ASTERIA Data Users Guide (v2)

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1 Overview

This document describes the formatting and idiosyncrasies of ASTERIA photometric data. ASTERIA is the Arcsecond Space Telescope Enabling Research In Astrophysics.

2 Brief ASTERIA System Description

ASTERIA is a 6U (10 cm x 20 cm x 34 cm) CubeSat spacecraft. ASTERIA was launched August 2017 as payload to the International Space Station and deployed into orbit on November 20, 2017. ASTERIA's current orbit matches the ISS inclination and has an average altitude of approximately 400 km. In this orbit, ASTERIA experiences an average of 30 minutes in Earth's shadow (eclipse) and 60 minutes in sunlight.

ASTERIA is 3-axis stabilized via a set of reaction wheels. The reaction wheels are part of the XACT attitude control system provided by Blue Canyon Technology (BCT). Torque rods are used for reaction wheel desaturation.

ASTERIA carries a small refractive telescope (f/1.4, ∼85 mm). The telescope focuses light on a 2592 x 2192 pixel CMOS detector. The detector pixels are 6.5 microns, yielding a plate scale of ∼15 arcsec/pixel. The full field of view of the detector is ∼9 x 10 degrees. ASTERIA's camera is deliberately defocused in order to oversample the PSF.

3 Definitions

List of definitions for acronyms and other terms with specific meanings in the context of ASTERIA.

- **Epoch**: The spacecraft epoch refers to the bootcount of the spacecraft. An epoch begins when ASTERIA's flight computer reboots and sets time to January 1, 1970 (the zero point for Unix timestamps).
- **Uptime**: Spacecraft time is relative and is tracked in seconds from flight computer boot. The native timestamp for spacecraft data is therefore seconds from last boot. A time correlation procedure is used to reference uptime in a particular epoch to UTC time.
- **PCS**: Pointing Control System. The fine pointing closed loop control system composed of the detector and piezo stage.
- **ACS**: Attitude control system. This refers to the XACT unit from BCT. The ACS system is responsible for pointing the spacecraft at the sun or at a designated target. It is also referred to as the 'coarse pointing' system.
- **EPS**: Electrical power system. Composed of battery pack and power regulation/distribution circuit board.
- **FSW**: Flight software. ASTERIA launched with FSW version 7.1.1 and upgraded in flight to 7.1.3.

- **RLT**: Realtime Telemetry. RLT refers both to the set of housekeeping telemetry collected and stored onboard the spacecraft and the telemetry that is streamed to the ground station automatically during a communications pass.
- **Payload**: Baffle, telescope, detector, piezo stage, and readout electronics. The payload is thermally isolated for the rest of the spacecraft.
- **Pass**: A communications opportunity. ASTERIA passes last 9-10 minutes. Up to 7 pass opportunities are available every 24 hours, with 4-5 of those opportunities occuring at a sufficiently high altitude to be viable.
- **Observation**: An observation is a continuous data collection period. The maximum duration of an observation is set by the memory buffer size available for storing coadded images (24 minutes in FSW 7.1.3, 21 minutes in FSW 7.1.1). Typically there is one observation per orbit, though it is possible to conduct more than one observation per orbit under special circumstances.
- **Tech Demo**: Tech demo refers both to the primary purpose of the ASTERIA mission and to the name given to observations designed to address ASTERIA's technology demonstration requirements. Tech demo observations are abbreviated 'td'.
- **Science Observation**: Observations designed to address specific scientific goals. Science observations are abbreviated 'so'.
- **Experimental Observation**: Observations designed to test a new observation mode, new parameter set, etc. Experimental observations may be used for science if data quality is sufficient. Experimental observations are abbreviated 'ex'.
- **Sequence**: Set of commands uplinked to the spacecraft and run to perform observation.
- **Mssn parameters**: Parameter file that includes window locations, quaternion defining spacecraft attitude during observation, weighting parameters for PCS algorithm, etc.
- **Buffer**: Name for binary file containing image, housekeeping, PCS, or other telemetry from the spacecraft. File extension '.buf'.

4 Image Types

ASTERIA's payload can produce three types of images: full frame images, windowed images, and coadded images.

4.1 Full frame images

4.2 Windowed images

Windowed images are short integrations used primarily as input for the fine pointing PCS algorithm. Typical integration time is 50 msec, though shorter integration times are used for very bright stars (Vmag < 3). Many windowed images may be coadded to produce longer integrations. The 50 msec integration time allows the PCS algorithm to run at 20 Hz.

4.3 Coadded images

The majority of ASTERIA technology demonstration and science images are coadded. Coadded images are generated by summing many windowed images together onboard the spacecraft. The most common coadding period is 1 minute, though other settings are possible. All coadded data to date uses a 1 minute coadding period. A set of 1200 windowed images with integration times ≤ 50 ms are summed to make one 1-minute coadded image.

The native bit depth of windowed images is 11 bits. Coadded image data is saved as an array of unsigned 32-bit integers to avoid saturation.

