The Johns Hopkins University
APPLIED PHYSICS LABORATORY

Space Nuclear Power and Propulsion: The Good, the Bad, and the Ugly

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Nuclear & Emerging Technologies for Space (NETS-2011)

Plenary II 10:30 am – 12:30 pm

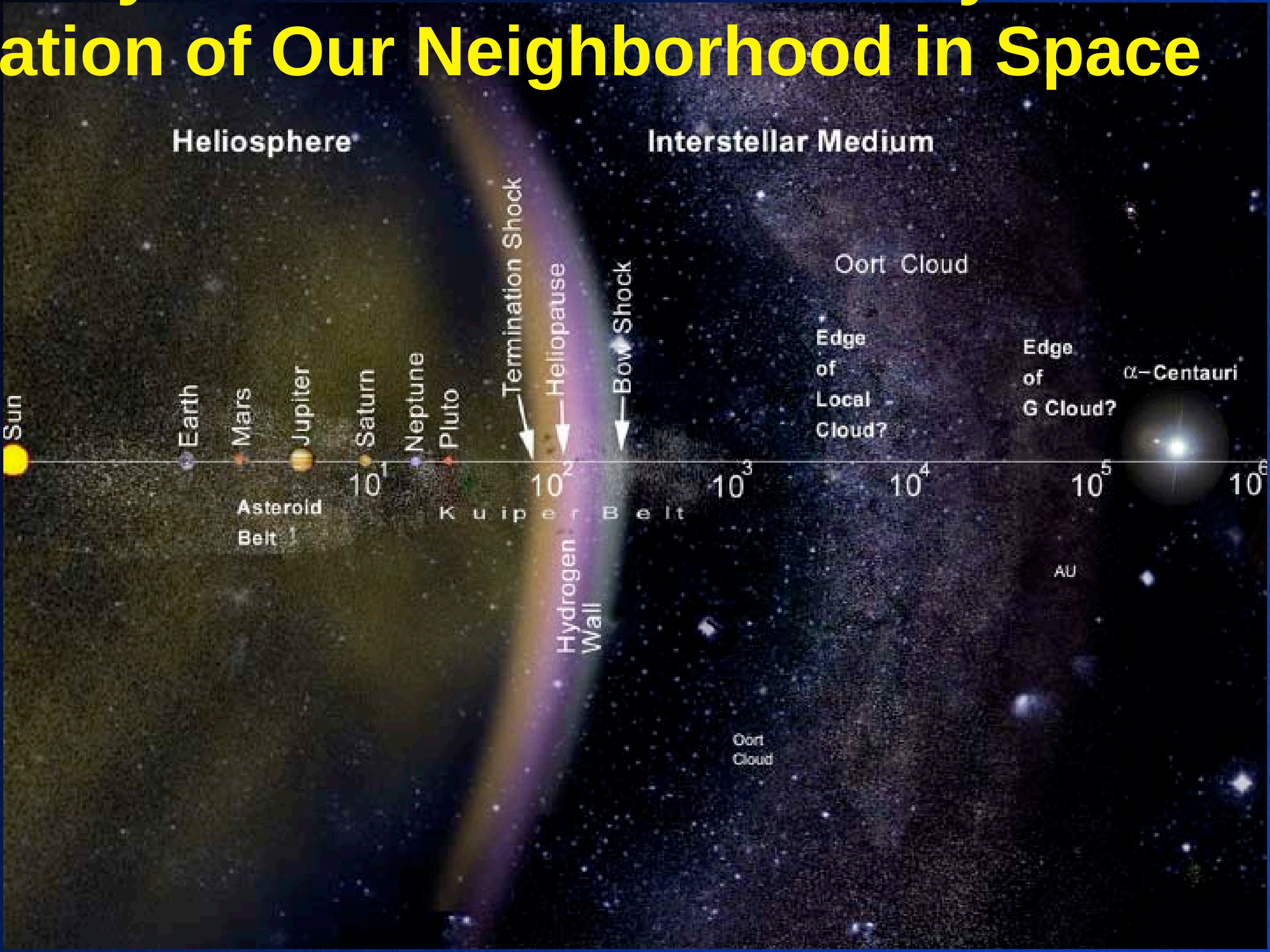
Science Missions Enabled by Nuclear Power and Propulsion

Albuquerque, New Mexico

7 February 2011

Planetary Science is the Discovery and Exploration of Our Neighborhood in Space

The Ultimate Goals Lead To the Edge of the Solar System and Beyond



Graphic from the Interstellar Probe Science and Technology Definition Team NASA/JPL

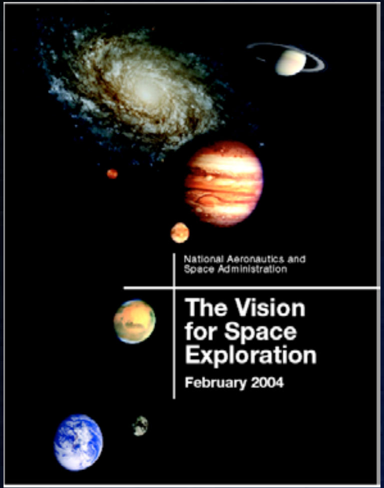
For Any Mission There Are Four Key Elements:

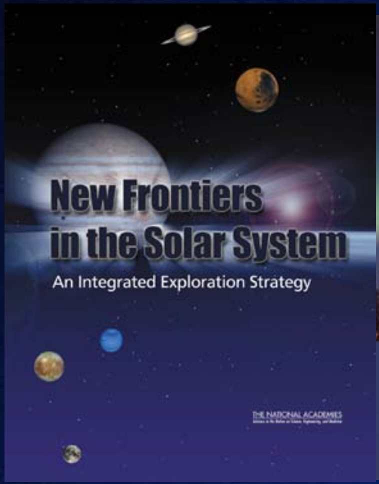
- National Policy/Science — the case to go
- Technology — the means to go
- Strategy — the agreement to go
- Programmatics — the funds to go

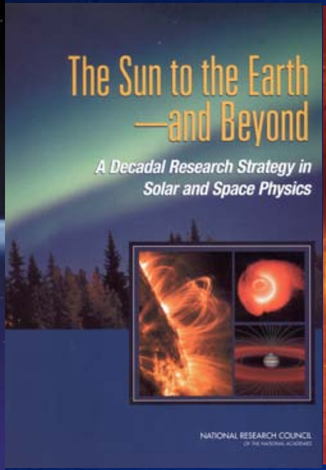
A well-thought-out approach with all key elements is required to promote and accomplish a successful exploration plan

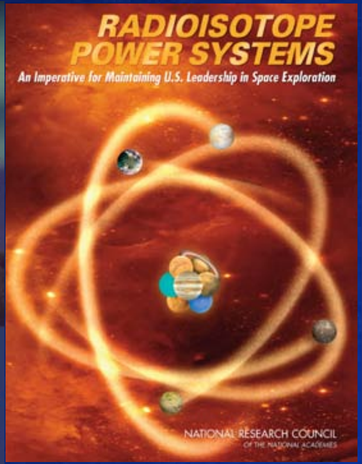
The Case for Going: Science/Politics

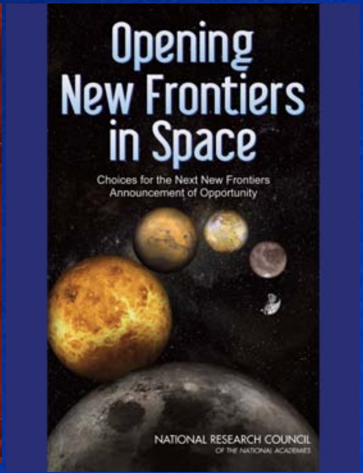
- The Vision for Space Exploration et al.
- NRC Reports [next Decadals in progress]

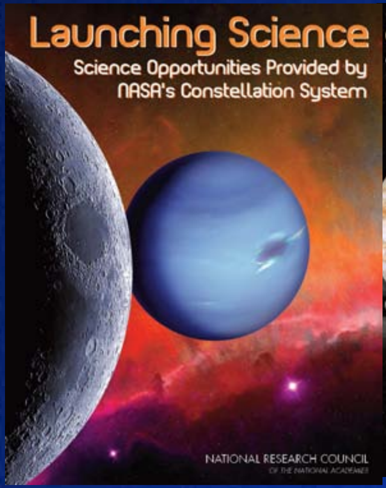


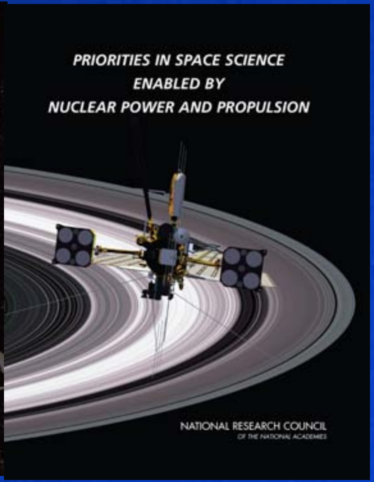












Rationales Have Not Changed

"The first principal objective is the *scientific exploration of space*, the planets, and later, the stars.

"This is an effort to learn the basic physics, chemistry, medicine, or biology of these new places.

"It includes the invention, research, and development of new instruments and scientific devices.

"A secondary objective is, of course, to apply the discoveries made in space exploration in the basic sciences to other important applications, devices, and pieces of equipment, thus making it possible that life on the earth will be more comfortable, more pleasant, or more useful because of these discoveries which are yet to come."

G. P. Sutton - §1.391 of "Trends in Astronautical Developments" in Handbook of Astronautical Engineering, ed. H. H. Koelle, 1961.

The "Good"

- **Technical means of using nuclear energy in space for power and propulsion are well understood**
- **If we do not have the technology at hand, we do know how to develop it**
- **Significant science from the past, present, and future have been – and continues to be – enabled by nuclear energy in space**

46 RPSs Flown on 26 Spacecraft 1961 – 2006

NASA usage on 36 of 18 S/C ~100 kg (1968-2006)

Radioisotope power systems (RPSs) developed as an outgrowth of nuclear weapons program

1943 – Polonium-210 (Po-210) project begun in Dayton, OH
1950 – Heavy water reactors at Savannah River Site (SRS) authorized

