The Voyage of Exploration & Discovery: Earth-Moon, Mars, and Beyond

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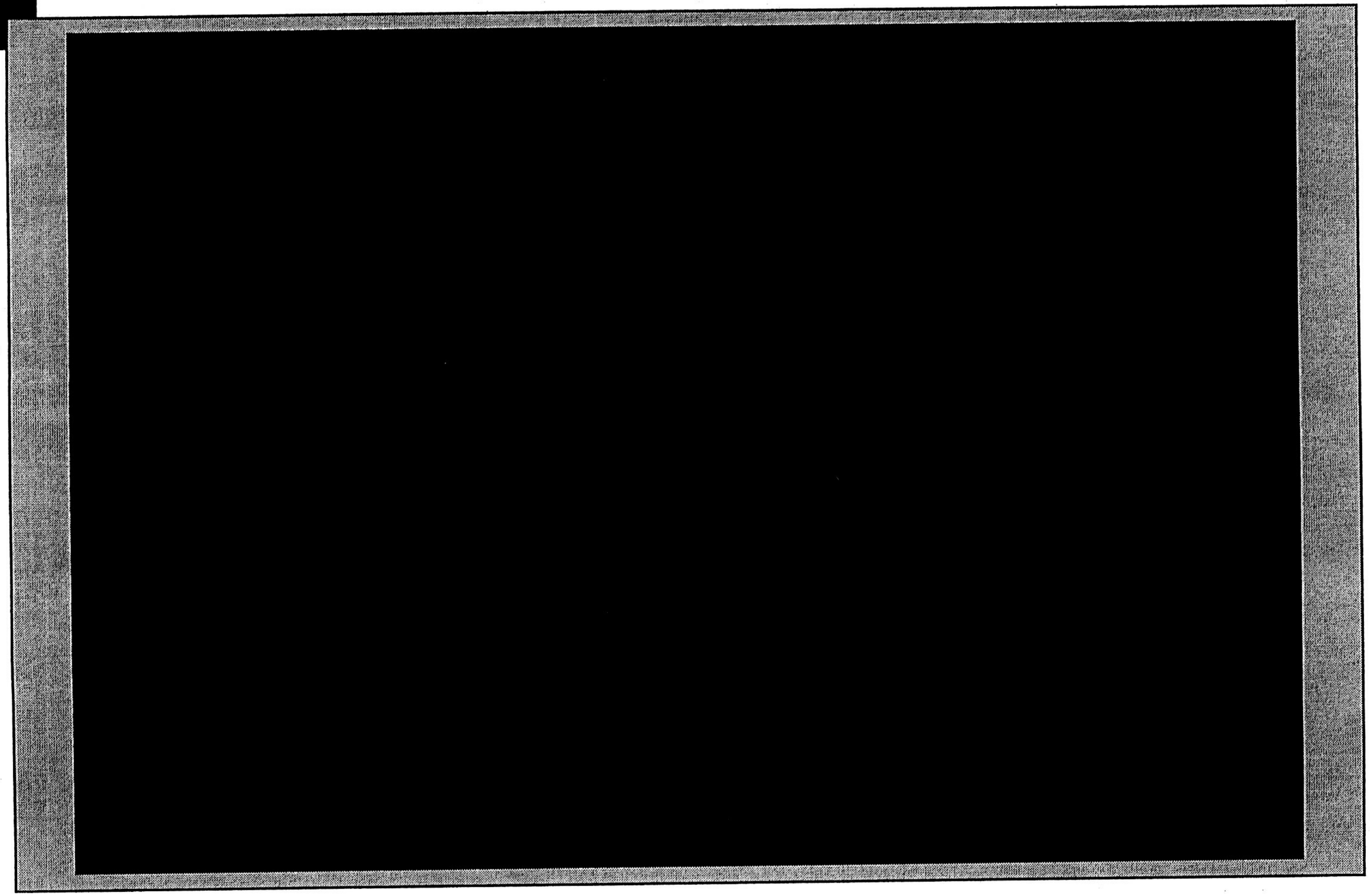
Washington and Northern Virginia Sections

Motivation

- The recent Huygens Probe landing on the distant surface of Titan has inspired us to look again at the outer solar system giants, and their extraordinary moons.
- This is a multimedia compilation of the Cassini-Huygens Mission, a visual symphony of color, a tribute to engineering and scientific achievements… and of course, a pragmatic look at how one might go about dreaming about an outer-planet mission.

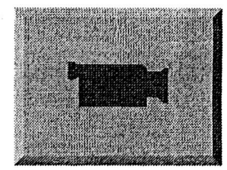
We are explorers …
We never cease to discover.




The Vision for Space Exploration, Public Service Announcement

*The Cassini-Huygens Mission to Saturn**

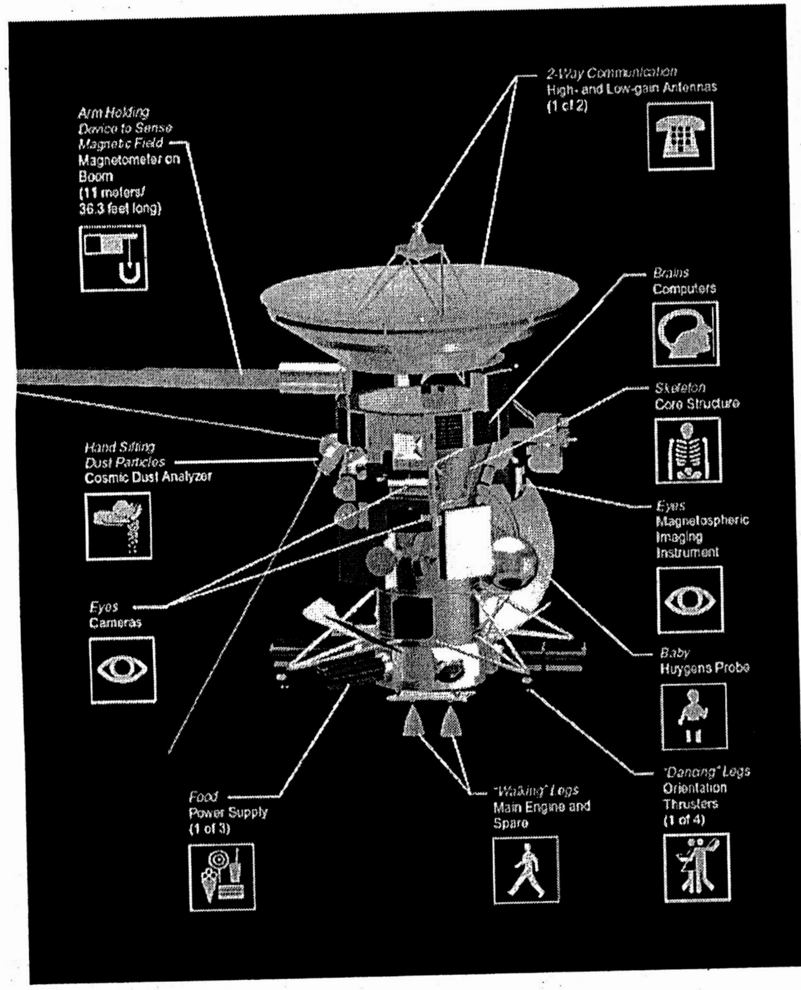
Cassini Launches October 1997 on a mission of Exploration & Discovery

