N91-13843

Biospheres and Solar System Exploration

Thomas O. Paine, Ph.D.
Administrator of NASA, 1968-70
Chairman, National Commission on Space, 1984-86

I believe in the research program initiated here at Space Biospheres Ventures. Humanity is a flourishing species because of our drive to explore and our technological ingenuity. Twenty thousand years ago our ancestors initiated the agricultural revolution with technologies that altered our relationship to nature. Herdsmen and cultivators can't revert to hunter-gatherers, nor can we abandon our half-completed industrial revolution, although we must better manage the environmental impact.

We meet here at a time of historic decision with modern nations at a crossroads, reconsidering the choice between developing technology for mutually-assured destruction, or for expanding life beyond Earth's biosphere. The news in late 1989 is encouraging. The superpowers appear to be turning onto the road of life, but — human nature being what it is — the issue can never be finally resolved. The next great evolutionary challenge to our species is to open the Inner Solar System to human settlement. Learning to "live off the land" on resource-rich Mars will double the territory available for life, and encourage our descendants in another century to settle countless planets circling distant suns.

In this historical context, I see Biosphere 2 as a shining beacon pointing the way to an expanding future for humanity. Closed ecology systems can free us from Malthusian limitations by making the Solar System our extended home. For the first time in the history of evolution, the human intellect can extend life beyond Earth's biosphere, following the lead of species that left the oceanic biosphere to inhabit dry land billions of years ago. In the 21st Century, a network of bases throughout the Inner Solar System, interconnected by space transportation and communication infrastructure, can sustain vigorous high-tech civilizations evolving on three worlds. The space settlement implication of Biosphere 2 is thus my theme for tonight.

IMPLICATIONS OF BIOSPHERE TECHNOLOGY

As you know, our Earth is one of nine known planets circling the Sun, which is one of about a trillion stars in our Milky Way Galaxy, which is one of about a trillion observable galaxies (which will probably grow to ten trillion galaxies when the space telescope goes into operation next year). So we have explored only eight of the universe's trillion trillion terrae incognitae (Figure 1). We can't snap a photo of our own Galaxy, but we can photograph the nearby Andromeda galaxy, which closely resembles our Milky Way. Our Sun is a star out near the galactic rim; it is from this perspective that we observe the heavens.

As far as science can tell, the only life in the entire cosmos is that riding through space on our precious blue planet, and the only intellect in all creation studying the universe is the human brain. With a trillion trillion possibilities, it's hard to believe that we're alone, but to date we have turned up no scientific evidence for the existence of life beyond Earth. So we are "E.T." — it's up to us to expand intelligent life to the stars.

THE FIRST STEP: OUR SOLAR SYSTEM

Our energy-giving Sun is circled by the four earth-like planets: Mercury, Venus, Earth, and Mars. Beyond Mars lies the asteroid belt, where more than 3000 small planetesimals have been discovered (and more than ten times that number are believed to exist). Beyond these are the four gas giants of the outer solar system: Jupiter, Saturn, Uranus, and Neptune, then the outermost planet, Pluto, and finally the great Oort cloud of comets extending for billions of miles. Occasionally one of these icy bodies is perturbed and swings through the Inner Solar System, boiling off a vaporous tail which the solar wind deflects across the night sky. Cometary impacts may have distributed water and organic chemicals throughout the Solar System from the enormous quantities stored in the Oort cloud. Let's briefly review the exploration status and prospects of each world in our Solar System.

The Sun

As Copernicus and Galileo showed, our Sun is the central star whose thermonuclear cycle provides the life-giving energy that drives Earth's biosphere. Surprisingly, we still don't fully understand the nuclear fusion cycles involved; the Sun's neutrino flux doesn't quite fit our physics equations. Since the Sun fuels all life, space-based observatories and underground neutrino detectors are being improved to clear up the mystery of solar physics.

