Development of the Science Plan for NASA's Science Mission Directorate

December 1, 2006

Greg Williams
Science Mission Directorate

Why a New Science Plan?

- **NASA released a new 2006 NASA Strategic Plan in February 2006, in keeping with the triennial requirement in the Government Performance and Results Act**
  - The Science organizations follow with a strategic document describing their implementation of the NASA Strategic Plan
  - The Space and Earth Science Enterprises produced strategy documents in 2003; it is timely now for the Science Mission Directorate to produce its first strategy document

- **The Congress requires NASA to produce such a plan in the 2005 NASA Authorization Act signed last December**

Congressional Req't for a Science Plan

NASA Authorization Act for 2005 (S.1281)

Title I Section 101

(d) SCIENCE.— (1) IN GENERAL.—The Administrator shall develop a plan to guide the science programs of NASA through 2016.

(2) CONTENT.—At a minimum, the plan developed under paragraph (1) shall be designed to ensure that NASA has a rich and vigorous set of science activities, and shall describe— **(A) the missions NASA will initiate, design, develop, launch, or operate in space science and earth science through fiscal year 2016, including launch dates; (B) a priority ranking of all of the missions listed under subparagraph (A), and the rationale for the ranking**; and (C) the budget assumptions on which the policy is based, which for fiscal years 2007 and 2008 shall be consistent with the authorizations provided in title II of this Act.

(6) SCHEDULE.—The Administrator shall transmit the plan developed under this subsection to the Committee on Science of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate **not later than 1 year after the date of enactment** of this Act.

Conference Report Accompanying 2005 Authorization Act

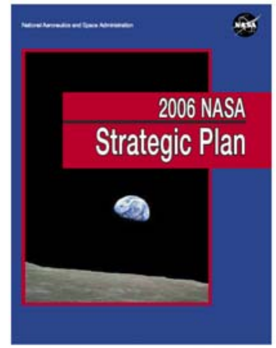
Section 101(d) directs the Administrator to develop a plan to guide the space science and earth science programs of NASA through 2016. The priority ranking required by this subsection is a single ranking of all the missions that NASA lists pursuant to paragraph (2)(A), not a ranking categorized by theme or any other category…

The conferees are aware that the National Academy of Sciences is continuing to work on an Earth Science and Applications from Space Decadal Survey which is due to be completed in 2006. In preparing the science plan, NASA should, to the greatest extent possible, take into consideration information available from the Decadal Survey. The conferees expect NASA to notify the authorizing committees if the completed Decadal Survey would change any of the information provided in the science plan.

A Great Team Effort !!

With participants from all SMD Divisions and senior scientists and program managers from the Centers

SMD Science Plan Development Flow



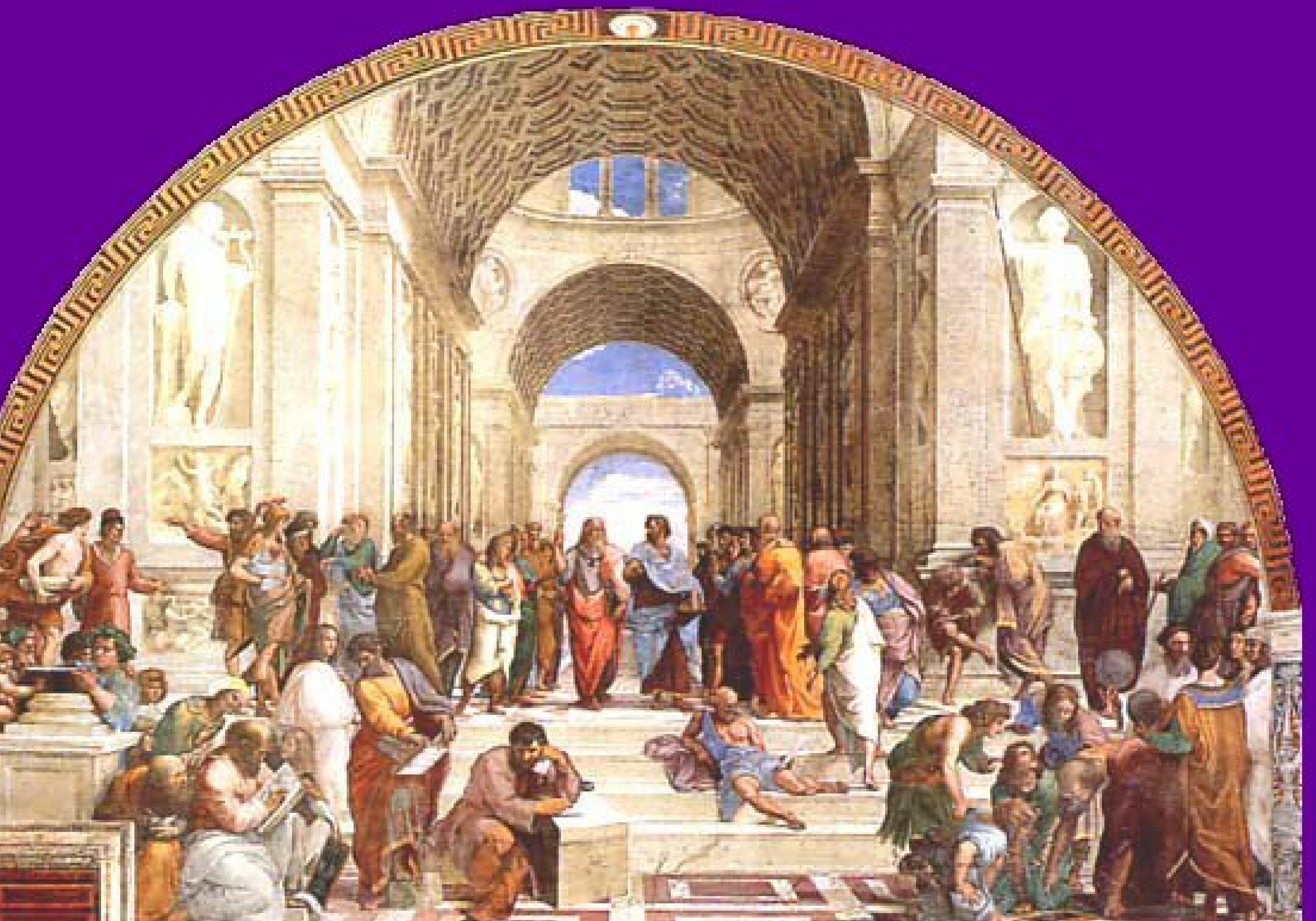
NRC Decadal Surveys → **Community Roadmaps** → **Policy Directives & Budget Constraints** → **Priorities** → **SMD Science Plan**

