Optical Sensor for ISRU Minerals (OSIM)

OSIM is a hyperspectral imaging camera that will primarily identify, characterize, and quantify mineral species of lunar in-situ resource utilization (ISRU) interest from a

- lander deck vantage or
- deployed on an articulating arm.

Hyperspectral and multispectral imaging systems are used throughout industry and the government to provide both spatial and spectral information for a vast number of applications. Hyperspectral imaging technology is used to: identify and characterize stressed plant ecosystems; identify mineral deposits associated with hydrocarbon and ore deposits; image and identify ion emission spectra in Jovian aurorae; identify hydrocarbon lakes on Titan; identify specific adulterants or harmful compounds in food; and detect and track specific pollutant plumes in the atmosphere and waterways. Many applications of hyperspectral imaging involve remote sensing, in which a hyperspectral sensor is coupled to a wideband imaging optical system such as a telescope or imaging camera lens.

This novel hyperspectral imaging technology has been developed and demonstrated for the visible and near-infrared spectral bands by micromachining a transmissive substrate that was then mounted directly on a commercial off-the-shelf (COTS) focal plane array (FPA). The brassboard system has full spatial-spectral registration—as opposed to a distributed Bayer-like mosaic—and its capture frame rate is only limited by the FPA frame rate and scene radiometry considerations (*i.e.*, there is no time multiplexing of the signal). Unlike a filter, it does not reject out-of-band light, improving radiometric sensitivity. This sub-gram addition to a standard imaging system can convert a panchromatic camera into a hyperspectral camera, providing access to the wealth of capabilities provided by spectral sensing. Unless with linear variable filters, the OSIM design does not require pushbroom scanning to acquire spectra for the scene. As in Bayer filter type cameras (2x2 super-pixel), the scene being observed is acquired with spectroscopic information within a super-pixel (10x10).

Landers/rovers often experience violent landing events, making bulky and fragile systems impractical, but a chip-scale technology would require far less ruggedization and could enable compositional mapping by identifying mineral signatures (Fig.1).

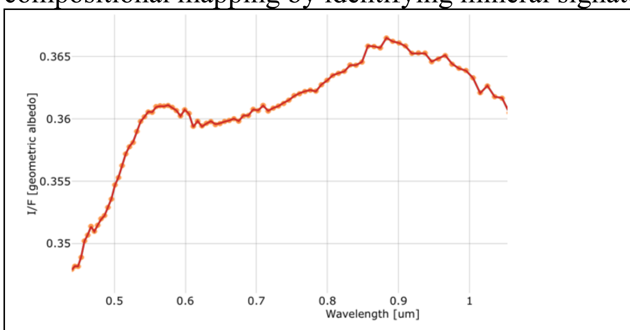

Figure 1: Minerals containing metals of interest in ISRU can be sensed by looking at spectral signatures. The pyroxene signature at ~0.5 µm (550 nm), plagioclase peak ~0.45 µm (450 nm), and Olivine 0.85 µm (>850 nm) are spectroscopic proxies within the OSIM that will be exploited for efficient identification (credit: Figure generated using GSFC planetary spectrum generator).

The OSIM technology provides a novel, small, low-cost chip-scale spectral separation technique that can be integrated with COTS optical hardware and is illustrated in Figure 2. An imaging system, such as a telescope, is used to focus broadband light onto a plate of microfabricated optical concentrators. The optical concentrators generate homogenized, point-like sources at their apices which are then scattered by a translucent, structured medium. Each wavelength of light interacts differently with the scatterers, producing a unique spectral image on the pixel array behind it. This pixel set acts as the basis vector for that wavelength. After calibration, an arbitrary spectrum can be reconstructed from the basis set using several computational techniques. The full frame is captured all at once, in a 'snapshot,' so all wavelengths are measured simultaneously. The integration time is driven by the size of optics, scene brightness, and system light efficiency—we are targeting a system-level efficiency of 30% throughput. This is a favorable

