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SMART-1

End to end validation of Smart-1 pointing

S1-RSSD-TN-009

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1. Introduction

1.1Background

This document is intended to demonstrate the validity of the pointing request from identification of a science opportunity through to the acquisition of science data.

MAPPS visualisations appeared to show that the off nadir excursions for Smart-1 were not following the anticipated profile. The projection of the ground-track from the reconstructed attitude file did not correspond with the pointing request sent to Flight Dynamics, which consisted of certain segments (nadir, slew, nadir with offset, slew, nadir). More importantly, if the MAPPS plots were to be believed the selected targets were being missed by a few degrees (Figure 1).

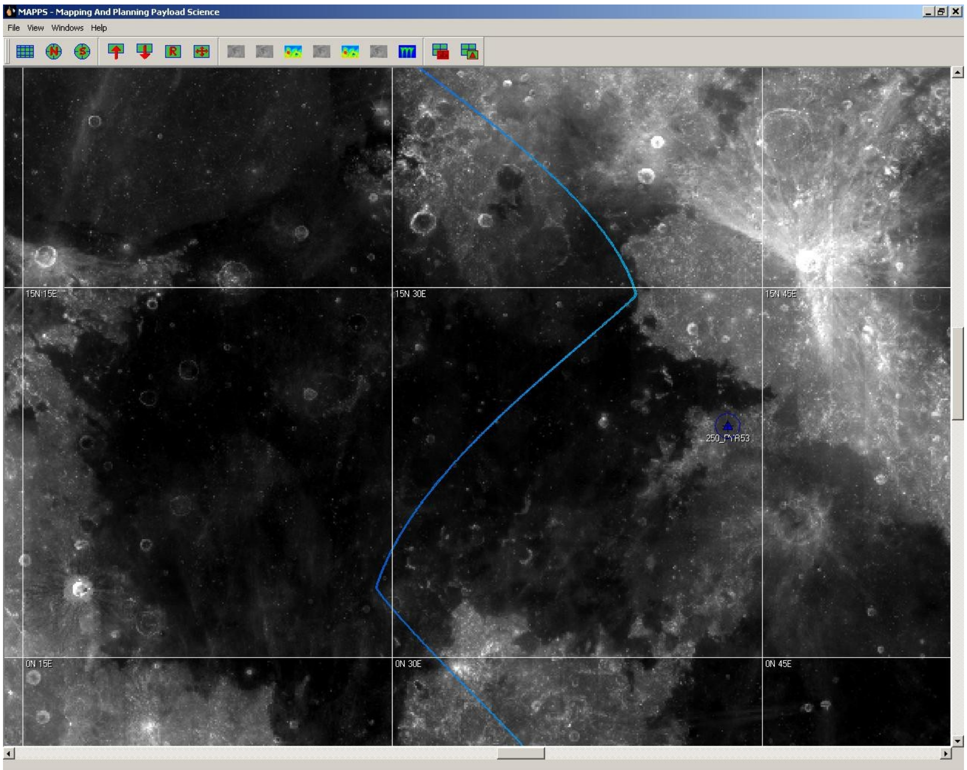


Figure 1: MAPPS visualisation of the problem: the shape of the ground track does not correspond with the pointing that was requested.

1.2Scope

The end-to-end validation of the pointing request has been reviewed in order to establish confidence in the STOC planning methodology and in the pointing accuracy of the spacecraft.

AMIE data was requested, and kindly delivered, to provide the feedback from completed operations.

1.3 Reference Documents

RD1 S1-SSD-TN-0003, PTB Generated Events for Constraint Implementation, Issue 3

RD2 SOP-RSSD-SP-016, Software Architectural Design for the Science Operations Coordinating System (SOCS), Issue 1

RD3 SOP-SSD-SP-002, PTR Software Specification Document (SSD), Issue 2.7

RD4 SOP-PTB-SPR-099-SM1, PTB Software Problem Report 099.

RD5 S1-AMIE-RSSD-TN-004, AMIE boresight analysis.

2. PTR generation process

2.1Overview

The chain of commanding starting from the identification of science opportunities and ending with the reconstruction of the spacecraft attitude profile consists of several steps:

1. The STOC simulator calculates identified targets (landmarks) visibility and science constraints. The output of the simulator is analysed by the SOPS client to identify all valid science opportunities.
2. Through the SOPS user interface a selection can be made which science opportunities will be taken.
3. The selections are exported as a PTR, which goes back into the PTB to estimate and validate slew periods.
4. The PTB outputs a validated PTR that is submitted to Flight Dynamics.
5. FD generates the platform commands to achieve the requested attitude profile. The corresponding products are delivered to the STOC. The projection of the payload FoV is visualised on MAPPS using the FD attitude file.

2.2Science opportunity window identification

The PTB reads in Flight Dynamics products (ORMS, ATNS, EVTS files) and calculates additional science opportunity events that supplement the information contained in the basic FD EVTS file. The output enhanced event file typically contains half a million events for each weekly planning cycle.

A landmark nadir visibility window is valid when an instrument FoV, centred on its boresight, intersects a landmark of a given radius. Along track and across track landmark visibility windows are offset from the nadir visibility. The PTB monitors a vector from the instrument FOV to the landmark. This “landmark vector” is split into a component along the velocity vector and a component perpendicular to it (Figure 2). For certain values/ranges consequently events/windows are generated.

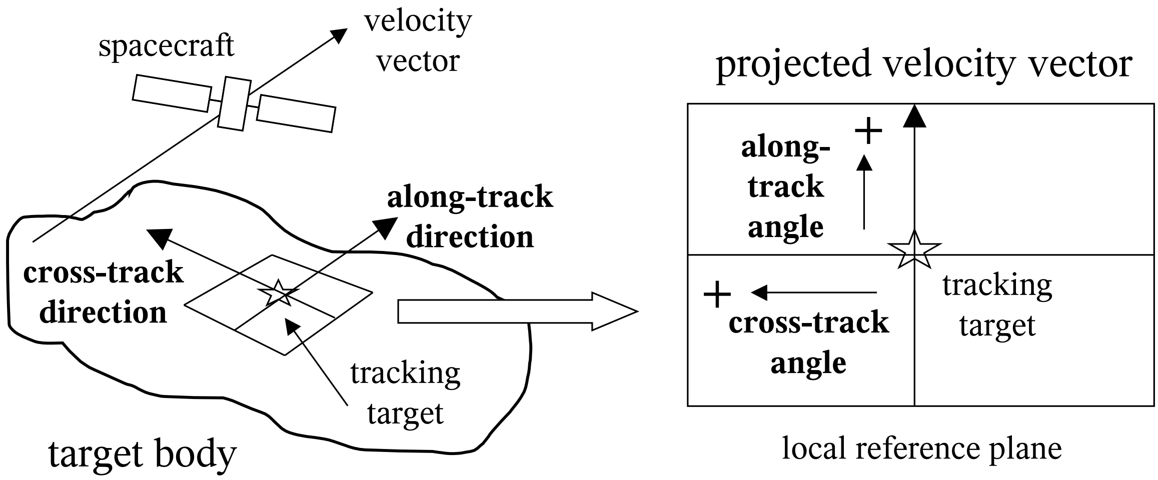


Figure 2: Off-track angles and local reference plane definition.

For a complete overview of events the PTB calculates, see Reference Document 1.

The information in the enhanced EVTS file is supplemented further by the Mission Master Plan (MMP), which contains the Earth communication passes and ground station availabilities, before being read into the Science Operations Planning System (SOPS) client. The client then synchronises to a knowledge base containing all the science constraints for each observation type. The analyser matches these constraints to the simulation results to establish all possible science opportunities.

2.3Target selection with SOPS client

All possible science observation opportunities are shown in the SOPS client, compatible selections can be made. When the science planning process is finalised the SOPS client produces two output files: a SCIOP events file and a PTR file. For more information concerning the SOPS, please see Reference Document 2.

2.4Slew estimations and validation

The PTB is used to validate fixed slew times, calculate excursion times and to substitute coordinates for platform maintenance slots in the SOPS PTR. Reference Document 3 contains the definition of the generic PTR format.

One pointing option that was implemented for Smart-1, CROSS_TRACK_LM, makes it possible to "hit a target", for example a central peak of a crater.

When CROSS_TRACK_LM is specified in the PTR, the PTB calculates the spacecraft centred across-track angle from the sub-satellite point to the landmark. This calculation is independent of the rolling of the spacecraft due to power optimisation. The value is calculated when the along track angle to the landmark is equal to zero.

Reported in Reference Document 4 (SPR):

```
Integration of the new EPS (1.9.1) including a new pointing mode
(CROSS_TRACK_LM).
When an across track to landmark pointing is found in a PTR, the PTB now
resolves this to an across track with the proper values (i.e. the across
track when the satellite passes the center of the landmark (along track
~0.0)).
Also changed, is the attitude calculation from a across/along track angle.
For smart1 the angles are as seen from the spacecraft and NOT from the
center body.
```

In our case we have defined a user axis. This is not used in the angle calculation, it is the vector pointed to the target in the PTR block (see Appendix A for examples).

3.MAPPS visualisations

In order to assess the performance in the pointing of the spacecraft it was necessary to compare the predictions with the results, i.e. MAPPS plots with acquired AMIE images. Three examples are used in the following sections and are summarised in Table 1below.

