MRD 141, 119- Color Ratio Maps / Global and Site-specific Color Mosaics

Color-ratio maps are false-color image mosaics that highlight spectral variations across the surface of Bennu. They satisfy MRDs 119 and 141 and are produced from MapCam images in the b', v, w and x filters (the central wavelengths for these filters are 450, 550, 700 and 850 nanometers respectively). After a photometric correction is performed for images in each color filter, ratios in I/F are used to create false-color images. The main color ratios are expected to be b'/v to characterize the UV slope, the v/x to characterize the visible slope, and a combination of the v, w and x images to characterize the presence and depth of any 0.7-micron (i.e. 700 nm absorption feature). Other ratios may be deemed diagnostic and also used. The color ratios can be represented as RGB color maps.

Color-ratios provide spectral information with the highest spatial resolution that can be diagnostic of composition, particle size distribution, space weathering etc. One of the main benefits of color-ratio maps is their ability to resolve the ambiguity between topographic shading and differences in surface materials. Hence, color data has been a powerful tool (in conjunction with higher spectral resolution information) in geologic interpretations at all spatial scales, and will provide the only spectral information at sub-meter scales. An example of how to identify the composition of color units on asteroid Vesta can be found in Le Corre et al. 2013 "Olivine or impact melt: Nature of the ''Orange'' material on Vesta from Dawn", which used imaging to identify color and morphological trends in combination with spectral data. An example of the diagnostic value of color ratio maps on a low-albedo primitive surface, the nucleus of comet 67P, is given by Fornasier et al. 2015 "Spectrophotometric properties of the nucleus of comet 67P/Churyumov-Gerasimenko from the OSIRIS instrument onboard the ROSETTA spacecraft". In this publication, Fornasier et al. searched for correlations between albedo, color variations, and geology of the nucleus of comet 67P. More specifically, they found the visible spectral slope to be most diagnostic of composition, with the bluest spectral slope strongly correlated with the most active surface on the comet nucleus (see their figures 13 and 14).

This product is generated by the IPWG. Color-ratios maps are not a useful product without an interpretation of the color units revealed when the color-ratios are combined into RGB images. Lucille Le Corre will develop a pipeline to generate the color-ratio image products. Humberto Campins will lead a team of collaborators to interpret the color units within the color-ratio images. This product will feed into the Science Value map and long-term science.

Overview

What is the Data Type?

Image Mosaics

What MRD does this data product satisfy or contribute to satisfying?

MRD 141: For ≥80% of the asteroid surface, map the surface in a panchromatic filter at ≤1-m resolution and map the ECAS b-v (450/550 nm) color index, v-x (550/850 nm) color index, and the depth of the 0.7-microns (700 nm) absorption feature, relative to one or more recognized

ECAS standard stars, with an accuracy of ≤2% in regions where the signal-to-noise ratio is ≥100 at a spatial resolution of ≤2 m.

MRD 119: For ≥80% of a 2-sigma TAG delivery error ellipse around at least the prime sampling site, map the surface in a panchromatic filter at ≤25 cm resolution and map the ECAS b-v color index, v-x color index, and the relative depth of the 0.7-micron adsorption absorption feature, relative to one or more recognized ECAS standard stars, with an accuracy of ≤2% in regions where the signal-to-noise ratio is ≥100 at a spatial resolution ≤50 cm.

What observations are required to provide the input data needed to make the data product?

MapCam Color Images during Detailed Survey at the 12:30 Equatorial Station and Reconnaissance.

What is the spectral and/or spatial resolution of this data product?

Spectral resolution ranges from 0.1 to 0.2 depending on the filter, with highest spectral resolution in the filter of the shortest wavelength (e.g. blue).

The required spatial resolution ≤ 2m for Detailed Survey and 0.5m for Reconnaissance, assuming a 4 pixel criterion.

When in the DRM are the observations that make the data product scheduled to be taken?

