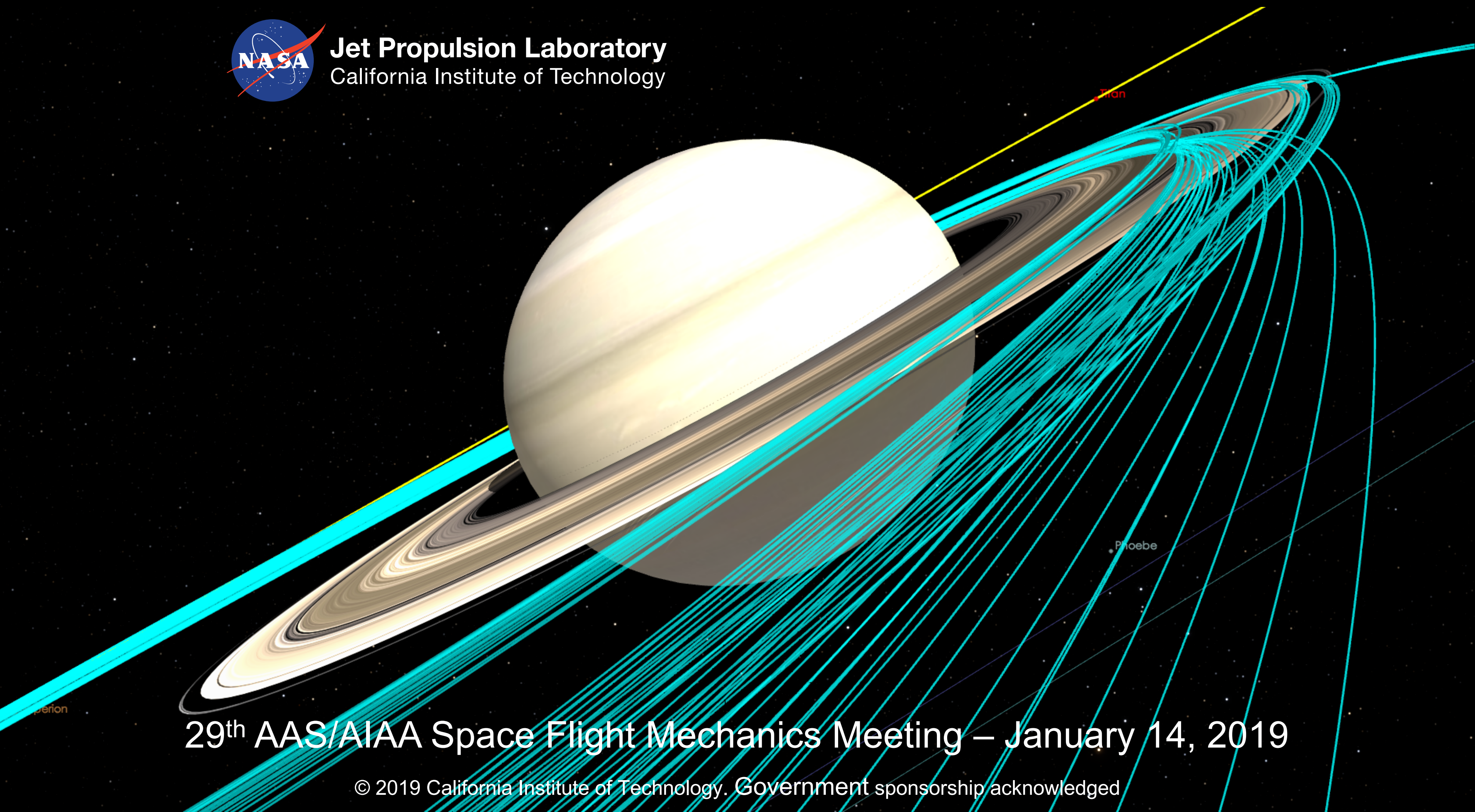
A Titan Gravity-Assist Technique for Ballistic Tours Skimming over the Rings of Saturn

Mar Vaquero, Juan Senent, and Matt Tiscareno

Jet Propulsion Laboratory
California Institute of Technology



29th AAS/AIAA Space Flight Mechanics Meeting – January 14, 2019

The Rings

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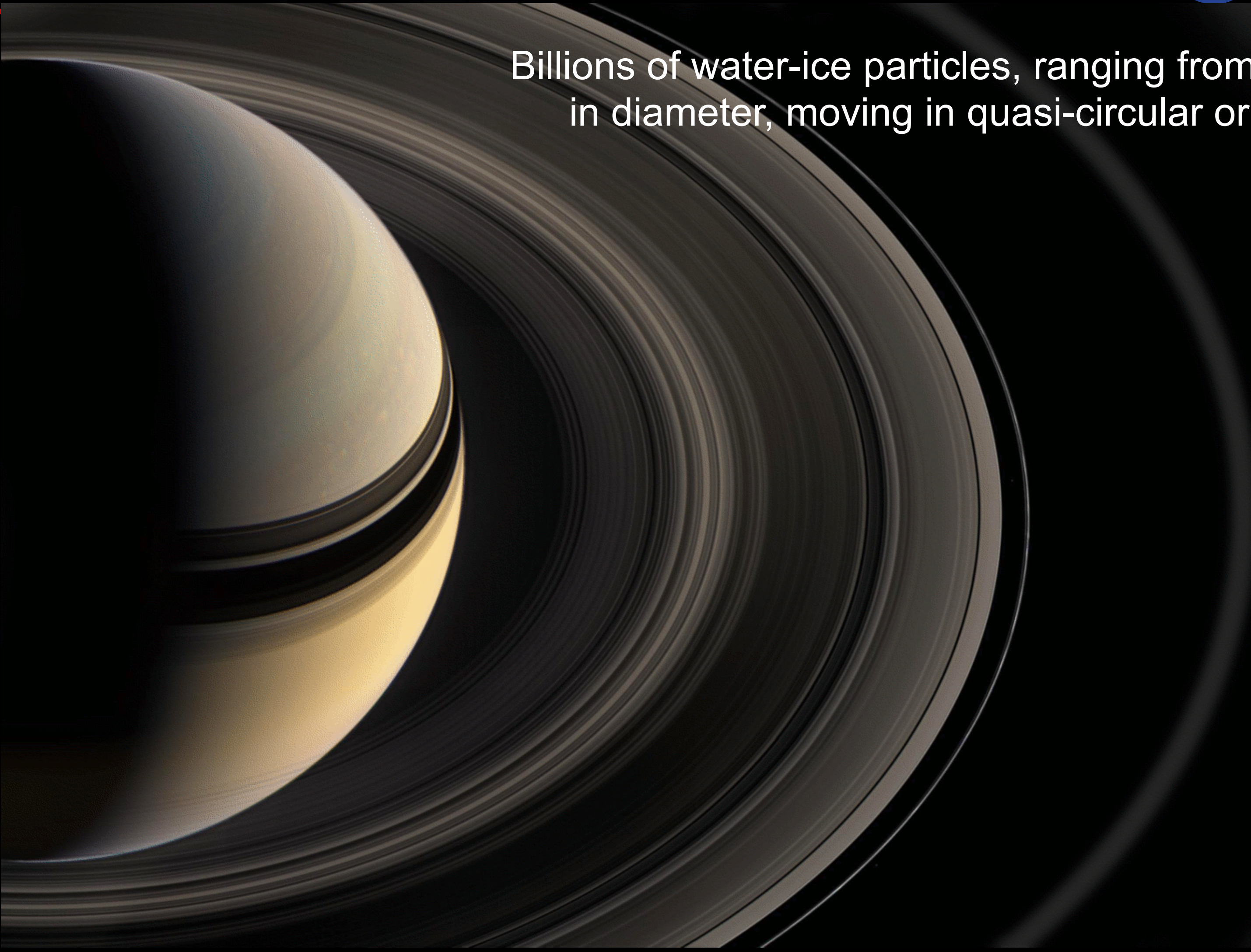
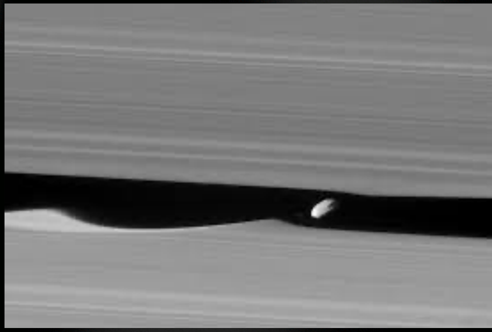
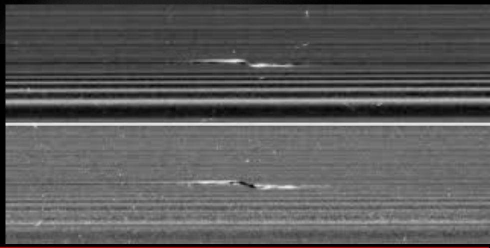


