ADITYA-L1 MISSION

VELC

VELC USER MANUAL

INDIAN INSTITUTE OF ASTROPHYSICS

BANGALORE

Technical Content Approvals

VELC User Manual

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CHANGE HISTORY

Version number	Date	Affected Section, Figure, Table	Nature of Change [A,M,D] *	Description
1.0	26th July, 2024	All	A	Document was generated.
2.0	29th July, 2024	2.2.2	D	Level1 XML file description is deleted (suggested by ISSDC team)
3.0	28th Oct, 2024	2.2.1	M	FITS header updated
4.0	06th Nov, 2024	2.4	A	Section on calibration data is added
5.0	12th Nov, 2024	2.4,2.7	M	Updated calibration data file name and reference list.
6.0	19th Nov, 2024	2.5, 2.6, 2.7	A, M	Section on Level-2, Data analysis are added and updated the reference list.
7.0	19th Dec, 2024		A, M	Filter profile data description is added. L1, L2 FITS filenames are modified and FITS header structure is modified.

* A – Addition, D – Deletion, M-Modification

Contents

1. INTRODUCTION

1.1 Spectroscopy-1 (5303 Å):

Spectroscopic observations of the solar corona with VELC is carried out in the emission line centred at 5303Å [Fe XIV]. This is also called the 'green' line. The pass band (Full Width at Half Maximum) of this spectroscopic channel is ~7Å. The field of view (FoV) covers the solar corona in the heliocentric distance range 1.05 - 1.5 solar radii (i.e. a height range of ~0.05 – 0.5 solar radii above the solar limb whose heliocentric distance is 1 solar radii). The radius of the occulting disk in the VELC is 1.05 solar radii. The pixel resolution for observations in the 5303 Å channel of VELC is 1.25 arcsec. Spectral dispersion is ~28mÅ.

VELC is designed for multi-slit spectrographic observations. The total FoV of 3 solar radii is covered by simultaneous observations using four slits. Each slit is of width 50um and height 15mm. The slits are spaced apart horizontally by 3.75mm. A Linear Scan Mechanism (LSM) consisting of two mirrors (FM-1 & FM-2) located in between the Imaging lens assembly (ILA-2) and slit plane (see Figure 1) is used to scan the FoV across the slits. Linear scan direction is perpendicular to the surface of FM1 & FM2. Mirror FM3 directs the scanned beam towards the slits of the spectrograph. To cover the entire FoV, total scan length of ±(3.75/2)mm is required for the scanning mechanism (see Figure 2). The minimum step interval in the scanning mechanism is 20um or 0.02mm (um is used for μm). This corresponds to ~0.008 solar radii or ~7.7 arcsec in the image plane since a movement of 1um by the LSM translates to 2um lateral shift of the FoV across the slits.

The center of four slits are at -1.125, -0.375, +0.375, & +1.125 solar radii w.r.t the occulter center. Each slit can observe a heliocentric distance range of 0.375 solar radii on either side of the above mentioned positions. This way the four slits together cover the total FoV from -1.5 to +1.5 solar radii in the horizontal direction (i.e. the wavelength or the spectral direction). The 15mm height of each slit covers similar heliocentric distance range from -1.5 to +1.5 solar radii in the vertical direction (i.e. the spatial or the slit direction).

Spectroscopic observations can be carried out in either Sit and stare (SS) mode or Raster scan (RS) mode. Observations could be carried out in frame binning or snapshot mode, either with or without spatial binning. A wide range of exposure times are possible. The length of each slit is along the north-south direction of Sun, and width (dispersion) is along the east-west direction of Sun. One of the user inputs for the SS mode is related to the LSM so that the coronal location to be observed is positioned on the slit. The input can be either positive or negative depending on whether the coronal location to be observed is to the right or left of the slit positions mentioned in the previous paragraph. In RS mode, the LSM is moved in steps at chosen time interval to obtain image of the corona by combining data obtained with the four slits.

