Mission Overview

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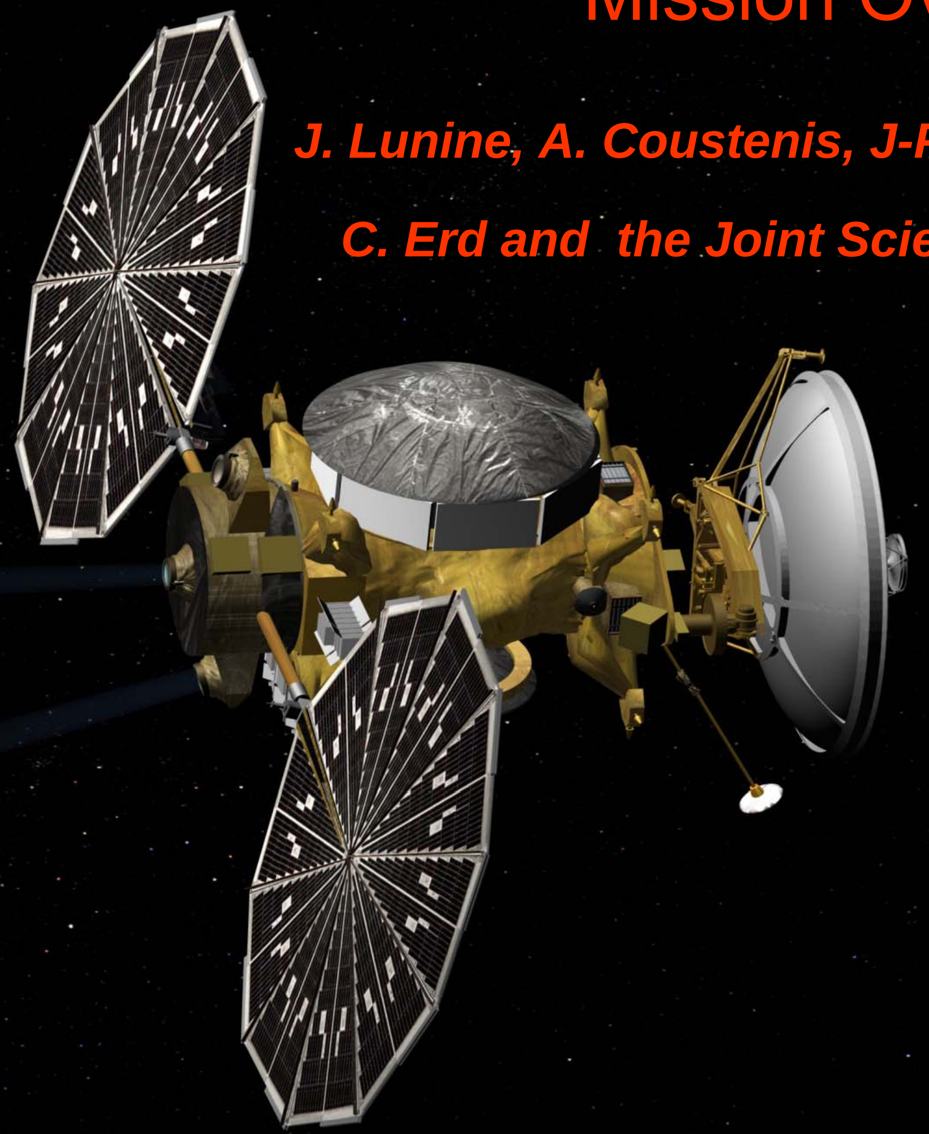
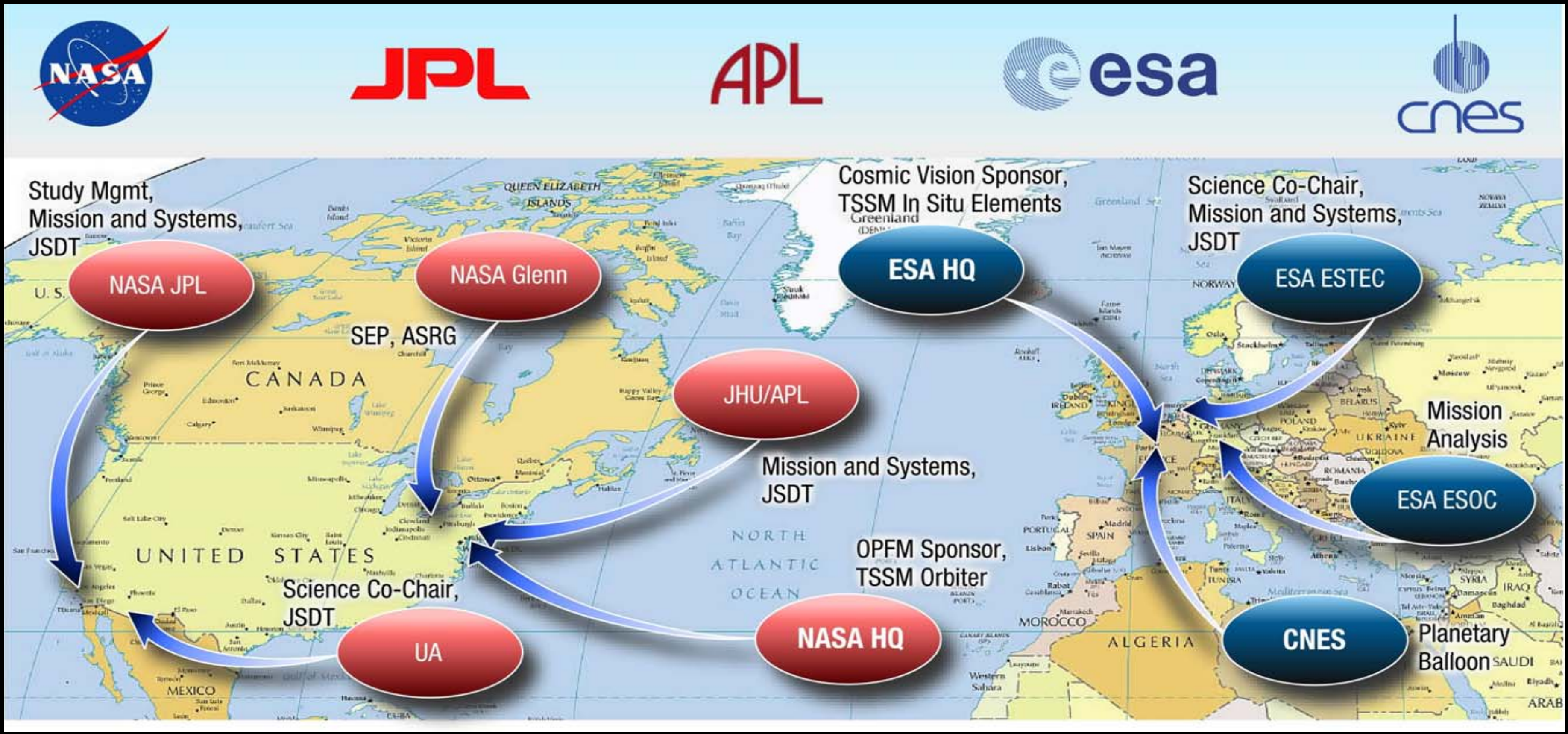
C. Erd and the Joint Science Definition Team



TSSM

06 Nov 2008

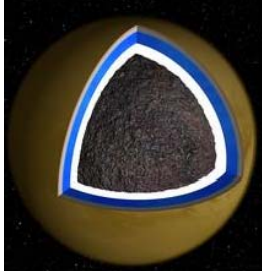
TSSM Study Team



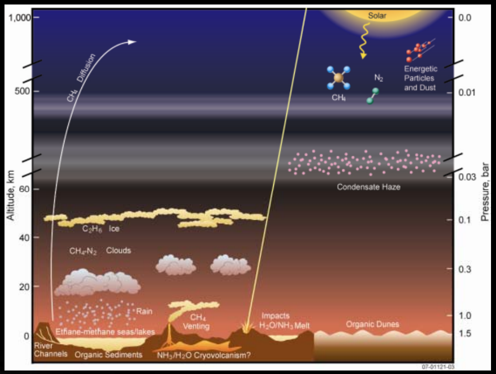
2008 Study Ground Rules

- **Ground Rules**
  - Respond to the 2007 Study independent review board findings.
  - Produce a mission concept that optimally balances science, cost, and risk.
  - Define a *NASA-ESA* Baseline and Floor mission that includes a NASA-provided Titan orbiter that does not utilize aerocapture. The orbiter shall have the capability of delivering and providing relay communications for multiple Titan *in situ* elements that would be provided by ESA as part of a collaborative program.
  - Define a *NASA-only* mission and Floor mission that can be implemented by NASA in the event ESA decides not to participate.
  - Include Saturn system and Enceladus as Level 1 science requirements.
  - Include minimum of 33% reserves/margins.
  - Use a launch date of 2020 for schedule and cost purposes. Alternative launch dates from 2018 through 2022 should be identified.
- **The Titan Saturn System Mission is the response to these Ground Rules.**

2008 Study Approach



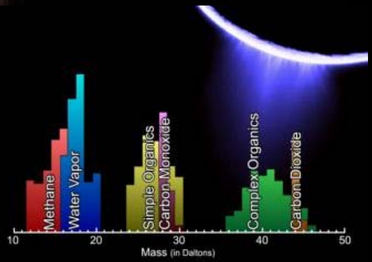
- *Dedicated Titan orbiter with ESA provided in situ elements*



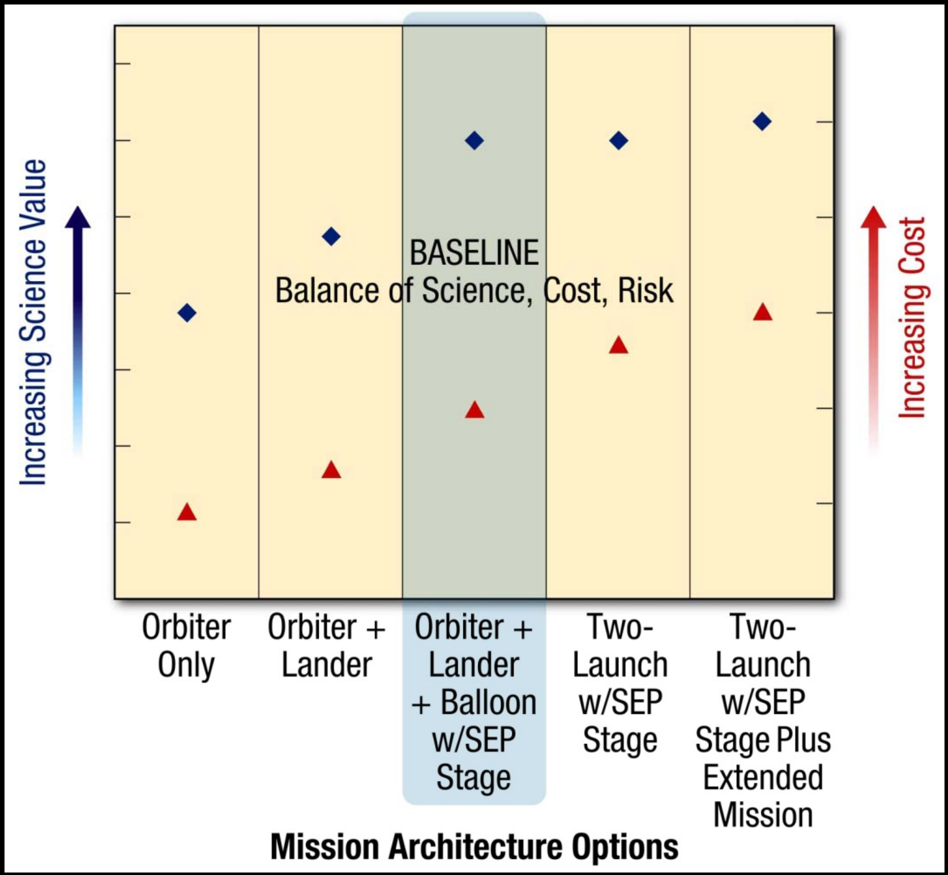
- *Enceladus science and Saturn magnetospheric interaction with Titan*

- *Advancement in focused understanding of Titan system well beyond the high bar set by the Cassini-Huygens survey*

