



# Expanding Science Knowledge: Enabled by Nuclear Power

Karla B. Clark

Jet Propulsion Laboratory

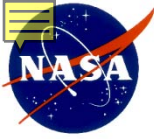
California Institute of Technology



# Introduction

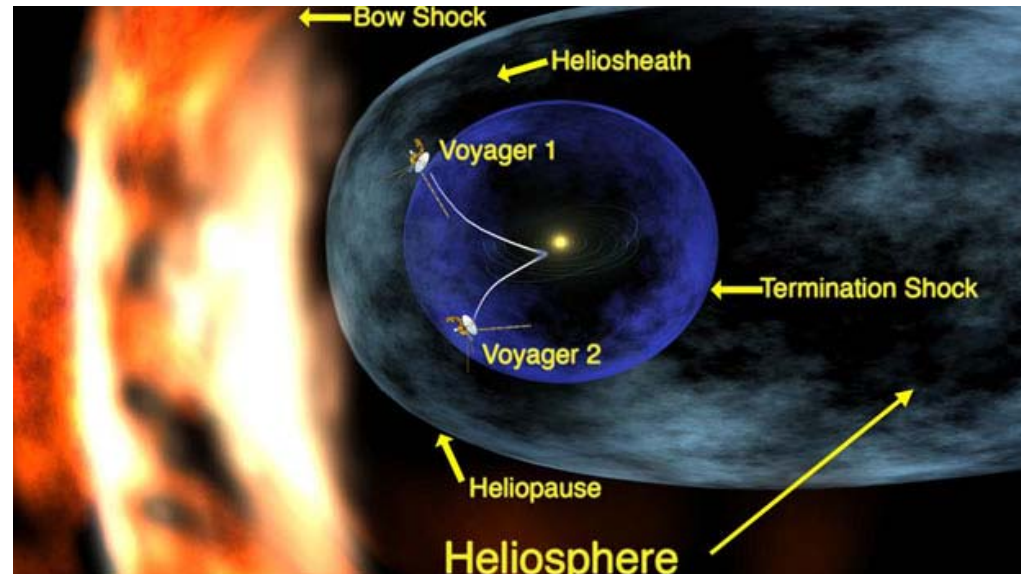
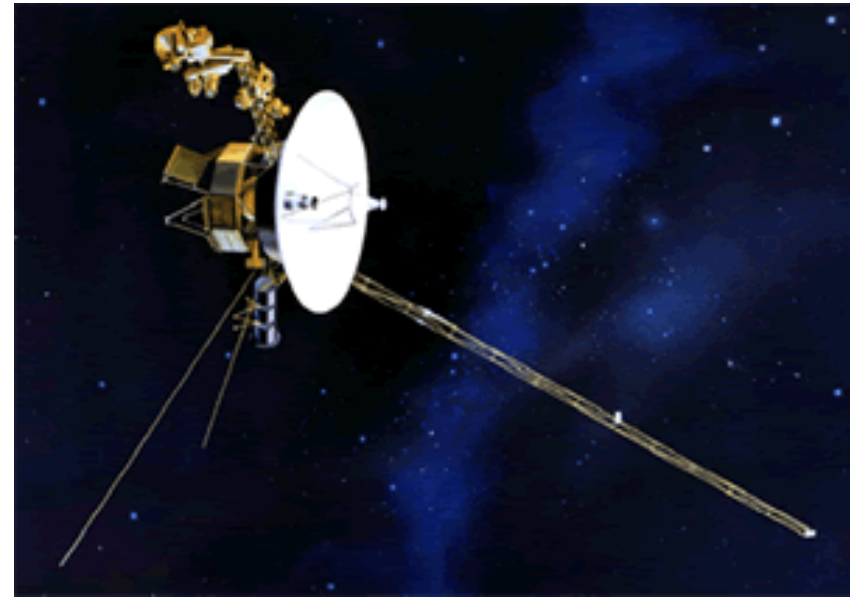
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- Nuclear power has a proud history
  - Successfully launched > 40 Radioisotope Power Sources (RPSs) on >20 space missions
- RPSs have been used to overcome the limitations of solar power
- Enables mission concepts
  - Opens possibility of trajectories far from Sun
  - Significant power for operating science instruments and returning significant science data
- Long life capability; > 25 years
- High in-flight reliability
- Operates effectively in extreme thermal and radiation environments