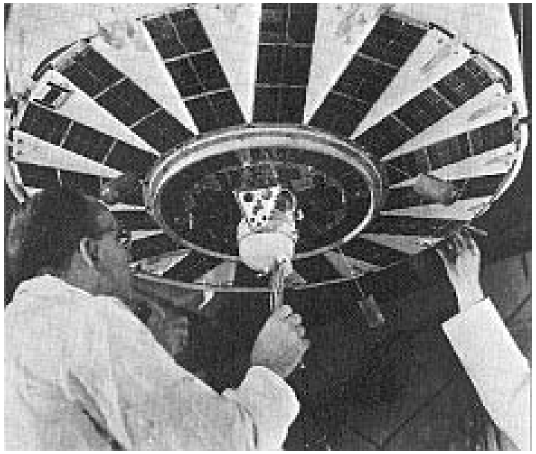
1954 – Mound Laboratory (Ohio) develops radioisotope thermoelectric generator (RTG) using Po-210 (Po-210)
1956 – Reactors at SRS begin production – cost is $1.1B then-year dollars

1958 – production of Pu-238 at SRS from Np-237 begins (Np-237 is a byproduct of weapons-grade Pu-239 production)
1960 – Mound isolates first metallic Pu-238

1961 – Transit 4A launched – this and all following satellites use Pu-238
1968 – Production reactors switch to HEU accelerating Np-237 production

1988 – U.S. production of Pu-238 ceases with shutdown of K-reactor at SRS
1996 – Chemical separation of Pu-238 at SRS ceases (“H-canyon” facility)

- **Transit 4A – Launched 29 June 1961 First RPS-powered satellite (built by APL)**



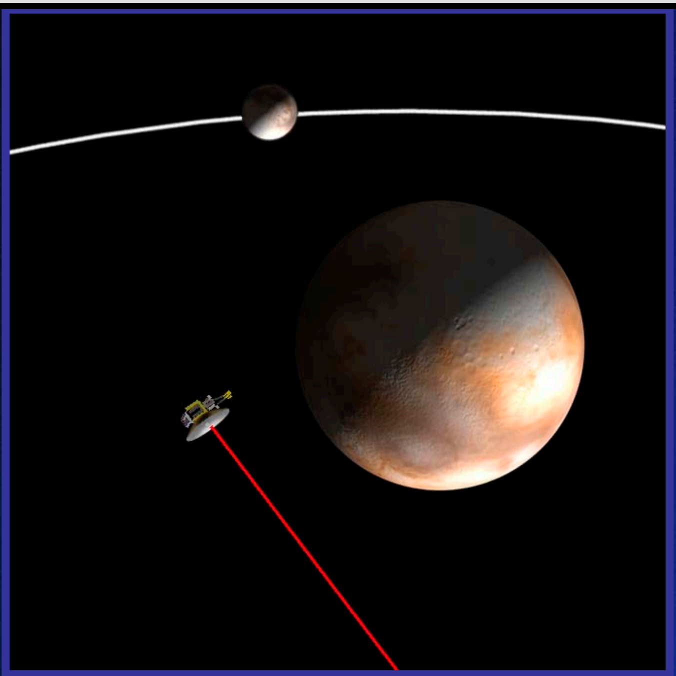
- **Check out and installation of the SNAP 3B-7 radioisotope power supply (2.7 Watts electric from Pu-238)**

New Horizons Baseline Mission

- Spacecraft: Heritage-based, RTG-powered, with an ~400 m/s ΔV budget, and redundant subsystems.

- Encounters: A 2-month Jupiter encounter, and a 5-monthPluto-Charon encounter; hopefully on to explore KBOs.

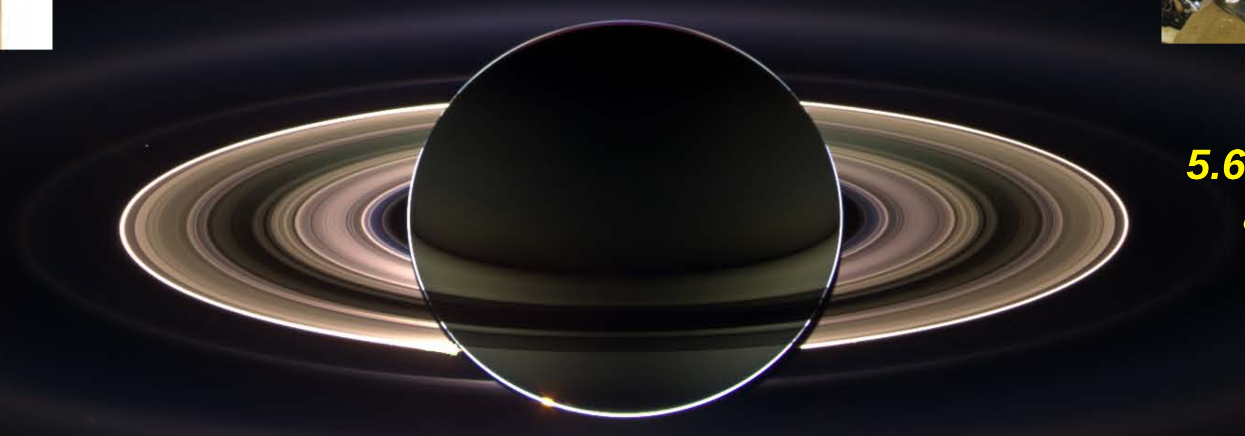
- Payload: 6 science instruments, plus the Student Dust Counter.