Target	Observation type	Orbit(s)	Comment
SIR BR 1	Target tracking	1775	Close to Kepler
SIR N3	Across track	1778	Hansteen crater
SIR N2B/C	Across track	1777 and 1778	Above the Billy crater

Table 1 selected targets for comparison of MAPPS prediction versus acquired results.

Appendix A contains the relevant parts of the PTR files for each of the examples

3.1Kepler target tracking in orbit 1775

A target tracking of 4 minutes and 14 seconds planned on SIR target BR1 (9N, 321W), just west of Kepler (8.1N, 322W).

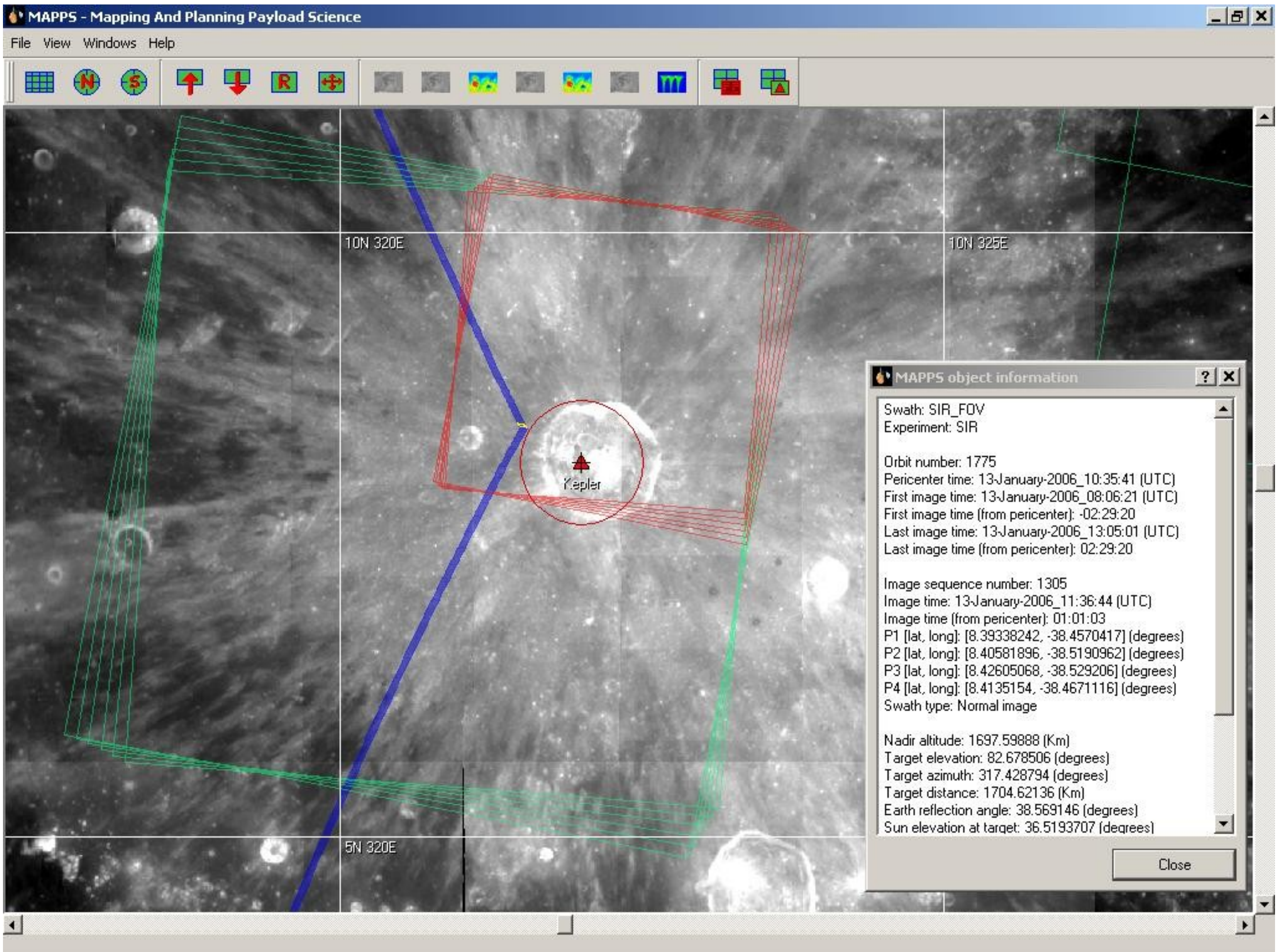


Figure 3: MAPPS visualisation of the tracking over BR1 (a SIR target close to Kepler) with AMIE full filter (green), clear filter (red) and SIR (blue) using an attitude file with a 1 second resolution. The subtle rotation of the spacecraft due to power optimisation can be clearly seen.

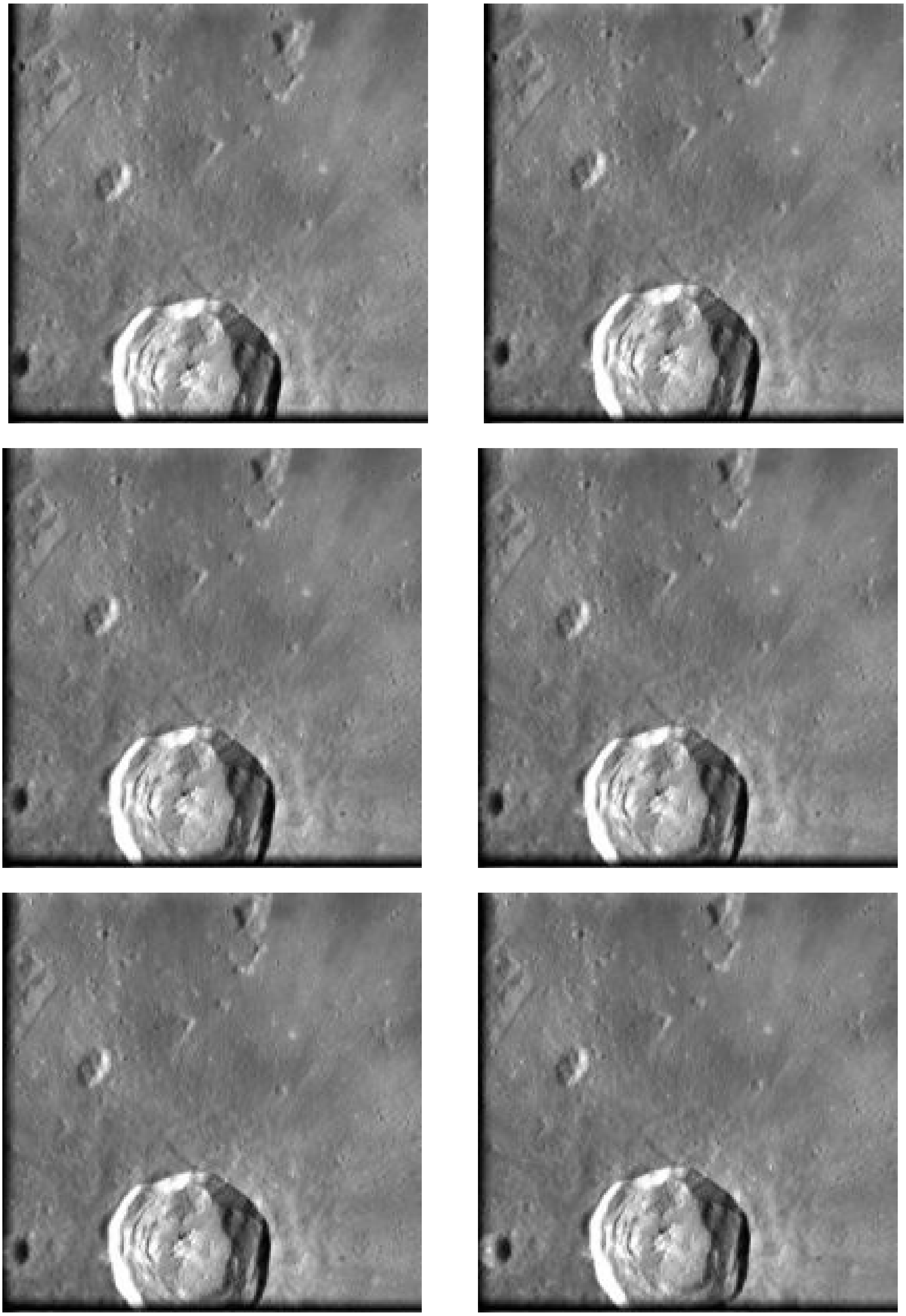


Figure 4: Sequence of AMIE clear filter images of a tracking of BR 1. A longitudinal shift is observed (the left crater should completely fall within all pictures).

3.2SIR_N3 across track orbit 1778

An across track pointing tracking of 2 minutes and 39 seconds on SIR target N3 (12.2S, 310.1 W), just above crater Billy (13.8S, 309.9W).

