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Interim Report

AXAF FITS Standard for Ray Trace Interchange

Prepared in accordance with DR #3

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AXAF FITS Standard for Ray Trace Interchange

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Contents

1 Introduction

This document describes a standard data format for the archival and transport of X-ray events generated by ray trace models. Upon review and acceptance by the AXAF Software Systems Working Group (SSWG), this standard shall become the official AXAF data format for ray trace events.

The Flexible Image Transport System (FITS)[1, 2] is well suited for the purposes of the standard and has been selected to be the basis of the standard. FITS is both flexible and efficient and is also widely used within the astronomical community for storage and transfer of data. In addition, software to read and write FITS format files are widely available.

In selecting quantities to be included within the ray trace standard, the AXAF Mission Support team, Science Instruments team, and the other contractor teams were surveyed. From the results of this survey, the following requirements were established:

- For the scientific needs, each photon should have associated with it: position, direction, energy, and statistical weight. The standard must also accommodate path length (relative phase), and polarization. Double precision is needed for all these quantities.
- A unique photon identifier is necessary for bookkeeping purposes.
- A log of individuals, organizations, and software packages that have modified the data must be maintained in order to create an audit trail.
- A mechanism for extensions to the basic kernel should be provided.
- The ray trace standard should integrate with future AXAF data product standards.

2 The Ray Trace Standard

The AXAF ray trace standard is based upon the Binary Table Extension to FITS. The FITS file structure shall consist of the following:

- Primary Array Header (with a NULL primary array).
- RAYTRACE Binary Table Extension Header.
- RAYTRACE Data.

Keyword	Value	Description
SIMPLE	T	FITS mandatory
BITPIX	8	FITS mandatory
NAXIS	0	FITS mandatory
EXTEND	T	FITS mandatory
CONTENT	'SIMULATION'	Identifies file as the result of simulation
ORIGIN	char	The organization generating the FITS file
OBSERVER	char	The person generating the ray trace
DATE	'dd/mm/yy'	Date the FITS file was created
TELESCOP	char	Name of telescope model used
PROGNAME	char	Name of simulation software used
OBJECT	char	name of observed object
DATE-OBS	'dd/mm/yy'	U.T. simulation was done
TIME-OBS	'hh:mm:ss'	U.T. simulation was done
HISTORY	comments	Each software module shall append a history line with its version and parameters
END		FITS mandatory

Table 1: Primary Header keywords required by the AXAF ray trace standard

The Primary Array Header shall contain all history and logging information associated with the data stored. All the information associated with individual photon events shall be stored in the RAYTRACE binary table extension.

2.1 Primary Header

Table 1 summarizes the FITS primary header keywords required by the AXAF ray trace standard. An example of both a primary and secondary header is given in Appendix B. The keywords required for the AXAF ray trace standard have been chosen from standard FITS reserved keywords and keywords in common use within the astronomical community.

2.1.1 Primary Header Required Keywords

The following keywords are required by FITS:

SIMPLE is required to be the first keyword and have logical value T to signify this file as a conforming FITS file.

BITPIX is required to be the second keyword. For AXAF ray trace, it has a value of 8 signifying eight bit bytes.

NAXIS is required to be the third keyword. For AXAF ray trace, it has a value of 0 signifying no data in the primary data array.

EXTEND is required to have a logical value T to signify that FITS extensions follow the primary data array.

END is required to be the last keyword of the primary header.

The remaining keywords described in this section are required by the AXAF ray trace standard in order to provide a description of the data file. It is important that these keywords be maintained so that each data file contains information about its own content and history. As much as possible, these keywords have been chosen from keywords currently in common use.

CONTENT shall contain the string 'SIMULATION'. The keyword identifies the FITS file as containing simulated data. Files in FITS format containing SIMULATION data may encompass data products from simulated science instruments as well as from ray trace models.

ORIGIN shall contain a string identifying the organization creating the FITS file. The keyword is a FITS reserved keyword.

OBSERVER shall contain a string identifying the person generating the ray trace. The keyword is a FITS reserved keyword.

DATE, DATE-OBS, TIME-OBS the DATE field shall contain the date the FITS file was created. The DATE-OBS, and TIME-OBS traditionally refer to date and time of observation; for ray trace, they will refer to the date and time of the original simulation. By FITS convention, dates and times are specified as 'dd/mm/yy' and 'hh:mm:ss' in Universal Time.

TELESCOP shall specify the name of the telescope model used for the ray trace.

PROGNAME shall specify the name of the ray trace program.