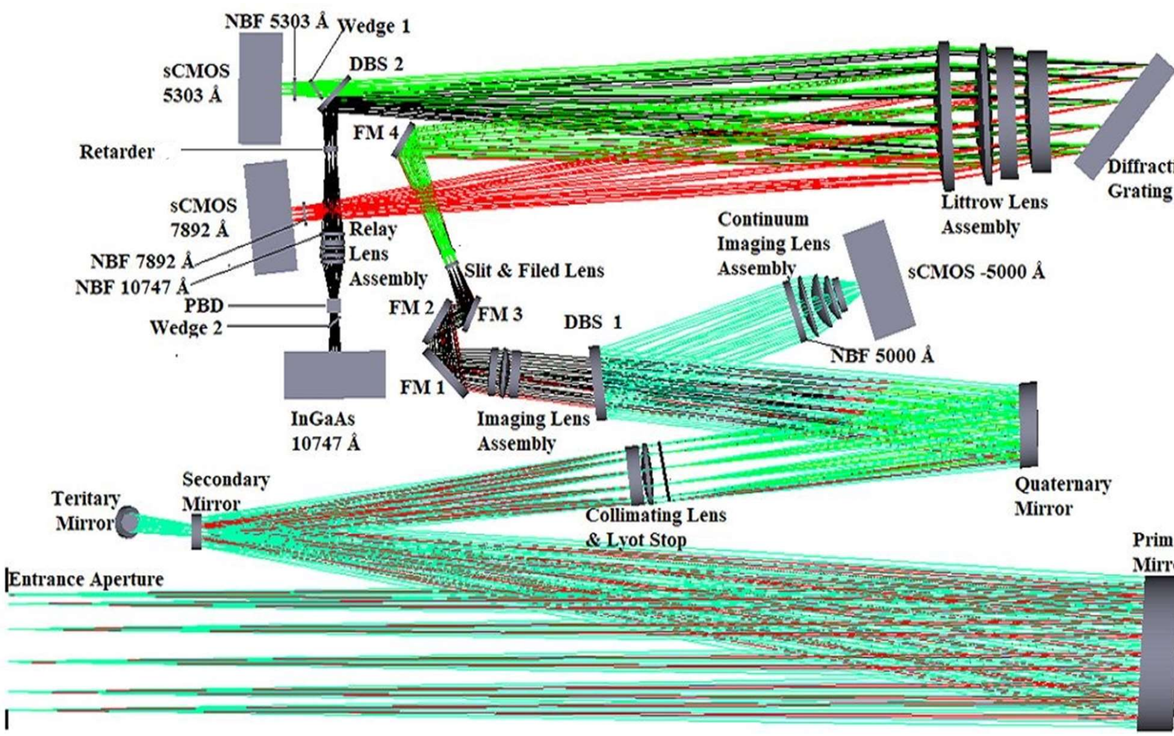

Figure 1: Optical layout of VELC.

