NMP

NEW MILLENNIUM PROGRAM

Space Flight Validation of Advanced Technologies for Future Science Missions

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Carol Raymond

October 10-15, 1999

Abstract

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A broad range of advanced technologies are needed to support NASA's ambitious plans for planetary exploration during the next decade. To address these needs, the NASA New Millennium Program (NMP) identifies breakthrough spacecraft and instrument technologies and validates them in space to reduce their cost and risk. The first NMP Deep Space mission, DS1, was launched on October 24, 1998. Since then, it has successfully validated a solar-powered ion propulsion system, a miniaturized deep space transponder, autonomous operations and navigation software, multifunctional structures, low-power microelectronics and 2 instruments: the Miniature Integrated Camera and Spectrometer (MICAS), and the Plasma Experiment for Planetary Exploration (PEPE). To validate these technologies in a realistic environment, DS1's trajectory includes a close (<10km) flyby of asteroid 1992KD. An extended mission will allow encounters with comets Wilson-Harrington and Borrelly.

The second NMP mission, DS2, consists of a pair of micro penetrators that are targeted near the Martian South Pole (71 to 76 S). DS2 was launched on January 3, 1999 as a piggyback payload on the Mars Surveyor '98 Lander cruise stage. After crashing into the Martian surface at greater than 200 m/s on December 3, 1999, these probes will validate technologies that will enable future Mars penetrator networks.

Abstract (continued)

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These technologies include a single-stage, passive atmospheric entry system and a high-impact landing system designed to deliver a payload up to 1 meter below the Martian surface. This mission will also validate a miniaturized telecom system, low-temperature batteries, a suite of miniaturized in-situ scientific instruments, and other innovative packaging technologies.

The Space Technology 3 (ST3) mission is still under study. If approved, this mission will validate technologies needed for separated spacecraft optical interferometry. These technologies are needed to enable the Terrestrial Planet Finder (TFP) mission, and other missions space science missions that require autonomous precision formation flying and interferometic capabilities.

The Nanosat Constellation Trailblazer Mission has just been approved as the New Millennium Space Technology 5 (ST5) mission. ST5 will deploy 3 small (20kg) spin-stabilized spacecraft in a highly elliptical orbit around the Earth to validate technologies needed for future magnetospheric spacecraft constellations and other applications that require large numbers of highly coordinated spacecraft.

Ambitious Plans for Space Science

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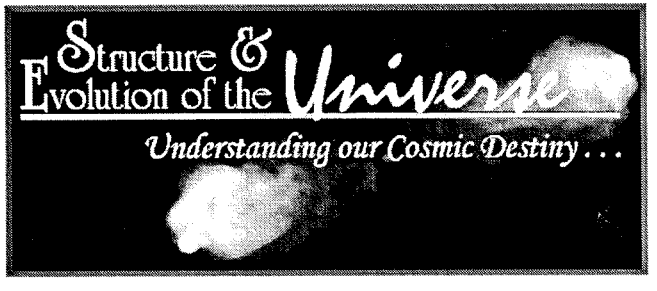
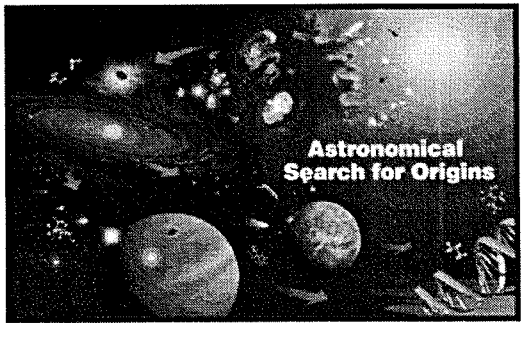
- Mars Exploration Program
  - Mars Sample Return[1,2]
  - Micromissions[1]
- Outer Planets
  - Europa Orbiter
  - Pluto-Kuiper Express
- Discovery
- Solar Terrestrial Probes
- UNEX/SMEX/MIDEX
- Laser Interferometery Space Antenna[3]
- FIRST/Planck[3]
- GLAST
- Next Generation Space Telescope[2]
- Space interferometry Mission
- Terrestrial Planet Finder





1) NASA/CNES Collaboration
2) NASA/ASI Collaboration
3) NASA/ESA Collaboration

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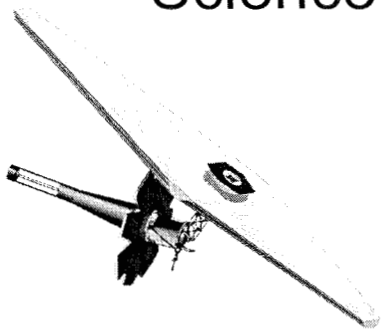
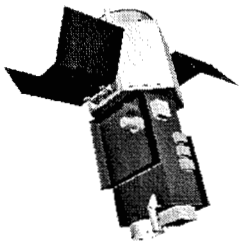
Advanced Technologies:
Essential to Achieve These Objectives

Science Missions





Impedance Mismatch

Technology Pipeline

Impediments to Rapid Technology Infusion:

- Lack of flight heritage
  - real or perceived risks
    - cost
    - schedule
    - performance
- Little visibility to mission planners
  - capabilities poorly understood
  - A complete paradigm shift is needed to fully exploit some technologies

The New Millennium Program

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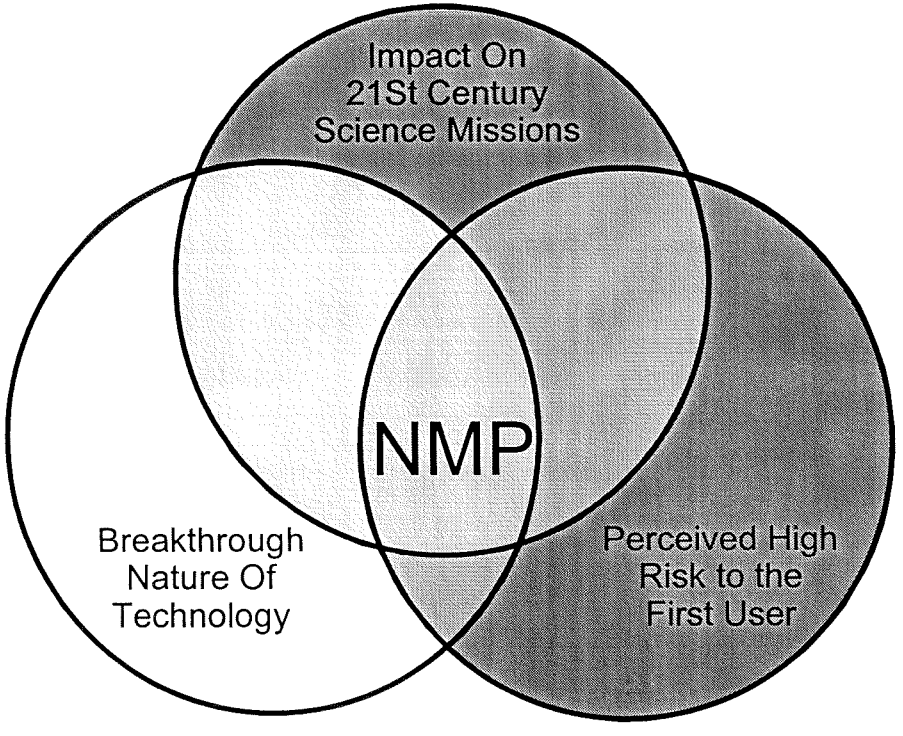
A cross-Enterprise program to identify and flight validate breakthrough technologies that will significantly benefit future Space Science and Earth Science missions



- Breakthrough technologies
  - Enable new capabilities to meet Earth and Space Science needs
  - Reduce costs of future missions
- Flight validation
  - mitigates risks to first users
  - enables rapid technology infusion into future missions

Cross-Enterprise Technology Thrust Areas

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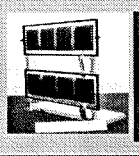
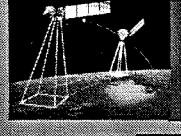
Office of Earth Science | Office of Space Sciences



