SUIT Data User Manual

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1 Introduction

Solar Ultraviolet Imaging Telescope (SUIT) is a payload onboard the Aditya-L1 mission of ISRO, India. It takes images of the Sun in the wavelength range of 200–400nm 24×7 from Lagrange point 1. SUIT has three different types of images: Full Frame, which is (4096×4096) in size; Binned Full Frame (2048×2048) in size; and Region of Interest, which captures only specific regions of the Sun as needed. SUIT takes the binned images every minute and full frame images every 2.5 hours in synoptic mode. Besides the normal synoptic mode, SUIT has onboard intelligence to detect and locate flares and observe the flare regions when they are triggered. This sequence is built into the synoptic mode.

1.1 Filters and Modes

- ROI images are taken in 8 Filters.
- Full frame images are taken in all 11 Filters.
- Binned image is only taken in NB03 filter.

1.2 Data Products from SUIT

SUIT obtains full-disk and RoI images of the Sun in the 200–400 nm Near Ultra Voilet (NUV) passabands. More details of the observing bandpasses and the details of the instrument can be found in SUIT instrument webpage. These images are used to generate higher-level data products, including the daily movies in the SUIT daily movies archive.

The different data levels are summarized as follows:

1. **Level-0:** Level-0 data is generated by the ISSDC team and sent to SUITPOC daily. These are binary files of each image. Health parameters, SPICE files, and HDR files are also attached to each bundle. This data is converted to FITS format and stored in the POC area. This is not available to the public.
2. **Level-1:** Level-1 data processing involves all header addition from aux files, SPICE files, and HK files. We perform gain and bias correction, orientation correction, flat fielding, PRNU correction, scatter removal, and WCS addition. Ghost removal is performed for NB08 when Sun is at the CCD center.
3. **Level-3:** Level-2 processing involves distortion correction, spike removal, and PSF deconvolution.

   The details of data processing to different levels and the methodology used to derive flats etc are given in different SUIT calibration papers, a dynamic page with list of SUIT papers can be found here

1.3 Naming

This is an example name of the SUIT FITS file:

`SUT_T24_1592_000634_Lev1.0_2024-10-31T00.32.06.755_0973NB01.fits`

The SUIT file name incorporates the following information:

- Instrument name: `SUT`
- Observation ID: `T24_1592_000634`
- `Lev1.0`: This is the level of the image. Is it `Lev1.0` or `Lev2.0`?
- Time of the image. `2024-10-31T00.32.06.755`

The last bit of the file name incorporates a lot of information. Let's take the last eight characters. Here it is `0973NB01`.

1. **0**: This is the first character. It represents the image type. The following types of images are available:

```
img_type_dictionary = {
  0:'Normal',
  1:'Star Cal 1',
  2:'Star Cal 2',
  3:'Off Pointing',
  4:'Engineering Mode',
  5:'Engineering Mode',
  6:'Engineering Mode',
  7:'Engineering Mode',
  8:'EEPROM Dump',
  9:'Engineering Mode',
  10:'LED 355nm',
  11:'LED 255nm',
  12:'Dark - Door Closed',
  13:'Dark - Door Open',
  14:'Bias - Door Open',
  15:'Bias - Door Closed'
}
```

2. **97**: This is the OBS ID to identify the program sequence.
3. **3**: This represents the image size. `1 = Full Frame, 2 = Binned, and 3 = ROI`
4. **NB01**: Filter name.

2 Images

The SUIT images are in FITS format. It has all the necessary WCS coordinate headers and it can be viewed in Jhelioviewer. If you use Jhelioviewer and add the SUIT images, the WCS coordinates will automatically be applied, and the images will be aligned according to them. This will make coaligning with other instruments way easier. The ROI images are also aligned in the same way. SUIT images are also configured for the SunPy package.

