Outer Planet Missions and Instruments

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Exoplanet Science Measurements from Solar System Probes
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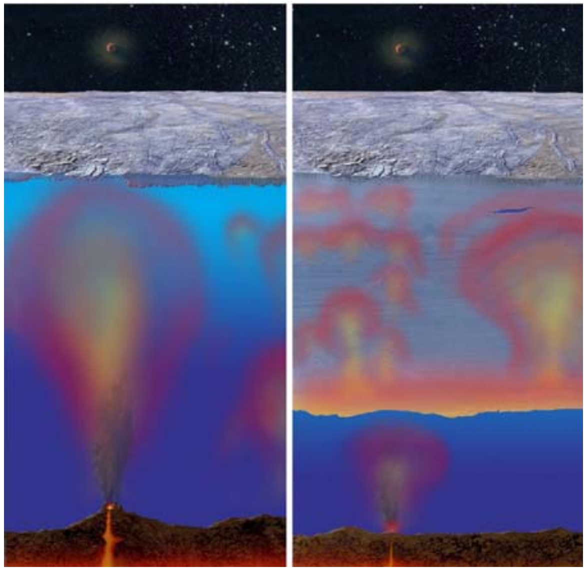
Topics

- Outer Planet Assessment Group Recommendations to Planetary Science Decadal Survey
- Europa Jupiter System Mission
- Future Missions to Titan and Enceladus
  - Flagship mission – Titan Saturn System Mission
  - Potential New Frontiers/small flagship class mission - LIFE
- Summary

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

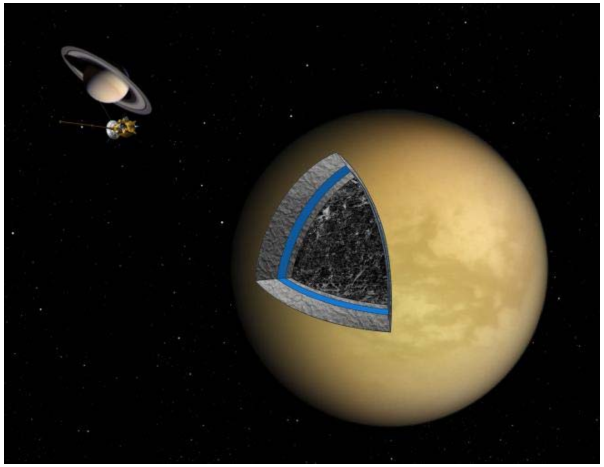
Destinations and Mission Architectures

- 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.



(Artwork by Michael Carroll.)

- 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.



NASA/JPL

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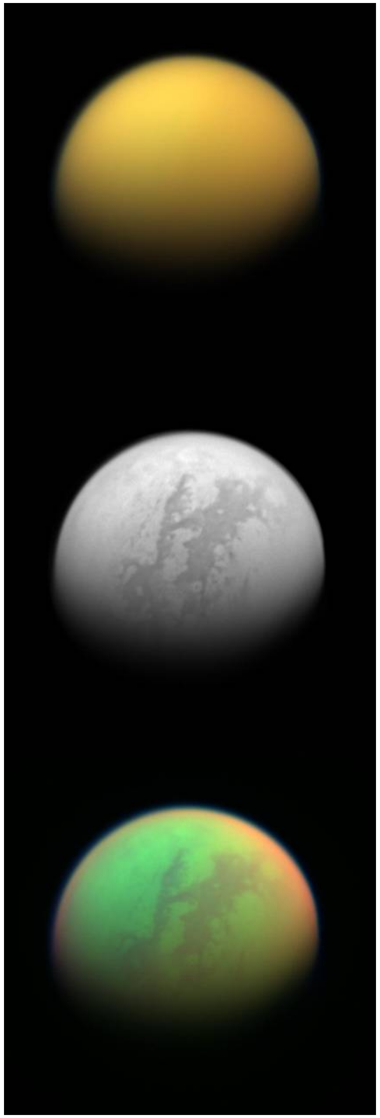
[1] Ref: Exploration Strategy for the Outer Planets 2013-2022: Goals and Priorities Outer Planets Assessment Group White Paper, 9-15-2009

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.



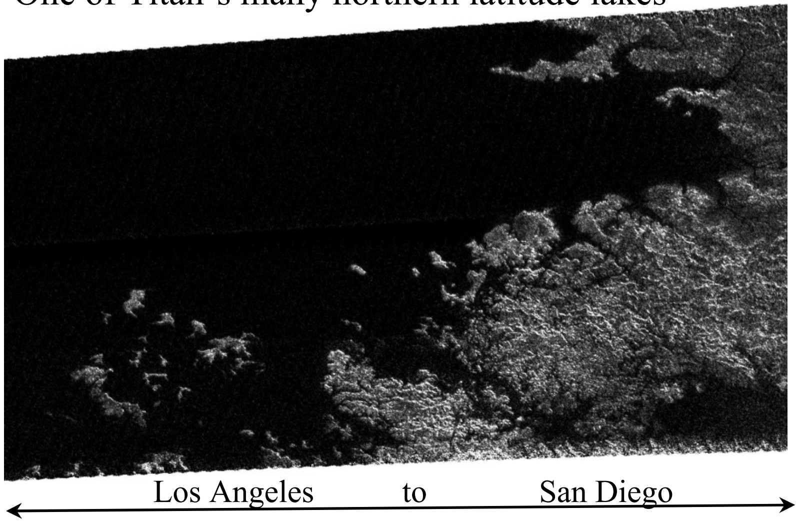
OPAG strongly recommends that NASA pursue development of the next outer planet flagship mission to Titan and Enceladus by funding a program to retire the associated technological risks. It also encourages NASA to further investigate the possibility of lower-cost missions to these objects.

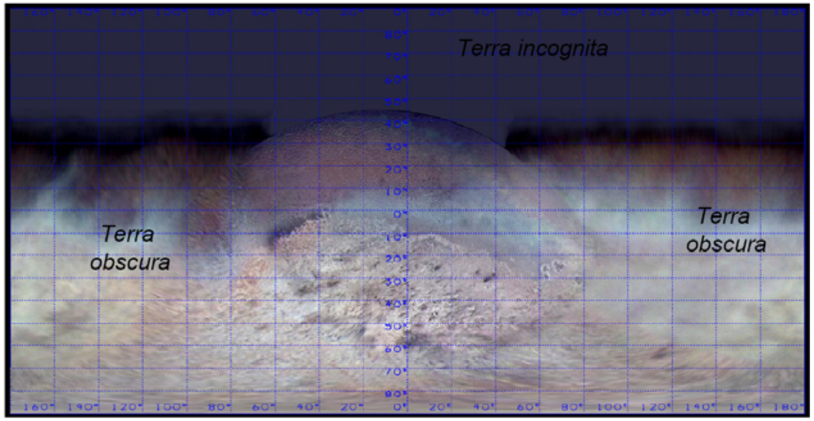
OPAG Destinations and Mission Architectures

- 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.