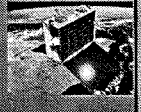
Advanced Power and Propulsion

Breakthrough Sensors and Instruments

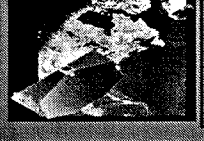
High Rate Data Delivery



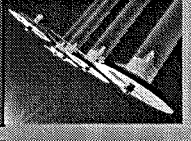
Thinking Space Systems



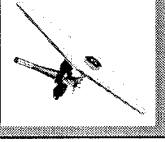
Micro-Nano Sciencecraft



Distributed Spacecraft



Ultra-Lightweight Structures / Space Observatories



Technology Program Elements

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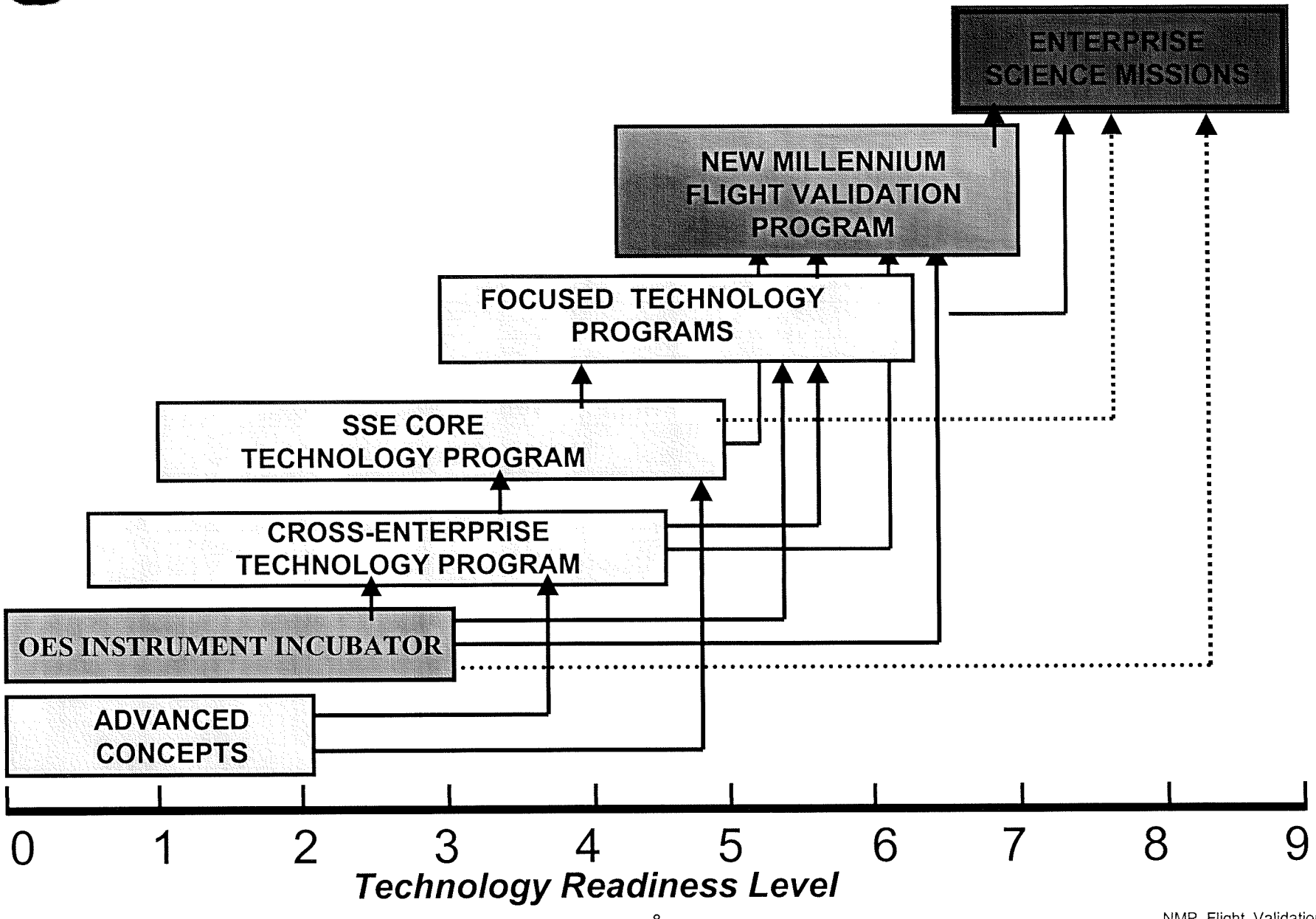
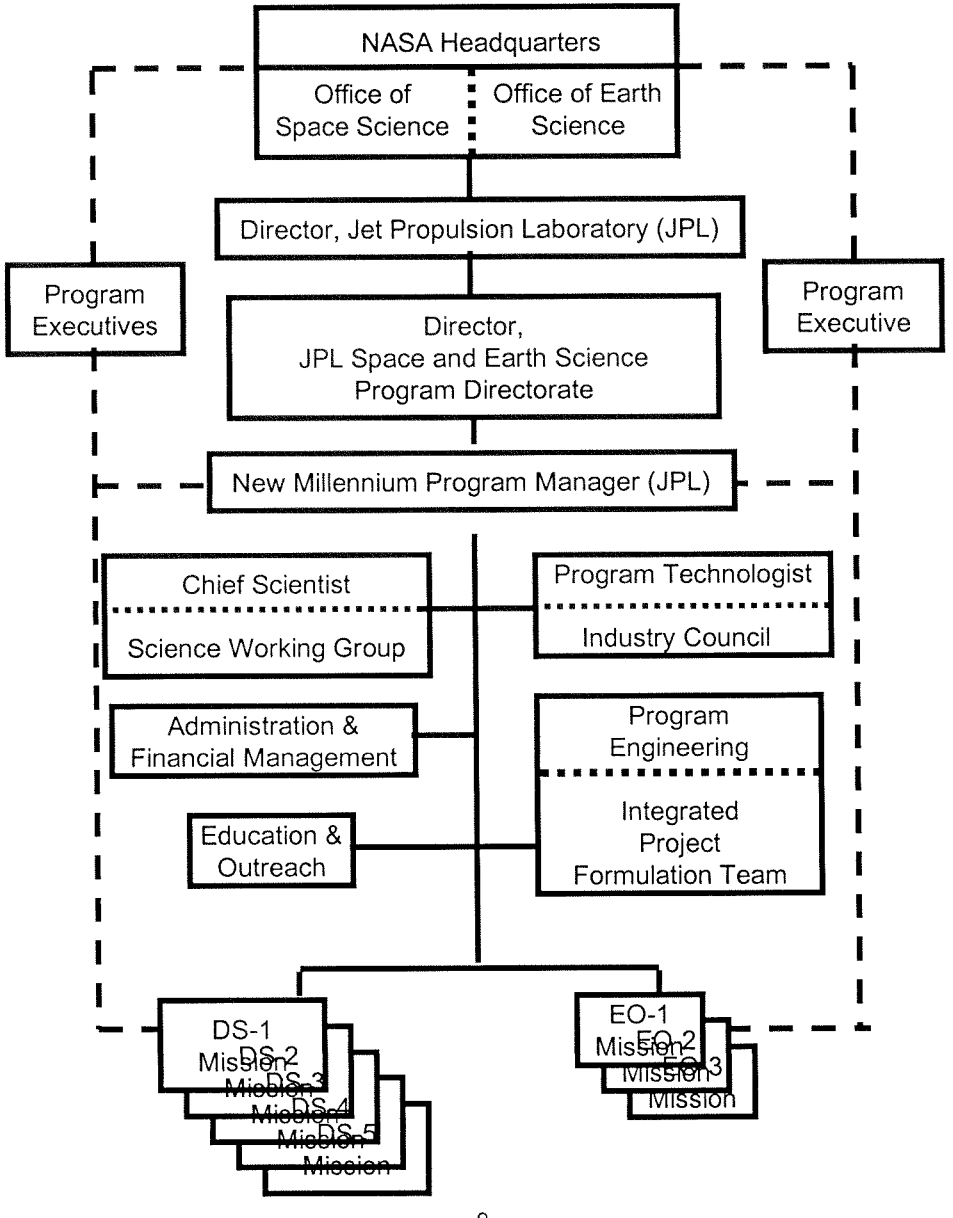