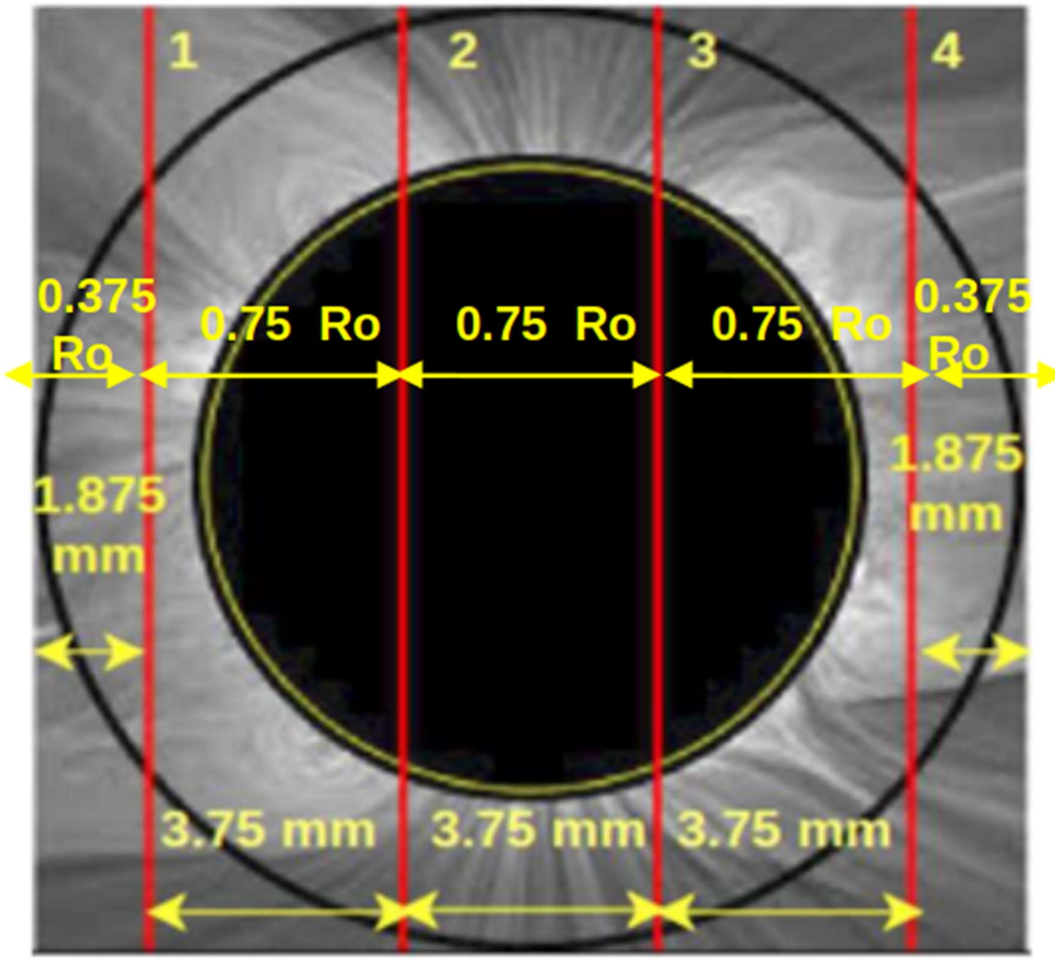

Figure 2: Slit positions in VELC multi-slit spectroscopy.

2. DATA PRODUCTS:

2.1 LEVEL-0:

The observed data are compressed onboard using RICE compression algorithm. Hence, after downloading the data at ISSDC, data decompression is carried out to begin with. The necessary header information are then incorporated. Subsequently the data (Level-0) are sent to the VELC-POC as dump files in .tar format. These would be in binary format. In addition to the Level-0 data, other files like orbit and attitude of the spacecraft (i.e. SPICE kernel), TCT, HK files are also sent to the VELC-POC.

2.2 LEVEL-1 DATA:

At VELC-POC, a python-based automated software extracts the data from each dump in gz.tar format, separates the files based on the filenames, and converts the raw binary data into FITS format. All the processed files will be in FITS format and updated with the necessary header information. The following are the steps involved in Level-1 data generation:

1. Reading binary image file.
2. Reading binary header.
3. Sequencing the images.
4. For each image, the observational details like mode, gain etc., will be identified from the corresponding binary header.
5. Separation of low gain and high gain data.
6. Merging top and bottom ports of each gain.
7. Removing inactive pixels.
8. Extracting the orbit attitude information (Roll, Pitch and Yaw angle).
9. Identification of bit error in each data set and patch up with zeros.
10. Image flipping to correct for the optical alignment.
11. Saving in FITS format with the required header.

These Level-1 data products will be uploaded to ISSDC-ISRO for dissemination.

