N85-35143

SPACE SCIENCE AND EXPLORATION: A HISTORICAL PERSPECTIVE*

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It is always hazardous to evaluate the historical significance of an era or a development—whether political or intellectual—when the observer is still contemporary with that era. However, when placed against the background of the most significant advances by man throughout history, the space age has a secure position. It is the *evaluation* of the character and significance of the space age, as we shall call it, that we are here to discuss.

Macauley and Livingstone have noted that "many ingredients are necessary for the making of great history . . . knowledge of the facts, truth to record them faithfully, imagination to restore life to dead men and issues. . . . Thucydides had all three ingredients and their union makes him the greatest of historians." I cannot pretend to have these credentials but as a scientist whose main objectives have involved scientific experiments in space and who has shared in some of the space exploration, I can at least present my personal views and perspective. My task is to examine science and exploration in space, not the applications of space science technology. Clearly today the main focus is the U.S. program. But from a historical viewpoint, it is also important to look at the totality of man's efforts in space, in order to recognize the significance of individual achievements within the space era. In this period, six nations (France, Italy, Japan, China, Australia, and the United Kingdom), in addition to the USSR, the European Space Agency, and the United States, have successfully launched their own satellites (app. A). Many other nations have contributed essential experiments or spacecraft for these launchings. My talk here is neither a definitive history or a chronology of developments and achievements in space. It is an overview of the main points of this unique period.

We are all aware of some of the most spectacular and important contributions to our knowledge of the physical world and the universe around us, which have been made by reaching directly to the planets and thereby opening exploration of our solar system. Some of these achievements will be reviewed later. But how does this revolutionary

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* This paper was supported in part by NASA Grant NGL 14-001-006 and the Arthur H. Compton Fund.

step into space compare with other giant strides that have triggered enormous increases in our knowledge and long-term benefits for man? As historical examples we could cite the development of the steam engine and the rise of the industrial revolution, or the achievement of the sustained and controlled nuclear reaction.

In my opinion, some important distinctions should be made among these advances by considering two (and there may be more) kinds of revolutionary developments. The revolutionary development of the *first kind* is one in which a series of critical discoveries were preconditions for the start of the new era or new advance. A recent example is the nuclear age. One can trace the direct steps from James Chadwick's discovery of the neutron (1932) to the Hahn-Meitner discovery of fission of uranium (1939), to the establishment of a sustained nuclear reaction (1942) and, thence, to applications of nuclear energy for both constructive or destructive ends.

I would define a revolution of the *second kind* as the confluence of many ideas and developments, each well known for extended periods of time, which finally come to perfection to trigger revolutionary developments. An example might be Watt's steam engine. His invention of the condenser, to save energy lost in the earlier Newcomen engine, was crucial to the rise of the industrial revolution and represented the revolution's principal technical driver. Concurrent with Watt (1736–1815), Joseph Black evolved the concept of latent heat. This period was followed by Sadi Carnot of France, who was motivated to understand the principles of energy conversion underlying the steam engine by the fact that England had the lead and France was behind in this technology. Even though his ideas were based on an erroneous assumption, he nevertheless laid the groundwork for the basic principles of energy conversion in thermodynamic systems. These examples are intended to show that there are qualitative differences between what I call revolutions of the *first* and *second* kind. The revolution of the *first kind* is a sequential series of discoveries of physical phenomena in nature leading, for example, to a new form of accessible energy. A revolution of the *second kind* has a broad base of many technical developments which, motivated by a need, are finally integrated in a way that leads to further development and a new stage of activity for man.

I believe the achievement of orbiting satellites and probes, as well as manned flight in space and to the Moon (app. B), was a revolution of the *second kind.* Why may we think so? Without recounting the detailed development of rocket power, we know there were two identifiable stages. The first was during World War II when suborbital carriers for destructive weapons were developed; and the second emerged in the 1950s, sparked by the International Geophysical Year (IGY)—a program of scientific exploration and discovery concentrating on the Earth and its surrounding space by scientists in the period 1957–1959. The study of the Earth was not enough. Earth was a part of a larger system involving the space around us that linked phenomena on Earth to the dynamics of the Sun. Consequently, there was a strong consensus among many scientists in the early 1950s that we must go into space with our instrumentation in order to understand the dynamics of the Earth's upper atmosphere, its magnetic field, and related issues. Of course, as recounted in stories throughout the past two centuries, there was always the dream and expectation of someday entering space. But the basis for the strong technological buildup was the need of the scientists, as well as the development of rocket power for national defense. By that time both the United States and the USSR each had the capabilities to launch satellites. Thus, it was only a matter of time until the first satellite, *Sputnik*, was launched successfully by the USSR as part of the International Geophysical Year (IGY) program in science. The success of the USSR effort did not appear to depend on the latest sophisticated technologies. Indeed, while the invention of the transistor in the United States led to the rapid development of electronic technology (which was to become essential for the pursuit of science and exploration in space, and for much of the leadership of U.S. science in space), the Soviet achievement was mainly based on utilizing what was commonly available—what we would call everyday technology of that period. (I can personally verify this since I was invited in 1958 to visit the laboratories where the instrumentation had been built for *Sputnik* and where I could examine firsthand the backup instruments for a *Sputnik*-type spacecraft.) Clearly, in addition to its importance as a political factor, the need to enter space was driven by scientific necessity.

But what are some of the major achievements in space sciences and exploration that could only have come about from activity in space? Before direct entry, the only matter accessible for detailed analysis was mainly from meteorites carrying samples of the early solar system material, and from cosmic rays which are the high-energy nuclei of atoms produced by the nuclear processes associated with the birth and death of stars in the galaxy.

Let us compare our knowledge of specific questions before and after entry into space:

- *Before,* direct entry into space, major questions were open on the nature of the medium between the Sun and the Earth. Was the interplanetary medium, as some believed, virtually a vacuum and static with only occasional interruptions by streams or bursts of particles from the Sun? Or was the medium a dilute gas, perhaps neutral or perhaps partly ionized? It had been deduced that magnetic fields were in interplanetary space. Were these fields continuously present and, if so, how were they distributed through space?

  After, it was proved that there was a continuous flow of ionized gas from the Sun, what we today call the solar wind, rushing outward past the orbit of Earth to the outer boundaries of the solar system. This was one of the alternatives deduced by U.S. experiments and theories prior to 1957, later followed by direct measurements by the USSR and confirmed by U.S. space experiments. The plasma drags a magnetic field, represented by lines of force, outward from the Sun, but since the Sun rotates within an approximately 25-day period, the field lines appear in the form of Archimedes spirals whose pitch depends upon the local speed of the solar wind (see fig. 1).
- *Before,* it was assumed that the Earth's magnetic field extended into space, supporting an equatorial current whose changing characteristics were the source of magnetic storms on Earth, including auroral displays. The only high-energy particles accelerated by natural phenomena known were the cosmic rays, solar flare particles, and auroral particles.

  After, it was found that the Earth's field supported accelerated charged particles and trapped them to form the radiation belts discovered by James Van Allen and confirmed by the USSR.
- *Before,* the general view of the Earth's magnetic field extending into space was dominated by an analogy with an internal source such as a bar magnet (fig. 2), the so-called dipole field.

