A User's Guide for the GBT Mapping Pipeline v1.3

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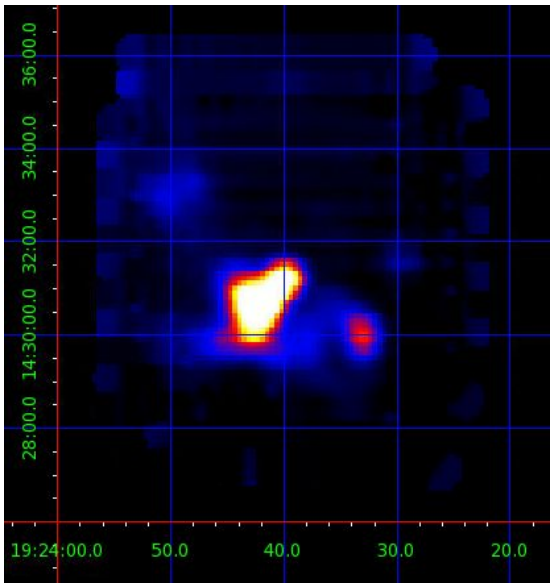


Introduction

This document describes how to use the GBT Mapping Pipeline. The pipeline calibrates and grids GBT spectral line mapping data, and creates FITS image cubes.

The pipeline was developed initially to support mapping observations made with the KFPA, but it can be applied to data taken with any of the receivers that use standard position-switched or frequency-switched observing modes. Pipeline tools can also help with reducing other types of data, such as W-band mapping observations. The pipeline can process data from either VEGAS or the GBT spectrometer.

The pipeline is designed to require minimal user input when data are taken using standard *astrid* mapping procedures. An example astrid script that makes pipeline-ready data is described later in this document. However, the pipeline is also versatile, and users in some cases will get the best results by tuning the pipeline parameters for their specific data set.

Getting Started

Where to Run the Pipeline: The GBT pipeline has certain dependencies and it runs only on 64-bit, RedHat 6 computers in Green Bank. The computer *arcturus.gb.nrao.edu* is reserved for pipeline use. We recommend that you use *arcturus* for all pipeline work at this time.

Disk Space: Due to the typically large datasets produced by the pipeline, especially for VEGAS data, we recommend you make use of the pipeline scratch area.

```
/lustre/pipeline/scratch/<user_id>/
```

where "<user_id>" is your linux user ID, e.g. "jbraatz". To create your own directory, at the command line type:

```
mkdir /lustre/pipeline/scratch/<user_id>
```

A First Look at the Mapping Pipeline

You can run the pipeline using the command:

```
% gbtpipeline
```

For quick help, type the command with no parameters.

Here is a sample pipeline execution using KFPA position-switched test data that observed NH_3 toward W51 using the spectrometer:

```
% gbtpipeline -i /home/gbtpipeline/reference-data/TKFPA_29/TKFPA_29.raw.acs.fits -m
14:24 --refscan 13 --units Jy
```

This command maps data from scans 14-24, using scan 13 as the reference observation. The data are calibrated to units of Jy. The program creates several data products, including three maps stored as FITS files, calibrated spectra from each spectrometer sampler in separate FITS files, and logs of the pipeline execution. The output maps are:

W51_14_24_23706_MHz_cont.fits – a single-channel "continuum" map
W51_14_24_23706_MHz_cube.fits – a multi-channel data cube
W51_14_24_23706_MHz_line.fits – a continuum-subtracted data cube

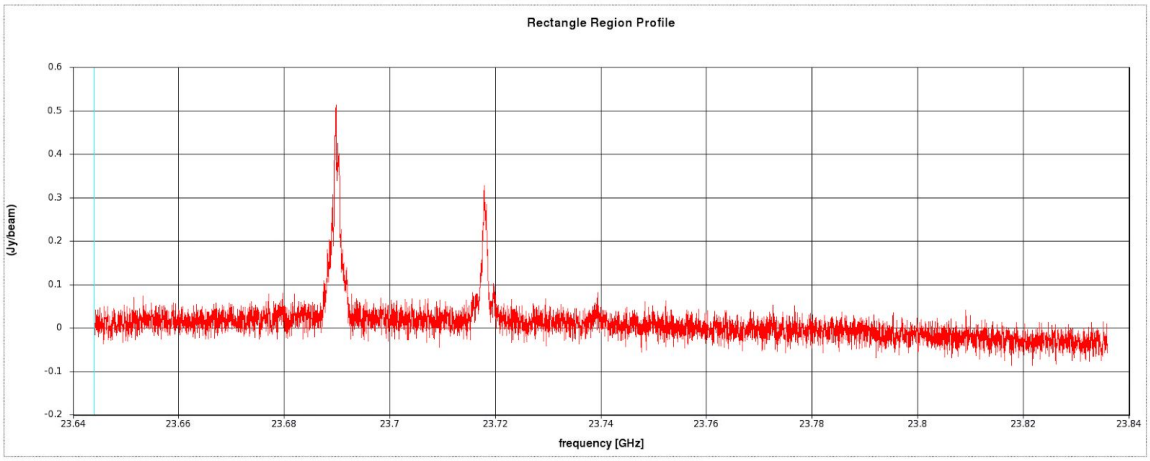
The naming convention of the output maps is:
*<target >_<start scan>_<stop scan>_<rest freq>*_MHz_*<product type>*.fits

The "continuum" map in fact is an average of all the spectral channels, and has no blanking of spectral data. So it includes both the continuum and any spectral lines in the cube. The "cube" includes both continuum and spectral data for each channel. The "line" data has a nominal continuum level subtracted. The continuum level is approximated, in this case, by looking at the flux level in channels near the edges of the spectral axis. If you want a careful continuum subtraction, you will need to modify the pipeline scripts (described later in this document).

