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From Mars Express to ExoMars: Two missions working together around Mars.

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Abstract

This year 2018 is very important for the Mars scientific community in Europe since for the first time two missions of the European Space Agency coincide around the orbit of Mars, opening a great opportunity for collaboration to improve our understanding of our neighbour planet.
The Mars Express mission is fully operational and has been providing great amounts of data since its arrival at Mars in Christmas 2003, covering a wide range of science objectives from the surface and sub-surface geology, atmosphere dynamics and composition, up to the interaction with the magnetosphere and the characterization of the Martian system including Phobos and Deimos.
The ExoMars 2016 Trace Gas Orbiter mission arrived successfully at Mars in October 2016 and after the first calibration observations in the initial capture orbit and the long aerobraking phase of more than 12 months, the mission started its operational science phase in April 2018 aiming to fulfill the scientific goals of the mission: atmospheric trace gases, climatology, surface geology and subsurface ice detection.
In this contribution we provide a short summary of each mission and their mission profiles, with the characteristics of each orbit and their differences that drive the observation capabilities. We will then focus on the synergistic capabilities between all the instruments and the observations that can be combined to improve the scientific outcome of both missions. In particular we will show the preparations done by the science operations centers at ESAC and the work within the Science Ground Segments for the long term analysis of the geometrical conditions of both missions to perform coordinated science operations. We will provide details on the science opportunity analysis process, using various operational tools inherited from previous planetary missions to perform geometrical and operational simulations of both spacecraft, taking into account the observation requirements of all the instruments and the operational requirements for feasibility checks.

1 Mars Express Mission

Launched in June 2003, the Mars Express spacecraft has been steadily returning enormous volumes of science data since its arrival in Mars orbit in December 2003. While the mission was originally conceived to last 687 Earth days (one full Martian year), it has now been operating continuously for almost 15 years, covering a wide range of science objectives from the surface and sub-surface geology, atmosphere dynamics and composition, up to the interaction with the magnetosphere and the characterization of the Martian system including Phobos and Deimos.

The Mars Express spacecraft is in a highly elliptical polar orbit, with an inclination of 86 degrees from the equator and a period of nearly 7.5 hours, producing about three orbit passes per day. The pericentre height is approximately 350 Km, while the apocentre is at approximately 10,000 Km. The orbit is not synchronized in any way with Mars, Earth or the Sun, and so it is drifting freely by celestial mechanics with a slow precession movement that changes the orbit latitude and the illumination conditions, defining the long term seasons with a long period of nearly 20 months.

This high eccentricity of the orbit provides a very wide range of distances that allow for the observation of the planet with very different resolutions and observing conditions. However the long term evolution of the orbit precession causes very stable and slow changing seasons, with very slow variations of the latitude and illumination at pericenter where we can identify long observation campaigns (3 6 months).

2 ExoMars 2016 Trace Gas Orbiter Mission

ExoMars 2016 is the first of the ExoMars Programme developed jointly by ESA and Roscosmos. The key goal of this mission is to gain a better understanding of atmospheric trace gases that are present in small concentrations (less than 1% of the atmosphere) which are key in the understanding of the atmospheric climate evolution and potential evidence for biological or geological activity in the past.

The Trace Gas Orbiter (TGO) carries a scientific payload capable of addressing this scientific question, namely the detection and characterisation of trace gases in the Martian atmosphere. The spectrometers ACS and NOMAD will make use of the solar occultation observations to obtain the maximum sensitivity in the vertical profiles, and will use also nadir pointing to map the atmospheric conditions of the whole planet to detect a wide range of atmospheric trace gases, with an improved accuracy two or even of three orders of magnitude compared to previous measurements. The instrument CASSIS will also observe in nadir geometry to obtain super high resolution colour and stereo images of selected targets on the surface. The FREND instrument will analyse the subsurface hydrogen to a depth of a metre, to reveal any deposits of water-ice hidden just below the surface, which, along with locations identified as sources of the trace gases, and stereo colour imaging, could influence the choice of landing sites of future missions.