OBJECT shall specify the object modeled (e.g., 'POINT SOURCE').

HISTORY this keyword may be repeated and is used to log transformations on the data. The AXAF ray trace standard requires each software package which operates on the data to append a HISTORY line with the name and version of the software package, the date, the user, and a statement of the parameters used. This line may be continued on multiple HISTORY lines by using a backslash (\) character as the last non-blank character in a line to be continued. A full description of formats in current use is included in Appendix C.

Keyword	Value	Description
XTENSION	'BINTABLE'	FITS mandatory
BITPIX	8	FITS mandatory
NAXIS	2	FITS mandatory
NAXIS1	int	FITS mandatory, bytes per row
NAXIS2	int	FITS mandatory, rows in data array
EXTNAME	'RAYTRACE'	Identifies data as result of ray tracing
RTVER	1	Identifies version of raytrace standard
ORIGIN	char	The organization generating the FITS file
OBSERVER	char	The person generating the ray trace
TELESCOP	char	Name of telescope model used
PROGNAME	char	Name of simulation software used
OBJECT	char	name of observed object
DATE-OBS	'dd/mm/yy'	U.T. simulation was done
TIME-OBS	'hh:mm:ss'	U.T. simulation was done
PCOUNT	0	FITS mandatory
GCOUNT	1	FITS mandatory
TFIELDS	int	fields per row
TTYPEn	char	Name of field n
TFORMn	char	Data type of field n
TUNITn	char	Physical units of field n
END		FITS mandatory

Table 2: Secondary Header keywords required by the AXAF ray trace standard

2.1.2 Primary Header Optional Keywords

The AXAF ray trace standard defines no optional keywords for the primary header.

2.2 Raytrace Extension Header

Table 2 summarizes the FITS secondary header keywords required by the AXAF ray trace standard. These keywords define a data array conforming to the binary table extension of FITS.

A FITS binary table can be thought of as a table of rows and columns. For the AXAF ray trace standard, there shall be one row for every ray. A description of the named columns (or fields) is given in Section 2.3 and for an example of both a primary and secondary header see Appendix B.

2.2.1 RAYTRACE Required Keywords

The following keywords are required by the FITS binary table extension standard:

XTENSION is required to be the first keyword and contain the string 'BINTABLE' signifying conformance with the binary table extension.

BITPIX is required to be the second keyword and to have a value of 8 signifying eight bit bytes.

NAXIS is required to be the third keyword. For binary table extensions it has a value of 2.

NAXIS1 is required to be the fourth keyword. It has an integer value specifying the number of bytes needed for each row of data.

NAXIS2 is required to be the fifth keyword. It has an integer value specifying the number of rows (or photon events) in the data array.

PCOUNT is required to have an integer value of 0.

GCOUNT is required to have an integer value of 1.

END is required to be the last keyword of the binary table extension header.

The remaining keywords described in this section are required by the AXAF ray trace standard in order to provide a description of the data file. It is important that these keywords be maintained so that each data file contains information about its own content. As much as possible, these keywords have been chosen from keywords currently in common use. The keywords are as follows:

EXTNAME this FITS reserved keyword shall contain the string 'RAYTRACE' identifying this binary table extension as one which contains the result of ray trace modeling.

RTVER shall contain an integer 1, which signifies that this file conforms to the current version (v 1) of the AXAF raytrace standard.

ORIGIN shall contain a string identifying the organization creating the FITS file. The keyword is a FITS reserved keyword and is duplicated from the primary header.

OBSERVER shall contain a string identifying the person generating the ray trace. The keyword is a FITS reserved keyword and is duplicated from the primary header.

DATE-OBS, TIME-OBS The DATE-OBS, and TIME-OBS traditionally refer to date and time of observation; for ray trace, they will refer to the date and time of the original simulation. By FITS convention, dates and times are specified as 'dd/mm/yy' and 'hh:mm:ss' in Universal Time. The keywords are duplicated from the primary header.

TELESCOP shall specify the name of the telescope model used for the ray trace. The keyword is duplicated from the primary header.

PROGNAME shall specify the name of the ray trace program. The keyword is duplicated from the primary header.

OBJECT shall specify the object modeled (e.g., 'POINT SOURCE'). The keyword is duplicated from the primary header.

TFIELDS this keyword shall contain an integer specifying the number of fields contained in the data array.

TTYPE*n* these keywords shall be character strings specifying the name of data field n (e.g., 'RT_X'). n shall be a value in the range 1 . . . TFIELDS.

