



EPIC Level 0 to Level 1A Processing Algorithm Description Document

Version 2

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**Goddard Space Flight Center
Greenbelt, Maryland**

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DOCUMENT CHANGE RECORD

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2	8 Dec 2025	A. Cede, R. Rajagopalan	Added change record Minor corrections in table 4 Updated figures 2, 4, 5, 6, 7, 8, 9 Updated dark correction section Updated latency correction section Updated flat field correction section

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1 INTRODUCTION

1.1 IDENTIFICATION

This document is version 2 of the Level 0 (L0) to Level 1A (L1A) Processing Algorithm Description Document for the DSCOV-R EPIC instrument science data products. Version 1 was delivered on 11 July 2016 [2]. It describes the conversion of raw EPIC data to corrected count rates (L1A). Products are archived at the Atmospheric Science Data Center (ASDC) in Hierarchical Data Format (HDF). Information about HDF and official documentation may be found at the HDF web site (<http://www.hdfgroup.org>).

1.2 L0 TO L1A PROCESSOR OVERVIEW

The Earth Polychromatic Imaging Camera (EPIC) instrument collects radiance data of the Earth and other sources through the Camera/Telescope Assembly. A complete description of the instrument can be found in the “EPIC Instrument Description Document” [1]. L0 data are processed using the L1A processing software (L1aP) resident on the NASA Center for Climate Simulation (NCCS) supercomputer.

The L1aP is written in Python. Corresponding instrument metadata files are also used as inputs in order to properly convert the images to L1A format.

The L1aP consists of two files, the L0_L1a.py which includes all functions necessary for the L1aP and also for the production of stray light correction arrays. L0_L1a_wrapper.py is a wrapper program that calls the L0_L1a.py routine. The purpose of the wrapper routine is to make sure all input parameters are correct and perform any error handling related to those inputs.

In general, the L1aP performs three steps. First, the wrapper imports the class ‘L1aP’ from L0_L1a.py. Second, the wrapper calls the ‘Get_CalData’ function which imports the EPIC calibration file, named EPIC_CalFile_vX.txt (X = version number). This ASCII file contains all of the information needed for the L1aP such as calibration parameter filenames and calibration parameter storage locations. These parameters are used as input into the ‘Make_L1a.py’ routine which assumes that the proper parameters were loaded and provided to it as input. In other words, it is the responsibility of the wrapper routine to load the proper EPIC calibration parameter files for the images being processed. Lastly, the wrapper calls the ‘Make_L1a’ function which returns the L1a image data and additional information obtained during the data processing. This additional information includes processing errors and warnings. This last step is performed for each L0 input image file. Table 1 summarizes the inputs accepted by the Make_L1a processing routine of L1aP.

Table 1 – Make_L1a input summary

Element	Description	Input Type
0	Filter number; integer; this is 0 for Dark, between 1 and 10 for single filters, and 11 for open-open; it can also be -1 in which case the filter number is defined by the first letter of the file name	Mandatory
1	(Commanded) exposure time [ms]; positive float	Mandatory
2	Shutter open time [ms]; positive float	Mandatory
3	Binning width; either 1 (unbinned) or 2 (2x2-binned); integer	Mandatory
4	CCUMode, either 3 or 4; integer	Mandatory
5	CCD-temperature [degC]; float	Mandatory
6	File names of dark images to be used for the dark correction; list of strings; this can be an empty list, in which case the dark count is determined by the calibration data.	Mandatory
01	Monotonically increasing list of processing steps to apply to the data. If no list is given, all processing steps will be performed.	Optional
02	Filename where the L1a data will be stored. If empty, no data will be stored.	Optional
03	List of settings for the stray light correction.	Optional

The output of the Make_L1a routine contains the corrected count rates for the input L0 image and a pixel-type array containing information for each processed image pixel. The L1a image is a float64 array with the same dimensions as the input image (e.g. 2048x2048 for unbinned images or 1024x1024 for 2x2 binned images). The pixel-type array is an unsigned, 8bit integer array of the same dimension as the L1a image (see section 2.1 for more details). An additional list of processing steps that were applied to the L0 data is output. It contains the same number of elements as the processing steps applied where each step contains a list of 4 elements describing the processing (see Table 2).