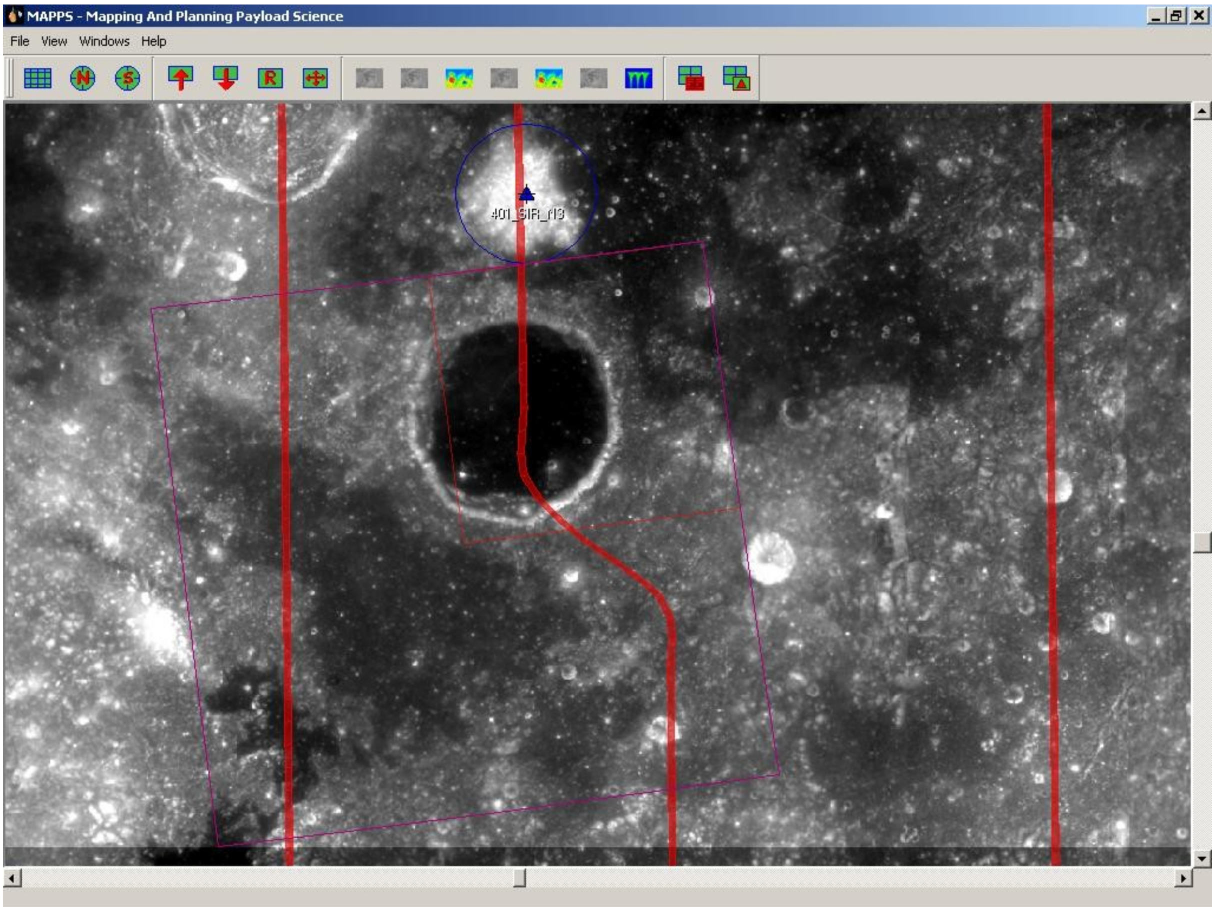


Figure 5: This image suggests that an event to take an AMIE picture is generated when the AMIE full (purple) or clear (red) filters intersect the radius of the SIR target (blue), but this is not true. AMIE has been scheduled to take an image driven by the start of the landmark visibility window (3 degrees along track). So it is pure chance that it works out such that the filters are adjacent to the radius of the SIR target. With the observation of SIR_N2B you can see this more clearly as the filter does not touch the radius of the target (see Figure 8). The red ground track of the SIR FOV goes almost through the target.

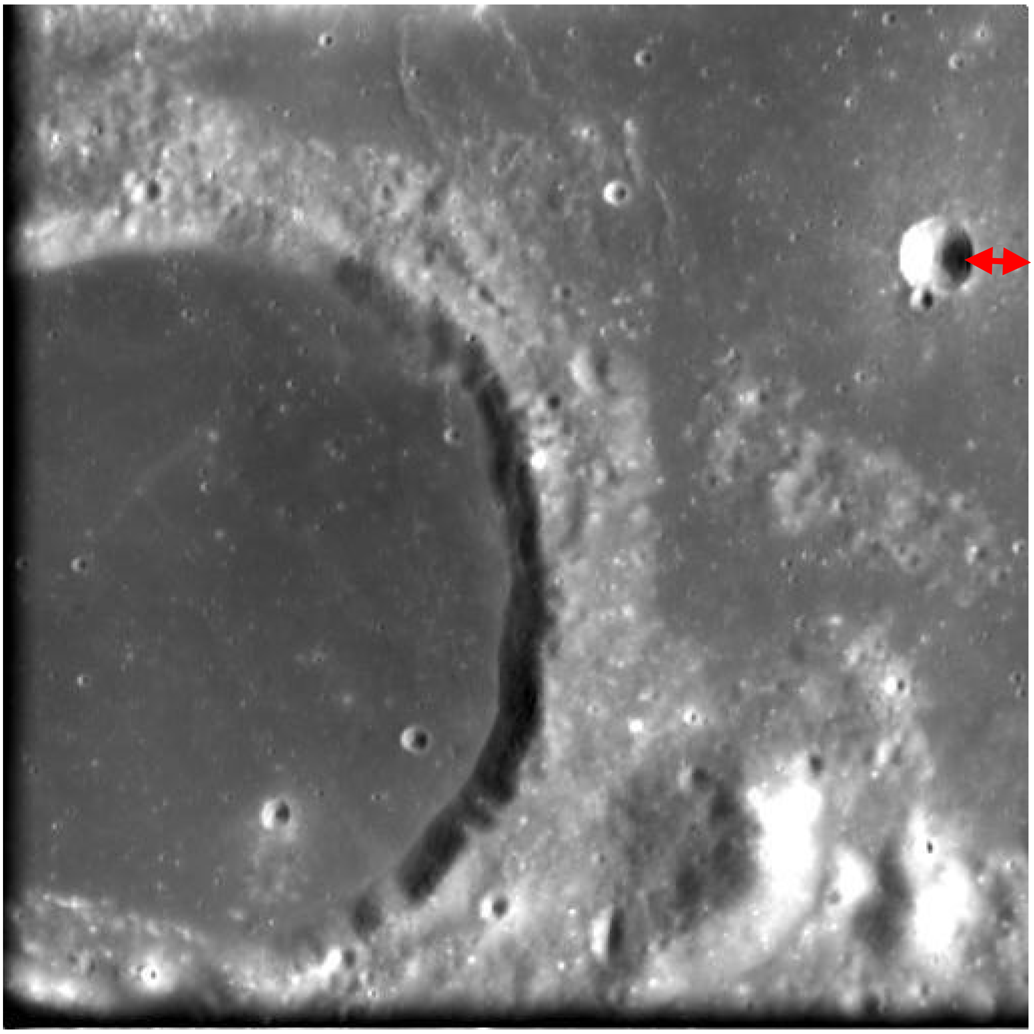


Figure 6: Note: Close inspection of the MAPPS visualisation (as shown in Figure 5) in comparison to the AMIE images reveals a longitude shift (indicated). In fact latitudinal shifts can be expected due to the inaccuracy of determining the on-board time. The off-set has been further investigated (see Appendix B for the images analysed) but no definitive conclusion could be reached.

The above comparisons between MAPPS plots and the real data in the form of AMIE images show that there is an offset between the reconstructed pointing and reality. This has been confirmed with further examples (see Appendix B) but no definitive conclusion can be reached as the differences appear unsystematic.

The projection of the AMIE FoV in MAPPS is based on values obtained during commissioning as described in Reference Document 5. A detailed analysis of the AMIE bore sight is a responsibility of the AMIE team and is outside the scope of this document.

3.3SIR N2B and N2C across tracks (orbits 1777 and 1778)

The observation of N2B and N2C in consecutive orbits turned out to be an interesting case. Figure 7 shows the ground track of the SIR field of view and the images that AMIE has taken.

