NASA/OPAG/JPL Enceladus Study: Preliminary Report

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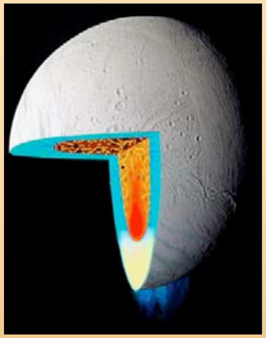
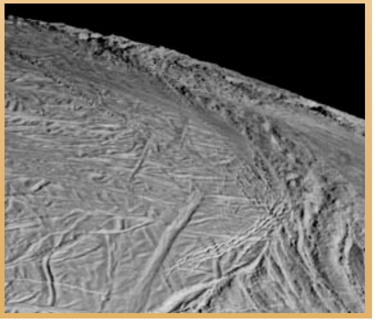
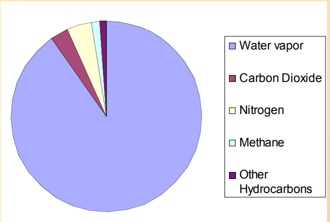
Science Goals



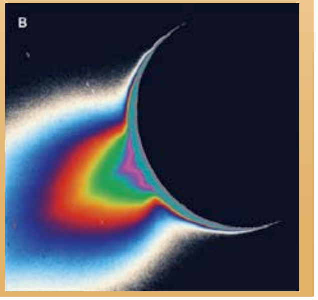
1. Tidal Heating
   a) Dissipation mechanism?
   b) Spatial distribution?
   c) Variability with time-
      - How did it get started?
      - Has it been continuous?
2. Interior Structure
   a) How big is the core?
   b) How thick is the lithosphere?
   c) Is there an ocean?
3. Composition
   a) What is the composition of the interior?
      - Are clathrates important?
      - Is ammonia important?
      - Role of organics?
4. Tectonics
   a) What drives the extensive tectonic activity?
      - Convection?
      - "Plate tectonics"?
      - Polar wander?
      - Changes in rotation rate?
   b) Why does the intensity of tectonism vary so widely across the surface?



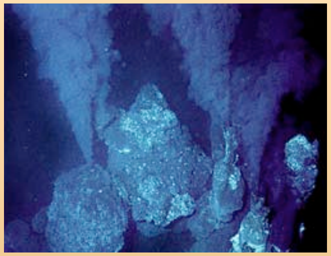
Science Goals, contd.



5. Cryovolcanism
   a) What is the nature of the plume source?
      - Are liquids involved, and how close to the surface?
      - How is energy supplied to the plumes?
   b) What are the resurfacing rates?
      - Due to particles?
      - Due to gas?
      - Spatial distribution?
   c) What are the escape rates?
      - Due to particles?
      - Due to gas?
      - What is the role of mass loss in the long-term chemical and physical evolution of the satellite?
   d) Is there ongoing activity away from the south polar region?
   e) Is there extrusive as well as pyroclastic cryovolcanic activity?
6. Surface processes
   a) Is photolytic or radiolytic surface chemistry important?
   b) Why is the surface albedo so high?



Science Goals, contd.



7. Biological potential
   a) Is liquid water present?
   b) Is it long-lived?
   c) What is its chemistry?
      - Inorganic?
      - Organic?
   d) What energy sources are available for life?
   e) Is life present now?
8. What should be the next mission to Enceladus?

Brainstorming Mission Concepts

Rejected Concepts:

- Single Flyby with improved instrumentation compared to Cassini
  - High risk
  - Small science return
- Hard lander on single flyby
  - Difficult to target
  - Difficult to communicate
  - Probably too expensive
- Hard lander on Saturn orbiter
  - Too expensive
- Instrumented impactor on flyby or orbiter to probe plume source region
  - Only a few seconds of unique data compared to close flybys
- Enceladus orbiter
  - Very high science return
  - Delta-v requirements are too high
    - Titan aerocapture into Saturn orbit would help, but not enough

Brainstorming Mission Concepts

Concepts retained for continued study:

- Saturn orbiter with multiple Enceladus flybys and improved instrumentation
  - Significant science gains over Cassini are possible with the right instruments
  - Stardust-like armoring might allow deeper plume sampling than Cassini
- Single flyby with plume sample return (free return trajectory)
  - High risk
  - Potentially large science return

Saturn Orbiter: Improvements over Cassini?

