EXPLORATIONS IN SPACE: ASTRONOMY IN THE SPACE AGE

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Summary

The classic instrument of the astronomer since the 16th and 17th centuries has been the optical telescope. Together with the spectroscope, the radio telescope and other instruments on the ground, this powerful tool has given later astronomers a good insight into the fantastic universe around us – and will continue to do so through technical improvements such as larger, better mirrors and adaptive optics. A new window to the universe was opened with the launching of Sputnik 1, the first artificial satellite, on October 4, 1957. In the Space Age we could place optical telescopes and other tools in orbit around the Earth, send instruments to other celestial bodies and put manned spacecraft on the surface of the Moon. Above the Earth's atmosphere it is possible to see further out with greater detail and study the universe in all wavelengths of the electromagnetic spectrum. And the space probes will, like a stretched hand, put instruments close to or in direct contact with the planets, moons, asteroids and comets of our solar system. This is a revolution, and it is only starting. The purpose of this

chapter to give a coarse outline of what the Space Age has contributed to astronomy through unmanned and manned spacecraft so far. Astronomical benefits through the use of scientific satellites and space observatories in low Earth orbits are not included.

1. The First Satellites

The Space Age did not "just happen". Unexpected to most people around the world, the October 4, 1957 launch of the Soviet Sputnik 1, the first artificial satellite, was the result of circumstances such as the missile race, the brilliant Soviet engineer Sergey P. Korolyov and the ICSU (International Council of Scientific Union) 1952 initiative on IGY (The International Geophysical Year).

The missile race appeared as an intense rivalry between the United States and the Soviet Union to develop military rockets with enough payload capability to carry nuclear payloads, even thermonuclear warheads, over so-called intercontinental ranges.

Figure 1. With Sputnik 1, launched on October 4, 1957, the Soviet Union initiated the Space Age. (NASA)

The two superpowers started work on the basis of the German V-2 ballistic missile, which was designed by a group of scientists under the leadership of Dr. Wernher von Braun and used against Antwerp and London from September 1944. Both the USA and the USSR captured a lot of V-2 parts and equipment in Germany at the end of World War II, but USA gained an added advantage with the surrender of Dr. Wernher von Braun and 117 of his foremost scientists and engineers in May 1945.

Sergey P. Korolyov (1906-1966) was an aeronautical engineer with a special interest in rocket propulsion and space flight. This interest cost him seven years as a badly treated Stalin prisoner, but when freed in June 1944 he resumed work on rocket propulsion for military purposes. In the fall of 1945 he was appointed as a colonel in the Red Army and sent to Germany with the specific task of obtaining more V-2 related equipment and information.

Korolyov had to wait until Stalin's death in 1953 to be fully rehabilitated, but was shortly after given the responsibility for the development of the Soviet long range missile, the R-7, nicknamed Semyorka.

Korolyov and his OKB-1 design bureau knew that the R-7 would develop enough thrust to place a simple satellite in a low Earth orbit, but was told that no R-7 would be available before it had demonstrated its ability to carry a two ton nuclear warhead in a ballistic orbit with a range of 7000 km. After three unsuccessful tests in the period May-July 1957, the R-7 achieved an almost full ballistic range capability in August 1957.

The ICSU 1952 IGY initiative specified the need for geophysical data collected from the ground, from airplanes and from balloons. In October 1954 the Council adopted a resolution promoting the use of satellites to map the surface of the Earth.

On July 29, 1955 the Eisenhower administration announced that the USA intended to launch small satellites as part of the IGY contribution. Three days later the Soviet Union also declared satellite plans. This and later reports from the superpower in the east were registered by the media, but rarely made headlines. A race to be the first nation to launch a satellite was on, but in the mind of almost everybody the winner would be USA, the technologically most advanced nation in the world.

The IGY was stated to last from July 1, 1957 to December 31, 1958, and there are indications that Korolyov had in mind to launch Sputnik 1 on September 17, 1957, the 100th anniversary of the birth of the Russian space pioneer Konstantin E. Tsiolkovky. The time available for preparations was too short, however, and the satellite was not orbited until October 4, 1957.

The launch came as a big surprise to most people, and was a media sensation where newspapers and radio commentators gave factual information and expressed admiration. In the US some editorials and politicians also reflected disappointment and even fear. Disappointment because it was expected that the Americans would take the lead in this high-technology endeavor, fear because the Soviets had demonstrated a powerful rocket with long-range capabilities.

Sputnik 1 carried instruments and equipment, including two radio transmitters broadcasting on 20 and 40 MHz. The signals could be received by radios around the world, and analysis was used to obtain information on electron density of the ionosphere, while temperature and pressure data were encoded in the duration of the radio beeps. The pressure data indicated that Sputnik 1 was not punctured by micrometeoroids.

The information about near-Earth space did not reveal any surprises, but were more comprehensive than what instrument-equipped rockets had collected in ballistic flights up to that point.

Sputnik 1 had the shape of a sphere with a diameter of 58 cm and with four whip antennas. The on-orbit mass was 84 kg.