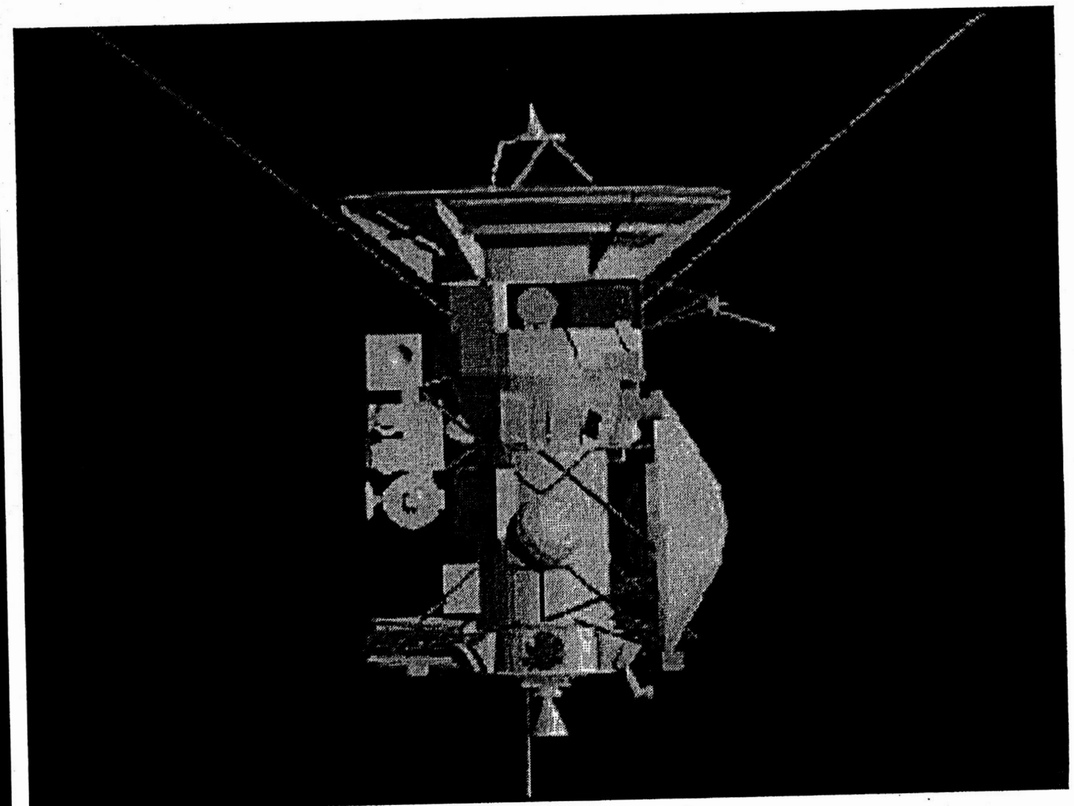


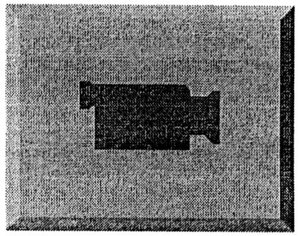
Overview Video

* Multi-media Credits: NASA/JPL, ESA
@ http://saturn.jpl.nasa.gov

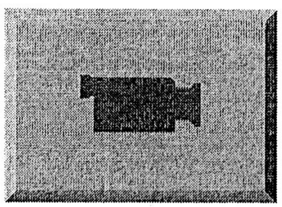
The Spacecraft





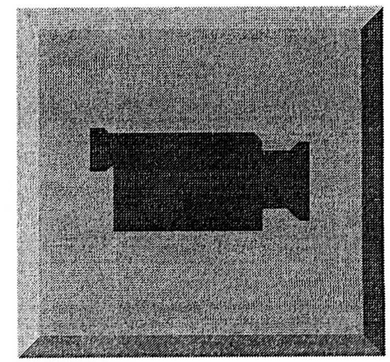


As Huygens descends, Cassini records telemetry from 72,000 kilometers.



Huygens enters Titan’s atmosphere & lands.

Huygens landing video: a view from the Descent Imager/Spectral Radiometer (DISR). From 152 km to the ground. Cloud deck at 30 km altitude.

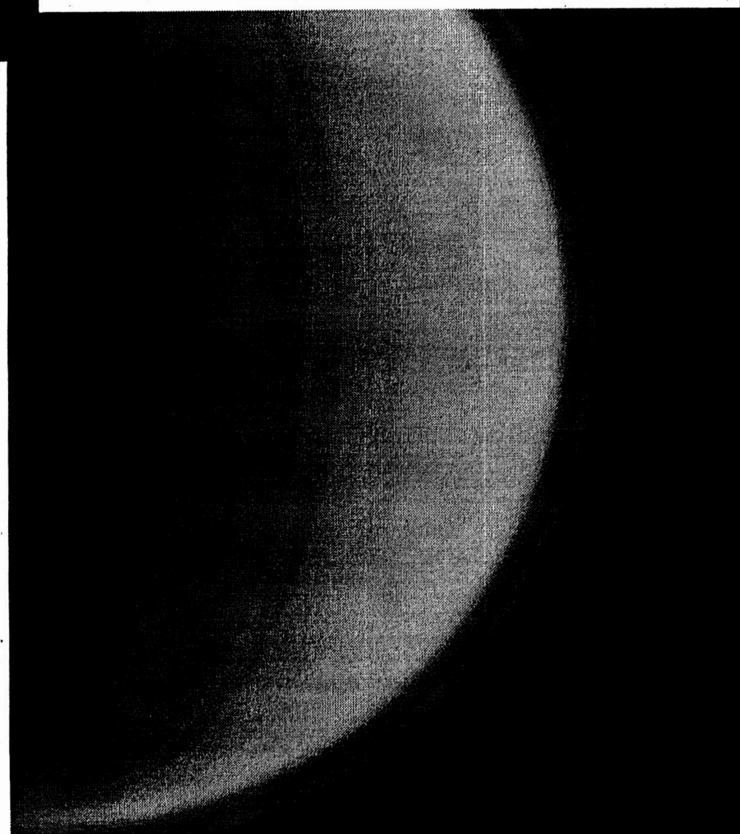


Sound samples from Huygens' microphones: one minute compilation.

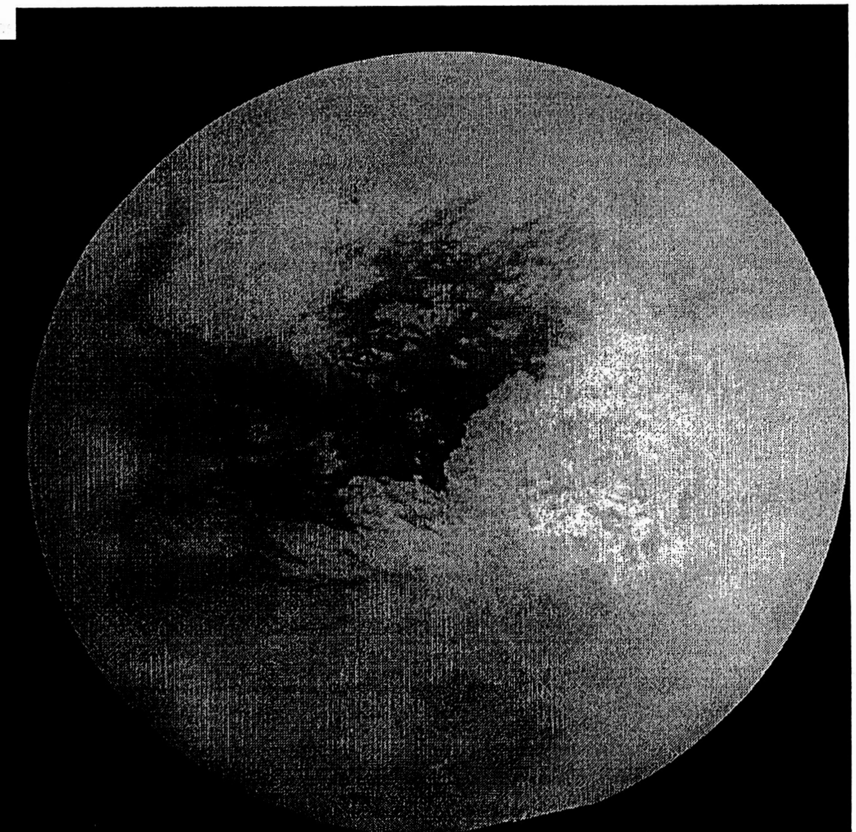
ESA/NASA/JPL/University of Arizona

Meanwhile, Titan science observations continue to stream down from the Cassini orbiter.

View from the Visual and Infrared Mapping Spectrometer (VIMS), over a range from 0.8 to 5.1 microns, shows surface visibility varies with wavelength.

