Pacific Basin Nuclear Conference 2004

What's Ahead for Project Prometheus?

Project Prometheus - What Does it Mean for NASA?

Presented
by

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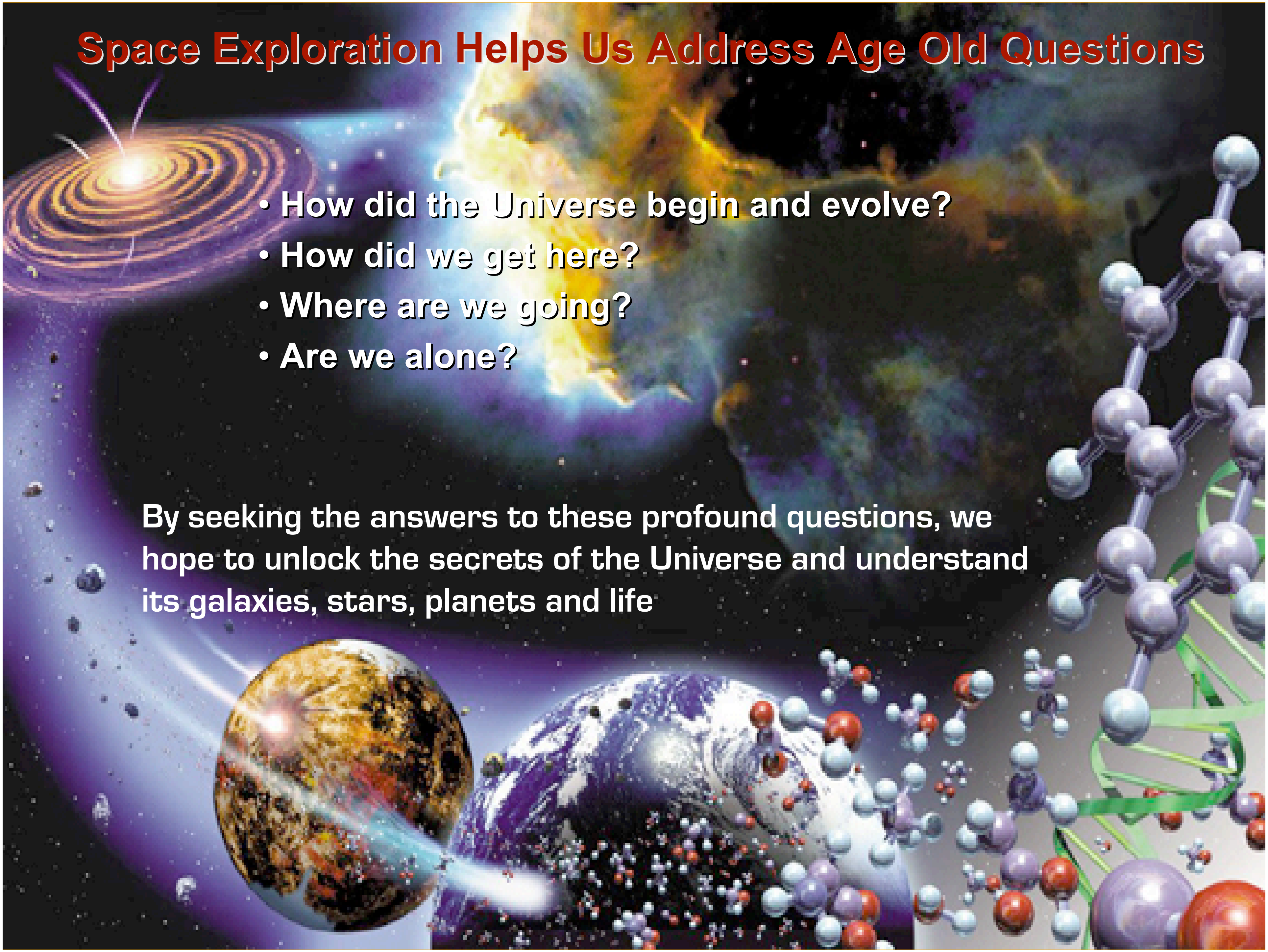
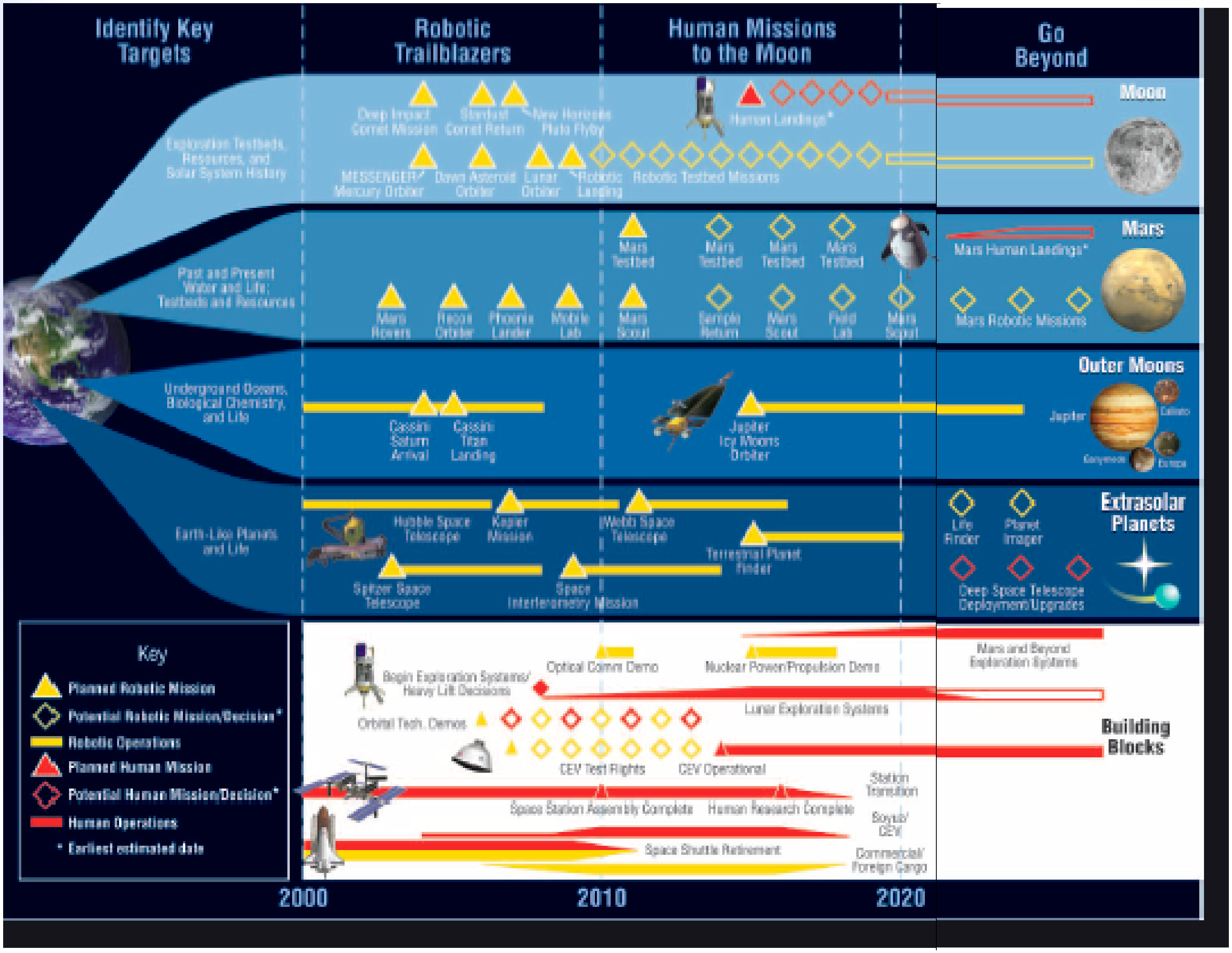