Mission Concept Formulation

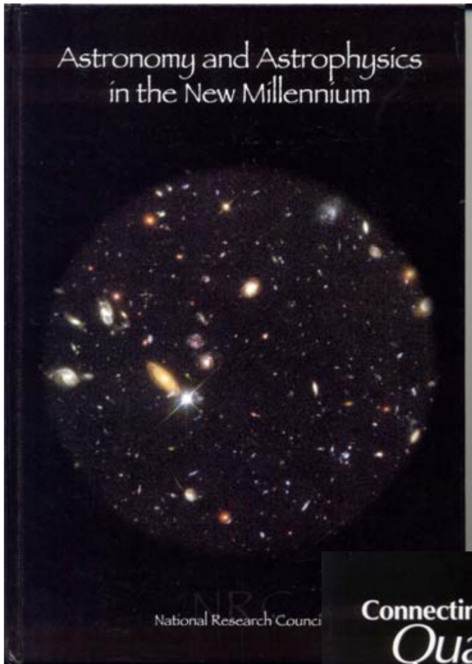
Technology Development

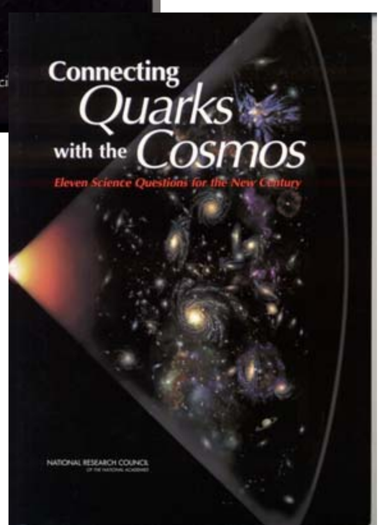
Research & Analysis

Review of draft Plan by:
* NAC & Subcommittees
* NRC Space Studies Board
* Agency partners
* Industrial partners



