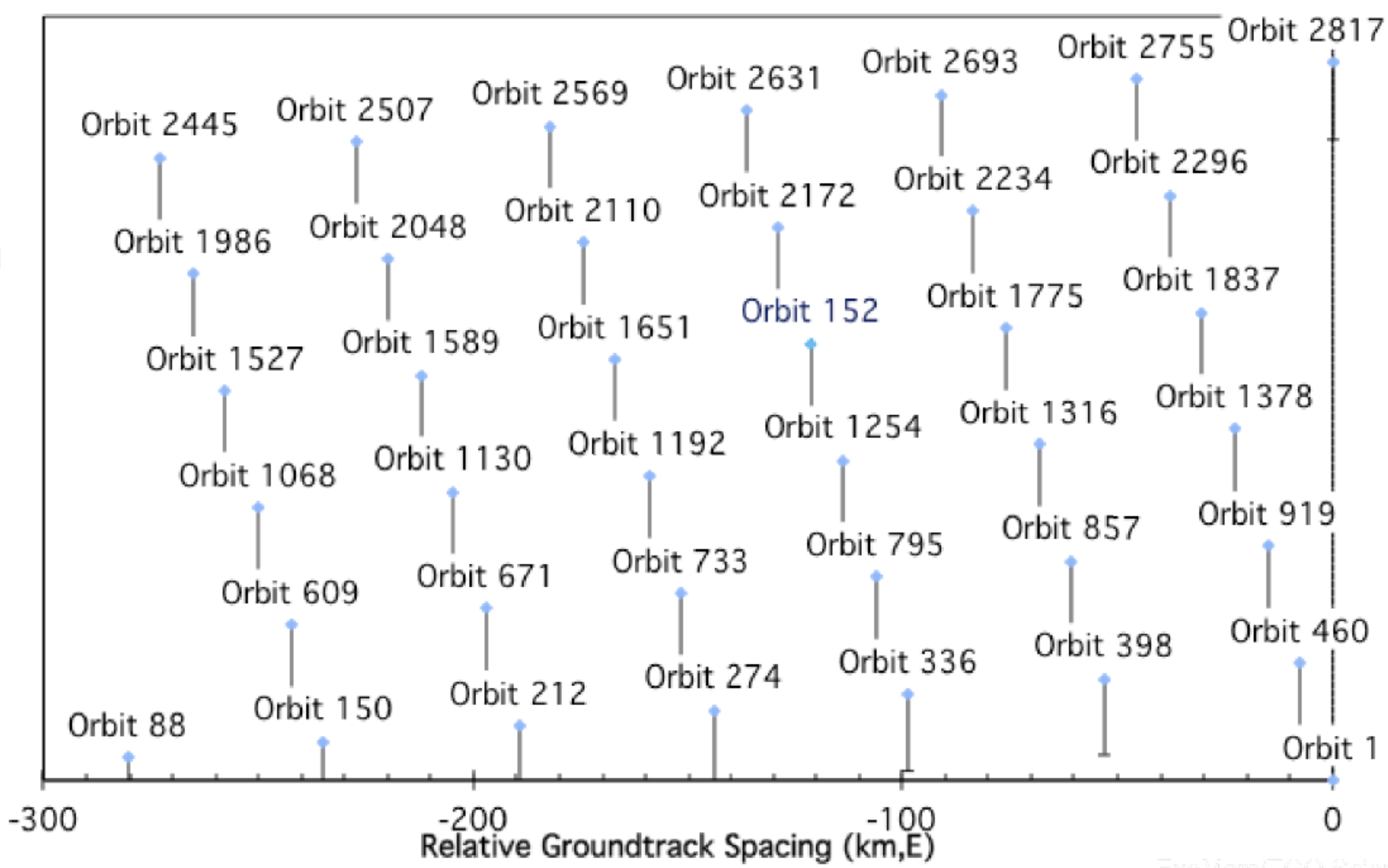


Long-Term Distribution

- Requirement: Ground track spacing less than 8 km apart at the equator over a long period of time.
- For Q=12.405, ground track repeats after 2816 orbits, 227 sols. Ground track spacing at 7.5km

Orbit Alt:
Hp=381km
Ha=435km

ExoMars Science Orbit Groundtrack Pattern



Reference Trajectory Development

- Used Morbiter v3.1 to generate a reference trajectory that matches the selected ground track properties.
    - Start with inclination and frozen orbit conditions developed from the Inclination trade space study
    - Adjust SMA until groundtrack spacing matches Excel results

- Morbiter setup:
    - Integration frame = IAU Mars Pole
    - 33x33 gravity field
    - No Sun, Atmospheric Drag, or SRP

Reference Science Orbit Parameters

	Mean Elements	Osculating Elements
Semimajor Axis	3787.5237 km	3779.2715 km
Eccentricity	0.0068	0.0040
Inclination	74.0405 deg	74.0090 deg
Argument of Periapsis	269.2147 deg	267.8467 deg
Right Ascension of Ascending Node (RAAN)	-158.9599 deg	-158.9690 deg
Mean Anomaly	0 deg	1.1374 deg

