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FITS — A Self-Describing Table Interchange Format

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Basic FITS, the "Flexible Image Transport System", is a data format which was designed by astronomers in 1979[3] to support interchange of n-dimensional integer and floating point matricies using a self-describing notation. FITS is the de facto interchange format used by astronomers everywhere since 1980. The rules of the format are controlled by the FITS Working Group of Commission 5 (Astronomical Data) of the International Astronomical Union, and there are North American and European FITS standards Committees as well. FITS is also the official interchange and archive format for NASA astrophysics missions, and NASA operates a FITS Support Office, including a hot-line service.[4] There is an anonymous-guest archive for FITS matters[5] and an E-mail exploder.[6]

The architecture of Basic FITS is extensible; the meta-rules for extensions are also

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[3] Wells, D.C. and Greisen, E.W., 1981, Astron. Astrophys. Suppl. Ser. **44**, 363-370, "FITS: A Flexible Image Transport System".

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[5] `fits.cx.nrao.edu`, 192.33.115.8, in directory `/FITS`; this text is `/FITS/doc/fitsdbmsapp.tex`

[6] send requests to be added to the mailing list to `fitsbits-request@fits.cx.nrao.edu`

a part of the standard.[7] In particular, extensions to transmit tables have been designed, and the ASCII tables extension is also a part of the FITS standard.[8] Numerous CDROMs containing databases in the FITS ASCII tables format have been published by NASA projects during the past two years. A binary tables extension to FITS has been proposed;[9] prototype implementations have demonstrated interoperability and this extension is currently being considered by the FITS committees for adoption.

The FITS ASCII tables extension is capable of conveying a set of tables as a self-documenting machine-independent and OS-independent bytestream. The logical record size is 2880 bytes;[10] record blocking by integer factors from one to some limit (typically ten) is allowed on media for which it is a relevant concept.[7] The data structures are preceded by "headers", which are 80-character lines in keyword-equals-value format. There are 36 header lines per logical record, and records are padded with blanks. FITS headers and tables extensions do not contain carriage returns or line feeds or other non-printing ASCII codes.

The FITS ASCII tables extensions are appended to the Basic FITS binary matrix. The matrix dimensions are allowed to be zero, but the minimum Basic FITS header must still be present. There are two reasons for this convention: (1) FITS is a *family* of formats which have internal consistency, and this simplifies documentation, shortens learning time and made standards negotiations easier, and (2) in many scientific applications auxiliary tabular data structures need to be associated with the main binary matrix data structures.

In this appendix we will display a typical FITS table, a single table in a FITS file. The table has 2268 rows and 22 columns encoded in 80 ASCII characters. The data were produced by automatic software which searched images of the Northern sky produced from scans made by the 300-foot telescope at Green Bank, WV (the 300-foot collapsed in November 1988, about a year after these data were recorded), and were given to D. Wells by James J. Condon of NRAO for use in this appendix. In the verbatim listings shown below two extra lines have been prefixed to the listing of each logical record to show the column alignments in the file, and the record number and line number are shown for each line (these are not a part of the FITS bytestream, of course). First, we show the minimum Basic FITS header:

[7] Grosbøl, P., Harten, R.H., Greisen, E.W. and Wells, D.C., 1988, Astron. Astrophys. Suppl. Ser. **73**, 359-364, "Generalized Extensions and Blocking Factors for FITS".

[8] Harten, R.H., Grosbøl, P., Greisen, E.W. and Wells, D.C., 1988, Astron. Astrophys. Suppl. Ser. **73**, 365-372, "The FITS Tables Extension".

[9] Cotton, W.D., 1990, "FITS Binary Tables", draft available from D. Wells.