Table 2 – Make_L1a output processing list summary

List Element Number	Description
0	Processing step number
1	List of error-indices raised in the processing step
2	Time needed for this processing step
3	Additional information specific to this processing step

2 EPIC L0 TO L1A PROCESSING DESCRIPTION

In order to produce scientifically meaningful and accurate data, the L0 data are processed on the ground to Level 1a (L1a) data by applying a sequence of correction steps. These correction steps utilize parameters that are saved in the processing software input calibration file and have been determined from analyses of pre-launch EPIC measurements performed in the laboratory.

Table 3 summarizes the list of processing steps performed in the L1aP. It should be noted that not every step applies a correction to the reported pixel signal. Section 2.1 describes the pixel-type output array while the subsequent sections describe each processing step.

Table 3 – Processing steps of L1aP

Step	Processing step	Description
1	Read Image	Reads raw images
2	Basic image checks	Checks for flat image, saturation, etc
3	Load dark count correction	Calibration or measurement based
4	Enhanced pixel detection	Detects outliers from image reading
5	Read wave correction	Correction for read wave
6	Dark offset correction	Based on data in Step 3
7	Latency correction	Removes latent readout charge
8	Dark slope subtraction	Based on data in Step 3
9	Non-linearity correction	Non-linearity of read-out electronics
10	Temperature Sensitivity correction	Temperature sensitivity of system
11	Conversion to count rates	Normalize by exposure time
12	Flat fielding	Vignetting, PRNU, etaloning, & surface inhomogeneity
13	Stray light correction	Matrix method
14	Conversion to radiances	Not applied in L1a processor

2.1 PIXEL-TYPE ARRAY

The L1a processor also provides a classification related to each pixel's location on the EPIC focal plane, magnitude of flat field correction, enhancement, and saturation level. Not all pixels are illuminated by the EPIC telescope (see optical design description in [1]) nor are they all illuminated by Earth or the lunar disk due to the optical design of the system and angular extent of the source. The EPIC focal plane also contains serial overclocked columns, or "oversampled pixels", prior to and after readout of the main active area of the focal plane [1]. Pixels of these types are classified by a unique identifier value located in a "pixel-type" array located in the L1a output data.

The pixel-type array (figure 1) is an unsigned, 8-bit array that has the same size (2048x2048, unbinned or 1024x1024, binned) as the observation image size taken by EPIC. Table 4

summarizes the pixel-type array values related to a pixel's focal plane location classification, correction size, and signal level warning.

Pixels that require additional information related to the size of correction or magnitude of measured signal have their pixel-type array values modified by a discrete value pertaining to the type and level.