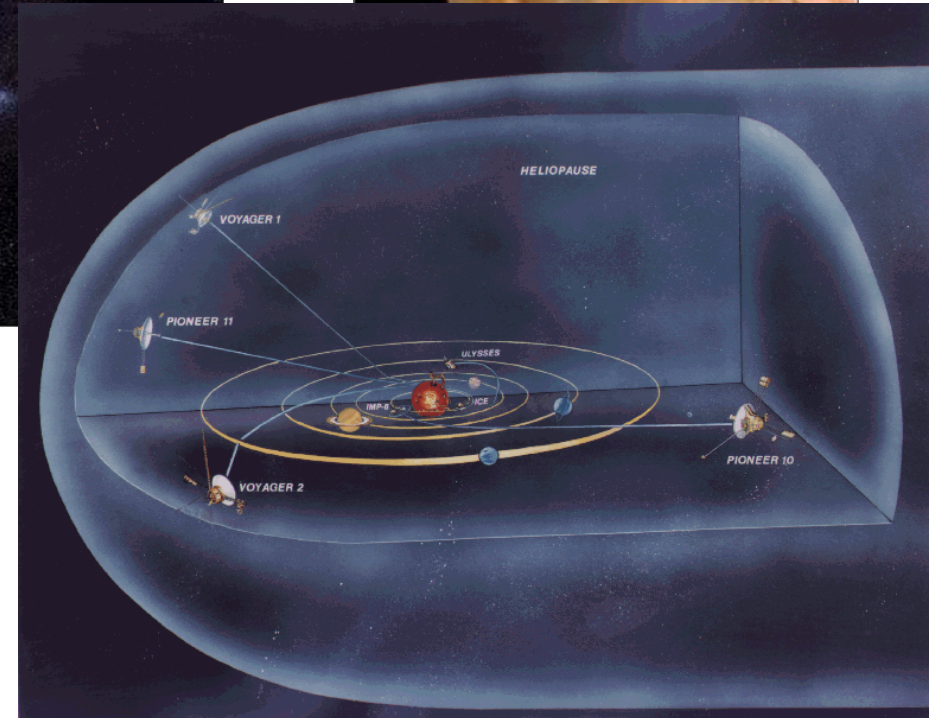
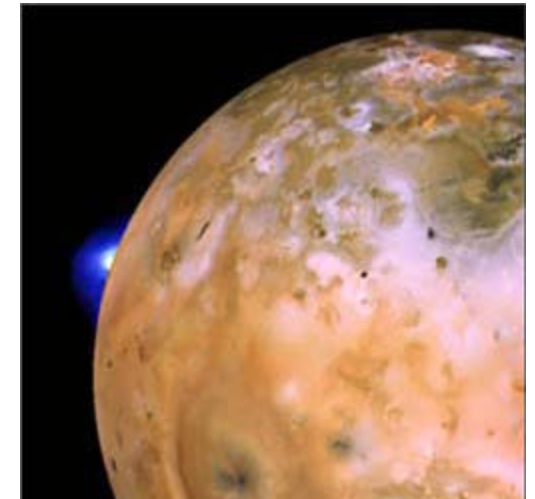
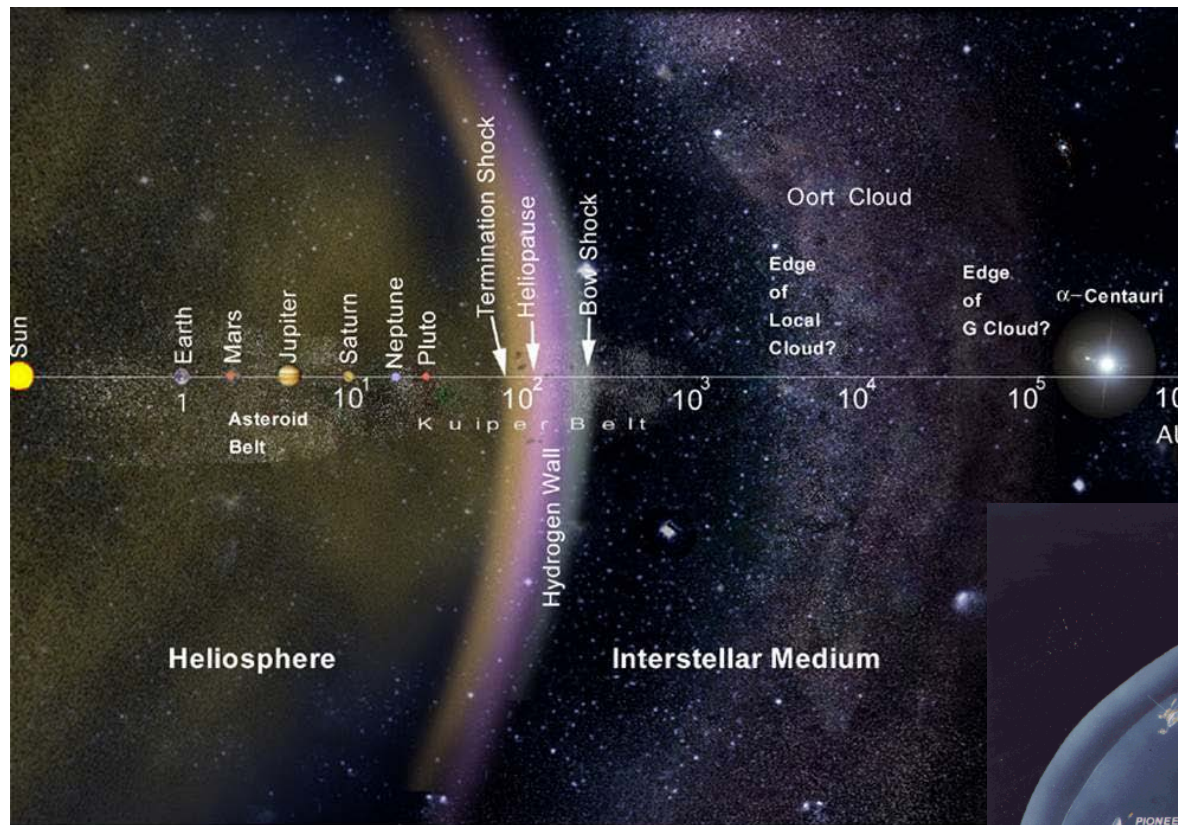
# Voyager Mission

- Two spacecraft, launched in 1977 to explore Jupiter and Saturn
  - Five year lifetime requirement
- Now in their 33rd year
- Voyager 1 and 2 are now in the "Heliosheath"
  - the outermost layer of the heliosphere where the solar wind is slowed by the pressure of interstellar gas.
- Voyager Interstellar Mission (VIM): to extend the NASA exploration of the solar system beyond the neighborhood of the outer planets to the outer limits of the Sun's sphere of influence, and possibly beyond.
  - Characterize the outer solar system environment
  - Search for the heliopause boundary, the outer limits of the Sun's magnetic field and outward flow of the solar wind.
  - Penetration of the heliopause boundary between the solar wind and the interstellar medium will allow measurements to be made of the interstellar fields, particles and waves unaffected by the solar wind





