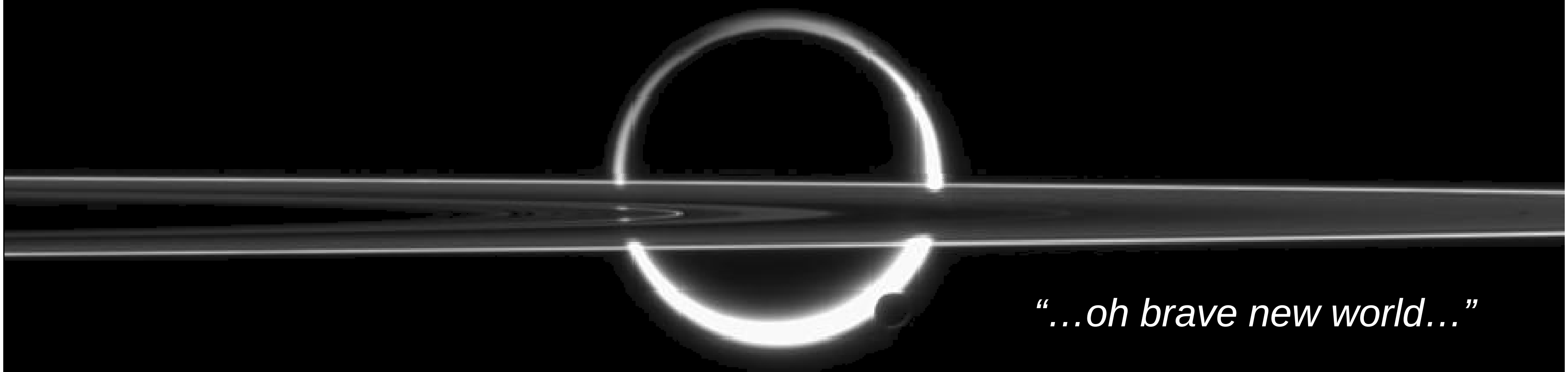
TSSM

Titan Saturn System Mission



"…oh brave new world…"

TSSM Architecture and Orbiter Design

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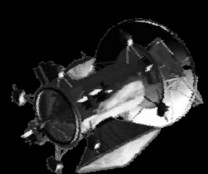


Titan after Cassini July 9, 2008

Agenda

- **Background**
- **TSSM Study Goals and Drivers**
- **Science Mission Architecture and Orbiter Design**
- **Results from 2nd NASA HQ Interim Review**
- **Go-Ahead Plan**

Background

- **In late FY05, NASA conducted a short study of a Europa Geophysical Explorer concept following cancellation of JIMO**
- **In FY06, JPL conducted internal studies on a Europa Explorer and Titan Prebiotic Explorer (TiPEX) concepts**
- **In FY07, NASA initiated Phase I studies of potential Outer Planet Flagship missions to four icy satellite targets**
  - Europa Explorer, Jupiter System Observer, Titan Explorer, Enceladus
- **ESA initiated its Cosmic Vision program and two outer planet missions were proposed and ultimately selected as L-Class mission mission candidates**
  - LAPLACE – A three spacecraft Jupiter system mission envisaged as a collaboration with NASA and JAXA
  - TandEM – A Titan Enceladus mission envisaged as a NASA collaboration

Outer Planet Flagship Mission Selection Process

Post June 08 Milestones currently are being replanned as result of 2nd NASA HQ Review

Submitted 8/07

Down-selected 12/07

Titan Saturn System Mission

Europa Jupiter System Mission

Key 2008 Milestones

Initial Instrument Workshop……………June 3-5, 2008
Initial Report due to HQ……………………Aug 4, 2008
Site Visit…………… …………………...…..Sept 9,11, 2008
Final Report……………………………………Oct 22, 2008
Final down-select ……………………………Nov. 21, 2008

Down-select 11/08

http://opfm.jpl.nasa.gov

Titan Saturn System Mission
or
Europa Jupiter System Mission

Key Aspects

- International cooperation incorporated in both concepts
  - ESA would be primary international partner
  - JAXA, RSA, ESA member-states might participate
- NASA-only concept also under study
- JPL would lead partnership with APL, other NASA centers
- President's FY09 budget: funding to begin in FY09

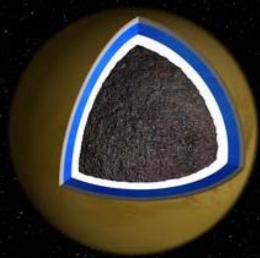
NASA Phase II Study – Key Milestones

- **Joint SDT members selected…………………………………Feb 1, 2008**
- **Study Kickoff……………………………………………………..Feb 9, 2008**
- **First Interim Review………………………………………….April 9, 2008**
- **Second Interim Review……………………………………….June 19-20, 2008**

Replanning underway

- **Phase II Initial Report……………………………………..Aug 4, 2008**
- **Science and TMC Panels reviews ………………………..Sep 9-11, 2008**
  - Europa Jupiter System Mission (EJSM)
  - Titan Saturn System Mission (TSSM)
- **Phase II Final Report………………………………………Oct 22, 2008**
- **Down-Select of mission…………………………………….Nov 2008**

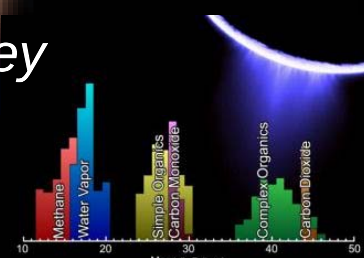
2008 Study Top Level Goals



- *Dedicated Titan orbiter with accommodation for ESA in situ elements*
- *Enceladus science and Saturn magnetospheric interaction with Titan*

- *Advancement in understanding Titan well beyond the high bar set by Cassini-Huygens*

- *Understanding of SSE Decadal Survey Science versus Cost*



Key Study Drivers

- **Propulsive (Non Aerocapture)**
  - Shortest possible flight times
  - Opportunity for Saturn science and Enceladus flybys
- **Cost**
  - Strong budgetary preference for Atlas V class LV and single launch
- **Level 1 Science: Titan, Saturn System, Enceladus**
  - Titan would be the primary target; other targets as they inform us about Titan
- **RPS Availability:** MMRTGs baselined only for orbiter
  - Study limit of 7 MMRTG worth of plutonium-238 for entire mission
- **Accommodate In situ elements**
  - In situ elements would be provided by ESA; accommodation, RPS and Launcher would be provided by NASA
- **2016-2017 Proposed Launch years**

Science Goals

- **Goal A: How does Titan function as a system; to what extent are there similarities and differences with Earth and other solar system bodies?**

- **Goal B: To what level of complexity has prebiotic chemistry evolved in the Titan system?**

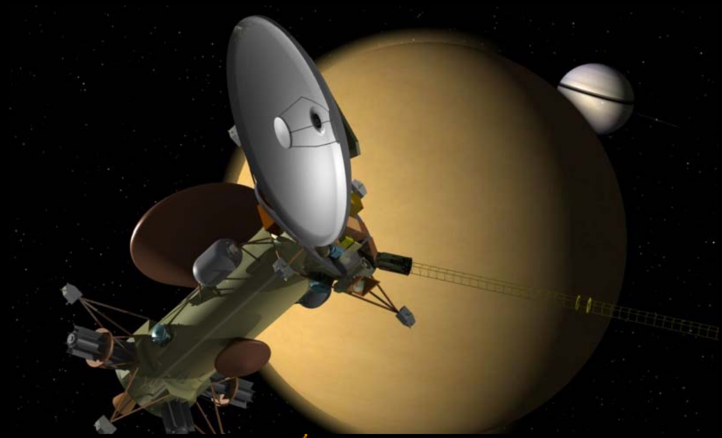
- **Goal C: What could be learned from Enceladus and Saturn's magnetosphere about the origin and evolution of Titan?**