Space Exploration Helps Us Address Age Old Questions
• How did the Universe begin and evolve?
• How did we get here?
• Where are we going?
• Are we alone?
By seeking the answers to these profound questions, we hope to unlock the secrets of the Universe and understand its galaxies, stars, planets and life

NASA's Vision for Space Exploration



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Enabling Technologies

Space Exploration and Scientific Discovery Relies on our Ability to Make Observations

- Earth-based
- Earth orbit-based
- In-situ
  - Orbiter
  - Lander
  - Human habitats

Space Nuclear Power and Advanced Propulsion Enables:

- **Getting there**
- **What you do once you are there**
- **Returning information**

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Key Technology Components

Energy Generation
- Fission reactor (10s-1000s of kWs)

Conversion to Electricity
- Static: Thermoelectrics, Thermophotovoltaic
- Dynamic: Stirling, Rankine, Brayton

Energy Generation
- Radioisotope (milli to kilowatts)

Ensuring safety is our paramount objective

Propulsion
- High-powered electric
- Nuclear thermal*

All program activities will be conducted in a manner to achieve this goal.

Space Exploration and Space Science

Space Exploration
- Moon, Asteroids, Mars missions*

Space Science
- Jupiter Icy Moons Orbiter (JIMO), Mars, New Frontiers, Large-Scale Outer Solar System Missions

Electricity Utilization

- Electric Propulsion
- Scientific Instruments
- Communications
- Auxiliary spacecraft/planetary habitat systems*

- Electric Propulsion
- Scientific Instruments
- Communications

* Analysis of future applications is in initial stages

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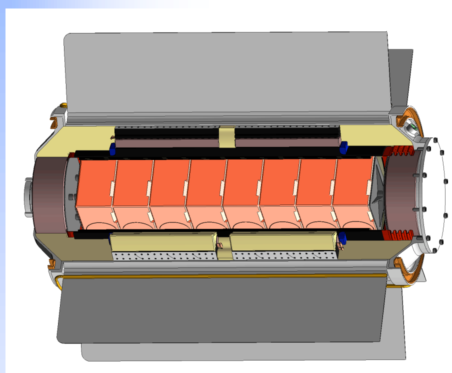
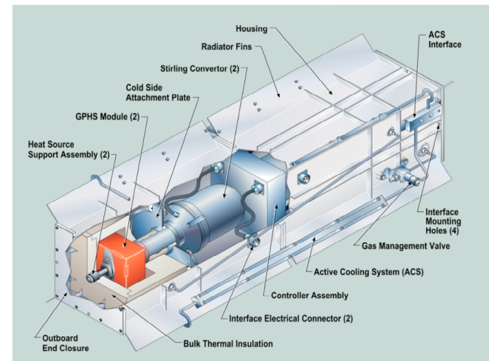
Radioisotope Power Systems Development

Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)



Stirling Radioisotope Generator (SRG)



- Provides approximately 120 Watts of electrical power (~90 W(e) at 14 years) for scientific instruments and spacecraft operations using current General Purpose Heat Source.
- Capable of operating in space, on Mars, and on other planetary bodies
- Provides continuous all-day/all-night operation at any location and latitude.
- Candidates of use on Mars Science Laboratory (planned launch in 2009) and subsequent RPS-powered missions

Advanced Systems Development

- 2nd generation MMRTG/SRG
- Milliwatt (~0.010 W) to Watt-scale systems: Power supplies for Mars network science, remote sensing stations, and very small spacecraft
- Power conversion technology development: Factor of 2 to 5 improvement beyond state-of-the-art in converter reliability, lifetimes, power levels, and overall efficiency
  - Technologies: thermoelectric, thermophotovoltaic (TPV), Stirling, and Brayton

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Radioisotope Power Systems Development

Accomplishments and Near-term Plans

Multi-Mission RTG (MMRTG)

- Signed definitized development contract with Boeing
- PDR for Engineering Development Unit (EDU) in early-March 2004

Stirling Radioisotope Generator (SRG)

- Signed definitized development contract with Lockheed-Martin
- Completed PDR for EDU; FDR (CDR) planned for April 2004
- Accumulated >3300 hrs on Stirling technology demonstration converter (TDC) units at GRC (2 units)

Radioisotope Power Conversion Technology (RPCT) NRA

- 10 competitively awarded, 3-year NRA contracts - all 10 NRA projects now underway.

