Section II-3 flight program: 2003 and

Here we present missions that we expect to graduate from the study and design phase and begin building in 2003 and beyond. We have grouped these projects to show how they address our science objectives. While the section mentions for context some of the missions that will already be under development or flying by 2003, those that will proceed from study and preliminary design to implementation (detailed design and fabrication) beginning in 2003 are named in **bold** when they are first mentioned under each objective. Note, however, that although many of our missions address more than one science objective, no effort has been made to mention every mission in every connection in which it can make a contribution.

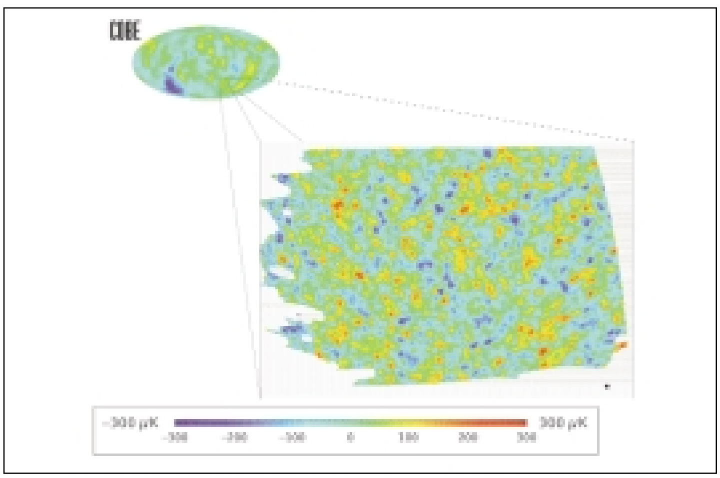
d beyond

This section emphasizes missions that will begin implementation in the period 2003-2007. Planning for the period 2008 through the following decade is necessarily less certain. The end of each subsection also presents ideas for missions in this more remote timeframe based on reasonable extrapolations from our current scientific understanding and nearer-term mission plans. These future mission concepts are also introduced in **bold** in their part of each subsection.

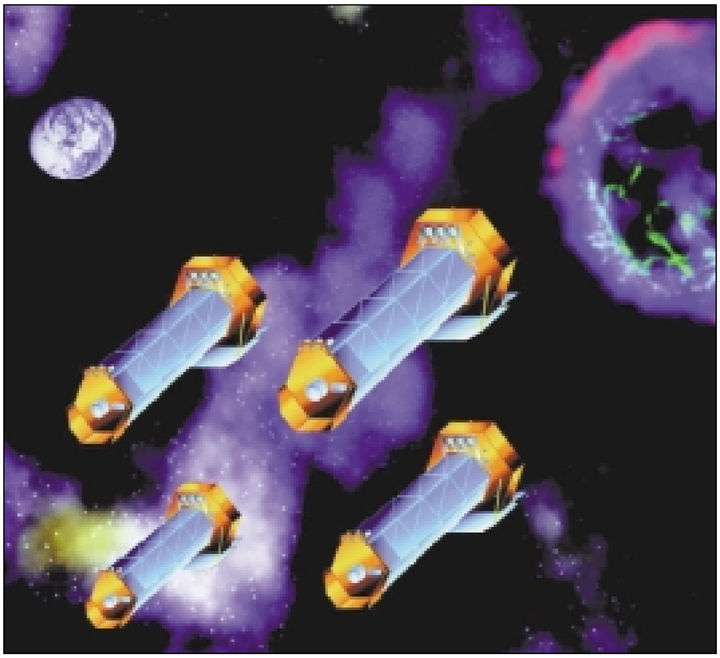
OBJECTIVE ONE: Understand the structure of the universe, from its earliest beginnings to its ultimate fate

The universe we see today is rich in structure, containing hundreds of billions of galaxies, each with hundreds of billions of stars. Clusters and super-clusters of galaxies are interspersed with vast, virtually empty voids, and the galaxies themselves can appear totally isolated or in the process of merging with local companions. Yet observations to date of the very early universe show it to have been very smooth and almost featureless. How did the later structure, the basic extragalactic building blocks of the universe, come to be? What laws of physics worked to fill the gap between the primitive universe and the complexity we observe in the present?

With the Cosmic Background Explorer (COBE), we have cap-



Detailed analysis of the cosmic microwave background can determine the geometry of the universe to high precision and shed light on the nature of the matter and energy that fill the universe. BOOMERANG observed this background over approximately 2.5 percent of the sky with angular resolution 35 times finer than COBE, and MAP and Planck will continue to extend and refine these measurements.



The Constellation-X spacecraft will work in unison to simultaneously observe the same distant objects. By combining their data, these satellites become 100 times more powerful than any previous single x-ray telescope.

tured a glimmer of the earliest clumpings in the remnant primordial fireball through ripples in today's pervasive microwave background. Balloon-borne instruments such as BOOMERANG map a small portion of the cosmic microwave background radiation, the fossil remnant of the Big Bang. The Microwave Anisotropy Probe (MAP) Explorer and the ESA/NASA Planck mission will extend these measurements and permit precise determination of a number of critical cosmological parameters that constrain models of the early universe.

But there is a missing link between the first condensations of matter after the Big Bang and the galaxies and clusters we see in the present. With the ability to identify the dark matter and learn how it shapes the galaxies and systems of galaxies, we will begin to determine the size, shape, and energy content of the universe. Ground-based surveys such as the Two Micron All Sky Survey (2MASS), Sloan Digital Sky Survey (SDSS), and Explorer-class space missions will provide an inventory of low-mass objects in the neighborhood of the Sun. Mass in the gaseous state will be studied at a variety of wavelengths, corresponding to the temperature of the gas. These range from millimeter waves observed by ground-based interferometers to the x-rays from hot cluster gas seen by the Chandra X-ray Observatory (CXO).

An important advance will be to estimate the total mass in galaxies, clusters of galaxies, and even in non-luminous, dense regions by measuring the gravitational bending of light from background galaxies. Observing this "gravitational lensing" is among many motivations for the **Next Generation Space Telescope (NGST)**, along with investigating the birth of galaxies, the fundamental structures of the universe. These observations must be made at near-infrared wavelengths and require a telescope with a large aperture (for sensitivity to faint objects), excellent angular resolution, and the stable images of a space observatory.

The evolution of the universe will also be probed by **Constellation-X**, the x-ray equivalent of a very large optical telescope. It will improve significantly on the spectral information returned by the current ESA X-ray Multi-Mirror Mission (XMM) and complement the high spatial resolution of CXO. Constellation-X will explore the epoch of formation of clusters of galaxies and how they evolve. The mission will trace black hole evolution with cosmic time and provide new insight into the contribution that the accretion of matter around black holes and other compact objects makes to the total energy output of the universe. Technological advances that will be needed for Constellation-X are under development: x-ray optics, x-ray calorimetry, reflection gratings, detectors for high-energy x-rays, cryogenic coolers, and focusing optics for hard x-rays.

For Possible Implementation After 2007

The very highest energy cosmic rays are extremely rare, and a huge detector would be needed to observe any significant number of them. Earth's atmosphere, with millions of square kilometers of exposed area and an interaction target up to 10^{13} tons, can act as a giant detector for the extreme energy cosmic rays and neutrinos. We do not know where these particles come from or how they are accelerated. It has been suggested that they might come from the annihilation of space-time defects formed at the beginning of the universe, so observing these mysterious particles with an **orbiting wide-angle light collector** could probe the Big Bang itself.

Beyond 2007, expected advances in detectors, interferometry, lightweight optics and cryogenics will allow a mission that can extend the Hubble Space Telescope-like (HST) resolution into the mid- and far-infrared to resolve the infrared background and to learn the history of energy generation and chemical element formation

Cosmic Journeys

The new Cosmic Journeys initiative is a series of major astrophysics observatories that will address aspects of three Enterprise science objectives:

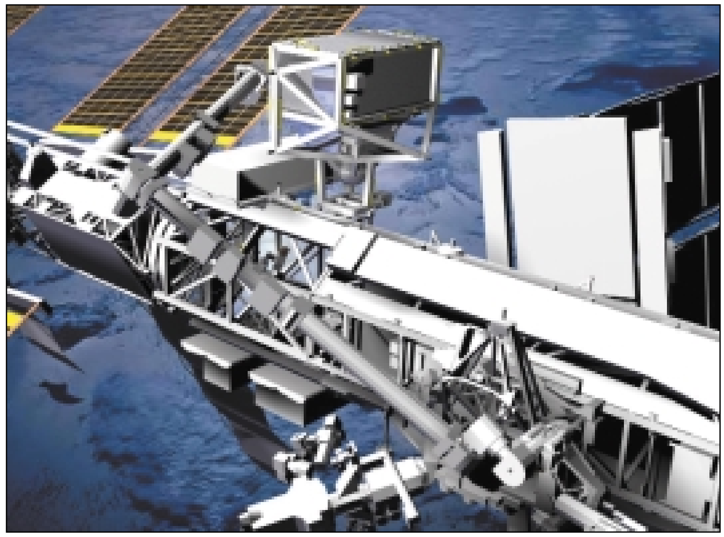
- Understand the structure of the universe, from its earliest beginnings to its ultimate fate;
- Explore the ultimate limits of gravity and energy in the universe; and
- Learn how galaxies, stars, and planets form, interact, and evolve.

