THE REGOLITH MOON EXPLORER (ROMEO) CAMERA SCIENCE CASE AND IMPLEMENTATION.

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Introduction: Rocks in the lunar crust shed light on the processes that operated in the lunar magma ocean, the range of magma compositions subsequent to primary differentiation, and the chemical and mineralogical composition of their mantle source regions. Surveying the rock types (and derived regolith) on the lunar surface at all scales and depths would allow us to constrain the geological history of the Moon, its volcanic activity, and could allow us to assess the composition of the lunar mantle, which remains poorly known [1-3]. Additionally, it is important to better understand the structure of the lunar regolith, the possible presence of paleo-regoliths and the effect of space weathering.

With the success of recent remote sensing missions (such as LRO, LCROSS, GRAIL, Chandrayaan and Chang'E), both new and unusual rock types have been discovered across the Moon, as well as areas that have been shown to contain abundant endogenous volatiles. These represent new areas where future missions can reveal aspects of the Moon that were not studied previously.

To achieve these objectives, it is important that the next generation of lunar missions embarks field instrumentation capable of classifying samples based on subtle chemical and mineralogical differences in rocks and soils, as well as sampling tools that can penetrate and sample deep enough into the regolith to get below outer layer altered by space weathering.

The ROMEO camera can map out down to very small scales (< 1 mm) the mineralogical composition of rocks and regolith of a given landing area on the Moon by imaging spectroscopy in the 0.4 – 1.7 µm. The geological context thus obtained will allow the classification of rocks and soils based on absorption bands located around the 1 µm region in the visible and near-infrared, which is known to contain relevant spectral mineralogical information (e.g. [4, 5]).

Context of previous studies: Lunar sample mineralogy is almost exclusively dominated by the following minerals: plagioclase, pyroxene, olivine, spinel and ilmenite as a consequence of formation in a rather dry and very reducing environment, leaving no alteration products [6, 7]. Troilite is the only sulfide and metallic iron grains are found in many rocks. Glass is present as residual melts, and the minerals that could have been added by meteorites have all been melted or vaporized by impact. Very little Na is present, therefore most lunar plagioclases are classified as almost pure anorthite.

To study lunar rock and soil compositions, it is critical to be able to differentiate amongst the major minerals (pyroxene, olivine, plagioclase, spinel and ilmenite) as well as the minor phases and different configurations of a given minerals such as the monoclinic and orthorhombic structures of the clino- and ortho-pyroxenes. Lunar mare basalt contains abundant high-Ca pyroxene (> 50%, with a strong absorption band at 0.9-1.0 µm) and variable amounts of olivine while lunar highland rocks have different proportions of feldspar minerals (mainly anorthite) and different kinds of ferromagnesian minerals. This means that both types of rocks can be separated by comparing their absorption spectra [5, 6]. Further, lunar mare basalts and lunar soils can be differentiated by their variable Ti content, as well as their optical maturity level defined by their nanoferric oxide content (Is/FeO: 14-94) [7, 8].

Global mineralogical maps of the Moon for olivine, plagioclase and pyroxenes were generated by the UVVIS CSR instrument on-board Clementine at the 100 m resolution, highlighting a mafic anomaly outside of mare units, at the South-Pole Aitken (SPA) basin possibly related to lower crustal or mantle material [9]. The mapping was further improved by Selene data and the M^3 instrument on-board Chandrayaan which detected Mg-spinel lithologies in the central peaks of several impact craters [e.g., 10] and with spectral range up to 3 µm, which allowed the detection of OH- and/or H2O-bearing materials at specific locations [e.g. 11, 12].

Finally, the in situ VNIS instrument on-board Chang'E 3 and 4 measured highly resolved spectra (450-2400 nm) over a large field of view. Chang'E 4, which landed on the far side of the Moon, detected the presence of low-calcium ortho-pyroxene and olivine, materials that may originate from the lunar lower crust or mantle, or from SPA differentiated melt sheet [e.g., 13]

ROMEO Science goals: In the context of a landing mission to the Moon, the goals of ROMEO would be to: 1. Determine and map the rocks and regolith mineralogy around the lander 2. Describe the geological context of the landing site 3. Investigate the sampling area in case the lander is equipped to dig.