2.1 Viewing Sun images using Python

The following code snippet shows how to view the SUIT image using Python:

```
from astropy.io import fits
import matplotlib.pyplot as plt

# Load the data
with fits.open('<fits file path>') as inFile:
    data = inFile[0].data
    header = inFile[0].header
print(header.keys) #Shows all the headers
plt.imshow(data, origin='lower') #Plot using matplotlib
plt.show()
```

Example:

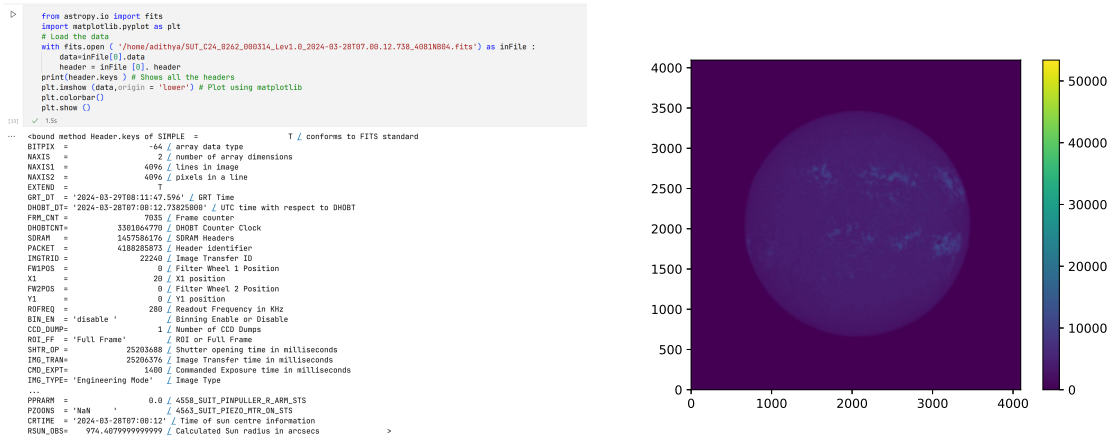

Figure 1: Example code segment executed

2.2 View the SUIT data using sunpy

SUIT data is compatible with sunpy package. Refer to the following snippet to view the Sun image using Sunpy. Once the fits file is read into a Sunpy map object, various procedures described in the Sunpy website and various affiliated packages can also be applied to the SUIT data. Please refer to the Sunpy example gallery for a detailed description of the various processes.

```
import sunpy.map
inputFile = '<SUIT FITS file path>' #Path to SUIT fits file.

amap = sunpy.map.Map(inputFile) #Define the amap object
amap.peek(draw_grid=True, vmin=100, vmax=6e4, cmap='inferno') #
    Sunpy function to view the object.
```

Figure 2 shows the output of this python snippet.

2.3 SUIT color scheme

The suit color scheme can be downloaded from suit-color-scheme. After cloning the repository. You can refer the following code snippet for adding the color map:

```

# Load the suit-color-scheme module
import sys
sys.path.insert(0,'path/to/suit-color-scheme/folder')
from suitcolormap import *

