Rotating Sunspots: FITS Keywords and Fields

File Structure

The FITS file uses the ASCII table extension to store rotation and related data about a sunspot. Each extension also has a header that contains additional information about the sunspot analysed.

Each file is for an individual active region, and where multiple sunspots are analysed, these are stored as additional ASCII table extensions.

Filenames take the following form:
`RSS_AR?????_?-?_L?.fits`

Where the active region number is given, and the sunspots analysed are given by the `?-?` part. E.g., `A-C` indicates that there are three sunspots analysed labelled A, B, and C. The `L?` indicates the level of the data. Additional keywords and fields were added after the initial definition, and this allows the contents to be easily identified.

The FITS header keywords for each extension and the column titles for the table data for each sunspot is summarised in the tables at the end of this document.

Working with rotation files in SSWIDL

In SSWIDL, sunspot information can be read in as follows:

```
IDL> tbla = mrdfits(filename, 1, hdra)
IDL> hdrastr = fitshdr2struct(hdra)
```

This reads in the data for sunspot A from the file given by `filename`. The rotation data is given in the structure array `tbla` and the general sunspot header in `hdra`. The second line converts the header to a structure. It may be useful to prune some of the less pertinant (for scientific analysis) keywords with

```
IDL> ii=where((strmatch(hdra, 'TTYPE*') eq 1) or (strmatch(hdra, 'TBCOL*') eq 1) &
        or (strmatch(hdra, 'TFORM*') eq 1), nii, complement=jj, ncomplement=njj)
IDL> hdrastr2 = fitshdr2struct(hdra(jj))
```

If further sunspots are stored in the file, they can be accessed by increasing the number in `mrdfits`, e.g., to get sunspot B

```
IDL> tblb = mrdfits(filename, 2, hdrb)
```

and so on.

The data can be be explored using other IDL commands and routines, for example

```
IDL> help, tbla, hdrastr, /str
```

To plot the rotation profile

```
IDL> plot, tbla.dtime, tbla.rotn
```

Other fields can be plotted in a similar manner, or histograms of fields can be generated, and so on.

Note, the routines `mrdfits.pro` and `fitshdr2struct.pro` should be standard routines in the SSWIDL distribution.

Working with rotation files in Python

The rotation profiles may also be read into scientific python using the astropy.io library.

```
>>> from astropy.io import fits
>>> RSSfile = 'RSS_AR11147_A-A_L1.12.fits'
>>> hdul = fits.open(RSSfile)
```

Information from the header can be accessed along the following lines

```
>>> print(hdul[1].header['AR'], hdul[1].header['SPOTNO'])
```

And a list of the table column headings can be obtained through

```
>>> hdul[1].columns
```

The rotation profile can be plotted with something like

```
>>> import matplotlib.pyplot as plt

>>> fig=plt.figure()
>>> ax = fig.add_subplot(111)
>>> ax.set_xlim(0,220)
>>> ax.set_ylim(-30,40)

>>> rdata = hdul[1].data
>>> ax.plot(rdata['DTIME'],rdata['ROTN'])
>>> ax.plot([0,220],[0,0],linestyle=':',color='Grey')

>>> xlabel='Time from '+hdul[1].header['T0']+' (hours)'
>>> ax.set_xlabel(xlabel)
>>> ax.set_ylabel('Rotation (degrees)')
>>> title='Rotation Profile of Sunspot '+hdul[1].header['SPOTNO']+' in '+hdul[1].header['AR']
>>> ax.set_title(title)

>>> plt.show()
```

If there is rotation data for multiple sunspots in the FITS file, then the other sunspots can be accessed through `hdul[2]`, `hdul[3]`, and so on.

Using other FITS readers

Other FITS readers should be able to read the FITS files. The data has been successfully tested with the interactive FITS File Editor fv, from NASA's HEASARC Software.