Beyond the fundamental scientific importance of these goals, can we discover new physics that we could use? For example, to send machines or people beyond our Solar System to even the nearest star at today's fastest speeds would take tens of thousands of years. As a result, we are particularly interested in the physics of these extreme phenomena:

- The source of cosmic gamma ray bursts;
- The acceleration of ultra-high energy cosmic rays;
- Energetics of black holes; and
- Gravitational waves: whether they exist, and whether they travel at the speed of light.

in the universe. A pathfinder mission using one of two alternate technologies would provide much greater angular resolution than that of the Space Infrared Telescope Facility (SIRTF), as well as better sensitivity and signal-to-noise. This descendant of the HST, discussed further in connection with Objective Three, could be either a **space infrared interferometric telescope** or a **filled-aperture infrared telescope**. Technical requirements on the mirrors for such an instrument are challenging, but the necessary capabilities may evolve from earlier development for the NGST and the Terrestrial Planet Finder (Objective Four).

Measuring the **cosmic microwave background polarization** could provide an important test of the inflation theory, possibly detecting cosmological background gravitational waves produced when the universe was much less than a second old.

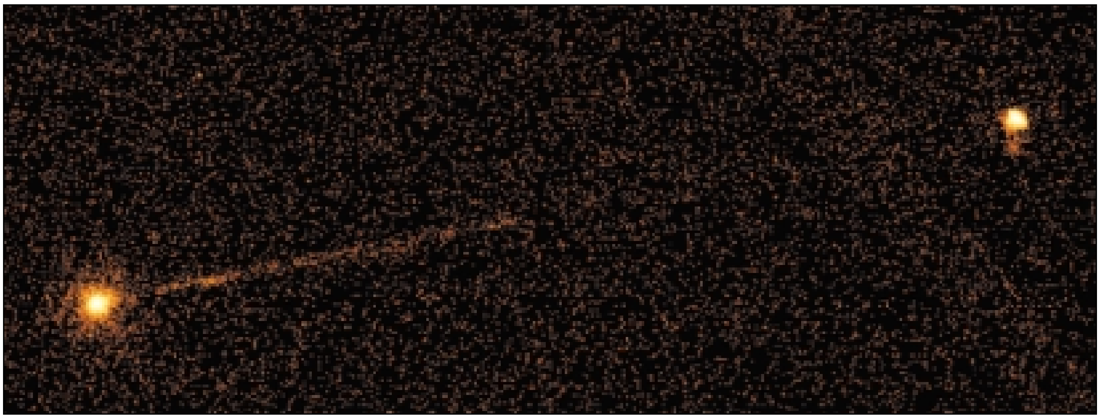


ACCESS instrument mounted on the International Space Station will explore the connection of cosmic rays with supernovae.

OBJECTIVE TWO: Explore the ultimate limits of gravity and energy in the universe

Cosmic rays, whose origin has long been a mystery, are important tracers of the dynamics and structure of our galaxy. The magnetic fields and shock structures with which cosmic rays interact along their journey are not directly visible to us, so we must study these fields and structures by detailed measurement of the arriving particles themselves. We currently believe that most cosmic rays are accelerated by the shock fronts produced by supernovae. The **Advanced Cosmic Ray Composition Experiment for the Space Station (ACCESS)** is being designed to explore this connection of cosmic rays with supernovae. ACCESS will have the sensitivity needed to study cosmic rays up to the highest energies believed achievable by supernova shock acceleration, and will enable us to analyze their composition and thus address the origin, acceleration, and ultimate fate of the individual nuclei, from hydrogen to iron and heavier ions. ACCESS will require a number of technological advances. For the charged particle detectors and calorimeter, silicon pixel detectors with a large dynamic range readout and good spatial resolution will be needed. Advances are also needed in readout electronics for gas-filled detector tubes used in the transition radiation detectors.

Do gravitational waves exist, and what is the structure of space-time near black holes? Complementing the ground-based gravitational wave detectors that will become operational within the next few



The Chandra x-ray image of Pictor A shows a spectacular jet that emanates from the center of the galaxy (left), probably a black hole, and extends across 360 thousand light-years toward a brilliant hot spot (right). The hot spot is thought to be the advancing head of the jet, which brightens where it plows into the tenuous gas of intergalactic space. By observing dramatic phenomena like this spectroscopically, Constellation-X will enable us to unravel their underlying physical causes.

years, the **Laser Interferometer Space Antenna (LISA)** will be able to observe low-frequency gravitational waves not detectable from the ground. A joint NASA-ESA undertaking, LISA will search for gravitational waves from massive objects, ranging from the very early universe before light could propagate, to super-massive black holes in the centers of galaxies, as well as short-period compact binary stars in the Milky Way. Three key technologies are needed to make LISA a reality. First, the experiment will require inertial sensors whose proof masses can be isolated from all forces other than gravitation. Micro-thrusters must keep each of LISA's three independent spacecraft centered on its proof mass. Then, to measure the motions of the isolated and widely separated proof masses, laser metrology to measure subpicometer changes between them is needed.

Constellation-X observations of broadened x-ray emission lines of iron in active galactic nuclei will measure black hole masses and spin, on the basis of relativistic effects that occur in the limit of very strong gravity fields.

For Possible Implementation After 2007

The key to understanding how condensed objects like quasars and pulsars work is to obtain more detailed observations of them. By using an orbiting telescope as part of a **space very long baseline interferometer (SVLBI)**, radio astronomy can achieve resolutions of about 25 microarcseconds. Such a mission could show us how matter is accreted onto black holes, how relativistic jets of matter are formed, and how gamma rays are produced near black holes. SVLBI can also investigate stellar evolution and the interstellar medium through observations of masers, pulsars, and close binary stellar systems. Among technical innovations in amplifiers and coolers, such a system would require very fast (gigabits per second) downlink communications to Earth.

Beyond this, the prize is to directly image a black hole, whose existence heretofore has been based on indirect evidence. This will require about

0.1 microarcsecond resolution, or almost ten million times better than CXO, which is itself about a factor of ten improvement over the earlier Einstein observatory. This is a technology leap that cannot be achieved in one step, so the plan is to focus on a mid-term mission as an intermediate step to this goal. The strawman configuration for a **microarcsecond x-ray imaging mission pathfinder** is a working interferometer with 100 microarcsecond resolution and about 100 cm^2 effective area. This would provide a substantial advance in scientific capability of its own, and allow us to detect and resolve an accretion disk around the massive black hole at the center of the Milky Way. It would also give us detailed images of jets, outflows, and broad-line regions in bright active galaxy nuclei, and to map the center of cooling flows in clusters of galaxies. The technology development for this investigation involves primarily matters of scale. The detectors would build upon both the Constellation-X micro-calorimeter and the CCD's designed for CXO, but with much larger arrays. Approaches to the technology for x-ray interferometry have been demonstrated in the laboratory.

A **high-resolution x-ray spectroscopy mission** (see Objective Three) would provide diagnostics of supernova mechanisms and a new view of accreting neutron stars and black holes in our galaxy, as well as the local group of galaxies.

The only full-sky survey we have in high energy x-rays dates from 1979. Observations of these hard x-ray emissions are key to studying accreting neutron stars, galactic black holes, active galaxies, and creation of the chemical elements. The needed x-ray observations in the 10-500 KeV range could be acquired by a proposed **energetic x-ray imaging survey telescope**.

As described in the previous section, an **orbiting wide-angle light collector** would enable us to observe the very highest energy cosmic rays. Observing these mysterious particles would be an investigation of the highest energy processes in the universe and a probe of the Big Bang within the framework of Grand Unified Theories of fundamental physics.

