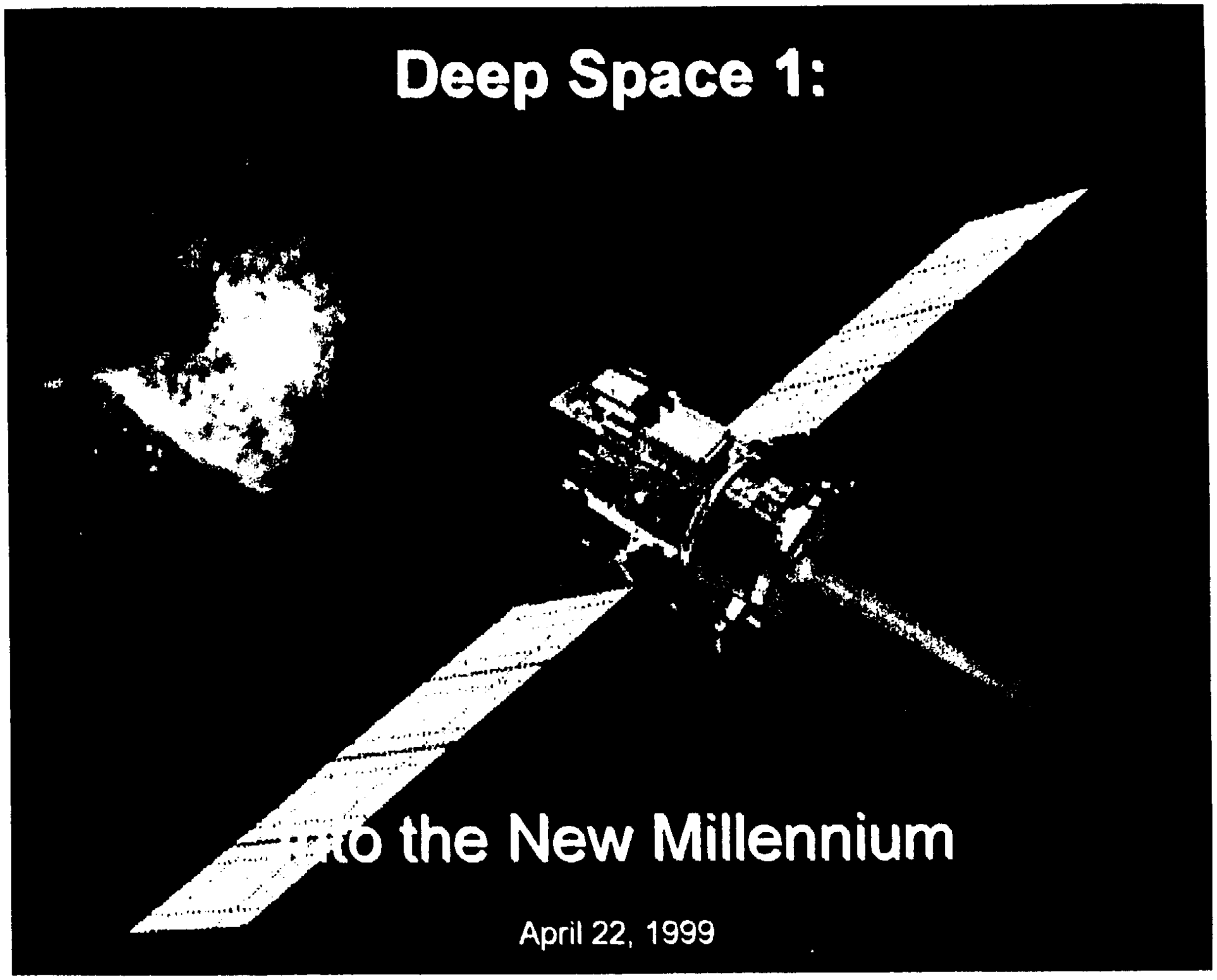
European Geophysical Society
XXIV General Assembly, The Hague



Philip Varghese, Marc D. Rayman
David H. Lehman, Leslie L. Livesay, and Robert M. Nelson
Jet Propulsion Laboratory

Agenda

- NASA's New Millennium Program
- Deep Space 1 (DS1) Project Overview
- Technology/Science Payload
- Mission Objectives and Status
- Extended Mission Opportunities
- Summary