  After, the Earth's magnetic field was seen as a deformable magnetosphere confined by the solar plasma with the solar wind pressing against the field on the sunward side and dragging the field lines out behind to form a large magnetotail (fig. 3).
- *Before,* the generation of magnetic fields in planets was a controversial subject, and it still is. The radio emission from Jupiter detected from Earth in the 1950s could be explained in terms of a radiation

belt around Jupiter two or three times the "size" of the planet, but there was no knowledge concerning the magnetic fields of other planets.

After, Jupiter was found to possess a giant field, full of high-energy particles, extending beyond the solid planet in radius to at least 100 planetary radii (fig. 4). From the *Pioneer* encounter in 1979 and *Voyager* in 1980, Saturn also was found to have a giant magnetic field with characteristics intermediate between Jupiter and Earth. Mercury was a surprise, being found to have a magnetic field and energized particles where none were expected. Mars is still somewhat an enigma with a trivially small field and no evidence of particle acceleration. (The relative sizes of the magnetospheres of the planets is shown in fig. 5.)

- *Before*, the contending views regarding the origin of the Moon extended from assuming that it evolved from the accretion of cold material to assuming that it underwent a heating and mixing cycle similar to that on Earth.

  After, the first instruments on the Moon to determine the lunar chemical composition were on the U.S. Surveyor using alpha-particle scattering techniques. The composition showed that the Moon had undergone heating and differentiation (fig. 6) and that the lunar rock was like basalt on Earth. Man's arrival on the Moon was a major technical achievement of the 20th century and samples were brought back which through the radioactive isotopes established the age of the Moon to be about 4 billion years.
- *Before*, planetology based on Earth observations and theory led to conflicting views on Mars, its seasons, and surface features important for deciding on the presence of prehistoric water or cratering by meteorites, etc.

  After, the surface features revealed much of the early history of Mars and reduced greatly the probability that some form of life would be found on Mars unless it was prehistoric. The Mars missions stimulated new chemistries, and the dynamics of Mars's atmospheres and polar caps made it possible to understand the seasons on Mars. The Mars missions stimulated renewed experimental interest in defining biophysical definitions of life and life forms and how to test for them.
- *Before*, Mercury appeared only as a fuzzy tennis ball in the highest-powered telescopes.

  After, Mercury's surface is heavily cratered, showing that in the early

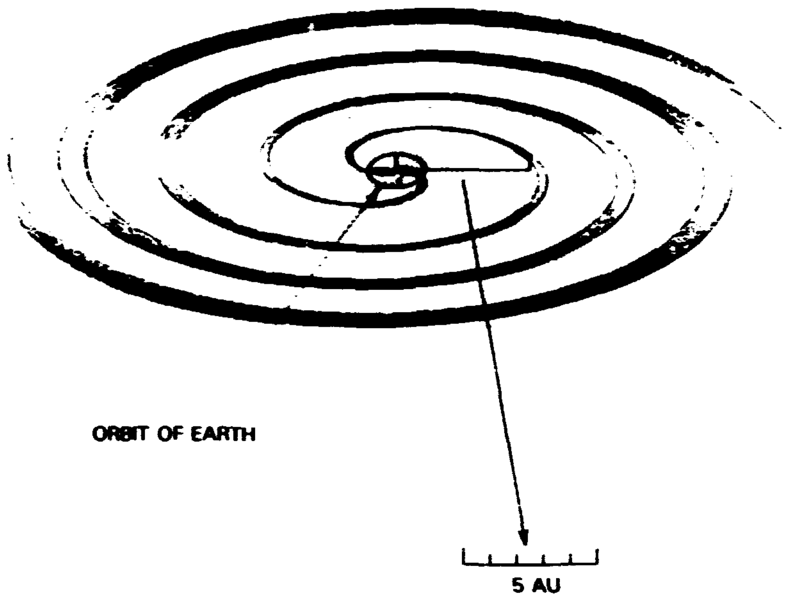


Figure 1. Idealized distribution of magnetic field lines of force in interplanetary space near the equatorial plane of the solar system. Magnetic field lines are carried out from the Sun by the solar wind. Spiral-like structure results from the Sun's rotation, which has a period of ~27 days. Concentrations of field lines rooted in solar active centers are regions which sweep past Earth each ~27 days to produce geomagnetic disturbances. (Note: 1 AU is 1 Astronomical Unit, which is the mean distance between Sun and Earth.)

phases of the development of the solar system meteorites were abundant in the inner portion of the solar system, opening a whole new field for planetologists.

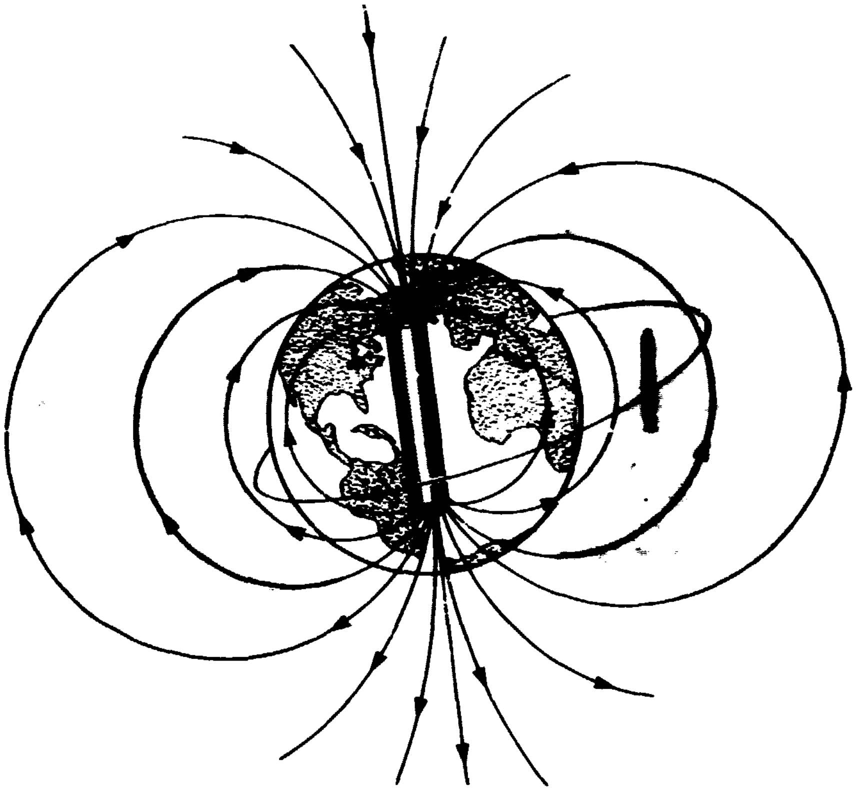
- *Before*, the moons of the outer planets were assumed to all have the same origin, although there were various models proposed for the origins of these moons.