Astrophysics

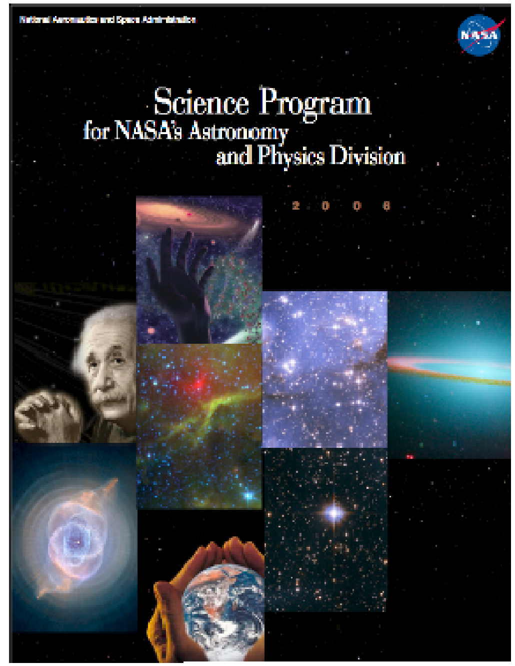




2001

NRC Decadal Survey

→



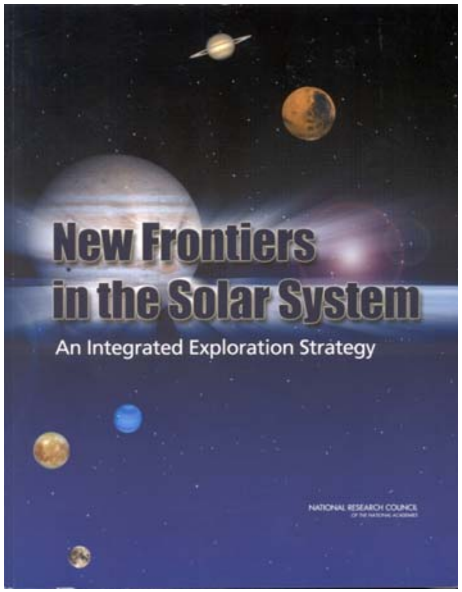
2006 Community Roadmap

→

2006 Science Plan

Astrophysics section

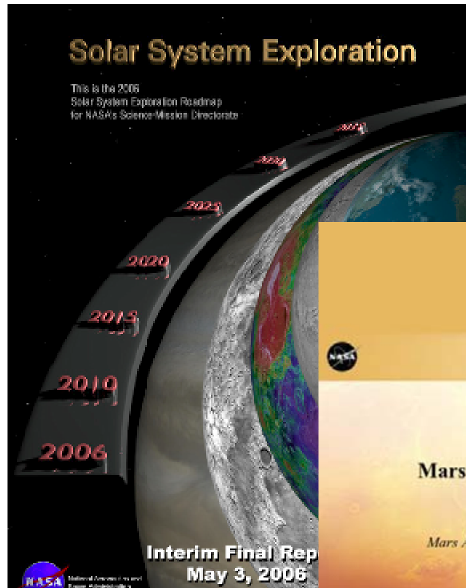
Planetary Science

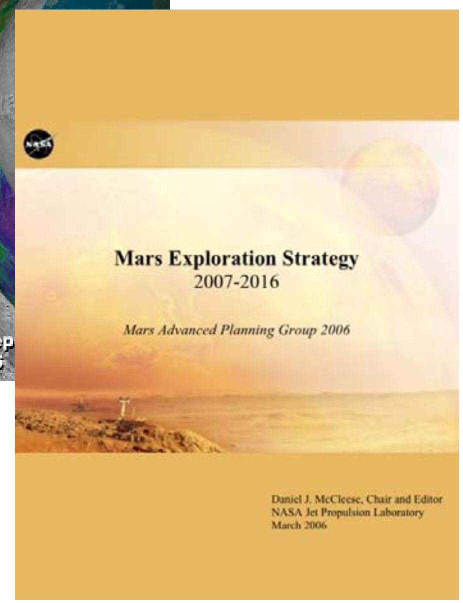


2003

NRC Decadal Survey

→





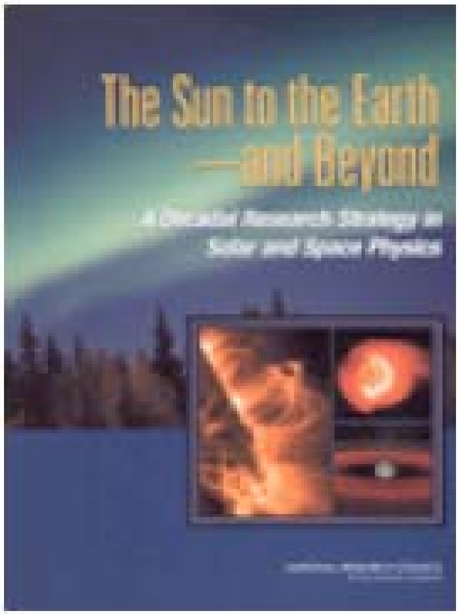
