Skyfits – the "sdfits" format for Skynet 20-meter telescope spectral data.

(F. Ghigo, June 2014, NRAO-Green Bank)

Introduction

The 20-meter radio telescope at Green Bank, West Virginia, is part of the UNC Skynet network of telescopes. This document describes the format of the data files produced by observations with the 20-meter telescope. The files conform to the FITS astronomical data exchange standard. They are binary tables, not image files. Refer to the appendix for references to the FITS standards and definitions.

The format is similar to the "SDFITS" or single-dish FITS format used for the telescopes at Green Bank and Arecibo. They can be processed by the Green Bank "gbtidl" package, for example. This format, which I am calling "Skyfits", differs from the standard SDFITS by the addition of a few columns useful for 20-meter observations, such as the sweep number and sweep valid flag used for raster mapping, the calibration status, and number of samples averaged in an integration.

These FITS file names all have the extension ".cyb.fits"

Basic Structure

As with all FITS format files, the size is an integral number of blocks of 2880 bytes each, a number left over from the card and magnetic tape days. The SDFITS file consists of a main header, an extension header, and binary data as described by the extension header. Each header is a series of lines of ascii text, 80 characters in each line, with no carriage returns or line feeds.

Main Header

Table 1 displays a typical main header for a 20-meter observation.

Comments:

INSTRUME='CYBORG' – Glen named the data acquisition software "Cyborg" and this has stuck.

OBSERVER='Skynet Consortium' -- this should be the Skynet user name, but that information so far is not being transmitted to Cyborg, hence this generic observer name.

Table 1 displays a typical main header for a 20-meter observation

```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                    8 / number of bits per data pixel
NAXIS   =                    0 / number of data axes
EXTEND  =                    T / FITS dataset may contain extensions
COMMENT   FITS (Flexible Image Transport System) format is defined in 'Astronomy
COMMENT   and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
DATE    = '2014-06-27T19:20:07' / date and time this HDU was created
ORIGIN  = 'NRAO Green Bank'    / origin of observation
TELESCOP= 'NRAO20  '           / the telescope used
INSTRUME= 'CYBORG  '           / backend
SDFITVER= 'skyfits ver14.06.27' / this file created by Cyborg
FITSVER = '1.7     '           / FITS definition version
OBSERVER= 'Skynet_Consortium'
PROJID  = 'Skynet_9188'
FRONTEND= 'Rx1_2   '
BACKEND = 'Spectrometer'
FD_POLN = 'XXYY    '
DATE-OBS= '2014-06-27T19:20:06.560' / Start of Observation
OBSFREQ =              1406.25 / Primary Observing Frequency, MHz
OBSBW   =               15.625 / Bandwidth, MHz
OBSNCHAN=                 1024
OBJECT  = 'jupiter '
OBSMODE = 'track   '
RA      = '07:51:03.10'
DEC     = '21:21:08.48'
BMAJ    =    0.733393600631533 / Beam Major axis, degrees
BMIN    =    0.733393600631533 / Beam Minor axis, degrees
SCANLEN =               21600.
COMMENT Geodetic coordinates of the Green Bank 20-meter telescope
SITELONG=            -79.82552 / E. longitude of intersection of the az/el axes
SITELAT =             38.43685 / N. latitude of intersection of the az/el axes
SITEELEV=                835. / height of the intersection of az/el axes
HISTORY BASENAME Skynet_56835_jupiter_9188_9987
HISTORY DATAMODE HIRES
HISTORY FOCUS       46.607           / 20-meter box focus position
HISTORY RFFILTER     1355_1435        / Receiver feed/filter
HISTORY START,STOP channels  204, 819   / range for continuum
HISTORY IF Attenuators    11.00,    8.00    /
HISTORY LO1 tuning         0.0000      / Actual LO1 synthesizer setting, MHz
HISTORY HIRES bands           1406.2500,  1421.8750 / HIRES band centers, MHz
HISTORY TBIN      0.00419430, / Roach Integration, sec
HISTORY ACCLEN    2048, / Roach accumulation length
END
```

PROJID = ‘Skynet_9188’ -- this is the Skynet observation ID number, a unique number assigned to the observation by the Skynet interface.

