# ASC FITS File Designers' Guide
# ASC-FITS-2.0.0*

Arnold Rots and Jonathan McDowell

1999-02-18

## Contents



*$Id: ascfits.tex,v 2.0 1999/02/19 21:48:15 arots Exp arots $

# 1 Introduction

This document contains recommendations for the contents of ASC data product FITS headers. It is assumed that the reader is familiar with the basics of FITS use.

For general FITS issues, see the information provided by the FITS Support Office at GSFC[1] and the FITS archive at NRAO[2].

The conventions outlined in this document comply with the FITS standards, of course, but also with the HEASARC FITS Working Group's[3] recommendations. There is no good document describing their recommended conventions; the best available are a summary[4] and a more detailed list[5]. We shall refer to those collectively as **HFWG/95**.

Additional conventions developed by the ASC are contained in the draft documents on the FITS REGION table format and the FITS Embedded Function.

## 1.1 General style considerations

- FITS files allow the possibility of arbitrarily large numbers of extensions (sections, 'HDUs') containing unrelated data. However, we recommend including only one main 'object' of information in each file, with extra extensions only when those extensions contain auxiliary information relevant specifically to the main object. For instance, a file might contain an event list, together with its associated good time intervals, which apply specifically to that event list.
- Most of our data are best stored in tabular form, and so most data products will contain a null FITS primary image, followed by a main binary table (BINTABLE) extension containing the main data (we will call this the **Principal HDU**), and possibly some auxiliary extensions (which we will call **Auxiliary HDUs**). The ASCII table extension type is to be avoided.
- Some of our data are in the form of binned images (of 1, 2 or 3 dimensions). These should be stored in the primary (first) HDU of a FITS file which then becomes its principal HDU. Do not make a null primary image followed by an IMAGE extension, since many FITS image viewers can only see the data if it is in the primary HDU.
- Each HDU must be as far as possible self contained. Some software extracts a single HDU without checking the rest of the file, and so we must repeat some of the basic information in each HDU. We define below the ASC header styles of a **major header** and a **minor header**: the minor header contains only the most basic information, while the major header contains all the relevant information about the observation. The principal HDU and (if different) the primary HDU should both have major headers; the remaining HDUs may have minor headers.

[1] http://fits.gsfc.nasa.gov/fits_home.html
[2] http://www.cv.nrao.edu/fits/
[3] http://heasarc.gsfc.nasa.gov/docs/heasarc/ofwg/ofwg_intro.html
[4] http://legacy.gsfc.nasa.gov/docs/heasarc/ofwg/ofwg_recomm.html
[5] ftp://legacy.gsfc.nasa.gov/fits_info/ofwg_recomm/recomm.txt

- All HDUs are to contain the DATASUM and CHECKSUM keywords, so that they are properly checksummed, in conformance with the FITS Checksum Convention proposed by Seaman and Pence. HDUs following this convention have a 32-bit one's complement checksum that is $-0$ (all ones). This is an important tool in our quest to ensure the integrity of the archive and to achieve fault-free file transfers.

- Avoid the use of the '-' (hyphen, minus) character in keyword and column (TTYPE$n$) names. Use the underscore ('_') instead. Exception: the hyphen may be used specifically to indicate negation. Exception: The preexisting DATE-OBS, DATE-END, MJD-OBS, MJD-END keywords are retained. (HEASARC rule HFWG/95 R1).

- Every column in a TABLE or BINTABLE extension shall be given a unique name using the TTYPE$n$ keyword. This name shall include only upper or lower case letters, digits, and the underscore character; it shall not include embedded blanks (trailing blanks are not significant) and it shall begin with a letter (*ASC may wish to use leading digits in some cases, violating this rule*). Case shall not be considered significant in searching for names, (so COL_NAME and col_Name are not considered to be unique) *but names shall be returned by software as they are, so low level software must write and read them in a case sensitive way.* Names shall be unique within the first 16 characters. (HEASARC rule HFWG/95 R15).

- Names need to be unique within each FITS header. Since several systems allow for particular data to be stored either in keywords or in columns, keyword and columns names are required to be unique. This means that within the same header one cannot have a keyword and a column with the same name.

- TLMIN$n$ and TLMAX$n$ are used to record the minimum and maximum legal (*i.e.*, meaningful) values for a column. For instance, they are used to define the image size for a positional column in an event list. (HFWG/95 R6) These keywords should be used for all table columns for which they are meaningful, since they are a key piece of information used by the XSELECT program.

- Units given in FITS files, for example those given as values of TUNIT$n$ or CUNIT$n$, should follow the convention of OGIP/93-001, (HFWG/95 R5) basically SI with some astronomical additions. Case is important in units – the classic example is the use of 'S', which is a unit of electrical conductance, and different from 's' which is a unit of time. Some units are allowed to have SI prefixes ('k' for kilo, *etc.*) and others are not. See the table of allowed units in Appendix 2.

  Compound units are formed using spaces to imply multiplication and / to imply division of the immediately following token, with tokens grouped by round parentheses (). The operator ** implies raising to the power. For example, 'erg /(cm**2 s)' is erg per sq cm per s, while 'erg /cm**2 s' is erg s per sq cm. Numerical prefixes of the form 10**n may be given, *e.g.* '10**(-12) erg /(cm**2 s)'.

  A restricted list of functional operators is also (reluctantly) permitted in unit strings. These are:

  - log, ln, exp, sqrt
  - sin, cos, tan, asin, acos, atan, sinh, cosh, tanh

although I would strongly discourage the use of the second group (sin, *etc.*). It is better to make the quantity dimensionless before you take its sin.

- String valued keywords in standard FITS are limited to 68 characters. To store a longer string in a header keyword, we use multiple keywords as follows: the string is split into segments of no more than 67 characters; each segment is terminated with the ampersand character & and written as an ordinary string keyword. The first keyword shall be the actual keyword name, subsequent keywords shall all be named CONTINUE and will be FITS no-value keywords, recognized by the absence of the equals sign. In addition, files using this convention will include the keyword LONGSTRN = 'OGIP 1.0'. (HFWG/95 R13). Example:

```
LONGSTRN= 'OGIP 1.0'
AUTHOR  = 'J.C. McDowell, &'  / Author keyword
CONTINUE  'G. d''Aurillac, V.I. Ulyan&' / Continuation
CONTINUE  'ov, and L.D. Ahenobarbus' /
REFERENC= 'Journal of Improbable CoAuthors, &' /
CONTINUE  'Vol 1., No. 1, p. 42.'/
```

- Quality flags (integer values used to encode the fact that data may have particular kinds of problem) should use the value zero to mean 'good data' and non-zero values to indicate varying degrees of bad or masked out data. (HFWG/95 R9).

- All FITS files should contain, in HISTORY keywords, the names of the data product files that were used as input for creating the current file. A draft design for complete processing history information encoding is presented in Appendix 3.

# 2 ASC conventions

## 2.1 Time information

The observation start and stop times are the most important pieces of data, and are carried in redundant ways. The TSTART and TSTOP keywords are the primary carriers of this information; the DATE-OBS and DATE-END keywords and the MJD-OBS keywords repeat the information in a format which is easier for the human reader. For specifying good time intervals one should use the HEASARC-style GTI tables (binary tables containing two columns: START and STOP).

### 2.1.1 GTI Tables

For integration with the Data Model, we require the addition of the following keywords in the header of GTI tables:

```
MTYPE1 = 'TIME'
MFORM1 = 'START,STOP'
METYP1 = 'R'
```

When we have implemented vector columns and range elements, this will tell the Data Model that the start and stop columns on the GTI are a range on the quantity time.

### 2.1.2 TIME, TSTART and TSTOP

All time tags in the table data, and all TSTART and TSTOP values, should be mission time measured in seconds from an AXAF specified mission reference epoch.

- The AXAF reference epoch for calibration data was 1993 Dec 31, 00:00:00 UTC.
- The AXAF reference epoch for flight data shall be 1998 Jan 1, 00:00:00 TT, or MJD 50814.0 TT.
- The reference epoch used shall be stored as an MJD (modified Julian Date) value in the header keyword MJDREF or, alternatively, MJDREFI and MJDREFF (integer and fractional parts) if greater precision is needed.
- The time tags shall be the total number of seconds in a continuous count since the reference epoch.
- To convert a time tag TIME to an absolute MJD(TT), use the formula

```
MJD(TT) = MJDREF(TT) + ( TIMEZERO  + TIME ) / 86400
```

where the TIMEZERO header keyword contains a time adjustment in seconds (usually zero).