  After, the Jupiter encounters were the first to reveal that the moons of a planet may be drastically different from each other, as are Callisto or Io. For Saturn the same diversity exists. For example, compare Titan versus Mimas.
- *Before*, Jupiter's atmosphere was an enigma of color bands with four or five spots.

  After, we have a startling view of a turbulent atmosphere whose dynamics are only beginning to be understood and which is leading to investigations that will revolutionize our knowledge of planetary atmospheres, including our own atmosphere.

- *Before*, the electromagnetic spectrum used for astronomical observations extended from the radio and infrared to the far ultraviolet. *After*, the useful spectrum was extended to the extreme ultraviolet on through to the x-ray emission from stars and recently to the gamma rays from nuclear processes in our galaxy. Space experiments and observations played an important, and many times crucial, role in the rapid advances in astronomy and astrophysics of the 1950s into the 1980s. They provided much evidence in support of the concept of neutron stars and, later, stars of even higher density—so dense that their gravitational fields prevented light from escaping, the so-called black holes, optically unobservable to an outside observer.

Figure 2. Before the 1950s, Earth's space environment was considered a near-vacuum; the extension of Earth's magnetic field would resemble the field of a simple bar magnet.



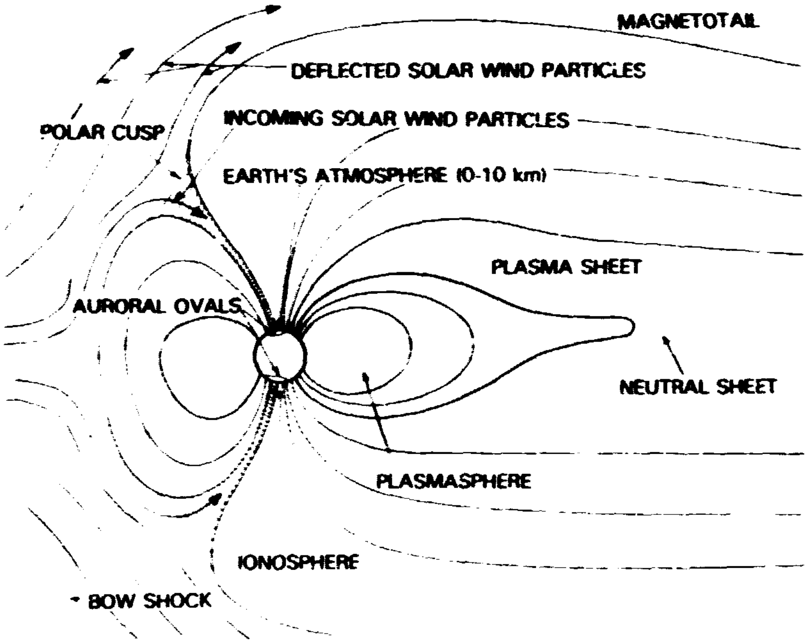


Figure 3. The current concept of geospace (shown here in a noon-midnight meridian plane view) involves a very complex system, and yet even the sophisticated picture is limited by the fact that it has been synthesized from a series of independent measurements collected at different times and places over the past two decades.

The most recent satellite for x-rays is the Einstein Observatory, expanding the regions of universe accessible to us by exploration in the light of the x-rays. These and other observations are providing the quantitative knowledge with which it will become possible to decide whether the universe is closed (and will eventually contract to a singularity), or whether the universe is destined to expand forever.

Even our Sun, viewed in the light of x-rays, reveals totally new aspects of the energetic processes occurring on the surface of the Sun—many of which have a profound impact on conditions on Earth. Furthermore, our view of Earth's atmospheric dynamics is decidedly modified by what has been learned from other planets. On the other hand, it is always difficult, and sometimes impossible, to decide whether or when new essential knowledge on a specific subject would have been acquired even if space vehicles did not exist. This is particularly true in some areas of astrophysics where the continuing development of balloons, high-altitude aircraft, and ground-based instruments are filling in new areas of the electromagnetic spectrum. An excellent example is ground-based observations of interstellar molecules.

But where do I stop with these examples? Much has been neglected and I must apologize for this sketchy overview.

There are three other novel, but qualitative, aspects of the entry into the space age which belong in our historical perspective.

First, teamwork and government support have combined to yield new approaches to experiments and explorations that are in some ways qualitatively different from the past efforts of a "loner" entrepreneur setting out for exploration. It is now necessary to have "programmed heroes." Only a few can carry out the experiments; only a few personally can enter space, and this rests on competitive processes occurring in advance of the event for the selection of scientists, engineers, or

