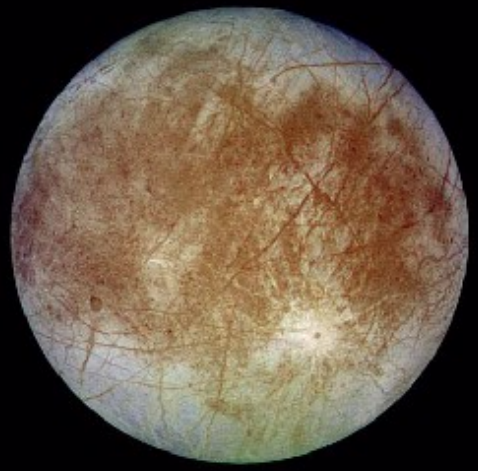
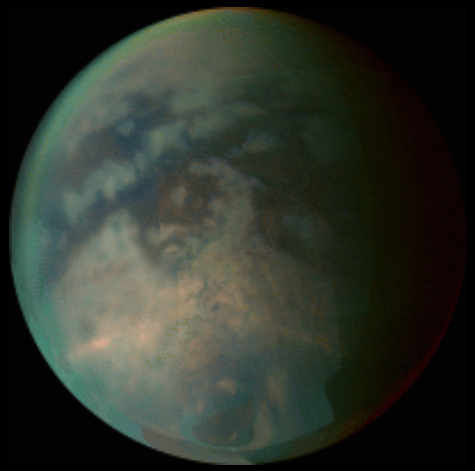
Outer Planets Flagship Mission Studies



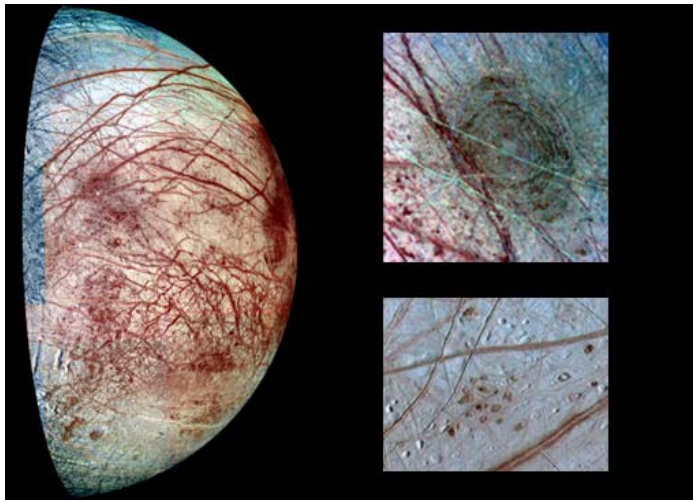


Curt Niebur
OPF Program Scientist
NASA Headquarters

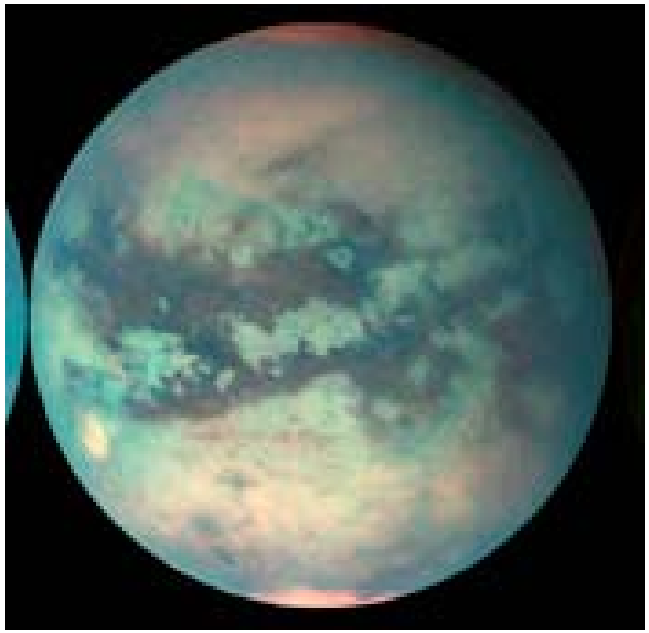
Planetary Science Subcommittee
June 23, 2008

Overview

- **NASA is currently mid way through a six month long Phase II study of the remaining two candidate Outer Planet Flagship Missions**
  - Europa Jupiter System Mission (EJSM)
  - Titan Saturn System Mission (TSSM)