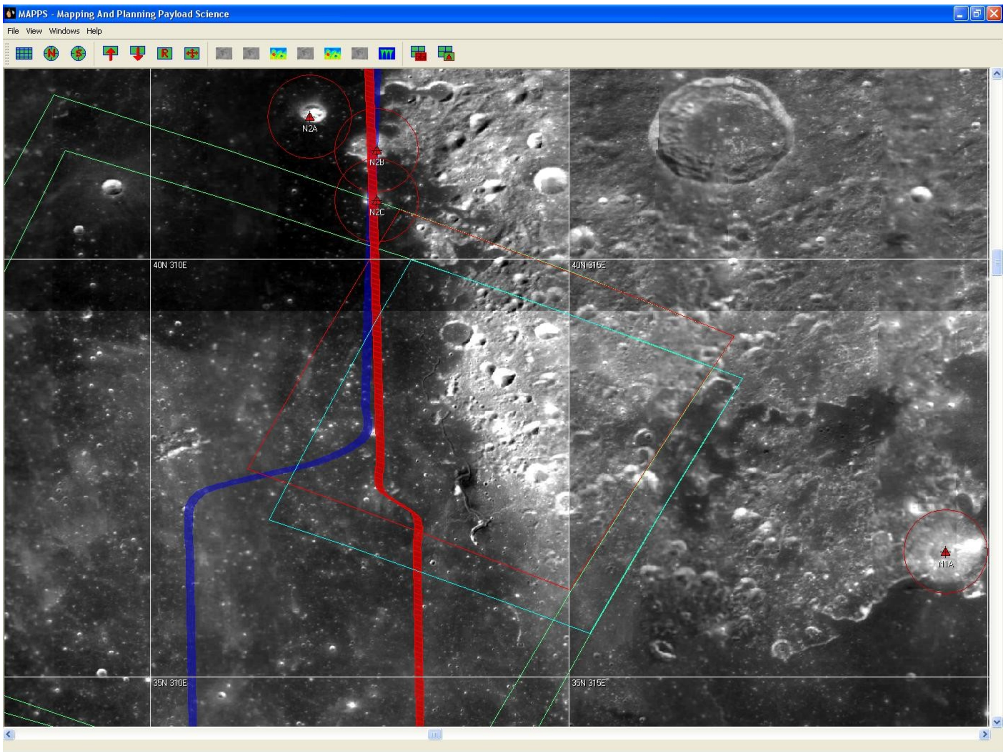


Figure 7: Successive observations of SIR targets N2B (orbit 1778) and N2C (orbit 1777) show how accurate the across track angle gets calculated by the PTB. Zooming into this image shows this even better, see Figure 8. Note that the AMIE image does not cover the required target.

Zooming in highlights the small difference in attitudes for the pointings of N2C and N2B. This can give us a first indication of the pointing accuracy when we look at the position of the landmarks compared to the width of the two ground tracks: it is on the order of 1/10 the SIR field of view. This is not a surprising result given the proximity of the SIR FoV to the +Z axis, the PTB calculated offset from the sub-spacecraft point will be extremely close to that required for SIR to pass over the selected target.

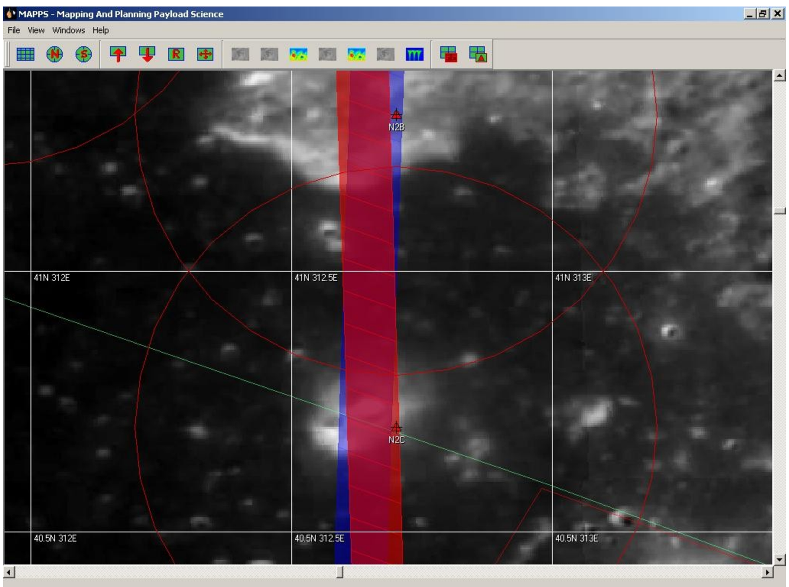
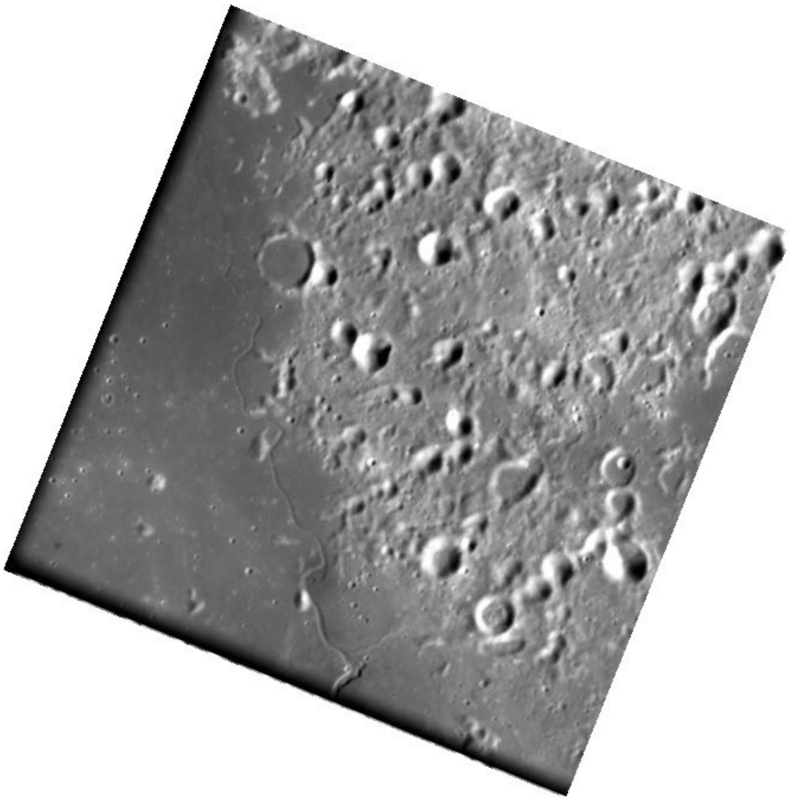


Figure 8: The blue ground track belongs to the observation of SIR target N2B (41.3,312.7), red belongs to N2C (40.7,312.7). From this picture an overall spacecraft pointing accuracy (position of

landmark compared to ground track width) would seem very good. Better than 1/10 SIR FOV.



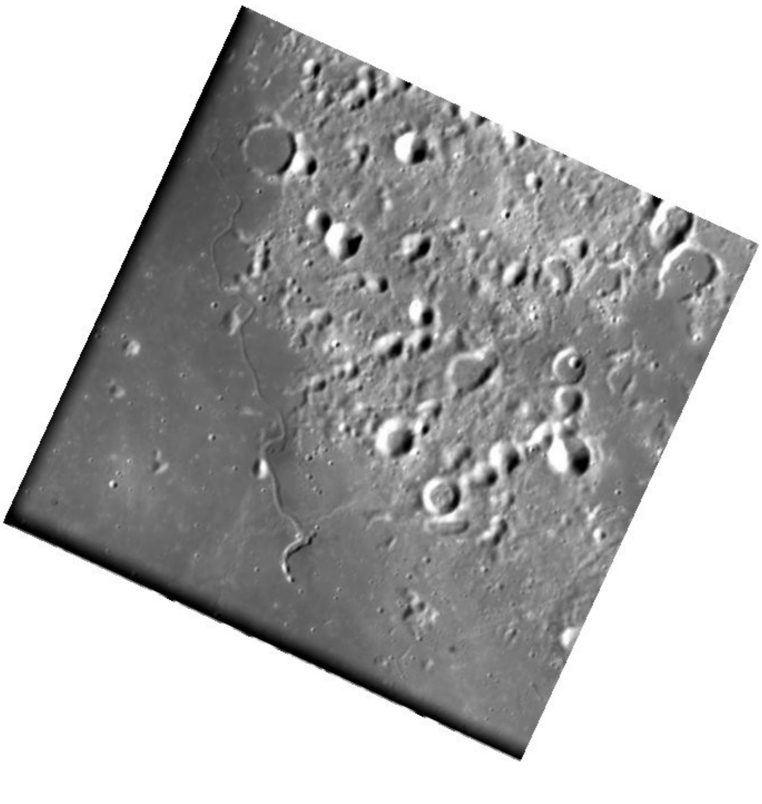


Figure 9: The resulting AMIE clear filter images of orbits 1777 and 1778. When compared with Figure 7 one can again detect a longitudinal and latitudinal shift, so further investigation of the AMIE bore sight determination is deemed necessary.

4.Conclusion

The problem that was discovered turned out to be a visualisation problem. The attitude file that was used in MAPPS was being under sampled. Instead of step sizes of 10 minutes that were being used, steps of 30 seconds or less should be taken in order to visualise short duration pointings correctly. The whole end-to-end implementation of pointings was verified to be working correctly. However unsystematic longitudinal and latitudinal offsets were detected for AMIE. The suspicion is that the AMIE FoV definition used by MAPPS may be slightly wrong, as the values are those obtained during the instrument calibration campaign their refinement must be performed by the AMIE team. The SIR visualisations show a very high degree of accuracy and confirm the angles calculated by the PTB are correct when using the +Z.