Segmented Thermoelectric Research

- Demonstrated 12.5% efficiency with single unicouple

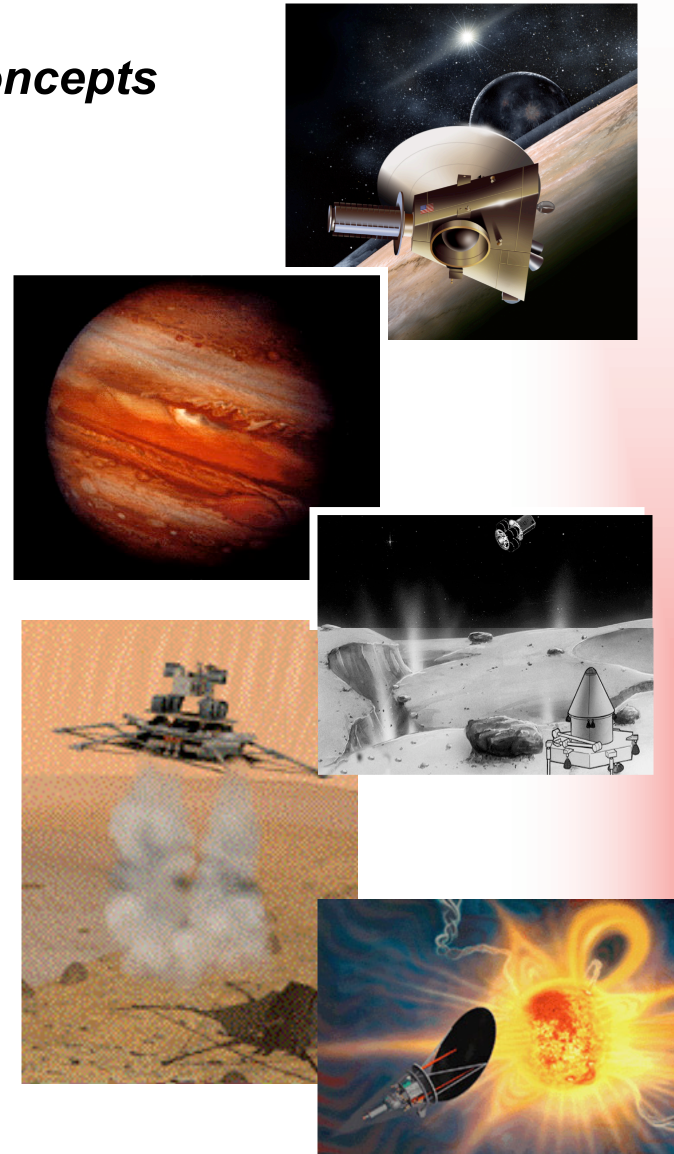
Milliwatt and/or multiwatt-scale RPS

- DOE/Orbital Sciences completed evaluation of concepts based on existing heat sources
- Workshop to review science mission applications, development options and technology (at JPL on 2 March)
- DOE Program Research and Development Announcement (PRDA) to support preliminary design studies in FY04/05

Potential RPS-Powered Missions

Near-term Interplanetary and Solar Mission Concepts

- New Horizons Mission - Single-pass flyby mission of Pluto-Charon system followed by possible targeting of one or more Kuiper Belt objects (launch planned for 2006-2007 timeframe)
- Mars Science Laboratory (launch planned for 2009)
- Lunar South Pole/Aitken Basin Sample Return
- Jupiter Polar Orbiter with Probes
- Venus In-situ Explorer
- Comet Surface Sample Return
- Solar Probe
- Mars Long-Lived Lander Network
- Mars Scout Missions
- Mars Sample Return



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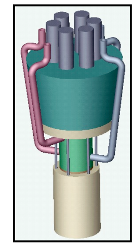
Nuclear Electric Propulsion (NEP) Research

Nuclear Fission Reactor Research

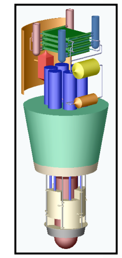
Objective: Research reactor power systems suitable for planetary science applications.

– Looking at three reactor types

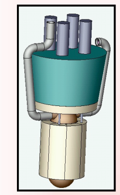
1) Heat pipe, 2) liquid metal, and 3) gas



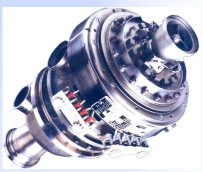
Heat-Pipe Cooled



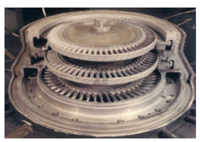
Liquid metal cooled reactor concept



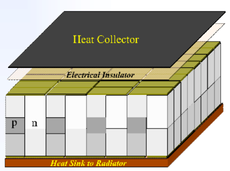
Gas Cooled



Brayton



Rankine



Thermoelectric

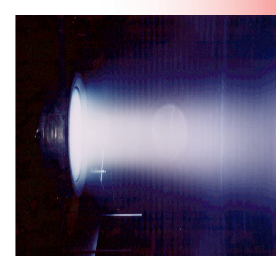
Power Conversion Research

Objective: Research multiple high power thermal-to-electrical conversion technologies.