5 Raw binary to FITS file

Raw binary files downlinked from the spacecraft are converted into FITS files via the following steps, illustrated in Figure 1

1. Binary files from one observation are concatenated into a single binary
2. Concatenated binary is converted into raw FITS files
3. Header values from binary are written to FITS header
4. Additional header data is calculated and/or extracted from realtime telemetry (housekeeping data, also downlinked from the spacecraft)
5. Information from the sequence that generated the observation and TLE added to the FITS header
6. Basic column correction is performed

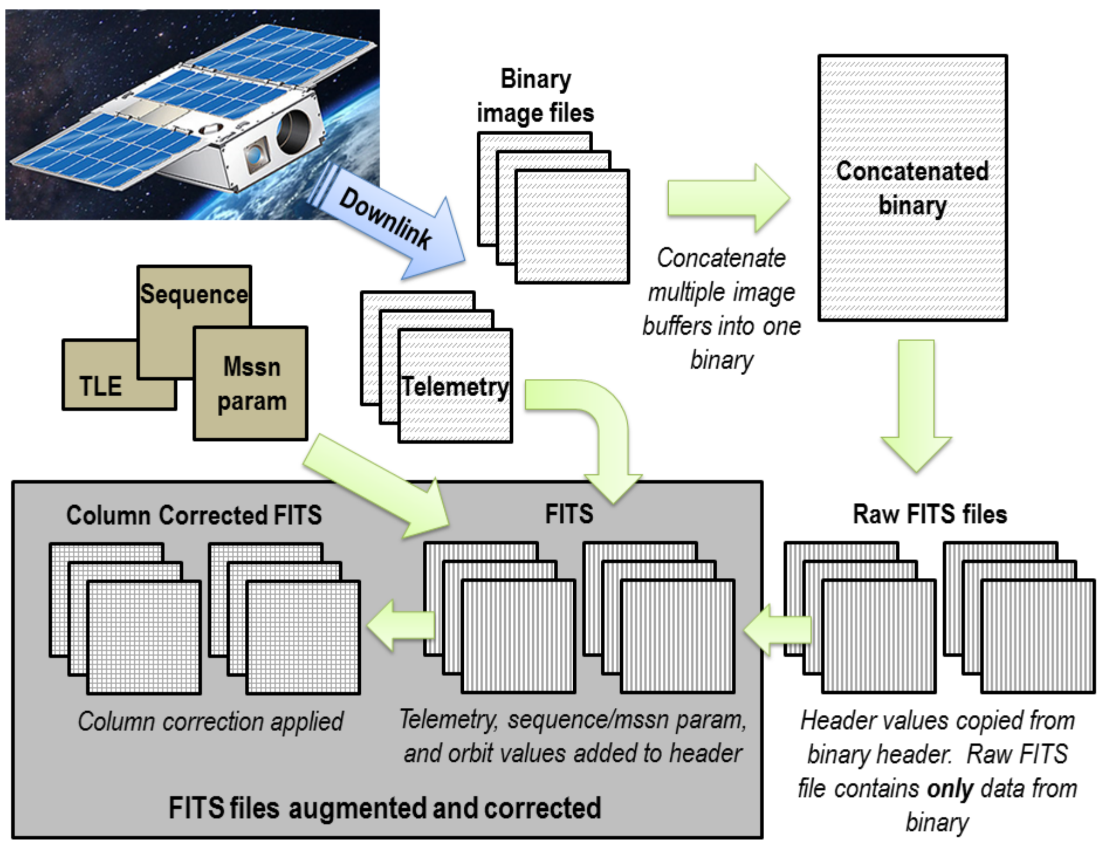


Figure 1: Binary-to-FITS processing pipeline.

5.1 Column correction

The CMOS detector is split into two halves — top and bottom. Each column in each half has its own amplifier. Offsets between the columns appear as a 'barcode' pattern on the detector. The top and bottom edges of the detector have 8 rows of optically dark (physically blocked from light) and electrically dark (tied to ground) pixels. See Figure 2 The electrically dark pixels can be used to correct for the offsets between column amplifiers. This correction must be done independently for the top and bottom sections

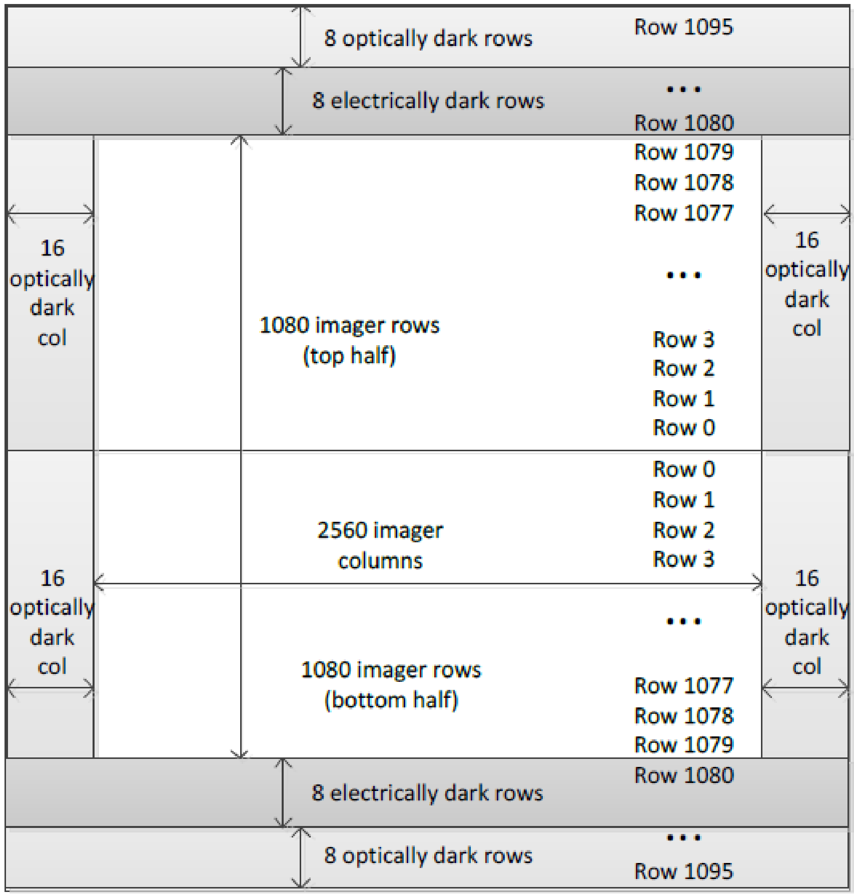


Figure 2: ASTERIA imager schematic. Optically/electrically dark rows/columns are shown along the edges of the detector (not to scale). Figure reproduced from detector vendor data sheet.

of the detector. Lab testing pre-flight demonstrated that the column offsets were stable across a range of temperatures.

