CRISM Hyperspectral Targeted Observation PDS Product Sets - TERs and MTRDRs. F. P. Seelos[1], C. E. Viviano-Beck[1], M. F. Morgan[1], G. Romeo[1], J. J. Aiello[1], S. L. Murchie[1], and the CRISM Team, [1]Johns Hopkins University Applied Physics Laboratory, 11100 John Hopkins Road, Laurel, MD 20723 (frank.seelos@jhuapl.edu).

Background and Motivation: The Mars Reconnaissance Orbiter (MRO) [1] Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) [2] team is delivering to the Planetary Data System (PDS) two suites of high-level targeted observation data products that include systematic corrections for atmospheric gas absorptions, aerosol scattering, photometric effects, and instrument artifacts. Correction of these effects makes the data far more accessible to the Mars science community than the CRISM PDS standard product Targeted Reduced Data Records (TRDRs; calibrated observed spectral radiance and reflectance).

The Targeted Empirical Record (TER) product set contains fully corrected, full spectral range (VNIR [S-detector; 365 – 1056 nm] + IR [L-detector; 1001 – 3937 nm]) data in sensor space. The Map-projected Targeted Reduced Data Record (MTRDR) product set is composed of map projected TERs with bad bands and spatially disconnected frames removed. Each product suite includes corrected I/F, spectral parameter images, and thematic browse versions of the data [3], along with corresponding data processing information products and visualizations. The MTRDRs are map-projected using MRO project standards and are Geographic Information System (GIS) ready with an ESRI coordinate system string in each product header. The two product sets standardize CRISM-measured spectral radiance – and quantities derived from it – to what they would be for each scene if viewed entirely at nadir, with normal illumination, without atmospheric gas absorptions, by an artifact-free instrument with a single optical path and full spectral range detector.

The TERs and MTRDRs are derived from Full Resolution Targeted (FRT), Half Resolution Long (HRL), and Half Resolution Short (HRS) observation class types and represent a significant advance in the accessibility of CRISM targeted observation spectral information content. It is expected that the TER/MTRDR product suite will become the preferred version of the data for a large portion of the Mars science community.

TER/MTRDR Product Characteristics: The TER/MTRDR product suite is designed to support a wide variety of use cases. This overarching objective motivated the specification of the paired product sets – the IR (L-detector) sensor space TERs which support additional high level spatial and spectral processing, and the map-projected MTRDRs which are GIS-ready and can be directly incorporated into mapping projects. Selected TER/MTRDR product characteristics and relevant CRISM data analysis and investigation activities are detailed in the following sections.

CRISM Targeted Observation Workflow. The typical CRISM hyperspetral targeted observation TRDR CRISM Analysis Toolkit (CAT) workflow employed by a member of the user community consists of applying a simple Lambertian photometric correction, an empirical 'volcano scan' correction for atmospheric gas absorptions [4], and the calculation of spectral summary parameters [5] which serve to highlight spatial pixels with spectral structure of interest. The TER/MTRDR data processing chain is a superset of this standard data processing flow. It begins with the most current implementation of the CAT processing procedures, including a completely revised and updated library of spectral summary parameter definitions [6] (which are also included in CAT v7.1+ available from the PDS Geoscience Node). In addition, the TER/MTRDR processing chain includes a volcano scan post-processing step which mitigates the reintroduction of detector nonuniformity type residuals (column striping in the ground plane), and a custom spectral summary parameter filtering procedure which identifies and ultimately interpolates spurious spatial pixels using a statistical outlier test applied to an iterative sampling kernel. As a result, the TER/MTRDR summary parameters have reduced noise and improved utility compared to typical CAT-generated products. A revised approach to the construction of CRISM browse products (byte-scaled RGB composites of thematically related spectral summary parameters) also ensures that the meaningful parameter dynamic range is retained in the browse product renderings (Figure 1).

Full CRISM Spectral Range. The TER/MTRDR data processing chain includes the registration of the VNIR (S-detector) data to the IR (L-detector) data in sensor space, allowing for the generation of full spectral range (VNIR + IR) corrected image cubes. The availability of the full CRISM spectral range in a spatially consistent data product supports the integrated evaluation of diagnostic spectral structure from the near-UV to the near-IR (e.g. ferric dust, mafic sands, and ices in the polar regions [7]), and the detailed evaluation of spectral structure across the VNIR/IR ~1000-nm detector boundary which can influence the spectral interpretation of olivine, pyroxene, iron bearing glasses [8], and iron substitution in feldspars [9]. In addition, the fully corrected, full spectral range TER/MTRDR spectral data products are suitable for processing by automated spectral classification, end-

member identification, and spectral interpretation procedures, including the Tetracorder expert system [10].