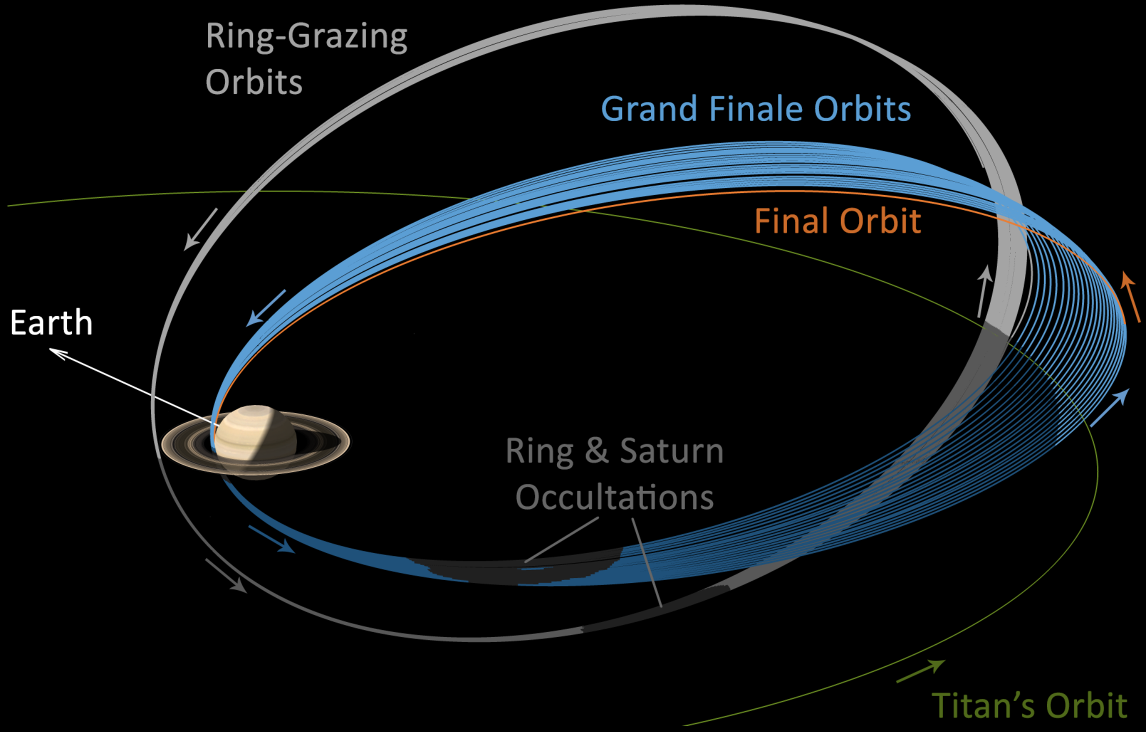
Billions of water-ice particles, ranging from millimeters to meters in diameter, moving in quasi-circular orbits around Saturn





Understanding the ring system’s formation and interactions between particles would help unveil the dynamics and time scales of planetary accretion disks that build planets around stars

The Rings as seen by Cassini



During the Grand Finale…

The Rings as seen by Cassini

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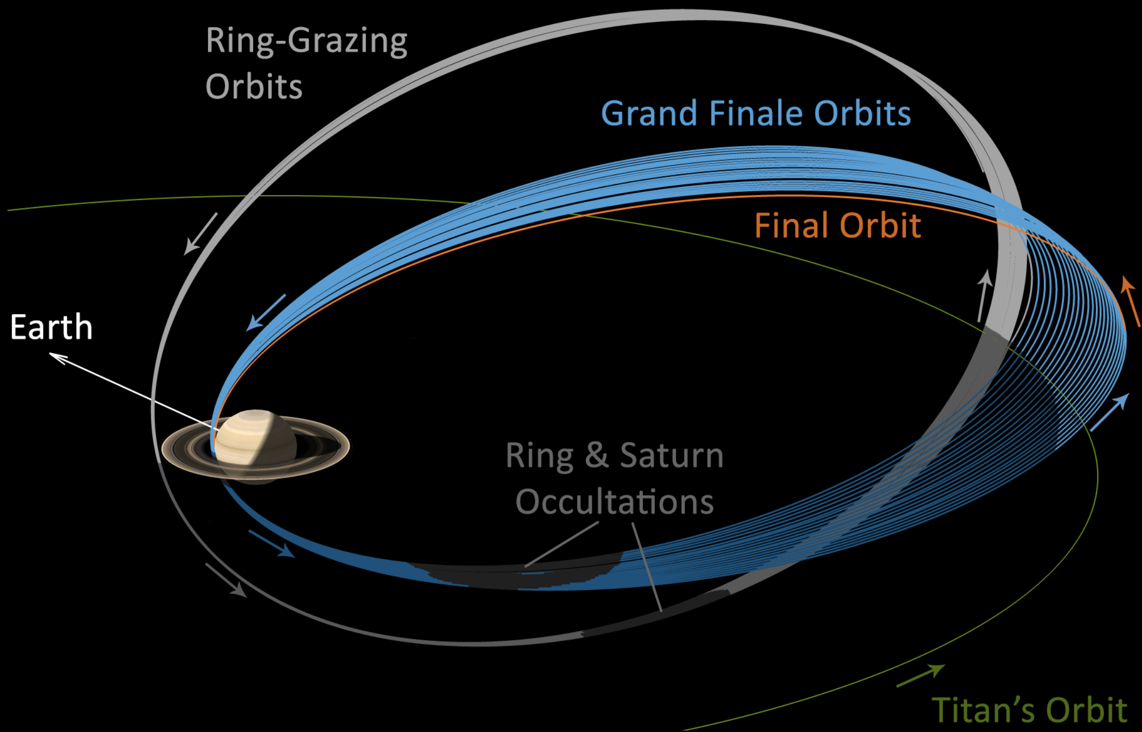