- Number of Enceladus flybys?
  - Cassini will have up to ~12 flybys
  - Some Cassini extended mission designs have 8 flybys in 2 years, in addition to fulfilling many other science goals.
  - Significant, but not dramatic, increase in number of flybys possible compared to Cassini?
- Speed of Enceladus flybys?
  - Minimum encounter speed in Cassini XM plans: 4.7 km/sec
  - Minimum speed possible with Titan gravity assist: 3.7 km/sec
  - Rhea, Dione gravity assists might reduce speed further
    - Large penalty in mission operations cost, time
- Closeness of Enceladus flybys?
  - Closeness of Cassini flybys limited by dust impact risk
    - Mm-sized particles could be fatal
    - Such particles are very hard to detect
  - Stardust-like shielding could enable closer plume flybys than Cassini?
  - Cassini experience will be crucial
    - Pathfinding for future missions should be a consideration in designing Cassini XM or XXM flyby geometries and observations

Saturn Orbiter Instrumentation?

Cassini remote sensing instruments vs. some modern instruments

Instrument	Wavelength	Mass (kg)	Power (W)	Resol-ution, m/pixel*	Swath width, km*	Comments
UVIS	0.05 – 0.19 µm	14	11	350	20	
ISS	Visible (~20 color)	58	56	15	15	
VIMS	0.35 – 5.1 µm	37	27	900	60	1 spatial pixel at a time
CIRS	7 – 16 µm	39	32	900	9	Poor SNR except tiger stripes
CIRS	16 – 500 µm			12,000	12	1 spatial pixel at a time
HiRise (MRO)	Visible (3 color)	65	60	0.3	6	
Ralph/MVIC (New Horizons)	Visible (4 color)	10	6	7	35	Good SNR during flyby if CCD readout speed can be improved
Ralph/LEISA (New Horizons)	Near-IR (1.2 – 2.5 µm)			22	5	A broader wavelength range would be desirable at Enceladus
THEMIS (Mars Odyssey)	Thermal IR (7 – 15 µm)	11	14	~100	30	SNR poor except for highest tiger stripe temperatures: longer wavelengths would provide better S/N

* 3000 km for Cassini, 350 km for pushbroom instruments

Saturn Orbiter Instrumentation?

Significant improvements over Cassini remote sensing are possible with modern instruments

- But will the quantitative improvements in resolution, coverage provide qualitative improvements in understanding?

Also consider remote sensing instrumentation not carried by Cassini:

- Sounding radar?
- Laser altimeter?
- Gamma-ray or X-ray spectrometer?

Improved In-Situ instrumentation?

- Hi-res mass spectrometer
  - Major improvements over Cassini INMS are possible
- Aerogel plume particle capture and subsequent pyrolysis?
- ?

Closer flybys will improve plume characterization, gravity data

Plume Sample Return

Free-return trajectories
- 14 km/sec capture speed
- ~17 year flight time

Solar power might be possible

Stardust experience (6 km/sec capture speed):
- Stardust probably captured ice grains which then sublimed:
  - some tracks have no particle at the end, or just a collection of small particles
- Ice particles can protect volatile materials during aerogel capture
  - E.g. FeS particles were seen: could not have survived aerogel capture unprotected
- Less dense, thicker, aerogel could enable intact capture of particles up to ~10 km/sec
  - 14 km/sec *might* be doable

There is therefore the potential to capture delicate molecules (or biological structures???) with aerogel at Enceladus, if these are protected within ice grains