2006 Community Roadmaps

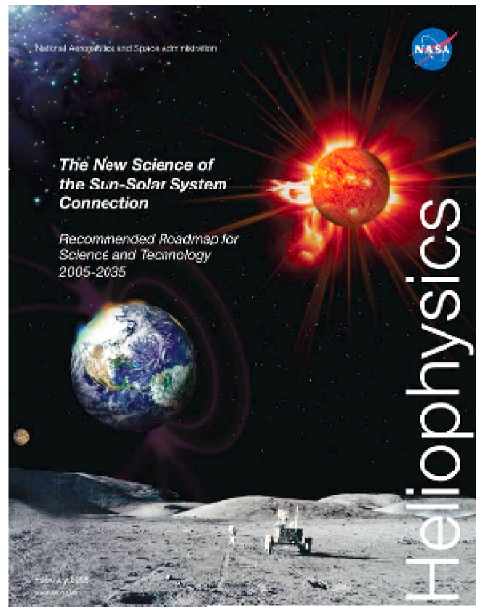
→

2006 Science Plan

Planetary Science section

Heliophysics





2006 Science Plan

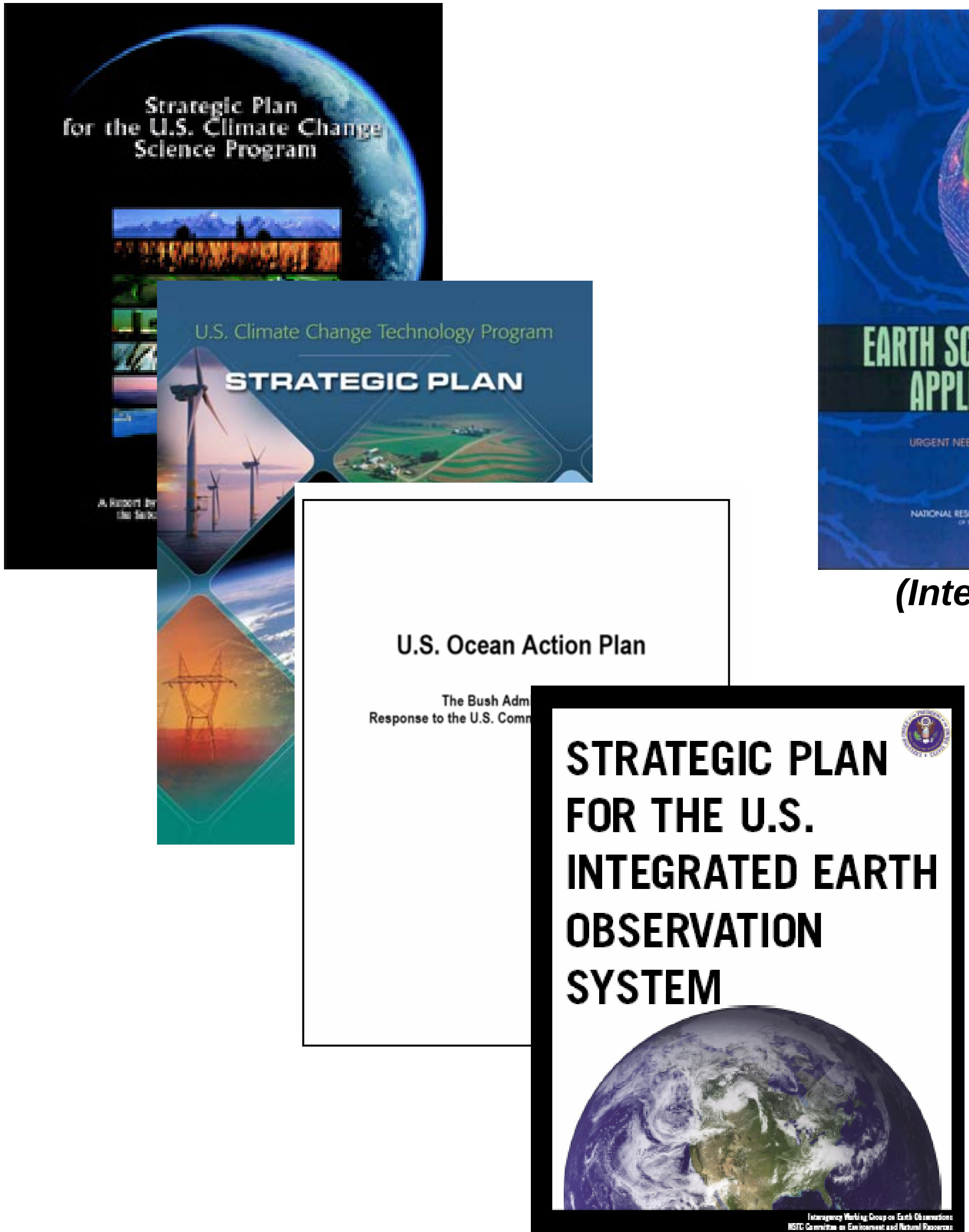
Heliophysics section

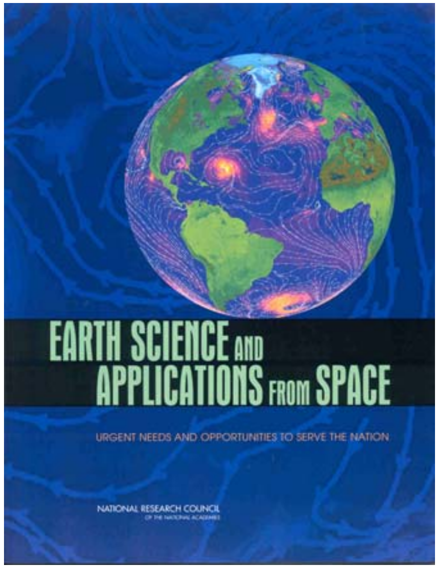
2002

NRC Decadal Survey

2006 Community Roadmap

Earth Science





(Interim Report)

