

# A NEW MARS DIGITAL IMAGE MODEL (MDIM 2.1) CONTROL NETWORK

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## ABSTRACT:

The U.S. Geological Survey has recently completed a final revised version of its 231 m/pixel global Viking image mosaic of Mars that has substantially improved geodetic accuracy compared to versions released in 1991 and 2001. This mosaic, known as MDIM 2.1, is currently available in the USGS ISIS file format (see <http://astrogeology.usgs.gov/Projects/MDIM21/>) and will be formatted and submitted to the NASA Planetary Data System (PDS) in the near future for archiving as a single ~5-MB DVD volume.

Positional control for MDIM 2.1 comes from a new geodetic/photogrammetric solution of the global Mars Mariner 9 and Viking image control network. The details of this network solution are described here. This network incorporates 1,054 Mariner 9 and 5,317 Viking Orbiter images. Accuracy of the new solution is improved primarily as the result of constraining all 37,652 control points to radii from Mars Orbiter Laser Altimeter (MOLA) data and adding 1,232 "ground control points" whose horizontal coordinates are also constrained by MOLA. The MOLA data are believed to have an absolute accuracy on the order of 100 m horizontally. Additional improvements result from use of updated timing and orientation data for the Viking Orbiter images, improved resampling measurements and hence distortion correction of the images, and careful checking and remeasurement of control points with large residuals. The RMS error of the solution is 15.8  $\mu\text{m}$  (~1.3 Viking pixels, ~280 m on the ground). The IAU/IAG 2000 coordinate system is used for the network and the mosaic.

## 1. INTRODUCTION

USGS has completed a new version of its global Mars digital image mosaic. This version is known as MDIM 2.1 (Kirk, et al., 1999, 2000, 2001), and is now available at <http://astrogeology.usgs.gov/Projects/MDIM21/>. As part of this process we completed a new photogrammetric solution of the global Mars control network. This is an improved version of the network established earlier by RAND and USGS (Davies and Arthur, 1973; Davies and Katayama, 1983; Wu and Schafer, 1984), as partially described previously (Archinal, et al., 2002, 2003). We describe here the details of this network solution.

The MDIM 2.1 mosaic itself has many improvements over earlier Viking Orbiter (VO) global mosaics. Geometrically, it is an orthoimage product, draped on the Mars Orbiter Laser Altimeter (MOLA)-derived radius model, thus accounting properly for parallax distortions in the commonly oblique VO imagery. Via the network being described here the mosaic is tied to the newly defined IAU/IAG 2000 Mars coordinate system (Duxbury, et al., 2002; Seidelmann, et al., 2002) via ties to MOLA data. Thus, MDIM 2.1 provides complete global orthorectified imagery coverage of Mars at the resolution of 1/256° (or ~231 m) of MDIM 2.0, and is compatible with MOLA and other products produced in the current coordinate system. Visual inspection of the entire mosaic confirms that mismatches between adjacent images and between images and overlaid MOLA contours, are almost everywhere less than one pixel, with maximum errors approaching 4 pixels (~1 km) in only a few, relatively featureless areas. Images in the monochrome mosaic have variable but generally large solar incidence angles and have been highpass-filtered to suppress

albedo variations and normalized to emphasize and to equalize the contrast of topographic features. Improvements to the surface/atmosphere photometric models used result in significantly better uniformity and dynamic range than previous versions of the mosaic. The equidistant (cylindrical) projection is used for the mosaic, which is divided into files corresponding to the 30 MC-quadrangles of the Mars 1:5M map series. For convenience, each polar quadrangle is provided as two sections in equidistant projection and also as one file in polar stereographic projection.

## 2. CONTROL NETWORK IMPROVEMENTS

Improvements over previous Mars control networks are as follows.

*New IAU/IAG 2000 coordinate system.* The IAU/IAG Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites has adopted new constants, which define the Mars body-fixed coordinate system for locations on Mars. The constants as adopted were recommended via the NASA Mars Geodesy and Cartography Working Group to the IAU/IAG WG (Duxbury, et al., 2002; Seidelmann, et al., 2002). The changes include the specification of new constants to define the spin (e.g.  $W_0 = 176.630^\circ$ ) and pole position of Mars.