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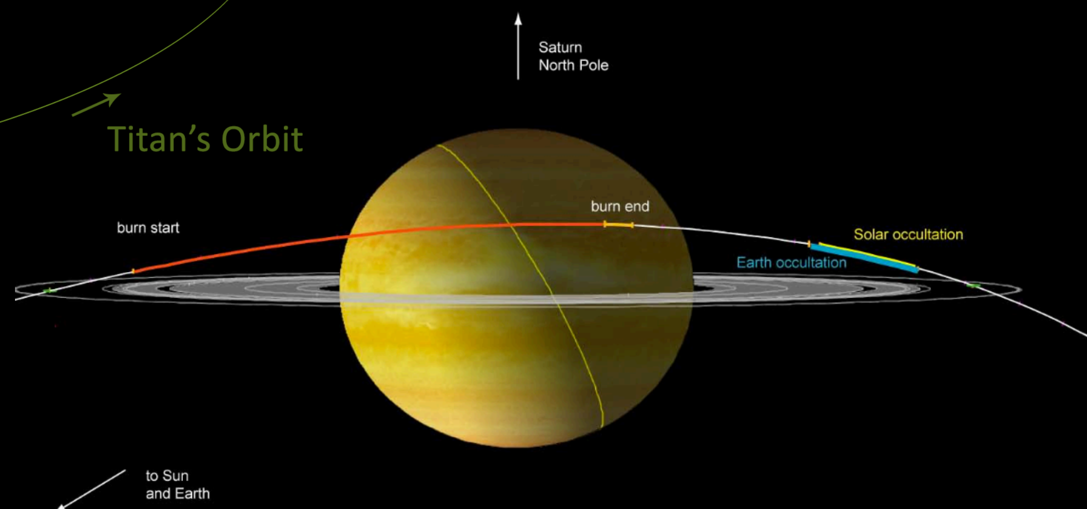

