Universitá di Pisa

Near Earth Objects
Space Mission Preparation:

Don Quijote Mission Executive Summary

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EUROPEAN SPACE AGENCY

Executive Summary of ESA Study Contract No. 26252/02/F/IZ

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This document shows the results of the **Don Quijote project**, a Near Earth Objects Space Mission Preparation study (Contract ref. 26252/02/F/IZ, issued by ESA) performed by DEIMOS Space, Astrium GmbH and scientific consultants from University of Pisa, Spaceguard Fundation, University of Bern and Institut de Physique du Globe de Paris.

1. THE MISSION

The Don Quijote mission has two correlated but conceptually independent goals:

1. **To obtain knowledge about the nature of asteroids which has a very high scientific priority but is inaccessible for the current generation of asteroid missions.**

2. **To obtain knowledge which would be critical in case we had the need to deflect an asteroid away from a collision course with the Earth.**

The mission would contain the following elements:

- Two spacecraft are to launch in separate interplanetary trajectories.
- One spacecraft, which will be referred to as **Hidalgo**, will impact an asteroid of approximately 500 m diameter at a relative speed of at least 10 km/s.
- The other spacecraft, called **Sancho**, will arrive earlier at the same asteroid along a very different route; perform a rendez-vous and remaining in orbit around the asteroid for several months before and after the impact.
- Sancho will also deliver at least 4 penetrators, to form a seismometer network on the asteroid. Before and after the Hidalgo impact an active seismic experiment (seismic tomography) to study internal structure will be carried out, by means of seismic activators (small explosives) that will be launched from Sancho.
- At the time of the impact, Sancho will retreat to a safe distance to observe the impact without taking unnecessary risk (with an attitude appropriate to its name). It will later return to a close orbit, to observe the changes in the orbit and rotation state of the asteroid, and (optionally) to collect samples from the dust ejected by the crater formation.

(Images: Gustavo Doré)

Top level scientific requirements

1. To determine the **asteroid internal structure**, especially the size f the main solid pieces, the average particle size and thickness of regolith and of the debris layers in the space left between the main pieces. This requires seismology, although very useful constraints can also be obtained from the shape changes and rotation dissipation.

2. To constrain the **mechanical properties of the asteroid material**. This is measured by the seismic propagation speeds, but also by the penetrators (with an accelerometer).

3. To measure the **orbital deflection of the asteroid** as a result of the impact of Hidalgo, with an accuracy of about 10%. This can be achieved with range-rate and/or with range, and also requires that the orbit determinations of the asteroid-centric orbit of Sancho before and after the impact are accurate as necessary: this implies the requirements on the accelerometer performance or altenative options.

4. To measure the **mass of the asteroid**, the **ratio of the moments of inertia** and the **low order harmonics of its gravity field**. This is needed also to achieve 3., but is a goal in itself. 3. and 4. together measure the transfer of linear momentum achieved with the Hidalgo impact.

5. To model the **asteroid shape** before and after the impact, to detect changes (if any). The main problem is that it is very difficult to estimate a priori the size of such changes, thus they may not be detected, apart from the impact crater (delayed changes are possible, and would be very interesting)

6. To measure the **asteroid rotation state** before and immediately after the impact; the accuracy must be such that the difference is measured with an accuracy of 10%. This allows determining the absolute value of the moments of inertia.

7. To detect the **dissipation of the non-principal axis rotation after the impact**, if possible. The problem is that the dissipation factor Q is very hard to predict, thus we do not know the time-scale of the dissipative changes in the rotation state. Note that the dissipative changes in the rotation state could be associated with delayed shape changes.

8. To determine the asteroid **large scale mineralogical composition**. Since such a small asteroid is likely to be rather homogeneous, this suggests low spatial resolution/high spectral resolution IR spectrometry.