Full Scene Radiometric Consistency. Two empirical processing procedures in the TER/MTRDR data processing chain – the Empirical Geometric Normalization (EGN) and Empirical Smile Correction (ESC) – transform CRISM targeted observation data to a self-consistent idealized radiometric framework. The EGN procedure characterizes the spectral geometric dependencies across all segments of a CRISM targeted observation (central scan plus all associated Emission Phase Functions (EPFs)), isolates the spectral continuum variability attributable to gimbal motion, and normalizes the central scan to an idealized (zero gimbal angle) photometric geometry. The ESC procedure similarly characterizes the scene cross-track structure in a given band as a function of the detector wavelength sampling map, isolates the structure attributable to the known detector row wavelength sampling variability (spectral smile), and normalizes the data to an idealized uniform spectral sampling. The effect of these corrections is to transform the data to a synthetic radiometric framework as though the data were acquired in a push-broom fashion by an instrument with minimal optical distortion. These corrections are wavelength-dependent, and the EGN procedure in particular can influence both the continuum level and the low-frequency continuum shape, including the shape of relatively broad mafic absorptions. The normalization ensures that spectra from across the scene are radiometrically compatible so that, for example, numerator and denominator spectra from different along-track positions can be radioed without concern of incorporating spectral-photometric variations into the result.

Targeted Observation Mosaicking and Spectral Transforms. The TER/MTRDR spectral data processing can be considered a prerequisite for quantitative top-of-atmosphere (TOA) CRISM targeted observation mosaicking. After TER/MTRDR processing the main factor contributing to inter-observation radiometric discrepancy among a spatially connected set of observations is the scene-specific atmospheric optical depth rather than inherent instrument or operational characteristics. This can be addressed using a straightforward overlap area cumulative distribution function (CDF) optimization to transform the entire set of observations to a common geometric, radiometric, and atmospheric reference [11]. The TER/MTRDR data products also support additional TOA spectral-radiometric transforms, including synthesis of High Resolution Imaging Science Experiment (HiRISE) [12] Infrared, Red, Blue-Green (IRB) color [13], Colour and Stereo Surface Imaging System (CaSSIS) [14] 4-band color [15], or wavelength integrated reflectance at CRISM spatial sampling.

Acknowledgments: We would like to thank the CRISM team members - and their students - that participated in the internal review and validation of the TER/MTRDR data processing procedures, the members of the Mars science community - and their students - that participated in the PDS peer review of the TER/MTRDR data products and archive, and the PDS Geoscience Node which has provided invaluable guidance toward the development of the TER/MTRDR PDS archive.

References: [1] Zurek R. W. and Smrekar S. E. (2007) *JGR, 112*, E05, S01. [2] Murchie S. L. et al. (2007) *JGR, 112*, E05, S03. [3] Seelos F. P. et al. (2012) *Planetary Data Workshop*, OFR 2014–1056, 159–162. [4] Morgan M. F. et al. (2011) *LPSC XLII*, 2453. [5] Pelkey S. M. et al. (2007) *JGR, 112*, E08, S14. [6] Viviano-Beck C. E. et al. (2014) *JGR, 119*, 06, 1403–1431. [7] Horgan B. H. and Seelos F. P. (2015) *Fourth Annual International Planetary Dunes Workshop*, 1843, 8054. [8] Horgan B. H. and Bell J. F. (2012) *Geology*, *40*, 5, 391–394. [9] Wray J. J. et al. (2013) *Nat. Geosci, 6*, 1013–1017. [10] Clark R. N. et al. (2016) *LPSC XLVII, this conference*. [11] Seelos F. P. et al (2013) *LPSC XLIV*, 2563. [12] McEwen A. S. et al. (2007) *JGR, 112*, E05, S02. [13] Seelos F. P. et al. (2011) *AGU Fall Meeting, 23*, 1714. [14] Thomas N. et al. (2014) *EPSC, 9*, 100. [15] Tornabene L. L. et al. (2016) *LPSC XLVII, this conference*.

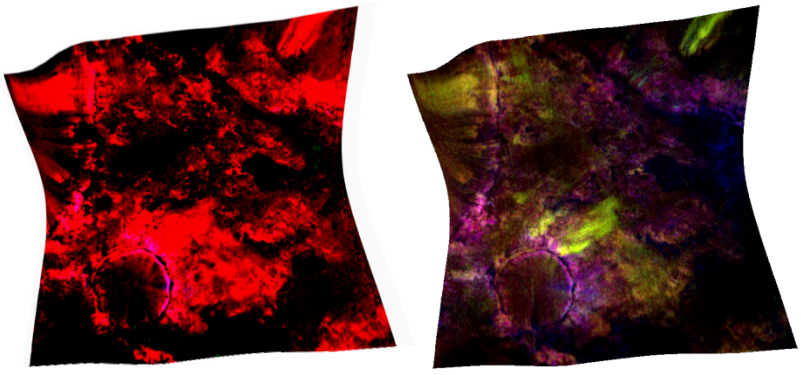

Figure 1. Comparison of phyllosilicate (PHY) browse products for CRISM hyperspectral targeted observation FRT000050F2. (Left) First generation map-projected PHY browse product (R: D2300; G: BD2210; B: BD1900). (Right) Current generation MTRDR PHY browse product. The aggregate result of the TER/MTRDR data processing chain is a much more scientifically compelling analysis product.