Future Exploration of the Outer Planet Satellites: A Decadal Perspective

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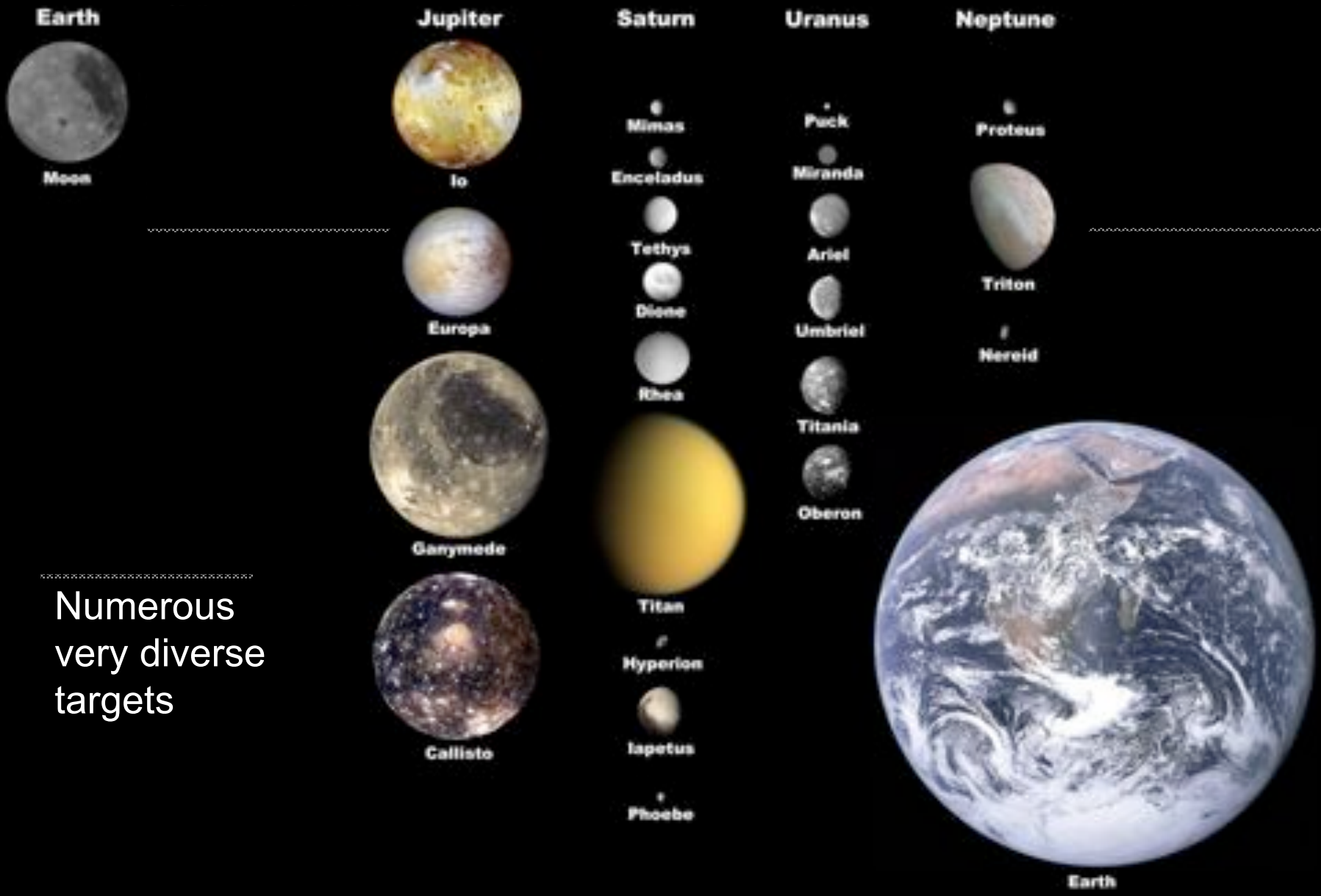
The Playing Field



Numerous very diverse targets

Satellite Meetings

- Open session audio transcripts and presentations are available via http://www.spacepolicyonline.com and http://sites.nationalacademies.org/SSB/CurrentProjects/ssb_052412

