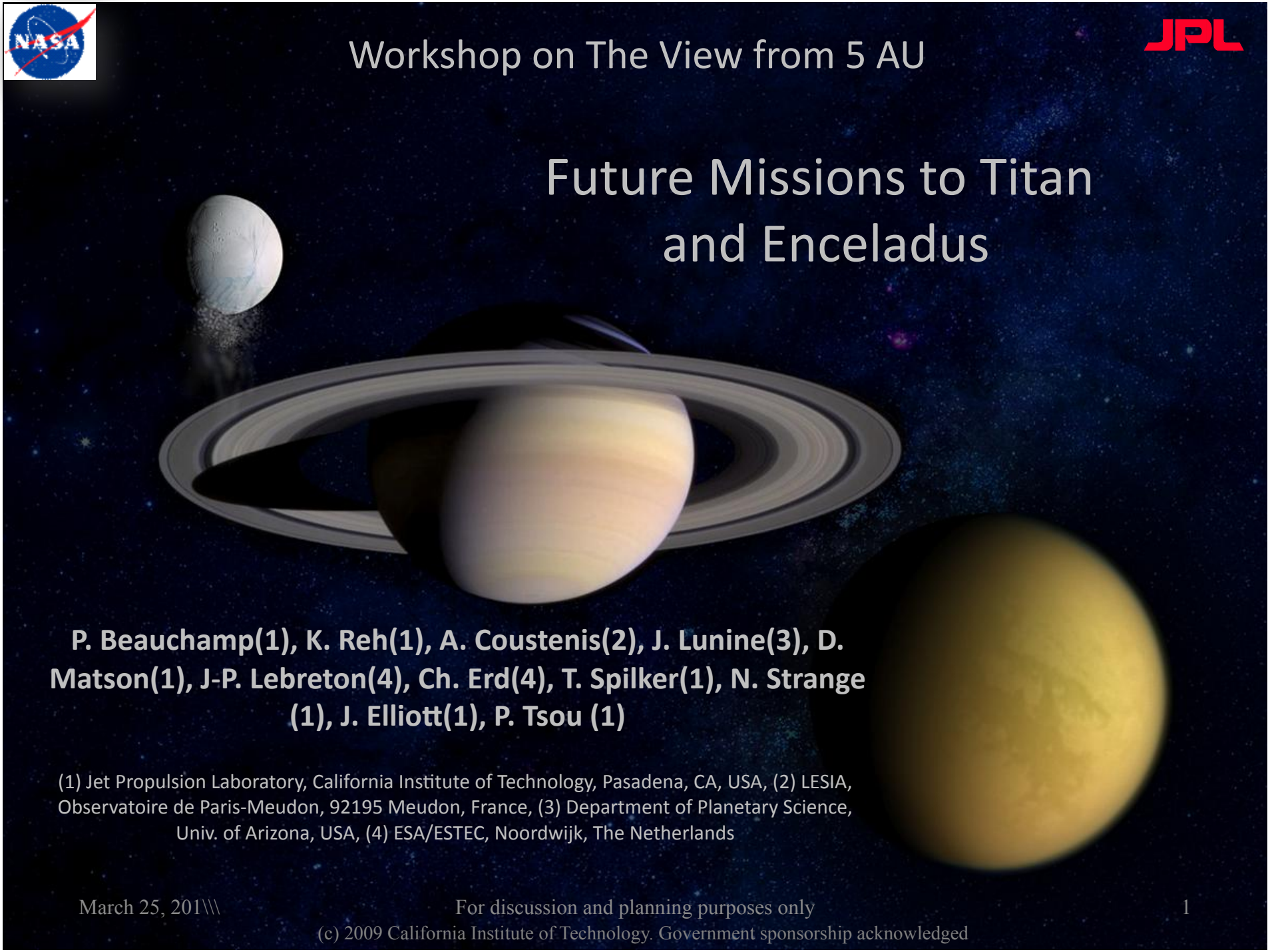

Workshop on The View from 5 AU

Future Missions to Titan and Enceladus

P. Beauchamp(1), K. Reh(1), A. Coustenis(2), J. Lunine(3), D. Matson(1), J-P. Lebreton(4), Ch. Erd(4), T. Spilker(1), N. Strange (1), J. Elliott(1), P. Tsou (1)