THE NEW MILLENNIUM

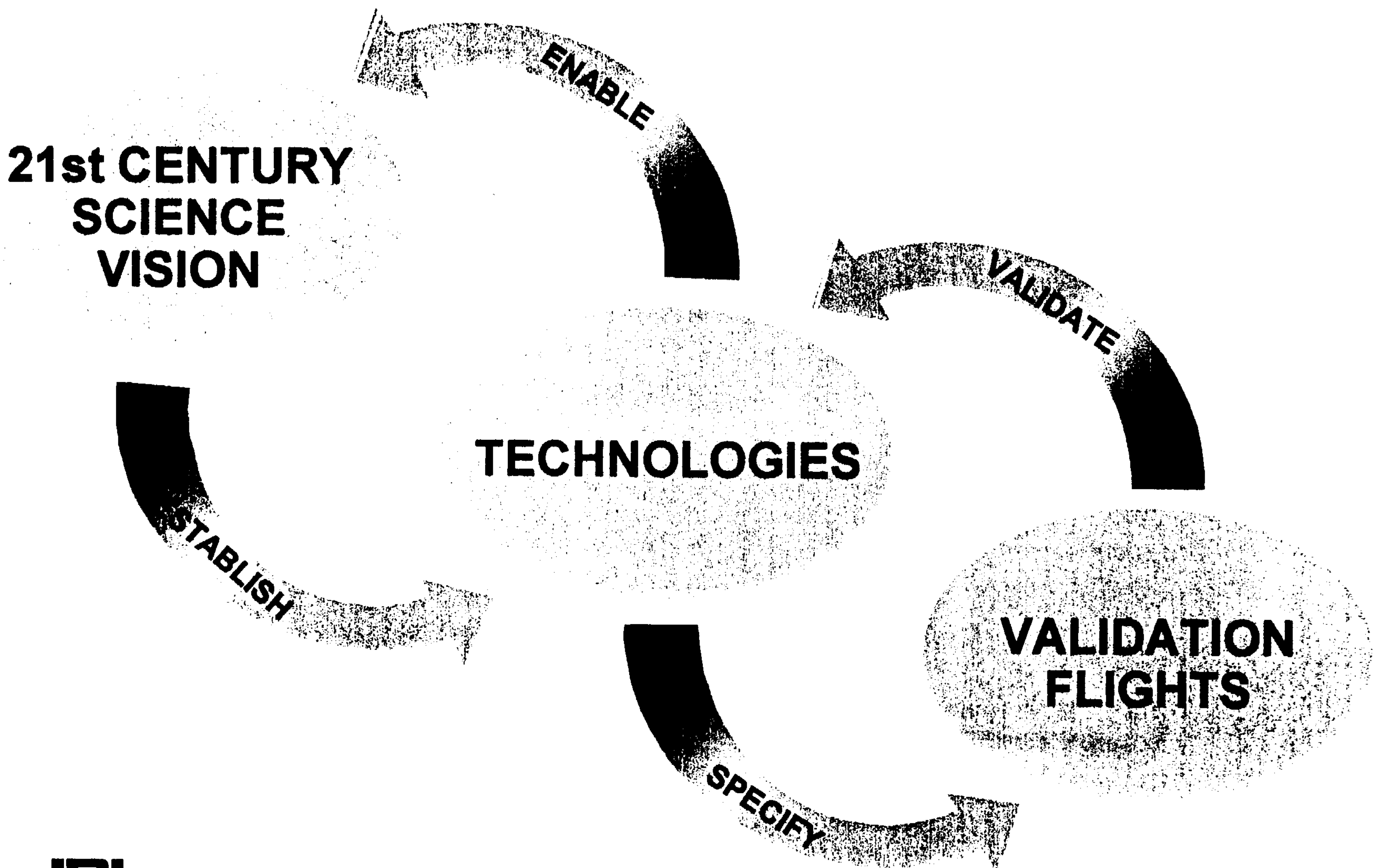
EXPLORATION FOR THE 21ST CENTURY

New Millennium Goals

Revolutionize NASA's space and Earth science programs to achieve exciting and frequent missions in the 21st Century through:

1. Developing and validating revolutionary technologies
2. Reducing development time and life cycle mission costs
3. Enabling highly capable and agile spacecraft
4. Promoting nationwide teaming and coordination

New Millennium Roadmap



New Millennium Program (NMP)

- Objective
  - Conduct space flight validation of breakthrough technologies that will enable future space science and earth science missions
- Technology Selection Criteria
  - Present a high risk to the first user and require in-flight validation
  - Reduce cost and risk of future science missions
  - Represent a significant improvement over state of the art
  - Enable rapid infusion into future missions
- Technology Validation
  - Assess the applicability of the technology product to future missions
  - Characterize its performance
    - Elucidating the limitations of an advanced technology is valuable
  - Diagnose in-flight failures and anomalies

Deep Space 1 (DS1) Project

- First flight of NMP
  - Launched on 24 October 1998
    - 486 kg injected mass
  - Primary mission ends on 18 September 1999
- Objectives
  - Flight validate twelve selected advanced technologies via an asteroid flyby "test track" profile
  - Conduct meaningful science during mission to prove compatibility of technology payload with future science missions
  - Attempt a challenging extended mission

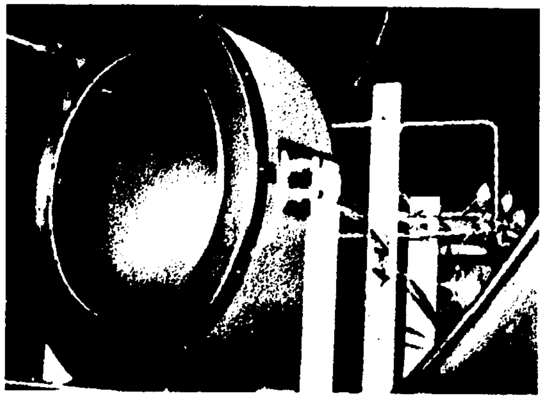
Boeing Delta II launch vehicle lifts off with DS1 on board

Technology Payload

Technology Description	*Technology Suppliers*	*Funding Sources*
Ion Propulsion System	Hughes, Moog, LeRC, SAI, JPL	NASA, Moog, Hughes
SCARLET Solar Concentrator Array	AEC-Able, Tecstar, LeRC, Entech	BMDO, NASA
Small Deep Space Transponder	Motorola	NASA, Motorola
Ka-Band Solid State Power Amplifier	Lockheed Martin (LM), JPL	NASA, Lockheed Martin
Autonomous Remote Agent Architecture	ARC, CMU, TRW, JPL	NASA
Autonomous Onboard Navigation	JPL	NASA
Beacon Monitor Operations	JPL, Univ. of Colorado at Boulder	NASA
Miniature Integrated Camera Spectrometer	SSG, Rockwell, Univ. of Arizona, JPL	NASA, SSG
Miniature Ion and Electron Spectrometer	SwRI, LANL	NASA, SWRI
Low Power Electronics	Georgia Tech., USC, MIT Lincoln Lab	NASA
Power Activation and Switching Module	LM	NASA, Lockheed Martin
Multi-Functional Structures	AF/PL, LM	AF/PL, LM

Solar Electric Propulsion

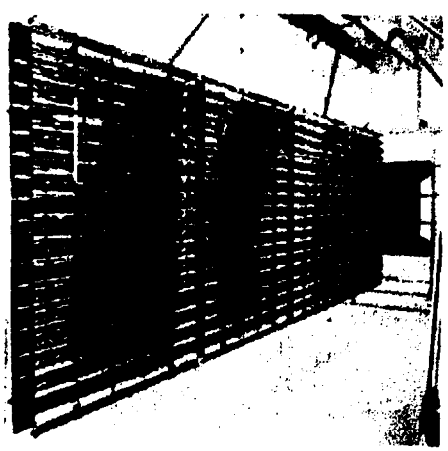
Ion Propulsion System



- Provided by NASA SEP Technology Applications & Readiness (NSTAR) Program
- Electrostatically accelerated Xe^{+} emitted through a molybdenum grid provide 92 mN thrust @ 2.3 kW peak thruster power (Isp =3100s) and 20 mN thrust @ 0.5 kW lowest thruster power (Isp =1900s)
- Diagnostics sensors for measuring interactions with spacecraft and space plasma environment

---

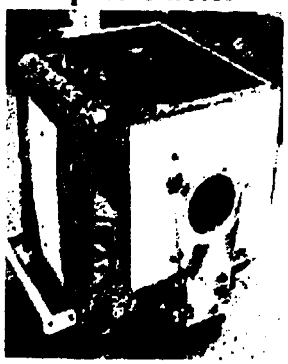
Advanced Solar Concentrator Array



- Provided by Ballistic Missile Defense Organization (BMDO) with support from NASA Lewis Research Center (LeRC)
  - Flight equipment delivered by industry
- Deployable concentrator array elements (7:1 concentration)
  - Multi-band gap solar cells
  - Fresnel lenses over strips of cells
- 2.5 kW at 1 AU (BOL)

