Radio science investigations with the Proteus mission

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1. The Proteus mission

Proteus is a mission proposed in the framework of the NASA Discovery program dedicated to the exploration of Main Belt Comets (MBCs), a new class of volatile-rich bodies in the main asteroid belt. High precision isotopic measurements will be carried out using a state-of-the-art mass spectrometer to determine the relative abundances of key volatiles and shed light on the original formation of water and its delivery mechanisms towards the inner solar system.

N	Scientific Goals
1	Determine where MBC ices formed: the inner solar system, giant planet formation region or outer solar system.
2	Determine at what temperature the MBC ices formed, and whether they are pristine or evolved.
3	Determine whether MBCs have a nitrogen signature more like Earth or outer solar system values.
4	Determine MBC physical properties and information on surface composition and geomorphology as a basis for comparison between comets and asteroids.
5	Determine if the outgassing is from diffuse regions or specific sources and estimate the dust scattering properties.

Table 1. Proteus main scientific goals

2. Proteus radio science investigation

The Proteus radio science investigation (RSI) is a system level experiment crucial to the accomplishment of Science Goal 4 (see Table 1). Precise orbit determination of the spacecraft provides a direct measurement of the MBCs mass, which can be combined with detailed shape reconstruction to determine the bulk density of the target (strictly coupled with porosity and ice abundance). The corresponding key requirement for the RSI is to estimate the target mass, with a relative formal uncertainty below 10%, which allows for a minimum density uncertainty of 30%.

The ability to meet the gravity science objectives of the Proteus mission has been assessed by means of detailed numerical simulations using MONTE (NASA/JPL) code.

A covariance analysis was carried out using a multi-arc approach, comparing different geometric conditions and operating scenarios, in order to derive some operational requirements during early design phases.

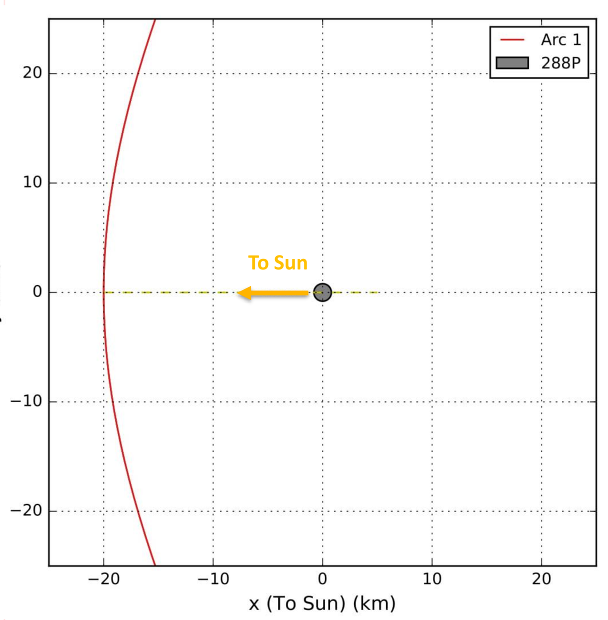

Figure 1. Proteus flyby geometry

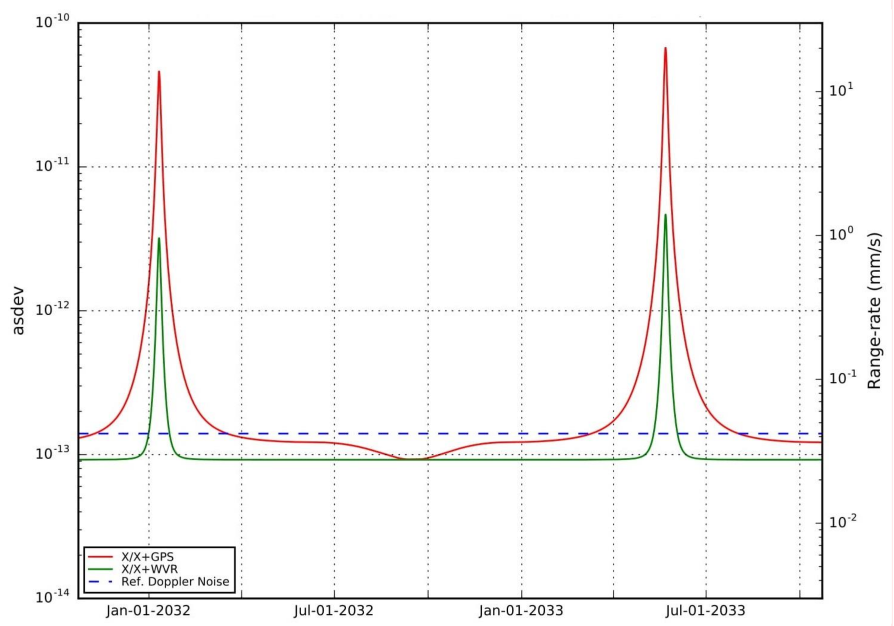

Figure 2. Proteus Doppler noise budget

3. Radio science expected performances

Two alternative mission profiles have been simulated for the rendezvous with the MBC 288P, according to the concept of operations shown in Table 2:

Mission phase	Date	Duration	Description
Arrival at 288P	01 March 2032	-	Rendezvous with MBC 288P
Flyby phase	06 August 2032	~2 weeks	Up to 3 hyperbolic flybys with closest C/A at 20 km
Orbital phase	04 September 2032	~6 weeks	Up to 12 polar orbits at a radius of 10 km with increasing β angle at 15° steps.
Departure	16 October 2032	-	

Table 2. Proteus main scientific goals

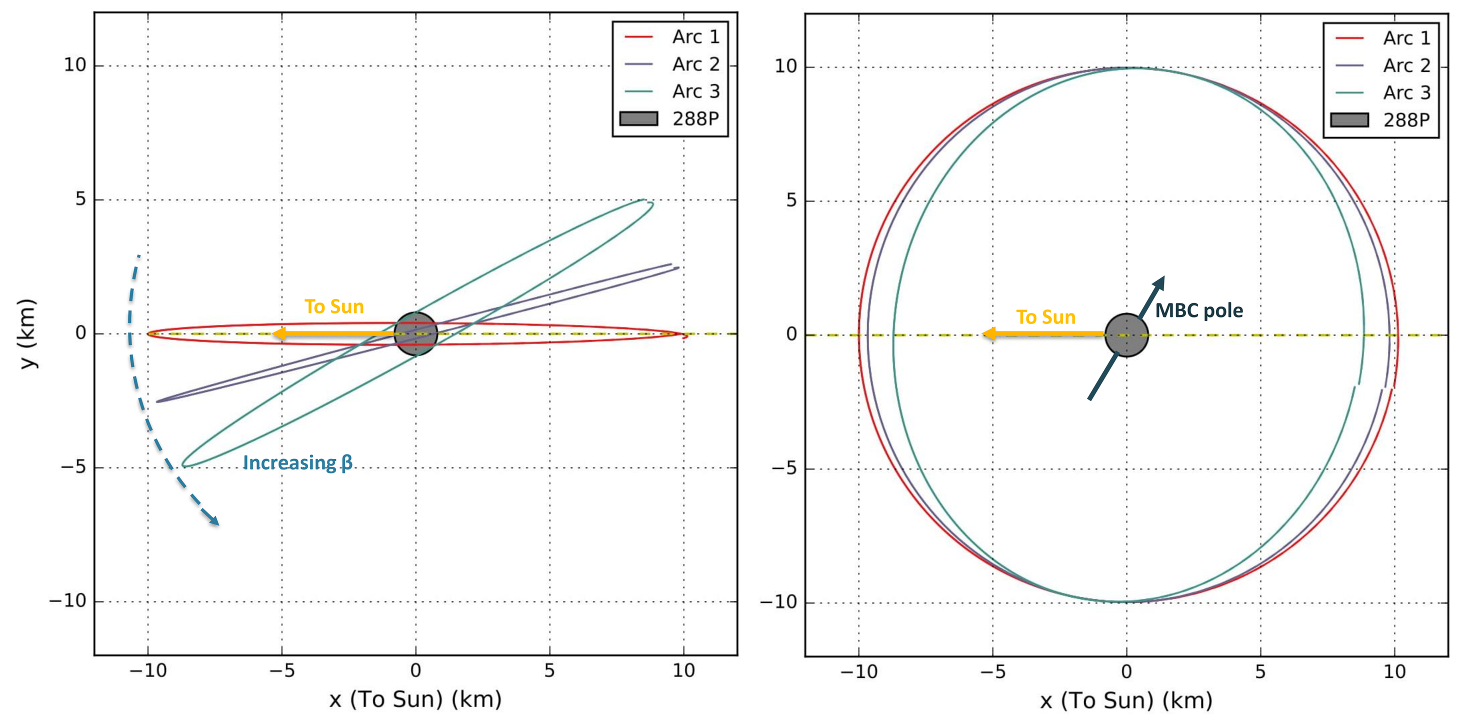

Figure 3. Proteus polar orbit geometry in the RTN reference frame. Top view (left) and side view (right)

Data selection

The main observables used in the analysis are:

- Two-way Doppler data (X/X) obtained from frequency shift of a highly stable microwave carrier between the spacecraft and the stations of NASA's Deep Space network (DSS-25, DSS-34 and DSS-55). A constant white noise of ~ 10 μm/s at 60 s integration times was applied as result of an accurate noise budget from the experience with Cassini Ka-band data [2] (see Figure 2).
- Sample and line coordinates of target surface landmarks taken from optical images of a nadir pointing camera. A constant noise of 2 pixels along each direction was applied, consistently with Rosetta data. Only coordinates of the landmark having a sun-target-probe angle of less than 90° were retained.

During the flyby phase, Doppler measurements were taken at the beginning and end of each arc and at closest approach (C/A), while optical images were collected with a 30 minute frequency during the rest of the arc (see Figure 4).

A similar approach was used for the orbital phase, this time foreseeing three 8h downlink sessions equally distributed along the arc.