In Detailed Survey:

Global b/v (450/550 nm), v/x (550/850 nm), 0.7micron (700 nm), Color Ratio Maps (MRD-141) from 3/12/19 to 3/25/19

In Reconnaissance:

Site #1 b/v, v/x, 0.7 µm color ratios (MRD-119) from 6/24/19 to 6/28/19
Site #2 b/v, v/x, 0.7 µm color ratios (MRD-119) from 6/24/19 to 6/28/19

How long does it take to produce the data product?

This process is done with the ISIS3 software and we estimate it would take one month to produce the Global Color Ratio Maps data product and then another month to perform the identification and interpretation of color units within the Global Color Ratio Maps. We estimate it would take two weeks to produce the Site #1 and #2 Color Ratio Maps data products and another two weeks to perform the identification and interpretation of color units within these sites. Once ISIS3 is refined and a synthetic color model of Bennu is available (late 2016), we intend to carry out a test run to refine these estimates.

We will regenerate this product each time a new shape model is released and each time a new photometric model is released.

Is this product used for sample site selection, science value, or long term science?

Science value and long-term science. Science value is used in sample site selection.

Observation Requirements

Nomenclature:

- *"Frame"* refers to an individual filter image within a color-set (e.g. a single v-image)
- A *"color-set"* is defined as b, v, w, and x frames of the same target that are acquired successively at the same time. These images should overlap to the greatest extent possible.
- A *"color-cube"* is defined as a color-set where all of the frames have been co-registered to each other and the edges of each frame have been "band-trimmed" to remove any non-overlapping pixels.
- *"Domain"* refers to the projected spatial extent (in terms or line and sample) of a single image.
- "*Line"* and *"Sample"* are used to refer to the "rows" and "columns", respectively, of an image.

Requirements

A good color imaging campaign taken at the 12:30 PM equatorial station during detailed survey should have the following characteristics:

- The total overlap of all frames included in a color-set should be as close to 100% as feasible. This will minimize the presence of seams in the mosaic, and minimize differences in phase angle between frames in a color-set. At a minimum, the color frames (b, v, w, x) should have a total overlap of 90% from end-to-end.
- The number of color-sets acquired along a single slew should provide 80% coverage of Bennu to fulfill MRD 141, including uncertainties. This number is currently estimated at 3 color-sets per slew.
- The images should be taken of the surface at Bennu at low phase, at either 11:00-11:30 AM or 12:30-1:00 PM local time, to ensure the best possible signal-to-noise ratio and the shortest possible exposure time.
- All images should be acquired at low emission angles (< 30 degrees) to minimize distortion, foreshortening, and other projection effects in the equatorial to mid-latitudes (~ 50 degrees latitude) for 80% coverage. This is a requirement for all images that are to be included in global mosaics.
- Blur should be minimized to the greatest extent possible, and should not exceed 1 pixel in the blue filter (where the longest exposure time is anticipated).
- The overlap between end-member color-sets (i.e. the first and third) of a single slew should be > 10%, with respect to latitude
- The overlap between color sets across longitude-band slews should be > 40%.

Data Product Structure and Organization

What is the structure of the data product (e.g. FITS file with 4 extensions)?

Calibrated ISIS3 Cubes for internal Science Team processing

FITS files for the PDS archive.

Data Format Descriptions

Header information (metadata) included with data product:

At a minimum the following information will be associated with each color-ratio map. The "Data_Set_ID" keyword will point to a file list that includes all images, SPICE kernels, and the shape model used to support the generation of this product.

