CubeSats technologies progressing from LEO to Lunar orbit for the next generation of Moon and deep space exploration missions

Microsatellite utilization symposium

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Aerospace Engineering

College of Science and Technology, Nihon University

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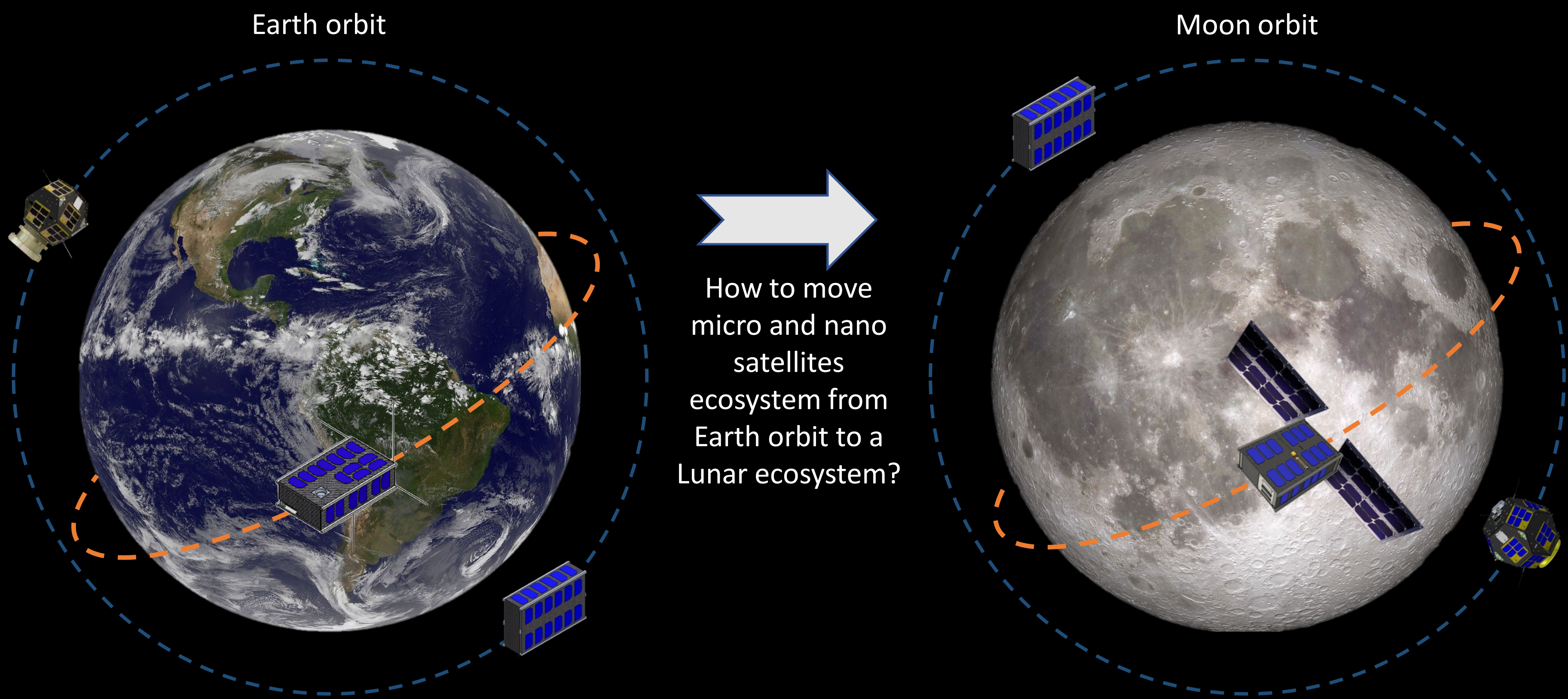
Looking into the future of micro and nano sats

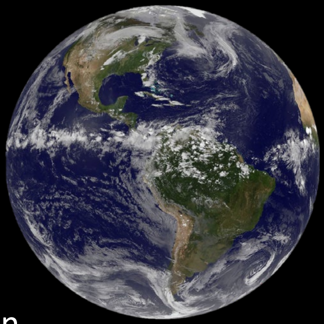


Earth vs Moon micro and nano space ecosystem

Multiple players

Diversification of applications

Well understanding of environment (physical and business)



Regular replacement

Growing ecosystem

Rapid evolution

Transportation infrastructure

Mature systems

Big missions

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Large transportation systems

