# Saturn Ring Skimmer:
# A New Concept for Exploring Saturn

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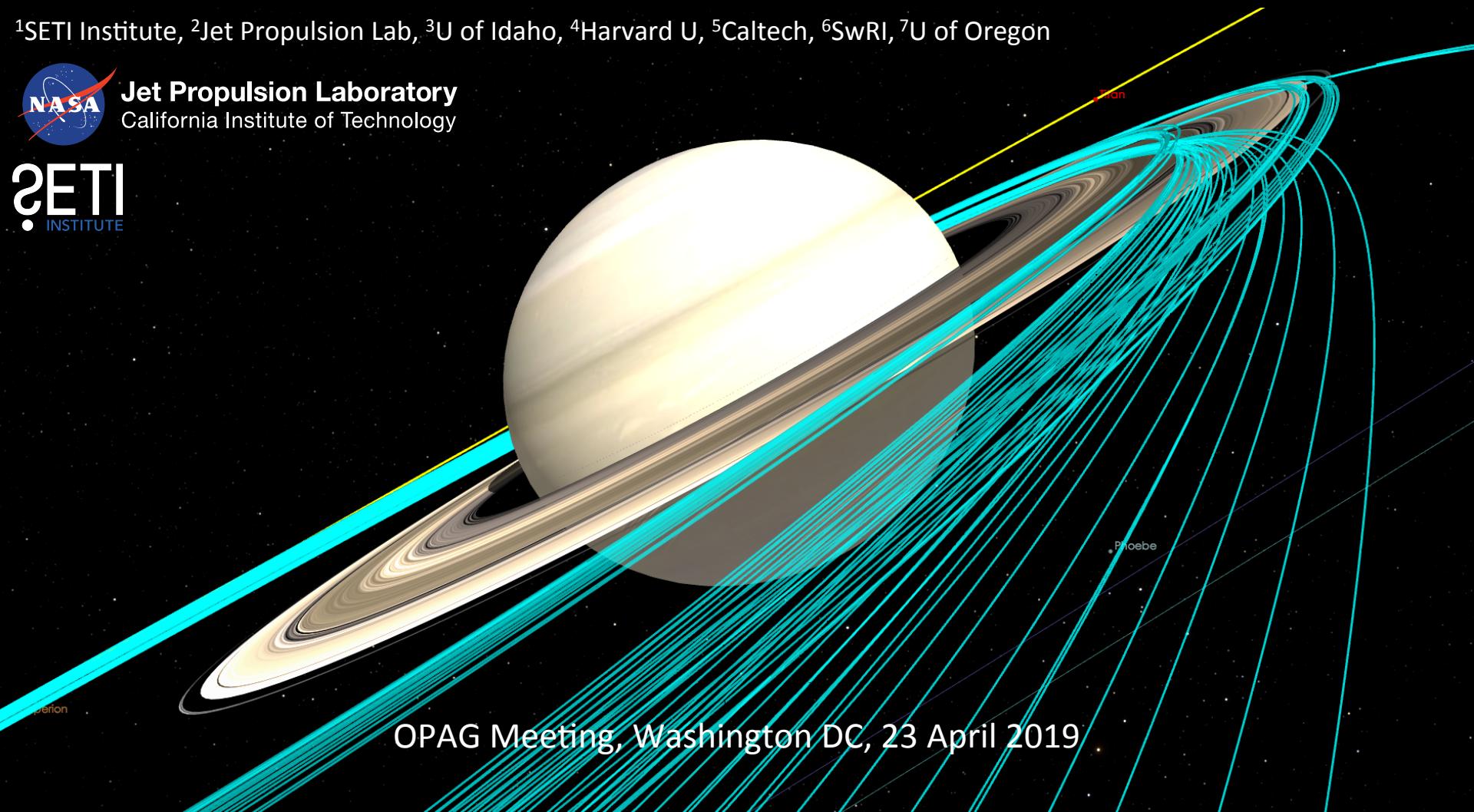
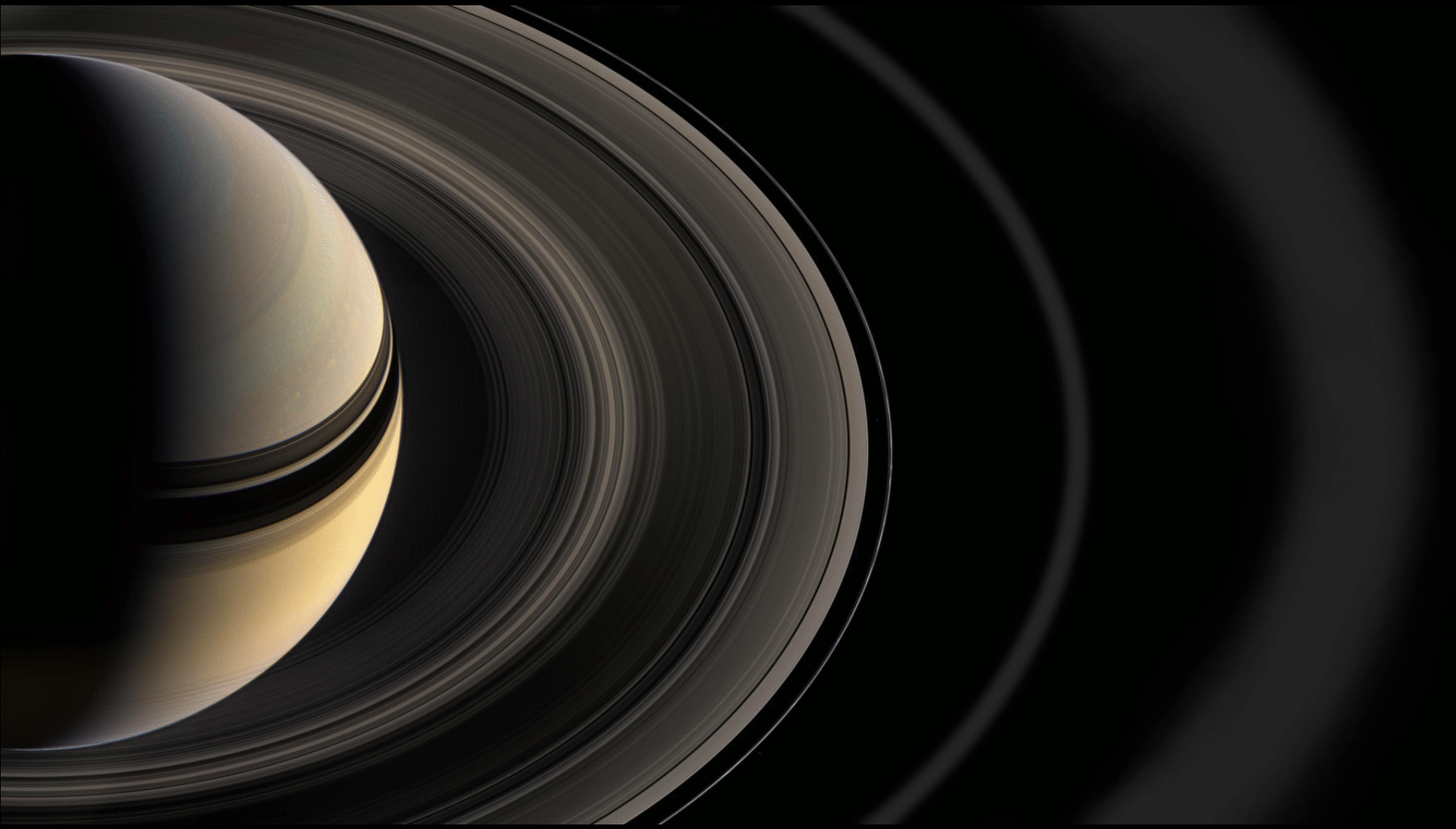
California Institute of Technology