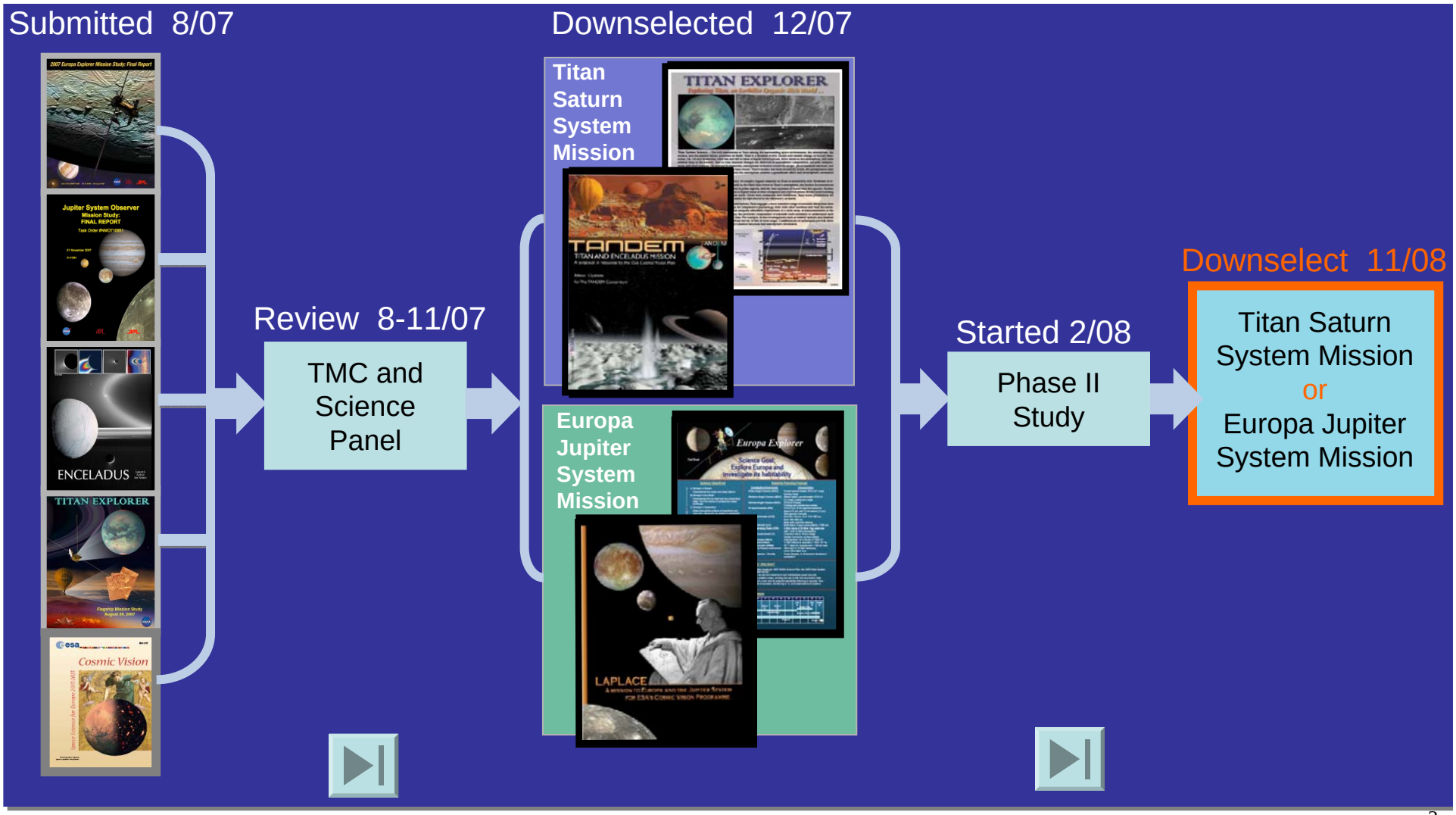


- **NASA plans to select a single Outer Planet Flagship mission to be pursued jointly with ESA and other international partners.**



- **The study plan includes a NASA only option in addition to the collaborative options. According to Phase II study ground rules the funding cap is $2.1B FY07**

Outer Planet Flagship Mission Study Process



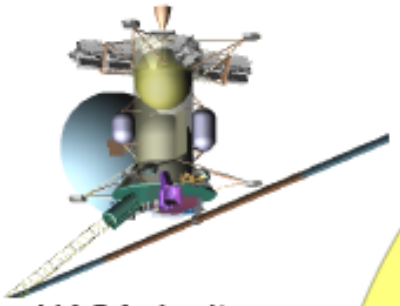
NASA Phase II Study – Key Milestones

- **Joint SDT members selected…….Feb 1, 2008**
- **Study Kickoff……..Feb 9, 2008**
- **First Interim Review…….April 9, 2008**
- **ESA Concurrent Design Facility Studies –kickoff…….May 21, 2008**
- **Science Instrument Workshop…….June 3-5, 2008**
- **Second Interim Review…….June 19-20, 2008**
- **ESA Concurrence Design Facility Studies – Outbrief……July 27, 2008**
- **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**
- **Decision on mission……Nov 2008**

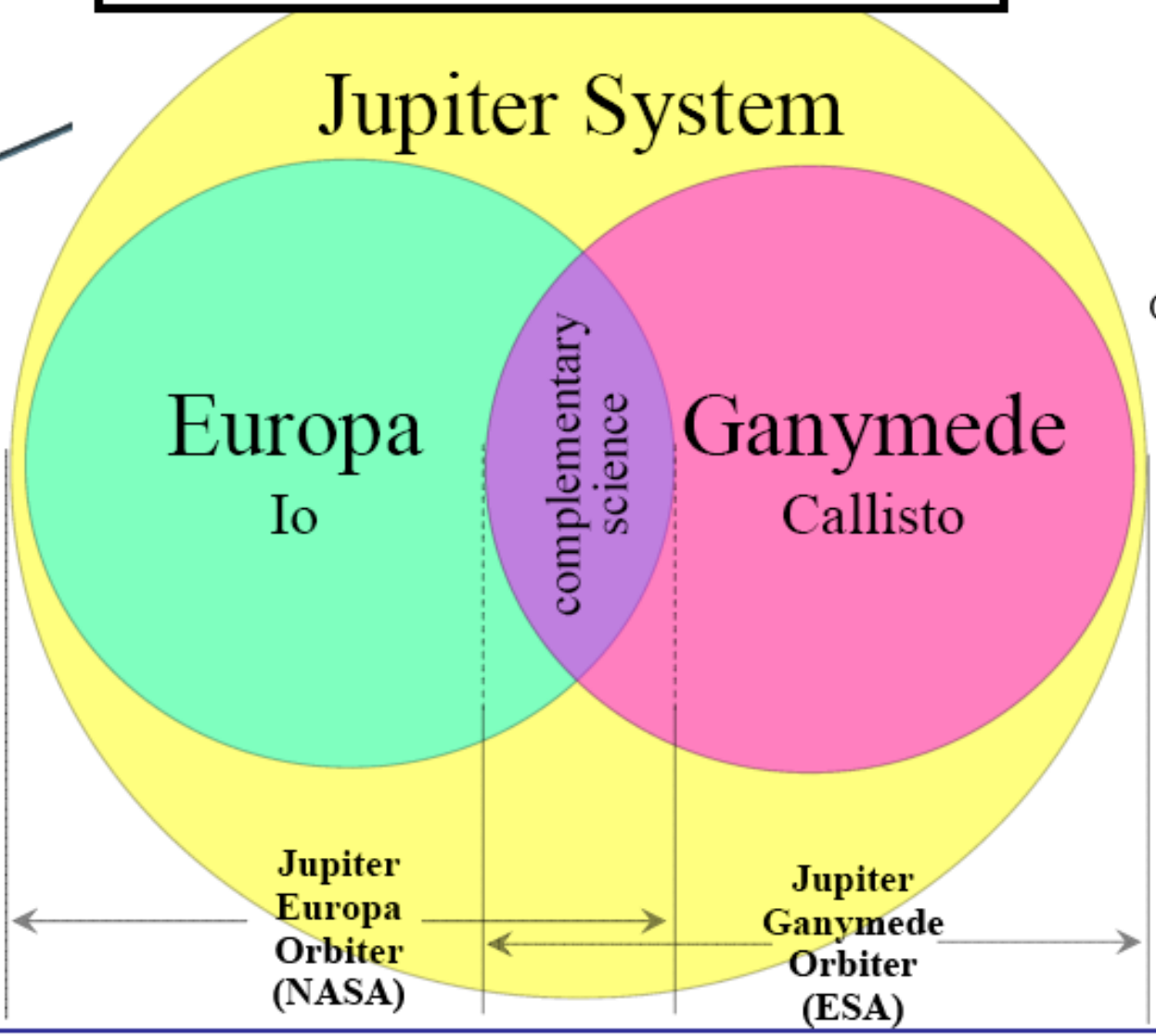
Second Interim Review – Objectives

- **Determine the portion of "decadal survey science" at both Europa and Titan that can be accomplished with the "core mission" that best meets the $2.1B FY07 funding cap established in the study ground rules**
- **Determine if there is a "sweet spot" in the trade space between science, cost and risk and estimate the additional cost of reaching this**
- **Estimate the cost to NASA of a mission that achieves "full decadal" science**
- **Characterize the launch opportunities between 2016 and 2022 for missions to Europa and Titan**
- **Assess the interrelationships between the ESA and NASA missions with respect to launch dates**