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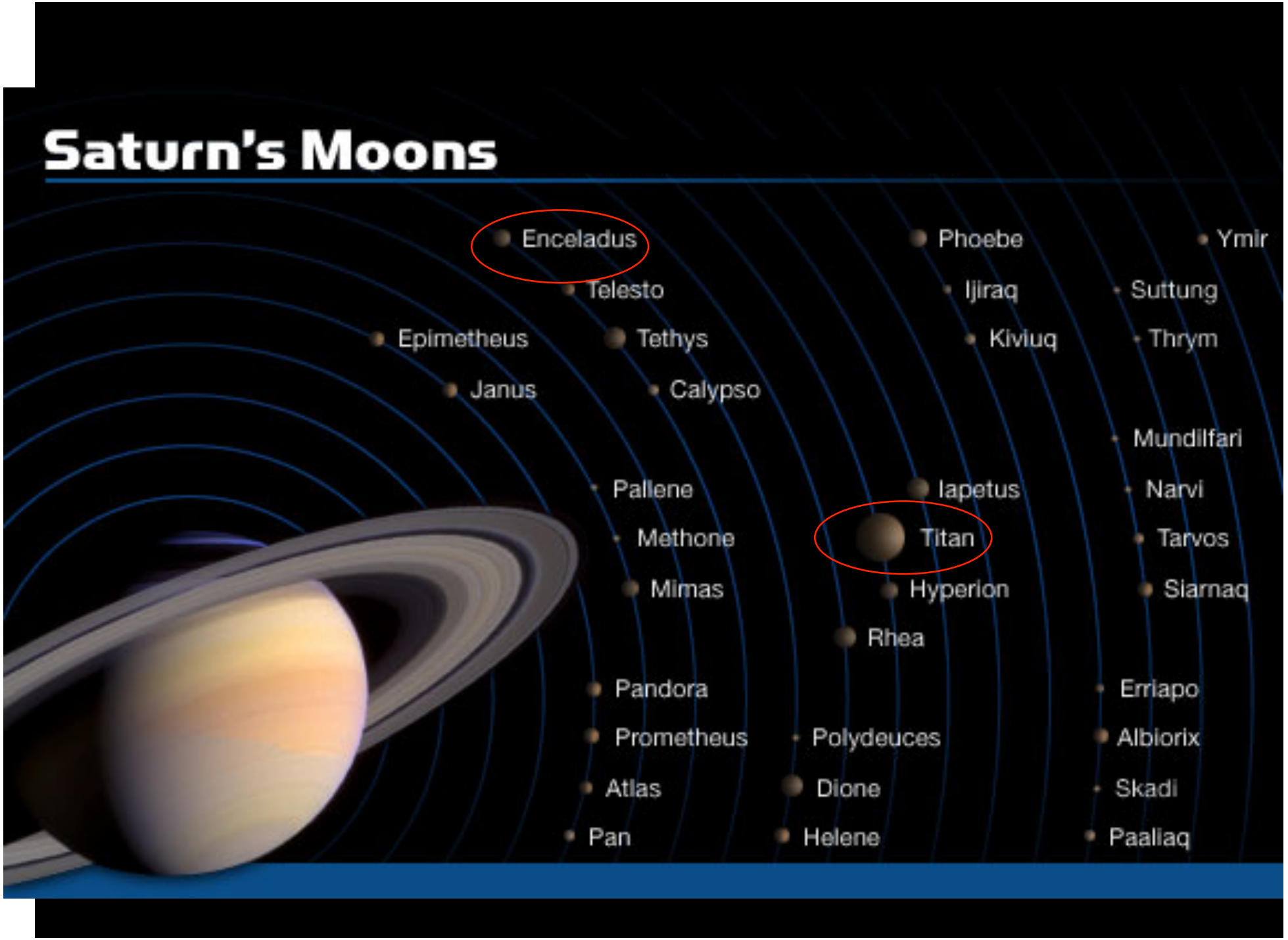
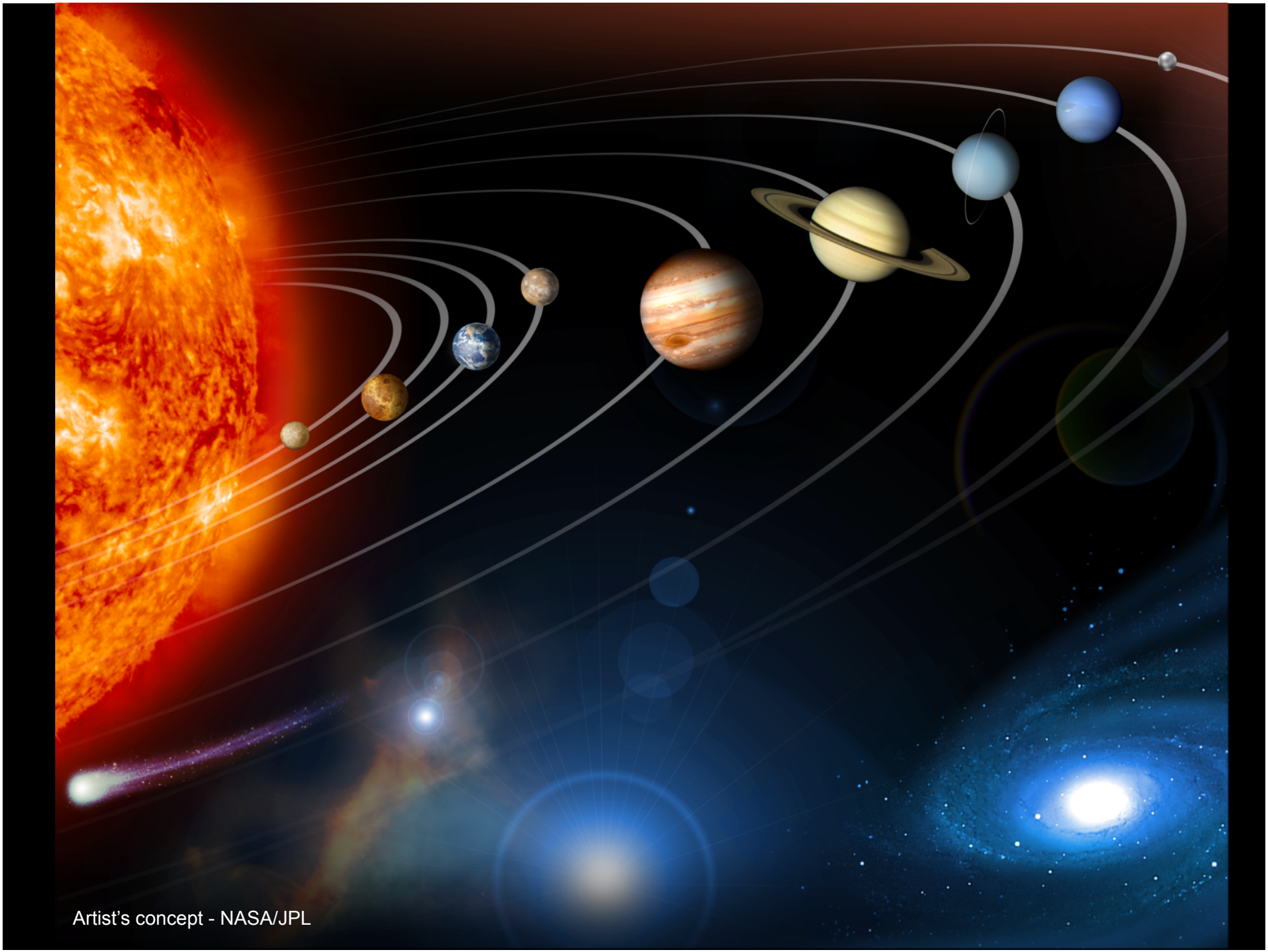
Topics