SETI INSTITUTE

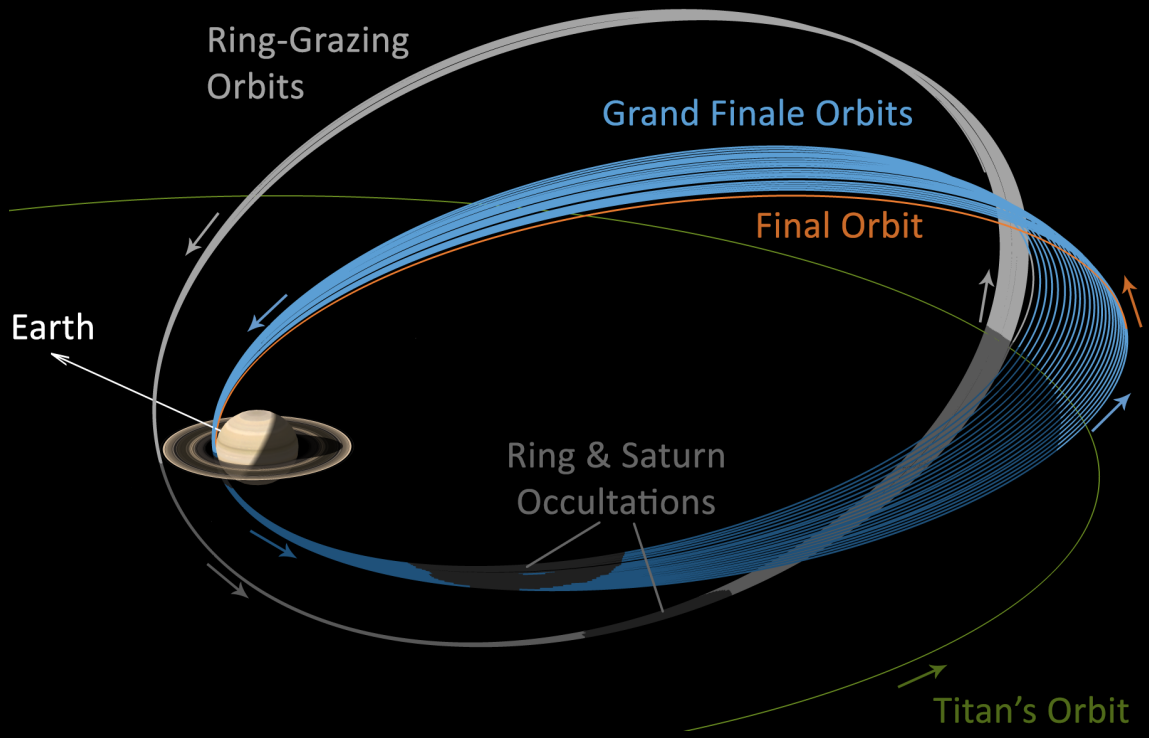



OPAG Meeting, Washington DC, 23 April 2019

# Answers and Questions at Saturn



# The Rings as seen by Cassini




During the Grand Finale…

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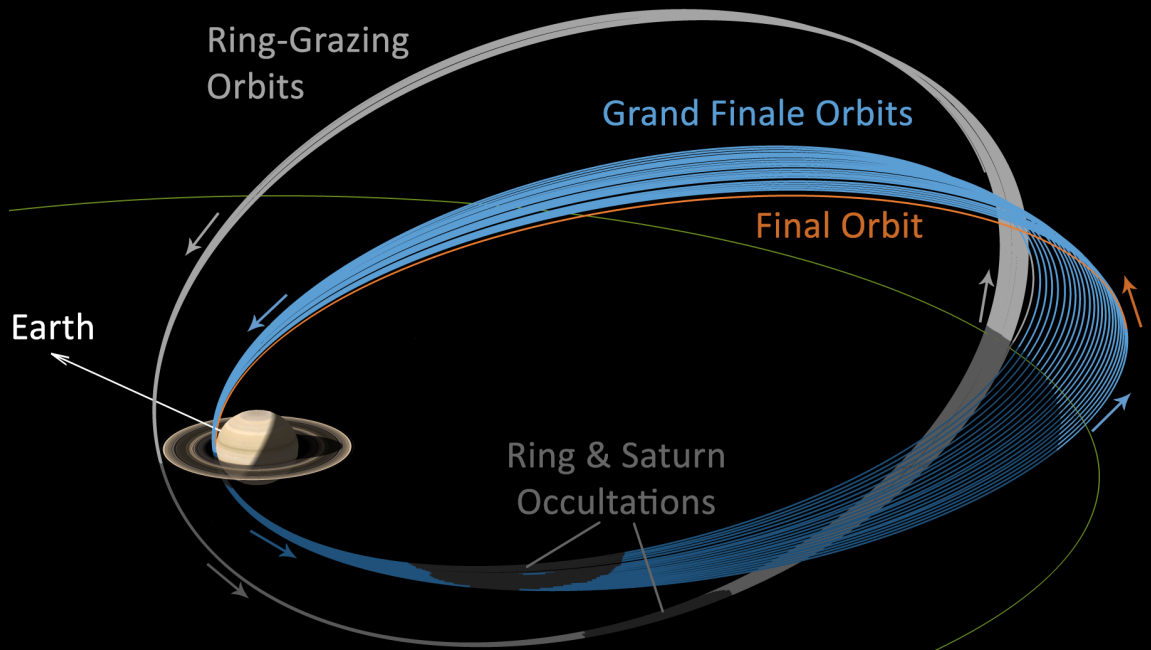
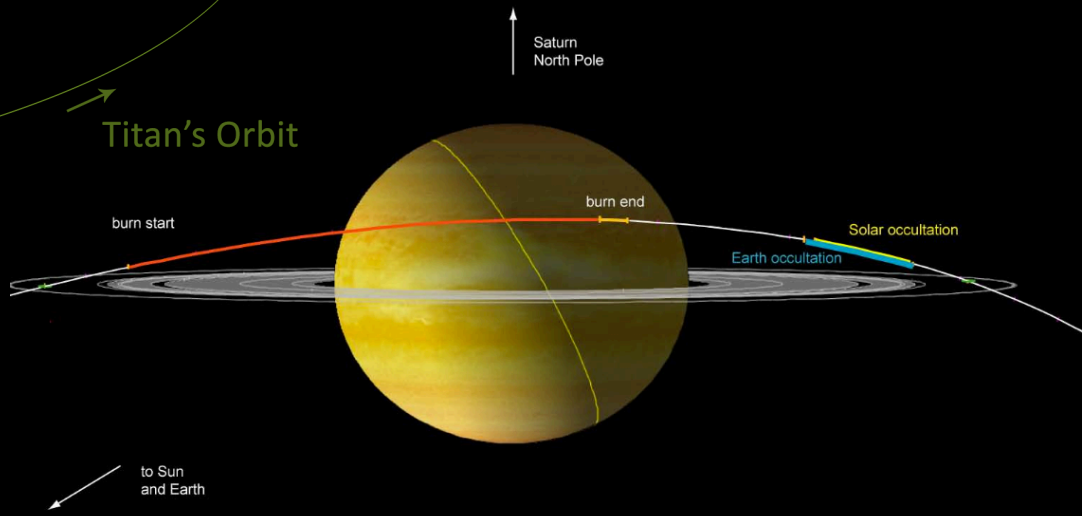
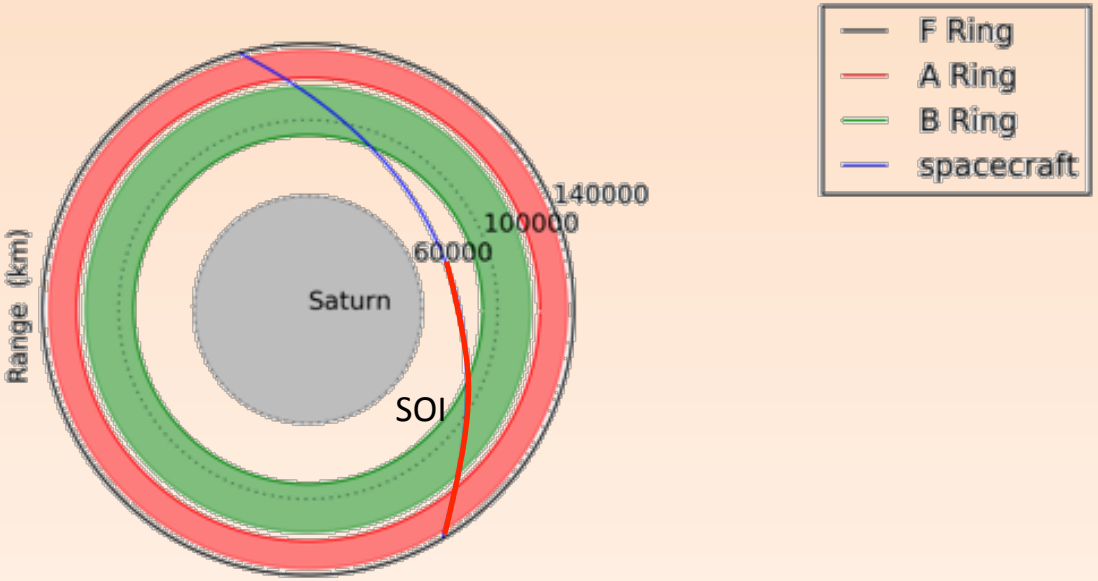