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Larger space systems

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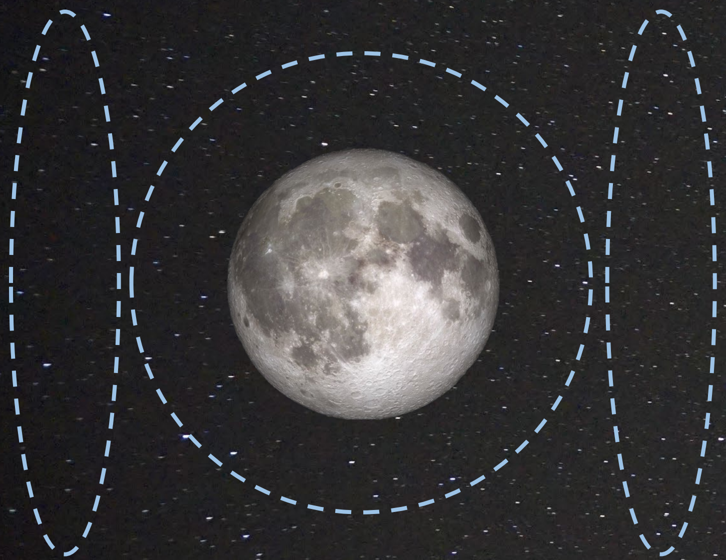
Nanosatellites have demonstrated to be exceptional tools at LEO. Exploration, transportation, reutilization, and recovery of extraterrestrial materials are the next step for nanosatellites beyond LEO.

Lunar orbit space



Lunar exploration & exploitation

- Propellant depots
- Servicing
- Testbed for deep space missions
- Mining
- Science missions
- Transit nodes
- Communication link services
- Transportation services

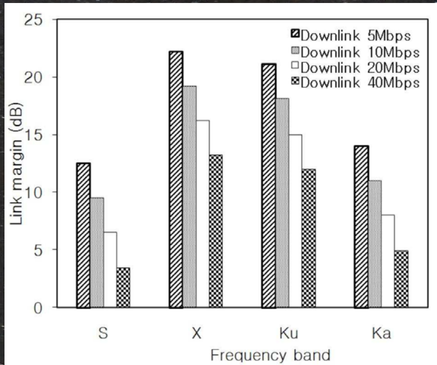
Lunar mission constrains and requirements

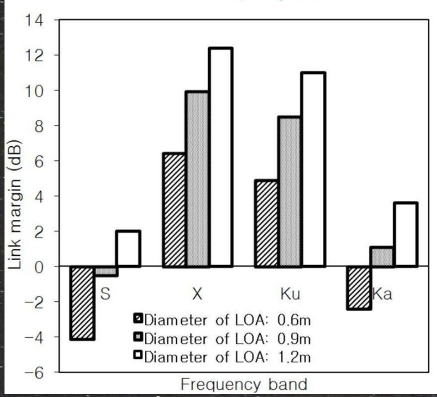
- Communication links
- Station keeping and navigation
- Power requirements
- Satellite size & mass

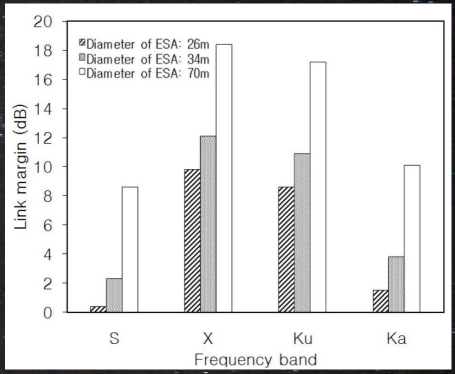
Lunar orbiter (LO) communication requirements

Downlink model parameters

Classification	Unit	S band	X band	Ku band	Ka band
System bandwidth	MHz	26	26	26	26
Distance	km	384,403	384,403	384,403	384,403
Transmit frequency	MHz	2,295	8,420	12,200	32,000
		Lunar orbiter			
Transmit power	W	20.0	20.0	20.0	20.0
	dBW	13.0	13.0	13.0	13.0
Antenna diameter	M	1.2	1.2	1.2	1.2
Antenna efficiency		0.7	0.7	0.7	0.7
Antenna gain	dBi	27.7	38.9	42.2	50.5
Antenna circuit loss	dB	0.6	0.4	0.3	0.25
Antenna pointing loss	dB	3.2×10^{-6}	4.4×10^{-5}	9.3×10^{-5}	6.4×10^{-4}
		Channel			
Free space loss	dB	211	222	225.9	234.2
Atmospheric attenuation	dB	0.033	0.039	0.1	0.154
Ionospheric loss	dB	0.2	0.2	0.2	0.2
Rain attenuation	dB	0.0	1.0	4.7	19.2
Lunar flux density loss	dB	5.34	5.4	5.0	3.96
		Earth station			
Antenna diameter	M	34.0	34.0	34.0	34.0
Antenna efficiency		0.7	0.7	0.7	0.7
Antenna gain	dBi	56.7	68.0	71.2	79.6
Antenna circuit loss	dB	0.6	0.4	0.3	0.25
Antenna pointing loss	dB	0.003	0.044	0.150	0.639
Noise temperature	K	34.0	31.9	38.0	44.9