→

2006 Science Plan

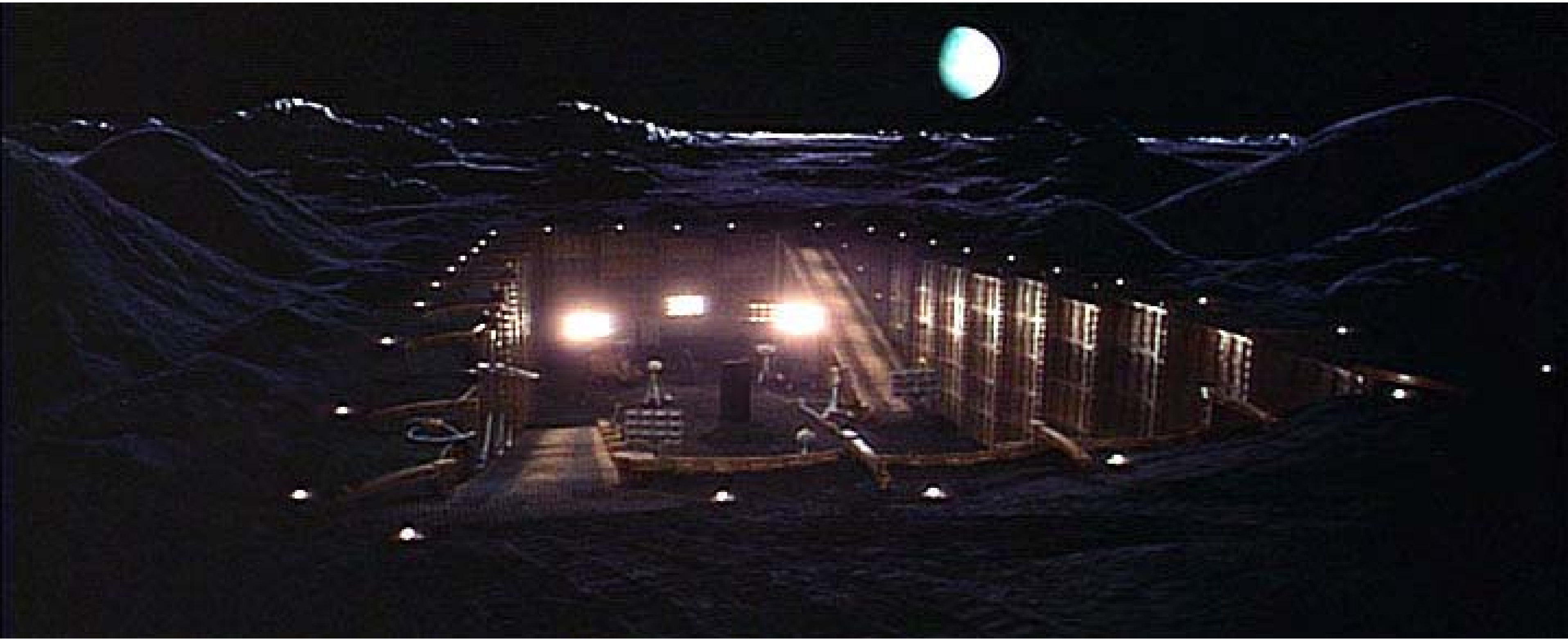
Earth Science section

↑

6 Science Focus Area roadmaps; yet to be integrated into a single Earth Science roadmap

2005

Embracing the Vision for Space Exploration



Embracing the Vision for Space Exploration

External Review Groups

- NAC Science Committee & Subcommittees
- National Research Council / Space Studies Board / Committee on Review of NASA Science Mission Directorate Science Plan
- NASA Science Associates Group (major industrial contractors)
- Partner US Government Agencies

Science Plan Draft Outline

- **Preamble: NASA's Vision for Science**
- **Purpose & Progress**
- **Summary of Science Questions and Prioritized Missions**
  - Principle requirement in the NASA Authorization Act
- **Common Elements of Strategy**
- **Research Areas**
  - Bulk of the Plan; a section for each of the four science areas
- **Science and Human Exploration**
- **Summary: On the Brink of Understanding**
- **Appendices**

Science Questions

Science Questions and Research Objectives

Science Area	Science Questions	Research Objectives [multi-year Outcomes, 2006 NASA Strategic Plan—Appendix 1]
Earth Science: Study planet Earth from space to advance scientific understanding and meet societal needs.	• How is the global Earth system changing? • What are the primary causes of change in the Earth system? • How does the Earth system respond to natural and human-induced changes? • What are the consequences for human civilization? • How will the Earth system change in the future?	1. Understand and improve predictive capability for changes in the ozone layer, climate forcing, and air quality associated with changes in atmospheric composition 2. Enable improved predictive capability for weather and extreme weather events 3. Quantify global land cover change and terrestrial and marine productivity, and improve carbon cycle and ecosystem models 4. Quantify the key reservoirs and fluxes in the global water cycle and improve models of water cycle change and fresh water availability 5. Understand the role of oceans, atmosphere, and ice in the climate system and improve predictive capability for its future evolution 6. Characterize and understand Earth surface changes and variability of Earth's gravitational and magnetic fields 7. Expand and accelerate the realization of societal benefits from Earth system science
Planetary Science: Advance scientific knowledge of the origin and history of the solar system, the potential for life elsewhere, and the hazards and resources present as humans explore space.	• How did the Sun's family of planets and minor bodies originate? • How did the solar system evolve to its current diverse state? • What are the characteristics of the solar system that lead to the origin of life? • How did life begin and evolve on Earth and has it evolved elsewhere in the solar system? • What are the hazards and resources in the solar system environment that will affect the extension of human presence of human presence in space?	1. Learn how the Sun's family of planets and minor bodies originated and evolved 2. Understand the processes that determine the history and future of habitability in the solar system, including the origin and evolution of Earth's biosphere and the characteristics and extent of prebiotic chemistry on Mars and other worlds 3. Identify and investigate past or present habitable environments on Mars and other worlds, and determine if there is or ever has been life elsewhere in the solar system 4. Explore the space environment to discover potential hazards to humans and to search for resources that would enable human presence
Heliophysics: Understand the Sun and its effects on Earth and the solar system.	• How and why does the Sun vary? • How do the Earth and planetary systems respond? • What are the impacts on humanity?	1. Understand the fundamental physical processes of the space environment from the Sun to Earth, to other planets, and beyond to the interstellar medium 2. Understand how human society, technological systems, and the habitability of planets are affected by solar variability and planetary magnetic fields 3. Develop the capability to predict the extreme and dynamic conditions in space in order to maximize the safety and productivity of human and robotic explorers
Astrophysics: Discover the origin, structure, evolution, and destiny of the universe, and search for Earth-like planets.	• What are the origin, evolution, and fate of the universe? • How do planets, stars, galaxies, and cosmic structure come into being? • When and how did the elements of life and the universe arise? • Is there life elsewhere?	1. Understand the origin and destiny of the universe, phenomena near black holes, and the nature of gravity 2. Understand how the first stars and galaxies formed, and how they changed over time into the objects recognized in the present universe 3. Understand how individual stars form and how those processes ultimately affect the formation of planetary systems 4. Progress in creating a census of extra-solar planets and measuring their properties

Missions in the Science Plan

(The following lists of missions do not necessarily reflect final Science Plan prioritization; Tables of missions in priority order for each Division will appear in Chapter 2 of the final Science Plan.)

