First inspection of the Chandrayaan-1 SPICE data Version-1 provided by ISRO on 2010-Aug-31

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1 Preliminaries

1.1 Reference documents

[CH1-ESA-TN-008] CH1 SPICE issues (Iss./Rev. D/-, 2009-Aug-04)

[SOP-RSSD-TN-010] Planetary Science Data Archive Technical Note Geometry and Position Information (Iss./Rev. 4/1, 2007-Apr-02)

1.2 Acronyms

AMIE — Advanced Moon microImaging Experiment (instrument on SMART-1)
CH1 — Chandrayaan-1 (India's first mission to the Moon)
CK — Camera-matrix kernel (SPICE)
ESA — European Space Agency
ESAC — European Space Astronomy Centre
FK — Frames Kernel (SPICE)
ISRO — Indian Space Research Organisation
LSK — Leap Seconds Kernel (SPICE)
PI — Principal Investigator
SC — spacecraft
SCLK — Spacecraft CLock Kernel (SPICE)
SIR — SMART-1 InfraRed spectrometer
SIR2 — Infrared Spectrometer (instrument on CH1; the acronym shall reflect the heritage from SIR)
SMART-1 — Small Missions for Advanced Research and Technology (Europe's first mission to the Moon)
SPICE — Spacecraft, Planet, Instrument, Camera-matrix, Event (an information system to assist scientists in planning and interpreting scientific observations from space-based instruments)
SPK — Spacecraft Position Kernel (SPICE)
TMC — Terrain Mapping Camera (instrument on CH1)

2 Introduction

Prior to the delivery of the SPICE dataset inspected herein, all SPICE computations conducted by the European CH1 PI teams and the support team at ESAC were based on the "21 day kernels" for the SC attitude (CK) which had regularly been provided by ISRO. For the SC position (SPK), in addition to respective 21 day kernels, a single full mission kernel was available.

The usage of the 21 day kernels was somewhat tedious, because the data was partly reconstructed and partly predicted and the kernels were largely overlapping and inconsistent with each other. It was believed that later kernels were more accurate than earlier kernels, therefore the simplest save approach was to load all 21 day kernels in the sequence in which they had been provided, which is of course not quite economic.

The SCLK provided with the 21 day kernels was a trivial one, assuming a constant clock rate, cf. the discussion of the SCLK in [CH1-ESA-TN-008]. The actual SC clock deviated from this trivial assumption by up to a few seconds, introducing respective errors in all SPICE computations.

The new SPICE dataset provided by ISRO to ESA and the European CH1 PI teams on 2010-Aug-31, dubbed "Version-1", should be superior to the old 21 day kernels in the following respects:

- A new SCLK computed from the actual raw clock data is provided. The new CKs have been computed based on this clock kernel (For the interdependence of SCLK and CKs, cf. the discussion of CKs in [CH1-ESA-TN-008]).

- The CKs are now non-overlapping and each one covers one month (with the exception of the first one, which is a little bit longer).
- The new CKs and (full mission) SPK have been validated (and optimized?) based on imagery data from the TMC.

Herein, we describe the results of a first inspection of the new CH1 SPICE dataset Version 1.

3 Short gaps in CKs

The gaps addressed in this section are *not* the large gaps with a length of 16 minutes to 57 hours which are described in the file '`bc_gaps_details_01.txt`' that came with the SPICE dataset. The gaps addressed here have just a length of a few seconds.

When the attitude of the SC is requested at a time point for which no data is available in the CK, SPICE throws an error (if the default behaviour of SPICE has not been modified by respective subroutine calls). Let us discuss an example of a gap found in the CK

'`ch1_attd_jul2009_01.bc`'.