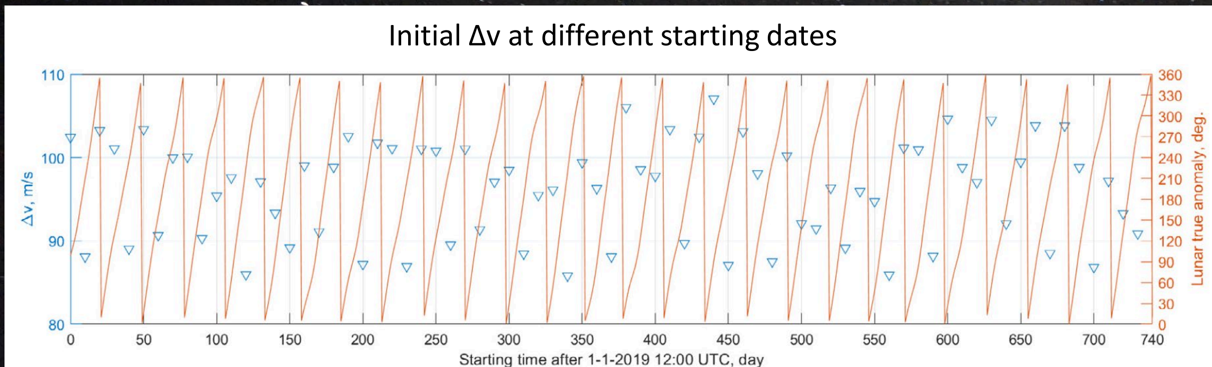


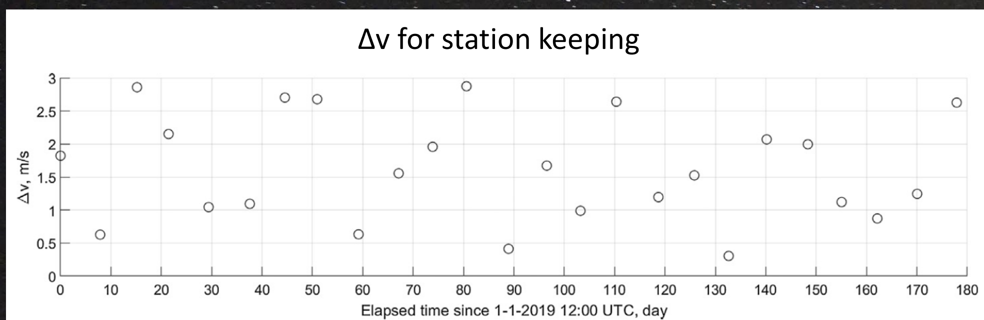


LO transmitter power, LO and GS antennas diameter, data rate and link marging must be considered.

Source: Lee, *et al.*

Lunar orbiter (LO) communication requirements





Example conditions:

- Halo orbit (15,000 x 35,000 km)
- Deployment Δv: 42 – 101 m/s
- Station keeping month average of 6.7 m/s

Δv, propulsion power, size and mass impose considerable constrains and requirements.

Model	Type	Dry, kg	Propel., kg	Power, W	Size, U	Thrust, mN	I_{sp}, s	Δv, m/s
Aerojet MPS-120[a]	Chemical	1.06	0.38	10	1	250	206	142.5
VACCO Hybrid ADN[b]	Chemical	1.01	0.53	14	1	100	200	192.5
JPL MarCo[c]	Cold-gas	1.56	1.93	10	2	50	40	106.5
Busek Bet-1mN[d]	Electrospray	1.07	0.08	15	1	0.7	800	119.6

Source: Chen, *et al.*

Lunar orbiter key technologies

Due to constrains and requirements a LO needs:

- Increased autonomous operation
- Increased precision in operations (pointing, in situ data processing)
- Increased reliability in a harsher environment
- Reduced mass to allow enough mission time (propellant)

Key parts and subsystems:

OBC & navigation controller
EPS controller
Payload controller(s)
Lightweight structure
Precision time keeping

When selecting parts and systems there is not a unique group of standards but a continuum qualification criteria

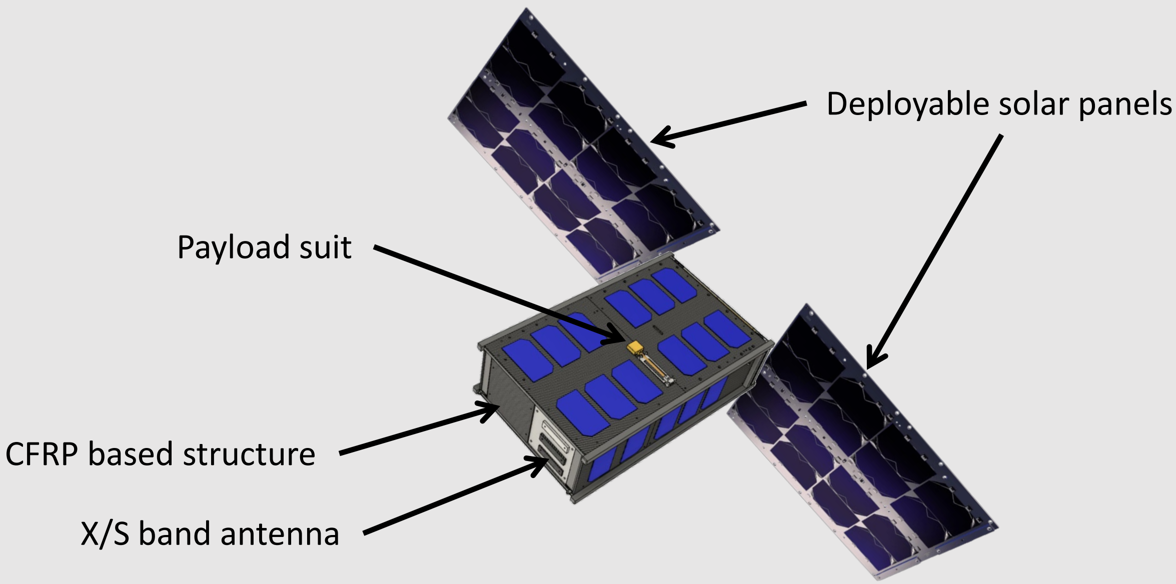
System level performance

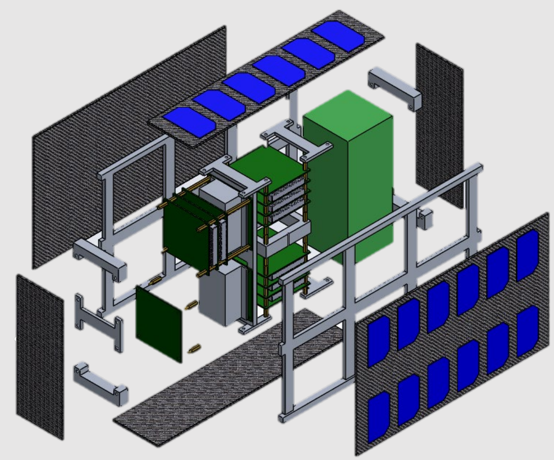
Qualification requirements

Lunar orbiter mission

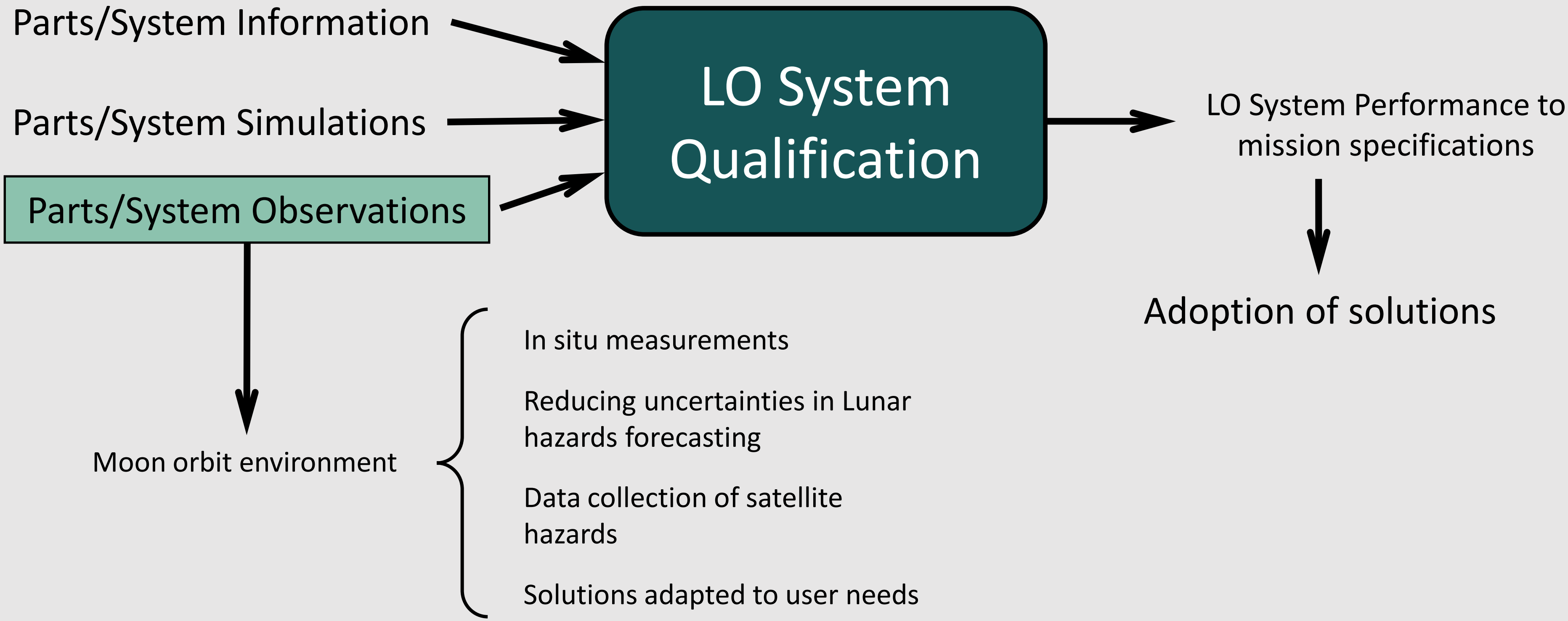
Mission: 6U CubeSat to measure the effects of the space environment in electronic systems, their performance and the use of protection materials against ionizing radiation such as charged particles and UV light at the Moon orbit.

Objetive: to strengthen and broaden the knowledge of SmallSat applied technology to the Moon orbit and deep space exploration.





Lunar orbiter key components qualification

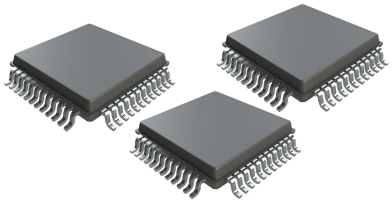


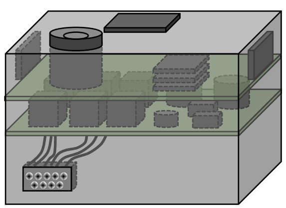
Lunar orbiter payloads

MENTALITY (Multiprocessor ExperimeNT At Lunar orbIT flYby)

Set of MCUs/MPUs for autonomous operation and in situ analysis of spacecraft and payload data

- AI-based core processor
- Milticore MCUs/MPUs with error correcting codes in memory





RADMOONX (RADiation Material eXperiment)

Test of protection material against ionizing radiation and UV electromagnetic radiation:

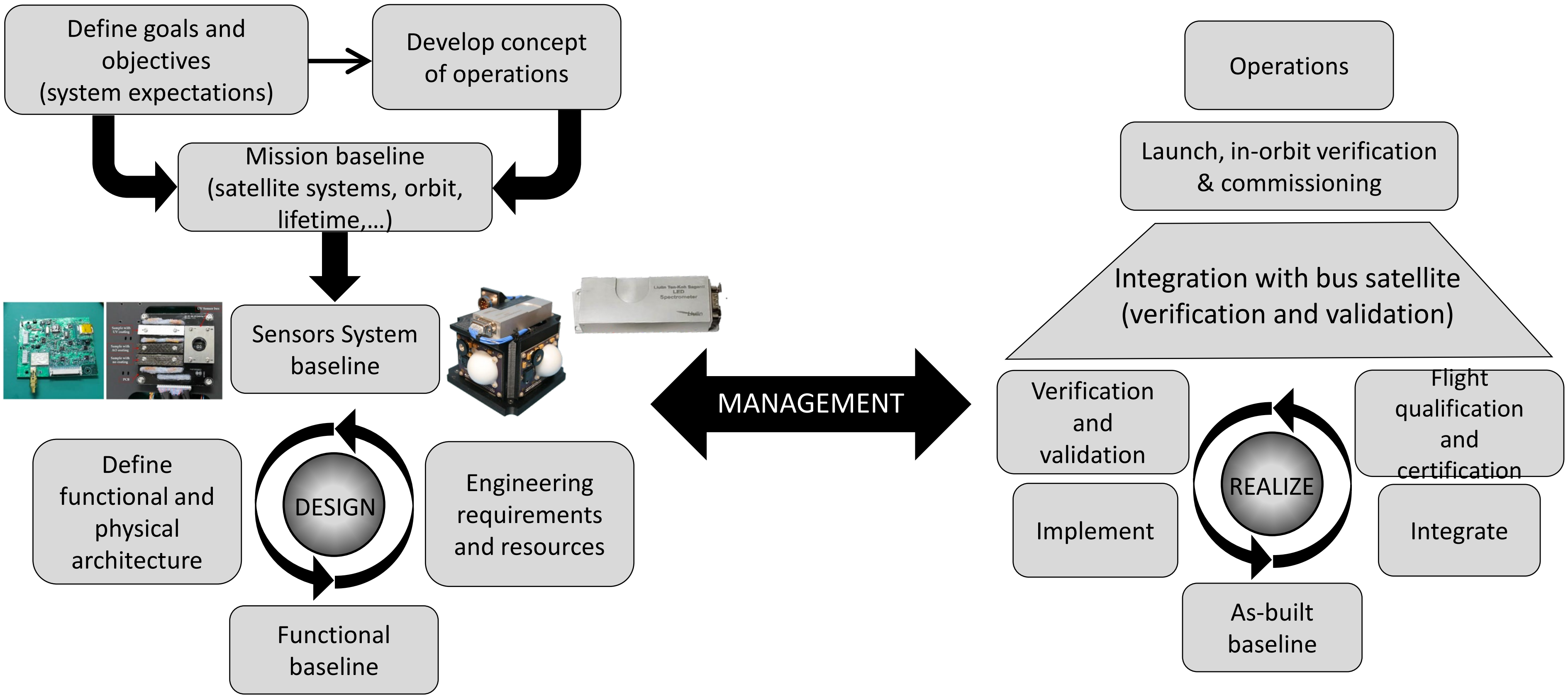
- Test of materials for use in infrastructure on the surface of the Moon
- Data of total dose, deposited energy spectra, material degradation, as well as thermal and mechanical properties change

SWEETMoon (Space Weather Environment Experiment aT the Moon)

Payload system for observing the interaction of the magnetosphere tail with the Moon and its environment.

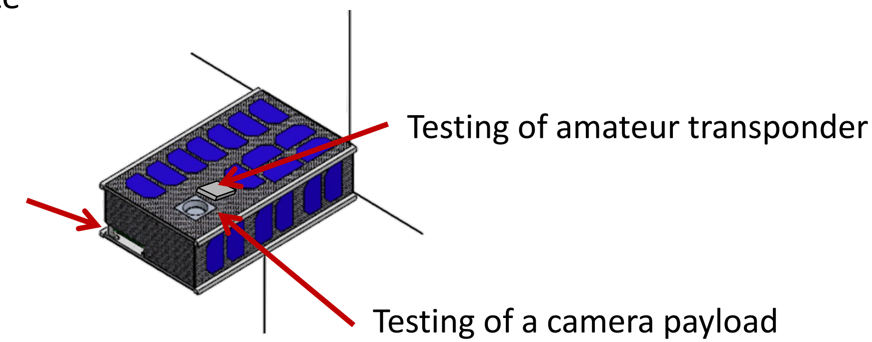
Under consideration with posible partners

Lunar orbiter development



Present projects and the path to the Moon

We are currently developing Ten-Koh 2 satellite



We have plans to develop Ten-Koh 3 and LO CubeSats

Ten-Koh 3: mission is planned for advanced and secure communications.

Ten-Koh 3 will also carry precursors of LO systems designs.

Shinen2 ⟶ Ten-Koh ⟶ Ten-Koh 2 ⟶ Ten-Koh 3 ⟶ LO

Thank you