

The Moon As a Laboratory for Biological Contamination Research

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Introduction

The Moon provides a high fidelity test-bed to prepare for the exploration of Mars, Europa, Enceladus, etc.

Much of our knowledge of planetary protection and contamination science are based on models, brief and small experiments, or measurements in low Earth orbit.

Experiments on the Moon could be piggybacked on human exploration or use the debris from past missions to test and expand our current understanding to reduce the cost and/or risk of future missions to restricted destinations in the solar system.

Planetary Protection Experiments

Currently the Moon is a Committee on Space Research's (COSPAR) planetary protection Mission Category I outbound V unrestricted Earth return¹. These categories levy no planetary protection requirements on a mission. Thus, maximum flexibility to test and evaluate organic and biological contamination is available for the project team.

Dust in the wind

- Conduct experiments in the vicinity around a lunar settlement or landing site to explore the the spread of contamination.

The road less traveled

- Conduct biological, organic, and engineering component exposure experiments without the interference of the diffuse atmosphere of low Earth orbit.
- Test the long distance spread of spacecraft gases.

Any port in the storm

- Scientists at a future facility could evaluate the safety of potentially hazardous samples or conduct the research and curation of such samples on the Moon.
- Such research facilities could already exist primarily to study *in situ* lunar science without fighting the pervasive biological^{4,5} and water⁶ contamination of Earth or for mining.

Lunar Artifacts: A Half Century of Exposure and Counting

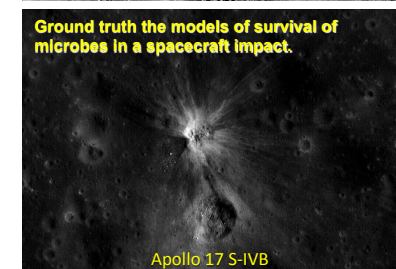
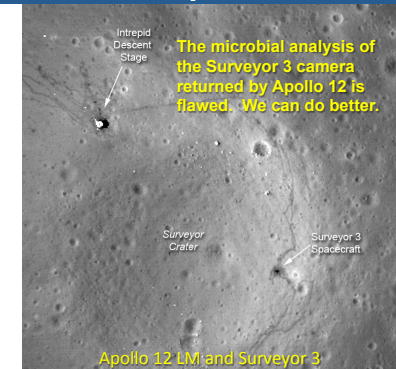
New experiments on old spacecraft^{2,3}

- Sterilized microbes are organic-rich. Does processing on lunar surface mask their origin?
- Were past planetary protection measures insufficient or excessive?
- How much contamination is spread when working in target?
- How do materials alter after lengthy space exposure?
- Do we sufficiently understand how to preserve sites of particular historical significance⁷?