NMP Organization



Ongoing NMP Flights

Validation Flight Launch Schedule

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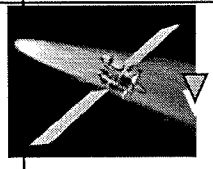
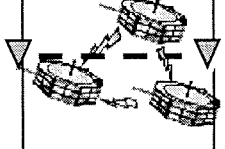
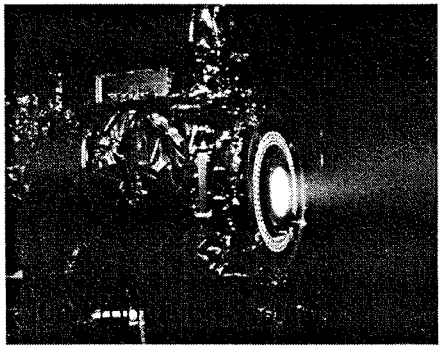
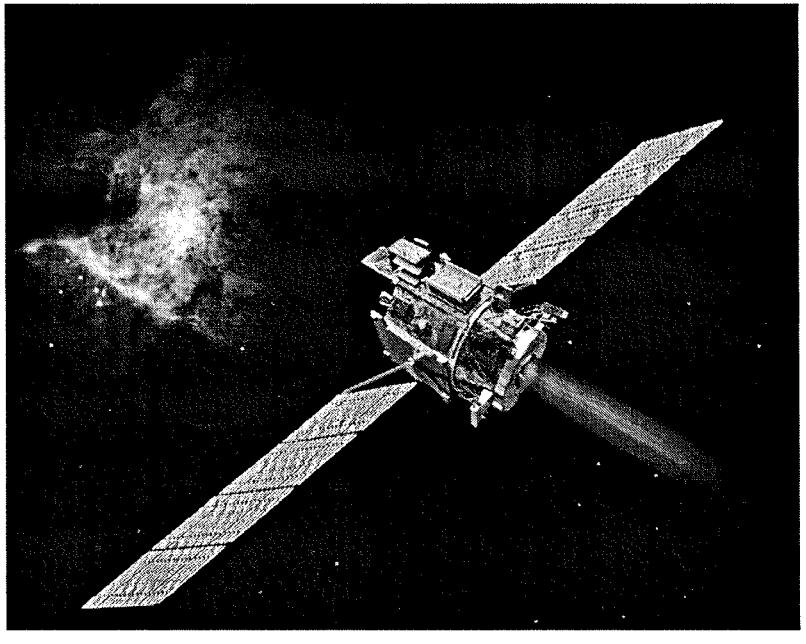
Year	98	99	00	01	02	03	04
DS1	 ▽ 10/98						
DS2	 ▽ 01/99						
EO1		 ▽ 12/99					
Future Flights							
ST3							
ST5							
EO3						▽ ▽	

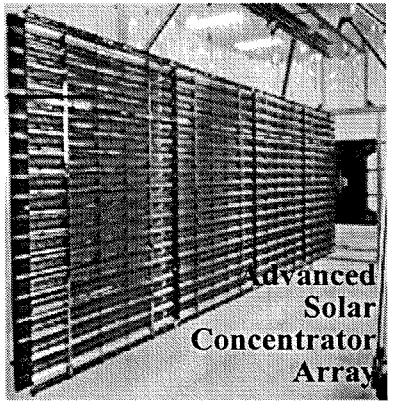
Deep Space 1

System Level Validation of 12 Breakthrough Technologies

NMP

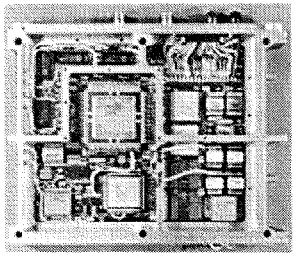




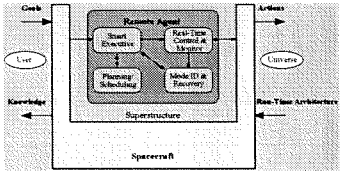


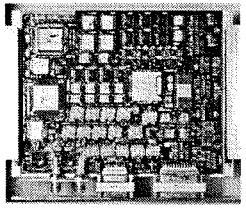
Advanced Solar Concentrator Array

Small Deep Space Transponder

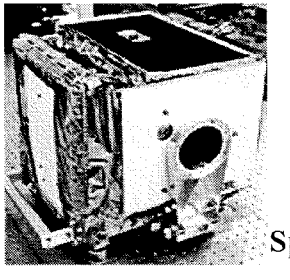


Remote Agent Architecture



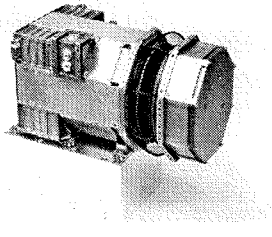


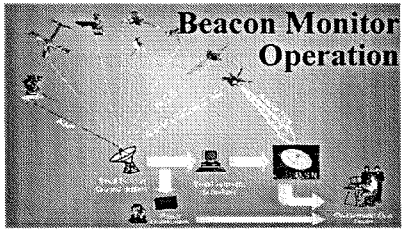
Low Power Electronics



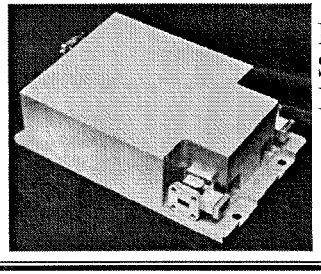
Miniature Integrated Camera Spectrometer

Plasma Experiment for Planetary Exploration



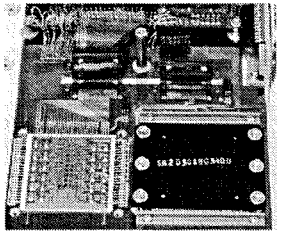


Beacon Monitor Operation

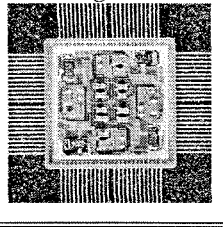


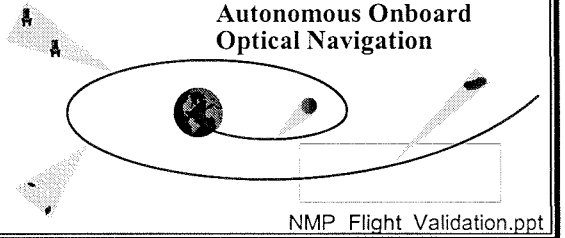
Ka-Band Solid State Power Amplifier

Multifunctional Structure



Power Activation & Switching Module



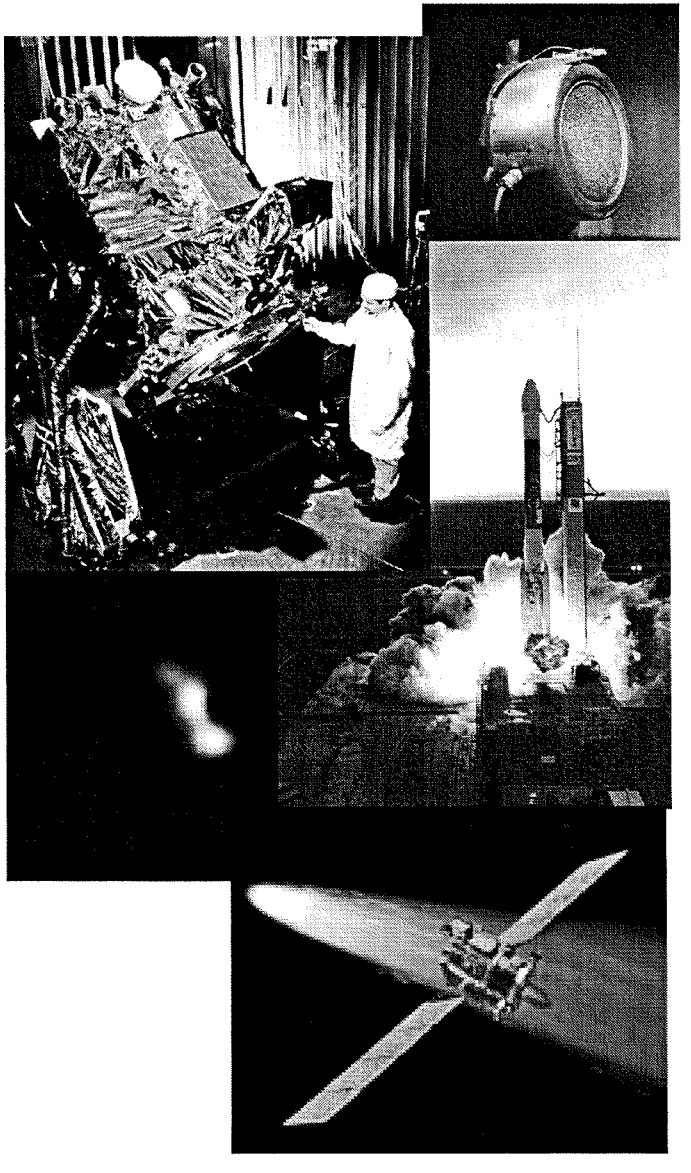


Autonomous Onboard Optical Navigation

Deep Space 1
Rapid Access to Small Bodies

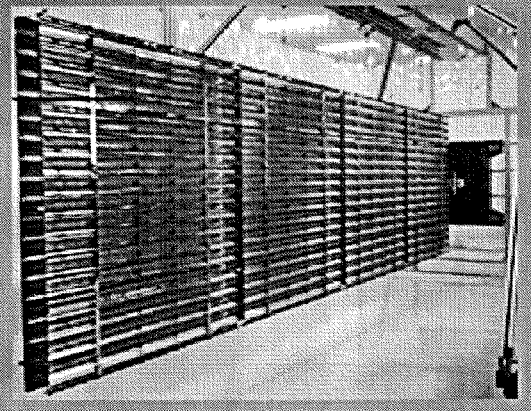
NMP

- Designed to validate ion propulsion and 11 other advanced technologies
- Successfully launched, October 24, 1998
- Technology Validation Status
  - all validation experiments completed
- Encountered Asteroid 1992KD on July 29, 1999
  - Provided opportunities to complete testing of technologies under realistic conditions
- Extended mission will allow encounters with 2 comets in 2001:
  - Comet Wilson-Harrington
  - Comet Borrelli