Science Instrumentation

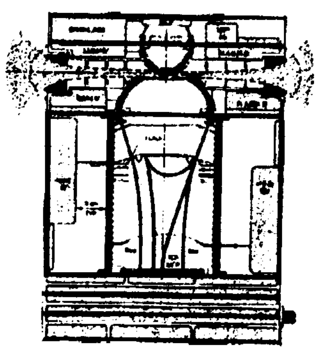
Miniature Integrated Camera Spectrometer



- Fully integrated camera and imaging spectrometer, developed by USGS, SSG, Inc.,University of AZ, Boston University, and JPL
  - Combines four different measurement capabilities into single instrument with common optics, electronics and structure
    - Two visible imaging channels
    - IR & UV imaging spectrometers
  - Silicon carbide optics & optical bench
  - Electronically shuttered visible channel eliminates need for moving parts

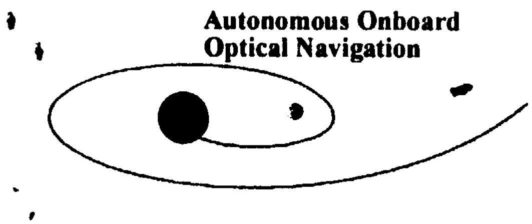
---

Plasma Experiment for Planetary Exploration

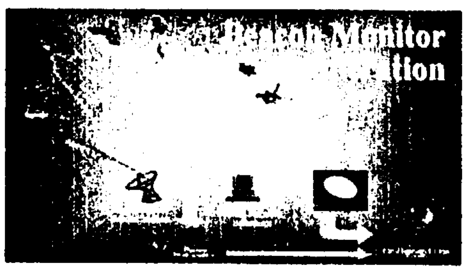


- Miniature integrated ion and electron spectrometer, built by Southwest Research Institute & Los Alamos National Laboratory
  - Combines multiple plasma physics instruments into one compact package
    - Energy and angle analysis for ions and electrons
    - Ion mass analysis
    - Very low power, low mass microcalorimeter

Autonomous Operations

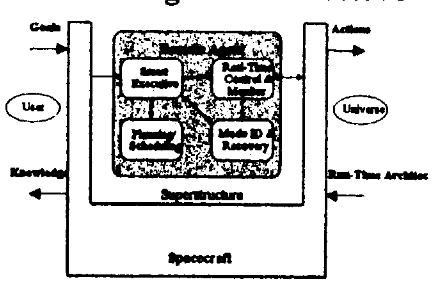


- Developed by JPL
- Integrated autonomous optical navigation and trajectory control system
  - Uses science-quality camera images of asteroids, stars and target bodies for orbit determination, and maneuver design and execution
  - Direct commanding of IPS, MICAS and Attitude Control System



- Developed by JPL
- On-board system to monitor spacecraft health and safety, and request ground action when necessary
  - On-board health and safety data summarization and spacecraft state categorization
  - Tone transmission to indicate urgency of ground action

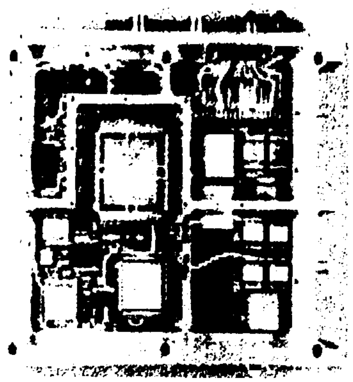
Remote Agent Architecture



- Developed by Carnegie Mellon University, NASA Ames, and JPL
- Autonomous "remote agent" that plans and executes on-board activities with only general direction from ground
  - Planner/scheduler to generate activities
  - Executive to expand the activity into a sequence of commands and monitor their execution
  - Mode identification and reconfiguration

Telecommunications

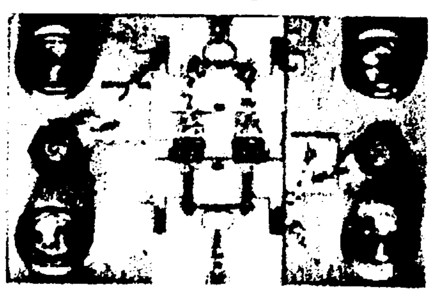
Small Deep Space Transponder



- Developed by Motorola Corporation
- Compact, low-mass transponder that combines multiple telecom subassemblies into a single unit
  - X-band receiver, X- and Ka-Band exciters, command detector unit, telemetry modulation unit, and beacon tone generator
  - Three times mass reduction
  - Greater functionality than conventional deep space transponders

---

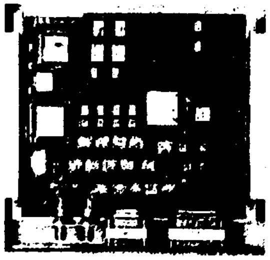
Ka-Band Solid State Power Amplifier



- Developed by Lockheed Martin
- Highest power solid state Ka-band amplifier ever used for deep space communications
  - Generates 2.6 W output with a 13% - 15% overall efficiency

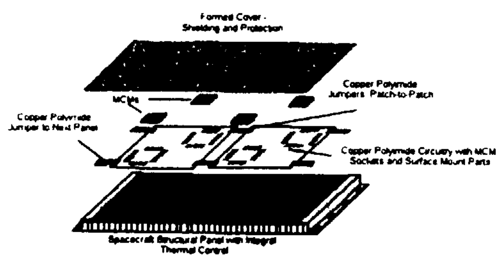
Microelectronics and Structures

Low Power Electronics



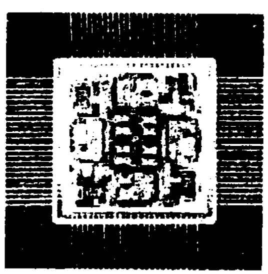
- Experiment provided by MIT Lincoln Laboratory for testing devices with very low voltage and low capacitance
  - Ring oscillator, multipliers and discrete transistors
  - 0.9 V logic, 0.25 μm gate lengths

Multifunctional Structure



- New packaging technology experiment provided by USAF Phillips Laboratory and Lockheed Martin Astronautics
  - Integrates electronics into load-bearing structural element to reduce mass of spacecraft cabling and traditional chassis

