AIA/SDO FITS Keywords for Scientific Usage and Data Processing at Levels 0.1, 0.3, 0.5, 1.0q, 1.0, and 1.5

(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. Level-0.1

1.1 Basic Image 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, consisting 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., plus that generated from the associated image status packet (ISP), including the status of mechanisms, 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 non-lossy compression, such as gzip (see http://www.gzip.org/) or rice.

(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.)

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

AHAPID = Packet APID (11b; from HDR)
AHTCS = Packet Time Code Seconds (32b; from HDR)
AHTCSS = Packet 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 32nd row or column)
AHT1CN = Target 1 Column Number (7b; from HDR) for the lower-left pixel of ROI1

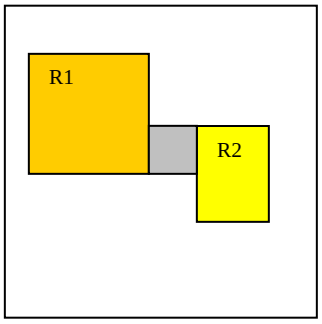
AHT2RN = Target 2 Row Number (7b; from HDR) for the lower-left pixel of ROI2
AHT2CN = Target 2 Column Number (7b; from HDR) for the lower-left pixel of ROI2
AHFDBID = Frame Definition Block ID (8b; from HDR)
AHTAPC = TAP Code (4b; from HDR)
AHBITID = Bit Select ID (4b; from HDR)
AHCPIDN = Compression 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)
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; TBD from GDB and crop tables) for height of region 1 in pixels
AFNC1 = NumCols1 (16b; TBD from GDB and crop tables) for width of region 1 in pixels
AFNR2 = NumRows2 (16b; TBD from GDB and crop tables) for height of region 2 in pixels
AFNC2 = NumCols2 (16b; TBD from GDB and crop tables) for width of region 2 in pixels

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 Region(s) of Interest (ROIs), 1, 2, and 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 ROIs ('TBD' = 0);
= 3 for extra region when first 2 regions have overlapping rows but not columns ('TBD' = 1), as in the figure]
ROI_LLX1 = ***AHT1CN*** * 32 [region 1 (R1) at center of lower left corner pixel, X variable]
ROI_LLY1 = ***AHT1RN*** * 32 [R1 at center of lower left corner pixel, Y variable]
ROI_LLX2 = ***AHT2CN*** * 32 [R2 at center of lower left corner pixel, X variable]
ROI_LLY2 = ***AHT2RN*** * 32 [R2 at center of lower left corner pixel, Y variable]
ROI_LLX3 = **ROI_LLX1** + **AFNC1** [gray region (R3) at center of lower left corner, X variable]
ROI_LLY3 = **ROI_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 = **ROI_LLX2** – **ROI_LLX1** – **AFNC1** [R3 number of pixels along X axis]
NAXISY3 = **ROI_LLY2** – **ROI_LLY1** + **AFNR2** [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.]

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***, **and AFDBSM.** The image observation time can be determined (TBD) from ***AHTCS*** and ***AHTCSS***.

1.2 Additional Information for Level-0.1 from Image Status Packet (ISP)

(See Appendix 2 for a recent list of the telemetry words in the Image Status Packet.)

1.2.1 Instrument, Mechanisms, & Observable Information

AISTATE = *A8284* = AIA_IMG_ISS_MODE (1b; from ISP), ISS on/off
ASQHDR = AIA_SEQ_HEADER (32b; from ISP), a combination of the camera number and the frame serial number, both of which have their own keywords below
ASQTNUM = AIA_SEQ_TEL_NUM (2b; in ISP), from which the camera (telescope) number that took this image, **CAMERA**, can be sanity checked
ASQFSN = AIA_SEQ_FRAME_SN (30b; in ISP), from which the frame serial number of this image, ***AHFSN***, can be sanity checked (independent of the camera number)
AIASEN = *A82BF* = AIA_IMG_AS_ENCODER (16b; from ISP), aperture selection encoder reading
AIFWEN = *A8292* = AIA_IMG_FW_ENCODER (8b; from ISP), filter wheel selector encoder reading (0-255) for this image
AIAWVLEN = AIA_IMG_WAVELENGTH (8b; from ISP), wavelength of this observation: 2 each for camera (telescope) 1, 2, 4 and 4 for camera 3 (as a float in nm (Phil)):

= 33.5, 13.1	for camera 1
= 19.3, 21.1	for camera 2
= 17.1, 160.0, 170.0, 450.0	for camera 3
= 9.4, 30.4	for camera 4