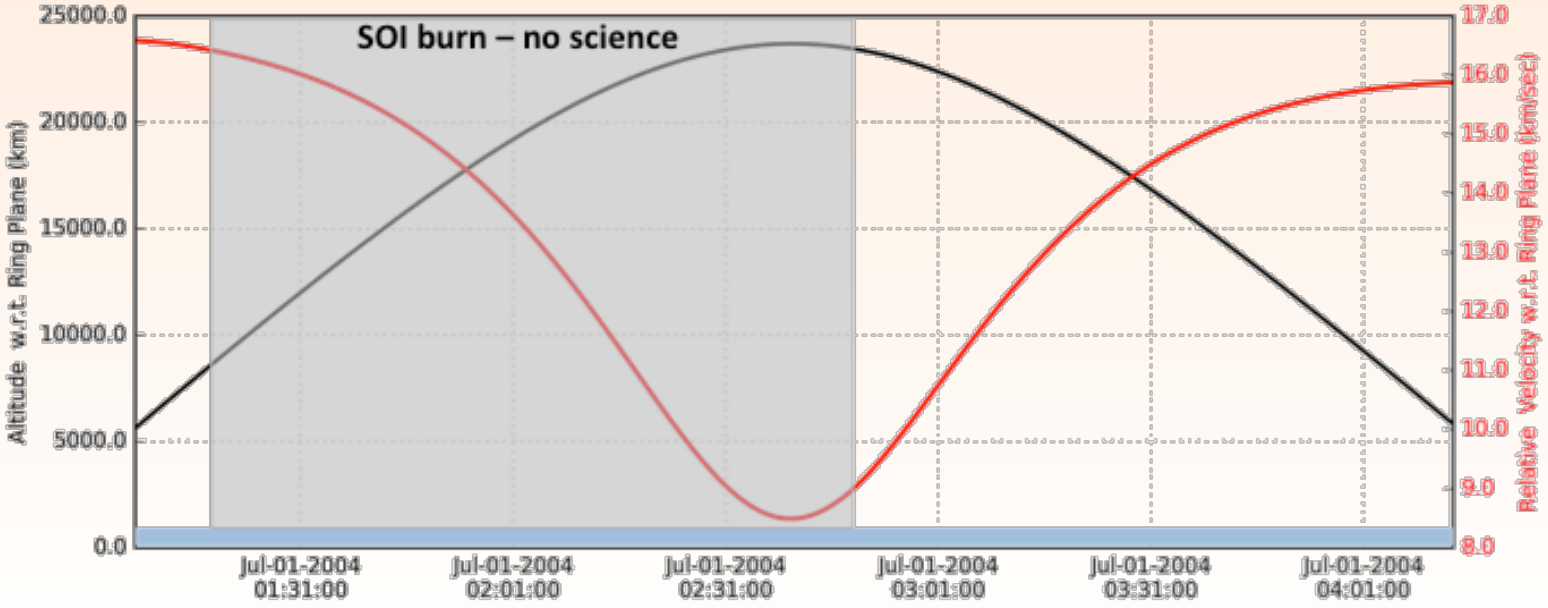

During the Grand Finale…




…and during the Saturn Orbit Insertion burn in 2004

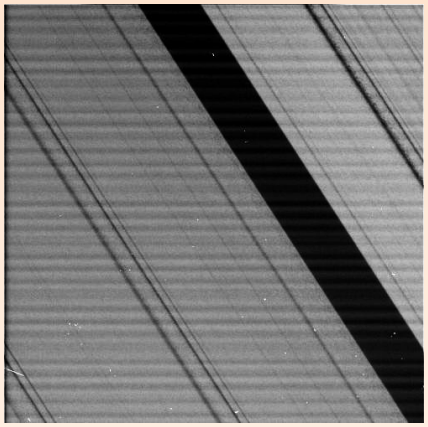
# Cassini SOI Ring Pass

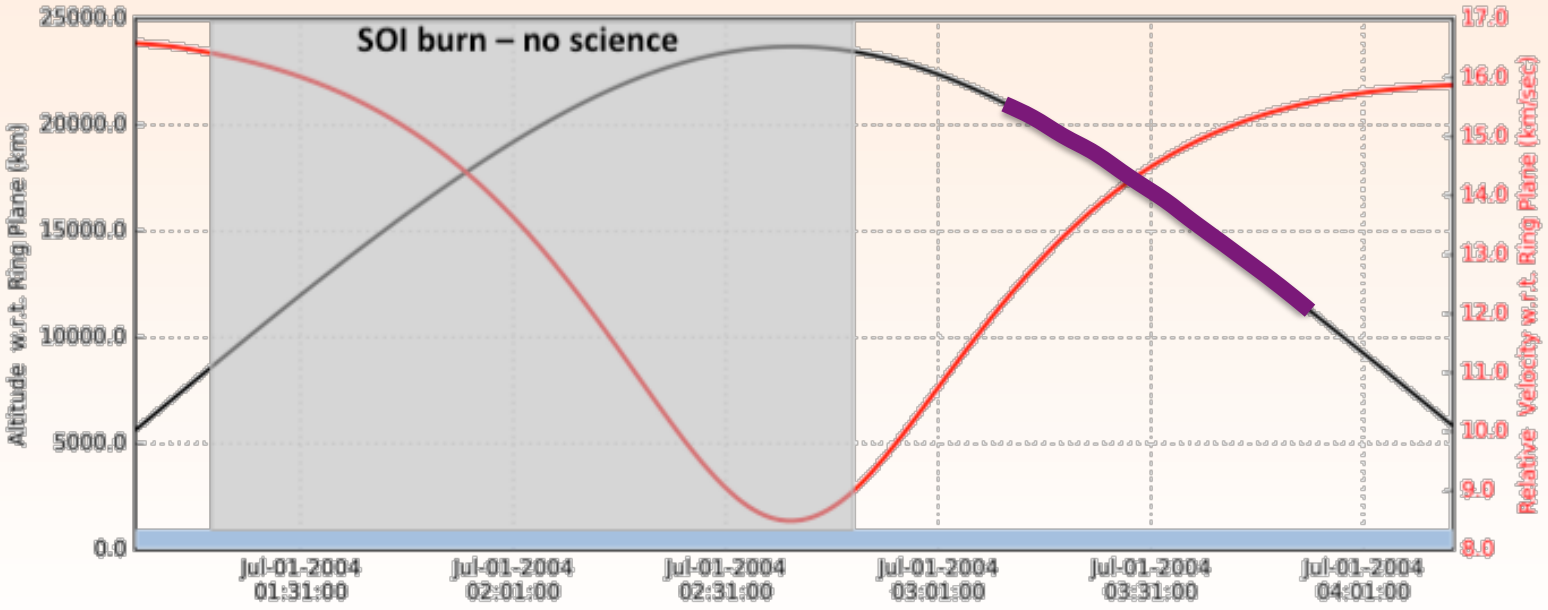


# Cassini SOI Ring Pass

**Cassini's closest images of the rings were taken from ~25,000 km, with ~200 m/pixel**





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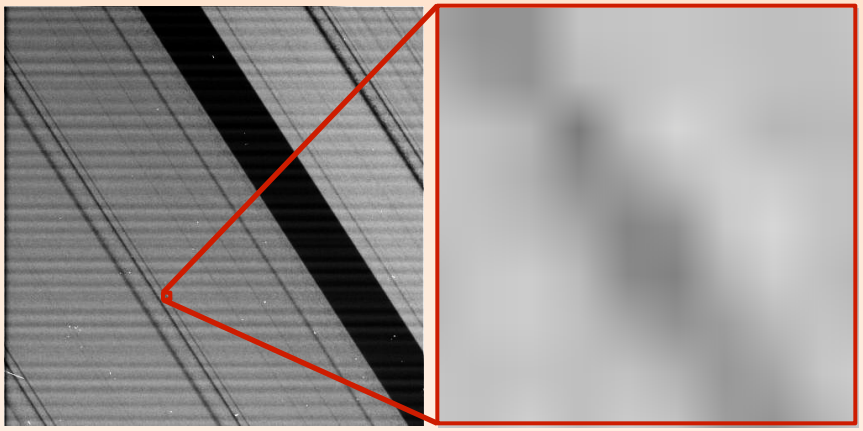
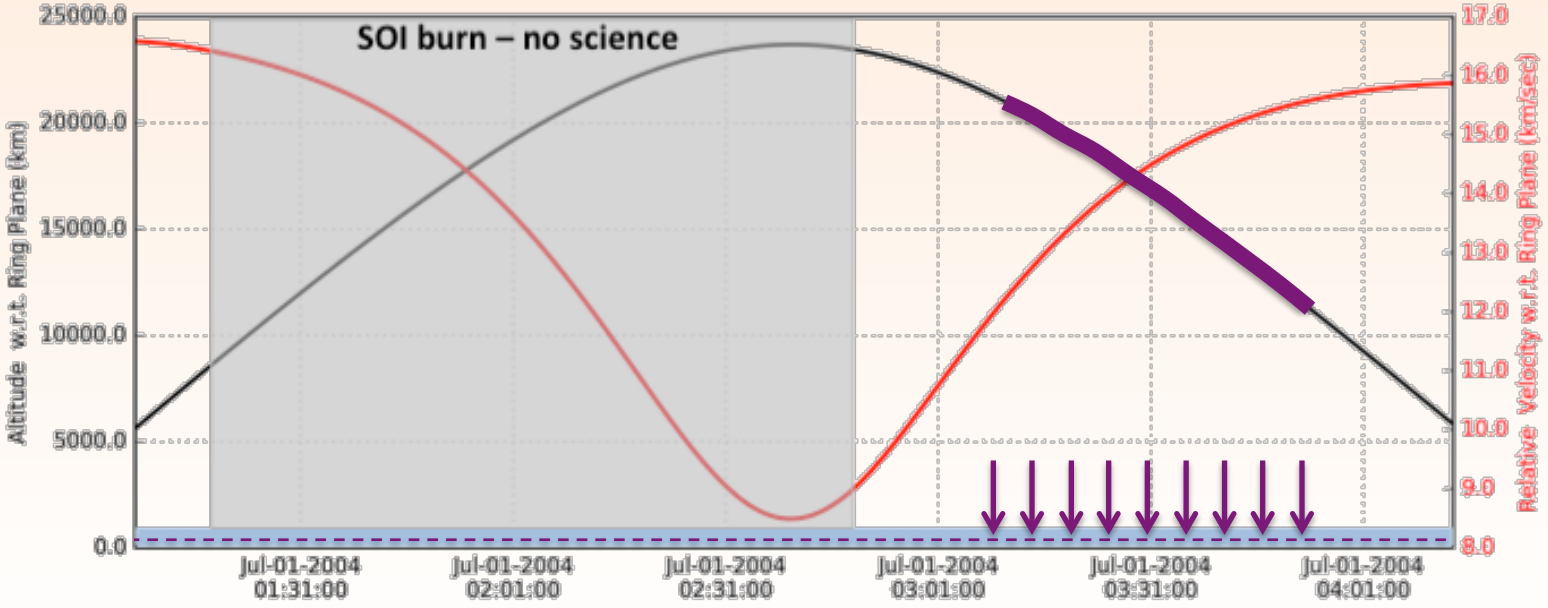
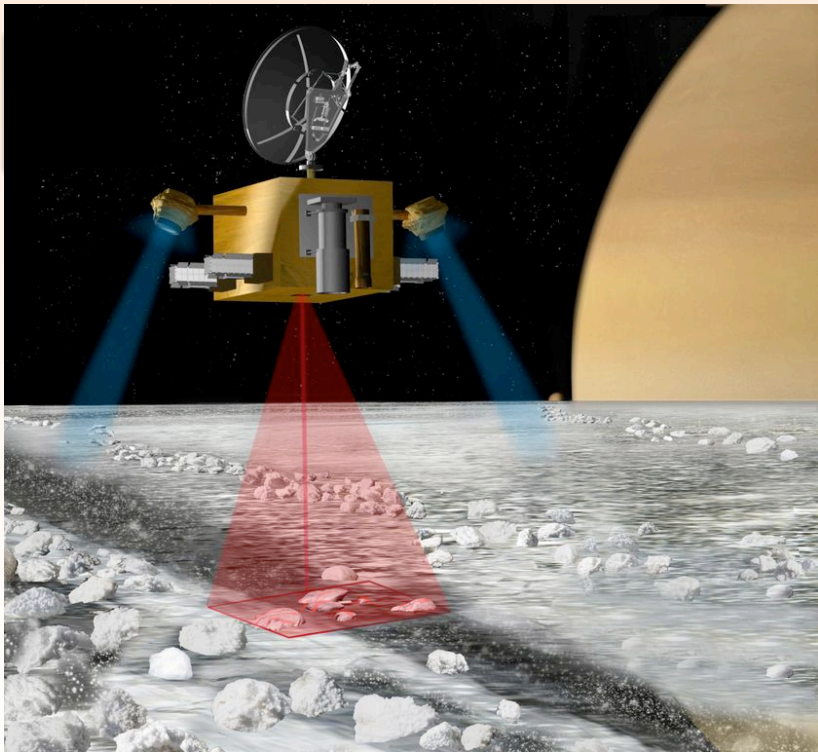