Future Users of Solar Electric Propulsion

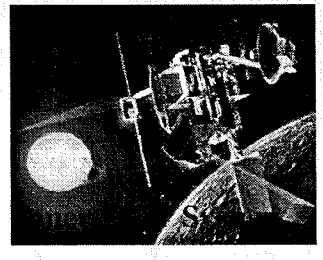
NMP

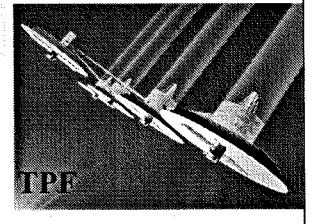


Advanced Solar Concentrator Array

Space Science

Comet Rendezvous

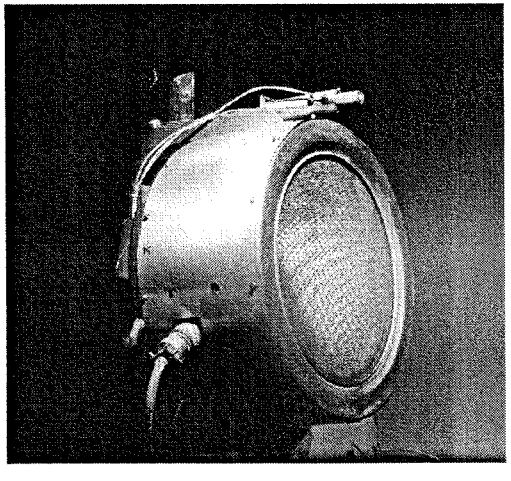




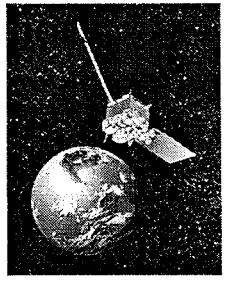
TPF

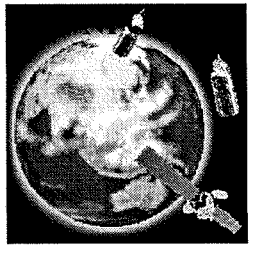
Benefits of Solar Electric Propulsion
- Transportation
- Formation Flying
- Station Keeping/Orbit Maintenance

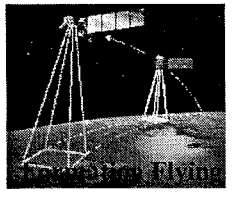
DS1



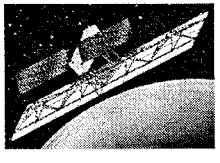
NSTAR Ion Propulsion







Formation Flying



ESSP

Earth Science

DS1 Science

NMP

NASA Program Scientist: Dr. Tom Morgan, NASA HQ
Project Scientist: Dr. Robert M. Nelson, JPL

The DS1 Science Team

- Fifteen scientists were chosen through a NASA AO

Frances Bagenal	University of Colorado
Daniel Boice	Southwest Research Institute
Daniel Britt	University of Arizona
Bonnie Buratti	Jet Propulsion Laboratory
Robert Brown	University of Arizona
Wing Ip	Max Plank Institut fur Aeronomy
Jurgen Oberst	DLR, Germany
Tobias Owen	University of Hawaii, Honolulu
Bill Sandel	University of Arizona
Laurence Soderblom	U.S. Geological Survey
Alan Stern	Southwest Research Institute
Nicolas Thomas	Max-Planck-Institut fur Aeronomy
Roger Yelle	Boston University
David Young	Southwest Research Institute
Joseph Wang	Jet Propulsion Laboratory

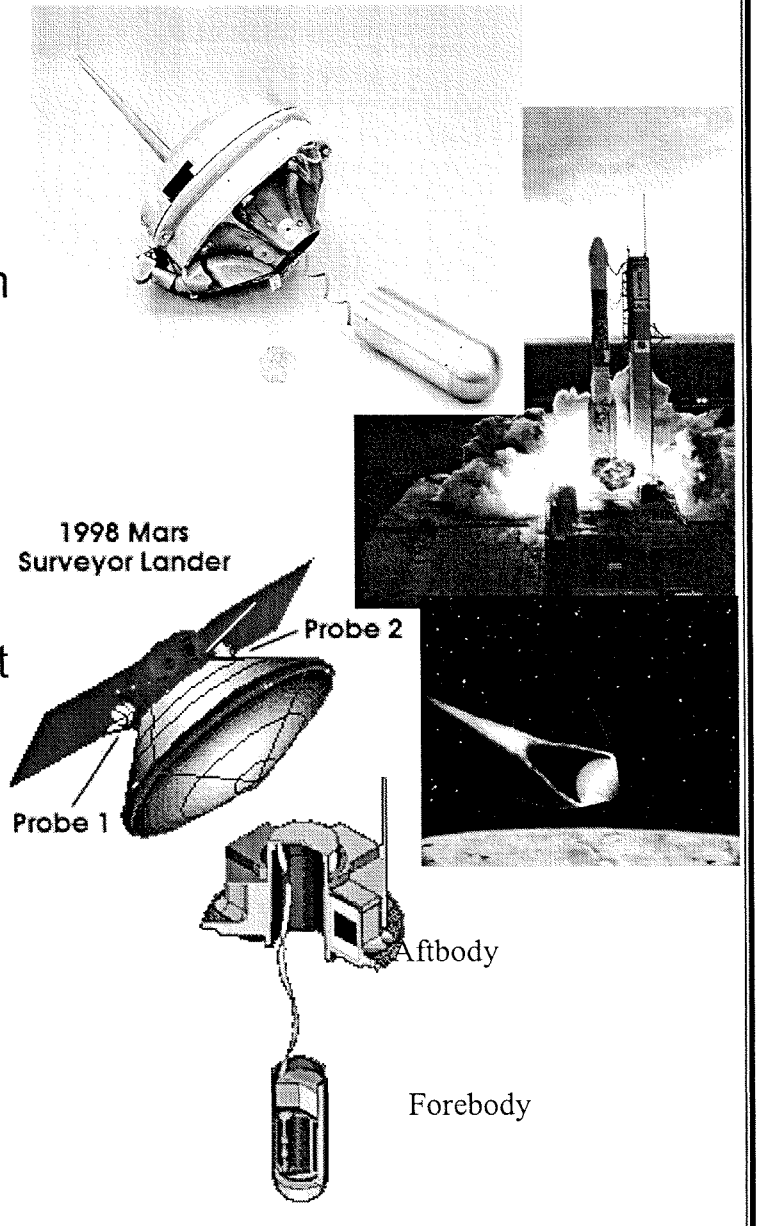
Science Team Responsibilities

- Provide scientific input for mission planning and instrument operations.
- Assist in instrument calibrations.
- Assist in technology validation activities.
- Reduce and validate technical and scientific data.
- Prepare raw and reduced data for archiving for future use by the scientific community.
- Analyze, interpret, and publish first results and findings in peer-review literature.
- Support advocacy and liaison efforts between Deep Space 1 and the scientific community.