/* Identification Information */
DATA_SET_ID = "OSIRIS-REx_B_OCAMS_CRMOS_0001_V1.0"
DATA_SET_NAME = "OSIRIS-REx CAMERA SUITE COLOR RATIO MOSAIC V1.0"
PRODUCER_INSTITUTION_NAME = "UNIVERSITY OF ARIZONA"
PRODUCER_ID = "UA"
PRODUCER_FULL_NAME = "CARINA JOHNSON"
PRODUCT_ID = = "DTbcd_LLLLLL_NNNN_RRRRRR_NNNN_Vnn"
PRODUCT_VERSION_ID = "V1.0"
INSTRUMENT_HOST_NAME = "Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer "
INSTRUMENT_HOST_ID = "OSIRIS-REx"
INSTRUMENT_NAME = "OSIRIS-REx CAMERA SUITE"
INSTRUMENT_ID= "OCAMS"
TARGET_NAME = "BENNU"
SOURCE_PRODUCT_ID = (XSP_LLLLLL_NNNN, XSP_RRRRRR_NNNN)
RATIONALE_DESC = "Brief descriptive text "
SOFTWARE_NAME = "ISIS3.4.11"

OBJECT = IMAGE_MAP_PROJECTION
DATA_SET_MAP_PROJECTION = "TEMPLATE.MAP"
MAP_PROJECTION_TYPE = "EQUIRECTANGULAR"
ROJECTION_LATITUDE_TYPE= PLANETOCENTRIC
A_AXIS_RADIUS = nnnn.nn <M>
B_AXIS_RADIUS = nnnn.nn <M>
C_AXIS_RADIUS = nnnn.nn <M>
COORDINATE_SYSTEM_NAME = PLANETOCENTRIC
POSITIVE_LONGITUDE_DIRECTION = EAST
KEYWORD_LATITUDE_TYPE = PLANETOCENTRIC
CENTER_LATITUDE = nn.0 <DEG>
CENTER_LONGITUDE = nnn.nn <DEG>
LINE_FIRST_PIXEL = 1

LINE_LAST_PIXEL = nnnnn
SAMPLE_FIRST_PIXEL = 1
SAMPLE_LAST_PIXEL = nnn
MAP_PROJECTION_ROTATION = nnn.nn <DEG>
MAP_RESOLUTION = nnnnnn.nnnnnnnn <PIX/DEG>
MAP_SCALE = n.nnnnnnnnnnnn <METERS/PIXEL>
MAXIMUM_LATITUDE = nnn.nnnnnnnn <DEG>
MINIMUM_LATITUDE = nnn.nnnnnnnn <DEG>
LINE_PROJECTION_OFFSET = nnnnnnnn.n <PIXEL>
SAMPLE_PROJECTION_OFFSET = nnnnnnnn.n <PIXEL>
EASTERNMOST_LONGITUDE = nnn.nnnnnnnn <DEG>
WESTERNMOST_LONGITUDE = nnn.nnnnnnnn <DEG>
END_OBJECT = IMAGE_MAP_PROJECTION

OBJECT = VIEWING_PARAMETERS
NORTH_AZIMUTH = nnn.nnnnnn <DEG>
PHASE_ANGLE = nnn.nnnnnn <DEG>
PHOTO_MODEL = "LOMMEL-SEELIGER"
R_CHANNEL = "V/X"
G_CHANNEL = "(W - ((X-V)*0.4984))/V"
B_CHANNEL = "B'/V"

END_OBJECT = VIEWING_PARAMETERS

END

Data Product Generation

By whom is the product generated?

The product will be generated using an ISIS3 pipeline developed by Lucille Le Corre with input from the IPWG lead and USGS. Humberto Campins will lead a team of collaborators to interpret the color units within the color-ratio images. This team will include, but is not limited to Julia de Leon, Yan Fernandez, Javier Licandro, Lucille Le Corre, and Moses Milazzo.

What are the input products needed to produce the product?

Calibrated MapCam Images in all four colors
SPICE kernels
Asteroid shape model (Digital Shape Kernel aka DSK)
Photometric model

Are there format expectations for the input products?

All input product images will need to conform to the OCAMS SIS.

The asteroid shape model will need to be in DSK format

What algorithms are used to generate products?

