

2002 Decadal Survey Large Satellites Panel Progress to 2007 mid-term review and 2009 retrospective to new Satellites panel

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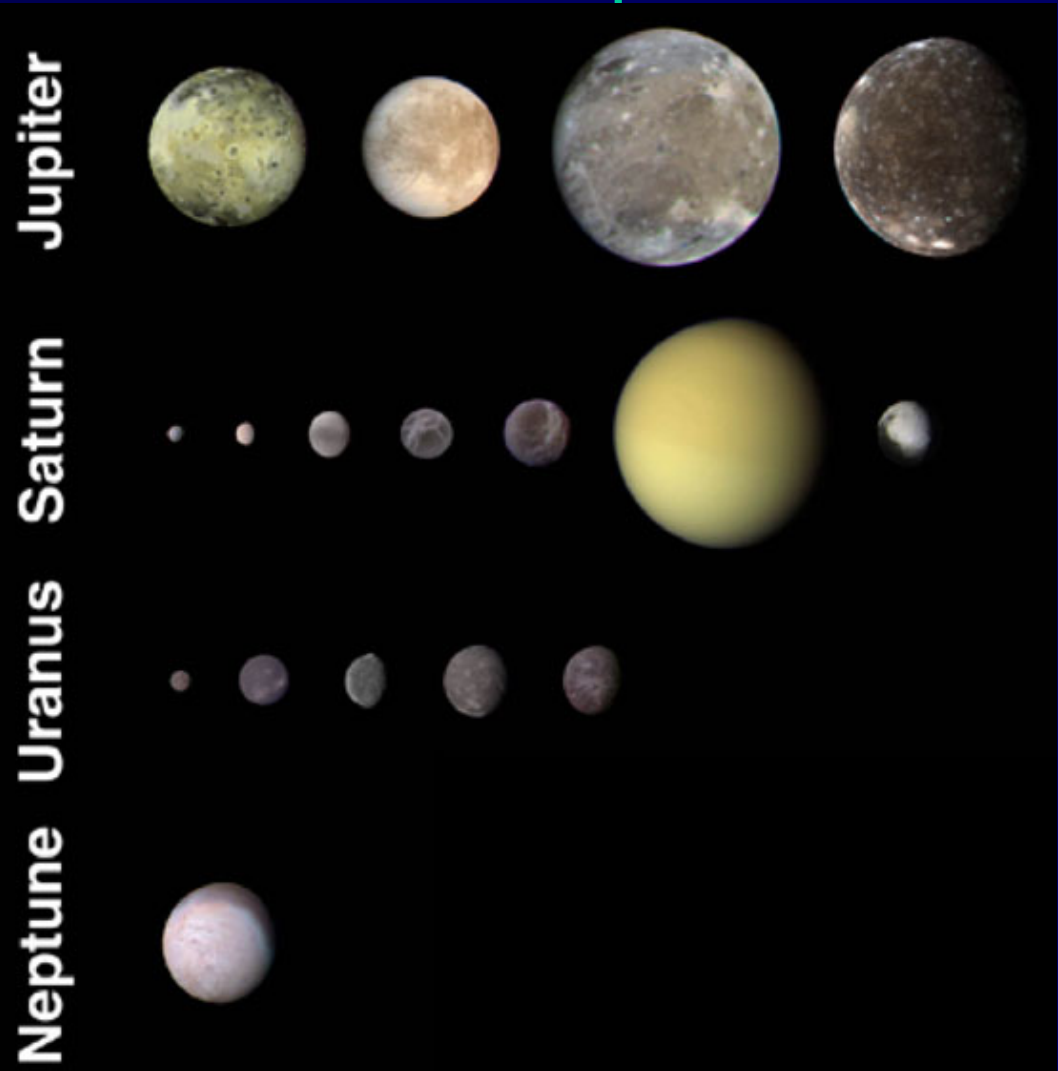
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LSP focused on the
Galilean satellites,
Titan, Triton





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Active Worlds and Extreme Environments

Scientific themes:

- A) Origin and evolution of satellite systems
- B) Origin and evolution of water-rich environments in icy satellites
- C) Exploring organic-rich environments
- D) Understanding dynamic planetary processes



Theme A: Origin and Evolution of Satellite Systems

Origins and orbital dynamics

Interiors

Surface chemistry

Geological processes

Atmospheric chemistry

Magnetospheric interactions



Theme A: Key Questions

How do conditions in proto-planetary nebula influence compositions, orbits, and sizes of resulting satellites?

How do factors such as size, composition, orbital evolution, and tidal heating influence differentiation and outgassing? (Why does only Titan have a thick atm.?)

To what extent are the surfaces of icy satellites coupled to their interiors (chemically and physically)?

How has the outer solar system impactor population evolved through time, and how is it different from the inner solar system?

What does the magnetic field of Ganymede tell us about its thermal evolution, and do other large satellites have intrinsic magnetic fields?