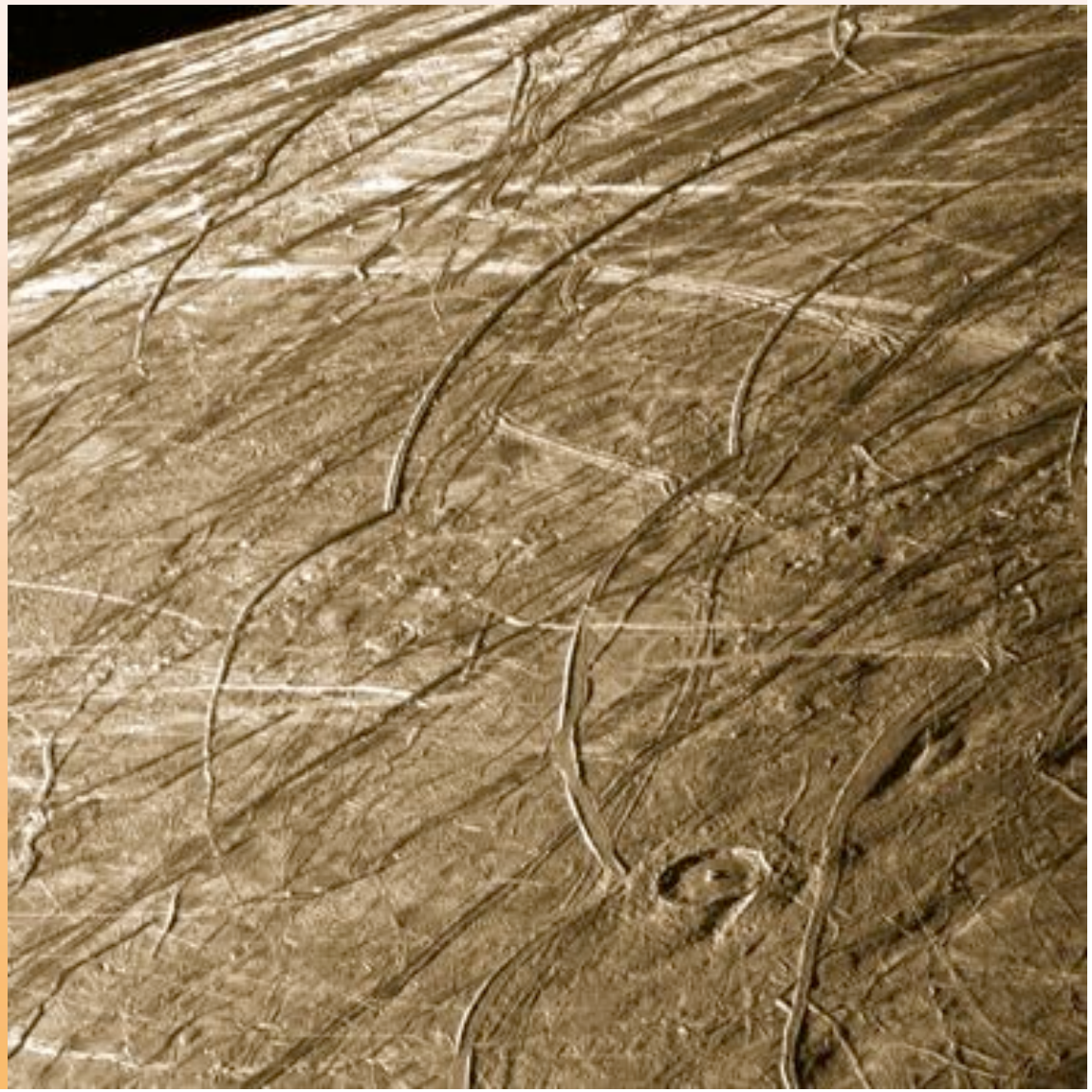
- Washington DC, August 24-26, 2009
- Irvine, CA, September 21-23, 2009
- Boulder, CO, April 14-16, 2010

- Weekly panel telecons throughout

- Multiple mission studies initiated...

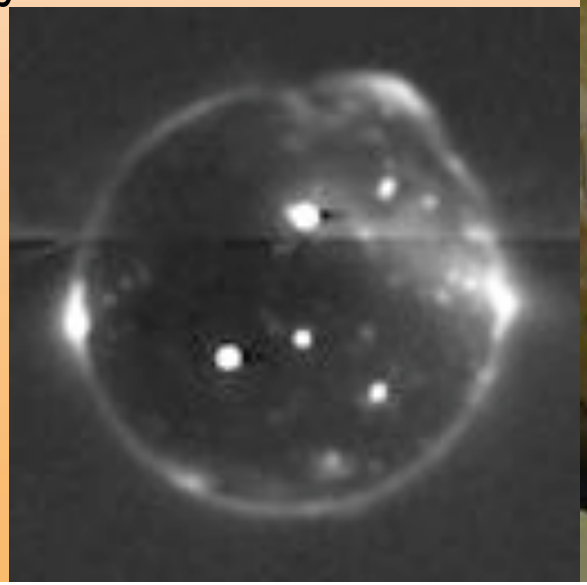
Europa Orbiter

- Highest priority outer satellite mission in the 2002 Decadal Survey
- Extensive study since then has converged on a specific mission design, JEO, part of EJSM
- JEO cost ~$2.7B (FY07)
- We have requested an Independent Cost Estimate of this mission concept



