Exploring the Uranian system with the Uranus Orbiter & Probe Radio Science experiment: expected performance and possible enhancements

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I - A flagship mission to the Uranian system

The Uranus Orbiter and Probe (UOP) has been prioritized as the **next flagship-class mission** by the 2023-2032 Planetary Science and Astrobiology Decadal Survey [1]

In order to investigate fundamental questions regarding Uranus, its rings, and moons, the UOP spacecraft will be equipped with a suite of scientific instruments still to be defined, but including a radio telecom system that we can use for **Radio-Science (RS) experiments** [2]

The current design foresees a 3.1-m High-Gain Antenna (HGA) and UltraStable Oscillator (USO) onboard the UOP spacecraft [2]

The objectives of this experiment for the large satellites of Uranus, namely **Miranda, Ariel, Umbriel, Titania and Oberon**, are to [2]:

- **constrain their internal structures and rock-to-ice ratios**
- **find out which ones possess substantial internal heat sources or possible oceans**

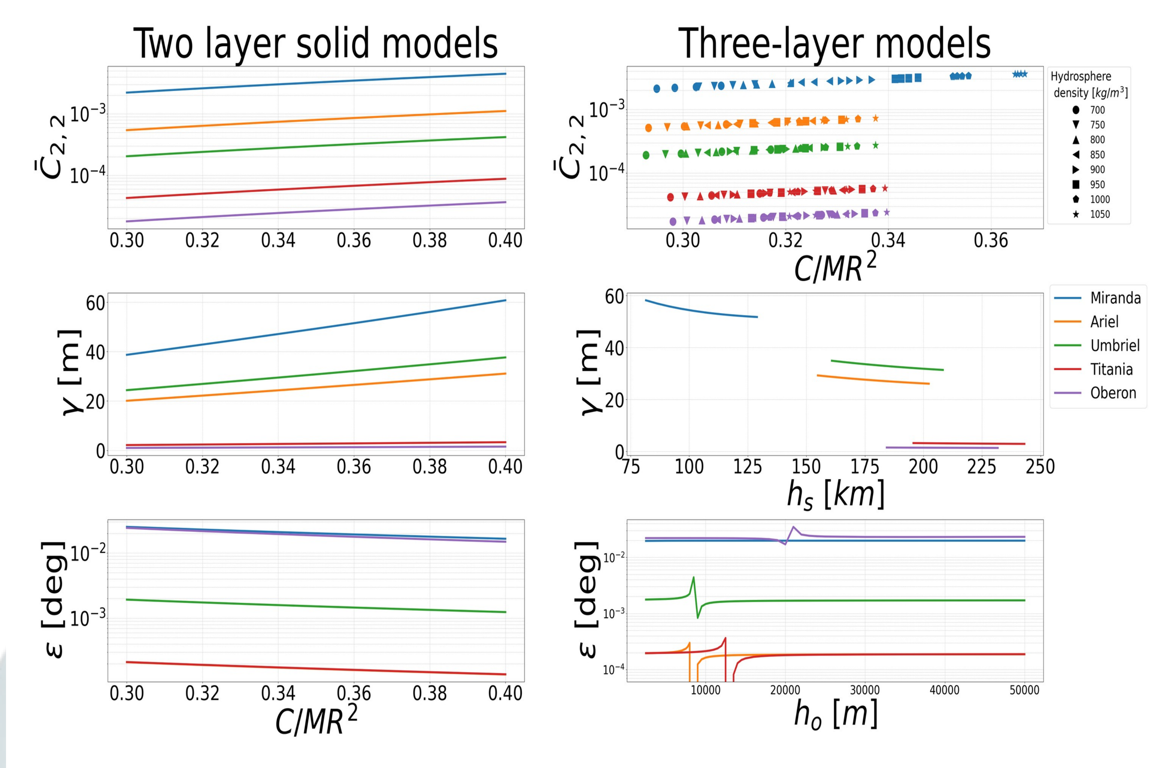
II – Interior modeling and target observables

Libration amplitude (γ) and **obliquity** (ε) are two target geodesy observables, that are directly influenced by the **interior structure.**

Developing from [3], [4], and [5], we model the moons as **two layer solid bodies (ice mantle + rock core)** and we calculate the J_2 and $C_{2,2}$ values as a function of the normalized polar moment of inertia C/MR^2 assuming hydrostatic equilibrium and using Radau's equation. We then estimate the expected libration amplitude and obliquity for the solid case.