```

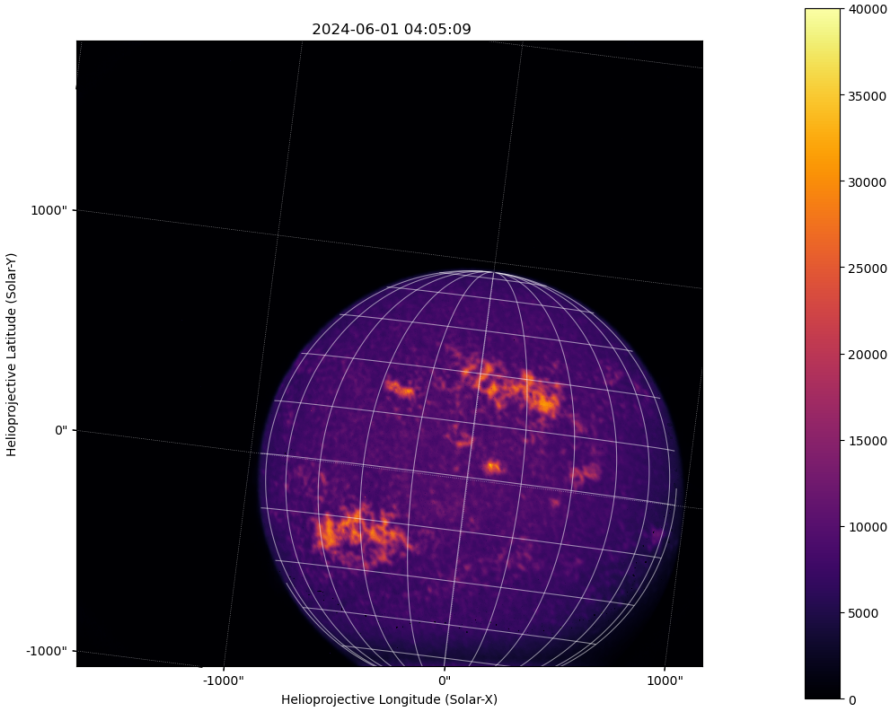

Figure 2: Plot using sunpy map

```
from astropy.io import fits
import matplotlib.pyplot as plt

#Load the data

inFile = '<input SUIT fits file>'
with fits.open(inFile) as inF:
    inData = inF[0].data
    filterName = inF[0].header['FTR_NAME'] #Get the filter name from
        the headers

#plot the image
plt.imshow(inData, cmap=filterColor.get(filterName), origin='lower',
    interpolation='none')
plt.show()
```

The same can be achieved within the Sunpy framework. The user can refer to the following code snippet to integrate the colormap into Sunpy:

```
import matplotlib.pyplot as plt
from sunpy.map import Map

# Load the suit-color-scheme module
import sys
sys.path.insert(0,'path/to/suit-color-scheme/folder/')
from suitcolormap import *

#load the data into a SunPy map structure
inFile = '<input SUIT fits file>'
a = Map(inFile)
filterName = a.meta['FTR_NAME'] # get the filter name from the header

#plot the image
a.peek(draw_grid=True, vmin=100, vmax=2e4,
```

```
        cmap=filterColor.get(ftr_name))
```