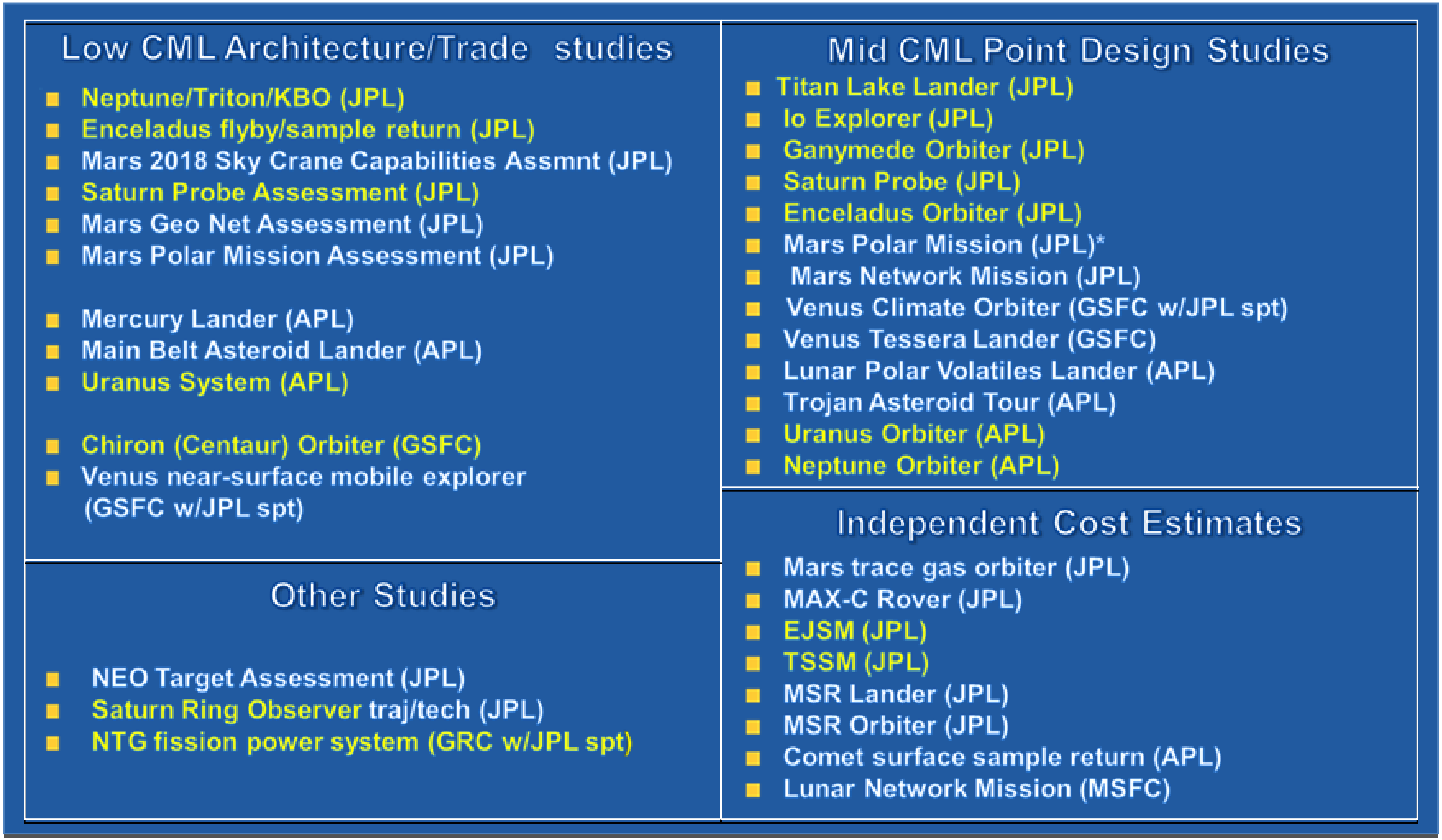
One of Titan's many northern latitude lakes





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

Decadal Studies to date



Low CML Architecture/Trade studies

- Neptune/Triton/KBO (JPL)
- Enceladus flyby/sample return (JPL)
- Mars 2018 Sky Crane Capabilities Assmnt (JPL)
- Saturn Probe Assessment (JPL)
- Mars Geo Net Assessment (JPL)
- Mars Polar Mission Assessment (JPL)

- Mercury Lander (APL)
- Main Belt Asteroid Lander (APL)
- Uranus System (APL)

- Chiron (Centaur) Orbiter (GSFC)
- Venus near-surface mobile explorer (GSFC w/JPL spt)

Other Studies

- NEO Target Assessment (JPL)
- Saturn Ring Observer traj/tech (JPL)
- NTG fission power system (GRC w/JPL spt)

Mid CML Point Design Studies

- Titan Lake Lander (JPL)
- Io Explorer (JPL)
- Ganymede Orbiter (JPL)
- Saturn Probe (JPL)
- Enceladus Orbiter (JPL)
- Mars Polar Mission (JPL)*
- Mars Network Mission (JPL)
- Venus Climate Orbiter (GSFC w/JPL spt)
- Venus Tessera Lander (GSFC)
- Lunar Polar Volatiles Lander (APL)
- Trojan Asteroid Tour (APL)
- Uranus Orbiter (APL)
- Neptune Orbiter (APL)

Independent Cost Estimates

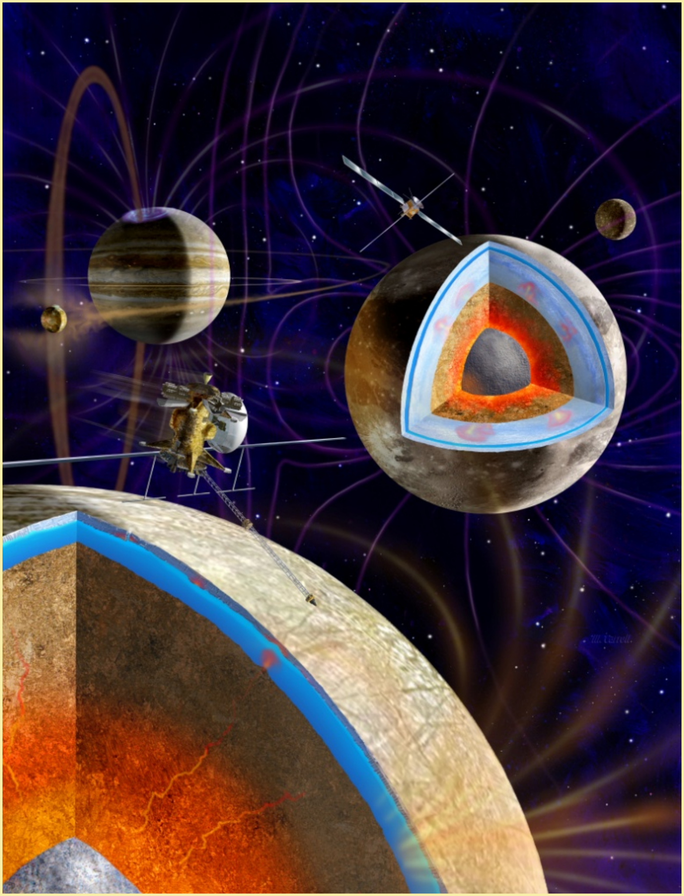
- Mars trace gas orbiter (JPL)
- MAX-C Rover (JPL)
- EJSM (JPL)
- TSSM (JPL)
- MSR Lander (JPL)
- MSR Orbiter (JPL)
- Comet surface sample return (APL)
- Lunar Network Mission (MSFC)

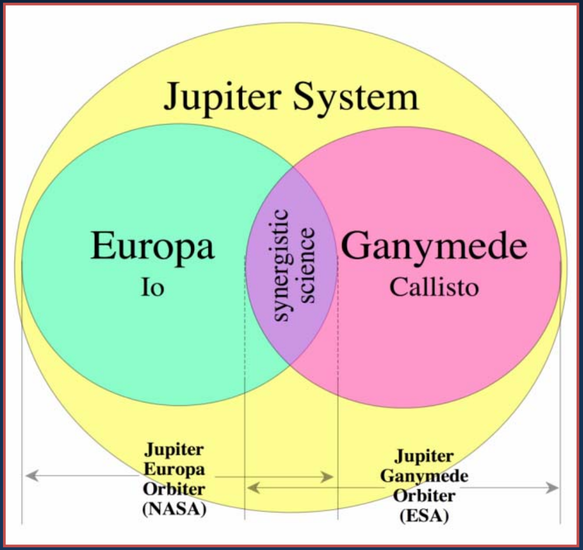
* Anticipated

POTENTIAL OUTER PLANET MISSIONS

EJSM Theme: The emergence of habitable worlds around gas giants

- NASA & ESA: shared mission leadership
- Two independently launched and operated flight systems with complementary payloads
  - Jupiter Europa Orbiter (JEO): NASA-led mission element
  - Jupiter Ganymede Orbiter (JGO): ESA-led mission element
- Mission Timeline
  - Nominal Launch: 2020
  - Jovian system tour phase: 2–3 years
  - Moon orbital phase: 6–12 months
  - End of Prime Missions: 2029
- ~10–11 Instruments on each flight system, including Radio Science