**Taking images from several hundred km would allow better than 7 m/pixel with modern cameras**



# A Previous Concept: Saturn Ring Observer

- S/C placed in a circular hover orbit, a few km above ring plane
  - Constant low-thrust ion engine to maintain vertical displacement
  - Chemical thrusters to “hop” over ring obstacles
  - Maintains zero velocity relative to local orbiting ring particles
- Study informing previous Decadal examined the technological feasibility for a mission focused on Saturn’s rings
- Technical challenges
  - Power, propulsion, and trajectory technologies need development
  - Pumpdown and insertion into hover orbit required ~3 km/s
  - Complex operations
  - Continuous maneuvering



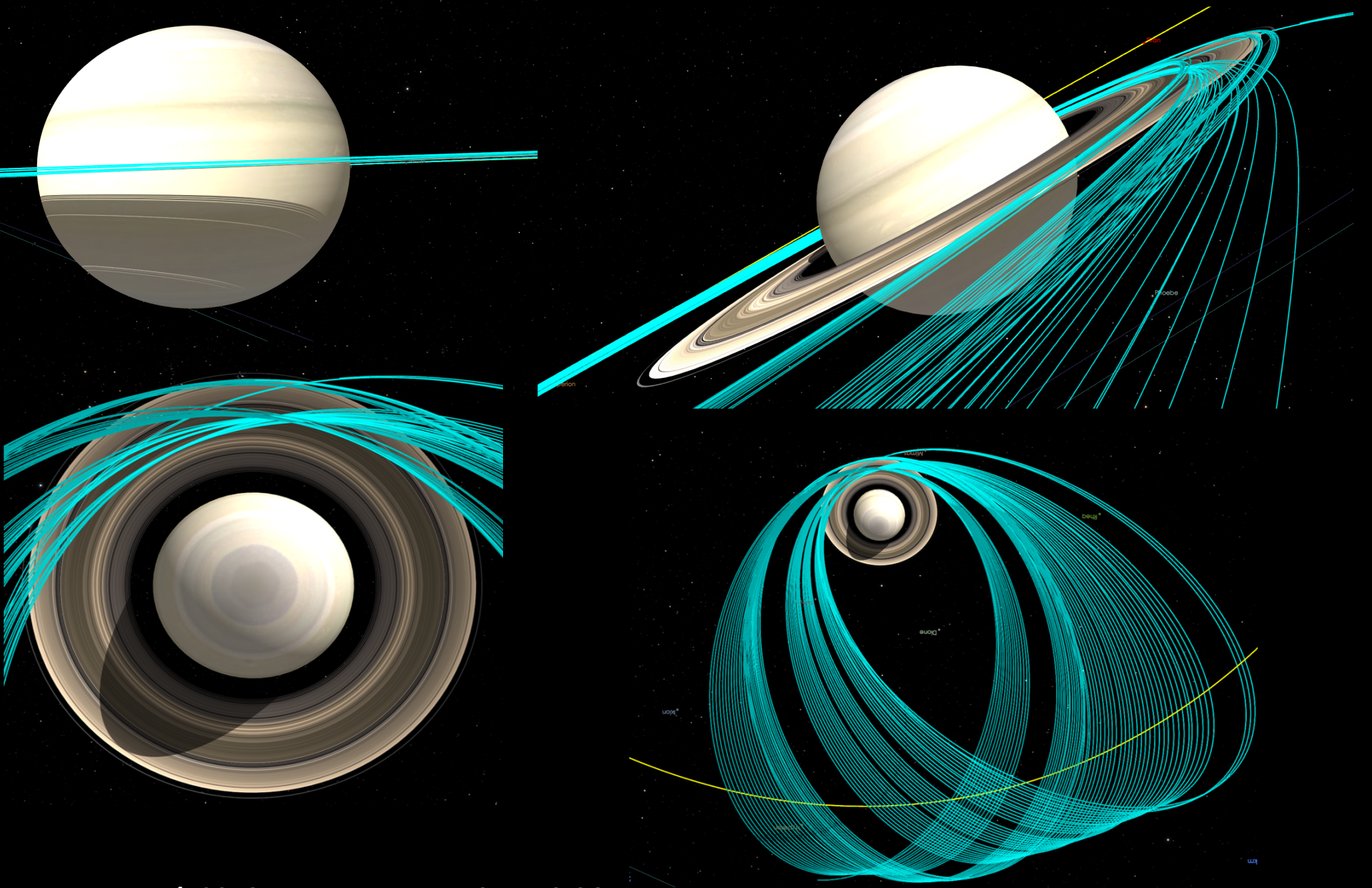
***Spilker et al. 2011, J. Brit. Interplan. Soc.***

# Our New Flyby Concept

- A flyby mission to study the rings from a S/C that repeatedly skims over different ring regions at close range
- Highlights
  - No new technology required
  - Could have been flown by Cassini in March 2016
  - Maintains ring plane crossings outward of the F ring
  - Features 4 ring passes per month, ~3hr long
  - Potentially all regions of the rings are explored
  - For prototype trajectory design, deterministic DV = 0 m/s
  - Simplified architecture and operations
- Drawbacks
  - High relative velocity (~8 km/s) − however, smear mitigation measures could be effective:  scanning platform, scanning mirror, TDI imager

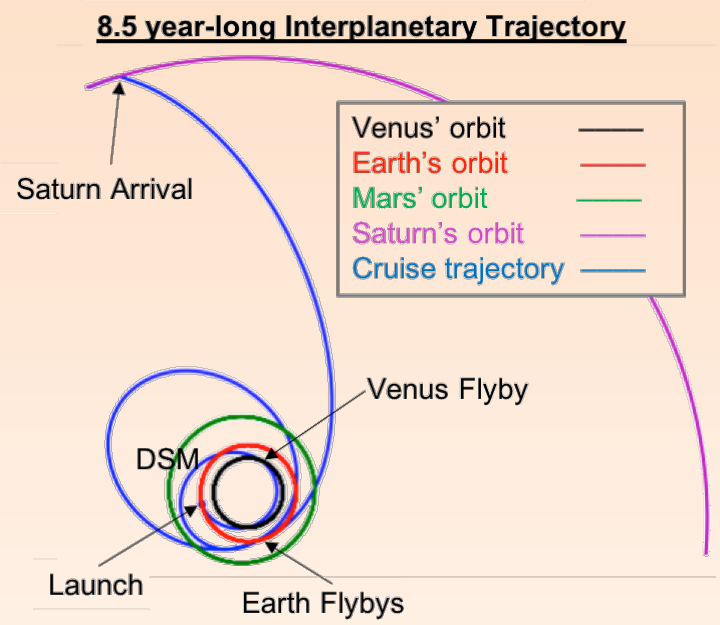
***Vaquero et al. 2019, Am. Astronaut. Soc. 19-265***

# Sample Ring Skimming Tour




*Vaquero et al. 2019, Am. Astronaut. Soc. 19-265*

# Getting to the Ring Plane




| Event | Epoch | |
|---|---|---|
| Earth Dep. | 25 FEB 25 | C3 = 17.65 |
| Venus Flyby | 23 AUG 25 | $V_\infty$ = 8.93 |
| Earth Flyby | 05 JUL 26 | $V_\infty$ = 11.12 |
| DSM | 25 FEB 28 | $\Delta V$ = 13 m/s |
| Earth Flyby | 05 JUL 29 | $V_\infty$ = 11.07 |
| Saturn Arrival | 04 JAN 34 | $V_\infty$ = 6.75 |
| TOF | | 8.5 yrs |