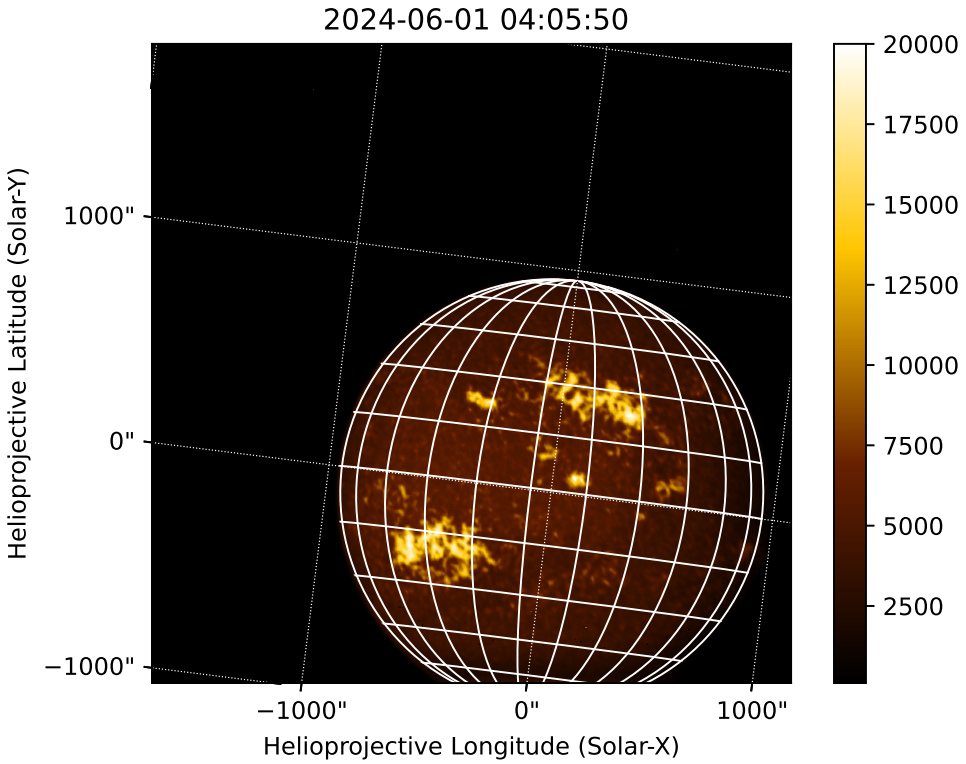

Figure 3: Plot of the data as shown in Fig. 2 with the suit-color-scheme incorporated.

3 FITS Headers

All necessary information about the image is provided in the SUIT header itself. You can see different types of headers.

- Observation details
- WCS-related information
- Processing details
- Health parameters

All these headers are available as primary headers. There are comments for each header to give a basic idea of its intuition.

3.1 Observation Details

This includes all the on-board generated headers. It includes information like image type, image size, etc. Most of the headers are flags related to onboard electronic prompts. Headers related to external triggers from SOLEX and HEL1OS are also included here.

1. **IMGTRID**: This is the onboard image counter. Using this, you can identify the order of the images and also make sure if there are any images missing in between.
2. **FW1POS**: Filter wheel 1 position
3. **FW2POS**: Filter wheel 2 position.
4. **X1**: X position of the bottom-right corner in pixel coordinates.
5. **Y1**: Y position of the bottom-right corner in pixel coordinates.
6. **X2**: X position of top-left corner in pixel coordinates.
7. **Y2**: Y position of top-left corner in pixel coordinates.
8. **FTR_NAME** Filter wheel name identified from both Filter wheel positions. This is the header to look for if you are trying to know the filter wheel combination.
9. **ROFREQ**: Read out frequency in KHz.
10. **BIN_EN**: Flag which shows binning is enabled of disabled.
11. **CCD_DUMP**: Number of CCD Dumps.
12. **ROI_FF**: ROI = Region of Interest, Full Frame = Full disk image. Full disk images can be binned or unbinned. Refer to the **BIN_EN** header for checking the binning status.
13. **ROI_FF**: ROI = Region of Interest, Full Frame = Full disk image.
14. **SHTR_OP**: Shutter opening time in milliseconds. This is right before the beginning of exposure.
15. **IMG_TRAN**: Image transfer time in milliseconds. This is the time of writing of the first pixel of the image to the disk.
16. **CMD_EXPT**: Commanded exposure time in milliseconds.
17. **IMG_TYPE**: This is the type of image we are expecting based on the program sequence. For instance, the science images of Default synoptic mode will be named 'Normal'. Refer the `img_type_dictionary` mentioned above for more details.
18. **OBS_MODE**: Unique ID for different modes within a program sequence.
19. **ROI_ID**: ID for ROIs uploaded as per user's request. It ranges from 1 to 249. 250 and 255 are reserved for Normal and Prominence flare modes.

