Astronomical Data Analysis Software and Systems XIII
ASP Conference Series, Vol. 314, 2004
F. Ochsenbein, M. Allen, and D. Egret, eds.

Developments in the Starlink AST Library - an Intelligent WCS Management System

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Abstract. Recent developments in the AST library for managing WCS information are described. These include support for spectral coordinate systems, and compliance with FITS WCS papers I, II and III.

1. The Starlink AST Library

- Home page at http://www.starlink.ac.uk/ast/.
- Provides a comprehensive range of facilities for attaching world coordinate systems to astronomical data, for retrieving and interpreting that information and for generating graphical output such as coordinate grids based upon it.
- Can read and write WCS information stored in the form of FITS-WCS headers, but also provides its own richer format.
- Object-oriented design implemented in pure ANSI C with interfaces for C, FORTRAN and Java (via JNI).
- Has built-in intelligence for identifying flavours of celestial, spectral and other coordinate systems and determining how to transform between them, allowing general purpose code to be written which makes no assumptions about the nature of the coordinate systems.
- Includes a flexible and versatile "tool-kit" for creating and modifying collections of coordinate frames interconnected by arbitrarily complex transformations.
- Easy-to-use graphical facilities allow the production of annotated grids. Graphics are drawn via a simple "driver" module which AST calls to draw lines, strings, markers, etc. AST includes a driver for PGPLOT; drivers for other graphics systems (*e.g.* Tcl/Tk, Java/Swing, *etc.*) can easily be (and have been) written. An example of code which draws a coordinate grid is shown on this poster.

2. What's New in AST

2.1. V2.0 - Highlights Only

- A new class called SpecFrame has been added which represents positions within an electro-magnetic spectrum . SpecFrame can convert spectral axis values between any of the coordinate systems or rest frames listed in FITS-WCS paper III, using any appropriate units.

- The astConvert method, which automatically finds a Mapping between any two coordinate Frames, now takes account of the "Units" string in the two Frames, so long as they use the conventions for described units included in FITS-WCS paper I.

2.2. V3.0 - Highlights Only

- Support for FITS-WCS papers I, II, III & IV has been extended significantly. The current status is shown in Tables 1 and 2.
- Includes new documentation giving the details of AST's implementation of FITS-WCS papers I, II and III.
- The SkyFrame class (which represents coordinate systems on the sky) now supports ICRS and helio-ecliptic coords.
- The Mapping class (which represents coordinate transformations) has a new method to determine the rate of change of any Mapping output with respect to any Mapping input.
- Several new sub-classes of Mapping have been added:

  PolyMap: Performs a general N-dimensional polynomial transformation.

  GrismMap: Models the dispersion in a grism or prism.

  ShiftMap: Shifts each axis by a specified constant.

- Simplification of complex Mappings has been extended.

3. Coming Soon

- New XML formats for WCS information, including IVOA Space-Time-Coordinate format.
- Support for coordinate systems representing time, including automatic identification and conversion between different temporal systems.
- Increased coverage of FITS-WCS papers.

Table 1. Support within AST V3.0 for FITS-WCS features.

Feature	**Status**
Axis distortions (as described in paper IV)	Ignored (except for the SIRTF-specific "-SIP" code which is interpreted correctly when reading a FITS header, but is never written out to a new FITS header).
Alternate axis descriptions	Supported
User-defined fiducial points	Supported
Choice of PCi_ja or CDi_ja matrix	Supported
Deprecated WCS conventions (*e.g.* keyword CROTAi, EPOCH, PCiiijjj, the NCP projection, *etc.*)	Supported
Alternate keyword formats for inclusion in tables	Unsupported
Units in comment strings	Unsupported
Uncertainties in the coordinates	Unsupported
"WCSDEP" convention	Unsupported
Use of longitude projection parameters to store LONPOLE and LATPOLE	Supported
Common, non-standard features	Support for reading (but not writing) various common, non-standard feature such as "TNX" and "ZPX" projections is included. More can easily be added as requested.

Table 2. Support within AST V3.0 for FITS-WCS keywords.

Keyword	**Description**	**Status**
WCSAXESa	WCS dimensionality	Supported
CRVALia	Value at reference point	Supported
CRPIXja	Pixel of reference point	Supported
CDELTia	Increment at reference point	Supported
CROTAi	Rotation at reference point	Supported (only written when producing a "FITS-AIPS" header)
CTYPEia	Coordinate/algorithm/distortion type	Supported (all coordinate systems [including helio-ecliptic] and algorithm codes listed in papers I, II and III, with the exception of the "STOKES" and "COMPLEX" values defined in paper I, the "CUBEFACE" value defined in paper II, and the "-TAB" algorithm defined in paper III)
CUNITia	Units of coordinate values	Supported (including automatic unit conversion if the units strings conform to paper I conventions)
PCi_ja	Transformation matrix	Supported
CDi_ja	Transformation matrix	Supported
PVi_ma	Algorithm numerical parameter	Supported
PSi_ma	Algorithm textual parameter	Unsupported
WCSNAMEa	Coordinate version name	Supported
CRDERia	Random error	Unsupported
CSYERia	Systematic error	Unsupported
LONPOLEa	Coordinate rotation (celestial axes)	Supported
LATPOLEa	Coordinate rotation (celestial axes)	Supported
RADESYSa	Frame of reference (celestial axes)	Supported (all systems, except ecliptic coordinates are currently assumed to be FK5)
EQUINOXa	Coordinate epoch (celestial axes)	Supported
EPOCH	Coordinate epoch (celestial axes)	Supported (only written when producing a "FITS-AIPS" header)
MJD-OBS	Time of observation	Supported
SPECSYSa	Spectral reference frame	Supported (all systems, except CMB-DIPOL)
SSYSOBSa	Spectral reference frame fixed during observation	Unsupported
OBSGEO-X/Y/Z	Observation position	Supported
MJD-AVG	Average date of observation	Supported
VSOURCEa	Physical velocity of source for SPECSYS=SOURCE cases	Supported
ZSOURCEa	Optical velocity of source for SPECSYS=SOURCE cases	Supported
VELOSYSa	Velocity w.r.t. standard of rest	Unsupported
RESTFRQa	Line rest frequency	Supported
RESTWAVa	Line rest wavelength in vacuum	Supported
CNAMEia	Descriptive axis label	Supported