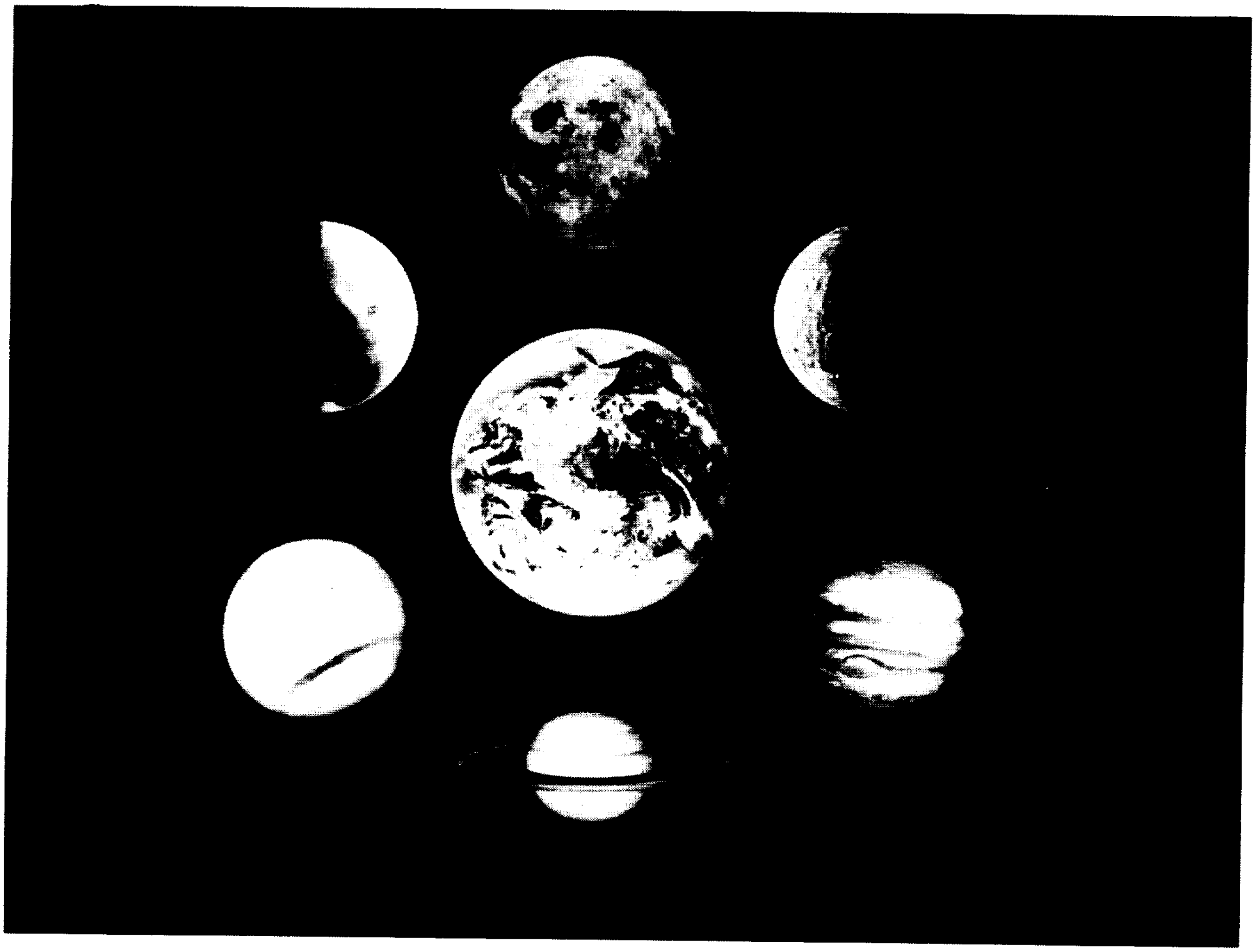

Figure 1. A portrait of seven of the planets in our Solar System studied by spacecraft. The one in the middle, Earth, has a unique life support system called a biosphere. (Photo: NASA.)

Mercury

The planet nearest the sun is slightly larger than our Moon. Mercury's surface resembles the Moon's because both sustained intense meteorite bombardment in the early history of the solar system, and an absence of water erosion preserved their cratered terrains. The prospects of astronauts exploring Mercury soon are remote. Because it is so close to the sun, elaborate thermal protection would be required on the illuminated side. On the other hand, we and the Soviets are discussing automated Mercury probes early in the next century, and it is certainly possible that humans might explore the planet later if sturdy robots find interesting resources and research opportunities.

Venus

Next comes Earth's twin planet, Venus, with its dense atmosphere of carbon dioxide, sulfuric acid, and other gasses. Atmospheric scientists have a fine laboratory here in which to study a run-away greenhouse effect. The pressure at the surface of Venus equals that two thousand feet beneath the ocean, with a temperature high enough to sustain puddles of molten lead. U.S. and Soviet spacecraft have shattered science fiction dreams of humid jungles teeming with seductive Amazons. Cloud-shrouded Venus has been mapped by orbiting side-looking radars, and several Soviet landers have parachuted to the hostile surface to transmit brief observations of basaltic rocks before being

Figure 2. Mars settlement in the 21st century. In the distance, a spacecraft departs the Martian base. (Artist: Robert McCall. Copyright 1986 by Bantam Books, Inc.)

incinerated. Powerful radar signals bounced off Venus from our giant Arecibo radio telescope in Puerto Rico show shiny areas at the base of conical peaks, suggesting major flows of volcanic lava. NASA's Magellan probe is now en route to Venus to obtain a high precision map of the Venusian mountains and plains.