Mission Lines

Program/Mission Lines

Mission Lines	Mission Class*	Objectives and Features	Example Missions
Earth System Science Pathfinder (ESSP)	Competed, PI-led small missions	Address focused Earth science objectives and provide opportunities for new science investigations.	OCO, Aquarius
Earth Science Systematic Missions	Strategic missions of all sizes	Make new global measurements to address unanswered questions and reduce remaining uncertainties with systematic missions that maintain continuity of key measurements awaiting transition to operational systems managed by other agencies.	NPP, LDCM, OSTM, Glory, GPM
Discovery	Competed, PI-led medium missions	Explore solar system bodies and/or remotely examine the solar system and extrasolar planetary system environments.	Dawn, Kepler
Mars Scout	Competed, PI-led medium missions	Provide regular opportunities for innovative research in support of Mars objectives.	Phoenix
New Frontiers	Competed, PI-led large missions	Explore the solar system with frequent missions that will conduct high-quality, focused scientific investigations designed to enhance our understanding of the solar system.	Juno
Mars Exploration (core)	Strategic medium and large missions	Maximize the scientific return, technology infusion, and public engagement of the robotic exploration of the Red Planet. Each strategic mission has linkages to previous missions and orbiters and landers support each other's operations.	MSL, MSO
Explorers	Competed, PI-led medium missions	Provide flight opportunities for focused scientific investigations from space with the Heliophysics and Astrophysics science areas.	WISE, IBEX
Solar Terrestrial Probes (STP)	Strategic medium missions	Execute a continuous sequence of defined strategic projects to provide in-situ and remote sensing observations, from multiple platforms, for the sustained study of the Sun-Earth System.	MMS, GEC
Living With a Star (LWS)	Strategic medium to large missions	Strategic sequences of missions to resolve the highest-priority unknowns in the connected system from the Sun to the Earth.	SDO, RBSP, ITSP, IHS, Solar Orbiter, Solar Probe
Beyond Einstein	Strategic medium and large missions	Complete Einstein's legacy and lead to understanding the underlying physics of the very phenomena that came out of his theories.	Con-X, LISA, JDEM, BHFP, IP
Navigator	Strategic large missions	Interrelated missions to explore and characterize new worlds, enable advanced telescope searches for Earth-like planets, and discover habitable environments around neighboring stars.	SIM, TPF

* Small missions have life cycle costs less than approximately $300M. Mid-size missions have life cycle costs between approximately $300M and $750M. Large missions have life cycle costs in excess of $750M. Flagship missions, in contrast to Mission Lines, are individual strategic missions and are in excess of $1 billion.

Earth Science

Earth Science Future Mission Summary

Program	Mission	Objective (See Table 2.1)							Mission Objectives & Features
		1	2	3	4	5	6	7	
Systematic	NPOESS Preparatory Project (NPP)	•	•	•		•		•	Extension of key Aqua and Terra measurements supporting long-term climate observations. Partnership with the NPOESS Integrated Program Office; dependence on IPO for key instruments
Systematic	Landsat Data Continuity Mission (LDCM)			•		•	•	•	Extension of multi-spectral moderate resolution land surface imaging. Partnership with USGS; NASA develops the observatory, USGS operates the satellite and distributes the data.
Systematic	Ocean Surface Topography Mission (OSTM)					•		•	Measurement of global sea surface height via radar altimetry. Partnership with France/CNES in development; partnership with NOAA & EUMETSAT for operations.
Systematic	Glory	•				•		•	Global measurement of aerosol and liquid-cloud properties, and total solar irradiance. NASA mission; migration to NPOESS is TBD.
ESSP	Orbiting Carbon Observatory (OCO)	•		•		•		•	Measurement of global column carbon dioxide. Competitively selected PI-led mission.
ESSP	Aquarius				•	•		•	Global measurement of sea surface salinity. Competitively selected PI-led mission; partnership with Argentina
Systematic	Global Precipitation Measurement (GPM)		•		•	•		•	Frequent, high spatial resolution, microphysically detailed global precipitation. Constellation of satellites; partnership with Japan on core satellite; other satellites contributed by a variety of partners.

Planetary Science -- Mars

Planetary Science Future Mission Summary							
Program	Mars Mission	Objective (See Table 2.1)					Mission Objectives & Features
		1	2	3	4	5	
ME Core	Mars Science Laboratory (MSL)	•	•	•	•	•	Mineralogy and chemistry of surface samples; atmospheric composition and radiation at the Martian surface. Roving analytical laboratory with robotic arm and sample analysis capability.
Scout	Pheonix			•	•	•	Volatiles and complex chemistry in northern polar plains of Mars. Competitively selected PI-led mission; fixed lander.
ME Core	Mars Science Orbiter (MSO)	•	•				Mars aeronomy (detailed measurements to be defined). Orbiting, strategic mission; instruments to be selected through open competition once detailed objectives defined.
ME Core	Astrobiology Field Laboratory			•	•	•	Detection and characterization of biomarkers. MSL-like rover with instruments focused on organics, and with next generation sample processing system. Strategic mission to be selected from among AFL, Mid-size Rovers, and Network Landers for the 2016 opportunity.
ME Core	Mid-Size Rovers	•	•			•	Spatial diversity of geology, geochemistry etc. Pair of MER-like rovers with updated instrument suit and sites selected based on MRO results. Strategic mission to be selected from among AFL, Mid-size Rovers, and Network Landers for the 2016 opportunity.
ME Core	Network Landers	•	•			•	Geophysical parameters. Spatial separate small landers linked by existing orbiter(s). Strategic mission to be selected from among AFL, Mid-size Rovers, and Network Landers for the 2016 opportunity.
Scout	Mars Scout-11		•	•			TBD based on competitive selection; PI-led mission