5.Appendix A: End to end verification of PTR files

5.1a) Edge of Kepler crater tracking (SIR target BR1, orbit 1775):

From enhanced EVTS file (EVTS_enhanced_P602__________00191.EVF):

007_11:30:38 LM_VIS_ALG_0_3_START (COUNT = 4150025)

007_11:34:52 LM_VIS_ALG_0_3_END (COUNT = 4150025)

Note: Kepler = PTB_landmark 415 with coordinates: 8.5 321.5

From SOPS EVTS file (EVTS_SOPS_P602.EVF):

378_11:30:38 LM_VIS_ALG_0_3_START (COUNT = 4150025)

378_11:34:52 LM_VIS_ALG_0_3_END (COUNT = 4150025)

From SCIOP EVTS file (EVTS_SOPS_SCIOP_P602.EVF):

013_11:30:38 SIR_TARGET_TRACK_START (COUNT = 4150004)

013_11:34:52 SIR_TARGET_TRACK_END (COUNT = 4150004)

From SOP_PTR (PTR__SSOSMA_DA_060107000000_SOP01.PTR):

013_11:30:38 STOC TRACK_START (OBJECT_TO_BE_POINTED = SIR OBJECT = 415_SIR_BR1 REF_BODY = MOON SLEW_POLICY = IMMEDIATE YDIR = POSITIVE)

013_11:34:52 STOC TRACK_END

From PTB PTR (PTR__SSOSMA_DA_060107000000_PTB01.PTR):

```
013_11:30:38          STOC    TRACK ( \
                        DURATION = 254 [seconds] \
                        OBJECT_TO_BE_POINTED = SIR \
                        REF_BODY = MOON \
                        LATITUDE = 8.5 [degrees] \
                        LONGITUDE = 321.5 [degrees] \
                        \#RADIUS = 1.738e+006 [meters] \
                        SLEW_POLICY = SMOOTH \
                        YDIR = POSITIVE)
```

From FD PTR (PTR__SSOSMA_DA_060107000000_00003.SM1):

```
BEGIN
TYPE = MOON_SPOT
TBEG = MPER_1776 +00:56:44
TEND = MPER_1776 +01:00:58
AXIS = -2.090001E-004 -9.250005E-004 9.999996E-001
YDIR = +1
LAT = 8.500000E+000
LON = 3.215000E+002
HEI = 0.000000E+000
END
```

5.2b) SIR target N3 ACROSS TRACK OBSERVATION (orbit 1778):

From enhanced EVTS file (EVTS_enhanced_P602__________00191.EVF):

008_02:12:12 LM_VIS_ALG_0_3_START (COUNT = 4010021)

008_02:14:51 LM_VIS_ALG_0_3_END (COUNT = 4010021)

Note: SIR_N3 = PTB_landmark 401 with coordinates: -12.2, 310.1

From SOPS EVTS file (EVTS_SOPS_P602.EVF):

⇊

379_02:12:12 LM_VIS_ALG_0_3_START (COUNT = 4010021)

379_02:14:51 LM_VIS_ALG_0_3_END (COUNT = 4010021)

From SCIOP EVTS file (EVTS_SOPS_SCIOP_P602.EVF):

⇊

014_02:12:12 SIR_OFFNAD_LSE_0_90_START (COUNT = 4010001)

014_02:14:51 SIR_OFFNAD_LSE_0_90_END (COUNT = 4010001)

From SOP_PTR (PTR__SSOSMA_DA_060107000000_SOP01.PTR):

⇊

014_02:12:12 STOC NADIR_START (OBJECT_TO_BE_POINTED = SIR SLEW_POLICY = IMMEDIATE ROLL_MODE = POWER_OPTIMISED YDIR = POSITIVE CROSS_TRACK_LM = 401_SIR_N3)

014_02:14:51 STOC NADIR_END

From PTB PTR (PTR__SSOSMA_DA_060107000000_PTB01.PTR):

```
014_02:12:12          STOC    NADIR ( \
                        DURATION = 159 [seconds] \
                        OBJECT_TO_BE_POINTED = SIR \
                        ALONG_TRACK_ANGLE = 0 [degrees] \
                        CROSS_TRACK_ANGLE = 1.38388 [degrees] \
                        ROLL_MODE = POWER_OPTIMISED \
                        SLEW_POLICY = SMOOTH \
                        YDIR = POSITIVE)
```

From FD PTR (PTR__SSOSMA_DA_060107000000_00003.SM1):

```
BEGIN
TYPE = SLEW
TBEG = MPER_1779 +00:41:05
TEND = MPER_1779 +00:41:46
END

BEGIN
TYPE = NADIR
TBEG = MPER_1779 +00:41:46
TEND = MPER_1779 +00:44:25
AXIS = -2.090001E-004 -9.250005E-004 9.999996E-001
YDIR = +1
ACROSS_OFFSET = 1.383880E+000
ALONG_OFFSET = 0.000000E+000
END

BEGIN
```

TYPE = SLEW

TBEG = MPER_1779 +00:44:25

TEND = MPER_1779 +00:45:15

END

Note:

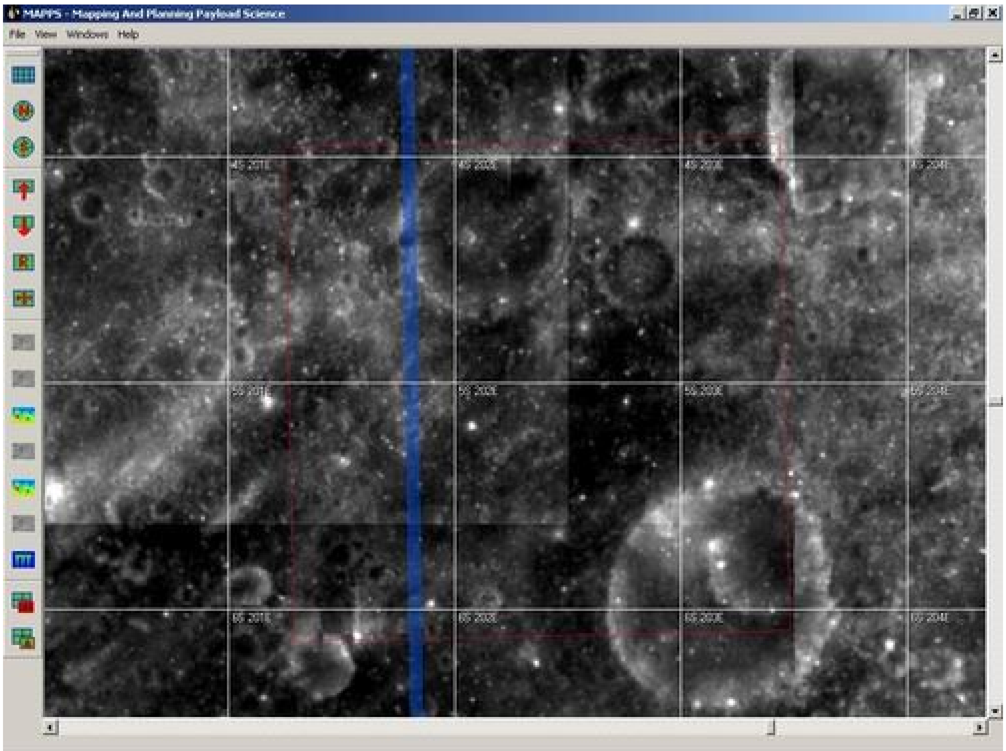
1) From enhanced to SOPS EVTS file: nothing happens with the calculated target visibility window, except a change of the reference date.

2) From SOPS to SCIOP EVTS file: the SOPS client has given the choice SIR_OFFNAD_LSE_0_90 on SIR_N3 or SIR_TARGET_TRACK on SIR_N3. Obviously the science planner has made a decision to scan over this target rather than track it.

3) From SOP PTR to PTB PTR: The PTB has calculated the angle.

4) FD apparently also uses spacecraft based angles as the attitude file that gets read in MAPPS shows that the target properly gets tracked.