2.2.1. FITS header keywords:

The description of FITS header is shown in the below:

```
SIMPLE      =                    T / conforms to FITS standard
BITPIX      =                   16 / array data type
NAXIS       =                    2 / number of array dimensions
NAXIS1      =                 2160
NAXIS2      =                 1280
OBSERVAT    = 'Aditya-L1'          / Name of the Observatory
INSTRUME    = 'VELC    '           / Visible Emission Line Coronagraph
CHANNEL     = 'Spectroscopy- 1'
DETECTOR    = 'VS1     '
WAVELENG    = '530.3 nm'
FOV         = '1.05Ro to 1.5Ro'    / Field of view
PIXELSIZ    = '6.5 microns/pixel'
PLATESCL    = '1.25 arcsec/pixel'
SP-DISP     = '28.4 mA/pixel'      / Spectral dispersion per pixel
SLIT_WID    = '50 microns'
CALIBTYP    = 'Science-data'       / Calibration data/Science data
DOOR        = 'Open    '           / VELC entrance Door Open/close status
CAMERA      = 'sCMOS   '
GAIN        = '1X10X   '           / Lowgain = 1x/2x, Highgain = 10x/30x
GAINCONV    = '15e/DN (1X); 8.3e/DN (2X); 1.75e/DN (10X); 0.5e/DN (30X)'
TEMP        = '-5 DegC '           / Detector temperature
PROPID      = 'T24_1083'           / Proposal ID
OBSID       = 'T24_1083_000814'    / Observation ID
DATE-OBS    = '2024-08-16T02:15:30.121435000' / Time in UT
DATE        = '2024-08-17T04:01:34.000000311' / Date of file generation
MODENAME    = 'Sit-stare'          / Mode of operation of the detector
SNAPSHOT    = 'Yes     '           / 1st frame is saved out of NFRAMES
ROI         = 'Full-Frame'         / Region of Interest Full-Frame/Window mode
FRAMEBIN    = 'NO      '           / NFRAMES are binned
NFRAMES     =                   10 / Number of frames
```

```
EXPTIME     = '5.0388  '      / Exposure time in sec
READTIME    = '72.29   '      / Read out time in msec, Time gap between two exp
FRA_TIME    =          5.11109 / Frame time in sec = Exposure time + Read time
CADENCE     =          51.1109 / cadence in seconds
ALT_FRA     = 'No      '      / Alternate LG and HG data
SPA_BIN     = 'YES     '      / Spatial Binning
XBIN        = 'No-binning'    / Binning in x direction in pixels
YBIN        = '2x1 binning'   / Binning in y direction in pixels
CDELT1      = '28.4    '      / Spectral dispersion
CDELT2      = '2.5     '      / Pixel resolution
CUNIT1      = 'milli-angstrom'
CUNIT2      = 'arcsec  '
SC_YAW      =  634.59 / YAW value of spacecraft to know drift of satell
SC_PITCH    =  601.25 / PITCH value of spacecraft to know drift of sate
SC_ROLL     = 202.99 / ROLL value of spacecraft to know drift of satel
SC_UNIT     = 'arcsec  '      / Unit in which yaw pitch and roll is given
HOTPIX      = '[60:70,1106:1117]'
DEADPIX     = 'NIL     '
MR_TOP_L    = '[]      '      / Missing row in low gain top port
MR_TOP_H    = '[]      '      / Missing row in high gain top port
MR_BOT_L    = '[]      '      / Missing row in low gain bottom port
MR_BOT_H    = '[]      '      / Missing row in high gain bottom port
ROIX1_TP=        0 / Starting Window location X1 of top port
ROIX2_TP=     1095 / Starting Window location Y1 of top port
ROIY1_TP=        0 / Starting Window location X2 of top port
ROIY2_TP=     2591 / Starting Window location Y2 of top port
ROIX1_BT=        0 / Starting Window location X1 of bottom port
ROIX2_BT=     1095 / Starting Window location Y1 of bottom port
ROIY1_BT=        0 / Starting Window location X2 of bottom port
ROIY2_BT=     2591 / Starting Window location Y2 of bottom port
SLIT_POS=    162.0 / Slit position in um
SLT1_POS=   1023.2 / Slit1 position in arcsec (Sun East)
SLT4_POS=   1109.3 / Slit4 position in arcsec (Sun West)
```

RETARDER = 'NO ' / Retarder status for Spectropolarimetry mode
LEVEL = 'L1 ' / Data processing level

Note:

- In the above header "SLIT_POS" should be 160um since the input provided for the observation was 160um. But the LSM is at 162um for the observation, as per the encoder reading. This indicates that LSM movement has an uncertainty of +/- 2um. For the conversion of slit position to arcsec, the occulter size of 1024 arcsec inferred from the observations is used. As mentioned in Section 1.1, movement of LSM by 1um will move the image across the slits by 2um. This corresponds to 0.384 arcsec in the image plane. For conversion to solar radii, the slit position in arc sec should be divided by the size of the Sun in arcsec on the particular day of observation. Since the slits are straight, the slit position given in arcsec corresponds to only the center of the slit. It will progressively increase along the slit length, above and below the center of the slit. Note that the slit position provided in the FITS header is estimated without considering the satellite drift.
- In Raster scan mode of observation, LSM movement from -940um to +940um covers a heliocentric distance of -/+ 1.5 solar radii. At the start of the observation, the LSM will move from its "home" position to the desired start position, e.g. -940um. Few spectra will be recorded, during this movement time also. The user may discard these spectra and consider only those spectra corresponding to the LSM positions in the range –940um to +940um (mentioned in the header for each frame) for further analysis. Likewise, the extra spectra recorded after the LSM reaches +940um also can be discarded.
- It is found that for Sit-Stare mode of observations at the occulter edge on Sun east and Sun west, the LSM is to be positioned at +160um (Slit 1) and -60um (Slit 4). For observations of coronal locations away from the occulter edge on Sun east and Sun west, the LSM position should be < +160um and > -60um, respectively.