-- Static (thermoelectric) and dynamic (Brayton & Rankine) conversion technologies

Electric Propulsion Research

Objective: Research multiple high-power (20-50 kWe & up to 250 kWe) electric propulsion technologies



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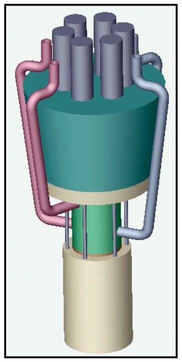
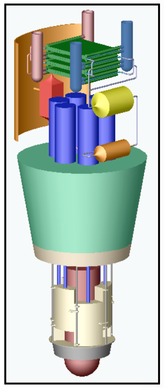
Nuclear Electric Propulsion

Nuclear Fission Reactor Research

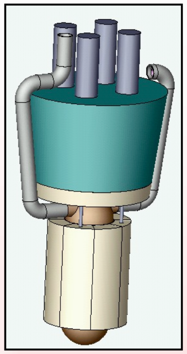
- Performed detailed nuclear reactor design screening evaluation to formulate acceptable performance parameters for interplanetary science missions
  - Key Participants: DOE HQ, NASA HQ, ORNL, LANL, SNL, GRC, MSFC, JPL
- Prepared design data packages for reactor concepts showing best potential for safe and successful mission accomplishment
- Nuclear Safety Requirements under development
  - Tiered approach
    - Tier 1: Project Prometheus Program-wide safety requirements for fission systems
    - Tier 2: JIMO flight project office safety requirements
    - Tier 3: Technical safety requirements offered by JIMO reactor provider



Heat-Pipe Cooled



Lithium Metal Cooled (SP-100 Derived)



Gas Cooled

- Nuclear criticality safety benchmark experiments underway to provide confidence in passive nuclear criticality safety concepts regarding accidental water immersion

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Nuclear Electric Propulsion (NEP) Research

EP Development Status/Preliminary Top Level Requirements

Current Electric Propulsion (EP) Development Status/Requirements

SOA – NSTAR Ion Engine
- Isp: 3100 sec (1200 V Beam)
- Life: 30,352 hours
- Power: 2.3 kWe
- Efficiency: 63%
- Electron Sources: Hollow Cathode (HC)
- Type: Ion
- DS1 Demo Flight (1999)/JPL test (2003)

NEXT GEN Ion Engine
- Isp: 4050 sec (1800 V Beam)
- Life: ~30,000 hours
- Power: 6-7 kWe
- Efficiency: ~ 68%
- Electron Sources: HC
- Type: Ion
- TRL-6 (2005)

NEXIS/HiPEP/VHITAL NRA Engines
- Isp: 6,000 – 9,000 sec (5 – 8 kV Beam)
- Life: 55,000 – 60,000 hours
- Power: 20 - 50 kWe
- Efficiency: > 65%
- Electron Sources: HC/Microwave
- Types: Ion/Hall
- TRL-5 (2005)

JIMO NEP Engine
- Isp: 5,000 - 9,000 sec (2.7 - 8 kV Beam)
- Life: 50,000 – 120,000 hours
- Power: 20 - 50 kWe
- Efficiency: > 65%
- Electron Sources: HC/Microwave
- Type: Ion (leading option, but not decided yet)
- TRL-6 (≥2007)

Mid-term NEP Engines
- Isp: 4,000 – ≥10,000 sec
- Life: 10,000 – 50,000 hours
- Power: 100 - 500 kWe
- Efficiency: ≥ 60%
- Electron Sources: Various
- Types: MPD/PIT/PPT/etc.
- Lower Mass/Alphas; Long Life
- TRL-6 (TBD)

Far-term NEP Engines
- Isp: 5,000 – 15,000 sec
- Life: 10,000 – 50,000 hours
- Power: > 1 MWe
- Efficiency: ≥ 60%
- Electron Sources: Various
- Types: Various
- Lower Mass/Alphas; Long Life
- TRL-6 (TBD)

EP Devel. Status/Reqmts. (Cont'd)

Planned NEP Research Efforts (Near-term to Far-term)

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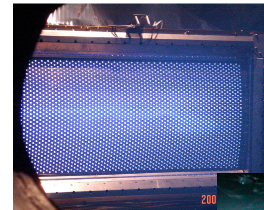
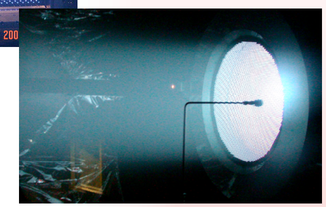
Nuclear Electric Propulsion (NEP) Research

Significant Accomplishments

- High Power EP NRAs
  - JPL's Nuclear Electric Xenon Ion System (NEXIS) & GRC's High Power Electric Propulsion (HiPEP)
    - Successfully demonstrated beam extractions and thrust operations at NRA parameters of interest:
      - NEXIS achieved NRA Goals: 23 - 27 kWe, Isp 7600 - 8500 s, 75 -78 % efficiency, 6000 V, ~3.8 A beam
      - HiPEP achieved similar goals except at ~12 kWe; expect to operate ~25 kWe during next test
  - Stanford's Very High Isp, Two-Stage Bismuth-Fed Hall Thruster (VHITAL))
    - Foreign participation review completed

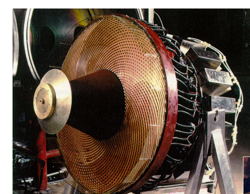


HiPEP thruster emitting ~6000V Xenon ion beam

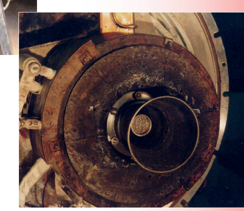


NEXIS thruster emitting a 4300V Xenon ion beam

- Advanced EP (100 - 250kWe) NRA
  - NRA ROSS 03 amendment issued on 1/23/04 with goal to advance SOA of advanced EP (AEP) thruster systems other than Ion and Hall
    - EP system alphas: □ 2 - 4 kg/kWe
    - Isp: 4,000 - ≥ 10,000 seconds
    - Thruster efficiency: ≥ 60%
    - Lifetime: 1 - 3 years



Pulsed Inductive Thrusters



MPD Thrusters

- High Power, High Isp Hall Thruster (400M)
  - Completed design/fabrication at GRC of high power (50 kWe), high Isp (~ 5,000 sec) NASA 400M thruster
  - New NASA 400M design based on NASA 457M

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Nuclear Electric Propulsion (NEP) Research

Near-term Items of Interest

- High Power EP NRAs
  - Complete initial lab model thruster performance testing and initiate fabrication of HiPEP and NEXIS development model thrusters and other EP components
  - Complete contract negotiations for Stanford/TsNIIMASH's NRA proposal; and initiate phase 1 NRA studies.