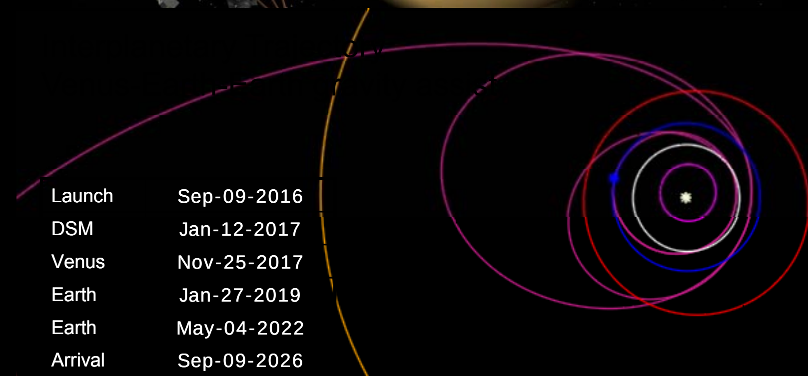
Mission Architecture Status

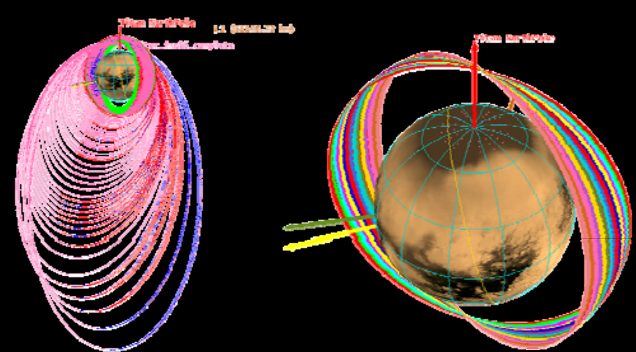
- **Many Chemical and SEP architectures were explored**
- **Preference was given to architectures that could address all Level 1 science requirements**
  - JSDT assessed science accommodation potential and balance of payload
- **Examined trip-time vs. delivered mass trades**
  - Attention paid to those with lowest estimated costs
- **Total Cost to NASA was the overriding factor in selecting the <u>core</u> architecture**
  - Comply with all ground rules
- **Balance between Science, Cost and Mission Risk was the overriding criterion in selecting the <u>sweet spot</u> architecture**
  - Achieve decadal science

Proposed Mission Overview

- **Level 1 Rqmts: Titan, Saturn system and Enceladus**
- **Proposed Architecture includes Orbiter that accommodates ESA provided in situ elements;**
  – Core mission includes lander
  – Sweet spot mission includes lander and Montgolfiere balloon
- **Proposed Core Mission Timeline:**
  – Launch on Atlas 551, Sep/2016
  – Saturn Arrival 9/2026
  – Saturn Tour; flybys: 4 Enceladus, 15 Titan
  – Dedicated Titan aerosampling and mapping Orbit
- **Sweet Spot mission would include Solar Electric Propulsion (SEP), 2 yr shorter trip time and delivery of lander and balloon**
- **Orbiter payload; 6 inst. + RSA**





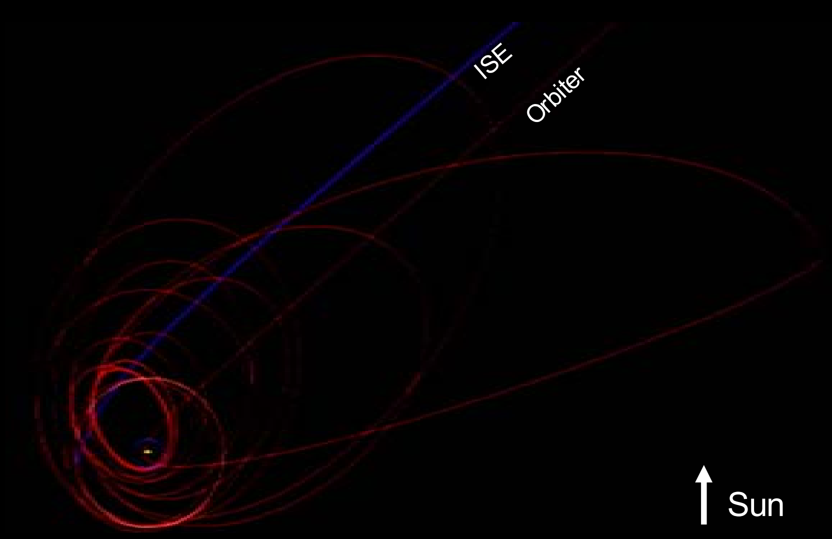


Artist's Concept Only

Saturn Tour

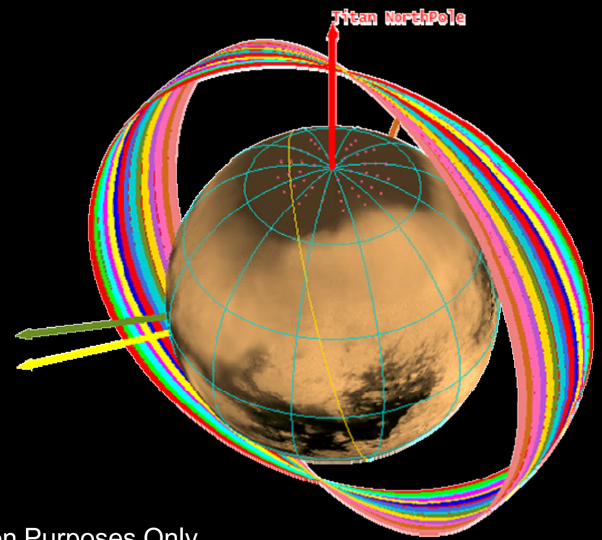
1.5 year Saturn gravity-assist tour; Sep 10, 2026 to March 3, 2028; 15 Titan flybys and 4 Enceladus flybys

- **Tour would consist of Three Phases:**
  - Initial Slow-Down
    - 100 day transfer from SOI to first Titan flyby used to reduce energy enough to set up Enceladus flybys
  - Enceladus Flybys
    - 4 Enceladus flybys (100-500 km)
  - Final Slow-Down
    - Reduces Titan V∞ from 4 km/s to 0.8 km/s for efficient Titan orbit insertion.



Titan Orbit

- **Would insert into initial 950 km by 15,000 km ellipse.**
- **Aerobraking would reduce ellipse over two months while sampling atmosphere down to 600 km.**
  - ~170 passes
  - ~400 m/s delta-v savings
- **Aerobraking phase to be followed by a 6 month mapping phase:**
  - 1500 km, circular orbit
  - Near-polar (85º inc)
  - Orbit plane varies from ~4 pm to ~3 pm over 6 month mapping period



International Mission Concept

- **NASA Would Provide Titan Orbiter**
  - Would be launched in 2016-2018
  - Would be Radioisotope powered
  - Would reach Saturn in ~10 years, spend ~2 years in Saturn orbit with 4 Enceladus and 15 Titan flybys before entering a Titan orbit phase
  - Would conduct extensive investigation of Titan and provide delivery and relay accommodations for in situ elements

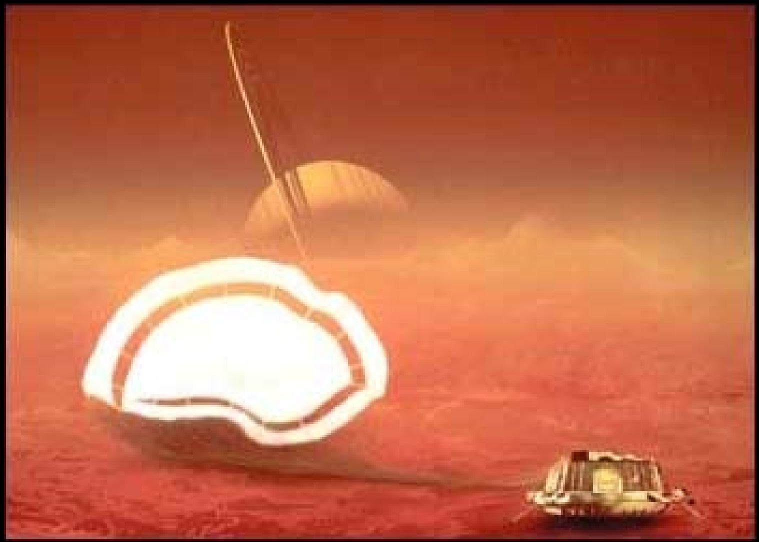
- **ESA To Provide In Situ Elements (Lander, Montgolfiere Balloon)**
  - Would be launched in 2016-2018
  - Radioisotope Powered; RPS and launcher would be provided by NASA
  - Would reach Titan in ~10 years -- potential for extended mission
  - Would conduct extensive in situ investigation of Titan's lower atmosphere, surface and interior