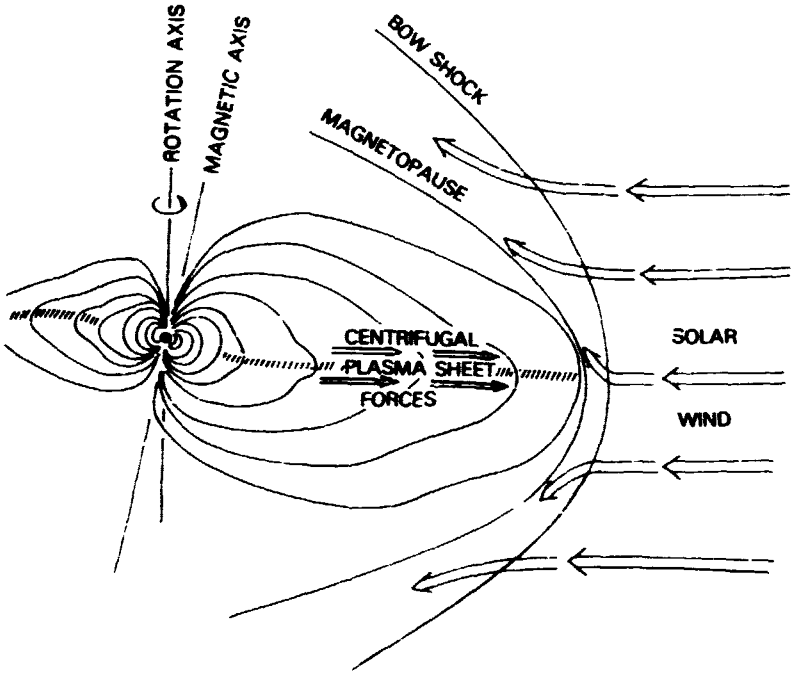


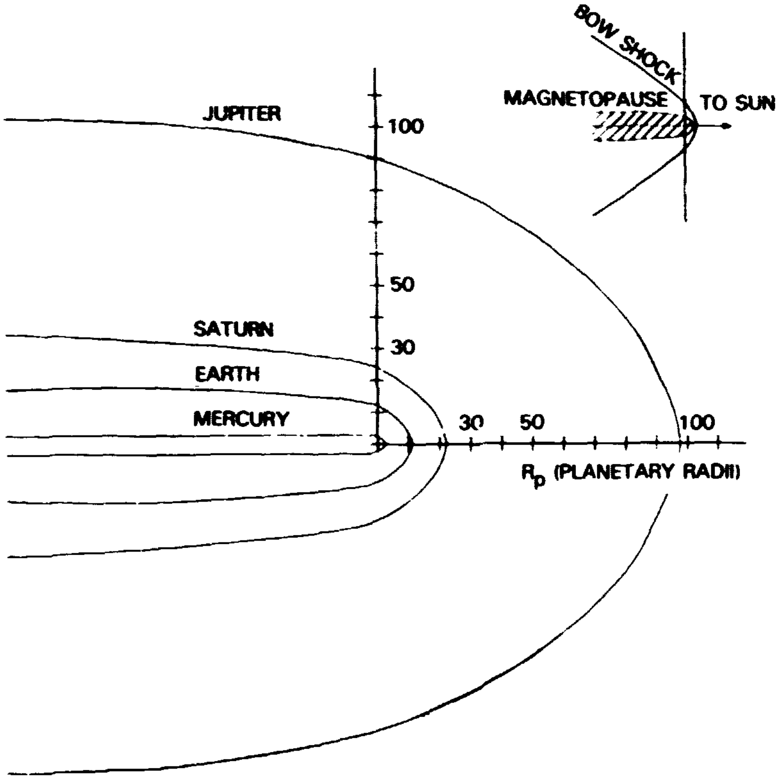
Figure 4. Cross-section sketch of Jupiter and its giant magnetosphere illustrating the fact discovered by *Pioneer 10* and *Pioneer 11* that the rotating magnetosphere is an enormous magnetoplasma "machine."

astronauts and their ideas. For the scientist this often means a commitment of a decade or more to obtain approval for a mission and to carry out an experiment.

Second, there has been and continues to be an extraordinary collaboration among nations for common objectives in space. As examples I could cite the Apollo-Soyuz or the European Space Agency (ESA)—National Aeronautics and Space Administration (NASA) International Solar Polar Mission intended to carry spacecraft over the poles of the solar system in the late 1980s—man's first excursion far away from the solar equatorial plane (fig. 7).

Perhaps the most significant cooperation, however, is the effort to establish worldwide treaties for space. An outstanding legacy of the IGY was the Antarctic Treaty for the scientific exploration of the continent. Hopefully, a legacy of our entry into space will be effective

Figure 5. The relative size of the magnetospheres of the planets is illustrated in cross-section by assuming that each planet located at the center of the drawing has the same radius.



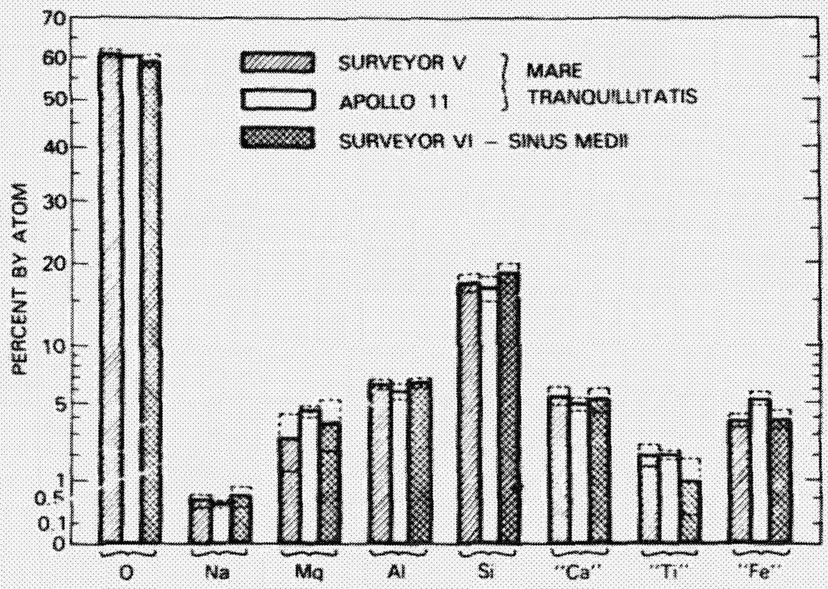


Figure 6. The *Surveyor* spacecraft carrying a University of Chicago experiment weighing ~5 kilograms was first to determine the principal constituents on the Moon which are in close agreement with the later Apollo samples returned to Earth for chemical analysis.

treaties for use and travel in space. The most recent example is the United Nations Moon Treaty (app. C), which is now under review by all nations.

Third, for the first time it has been possible for substantial fractions of the world's population to join the scientists and astronauts in their moments of discovery and exploration, to share in the excitement and wonderment of those moments. This fact, and the pictures of Earth from space, appear to have had an impact on the outlook of millions regarding their place in the universe—a humbling and significant experience for the development of man's concept of himself.

As the most recent example of the participation of the world in discovery, a policy of NASA and the United States, let me cite the encounters of the *Voyager* spacecraft with Saturn which have revealed the fabulous structure of Saturn's rings and atmosphere. These and many more high resolution views were shown on television to the entire world nearly in real time so people throughout the world could participate in the excitement and discovery along with scientists.

For the science and exploration which had been planned in the 1960s and 1970s, we are still succeeding in executing those plans

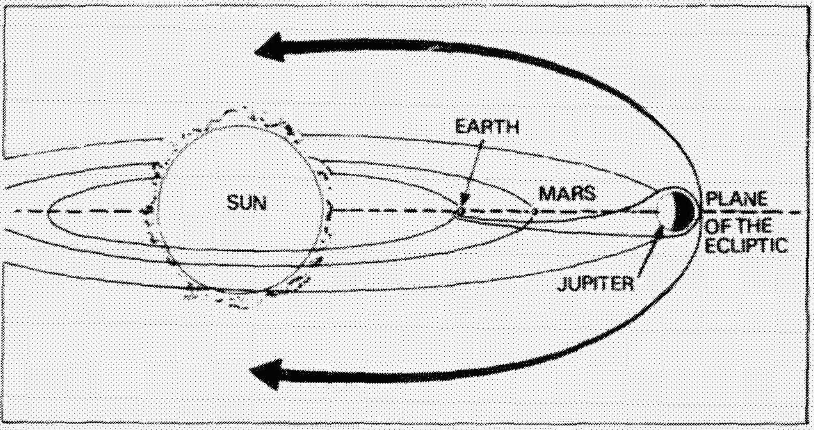


Figure 7. For the first time investigators will be able to send instruments far out of the equatorial plane to obtain three-dimensional studies of phenomena at the Sun, and in interplanetary and interstellar space. The mass of Jupiter will be used as a "slingshot" to enable the spacecraft to travel over the poles of the Sun. (Since this illustration was prepared, the United States has cancelled its spacecraft and only the European spacecraft will be launched in 1986 to be over the poles in ~1989.)

remarkably well. For example, the first generation of space probes (*Pioneer 10* and *11*) are now on their way out of the solar system and may continue to transmit their data to at least 1989–1990 (fig. 8). These probes prove that the United States is invading the solar system. Second-generation *Voyager* spacecraft have now, with sophisticated instruments, followed in the footsteps of *Pioneer 10* and *Pioneer 11*.

The remarkable advances of the USSR—particularly in the areas of early Venus exploration—returned samples from the Moon, and the development of early forms of orbital space stations. Europe, primarily through ESA (app. A-3) is putting its effort heavily on experiments, leaving mainly to the U.S., and soon also to France, the required launch capabilities. Several outstanding examples of European scientific effort include the COS-B, GEO-1, etc. Six other nations are now part of the "club."