…and during the Saturn Orbit Insertion burn in 2004

Cassini SOI Ring Pass

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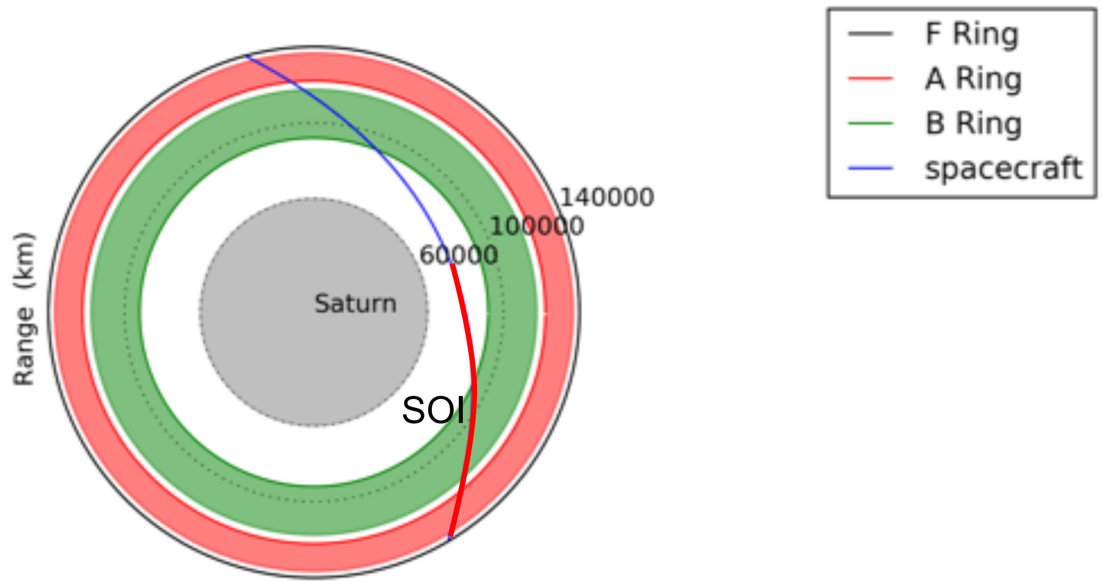
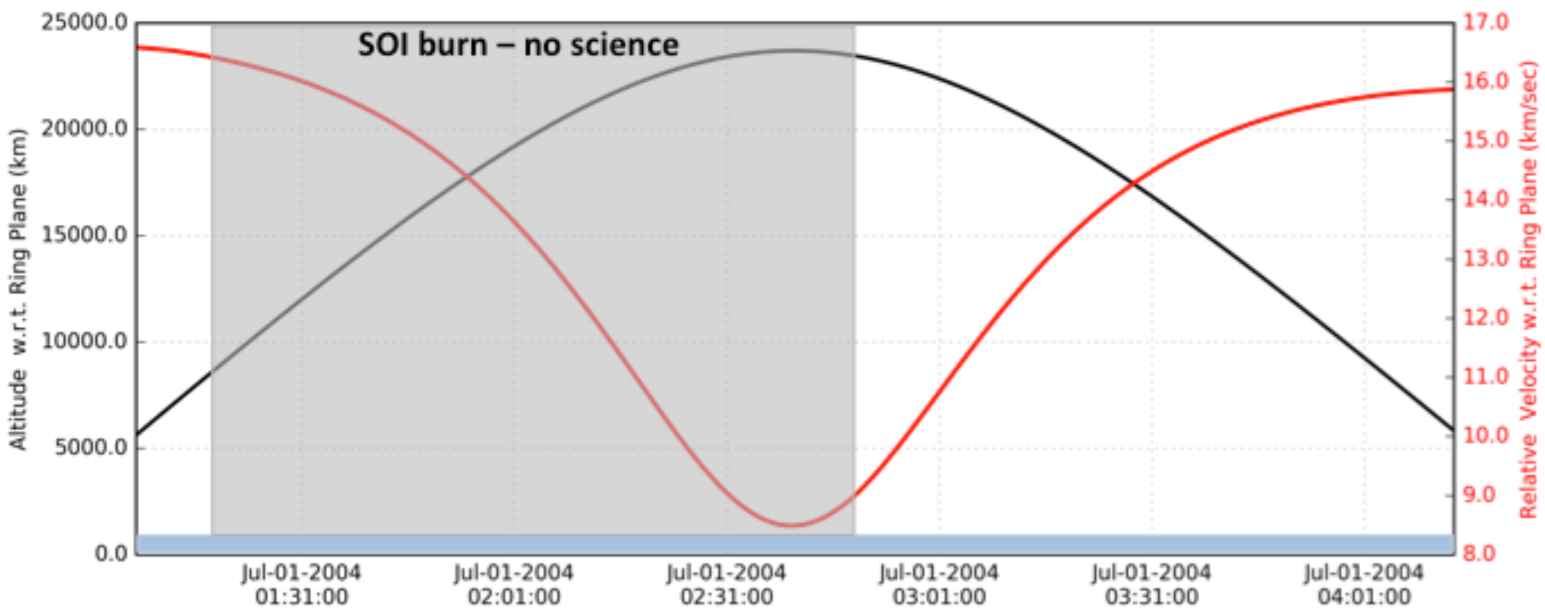
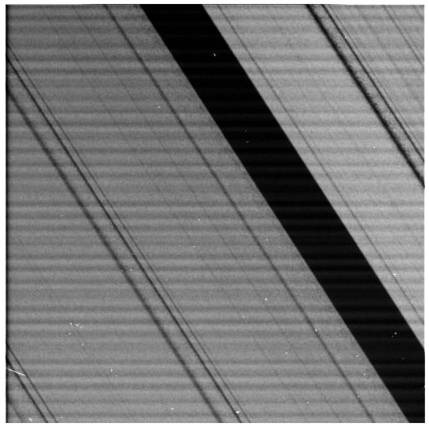
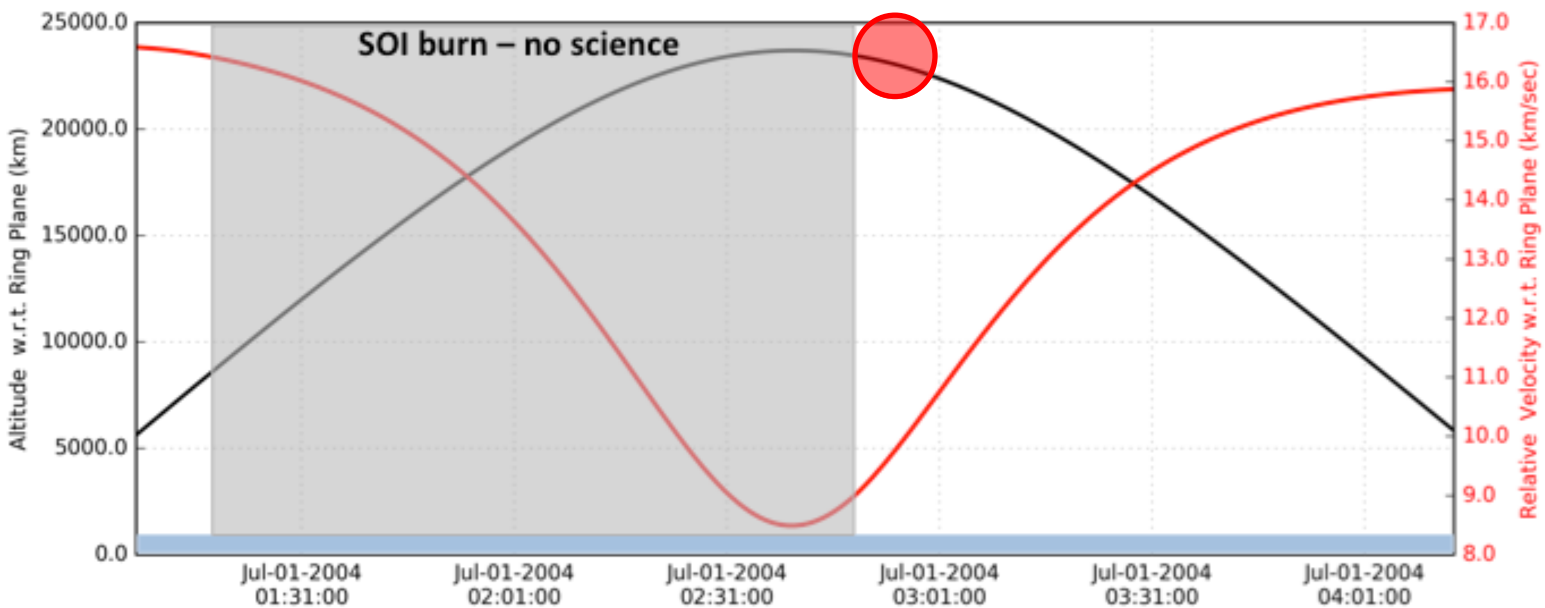




