Luna-Glob project in the context of the past and present lunar exploration in Russia

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The Russian Luna-Glob project has been conceived with a view to understand the origin of the Earth–Moon system. The objectives and main features of the Luna-Glob mission, which will mainly study the internal structure of the Moon by seismic instruments, are described in the context of the past and current program of lunar exploration in Russia.

1. Introduction

We have recently developed a model of the formation of Earth and Moon from a common cloud of particles of primitive (chondritic) composition (Galimov and Krivstov 2005a). The model predicts formation of two fragments, which become embryos of the Earth and Moon. Depletion of volatiles as well as of iron in the Moon is explained in this model to be due to the evaporation of particles. This model is an alternative to the 'Giant Impact Hypothesis', which suggests formation of the Moon from the Earth's mantle material ejected as a result of collision of Earth with a large (Mars size) body. Some geochemical characteristics of the Moon are difficult to reconcile with its origin from the Earth's mantle as proposed in the Giant Impact Hypothesis (Galimov 2004).

There are several geochemical criteria, which allow us to resolve between the various alternative models of the origin of the Moon. One of the key points is the concentration of the refractory elements including Al, Ca, Ti, U, Th and Sr. At present there is no reliable estimate of the concentration of refractory elements in the bulk Moon. However, elastic properties of the mantle depend on its chemical and mineral composition, in particular, on Al_2O_3 content. The concentration of Al and hence other refractory elements can be estimated through seismic studies. One can show that if the Moon originated from the Earth's mantle, a very small core, not more than 0.4% of the lunar mass, is required. In contrast, if the Moon formed from the primary material it must have a core as massive as 5% of the total lunar mass. Thus the size of the lunar core is of crucial importance for resolving the problem of the Moon's origin. The current Russian Lunar Project 'Luna-Glob' has been conceived keeping the problem of the Moon–Earth origin in mind.

2. Science goals of Luna-Glob mission

The first objective of the Luna-Glob project is to conduct seismic experiments, which would allow us to get information on the internal structure of the Moon (figure 1). This is proposed to be carried out through two types of seismic experiments:

- small aperture seismic array with high-speed penetrators (HSP) and
- broadband seismometery (penetrator–landers, PL).

The experiment based on the concept of small aperture seismic array has been proposed by O B Khavroshkin and other seismologists at the Institute of the Earth Physics in Moscow.

Keywords. Luna-Glob mission; lunar core; penetrators; seismology.

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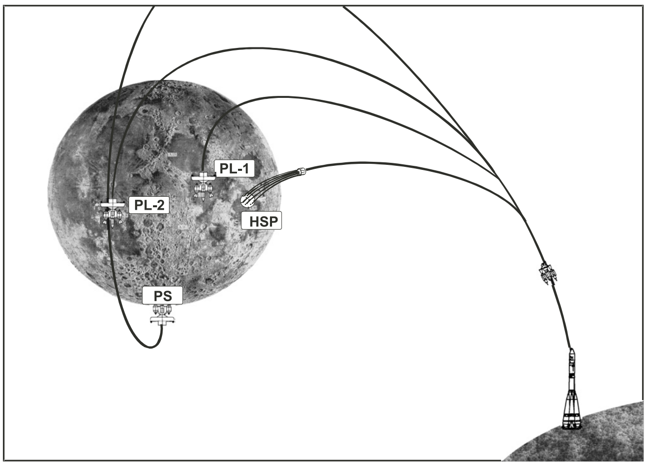

Figure 1. Lunar landing sites proposed in the Luna-Glob project. HSP – high-speed penetrators of the small aperture seismic array (18°S, 38°N); PL-1 and PL-2 – penetrator–landers at 0.7°N23.5°E and 3°N, 23.4°W; PS – Polar Station (88°S).