- Titan's Place in the Solar System
- Context for Titan-Enceladus Missions - Outer Planets Assessment Group and the Planetary Science Decadal Survey
- Future Missions to Titan and Enceladus
  - Flagship mission – Titan Saturn System Mission
  - Potential New Frontiers/small flagship class mission - LIFE
- Summary

Saturn's Moons



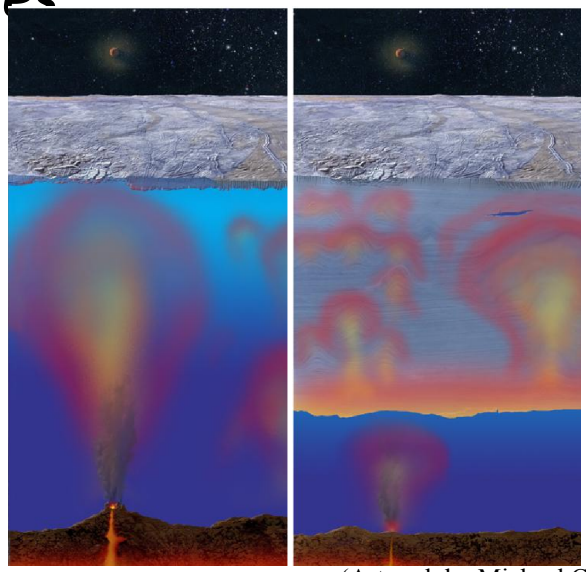

Artist’s concept - NASA/JPL

Outer Planets Assessment Group (OPAG)
Exploration Strategy for the Outer Planets 2013-2022:
Goals and Priorities[1]

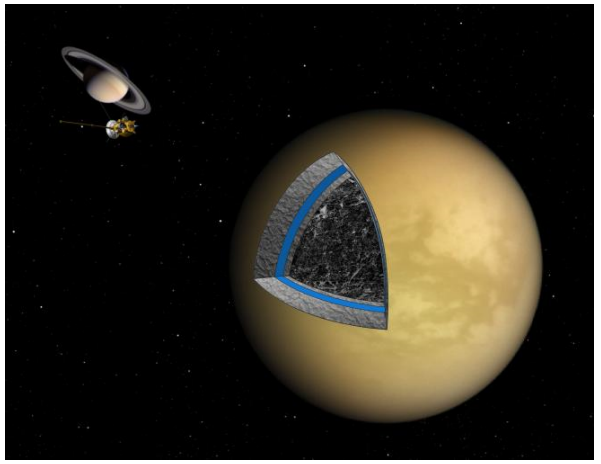
Destinations and Mission Architectures

- Europa and Ganymede are two worlds of fundamental planetological and astrobiological interest. OPAG supports the prioritization of JEO as NASA's next Outer Planets Flagship, and as part of the EJSM collaboration with ESA, and vigorously recommends its support in the Decadal Survey.

- Titan and Enceladus are two satellites of great planetological and astrobiological interest. OPAG strongly endorses approval by NASA of this extension to the Cassini mission, including the Juno-like end-of-mission scenario.



(Artwork by Michael Carroll.)



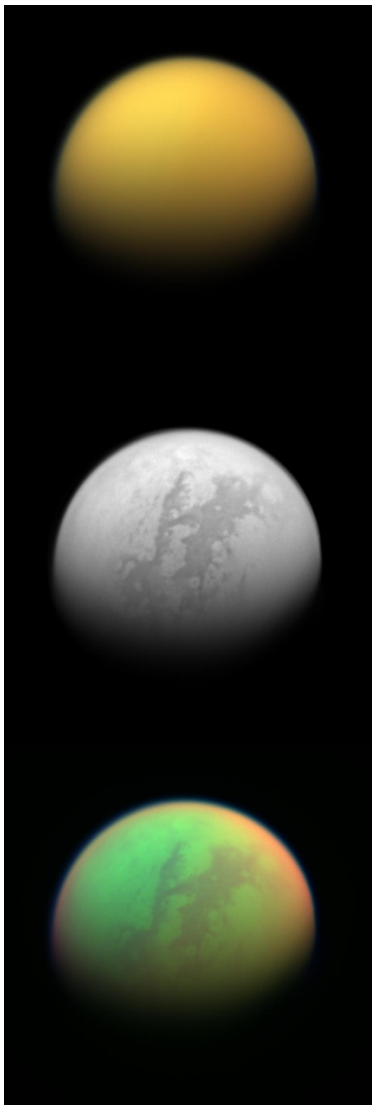
NASA/JPL

[1]**Ref: Exploration Strategy for the Outer Planets 2013-2022: Goals and Priorities Outer Planets Assessment Group White Paper, 9-15-2009**

OPAG Destinations and Mission Architectures

- **Future Missions to Titan and Enceladus**

  Cassini-Huygens has begun to uncover the complexities of Titan and discovered plumes on the fascinating moon Enceladus. It continues to do so, but is limited by on-board instrumentation. Exploring Titan, a diverse and active world, beyond Cassini's equinox and solstice investigations of seasonal change will require landed studies, airborne sounding platforms (most plausibly from a balloon), and an orbiter. The 2008 Titan Saturn System Mission (TSSM) encompassed the scientific requirements of both these remarkable bodies. It is possible that a mission to each could be accomplished individually, but a flagship mission would provide the rich and comprehensive knowledge that orbiting and *in situ* elements are capable of generating.