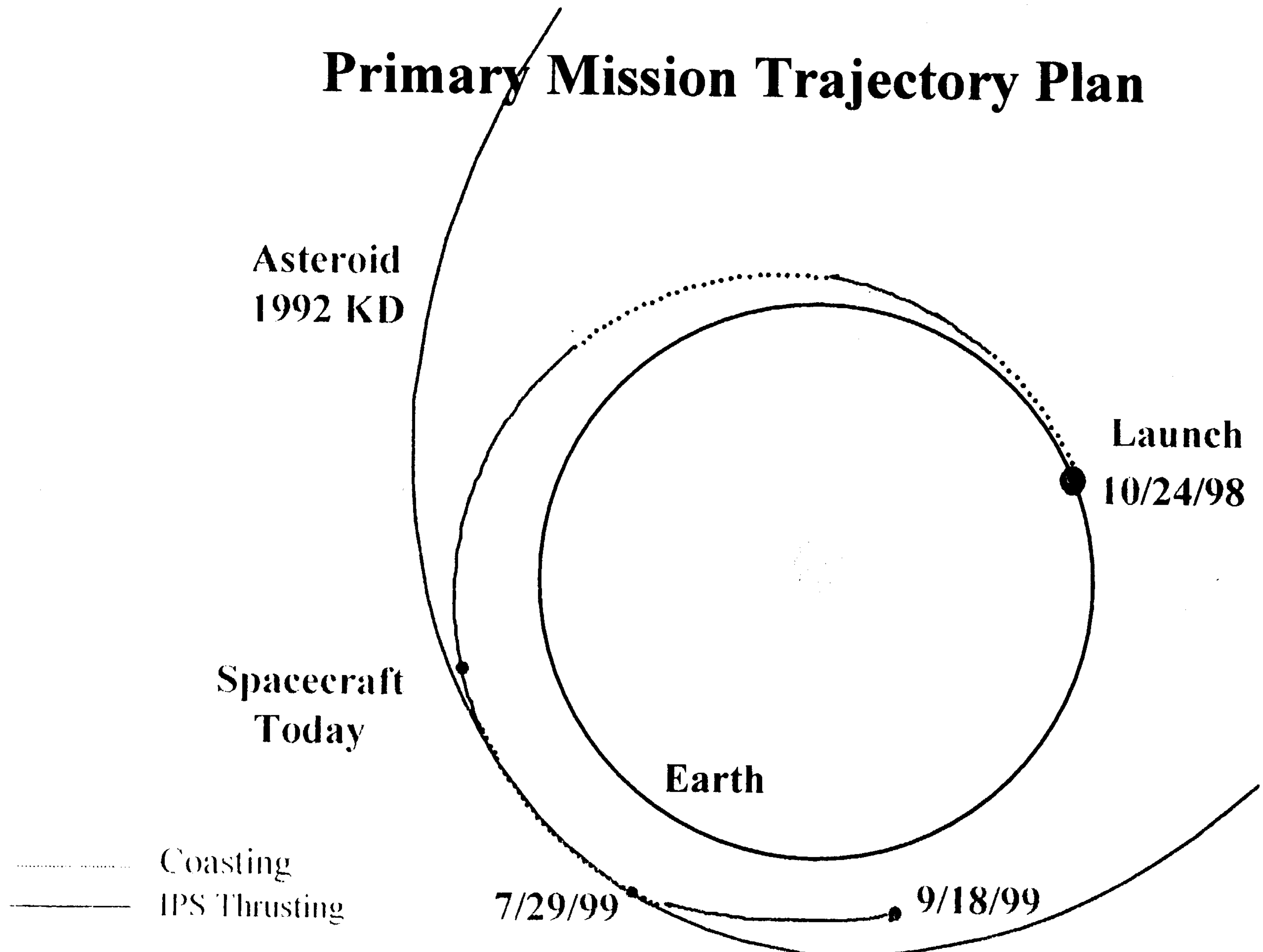
Power Activation & Switching Module



- Developed jointly by Lockheed Martin, Boeing, and JPL
- Miniature high-voltage, high-current switching device using high density interconnects
- High-density packaging technology achieves four times reduction in module size over current state-of-the-art switches

JPL

Primary Mission Trajectory Plan

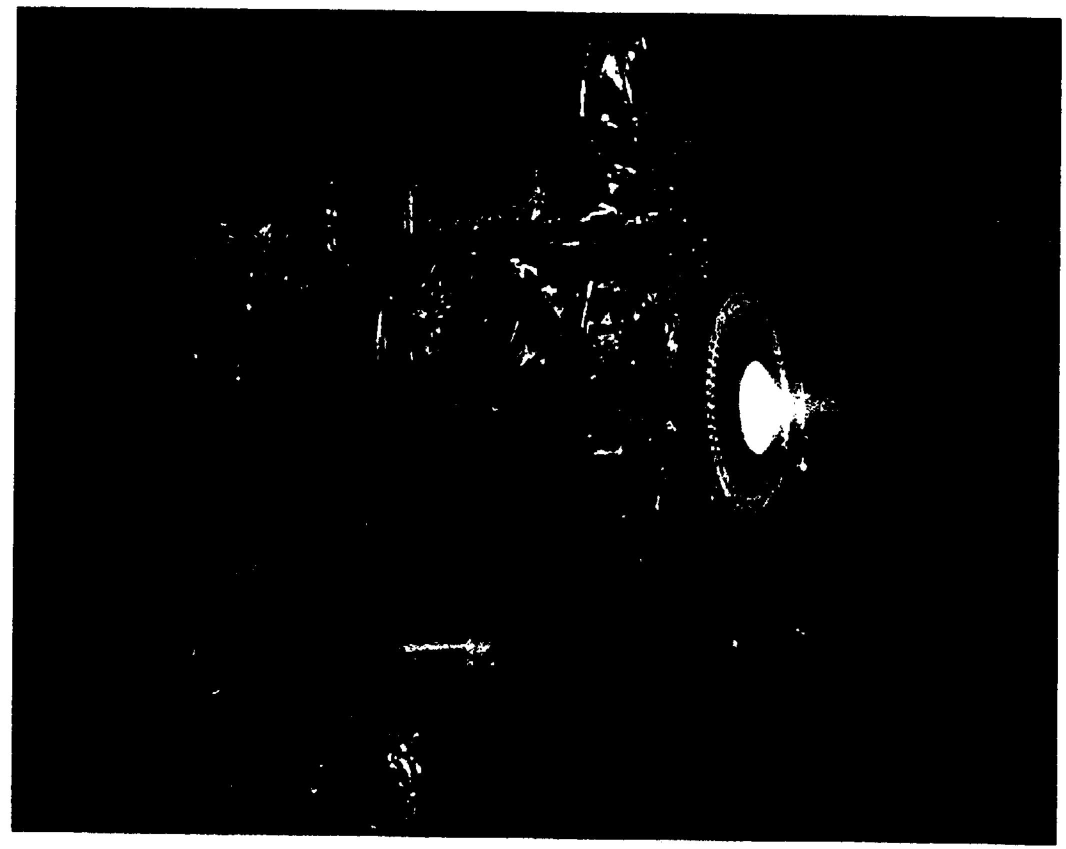


Mission Objectives and Status

Ion Propulsion System (IPS)