Cassini SOI Ring Pass

Cassini's closest image of the rings taken from 24,884 km; ~400 m/pixel





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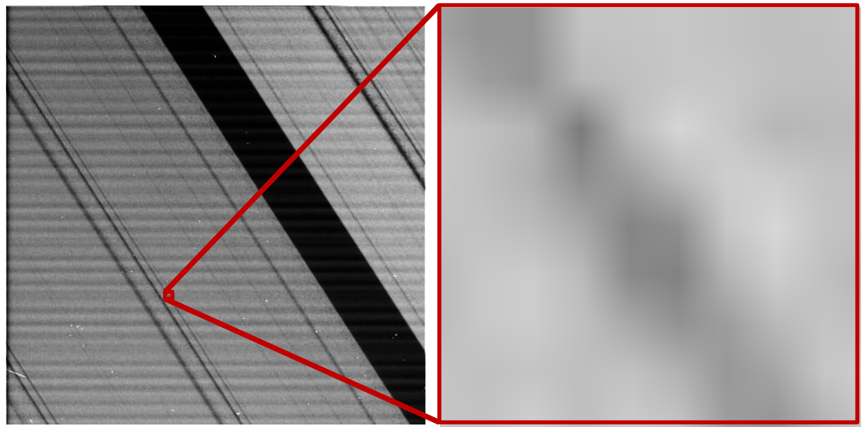
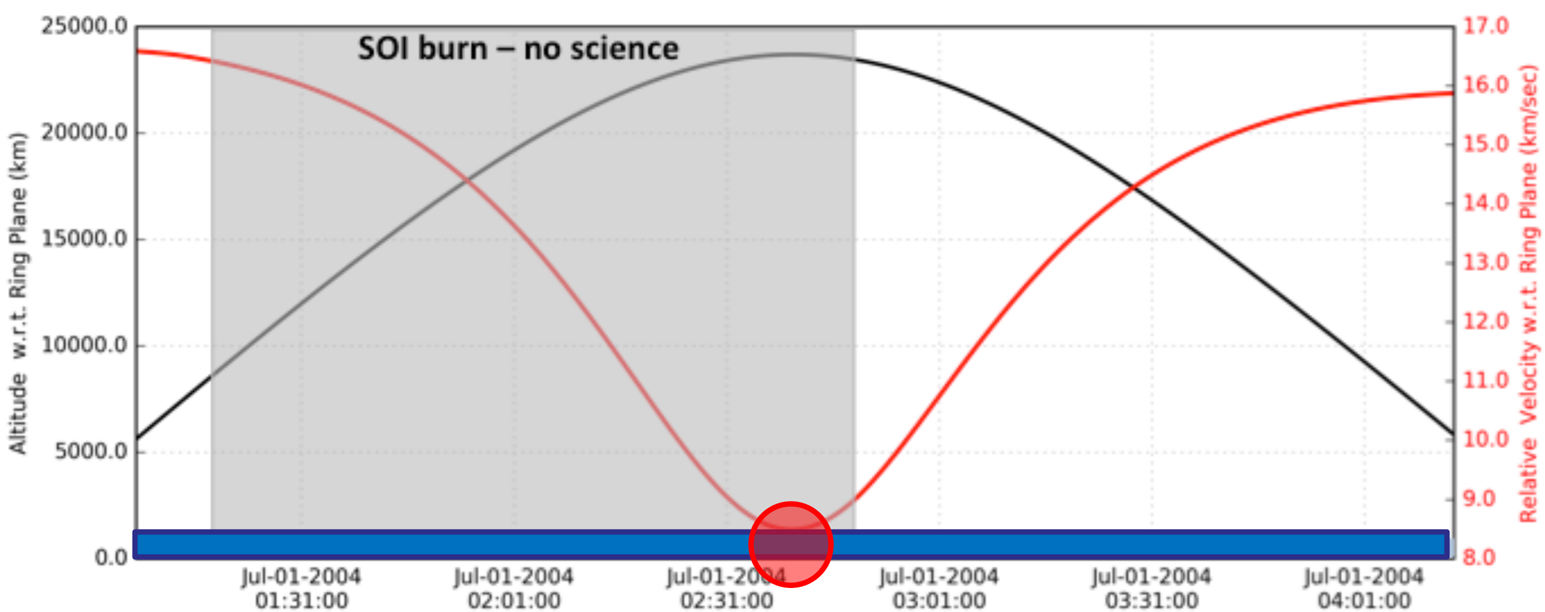


Taking images from 800 km or closer would allow better than 7 m/pixel with modern cameras



Saturn Ring Observer

JPL-led study to examine the technological feasibility for a Saturn ring focused mission

Goal

Conduct in situ studies from a SC placed in a circular hover orbit a few km above ring plane

Highest priorities

Power, propulsion, trajectory technologies

Proposed method

Continuous low-thrust ion engine to maintain vertical displacement and chemical thrusters to “hop” over ring obstacles

Technical challenges

Direct insertion into hover orbit (<10 km/s), complex operations, continuous maneuvering

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New Flyby Technique

A flyby mission to study the rings from a SC that repeatedly skims over different ring regions at close ranges

Highlights

Does not require any new technology

Could have been flown by Cassini in March 2016

Maintains ring plane crossings outside of F ring

Features 4 ring passes/month, 2.5-3.5 hrs long

Potentially all regions of the rings are explored

Deterministic DV = 0 m/s

Simplified architecture and operations

Drawback

High relative velocity (~ 8 km/s)
(a scanning platform could mitigate smearing)

Sample Ring Skimming Tour

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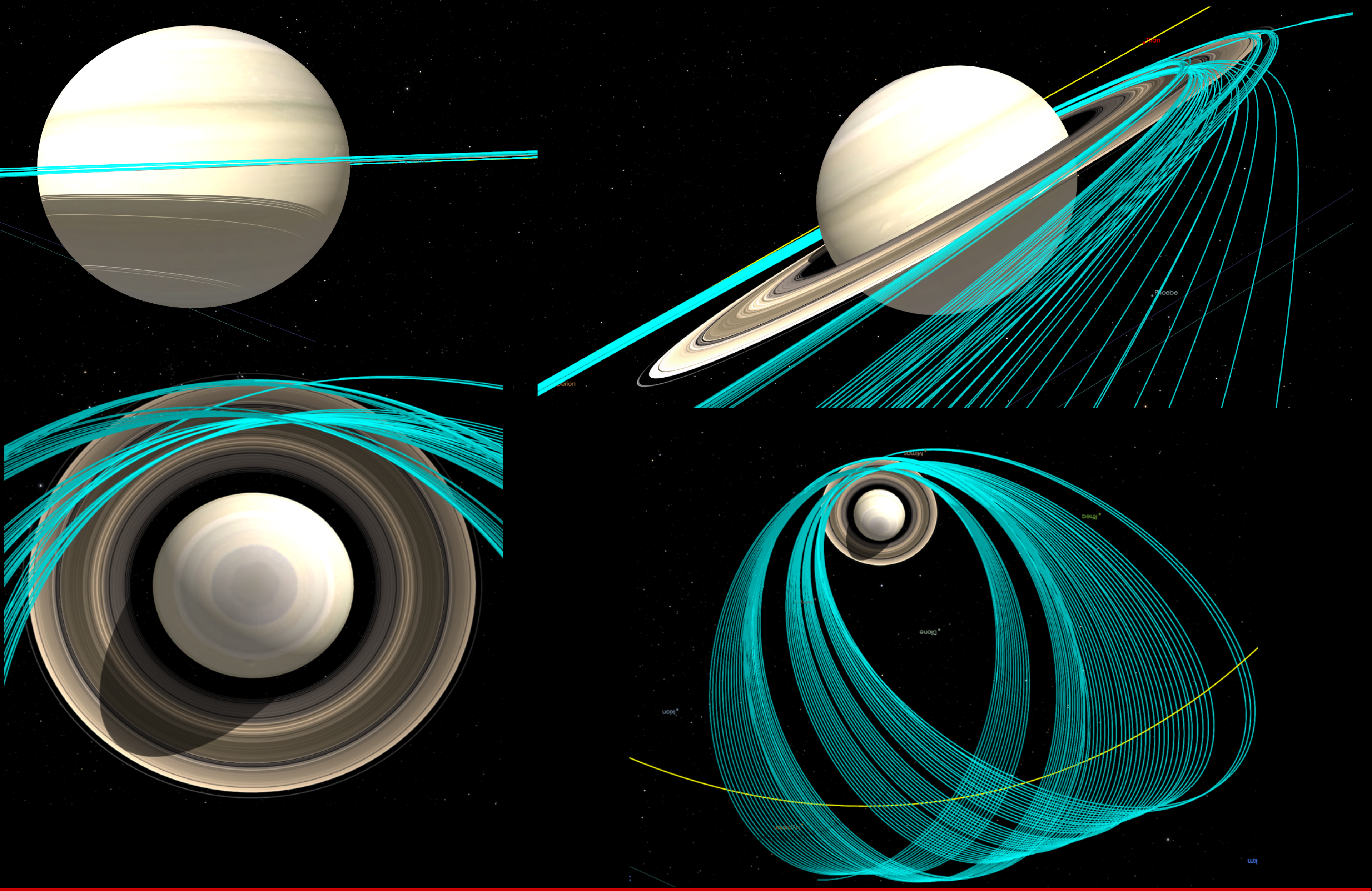
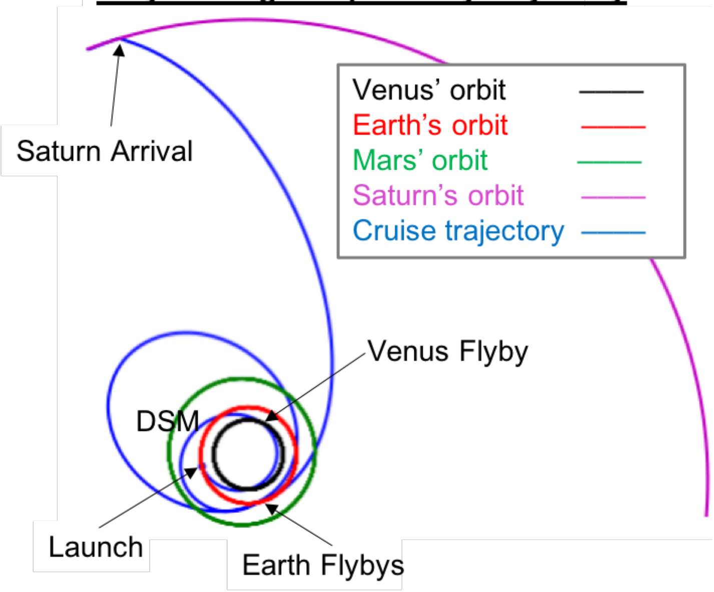
California Institute of Technology



