Virtual Research Presentation Conference

An Innovative Study on Planetary Ring Mass: Determining the Radial Profile And Temporal Variations Using the Ring Skimmer Trajectory

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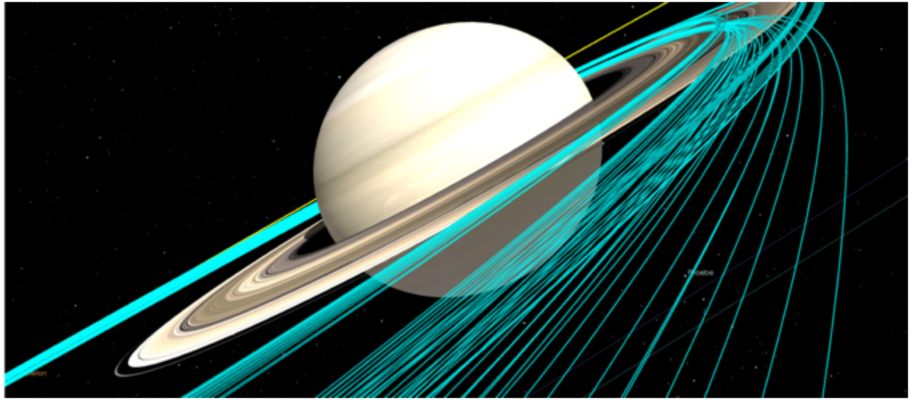
Tutorial Introduction

Abstract

We present an in-depth feasibility study of innovative gravity science measurements at planetary ring systems of outer planets, enabled by the novel Ring Skimmer mission concept [1]. The unique characteristics of the trajectory design allow to graze repeatedly different regions of equatorial, concentric rings, obtaining observations during tens of passes.

These very close observations of the rings enable the determination of the mass density distribution of the rings with great accuracy, as a function of the radial distance from the planet.

Image credit: Vaquero et al., 2019 [1]



The Saturnian inner system is a natural laboratory for studying this novel class of observations. We assess the feasibility of such measurements for two scenarios characterized by different trajectory design, including: altitude over the ring system, visibility of the spacecraft from NASA's Deep Space Network stations, proximity to Saturn, occultation events and number of passes.

Problem Description

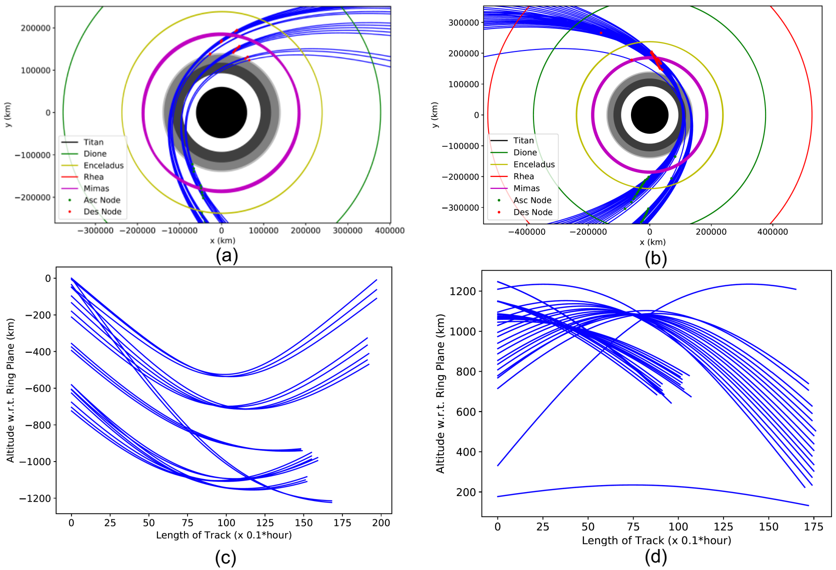
a) **Context**. The emergence of planetary seismology in the last decade has highlighted the interconnection between the interior structure of planets, the presence or absence of rings and the dynamics of inner moons. The study of planetary ring systems provide us with clues on the condition of formation for icy moons and disks alike. One of the key aspects is the measure of the mass density distribution with the required accuracy as a function of the radial distance from the planet, which is crucial to the understanding of mass transportation within the system and formation and evolution of icy moons.