Earth

Next outward from the Sun is our own beautiful blue planet, 75% covered by oceans. Distant photographs by Apollo astronauts of Earth's unique biosphere floating in space provided great impetus to the environmental movement. Space observations allow us to scan continuously the entire surface of Earth, monitoring ozone, agriculture, glaciers, tectonic plates, polar icecaps, vulcanism, the interaction of ice and water with the atmosphere and land, and many other critical processes. From orbit we can study pollution and urbanization, the destruction of great rain forests, desertification, erosion, and resulting changes in the Earth's climate.

In 1992 a major Mission to Planet Earth will celebrate the 500th anniversary of Columbus' discovery of a new world. Many nations will join an intensive Earth monitoring program combining space and surface systems. Photographs from space will record the temperature of the entire globe each day of the year, while other satellites scan auroral zones. When I visit my Alaskan daughter and watch the beautiful northern lights, I can't see that the flickering sheets of solar ions extend all the way around the magnetic pole, but satellites can. The pioneering flight of the Wright brothers reminds us that the most interesting phenomenon on our planet is the human intellect. Sixty five years after the first airplane flight in 1903, Apollo astronauts flew 240,000 miles from Earth to explore the Moon.

The Moon

Although the barren lunar surface provides a great contrast to Earth's teeming life, we've operated six research stations there, and a dozen astronauts have traversed the cratered terrain. The Moon is a geologist's paradise of ancient rock formations.

We've learned a great deal about lunar resources from the Apollo expeditions. The rocks are about 40% oxygen, which can be extracted for life support and spacecraft propellants. Terrestrial plants thrive in lunar soils, which contain finely powdered glasses, metallic particles and minerals. Indigenous resources will be valuable for future lunar operations, including a rich inventory of heavy elements, but the Moon lacks water. Hydrogen, carbon, and other essential light elements are scarce on the Moon, but abundant on Mars.

Mars

Humanity's next destination in space is resource-rich Mars and its moons (Figures 2 and 3). Voyaging hundreds of times the lunar distance from Earth will become routine in the first quarter of the 21st Century. Robotic spacecraft orbiting Mars have transmitted detailed photos, including spectacular features like Mons Olympus, the greatest volcano in the solar system. This giant cone spreads 420 miles across the plain and soars 15 miles to a lofty caldera. The enormous bulk reflects the lack of tectonic plate movement on Mars. We believe that the Hawaiian Islands were formed as a tectonic plate drifted above a subterranean magma source, throwing up a long chain of volcanic islands. On Mars, however, the plates appear to be fixed, so volcanoes grew larger and larger. This is just one of many terrestrial insights scientists are gaining from comparative planetology.

The most surprising discoveries from Viking spacecraft orbiting Mars were pictures showing evidence that at one time liquids flowed across the Martian surface. No rivers can exist today because the pressure of the thin carbon dioxide atmosphere is below the critical point of water; Martian ice therefore sublimes directly into vapor. Yet water eroded the surface for some time after the Martian impact craters were formed, and underground permafrost may still exist. Further evidence is provided by impact craters that show a muddy-looking fringe, as though the heat of collision produced a mushy outward wash. Looking down from orbit in the early morning we saw water fog forming in some valley areas, so substantial water resources exist in the atmosphere. Martian water frozen in polar icecaps, possibly underground, and in the atmosphere, will provide future pioneers with a resource essential for life.

Two robotic Viking explorers landed on Mars in 1976 carrying TV cameras, weather stations, and life-detection experiments. Their transmitted data followed the seasons throughout the Martian year (669 24-hour, 40-minute days), including great planet-wide dust storms. Pictures they took of a frosty morning on Mars shows the abundance of extractable water in the atmosphere. The soils sampled revealed no organic materials or evidence of life. Although these results were negative, life may exist elsewhere on Mars. The era of liquid water on Mars lasted longer than the time required for the first terrestrial life to appear in Earth's oceans, so fossils may record earlier life. We have much yet to learn about the possibility of life beyond Earth, and Mars is a superb laboratory.