Will history show that the United States is now "playing out" the last phases of its leadership in space exploration? It is not at all evident that having taken this lead in space sciences and exploration we in the U.S. will keep it. Even at this stage in our history, there is evidence of uncertainty of commitment by the United States in the face of continued dedication by Europe and the USSR for sustaining a high level

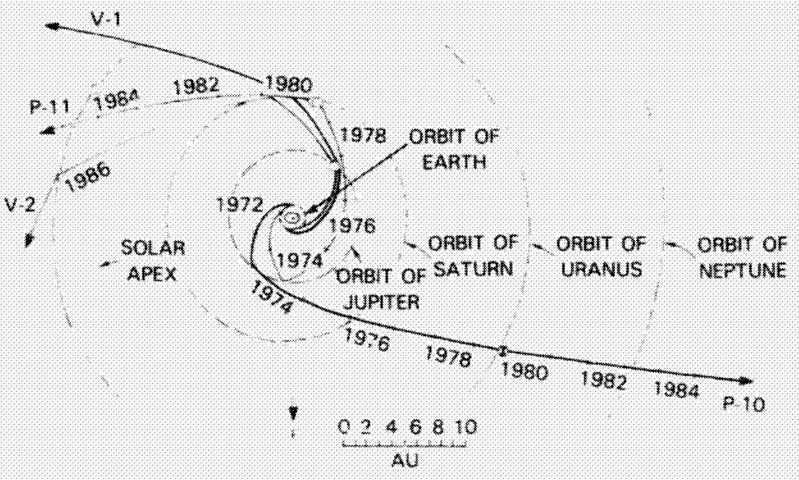


Figure 8. Trajectories of U.S. deep space probes *Pioneer 10* (P-10); *Pioneer 11* (P-11); *Voyager I* (V-1); and *Voyager 2* (V-2). *Pioneer 10* will transmit data until at least 1990 when it will be beyond the orbits of the planets.

of activity in space. A recent example is the failure of the U.S. to prepare a mission to meet the Halley Comet challenge. There are all too many analogies drawn from history. For example, compare the Spanish explorers and their decline in importance on the seas in the face of Great Britain's major technologies for navigation and naval architecture—a technology on display in Greenwich—which must have played a major role in Britain's dominance of the seas and exploration for centuries.

If nuclear war can be prevented, it appears that we will enter the 21st century greatly troubled over sources of energy, with approximately 80% of the world's population poor, and with dangers of conflict among nations ever present. The many applications derived from space science and exploration and the application of space vehicles to assist in world problems will be crucial in linking the nations of the world.

Finally, it may turn out that the most significant aspect of the entry into space of mankind and his instruments is a new perception people have of their place in the universe, the value of the Earth, and the coming to terms with those factors which could destroy civilization as we know it. This judgment must be left to the historians of the 21st century.

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Appendix A-1. U.S. Spacecraft Record*

(Includes spacecraft from cooperating countries launched by U.S. launch vehicles.)

Year	Earth Orbit[a]		Earth Escape[b]	
	Success	Failure	Success	Failure
1957	0	1	0	0
1958	5	8	0	4
1959	9	9	1	2
1960	16	12	1	2
1961	35	12	0	2
1962	55	12	4	1
1963	62	11	0	0
1964	69	8	4	0
1965	93	7	4	1
1966	94	12	7	1[b]
1967	78	4	10	0
1968	61	15	3	0
1969	58	1	8	1
1970	36	1	3	0
1971	45	2	8	1
1972	33	2	8	0
1973	23	2	3	0
1974	27	2	1	0
1975	30	4	4	0
1976	33	0	1	0
1977	27	2	2	0
1978	34	2	7	0
1979	18	0	0	0
1980	13	4	0	0
Total	954	133	79	15

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[a] The criterion of success or failure used is attainment of Earth orbit or Earth escape rather than judgment of mission success. "Escape" flights include all that were intended to go to at least an altitude equal to lunar distance from the Earth.

[b] This Earth-escape failure did attain Earth orbit and therefore is included in the Earth-orbit success totals.

*From the *Aeronautics and Space Report of the President: 1980 Activities*, Annual Report of the President to Congress (Washington: NASA, 1981).

Appendix A-2. World Record of Space Launchings Successful in Attaining Earth Orbit or Beyond*

(Enumerates launchings rather than spacecraft; some launches orbited multiple spacecraft.)

Year	United States	USSR	France	Italy	Japan	People's Republic of China	Australia	United Kingdom	European Space Agency	India
1957		2								
1958	5	1								
1959	10	3								
1960	16	3								
1961	29	6								
1962	52	20								
1963	38	17								
1964	57	30								
1965	63	48	1							
1966	73	44	1							
1967	57	66	2	1			1			
1968	45	74								
1969	40	70								
1970	28	81	2	1[a]	1	1				
1971	30	83	1	2[a]	2	1		1		
1972	30	74		1	1					
1973	23	86								
1974	22	81		2[a]	1					
1975	27	89	3	1	2	3				
1976	26	99			1	2				
1977	24	98			2					
1978	32	88			3	1				
1979	16	87			2				1	
1980	13	89			2					1
Total	756	1339	10	8	17	8	1	1	1	1

[a] *Includes foreign launchings of U.S. spacecraft.*

*From the *Aeronautics and Space Report of the President* (1980), Annual Report of the President to Congress (Washington: NASA, 1981)

Appendix A-3. ESA/ESRO Scientific Spacecraft Launched

	Launch Date	End of Useful Life	Mission
ESRO-II	May 17, 1968	May 9, 1971	Cosmic rays, solar x-rays
ESRO-IA	October 3, 1968	June 26, 1970	Auroral and polar cap phenomena, ionosphere
HEOS-1	December 5, 1968	October 28, 1975	Interplanetary medium, bow shock
ESRO-1B	October 1, 1969	November 23, 1969	As ESRO-IA
HEOS-2	January 31, 1972	August 2, 1974	Polar magnetosphere, interplanetary medium
TD-1	March 12, 1972	May 4, 1974	Astronomy (UV,x-, and gamma-ray)
ESRO-IV	November 22, 1972	April 15, 1974	Neutral atmosphere, ionosphere, auroral particles
COS-B	August 9, 1975		Gamma-ray astronomy
GEOS-1	April 20, 1977	June 23, 1978	Dynamics of the magnetosphere
ISEE-2	October 22, 1977		Sun/Earth relations and magnetosphere
IUE	January 26, 1978		Ultraviolet astronomy
GEOS-2	July 14, 1978		Magnetospheric fields, waves, and particles