The nominal science orbit of TGO around Mars is circular at an altitude of 400km, with a high inclination of 74 deg and a characteristic node regression that makes the orbit plane rotate around the planet with a typical cycle of 7 weeks. The evolution of the beta angle (the angle between the orbit plane and the sun) drives the main seasons of the mission and defines the long term planning campaigns for solar occultation and nadir observations.

3 Sinergies and Areas for Collaboration

In general the ExoMars long term evolution is very dynamic compared to the evolution of Mars Express, and has short observing seasons that vary regularly on a weekly basis, based on the orbital node regression. That allows for a full surface and local time coverage on a monthly basis, except for the polar regions that the spacecraft is not able to reach.

The main advantage of ExoMars TGO compared to Mars Express is the capability to have almost continuous science observations. Thanks to a simplified mission profile the spacecraft is basically pointing Nadir by default and pointing the solar occultation channels to the Sun whenever needed for occultation measurements. Mars Express does not operate continuously, as most observations need to be stopped during ground communications but at least on the other side it provides a lot of pointing flexibility thanks to the maturity of the mission.

Here we list a few of the common scientific research areas for collaboration between both missions:

- Geology and subsurface: photometric properties, including temporal and spatial variations, evolution of the polar caps, sub-surface ice, surface water abundance and their correlation with surface geology and mineralogy.

- Meteorology and climate: extending record of climatological parameters (temperature, minor species, dust, clouds), improving the coverage (spatial, temporal, local time), study of couplings between the atmospheric layers and dependence of atmospheric parameters on dust loading

- Ionosphere and escape: structure of the ionosphere and upper atmosphere, dependence of escape on the state of the lower atmosphere, characterisation of water escape and its dependence on the state of the lower atmosphere and study of couplings between the atmospheric layers

In order to take advantage of these sinergies there is a common effort to promote the collaboration lines between both missions, not only in the data analysis, but also in the sharing and discussion of results, the comparison of retrieval tools and radiative transfer codes, climatological parameters, and the joint use of TGO and MEX data in Global Climate Models.

4 Analysis of coordinated science observations

This work focuses in the analysis of coordinated science observations and combined observation opportunities (surface, sun occultations, ...), which would then be used for the cross-calibration of different instruments that may contribute to complementary science objectives (surface, temperatures, clouds, context,...) and will be used in the preparation of a joint long-term science activity plan between both missions.

In order to study the various possibilities of coordinated science operations, we define here various types of combined observations:

- Simultaneous observations: these are observations of both missions that observe the same exact position, latitude and longitude coordinates, and occur exactly at the same time, therefore having the same illumination and local time conditions. These kinds of observations are the most interesting and would be extremely useful for cross-comparison and cross-calibration between the different instruments, however they are limited by the geometrical evolution of the orbit and may not be possible in all cases.

- Quasi-simultaneous observations: these are observations that are almost simultaneous but have one or more requirements relaxed, in terms of position, time or conditions. These may cover a wide range of options depending on the flexibility of the scientific requirements of each type of observation, and are still very useful for comparison and can provide very important information for wide scientific objectives both at the surface and atmosphere. We can distinguish here two main type of quasi-simultaneous observations:

  - Surface driven: these are observations of the same latitude and longitude coordinates, but performed at different times. This kind of observations may be useful for some scientific objectives, in particular for surface features and in general for the imaging cameras where the comparison of the results can still be relevant even if observations are taken at very different times, as long as the illumination conditions at the surface are similar.

  - Sun illumination driven: these are observations taken at the same latitude region and with the same illumination conditions, but the longitude coordinates may be different. In other words, these are two observations of the same geometry on Mars with respect to the sun, but where the actual point in the surface is different.

- Non-simultaneous seasonal observations: these are observations that do not occur close in time, but are at least performed in the same season with similar conditions and therefore they can still be used to infer useful information. This is in particular applicable to surface geology or mineralogy observations that are not expected to change within short time scales. In general the overall scientific requirement for both missions is to reach as much as possible a full coverage of the planet, not only in terms of surface latitude and longitude, but also in terms of season (Solar Longitude) and illumination conditions (Solar Elevation angle and Local Time) so that all the data can be ingested into the climate models for comparison.