We then replace the ice mantle by an « **hydrosphere** » (**ice shell + liquid ocean in contact with rock**) and consider realistic values for the water and rock densities, based on [5]. We vary the ocean thickness (up to 50 km) and investigate the shell's libration and obliquity signals as a function of the **shell (h_s) and ocean (h_o) thickness**, respectively.

We confirm and assume the same target levels as [5] for the measurements of the polar moment of inertia



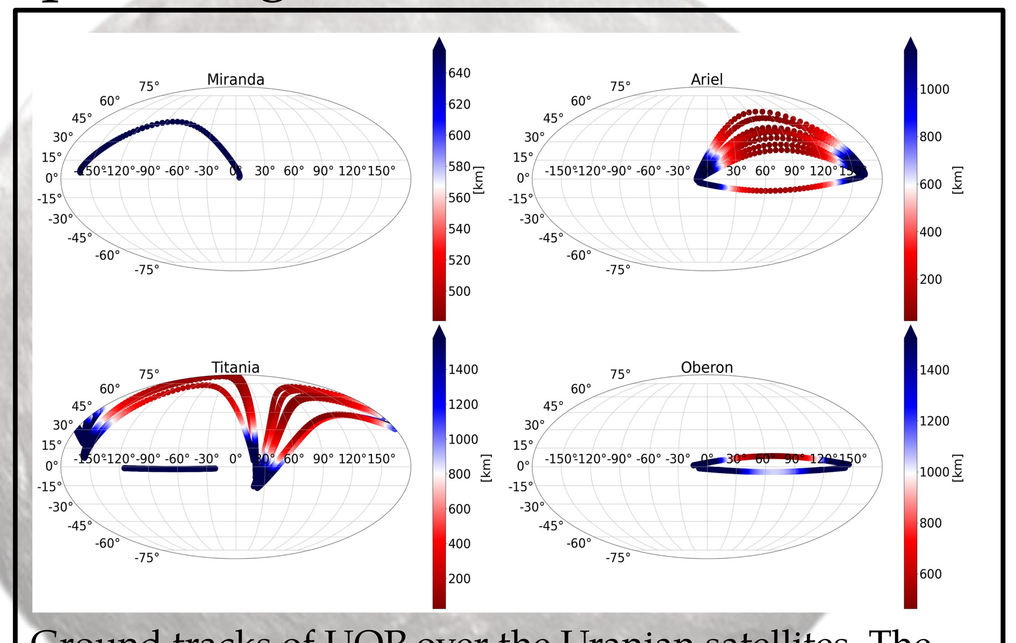
III – Nominal Tour

The nominal UOP tour is characterized by two phases, the **equatorialization phase** immediately following Uranus Orbit Insertion (UOI) and the equatorial science phase, for a total science mission of 4.5 years.