Time: 30-JUN-2017 09:15:01 ET
Coordinate System: IAU Mars Pole

Final Thoughts

- The spacecraft is required to provide support for the 2018 lander mission.
- In order to provide support, the spacecraft will most likely have to maneuver to a different orbit in order to drift over to the proper position at the time of landing.
- Maneuvering to the different orbit will occur several months ahead of the landing time.
- The ground track pattern will be different for the new orbit.
- After the landing event, the spacecraft could maneuver again to another orbit with a more desirable ground track pattern (depending on remaining propellant budget)

Backup

ESA Aerobraking and Science Orbit Requirements

MI-200: The mission design shall guarantee that the science orbit is, initially, a circular orbit with a mean altitude in the 350 km to 420 km range and an inclination of 74 degrees. The orbit ground track shall repeat over a 3-5 day interval such that the ground tracks are roughly evenly spaced at the end of that interval . *Note: The science orbit shall be initially circular but natural variations in eccentricity will, cyclically, make the orbit slightly eccentric. Those variations do not need to be corrected for.*

MI-201: The mission design shall allow for the acquisition, via aerobraking, of the final orbit specified in MI-200 two months (TBC) before the Solar Conjunction (i.e. 1.5 months before the SES is 5 deg)

MI-202: Once in the science orbit, the mission design shall guarantee at least 1 Martian year of orbital science operations.

MI-203: The mission design shall allow for the Orbiter Module to provide a data relay function to any potential surface assets up to the end of 2022. *Note: The ΔV budget allocation to cover potential orbit maintenance manoeuvres needed to comply with and MI-203 is capped to 25 m/s as per [NR 76]*

MI-300: The design of the aerobraking phase shall be such that a pericentre control manoeuvre is needed a maximum of once per day. *Note: Ground Control shall be ready to perform one additional manoeuvre if required (i.e. heating limits exceeded)*

MI-350: The mission design shall guarantee at least 48 hours (TBC) of orbit lifetime before apoares decay at all times during the Aerobraking Phase. *Note: The orbit lifetime is defined as the time necessary for apoapsis altitude to decay to an altitude of 350 km (TBC) using a nominal atmospheric model.*

ESA Aerobraking and Science Orbit Requirements

SC-SY-210: For calculation of the propellant mass the following margins on the effective mission delta-V's (e.g. including gravity losses) shall apply:

- 3% for the following manoeuvres: DSM, MOI, inclination change, 1-sol orbit acquisition, science orbit acquisition and data relay for future assets.
- 100% for attitude control manoeuvres
- No additional margin delta-V value specified for Navigation manoeuvres.

SC-SY-220: The magnitude error of any Spacecraft Composite delta-V manoeuvre bigger than 1m/s shall be less than 1%, 3 sigma, of the nominal commanded value.

SC-SY-221: The error in the direction of any Spacecraft Composite delta-V vector shall be less than 0.3 deg, 3 sigma, with respect to the nominal commanded value.

SC-SY-222: The magnitude error of any Spacecraft Composite delta-V manoeuvre smaller than 1m/s shall be less than 3 mm/s.

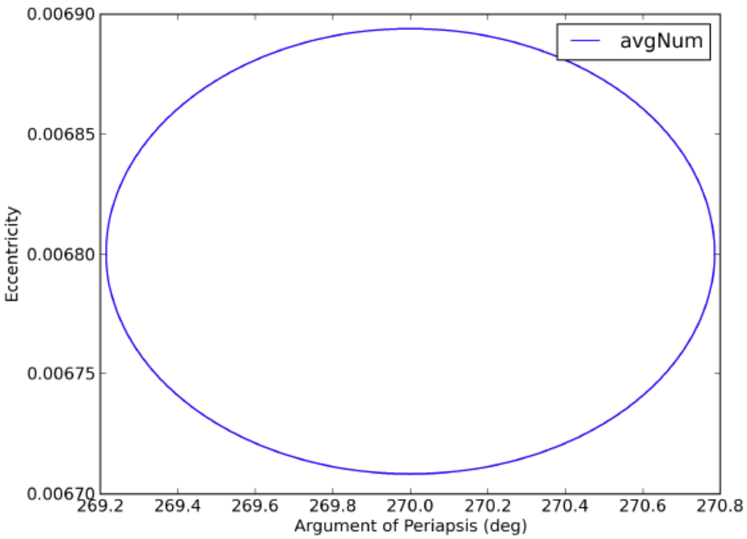
SC-SY-230: A minimum of 2 % provision on the total propellant mass shall be applied to estimate the propellant residuals mass for calculating the total propellant needs. *Note: The contractor shall justify the amount of propellant residuals considered.*