Theme A: Future Directions

Earth-based observations

Orbital dynamics; activity monitoring

Remote sensing missions

Surface processes; surface chemistry; interiors;
atmospheric chemistry; magnetospheric interactions

Landed missions

Surface characterization; geophysical studies

Theoretical studies

Orbital dynamics; accretion; differentiation; heat
transport; tidal deformation and dissipation



Theme B: Water-rich Environments in Icy Satellites

Interior models

Link to geologic processes

Link to surface chemistry
and atmospheres

Magnetospheric interactions



Theme B: Key Questions

Can and does life exist in the internal ocean of an icy satellite?

What combination of size, energy sources, composition, and history produce long-lived internal oceans?

What is the distribution of internal water, in space and time?

What is the chemical composition of the water-rich phase, and does surface chemistry reflect interior ocean composition?



Theme B: Future Directions

Europa is a compelling target for detailed exploration

Evidence for relatively shallow water

Ocean-surface communication on some timescale

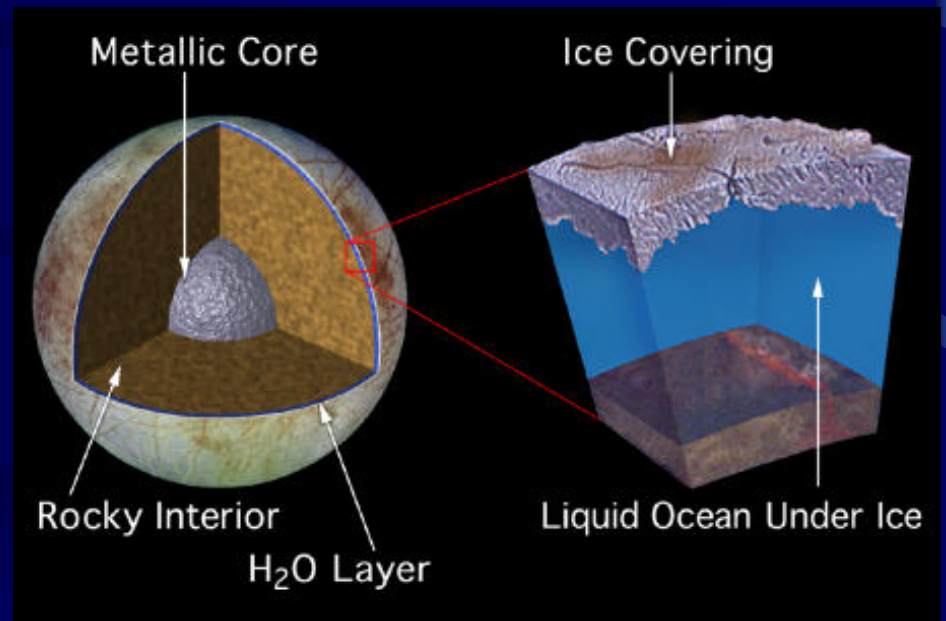
Water may contact silicate mantle

Youthful surface (active?)

