Title: CONSTELLATION OF CUBESAT TO ANALYZE THE EFFECTS OF EARTH'S MAGNETIC TAIL ON THE MOON (MAGNETA-CUBE)

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1. NEED

The solar wind impacts on the Earth's magnetic field, produces a "tail" in the direction of the wind. The Moon passes once (lasting six days) through this wake or "magnetic tail" during its orbital period. It is speculated that this event can cause "lunar dust storms", electrostatic discharges and even that it could "seed" water from the Earth's atmosphere on the lunar surface[1]. Therefore, it is expected to study the vicinity of the Shackleton crater, it is worth mentioning that this area and its surroundings will be studied as a potential landing site by the Artemis 3 mission that will be launched in 2025[2], taking into account that this region has a favorable lighting, we must study these effects and make sure that they are not harmful to our missions, or failing that, to know them, in order to mitigate them in the future.

2. OBJECTIVES

Primary objective

1. To study the variations of the electromagnetic field intensity in a circular lunar low orbit at 100 km and the lunar dust at the south pole of the Moon in an area of about 25,000 km^2 (90 km in all directions from the center of the Shackleton crater) when it encounters the "magnetic tail" of the Earth with a revisit time of 2 hours.

Secondary objective

1. To demonstrate if there is a relationship between the Earth's magnetosphere and the distribution of ice on the Moon.[3]

3. CONCEPT OF OPERATIONS

Space segment:

The space segment will consist of a constellation of three 6U CubeSats in low-altitude lunar orbit, known as “frozen orbits” for their stability. These CubeSats will be placed every 120° so that they can cover 25,000 km^2 with the aim that the area is monitored every 2 hours. The measurements data from the south pole will be taken when the Moon comes into contact with the magnetic tail of the Earth. The constellation will have the capability to activate its payload three days before the Moon enters the full Moon phase (it is worth mentioning that the full moon phase coincides with the entrance to the magnetic tail[1]), the payload will be deactivated three days after the magnetic entry.

Ground segment:

For the purposes of this mission, it has been decided to use the services that can be provided by the "Lunar Pathfinder" mission, which is being developed by ESA in conjunction with other European collaborators such as Surrey Satellite Technology Ltd and Goonhilly Barth Station.

The "Lunar Pathfinder" spacecraft is designed to provide affordable communications services for lunar missions, via S-band and UHF links, to lunar assets on the surface and in orbit around the Moon, and an X-band link to Earth. The stations with it will communicate will include ESA's own network, which will be complemented by the new commercial ground stations for deep space.[4]

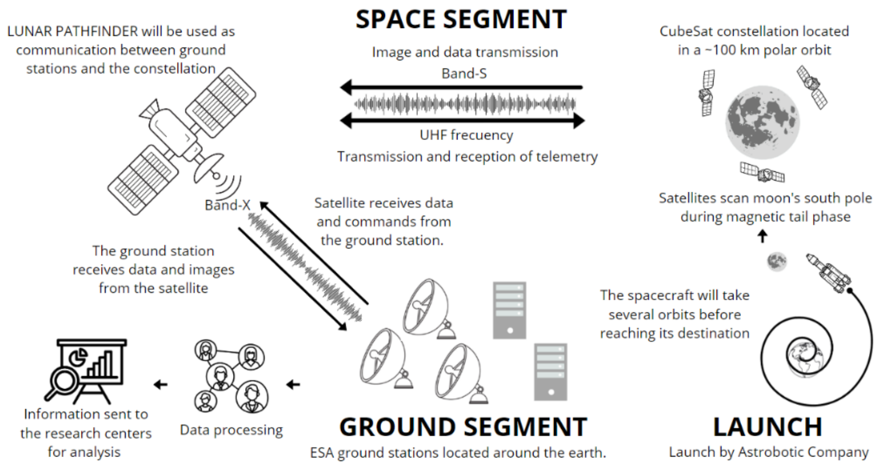

Figure 1. Graphical description of the concept of operation

4. KEY PERFORMANCE PARAMETERS

1. The constellation will take imagery (8-bit or 16-bit) from an altitude of 100 km with a 10 m GSD (this spatial resolution was selected based on evidence about the physical dimensions of the dust clouds, which extend horizontally for approximately 14 meters). The imagery will be taken 3 days prior to the magnetic tail phase every 120 minutes, while the magnetic tail phase every 12 minutes, and 3 days after the magnetic tail phase every 120 minutes.

