Cartography at the Edge of the Solar System

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Prior to the New Horizons flyby of the Pluto system this past summer [1] the only kind of map for Pluto and Charon came from HST data [2], and we could only speculate on the types of surface features that we might see [3]. As such, there is no established cartographic reference for Pluto or Charon, aside from that currently defined by the IAU based on ephemerides, not surface characteristics [see 4].

Data: We made use of the New Horizons LORRI and MVIC data for purposes of establishing a control network and cartographically controlling the data. Images prior to one Pluto rotation (approximately seven days prior to closest approach) were of low enough resolution that they were not helpful in providing identifiable features for matching and were also superseded by images that covered the same area but with better resolution nearer to closest approach.

SPICE data is key to this work [5, 6]. At the time of the flyby only predict kernels were available which had discrepancies when used with the images that were taken, and required extra manual effort to make use of in that period. As expected, the reconstructed SPICE kernels provided 90 days after the encounter provided a more accurate description of the position and pose of the spacecraft. However, while those kernels were a significant improvement, there was often still a slight mismatch of the reconstructed SPICE position and the actual location of the object (see figure 1, again, as expected).

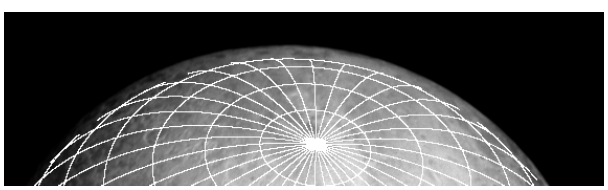

Figure 1: P_LORRI_FULLFRAME (lor_0299123689) showing an offset of about 14 pixels from where the SPICE data calculate the limb and where it is in the image.

Geometric Correction Method: Images were brought into the ISIS [7] system and associated with their reconstructed SPICE information. Due to current limitations in the way that ISIS treats framing cameras and line-scan cameras, the LORRI and MVIC data had to be worked with independently.

LORRI network: All LORRI images for a body (the same method was used for both Pluto and Charon) were inspected and image to image control points were assigned with the ISIS `qnet` program. Where possible, a control point was located on a feature that was identifiable in many images and a 'measure' was added for each image. This way control points were not just image pairs, but consisted of the same feature in multiple images, which provided for better control solutions.

Once selecting control points was completed, the ISIS bundle adjustment program `jigsaw` [8] was used on all of the LORRI images to adjust only the instrument pointing parameter (but not the spacecraft position). We found that we got improved results when we also let `jigsaw` solve for the local radii of the given control points, rather than forcing the program to leave them fixed at a surface of average radius for the body.

This process resulted in a pointing solution for each LORRI image that allowed robust mosaicking. Practically, the result of this process is an improved SPICE C kernel that describes the updated spacecraft pointing at the time of each observation.

A controlled LORRI mosaic was then created from this control solution.

MVIC network: Ideally, the above process would also include MVIC images such that the bundle adjustment process in `jigsaw` would operate on a pool of control points that connect both LORRI and MVIC images. However, they must be treated separately. The MVIC images were inspected and given control points in a similar fashion, such that control points representing a feature were identified in as many MVIC pan and color bands as possible. However, in order to get these images to match the LORRI solution, we used `qnet` to identify the LORRI mosaic as a 'Ground Source' such that the locations of features in the LORRI mosaic were treated as known control points.

This resultant control network that contained MVIC to MVIC control points, as well as MVIC to LORRI mosaic ground control points was then given two runs through `jigsaw`. The first run did not solve for camera pointing, but only adjusted the spacecraft position. The second run of jigsaw was then allowed to solve for cam-

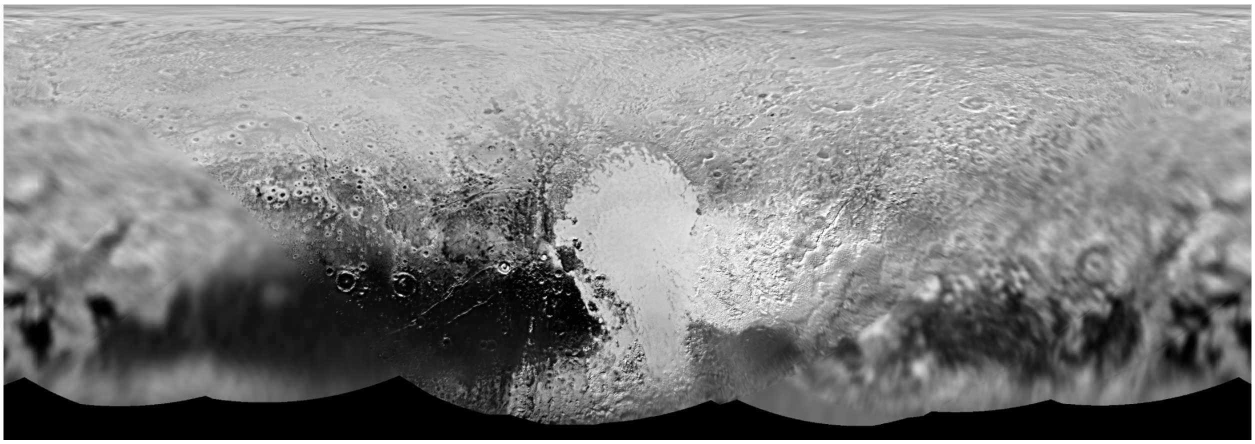

Figure 2: Mosaic of LORRI images of Pluto.

era angles and their angular velocities as well as update spacecraft position.

This produces a pointing (CK) and spacecraft location (SPK) solution for each MVIC image that allows reprojection of the individual MVIC color bands together to allow for registered color mosaics, as well as allowing mosaicking of MVIC and LORRI products together.

Photometric correction Method: We use the equations in [9] to make an approximation from instrument DN to I/F values. We also used the `photomet` program with a lunar Lambert photometric function to correct for the changing observation angles due to planetary curvature within a scene. This process allowed for much better seam matching and more visually consistent mosaics.

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