Cassini: Ongoing Mission at Saturn

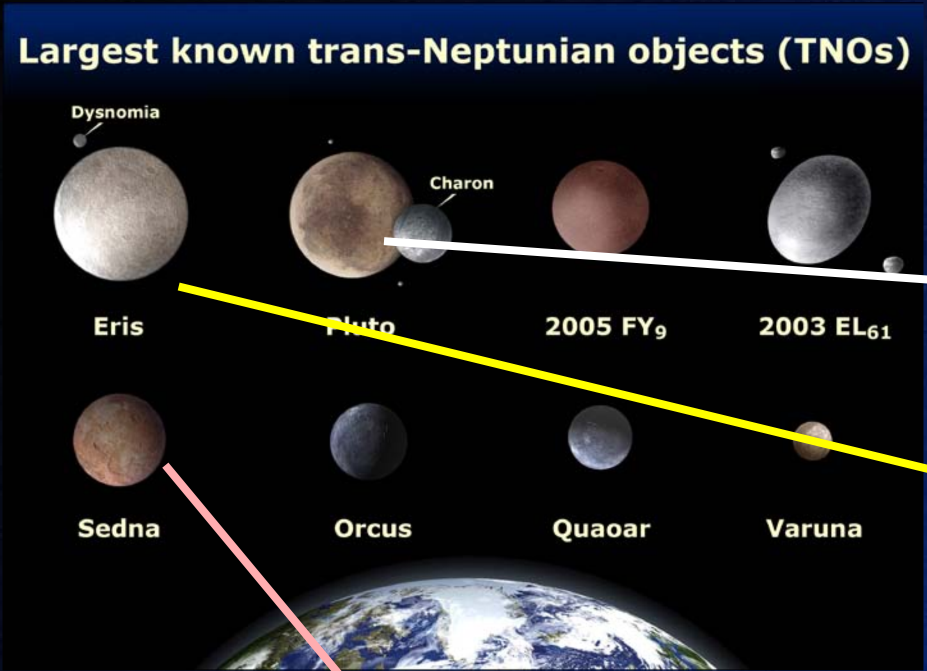
Titan: A New World to Explore

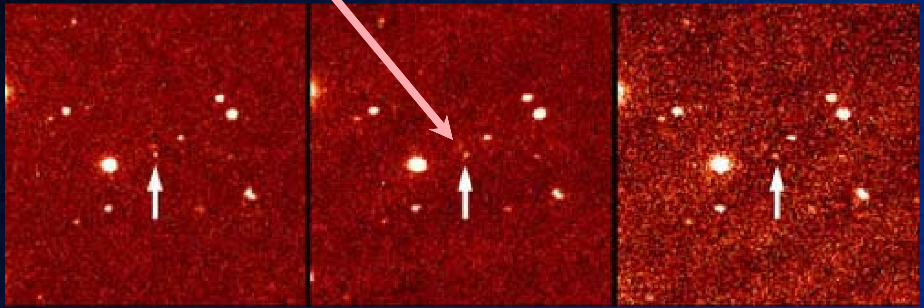
Cassini-Huygens
5.6 metric tons at launch