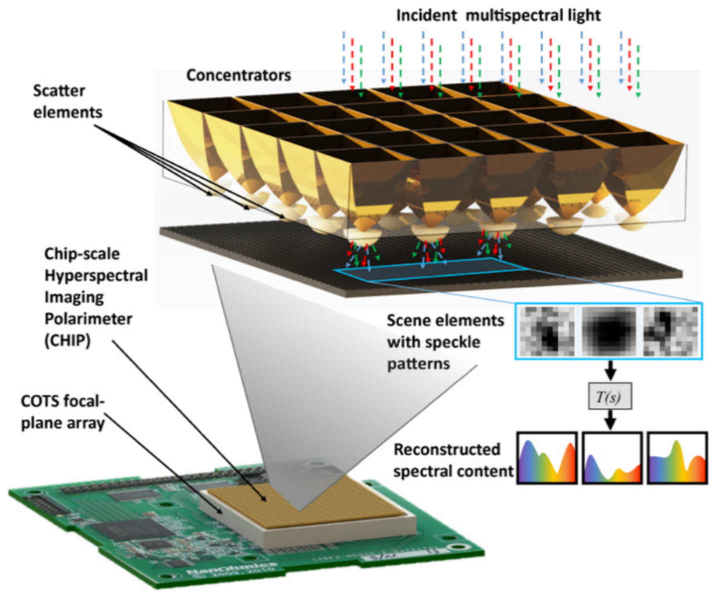

Figure 2: The OSIM focal plane provides a high-resolution chip-scale spectral imaging system that enables NASA's Game Changing Development by reducing payload size and mass while improving the science capabilities. Incident light is concentrated onto a microaperture array, then passes through engineered scattering elements. The scatterers separate the light into unique speckle patterns that identify the spectral and polarimetric signals through a computational reconstruction step. The total mass penalty is on the order of a gram, and the total thickness of the chip is ~1 mm. The camera is commercially procured and focal plane enhancement implemented.

comparison to bandpass filters, either tunable or arrayed, of similar target spectral resolution, where typically only 0.5-1% of the light would be passed in each band.

Most existing spectral imaging satellites are large, heavy, and expensive. However, current microscale fabrication techniques enable the design and production of highly compact, low-mass and low-power instruments at greatly reduced costs. Furthermore, miniaturized optical devices can now be integrated with CubeSats for space-based remote sensing in ways not previously possible due to size and mass constraints. Using these recently available, low-profile and lightweight materials and devices, developed a microchip-scale prototype hyperspectral sensor that images over the visible range of the electromagnetic spectrum has been developed. Incident light reaching each pixel on the microchip is scattered into wavelength-dependent patterns, and special algorithms are then applied to these patterns to calculate the spectrum. This technique is known as computational spectroscopy. The prototype hyperspectral imager was successfully flown and tested using a quadcopter and also launched to the ISS in 2021 under CASIS program.

OSIM operations specific to the COTS cameras commensurate with cost efficiency. These devices have known survival temperatures of -50˚C to +100˚C and operations in -40˚C to +100˚C. The focal plane filter assembly is robust to an extended thermal environment. With a volumetric profile of 100 mm x 100 mm x 50 mm, mass of 0.35 kg, nominal operating power 4 W, peak power 5 W, and exposure range from 1 ms-1 second, OSIM is capable of being deployed from a lander deck for minerals sensing from near lander proximity to horizon. OSIM can also be mounted (or adaptably connected) to an articulating arm for exploring the lunar regolith fine structure. In latter case, low power LEDs can be added with minimal cost, power, or mass penalty. OSIM will image the scene without the need for mechanical motion (such as pushbroom operations).

The OSIM is a novel integral field hyperspectral technology that:

- Provides complete spatial-spectral-temporal registration; no demosaicing or scanning artifacts
- Operates as a global shutter/snapshot imager; capture framerates are limited by underlying sensor integration times. It does not scan. No spectral scanning, no spatial whiskbrooming.
- Is a focal plane augmentation, adding only 1-2 grams of mass to a COTS camera system
- Exploits a novel multiplexed computational spectroscopy technique
- Spectral resolution is still being constrained, anticipate ~80 spectral bands across 400-800nm (5nm nominal resolution)
- Leverages NASA STTR funding to Nanohmics and University of Maryland for CubeSat applications.

The target solicitation is primarily intended for lunar investigations, but New Frontiers, Discovery and other opportunities are being looked into.