- When converting to UTC calendar dates, remember that you may need to account for leap seconds. As long as you stick with the time tags, or TT calendar dates, leap seconds are not a problem.
- Clock correction (or time conversion) parameters are stored in the five keywords BTIMNULL (s), BTIMRATE (s/count), BTIMDRFT (s/(count*count)), BTIMCORR (s), STARTOBT (s). Here, the relation between VCDU count $n_v$ and Mission Elapsed Time (MET) is:

  $$MET = T_{0,b} + R_b * n_v + 0.5 * D_b * n_v^2 + T_{c,b}$$

  where:

  BTIMNULL $= T_{0,b}$

  BTIMRATE $= R_b$

  BTIMDRFT $= D_b$

  BTIMCORR $= T_{c,b}$

  The VCDU count is a 24-bit number constructed by adding the minor frame count to the major frame count times 128 (or: left-shifted by 7 bits). STARTOBT is the On-Board Time transmitted in the telemetry closest to STARTMJF and STARTMNF; it only serves to discriminate between different rool-overs and resets of the VCDU count.

  In Level 0 data, we expect the recorded times (excluding TIMEZERO) to be calculated using the first three terms, with $T_{c,b}$ recorded in TIMEZERO (and, hence, TIMEZERO = BTIMCORR). For higher products, the first three coefficients serve as a fiducial clock (*basic time*, see below), with BTIMCORR indicating the difference between *basic time* and the times recorded using the best available estimate of the clock corrections. In the higher products, the TIMEZERO keyword will be set to zero. The CLOCKAPP keyword will always be set to *true* (T).

#### 2.1.3 DATE keywords

There is a family of DATE keywords, of which we use DATE (date of FITS file creation), DATE-OBS (date of observation start), and DATE-END (date of observation end). The format of these keywords is currently undergoing a change in the FITS standard to handle the year 2000 problem. Dates prior to 1999 Jan 1 are required to be written the old way, but for the purposes of AXAF we will deem 1999 to start early so we don't have to have IF statements everywhere. The old style required two keywords, *e.g.* , DATE-OBS and TIME-OBS:

```
DATE-OBS= '23/02/98'          / Day, month, year as per FITS standard
TIME-OBS= '11:22:33'          / Hour minute second UTC as per FITS standard
```

The new format uses the ISO standard date representation ccyy-mm-ddThh:mm:ss, and combines the date and time info into one keyword:

```
DATE-OBS= '1999-02-23T11:22:33'  / ISO standard date and time
```

#### 2.1.4 Other time keywords

- MJDREF records the Modified Julian Day of the mission time zero point. It implies a coordinate system on the TIME column, with the TCRVLn value of MJDREF, an implied TCRPXn of 0.0 and TCUNIn of 'd'. (See the section below on column coordinate systems for the meanings of TCRVL, TCRPX and TCUNI). For greater precision, it can be split into integer and fractional parts MJDREFI and MJDREFF.
- TSTART and TSTOP record the start time and stop time of the observation, in units of TIMEUNIT since MJDREF (unless TIMESYS='MJD' or 'JD'). They can be split into integer and fractional parts TSTARTI, TSTARTF, TSTOPI, TSTOPF. If a TIME column is present in the data, its TUNIT$n$ value must be the same as TIMEUNIT.
- TIMEDEL records the time resolution of the data: the bin size between rows for a binned dataset, the resolution of the time stamp for event lists.
- TIMEPIXR indicates where in each bin the time stamp falls. It has a value between 0.0 and 1.0. The default is 0.5 (center of the bin). If the time stamp refers to the beginning of the bin (as is the case for event data if the event was received between TIME and TIME+TIMEDEL), one should set TIMEPIXR=0.0.
- TIMEZERO and TIMEDEL record the time of the bins in a binned dataset. The nominal time of the time bin center of row $n$ is TIMEZERO $+(n - 0.5-$ TIMEPIXR $)*$ TIMEDEL. The keywords have the unit of TIMEUNIT. TIMEZERO can be split into TIMEZERI and TIMEZERF.
- TIMESYS records the time system used for MJDREF. We will use TIMESYS = 'TT '. When the time is corrected to the barycenter of the solar system TIMESYS = 'TDB' (but see also TIMEREF and PLEPHEM below).

This system supports three different time systems at once: the absolute MJD time system (given in MJDREF); the system used to record header times (given in TIMESYS); and the system used to record times in the table itself (given in TIMESYS and the TUNIT$n$ keyword). For example, suppose we have:

```
MJDREF  =       44238.0 / Reference time
TIMESYS = 'TT      '    / Time system
TIMEUNIT= 'd       '    / Time unit
TIMEZERO=          14.0 / Time zero point
```

```
TTYPE1  = 'TIME    '   / Time column
TUNIT1  = 'd       '   / Time unit
TSTART  =          0.1 /
TSTOP   =          0.2 /
  TIME
     0.01
     0.02
```

Then the first row encodes a time which is 0.01d from TIMEZERO, which is 14.0 days from MJDREF=44238.0, in other words 1980 Jan 14.01. If instead we have

```
MJDREF  =      44238.0 / Reference time
TIMESYS = 'MJD     '   / Time system
TIMEUNIT= 'd       '   / Time unit
TIMEZERO=      44252.0 / Time zero point
TTYPE1  = 'TIME    '   / Time column
TUNIT1  = 'd       '   / Time unit
TSTART  =         0.01 /
TSTOP   =         0.02 /

  TIME
    0.01
    0.02
```

This is unneccessarily baroque for most purposes, and the following is essentially equivalent and much more generic (requiring fewer new keyword inventions):

```
TSTART  =          0.0 /
TSTOP   =       8640.0 /
TTYPE1  = 'TIME    '   / Time column
TUNIT1  = 's       '   / Time unit
TCTYP1  = 'DATE    '   / Absolute date
TCUNI1  = 'd       '   / Date unit
TCRVL1  =      44252.0 / Reference value
TCRPX1  =          0.0 / Reference pixel
  TIME
  1800.0
  3600.0
```

We recommend the following style and convention. TIMEUNIT ='s', always. A very simple transformation from VCDU number to *basic time* will be defined for the duration of the mission. This conversion will be documented in the keywords BTIMNULL, BTIMRATE, and BTIMDRFT.

All clock corrections (given in BTIMCORR) will be relative to *basic time*. In files at Level 0 and below, all times (TIME column, TSTART, TSTOP) will be in *basic time* and both TIMEZERO BTIMCORR will contain the best clock correction available at the time the file was created. Files above Level 0 will have TIMEZERO = 0.0, with all clock corrections applied, so that TSTART, TSTOP *etc.* and the values in the TIME column are true time, but write the clock correction (relative to *basic time*) in BTIMECORR. This convention allows later clock corrections to be applied without the need for reprocessing. Include a WCS on the TIME column so that generic software can convert the times to absolute dates, assuming that CLOCKAPP = T. Simple software can then ignore TIMESYS, TIMEUNIT, TIMEZERO and just use MJDREF or TCRVL1, while the other keywords are retained for HEASARC compatibility and all information about clock corrections is retained. This gives us:

```
MJDREF  =      50814.0 / Reference time
TIMESYS = 'TT      '   / Time system
TIMEUNIT= 's       '   / Time unit
TIMEZERO=          0.0 / 0.896745 is the cumulative clock correction
TSTART  =    1209600.0 / Seconds since MJDREF
TSTOP   =    1218240.0 / Seconds since MJDREF
CLOCKAPP=            T /
COMMENT Column related keywords
TTYPE1  = 'TIME    '   / Time column
TUNIT1  = 's       '   / Time unit
TCTYP1  = 'DATE    '   / Absolute date
TCUNI1  = 'd       '   / Date unit
TCRVL1  =      50814.0 / Reference value
TCRPX1  =          0.0 / Reference pixel
TCDLT1  = 1.15740740741e-05 /
  TIME
1211400.0
1213200.0
```

- TIMEREF records what corrections have been made to event times. It applies only to tables which contain a single time which represents a photon arrival time. The default value is TIMEREF='LOCAL' which means that the actual arrival time is stored. Other values give a location and indicate that TIME has been corrected to the time that other photons in the same wavefront would have arrived at the given location. Note that this is NOT a change of time frame, since it depends on the direction the photon is coming from. For a wide field of view instrument, two photons with the same arrival time but coming from different directions would have different corrected times. Note that this makes the definition of TSTART and TSTOP, *etc.*, problematic unless a specific direction (RA_OBJ or RA_PNT, for instance) is intended.

  The possible locations (values of TIMEREF) are: 'GEOCENTRIC' (Earth center), 'HELIOCENTRIC' (Sun center), and 'SOLARSYSTEM' (Solar system barycenter). This last value is implied when TIMESYS = 'TDB'. See also PLEPHEM, below.

When photon times with different location corrections are stored in different columns of the same file, HEASARC recommends that the column name itself be given special values, DIFFERENT from the corresponding values of TIMEREF. GEOCENTRIC maps to REFEARTH, HELIOCENTRIC maps to REFSUN, and SOLARSYSTEM maps to REFBSOLS. In addition, special keywords for each of these cases replace TSTART, TSTOP and TIMEZERO, namely ESTART, ESTOP, ETIMEZER, SSTART, SSTOP, STIMEZER, and BSTART, BSTOP, BTIMEZER. Note that these special keywords for each case would not have been needed if some kind of WCS-type indexed keyword had been used to store time coordinate information. This is not one of HEASARC's most well-considered recommendations and such practices are not to be encouraged. Note also, that TIMESYS may become ambiguous.