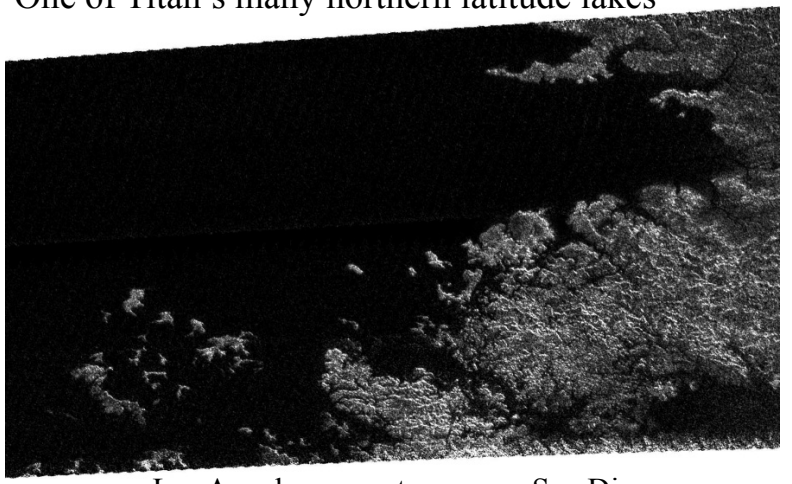
OPAG strongly recommends that NASA pursue development of the next outer planet flagship mission to Titan and Enceladus by funding a program to retire the associated technological risks. It also encourages NASA to further investigate the possibility of lower-cost missions to these objects.

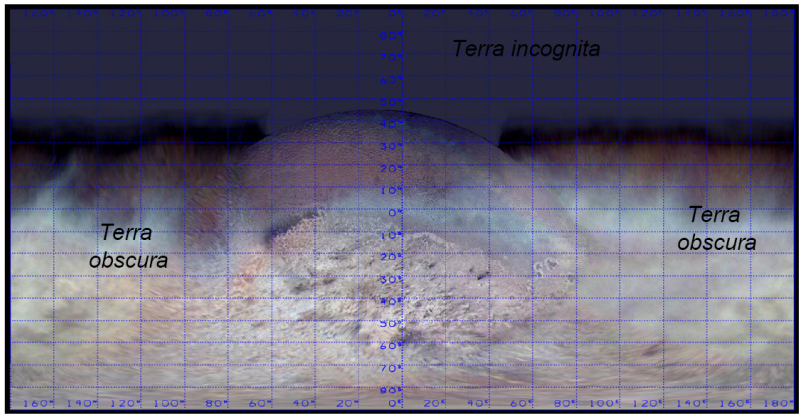
OPAG Destinations and Mission Architectures

- OPAG recommends that well-funded studies of the following mission concepts be undertaken, and their feasibility for inclusion in the New Frontiers mission set be assessed. OPAG does not expect that all these mission concepts can or will prove feasible for New Frontiers. Not in priority order, these missions are a:

1) **shallow Saturn probe (with microwave sounder);**
2) **Io observer (on the present New Frontiers list);**
3) **Titan in-situ explorer or probe;**
4) **Neptune/Triton/KBO flyby; and**
5) **Uranus orbiter.**

One of Titan's many northern latitude lakes

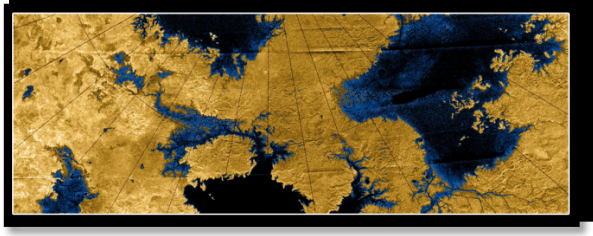




Triton's anti-Neptune hemisphere has been imaged at only 60 km/pixel.

Titan: A complex world of high priority

- Cassini-Huygens has found lakes, seas, rivers, clouds, rain, and in the extended mission strong evidence for a dynamic changing climate system and interior ocean
- Titan is the only world besides Earth with an active climate/hygrology cycle: methane vs water (hydrology)
- Titan's wealth of organic molecules and diverse sources of free energy make it of high priority for exploring chemistry that preceded life's origin on Earth, and possible exotic life in the methane seas



Water on Enceladus

Enceladus Plume

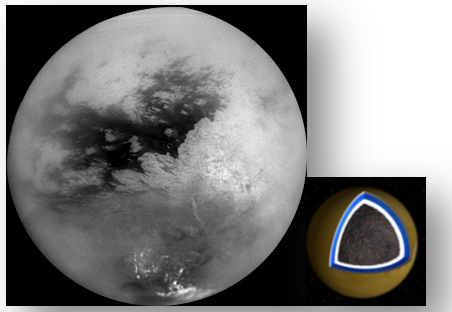
27 Nov. 2005

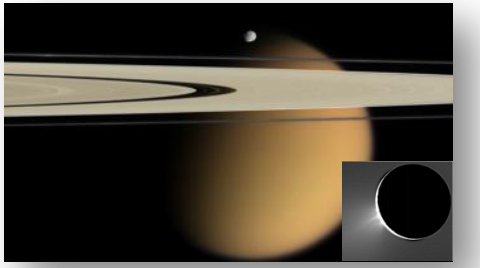
Images yielded evidence that the geologically young south polar region of Enceladus may possess reservoirs of near-surface liquid water that erupt to form geysers.

Gas and fine, icy particles jet from vents in moon's active south polar region.

*The plume towers at least an **Enceladus** diameter above the surface.*

High Priority Science Questions (established by joint science definition team)





- Goal A: Explore Titan, an Earth-Like System
  - What is Titan's climate like?
  - How does it change with time?
  - What can it teach us about Earth's climate?
- Goal B: Examine Titan's Organic Inventory—A Path to Prebiological Molecules
  - What kind of organic chemistry goes in Titan's atmosphere, in its lakes and seas, and underground?
  - Is the chemistry at the surface mimicking the steps that led to life on Earth?
  - Is there an exotic kind of life—organic but totally different from Earth's—in the methane/ethane lakes and seas?
- Goal C: Explore Enceladus and Saturn's magnetosphere — clues to Titan's origin and evolution
  - What is the source of geysers on Enceladus?
  - Is there life in the source water of the geysers?