Our SPICE program loops through the SIR2 observation acquired in orbit 2972. The loop contains these lines of code:

```
call et2utc( et, 'ISOC', 0, utc )
print*, utc
call pxform( frame, 'J2000', et, rotation )
```

Here `et` is the ephemeris time of the observation to be processed, so we get the UTC time, print it, and try to compute a rotation matrix which requires knowledge of the SC attitude. When we reach a certain observation, SPICE throws an error and stops. These are the last few lines of the output of the program:

```
 2009-07-14T06:19:12
 2009-07-14T06:19:12
 2009-07-14T06:19:13

================================================================================

Toolkit version: N0061

SPICE(NOFRAMECONNECT) --
```

```
There is insufficient information available to transform from -86700 (CH1_SIR2)
to frame 1 (J2000). Frame -86700 could be transformed to -86001
(CH1_SPACECRAFT). Frame 1 could be transformed to 1 (J2000).'

A traceback follows.  The name of the highest level module is first.
PXFORM --> REFCHG

Oh, by the way:  The SPICELIB error handling actions are USER-TAILORABLE.  You
can choose whether the Toolkit aborts or continues when errors occur, which
error messages to output, and where to send the output.  Please read the ERROR
"Required Reading" file, or see the routines ERRACT, ERRDEV, and ERRPRT.

================================================================================
```

So this tells us that SPICE does not find SC attitude information for the time

`2009-07-14T06:19:13`.

The first thing to do in such a case is to check the CK, and most SPICE users would know about a tool from the SPICE toolkit called '`ckbrief`', which gives a summary of the data in the CK. One needs to provide also an SCLK and an LSK to '`ckbrief`', so we call it like this:

`ckbrief ck/ch1_attd_jul2009_01.bc sclk/ch1_sclk_01.tsc lsk/naif0009.tls`,

and obtain the following output:

```
CKBRIEF Version: 3.2.0, 2006-11-02. SPICE Toolkit Version: N0061.


Summary for: ck/ch1_attd_jul2009_01.bc

Object:  -86001
  Interval Begin ET        Interval End ET          AV
  ------------------------ ------------------------ ---
  2009-JUL-01 01:04:32.979 2009-JUL-01 03:12:09.171 N
  2009-JUL-01 03:12:11.245 2009-JUL-01 05:19:46.924 N
  2009-JUL-01 05:19:51.058 2009-JUL-01 07:27:27.251 N
 ...
  2009-JUL-13 23:57:03.647 2009-JUL-14 02:04:38.814 N
  2009-JUL-14 02:04:42.956 2009-JUL-14 04:12:28.876 N
  2009-JUL-14 04:12:33.020 2009-JUL-14 06:20:18.684 N       <======
  2009-JUL-14 06:20:23.216 2009-JUL-14 08:27:58.896 N
  2009-JUL-14 08:28:03.424 2009-JUL-14 10:35:48.833 N
  2009-JUL-14 10:35:52.977 2009-JUL-14 12:43:29.168 N
```

From this, we would conclude that the time in question should be covered by this CK, as it falls in the interval marked by the arrow to the right. At this point, the average SPICE user would be confused and start to search for errors in his SPICE program.

However, the SPICE expert would know that the summary provided by '`ckbrief`' would not necessarily reflect the exact time coverage of the CK, and that more detailed information can be obtained with another tool from the SPICE toolkit, which is '`spacit`'.

With '`spacit`', which is an interactive tool, we can extract information for any particular time range. Near the time in question, we find the following:

```
*******************************************************************************

Summary for CK file: ck/ch1_attd_jul2009_01.bc
Leapseconds File   : lsk/naif0009.tls
SCLK File          : sclk/ch1_sclk_01.tsc
Summary Type       : By UTC Time Interval (2009 JUL 14 04:12:33.020, 2009 JUL 14

-------------------------------------------------------------------------------
   Segment ID     : sg0001
   Instrument Code: -86001
   Spacecraft     : Body -86
   Reference Frame: Frame 1, J2000
   CK Data Type   : Type 3
      Description : Continuous Pointing: Linear Interpolation
   Available Data : Pointing Only
   UTC Start Time : 2009 JUL 14 04:11:26.837
   UTC Stop Time  : 2009 JUL 14 06:19:12.501
   SCLK Start Time: 13/1138466.011
   SCLK Stop Time : 13/1146131.666
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
   Segment ID     : sg0001
   Instrument Code: -86001
   Spacecraft     : Body -86
   Reference Frame: Frame 1, J2000
   CK Data Type   : Type 3
      Description : Continuous Pointing: Linear Interpolation
   Available Data : Pointing Only
   UTC Start Time : 2009 JUL 14 06:19:17.033
   UTC Stop Time  : 2009 JUL 14 08:26:52.713
   SCLK Start Time: 13/1146136.198
   SCLK Stop Time : 13/1153791.869
-------------------------------------------------------------------------------

*******************************************************************************
```