Asteroid Belt

Beyond Mars lies a swarm of small asteroids that never aggregated to form a planet, but remain as tens of thousands of planetesimals. The Martian moons, Phobos and Deimos, are believed to be captured asteroids. As NASA's Galileo spacecraft flies through the asteroid belt on its six-year journey to Jupiter, it will observe asteroids Gaspra in Octo-

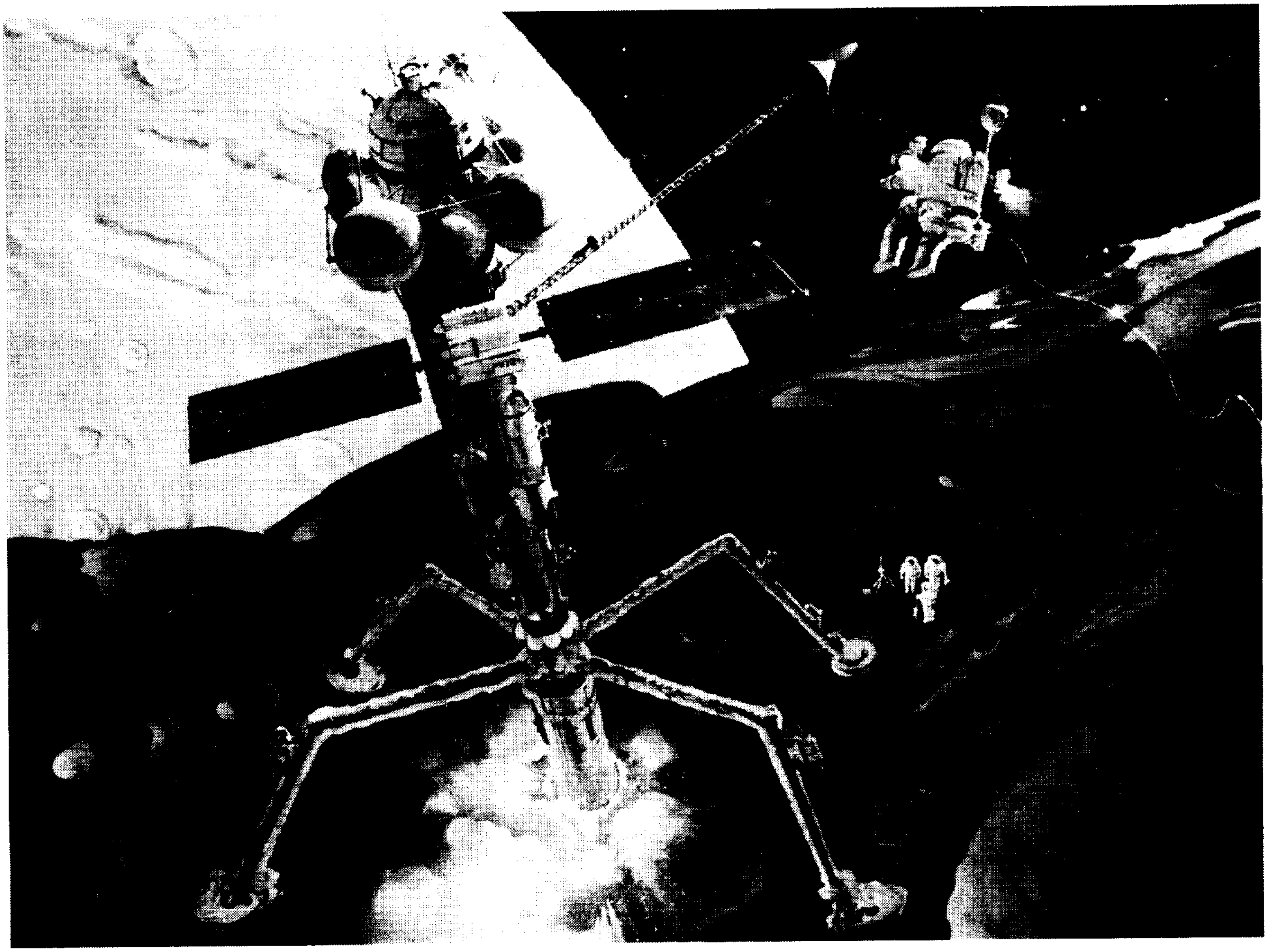

Figure 3. Mining propellant on Phobos, a moon of Mars. (Artist: Robert McCall. Copyright 1986 by Bantam Books, Inc.)

ber, 1991, and Ida in August, 1993. All future planetary missions beyond Mars will be targeted to fly by asteroids. In the 21st Century, six-month piloted missions to nearby asteroids should follow the initial human exploration of Mars.

Jupiter

Beyond the asteroid belt is giant Jupiter, which contains most of the mass of the solar system outside the Sun. One of its remarkable moons is Io, with active volcanoes that spout sulfur high into the sky. These volcanoes were actually discovered by a computer and an alert technician, Linda Morabito, of NASA's Jet Propulsion Laboratory. She fed incoming photos into an automated navigation program that pinpointed spacecraft position by scanning the limb of the moon in relation to nearby stars. When the computer kept rejecting the pictures of Io's limb, she checked and noticed a mushroom cloud where no cloud should be. Additional pictures showed soaring volcanic plumes distorting the smooth arc of Io's horizon; thus, to everyone's amazement, vulcanism was discovered in the Outer Solar System.