The Soviet premier, Nikita S. Khruschev, impressed by the national and international reactions to Sputnik 1, requested from Korolyov a new spectacular event to celebrate the 40th anniversary of the 1917 Revolution. Time was extremely short, and Korolyov knew it could not be spent on a thorough development. Nevertheless Sputnik 2 was a new sensation when the launch was announced on November 3, 1957: Not only did the satellite carry Laika, a mongrel dog and the first living being in orbit around the Earth, but the mass was an impressive 508 kg. Laika survived only 5-7 hours in space due to stress and high temperatures, but instruments to observe solar and cosmic radiation carried out some space exploration.

The initial US plan for IGY satellite participation came to involve a launch vehicle called Vanguard, but met with technical problems. The first attempt to launch a satellite by the same name on December 6, 1957, was a complete failure right before the eyes of the invited world press, but at that time President Eisenhower had already turned to Dr. Wernher von Braun. The German rocket engineer, now an American citizen working for the US Army Ballistic Missile Agency at Redstone Arsenal in Huntsville, Alabama, led the assembly of a four-stage Jupiter C variant. The three-stage Jupiter C with a Redstone first stage was developed mainly for military re-entry testing, and the new four-stage variant, sometimes called Juno 1, was used to launch the first US satellite. The name was Explorer 1, the date January 31, 1958.

Explorer 1 was built by California Institute of Technology's Jet Propulsion Laboratory and equipped with instruments delivered by Dr. James Van Allen, professor of geophysics at the University of Iowa. The instruments collected data on cosmic radiation, temperatures and micrometeoroid-hits. The discovery of the Earth's inner radiation belt, the so-called inner Van Allen belt, was made by Explorer 1.

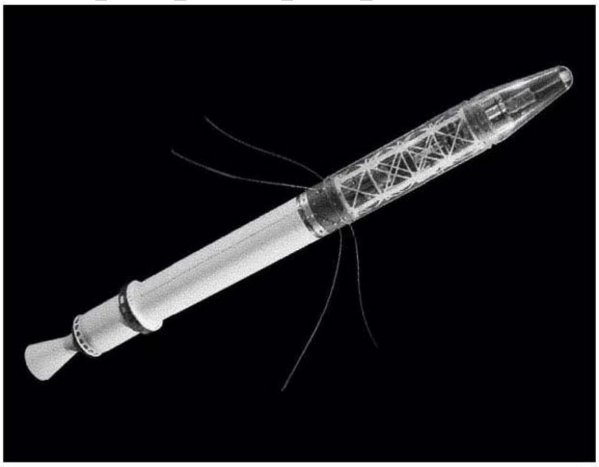

Figure 2. Explorer 1, the first US satellite, was launched on January 31, 1958. It's on orbit mass was 14 kg, not much compared to Sputnik 1's 84 kg. But Explorer 1 discovered the Earth's inner radiation belt, later called the inner Van Allen belt. (NASA)

The successful launch of the first US satellite was widely applauded, and for the Americans it created a sense of relief – they were at least participating in what was now referred to as the space race. It is important to note, however, that the Explorer 1 on orbit mass of 14 kg was only one sixth the mass of Sputnik 1 and roughly one hundredth the mass of the next Soviet sensation, Sputnik 3.

This satellite was launched on May 15, 1958, after an unsuccessful attempt on April 27. Sputnik 3 was actually a Sputnik 1 proposal, and an on orbit mass of 1327 kg included instruments to measure high-energy particles, radiation, solar radiation, upper atmosphere density, and micrometeoroid-hits. Unfortunately a failed tape recorder severely limited the volume of data transmitted to the ground.

The first successful Vanguard-satellite was launched on March 17, 1958. This relatively small satellite, still in orbit, was in operation until May 1964. It's most important scientific contribution was tracking data indicating that the Earth was somewhat pear-shaped.

2. Towards the Moon

The early Soviet ambitions in the space race extended considerably further than low Earth orbits – the first lunar probe, Luna 1, also known as Mechta (Dream), was launched on January 2, 1959. The mission was to hit our celestial neighbor, but it missed by about 6000 km and instead became the first manmade object in a solar orbit. Position measurements were made 113 000 km from the Earth on the way to the Moon, when 1 kg sodium-gas was released. The gas formed an orange-colored cloud visible for a short moment from the Indian Ocean.

The almost identical Luna 2 was launched on September 12, 1959 and hit the Moon at the end of a 33.5 hours flight. Radiation and magnetic field measurements were made on the way, in addition to a recording of micrometeoroid hits. In the collision, small Soviet emblems were spread out locally on the lunar surface.

Luna 3 was an Earth satellite in a highly elliptical orbit that took it around the Moon. Launched on October 4, 1959 it gave us the first view of the up till then unknown rear side of our celestial neighbor. 29 photographs, covering about 70 percent of the rear side area, were taken in 40 minutes on October 7 from an altitude of 63 500-66 700 km. The film was developed on board the satellite, and 17 were transmitted to Earth by telephoto-technology. Six were publicized. The quality was of course not comparable to the present standard, but in 1959 the photographs were sensational.