Preservation of ice grains themselves is much more difficult

High-risk

Prefer some onboard analysis and remote sensing for risk reduction

Non-trivial planetary protection issues

Requirements Matrix

	Instrument	Gravity field	Tidal response	Magnetic response	Intrinsic magnetic field	Orbit determination	Global shape	Distribution of heat flow	Subsurface liquid distribution	Surface morphology	Crater counts	Crater morphology	Tectonic morphology	Surface composition	Surface thermal properties	Surface photometry	Plume vent morphology	Plume vent composition	Plume vent temperature distribution	Plume morphology	Plume temporal variability	Plume gas density	Plume gas chemistry	Plume gas speed	Plume particle size distribution	Plume particle speed	Plume particle chemistry	Plume particle morphology	Plume particle organic analysis	Plasma environment	Dione
	Hi-res pushbroom camera		?			?	o			y	y	y	y	?		o	y			o	o				o	y		?			o
	Hi-res NIR spectrometer													y		y		y				?	?				y	?			?
	Hi-res thermal mapper							y							y				y			?	?		?						?
	Hi-res UV spectrometer													?				?			o	y	y	y	?		?	?			?
	Doppler tracking	o	o																			?		?							?
	Laser or radar altimeter		o			o	o			y							?			?											?
	Sounding radar								y																						?
	Magnetometer			o	o																										o
	Plasma instrument(s)																													y	o
	Impactor camera																y														
	Impactor NIR spectrometer																	y				?									
	Impactor mass spectrometer																					y	y	y			?				
	Flyby hi-res mass spectrometer																					y	y	?						y	o
	Flyby dust counter																								y	y	y				o
	Flyby microscope																								y			y	y		
	Flyby chemical analysis of collected samples (beyond real-time MS)																						?				y		y		
	Particle sample return																								y		y	?	y		
	Gas sample return																						y								
Tidal Heating	Dissipation Mechanism?	4	8	5		3	2	5	5				4			2															3
	Spatial Distribution?							7				3	4			2															
	Variability with Time?					3					3	3	3								3										3
Interior Structure	Size of core?	4		3	3		2																								
	Thickness of lithosphere?	6	4				2					3	4																		
	Presence of ocean?	4	8	4					7			3	4										4				6				
Composition	Composition of the interior?	3												3				7					4				4				
Tectonics	What mechanisms drive tectonic activity?		7				2	5			3	3	6				6		6												
Cryovolcanism	Nature of the plume source?								8							3	6	6	6	4	3	5	5	6	5	4	6	6		3	
	Resurfacing rates?										4	3	3							4	3	5		6	5	4					
	Escape rates?												2							3	3	5		5	5	4				5	
	Activity away from the S. pole?								7	3				4		3				5										4	
	Extrusive activity?							5		4				5	4																
Surface processes	Photolytic or radiolytic chemistry?													5																4	
	High surface albedo?													3	3	3														4	
Biological potential	Presence of liquid water?	3	6	5					8			3	4				4	5	5	3	2	4	5	4	5	3	5	7		2	
	Longevity of liquid water?		5			3					3	3	3								4										
	Water chemistry?													3				5					6				7				
	Energy sources for life?							5						4				4	6				6				7			3	
	Presence of life?																												6		
Future missions	What should be the next mission?																														