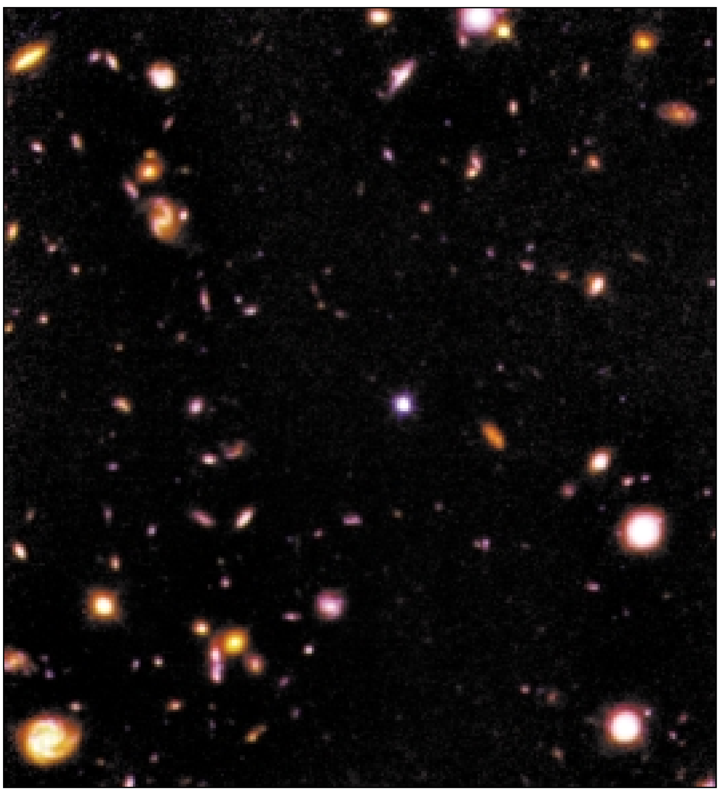
OBJECTIVE THREE: Understand how galaxies, stars, and planets form, interact, and evolve

One of our fundamental science goals is to understand how structure first arose in the extremely dense but featureless early uni-verse. Images that show that galaxies looked very different billions of years ago from our familiar modern universe are clues to the link between the first condensations of matter after the Big Bang and the galaxies and clusters of galaxies we see today. The HST has shown that after galaxies form, they can be observed colliding with one another or being badly disrupted. SIRTF will expand on these investigations by studying the evolution of the most energetic galaxies. But these important observations will not fully answer the core question of how galaxies—the fundamental building blocks of the universe —originated.

One possible concept for an NGST design, showing the telescope beneath a large Sun shade.

The HST's aperture is too small to gather enough faint light from the remote past to detect galaxies in the process of formation. To do so, we will need observations at near-infrared wavelengths from a telescope with a larger aperture (to provide sensitivity to faint objects) and superb angular resolution (to observe structure in distant objects)—the **Next Generation**

Space Telescope (NGST). First of the Origins Observatories, NGST will have about ten times the light-collecting area of HST and will be most sensitive at the infrared wavelengths where galaxies being born are expected to be brightest. Also, although the HST and ground-based observatories have revealed much about the formation of stars and their potential retinues of planets—and SIRTF and SOFIA will reveal much more—essential processes and events in the early lives of stars and planets are poorly known. Very young stars, as well as planets in the process of formation, will be important targets for NGST's powerful infrared instruments. When stars are first born, they are cocooned in the dusty gas clouds from which they formed. This dust very effectively absorbs visible light but emits copious infrared radiation. NGST will be able to peer into the clouds in which the youngest stars and planets are found, and will reveal their location, mass, chemical composition, and dynamics. (As an example of scientific synergy, Cassini's observations of Saturn's rings will help us interpret observations of these clouds by providing a close-up view of the behavior of dust, ice, and magnetic fields in a relatively nearby setting.) To achieve NGST's demanding scientific goals, we are developing very lightweight optical structures, new generations of infrared detectors, energy-efficient cooling techniques, and precision deployable structures.



An image of the darkest portion of the sky reveals the structure of young galaxies at cosmological distances, as shown by the near infrared camera (NICMOS) on the Hubble Space Telescope. Some of the reddest and faintest objects may be over 12 billion light-years away.

NGST observations will be complemented by data from the ESA/NASA Far Infrared and Submillimeter Telescope (FIRST). Observing at longer wavelengths where many galaxies emit most of their radiation, FIRST will be well suited to finding high red-shift galaxies and studying the most luminous galaxies, complementing NGST's searches in the near-infrared. The ESA-led INTEGRAL gamma ray mission will be supplying information on stellar formation via both high-energy spectroscopy and imaging.

The **Space Interferometry Mission (SIM)** will serve important objectives in both technology and science. For technology, it will demonstrate precision metrology and aperture synthesis imaging, both vital for future optical space interferometer missions. Its science contributions stem from its anticipated tiny positional error circle for observed objects, only four micro-arcseconds; this is about 100 times better than the Hipparcos astrometry mission. This precision will make SIM a powerful tool for studying the distances, dynamics, and evolution of star clusters in our galaxy, helping us understand how stars and our galaxy were formed and will evolve. It will extend our census of nearby planetary systems into the range of small, rocky planets for the first time. SIM will also improve the calibration of luminosities of standard stellar distance indicators to enable us to more accurately measure distances in the universe.

The **Terrestrial Planet FInder (TPR)** (see Objective Four) will build on these missions to extend our understanding of planetary systems.

With a hundred-fold increase in sensitivity for high resolution spectroscopy over previous observatories, **Constellation-X** will look across a broad range of redshifts to date the formation of clusters of galaxies. Matter predicted by Big Bang creation and subsequent stellar processing seems to be missing, and Constellation-X will search for it in the hot, metal-enriched intergalactic medium. Constellation-X will also be able to analyze the chemical composition of stellar coronae, supernova remnants, and the interstellar medium by observing x-ray spectral lines.

For Possible Implementation After 2007

An exciting new approach to studying the origin of the chemical elements (nucleosynthesis) is embodied in a concept for a **high-resolution x-ray spectroscopy mission**, which would enable sensitive spectroscopic and imaging observations of emitted radiation related to nucleosynthesis. Many of these spectral features lie in the hard x-ray range. Observations of the spectra of young supernova remnants, and studies of the time-evolution of prompt emissions from recent explosions, would provide diagnostics on the production and distribution of heavy elements, and on the explosion mechanism itself. Such a mission would also provide sensitive spectral studies of active galaxies and measurements of magnetic field strengths in galaxy clusters. Technology development is needed for both the optics and the focal plane sensors. More complex multilayers will be needed to extend instrument response to the 200 KeV region. Germanium sensors will need the development of contact technologies and very large scale integration readout electronics operable at cryogenic temperatures.

An **x-ray interferometry pathfinder** system, such as the one described for Objective Two above, would add importantly to our knowledge of stellar structure, stellar plasma interactions, jets and outflows from active galactic nuclei, cooling flows in clusters of galaxies, as well as locate and resolve star formation regions.

Within our own galaxy, we are at the brink of understanding how planetary systems form. We have obtained spectacular images of stellar nurseries, and possibly of dust disks in the process of creating new planetary systems. We are beginning to peer more deeply into dusty clouds to identify the youngest members of new stellar clusters and probe the structure and basic physical properties of star forming regions. A **filled-aperture infrared telescope**, which would also serve Objective One above, would determine how planetary system-forming disks evolve. With its keen infrared vision, it would probe deeper into protostellar disks and jets to investigate the physical processes that govern their formation, evolution, and dissipation, as well as those that determine their temperature, density, and compositional structure. As outlined above, a competing concept with the same science goals would be a **space infrared interferometric telescope**, whose high sensitivity, spectral, and angular resolution would allow the far infrared background to be resolved almost completely into individual sources. Major technology development for both is needed in the areas of ultra-lightweight aperture technology, active sensing wavefront control, passive and active cooling, and enabling detector technologies. These technologies will build upon the ones developed for preceding missions such as NGST, SIRTF, and the Terrestrial Planet Finder.

Once the NGST has given us an understanding of the formation of the first galaxies in the early universe, we will be challenged to trace galaxy evolution back to the initial era of star formation, super-massive black holes, and metal element production in the present epoch. Capable of high resolution ultraviolet spectroscopy at a sensitivity a hundred times that of the HST, a follow-on **space ultraviolet optical telescope** would enable astronomers to follow the chemical evolution of the universe and determine its fate. Tracing the distribution of visible matter would make it possible to quantify the birth rate of galaxies and the energetics of quasars. It might also shed light on the distribution of the underlying dark matter.

Ultimately, we would like to make in situ measurements of matter and magnetic fields outside the bubble of space filled by the Sun's solar wind. An **interstellar probe** mission would explore the structure of the heliosphere and go on to sample matter and magnetic fields in the interstellar medium directly, for the first time. To travel this distance in just two decades will require a new approach to propulsion, perhaps solar sails.

Origins Observatories

The Origins Observatories are a series of astronomical telescopes in which each successive mission builds on the technological and scientific capabilities of previous ones. The vision is to observe the birth of the earliest galaxies in the universe, to detect all planetary systems in the solar neighborhood, and to find those planets that are capable of supporting life. To achieve this vision, the Origins Observatories line includes these components:

- A series of spectroscopic, imaging, interferometric missions, observing at visual and infrared wavelengths to answer the vision's fundamental scientific questions.
- A systematic technology development program in which technology enabling one mission leads naturally into the technology needed for the next one.
- Basic research to understand new observations.
- A comprehensive education and public outreach effort.