TFORM*n* these keywords shall contain character strings specifying the data type of field n (e.g., 'D' for double precision, 'J' for 32-bit integer). n shall be a value in the range 1 . . . TFIELDS.

TUNIT*n* these keywords shall contain character strings specifying the physical units of field n (e.g., 'mm', 'KeV'). n shall be a value in the range 1 . . . TFIELDS.

2.2.2 Raytrace Header Optional Keywords

At present, the AXAF ray trace standard defines no optional keywords for the ray trace binary extension header.

2.3 Required Photon Event Fields

Table 3 summarizes the required fields for the RAYTRACE binary extension. An example of their definition within the FITS extension header is given in Appendix B. These keywords were chosen to represent quantities currently used or anticipated to be useful within the AXAF community. The names are prefixed with "RT_" to signify raytrace quantities and to prevent clashes with FITS fields used in other extensions. The units and axes were chosen to conform as much as possible to common usage.

Field Name	Type	Units	Description
RT_X	double	mm	X Position
RT_Y	double	mm	Y Position
RT_Z	double	mm	Z Position
RT_COSX	double	-	X direction cosine
RT_COSY	double	-	Y direction cosine
RT_COSZ	double	-	Z direction cosine
RT_KEV	double	KeV	Energy of photon
RT_WGHT	double	cm**2	Statistical weight of ray
RT_ID	32-bit	-	Photon ID number from ray trace

Table 3: Photon fields required by the AXAF ray trace standard

All fields listed in Table 3 shall be required even if they are of constant value (e.g., RT_KEV = 1.0, RT_Z = 0.0). This allows the standard to be used by the most rudimentary FITS readers.

2.3.1 Coordinate System and Units

Positions and directions within the AXAF ray trace standard shall be defined according to a right-handed coordinate system with the following properties:

- The Z axis is co-incident with the optical axis of a perfect system.
- A standard origin of the coordinate system shall be defined for each optical system modeled. For all AXAF optics, the XY plane shall be defined as the plane bisecting the AXAF Central Aperture Plate (CAP).
- The rays travel in the positive z direction. Thus a typical object to be imaged will have a large negative z coordinate.
- The Y axis shall be aligned with the "vertical axis" with positive y corresponding with "up" and negative y corresponding with "down." Where appropriate, "down" is defined as the direction of gravity.

The AXAF ray trace standard has not adopted AXAF spacecraft coordinates ("forward" is positive X, "down" is positive Z). The spacecraft coordinates were chosen according to standard aeronautical practices, but conforms to neither standard optical practices nor standard astronomical practices. In order to minimize confusion, the AXAF ray trace standard has chosen a coordinate system in common use by the raytracing community.

Several quantities associated with X-ray photon events have associated physical dimensions. The AXAF ray trace standard shall specify a particular choice of units. It is felt that allowing arbitrary units would add unnecessary complexity to the ray trace standard and to any FITS reader used to read the standard.

2.3.2 Photon Position: RT_X, RT_Y, RT_Z

The position of each photon shall be stored as three IEEE double precision numbers and be in fields named RT_X, RT_Y, and RT_Z. In keeping with the standard practice in Optical Engineering, the positions of each individual rays shall be stored in units of millimeters (mm).

2.3.3 Photon Direction: RT_COSX, RT_COSY, RT_COSZ

The direction of each photon ray shall be stored as three IEEE double precision numbers and be in fields named RT_COSX, RT_COSY, and RT_COSZ. These numbers are dimensionless and defined to be the cosine of the angle between the photon ray and the x, y, and z coordinate axes, respectively.

2.3.4 Photon Energy: RT_KEV

The energy of each photon shall be stored as an IEEE double precision number and be in a field named RT_KEV. This number shall have units of KeV. This quantity can be converted to wavelength using the equation $\lambda = hc/E$ where λ is the wavelength, $h = 4.135669 \times 10^{-18}$ KeV s is Plank's constant, and $c = 2.99792458 \times 10^{8}$ m s^{-1}.

If the ray trace modeling software does not give energies, a canonical value of RT_KEV = 0.0 should be used.

2.3.5 Statistical Weight: RT_WGHT

The statistical weight of each photon event shall be stored as an IEEE double precision number and be in a field named RT_WGHT. This number has units of square centimeters. This value is defined by the following identity:

$$\sum_{i}^{N} \mathrm{RT\_WGHT}_i = A \qquad (1)$$

Namely the sum of the statistical weights give the effective area (in square centimeters) of the optic modeled by the ray trace.