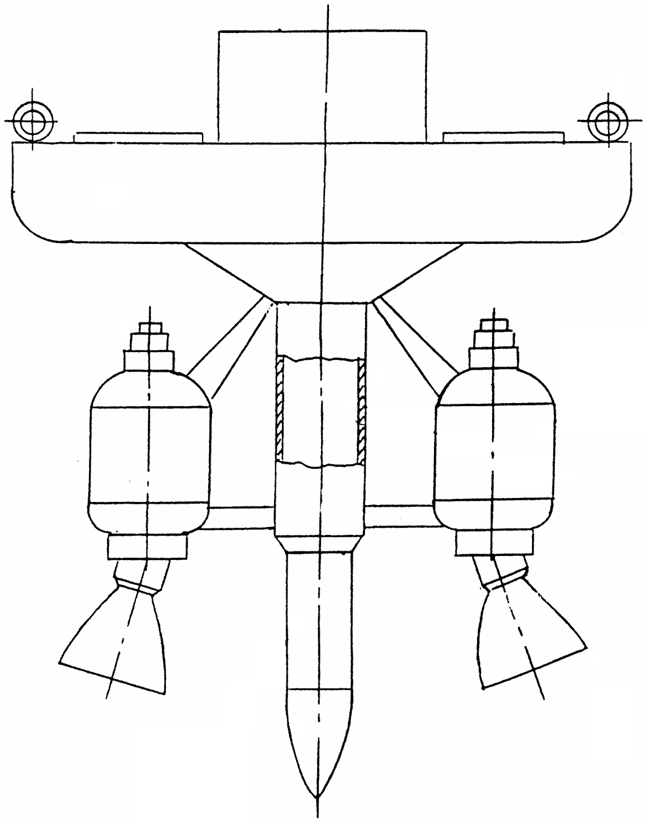

Figure 2. Design of the 'Luna-Glob' penetrator–lander.

Preliminary calculations show that satisfactory results can be obtained by deployment of a network of 10 seismic sensors, which should be emplaced on the lunar surface by penetrators. The penetrators are expected to intrude into the lunar surface with high speed over an area of about 80 km^2($D = 10$ km) within 2 to 3 km of each other.

The peculiarity of the small aperture seismic array experiment is that the penetrators are thrown from an approaching trajectory and intrude into the ground with high speed. In an extreme case (without any decelerating impulse) the speed of impact is expected to be 2.5 km/s. The shape of the penetrator is designed to reduce overloading and the scientific instrument is designed to survive a hard impact (up to 10,000 G). Preliminary tests show that the scientific instruments would survive under these conditions. The high-speed penetrators (HSP) are assembled into a ring cassette. The cassette is provided with a battery, solid-fuel engines and a control unit. The seismic array is best deployed in an area having low seismicity and thick regolith layer. A site in the Mare Fecunditatis (18°S, 52°E) has been selected for emplacement of the seismic network.

The second seismic experiment is designed to use a broadband seismometer. Information about the interior of the Moon is limited due to the attenuation of seismic waves. The higher the frequency, the greater is the extent of attenuation. Therefore, it is essential to have an instrument with high sensitivity at low frequencies as in the broadband seismometer. Two landers carrying broadband seismometers will be deployed in the equatorial region of the Moon at a distance of about 300 km from each other. The landers will have the shape of a penetrator as shown in figure 2. Unlike the high-speed penetrator, the penetrator–lander will be equipped with decelerating engines, which will result in semi-hard landing (80 ± 20 m/s). The overload should not exceed 500 G. In addition, the penetrator contains radio transmitter, antenna, power supply, and a control unit. The sites with coordinates 0.7°N, 23.5°E and 3°N, 23.4°W, near the landing places of Apollo 11 and Apollo 12, have been selected for the first and the second penetrators respectively.

The second objective of the Luna-Glob mission is to test the presence of volatiles including water in the polar regions of the Moon. In order to study the concentration of volatiles supposedly present in the permanently shadowed lunar polar regions, soft landing of the analytical station containing a mass-spectrometer and neutron spectrometer, combined with seismic station has been proposed. The polar station (PS) consists of a landing module, braking engine and inflated shock absorber. The braking engine first decelerates to leave the orbit and then decreases the vertical speed. Overload at the moment of shock on the lunar surface does not exceed 200 G. A crater of 56 km size with coordinates of the center 88°S, 38°E has been selected as its landing site.