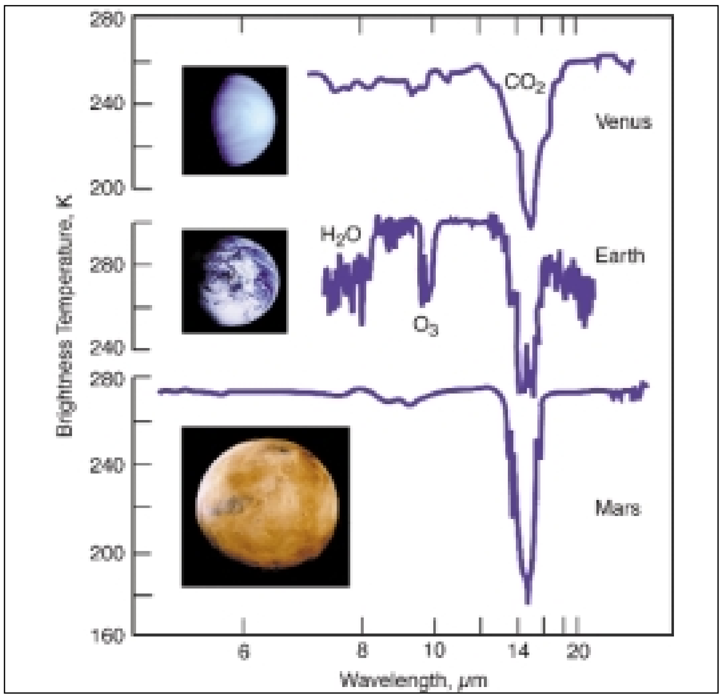
OBJECTIVE FOUR: Look for signs of life in other planetary systems

Determining whether habitable or life-bearing planets exist around nearby stars is a fundamental Enterprise goal. In addition, learning about other nearby planetary systems will provide precious context for research on the origin and evolution of our own Solar System. By measuring the velocity variation of a star's motion caused by the gravitational effect of unseen companions, ground-based observations have revealed dozens of circumstellar objects in the solar neighborhood that are much less massive than stars, but still far heavier than Earth. It is not certain, however, that the objects so far discovered are "planets" as we usually think of them, and new generations of missions will be required to discover orbiting objects that are more like Earth.

In 2003, several important projects that promise to detect planets substantially lower in mass than those known today will be nearing operation. These include the Keck Interferometer and the Full-sky Astrometric Mapping Explorer (FAME) mission.

While detecting the presence of Earth-mass planets is an important objective, determining their key characteristics—above all, the possibility of life—is much more difficult. **Astrobiology** research is developing a working catalogue of possible atmospheric signatures that would be indicative of life on a planetary scale. For example, today's Earth is recognizable as living primarily because of its oxygenated atmosphere, but this was not always the case. Astrobiology is seeking to discover what Earth's biosignature would have looked like at a time when free oxygen was negligible and other biogenic products would have been present in atmosphere.

Looking outside the Solar System, the discovery of numerous low-mass "non-stellar" bodies orbiting other stars is challenging our understanding of planet formation and implying that planetary systems may be commonplace. With our Solar System as a model for the propensity for



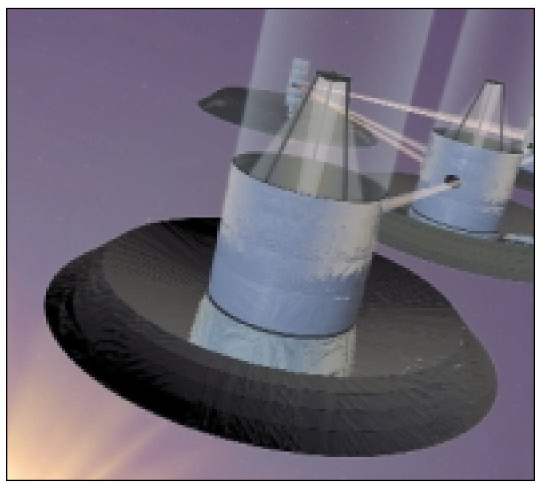
The atmospheric infrared spectra of Venus, Earth, and Mars all show a dominant carbon dioxide feature. In addition, Earth's spectrum exhibits water and ozone—the simultaneous presence of all three gases indicates a living planet.

life, we can conjecture that there are other worlds in our galactic neighborhood capable of supporting life. Our exploration of the diversity of planetary systems around other stars will emphasize systems that may have characteristics necessary for life. In additional to contributing to our knowledge of the structure and dynamics of our galaxy, **SIM**, described under Objective Three, will be the first observatory capable of indirectly detecting planetary bodies with only a few times the mass of Earth in orbit around other stars.

Continuing the Origins Observatories line, the **Terrestrial Planet Finder (TPF)** will extend the search for signatures of life beyond our Solar System. TPF will be an interferometric telescope array that will separate the infrared light of a planet from that of the star that it orbits in order to measure the spectrum of the planet. It will be able to search about 200 nearby stars for planets that possess warm atmospheres containing significant amounts of water or oxygen, which would indicate the possible presence of biological activity of some kind. To do so, the design for TPF will build upon large aperture, cryogenic optics, and infrared detector technologies also needed for the NGST, the beam control and nulling capabilities of the ground-based Keck Interferometer and SIM, and the precision free-flying demonstration of the **Space Technology-3 (ST-3)** mission.

For Possible Implementation After 2007

The first decade of the new millennium should have yielded tantalizing clues about the nature of the planets in the solar neighbor-



Left: The Space Technology-3 (ST-3) mission will test new technologies by flying two spacecraft in formation and using laser beams to keep the spacecraft aligned in precise positions relative to each other.

Right: By combining the high sensitivity of space telescopes with the high resolution of an interferometer, TPF will be able to reduce the glare of parent stars by a factor of more than one hundred-thousand to see planetary systems as far away as 50 light-years. TPF's spectroscopy will allow atmospheric chemists and biologists to analyze the relative amounts of gases like carbon dioxide, water vapor, ozone, and methane to ascertain whether a planet might support life.

hood, and about the presence—or absence—of life there. However, the TPF will be only the first step toward a detailed understanding of planetary systems in our neighborhood. The modest collecting area of the elements of TPF will permit only the first reconnaissance of these systems. The next step in studying other planetary systems will be observatories with significantly larger apertures and wider wavelength coverage.

The sensitivity of astronomical observatories depends strongly on the size of the light-collecting aperture, so that much larger successors to TPF would be able to observe far more target systems and search for rarer chemical species in planetary atmospheres. This will allow a less ambiguous interpretation of planetary spectra and permit a much wider range of planetary types to be observed. Two concepts on the horizon are a spectroscopic mission, a "**life finder**," and later, a complementary "**planet imager**." The prize from this new generation of observatories would be a truly comprehensive picture of planetary systems, including their physical characteristics and more conclusive signatures of life outside our Solar System. These missions to follow TPF will depend on even more ambitious optical systems, in particular, mirrors tens of meters in diameter. Since current space telescope technologies appear limited to smaller collecting areas, large optical systems technology will continue to have high priority for the Space Science Enterprise. Astronaut-assisted deployment or positioning approaches might be of great value in assembling and operating these future observatories, and advanced remotely-supervised robotic systems may also be available in that time frame.

OBJECTIVE FIVE: Understand the formation and evolution of the Solar System and Earth within it

Earth and all of the other bodies in the Solar System formed at about the same time from the same reservoir of material—a disk of gas and dust encircling the early Sun. These bodies have similarities, but also exhibit striking differences. For example, Jupiter and Saturn both have massive hydrogen-helium atmospheres apparently surrounding ice and rock cores, while Uranus and Neptune are mostly large ice and rock cores with much less surrounding gas. All of these outer planets, in turn, differ dramatically from Earth and the other "rocky" bodies that inhabit the inner Solar System. What were the differences in formation and evolution that led to these and other striking differences among the diverse bodies of the Solar System?

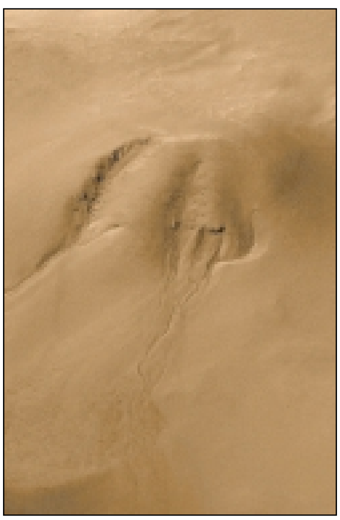
Looking more closely at the inner planets, we see that they are similar in size, but differ dramatically from one another in their atmospheres and surface properties. We believe that these rocky planets probably shared common origins but followed very different paths to the present. What evolutionary processes account for these differences? Are these processes still at work, and what do they imply about our future on Earth?