Planetary Science -- Other Solar System Destinations

Planetary Science Future Mission Summary—Continued

Program	Other Planetary Science Mission	Objective (See Table 2.1)					Mission Objectives & Features
		1	2	3	4	5	
FN	Juno	●	●	●			Jovian gravity and magnetic fields and atmospheric composition. PI-led mission; polar orbit around Jupiter.
Disc	Dawn	●		●		●	Investigations of Ceres and Vesta. Competitively selected PI-led mission.
Flagship	Europa Explorer	●	●	●	●		Probe habitability and accessibility of Europa. Flagship mission; orbiter touring the Jovian system with focus on Europa; perhaps with an impactor or other means to probe the crust.
Disc	Discovery 2006	o	o	o	o	o	ORISIS asteroid survey and sample return, Vesper Venus atmospheric chemistry and dynamics orbiter, or GRAIL lunar gravity field mapper
Flagship	Titan/Enceladus Explorer	●	●	●	●		Survey Titan's atmosphere and surface composition and processes. Insertion of an instrumented aerial vehicle into Titan's atmosphere; Enceladus portion is TBD.
NF	New Frontiers-3	o	o	o	o	o	TBD; large competitively-selected, PI-led mission; will reassess field of candidates prior to next Announcement of Opportunity.
Disc	Discovery 2008	o	o	o	o	o	TBD; competitively-selected, PI-led mission.

Heliophysics

Heliophysics Future Mission Summary

Program	Mission	Objective (See Table 2.1)			Mission Objectives & Features
		1	2	3	
STP	Solar TErrestrial RElations Observatory (STEREO)	●	●	●	A two-observatory mission to provide 3D measurements of the Sun and inner heliosphere to study the nature of coronal mass ejections. These powerful eruptions are a major source of the magnetic disruptions on Earth and a key component of space weather. Launch is in 2006.
Explorer	Time History of Events and Macroscale Interactions during Substorms (THEMIS)	●	●	o	THEMIS is a five-spacecraft constellation mission that will resolve a long-standing controversy concerning the spatial and temporal development of magnetospheric substorms – a fundamental mode of the magnetosphere. THEMIS is scheduled for launch in 2006.
Explorer	Aeronomy of Ice in the Mesosphere (AIM)	o	●	o	AIM will explain polar mesospheric cloud formation and variability as well as their relationship to global change in the upper atmosphere and the response of the mesosphere to solar energy deposition. AIM is scheduled for launch in 2007
LWS	Solar Dynamics Observatory (SDO)	●	●	o	A single geosynchronous spacecraft to observe how the Sun's magnetic field is generated and structured in its interior and how stored magnetic energy in the corona is released into the heliosphere. Launch is in 2008.
Explorer	Interstellar Boundary Explorer (IBEX)	●	o	o	IBEX will image the 3D boundary region of our heliosphere, the vast (~100 AU thick) region where the solar wind decelerates because of the pressure of the local interstellar plasma. IBEX will launch in 2008.
STP	Magnetospheric Multiscale (MMS)	●	●	o	A four-spacecraft mission designed to study magnetic reconnection, charged particle acceleration, and turbulence in key boundary regions of Earth's magnetosphere. These results will enable a predictive science of space weather. MMS is in transition to Phase B; STP funding will allow MMS to launch in 2013.
LWS	Geospace/Radiation Belt Storm Probes (RBSP)	●	●	●	Twin spacecraft in elliptical Earth orbit to answer how, in response to the variable inputs of energy from the sun, charged particles in space are accelerated to hazardous radiation energies producing satellite anomalies and affecting the safety of astronauts and of flight crews in high-altitude aircraft. RBSP is conducting Phase A studies; launch is planned for 2012.
LWS	Geospace/ Ionosphere - Thermosphere Storm Probes (ITSP)	●	●	o	Twin-spacecraft in low-Earth orbit to understand ionospheric variability and the irregularities that adversely affect communications, navigation and radar systems. Concept studies are complete.