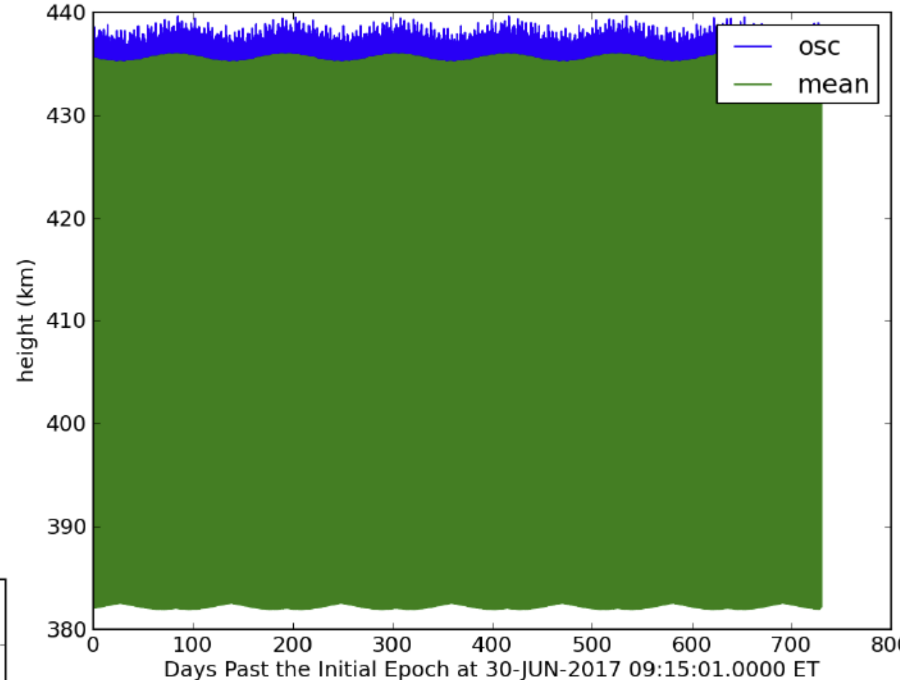
SC-SY-231: All delta-V manoeuvres shall be performed with a confidence level of at least 99.7%, 3 sigma.

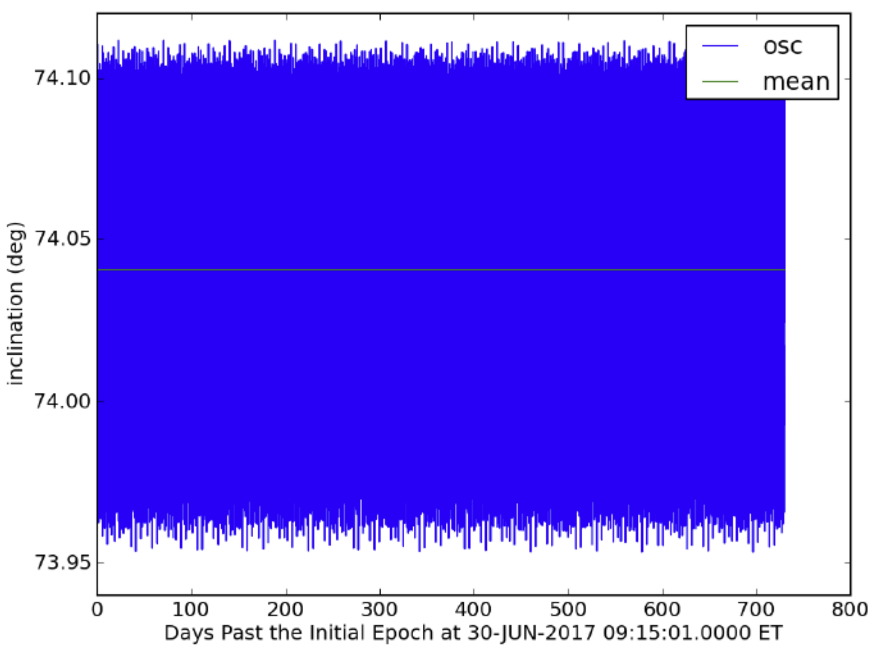
ESA DV Budget

	Thrust	Isp	Delta-V	Remarks
Launch Dispersion Correction	40 N	290 s	25 m/s	
Cruise Navigation	40 N	290 s	25 m/s	
Deep Space Maneuver - DSM	437.5 N	318.8 s	594 m/s	Includes the two parts of the DSM 1 & 2
Orbiter Retargeting Maneuver - ORM	40 N	290 s	15 m/s	Includes allocation for periares advance
Mars Orbit Insertion - MOI	450.9 N	317.8 s	1364 m/s	Includes gravity losses and allocation for periares advance
Mars Orbit Convtrol	40 N	290 s	15 m/s	Covers navigation and orbit maintenance maneuvers during acquisition of preaerobraking orbit
Inclination Change Maneuver - ICM	437.5 N	318.8 s	141 m/s	
Apocenter Lowering Maneuver - ALM	437.5 N	318.8 s	136 m/s	
Science Orbit Acquisition – Aerobraking Phase	40 N	290 s	120 m/s	Includes: Periapsis lowering and control, one contingency during aerobraking and circularization (final periapsis raise)
Phasing for data relay of 2018 Mission EDL coverage	40 N	290 s	43 m/s	
Phasing for data relay of 2020 Mission EDL coverage	40N	290 s	43 m/s	
Orbit maintenance/OTM until end of 2022	40 N	290 s	25 m/s	

Reference Trajectory Orbit Parameters







Reference Trajectory Orbit Parameters