Jupiter System

Europa
Io

synergistic science

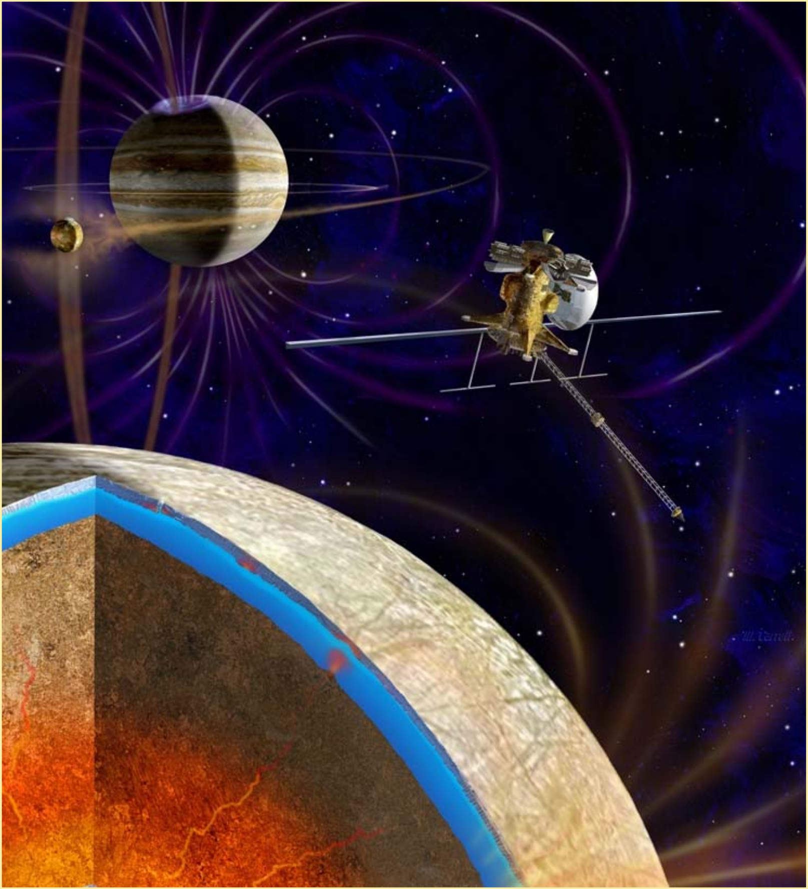
Ganymede
Callisto

Jupiter Europa Orbiter (NASA)

Jupiter Ganymede Orbiter (ESA)

For discussion and planning purposes only.

JEO Goal: Explore Europa to Investigate Its Habitability



Objectives:

- Ocean and Interior
- Ice Shell
- Chemistry and Composition
- Geology and Landing Sites
- Jupiter System
  - Satellite surfaces and interiors
  - Satellite atmospheres
  - Plasma and magnetospheres
  - Jupiter atmosphere
  - Rings

JEO would characterize the archetype of icy world habitability

JEO Model Payload

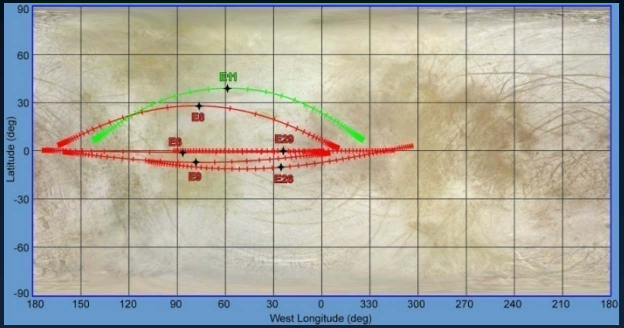
JEO Instrument	Similar Instruments
Radio Science	New Horizons USO, Cassini KaT
Laser Altimeter	MESSENGER MLA, NEAR NLR
Ice Penetrating Radar	MRO SHARAD, Mars Express MARSIS
VIS-IR Spectrometer	MRO CRISM, Chandrayaan MMM
UV Spectrometer	Cassini UVIS, New Horizons Alice
Ion & Neutral Mass Spectrometer	Rosetta ROSINA RTOF
Thermal Instrument	MRO MCS, LRO Diviner
Narrow-Angle Camera	New Horizons LORRI, LRO LROC
Camera Package	MRO MARCI, MESSENGER MDIS
Magnetometer	MESSENGER MAG, Galileo MAG
Particle and Plasma Instrument	New Horizons PEPSSI, Deep Space 1 PEPE

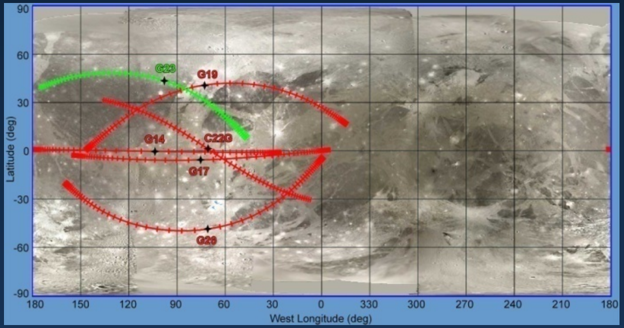
Capable model payload with a conservative approach

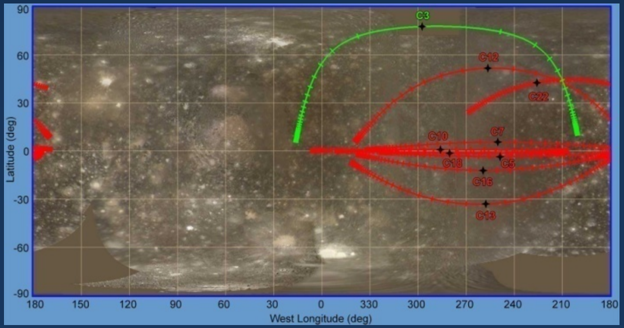
JEO Baseline Mission Overview

- NASA-led portion of EJSM, extensively studied in 2007–2008
- Objectives: Jupiter System, Europa
- Launch vehicle: Atlas V 551
- Power source: 5 MMRTG
- Mission timeline:
  - Launch: 2018 to 2022, nominally 2020
    - 6-year Venus-Earth-Earth gravity assist trajectory
  - Jovian system tour phase: 30 months
    - Multiple satellite flybys: 4 Io, 6 Ganymede, 6 Europa, and 9 Callisto
  - Europa orbital phase: 9 months
  - End of prime mission: 2029
  - Spacecraft final disposition: Europa impact
- 11 Instruments, including radio science
- 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

JEO Jupiter System Science





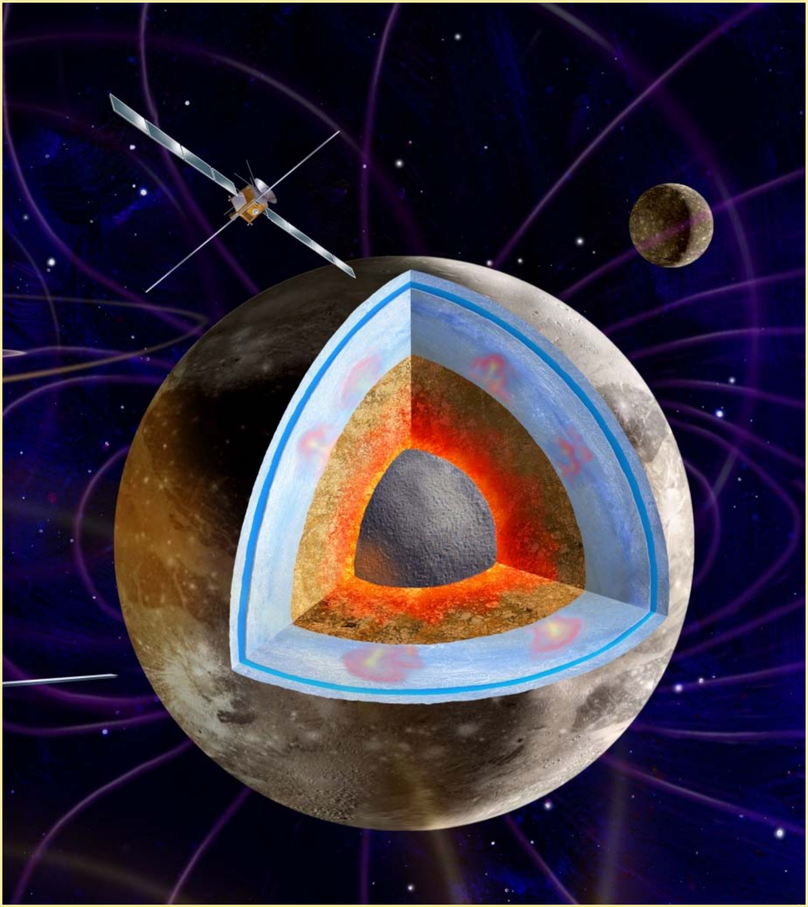


- Jupiter and Io monitoring, atmospheres, magnetospheres, rings, and small bodies
- Io: 3 flybys
  - Opportunities for imaging, IR spectroscopy, altimetry
  - *In situ* analysis of extended atmosphere with INMS at ~75 km
- Europa: 6 flybys
  - Radar and optical remote sensing characterization and calibration
  - Imaging up to 10–50 m resolution, NIR 250–1250 m
- Ganymede: 6 flybys
  - Radar and optical remote sensing of grooved and dark terrains
  - Range of lats, lons for *in situ* magnetosphere sampling
- Callisto: 9 flybys
  - High-latitude flyby for gravity field determination
  - Ocean characterization with magnetometer