AIFILTYP = AIA_IMG_FILTER_TYPE (1b; from ISP), filter type, thick or thin (used for 131 A image only)
AIMGTYP = AIA_IMG_IMAGE_TYPE (8b; from ISP), dark or light "shutter type", and maybe cal in open filter of UV light curve (?)
AIGT1SVY = AIA_IMG_GT1_SUNVECTOR_Y (16b; from ISP), Guide Telescope (GT) 1 Sun vector in y direction
AIGT1SVZ = AIA_IMG_GT1_ SUNVECTOR _Z (16b; from ISP), Guide Telescope (GT) 1 Sun vector in z direction
AIGT2SVY = AIA_IMG_GT2_SUNVECTOR_Y (16b; from ISP), Guide Telescope (GT) 2 Sun vector in y direction
AIGT2SVZ = AIA_IMG_GT2_ SUNVECTOR _Z (16b; from ISP), Guide Telescope (GT) 2 Sun vector in z direction
AIGT3SVY = AIA_IMG_GT3_SUNVECTOR_Y (16b; from ISP), Guide Telescope (GT) 3 Sun vector in y direction
AIGT3SVZ = AIA_IMG_GT3_ SUNVECTOR _Z (16b; from ISP), Guide Telescope (GT) 3 Sun vector in z direction
AIGT4SVY = AIA_IMG_GT4_SUNVECTOR_Y (16b; from ISP), Guide Telescope (GT) 4 Sun vector in y direction
AIGT4SVZ = AIA_IMG_GT4_ SUNVECTOR _Z (16b; from ISP), Guide Telescope (GT) 4 Sun vector in z direction
AIAECTI = *A82CA* = AIA_IMG_AEC_TABLE_ID (16b; from ISP), Automatic Exposure Control (AEC) tables used with this image
AIAECENF = AIA_IMG_AEC_ENA_FLAG (1b; from ISP), AEC enable flag for this image

AECTYPE = AIA_IMG_AEC_TYPE (2b; from ISP), AEC table for current wavelength (4 tables per wavelength)
AECDELAY = AIA_IMG_AEC_DELAY (16b; from ISP), time since image used for AEC
AECMODE = AIA_IMG_AEC_MODE (1b; from ISP), mode of AEC (on/off)
AIFOENFL = AIA_IMG_FOCUS_ENA_FLAG (1b; from ISP), flag to indicate if focus table used or not
AIFTSWTH = AIA_IMG_FLT_TYPE_SW_TH (16b; from ISP), filter switch threshold for 131A wavelength (exposure)

Exposure Information:

AIMGSHEN = *A8296* = AIA_IMG_SH_ENCODER (8b; from ISP), shutter selector encoder reading (0-255) for this image
AIMGOTS = *A8285* = AIA_IMG_OBT_TIME_SH_SEC (32b; from ISP), seconds time tag read from OBC shutter time tag register for the shutter operation making this image
AIMGOTSS = *A8286* = AIA_IMG_OBT_TIME_SH_SS (16b; from ISP), subseconds time tag read from OBC shutter time tag register for the shutter operation making this image
AIMGSHCE = *A8213* = AIA_IMG_SH_CMDED_EXPOSURE (19b; from ISP), commanded exposure for this image
AIMSHOBC = *A853E* = AIA_IMG_SH_OPEN_BOT_CENTR (24b; from ISP), shutter timer register value for this position of this image
AIMSHOBE = *A853F* = AIA_IMG_SH_OPEN_BOT_EDGE (24b; from ISP), (same as above)
AIMSHOTC = *A8540* = AIA_IMG_SH_OPEN_TOP_CENTR (24b; from ISP), (same as above)
AIMSHOTE = *A8541* = AIA_IMG_SH_OPEN_TOP_EDGE (24b; from ISP), (same as above)
AIMSHCBC = *A8214* = AIA_IMG_SH_CLOSE_BOT_CENTR (24b; from ISP), (same as above)
AIMSHCBE = *A8291* = AIA_IMG_SH_CLOSE_BOT_EDGE (24b; from ISP), (same as above)
AIMSHCTC = *A853C* = AIA_IMG_SH_CLOSE_TOP_CENTR (24b; from ISP), (same as above)
AIMSHCTE = *A853D* = AIA_IMG_SH_CLOSE_TOP_EDGE (24b; from ISP), (same as above)

1.2.2 Time Information

ATCS027 = APID027_TIMECODE_SECONDS (32b; from ISP), APID027 timecode in seconds
ATCSS027 = APID027_TIMECODE_SUBSECS (32b; from ISP), APID027 timecode in subseconds