Other Jovian moons show intriguing features, too, including Ganymede, Callisto, and Europa, with ice-crusted oceans. The Galileo spacecraft will study them all after it deploys a European Space Agency probe into Jupiter's atmosphere. The isotopic compositions of Jupiter's gasses is of great interest to planetologists and astrophysicists, since they preserve the primitive material from which the Solar System was born. Galileo will

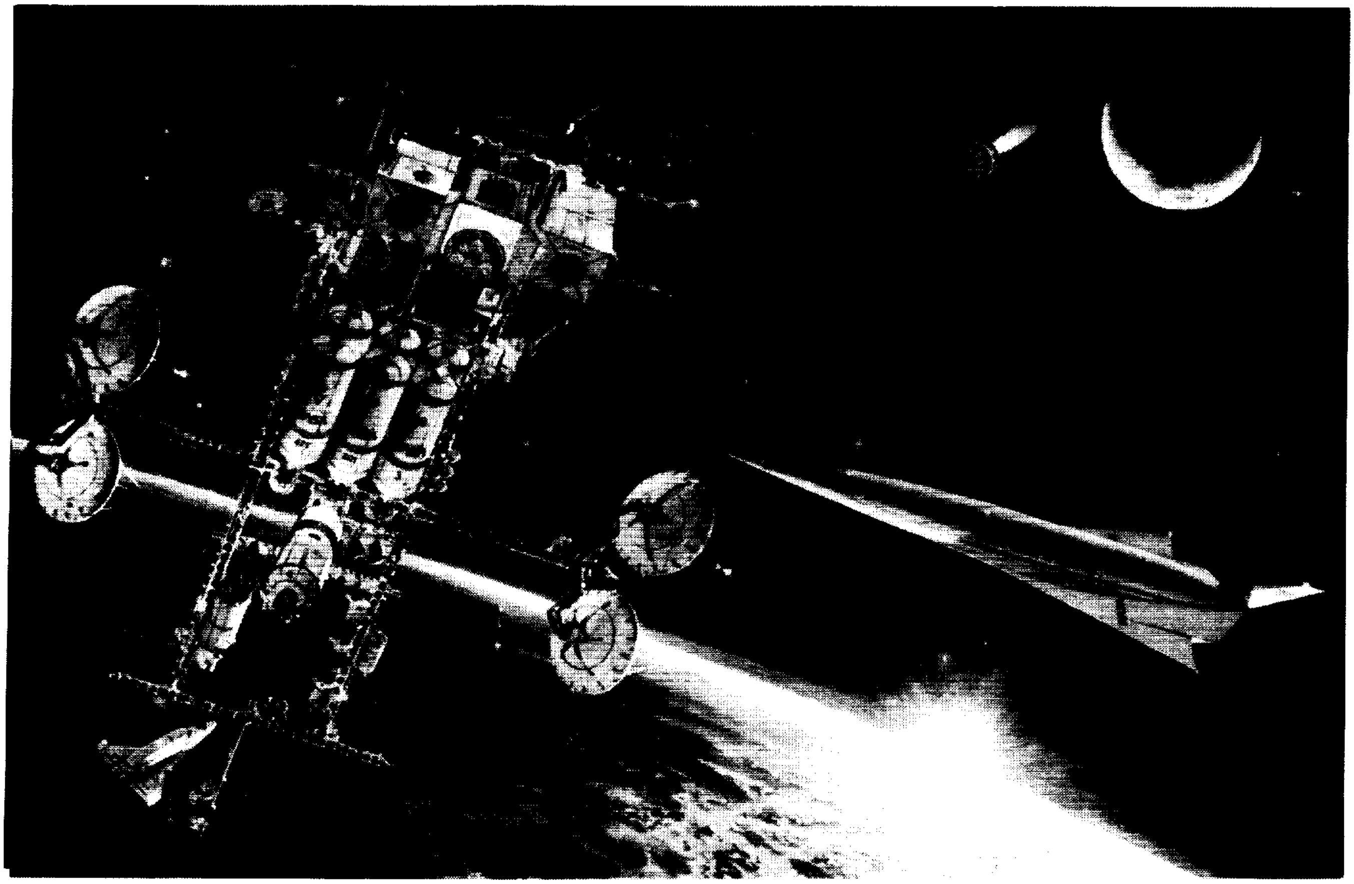

Figure 4. In the foreground is an aerospace plane and the Earth Spaceport. The spaceport is receiving cargo from a cargo transport vehicle (lower left-hand corner). In the background, a two stage transfer vehicle is returning to the Earth Spaceport from the Moon. (Artist: Robert McCall. Copyright 1986 by Bantam Books, Inc.)

journey throughout the Jovian moon system for several years, transmitting back to Earth pictures with a thousand times the resolution of previous images.