- **Single Launch of orbiter and lander on Atlas V is Core – Orbiter + Lander + Balloon with SEP on single or two-launch Atlas class is the sweet spot**

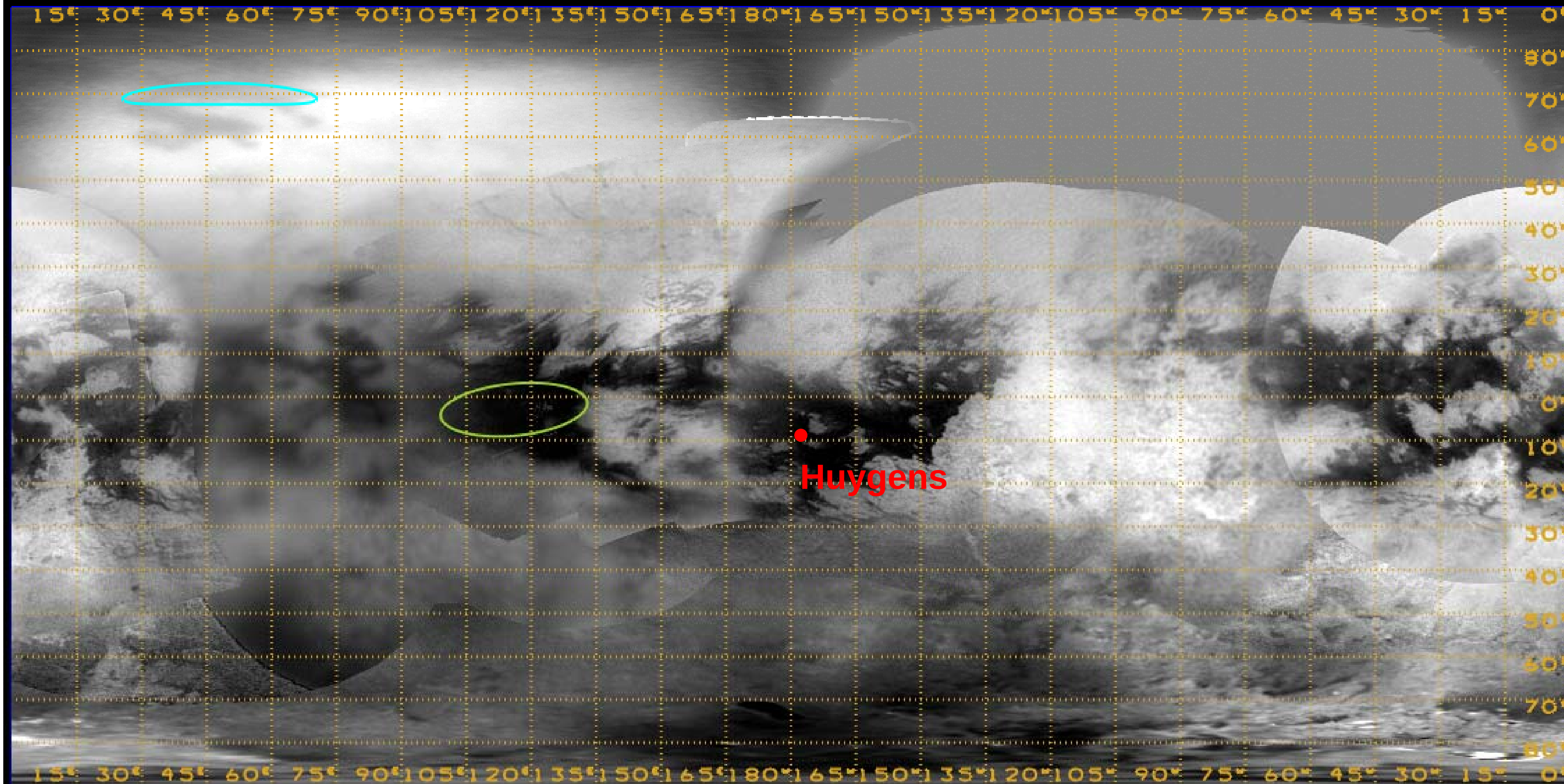
ESA *In situ* elements

- **Montgolfiere Balloon**
  - Release 6 months prior to SOI; <6km/s
  - Near equatorial to mid latitude location
  - Relay to orbiter and Direct to Earth (DTE) in Saturn tour and after TOI
  - Floats at ~10km nominal altitude
  - Circumnavigates the globe more than once
  - Lower atmosphere and surface science
  - > 6 months earth year lifetime desired

- **Capable Lander**
  - Considering lake or dry lake bed at northern latitudes, or dunes at mid latitude
  - Very similar entry conditions to balloon
  - Similar relay options as balloon
  - Surface, hydrology and interior science
  - >1 earth month (2 Titan days) life time desired
    - >1 hour lifetime for lake landing, possibly battery power



Potential *In Situ* Entry Regions



- Lander would be targeted to north polar region or mid-latitude dunes
- Balloon would be targeted to mid-latitude region

NASA-ESA Mission Timing Considerations

- **Programmatic - Schedule**
  - NASA and ESA launch planning dates are yet not aligned
    - Current planned NASA OPFM launch dates are 2016-2017
    - ESA's in situ element launch availability is 2018
    - Study assumes alignment
    - Timing is continuing subject of NASA/ESA discussions

- **Technical – Orbiter and in situ mission overlap**
  - For the Core and Sweet Spot missions, delivering a capable in situ element could be done at any point during the mission, however the current approach considers pre-SOI release to maximize potential delivered mass
    - For pre-SOI release the in situ prime mission would be completed while the orbiter is in Saturn orbit – impacts data rates
    - For post-SOI release the in situ prime mission and orbiter prime missions would overlap – impacts data rates
    - Trades are being assessed by NASA and ESA design teams

TSSM Launch Opportunities

- **No major discriminators in launch performance in the period from 2016 to 2022**
  - No favorable alignment of Jupiter after 2015
  - Opportunities most years (2017 and 2019 have longer flt times)
  - Best opportunities involve favorable alignments of Venus and Earth
- **SEP combined with gravity-assist opportunities would enable delivery of full suite of in situ elements and shorter trip times**
- **Separate launch of orbiter and in situ element would offer optimization of schedules, higher delivered mass and shorter trip times**

Operations

- **Saturn Approach – Instrument calibration, operations exercises and MAPP magnetospheric measurements as spacecraft crosses magnetopause**

- **Saturn Tour - Saturn, Enceladus and Titan Science**
  - 4 low-altitude Enceladus flybys
    - Power - Telecom in standby for Closest Approach (C/A) +/- 2 hours, all instruments operating
    - Attitude – Near C/A PMS facing RAM, otherwise optical remote sensing (ORS) instruments pointed toward Enceladus
    - Data Flow – 1.7Gb of science recorded; playback from +2hrs to +8.5hrs (at 75kb/s)
  - 15 Titan Flybys (Altitudes → 5 low flybys < 1200km, 10 higher flybys > 1200km)
    - Power – Telecom in standby for Closest Approach +/- 5hours
    - Attitude for low flybys – Near C/A PMS facing RAM, otherwise ORS pointed towards Titan
    - Attitude for higher flybys – ORS pointed towards Titan throughout
    - Data Flow ~4Gb of science recorded on each flyby; playback from +5hrs to +19hrs

- **Aerobraking – ~100 Titan passes, many at 600–700km altitude**
  - Power – Telecom on continuously, only PMS & MAPP would operate when in atmosphere, only ORS would operate when outside atmosphere.
  - Attitude – Near periapse PMS to RAM and ORS pointed toward to Titan
  - Data Flow – Each aeropass will acquire ~50Mb, ORS records up to 300Mb each orbit.