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

State Information

AIFCPS = *A8225* = AIA_IMG_FC_POSITION (16b; from ISP), currently loaded target value for this mechanism
AIFDBID = *A8315* = AIA_IMG_FDB_ID (16b; from ISP), frame definition block id

Quality/Sanity Check of FDB ID: Does ***AIFDBID = AFDBID ?***

AIFTSID = AIA_IMG_FTS_ID (16b; from ISP), framelist timeline schedule (FTS) id for this image
AIFRMLID = AIA_IMG_FRMLIST_ID (16b; from ISP), framelist id for this image
AIMGFSN = AIA_IMG_FRLIST_POS (8b; from ISP), position within framelist of this frame
AICFGDL1 = AIA_IMG_CFG_DELAY_1 (8b; from ISP), mechanism delay 1 for this image
AICFGDL2 = AIA_IMG_CFG_DELAY_2 (8b; from ISP), clear table delay for this image
AICFGDL3 = AIA_IMG_CFG_DELAY_3 (8b; from ISP), shutter operation delay for this image
AICDGDL4 = AIA_IMG_CFG_DELAY_4 (8b; from ISP), readout delay for this image
AIHISMXB = AIA_IMG_HIST_MAX_BIN (16b; from ISP), bin number of maximum of standard histogram for previous image in this wavelength used for the current AEC
AIHIS192 = AIA_IMG_HISTC_BN_192 (24b; from ISP), cumulative histogram value at bin #192
AIHIS348 = AIA_IMG_HISTC_BN_348 (24b; from ISP), cumulative histogram value at bin #348
AIHIS604 = AIA_IMG_HISTC_BN_604 (24b; from ISP), cumulative histogram value at bin #604
AIHIS860 = AIA_IMG_HISTC_BN_860 (24b; from ISP), cumulative histogram value at bin #860
AIAHFSN = AIA_IMG_HIST_FSN (32b; from ISP), the FSN of the image from which the histogram data was obtained
AIAGP1 = AIA_IMG_GP1 (32B; from ISP), general purpose register word 1
AIAGP2 = AIA_IMG_GP2 (32B; from ISP), general purpose register word 2
AIAGP3 = AIA_IMG_GP3 (32B; from ISP), general purpose register word 3
AIAGP4 = AIA_IMG_GP4 (32B; from ISP), general purpose register word 4
AIAGP5 = AIA_IMG_GP5 (32B; from ISP), general purpose register word 5
AIAGP6 = AIA_IMG_GP6 (32B; from ISP), general purpose register word 6
AIAGP7 = AIA_IMG_GP7 (32B; from ISP), general purpose register word 7
AIAGP8 = AIA_IMG_GP8 (32B; from ISP), general purpose register word 8
AIAGP9 = AIA_IMG_GP9 (32B; from ISP), general purpose register word 9
AIAGP10 = AIA_IMG_GP10 (32B; from ISP), general purpose register word 10

Reformatter Information

AIVNIMST = *A831A* = AIA_VER_NUM_IMAGE_STATUS(16b; from ISP), ISP version number
ACSUM027 = APID027_CHECKSUM (16b; from ISP), ISP checksum (last of ISP telemetry words)

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

1.2.3 Keywords Used by AIA and HMI in Level 0.1

----------(These keywords are to be populated when information is available)

ORIGIN string, location where file was made, e.g., “SDO/JSOC-SDP”
DATE string, date and time of file creation in format:
yyyy.mm.ddThh:mm:ss[.sss] in UTC
DATE_OBS = T_OBS – (EXPTIME/2**)** string, date when image observation started
T_OBS time**, s**hutter open start time plus the middle of the exposure time
EXPTIME double, Exposure time in seconds
EXPTIME_SD Standard deviation of the exposure time

(see Appendix 1: AIA Camera Exposure Time Calculation for details on the 4 keywords above.)

DATE-OBS string, date and time when observation of this image started (uses DATE format) (**DATE-OBS = DATE_OBS** for AIA)
TIME double, time of observation in seconds within a day. MJD and TIME describe the same instant as DATE_OBS
MJD double, date of observation as modified julian day
TELESCOP = “SDO/AIA” string, name of source telescope package
INSTRUME = “AIA_i” string, name of instrument (within telescope package) where i = camera number = 1, 2, 3, or 4
CAMERA = **AHTELID** + 1, int, camera number = 1, 2, 3, or 4 for AIA
WAVELNTH = ***AIAWVLEN***, wavelength of this observation:
2 each for camera (telescope) 1, 2, 4 and 4 for camera 3 (as a float in nm (Phil)):
= 33.5, 13.1 for camera 1
= 19.3, 21.1 for camera 2
= 17.1, 160.0, 170.0, 450.0 for camera 3
= 9.4, 30.4 for camera 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)