***Vaquero et al. 2019, Am. Astronaut. Soc. 19-265***

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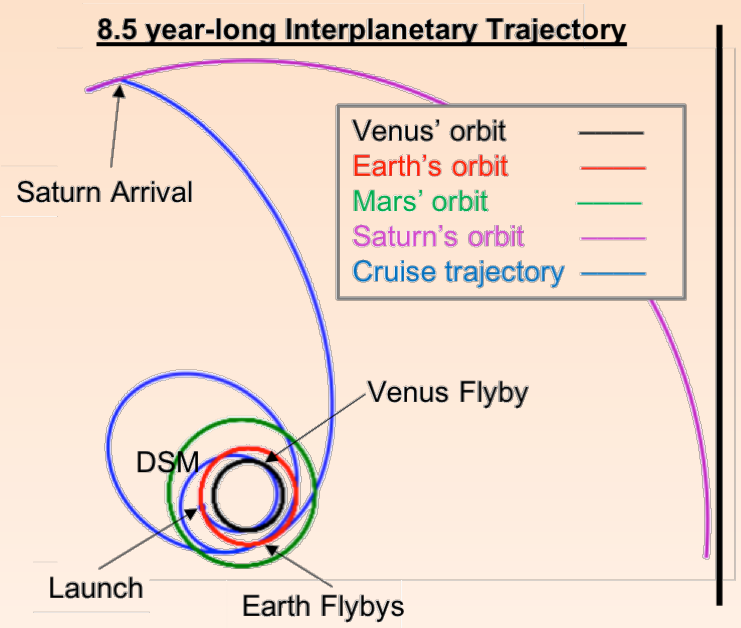


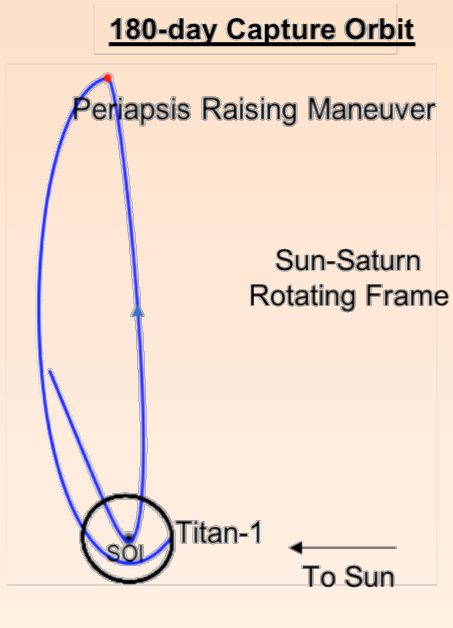


| Event | Epoch | | Event | Epoch | |
|---|---|---|---|---|---|
| Earth Dep. | 25 FEB 25 | C3 = 17.65 | SOI | 04 JAN 34 | 646 m/s |
| Venus Flyby | 23 AUG 25 | $V_\infty$ = 8.93 | PRM | 30 MAR 34 | 381 m/s |
| Earth Flyby | 05 JUL 26 | $V_\infty$ = 11.12 | Titan-1 | 27 JUN 34 | 1000 km |
| DSM | 25 FEB 28 | ΔV = 13 m/s | TOF | | 174 days |
| Earth Flyby | 05 JUL 29 | $V_\infty$ = 11.07 | | | |
| Saturn Arrival | 04 JAN 34 | $V_\infty$ = 6.75 | | | |
| TOF | | 8.5 yrs | | | |

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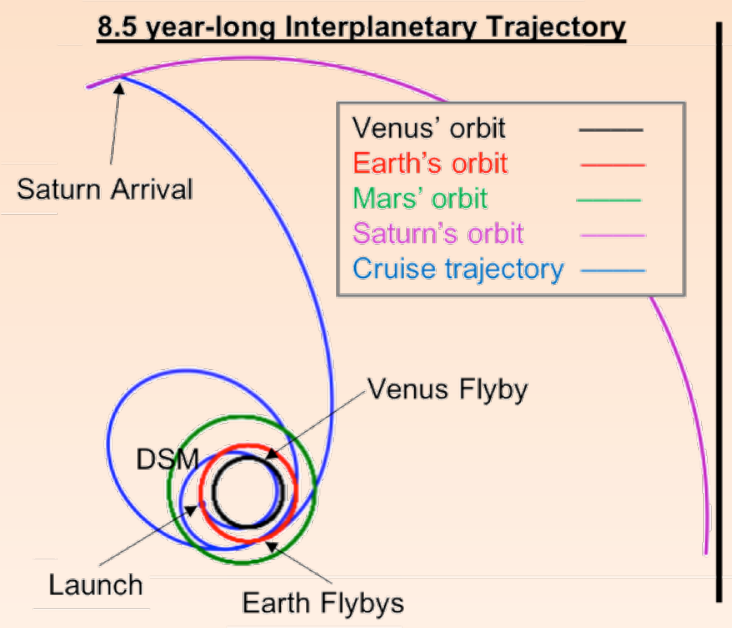


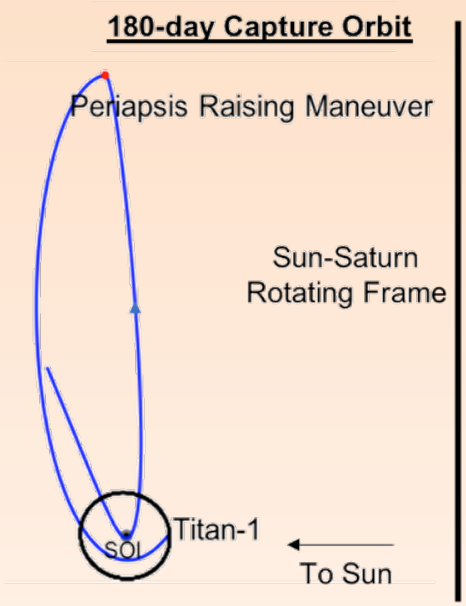


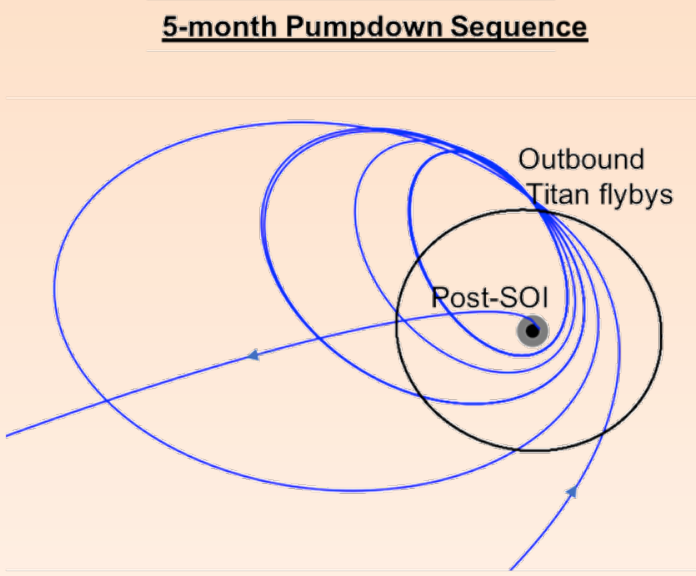


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| PRM | 30 MAR 34 | 381 m/s |
| Titan-1 | 27 JUN 34 | 1000 km |
| TOF | | 174 days |

| Event | Epoch | Alt (km) |
|---|---|---|
| Titan-2 | 14 AUG 34 | 1000 km |
| Titan-3 | 30 SEP 34 | 999 km |
| Titan-4 | 16 OCT 34 | 1946 km |
| Titan-5 | 02 DEC 34 | 6970 km |
| TOF | | 159 days |

Titan flybys $V_\infty$ ~ 5.14 km/s
Total TOF to ring plane = 9.34 yrs
Total ΔV = 1028 m/s

