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METIS-VLC: purposed imaging data processing pipeline

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List of Acronyms

DPP	Data Processing Pipeline
METIS	Multi Element Telescope for Imaging and Spectroscopy
pB	polarization brightness
PSF	Point Spread Function
VLC	Visible Light Channel

Revision Log

Date	*Issue*	*Release*	*Released by*	*Comment*
2012.08.06	*0*	*0*	*G.Capobianco*	*First issue*
2012.08.16	0	1	G. Capobianco	First review
2012.09.13	0	2	G. Capobianco	OATo technical report format applied, reduced # of levels

Introduction

The data processing pipeline for the METIS Visible Light Channel (VLC) can be schematized as in Figure 1.

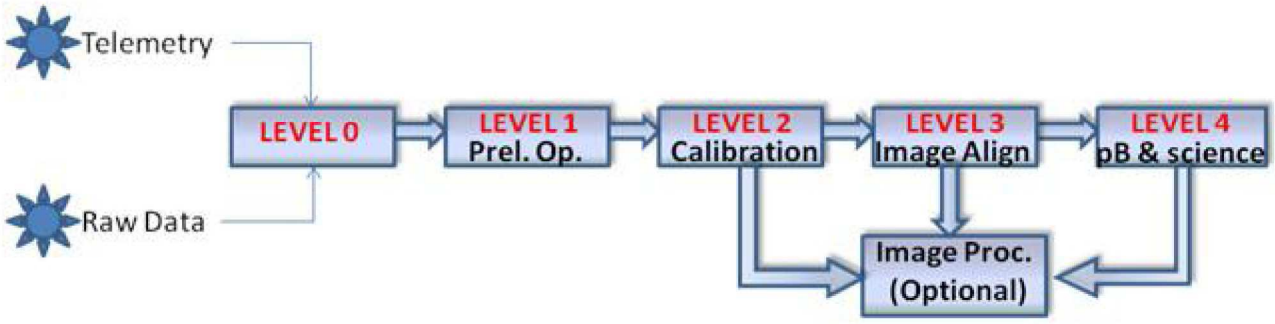

Figure 1 – METIS VLC: Data Processing Pipeline

The Level 0 data contains the telemetry and the raw data as sent from the spacecraft.

The Level 1 is referred for Preliminary Operations on the data (see Level 1 – Preliminary Operations);

The Level 2 is referred for the Calibration and at the end the data should be saved in a standard format (see Level 2 – Calibration);

The Level 3 is reserved for the alignment of the frames that have to be used for the evaluation of the pB (see Level 3 – Image Alignment) ;

The Level 4 is for the evaluation of the polarization (see Level 4 – Evaluation of the polarization) and for the preliminary scientific results (electron density);

The results of Level 2, Level3 and Level4 should be processed (see Image Processing (optional)).

1. Level 0 data

At this level, the data and the telemetry are as sent from the spacecraft.

2. Level 1 – Preliminary Operations

At this level, the data are decompressed (if applied), converted and saved in the standard FITS format, including in the header the most relevant telemetric informations.

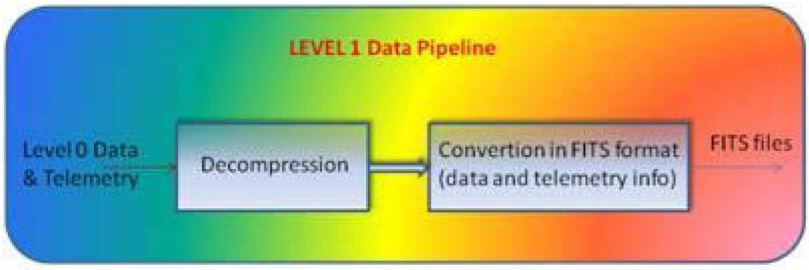

Figure 2 – Level 1 data pipeline

3. Level 2 – Calibration

The calibration level give out the calibrated Data File in standard FITS format.