# Voyager Science Highlights

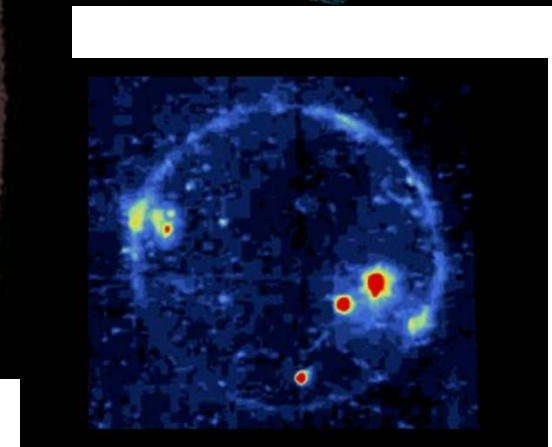
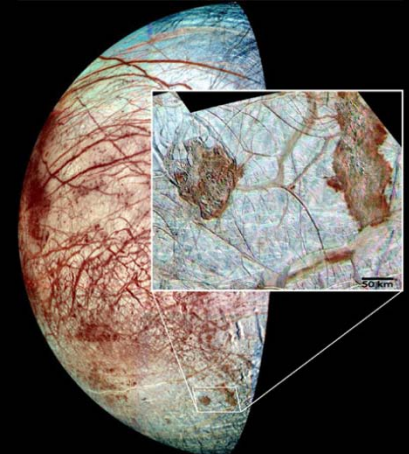
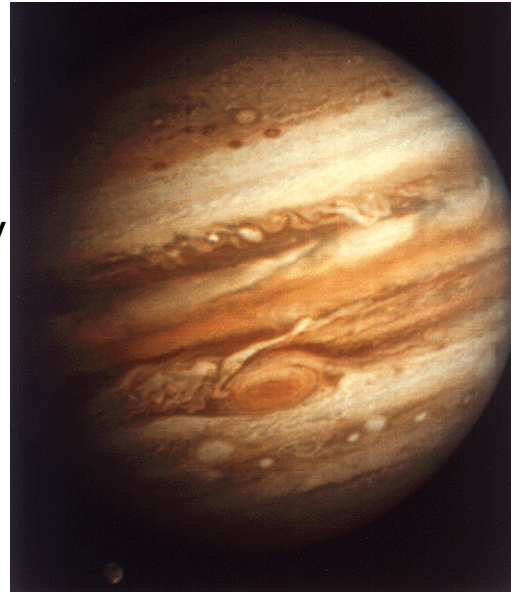


- Rewrote the planetary science and astrophysics books
  - observed nine erupting volcanoes on Io: first evidence in the solar system of active volcanism on a body other than Earth
  - Discovered moons, rings, magnetic fields, atmospheres, storms etc of Jupiter, Saturn, Uranus and Neptune
  - Found first direct evidence of the heliopause
  - Provided estimate for the location of the termination shock



# Galileo Mission

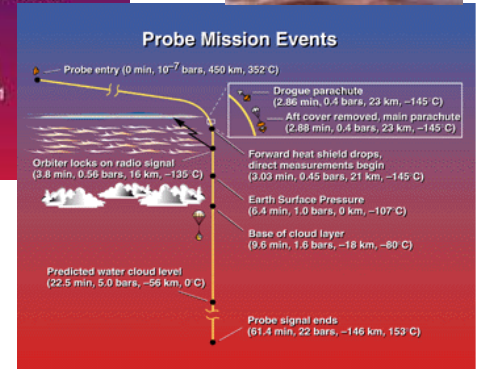
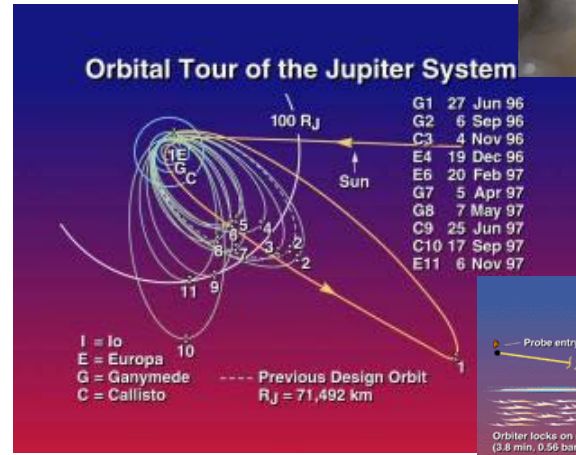
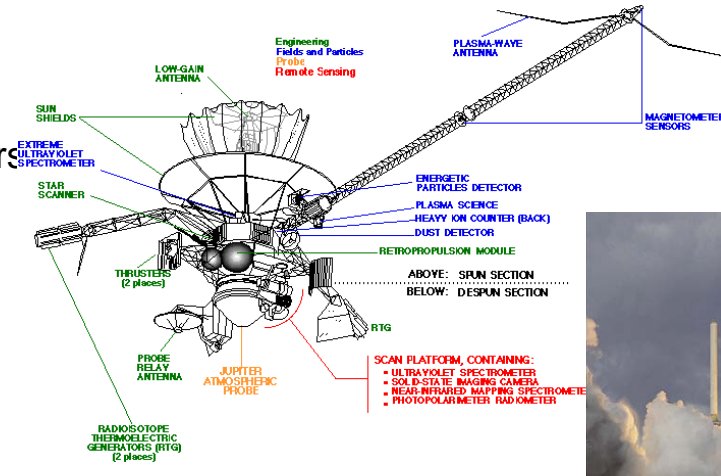
- Explore the Jupiter System
- International Mission
  - Galileo orbiter : NASA's JPL
  - Propulsion System : Germany
  - Probe : Ames Research Center and Hughes Aircraft Company
  - More than 100 scientists worldwide
- Jupiter :
  - Giant Gas planet comprised mostly of Hydrogen and Helium
  - Galileo Galilei discovered original 4 moons (Io, Europa, Ganymede and Callisto)
  - Now over 63 moons known
  - Small ring system
  - Average distance from Sun : 5.2 AU