● Major Contribution o Supporting Contribution

Astrophysics - 1 of 2

Astrophysics Future Mission Summary

Program	Mission	Objective (See Table 2.1) 1	2	3	4	Mission Objectives & Features
Flagship	James Webb Space Telescope (JWST)	•	•	•	•	Infra-red successor to the Hubble Space Telescope; 6.5 meter telescope with four infrared instruments at L2; partnership between NASA, the European Space Agency (ESA), and the Canadian Space Agency.
Flagship	Hubble Space Telescope - Servicing Mission 4 (HST-SM4)	•	•	•	•	Enhance Hubble's range and dramatically increasing both the survey power and the panchromatic science capabilities. Space Shuttle servicing to add two instruments: Cosmic Origins Spectrograph operating at near ultraviolet wavelengths; and Wide Field Camera 3 (WFC3) operating at near infrared wavelengths.
	Gamma-ray Large Area Space Telescope (GLAST)	•	•	•		Observations of celestial high energy gamma-ray sources. Joint NASA/DOE mission with a large area telescope for an all sky survey in the highest energy gamma rays.
ISSC	Herschel Space Observatory)		•	•		Completely cover the peak of the spectrum of galaxies and of star-forming regions out to redshifts of 6. Fills wavelength gap between JWST and Spitzer. ESA mission with NASA contribution.
ISSC	Planck Surveyor	•				The third-generation space mission to measure the anisotropy of the cosmic microwave background radiation. An ESA mission with major contributions from NASA.
Discovery	Kepler				•	Monitor 100,000 stars continuously for 4 years to detect Earth-sized planets using transit photometry. Discovery PI-led mission; sensitive detectors capable of detecting a change in a star's brightness as small as 20 parts-per-million.
Explorer	Wide-field Infrared Survey Explorer (WISE)		•	•		Survey the whole sky in 4 mid-infrared bands to sensitivities 500 or more times better than previous all-sky surveys. The survey will provide an important catalog for JWST. Explorer MIDEX PI-led mission; 40 cm telescope continuously scanning spacecraft with scan mirror to freeze images on arrays for 8.8 second exposures
Flagship	Stratospheric Observatory for Infrared Astronomy (SOFIA)		•	•	•	Infrared and sub-millimeter observations of stellar and planet-forming environments. Joint NASA/DLR (Germany) airborne 2.5 meter telescope on a Boeing 747; nine first generation instruments
Explorer	Explorer (MIDEX)	o	o	o		Competitively-selected PI mission; could address any of the first three objectives.
Explorer	Explorer (SMEX)	o	o	o		Competitively-selected PI mission; could address any of the first three objectives.

Astrophysics - 2 of 2

Astrophysics Future Mission Summary—Continued

Program	Mission	Objective (See Table 2.1)				Mission Objectives & Features
		1	2	3	4	
Navigator	Space Interferometry Mission (SIM)		•	•	•	Detect and characterize other planetary systems; measure the mass of planets and stars; measure the internal dynamics and external motions of galaxies in the Local Group and beyond; investigate quasar physics and establish the successor to the International Celestial Reference Frame. A 9-m baseline interferometer with two 7.2-m guide interferometers in Earth-trailing solar orbit.
BE	Constellation-X (Con-X)	•	•	•		X-ray imaging and spectroscopy for the study of black holes, dark matter & energy and neutron stars. Single spacecraft carrying a constellation of four telescopes placed in an L2 orbit with a combined collecting area of 1.5 square meters.
BE	Joint Dark Energy Mission (JDEM)	•				Measure the cosmological parameters of the expanding Universe. Joint NASA/DOE mission; three mission concept studies (ADEPT, DESTINY, SNAP) have been selected by NASA to examine differing mission implementations.
BE	Laser Interferometry Space Antenna (LISA)	•	•	•		First measurement of low-frequency gravitational waves. Three independent, free-flying, drag-free spacecraft provide for three-arm interferometry of a variety of astrophysical sources in the frequency band of 104 to 100 Hz. Collaboration with ESA.
BE	Black Hole Finder Probe (BHFP)	•				Conduct a thorough census of black holes in the universe.
BE	Inflation Probe (IP)	•				Provide a stringent test of inflationary cosmology, the physics of the universe at less than a trillionth of a second after the Big Bang. TBD. This is a PI-class mission that will be selected by competition.
Navigator	Terrestrial Planet Finder—Interferometer (TPF)		•	•	•	*Interferometer* -Detect and characterize all components of other planetary systems, including terrestrial planets, gas giant planets, asteroid belts; search for signs of life in terrestrial planets. Four 3-4 m passively-cooled telescopes on separate formation flying spacecraft feeding light to a nulling interferometer on a 5th spacecraft; Proposed joint project with ESA's Darwin mission. *Chronagraph* - Image Earth-like planets, giant planets, and zodiacal dust around nearby stars; search for signs of life on Earth-like planets; carry out general astrophysics observations probing dark energy and dark matter. Single telescope at L2 with a narrow-field coronagraph and spectrometer to see 10-10 brightness planets, and a wide-field camera to see fainter and wider than Hubble Deep Fields; visible and near-infrared wavelengths

• Applies to the objective ○ Could apply to any objective

Mission Prioritization: Degrees of Freedom Presumed

- **Prioritizing by Division; not attempting a single prioritized list of all SMD missions**
  - Language in report accompanying the Act called for a single list
  - Both the NRC and NASA's industrial partners support NASA's approach to mission prioritization
  - Dialog on this is continuing with Congressional staff
- **Not including missions already in orbit**
  - Describing in the draft Plan how we use the Senior Review Process to prioritize missions in extended operations phase
- **Prioritization of Mars separately from other solar system destinations**


WISE
18 3:01PM

Creating Lists of Prioritized Missions

- **Prioritized competed missions / opportunities and strategic / core missions in same list**
  - Decadal surveys bin them separately, but…
  - The budget process forces us to make trades
- **The top priorities in each list have heritage in the NRC Decadal Survey in each area**
  - For Earth Science, the top priorities for current missions reflect Congressional or Executive mandates; future representative mission concepts listed alphabetically
- **Capture the logic that underlies the launch order of missions currently in development**
- **Identify branch points where decisions on ultimate priority depends on future science findings, e.g., Beyond Einstein; Mars missions for 2016 and beyond**

Next Steps

- Seek formal concurrence of the SMD Associate Administrator
- Seek formal Agency-level concurrence
- OMB will have to approve since the Plan is also a response to a Congressional requirement
- Post, print, and distribute