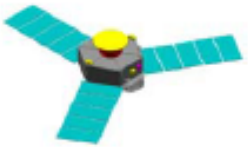
The Emergence of Habitable Worlds Around Gas Giants



NASA Jupiter Europa Orbiter (JEO)



ESA Jupiter Ganymede Orbiter (JGO)

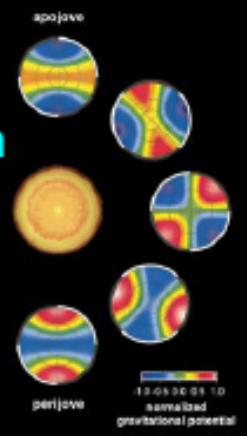


JAXA Jupiter Magnetospheric Orbiter (JMO)

JEO is designed to stand alone or operate synergistically with ESA JGO

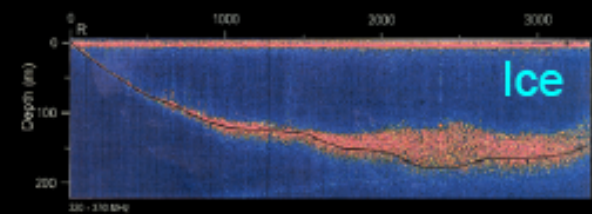
Goal: Explore Europa to Investigate Its Habitability

Ocean

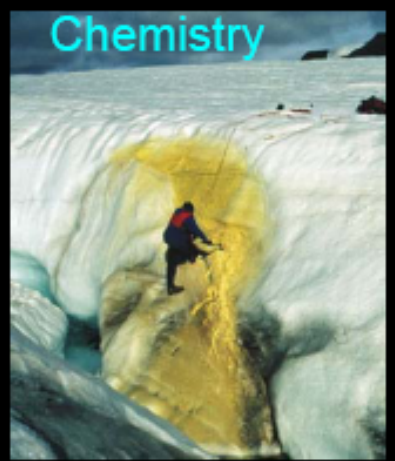


A. Characterize the extent of the ocean and its relation to the deeper interior.

B. Characterize the ice shell and any subsurface water, including their heterogeneity, and the nature of surface-ice-ocean exchange.



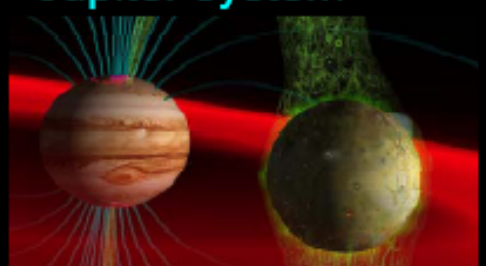
Chemistry



C. Determine global surface compositions and chemistry, especially as related to habitability.

D. Understand the formation of surface features, including sites of recent or current activity, and identify and characterize candidate sites for future *in situ* exploration.