Deep Space 2: Mars Microprobes

NMP

- Designed to validate technologies for surface penetrators and network science
  - Passive entry, descent, and landing system
    - built to survive high-g impact (30,000 - 80,000 g's)
  - Miniaturized Electronics
    - power, microprocessor, telecom
  - Low-temperature batteries
  - Soil acquisition/Water detection experiment
- 2 probes successfully launched
  - January 3, 1999
  - Piggyback on Mars Surveyor 98 Lander cruise stage
- Landing in Martian South polar regions
  - December 3, 1999
  - Primary Mission: 2 Sols



Deep Space 2

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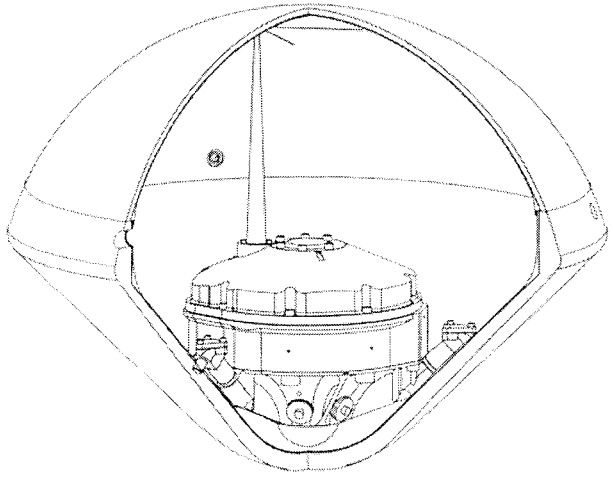
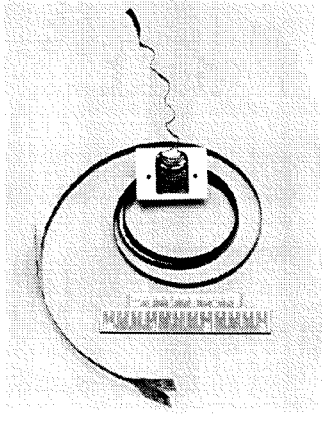
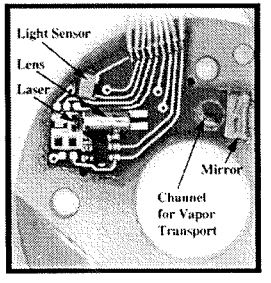
Technologies for Surface Penetrators and Network Science



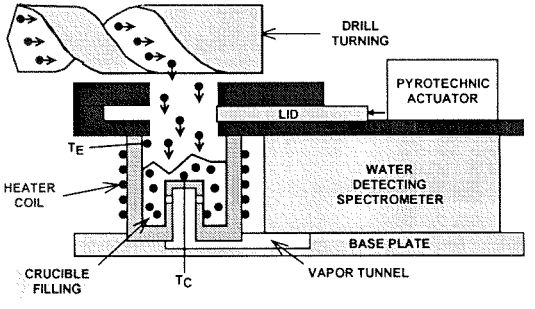
Single-Stage, Passive Aeroshell Entry System

Flexible Interconnect

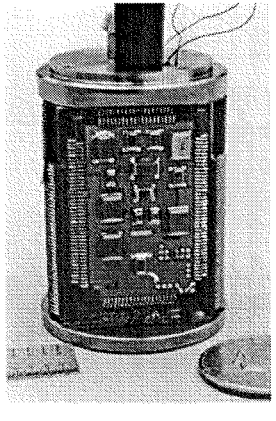




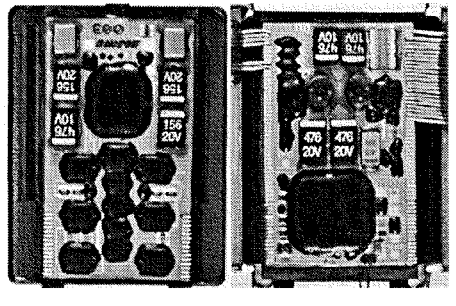
Miniaturized Tunable Diode Laser Spectrometer
Subsurface Water Detection

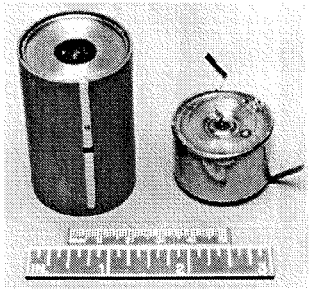


Advanced Microcontroller

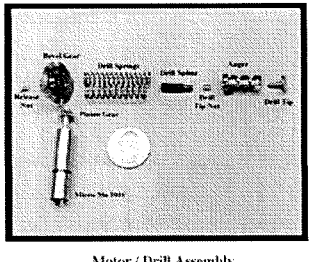


Power Microelectronics





Low Temperature Lithium Ion Batteries

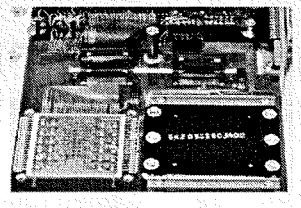


Motor / Drill Assembly

Soil Acquisition System

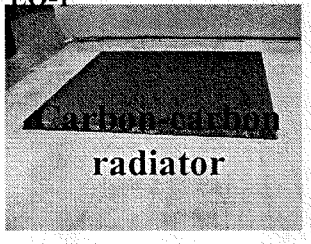
Future Users of Micro and Nano Spacecraft

NMP



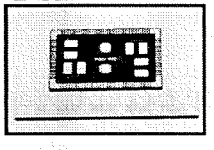
Multifunctional structure

EO-1



DS1

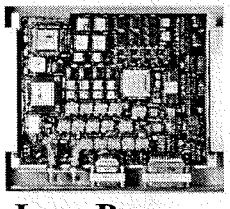
DS2



Advanced Micro Controller

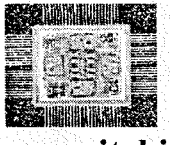
Small Deep Space Transponder

DS1



Low Power Electronics

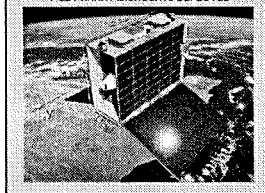
DS1

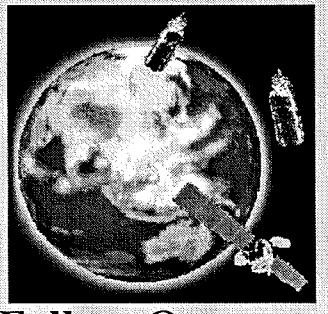


Power switching module

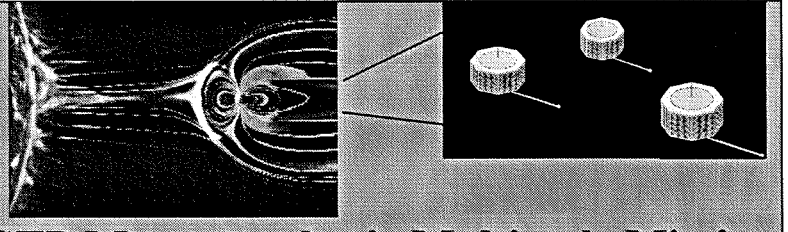
Innovations that simplify design, fabrication, reduces mass & reduce resource requirements

Earth Science





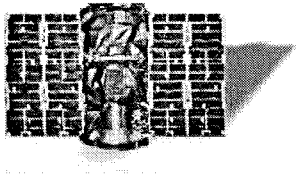
- Potential for EOS Follow-On
- ESSP and Earth Probes



- STP Magnetospheric Multiscale Mission

DISCOVERY

SMEX



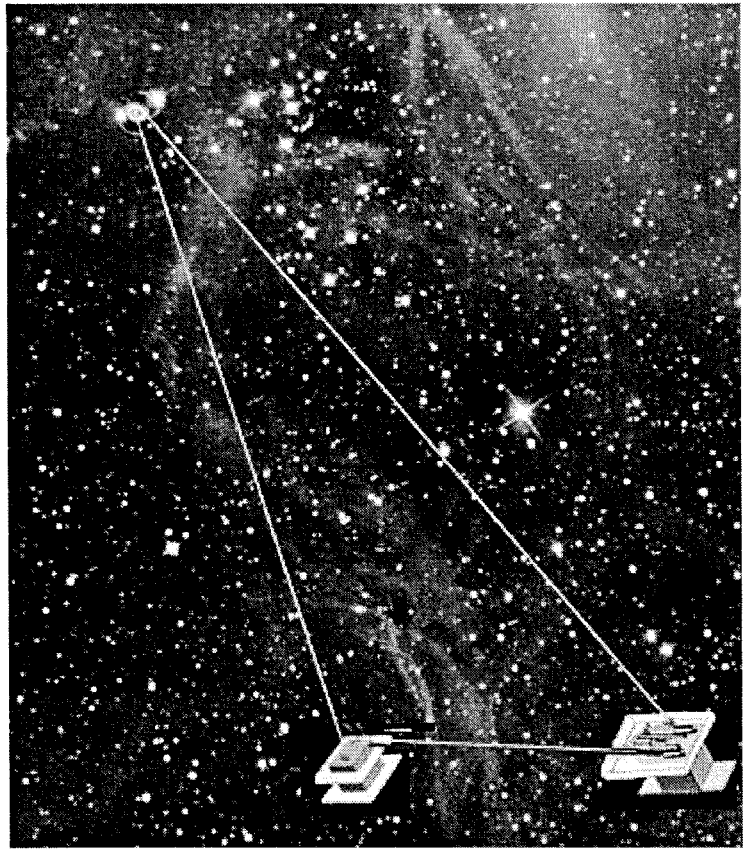
- Mars Micro missions
- Discovery
- UNEX/SMEX/MIDEX