- **Orbital Phase - (Discussed on the following slide)**

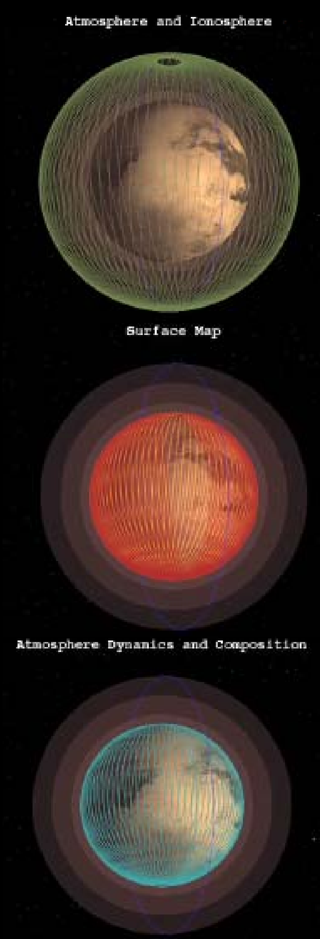
- **Decommissioning – HiRIS and TBD data capture and playback until impact**

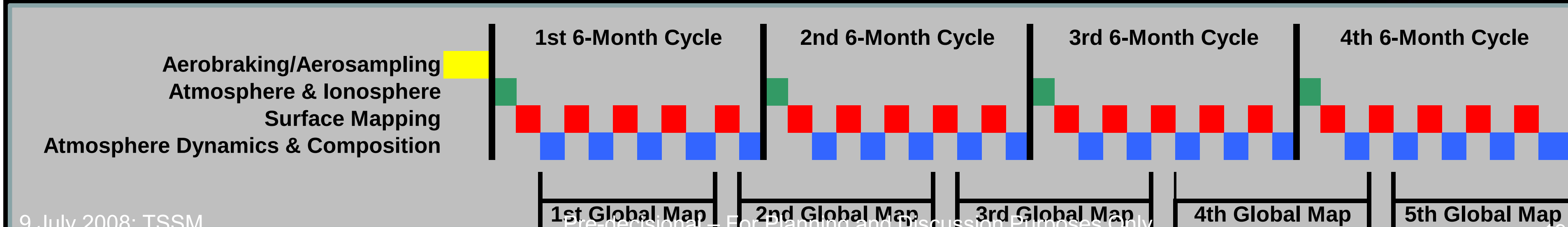
Titan Mapping Orbit Example

Three Titan science orbit types (16-day) enable global coverage

- Atmosphere & ionosphere (PMS & MAPP): identify and measure ions and neutrals globally for various Sun angles
  - Unloads SSR by 26Gb during campaign
- Surface map (HiRIS, TIPRA, & MAPP): global map in up to 4 colors; global altimetry with better than 10-m accuracy; surface spectroscopy
  - Loads SSR by 20.6Gb during campaign
- Atmosphere dynamics and composition (TIRS & SMS): measure temperatures, composition, and winds, globally

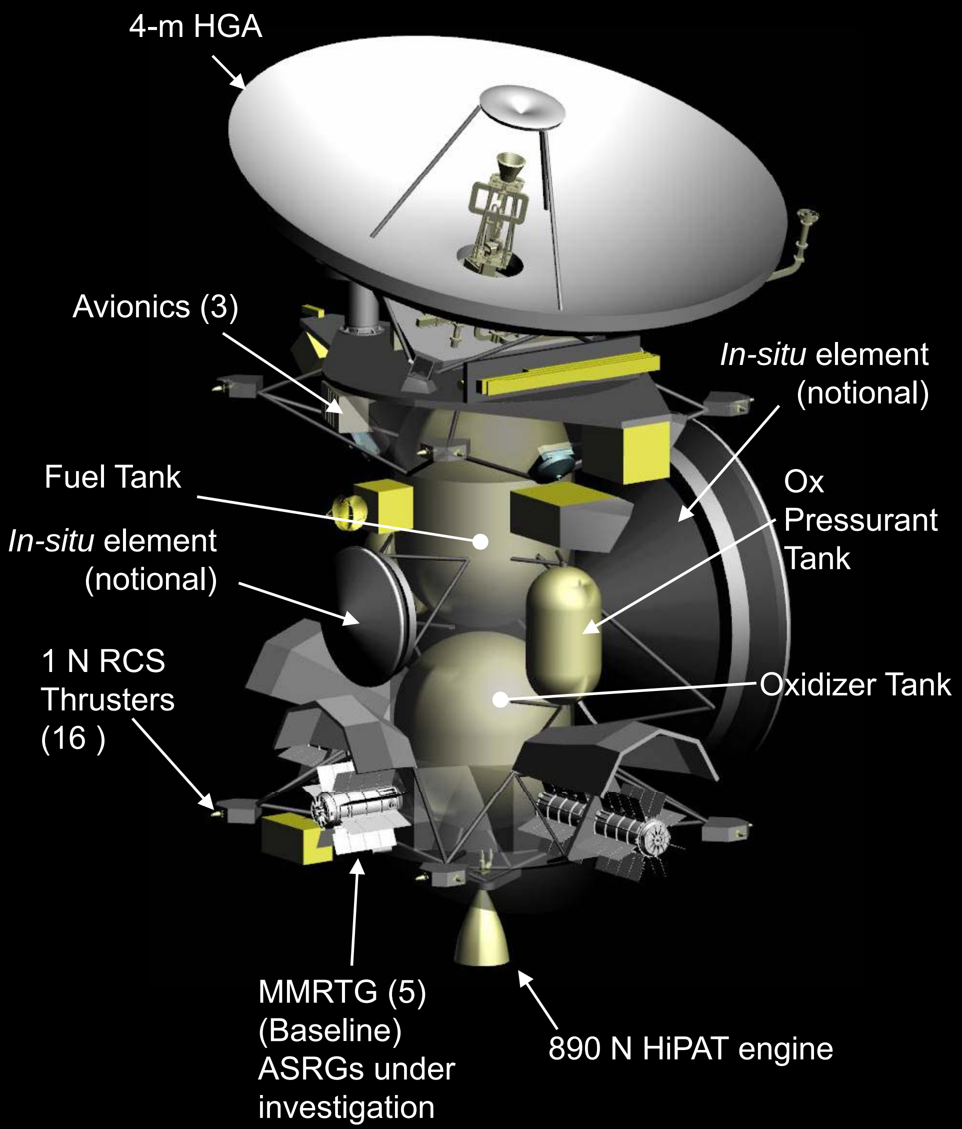
Example scenario demonstrates capture of science objectives





Proposed Core Spacecraft Configuration

- **Configuration represents a balance of science, mass, cost & risk**
- **Orbiter dry mass ~1636 kg including 33% margin**
  - 150 kg allocated to orbiter instruments
  - Current *in situ* mass capability delivered to Titan orbit ~150 kg
    - Equates to 300 kg pre-SOI release
    - ESA currently designing to 150 kg allocation
- **Total Mission Dose estimated at ~21 krad (behind 100 mil Al)**



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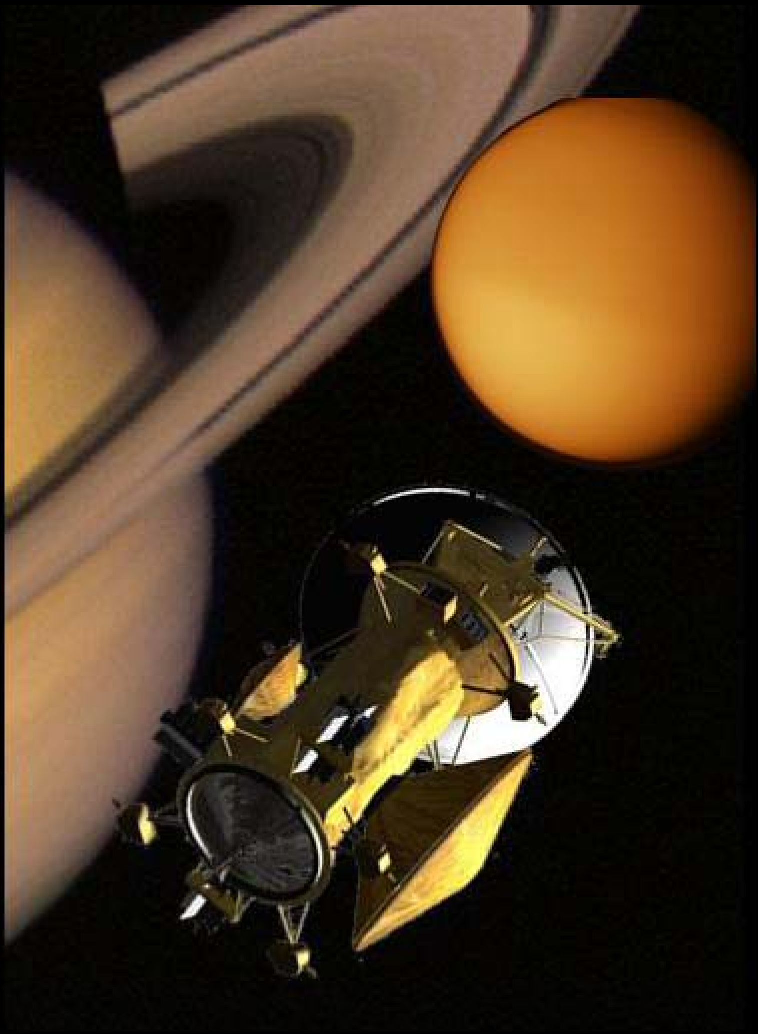
Proposed Orbiter Design Features