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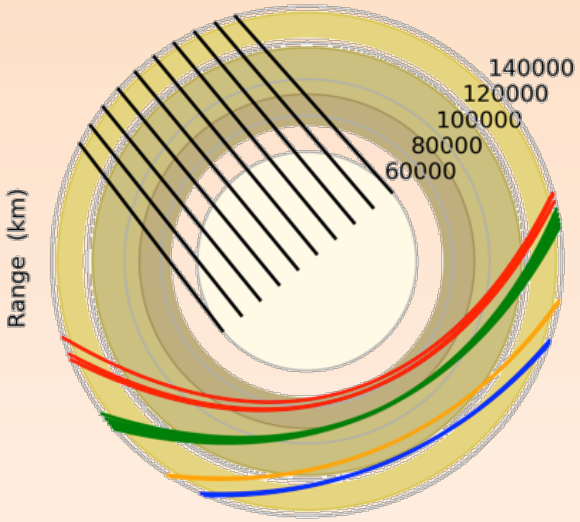
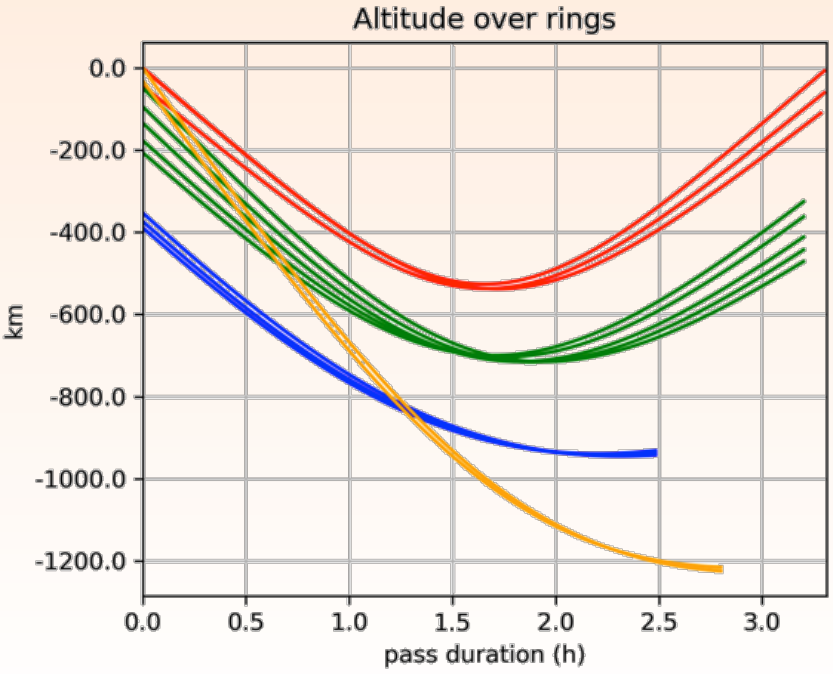
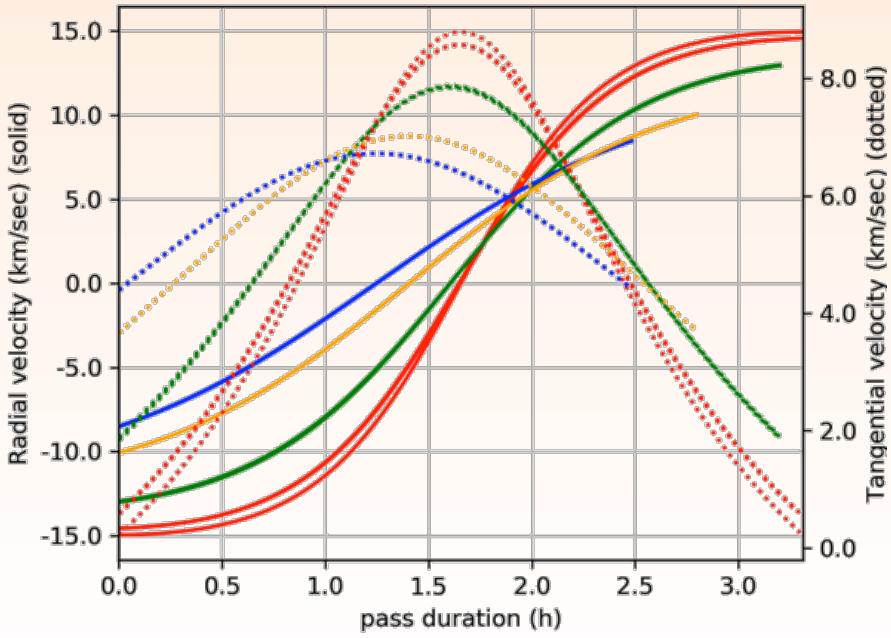
# Ring Skimming Campaign




| Flyby | Epoch | Alt (km) | $V_\infty$ (km/s) |
|---|---|---|---|
| Titan-6 | 19-DEC-2034 | 56,882 | 5.30 |
| Titan-7 | 03-JAN-2035 | 15,039 | 5.53 |
| Titan-8 | 10-MAR-2035 | 6,222 | 5.49 |
| Titan-9 | 08-APR-2035 | 28,036 | 5.29 |

13 passes over the rings (2.5-3.5 hrs long)
tour duration = 162 days
deterministic ΔV = 0 m/s

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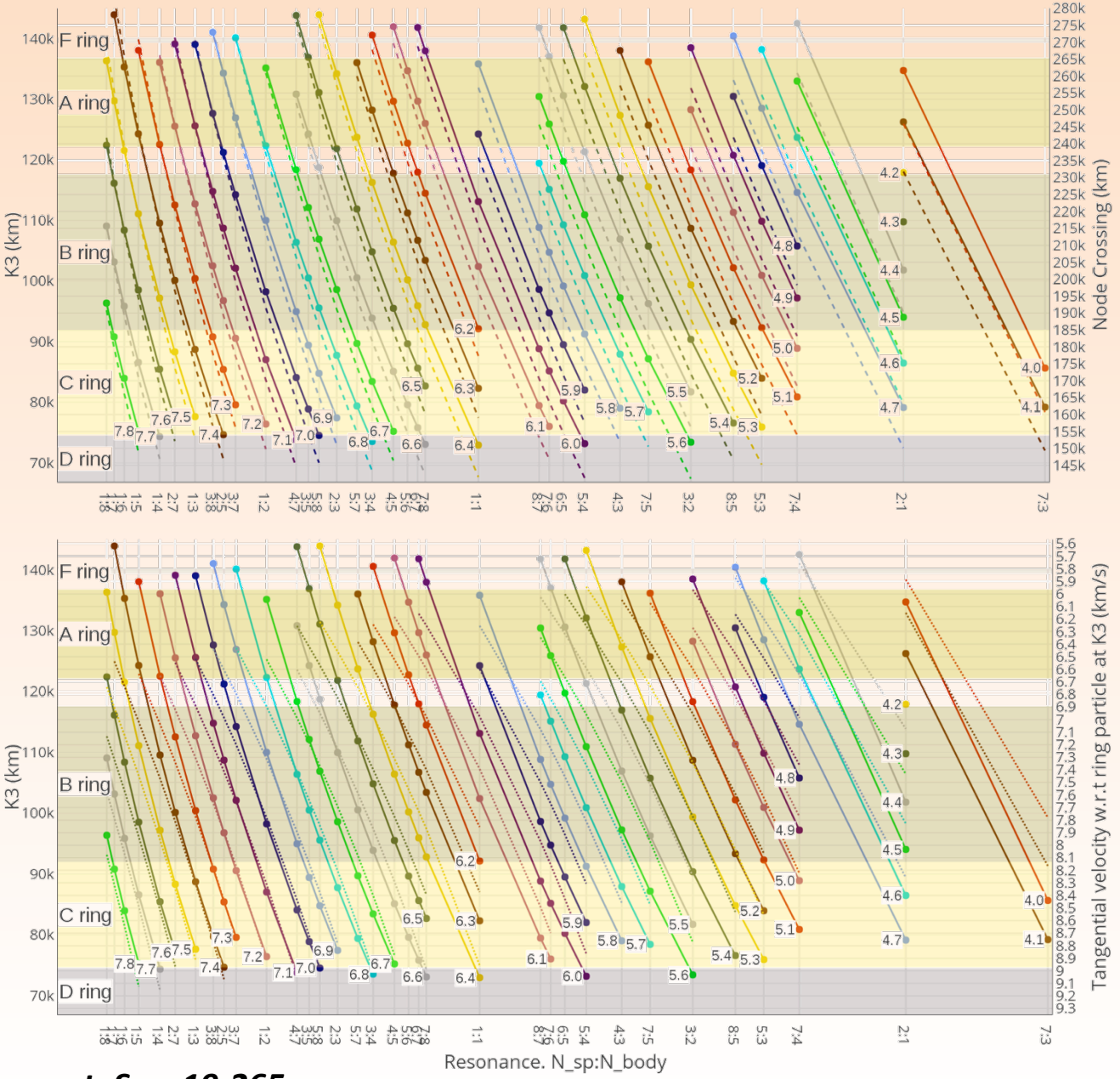
# Ring Skimming Tour Space

Exploit Titan flybys to design “ring tours” rather than “moon tours”

Graphical approach to characterize ring-skimming enabling flybys

Two key parameters for ballistic tours: Titan $V_\infty$ and resonance

Each family of Titan flybys corresponds to a value of Titan $V_\infty$

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# Icy Moons Bonus Flybys

- Low inclination means that icy moon flybys come naturally
- Of course, Titan flybys are also numerous
- Can we compatibly optimize for different science targets?

| Flyby | Epoch | Alt (km) | Vinf (km/s) |
|---|---|---|---|
| Titan-6 | 19 DEC 34 | 56,882 | 5.30 |
| Enceladus-1 | 21 DEC 34 | 33,289 | 11.77 |
| Mimas-1 | 01 JAN 35 | 36,291 | 11.84 |
| Titan-7 | 03 JAN 35 | 15,039 | 5.53 |
| Dione-1 | 13 JAN 35 | 69,368 | 13.15 |
| Rhea-1 | 24 JAN 35 | 25,373 | 9.31 |
| Rhea-2 | 05 FEB 35 | 16,306 | 9.99 |
| Mimas-2 | 05 FEB 35 | 43,698 | 10.24 |
| Enceladus-1 | 16 FEB 35 | 16,307 | 13.76 |
| Mimas-3 | 16 FEB 35 | 16,001 | 14.78 |
| Enceladus-3 | 28 FEB 35 | 56,950 | 15.97 |
| Titan-8 | 10 MAR 35 | 6,222 | 5.49 |
| Rhea-3 | 06 APR 35 | 33,298 | 8.75 |
| Titan-9 | 08 APR 35 | 28,036 | 5.29 |
| Mimas-4 | 19 APR 35 | 94,976 | 19.38 |
| Mimas-5 | 02 MAY 35 | 21,328 | 13.44 |
| Enceladus-4 | 02 MAY 35 | 68,812 | 8.32 |