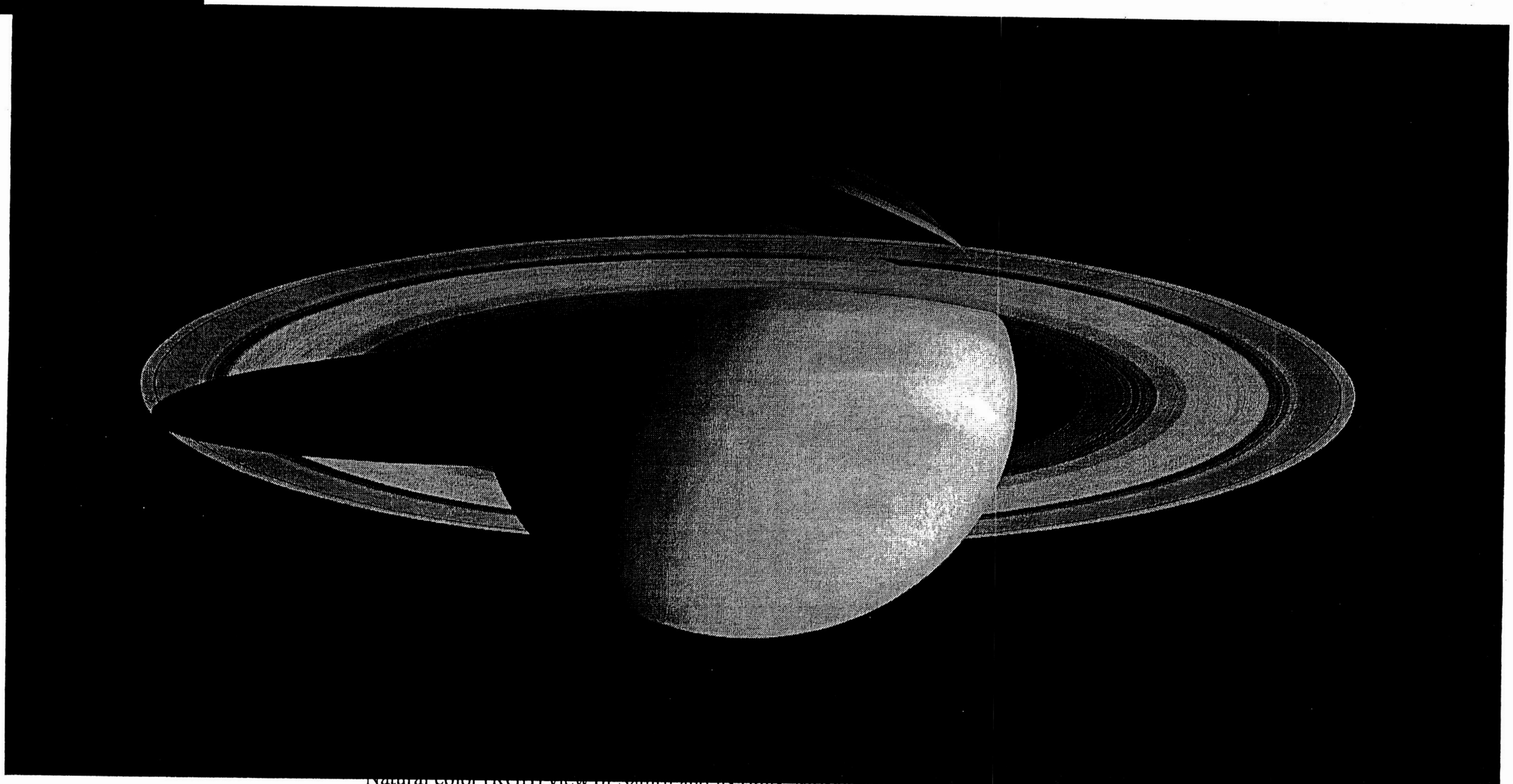


Titan encircled in purple stratospheric haze, with thin detached layer.



Narrow angle camera view: polarized infrared light filter (16-image mosaic).

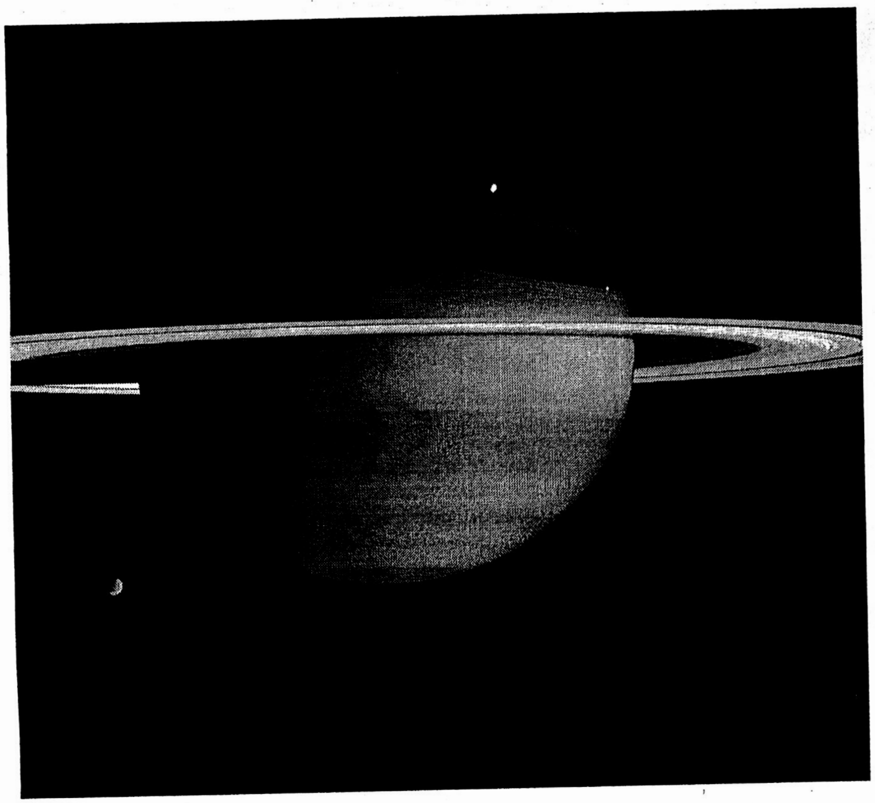
Cassini continues to explore Saturn



Natural color (RGB) view of Saturn and its rings. Mosaic consists of 12[illegible] images taken over the course of two hours on Oct. 6, 2004, while Cassini was about 6.3 million Km away.

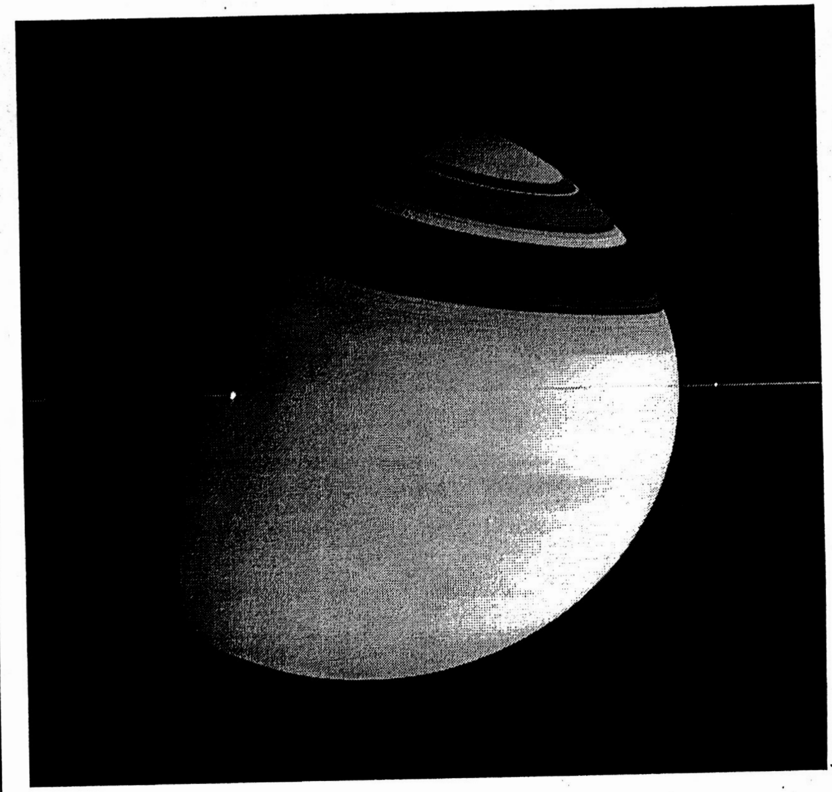
Saturn's rings: a celestial "mirage"

