AIA/SDO FITS Keywords for Scientific Usage and Data Processing at Levels 0, 0.1, 0.3, 0.5, 0.8, and 0.9

(A document in progress)

Keyword Nomenclature:
(Telemetry keywords are ***bold italic***; derived keywords are **bold**; & potential keywords are *italic*)
{# = Integer (~ 0-999); @ = Optional single character A-Z; & = Alpha-numeric}

LL@#	Lower Left corner pixel for row (X) / column (Y) for Region of Interest (ROI) # on CCD
NAXIS@#	Dimension (in pixels) along row (X) / column (Y) for ROI # on CCD
A@&&&&&&	Originating from telemetry data (@: H = HDR, F = FDB, I = ISP)

(Note: The definitions of the output data levels included below have been extracted in part from the Stanford SDO DRMS and SUMS computer database, as well as from Phil Scherrer's JSOC Keywords Notes and Processing Plan for Level-0.)

1. Basic Image Information for Level-0 (and Above)

Definition of Level-0

1. Image Header
   Generated from metadata, it consists only of keywords derived directly from the image camera header data and those stored in a ground database containing the image characteristics, such as image size, date of observation, telescope, instrument, etc.
2. Image Data
   Decompressed raw data recompressed using gzip (see http://www.gzip.org/).

From science data packet image header (HDR) information (definition in Doc. AIA02019):

AHAPID = Packet APID (11b; from HDR)
AHTCS = Time Code Seconds (32b; from HDR)
AHTCSS = Time Code Sub Seconds (32b; from HDR)
AHTLFSN = Camera/Frame Serial Number (32b; from HDR)
AHT1RN = Target 1 Row Number (7b; from HDR) for the lower-left pixel of ROI1 (to the nearest 32^{nd} row or column)
AHT1CN = Target 1 Column Number (7b; from HDR) for the lower-left pixel of ROI1
AHT2RN = Target 2 Row Number (7b; from HDR) for the lower-left pixel of ROI2
AHT2CN = Target 2 Column Number (7b; from HDR) for the lower-left pixel of ROI2
AHFDBID = Frame Definition Block ID (8b; from HDR)
AHTAPC = TAP Code (4b; from HDR)
AHBITID = Bit Select ID (4b; from HDR)
AHCPIDN = Compression parameter *n* (4b; from HDR)
AHCPIDK = Compression parameter *k* (4b; from HDR)
AHLUTID = Lookup Table ID (8b; from HDR)

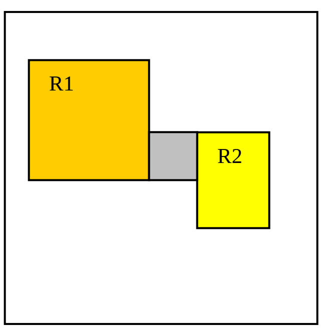
The 2 highest order bits in the 32b Frame Serial Number field will be used to specify the AIA camera (telescope) number, **CAMERA** , associated with the data image, such that

AHTLFSN = **AHTELID** (2b; telescope # -1) + **AHFSN** [Frame Serial Number (the least significant 30b)], where
AHTELID = [0, 1, 2, 3] = **CAMERA** – 1, or **CAMERA** = **AHTELID** + 1 = [1, 2, 3, 4].

From Frame Definition Block (FDB) (generated and stored in database on the ground [GDB]):

AFDBID = Frame Definition Block ID (8b; from GDB)
AFCRM = CCDReadoutMode (4b; from GDB) for number of ports: 1, 2, 4 (= 3, 2, 1)
AFDBSM = SummingMode (4b; from GDB) for summing: 1x1, 2x2, 4x4 (= 0, 1, 2)
AFDBNW = NumWindows (4b; from GDB) for number of ROI windows (= 0, 1, 2)
AFNR1 = NumRows1 (16b; from GDB) for height of region 1 in pixels
AFNC1 = NumCols1 (16b; from GDB) for width of region 1 in pixels
AFNR2 = NumRows2 (16b; from GDB) for height of region 2 in pixels
AFNC2 = NumCols2 (16b; from GDB) for width of region 2 in pixels
AFDBRL = RowLength (16b; from GDB) for row length in pixels for all extracted regions

