SIR2-M3 co-alignment-analysis

Björn Grieger Joseph W. Boardman

2009Feb16

Document number	CH1-ESA-TN-007
Issue/Revision	D/-

Document change record			
Iss./Rev.	Date	Sections affected	Description
D/-	2009Feb13	All	First draft.

Contents

1 Preliminaries

1.1 Scope

This document discusses the co-alignment between two instruments on CH1: SIR2, a point spectrometer, and M2, a line scanning spectrometer.

1.2 Reference documents

[S1-AMIE-SGS-RP-008]	The offset between AMIE images and the Clementine basemap (Iss./Rev. D/-, 2007-Nov-16)
[CH1-ESA-TN-005]	Description of the SIR2 and SARA instruments in the Chandrayaan-1 spacecraft frames kernel (Iss./Rev. D/c, 2009-Jan-15)

1.3 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)
FK	— Frames Kernel (SPICE)
IK	— Instrument Kernel (SPICE)
M3	— Moon Mineralogy Mapper (instrument on CH1)
NAIF	— NASA's Navigation and Ancillary Information Facility
OBT	— On Board Time
RMS	— Root Mean Square (gives the Euclidean distance between two vectors in a finite dimensional vector space)
SC	— spacecraft
SCLK	— Spacecraft CLocK (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)
ULCN	— Unified Lunar Control Network

2 Introduction

The alignment of the SIR2 and the M3 instruments with the CH1 SC frame had been measured on the SC before launch. However, because of the limited accuracy of the measurements and possible shifts during launch and cruise, the obtained values are preliminary and should be replaced by values obtained from flight data.

With the SPICE system, the measured data can be projected onto the lunar surface. Using data acquired during and after the commissioning phase up to end of January 2009, the instrument teams of M3 and SIR2 noticed independently significant inconsistencies between the CH1 data and data from former missions. For these comparisons, the M3 team used Clementine base images reprojected to the 2005 ULCN reference system (which largely reduces the location errors of up to 15 km in the widely used Clementine photographic basemap, cf. [S1-AMIE-SGS-RP-008]). The SIR2 team used SMART-1/AMIE images, which have a pointing accuracy of about 1 km.

The found pointing offsets of CH1 data of a few degrees in viewing direction (corresponding to several kilometers on the lunar surface) can have several causes:

- Timing inaccuracies (implied by the SCLK SPICE kernel)
- SC position inaccuracies (implied by the SPK)
- SC attitude inaccuracies (implied by the CK)
- Instrument alignment inaccuracies (implied by the FK and/or IK)

Timimg is a complicated issue for CH1, and a comprehensive description of the problems is beyond the scope of this document (there will probably be a separate technical note on this in the near future). Here we only note this: There are indeed timing inaccuracies of up to one second, which lead to pointing offsets of 1–2 km on the lunar surface. These contribute to the observed offsets, but they can not completely explain them, as the observed offsets are larger and not only along track, but also cross track.

Even when corrected for timing errors, the residual offsets are not constant. For M3, no solution for the (time fixed) instrument alignment angles can be found which is consistent with all the data. Therefore, there must be errors in the SC position and/or attitude. As long as these are not sorted out, the absolute alignment angles of the instruments can not be optimized.

However, even when the absolute alignment angles relative to the SC frame can not be determined (yet), the relative co-alignment between M3 and SIR2 can be investigated. In fact, even the estimation of just the relative co-alignment depends on the SPICE kernels, but the requirements on their accuracy are much less demanding than for the estimation the absolute alignment, cf. section 5.1. Herein, we describe the estimation of the relative co-alignment of M3 and SIR2: the data used (section 3), a first feasibility study (section 4), and the final nonlinear optimization procedure (section 5).

3 Data used

3.1 Selection of the data

On 2009-Jan-14, the SIR team provided a list of SIR2 data files and their respective time coverage to the M3 team, cf. appendix A. The M3 team cross checked this with the M3 time coverage and came up with a list of M3 spatial optimization files and corresponding SIR2 files, cf. appendix B. A file derived from one of the SIR2 files matching an M3 file, namely

'`out_CH1SIR2_NE2_08339140708549_D32_02.FITS`',

was provided to the M3 team on 2009-Jan-23. It was condensed to the mean spectral value of the raw data (DN values). This file was used to conduct a first feasibility investigation, which is described in section 4. On 2009-Jan-30, a set of files derived from the matching M3 file, namely

'`M3G20081203T115326_V01_L0.IMG`',

was provided to the SIR2 team, cf. appendix C. Just two of these files were used for the optimization described in section 5.

3.2 M3 data

Out of the various available files, which also comprise orthocorrected images, only two files where used, one providing spectrally averaged observed brightnesses and one providing the respective locations on the lunar surface.

The brightnesses are taken from the file

'`M3G20081203T115326_ALBEDO`',

which is described by this header:

```
ENVI
description = {
  File Imported into ENVI.}
samples = 300
lines   = 5954
bands   = 1
header offset = 0
file type = ENVI Standard
data type = 4
interleave = bsq
sensor type = Unknown
byte order = 0
wavelength units = Unknown
```

Obviously, the file contains 300 samples $\times$ 5954 samples in one band (the spectral mean). The respective viewpoint on the lunar surface for each sample is provided by the file

‘M3G20081203T115326_V01_LOC.IMG’,

which is described by this header:

```
ENVI
description = {
  M3 Level 1B Pixel Center Locations, MOON_ME frame, decimal degrees and
  meters [Wed Jan 21 21:10:32 2009]}
samples = 300
lines   = 5954
bands   = 3
header offset = 0
file type = ENVI Standard
data type = 5
interleave = bil
sensor type = Unknown
byte order = 0
wavelength units = Unknown
band names = {
 Longitude, Latitude, Radius}
```

Thus, for the same number of samples as the file with the brightnesses, this file contains 3 bands, latitude, longitude, and altitude. The M3 data is illustrated in Fig. 1. Fig. 2 shows a pointing comparison of the M3 image with an AMIE image. The CH1 pointing offset addressed in section 2 is clearly visible. The pointing error of the AMIE image should hardly be noticeable on this scale.

3.3 SIR2 data

While the feasibility investigation described in section 4 is performed with pre-computed spectral means, the optimization described in section 5 uses the original PDS data product, i. e., the files

‘CH1SIR2_NE2_SC_08339140708_01.LBL’

and

‘CH1SIR2_NE2_SC_08339140708_01.FITS’,

and computes the means on the fly. The full PDS label of the data used is listed in appendix D. The SIR2 ground track on top of the M3 image is illustrated in Fig. 3. The Variation of the SIR2 spectral mean is plotted in Fig. 4.

4 Feasibility investigation

We explore the solution space by applying integer number shifts to the samples and lines of the M3 image and computing the resultant deviations between the M3 and the SIR2 data. This first cut shows that the data do want to align and that the solution space for alignment is well behaved and unimodal.

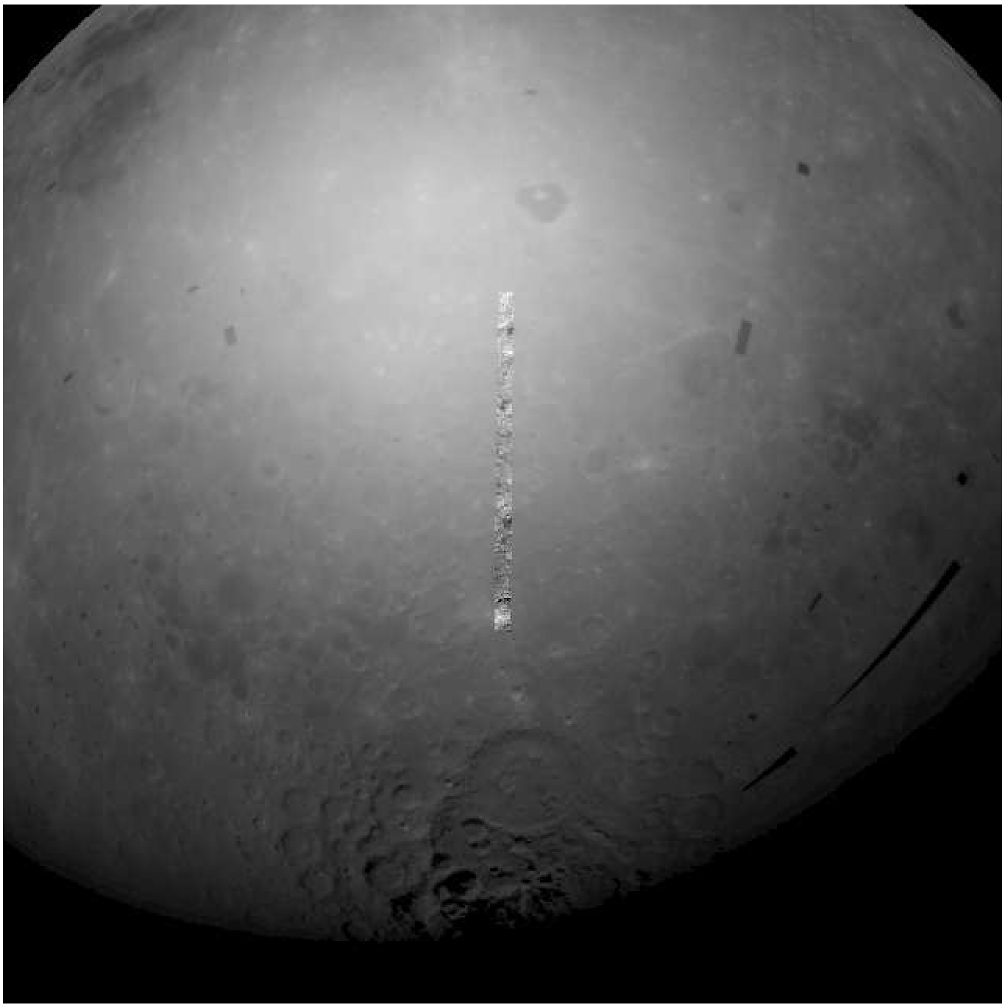

Figure 1: The M3 data strip used, shown on top of the Clementine basemap, which is warped onto the lunar sphere and rendered according to the present illumination (simply assuming Lambert reflection).

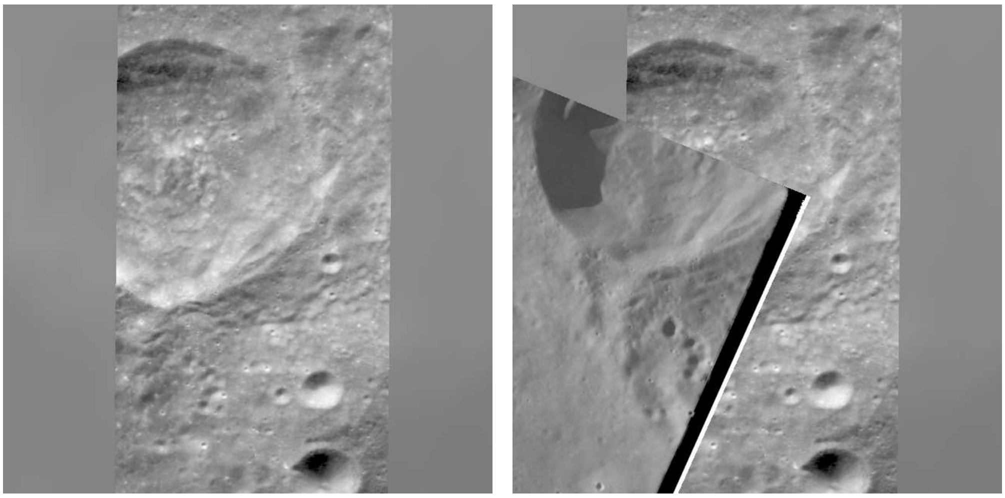

Figure 2: Zoomed-in part of the M3 image, on the right hand side overlaid with an AMIE image.

We use the SIR2 profile of spectral averages (cf. section 3.1) and Internal Average Reflectance M3 data as input. A simple calibration, i. e.,

$$\frac{\text{raw} - \text{dark}}{\text{average image frame}} \tag{1}$$

is applied to the M3 data, and the bands 2–66 are averaged to match the spectral range of SIR2 roughly. We use non-orthoed M3 data.

For matching M3 and SIR2 data, we allow sample offsets to find across track angle and line offsets to find combined downtrack angle and uncompensated timing deltas. We just check a range of sample and line offsets (± 30). An improved process using a nonlinear optimization to retrieve sub-pixel alignment is described in section 5.

For each possible offset we build a unit-sum resampled M3 spectrum to match the unit-sum SIR2 profile and calculate the RMS error. The minimum error location is obvious and well behaved: 4 sample offset, 14 line/time offset, cf. Fig. 5. The best location is obvious and we can surely do sub-pixel alignment with a more sophisticated optimization. Fig. 6 shows a plot of the best fit SIR2 and the best fit M3 data. They are not perfect but very close for this first cut. The obtained preliminary alignment between M3 and SIR2 encourages us that we will be able to align the data sets very well, most likely at the sub-pixel level.

5 Optimization of the co-alignment angles

5.1 Approach

Ideally, we would like to match the viewing directions of both instruments in the spacecraft frame, so that none of the inaccurate dynamical kernels (SPK and CK) are involved. However, the SIR2 boresight lies off M3's line FOV.