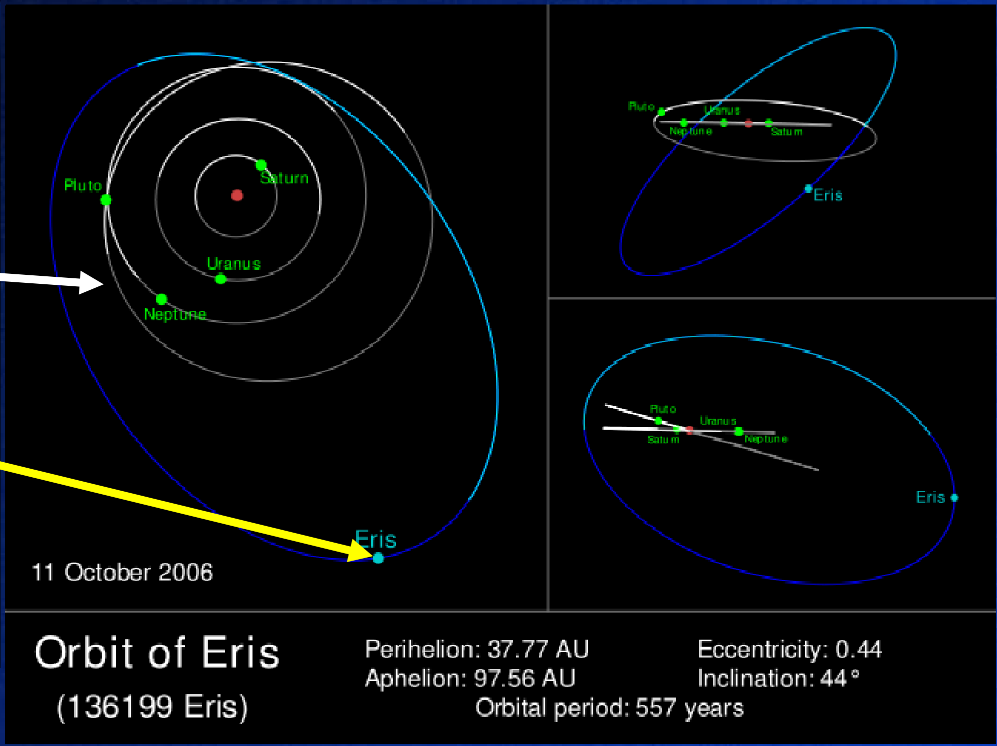


Saturn from Cassini in forward-scattered sunlight
The E-ring is clearly visible

Primitive Bodies Lie at the Edge of the "New" Solar System





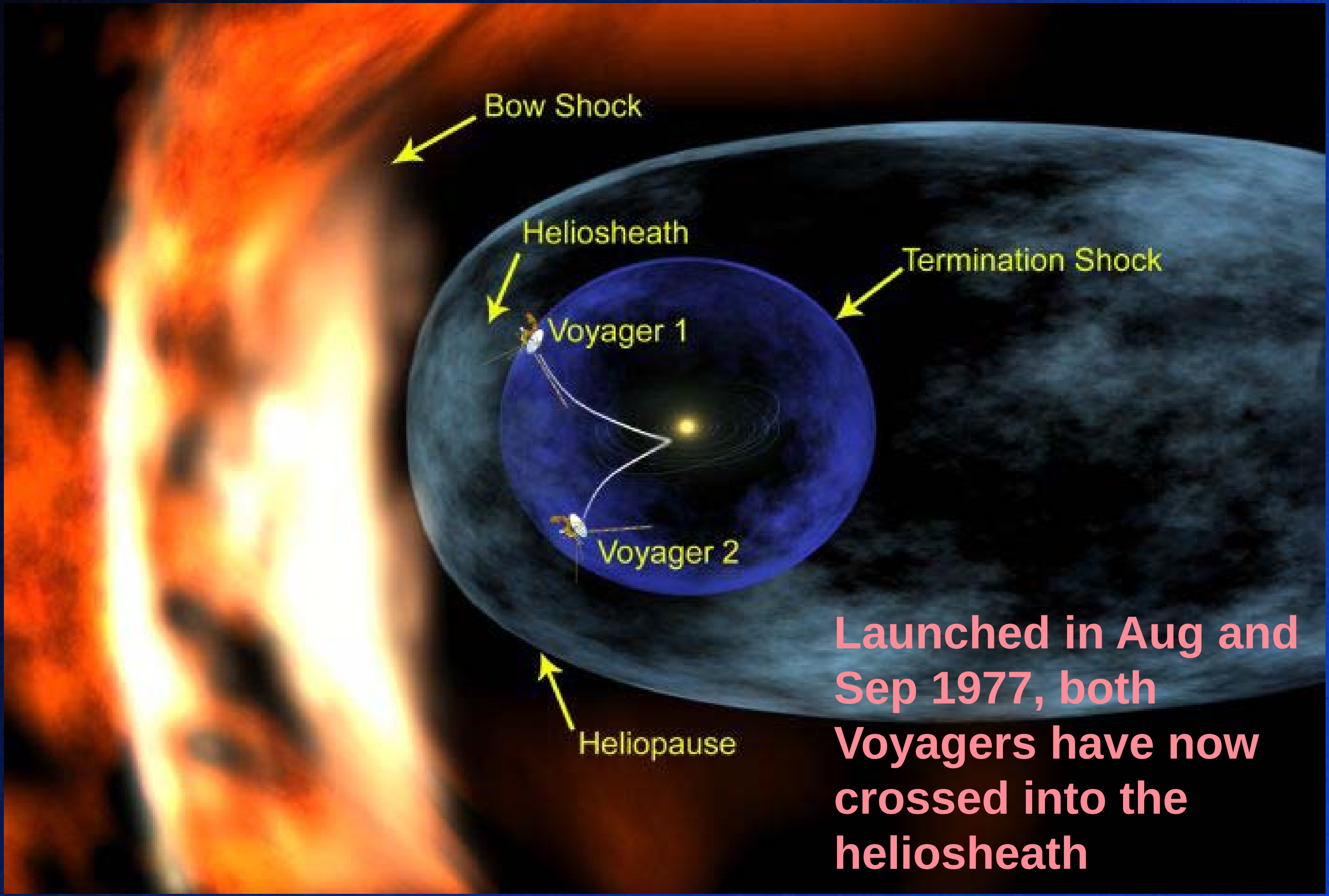


Discovery of Sedna 14 Nov 2003

- **Trans-Neptunian objects (TNOs) are primitive bodies**
- **Pluto and Eris currently classified as "dwarf planets"**
- **Sedna is most distant: out to 975 AU and period ~12,000 years**

