

A composite space image featuring Earth in the upper left, the Moon in the center, Mars in the lower center, and Jupiter in the bottom right. A comet streaks across the upper right, and a spiral galaxy is visible in the far background.

# Outer Planets Flagship Mission Results

Curt Niebur  
OPF Program Scientist  
NASA Headquarters

OPAG Meeting  
March 9, 2008





# Study Background and Purpose



- NASA and ESA are using a multistep downselection process to carefully select their next “flagship” missions
  - Multiple studies in this process intended to inform decisionmakers on science value, implementation risk/issues, cost and cost risk, and technology needs
- Step 1 (2007): NASA and ESA operated independently of one another
  - PSD conducted detailed studies for several flagship missions (Europa, Titan, Enceladus, and Jovian System Observer)
    - AA Stern selected two of these concepts (Europa and Titan) for further study/evaluation in 2008
  - ESA solicited Cosmic Vision Class L proposals
    - ESA selected Laplace and Tandem proposals (as well as IXO and LISA)
- Step 2 (2008): NASA and ESA began a closer collaboration
  - Europa and Laplace concepts combined into Europa Jupiter System Mission
  - Titan and Tandem concepts combined into Titan Saturn System Mission
- Step 3 (2009): Single concept moves forward for further work
  - NASA will focus on risk mitigation
  - ESA will conduct industry studies of 3 Class L concepts (OP, IXO, an LISA) for downselect beyond 2010



# Organization and Implementation



- Two concepts downselected for further joint NASA-ESA study in 2008
  - Europa Jupiter System Mission (EJSM) consisting of a Jupiter Europa Orbiter (JEO, contributed by NASA) and a Jupiter Ganymede Orbiter (JGO, contributed by ESA)
  - Titan Saturn System Mission (TSSM) consisting of a Saturn Titan Orbiter (STO, contributed by NASA) and Titan In Situ Elements (TISE, contributed by ESA: lake lander and balloon)
- JPL led the NASA technical effort
- Science community participation on each study via large SDTs and regular reporting to various organizations
- Study reports underwent independent TMC and Science Panel review



# Study Schedule



- SDTs formed: February 2008
- Kickoff Meeting: February 9, 2008
- First Interim Review: April 9, 2008
- ESA Concurrent Design Facility Studies Kickoff: May 21, 2008
- Second Interim Review: June 19-20, 2008\*
- ESA Concurrence Design Facility Studies Outbrief: July 27, 2008
- Final Reports Submitted: Nov. 3, 2008
- Site Visits: Dec. 9-12, 2008
- NASA/ESA Evaluation Board Meeting: Jan. 26, 2009
- NASA/ESA Decision Board Meeting: Feb. 12, 2009
- Public Announcement: Feb. 18, 2009
- Briefings to community
  - Outer Planets Assessment Group: Spring and Fall 2008
  - Planetary Science Subcommittee: June and October 2008
  - Science Instrument Workshop: June 2008
  - As requested to OMB and Congressional staff



# Review Process



- NASA conducted its standard independent review for pre-phase A concepts submitted in response to an AO
  - TMC panel evaluated feasibility of science implementation and mission implementation of NASA contributions (JEO and STO)
  - Science panel addressed the scientific merit of full international mission (EJSM and TSSM) and feasibility of science implementation of NASA contributions (JEO and STO)
- ESA conducted its own independent review process
  - Board of Technical Experts evaluated technical aspects of ESA contributions (JGO and TISE)
  - Solar System Working Group evaluated science of full international missions (EJSM and TSSM)





# NASA Review Results - Summary



<b>Study</b>	<b>Form A: Science Merit (EJSM &amp; TSSM)</b>	<b>Form B: Science Implementation Risk (JEO &amp; STO)</b>	<b>Form C: Mission Implementation Risk (JEO &amp; STO)</b>
<b>Europa Jupiter System Mission</b>	Excellent	Low Risk	Low Risk
<b>Titan Saturn System Mission</b>	Excellent	Low Risk	High Risk



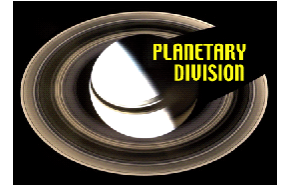
# Form A Significant Findings for EJSM (1)



- +The Europa Jupiter System Mission (EJSM) brings together a diverse, well-focused suite of measurements designed to investigate Europa as well as the environment in which it formed and evolved.
- +The science objectives of the EJSM are highly responsive and consistent with the 2003 NRC Decadal Survey goals and NASA's Solar System Exploration Roadmap.
- +The Jupiter Europa Orbiter (JEO) fills critical gaps in our understanding of Europa's interior (and especially its ocean and ice shell) and makes fundamental progress beyond Voyager and Galileo.
- +The joint EJSM represents an outstanding advance for satellite science and comparative planetology.
  - + The final phase of the Jupiter Ganymede Orbiter (JGO) mission, an orbital tour of Ganymede, will investigate the gravitational field, internal structure, surface features, and especially the intrinsic and induced magnetic fields of Ganymede.



## Form A Significant Findings for EJSM (2)



- +JGO also provides complimentary Jupiter system science, including a sub-millimeter wave sounder of Jupiter's atmosphere.
- +EJSM is a mission of considerable breadth and is a superb example of Flagship science.
- +The Study demonstrated the ability to distinguish between competing models of Europa's interior, constraining the thickness of the icy crust and the volume of liquid water below, using a combination of geophysical measurements (electromagnetic induction, gravity and topography, and radar sounding).
- +Thoroughly exploring Europa from orbit will feed forward to any future landed mission.
- There were no significant weaknesses
- The NASA-only JEO mission represents a highly capable mission that retains essentially all of the components for the study of Europa, and some of those for the study of Jupiter, that the full EJSM provides.





## Form B Significant Findings for JEO



- +The Traceability Matrix (TM) is very well done and comprehensive, particularly for Europa investigations.
  - Science Objectives are clearly flowed to Science Investigations, to detailed Measurement Requirements in Table 2.4-2, and finally to Instruments in F/O-1. A very thorough discussion is provided of the rationale for measurements and measurement requirements needed to support each science investigation. Hypotheses, Questions and their corresponding Hypotheses Tests are listed in Tables 2.4-4, 2.4-5, 2.4-10, 2.4-11 and 2.4-12, following the various Science Investigations given.
- There were no significant weaknesses.



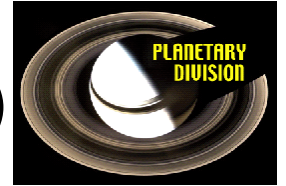
## Form C Significant Findings for JEO



- +The overall discussion of mission operations is excellent, and the operations impact on the design of the flight segment has clearly been considered, which is indicative of an appreciation of the importance of operations considerations early in the mission lifecycle.
- +The current JEO baseline builds upon a large body of previous studies to produce the current design concept, resulting in a relatively mature flight system concept for pre-Phase A and substantially reducing implementation risk.
- +The report presents a technical approach to risk identification and mitigation that demonstrates an excellent understanding of the major risks and the actions required to effectively mitigate those risks.
- The JEO ability to meet a stringent stability requirement in Europa orbit is not supported.
- The proposed funding profile for the Payload System (WBS 5) is too back-loaded to allow for efficient mitigation of issues and adequate early understanding of design details and requirements.



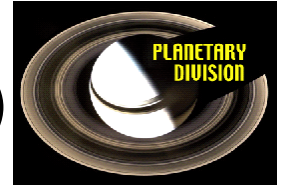
## Form A Significant Findings for TSSM (1)



- +The goals of the Titan and Enceladus exploration are clear, concise, and important.
- +The baseline TSSM is highly responsive to the NASA Solar System Roadmap and the 2003 NRC Decadal Survey.
- +The Enceladus science included in the TSSM mission is substantial and significant.
- +The synergistic approach of the baseline TSSM is ideal for making fundamental progress well beyond the Cassini Mission.
- +TSSM is a mission of considerable breadth and is a superb example of Flagship science.
- +The measurement set is well-defined and appropriate for meeting the scientific objectives of the mission.



## Form A Significant Findings for TSSM (2)



- +The descoped version of the international mission, in which the SEP is eliminated, maintains the full science capability of the mission in terms of instruments and measurements, although the time in Titan orbit will be reduced by 30%, from 20 to 14 months.
- There were no significant weaknesses
- The NASA-only mission, consisting of only a Titan orbiter as described in the Final Report, clearly makes fundamental advances in our understanding of Titan and Enceladus. However, in the absence of an in situ element, the mission falls short of providing the fundamental advances expected of flagship missions such as Galileo and Cassini.



## Form B Significant Findings for STO



- +The Traceability Matrix and associated discussions clearly show the connection between objectives and measurements and further show the priorities involved.
  - + A detailed science traceability matrix is provided that clearly flows from the three mission goals to science objectives, to proposed science investigations, to the required payload, to a planned measurement approach, leading on to a strong planning payload. Excellent discussion with detailed background is provided describing the rationale for the science payload measurements and the measurement requirements.
- There were no significant weaknesses.



## Form C Significant Findings for STO (1)

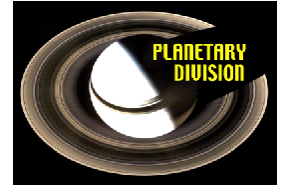


- +The report provides an excellent technical basis for the estimates and assumptions related to payload accommodation, with a thorough description of the individual instruments in the planning payload.
- The dry mass margin is too low for a pre-Phase A mission concept with significant technical challenges.
- The design drivers resulting from the inclusion of aerobraking in the TSSM mission have not been adequately defined and their resulting impact to the design has not been assessed.
- The changes for TIRS from the heritage CIRS instrument on Cassini are large, and the ability to successfully implement these changes is not well supported.
- The HGA pointing budget is extremely optimistic with little justification of the improvements presented.
- The TSSM ability to meet the stringent pointing stability requirement is not supported.





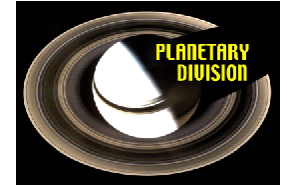
## Form C Significant Findings for STO (2)



- Analysis, engineering, and test of the TSSM thermal subsystem will be challenging and the report does not acknowledge the complexity of the task to address the substantial thermal design constraints posed by solar insolation, Venus albedo, the Montgolfière Multimission Radioisotope Thermoelectric Generator (MMRTG) waste heat, capillary pumped heat pipes (CPHPs), and aeroheating.
- Systems Engineering (SE) lacks the rigorous approach necessary for this highly complex mission, which leads to substantial technical, cost and schedule risk in both design and implementation.
- The complexity of the SEP stage development and lack of technical maturity are not reflected in the project cost estimate.
- The cost impact to accommodate the in situ elements seems unrealistically low.
- The allocated budget for Project System I&T appears insufficient.



# Decision & Rationale



## **NASA and ESA have assigned the highest priority to the Europa Jupiter System Mission for a late next decade launch.**

- Science value was not a discriminator between the two missions.
  - If flown, either mission would conduct outstanding science of significant breadth and depth that could be expected to dramatically advance our understanding of their targets.
  - The NASA Science Panel rated both the EJSM and TSSM science as Excellent.
  - The ESA SSWG concluded that the relative scientific merits of the two missions could not be separated and gave the missions equal priority for implementation.
- The EJSM is more technically mature, with the flight elements, their supporting technologies, and associated risks well understood and at a relatively high level of flight readiness.
  - The JEO mission concept was a medium to low risk development that effectively built upon many years of previous work to produce a relatively mature flight system concept for pre-phase A. This substantially reduces implementation risk and demonstrated excellent understanding of the major risks and the actions required to effectively mitigate those risks.
  - The ESA Board of Technical Experts concluded that established heritage and pathways are available to address radiation issues in a timely manner.
- The TSSM is a complex mission that possesses several technical challenges requiring significant study and technology development, and this increases the uncertainty that this mission can meet its schedule, cost, and science goals.
  - The STO mission concept was a high-risk development with significant technical challenges ahead.
  - ESA Board of Technical Experts concluded the TISE portion of the mission required multiple new technologies that would require a significant development effort. In addition, the thermal control system for the Multi-Mission Radioisotope Thermoelectric Generator and the complexity of the interfaces were a shared concern.



# The Road Ahead



- Execute Risk Mitigation Plan identified in report and endorsed by TMC
- Address shortcomings identified by review
- Prepare for instrument proposal and selection
  - Educate community on mission parameters and radiation
  - Next instrument workshop will be jointly sponsored by NASA and ESA is being planned for late summer 2009
  - Define instrument acquisition strategy, schedule, and support to community
- Define Outer Planets Program architecture (Tues. @ 10 am)
- NASA and ESA have made tremendous progress but many hurdles remain (budgetary, technical, political)
- Keep in mind that EJSM is a complex international mission that is currently in pre-phase A
  - We should expect some changes as we move toward and through Phase A (programmatics, schedules, unforeseen technical issues)
  - But the important things will not change (Europa radiation environment, key science objectives)



# Backup Slides



- ▶ EJSM Science
- ▶ EJSM Concept
- ▶ EJSM Ops
- ▶ EJSM Radiation
- ▶ EJSM Programmatics

- ▶ TSSM Science
- ▶ TSSM Concept
- ▶ TSSM Ops
- ▶ TSSM Programmatics



# Initial Groundrules – Feb. 2008



- Studies were guided by common Groundrules intended to simplify and level studies by providing a standard for content, final product, and common assumptions
  - Cost Cap<sup>1</sup>: \$2.1B (\$FY07) with 33% reserves
  - Power System<sup>1</sup>: only MMRTG's or solar allowed
  - Launch Vehicle: Atlas 5, Delta IV-H, Ares 5
  - Launch and Cruise<sup>1</sup>: Launch nlt 2017 and cruise ngt 7 years
  - DSN: utilize 34 m stations only
  - Technology: “Rule of One” and missions own necessary technology development
  - International Contributions: Partnerships are expected and are being pursued, but international contributions must provide capability above the mission science floor and cannot impinge on the ability of NASA to fly a complete mission for \$2.1B

<sup>1</sup>These groundrules were amended as a result of the Second Interim Review





# “Sweet Spot” Mission – June 2008



- At the Second Interim Review in June 2008 NASA changed its strategy
  - Strict cost cap strategy with science as the only free variable was dropped since the \$2.1B cost capped mission was not compelling
  - A new strategy to seek the “sweet spot” was adopted: optimize balance between science and cost to better respond to the Decadal Survey
- The study teams were directed to identify a “sweet spot” mission consistent with this new strategy
- An assessment of science value vs. cost was developed based on science goals set down by the Decadal Survey
- Following the second interim briefing to HQ management in June 2008 the study teams were directed to:
  - Focus the remaining study efforts on the “sweet spot” mission
  - Defer the nominal launch date from nlt 2017 to 2020 (with evaluation of launch options from 2018-2022)
  - Assess the impact of ASRG and MMRTG power sources and select the preferred system
- This slipped the original study schedule and increased study costs