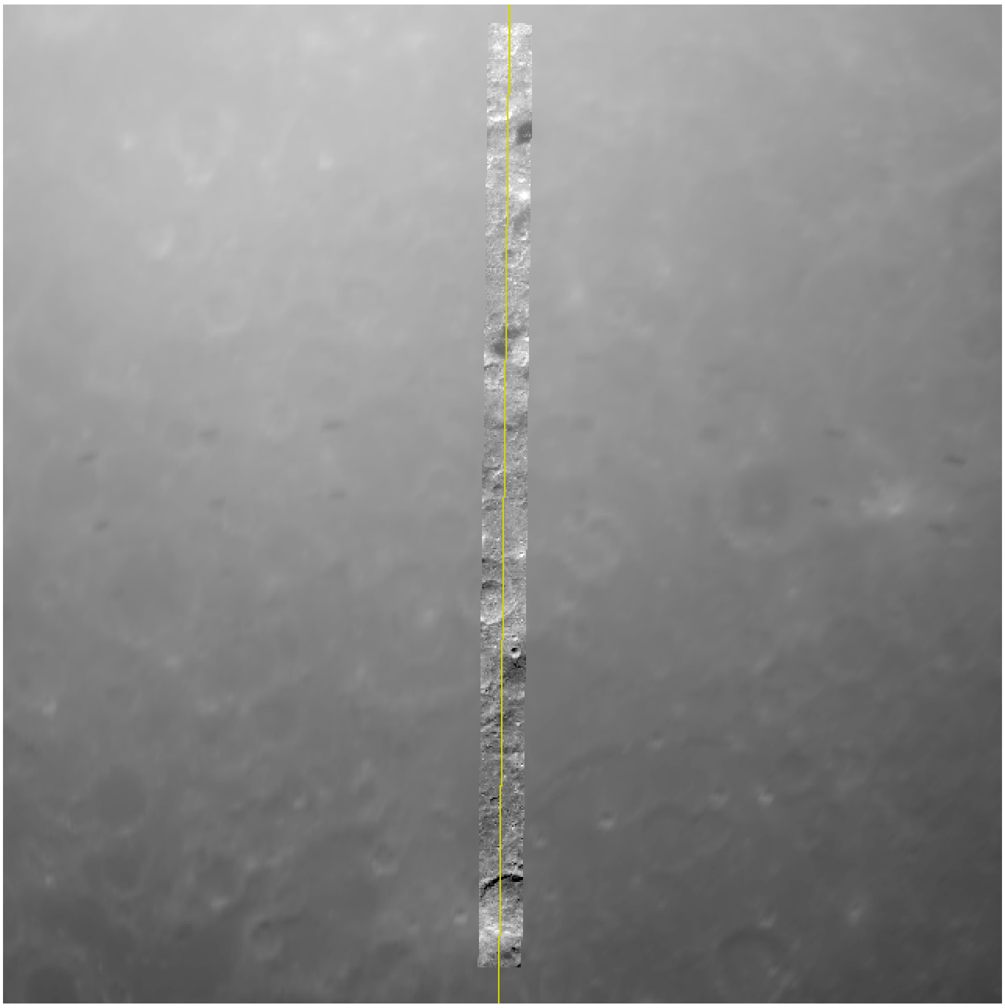

Figure 3: SIR2 ground track on top of the M3 image, computed based on the nominal alignment angles as measured before launch.

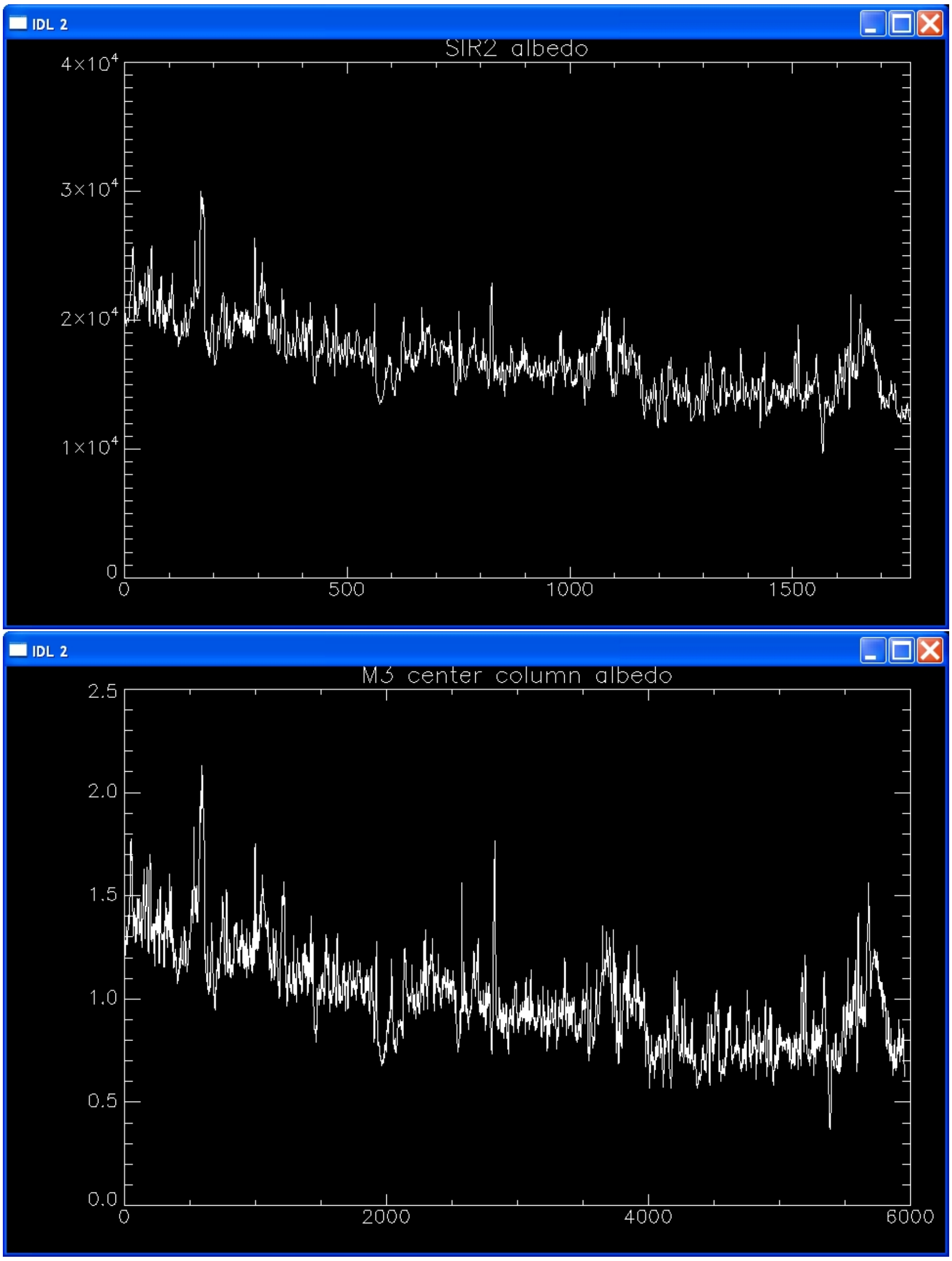

Figure 4: *Top:* Variation of the SIR2 spectral mean. The x-axis is just the count of the spectrum. The range shown of almost 1800 spectra represents the part of the ground track overlapping with M3. The y-axis gives the mean of all spectral channels' raw data numbers. *Bottom:* Variation of the spectral mean of the M3 center sample over the strip, cf. Fig. 3.

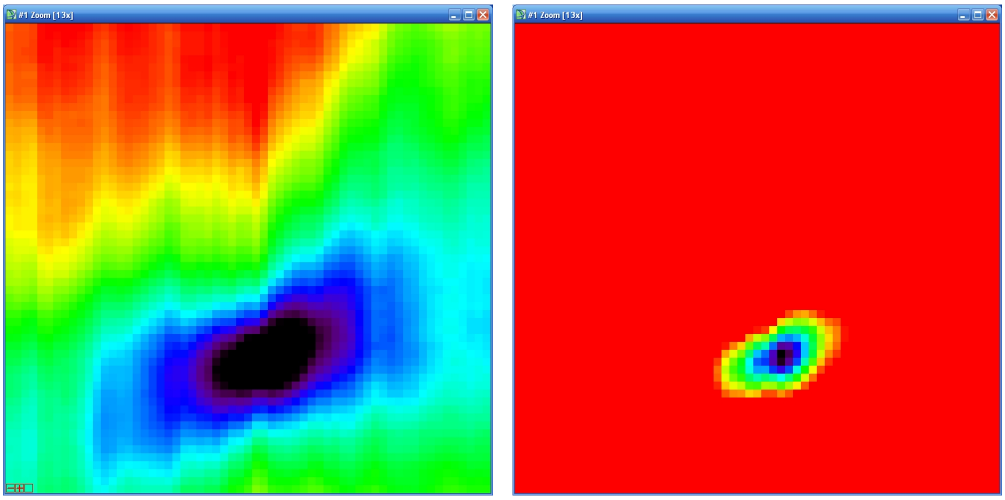

Figure 5: Two views of the 61 Δ-sample by 61 Δ-line RMS image built in this simple first cut. The first shows the full dynamic range. The second focuses on the range near the minimum.

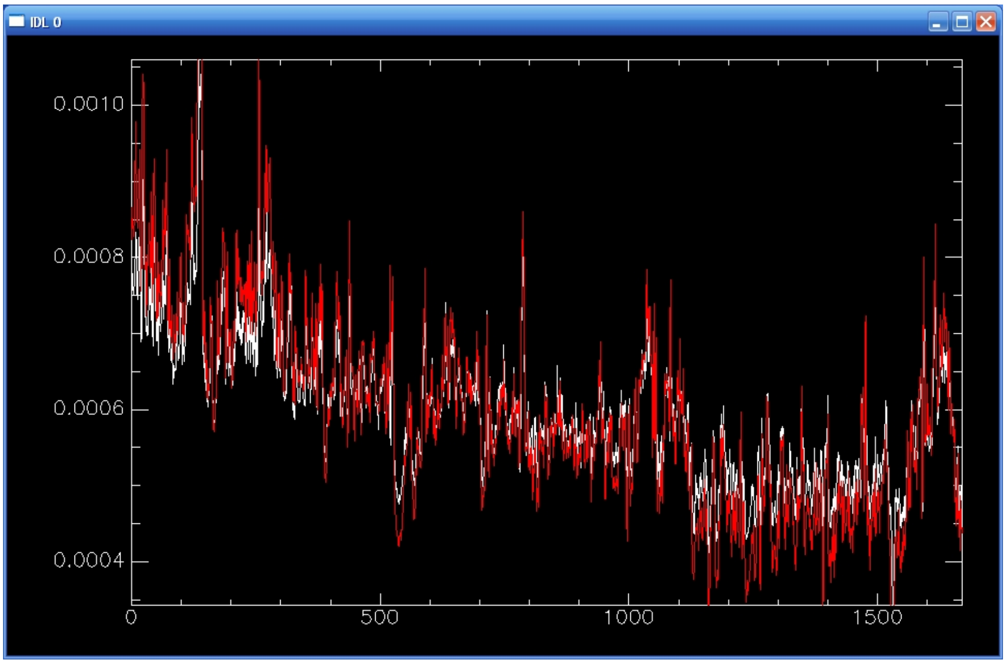

Figure 6: Plot of the best fit SIR2 (white) and the best fit M3 (red) data along the SIR2 ground track.

We have to match brightnesses measured at different times. But then we have to convert the time difference to a (along track) viewing angle difference, and there the projection onto the lunar surface which depends on the dynamical kernels comes into play. The conversion of a fitted time difference to an angle depends on the distance of the viewpoint and the speed of travel. Although we know that the dynamical kernels are not completely accurate, the co-alignment can correctly be estimated as long as any error in the distance to the viewpoint is small compared to the distance itself and any error in the SC attitude does not vary significantly on the timescale given by the time lag between M3 and SIR2 in crossing the same surface point, which is expected to be at most a few seconds.

To estimate the co-alignment angles of SIR2 relative to M3, we perform a real end-to-end modelling, actually iteratively modifying the FK and using it to project the SIR2 data onto the lunar surface, then mapping the M3 data onto the SIR2 viewpoints and computing the correlation.

5.2 Kernels used

These are the SPICE kernels used for the optimization:

- SPK:

  ‘`isro_21_day_eph_2008339_00.bsp`’

  This kernel can be obtained from

  ‘`ftp://ssols01.esac.esa.int/pub/data/SPICE/CH1/kernels/spk/`’

- CK:

  ‘`isro_21_day_att_2008339_00.bc`’

  This kernel can be obtained from

  ‘`ftp://ssols01.esac.esa.int/pub/data/SPICE/CH1/kernels/ck/`’

- SCLK:

  ‘`isro_2008295235703_2010365000000_00.sclk`’

  The kernel is listed in appendix E.

- FK:

  ‘`CH1_V02.TF`’

  The kernel is listed in appendix F. How the kernel was created is documented in [CH1-ESA-TN-005]. The FK is actually modified during the optimization of the co-alignment. The original version provides the starting point for the iterations and then serves as a template where the original SIR2 alignment angles are overwritten with those found in the course of the optimization.

- IK:

  'CH1_SIR2_V01.TI'

  The kernel is listed in appendix G.

- Generic NAIF kernels:

  'pck00008.tpc'
  'naif0009.tls'
  'de421.bsp'
  'moon_pa_de421_1900-2050.bpc'
  'moon_080317.tf'
  'moon_assoc_me.tf'

5.3 Mapping M3 data to SIR2 viewpoints

Based on their OBT stamps, the viewpoints of the individual SIR2 spectra in longitude and latitude on the lunar surface are computed with SPICE. The M3 data was already provided with accompanying longitude and latitude for each brightness value, cf. section 3.2. We determine the elementary quadrangle of M3 data which encompass the SIR2 viewpoint. Then the M3 data is mapped onto the SIR2 viewpoint by bilinear interpolation. For simplicity of the interpolation, we assume that the quadrangle of M3 data is aligned with meridians and parallels of latitude. This approximation should hold unless we get close to the poles.

Thus, for each SIR2 data value, we obtain the M3 data value at the SIR2 viewpoint, based on the SIR2 alignment angles in the SC frame as defined in the FK.