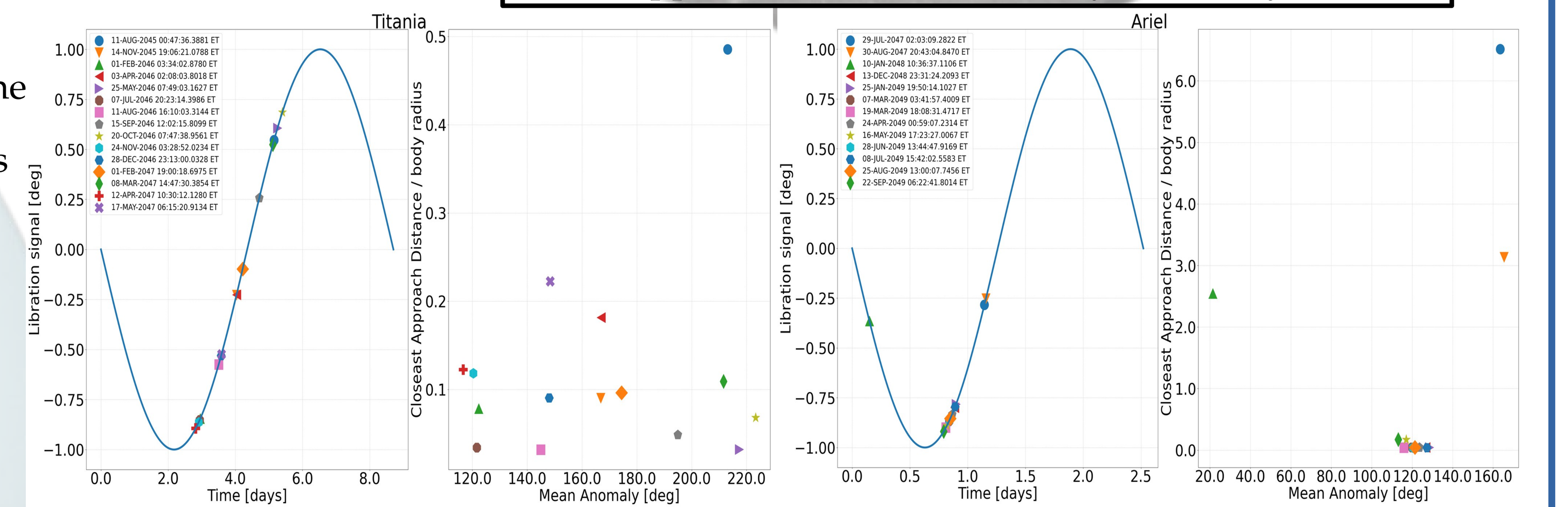
34 flybys of the satellites: **14 for Ariel, 16 for Titania, 2 for Oberon, 1 for Umbriel and Miranda.**

The tour design strategy is highly flexible, with different options available depending on which moon is used for equatorialization: the current tour uses Titania.

Incomplete sampling of the mean anomaly of the moons, limiting the sensitivity to signals at the orbital frequency, such as tides and librations.



Ground tracks of UOP over the Uranian satellites. The equatorial flyby of Umbriel is not shown because the closest approach is more then 6 body radii away.



IV – Covariance analysis

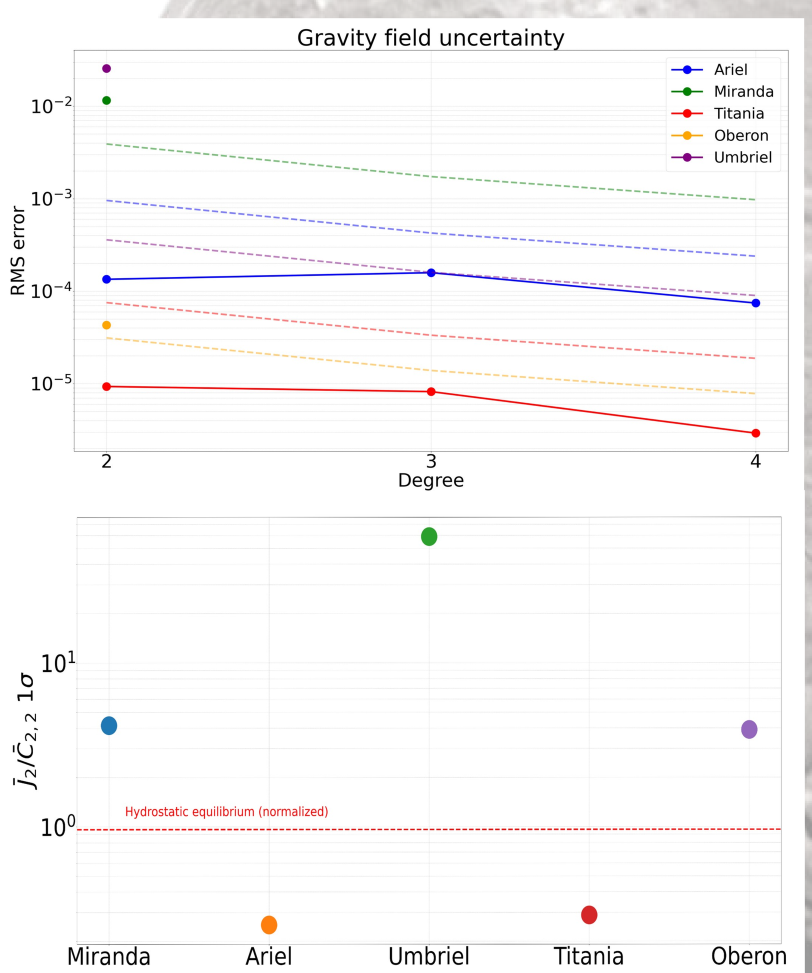
Assessment of the **precision of geodetic parameters** estimate of the moons (listed in Table):