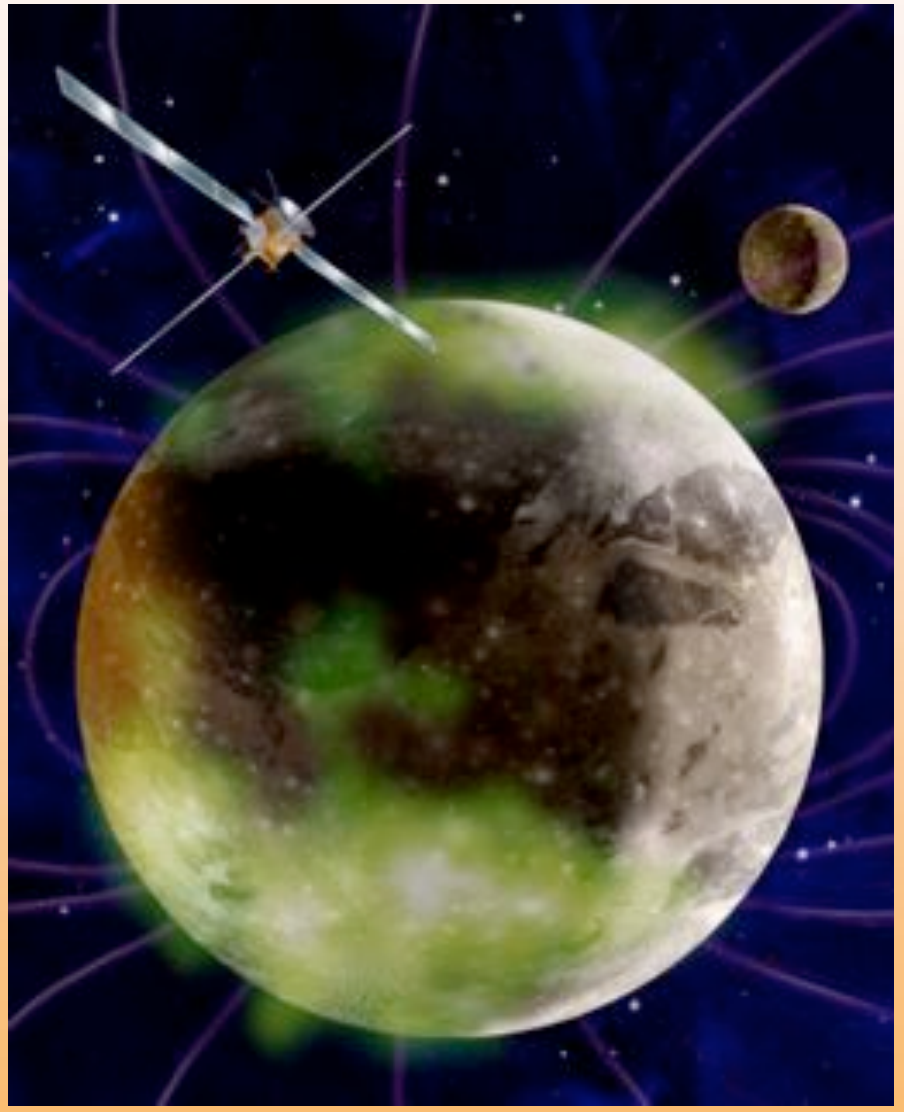
Io Observer

- A recommended Mid-Sized mission in the 2002 Decadal Survey
- Multiple Io flybys from eccentric Jupiter orbit
  - Radiation can be minimized by high-inclination orbit
- Detailed study beginning at JPL, based on 2008 Discovery/SMEX Mission Capability Extension (DSMCE) study