- Demonstrate high efficiency operation
  - 11 kg expended to reach 650 m/s (April 22, 1999). Thrust is within 2% of prelaunch prediction
- Demonstrate reliable operation for at least 200 hours
  - 1700 hours of operation achieved (April 22, 1999)
- Assess effects on spacecraft operation
  - All spacecraft systems operate nominally during IPS thrusting. Telecommunications conducted routinely while thrusting and through beam.

NSTAR Ion Engine operating during end-to-end test as part of DS1 STV testing



Mission Objectives and Status (Cont'd)

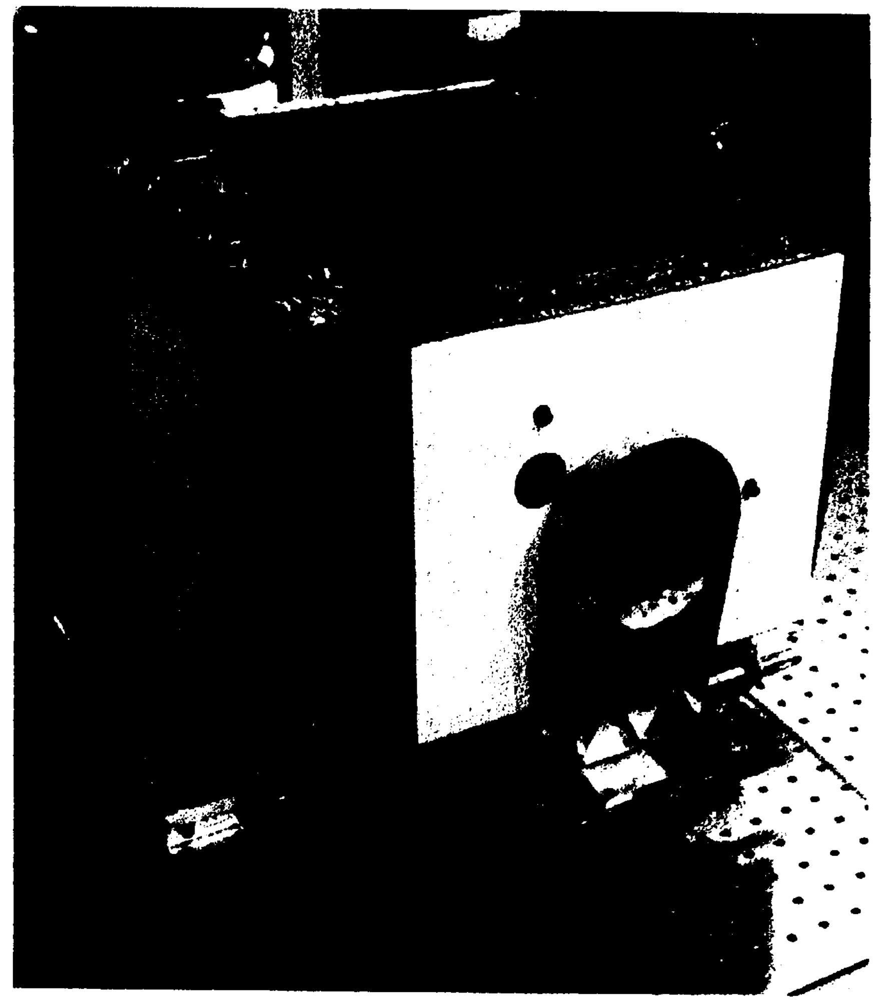
Solar Concentrator Array (SCARLET)

- Demonstrate reliable deployment and stable operation
  - Alignment was so accurate, no pointing corrections were needed. Array operation stable through 6 months of flight.
- Demonstrate high efficiency power generation
  - Cells operate at 22.5% optical-to-electrical efficiency.
- Validate prelaunch models of power generation capability
  - Power generation is about 1% higher than predicted before launch.

Mission Objectives and Status (Cont'd)

Miniature Integrated Camera Spectrometer (MICAS)

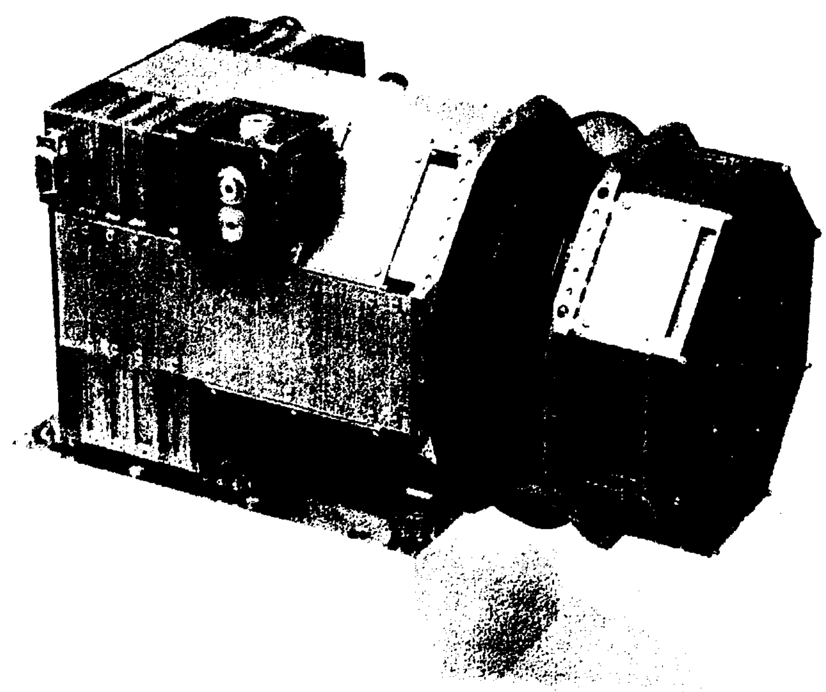
- Demonstrate launch and integrity of silicon carbide bench
  - No in-flight changes in MICAS focus since final alignment before launch
- Demonstrate use of electronically shuttered visible channel (eliminating moving parts)
  - Used extensively for autonomous navigation imaging
- Demonstrate capability to return science-quality data
  - Calibrations conducted on 3 of 4 channels
- Note: Currently, UV channel is not working. Diagnosis is ongoing