Using the basic keywords above for the lower-left pixel of the 2 target regions of interest (ROI) and for the widths and heights of the regions, together with the following figure from the AIA Sequence Control Document (#AIA02019), where the lower-left corner pixel (LLC) is the origin with columns designated along the horizontal axis and rows along the vertical axis, the derived keywords below can be determined for each of the ROIs, 1, 2, and ROI 3 in between, if the first two ROIs are overlapping in rows but not columns, as shown. It is assumed in the ROI figure below that nominal solar north direction is at the top of the figure. (This will be validated, or rotations will be made so solar north is up, in Level-0.3 when the ancillary data for instrument pointing and spacecraft pointing, roll, location, and velocity become available.)



LLC

Derived Keywords:

NUMWIN = ***AFDBNW*** **+** TBD [number of window ROIs:
= 0 for full (4kx4k) CCD (TBD = 0);
= 1 for 1 ROI (TBD = 0);
= 2 for 2 ROI (TBD = 0);
= 3 for extra region when first 2 regions have overlapping rows but not columns (TBD = 1), as in the figure.]

LLX1 = ***AHT1CN*** * 32 [region 1 (R1) at center of lower left corner pixel, X variable]
LLY1 = ***AHT1RN*** * 32 [R1 at center of lower left corner pixel, Y variable]
LLX2 = ***AHT2CN*** * 32 [R2 at center of lower left corner pixel, X variable]
LLY2 = ***AHT2RN*** * 32 [R2 at center of lower left corner pixel, Y variable]
LLX3 = **LLX1** + ***AFNC1*** [gray region (R3) at center of lower left corner, X variable]
LLY3 = **LLY1** [R3 at center of lower left corner, Y variable]
NAXISX1 = ***AFNC1*** [R1 number of pixels along X axis]
NAXISY1 = ***AFNR1*** [R1 number of pixels along Y axis]
NAXISX2 = ***AFNC2*** [R2 number of pixels along X axis]
NAXISY2 = ***AFNR2*** [R2 number of pixels along Y axis]
NAXISX3 = ***AFDBRL – AFNC1 – AFNC2*** [R3 number of pixels along X axis]
NAXISY3 = **LLY2** + ***AFNR2*** **– LLY1** [R3 number of pixels along Y axis]
NAXIS = 2, 2, 1, 1 [corresponds to number of axes of images for **NUMWIN** = 0, 1, 2, 3, respectively, to not confuse simple FITS file readers.]
NAXIS1 = 4096, **NAXISX1,** total number of pixels in area**,** total number of pixels in area
NAXIS2 = 4096, **NAXISX2,** 0, 0
[the first 2 values of **NAXIS#** correspond, respectively, to the axis length for **NUMWIN** = 0, 1 and the last 2 values correspond to the total number of pixels in ROIs for **NAXIS1** and to zero by definition for **NAXIS2** to not confuse simple FITS file readers for **NUMWIN** = 2, 3.]
(TBD if any ROI frames will be directly viewable without further processing at Level-0.1.)

Quality/Sanity Check of FDB ID:

Does ***AHFDBID = AFDBID*** **?**

Reconstructing the acquired image requires, in addition, the appropriate use of ***AHCPIDN***, ***AHCPIDK***, ***AHTAPC, AHBITID, AHLUTID, AFDBSM,*** and ***AFCRM.*** The observation time can be determined (TBD) from ***AHTCS*** and ***AHTCSS***.

TELESCOP = "SDO/AIA"	text, Name of source telescope package
INSTRUME = "AIA_i"	text, Name of instrument (within telescope package) where i = camera number = 1, 2, 3, or 4
SIMPLE = "T"	Boolean, always T for True, if conforming FITS file
BITPIX = "16" (?)	integer, Bits/pixel: 16, 32, -32, or -64 (negative for floating point) (HMI uses as 16 in L0)
DATE	text, Date and time of file creation in format: yyyy.mm.ddThh:mm:ss[.sss] in UTC as text
DATE-OBS	Date and time when observation of this image started (uses DATE format)
MJD	float, Date of observation as modified julian day
TIME	float, Time of observation in seconds within a day. MJD and TIME describe the same instant as DATE-OBS

ORIGIN text, Location where file was made, e.g., “SDO/JSOC-SDP”

2. Additional Information for Level-0.1 (and Above)

Definition of Level-0.1 (Note: The intended use of this level is for JSOC-OPS quick-look viewing in near-real time.)

