# TRAJECTORY DESIGN OF SOLAR ORBITER

**José Manuel Sánchez Pérez**
*ESA/ESOC HSO-GFA, Robert-Bosch-Str. 5, Darmstadt, 64293,Germany, 0049-6151-902494,*
*jose.manuel.sanchez.perez@esa.int*

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## ABSTRACT

Over more than 10 years mission studies for the ESA Solar Orbiter were conducted showing that the scientific relevance and timeliness of the mission have only increased, making the broad international community support for the mission stronger than ever. Solar Orbiter was finally approved in October 2011 as M-class mission of the ESA's '*Cosmic Vision 2015-25'* programme and is now in the development phase aiming at launch in early 2017. Solar Orbiter is in addition an ESA-NASA joint contribution to NASA's '*Living with a Star*' programme and has strong science synergies with NASA's Solar Probe Plus, planned for launch within a similar timeframe.

The baseline mission design regards launch onto a NASA-provided evolved expendable launch vehicle (Atlas V or Delta IV) followed by a sequence of Venus and Earth gravity assists in order to eventually reach Venus with a large relative velocity. The spacecraft will then be inserted into a heliocentric science orbit with perihelion close to the Sun from which unprecedented in-situ and remote sensing Sun measurements will be performed. Additional Venus gravity assists will be used to modify the science orbit in order to increase gradually the solar inclination until reaching the mission goal of 33 deg that will permit clear observation of the Sun poles.

Solar Orbiter trajectory design has considered a number of competing objectives and constraints:

- the trajectory must be ballistic with no deterministic deep space manoeuvres to simplify the propulsion system and minimize the spacecraft mass
- the Earth escape velocity must be minimized to fit within the launch vehicle performance
- the minimum perihelion of the science orbit is constrained to 0.28 AU (60 Sun radii) to reduce the mission development risk by allowing maximum re-use of technologies developed for the ESA Bepi-Colombo mission
- the maximum distance to the Sun is limited to about 1.5 AU in order to simplify power and thermal spacecraft design
- reduced duration of the cruise phase for an early start of the science observations
- maximization of scientific return by reaching soon the lowest perihelion and achieving at least 33 deg solar inclination before the mission end 10 years after launch
- gravity assist manoeuvres must be out of the solar conjunction periods to permit a safe navigation of the planetary swing-by
- in addition the design must also aim at minimizing the duration of the solar conjunctions

The trajectory design problem was tackled in two steps. In the first step, the cruise phase to Venus including multiple Earth and Venus gravity assists is regarded alone. Transfer options consistent with the mission requirements and constraints have been systematically obtained for launch within the 2017-2018 timeframe. These transfers are optimized to reach Venus with a

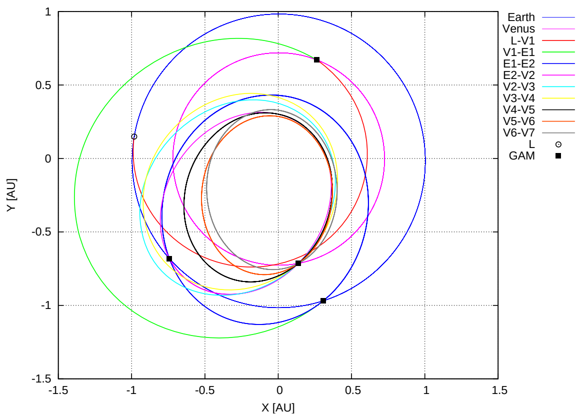
high relative velocity of about 18-20 km/s and close to one of its orbit nodes with respect to the Sun equator such that ultimately the required high solar inclination can be achieved.

In the second step, the science phase consisting on a sequence of resonant orbits with Venus is regarded. Gravity assist manoeuvres at Venus are used to transfer between the resonant orbits. Trajectories designed for Solar Orbtier make use of different resonant ratios: 1:1, 4:3, 5:4, 3:2 or 5:3 (S/C:Venus revolutions). Maximization of the science return is achieved by maintaining the perihelion low during the sequence such as to provide closer Sun observations and a certain level of pseudo-corotation that allow tracking features on the Sun surface for extended periods. In addition, the final solar inclination at the last resonance orbit is maximized. For the design of the science phase V-infinity direction diagrams have proven a very valuable tool for the fast analysis and optimization of the sequences of resonances.

As outcome of this trajectory design, the Solar Orbiter mission now relies on 3 launch opportunities consistent with the mission objectives and constraints. This mission design aims at increasing the mission robustness and the probability of success. The first launch opportunity spans through late December 2016 and January 2017 and is currently regarded as the baseline. An additional launch opportunity is possible in March 2017. While a further launch opportunity occurs in September 2018 offering a mission backup in case of severe programmatic delays.

*Accompanying figures for baseline trajectory based on Launch-Venus-Earth-Earth-Venus transfer and a science phase with the sequence of Venus resonances 4:3-4:3-3:2-5:3.*

2017 January
X-Y Trajectory
Ecliptic Projection




V-infinity direction
diagram of the
science phase