Orbital science

Landed missions

Theoretical studies





Theme C: Exploring Organic-Rich Environments

Titan

Interior

Geological processes

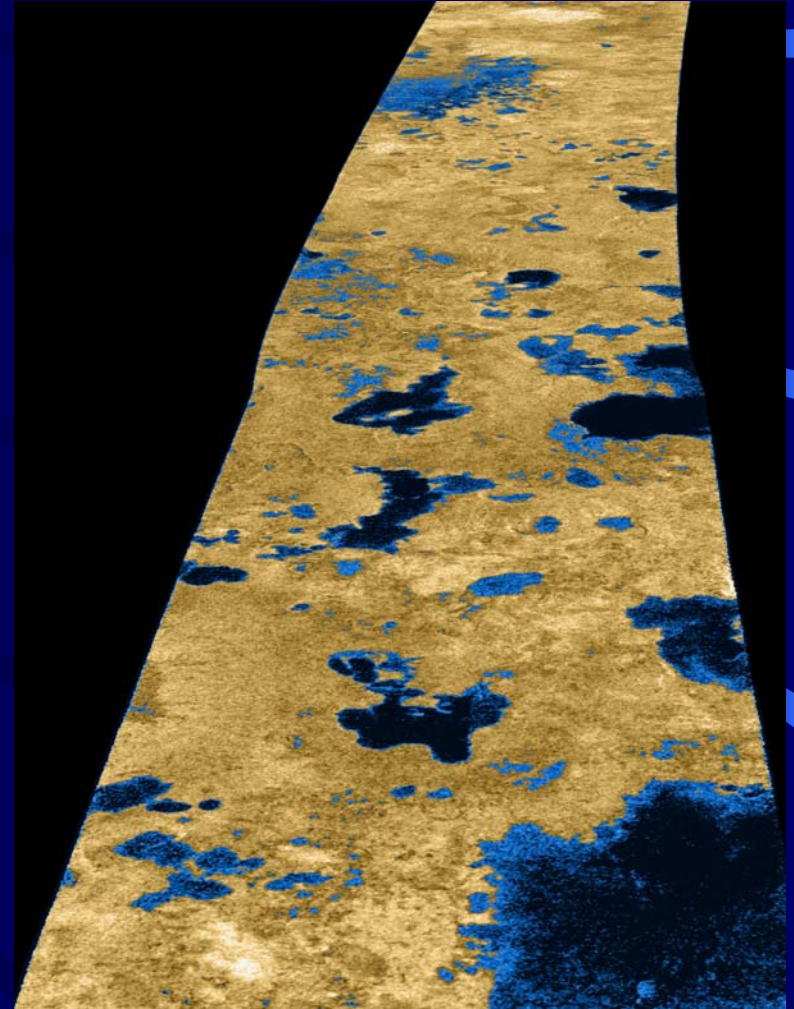
Surface chemistry & atmosphere

Magnetospheric interactions

Other organic-rich satellites

Iapetus

Triton





Theme C: Key Questions

What is the chemistry, distribution, and cycling of organic materials on Titan?

Is Titan internally active, producing water-rich environments with potential habitability?

What is the current state and history of Titan's surface?

What drives Titan's meteorology?

Has there been climate change on Titan?

Could Titan support life that does not require water?



Theme C: Future Directions

Cassini

What we expect to learn

What we don't expect to learn

Ground-based observations

Orbital science

Airborne and landed science



Theme D: Understanding Dynamic Planetary Processes



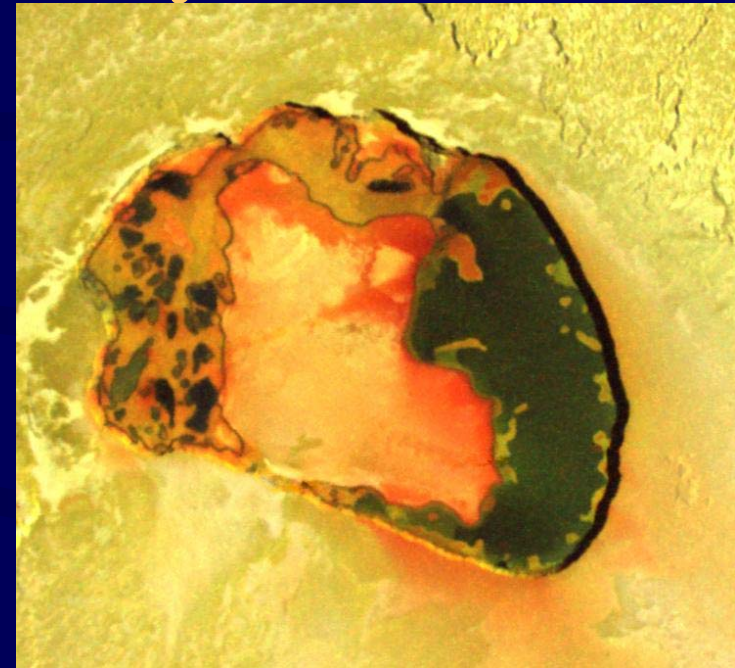
Io, Titan, Triton

Interior

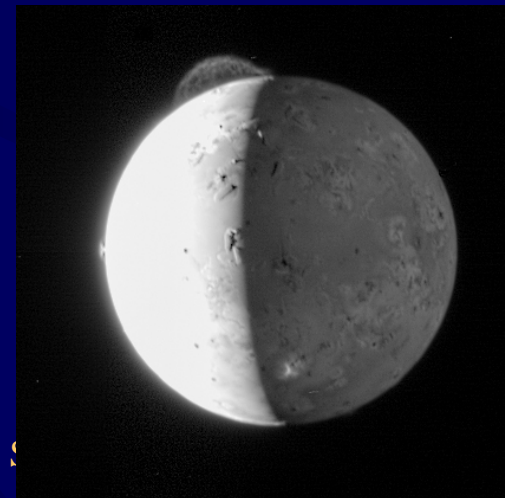
Geological processes

Surface chemistry & atmosphere

Magnetospheric interactions



Europa, Ganymede, Enceladus also
important targets for Theme D





Theme D: Key Questions

What are the active interior processes and relationships to tidal heating, heat flow, and global patterns of volcanism and tectonism? (Does Io have a magma ocean?)

What are the currently active endogenic geologic processes (volcanism, tectonism, diapirism) and what can we learn about such processes from these active worlds? (What can Io tell us about ancient volcanism on terrestrial planets?)

What are the complex processes and interactions in the surfaces, and in volcanic or geyser-like plumes, atmospheres, exospheres, magnetospheres? (What can we learn about meteorology from Titan and Triton?)