TLMDSNAM string, "Telemety data series name with first packet of image"
IMGFPT time, "FIRST_PACKET_TIME"
IMGAPID int, "Image Application ID"
BITSELID = *AHBITID* int, "Bit select ID, r"
COMPID = ***AHCPIDN, AHCPIDK*** int, "Compression ID; n,k"
TAPCODE = *AHTAPC* int, "Take A Picture code"
DATAVALS int, "Actual number of data values in image"
MISSVALS int, "Missing values: TOTVALS - DATAVALS"
TOTVALS int, "Expected number of data values (pixels)"
NERRORS int, "Number of decompression errors"
NPACKETS int, "Number of packets in image"
QUALLEV0 int, "Quality word"

DATAMIN	double, "Minimum value from all pixels"
DATAMAX	double, "Maximum value from all pixels"
DATAMEDN	double, "Median value from all pixels"
DATAMEAN	double, "Mean value for all pixels"
DATARMS	double, "Rms deviation from the mean value of all pixels"
DATASKEW	double, "Skewness from the mean value of all pixels "
DATAKURT	double, "Kurtosis of all pixels"

2. Other Keywords for Higher Levels (0.3, 0.5, 1.0q, 1.0, and 1.5)

(These keywords are to be populated separately for each instrument when information becomes available following the guidelines for the various levels below. See latest JSOC Keywords Notes for the full implementation of these 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

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
LEVEL NUMBER	of image
VERSION	of reformatter, data, and/or metadata (?)
QUALITY	of data
PIPELINE VERSION	

TBD: keywords for S/C information, orbit information, etc., when available and derived keywords, e.g., statistics, bad pixels, flat fielding, image center, etc.

More level definitions

Definition of Level-0.3 (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 non-lossy compression, such as gzip or rice. (Same as that for Level-0.1)

(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.)

Definition of Level-0.5 (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 non-lossy compression, such as gzip or rice. (Same as that for Level-0.1)

Definition of Level-1.0q (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 reduced to those scientific FITS keywords needed for analysis at Level-1 plus updating the image coordinate mapping keywords to meaningful and nearly correct values.
2. Data
   Decompressed raw data (level 0) calibrated by applying pixel corrections for exposure time, integer pixel shifts for alignment between telescopes, identifying bad pixels to be carried along with the image segment, as well as time-dependent, on-orbit calibrations, such as gain variations of 4 quadrants, and finally recompressed using non-lossy compression, such as gzip or rice.

(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-1.0 (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 reduced to those scientific FITS keywords needed for analysis at Level-1 plus updating the image coordinate mapping keywords to meaningful and nearly correct values.
   (Note that the data of this level are equivalent to the lowest level provided by TRACE, except for the reversible pixel and gain adjustments.)
2. Data
   Decompressed raw data (level 0) calibrated by applying pixel corrections for exposure time, integer pixel shifts for alignment between telescopes, identifying bad pixels to be carried along with the image segment, as well as time-dependent, on-orbit calibrations, such as gain variations of 4 quadrants, and finally recompressed using non-lossy compression, such as gzip or rice.

Definition of Level-1.5 (Note: The output from this level will be permanently stored.)

1. Header
   Metadata for Level-1.0 updated for the applied calibrations below (that have irreversibly modified the data).
2. Data
   Decompressed Level-1.0 data images that are de-spiked using the bad pixel map, adjusted for plate scale and sub-pixel registration, roll corrected, as well as applied vignette and optical correcting flat fields, and finally recompressed using non-lossy compression, such as gzip or rice.

3. Draft of a Sample Level 1.0 Header with Keywords

			Section of this document
SIMPLE	=	T	1.2.2
BITPIX	=	16	1.2.2
NAXIS	=	2	1.1
NAXIS1	=	4096	1.1
NAXIS2	=	4096	1.1
BLANK	=	-32768	(definition)
DATE	=	‘2008-01-08T18:57:38’	1.2.2
DATE-OBS	=	‘2008-01-08T18:56:00’	1.2.2
MJD	=	2454474	1.2.2
TIME	=	24960.0	1.2.2