*New derivation of VO image acquisition information.* New values for the exposure epochs and derived camera pointing and spacecraft position information have been determined by NASA NAIF personnel (Semenov and Acton, 1996a; 1996b). These values have been adopted for use in the control solution here for all VO images (except for images FSC 39151122, 52128638,

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and 52653629, where it was necessary to use older values to get a reasonable solution). This better a priori camera station information should result in a better solution, particularly since we do not adjust the exposure epoch or spacecraft position. Solutions using this new information do indeed show at least a 5% lower overall RMS, changing (in image space) from 17.8  $\mu\text{m}$  to 16.9  $\mu\text{m}$ .

*New camera reseau-finding procedure.* An improved algorithm has been created in the USGS ISIS (Eliason, 1997; Gaddis, et al., 1997; Torson and Becker, 1997; also see <http://isis.astrogeology.usgs.gov/>) software for determining the locations of the reseau marks on VO images. In the cases where we have the original RAND and USGS pixel VO image measurements of control points (which is the case for 77,225 measurements), these new locations have been used to recalculate (mm) control point locations in the image plane prior to adjustment. In addition, a number (329) of measurements of control points near the edges of the images and outside the available reseau information (and therefore of questionable value) have been removed. Solutions with these changes show a 4% lower overall RMS, changing from 16.9  $\mu\text{m}$  to 16.2  $\mu\text{m}$ , although some of this decrease is simply due to a reduced number of observations.

*The radii of all 37,652 control points (Figure 1) have been derived by interpolation of a MOLA global radii grid* (see <http://wufs.wustl.edu/missions/mgs/mola/egdr.html>). The MOLA radii should be accurate to  $\sim 10$  m vertically and  $\sim 100$  m horizontally (Neumann, et al., 2001). This procedure has been iterated a number of times so that as changes are made in the solution, or new data are introduced and new horizontal coordinates are derived for control points, new a priori radii information is obtained from the MOLA dataset. Again, that there is an improvement in using the MOLA data in these successive steps is shown by an 11% decrease in the overall control network solution RMS.

*Measures from additional images are included.* Measures of 52 images that were used in MDIM 2.0 but not rigorously included in the previous RAND adjustment for MDIM 2.0 have now been included in this solution. There are 406 such measurements of 203 control points on 102 images (including the new images and images that overlap them).

*Horizontal positions of a number of control points have been fixed to MOLA-derived values.* This in effect provides equally spaced "ground control" for Mars globally. Our procedure was to match high resolution MOLA DIMs (as derived by Duxbury) with VO images, and measure the positions of existing and new control points on both. Such measurements were made using an annulus cursor centered on a crater rim in order to avoid parallax problems in measuring the position of the center of a crater. In the network solution, the latitudes and longitudes of these points, as derived from the MOLA DIMs, were held fixed. A grid of such points has been measured globally on Mars, with 15° latitude and 30° longitude spacing. Some additional points were also measured on the area to the west of Olympus Mons, due to the difficulty of finding suitable points on both the MOLA DIMs and on Viking images in this area of mantled terrain (Figure 2). We have assumed that at the locations of these points the horizontal positions are therefore similar in accuracy to the inherent accuracy of the MOLA DIMs, or about 100 to 200 m, with most of the uncertainty resulting in the correct measurement of the VO images and the MOLA DIMs. The accuracy will obviously be less as one moves to areas away from these MOLA tie points, but we are planning to verify (below) that the horizontal positional accuracy does not degrade substantially from these estimates.

