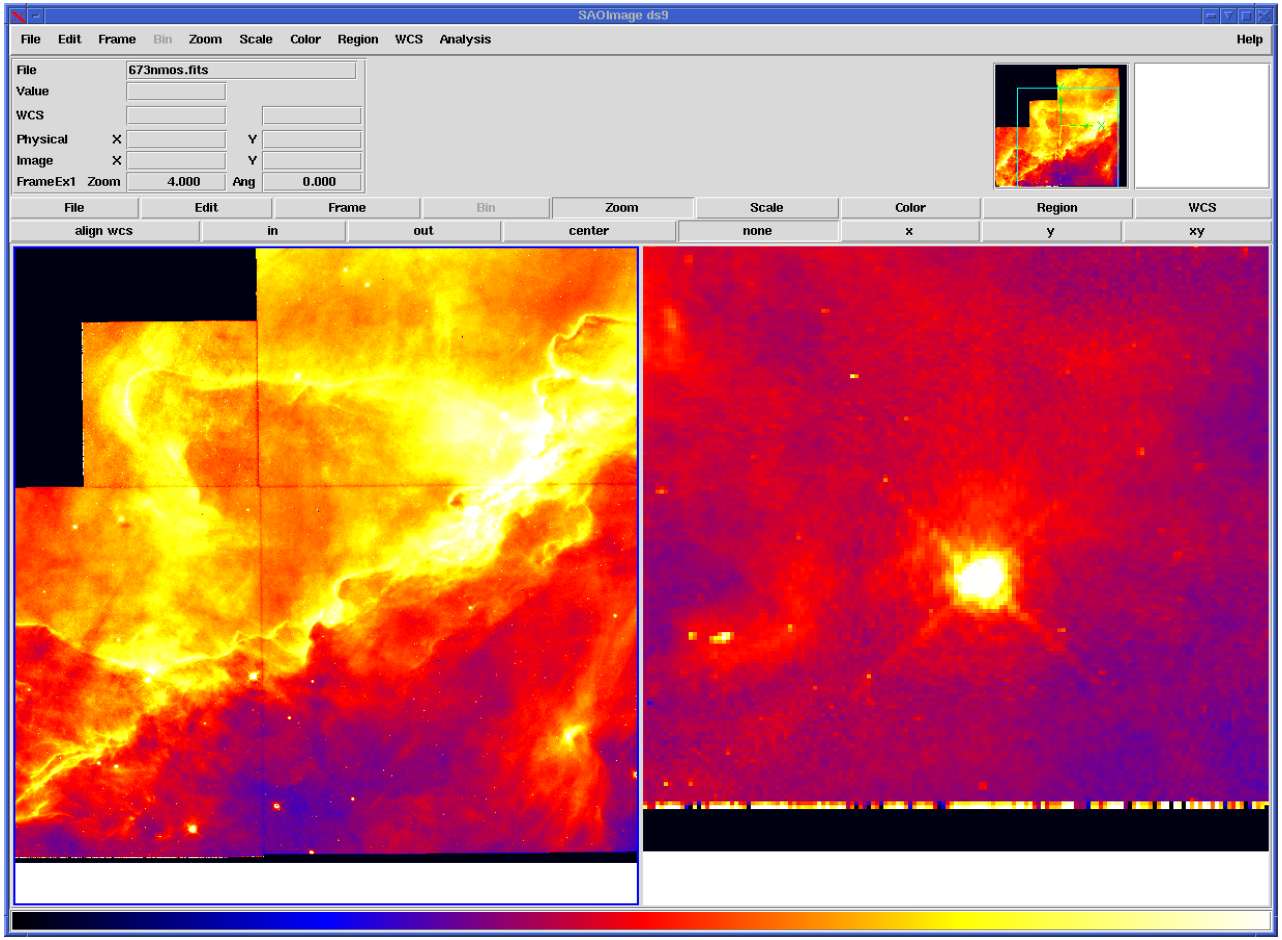
ASTR 310
Computing in Astronomy

Spring 2024

Lecture 18: Data V: working with FITS files



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Topics covered in the reading

FITS file structure

- Header-data units (HDUs)
- Primary vs. extension headers
- Header keywords
- Data segment types (esp. image and binary table data)