# Galileo Mission

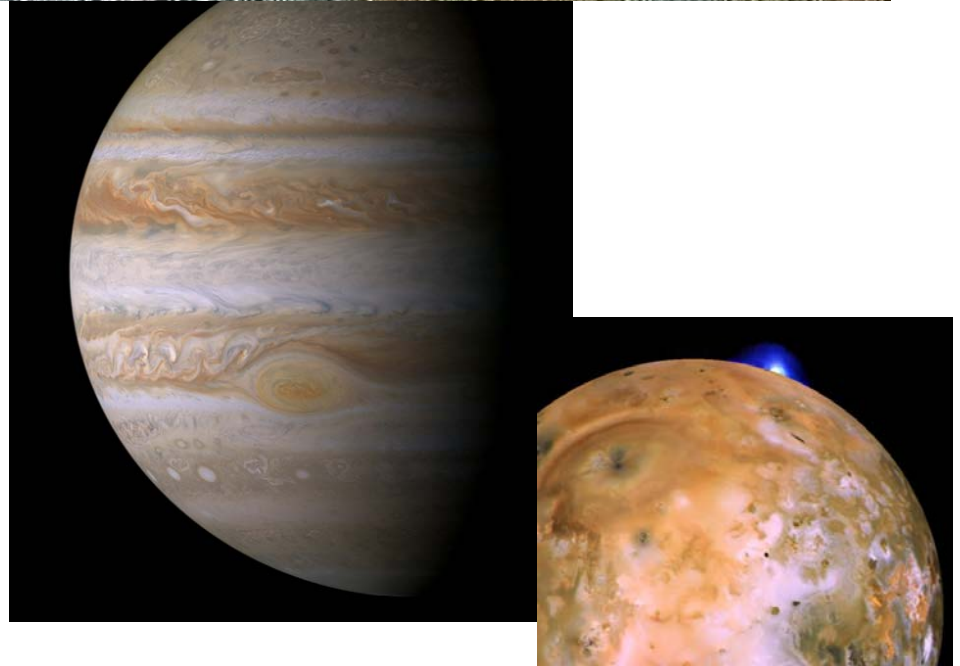
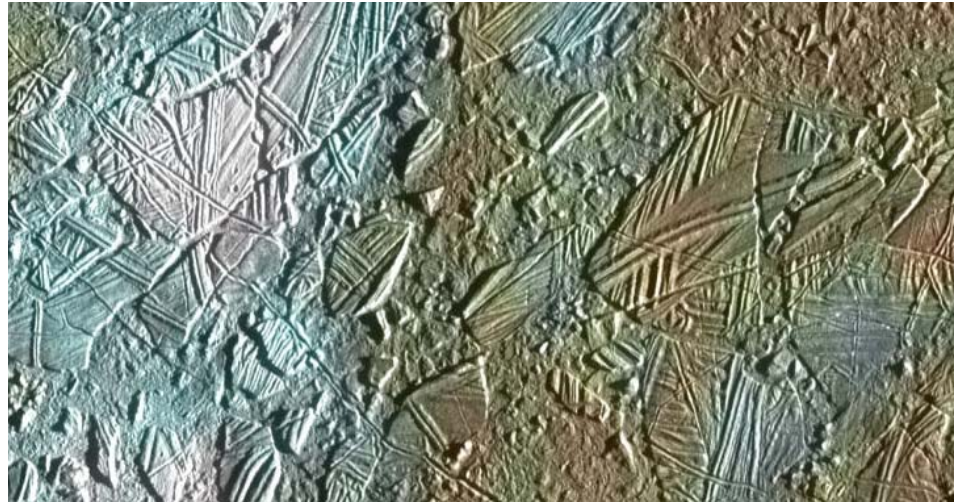
- Spacecraft
  - Stands ~5.3 m (20 ft)
  - Weighs ~1298 kg (4,902 lb) dry
  - Propellant ~925 kg (2040 lb)
  - 2 Radioisotope Thermoelectric Generators (RTGs) for ~570 W at launch
  - 10 instruments
- Probe
  - 339 kg (750 lb)
  - 6 instruments
- Mission Design
  - Shuttle launch : October 1989
  - Release probe : July 1995
  - Jupiter Orbit Insertion : December 1995 using main engines
  - Prime Mission : 11 orbits (3 Europa flybys) in 2 years
  - Extended Mission : 23 orbits (8 Europa flybys) in 6 years
  - Distance traveled : ~2.8 Billion miles
- Probe Mission: 1 hour descent into Jupiter's Atmosphere
- Plunged into Jupiter (Sept 2003) to protect possible ocean on Europa
  - Speed at impact ~108,000 miles/hr





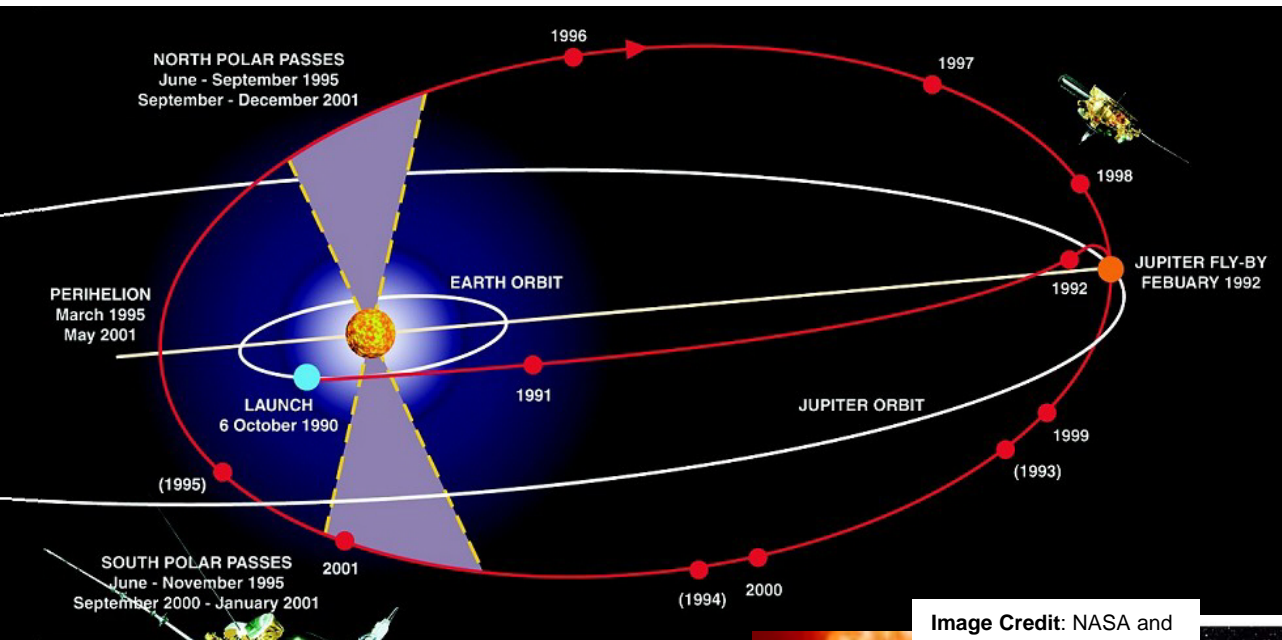
# Galileo Science Highlights

- Discovered evidence of sub-surface saltwater oceans on Europa, Ganymede and Callisto
- First direct probe measurements of the clouds and atmosphere of Jupiter
- Conducted long term observations of the Jovian system including atmosphere, rings, moons and magnetosphere.
- Revealed the intensity of volcanic eruptions on Io