Figure 1: Pixel-type classifications array

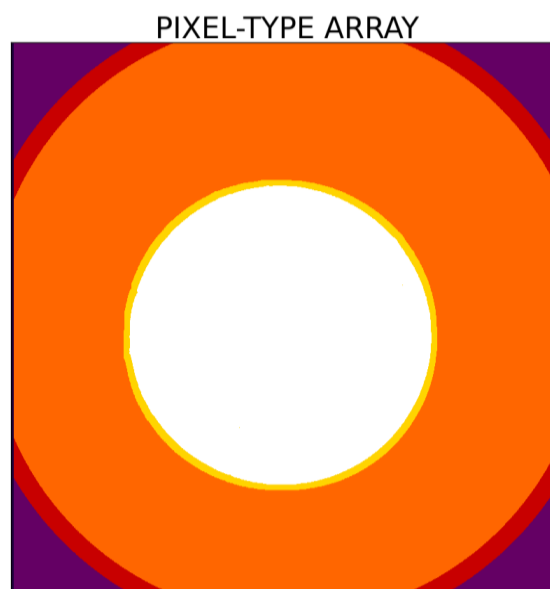


Table 4 – Pixel-type array value descriptions

Pixel-Type	Pixel-Type value	Description
Regular Pixels	0	Inside FOV and illuminated by source (white in Figure 1)
	1	Inside FOV and surrounding the illuminated source region. Signal level likely influenced by source. (yellow in Figure 1)
	2	Inside FOV, not directly illuminated by source and signal level unlikely influenced by source. (orange in Figure 1)
	3	Inside FOV, not directly illuminated by source. Transition region to pixels outside FOV. (red in Figure 1)
	4	Outside FOV with no direct illumination by source. (violet in Figure 1)
Oversampled Pixels	10	Fast (Type1) oversampled pixel not in an edge column (dark blue in Figure 1)
	11	Slow (Type2) oversampled pixel
	12	Double oversampled pixel
	13	Edge column pixel of the fast oversampled pixels
Edge Pixels	20	Edge column pixel
	21	2 nd edge column pixel
	22	Edge row pixel
Correction and Signal Level	+25	Extreme flat field correction (>50%)
	+50	Moderately (type1) enhanced pixel
	+100	Strongly (type2) enhanced pixel
	+150	Saturated

	+200	“Bad” pixel
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2.2 READ IMAGE (STEP 1)

This step reads the image with the input file name. Three different file extensions/formats are accepted. These are:

- **epc**: this is the “Lockheed binary format”. The program reads the file header (with metadata such as the CCU mode and the exposure time) and the raw image.
- **j***: This is a compressed JPG file. The program calls the JPG Decompression function ‘JPG_Decompress_C’, and then reads the raw image from the binary file made by ‘JPG_Decompress_C’.
- **b***: This is the raw image in a binary file without a header, which is read by the program.

For .epc-data, it shifts the row and columns to go from the EPIC readout arrangement (i.e. the pixels in the order they were read) to the physical arrangement (i.e. the pixels in the order as they are on the CCD). In the other cases the images are already in the physical arrangement.

2.3 BASIC IMAGE CHECKS (STEP 2)

This step determines whether the image is “flat”, meaning that all image pixels have the same value. It also determines which, if any, pixels are saturated and updates the pixel-type array accordingly.

2.4 LOAD DARK COUNT CORRECTION (STEP 3)

This step returns the best estimation for the dark current present during the conditions of the image. In the case no dark images are given (i.e. element 5 of the metadata is empty), the dark current DC_i at each pixel i is estimated from equation 1:

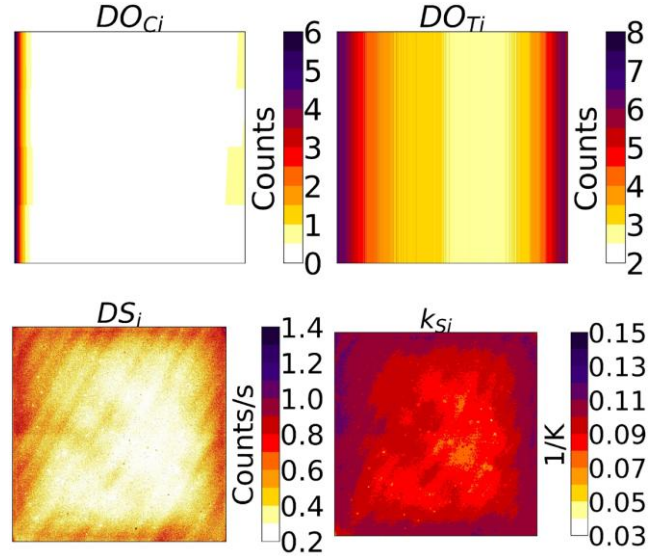
$$(1) \quad DC_i(t_{EXP}, T_{CCD}, t_{IM}) = DO_{OV}(T_{CCD}) + DO_{Ci} + DO_{Ti} \cdot \exp[k_0 \cdot (T_{CCD} - T_{REF})] + DS_i \cdot \exp[k_{Si} \cdot (T_{CCD} - T_{REF})] \cdot t_{EXP} + DO_T(t_{IM})$$

t_{EXP} is the exposure time, T_{CCD} the CCD temperature, T_{REF} the reference temperature ($=-20.8^\circ\text{C}$) and t_{IM} is the time since 1 Jan 2017 0:00 UTC. The DO-terms represent the dark offset and are independent of t_{EXP} . The dark slope DS depends linearly on t_{EXP} . DO_{OV} is the average dark count over the oversampled pixels (see table 4). It is mostly a function of T_{CCD} , but also depends on the electronic state of the detector system at the measurement time. This term does not need to be taken from the calibration, since it can be calculated for each operational measurement. All 2048 x 2048 arrays DO_{Ci} , DO_{Ti} , DS_i and k_{Si} from equation 1 are shown in figure 2. The values are for CCU mode 3. k_0 is 0.166/K.