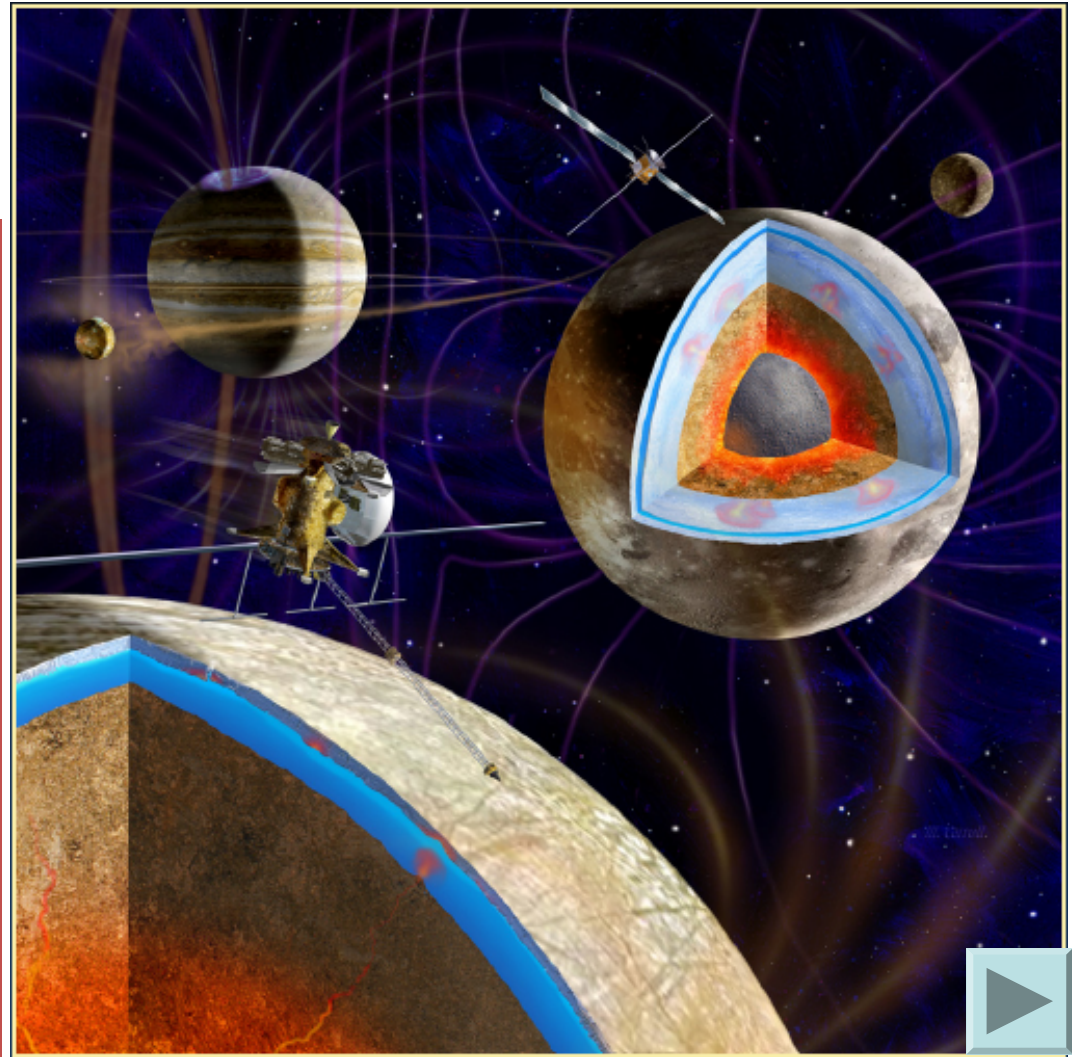
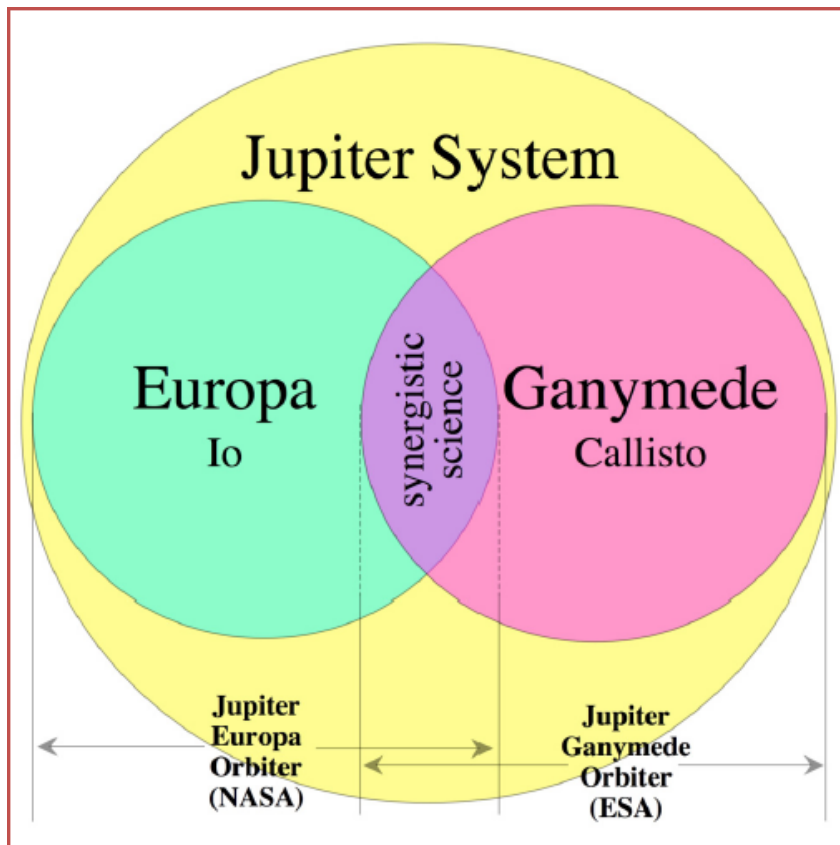




# EJSM Goals

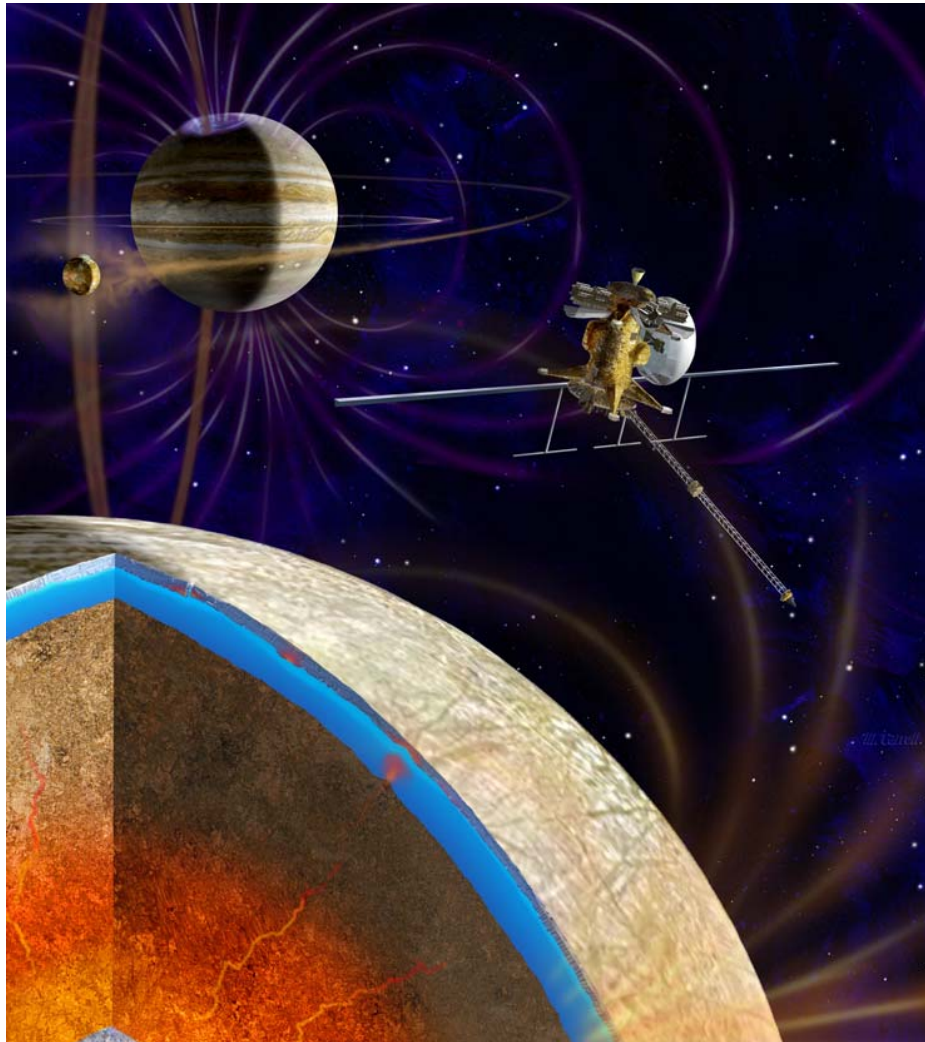
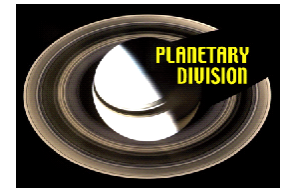


- The emergence of potentially habitable worlds around gas giants
  - Does the Jupiter system harbor habitable worlds?
  - What are the processes within the Jupiter system?





# JEO Science Goal & Objectives



- Explore Europa to investigate its habitability
  - Ocean Characterization
  - Surface-ice-ocean exchange
  - Chemistry & Composition
  - Geologic evolution
  - Jupiter System
    - Galilean satellite evolution
    - Satellite atmospheric interactions
    - Plasma & magnetospheres
    - Jupiter atmospheric dynamics
    - Rings

*Rich and robust science of Europa and the Jupiter System*





# EJSM Science: JEO and JGO



EJSM Theme:	The emergence of habitable worlds around gas giants	
Element:	JEO	JGO
Goal(s):	Explore Europa to investigate its habitability	How did the Jupiter system form? How does the Jupiter system work? Does the Jupiter system harbor a habitable world?
Objectives:	<ul style="list-style-type: none"><li>A. <b>Ocean:</b> Characterize the extent of the ocean and its relation to the deeper interior.</li><li>B. <b>Ice Shell:</b> Characterize the ice shell and any subsurface water, including their heterogeneity, and the nature of surface-ice-ocean exchange.</li><li>C. <b>Chemistry:</b> Determine global surface compositions and chemistry, especially as related to habitability.</li><li>D. <b>Geology:</b> Understand the formation of surface features, including sites of recent or current activity, and identify and characterize candidate sites for future <i>in situ</i> exploration.</li><li>E. <b>Jupiter System:</b> Understand Europa in the context of the Jupiter system.</li></ul>	<ul style="list-style-type: none"><li>A. <b>Ganymede:</b> Characterize Ganymede as a planetary object including its potential habitability.</li><li>B. <b>Satellite System:</b> Study the Jovian satellite system.</li><li>C. <b>Jupiter:</b> Study the Jovian atmosphere.</li><li>D. <b>Magnetosphere:</b> Study the Jovian magnetodisk /magnetosphere</li><li>E. <b>Jupiter System:</b> Study the interactions occurring in the Jovian system.</li></ul>



Back 23





# JEO Hypothesis Testing



*Table 2.4-4. Hypothesis Tests to Address Selected Key Questions Regarding Europa's Ocean and Interior.*

Example Hypothesis Questions		Example Hypothesis Tests
A1.	Does Europa undoubtedly have a subsurface ocean?	Measure the gravity field at Europa over the diurnal cycle.
A2.	What are the salinity and thickness of Europa's ocean?	Determine the magnetic induction signal over multiple frequencies to derive ocean salinity and thickness.
A3.	What is the internal structure of Europa's outermost H <sub>2</sub> O-rich layers?	Use measurements of the time-variable topography to derive the Love number $h_2$ , to relate the ice shell and ocean layer thicknesses.
A4.	Does Europa have a non-zero obliquity and if so, what controls it?	Use gravitational and topographic measurements of the tides to infer obliquity, which in turn constrains moments of inertia especially in combination with libration amplitude(s).
A5.	Does Europa possess an Io-like mantle?	Radar, magnetic and/or gravitational inferences of the ice shell thickness constrain how much heat the silicate interior is producing; magnetometer inferences of ocean salinity constrain the rate of chemical exchange between silicates and water, and the conductivity structure of the deep interior; local thinning of the ice shell (identified by radar) can be linked to hydrothermal plumes; time-variable gravity place bounds on the rigidity of the silicate interior.

*Table 2.4-11. Hypothesis Tests to Address Selected Key Questions Regarding Europa's Geology*

Example Hypothesis Questions		Example Hypothesis Tests
D1.	Do Europa's ridges, bands, chaos, and multi-ringed structures require the presence of near-surface liquid water to form?	Combine high-resolution imaging, compositional, subsurface, and thermal data sets to determine the style of surface deformation and the links to interior structure and water.
D2.	Where are the youngest regions on Europa and how old are they?	Use repeat imaging, sputtering measurements, vapor transport observations and thermal data to determine absolute age ranges.
D3.	What is the roughness and thickness of the regolith?	Use thermal measurements and imaging, combined with plasma measurements, to characterize the uppermost surface.