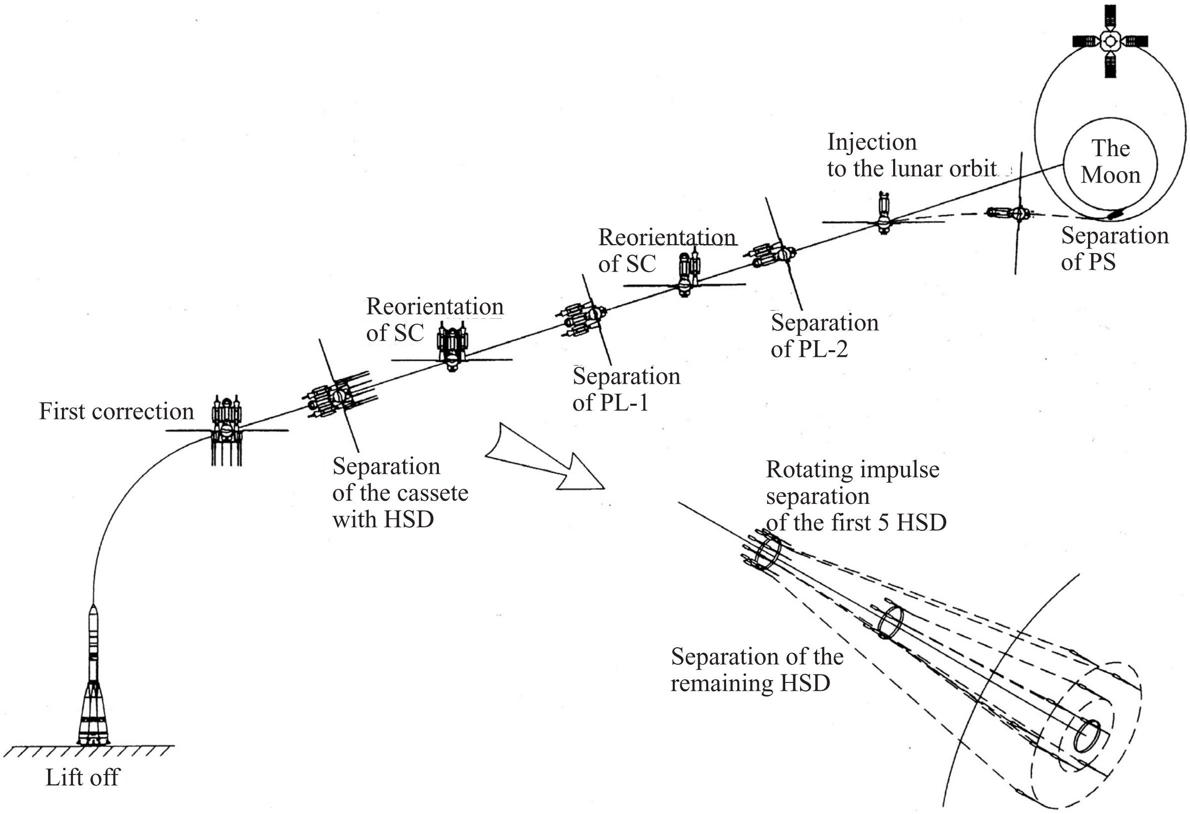

Figure 3. Schematic diagram of the mission profile of the 'Luna-Glob' project.

3. Mission configuration

Luna-Glob will be launched using either the 'Molnia' or 'Soyuz' rockets. The launch profile of the mission is shown in figure 3. Duration of the flight to the Moon is estimated to be 4.5 days. 29 hours before arriving at the Moon after correction and reorientation of the spacecraft, the HSP-carrying cassette is detached from the spacecraft. Then after reorientation, the first penetrator–lander, and after new reorientation, the second penetrator–lander are detached.

The HSP-cassette after detachment from the spacecraft moves along the hit trajectory rotating with 3 rad/s. At 700 km altitude above the lunar surface, the rotation speed increases to 20 rad/s and the first set of HSP is detached from the cassette. The penetrators during their travel to the lunar surface, which will take about 250 s, fly in a circle of diameter $\sim$8–10 km. At an altitude of 350 km, the remaining 5 penetrators leave the cassette and during the time of impacting on the lunar surface, fly in a circle of 5 km diameter.

The braking engines of PL are activated at an altitude of 2 km, which decreases the speed to nearly zero. Then, the braking engines are detached and the penetrator enters the surface with a speed of about 60–120 m/s.

After releasing the HPL and PL, the spacecraft is injected into a polar circular orbit, selected to pass over the landing site of the polar station. The PS is detached from the spacecraft and decelerated to zero orbital speed. It descends to an altitude of about 2 km, where the braking engines decrease the vertical speed to zero. The braking engines are ejected and the station touches the lunar surface with a speed of 5–25 m/s.

It is believed that the successful achievement of the objectives of the Luna-Glob project would result in a significant breakthrough in geosciences and planetology. Unfortunately there has not been much progress of this project since the Third Conference on Exploration and Utilization of the Moon held in Moscow in October 1998 (see Galimov *et al* 1999; Galimov 1998). The stagnation of the planetary research program in Russia is especially regrettable as we have unparalleled experience in the exploration of the Moon by automatic instruments, as summarized below. This experience could be helpful in collaborating with countries now planning their first lunar expeditions such as Japan, China and India.

Table 1. *History of lunar exploration*[*].