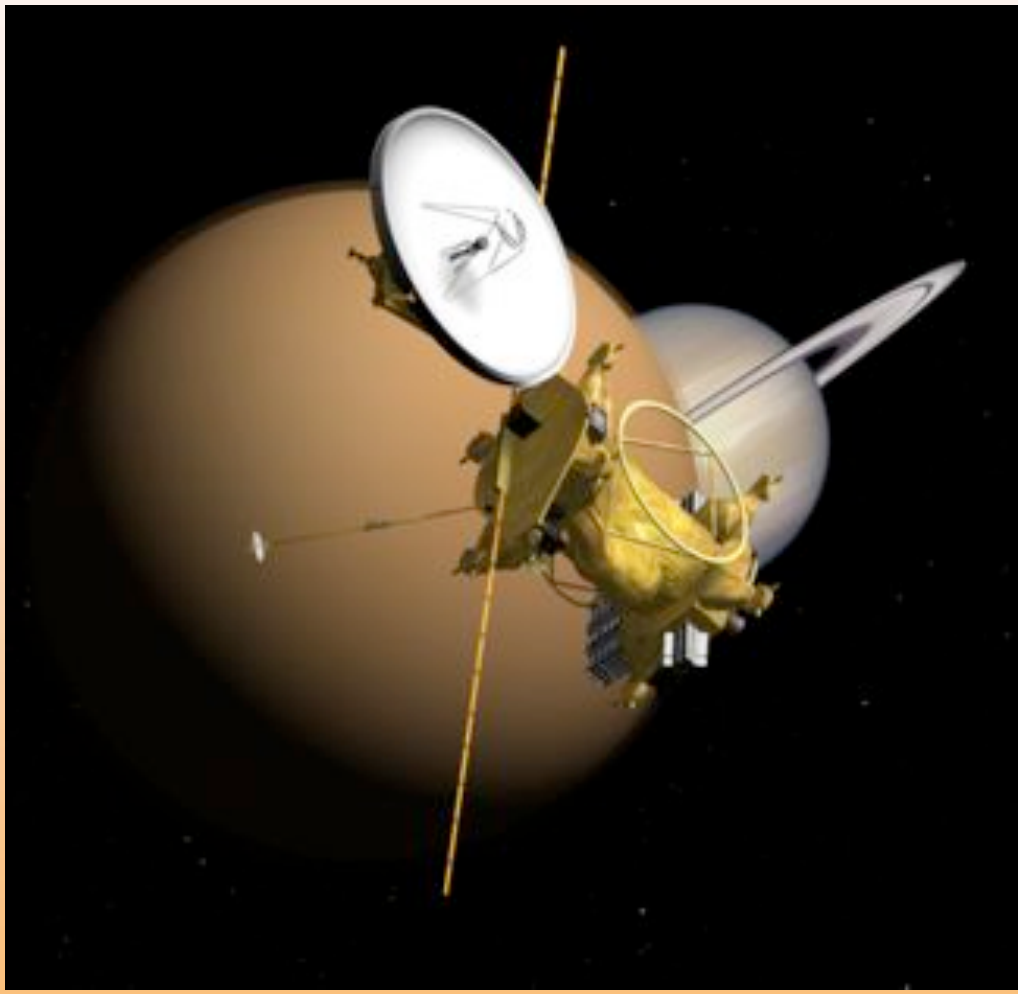
Ganymede Orbiter

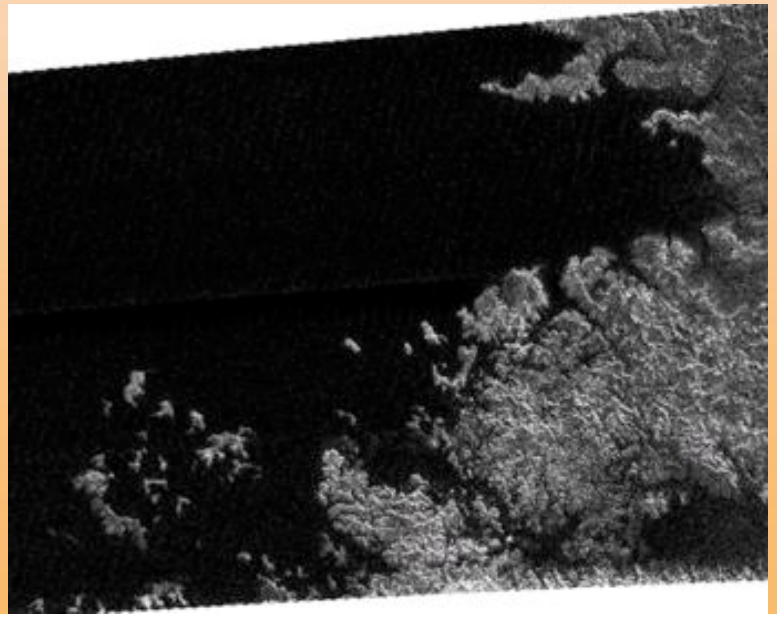
- A recommended Mid-Sized mission in the 2002 Decadal Survey
- Likely to be realized by the ESA Jupiter Ganymede Orbiter (JGO) component of EJSM
- However JGO is one of three missions competing for a single “L” class mission slot
- We recommend a study so the mission can potentially be competed under New Frontiers if JGO does not proceed to a new start



Titan Saturn System Mission (TSSM)

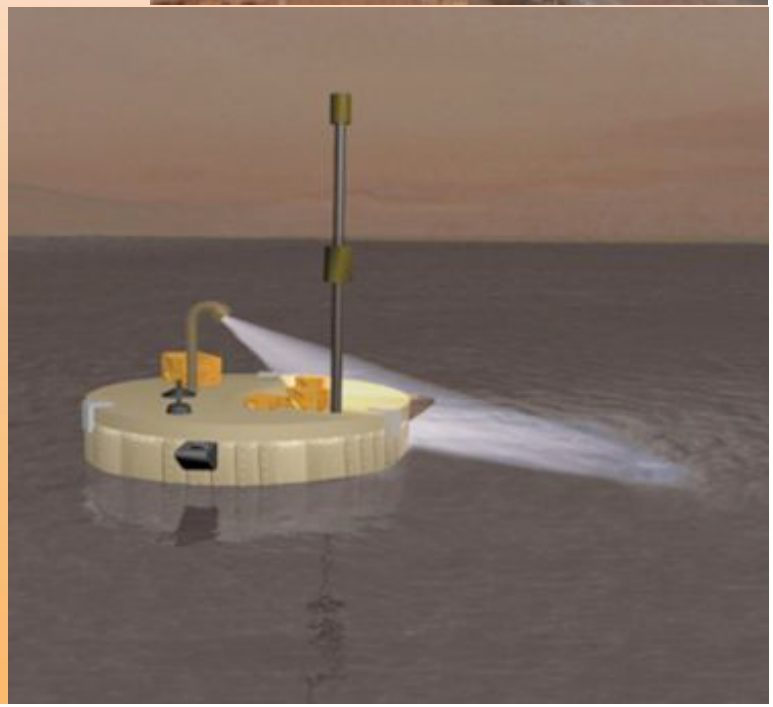
- 2008 Flagship study:
  - NASA-supplied Saturn/Titan orbiter
  - ESA-supplied balloon and lake lander, costed separately
  - Several Enceladus flybys
- Independent Cost Estimate required for recommendation by the Decadal Survey for the next decade





