COLOUR AND STEREO SURFACE IMAGING SYSTEM ON THE EXOMARS TRACE GAS ORBITER: COLOUR DATA PRODUCTS AND THEIR USE FOR SCIENTIFIC INVESTIGATIONS.

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Introduction: The Colour and Stereo Surface Imaging System (CaSSIS) is a full-colour visible to near-infrared (VNIR) bi-directional pushframe stereo camera onboard the ExoMars 2016 Trace Gas Orbiter (TGO) [1]. CaSSIS provides colour surface images with four broadband colour filters optimized for Mars photometry (**Table 1.**) and generally ≤ 9.5 km wide and ~30-40 km long; images are acquired at ~ 4.5 m/px resolution from TGO's nearly circular ~360 km x 420 km orbit and are resampled to 4 m/px. TGO's orbit is not Sun-synchronous due to an inclination of 74° [1]. Therefore, CaSSIS images the surface at different local solar times (LSTs), covering a wider range of observation geometries than previous Mars imagers, and includes very low phase for optimal surface colour/spectral contrast. The combination of fixed pointing at ~10° off nadir and a rotation mechanism are used to acquire stereo images in a single pass over the target [1]. TGO is currently permitted to roll up to a maximum of 5° to facilitate the targeting of key locations on the surface by CaSSIS.

Table 1 CaSSIS Bands

Band# / Name	Band Centre	Bandwidth	[1]Colour
0 / Synthetic "Blue"	*"475.0" nm*	*N/A*	*Blue*
1 / BLU	499.9 nm	118.0 nm	Blue-Green
2 / PAN	675.0 nm	229.4 nm	Orange-Red
3 / RED	836.2 nm	94.3 nm	NIR
4 / NIR	936.7 nm	113.7 nm	NIR

[1]Based on band centre wavelength

Here we present a summary on how CaSSIS operates, and on the colour data products that can be produced and used to address a variety of scientific investigations.

CaSSIS Imaging: As noted in [1], CaSSIS is a pushframe imager. The CaSSIS detector was a spare for the one used in the SIMBIOSYS instrument for the Mercury-bound BepiColombo. The device has a hybrid CMOS architecture and allows for direct pixel read-out at a rapid imaging frequency. However, a data transfer rate restriction between the CaSSIS detector, the proximity electronics and the digital processing module was determined to limit the total number of pixels that can be transferred within the time between the frames. If TGO's altitude is high enough, the ground-track velocity is lower and the timing to obtain a full 4 colour image with full swath may be achieved. However, at the nominal TGO altitude, a down-selection is required to balance the framing rate and the read-out. This is a consequence of several aspects in the final hardware performance, including a higher than expected overhead on the internal SpaceWire links and the need for adequate overlap between the framelets (~10%) to ensure complete coverage along track. Thus, planners must switch off colour filters and/or reduce the swath-width size from the maximum value of 2048 px to maintain a continuous colour swath and reduce the read-out to a rate that can be handled. Hence, many of the CaSSIS images are 3-colour (with a 0-30% width-reduction in one of the 3 filters) with fewer images taken with all 4 colours (with a 30-50% width-reduction in 3 of the filters). Because the optimum frame repetition frequency is dependent upon the ground-track velocity (and therefore a function of altitude) imaging limitations are minimized when TGO is near or at apoapsis in its orbit, and most severe near periapsis. One strategy to prevent excluding a colour filter is to take a stereo observation where all four are acquired between the two images that make up the pair (*e.g.*, **PAN**, **BLU**, ****NIR*** on the 1st half, **PAN**, **BLU**, ****RED*** on 2nd). While this imaging mode offers a promising solution, the reconstruction of a 4-band image cube with a filter observed from a different observation geometry presents radiometric and geometric challenges that are currently under investigation. As such, we are still looking into alternate imaging modes and their colour data products to assess their usefulness given the imaging limitations of CaSSIS.