5.4 Iterative adjustment

Now having for each SIR2 viewpoint one SIR2 and one M3 data value, we can just compute the correlation. We prefer the correlation over some difference of (normalized) profiles to allow for a dark current contribution and bias offset in the raw SIR2 data. We expect any such offset to be constant, as the SIR2 sensor temperature is controlled and the exposure time was fixed.

With the originally measured alignment angles

$$\begin{aligned} \text{Initial rotation around } x_{\text{SIR2}} &= +0.0534806^\circ \\ \text{Initial rotation around } y_{\text{SIR2}} &= -0.1383778^\circ \end{aligned} \tag{2}$$

in the FK, we obtain an initial correlation of

$$r_{\text{initial}} = 0.72. \tag{3}$$

SIR2 and M3 data according to this initial projection are illustrated for an example section of the strip in Fig. 7. It is obvious that the agreement is not very good.

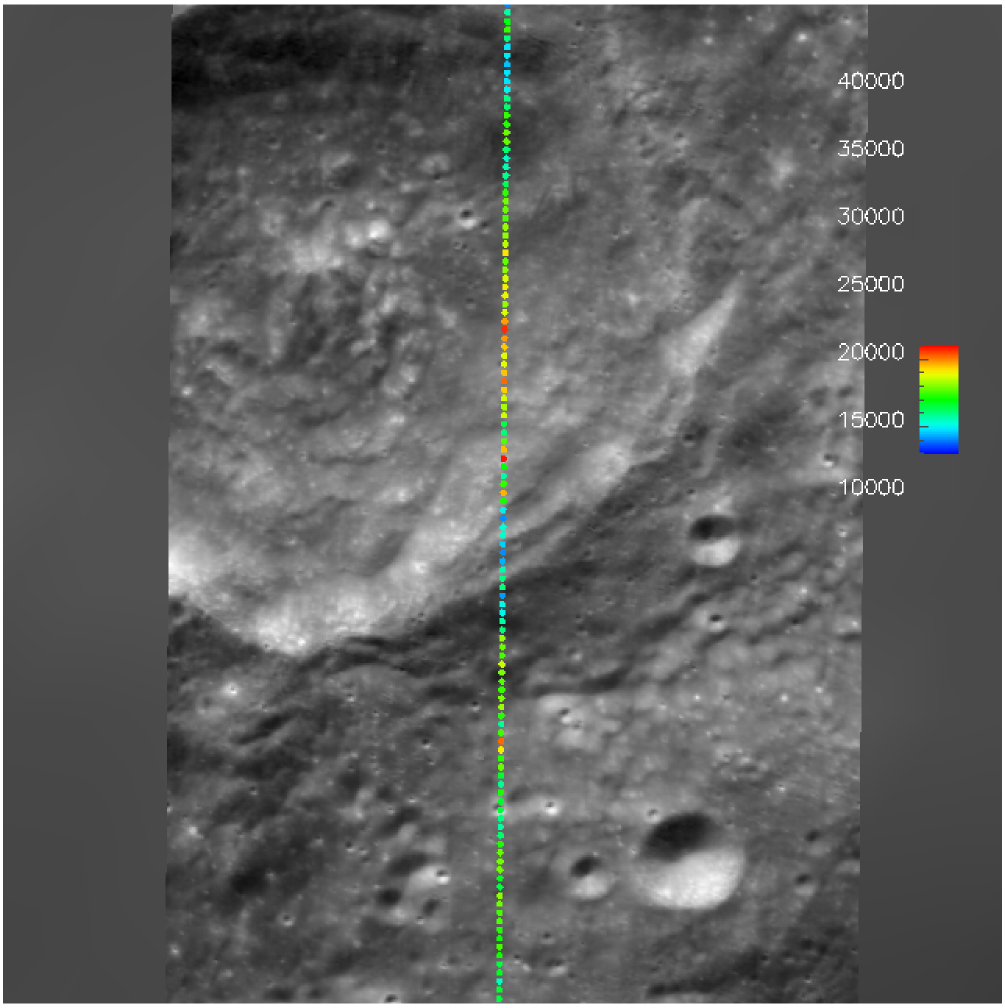

Figure 7: SIR2 spectrally averaged data on top of the spectrally averaged M3 image for the original alignment angles. Each dot represents one SIR2 measurement. The color represents the brightness measured by SIR2 in raw data numbers.

In order to optimize the alignment angles, we employ an evolutionary strategy. Each angle is modified by adding a random value of the range $-0.1°$ $\ldots +0.1°$, but the old angles are stored. We recompute the correlation between SIR2 and M3 as described above for the new angles. If the correlation has improved, we keep the new angles as starting point for the next modification. If the correlation has decreased, we switch back to the old angles and try a different random modification on them. Such an evolutionary strategy is straight forward to implement and computationally reasonably effective as long as the number of unknown parameters is small.

The rotation angles we optimize have to be applied in the instrument frame to rotate the instrument from its actual mounted orientation to its nominal orientation. These angles are not directly used in the FK. The rotation defined by them has to be combined with a rotation from the instrument frame to the SC frame. The resultant total rotation is then described in the FK. For each new set of rotation angles in the course of the optimization, we compute the respective total rotation with SPICE and insert the resultant angles for `TKFRAME_-86700_ANGLES` in the FK, overwriting the previous values. This modified FK is then actually used to map the SIR2 viewpoint to the lunar surface for the next iteration step.

6 Result

After about thousand iterations, the alignment angles do not change any more. The angles finally found are

$$\begin{aligned} \text{Final rotation around } x_{\text{SIR2}} &= -2.366° \\ \text{Final rotation around } y_{\text{SIR2}} &= +0.562°. \end{aligned} \tag{4}$$

The correlation achieved is

$$r_{\text{final}} > 0.99. \tag{5}$$

SIR2 and M3 data according to this finally found projection are illustrated for an example section of the strip in Fig. 8. By eye we can notice a very good spatial agreement between SIR2 and M3.

The very high correlation obtained does not only reflect that our optimization procedure works well, but also shows that both instruments behave linear with a high signal to noise ratio.

7 Limitations and work to be done

- We have to confirm that the the kernels we use to project the SIR2 data (see section 5.2) are the same as those which have been used to project the M3 data (cf. section 3.2).

- We should include a listing of the FK and IK which have been used to project the M3 data as appendices in this document for future reference.

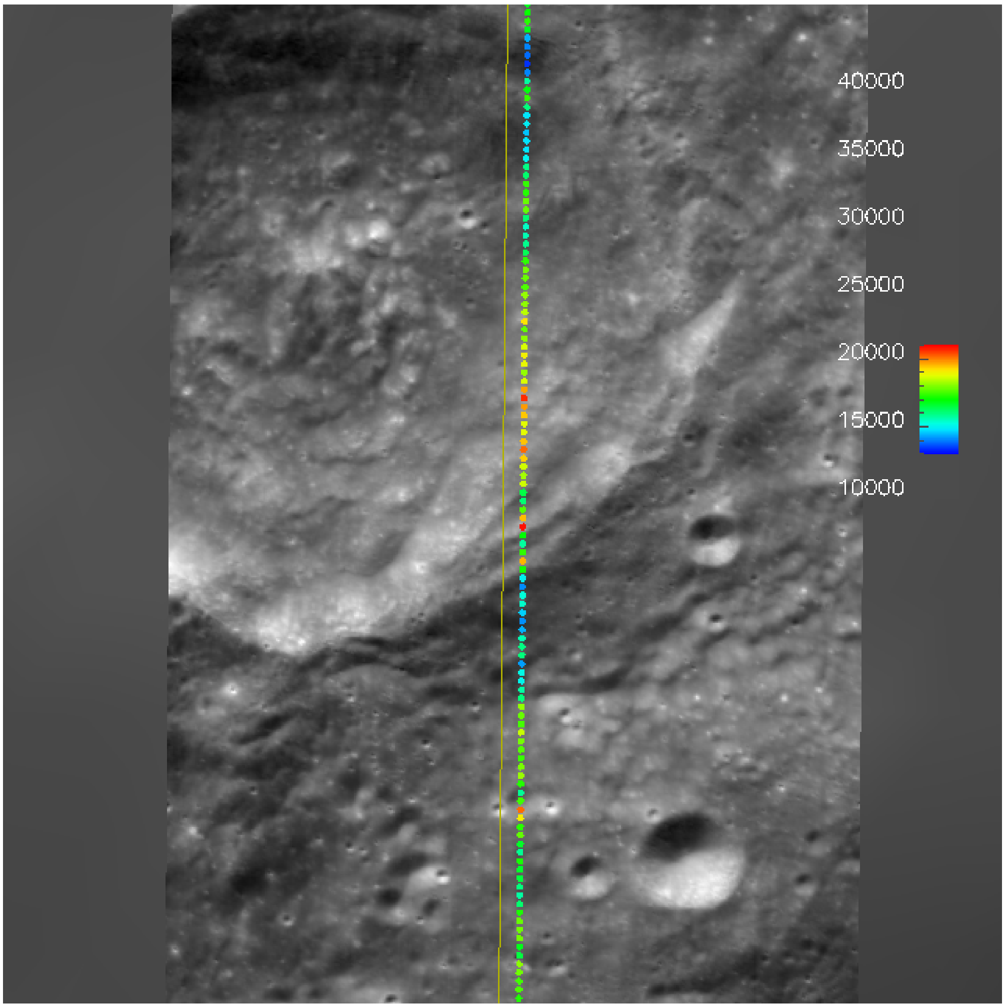

Figure 8: SIR2 spectrally averaged data on top of the spectrally averaged M3 image for the optimized alignment angles. Each dot represents one SIR2 measurement. The color represents the brightness measured by SIR2 in raw data numbers. The yellow line is the pre-optimization SIR2 ground track.

- While we have estimated the relative co-alignment between SIR2 and M3, the absolute alignment of both instruments with respect to the SC frame is still undetermined. The optimized SIR2 alignment angles as given by Eq. (4) provide the orientation of SIR2 in the SC frame, but they would only be correct if the M3 orientation was described correctly in the M3 FK, and it is clear that there is still some error, cf. Fig. 2. We have to update the estimated SIR2 alignment angles when the absolute M3 alignment has been determined.
- We have to test the optimization over many data set pairs to assess the stability of this inter-sensor alignment.