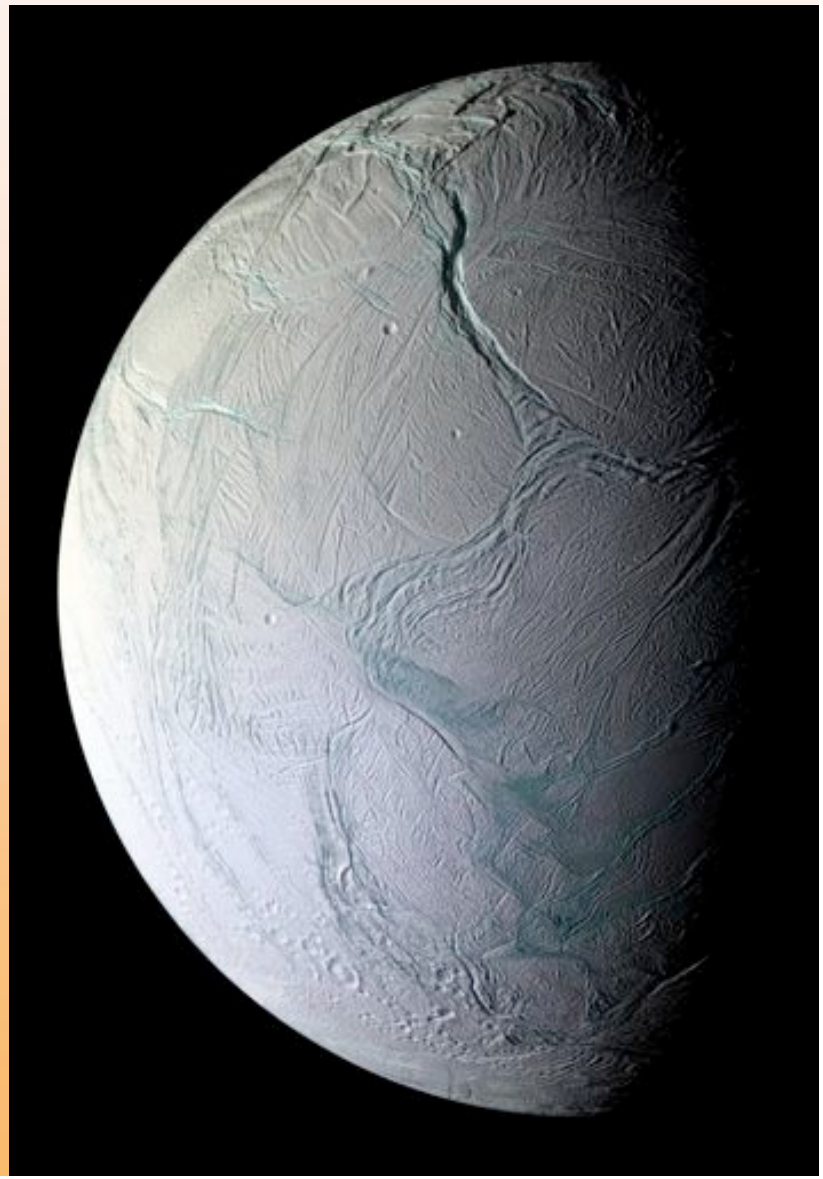
Titan In Situ Elements

- ESA-supplied TSSM in situ elements
  - Montgolfière balloon
  - Lake lander
- Can these elements be flown as stand-alone missions before the next Flagship?
  - Mongolfière requires high data rate for remote sensing of surface: difficult to support with direct-to-Earth communication
  - Considerable technology development
  - Lake Lander's prime goal is chemistry: requires lower data rates, so direct-to-Earth communication is feasible
  - Also, likely to require less technology development
- Lake Lander thus chosen for detailed study by the Decadal Survey
  - Stand-alone mission, or
  - Element of Flagship



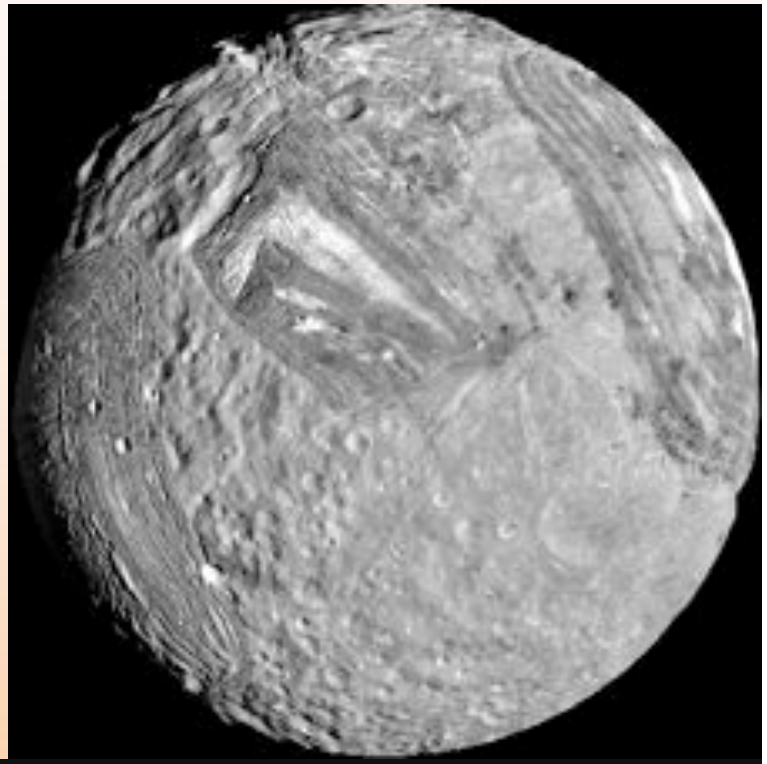
Enceladus

- Biggest game-changer in satellite science since the 2002 Decadal Survey
  - Active tectonics and tidal heating
  - Potential habitable zone with increasing evidence for liquid water
  - Ability to sample the PHZ directly
- Many potential mission architectures
  - Saturn Orbiter
  - Enceladus Orbiter
  - Lander
  - Sample Return
- These are being studied as part of a Rapid Mission Architecture study at JPL
  - Incorporate improved trajectory options relative to previous studies (Thursday talk by Nathan Strange)
  - Emphasize lower cost missions
- Follow-on full studies of promising architectures may follow



