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Abstract: The innovative Saturn Ring Skimmer mission concept will observe individual ring particles for the first time, will directly measure the magnetosphere in the region where it is shaped by the rings, and will directly measure the atmosphere of a disk. A broad look at how the rings, the magnetosphere, the upper atmosphere, and the planetary interior compose a coherent interconnected system will enable understanding of a whole class of exoplanets. Spatial mapping and time-domain science will elucidate mysteries uncovered by the Cassini mission**.**

We advocate for the New Frontiers list to include an entry that addresses these science objectives.

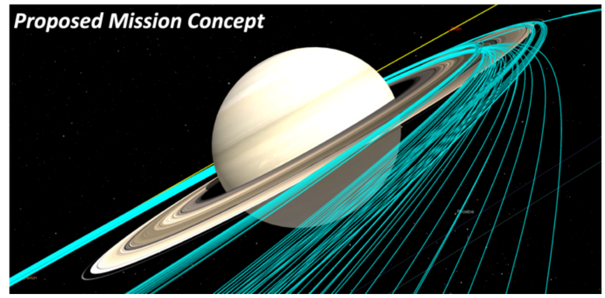

Figure 1. Using an innovative trajectory design [1], the Saturn Ring Skimmer would ***repeatedly pass across the face of the rings at altitudes of a few hundred km.***

Introduction: As always happens with groundbreaking science, the answers provided by the enormously successful Cassini mission revealed a whole new suite of pressing scientific questions. The Saturn Ring Skimmer addresses these new questions with an integrated multi-disciplinary set of Science Themes.

The Saturn Ring Skimmer mission concept uses an innovative trajectory design [1] to ***explore the inner Saturn system with a proximity and frequency that were previously thought to be impossible with current technology and feasible costs.***

The Ring Skimmer approaches ~100x closer to Saturn's rings than Cassini was when the best ring images to date were taken; enables *in situ* observations immediately above and below the ring plane, as well as close-range observations of Saturn's atmosphere, magnetosphere and gravitational fields; and does so with a frequency and longevity that enable both spatial mapping and time-domain science.

Our science team has identified the themes and objectives identified below, which we propose can be answered with the following core investigations:

IMG = Imaging	PW = Plasma Wave
MS = Mass Spectrometer	MAG = Magnetometer
DD = Dust Detector	GS = Gravity Science

Science Theme #1: What processes shape particle-rich astrophysical disks? Saturn's rings comprise a natural laboratory, our only easily accessible analogue for debris disks and other particle-rich disks. Cassini never had the resolution to directly detect typical individual ring particles (which are millimeters to meters across, while the main rings span 300,000 km), and doing so likely holds the key to understanding many of Cassini's most enigmatic discoveries [2]. Furthermore, since analogous processes probably occurred in protoplanetary disks like the one that gave rise to our solar system, more detailed information about these particle-level dynamics would allow us to better understand our own origins.

- **Objective 1-1:** Measure particle size distribution in diverse parts of Saturn's rings (IMG).
- **Objective 1-2:** Measure the properties (size, shape, density, color) of individual ring particles at various locations in Saturn's rings (IMG).
- **Objective 1-3:** Measure clumping at various scales in different regions of Saturn's rings (IMG).
- **Objective 1-4:** Observe propeller objects and their interactions with surrounding ring material (IMG).
- **Objective 1-5:** Characterize the steady-state atmosphere of Saturn's rings (MS).
- **Objective 1-6:** Characterize the radial mass distribution of Saturn's rings (GS).
- **Objective 1-7:** Characterize ring-moon shapes and surfaces at very close range (IMG)

Science Theme #2: What are the origins and fate of Saturn's rings? Measurements made during Cassini's Grand Finale revealed a surprisingly high flux of material into Saturn. Steady-state interpretation of these fluxes implies that Saturn's rings are young and/or short-lived, but we lack a clear picture of the total mass and composition of the material being transported across the rings and into the planet, nor do we understand its spatial and temporal variations.

Furthermore, the equatorial mass flux has a surprisingly low water fraction [3], which points to a fractionation process by which non-water constituents are preferentially removed from rings. Such a "self-cleaning" mechanism [4], combined with possible influx of water-rich material from Enceladus, may complicate the conclusion that the measured low mass of the rings [5] points to a relatively young age.