Also the US had a lunar program in 1958-1959, but it did not achieve much. The impressive Luna-results emphasized the Soviet lead in the space race. So did other space projects, and the American frustration grew. Impatient with efforts to catch up was expressed by politicians, the media and the general public.

The frustration level reached a new high with the Soviet launching of Yuri A. Gagarin, the first human in space, in Vostok 1 on April 12, 1961, and after the failed, CIA-supported invasion on Cuba on April 17, 1961, the young, newly inaugurated US president John F. Kennedy on April 20 sent a note to vice president Lyndon B. Johnson asking what could be done to beat the Soviets. The note suggested several alternatives.

The vice president was also the head of what was then known as the National Aeronautics and Space Council, a high level advisory board, and went to work immediately with a group of hand-picked, competent people within and outside NASA, among them Dr. Wernher von Braun and Dr. Jerome B. Wiesner. Von Braun was now the director of George C. Marshall Space Flight Centre in Huntsville, Alabama, one of the most important NASA field centers; Dr. Wiesner was President Kennedy's scientific advisor.

NASA had already started preliminary planning of a manned lunar mission, which could include a landing provided von Braun's giant Saturn V launch vehicle would perform as specified. The manned lunar landing mission, called Apollo, was not the only project considered by vice president Johnson's task group, but was the first priority alternative in the recommendation decided upon May 3, 1961.

On May 5, 1961, NASA-astronaut Alan B. Shepard became the first American in space with a 15 minutes suborbital mission in the Mercury-capsule Freedom 7, and on May 25, 1961, president Kennedy delivered to the Congress his famous speech in which he challenged the US to send a man to the Moon and return him safely to Earth – before the end of the decade.

Based on what was known in May 1961 about the Moon and the possibilities to reach it with a manned spacecraft, the challenge must have been one of the toughest ever presented by a politician. But obviously the speech was the right message given by the right person at the right time.

2.1. The Apollo Program

The main objective of President Kennedy's Apollo vision was to catch up with the Soviet Union in space. It had to do with national pride and international prestige, exploration was a secondary motive. But exploration definitely was there.

Realizing the vision required a considerably extended knowledge of the general technology needed for the mission, of the human body reaction to a zero gravity environment lasting several days, to radiation, to moving around in a bulky pressure suit, and of the lunar surface conditions. Knowledge of the needed technology and the human factor was acquired mainly in the Mercury and Gemini programs, while much of the needed information on the lunar surface conditions came from series of lunar probes called Ranger, Surveyor and Lunar Orbiter.

The lack of facts about the lunar surface had resulted in a variety of theories, not all of them encouraging and well founded – the respected Cornell University astronomer Thomas Gold's assertion that at least the Moon's maria were covered by a dust layer with a thickness of several meters is an example.

The Ranger program was actually started by NASA in December 1959 as an answer to the Soviet Union's Luna 1, 2 and 3. It consisted of nine probes in three groups, all designed to hit the Moon. Only Ranger 7, 8 and 9 from the third group of four spacecraft were successful. These probes had six electronic cameras, and the plan was to transmit images of the surface from about 20 minutes before hitting. The last images would show details down to about 25 cm, much better than was achieved through the best telescopes on the Earth. Ranger 7, launched on July 28, 1964, transmitted more than 4300 images of the Moon before crashing into the Mare Nubium south of the Copernicus crater. The area was later named Mare Cognitum, the Sea that is known, by the International Astronomical Union. The images showed lots of impact craters on the lunar surface. Ranger 8 (launched on February 17, 1965) transmitted more than 7000 images before hitting the Sea of Tranquility not far from the place where the manned lunar lander Eagle from Apollo 11 would touch down four and a half years later. Ranger 9 (launched on March 21, 1965) transmitted 5814 images before hitting the crater Alphonsus. The solar angle was low, and the shadow effect gave useful information.

The Surveyor program consisted of seven soft-landing lunar probes launched during the period of May 1966-January 1968 to collect data on the mechanical characteristics of the Moon's surface. Surface data were needed e.g. to design the Apollo lunar lander landing gear. Surveyor 1, 3, 5, 6, and 7 were successful, and a total of close to 87 000 images were transmitted to Earth. Surface details down to 0.5 mm (millimeters) were visible. Information on surface mechanical properties was obtained by instruments on the landing gear and (on Surveyor 3 and 7) a robotic arm with a scoop. Small thrusters pointing downwards were used so that images would show the surface erosion. Temperatures were measured, and three of the probes (Surveyor 5, 6, and 7) carried an instrument to indicate some of the elements present in the lunar top soil.

Figure 3. Astronaut Edwin E./Buzz Aldrin, the Apollo 11 lunar module pilot, on the Moon. The date is July 21 (European time), 1969. Part of the lunar module is seen in the shadow on the left, and footprints are clearly visible in the foreground. The other two members of the Apollo 11 crew were Neil A. Armstrong (commander) and Michael Collins (command module pilot). Armstrong and then Aldrin became the first humans to set foot on the Moon; Collins waited in the command/service module orbiting the Moon.