- *Balance science, cost and risk*

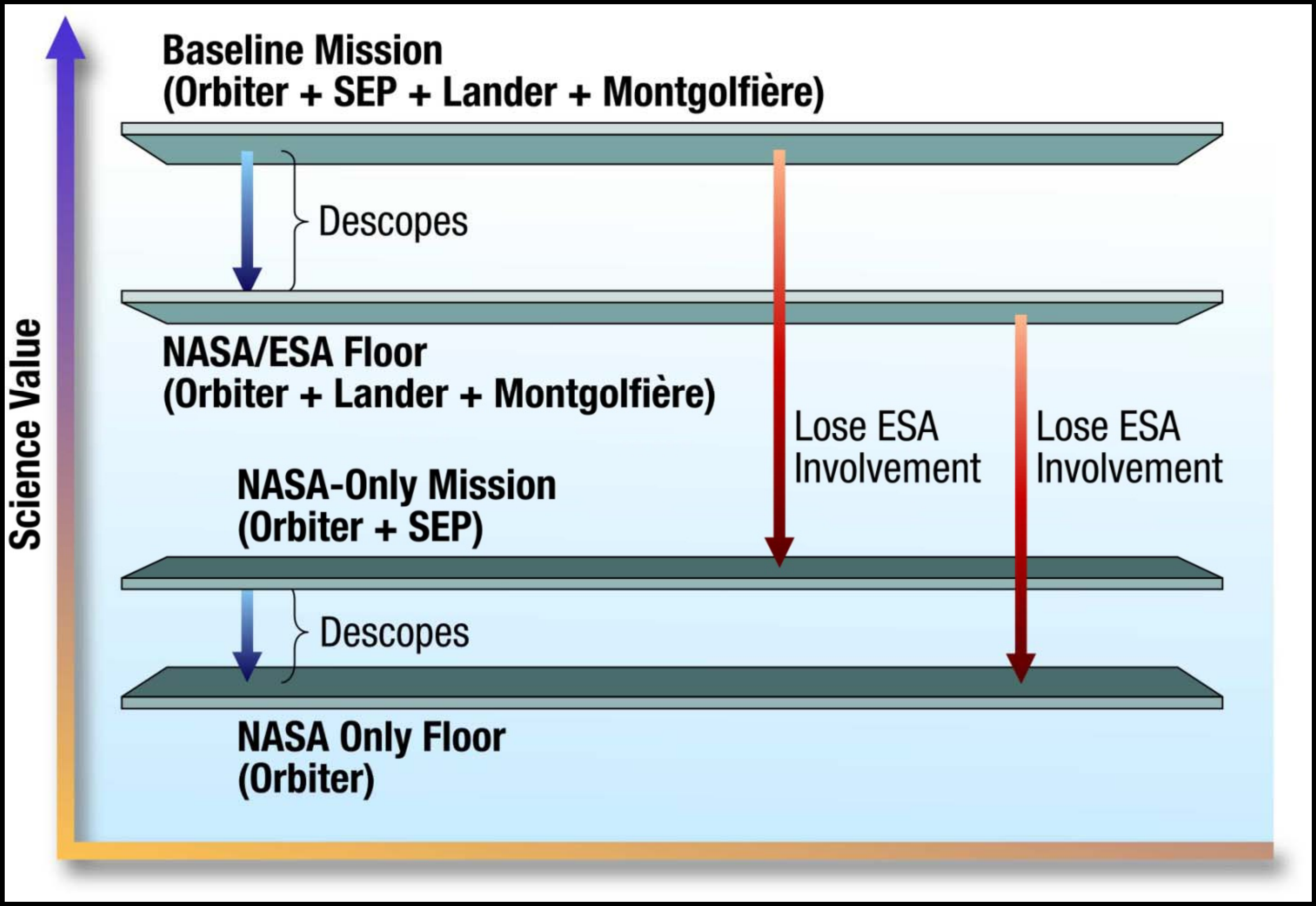


Finding the "Sweet Spot"



Assessment of alternative architectures indicates that an orbiter with SEP Stage, Lander and Montgolfiere provides highest value.

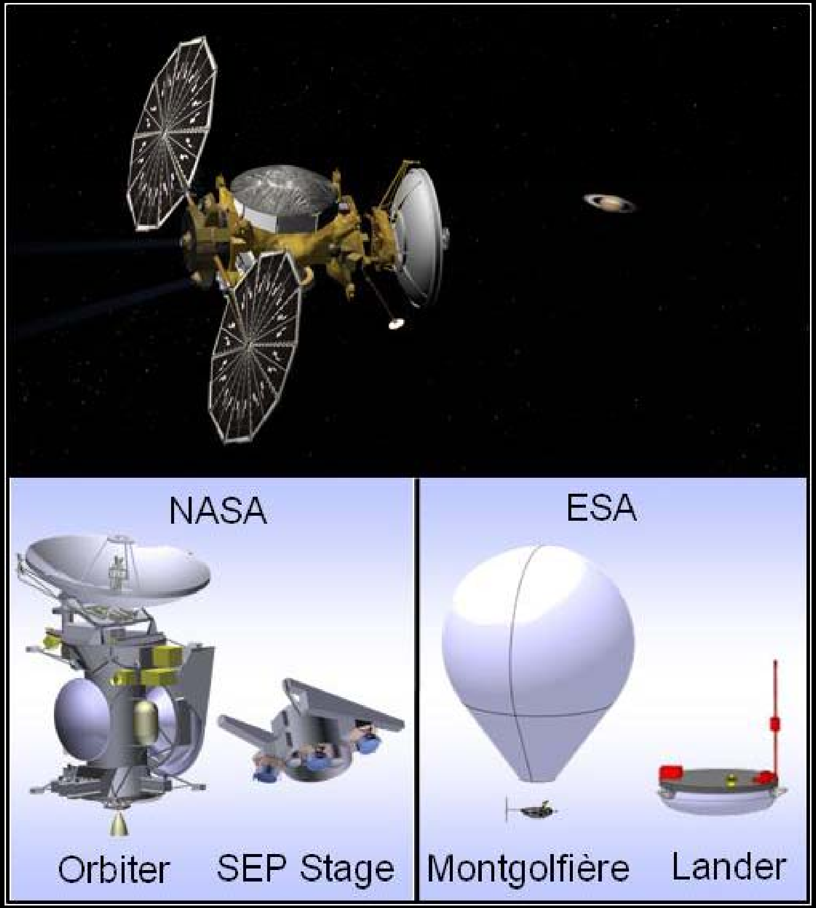
TSSM Architecture



TSSM Architecture provides robust programmatic NASA/ESA and NASA only options

TSSM Baseline Overview

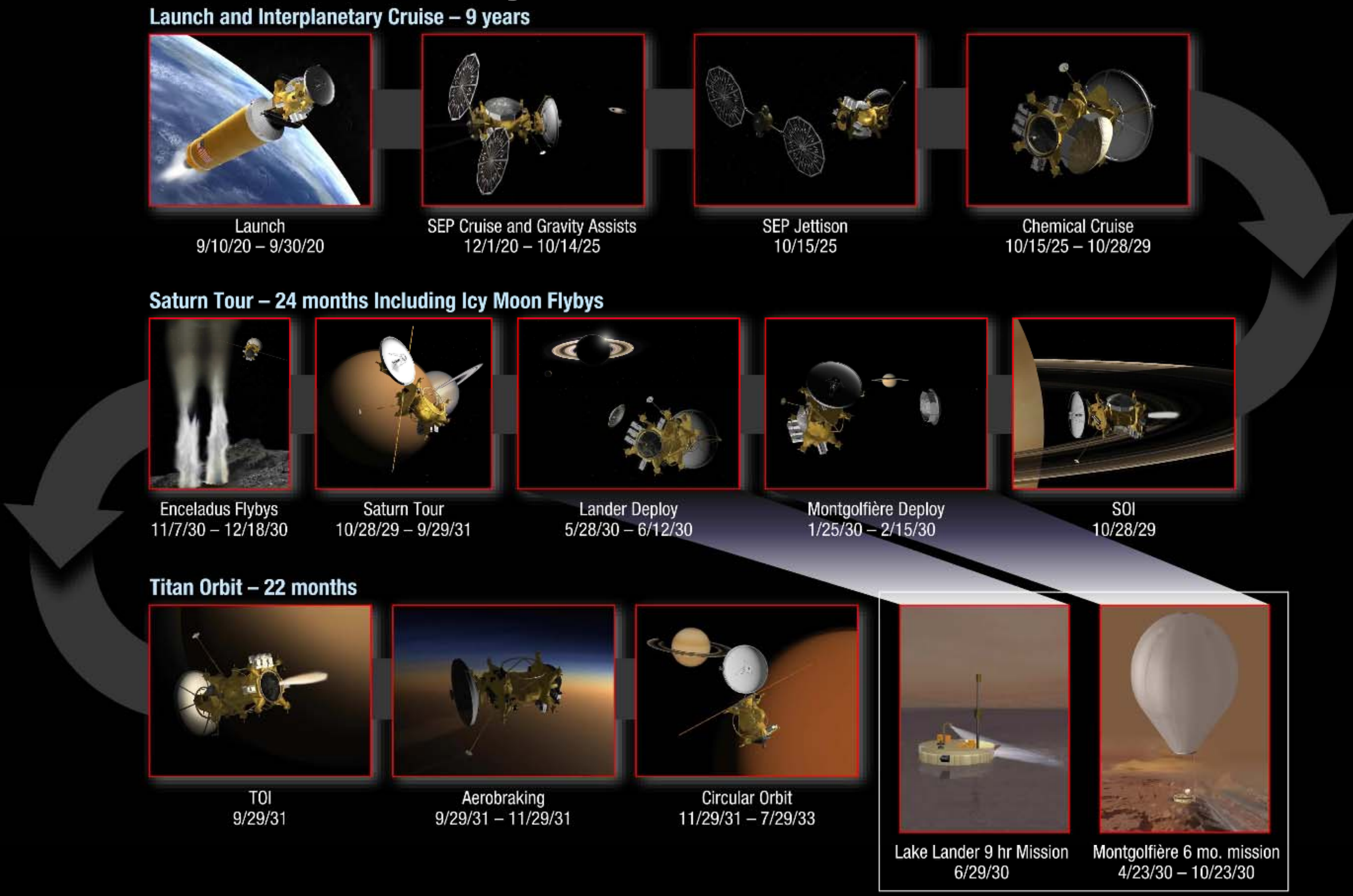
- **Titan, Saturn System and Enceladus**
- **NASA Orbiter with ESA in situ elements**
  - Orbiter – ASRG power (also MMRTG compatible
  - Solar Electric Propulsion (SEP)
  - Lake Lander – battery powered
  - Montgolfière Balloon – MMRTG powered
  - NASA provided Launch Vehicle and RPS



- **Mission Design**
  - 2020 Gravity Assist SEP trajectory
  - 9 years to Saturn arrival
  - SEP stage released ~5 yrs after launch
  - Balloon released on 1st Titan flyby, Lander on 2nd Titan flyby
  - ~4 year prime mission: 2 year Saturn tour, 2 mo Titan aerosampling; 20 mo Titan orbit
- **Planning Payload Complement**
  - Orbiter: 6 Instruments + Radio Science
  - Lander: 5 instruments + Radio Science
  - Balloon: 7 instruments + Radio Science