- **Objective 2-1:** Constrain time variability, spatial variability, and average value of the mass transfer between the rings and Saturn (MS, DD).
- **Objective 2-2:** Constrain composition of the ring reddening material for comparison to primitive sources such as cometary/asteroidal impactors, and evolved sources such as organics at Titan and Enceladus (MS, DD).
- **Objective 2-3:** Measure impact flux into rings and properties of impact ejecta clouds (IMG, MS, DD).
- **Objective 2-4:** Observe secular radial evolution of ring material (IMG).
- **Objective 2-5:** Measure water vapor fraction produced from impacts relative to ejected mass (MS).

Science Theme #3: How do planets and magnetospheres co-evolve with their rings? Saturn's rings are the only broad dense disk in our solar system, but many exoplanets may have similar ring systems [6]. Many of the unique aspects of Saturn's magnetosphere, atmosphere, and interior are likely connected to the ring system's influence [7,8], and the best way to confirm and understand that influence is to directly explore the interface region between the rings and the rest of the system.

- **Objective 3-1:** Determine the rate and mechanism of material transport between the rings and the upper atmosphere of Saturn (MS, DD).
- **Objective 3-2:** Determine the nature of electromagnetic coupling between Saturn and the rings (PW, MAG).
- **Objective 3-3:** Determine the connection between properties of Saturn's magnetosphere, including its periodicities and composition, and dynamics in the rings (PW, MAG, IMG).
- **Objective 3-4:** Measure the properties of spokes at close range and *in situ* (DD, PW, MAG, IMG)

Science Theme #4: What are the dominant dynamical processes in Saturn's atmosphere? Cassini's Grand Finale revealed a new view of Saturn's atmosphere when close-up images revealed previously unexpected atmospheric structures at scales of 1–10 km [9]. Notable features include puffy clouds resembling terrestrial cumulus, shadows indicating cloud height, dome and bowl shaped cloud structures indicating upwelling and downwelling, and thread-like cloud filaments that remain coherent over distances of 20,000 km. The spatial and temporal character of these structures is very poorly known.

- **Objective 4-1:** Characterize the spatial and temporal distribution of 1–10 km structures in Saturn's atmosphere (IMG).
- **Objective 4-2:** Characterize the processes that transport energy from the interior to the level where it is radiated to space (IMG).

Science Theme #5: What are the dominant dynamical processes in Saturn's interior? Cassini's Grand Finale also revealed that Saturn's gravitational field is far more dynamic than anyone had expected, with time-variable and/or azimuthal structures in its deep interior that are unlike anything seen at Jupiter [5,8]. Further study of these variations would not only help us to better understand the interior structure and dynamics of Saturn in particular, but give us new insights into the history and workings of giant planets in general.

- **Objective 5-1:** Characterize the unexpected longitudinal asymmetries (or temporal variations) in Saturn's gravity field (GS).
- **Objective 5-2:** Observe waves in Saturn's rings due to weak resonances with interior oscillation modes and mass anomalies (IMG).

Relationship to other Saturn system missions: A Saturn Ring Skimmer could also explore Titan, Enceladus, or other moons, or carry a Saturn atmosphere descent probe. Indeed, flybys of Titan are a required part of ring skimming, and close proximity to Enceladus as well as Saturn occurs naturally. Although polar moon flybys and ring skimming cannot be done on the same orbit, a mission could operate in multiple phases, focusing on one and then the other.

The New Frontiers list: A robust multi-disciplinary Ring Skimmer mission is best suited for a New Frontiers budget, but current New Frontiers rules do not allow Saturn system mission proposals that are not focused on either an Ocean World or an Atmospheric Entry Probe. We petition the Planetary Science Decadal Survey committee to consider adding <u>Inner Saturn System Science</u> to the New Frontiers list, so that a Saturn Ring Skimmer can receive full consideration in the future.

References: [1] Vaquero M, Senent J, and Tiscareno MS (2019). *American Astronautical Society Meeting Abstracts*, 19–265. [2] Tiscareno MS *et al.* (2019). *Science* **364,** aau1017. [3] Waite JH *et al.* (2018). *Science* **362,** aat2382. [4] Crida A *et al.* (2019). *Nature Astronomy* **3,** 967. [5] Iess L *et al.* (2019). *Science* **364,** aat2965. [6] Schlichting HE and Chang P (2011). *Astrophys. J.* **734,** 117. [7] Khurana K *et al.* (2018). *Geophys. Res. Lett.* **45,** 10068. [8] Mankovich C *et al.* (2019). *Astrophys. J.* **871,** 1. [9] Ingersoll AP *et al.* (2018). *Geophys. Res. Lett.* **45,** 7851.