Satellite	≤1000m	≤200m	≤50m	≤10m	Length IPR (km)	Length LA (km)
Io	30%	20%	5%	-	1000	7400
Europa	60%	60%	15%	0.01%	6600	19000
Ganymede	50%	50%	10%	0.02%	17000	28000
Callisto	85%	75%	5%	0.01%	15000	30000

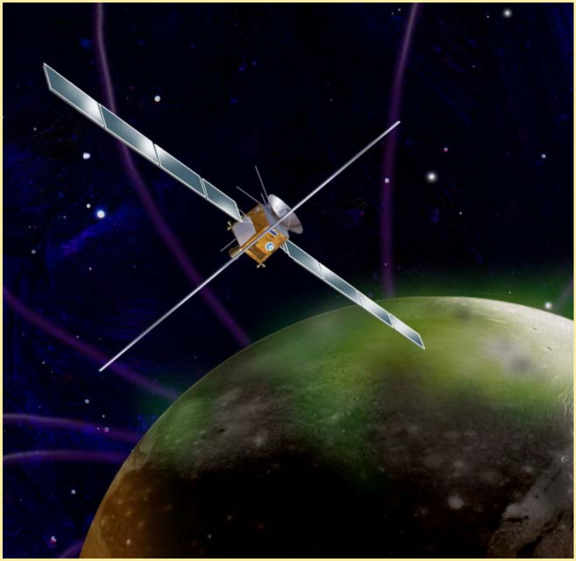
JGO Science

- Key Science Objectives
  - In-depth post-Galileo exploration of the **Jupiter system**, synergistically with JEO
    - En route to Callisto and Ganymede
  - In-depth study and full mapping of **Callisto**
    - Multiple flybys using a resonant orbit
  - Detailed orbital study of **Ganymede**
    - Elliptical orbit first, then circular orbit
- A major step forward in our understanding of the two iciest Galilean satellites, Ganymede and Callisto:
  - Ocean detection and characterisation
  - State of internal differentiation
  - Global surface mapping: geology and chemistry
  - Comprehensive study of Ganymede’s magnetism
  - Relations between thermal history, geology, oceans and the Laplace resonance



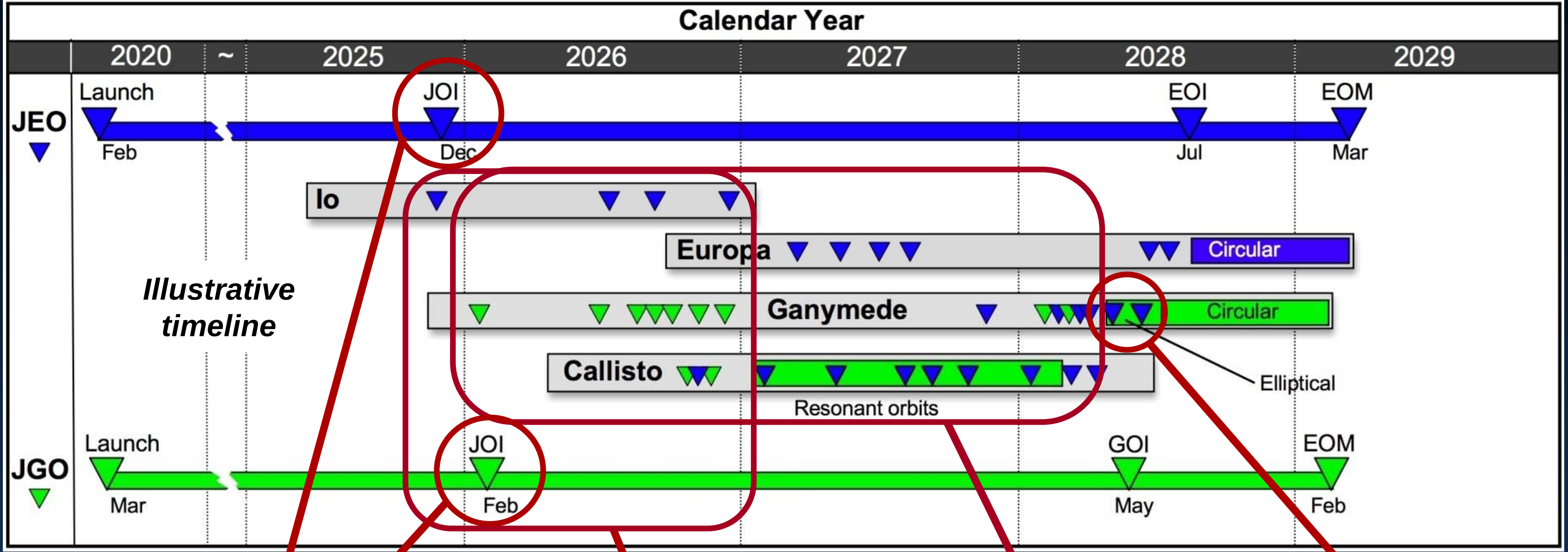
JGO Baseline Mission

- ESA-led portion of EJSM
- Objectives: Jupiter System, Callisto, Ganymede
- Launch vehicle: Arianne 5
- Power source: Solar Arrays
- Mission timeline:
  - – Launch: 2020
    - 6-year Venus-Earth-Earth gravity assist trajectory
  - – Jovian system tour phase: ~28 months
    - 9 Ganymede flybys
    - 21 Callisto (19 close flybys)
  - – Ganymede orbital phase: ~9 months
  - – End of prime mission: 2029
  - – Spacecraft final disposition: Ganymede impact
- **Radiation**: ~85 krad behind 320 mils of Al (requirement to keep below 100 krad)

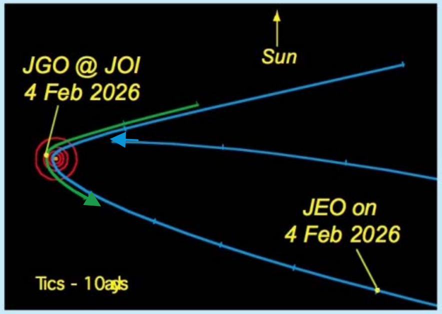


- Wide Angle and Medium Resolution Camera
- V/NIR Imaging Spectrometer
- EUV/FUV Imaging Spectrometer
- Radio Science
- Magnetometer
- Radar Sounder
- Micro Laser Altimeter
- Thermal IR Mapper
- Sub-millimeter wave sounder
- Plasma Package