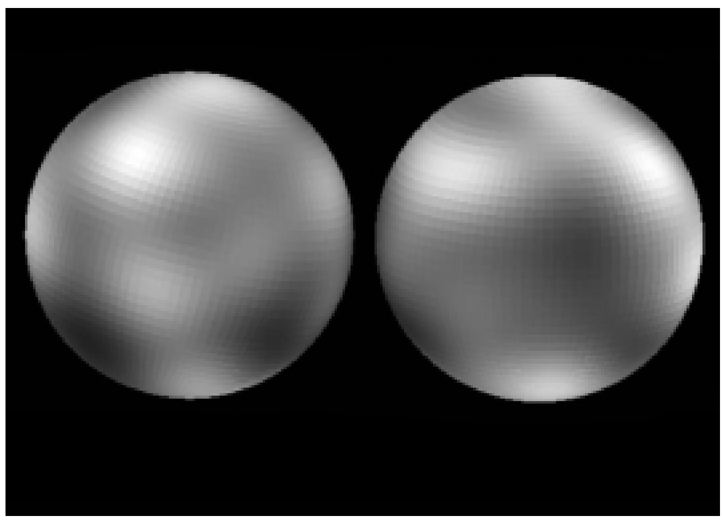
Superficially so different from Earth, Mars appears to have been much more Earthlike earlier in its history. One of the major objectives of the **Mars Exploration Program (MEP)** is to trace the evolutionary history of our neighbor planet. The Mars scientific community has adopted a "seek, in situ, sample" approach that employs surface and orbital reconnaissance to gain an understanding of the planet that will lead to multiple sample returns. To support this strategy, high-resolution orbital imaging will follow up on Mars Global Surveyor results that suggest the presence of near-surface water in recent times. Increasingly advanced landers will be interspersed with these orbital missions. One aspect of the program approach is to establish high bandwidth data return capabilities to support the "seek, in situ, sample" approach.

Key capabilities for near-term Mars missions include precision guidance and landing, surface hazard avoidance or tolerance, surface and atmospheric mobility, and aero-entry systems. Aerocapture would reduce propellant requirements. We need advances in systems for in situ analysis of materials that can help guide the selection of the small samples that we will be able to return. Sample return missions will also require development of high-specific thrust, compact ascent propulsion systems. A variety of advanced information system and communications technologies, including autonomy, inter-spacecraft communication systems, and optical communications, will be applied to future missions.

Valuable information about the early history of the Solar System resides at its boundaries. A **Pluto-Kuiper Express** mission would carry out the first reconnaissance of the last planet not visited by spacecraft and scout the inner edge of the Kuiper Belt. Pluto and its large satellite Charon represent a poorly understood class of remote and icy dwarf planets. The Kuiper Belt is a flattened disk of icy debris, believed to be in a primitive state, remaining from the processes that formed the major planets in our Solar System.

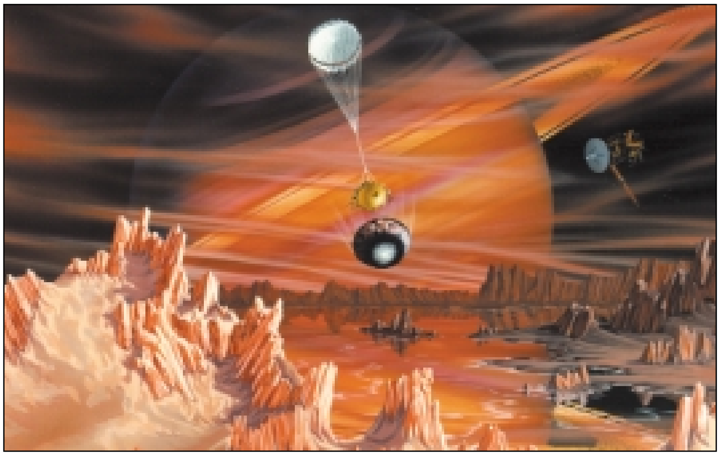
Other candidate missions in the **Outer Planets Program** to follow the Europa Orbiter include the **Titan Explorer** and **Europa Lander**. These missions would





Left: High-resolution images from the Mars Global Surveyor (MGS) Mars Orbiter Camera (MOC) suggest that liquid water has seeped onto the surface in the geologically recent past.

Right: The surface of Pluto is resolved in these Hubble Space Telescope pictures. These images show that Pluto is an unusually complex object, with more large-scale contrast than any planet besides Earth. Variations across Pluto's surface may be caused by topographic features such as basins or fresh impact craters. However, most of the surface features, including the northern polar cap, are likely produced by a distribution of frosts and chemical byproducts.



Artist's concept: The Cassini spacecraft flies by with its high gain antenna pointed at ESA's Huygens probe as it reaches the surface of Titan. Saturn is dimly visible in the background through Titan's thick atmosphere of methane, ethane, and (mostly) nitrogen. Cassini is a joint mission of NASA, the European Space Agency, and the Italian Space Agency.

build on the results from preceding missions to conduct in-depth analyses of these icy, organic-rich environments to determine whether they hold the possibility of life. Mission sequence decisions will be based on continuing scientific discoveries and the progress of our technology programs. For example, exciting results from the Cassini-Huygens mission arriving in the Saturn system in 2004 might advance the Titan Explorer ahead of other missions under study.

Highly capable, autonomous micro-avionics and very efficient on-board power subsystems are key to all future outer planetary missions. Multi-megarad radiation tolerance is a stringent requirement for all missions that operate in the Jovian environment. Avionics technologies projected for readiness in 2003 could support the Europa missions, while further advances will be required for the Titan Explorer. The Titan mission will rely on advanced solar electric propulsion and aerocapture. Special requirements for Europa Lander readiness include progress in bioload reduction and advanced chemical propulsion for landing on this massive airless body.

The so-called primitive bodies, comets and asteroids, contain important clues to the early history of the Solar System. It is hypothesized that comets and asteroids were the fundamental "building blocks" of planet formation and that most of these bodies that we see today are the debris left over from this process. Impacts on Earth by comets may have delivered the materials needed for the origin of life here: water, atmospheric gases, and perhaps organic chemicals. The Deep Impact mission, which will advance the

Outer Planets Program

Exploration of the outer Solar System has revealed that the outer planets and their moons are rich in organic material, that subsurface liquid water may exist in some places, and that prebiotic chemical processes occur in some of these environments. The Galileo spacecraft has returned fascinating information about the moon Europa. The Cassini-Huygens mission, now en route to Saturn, will extend this exploration through intensive investigations of the organic-rich atmosphere and surface of Saturn's giant moon, Titan.

Continuing this exploration thrust, the Outer Planets program will focus on prebiotic chemistry in likely places in the outer Solar System. Mission sequence decisions will be based on ongoing scientific discoveries and technological progress. Destinations for missions in this line include returns to Europa and Titan, reconnaissance of the Kuiper Belt, and a more comprehensive study of the Neptune system, including its moon Triton.

study of the composition of primitive bodies pioneered by earlier missions to Halley's comet, will be launched in mid-decade. To take the next step, a **Comet Nucleus Sample Return** is a high priority new implementation start to complement ongoing Solar System exploration programs. The goal of this mission, which could initiate a new "To Build a Planet" mission line, is to return a pristine sample of material from a comet nucleus for detailed chemical analysis. The Comet Nucleus Sample Return will depend on micro-avionics, advanced computing, and spacecraft autonomy technologies that are currently being developed. Advances in solar electric propulsion that focus on increased lifetime and reliability are needed. Other key capabilities include an Earth-entry system that can survive very large entry speeds into our atmosphere.

The composition and physical and chemical processes of comets are key to unlocking the secrets of the early Solar System. This dramatic pioneering image of the nucleus of Halley's Comet was obtained by the ESA Giotto spacecraft in March 1985.

For Possible Implementation After 2007

According to current planning, the Europa Orbiter, Pluto-Kuiper Express, Titan Explorer, and Europa Lander could be followed within the Outer Planets line by a **Neptune orbiter.** This mission is an important component of our investigation of the outer Solar System, including Neptune's moon, Triton, which may be an icy, organic-rich, captured Kuiper Belt object.

A number of other exciting opportunities are being considered for implementation as follow-ons in the "To Build a Planet" line after 2007. For example: so Earth-like in some respects, but so alien in others, Venus presents a genuine puzzle. Why did a planet with strikingly Earth-like size, composition, and geological activity develop a radically different surface and atmospheric environment? Understanding this evolutionary divergence has important implications for the study of life-sustaining environments as well as for our understanding of Earth's fragile, changing environment. A **Venus surface sample return** mission would help us to answer fundamental questions about the evolution of Earth-like planets.

Understanding the behavior of gas, dust, and radiation together is an important key to understanding the formation of the Solar System. In some ways, the rings of Saturn constitute a laboratory for the behavior of uncoalesced material in the primitive solar nebula. A **Saturn ring**

observer mission could perform detailed investigations of complex dynamic processes in Saturn's rings. In effect, we would be able to peer back in time to the epoch of planetary formation, when the material now contained in the planets was spread out in a disk encircling the Sun. It would also provide critical "ground truth" for a variety of observational and theoretical astrophysical studies. The Venus and Saturn ring missions would continue the "To Build a Planet" line.