20. **SOLX1TR** : SOLEX 1 Trigger. This flag will show if there is any flare trigger from SOLEX 1
21. **SOLX2TR** : SOLEX 2 Trigger. Flare trigger for SOLEX 2.
22. **HELIOSTR** : HEL1OS Trigger. The flag will be 1 if there is any flare trigger from HEL1OS.
23. **FLR_TRIG** : External Flare Trigger time in milliseconds.
24. **REJ_BIT**: Shows if there are any rejected bits.
25. **SHTR_STR** : Shutter Start Position in Degrees
26. **CCD_RDOM** : CCD Read Output Mode. The default mode is 4 output modes, all quadrants.
27. **SHTR_STO** : Shutter Stop Position in Degrees.
28. **ROI_M_EN** : ROI tracking Enable or Disable.
29. **SHTR_HTE** : Shutter Home Timeout Error
30. **EXP_NIR** : Flag to check Exposure LUT not in range
31. **EXP_ND8** : Flag to check Exposure address not divisible by 8
32. **ROI_ND16** : Flag to check ROI coordinates not divisible by 16
33. **ROI_CHKM** : ROI checksum mismatch
34. **NORM_FLR** : Normal flare. It is defined as a flare that occurs within a 0.9 Solar radius.
35. **PROM_FLR** : Prominance flare. It is defined as a flare that occurs outside a 0.9 solar radius.
36. **ER_FL_E**: Data from E channel is more than expected error flag
37. **ER_FL_F**: Data from F channel is more than expected error flag
38. **ER_FL_G**: Data from G channel is more than expected error flag
39. **ER_FL_H**: Data from H channel is more than expected error flag
40. **ER_FL_DL** : Data is less than expected flag
41. **SHTR_TRQ** : Shutter torque
42. **FL_SELF** : Self Trigger timeout
43. **FL_EXT** : External Trigger timeout
44. **PE_CRC** : PE TE FPGA CRC error flag
45. **BIN_CNTR** : Bin Counter
46. **LIN_ENC** : Linear encoder value in microns
47. **FLR_ED** : Helios & Solex1 & Solex0 & Self_trig Enable values. Convert the decimal value to binary to decode the status of each trigger.
48. **TRK_ED** : Tracking Enable/Disable flag.
49. **OB_ED** : mux selection in the TE
50. **LED_DAC1** : LED DAC1 current in mA
51. **LED_DAC2** : LED DAC2 current in mA
52. **LED_DAC3** : LED DAC3 current in mA
53. **LED_DAC4** : LED DAC4 current in mA
54. **AMP_G_E** : Amplifier gain of channel E

55. **AMP_G_F** : Amplifier gain of channel F
56. **AMP_G_G** : Amplifier gain of channel G
57. **AMP_G_H** : Amplifier gain of channel H
58. **OVERSCAN** : Number of overscan pixels
59. **OD_BIAS** : Output Drain Voltage in Volts
60. **RD_BIAS** : Reset Drain Voltage in Volts
61. **DD_BIAS** : Common Drain Voltage in Volts
62. **OG_BIAS** : Output Gate Voltage in Volts
63. **OFFSET1** : DAC offset value for channel E
64. **OFFSET2** : DAC offset value for channel F
65. **OFFSET3** : DAC offset value for channel G
66. **OFFSET4** : DAC offset value for channel H
67. **LEDONOFF** : LED ON/OFF status in HEX (0 = OFF, 1 = ON)
68. **SEQ_IDF** : Sequence Identifier
69. **S_PIX_V** : Superpixel Value
70. **S_PIX_S** : Superpixel Number
71. **MEAS_EXP** : Measured exposure in milliseconds

3.2 Processing Details

We keep track of all the processing done to the image using the headers mentioned here. You can see headers like `FLAT_CF`, `SCAT_CF` tags the calibration file used on the image. It has flags to keep track of gain correction and bias correction.

1. **MFGDATE** : Time of making the image file
2. **IMGNUM** : Image number in the packet
3. **FOLDNAME** : Data product name
4. **FTR_NAME** : Filter Combination Name
5. **T_OBS** : Observation time
6. **DATE-OBS** : Observation date
7. **F_NAME** : FITS file name
8. **PROP_ID** : Proposal ID
9. **OBS_ID** : Observation ID
10. **F_VER** : File Version
11. **F_LEVEL** : Level of the file
12. **QVAL** : Percentage of quality for image
13. **QDESC** : Quality description
14. **OBS_STRT** : Observation start time
15. **OBS_STP** : Observation stop time