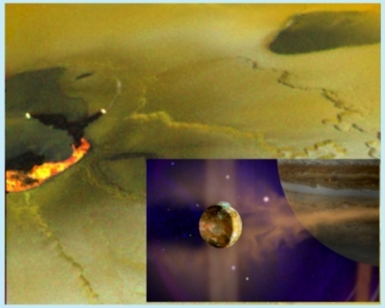
EJSM Synergistic Science



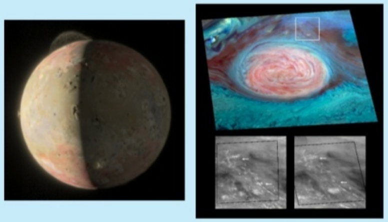
Jupiter Magnetosphere Studies



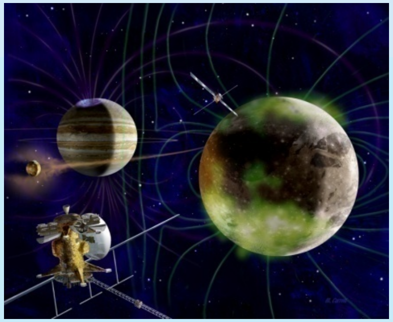
Io Volcanism & Io Torus Dynamics



Satellite/Jupiter Monitoring



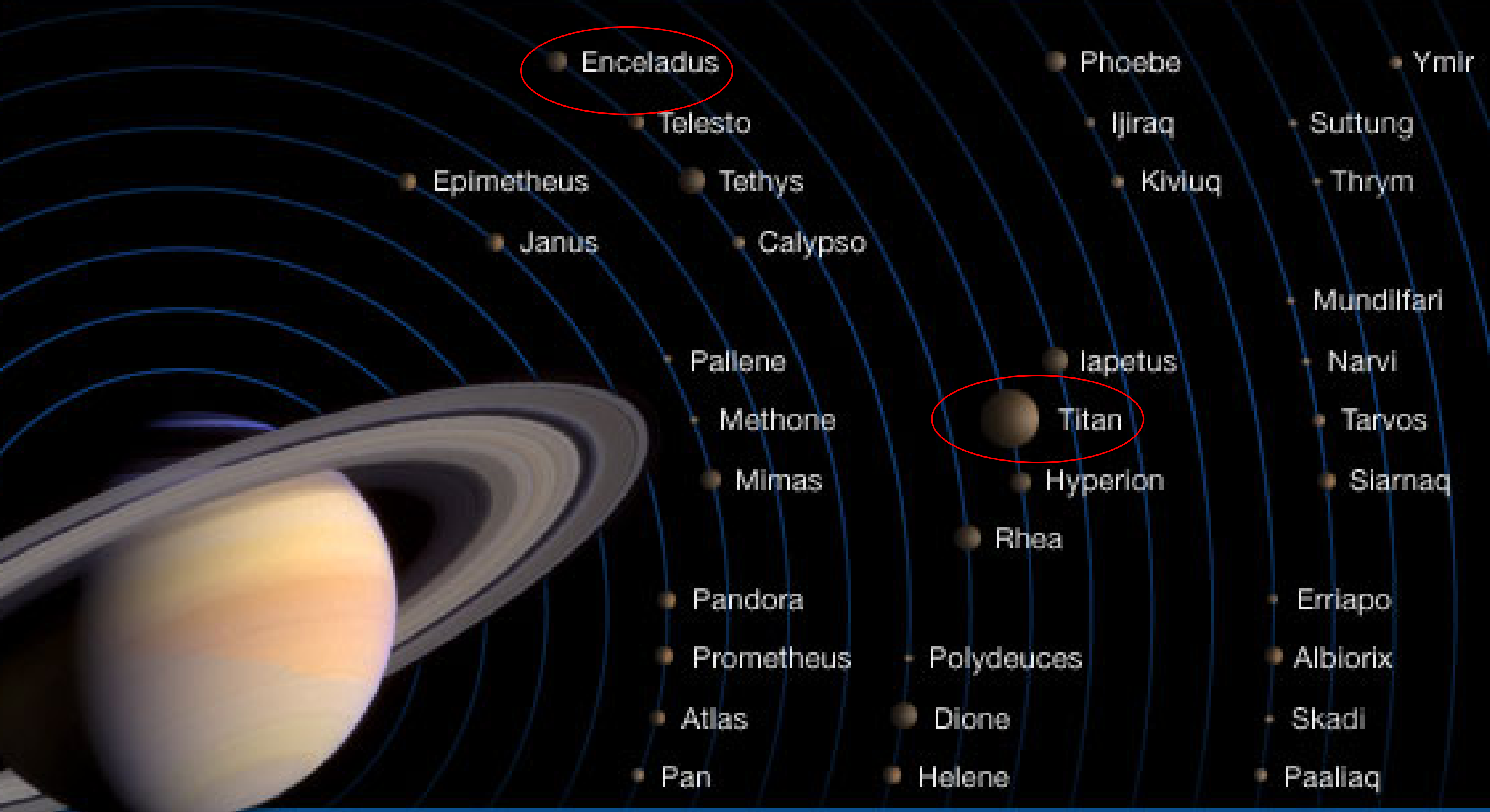
Ganymede Magnetosphere Studies



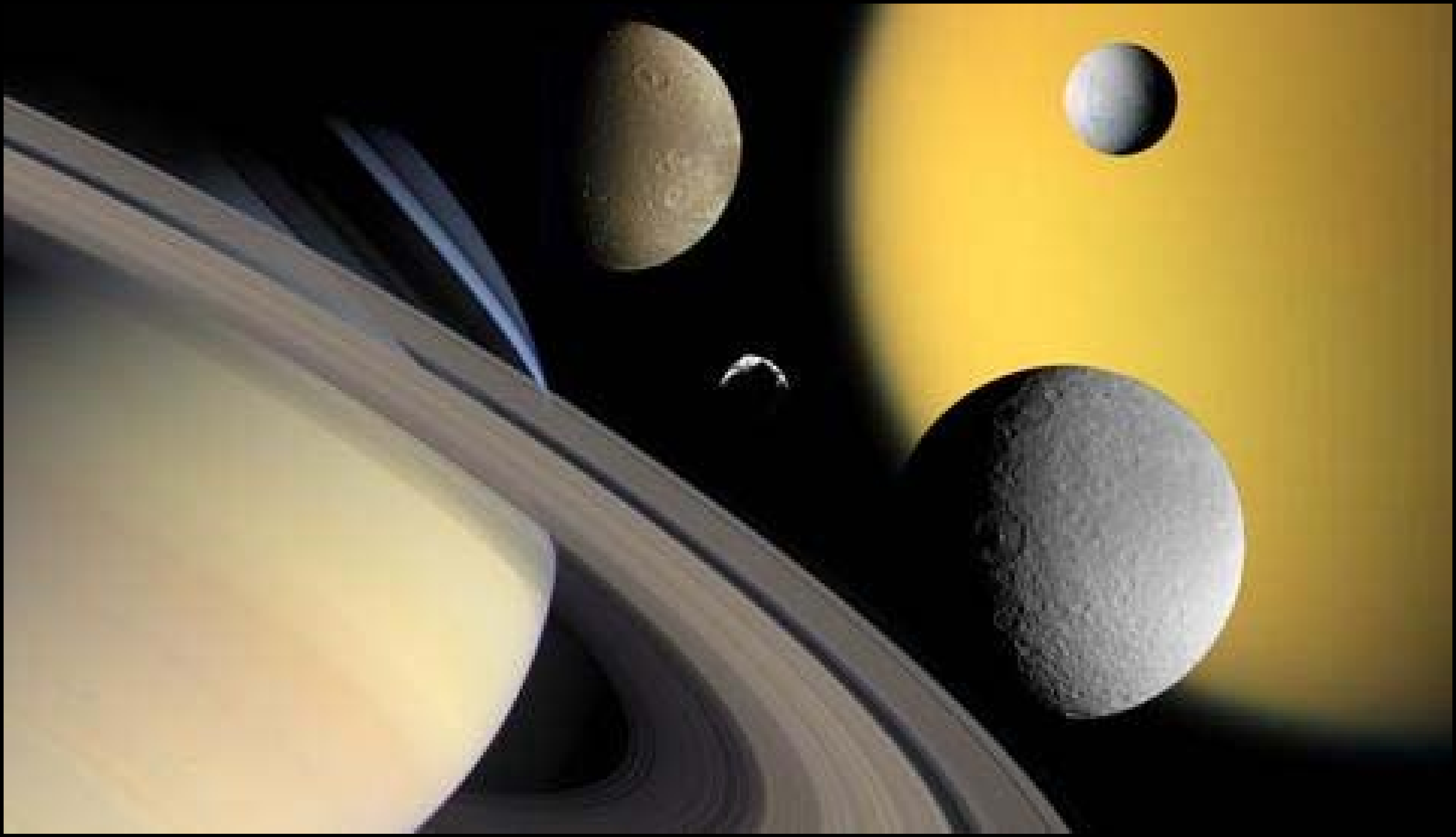
More information

- NASA and ESA are organizing the 4th Europa Jupiter System Mission (EJSM) Instrument Workshop on:
- July 26-29, 2010 at the:
- Sheraton Universal Hotel in Universal City, California.
- See http://opfm.jpl.nasa.gov/InstrumentWorkshop/ for details and updates on this workshop.