1. Image Header
   Metadata for Level-0 plus that generated from the associated image status packet (ISP), including the status of every mechanism, the camera itself, the image stabilization system (ISS), and the guide telescope (GT). (See latest image status packet list)
2. Image Data
   Decompressed raw data recompressed using gzip. (Same as that for Level-0)

(Note: At Level-0.1 there will be a different series of header and image data for each camera (telescope) and possibly three series for ROIs, differentiated by the number of ROI.)

More Basic Keywords for ROI Quality/Sanity Check:

AICRS = *A838F* = AIA_IMG_CCD_ROW_START (16b; from ISP) in pixels
AICRE = *A8390* = AIA_IMG_CCD_ROW_END (16b; from ISP) in pixels
AIR1CS = *A8396* = AIA_IMG_ROI_1_COL_START (16b; from ISP) in pixels
AIR1CE = *A839A* = AIA_IMG_ROI_1_COL_END (16b; from ISP) in pixels
AIR2CS = *A8397* = AIA_IMG_ROI_2_COL_START (16b; from ISP) in pixels
AIR2CE = *A839B* = AIA_IMG_ROI_2_COL_END (16b; from ISP) in pixels

ROI Quality/Sanity Check (using ISP & FDB keywords to obtain the same derived keywords as above):

LLX1 = ***AICRS***	[R1 lower left corner, X variable]
LLY1 = ***AIR1CS***	[R1 lower left corner, Y variable]
LLX2 = ***AICRE – AFNC2***	[R2 lower left corner, X variable]
LLY2 = ***AIR2CS***	[R2 lower left corner, Y variable]
LLX3 = LLX1 + ***AFNC1***	[R3 lower left corner, Y variable]
LLY3 = LLY1	[R3 lower left corner, Y variable]
NAXISX1 = ***AFNC1***	[R1 number of pixels along X axis]
NAXISY1 = ***AIR1CE*** **– LLY1**	[R1 number of pixels along Y axis]
NAXISX2 = ***AFNC2***	[R2 number of pixels along X axis]
NAXISY2 = ***AIR2CE*** **– LLY2**	[R2 number of pixels along Y axis]
NAXISX3 = **LLX2 – LLX1 –** ***AFNC1***	[R3 number of pixels along X axis]
NAXISY3 = ***AIR2CE*** **– LLY1**	[R3 number of pixels along Y axis]

AICNTC = *A8317* = AIA_IMG_CENTER_COL (16b; from ISP)
AICNTR = *A8316* = AIA_IMG_CENTER_ROW (16b; from ISP)
AICSFT = *A8319* = AIA_IMG_COL_SHIFT (16b; from ISP)
AIRSFT = *A8318* = AIA_IMG_ROW_SHIFT (16b; from ISP)

CCD Information

AIPSM = A838B = AIA_IMG_PAR_SUM_MODE (8b; from ISP)
AISSM = A8388 = AIA_IMG_SER_SUM_MODE (8b; from ISP)

Quality/Sanity Check with FDB Summing Mode (TBD)