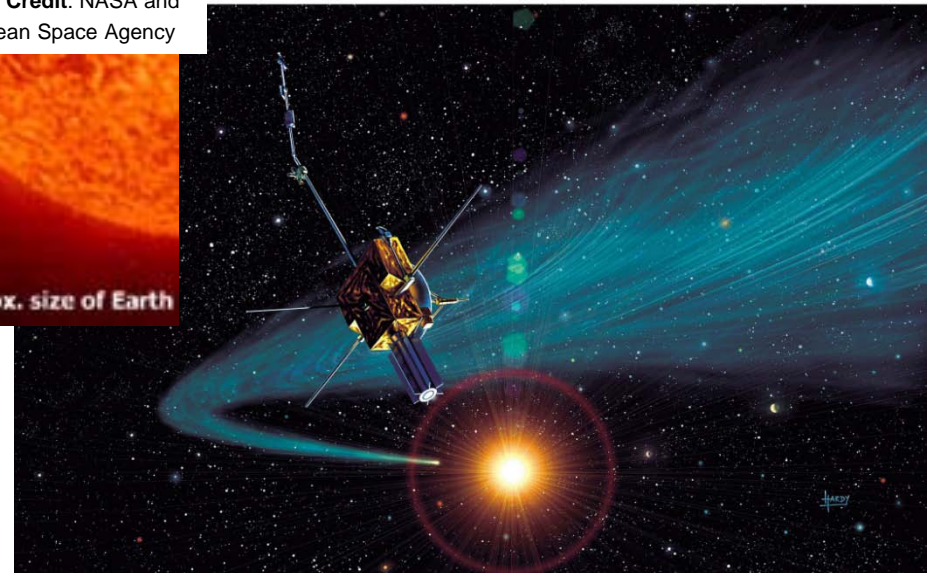
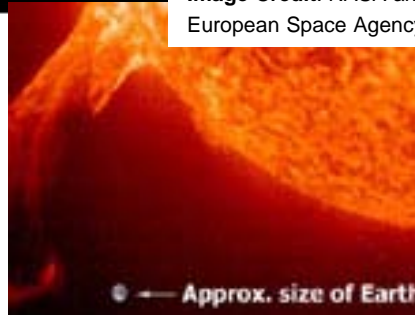
# Ulysses Mission



## Understanding of the Global Structure of the Sun's environment

- International Mission
  - Spacecraft : European Space Agency
  - RTG, Shuttle : United States
  - More than 250 scientists worldwide
- Sun
  - 22 year magnetic field cycle
  - 11 year solar cycle

Image Credit: NASA and European Space Agency



## Mission Design

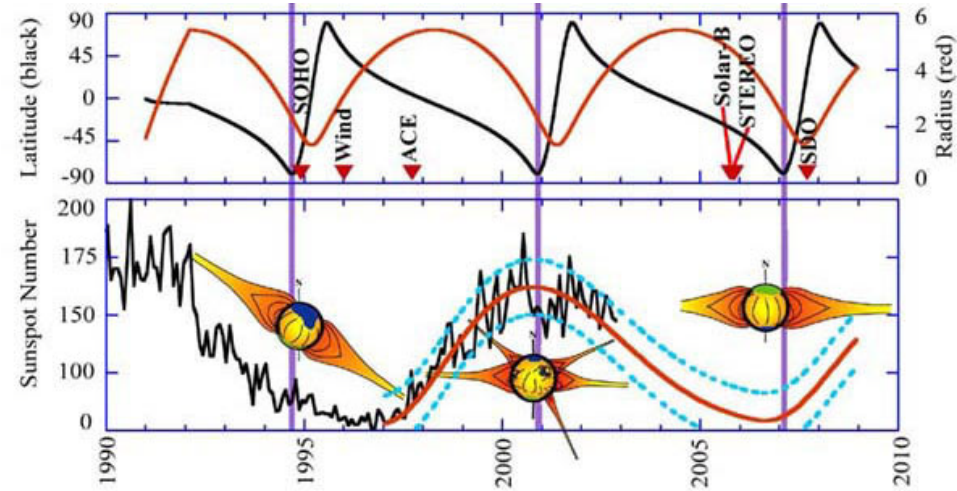
- Shuttle launch : October 1990
- Jupiter Gravity Assist trajectory to polar orbit about the Sun out of ecliptic plane
- Prime Mission : 5 year – 2 polar passes (1 South, 1 North)
- To Date : 6 polar passes (3 South, 3 North)
- End of mission: June 2009



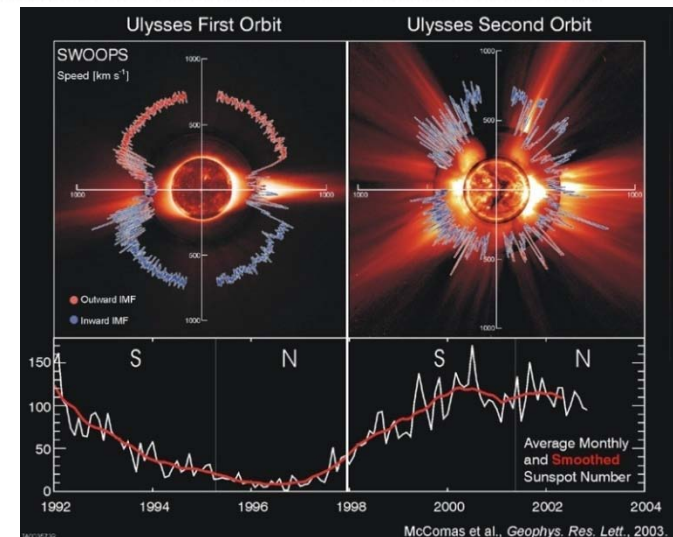


# Ulysses Science Highlights

- Characterized the global structure of the heliosphere near solar minimum and at solar maximum
- First survey of the heliosphere in four dimensions (three spatial dimensions and time)
- Measured properties of particles and fields in the inner heliosphere leading to major impacts on our knowledge of the interstellar medium surrounding the heliosphere and on the origin of gamma-ray bursts
- Discovered two distinct solar wind states, a fast high-latitude wind and a slow low-latitude wind separated by a sharp boundary
- The first-ever measurement of the interstellar  $3\text{He}/4\text{He}$  ratio, the value of which suggests that the amount of dark matter produced in the Big Bang was greater than previously thought



**Middle:** Ulysses orbital latitude and radius, plus the launch dates for SOHO, Wind, ACE, Solar-B, STEREO, and SDO. Bottom: Solar sunspot number and predicted sunspot number through 2008 (Hathaway et al., 1994, & priv. comm.). Schematics of the typical shape of the corona at various times in the solar cycle are superimposed on this panel. The time scale runs from just before the launch of Ulysses in 1990 through 2010. Vertical lavender bars mark the beginning of each Ulysses fast latitude scan.