[10] This (peculiar) size is rich in prime factors; it is commensurate with the word and byte sizes of all computers that have ever been sold in the commercial market. In 1979, when FITS was designed, machines with 6-bit bytes and 24-, 36-, and 60-bit word sizes and ones-complement arithmetic were still commonly used by astronomers. Indeed, the first FITS file was written by an IBM 360 (32-bit, twos-complement, EBCDIC codes, PL/I program) and was read by a CDC 6400 (60-bit, ones-complement, 6-bit "Display" codes, Fortran program); that interchange worked on the first try and the file is still readable today by all FITS readers, long after both original environments have become irrelevant to astronomical computing. Obviously a new format design today would use record lengths of 2^n but most astronomers believe that the principle of protecting the older bits is still important.

```
            1         2         3         4         5         6         7         8
 r/l    12345678901234567890123456789012345678901234567890123456789012345678901234567890

01/01:  SIMPLE  =                    T / Standard FITS format (AA Suppl. 73, 365)
01/02:  BITPIX  =                    8 / 8-bit characters
01/03:  NAXIS   =                    0 / No image data array present
01/04:  EXTEND  =                    T / There may be standard extensions
01/05:  BLOCKED =                    T / Tape may be blocked (2880 byte records)
01/06:  TELESCOP= 'NRAO91M '           / 91m = 300-ft telescope (r.i.p.)
01/07:  INSTRUME= '7BEAM6CM'           / 7-beam receiver
01/08:  OBJECT  = '87GB CAT'           / The 87GB 4.85 GHz source catalog
01/09:  EPOCH   =               1950.0 / Equinox (yr) of RA, dec values in table
01/10:  DATE-OBS= '01/10/87'           / Observation start date (dd/mm/yy)
01/11:  OBSERVER= 'CBS     '           / Condon, Broderick, and Seielstad
01/12:  ORIGIN  = 'NRAOCV  '           / Written at NRAO, Charlottesville
01/13:  DATE    = '11/06/90'           / Date file written (dd/mm/yy)
01/14:  HISTORY  AIPS IMNAME = 'B1950.11H'
01/15:
01/16:  COMMENT  This table contains all sources from the 87GB catalog
01/17:  COMMENT  with hours of right ascension = 11 (equinox B1950)
01/18:  COMMENT  derived from the Green Bank 4.85 GHz sky survey made in 1987
01/19:  COMMENT  with the 91-m telescope  (J. J. Condon, J. J. Broderick, and
01/20:  COMMENT  G. A. Seielstad 1989, A. J. 97, 1064),
01/21:  COMMENT  in standard FITS table format (see Astr. Ap. Suppl. 73, 365).
01/22:  COMMENT  Catalog reference:  P. C. Gregory and J. J. Condon,
01/23:  COMMENT  Ap. J. Suppl., submitted May 1990.
01/24:  END
01/25:
01/26:
01/35:
01/36:
```

The NAXIS line declares that the binary matrix does not exist (it's dimensionality, the number of axes, is zero); the type of the matrix elements (BITPIX=8) does not matter in this case. The following keyword-value pairs of this header are optional (except the END). The next logical record begins the header of the ASCII table:

```
            1         2         3         4         5         6         7         8
 r/l    12345678901234567890123456789012345678901234567890123456789012345678901234567890

02/01:  XTENSION= 'TABLE   '           / Table extension
02/02:  BITPIX  =                    8 / 8-bit characters
02/03:  NAXIS   =                    2 / Simple 2-D matrix
02/04:  NAXIS1  =                   80 / Number of characters per row
02/05:  NAXIS2  =                 2268 / Number of rows = number of sources
02/06:  PCOUNT  =                    0 / No random parameters
02/07:  GCOUNT  =                    1 / Only one group
02/08:  TFIELDS =                   22 / Number of fields per row
02/09:  EXTNAME = 'B1950.11H'          / Name (Epoch.hours of right ascension)
02/10:  EXTVER  =                    1 / Version number
02/11:  EXTLEVEL=                    1 / Hierarchical level
02/12:
02/13:  TTYPE1  = 'RAH     '           / right ascension (hours)
02/14:  TBCOL1  =                    1 / start in column 1
```

```
02/15:  TFORM1  = 'I2      '           / 2-digit integer
02/16:  TUNIT1  = 'HR      '           / units are hours
02/17:  TNULL1  = '99      '
02/18:
02/19:  TTYPE2  = 'RAM     '           / right ascension (minutes)
02/20:  TBCOL2  =                    3 / start in column 3
02/21:  TFORM2  = 'I2      '           / 2-digit integer
02/22:  TUNIT2  = 'MIN     '           / minutes of time
02/23:  TNULL2  = '99      '
02/24:
02/25:  TTYPE3  = 'RAS     '           / right ascension (seconds)
02/26:  TBCOL3  =                    5 / start in column 5
02/27:  TFORM3  = 'E4.1    '           / xx.x SP floating point
02/28:  TUNIT3  = 'S       '           / seconds of time
02/29:  TNULL3  = '99.9    '
02/30:
02/31:  TTYPE4  = 'URAS    '           / rms uncertainty in RAS (seconds)
02/32:  TBCOL4  =                   10 / start in column 10
02/33:  TFORM4  = 'E3.1    '           / x.x SP floating point
02/34:  TUNIT4  = 'S       '           / seconds of time
02/35:
02/36:  TTYPE5  = 'DECDSIGN'           / declination sign
```