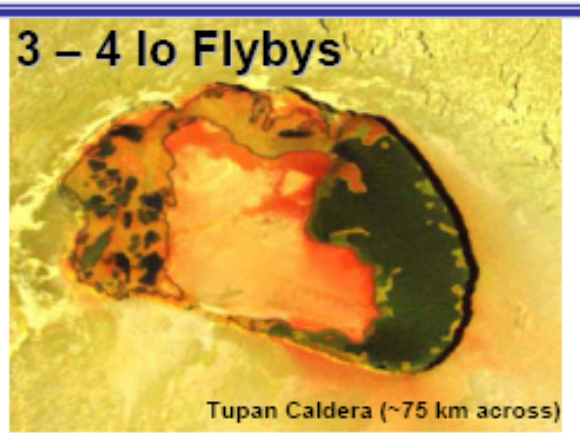
Jupiter system

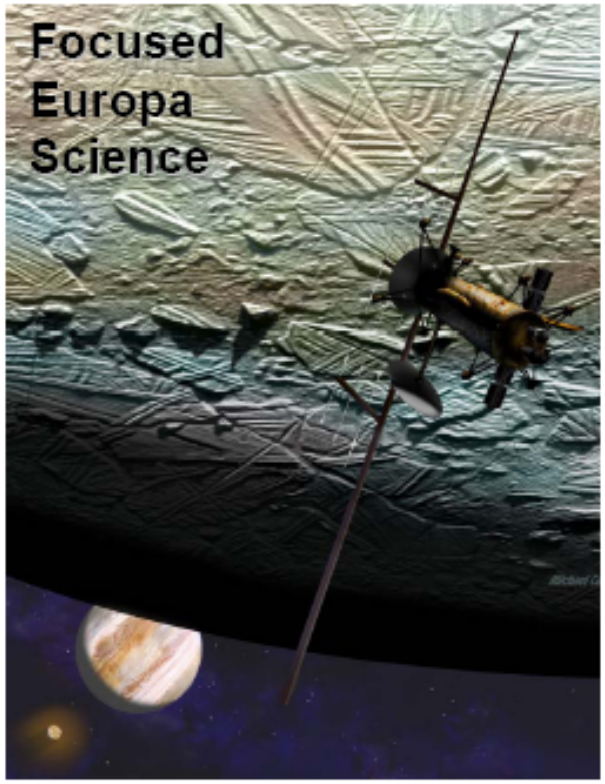


E. Understand Europa in the context of the Jupiter system.

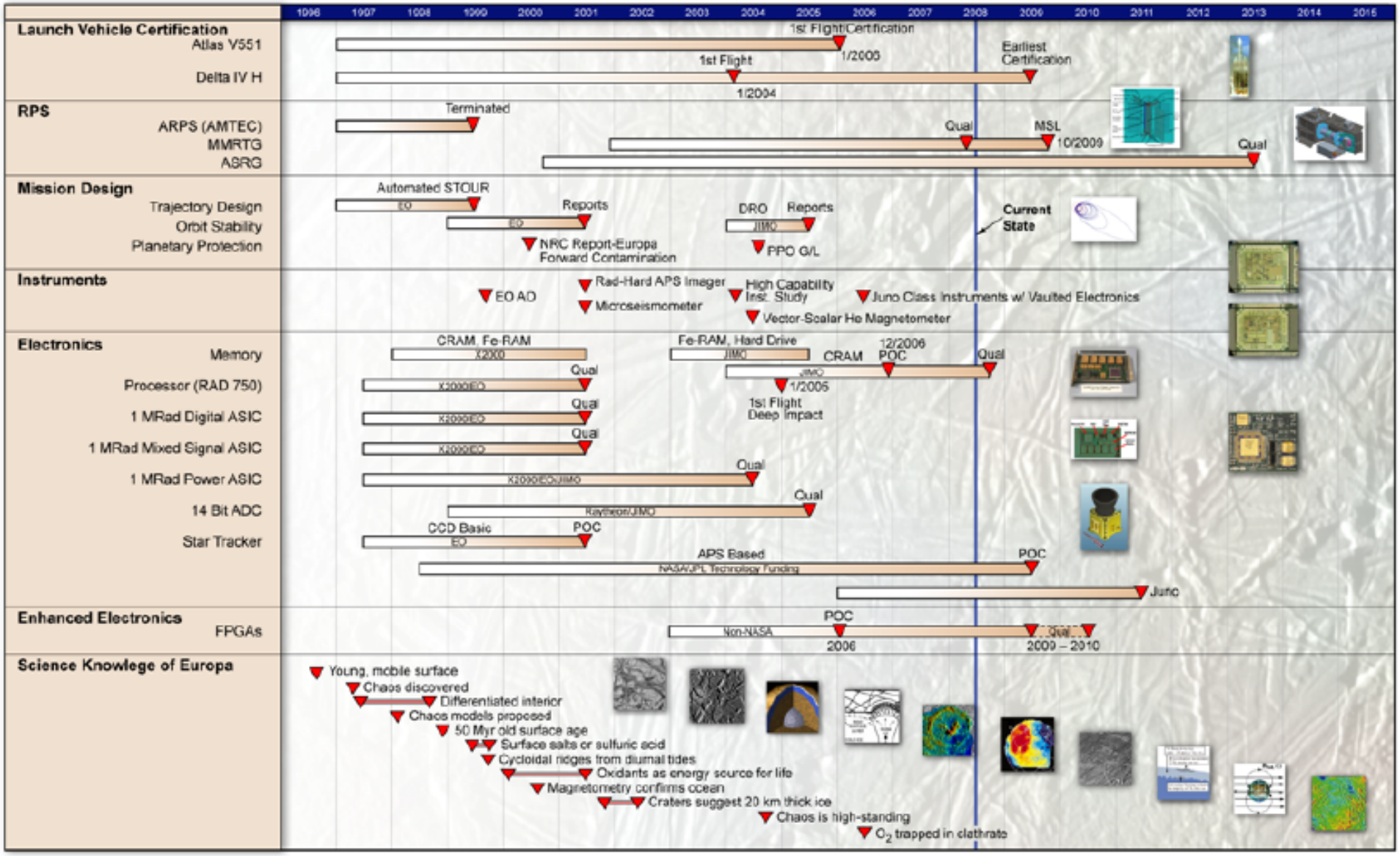
2008 JEO Core Mission Concept

- **Objectives: Jupiter System, Europa**
- **Launch Vehicle:** Atlas V 541
- **Power Source:** 5 MMRTG (530 W EOM)
- **Mission Timeline:**
  - Launch: 8/2016 (VEGA)
    - Many options available in later years
  - Jupiter arrival: 9/2021
  - Jovian system tour phase: ~21-28 months
    - 3-4 Io flybys
    - 8-10 Ganymede flybys
    - 4-6 Callisto flybys
  - Europa orbital phase: 105 days
    - Expected lifetime up to a year
  - Spacecraft final disposition: Europa surface Impact
- **5 Science Investigations**
  - 6 Instruments **(LA, IPR, IRS, MAC, WAC, MAPS)**
  - Radio Science
  - 68 kg. 101 W