The symbolic value of this particular photograph did a lot to lift the pride and spirit of a whole nation. (NASA)

In the Lunar Orbiter program five orbital probes were launched in the period August

1966 to August 1967. The purpose was to map the lunar surface for the selection of Apollo landing areas. The film from the two cameras – one with a 610 mm tele lens, the other with a 80 mm wide angle lens – was processed on board, and the negatives scanned with a focused light beam for electronic transmittal to Earth. The Lunar Orbiter probes obtained 2180 images with high and 882 with medium resolution. The wide angle images covered 99 % of the total lunar surface. In addition the spacecraft collected data on the micrometeoroid and radiation levels in the vicinity of the Moon. After serving their purpose, all Lunar Orbiters were impacted on our neighbor in space.

The exploration aspect of the manned Apollo missions was valuable, and contributed considerably to the excitement and enthusiasm expressed by most people.

Apollo 8 was mankind's first visit to another world – Frank F. Borman, James A. Lovell and William A. Anders traveled to the Moon in an Apollo command and service module after launch on a Saturn V on December 21, 1968. It was a daring feat. Apollo 8 was initially planned as a first test in Earth orbit of a complete, manned Apollo spacecraft launched by a Saturn V, but when the delayed lunar lander finally arrived at Kennedy Space Center in June 1968, the quality inspectors discovered too many defects for it to be launched before the end of the year. At the same time intelligence reports gave hints that that the Soviet Union was preparing a one-cosmonaut mission around the Moon in a Zond spacecraft (actually a Soyuz derivative), and in early August it was suggested to send the Apollo spacecraft, minus the lunar lander, to the Moon in the first manned Saturn V.

Apollo 8 was placed in a 311/112 km orbit around the Moon, and completed ten two-hour revolutions before returning to Earth. The astronauts became the first humans to see the far side of the Moon, but one of the major tasks was reconnaissance of proposed landing sites on the near side, in particular one in Mare Tranquilitatis on top of the list for Apollo 11. The launch time for Apollo 8 had been chosen to give the best lighting conditions for examining the site. A film camera had been installed in one of the spacecraft windows to record a frame of the Moon below every second. Anders spent much of the 20 hours taking photographs, and by the end of the mission the crew had a total of 700 images of the Moon and 150 of the Earth. The most well known photograph from the mission is definitely the color shot of the Earth rising from the lunar horizon. It was taken by Anders, and probably is one of the most famous photographs ever.

The crew was also the first humans to observe the Moon near by, and this is how Lovell described the surface: "The Moon is essentially grey, no color; looks like plaster of Paris or sort of a grayish beach sand. We can see quite a bit of detail. The Sea of Fertility doesn't stand out so well here as it does back on Earth. There is not as much contrast between that and the surrounding craters. The craters are all rounded off. There are quite a few of them, some of them are newer. Many of them look like – especially the round ones – hit by meteorites or space debris of some sort. Langrenius is quite a huge crater; it has got a central cone to it. The walls of the crater are terraced, about six or seven different terraces on the way down".

What few of the people with access to a television set at the time will never forget is a transmission started when Apollo 8 rounded the Moon for the ninth time, Borman introduced the crew, followed by each member giving his impression of the lunar surface and what it was like to orbit the Moon. Borman described it as being “a vast, lonely, forbidding expanse of nothing”. Then, after talking about they were flying over, Anders said that the crew had a message for all those on Earth. Each of them read the story of creation from The Book of Genesis, and Borman finished the broadcast by wishing a Merry Christmas to everyone on Earth.

Manned exploration on the lunar surface was carried out in the period from July 1969 to December 1972 by two-man crews on the landing vehicles from Apollo 11, 12, 14, 15, 16, and 17. The astronauts ventured outside up to three times to observe, take photographs, collect samples and unload/install scientific instruments. Their mobility was increased a great deal when they, from Apollo 15, started to use a four wheel, electrically driven vehicle. The geological training given to each crew before the mission varied, but for the last three crew it was in many ways on a Masters Degree level. One crew member Harrison H. “Jack” Schmitt, the lunar module pilot on Apollo 17, was a professional geologist and the first true scientist to explore the Moon. During the extravehicular activities the astronauts had continuous support from specialists available at or within reach from the Mission Control Centre in Houston.

Figure 4. The Columbia Command Module from Apollo 11 has landed in the Pacific after a historic lunar mission, and the crew awaits pickup by a helicopter. The date is July 24, 1969. The US has won the Space Race, and has been in the lead ever since. (NASA)

Relevant information on the lunar landing sites, the activities on the surface, the experiments performed and the instruments left on the Moon is found in Table I, but these are, according to NASA, the top ten scientific discoveries made during the Apollo exploration of our neighbor in space:

1. The Moon is not a primordial object; it is an evolved terrestrial planet with internal

zoning similar to that of the Earth.

2. The Moon is ancient and still preserves an early history (the first billion years) that must be common to all terrestrial planets.