A SIR2 time coverage

```
filename,start time,end time
/home/sir2/dat/issdc/SIR/08325/CH1SIR2_NE2_08325204752891_D32_01.FITS,2008-11-19T08:37:08.162,2008-11-19T09:14:13.019
/home/sir2/dat/issdc/SIR/08337/CH1SIR2_NE2_08337064910086_D32_01.FITS,2008-12-02T06:16:24.752,2008-12-02T06:30:11.979
/home/sir2/dat/issdc/SIR/08339/CH1SIR2_NE2_08339140708549_D32_02.FITS,2008-12-03T11:50:28.861,2008-12-03T12:03:42.474
/home/sir2/dat/issdc/SIR/08338/CH1SIR2_NE2_08338122601911_D32_02.FITS,2008-12-03T11:50:28.861,2008-12-03T12:03:42.474
/home/sir2/dat/issdc/SIR/08339/CH1SIR2_NE2_08339135812933_D32_03.FITS,2008-12-03T23:40:28.735,2008-12-03T23:53:12.914
/home/sir2/dat/issdc/SIR/08339/CH1SIR2_NE2_08339141225415_D32_02.FITS,2008-12-04T13:27:28.801,2008-12-04T13:41:12.894
/home/sir2/dat/issdc/SIR/08340/CH1SIR2_NE2_08340133047146_D32_02.FITS,2008-12-04T23:19:27.392,2008-12-04T23:32:41.352
/home/sir2/dat/issdc/SIR/08340/CH1SIR2_NE2_08340134332456_D32_02.FITS,2008-12-05T13:07:27.004,2008-12-05T13:20:11.184
/home/sir2/dat/issdc/SIR/08341/CH1SIR2_NE2_08341171649905_D32_02.FITS,2008-12-06T02:55:26.959,2008-12-06T03:08:11.151
/home/sir2/dat/issdc/SIR/08341/CH1SIR2_NE2_08341171224220_D32_02.FITS,2008-12-06T16:41:27.120,2008-12-06T16:56:11.494
/home/sir2/dat/issdc/SIR/08342/CH1SIR2_NE2_08342144655733_D32_02.FITS,2008-12-07T02:32:26.993,2008-12-07T02:47:39.045
/home/sir2/dat/issdc/SIR/08342/CH1SIR2_NE2_08342144654973_D18_02.FITS,2008-12-07T02:32:26.993,2008-12-07T02:47:36.593
/home/sir2/dat/issdc/SIR/08342/CH1SIR2_NE2_08342145046570_D32_02.FITS,2008-12-07T14:22:27.340,2008-12-07T14:37:10.314
/home/sir2/dat/issdc/SIR/08342/CH1SIR2_NE2_08342145046447_D18_02.FITS,2008-12-07T14:22:27.340,2008-12-07T14:37:10.314
/home/sir2/dat/issdc/SIR/08343/CH1SIR2_NE2_08343162655748_D32_02.FITS,2008-12-08T02:11:27.281,2008-12-08T02:26:38.951
/home/sir2/dat/issdc/SIR/08343/CH1SIR2_NE2_08343163051767_D32_02.FITS,2008-12-08T15:59:29.232,2008-12-08T16:14:42.336
/home/sir2/dat/issdc/SIR/08345/CH1SIR2_NE2_08345122201147_APL_02.FITS,2008-12-09T01:50:27.023,2008-12-09T02:06:09.178
/home/sir2/dat/issdc/SIR/08345/CH1SIR2_NE2_08345144655676_D32_02.FITS,2008-12-10T01:30:27.533,2008-12-10T01:45:39.208
/home/sir2/dat/issdc/SIR/08346/CH1SIR2_NE2_08346132004796_D32_03.FITS,2008-12-11T03:08:27.441,2008-12-11T03:23:09.328
/home/sir2/dat/issdc/SIR/08346/CH1SIR2_NE2_08346132318877_D32_02.FITS,2008-12-11T12:59:27.279,2008-12-11T13:14:10.571
/home/sir2/dat/issdc/SIR/08348/CH1SIR2_NE2_08348134841803_D18_03.FITS,2008-12-12T02:46:27.313,2008-12-12T03:01:39.334
/home/sir2/dat/issdc/SIR/08348/CH1SIR2_NE2_08348175806394_D18_02.FITS,2008-12-13T14:15:27.410,2008-12-13T14:20:58.860
/home/sir2/dat/issdc/SIR/08348/CH1SIR2_NE2_08348175806394_D18_03.FITS,2008-12-13T14:20:59.210,2008-12-13T14:30:40.481
/home/sir2/dat/issdc/SIR/08349/CH1SIR2_NE2_08349152436125_D18_02.FITS,2008-12-14T02:05:27.725,2008-12-14T02:20:09.615
/home/sir2/dat/issdc/SIR/08349/CH1SIR2_NE2_08349152007491_D18_02.FITS,2008-12-14T13:55:27.537,2008-12-14T14:09:40.694
/home/sir2/dat/issdc/SIR/08351/CH1SIR2_NE2_08351005557655_D32_02.FITS,2008-12-15T09:36:27.823,2008-12-15T09:52:09.628
/home/sir2/dat/issdc/SIR/08351/CH1SIR2_NE2_08351004933139_D32_04.FITS,2008-12-15T23:25:27.601,2008-12-15T23:39:39.708
/home/sir2/dat/issdc/SIR/08352/CH1SIR2_NE2_08352022549198_D32_02.FITS,2008-12-16T09:16:27.439,2008-12-16T09:30:54.965
/home/sir2/dat/issdc/SIR/08352/CH1SIR2_NE2_08352022009869_D32_02.FITS,2008-12-17T01:03:26.384,2008-12-17T01:17:38.491
/home/sir2/dat/issdc/SIR/08352/CH1SIR2_NE2_08352180029053_D18_02.FITS,2008-12-17T12:53:13.903,2008-12-17T13:07:10.244
/home/sir2/dat/issdc/SIR/08353/CH1SIR2_NE2_08353030649529_D18_02.FITS,2008-12-18T02:41:15.824,2008-12-18T02:55:10.063
/home/sir2/dat/issdc/SIR/08354/CH1SIR2_NE2_08354034503009_D32_02.FITS,2008-12-18T12:32:27.947,2008-12-18T12:46:40.054
/home/sir2/dat/issdc/SIR/08354/CH1SIR2_NE2_08354035011912_D32_02.FITS,2008-12-19T02:20:27.945,2008-12-19T02:34:55.470
/home/sir2/dat/issdc/SIR/08354/CH1SIR2_NE2_08354212714012_D18_01.FITS,2008-12-19T02:34:57.222,2008-12-19T02:36:00.990
/home/sir2/dat/issdc/SIR/08354/CH1SIR2_NE2_08354212714012_D18_02.FITS,2008-12-19T14:10:28.138,2008-12-19T14:24:40.372
/home/sir2/dat/issdc/SIR/08354/CH1SIR2_NE2_08354212905290_D18_02.FITS,2008-12-19T19:35:28.171,2008-12-19T19:59:55.183
/home/sir2/dat/issdc/SIR/08355/CH1SIR2_NE2_08355220839789_D18_02.FITS,2008-12-20T11:21:28.105,2008-12-20T11:46:09.835
/home/sir2/dat/issdc/SIR/08355/CH1SIR2_NE2_08355220058554_D18_02.FITS,2008-12-20T19:15:28.171,2008-12-20T19:39:25.052
/home/sir2/dat/issdc/SIR/08356/CH1SIR2_NE2_08356060758364_D18_03.FITS,2008-12-21T05:06:28.012,2008-12-21T05:31:09.738
/home/sir2/dat/issdc/SIR/08357/CH1SIR2_NE2_08357014800217_D18_02.FITS,2008-12-21T11:01:28.105,2008-12-21T11:26:09.835
/home/sir2/dat/issdc/SIR/08357/CH1SIR2_NE2_08357014800203_D18_02.FITS,2008-12-21T11:01:28.105,2008-12-21T11:26:09.835
/home/sir2/dat/issdc/SIR/08357/CH1SIR2_NE2_08357015158921_D18_02.FITS,2008-12-21T20:53:27.850,2008-12-21T21:17:25.081
/home/sir2/dat/issdc/SIR/08357/CH1SIR2_NE2_08357063802468_D18_03.FITS,2008-12-22T04:45:28.107,2008-12-22T05:10:40.318
/home/sir2/dat/issdc/SIR/08358/CH1SIR2_NE2_08358015655816_D18_02.FITS,2008-12-22T10:40:27.692,2008-12-22T11:05:24.965
/home/sir2/dat/issdc/SIR/08358/CH1SIR2_NE2_08358020158790_D18_02.FITS,2008-12-22T22:30:26.473,2008-12-22T22:55:08.202
/home/sir2/dat/issdc/SIR/08358/CH1SIR2_NE2_08358072458080_D18_02.FITS,2008-12-23T06:23:27.786,2008-12-23T06:48:09.515
/home/sir2/dat/issdc/SIR/08358/CH1SIR2_NE2_08358231108266_D18_02.FITS,2008-12-23T12:18:26.347,2008-12-23T12:43:18.587
/home/sir2/dat/issdc/SIR/08358/CH1SIR2_NE2_08358231447859_D18_02.FITS,2008-12-23T22:09:27.720,2008-12-23T22:34:18.558
/home/sir2/dat/issdc/SIR/08360/CH1SIR2_NE2_08360005743662_D18_02.FITS,2008-12-24T06:03:27.797,2008-12-24T06:27:40.123
/home/sir2/dat/issdc/SIR/08360/CH1SIR2_NE2_08360004841900_D18_02.FITS,2008-12-24T13:56:27.511,2008-12-24T14:20:39.834
/home/sir2/dat/issdc/SIR/08360/CH1SIR2_NE2_08360005338658_D18_02.FITS,2008-12-24T23:47:27.811,2008-12-25T00:11:40.138
/home/sir2/dat/issdc/SIR/08360/CH1SIR2_NE2_08360093548439_D18_02.FITS,2008-12-25T07:40:27.520,2008-12-25T08:04:39.839
/home/sir2/dat/issdc/SIR/08361/CH1SIR2_NE2_08361004713713_D18_02.FITS,2008-12-25T13:35:27.787,2008-12-25T13:59:29.954
/home/sir2/dat/issdc/SIR/08361/CH1SIR2_NE2_08361005018801_D18_02.FITS,2008-12-25T23:26:27.450,2008-12-25T23:50:39.777
/home/sir2/dat/issdc/SIR/08361/CH1SIR2_NE2_08361091244326_D18_02.FITS,2008-12-26T07:19:27.672,2008-12-26T07:43:24.583
/home/sir2/dat/issdc/SIR/08362/CH1SIR2_NE2_08362021203247_D18_02.FITS,2008-12-26T15:12:25.849,2008-12-26T15:36:56.047
/home/sir2/dat/issdc/SIR/08362/CH1SIR2_NE2_08362020947347_D18_03.FITS,2008-12-27T01:03:28.229,2008-12-27T01:28:24.338
/home/sir2/dat/issdc/SIR/08362/CH1SIR2_NE2_08362095419895_D18_02.FITS,2008-12-27T08:57:27.307,2008-12-27T09:21:27.372
/home/sir2/dat/issdc/SIR/08363/CH1SIR2_NE2_08363021345785_D18_02.FITS,2008-12-27T14:51:27.528,2008-12-27T15:16:09.288
/home/sir2/dat/issdc/SIR/08363/CH1SIR2_NE2_08363021711770_D18_02.FITS,2008-12-28T00:42:27.337,2008-12-28T01:06:54.382
/home/sir2/dat/issdc/SIR/08363/CH1SIR2_NE2_08363093040254_D32_01.FITS,2008-12-28T01:06:56.134,2008-12-28T08:59:54.762
/home/sir2/dat/issdc/SIR/08363/CH1SIR2_NE2_08363093040488_D18_02.FITS,2008-12-28T08:35:27.020,2008-12-28T08:59:54.762
/home/sir2/dat/issdc/SIR/08364/CH1SIR2_NE2_08364031516749_D32_02.FITS,2008-12-28T16:28:25.707,2008-12-28T16:42:52.559
```

```
/home/sir2/dat/issdc/SIR/08364/CH1SIR2_NE2_08364031516596_D18_02.FITS,2008-12-28T16:28:25.707,2008-12-28T16:42:52.559
/home/sir2/dat/issdc/SIR/08364/CH1SIR2_NE2_08364031825140_D32_02.FITS,2008-12-29T02:19:27.049,2008-12-29T02:44:08.808
/home/sir2/dat/issdc/SIR/08364/CH1SIR2_NE2_08364110746558_D32_02.FITS,2008-12-29T10:12:26.763,2008-12-29T10:37:09.224
/home/sir2/dat/issdc/SIR/08365/CH1SIR2_NE2_08365044933190_D32_02.FITS,2008-12-29T18:05:26.986,2008-12-29T18:30:10.844
/home/sir2/dat/issdc/SIR/08365/CH1SIR2_NE2_08365045151782_D18_02.FITS,2008-12-30T02:00:27.015,2008-12-30T02:24:23.926
/home/sir2/dat/issdc/SIR/08365/CH1SIR2_NE2_08365124316897_D32_02.FITS,2008-12-30T11:51:41.671,2008-12-30T12:15:52.217
/home/sir2/dat/issdc/SIR/08366/CH1SIR2_NE2_08366042654404_D18_02.FITS,2008-12-30T17:46:26.833,2008-12-30T18:10:37.790
/home/sir2/dat/issdc/SIR/08366/CH1SIR2_NE2_08366042959535_D18_03.FITS,2008-12-31T03:37:56.520,2008-12-31T04:02:07.827
/home/sir2/dat/issdc/SIR/08366/CH1SIR2_NE2_08366121823774_D18_02.FITS,2008-12-31T11:29:41.546,2008-12-31T11:54:07.570
/home/sir2/dat/issdc/SIR/09001/CH1SIR2_NE2_09001050528874_D32_02.FITS,2008-12-31T19:22:56.684,2008-12-31T19:47:07.230
/home/sir2/dat/issdc/SIR/09001/CH1SIR2_NE2_09001050755290_D18_02.FITS,2009-01-01T03:16:09.288,2009-01-01T03:40:21.586
/home/sir2/dat/issdc/SIR/09001/CH1SIR2_NE2_09001135218140_D18_02.FITS,2009-01-01T13:07:26.533,2009-01-01T13:31:55.647
/home/sir2/dat/issdc/SIR/09003/CH1SIR2_NE2_09003101612507_D18_02.FITS,2009-01-01T19:01:26.784,2009-01-01T19:25:38.094
/home/sir2/dat/issdc/SIR/09003/CH1SIR2_NE2_09003102610068_D18_03.FITS,2009-01-03T08:37:12.323,2009-01-03T09:01:08.563
/home/sir2/dat/issdc/SIR/09003/CH1SIR2_NE2_09003161224181_D18_02.FITS,2009-01-03T14:35:52.713,2009-01-03T14:59:48.540
/home/sir2/dat/issdc/SIR/09005/CH1SIR2_NE2_09005043351642_APL_02.FITS,2009-01-03T22:28:12.552,2009-01-03T22:52:08.729
/home/sir2/dat/issdc/SIR/09004/CH1SIR2_NE2_09004065121739_D18_02.FITS,2009-01-04T06:20:32.320,2009-01-04T06:44:28.560
/home/sir2/dat/issdc/SIR/09004/CH1SIR2_NE2_09004110401760_D18_02.FITS,2009-01-04T10:16:32.521,2009-01-04T10:40:48.386
/home/sir2/dat/issdc/SIR/09004/CH1SIR2_NE2_09004163858463_D18_02.FITS,2009-01-04T16:10:52.225,2009-01-04T16:34:48.465
/home/sir2/dat/issdc/SIR/09005/CH1SIR2_NE2_09005074109132_D18_02.FITS,2009-01-04T22:04:52.553,2009-01-04T22:29:11.506
/home/sir2/dat/issdc/SIR/09005/CH1SIR2_NE2_09005073913321_D18_02.FITS,2009-01-05T05:57:12.385,2009-01-05T06:21:28.535
/home/sir2/dat/issdc/SIR/09005/CH1SIR2_NE2_09005141420331_D32_02.FITS,2009-01-05T13:43:52.610,2009-01-05T14:09:08.670
```

B M3 spatial optimization files and corresponding SIR2 files

```
M3G20081122T232906_V01_L0.IMG  ?
M3G20081128T153719_V01_L0.IMG  ?
M3G20081129T052457_V01_L0.IMG  ?
M3G20081130T050349_V01_L0.IMG  ?
M3G20081130T165321_V01_L0.IMG  ?
M3G20081202T061932_V01_L0.IMG  ?
M3G20081203T115326_V01_L0.IMG /home/sir2/dat/issdc/SIR/08339/CH1SIR2_NE2_08339140708549_D32_02.FITS
M3G20081203T234306_V01_L0.IMG /home/sir2/dat/issdc/SIR/08339/CH1SIR2_NE2_08339135812933_D32_03.FITS
M3G20081205T131000_V01_L0.IMG /home/sir2/dat/issdc/SIR/08340/CH1SIR2_NE2_08340134332456_D32_02.FITS
M3G20081207T023705_V01_L0.IMG /home/sir2/dat/issdc/SIR/08342/CH1SIR2_NE2_08342144654973_D18_02.FITS
M3G20081208T021621_V01_L0.IMG /home/sir2/dat/issdc/SIR/08343/CH1SIR2_NE2_08343162655748_D32_02.FITS
```