2.1 Instrument, Mechanisms, & Observable Information

AISTATE *= A8284* = AIA_IMG_STATE (3b; from ISP)
from which the camera (telescope) number, **CAMERA,** can be sanity checked and the ISS status bit on, **ISS,** can be obtained.
AITELID *= AIA_IMG_TELESCOPE_ID* (2b; from ISP)
from which again the camera (telescope) number, **CAMERA**, can be sanity checked.
AIMGFSN *= AIA_IMG_FSN* (30b; from ISP)
from which frame serial number can be sanity checked.
AIASEN *= A82BF* = AIA_IMG_AS_ENCODER (16b; from ISP)
AIFWEN *= A8292* = AIA_IMG_FW_ENCODER (8b; from ISP)
WAVELNTH = AIA_IMG_WAVELENGTH (8b; from ISP), wavelength of observation:
2 each for telescopes 1, 2, 4 and 4 for telescope 3 (as a float in nm (Phil))
AIFILTYP = AIA_IMG_FILTER_TYPE (1b; from ISP)
AIMGTYP = AIA_IMG_IMAGE_TYPE (8b; from ISP), dark/light/cal, “shutter type”
AIDCOFST = AIA_IMG_DC_OFFSET (16b; from ISP)
AIIOFSTY = AIA_IMG_ISS_OFFSET_Y (16b; from ISP)
AIIOFSTZ = AIA_IMG_ISS_OFFSET_Z (16b; from ISP)
AIGTSIGV = AIA_IMG_GT_SIGNAL_VAL (16b; from ISP)
AIAECTI = A82CA = AIA_IMG_AEC_TABLE_ID (16b; from ISP)
AIAECENF = AIA_IMG_AEC_ENA_FLAG (1b; from ISP)
AIAECTYP = AIA_IMG_AEC_TYPE (2b; from ISP), “target type”
AIAECSUP = AIA_IMG_AEC_STEPUP (16b; from ISP)
AIAECSDN = AIA_IMG_AEC_STEPDN (16b; from ISP)
AIFOENFL = AIA_IMG_FOCUS_ENA_FLAG (1b; from ISP)
AIFTSWTH = AIA_IMG_FLT_TYP_SW_TH (16b; from ISP), filter switch threshold

Exposure Information:

AIMGSHEN = A8296 = AIA_IMG_SH_ENCODER (8b; from ISP)
AIMGOTS = A8285 = AIA_IMG_OBT_TIME_SH_SEC (32b; from ISP)
AIMGOTSS = A8286 = AIA_IMG_OBT_TIME_SH_SS (16b; from ISP)
AIMGSHCE = A8213 = AIA_IMG_SH_CMDED_EXPOSURE (16b; from ISP)
AIMSHOBC = A853E = AIA_IMG_SH_OPEN_BOT_CENTR (24b; from ISP)
AIMSHOBE = A853F = AIA_IMG_SH_OPEN_BOT_EDGE (24b; from ISP)
AIMSHOTC = A8540 = AIA_IMG_SH_OPEN_TOP_CENTR (24b; from ISP)
AIMSHOTE = A8541 = AIA_IMG_SH_OPEN_TOP_EDGE (24b; from ISP)

AIMSHCBC = A8214 = AIA_IMG_SH_CLOSE_BOT_CENTR (24b; from ISP)
AIMSHCBE = A8291 = AIA_IMG_SH_CLOSE_BOT_EDGE (24b; from ISP)
AIMSHCTC = A853C = AIA_IMG_SH_CLOSE_TOP_CENTR (24b; from ISP)
AIMSHCTE = A853D = AIA_IMG_SH_CLOSE_TOP_EDGE (24b; from ISP)

EXPTIME Exposure time in seconds

2.2 Time Information

ATCSO27 = APID027_TIMECODE_SECONDS (32b; from ISP)
ATCSS027 = APID027_TIMECODE_SUBSECS (32b; from ISP)

Another Quality/Sanity Check can be performed for the observation time

Sequence/State Information

ASQFGSN = AIA_SEQ_FRAME_SN (32b; from ISP)
ASQFGID = AIA_SEQ_FRAME_ID (32b; from ISP)