- **Telecom**
  – 4m X/Ka band HGA with 35W Ka TWTA
  – ~75 kbps downlink to 34m DSN station
- **C&DH**
  – JPL MSAP-based architecture
  – RAD 750 computer (132 MHz)
  – 32 Gb memory
- **Propulsion**
  – Single 890 N gimbaled main engine
  – 16 4.5N RCS thrusters in 8 pods of two each (coupled)
  – COPV propellant tanks hold ~2700 kg propellant
- **Power**
  – 5 MMRTGs baselined + redundant 25 Ahr batteries
  – ~475W at EOM
- **AACS**
  – Three-axis stabilized spacecraft
    - 30 arcsec pointing control (3σ)
    - 0.35 arcsec/sec pointing stability (3σ/axis)
- **Structure**
  – Composite and Aluminum for low mass, rigidity
- **Thermal Control**
  – Thermal louvers, RHUs and electric heaters combined with MMRTG waste heat used to minimize electric power demand



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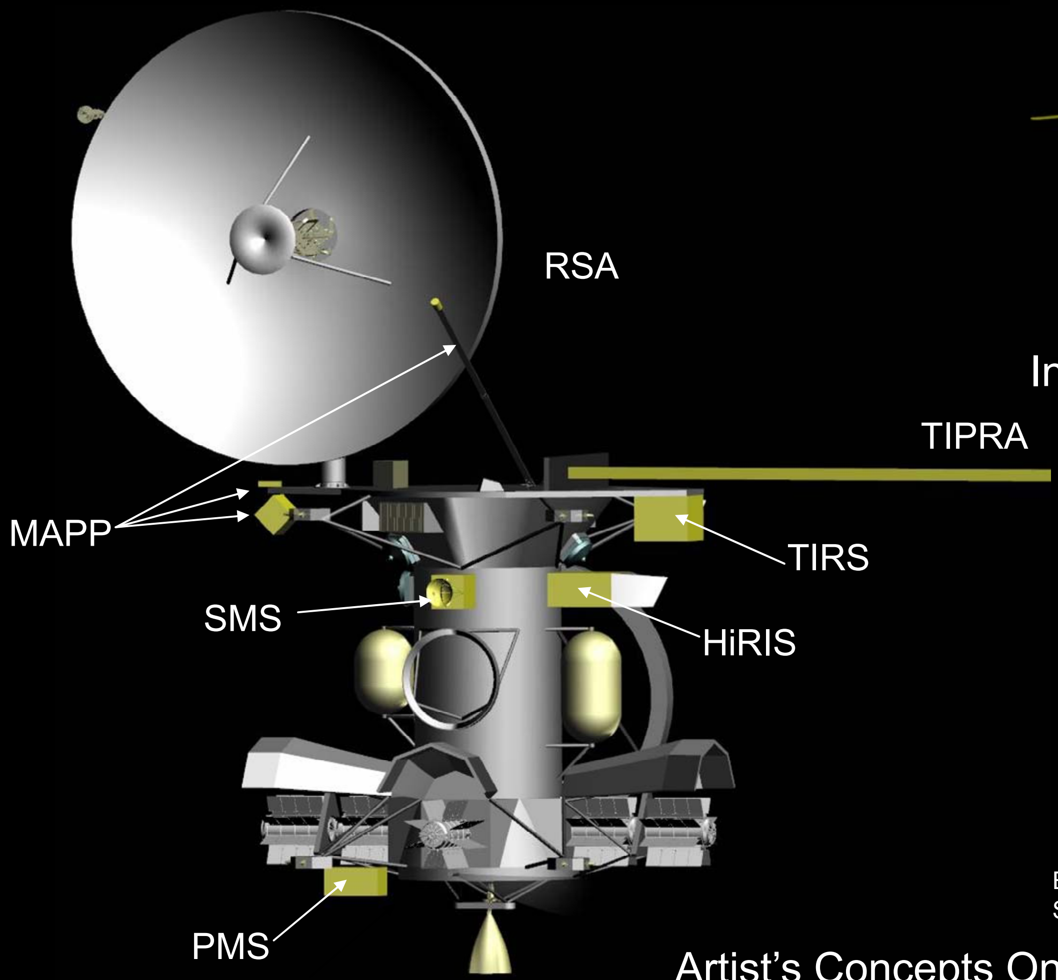
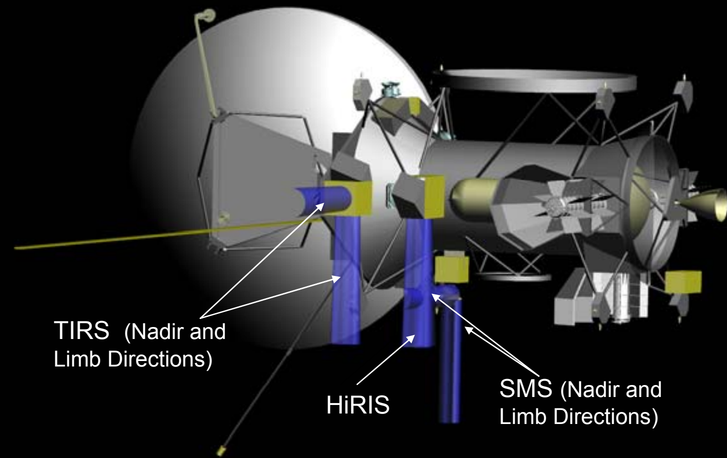
Instrument Layout