4.1 Solar Occultations

The main scientific goal of ExoMars TGO is the analysis of trace gas species and the most important observation that will cover the sensitivity requirements are the solar occultations that will use the signal of the sun as it gets occulted by the atmosphere, providing very important information of the vertical profile of various gas molecules and their densities with the NOMAD and ACS spectrometers. Mars Express also has the SPICAM instrument that is able to perform solar occultation measurements in the infrared range and their results are very important for comparison of the measurements of the vertical profiles and the retrieval methods for various gases.

For this we have performed an analysis of all the occultation points MEX-Mars-Sun and TGO-Mars-Sun both for the in-gress and e-gress points (that is dusk and dawn). In order to identify all the quasi-simultaneous opportunities we have computed all occultations from both missions for the year 2018 and compared all times and geometrical conditions. This analysis has shown that MEX-TGO combined occultations are geometrically possible and occur every few weeks. We have found at least three optimal opportunities in 2018 (23-May, 16-August and 29-August) where the time difference is less than one minute, and we have identified many other quasi-simultaneous occultations that can be observed at the similar times in the same region of the planet within a few minutes difference. In particular we can observe that the periods May-June and August-September have quite a few combined occultation events that occur within 15min difference in the same region of the planet (0 30deg difference in latitude).

4.2 Nadir Observations

Both the Mars Express and Trace Gas Orbiter mission are also observing in Nadir geometry, not only performing high resolution imaging of the surface with MEX/HRSC, TGO/CASSIS, and characterizing the surface composition with MEX/OMEGA but also complementing the atmospheric analysis of various gases of the previously mentioned solar occultations, providing temperature profiles and various gas abundance maps with MEX/PFS and MEX/SPICAM, cloud monitoring and overall contextual information with MEX/HRSC, MEX/OMEGA and MEX/VMC. The nadir observations are also used by other instruments like TGO/FREND and MEX/MARSIS to provide mapping information of the subsurface that is of great importance to the analysis of ice content below the surface and other contextual interpretation of the data.

When looking at the orbits of both spacecrafts, it is easy to identify that there are orbit "alignment" seasons every few months, where both spacecrafts can fly "quasi-parallel" to each other, with elongated similar tracks on the surface. Also at any point in time there are always two crossing points between the orbits, although the distances may be very different due to the eccentricity of the MEX orbit, affecting the chances of having a simultaneous observation between the two spacecrafts.

5 Summary and Conclusions

In this contribution we have shown some of the potential science opportunities for combined observations between Mars Express and Trace Gas Orbiter that are an important input for the science operations planning of both missions. Our analysis shows that there are regular opportunities for combined observations between the missions for both the most important observation types, solar occultation and nadir.

MEX-TGO combined occultations are geometrically possible and occur every few weeks. Although we may not have many exact simultaneous observations of the same spot in time, we have identified many quasi-simultaneous occultations that can be observed at similar times in the same region of the planet within a few minutes difference. In particular the periods May-June and August-September have combined occultation events within 15min difference in the same region of the planet.

For nadir observations, simultaneous cross-calibrations are possible regularly at different distances, and all latitudes/longitudes can be covered by both spacecrafts, with the exception of the polar regions due to the TGO orbit inclination (74deg). Quasi-simultaneous observations are very common as there are always two TGO-MEX crossing points, which can be seen within one 1h difference thanks to TGO shorter orbital period. This 1 hour difference may be important or not depending on the scientific objective, or the proximity to terminator. The main driving factor is the distance of Mars Express, but depending on the type of observation it may be interesting to observe at pericenter (for high resolution) or at the apocenter for contextual information.

The results of this work are based on the lessons learned from Mars Express and other planetary missions and are intended to identify as soon as possible the feasible coordinated science campaigns so they can be allocated during the Long Term Planning process (LTP, 6-month cycles) for the definition of high level priorities between the two missions and all their instruments. This science campaigns can then be iterated, confirmed and implemented during the Medium Term Planning process (MTP, 4-week cycles), where all the observations are frozen and expanded for the final commanding of the instruments at Short term Planning (STP, 1-week cycles).

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