C Derived M3 files provided for this study

```
m3_base_image_984.jpg
M3G20081203T115326_ALBEDO
M3G20081203T115326_ALBEDO.HDR
M3G20081203T115326_LOCAL_TM_GLT
M3G20081203T115326_LOCAL_TM_GLT.HDR
M3G20081203T115326_LOCAL_TM_ORT
M3G20081203T115326_LOCAL_TM_ORT.HDR
M3G20081203T115326_V01_LAC101_GLT
M3G20081203T115326_V01_LAC101_GLT.HDR
M3G20081203T115326_V01_LAC101_ORT
M3G20081203T115326_V01_LAC101_ORT.HDR
M3G20081203T115326_V01_LAC117_GLT
M3G20081203T115326_V01_LAC117_GLT.HDR
M3G20081203T115326_V01_LAC117_ORT
M3G20081203T115326_V01_LAC117_ORT.HDR
M3G20081203T115326_V01_LAC130_GLT
M3G20081203T115326_V01_LAC130_GLT.HDR
M3G20081203T115326_V01_LAC130_ORT
M3G20081203T115326_V01_LAC130_ORT.HDR
```

```
M3G20081203T115326_V01_LOC.HDR
M3G20081203T115326_V01_LOC.IMG
M3G20081203T115326_V01_OBS.HDR
M3G20081203T115326_V01_OBS.IMG
M3G20081203T115326_V01_TIM.TXT
M3_GLOBAL_LAC200.JPG
M3_GLOBAL_LAC300.JPG
out_CH1SIR2_NE2_08339140708549_D32_02.FITS
pts.evf
read_urs_fits.pro
temp_lon_lat.txt
urs_sir2_albedo_20081203_1150_1203_columns_readme.txt
urs_sir2_albedo_20081203_1150_1203.txt
```