6.Appendix B: Analysis of AMIE off-set



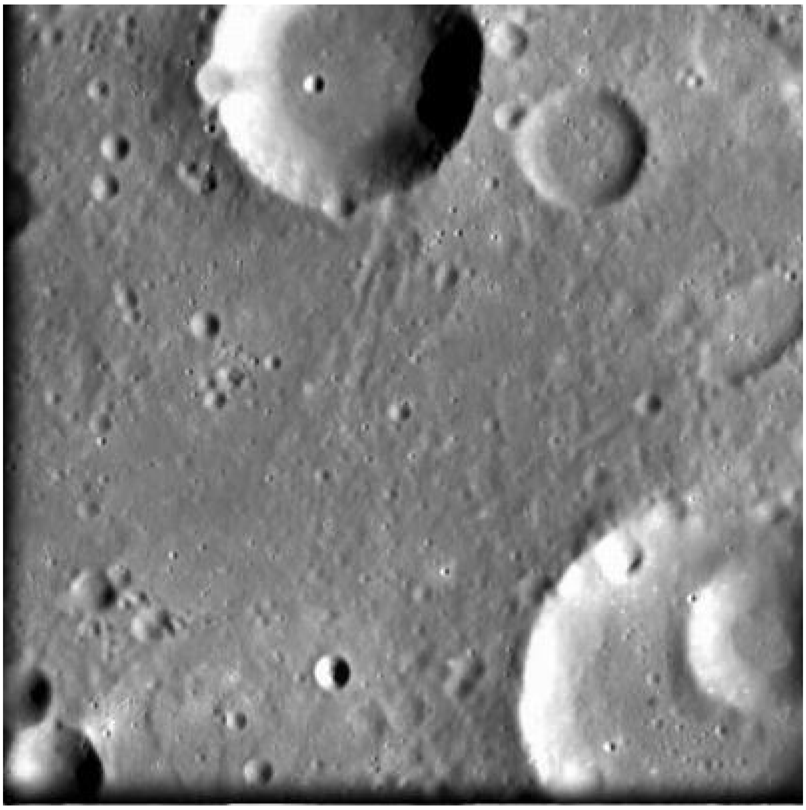
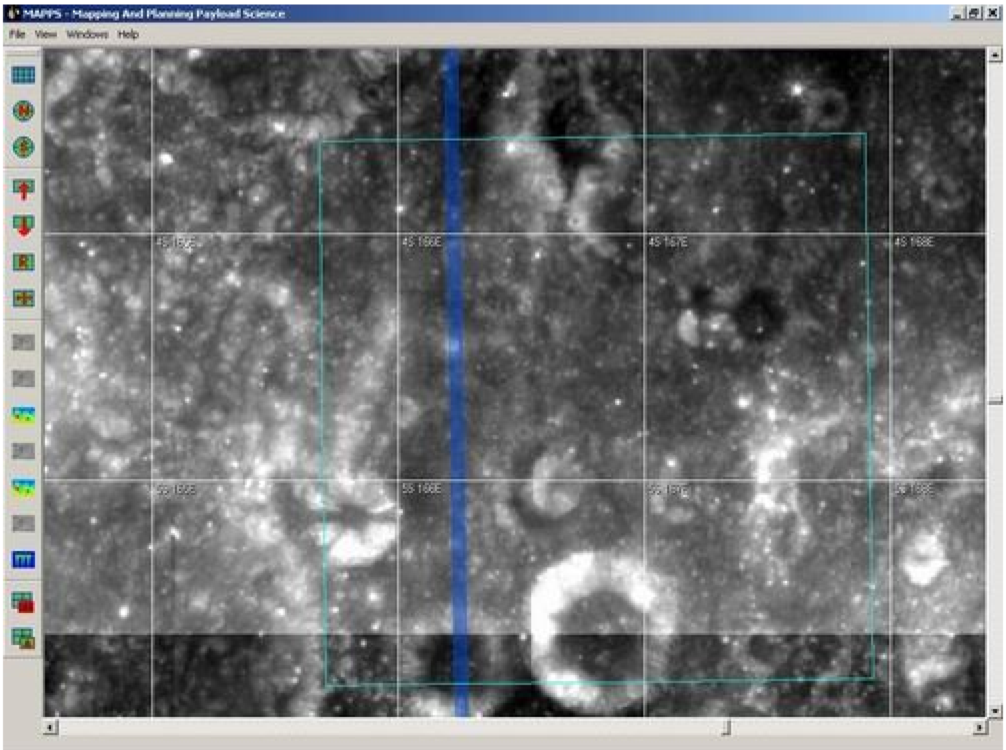


Figure 10: Orbit 1818, image 37 (near the equator): An altitudinal offset can be observed between AMIE data and MAPPS. The red (horizontal) line represents the (clear) filter edge as calculated by MAPPS, which as can be seen in the subsequent images, varies unsystematically.



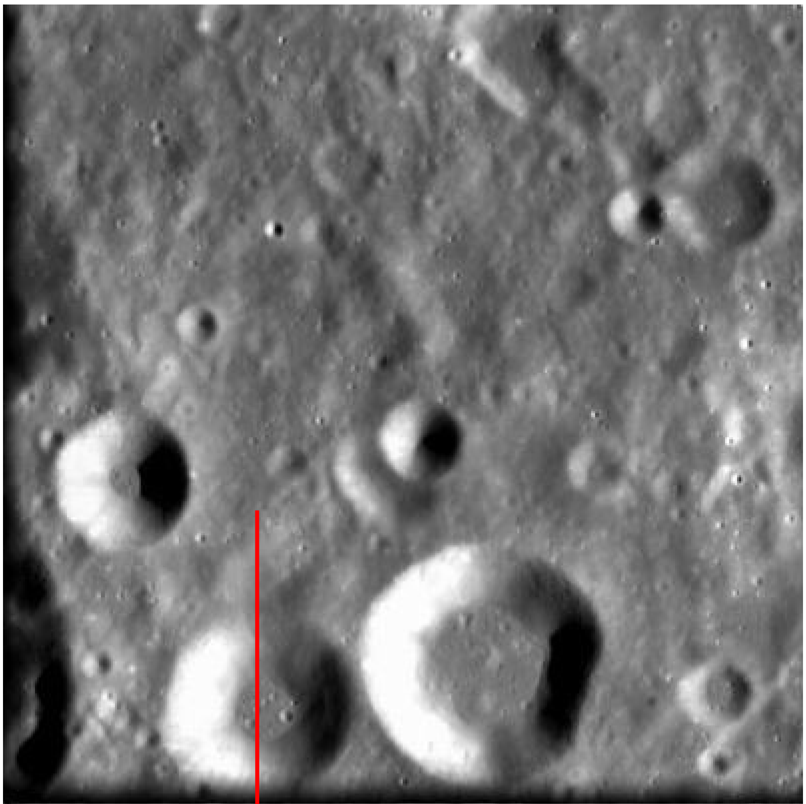
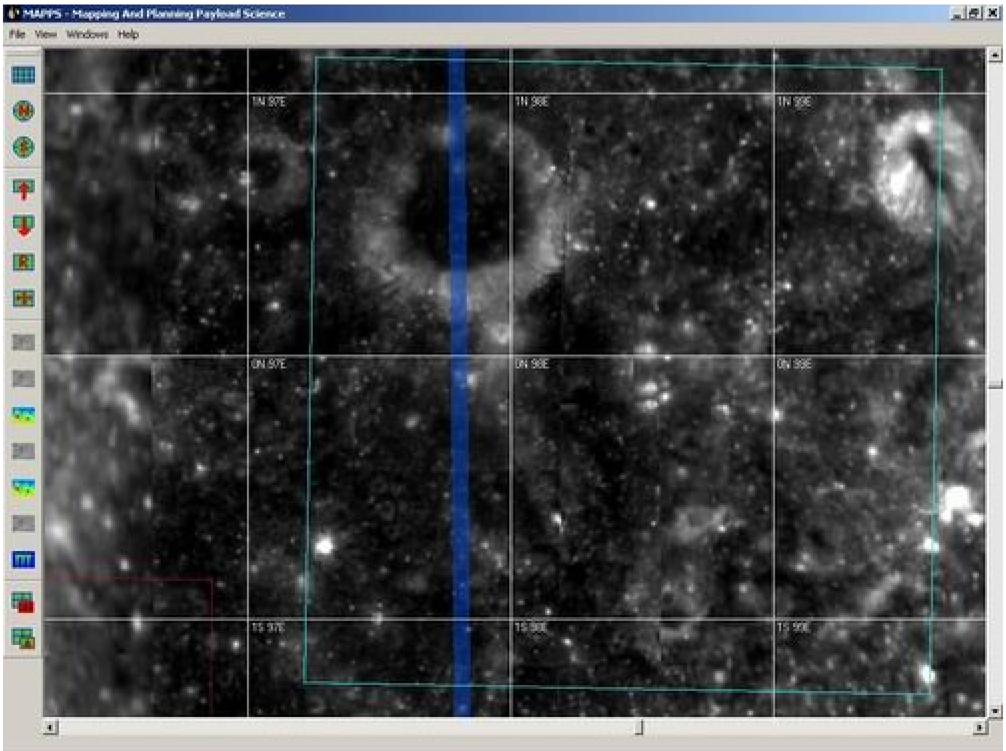


Figure 11: Orbit 1831, image 25 (near the equator)