The “trend term” DO_T in equation 1 was not included in the initial dark model. It was added in 2017 when we discovered some pattern of the true dark count drifting away from the dark model. DO_T is a combination of a linear trend of 0.5 counts/year and a seasonal temperature cycle of ± 0.3 counts.

Also in this step 3, a rough estimation of the target extension is made and the pixel type array is updated accordingly.

Figure 2: EPIC dark map parameters

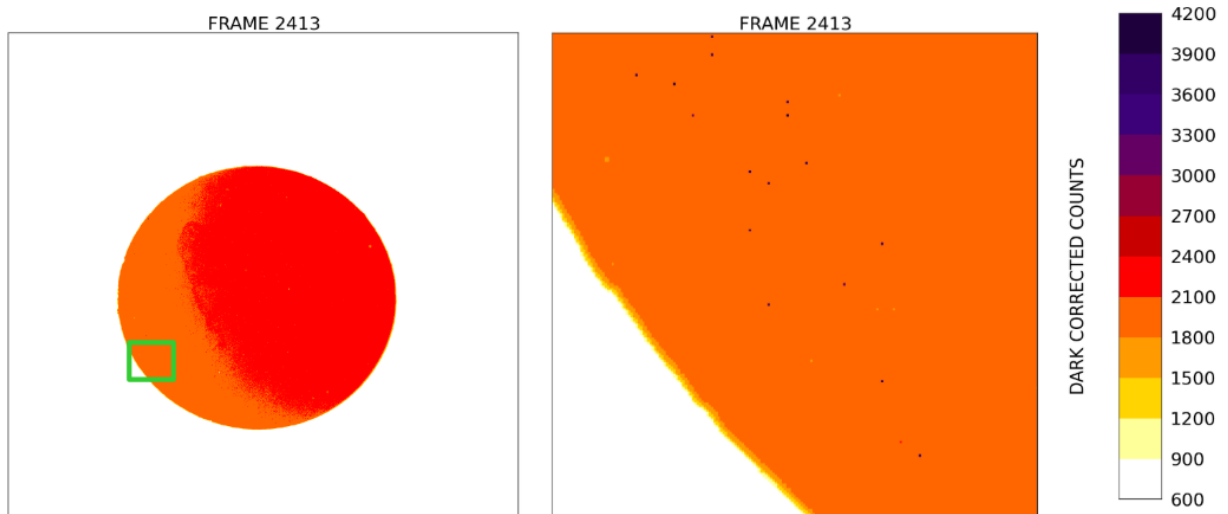


2.5 ENHANCED PIXEL DETECTION

(STEP 4)

This step tries to detect enhanced pixels in the data and flags them in the pixel type array. Enhanced pixels are pixels with values significantly above the values of the neighbor pixels, which cannot be caused by the input. It is suspected they are either an effect of the readout electronics or ‘temporary’ hot pixels. In the example shown in figure 3 below, the violet pixels have values of about 3200 counts, while the surrounding pixels have only about 2000 counts.