- Another keyword which has a slightly different meaning to TIMEREF is TASSIGN. TASSIGN "specifies where the time assignment of the data is done. for example, for EXOSAT time assignment was made at the Madrid tracking station, so TASSIGN ='Madrid'. Since the document goes on to state that this information is relevant for barycentric corrections, one assumes that this means what is of interest is not the location of the computer where time tags where inserted into the telemetry stream, but whether those time tags refer to the actual photon arrival time or to the time at which the telemetry reached the ground station, *etc.* For example, for Einstein the time assignment was performed at the ground station but corrected to allow for the transmission time between satellite and ground, so I presume in this case TASSIGN='SATELLITE'. I believe that for AXAF, TASSIGN = 'SATELLITE'. OGIP/93-003 also specifies the location for the case of a ground station should be recorded the keywords GEOLAT, GEOLONG, and ALTITUDE. This is rather unfortunate since it would be nice to reserve these keywords for the satellite ephemeris position. However, since no ground station is defined for AXAF, we feel that we can use GEOLONG, GEOLAT, and ALTITUDE for these purposes, especially since such usage is consistent with their usage for ground-based observations. TASSIGN has obviously no meaning when TIMESYS = 'TDB'.

- TIERRELA and TIERABSO give the dimensionless clock rate error and the absolute timing precision in seconds. They may be included for informational purposes.

- PLEPHEM indicates, when times are corrected to the barycenter of the solar system, which planetary ephemeris was used. There are two legal values, at present: 'JPL-DE405' and 'JPL-DE200'. The former will be the normal value. However, one should be aware that it can only be used in conjunction with RADECSYS = 'ICRS', whereas the latter value can only be used with RADECSYS = 'FK5'. In certain cases it may be necessary to use DE200, *e.g.*, when one needs to compare the data with a timing ephemeris that is derived on the basis of DE200. To summarize, the following keyword value combinations are legal:

```
TIMESYS = 'TDB        '   / Time scale: Barycentric Dynamical Time
TIMEREF = 'SOLARSYSTEM'   / Reference location of photon arrival times
EQUINOX =        2000.0   / J2000
RADECSYS= 'ICRS       '   / International Celestial Reference System
PLEPHEM = 'JPL-DE405'     / Planetary ephemeris used
```

and:

```
TIMESYS = 'TDB     '     / Time scale: Barycentric Dynamical Time
TIMEREF = 'SOLARSYSTEM'  / Reference location of photon arrival times
EQUINOX =         2000.0 / J2000
RADECSYS= 'FK5     '     / International Celestial Reference System
PLEPHEM = 'JPL-DE200'    / Planetary ephemeris used
```

## 2.2 Coordinate information

As a rule, coordinates are to be specified using the corrdinate systems given in the documents SDS-2.0, *Coordinate Systems*, SDS-9.0 *FITS names for ASC Coordinates*, and SDS-12.0 *Coordinate system design for data model*, all by Jonathan McDowell. For calibration-related coordinate issues, see also the applicable HEASARC documents.

For regularly spaced coordinates, it appears that consensus is building in the FITS community to have the pixel grid defined by an $NAXIS \times NAXIS$ matrix stored in the keywords "CD$i$_$j$". However, since the formal acceptance of the current WCS proposal is still some way off and since it is not clear what the status of the CDELT$i$ and CROTA$i$ keywords is going to be, we shall allow both forms to be used in the ASC: either CD$i$_$j$ or CDELT$i$ and CROTA$i$. In addition, alternate coordinate axis may be indicated by adding WCS keywords that have a letter appended, such as CTYPE1A, CDELT1A, CUNIT1A, *etc.*

We have adopted one additional convention for specifying enumerated coordinates (irregularly spaced bins or pixels. If, for instance, the third coordinate of a multi-dimensional image in the primary array is energy ('ENERG'), sampled irregularly, the actual energy values of the pixels may be listed in a subsequent extension in the same file, with the referencing done as follows.

```
HDU0:
...
NAXIS3  =           10   / Number of pixels along 3rd axis
CTYPE3  = 'ENERG_BIN'    / Name of this pseudo coordinate
CD3_3   =            1   / Pixel increment (or CDELT3)
CRPIX3  =            1   / Better make this 1
CRVAL3  =            1   / ... And this one, too, or confusion will reign
CEXTN3  = 'ENERGY_BINS' / It will be enumerated in an HDU with EXTNAME='ENERGY_BINS'
CEXTV3  =            1   / ... and EXTVER=1 (first HDU of that name if CEXTV omitted)
...

HDU1:
...
TFIELDS =            2   / Needs to be at least 2
NAXIS2  =           10   / There are 10 rows (at least NAXIS3 above)
...
EXTNAME = 'ENERGY_BINS' / EXTNAME
EXTVER  =            1
```

```
TTYPE1  = 'ENERG_BIN'   / First column: the bin numbers
TFORM1  = '1I'
TTYPE2  = 'ENERG'       / Second column: the real energy values
TFORM2  = '1D'
TUNIT2  = 'keV'
...
```

This introduces the new keywords CEXTN$i$ and CEXTV$i$, which link a table in the same FITS file to a particular coordinate axis. CEXTV$i$ is optional.

The HDU with the enumerated coordinate pixels needs to:

- ... have the same EXTNAME as CEXTN$i$.
- ... have a column with TTYPE identical to the value of CTYPEi.
- ... have a column with TTYPE the name of the "real" coordinate axis.

If the table provides pixel (bin) bounds, rather tha pixel coordinate values, the example above would look like this (HDU1 only):

```
...
TFIELDS =           3   / Needs to be at least 2
NAXIS2  =          10   / There are 10 rows (at least NAXIS3 above)
...
EXTNAME = 'ENERGY_BINS' / EXTNAME
EXTVER  =           1
TTYPE1  = 'ENERG_BIN'   / First column: the bin numbers
TFORM1  = '1I'
TTYPE2  = 'ENERG_LO'     / Second column: the lower energy bin bounds
TFORM2  = '1D'
TUNIT2  = 'keV'
TTYPE3  = 'ENERG_HI'     / Third column: the upper energy bin bounds
TFORM3  = '1D'
TUNIT3  = 'keV'
...
```

Of course, that table may have more rows than NAXIS$i$; and CRPIX$i$, CDELT$i$, and CRVAL$i$ need not be 1; but one should not complicate matters when it's not necessary.

### 2.2.1 Observation Details

Observation details derived from the observation catalog will be included in Level 1 products and beyond.

- OBJECT is the name of the target.
- OBSERVER is the principal investigator of the observation.
- OBS_ID is a string denoting the observation.
- SEQ_NUM is the observation's sequence number designated by USG.
- TITLE is the proposal title.
- RA_NOM and DEC_NOM, in degrees, are the nominal ICRS/J2000 RA and Dec of the observation, used as the center of the sky plane. At Level 1 processing these may be overridden with values actually derived from the aspect solution, if those conflict with the planned ones.
- EQUINOX = 2000.0 denotes that all equatorial coordinate positions use equinox 2000.0. (HFWG/95 R3)
- RADECSYS = 'ICRS' denotes that our positions derive from the ICRS (Hipparcos) reference frame, rather than the earlier FK4 or FK5 systems. (Actually our star catalog is technically an ICRS/FK5 hybrid, but is consistent with ICRS within our errors). (HFWG/95 R3)
- ROLL_NOM, in degrees, is the nominal roll angle of the observation. At Level 1 processing this may be overridden with a value actually derived from the aspect solution, if this conflict with the planned one.

### 2.2.2 Other RA and Dec keywords

The following keywords may also be used, but we won't normally have them.

- RA_OBJ and DEC_OBJ record the position of the source, if the data file contains data on a single extracted source (or if there is a defined target source). Values are decimal degrees. (HFWG/95 R3)
- RA_PNT, DEC_PNT, and ROLL_PNT record the mean pointing direction of the telescope optical axis during the observation. (HFWG/95 R3)
- RA_SCX, DEC_SCX, RA_SCY, DEC_SCY, RA_SCZ, DEC_SCZ record the orientation of the spacecraft X, Y and Z axes in the equatorial coordinate frame. (HFWG/95 R3)

### 2.2.3 Column coordinate systems

The HEASARC conventions for storing coordinate systems in columns will be followed.

We can distinguish three types of coordinate system transformations in FITS files: linear transformations on a single axis or column, two-dimensional projections on a pair of axes or columns, and linear matrix transformations on all the axes and columns. I believe that the last type is needed only in rare cases.