2. In situ measurements are getting more and more attention, and new technologies like the miniaturized mass spectrometer "INMS" are looking for flight opportunities, both to upgrade the technology and test it. The mini INMS it's going to look for H and O ions and will make measurements in orbit (if the mission is in the magnetic tail phase), every 10 minutes, making for 12 measurements for 120 minutes per orbit.

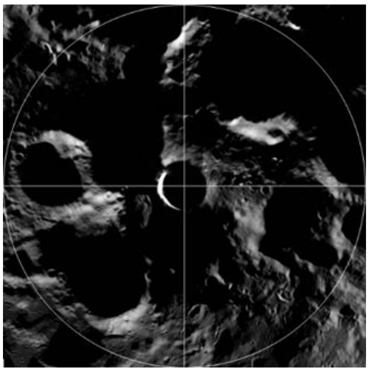

Figure 2. Conventional map of the lunar south pole Scale: 400m/pixel.

3. When orbiting over the south pole the magnetometer will make measurements 3 days prior to the magnetic tail phase every 120 minutes, during the magnetic tail phase every 12 minutes, and 3 days after the magnetic tail phase every 120 minutes in a range from 6 nT to 313 nT with a resolution of at least 8 nT.

5. SPACE SEGMENT DESCRIPTION

Overview of components:

Component	Note	Mass (g)	COTS/Custom
General			
CubeSat 6U Platform[5] (ADCS, EPS, Solar Panels, Flight Computer, Reaction Wheels, C&DH, Propulsion System)	M6P Nanoavionics	4500/5500	COTS
Payload			
Mass spectrometer	Mini-INMS[6]	560	COTS
Optical sensor	Chameleon Imager, Dragonfly Aerospace[7]	1600	COTS
Magnetometer FG			CUSTOM

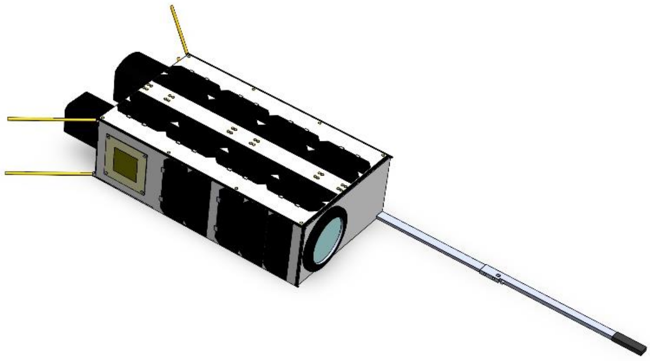

Figure 2. Illustrative image of the M6P platform with the attached payload

Communication Subsystem:

The communication system is a commercial full-duplex S-band transceiver, designed for high-speed data transfer on nanosatellites. Since ESA's Lunar Pathfinder mission to the Moon will carry an advanced satellite navigation receiver, it will assist in communication to the ground.

- Visibility window for communication with Pathfinder: for the ~ 100 km altitude orbit, the visibility window that makes the Downlink/Uplink connection possible is about 90-150 minutes per day, according to the user manual provided by Surrey Satellite Technology Ltd, the company in charge of the Lunar Pathfinder mission.[4]
- Mission data size: each image will have a maximum size of 10 MB (determined by the camera system) and the available data rate is 10 Mbps, which makes it possible to transmit 10 MB mission data in less than 1 minute.
- Frequency: the telemetry will be transmitted over UHF.