So we see that there is indeed a gap of three and a half seconds:

from `2009 JUL 14 06:19:12.501` to `2009 JUL 14 06:19:17.033`.

This matches the occurrence of the error in our SPICE program, which processed `2009-07-14T06:19:12` fine but crashed on `2009-07-14T06:19:13`.

We came across similar gaps in other CKs, e. g.,

‘`ch1_attd_dec2008_01.bc`’

and

‘`ch1_attd_aug2009_01.bc`’.

Given the fact that we only checked a dozen orbits, such gaps seem to be quite frequent in the CKs. The amount of data affected is very small, e. g., for SIR2, only some tens of spectra of some thousand spectra of one orbit fall into such a gap. The stopping of SPICE on such a gap can be avoided by changing SPICE’ error behaviour prior to calls to subroutines requiring attitude information, checking explicitly if attitude information was found, performing some alternative action (like marking the respective spectrum invalid), and afterward switching back to normal error behaviour.

So this problem can in principle be solved by the user, however, it requires some additional programming effort and less experienced SPICE users may be confused and waste time trying to understand what is going on. Considering the frequent occurrence of the gaps, it may be recommendable to revise the CKs. Small gaps of just a few seconds can probably be safely interpolated by SPICE, but the directive to do so has to be built into the CK when it is created.

4 Kinks and jumps in the viewpoint track

When inspecting the tracks of viewpoints of SIR2 on the lunar surface for various orbits, we repeatedly came across strange kinks in the track, e. g., in orbit 2972 and in orbit 3239. One example is shown in Fig. 1.

We discussed these kinks in the team at ESAC, and for us it is not completely clear if they reflect real SC attitude movements or if they are just artifacts created by a certain interpolation algorithm when reconstructing the SC attitude. The time between the spots representing the locations of SIR2 footprints is about 300 ms, so the SC movement to create such a kind would have to be quite abrupt. Also the fact that the spectra involved in the kink have very much the same mean brightness (represented by the color of the respective spots) points towards the hypothesis that the kinks are artifacts of the attitude reconstruction procedure.

The amount of data affected is very small (only a few spectra out of some thousand of an orbit), however, apart form just confusing a user who notices these kinks, they have some consequences. E. g., to facilitate location based searches in the PSA, we create a ‘`GEO_MOON.TAB`’ index table file which describes the swath of the instrument on the lunar surface. For SIR2, the number of discrete points needed to accurately describe the swath is automatically determined, thus the algorithm inserts additional points to encompass the kinks. This increases the size of the ‘`GEO_MOON.TAB`’ file and can yield false positives when searching for orbits which cross a particular area on the lunar surface.