For single-axis rescalings, we use the following algorithm: the data quantity p with name P is related to a world coordinate x with name X by

$$x = x_0 + \Delta(p - p_0)$$

P can be an IMAGE axis or a TABLE/BINTABLE column.

Table 1: Simple coordinate keywords

| Quantity | Meaning | IMAGE keyword | TABLE keyword |
|---|---|---|---|
| P | data quantity name | - | TTYPE$n$ |
| X | coordinate name and transform type | CTYPE$n$ | TCTYP$n$ |
| $p_0$ | Reference pixel | CRPIX$n$ | TCRPX$n$ |
| $x_0$ | Reference value | CRVAL$n$ | TCRVL$n$ |
| $\Delta$ | Pixel increment | CDELT$n$ | TCDLT$n$ |

For two-dimensional coordinates, the standard FITS WCS does not explicitly tie the two columns together. You use a special pair of CTYPE/TCTYP value strings, *e.g.*

```
TTYPE4 = 'X'
TTYPE5 = 'Y'
TCTYP4 = 'RA---TAN'
TCTYP5 = 'DEC--TAN'
```

which combine both the coordinate names and the transform projection type. For the ASC data model, we introduce extra keywords to group columns together under a common name:

```
MTYPE1 = 'POS'
MFORM1 = 'X,Y'
MTYPE2 = 'EQPOS'
MFORM2 = 'RA,DEC'
```

Finally, the keyword TDBIN$i$ may be used to specify a binning size for a binary table column, to let data model software know how to bin by default; the units are TUNIT$i$:

```
TDBIN1   =     4.2  /  Default bin size
```

## 2.3 What kind of data am I? - the HDUCLAS keywords

Each HDU should contain information allowing generic software to identify what kind of data it contains.

- The FITS standard keyword EXTNAME is used to give the name of an HDU. The ASC keyword HDUNAME plays a similar role but may be different if EXTNAME has to have some other value for compatibility reasons. In a primary HDU, there is some argument that EXTNAME is illegal, and so there we always use HDUNAME. EXTNAME is more generic and is augmented by EXTVER which numbers extensions with the same EXTNAME in a single file. The conventions are:
  - The DM will always write both EXTNAME and HDUNAME except in the case of the primary extension, HDU0, when only HDUNAME is written.
  - HDUNAME will contain the DM block name.
  - The value of EXTNAME and EXTVER will be determined as follows: any trailing digits on the block name will be peeled off and used as the value of EXTVER. The remaining characters of the blockname will be used as EXTNAME.
  - On reading, the DM will set the block name to be HDUNAME if it is present, otherwise it will use EXTNAME, concatenated with EXTVER if EXTVER is present.
- The ASC keyword CONTENT is used to store basic information about the content of a file and is the primary key when searching for a particular data product in the arcive. Hence, each data product has been assigned a unique value for the CONTENT keyword, except for science data where ACIS and HRC may produce functionally but not structurally identical products.
- The HDUCLAS hierarchy is used by FTOOLS and other software to determine the type of a file. HDUCLAS gives the origin of the hierarchy, either 'OGIP' or 'ASC'. HDUCLAS1 gives the highest level filetype, *e.g.* 'LIGHTCURVE', HDUCLAS2 is more specific, *e.g.* 'NET', HDUCLAS3 more specific still, *e.g.* 'RATE'. All HDUs have an HDUCLAS1 keyword, but the presence of the subsequent enumerated HDUCLAS keywords depends on the type of HDU.
- The ASC keyword HDUSPEC contains, if applicable, a (human readable) reference to the Interface Control Document (ICD) or other design document, including its version, that specifies the detailed format of the HDU.

The dictionary of EXTNAME, content and HDUCLAS keywords is given at the end of this document; hence, this document is referenced in HDUDOC.

### 2.4 Keywords describing the instrumental setup

- MISSION is used to define the overall project, *e.g.* AXAF, HTXS, *etc.*, even when different telescopes (*e.g.* ground based cal optics) are being used. This keyword is an ASC internal invention and is not yet adopted by HEASARC. The ASC keyword MISSION = 'AXAF' labels data as being part of the AXAF project, even if not taken with the AXAF (Chandra) telescope; it is used to group together ground cal data with flight data.

- TELESCOP is a FITS standard reserved keyword; HEASARC (OGIP/93-013 R12) specifies the strings used in particular missions. We will use the following values:

Table 2: TELESCOP keyword values

| Value | Use |
|---|---|
| CHANDRA | Flight |
| (AXAF) | Flight |
| XRCF/HRMA | XRCF |

- INSTRUME is a FITS standard reserved keyword. HEASARC (OGIP/93-013 R12) specifies that INSTRUME should refer to the focal plane instrument even when a grating is in place, *i.e.*, INSTRUME='HRC', not INSTRUME='LETGS'. We consider ACIS to be a single instrument, since any six of its chips can be read out.

  We use the following values:

Table 3: INSTRUME keyword values

| Value | Use | Description |
|---|---|---|
| ACIS | Flight, XRCF | AXAF CCD Imaging Spectrometer subsystem |
| HRC | Flight, XRCF | High Resolution Camera subsystem |
| EPHIN | Flight | |
| PCAD | Flight | Pointing Control and Attitude Determination subsystem |
| TEL | Flight | Telescope subsystem |
| SIM | Flight | Science Instrument Module subsystem |
| OBC | Flight | Software subsystem |
| CCDM | Flight | Communications Command and Data Management subsystem |
| CPE | Flight | CPE hardware and software subsystem |
| EPS | Flight | Electrical Power Subystem |
| THM | Flight | Thermal control subsystem |
| SMS | Flight | Structure subsystem |
| PROP | Flight | Propulsion and pyro subsystems |
| MISC | Flight | Other AXAF signals |
| ORBIT | Flight | Orbit ephemeris |
| SUN | Flight | Solar ephemeris |
| MOON | Flight | Lunar ephemeris |
| CLOCK | Flight | Clock measurements |
| AXAF | Flight | Certain mission-level items |
| FPC | XRCF | |
| SSD | XRCF | |
| HSI | XRCF | |
| HRC-I | XRCF | |
| HRC-S | XRCF | |
| ACIS-2C | XRCF | |

  PCAD includes ACA, Gyro, Earth and Sun Sensors, Attitude, Earth Angle. SPACECRAFT includes Power, Thermal, Status, Alignment, Grating, SIM, HRMA, Telemetry. GENERAL includes Orbit Ephemeris, Orbit Events, Mission Timeline.

- GRATING is introduced to record the gratings. We will use the values LETG and HETG (and TOGA at XRCF), and (optionally) NONE.

- DETNAM is used in HEASARC OGIP/93-013 R12 to record the sub-detector or combination of sub-detectors used. We recommend for the AXAF science instrument the following: in general, use ACIS- followed by the chip numbers in use (any 6 for ACIS, *e.g.* ACIS-012789). However, we prefer certain mnemonics for the commonly used cases:

Table 4: DETNAM keyword values

| DETNAM | Equivalent | INSTRUME |
|---|---|---|
| HRC-I | | HRC |
| HRC-S | | HRC |
| HRC-SI | | HRC |
| ACIS-I | ACIS-012367 | ACIS |
| ACIS-S | ACIS-456789 | ACIS |
| ACA-P | | PCAD |
| ACA-R | | PCAD |
| GYRO | | PCAD |
| FSSA | | PCAD |
| CSSA | | PCAD |
| ESA | | PCAD |
| GRATING | | TEL |
| HRMA | | TEL |

  In fact we hope always to use the mnemonics. Note that DETNAM is not required.

- FILTER is not used in this mission. By default, the FILTER keyword will be omitted which is equivalent to the value "NONE".

- OBS_MODE (OGIP/94-001) is used to record the observing mode. The valid values are 'POINTING', 'SLEW', 'RASTER', and 'SCAN', of which POINTING and SLEW are used by AXAF. ASC also uses the value 'GROUND' to denote ground calibration data and 'SECONDARY' for data from the secondary ("next in line"; *i.e.* the one not primarily selected for the observation) science instrument.

- DATAMODE (OGIP/94-001) is used for detector operating modes. Values for the ASCA SIS CCD were BRIGHT, FAINT, FAST. In the ASCA project, the DATAMODE keyword was changed when extra information was added to the data in later processing, thus it reflected not the way the data was taken but the current state of processing. We believe that it is better to retain information on the original experiment configuration, and determine the current state of processing from the presence or absence of the appropriate table columns. We note this is an incompatibility with ASCA.