*Existing and new image measurements have been verified.* Measurements with solution residuals having pixel values over 4-5 Viking-sized pixels (85 pixels/mm) were carefully checked in order to reduce such residuals. In the final solution, the largest measurement residual was less than 4.7 pixels. Out of 90,130 measures, cumulatively only 31 measures had residuals over 4 pixels, 553 over 3 pixels, 3,423 over 2 pixels, and 25,590 over 1 pixel. This is in comparison to previous (RAND) solutions where the largest residuals were about 7.5 pixels. The last RAND solution, with 88,325 measures, had 2 measures with residuals over 7 pixels, 4 over 6 pixels, 21 over 5 pixels, 140 over 4 pixels, 883 over 3 pixels, 4,326 over 2 pixels, and 26,531 over 1 pixel. Many measurements have been redone, while others have been removed from the solution in cases where it was felt the control point in question could not be adequately remeasured (e.g. because of a poorly defined feature, a low contrast image, or a point near the edge of an image). We additionally prepared large-area test MDIM 2.1 mosaics based on our solutions, which were carefully examined for any problems. We added MOLA-derived contours to these mosaics (Figure 3 shows an example using the final MDIM 2.1 mosaic) to check the registration of the mosaic to the MOLA data. In cases where the registration showed differences (at the more than a few hundred meter level) or in cases where there appeared to be any misregistration of VO images with each other, we made additional image and MOLA control point measurements, and improved the solution with these measurements in order to eliminate the problems. This process was repeated using the final solution and MDIM 2.1 mosaic, and no significant differences were seen in the registration of MOLA contours with features on the mosaic.

### 3. RESULTS

We still plan to do additional checks on the overall horizontal accuracy of the control network by checking the locations of additional MOLA tie points and also of the Viking, Pathfinder, and MER landers (whose horizontal positions are also known to high accuracy via spacecraft tracking (Folkner, et al., 1997; Golombek and Parker, 2004a, 2004b)). This will be done *not* by fixing their coordinates in the control network adjustment, but rather by comparing their solved-for coordinates with the known locations.

The final MDIM 2.1 Mars control network solution contains 90,130 measurements of 37,652 control points on 6,371 images. Of these measurements, 77,621 are on 5,317 VO images, whereas 12,509 of the measurements are on 1,054 Mariner 9 images, as a carry-over from the original RAND networks. The Mariner 9 image measurements had generally lower residual values than the highest residual VO image measurements, so were maintained in the solution both to add geometrical strength and also to allow for the production of updated Mariner 9 camera pointing information. A total of 1,232 control points were tied to MOLA DIM tiles, and it is the coordinates of these control points that were held fixed (to the appropriate MOLA-derived latitude and longitude). The solution RMS is 15.8  $\mu\text{m}$  or about 1.3 Viking pixels.

### 4. CONCLUSIONS

We have completed a new global Mars control network, extending earlier work done at RAND and USGS. This new network is consistent with the IAU/IAG 2000 Mars body-fixed reference system, and in particular, topography derived from MOLA data in that system. The overall accuracy of positions derived is expected to be similar to that of MOLA in both the

horizontal (~250 m) and vertical (~10 m). This network and the associated solved-for VO camera angles have been used to create the USGS MDIM 2.1 mosaic, thus assuring that the mosaic will have a similar level of accuracy, and that it can be used directly with MOLA derived products. A further product is camera angles in the IAU/IAG 2000 system for 1,054 Mariner 9 and 5,317 VO images, which will also (e.g.) allow for their direct registration on MOLA topography.