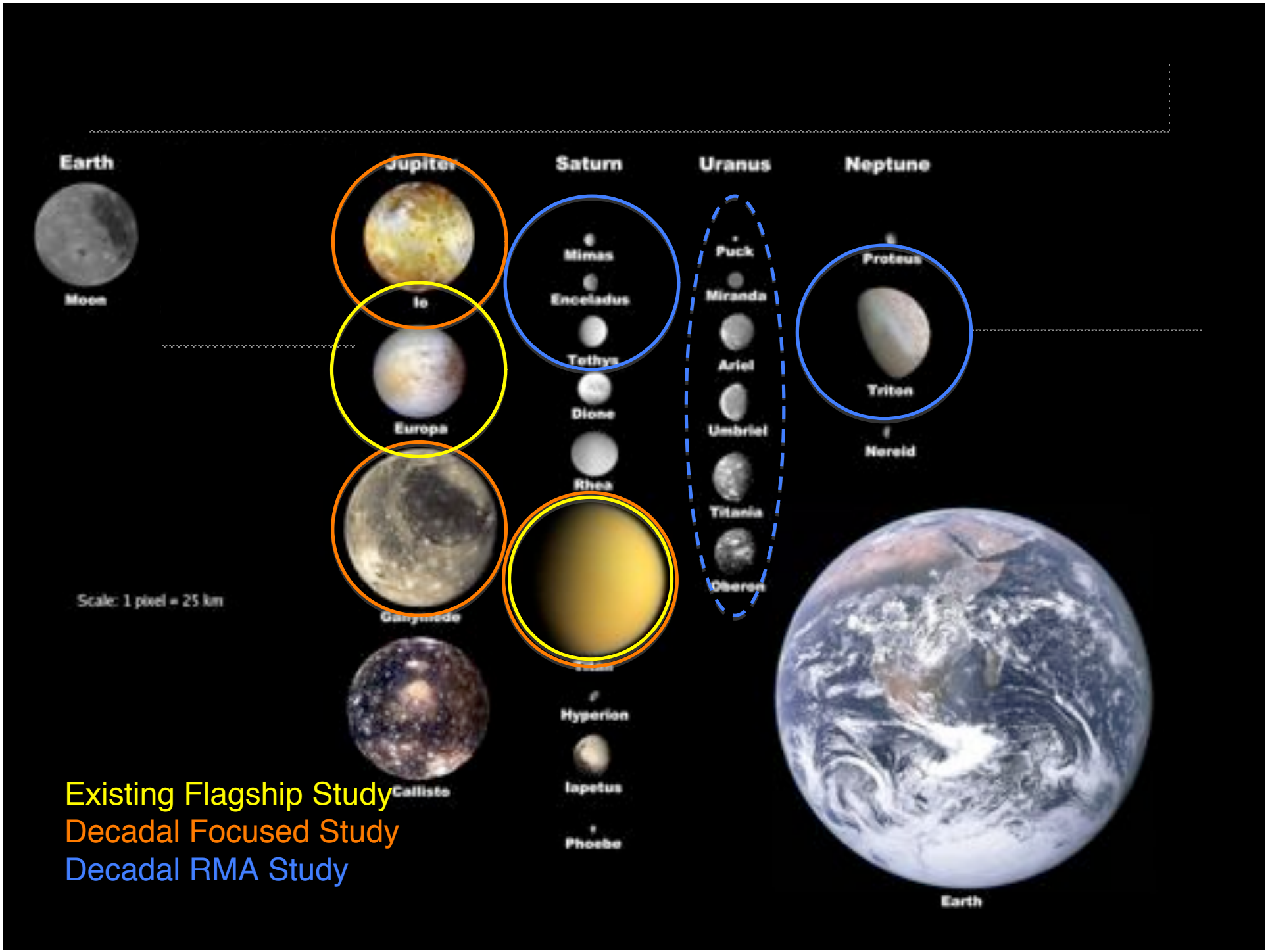
Uranian Satellites

- Not clones of the mid-sized Saturnian satellites!
- Only intact ice-giant satellite system
- Satellite science is being considered as part of a Uranus orbiter study



Neptune and Triton

- Neptune orbiter and flyby were discussed by the 2002 Decadal survey
  - Neptune orbiter: High priority but deferred
  - Neptune flyby: not highly rated
- Improved instrumentation and the addition of the KBO flyby (and possible continued deferrment of a Neptune Flagship) make the flyby worth reconsidering
- JPL Rapid Mission Architecture study nearing completion
  - Flybys optimized for Neptune, Triton, or KBO
  - Simple orbiter
  - Complex orbiters
- Follow-on full mission studies TBD


Earth
Moon
Jupiter
Io
Europa
Ganymede
Callisto
Saturn
Mimas
Enceladus
Tethys
Dione
Rhea
Titan
Hyperion
Iapetus
Phoebe
Uranus
Puck
Miranda
Ariel
Umbriel
Titania
Oberon
Neptune
Proteus
Triton
Nereid
Scale: 1 pixel = 25 km
Earth
Existing Flagship Study
Decadal Focused Study
Decadal RMA Study