- For Ariel and Titania, we fit also the k2 and the gravity coefficients up to degree 4
- only degree 2 for the others

Numerical simulations using the **JPL orbit determination software MONTE** [6]:

- 8h Doppler tracking
- direct-to-Earth radio links
- X/X band (noise 0.1 mm/s@60s)

Estimated parameter	apriori
State	$1\ km,\ 1m/s$
GM	$100\ km^3\ sec^{-2}$
α	$5e\text{-}2\ deg$
δ	$5e\text{-}2\ deg$
$\dot{\phi}$	$1e\text{-}7\ deg/day$
k_2	10
J_l	1
$C_{l,m}$	1
$S_{l,m}$	1

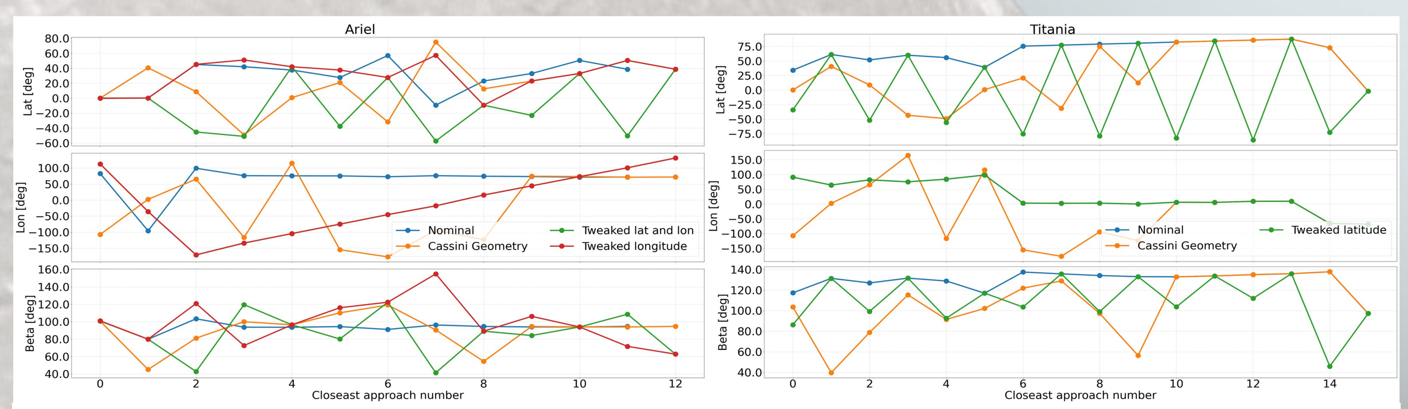


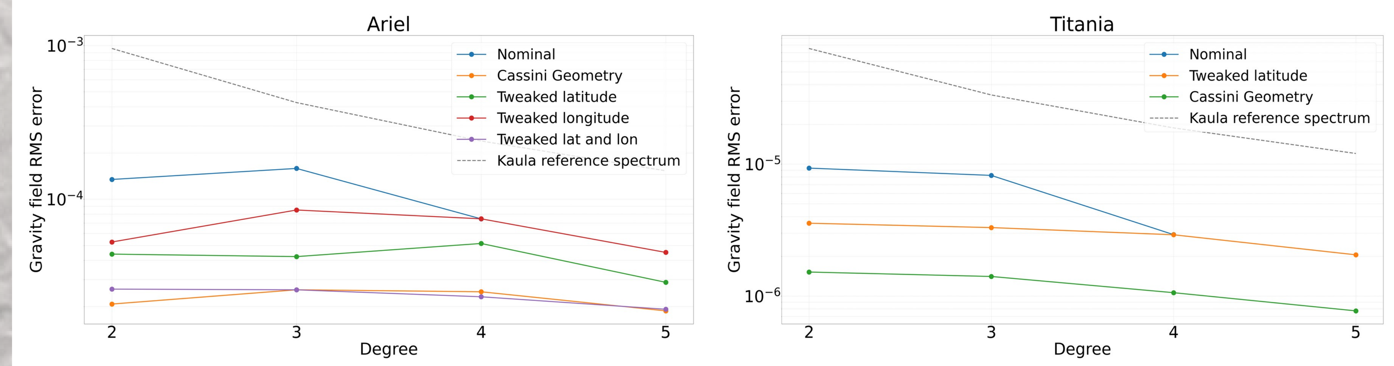
V – Tour Tweaks

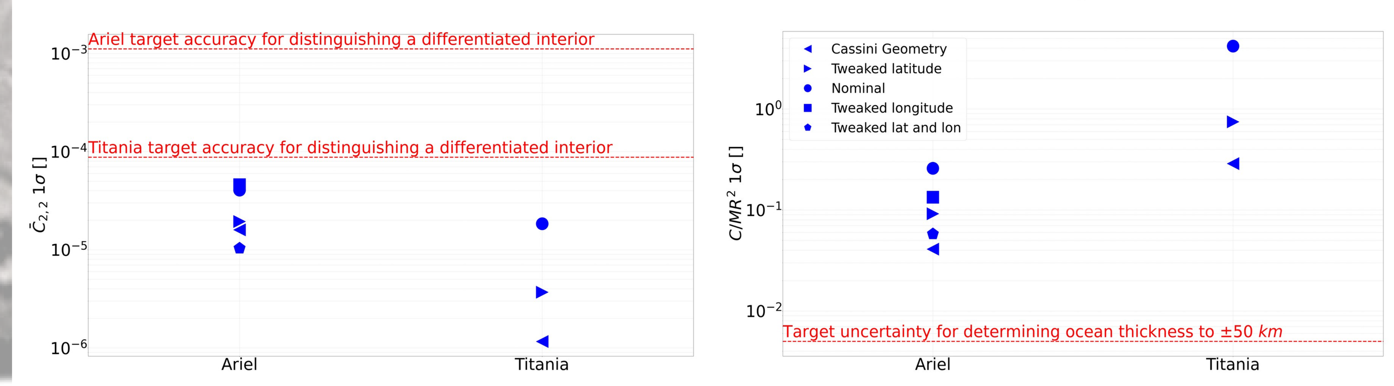
Nominal orbit:

- flybys of **Titania** are all concentrated in the **northern hemisphere** with closest approaches (CA) at **high latitudes**
- **Ariel** flybys are all (but one) in the **North-East hemisphere** with CAs at **mid-latitude**
- **Titania** orbit is close to **face-on** (β=90°)

We tweak the orbit geometry **to improve spatial coverage and science return**: we slightly change the latitudes and longitudes of the current CAs and we test Cassini geometries during Titan flybys







VI – Libration and obliquity

We investigate also the expected uncertainty on the **measurements of the libration amplitude and obliquity**

Radiometric data have small sensitivity to rotation parameter especially during flybys.

We simulate **optical data** using the Janus camera model [6] and combine them with radiometric data in the covariance analysis using the **Landmark tracking** technique.