If the ray trace modeling software does not generate statistical weights, the value A/N, (i.e. effective area divided by number of rays) should be used.

2.3.6 Photon Identifier: RT_ID

Each ray in the event list shall have an identifier stored as a 32-bit integer and be in a field named RT_ID. The AXAF ray trace standard makes no requirement for the RT_ID field aside from its existence.

2.4 Optional Photon Event Fields

Field Name	Type	Units	Description
RT_LEN	double	mm	Path length of Ray
RT_STK1	double	-	S1 Stokes Parameter (Polarization)
RT_STK2	double	-	S2 Stokes Parameter (Polarization)
RT_STK3	double	-	S3 Stokes Parameter (Polarization)
RT_TIME	double	s	Simulated arrival time
RT_ALPn	double	rad	grazing angles
RT_MP	int	-	mirror pair of ray

Table 4: Optional photon fields AXAF ray trace standard

Table 4 lists the optional fields that may be included or left out. If the field is not present, the canonical value may be assumed.

2.4.1 Path Length: RT_LEN

The optical path length of each ray shall be stored as an IEEE double precision number and be in a field named RT_LEN. This number has units of millimeters. It is defined as the distance the ray has traveled from an arbitrary plane perpendicular to the optical axis. This value may also be converted the optical phase of the ray.

A canonical value of 0.0 may be used for event lists where there is no associated optical path length information.

2.4.2 Photon Polarization: RT_STK1, RT_STK2, RT_STK3

The polarization of each ray shall be stored as three IEEE double precision numbers and be in fields named RT_STK1, RT_STK2, and RT_STK3. These fields correspond to the Stokes parameters s_1, s_2, and s_3 modified to be dimensionless.

The standard definition of Stokes parameters have units of electric field intensity. For ray traces of polarized photon events, the AXAF ray trace standard shall require that the polarization fields obey the relation

$$\mathrm{RT\_STK1}^2 + \mathrm{RT\_STK2}^2 + \mathrm{RT\_STK3}^2 = 1 \tag{2}$$

Unpolarized light is characterized by

$$s_1 = s_2 = s_3 = 0. \tag{3}$$

A canonical value of 0.0 should be used for event lists where there is no associated polarization information.

A full description of the Stokes parameters may be found in Appendix A.

2.4.3 Arrival Time: RT_TIME

The simulated arrival time shall be stored as an IEEE double precision number and be in a field named RT_TIME. This field has units of seconds and shall time tag the arrival of a ray. The beginning of the ray trace shall be RT_TIME of 0.0. This field has no default value.

2.4.4 Grazing Angles: RT_ALPn

The grazing angles $\alpha_1, \alpha_2, \ldots, \alpha_n$ shall be stored as IEEE double precision numbers in the fields named RT_ALP1, RT_ALP2, ..., RT_ALPn. The grazing angles are measured in radians and defined as the angle between the incident ray and the tangent to each mirror surface. Thus, for X-rays, each grazing angle will be a small number close to 0.0 (as opposed to a number near $\pi/2$). The angles are numbered such that α_1 is the first reflection the ray encounters while propagating from the source.

2.4.5 Mirror Pair Index: RT_MP

Each ray in the event list may also be tagged by a mirror pair index. This index shall be stored as a 32-bit integer in the field named RT_MP. This field will be used to allow the resulting rays from a ray trace to be separated according to the component of the optics with which they interacted.

3 Future Extensions

The AXAF ray trace standard will be maintained by the AXAF SSWG and may ultimately be adopted by the AXAF Science Center (ASC). The maintainer of the standard shall be responsible for documenting extensions to the standard. Extensions to the ray trace standard may consist of additional optional fields to the RAYTRACE binary table array. Additional SIMULATION extensions may also be defined to accommodate simulated instrument responses.

3.1 Extensions to RAYTRACE

Optional keywords and data fields may be added to the RAYTRACE standard. It is strongly recommended that new field names all be prefixed with the string 'RT_' to signify ray trace data. It is important to avoid field name clashes with field names currently in use to archive real X-ray data.

Essential housekeeping information that is specific to a software package may be passed in an optional field named "RT_[package]." For example, CYGNUS may have a field named "RT_CYGNU" to pass CYGNUS specific data. Use of such fields should be minimized since they decrease the portability of the ray trace data.

The maintainer of the standard shall make every effort to incorporate new optional keywords and fields that the community finds useful.