Mission Objectives and Status (Cont'd)

Plasma Experiment for Planetary Exploration (PEPE)

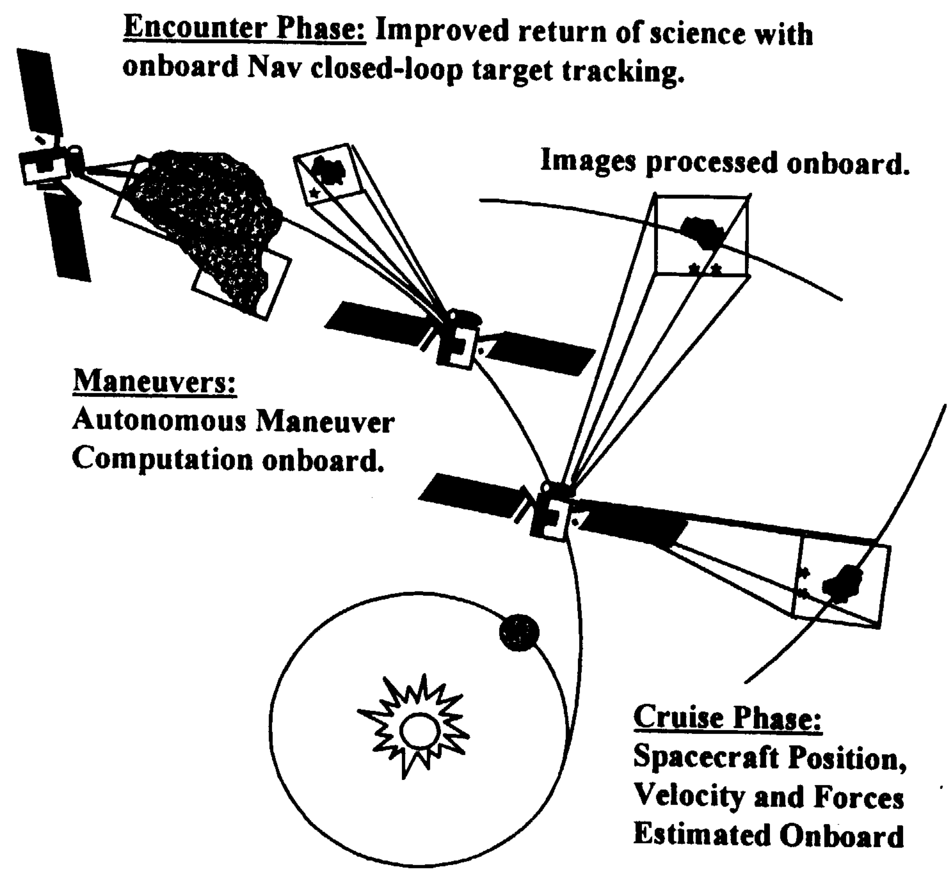
- Demonstrate ability to measure solar wind, including in presence of Xe plasma from IPS
  - Solar wind observations routinely conducted, including collaborative observations with Cassini Plasma Spectrometer



Mission Objectives and Status (Cont'd)

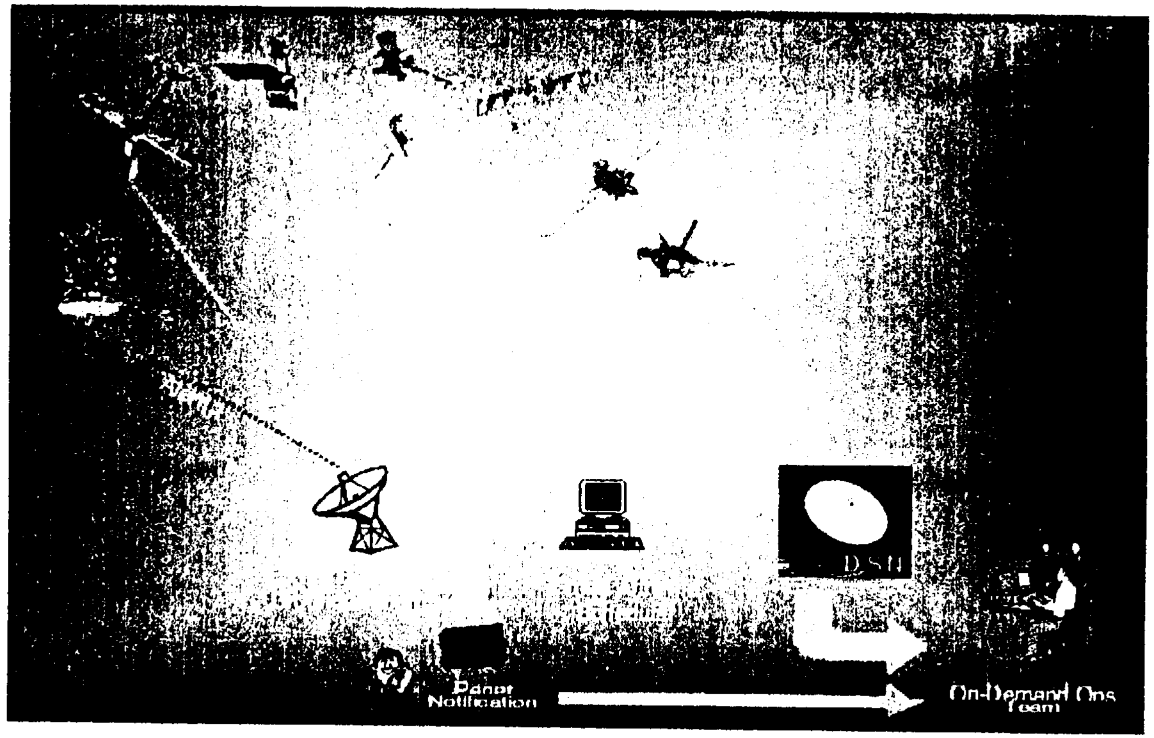
Autonomous Navigation (AutoNav)

- Demonstrate autonomous picture planning and sequencing
  - Autonomously turns spacecraft, images asteroids and stars, returns to correct attitude
- Demonstrate autonomous orbit determination and maneuver planning
  - Autonomously processes pictures, determines orbit (~10,000 km accuracy), and updates IPS thrust profile to keep on target for asteroid encounter
- Demonstrate autonomous control of IPS thrusting
  - Autonomously commands spacecraft attitude; pressurizes, starts, and stops IPS; updates throttle level and thrust attitude regularly.