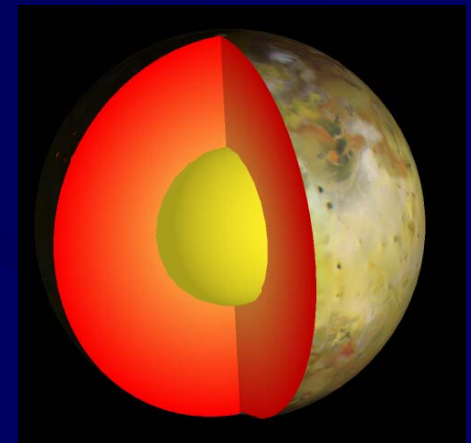
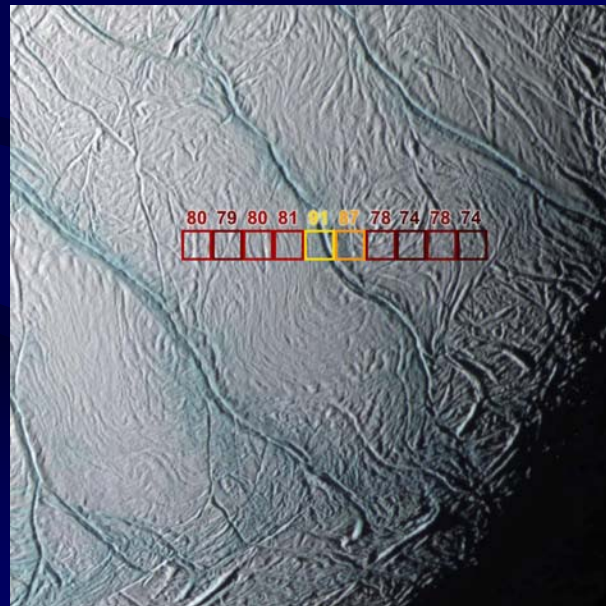
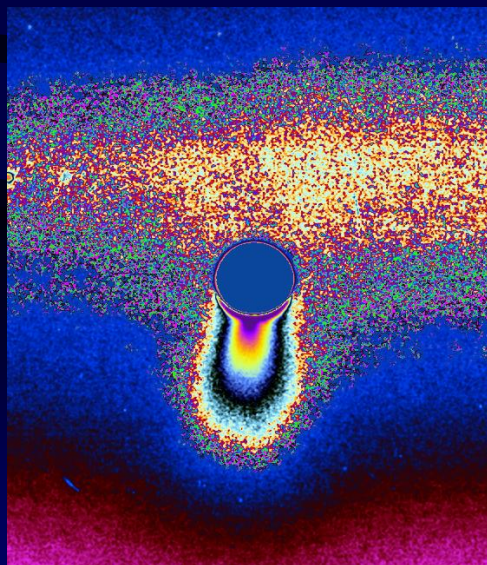


Theme D: Future Directions

Earth-based observations

Orbital science

Landed (probe) science





Candidate Missions

High cost

Europa Orbiter (with Jupiter system science)

Tech: radiation-tolerant electronics

Titan Explorer (with *in situ* organic chemistry lab)

Tech: atmospheric mobility; analysis techniques for organics

(We assumed this required a high-cost mission.)

Europa Lander ("Pathfinder" or "Astrobiology Lander")

Tech: lander; sample retrieval & analysis methods; planetary protection

Neptune Orbiter

Tech: advanced propulsion and aerocapture

Uranus Orbiter



Candidate Missions (cont.)

Medium cost

Io Observer

Inclined Jupiter orbit with polar passes of Io to minimize radiation dose and compatible with studies of magnetosphere, Jupiter's aurora, rings

Equatorial orbiter compatible with study of other satellites

No orbit found to be compatible with Giant Planet Panel top priority (deep Jupiter)

Ganymede Orbiter

Neptune Flyby



Observation and Measurement Objectives

Table 2 of report links key questions for each theme to measurement objectives, and ranks candidate missions

Europa orbiter and landers, Titan Explorer, Neptune Orbiter, and Io Observer score high

Neptune Orbiter (with many Triton flybys) far better than Neptune Flyby (more than snapshot; search for subsurface water via induced magnetic field)

Tendency to highly rank poorly-defined missions due to optimistic assumptions.



Highest-Priority Questions

Is there extant life in the outer Solar System? (Are we alone?)

How far towards life does organic chemistry proceed in extreme environments? (Where did we come from?)

How common are liquid layers within icy satellites?

How does tidal heating affect the evolution of worlds?



The Potential of Europa

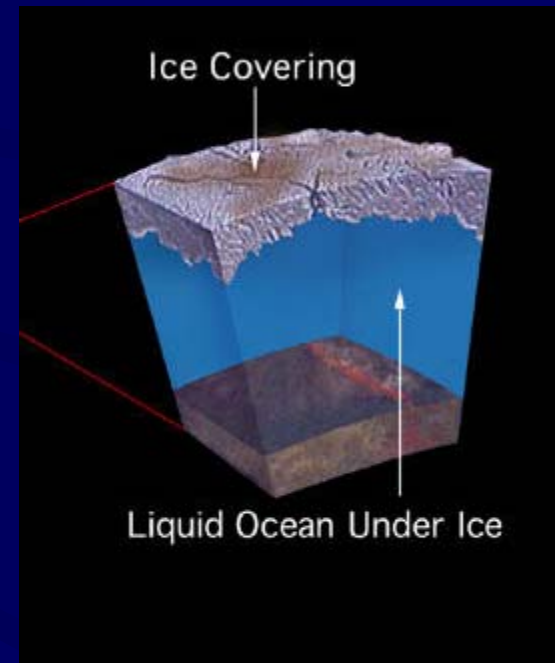
Europa exploration addresses science themes and highest priority questions