Now you see them …



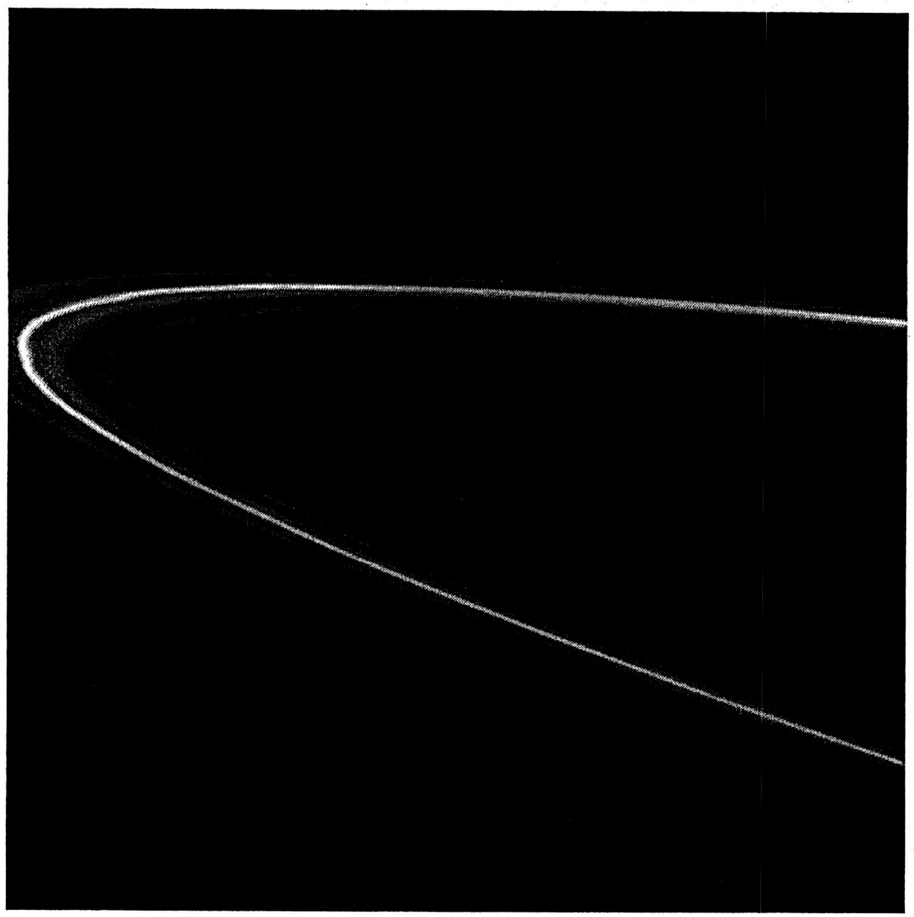
Rings near edge-on. Titan (lower left, far side) and Rhea (upper right) are visible.

Now you don't … ?

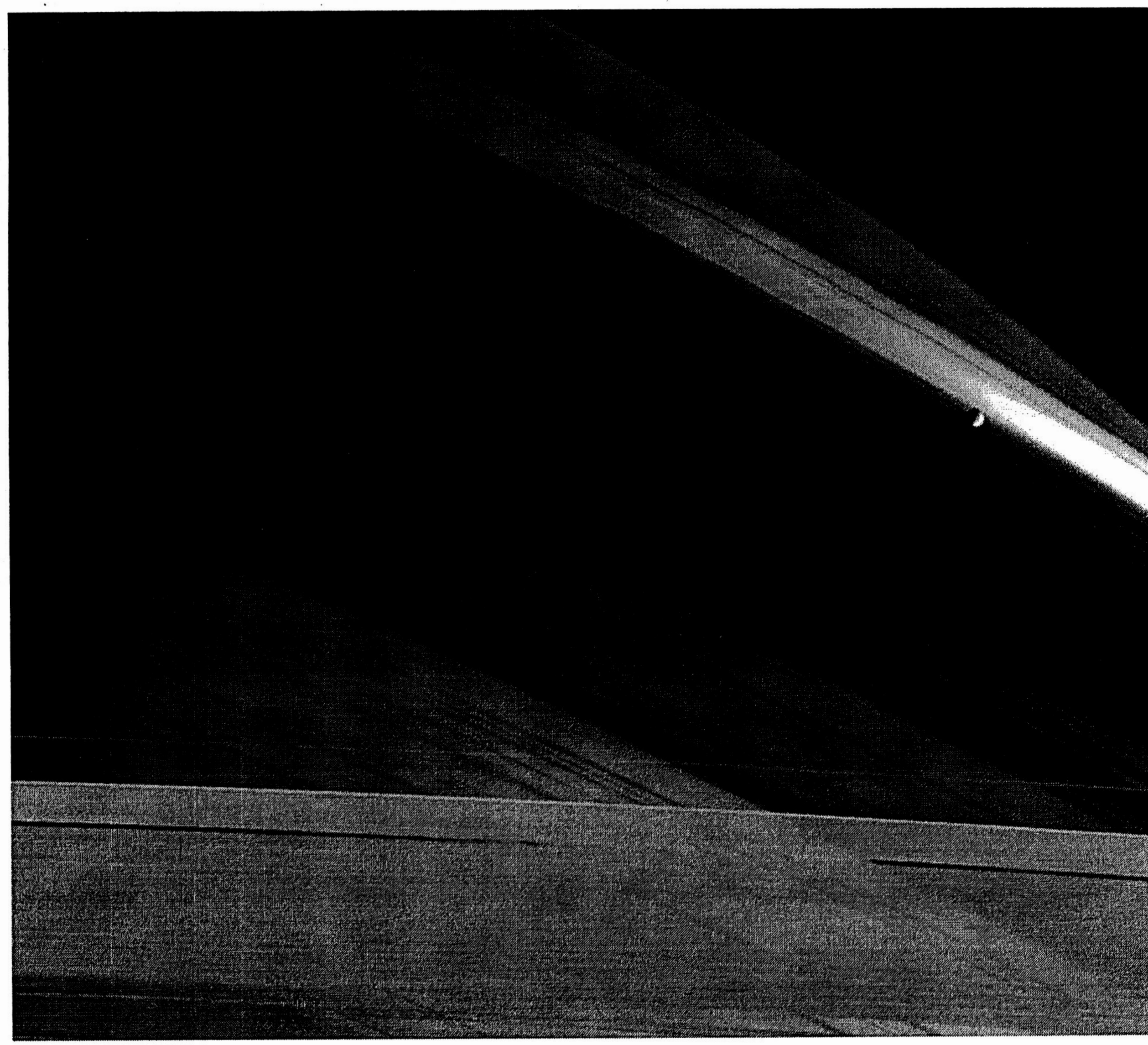


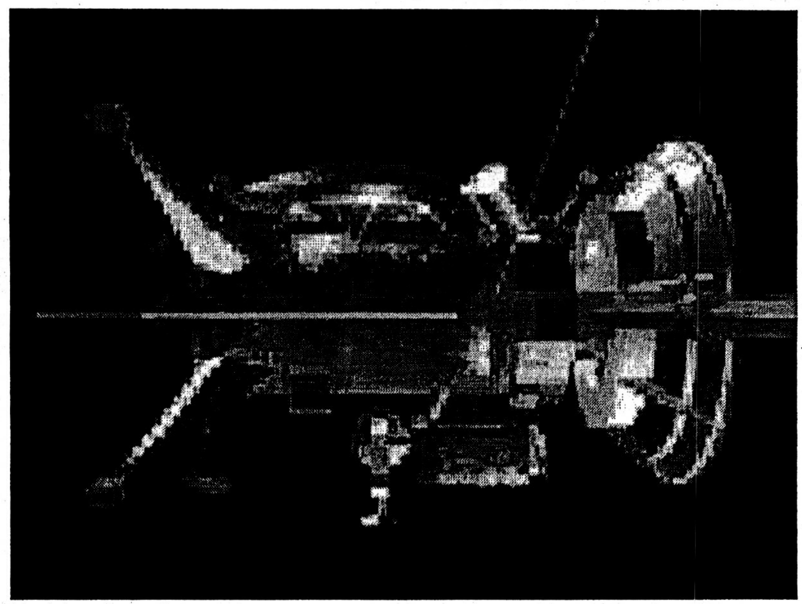
Rings edge-on: only 100 meters across! Dione (left) and Enceladus (right).

A dynamic ring system



Ring Splendor: preferential scattering of blue light gives Saturn's northern hemisphere its color. Shadows cast by the myriad rings are seen on the upper atmosphere, with the "A" ring in the foreground, and Mimas (398 km across) right of center.