- Advanced EP (AEP) and Critical Issues in EP (CIEP) NRAs
  - Notice of Intent forms due by 2/23/04 for AEP NRA and by 3/5/04 for CIEP NRA
  - Proposals due by 3/22/04 for AEP NRA and by 4/30/04 for CIEP NRA
  - NRA selections anticipated by July for AEP NRA and by September for CIEP NRA
  - CIEP Emphasis on dramatically improving EP thruster life and/or significantly improving performance and usefulness of EP thrusters

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Representative Technology Options

Reactor

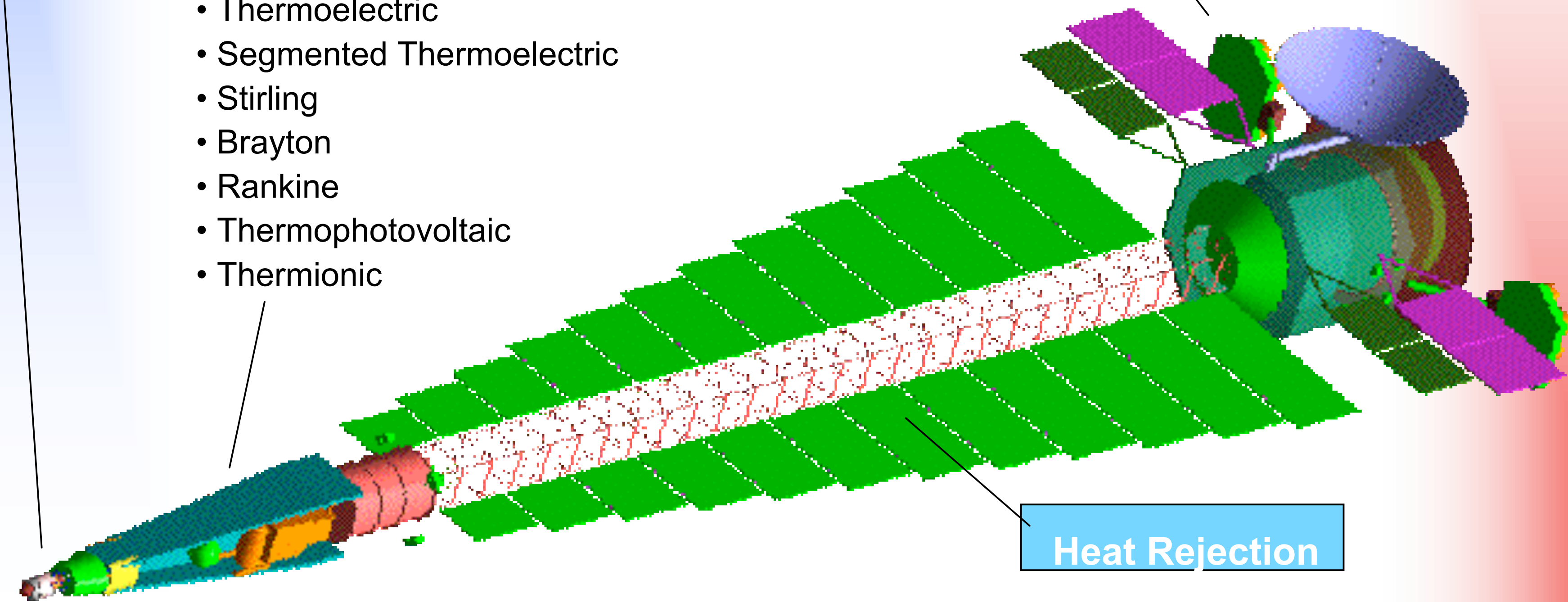
- Heat pipe cooled
- Liquid metal cooled
- Gas cooled

Electric Thrusters

- Ion Thruster
- Hall Thruster
- MPD, PIT, VASMIR

Power Conversion

- Thermoelectric
- Segmented Thermoelectric
- Stirling
- Brayton
- Rankine
- Thermophotovoltaic
- Thermionic



Heat Rejection

- 2-Phase Loops
- Heat Pipes
- Pumped loops

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Decadal Survey

- In 2002, the National Academy of Sciences conducted Solar System Exploration Survey to prioritize technologies and missions
- The Survey identified the following areas in which it believed that technology development is appropriate:
  - "The two most-constrained resources in the current generation of planetary spacecraft are *onboard power and propulsion*. Improvements in these two areas will enable the largest leaps forward in capability."
    - *Power*: Advanced RTGs and in-space nuclear fission reactor power source
    - *Propulsion*: Nuclear electric propulsion, advanced ion engines, aerocapture
- The Survey identified a Jupiter Geophysical explorer as its top priority flagship mission
- "The proposed Jupiter Icy Moons Mission will *more than fulfill our goal of a flagship mission* to further explore the subsurface oceans on Europa while simultaneously applying the new technologies that the Survey advocates as a basis for much of the future program."*

***Dr. Michael J.S. Belton, Ph.D. Chair, Solar System Exploration Survey Committee, National Research Council in testimony given to US Senate Committee on Commerce, Science, & Transportation at a Science, Technology, and Space Hearing: Space Exploration Wednesday, July 30 2003 -**

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Jupiter Icy Moons Orbiter (JIMO)

- JIMO is a ***science-driven*** mission that would use new nuclear power technologies to enable science return far beyond previous outer planets missions
  - High power for instruments (including active) & high duty cycle
  - High data rates during acquisition and transmission
  - Large payload mass
  - Global orbital reconnaissance of all Jupiter's icy Galilean moons: Europa, Ganymede, and Callisto.
  - Highly fuel efficient use of xenon propellant enables multi-target rendezvous and close-range orbit and increased observation time at moons

Artist's rendering of possible JIMO spacecraft

- JIMO would be the first flight mission, of a possible series, to use nuclear power and propulsion technologies.