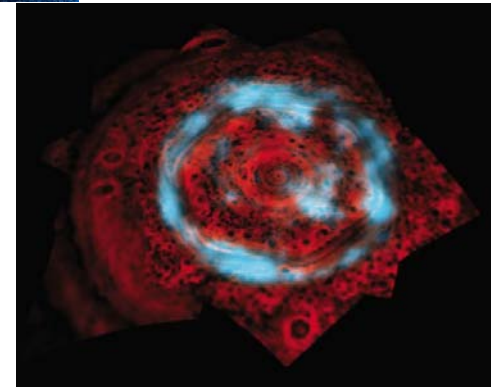
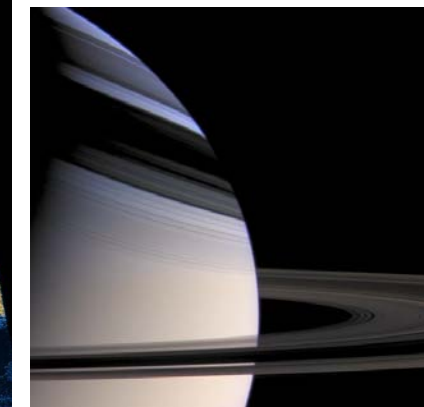
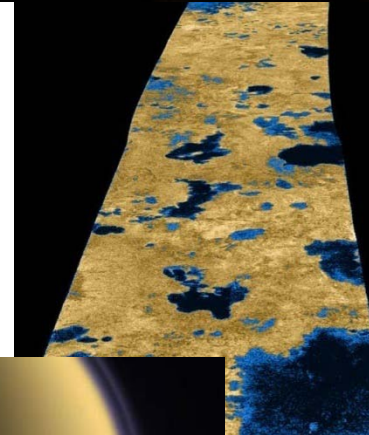




# Cassini-Huygens Mission

## *Explore the Saturnian System including the Rings and Titan*

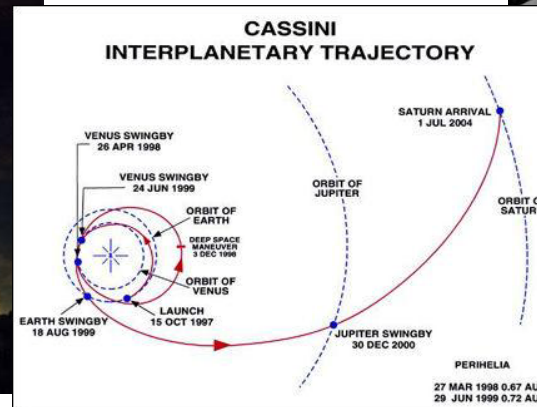
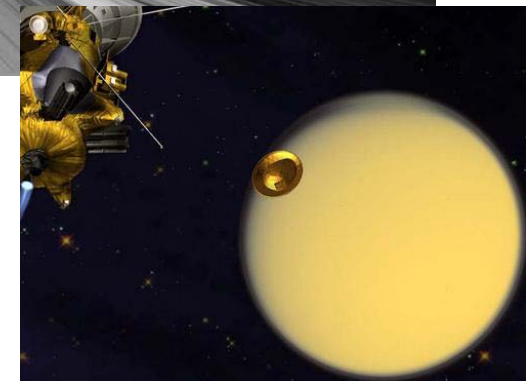
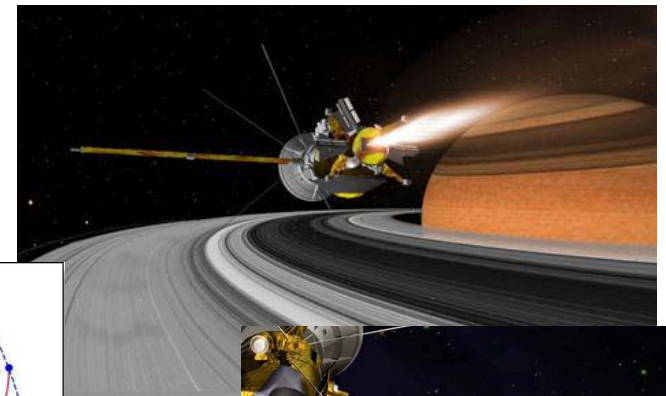
- International Mission
  - 3 space agencies
    - Cassini orbiter : NASA's JPL with 17 nations contributing
    - Huygens probe : European Space Agency
    - The Italian Space agency : high-gain communication antenna.
  - More than 250 scientists worldwide
- Saturn :
  - Giant Gas planet comprised mostly of Hydrogen and Helium
  - Equatorial winds ~1800 km/s
  - extensive and complex ring system, extending hundreds of thousands of miles, made up of billions of particles of ice and rock
  - 34 moons
  - Average Distance from Sun : 10 AU
- Titan :
  - Larger than Mercury and Pluto
  - Has its own atmosphere
  - May contain pre-biotic clues to Earth's past