D PDS label of the SIR2 data file used

```
PDS_VERSION_ID              = PDS3


/* FILE CHARACTERISTICS DATA ELEMENTS */

FILE_NAME                   = "CH1SIR2_NE2_SC_08339140708_01.LBL"
RECORD_TYPE                 = FIXED_LENGTH
RECORD_BYTES                = 2880
FILE_RECORDS                = 580
INTERCHANGE_FORMAT          = BINARY
RELEASE_ID                  = 0001
REVISION_ID                 = 0000


/*  DATA OBJECT POINTERS  */

^SIR2_SC_HEADER = ("CH1SIR2_NE2_SC_08339140708_01.FITS",1<BYTES>)
^SIR2_SC_TABLE  = ("CH1SIR2_NE2_SC_08339140708_01.FITS",14401<BYTES>)


/* IDENTIFICATION DATA ELEMENTS */

DATA_SET_ID                 = "CH1ORB-L-SIR2-2-NPO-EDR-V1.0"
DATA_SET_NAME               = "CHANDRAYAAN-1-ORBITER MOON SIR2 NPO EDR V1.0"

PRODUCT_ID                  = "CH1SIR2_NE2_SC_08339140708_01"
PRODUCT_CREATION_TIME       = 2008-12-10T13:16:54
PRODUCT_TYPE                = EDR
PROCESSING_LEVEL_ID         = 2
PROCESSING_LEVEL_DESC       = "EXPERIMENT DATA RECORD"
```

```
PRODUCER_ID                   = SIR2_TEAM
PRODUCER_FULL_NAME            = "TBD"
PRODUCER_INSTITUTION_NAME     = "MAX PLANK INSTITUTE FOR SOLAR SYSTEM RESEARCH"
DATA_QUALITY_ID               = 4
DATA_QUALITY_DESC             = "THE DATA QUALITY ID FOR A COMPLETE ORBIT
                                 IS CALCULATED AS THE AVERAGE OF THE
                                 INDIVIDUAL QUALITY ID FOR EACH
                                 SPECTRA ROUNDED TO AN INTEGER VALUE"

MISSION_ID                    = CH1
MISSION_NAME                  = "CHANDRAYAAN-1"
INSTRUMENT_HOST_ID            = CH1ORB
NSTRUMENT_HOST_NAME           = "CHANDRAYAAN-1-ORBITER"
MISSION_PHASE_NAME            = "NORMAL PHASE OPERATIONS"

TARGET_NAME                   = "MOON"
TARGET_TYPE                   = SATELLITE
START_TIME                    = 2008-12-02T06:30:13
STOP_TIME                     = 2008-12-03T12:03:42
SPACECRAFT_CLOCK_START_COUNT  = "2/1751589.923"
SPACECRAFT_CLOCK_STOP_COUNT   = "3/43599.367"
START_ORBIT_NUMBER            = 279
STOP_ORBIT_NUMBER             = 294


/* DESCRIPTIVE RELATED PARAMETERS */

INSTRUMENT_ID                 = SIR2
INSTRUMENT_NAME               = "INFRARED SPECTROMETER"
INSTRUMENT_TYPE               = "SPECTROMETER"
INSTRUMENT_MODE_ID            = OPERATING
INSTRUMENT_MODE_DESC          = "OPERATING"


NOTE                          = "THIS DATA PRODUCT HAS BEEN GENERATED BY THE
                                 GDP SOFTWARE.

                                 SPACE PACKET FILE AND CONFIGURATION FILES
                                 USED:
                                    CH1_SIR_SC_0050_2008339140708.dat
                                    CH1_SIR2_50_SCDP.tcf
                                    CH1_SIR2_50_SCDP_V3.0.dcf
                                    CH1_SIR2_50_SCDP_V3.0.pcf

                                 SPICE KERNELS USED:
                                    ch1_meta.ker
```

```
                                       NAIF0009.TLS
                                       isro_2008295235703_2010365000000_00.sclk
                                       isro_21_day_att_2008324_00.bc
                                       isro_21_day_eph_2008298_00.bsp
                                       isro_21_day_eph_2008315_00.bsp
                                       isro_21_day_eph_2008324_00.bsp
                                       isro_21_day_eph_2008338_00.bsp
                                       isro_21_day_eph_2008336_00.bsp
                                       isro_21_day_eph_2008337_00.bsp
                                       isro_21_day_eph_2008339_00.bsp
                                       isro_21_day_eph_2008340_00.bsp
                                       isro_21_day_eph_2008341_00.bsp
                                       isro_21_day_eph_2008342_00.bsp
                                       CH1_V01.TF
                                       CH1_SIR2_V01.TI
                                       PCK00008.TPC
                                       EARTHFIXEDIAU.TF
                                       EARTHFIXEDITRF93.TF
                                       RSSD0001.TF
                                       DE405S.BSP
                                    "

/*  DATA OBJECTS DEFINITION */

OBJECT                        = SIR2_SC_HEADER
  BYTES                       = 14400
  HEADER_TYPE                 = FITS
  INTERCHANGE_FORMAT          = BINARY
  RECORDS                     = 5
  DESCRIPTION                 = "SIR2 FITS HEADER"
END_OBJECT                    = SIR2_SC_HEADER

OBJECT                        = SIR2_SC_TABLE
  NAME                        = "SIR2 SPECTRAL OBSERVATIONS"
  INTERCHANGE_FORMAT          = BINARY
  COLUMNS                     = 42
  ROWS                        = 2352
  ROW_BYTES                   = 703
  DESCRIPTION                 = "SIR2 TIME-TAGGED SPECTRAL
                                 OBSERVATIONS IN ORIGINAL
                                 DIGITAL NUMBER"

  OBJECT                      = COLUMN
    NAME                      = "UTC_TIME"
    COLUMN_NUMBER             = 1
    BYTES                     = 23
    DATA_TYPE                 = TIME
```

```
  START_BYTE                = 1
  DESCRIPTION               = "START TIME OF MEASUREMENT (UTC)"
  UNIT                      = "UT"
  VALID_MAXIMUM             = "N/A"
  VALID_MINIMUM             = "N/A"
END_OBJECT                  = COLUMN

OBJECT                      = COLUMN
  NAME                      = "SCET_TIME"
  COLUMN_NUMBER             = 2
  BYTES                     = 17
  DATA_TYPE                 = CHARACTER
  START_BYTE                = 24
  DESCRIPTION               = "START TIME OF MEASUREMENT (SCET)"
  UNIT                      = "N/A"
  VALID_MAXIMUM             = "N/A"
  VALID_MINIMUM             = "N/A"
END_OBJECT                  = COLUMN

OBJECT                      = COLUMN
  NAME                      = "EXPOSURE_TIME"
  COLUMN_NUMBER             = 3
  BYTES                     = 2
  DATA_TYPE                 = MSB_INTEGER
  START_BYTE                = 41
  DESCRIPTION               = "DETECTOR EXPOSURE TIME SPECIFIED IN
                               THIS PARAMETER IS GIVEN IN UNITS OF
                               8 CLOCK PERIODS. THIS VALUE IS THEN
                               DEPENDING ON THE SENSOR READOUT CLOCK
                               DIVISOR PARAMETER (READDIV), SEE COLUMN
                               16.

                               THE REAL EXPOSURE TIME CAN BE CALCULATED
                               WITH THIS FORMULA:

                               EXPOSURE_TIME * 8 / (20MHz / READDIV) s

                               WHERE READDIV IS THE SENSOR READOUT
                               FREQUENCY DIVISOR."
  UNIT                      = "N/A"
  VALID_MAXIMUM             = 1
  VALID_MINIMUM             = 65535
  OFFSET                    = 32768
END_OBJECT                  = COLUMN

OBJECT                      = COLUMN
  NAME                      = "REAL_EXPOSURE_TIME"
```

```
  COLUMN_NUMBER            = 4
  BYTES                    = 4
  DATA_TYPE                = IEEE_REAL
  START_BYTE               = 43
  DESCRIPTION              = "DETECTOR EXPOSURE TIME IN MILLISECONDS."
  UNIT                     = "MS"
  VALID_MAXIMUM            = "N/A"
  VALID_MINIMUM            = "N/A"
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
  NAME                     = "SPECTRUM"
  COLUMN_NUMBER            = 5
  BYTES                    = 512
  DATA_TYPE                = MSB_INTEGER
  START_BYTE               = 47
  ITEMS                    = 256
  ITEM_BYTES               = 2
  DESCRIPTION              = "DETECTOR 256 PIXEL VALUES CCD
                              MEASUREMENTS IN ORIGINAL DIGITAL
                              NUMBERS."
  UNIT                     = "N/A"
  VALID_MAXIMUM            = "N/A"
  VALID_MINIMUM            = "N/A"
  OFFSET                   = 32768
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
  NAME                     = "DATA_QUALITY_ID"
  COLUMN_NUMBER            = 6
  BYTES                    = 2
  DATA_TYPE                = MSB_INTEGER
  START_BYTE               = 559
  DESCRIPTION              = "THE DATA QUALITY IS EVALUATED ACCORDING
                              TO THE NUMBER OF SATURATED PIXELS OUT
                              OF THE 235 WELL FUNCTIONING PIXELS.

                              - 4 IS HIGHEST QUALITY, NO SATURATED
                                PIXELS.
                              - 3 IS HIGH QUALITY, 14 OR LESS -
                                SATURATED. 2 IS MEDIUM QUALITY, 58 OR
                                LESS SATURATED.
                              - 1 IS LOW QUALITY, 132 OR LESS
                                SATURATED.
                              - 0 IS LOWEST QUALITY, MORE THAN 132
                                SATURATED.
                              - -1 IS NON EXISTENT."
```

```
  UNIT                       = "N/A"
  VALID_MAXIMUM              = -1
  VALID_MINIMUM              = 4
END_OBJECT                   = COLUMN

OBJECT                       = COLUMN
  NAME                       = "LONGITUDE"
  COLUMN_NUMBER              = 7
  BYTES                      = 4
  DATA_TYPE                  = IEEE_REAL
  START_BYTE                 = 561
  DESCRIPTION                = "LONGITUDE"
  UNIT                       = "DEGREES"
  VALID_MAXIMUM              = 180
  VALID_MINIMUM              = -180
END_OBJECT                   = COLUMN

OBJECT                       = COLUMN
  NAME                       = "LATITUDE"
  COLUMN_NUMBER              = 8
  BYTES                      = 4
  DATA_TYPE                  = IEEE_REAL
  START_BYTE                 = 565
  DESCRIPTION                = "LATITUDE"
  UNIT                       = "DEGREES"
  VALID_MAXIMUM              = 90
  VALID_MINIMUM              = -90
END_OBJECT                   = COLUMN

OBJECT                       = COLUMN
  NAME                       = "INCIDENCE_ANGLE"
  COLUMN_NUMBER              = 9
  BYTES                      = 4
  DATA_TYPE                  = IEEE_REAL
  START_BYTE                 = 569
  DESCRIPTION                = "INCIDENCE ANGLE"
  UNIT                       = "DEGREES"
  VALID_MAXIMUM              = 180
  VALID_MINIMUM              = 0
END_OBJECT                   = COLUMN

OBJECT                       = COLUMN
  NAME                       = "PHASE_ANGLE"
  COLUMN_NUMBER              = 10
  BYTES                      = 4
  DATA_TYPE                  = IEEE_REAL
  START_BYTE                 = 573
```

```
  DESCRIPTION              = "PHASE ANGLE"
  UNIT                     = "DEGREES"
  VALID_MAXIMUM            = 180
  VALID_MINIMUM            = 0
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
  NAME                     = "EMISSION_ANGLE"
  COLUMN_NUMBER            = 11
  BYTES                    = 4
  DATA_TYPE                = IEEE_REAL
  START_BYTE               = 577
  DESCRIPTION              = "EMISSION ANGLE"
  UNIT                     = "DEGREES"
  VALID_MAXIMUM            = 180
  VALID_MINIMUM            = 0
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
  NAME                     = "LOCAL_HOUR_ANGLE"
  COLUMN_NUMBER            = 12
  BYTES                    = 4
  DATA_TYPE                = IEEE_REAL
  START_BYTE               = 581
  DESCRIPTION              = "LOCAL HOUR ANGLE"
  UNIT                     = "DEGREES"
  VALID_MAXIMUM            = 360
  VALID_MINIMUM            = 0
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
  NAME                     = "SITIME"
  COLUMN_NUMBER            = 13
  BYTES                    = 2
  DATA_TYPE                = MSB_INTEGER
  START_BYTE               = 585
  DESCRIPTION              = "SAMPLE INTERVAL TIME. TIME PERIOD
                              BETWEEN TWO SPECTRA ARE TAKEN IN UNITS
                              OF 10 MILLISECONDS."
  UNIT                     = "N/A"
  VALID_MAXIMUM            = 5
  VALID_MINIMUM            = 65535
  OFFSET                   = 32768
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
  NAME                     = "MMODE"
```

```
  COLUMN_NUMBER             = 14
  BYTES                     = 2
  DATA_TYPE                 = MSB_INTEGER
  START_BYTE                = 587
  DESCRIPTION               = "MEASUREMENT MODE. THERE ARE TWO POSSIBLE
                               MODES: NORMAL MODE AND AVERAGE MODE. IN
                               NORMAL MODE, SINGLE SPECTRA ARE SENT
                               WITH NO PROCESSING. IN AVERAGE MODE, A
                               CONFIGURABLE NUMBER OF SPECTRA ARE
                               AVERAGED (ARITHMETIC MEAN) BEFORE THEY
                               ARE SENT. AVERAGING LEADS TIPICALLY TO A
                               DECREASE OF NOISE. THE NUMBER OF SPECTRA
                               TO AVERAGE IS SPECIFIED IN THE SPECTRA
                               TO AVERAGE PARAMATER (AVERAG), SEE
                               COLUMN 14."
  UNIT                      = "N/A"
  VALID_MAXIMUM             = "N/A"
  VALID_MINIMUM             = "N/A"
  OFFSET                    = 32768
END_OBJECT                  = COLUMN

OBJECT                      = COLUMN
  NAME                      = "AVERAG"
  COLUMN_NUMBER             = 15
  BYTES                     = 2
  DATA_TYPE                 = MSB_INTEGER
  START_BYTE                = 589
  DESCRIPTION               = "SPECTRA TO AVERAGE IN AVERAGE MODE. THIS
                               VALUE IS IGNORED IN NORMAL MODE. THE
                               AVERAGING METHOD USED IS THE ARITHMETIC
                               MEAN."
  UNIT                      = "N/A"
  VALID_MAXIMUM             = 2
  VALID_MINIMUM             = 32768
  OFFSET                    = 32768
END_OBJECT                  = COLUMN

OBJECT                      = COLUMN
  NAME                      = "ADCDEL"
  COLUMN_NUMBER             = 16
  BYTES                     = 2
  DATA_TYPE                 = MSB_INTEGER
  START_BYTE                = 591
  DESCRIPTION               = "ADC TRIGGER DELAY. THE NUMBER OF SENSOR
                               CLOCK PERIODS TO WAIT BETWEEN THE ANALOG
                               PIXEL VALUE BEING AVAILABLE, TO IT BEING
                               READ."
```

```
  UNIT                        = "N/A"
  VALID_MAXIMUM               = "N/A"
  VALID_MINIMUM               = "N/A"
  OFFSET                      = 32768
END_OBJECT                    = COLUMN

OBJECT                        = COLUMN
  NAME                        = "READDIV"
  COLUMN_NUMBER               = 17
  BYTES                       = 2
  DATA_TYPE                   = MSB_INTEGER
  START_BYTE                  = 593
  DESCRIPTION                 = "SENSOR READOUT FREQUENCY DIVISOR.
                                 DEFINES WHICH NUMBER THE SYSTEM CLOCK
                                 (20MHz) HAS BEEN DIVIDED BY TO GET THE
                                 SENSOR READOUT CLOCK."
  UNIT                        = "N/A"
  VALID_MAXIMUM               = 13
  VALID_MINIMUM               = 65535
  OFFSET                      = 32768
END_OBJECT                    = COLUMN

OBJECT                        = COLUMN
  NAME                        = "NSPEC"
  COLUMN_NUMBER               = 18
  BYTES                       = 2
  DATA_TYPE                   = MSB_INTEGER
  START_BYTE                  = 595
  DESCRIPTION                 = "NUMBER OF SPECTRA COLLECTED IN THIS RUN."
  UNIT                        = "N/A"
  VALID_MAXIMUM               = "N/A"
  VALID_MINIMUM               = "N/A"
  OFFSET                      = 32768
END_OBJECT                    = COLUMN

OBJECT                        = COLUMN
  NAME                        = "PXPER"
  COLUMN_NUMBER               = 19
  BYTES                       = 2
  DATA_TYPE                   = MSB_INTEGER
  START_BYTE                  = 597
  DESCRIPTION                 = "PIXEL PERIOD TIME. THE TIME ELAPSED
                                 AFTER A PIXEL HAS BEEN SHIFTED OUT UNTIL
                                 THE NEXT PIXEL BEING SHIFTED OUT."
  UNIT                        = "N/A"
  VALID_MAXIMUM               = "N/A"
  VALID_MINIMUM               = "N/A"
```

```
  OFFSET                    = 32768
END_OBJECT                  = COLUMN

OBJECT                      = COLUMN
  NAME                      = "NSMPL"
  COLUMN_NUMBER             = 20
  BYTES                     = 2
  DATA_TYPE                 = MSB_INTEGER
  START_BYTE                = 599
  DESCRIPTION               = "NUMBER OF SAMPLES TAKEN PER PIXEL. IF
                               MORE THAN ONE, ALL SAMPLES WILL BE
                               AVERAGED (ARITHMETIC MEAN) BY THE
                               INSTRUMENT BEFORE BEING SENT."
  UNIT                      = "N/A"
  VALID_MAXIMUM             = "N/A"
  VALID_MINIMUM             = "N/A"
  OFFSET                    = 32768
END_OBJECT                  = COLUMN

OBJECT                      = COLUMN
  NAME                      = "CCSDS_COUNTER"
  COLUMN_NUMBER             = 21
  BYTES                     = 2
  DATA_TYPE                 = MSB_INTEGER
  START_BYTE                = 601
  DESCRIPTION               = "CCSDS SEQUENCE COUNTER"
  UNIT                      = "N/A"
  VALID_MAXIMUM             = "N/A"
  VALID_MINIMUM             = "N/A"
  OFFSET                    = 32768
END_OBJECT                  = COLUMN

OBJECT                      = COLUMN
  NAME                      = "HK_CLOCK"
  COLUMN_NUMBER             = 22
  BYTES                     = 13
  DATA_TYPE                 = CHARACTER
  START_BYTE                = 603
  DESCRIPTION               = "HK CLOCK AT TIME OF MEASUREMENT STARTS"
  UNIT                      = "N/A"
  VALID_MAXIMUM             = "N/A"
  VALID_MINIMUM             = "N/A"
END_OBJECT                  = COLUMN

OBJECT                      = COLUMN
  NAME                      = "HK_CLOCK_OBT_SYNCRONIZATION"
  COLUMN_NUMBER             = 23
```

```
  BYTES                      = 13
  DATA_TYPE                  = CHARACTER
  START_BYTE                 = 616
  DESCRIPTION                = "HK CLOCK AT TIME OF OBT SYNCHRONIZATION"
  UNIT                       = "N/A"
  VALID_MAXIMUM              = "N/A"
  VALID_MINIMUM              = "N/A"
END_OBJECT                   = COLUMN

OBJECT                       = COLUMN
  NAME                       = "OBT_SYNCRONIZATION"
  COLUMN_NUMBER              = 24
  BYTES                      = 8
  DATA_TYPE                  = IEEE_REAL
  START_BYTE                 = 629
  DESCRIPTION                = "OBT AT TIME OF SYNCHRONIZATION"
  UNIT                       = "N/A"
  VALID_MAXIMUM              = "N/A"
  VALID_MINIMUM              = "N/A"
END_OBJECT                   = COLUMN

OBJECT                       = COLUMN
  NAME                       = "TEC"
  COLUMN_NUMBER              = 25
  BYTES                      = 1
  DATA_TYPE                  = MSB_UNSIGNED_INTEGER
  START_BYTE                 = 637
  DESCRIPTION                = "THERMO ELECTRICAL COOLER SET VALUE"
  UNIT                       = "N/A"
  VALID_MAXIMUM              = "N/A"
  VALID_MINIMUM              = "N/A"
END_OBJECT                   = COLUMN

OBJECT                       = COLUMN
  NAME                       = "TEC_VOLT"
  COLUMN_NUMBER              = 26
  BYTES                      = 4
  DATA_TYPE                  = IEEE_REAL
  START_BYTE                 = 638
  DESCRIPTION                = "THERMO ELECTRICAL COOLER VOLTAGE"
  UNIT                       = "N/A"
  VALID_MAXIMUM              = "N/A"
  VALID_MINIMUM              = "N/A"
END_OBJECT                   = COLUMN

OBJECT                       = COLUMN
  NAME                       = "TEC_CURR"
```

```
  COLUMN_NUMBER            = 27
  BYTES                    = 4
  DATA_TYPE                = IEEE_REAL
  START_BYTE               = 642
  DESCRIPTION              = "THERMO ELECTRICAL COOLER CURRENT"
  UNIT                     = "N/A"
  VALID_MAXIMUM            = "N/A"
  VALID_MINIMUM            = "N/A"
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
  NAME                     = "VCC_CURR"
  COLUMN_NUMBER            = 28
  BYTES                    = 4
  DATA_TYPE                = IEEE_REAL
  START_BYTE               = 646
  DESCRIPTION              = "VCC CURRENT"
  UNIT                     = "N/A"
  VALID_MAXIMUM            = "N/A"
  VALID_MINIMUM            = "N/A"
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
  NAME                     = "ICU15_CURR"
  COLUMN_NUMBER            = 29
  BYTES                    = 4
  DATA_TYPE                = IEEE_REAL
  START_BYTE               = 650
  DESCRIPTION              = "ICU CURRENT 1.5V"
  UNIT                     = "N/A"
  VALID_MAXIMUM            = "N/A"
  VALID_MINIMUM            = "N/A"
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
  NAME                     = "ICU33_CURR"
  COLUMN_NUMBER            = 30
  BYTES                    = 4
  DATA_TYPE                = IEEE_REAL
  START_BYTE               = 654
  DESCRIPTION              = "ICU CURRENT 3.3V"
  UNIT                     = "N/A"
  VALID_MAXIMUM            = "N/A"
  VALID_MINIMUM            = "N/A"
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
```

```
  NAME                     = "ICU50_CURR"
  COLUMN_NUMBER            = 31
  BYTES                    = 4
  DATA_TYPE                = IEEE_REAL
  START_BYTE               = 658
  DESCRIPTION              = "ICU CURRENT 5.0V"
  UNIT                     = "N/A"
  VALID_MAXIMUM            = "N/A"
  VALID_MINIMUM            = "N/A"
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
  NAME                     = "ICUVCC_CURR"
  COLUMN_NUMBER            = 32
  BYTES                    = 4
  DATA_TYPE                = IEEE_REAL
  START_BYTE               = 662
  DESCRIPTION              = "ICU VCC VOLTAGE"
  UNIT                     = "N/A"
  VALID_MAXIMUM            = "N/A"
  VALID_MINIMUM            = "N/A"
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
  NAME                     = "V14_VOLT"
  COLUMN_NUMBER            = 33
  BYTES                    = 4
  DATA_TYPE                = IEEE_REAL
  START_BYTE               = 666
  DESCRIPTION              = "14V VOLTAGE"
  UNIT                     = "N/A"
  VALID_MAXIMUM            = "N/A"
  VALID_MINIMUM            = "N/A"
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
  NAME                     = "ICU33_VOLT"
  COLUMN_NUMBER            = 34
  BYTES                    = 4
  DATA_TYPE                = IEEE_REAL
  START_BYTE               = 670
  DESCRIPTION              = "ICU 3.3V VOLTAGE"
  UNIT                     = "N/A"
  VALID_MAXIMUM            = "N/A"
  VALID_MINIMUM            = "N/A"
END_OBJECT                 = COLUMN
```

```
OBJECT                      = COLUMN
  NAME                      = "PDA_TEMP"
  COLUMN_NUMBER             = 35
  BYTES                     = 4
  DATA_TYPE                 = IEEE_REAL
  START_BYTE                = 674
  DESCRIPTION               = "PHOTO DIODE ARRAY TEMPERATURE
                               (ON-CHIP THERMISTOR)"
  UNIT                      = "N/A"
  VALID_MAXIMUM             = "N/A"
  VALID_MINIMUM             = "N/A"
END_OBJECT                  = COLUMN

OBJECT                      = COLUMN
  NAME                      = "PCB_TEMP"
  COLUMN_NUMBER             = 36
  BYTES                     = 4
  DATA_TYPE                 = IEEE_REAL
  START_BYTE                = 678
  DESCRIPTION               = "ISU PCB TEMPERATURE"
  UNIT                      = "N/A"
  VALID_MAXIMUM             = "N/A"
  VALID_MINIMUM             = "N/A"
END_OBJECT                  = COLUMN

OBJECT                      = COLUMN
  NAME                      = "PSU_TEMP"
  COLUMN_NUMBER             = 37
  BYTES                     = 4
  DATA_TYPE                 = IEEE_REAL
  START_BYTE                = 682
  DESCRIPTION               = "PSU PCB TEMPERATURE"
  UNIT                      = "N/A"
  VALID_MAXIMUM             = "N/A"
  VALID_MINIMUM             = "N/A"
END_OBJECT                  = COLUMN

OBJECT                      = COLUMN
  NAME                      = "COOL_TEMP"
  COLUMN_NUMBER             = 38
  BYTES                     = 4
  DATA_TYPE                 = IEEE_REAL
  START_BYTE                = 686
  DESCRIPTION               = "COOLING CONSOLE TEMPERATURE"
  UNIT                      = "N/A"
  VALID_MAXIMUM             = "N/A"
  VALID_MINIMUM             = "N/A"
```

```
END_OBJECT                   = COLUMN

OBJECT                       = COLUMN
  NAME                       = "MIR_TEMP"
  COLUMN_NUMBER              = 39
  BYTES                      = 4
  DATA_TYPE                  = IEEE_REAL
  START_BYTE                 = 690
  DESCRIPTION                = "QUARTZ-BODY TEMPERATURE"
  UNIT                       = "N/A"
  VALID_MAXIMUM              = "N/A"
  VALID_MINIMUM              = "N/A"
END_OBJECT                   = COLUMN

OBJECT                       = COLUMN
  NAME                       = "ICU5_VOLT"
  COLUMN_NUMBER              = 40
  BYTES                      = 4
  DATA_TYPE                  = IEEE_REAL
  START_BYTE                 = 694
  DESCRIPTION                = "ICU 5.0V VOLTAGE"
  UNIT                       = "N/A"
  VALID_MAXIMUM              = "N/A"
  VALID_MINIMUM              = "N/A"
END_OBJECT                   = COLUMN

OBJECT                       = COLUMN
  NAME                       = "ICU15_VOLT"
  COLUMN_NUMBER              = 41
  BYTES                      = 4
  DATA_TYPE                  = IEEE_REAL
  START_BYTE                 = 698
  DESCRIPTION                = "ICU 1.5V VOLTAGE"
  UNIT                       = "N/A"
  VALID_MAXIMUM              = "N/A"
  VALID_MINIMUM              = "N/A"
END_OBJECT                   = COLUMN

OBJECT                       = COLUMN
  NAME                       = "ERRORID"
  COLUMN_NUMBER              = 42
  BYTES                      = 2
  DATA_TYPE                  = MSB_INTEGER
  START_BYTE                 = 702
  DESCRIPTION                = "ERROR IDENTIFIER FROM THE LAST IHDM
                                THAT WAS SENT"
  UNIT                       = "N/A"
```

```
    VALID_MAXIMUM            = "N/A"
    VALID_MINIMUM            = "N/A"
    OFFSET                   = 32768
  END_OBJECT                 = COLUMN

END_OBJECT        = SIR2_SC_TABLE

END
```