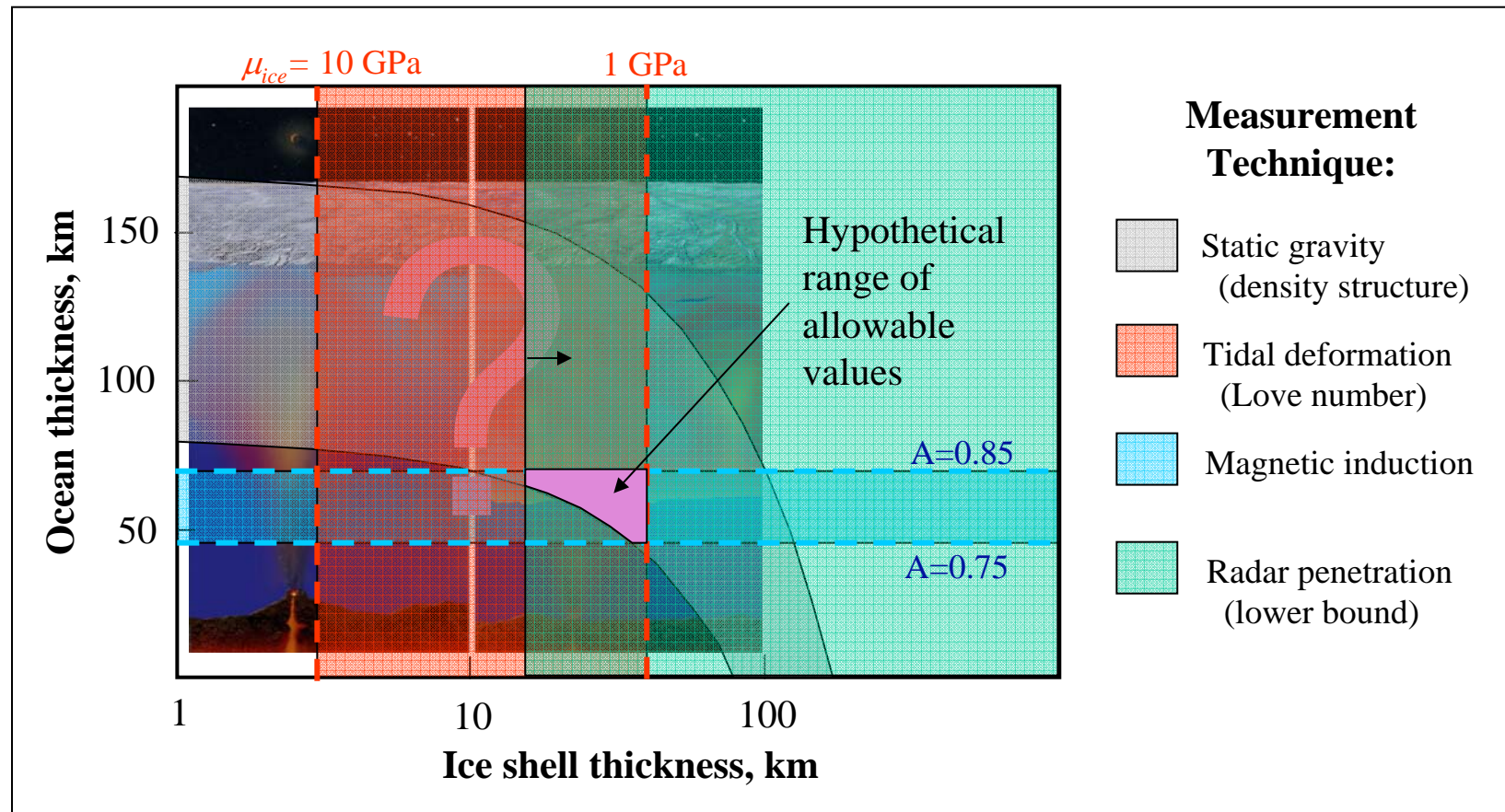
Back



# Constraining Ice Shell Thickness



## *Hypothetical Example*



*Multiple techniques constrain ice shell thickness*

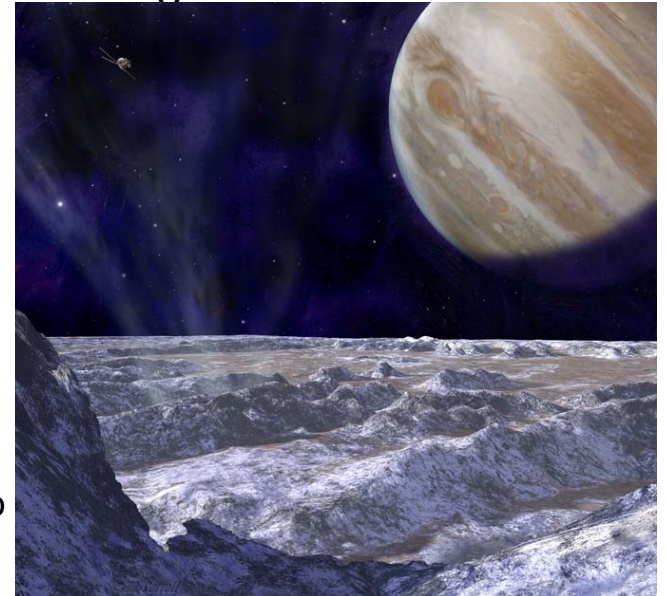




# JEO Mission Concept



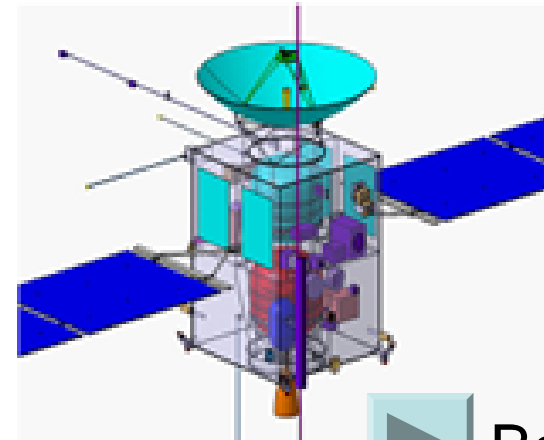
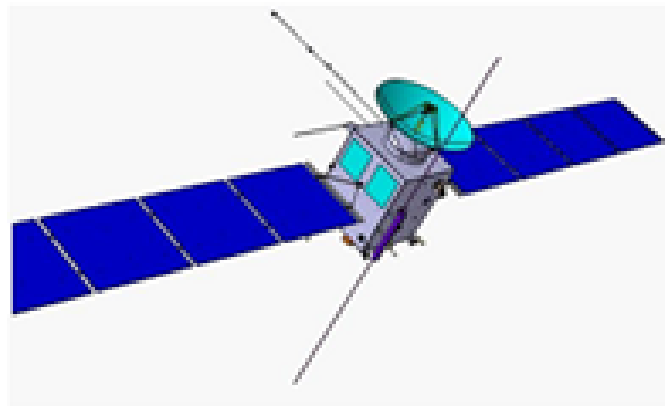
- Concept: Europa Orbiter with Jovian/Galilean tour coordinating science with ESA Jupiter Ganymede Orbiter
- Launch Vehicle: Atlas V 551
- Trajectory: 6 year VEEGA chemical
- Power Source: 5 MMRTG or 5 ASRG
- Mission Timeline:
  - Launch: 2018 to 2022, nominally 2020
  - Jupiter Arrival: Dec. 2025
  - Jovian system tour phase: 30 months
    - Multiple satellite flybys: 4 Io, 6 Ganymede, 6 Europa, 9 Callisto
  - Europa orbital phase: 9 months
  - End of Prime Mission in 2029; s/c eventually impacts Europa
- Instruments: 11 (211 kg<sup>1</sup>, 71 W) including Radio Science
- Cost: \$2.7B (FY07)/\$3.8B (RY)
- Floor Mission: 7 instruments, 1.5 yr tour, 3.5 months at Europa, \$2.1 B (FY07)
- Radiation Dose: 2.9 Mrad (behind 100 mils of Al)
  - Handled using a combination of rad-hard parts and tailored component shielding
  - Key rad-hard parts are available, with the required heritage
  - Team is developing and providing design information and approved parts list for prospective suppliers of components, including instruments





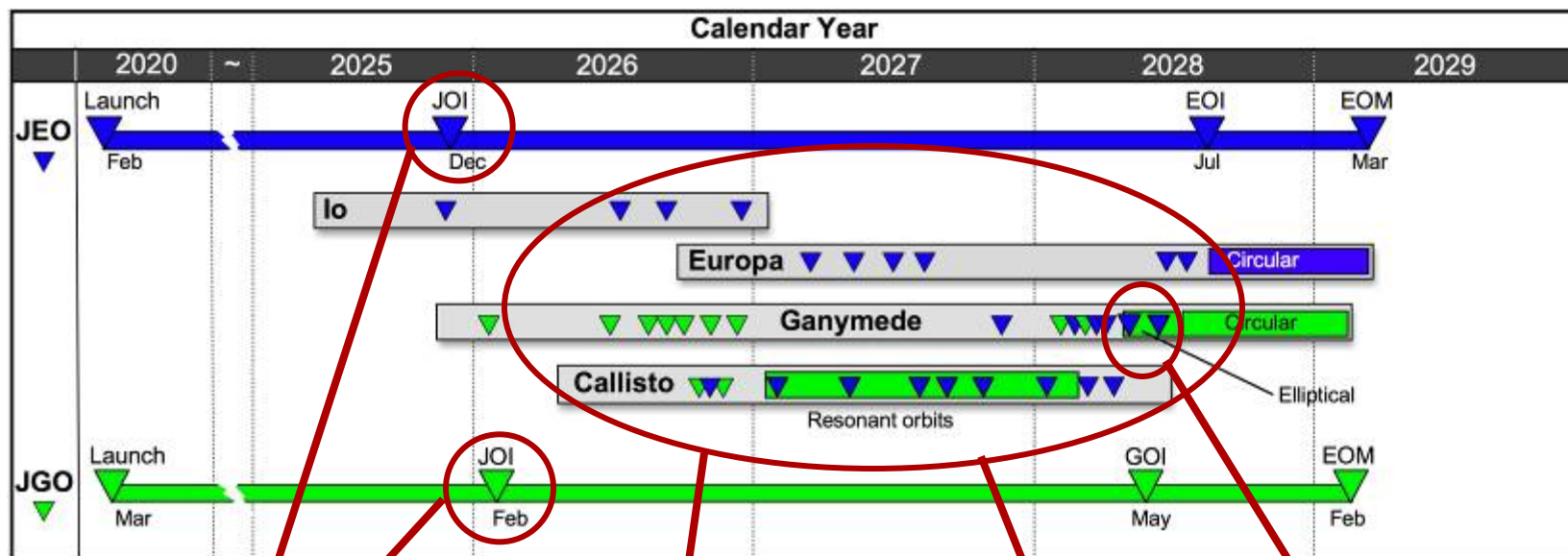
## Mission architecture for Jupiter Ganymede Orbiter

- Launch into direct escape by Ariane 5 ECA (11 March 2020)
- VEEGA → arrival at Jupiter on 4 Feb. 2026 (5.9 year transfer)
- Jupiter Orbit Insertion with Ganymede GAM into  $13 \times 245R_J$
- Jupiter science for ~2 years
- Callisto Science Phase: resonance with low altitude (200km), 19 fly-bys
- Ganymede Science Phase:
  - Elliptic phase (200 x 6000km, 80 days)
  - Circular phase (200km near polar orbit, 180 days)
- End of Nominal mission ~ Feb. 2029 (mission duration ~ 8.9 yr)

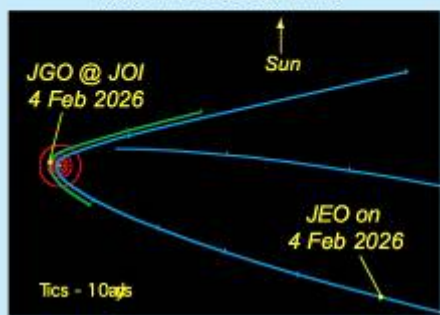




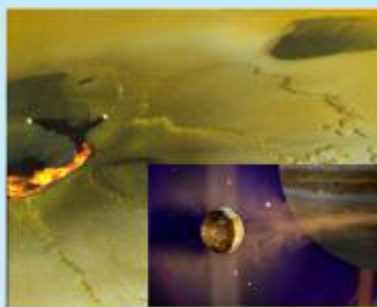
# EJSM Synergistic Science



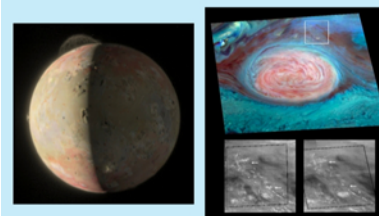
## Jupiter Magnetosphere Studies



## Io Volcanism & Io Torus Dynamics



## Satellite/Jupiter Monitoring

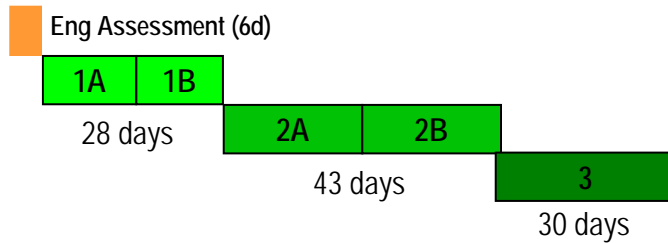
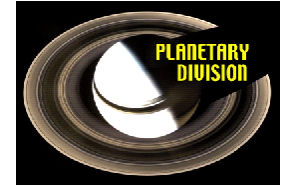


## Ganymede Magnetosphere Studies





# Europa Science Campaigns



Focused Science: Follow up on discoveries (~6 mo)

## By end of Europa Campaign 3:

4 global maps

- 2 @ 200m Color + Stereo
- 2 @ 100m Stereo

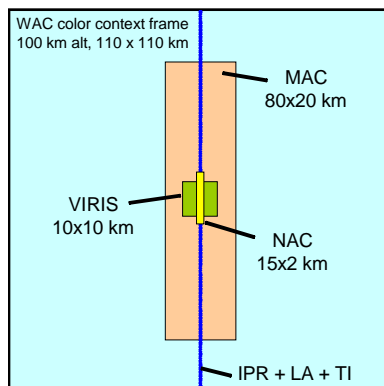
730 imaging and radar targets

18 km profile spacing for LA and TI

35 km spacing for IPR and VIRIS

400 UVS stellar occultations

- Finer global and regional grid of profiling observations (IPR, VIRIS, TI)
- Continue gravity, laser altimetry, and fields and particles measurements
- Additional coordinated target sets
  - Investigate new discoveries and priorities
  - Characterize candidate future landing sites
- Off-nadir NAC stereo images
- Lower altitude operations
- Monitor Io and Jupiter, 1 to 2 times per week



