FULLY CONTROLLING MARS RECONNAISSANCE ORBITER CONTEXT CAMERA IMAGES AND PRODUCING COSMETICALLY STABLE MOSAICS (2023 UPDATE). R.H. Hoover*,1 S.J. Robbins[1], M.R. Kirchoff[1],*rhoover@boulder.swri.edu, [1]Southwest Research Institute, 1050 Walnut Street, Suite 300, Boulder, CO 80302.

Introduction: The Context Camera (CTX) aboard NASA's *Mars Reconnaissance Orbiter* (*MRO*) spacecraft [1] has been returning high-resolution (5–6 mpp) and -quality data of Mars' surface for over a decade. As of PDS release 63 (December 2022, including data through May 2022), the instrument has returned over 130,000 images that cover ~99% of the planet in good quality. However, images often have ~100s meter offsets from each other and a controlled ground source, resulting in seam mismatches when mosaicking and poor matches to other, high-resolution datasets. We developed an efficient, accurate workflow within *ISIS* (USGS's *Integrated Software for Imagers and Spectrometers v3–7*), driven by Python scripts, to automate much of the control process to create a fully controlled CTX dataset. We demonstrated the viability of this workflow by controlling Mare Australe ("MC-30"), covering south of –65°N, or 4.7% of Mars' surface [2], and all equatorial Mars Charts (MC-08 through MC-23, between ±30° latitude, covering 50.0% of Mars); we have both controlled and mosaicked >70,000 image across >70% of Mars. The paper describing the equatorial mosaic was recently accepted to *Earth and Space Science* [3].

This work has now been funded through a NASA-PDART21 grant to cartographically control all of Mars, updating our past work and making a single, cohesive control network from which we will generate mosaics. We have begun work on this, starting with the north pole, and are on track to produce the mosaics for release in the ≈2025 timeframe.

Our process at its heart is aimed towards producing updated SPICE camera and spacecraft kernels, although the primary output most researchers would be interested in is a mosaic. The CTX instrument is poorly calibrated, and factors like seasonal and atmospheric changes prevent seamless mosaics from being constructed. While [4] have presented a workflow to create the appearance of a seamless product by mosaicking images along lines of minimal contrast, we have developed a different method of empirical photometric control [5], which uses a reference source to produce an equalized product that minimizes brightness mismatches.

Updated Automated Control Network Workflow [3]: We have worked to improve upon our previously published workflow [2] to minimize time spent on manual efforts. Through our now-funded PDART we are revisiting previously controlled regions to include the latest PDS release (up to 63 for the north pole, and expected through 66 for the remainder of the planet) and utilize our updated workflow. We still begin with regions that are manageable for the automated process by dividing the planet into "Mars Charts:" 30 approximately equal-area quadrangles. We follow the same standard image processes in *ISIS* software, and still manually examine the images to remove images with bad signal-to-noise.

As discussed in our 2022 LPSC abstract [6] we use standard tools within *ISIS* to create a relative control network, including POINTREG and JIGSAW. Our current approach is more efficient than our original methodology that utilized a more brute-force grid approach, creating smaller networks in less time.

Updated Manual Adjustment Workflow [3]: We create several points in a region and constrain them through registration to a known ground source. For non-polar regions, we use the fully controlled THEMIS Daytime IR mosaic available from USGS. For polar regions, we use the MOLA gridded data product. This process is manual due to the significant scale and lighting differences between CTX and either THEMIS or MOLA.

When separate, adjacent regions are fully controlled, the networks are merged together. Due to the nature of the CTX linescan camera and *MRO*'s orbit, the networks for adjacent regions merge together well without need for manual effort.

Standards: We emphasize that our work uses the community-standard *ISIS* software, meaning that all tracking of uncertainties and other types of output produced by this software are maintained. Our Python wrapper uses standard libraries, and Python is a free compiler that can be run on almost any computer. Additionally, we use native Python libraries to divide the work for each region into multiple files so we can take advantage of modern high-thread-count computers, allowing it to scale well, even up to a cluster. Only a few tasks truly need to be done in serial, on one processor (*e.g.*, the JIGSAW network solver).

Mosaic Summary [2, 3]: Thus far we have controlled 70.3% of Mars' surface. The south polar mosaic contains 3.1M tie points and is available from the USGS Astrogeology's data portal as four separate quadrants due to the large file size. It was made with our older code so has a less efficient control network that we will be updating last in our PDART-funded effort. Our equatorial mosaic covers ±30° latitude and contains 1.74M tie points. The significant decrease in tie points is due to our new, more efficient methods. The final equatorial mosaic is approximately 2.108 Tpix, over 150× larger than the THEMIS mosaic, and can be accessed also through the USGS at <https://asc-pds-services.s3.us-west-2.amazonaws.com/mosaic/Mars/Mars_MRO_CTX_Equi_Mosaics_Robbins/index.html> (please note there are no hyphens in the URL, that is just Word's hyphenation). We have begun work on the new north polar mosaic that will include

data released through December 1, 2022, which was the start of northern winter for Mars Year 36.