Appendix B. History of U.S. and Soviet Manned Space Flights*

Spacecraft	Launch Date	Crew	Flight Time	Highlights
Vostok 1	Apr. 12, 1961	Yuri A. Gagarin	1 h 48 min	First manned flight.
Mercury-Redstone 3	May 5, 1961	Alan B. Shepard, Jr.	15 min	First U.S. flight; suborbital.
Mercury-Redstone 4	July 21, 1961	Virgil I. Grissom	16 min	Suborbital; capsule sank after landing.
Vostok 2	Aug. 6, 1961	Gherman E. Titov	25 h 18 min	First flight exceeding 24 h.
Mercury-Atlas 6	Feb. 20, 1962	John H. Glenn, Jr.	4 hr 55 min	First American to orbit.
Mercury-Atlas 7	May 24, 1962	M. Scott Carpenter	4 h 56 min	Landed 400 km beyond target.
Vostok 3	Aug. 11, 1962	Andrian G. Nikolayev	94 h 22 min	First dual mission (with Vostok 4).
Vostok 4	Aug. 12, 1962	Pavel R. Popovich	70 h 57 min	Came within 6 km of Vostok 3.
Mercury-Atlas 8	Oct. 3, 1962	Walter M. Schirra, Jr.	9 h 13 min	Landed 8 km from target.
Mercury-Atlas 9	May 15, 1963	L. Gordon Cooper, Jr.	34 h 20 min	First U.S. flight exceeding 24 h.
Vostok 5	June 14, 1963	Valeriy F. Bykovskiy	119 h 6 min	Second dual mission (with Vostok 6).
Vostok 6	June 16, 1963	Valentina V. Tereshkova	70 h 50 min	First woman in space: within 5 km of Vostok 5.
Voskhod 1	Oct. 12, 1964	Vladimir M. Komarov Konstantin P. Feoktistov Dr. Boris G. Yegorov	24 h 17 min	First 3-man crew.
Voskhod 2	Mar. 18, 1965	Aleksey A. Leonov Pavel I. Belyayev	26 h 2 min	First extravehicular activity (Leonov, 10 min).
Gemini 3	Mar. 23, 1965	Virgil I. Grissom	4 h 53 min	First U.S. 2-man flight; first manual

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*From the ***Aeronautics and Space Report of the President*** (1980), Annual Report of the President to Congress (Washington: NASA, 1981).

Appendix B. (Continued)

Spacecraft	Launch Date	Crew	Flight Time	Highlights
Gemini 4	June 3, 1965	James A. McDivitt Edward H. White, II	97 h 56 min	maneuvers in orbit. 21-min extravehicular activity (White).
Gemini 5	Aug. 21, 1965	L. Gordon Cooper, Jr. Charles Conrad, Jr.	190 h 55 min	Longest-duration manned flight to date.
Gemini 7	Dec. 4, 1965	Frank Borman James A. Lovell, Jr.	330 h 35 min	Longest-duration manned flight to date.
Gemini 6-A	Dec. 15, 1965	Walter M. Schirra, Jr. Thomas P. Stafford	25 h 51 min	Rendezvous within 30 cm of Gemini 7.
Gemini 8	Mar. 16, 1966	Neil A. Armstrong David R. Scott	10 h 41 min	First docking of 2 orbiting spacecraft (Gemini 8 with Agena target rocket).
Gemini 9-A	June 3, 1966	Thomas P. Stafford	72 h 21 min	Extravehicular activity; rendezvous.
Gemini 10	July 18, 1966	John W. Young Michael Collins	70 h 47 min	First dual rendezvous (Gemini 10 with Agena 10, then Agena 8).
Gemini 11	Sept. 12, 1966	Charles Conrad, Jr. Richard F. Gordon, Jr.	71 h 17 min	First initial-orbit docking; first tethered flight; highest Earth-orbit altitude (1,372 km).
Gemini 12	Nov. 11, 1966	James A. Lovell, Jr. Edwin E. Aldrin, Jr.	94 h 35 min	Longest extravehicular activity to date (Aldrin, 5 h 37 min).
Soyuz 1	Apr. 23, 1967	Vladimir M. Komarov	26 hr 37 min	Cosmonaut killed in reentry accident.
Apollo 7	Oct. 11, 1968	Walter M. Schirra, Jr. Donn F. Eisele R. Walter Cunningham	260 h 9 min	First U.S. 3-man mission.

Appendix B. (Continued)

Spacecraft	Launch Date	Crew	Flight Time	Highlights
Soyuz 3	Oct. 26, 1968	Georgiy Beregovoy	94 h 51 min	Maneuvered near unmanned Soyuz 2.
Apollo 8	Dec. 21, 1968	Frank Borman James A. Lovell, Jr. William A. Anders	147 h 1 min	First manned orbit(s) of Moon; first manned departure from Earth's sphere of influence; highest speed ever attained in manned flight.
Soyuz 4	Jan. 14, 1969	Vladimir Shatzlov	71 h 23 min	Soyuz 4 and 5 docked and transferred 2 cosmonauts from Soyuz 5 to Soyuz 4.
Soyuz 5	Jan. 15, 1969	Boris Volynov Aleksey Yeliseyev Yevgeniy Khrunov	72 h 56 min	
Apollo 9	Mar. 3, 1969	James A. McDivitt David R. Scott Russell L. Schweickart	241 h 1 min	Successfully simulated in Earth orbit operation of lunar module to landing and take-off from lunar surface and rejoining with command module.
Apollo 10	May 18, 1969	Thomas P. Stafford John W. Young Eugene A. Cernan	192 h 3 min	Successfully demonstrated complete system including lunar module descent to 14,300 m from the lunar surface.
Apollo 11	July 16, 1969	Neil A. Armstrong Michael Collins Edwin E. Aldrin, Jr.	195 h 9 min	First manned landing on lunar surface and safe return to Earth. First return of rock and soil samples to Earth, and manned

Appendix B. (Continued)

Spacecraft	Launch Date	Crew	Flight Time	Highlights
				deployment of experiments on lunar surface.
Soyuz 6	Oct. 11, 1969	Georgiy Shonin Valeriy Kubasov	118 h 42 min	Soyuz 6, 7, and 8 operated as a group flight without actually docking. Each conducted certain experiments, including welding and earth and celestial observation.
Soyuz 7	Oct. 12, 1969	Anatoliy Filipchenko Vladislav Volkov Viktor Gorbatko	118 h 41 min	
Soyuz 8	Oct. 13, 1969	Vladimir Shatalov Aleksey Yeliseyev	118 h 50 min	
Apollo 12	Nov. 14, 1969	Charles Conrad, Jr. Richard F. Gordon, Jr. Alan L. Bean	244 h 36 min	Second manned lunar landing. Continued manned exploration and retrieved parts of Surveyor III spacecraft which landed in Ocean of Storms on Apr. 19, 1967.
Apollo 13	Apr. 11, 1970	James A. Lovell, Jr. Fred W. Haise, Jr. John L. Swigert, Jr.	142 h 55 min	Mission aborted due to explosion in the service module. Ship circled Moon, with crew using LEM as "lifeboat" until just prior to reentry.
Soyuz 9	June 1, 1970	Andrian G. Nikolayev Vitaliy I. Sevastianov	424 h 59 min	Longest manned spaceflight to date, lasting 17 days 16h 59 min.
Apollo 14	Jan. 31, 1971	Alan B. Shephard Jr. Stuart A. Roosa Edgar D. Mitchell	216 h 2 min	Third manned lunar landing. Mission demonstrated pinpoint landing capability and continued manned exploration.
Soyuz 10	Apr. 22, 1971	Vladimir Shatalov	47 h 48 min	Docked with Salyut 1, but crew did not