Suggested Colour Data Products: CaSSIS colour data products were initially assessed as part of a study on simulated CaSSIS image cubes [see 2-3], and recently re-evaluated after the team collected a sufficient number of actual CaSSIS observations.

Simple combination products. Colour combinations with CaSSIS order the available colours from long to short wavelengths in R-G-B, such as **NPB**, **RPB**, **NRB** and **NRP** (see **Fig. 1**). Here **BLU**, **PAN**, **RED**, **NIR** are abbreviated as **B**, **P**, **R**, **N** when expressed as colour image combinations for the R-G-B channels that make-up a colour image. **NPB** and **RPB** provide colour images that can be used with and are quite similar in colour to the IRB colour images from HiRISE [*e.g.*, 4]. Due to the near-simultaneous acquisition of stereo pairs by CaSSIS, colour anaglyphs are also being successful produced where two or more colours are acquired for both halves of the stereo pair.

A simulated 'True Colour' product. A CaSSIS image with only two filters (*i.e.*, specifically **PAN** and **BLU**) may be used to synthesize an additional colour, in this case a synthetic 'blue' band ('**sB**'), to produce an R-G-B combination that simulates a true colour image (**Fig. 1**). This is accomplished in a similar fashion as the HiRISE RGB product [4] by combining PAN (**P**), BLU (**B**), and the calculated '**sB**' band in R-G-B (*i.e.*, **PBsB or 'RGB'**).