Additional Work: We are now funded to do this work fully, globally, using all currently released CTX data. We began this work in September 2022 with Mars' north pole, for the poles take the longest to control, and then we will work through other regions. We have partnered with CosmoQuest to have volunteer citizen scientists assist with the validation work. If time allows, we hope to add in newly released images towards the end of our period of performance, but that remains to be determined.

Photometric Correction [5, 6, 7, 8]: Normal equalization methods that adjust brightness and contrast are insufficient for images that are internally variable relative to others, such as containing an along-track gradient. A method that has been somewhat informally used in the literature but described in detail by [7] is to use a low-resolution, photometrically stable source image or mosaic, and tie the brightness of the higher resolution images to it. Mars Orbiter Camera Wide-Angle images, taken limb-to-limb, have this property when hundreds of images are combined. We created mission-averaged mosaics at cardinal L_s times (±5°) to generate this photometrically stable, low-resolution (9 ppd) basemap [8]. To that we tie CTX images in order to create a photometrically stable, high-resolution product (Figs. 1–2).

References: [1] Malin et al. (2007). doi:10.1029/2006JE002808. [2] Robbins et al. (2020). "Fully Controlled 6 meters per pixel Mosaic of Mars' South Polar Region." doi:10.1029/2019EA001053. [3] Robbins et al. (2023) "Fully Controlled 6 meters per pixel Equatorial Mosaic of Mars from Mars Reconnaissance Orbiter Context Camera Images, Version 1 doi: 10.1029/2022EA002443. [4] Dickson et al. (2018). LPSC #2480 doi:10.1029/2010JE003755. [5] Robbins et al. (2020) "Empirical Photometric Control of Mars Context Camera Images." doi:10.1029/2019JE006231. [6] Robbins et al. (2022) 53rd LPSC Abstract #2219 [7] Michael et al. (2016) doi:10.1016/j.pss.2015.12.002. [8] Robbins (2020) "Mars' Red … Reflectivity Averaged Over Mars Year 24–28 from Mars Orbiter Camera." doi:10.1029/2019EA001053.

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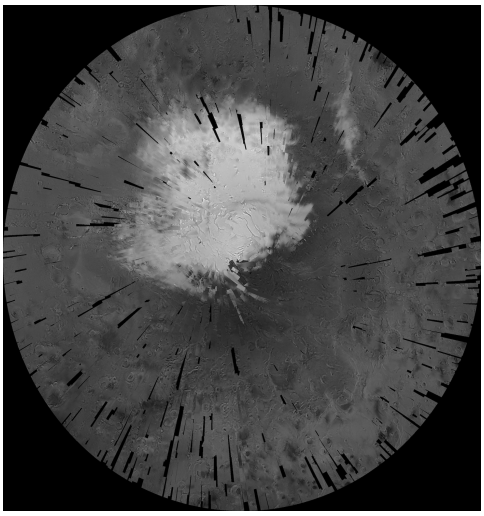

Figure 1: Very low-resolution version of the MC30 mosaic, with non-linear brightness scaling applied.

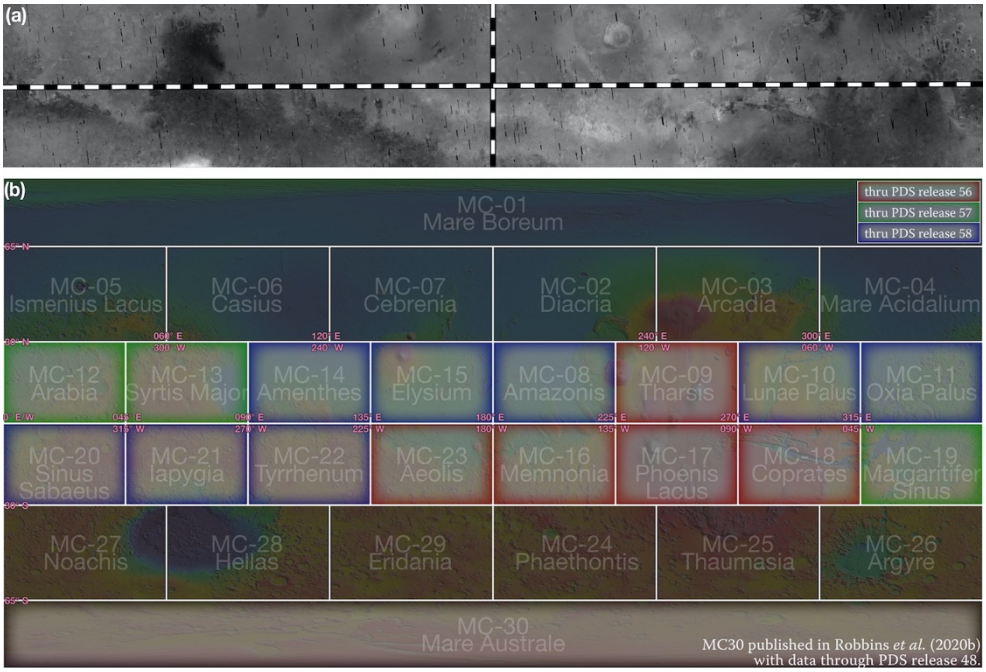

Figure 2: Panel (a) shows our equatorial mosaic, while panel (b) shows our published work so far.