-Optimal balance of science, cost and risk
-Leverages NASA-ESA collaboration

Key Mission Events

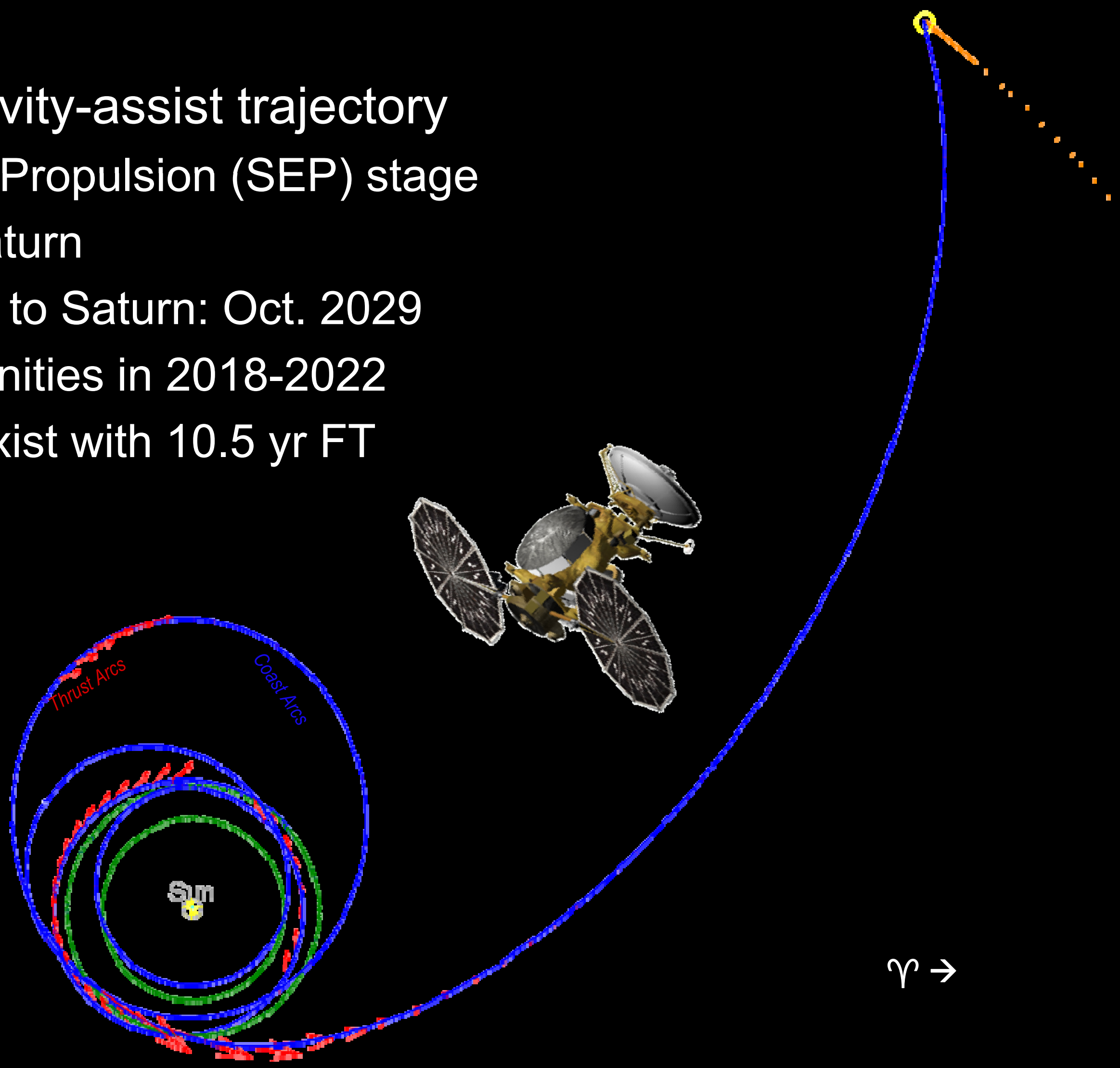


2020 Launch With SEP

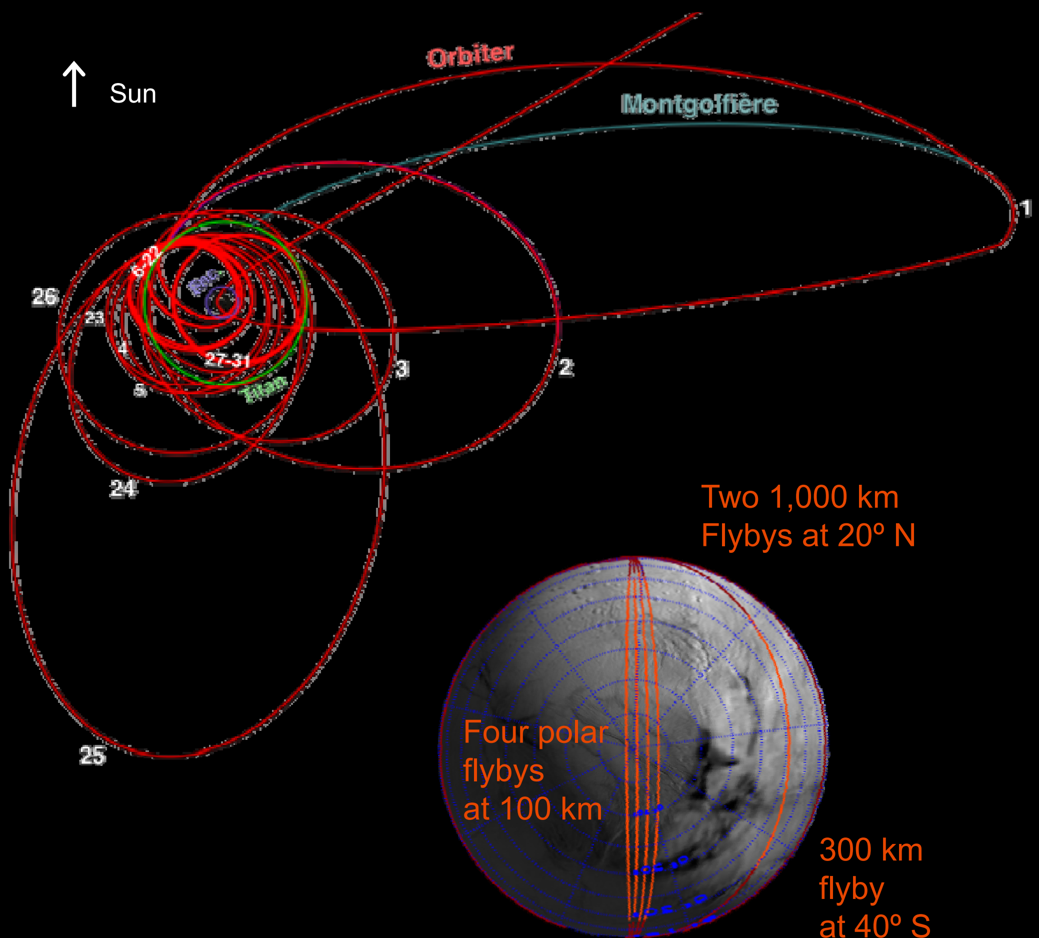
Current Baseline:

2020 EVEE SEP gravity-assist trajectory

- Uses Solar Electric Propulsion (SEP) stage
- 9 yr flight time to Saturn
- Launch: Sept. 2020 to Saturn: Oct. 2029
- Many other opportunities in 2018-2022
- Non-SEP options exist with 10.5 yr FT



2 Year Saturn Tour



7 Close Enceladus Flybys

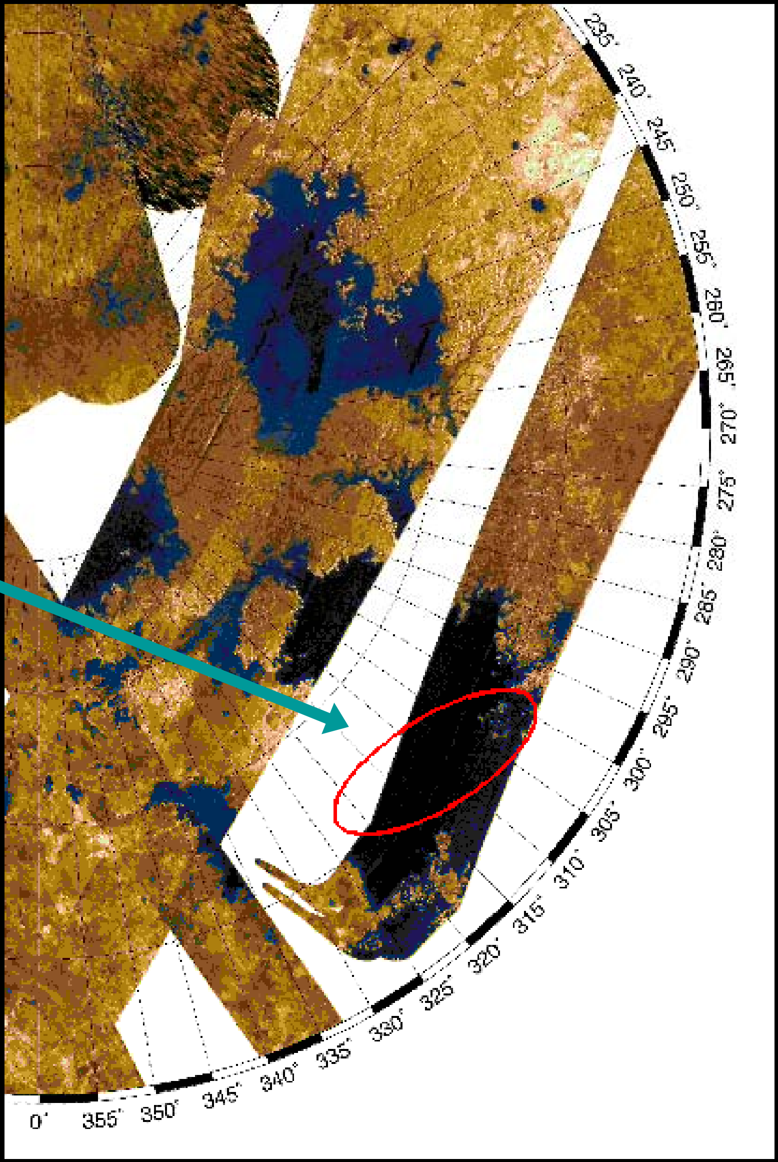
	Body	Date	Alt [km]	Vinf [km/s]	Per [d]	Inc [deg]
SOI	Saturn	28-Oct-29	11236	6.6	214	5.7
Ti1	Titan	26-Apr-30	1000	2.8	91.3	17.2
Ti2	Titan	29-Jun-30	1200	2.7	45.6	24.1
Ti3	Titan	31-Jul-30	900	2.7	22.9	26.6
Ti4	Titan	16-Aug-30	1077	2.7	22.9	19.3
Ti5	Titan	1-Sep-30	800	2.7	22.8	5.3
Ti6	Titan	17-Sep-30	2331	2.7	15.1	0.6
Rh1	Rhea	5-Oct-30	1273	3.6	15.5	0.5
Ti7	Titan	18-Oct-30	1817	2.8	11.4	0.5
Ti8	Titan	3-Nov-30	1241	2.8	10.0	0.5
En1	Enceladus	7-Nov-30	1000	7.1	9.8	0.5
En2	Enceladus	14-Nov-30	100	7.1	9.8	0.5
En3	Enceladus	21-Nov-30	100	7.2	9.8	0.5
En4	Enceladus	28-Nov-30	307	7.1	9.8	0.5
En5	Enceladus	5-Dec-30	100	7.1	9.8	0.5
En6	Enceladus	11-Dec-30	100	7.1	9.8	0.5
En7	Enceladus	18-Dec-30	1110	7.2	9.8	0.5
Ti9	Titan	21-Dec-30	2127	2.8	11.4	4.8
Ti10	Titan	6-Jan-31	2688	2.8	15.2	4.8
Ti11	Titan	7-Feb-31	3462	2.8	22.9	3.8
Ti12	Titan	23-Feb-31	2715	2.8	45.7	1.5
Ti13	Titan	27-Mar-31	3487	2.8	133.9	0.5
Ti14	Titan	29-Jun-31	750	1.7	43.4	0.3
Ti15	Titan	28-Jul-31	725	1.0	22.9	5.1
Ti16	Titan	13-Aug-31	3933	1.0	17.2	7.9
TOI	Titan	29-Sep-31	725	0.9		

For planning and discussion purposes only

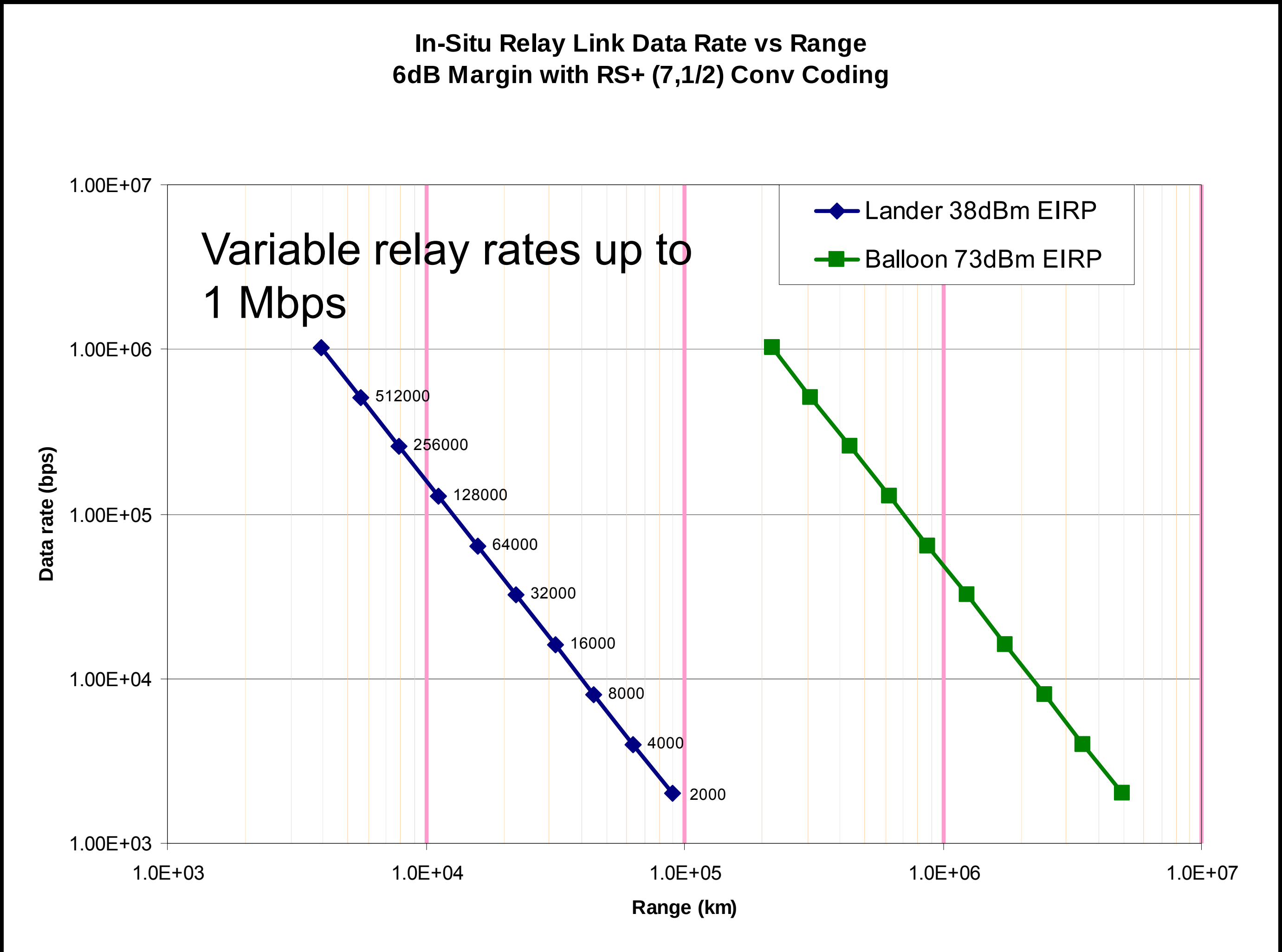
In Situ Element Delivery

- **Lake Lander would be released at 2nd Titan flyby and targeted to land in a northern polar lake – Kraken Mare**