## 5. ACKNOWLEDGEMENTS

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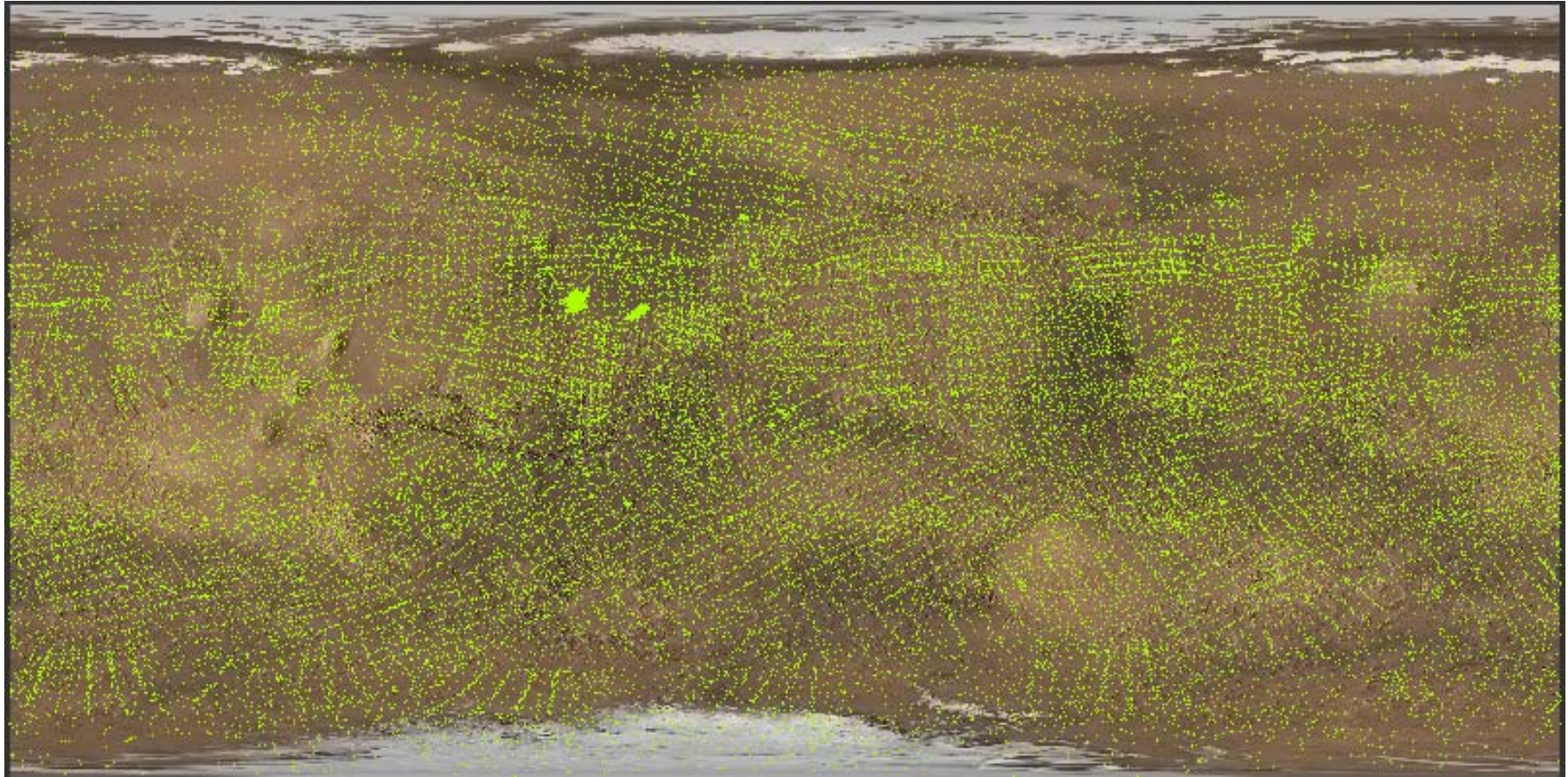


Figure 1: The 37,652 control (or tie) points in the MDIM 2.1 network. The patterned effect is primarily due to the tie points having been selected on the edges of the strips of Mariner 9 and Viking Orbiter image coverage. Some traces of an overall grid effect (e.g. denser sets of points at  $\pm 30^\circ$  latitude) are also visible due to the way that the control network was originally created at RAND, in order to tie lower resolution images together. The two areas of dense point coverage at left center are the areas of the Viking 1 and Mars Pathfinder landing sites. Simple Cylindrical projection with  $0^\circ$  longitude at center, north up, and east to the right. Background from ArcIMS Image Service (<http://www.geographynetwork.com>, image NASA\_Mars), originating from the combined MOC/MOLA/USGS-MDIM-color color mosaic published by the National Geographic Society (2001). The MDIM 2.1 mosaic itself is not shown as the background because few features are obvious on it after resampling to this small scale.