The **Mars Exploration Program** will continue its search for evidence of water, the quintessential ingredient for life. A Mars synthetic aperture radar orbiter mission could detect buried water channels and help direct our search for ancient and modern water reservoirs. Advanced missions that could follow initial sample return missions could drill deeply (perhaps 10 to 100 meters) into the Martian cryosphere and hydrosphere to follow up results from earlier sample return missions. Surface, subsurface, orbiting, and airborne elements would extend our ability to carry out wide-area exploration and sampling in three dimensions. Far-term missions will require many of the technology advances that will be developed for the nearer-term, as well as further progress in the areas of thermal control, inflatables, aerobraking, precision landing, autonomy, advanced electric propulsion, advanced power systems, optical guidance, and control.

Other mission candidates for later implementation include a Jupiter polar orbiter for long-term detailed investigations of Jupiter's interior, atmosphere, and magnetosphere; giant planet deep probes to measure bulk composition, chemical processes, and atmospheric dynamics of the giant planets; a lunar giant basin sample return to collect samples from a very old impact basin far from previously sampled sites on the Moon; and a multiple asteroid mission/protoplanet explorer to investigate the relationship of main-belt asteroids to planetary evolution. As technological progress continues, some of these missions come within the scope of the Discovery program.

OBJECTIVE SIX: Probe the origin and evolution of life on Earth and determine if life exists elsewhere in our Solar System

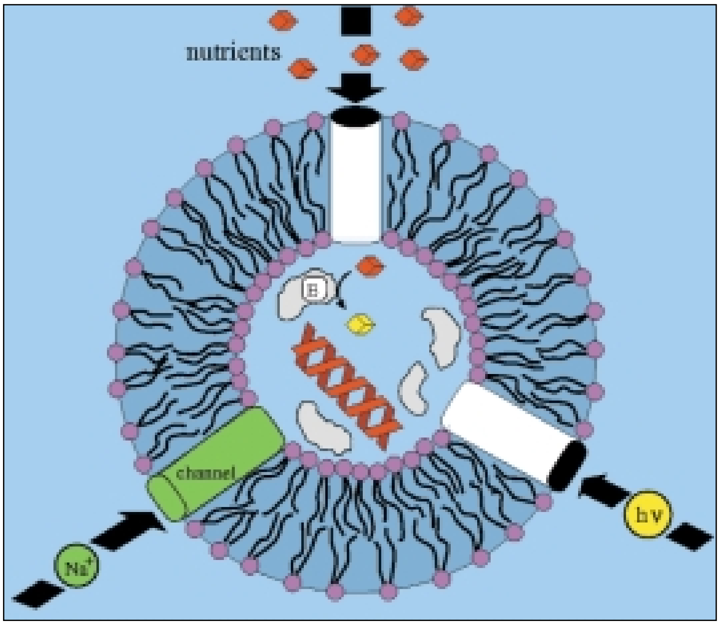
NASA research on the origin, evolution, and distribution of life in the universe is focused on tracing the pathways of the biologically critical elements from the origin of the universe through the major epochs in the evolution of living

To Build a Planet

An understanding of the formation and development of planets and their environments is a crucial missing link in our understanding of the Solar System and the development of life. At this juncture, we have learned enough to frame this subject in terms of three fundamental questions:

- What are the building blocks of which planets are made?
- What dynamic processes are involved in the initial formation of planets and planetary systems?
- What determines the diverse outcomes of planetary formation and evolution?

Answers to these questions are accessible to us in present-day Solar System objects: comets and asteroids, planetary rings, and the planets themselves.



A computer-generated dynamic model of a primitive cell used to test theories about the formation and behavior of Earth's earliest life.

systems. To understand the possibilities for life, we need to study the only known example, life here on Earth. NASA has made major contributions to discoveries in this area, such as the recognition that life began very early in Earth's history (3.85 billion years ago) and that our earliest microbial ancestor may have been a heat-loving, hydrogen-utilizing microbe. Major changes in the evolution of life have been tied to biological and geological processes (for example, the oxygenation of our atmosphere) and to extraterrestrial events such as an asteroid impact 65 million years ago that ended the age of the dinosaurs. Stellar evolution models suggesting that the Sun was much fainter at the time life was arising on Earth have called attention to the influence of solar vari-

The Astrobiology Institute

The new science of astrobiology synthesizes many scientific disciplines—astronomy to biology, geology to ecology, chemistry to informatics. Scientists from these disciplines, working toward the common goal of discovering the thread of life in the universe, have developed an Astrobiology Roadmap with three fundamental questions, ten goals, and 17 specific program objectives (*http://astrobiology.arc.nasa.gov*).

To pursue these goals and objectives, NASA has adopted an innovative approach to integrating efforts in these disparate disciplines by establishing the NASA Astrobiology Institute. The Institute advances our knowledge by forming interdisciplinary teams of researchers to attack major questions across a broad scientific front. It is a "virtual institute," in that it is a collaborative activity rather than a physical location. The members of these teams are geographically dispersed, but synthesize expertise in diverse fields by coordinating research goals, by frequent personnel exchanges, and by ongoing series of workshops, seminars, and courses, supported by the Institute's electronic networks.

ability on both the emergence and persistence of life on Earth.

A new space science research and analysis initiative, the **Astrobiology Initiative**, will study life in the Universe to determine how life began and evolves, whether there is life elsewhere than on Earth, and what the future of life is, on Earth and possibly beyond it. Understood broadly, the new field of astrobiology encompasses not only fundamental biology, but also cosmochemistry, exobiology, evolutionary biology, gravitational biology, and even terrestrial environmental science and ecology. At NASA, some elements of this syncretic discipline fall into the purview of other enterprises. But the space science program addresses many of its most fundamental issues.

While not strictly a mission, the Astrobiology Initiative is comparable in scope and ambition to a major flight program. As a new research field, astrobiology intends to expand exobiology research and encompass areas of evolutionary biology to further our understanding of how life may persist and evolve to exert a global environmental influence. One objective of astrobiology is to reconstruct the conditions on early Earth that were required for the origin of life and to determine the nature of processes that govern the evolution of life. Two approaches to learn about life on early Earth are to investigate the geological record and to use the genetic record, contained in contemporary microorganisms, to

Goals of Astrobiology

Question: How does life begin and develop?

Goal 1: Understand how life arose on Earth.
Goal 2: Determine the general principles governing the organization of matter into living systems.
Goal 3: Explore how life evolves on the molecular, organism, and ecosystem levels.
Goal 4: Determine how the terrestrial biosphere has co-evolved with Earth.

Question: Does life exist elsewhere in the universe?

Goal 5: Establish limits for life in environments that provide analogues for conditions on other worlds.
Goal 6: Determine what makes a planet habitable and how common these worlds are in the universe.
Goal 7: Determine how to recognize the signature of life on other worlds.
Goal 8: Determine whether there is (or once was) life elsewhere in our Solar System, particularly on Mars and Europa.

Question: What is life's future on Earth and beyond?

Goal 9: Determine how ecosystems respond to environmental change on time-scales relevant to human life on Earth.
Goal 10: Understand the response of terrestrial life to conditions in space or on other planets.

characterize traits of our microbial ancestors. From an experimental approach, researchers will develop and test pathways by which the components of life assemble into replicating systems that can evolve. Current research is expanding our understanding of the possibilities for the earliest life, utilizing simpler molecules and systems that could have been the precursors to the protein/RNA/DNA system used by all life today. It is only recently that we have been able to measure the scope of biological diversity. We have found that life thrives on Earth across the widest range of environments, inhabiting hydrothermal vents, extreme cold-deserts, environments at the limits of pH and salinity, and rocks kilometers beneath Earth's surface. This information will give us clues to how life may have evolved and where it could persist elsewhere.

In order to develop a complete program, the Astrobiology Initiative is being complemented by new thrusts in advanced concepts and technology. Elements already identified are sample acquisition, preparation, processing, and quarantine; hyperspectral remote sensing and imaging; in situ detection of life and "smartlabs;" detection and analysis of non-equilibrium thermochemical states; extreme environment simulation chambers; biotechnology and bioinformatics; technologies to access planetary surfaces and subsurfaces; and next-generation planet imaging and analysis techniques. The intent is to identify specific areas in biotechnology, instrumentation, field studies, and missions where investment will significantly advance this new field.

Astrobiology is a major component of the **Research and Analysis Program** (R&A, described at greater length in section II-5). The R&A program also supports the analysis of primitive meteorites—and will extend this work to returned samples from asteroids and comets—to learn about the early Solar System and the biologic potential of planetary bodies.