Nominal measurement strategy:

- **4 images per flyby**, 2 ingress and 2 egress every 5 minutes around CA
- **noise level equal to 1 pixel**
- **50 landmarks** randomly spread over the surface
- control point coordinates, camera position and orientation assumed as well known

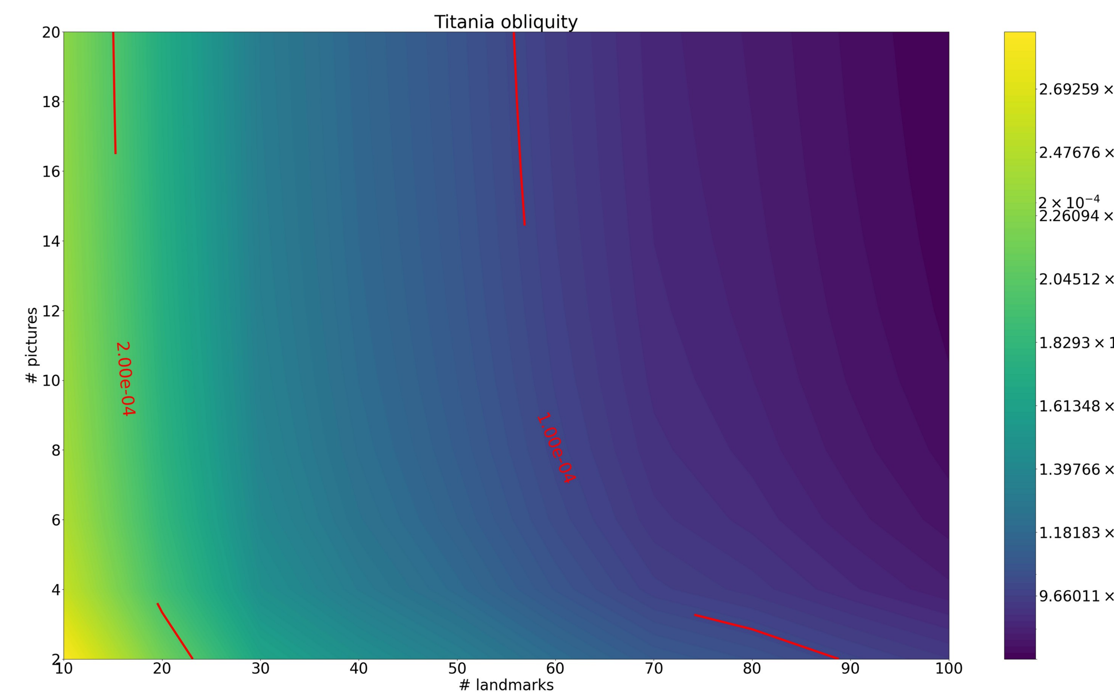
Ariel

Case	Libration 1σ [km]	Obliquity 1σ [deg]
Radio	1773.44	4.86e-02
Radio+Optical	1767.62	3.76e-04

Titania

Case	Libration 1σ [km]	Obliquity 1σ [deg]
Radio	736.51	4.83e-02
Radio+Optical	733.12	1.19e-04

Simulated scenarios and formal uncertainties (1σ) of the target parameters.



VII – Conclusion

We have performed a **covariance analysis** to evaluate the ability of the RS experiment on board the UOP mission to meet the scientific requirements of the mission

- The **current nominal tour** will flyby Ariel and Titania 14 and 16 times, respectively, but **will not provide complete coverage of the signal at the orbital frequency**
- Given the limited number of flybys **for Umbriel, Oberon and Miranda, the hydrostatic constraint must be applied** to measure the mean moment of inertia
- The **complete gravity field up to degree 4 of Ariel and Titania** can be estimated by the nominal tour, **but with better coverage**, the gravity field can be estimated up to **degree 5**
- The determination of the $C_{2,2}$ coefficients of **Ariel and Titania** with the nominal tour is already **precise enough to distinguish between a differentiated and an undifferentiated interior**
- Neither the nominal nor the analyzed tweaked tours allow to determine the polar moment of inertia with an accuracy that allows to determine the hydrosphere thickness no better than $\pm$50 km [5]
- **We have no sensitivity to the K_2 Love number**, not unexpected for a flyby mission although future design optimization with a better spatial and temporal coverage may bring improvements (e.g., Europa Clipper)
- **Optical data do not help to determine the librations, but allow to measure the obliquity at signal level for both Ariel and Titania**. Increasing the number of images and landmarks will allow us to determine the obliquity with up to 100% better accuracy.

References

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