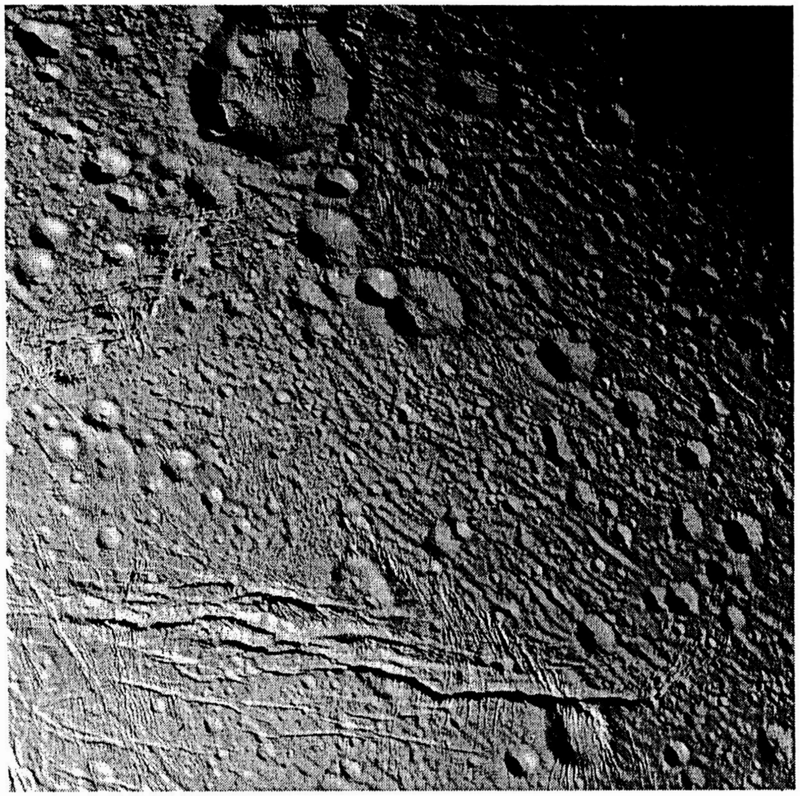




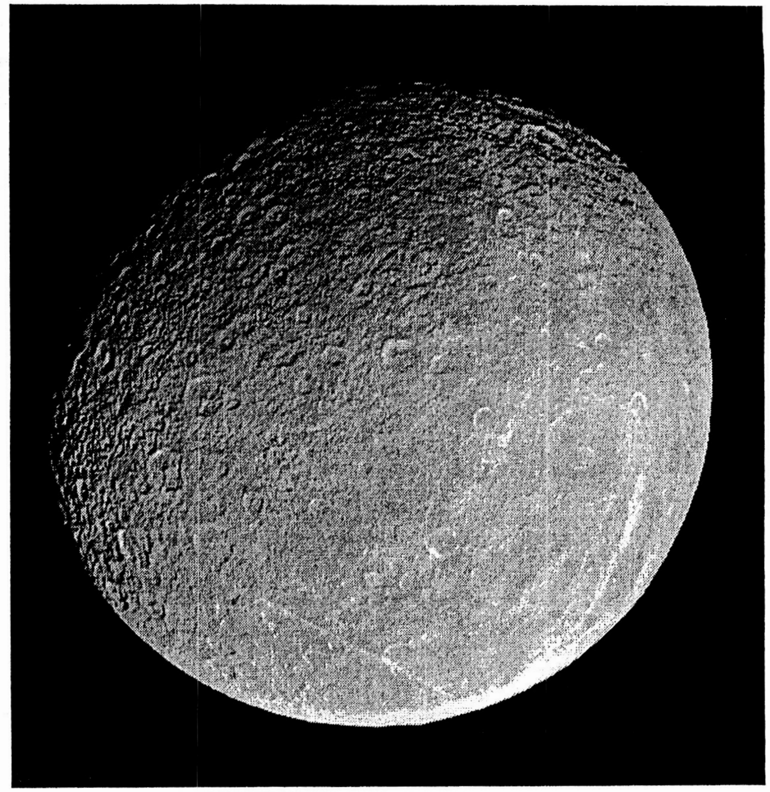
The spacecraft needs protection from small ring debris particles

What about the other moons?

Saturn's exploration continues …



False color image of Enceladus: to the human eye, it would appear almost completely white, as it reflects 90% of incident light.



Rhea: 1,528 km across, is the second largest moon of Saturn.

*Knowledge Capture: The Engineering Perspective**

- Concept Feasibility Study: What does it take to conceptualize a mission to an outer planet?

* Reference: Esper, J., "The Neptune / Triton Explorer Mission: A Concept Feasibility Study," Proceedings of the 5th IAA International Conference on Low-Cost Planetary Missions, ESTEC, Noordwijk, The Netherlands, 24-26 September 2003, ESA SP-542, November 2003.

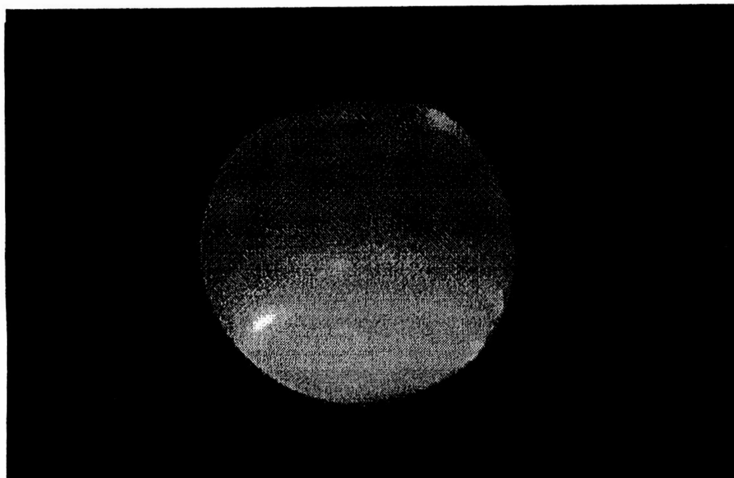
INTRODUCTION

- The outer solar system remains largely unexplored by robotic spacecraft. But we are slowly getting there …

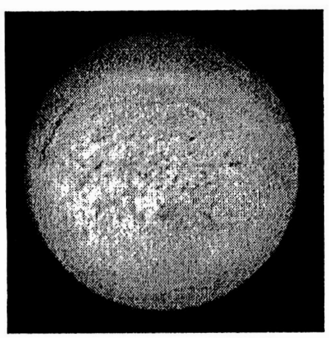
- Technological advances hold the promise to enable routine exploration affordably

- Neptune and Triton are high-priority scientific targets, and are the target of this example: The Neptune-Triton Explorer (*NExTEP*)

The Beginning: SELECT MEASUREMENTS & SCIENCE INSTRUMENTS



Triton



- Mapping and morphology
- Atmospheres and composition
- Neptune's rings and small satellites

• UV, VIS, IR Camera / Spectrometer:

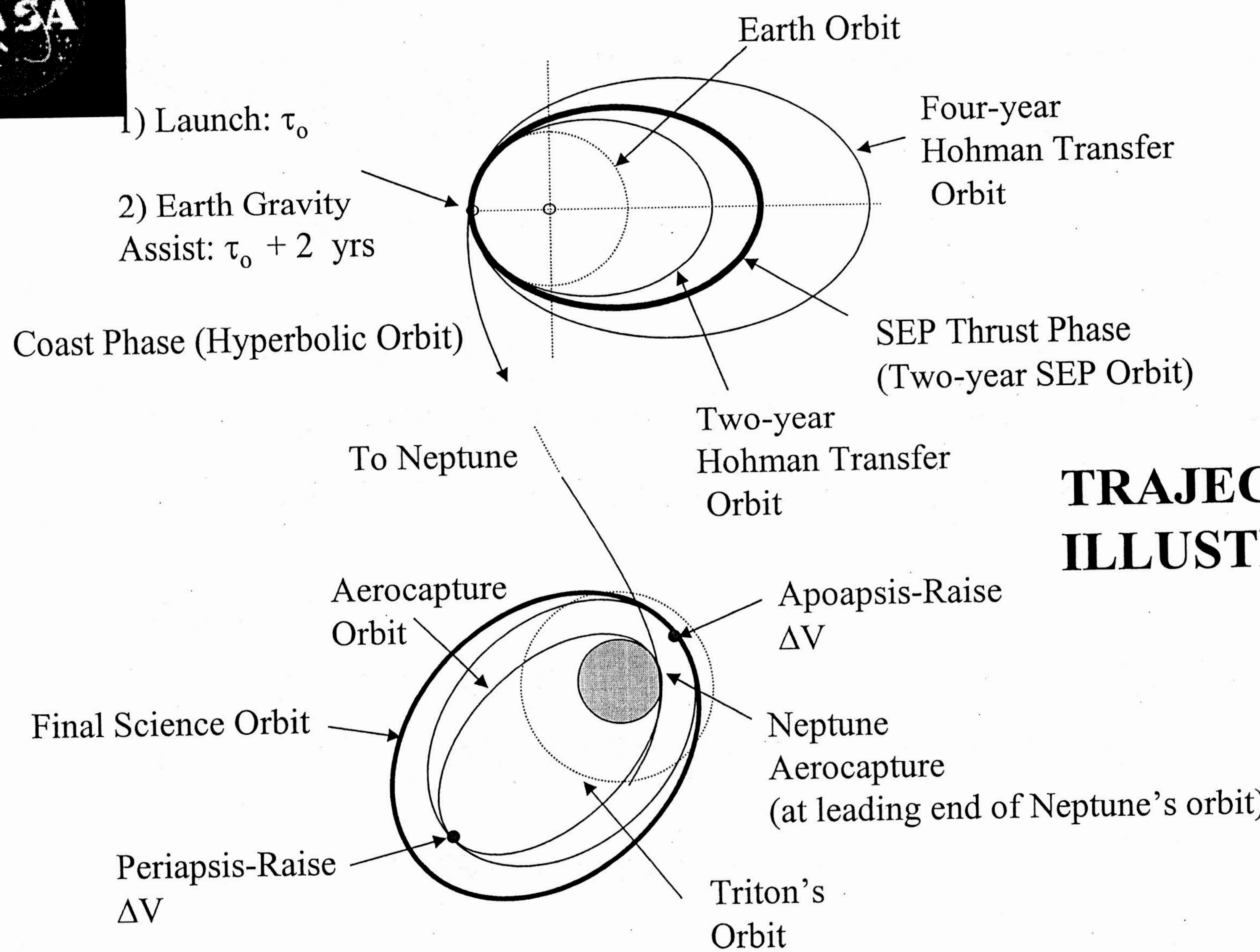
- Magnetospheres
- Ionospheres
- Plasma density, structure
- Composition, origin

• Particles and Fields Package:

TRAJECTORY COMPUTATION

- Analytical approximation method.
- SEP system used to gain energy equivalent to a 4-year Hohman Transfer orbit. Launch on a 2-year Hohman Transfer.
- Earth Gravity assist after two years with non-zero flight path angle. Injects spacecraft into a 6.7-year hyperbolic trajectory to Neptune.
- Aerocapture maneuver at Neptune, 500 km entry interface.
- Total Flight time = 8.7 years.

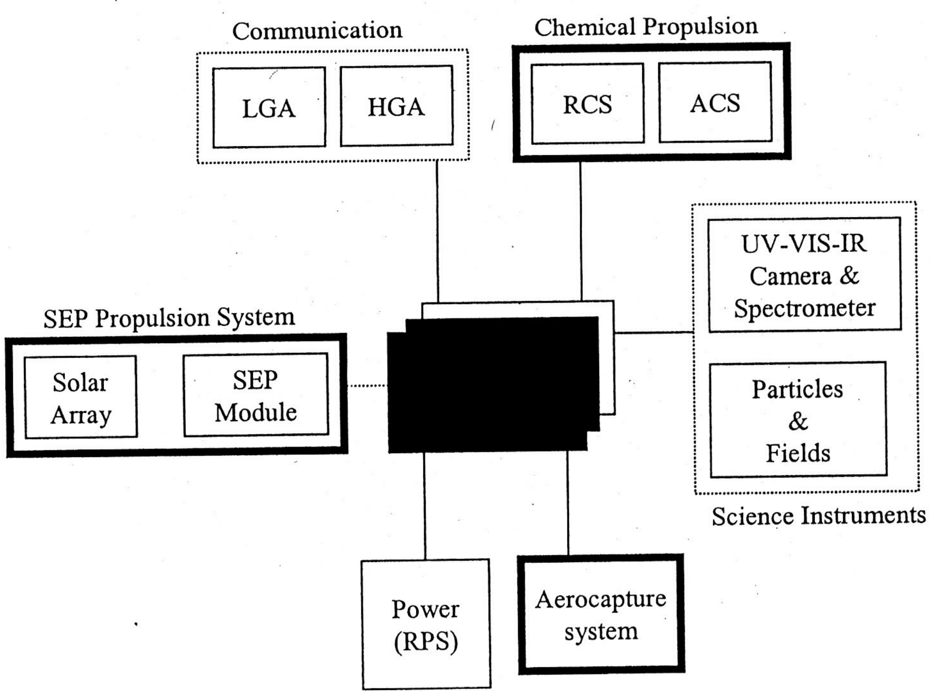
TRAJECTORY ILLUSTRATION



TRAJECTORY& AEROCAPTURE PARAMETER SUMMARY

SEEGA		**Aerocapture**	
Launch Energy, C_3 (km^2/sec^2)	25.7	Neptune-Centered Arrival Velocity (km/sec)	30.1
SEP on-board ΔV (km/sec)	2.9	B-Plane Offset (km)	25,264
Vehicle Injected Mass (kg)	77	Entry Interface Altitude (km)	500
Taurus Performance for C_3 (kg)	115	Desired ΔV at Aerocapture (km/sec)	7.1
First Leg Duration (years)	2	Entry Flight Path Angle (degrees)	-1.0
Flight Path Angle at Earth Swing-by (degrees)	9.2	Lift / Drag	0.1295
Heliocentric ΔV gained (km/sec)	7.8	Atmospheric Scale Height (km)	39.6
		Maximum Aerodynamic Load (g)	2
Hyperbolic Trajectory		Pull-up Altitude (km)	200 – 400
Flight Time (years)	6.7	Total Heat Load (Joules)	1.7×10^8
Excess Hyperbolic Velocity at Neptune (km/sec)	19.2	Maximum Body Average Heating Rate ($watts/m^2$)	9.4×10^6

SPACECRAFT DESIGN



- Subsystem and system integration
- Sharing of resources
- Advanced technology use

CHEMICAL PROPULSION SYSTEM

- Hydroxylammonium Nitrate (HAN) based monopropellant.

- Provides advantages for a deep space mission in the areas of safety, performance, density, and thermal management.

  - Operating temperature: -33° C to 65° C
  - Operating Power Requirement: ~ 1 watt
  - Operating Modes: Continuous and Pulsed
  - Specific Impulse: 260 seconds

CHEMICAL PROPULSION SYSTEM SIZING

CHEM Propulsion system sizing input	
Science Orbit Period (days)	11.8
Periapsis Raise ΔV (m/sec)	81
Apoapsis Lower ΔV (m/sec)	31
Trajectory Corrections and Orbital Maneuvering (m/sec)	223
Total CHEM on-board ΔV (m/sec)	335
CHEM System Parameters	
Monopropellant I_{sp} (sec)	260
Propellant Mass (kg)	5
Tank Mass (kg)	1
Main Engine Mass (kg)	0.6
Main Engine Thrust (Newton)	80

- Same system for RCS and ACS
- Simple Design

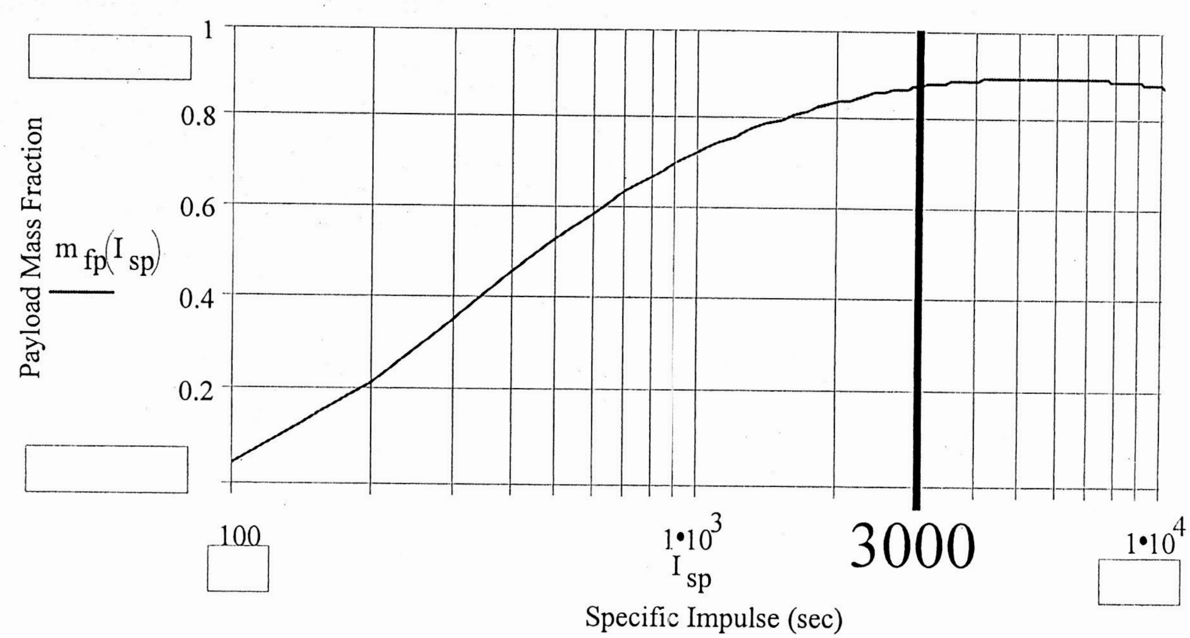
SOLAR ELECTRIC PROPULSION (SEP)