Mission Objectives and Status (Cont'd)

Beacon Monitor Operations Experiment (BMOX)

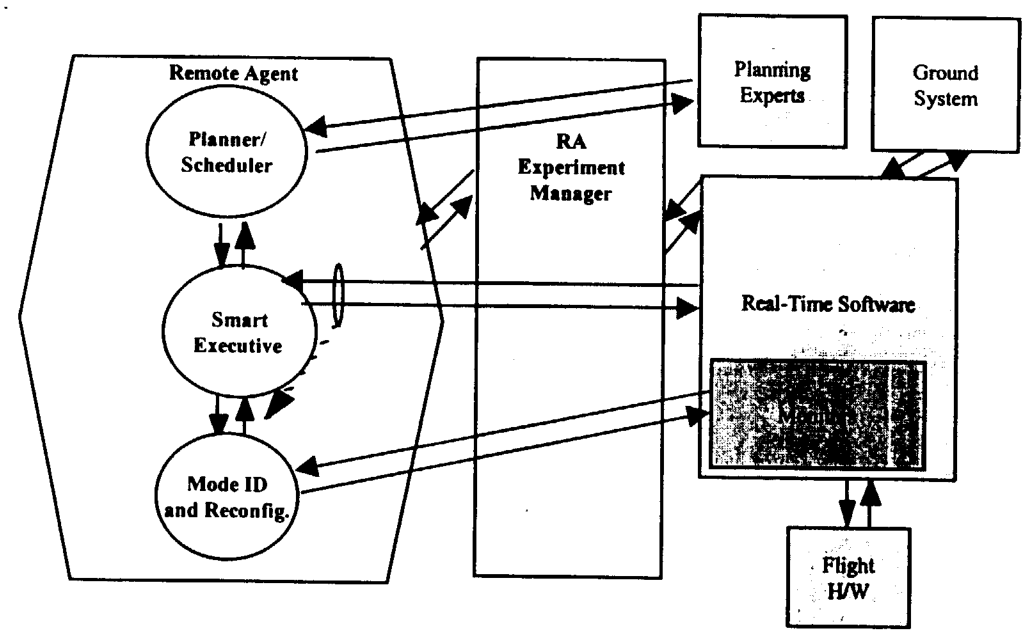


- Demonstrate detectability of beacon tones
  - Beacon signals detected under variety of signal conditions
- Demonstrate data summarization
  - Spacecraft data summarized and consistent with ground analysis

Mission Objectives and Status (Cont'd)

Remote Agent Experiment (RAX)

- RAX validation planned for May, 1999
  - Phase 1: Demonstrate ground-based Artificial Intelligence planning and scheduling
    - High-level control of Auto Nav camera pointing, attitude control maneuvers and power switching
  - Phase 2: On-board plan generation and execution
    - Control of IPS thrusting
    - Handling of anomalous behavior, including on-board replanning



Mission Objectives and Status (Cont'd)

Telecommunications Technologies

Small Deep Space Transponder (SDST) and Ka-Band Solid State Power Amplifier (KAPA)

- Demonstrate reliable operation for communications (X-band uplink and downlink and Ka-band downlink), ranging (X and Ka), Doppler (X and Ka), tone generation (X-band)
  - All functions verified through routine use and dedicated experiments. Consistent with prelaunch predictions
  - DSN using Ka signals for facility development

Mission Objectives and Status (Cont'd)

Microelectronics Technologies

MFS

- Demonstrate integration of electronics into spacecraft structure, with embedded thermal control
  - In-flight performance consistent with ground tests; no degradation observed during flight in flex connectors or multichip module sockets. Thermal gradients consistent with preflight predictions.