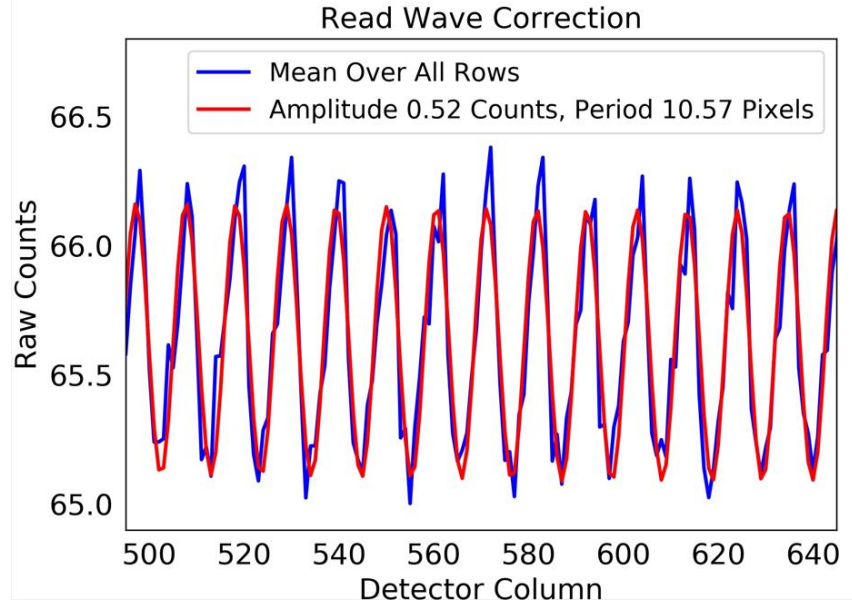
Figure 3: EPIC enhanced pixel detection



2.6 READ WAVE CORRECTION (STEP 5)

This step removes the “read wave” caused by the EPIC readout electronics. The read wave has a period of about 11 pixels and an amplitude between 0 and 0.6 counts (see figure 3).

Figure 4 – Example read wave correction



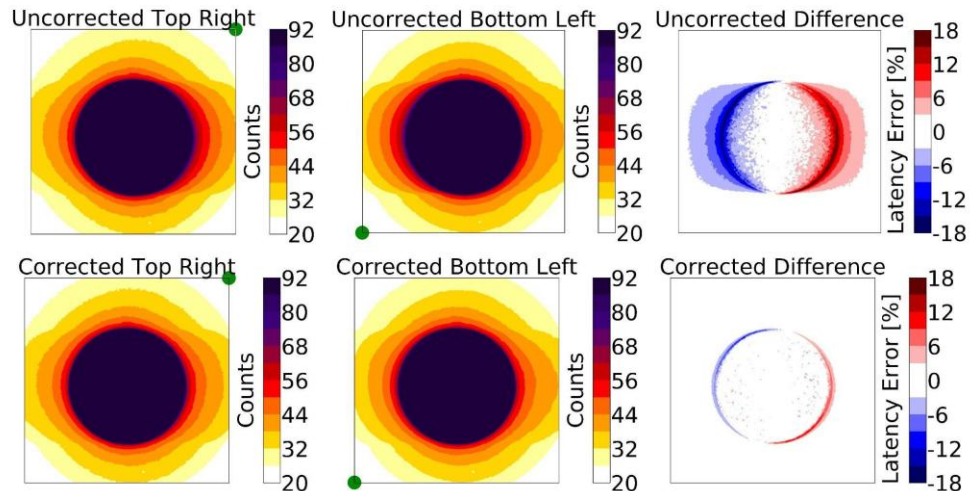
2.7 OFFSET CORRECTION (STEP 6)

The offset correction is performed using the dark offset determined during Step 3.

2.8 LATENCY CORRECTION (STEP 7)

The latency of the EPIC readout electronics adds an offset to each reading, which depends on the ‘strength’ of the previous readings. So pixels with low values are significantly biased high when they are read after a number of pixels with high values. This causes e.g. CCU mode 3 (reading the image through the top right corner) and 4 (reading the image through the bottom left corner) give different results for the same target (figure 5 - top panels). This correction step reduces the differences significantly (figure 4 - bottom panels).

Figure 5: Example latency correction



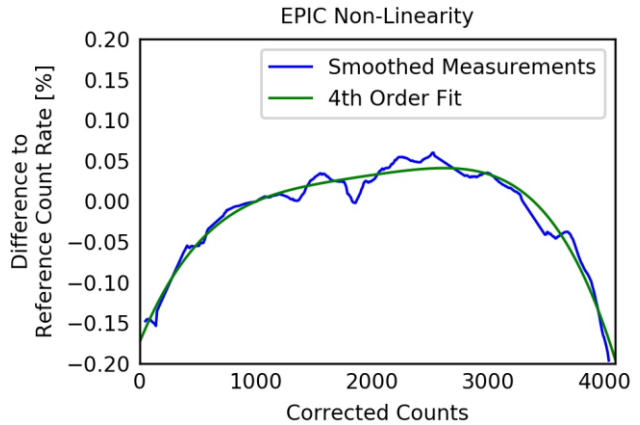
2.9 DARK SLOPE CORRECTION (STEP 8)

The dark slope correction is applied on a per pixel basis using the dark slope determined during Step 3, Loading Dark Current Correction.