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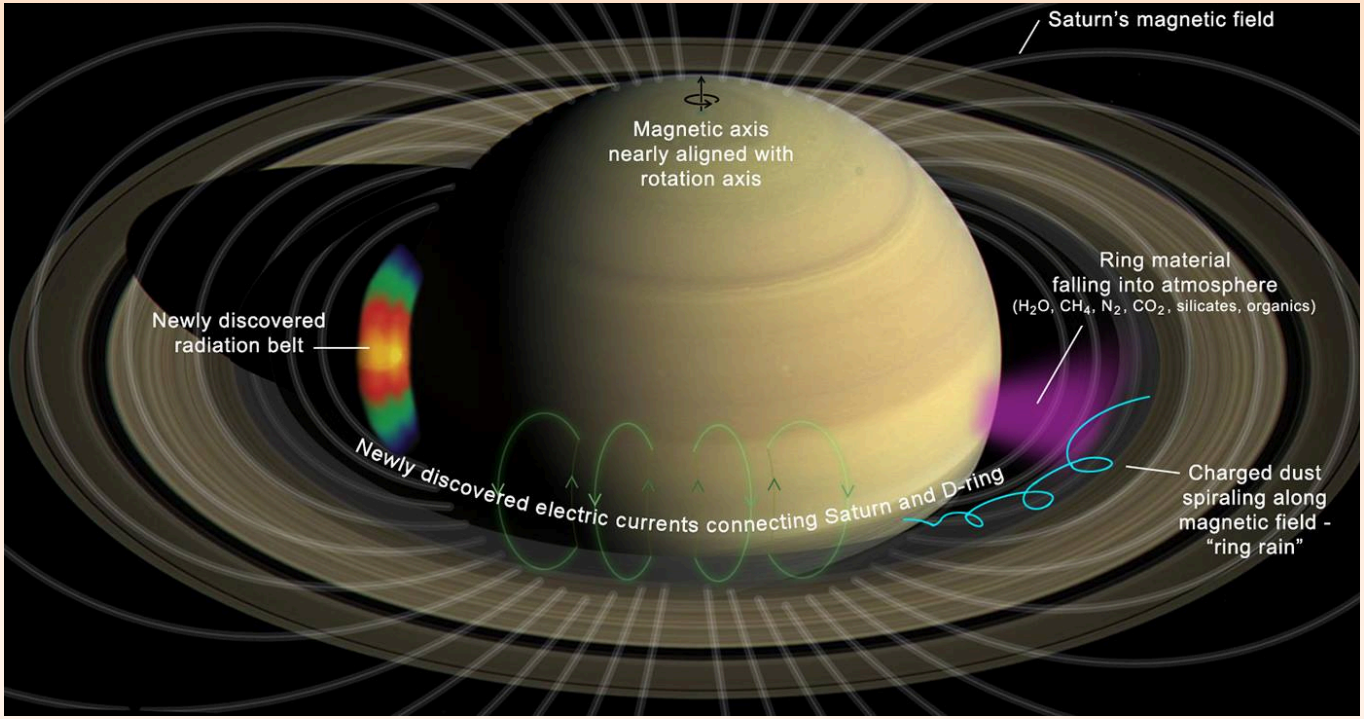
# Science Capabilities of a Ring Skimmer

- 100x closer to the rings than Cassini images
- Probes *in situ* space not visited (or seldomly visited) by Cassini, with many repeated passes
- Repeated observations of Saturn at Cassini Grand Finale range
- Compelling science in multiple disciplines
  - Rings
  - Plasma and Magnetosphere
  - Ring Neutral Atmosphere
  - Saturn Atmosphere and Interior

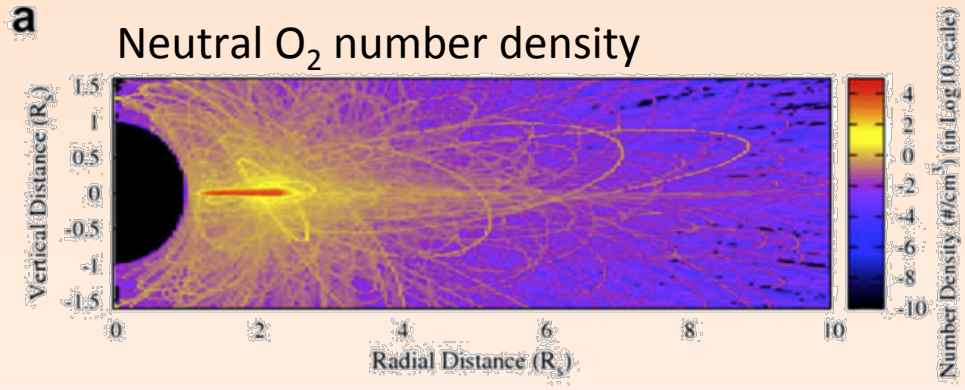
# Plasma and Magnetospheric Science




[NASA-JPL]

- Determine how material is transported among Saturn's rings, magnetosphere, and atmosphere with in situ gas, dust, and plasma measurements
- Determine the nature of electromagnetic coupling between the rings and Saturn with in-situ magnetic and plasma measurements

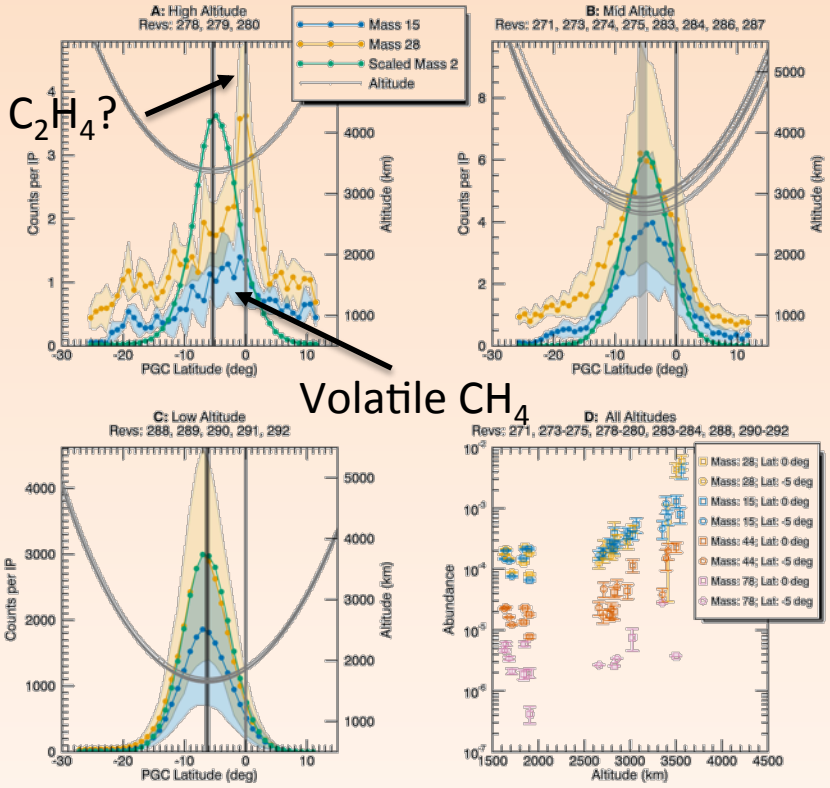
# Neutral Ring Atmosphere




[Tseng+ 2010]

Refractory $C_2H_4$?

Volatile $CH_4$

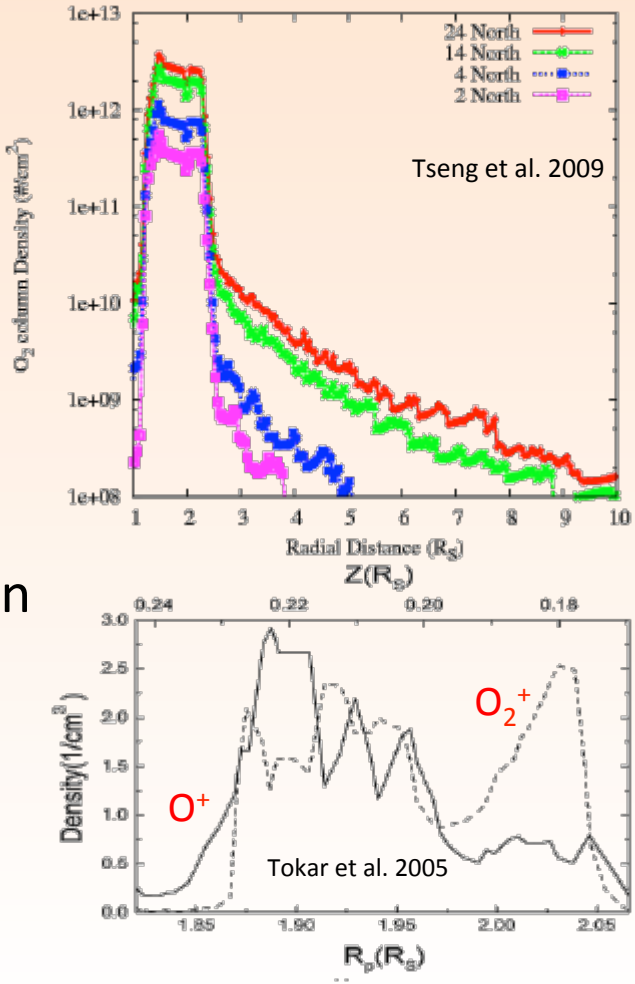



[Waite+ 2018]

- Cassini CAPS & INMS during SOI: Ions consistent with O-dominated ring atmosphere (Tokar+ 2005; Johnson+ 2006; Waite+ 2005), but did not directly detect neutrals.
- INMS measured volatile + refractory mixture during Grand Finale (Waite+ 2018; Miller+ in revision).
- How does neutral atmosphere vary with ring region?
  How does the ring atmosphere vary with height above the ring plane?
  What chemical and physical processes control this variation?

