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Sensitivity of Triton gravity field of different radio science experiment configurations

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The ideal conditions for RS measurements require an optimization of the communications and tracking systems, the spacecraft trajectories and mission operations for RS investigation. However, these ideal conditions are rarely achieved because of the several trades off that should be made with many other mission and science requirements. This is particularly true for missions in the Neptune system where the identified scientific goals are broad and varied.

The exploration of Triton has been always identified as a key science goal for such a mission. In fact, Neptune's largest moon Triton is presumably one of the ocean worlds in the outer solar system. With its own atmosphere, active geology, plumes of nitrogen gas and dust entrained deposited up to 150 km downwind, Triton intrigues planetary scientists, who proclaimed it as key 'ocean world' for future exploration [1]. According to space agencies' long term plans (e.g. the US decadal surveys in planetary science, the ESA Cosmic Vision 2 and Voyage 2050 programs), Triton will certainly be visited by the end of the 21st century as also recommended by the radio-science (RS) community which declared Triton's liquid layer investigation a "key RS goal" [2]. As a result of the general enthusiasm for Triton and similar icy moons of the outer solar system, several mission concepts have recently been proposed, all within the 2029–2035 time frame (e.g. [3-8]).

According to the mission designs proposed in literature, most of the time Neptune is identified as the main target, but fly-bys of Triton will provide in-situ measurements whether there will be just one as Voyager 2 did and the TRIDENT team proposed [9], or multiple fly-bys by leveraging particular Neptune centric orbit (periodic and quasi-synchronous orbits) as Cassini did in the Saturn system or the as the "Triton tour" proposed by the Neptune Odyssey mission concept [10].

We focus on gravity science, i.e. the study of gravitational field with the purpose of inferring planetary properties such as bulk mass, mass/density distribution, internal density gradients, and interior structures and composition. In fact, radio tracking observations of changes in the velocity vectors of a spacecraft as it flies near Triton can be used to define the gravitational field.

We perform a sensitivity study in order to asses the expected precision of the gravity recovery of a combination of different onboard instrumentation, trajectory geometries and radio science experiment configurations. In particular, we perform a covariance analysis in order to determine how the precision in the estimated parameter depend upon the various characteristics of an RS campaign, including:

- Orbit geometry
- Measurement accuracy/data quality (Doppler noise)
- Nongravitational forces
- Arc length
- Mission duration

As an example of the proposed discussion, in Fig.1 we investigated the impact of different orbit geometries: we perform a covariance analysis on several fly-by geometries (see Fig.2), simulating Doppler tracking data performed with an onboard coherent X-band transponder and an High Gain Antenna (accuracy of 0.1mm/s at 60s integration time) over an 8h long arc. We modeled the gravity field the as a spherical harmonic expansion characterized by the $C_{l,m}$, $S_{l,m}$ coefficients [11]. Since the spherical harmonics of Triton have never been measured, we used the Kaula power law in order to have an estimation of the power spectrum of the gravity field. Given the Doppler geometry configuration and relative position between Triton and the Earth in January 2030, we see that the $C_{2,1}$ and $S_{2,1}$ will be better determined if the spacecraft has an highly inclined orbit, whereas the estimation of $C_{2,2}$ and $S_{2,2}$ has a low uncertainty with slightly inclined orbits.

Similar sensitivity analyses will be discussed over a wide range of mission scenarios, that is with different values for the aforementioned RS settings. The end goal of this study is to provide not only the optimal combination of these settings, but a complete parametric study that will help the design of a future mission to Triton.