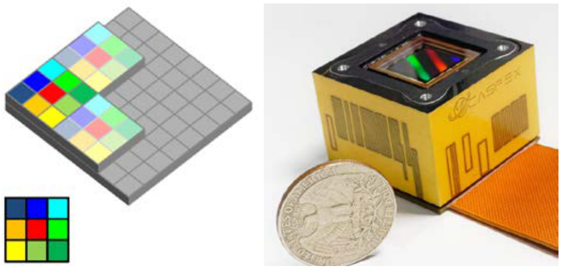

Figure 1: Concept of on-chip macro-pixels and 3D integration of the detector with its FEE. Photo of the SuperCam CMOS imager

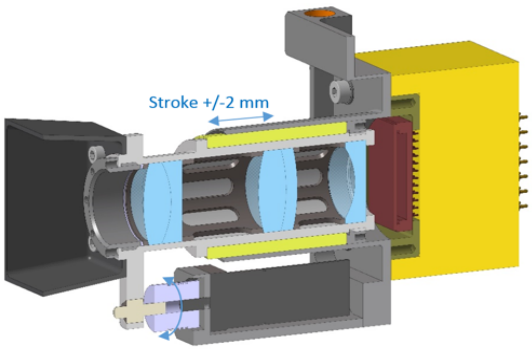

Figure 2: Camera mechanical design: mass <200 g with harness and margin; volume < 250 cm^3.

To achieve these objectives, the instrument consists of 2 imaging cameras equipped with specific narrow filters (10-50 nm) over each pixel adapted as on-chip macro pixels (illustrated in Fig. 1). The VIS imager (4 Mpxl) will be able to detect spectral bands in the 450 – 900 nm range while the SWIR detector (640×512 pixels) is complementary in the 0.9 – 1.7 µm range. To contextualize the landing area, the cameras have a large field of view of 17.4°×17.4° for the VIS imager and 10.8°×8° for the SWIR imager. Mechanical movement of the camera objectives is implemented to allow panoramic registration from about 1 m of the lander up to the horizon, giving a highest resolution at close distance of less than a mm. A stereo mode can also be implemented taking advantage of the camera different points of view.

The combination of small and large scale imaging capability with narrow spectral detection will allow us to fill the gap between the mineralogical orbital context obtained at large scale (~100 m for Clementine; 20-500 m for Selene; 80-140 m for Chandrayaan-1) and the high resolution spectra integrated over a single spot analysis like the observations of CE 3 and 4 point spectrometers (~20 cm).

Experiment implementation: The VIS and SWIR camera have the same architecture with an imager and a scan platform. The imager consits of the image sensor (CMOS for the VIS and hybrid InGaAs for the SWIR) and its Front-End-Electronics (FEE), the filters (Fig. 1)

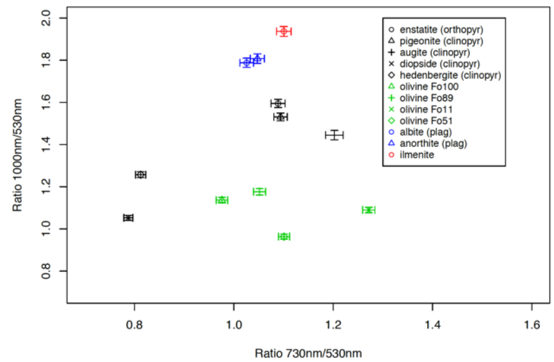

Figure 3: Major lunar minerals separation by the instrument using 3 narrow filters with a SNR of 50 and 3σ error. Spectral data taken from [4]

and its fore optics with the focus capability for a mass of 200 g with margins (Fig. 2). The scan platform carries the imager to insure the azimuth (AZ) and elevation (EL) pointing capability. It can be quite compact within a volume of 170×90×160 mm and a mass of 500 g. All included with margins the maximum power consumption is 9 W per camera. A set of calibration targets should be included.

A radiometric model of the experiment has been developed to validate the possible discrimination of lunar minerals under lunar measurement conditions (albedo of 9% in VIS, and 15% in SWIR, and solar angle of 45°) with best exposure time to obtain SNR of 50 ranging from 3 to 200 ms depending on the wavelength. Most major lunar minerals can be discriminated as shown in Fig. 3. A full landing site panorama can be acquired within 1 hour for a total of 500 MB of uncompressed data.

Conclusion: The ROMEO camera concept provides a compact design and flexible accommodation to obtain the best mineralogical documentation of a lunar landing site to date and to fill the gap in our knowledge between orbital data and local sampling. It can also be of interest to explore other planetary bodies such as asteroids.

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