FRONTEND = ‘Rx1_2’ -- identifies the receiver. Rx1_2 for the L-band receiver, frequency range 1300-1800 MHz. Rx8_10 for the X-band receiver, frequency range 8-10 GHz.

FD_POLN – the feed polarization, which may be “XXYY” for dual linear polarization, or “RRLL” for dual circular.

DATE_OBS – the UT date and time of the start of the observation.

OBSFREQ (in MHz)-- The observing frequency requested by the user. In the case of the wide-band L-band setup in use now, this is not user-settable but just records the center of the observable spectrum. It will become user-settable later in the summer. For the HIRES mode, this is the primary frequency specified by the user (both frequencies are listed in the "HISTORY HIRES bands" card later in the header).

OBSBW (in MHz) – the bandwidth of the spectrometer. In the high-resolution mode, there are two bands of this bandwidth. In wide-band mode, a 500 MHz bandwidth is recorded, but only a portion of it may be usable.

OBSNCHAN – number of frequency channels from the spectrometer. In the wide-band mode, this is always 1024. For the high-resolution mode, this may be 1024, 4096, 8192, or 16384.

OBJECT is the name of the source being observed, as entered by the user. This may have up to 30 characters. Certain characters are not allowed, and if the user includes them in the name, they are removed or replaced with underscores. Unallowed characters are blank spaces, / ; " % & : | , . # ! $ * @ ? = ( ) . The table extension may have data for many different objects, if that is the case, the object name in the main header is the first object observed.

OBSMODE – the scan pattern: Daisy, Map, Track, or OnOff.

RA, DEC are the J2000 coordinates of the first integration of the scan. These are intended to be the coordinates of the OBJECT, but the Skynet controller does not provide these values to Cyborg.

BMAJ, BMIN are the beam half-max major and minor width, in degrees.

SCANLEN is the requested scan length in seconds. This is bogus at the moment because Skynet doesn't send Cyborg the scan length.

SITELONG, SITELAT, and SITEELEV are the geodetic coordinates of the 20-meter telescope.

The HISTORY lines add comments and give parameters that do not have standard FITS keywords.

HISTORY BASENAME `Skynet_56835_jupiter_9188_9987`

The names of all the files associated with an observation start with the BASENAME, with the addition of various extensions such as .txt, .cyb.fits, .png etc.

The BASENAME has several parts that are concatenated together:

1. "Skynet" (this can be "Manual" if running not thru the Skynet interface)
2. The 5-digit MJD, i.e. the modified Julian Day number.

3. The name of the object as given by the user, may have up to 30 characters.
4. The Skynet ID number
5. The Cyborg scan number.

(thus basename may have up to 6+5+30+5+5+4 = 55 characters)

Whenever there is an attempt to start a new observation, it gets an incremented scan number, but not necessarily a new ID number. For example an ON/OFF observation has 2 successive scan numbers, but the same ID number.

HISTORY DATAMODE HIRES -- The DATAMODE may be “LOWRES”, “HIRES”, or “PSR_SEARCH”

(but of course if it is “PSR_SEARCH”, then these .cyb.fits files are not produced at all; the fits files are in the “psrfits” format.)

HISTORY FOCUS 46.307 -- The receiver box focus position in mm.

HISTORY RFFILTER 1355_1435 – this gives the designation of the band pass of the feed/filter combination, in MHz.

HISTORY START,STOP CHANNELS 204, 819 – this is the range of spectral channels with signal. For the 1355_1435 filter in LOWRES mode, 700 and 900 are the channels corresponding to 1355 and 1435 MHz. In HIRES mode, these are 0.2 and 0.8 times NCHAN. This is the range of channels averaged to get the continuum amplitudes that go in the “.txt” files.

HISTORY IF ATTENUATORS – these are the values of the two attenuators in the RF/IF box.

HISTORY LO1 TUNING – the actual frequency setting of the LO synthesizer, in MHz. This is zero for the case where the synthesizer is not used.