Column correction is performed by taking a median of the 8 electrically dark pixels in each column and subtracting that median value from the entire column. See Figure 4a (before column correction) and Figure 4b (after column correction). For full frame images, all electrically dark pixels are present and the calibration can be applied directly from data contained within the image. Windowed/coadded data, however, does not necessarily have dark pixels corresponding to each window. The correction is therefore performed using values from a full frame image taken in flight.

5.2 Calibration windows

In some observations, windows are placed at the edge of the detector where there are several rows/columns of optically and/or electrically dark pixels. These calibration windows generally do not contain stars and are used to correct for column/row fixed pattern noise. In most cases, there are not enough spare windows to place a calibration window for every window with a star. Calibration windows are used for the science target only in most cases. The remaining widows are corrected as described above. See Figure 3 for an example of the calibration window (8) aligned on the same columns as the target window (1).

The eight electrically dark pixels in each column in calibration window(s) are median combined column-wise, yielding a single value for each column. The median-combined values for each column are then normalized by their median. Each column in the light window is then divided by the normalized value of the electrically dark pixels.

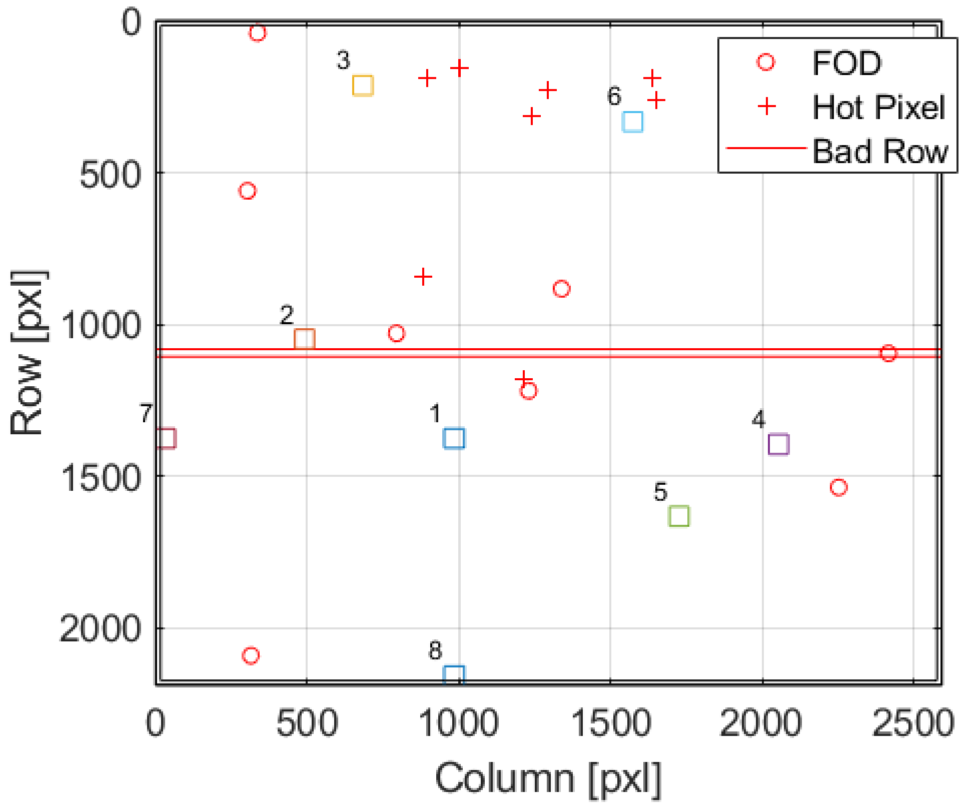
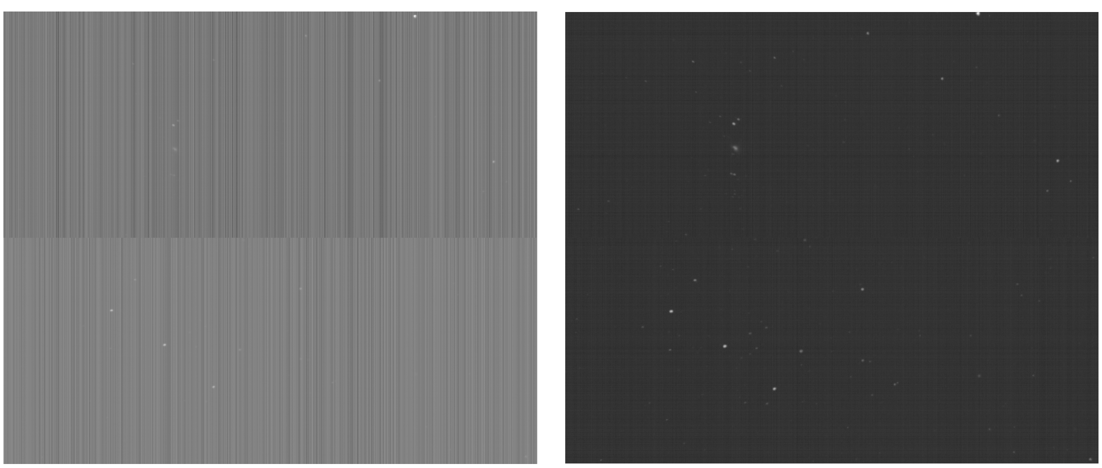