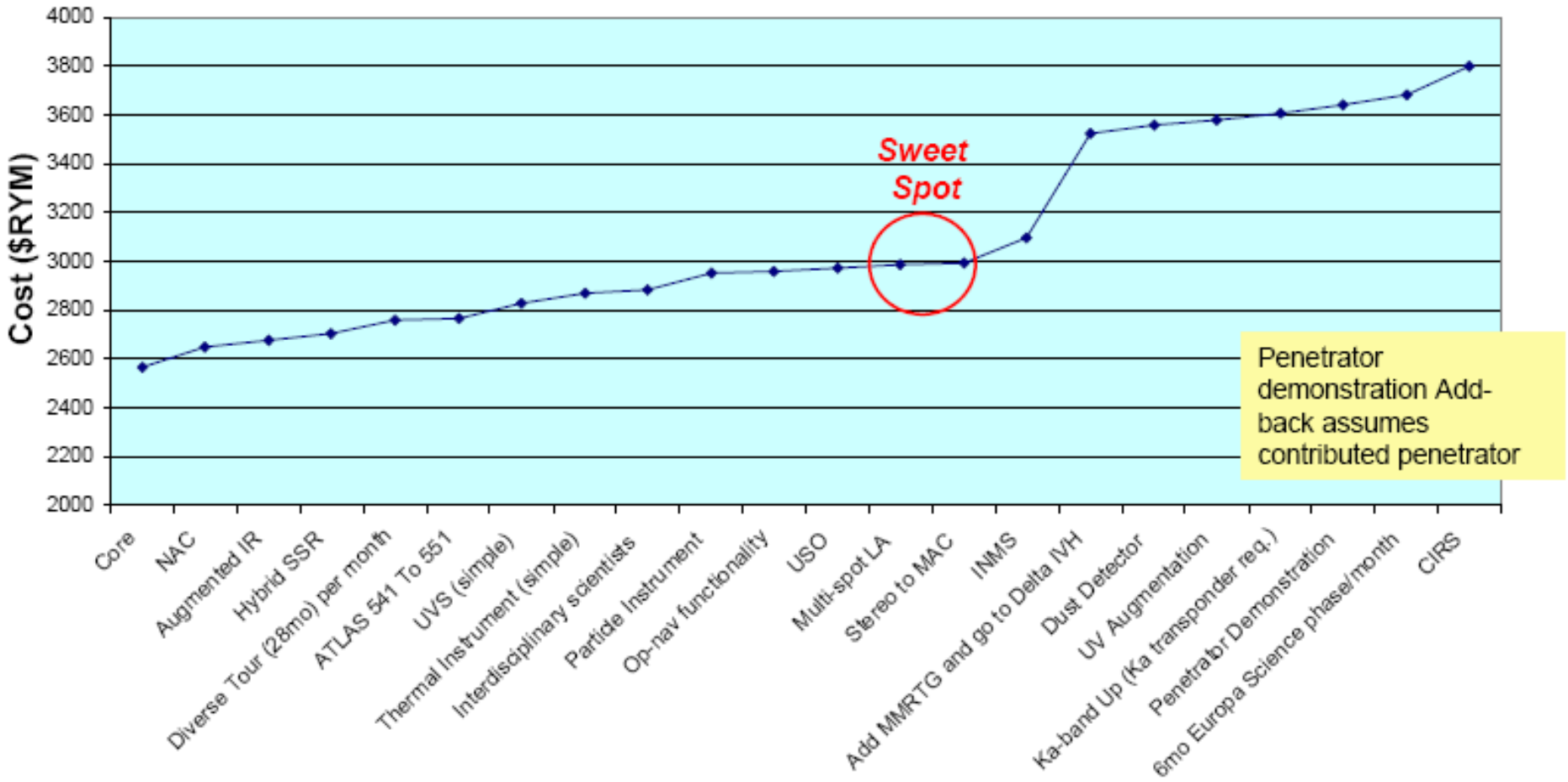


A Decade of Investment Has Reduced JEO Risk



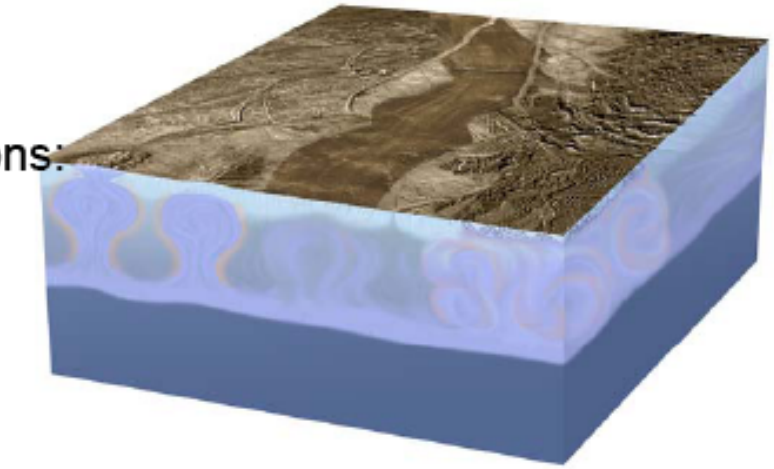
Sweet Spot Determination

- Stay on Atlas launch vehicle and within capability of 5 MMRTGs including 33% margin
- Increase resiliency to future changes in direction



Jupiter Europa Orbiter

- Science questions are mature:
  - Clearly testable hypotheses have been honed
- JEO Achieves Decadal Survey Recommendations:
  - Top Recommendation for Flagship in 2003-2013
  - Reaffirmed by NRC's CASSE Report (2007)
- Significant technical advances over decade
  - Launch vehicle capability
  - Power source technology
  - Trajectory tools
  - Radiation hardened components
- NASA-only mission is highly capable
  - Plus-up analysis allows optimization of science, cost and risk
  - Synergy with ESA mission enhances science return
  - Programmatic flexibility allows mission launch independence



We know enough to ask the key questions,
yet we anticipate being surprised by discoveries!

Science Goals for TSSM

- **Goal A: 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?
- **Goal B: 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?
- **Goal C: 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?

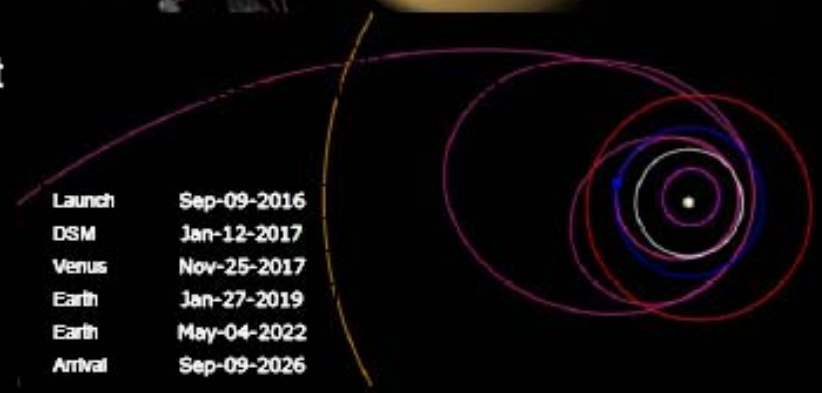
Core Mission Overview

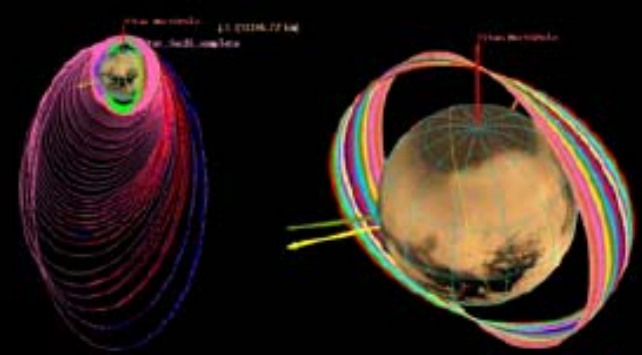
- **Objective: Titan orbit, Saturn system and Enceladus**

- **Orbiter accommodates ESA provided in situ elements;**
  - Core mission includes lander
  - Sweet spot and Enhanced missions include both lander and Montgolfiere but exceed study cost cap

- **Mission Timeline:**
  - Launch 9/2016
  - Saturn Arrival 9/2026
  - Saturn Tour; includes 4 Enceladus and 15 Titan flybys
  - Dedicated Titan aerosampling and mapping Orbit