Relationship to Cassini-Huygens

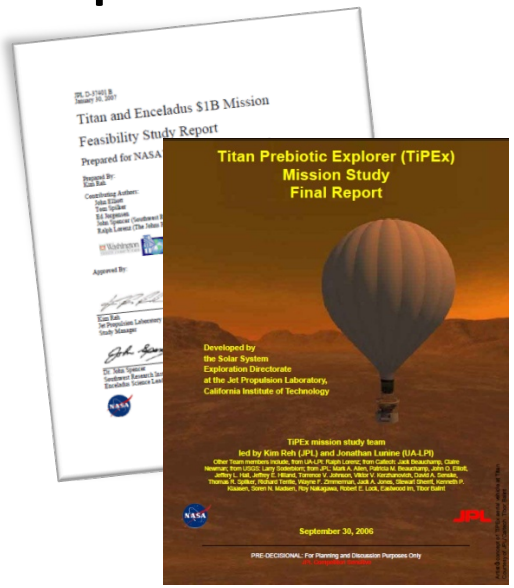
- The Cassini-Huygens mission continues to uncover the mysteries of Titan
  - Has discovered most of what we know about the Saturnian system and reset the paradigms: Plumes on Enceladus; organic seas on Titan
  - Mission is shifting toward (a) observing seasonal changes on Saturn and Titan as the Saturnian year (30 Earth years) proceeds; and (b) search for more definite evidence of liquid water near the base of Enceladus' plumes

- Limits of Cassini-Huygens instruments have been reached and they cannot carry out some key investigations needed to answer new questions
  - What are Titan's lakes and seas made of? What's in them?
  - How vast and intricate are the river systems? Do they flow today?
  - Is there a vast reservoir of organics resident beneath the surface?
  - Is Titan's climate changing? What seasonal effects exist?

- A dedicated Titan mission can address these intriguing questions

Mission studies have identified key elements needed to answer the science questions

- Mission studies focused on high priority science
  - Various studies in the 1990s
  - 2002 Aerocapture Systems Analysis Study
  - 2004 Titan Organic Exploration Study (TOES) under NASA's Vision Missions Program
  - 2006 Titan Prebiotic Explorer (TiPEx) study
  - 2007 "Billion Dollar Box" study

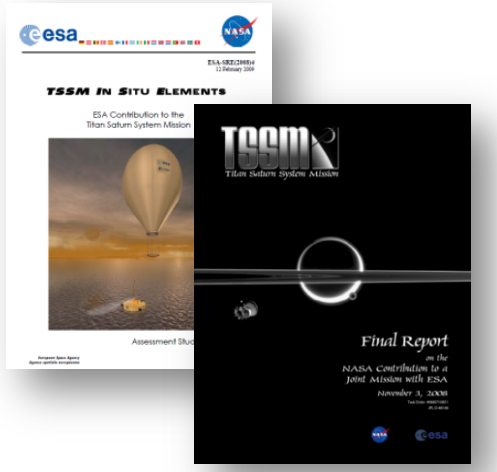


- Technology development to retire risk
  - Focused on balloon and *in situ* elements

- 2007 NASA Titan Explorer study confirmed the ***Orbiter, Lander and Balloon*** as key elements for a flagship mission to Titan ===> basis for 2008 NASA-ESA joint OPFM studies

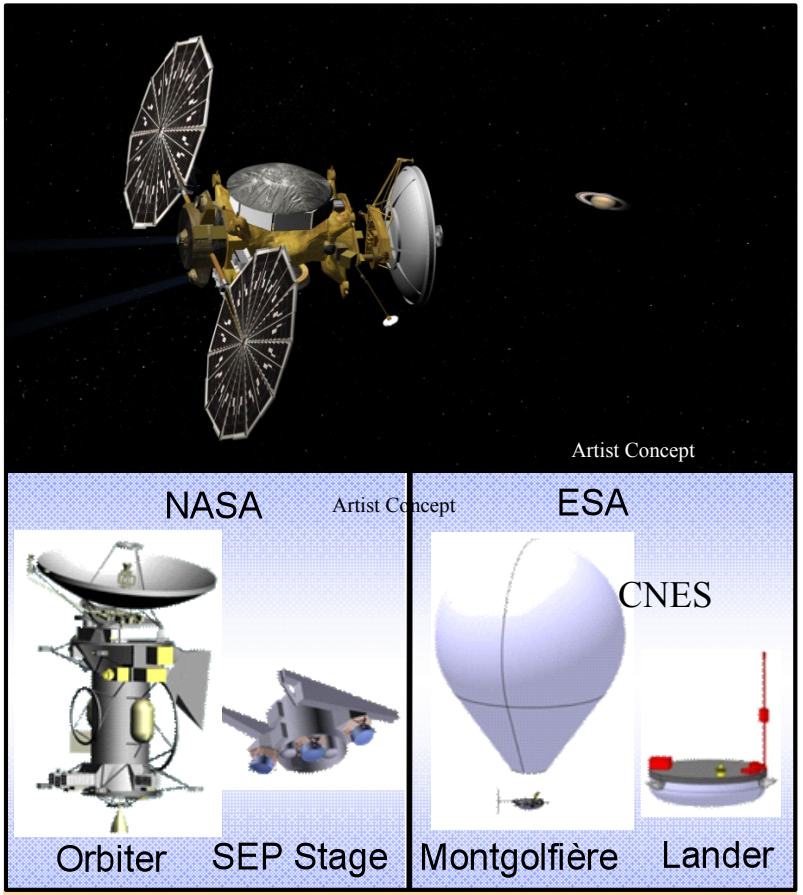
NASA-ESA 2008 studies focused on a joint mission to Titan and Enceladus