Catalog of Lunar Artifacts

Spacecraft	Landing Type	Landing Date	Latitude, Longitude	Ref.
Luna 2	Impact	14 September 1959	29.1 N, 0 E	a
Ranger 4	Impact	26 April 1962	15.5 S, 130.7 W	b
Ranger 6	Impact	2 February 1964	9.39 N, 21.48 E	c
Ranger 7	Impact	31 July 1964	10.63 S, 20.68 W	c
Ranger 8	Impact	20 February 1965	2.64 N, 24.79 E	c
Ranger 9	Impact	24 March 1965	12.83 S, 2.39 W	c
Luna 5	Impact	12 May 1965	31 S, 8 W	b
Luna 7	Impact	7 October 1965	9 N, 49 W	b
Luna 8	Impact	6 December 1965	9.1 N, 63.3 W	b
Luna 9	Soft Landing	3 February 1966	7.13 N, 64.37 W	b
Surveyor 1	Soft Landing	2 June 1966	2.47 S, 43.34 W	c
Luna 10	Impact	Unknown (1966)	Unknown	d
Luna 11	Impact	Unknown (1966)	Unknown	d
Surveyor 2	Impact	23 September 1966	5.5 N, 12.0 W	b
Lunar Orbiter 1	Impact	29 October 1966	6.7 N, 162 E	b
Luna 13	Soft Landing	24 December 1966	18.87 N, 62.05 W	b
Luna 12	Impact	Unknown (1967)	Unknown	d
Surveyor 3	Soft Landing	20 April 1967	3.02 S, 23.42 W	c
Surveyor 4	Impact	17 July 1967	Unknown	e
Surveyor 5	Soft Landing	11 September 1967	1.46 N, 23.19 E	c
Lunar Orbiter 3	Impact	9 October 1967	14.3 N, 97.7 W	a
Lunar Orbiter 2	Impact	11 October 1967	3 N, 119 E	a
Surveyor 6	Soft landing	10 November 1967	0.47 N, 143 W	c
Lunar Orbiter 4	Impact	Unknown (1967)	Unknown	d
Surveyor 7	Soft Landing	10 January 1968	40.98 S, 11.51 W	c
Lunar Orbiter 5	Impact	31 January 1968	3 S, 83 W	a
Luna 14	Impact	Unknown	Unknown	d
Apollo 10 LM descent stage	Impact	Unknown (1969)	Unknown	d
Luna 15	Impact	21 July 1969	17 N, 60 E	b
Apollo 11 LM descent stage	Crewed Landing	20 July 1969	0.67 N, 23.47 E	a
Apollo 11 LM ascent stage	Impact	Unknown	Unknown	d
Apollo 12 LM descent stage	Crewed Landing	19 November 1969	3.01 S, 23.42 W	a
Apollo 12 LM ascent stage	Impact	20 November 1969	3.94 S, 21.20 W	a
Apollo 13 S-IVB	Impact	15 April 1970	2.56 S, 27.89 W	c
Luna 16	Soft Landing	20 September 1970	0.51 S, 56.36 E	c
Luna 17	Soft Landing	17 November 1970	38.24 N, 35.00 W	c
Lunokhod 1	Rover	17 November 1970	38.32 N, 35.01 W	c
Apollo 14 S-IVB	Impact	4 February 1971	8.18 S, 26.03 W	c
Apollo 14 LM descent stage	Crewed Landing	5 February 1971	3.65 S, 17.47 W	a
Apollo 14 LM ascent stage	Impact	7 February 1971	3.42 S, 19.67 W	a
Apollo 15 S-IVB	Impact	29 July 1971	1.29 S, 11.82 W	c
Apollo 15 LM descent stage	Crewed Landing	30 July 1971	26.13 N, 3.63 E	a
Apollo 15 LM ascent stage	Impact	3 August 1971	26.36 N, 0.25 E	a
Luna 18	Impact	11 September 1971	3.76 N, 56.66 E	c
Apollo 15 subsatellite	Impact	Unknown	Unknown	d
Luna 20	Soft Landing	21 February 1972	3.79 N, 56.62 E	c
Apollo 16 S-IVB	Impact	19 April 1972	1.3 N, 23.8 W	c
Apollo 16 LM descent stage	Crewed Landing	21 April 1972	8.97 S, 15.50 E	a
Apollo 16 LM ascent stage	Impact	Unknown (1972)	Unknown	d
Apollo 16 subsatellite	Impact	Unknown (1972)	Unknown	d
Apollo 17 S-IVB	Impact	10 December 1972	4.17 S, 12.33 W	c
Apollo 17 LM descent stage	Crewed Landing	11 December 1972	20.19 N, 30.77 E	a
Apollo 17 LM ascent stage	Impact	15 December 1972	19.97 N, 30.49 E	a
Luna 19	Impact	Unknown (1973)	Unknown	d
Luna 21	Soft Landing	15 January 1973	26.00 N, 30.41 E	c
Lunokhod 2	Rover	15 January 1973	25.83 N, 30.92 E	c
Explorer 35 / IMP-E	Impact	Unknown (1973 or later)	Unknown	d
Luna 23	Soft Landing	6 November 1974	12.67 N, 62.15 E	c
Luna 22	Impact	Unknown (1976)	Unknown	d
Luna 24	Soft Landing	18 August 1976	12.71 N, 62.21 E	c
Explorer 49 / RAE-B	Impact	Unknown (1977 or later)	Unknown	d
Hiten	Impact	10 April 1993	34.0 S, 55.3 E	f
Hagoromo	Unknown	Unknown	Unknown	g
Lunar Prospector	Impact	31 July 1999	87.7 S, 42.35 E	h
SMART-1	Impact	3 September 2006	33.3 S, 46.2 W	i
Chandrayaan MIP	Impact	14 November 2008	Unknown	j
Quna	Impact	Unknown	Unknown	h
Okina	Impact	12 February 2009	28 N, 159 W	a
Chang'e 1	Impact	1 March 2009	1.5 S, 52.36 E	k
Kaguya	Impact	10 June 2009	65.5 S, 80.4 E	l
LCROSS Centaur	Impact	9 October 2009	84.68 S, 48.69 W	a
LCROSS spacecraft	Impact	9 October 2009	84.73 S, 49.36 W	a
GRAIL A	Impact	17 December 2012	75.61 N, 26.59 W	c
GRAIL B	Impact	17 December 2012	75.65 N, 26.83 W	c
Chang'e 3	Soft Landing	14 December 2013	44.12 N, 19.51 W	c
LADEE	Impact	18 April 2014	11.85 N, 93.25 W	c

Some Apollo Sites



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- ⁷<https://www.nasa.gov/directorates/heo/library/reports/lunar-artifacts.html>
- ⁸ISSDC database and Orloff, R.W., *Apollo by the Numbers*, 2000
- ⁹Siddiqi, A., *Deep Space Chronicle*, 2002
- ¹⁰Object imaged on surface by Lunar Reconnaissance Orbiter Camera
- ¹¹Object left in lunar orbit with no tracking or communication, orbit presumably decayed, estimated year of decay in parentheses if available.
- ¹²Possibly exploded before impact, original target 0.40 N, 1.33 W
- ¹³Uesugi, K., Results of the MUSES-A "Hiten" Mission, *Adv. Space Res.*, 18, 11, 69-72, 1996
- ¹⁴Lunar orbit/impact unconfirmed, Hagoromo may have gone into heliocentric orbit h. Estimated/Projected
- ¹⁵Burchell et al. The SMART-1 lunar impact, *Icarus* 207, 28-38, 2010
- ¹⁶Impacted in Shackleton crater near south pole, exact coordinates unknown
- ¹⁷Xinhua News Agency, China's lunar probe Chang'e-1 impacts moon, 1 March 2009
- ¹⁸Kaguya press release, 19 June 2009