- **Montgolfière would be released at 1st Titan flyby and targeted to ~20 deg N. The balloon would circumnavigate Titan.**



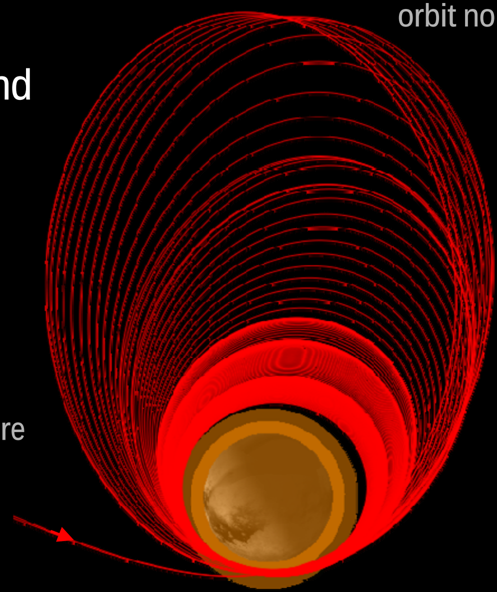
In Situ Element Relay



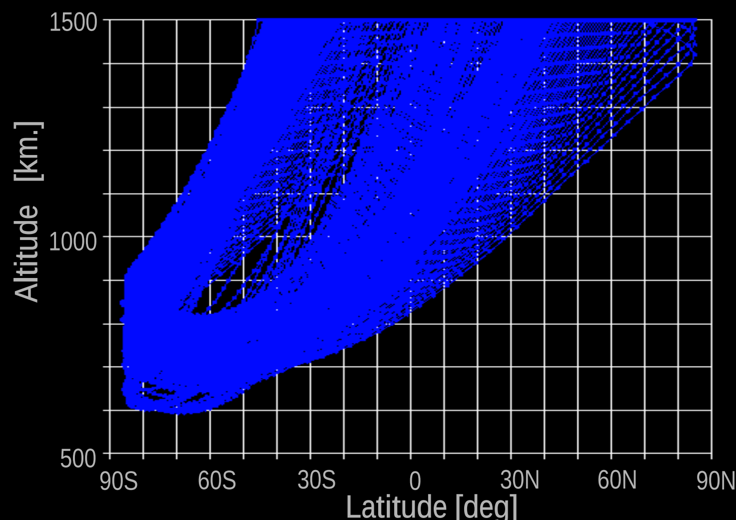
TSSM *in situ* relay links are optimized for the communication geometry and provide a capability that is 3 to 4 times the current estimated demand.

~ 2 Year Titan Orbit

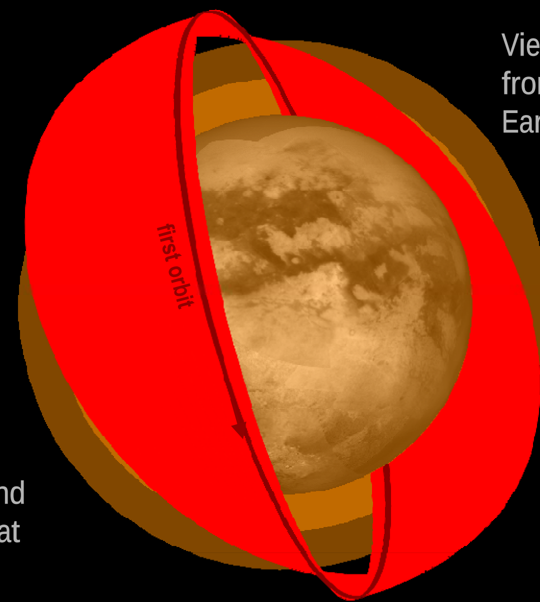
2 Months Aerobarking and Aerosampling



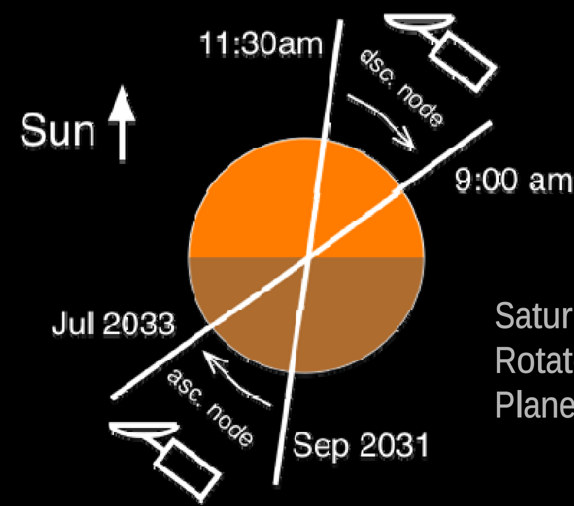
In situ sampling of Titan's entire southern hemisphere below 1,000 km.



20 Months in Circular Polar Orbit



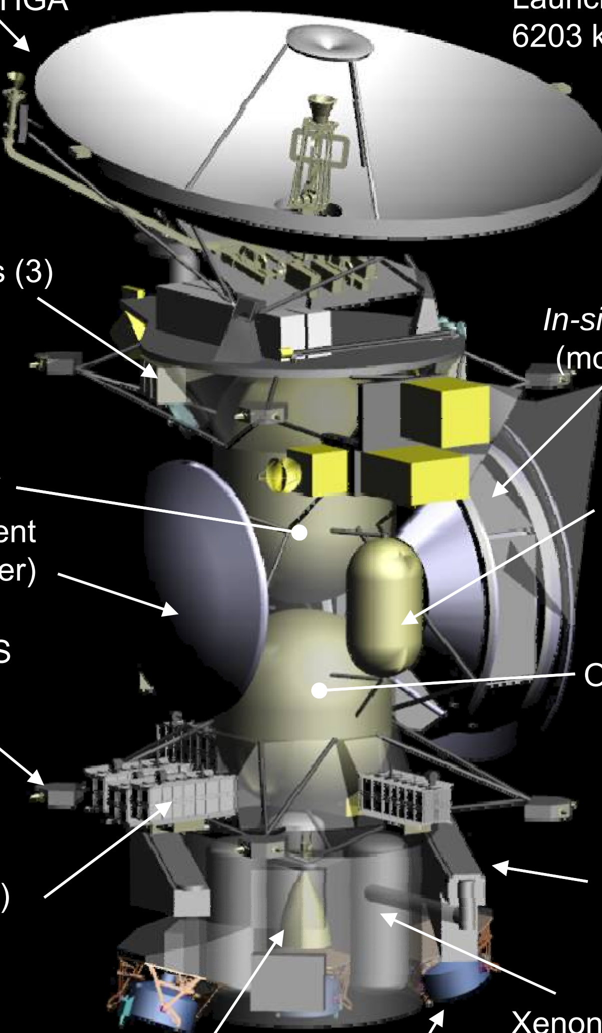
2.5 hr. Variation in LST time of orbit and radio occultations at wide range of latitudes.



Saturn's Gravity Rotates Orbit Plane

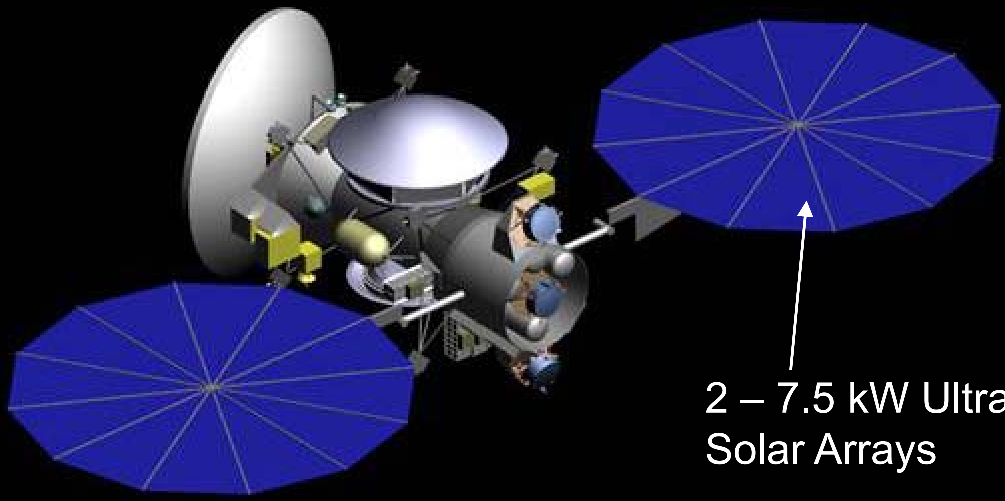
Baseline Flight System Configuration

- **Configuration is a balance of science, mass, cost & risk**
- **Orbiter dry mass 1613 kg including 35% margin**
  - 165 kg allocated to orbiter instruments
  - Current *in situ* mass allocation ~830 kg
    - 600 kg montgolfiere
    - 190 kg lander
    - Remainder for probe support equipment
- **Design incorporates 5 ASRGs**
  - 4 for power, one spare
  - ~540 W EOM (4 operating)
- **Total Mission Dose estimated at <15 krad (behind 100 mil Al)**