The imaging strategy outlined above is intended to acquire images that can be processed into color-ratio mosaics in an established way that is straightforward to accomplish using the ISIS3 planetary image processing software. The following section explains the details of this data processing.

All frames belonging to color-set must be co-registered. In particular, sub-pixel image registration is required to create scientifically valuable color-ratio products. Without this level of registration, color-ratio products can possess significant artifacts that may be falsely interpreted as spectral signatures, especially along morphological boundaries. In general, all frames in the color-set are co-registered to a single "master frame", which is held fixed throughout the image registration process **[question from Beth Clark: will the Panchromatic Filter Mosaic and control network be used as the "master frame"] [answer from Dani: Beth--No, not likely. The pan mosaic will come from the earlier BBD imaging campaign, so it does not make sense use that control network, as it will have been generated from different camera pointing and spacecraft ephemeris information. We will generate a seperate control network for the color-images, but perhaps we will merge these control networks for later image processing.]**. To ensure the best possible sub-pixel registration is achieved, image frames are translated and sometimes rubbersheeted (i.e. resampled) to match the domain of the master frame. The master frame is usually chosen as the frame that has the best signal-to-noise and least amount pixel blur in the color-set; typically the clear filter is chosen as the master frame.

The algorithm responsible for performing sub-pixel co-registration, *coreg*, applies an area-based matching technique within a search pattern chip. This technique will perform best when images have nearly the same domain (e.g. 100% overlap), as this will minimize the size of the search chip and therefore minimize the time spent searching for matches, as well as the number of false positives.

After all frames in a color-set are co-registered, the edge of frames that do not have common overlap with the rest of the color-set are trimmed using *bandtrim* algorithm in ISIS3. Although image-edge pixels are removed during the trimming process, the geometry of the frame footprint remains intact and attached to the frame. Color-sets that have been co-registered and band trimmed can be combined into color-cubes and stored as an intermediate data product using the algorithm *cubeit*.

Bundle adjustment is the photogrammetric algorithm used to create controlled mosaics. Typically bundle adjustment is only performed on the master-frame images for color products with multiple filter frames. Using only the master-frame allows for the extrinsic camera parameters to be refined across an entire observation sequence (resulting in smithed SPICE kernels) while avoiding the labor-intensive process of globally controlling every color frame acquired. Globally controlling a full set of color images may have additional drawbacks not discussed in this document. Color-set co-registration usually takes place after the master-frame images are controlled and their geometry is refined via bundle adjustment. The refinement process is described as follows: Camera models implemented in ISIS3 define a relationship between ground and image, and include the camera system's intrinsic parameters (calibrated focal length, pixel pitch, geometric distortion models, etc.). Initial estimates of image extrinsic parameters are gathered from spacecraft trajectory and pointing data, available from SPICE kernels. Users will generate tie points between overlapping images by-hand or using automated image-matching techniques. A tie point is a point that has ground coordinates that are not known, but is visually recognizable in the overlap between images. Prior to bundle adjustment, initial ground coordinates of tie points are generated by intersection with an available shape model, such as a sphere, ellipsoid, or digital shape kernel (DSK) [Edmundson et al.]. During bundle adjustment the estimates of the extrinsic camera parameters and the 3D position of common points of features are refined, updated, and exported as smithed SPICE kernels. The elements of the cost function optimized during this process are derived from the corresponding features in the images. Because the extrinsic camera parameters are refined on a per image basis, it is important to recognize that it is only feasible to bundle adjust individual images to produce mosaics. It does not make sense to bundle adjust multiple mosaics that are no longer associated with geometry of individual frames, but instead represent the averaged geometries for a group of frames.

Once frames have updated geometry and have been combined into color cubes, a photometric correction can be applied using the photometric angles determined by the geometry refinement. Individual frames in a color set can then be combined algebraically (e.g. ratioed) at the pixel level using the ISIS3 *algebra* algorithm. This will produce derived image frames whose signal is the algebraic combination of the signal from other images (e.g. "color-ratio" images). Color-ratio images can be visually illustrated in combination with other derived image frames using standard RGB color image channels to highlight spectral variations as a function of geospatial extent.