Saturn's Moons



Titan: A Moon of Saturn



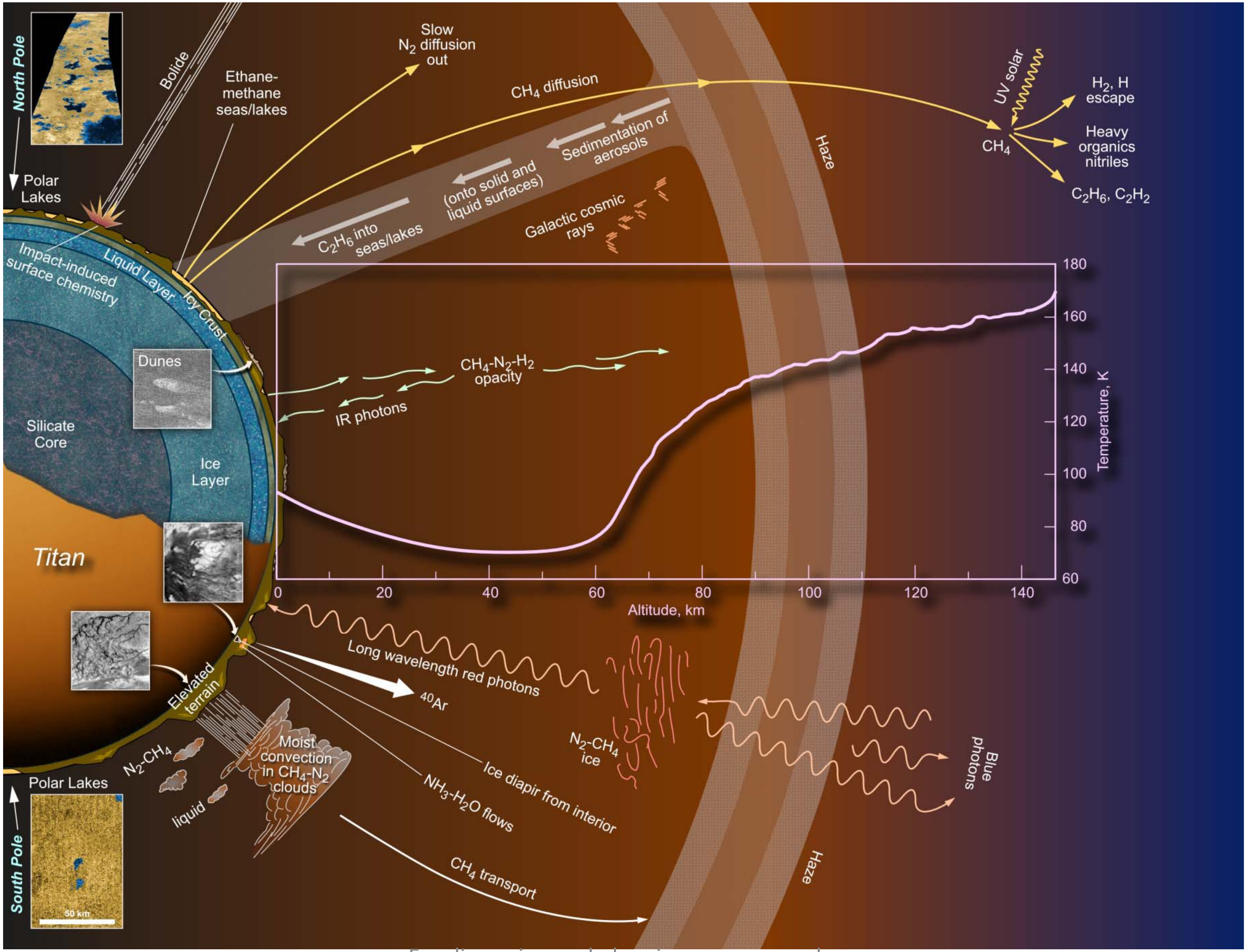
Cassini-Huygens and follow-on Titan missions

- 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

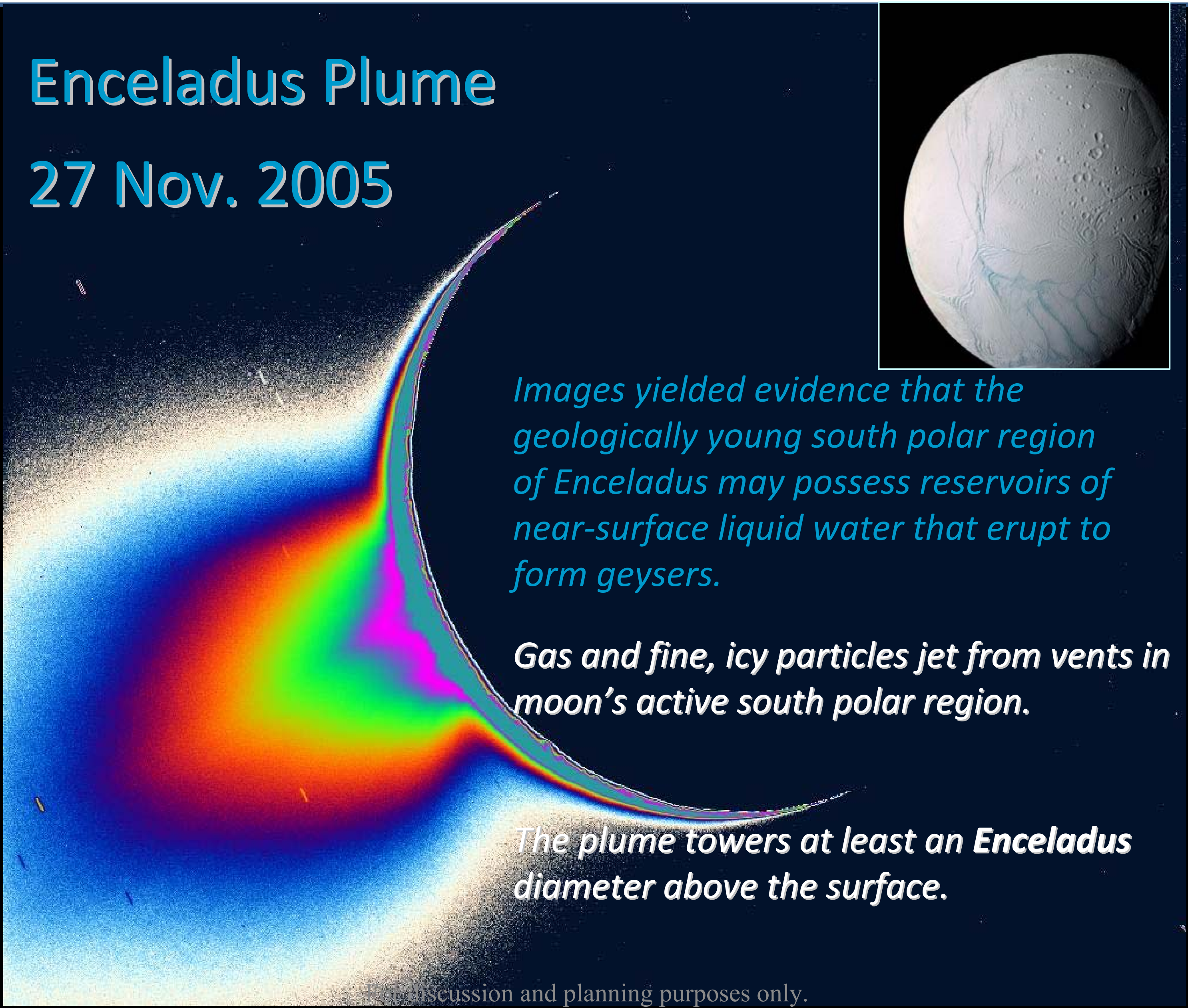
- Limits of Cassini-Huygens instruments have been reached and they cannot carry out some key investigations needed to answer new questions
  - What are Titan's lakes and seas made of? What's in them?
  - How vast and intricate are the river systems? Do they flow today?
  - Is there a vast reservoir of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

- A dedicated Titan mission can address these intriguing questions

Titan as an object is of keen interest for virtually all areas of planetary science



Water on Enceladus



Enceladus Plume

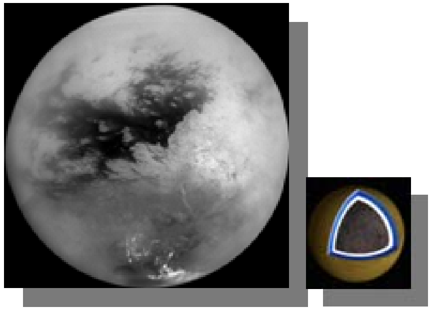
27 Nov. 2005

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.

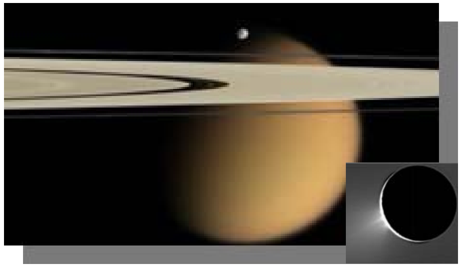
The plume towers at least an ***Enceladus*** *diameter above the surface.*

High Priority Science Questions
(established by TSSM 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?