3. The youngest Moon rocks are virtually as old as the oldest Earth rocks. The earliest processes and events that probably affected both planetary bodies can now only be found on the Moon.

4. The Moon and the Earth are genetically related and formed from different proportions of a common reservoir of materials.

5. The Moon is lifeless; it contains no living organisms, fossils, or native organic compounds.

6. All Moon rocks originated through high-temperature processes with little or no involvement with water. They are roughly divisible into three types: basalts, anorthosites, and breccias.

7. Early in its history, the Moon was melted to great depths to form a “magma ocean”. The lunar highlands contain the remnants of early, low density rocks that floated to the surface of the magma ocean.

8. The lunar magma ocean was followed by a series of huge asteroid impacts that created basins later filled by lava flows.

9. The Moon is slightly asymmetrical in bulk form, possibly as a consequence of its evolution under the Earth’s gravitational influence. Its crust is thicker on the far side, while most volcanic basins – and unusual mass concentrations – occur on the near side.

10. The surface of the Moon is covered by a rubber pile of rock fragments and dust, called the lunar regolith that contains a unique radiation history of the Sun that is of importance to understanding climate changes on Earth.

2.2. Soviet Plans for a Manned Lunar Landing

When President Kennedy delivered his ay 25, 1961 vision for landing a man on the Moon and returning him safely to the Earths before the end of the decade, the Soviet Union was busy with the Vostok Program and its positive media reactions both nationally and abroad.

The development of a huge new launch vehicle called the N1 was authorized, but a particular use was not specified. Possibilities included civilian and military tasks such as the assembly of a large space station, sending a manned spacecraft to Mars or establishing an anti-satellite weapon system in space.

The situation changed in 1963, when the political leadership received reports indicating that NASA was working intensely on President Kennedy's challenge and that progress was being made. Not to be beaten in a manned lunar landing race, Korolyov, or "the Chief Designer" as he was called, in July 1963 changed the priorities. In a document sent to his superiors, he specified three important tasks for the N1: Exploration of the Moon, exploration of the planets and the assembly of a space station.

Korolyov initially envisioned the use of three N1 launch vehicles in a manned lunar landing, and plans for a L3 lunar landing vehicle were drafted in September 1963. At first the Soviet government had doubts about the idea of landing humans on the Moon because of the costs involved in a period with social and economic problems. On the other hand it was important to be a leader in the space race.

Early 1964 meetings were held on a high level to discuss the lunar landing and the N1. During a meeting in the Kremlin on July 17, Korolyov presented revised lunar landing plans to First Secretary Nikita S. Khrushchev. One of the changes was to use the rendezvous in lunar orbit concept (as NASA would for Apollo) instead of rendezvous in Earth orbit. The former could be carried out with one instead of three N1 launch vehicles. But it would be necessary to increase its payload capacity. Going from 24 to 30 rocket engines in the first stage and improving the upper stages would raise the load carrying capacity to a low Earth orbit from 75 to 93 metric tons, but not even this was enough. It was decided to reduce the crew on a lunar landing mission from three to two, of which only one would be able to walk on the lunar surface.

Khrushchev supported the revised plans, and the Central Committee asked for a draft decree.

A draft was written by Korolyov and discussed with both other chief designers and industrial leaders before a document was completed in four parts – the decree itself, an enclosure with details, a budget plan and a covering letter. The document was sent to Khrushchev in the last part of July, and on August 3, 1964, Decree 655-268 was signed. The document was classified as secret until June 2003.

As initially planned, the first Soviet manned lunar landing was to take place in 1967/68, but before final design of the spacecraft needed could start it was necessary to collect more relevant information about the Moon.

2.3. A New Wave of Soviet Lunar Probes

Following a hard landing on the Moon, the next step would be to soft land a probe or an instrumented capsule from a probe. But this is of course several orders of magnitude more difficult, and the Soviet Union is believed to have made eleven attempts before they succeeded with Luna 9 on February 3, 1966.

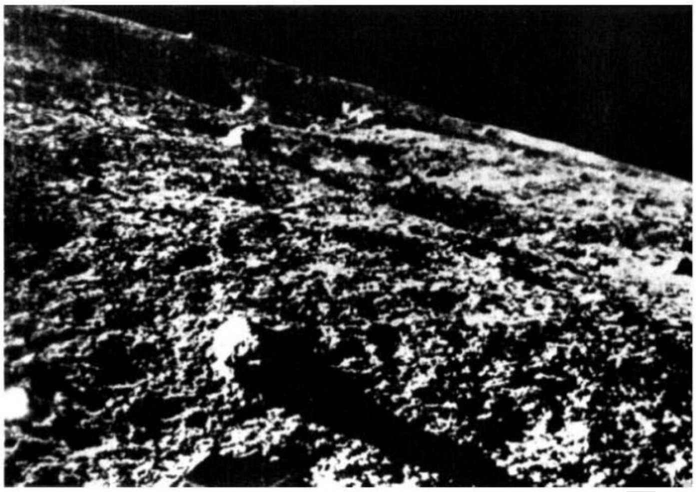

Figure 5. This image is one of the first ever from the surface of the Moon. It was taken by the Soviet Luna 9 soft landing instrument capsule soon after coming to rest in Oceanus Procellarum on February 3, 1966. (NASA)