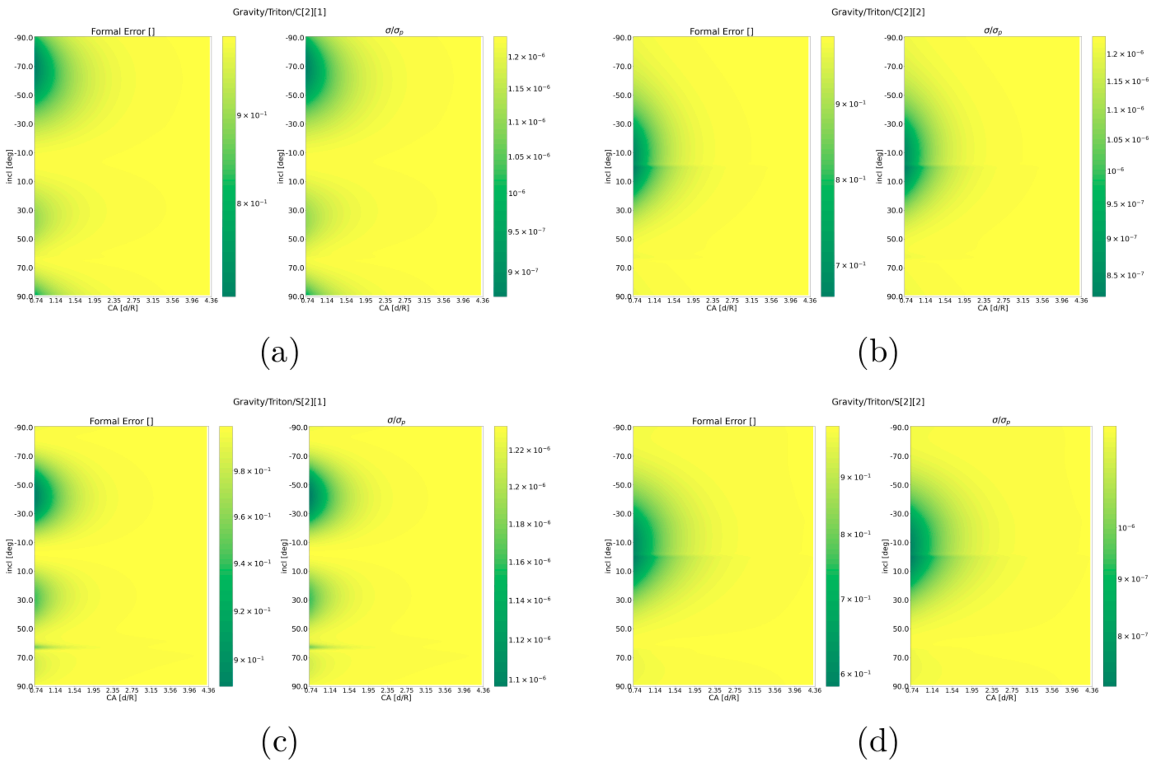
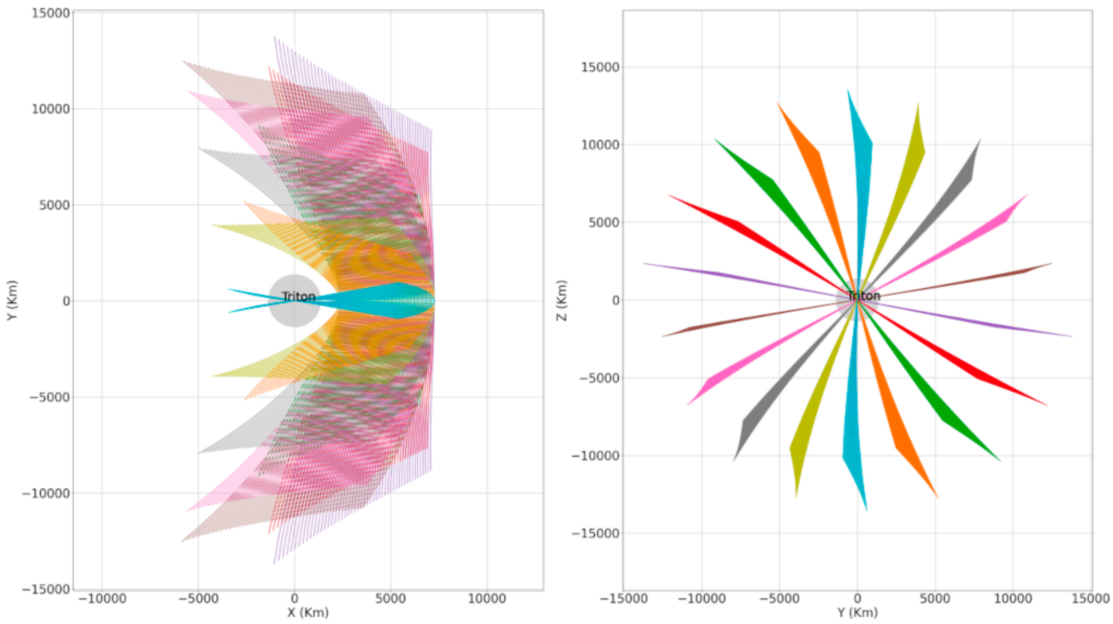
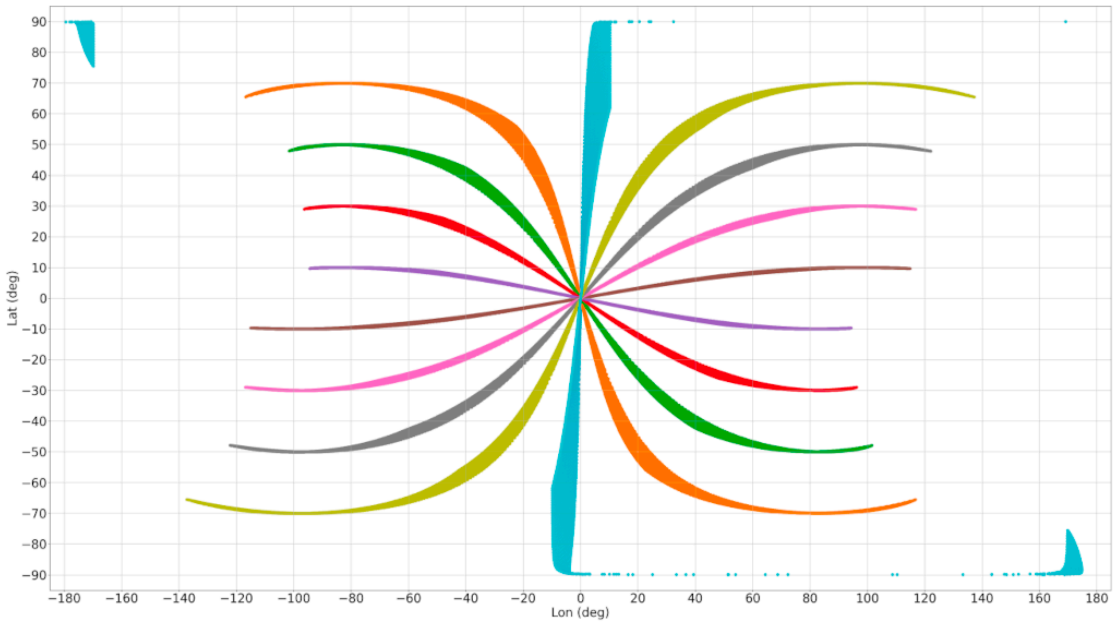


Figure 1: Formal error of the spherical harmonics gravity field quadrupole coefficients. The power spectrum of the gravity field has been calculated following the Kaula rule [11]. In the x axis, the closest approach distance d is scaled by the radius of Triton $R = 1352.6\ km$.



(a)



(b)

Figure 2: (a) Family of fly-by trajectories used in the covariance analysis in the X-Y and Y-Z plane w.r.t. Triton's inertial reference frame. The closest approach distance varies between $[1000km : 4 * R]$ where R is the radius of Triton $R = 1352.6\ km$. (b) Ground tracks of the analyzed trajectories.

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