2.10 NON-LINEARITY CORRECTION (STEP 9)

EPIC slightly underestimates the measurements at very low (<500) and very high (>3500) counts (see figure 6). This step applies a correction to each pixel based on its signal level.

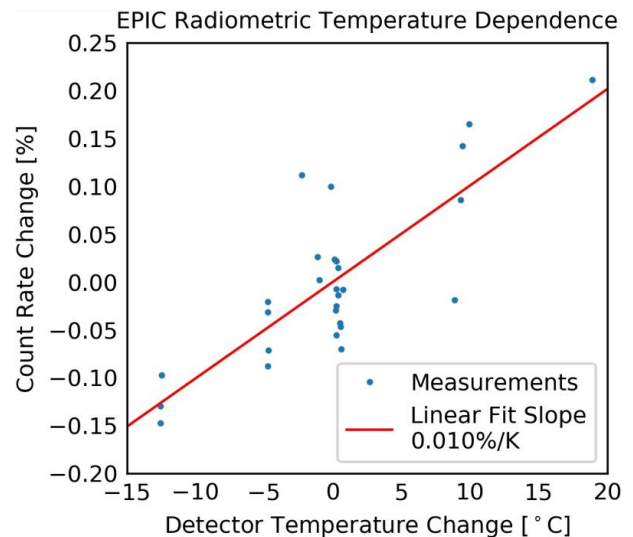
Figure 6: EPIC electronics non-linearity error and correction



2.11 TEMPERATURE SENSITIVITY CORRECTION (STEP 10)

EPIC's radiometric sensitivity increases slightly with temperature (0.01% per K, see figure). This effect has been characterized pre-launch and is shown in figure 7.