Getting to the Ring Plane

8.5 year-long Interplanetary Trajectory



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

Getting to the Ring Plane

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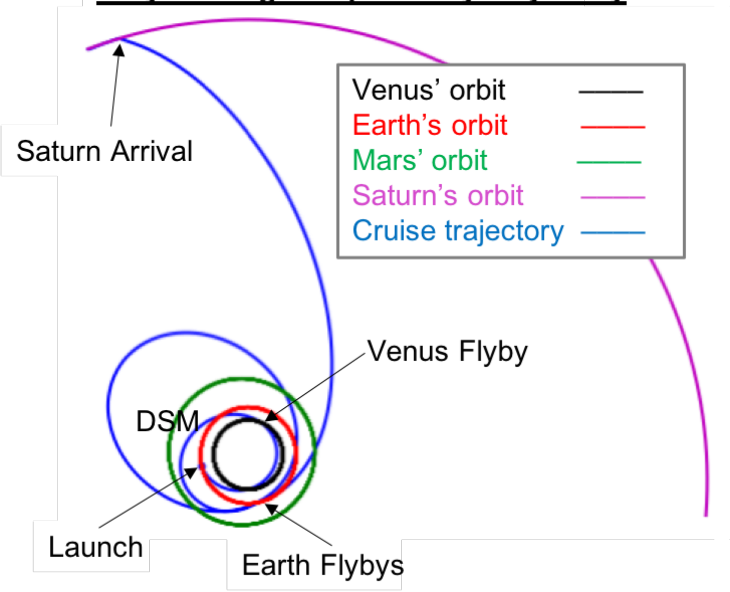
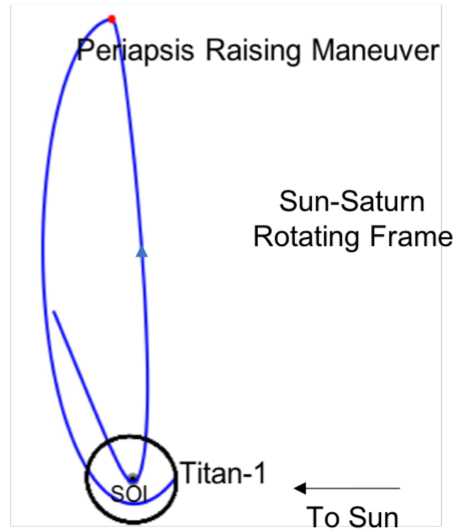


180-day Capture Orbit



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SOI	04 JAN 34	646 m/s
PRM	30 MAR 34	381 m/s
Titan-1	27 JUN 34	1000 km
TOF		174 days

Getting to the Ring Plane

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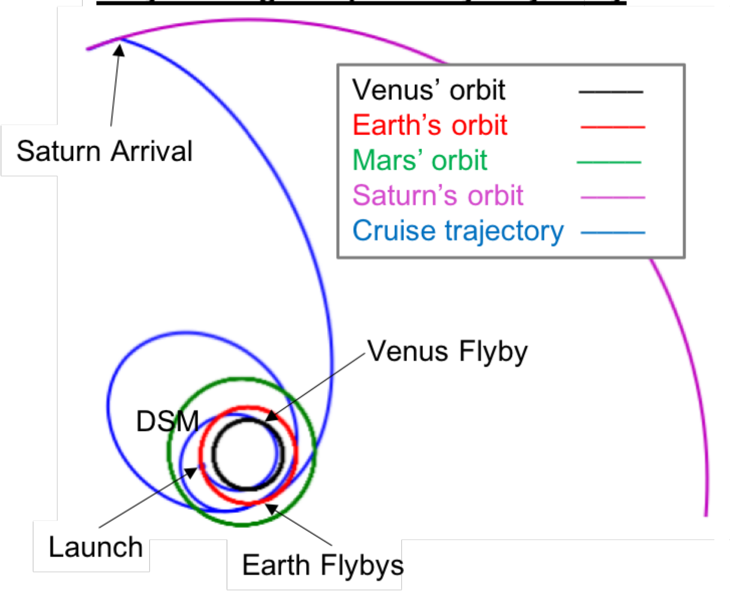