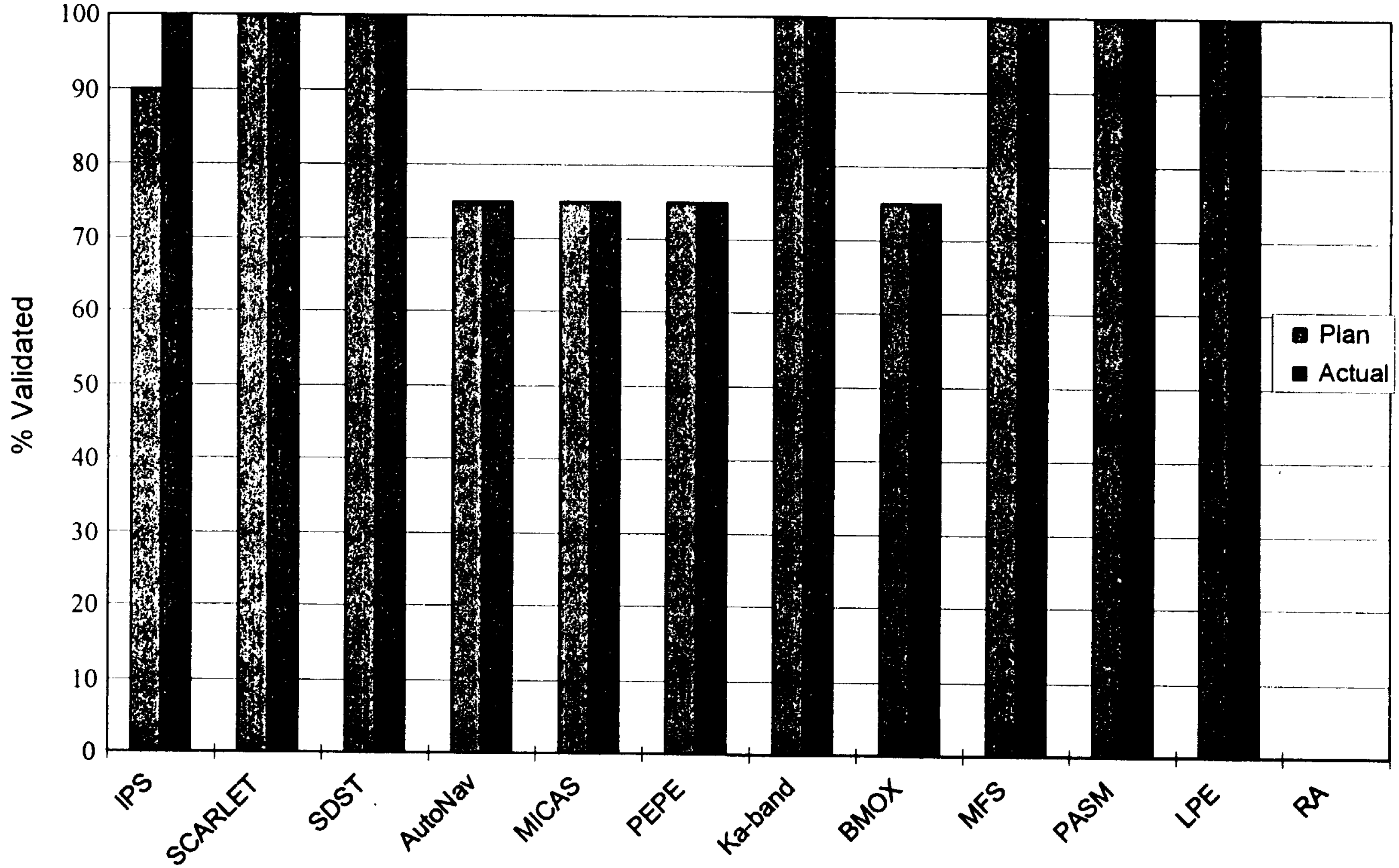
LPE

- Demonstrate radiation-resistant low-power devices in space environment
  - In-flight performance consistent with ground predictions. No degradation observed from radiation; tests repeated each week to monitor radiation effects.

PASM

- Demonstrate operation of smart power switching and current monitoring in spacecraft power system
  - In-flight performance consistent with ground tests.

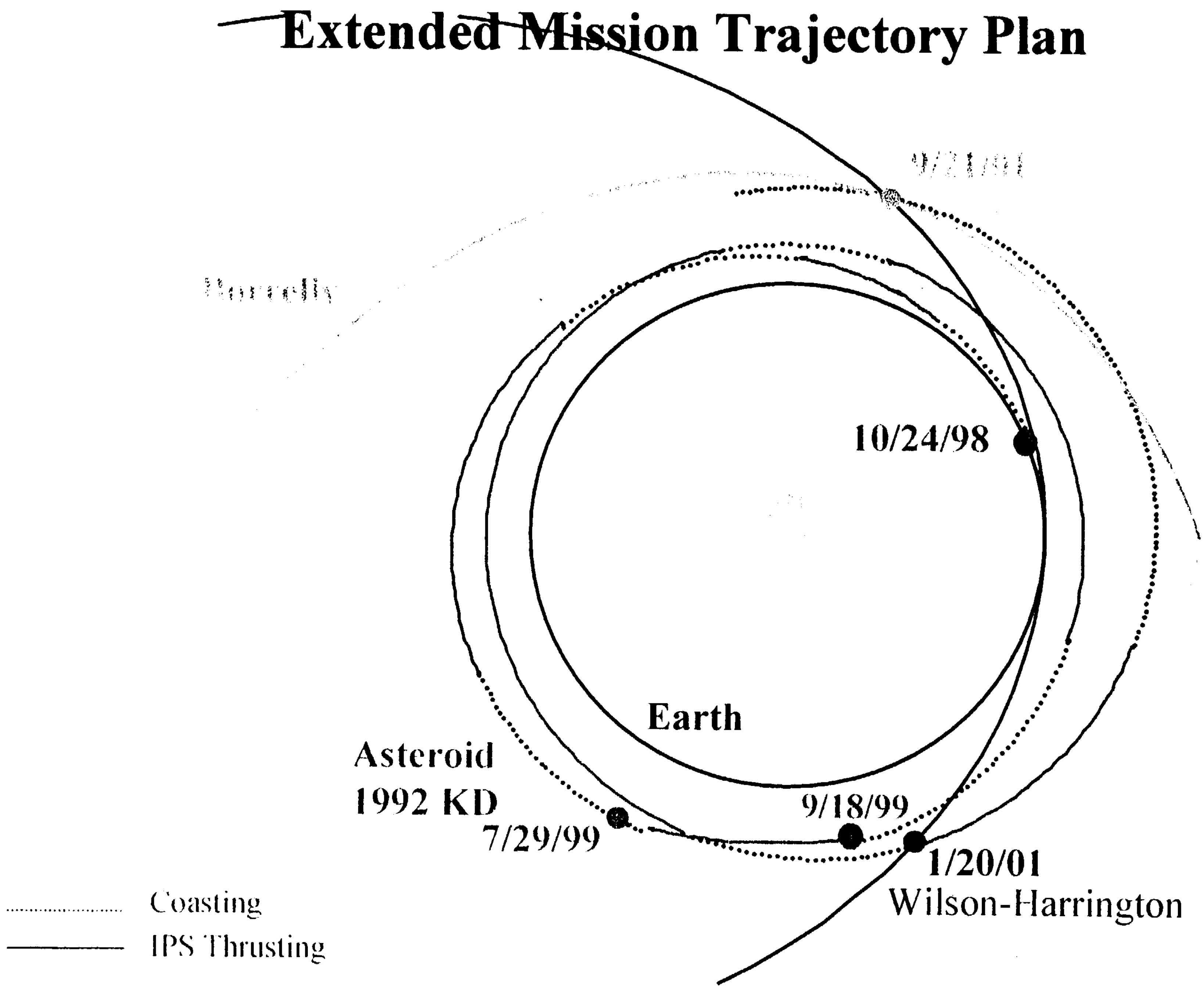
Technology Validation Status



1992 KD Asteroid Encounter Plan

- DS1 will encounter 1992 KD on July 29
  - Asteroid ~ 2km in diameter, with rotation period > 10 days.
  - Relative speed = 15 km/s
  - Closest approach = 8 km
- Technology Objectives
  - Use autonomous navigation to design and execute trajectory correction maneuvers to accomplish extremely close encounter
  - Ground in loop only to assist AutoNav in the event it does not work correctly
  - Use autonomous navigation to provide rapid updates to ACS on asteroid location for approach imaging
- Science Objectives
  - Using MICAS, PEPE, and the diagnostics sensors for the ion propulsion system, determine size, shape, albedo, morphology, chemical composition and properties of the surface material, and interaction with the solar wind. Search for satellites.

Extended Mission Trajectory Plan



Summary

- DS1 is validating tomorrow's technologies today
  - New methods of propulsion into deep space
  - New techniques of navigating through space
  - New flight equipment that makes spacecraft much smaller
  - New capabilities to make spacecraft more autonomous
- Significant progress to-date in validating the advanced technologies
- Asteroid flyby in July offers opportunities for science
- Extended mission trajectory plan provides two exciting comet flybys