b) **State of the Art**. The Cassini mission provided us with numerous and unprecedented ring observations. Throughout its mission, the spacecraft observed gravity and density waves rippling through the rings in connection to Saturn's seismic events, through its onboard imaging instrument. Such observations have been related to extremely accurate surface density measurements at specific locations in the A, B and C rings [2][3][4]. These density measurements were dependent on assumptions on the ring opacity. As a result, the observations were extremely localized and did not provide a continuous profile of the continuous radial density distribution. During the Cassini Grand Finale, the spacecraft performed the first independent measurement of the total mass of the rings [5], with a relative 1σ uncertainty of about 0.32. As opposed to the density wave observations, gravity measurements provided a global measurement of the ring mass but lacked the necessary level of detail for providing a radial map of the ring density.

c) **Relevance to NASA and JPL**. The Cassini mission has provided us with an unprecedented knowledge of the Saturnian system. However, the great discoveries also opened a new class of scientific questions, that can only be addressed by continuing the exploration of the gas giant and its inner system. The relevance of this study resides in the assessment of its feasibility. Also, the results obtained from this analysis can be easily applied to the study of the remaining ring systems in the Solar System.

Methodology

We consider two different scenarios for the orbital geometry. In Scenario 1 (left), the spacecraft flies over the rings and the planet 21 times (8 months), sweeping the different regions of the rings within 3-5 hours, with low relative velocities. The spacecraft altitude over the ring plane reaches minima well below 100 km. In Scenario 2 (right), the number of overflights increases to 32 (11 months), but the spacecraft altitude over the ring plane is higher on average, with minimum values around 200 km.



(a) (b) (c) (d)

An orbiting spacecraft maintains an almost continuous radio links with ground stations of NASA’s DSN. In our simulations we consider the spacecraft to be equipped with X- and Ka-band translators [6]. The main simulated observable is the two-way spacecraft range-rate, which can be measured with accuracies of about 5 to 10 micron/s each way [7].

Once the spacecraft Doppler tracking has been simulated for all passes the range-rate measurements are combined in a multiarc, least-square filter for the estimation of parameters of interest (such as the mass of the rings).

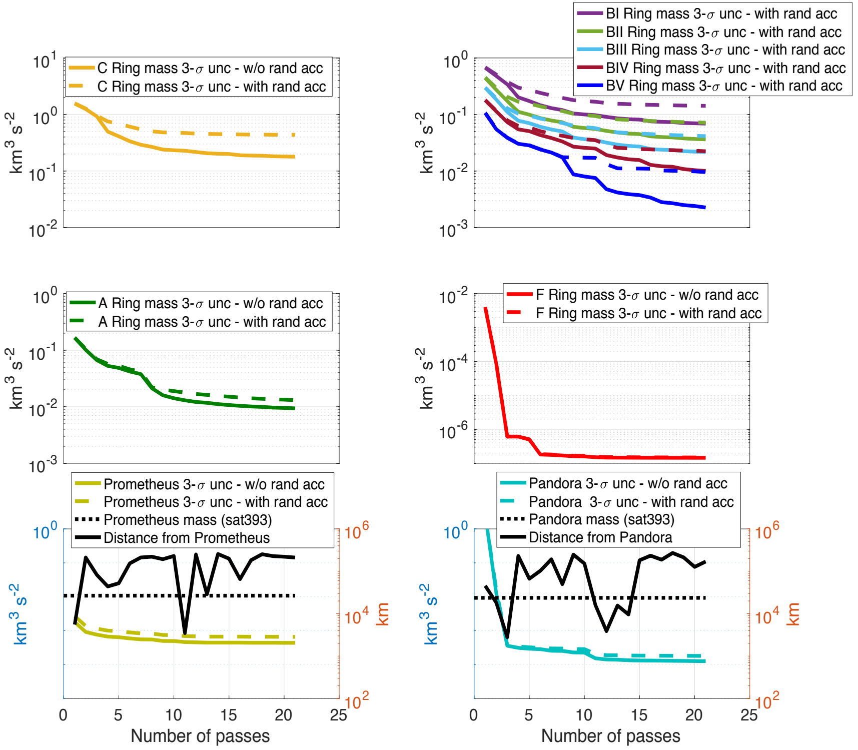
Results (1)

In this study we take into account the potential asymmetry of Saturn's gravity field by introducing constant random accelerations into the dynamical model for the Ring Skimmer mission.