Launch date	Mission	Accomplishment
2 Jan 1959	***Luna 1***	***FIRST lunar flyby, magnetic field***
12 Sept 1959	***Luna 2***	***FIRST hard landing, magnetic field***
20 Apr 1960	***Luna 3***	***FIRST photos of lunar far-side***
26 Jan 1962	Ranger 3	Missed the Moon by 36,793 km
23 Apr 1962	Ranger 4	Crashed on the lunar far-side
18 Oct 1962	Ranger 5	Missed the Moon by 724 km
2 Apr 1963	***Luna 4***	***Missed the Moon by 8500 km***
30 Jan 1964	Ranger 6	Hard landing, television failed
29 July 1964	Ranger 7	Hard landing, close-up TV
17 Feb 1965	Ranger 8	Hard landing, close-up TV
21 Mar 1965	Ranger 9	Hard landing, close-up TV
9 May 1965	***Luna 5***	***Crashed on the Moon***
8 June 1965	***Luna 6***	***Missed the Moon by 161,000 km***
18 July 1965	***Zond 3***	***Photographed lunar far-side***
4 Oct 1965	***Luna 7***	***Crashed on the Moon***
3 Dec 1965	***Luna 8***	***Crashed on the Moon***
31 Jan 1966	***Luna 9***	***FIRST soft landing, TV panorama***
31 Mar 1966	***Luna 10***	***FIRST lunar satellite, gamma-spectra, magnetic and gravity measurements***
30 May 1966	Surveyor 1	On-surface TV, soil-mechanics
10 Aug 1966	Lunar Orb 1	TV imaging, radiation, micrometeorites
24 Aug 1966	***Luna 11***	***Gravity, micrometeorites***
22 Oct 1966	***Luna 12***	***TV imaging from orbit***
6 Nov 1 966	Lunar Orb 2	TV imaging, radiation, micrometeorites
21 Dec 1966	***Luna 13***	***On-surface TV, soil mechanics***
5 Feb 1967	Lunar Orb 3	TV imaging, radiation, micrometeorites
17 Apr 1967	Surveyor 3	On-surface TV, soil-mechanics
4 May 1967	Lunar Orb 4	TV imaging, radiation, micrometeorites
19 July 1967	Explorer 35	Fields and particles
1 Aug 1967	Lunar Orb 5	TV imaging, radiation, micrometeorites
8 Sept 1967	Surveyor 5	On-surface TV, first chemistry data
7 Nov 1967	Surveyor 6	On-surface TV, chemistry
7 Jan 1968	Surveyor 7	On-surface TV, chemistry
7 Apr 1968	***Luna 14***	***Gamma spectra, magnetic measurements***
14 Sep 1968	***Zond 5***	***FIRST lunar flyby and Earth return, returned biological objects and photos***
10 Nov 1968	***Zond 6***	***Lunar flyby and Earth return, returned biological objects and photos***
21 Dec 1968	Apollo 8	FIRST humans to orbit the Moon
18 May 1969	Apollo 10	FIRST docking in lunar orbit
13 July 1969	***Luna 15***	***Failed robot sampler***
16 July 1969	Apollo 11	FIRST humans on the Moon (20 July)
8 Aug 1969	***Zond 7***	***Lunar flyby and Earth return, returned biological objects, photos***
14 Nov 1969	Apollo 12	Human landing, Oceanus Procellarum
11 Apr 1970	Apollo 13	Aborted human landing
12 Sept 1970	***Luna 16***	***FIRST robot sample return, Mare Fecunditatis***
20 Oct 1970	***Zond 8***	***Lunar flyby and Earth return, returned photos, landing in the Indian Ocean***
10 Nov 1970	***Luna 17***	***FIRST robotic rover Lunokhod 1, Mare Imbrium***
31 Jan 1971	Apollo 14	Human landing, Fra Mauro
26 July 1971	Apollo 15	Human landing, Hadley-Apennine
2 Sept 1971	***Luna 18***	***Failed robot sampler***
28 Sept 1971	***Luna 19***	***Orbiter, lunar gravity, TV, micrometeorites***
14 Feb 1972	***Luna 20***	***Robot sample return, Apollonius***
16 Apr 1972	Apollo 16	Human landing, Descartes
7 Dec 1972	Apollo 17	Human landing, FIRST geologist on the Moon, Taurus-Littrow
8 Jan 1973	***Luna 21***	***Lunokhod 2, Le Monier***
29 May 1974	***Luna 22***	***Orbiter, lunar gravity, TV, micrometeorites***
28 Oct 1974	***Luna 23***	***Failed robot sampler***
9 Aug 1976	***Luna 24***	***Robot sample return, Mare Crisium***

[*]Soviet missions are shown in bold-italic, US missions are shown in normal font.

