OSIRIS-REx Camera Suite (OCAMS) Observations of the Earth and its Moon During Earth Gravity Assist.

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Introduction: The Origins, Spectral Interpretation, Resource Identification, Security–Regolith Explorer (OSIRIS-REx) is a NASA mission to study and return a sample of asteroid (101955) Bennu [1]. OSIRIS-REx performed its Earth Gravity Assist (EGA) maneuver on September 22, 2017. Immediately after the encounter, the OSIRIS-REx Camera Suite (OCAMS) captured images of the Earth and its Moon. OCAMS comprises three cameras, all of which were used during EGA: PolyCam (the high-resolution imager), MapCam (the color imager), and SamCam (the sampling event imager) [2]. The Image Processing Working Group (IPWG) of the OSIRIS-REx mission is responsible for processing the images taken by OCAMS. In proximity operations around Bennu, the IPWG will create high-level data products that are critical inputs to sample site selection. EGA offered the IPWG an opportunity to test many of its processing pipelines and image manipulation algorithms, as well as overall workflow within the mission's operational structure. EGA images were taken as part of a 10-day campaign following the point of closest approach, from September 22nd through October 2nd. We took images on the 1st, 3rd, 6th, and 10th days after EGA. Here we present details of processing that data, including color images and color indices of the Earth, as well as high-resolution images and color ratios of the Moon.

Earth Imagery: On EGA+1, when OSIRIS-REx was approximately 170,000 kilometers from the Earth, MapCam imaged the Earth with its four color filters, roughly corresponding to blue (473 nm), green (550 nm), red (698 nm), and near-infrared (847 nm). At this distance, the Earth slightly overfilled MapCam's field of view. A color composite of the Earth was formed using the 698, 550, and 473 nm filters for the R, G, and B channels, respectively. To create the composite, individual images were processed in the United States Geological Survey's Integrated Software for Imagers and Spectrometers 3 (ISIS3). In ISIS3, a priori observation geometry (i.e., spacecraft position and attitude) was attached to the images via SPICE kernels. The images were visually co-registered to one another to minimize color artifacts. The color channels were white-balanced using the clouds as a reference point. In the final image, shown in Figure 1, several recognizable landmasses are visible, including North America in the upper right and Australia in the lower left. The missing data at the top of the image is due to a known detector effect that occurs at short exposure times. Because OCAMS is designed to image the dark carbonaceous asteroid Bennu (geometric albedo ~4%), short exposure times (1.5 milliseconds) were required to image a target as bright as the Earth (geometric albedo ~37%). The short exposures cause un-cleared signal to leak from the readout register into the image. We removed that unphysical signal from the composite, which left missing data at the top of the image.

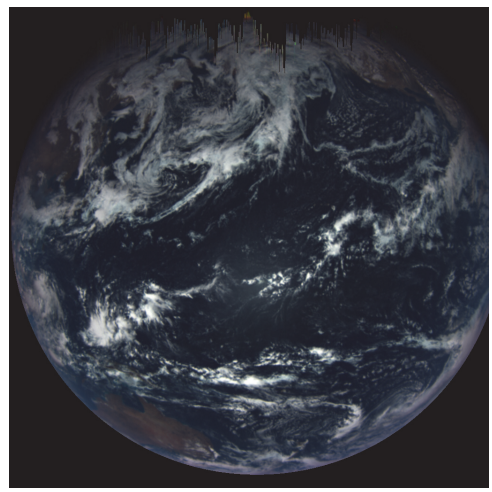

Figure 1. True color MapCam image of Earth on EGA+1, at a distance of 170,000 km. The image is a composite of MapCam's 698, 550, and 473 nm filters.

In addition to a true color composite, we also calculated common color indices to highlight specific features on the Earth; Figure 2 shows two such indices. The first, shown on the left, is the Normalized Difference Vegetation Index (NDVI) [3], which was calculated using the 698 and 847 nm filters and highlights locations with vegetation, such as Asia in the top left, and the coasts of Australia in the bottom left. The color index shown on the right is the Normalized Difference Infrared Index (NDII) [4], calculated using the 550 and 847 nm filters. NDII typically uses a mid-infrared wavelength and indicates ice cover. Because our 847 nm filter is only at the near-infrared, the index highlights water content and represents the ocean surface that is not obscured by clouds. Though these indices are not directly relevant for Bennu, applying them here allowed the IPWG to practice color index techniques.