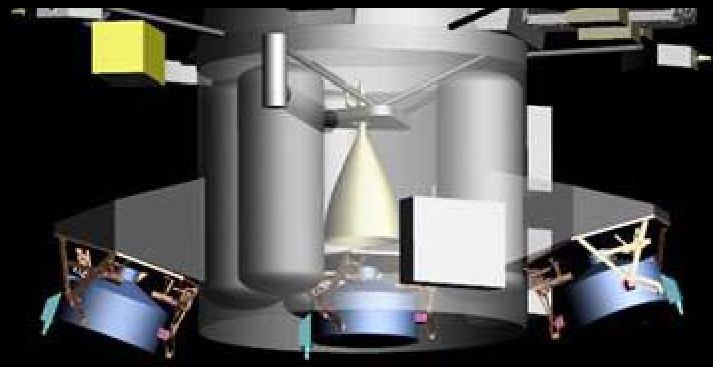
SEP Stage Configuration

Flight Configuration

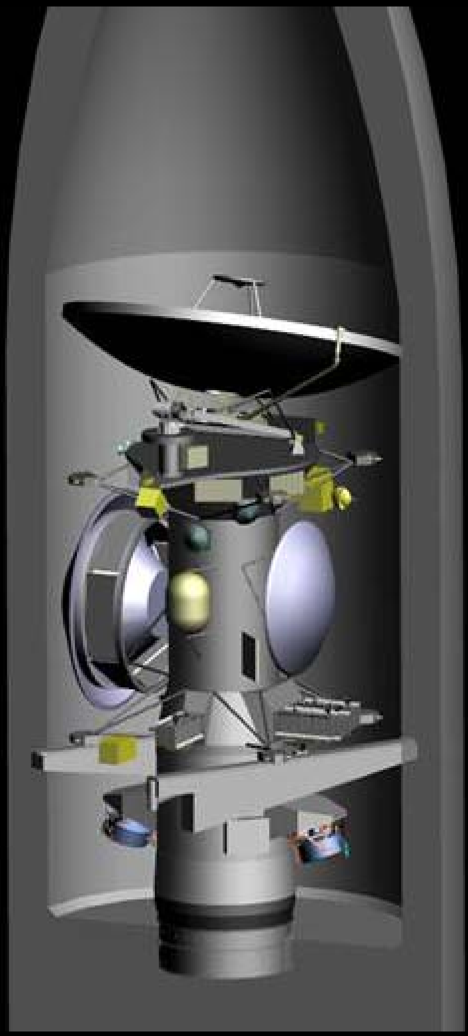


2 – 7.5 kW Ultraflex Solar Arrays

Stage includes SEP integrated into LV adapter



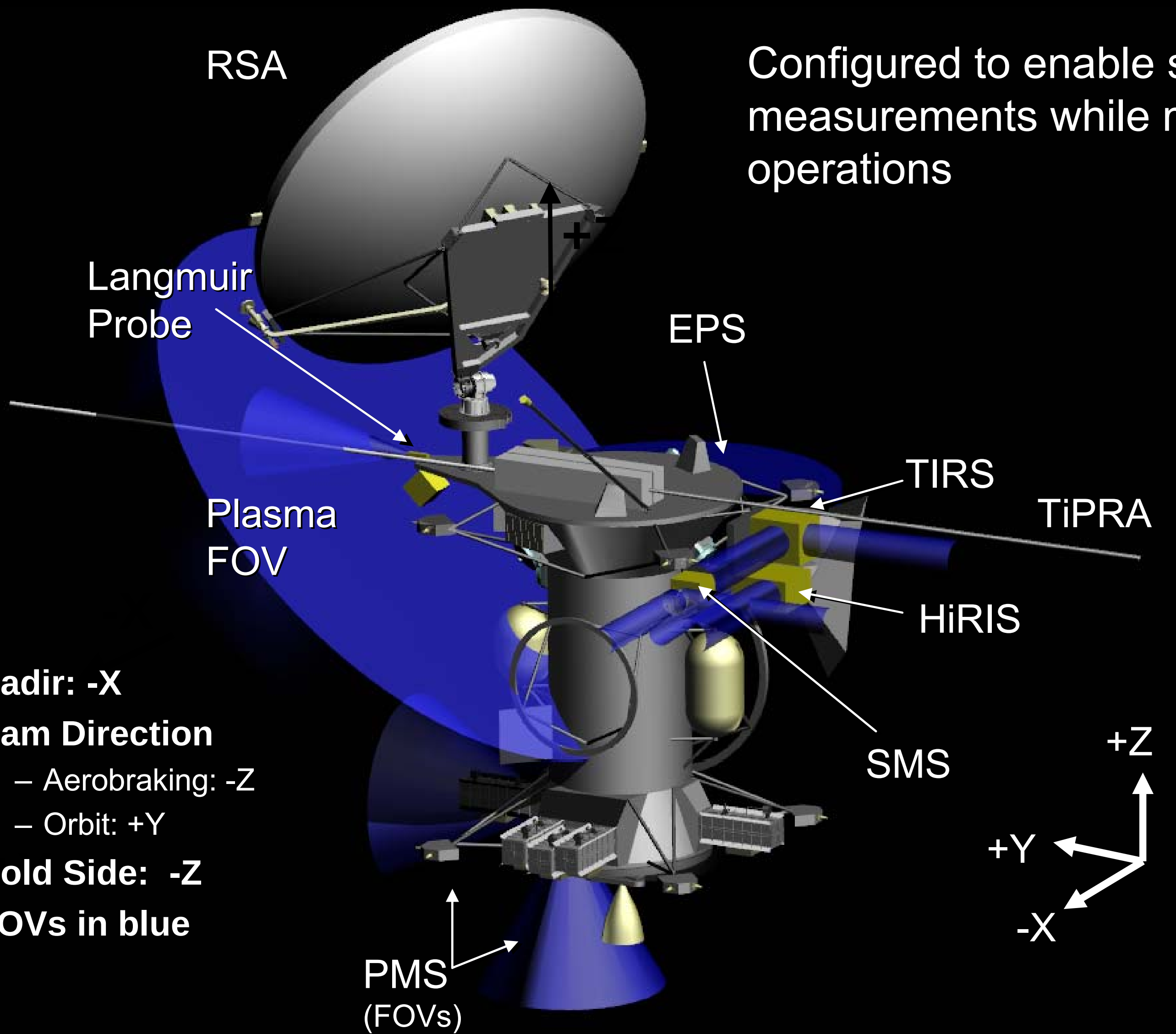
Integrated Stage fits around Orbiter Engine



SEP Option Stowed Configuration in Atlas V Fairing

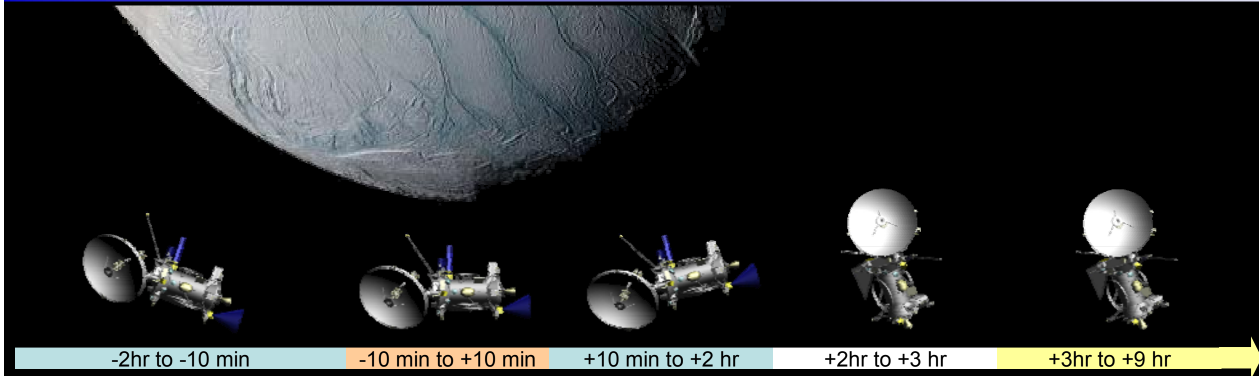
Planning Payload Layout

Configured to enable science measurements while minimizing operations



- **Nadir: -X**
- **Ram Direction**
  - Aerobraking: -Z
  - Orbit: +Y
- **Cold Side: -Z**
- **FOVs in blue**

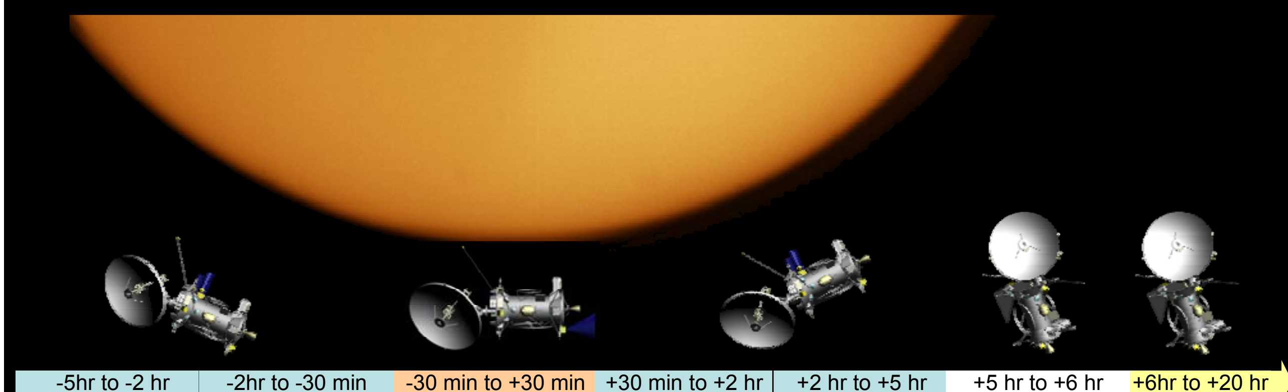
Summary of Saturn Tour Phase Operations Scenarios



-2hr to -10 min	-10 min to +10 min	+10 min to +2 hr	+2hr to +3 hr	+3hr to +9 hr
High resolution imaging, Near & mid-IR mapping spectrometry	Direct sampling mass spectrometry, Ice thickness measurements	High resolution imaging, Near and mid-IR mapping spectrometry	Allow battery recharge before telecom turns on	Downlink to 34 m DSN

7 Enceladus Flybys

- Closest approach time dedicated to direct sampling of the plume environment
- Gimbaled HGA (to Earth) will allow Radio Science gravity measurements.
- For each Enceladus flyby, 15 Gb of data will be collected.

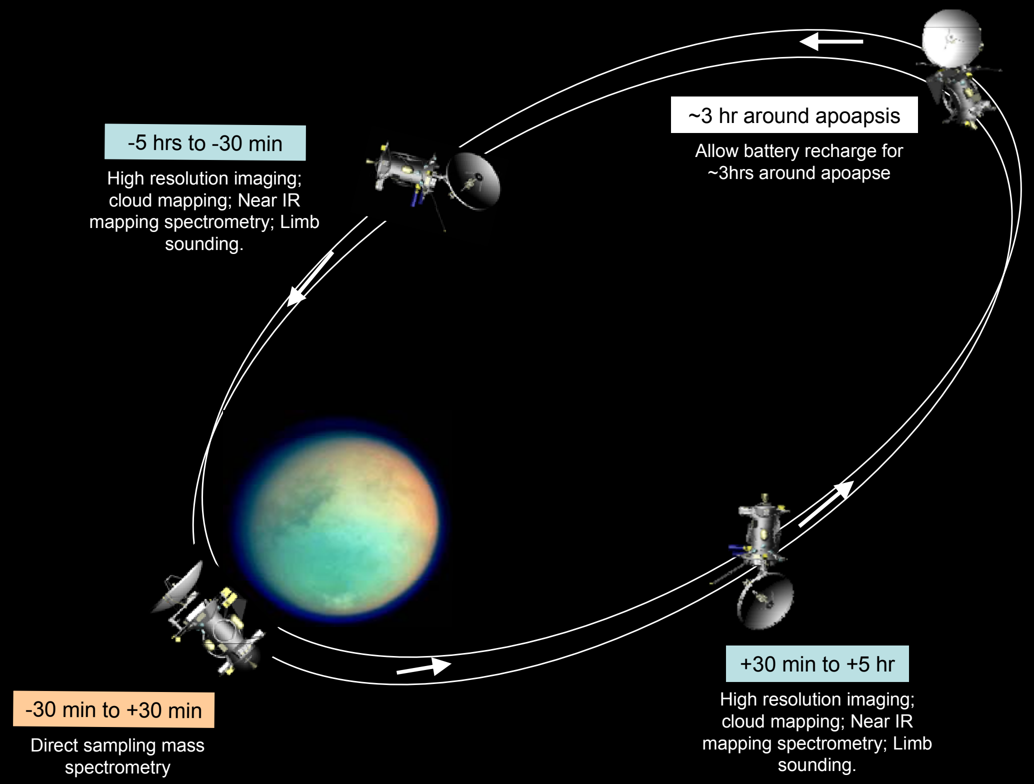


-5hr to -2 hr	-2hr to -30 min	-30 min to +30 min	+30 min to +2 hr	+2 hr to +5 hr	+5 hr to +6 hr	+6hr to +20 hr
Global imaging; Cloud mapping; Near & mid IR mapping spectrometry	High resolution imaging; IR mapping spectrometry, Observe Titan/magnetosphere interaction	Direct sampling mass spectrometry	High resolution imaging; IR mapping spectrometry; Observe Titan/magnetosphere interaction	Global imaging; Cloud mapping; Near & mid IR mapping spectrometry	Battery recharge before telecom system turns on	Downlink to 34 m DSN

16 Titan Flybys

- Optimized for mass spectrometry (F&P direct sampling) when within Titan's atmosphere (i.e., near closest approach).
- Optimized for imaging and other remote sensing when above the atmosphere.
- For each Titan flyby, 26 Gb of data will be collected.

Summary of Titan Orbit Phase Operations Scenarios



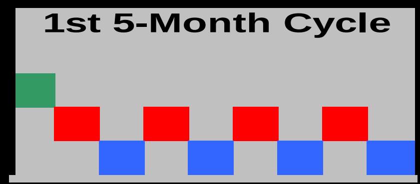
- Aerobraking period is 2 months, ~200 orbits, down to 600 km
- Closest approach period dedicated to direct sampling of the atmosphere and magnetospheric environment.
- Gimbaled HGA will allow Radio Science gravity and atmospheric occultation measurements at various latitudes.
- Higher altitude portions yield opportunities for cloud imaging. limb sounding, and global mapping.
- Up to 11 Gb collected on each aerobraking orbit.