Satellite-Relevant White Paper Inventory: 1

Subject	First Author
General Science	
Exploration Strategy for the Outer Planets 2013-2022: Goals and Priorities	Bill McKinnon
Icy Satellite Processes in the Solar System: A plurality of worlds	Steve Vance
Small Bodies Community White Paper: The Small Satellites of the Solar System	Bonnie Buratti
Space Weathering Impact on Solar System Surfaces and Mission Science	John Cooper
Astrobiology Priorities for Planetary Science Flight Missions	Carl Pilcher
An Astrobiological Lens on Planetary System Science	Carl Pilcher
Planetary Science & Astrobiology: Cold habitats for life in the Solar system	Mark Skidmore
Astrobiology Research Priorities for the Outer Solar System	Dirk Schulze-Makuch
Science: Specific Targets	
Future Io Exploration for 2013-2022 and Beyond, Part 1: Justification and Science Objectives	Dave Williams
Exploration of Europa	Cynthia Phillips
Ganymede science questions and future exploration	Geoff Collins
The Case for Enceladus Science	Terry Hurford
The Science of Titan and its Future Exploration	Jon Lunine
Saturn's Titan: A strict test for life's cosmic ubiquity	Jon Lunine
Titan's Greenhouse Effect and Climate	Conor Nixon
Prebiotic Atmospheric Chemistry on Titan	Roger Yelle
Titan’s unique attraction: it is an ideal destination for humans	Julian Nott
Astrobiological Research Priorities for Titan	Mark Allen
The Exploration of Neptune and Triton	Craig Agnor
Specific Missions	
Limits of Terrestrial Life in Space	Andrew Pohorille
The Mars Hopper: Long Range Mobile Platform Powered by Martian In-Situ Resources	Steven Howe
SCIENCE OF THE EUROPA JUPITER SYSTEM MISSION	Pappalardo
Europa Jupiter System Mission	Karla Clark
RADIATION FACTS AND MITIGATION STRATEGIES FOR THE JEO MISSION	Tsun-Yee Yan
A budget phasing approach to Europa Jupiter System Mission Science	David E. Smith
Future Io Exploration for 2013-2022 and Beyond, Part 2: Recommendations for Missions	Dave Williams
Cassini-Huygens Solstice Mission	Linda Spilker
The Case for an Enceladus New Frontiers Mission	Terry Hurford
Enceladus Flyby Sample Return, LIFE (Life Investigation For Enceladus)	Peter Tsou
The Case for a Titan Geophysical Network Mission	Ralph Lorenz
Future in situ balloon exploration of Titan’s atmosphere and surface	Athena Coustenis
Advanced Titan Balloon Design Concepts	Julian Nott
Titan Lake Probe	Hunter Waite
Heavier Than Air Vehicles For Titan Exploration	Lawrence Lemke
The Case for a Uranus Orbiter	Mark Hofstadter
Triton science with Argo - A Voyage through the Outer Solar System	Candy Hansen

Satellite-Relevant White Paper Inventory: 2

Subject	First Author
Telescopes / Near-Earth Observations	
A dedicated space observatory for time-domain Solar System science	Mike Wong
Study of Planetary Systems and Solar System Objects with JWST	George Sonneborn
SOFIA (Stratospheric Observatory for Infrared Astronomy) and Planetary Science	Dana Backman
The NASA Infrared Telescope Facility	Alan Tokunaga
Stratospheric Balloon Missions for Planetary Science	Karl Hibbitts
Balloon-Borne Telescopes for Planetary Science: Imaging and Photometry	Eliot Young
Solar System Suborbital Research: A Vital Investment in the Scientific Techniques, Technology, and Investigators of Space Exploration in the 21st Century.	Walter Harris
Laboratory Studies	
Recommended Laboratory Studies in Support of Planetary Science	Brad Dalton
Laboratory Studies in Support of Planetary Surface Composition Investigations	S. W. Ruff
Laboratory Spectroscopy to Support Remote Sensing of Atmospheric Composition	Linda R. Brown
Recommended Laboratory Studies in Support of Planetary Science: Surface Chemistry of Icy Bodies	Robert Hodyss
Laboratory Studies in Support of Planetary Geophysics	Julie Castillo-Rogez
Laboratory Studies for Planetary Sciences	Murthy Gudipati_WGLA
Mission Technology	
Thermal Protection System Technologies for Future Sample Return Missions	Ethiraj Venkatapathy
Thermal Protection System Technologies for Enabling Future Mars/Titan Science Missions	Ethiraj Venkatapathy
Thermal Protection System Sensors	Edward R. Martinez
Technologies for Outer Planet Missions: A Companion to the Outer Planet Assessment Group (OPAG) Strategic Exploration White Paper	Pat Beuchamp
In-Situ Mass Spectrometry of Atmosphereless Planetary Objects	Eberhardt Grun
The Importance of Utilizing and Developing Radioisotope Electric Propulsion for Missions Beyond Saturn	Mohammed Omair Khan
New Opportunities for Outer Solar System Science using Radioisotope Electric Propulsion	Robert Noble
Onboard Science Data Analysis: Implications for Future Missions	David Thompson
Planetary Protection for Planetary Science and Exploration	John Rummel
Radio Science Investigations of Planetary Atmospheres, Interiors, Surfaces, Rings, and Solar and Fundamental Physics	Sami Asmar
Electromagnetic Sounding of Solid Planets and Satellites	Bob Grimm
Future Plans for the Deep Space Network (DSN)	Barry Geldzahler
A Survey of the Technologies Necessary for the Next Decade of Small Body and Planetary Exploration	J. Edmund Riedel
Research, Analysis, Archiving	
Data Management, Preservation and the Future of PDS	Reta Beebe
Astrodynamics Research and Analysis Funding	Nathan Strange
The Importance Of A Planetary Cartography Program: Status and Recommendations for NASA 2013-2023	Jeff Johnson
Other	
ROSI - Return on Science Investment	Robert Schingler
Sociological Considerations for the Success of Unmanned Planetary Exploration Missions	Janet Vertesi