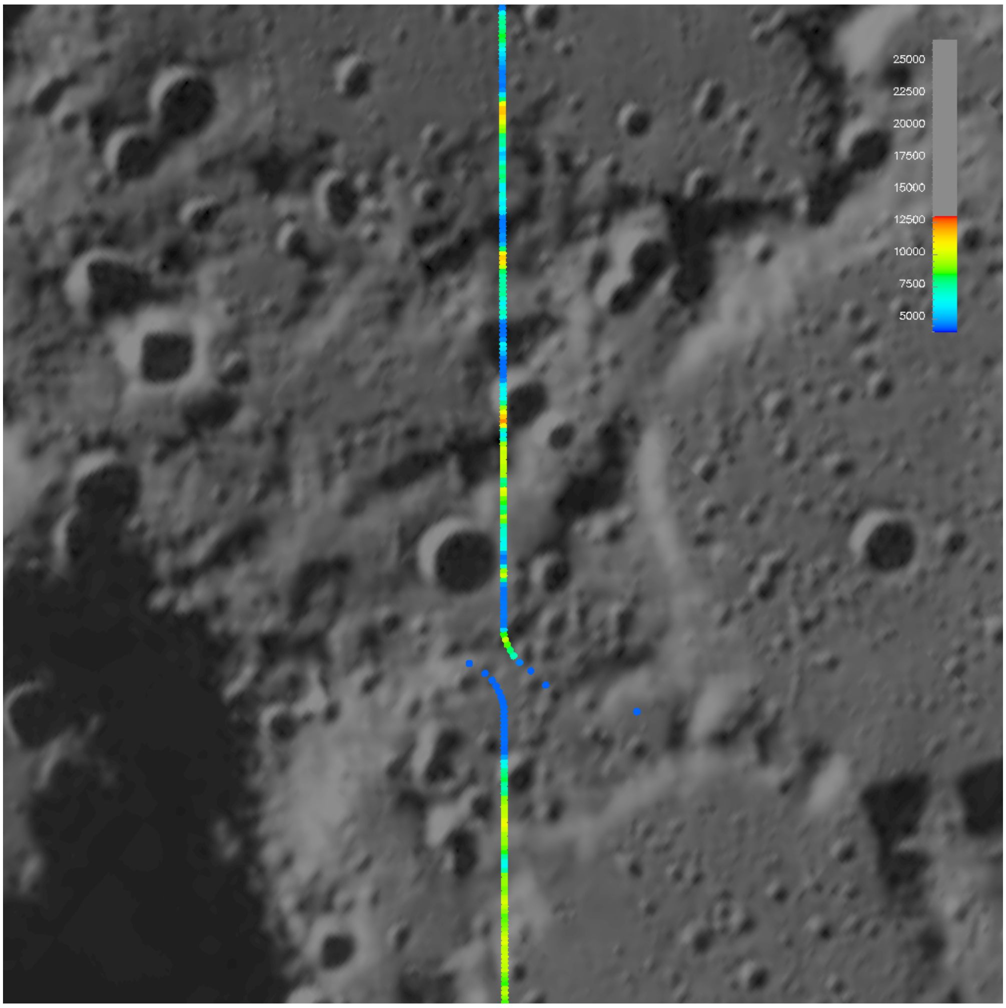

Figure 1: Part of the track of SIR2 viewpoints from orbit 3239. The color represents the mean brightness of the respective spectrum in data numbers.