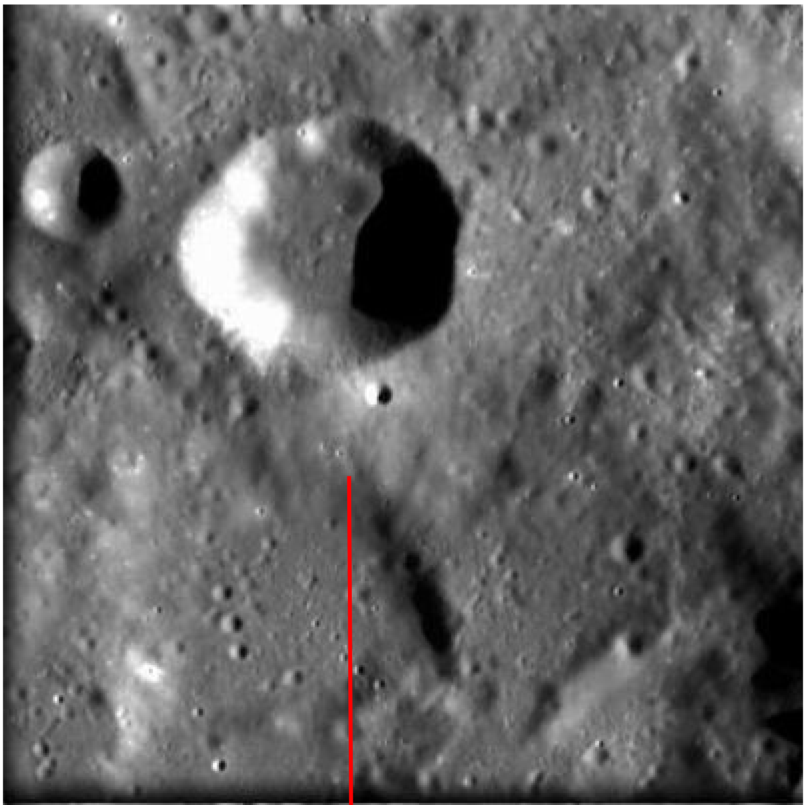
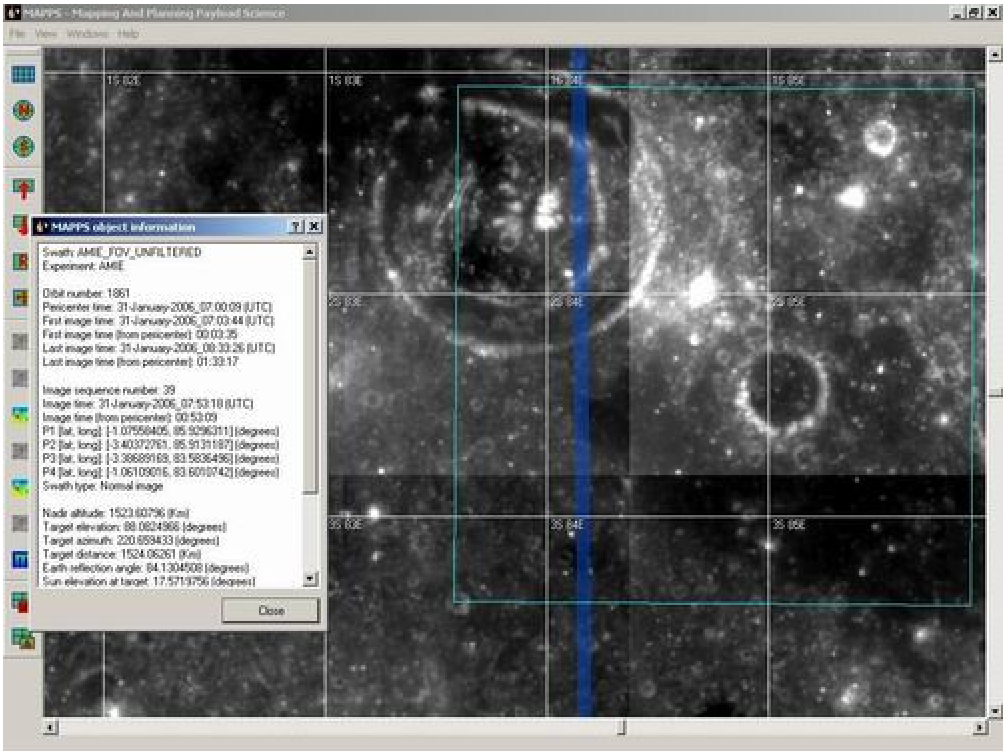


Figure 12: Orbit 1856, image 39 (near the equator)



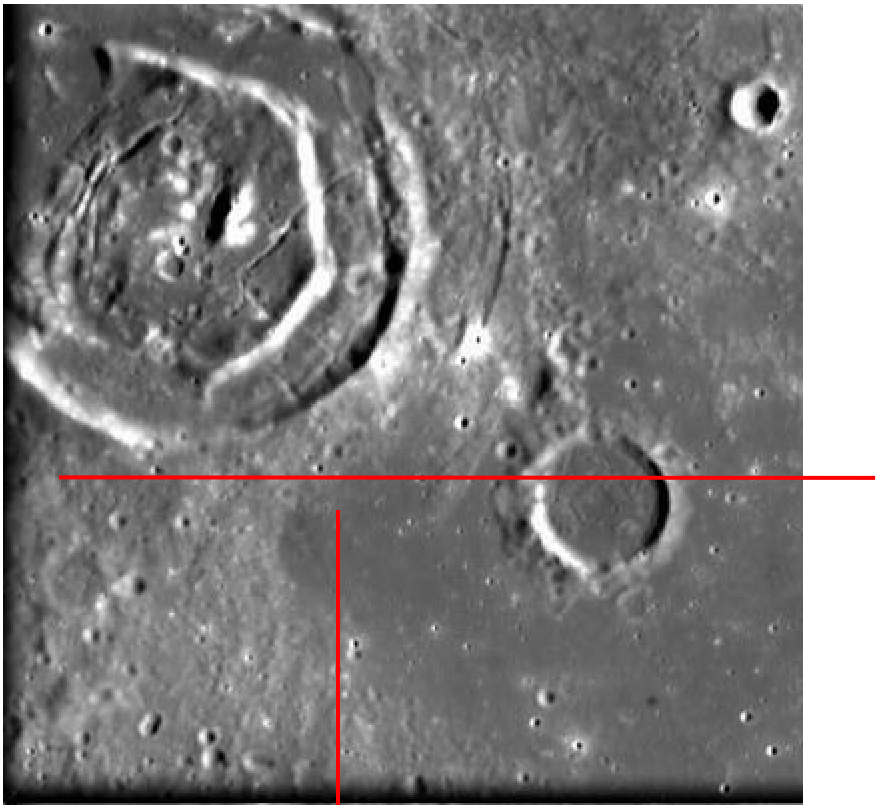
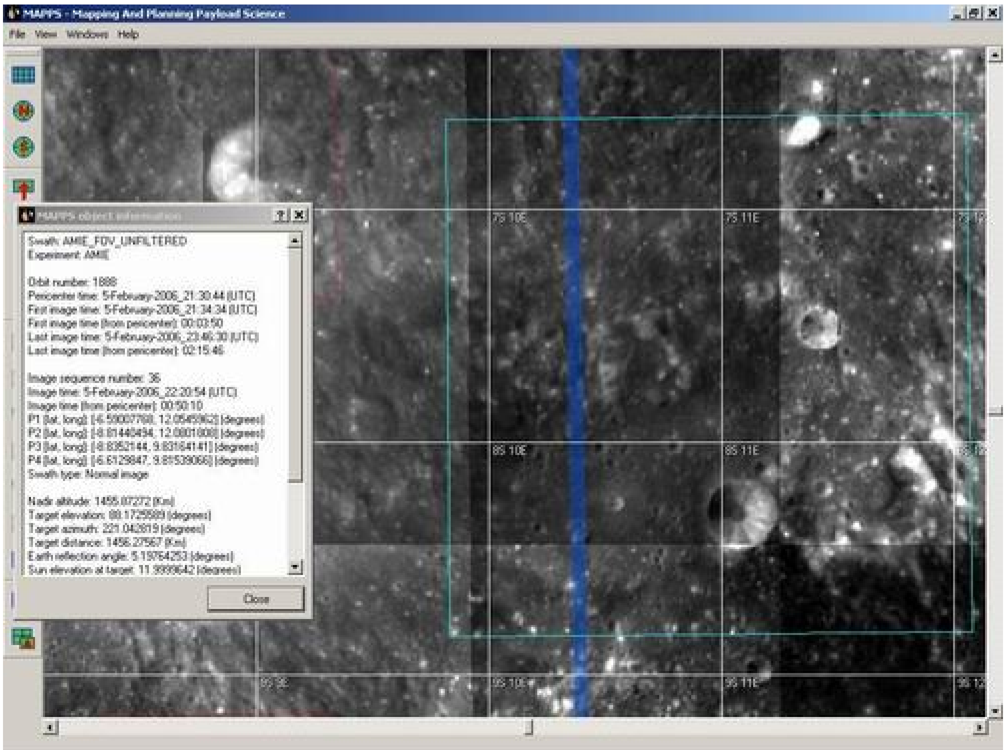


Figure 13: Orbit 1861, image 40 (near the equator)