Electrical Power Subsystem:

Subsystem	ADCS	PAYLOAD	COMMUNICATION	THERMAL	C&DH
Power (W)	5	14	12	20	10

The electrical power system is based on 8 rechargeable lithium-ion batteries (7.4 V, 13600 mAh, 92 Wh) and triple-junction solar panels with epitaxial structure (30% efficiency). The EPS is dimensioned according to the study of the light periods during the satellite's translation process, carried out with the help of the Systems Tool Kit (STK) software, thus generating a report of times in which the satellite will be positioned in penumbra and umbra regions.

Thermal Control Subsystem:

For the thermal aspect, based on the payload data sheet, the minimum operational temperature is approximately - 30 ° C and the maximum of 400 ° C. Therefore, the platform manufacturer will guarantee the payload required operational temperature despite the space environment temperature, which ranges from -213.15 ° C to 16.85 ° C depending on the characteristic of the orbit at 100 km.

ADCS:

The “SatBus 3C2” flight computer will be responsible for this through its ADCS functionality, the ADCS will work with a sun sensor, start tracker, reaction wheels and propulsion system, this elements will provide the following benefits: Attitude Control Type: 3-Axis Stabilization, Attitude Pointing Accuracy: Up to 0.1°, Attitude Pointing Knowledge: Up to 0.05°, stability accuracy (Jitter): ±0.004°/s (at f>4Hz), attitude maneuverability (slew rate): up to 5°/s. Plus the platform will use the included propulsion system to desaturate the reaction wheels if needed.

C&DH:

The Command and Data Handling (C&DH) subsystem consists of a SatBus 3C2 single board computer, the architecture of this board is based on a STM32 H7 series microcontroller with high performance and low power consumption ARM Cortex™ M7 core MCU, operating at a frequency of up to 400 MHz. The same M7 core MCU performs OBC and ADCS functions. External flash and F-RAM memories provide reliable storage for telemetry and user data, as well as several digital interfaces are available to support sensors and other CubeSats constellation hardware.

Payload Subsystem:

The Chameleon Imager is a high-performance camera system for CubeSats, which will allow us to take panchromatic band images with a spatial resolution (GSD) of 10 meters. The panchromatic images will help to clearly define the contours of various surface features or to highlight certain spectral features of an image to obtain correct estimated data, which in turn will allow to identify dust clouds in the study area.

The INMS is a mass spectrometer that thanks to its equipped technology will be able to detect H and O ions with an energy range of 0-50 eV, this will allow to analyze if there is a significant exchange of water-forming ions during the phase of magnetic tail.

With the help of the fluxgate magnetometer in a range of 6nT to 313 nT and resolution of at least 8 nT we will be able to measure the magnitude and variations of the remaining magnetic field when it meets the magnetic tail, once having the measurements we can compare the behavior of this before, after and during the phenomenon.

6. ORBIT/CONSTELLATION DESCRIPTION

The constellation will consist of 3 CubeSats, placed every 120°, in a circular lunar low orbit, also known as a "frozen" orbit, for its relative stability performance. The altitude of the orbit will be 100 km, and it will have an orbital period of around 2 hours. To achieve the stability sought we will require giving an inclination to the orbit, we have four options; 27°, 50°, 76°, and 86°, the latter passes near the lunar poles, making it best suited for our goals.[8]