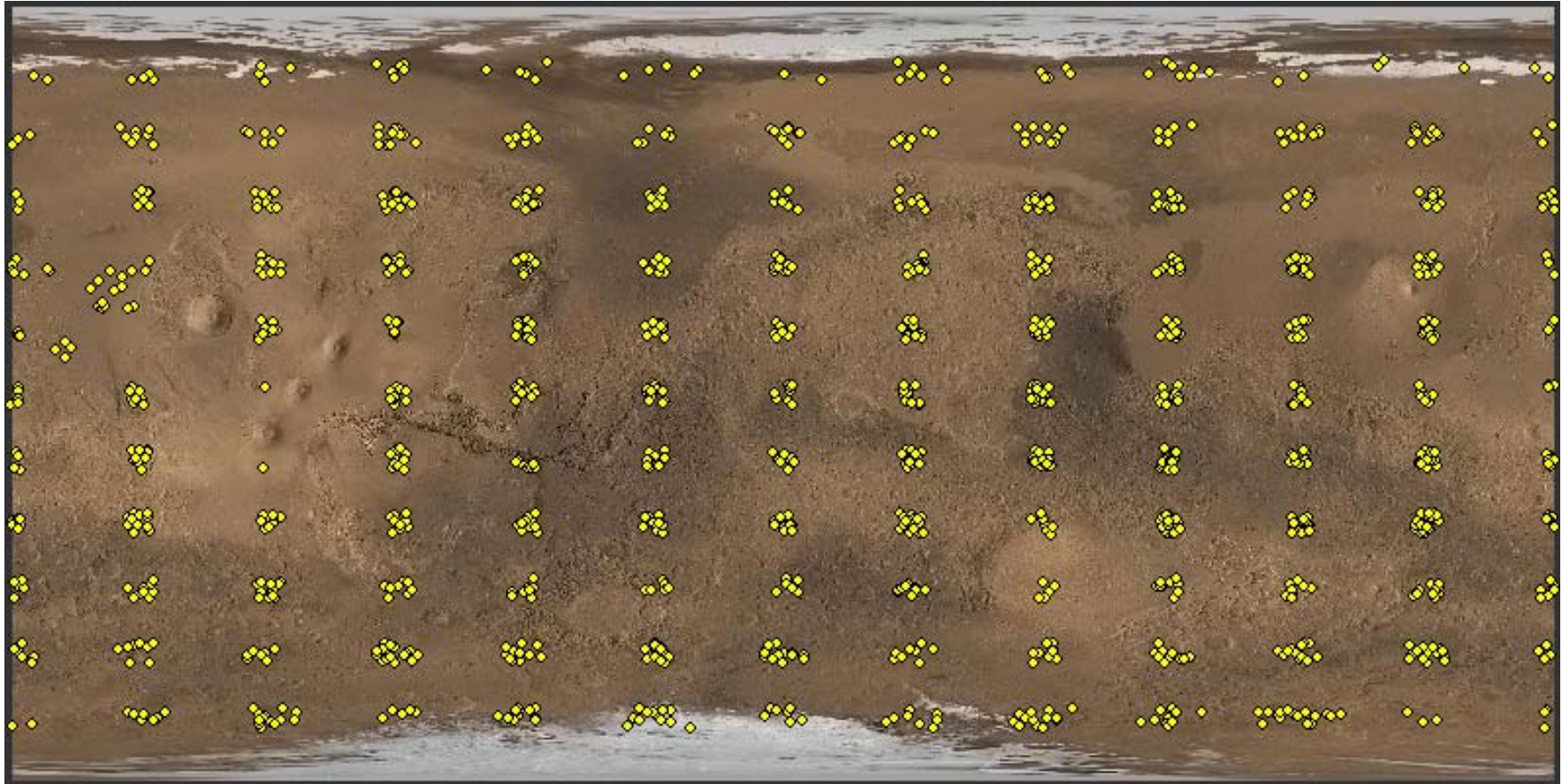


Figure 2: The 1,232 MOLA control (or tie) points, measured in groups with spacing of  $30^\circ$  in longitude and  $15^\circ$  in areocentric latitude. Note the additional points measured to the west of Olympus Mons (upper left). These points were added both since the mantled terrain was essentially featureless at one preferred location ( $210^\circ$  east,  $15^\circ$  north), and since it was difficult to tie Viking images together in this area due to their limited overlap and the lack of features. Same map projection, orientation, and background image as in Figure 1.