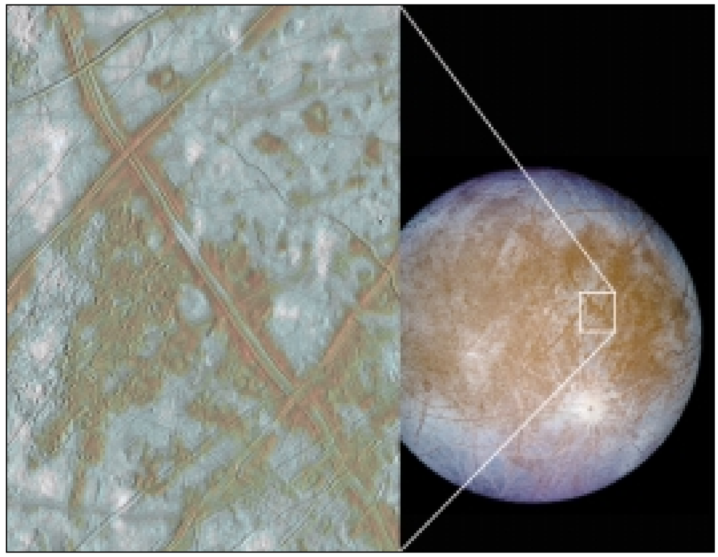
Studies of hot springs on Earth will help guide the search for life on other planetary bodies by showing life at its limits and fossilization processes.

Flight missions will also contribute directly to the search for life or its antecedents in the Solar System. **Cassini**, en route since 1997, will arrive at Saturn in 2004. Its **Huygens** probe (provided by the European Space Agency) will explore the organic-rich atmosphere of Titan, Saturn's largest moon, to broaden our understanding of organic chemistry in our Solar System, perhaps discovering an organic sea or a record of the satellite's organic history.

A number of flight programs that will go into implementation after 2003 will also contribute vitally to the search for life and its origins. For example, it is ironic that the ancient surface on Mars may contain the best record in the Solar System of the processes that have led to life on Earth. The **Mars Exploration Program** will expand our understanding of volatiles on the planet, study its atmospheric history, and determine the elemental composition and global characteristics of Mars' surface. Future missions will explore the ancient terrain and return samples, unveiling the Mars of over three billion years ago and, perhaps, also unveiling the precursors to life on ancient Earth. Part of the challenge will be to establish criteria to distinguish between materials of biological and non-biological origin both during sample selection and in subsequent detailed analysis of these samples on Earth. We will continue to search for and analyze Martian meteorites present on Earth to understand Mars and the exchange of materials between planets.

An understanding of Saturn's moon Titan could provide an important bridge between the study of life's chemical building blocks and the study of more evolved environments such as Mars and Earth. Follow-on to Huygens, **Titan Explorer** could investigate chemical conditions that might be similar to the early environment of Earth, and could offer a key to an ultimate understanding of the origin of life.

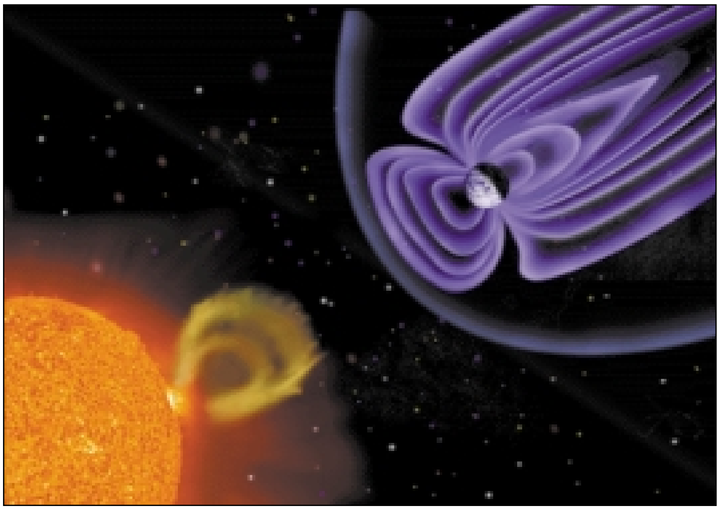
Images of Europa, an ice-covered moon of Jupiter, suggest existence of a sub-surface world of liquid water. We will pursue this suggestion of a second liquid water world in our Solar System with the Europa Orbiter, scheduled for launch in mid-decade. Actually, the presence of subsurface liquid water worlds now seems plausible in a number of satellites of the outer planets. These findings and our understanding of the early appearance and ubiquity of life on Earth reinforce the suspicion that life could exist elsewhere in the Solar System. By applying an understanding of the early evolution of life on Earth, as well as of its ability to thrive in extreme environments here, we can search for evidence of life elsewhere in our Solar System. A **Europa Lander** could be an important next step for this objective.



Images of Europa's surface indicate that water or slush may have oozed up through cracks in its icy crust. This suggests that a subsurface ocean has existed on this moon of Jupiter, and the discovery of a magnetic field around Europa indicates that a liquid ocean is still there beneath the ice.

For Possible Implementation After 2007

If a Europa Lander returns evidence of a subsurface water ocean, we could consider how to carry out more technologically difficult penetration of the frozen crust to hunt for life below by a **Europa subsurface explorer**. As we learn more about the potential for life in the universe, astrobiology research will suggest new targets for missions. For instance, already being contemplated as other potential water habitats are Callisto and the deep subsurface



Solar activity interacts with Earth and its magnetosphere in complex ways.

of Mars, which could also be targets of very advanced spacecraft.

OBJECTIVE SEVEN: Understand our changing Sun and its effects throughout the Solar System

The Sun has profound effects throughout the Solar System, both on the bodies that orbit our own star and on the space between them. To explain these effects, we need to understand both the inherent characteristics of the Sun and how its emissions interact with the rest of the Solar System. These interactions at Earth are particularly important because of their practical near-term effects (e.g., interference with satellite communications) and possible long-term implications (e.g., the effects of solar variability on climate). An understanding of the Sun and the consequences of its variation are also needed if we are to comprehend conditions at the dawn of life on Earth and predict our long-term future.

We are dramatically advancing our knowledge of how the Sun works through studies of solar interior dynamics. Using a growing fleet of spacecraft, we are making coordinated measurements of events that start at the Sun, propagate through interplanetary space, and ultimately impact Earth's magnetosphere and upper atmosphere. The next step is a first survey of the region where the terrestrial atmosphere transitions to space, opening a new view of the response of Earth's magnetosphere to the solar wind. We are also gaining important insights into the workings of extraterrestrial magnetospheres, exploring the most distant reaches of the Solar System, and completing the first exploration of the solar wind at the Sun's poles.

The **Solar Terrestrial Probe (STP)** program is a line of missions specifically designed to systematically study the Sun-Earth system. The STP program seeks an understanding of solar variability on time scales from a fraction of a second to many centuries. It will also determine cause (solar variability) and effect (planetary and heliospheric response) relations over vast spatial scales. Our first STP projects are the Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED) mission, NASA's contribution to the Japanese Solar-B mission, and the Solar Terrestrial Relations Observatory (STEREO); these will proceed into implementation before 2003. Planned follow-on STP missions focus on the responses of near-Earth space to solar input. **Magnetospheric Multiscale (MMS)** should help us quantitatively understand the fundamental plasma physics underlying the processes (including magnetic reconnection, plas-

Passing within three solar radii of the Sun, inside its outer atmosphere, Solar Probe will endure extreme conditions to provide unique data.

ma turbulence, and energetic particle acceleration) that control magnetospheric dynamics and thus clarify the impact of solar processes on the geospace system. The **Geospace Electrodynamic Connections (GEC)** mission will determine the spatial and temporal scales that govern the coupling between the magnetosphere and ionosphere, a major step toward understanding the connection between the solar wind, magnetosphere, and ionosphere. **Magnetotail Constellation (MagCon)** will employ a large number of very small satellites to map the structure of the magnetosphere. The availability of simultaneous multi-point measurements from missions such as MagCon will make it possible to construct the first high-fidelity "images" of the regional structure of the magnetosphere and to characterize in detail its response to variations in solar input.

Solar Probe will be our first voyage to a star, a mission to explore the near-environment of our Sun. Solar Probe will make a close flyby of the Sun, making the first in situ measurements deep within its outer atmosphere. In addition to providing data essential for understanding the source of the solar wind, these observations will allow us to relate remote observations of solar phenomena to the actual physical processes that occur in the solar atmosphere.

The Gamma Ray Large Aperture Space Telescope's (GLAST) greatly enhanced sensitivity relative to previous high energy gamma ray instruments will allow detailed studies of the physical mechanisms underlying the vast energy releases observed in solar flares.