  For AXAF HRC, we will use: OBSERVING, NEXT_IN_LINE (note these refer to the telemetry mode in use, not the actual purpose of the observation). For AXAF ACIS, we earlier used: GRADED, RAW, HISTO, FAINT, FAINT-BIAS, SPECIAL. These values have now been revised. The new values are:

Table 5: DATAMODE keyword values for ACIS

| ACIS mode | DATAMODE |
|---|---|
| TE Raw | RAW |
| TE Histogram | HISTO |
| TE Faint | FAINT |
| TE Faint with Bias | FAINT_BIAS |
| TE Very Faint | VFAINT |
| TE Graded | GRADED |
| TE Graded Histogram | GRADED_HISTO |
| CC Raw | CC_RAW |
| CC Faint | CC_FAINT |
| CC Graded | CC_GRADED |
| CC 3x3 Faint | CC33_FAINT |
| CC 3x3 Graded | CC33_GRADED |
| Other | SPECIAL |

- READMODE is an ASC ACIS-specific keyword used to denote the ACIS read mode. It has values TIMED or CONTINUOUS to denote whether the data is in timed exposure (TE) or continuous clocking (CC) mode.

An example of a standard observation identification segment of the FITS header would then be:

```
MISSION = 'AXAF    '      / Project
TELESCOP= 'CHANDRA '      / Telescope
INSTRUME= 'HRC     '      / Instrument
GRATING = 'LETG    '      / Grating
DETNAM  = 'HRC-S   '      / Detector
OBS_MODE= 'POINTING'      / Observation mode
DATAMODE= 'OBSERVING'     / Data mode
```

## 2.5 Traceability

In order to facilitate tracing the pedigree of the FITS files, the following keywords need to be included:

- ORIGIN contains place where the file is created; always 'ASC'.
- CREATOR contains the name of the program/tool that created the file, plus version information. Example: 'mytool - Version 12.7.3'.
- ASCDSVER provides the ASC-DS release that CREATOR was part of, such as 'R4C2.0'.

- TLMVER is only required for Level 0 products and contains the IP&CL version, for instance 'IP&CL 6.6'.
- REVISION is an integer that indicates the version of the data. this is intended to be incremented for each reprocessing run.

### 2.6 Exposure Keywords

- ONTIME records the sum of all good time intervals. TELAPSE records the difference between the start and stop times of an observation. LIVETIME records the ONTIME corrected for dead time corrections. EXPOSURE is the time corrected for all effects, including spatial ones such as vignetting, that are specified. Beware that Xspec wants a value for EXPOSURE; hence, it is prudent to include an EXPOSURE keyword in spectral and light curve headers, even if the contents is identical to LIVETIME. This should not lead to confusion since the corrections applied to EXPOSURE are all explicitly named in the various "correction applied" logical keywords. All of these should have units of seconds. (HFWG/95 R11). TELAPSE is not particularly profound and its use is optional.
- DEADC is equal to LIVETIME/ONTIME and is used to record the dead time correction, in the range 0 to 1. (O HFWG/95 R11). It may be used as a table column if the correction varies from row to row. (OGIP/93-003). If several energy bands are present with different corrections, the DEADC column is a vector with one value per band; as a header keyword it is replaced by the indexed keyword DEADCn. SAO has historically used DTCOR instead of DEADC. For reasons of PROS compatibility we shall use DTCOR.
- DEADAPP = T indicates that dead time corrections have been applied to count rates in the file. (OGIP/93-003).

### 2.7 Count and Count Rate

Count and count rate data are described in OGIP/92-007 and OGIP/93-003. There are two paradigms for storing count and count rate data. In type I tables, the table can store one detector channel or energy band per table row, with one corresponding count or count rate value each. In type II tables, each table row contains the entire set of count values for all channels or bands, the corresponding channel or band values are inferred from header keywords, and the different rows represent the changing of some other parameter such as time. In this case, the keyword NUMBANDS gives the number of different count values per row.

- NUMBANDS gives the number of different bands for type II files. (OGIP/93-003)
- COUNTS, of type integer, is a table column giving the uncorrected counts. In type II files, it is an array of NUMBANDS values. (OGIP/92-007, OGIP/93-003)

- RATE, of type real, is a table column giving the count rate. In type II files, it is an array of NUMBANDS values. RATE and COUNTS should not both be present. (OGIP/92-007, OGIP/93-003)
- ERROR, of type real, is a table column giving the error on the COUNTS or the RATE. (OGIP/93-003)
- BACKV, of type real, is a table column giving the background value. (OGIP/93-003). Although OGIP/93-003 does not say this explicitly, we assume that if the table contains the COUNTS column, BACKV is interpreted as being the background counts, while if the table contains RATE, BACKV is interpreted as being the background rate. It is recommended to include a TUNIT$n$ keyword to this effect, in order to avoid unnecessary confusion. If BACKV is constant with row number, it is used as a header keyword; if NUMBANDS is more than 1, an indexed keyword BACKVn is used.
- BACKE, of type real, is a table column giving the error on BACKV. (OGIP/93-003). The keyword BACKEn allows storage of these values as an indexed header keyword, similar to BACKVn.

## 2.8 Source and Background related keywords

These keywords presume the existence of a 'source' and a 'background', usually defined as spatial subsets of a set of observational data. The keywords are mostly meaningful for histogram tables such as PHA files and light curves. The specification of spatial filtering that is applied to the data may be presented in the format of a REGION table (see ASC-FITS-REGION-1.0).

- ERRCOR is used to apply a correction to the errors. The definition is unclear, but I am guessing what is meant is that in a PHA dataset or light curve dataset with counts and errors on counts, software which applies a conversion to counts/s and errors on count/s using correction factors such as VIGNET should multiply the error by this extra value. (HFWG/95 R11)
- GEOAREA records the geometric area of the detector, usually in sq. cm. (OGIP/93-003).
- AREASCAL is an 'area scaling factor' which is used to renormalize the histogram. It is an alternative to the use of an ARF calibration file; usually we use the ARF and set AREASCAL equal to 1.
- VIGNET is used to record the vignetting factor needed to convert the data to the equivalent on-axis values. The keyword is used for datasets which contain uncorrected values, not to record a correction which has already been made. The definition is value(on-axis) = value(datafile) / VIGNET. It usually lies between zero and one.
- VIGNAPP = T indicates that vignetting corrections have been applied. It is defined in OGIP/93-003 where it refers specifically to the values of RATE.
- BACKFILE is the filename of a background data file associated with the current one.

- BACKSCAL is a 'background scaling factor' which will be applied to the data in BACKFILE when it is used with the given dataset.
- BACKAPP = T indicates that background subtraction has been performed. As currently defined it applies specifically to the values of the RATE column (OGIP/93-003).
- NPIXSOU and NPIXBACK are used to record the area in pixels of the source and background regions. (OGIP/93-003).
- CORRFILE is a 'correction file', containing a spectrum that is to be subtracted from the source spectrum.
- CORRSCAL is used to scale the data in the correction file.
- RESPFILE is the spectral response matrix RMF file to be used with the data.
- ANCRFILE is the ancillary response file (effective area versus energy) to be used with the data.
- POISSERR is a logical keyword set to T if Poission rather than Gaussian errors should be used with the data. In a table with a column COUNTS, the STAT_ERR statistical errors may be omitted and inferred from the COUNTS if POISSERR is T.
- SYS_ERR is the fractional systematic error on the data in a column called COUNTS or RATE.
- QUALITY is a quality flag describing the data. As a header keyword, it usually is used with value zero to indicate that all the data is good.
- BPIXFILE is the name of the file containing the bad pixel map.

# 3 AXAF data product header components

We define the following header components:

- M: Mandatory FITS keywords for HDU type
- CC: Configuration control component
- T: Timing component
- O: Observation info component
- IC: Image coordinate system keywords (CTYPE$n$, *etc.*)
- TC: Table column specifications (TTYPE, *etc.* ) and coordinate system (TCRPIX) and ranges (TLMIN/TLMAX)

Each of the first three has full and short versions which are defined below. The components should be present as follows:

Table 6: Required FITS header components

| Type | FITS Primary or extension | ASC Principal or auxiliary | Header components |
|---|---|---|---|
| Image | Primary | Principal | M, CC, T, O, IC |
| Null | Primary | Aux | M, Null CC, Short T, Short O |
| Table | Extn | Principal | M, CC, T, O, TC |
| Table | Extn | Aux | M, Short CC, Short T, Short O, TC |
| Image | Extn | Aux | M, Short CC, Short T, Short O, IC |

The components should appear in the order specified, followed by optional additional `COMMENT` and `HISTORY` keywords, and the `END` keyword as the very last one. Non-Science Instrument data files should use the non-SI O component in all HDUs. If there is any uncertainty as to the precise intention, please consult the text of this document.

Entries marked with hash marks (#) are required to be populated by software. In the reference components, brackets ([ ]) surround keywords that must only be included per the notes. The notes provide additional instructions or limitations. A leading blank ( ) must be deleted from each header line prior to use. Each header line is 80 characters long. The HDU number n in the comment field of the `SIMPLE` and `XTENSION` keywords (for example, zero in the following: `/ HDU 0========================================`) must be updated to represent the actual ordinal value of the HDU in the FITS file, counting from zero. All components are terminated wither by a blank line or by a blank line followed by the `END` keyword.