- **Focused payload;** 6 instr. (HiRIS, TiPRA, PMS, SMS, TIRS, MAPP) + RSA





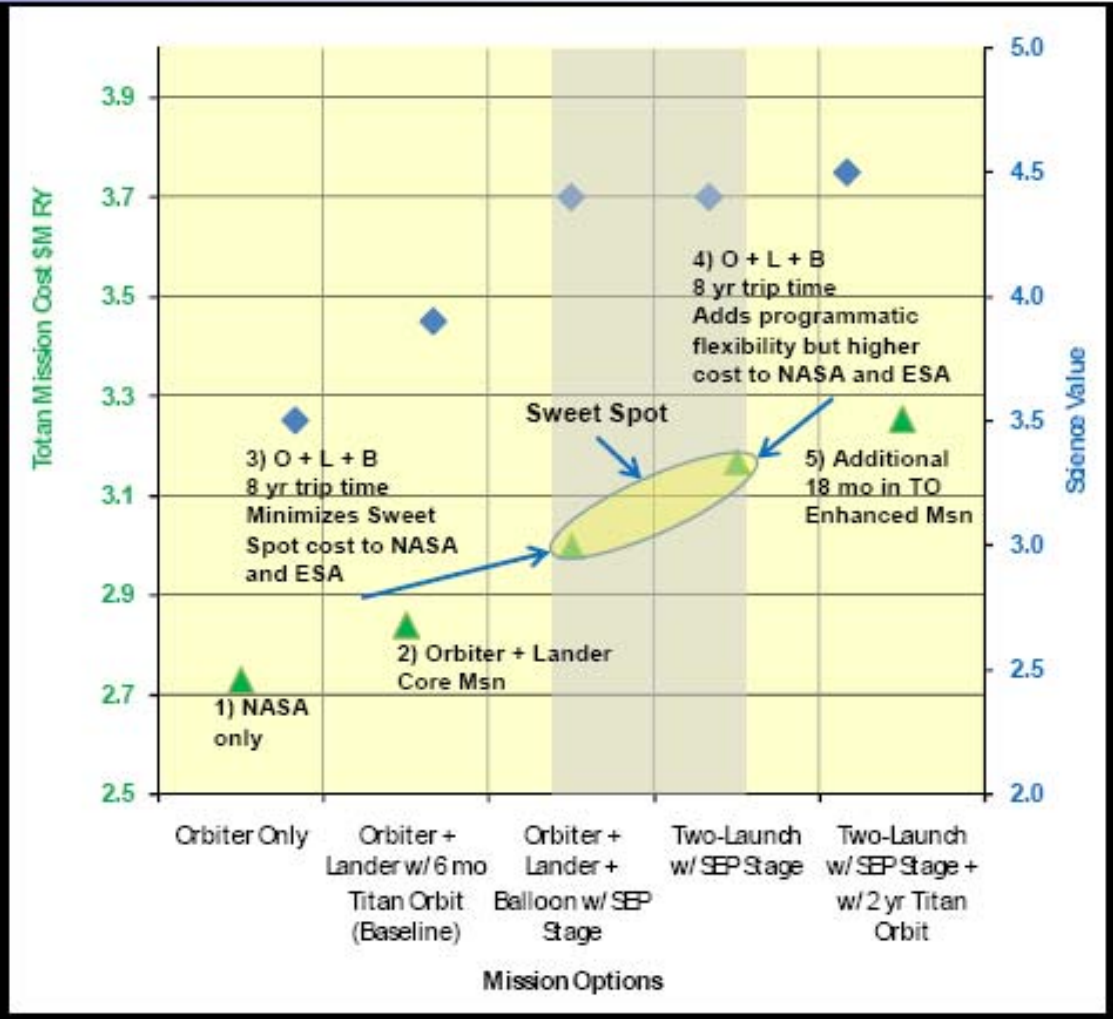
ESA Provided *In situ* elements

- **Montgolfiere Balloon**
  - Release 6 months prior to arrival; <6km/s
  - Near equatorial to mid latitude location
  - Relay to orbiter and Direct to Earth (DTE) in Saturn tour; relay after TOI
  - Floats at 10km (+2 -8 km) altitude
  - Circumnavigates the globe
  - Lower atmosphere and surface science
  - > 6 months earth year life science reqmt
- **Capable Lander**
  - Would land in lake or dry lake bed at northern latitudes, or mid latitude
  - Very similar entry conditions to balloon
  - Similar relay options to balloon
  - Surface, hydrology and interior science
  - >1 earth month (2 Titan days) life for dry landing
    - >1 hours lake landing, battery power

ESA CDF efforts underway to define in situ elements

Sweet Spot

- Prioritization driven by decadal science
- Includes ESA full complement in situ payload
- In situ elements add considerable science value at limited accommodation cost to NASA
- Sweet Spot and enhanced decadal for NASA-only mission not shown in these charts



An orbiting mission that accommodates both an ESA lander and Montgolfiere balloon, while balancing cost, risk and science has an estimated cost ~$3.2 ($2.4B FY07)

Summary

- **A mission to study Titan in depth, with visits to Enceladus, addresses key Decadal objectives and questions raised by spectacular discoveries of Cassini-Huygens**
- **NASA only Orbiter represents a significant advance beyond Cassini in accomplishing Decadal objectives**
- **NASA/ESA mission addresses additional Decadal objectives through the inclusion of in situ elements**
  - In situ elements would be provided by ESA at minimal accommodation costs to NASA; NASA provides RPS and Launcher
- **Flexible mission timing results from launch opportunities available in most years**

Comparison of Europa & Titan Options

Mission	Europa Jupiter System Mission NASA Jupiter Europa Orbiter	Titan Saturn System Mission
NASA only	Atlas 541, 5 MMRTGs 6 instruments plus Radio Science	Atlas 541, 5 MMRTGs 6 instruments plus Radio Science(O)
Core		Atlas 551, 5 MMRTGs 6 instruments plus Radio Science(O) ESA Lander (300 kg available, 150 kg allocation)
Sweet Spot	Atlas 551; 5 MMRTGs 10 instruments plus Radio Science More diverse tour	SEP or Two launch; 5 MMRTGs (Atlas 551 w SEP, A401 for 2nd LV) 6 instruments plus Radio Science(O) ESA Lander plus ESA Montgolfiere (>600 kg allocation)
Decadal / Enhanced	Delta IVH; 6 MMRTGs 13 instruments plus Radio Science 2.5 more months in Europa orbit penetrator demonstration	Same launch as above 6 instruments plus Radio Science(O) 18 additional months in Titan orbit ESA Lander plus ESA Montgolfiere (>600 kg allocation)

Cost summaries for Europa and Titan options

	Europa Jupiter System Mission		Titan Saturn System Mission	
	FY07 $B	RY $B	FY07 $B	RY $B
NASA Only	2.1	2.6	2.1	2.7
Core			2.2	2.8
Sweet Spot	2.5	3.0	2.3	3.0
Full Decadal	3.1	3.8	2.4	3.2