Living with a Star (LWS), described under Objective Eight, is a special NASA initiative that directly addresses those aspects of the Sun-Earth system that affect life and society. Its program elements include a space weather research network; a theory, modeling, and data analysis program; and space environment test beds. The first LWS mission will be the **Solar Dynamics Observer**, which will focus on the solar interior with the goal of understanding the sub-surface roots of solar activity.

Community-formulated missions in the **Explorer Program** will take advantage of new scientific ideas and technologies to advance our knowledge of the Sun-Earth connection. In addition, missions undertaken within the **Discovery Program** will also contribute to our understanding of the terrestrial system. One example is information on Mercury's magnetosphere to be returned by the MESSENGER Discovery mission.

For Possible Implementation After 2007

Atmospheric waves link the troposphere and upper atmosphere and redistribute energy within the ionosphere-thermosphere-mesosphere (ITM) system. Clusters of satellites using high-resolution visible and infrared sensors could provide **ITM wave imaging**, enabling us to understand generation and loss mechanisms of these waves, their interactions, and their role in energy transport within the region. Significant improvement in infrared sensors will be required in order to enable this mission.

Understanding the heating and cooling of the solar corona by distinguishing between proposed heating mechanisms remains a challenge. Because much of the physics governing this activity occurs very rapidly and at very small spatial scales, this will require imaging and spectroscopic data able to resolve **microscale coronal features**. Implementation of such a mission will require significant developments in optics and detectors.

To fully understand the structure of the solar corona and to obtain a three-dimensional view of coronal mass ejections, we will need observations from above the Sun's poles to complement data obtained from the ecliptic plane. Viewing the Sun and inner heliosphere from a high-latitude perspective could be achieved by a **solar polar imager** in a Sun-centered orbit about one half the size of Earth's orbit, perpendicular to the ecliptic. Solar sail technology will be required to put a spacecraft in such an orbit in a reasonable time.

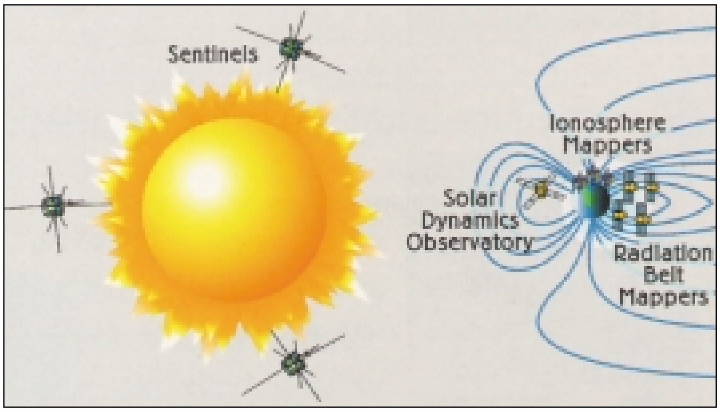
Future **LWS** missions will continue to contribute importantly to our scientific understanding of the underlying physical processes through which the Sun impacts Earth and society.

An **interstellar probe**, traveling more than 30 billion kilometers in 15 years or so, could directly study for the first time how a star, our Sun, interacts with the surrounding interstellar medium. On the way, it would investigate Solar System matter beyond Neptune, and then determine the structure and dynamics of the shock wave that separates our heliosphere from the space between the stars. Continuing on, it would explore the plasma, neutral atoms, dust, magnetic fields, and cosmic rays of the interstellar medium.

OBJECTIVE EIGHT: Chart our destiny in the Solar System

Evolutionary processes that have shaped Earth and other planets are still at work in the Solar System today. For example, there is strong evidence that large impacts caused biological mass extinctions on Earth in the past, altering the course of biological evolution. The impact of Comet Shoemaker-Levy 9 on Jupiter in 1994 vividly demonstrated that major impacts still occur and could alter the future human habitability of Earth. The Space Science Enterprise supports the search for near Earth objects (**NEOs**). We believe there are between 700 and 1100 NEOs larger than 1 km whose orbits traverse Earth's, and we have discovered less than 450 of them to date. The motions of these objects are clearly of interest as potential hazards. Many of them are also the easiest objects for a spacecraft rendezvous, and may contain water or even rich mineral deposits.

Hubble Space Telescope image of Jupiter in July 1994. The dark spots are scars left by multiple impacts of the fragments of Comet Shoemaker-Levy 9. Jupiter's diameter is approximately eleven times that of Earth, which would fit into the Great Red Spot (at left in the image).



Living With a Star is a new initiative to understand space weather and the effects of the Sun on Earth. Various LWS spacecraft will provide information about Earth's upper atmosphere, the heliosphere, and the Sun itself.

We know that solar activity can strongly affect daily life in today's technological civilization by causing power-grid failures, temporary communications interruptions, and even outright failure of communications and defense satellites. Particle radiation from the active Sun can endanger astronauts in space. Solar variability is also one of the natural drivers of global climate that must be better understood for accurate evaluation of the impact of human activities on global climate. An understanding of the evolution of the Sun and the consequences of its variations are critical if we are to properly understand the conditions at the dawn of life and to predict our long-term future.

Future **Solar Terrestrial Probe** missions and Sun-Earth connection-related **Explorers** will continue to improve our understanding of solar variability and how a habitable environment is maintained on Earth in spite of it.

Living with a Star (LWS) is a NASA initiative that directly addresses those aspects of the Sun-Earth system that affect life and society. It includes a space weather research network; theory, modeling, and data analysis programs; and space environment test beds. The flight component of LWS is a network of spacecraft that will provide coordinated measurements from a variety of vantage points distributed around the Sun and Earth. Analyzed together, these measurements will allow us to better understand and predict the effects of space weather events. The first planned LWS mission is the **Solar Dynamics Observatory (SDO)**, which will observe the Sun's outer layers to determine its interior dynamics and the activity of the solar corona, the source of sunspots and active regions, and origin of coronal mass ejections. A second LWS component is a constellation of **Sentinels** around the Sun to observe the movement and evolution of eruptions and flares from the dynamic Sun through the interplanetary medium to Earth's orbit. LWS geospace missions are the **Radiation Belt Mappers** and the **Ionospheric Mappers**. The Radiation Belt Mappers will characterize the origin and dynamics of terrestrial radiation belts and determine the evolution of penetrating radiation during magnetic storms. The LWS Ionospheric Mappers will gather knowledge of how Earth's ionosphere behaves as a system, linking incident solar energy with the top of Earth's atmosphere.

Beyond elucidating events and processes that might affect our destiny on Earth, missions to the Moon, Mars, and near-Earth asteroids will also contribute to our understanding of potential human destinations in the Solar System. Lunar Prospector returned evidence for hydrogen, possibly in the form of water ice, trapped in permanently shadowed regions near our Moon's north and south poles. Goals of the **Mars Exploration**

Program include investigating selected sites on that planet in detail and improving our understanding of how to ensure the safety and effectiveness of future human explorers, and perhaps eventually settlers. Future missions to Earth-approaching asteroids will assess the resource potential of these objects.

For Possible Implementation After 2007

Future elements of the **LWS** Initiative will provide coordinated measurements from an improved space weather research network, distributed around the Sun and Earth, to advance our ability to understand and predict space weather events and their effects. Future LWS components, such as a **solar-polar orbiter** and Earth **north and south "pole-sitters,"** are under study.

The **Mars Exploration Program** will continue and will build on the results of the nearer-term missions. From laboratory studies and space experimentation, astrobiology research may reveal whether life is limited to its planet of origin or can expand its evolutionary trajectory beyond. Outer Solar System missions to Europa and Titan would help clarify the larger context for life in our own family of planets and satellites.

Living With a Star

The Living With a Star Initiative is a set of missions and enhancements to our current program to augment our study of solar variability and its effects. Why do we care? The sphere of the human environment continues to expand above and beyond our planet. We have an increased dependence on space-based systems, a permanent presence of humans in Earth orbit, and eventually humans will voyage beyond Earth. Solar variability can affect space systems, human space flight, electric power grids, GPS signals, high frequency radio communications, long range radar, microelectronics and humans in high altitude aircraft, and Earth's climate. Prudence demands that we fully understand the space environment affecting these systems. In addition, given the enormous economic impact of even small changes in climate, we should fully understand both natural and anthropogenic causes of global climate change.

The Living With a Star Initiative includes:

- A space weather research network of spacecraft providing continuous observations of the Sun-Earth system for interlocking, dual use, scientific and applications research.
- A special data analysis and modeling program targeted at (1) improving knowledge of space environmental conditions and variations over the solar cycle, (2) developing techniques and models for predicting solar and geospace disturbances that affect human technology, and (3) assimilating data from networks of spacecraft.
- Space Environment Test beds for low cost validation of radiation-hardened and radiation-tolerant systems in high radiation orbits.
- Establishing and expanding partnerships for interdisciplinary science and applications with other NASA programs (Earth Science, Human Space Flight, Life Sciences), with other Federal agencies (e.g., via the interagency National Space Weather Program), with international collaborators, and with industry.