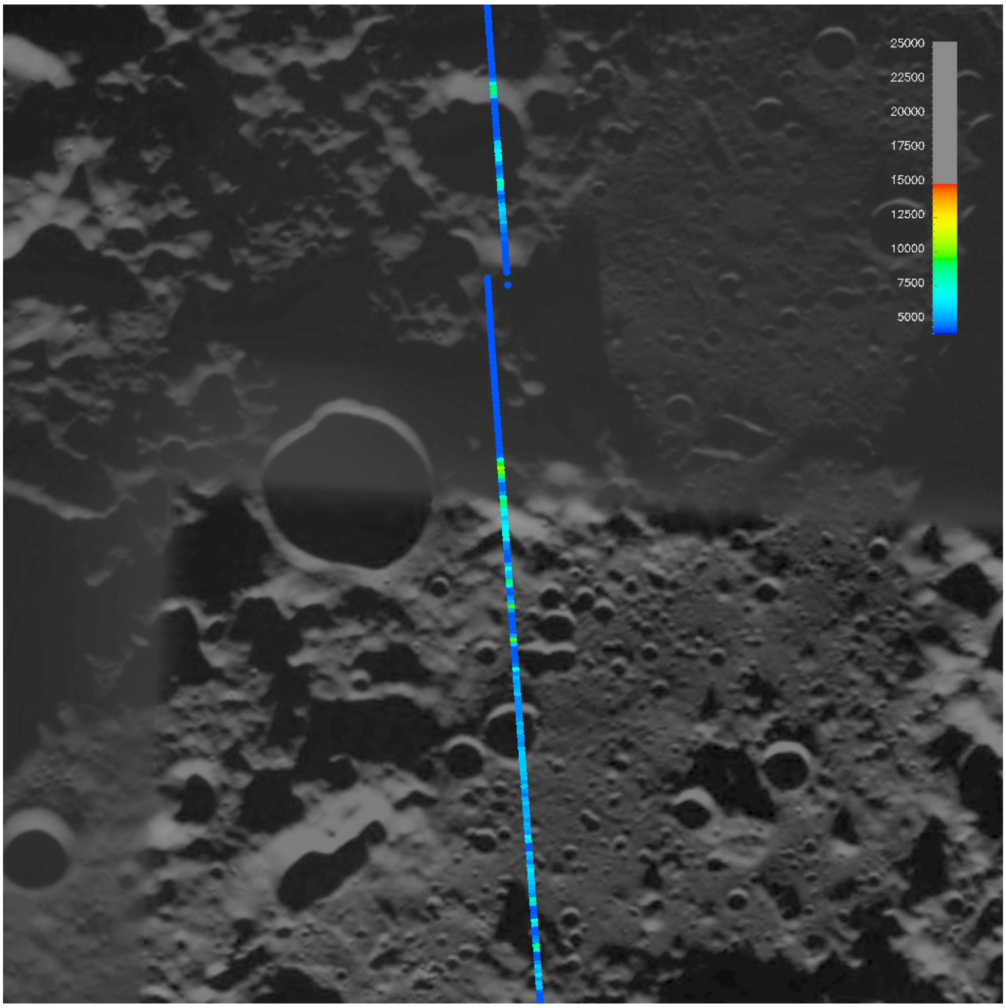

Figure 2: Part of the track of SIR2 viewpoints from orbit 2605. The color represents the mean brightness of the respective spectrum in data numbers.

While such kinks as shown in Fig. 1 seem to occur quite frequently, we only came across one instance of a different specimen of track discontinuity. It is shown in Fig. 2. Note that this is not just begin and end of the orbit; time runs continuously over the jump. This jump is completely different from the kinks discussed before. The viewpoints do not resume the original track but remain shifted after the incident. Like for the kinks, it would be helpful to know if this jump represents a real SC attitude movement or is an artifact of the attitude reconstruction procedure.

5 Erroneous attitude information for the SIR2 commissioning period

The commissioning of SIR2 was conducted on 2008-11-19. This time is covered by the CK ‘ch1_attd_oct2008_nov2008_01.bc’.

When we try to compute the viewpoint of SIR on the lunar surface during the commissioning, SPICE does not return any valid surface point, i. e., the CK implies that SIR2 is pointing towards the sky during the whole commissioning. However, we are pretty sure that the spectra which we acquired are from the lunar surface, and previous version of the SPICE dataset (the 21 day kernel) did indeed return reasonable surface points. Thus it seems that the CK encompassing the SIR2 commissioning period is erroneous.

The spectra acquired during the SIR2 commissioning are of particular interest for the calibration, as a large range of exposure times were tested. To assess these spectra, it is essential to know the viewpoints on the lunar surface. Therefore, the CK listed above should be revised.

6 Accuracy

In order to assess the accuracy of the pointing information, we stepped through a dozen of orbits and tried to match the mean brightness of the SIR spectra to SMART1/AMIE images. The matching was done by manually adjusting the alignment angles (rotation around x-axis and rotation around y-axis) of the instrument relative to the SC frame. The used FK was actually modified by inserting the angles to be tried, so this was a real end-to-end SPICE computation. Figs. 3 and 4 shown one example of an adjustment of the alignment angles.