Appendix B. (Continued)

Spacecraft	Launch Date	Crew	Flight Time	Highlights
		Aleksey Yeliseyev Nikolai Rukavishnikov		board space station launched Apr. 19. Crew recovered Apr. 24, 1971.
Soyuz 11	June 6, 1971	Georgiy Timofreyevich Dobrovolskiy Vladislav Nikolayevich Volkov Viktor Ivanovich Patsayev	570 h 22 min	Docked with Salyut 1 and Soyuz 11 crew occupied space station for 22 days. Crew perished during final phase of Soyut 11 capsule recovery on June 30, 1971.
Apollo 15	July 26, 1971	David R. Scott Alfred M. Worden James Bensen Irwin	295 h 12 min	Fourth manned lunar landing and first Apollo "J" series mission which carry the Lunar Roving Vehicle. Worden's in-flight EVA of 38 min 12 s was performed during return trip.
Apollo 16	Apr. 16, 1972	John W. Young Charles M. Duke, Jr. Thomas K. Mattingly, II	265 h 51 min	Fifth manned lunar landing, with Lunar Roving Vehicle.
Apollo 17	Dec. 7, 1972	Eugene A. Cernan Harrison H. Schmitt Ronald E. Evans	301 h 52 min	Sixth and final Apollo manned lunar landing, again with roving vehicle.
Skylab 2	May 25, 1973	Charles Conrad, Jr. Joseph P. Kerwin	627 h 50 min	Docked with Skylab 1 for 28 days. Repaired damaged station.

Appendix B. (Continued)

Spacecraft	Launch Date	Crew	Flight Time	Highlights
		Paul J. Weitz		
Skylab 3	July 28, 1973	Alan L. Bean Jack R. Lousma Owen K. Garriott	1427 h 9 min	Docked with Skylab 1 for over 59 days.
Soyuz 12	Sept. 27, 1973	Vasiliy Lazarev Oleg Makarov	47 h 16 min	Checkout of improved Soyuz.
Skylab 4	Nov. 16, 1973	Gerald P. Carr Edward G. Gibson William R. Pogue	2017 h 16 min	Docked with Skylab 1 in long-duration mission; last of Skylab program.
Soyuz 13	Dec. 18, 1973	Petr Klimuk Valentin Lebedev	188 h 55 min	Astrophysical, biological, and Earth resources experiments.
Soyuz 14	July 3, 1974	Pavel Popovich Yuriy Artyukhin	377 h 30 min	Docked with Salyut 3 and Soyuz 14 crew occupied space station for over 14 days.
Soyuz 15	Aug. 26, 1974	Gennadiy Sarafanov Lev Demin	48 h 12 min	Rendezvoused but did not dock with Salyut 3.
Soyuz 16	Dec. 2, 1974	Anatoliy Filipchenko Nikolai Rukavishnikov	142 h 24 min	Test of ASTP configuration.
Soyuz 17	Jan. 10, 1975	Aleksey Gubarev Georgiy Grechko	709 h 20 min	Docked with Salyut 4 and occupied station during a 29-day flight.
Anomaly	Apr. 5, 1975	Vasiley Lazarev Oleg Makarov	20 min	Soyuz stages failed to separate; crew recovered after abort.

Appendix B. (Continued)

Spacecraft	Launch Date	Crew	Flight Time	Highlights
Soyuz 18	May 24, 1975	Petr Klimuk Vitaliy Sevastiyanov	1,511 h 20 min	Docked with Salyut 4 and occupied station during a 63-day mission.
Soyuz 19	July 15, 1975	Aleksey Leonov Valeriy Kubasov	142 h 31 min	Target for Apollo in docking and joint experiments ASTP mission.
Apollo	July 15, 1975	Thomas P. Stafford Donald K. Slayton Vance D. Brand	217 h 28 min	Docked with Soyuz 19 in joint experiments of ASTP mission.
Soyuz 21	July 6, 1976	Boris Volynov Vitaliy Zholobov	1,182 h 24 min	Docked with Salyut 5 and occupied station during 49-day flight.
Soyuz 22	Sept. 15, 1976	Valeriy Bykovskiy Vladimir Aksenov	189 h 54 min	Earth resources study with multispectral camera system.
Soyuz 23	Oct. 14, 1976	Vyacheslav Zudov Valeriy Rozhdestvenskiy	48 h 6 min	Failed to dock with Salyut 5.
Soyuz 24	Feb. 7, 1977	Viktor Gorbatko Yuriy Glazkov	425 h 23 min	Docked with Salyut 5 and occupied station during 18-day flight.
Soyuz 25	Oct. 9, 1977	Vladimir Kovalenok Valeriy Ryumin	48 h 46 min	Failed to achieve hard dock with Salyut 6 station.
Soyuz 26	Dec. 10, 1977	Yuriy V. Romanenko Georgiy M. Grechko	898 h 6 min	Docked with Salyut 6. Crew returned in Soyuz 27; crew duration 2,314 h.
Soyuz 27	Jan. 10, 1978	Vladimir A. Dzhanibekov Oleg G. Makarov	1558 h 53 min	Docked with Salyut 6. Crew returned in Soyuz 26; crew duration 142 h 59 min.

Appendix B. (Continued)

Spacecraft	Launch Date	Crew	Flight Time	Highlights
Soyuz 28	Mar. 2, 1978	Aleksey A. Gubarev Vladimir Remek	190 h 17 min	Docked with Salyut 6. Remek was first Czech cosmonaut to orbit.
Soyuz 29	June 15, 1978	Vladimir V. Kovalenok Aleksandr S. Ivanchenkov	1,911 h 23 min	Docked with Salyut 6. Crew returned in Soyuz 31; crew duration 3,350 h 48 min.
Soyuz 30	June 27, 1978	Petr I. Klimuk Miroslaw Hermaszrewski	190 h 4 min	Docked with Salyut 6. Hermaszewski was first Polish cosmonaut to orbit.
Soyuz 31	Aug. 26, 1978	Valeriy F. Bykovskiy Sigmund Jaehn	1,628 h 14 min	Docked with Salyut 6. Crew returned in Soyuz 29; crew duration 188 h 49 min. Jaehn was first German Democratic Republic cosmonaut to orbit.
Soyuz 32	Feb. 25, 1979	Vladimir A. Lyakhov Valeriy V. Ryumin	2,596 h 24 min	Docked with Salyut 6. Crew returned in Soyuz 34; crew duration 4200 h 36 min, or 175 days.
Soyuz 33	Apr. 10, 1979	Nikolay N. Rukavishnikov Georgi I. Ivanov	47 h 1 min	Failed to achieve docking with Salyut 6 station. Ivanov was first Bulgarian cosmonaut to orbit.
Soyuz 34	June 6, 1979	(unmanned at launch)	1,770 h 17 min	Docked with Salyut 6, later served as ferry for Soyuz 32 crew while Soyuz 32 returned unmanned.
Soyuz 35	Apr. 9, 1980	Leonid I. Popov Valeriy V. Ryumin	1,321 h 29 min	Docked with Salyut 6. Crew returned in Soyuz 37; crew duration 4,436 h 12 min.