- Following from NASA's 2007 Titan Explorer study and ESA's TandEM study, NASA and ESA initiated a joint mission study
- The 2008 concept was shaped by results from previous NASA and ESA studies and driven by NASA ground rules
- Key driving NASA ground rules
  - Level 1 science requirements include Titan, Saturn system and Enceladus
  - NASA provides orbiter and ESA provides *in situ* elements
  - Orbiter must deliver and support the *in situ* elements
  - Must achieve Titan orbit without using aerocapture
  - Must achieve best balance of science, cost, and risk
- The Titan Saturn System Mission (TSSM) emerged



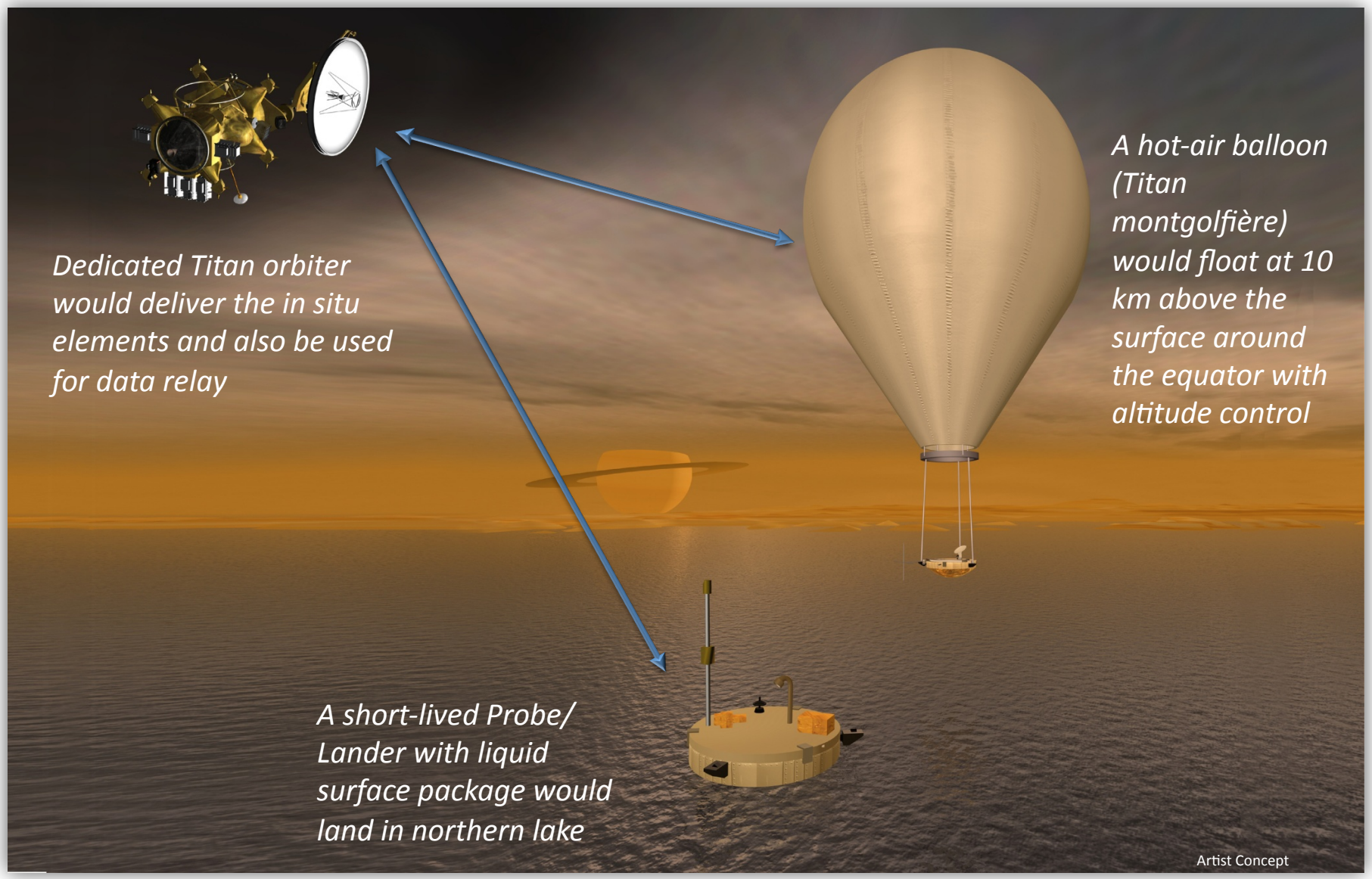
2008 TSSM Overview

- Titan, Enceladus and Saturn system science
- Mission Design
  - 2020 Launch to Gravity Assist SEP trajectory
  - 9 years to Saturn arrival
  - SEP stage released ~5 yrs after launch
  - Montgolfière released on 1st Titan flyby, Lander on 2nd Titan flyby
  - ~4 yr mission: 2 yr Saturn tour with Enceladus, 2 mo Titan aerosampling; 20 mo Titan orbit
- NASA Orbiter and Launcher
  - ASRG power baselined (MMRTG compatible)
  - Solar Electric Propulsion (SEP)
  - 6 Instruments + Radio Science
  - NASA provided Launch Vehicle and RPS
- ESA *In situ* Elements
  - Lake Lander – battery powered
    - 4 instruments + Radio Science
  - Montgolfière – MMRTG powered
    - 7 instruments + Radio Science



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

Relationship between key mission elements



Path forward from 2008 Studies

- NASA science panel confirmed that *in situ* elements are needed for a highly capable flagship mission to Titan
  - Science rated Excellent; science implementation – rated low risk; mission implementation – rated high risk