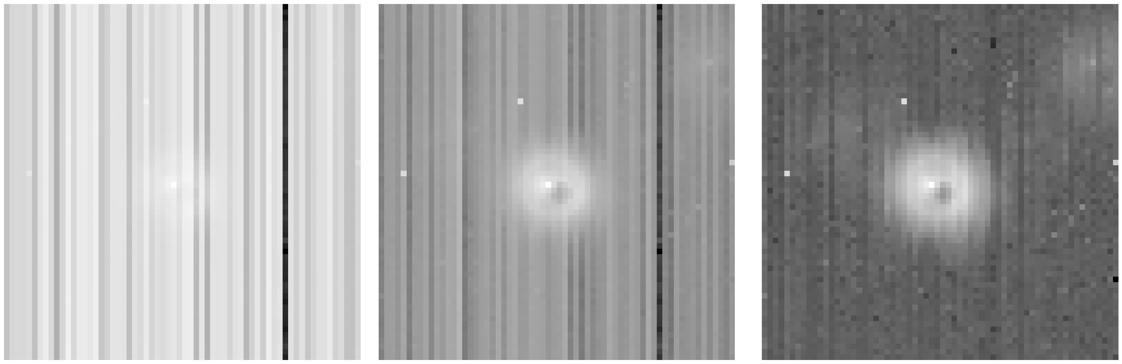
Figure 3: Schematic representation of window locations on the ASTERIA detector. Each 64x64 pixel window is noted by a colored square with a number at the upper left corner. Regions of the detector with known hot pixels or FOD are noted as red crosses and circles, respectively. The known bad rows at the center of the detector are also noted. In this example, window 8 is placed at the bottom edge of the detector to serve as a calibration window for window 1. Window 8 and window 1 sit on the same set of columns. Window 7 is placed on the left edge of the detector on the same set of rows as window 1.



(a) ASTERIA full frame image before column correction (log scale)

(b) ASTERIA full frame image after column correction (log scale)

Figure 4: Example full frame images pre- and post-column correction.



(a) Raw windowed image (_coadd.fits)
(b) Standard column correction (_colcorr.fits)
(c) Cal window corrected (_windivcorr_norm.fits)

Figure 5: Windowed images in raw form (left) and with two different column corrections applied (center, right). All images use a logarithmic colorscale.

Figure 5 provides an example of each level of correction (including a raw image, left).

6 Data Idiosyncrasies

ASTERIA, like most telescopes, has 'quirks'. Several known issues with ASTERIA data are described below.

6.1 Hot pixels

ASTERIA's CMOS detector has permanently 'hot' pixels as well as 'warm' pixels that are more sensitive to dark current than average. These 'warm' pixels can confuse the PCS centroiding algorithm, leading to pointing errors. Window locations are chosen with care to avoid known hot and warm pixels, though occasionally a parameter set will place a window on a previously unknown warm pixel. When this happens, the PCS algorithm misidentifies the warm pixel as a star and tries unsuccessfully to move the hot pixel to the center of the window. An algorithm update to address this issue is planned.

When ASTERIA passes through the South Atlantic Anomaly (SAA), radiation causes transient hot pixels that last for 1-2 windowed images. These transient hot pixels are sometimes misidentified by the PCS algorithm as star centroids. Since the radiation-induced hot pixels are transient, the PCS algorithm returns to the real star centroid quickly. Transient hot pixels may cause a small decrease in pointing precision.

6.2 Reaction wheel zero crossings

Reaction wheel speed zero crossings induce a transient pointing error. When possible, the reaction wheel speeds are biased to avoid crossing through zero RPM during observations. The transient caused by wheel speed zero crossings is observable in PCS pointing data. Zero crossings are sometimes unavoidable given the torque imposed on the spacecraft by its residual dipole moment. The effect of the residual dipole can be mitigated somewhat by rotating the field of view about the boresight until the magnetic torque is minimized, though the fixed locations of hot pixels and suitable guide stars complicate this optimization.

6.3 Fixed pattern noise

Column effects are very prominent and are only partially corrected by the simple column correction procedure described above. There are more subtle row offsets as well, as seen in Figure 4b. Fixed pattern noise due to column/row offsets is currently the largest systematic noise source in ASTERIA photometric data. Several calibration procedures are under study, including the use of calibration windows as described in Section 5.2.

6.4 Thermal transient

ASTERIA's thermal control system stabilizes the temperature of the focal plane to a precision of ± 10 milliKelvin around a user-specified setpoint. There is an initial thermal transient when starting a sequence of observations that takes 1-2 orbits to decay. The first 1-2 observations in a series may therefore display a trend related to thermal settling.

6.5 Observation success rate

ASTERIA's camera occasionally gets into a 'bad state' for reasons that are unclear (though EMI is suspected). The camera is power cycled and reinitialized before and after every observation to mitigate this known issue. Even with reinitialization, the camera fails to collect data for 10-20% of observations. In long observation sequences, the time sampling of the data is therefore not necessarily even. Some observations are missed, so the observation cadence is not always one observation per orbit. An upcoming flight software update will address this issue to improve observing efficiency.