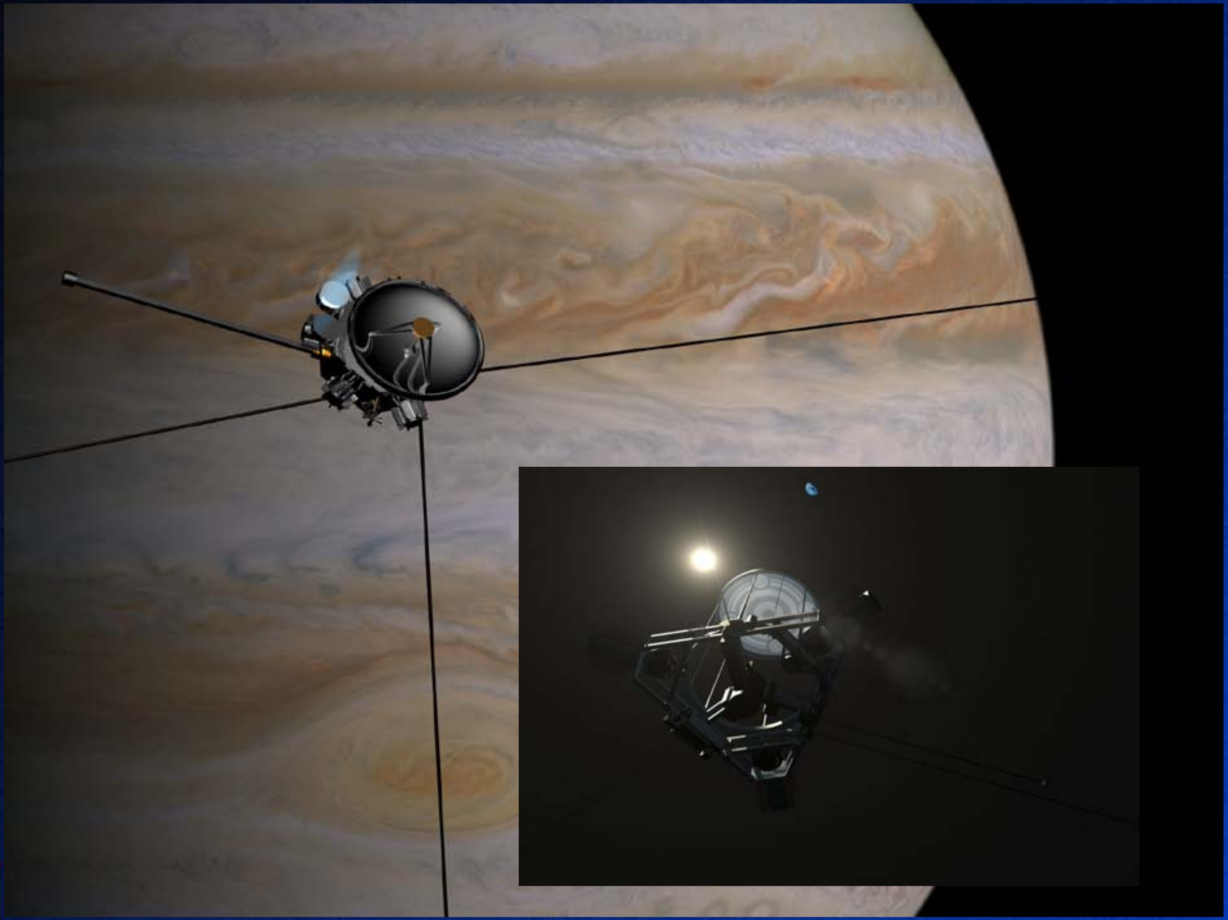
Interstellar Space: Our "Local" Backyard

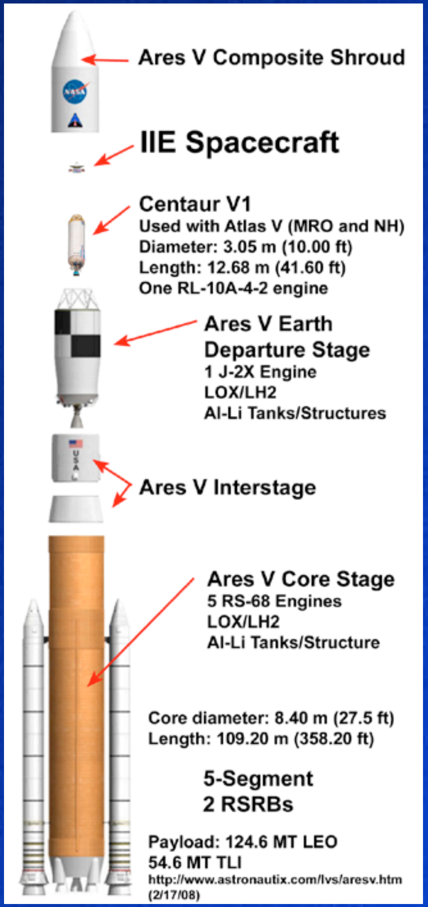
The Voyagers - data still coming back on their way to the stars



Launched in Aug and Sep 1977, both Voyagers have now crossed into the heliosheath

