**FITS Files**

Astronomical data are stored in FITS – Flexible Image Transport System – files whose definition can be found here: <https://fits.gsfc.nasa.gov/standard40/fits_standard40aa-le.pdf>

There is an excellent primer on the structure of FITS files here: <https://fits.gsfc.nasa.gov/fits_primer.html> . The following contains direct excerpts from this document.

FITS (Flexible Image Transport System) is the data format most widely used within astronomy for transporting, analyzing, and archiving scientific data files. FITS is much more than just another image format (such as JPG or GIF) and is primarily designed to store scientific data sets consisting of multidimensional arrays (images) and 2-dimensional tables organized into rows and columns of information.

A FITS file is comprised of segments called Header/Data Units (HDUs), where the first HDU is called the `Primary HDU', or `Primary Array'. The primary data array can contain a 1-999 dimensional array of 1, 2 or 4-byte integers or 4 or 8 byte floating point numbers… A typical primary array could contain a 1-D spectrum, a 2-D image, or a 3-D data cube.

Header Units:

Every HDU consists of an ASCII formatted `Header Unit' followed by an optional `Data Unit'. Each header or data unit is a multiple of 2880 bytes long. Each header unit contains a sequence of fixed-length 80-character keyword records which have the general form:

KEYNAME = value / comment string

The keyword names may be up to 8 characters long and can only contain uppercase letters A to Z, the digits 0 to 9, the hyphen, and the underscore character. The keyword name is (usually) followed by an equals sign and a space character in columns 9 and 10 of the record, followed by the value of the keyword which may be either an integer, a floating point number, a complex value (i.e., a pair of numbers), a character string (enclosed in single quotes), or a Boolean value (the letter T or F). Some keywords, (e.g., COMMENT and HISTORY) are not followed by an equals sign and in that case columns 9 - 80 of the record may contain any string of ASCII text.

Each header unit begins with a series of required keywords that specify the size and format of the following data unit. A 2-dimensional image primary array header, for example, begins with the following keywords:

SIMPLE = T / file conforms to FITS standard

BITPIX = 16 / number of bits per data pixel

NAXIS = 2 / number of data axes

NAXIS1 = 440 / length of data axis 1

NAXIS2 = 300 / length of data axis 2

The required keywords may be followed by other optional keywords to describe various aspects of the data, such as the date and time of the observation. COMMENT or HISTORY keywords are also frequently added to further document the contents of the data file.

The last keyword in the header is always the `END' keyword which has blank value and comment fields. The header is padded with additional blank records if necessary so that it is a multiple of 2880 bytes (equivalent to 36 80-byte keywords) long.

Data Units:

The data unit, if present, immediately follows the last 2880-byte block in the header unit. Note that the data unit is not required, so some HDUs only contain the header unit.

The image pixels in a primary array or an image extension may have one of 5 supported data types:

* 8-bit (unsigned) integer bytes
* 16-bit (signed) integers
* 32-bit (signed) integers
* 32-bit single precision floating point real numbers
* 64-bit double precision floating point real numbers

A 64-bit integer datatype has also been proposed and is currently in experimental use. Unsigned 16-bit and 32-bit integers are supported by subtracting an offset from the raw pixel values (e.g., 32768 (2\*\*15) is subtracted from each unsigned 16-bit integer pixel value to shift the values into the range of a signed 16-bit integer) before writing them to the FITS file. This offset is then added to the pixels when reading the FITS image to restore the original values.

The other 2 types of standard extensions, ASCII tables and binary tables, contain tabular information organized into rows and columns. Generally speaking, binary tables are more compact and are faster to read and write than than ASCII tables because the numeric entries are stored in machine readable binary representation.

All the entries within a given column of an ASCII or Binary table extension have the same datatype. The allowed data formats for an ASCII table column are: integer, single or double precision floating point value, or character string. Binary table extensions also support logical (T/F), bit, and complex data formats.

Each entry, or field, in an ASCII table may only contain 1 scalar value. Binary tables are more flexible and allow N-dimensional arrays of of data (either fixed length or variable length) to be stored within each field. Variable-length arrays are implemented by storing a pointer in the field of the table which defines the length and byte offset to the start of the data array which is located in the "heap" area that follows the table proper. The variable-length-arrays convention is not strictly part of the FITS standard but is widely used.

**Example: FITS Header for DAO Data**

BSCALE = 1.0 /

BZERO = 32768 /

EXPTIME = 90 /

XBIN = 2 /

YBIN = 2 /

CTYPE1 = 'PIXEL' / axis1 in pixels

CTYPE2 = 'PIXEL' / axis2 in pixels

CCDTEMP = -104.1 / detector temperature [C]

DATE-OBS= '2014-07-03T10:58:28'/

UT-DATE = '2014-07-03' /

UT = '10:58:28' /

MJD-OBS = 56841.45727 / modified Julian Date start of observation

OBSTYPE = 'flat ' / OBSERVATION TYPE

OBJECT = 'long Flat'

TELESCOP= '1.8-m' / This telescope

OBSERVAT= 'DAO' / Location

ORIGIN = 'NRC/HIA' / Organization responsible for FITS file

WIND\_SPD= 4.0 / Wind speed, m/s

MAX\_WND = 7.5 / Max wind speed last min,m/s

WIND\_DIR= 229.3 / Wind direction, degrees

WIND\_CHL= 7.8 / Wind chill, deg C

OUT\_TEMP= 12.0 / Outside Temperature, deg C

REL\_HUMI= 77.0 / Outside relative humidity, percent

DEWPOINT= 8.0 / Outside dew point, deg C

TELFOCUS= 8960 / Newtonian focus

FILPOS = 3 / Newt. raw filter pos

WAVELENG= 6200 / Newt. filter central wavelength

BANDPASS= 1300 / Newt. filter bandpass width

FILTER = 'SDSS r prime' / Newt. filter name

ST = '21:30:21.65' / AT START OF EXPOSURE

RA = '23:00:06.20' / AT START OF EXPOSURE

DEC = '+19:55:44.2' / AT START OF EXPOSURE

HA = '-01:29:44.54' / AT START OF EXPOSURE

DOMEAZ = 125.57 / AT START OF EXPOSURE

ZD = 33.81 / AT START OF EXPOSURE

EQUINOX = 2014.50 / AT START OF EXPOSURE

ALTITUDE= 56.19 / AT START OF EXPOSURE

AIRMASS = 1.2035 / AT START OF EXPOSURE

INSTRUME= 'Newtonian Imager' / Instrument used

OBSMODE = 'Imaging' / Observing mode

OBSERVER= 'Balam' / Observer

PINAME = 'DeRobertis' / Principal investigator name

DATASEC = '[5:1015,1:2306]'

BIASSEC = '[1:4,1:2306]'

RELEASE = '2014-07-03T11:00:32'/