Space Science

Future NMP Flights

ST3: Separated Spacecraft Optical Interferometer

NMP

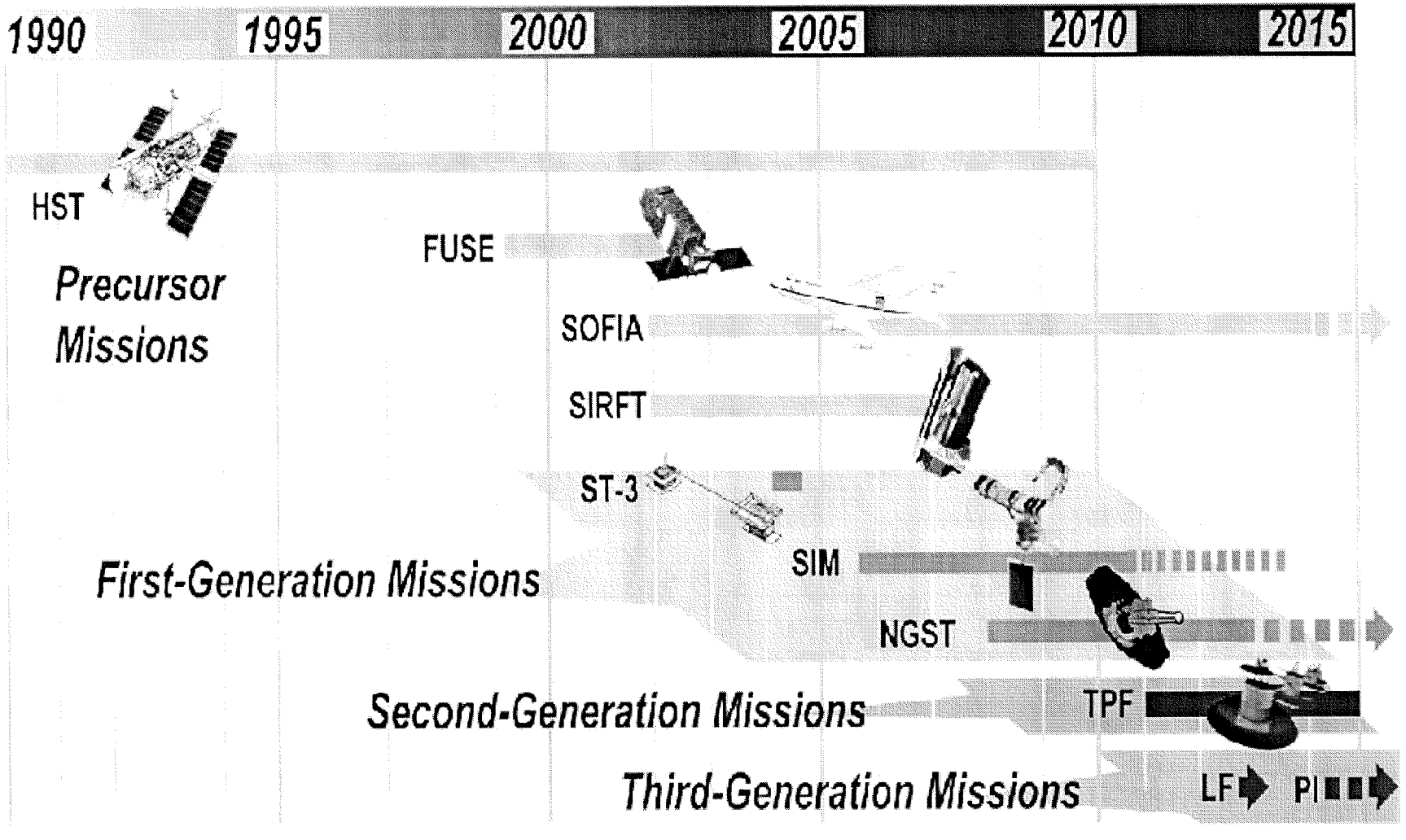


Mission Configuration:

- 2 spacecraft, separated by 50 m to 1 km
  - Observation baselines of 40 to 200 m
  - 8th magnitude stellar targets
  - Parabola is locus of constant delay
- Combiner contains 20 m fixed delay line
- Combiner can operate as a 1 m monolithic interferometer
  - No collector, bypass fixed delay
- Both S/C maintain fixed orientation relative to each other during baseline changes

Astrophysical Search for Origins Mission Timeline

NMP



ST3: End-to-End Validation of Technologies for Separated Spacecraft Interferometry

NMP

Validation Objectives:

- Precision Autonomous Formation Flying
  - uses RF system (GPS-like transmitters and receivers)
  - Estimated control accuracy of 1 cm in range, ~2 arcmin in angle
  - Easily scalable to multiple spacecraft
- Angular Metrology
  - uses Lasers and Starlight
  - validation requires
    - finding fringes to get true delay to <1 micron
    - measuring the true delay rate to <<1 micron/second
- Michelson Interferometry with separated spacecraft
  - baselines from 40 to 200 m
  - calibration on multiple sources will characterize visibility and stability as a function of source brightness and time
- About 100 sources will be observed during the 7-month mission
  - detection limit is M_V=8 to 10 using 12 cm apetures

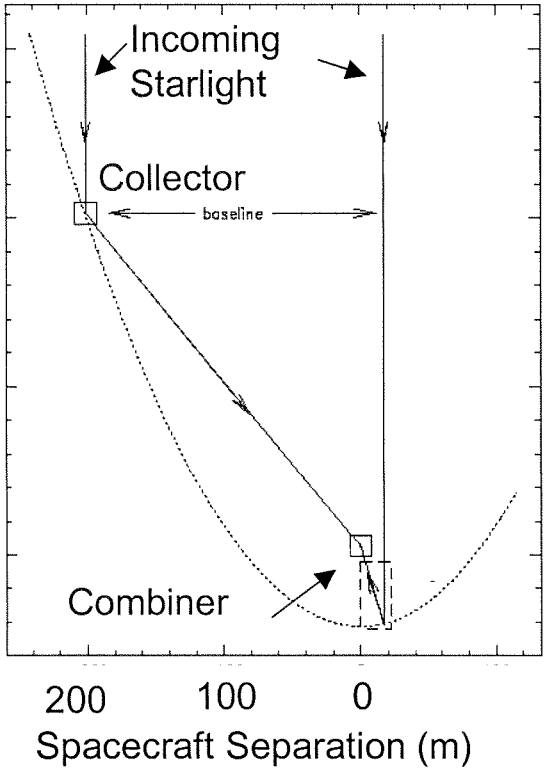


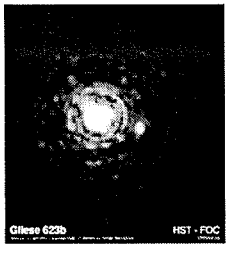
Figure showing relative positions of collector and combiner spacecraft

ST3 Science Targets

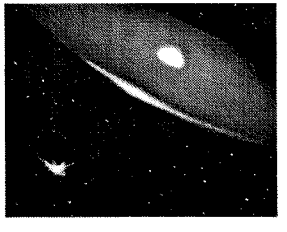
NMP

ST3 will be able to resolve:

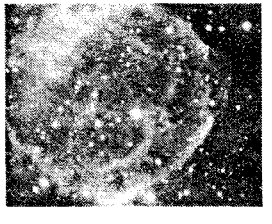
- M Dwarfs
  - Imaging observations will facilitate photospheric temperature determination

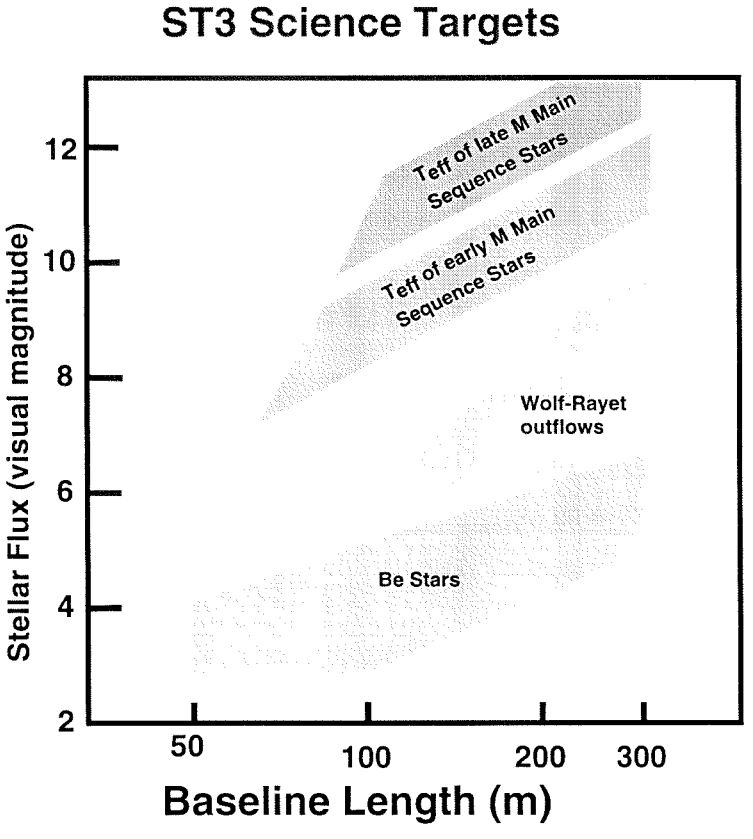


- Be Stars:
  - hot stars surrounded by gaseous disks
  - ST3 images of Be stars will resolve the star from its circumstellar disk, facilitating studies of the disk evolution



- Wolf-Rayet Stars
  - hot stars with very strong stellar winds
  - ST3 images of this outflow will determine it morphology
    - polar
    - equatorial,
    - spherically symmetric





Candidate science targets are are shown as a function of baseline separation. The nominal maximum baseline is 200 m.