2.2.2. Level-1 data filename structure:

VS1_T24_1083_000814_20240816_020009_LG_lev1_V2_1.fits

Description:

PLD – Spectroscopy-1 (VS1)

ObsId – Observation ID (T24_1083_000814)

YYYY – Year (2004)

MM – Month (08)

DD – Day (16)

HH – Hour (02)

MM – Minute (00)

SS – second (09)

gain – Gain information (LG, HG, or AG(Alternate gain))

lev1 – Level 1 data

V2_1 – Version number of the data generation.

2.3 Dark Current:

Figure 3 show the Spectroscopy-1 detector (CMOS) dark current variation with exposure time. The data points in black color symbols represent the in-orbit dark current observations on 9th Feb 2024. The red colour symbols correspond to the in-orbit dark current observations on 20th June 2024. Each data point with its associated error bar represents the mean dark current count in the detector. There is very minimal in the dark current with respect to exposure time. Further dark current counts obtained during the different epochs (Feb 2024 and June 2024) at different exposure times are also nearly the same.

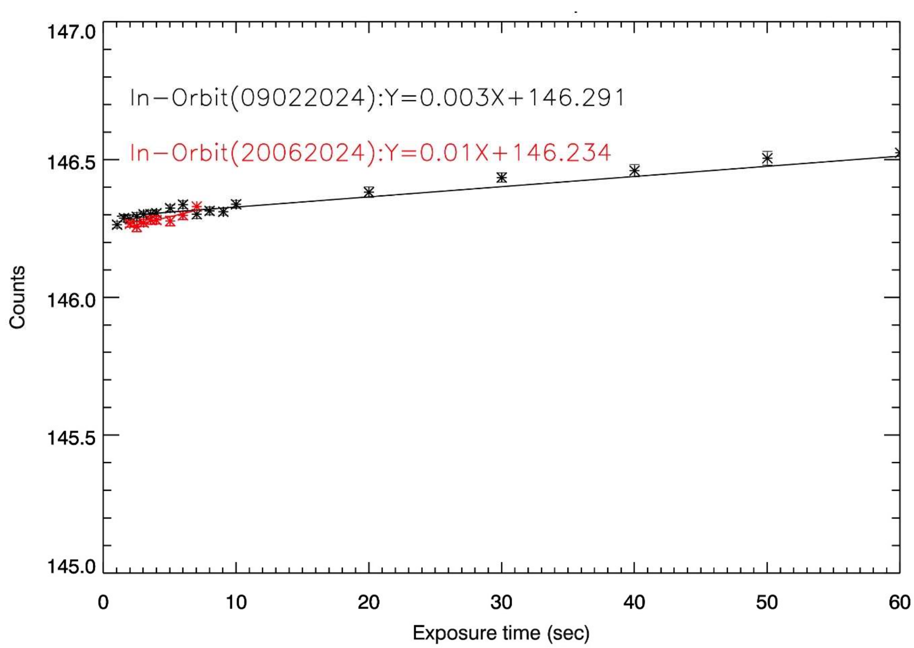

Figure 3: Spectroscopy-1 detector (CMOS) dark current variation with exposure time.

2.4 Calibration database:

The files required for Spectroscopy-1 data calibration are the dark current data, flat-field data and filter profile data. These files are called as "Calibration database". They are available as FITS files of size 2160 * 2560. Dark current data and filter profile data were observed in-orbit. The flat-field data was observed on ground, at the detector level.

2.4.1 Dark and Flat-field data:

The dark current does not vary with exposure time (see Figure 3). These dark current data are observed in-orbit and will be repeated every three months. Hence, every three months, the dark current data will be updated. Note that exposure times in the range 3sec to 5sec is found to be optimal for the Spectrosopy-1 observations. So, dark current data corresponding to exposure time of 4sec is provided for the user. The flat-field data, generated on ground, is also provided to the user. It is for the detector alone. There is no provision to take flat-field data in-orbit with an uniform light source. So, the ground flat-field data is used for calibration. The flat-field data was generated as mentioned below:

1. Detector is illuminated with an uniform light source, and several images are obtained.
2. Average light image is generated (I_L).
3. Several dark images (frames) are observed.
4. Average dark image is generated (I_D)
5. Subtracted the average dark image from average light image ($I_L – I_D$).
6. Using the above, flat-field data [$(I_L – I_D)$/mean $(I_L – I_D)$] is generated.