E SCLK used

```
KPL/SCLK

This is a CHANDRAYAAN-1 SCLK file. It has two fields -- OBT seconds and
milliseconds. It start at 2008-OCT-21 23:57:03 UTC. It rolls over every
21 days resulting in a large number of partitions, each starting at 0 ticks
and ending at 1814400000 ticks. The total of 40 partitions set in this
file should allow conversions from the clock start up to 2010-DEC-31.

OCTOBER 22, 2008.

\begindata

SCLK_KERNEL_ID           = ( @2008-10-21/23:57:03.109 )

SCLK_DATA_TYPE_86        = ( 1 )
SCLK01_TIME_SYSTEM_86    = ( 2 )
SCLK01_N_FIELDS_86       = ( 2 )
SCLK01_MODULI_86         = ( 1814400 1000 )
SCLK01_OFFSETS_86        = ( 0 0 )
SCLK01_OUTPUT_DELIM_86   = ( 1 )

SCLK_PARTITION_START_86  = (
                             0
                             0
                             0
                             0
                             0
                             0
                             0
                             0
                             0
                             0
                             0
                             0
                             0
```

```
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                                 0
                              )

SCLK_PARTITION_END_86     = (
                                 1814400000
                                 1814400000
                                 1814400000
                                 1814400000
                                 1814400000
                                 1814400000
                                 1814400000
                                 1814400000
                                 1814400000
                                 1814400000
                                 1814400000
                                 1814400000
                                 1814400000
                                 1814400000
                                 1814400000
                                 1814400000
                                 1814400000
```

```
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                              1814400000
                            )

SCLK01_COEFFICIENTS_86   = (
                              0      277905488.291414  1.00000000
                            )

\begintext
```

F FK used

```
KPL/FK

Chandrayaan-1 Frames Kernel
===========================================================================

     This frame kernel is based on a preliminary template provided  by
     ISRO,  which  only contained the description of the Chandrayaan-1
     spacecraft frame itself.  Descriptions of the SIR2 and  the  SARA
     instruments have been added by Bjoern Grieger, ESA/SRE-OS, +34 91
     81 31 107, bgrieger@sciops.esa.int.

Chandrayaan-1 Mission NAIF ID Codes -- Summary Section
```

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

   The following names and NAIF ID codes are assigned to the Chandrayaan-1
   spacecraft, its structures and science instruments (the keywords
   implementing these definitions are located in the section "Chandrayaan-1
   Mission NAIF ID Codes -- Definition Section" at the end of this
   file):

   Chandrayaan-1 Spacecraft and Spacecraft Structures names/IDs:

            CHANDRAYAAN-1         -86
            CH1                   -86
            CH1_SPACECRAFT        -86000

   SIR2 names/IDs:

            CH1_SIR2              -86700

   SARA names/IDs:

            CH1_CENA              -86600

            CH1_SWIM              -86610

Chandrayaan-1 Frames
========================================================================

   The following Chandrayaan-1 frames are defined in this kernel file:

           Name                  Relative to           Type       NAIF ID
      ======================  ===================  ============   =======

            CH1_SPACECRAFT    J2000                CK             -86000

   SIR2 Frames:
   ------------
      CH1_SIR2                CH1_SPACECRAFT       FIXED          -86700

   SARA Frames:
   ------------
      CH1_CENA                CH1_SPACECRAFT       FIXED          -86600

      CH1_SWIM                CH1_SPACECRAFT       FIXED          -86610

Frame Tree
========================================================================
```

   The diagram below shows the frame hierarchy for the Chandrayaan-1 spacecraft
   and its structure frame.

```
                               "J2000" INERTIAL
           +------------------------------------------------------+
           |                          |                           |
           |<-pck                     |<-ck                       |<-pck
           |                          |                           |
           V                          |                           V
      "IAU_MOON"                      |                     "MOON_PA"
       MOON BFXD                      |                     MOON HIGH-PREC BFXD
      -------------                   |                     -------------------
                                      |
                                      |
                                      |
                                      |
                                      |
      "CH1_SN1/2"                     |
      -----------                     |
           ^                          |
           |                          |
           |<-fixed                   |
           |                          V
           |                 "CH1_SPACECRAFT"
           +------------------------------------------------------+
           |                |                        |            |
           |<-ck            |<-ck                    |<-fixed     |<-fixed
           |                |                        |            |
           V                V                        V            V
       "CH1_SA_GIMBAL" "CH1_HGA_GIMBAL"         "CH1_TMC"    "CH1_LLRI"
       --------------- ---------------          ------------ ----------
           |                |                        |            |
           |<-fixed         |<-fixed                 |<-fixed     |<-fixed
           |                |                        |            |
           V                V                        V            V
       "CH1_SA"         "CH1_HGA"        "AFT" "NADIR" "FORE"   "BEAM" "RECEIVER"
       --------         ---------        ----- ------- ------   ------ ----------
```

```
CH1 Spacecraft Frame
========================================================================

            CH1_SPACECRAFT    J2000               CK            -86000

CH1 Spacecraft Frame
--------------------------------------
```

   The CH1 spacecraft frame is defined as follows:

```
      -  +Z towards solar array side -- positive or negative normal to
         orbit plane

      -  +X is along instrument boresights - towards Moon

      -  +Y towards MIP side -- along velocity or along anti-velocity

      -  the origin of this frame is the launch vehicle interface point.

   These diagrams illustrate the CH1_SPACECRAFT frame:

      To be completed.

   Since the orientation of the CH1_SPACECRAFT frame is computed
   on-board, sent down in telemetry, and stored in the s/c CK files, it
   is defined as a CK-based frame.

   \begindata

      FRAME_CH1_SPACECRAFT             = -86001
      FRAME_-86001_NAME               = 'CH1_SPACECRAFT'
      FRAME_-86001_CLASS              =  3
      FRAME_-86001_CLASS_ID           = -86001
      FRAME_-86001_CENTER             = -86
      CK_-86001_SCLK                  = -86
      CK_-86001_SPK                   = -86
      OBJECT_-86_FRAME                = 'CH1_SPACECRAFT'
   \begintext

SIR2 frames:
========================================================================

   This section of the file contains the definitions of the SIR2
   frames.

SIR2 Frame Tree
--------------------------------------

   The diagram below shows the SIR2 frame hierarchy.

                         "J2000" INERTIAL
        +----------------------------------------------------+
        |                         |                          |
        |                         |                          |
        |<-pck                    |                    pck->|
        |                         |                          |
```

```
      V                         |                          V
   "IAU_MOON"                   |                     "IAU_EARTH"
 MOON BODY-FIXED                |                   EARTH BODY-FIXED
 ---------------                |                   ----------------
                                |
                                |<-ck
                                |
                                V
                        "CH1_SPACECRAFT"
                        ----------------
                                |
                                |
                                |
                                |<-fixed
                                |
                                V
                            "CH1_SIR2"
                            ----------
```

```
SIR2 Detector Frame
--------------------------------------

   Since the SIR2 detector receives radiation through a prism and essentially
   has a single pixel in terms of spatial resolution, its frame, CH1_SIR2,
   is orientated in such a way that the SIR2 boresight direction is nominally
   co-aligned with the spacecraft +X axis.

   The SIR2 Detector frame -- CH1_SIR2 -- is defined as follows:

      -  +Z axis points along the camera boresight;

      -  +X axis is nominally co-aligned with the s/c +Z axis;

      -  +Y axis completes the right hand frame;

      -  the origin of the frame is located at the fiber tip focal point.

   +X s/c side view:
   -----------------

                  ^
      ------------|--------------
      |           |             |
      |           |+Zsc         |------------
      |           |             |           |
      |           |             |           |
      |           |             |           |
```

```
|           o--------->   |           |
|                    +Ysc |           |
|                         |           |
|                         |   ^       |
|                         |___|_______|
|                         |   |+Xsir
|_________________________|___|___
                            |  |  |
                      <--------o  |
                      +Ysir |_____|

                                           +Xsc and +Zsir are
                                               out of page
```

Exactly nominal mounting would require this rotation:

```
Angles:   (   0.0,   -90.0,   180.0   )
Axes:     (    1,      2,       3     )
```

Additionally to this rotation, we have to take into account deviations from the nominal mounting. The alignment values given below have been provided by

```
                 SPACECRAFT ALIGNMENT SECTION
               MECHANICAL INTEGRATION DIVISION
                          SIG, ISAC
```

on 2008-Oct-31 in the form of two tables. This is the first table:

```
+----------------------+-----------+----------------+----------------+
|                      | Rotation  | Rotation       | Rotation       |
+----------------------+-----------+----------------+----------------+
|                      | about YAW | about ROLL     | about PITCH    |
+----------------------+-----------+----------------+----------------+
|Pre dynamic           | -         | - 0 deg0' 40'' | + 0 deg2' 35'' |
+----------------------+-----------+----------------+----------------+
|Post dynamic          | -         | + 0 deg1' 07'' | + 0 deg2' 44'' |
+----------------------+-----------+----------------+----------------+
|Difference (Pre-Post) | -         | - 0 deg1' 47'' | - 0 deg0' 09'' |
+----------------------+-----------+----------------+----------------+
```

It is noted that all the alignment values given are cube normals only. Cube errors are accounted for in the second table provided:

```
  +-------------+-----------+-------------------+--------------------+
  |             | Rotation  | Rotation          | Rotation           |
  +-------------+-----------+-------------------+--------------------+
```

	about YAW	about ROLL	about PITCH
Post dynamic	-	- 0 deg8' 18.16''	- 0 deg3' 12.53''

Thus we take the values from the second table.

These angles are so small that the sequence of rotations does not really matter, however, we assume that the required sequence of rotations is first yaw (which is zero), second pitch, third roll. We assume that the negative values indicate a left-handed rotation around the specified axes.

Converted to degrees, we have this rotation angles:

First rotation around PITCH: -0.05348055555555556
Second rotation around ROLL: -0.138377777777778

The above sequence and signs of rotations would transform the instrument from the nominal mounting position to the actual mounting position. In this kernel we have to provide the opposite transformation, from the actual to the nominal position of the instrument. Thus we have to reverse the sequence of rotations and negate the angles:

First rotation around ROLL: 0.138377777777778
Second rotation around PITCH: 0.05348055555555556

In the instrument frame's coordinate system --- this is the system in which the rotation axes have to be defined ---, this corresponds to

First rotation around -Y: 0.138377777777778
Second rotation around +X: 0.05348055555555556

To replace -Y by +Y, we have to negate the angle, thus:

First rotation around +Y: -0.138377777777778
Second rotation around +X: 0.05348055555555556

In SPICE encoding, this rotation is described by

```
Angles:   (   0.05348055555555556,   -0.138377777777778,   0.0   )
Axes:     (             1,                      2,            3   )
```

This rotation transforms the instrument from the actual mounting to the nominal mounting. We have first to apply this rotation and then apply the rotation which transforms the axes of the instrument frame to the respective axes of the spacecraft frame. As stated above, this second rotation is described by

```
     Angles:   (   0.0,   -90.0,   180.0   )
     Axes:     (    1,      2,       3     )
```

To compute the combination of these two rotations we use the SPICE routines eul2m, mxm, and m2eul. The resultant rotation is

```
     Angles:   (   -21.1305922,   -89.8516471,   -158.869343   )
     Axes:     (        1,              2,              3       )
```

The resultant rotation is reflected in the below data section.

