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SDFITS: A Standard for Storage and Interchange of Single Dish Data

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Abstract. SDFITS is a FITS binary table convention for the interchange of single dish data in radio astronomy. It is derived from an agreement reached during an international meeting of interested parties at Green Bank, West Virginia, in 1989 October.

1. Introduction

In October of 1989 a meeting of interested representatives of many of the world's radio-astronomical observatories was held in Green Bank, West Virginia, to consider the creation of a standard data transport and interchange format for single dish (i.e. non-synthesis) radio astronomy data. Single dish radio astronomy data typically consists of a data array and a number of associated values (the header) which are necessary to describe the data and the state of the telescope and its environment. This meeting resulted in an agreement which held that FITS binary tables (Cotton, Tody, & Pence 1995; known as "3-D" tables in 1989) should be used to hold single dish data. A convention for storing the data matrix and its coordinate system was described. A set of required (CORE) and recognized but not required (SHARED) column names were also agreed to.

In 1992, prototype readers and writers were constructed at NRAO and IRAM. The NRAO prototype has been distributed since then as part of the UniPOPS package. In 1996, the Parkes HI Multibeam Survey (Saveley-Smith et al. 1996) adopted AIPS++[2] as their reduction package and the convention described here as their data archive format. This convention was revised at that time in light of FITS developments over the previous seven years and Parkes Multibeam and AIPS++ needs. The resulting standard is known as single dish FITS or SDFITS. The primary difference between the current standard and that proposed in 1989 is in the the storage of the data matrix and its associated coordinate axes.

Space limitations do not permit a full and complete description of this convention here. Interested readers should contact the AIPS++ project for a more complete description.

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[1] The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

[2] `http://aips2.nrao.edu`

2. Columns and Keywords

The presence of an EXTNAME keyword having a value of ''SINGLE DISH'' signals that the table follows the convention described here.

The single dish header information is stored in the columns in the FITS binary table. Each row in the table contains a data matrix and its associated header information.

2.1. Virtual Columns

Single dish headers oftain contain information which does not change throughout a data set. This information may be stored in a column having a the same value in each row of the table or this information may be represented by a FITS keyword in the table header having a value equal to the value found in each row of the column. A constant-valued column represented by a keyword value pair is a virtual column. Any constant-valued scalar column which has a column name (TFIELDn) consisting of eight or fewer characters may be expressed as a virtual column. All keywords except those required to describe the FITS header and binary table structure (e.g. NAXIS, BITPIX, XTENSION, TFIELDS, etc.) are virtual columns.

2.2. CORE Columns

All CORE columns are required in all SDFITS tables. They are essential and common to all observatories and telescopes. All SDFITS readers and writers must acknowledge (write and properly interpret) all CORE columns. The CORE columns are BANDWID, DATA, DATE-OBS, EXPOSURE, OBJECT, TELESCOP, and TSYS. The DATA column and its coordinate system are described in Section 3.

2.3. SHARED Columns

The SHARED columns are optional. These were held, during the Green Bank meeting, to be largely common to all observatories and telescopes, but not essential. They may be ignored by an SDFITS reader or writer. The SHARED columns are: OBSERVER, OBSID, PROJID, SCAN, OBSMODE, MOLECULE, TRANSITI, FRONTEND, BACKEND, TEMPSCAL, TCAL, THOT, TCOLD, TRX, FREQRES, VELDEF, VFRAME, RVSYS, OBSFREQ, IMAGFREQ, RESTFREQ, TIMESYS, LST, AZIMUTH, ELEVATION, TAU, TAUIMAGE, TAUZENIT, BEAMEFF, APEREFF, ETAL, ETAFSS, ANTGAIN, BMAJ, BMIN, BPA, SITELONG, SITELAT, SITEELEV, HUMIDITY, DEWPOINT, TAMBIENT, PRESSURE, WINDSPEE, and WINDDIRE.

2.4. Other Columns

Any additional columns not explicitly mentioned as part of this convention may be added to an SDFITS table. Readers may ignore them.

3. The DATA Column and Coordinate System

A multi-dimensional DATA column is required. For fixed-shape columns, the TDIMn convention described in Cotton, Tody, & Pence (1995) is adopted to describe the shape of the array stored in that column. In this case, the product of all elements of `TDIMn` must be equal to `TFORMn`.