### 3.1 "CHANDRA" *versus* "AXAF"

As of ASC-FITS-2.0.0 we allow various AXAF/Chandra synonyms. This potentially affects six keywords, the old versions of which are:

```
 HDUDOC  = 'ASC-FITS-1.4: McDowell, Rots: ASC FITS File Designers Guide'
 ASCDSVER= '########'           / ASC-DS processing system revision (release)
 ORIGIN  = 'ASC     '
 TIMVERSN= 'ASC-FITS-1.4'       / AXAF FITS design document
 MISSION = 'AXAF    '           / Mission is AXAF
 TELESCOP= 'AXAF    '           / Telescope is AXAF
```

The new versions:

```
 HDUDOC  = 'ASC-FITS-2.0: Rots, McDowell: ASC FITS File Designers Guide'
 ASCDSVER= '########'           / ASC-DS processing system revision (release)
 ORIGIN  = 'ASC     '
 TIMVERSN= 'ASC-FITS-2.0'       / AXAF FITS design document
 MISSION = 'AXAF    '           / Mission is AXAF
 TELESCOP= 'CHANDRA '           / Telescope is CHANDRA
```

It seemed prudent to leave the first four alone, except to allow reading software to recognize secondary synonyms:

```
HDUDOC:
 HDUDOC  = 'ASC-FITS-2.0: McDowell, Rots: ASC FITS File Designers Guide'
HDUDOC, synonym for reading:
 HDUDOC  = 'CXC-FITS-2.0: McDowell, Rots: CXC FITS File Designers Guide'

ASCDSVER, only allowed:
 ASCDSVER= '########'           / ASC-DS processing system revision (release)

ORIGIN:
 ORIGIN  = 'ASC     '
ORIGIN, synonym for reading:
 ORIGIN  = 'CXC     '

TIMEVERSN:
 TIMVERSN= 'ASC-FITS-2.0'       / AXAF FITS design document
TIMEVERSN, synonym for reading:
 TIMVERSN= 'CXC-FITS-2.0'       / AXAF FITS design document
```

In order to maintain compatibility with XRCF data, we keep AXAF as the primary choice for MISSION, but change TELESCOP (although, upon reading, synonyms will be recognized):

```
MISSION:
 MISSION = 'AXAF    '
MISSION, synonym for reading:
 MISSION = 'CHANDRA '
 MISSION = 'CXO     '

TELESCOP:
 TELESCOP= 'CHANDRA '
TELESCOP, synonym for reading:
 TELESCOP= 'AXAF    '
 TELESCOP= 'CXO     '
```

### 3.2 Mandatory component for Image Primary Header (M)

The following keywords are required to appear in the given order at the top of the header, with the END keyword being the last keyword of the header.

```
 SIMPLE  =                    T / HDU 0=========================================
 BITPIX  =                    # / Number of bits per data pixel
 NAXIS   =                    # / Number of data axes
[NAXIS1  =                    # / Number of pixels on first axis                ]
[NAXIS2  =                    # / Number of pixels on second axis               ]
 EXTEND  =                    T / FITS dataset may include extensions

 END
```

Notes: (1) There must be as many NAXIS$i$ keywords as the value of NAXIS.

### 3.3 Mandatory component for Null Primary Header (M)

The following keywords are required to appear in the given order at the top of the header, with the END keyword being the last keyword of the header.

```
 SIMPLE  =                    T / HDU 0=========================================
 BITPIX  =                    8 / Number of bits per data pixel
 NAXIS   =                    0 / Number of data axes
```

```
EXTEND  =                    T / FITS dataset may include extensions

END
```

### 3.4 Mandatory component for Binary Table extension (M)

The following keywords are required to appear in the given order at the top of the header, with the END keyword being the last keyword of the header.

```
 XTENSION= 'BINTABLE'           / HDU 1========================================
 BITPIX  =                    8 / 8-bit bytes
 NAXIS   =                    2 / 2-dimensional Binary Table
 NAXIS1  =                    # / Number of bytes per row
 NAXIS2  =                    # / Number of rows
 PCOUNT  =                    0 / No group parameters (required keyword)
 GCOUNT  =                    1 / One data group (required keyword)
 TFIELDS =                    # / Number of columns
 EXTNAME = '########'           / EXTNAME, usually identical to HDUNAME
[EXTVER  =                    # / EXTVER - sequence number of <EXTNAME> HDU      ]

 END
```

Notes: (1) EXTVER is mandatory only if more than one HDU exists with the same EXTNAME in one file.

### 3.5 Mandatory component for Image extension (M)

The following keywords are required to appear in the given order at the top of the header, with the END keyword being the last keyword of the header.

```
 XTENSION= 'IMAGE   '           / HDU 1========================================
 BITPIX  =                    # / 8-bit bytes
 NAXIS   =                    # / Number of image axes
 NAXIS1  =                    # / Number of pixels along axis 1
[NAXIS2  =                    # / Number of pixels along axis 2                  ]
 PCOUNT  =                    0 / No group parameters (required keyword)
 GCOUNT  =                    1 / One data group (required keyword)
 EXTNAME = '########'           / EXTNAME, usually identical to HDUNAME
[EXTVER  =                    # / EXTVER - sequence number of <EXTNAME> HDU      ]

 END
```

Notes:
(1) There must be as many NAXISi keywords as the value of NAXIS.
(2) EXTVER is mandatory only if more than one HDU exists with the same EXTNAME.

### 3.6 Full configuration control component (CC)

```
 COMMENT                                         +------------------+
 COMMENT                                         | AXAF FITS   File |
 COMMENT                                         +------------------+
 COMMENT              *********************************************************
 COMMENT              >    This file is written following certain AXAF-ASC    <
 COMMENT              >    conventions which are documented in ASC-FITS-2.0   <
 COMMENT              *********************************************************

                                / Configuration control block--------------------
 ORIGIN  = 'ASC     '
 CREATOR = '### - Version ###'
 ASCDSVER= '########'           / ASC-DS processing system revision (release)
[TLMVER  = '########'           / Telemetry revision number (IP&CL)            ]
 REVISION=                    # / Processing version of data
 CHECKSUM= '################'   / ASCII encoded HDU checksum
 DATASUM = '##########'         / Data unit checksum written in ASCII
 CONTENT = '########'           / Data product identification
 HDUNAME = '########'           / Dataset name; usually identical to EXTNAME
 HDUSPEC = '########          ' / ICD reference
 HDUDOC  = 'ASC-FITS-2.0: Rots, McDowell: ASC FITS File Designers Guide'
 HDUVERS = '########'
 HDUCLASS= '########'
 HDUCLAS1= '########'
[HDUCLAS2= '########'                                                          ]
[HDUCLAS3= '########'                                                          ]
 LONGSTRN= 'OGIP 1.0'           / The OGIP long string convention may be used.
 COMMENT   This FITS file may contain long string keyword values that are
 COMMENT   continued over multiple keywords.  This convention uses the  '&'
 COMMENT   character at the end of a string which is then continued
 COMMENT   on subsequent keywords whose name = 'CONTINUE'.
[HISTORY   Input event file: hrcx123456789N000_evt0.fits                       ]
[HISTORY  PARM  :infile=hrcx123456789N000_evt0.fits                    ASC00001]
```

Notes:
(1) The keyword TLMVER is only required for L0 products.
(2) The number of HDUCLASi keywords is variable and depends on the data product. HDUCLASS and HDUCLAS1 are mandatory. HDUCLAS2 and higher are optional and must be included only if populated with non-blank values.
(3) The format of the HDUVERS keyword is 'i.j.k ', and should be be populated with a default value of '1.0.0 '.
(4) The HDUCLASS keyword must be populated with either 'OGIP ' or 'ASC ' as appropriate.
(5) We expect that HISTORY keywords will eventually be written in a standard format; until such time, both formats above are legal.

### 3.7 Short configuration control component (Short CC)

```
                                / Configuration control block--------------------
 ORIGIN  = 'ASC     '
 CREATOR = '### - Version ###'
 CHECKSUM= '################'   / ASCII encoded HDU checksum
 DATASUM = '##########'         / Data unit checksum written in ASCII
 CONTENT = '########'           / What data product
 HDUNAME = '########'           / Dataset name; usually identical to EXTNAME
 HDUDOC  = 'ASC-FITS-2.0: Rots, McDowell: ASC FITS File Designers Guide'
 HDUVERS = '########'
 HDUCLASS= '########'
 HDUCLAS1= '########'
[HDUCLAS2= '########'                                                           ]
[HDUCLAS3= '########'                                                           ]
```

Notes:
(1) The number of HDUCLASi keywords is variable and depends on the data product. HDUCLASS and HDUCLAS1 are mandatory. HDUCLAS2 and higher are optional and must be included only if populated with non-blank values.
(2) The format of the HDUVERS keyword is 'i.j.k ', and should be be populated with a default value of '1.0.0 '.
(3) The HDUCLASS keyword must be populated with either 'OGIP ' or 'ASC ' as appropriate.