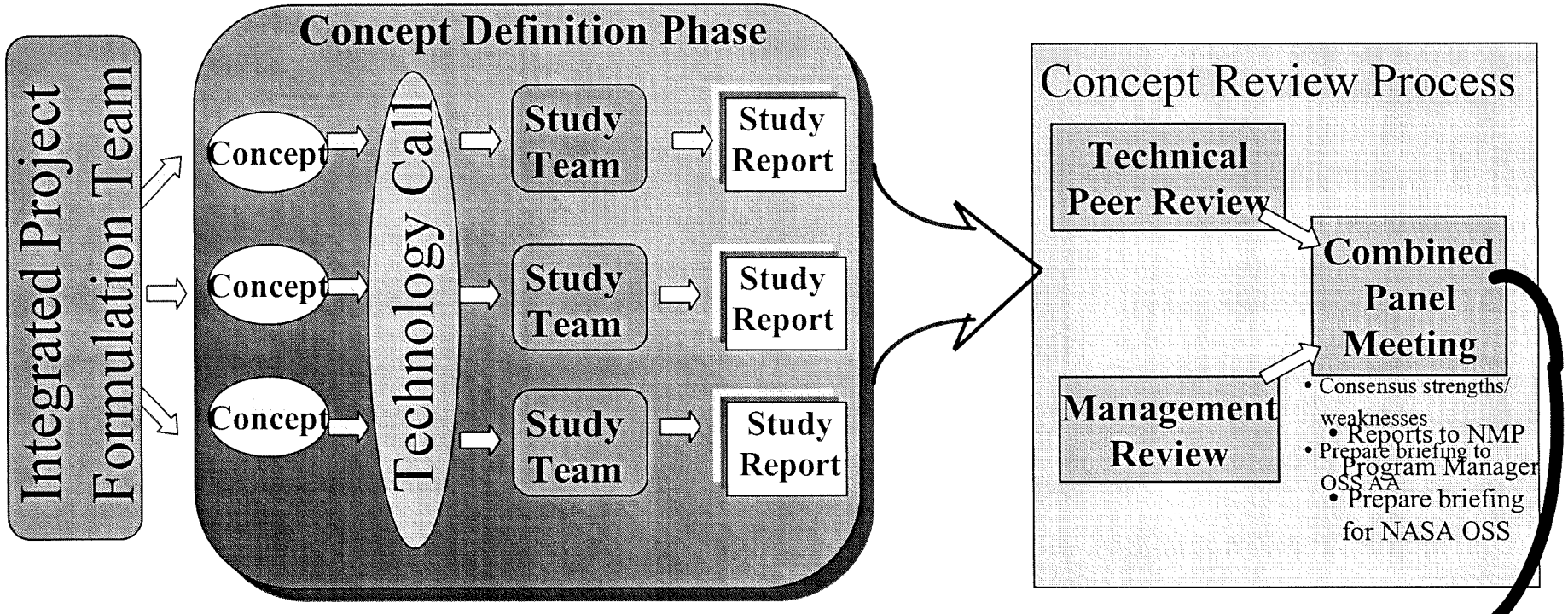
The ST5 Opportunity

NMP

- ST5 is a low-cost validation flight
  - Total implementation phase budget of <$30M
- NASA HQ directed NMP to focus on technologies for
  - Structure and Evolution of the Universe (SEU)
  - Sun-Earth Connection (SEC)
- Three high-priority technology themes were identified
  - Disturbance reduction system technologies (for SEU LISA Mission)
  - Solar sail (for SEC Solar Polar Orbiter, Interstellar probe, etc)
  - Nanosatellite (for SEC Magnetospheric Constellation, etc.)
- RFP issued for technologies in March 1999
  - 73 proposals submitted, 24 selected.
  - Successful proposers incorporated into study teams
  - Each team prepares a report for mission selection review

ST5 Mission Selection Process

NMP



Selection/ Notification

- Selection Official OSS AA
- Designates implementation organization

Project Formulation Refinement Phase

- Solicitation for Science Payloads (if any)

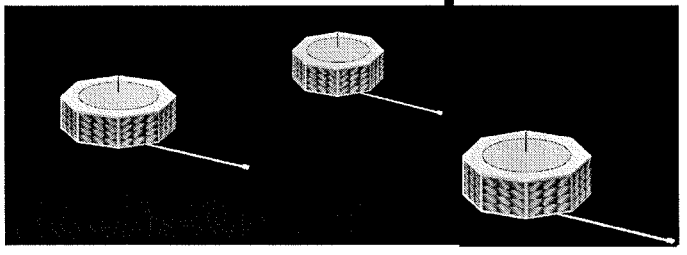
Project Approval Review

Project Implementation Phase

- NRA Issued for Science Validation Team

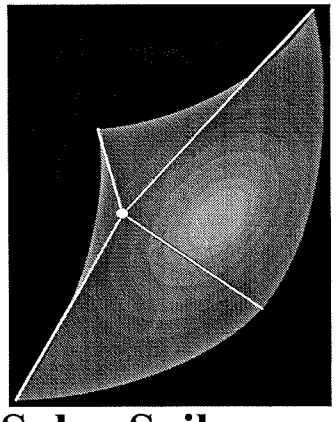
ST5 Concepts

NMP



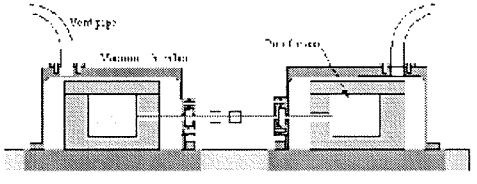
Nanosatellites

- Small (spinning) spacecraft, deployed and operated in constellations
- Each with multiple small Fields and Particles Instrument Technologies



Solar Sail

- Propulsion system to place spacecraft in desired locations unreachable (or un-maintainable) by alternative propulsion systems
- Small Fields and Particles Instrument Technologies (on bus, sail or sub-sat.)



Disturbance Reduction System

- Inertial and position sensing technologies for precision spacecraft positioning - for future gravitational and interferometric applications

ST5 Nanosat Constellation Trailblazer Mission

NMP

Miniature Spacecraft

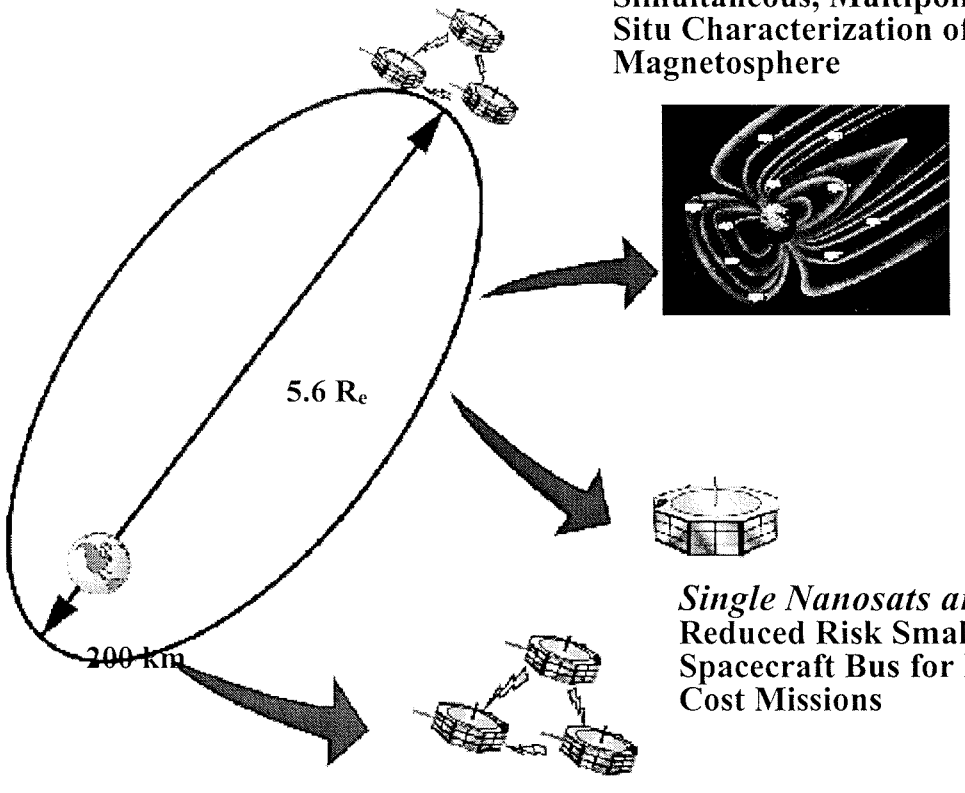
- Systems Design Integration and Test Technologies