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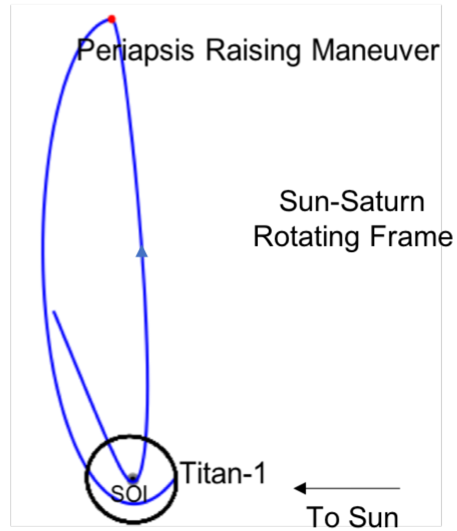
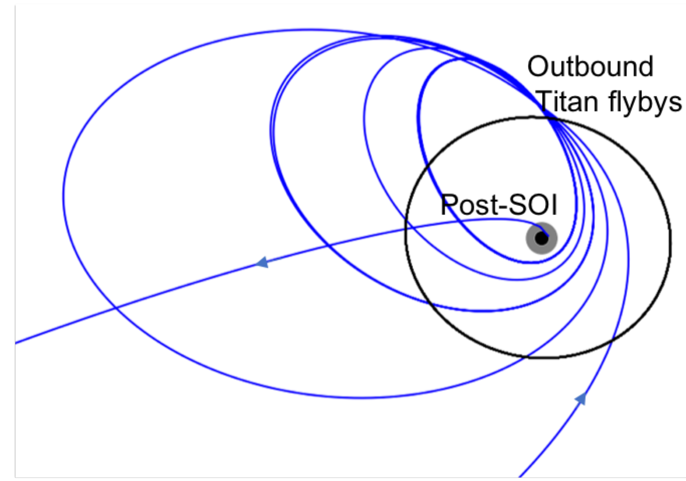


5-month Pumpdown Sequence



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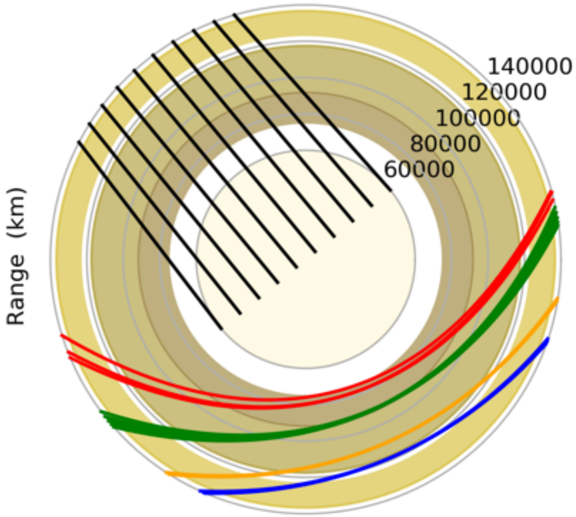
Event	Epoch	Alt (km)
Titan-2	14 AUG 34	1000 km
Titan-3	30 SEP 34	999 km
Titan-4	16 OCT 34	1946 km
Titan-5	02 DEC 34	6970 km
TOF		159 days

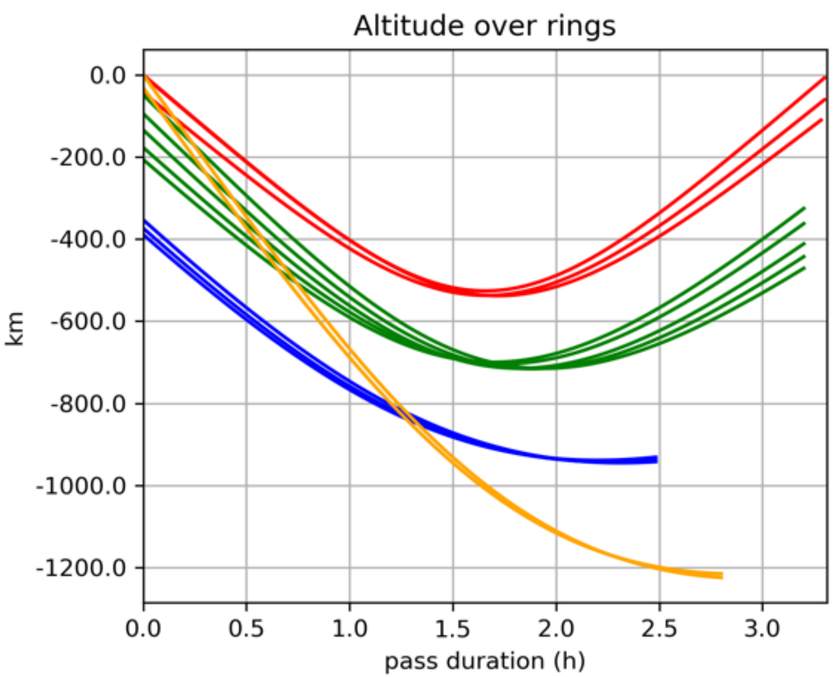
Titan flybys V_∞ ~ 5.14 km/s
Total TOF to ring plane = 9.34 yrs
Total ΔV = 1028 m/s

