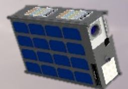
LUNARAD – A Study of Radiation Shielding Technologies in Cis-lunar Space



ISSC – May 11-12, 2020 – Pauline Faure and Dave Pignatelli

CAL POLY

CUBESAT

OUTLINE

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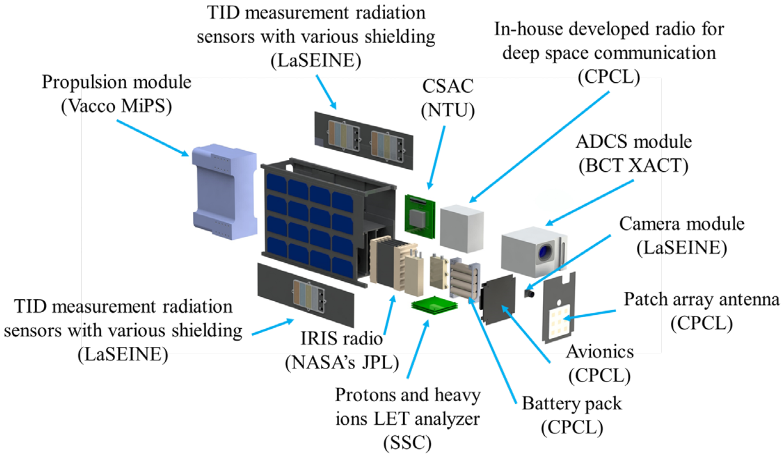
LUNARAD at a GLANCE

- **Project lead –** Cal Poly CubeSat Laboratory (CPCL)
- **Partners –** Kyushu Institute of Technology (Kyutech), Japan, and Nanyang Technological University (NTU), Singapore
- **Primary mission –** Test radiation shielding technologies in cis-lunar space
- **Secondary missions –** Test a chip scale atomic clock (CSAC), test in-house developed radio for deep space communication, and take photographs of the Moon



Spacecraft	6U CubeSat
Mass	10kg
Power	12W average; 35W peak
Orbit	Periapsis: 174,500km Apoapsis: 375,000km
Mission lifetime	56 Earth days

MOTIVATIONS

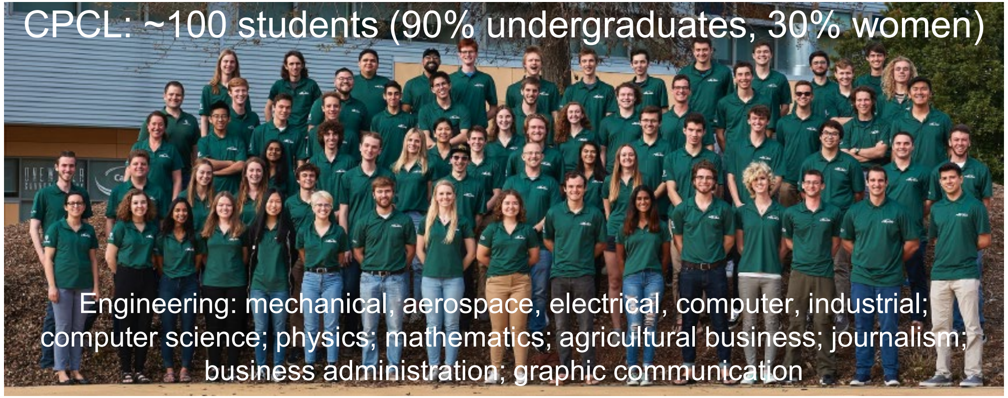
- Cal Poly CubeSat Laboratory's mission statement is to

  "advance the space industry by providing inclusive, high-quality workforce development and community engagement programs that enable the next generation of space discoveries"

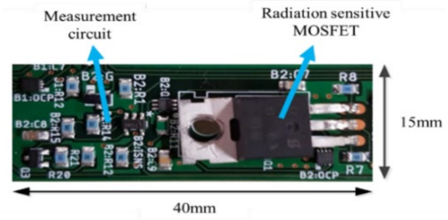
- NASA's Strategic Goals and Strategic Knowledge Gaps (SKGs)
  - **SKG III-G "Test radiation shielding technologies" –** LunaRad's primary mission (TID, LET) will help support long-term lunar exploration programs
  - **SKG III-B-3 "Autonomous surface navigation" –** LunaRad's CSAC demonstration will be the first step toward a constellation of CubeSats for a global navigation system in lunar orbit
  - **Strategic Goal 3.3 "Inspire and engage the public in aeronautics, space, and science" –** LunaRad's Moon photographs will contribute to developing general public curiosity in space sciences and engineering

MOTIVATIONS

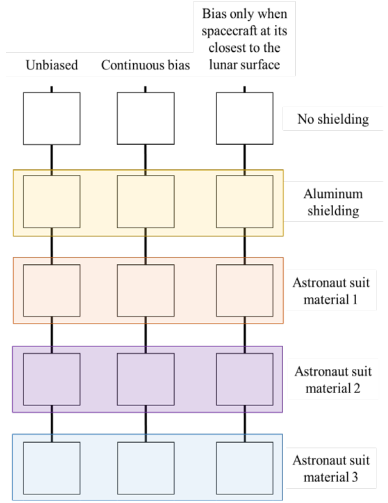
- Engineering advances – In-house deep space communications system
- Global science, technology, engineering, and mathematics project-based learning opportunities
    - 100+ multidisciplinary undergraduate and graduate students involved
    - International cooperation and outreach capabilities
    - Stimulate the number of players to engage in space activities