ORIGIN	=	‘SDO/JSOC-SDP’		1.2.2
TELESCOP	=	‘SDO/AIA’		1.2.2
INSTRUME	=	‘AIA_i’		1.2.2
CAMERA	=	3		1.1, 1.2.1
WAVELNTH	=	17.1		1.2.1
OBJECT	=	‘NAME OF OBSERVATION OBJECT’		2.0
OBJ_ID	=	‘OBJECT IDENTIFIER’		2.0
OBSERVER	=	‘NAME OF OBSERVER’		2.0
OBS_PROG	=	‘NAME OF OBSERVING PROGRAM’		2.0
SCI_OBJ	=	‘SCIENCE OBJECTIVE’		2.0
FSN	=	75000		1.1, 1.2.1
ROI_LLX1	=	0		1.1
ROI_LLY1	=	0		1.1
ROI_LLX2	=	0		1.1
ROI_LLY2	=	0		1.1
ROI_LLX3	=	0		1.1
ROI_LLY3	=	0		1.1
NAXISX1	=	4096		1.1
NAXISY1	=	4096		1.1
NAXISX2	=	0		1.1
NAXISY2	=	0		1.1
NAXISX3	=	0		1.1
NAXISY3	=	0		1.1
FOVX1	=	1020	“Field of View in CUNITi”	TBD
FOVY1	=	1020	“Field of View in CUNITi”	TBD
FOVX2	=	0	“Field of View in CUNITi”	TBD
FOVY2	=	0	“Field of View in CUNITi”	TBD
FOVX3	=	0	“Field of View in CUNITi”	TBD
FOVY3	=	0	“Field of View in CUNITi”	TBD
CTYPE1	=	‘SOLARX’		2.0
CTYPE2	=	‘SOLARY’		2.0
CROTA1	=	0.0		2.0
CROTA2	=	0.0		2.0
CDELT1	=	0.5		2.0
CDELT2	=	0.5		2.0
CRPIX1	=	-357.291		2.0
CRPIX2	=	850.624		2.0
CRVAL1	=	0.0		2.0
CRVAL2	=	0.0		2.0
CUNIT1	=	‘ARCSEC’		2.0
CUNIT2	=	‘ARCSEC’		2.0
CRDER1	=	‘Estimate of random error in 1 as CUNITi’		2.0
CRDER2	=	‘Estimate of random error in 2 as CUNITi’		2.0
CSYSER1	=	‘Estimate of systematic error in 1 as CUNITi’		2.0
CSYSER2	=	‘Estimate of systematic error in 2 as CUNITi’		2.0
RSUN_REF	=	696000000		2.0

X0	=	0.0		2.0
Y0	=	0.0		2.0
SDO_ROLL	=	0.0		2.0
R_SUN	=	‘Radius of the Sun’s image in pixels’		2.0
SAT_ROT	=	‘Position angle of solar pole wrt the SDO Z axis’		2.0
INST_ROT	=	‘Rotation of the camera from the SDO Z axis’		2.0
IM_SCALE	=	0.5		2.0
XCEN	=	434.895		2.0
YCEN	=	-169.062		2.0
SUM_MODE	=	1		1.0
TEMP1	=	17.9	“Temperature Reading”	TBD
TEMP2	=	25.2	“Temperature Reading”	TBD
TEMP3	=	-30.3	“Temperature Reading”	TBD
TEMP4	=	-60.5	“Temperature Reading”	TBD
COMDEXPT	=	5.0		1.2.1
EXPTIME	=	5.0399		1.2.1, App. 1
FILT_TYP	=	1		1.2.1
IMG_TYP	=	‘LIGHT’		1.2.1
PERCENTD	=	100.0		TBD
DATAMIN	=	81.0		TBD
DATAMAX	=	4100.0		TBD
DATAMEDN	=	218.345670		TBD
DATAMEAN	=	218.345670		TBD
DATARMS	=	22.687300		TBD
DATASKEW	=	218.345670		TBD
DATAKURT	=	218.345670		TBD
DATAP01	=	722.00000		TBD
DATAP10	=	726.00000		TBD
DATAP25	=	730.00000		TBD
DATAP75	=	1094.0000		TBD
DATAP90	=	1368.0000		TBD
DATAP95	=	1662.0000		TBD
DATAP98	=	2282.0000		TBD
DATAP99	=	2826.0000		TBD
EXTEND	=	‘FITS FILE EXTENDED? T or F		2.0
COMMENT	=	‘COMMENT’		2.0
HISTORY	=	‘ASCII HISTORY RECORD, ONE OR MORE’		2.0
FILENAME	=	‘NAME OF DATA FILE’		2.0
LVL _NUM	=	‘LEVEL NUMBER’		2.0
VERSION (of reformatter)				2.0
QUALITY (of data)				2.0
PIPELINE VERSION				2.0
END				

Appendix 1: AIA Camera Exposure Time Calculation

Telemetry parameters required from AIA Image Status Packet:

AIMGOTS = AIA_IMG_OBT_TIME_SH_SEC
AIMGOTSS = AIA_IMG_OBT_TIME_SH_SS
cmdexp = double(***AIMGSHCE***) = AIA_IMG_SH_CMDED_EXPOSURE
shopbc = double(***AIMSHOBC***) = AIA_IMG_SH_OPEN_BOT_CENTR
shopbe = double(***AIMSHOBE***) = AIA_IMG_SH_OPEN_BOT_EDGE
shoptc = double(***AIMSHOTC***) = AIA_IMG_SH_OPEN_TOP_CENTR
shopte = double(***AIMSHOTE***) = AIA_IMG_SH_OPEN_TOP_EDGE
shclbc = double(***AIMSHCBC***) = AIA_IMG_SH_CLOSE_BOT_CENTR
shclbe = double(***AIMSHCBE***) = AIA_IMG_SH_CLOSE_BOT_EDGE
shcltc = double(***AIMSHCTC***) = AIA_IMG_SH_CLOSE_TOP_CENTR
shclte = double(***AIMSHCTE***) = AIA_IMG_SH_CLOSE_TOP_EDGE

AIMGSHCE is the commanded exposure (19 bits) starting from ~0.005 s (due to size of narrow shutter slit) in 0.001 s steps to 524.28 s [$(2^{19} -1)*10^{-3} = 524287*10^{-3}$] (timings are from document AIA01259 rev H). The maximum exposure of the AIA shutter mechanism is ~268.4 s. The 24 bit shutter open and close time measurements have a resolution of 0.000004 s, starting at 0.000004 s up to ~67 s [$(2^{24} – 1) * 4*10^{-6} = 67108860*10^{-6}$]. The commanded exposure value can be used to determine the rollover value. The expected value of the commanded exposure to the nearest 0.1 sec just before each of the three possible rollover steps is 67.1 s, 134.2 s, and 201.3 s, respectively. When ***AIMGSHCE*** is above any of these values it has rolled over 1, 2, or 3 times, respectively, and the number of rollovers multiplied by 67.108864 s needs to be added to the respective shutter close minus open time before averaging. Please note that the programmer needs to take care near the rollover steps because the hardware and/or software may not work quite the same as in the ideal case presented here.

The actual exposure is the average of the difference of the closing time minus the opening time for each of the four measurements positions, except when ***AIMGSHCE*** is less than 0.072 s, in which case the shutter mechanism is in its narrow slit mode. In the latter mode the narrow slit opening (smaller by 0.35) is utilized for one or more passes. Current operational planning calls for the shutter exposure to be about 5 s per image for each camera.

Using the above, together with Rock Bush's email of 28-Feb-08 on HMI T_OBS and EXPTIME and John Serafin's email of 20-May-08 on a rollover algorithm in C, the following algorithm has been written in IDL for calculating the AIA camera shutter exposure time for each camera, **EXPTIME;** standard deviation, **EXPTIME_SD;** the shutter open start time plus the middle of the exposure time, **T_OBS;** and the date when the observation started, **DATE_OBS.**

; Computer quantities (note: all variables should be double precision and time is in seconds):

AIA_Shutter_Open_Start_Time **= *AIMGOTS + AIMGOTSS*** ;combine these in TAI

;Intermediate calculation variables:

```
   cshclbc = shclbc + 67.108864d0 * nrollct(cmdexp, shclbc)        ;correct for rollovers
   cshclbe = shclbe + 67.108864d0 * nrollct(cmdexp, shclbe)
   cshcltc = shcltc + 67.108864d0 * nrollct(cmdexp, shcltc)
   cshclte = shclte + 67.108864d0 * nrollct(cmdexp, shclte)

   shebc = cshclbc – shopbc                                        ;close time – open time
   shebe = cshclbe - shopbe
   shetc = cshcltc - shoptc
   shete = cshclte - shopte

   mean = (shebc + shebe + shetc + shete)/4.0d0                    ;mean and standard deviation
   exp_sd = sqrt(1/3 * ( (shebc-mean) * (shebc-mean) + (shebe-mean) * (shebe-mean) + $
(shetc-mean) * (shetc-mean) + (shete-mean) * (shete-mean) ))       ;continued from previous line

   if (cmdexp lt 0.072d0) then begin                               ;in narrow slit mode
         mean = mean * 0.35
         exp_sd = expsd * 0.35
   endif
```

EXPTIME = mean ;AIA_Shutter_Exposure_Time
EXPTIME_SD = exp_sd ;AIA_Shutter_Exposure_SD

```
EXPTIME_Offset = (cshclbc + shopbc + cshclbe + shopbe + cshcltc + shoptc + cshclte + $
shopte)/8.0d0                                                      ;continued from previous line
```