The Next Step: Planning for an Interstellar Probe

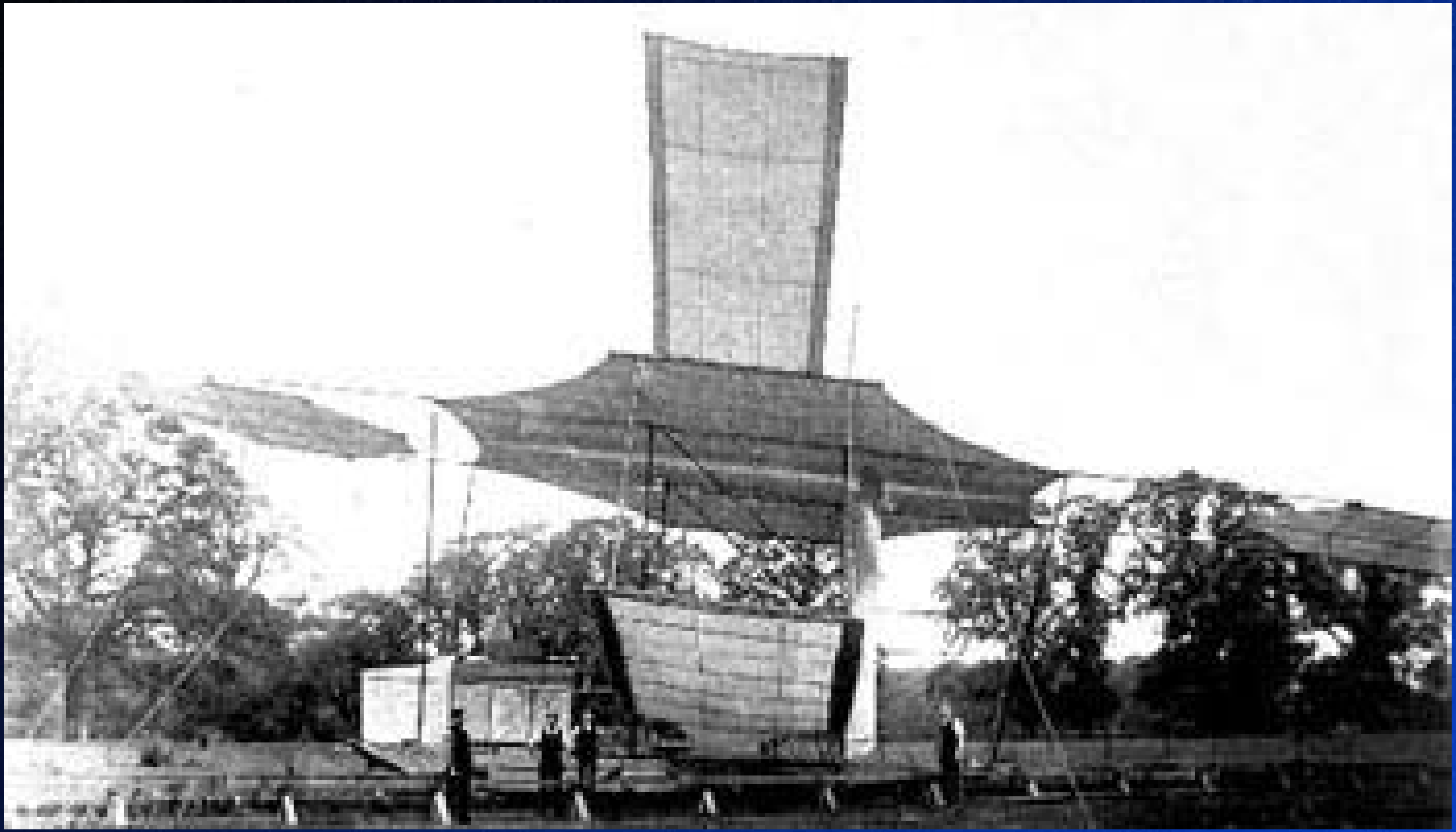




The "Bad"

- Nuclear electric propulsion has not worked out for robotic missions
  - Estimates from the JIMO study were prohibitive
  - The system was underpowered
    - Mass driven by shielding, heat rejection, and associated structural mass
- A new technical paradigm is needed
- Development of a space-qualified reactor is out of scope for NASA's current science budget
  - Development will have to come elsewhere
  - Use in science missions will depend upon cost and specific mass

What “Underpowered” Means



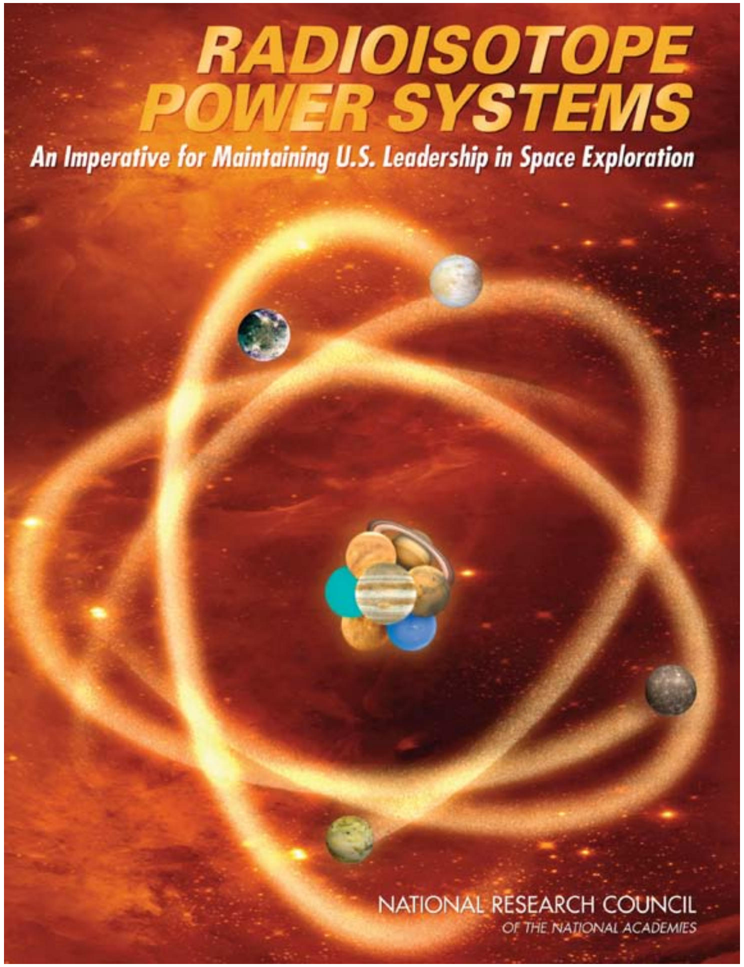
Hiram Maxim’s steam-powered airplane

The "Ugly"