HISTORY HIRES BANDS – the frequencies of the centers of the two bands if one is using the high-resolution spectral line mode.

HISTORY TBIN 0.00419430 (in seconds) -- the sample time interval at which the Roach board is sending spectra to the data acquisiton program.

HISTORY ACCLEN 2048. – the Roach accumulation length. This goes along with the TBIN. The ACCLEN can be reduced in factors of 2, which makes a similar reduction of TBIN. 2048 seems to be the largest ACCLEN we can use. TBIN and ACCLEN are used in the LOWRES mode; in HIRES they are irrelevant, but put into the header nevertheless.

Extension Table Header

Table 2 displays a typical header for the extension table.

```
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                 4629 / width of table in bytes
NAXIS2  =                 1808 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                   67 / number of fields in each row
COMMENT Start of SDFITS CORE keywords/columns.
TTYPE1  = 'OBJECT  '           / name of source observed
TFORM1  = '32A     '
TUNIT1  = '        '
TELESCOP= 'NRAO20  '           / The Telescope Used
TTYPE2  = 'BANDWID '           / bandwidth
TFORM2  = '1D      '
TUNIT2  = 'Hz      '
TTYPE3  = 'DATE-OBS'           / date and time of observation start
TFORM3  = '22A     '
TUNIT3  = '        '
TTYPE4  = 'DURATION'           / effective integration time in seconds
TFORM4  = '1D      '
TUNIT4  = 's       '
TTYPE5  = 'EXPOSURE'           / effective int time minus blanking in secs
TFORM5  = '1D      '
TUNIT5  = 's       '
TTYPE6  = 'TSYS    '           / system temperature in Kelvin
TFORM6  = '1D      '
TUNIT6  = 'K       '
COMMENT End of SDFITS CORE keywords/columns.
COMMENT Start of SDFITS DATA column and descriptive axes.
TTYPE7  = 'DATA    '           / actual data
TFORM7  = '1024E   '
TUNIT7  = '        '
TTYPE8  = 'TDIM7   '           / data dimensions of the array
TFORM8  = '16A     '
TUNIT8  = '        '
TTYPE9  = 'TUNIT7  '

TFORM9  = '6A      '
TUNIT9  = '        '
TTYPE10 = 'CTYPE1  '           / first data axis is frequency-like
TFORM10 = '8A      '
TUNIT10 = 'Hz      '
TTYPE11 = 'CRVAL1  '
TFORM11 = '1D      '
TUNIT11 = 'Hz      '
TTYPE12 = 'CRPIX1  '
TFORM12 = '1D      '
TUNIT12 = '        '
TTYPE13 = 'CDELT1  '
TFORM13 = '1D      '
TUNIT13 = 'Hz      '
TTYPE14 = 'CTYPE2  '           / second axis is longitude-like
TFORM14 = '4A      '
TUNIT14 = '        '
TTYPE15 = 'CRVAL2  '
TFORM15 = '1D      '
```

```
TUNIT15 = 'deg     '
TTYPE16 = 'CTYPE3  '           / third axis is latitude-like
TFORM16 = '4A      '
TUNIT16 = '        '
TTYPE17 = 'CRVAL3  '
TFORM17 = '1D      '
TUNIT17 = 'deg     '
CTYPE4  = 'STOKES  '           / fourth axis is Stokes
TTYPE18 = 'CRVAL4  '
TFORM18 = '1I      '
TUNIT18 = '        '