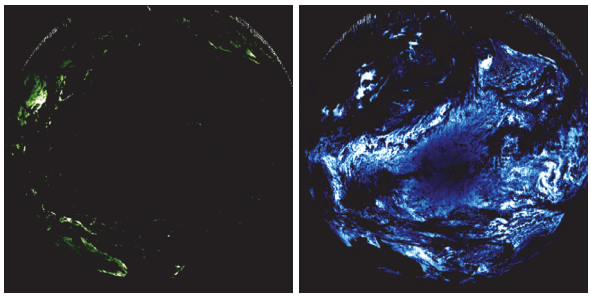

Figure 2. Color indices of MapCam images from EGA+1, taken from a distance of 170,000 km: the Normalized Difference Vegetation Index (left) and the Normalized Difference Infrared Index (right).

Moon Imagery: On EGA+3, from approximately 1.2 million kilometers, OCAMS imaged the Moon with both PolyCam and MapCam. PolyCam captured the high-resolution image of the Moon shown in Figure 3. MapCam also imaged the Moon with its four color filters. Though a color image of the Moon is not compelling, ratios of the color images can be calculated to highlight compositional differences. To this end, we attempted to mimic the color ratios used for the UV/Visible Camera on the Clementine lunar orbiter [5]. We used the MapCam filters that are closest in wavelength to their Clementine counterparts: 473 nm for 415 nm on Clementine, 698 nm for 750 nm, and 847 nm for 1000 nm. Ratios of 698/473, 698/847, and 473/698 were assigned the R, G, and B channels, respectively, to create the color ratio composite. The relative stretch for each channel was set to exaggerate some features. Figure 4 depicts an overlay of the MapCam color ratio composite image on top of the higher resolution PolyCam image. Both images were projected to an equirectangular projection using ISIS3, aligned to one another, and combined. The dark blue colors correspond to some lunar maria; light blue colors indicate high titanium content.

Future Work: The Moon, distinct from any other object OCAMS will image before its encounter with Bennu, is a well-studied and static calibration target. The IPWG and OCAMS teams will use RObotic Lunar Observatory (ROLO) observations of the Moon as a standard to verify and update the absolute radiometric calibration of the cameras.

Stereo photogrammetry pipelines are being developed in BAE System's SOCET SET®, which will use PolyCam and MapCam stereo images to produce digital terrain models of Bennu. EGA images were used to validate the stereo photogrammetry software.

The data products presented here represent a subset of those for Bennu. Color cubes and color indices will be inputs to the site selection process. EGA data allowed us to test algorithms and interfaces for making such products. Though EGA images did not provide an opportunity to practice mosaicking techniques (the most significant component of Bennu image processing), we are currently using analog surfaces such as Eros to prepare our processing pipelines [6].

Figure 3. A PolyCam image of the Moon taken on EGA+3, at a distance of 1.2 million km.

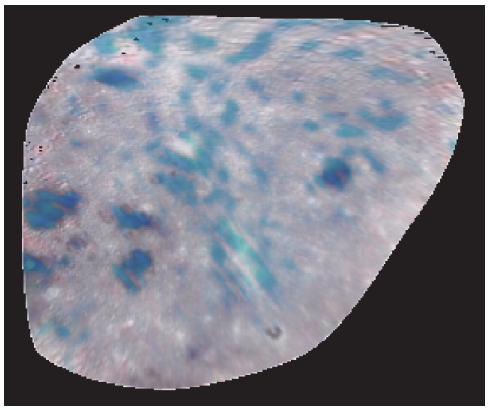

Figure 4. A MapCam color ratio composite image (using Clementine ratios) overlaid on a projected PolyCam image of the Moon from EGA+3, at a distance of 1.2 million km.

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