9. To determine the detailed **mineralogical composition and texture**. Mass spectrometry could be interesting, but may not be top priority. This requires capture and in situ analysis of some particles, e.g., the ones released in orbit around the asteroid by the Hidalgo impact.

10. To provide a **model for non-gravitational forces**, such as Yarkovsky effect, acting on the asteroid orbit and rotation. This requires a thermal model.

Note: of these goals, most refer to the determination of the asteroid internal structure. Only 3. and the mass determination of 4. (and, to some extent, 6.) are directly relevant for the deflection experiment, although the information on the internal structure could be relevant for other deflection methods.

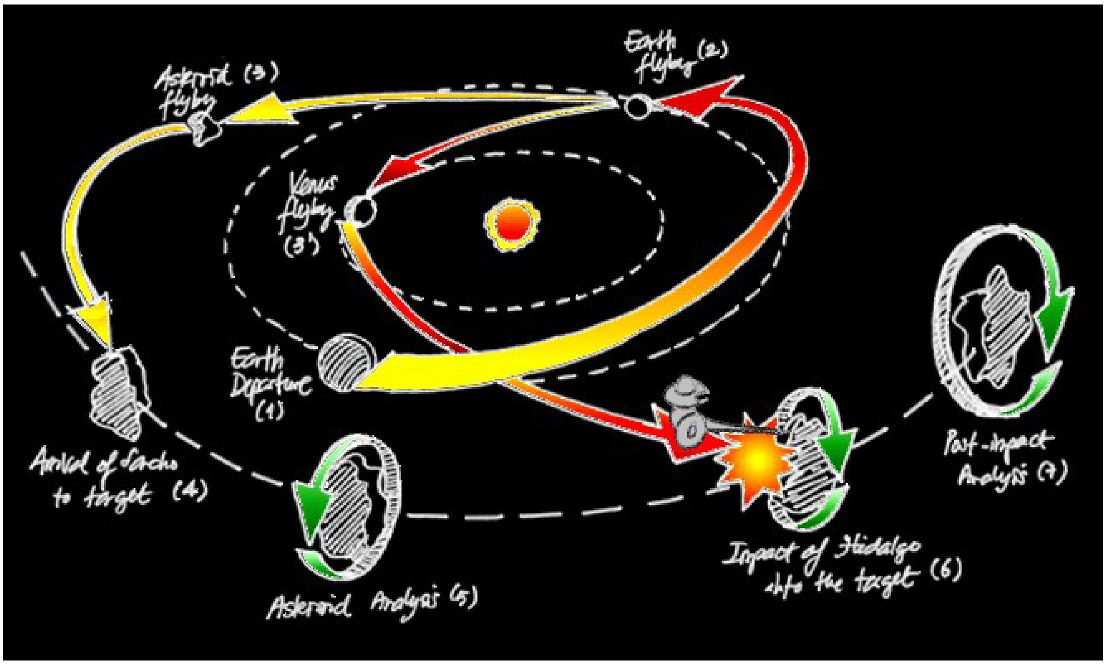
2. THE TRAJECTORY

The two spacecraft hace to arrive to the same asteroid but with very different conditions:

- ☐ The first spacecraft to arrive shall be Sancho. This S/C shall rendezvous the asteroid and remain in orbit until the second spacecraft arrives. The arrival conditions for Hidalgo are those that:
    - Maximise the mass reaching the asteroid vincinity
    - Minimise the ΔV required for orbit insertion.
    - Result in an arrival date with sufficient anticipation (around 6 months) to allow the proper characterisation of the asteroid prior to Hidalgo arrival.
- ☐ The second spacecraft, Hidalgo, shall arrive to the asteroid with:
    - High relative velocity, impacting the target with a given accuracy
    - Maximising the mass at impact

Other constraints such as impact geometry for measuring the impact consequences are also considered.