Circular Orbit Phase

- 20 month period divided into 16 day campaigns to manage power and data flow
- Titan completes 1 rotation and 1 revolution of Saturn every 16 days.
- Campaigns based on science discipline (see below) execute for 80 consecutive orbits
- More than 4 Tb returned during Orbit Phase

Orbital Campaigns

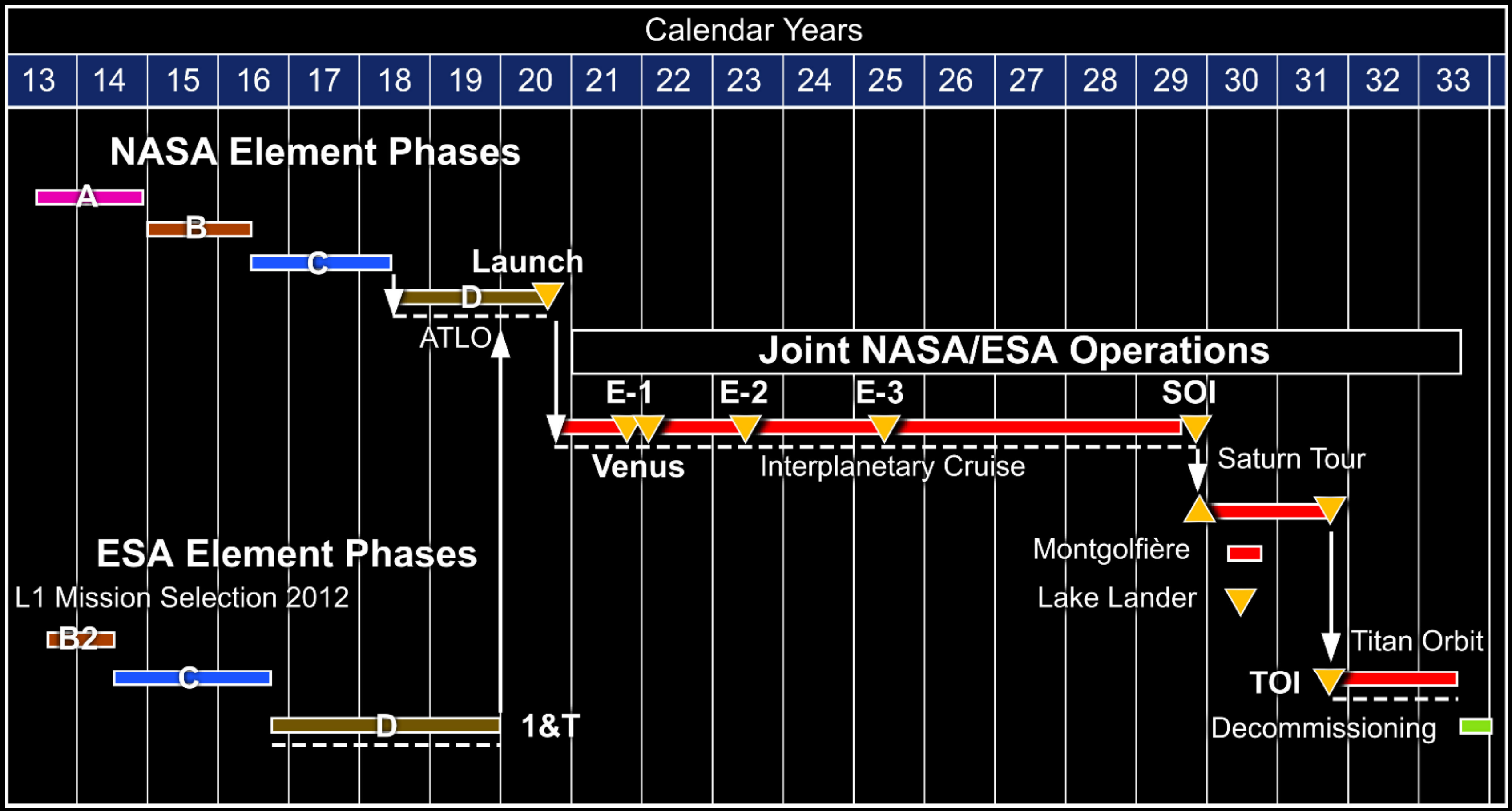
- Atmosphere and ionosphere (**PMS and MAPP**): Identify and measure ions and neutrals globally for various Sun angles. Each of these 16-day campaigns collects 48.3 Gb.
- Surface map (HiRIS, TIPRA, and MAPP): Global map in up to four colors; global altimetry with better than 10-m accuracy; surface spectroscopy. Each of these 16-day campaigns collects 475 Gb.
- Atmosphere dynamics and composition (TIRS and SMS): Measure temperatures, composition, and winds, globally. Each of these 16-day campaigns collects 36.5 Gb.



Risks are Identified and Mitigated

- **NEXT IPS flight qualification**
  - Cost carried for NEXT qual with 50% cost reserves, two flight proven fall –back options available
- **RPS Availability (ASRG or MMRTG)**
  - Work with NASA to ensure Phase A decision
- **Final integration of RPS**
  - Design for RPS installation and perform pre-installation Trailblazer
- **Mission Length**
  - Mitigated by proven LL design rules and EEE parts process from Voyager, Galileo, Cassini, New Horizons
- **Operational Cost**
  - Focused payload, sequential and simple delivery of in situ elements, simplified mission planning and sequencing through pre-planned observational scenarios

Top Level Implementation Schedule



Summary of TSSM Features

- **TSSM represents the logical next step in outer planets exploration with a host of features, ready to be implemented now:**
  - Unequalled exploration of two worlds of intense astrobiological interest (Titan and Enceladus) in a single combined NASA/ESA mission
  - Major scientific advance beyond the Cassini–Huygens survey
  - Covers the full range of planetary science disciplines – Geology, Atmospheres, Astrobiology……………………..
  - Built upon successful design and operational experience in landing probes on Titan (ESA Huygens), and Saturn-based orbiters (NASA Cassini)
  - Baseline mission provides modular solar electric propulsion stage that could be used on other solar system missions
  - Leverages synergistic NASA–ESA resources, reduces risk, and ensures technical readiness
  - Ensures programmatic flexibility with frequent launch opportunities
- **A unique mission for an extraordinary world, the Titan Saturn System Mission provides a kind of planetary exploration ideally suited to the environment of Titan that will return Flagship class science.**

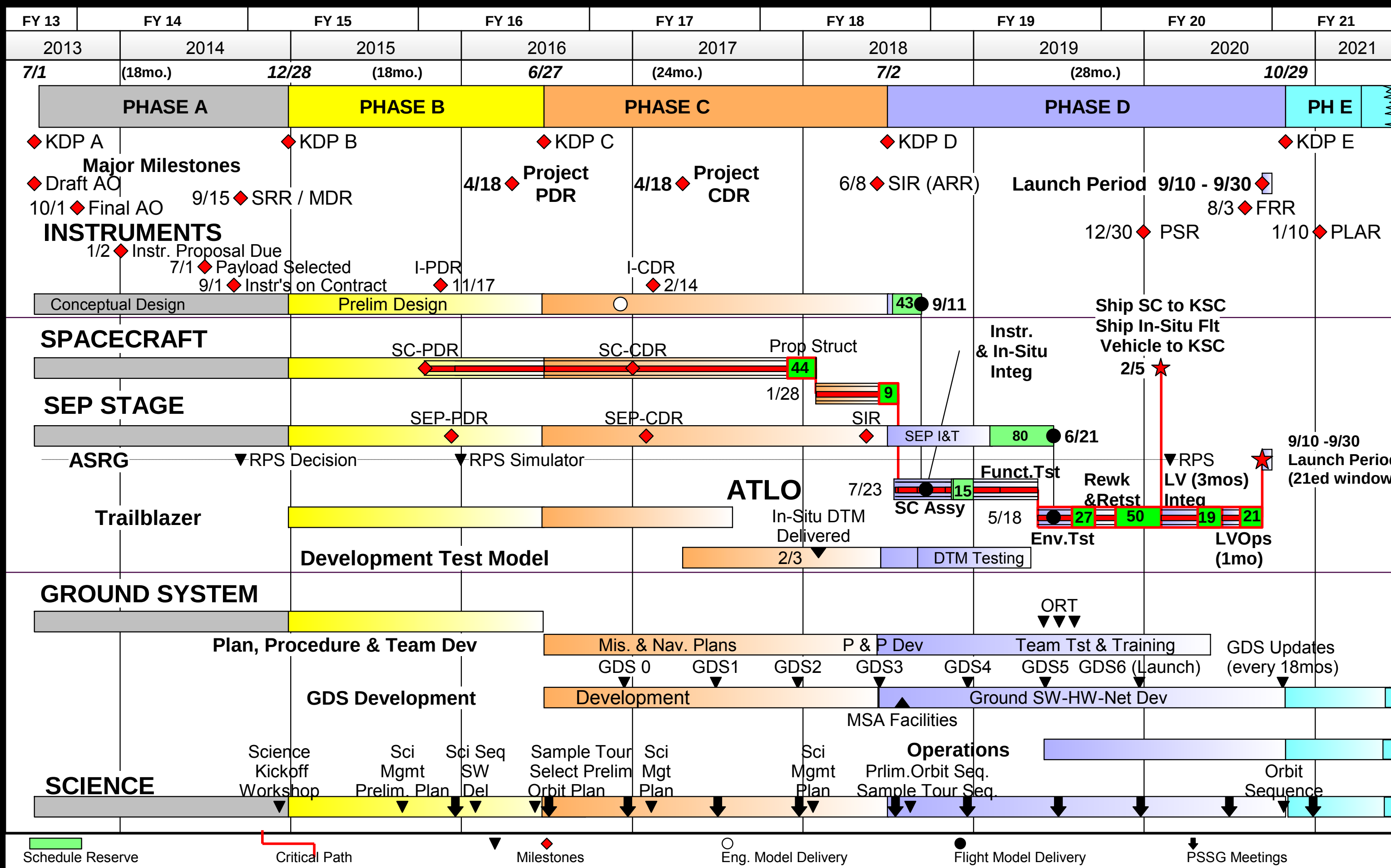
Now, on to the In Situ Elements…………..

BACKUP

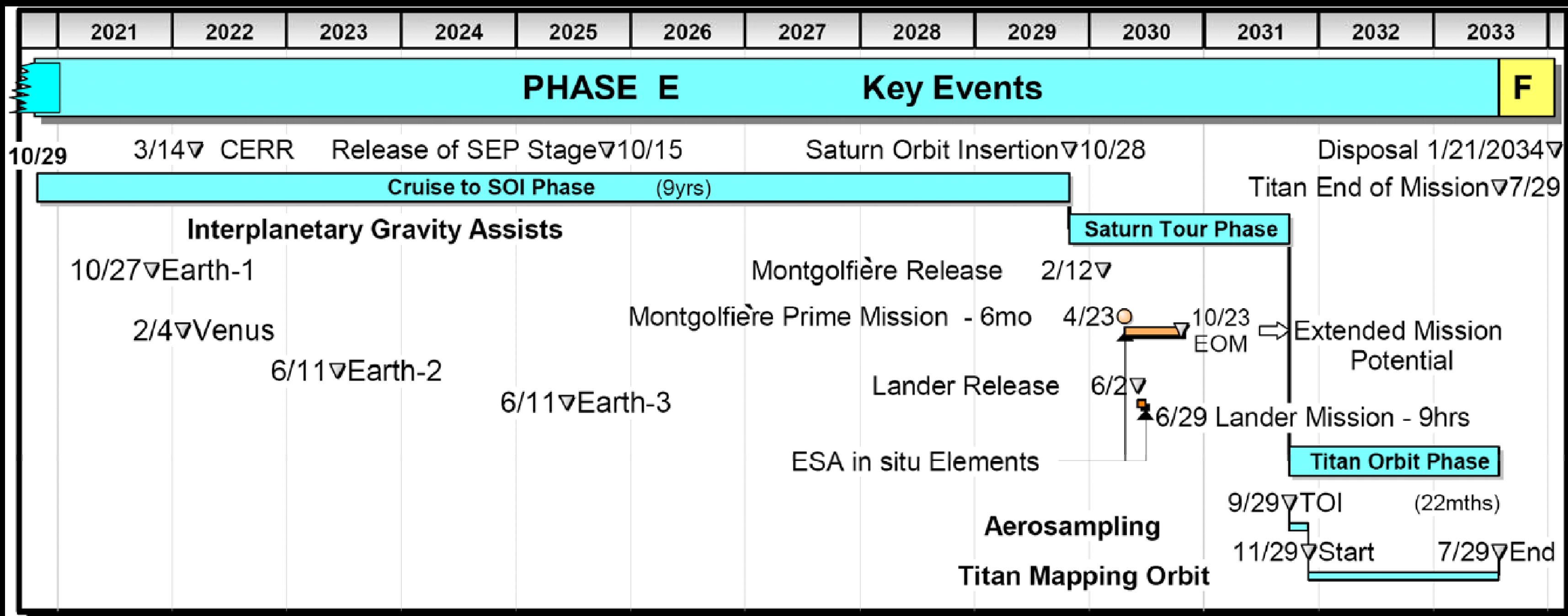
Orbiter Science Scenarios

- **Saturn Approach**
  - Instrument calibration, ops exercises and magnetospheric measurements
- **Saturn Tour - Saturn, Enceladus and Titan Science**
  - 7 low-altitude Enceladus flybys (4@100 km, 3 < 1100 km)
    - High resolution imaging; Near & mid IR mapping spectrometry
    - Direct sampling mass spectrometry
    - Subsurface radar measurements
    - Radio Science gravity field measurements
  - 16 Titan Flybys (Altitudes → 8 < 1200km, 8 higher)
    - High res. imaging; IR mapping spectrometry; observe Titan/magnetosphere interaction
    - Global imaging; cloud mapping; near & mid IR mapping spectrometry
    - Direct sampling mass spectrometry
    - Limb sounding; IR mapping; cloud imaging
- **Aerobraking - ~200 Titan passes, many at 600–700km altitude**
  - High resolution imaging; Near IR mapping spectrometry
  - Direct sampling mass spectrometry
- **Titan Orbit - (Discussed on the following slide)**
- **Decommissioning and Disposal**
  - TBD data capture and playback until impact