7 FITS File Description

ASTERIA image data is translated from raw binary values to FITS images as described above. Each FITS file contains an image cube with dimensions 64 x 64 x 8. The third dimension of the image cube stores the 8 windows read out from the detector in windowed or coadded mode. All images in the cube are from the same integration and share the same timestamp. The detector coordinates of the windows can be found in the FITS header. Windows are ordered 0 to 7 along the third dimension of the image cube.

7.1 Naming conventions

The raw binary files downlinked from the spacecraft obey the following naming convention:

```
img_<FSW epoch>_<uptime seconds>_<uptime microsec>_<datetime downlinked>.buf
```

Example raw image buffers (td10):

```
img_24_441636_341329_2018_01_03_17_07_02.buf
img_24_441636_969648_2018_01_03_17_07_18.buf
img_24_441637_593661_2018_01_03_17_07_33.buf
```

The first file above was written in epoch 24 at uptime 441636.341329 and downlinked on 2018/01/03 17:07:02 UTC. The set of three files together comprise one observation (20x 1-minute coadded images in this case).

When a set of image files is concatenated together, the naming convention for the concatenated file is:

```
img_<FSW epoch>_<uptime seconds first file>_to_<uptime seconds last file>.buf
```

Example:

```
img_24_441636_to_441637.buf
```

The concatenated buffer name forms the base for the names of the FITS files generated from that binary. Raw FITS files (without column correction applied) are named as follows:

```
img_<FSW epoch>_<uptime seconds first file>_to_<uptime seconds last
file>_img<??>_coadd.fits
```

The `img<??>` denotes the image number in the observation. In this example, there are 20 images in the concatenated binary, so the image number runs from 00 to 19 (zero-indexed). Example:

```
img_24_441636_to_441637_img00_coadd.fits
```

After column correction is applied, `_colcorr` is appended after `_coadd`.

`img_24_441636_to_441637_img00_coadd_colcorr.fits`

Both 'raw' (un-column corrected) and corrected FITS files are available.

An alternative mode of column correction, described in Section 5.2, can be applied manually (i.e. it is not applied as a standard part of the FITS production pipeline). Images that have been corrected using the calibration windows taken contemporaneously with the light images are named as follows:

`img_24_441636_to_441637_img00_coadd_windivcorr_norm.fits`

The suffix '_windivcorr_norm' refers to the fact that the light window is corrected by dividing by a normalized version of the matching calibration window.

7.2 FITS Header Information

Each FITS file includes a header containing metadata. The keywords or 'cards' in the header are described in Table 1. The FITS header contains information on the setup of the ASTERIA camera, including the corner locations of each window in pixel coordinates, housekeeping telemetry collected during image capture, and timing information. The information added to the FITS header comes from three sources: values written into the binary header in the image file, realtime telemetry downlinked separately from the image data, sequences and parameter files for the pointing control system, and derived products using one or more of these sources (Figure 1).

7.2.1 Camera setup

The binary image header contains register-level information on how the camera was configured for the observation. The parameters `INTROWS` and `COADDNUM` define the fundamental integration time and number of images summed onboard the spacecraft, respectively. The value for `INTROWS` is in units of 'row time'. One 'row time' is approximately 22.6 microseconds, so the standard integration of 2210 row times is 50 msec. The total integration time for each image is the product of the `INTROWS` (translated to seconds) and `COADDNUM`, which is the number of subintegrations summed onboard. Standard values of `INTROWS`=2210 and `COADDNUM`=1200 yields a 1 minute integration time for each image.

The pointing mode is listed in the `ACS_MODE` keyword. The three possible modes are 'Fine Pointing', 'ACS+Feedback', and 'ACS Only'. In the ACS Only mode, only the reaction wheel system controls the pointing of the focal plane.

The header contains two time values for when each image was collected: `DATE-OBS` (UTC) and `BJD-OBS` (Barycentric Julian Date). BJD is calculated with knowledge of the spacecraft's position, which is derived from the TLE. The `DATE-OBS` is recorded at the time the subintegrations are coadded, so it represents the end of the integration period for each image. Approximate spacecraft latitude (`OBS_LAT`) and longitude (`OBS_LON`) at this time are also provided.

The pixel coordinates for the corner of each window are provided (see Table 1). Indexing for the detector is shown in Figures 2, 3. The HIP number and RA-DEC coordinates of the stars in each window are provided as well.

7.2.2 Realtime telemetry (RLT)

Spacecraft housekeeping telemetry, often called realtime telemetry, is collected and downlinked separate from the image data. This telemetry includes temperatures, voltages, currents, reaction wheel speeds, and mode/status indicators for various subsystems. The timestamp on the realtime data in the header is not exactly the same as the image timestamp, but is always within 5 seconds. The values are 'snapshots' collected near the image timestamp, not averages over the duration of the image integration. The description field for each card describes the telemetry point.

7.2.3 Pointing control telemetry (PCS)

Snapshot information from the pointing control algorithm is included in the image binary header (for images generated in FSW 7.2+). For each window, the pointing control algorithm reports the measured centroid location in detector X-Y coordinates in each window (relative to the 64x64 pixel window). Values of 100 indicate that the algorithm was not able to compute a valid centroid. The pointing control algorithm also reports the average background counts in each window and the value and location of the brightest pixel in each window. Values of 99 or 99.99 indicate invalid data. Windows that are not used by the pointing control algorithm, often because they are used for calibration, have 'invalid' values. The pointing error is also reported (`PNTERMNX`, `PNTERMNY`, `PNTERMXX`, `PNTERMXY`).