The angles needed to match the CH1/SIR spectra to SMART1/AMIE images varied over a large range, within an orbit as well as between different orbits. These are the ranges found:

Rotation around x-axis	$-4.0°$	–	$3.5°$
Rotation around y-axis	$0.0°$	–	$3.0°$

These angles are much larger then the alignment angles actually measured before launch, and their variation is much larger then the pointing uncertainty of the AMIE images, which were used as ground truth.

The magnitude of the found CH1 pointing inaccuracies is comparable with the magnitude of the location errors in the Clementine Basemap (old, original version). Thus one might suspect that the old Clementine Basemap has been used to match TMC images and by this to estimate the SC attitude. However, this is just a wild guess; we did no actually check any resemblance of CH1 pointing deviations with the Clementine Basemap.

It seems that along-track errors (rotation around x-axis) are larger than cross-track errors (rotation around y-axis), but this is based on quite a small sample. If we nevertheless tended to believe it, it would indicate that there is still a considerable timing inaccuracy.

For one of the inspected orbits, namely orbit 3239, which falls in the range of the CK

‘ck/ch1_attd_aug2009_01.bc’,

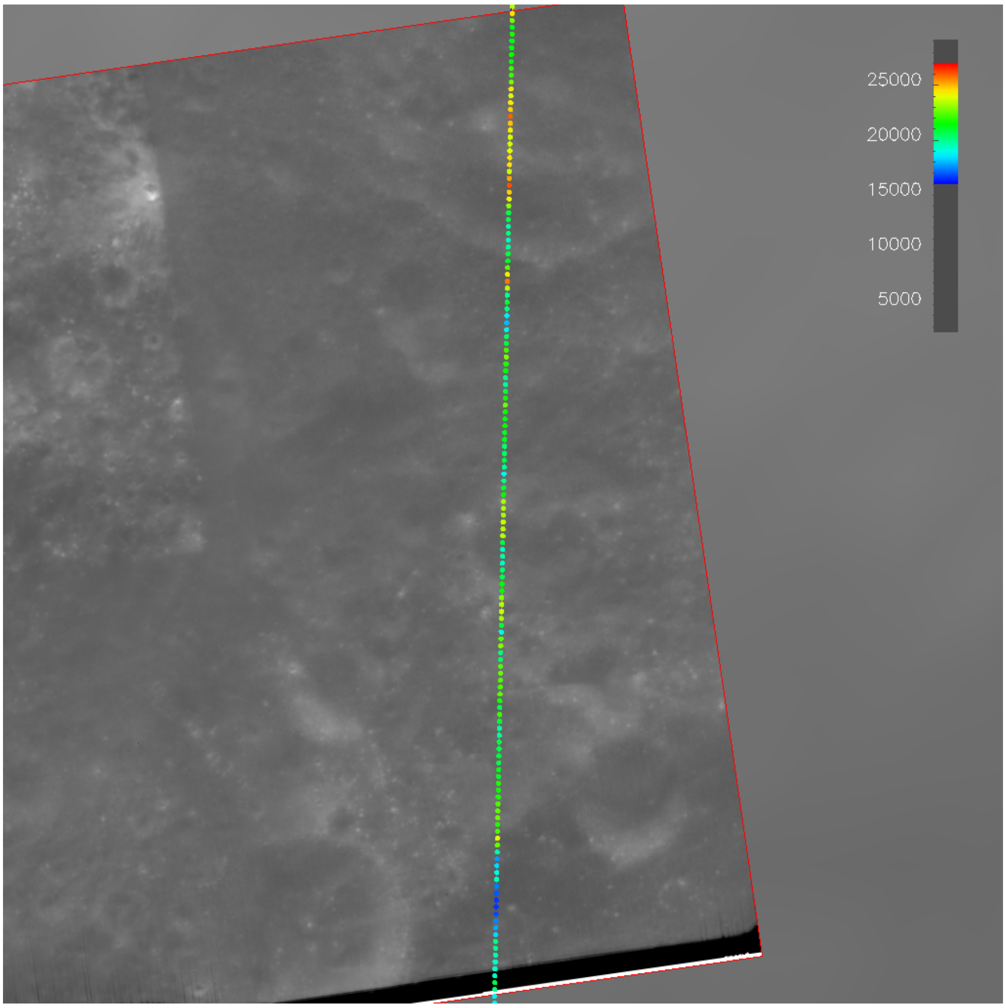

Figure 3: Part of the track of SIR2 viewpoints from orbit 279 with alignment angles not modified. The color represents the mean brightness of the respective spectrum in data numbers.