COMMENT End of SDFITS DATA column and descriptive axes.
COMMENT Start of SDFITS SHARED keywords/columns.
TTYPE19 = 'OBSERVER'           / name of observer(s)
TFORM19 = '32A     '
TUNIT19 = '        '
TTYPE20 = 'OBSID   '           / observation description
TFORM20 = '32A     '
TUNIT20 = '        '
PROJID  = 'Skynet_56832_Saturn_RATs_20140624_9132_9925' / Project Identifier
TTYPE21 = 'SCAN    '           / scan number
TFORM21 = '1J      '
TUNIT21 = '        '
TTYPE22 = 'OBSMODE '           / observing mode
TFORM22 = '32A     '
TUNIT22 = '        '
TTYPE23 = 'FRONTEND'           / frontend device
TFORM23 = '16A     '
TUNIT23 = '        '
BACKEND = 'Spectrometer'       / Backend device
TTYPE24 = 'TCAL    '           / calibration temperature
TFORM24 = '1E      '
TUNIT24 = 'K       '
TTYPE25 = 'VELDEF  '           / velocity definition and frame
TFORM25 = '8A      '
TUNIT25 = '        '
TTYPE26 = 'VFRAME  '           / radial velocity of the reference frame
TFORM26 = '1D      '
TUNIT26 = 'm/s     '
TTYPE27 = 'RVSYS   '           / radial velocity, Vsource - Vtelescope
TFORM27 = '1D      '
TUNIT27 = 'm/s     '
TTYPE28 = 'OBSFREQ '           / observed center frequency
TFORM28 = '1D      '
TUNIT28 = 'Hz      '
TTYPE29 = 'LST     '           / LST at midpoint of integration/scan
TFORM29 = '1D      '
TUNIT29 = 's       '
TTYPE30 = 'AZIMUTH '           / azimuth
TFORM30 = '1D      '
TUNIT30 = 'deg     '
TTYPE31 = 'ELEVATIO'           / elevation
TFORM31 = '1D      '
TUNIT31 = 'deg     '
TTYPE32 = 'TAMBIENT'           / ambient temperature
TFORM32 = '1D      '
TUNIT32 = 'K       '
TTYPE33 = 'PRESSURE'           / ambient pressure
TFORM33 = '1D      '
TUNIT33 = 'mmHg    '
TTYPE34 = 'HUMIDITY'           / relative humidity
TFORM34 = '1D      '
TUNIT34 = '        '
```

```
SITELONG=            -79.82552 / E. longitude of intersection of the az/el axes
SITELAT =             38.43685 / N. latitude of intersection of the az/el axes
SITEELEV=                835. / height of the intersection of az/el axes
TTYPE35 = 'RESTFREQ'           / rest frequency at band center
TFORM35 = '1D      '
TUNIT35 = 'Hz      '
TTYPE36 = 'FREQRES '           / frequency resolution
TFORM36 = '1D      '
TUNIT36 = 'Hz      '
COMMENT End of SDFITS SHARED keywords/columns.
COMMENT Start of GBT-specific keywords/columns.
TTYPE37 = 'EQUINOX '           / equinox of selected coordinate reference frame
TFORM37 = '1D      '
TUNIT37 = '        '
TTYPE38 = 'RADESYS '           / Equitorial coordinate system name
TFORM38 = '8A      '
TTYPE39 = 'TRGTLONG'           / target longitude in coord. ref. frame
TFORM39 = '1D      '
TUNIT39 = '        '
TTYPE40 = 'TRGTLAT '           / target latitude in coord. ref. frame
TFORM40 = '1D      '
TUNIT40 = '        '
TTYPE41 = 'SAMPLER '           / sampler description (e.g., "A1" or "A1xA3"