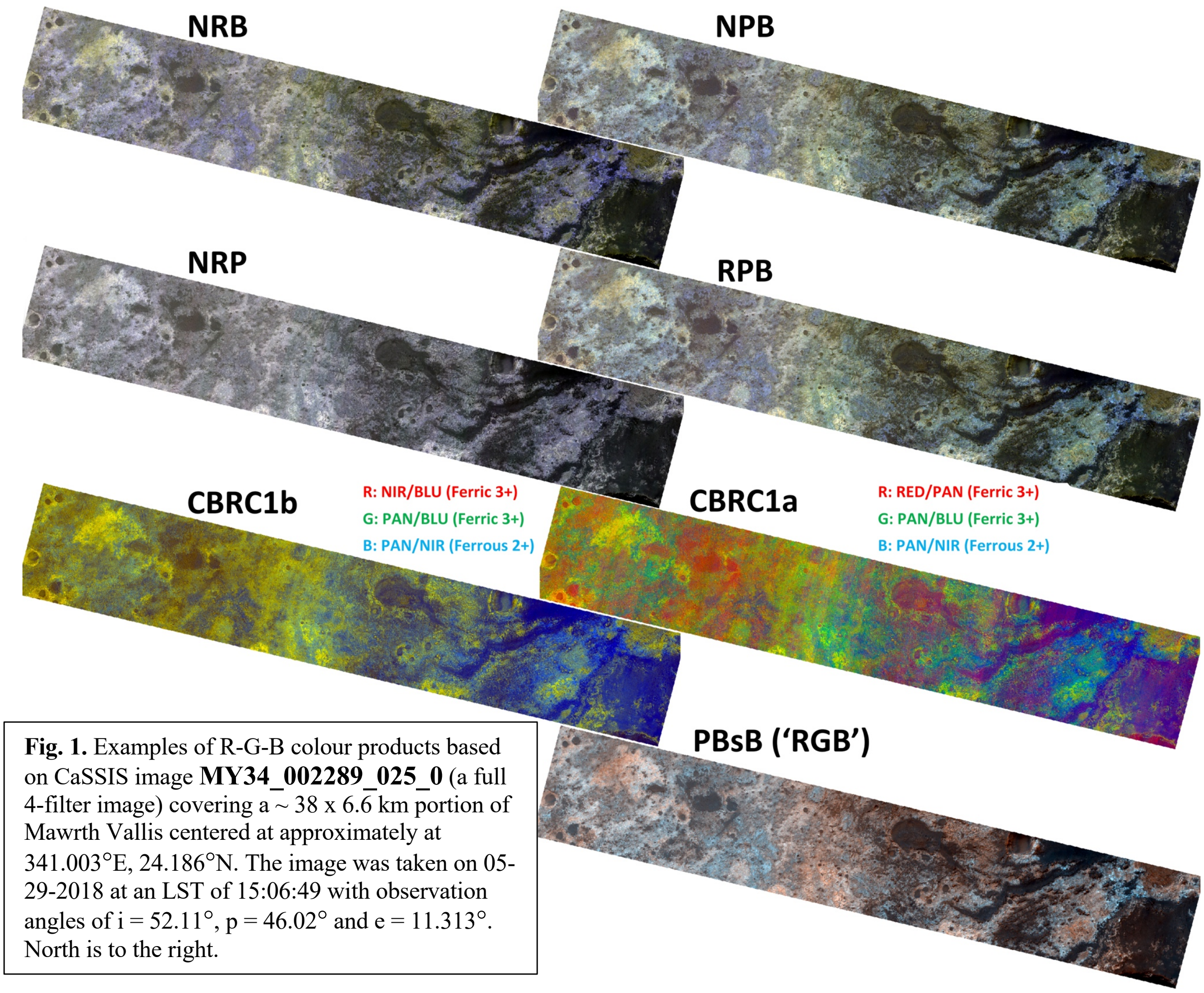

Fig. 1. Examples of R-G-B colour products based on CaSSIS image **MY34_002289_025_0** (a full 4-filter image) covering a ~ 38 x 6.6 km portion of Mawrth Vallis centered at approximately at 341.003°E, 24.186°N. The image was taken on 05-29-2018 at an LST of 15:06:49 with observation angles of i = 52.11°, p = 46.02° and e = 11.313°. North is to the right.

Advanced colour products: Band ratio and spectral parameters. Based on the sensitivity of the CaSSIS filters to the presence, and even absence, of Fe-bearing species [1,2], several band ratios and spectral parameters (and their alternates) are recommended and summarized in Table 3 presented in [2]. Colour Band Ratio Composites (**CBRCs**) [see 2] based on a 4-filter image (1a), and an alternate based on only 3-filters (1b), are shown in **Fig. 1**. Spectral parameters for highlighting the presence of frost or ice, and atmospheric phenomena captured in CaSSIS images are also suggested and discussed in [2] but are not shown here.

Inter-instrument colour products. CaSSIS colour information can be combined with the spatial information of a greyscale HiRISE RED mosaic image providing much higher spatial scales at 25–50 cm/px. A Gram-Schmidt spectral pan-sharpening algorithm has provided excellent results in this regard that will augment both CaSSIS and HiRISE science goals and investigations.

As demonstrated in [2], the CaSSIS bandpass information can be used to synthesize radiometrically comparable color information from CRISM. These CaSSIS-compatible CRISM products will be used to provide a radiometric link between the color/spectral information in the two datasets, and thereby inform on the spectral and mineralogical interpretation of CaSSIS color variability.

Observation and Product IDs. CaSSIS has adopted a general observation/product ID convention as such*:* ***MY-aaa_bbbbbb_ccc_d***, where: **a** = Mars Year of observation; **b** = TGO orbit number; **c** = the angle between the ascending node and the s/c at the time of acquisition (in degrees) that approximates the location of the target on the surface; **d** = 0, 1 or 2 (0 = individual or non-stereo observation; 1= 1st look stereo image; 2nd look stereo image) [*e.g.*, the ID **MY34_002289_025_0_NPB** describes an individual (non-stereo) observation taken in Mars Year 34, on orbit 2289, at 25 degrees past the ascending node and that combines the **NIR**, **PAN** and **BLU** filters in R-G-B].

References: [1] Thomas, N. et al. (2017) Space Sci. Rev., 212, 1897. [2] Tornabene, L.L. et al. (2018) *Space Sci. Rev.*, 214, 18. [3] Tornabene L. et al. (2016) *LPSC 47*, Abstract #2695. [4] Delamere A. et al. (2010), *Icarus*, 205, 38-52.

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