T_OBS = AIA_Shutter_Open_Start_Time + EXPTIME_Offset ;(add in seconds, calculate DATA_OBS, then convert T_OBS to UTC)

DATE_OBS = **T_OBS -** (**EXPTIME**/2.0) ;(add in seconds then convert to UTC time)

Note: the T_OBS time is the shutter open start time plus the middle of the exposure time. As such a shutter exposure offset is the mean of all the open and close times. The EXPTIME is the shutter open time duration. DATE_OBS is the date when observation started.

```
;Rollover procedure nrollct
;for rollovers at 67.1, 134.2 and 201.3 with integers used below that are about one quarter of the
;interval away from the rollover values and thus not critical

   Pro nrollct, cmdexp, clostim

   If (cmdexp < 51.0) then  return 0
   If (cmdexp < 84.0) then  if (clostim > 33.0)  then return 0  else return 1
   If (cmdexp < 117.0)  then return 1
   If (cmdexp < 151.0) then  if (clostim > 33.0)  then return 1  else return 2
   If (cmdexp < 184.0) then  return 2
   If (cmdexp < 217.0) then  if (clostim > 33.0)  then return 2  else return 3
   If (cmdexp < 251.0) then  return 3
   return  if (clostim > 33.0)  then return 3  else return 4
   end
```

Appendix 2: AIA Image Status Packet (as of May 2008)

```
# hkdpf file created by make_hkdpf.pl script
FILE STANFORD_TLM_HMI_AIA.txt  1.163   2008/05/16  01:05:39
APID 0x027 158   AIA  "Image Status - Image Status Packet" 20080514
KWD  ATCS027      APID027_TIMECODE_SECONDS        0   0  32  UL1 R  20080514
KWD  ATCSS027     APID027_TIMECODE_SUBSECS        4   0  32  UL1 R  20080514
KWD  AIVNMST      AIA_VER_NUM_IMAGE_STATUS        8   0  16  IU1 R  20070513
KWD  AIMGOTS      AIA_IMG_OBT_TIME_SH_SEC         10  0  32  UL1 R  20070513
KWD  ASQHDR       AIA_SEQ_HEADER                  14  0  32  UL1 R  20080511
KWD  ASQTNUM      AIA_SEQ_TEL_NUM                 14  0  2   UB  R  20080511
KWD  ASQFSN       AIA_SEQ_FRAME_SN                14  2  30  UL1 R  20080511
KWD  AIAHFSN      AIA_IMG_HIST_FSN                18  0  32  UL1 R  20080325
KWD  AECDELAY     AIA_IMG_AEC_DELAY               22  0  16  IU1 R  20080325
KWD  AIAECTI      AIA_IMG_AEC_TABLE_ID            24  0  16  IU1 R  20070513
KWD  AIASEN       AIA_IMG_AS_ENCODER              26  0  16  IU1 R  20070513
KWD  AIFDBID      AIA_IMG_FDB_ID                  28  0  16  IU1 R  20070515
KWD  AIMGOTSS     AIA_IMG_OBT_TIME_SH_SS          30  0  16  IU1 R  20070513
KWD  AIFCPS       AIA_IMG_FC_POSITION             32  0  16  IS1 R  20070515
KWD  AIFTSWTH     AIA_IMG_FLT_TYPE_SW_TH          34  0  16  IU1 R  20070513
KWD  AIFRMLID     AIA_IMG_FRMLIST_ID              36  0  16  IU1 R  20070513
KWD  AIFTSID      AIA_IMG_FTS_ID                  38  0  16  IU1 R  20070513
KWD  AIHISMXB     AIA_IMG_HIST_MAX_BIN            40  0  16  IU1 R  20070513
KWD  AIHIS192     AIA_IMG_HISTC_BN_192            42  0  24  UL1 R  20080228
KWD  AIHIS348     AIA_IMG_HISTC_BN_348            45  0  24  UL1 R  20080228
```