### 3.8 Configuration control component for null primary HDU (Null CC)

```
                                / Configuration control block--------------------
 ORIGIN  = 'ASC     '
 CREATOR = '### - Version ###'
 CHECKSUM= '################'   / ASCII encoded HDU checksum
 DATASUM = '##########'         / Data unit checksum written in ASCII
```

### 3.9 Level 0 full timing component (T)

```
                               / Time information block-------------------------
DATE    = '####-##-##T##:##:##'  / Date and time of file creation (UTC)
DATE-OBS= '####-##-##T##:##:##'  / TT, with clock correction if CLOCKAPP
DATE-END= '####-##-##T##:##:##'  / TT, with clock correction if CLOCKAPP
TIMESYS = 'TT      '           / AXAF time will be TT (Terrestrial Time)
MJDREF  =                50814 / 1998-01-01T00:00:00 (TT) expressed in MJD (TT)
                               / MJD = JD - 2400000.5
TIMEZERO=                    # / Clock correction (if not zero)
TIMEUNIT= 's       '
BTIMNULL=                    # / Basic Time offset (s)
BTIMRATE=                    # / Basic Time clock rate (s / VCDUcount)
BTIMDRFT=                    # / Basic Time clock drift (s / VCDUcount^2)
BTIMCORR=                    # / Correction applied to Basic Time rate (s)
TIMEREF = 'LOCAL   '           / No pathlength corrections
TASSIGN = 'SATELLITE'          / Spacecraft clock
CLOCKAPP=                    T / Clock correction applied
TIERRELA=                    # / Short-term clock stability
TIERABSO=                    # / Absolute precision of clock correction
TIMVERSN= 'ASC-FITS-2.0'       / AXAF FITS design document
TSTART  =                    # / As in the "TIME" column: raw space craft clock;
TSTOP   =                    # /   add TIMEZERO and MJDREF for absolute TT
STARTMJF=                    # / Major frame count at start
STARTMNF=                    # / Minor frame count at start
STARTOBT=                    # / On-Board MET close to STARTMJF and STARTMNF
STOPMJF =                    # / Major frame count at stop
STOPMNF =                    # / Minor frame count at stop
TIMEPIXR=                    # / Time stamp reference as bin fraction
TIMEDEL =                    # / Time resolution of data (in seconds)
```

Notes:
(1) If a different value for TIERRELA is not determined, a default value of 1.0E-9 should be used.
(2) If a different value for TIERABSO is not determined, a default value of 1.0E-4 should be used.

### 3.10 Level 0.5-1.5 full timing component (T)

```
                              / Time information block-------------------------
DATE    = '####-##-##T##:##:##'  / Date and time of file creation (UTC)
DATE-OBS= '####-##-##T##:##:##'  / TT, with clock correction if CLOCKAPP
DATE-END= '####-##-##T##:##:##'  / TT, with clock correction if CLOCKAPP
TIMESYS = 'TT      '           / AXAF time will be TT (Terrestrial Time)
MJDREF  =                50814 / 1998-01-01T00:00:00 (TT) expressed in MJD (TT)
                               / MJD = JD - 2400000.5
TIMEZERO=                    # / Clock correction (if not zero)
TIMEUNIT= 's       '
BTIMNULL=                    # / Basic Time offset (s)
BTIMRATE=                    # / Basic Time clock rate (s / VCDUcount)
BTIMDRFT=                    # / Basic Time clock drift (s / VCDUcount^2)
BTIMCORR=                    # / Correction applied to Basic Time rate (s)
TIMEREF = 'LOCAL   '           / No pathlength corrections
TASSIGN = 'SATELLITE'          / Spacecraft clock
CLOCKAPP=                    T / Clock correction applied
TIERRELA=                    # / Short-term clock stability
TIERABSO=                    # / Absolute precision of clock correction
TIMVERSN= 'ASC-FITS-2.0'       / AXAF FITS design document
TSTART  =                    # / As in the "TIME" column: raw space craft clock;
TSTOP   =                    # /   add TIMEZERO and MJDREF for absolute TT
TIMEPIXR=                    # / Time stamp reference as bin fraction
TIMEDEL =                    # / Time resolution of data (in seconds)
```

Notes:
(1) If a different value for TIERRELA is not determined, a default value of 1.0E-9 should be used.
(2) If a different value for TIERABSO is not determined, a default value of 1.0E-4 should be used.

### 3.11 Level 2 or greater full timing component (T)

```
                               / Time information block-------------------------
DATE    = '####-##-##T##:##:##'  / Date and time of file creation (UTC)
DATE-OBS= '####-##-##T##:##:##'  / TT, with clock correction if CLOCKAPP
DATE-END= '####-##-##T##:##:##'  / TT, with clock correction if CLOCKAPP
TIMESYS = 'TT      '           / AXAF time will be TT (Terrestrial Time)
MJDREF  =                50814 / 1998-01-01T00:00:00 (TT) expressed in MJD (TT)
                               / MJD = JD - 2400000.5
TIMEZERO=                    # / Clock correction (if not zero)
TIMEUNIT= 's       '
TIMEREF = 'LOCAL   '           / No pathlength corrections
TASSIGN = 'SATELLITE'          / Spacecraft clock
CLOCKAPP=                    T / Clock correction applied
TIERRELA=                    # / Short-term clock stability
TIERABSO=                    # / Absolute precision of clock correction
TIMVERSN= 'ASC-FITS-2.0'       / AXAF FITS design document
TSTART  =                    # / As in the "TIME" column: raw space craft clock;
TSTOP   =                    # /   add TIMEZERO and MJDREF for absolute TT
TIMEPIXR=                    # / Time stamp reference as bin fraction
TIMEDEL =                    # / Time resolution of data (in seconds)
```

Notes:
(1) If a different value for TIERRELA is not determined, a default value of 1.0E-9 should be used.
(2) If a different value for TIERABSO is not determined, a default value of 1.0E-4 should be used.

### 3.12 Short timing component (short T)

```
                               / Time information block-------------------------
DATE    = '####-##-##T##:##:##'  / Date and time of file creation (UTC)
DATE-OBS= '####-##-##T##:##:##'  / TT, with clock correction if CLOCKAPP
DATE-END= '####-##-##T##:##:##'  / TT, with clock correction if CLOCKAPP
TIMESYS = 'TT      '           / AXAF time will be TT (Terrestrial Time)
CLOCKAPP=                    T / Clock correction applied (if false)
TIMEZERO=                    # / Clock correction (if not zero)
TIMEUNIT= 's       '
MJDREF  =                50814 / 1998-01-01T00:00:00 (TT) expressed in MJD (TT)
TSTART  =                    # / As in the "TIME" column: raw space craft clock;
TSTOP   =                    # /   add TIMEZERO and MJDREF for absolute TT
```

### 3.13 Full observation info component (O)

Only include those keywords which are determined by that stage of processing.

```
                                / Observation information block------------------
[OBSERVER= '########'           / Name of Principal Investigator/Guest Observer  ]
[TITLE   = '########'           / Proposal title                                 ]
[OBS_ID  = '########'           / ObsId/Sequence number                          ]
[SEQ_NUM = '########'           / Sequence number                                ]
 MISSION = 'AXAF    '           / Mission is AXAF
 TELESCOP= 'CHANDRA '           / Telescope is CHANDRA
 INSTRUME= '########'           / HRC, ACIS, EPHIN, S/C subsystems
 DETNAM  = '########'           / Detector name
 GRATING = '########'           / Grating
[OBS_MODE= '########'           / Pointing, slew, raster, or scan                ]
[DATAMODE= '########'           / Datamode (varies only for science instr. data) ]
 SIM_X   =                    # / Position of SIM in mm
 SIM_Y   =                    # /
 SIM_Z   =                    # /
 FOC_LEN =                    # / Assumed focal length, mm; Level 1 and up
 ONTIME  =                    # / Sum of GTIs
 LIVETIME=                    # / Ontime multiplied by DTCOR
 EXPOSURE=                    # / Total exposure time, with all known corr. appl.
 DTCOR   =                    # / Dead time correction
 DATACLAS= '########'           / Data class
```

Notes:
(1) The keywords OBSERVER and TITLE should be included only if the associated values are determined.
(2) OBS_ID is the observation Id; its presence depends on processing level (not available before L1).
(3) SEQ_NUM is the sequence number; its presence depends on processing level (not available before L1).
(4) GRATING must be one of 'NONE ', 'LETG ', or 'HETG '.
(5) The keywords OBS_MODE and DATAMODE should be included only if the associated values are determined.
(6) The default value for DTCOR is 1.0 if not otherwise determined.
(7) The default value for DATACLAS is 'OBSERVED' unless another value (SIMULATED) is specified.