16. **BZERO** : Zero bias value
17. **BSCALE** : Scale factor
18. **TOTSHTRT** : Total Shutter Movement time
19. **RM_OVER** : Overscan removal status
20. **IN_OSCOR** : In-situ overscan correction status
21. **GAINCOR** : Gain correction status
22. **NORM** : Normalization status
23. **FIR_ROT** : Orientation correction status
24. **FLAT_CF** : Flat calibration file name
25. **SCAT_CF** : Scatter calibration file name
26. **PRNU_CF** : PRNU calibration file name
27. **DIST_CF** : Distortion correction file name
28. **PSF_CF** : PSF calibration file name
29. **NSPIKES** : Number of spikes detected
30. **MBIAS_E** : Mean bias for channel E
31. **MBIAS_F** : Mean bias for channel F
32. **MBIAS_G** : Mean bias for channel G
33. **MBIAS_H** : Mean bias for channel H
34. **MISSION** : Mission Name
35. **PNAME** : Payload Name
36. **DESCR** : Description of SUIT

3.3 WCS related headers

These are the headers required for WCS. There are other headers related to Sun center information that help determine the ROI in arcsecs.

1. **CTYPE1** : Projection name for x-axis
2. **CUNIT1** : Axis unit for x-axis
3. **CDELT1** : Pixel size in x
4. **CTYPE2** : Projection name for y-axis
5. **CUNIT2** : Axis unit for y-axis
6. **CDELT2** : Pixel size in y
7. **CROTA2** : Rotation angle about reference pixel
8. **CRPIX1** : Sun center X-position in pixels
9. **CRPIX2** : Sun center Y-position in pixels
10. **CRVAL1** : Location of reference pixel in x-direction
11. **CRVAL2** : Location of reference pixel in y-direction
12. **R_SUN** : Radius of the sun in pixels

13. **RSUN_OBS** : Calculated Sun radius in arcsecs
14. **CRTIME** : Time of Sun center information
15. **SUN_CX** : Sun center x-position (pixel)
16. **SUN_CY** : Sun center y-position (pixel)
17. **APSSPCH** : 140_APSS-1_PCH_ASPECT_ANG. Pitch angle from APSS in degrees.
18. **APSSROL**: 141_APSS-1_ROL_ASPECT_ANG. Roll angle from APSS in degrees.
19. **HGLT_OBS**: Stoneyhurst heliographic latitude of the observer in degrees.
20. **HGLN_OBS**: Stoneyhurst heliographic longitude of the observer in degrees.
21. **CRLT_OBS**: Carrington latitude of the observer in degrees.
22. **GAEX_OBS**: Geocentric inertial X position of the observer in meters.
23. **GAEY_OBS**: Geocentric inertial Y position of the observer in meters.
24. **GAEZ_OBS**: Geocentric inertial Z position of the observer in meters.
25. **HAEX_OBS**: Heliocentric inertial X position of the observer in meters.
26. **HAEY_OBS**: Heliocentric inertial Y position of the observer in meters.
27. **HAEZ_OBS**: Heliocentric inertial Z position of the observer in meters.
28. **DSUN_OBS**: Distance from the Sun center to Aditya in meters.
29. **DSUN_REF**: Distance from the Sun center to Earth in meters.
30. **RSUN_REF**: Reference radius of the Sun in meters.
31. **P_ANGLE**: P angle in degrees.
32. **ROLL**: Roll angle in degrees.
33. **YAW**: Yaw angle in degrees.
34. **PITCH**: Pitch angle in degrees.

3.4 Health Parameters

These are the useful headers scraped from analog and status hk files and incorporated into the image. Most of the headers are self-explanatory.