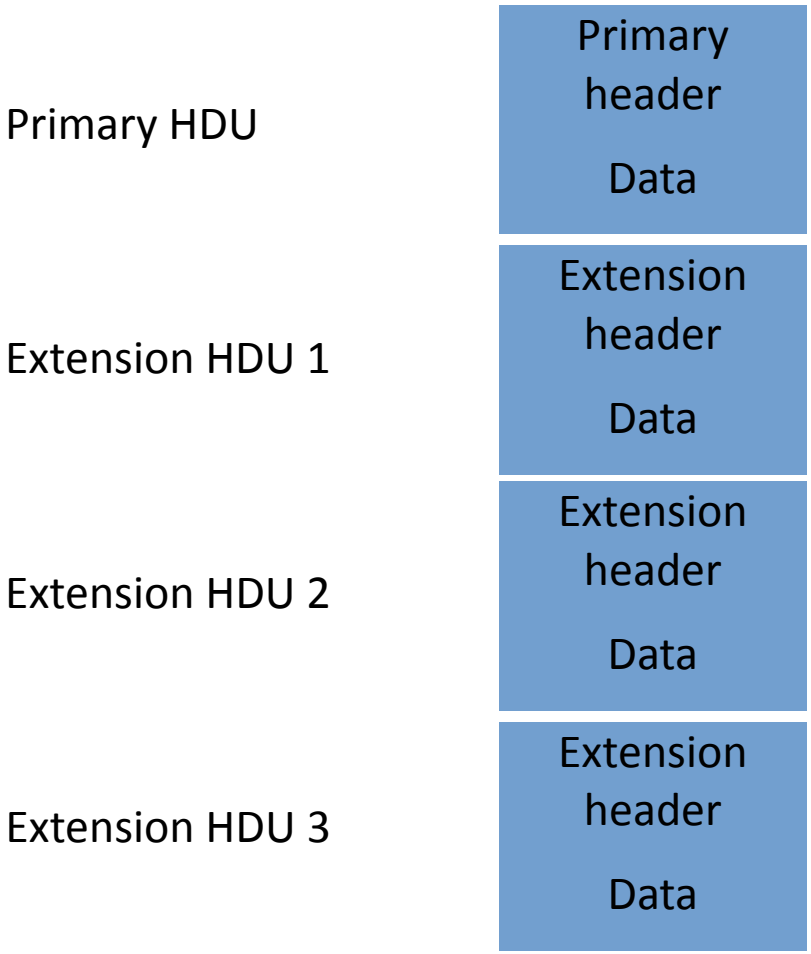
AstroPy FITS support – astropy.io.fits

- Reading FITS files – produces an HDUList object
- Accessing HDU header and data segments
- Accessing and setting header keyword names and values
- Image data
- Table data
- Writing FITS files

FITS files

FITS = Flexible Image Transport System; the most common astronomical file format

Basic structure of a FITS file:



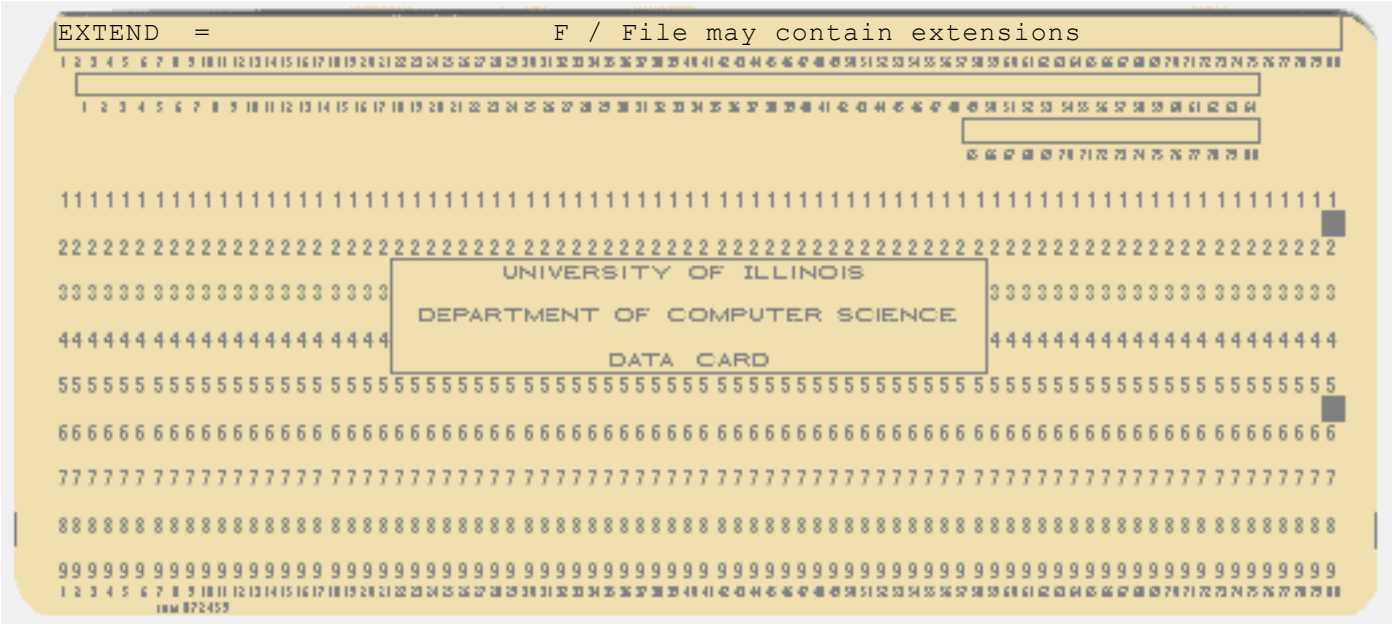
Header-Data Units (HDUs) contain

- Header: collection of 80-byte ASCII records ("cards"), each containing metadata organized as
  - A keyword name (e.g. `NAXIS1`)
  - Its value
  - An optional comment
- Data: any of
  - Binary image data
  - ASCII table data
  - Binary table data
  - Random access group data (less common)

The first or "primary" HDU must be an image or a random access group. We will work with images and binary tables, since those are most common.

Example FITS header

```
SIMPLE  =                    T / Fits standard
BITPIX  =                  -32 / Bits per pixel
NAXIS   =                    2 / Number of axes
NAXIS1  =                  540 / Axis length
NAXIS2  =                  540 / Axis length
EXTEND  =                    F / File may contain extensions
ORIGIN  = 'NOAO-IRAF FITS Image Kernel July 2003' / FITS file originator
IRAF-TLM= '17:46:17 (04/04/2007)' / Time of last modification
OBJECT  = 'LMC Ha MCELS Mosaic'
DATE    = '2007-04-04T22:46:24' /
IRAF-MAX=           6.553500E4  /  DATA MAX
IRAF-MIN=           1.134000E3  /  DATA MIN
OPICNUM =                 1062 / Original picture number
```



https://www.landley.net/history/mirror/pre/punchedcards/history.html

Interactive FITS viewers

If you just want to look at the contents of a FITS image, try an interactive FITS viewer.

https://sites.google.com/cfa.harvard.edu/saoimageds9
(tends to be more commonly used by optical/X-ray observers)