As a result of these constraints, the following sequence of events has been selected:

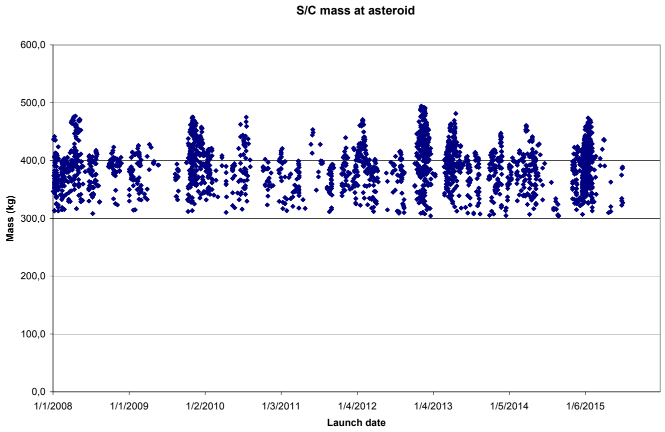


Don Quijote Baseline Trajectory Design

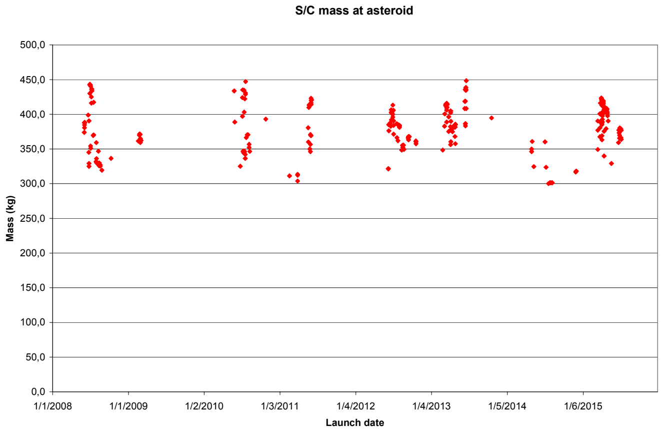
- ☐ Single launch for both S/C (Soyuz-Fregat like) (see figure above, point 1)
- ☐ Both S/C in a trajectory that will encounter the Earth 6 months later.
- ☐ The Earth swingby (2) is used to separate both spacecraft in two different interplanetary trajectories. Each S/C reach the Earth with a small difference that result in completely different gravity assist manoeuvre, routing Sancho to the target asteroid and directing Hidalgo towards Venus (or Mars).

- Sancho might perform a midcourse asteroid flyby (3) as a scientific add-on to the main mission.
- Sancho rendezvous the asteroid with a small relative ΔV (4) and starts to characterise it (5) (i.e. estimation of its geometrical properties and gravity field), deploying the penetrators.
- Hidalgo performs a Venus (or Mars) swingby that redirects it to the asteroid (3')
- Hidalgo impacts the asteroid with a high relative velocity (6), while Sancho witnesses it.
- Sancho explores the consequences of the impact (7)

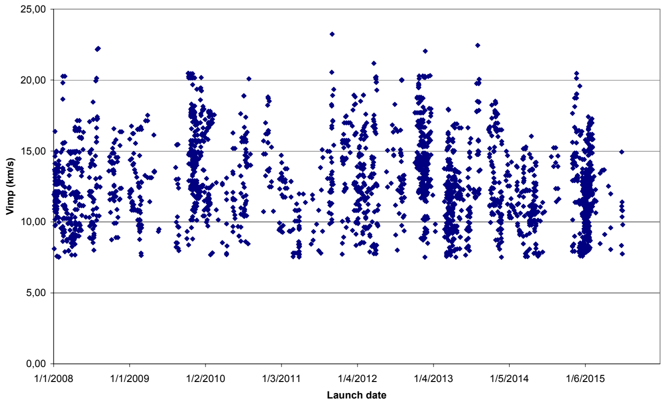
A large number of solutions have been found following this scheme:



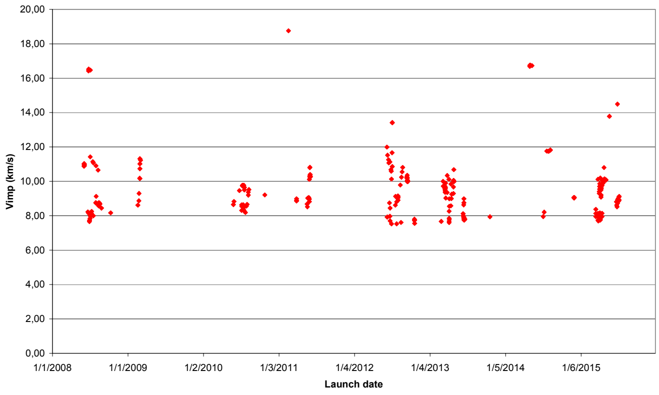
S/C Mass at asteroid (both Sancho and Hidalgo) (Venus case).



S/C Mass at asteroid (both Sancho and Hidalgo) (Mars case).



Impact velocity for Hidalgo (Venus case).



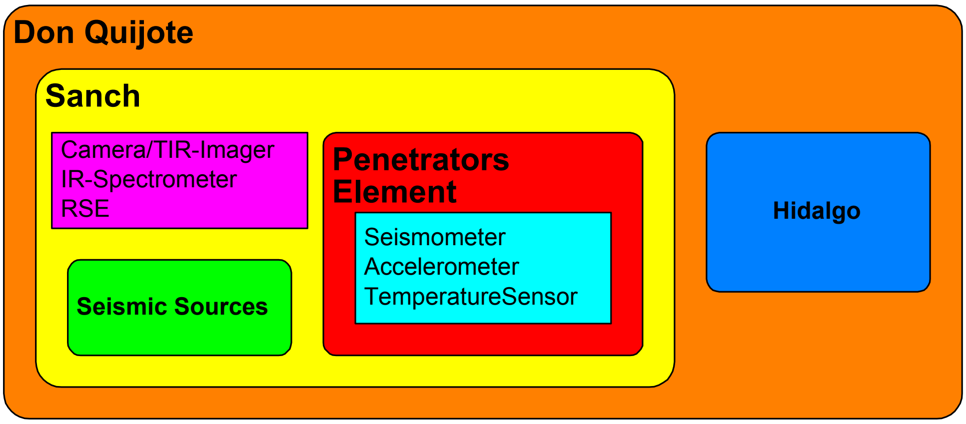
Impact velocity for Hidalgo (Mars case).

The following mission, to asteroid (10302) 1989 ML is taken as a reference case (several launch windows are available every year to this NEO and others with even better configurations, providing back-up options):

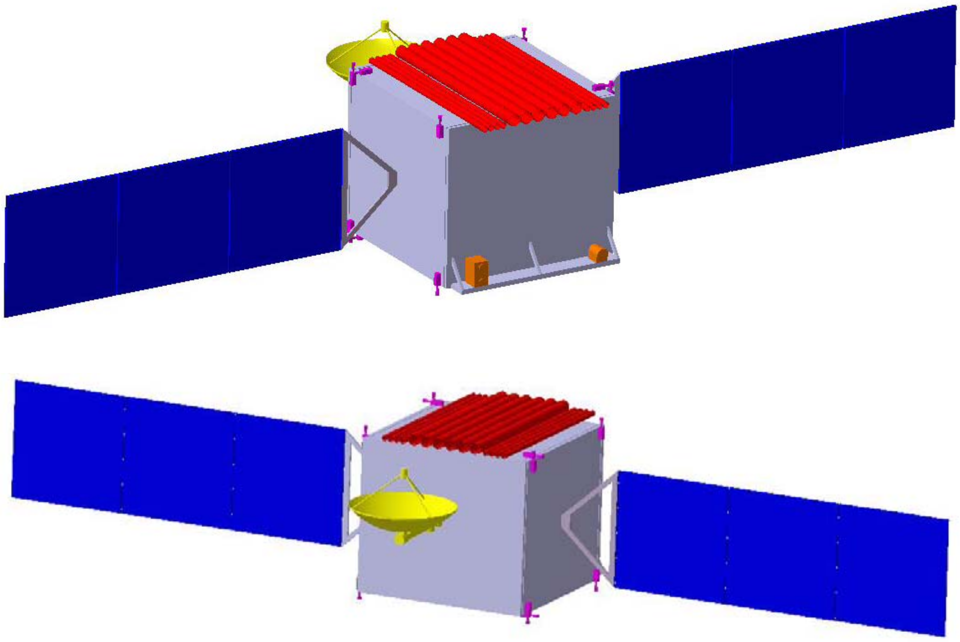
	SANCHO	HIDALGO
Departure mass (kg)	582.3	388.2
Final injected mass (kg)	394.0	379.1
Relative arrival velocity (km/s)	1.089	13.437
Initial Earth departure date	2011/ 1/ 6 9:36: 0.0 (4023.4 MJD2000)	