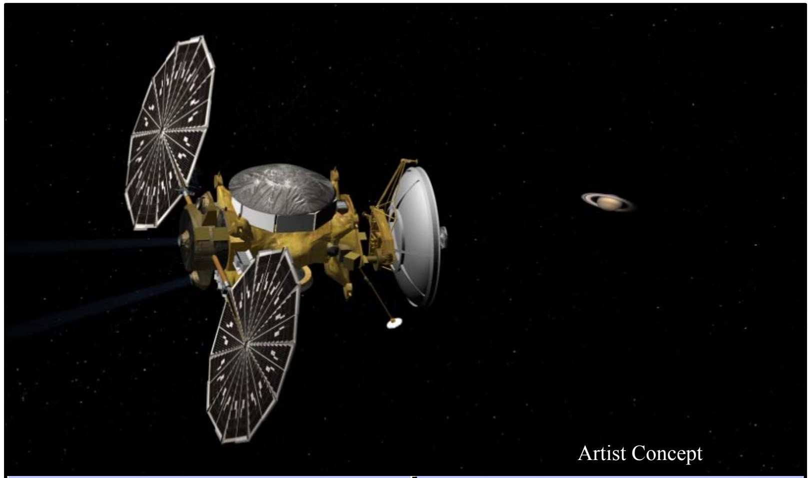
- Goal B: Examine Titan’s Organic Inventory—A Path to Prebiological Molecules
  - What kind of organic chemistry goes in Titan’s atmosphere, in its lakes and seas, and underground?
  - Is the chemistry at the surface mimicking the steps that led to life on Earth?
  - Is there an exotic kind of life—organic but totally different from Earth’s—in the methane/ethane lakes and seas?



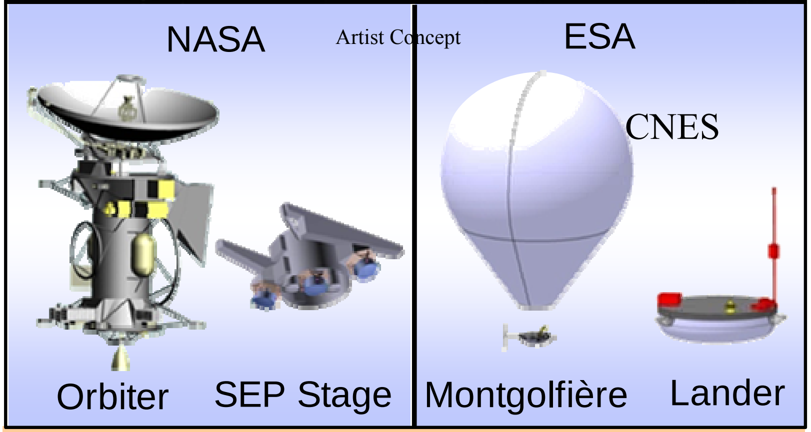
- Goal C: Explore Enceladus and Saturn’s magnetosphere— clues to Titan’s origin and evolution
  - What is the source of geysers on Enceladus?
  - Is there life in the source water of the geysers?

2008 TSSM Study 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



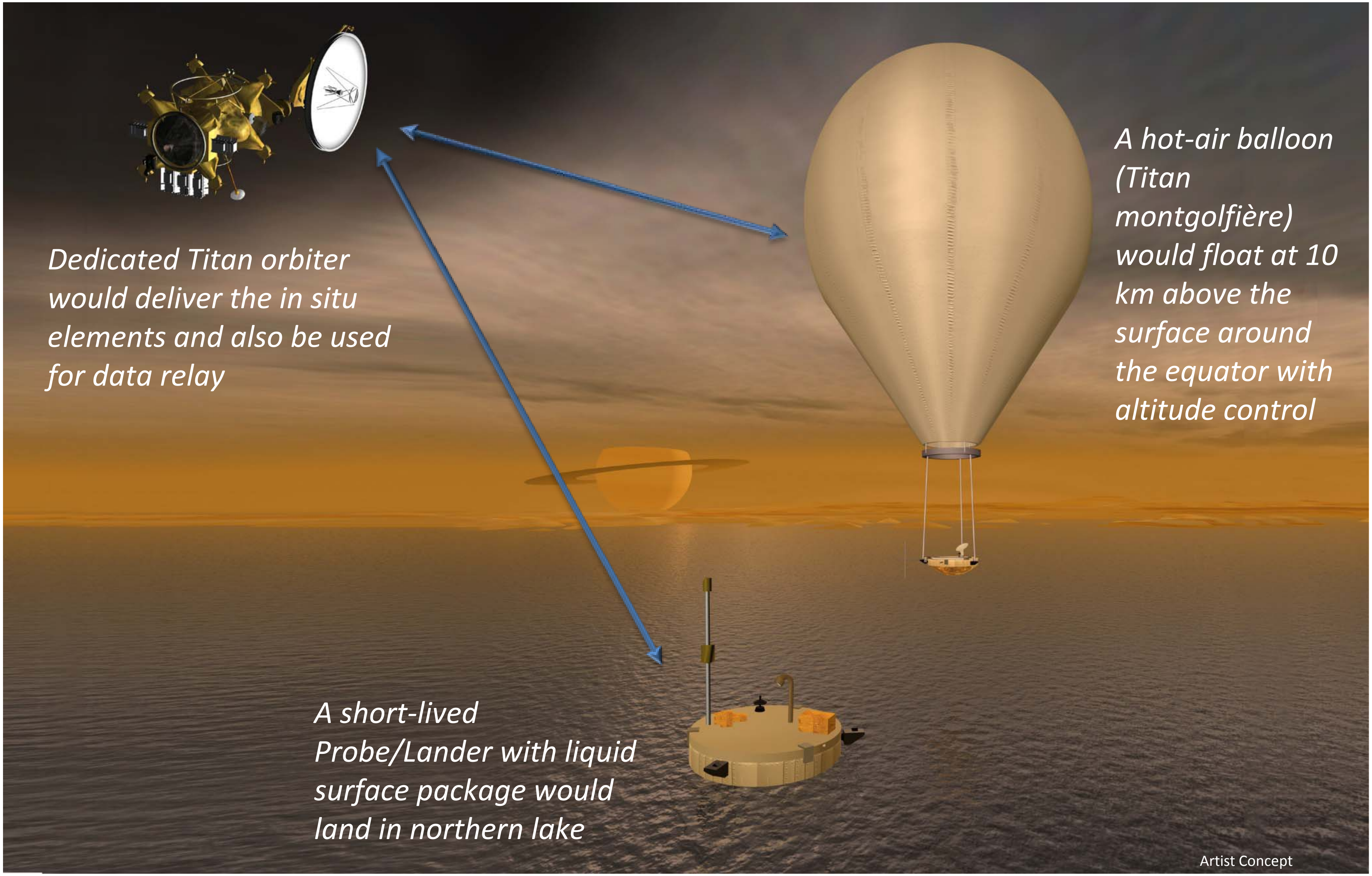
Artist Concept



Artist Concept

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

Relationship between key mission elements



Dedicated Titan orbiter would deliver the in situ elements and also be used for data relay

A hot-air balloon (Titan montgolfière) would float at 10 km above the surface around the equator with altitude control

A short-lived Probe/Lander with liquid surface package would land in northern lake