The dark current and flat data is provided for each gain, i.e. 1X, 2X, 10X and 30X. The user can use the necessary data for analysis.

The filename structure for the dark current data and flat-field data is as follows:

Dark and Flat-field data filename:

- VS1_DARK_01X_20240209.fits
- VS1_FLAT_01X.fits

Description:

VS1 - Indicates the Spectroscopy channel-1.

DARK, FLAT – Represents the Dark current and flat-field data.

01X – Indicates the gain. The gain can be 01X, 02X, 10X, and 30X.

20240209 – YYYYMMDD, Date of dark observation

2.4.2 Filter profile data:

On 1st April 2024, VELC closed door observations were carried out in 16 arc min off-pointing position on the east, west, north and south w.r.t the center of the Sun. Light from ~15 arcmin portion of the Sun disk was incident on Slit-1 (Sun east), Slit-2&3 (Sun north and south) and Slit-4 (Sun west). This observation provided Sun disk spectra using which filter profiles at different locations were generated.

Filter Profile data filename:

- VS1_FILTER_S1_02X_20240401.fits
- VS1_FILTER_S2_02X_20240401.fits
- VS1_FILTER_S3_02X_20240401.fits
- VS1_FILTER_S4_02X_20240401.fits

Description:

VS1 - Indicates Spectroscopy channel-1

Filter – Indicates Filter profile data

S1 – Corresponds to Sun east (Slit 1)

S4 – Corresponds to Sun west (Slit 4)

S2 – Corresponds to the Sun north of Slits 2 & 3

S3 – Corresponds to the Sun south of Slits 2 & 3

02X – Indicates the gain (01X, 02X, 10X, and 30X)

20240401 – YYYYMMDD, Date of observation

2.4.3 Wavelength reference:

Figure 4 shows the emission spectra profile at the center of the slit obtained from Sun-pointing observations in open door condition on 16th August 2024. The absorption lines at wavelengths 5300.7Å, 5302.3Å, and 5307.3Å (shown in red colour) were identified using the solar atlas. The emission line (5302.3Å) is shown in purple colour. Equating the difference between 5300.7Å and 5302.3Å to pixel separation between them, the spectral dispersion was estimated as ~28.4mÅ. Using the pixel value corresponding to the prominent absorption line at 5302.3Å as reference and the above mentioned spectral dispersion, the wavelengths corresponding to the pixel values in the x-axis could be inferred.

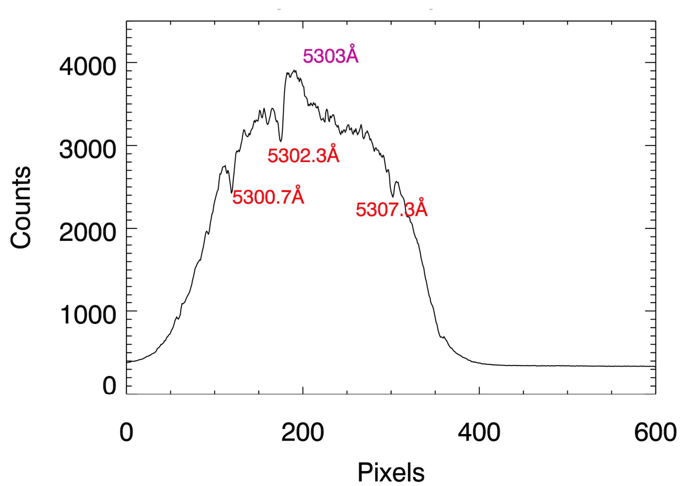

Figure 4: Emission at 5303Å along with the identified absorption lines.

2.5 Level-2 Data:

At VELC-POC, a python-based automated software generates the Level-2 data from the corresponding Level-1 data. All the processed files will be in FITS format with updated header, if any. The following are the steps involved in Level-2 data generation:

1. Reading Level-1 data.
2. Reading Leve1-1 data headers.
3. Extracting the exposure time, gain and spatial binning information from the header.
4. Fetching the dark data corresponding to the exposure time, gain from the calibration database.
5. Fetching the flat data for the corresponding gain from the calibration database.
6. Making dark and flat data array size to be the same as the Level-1 data according to the spatial binning/Frame binning.
7. Subtracting the corresponding dark from the Level-1 data (L_d).
8. Dividing the corresponding flat from L_d , which is the Level-2 data.
9. Updating the FITS header.
10. Saving in FITS format header. Header structure will be similar to the Level-1 header.