# Cassini-Huygens Mission

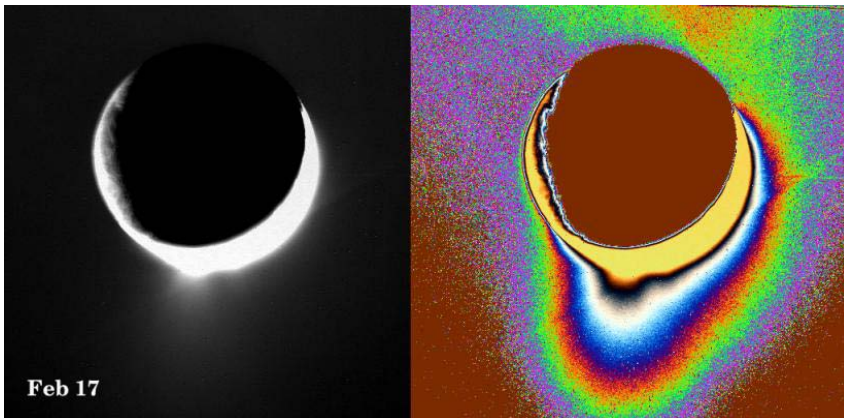
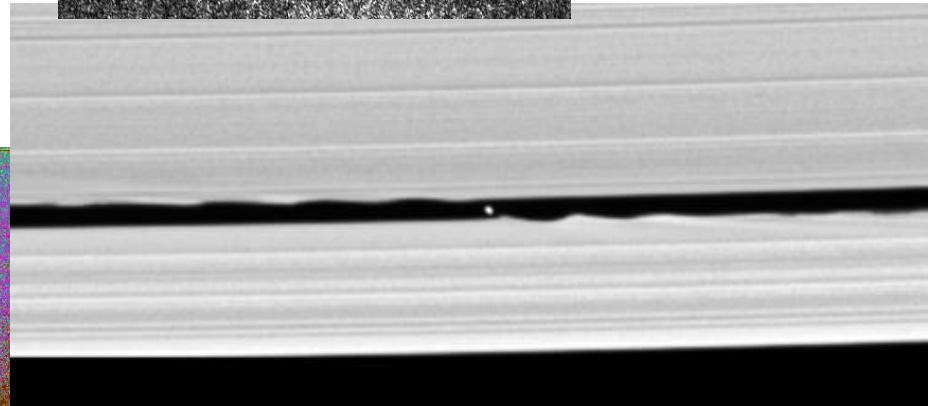
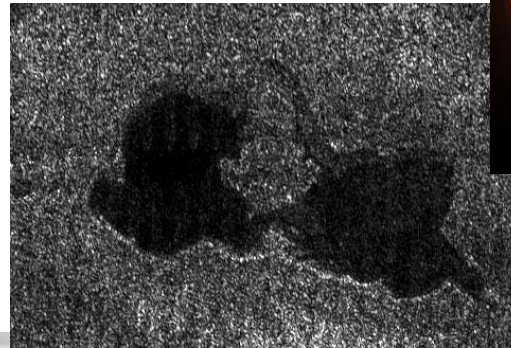
- **Spacecraft**
  - Stands ~8 m (26 ft)
  - Weighs ~2,442 kg (5384 lb) dry
  - Propellant ~3,132 kg (6,905 lb)
  - 3 Radioisotope Thermoelectric Generators (RTGs) for ~875W at launch
  - 12 instruments
- **Probe**
  - 319 kg (703 lb)
  - 6 instruments
- **Mission Design**
  - Titan IV launch : October 1997
  - Venus-Venus-Earth-Jupiter Gravity Assist trajectory
  - Saturn Orbit Insertion : July 2004 using main engines
  - Release probe
  - Prime Mission : 74 orbits (44 Titan flybys) in 4 years
- **Probe Mission:**
  - 3 hour descent into Titan's Atmosphere





# Cassini-Huygens Science Highlights

- First probe of Titan's atmosphere and surface landing
- Infrared and radar mapping of Titan's cloud covered surface discovers hydrocarbon lakes
- Long term studies of the ring system and ring moons
- Discovery of erupting geysers on Enceladus





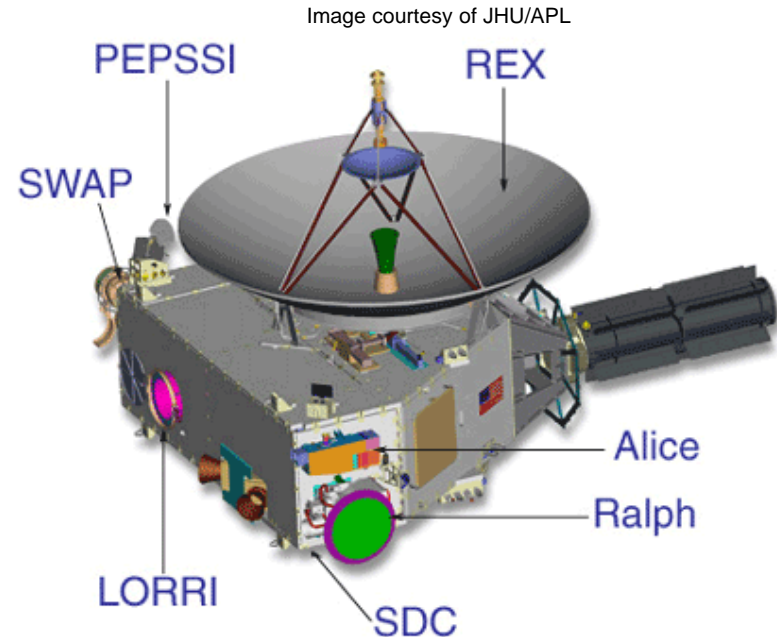
# New Horizons

## Mission Objectives

- Map surface composition of Pluto and Charon
- Characterize geology and morphology ("the look") of Pluto and Charon
- Characterize the neutral atmosphere of Pluto and its escape rate
- Search for an atmosphere around Charon
- Map surface temperatures on Pluto and Charon
- Search for rings and additional satellites around Pluto
- PLUS... conduct similar investigations of one or more Kuiper Belt Objects

## Instruments

- **Ralph's** main objectives are to obtain high resolution color maps and surface composition maps of the surfaces of Pluto and Charon.
- **Alice** is an ultraviolet imaging spectrometer that will probe the atmospheric composition of Pluto.
- **REX** is an radio experiment
- **LORRI** consists of a telescope with a 8.2-inch (20.8-centimeter) aperture that focuses visible light onto a charge coupled device (CCD).
- **SWAP** measures charged particles from the solar wind near Pluto to determine whether Pluto has a magnetosphere and how fast its atmosphere is escaping.
- **PEPSSI** searches for neutral atoms that escape Pluto's atmosphere and subsequently become charged by their interaction with the solar wind
- **SDC** counts and measure the sizes of dust particles along New Horizons' entire trajectory