Table 1: ASTERIA FITS header definition

	Keyword	Example Value	Data type	Description
FITS file size parameters	SIMPLE	T	Boolean	Conforms to FITS Standard
	BITPIX	32	Int	Bits/pixel
	NAXIS	3	Int	Number of array dimensions
	NAXIS1	64	Int	Length of dimension 1
	NAXIS2	64	Int	Length of dimension 2
	NAXIS3	8	Int	Length of dimension 3
Telescope parameters	TELESCOP	'ASTERIA'	String	Telescope name
	FOCALLEN	83.93	Float	Focal length of telescope (mm)
	APTDIA	60	Float	Aperture diameter (mm)
Values from binary file header data	PRODVER	3	Int	Product version number
	FILETYPE	2	Int	File type (0 = Full frame, 1 = windowed, 2 = coadded)
	FPGAVER	33751051	Int	FPGA version number (will not change)
	FPGABLDT	706914946	Int	FPGA build date (will not change)
	FPGASTAT	983055	Int	FPGA diagnostic field
	FPGACLK	3875146238	Int	FPGA clock cycles since power-on
	FPGAUPTM	551764	Int	FPGA uptime since power-on (milliseconds)
	COADDIDX	1200	Int	Image index in coadded image set (0=no coadd)
	WINCOUNT	7199	Int	Number of windowed images produced since camera power-on
	FFCOUNT	2	Int	Number of full frame images produced since camera power-on
	NUXISTAT	0	Int	FPGA diagnostic field
	FPGACTRL	0	Int	FPGA diagnostic field
	FPGAMNCM	0	Int	FPGA diagnostic field
	PRSCNTST	1130	Int	Number of prescan rows in tes mode
	TSTINTTM	9999	Int	Integration time in test mode (microseconds)
	COADDNUM	1200	Int	Number of images coadded
	CREG5	0	Int	FPGA reserved
	CREG6	0	Int	FPGA reserved
	NUXICTRL	0	Int	FPGA diagnostic field
	NWINDOWS	8	Int	Number of windows
	NROWS	64	Int	Rows in each window
	NCOLS	64	Int	Columns in each window
	WIN0STRW	1346	Int	Pixel row index for corner of window 0
	WIN0STCL	952	Int	Pixel column index for corner of window 0
	WIN1STRW	1017	Int	Pixel row index for corner of window 1
	WIN1STCL	459	Int	Pixel column index for corner of window 1
	WIN2STRW	181	Int	Pixel row index for corner of window 2
	WIN2STCL	650	Int	Pixel column index for corner of window 2
	WIN3STRW	1365	Int	Pixel row index for corner of window 3
	WIN3STCL	2021	Int	Pixel column index for corner of window 3
	WIN4STRW	1602	Int	Pixel row index for corner of window 4

Table 1: ASTERIA FITS header definition

	Keyword	Example Value	Data type	Description
	WIN4STCL	1694	Int	Pixel column index for corner of window 4
	WIN5STRW	301	Int	Pixel row index for corner of window 5
	WIN5STCL	1541	Int	Pixel column index for corner of window 5
	WIN6STRW	1346	Int	Pixel row index for corner of window 6
	WIN6STCL	0	Int	Pixel column index for corner of window 6
	WIN7STRW	2128	Int	Pixel row index for corner of window 7
	WIN7STCL	952	Int	Pixel column index for corner of window 7
Image capture time	SC_EPOCH	44	Int	Spacecraft epoch (bootcount-1)
	UPTIME	443971.2138	Float	Spacecraft uptime (seconds since boot)
	RX_TIME	44401300415647	Int	Time FSW received image (bus clock ticks, 100 MHz clock)
UTC and int time	DATE-OBS	'2018-04-05T20:10:49.213750'	String	UTC time corresponding to uptime
	INT_TIME	60	Float	Integration time for coadded image (seconds)
Source for telemetry	RLTFILE	'rlt_44_443313_672787[...].txt'	String	RLT file corresponding to image
	RLTUPTME	443958	Int	FSW uptime for RLT packet closest to image uptime (seconds since boot)
PRT temperatures	TMPBAFL1	264.006	Float	Baffle PRT 1 (K)
	TMPBAFL2	264.023	Float	Baffle PRT 2 (K)
	TMPBAFL3	263.856	Float	Baffle PRT 3 (K)
	TMPFPL1	270.209	Float	Focal plane PRT 1 (K)
	TMPFPL2	270.176	Float	Focal plane PRT 2 (K)
	TMPFPL3	270.272	Float	Focal plane PRT 3 (K)
	TMP_LENS	263.109	Float	Lens housing temp (K)
	TMP_PIEZ	263.626	Float	Piezo stage temp (K)
	TMP_PZDR	282.362	Float	Piezo driver board frame temp (K)
	TMPBATT	285.168	Float	Battery chassis temp (K)
	TMPBTPLT	280.834	Float	Bottom plate temp (+Z face) (K)
	TMPTPPLT	276.419	Float	Top plate temp (-Z face) (K)
	TMPCOMP	282.368	Float	Flight computer frame temp (K)
	TMP_GPS	275.76	Float	GPS temp (K)
	TMP_IFB	281.268	Float	Interface board temp (K)
	TMP_IFBB	280.542	Float	Interface board bracket temp (K)
	TMP_ANT1	279.699	Float	Antenna 1 temp (+Z) (K)
	TMP_ANT2	277.56	Float	Antenna 2 temp (-Z, solar panel side) (K)
	TMP_RAD	281.128	Float	Radio bracket temp (K)
	TMP_X1	282.816	Float	EPS temp (K)
	TMP_X3	282.847	Float	EPS temp (K)
Heater duty cycles	HEATER1	0.0	Float	Heater 1 duty cycle between 0 (OFF) and 1 (ON max)
	HEATER2	0.0	Float	Heater 2 duty cycle between 0 (OFF) and 1 (ON max)
	HEATER3	0.0	Float	Heater 3 duty cycle between 0 (OFF) and 1 (ON max) [Not present in FSW 7.1.3]