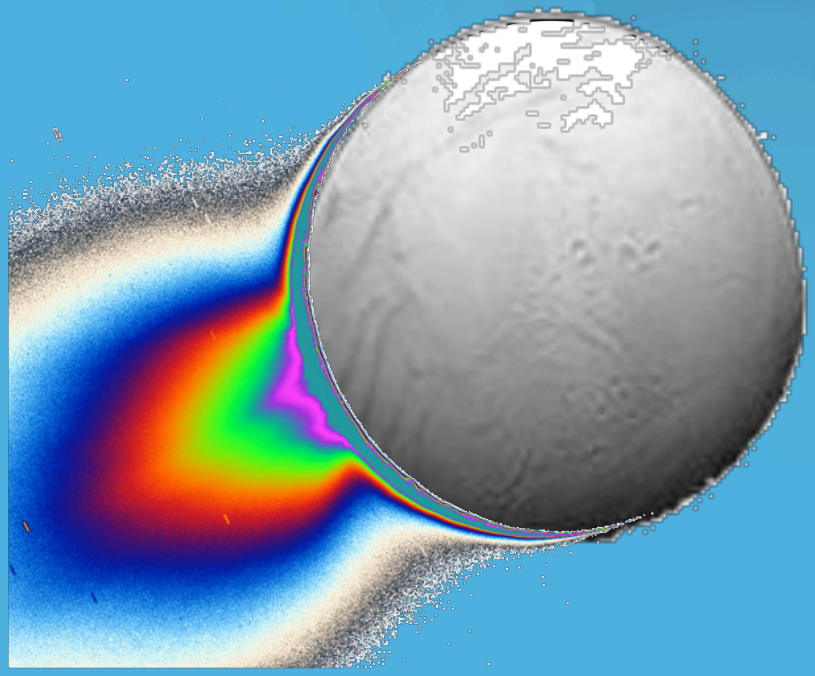
- NASA-ESA panels identified risks needing further attention
  - Orbiter and lake lander risks can be mitigated in formulation
  - Technical risks related to the montgolfière call for early mitigation:
    - Balloon deployment and inflation upon arrival at Titan
    - Balloon packaging and thermal mgmt. inside the aeroshell
    - Interface complexity between balloon, RPS and aeroshell
    - Integration of the NASA provided MMRTG
  - TSSM team identified *in situ* instrument systems and high performance remote sensing instruments as areas that could also benefit from risk reduction
    - Sampling systems and chemical analyzers (1-600 Da mass spec.)
    - Hi res. IR Imager/Spec. (<50m/pixel) and Mass Spec. (M/DM <105 for masses up to 10,000 Da)

NASA STMC Review Findings

- To advance readiness of the montgolfière, NASA and CNES are discussing entering into a joint risk reduction effort directed at a Titan aerobot – Focus areas highlighted on following charts

Example of a Possible Lower Cost mission Opportunity

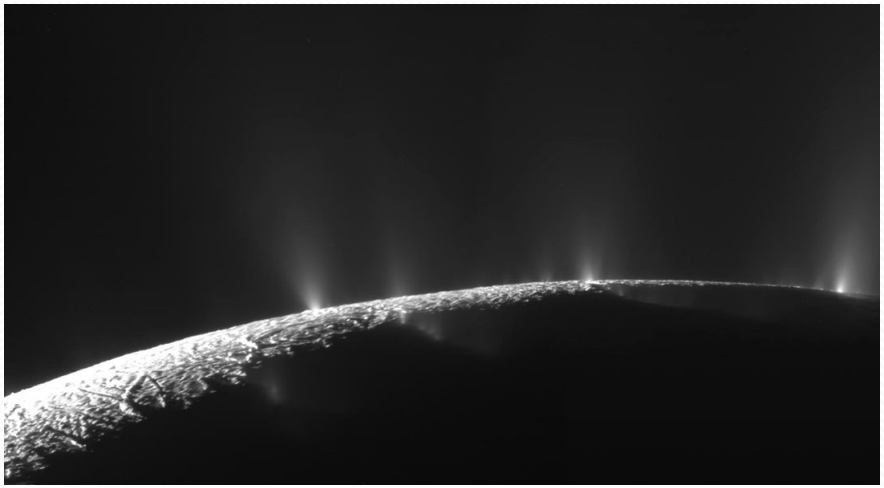
LIFE
(Life Investigation For Enceladus)



PI: Peter Tsou
Jet Propulsion Laboratory
Caltech

LIFE, Life Investigation For Enceladus

Cassini found liquid water and organic-rich mixtures in the Enceladus jets



- No in situ instruments can determine “life” on Enceladus
- LIFE brings samples from Enceladus to Earth’s laboratories
- LIFE brings to “life search” as STARDUST did for comets
- LIFE can return samples within our life times

Sample Return Opportunity

- Low cost flyby sample return from Enceladus
  - Preserving organics/volatiles, signature of “life”
  - Capture Enceladus jet samples and Saturn E ring materials
  - Titan upper atmospheric measurements
  - Follows STARDUST with volatiles & cooling augmentations
- This type of fly-through sample return is a opportunity to catch samples by low-cost flyby of