Saturn

Next after Jupiter is spectacular Saturn, with its magnificent ring structure. In April, 1996, NASA plans to launch the Cassini Mission with a European lander targeted for Titan, Saturn's largest moon. Titan's cloudy atmosphere is rich in organic compounds, which react under solar and cosmic ray irradiation to form Los Angeles-like smogs. From Titan's clouds methane may snow onto oceans and glaciers of organic compounds and continents of ice. The European Space Agency's probe should give us an exciting view of Titan's surface, perhaps shedding light on the conditions on ancient Earth when organic molecules first combined to form living systems. After deploying the ESA probe at Titan, the Cassini spacecraft will carry out an ambitious observation program of Saturnian moons and rings.

Uranus and Neptune

Beyond Saturn is Uranus, with equally fascinating moons. Miranda, for example, appears to have suffered an enormous impact that fractured it into a number of fragments, which then reconstituted themselves under low gravity into an incredibly jumbled topography. The geology of the Uranian moons, and of the more distant Neptunian moons, exhibit a fascinating diversity. Voyager's final detailed photographs of the large Neptunian moon, Triton, show geysers spouting liquid nitrogen five miles into the atmosphere, with debris falling onto continents of ice along a line 60 miles downwind. Triton is indeed a fascinating world.

Pluto

The one planet NASA's far-ranging reconnaissance robots have yet to visit is remote Pluto and it's large moon, Charon. This distant duo also promises to exhibit the diversity we've come to expect in the outer Solar System. We need to understand the energetics of these worlds far from the Sun, which appear to emit more energy than they receive. Missions to Pluto/Charon involving flight times up to forty years are under study. NASA's reconnaissance of our Sun's planets and moons is teaching us much that is applicable to potentially habitable worlds circling other stars.

Comets

Comets bring primitive material from the fringes of the Solar System into range of our spacecraft. Early in the next century NASA is planning to land a probe on a comet as it passes the orbit of Jupiter on its inward journey past the Sun. The goal is to monitor the comet through its closest approach to the Sun, studying the emissions from its outgassing surface as they stream out to form the tail. A refrigerated sample of its icy core may be brought back to Earth for study by a parallel probe that the Japanese Space Agency and NASA are discussing. Such a sample would represent invaluable material from interstellar space.

THE COMING EXTRATERRESTRIAL CENTURY

The 21st century will usher in a new Age of Discovery based upon reliable, low cost travel throughout the Inner Solar System. President Bush has directed his National Space Council and NASA to prepare plans for an evolutionary space station in Earth orbit in the next decade, a return to the Moon to establish permanent bases about 2004, and the manned exploration of Mars starting about 2015. This follows the recommendations of the National Commission on Space Report, Pioneering the Space Frontier[1], which listed five program elements as particularly critical for future interplanetary operations:

1. A Highway to Space to provide reliable, low-cost access to Earth orbit for passengers and cargo;
2. Orbital Spaceports circling the Earth, the Moon and Mars, to support spacecraft assembly, storage, repair, maintenance, refueling,

check-out, launch and recovery of robotic and piloted spacecraft:

3. A Bridge between Worlds to transport cargo and crews to the Moon, and to extend human spaceflight hundreds of times the lunar distance to Mars, with cycling spaceships in permanent orbits between Earth and Mars;

4. Prospecting & Resource Utilization Systems to map and characterize the resources of planets, moons and asteroids, and learn how to "live off the land" using indigenous materials on other worlds; and

5. Closed-Ecology Biospheres, like Biosphere 2, that can provide food and recycled air and water within secure habitats remote from Earth.

Each of these five elements is challenging, and each requires technological advances across a broad front. Yet we know much more today about establishing a network of evolutionary outposts and bases around the Inner Solar System than we knew about lunar landing when President Kennedy initiated the Apollo Program in 1961. We also have a broader base of international cooperation, a larger gross world product, and far greater astronautical experience. Let's review progress in each of these five fields.

The Highway to Space

Our most urgent need is a significant reduction in the cost of transporting cargo and crews between Earth and Low Earth Orbit. The U.S. Space Shuttle pioneered high-pressure hydrogen/oxygen engines, recoverable solid boosters, lightweight structures, high temperature re-entry tiles, automated landing from orbit, winged flight through the range of Mach numbers from zero to twenty five, vehicle reusability, payload return to Earth, and many other significant innovations. It is a superb craft for carrying 2 to 8 astronauts and substantial payloads between Earth and orbit in infrequent missions lasting several weeks. But the objective of routine low-cost transport cannot be achieved by this piloted vehicle, and shuttle operations are too expensive to continue indefinitely. Candidate new piloted systems include the Advanced Launch System (ALS), a Personnel Launch System (PLS), and the X-30 National Aero-Space Plane (NASP). The shuttle has taught us much about the system requirements for routine access to orbit, but a major reduction is needed in the cost of transporting large tonnages of cargo into orbit for 21st Century operations on the Moon and Mars.