For variable-shaped columns, a modified `TDIMn` convention is used. In this case, a column having the name `TDIMn` where n is the `DATA` column number is used to store the shape of the `DATA` column in each row. The product of all of the elements in any cell of `TDIMn` must be less than or equal to `TFORMn` for the `DATA` column. The table "heap" ("`P`" data type, variable length array descriptor) can be used to store the `DATA` values in which case the product of the elements of `TDIMn` for that row must be less than or equal to the number of elements stored in the heap for that row. Any unused elements of the `DATA` array should be set to either IEEE NaN (not a number) for floating point arrays or to the value of the `TNULLn` keyword for integer data arrays.

This convention on storing multi-dimensional arrays in a table may be used on any column in an SDFITS table.

The axes in the `DATA` column are described using columns (which may be virtual) containing standard FITS image axis descriptions (including the WCS convention described in Calabretta & Greisen 2000). The following three axes are required: frequency-like ("FREQ", "VELO", "FELO"), longitude-like ("RA", "GLON", "ELAN") and latitude-like ("DEC", "GLAT", "ELAT"). The following are recognized optional axes: "TIME" (the time since "DATE-OBS"), "STOKES", "BEAM" (a beam ID number) and "RECEIVER" (a receiver ID number).

The axis descriptions may also apply to any other column having a `TMATXn` keyword with a value of `True`.

4. Example

The following incomplete example illustrates some of the elements of the SDFITS convention. Here, the `DATA` column has, at most, 226 elements and the shape for each row is stored in the `TDIM1` column. Only two of the required three axes are shown here. There are several virtual columns, including `CRPIX2` and `BANDWID`. Any of these could have been true columns with constant values. Not all of the CORE keywords are shown. There are two columns `GLON-ARC` and `GLAT-ARC` which are not defined by this convention. These are shown to illustrate that writers are free to add any number of additional columns although readers may choose to ignore these. The order shown here is not required by this convention.

```
...
EXTNAME = 'SINGLE DISH'        / Single Dish convention
           / DATA column and coordinate system
TTYPE1  = 'DATA    '           / DATA column
TFORM1  = '226E    '
TUNIT1  = 'DEGREES '
TTYPE2  = 'TDIM1   '           / TDIM for DATA column (column 1)
TFORM2  = '12A     '
TTYPE3  = 'CTYPE1  '           / Velocity axis
TFORM3  = '8A      '
TTYPE4  = 'CRPIX1  '           / Velocity axis reference pixel
```

```
TFORM4  = '1I      '
TTYPE5  = 'CRVAL1  '           / Velocity at reference pixel
TFORM5  = '1D      '
TUNIT5  = 'M/SEC   '
TTYPE6  = 'CDELT1  '           / Velocity increment
TFORM6  = '1D      '
TUNIT6  = 'M/SEC   '
TTYPE7  = 'CTYPE2  '           / Longitude-like axis
TFORM7  = '8A      '
CRPIX2  =                  1.0 / Longitude reference pixel
TTYPE8  = 'CRVAL2  '           / Value at longitude ref. pixel
TFORM8  = '1D      '
TUNIT8  = 'DEGREES '
...
           / CORE columns
TELESCOP= 'NRAO12M '           / Designation of telescope
BANDWID =           22070316.0 / Total bandwidth (Hz)
TTYPE12 = 'OBJECT  '           / Observed object name
TFORM12 = '12A     '
TTYPE13 = 'DATE-OBS'           / Date of observation YYYY-MM-DD
TFORM13 = '10A     '
...
           / SHARED columns
OBSERVER= 'GARWOOD '           / Name of observer
TTYPE16 = 'SCAN    '           / Scan number
TFORM16 = '1E      '
TTYPE17 = 'RESTFREQ'           / Rest frequency at ref. pixel
TFORM17 = '1D      '
TUNIT17 = 'HZ      '
TTYPE18 = 'TCAL    '           / Calibration temperature
TFORM18 = '1D      '
TUNIT18 = 'KELVINS '
...
           / All other columns
TTYPE25 = 'GLON-ARC'
TFORM25 = '1D      '
TUNIT25 = 'DEGREES '
TTYPE26 = 'GLAT-ARC'
TFORM26 = '1D      '
TUNIT26 = 'DEGREES '
```

References

Calabretta, M., & Greisen, E. 2000, this volume, 572

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Staveley-Smith, L., Wilson W. E., Bird T. S., Disney M. J., Ekers R. D., Freeman K. C., Haynes R. F., Sinclair M. W., Vaile R. V., Webster R. L., & Wright A. E. 1996 PASA, 13, 243