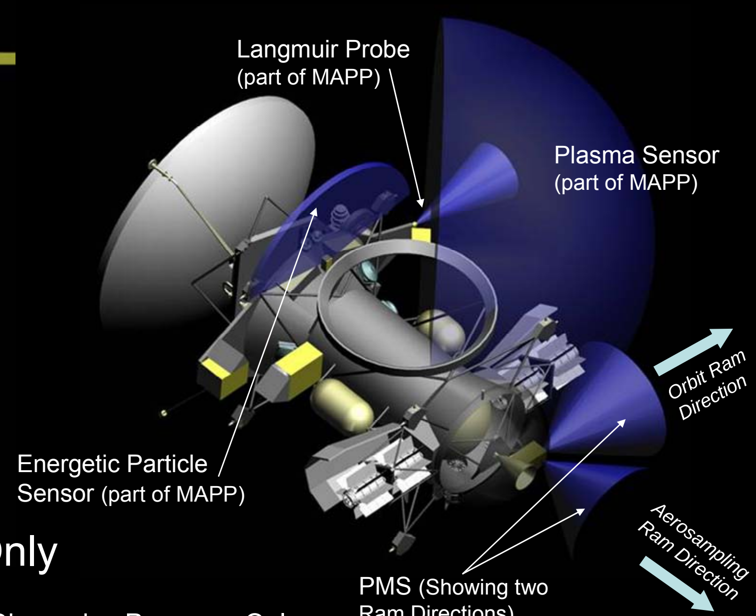
Instrument Locations



Instrument FOVs: Nadir Viewing



Instrument FOVs: Plasma Instruments



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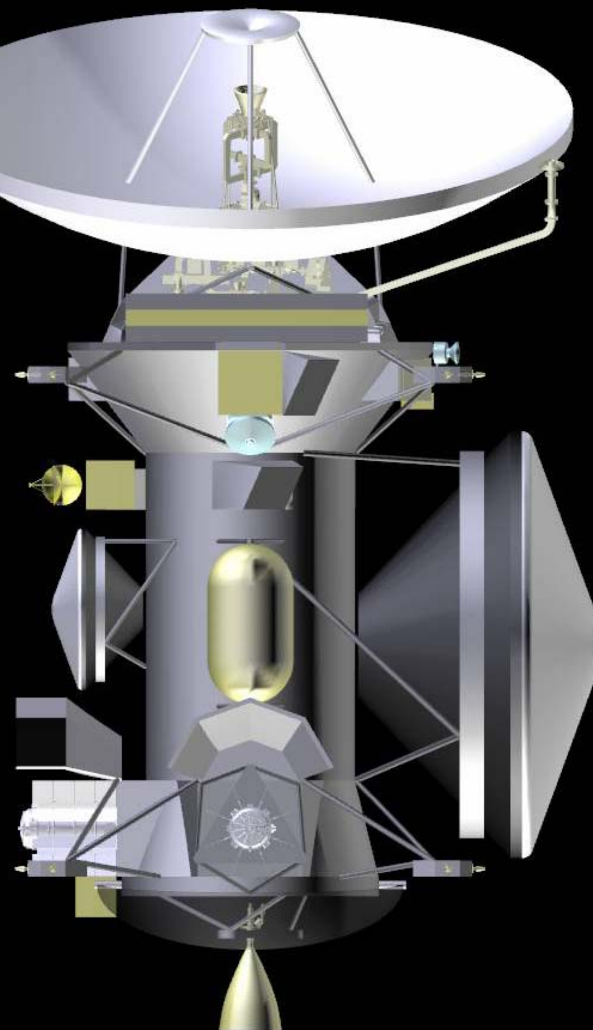
Accommodation of In-Situ Elements

- **Orbiter design would provide accommodation for up to two in-situ elements**
  - Planning target is one ~2.6m aeroshell and one ~1m aeroshell
    - Total target in situ mass is 600 kg
      - Core mission limited to ~300 kg (pre-SOI)
    - Mounting interface provided by Spacecraft, Spin/Eject device provided by ESA
  - Delivery would be pre-SOI
    - Mission of in-situ vehicles would be completed during Saturn Tour
  - Power and data interfaces would be provided pre-deployment
  - Orbiter would provide telecom relay post-deployment using orbiter telecom system
    - Orbiter transponder capable of accommodating relay in S, X, or Ka band



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SEP Stage for Sweet Spot Mission

- **Detailed SEP stage design has been performed by JPL working closely with GRC**
  - Designs evaluated using NEXT (ion) and BPT-4000 (Hall) thrusters
    - Baseline would be NEXT with BPT-4000 as backup
- **SEP stage built around launch vehicle adapter**
  - Minimal impact on Orbiter design
  - Mechanical interface to SEP stage same as EELV
  - Minimal control and power interface additions necessary
- **SEP design based on high TRL components**
  - Commercially available tanks, feed system components
  - BPT-4000 thrusters are off the shelf, NEXT in advanced development
  - Ultraflex solar arrays of necessary size being developed for Orion

NEXT Thruster and Gimbal

NEXT PPU

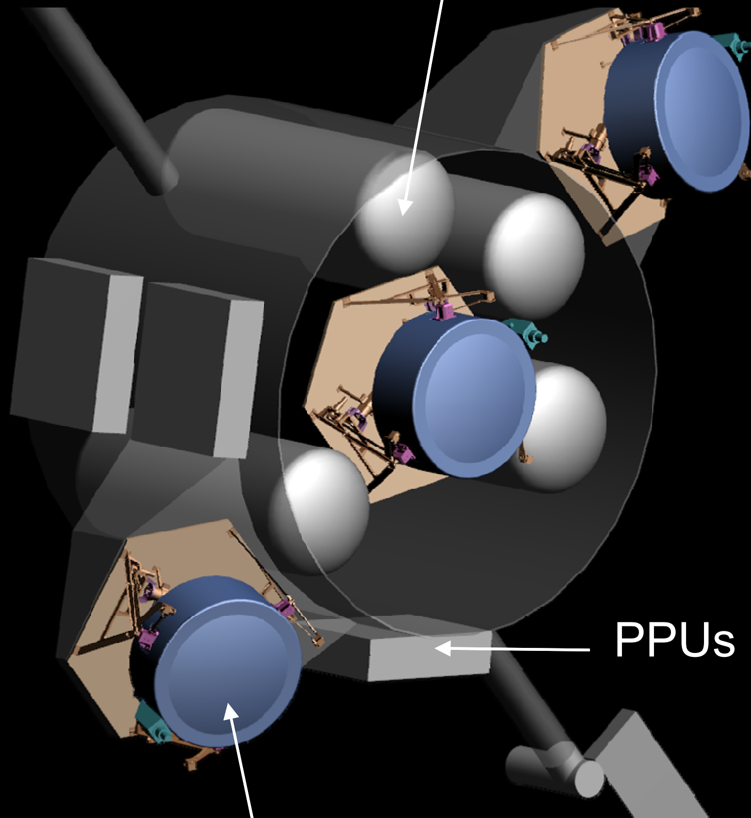
Prototype CEV Array

SEP Stage Design

SEP Stage MEL

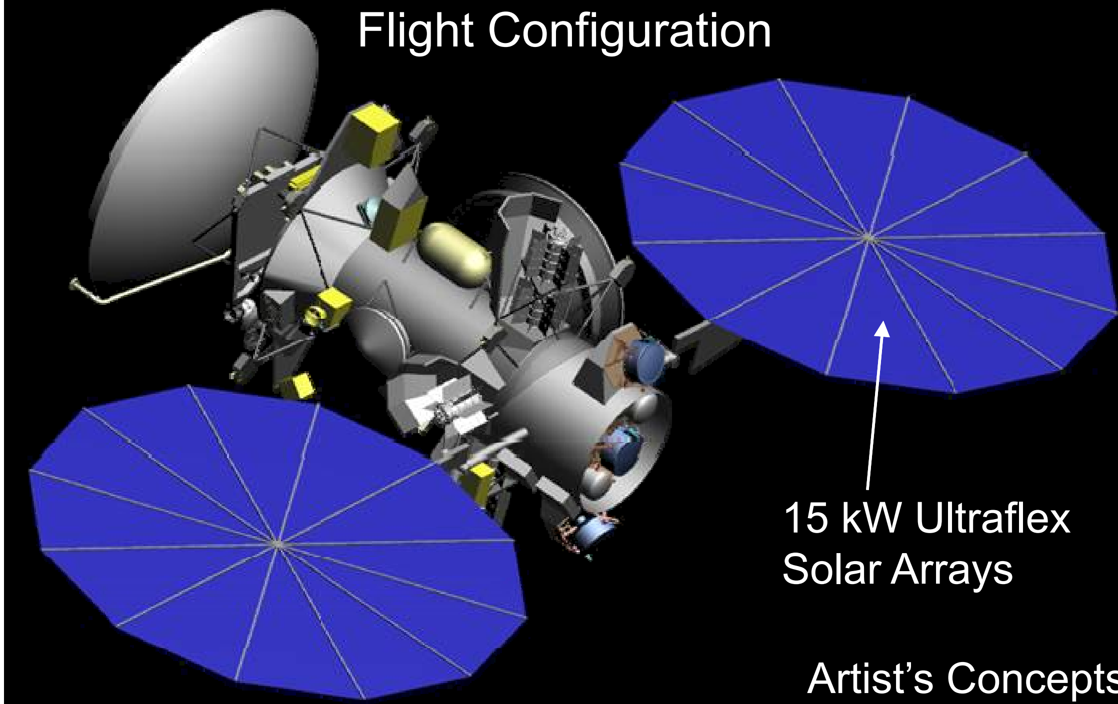
	Mass, kg		
	CBE	Cont.	CBE+ Cont.
SEP Stage	531	28%	678.3
Power	120.7	28%	154.5
IPS	218.4	26%	274.2
Structure	117.9	30%	153.3
Cabling	34.1	30%	44.3
Thermal	40.0	30%	52.0
SEP Stage Dry Mass	531	28%	678
Additional SEP Stage Margin			118
Total SEP Stage Dry Mass	**531**	**50%**	**797**