Figure 7: EPIC temperature sensitivity



2.12 INTEGRATION TIME NORMALIZATION (STEP 11)

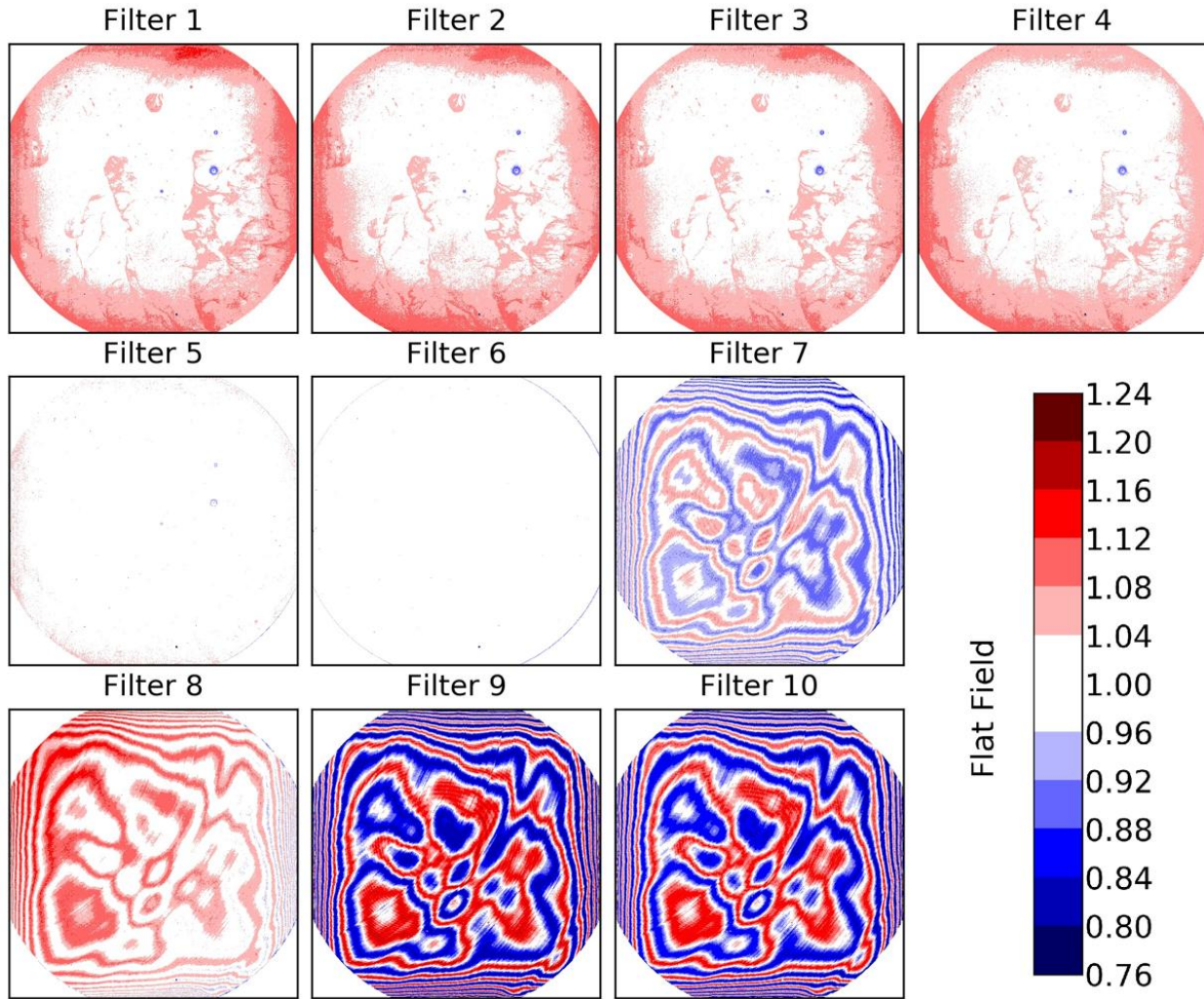
Image data are normalized by the exposure time (in seconds), converting the units of the data from 'counts' to 'count rates' [counts per second].

2.13 FLAT FIELD CORRECTION (STEP 12)

EPIC CCD introduces instrument artifacts in the reported image data due to vignetting, pixel response non-uniformity, etaloning, and surface inhomogeneity. These effects are classified as flat fielding errors and corrected by dividing the image by the filter-specific flat field correction

matrix. Filter 6 (551nm) has the ‘best’ flat field. The UV filters 1 to 5 are dominated by the surface inhomogeneity, while filters 7 to 10 (above 600nm) are dominated by etaloning. The EPIC flat field maps are shown in figure 8.