The instrument capsule, almost spherical with a diameter of 58 cm and a mass of 99.8 kg, came down 25 m from the rim of a small crater and west of the two larger craters Reiner and Marius in Oceanus Procellarum after separation from the probe and 46 seconds of engine braking. The hermetically sealed capsule contained radio equipment, a program timing device, temperature control devices, a scientific instrument, batteries, and a television camera. Upon coming to rest on the surface, four petals opened and stabilized the spacecraft. Spring-loaded antennas assumed operating positions, and the television camera, equipped with a rotating and tilting mirror, was prepared for the first survey of the lunar surface.

About five minutes after landing the spacecraft started transmitting data to Earth, but it had to wait seven hours before the Sun elevation had risen to 7 degrees and the first of nine images (including five panoramas) could be sent. The total transmission time was 8 hours and 5 minutes spread out over seven sessions in four days. Strangely enough the first images were released by the British Jodrell Bank Observatory, which was monitoring the mission and had noticed that the signal format used was identical to the international standard adopted by newspapers for transmitting pictures. The images provided close-up views with details down to 1-2 mm and panoramas with the horizon about 1.4 km away. The scientific instrument, a radiation detector, reported a dosage of 30 millirads per day.

Luna 9 carried out the first soft landing on and sent the first images from the surface of another celestial body. It was a new Soviet success, and it established a very important fact: The lunar surface is relatively flat, and can support a landing vehicle.

The first Soviet attempt to put a probe in orbit around the Moon was made in early March 1966, but it failed – Cosmos 111 never made it out to our celestial neighbor. Luna 10, on the other hand, entered a lunar orbit on April 3, 1966, and became the first man-made object to orbit another celestial object (not counting the Sun). The apogee/perigee of the orbit were 1017 and 350 km, the inclination 71.9 degrees.

A separated, 245 km compartment carried seven scientific instruments to collect important data on the Moon's weak magnetic field, its radiation belt, the nature of lunar rocks (found to be comparable to terrestrial basalt rocks), cosmic radiation, and the micrometeoroid level. Luna 10 gave indications of mass concentrations (called "mascons") – areas of high density below the mare basins that distort lunar orbit trajectories, but their discovery is usually attributed to Paul M. Muller and William Sjogren of NASA's Jet Propulsion Laboratory in 1968 from analysis of the highly precise navigation data from the Lunar Orbiter spacecraft.

As a side point – Luna 10 carried a set of solid state oscillators pre-programmed to replay the notes of the Internationale so that it could be broadcast live to the 23rd Communist Party Congress. During a test on the night of April 3 the playback went well, but the following morning controllers discovered a missing note and played the tape of the previous night to the assembled gathering at the Congress – claiming it was a live broadcast from the Moon. The last contact with Luna 10 was on May 30, 1966.

Luna 11 entered a lunar orbit of 1200/160 km and an inclination of 27 degrees on August 28, 1966, to begin observations of gamma and X-ray emissions in order to determine the chemical composition of the surface, map gravitational anomalies, locate concentrations of meteoroid streams, and find the intensity of hard corpuscular radiation near the Moon. The tasks probably also included the transmission of lunar surface images, but the probe failed to do so.

Luna 12 achieved a 1740/100 km lunar orbit with a 10 degree inclination on October 25, 1966, and concentrated on taking pictures with a television system of potential landing areas for a manned mission. The images contained 1100 scan lines with a maximum resolution of 15-20 m. Images of the surface were transmitted on October 27, 1966, but the number is not known. Transmissions from Luna 12 stopped on January 19, 1967.

Luna 13, an advanced version of Luna 9, soft landed an instrument capsule in Oceanus Procellarum at 18.87 degrees north and 62.05 degrees west on December 24, 1966. In addition to the television camera the instrument capsule was equipped with a three axis accelerometer for recording the landing shock in order to determine the soil structure down to a depth of 20 to 30 cm. A pair of spring-loaded booms was also deployed. One of the booms carried a penetrometer designed to measure the forces needed to break through the regolith with a small explosive charge. The other boom was equipped with a backscatter densitometer to infer the density of the near-surface regolith. Four radiometers recorded infrared radiation from the surface, indicating a Moon temperature of 117 plus/minus 3 °C. A radiation detector reported non-hazardous levels for humans.

The lander transmitted a total of five lunar surface panoramas, showing a more smooth terrain than seen by Luna 9. Of the two cameras for stereo imaging, one failed. Nevertheless the mission as a whole was a success. Contact with the spacecraft was lost on December 28, 1966, when the on board batteries were exhausted.

Luna 14 was probably similar to Luna 10 and Luna 12. It entered an 870/160 km lunar orbit with an inclination of 42 degrees on April 10, 1968. The primary objective was to test communications systems for a manned lunar landing, but ground tracking of the probes orbit also facilitated the accurate mapping of lunar gravitational anomalies in order to predict orbits of future spacecraft. Luna 14 carried scientific instruments to study cosmic radiation and charged particles from the Sun, but few results have been published.