- **Total cost of the SEP stage has been estimated at $98M (NEXT version)**
  - BPT-4000 version of SEP stage estimated at ~ $76M



SEP Stage Configuration

Flight Configuration



15 kW Ultraflex
Solar Arrays

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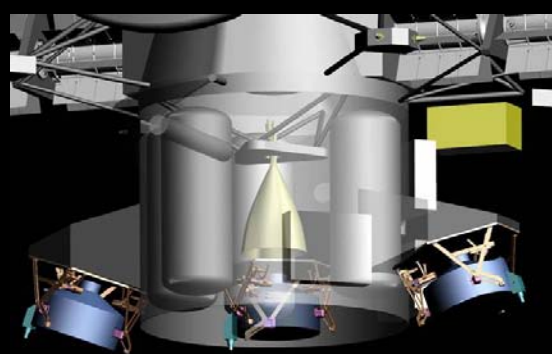
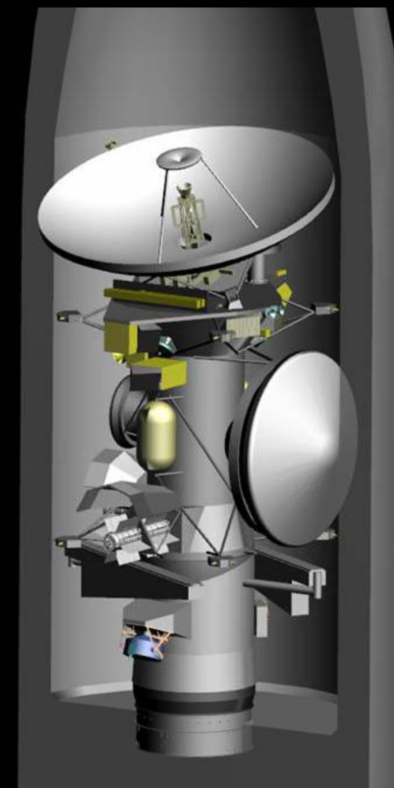


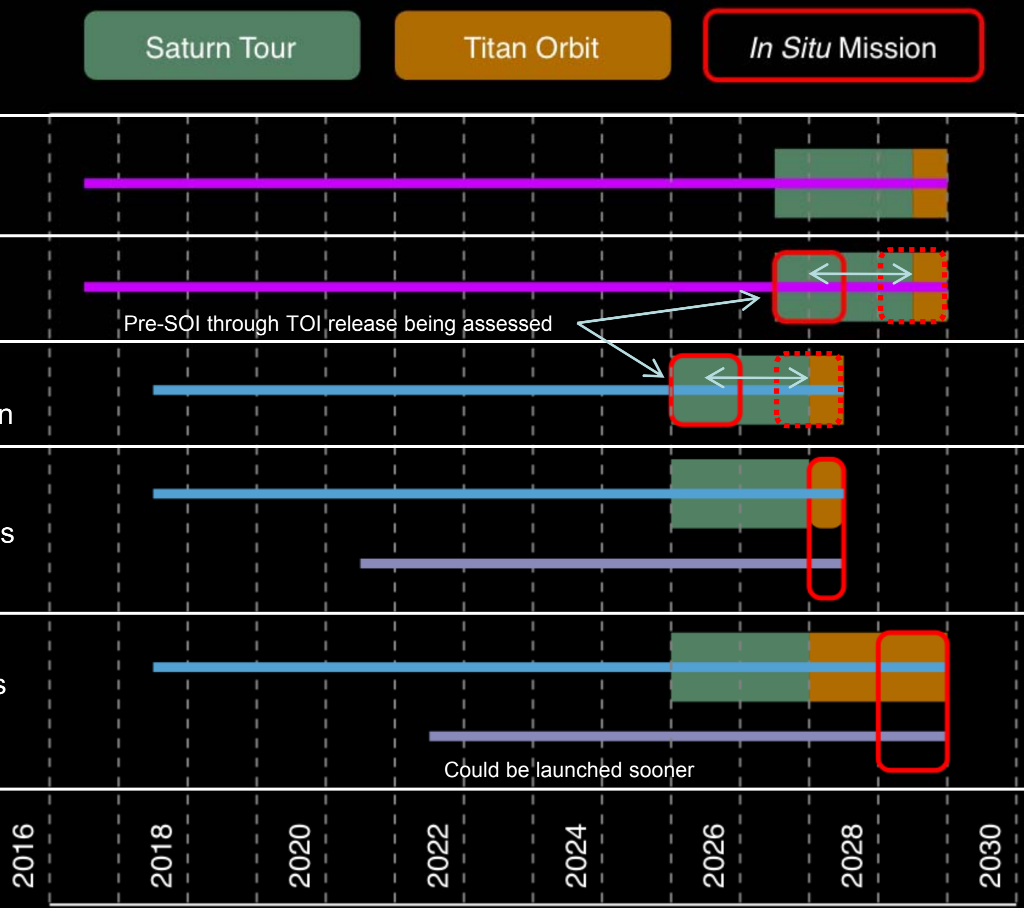
Integrated Stage Fits Around Orbiter Engine



SEP Option Stowed Configuration
in Atlas V Fairing

Options presented at 2nd NASA HQ Interim Rev.

Mission Option		Benefit
Orbiter only	NASA only orbiter	Decadal science from orbit
[1]Orbiter + Lander	Core	Surface science in single location
[1]O + L + B w/ SEP	Sweet Spot	Lower atm/surf science over broad regions; 2 yr sooner return
[1]Two Launch w/ [3]SEP	Sweet Spot	Enables mapping prior to in situ arrival, additional delivered mass and programmatic flexibility
Two Launch w/ [3]SEP & 2 yr TO	Enhanced	Enables follow-on to discoveries and repeat orbital coverage



[1]ESA CDF activity underway to examine com. scenarios for in situ release conditions between SOI and Titan orbit
[2]In situ elements to be provided at minimal accommodation costs to NASA
[3]SEP appears to be more cost effective than staging, D IVH and Ares; results in propulsion element feed forward

Results from 2nd Interim NASA HQ Review

- First opportunity to brief Ed Weiler and Staff; critical briefing went very well
- Study ground rules focused on the science that could be done for $2.1B; New SMD strategy is centered on defining a flagship mission that would best balance science, cost and risk
- OPFM Team was redirected to focus on sweet spot mission; consider 2018-2022 launch opportunities; 2020 nominal date
- NASA HQ is editing study ground rules and the OPFM team is replanning the balance of study activities
- The Go-Ahead plan and Downselect strategy and approach will be a topic of discussion at NASA/ESA bi-lateral scheduled for mid-July; could result in further changes

New Study Focus

- **Sweet Spot Mission – Orbiter + Lander + Balloon**
  - Orbiter
    - 150 kg mass allocation for orbiter instruments
    - >600 kg mass allocation for in situ elements
  - SEP Stage
    - NEXT Ion thruster system; BPT-4000 Hall thruster system as backup
    - Balance power level, delivered mass, trip time and mission timing
  - In situ elements
    - Lander (release during tour) and Balloon (release pre-SOI)
  - Proposed Mission Design
    - Would launch on Atlas V from U.S. in 2020
    - Shortest trip time possible; 2 yrs in Saturn tour, 2 month aerosampling at Titan, TBD months Titan mapping orbit (current plan is 6 months)
    - Overlap of Orbiter and In situ prime missions (goal)