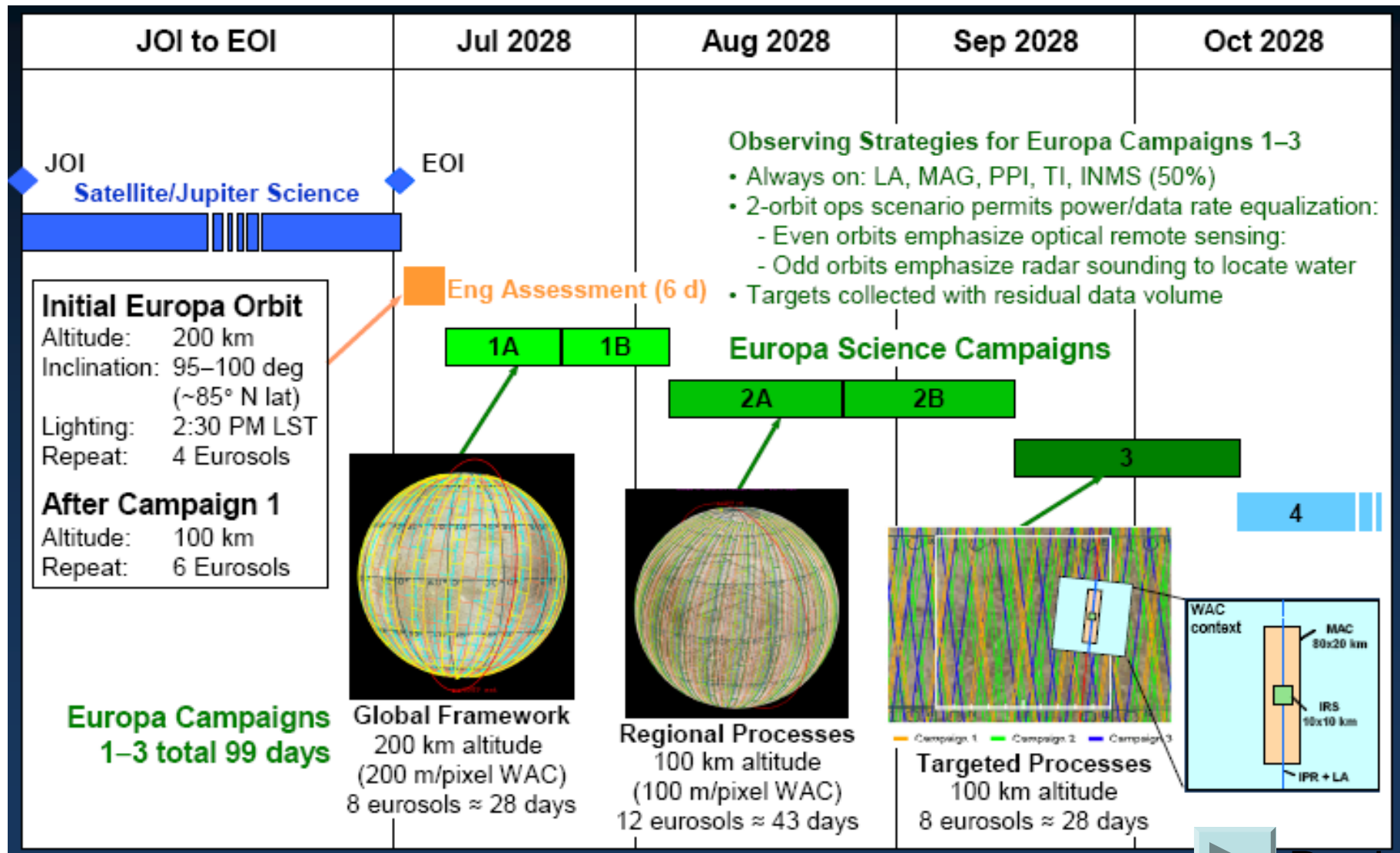
*Extended time in Europa orbit allows additional investigations and exploration*