Header Keywords

Each FITS extension (i.e., sunspot) has the following header keywords. Many of these are the standard keywords required for a table extension, but some keywords may be scientifically more useful (e.g., AR and SPOTNO)

Keyword	Level	Type	Description
XTENSION	1	String	Required keyword (defaults to TABLE for the ASCII table extension)
BITPIX	1	Integer	Required keyword (defaults to 8 for ASCII characters)
NAXIS	1	Integer	Required keyword (defaults to 2)
NAXIS1	1	Integer	Number of characters in a row of the ASCII table (used for reading/writing files)
NAXIS2	1	Integer	Number of rows (same as the number of observations analysed, i.e., the number of data points in the rotation profile, etc)
PCOUNT	1	Integer	Required keyword (defaults to 0)
GCOUNT	1	Integer	Required keyword (defaults to 1)
TFIELDS	1	Integer	Number of fields in table (e.g., HMI filename, observation time, rotation, etc)
AR	1	String	Active Region number
SPOTNO	1	String	Sunspot number in AR (e.g., A, B, C, ...)
T0	1	String	Reference time (a numerical time in hours from the reference time is provided in the fields)
RADEXT1	1	Integer	Minimum annuli radius used during rotation calculation
RADEXT2	1	Integer	Maximum annuli radius used during rotation calculation
THRESH	1	Float	Umbral threshold applied during rotation calculation
LTHRESH	1	Float	Lower threshold applied (to ignore dropped data, etc)
PTHRESH	1	Float	Penumbral threshold applied during rotation calculation
MAXDT	1	Float	Maximum time between observations for tracking (hour)
LEVEL	1.1	String	Level of processed rotation data (i.e., which keywords/fields are included)
TTYPE*i*	1	String	List of field titles, *i* increases from 1 to TFIELDS listing all the column headings for the table
TBCOL*i*	1	Integer	Character location of start of column *i* (required for reading/writing files)
TFORM*i*	1	String	Format code for column *i* entry (required for reading/writing files)

Data Fields

The following table gives the column titles for the table extension. Each of these will contain a column of N data points corresponding to the number of files analysed, and will map the rotation profile (ROTN) and other key measurements over time.

Field	Level	Type	Description
FILE	1	String	Filename of HMI observation used (different filename structures reflect different sources used (e.g., ROB, etc)
TIME	1	String	Date/time stamp of observation analysed
DTIME	1	Float	Time elapsed (in hours) from reference time (T0)
PCENX	1	Float	Calculated x-coordinate (in pixels) of the centre of the sunspot in the observation
PCENY	1	Float	Calculated y-coordinate (in pixels) of the centre of the sunspot in the observation
SIGPCX	1	Float	Calculated one-sigma error on PCENX
SIGPCY	1	Float	Calculated one-sigma error on PCENY
ACENX	1	Float	Calculated x-coordinate (in arcsecs) of the centre of the sunspot in the observation
ACENY	1	Float	Calculated y-coordinate (in arcsecs) of the centre of the sunspot in the observation
UMBRAREA	1.1	Float	Calculated reprojected area (i.e., area if the sunspot was at disk centre) of the umbra of the sunspot (pixels with intensity below THRESH)
PANN1	1	Float	Inner radius (pixels) of the penumbral annulus averaged over a 1 hour window centred on the observation
PANN2	1	Float	Outer radius (pixels) of the penumbral annulus averaged over a 1 hour window centred on the observation
SIGPANN1	1	Float	One-sigma error on PANN1
SIGPANN2	1	Float	One-sigma error on PANN2
DROTN	1	Float	Calculated rotation (degrees) between previous observation and current
SIGDROTN	1	Float	One-sigma error on DROTN
ANGVEL	1	Float	Bulk angular velocity based on a 1 hour window centred on the observation
SIGAV	1	Float	One-sigma error on ANGVEL
ROTN	1	Float	Cumulative rotation of the sunspot from the first observation
SIGR	1	Float	Total error on ROTN
SIGRM	1	Float	Error on ROTN due to the method (e.g., error propagation and scale errors)
SIGRP	1	Float	Error on ROTN due to the error on the penumbral radii
SIGRC	1	Float	Error on ROTN due to the error on the centre of the sunspot
ABSROTN	1.1	Float	Cumulative absolute rotation of the sunspot from the first observation