This is an extension of type "TABLE"; it is a 2-dimensional matrix of 8-bit bytes, with 80 bytes per row and 2268 rows in the matrix. The keyword `TFIELDS` on line 8 tells us that there are 22 columns in the table. Keyword `EXTNAME` specifies a name for this extension (multiple extension structures can be concatenated within a single FITS file, and can be distinguished by their names). Each of the table columns is documented by a set of five keywords. `TTYPE`*ii* specifies the column label for the *ii*-th column. `TBCOL`*ii* specifies the ordinal in the matrix of the first character of the data field of the column, and `TFORM`*ii* specifies the format (and the field width) in Fortran style. `TUNIT`*ii* specifies the physical units of the column and `TNULL`*ii* specifies the field value that signifies nulls. Here is the last header record:

```
                 1         2         3         4         5         6         7         8
 r/l    12345678901234567890123456789012345678901234567890123456789012345678901234567890

05/01:
05/02:  TTYPE20 = 'ZERO    '           / zero-level of fit (Jy)
05/03:  TBCOL20 =                   67 / start in column 67
05/04:  TFORM20 = 'E3.3    '           / (.)xxx SP floating point
05/05:  TUNIT20 = 'JY      '           / Jansky
05/06:
05/07:  TTYPE21 = 'PIXX    '           / x-coordinate pixel number
05/08:  TBCOL21 =                   71 / start in column 71
05/09:  TFORM21 = 'I4      '           / 4-digit integer
05/10:
05/11:  TTYPE22 = 'PIXY    '           / y-coordinate pixel number
05/12:  TBCOL22 =                   76 / start in column 76
05/13:  TFORM22 = 'I4      '           / 4-digit integer
05/14:
05/15:  AUTHOR  = 'P. C. Gregory and J. J. Condon'
05/16:  REFERENC= 'Ap. J. Suppl., submitted 1990 May'
```

```
05/17:  DATE    = '11/06/90'           / file generation data (dd/mm/yy)
05/18:
05/19:  END
05/20:
05/35:
05/36:
```