There is little doubt that the main purpose of the new wave or second generation Soviet lunar probes was to collect data on the Moon and its environment in support of the manned lunar landing program as described in Decree 655-268 – just as the US had to fly Ranger, Surveyor, and Lunar Orbiter probes to get data necessary for the Apollo program.

Work on the Soviet manned lunar program started late compared to the US May 25, 1961, initiation date, and it did not take long after the signing of the Decree on August 3, 1964, before the Soviets realized that the initial target of 1966/67 for a manned landing was not achievable. At the same time NASA's Apollo program was gathering momentum, and in late 1968 there were indications that the US would be able to try a manned landing in 1969.

In an attempt to maintain the image of the worlds leading space superpower it was decided to accelerate the development of the first series of third generation Soviet lunar probes – spacecraft capable of a soft landing on the Moon and return to Earth with a small sample of lunar soil in addition to a more conventional collection of scientific data.

It was a difficult task, and two failed attempts were made before Luna 15 was launched on July 13, 1969. This was three days before Apollo 11 started: To steal some of the limelight, the Soviet Union planned to return a part of Luna 15 to Earth with lunar soil before the American manned spacecraft.

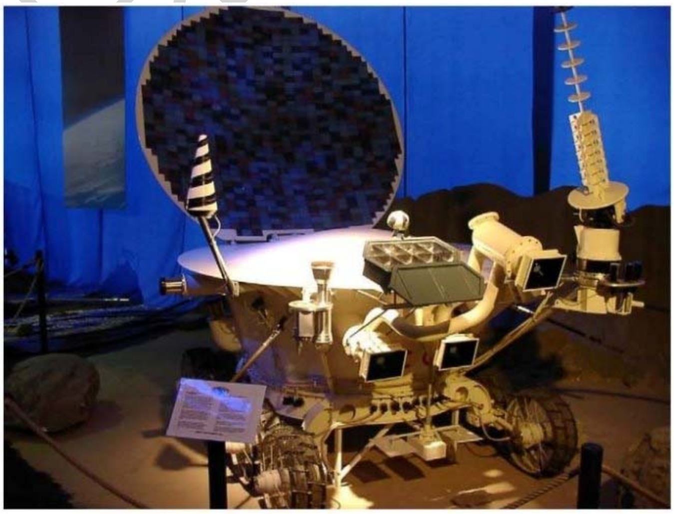

Figure 6. A model of the Soviet Lunokhod 2, an improved version of the Lunokhod 1 lunar vehicle. Lunokhod 2 landed aboard Luna 21 in January, 1973, and covered a total

of 37 km in its five months lifetime.

As an interesting note – Lunokhod 2 and Luna 21 were sold for 68 500 dollars in 1993 at a Sotheby's auction, both sitting lifeless on the lunar surface. (de Benutzer.HPH)

Luna 15 studied circumlunar space, the lunar gravitational field, and the chemical composition of lunar rocks. It was also capable of lunar surface photography. The spacecraft entered an orbit around the Moon on July 17, and stayed there for two days. When NASA had worries about Luna 15 interfering with Apollo 11 operations, the Soviets released their flight plan, showing there was nothing to fear. Besides, Luna 15 failed during landing – it crashed in Mare Crisium on July 21.

Luna 16, launched on September 12, 1970, did much better – it became the first probe to land on the Moon and return to Earth with a soil sample. The spacecraft consisted of two main parts, or stages, an ascent stage on top of a much larger descent stage. The soft landing took place on September 20 in the northeast part of Mare Foecundatis after a free fall from about 2 m. On the surface an automatic drill was lowered, and needed 7 minutes to reach a stop at 35 cm depth. The drill arm was withdrawn, and 101 g of collected material deposited in a small, spherical capsule on top of the ascent stage. After 26 hours and 25 minutes on the lunar surface the ascent stage lifted off and continued towards the Earth. The capsule entered the atmosphere at a velocity of 11 km/s, and a parachute landing took place on September 24 about 80 km southeast from the town of Dzhezkazgan in Kazakhstan – an impressive engineering feat.

The Luna 16 descent stage remained on the Moon to continue transmitting data on temperature and radiation levels, while analysis of the basalt material brought to the Earth indicated a close resemblance to soil recovered by the US Apollo 12 mission.

Luna 17 was a new Soviet engineering success. The probe was launched on November 10, 1970, and soft landed in Mare Imbrium on November 17 with an electric driven lunar roving vehicle called Lunokhod 1 on top of the descent stage instead of a Luna 16 type ascent stage. The 756 kg rover was 1.5 m high and measured 2.15 m across. Each of its eight wheels was independently controllable in two forward and two reverse speeds. The top speed was about 100 m/h (meters per hour), with commands issued by a five man team in a control centre which had to deal with a five second delay. The wheels and a set of instruments were powered by solar cells under a hinged top lid on the rover, and batteries.