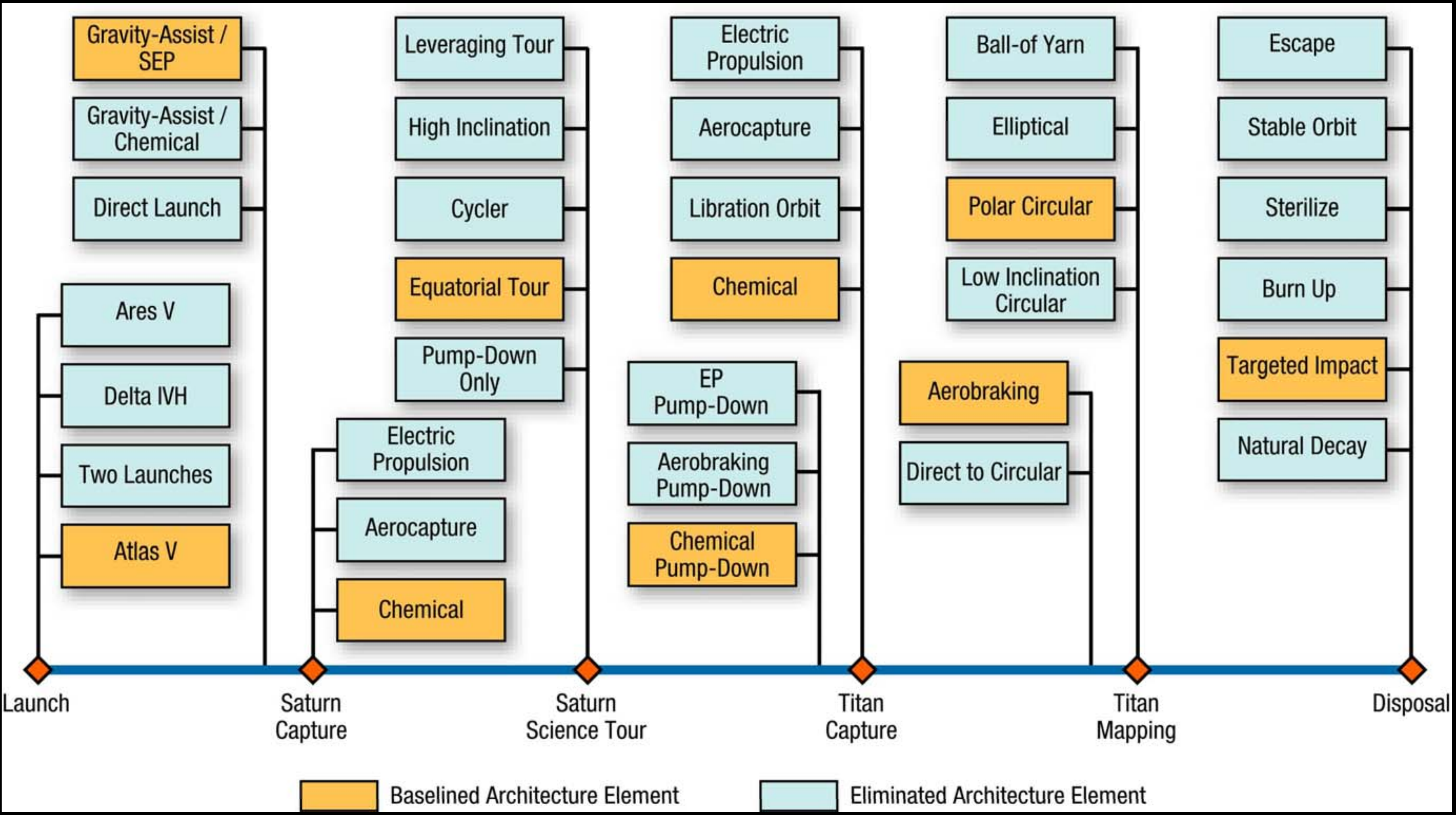
Top Level Project Schedule



Phase E Timeline



Architectural Trades



Mission Option Characteristics

Table 3.3-1. *Summary characteristics of the Baseline architecture and alternates.*

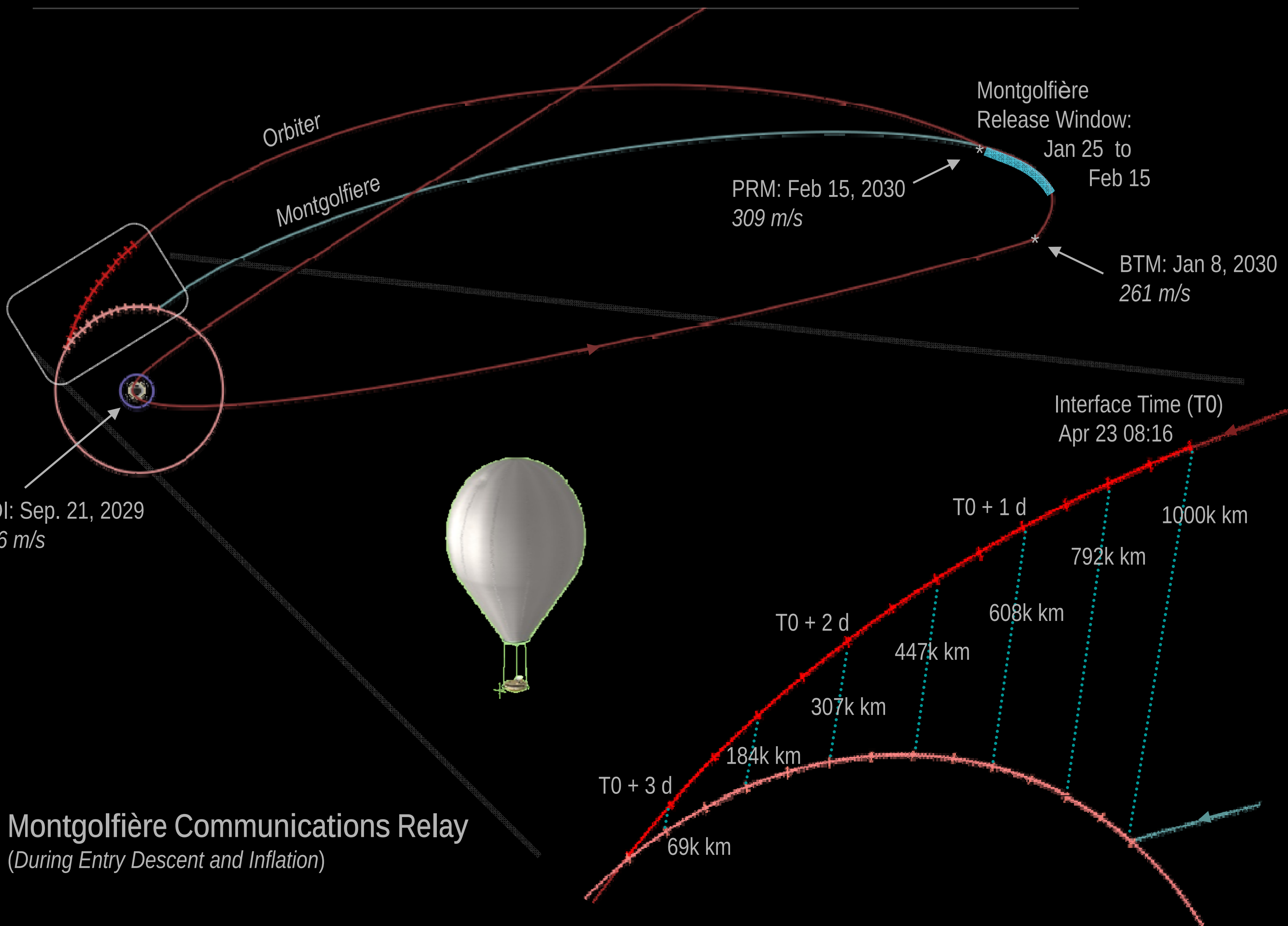
	Baseline	*NASA / ESA Floor*	*NASA-only*	*NASA-only Floor*
Flight Elements	NASA orbiter and SEP stage, ESA montgolfière and lander	NASA orbiter, ESA montgolfière and lander	NASA orbiter; SEP stage	NASA orbiter only
Launch Vehicle	Atlas V 551	Atlas V 551	Atlas V 551	Atlas V 551
Launch Date	2020	2020	2020	2020
Backup Launch Date	2022	2022	2022	2022
Transfer Trajectory	SEP/EVEE, 9 yrs	VEE or other gravity assist, 10.5 yrs	SEP/EVEE, 9 yrs	VEE or other grav assist, 10.5 yrs
SOI & Initial Orbit	Chemical; 214-day period	Chemical; 214-day period	Chemical; 214-day period	Chemical; 214-day period
ESA *in situ* element release timing	Montgolfière: 1st Titan flyby; Lander: 2nd Titan flyby	Montgolfière: 1st Titan flyby; Lander: 2nd Titan flyby	NA	NA
Saturn System Tour Duration	2 years	2 years	2 years	2 years
Enceladus Flybys During Tour	7 or more	7 or more	7 or more	7 or more
Titan Flybys During Tour	16	16	16	16
Data Relay for *in situ* elements	During Saturn tour	During Saturn tour	NA	NA
TOI & Initial Orbit	Chemical; 720 × 15,000 km	Chemical; 720 × 15,000 km	Chemical; 720 × 15,000 km	Chemical; 720 × 15,000 km
Aerobraking/ Aerosampling Duration	2 months	2 months	2 months	2 months
Mapping Science Mission Duration	20 months	16 months	20 months	16 months
Extended Orbital Mission Possible?	Yes	Yes	Yes	Yes
Option for high-rate relay for *in situ* element extended mission?	Yes	Yes	NA	NA
Spacecraft Disposal	Naturally assisted, targeted burnup/breakup into Titan atmosphere	Naturally assisted, targeted burnup/breakup into Titan atmosphere	Naturally assisted, targeted burnup/breakup into Titan atmosphere	Naturally assisted, targeted burnup/breakup into Titan atmosphere

Mission Phases

Table 4.3-1. Mission phase definition and description.

Phase	Activity	Duration
Interplanetary Cruise (9 years)	Launch and Early Operations: Launch from CCAFS and activities, including initial acquisition by the DSN, checkout and deployment of all critical spacecraft systems and preparations to begin thrusting with the Ion Propulsion System (IPS).	2 months
	Solar-Electric Cruise: Thrusting with the IPS and gravity-assist flybys of Earth and Venus. Several activities associated with flybys, thrust arc design, and Earth avoidance.	5.0 years
	Ballistic Cruise: Once the SEP stage is jettisoned, the spacecraft enters a period of low activity.	3.3 years
	Saturn Approach: Preparations and readiness testing for Saturn Orbit Insertion (SOI). Optical navigation for upcoming Enceladus flybys.	6 months
Saturn Tour (2 years)	Saturn Arrival: SOI performed between Cassini-like ring plane crossing in the F–G gap	2 years
	ISE Delivery: Starts with 214 d period orbit with a Balloon Targeting Maneuver (BTM) to target to the montgolfière entry position and velocity, release of the montgolfière, and a Periapsis Raise Maneuver (PRM) to target the first Titan flyby. On the following orbit, a Lander Targeting Maneuver (LTM), Lander Release, and Orbiter Deflection Maneuver (ODM) deliver the Lander to Kraken Mare.	
	Enceladus Flybys: Seven close (100–500 km) flybys of Enceladus allowing *in situ* measurements of the plume and remote sensing of active region. Additional opportunistic flybys of other icy moons possible, such as Rhea in the example tour.	
	Final Energy Reduction: Series of orbits with large maneuvers to lower Titan V_∞ to ~940 m/s prior to Titan orbit insertion. Moderate-sized maneuver sets up proper initial orbit plane geometry.	
Titan Orbit (1.9 year)	Aerobraking: Starting from an 720 km by 15,000 km orbit, Titan aerobraking is used to help circularize orbit and provide deep sampling of Titan atmosphere to 600 km.	2 months
	Circular Orbit: Detailed surface mapping of Titan from a 1500 km, circular, polar (85°) orbit that starts with and a decending node at 11:30 am LST and reaches 9:00 am by the end of the mission.	20 months
Decommissioning and Disposal	At end of prime mission, a ~15 m/s maneuver places spacecraft in an orbit that will decay in < 6 months. During this phase small maneuvers will be used to keep the final entry point away from any regions of concern for planetary protection.	6 months
Extended Mission	Minimal orbit maintenance requirements mean that the spacecraft could continue in Titan orbit for an extended mission of several years as allowed by funding and spacecraft health.	