These Level-2 data products will be uploaded to ISSDC-ISRO for dissemination. Users can work with the Level-1 data also. But, they have to correct for dark and flat with their own software. The dark and flat data are provided in the calibration database for each gain. Since the dark current variation is very minimal with exposure time, dark data corresponding to the exposure time of 4 sec is provided. Note that optimal exposure times for the spectroscopy-1 observations with VELC are found to be in the range 3 sec to 5 sec.

2.5.1 Level-2 data filename structure:

VS1_T24_1083_000814_20240816_020009_LG_lev2_V2_1.fits

Description:

PLD – Spectroscopy-1 (VS1)

ObsId – Observation ID (T24_1083_000814)

YYYY – Year (2004)

MM – Month (08)

DD – Day (16)

HH – Hour (02)

MM – Minute (00)

SS – second (09)

gain – Gain information (LG, HG, or AG(Alternate gain))

lev2 – Level 2 data

V2_1 – Version number of the data generation.

2.6 Spectral plots:

The spectral plots and profiles for Spectroscopy-1 data can be generated using either SSWIDL or PYTHON. Some of the commands in IDL to read the data, correct for dark, flat, and to plot the spectra are shown here.

IDL>data=readfits (“VS112N18P1AL100142010115242300359556 76_T24_1083_00 0814_00_0002_LG_lev1.fits”, hdr)

- data - the spectra of array size 2160x2560 (this will vary according to the spatial binning option)
- hdr – Header.
- print,hdr will display the corresponding header.

IDL> plot_image, data

refer upper left panel of figure 4.

IDL> plot, data [*,520]

refer upper right panel of figure 4. Shows the row profile for slit1 and slit4

IDL> plot, data [0:600,520]

refer lower left panel of figure 4. Shows the row profile for slit1 alone.

IDL> plot, reverse (data [0:600,520])

refer lower right panel of figure 4.

Before proceeding further, the spectra should be reversed if the wavelengths corresponding to the emission and absorption features are to be present in the increasing order. Slit1, slit2, slit3 and slit4 should be reversed separately, and then merged (see Figure 5). Note that reversing the spectra should be done after correcting for the dark and flat.