KWD	AIHIS604	AIA_IMG_HISTC_BN_604	48	0	24	UL1	R 20080228
KWD	AIHIS860	AIA_IMG_HISTC_BN_860	51	0	24	UL1	R 20080228
KWD	AIFWEN	AIA_IMG_FW_ENCODER	54	0	9	IU1	R 20080514
KWD	AIMGSHCE	AIA_IMG_SH_CMDED_EXPOSURE	56	0	19	UL1	R 20080210
KWD	AECTYPE	AIA_IMG_AEC_TYPE	58	3	2	UB	R 20080325
KWD	AECMODE	AIA_IMG_AEC_MODE	58	5	1	UB	D 20080325
KWD	AISTATE	AIA_IMG_ISS_LOOP	59	3	1	UB	D 20080228
KWD	AIAECENF	AIA_IMG_AEC_ENA_FLAG	59	6	1	UB	R 20070513
KWD	AIFILTYP	AIA_IMG_FILTER_TYPE	59	7	1	UB	R 20070513
KWD	AIMSHOBC	AIA_IMG_SH_OPEN_BOT_CENTR	60	0	24	UL1	A 20071003
KWD	AIMSHOBE	AIA_IMG_SH_OPEN_BOT_EDGE	63	0	24	UL1	A 20071003
KWD	AIMSHOTC	AIA_IMG_SH_OPEN_TOP_CENTR	66	0	24	UL1	A 20071003
KWD	AIMSHOTE	AIA_IMG_SH_OPEN_TOP_EDGE	69	0	24	UL1	A 20071003
KWD	AIMSHCBC	AIA_IMG_SH_CLOSE_BOT_CENTR	72	0	24	UL1	A 20071003
KWD	AIMSHCBE	AIA_IMG_SH_CLOSE_BOT_EDGE	75	0	24	UL1	A 20071003
KWD	AIMSHCTC	AIA_IMG_SH_CLOSE_TOP_CENTR	78	0	24	UL1	A 20071003
KWD	AIMSHCTE	AIA_IMG_SH_CLOSE_TOP_EDGE	81	0	24	UL1	A 20071003
KWD	AICFGDL1	AIA_IMG_CFG_DELAY_1	84	0	8	UB	R 20080228
KWD	AICFGDL2	AIA_IMG_CFG_DELAY_2	85	0	8	UB	R 20080228
KWD	AICFGDL3	AIA_IMG_CFG_DELAY_3	86	0	8	UB	R 20080228
KWD	AICFGDL4	AIA_IMG_CFG_DELAY_4	87	0	8	UB	R 20080228
KWD	AIFOENFL	AIA_IMG_FOCUS_ENA_FLAG	88	0	1	UB	R 20070513
KWD	AIMGFSN	AIA_IMG_FRLIST_POS	88	1	8	IU1	R 20070820
KWD	AIMGTYP	AIA_IMG_IMAGE_TYPE	89	1	8	IU1	R 20070513
KWD	AIAWVLEN	AIA_IMG_WAVELENGTH	90	1	8	IU1	R 20080325
KWD	AIAGP1	AIA_IMG_GP1	92	0	32	UL1	R 20080325
KWD	AIAGP2	AIA_IMG_GP2	96	0	32	UL1	R 20080325
KWD	AIAGP3	AIA_IMG_GP3	100	0	32	UL1	R 20080325
KWD	AIAGP4	AIA_IMG_GP4	104	0	32	UL1	R 20080325
KWD	AIAGP5	AIA_IMG_GP5	108	0	32	UL1	R 20080325
KWD	AIAGP6	AIA_IMG_GP6	112	0	32	UL1	R 20080325
KWD	AIAGP7	AIA_IMG_GP7	116	0	32	UL1	R 20080325
KWD	AIAGP8	AIA_IMG_GP8	120	0	32	UL1	R 20080325
KWD	AIAGP9	AIA_IMG_GP9	124	0	32	UL1	R 20080325
KWD	AIAGP10	AIA_IMG_GP10	128	0	32	UL1	R 20080325
KWD	AGT1SVY	AIA_GT1_SUNVECTOR_Y	132	0	16	IS1	R 20080423
KWD	AGT1SVZ	AIA_GT1_SUNVECTOR_Z	134	0	16	IS1	R 20080423
KWD	AGT2SVY	AIA_GT2_SUNVECTOR_Y	136	0	16	IS1	R 20080423
KWD	AGT2SVZ	AIA_GT2_SUNVECTOR_Z	138	0	16	IS1	R 20080423
KWD	AGT3SVY	AIA_GT3_SUNVECTOR_Y	140	0	16	IS1	R 20080423
KWD	AGT3SVZ	AIA_GT3_SUNVECTOR_Z	142	0	16	IS1	R 20080423
KWD	AGT4SVY	AIA_GT4_SUNVECTOR_Y	144	0	16	IS1	R 20080423
KWD	AGT4SVZ	AIA_GT4_SUNVECTOR_Z	146	0	16	IS1	R 20080423
KWD	AIMGSHEN	AIA_IMG_SH_ENCODER	148	0	8	UB	R 20070513
KWD	ACSUM027	APID027_CHECKSUM	150	0	16	IU1	R 20080514