Commercial cargo launch services are now available from many nations, but most employ labor-intensive, one-shot, missile technologies from the 1960s, with inherent high cost and single-point failure modes. New Ariane, ALS, and other launch vehicles are in prospect, but launch technology is about where aircraft design was in the 1920s, when barnstorming pilots flew with canvas and piano wire. But we can envision a future space transport equivalent of the economical Douglas DC-3, and the required technology base is under development in NASA's "Civil Space Technology Initiative" and "Pathfinder Program" (R&D in support of Solar System exploration).

For cargo transport, NASA is studying an unmanned Shuttle C, and a joint NASA-Air Force Advanced Launch System. Similar programs are under study by other countries. Now that President Bush has set the long-range U.S. goal of exploring Mars via the Moon, NASA can specify the characteristics of future payloads and launch systems. Serial production of fully-automated launch vehicles will significantly reduce the cost and hazards of spaceflight.

Orbital Spaceports

The U.S. *Skylab* and U.S.S.R. *Salyut* and *Mir* space stations have demonstrated the feasibility and utility of manned orbital laboratories. Astronauts and cosmonauts have carried out Earth observations, zero-gravity processing, ultraviolet and X-ray astrophysics, studies of the physiological effects of months of prolonged weightlessness, and many other experiments. Cosmonauts aboard the space station Mir have conducted medical and biological experiments demonstrating the possibility of a one-year, zero-g flight to Mars. Modules for the international Space Station *Freedom* are being designed by NASA and the European Space

Agency (ESA) in collaboration with Japanese and Canadian teams.

The new challenge is to design Space Station *Freedom* for the mid-90s with the flexibility to evolve into an international Spaceport by the turn of the century. Spaceport Earth must also provide the prototype for Spaceport Moon by 2001, and Spaceport Mars a decade later. This will establish an international network of orbital bases around the Inner Solar System combining the functions of space transportation nodes, communication centers, space laboratories, habitats, medical outposts, general purpose workshops, spacecraft assembly and checkout facilities, supply depots, maintenance bases, and fuel farms. Just as seaports assemble and service ships, orbital spaceports will assemble and service spacecraft. They will support a diverse fleet of satellite platforms circling three worlds, and dispatch and recover spacecraft for interplanetary cargo and passenger transport (Figure 4).

The Bridge Between Worlds

Modular space transfer vehicles with hydrogen-oxygen engines and aerobraking shields are being developed for Earth-Moon and Earth-Mars cargo and passenger flights. Lower-cost cargo transport is in prospect using low-thrust, high-specific-impulse solar or nuclear electric propulsion systems, with the propulsion electric generators adding to the useful delivered payloads.

Large cycling spaceships swinging permanently between the orbits of Earth and Mars appear promising for interplanetary passenger transport in the 21st Century. Aerobraking transfer vehicles can ferry passengers between the cyclers and Spaceport Earth at one end of the voyage, and Spaceport Mars at the other, eliminating the need to accelerate and decelerate the massive transports. Cycling spaceships on the Mars run will be more like the *Queen Elizabeth II* than a Boeing 747. Their large mass and volume will permit redundant power and life-support systems, well-equipped laboratories, comfortable living quarters, and closed-ecology biospheres (future generations of Biosphere 2). Safety features will include heavy shielding to protect crews from cosmic rays and solar flares, medical clinics, artificial gravity chambers, exercise gyms, and other health maintenance facilities.

Although Apollo demonstrated the feasibility of expendable spacecraft for flights to the Moon, NASA's new Martian goal suggests using prototype cycling spaceships on the Earth-Moon run to gain operational experience. Well-equipped lunar cyclers would also give scientists valuable research platforms for interferometry and other deep space experiments, and allow engineers to check out robotic operation, artificial gravity chambers, and closed-ecology biospheres with 24 hour daily illumination. During solar flares and passages through the Van Allen Radiation Belts, lunar travelers would be protected by the massive shielding that will be required aboard spaceships on the Mars run.

Prospecting and Resource Utilization Systems

Automated and piloted lunar orbiters, landers and rovers have taught us much about the Moon's resources, but we've literally only scratched the surface. The scarcity of hydrogen and other light elements on the Moon may make it less promising than Mars for self-sufficient settlements in the long run, since water may have to be imported. Sunless craters at the lunar poles might contain trapped volatiles like ice, however, so polar prospecting is planned in the next few years, starting with a Japanese lunar probe. The Moon's proximity to Earth permits teleoperated systems, which are difficult on Mars due to communication time delays across tens of million of miles. Robotic mapping, prospecting, and sample-return rover missions in the next decade will provide the engineering data needed to design Lunar and Martian bases.