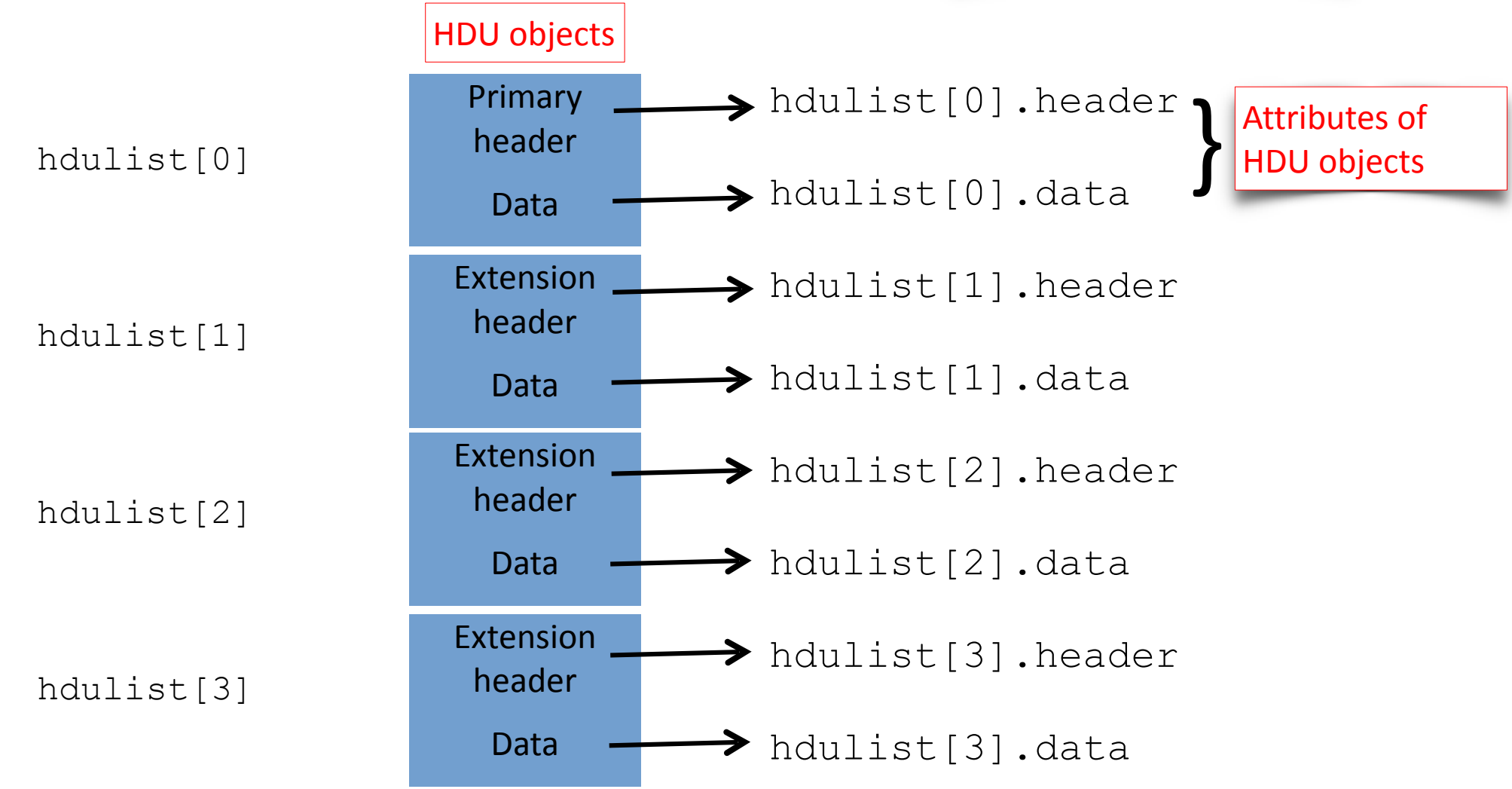
https://cartavis.org/
(more commonly used by radio astronomers)

If you need to manipulate the contents of the data or do more sophisticated analysis, you'll want to open the file with AstroPy tools.

Using FITS files with Astropy

```
from astropy.io import fits
hdulist = fits.open('lmc.ha.b20.fits')
```

Returns an HDUList object




```
hdulist.close()
```

HDU data attribute

Image data

Stored as 2D Numpy array: e.g.

`hdulist[0].data[:,:]` pixel values

Note: `NAXIS1` refers to range of second index

`NAXIS2` refers to range of first index

Numpy default behavior is that the first axis is the row # (vertical coordinate) whereas FITS standard has the first axis as the column # (horizontal coordinate)

Table data

Stored as a FITS record array, similar to a Numpy record array: e.g.