1. **DCNTC1R**: Temperature of 5271_SUIT_DET_CF_NHP_TEMP_CPRT1-R in Celsius.
2. **DHNTC1**: Temperature of 5275_SUIT_DHA-HP_NCF_TEMP_CPRT1 in Celsius.
3. **DMTTC2R**: Temperature of 5276_SUIT_DET_MNT_TEMP_CPRT2-R in Celsius.
4. **DHTC2R**: Temperature of 5277_SUIT_DHA-HP_TEMP_CPRT2-R in Celsius.
5. **DCNTF1R**: Temperature of 5335_SUIT_DET_CF_NHP_TEMP_FPRT1-R in Celsius.
6. **RLTF1**: Temperature of 5337_SUIT_RADIATOR-L2_TEMP_FPRT1 in Celsius.
7. **DHNTF1**: Temperature of 5339_SUIT_DHA-HP_NCF_TEMP_FPRT1 in Celsius.
8. **DMTF2R1**: Temperature of 5340_SUIT_DET_MNT_TEMP_FPRT2-R in Celsius.
9. **DHTF2R1**: Temperature of 5341_SUIT_DHA-HP_TEMP_FPRT2-R in Celsius.
10. **DMTF2R2**: Temperature of 5342_SUIT_DET_MNT_TEMP_FPRT2-R in Celsius.
11. **DHTF2R2**: Temperature of 5343_SUIT_DHA-HP_TEMP_FPRT2-R in Celsius.

12. **FD2TT**: Temperature of 6811_SUIT_FW_DRIVE-2_TEMP_THR in Celsius.
13. **SMTTR**: Temperature of 6815_SUIT_SHUTER_MOT_TEMP_TCPL-R in Celsius.
14. **FWMTT**: Temperature of 11514_SUIT_FW_MNT_TEMP_THR in Celsius.
15. **SHUMTT**: Temperature of 11529_SUIT_SHUTTER_MNT_TEMP_THR in Celsius.
16. **DHAM1TT**: Temperature of 11607_SUIT_DHA_MNT-1_TEMP_THR in Celsius.
17. **DHAM2TT**: Temperature of 11617_SUIT_DHA_MNT-2_TEMP_THR in Celsius.
18. **FD1TT**: Temperature of 11623_SUIT_FW_DRIVE-1_TEMP_THR in Celsius.
19. **FCLAMTT**: Temperature of 11640_SUIT_FCLA_MNT_TEMP_THR in Celsius.
20. **ELX_THR**: Temperature of 11686_SUIT_ELX_TEMP_THR in Celsius.
21. **THFMTT**: Temperature of 11702_SUIT_TH-FLTR_MNT_TEMP_THR in Celsius.
22. **DMTC2M**: Temperature of 11771_SUIT_DET_MNT_TEMP_CPRT2-M in Celsius.
23. **DHTC2M**: Temperature of 11772_SUIT_DHA-HP_TEMP_CPRT2-M in Celsius.
24. **DCNTF2M**: Temperature of 11781_SUIT_DET_CF_NHP_TEMP_FPRT2-M in Celsius.
25. **OBNTTF**: Temperature of 11783_SUIT_OB_NEAR_TF_TEMP_FTS in Celsius.
26. **OBNSTF**: Temperature of 11793_SUIT_OB_NEAR_SHTR_TEMP_FTS in Celsius.
27. **DCNTC2M**: Temperature of 11834_SUIT_DET_CF_NHP_TEMP_CPRT2-M in Celsius.
28. **DMTF2M**: Temperature of 11840_SUIT_DET_MNT_TEMP_FPRT2-M in Celsius.
29. **DHTF2M**: Temperature of 11844_SUIT_DHA-HP_TEMP_FPRT2-M in Celsius.
30. **DBTFM**: Temperature of 11851_SUIT_DHA-BCVR_TEMP_FTS-M in Celsius.
31. **OBNM2TF**: Temperature of 11855_SUIT_OB_NEAR_M2_TEMP_FTS in Celsius.
32. **OBNDTF**: Temperature of 11856_SUIT_OB_NEAR_DHA_TEMP_FTS in Celsius.
33. **SHUMTTM**: Temperature of 11878_SUIT_SHUTER_MOT_TEMP_TCPL-M in Celsius.
34. **RESTRPOS**: Start position of 4230_SUIT_RESOLVER_START_POS in degrees.
35. **RESTPPOS**: Stop position of 4231_SUIT_RESOLVER_STOP_POS in degrees.
36. **HKFW2POS**: Filter wheel 2 position.
37. **HKFW1POS**: Filter wheel 1 position.
38. **SEQNUM**: Sequence number from program sequence.
39. **CYCNUM**: Cycle number from program sequence.
40. **SECMDID**: 4383_SUIT_SUCCESS_EXE_CMD_ID. This is the command execution status.
41. **HKROIID**: 4384_SUIT_ROI_ID. Same as ROI ID
42. **FW2CURS**: 4568_SUIT_FW2_MTR_CURR_SINE.
43. **FW2CURC**: 4569_SUIT_FW2_MTR_CURR_COSINE.
44. **FW1CURS**: 4572_SUIT_FW1_MTR_CURR_SINE
45. **FW1CURC**: 4573_SUIT_FW1_MTR_CURR_COSINE
46. **FW1DCDC**: 4574_SUIT_FW1_DCDC_15V_MON
47. **DM1TEMP**: 4566_SUIT_DHA_MOUNT1_TEMP