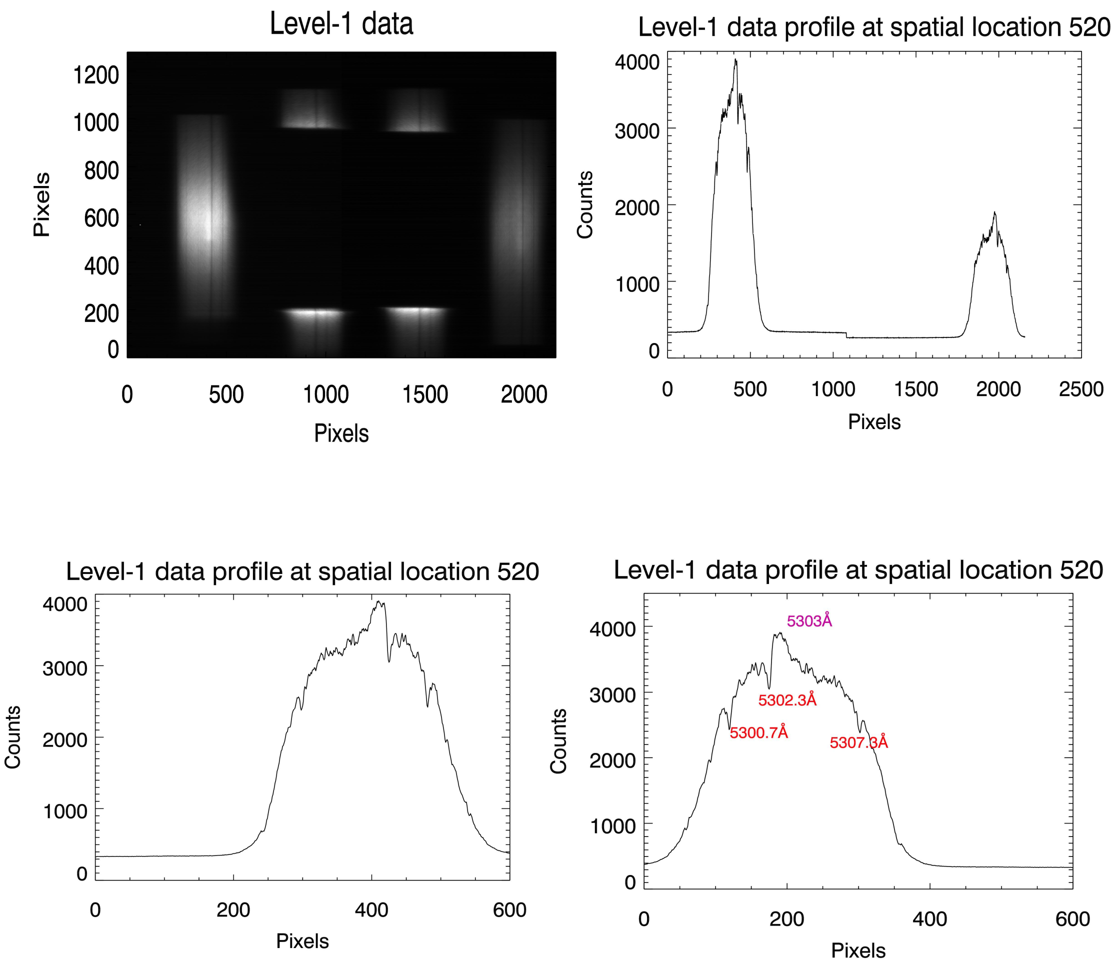

Figure 5: The upper left panel shows the spectra observed with all the four slits in the Sit-stare mode on 16th August 2024. Slit length is along the vertical direction and dispersion is along the horizontal direction. Solar north is straight up and Solar East is to the left. Slits 1 & 4 are at the extreme left and right, respectively. The upper right panel shows the spectral profile (row profile at pixel location 520 along the slit length). The lower left panel shows the profile for Slit-1; the lower right panel shows the same after reversing with identified absorption and emission lines.

For dark and flat correction, the following steps can be followed:

First, check for the array size of dark, flat with that of the emission spectra. If it not matching, make the array size of dark and flat equal to that of the emission spectra.

IDL> sz=size(data)

IDL> dark = readfits('VS1_DARK_1X_20240209.fits')

IDL> flat=readfits('VS1_FLAT_1X.fits')

IDL> dark_resize = frebin(dark,sz[1],sz[2], /total). Here, the keyword total represents that the resizing the array by adding the pixels.

IDL> flat_resize = frebin(flat,sz[1],sz[2])

IDL> data_cor = (data – dark_resize) / flat_resize

The above steps are to generate the dark, flat corrected data from the Level-1 data. If user analyzes the spectra from the Level-2 data, then the above steps can be skipped.

2.7 References:

1). "Optical design of visible emission line coronagraph on Indian space solar mission Aditya-L1", Experimental Astronomy, Volume 45, Issue 2, pp.219-229 (2018). [journal:https://doi.org/10.1007/s10686-017-9569-7]

2). "Exploring the outer emission corona spectroscopically by using Visible Emission Line Coronagraph (VELC) on board ADITYA-L1 mission", Advances in Space Research, Volume 64, Issue 7, p. 1455-1464 (2019). [journal:https://doi.org/10.1016/j.asr.2019.07.007]

3). "Ground calibration of visible emission line coronagraph on board Aditya-L1 mission", Journal of Astronomical Telescopes, Instruments, and Systems, Volume 9, id. 044001 (2023). [journal: https://doi.org/10.1117/1.JATIS.9.4.044001]

4). "Calibration of VELC detectors on-board Aditya-L1 mission", Experimental Astronomy, Volume 57, Issue 2, article id.7 (2024).[journal: https://doi.org/10.1007/s10686-024-09922-2]

5). "Data processing of visible emission line coronagraph onboard ADITYA-L1", Advances in Space Research, Volume 74, Issue 1, pp. 547-560 (2024). [journal: https://doi.org/10.1016/j.asr.2024.03.058]

6). "Calibration of spectropolarimetry channel of visible emission line coronagraph onboard Aditya-L1", Experimental Astronomy, Volume 58, Issue 2, id.6 (2024). [journal: https://doi.org/10.1007/s10686-024-09954-8]

7). "New results on the onset of a coronal mass ejection from 5303Å emission line observations with VELC/ADITYA-L1", The Astrophysical Journal Letters, Volume 976, Issue 1, id. L6 (2024). [journal: https://doi.org/10.3847/2041-8213/ad8c45]