- This mission would set the stage for the next phase of exploring the outer Solar System.

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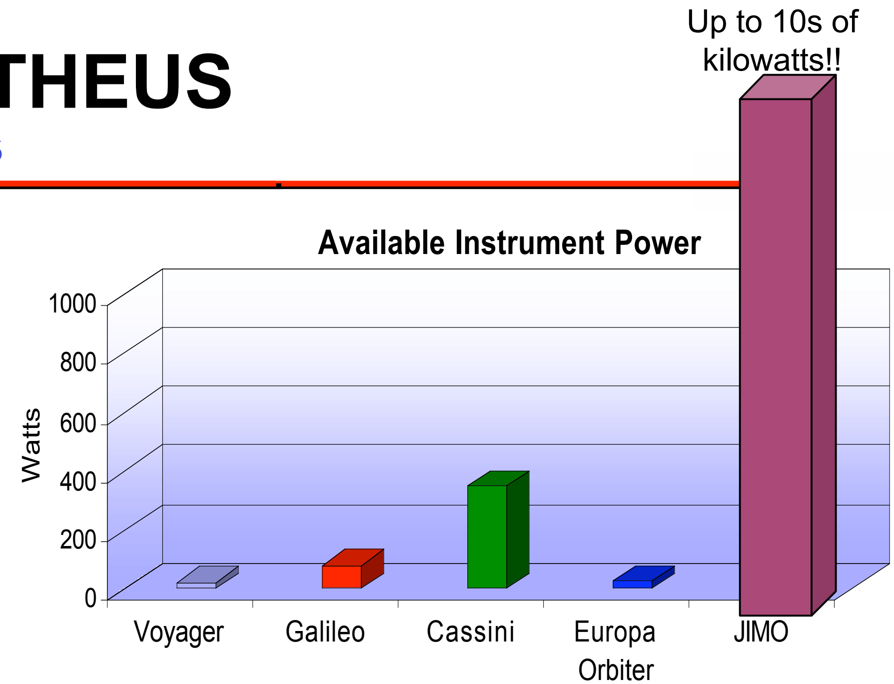
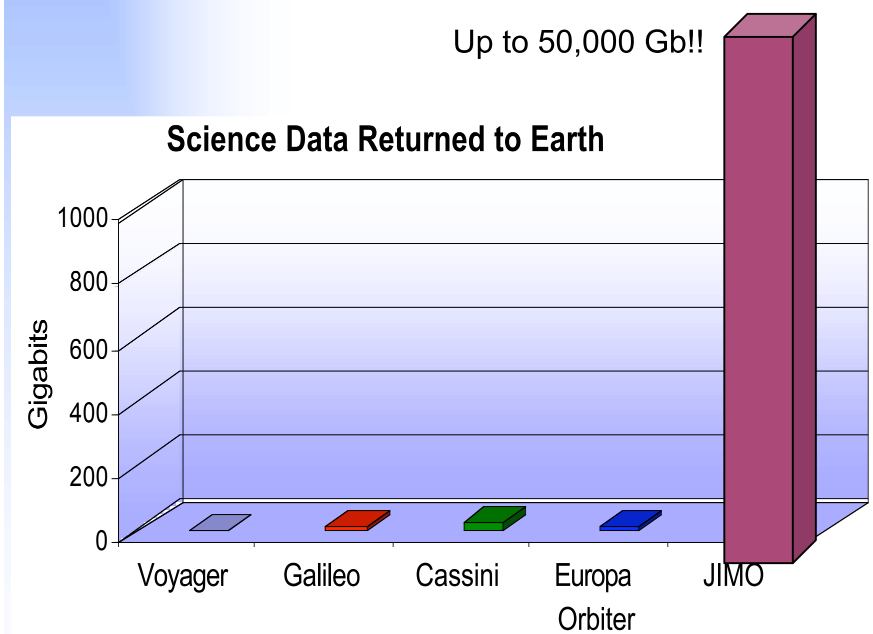
Jupiter Icy Moons Orbiter (JIMO)

- **Mission Studies and Conceptual Design**
  - Parallel mission study contracts to perform technology trades, develop detailed mission concepts (awarded April 03 – Boeing, Lockheed Martin, Northrup Gruman) – Task 1 trade studies complete; Task 2 conceptual design initiated
  - NASA/DOE in-house mission conceptual design
- **Technology Development and Recapture**
  - Initiate (or continue) development of enabling technologies
  - Recapture critical materials and testing technologies and capabilities
- **Scientific Payload Selection (NASA)**
  - NASA Research Announcement for high-capability instrument for planetary exploration (HPIPE) (released)
    - Develop concepts and technology for scientific instruments that can take advantage of the power and return data rate made possible by nuclear electric power
  - AO for JIMO science instruments (release TBD)
    - Select science instrument to be carried by the JIMO
    - Science Definition Team finish report in near future