3. THE SPACECRAFT

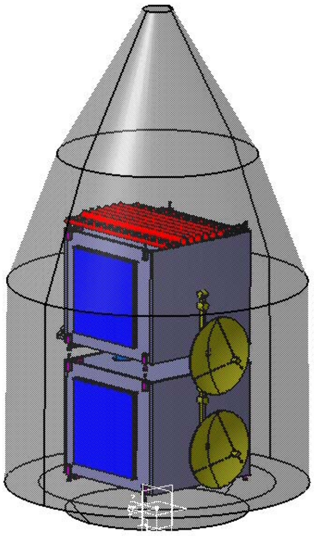
The Don Quijote mission is divided in four dedicated mission elements. There is the orbiter Sancho that carries the combined camera/TIR-imager, the IR spectrometer, the Penetrators/Surface elements (P/SE), and the seismic sources. The P/SE and the seismic sources (SS) are considered as separate elements, since they perform the "landing" and surface operation on the asteroid, which in itself is a complex "sub-mission" of Don Quijote. The P/SE carry a seismometer, an accelerometer, and a temperature sensor as scientific payload, whereas the seismic sources comprise merely an explosive charge and a timed detonator. The fourth element is Hidalgo, which serves solely as impactor and its main task is to hit the asteroid with a given accuracy and relative velocity.



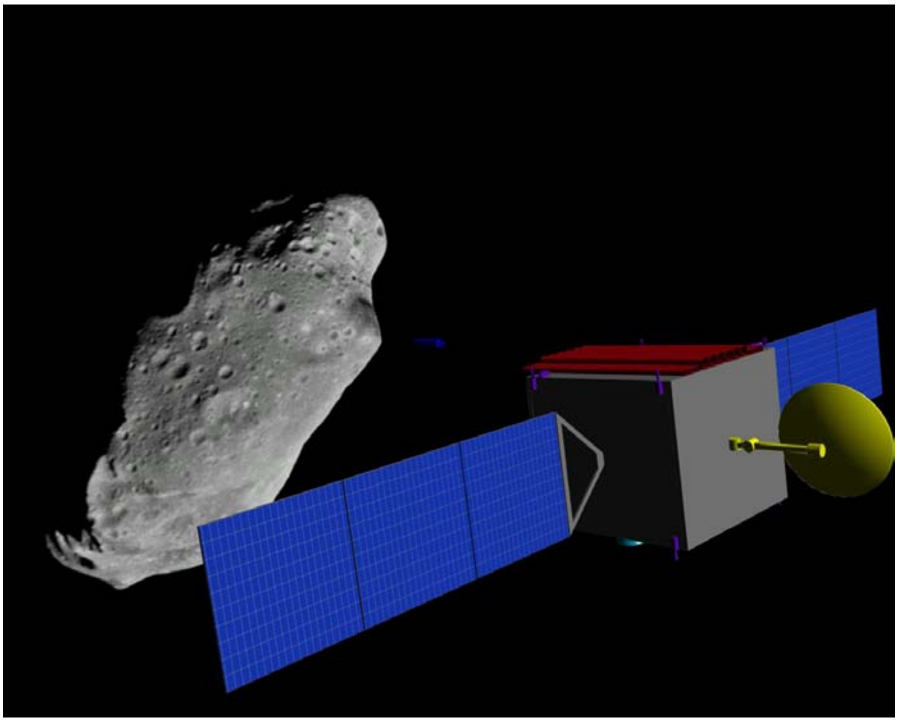
The S/C Sancho is carrying the scientific instruments and will arrive at the asteroid about 6 month before the impact of Hidalgo. While Sancho is orbiting the asteroid, the seismic network is deployed and different scientific measurements are conducted.