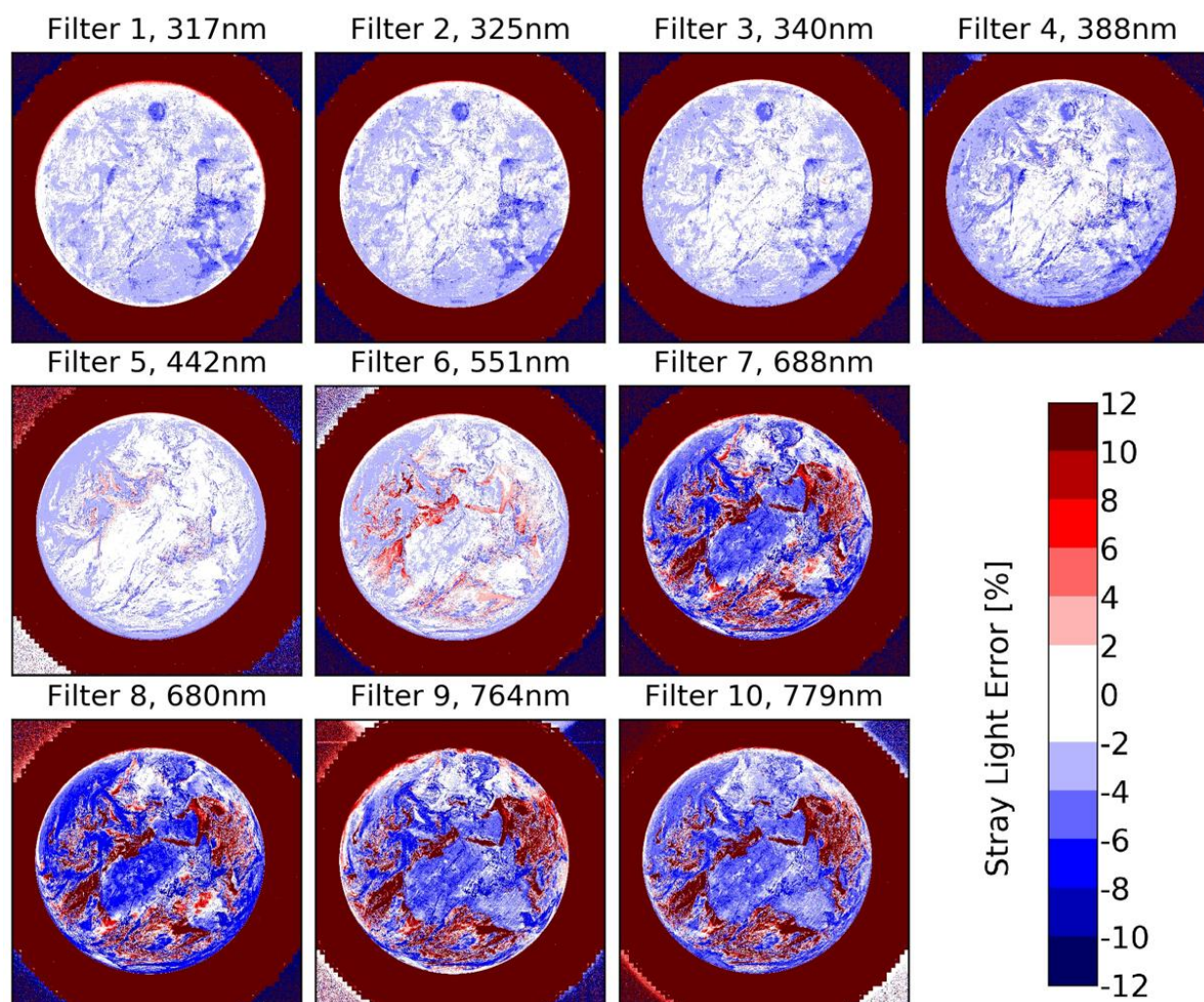
Figure 8: EPIC flat field maps



2.14 STRAY LIGHT CORRECTION (STEP 13)

EPIC's stray light causes the signal of a point source to spread around the whole CCD. To correct for this effect, a stray light correction matrix is applied to the image. This matrix is stored in several files. Note that before this correction is done, bad, oversampled, and saturated pixels are replaced with average values over the surrounding pixels.

The images in figure 9 show the stray light error in percent for a sample Earth image for filters 1 to 10.

Figure 9 – EPIC stray light error

2.15 CONVERSION TO RADIANCES (STEP 14)

In this step the absolute calibration factors for each filter are applied, which convert the corrected count rates [count per second] to radiances [$\text{mW}/\text{m}^2/\text{nm}/\text{sr}$].

Since we expected this conversion to possibly change “faster” over time than all the other calibration corrections listed above, it was decided to not apply this conversion in the L1aP. Instead this step is expected to be performed by the L2 teams. Consequently the final L1a data are still in units of counts per second.

3 SUMMARY

The L1aP applies the necessary corrections to the L0 data in order to calculate corrected count rates while the geolocation calculations occur independent of this software. Conversions in order to calculate radiances are to be applied outside of this software as accurate sensitivities must be determined based on in-flight data. All processing steps related to the conversion have been described as well as the required and optional inputs into the processing software.

4 REFERENCES

1. EPIC Instrument Description Document, Tobin, J. and J. Mobilia, October 2001.
2. DSCOVN EPIC L1a Processor Description Version 1, Kowalewski, M. and A. Cede, July 2016.

5 ABBREVIATIONS AND ACRONYMS

[illegible]