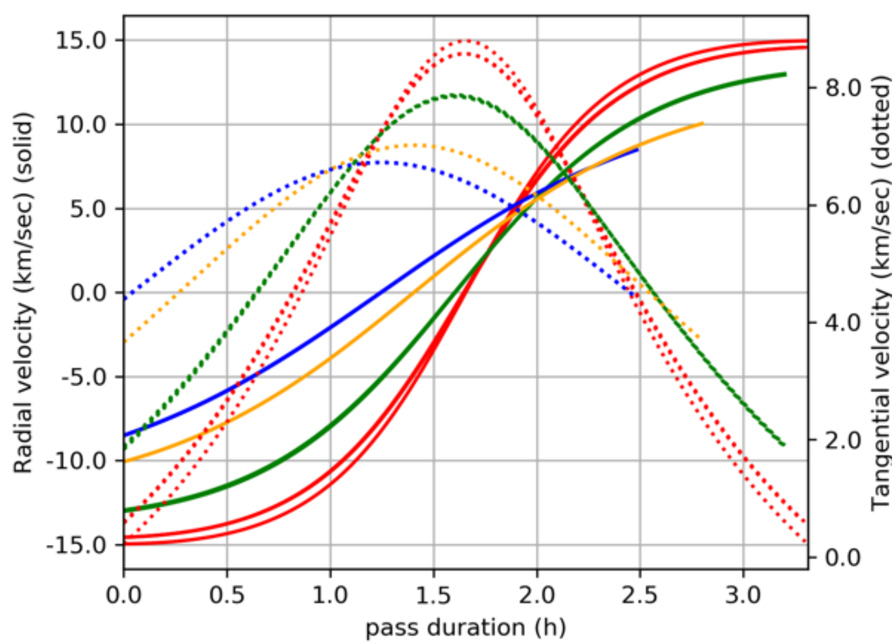
Ring Skimming Campaign



Flyby	Epoch	Alt (km)	V_∞ (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





Ring Skimming Tour Space

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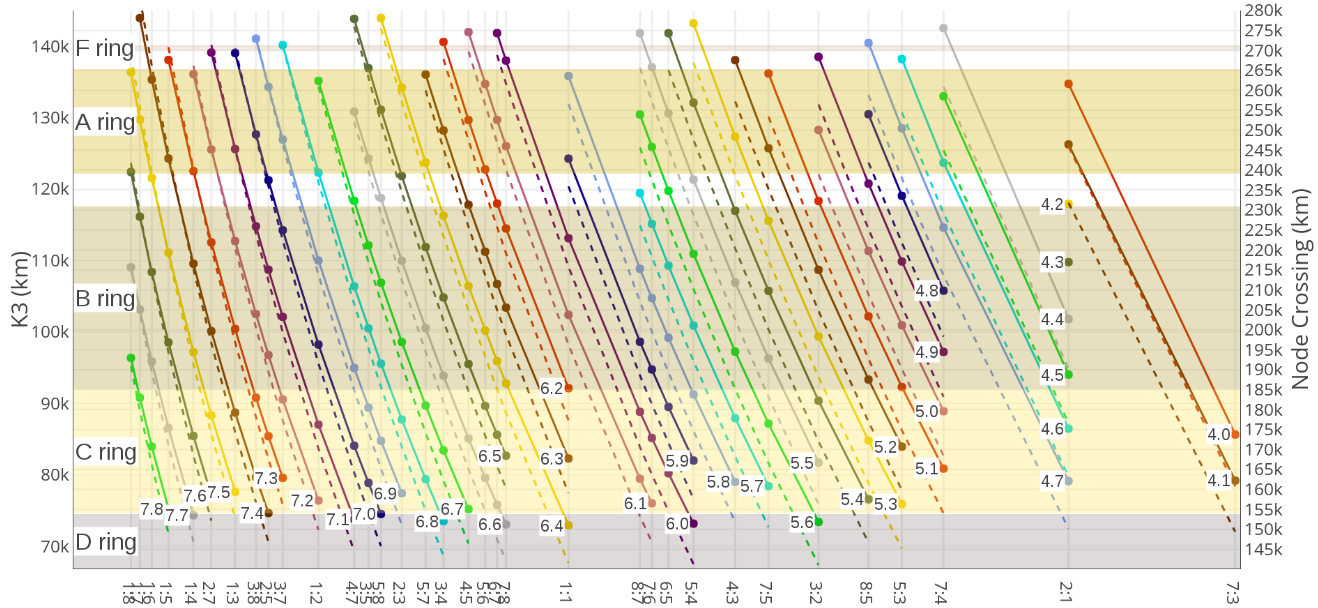
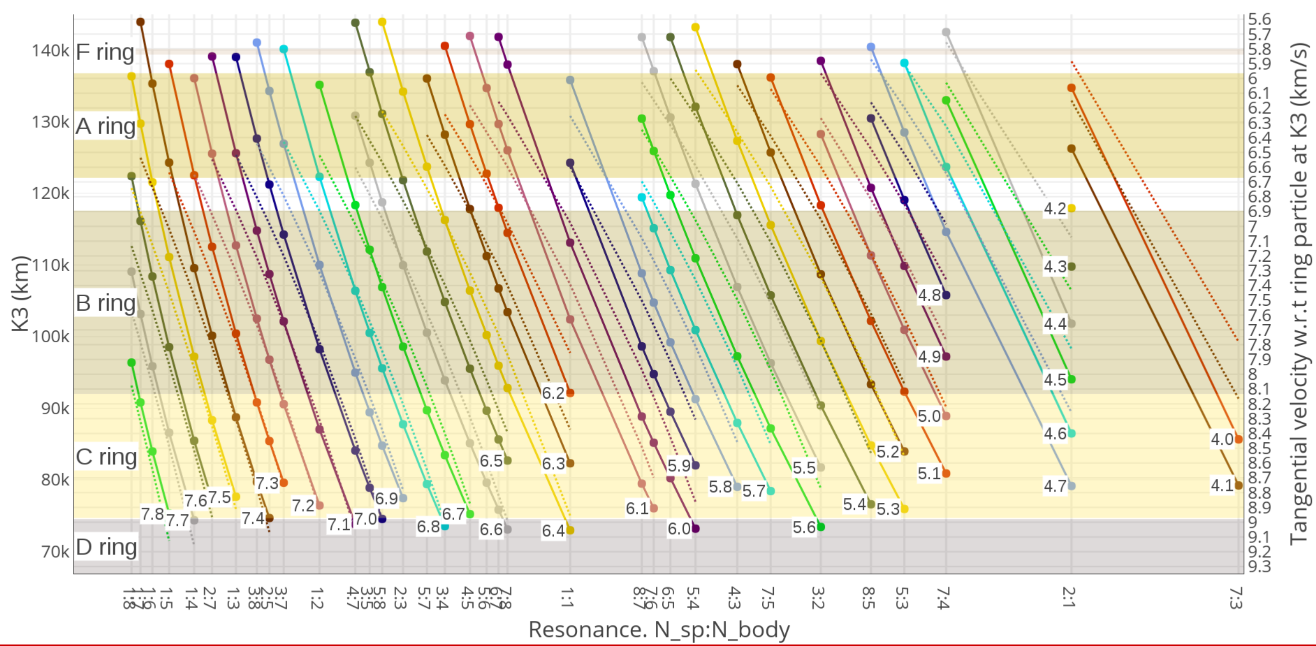
Exploit Titan flybys to design “ring tours” rather than “moon tours”

Graphical approach to characterize ring-skimming enabling flybys

Two key parameters for ballistic tours: Titan V_∞ and resonance

Each family of Titan flybys corresponds to a Titan V_∞ value





Icy Moons Bonus Flybys

One key aspect of ring-skimming orbits is low orbital inclination wrt ring plane, which is also the orbital plane of the icy moons.

This orbital geometry results in multiple untargeted flybys of the icy moons:
Mimas (5), Enceladus (4), Dione (1), Rhea (3)

With a submillimeter microwave instrument:

- distant flyby imaging when the SC passes within 100,000 km of the target
- distant plume imaging could be done from as far as 200,000 km

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

Significance of Results

New flyby-powered ring-skimming orbits

address the needs in the current Decadal in an elegant and affordable way

Scientific appeal

Mission enabling

Simple concept

could support a Discovery or New Frontiers mission with today's technology

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