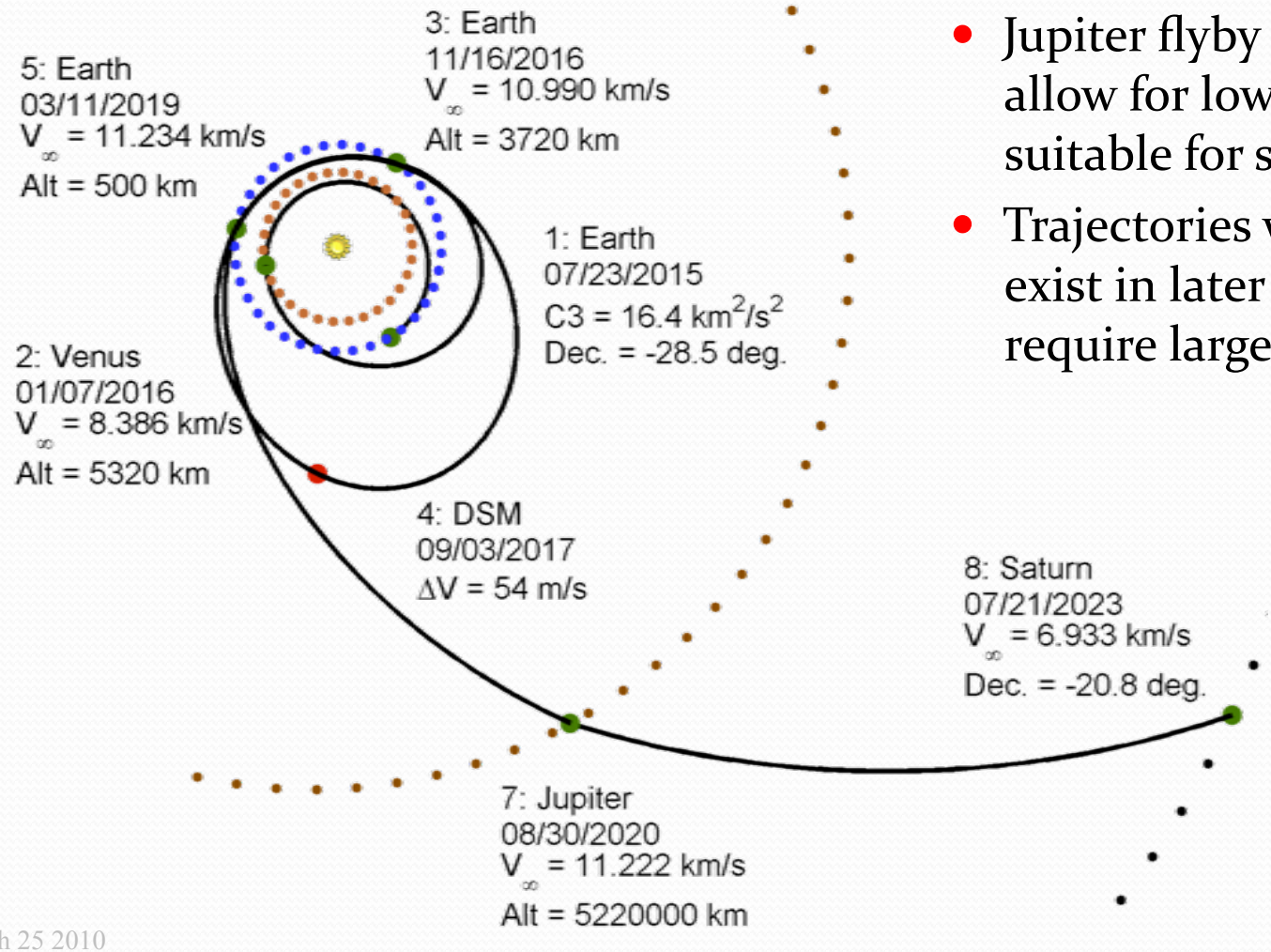
Recognized Challenges
2007 JPL and GSFC studies

- High sampling speed, 20 km/s ~2km/s
- Long mission duration, 30 yr ~14 yr
- Risk of a single flyby sampling multiple
- Fit within project cost caps

Instrument Payload

- Sample Collectors
  - Silica aerogel & volatiles capture/sealer
- Mass Spectrometer, 1000 Daltons
- 0.4 – 5 μ Imaging spectrometer
- Camera

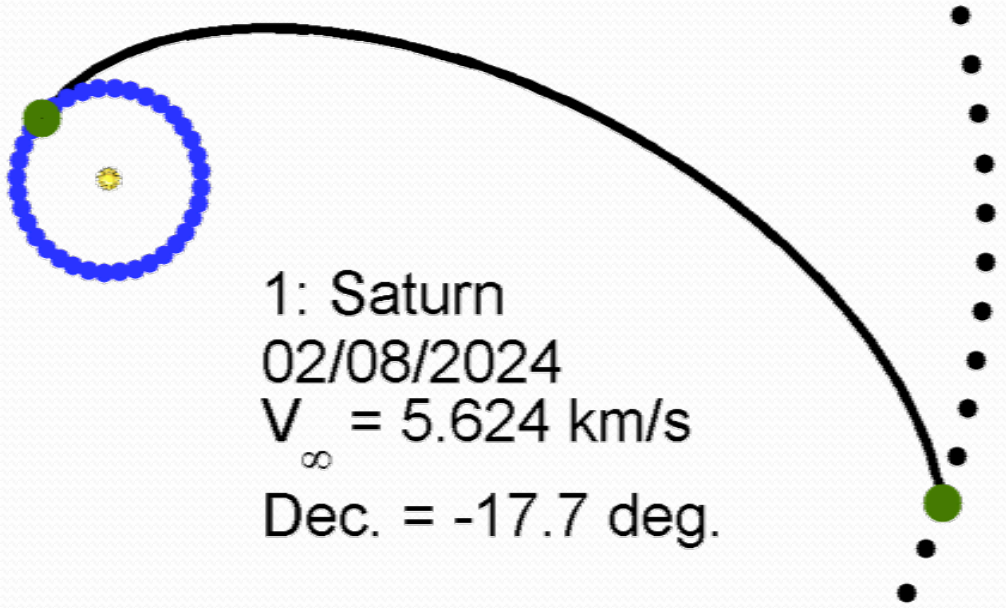
Example 2015 launch opportunity



- Jupiter flyby opportunities allow for low launch energies suitable for smaller EELVs.
- Trajectories without Jupiter exist in later years, but require larger EELVs.

Return Trajectory

- 5 year return trajectory enables a total mission **duration of 13.5 years.**
- Multiple return opportunities are available, allowing for a great deal of operational flexibility.



2: Earth
02/06/2029
V_∞ = 11.498 km/s
Dec. = -5.1 deg.

1: Saturn
02/08/2024
V_∞ = 5.624 km/s
Dec. = -17.7 deg.

LIFE Flight Possibilities

- Immediate – Discovery Mission AO in 2010
  - Cost cap of $425M with free ASRGs
- Near Term - New Frontiers AO in ~2015
  - Cost cap of $650M in 2009
- Possible – mini Flagship
  - Cost of ~ $800M