```
   \begindata

      FRAME_CH1_SIR2                  =  -86700
      FRAME_-86700_NAME               = 'CH1_SIR2'
      FRAME_-86700_CLASS              =  4
      FRAME_-86700_CLASS_ID           =  -86700
      FRAME_-86700_CENTER             =  -86
      TKFRAME_-86700_RELATIVE         = 'CH1_SPACECRAFT'
      TKFRAME_-86700_SPEC             = 'ANGLES'
      TKFRAME_-86700_UNITS            = 'DEGREES'
      TKFRAME_-86700_ANGLES           = (-21.1305922, -89.8516471, -158.869343)
      TKFRAME_-86700_AXES             = (   1,     2,     3   )

   \begintext
```

SARA frames:
==

This section of the file contains the definitions of the SARA frames.

SARA Frame Tree

The diagram below shows the SARA frame hierarchy.

```
                          "J2000" INERTIAL
       +----------------------------------------------------+
       |                         |                          |
       |                         |                          |
       |<-pck                    |                     pck->|
       |                         |                          |
       V                         |                          V
```

```
  "IAU_MOON"                        |                  "IAU_EARTH"
 MOON BODY-FIXED                    |                EARTH BODY-FIXED
 ---------------                    |                ----------------
                                    |
                                    |<-ck
                                    |
                                    V
                            "CH1_SPACECRAFT"
                            ----------------
                                    |
       +--------------------------+-------------+
       |                                        |
       |<-fixed                                 |<-fixed
       |                                        |
       V                                        V
   "CH1_CENA"                              "CH1_SWIM"
   ----------                              ----------
```

SARA Detector Frame

The SARA instrument comprises two sensors, CENA and SWIM. These
sensors look in
different directions, as CENA measures particles from the lunar surface
while SWIM monitors the solar activety.
However, the coordinate systems in which both sensors are defined
are co-aligned. The different viewing direction are implemented
through different boresight vectors.

Although the co-ordinate systems of both sensors are co-aligned,
we define two separate sensor base frames. For the time being, we assume
nominal mounting of the sensors on the spacecraft, but if we
later want to consider missalignment angles (which would be different
for the two sensors), we need the seperate
frames.

The SARA instrument frames -- CH1_CENA and CH1_SWIM -- are defined as
follows:

- +X axis is nominally co-aligned with the s/c +Z axis;

- +Y axis is nominally co-aligned with the s/c +X axis;

- +Z axis is nominally co-aligned with the s/c +Y axis;

+X s/c side view:

```
            ^
            |
____________|______________
|           |             |
|           |+Zsc         |_____________
|           |             |           |_|    ^
|           |             |           |SWIM  |+Xcena
|           |             |           |__    |+Xswim
|           o--------->   |           | |    |
|                    +Ysc |           |_|    o------->
|                         |           |CENA     +Zcena
|                         |           |         +Zswim
|                         |___________|
|                         |
|_________________________|

                                       +Xsc and +Ycena/+Yswim are
                                       out of page
```

Aligning the CENA and SWIM frames with the spacecraft frame requires this rotation:

```
Angles:   (   90.0,   0.0,   90.0   )
Axes:     (    1,      2,     3     )
```

The applicable rotations are reflected in the below data section.

```
\begindata

   FRAME_CH1_CENA                = -86600
   FRAME_-86600_NAME             = 'CH1_CENA'
   FRAME_-86600_CLASS            =  4
   FRAME_-86600_CLASS_ID         = -86600
   FRAME_-86600_CENTER           = -86
   TKFRAME_-86600_RELATIVE       = 'CH1_SPACECRAFT'
   TKFRAME_-86600_SPEC           = 'ANGLES'
   TKFRAME_-86600_UNITS          = 'DEGREES'
   TKFRAME_-86600_ANGLES         = ( 90.0,  0.0, 90.0 )
   TKFRAME_-86600_AXES           = (    1,    2,    3 )

   FRAME_CH1_SWIM                = -86610
   FRAME_-86610_NAME             = 'CH1_SWIM'
   FRAME_-86610_CLASS            =  4
   FRAME_-86610_CLASS_ID         = -86610
   FRAME_-86610_CENTER           = -86
   TKFRAME_-86610_RELATIVE       = 'CH1_SPACECRAFT'
   TKFRAME_-86610_SPEC           = 'ANGLES'
```

```
      TKFRAME_-86610_UNITS            = 'DEGREES'
      TKFRAME_-86610_ANGLES           = ( 90.0,  0.0, 90.0 )
      TKFRAME_-86610_AXES             = (    1,    2,    3 )

   \begintext

         \begindata

            NAIF_BODY_NAME += ( 'CHANDRAYAAN-1' )
            NAIF_BODY_CODE += ( -86 )

            NAIF_BODY_NAME += ( 'CH1' )
            NAIF_BODY_CODE += ( -86 )

            NAIF_BODY_NAME += ( 'CH1_SPACECRAFT' )
            NAIF_BODY_CODE += ( -86001 )

         \begintext

SIR2 IDs
--------------------------------------

   This table summarizes SIR2 IDs:

            Name                    ID
            ---------------------  -------
            CH1_SIR2               -86700

   Name-ID Mapping keywords:

         \begindata

            NAIF_BODY_NAME += ( 'CH1_SIR2' )
            NAIF_BODY_CODE += ( -86700 )

         \begintext

SARA IDs
--------------------------------------

   This table summarizes SARA IDs:

            Name                    ID
            ---------------------  -------
            CH1_CENA               -86600
            CH1_SWIM               -86610
```

```
   Name-ID Mapping keywords:

         \begindata

            NAIF_BODY_NAME += ( 'CH1_CENA' )
            NAIF_BODY_CODE += ( -86600 )

            NAIF_BODY_NAME += ( 'CH1_SWIM' )
            NAIF_BODY_CODE += ( -86610 )

         \begintext
```

G IK used

```
KPL/IK

SIR-2 Instrument kernel
===========================================================================

   This instrument kernel (I-kernel) contains CHANDRAYAAN-1 Near Infrared
   Spectrometer (SIR-2) optics, detector, and FOV parameters.


Version and Date
---------------------------------------------------------------------------

   Version 0.1 -- 2008 November 18 -- Bjoern Grieger, ESA/SRE-OS

      Changed the instrument ID from 200 to 700, as defined in the
      preliminary frames kernel ch1_sample.tf from 2008-Nov-12.
      Confirmed that the fiber shape is circle. Changed the fiber
      size from 0.200 mm to 0.400 mm. Confirmation of spectral range
      and approval by team is still pending.

   Version 0.0 -- 2008 October 13 -- Bjoern Grieger, ESA/SRE-OS

      Preliminary Version. Copied from the SMART-1 SIR kernel (created
      by Jorge Diaz del Rio) and updated spacecraft name and ID,
      instrument name, and the IFOV. Copied the instrument overview
      from the SIR-2 ICD. The instrument ID is still set to the
      SMART-1 value (200); this has certainly to be updated when the
      FK is available. Pending review and approval by SIR-2 instrument
      team.
```

```
References
--------------------------------------------------------------------------

   1. ``Kernel Pool Required Reading''

   2. ``C-kernel Required Reading''

   3. ``SIR-2 ICD'', C1-SIR-ICD-3001, V2.3, 2007-Sep-26

   4. CH1 Frames Definition Kernel (FK), (not yet available).


Contact Information
-----------------------------------------------------------------------

   Bjoern Grieger, ESA/SRE-OS, +34 91 81 31 107, bgrieger@sciops.esa.int


Implementation Notes
-----------------------------------------------------------------------

   Applications that need SPICE I-kernel data must ``load'' the
   I-kernel file, normally during program initialization.

   Loading the kernel using the SPICELIB routine FURNSH causes the data
   items and their associated values present in the kernel to become
   associated with a data structure called the ``kernel pool''. The
   application program may then obtain the value(s) for any IK data
   item using the SPICELIB routines GDPOOL, GIPOOL, GCPOOL. Routine
   GETFOV may also be used if the file contains instrument
   field-of-view (FOV) specifications. See [1] for details.

   This file was created and can be updated with a text editor or
   word processor.


Conventions for Specifying Data
-----------------------------------------------------------------------

   Data items are specified using ``keyword=value'' assignments [1].
   All keywords referencing values in this I-kernel start with the
   characters `INS' followed by the NAIF CHANDRAYAAN-1 instrument ID code,
   constructed using the spacecraft ID number, -86, followed by the
   NAIF three digit ID number for SIR-2 (700). This ID is defined in
   [4] as follows:
```

```
            Instrument name           ID
            --------------------   -------
            CH1_SIR2                -86700

   The remainder of the keyword is an underscore character followed by the
   unique name of the data item. For example, the number of pixels of
   the SIR-2 is specified by

            INS-86700_NUMBER_OF_PIXELS

   The upper bound on the length of all keywords is 32 characters.

   If a keyword is included in more then one file, or if the same
   keyword appears more than once within a single file, the last
   assignment supersedes any earlier assignments.


Instrument Overview
--------------------------------------------------------------------------

   From [3]:

   SIR-2 is a highly compact, grating, near-infrared point spectrometer,
   covering the wavelength range between 0.9 and 2.4 microns, with a
   spectral resolution of 6 nm.

   The near-infrared spectrometer SIR-2 consists of three individual units:

    - O-Box (front-end optics), located on an extension of the Anti-SS panel

    - Sensor-Head/Radiator Unit (spectrometer), located on the Anti-SS panel

    - E-Box (digital electronics and power converter), located inside the
      S/C cube on the Anti-SS panel

   These units are linked by:

    - An optical fiber connecting O-Box and Sensor-Head/Radiator Unit

    - An electrical harness (ILH) connecting Sensor-Head/Radiator Unit and
      E-Box

   SIR-2 collects the Sun's light reflected by the Moon with the help of the
   optical box (O-Box) which houses a main and secondary mirror. This light
   then enters an optical fiber, which transmits the light to the
   Sensor-Head/Radiator Unit. Inside the Sensor-Head the light passes filter,
   slit and the quartz body and reaches the dispersing grating. The dispersed
```

light then passes the quartz body again to reach a second order filter, which is glued onto the detector window. After passing this window the light is detected by the photosensitive pixels. The electrons released by the individual pixels are collected and a sequential read out is performed after the integration time has ended. The adjacent voltage will be measured for each pixel and the obtained values are converted to digits. The obtained values (counts) are finally embedded in the TM packages in order to send them to the spacecraft's mass memory.

Mounting Alignment

Refer to the latest version of the CHANDRAYAAN-1 Frames Definition Kernel (FK) [4] for the SIR-2 reference frame definitions and mounting alignment information.

Optics and Detector Parameters

This section contains assignments specifying the SIR-2 optics and detector parameters.

The following SIR-2 optical and fiber shape/size parameters are included in the data section below, taken from [3]:

parameter	SIR-2
Focal Length, mm	180
f/ratio	2.5
Fiber shape	circle
Fiber size, mm	0.400
Number of pixels	1
IFOV, rad/pixel	
nominal	0.0022

These values are provided in the assignments below, with the same units as in the table.

```
\begindata

   INS-86700_FOCAL_LENGTH       = (  180       )
   INS-86700_F/RATIO            = (    2.5     )
```

```
      INS-86700_FIBER_SIZE         = (    0.200   )
      INS-86700_NUMBER_OF_PIXELS   = (    1       )
      INS-86700_IFOV               = (    0.0022  )

   \begintext


FOV Definitions
-------------------------------------------------------------------------

   This section contains assignments defining the SIR-2 FOV.
   These definitions are based on the SIR-2 detector and optics
   parameters provided in the previous section and are provided in a
   format consistent with/required by the SPICE (CSPICE) function
   GETFOV (getfov_c).

   The SIR-2 FOV is defined as a cone with a half angle of 0.0011 radians.
   It is defined with respect to the CH1_SIR2 frame. The boresight
   vector, along the +Z axis of the frame, was scaled to be equal to the
   focal length. The cross-reference vector is a unit vector along the
   +X axis of the frame.

      \begindata

         INS-86700_FOV_FRAME          = 'CH1_SIR2'
         INS-86700_FOV_SHAPE          = 'CIRCLE'
         INS-86700_BORESIGHT          = ( 0.0     0.0    180.0 )
         INS-86700_FOV_CLASS_SPEC     = 'ANGLES'
         INS-86700_FOV_REF_VECTOR     = ( 1.0    0.0     0.0 )
         INS-86700_FOV_REF_ANGLE      = ( 0.0011 )
         INS-86700_FOV_CROSS_ANGLE    = ( 0.0011 )
         INS-86700_FOV_ANGLE_UNITS    = 'RADIANS'

      \begintext


Spectral Parameters
-------------------------------------------------------------------------

   This section contains assignments specifying SIR-2 spectral resolution
   parameters.

   The SIR-2 spectral resolution parameters, included in the data section
   below, are taken from [3].

      -----------------------------------------------------------------
             parameter                     SIR-2
```

```
      ---------------------------------------------------------------
      Spectral range, microns
         nominal                        0.9 - 2.40 (S1-SIR was 0.94 ???)
      Number of spectral bins               256
      ---------------------------------------------------------------
```

These values are provided in the assignments below, with the same units as in the table.

```
   \begindata

      INS-86700_SPECTRAL_RANGE     = (  0.9, 2.40 )
      INS-86700_NUMBER_OF_BINS     = (     256     )

   \begintext
```

Platform ID

This number is the NAIF instrument ID of the platform on which the instrument is mounted. SIR-2 is mounted directly on the spacecraft.

```
   \begindata

      INS-86700_PLATFORM_ID        = ( -86000 )

   \begintext
```