Appendix B. (Continued)

Spacecraft	Launch Date	Crew	Flight Time	Highlights
Soyuz 36	May 26, 1980	Valeriy N. Kubasov Bertalan Farkas	1,580 h 54 min	Docked with Salyut 6. Crew returned in Soyuz 35; crew duration 188 h 46 min. Farkas was first Hungarian to orbit.
Soyuz T-2	June 5, 1980	Yuriy V. Malyshev Vladimir V. Aksenov	94 h 21 min	Docked with Salyut 6. First manned flight of new generation ferry.
Soyuz 37	July 23, 1980	Viktor V. Gorbatko Pham Tuan	1,911 h 17 min	Docked with Salyut 6. Crew returned in Soyuz 36; crew duration 188 h 42 min. Pham was first Vietnamese to orbit.
Soyuz 38	Sept. 18, 1980	Yuriy V. Romanenko Arnaldo Tamayo Mendez	188 h 43 min	Docked with Salyut 6. Tamayo was first Cuban to orbit.
Soyuz T-3	Nov. 27, 1980	Leonid D. Kizim Oleg G. Makarov Gennadiy M. Strekalov	307 h 8 min	Docked with Salyut 6. First 3-man flight in Soviet program since 1971.

Appendix C. The United Nations Moon Treaty

The Moon Treaty has been under discussion since late 1971 when the General Assembly adopted resolution 2779, in which it took note of a draft treaty submitted by the USSR and requested the Committee on the Peaceful Uses of Outer Space (COPUOS) and its legal Subcommittee (LSC) to consider the question of the elaboration of a draft international treaty concerning the Moon on a priority basis.

The draft Moon Treaty is based to a considerable extent on the 1967 Outer Space Treaty. Indeed, the discussion in the Outer Space Committee confirmed the understanding that the Moon Treaty in no way derogates from or limits the provisions of the 1967 Outer Space Treaty.

The draft Moon Treaty also is, in its own right, a meaningful advance in the codification of international law dealing with outer space, containing obligations of both immediate and long-term application to such matters as the safeguarding of human life on celestial bodies, the promotion of scientific investigation and the exchange of information relative to and derived from activities on celestial bodies, and the enhancement of opportunities and conditions for evaluation, research, and exploitation of the natural resources of celestial bodies.

The General Assembly, by consensus, opened the treaty for signature on December 5, 1979.

This appendix presents the text of the draft treaty in the left column on each page; in the right column, opposite the appropriate sections of the text, are some comments by the Department of State on the attitude of the United States regarding particular provisions.

Treaty Text	Commentary by Department of State
Draft agreement governing the activities of States on the moon and other celestial bodies. *The States Parties to this Agreement,* *Noting* the achievements of States in the exploration and use of the moon and other celestial bodies, *Recognizing* that the moon, as a natural satellite of the earth, has an important role to play in the exploration of outer space, *Determined* to promote on the basis of equality the further development of co-operation among States in the exploration and use of the moon and other celestial bodies, *Desiring* to prevent the moon from becoming an area of international conflict, *Bearing in mind* the benefits which may be derived from the exploitation of the natural resources of the moon and other celestial bodies, *Recalling* the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, the Convention on International Liability for Damage Caused by Space Objects, and the Convention on Registration of Objects Launched into Outer Space. *Taking into account* the need to define and develop the provisions of these international instruments in relation to the moon and other celestial bodies, having regard to further progress in the exploration and use of outer space, *Have agreed* on the following:	
Article 1 1. The provisions of this Agreement relating to the moon shall also apply to other celestial bodies within the solar system, other than the earth, except in so far as specific legal norms enter into force with respect to any of these celestial bodies. 2. For the purposes of this Agreement reference to the moon shall include orbits around or other trajectories to or around it. 3. This Agreement does not apply to extraterrestrial materials which reach the surface of the earth by natural means.	There has been considerable discussion of Article 1 of the draft treaty. The United States accepts the Outer Space Committee's conclusions as to this article—namely, first, that references to the moon are intended also to the references to other celestial bodies within our solar system other than the earth; secondly, that references to the moon's natural resources are intended to comprehend those natural resources to be found on these celestial bodies; and, thirdly that the trajectories and orbits referred to in Article 1, paragraph 2, do not include trajectories and orbits of space objects between the earth and earth orbit or in earth orbit only. In regard to the phrase "earth orbit only", the fact that a space object in earth orbit also is in orbit around the sun does not bring space objects which are only in earth orbit within the scope of this treaty.

Treaty Text	**Commentary by Department of State**
Article II All activities on the moon, including its exploration and use, shall be carried out in accordance with international law, in particular the Charter of the United Nations, and taking into account the Declaration on Principles of International Law concerning Friendly Relations and Cooperation among States in accordance with the Charter of the United Nations, adopted by the General Assembly on 24 October 1970, in the interest of maintaining international peace and security and promoting international co-operation and mutual understanding, and with due regard to the corresponding interests of all other States Parties.	Article II reaffirms the application of the Charter of the United Nations and of international law to outer space. While the Charter predates man's entry into space, its principles and provisions, including those relating to the permissible and impermissible uses of force, are as valid for outer space as they are for our seas, land, or air. The United States welcomes the international community's reaffirmation in the Moon Treaty of this essential point.
Article III 1. The moon shall be used by all States Parties exclusively for peaceful purposes. 2. Any threat or use of force or any other hostile act on the moon is prohibited. It is likewise prohibited to use the moon in order to commit any such act or to engage in any such threat in relation to the earth, the moon, spacecraft, the personnel of spacecraft or manmade objects.	Article III contains a statement of the principle that the celestial bodies and those orbits around them and to them are only to be used for peaceful—i.e., nonaggressive—purposes. Paragraph 2 of Article III spells out in some detail some of the consequences to be drawn from Article II. Specifically, paragraph 2's purpose is to make clear that it is forbidden for a party to the Moon Treaty to engage in any threat or use of force on the moon or in other circumstances set forth in paragraph 2 if such acts would constitute a violation of the party's international obligations in regard to the threat or use of force.
3. States Parties shall not place in orbit around or other trajectory to or around the moon objects carrying nuclear weapons or any other kinds of weapons of mass destruction or place or use such weapons on or in the moon. 4. The establishment of military bases, installations and fortifications, the testing of any type of weapons and the conduct of military manoeuvres on the moon shall be forbidden. The use of military personnel for scientific research or for any other peaceful purposes shall not be prohibited. The use of any equipment or facility necessary for peaceful exploration and use of the moon shall also not be prohibited.	
Article IV 1. The exploration and use of the moon shall be the province of all mankind and shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development. Due regard shall be paid to the interest of present and future generations as well as to the need to promote higher standards of living conditions of economic and social progress and development in accordance with the Charter of the United Nations.	