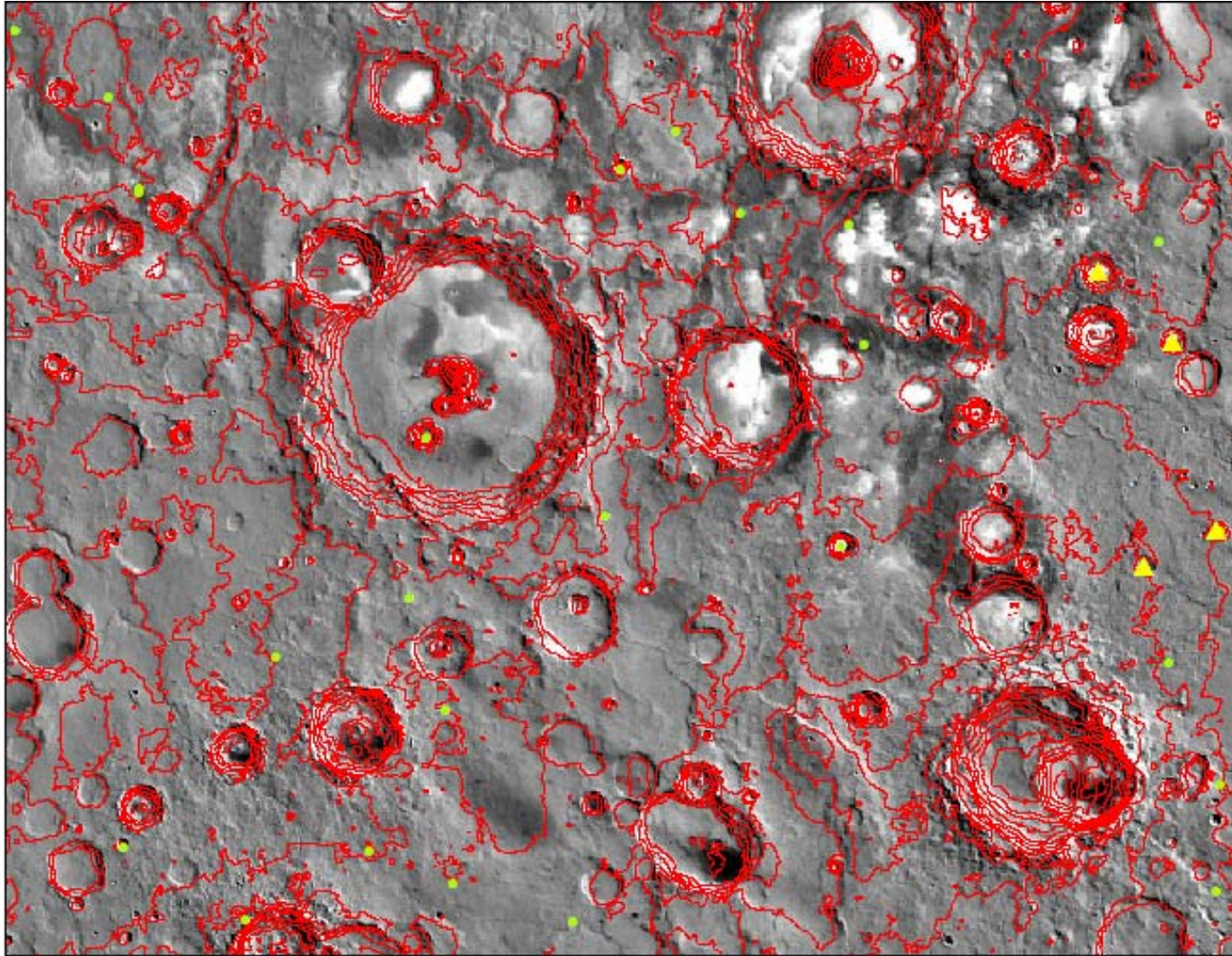


Figure 3: Sample portion of MDIM 2.1 mosaic with MOLA-derived 300-m contour lines (red on electronic version of this document) superposed, in order to show the registration accuracy of features on the mosaic with the MOLA data. Note in particular the good agreement in the linear features (faults, valleys) in the upper left of the image. This image shows a ~400 km-wide region in Daedalia Planum. The large crater is located at about 203.5° east longitude, and 14.3° south areocentric latitude. Control points are filled circles (green) and MOLA tie points are filled triangles (yellow). Simple Cylindrical projection with north up and east to the right.