AIFCPS = A8225 = AIA_IMG_FC_POSITION (16b; from ISP)
AIFDBID *= A8315* = AIA_IMG_FDB_ID (16b; from ISP)
AIFTSID = AIA_IMG_FTS_ID (16b; from ISP)
AIFRMLID = AIA_IMG_FRMLIST_ID (16b; from ISP)
AIEVENT = AIA_IMG_EVENT (8b; from ISP)
AICFGDL1 = AIA_IMG_CFG_DELAY_1 (8b; from ISP)
AICFGDL2 = AIA_IMG_CFG_DELAY_2 (8b; from ISP)
AICFGDL3 = AIA_IMG_CFG_DELAY_3 (8b; from ISP)
AICDGDL4 = AIA_IMG_CFG_DELAY_4 (8b; from ISP)
AIE1ENTH = AIA_IMG_EVT_1_ENTR_TH (16b; from ISP), event 1 entry threshold
AIE1ENCN = AIA_IMG_EVT_1_ENTR_CNT (16b; from ISP), event 1 entry counts
AIE1EXTH = AIA_IMG_EVT_1_EXIT_TH (16b; from ISP), event 1 exit threshold
AIE1EXCN = AIA_IMG_EVT_1_EXIT_CNT (16b; from ISP), event 1 exit counts
AIE2ENTH = AIA_IMG_EVT_2_ENTR_TH (16b; from ISP), event 2 entry threshold
AIE2ENCN = AIA_IMG_EVT_2_ENTR_CNT (16b; from ISP), event 2 entry counts
AIE2EXTH = AIA_IMG_EVT_2_EXIT_TH (16b; from ISP), event 2 exit threshold
AIE2EXCN = AIA_IMG_EVT_2_EXIT_CNT (16b; from ISP), event 2 exit counts
AIHISMXB = AIA_IMG_HIST_MAX_BIN (16b; from ISP), bin number of maximum of standard histogram
AIHIS192 = AIA_IMG_HISTC_BN_192 (16b; from ISP), cumulative histogram value at bin #192
AIHIS348 = AIA_IMG_HISTC_BN_348 (16b; from ISP), cumulative histogram value at bin #348
AIHIS604 = AIA_IMG_HISTC_BN_604 (16b; from ISP), cumulative histogram value at bin #604

AIHIS860 = AIA_IMG_HISTC_BN_860 (16b; from ISP), cumulative histogram value at bin #860

Quality/Sanity Check of FDB ID: Does ***AIMFDBID = AFDBGID*** **?**

3. Other Keywords

Coordinate Information (including instrument & spacecraft pointing)

CD#_#@	Dimensioned transformation matrix
CDELT#@	Pixel spacing along axis #
CROTA#	Coordinate rotation (note: PC or CD transformation matrix is preferred)
CRPIX#@	Reference pixel along axis #
CRVAL#@	Reference value along axis #
CTYPE#@	Type of coordinate axis #

Some **CTYPE** axes:

RAW	Image or array with no know coordinate mapping
SOLARX	Axis represents position East-West in arc-seconds, positive is to west from the solar disk center
SOLARY	Axis represents position North-South in arc-seconds from the solar disk center. **CUNIT1** and **CUNIT2** default to "arcsec" if not present.
HPLN-TAN	Helioprojective longitude, tangent projection (Same as SOLARX but CDELT1 must be in degrees).
HPLT-TAN	Helioprojective latitude, tangent projection (Same as SOLARY but CDELT2 must be in degrees).

CUNIT#@	Units along axis #
PC#_#@	Transformation matrix
R-SUN	Radius of the Sun in m (float)
DSUN_OBS	Distance from Sun's center to SDO in m (float)
RSUN_REF	Radius of the Sun in m, depends on wavelength (float)
X0	X-axis location of solar disk center in pixels (float)
Y0	Y-axis location of solar disk center in pixels (float)
SDO_ROLL	Position angle of solar pole wrt the SDO Z axis (float, degrees)
IM_SCALE	Arc-sec per pixel default value for the particular instrument (float)
XCEN	X co-ordinate of array center (float)
YCEN	Y co-ordinate of array center (float)

where **a** = **CROTA2**

XCEN = CRVAL1 + CDELT1*cos(a)*((NAXIS1+1)/2 – CRPIX1)
– CDELT2*sin(a)*((NAXIS2+1)/2 – CRPIX2)

YCEN = CRVAL2 + CDELT1*sin(a)*((NAXIS1+1)/2 – CRPIX1)
+ CDELT2*cos(a)*((NAXIS2+1)/2 – CRPIX2)

Observation Planning Information

OBJECT	Name of object
OBJ_ID	Object identifier, e.g. active region number
OBSERVER	Name of observer
OBS_PROG	Name of the observing program
SCI_OBJ	The science objective of the observation

Temperature Information:

AIMCCTP1 = A8282 = AIA_IMG_CEB_CCD_TEMP1 (8b; from ISP)
AIMCCTP2 = A8283 = AIA_IMG_CEB_CCD_TEMP2 (8b; from ISP)