Back



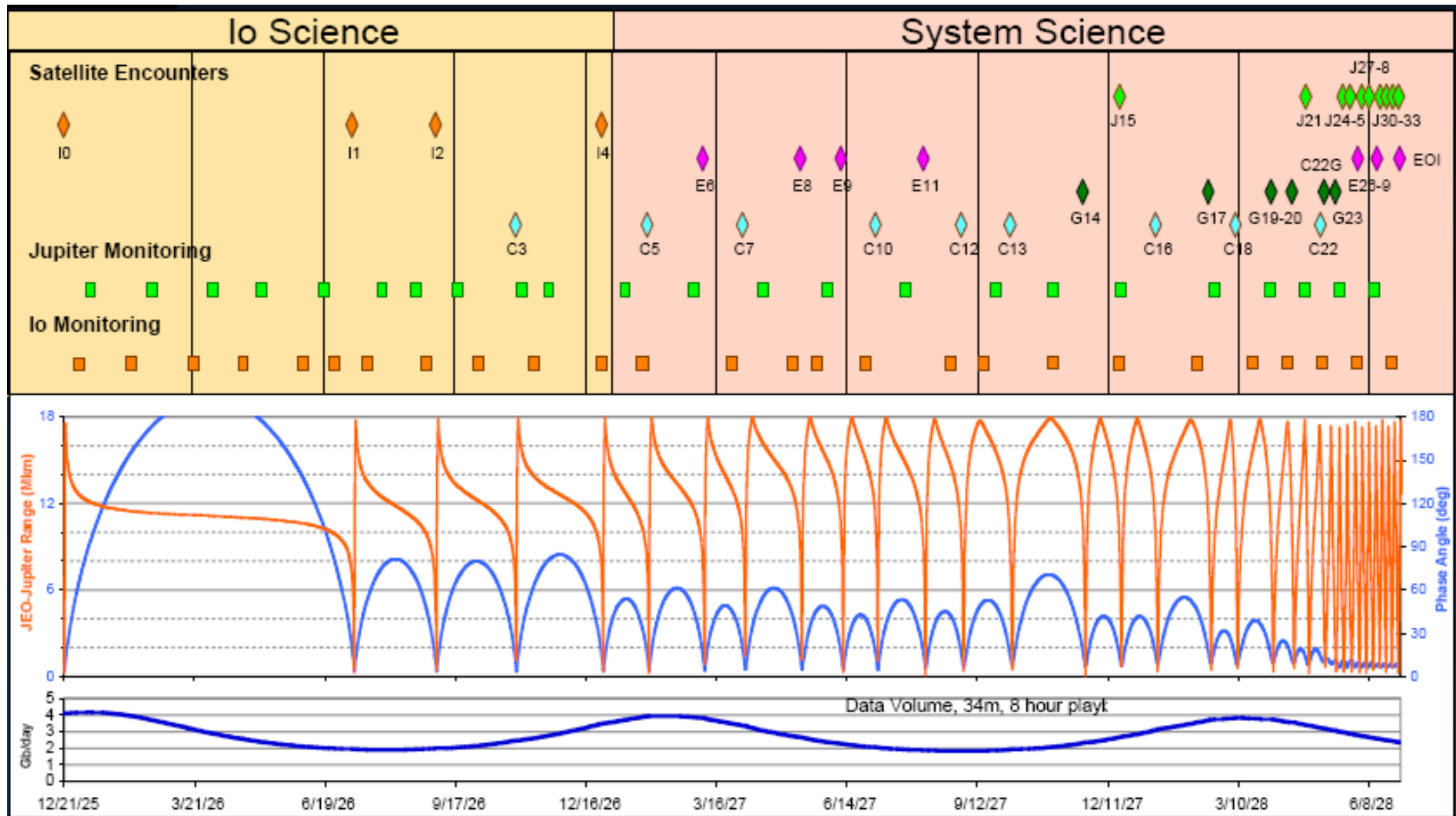
# Europa Science Campaigns



Back



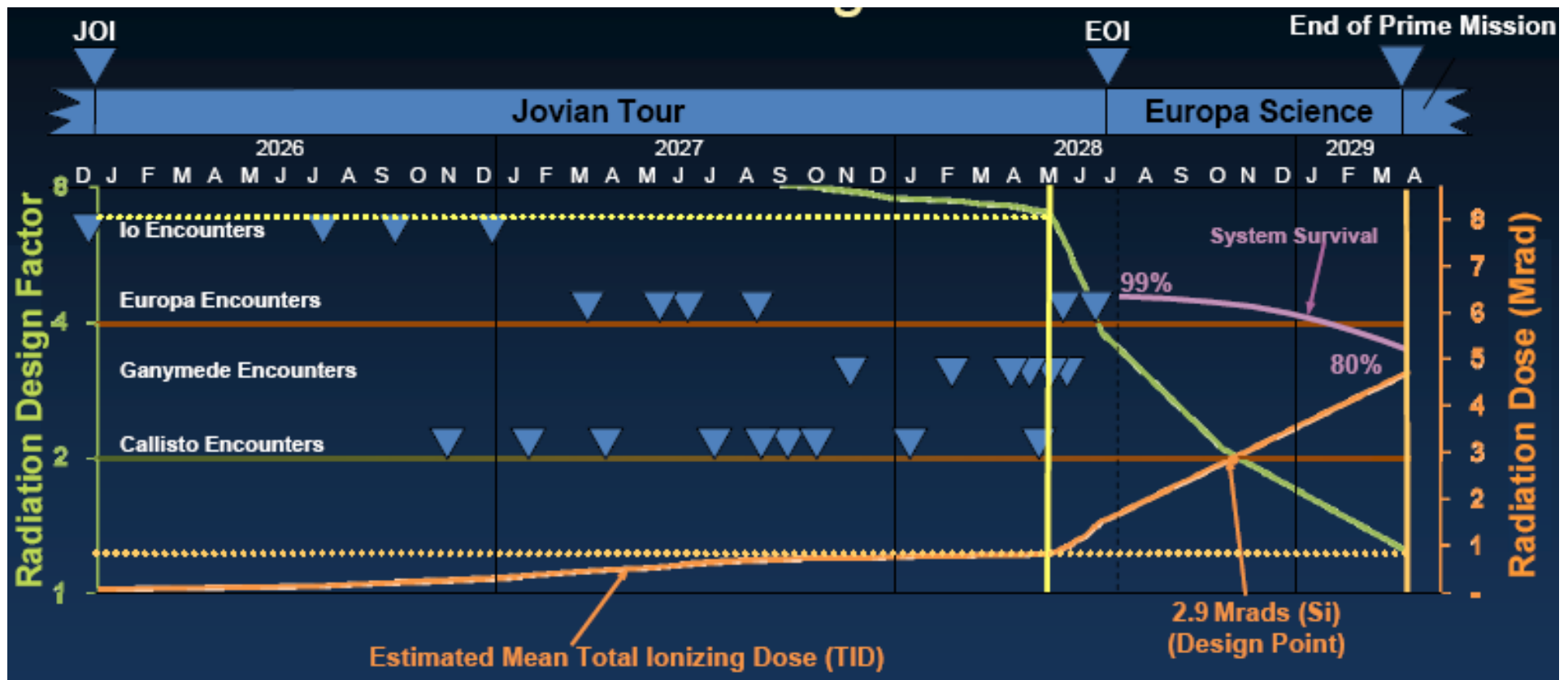
# JEO Jovian Tour Phase



Back



# 2008 JEO Radiation Design Baseline

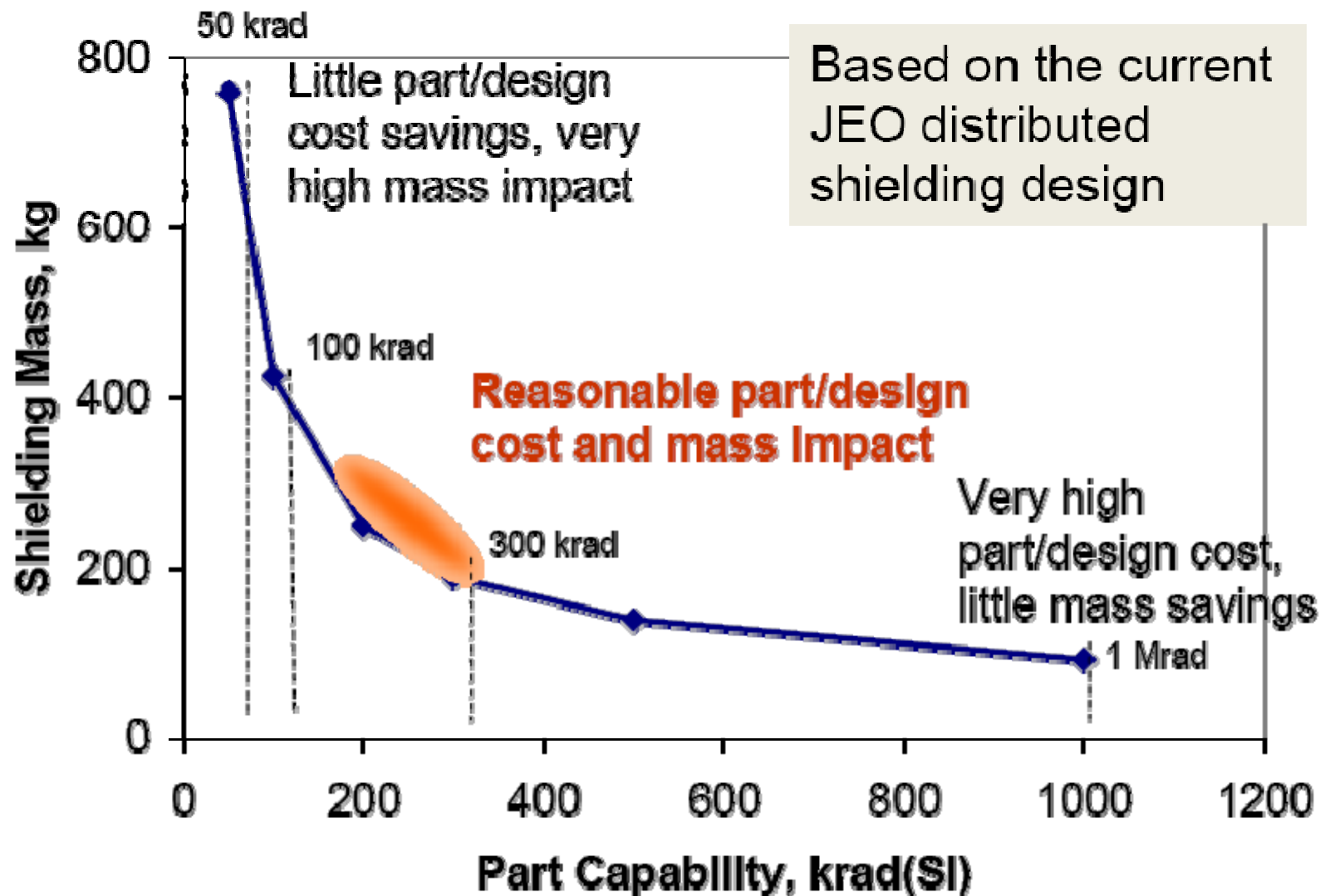


Back <sub>32</sub>





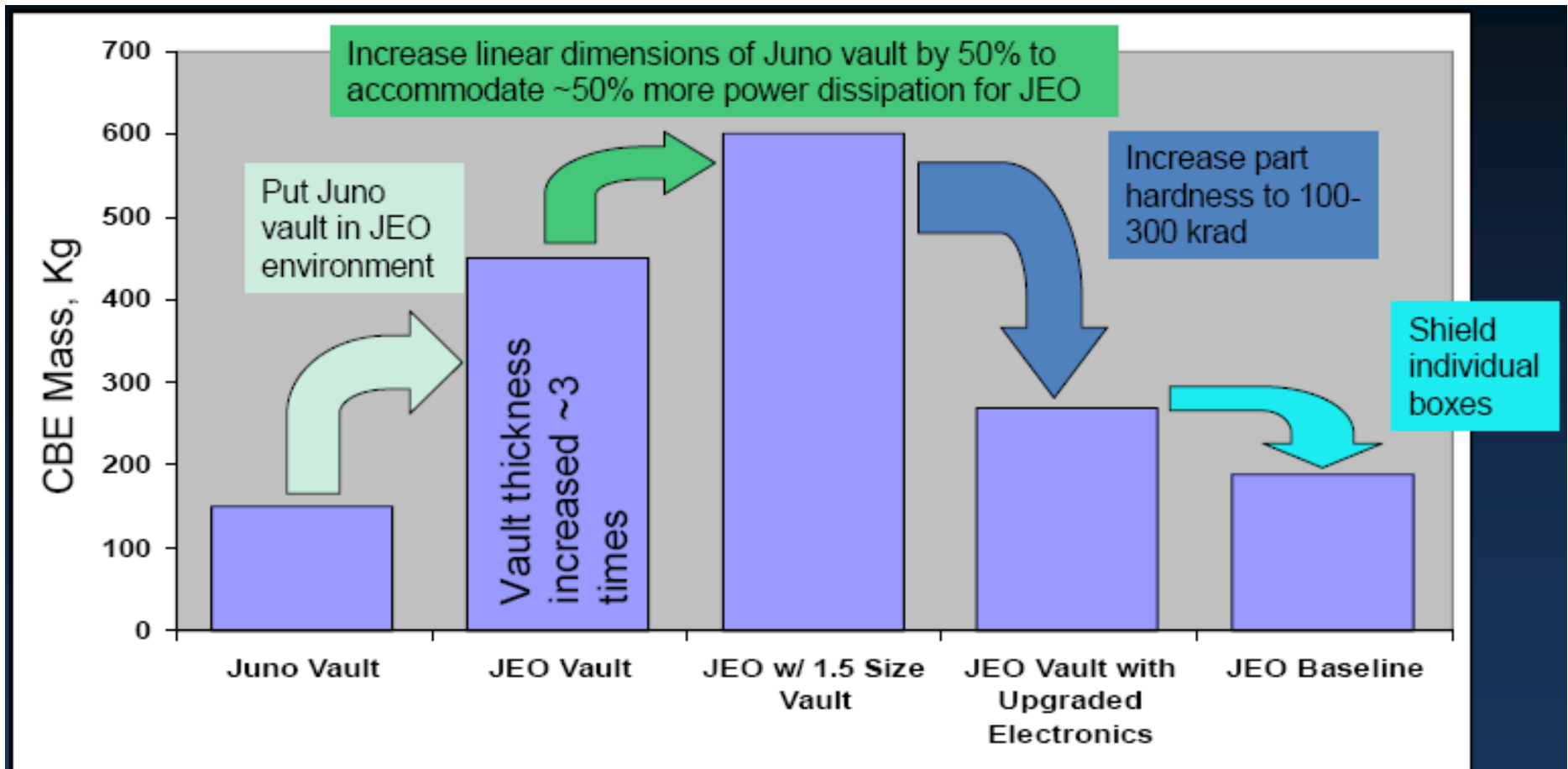
# Shielding Mass vs. Parts Capability



Back 33



# Shielding Design Options



*Increasing part hardness to 100 to 300 krad from 50 krad provides dramatic decrease in shield mass for little, if any cost impact*



Back



# JEO Risks

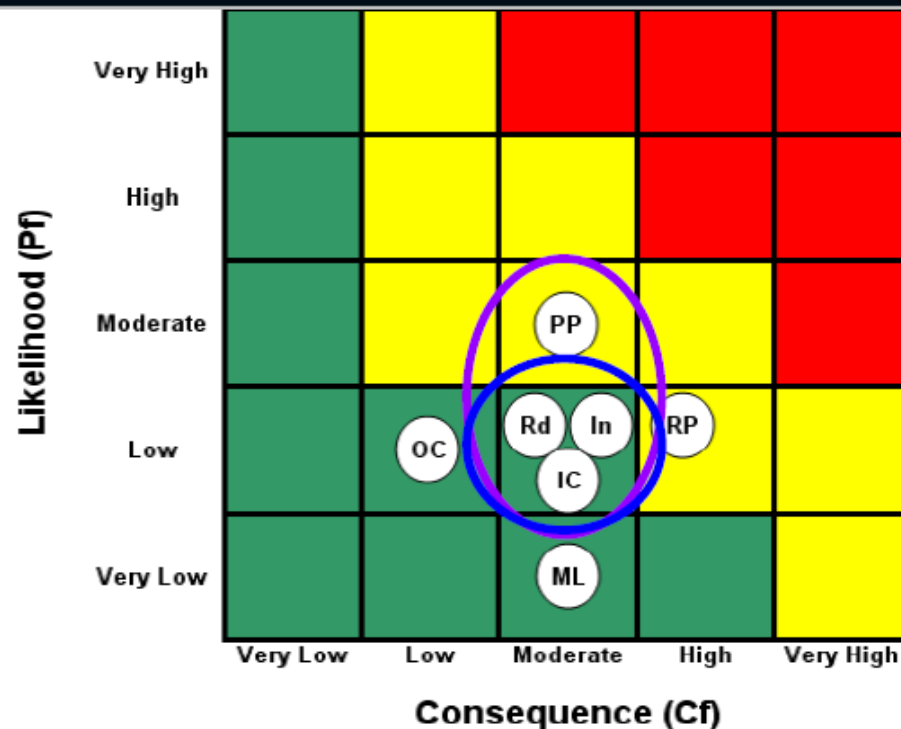


## Risk Assessment

- Risks identified here are summary of many individual risks which could have different ratings
- Ratings are for overall assessment, not individual detailed assessment

Taken as a whole = “Radiation Risk”

Covered in Risk Mitigation Plan:  
Radiation and Planetary Protection



Rd Radiation effects in parts, materials, & sensors  
IC Internal charging  
In Instrument development  
PP Planetary protection  
OC Operational complexity  
RP Radioisotope power source  
ML Mission life time



Back



# JEO Resolution Improvement over Previous Missions



*Table 2.5-5. JEO Resolution Improvement Over Galileo and Voyager, and Profiling Coverage*

Galilean satellite	VGR+GLL Imaging $\leq 1$ km	JEO Imaging $\leq 1$ km	VGR+GLL Imaging $\leq 200$ m	JEO Imaging $\leq 200$ m	VGR+GLL Imaging $\leq 50$ m	JEO Imaging $\leq 50$ m	VGR+GLL Imaging $\leq 10$ m	JEO Imaging $\leq 10$ m	JEO IPR Length (km)	JEO LA Length (km)
Io	~25%	30%	~3%	20%	~1%	5%	0%	tbd	1000	7400
Europa	13%	60%	0.4%	60%	~0.4%	15%	~0%	0.01%	6600	19000
Ganymede	25%	50%	0.3%	50%	~0.3%	10%	0%	0.02%	17000	28000
Callisto	30%	85%	0.3%	75%	~0.3%	5%	~0%	0.01%	15000	30000





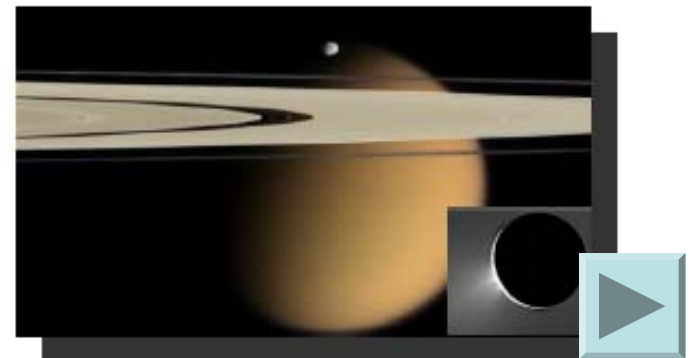
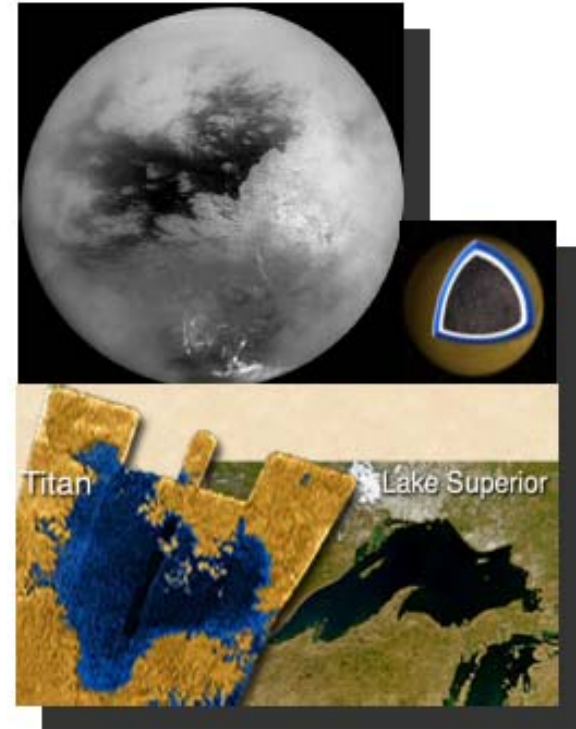
# STO Science Objectives



Explore Titan, an Earth-like system: How does Titan function as a system? How are the similarities and differences with Earth, and other solar system bodies, a result of the interplay of the geology, hydrology, meteorology, and aeronomy present in the Titan system?

Examine Titan's Organic Inventory – A Path to Prebiological Molecules: What is the complexity of Titan's organic chemistry in the atmosphere, within its lakes, on its surface, and in its putative subsurface water ocean and how does this inventory differ from known abiotic organic material in meteorites and therefore contribute to our understanding of the origin of life in the Solar System?

Explore Enceladus and Saturn's Magnetosphere – Clues to Titan's Origin and Evolution: What is the exchange of energy and material with the Saturn magnetosphere and solar wind? What is the source of geysers on Enceladus? Does complex chemistry occur in the geyser source?







# In Situ Science Objectives

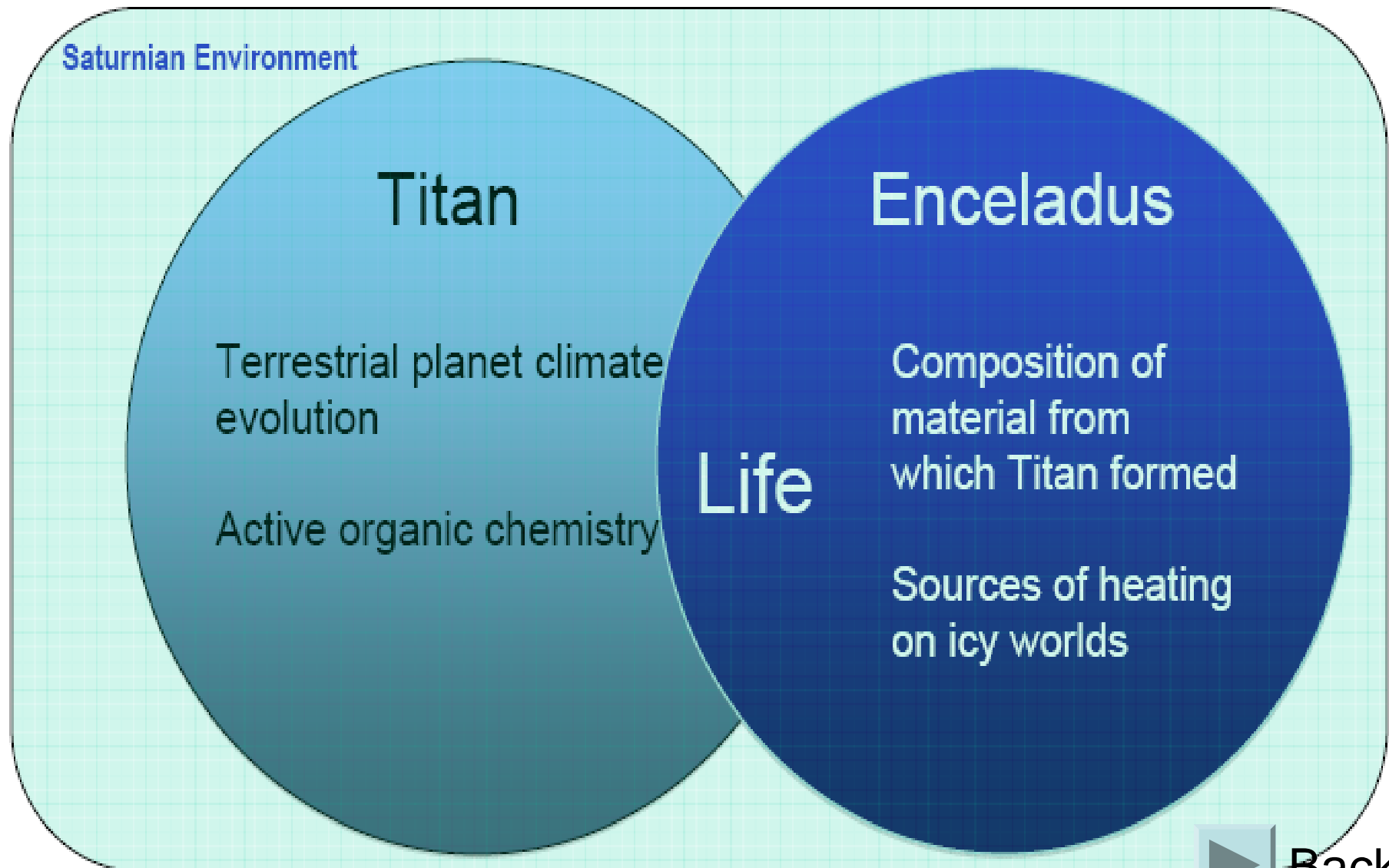


- Perform **chemical analysis**, both in the atmosphere and in the liquid of the lake, the latter to determine the kinds of chemical species that accumulate on the surface, to describe how far such complex reactions have advanced and define the rich inventory of complex **organic molecules** that are known or suspected to be present at the surface. New **astrobiological** insights will be delivered through the montgolfière and the lander investigations.
- Analyze the **composition of the surface**, in particular the liquid material and in context, the ice/organics content in the surrounding areas.
- Study the forces that shape Titan's diverse **landscape**. This objective benefits from detailed investigation at a range of locations, a demanding requirement anywhere else, but that is uniquely straightforward at Titan with the montgolfière high-resolution cameras and **subsurface**-probing radar.