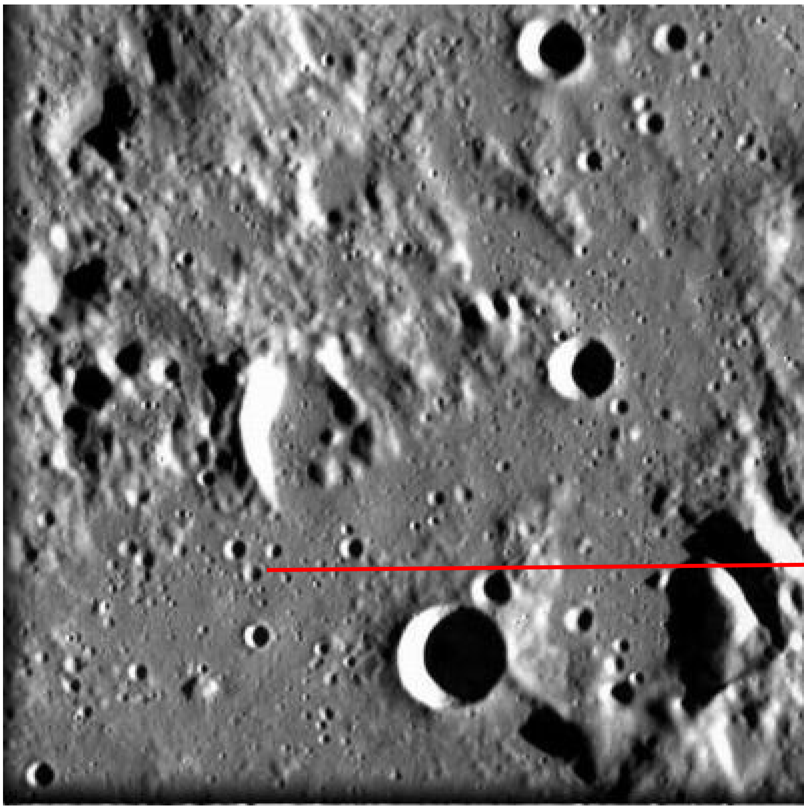
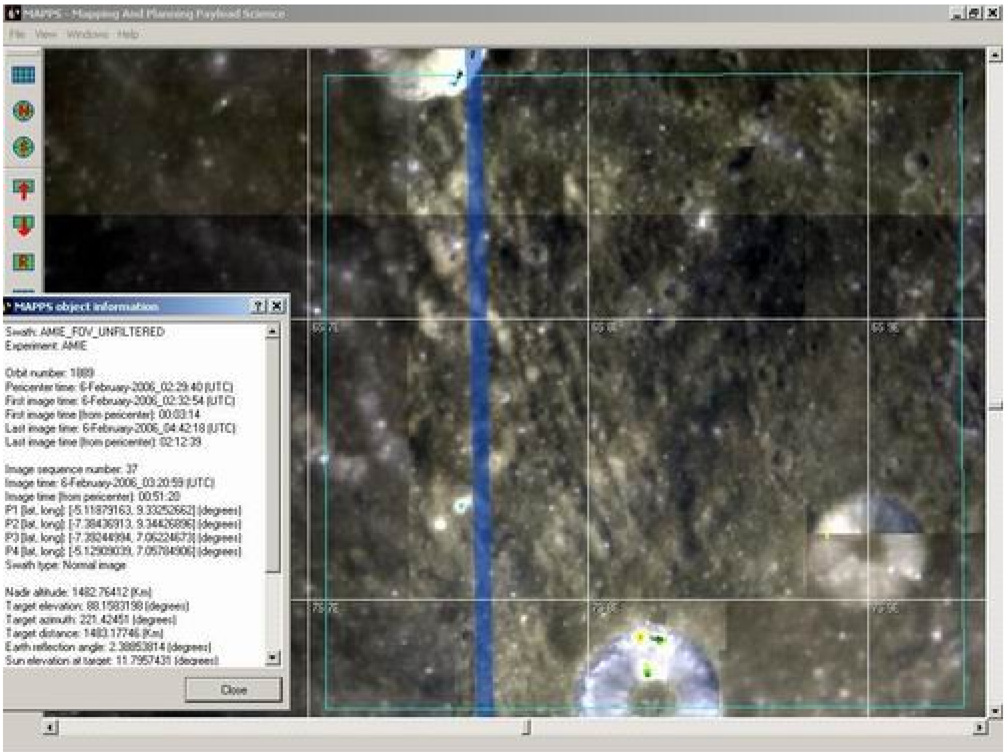


Figure 14: Orbit 1888, image 36 (near the equator)



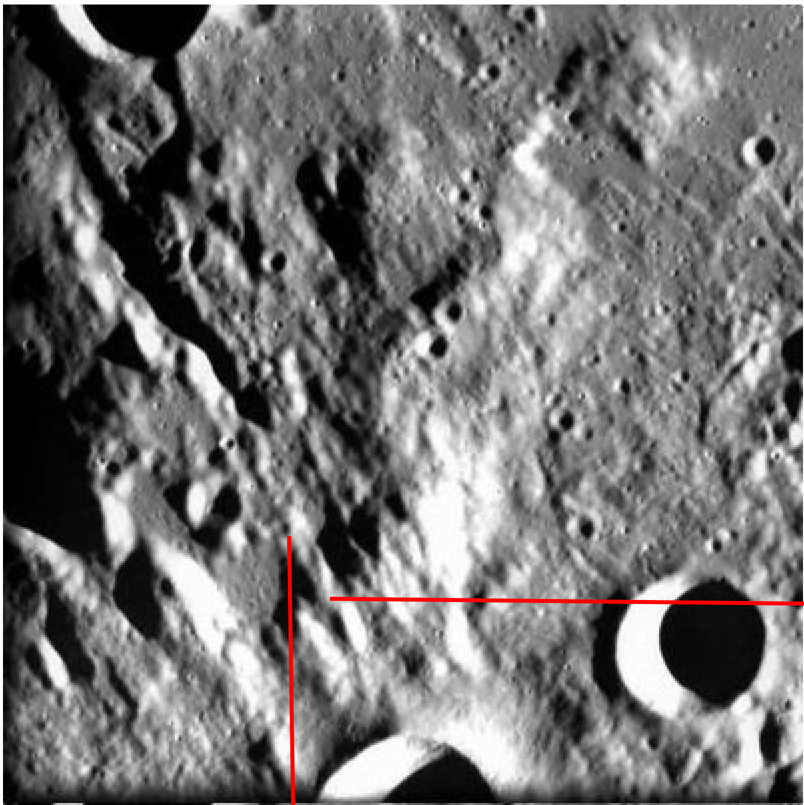
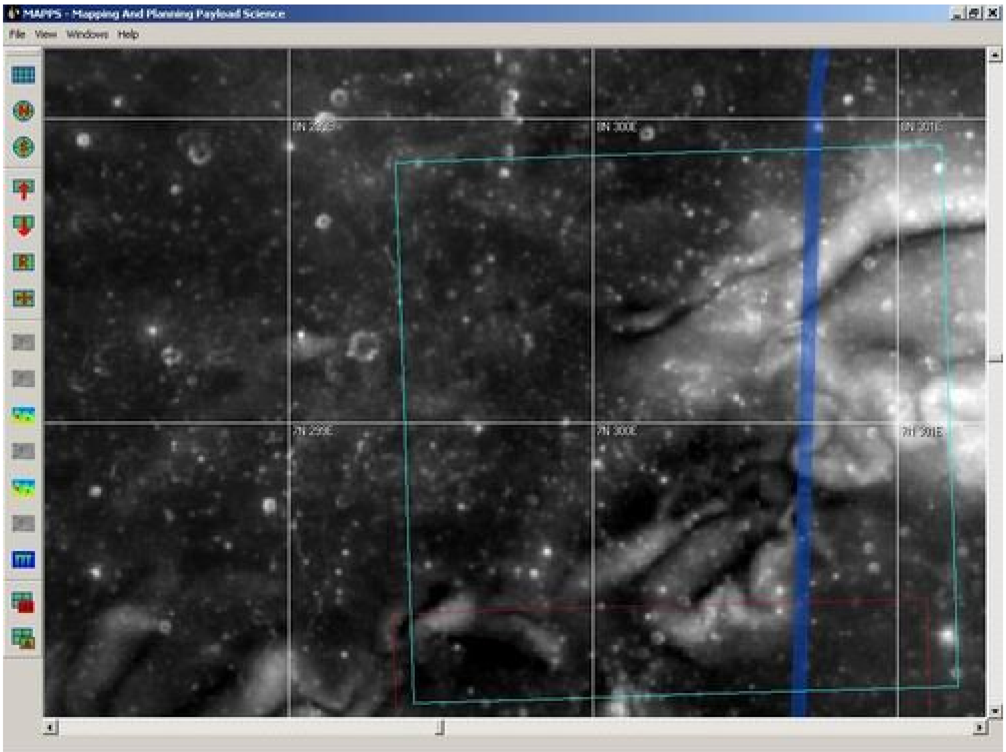


Figure 15: Orbit 1889, image 38 (near the equator)



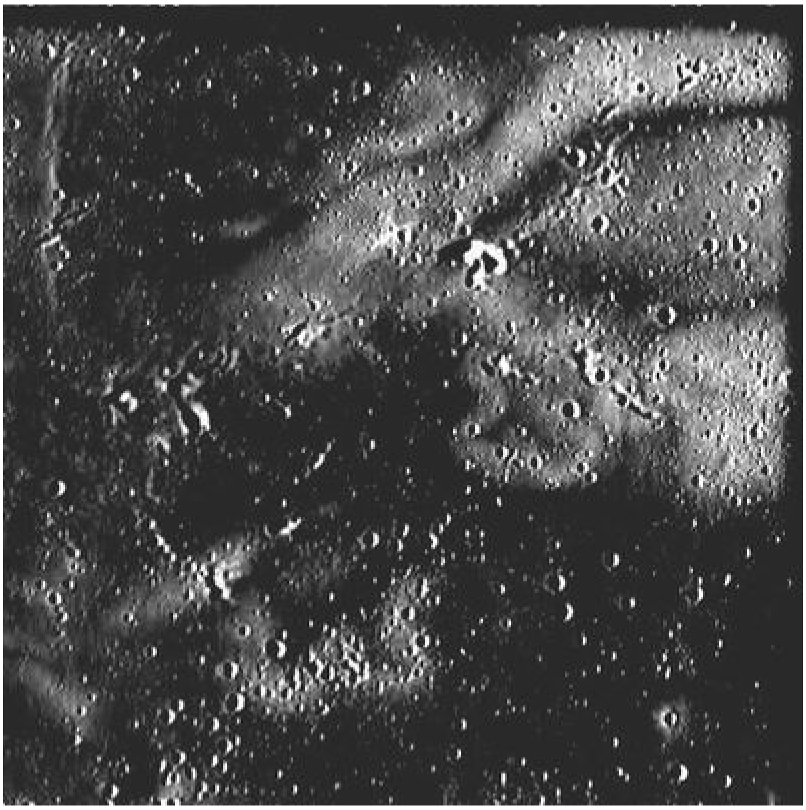


Figure 16: Orbit 1980, image 1 (near the equator)