The next FITS logical record begins the table itself, which extends for 63(= 2268/36) FITS records. Here are the first and last rows of the table:

```
                 1         2         3         4         5         6         7         8
 r/l    12345678901234567890123456789012345678901234567890123456789012345678901234567890

06/01:  11 0 1.5 1.0 +181916 19  63.2 226.9    67   10      1.13 0.96 -64  -3  513  362
06/02:  11 0 3.2 1.5 +322917 23  65.7 194.2    35    7      1.38 0.68  55  -1  512  735
06/03:  11 0 5.6 1.6 +27 6 9 26  65.6 207.3    30    7      1.58 0.75  44   0  511  253
06/04:  11 0 9.7 2.0 +451913 25  61.8 166.3    27    6      1.28 0.69 -55  -2  510   93
06/05:  11 011.0 1.1 +105913 20  59.4 240.1    67   11      1.15 0.67  -4  -6  509  601
06/06:  11 011.7 0.9 + 515 9 18  55.8 248.3   135   20      1.22 0.66 -10   1  509   86

68/04:  115859.9 2.1 + 917 1 44  68.3 267.0    40    9   W  1.94 1.32 -32  -4   92  450
68/05:  1159 5.1 1.5 +472035 19  67.7 146.2    50    8      0.87 0.69 -80   1  222  283
68/06:  1159 6.2 1.6 +231311 27  77.8 230.2    35    7      1.20 0.73 -71  -1  119  804
68/07:  1159 6.9 0.9 +113140 19  70.1 263.6   146   21      0.92 0.74 -51  -2   92  651
68/08:  115911.4 0.9 +144814 19  72.7 257.3   211   29      1.01 0.81 -59  -1   96  942
68/09:  115914.0 0.9 +105335 19  69.6 264.7   153   22      1.12 0.68   5   0   89  594
68/10:  115915.7 2.0 +502524 24  65.0 142.4    32    7      1.66 0.98 -65  -6  237  559
68/11:  115916.7 1.0 +393541 16  73.9 160.6   261   32      1.15 0.85   8   1  179  484
68/12:  115919.2 1.1 +3313 5 19  77.6 181.9    73   11      1.03 0.72  -8   1  150  806
68/13:  115920.1 1.2 +445634 17  69.8 149.6    90   11      0.87 0.71   7   0  205  960
68/14:  115920.7 1.1 +3651 2 18  75.7 168.4    86   12      1.24 0.96  88  -3  165  238
68/15:  115929.5 1.4 +3130 0 23  78.3 189.5    43    8      0.99 0.67 -84   0  140  653
68/16:  115930.2 1.2 +581838 14  57.9 135.5   268   27      1.09 0.81  -4   0  283  369
68/17:  115933.9 1.9 +504917 22  64.7 141.8    36    6      0.94 0.79 -13  -2  235  595
68/18:  115934.4 1.0 +13 228 20  71.4 261.1   107   16      1.15 0.84 -25   1   85  786
68/19:  115935.0 2.3 +595826 22  56.3 134.4    35    6      1.77 0.99  89  -5  293  518
68/20:  115936.1 1.2 +45 122 17  69.7 149.4    78   10      0.96 0.81 -78  -5  202   75
68/21:  115937.6 1.6 +342824 25  77.1 176.7    36    7      1.34 0.70 -43   0  149  918
68/22:  115939.8 1.0 +214047 19  77.2 236.8   116   16      1.04 0.72  25  -1  102  667
68/23:  115941.5 2.5 +552123 26  60.6 137.6    27    6      1.25 0.83 -48  -5  262  104
68/24:  115941.8 2.2 +622451 19  54.0 132.9    43    6      1.12 0.78  48  -2  308  736
68/25:  115942.0 1.4 +182235 25  75.3 248.3    44    8      1.33 0.94 -85  -3   93  372
68/26:  115942.6 1.8 +721656 11  44.6 128.3   140   12      1.07 0.79 -20  -1  378  722
68/27:  115946.2 1.4 + 85619 26  68.1 267.9    48   10      1.19 0.61 -22   0   74  419
68/28:  115946.4 1.2 + 83314 24  67.7 268.4    61   11      0.95 0.61 -41   1   74  384
68/29:  115951.3 2.4 +272523 41  78.9 210.0    32    8   W  2.04 1.31  37  -8  117  288
68/30:  115951.6 2.3 +534640 25  62.1 138.9    29    6      1.05 0.76 -41  -1  249  858
68/31:  115952.1 1.4 +141830 26  72.5 258.8    43    9      1.35 0.66 -70  -2   81  898
68/32:  115952.1 1.3 +133037 25  71.8 260.4    48    9   W  1.05 0.56   4  -3   79  827
68/33:  115954.1 2.2 +514810 26  63.8 140.7    28    6      1.40 0.87  18   0  236  682
68/34:  115956.7 1.9 +482732 25  66.8 144.4    42    7  E   1.49 1.14  32  -5  216  384
68/35:  115957.3 2.2 +142322 57  72.5 258.6    37    8   W  2.83 0.80  29  -5   79  905
68/36:  115957.7 1.9 +585831 19  57.3 134.9    44    7      1.35 0.92 -40   1  282  429
```

This FITS bytestream consists of 68 logical records: 1 Basic FITS header record, 4 header records for the table header and 63 records for the table itself. The fact that the last row of the table *exactly* fills the 36^{th} line of the 63^{rd} record is accidental; normally the last record is padded with blanks. Also, the fact that the rows are 80 characters long, commensurate with 2880, is peculiar to this table; other tables might have other row lengths. If the row length is not commensurate the rows of the FITS matrix are written as a contiguous stream without regard to logical record boundaries. The total stream is $195840 (= 68 \times 2880)$ bytes long.

This file is number 11 of 24, covering the eleventh hour of Right Ascension, the celestial longitude coordinate, and the total survey contains about 50000 sources. Other analogous radio surveys at different frequencies can be compared and composite tables containing source strengths or non-detections as a function of frequency can be constructed. Similar surveys in other frequency ranges (X-ray, ultraviolet, optical, infrared) can also be compared with this source list, and valuable astrophysical insight comes from such "panchromatic" astronomy.