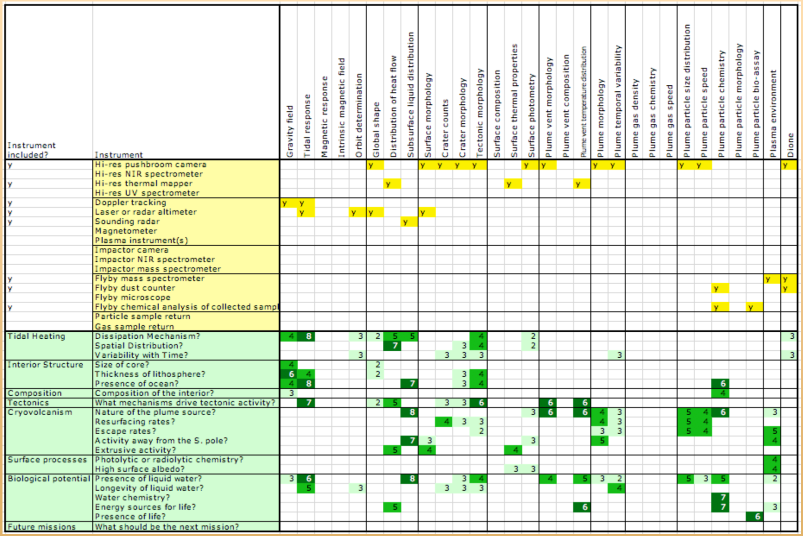
Minimum Payload

Strawman payload to test the "existence theorem"

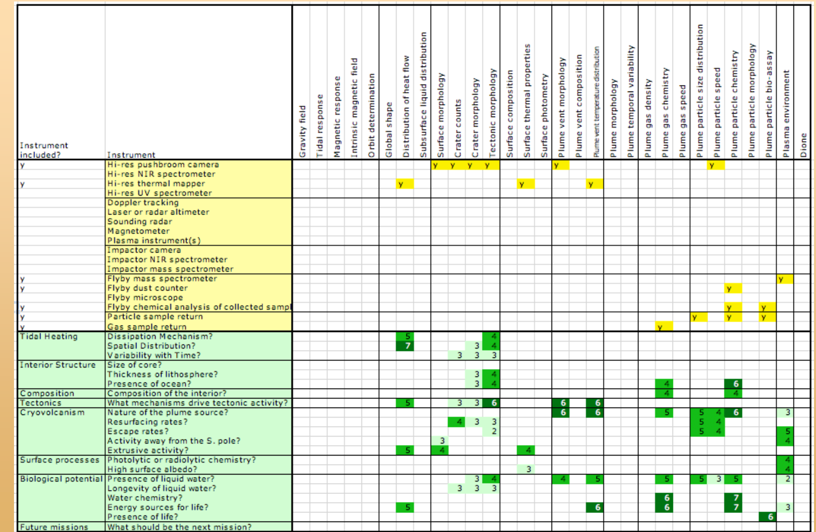
What's the minimum we can carry and still be worth $1B?

- Saturn Orbiter
  - Visible imager
  - Thermal mapper
  - Laser altimeter(?)
  - Sounding radar
  - In-situ plume measurement
- Sample Return
  - Visible imager
  - Thermal mapper
  - In-situ plume measurement
  - Onboard analysis of captured sample
    - Heat aerogel sample, analyze gases?

Saturn Orbiter: Minimum Payload



Sample Return: Minimum Payload



Summary Matrix

	Saturn Orbiter				
	Imager	Thermal Mapper	Laser Altimeter	Sounding Radar	In-Situ Plume Analysis
Tidal Heating	X	XXX	XXX	XX	
Interior Structure	X	X	XXX	XXX	XX
Bulk Composition					X
Tectonics	XX	XX	XXX	X	
Cryovolcanism	XX	XX	X	XXX	XX
Surface Processes					X
Biological Potential	X	XX	XX	XXX	XXX

	Sample Return				
	Imager	Thermal Mapper	In-Situ Plume Analysis	Onboard analysis of Captured Sample	Earth analysis of Captured Sample
Tidal Heating	X	XX			
Interior Structure	X		X	X	X
Bulk Composition			X	X	XXX
Tectonics	XX	XX			
Cryovolcanism	XX	XX	XX	XX	XXX
Surface Processes				XX	XXX
Biological Potential				XX	XXX

Next Steps

- Flesh out instruments
  - Capabilities
  - Mass
  - Power
  - Cost
- Further investigation of sample return feasibility
- Flesh out mission scenarios
  - Trajectories
  - Technologies
  - Mass
  - Power
  - Cost

Hope for overlap!