`hdulist[0].columns` info about columns in table

`hdulist[0].data.field(3)` fourth column (can also pass column name as argument)

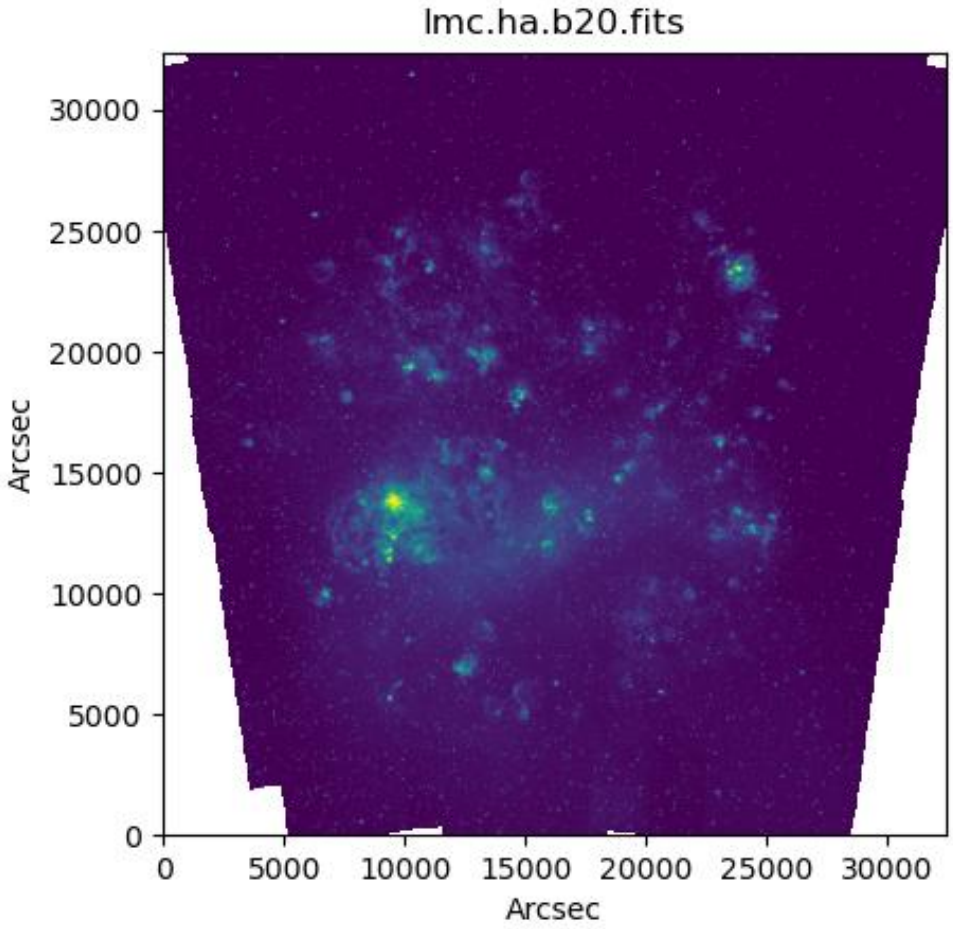
`hdulist[0].data['spec_type'][7]` eighth item in 'spec_type' column

`hdulist[0].data[7]` eighth row (`FITS_record`)

Exercise 1: plotting an image from a FITS file

Using NumPy, Matplotlib, and Astropy, read in the file `lmc.ha.b20.fits` and do the following:

- Get the image data from the first HDU.
- Take the logarithm of the image data.
- Get the first HDU's keywords `NAXIS1`, `NAXIS2`, `CDELT1`, and `CDELT2` (the latter two are in degrees/pixel). Use this information to compute the extent of the image. (Use the abs val of `CDELT1`... RA goes backwards)
- Plot the log image using the extent determined by the above keywords and placing the origin at lower left. You will want to adjust the color mapping using the `vmin` and `vmax` parameters.



Soon we will see easier ways to have AstroPy manage the coordinates for us.

Exercise 2: modifying a FITS table

The files `table1.fits` and `table2.fits` each contain an empty primary HDU and a binary table extension HDU. The table data are drawn from a sample of nearby clusters of galaxies.

The file `table1.fits` contains: cluster name, redshift, RA (J2000) and dec (J2000).

The file `table2.fits` contains: cluster name, 2-10 keV X-ray luminosity, X-ray temperature in keV.

Using NumPy and AstroPy, read the two files in, merge the tables into one new table, and write the results to a new file `newtable.fits`.

When you're done, please upload your notebook and newtable.fits to Canvas.