Themes A, B, D; maybe C

Three or four highest-priority questions

COMPLEX assigned "the future exploration of Europa a priority equal to that for the future exploration of Mars" (COMPLEX, 1999, A Science Strategy for the Exploration of Europa)

Ganymede or Callisto are not substitutes (less communication of water with surface or silicate core)





Europa Orbiter Science Objectives Remain Top Priorities

Europa Orbiter SDT Group 1 Objectives:

Determine the presence or absence
of a subsurface ocean

Characterize the three-dimensional
distribution of any subsurface liquid
water and its overlying ice layers

Understand the formation of surface
features, including sites of recent or
current activity, and identify candidate
landing sites for future lander missions





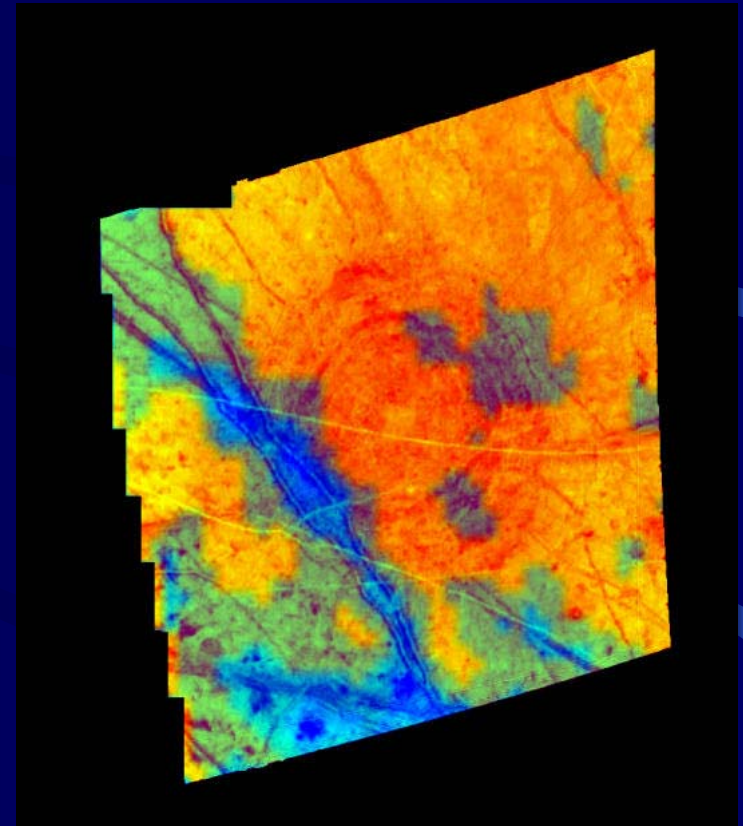
Europa Orbiter Science Objectives Remain Top Priorities

Europa Orbiter SDT Group 2 Objectives

Characterize the surface composition, especially compounds of interest to prebiotic chemistry

Map the distribution of important constituents on the surface

Characterize the radiation environment in order to reduce the uncertainty for future missions, especially landers





LSP Recommendation: Europa Exploration

Europa Orbiter with Jupiter system science is strongly recommended next step

EO Group 1 and 2 science objectives are compelling

Orbiter is required to achieve all of these objectives

Jupiter system science is critical context

Drop-off lander is an attractive augmentation

But additional cost; planetary protection uncertainties

Orbiter should be followed by a lander

Physical, chemical, and biological studies



Titan Next Step: Questions & Measurement Goals

How far has Titan's organic chemistry progressed?

- Stratospheric photochemistry

- Long-term chemical evolution at the surface, especially where exposed to water

How does Titan's liquid cycle manifest itself?