PROJECT PROMETHEUS
Revolutionary Capabilities

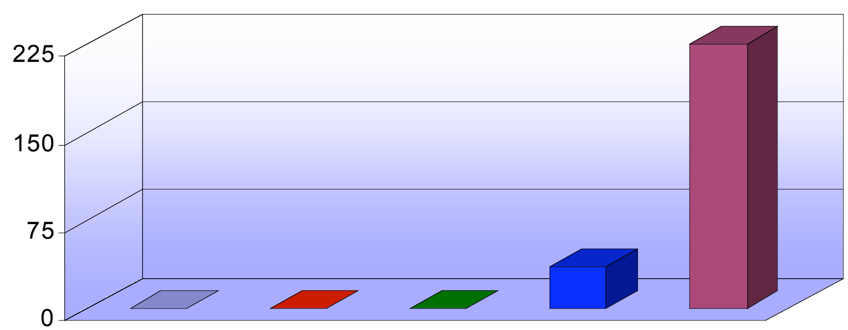
Amount of **power** available
to science instruments
One bedside reading lamp
compared to several homes





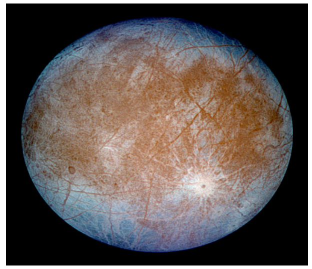
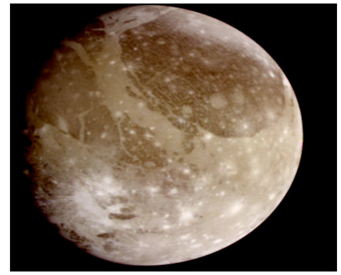
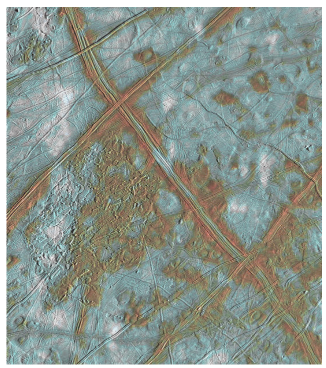
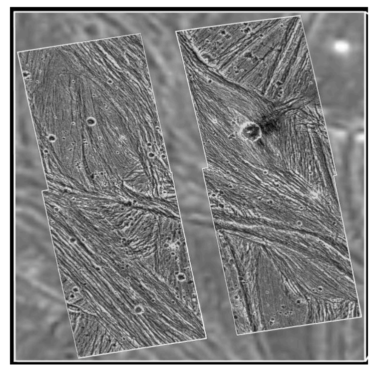
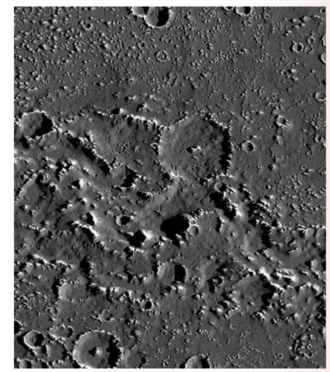
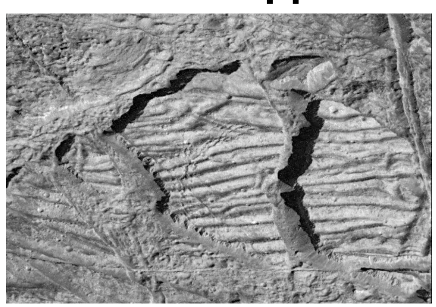
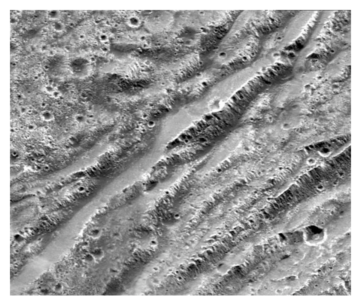
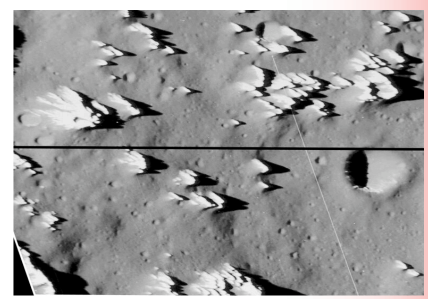
Amount of science **data** return
1 – 2 floppy disks as compared to >20 CD-ROMs

Time available for science
observation of moons
1 to 5 hours compared to 180 days



Jupiter Icy Moons Orbiter

Orbital Coverage

	Europa	Ganymede	Callisto
Voyager: Global mapping at ~10 km resolution	 95% mapped	 95%	 95%
Galileo: Regional mapping at ~100 m resolution	 10% mapped	 5%	 1%
JIMO: Local mapping at <10 m resolution	 ~100% mapped	 ~100%	 ~100%

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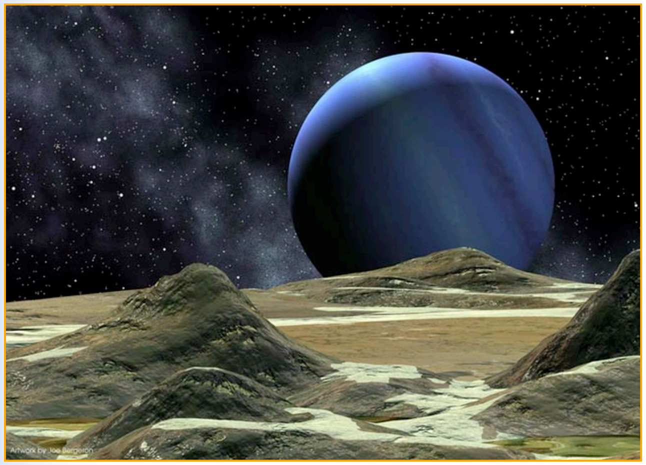
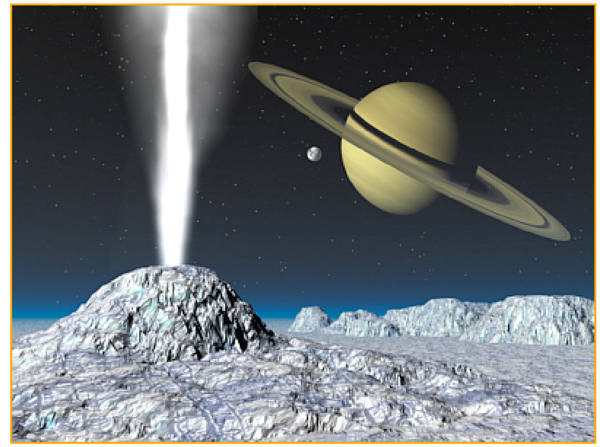
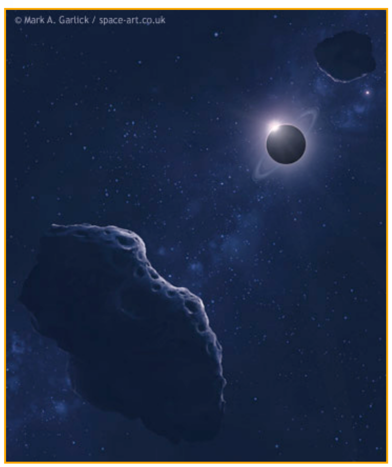
Potential Reactor-Powered Destinations