Candidate Spacecraft Technologies

- 5V bus - 1/4V logic
- Li-Ion batteries
- Miniature transponder
- Miniature Thrusters
- Multi-functional structure
- Variable emittance coatings

Constellation Control, Coordination, and Operations Architecture

- Ground system autonomy
- Relative ranging
- Intra-constellation communications



Constellation Class Missions
Simultaneous, Multipoint, In-Situ Characterization of the Magnetosphere

Single Nanosats and Probes
Reduced Risk Small Spacecraft Bus for Low Cost Missions

Virtual Platforms
For Science Missions

TECHNOLOGY ⇒ **VALIDATION** ⇒ **INFUSION**

Sun-Earth Connection Technology Needs

NMP

7 mission concepts require enabling technologies for nanosats and microsats

- large numbers of small, simple spacecraft needed for in-situ studies of
  - •Magnetospheres
  - •Solar Plasma

	Constellation Name	Number of Spacecraft	Mass (kg)	Begin Phase C/D	Orbit	Technology Needs
Near	Cluster	4	1180	'00 (launch)	4 x 20 Re	Formation flying
	Mag Multiscale	5	240	'04	Apogees from 12 to 127 Re	Variable cluster
	GEC	4	600	'05	130 x 2000 km	Dipping satellites
	Mag Constellation	100	10	'07	10-35 Re	Deployer ship, miniaturization
Mid	Inner Mag	42	10	'08-'14	2-12 Re	Deployer ship
	Dayside Boundary	39	10	'08-'14	2-20 Re	Multiple inclination
	Global ITM	24	50	'08-'14	150x2000 km & 500 km circular	Dipping satellites, neutral composition instruments
Far	Solar Flotilla	12	50	'15-'25	Heliocentric, near-Sun 0.2 AU, orbits	Injection into high-inclination solar orbit (solar sails), communications
	Inner Heliospheric Constellation	12	50	'15-'25	Heliocentric, 0.2-0.5 AU, various inclinations	Solar sails, imaging sensors, communications
	Outer Heliospheric Radio Imager	17	25	'15-'25	20-40 AU	Interferometric measurements with 1 mother s/c and 16 small s/c

Technology Infusion from ST5 into Future Missions

NMP

[ ] Numbers in brackets correspond to the NCT Project technologies.

SEC
Enable multipoint observations separating space and time measurement of dynamic phenomena in the Sun-Earth Environment

SSE
Enable multipoint observations separating space and time measurement of dynamic phenomena in magnetospheres and atmospheres of inner and outer planets

Earth Science
Enable multiplatform coordinated observations, reductions in satellite size, mass and cost, virtual platforms with distributed instrumentation

Commercial and General Space Industry

NCT

Validation of technology enabling intelligent constellations of smart spacecraft

Technologies

1 - A Formation Flying & Communications Instrument
2 - Li-ion batteries
3 - Multifunctional structures
4 - Variable emittance thermal suite
5 - Ultra low power (1/4v) logic
6 - Miniaturized communications components
7 - Cold gas micro thrusters
8 - Software tools for autonomous ground operations

Mag Constellation
Simultaneous in-situ observations of the earth's magnetic tail
~100 nanospacecraft
[1,2,3,4,5,6,7,8]

Inner Mag Constellation
Radiation belt dynamics
~42 nanospacecraft
[1,2,3,4,5,6,7,8]

Dayside Boundary Constellation
Energy transfer into magnetosphere
~39 nanospacecraft
[1,2,3,4,5,6,7,8]

Global ITM Constellation
Upper atmosphere space weather
24 nanospacecraft
[1,2,3,4,5,6,7,8]

Solar Flotilla
In-situ solar system wide space weather
12 nanospacecraft
[1,2,3,4,5,6,7,8]

Explorers
Supports lower cost future missions by reduction in spacecraft mass/power increased constellation size without increase in cost for missions like Grand Tour Cluster [1,2,3,4,5,6,7,8]

Other Potential Constellation Missions
- *Inner Heliospheric Constellation*
- *Heliospheric Radio Imager*

Mars
Supports future missions establishing permanent presence, coordination of multiplatform observations (aerobot, airplane, suface, micromissions, and orbit) [1,2,3,4,5,6,7]

Pluto-Kuiper Express
Demonstrates onboard autonomy and spacecraft miniaturization in concert with X2000 program objectives [2,3,4,5,6,7]

Discovery
Supports future inner planet missions such as JANUS [1,2,3,4,5,6,7]

Other Outer Planetary Missions
Demonstrates onboard autonomy and spacecraft miniaturization in concert with X2000 program objectives
[2,3,4,5,6,7]

EX-2 Enhanced Science Follow-On
Time varying spectrally resolved radiative flux
12 or more clusters of 3 spacecraft each
[1,2,3,4,5,6,7,8]

EOS-9
Global precipitation monitoring 8 nanosatellites in formation with core spacecraft
[1,2,3,4,5,6,7,8]

OP-3
Temperature and moisture sounding
8 or more spacecraft
[1,2,3,4,5,6,7,8]

ESSP
Supports lower cost future missions by reduction in spacecraft mass/power opens up new avenues for research through increased temporal resolution and coordinated observations/virtual platforms
[1,2,3,4,5,6,7,8]

Technologies would be generally available for use on future NASA science missions as well as for commercial and other space ventures. Small satellite buses and components could be made available through future RSDO procurements.
[1,2,3,4,5,6,7,8]

NMP

Validation Flight Formulation and Technology Selection Process

Technology-focused NMP Process

NMP

- Alignment with Science theme need insured by
  - selecting technologies to address specific capability needs in science roadmaps
  - involvement of science community in identification, review and where appropriate, validation of technologies
- Phase A Concept Definition is technology focused
  - Open, peer-reviewed competition for technologies
  - For system validation, science AO in Phase B where appropriate
  - Provide capabilities needed to enable future high-priority science missions
  - Provide significant improvements in performance, or reductions in life-cycle cost
  - Require validation to mitigate risks to first science user
  - selected technologists participate in project concept definition team
- Independent review of project concepts prior to selection

Key Participants in NMP Process

NMP

Science Community

- Defines capability needs in theme roadmaps
- Participates with NMP to identify technology requirements, review technology candidates / concept studies, and participates via AO where appropriate

NASA HQ

- Defines priorities and constraints for Projects
- Authorizes project concept definition studies
- Leads peer reviews of technology solicitation
- Assigns project implementation center
- Conducts independent reviews
- Selects and approves project for implementation
- Where appropriate, selects science support via AO

NMP

- Leads identification of technology validation candidates
- Conducts project concept definition studies
- Selects technology providers through open competition
- Oversees project implementation

NMP Role in Technology Infusion*

NMP

Project Role

- Spacecraft providers for NMP validation projects selected through industry competition
- Spacecraft provider joins project team in Formulation
- Technology providers and spacecraft provider are members of validation project team
- Involvement of all parties in Formulation facilitates technology transfer to industry

Program Role

- Web-based Technology Infusion Database of validated technologies
- Technology Infusion workshops part of project Technology Infusion plan
- Publication of technology validation results in refereed journals
- Inclusion of Technology Database in NASA announcements for science missions

*Subject to ITAR and EAR

Benefits of NMP Processes

NMP

- Enhanced NASA's technology community through partnerships
  - Industry
  - Academia
  - Government Laboratories
- Infusion into future missions
  - Future projects using NMP validated technologies
  - Technology database for PI missions
    - New capabilities enable new opportunities
    - MIDEX/SMEX/Discovery/ESSP