Table 2. *Spacecrafts launched in 2002 by various countries.*

Country	Number of launches	Number of spacecrafts
Russia	25	35
USA	18	23
Western Europe	12	14
China	5	6
Japan	3	8
India	1	1
Israel	1	1

Table 3. *Scientific launches during 1996–2005 by various countries.*

Country	Number of launches
Russia	1
USA	21
ESA	5
Japan	4

4. Historical perspective

We now briefly describe the historical perspective of the Russian lunar exploration program for the study of the Moon in the context of space programs of various countries. The Russian missions carried out so far, for exploration of the Moon, are summarized in table 1. The first spacecraft (Luna 1) was sent towards the Moon on January 2nd, 1959. In the same year Luna 2 hard-landed on the Moon. It was the first man-made object that landed on the lunar surface. The following year Luna 3 took the first photographs of the lunar far-side which humans had never seen before. In 1962–1965 America sent several spacecrafts of the Ranger series to the Moon. A significant achievement came when Luna 9 made the first soft landing and provided a TV-panorama of the lunar surface. In 1968, Zond 5 and Zond 6 were the first lunar flyby with biological objects and safely returned to Earth. In December 1968, the first humans orbited the Moon during the

Table 4. *Spacecraft launches in Russia, 2002.*

Date	Carrier rocket	Spacecraft	Purpose
25 February	Soyuz-5	Cosmos-2387	Military
17 March	Rokot-Briz	Grace (USA)	On behalf of USA
19 March	Rokot-Briz	Colibri-200	On behalf of Australia (partially of Russia)
21 March	Soyuz-5	Program MI-8	International Space Station
30 March	Proton-K	Intelsat-903 (USA)	On behalf of USA (partially of Russia)
1 April	Molniya-M	Cosmos-2388	Military
25 April	Soyuz-5	Soyuz-TM-34	International Space Station
7 May	Proton-K	Direc TV-5 (USA)	On behalf of USA
28 May	Cosmos-3M	Cosmos-2389	Military
10 June	Proton-K	Express-A No 4	Communication
20 June	Rokot-Briz	Iridium-97, 98 (USA)	On behalf of USA (partially of Russia)
26 June	Soyuz-5	Progress M-46	International Space Station
8 July	Cosmos-3M	Cosmos-2390, 2391	Military
25 July	Proton-K	Cosmos-2392	Military (partially ecological)
22 August	Proton-K	EchoStar-8 (USA)	On behalf of USA
25 September	Soyuz-FG	Progress MI-9	International Space Station
26 September	Cosmos-3M	Nadezhda	Navigational
15 October	Soyuz-5	Foton–M No 1	–
17 October	Proton-K	Integral (ESA)	On behalf of ESA (partially of Russia)
30 October	Soyuz-FG	Soyuz TMA-1	International Space Station
25 November	Proton-K	Astra–1 K (Luxembourg)	On behalf of private companies SEC
28 November	Cosmos-3M	Mozhaets, Rubin-1	In behalf of Germany (partially of Russia)
20 December	Dnepr-1	Rubin-2, LatinSat A, SaudiSat-1C, UniSat-2, Traiblazer	On behalf of Germany, Argentina, Saudi Arabia, Italy and USA: 5 satellites
24 December	Molniya-M	Cosmos-2393	Military
25 December	Proton-K	Cosmos-2394–2396	Military
29 December	Proton-K	Nimiq-2	On behalf of Canada

Apollo 8 mission, and on July 20th, 1969, Apollo 11 landed the first humans on the Moon's surface. After that there were the first automatic sample return missions (Luna 16, Luna 20 and Luna 24), first robotic rover Lunokhod-1 (1970) which were followed by five successful American human landings by Apollo missions. The last mission of that unprecedented lunar race was Luna 24, which automatically returned sample from Mare Crisium in August 1976.

As one can see from table 2, in 2002, for example, Russia had launched more spacecrafts than any other country. However, during the last decade, Russia has launched (unsuccessfully) only one spacecraft for the purpose of planetary research, while the United States has launched 21 (table 3). Table 4 gives an idea about the current program of Russian space launches, mainly with non-scientific objectives, such as for communication and military purposes. In this context, the Luna-Glob project will be a path-breaking mission in planetary and geoscience studies and will provide important data regarding the origin of the Moon.

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