Configuration of Sancho S/C.



Launch configuration with Soyuz Fairing



Hidalgo will in principle be a rebuild of the Sancho S/C omitting the instruments, launch mechanisms for the penetrators and seismic sources, and probably the HGA. Due to the reduced power demand the electrical power system, and in particular the solar arrays, may also be reduced in size and mass. The same is true for the propulsion system. For Hidalgo no orbit capture is necessary. Therefore the orbit corrections can be done with thrust vectoring using the AOCS thrusters. Due to these changes, the Hidalgo S/C will be simpler than Sancho except the autonomy/FDIR concept, since it must perform the final targeting prior to the impact without substantial ground support and with a very high reliability.

4. THE INSTRUMENTS

Instrument	**Mass, kg**	**Power, W**	**remarks**
Sancho Orbiter			
Baseline Instruments			
Compact Camera + comp. TIR Imager	6.5	12	TIR: micro-bolometer array
IR Spectrometer	8.5	2 x 8	SIR type micro-bolometer based
Ka Transponder	3.5	9	BepiColombo design
Design Variation			
BepiColombo Camera	3.5	4	BepiColombo design
BepiColombo IR spectrometer	3	9	BepiColombo design (includes TIR)
Penetrator/Surface Elements			
Seismometer	0.2	TBD	Estimated
Accelerometer	0.06	TBD	Estimated
Thermo-Sensor	< 0.05	TBD	Estimated
Sensor electronics	< 0.25	0.6	Estimated

The main task for the camera is the imaging of the asteroid at high resolution when Sancho is in orbit around it. In addition, it will be used for navigational purposes during the far and close approach phases. In addition a TIR channel with a micro-bolometer array will be implemented. For the design variation the NAC/WAC design of BepiColombo is considered as possible instrument.

The IR-spectrometer is primarily used for the classification of the asteroid and a high diversity of the soil is not expected. Thus, the requirements with respect to spatial and spectral resolution are moderate. Therfore, a SIR-type micro-spectrometer was selected as baseline. For the design variation the IR spectrometer of BepiColombo was selected, which covers also the TIR region of the spectrum.

The Ka-Transponder is needed for the precise determination of the trajectory and its changes of the asteroid. As a starting assumption exactly the same instruments planned for BepiColombo might be used. Further analysis indicates that the main requirement on the knowledge of non gravitational perturbations can be met without an accelerometer, provided the spacecraft can be kept in a fixed attitude during the Radio Science mission phases. Moreover, the requirements on the range measurements can be met without using a dedicated wide band ranging system, like the one envisaged for BepiColombo. We shall assume performance of the Doppler measurements to be the same of BepiColombo, because they have already been demonstrated with the Cassini Radio Science experiment.

The seismometers and accelerometers carried by the penetrators are dedicated to the seismic experiments conducted in the course of the mission in order to determine the internal structure of the asteroid.

5. THE TEAM

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