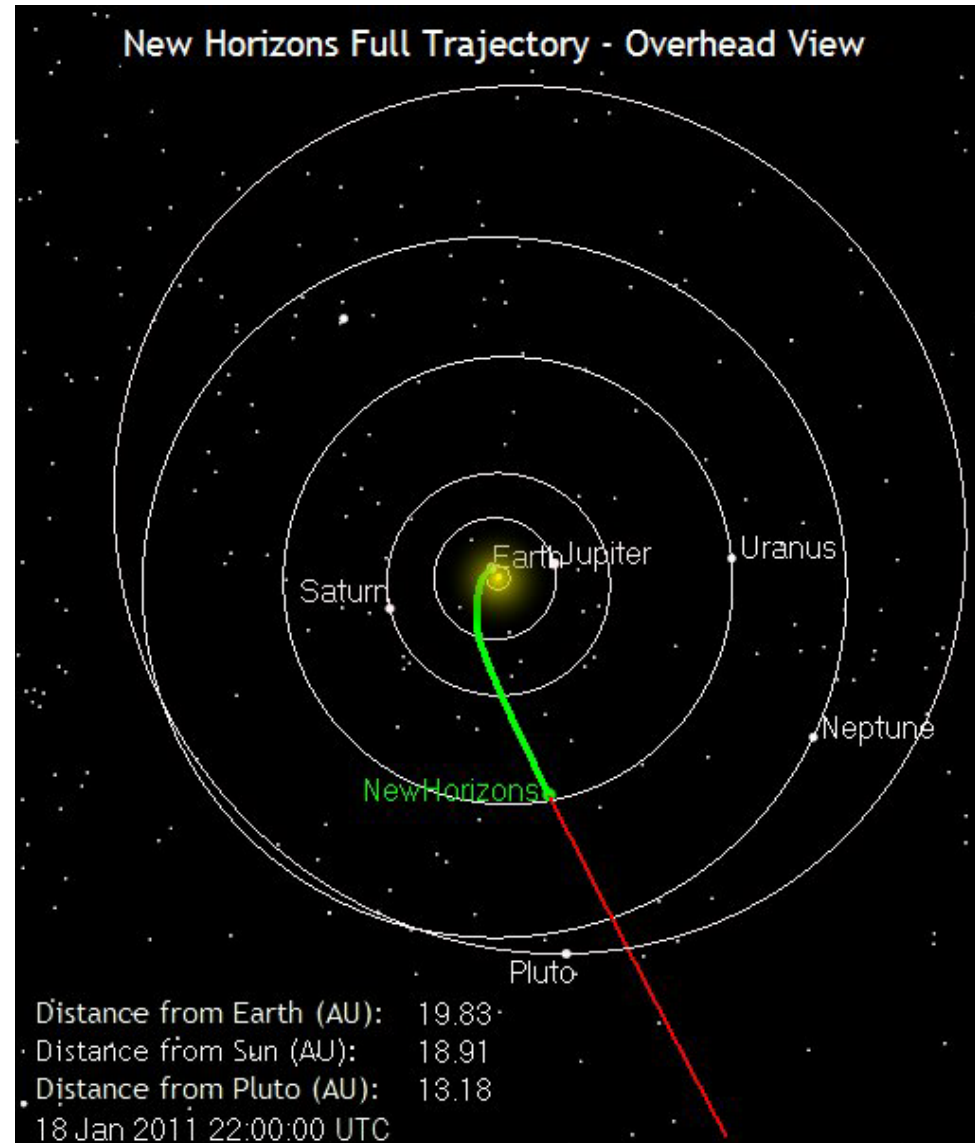




# New Horizons Mission Design

- Jupiter Gravity Assist
- Jupiter closest approach distance and speed at Jupiter: About 2.27 million kilometers (1.4 million miles) at 21 kilometers per second (47,000 miles per hour).
- Earliest possible Pluto-Charon Flyby: July 2015.
- Planned Pluto closest approach distance and speed: About 10,000 kilometers (6,200 miles) at 14 kilometers per second (31,300 miles per hour).
- Planned Charon closest approach and speed: About 27,000 kilometers (16,800 miles) at same approximate Pluto flyby speed.
- One-way speed-of-light (radio transmission) time from Pluto to Earth in July 2015: 4 hours, 25 minutes. This increases by a little less than two minutes per year for later arrivals.
- Pluto distance from Earth in July 2015: Approximately 4.92 billion kilometers (3.06 billion miles, or 32 astronomical units). This increases by about 1% per year for later arrivals.

Image courtesy of JHU/APL





# Curiosity – Mars Science Laboratory

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# Mars Science Laboratory Science



Determine whether life ever  
arose on Mars



Characterize the climate  
of Mars



Characterize the  
geology of Mars



Prepare for Human  
Exploration

## Biological objectives:

- Determine the nature and inventory of organic carbon compounds
- Inventory the chemical building blocks of life (carbon, hydrogen, nitrogen, oxygen, phosphorous, and sulfur)
- Identify features that may represent the effects of biological processes

## Geological and geochemical objectives:

- Investigate the chemical, isotopic, and mineralogical composition of the martian surface and near-surface geological materials
- Interpret the processes that have formed and modified rocks and soils

## Planetary process objectives:

- Assess long-timescale (i.e., 4-billion-year) atmospheric evolution processes
- Determine present state, distribution, and cycling of water and carbon dioxide

## Surface radiation objective:

- Characterize the broad spectrum of surface radiation, including galactic cosmic radiation, solar proton events, and secondary neutrons





# Future potential missions

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- Discovery12 or Mars Lander
- Lunar Precursor
- JEO
- Discovery 14
- New Frontiers 4 and 5
- Discovery 16
- OPF2 (TSSM)



# Summary

- The availability of RPS power opens up new and exciting mission concepts
  - New trajectories available
  - Power for long term science and operations
- Astonishing science value associated with these previously non-viable missions

Example extended mission opportunities are extensive with RPS power

	Prime Mission	Extended Mission
Voyager	5 years	33+ years
Galileo	2 years at Jupiter	8 years at Jupiter
Ulysses	5 years	19 years
Cassini-Huygens	4 years at Saturn	16 years at Saturn planned