Montgolfière Delivery

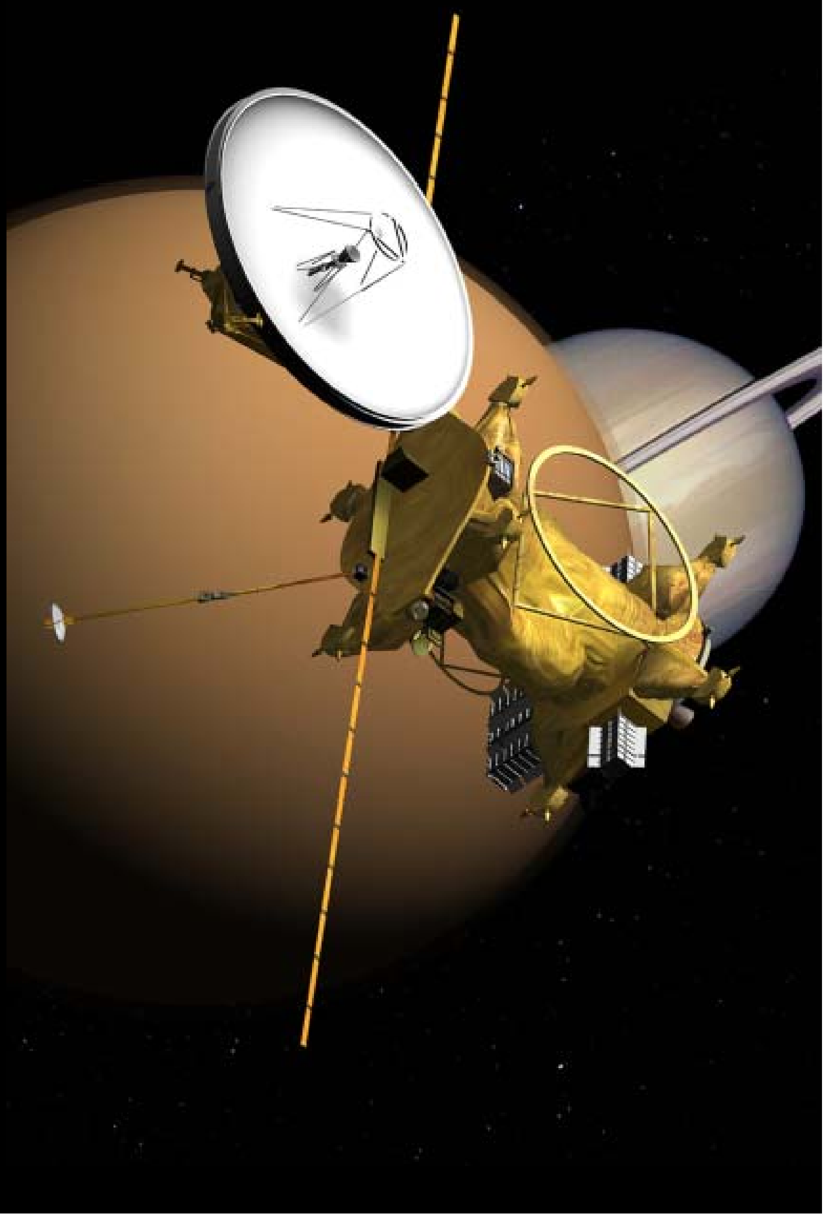


Montgolfière Communications Relay

(During Entry Descent and Inflation)

Orbiter Design Features

- **Telecom**
  - 4m X/Ka band HGA with 35W Ka TWTA
  - >140 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 ~2500 kg propellant
- **Power**
  - 5 ASRGs + redundant 25 Ahr batteries
  - ~540W 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, variable RHUs and electric heaters combined with ASRG waste heat used to minimize electric power demand

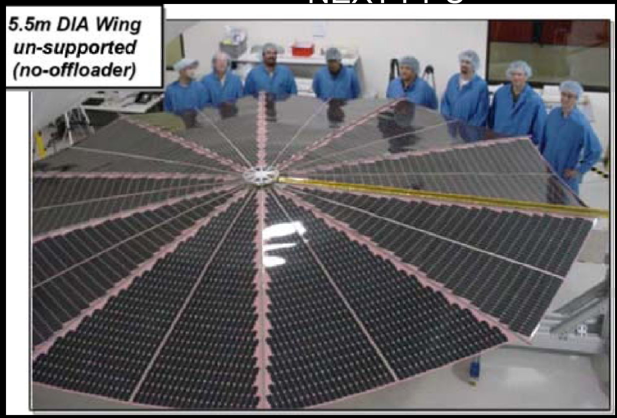


SEP Stage Design

- **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

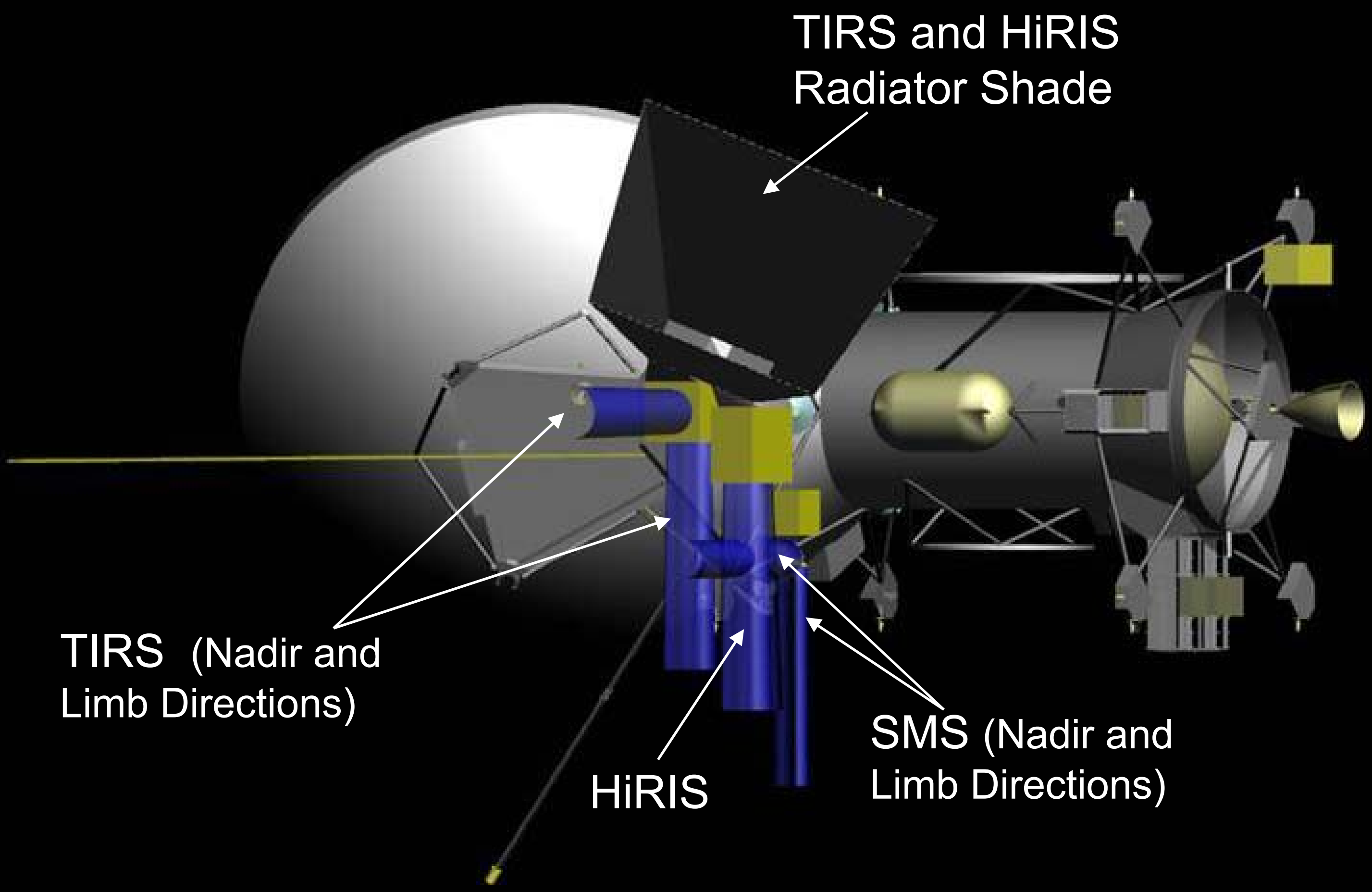
NEXT Thruster and Gimbal

NEXT PPU

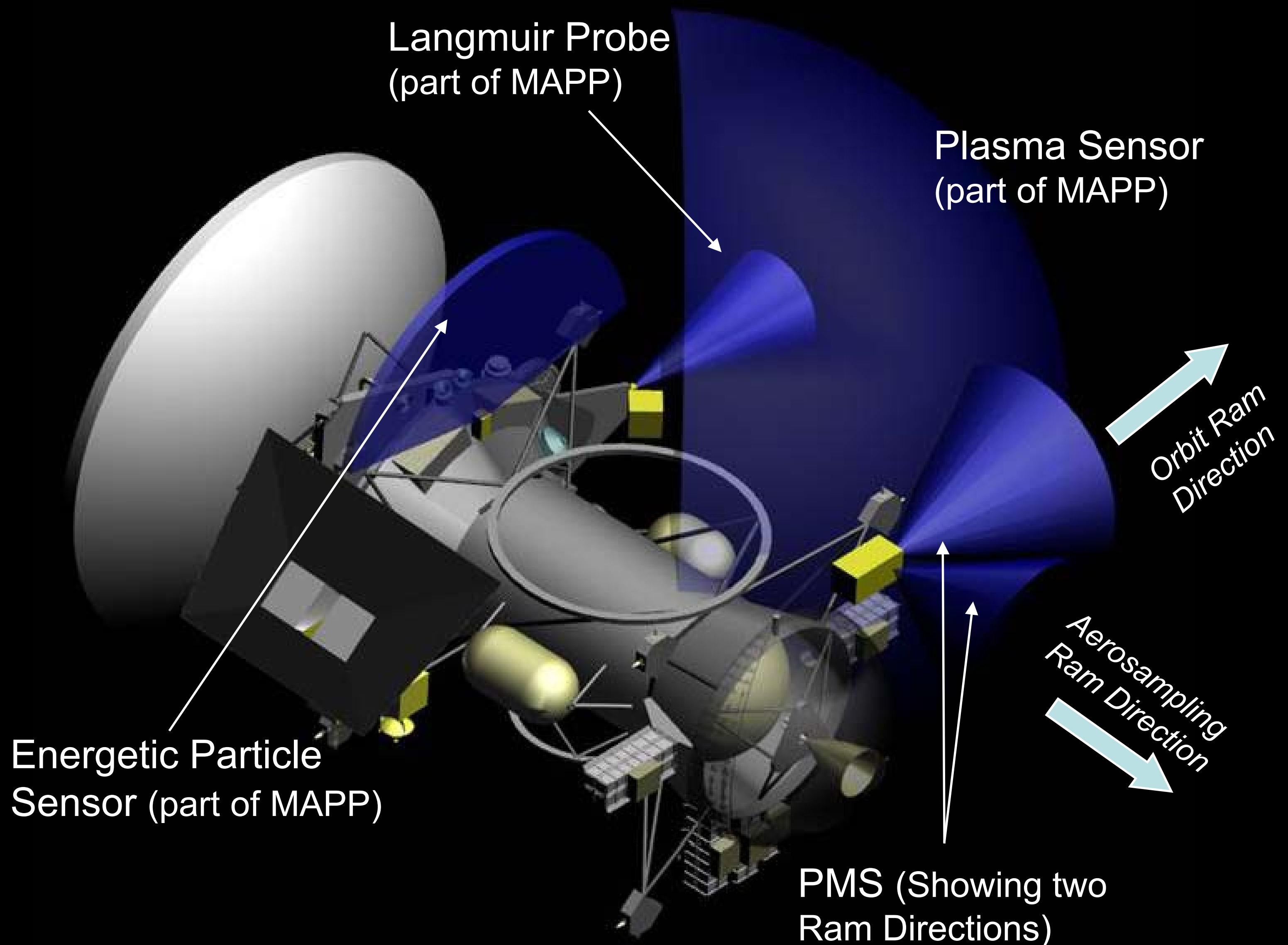


Prototype CEV Array

Instrument FOVs: Nadir Viewing



Instrument FOVs: Plasma Instr.



In Situ Element Delivery Parameters

Parameter	Value
Montgolfière Destination	20º N at steady state
Montgolfière Interface Altitude	2000 km
Montgolfière Entry Speed	6.3 km/s
Montgolfière Entry Ang. Corridor	65º +/- 3º
Mont. Release Vel. Uncertainty	35 mm/s 1-sigma
Lander Landing Site	72ºN 310ºW, Kraken Mare
Lander 3-σ Landing Footprint	600 km E-W X 160 km N-S
Lander Interface Altitude	2000 km
Lander Entry Speed	3 km/s
Lander Entry Angle Corridor	65º +/- 1.5º
Lander Release Vel. Uncertainty	35 mm/s 1-sigma

In-Situ Element Accommodation

- **Spacecraft design provides accommodation for up to two in-situ elements**
  - Design supports one 2.6m aeroshell and one 1.8m aeroshell
    - Total allocated mass is 830 kg
      - Baseline mission capability varies with drop-off scenario
    - Mounting interface provided by Spacecraft, Spin/Eject device provided by ESA
  - Power and data interfaces provided pre-deployment
  - Orbiter provides telecom relay post-deployment using orbiter telecom system
    - Orbiter transponder capable of accommodating relay in S, X, or Ka band