- **Fuel**
  - We are (almost) out of Pu-238
  - Nuclear reactors need to be looked out for
- **Cleanup**
  - Cleanups continue at Hanford, Savannah River and other sites connected with Cold-War plutonium production
- **Proliferation concerns**
  - Materials that are required for space nuclear power and propulsion have other potential "uses"

U.S. Space Dominance is in Jeopardy

- **No domestic Pu-238 production since 1988**
- **NASA has been relying on Russian purchases**
  - Prescribed from use on defense systems
  - Last Russian deliveries (10 kg remaining) have been cancelled by Rosatom
- **Known world inventory is likely less than 30 kg**
- **“Breeding stock” of U.S. Np-237 is ~300 kg**
  - Secured at Idaho National Laboratory
- **U.S. plans for new production were put on hold by 9/11**



Plutonium 238

^{238}Pu does not occur in nature

It is created by irradiating ^{237}Np in a nuclear reactor.

Unlike ^{239}Pu, ^{238}Pu CANNOT be used to produce nuclear weapons.

Pu oxide fuel pellet

Domestic Pu-238 Production Must Be Reestablished if U.S. RPS Use is to Continue

- **Start-up costs currently estimated at ~$80M to ~$150M**
- **Pu-238 can be produced with existing facilities at rate of ~1.5 to 5 kg/yr**
- **DOE Record of Decision has been in place for over 5 years**
- **Start to first new material will take ~5 to 7 years**

Current Stalemate is Budget Issue Across Stakeholders

- **NASA budget already under pressure to “go it alone”**
- **No requirements for this capability have come forward from any other Federal Agencies**
- **Administration has proposed a 50/50 split between NASA and DOE for funding**
- **Congress has rejected any approach other than NASA paying full amount in the absence of any other needs coming forward**

HIGH-PRIORITY RECOMMENDATION
^{238}Pu Production

The FY 2010 federal budget should fund the DOE to reestablish production of ^{238}Pu.

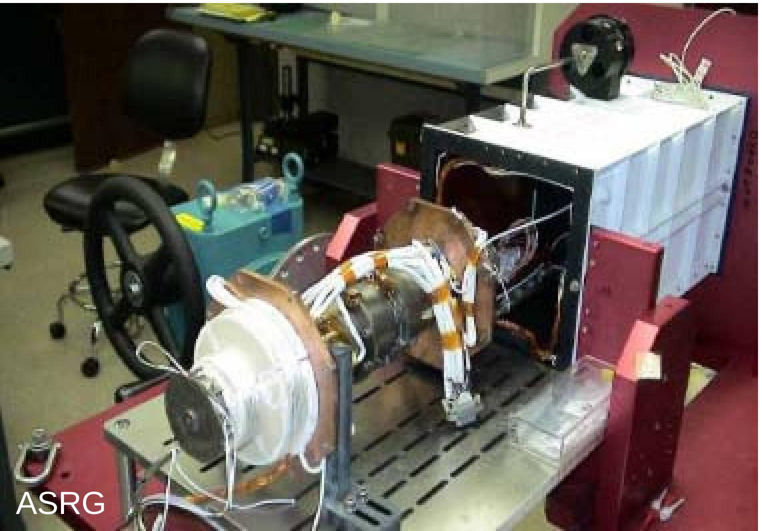
- **As soon as possible, the DOE and the OMB should request–and Congress should provide–adequate funds to produce 5 kg of ^{238}Pu per year.**

INL Materials and Fuels Complex

- **NASA should issue annual letters to the DOE defining future demand for ^{238}Pu.**

HIGH-PRIORITY RECOMMENDATION
ASRG Development

NASA and DOE should complete the development of the ASRG with all deliberate speed, with the goal of demonstrating that ASRGs are a viable option for the Outer Planets Flagship 1 mission. As part of this effort, NASA and the DOE should put final design ASRGs on life test as soon as possible (to demonstrate reliability on the ground) and pursue an early opportunity for operating an ASRG in space (e.g., on Discovery 12).


ASRG

Safety and the Environment

- **Safety and the preservation of the environment must be – and can be – top priorities as we go forward**
- **These items are not cheap – but they are a lot less expensive than the life-cycle costs associated with cleanup "down the road"**
- **This global perspective must be articulated outside the technical community to the other stakeholders in use of nuclear power for space**

Hanford Site

Hanford Site: Nuclear reactors line the riverbank at the Hanford Site along the Columbia River in January 1960. The N Reactor is in the foreground, with the twin KE and KW Reactors in the immediate background. The historic B Reactor, the world's first plutonium production reactor, is visible in the distance.

Savannah River Site

Savannah River Site: L Reactor Facility: L Area, Savannah River Site, September 16, 1982

The Johns Hopkins University Applied Physics Laboratory

The Agreement to Go: Strategy

- *“The main problem is not the lack of appropriate technology or financial resources, but the lack of a program deemed socially and politically desirable !”*

    - **NOVA AND BEYOND: A Review of Heavy Lift Launch Vehicle Concepts in the POST-SATURN Class**
    - **H.H.Koelle (2001)**

In the meantime, we must keep doing science and moving out

Radioisotope electric propulsion spacecraft **en route** ***to the heliopause ~150 AU away***

The greatest gain from space travel consists in the extension of our knowledge. In a hundred years this newly won knowledge will pay huge and unexpected dividends.

Wernher von Braun