- State of surface liquids

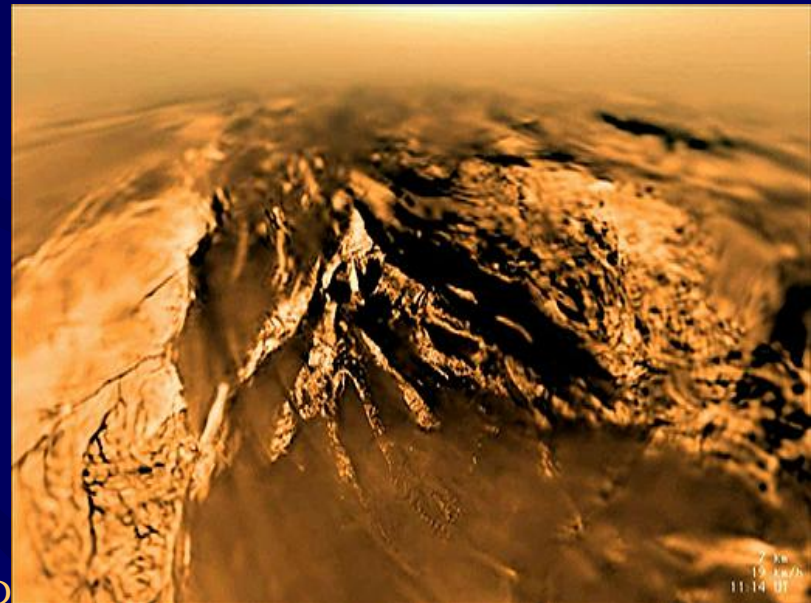
- Geological activity

- Thermal profile, humidity, and stability

- Circulation

What is the state of Titan's interior?

- liquid water; exotic ices





Titan Next Step: Questions & Measurement Goals (cont.)

What is the origin and evolution of Titan's atmosphere?

Nitrogen: atmospheric Ar content

Methane: lakes or present geological activity?

Atmosphere: old or new (crater record)

What causes Titan's super-rotating winds?

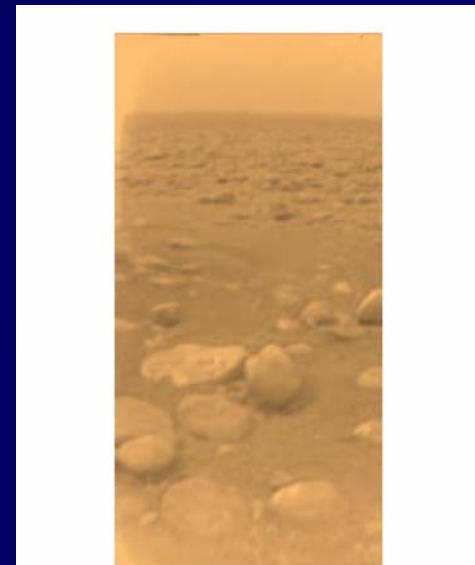
Opacity structure of particles and gases

Wind profiles, waves, and temperature fields

Seasonal variations

What is Titan's geologic history?

Context of other icy satellites





LSP Recommendation: Post-Cassini Titan Exploration

Titan Explorer is a vital Cassini-Huygens follow-up

Analyze heterogeneous surface organic chemistry

In situ studies of surface geology

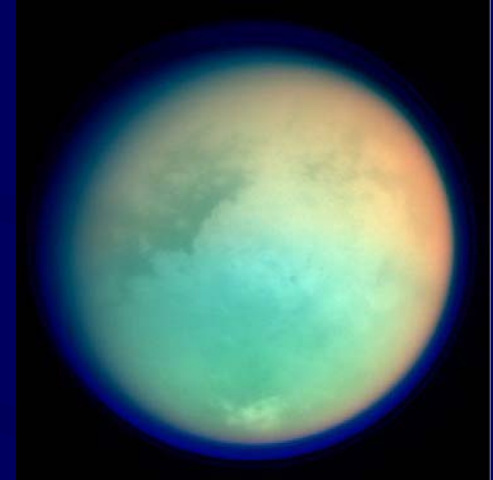
Atmospheric structure over latitude

Examine liquid cycling & cloud formation

Several viable exploration concepts

Lander, aerobot, helicopter?

Didn't consider a "splasher"



Titan exploration addresses 3 of 4 highest-priority questions
and all 4 themes.