- Used payload mass-fraction-optimization

β_{Tm} => Prop sys specific mass = 0.01 kg/watt

η_T => Prop sys efficiency = 0.589

$$m_{fp}(I_{sp}) := \exp\left(\frac{-\Delta V_{SEPm}}{g_{em} \cdot I_{sp}}\right) - \left(1 - \exp\left(\frac{-\Delta V_{SEPm}}{g_{em} \cdot I_{sp}}\right)\right) \cdot \frac{\beta_{Tm} \cdot (g_{em} \cdot I_{sp})^2}{2 \cdot \eta_T \cdot \tau_{SEPs}}$$



SEP SYSTEM CHARACTERISTICS

- Optimum Specific Impulse (Isp) is above 3000 seconds. Choose Isp = 3,300 based on NSTAR derivative.

Specific Impulse (sec)	3,300
Payload Mass Fraction	0.882
Propellant Mass (kg)	6.4
Propellant Flow Rate (kg/sec)	2.2×10^{-7}
Electric Power Source (watts)	197
Thruster and PPU Mass (kg)	1.5
Tank and Feed System Mass (kg)	0.96
Solar Array Mass (kg)	2
SEP System Wet Mass (kg)	11

- Size array to provide 197 watts at 2.3 AU from the Sun (EOL).

- Power at BOL = 305 W
- Array Area = 3.6 m2
- Mass = 3.3 kg

COMMUNICATIONS SYSTEM: DOWNLINK

Characteristics

Science data communications through a 2-meter diameter High Gain Antenna (HGA).

Transmit using Ka-band (35 GHz) to the DSN 70-meter antenna. Maximum RF output 5 watts.

- Bandwidth = 4000 Hz
- Data Rate = 7 kbps
- SNR = 3.8 dB

Science Data Return

Orbital tour duration of 2 years.

