SATURN RING SKIMMER MISSION CONCEPT M. S. Tiscareno[1], M. M. Hedman[2], M. Vaquero[3], H. Cao[4], P. R. Estrada[5], J. Fuller[6], A. P. Ingersoll[6], K. E. Miller[7], M. Parisi[3], C. S. Paty[8], J. N. Cuzzi[5], A. R. Hendrix[9], R. E. Johnson[10], T. Koskinen[11], W. S. Kurth[12], J. I. Lunine[13], P. D. Nicholson[13], R. Schindhelm[14], M. R. Showalter[1], L. J. Spilker[3], W. Tseng[15]. [1]SETI Institute, [2]Univ of Idaho, [3]Jet Propulsion Laboratory, [4]Harvard Univ, [5]NASA Ames, [6]Caltech, [7]Southwest Research Institute, [8]Univ of Oregon, [9]Planetary Science Institute, [10]Univ of Virginia, [11]Univ of Arizona, [12]Univ of Iowa, [13]Cornell Univ, [14]Ball Aerospace, [15]National Taiwan Normal Univ.

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.

- By taking a broad look at how the rings, the magnetosphere, the upper atmosphere, and the planetary interior compose a coherent interconnected system, the Saturn Ring Skimmer will address questions about this system that could only be posed after Cassini's grand finale.
- By studying disk dynamics at the individual particle level, the Saturn Ring Skimmer will use this natural laboratory to help us understand exo-disks and planetary formation.
- By determining the role played by Saturn's rings in driving the Saturn system to be very different from Jupiter, the Saturn Ring Skimmer will help us understand a whole class of exoplanets.

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

Background: The Cassini mission revolutionized our understanding of the Saturn system. Its close proximity to the planet, especially during the mission's final year, combined with its 13-year time domain, enabled it to substantially address dozens of scientific questions and mysteries. As always happens with ground-breaking science, the answers provided by Cassini revealed a whole new suite of pressing scientific questions.

The new set of fundamental questions about the inner Saturn system includes the following top-level science questions:

How do rings and disks work at the particle level? Saturn's rings span 300,000 km, but are composed primarily of particles millimeters to meters across. Cassini never had the resolution to directly detect typical individual ring particles, 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.

How long will the rings last? Measurements made during Cassini's Grand Finale revealed surprisingly high fluxes of material into Saturn. A steady-state interpretation of these fluxes may imply 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.

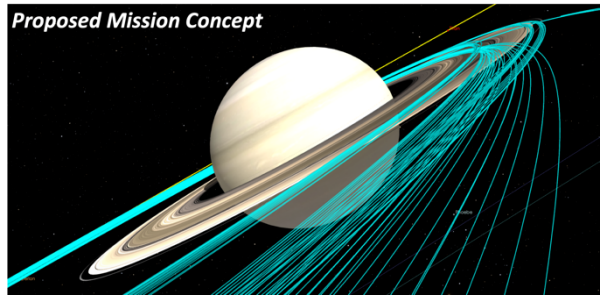

Figure 1. Using an innovative trajectory design [1], the Saturn Ring Skimmer would repeatedly pass across the face of the rings at altitudes of a few hundred km.

What is happening inside Saturn? Cassini's Grand Finale also revealed that Saturn's gravitational field is far more dynamic than anyone had expected. Variations in the gravitational accelerations felt by Cassini during different passages between the planet and the rings imply that Saturn has time-variable and/or azimuthal structures in its deep interior that are unlike anything seen at Jupiter. 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.

How does the presence of the rings alter Saturn and its system? Saturn's rings are the only broad dense disk in our solar system, but many exoplanets may have similar ring systems [3]. Many of the unique aspects of Saturn's magnetosphere, atmosphere, and interior are likely connected to the ring system's influence [4,5], 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.

The Saturn Ring Skimmer mission concept would address these important science questions. Using an innovative trajectory design [1], ***the Ring Skimmer explores 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 ~100× closer to Saturn's rings than Cassini's distance when the best ring images to date were taken, but that's not all. The Ring Skimmer also 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.

The science topics addressed by the Ring Skimmer are broadly based within the inner Saturn system. The role of Saturn's rings in these investigations can be understood via three main themes:

Theme 1: Study disk processes, using the rings as a natural laboratory. Saturn's rings are an exemplary astrophysical disk in a location amenable to close observation. Understanding the detailed workings of disk processes in Saturn's rings informs the study of less accessible disks, including protoplanetary disks.

Theme 2: Study Saturn system origin and history, using the rings as a tracer. The structural and chemical makeup of Saturn's rings constitute clues that constrain the possible processes that may have produced them.

Theme 3: Use the rings as a detector to understand surrounding processes. Saturn's rings are large and delicate, and in many cases serve to amplify subtle processes, such as interior gravity perturbations or micrometeoroid impacts [6].

We are in early stages of developing the science case for this mission concept. We have identified the following key science questions, grouped in terms of five science disciplines:

Saturn's Rings

- What do individual ring particles look like?
- What happens when ring particles collide, fragment, and/or form aggregates?
- What are the properties of micrometeoroid impacts and how do they sculpt the rings?
- How polluted are the rings, and what are the implications for the rings' origin and evolution?

Plasma and Magnetosphere

- How does the material transport between the rings, the magnetosphere, and the atmosphere constrain the origin and evolution of the rings?
- What is the angular momentum exchange rate between Saturn and its rings and how does it contribute to the long term evolution of Saturn rings?
- How do the periodicities in Saturn's magnetosphere affect the rings?

Ring Atmosphere and Neutral Gas

- How do meteoroid bombardment and solar irradiation affect production of gas from ice-organic surfaces?
- What physical processes govern gas-solid interactions in a disk configuration, including protoplanetary disks?

Saturn's Atmosphere

- What are the basic cloud types at Saturn, and how do they vary with location and time?
- How do Saturn's atmospheric processes compare to those at other planets?
- What are the patterns of cloud motion at Saturn? How do they vary regionally and with time?
- What is the vertical structure of clouds at Saturn?

Saturn's Interior

- How does Saturn's interior structure vary with azimuth and/or time?
- How is Saturn's deep interior changing over timescales of years to decades?

Relationship to other Saturn system missions: A Saturn Ring Skimmer could also explore Titan, Enceladus, or other moons of Saturn, or carry a Saturn atmosphere descent probe. Indeed, flybys of Titan are a required part of ring skimming, and close proximity to Enceladus, other moons, and Saturn occurs naturally. Although polar moon flybys and ring skimming cannot be done at the same time, a mission could operate 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 Inner Saturn System Science 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] Schlichting HE and Chang P (2011). *Astrophys. J.* **734,** 117. [4] Khurana K *et al.* (2018). *Geophys. Res. Lett.* **45,** 10068. [5] Waite JH *et al.* (2018). *Science* **362,** aat2382. [6] Mankovich C *et al.* (2019). *Astrophys. J.* **871,** 1.