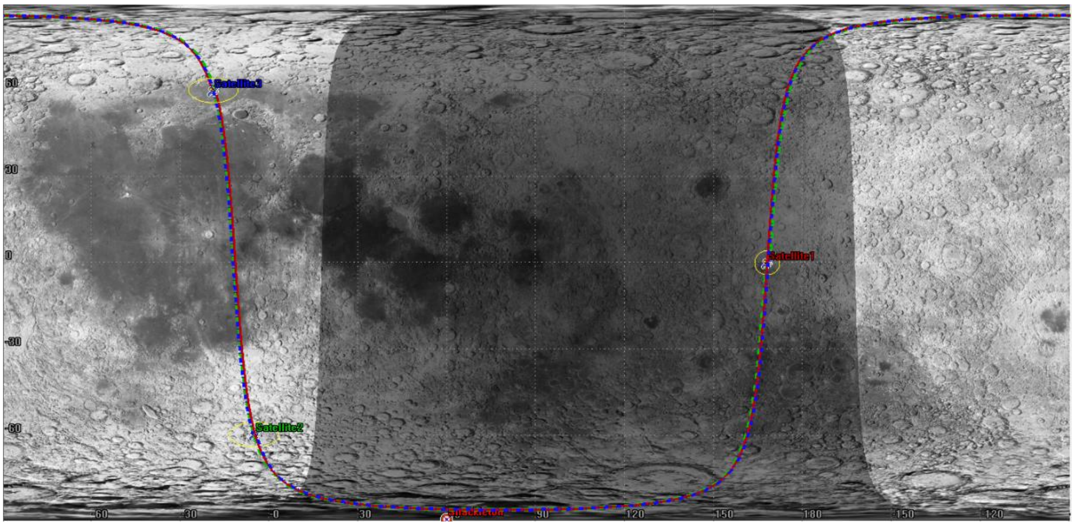

Figure 3. Orbit description of the constellation (elaborated in STK)

7. IMPLEMENTATION PLAN

The implementation plan, project schedule and preliminary cost breakdown is outlined below:

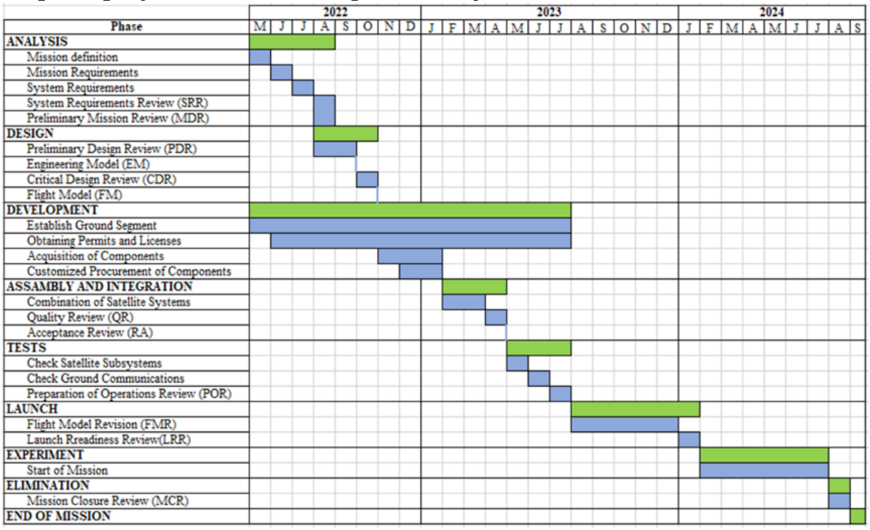

Figure 4. Schedule of activities

The estimated cost for mission design, launch and transportation of the CubeSats constellation to low lunar orbit is approximately 5 million dollars, with a 25% margin of error.

- The 6U CubeSat platforms for the constellation will be acquired through NanoAvionics.
- The Communication to the ground will be given with the service that Lunar Pathfinder offers, in conjunction with the company Surrey Satellite Technology Ltd and the European Space Agency (ESA).
- The launch is planned for the end of 2023 by the private company Astrobotics, in charge of taking the rover "VIPER" (Volatiles Investigating Polar Exploration Rover) to the lunar surface.
- The lifetime of the mission is approximately 6 months, considering the amount of information needed for the study, in addition to the link provided by Lunar Pathfinder.
- Once the mission is completed, the CubeSat constellation will enter winter mode and with the fuel reserve will be taken out of orbit so as not to generate risks for future missions.

Risks that may affect the mission:

1. Launch delay of the Lunar Pathfinder, since being the one who would provide us with the communications service, we could not send the data obtained to the ground station
2. Delay of licenses for launch.
3. Gravitational perturbation effects which would make it have instability and distortion in the orbits, being an obstacle to our mission.
4. Communication failure between the Lunar Pathfinder and the constellation of CubeSats or ground segment.
5. Failure of an electrical or mechanical component.

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