48. **DBTTR**: 11718_SUIT_DHA-BCVR_TEMP_THR-R
49. **ACQENA**: 912_SUIT_ACQ_ENA.
50. **FRMSIZE**: 4372_SUIT_FRAME_SIZE. Frame size
51. **COMPINC**: 911_SUIT_COMP_INC
52. **HLACQEN**: 910_SUIT_HELIOS_ACQ_ENA. Flag for hel1os acquisition enabled or disabled.
53. **FFEXTTO**: 4367_SUIT_FIND_FLARE_EXT_TIMEOUT. Flag for external flare enabled or disabled.
54. **FFSELFTO**: 4366_SUIT_FIND_FLARE_SELF_TIMEOUT. Flag for self-flare triggered enabled or disabled.
55. **AUXACQ**: 913_SUIT_AUX_ACQ_ENA.
56. **CVSTWSTS**: 2471_SUIT_COVER_STOWED_STS. SUIT Door stowed status.
57. **CVDEPSTS**: 2470_SUIT_COVER_DEPLOY_STS. SUIT Door deployed status
58. **BDMOMHX**: 158_BODY_MOMENTUM_HX.
59. **BDMOMHY**: 159_BODY_MOMENTUM_HY
60. **BDMOMHZ**: 160_BODY_MOMENTUM_HZ
61. **ONM1TFTS**: 11846_SUIT_OB_NEAR_M1_TEMP_FTS
62. **HL1OSFLG**: 4362_SUIT_HEL1OS_FLARE_FLAG.
63. **FW2MSTS**: 4232_SUIT_FW-2_MOTOR_STS
64. **PRMFLG**: 4363_SUIT_PROMINANCE_FLARE_FLAG
65. **PLSTS**: 4382_SUIT_P/L_STS
66. **PGEXFLG**: 4381_SUIT_PROG_EXE_FLAG
67. **CCDSTS**: 4380_SUIT_CCD_STS
68. **BINSTS**: 4373_SUIT_BINNING_STS
69. **SX2FLG**: 4360_SUIT_SOLEXS-2_FLARE_FLAG
70. **FW1MSTS**: 4342_SUIT_FW-1_MOTOR_STS
71. **PPMSTS**: 4561_SUIT_PINPULLER_M_STS
72. **SMONSTS**: 4562_SUIT_SHUTTER_MTR_ON_STS
73. **PPRSTS**: 4559_SUIT_PINPULLER_R_STS
74. **NRMFLG**: 4364_SUIT_NORMAL_FLARE_FLAG
75. **PPMARM**: 4560_SUIT_PINPULLER_M_ARM_STS
76. **ENCONS**: 4564_SUIT_ENCODER_ON_STS
77. **SX1FLG**: 4361_SUIT_SOLEXS-1_FLARE_FLAG
78. **PPRARM**: 4558_SUIT_PINPULLER_R_ARM_STS
79. **PZOONS**: 4563_SUIT_PIEZO_MTR_ON_STS.