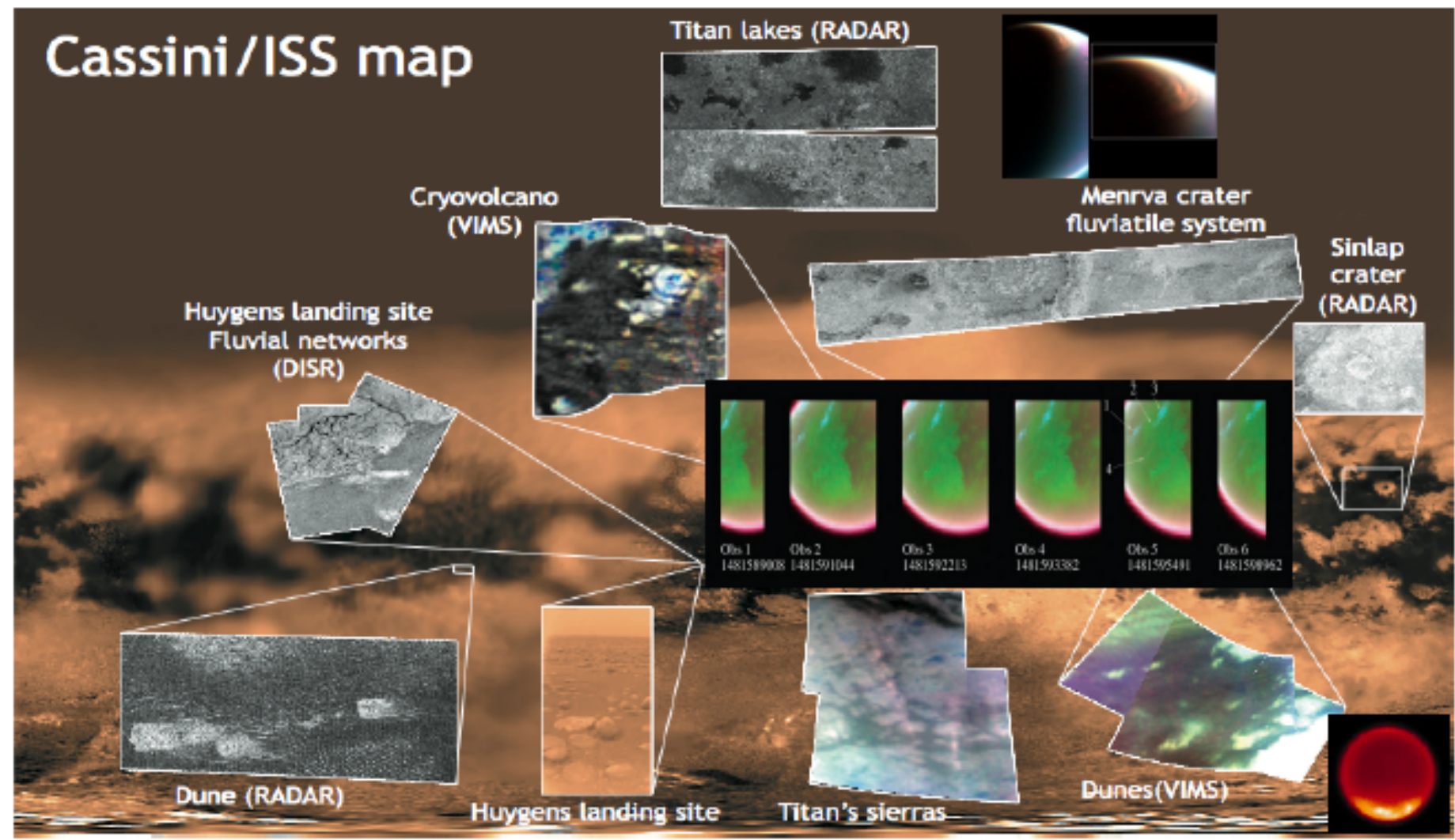
# Why Titan and Enceladus



Back 39



# Titan's complex surface and atmosphere



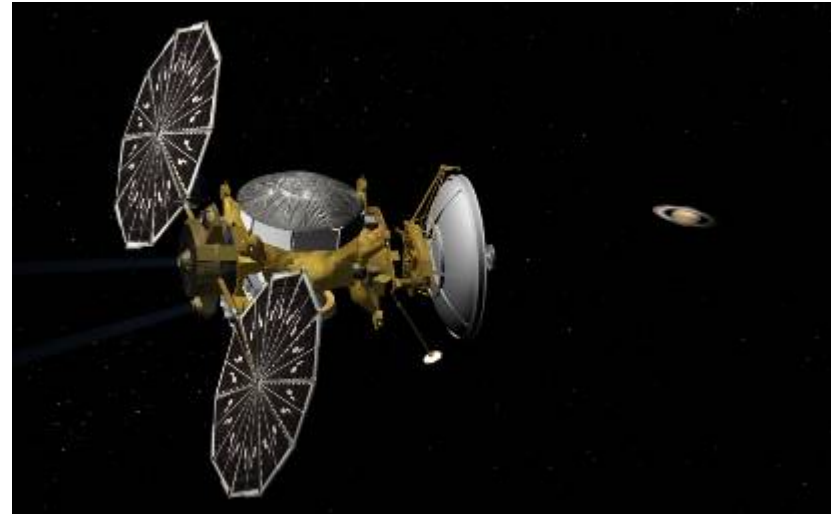
Back



# STO Mission Concept



- Concept: Titan Orbiter delivering ESA Balloon and Lake Lander
- Launch Vehicle: Atlas 551
- Trajectory: Gravity assist SEP (9 yrs)
- Power Source: 5 ASRG
- Mission Timeline
  - Launch: 2018 to 2022, nominally 2020
  - Saturn Arrival: Oct. 2029
  - Saturn system tour phase: 2 years
    - 16 Titan flybys, 7 Enceladus flybys
  - Balloon released Feb. 2030 and enters Apr. 2030 (T1)
  - Lake Lander released and enters June 2030 (T2)
  - Titan orbital phase: starts Sept. 2031 lasting 2 years with aerobraking
  - End of Prime Mission in 2033; s/c eventually impacts Titan
- Instruments: 7 (165 kg<sup>1</sup>, 55 W) including Radio Science
- Cost: \$2.5B (FY07)/\$3.7 (RY)
- Floor Mission: No SEP stage, 10.5 yr cruise, less time in Titan orbit
- SEP Stage: Detailed SEP stage design has been performed by JPL working closely with GRC
  - Designs evaluated using NEXT (ion) engines
  - SEP design based on high TRL components
  - SEP stage built around launch vehicle adapter with minimal impact on STO design



Back 41



# ESA In Situ Elements



## Montgolfiere Balloon

- Delivered by STO in 2.6 m aeroshell prior to first Titan flyby (600 kg)
- Autonomous self-deploy after entry
- 10.5 m diameter balloon (CNES) with 8 instruments (22 kg)
  - Heated & powered by NASA MMRTG
- Floats at ~10 km altitude; no directional control
- Balloon HGA relays data to STO when orbiter is in range
- Prime mission of 6 months allows at least one circum-navigation of Titan



## Lake Lander

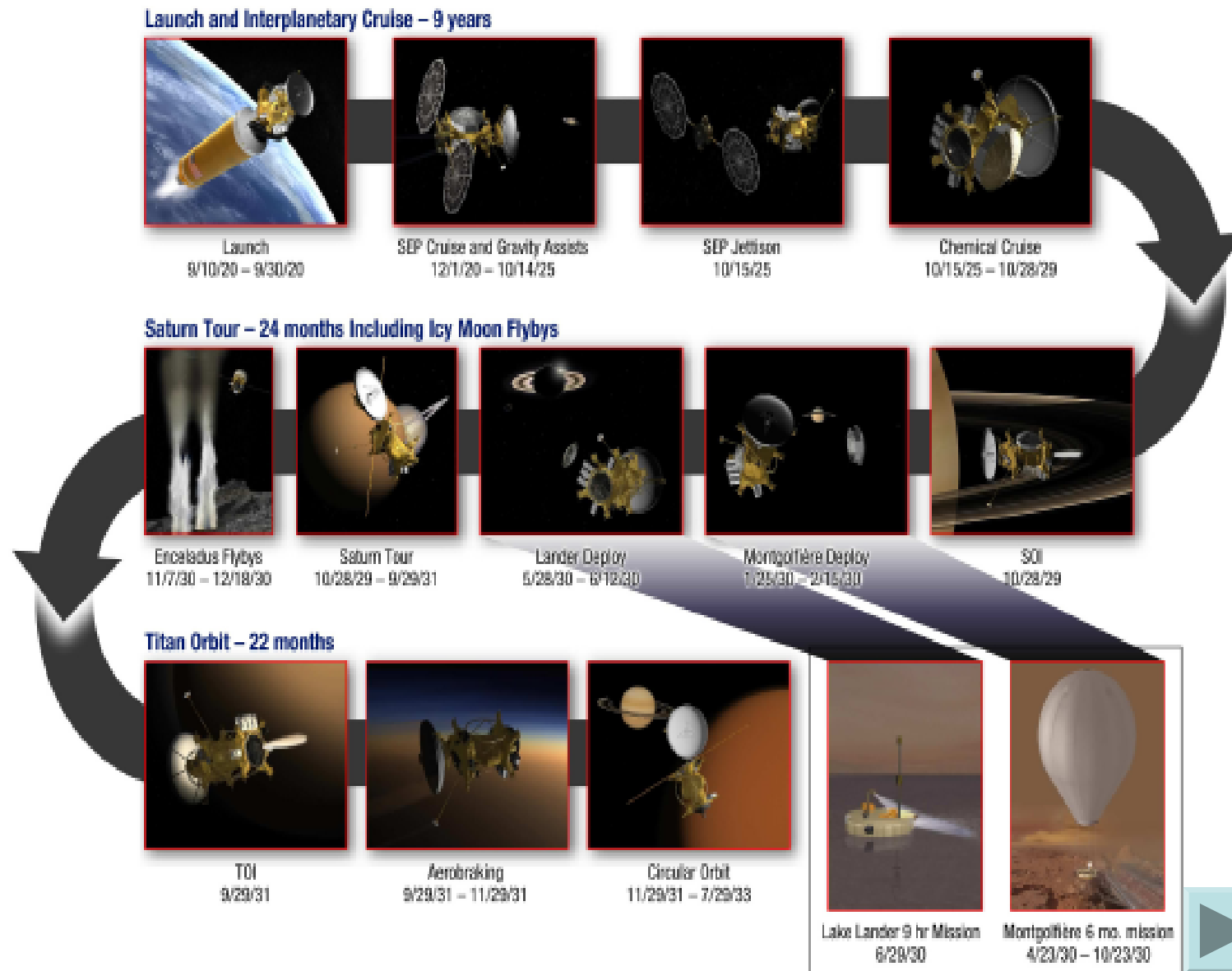
- Delivered by STO in 1.8 m aeroshell prior near second Titan flyby (190 kg)
- Targeted to Kraken Mare for lake landing (lander has floating capability)
  - Lands near terminator
- Battery powered with 9 hour lifetime (6 hours descent, 3 hours on lake)
- 5 instruments (23 kg) dominated by chemical analyzer
- Lander relays data to STO





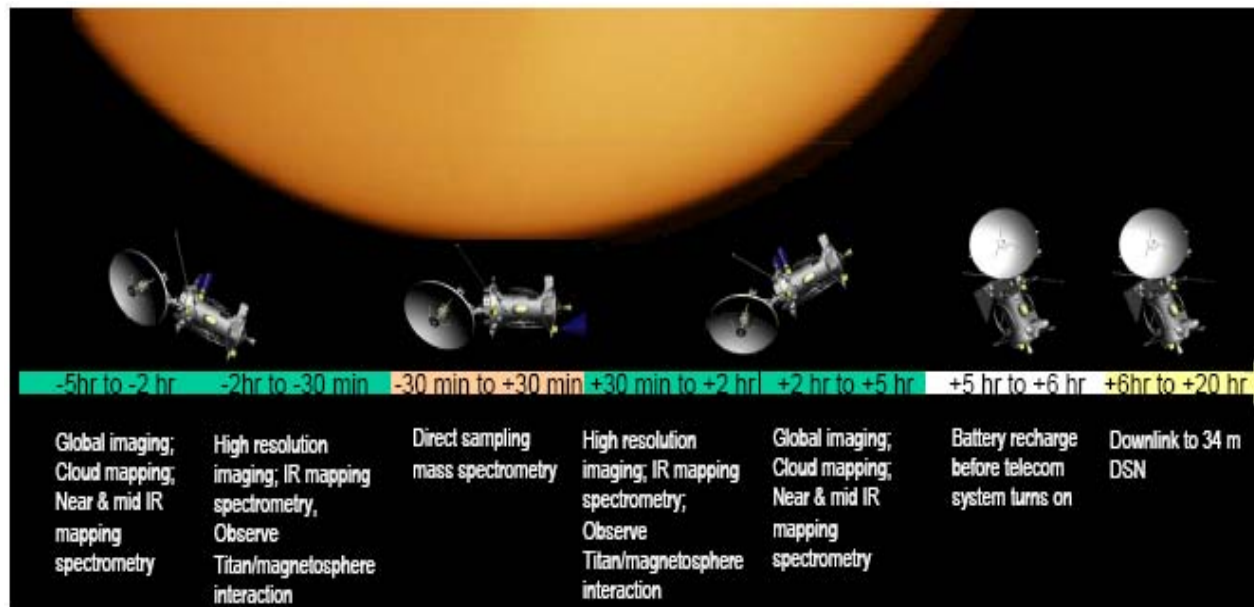
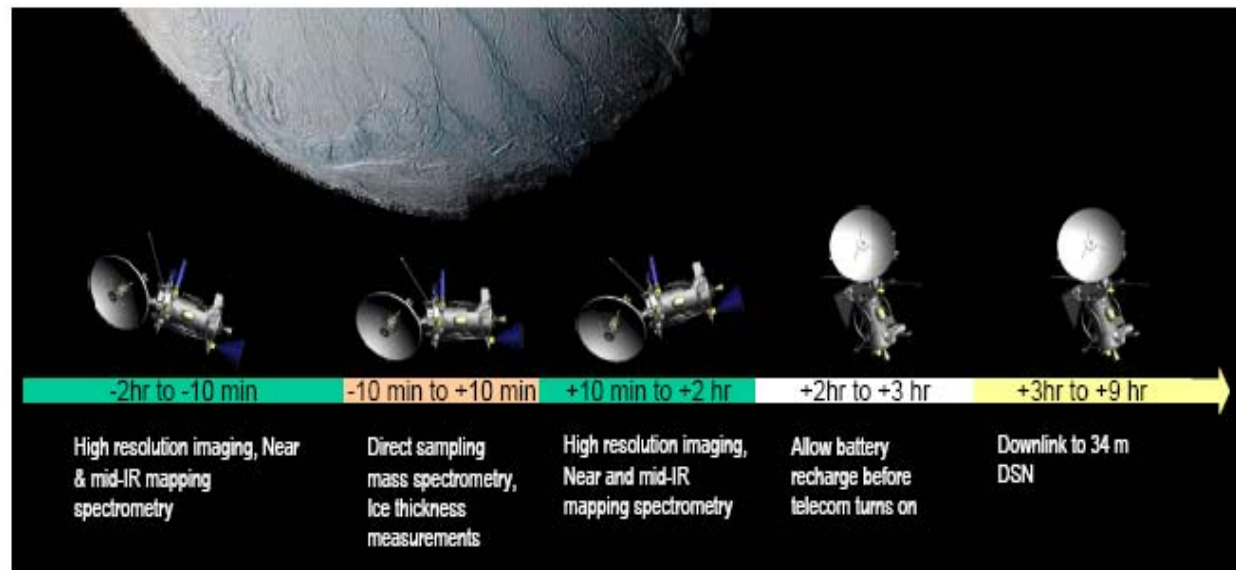