OPAG White Papers

- McKinnon et al: Exploration Strategy for the Outer Planets 2013-2022: Goals and Priorities
- Recommendations:
  - The Decadal Survey should explore the possibilities for a program structure/categorization that could allow ‘small flagship’ class missions to be considered
  - Endorses the prioritization by NASA of the Jupiter Europa Orbiter (JEO) as the next Outer Planets Flagship and as part of the Europa Jupiter System Mission (EJSM) with ESA.
  - Strongly endorses approval by NASA of the Cassini Solstice Mission
  - Advocates the need for a focused technology program for the next Outer Planet Flagship Mission, which should be to Titan and Enceladus, in order to be ready for a launch in the mid-2020s
  - New Frontiers class missions that should be considered in the interim include (*not in priority order)* a shallow Saturn probe, an Io observer, a Titan in-situ explorer or probe, a Neptune/Triton/KBO flyby, Uranus Orbiter

OPAG White Papers

Beauchamp et al: *Technologies for Outer Planet Missions*.

Recommendations:

Technology Development	Missions								
	Titan Orbiter *In Situ* Sampler	Neptune Orbiter	Neptune Flyby to KBO Flyby	Uranus Orbiter	Saturn Probe	Jupiter Probe	Neptune Probe	Enceladus Sample Return	Europa Lander
Power									
RPS	E	E	E	E	e	e	E	E	e
Low intensity, low temperature solar arrays				e	e	e			
Transportation									
Electric propulsion	e	E	e	e	e		e	e	
Aerocapture		E		E					
Communications									
Expanded Ka capability	e	e	e	e			e		e
Improved proximity links	e				e	e	e	e	e
Improved UHF systems	e				E	e	E	e	e
Planetary protection measures	e							e	e
Mobility and Landers	E								e
Autonomy	e							E	E
Extreme environments	e				e	e	e	e	E
Entry systems (includes TPS)	e	E		e	e	E	E	E	E
Planetary probe S/C technologies					e	e	E		
***In situ* sensing of surface and atmospheres**	E				e	E	E	E	E
Components and miniaturization	E	e	e	e	e	e	E	E	E
Remote sensing	e	e	e	e	e	e	e	e	e

Selected White Paper Findings

Missions and Science

- Outer planets program with small flagships?
- Include outer small satellite flybys in missions when possible
- Europa lander needed for astrobiology
- New Frontiers mission to Enceladus might be solar powered
- Enceladus sample return - Organics captured by Stardust technology
- Importance of astrodynamics for enabling missions e.g. to Enceladus
- Titan geophysical network
- Titan aircraft- some of the advantages of balloon, but steerable
- Life in hydrocarbons- plausible?
- Titan greenhouse as an analog for Earth greenhouse
- Uranus orbiter- possibly doable under New Frontiers on solar power?
- Good Triton science from a flyby

Some White Paper Findings

Near-Earth observations

- Importance of Thirty Meter Telescope and other giant telescopes for outer satellite science
- UV space telescope for Io and Europa observations
- Small telescopes for monitoring Io
- More NASA time on 8-meter telescopes
- IRTF capability needs to be maintained, in the absence of a larger dedicated planetary telescope
- SOFIA- Valuable for Titan, but also Io, stellar occultations
- Balloons- working group, balloon-borne observatory. Satellite spectroscopy in the UV (if we can get down to 200 nm) and some near-IR wavelengths obscured from the ground
- Space telescope for temporal monitoring- useful for Io and Titan
- JWST- can track moving target

Lab work

- Importance of lab work, need for increased support
- Planetary surface simulators
- Instrument development funded element NASA of strategic plan?
- Need to invest in infrastructure, train new people
- Lab work is slow and therefore expensive and can thus have trouble competing in current funding programs
- Encourage archiving of lab results in the PDS

Some White Paper Findings

Technology

- Need for a focused long-term technology program
- Radioisotope electric propulsion
- Entry technology, including thermal protection. Research into new materials and maintenance of facilities
- Ka-band improvements
- Spacecraft autonomy: data mining and autonomous acquisition
- Planetary protection- research into less invasive techniques for sterilizing spacecraft

Research Data Analysis and Archiving

- PDS needs to be able to keep up with increasing volume and complexity of data sets
- Need for making archived data user-friendly, e.g. archiving in physical units and high-level cartographic products

Other

- Importance of high-value, high-risk missions- something like New Millennium
- Importance of team member interactions and management structure in the effectiveness of a mission, and how these might be improved
- Concerns about ITAR

Specific Infrastructure Concerns

- ^{238}Pu supply
  - Essential for ambitious outer planet satellite program
- Deep Space Network
  - Current DSN plan:
    - Possible retirement of 70-m antennas, construction of new 34-m antennas, by early 2020s
    - Transition from X-band to Ka-band as primary wavelength for commuications
    - Need to maintain X-band for time-critical radio science, contingency communications