3:1 data compression ratio

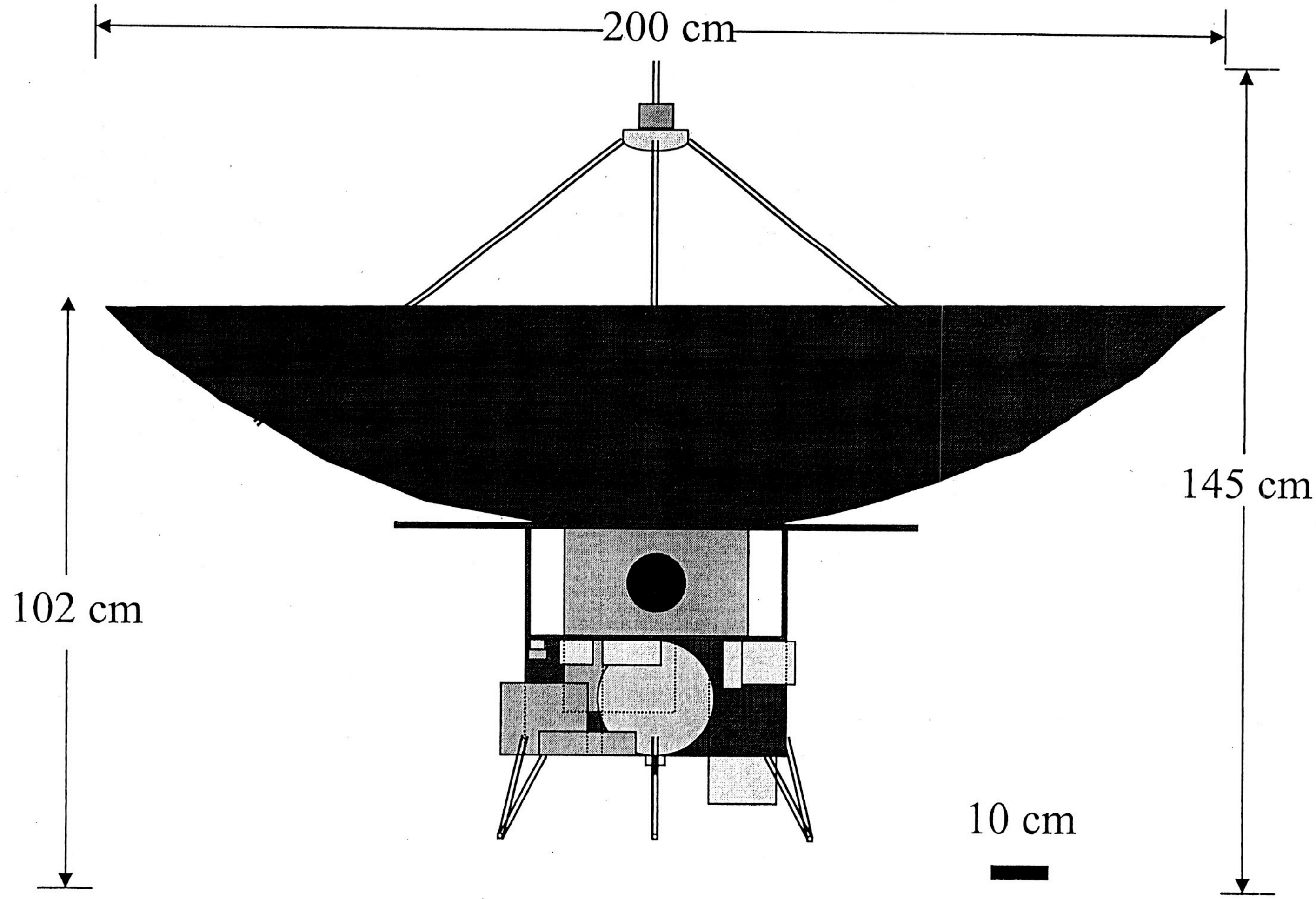
33 % DSN usage per 11.8-day orbit

446 Gbits of science data returned

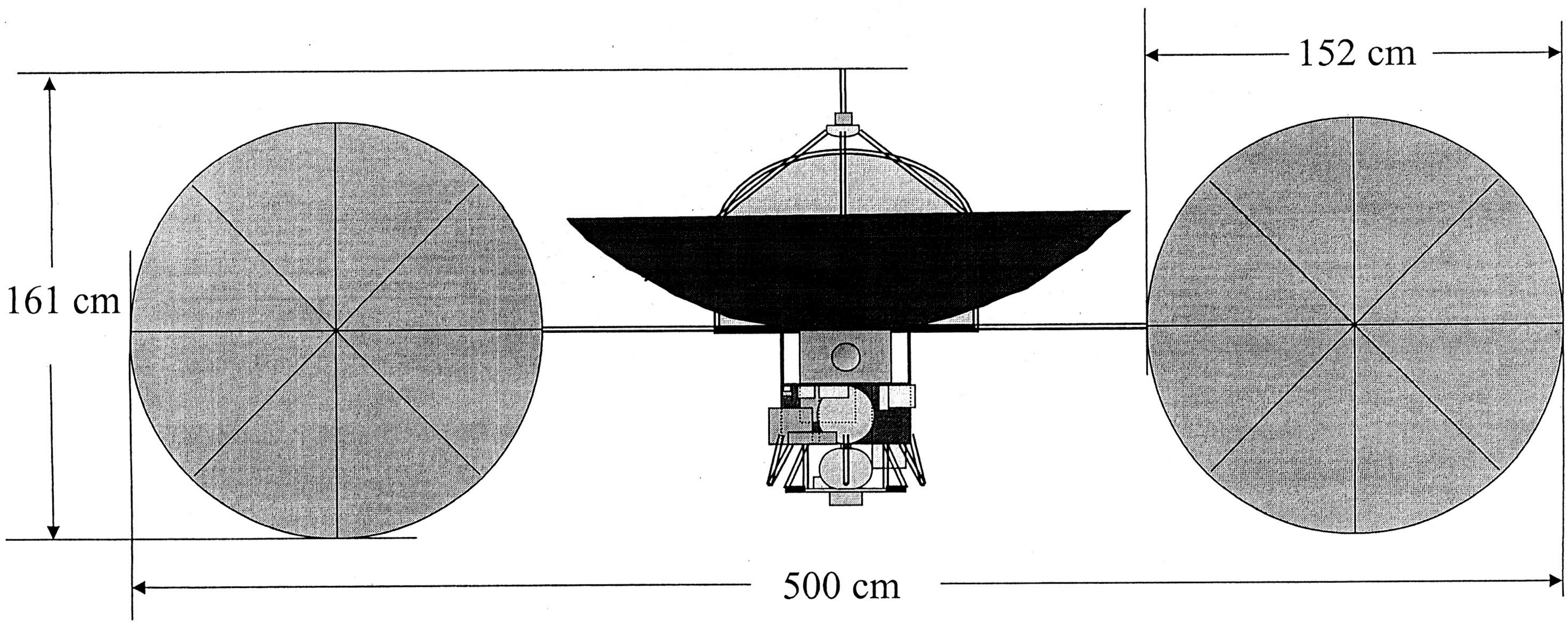
POWER SYSTEM

- Power required ~ 37 watts.
- Use a Radioactive Power Source.
- Scaled from prior X2000 program development.
- Roughly a 30-fold mass reduction in PuO_2 content from Cassini RTG.
- *Solar collector alternatives studied but not practical.*

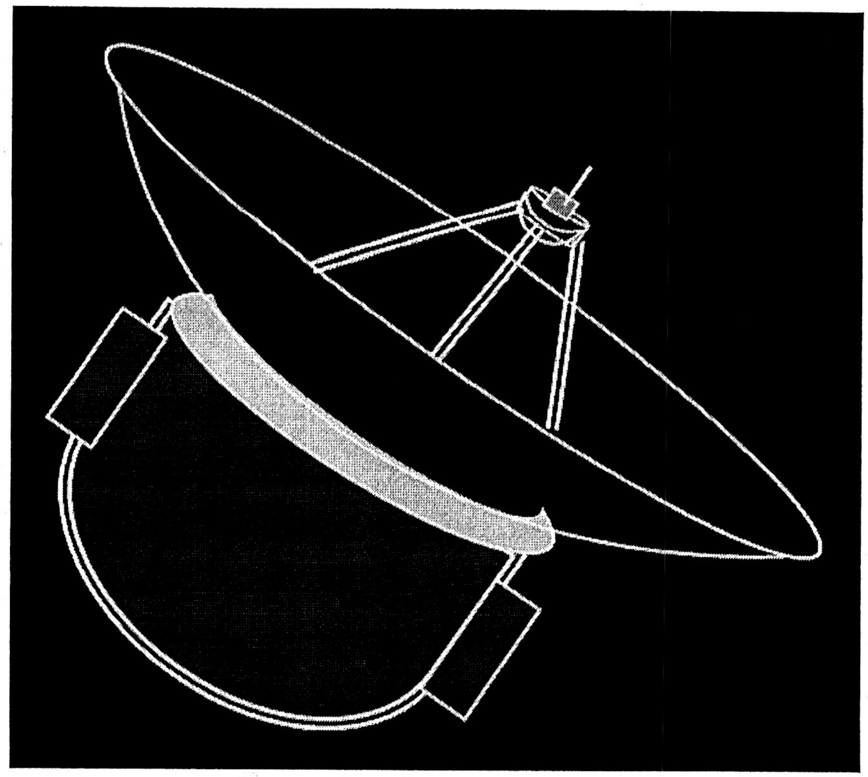
NEPTUNE ORBITER CONFIGURATION



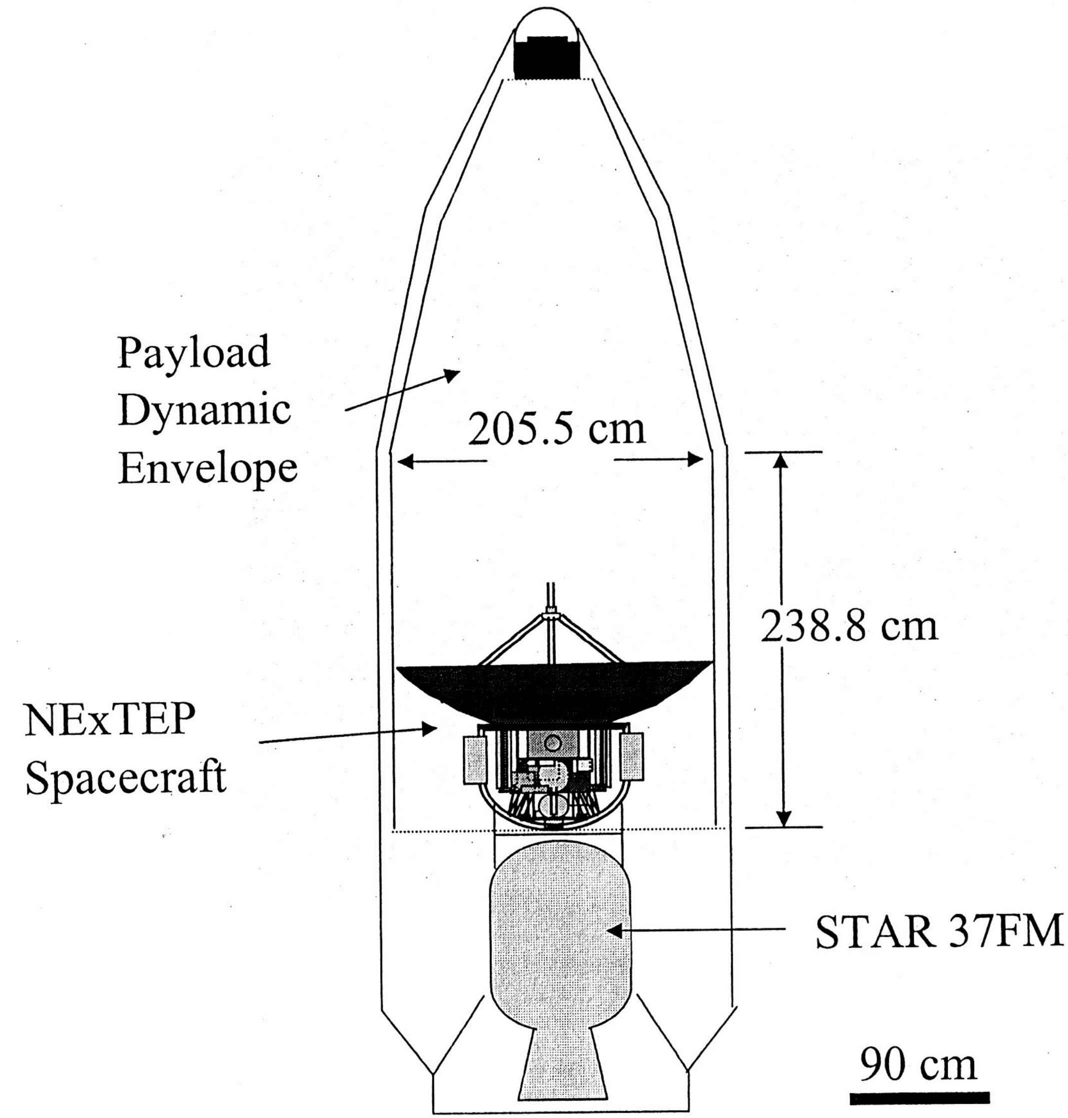
SEP MODE CONFIGURATION



AEROCAPTURE MODE CONFIGURATION



LAUNCH VEHICLE CONFIGURATION



MASS AND POWER SUMMARY

	Mass (kg)	Power (W)
Science	14	14
Str. & Mech	6	
C&DH	0.1	0.5
RF Comm	1	10
Power	4	
Thermal	0.7	1
Harness	1	
Rad Shield	3	
ACS	1	2
CHEM	7	3
Aeroshell	10	
SEP	17	198

Total Mass ~ 77 kg

Total Spacecraft Power ~ 37 W

Exploration must continue …