### 3.14 Source info component (S)

Appended to full observation info component (O) only if source information is available.

```
                               / Source information block-----------------------
 OBJECT   = '########'         / Source name
 RA_NOM   =                  # / Nominal pointing right ascension, deg
 DEC_NOM =                   # / Nominal pointing declination, deg
 ROLL_NOM=                   # / Nominal roll angle, deg
 EQUINOX =             2000.0 / J2000.0
 RADECSYS= 'ICRS    '          / Julian coordinate reference frame
```

### 3.15 Short observation info component (short O)

```
                               / Observation information block------------------
[OBS_ID  = '########'          / ObsId/Sequence number                           ]
[SEQ_NUM = '########'          / Sequence number                                 ]
 MISSION = 'AXAF    '          / Mission is AXAF
 TELESCOP= 'CHANDRA '          / Telescope is CHANDRA
 INSTRUME= '########'          / HRC, ACIS, EPHIN, S/C subsystems
```

Notes: (1) OBS_ID is the observation Id; its presence depends on processing level (not available before L1).
(2) SEQ_NUM is the sequence number; its presence depends on processing level (not available before L1).

### 3.16 Non-SI observation info component (non-SI O)

```
                               / Observation information block------------------
 MISSION = 'AXAF    '          / Mission is AXAF
 TELESCOP= 'CHANDRA '          / Telescope is CHANDRA
 INSTRUME= '########'          / HRC, ACIS, EPHIN, S/C subsystems
```

# A Appendix 1: EXTNAME/HDUCLAS/CONTENT dictionary

Note that this appendix is now largely empty and present for illustrative purposes only. The table itself is a living document; the current version can be found at http://hea-www.harvard.edu/~arots/asc/fits/content.txt but is also accessible through links from the Archive pages on the ASC-DS home page and from the authors home page http://hea-www.harvard.edu/~arots.

In addition, that document contains the standard FITS header components from this document in ASCII form and the file naming convention.

| Data product | HDUNAME | CONTENT | HDUCLASS | HDUCLAS1 | HDUCLAS2 | HDUCLAS3 |
|---|---|---|---|---|---|---|
| **Primary Products** | | | | | | |
| L1 Events | EVENTS | EVT1 | OGIP | EVENTS | ALL | |
| | GTI | GTI | OGIP | GTI | ALL | |
| L1(TG) Events | EVENTS | TGEVT | OGIP | EVENTS | ALL | |
| Mission Timeline | MTL | MTL | OGIP | TEMPORALDATA | TSI | |
| L2 Events | EVENTS | EVT2 | OGIP | EVENTS | ACCEPTED | |
| | GTI | GTI | OGIP | GTI | STANDARD | |
| | REGION | REGION | ASC | REGION | STANDARD | |
| L2 Spectrum | SPECTRUM | SPECTRUM | OGIP | SPECTRUM | TOTAL | COUNT |
| | GTI | GTI | OGIP | GTI | STANDARD | |
| L2 Spectrum | SPECTRUM | SPEC_BKG | OGIP | SPECTRUM | BKG | COUNT |
| | GTI | GTI | OGIP | GTI | STANDARD | |
| L2 Lightcurve | LIGHTCURVE | LIGHTCURVE | OGIP | LIGHTCURVE | TOTAL | RATE |
| | GTI | GTI | OGIP | GTI | STANDARD | |
| L2 Lightcurve | LIGHTCURVE | LTCRV_BKG | OGIP | LIGHTCURVE | BKG | RATE |
| **Secondary Products** | | | | | | |
| L2 Summary | SUMMARY | SUMMARY | ASC | CONFIG | ALL | |
| Sky image | IMAGE | IMG | OGIP | IMAGE | TOTAL | |
| Aspect solution | ASPECT | ACASOL | OGIP | TEMPORALDATA | ASPECT | |
| Source list | SRCLIST | SRC | OGIP | SRCLIST | | |
| Source Regions | SRCREG | SRCREG | ASC | REGION | | |
| Observed Bkg | BKG | BKG | ASC | IMAGE | BACKGROUND | |
| Orbit ephemeris | EPHEM | EPHEM | OGIP | TEMPORALDATA | EPHEM | |
| Aspect offsets | ASPOFF | ACAOFF | ASC | TEMPORALDATA | ASPOFF | |
| **Supporting Products** | | | | | | |
| L0 Events | EVENTS | EVT0 | OGIP | EVENTS | ALL | |

# B Appendix 2: Allowed units from OGIP/93-001

Table 8: OGIP/93-001 SI prefixes

| HEASARC Prefix | SI prefix | Value |
|---|---|---|
| y | yocto (y) | $10^{-24}$ |
| z | zepto (z) | $10^{-21}$ |
| a | atto (a) | $10^{-18}$ |
| f | femto (f) | $10^{-15}$ |
| p | pico (p) | $10^{-12}$ |
| n | nano (n) | $10^{-9}$ |
| u | micro ($\mu$) | $10^{-6}$ |
| m | milli (m) | $10^{-3}$ |
| c | centi (c) | $10^{-2}$ |
| d | deci (d) | $10^{-1}$ (deprecated) |
| da | deca (D) | 10 (deprecated) |
| h | hecto (h) | $10^{2}$ (deprecated) |
| k | kilo (k) | $10^{3}$ |
| M | mega (M) | $10^{6}$ |
| G | giga (G) | $10^{9}$ |
| T | tera (T) | $10^{12}$ |
| P | peta (P) | $10^{15}$ |
| E | exa (E) | $10^{18}$ |
| Z | zetta (Z) | $10^{21}$ |
| Y | yotta (Y) | $10^{24}$ |

Note in particular the use of the ASCII letter u in the HEASARC system to represent the symbol $\mu$ in the SI system.

Table 9: OGIP/93-001 allowed units

| Unit | Name | Type | Prefix? |
|---|---|---|---|
| m | metre | SI | Y |
| kg | kilogram | SI | Y (on g) |
| s | second | SI | Y |
| rad | radian | SI | Y |
| sr | steradian | SI | Y |
| K | kelvin | SI | Y |
| A | ampere | SI | Y |
| mol | mole | SI | Y |
| cd | candela | SI | Y |
| Hz | hertz | SI | Y |
| J | joule | SI | Y |
| W | watt | SI | Y |
| V | volt | SI | Y |

| | | | |
|---|---|---|---|
| N | newton | SI | Y |
| Pa | pascal | SI | Y |
| C | coulomb | SI | Y |
| ohm | ohm | SI | Y |
| S | siemens | SI | Y |
| F | farad | SI | Y |
| Wb | weber | SI | Y |
| T | tesla | SI | Y |
| H | henry | SI | Y |
| lm | lumen | SI | Y |
| lx | lux | SI | Y |
| deg | arc degree | | N |
| arcsec | arc second | | N |
| arcmin | arc minute | | N |
| min | minute | | N |
| h | hour | | N |
| yr | Julian year 365.25d | | N |
| d | day | | N |
| eV | electron volt | | Y |
| erg | erg | | N |
| angstrom | angstrom | | N |
| AU | astronomical unit | | N |
| lyr | light year | | N |
| pc | parsec | | Y |
| Jy | Jansky | | Y |
| mag | stellar magnitude | | N |
| Crab | Crab flux | | Y |
| G | gauss | | N |
| | | | |
| count | counts | | N |
| photon | photons | | N |
| pixel | pixel | | N |
| barn | barn | | N |
| chan | detector channel | | N |
| adu | analog-to-digital converter unit | | N |
| bin | bin | | N |
| voxel | 3-D pixel | | N |
| byte | byte | | N |

# C Appendix 3: Processing History Records

The processing history of ASC data products shall be inserted at the end of the headers of principal HDUs through HISTORY keywords.

The format shall be:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

HISTORY  llll  :ssssssssssssssssssssssssssssssssssssssssssssssssssssssssASCnnnnn


llll    label in columns 10-13 :  TOOL | PARM | CONT
s..s    string in columns 17-72
nnnnn   Sequence number in columns 76-80, with leading zeroes
```

TOOL
The string contains the tool's name and version, separated by one or more blanks.

PARM
The string contains one (or more?) ¡keyword¿=¡value¿ pairs

CONT
Continuation; the contents in columns 17-72 will be concatenated with the contents of columns 17-72 of the HISTORY keyword that has a sequence number one less than that of the current one.

These HISTORY keyword values will be used in the order specified by the sequence number, not necessarily in the order in which they appear.

The short version will contain only the parameters "infile" and "outfile", the long version all parameters.

Example:

```
HISTORY  TOOL  :mytool  12.03.09                                        ASC00001
HISTORY  PARM  :infile=something.img                                    ASC00002
HISTORY  PARM  :outfile=/local/data/xebec/arots/mydata/axaf/b1509/resultASC00003
HISTORY  CONT  :s/fileWithALongName                                     ASC00004
```