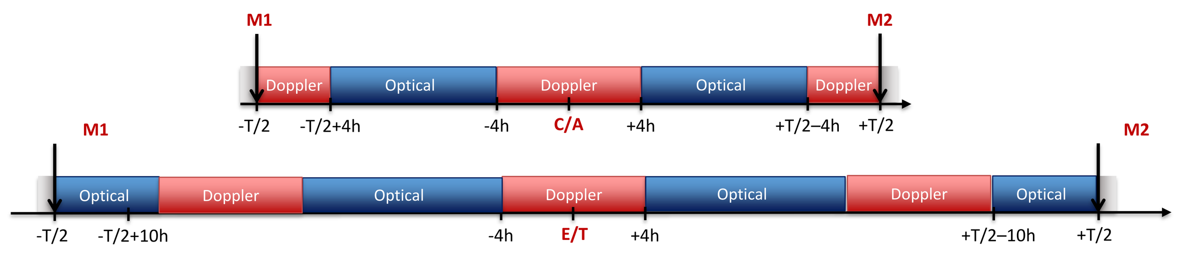

Figure 4. Observation collection scheme

Dynamical model

The dynamical model used in the simulations includes:

- Point mass gravity from the Sun and all solar system planets.
- Full degree 10 gravitational harmonics of 288P primary, obtained assuming uniform density and a scaled polyhedral shape model from comet Tempel-1.
- Non gravitational accelerations (NGA) due to solar radiation pressure and comet outgassing. In particular, NGA from outgassing was assumed to act mostly in the radial direction and was modelled using a constant a-priori uncertainty for the orbital phase and a stochastic one for the flybys

4. Preliminary Results

Figure 5 shows the estimated formal uncertainties for the GM of 288P as a function of the number of arcs dedicated to radio science. These results already include a safety factor of 10 to account for simplified dynamical modeling (in particular due to outgassing) and other unaccounted factors such as momentum dumping and orbit correction maneuvers.

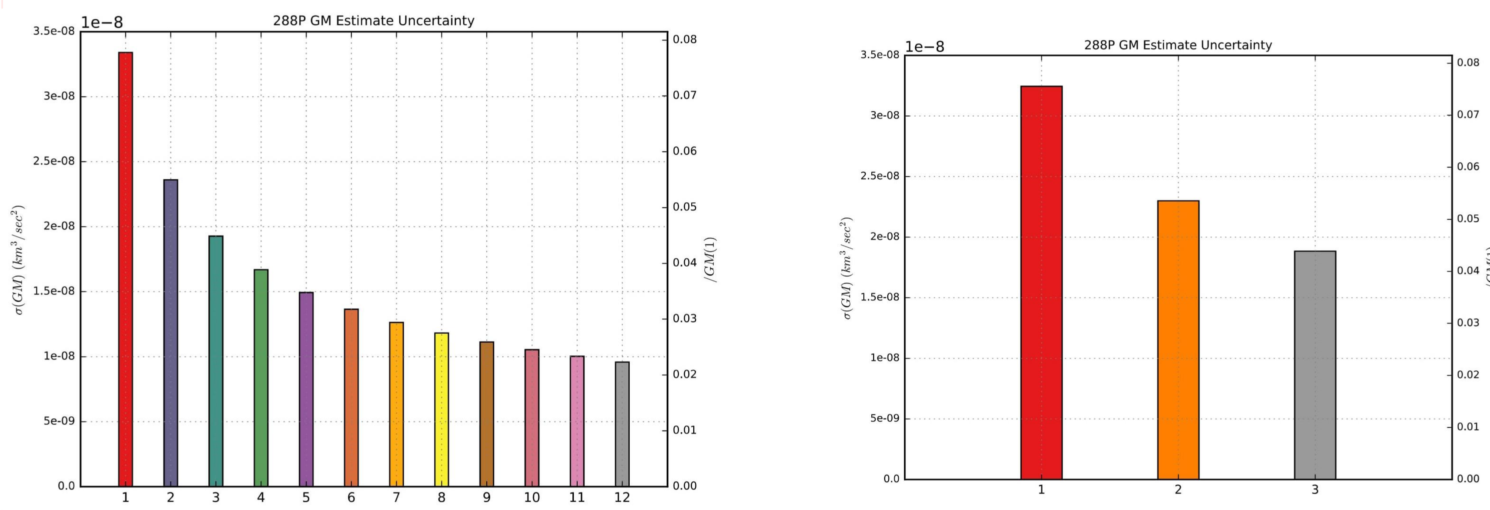

Figure 5. GM formal uncertainties for the flyby (right) and orbital (left) scenarios.

5. Conclusions & Future Work

Our results show that the target accuracy requirements for the GM estimation are satisfied after a single arc for both the flyby and orbital mission scenarios, with relative formal uncertainties of roughly 7.5%. The introduction of additional arcs allows for a significant improvement of the accuracy and puts an additional constraint on a number of other dynamical parameters of scientific interest, including the extended gravity field and the rotational state.

Future work will focus on the introduction of more complex dyncamical models for the non-gravitational accelerations.

References

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