PROJECT DESCRIPTION – Primary Mission

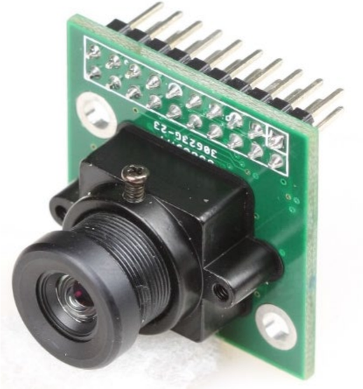


- Primary mission lead: Kyutech
- Total ionization dose measurements using MOSFETs – TRL 6
  - To be flown on board BIRDS-4 in summer 2020
  - Unbiased MOSFETs to minimize error from environmental factors and continuously biased MOSFETs (5V) to emphasize change in gate voltage and increase range of measurements at lunar periapsis
- Evaluation of aluminum and astronaut suit materials (polybenzimidazole-based material, urethane coated nylon, or neoprene coated nylon)
- Linear energy transfer analyzer for protons and heavy ions – TRL 6
  - Flown on board TechDemoSat-1 in 2014
  - LET range: 0.9 to 7MeV.cm^2/mg for heavy ions and 0.1 to 5MeV.cm^2/mg for protons



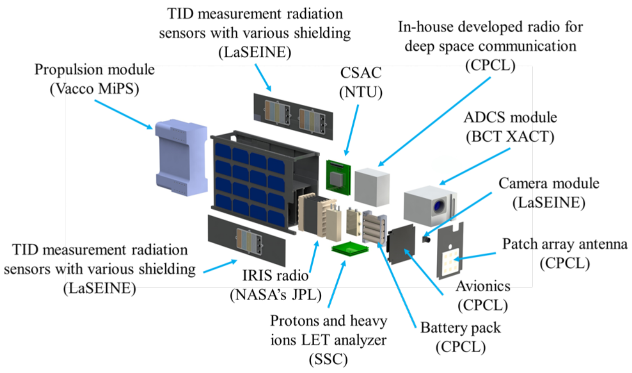
PROJECT DESCRIPTION – Secondary Missions

- Secondary missions leads: Kyutech and NTU
- Chip-scale atomic clock – TRL 7
  - Flown on board SPATIUM in 2018
  - Volume: less than $20cm^3$; Mass: less than 50g; and Power consumption: about 100mW
  - 10MHz output signal and $3.0*10^{-10}$ Allan deviation
- Camera, OmniVision's OV5642 – TRL 9
  - Flown on board several Kyutech's missions
  - Image sensor: 5MP; Mass: less than 20g; and Power consumption: less than 1W



PROJECT DESCRIPTION – Satellite Bus Design

- Bus design lead: Cal Poly CubeSat Laboratory
- Further the development of low-resource, easily manufacturable, but scientifically capable deep space spacecraft
  - Selection of COTS components
  - Use of in-house developed sub-systems
  - Decrease risk by selecting commercially available capabilities that are missing at CPCL
  - Validate CPCL capabilities for deep space missions
  - Involve undergraduate and graduate students

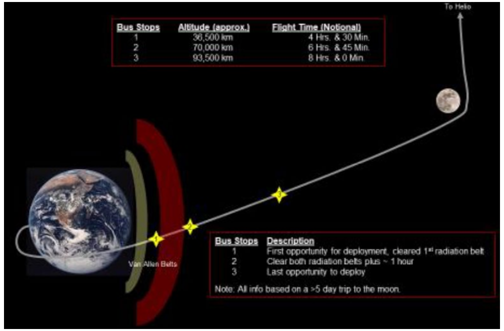


System	Volume [U]	Mass [kg]	Peak Power [W]	TRL [-]
CPCL standard bus – Structure, C&DH, EPS	0.5	2.0	7	4 to 9
ADCS – Blue Canyon XACT	0.5	1.2	3	9
COM – IRIS radio	0.5	1.2	35	9
COM – CPCL's deep space radio	0.5	0.8	15	1
Propulsion – Vacco MiPS	3	3.5	15	7
Payload – TID radiation sensors, LET analyzer, CSAC, camera	1	1.0	5	6 to 9

PROJECT DESCRIPTION – Satellite Bus Design

Orbital dynamics and propulsion

- Assumed LunaRad deployed at Bus Stop 3 from the Interim Cryogenic Upper Stage (ICPS)
- From Bus Stop 3, perform a total of two maneuvers to put LunaRad on elliptical orbit around the Moon
  - Maneuver 1 at separation + 2 hours
  - Maneuver 2 at separation + 5 days
  - Total ΔV = 40m/s
- End of life
  - Spacecraft lifetime: 60 days
  - De-orbit and burn through Earth's atmosphere