Data and Image Data Information

AIMGCPPR = A838C = AIA_IMG_COMPR_PAR (32b; from ISP)
AIMPCGT1 = A830C = AIA_IMG_PIX_COUNT_GT_TH1 (16b; from ISP)
AIMPCGT2 = A830D = AIA_IMG_PIX_COUNT_GT_TH2 (16b; from ISP)
AIMPCGT3 = A830F = AIA_IMG_PIX_COUNT_GT_TH3 (16b; from ISP)
AIMPCGT4 = A8310 = AIA_IMG_PIX_COUNT_GT_TH4 (16b; from ISP)
AIMPCLT1 = A8311 = AIA_IMG_PIX_COUNT_LT_TH1 (16b; from ISP)
AIMPCLT2 = A8312 = AIA_IMG_PIX_COUNT_LT_TH2 (16b; from ISP)
AIMPCLT3 = A8313 = AIA_IMG_PIX_COUNT_LT_TH3 (16b; from ISP)
AIMPCLT4 = A8314 = AIA_IMG_PIX_COUNT_LT_TH4 (16b; from ISP)

EXTEND	FITS file may contain extensions
COMMENT	ASCII comment (can be multiple)
HISTORY	ASCII history record (can be multiple)
FILENAME	Name of the data file

TBD: keywords for focus, GT statistics, H/K packet #, S/C info., orbit info., etc., when available and derived keywords, e.g., statistics, bad pixels, flat fielding, image center, etc.

Reformatter Information

AIVNIMST = A831A = AIA_VER_NUM_IMAGE_STATUS
ACSUM027 = APID027_CHECKSUM

VERSION
QUALITY
LEVEL NUMBER
PIPELINE VERSION

(Note: Some of the above keywords can be updated based on values in the ISP, e.g., **CDELTi** may be set since darks and normal images can be differentiated.

More level definitions

<u>Definition of Level-0.3</u> (Note: The intended use of this level is for quick-look higher-level data products in near-real time with a few minute lag from Level-0.1.)

1. Header
   Metadata for Level-0.1 plus that generated or updated from ancillary information about instrument pointing and roll, spacecraft location and velocity using flight dynamics predict data (FDS), the time of the observation with respect to the spacecraft or instrument clock, and known errors in such clocks, as well as information concerning the state of the instrument, etc., to provide the lowest level of scientifically-useful data for quick look and other applications.
2. Data
   Decompressed raw data recompressed using gzip. (Same as that for Level-0)

(Note: Since FDS data will be available at this level, it should be possible to set **CTYPEi** to SOLARX and SOLARY, and add **CRPIXj, CRVALi, and CROTAj** estimates assuming the image is centered on the CCD.)

<u>Definition of Level-0.5</u> (Note: This is a delayed but more complete version of Level-0.3, lagging real time by hours up to a day.)

1. Header
   Metadata for Level-0.3 plus that updated from the final versions of SDO HK roll information and FDS data.
2. Data
   Decompressed raw data recompressed using gzip. (Same as that for Level-0)

<u>Definition of Level-0.8</u> (Note: The intended use of this intermediate, temporary data series is to facilitate quick-look observable computations lagging real time by at most a few minutes.)

1. Header
   Metadata for Level-0.3 plus updating the image coordinate mapping keywords to meaningful and nearly correct values.
2. Data
   Decompressed raw data (level 0) calibrated by applying a flat field and then recompressed using gzip.

(Note: At this level the following can be set: **CTYPEi, CRPIXj, CRVALi, CROTAj, R_SUN, X0, Y0, XCEN, and YCEN** to meaningful and nearly correct values.)

Definition of Level-0.9 (Note: This temporary level is generated on demand from Level-0.5 and is held for up to 60 days.)

1. Header

   Metadata for Level-0.5 plus the best possible flat field is applied and bad pixels are identified in a list in a second segment to be carried along with the image segment, to provide the lowest level of scientifically-useful data, with the metadata expressed in terms of the Level-1.2 AIA/SDO FITS keywords. (Note that the header and data of this level is equivalent to the lowest level provided by TRACE, except for the application of the flat field.)

2. Data

   Decompressed raw data (level 0) calibrated by applying the best possible flat field and then recompressed using gzip.