Neptune and its Moons



Saturn and its Moons



Kuiper Belt Region

Interstellar Space

PROJECT PROMETHEUS

Advanced Nuclear Concepts

Significant Accomplishments

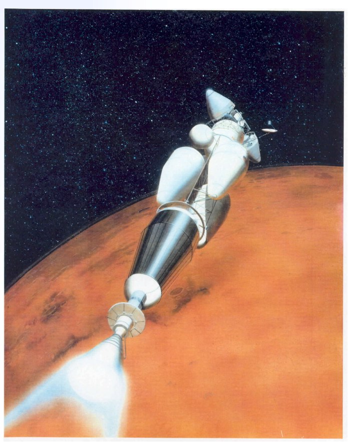
- Developed Mars mission study comparing NEP, NTP and Chemical propulsion capabilities.
- Organizing technology and concept studies in a "Team Prometheus" manner, integrating different centers/agencies to support.
- Sponsored a Nuclear Thermal Propulsion workshop at Glenn Research Center to status that technology.
- Analyzing trends in heavy lift ETO and in-space assembly.

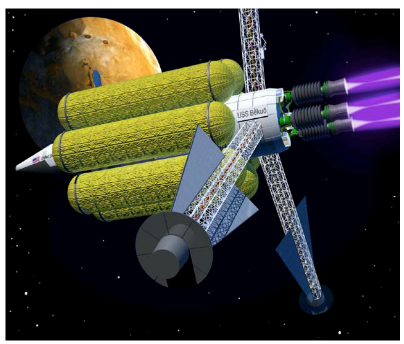
Future Plans

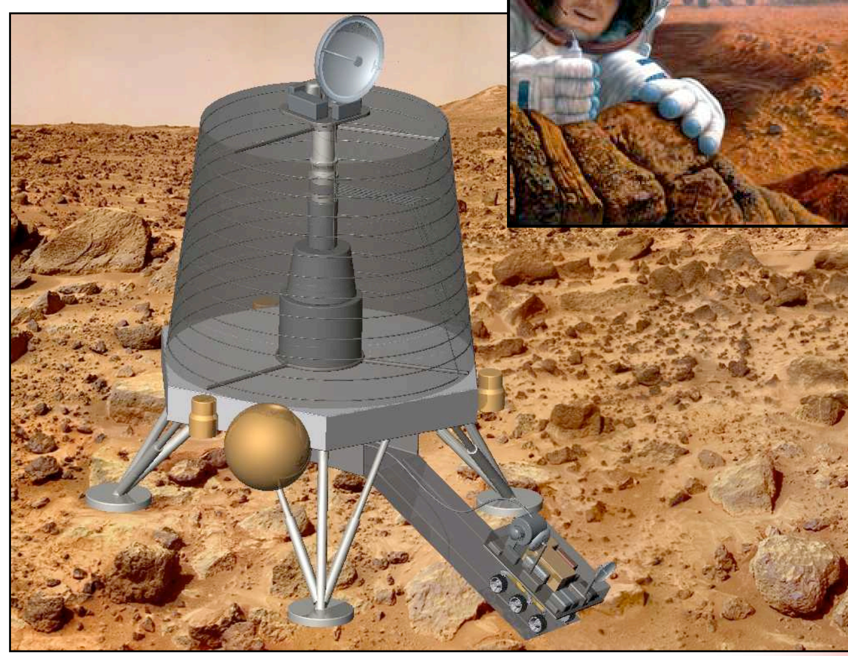
- Develop industry trade study plan for Lunar/Mars nuclear surface power.
- Develop nuclear fuels development and test plan for Nuclear Thermal Propulsion (with DOE).
- Support JIMO team heavy lift/in space assembly activities.

Potential Support to Human Space Exploration

- **Nuclear power and propulsion are key enablers of expanded human exploration**
  - Enables human exploration beyond earth orbit
  - Can enable shorter trip times, lower initial mass requirements than conventional technologies
  - Provides abundant power at destination
  - Enables complex, long duration missions
- **Nuclear surface power is essential for reconnaissance of the Moon and Mars**
  - Human habitat and life support
  - Long-range surface and sub-surface exploration
  - *In-situ* manufacturing of consumables and propellant
  - Compact power source, latitude independent







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Conclusion

- Project Prometheus technologies can revolutionize the scientific exploration of the Solar System
  - Safety is the absolute highest priority
  - Risk communication and stakeholder engagement process underway
- The proposed JIMO mission would start a new generation of missions characterized by more maneuverability, flexibility, power and lifetime
- Formulated science driven near-term and long-term plan for the safe utilization of nuclear propulsion based missions
- Project Prometheus organization is well established at NASA Headquarters throughout the NASA complex and well situated to support the President's new exploration initiative