NASA – SLS Artemis 2 Secondary Payloads 6U & 12U Potential Cubesat Accommodation, August 2019

Baselined Propulsion System

Model	Vacco MiPS
Total impulse [Ns]	755
Available ΔV [m/s]	~93 for 10kg CubeSat
Operations	Orbital maneuvers (40m/s) Orbit maintenance, conjunction avoidance, contingency operations (~53m/s)

PROJECT DESCRIPTION – Satellite Bus Design

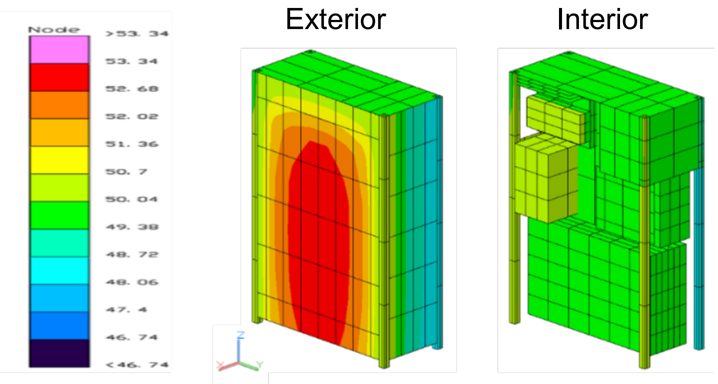
Electrical power system and thermal

- Total estimated average power consumption: 12W
  - 32 body-mounted solar cells: 28% efficiency at 25°C
  - 4 Li-ion batteries: 230Wh/kg energy density
- Passive thermal control
  - Worst hot or cold cases: ~50°C for external and internal components
  - Critical operating temperature range: IRIS radio (-20 to +50°C) and Li-ion batteries (0 to +45°C)

Operational Modes	Science	Standby	Desaturation†	X-band Downlink††
Duty Cycle (% per orbit)	20.00	77.50	1.00	1.50
Subsystems	Power Consumption [W]			
Propulsion	0.50	0.50	15.00	0.50
Communication	12.60	0.50	12.60	35.00
Thermal	3.00	3.00	3.00	5.00
Power	2.10	0.50	3.20	4.20
C&DH	0.30	0.30	0.30	0.30
ADCS	3.00	1.00	1.00	3.00
Payload	2.00	0.00	0.00	0.00
Average Power Consumption [W]	4.70	4.50	0.35	0.72
Average Power Consumption + 20% Margin [W]	5.64	5.39	0.42	0.89
Total Average Power Consumption + 20% Margin [W]	12.36			

†Assume a 15min desaturation time
††Based on payload data size, assumed 30min downlink time

Worst hot case analysis results



PROJECT DESCRIPTION – Satellite Bus Design

Communication and attitude determination and control

- Communications system assumptions
  - Primary: IRIS radio with Deep Space Network as ground support, TRL 9
  - Secondary: CPCL's X-band radio with CPCL's X-band ground station as support, TRL 1
- With IRIS and DSN: link margin of 6.5dB at 384,000km
- ADCS requirement driven by communications and propulsion
- ADCS baselined to commercially available BCT's XACT module, TRL 9

Assumption/Input	Entry
Central frequency [GHz]	8.40
Spacecraft transmission power [W]	3.80
Spacecraft antenna gain [dB]	16.00
Spacecraft max. distance from Earth [km]	384,000.00
Ground station EIRP [dBm]	139.60
Ground station dish diameter [m]	34.00
Ground station power output [kW]	20.00
Ground station min. elevation angle [rad]	0.02
Max. slant range [km]	384,000.00

Parameter	Entry
Spacecraft transmit power [dBW]	5.80
Pointing losses [dB]	0.00
Line losses [dB]	3.00
Rain losses [dB]	3.00
Atmospheric losses [dB]	0.00
Eb/N0 [dB]	11.00
Receive antenna gain [dB]	78.00
Electron losses [dB]	0.15
Transmit antenna gain [dB]	16.00
Polarization losses [dB]	1.00
Free space path loss [dB]	222.62
System noise temperature [K]	250.00
Fixed data rate [bps]	512,000.00
Data rate term [dB-Hz]	-147.53
Total gains [dB]	99.80
Total losses [dB]	82.25
Link margin	6.55

MOVING FORWARD

- Advance CPCL's capabilities for deep space missions
    - Communications (space and ground segments)
    - Electrical power system
    - Attitude determination and control
    - Propulsion

- Funding and launch opportunities

- Planned demonstration of some of the capabilities from 2021

SUMMARY

- LunaRad – 6U CubeSat for the study of radiation shielding technologies to support long-term lunar exploration programs

- Further the development of low-resource, easily manufacturable, but scientifically capable deep space spacecraft
  - Address NASA's Strategic Plan and Strategic Knowledge Gaps
  - Involve multidisciplinary undergraduate and graduate students

- Advance Cal Poly CubeSat Laboratory's bus capabilities to tackle deep space missions

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LunaRad