TFORM41 = '8A      '
TUNIT41 = '        '
TTYPE42 = 'FEED    '           / (signal) feed number
TFORM42 = '1I      '
TUNIT42 = '        '
TTYPE43 = 'SRFEED  '           / reference feed number
TFORM43 = '1I      '
TUNIT43 = '        '
COMMENT Feed offsets ARE included in the CRVAL2 and CRVAL3 columns
TTYPE44 = 'FEEDXOFF'           / feed XEL offset
TFORM44 = '1D      '
TUNIT44 = 'deg     '
TTYPE45 = 'FEEDEOFF'           / feed EL offset
TFORM45 = '1D      '
TUNIT45 = 'deg     '
TTYPE46 = 'SUBREF_STATE'       / subreflector state (1,0,-1) - 0=moving
TFORM46 = '1I      '
TUNIT46 = '        '
TTYPE47 = 'SIDEBAND'           / resulting sideband ('U'pper or 'L'ower)
TFORM47 = '1A      '

TUNIT47 = '        '
TTYPE48 = 'PROCSEQN'           / scan sequence number
TFORM48 = '1I      '
TUNIT48 = '        '
TTYPE49 = 'PROCSIZE'           / number of scans in procedure
TFORM49 = '1I      '
TUNIT49 = '        '
TTYPE50 = 'LASTON  '           / last 'on' for position switching
TFORM50 = '1J      '
TUNIT50 = '        '
TTYPE51 = 'LASTOFF '           / last 'off' for position switching
TFORM51 = '1J      '
TUNIT51 = '        '
TTYPE52 = 'TIMESTAMP'          / date and time of scan start
TFORM52 = '22A     '
TUNIT52 = 'UTC     '
TTYPE53 = 'VELOCITY'           / line velocity in rest frame
TFORM53 = '1D      '
```

```
TUNIT53 = 'm/s     '
TTYPE54 = 'ZEROCHAN'           / zero channel
TFORM54 = '1E      '
TUNIT54 = '        '
TTYPE55 = 'SIG     '           / signal is true, reference is false
TFORM55 = '1A      '
TUNIT55 = '        '
TTYPE56 = 'CAL     '           / cal ON is true, cal OFF is false
TFORM56 = '1A      '
TUNIT56 = '        '
TTYPE57 = 'CALTYPE '           / LOW or HIGH, may eventually be other types
TFORM57 = '8A      '
COMMENT End of GBT-specific keywords/columns.
EXTNAME = 'SINGLE DISH'        / name of this binary table extension
TTYPE58 = 'INT     '           / Integration Number
TFORM58 = '1I      '           /
TTYPE59 = 'FDNUM   '           / Feed Number
TFORM59 = '1I      '           /
TTYPE60 = 'IFNUM   '           / IF Number
TFORM60 = '1I      '           /
TTYPE61 = 'PLNUM   '           / Polarization Number
TFORM61 = '1I      '           /
TTYPE62 = 'CALSTATE'           / Calibration status
TFORM62 = '1I      '           /
TTYPE63 = 'NSAMPS  '           / Number of samples averaged for this integration

TFORM63 = '1I      '           /
TTYPE64 = 'SWPINDEX'           / Sweep number when mapping
TFORM64 = '1I      '           /
TTYPE65 = 'SWPVALID'           / Sweep data valid flag
TFORM65 = '1I      '           /

TTYPE66 = 'MJD     '           / Time as MJD of this integration
TFORM66 = '1D      '           /
TTYPE67 = 'UTSECS  '           / Time in UT seconds of this integration
TFORM67 = '1D      '           /
END
```