Should be placed high in mission queue

Await Cassini-Huygens results to choose the 'best' platform and
mission scenario



LSP Recommendations: Science Priorities

Titan may prove to have a science priority equal to that of Europa

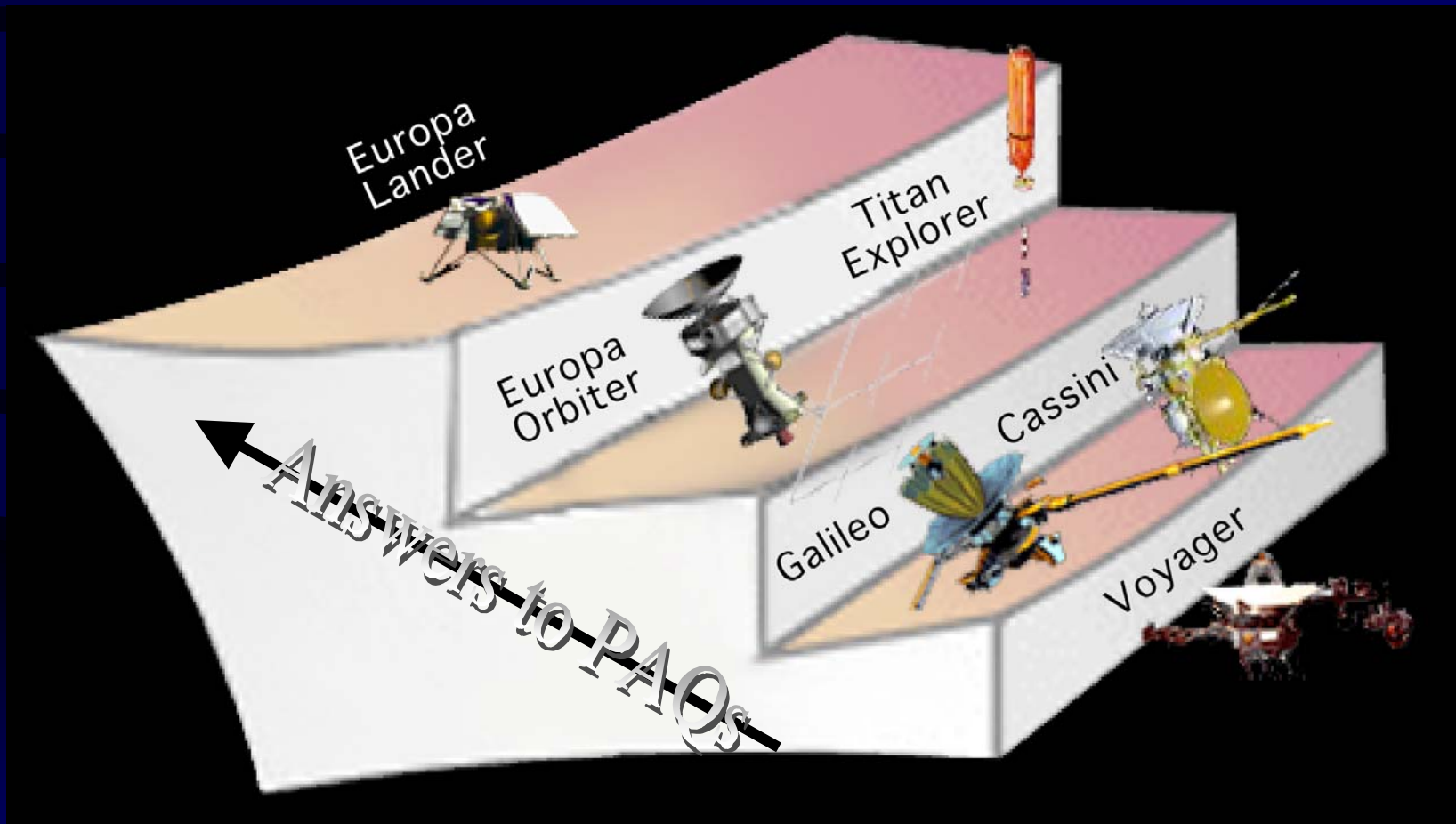
Exploration addresses science themes and highest-priority science questions

Exploration should proceed in a *systematic stepped program*

Io and Triton are also of high science priority



LSP Recommendation: Stepped Europa-Titan Exploration





LSP Recommendation: Io and Triton Exploration

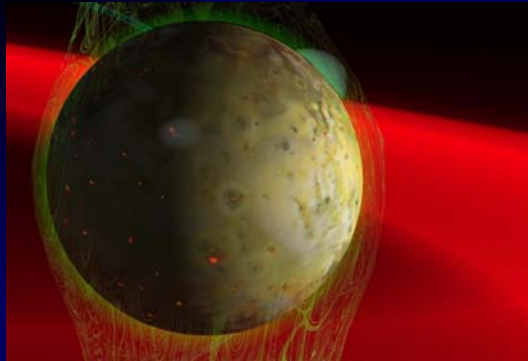
Jupiter Orbiter with multiple Io fly-bys (#1 medium-cost mission)

Achieves goals at Io and other parts of Jupiter system

Neptune Orbiter with multiple Triton fly-bys

Achieves goals at Triton and other parts of Neptune system

Primitive Bodies panel recommended a Neptune/Triton flyby with Centaur or KBO flyby (#5 of medium-cost missions). LSP recommended Neptune Orbiter with multiple Triton flybys (#3 of high-cost missions).





LSP Mission Recommendations and Cost Categorization

High cost:

Europa Orbiter
(Groups 1&2;
Jupiter system
science)

Titan Explorer
(scenario TBD)

Neptune Orbiter
(multiple close
Triton encounters)

Moderate cost:

Io Observer

Ganymede Orbiter

(Both missions simply assumed
to be moderate cost)

Low cost:

Enhanced/extended Cassini

Part of GSMT

or other ELT



LSP Recommendation: Ground-Based Exploration

Ground-based observations are required to:

- Understand long-term seasonal response of Titan and Triton

- Observe sporadic & infrequent massive cloud systems on Titan

- Monitor active volcanism on Io

Large telescopes (10 meter GSMT) are necessary

- Light gathering capabilities needed for high spectral resolution compositional and Doppler information

- Spatial resolution needed to study variations in Io's volcanic surface, Titan's clouds, Triton's surface