Lunokhod 1 rolled down ramps onto the lunar surface. The vehicle had an expected lifetime of three lunar days, but operated for eleven. During its 322 days of operation, Lunokhod 1 traveled 10.54 km and transmitted more than 20 000 television images and 206 high-resolution images. In addition, it carried out 25 soil analyses with an X-ray fluorescence spectrometer and used a penetrometer at 500 different locations. The operators completed the last communications session with the rover on October 4, 1971.

Luna 18, launched September 2, 1971, was the seventh Soviet attempt to recover lunar soil samples, and the first following the success of Luna 16. It was supposed to soft land in a mountainous area near the edge of Mare Foecundatis, but radio contact was lost during the descent.

Luna 19 was the first in a series of advanced lunar orbiters which used the same bus as Luna 16 and 17 but with a pressurized instrument container replacing the ascent stage. The instruments included a camera system, gamma-ray spectrometer, radio altimeter, meteoroid detectors, magnetometer, cosmic ray detectors, and radiation detectors. The orbiter was launched on September 28, 1971, and entered a 140 km lunar orbit with an inclination of about 41 degrees on October 3. Here it extended a systematic study of the lunar gravitational field and the location of mascons, the lunar radiation environment, the gamma-active lunar surface, and the solar wind until about October 20, 1972.

The purpose of Luna 20 was to complete the mission that Luna 18 failed to accomplish. It was launched on February 14, 1972, entered lunar orbit four days later and soft-landed on February 21. The landing area in the Apollonius highlands near Mare Foecundatis was only 1.8 km from the Luna 18 crash site. The extendable drilling apparatus collected about 30 g of lunar soil, and placed it in the sealed, spherical capsule on top of the ascent stage. After takeoff from the Moon on February 22, the capsule parachuted to a safe landing on February 25 on an island in the Karkingir River about 40 km north of Dzhezkazgan.

The 30 g collected material differed from the Luna 16 material in that 50-60 % of the rock particles were ancient lunar highland anorthosite (which consists largely of feldspar) rather than the basalt (with 1-2 % anorthosite). The US Apollo 16 mission returned similar highland material from Descartes two months later. Like the Luna 16 soil, samples of the Luna 20 collected material were shared with American and French scientists.

Luna 21, launched on February 8, 1973, was another Lunokhod mission. A soft landing was achieved on January 15 in the Le Monnier crater between Mare Serenitatis and the Taurus Mountains, and less than 3 hours later Lunokhod 2 disembarked onto the lunar surface. The 840 kg vehicle was an improved version of its predecessor and was equipped with a more advanced eight-wheel traction system, a third television camera, and additional scientific instrumentation. By the end of its first lunar day, Lunokhod 2 had traveled further than Lunokhod 1 in its entire operational life. On May 9, the rover inadvertently rolled into a crater so that dust covered solar panels and radiators. Attempts to save it failed, and on June 3 the mission was declared over. At that time Lunokhod 2 had transmitted 80 000 television images and 86 panoramas. Hundreds of mechanical and chemical investigations of the soil were carried out. To navigate on the surface, the operators also used American photographs of the landing area taken prior to the Apollo 17 landing.

Luna 22, launched on May 29, 1974, was a repeat of the Luna 19 mission. Extensive scientific surveys from a lunar orbit included surface photography, investigations to determine the chemical composition of the surface, recording of meteoroid activity, and search for a magnetic field, in addition to measurement of solar and cosmic radiation flux. The spacecraft made several orbit adjustments to optimize instrument operation, in one case reducing the lowest point of the orbit to only 25 km. Maneuvering fuel was exhausted on September 2, and the mission formally terminated in early November

1975.

Luna 23, launched on October 28, 1974, was a new sample return mission, and landing in the southernmost part of Mare Crisium on the Moon took place on November 6. The drill was designed to collect samples from a depth of up to 2.5 m (vs. 0.3 m for Luna 16 and 20), but the drilling device, possibly damaged during the landing, did not work. No samples were returned.

Luna 24 did better. After launch on August 9, 1976, it soft-landed on August 18 in the same area of Mare Crisium as the unsuccessful Luna 23 and collected 170 g of samples from a depth of up to 2 m. The ascent stage with the sample container lifted off from the Moon on August 19, and the container parachuted to a landing on August 22 about 200 km southeast of Surgut in western Siberia. Study of the soil sample indicated a laminated type structure, as if laid down in successive deposits. Tiny portions of the sample were shared with NASA in December 1976.

The successful Luna 24 ended the Soviet Luna series, at least for now.

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Biographical Sketch

Erik Tandberg received his engineering education at the University of Santa Clara (BS, 1957) and Stanford University (MS, 1959) in California, and carried out postgraduate studies in Rocket Propulsion at Princeton University in New Jersey (1965). He has served 17 years with the Royal Norwegian Air Force, and has held positions in private companies. Tandberg has written several books and numerous articles on space related matters, and has been a space science/technology consultant to the Norwegian Broadcasting Corporation (radio/TV), covering many space events. At the time of writing this chapter he was running his own consultancy company, mainly working for the Norwegian Space Center in Oslo, Norway.