# Mission Overview





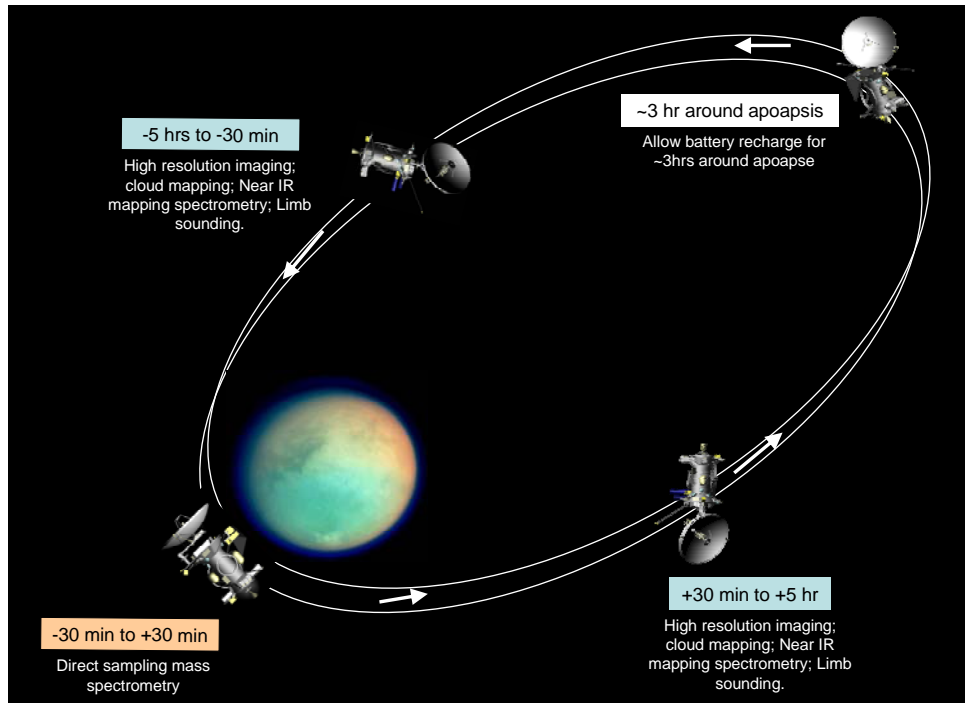
# Flyby Operations Scenarios



Back 44



# STO Science Phases



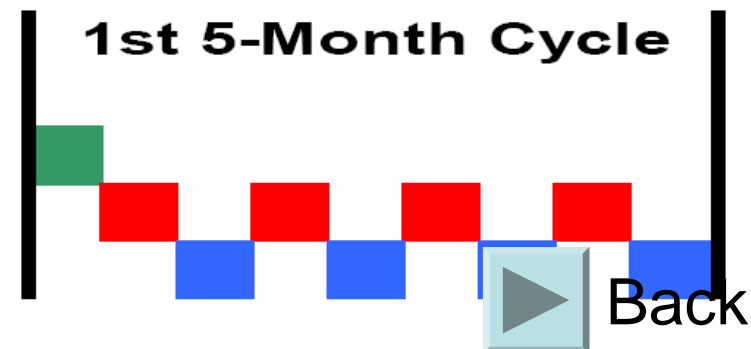
## Aerobraking Phase

- 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

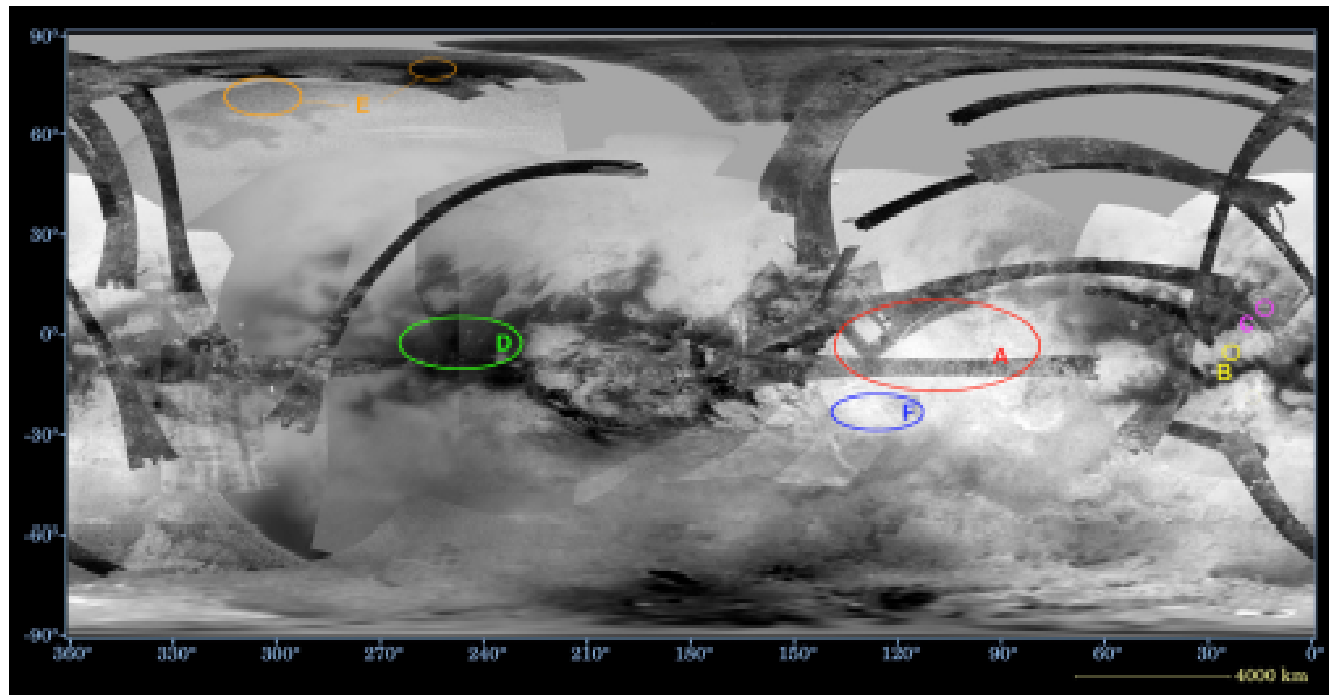
- 20 month period divided into 16 day campaigns to manage power and data flow
- Titan completes 1 rotation and 1 revolution of Saturn every 16 days.
- Campaigns based on science discipline (see below) execute for 80 consecutive orbits
- More than 4 Tb returned during Orbit Phase

- 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.



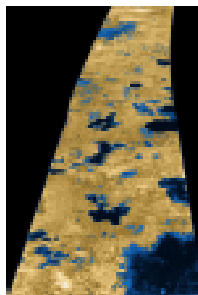


# Potential Landing Sites



## First order targets from the results of the Surface Working Group of the JSDT:

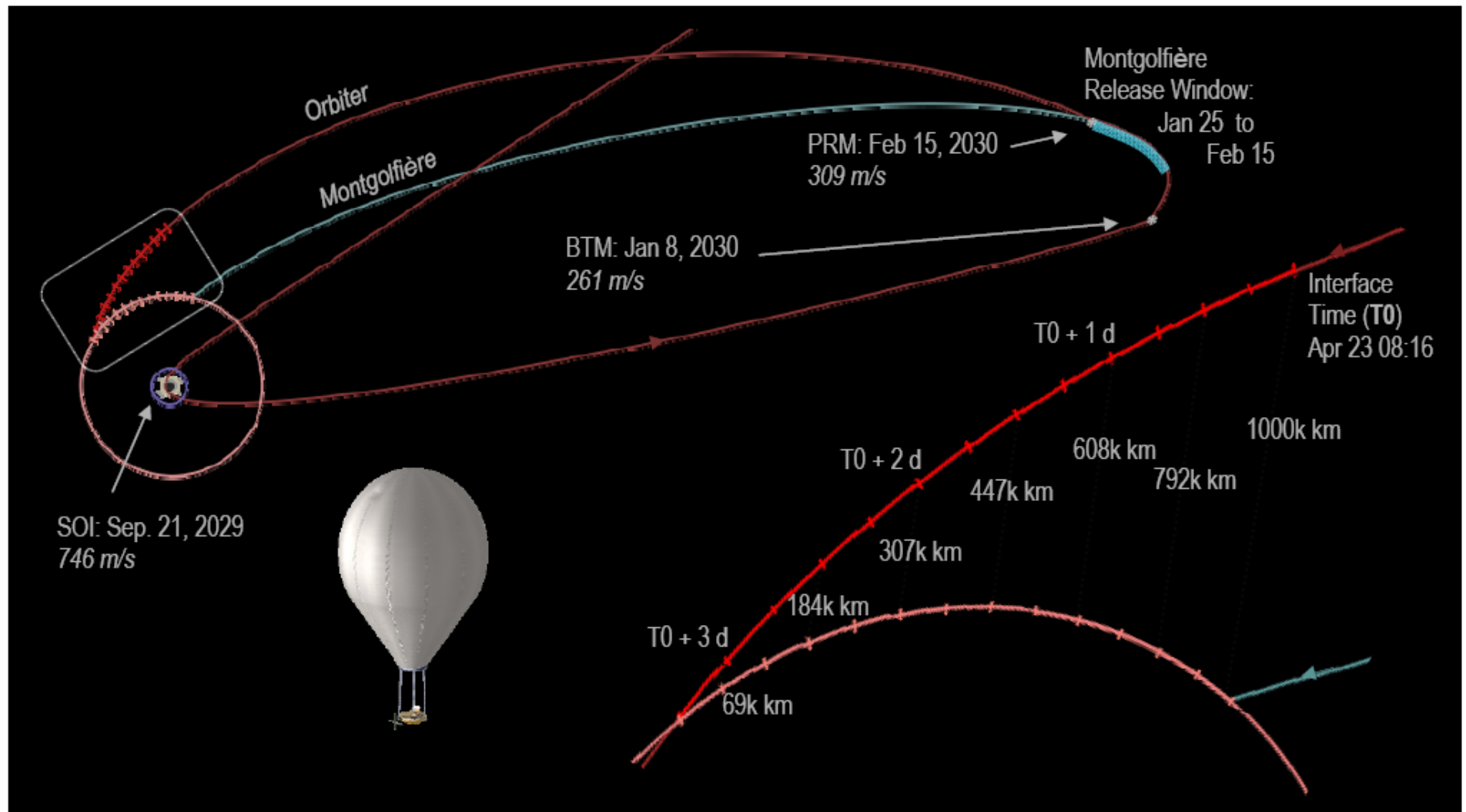
- **(D)** Brownish dune units, e.g., Belet dunefield (can be hit by  $15 \times 40^\circ$  ellipse [ $600 \times 1600\text{km}$ ]); coordinates:  $255^\circ\text{W } 5^\circ\text{S}$  (center of ellipse)
  - Reason: fits most of engineering requirements and addresses most of science objectives
- **(E)** North Polar Lakes above  $65^\circ\text{N}$  (200 km circular delivery error can be accommodated in Kraken Mare) coordinates:  $>72^\circ$ 
  - Reason: fits the most exciting science goals of the methanological cycle and production of organics