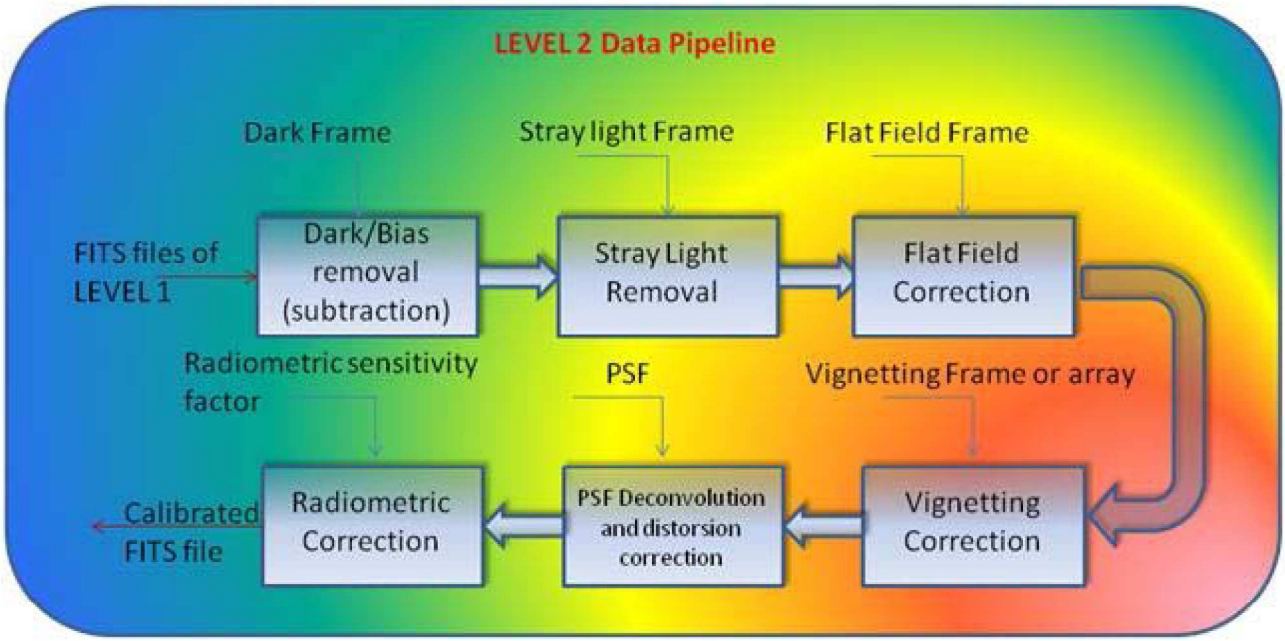

Figure 3 – Level 2 data pipeline

The operations are the followings:

- Bias/dark subtraction;
- Stray light Removal;
- Flat Field multiplication;
- Vignetting correction (multiplying by the inverse vignetting function);
- PSF deconvolution and distortion correction;
- Multiplication for the radiometric sensitivity (Radiometric correction).

The calibrated data must be saved. Is possible to re-apply the compression algorithm in order to reduce the required storage space. To the calibrated data files should be applied the imaging processing in order to show up structures, enhance contrast,...(see Image Processing (optional)).

4. Level 3 – Image Alignment

For the evaluation of the polarization, different images acquired at different retardance have to be combined (see Level 4 – Evaluation of the polarization). For that reason, the alignment is required. One of the follows algorithms should be used:

a. Fixed stars algorithm

This algorithm is the most used in astronomy. Choosing a star in the field-of-view of the instrument, eventually applying the proper motion of this star for different frames, is possible to use this star as reference and align all the frames to this star.

b. FFT-based algorithm

This algorithm is based on the Fourier Transform of the frames. Is fully described in [1]. It works with differences between images, requires to have a reference image.

c. 5-Parameters fit algorithm

This method is based on the assumption that the direction of the K-corona polarization is tangent to the solar limb. Is an iterative method, that requires a preliminary image alignment based on the center of the occulter, a raw estimation of the pB and after the fit operation, giving the sun centre [2,3].

5. Level 4 – Evaluation of the polarization and science

Using the Stokes formalism, the polarization state of the light beam can be expressed in the form $S = (I \quad Q \quad U \quad V)^T$ where T is the transpose operation, I the intensity, Q and U the linear polarization parameters and V the circular polarization element. The METIS polarimeter is sensitive only to the linear polarization, so that only I, Q, and U parameters must be taken into account.

The measured signal of the single exposure should be written as:

$$m_i = g(I + Q\cos\delta_i + U\sin\delta_i) + b$$

where g is the efficiency of the system (containing the transmission of the polarimeter and the quantum efficiency of the detector), I, Q and U as said are the Stokes parameters, ∂_i are the LCVR retardances and *b* is the detector bias and dark current. The linear combination of the 4 measurements acquired at the same exposure time but with different retardance are used in order to obtain the Stokes parameters I, Q and U. Using the matrix formalism we can write:

$$\begin{pmatrix} m_0 \\ m_1 \\ m_2 \\ m_3 \end{pmatrix} = g \begin{pmatrix} 1 & \cos\delta_0 & \sin\delta_0 & 0 \\ 1 & \cos\delta_1 & \sin\delta_1 & 0 \\ 1 & \cos\delta_2 & \sin\delta_2 & 0 \\ 1 & \cos\delta_3 & \sin\delta_3 & 0 \end{pmatrix} \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix}$$