LSP Recommendation: Cassini Enhanced and Extended Missions

Cassini/Huygens is a highly capable mission, the likes of which we may not see again for decades in the outer Solar System

Nominal mission science analysis is not adequately funded
Extended mission has great potential which should be fully exploited

Adequate funding of Cassini is far more cost effective for science than any new mission



New Technology Recommendations

1. Radiation-hard electronics (for Europa, Io)
2. Advanced telemetry and power (for all deep-space missions)
3. Atmospheric mobility (for Titan Explorer)
4. Compact organic chemistry lab (for Titan Explorer and Europa lander)
5. Planetary protection (for Europa lander)
6. In-situ age dating (for Titan Explorer and Europa Lander)
7. Advanced propulsion and aerocapture (for Neptune Orbiter)



New Technology Retrospective

We should have given more emphasis to deep space communication. Full Decadal report says:

In the area of spacecraft communications it is assumed that current development of Ka-band capability and antenna arrays will mature in the early years of this decade. The next most important step is development of optical communications for a major leap forward in communications bandwidth, particularly for video-rate communications from Mars and for advanced exploration in the outer solar system.

The assumption about maturation has proven false, and this is currently a major handicap to exploring the outer SS. Only single 34 m antennae are expected post-NH. X-band is required for contingency/safe modes in outer SS, so Ka is added cost and mass, not affordable to low/moderate cost missions. High-power TWTAs are difficult to accommodate due to power limits. New outer SS missions of low-moderate cost are left with little choice but to live with low data rates.

2002 Survey report did say good things about upgrading DSN on P. 379, but NASA didn't follow this advice.



Far Future (20+ years)

Nuclear Electric Propulsion could enable:

- Sequential orbits of Callisto, Ganymede, and Europa
- Titan sample return

NEP not needed for an orbiter around Europa

Decadal steering committee report more positive towards NEP





NEP warning in LSP report

Although the technology recommendations above follow logically from our science and mission rankings, technologies may be developed for other reasons. For example the administration's FY 2003 budget proposal includes funding for nuclear-electric propulsion. Once nuclear propulsion is developed, this capability would then open up new mission possibilities, such as a spacecraft that could sequentially orbit all three icy Galilean satellites. Why not postpone Europa Geophysical Explorer until nuclear electric propulsion is available? There are several good reasons not to postpone this important mission. First, nuclear electric propulsion is not expected to be ready for an actual mission for at least 10 years, and we consider Europa exploration too scientifically important to postpone for a decade. Second, an orbiter around Europa is far more important for our key objectives than orbiters around Callisto or Ganymede because the tides are much larger (i.e., measurable via altimetry) and because Europa's ice shell is significantly thinner (permitting radar sounding).

Our warning went unheeded but we were right (JIMO just delayed a realistic mission).



Additional Recommendations

Extended missions

Maintain existing Earth-based
telescopic programs

Data analysis / R&A

Infrastructure



Large Satellites Panel Recommendations: Summary

Europa exploration should be among the highest mission priorities of the Decadal Survey Steering Committee

Titan exploration may merit a science priority equal to that of Europa, but it is (or was) premature to define the 'best' Cassini-Huygens follow-on mission

Io Observer (Jupiter orbit) and Neptune Orbiter (with many Triton flybys) should have high priorities in the mission queue

Enhanced/extended Cassini and Earth-based telescopic programs are highly cost-effective and must be supported



Progress Since 2002

Europa

Studies, no new start (Flagship missions given a “D” in final report)

JIMO was a setback

Technology development

Significant progress has been realized in low-power, low-mass and high-speed science instruments

Cassini

Ambitious extended mission plan with emphasis on Titan and Enceladus

CDAP

R&A and ground-based observing have continued



Recommendations LSP Might Make in 2007

1. Flagship Mission: Europa Orbiter
+ Plan ahead for Titan, Neptune Orbiter,
Enceladus?
2. Open New Frontiers to Io, Ganymede,
Enceladus
3. Support Cassini extended mission plan
4. Support R&A, ground-based observing



Additional Recommendations LSP might make in 2009

- Study (and cost) NF-class missions to Titan, Enceladus, and Neptune/Triton along with Io and Ganymede
- Study and cost potential Discovery+ missions to outer planets moons (as recently done with DSMCE)
- Continue to address radioisotope power and other technologies
- Don't assume NASA will do sensible things (e.g., maintain DSN or mature new technologies like Ka-band for the outer SS)
- Implement arrays of small antennae for X-band downlink and/or procedures for low-risk use of Ka and/or optical comm.
- Support second Cassini extended mission



How to Improve LSP Process

More time for deliberations (and don't have another 9/11)

Cost estimates

The higher the fidelity the better, but anything is better than the null set we had in 2002 (or is it?)

Greater emphasis on technology *maintenance* as well as new development

Greater consideration of mission concepts that contribute to the science of multiple subpanels and other Decadal groups like Astrophysics and Heliospheric/Space Physics.