Commentary –

The table header describes the binary data that follows. It is organized as many rows, in this case 1808 rows, as specified by the NAXIS2 keyword. Each row has 67 fields (TFIELDS). In the FITS tables convention, a field may actually contain a multi-dimensional array. For these FITS files, field number 7 is an array that contains the spectrum, actually a one-dimensional array, but labeled with 4 dimensions with CTYPE1=frequency, CTYPE2=RA, CTYPE3=DEC, CTYPE4=stokes. Only the first dimension has any extent, as described by CRVAL1, CRPIX1, CDELT1, where CRVAL1 is the frequency at pixel CRPIX1, with the frequency step CDELT1.

TFORM7 gives the data format for the data array, in this case “1024E” meaning 1024 single-precision floating point numbers.

Data Array

The data array is described by the following fields:

```
TTYPE7  = 'DATA    '           / actual data
TFORM7  = '1024E   '
-- number of elements in the spectrum array; "E" means single-precision floating point
numbers.

TTYPE8  = 'TDIM7   '           / data dimensions of the array
TFORM8  = '16A     '
      The contents of "TDIM7" field is "(1024,1,1,1)" which gives the dimensions of
the data array.  It extends 1024 on the first axis, and extent of 1 on the other 3
axes.
TTYPE9  = 'TUNIT7  '
      TUNIT7 gives the units of the data in the data array.  In this case this field
is always "counts", i.e, uncalibrated numbers.

TTYPE10 = 'CTYPE1  '
TTYPE11 = 'CRVAL1  '
TTYPE12 = 'CRPIX1  '
TTYPE13 = 'CDELT1  '

CTYPE1,CRVAL1, CRPIX1, and CDELT1 describe the frequency axis.
      CTYPE1 is the name of the axis, in this case "FREQ_OBS"
      CRVAL1 is the frequency value in Hz associated with the reference channel.
      CRPIX1 is the reference pixel, counting from zero.
      CDELT1 is the frequency interval from one channel to the next.

TTYPE14 = 'CTYPE2  '
TTYPE15 = 'CRVAL2  '
      CTYPE2 is "RA", CRVAL2 is the right ascension value, in degrees.
TTYPE16 = 'CTYPE3  '
TTYPE17 = 'CRVAL3  '
      CTYPE3 is "DEC", CRVAL3 is the declination, in degrees.

The RA and DEC probably are where the antenna was at the end of the integration.

CTYPE4  = 'STOKES  '           / fourth axis is Stokes
TTYPE18 = 'CRVAL4  '
      The meaning of the Stokes "axis" is as follows:
      Stokes parameters I, Q, U, V are represented as numbers 1,2,3,4.
      Circular pol RR, LL, RL, LR are  -1, -2, -3, -4
      Linear pol XX, YY, XY, YX are -5, -6, -7, -8

Normally only 2 polarization values are recorded in these skyfits files.  If using the
L-band receiver which has linear polarization, CRVAL4 will be -5 or -6.
Likewise if X-band with circular polarization, CRVAL4 will be -1 or -2.
```

20-meter-specific columns:

We mention first the columns that are unique to the 20-meter Skynet system:

TTYPE62 = "CALSTATE"

Indicates whether the noise cal is on for this integration. If on, the value is +1, zero if off, or -1 if in an intermediate state.

We do not use the “CAL” field because in the usual GBT practice the cal is switching on and off frequently. The GBT program “gbtidl” objects if there are not equal CAL on and off states, so we do not use CAL, enabling GBT programs to display and process these files without fuss.

TTYPE63 = “NSAMPS”

Number of samples averaged together for this integration. Samples are of length TBIN. An integral number of samples are averaged, so the actual integration time (given by EXPOSURE) is different from the requested integration time (DURATION). For HIRES data, this number is not known, so is just set to 1.

TTYPE64 = “SWPINDEX”

When doing raster scanning, the sweeps are numbered zero to the number of sweeps-1.

TTYPE65 = “SWPVALID”

This is = 1 when doing a sweep, zero otherwise, i.e, its zero when the telescope is turning around getting ready for the next sweep.

TTYPE66 = “MJD”

The MJD (modified Julian day) including the fractional part

TTYPE67 = “UTSECS”

The number of seconds since the last MJD midnight.

These time fields, and the “DATE-OBS” field, give the end time of the integration.

Some useful index numbers in fields 58-61.

```
TTYPE58 = 'INT     '           / Integration Number
      This counts integrations starting at zero.  For the wide-band LOWRES mode there
are 2 rows per integration, for the 2 polarization states.  For HIRES, there are 4
rows per integration, 2 polarization states, and two IF bands.

TTYPE59 = 'FDNUM   '           / Feed Number
      For multi-feed receivers, enumerates the feeds.  For the 20-meter this is
always zero.

TTYPE60 = 'IFNUM   '           / IF Number
      This enumerates the IF bands.  In HIRES mode, there are 2 Ifs hence this field
is zero or one.  Of course the actual frequencies are given by CRVAL1,CRPIX1,CDELT1.

TTYPE61 = 'PLNUM   '           / Polarization Number
      Counts polarization states; zero or one.  The actual polarization state is
given by CRVAL4.
```