Over the next 40 years, we must develop the broad technology base, transportation infrastructure, and network of self-sustaining bases beyond Earth that will permit men and women to "live off the land" on the space frontier. In addition to habitats and laboratories, Lunar and Martian bases will require solar or nuclear electric generators in the 1-10 megawatt range, automated plants to process indigenous materials, construction machinery, general purpose robotic fabrication plants (with software links to twin factories on Earth), maintenance shops, and transportation support facilities. Innovative architecture should take advantage of the Martian environment; for example, on-site materials with an ice binder can substitute for concrete on sub-freezing Mars. With NASA's sights set ultimately on Mars, Lunar base prototype systems should be specifically designed for adaptibility to Martian conditions.

Closed-Ecology Biospheres

To support people living in bases remote from Earth, air and water must be recycled, and nourishing food produced within automated, closed-cycle life-support systems like Biosphere 2. Air and water have been successfully regenerated in prototype systems, and the problems are reasonably well understood, but little is known about constructing reliable biospheres that can be depended upon to supply food and fiber. Closed-ecology experiments include the Soviet Bios-3 project and NASA's Closed Ecology Life Support Systems (CELSS) projects. Test subjects have spent more than six months sealed within Bios-3, although some food was imported. Less ambitious, but more compact, closed-ecology systems are being studied at NASA's Kennedy and Johnson Space Centers. Of all the critical elements, the Space Biospheres Ventures' goal of a closed-ecology biosphere remains the least understood and the most challenging, so you can understand why I'm enthusiastic about Biosphere 2.

CONCLUSIONS

Scientific progress interacting with the vastness of the Space Frontier can eliminate Malthusian limits to human aspirations. Our advancing technology base is ushering in an age of space exploration that has already brought great rewards to Earth, and in the 21st Century will expand life from its earthly cradle to the Moon and Mars. Developing the limitless space frontier will contribute to science, technology, productivity, economic growth, education, medicine, agriculture, international cooperation — indeed, to every feature of terrestrial life. Beating our terrestrial swords into extraterrestrial plowshares can convert yesterday's arms race into tomorrow's international space settlement.

Establishing a base on Mars and supporting it will be well within our capabilities by 2015. As I've stressed: the critical problem is learning to "live off the land" on Mars. Since we can't carry frozen dinners from Earth across millions of miles to Mars, Biosphere 2 is essential to make Mars self-supporting.

What about the distant future? Let me close by considering the Drake Equation, which starts with the trillion suns in the galaxy and the trillion galaxies in the universe, and estimates the probability of life beyond Earth. For a first approximation, multiply the number of stars formed each year, times the fraction of the stars that have planets, times the fraction of planets where water is liquid, times the fraction where life develops, times the fraction with evolutionary species, times the fraction with intelligent beings, times the fraction that develops technology, times the fraction that wishes to communicate across the cosmos before they wipe themselves out or lose interest. Despite all these fractions, you begin with such large numbers that it appears life must exist elsewhere. So the search has started; the Planetary Society, NASA, Soviet observatories, and others are operating banks of computers linked to large antennas that scan the sky for an E.T. "I Love Lucy" broadcast.

We do have initial evidence for the existence of planets in other solar systems. Recent observations of Beta Pictorus by an infrared satellite show material in orbit around the star. This evidence, and the history of our own Solar System, suggests that planets may be the usual result of star formation. We still don't know whether life normally appears and evolves on temperate aqueous planets. As M.I.T.'s Philip Morrison points out, however: either there is life elsewhere in the universe, or there is not — and in either case it boggles the mind!

If we can detect planets circling a nearby star, using observatories in Earth orbit or large infrared telescopes on the back of the Moon, and if one of them exhibits an atmospheric spectrum showing the presence of water vapor and plant-generated oxygen, I'm sure that our grandchildren or great grandchildren will organize a new megaproject to dispatch a starship across light-years of interstellar space. We may not live to see that, but we saw Apollo astronauts launch the exploration of other worlds (Figure 5). The Biosphere 2 Project is contributing to the critical next step: closed ecology systems that will expand terrestrial life throughout the Solar System.

REFERENCES

1. *Pioneering the Space Frontier: Final Report of the National Commission on Space.* Bantam Books, New York 1986.

Figure 5. Apollo 16 astronaut Charles M. Duke Jr. collects lunar rock samples, April, 1972. On the lunar surface, Duke and John Young collected over 200 pounds of rock samples including one determined to be 4.25 billion years old, thought to be part of the Moon's original crust. (Photo: NASA.)