3.2 Extensions to SIMULATION

The FITS standard allows a data file to contain many extensions, each of which is a separate block of data. The AXAF ray trace standard has defined a block named RAYTRACE within a SIMULATION FITS file. It would be natural to define additional types of data blocks which can accommodate the results of simulated science instrument responses to ray trace inputs. Data blocks may also be used to record ancillary data about the ray trace (e.g., source spectrum, source geometry, optical constants). The feasibility and desirability of such future standards should be explored.

A Stokes Parameters

It is common practice in the study of optics and radiative processes to characterize polarization in terms of a set of four Stoke's parameters. The term "Stoke's parameters" refer to a class of parameterization schemes rather than a single unique parameterization. In particular, there is neither a consistent normalization nor a consistent sign convention to specify the helicity of a ray. For the AXAF ray trace standard, we have no meaningful measure of intensity and we shall impose a normalization to unity. For the helicity we have chosen to follow a parameterization scheme that seems to be more popular within the radio and optical polarimetry community. This convention is described in Jackson's *Classical Electrodynamics.* and Hecht and Zajac's *Optics.* The standard is opposite the convention found in Born and Wolf.

Specifically, imagine a plane wave propagating in the positive z direction. The x direction shall be defined as the projection of the AXAF ray trace x-axis upon the plane normal to the incident ray. The x and y components of the electric field can then be described as

$$E_x = a_1 e^{i(kz-\omega t+\delta_1)}, \tag{4}$$
$$E_y = a_2 e^{i(kz-\omega t+\delta_2)}. \tag{5}$$

Then the four Stokes parameters are defined as

$$\begin{aligned} s_0 &= {a_1}^2 + {a_2}^2, & (6)\\ s_1 &= {a_1}^2 - {a_2}^2, & (7)\\ s_2 &= 2a_1a_2\cos(\delta_2-\delta_1), & (8)\\ s_3 &= 2a_1a_2\sin(\delta_2-\delta_1), & (9) \end{aligned}$$

One can also parameterize the electric field in terms of helicity. A wave with positive helicity appears to rotate counter-clockwise to an observer being approached by the wave. Positive helicity is also referred to as *right-handed* circular polarization and *left* circular polarization. With the electric field parameterized as:

$$E_+ = a_+ e^{i(kz-\omega t+\delta_+)}, \tag{10}$$
$$E_- = a_- e^{i(kz-\omega t+\delta_-)}. \tag{11}$$

Then the four Stokes parameters are defined as

$$\begin{aligned} s_0 &= {a_+}^2 + {a_-}^2, & (12)\\ s_1 &= 2a_+a_-\cos(\delta_- - \delta_+), & (13)\\ s_2 &= 2a_+a_-\sin(\delta_- - \delta_+), & (14)\\ s_3 &= {a_+}^2 - {a_-}^2, & (15) \end{aligned}$$

For a wave traveling in the $+z$ direction, the definitions chosen have the following physical interpretations:

$(s_1, s_2, s_3) = (+1, 0, 0)$	linearly polarized in x direction
$(s_1, s_2, s_3) = (-1, 0, 0)$	linearly polarized in y direction
$(s_1, s_2, s_3) = (0, +1, 0)$	linearly polarized in $\hat{x} + \hat{y}$ direction
$(s_1, s_2, s_3) = (0, -1, 0)$	linearly polarized in $\hat{x} - \hat{y}$ direction
$(s_1, s_2, s_3) = (0, 0, +1)$	pure positive helicity
$(s_1, s_2, s_3) = (0, 0, -1)$	pure negative helicity

The polarization of rays stored in the AXAF ray trace standard shall be described by three Stoke's parameters stored in the data fields named RT_STK1, RT_STK2, and RT_STK3. These three values shall correspond to (s_1, s_2, s_3) normalized so that ${s_1}^2 + {s_2}^2 + {s_3}^2 = 1$.

In the astronomical literature, (s_0, s_1, s_2, s_3), are often denoted as (I, Q, U, V) and use a coordinate system aligned with the celestial declination and right ascension axes. We have chosen to forgo this nomenclature in order to avoid confusion.