Artist Concept

TSSM Planning Payload for the NASA Orbiter

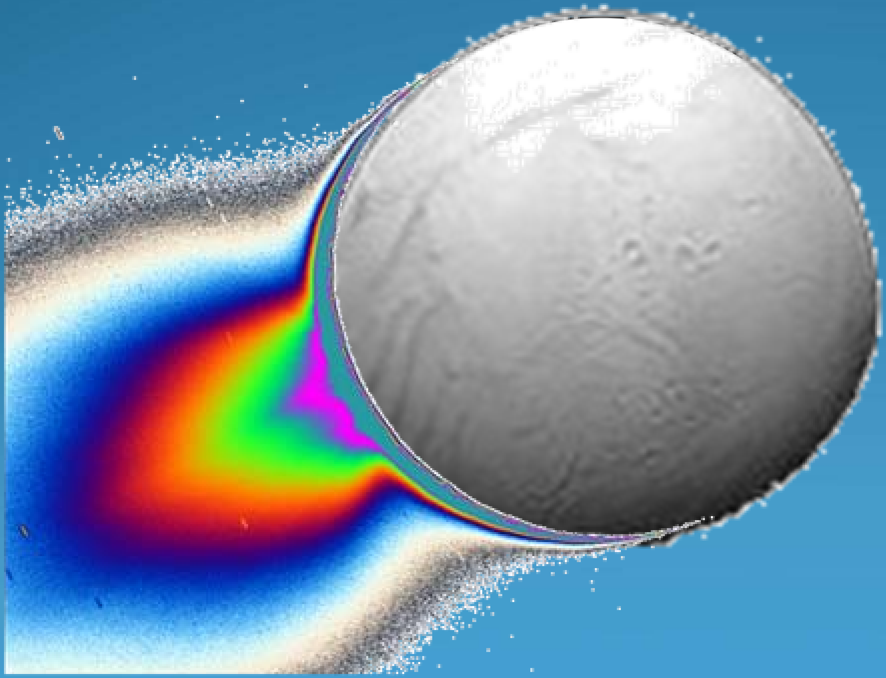
	Planning Science Instruments	Instrument Capabilities
HiRIS	High-Resolution Imager and Spectrometer (near IR)	Global surface mapping at 50 m/pixel in three colors (~2.0, 2.7, and 5–6 µm). Two spectral mapping bands 0.85 to 2.4 µm (5 nm spectral resolution) and 4.8 to 5.8 µm supporting surface/atmosphere studies
TiPRA	Titan Penetrating Radar and Altimeter	>20 MHz global mapping of subsurface reflectors with 10 m height resolution in altimetry mode and better than 10 m in depth resolution. Lower data rate depth sounding mode with ~100 m depth resolution. Approximately 1 km x 10 km spatial resolution.
PMS	Polymer Mass Spectrometer	Upper atmospheric *in situ* analysis of gases and aerosol precursors—$M/\Delta M$ ~10,000 for masses up to 10,000 Da. Focus instrument for aerosampling down to 600 km. Better than 10^4 particles/cm^3
SMS	Sub-Millimeter Spectrometer	Direct winds from Doppler and temperature mapping from ~200–1000 km altitude; CO, H_2O, nitrile and hydrocarbon profiles; heterodyne spectrometer with scanned mirror.

	Planning Science Instruments	Instrument Capabilities
TIRS	Thermal Infrared Spectrometer	Organic gas abundance, aerosol opacity and temperature mapping 30–500 km. Passively cooled Fourier Spectrometer 7–333 µm. Spectral resolution 0.125-15 cm^{-1}.
MAPP	Magnetometer	Interaction of field with ionosphere: internal and induced field.
	Energetic Particle Spectrometer	Magnetospheric particle fluxes, ~10 keV to >MeV with 150° x 15° FOV.
	Langmuir Probe	Swept voltage/current probe. *In situ* electron density and temperature, ion speed constraint, including during aerosampling.
	Plasma Spectrometer	Electrostatic analyzer system, with a linear electric field (LEF) time-of-flight mass spectrometer. Measures ion and electron fluxes at few eV to a few keV. $M/\Delta M$~10.
RSA	Radio Science and Accelerometer	Lower stratosphere and troposphere temperature profile. Gravity field. Mass and power are zero because all hardware components are part of the spacecraft bus: USO, UST, and accelerometers.

Example of a Possible Lower Cost Outer Planet mission Opportunity

LIFE

(Life Investigation For Enceladus)



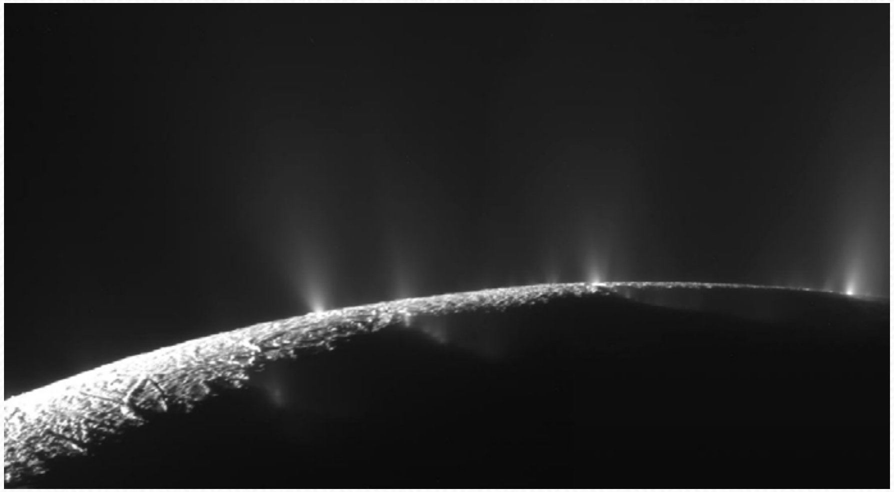
PI: Peter Tsou

Jet Propulsion Laboratory

Caltech

LIFE, Life Investigation For Enceladus

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



- Difficult for in situ instruments to determine “life” on Enceladus
- LIFE would bring samples from Enceladus to Earth’s laboratories
- LIFE would bring to “life search” as STARDUST did for comets
- LIFE could 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 would be a opportunity to catch samples by a low-cost flyby

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

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

Summary

- Outer Planet scientific community is vibrant and active
- Cassini images and data continue to amaze and Cassini Solstice mission has started and will continue until ~2017
- Significant future OP mission planning has been and is underway
  - EJSM prioritized by NASA/ESA last year
  - Awaiting Decadal Survey prioritization
- Studies also being performed for Decadal Survey for Neptune, Saturn probe, Enceladus, Titan Submersible etc.
- More information on outer planet missions: http://opfm.jpl.nasa.gov
- For details of Planetary Science Decadal Survey white papers see OPAG website: http://www.lpi.usra.edu/opag or the National Academy of Science site: http://www8.nationalacademies.org/ssbsurvey/publicview.aspx.

Traceability Matrix is the road from goals to instruments

MISSION GOALS	SCIENCE OBJECTIVES	SCIENCE INVESTIGATIONS	REQUIRED MEASUREMENTS/ DETERMINATIONS	PLANNING MEASUREMENT APPROACH	PLAN INSTR.	DATA PRODUCTS	MISSION REQUIREMENTS
Goal A: How does Titan function as a system; to what extent are there similarities and differences with Earth and other solar system bodies?	**O8:** Determine the state of internal differentiation, whether Titan has a metal core and an intrinsic magnetic field, and constrain the crustal expression of thermal evolution of Titan's interior.	**I1:** Map interior structure of Titan.	**M1:** Global gravity field to at least degree six. Doppler accurate to 50 µm/s with 60 s integration periods.	**A1:** Relative velocity between the spacecraft and ground station determined from Doppler tracking with an accuracy up to 50 µm/s with 60 s integration periods. (Ka-band link stability ~10^{-15} after all calibrations including accelerometer for non-gravitational forces).	RSA	Coefficients of spherical harmonic expansion of gravity field for further analysis and interpretation in terms of internal structure. The static degree-two gravity field will lead to constraints on the global density structure of the interior. Time variations of the degree-two field will lead to investigating the tidal response of the satellite and constraining its viscoelastic structure and crustal structure.	Prefer mapping phase orbit height of 1500 km
		I2: Determine whether Titan has a dynamo.	**M1:** Detect or set limits on the intrinsic magnetic field of Titan. Measure vector magnetic field perturbations of order a few nT (with a resolution of order 0.04 nT).Thermal and magnetospheric plasma measurements will provide supportive role with regard to external currents from magnetospheric measurements.	**A1:** Vector Magnetometry (part of a combined instrument).	MAPP	Magnetic field vector at 1 s resolution from both sensors Ion and electron thermal and suprathermal velocity moments of density, temperature and magnetosphere-ionosphere winds.	Continuous measurements, globally distributed at varying altitudes. Knowledge of orbiter attitude and location, and a rigid magnetometer boom. Consideration of magnetic cleanliness requirements vs. boom length.
Goal B: To what level of complexity has prebiotic chemistry evolved in the Titan system?	**O1:** Determine the processes leading to formation of complex organics in the Titan atmosphere and their deposition on the surface.	**I1:** Assay the speciation and abundances of atmospheric trace molecular constituents.	**M1:** Abundances of monomer and polymer organic species and inorganic species with a detectability of <1 ppb and an accuracy of better than 3% over an altitude range from 30–1500 km.	**A1:** Passive Thermal-infrared Fourier Transform spectrometry, in the region from 30–1400 wavenumbers (7–333 µm); resolution 0.1–3.0 wavenumber.	TIRS	Thermal and compositional maps and profiles of the stratosphere (50–450 km) with altitude and latitude	Limb and nadir viewing on polar orbit, rotation in
				A2: Submillimeter sounding at 540–640 GHz with resolution 300 khz and 10% precision in retrieved abundances.	SMS	Alt/lat maps of selected organics	Limb viewing from polar orbit, in-track and off-track orientation