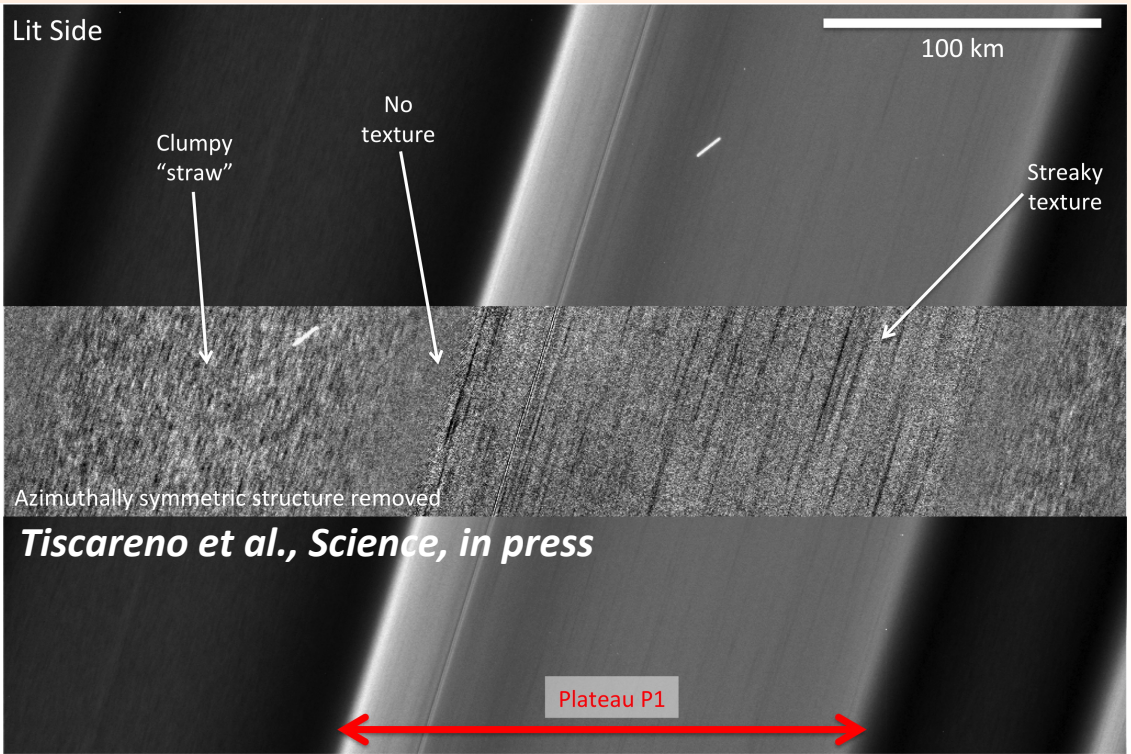
# Rings (in situ)

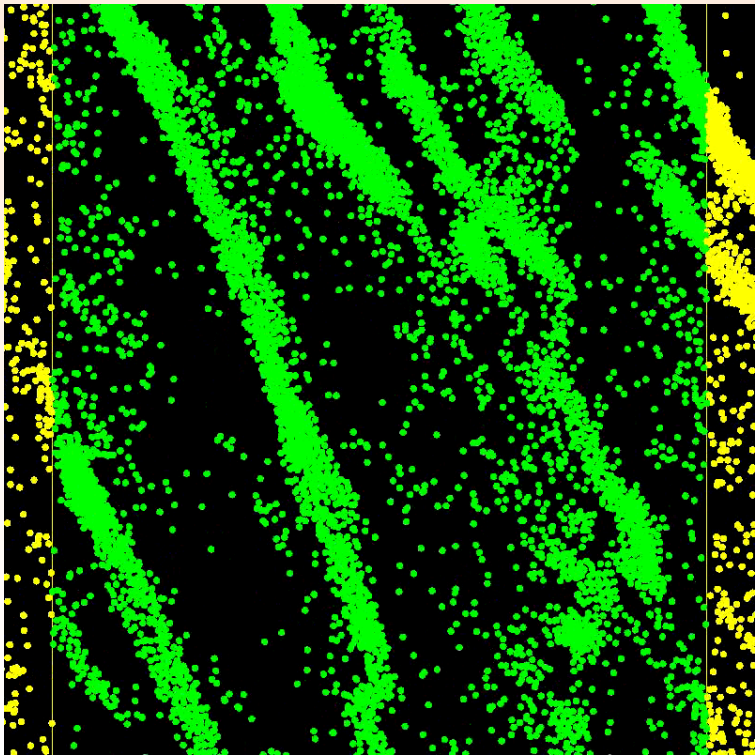
- What are the detailed workings of ballistic transport of ejecta from meteoroid bombardment of the rings? What are typical ejecta yields and velocity distributions? How does this process sculpt ring structure and affect the age of the rings?
- What is the distribution of dust and vapor with height and ring region?
- Are the rings really losing mass as rapidly as Cassini Grand Finale measurements indicate? How is this sustainable?
  ***(Waite et al. 2018; Hsu et al. 2018)***
- Cassini INMS Grand Finale measured ring inflow to be 25% water, but ring composition is >95% water: Where is the water?



# Rings (remote sensing)

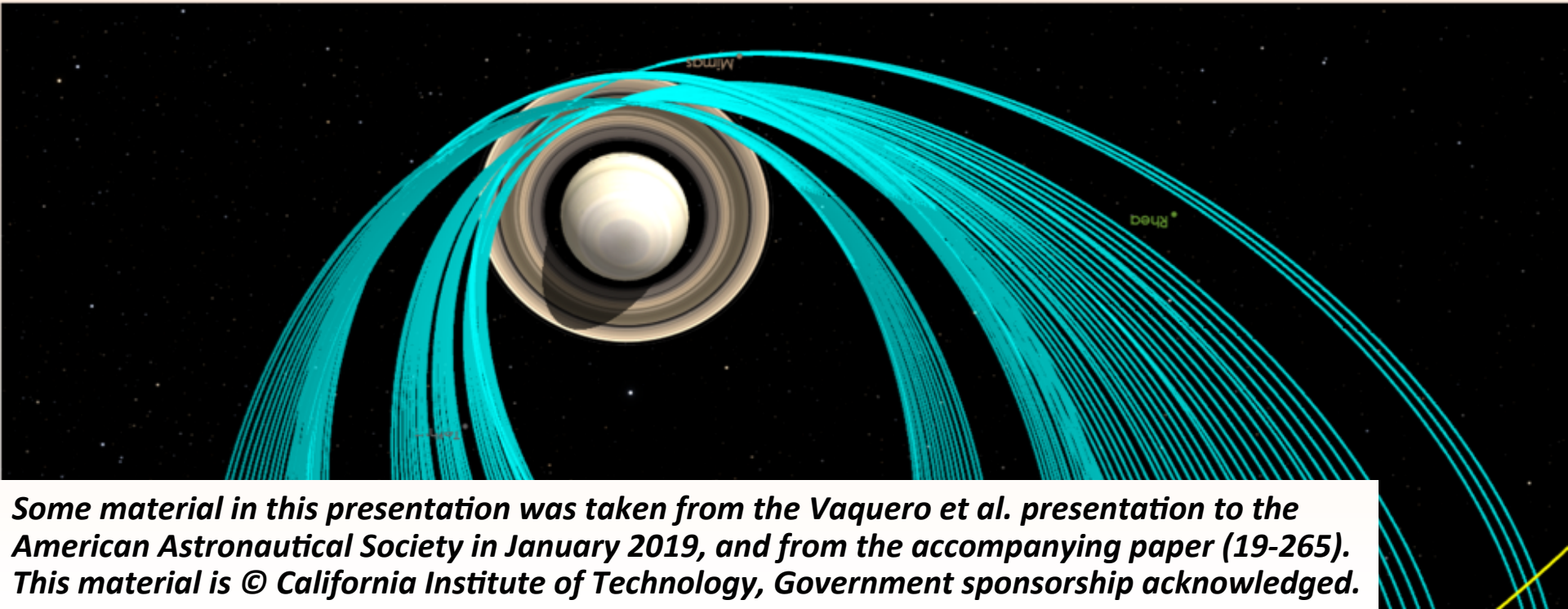
- What do individual ring particles look like? What are their colors? Shapes? Regolith properties? How do these vary with ring region?
- What happens when ring particles collide? What governs restitution? Do sharp-edged ring texture belts result from different regolith properties and/or particle size distributions?
- What are the mechanics of self-gravity wakes? How do they vary?



# Conclusions

- Innovative trajectory technique enables weekly low-altitude flybys of Saturn's rings
- Compelling science beyond Cassini for rings, magnetospheres, atmospheres, and interior (Titan and icy sats science comes free)
- Further study needed to characterize mission concept trade space, for realistic and compelling science objectives




***Some material in this presentation was taken from the Vaquero et al. presentation to the American Astronautical Society in January 2019, and from the accompanying paper (19-265). This material is © California Institute of Technology, Government sponsorship acknowledged.***