B Sample FITS headers

The listing of the primary header for this FITS file follows:

```
***************************************
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                    8 / number of bits per data pixel
NAXIS   =                    0 / number of data axes
EXTEND  =                    T / FITS dataset may contain extensions

CONTENT = 'SIMULATION'         / file contains simulated data
ORIGIN  = 'SAO     '           / origin of FITS file: NASA/GSFC
OBSERVER= 'hsieh'              / person creating ray trace
DATE    = '01/03/93'           / FITS file creation date (dd/mm/yy)
TELESCOP= 'S-AXAF  '           / Modeled telescope: simulated AXAF
PROGNAME= 'OSAC    '           / ray trace program: OSAC
OBJECT  = 'pointsource'        / name of observed object
DATE-OBS= '01/03/93'           / U.T. date of observation start  (dd/mm/yy)
TIME-OBS= '21:11:36'           / U.T. time of observation start (hh:mm:ss)
HISTORY   OSAC v1.0 1-MAR-1993 run with foo source parameters \
HISTORY   and bar mirror parameters
HISTORY   FITOSAC v0.1 1-MAR-1993 applied vignetting with foo parameters
END
```

The listing of the secondary header for this FITS file follows:

```
*********************************************
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                  100 / width of table in bytes (12*8+1*4)
NAXIS2  =                   30 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
EXTNAME = 'RAYTRACE'           / name: table of ray trace photon events
ORIGIN  = 'SAO     '           / origin of FITS file: NASA/GSFC
OBSERVER= 'hsieh'              / person creating ray trace
TELESCOP= 'S-AXAF  '           / Modeled telescope: simulated AXAF
PROGNAME= 'OSAC    '           / ray trace program: OSAC
OBJECT  = 'pointsource'        / name of observed object
DATE-OBS= '01/03/93'           / U.T. date of observation start  (dd/mm/yy)
TIME-OBS= '21:11:36'           / U.T. time of observation start (hh:mm:ss)
TFIELDS =                   13 / number of fields in each row
TTYPE1  = 'RT_X    '           / X Position
```

```
TFORM1  = 'D        '           / X Position
TUNIT1  = 'mm       '           / X Position
TTYPE2  = 'RT_Y     '           / Y Position
TFORM2  = 'D        '           / Y Position
TUNIT2  = 'mm       '           / Y Position
TTYPE3  = 'RT_Z     '           / Z Position
TFORM3  = 'D        '           / Z Position
TUNIT3  = 'mm       '           / Z Position
TTYPE4  = 'RT_COSX  '           / X direction cosine
TFORM4  = 'D        '           / X direction cosine
TUNIT4  = '         '           / X direction cosine
TTYPE5  = 'RT_COSY  '           / Y direction cosine
TFORM5  = 'D        '           / Y direction cosine
TUNIT5  = '         '           / Y direction cosine
TTYPE6  = 'RT_COSZ  '           / Z direction cosine
TFORM6  = 'D        '           / Z direction cosine
TUNIT6  = '         '           / Z direction cosine
TTYPE7  = 'RT_KEV   '           / Energy of photon
TFORM7  = 'D        '           / Energy of photon
TUNIT7  = 'KeV      '           / Energy of photon
TTYPE8  = 'RT_WGHT  '           / Statistical weight of ray
TFORM8  = 'D        '           / Statistical weight of ray
TUNIT8  = 'cm**2    '           / Statistical weight of ray
TTYPE9  = 'RT_ID    '           / Arbitrary ID
TFORM9  = 'J        '           / Arbitrary ID
TUNIT9  = '         '           / Arbitrary ID
TTYPE10 = 'RT_LEN   '           / Path Length of Ray
TFORM10 = 'D        '           / Path Length of Ray
TUNIT10 = 'mm       '           / Path Length of Ray
TTYPE11 = 'RT_STK1  '           / S1 Stokes Parameter (Polarization)
TFORM11 = 'D        '           / S1 Stokes Parameter (Polarization)
TUNIT11 = '         '           / S1 Stokes Parameter (Polarization)
TTYPE12 = 'RT_STK2  '           / S2 Stokes Parameter (Polarization)
TFORM12 = 'D        '           / S2 Stokes Parameter (Polarization)
TUNIT12 = '         '           / S2 Stokes Parameter (Polarization)
TTYPE13 = 'RT_STK3  '           / S3 Stokes Parameter (Polarization)
TFORM13 = 'D        '           / S3 Stokes Parameter (Polarization)
TUNIT13 = '         '           / S3 Stokes Parameter (Polarization)
END
```

C HISTORY keyword

The AXAF ray trace standard keeps a log of all software that has operated upon the photon event list. This log is maintained by appending HISTORY keywords to the the primary header of the FITS file. In this section, we tabulate the content and format that various software packages use to log history information.

C.1 CYGNUS

C.2 IRT

C.3 MIRROR

C.4 OSAC

References

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