Table 1: ASTERIA FITS header definition

	Keyword	**Example Value**	**Data type**	**Description**
	HEATER4	0.0	Float	Heater 4 duty cycle between 0 (OFF) and 1 (ON max) [Not present in FSW 7.1.3]
Battery telemetry	TMPBATTS	’[12 12 12 12]’	String	Array of battery temperatures (°C)
	BATTV	31370.0	Float	Battery voltage (mV)
	BATTC	-445.0	Float	Battery current (mA)
Reaction wheel speeds	RXWHEEL1	-3517	Int	Reaction wheel 1 speed (0.4*RPM)
	RXWHEEL2	-1553	Int	Reaction wheel 2 speed (0.4*RPM)
	RXWHEEL3	-1647	Int	Reaction wheel 3 speed (0.4*RPM)
ECI position	ECI_X	-296064922	Int	ECI X position (m), calculated by XACT
	ECI_Y	39586325	Int	ECI X position (m), calculated by XACT
	ECI_Z	159206715	Int	ECI X position (m), calculated by XACT
Date and orbital parameters	JD-OBS	2458214.34084738	Float	Julian Date of observation (calculated from UTC)
	MEANMOTN	15.57588178	Float	Orbital mean motion (orbits per day)
	ORB_PER	92.45062465	Float	Orbital period (minutes)
Sequence info	SEQ_FILE	’2225_ex10.seq’	String	Sequence file that produced image
	MSSNPARM	’2222_pcs_mssn_params_14’	String	Mssn parameter file called by sequence
Information from mssn param	OBS_TARG	’HIP114622’	String	Target’ star for PCS algorithm. NOTE: not necessarily the science target
	INTROWS	2210	Int	Integration time of windowed image in rows (2210 = 50 msec)
	STRS4CEN	6	Int	Number of stars used in PCS fine pointing algorithm
	NEA	0.11	Float	Noise equivalent angle (arcsec/sqrt(Hz)), estimate of pointing performance
	FIELDROT	0.0	Float	Rotation angle about boresight (deg)
	RA_BRST	346.7086	Float	RA of boresight (center of detector) (deg)
	DEC_BRST	58.3158	Float	DEC of boresight (center of detector) (deg)
PCS Telemetry	CNTRD_W0	’[31, 32]’	String	Window 0 centroid (pix)
	CNTRD_W1	’[31, 30]’	String	Window 1 centroid (pix)
	CNTRD_W2	’[31, 31]’	String	Window 2 centroid (pix)
	CNTRD_W3	’[31, 31]’	String	Window 3 centroid (pix)
	CNTRD_W4	’[100, 100]’	String	Window 4 centroid (pix)
	CNTRD_W5	’[100, 100]’	String	Window 5 centroid (pix)
	CNTRD_W6	’[100, 100]’	String	Window 6 centroid (pix)
	CNTRD_W7	’[100, 100]’	String	Window 7 centroid (pix)
	AVGBKG_0	10	Int	Meas. background in win 0 (ADU)
	AVGBKG_1	7	Int	Meas. background in win 1 (ADU)
	AVGBKG_2	6	Int	Meas. background in win 2 (ADU)
	AVGBKG_3	99	Int	Meas. background in win 3 (ADU)
	AVGBKG_4	99	Int	Meas. background in win 4 (ADU)
	AVGBKG_5	99	Int	Meas. background in win 5 (ADU)
	AVGBKG_6	99	Int	Meas. background in win 6 (ADU)
	AVGBKG_7	99	Int	Meas. background in win 7 (ADU)