In the *ideal* case:

$$\begin{cases} g = \frac{1}{2} \\ \delta_0 - \frac{3\pi}{2} \\ \delta_1 = \pi \\ \delta_2 = \frac{\pi}{2} \\ \delta_3 - 0 \end{cases} \rightarrow \begin{pmatrix} m_0 \\ m_1 \\ m_2 \\ m_3 \end{pmatrix} = \frac{1}{2} \begin{pmatrix} 1 & 0 & -1 \\ 1 & -1 & 0 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{pmatrix} \begin{pmatrix} I \\ Q \\ U \end{pmatrix} \equiv M = X \cdot S$$

Inverting the system:

$$S = X^+ \cdot M$$

Where:

$$X^{+} = \frac{1}{2}\begin{pmatrix} 1 & 1 & 1 & 1 \\ 0 & -2 & 0 & 2 \\ -2 & 0 & 2 & 0 \end{pmatrix} \equiv \begin{pmatrix} X_{00}^{+} & X_{01}^{+} & X_{02}^{+} & X_{03}^{+} \\ X_{10}^{+} & X_{11}^{+} & X_{12}^{+} & X_{13}^{+} \\ X_{20}^{+} & X_{21}^{+} & X_{22}^{+} & X_{23}^{+} \end{pmatrix}$$

is the *demodulation matrix* for 4 measurements.

The minimum number of measurements to retrieve the Stokes parameters for linear polarization is three. The demodulation matrix for 3 measurements is:

$$X^{+} = \frac{1}{6}\begin{pmatrix} 1 & 1 & 1 \\ -1 & -1 & 2 \\ -\sqrt{3} & \sqrt{3} & 0 \end{pmatrix} \equiv \begin{pmatrix} X_{00}^{+} & X_{01}^{+} & X_{02}^{+} \\ X_{10}^{+} & X_{11}^{+} & X_{12}^{+} \\ X_{20}^{+} & X_{21}^{+} & X_{22}^{+} \end{pmatrix}$$

Applying the equations described is possible to extract the S matrix, containing the I, Q and U values. This operation is a simple pixel by pixel linear combination of the 4 (3) images m_i:

$$\begin{cases} I = X_{00}^{+} \cdot m_0 + X_{01}^{+} \cdot m_1 + X_{02}^{+} \cdot m_2 + X_{03}^{+} \cdot m_3 \\ Q = X_{10}^{+} \cdot m_0 + X_{11}^{+} \cdot m_1 + X_{12}^{+} \cdot m_2 + X_{13}^{+} \cdot m_3 \\ U = X_{20}^{+} \cdot m_0 + X_{21}^{+} \cdot m_1 + X_{22}^{+} \cdot m_2 + X_{23}^{+} \cdot m_3 \end{cases} \text{ or } \begin{cases} I = X_{00}^{+} \cdot m_0 + X_{01}^{+} \cdot m_1 + X_{02}^{+} \cdot m_2 \\ Q = X_{10}^{+} \cdot m_0 + X_{11}^{+} \cdot m_1 + X_{12}^{+} \cdot m_2 \\ U = X_{20}^{+} \cdot m_0 + X_{21}^{+} \cdot m_1 + X_{22}^{+} \cdot m_2 \end{cases}$$

In particular cases, a background, I_b, must be removed from the derived intensity, $I=I_c+I_b$. The background might be a constant F corona model [5].

Once the background has been removed, it is possible to evaluate the polarization and the polarization brightness:

$$p = \frac{\sqrt{Q^2 + U^2}}{I_c} \; ; \quad pB = \sqrt{Q^2 + U^2}$$

and the direction of the polarization:

$$\theta = \frac{1}{2} atan\left(\frac{U}{Q}\right)$$

Images can be saved in the FITS standard format. At least the *pB* images have to be saved. From the *pB* is possible to evaluate the electron density and the effective temperature.

6. Image Processing (optional)

The Image processing include the follows steps:

- Filtering;
- Image Enhancement (smoothing, stretching,...).

This step is useful to show some coronal structures for increase the contrast,... Is possible to apply the image processing to Level2, Level3 and Level4 data.

7. File I/O

All the files from LEVEL 1 to LEVEL 4 have to be saved in the standard FITS format. A specific keyword in the header should indicate the data level.

References

[1] Druckmuller, Phase Correlation Method For The Alignment of Total Solar Eclipse Images, APJ-706 (2009)

[2] Balboni, Master Degree Thesis, Università degli Studi di Torino (2009)

[3]Elmore et al., Calibration procedure for the polarimetric instrument for solar eclipse-98, Proc. SPIE, 4139:370–377 (2000);

[4] Capobianco et al., Electro-optical polarimeters for ground-based and space-based observations of the solar K-corona, Proc. SPIE 8450 (2012)

[5] Koutchmy, S., and Lamy, P.L.: 1985, "The F-Corona and the Circum-Solar Dust Evidences and Properties", in Properties and Interactions of Interplanetary Dust, ed. Giese, R.H. and Lamy, P., New York: Reidel, pp. 63-74.