These costs are still under review and will be refined in the final study report

The Road Ahead

- **Clear to HQ management that the added science of these missions was clearly worth the (relatively) small additional investments over the imposed $2.1B cap**
  - Directed to refocus study effort on “Sweet Spot” missions with launch regime of 2018-2022
  - Replan study schedule and budget
- **Continue community involvement and Instrument Workshops**
  - OPAG meeting (Nov. 6-7)
  - Instrument Workshops (June 3-5, TBD)
  - OPFM website at http://opfm.jpl.nasa.gov/
- **Keep in mind that OPF 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, Titan surface conditions, key science objectives)

Backup Slides

2007 Study Review Results

Study	Form A: Science Merit	Form B: Science Implementation Risk	Form C: Mission Implementation Risk
Enceladus	G/F	Not Voted	Not Voted
Titan Explorer	E/VG	Medium	High
Europa Explorer (2015)	E/VG	Medium	High
Europa Explorer (2017)	E/VG	Medium	Medium
Jupiter System Observer	VG/G	High	High

Science Panel Significant Findings from 2007 Study (1)

Enceladus

Science Merit: Good/Fair

- Enceladus is an obvious and tempting target
- The desirability of a lander to do chemical analyses is demonstrated
- The polar orbits used by the Enceladus Orbiter contain the high priority science but are too short, too few, and too late
- For the Saturn Orbiter with Lander concept, too much of the anticipated science yield depends on Enceladus flybys
- The report does not adequately address the multiple competing hypothesis for plume origin, so the mission's potential biological significance is compromised

Titan Explorer

Science Merit: Excellent/Very Good

- Science return from the baseline mission (orbiter plus lander plus balloon) will be extremely rich
- The descope from baseline mission (orbiter plus lander plus balloon) to orbiter plus lander still provides a viable flagship mission with compelling science
- The orbiter-only mission addresses the first of two major objectives (to explore Titan as an evolving Earthlike system) of the mission very well.
- An orbiter only-mission severely compromises the second of two major objectives (to explore Titan's organic inventory) for the mission

Science Panel Significant Findings from 2007 Study (2)

Europa Explorer

Science Merit: Excellent/Very Good

- Science objectives are comprehensive, compelling, and mature
- The geological and geophysical objectives, investigations, and proposed measurements in particular are comprehensive
- Jovian tour offers important advance in comparative planetology
- The Europa Explorer mission provides a clear descope pathway from a comprehensive baseline mission, through staged steps, to a floor mission that still meets all "priority 1" science objectives
- The chemistry objective, including portion related to habitability, was not comprehensively addressed

Jupiter System Observer (JSO)

Science Merit: Very Good/Good

- JSO offers a unique opportunity to study all four Jovian satellites
- The mission design provides comprehensive geophysical and geological interrogation of Ganymede
- Nearly continuous monitoring of Ionian volcanism for 3 years or more
- JSO will acquire extensive global visible and IR and stereo topographic mapping data of the other Galilean satellites
- Synoptic Jupiter atmosphere measurements will be obtained with greatly improved spatial resolution and potential spatial and temporal coverage
- The Jupiter atmospheric scientific investigations in particular were poorly justified
- The science theme of Habitability, which is called out in the Roadmap and is important to astrobiology, was not considered in formulating the science plan
- The SDT did not address how the mission and expected results can be used to study solar system formation and the chemical evolution of the proto-stellar disk

TMC Panel Significant Findings from 2007 Study (1)

Enceladus

Science Implementation: Not Voted; Mission Implementation: Not Voted

- Immature mission architecture
- None of the design concepts presented appear feasible
- Mission lifetimes too long to be considered an acceptable risk
- Mass margins are inadequate.
- Feasibility of landing on Enceladus could not be assessed
- Lack of definition in the requirements for the site selection, the landing event and the characterization of the landed operating environment and impacts on the Lander Design.

Titan Explorer

Science Implementation: Medium; Mission Implementation: High

- Extremely challenging design concept in terms of complexity, mass and cost
- Aerocapture for the baseline architecture drives substantial design risk for the Orbiter
- Lander and Aerial Vehicle entry systems and the Orbiter aeroshell are new designs
- Instrument concepts may not meet a number of the required science objectives
- Considerable uncertainty and immaturity associated with the design and implementation of the Chemical analysis Instrument operating in the Titan environment.

TMC Panel Significant Findings from 2007 Study (2)

Europa Explorer

2015: Science Implementation: Medium; Mission Implementation: High

2017: Science Implementation: Medium; Mission Implementation: Med

- 2015 launch of EE is not credible, considering the time required to resolve radiation issues prior to the release of instrument AO's and funding availability
- Detailed science traceability matrix that identifies goals and objectives, offers methods for the investigation and details measurement requirements
- Radiation-induced effects on the measurement quality is a significant issue
- The flight system instrument accommodation concept is detailed
- The 2017 launch provides considerable mitigation for the identified major issues, resulting in a reduced risk level.

Jupiter System Observer (JSO)

Science Implementation: High; Mission Implementation: High

- Traceability Matrix fails to clearly tie the particular instruments to the science goals
- Some of the highest in science value investigations may not lead to definitive answers
- Radiation-induced effects on the measurement quality is a significant issue
- Launch configuration with the JSO instrument platform located near the launch vehicle separation interface significantly increases instrument assembly, handling and access risk
- Unacceptable dry mass margin

Groundrules for 2008 Study

- **Cost Cap: $2.1B ($FY07) with 33% reserves**
- **Power System: only MMRTG's or solar allowed**
- **Launch Vehicle: Atlas 5, Delta IV-H, Ares 5**
- **Launch and Cruise: 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**

Rating JEO to the Decadal Survey's Steering Group Recommendations

DECADAL SURVEY STEERING GROUP "EUROPA GEOPHYSICAL EXPLORER" SCIENCE	Core JEO	Sweet Spot	Decadal JEO
Determine the presence or absence of an ocean.	5	5	5
Characterize the three-dimensional distribution of any subsurface liquid water and its overlying ice layer.	4	5	5
Understand the formation of surface features, including sites of recent or current activity, and identify candidate landing sites for future lander missions.	3	5	5
Characterize the surface composition, especially compounds of interest to prebiotic chemistry.	3	4	4
Map the distribution of important constituents on the surface.	3	5	5
Characterize the radiation environment in order to reduce the uncertainty for future missions, especially landers.	2	5	5