Table 1: ASTERIA FITS header definition

Keyword	Example Value	Data type	Description
MXPXVAL0	32	Int	Win 0 brightest pixel (ADU)
MXPXVAL1	73	Int	Win 1 brightest pixel (ADU)
MXPXVAL2	82	Int	Win 2 brightest pixel (ADU)
MXPXVAL3	99	Int	Win 3 brightest pixel (ADU)
MXPXVAL4	99	Int	Win 4 brightest pixel (ADU)
MXPXVAL5	99	Int	Win 5 brightest pixel (ADU)
MXPXVAL6	99	Int	Win 6 brightest pixel (ADU)
MXPXVAL7	99	Int	Win 7 brightest pixel (ADU)
MXPX_W0	'[27, 29, 36, 34]'	String	Loc of max pix [xmin, ymin, xmax, ymax]
MXPX_W1	'[29, 30, 30, 31]'	String	Loc of max pix [xmin, ymin, xmax, ymax]
MXPX_W2	'[30, 31, 31, 32]'	String	Loc of max pix [xmin, ymin, xmax, ymax]
MXPX_W3	'[99, 99, 99, 99]'	String	Loc of max pix [xmin, ymin, xmax, ymax]
MXPX_W4	'[99, 99, 99, 99]'	String	Loc of max pix [xmin, ymin, xmax, ymax]
MXPX_W5	'[99, 99, 99, 99]'	String	Loc of max pix [xmin, ymin, xmax, ymax]
MXPX_W6	'[99, 99, 99, 99]'	String	Loc of max pix [xmin, ymin, xmax, ymax]
MXPX_W7	'[99, 99, 99, 99]'	String	Loc of max pix [xmin, ymin, xmax, ymax]
PNTERMNX	-1.3169432349968E-05	Float	Pointing error minimum x (rad)
PNTERMXX	-1.3936316463514E-05	Float	Pointing error minimum y (rad)
PNTERMXX	2.21410300582647E-05	Float	Pointing error maximum x (rad)
PNTERMXY	1.40974116220604E-05	Float	Pointing error maximum y (rad)
ROLL_ERR	0.000155580128193832	Float	Roll error (rad)
SLEWTIME	400	Int	Slew time held (cycles)
ACQ_TIME	200	Int	Slew time held (cycles)
WIN0STAR	'HIP114622'	String	Star at center of window 0
RA_WIN0	'23:13:16.9763'	String	RA of window 0 center (extracted from Hipparcos using star HIP ID)
DEC_WIN0	'57:10:06.082'	String	DEC of window 0 center (extracted from Hipparcos using star HIP ID)
VMG0STAR	5.57	Float	Vmag of star at center of window 0
ANG0STAR	1.863	Float	Angular distance from boresight for star in window 0
WIN1STAR	'HIP112731'	String	Star at center of window 1
RA_WIN1	'23:13:16.9763'	String	RA of window 1 center (extracted from Hipparcos using star HIP ID)
DEC_WIN1	'55:54:09.999'	String	DEC of window 1 center (extracted from Hipparcos using star HIP ID)
VMG1STAR	5.43	Float	Vmag of star at center of window 1
ANG1STAR	3.0945	Float	Angular distance from boresight for star in window 1
WIN2STAR	'HIP111362'	String	Star at center of window 2
RA_WIN2	'22:33:40.65'	String	RA of window 2 center (extracted from Hipparcos using star HIP ID)
DEC_WIN2	'56:37:29.061'	String	DEC of window 2 center (extracted from Hipparcos using star HIP ID)
VMG2STAR	5.72	Float	Vmag of star at center of window 2
ANG2STAR	4.3235	Float	Angular distance from boresight for star in window 2
WIN3STAR	'HIP111795'	String	Star at center of window 3
RA_WIN3	'22:38:37.9229'	String	RA of window 3 center (extracted from Hipparcos using star HIP ID)
DEC_WIN3	'56:47:44.282'	String	DEC of window 3 center (extracted from Hipparcos using star HIP ID)

Star IDs, coordinates, magnitudes

Table 1: ASTERIA FITS header definition

	Keyword	**Example Value**	**Data type**	**Description**
	VMG3STAR	5.11	Float	Vmag of star at center of window 3
	ANG3STAR	3.6442	Float	Angular distance from boresight for star in window 3
	WIN4STAR	'HIP115990'	String	Star at center of window 4
	RA_WIN4	'23:30:01.9394'	String	RA of window 4 center (extracted from Hipparcos using star HIP ID)
	DEC_WIN4	'58:32:56.112'	String	DEC of window 4 center (extracted from Hipparcos using star HIP ID)
	VMG4STAR	4.89	Float	Vmag of star at center of window 4
	ANG4STAR	3.5358	Float	Angular distance from boresight for star in window 4
	WIN5STAR	'HIP114365'	String	Star at center of window 5
	RA_WIN5	'23:09:44.1389'	String	RA of window 5 center (extracted from Hipparcos using star HIP ID)
	DEC_WIN5	59:19:57.686'	String	DEC of window 5 center (extracted from Hipparcos using star HIP ID)
	VMG5STAR	5.68	Float	Vmag of star at center of window 5
	ANG5STAR	1.2572	Float	Angular distance from boresight for star in window 5
	WIN6STAR	[May be omitted]	String	Star at center of window 6
	RA_WIN6	[May be omitted]	String	RA of window 6 center (extracted from Hipparcos using star HIP ID)
	DEC_WIN6	[May be omitted]	String	DEC of window 6 center (extracted from Hipparcos using star HIP ID)
	VMG6STAR	[May be omitted]	Float	Vmag of star at center of window 6
	ANG6STAR	[May be omitted]	Float	Angular distance from boresight for star in window 6
	WIN7STAR	[May be omitted]	String	Star at center of window 7
	RA_WIN7	[May be omitted]	String	RA of window 7 center (extracted from Hipparcos using star HIP ID)
	DEC_WIN7	[May be omitted]	String	DEC of window 7 center (extracted from Hipparcos using star HIP ID)
	VMG7STAR	[May be omitted]	Float	Vmag of star at center of window 7
	ANG7STAR	[May be omitted]	Float	Angular distance from boresight for star in window 7
Pointing Control Mode	MCPARM	'2800_pcs_mc_params_6'	String	MC param file name
	MCPARM_V	6	Int	MC param version number
	MC_SW_VN	1	Int	MC param software version
	PC_ENBL	T	Bool	Fine pointing enabled
	PRO_ENBL	T	Bool	Detector feedback enabled
	ACS_MODE	'Fine Pointing'	String	ACS mode
Spacecraft position and BJD	OBS_LAT	-44.84852405	Float	Approximate spacecraft latitude
	OBS_LON	35.82241711	FLoat	Approximate spacecraft longitude
	BJD-OBS	2458214.33834357	Float	Barycentric Julian Date (BJD_TDB)
FITS constants	ZEROSHFT	0	Int	Pixel values shifted by this value to avoid negative pixel values
	BSCALE	1	Int	FITS file autogenerated
	BZERO	2147483648	Int	FITS file autogenerated