The final step in the mosaicking process consists of stacking the individual image frames according to pixel priority, using the *automos* or *noseam* algorithms in ISIS3. The "priority" parameter will determine how input pixels are combined with the output mosaic. The selection of input pixels can be based on resolution, photometric angles, averaging schemes, etc. The final mosaic will be generated in a standard cartographic projection, such as equirectangular or polar stereographic.

References

Edmundson et al. "Jigsaw: The Isis3 Bundle Adjustment For Extraterrestrial Photogrammetry" SPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume I-4, 2012

What calibration data are used to generate products?

MapCam L2 images are used to create this product. These products will be radiometrically calibrated by the OCAMS pipeline prior to use by the IPWG. In ISIS3 the products will be geometrically corrected by the ISIS3 using the MapCam camera models. Each MapCam filter will be treated as a separate camera model in ISIS, as the distortion of MapCam will change per filter (each filter has a different thickness to compensate for chromatic aberration). The images will be photometrically corrected in ISIS3 using the parameters of the photometric model generated by the Photometric Modeling Team that is led by Co-I Dr. Beth Clark.

Has a specific Science Team Member been assigned to produce this product?

Creating the color-ratio ISIS3 mosaicking pipeline has be assigned to Dr. Lucille Le Corre. Color-ratios are not a useful product without an interpretation of color units revealed when the color-ratios are combined into RGB images. Dr. Humberto Campins will lead a team of collaborators to interpret the color units within the color-ratio images.

Will multiple versions of the product be generated?

We will regenerate this product each time a new shape model is released, and each time a new photometric model is released.

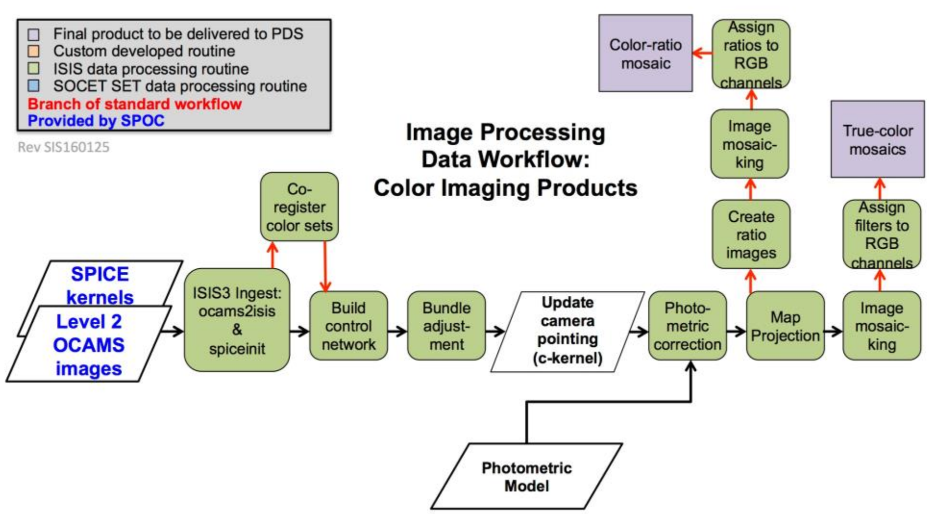
Data Product Validation

How will the product be validated to ensure contents and formats are correct?

This data product will need to pass an IPWG acceptance test before being delivered to the SPOC. The IPWG acceptance test will ensure that format is correct.

The IPWG lead will review the content of the data product and the data provenance before it is delivered to the SPOC.

Data Flow



Standards used to generate data product

Cartographic Standards

IPWG mosaics will be generated in either equirectangular or polar stereographic cartographic projections. The equations describing these projections are included in the Image Processing Software Interface Specification (SIS) document.