5	Definitely addresses full science.
4	May address full science.
3	Definitely addresses partial science.

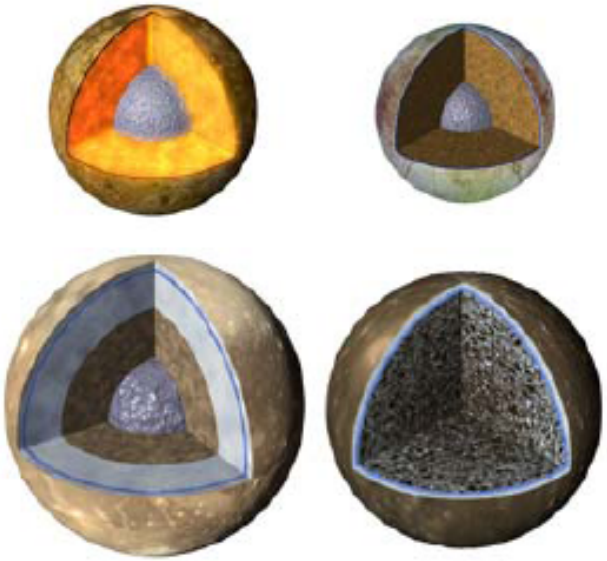
2	May address partial science.
1	Touches on science.
0	Does not address science.

Rating JEO to the Decadal Survey's Large Satellites Panel Recommendations

Theme 1. Origin and Evolution of Satellite Systems	Core JEO	Sweet Spot	Decadal JEO
1. How do conditions in the protoplanetary nebula influence the compositions, orbits, and sizes of the resulting satellites?	1	2	3
2. What affects differentiation, outgassing, and the formation of a thick atmosphere? (Why is Titan unique?)	2	3	3
3. To what extent are the surfaces of icy satellites coupled to their interiors (chemically and physically)?	4	5	5
4. How has the impactor population in the outer solar system evolved through time, and how is it different from the inner solar	3	5	5
5. What does the magnetic field of Ganymede tell us about its thermal evolution, and is Ganymede unique?	2	3	3
Theme 2. Origin and Evolution of Water-Rich Environments in Icy Satellites			
1. What is the chemical composition of the water-rich phase?	2	4	4
2. What is the distribution of internal water, in space and in time?	3	4	4
3. What combination of size, energy sources, composition, and history produce long-lived internal oceans?	3	4	4
4. Can and does life exist in the internal ocean of an icy satellite?	2	3	3
Theme 3. Exploring Organic-Rich Environments			
1. What is the nature of organics on large satellites?	2	3	4
4. How do atmospheric processes affect organic chemistry?	1	2	3
Theme 4. Understanding Dynamic Planetary Processes			
1. What are the active interior processes and their relations to tidal heating, heat flow, and global patterns of volcanism and tectonism?	3	4	4
2. What are the currently active endogenic geologic processes (volcanism, tectonism, diapirism) and what can we learn about such processes in general from these active worlds?	3	4	5
3. What are the complex processes and interactions on the surfaces and in volcanic or geyser-like plumes, atmospheres, exospheres, and magnetospheres?	2	4	5
Large Satellites Panel overall high-priority questions:			
1. How common are liquid-water layers within icy satellites?	2	4	4
2. How does tidal heating affect the evolution of worlds?	3	4	4

5	Definitely addresses full science.
4	May address full science.
3	Definitely addresses partial science.
2	May address partial science.
1	Touches on science.
0	Does not address science.

Recommendations and ratings relate to all outer planet satellites



Rating Titan Saturn System Mission to the Decadal Survey's Large Satellites Panel Recommendations

"Exploring Organic Environments" theme uses Titan-specific questions from the decadal text rather than the more generic questions from the table

LARGE SATELLITES PANEL THEMES AND KEY QUESTIONS:	NASA Only: Orbiter only	Core Mission: Orbiter + lander	Sweet Spot: Orbiter + lander + ball-oon
Theme 1. Origin and Evolution of Satellite Systems			
1. How do conditions in the protoplanetary nebula influence the compositions, orbits, and sizes of the resulting satellites?	3	4	4
2. What affects differentiation, outgassing, and the formation of a thick atmosphere? (Why is Titan unique?)	4	5	5
3. To what extent are the surfaces of icy satellites coupled to their interiors (chemically and physically)?	3	4	4
4. How has the impactor population in the outer solar system evolved through time, and how is it different from the inner solar system?	4	4	4
5. What does the magnetic field of Ganymede tell us about its thermal evolution, and do other large satellites have intrinsic magnetic fields?	1	3	4
Theme 2. Origin and Evolution of Water-rich environments			
1. What is the chemical composition of the water-rich phase?	5	5	5
2. What is the distribution of internal water, in space and in time?	4	4	4
3. What combination of size, energy sources, composition, and history produce long-lived internal oceans?	5	5	5
4. Can and does life exist in the internal ocean of an icy satellite?	1	2	3
Theme 3. Exploring organic-rich environments			
1. What are the chemistry, distribution, and cycling of organic materials on Titan?	4	5	5
2. Is Titan internally active, producing water-rich environments with potential habitability?	4	5	5
3. What are the current state and history of Titan's surface?	5	5	5
4. What drives the meteorology of Titan?	2	3	4
5. Has there been climate change on Titan?	4	5	5
6. Could Titan support life forms that do not require liquid water?	1	2	3
Theme 4. Understanding dynamic planetary processes			
1. What are the active interior processes and their relations to tidal heating, heat flow, and global patterns of volcanism and tectonism?	4	4	5
2. What are the currently active endogenic geologic processes (volcanism, tectonism, diapirism) and what can we learn about such processes in general from these active worlds?	4	4	5
3. What are the complex processes and interactions on the surfaces and in volcanic or geyser-like plumes, atmospheres, exospheres, and magnetospheres?	5	5	5

Getting to Europa and Titan

- **Launch Opportunities between 2016-2022**
  - Numerous opportunities using inner planet GA trajectories have been identified with no pronounced secular trends from 2016-2022.
  - Opportunities exist for all these years, though more limited and/or less desirable opportunities exist in 2017, 2019 and (for Europa) in 2022
  - Solar electric propulsion (SEP) can enable more mass and less trip time for the Saturn Titan mission

- **Launch interdependencies between NASA and ESA**
  - Credible Jupiter Europa Orbiter (JEO) and Saturn Titan Orbiter (STO) missions have been defined. They can be executed as NASA-only missions if ESA participation does not materialize
  - JEO and the Jupiter Ganymede Orbiter (JGO) are planned to be launched on separate NASA and ESA LVs. A later launch of JGO will only impact the concurrent science that requires simultaneous observations in the Jupiter system
  - For the Titan In Situ Element, ESA needs NASA to deliver the vehicle(s) to Titan and provide RPS power system(s). A number of options for accomplishing this have been examined but the ESA study of these options is still in progress