Other fields you ought to know about

```
TTYPE3  = 'DATE-OBS'           / date and time of observation start
      UT date and time as ascii text of the end of the integration.

TTYPE4  = 'DURATION'           / effective integration time in seconds
      The time step from one integration to the next.

TTYPE5  = 'EXPOSURE'           / effective int time minus blanking in secs
      The effective integration time.  For the HIRES mode this is a little less than
the DURATION because some of the time is taken up in doing the FFTs and averaging the
spectra. In the LOWRES mode, the DURATION and EXPOSURE are not exactly what was
requested but are instead an integral number of ROACH samples, i.e., a multiple of
TBIN, usually slightly larger than the requested integration time.

TTYPE6  = 'TSYS    '           / system temperature in Kelvin
      We don't have on-line calibrations, so this is just set to a nominal 100.

OBJECT, OBSERVER, OBSID, PROJID, SCAN, OBSMODE –
      More or less the same as described in the header.  They may seem redundant, but
the SDFITS format allows many scans and objects to be in the same table.  We just put
data for a single scan in these Skynet files, but all these fields are kept in order
to be compatible with "gbtidl" and other NRAO software.

TTYPE24 = 'TCAL    '           / calibration temperature in Kelvin
      The most recent calibration of the noise cal, estimated for the OBSFREQ.  The
engineers have calibrated the TCALs and produced a table of TCALs vs frequency.  This
table is consulted, and the TCAL given here is interpolated to the OBSFREQ, or
secondary frequency.

TTYPE25 = 'VELDEF  '           / velocity definition and frame
      VELDEF is a code indicating the velocity reference frame and definition.  This
is always "RADI-OBS".  "RADI" means radio relation of velocity to frequency, and "OBS"
means the reference frame of the observer, i.e., the telescope.

TTYPE26 = 'VFRAME  '           / radial velocity of the reference frame
TTYPE27 = 'RVSYS   '           / radial velocity, Vsource – Vtelescope
      We do not attempt to correct for the velocity of the source, so VFRAME and
RVSYS are set to zero.


TTYPE28 = 'OBSFREQ '           / observed center frequency
      OBSFREQ is the center of the observed band.  Note in HIRES mode the spectra for
the two band centers are in different rows.

TTYPE29 = 'LST     '           / LST at midpoint of integration/scan
      Local Sidereal Time to the nearest second.

TTYPE30 = 'AZIMUTH '           / azimuth
TTYPE31 = 'ELEVATIO'           / elevation
      AZIMUTH and ELEVATIO probably refer to where the antenna was at the end of the
integration.

TTYPE32 = 'TAMBIENT'           / ambient temperature
TTYPE33 = 'PRESSURE'           / ambient pressure
TTYPE34 = 'HUMIDITY'           / relative humidity
      Weather information at the moment is just set to dummy values.  Someday we may
arrange to include actual weather data.

TTYPE35 = 'RESTFREQ'           / rest frequency at band center
```

```
      I have been filling this in with the HI rest frequency.  If you process these
files in "gbtidl" then you can display the line with either a velocity or frequency
axis.  But for X-band this will not be set.
```

The rest of the fields are more or less explained by the comments. You may well complain that many of the fields are not relevant to the 20-meter data, but they have been left in to keep compatibility with GBT software.

Appendix:

References to the FITS format:

Information may be obtained from the FITS Support Office at: http://fits.gsfc.nasa.gov.

Wells, Greisen, and Harten. 1981, "FITS: A Flexible Image Transport System," *Astron. Astrophys*. *Suppl*., **44**, 363-370.

Harten, Grosbol, Greisen, and Wells. 1988, "The FITS Tables Extension," *Astron. Astrophys*. *Suppl*., **73**, 365-372.

Hanisch et al, 2001, "Definition of the Flexible Image Transport System (FITS)", *Astronomy & Astrophys.*, **376**,359.

.. and numerous other papers you may be able to find by consulting the FITS Support Office.

Software: python routines for access to FITS files are in the "pyfits" package:

http://www.stsci.edu/institute/software_hardware/pyfits

C-routines are in the CFITSIO package:

http://heasarc.gsfc.nasa.gov/docs/software/fitsio/