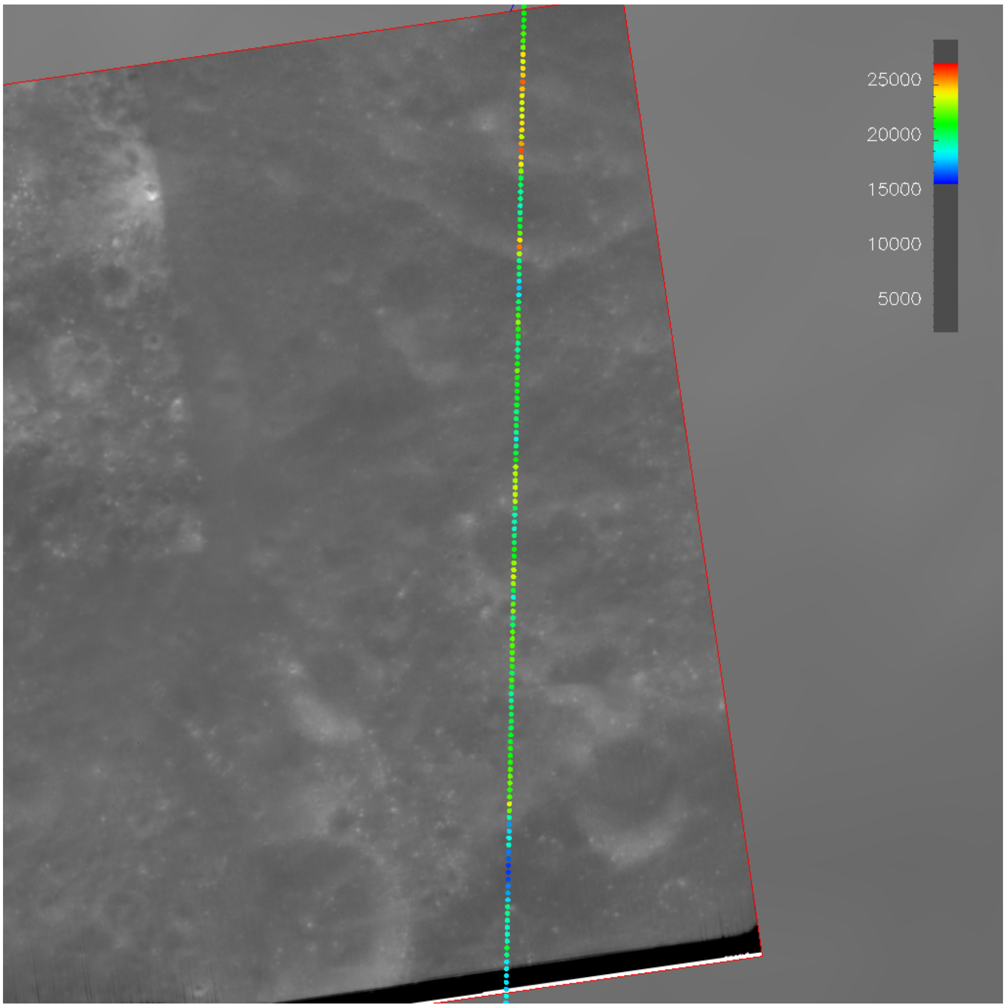

Figure 4: Part of the track of SIR2 viewpoints from orbit 279 with alignment angles adjusted to fit the AMIE image. The color represents the mean brightness of the respective spectrum in data numbers.

we were not able to match the SIR2 spectra to any surface features. For this orbit, the pointing implied by the SPICE computations seems to be very far from the true pointing.