<u>Scenario 1</u>. The results are shown in the plot for a solution without empirical accelerations (solid lines) versus solutions that include them (dashed lines). The spacecraft happens to be closer to the ring plane while flying over the outer edges of the rings.

The C ring is the farthest from the spacecraft during the flybys. Our simulations show a predicted formal uncertainty (3**σ**) of about $2{\cdot}10^{-1}$ km^3s^{-2} at the end of the 21 passes (the mass of Mimas is roughly 2.5 km^3s^{-2}), which is degraded by a factor of 2.5 with the use of random accelerations.

As we move away from the center of the planet, the spacecraft is bound to fly closer to the ring plane. The masses of the separate B ring regions are determined with uncertainties between $7{\cdot}10^{-2}$ and $3{\cdot}10^{-3}$ km^3s^{-2} (degraded by a factor of 3 with accelerations). The results are outstanding for the mass of the F ring, located at the outer edge of the system and only 500 km wide. The 3**σ** uncertainty is as low as $2{\cdot}10^{-7}$ km^3s^{-2}, which allows for an extremely detailed mapping of the radial density distribution of this region.

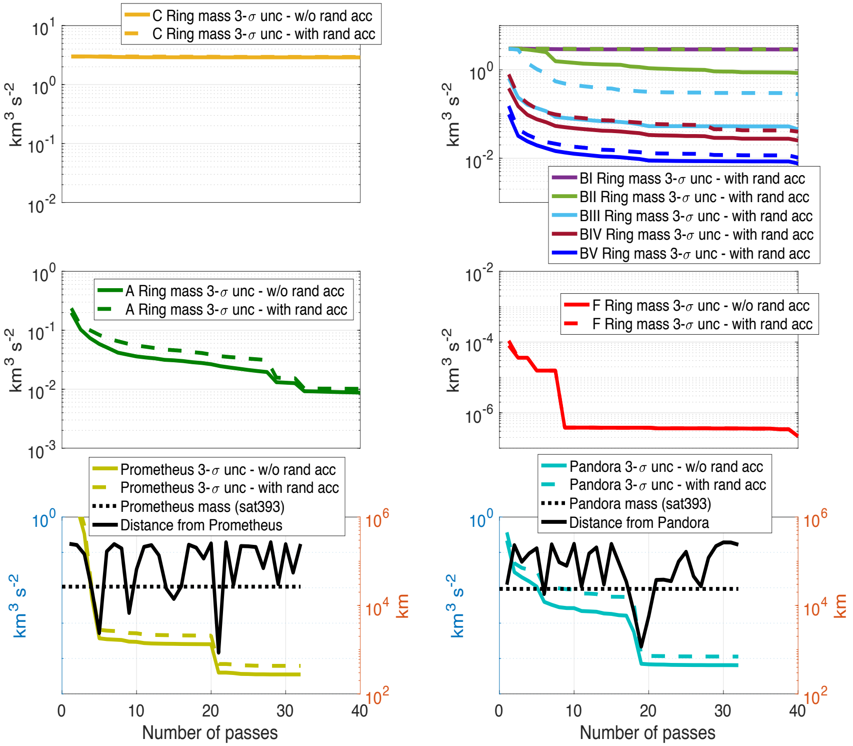


Results (2)

Scenario 2. The trajectory design provides a larger number of ring overflights (32), at higher altitude. The scope of analyzing this second case is to study the trade-off between number of passes and altitude. In general, the results in the plot show that the altitude over the ring plane and the number of flybys both play an important role in the estimation process, and the optimal combination is chosen considering these two balancing effects.

For example, in the case of the determination of the mass of the C ring, one can see that the average altitude over this region went from about 600 km in Scenario 1 to about 1,000 km in Scenario 2. As a result, this parameter is undetermined under the premises of the second scenario. On the other hand, the results pertaining the masses of the A and F ring do not change remarkedly between the two scenarios, suggesting that 10 to 15 passes could potentially be enough to determine these parameters with the desired accuracy.

Conclusion and next step: The Ring Skimmer trajectory has the potential to carry an innovative onboard gravity experiment for the determination of ring masses with unprecedented accuracy. The next step requires an in-depth study of the parameter space for the optimization of the science return.



Publications and References

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