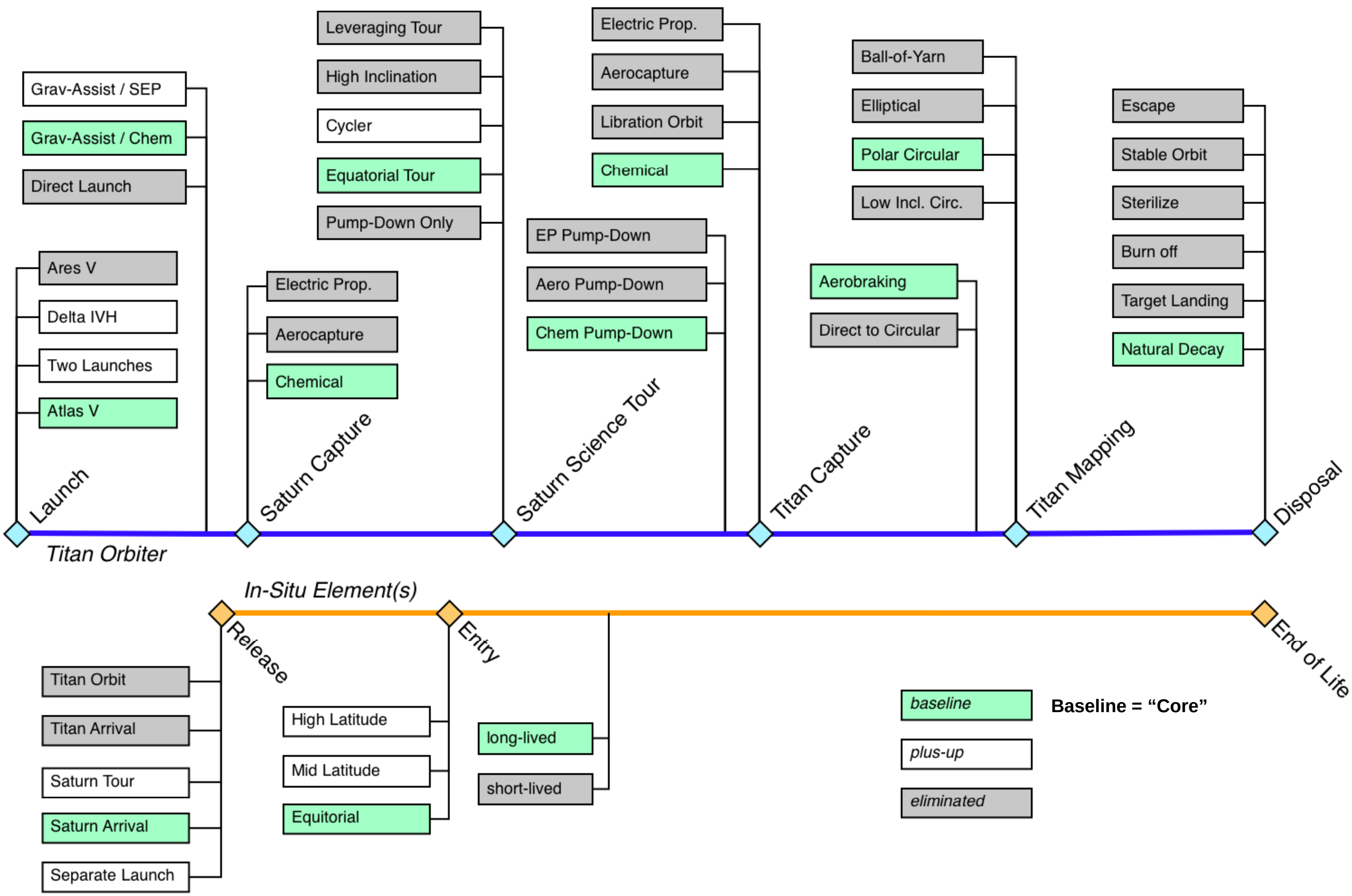
- **Orbiter-Only mission as the descope**

Summary

- **A mission to study Titan in depth, with visits to Enceladus, would address key objectives in the 2003 Solar System Decadal Survey and questions raised by spectacular discoveries of Cassini-Huygens**
  - This mission study suggests a Titan orbiting mission would make a significant advance beyond Cassini-Huygens in accomplishing Decadal objectives and is possible within a $2.1B cap initially imposed on the study
  - A Titan orbiting mission that would accommodate an ESA-provided lander (Core mission) is estimated to cost slightly more than the orbiter-only mission because ESA would provide in situ elements at minimal accommodation costs to NASA; NASA would provide RPS and launch vehicle
  - Use of a SEP stage or implementation of a two-launch mission architecture would allow accommodation of both an ESA lander and Montgolfiere (Sweet Spot) at a correspondingly higher cost
- **Launch opportunities that deliver equal or greater mass to Titan are available in most years; offers flexible mission timing**

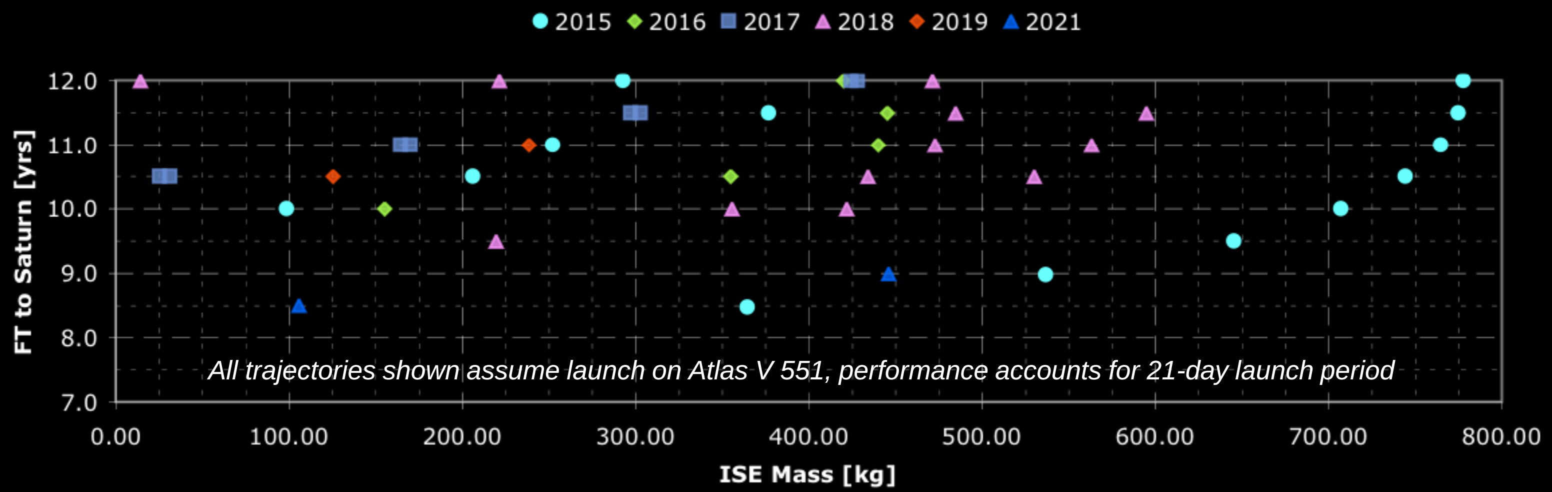
BACKUP

Architecture Options Considered



2016-2021 Launch Opportunities (Chem)

In Situ Element (ISE) mass with 1700 kg NASA Orbiter:



- 2015, 2016, 2018, and 2021 show best trajectories
- 2017 and 2019 would have longer FTs

Path	Launch Date	Arrival Date	FT to Saturn [yrs]	ISE Mass [kg]
EVVEJS	Jun, 2015	Dec, 2023	8.5	360
EVEES	Sep, 2016	Sep, 2026	10	150
EVVEJS	Jan, 2017	Jan, 2028	11	170
EVVEES	Sep, 2018	Mar,2028	9.5	220
EVEES	Nov, 2019	May, 2030	10.7	150
EVEES	Nov, 2021	Nov, 2030	9.0	440

2016-2021 Launch Opportunities (SEP)

In Situ Element (ISE) mass with 1700 kg NASA Orbiter and 800 kg SEP stage

Path	Launch Date	Arrival Date	FT to Saturn [yrs]	ISE Mass [kg]	
				Saturn Approach	During Tour
EEVVES	Jul, 2016	Sep, 2026	8.7	660	440
EEVVES	Sep, 2017	Jan, 2028	7.5	845	565
EEVEES	Dec, 2018 / Jan, 2019	Dec, 2027	9.0	730	490
EEVVES	Nov, 2020	Jul, 2029	8.7	620-900	400-600

*All trajectories shown launch on Atlas V 551, performance accounts for **30**-day launch period*

- SEP would enable substantially greater delivered mass and shorter trip times
- Delivery from Saturn approach would enable the highest mass
- Delivery during tour would enable opportunity to align Titan orbit phase with in situ element prime mission
- All years have freedom to increase mass with more flight time