Back 46



# Montgolfiere Delivery and Initial Relay

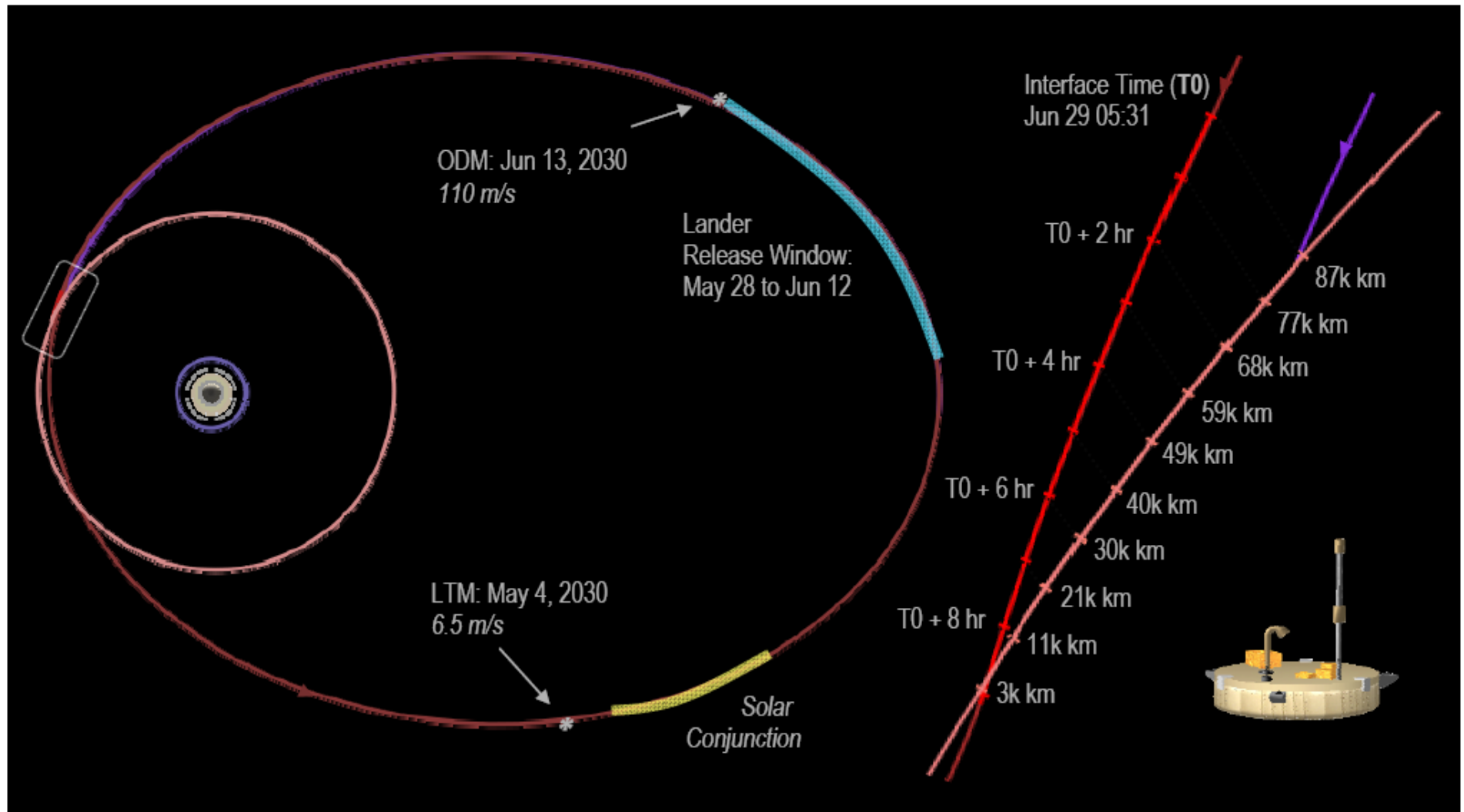


Back <sub>47</sub>





# Lander Delivery and Relay



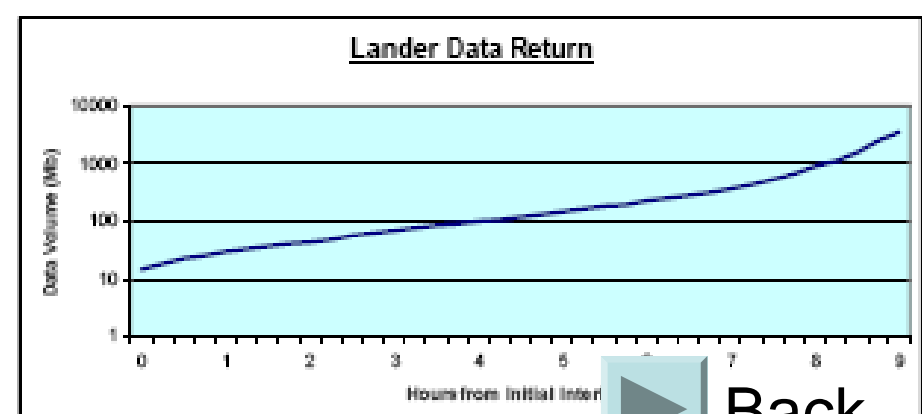
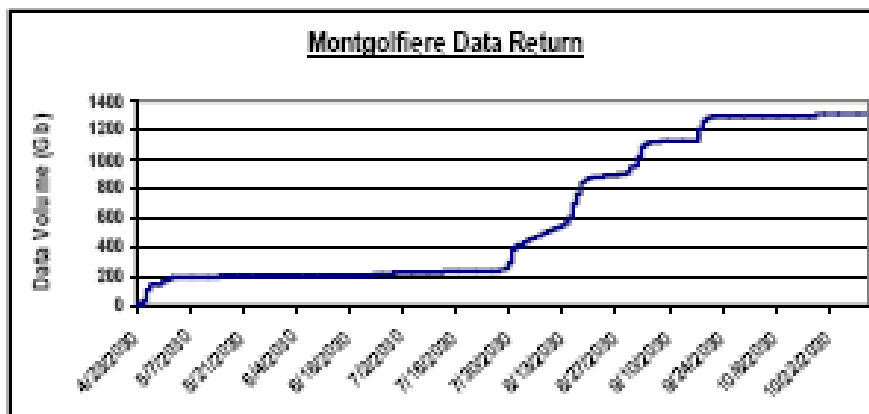
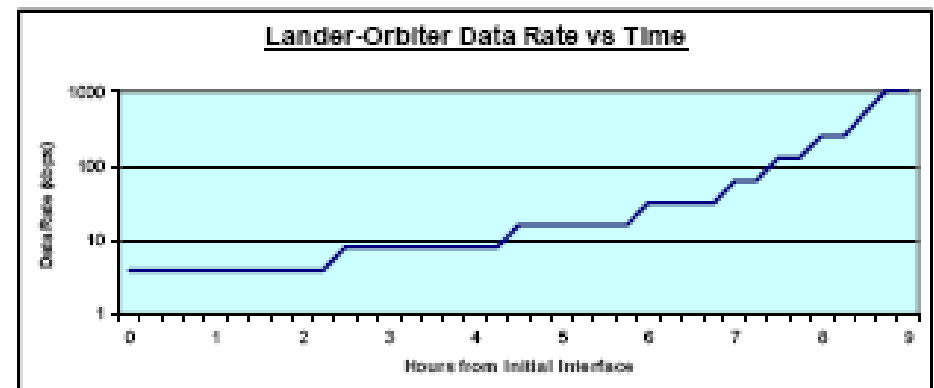
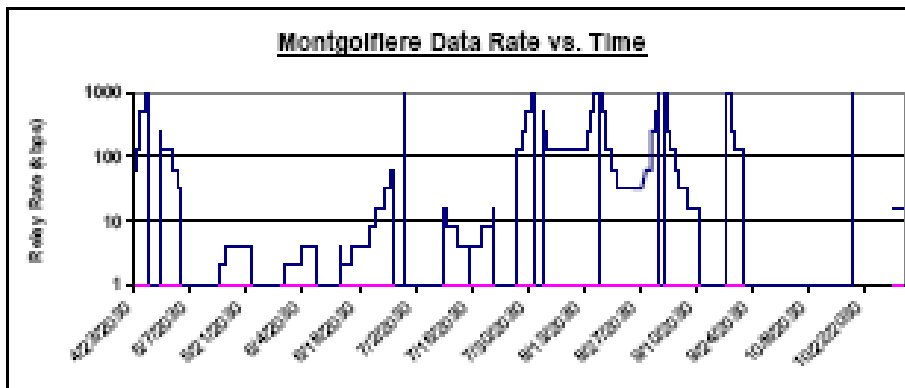
Back 48



# In situ relay during Saturn Tour Phase



- In situ elements complete their mission before STO TOI
- Montgolfiere data rate is a function of range and view period
- Lake Lander data rate is a function of range. After 9 hours the orbiter goes over the horizon



Back

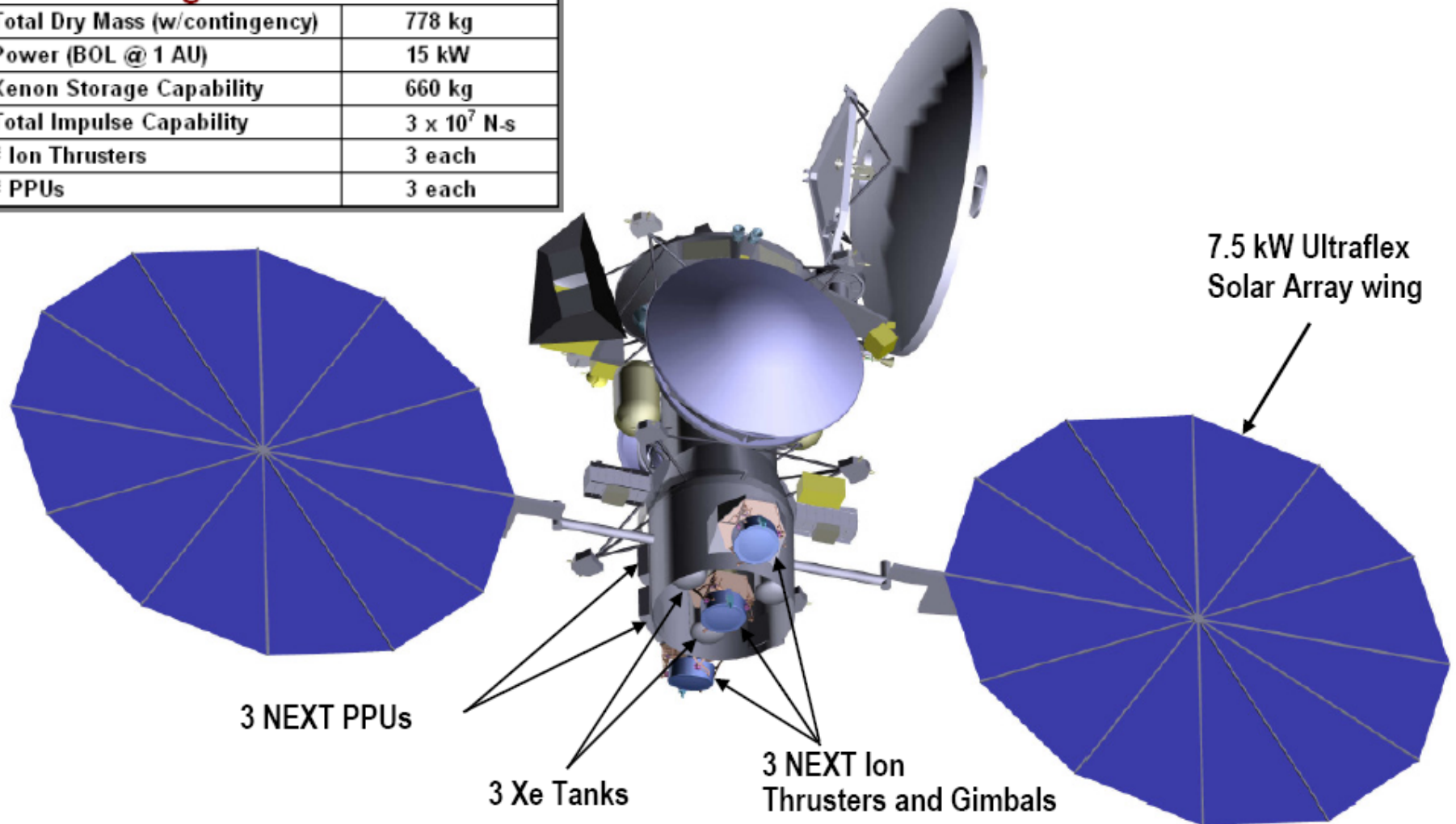


# SEP Stage with NEXT Thrusters



## SEP Stage Characteristics

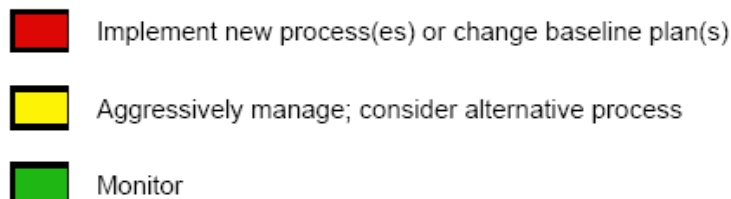
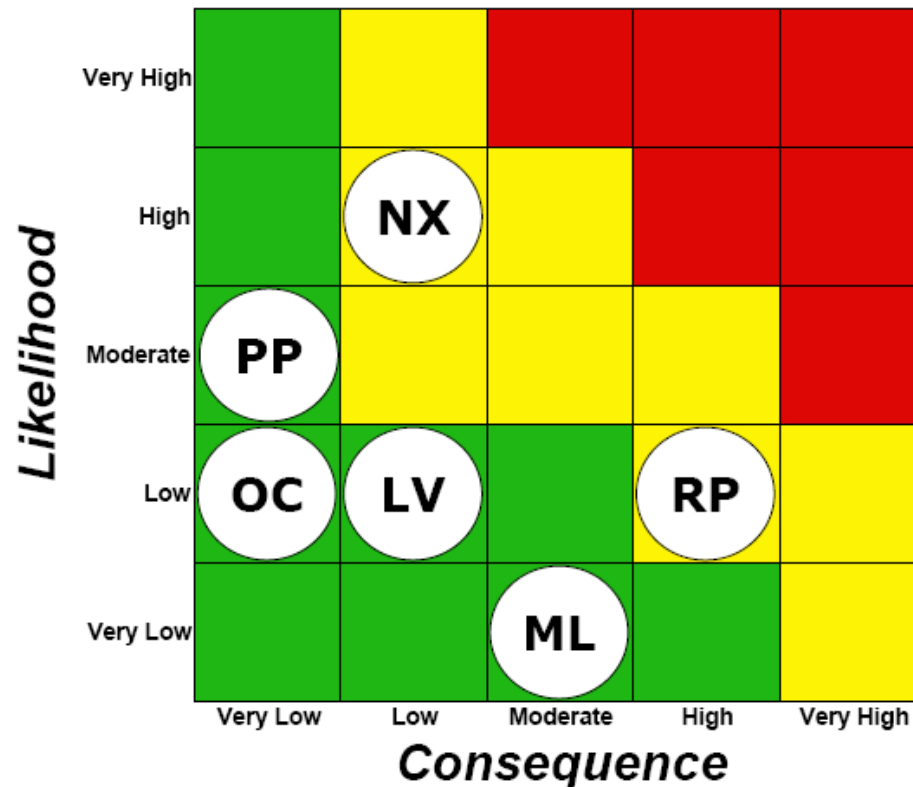
Total Dry Mass (w/contingency)	778 kg
Power (BOL @ 1 AU)	15 kW
Xenon Storage Capability	660 kg
Total Impulse Capability	$3 \times 10^7$ N-s
# Ion Thrusters	3 each
# PPUs	3 each



Back 50



# STO Risks



- ML—Mission Length
- LV—Launch Vehicle Logistics and Integration of RPS
- NX—NEXT system development impact on cost and schedule
- RP—Radioisotope Power System Availability
- OC—Operational Complexity
- PP—Planetary Protection