You can examine these data cubes using the CASA viewer, e.g. :

```
% casaviewer W51_14_24_23740_MHz_line.fits
```

Select the menu option “Tools -> Spectral Profile”, then left-click on the crosshair icon, and left-click on the map. This will display a spectral cut through the cube.



Another useful data cube viewer is *ds9*, e.g.:

```
% /home/gbtpipeline/bin/ds9  W51_14_24_23740_MHz_line.fits
```

Note that the pipeline uses the same numeric identifiers for window, feed and polarization as GBTIDL. In other words, (feed 1, window 0) refers to the same spectra in the pipeline as it does in GBTIDL.

Using the Pipeline with VEGAS

The pipeline works with observations using either the spectrometer or VEGAS. The syntax is identical between the two. The primary difference relating to the pipeline is that spectrometer data are filled into a single FITS file, while VEGAS data get filled into a directory of FITS files. You will typically want to use the VEGAS directory as input, e.g.:

```
% gbtpipeline -i /home/gbtpipeline/reference-data/TREG_140917.raw.vegas
```

However, if you only want to process data from a specific bank it may be more efficient to use that bank's SDFITS file as input, e.g.:

```
% gbtpipeline -i
/home/gbtpipeline/reference-data/TREG_140917.raw.vegas/TREG_140917.raw.vegas.B.fits
```

So a pipeline call using VEGAS data can reference either the top-level directory, or one of the FITS files within that directory.

Basic Operation of the Pipeline

The input to the pipeline is SDFITS data generated by the *sdfits* filler, from a GBT mapping observation. From that, the pipeline generates image cubes. The pipeline operates in two basic stages.

1. The first stage calibrates the spectral line data and produces FITS files compatible with the GBTIDL "keep file" format of SDFITS.
2. The second stage creates an image from the calibrated spectra using the *gbtgridder* program.

In typical use, a single call to the *gbtpipeline* command executes both stages of operation. You can specify the range of scans to be mapped and identify the reference scans used for calibration, as in the NH_3 mapping example above. A standard position-switched mapping observation begins with a reference scan, executes the mapping scans, and then (optionally) finishes with a second reference scan, all using a common VEGAS configuration. The pipeline understands this sequence and will calibrate the mapping scans using the adjacent reference scans, even if the mapping and reference scans are not identified specifically in the call line. Or, you can specify the mapping scans and reference scans explicitly. When two reference scans are used for calibration, the reference data for each integration of the map will be determined by interpolating between the two reference scans.

Here is an example where the pipeline automatically detects mapping and reference scans within the FITS file:

```
% gbtpipeline -i /home/gbtpipeline/reference-data/TKFPA_29/TKFPA_29.raw.acs.fits
```

And here is an example pipeline call explicitly setting the mapping and two reference scans:

```
% gbtpipeline -i /home/gbtpipeline/reference-data/TKFPA_29/TKFPA_29.raw.acs.fits -m
14:24 --refscan 13,26
```

In the case of this FITS file, the preceding two examples produce the same maps.

When processing frequency-switched data, the map scans should be specified at the command line. Reference scan numbers are not required for frequency-switched maps.

Pipeline Options

Here are the standard options available from the *gbtpipeline* command line:

```
usage: gbtpipeline [options]
```

```
Calibrate spectra and create maps from GBT observations.

optional arguments:
  -h, --help            show this help message and exit
  -V, --version         Prints the pipeline version.

Input:
  -i INFILENAME, --infile INFILENAME
                        SDFITS file name containing map scans

Data Selection:
  -m MAPSCANS, --map-scans MAPSCANS
                        map scans, e.g. "10:20,30:40" identifies two ranges of
                        11 scans each
  --refscan REFSCANS, --refscans REFSCANS
                        reference scan(s), e.g. "4,13" to identify two
                        reference scans
  -f FEED, --feed FEED  feeds, e.g. "0:6" identifies feeds 0 through 6
  -p POL, --pol POL     polarizations, e.g. "0,1"
  -w WINDOW, --window WINDOW
                        spectral windows, e.g. "0,1,2,3"

Control:
  --imaging-off         If set, will calibrate data and write calibrated
                        SDFITS files but will not create image FITS files.

Calibration:
  -u {ta,ta*,tmb,jy}, --units {ta,ta*,tmb,jy}
                        calibration units. Default: tmb
  --no-sky-brightness-correction
                        Disable adjustment for sky brightness.
  --spillover-factor SPILLOVER
                        rear spillover factor (eta_l). Default: .99
  --aperture-efficiency APERTURE_EFF
                        aperture efficiency for spectral window 0. Other
                        window efficiencies are adjusted to this value.
                        (eta_A) Default: .71
  --main-beam-efficiency MAINBEAM_EFF
                        main beam efficiency for spectral window 0. Other
                        window efficiencies are adjusted to this value.
                        (eta_B) Default: .91
  --beam-scaling BEAMSCALING
                        comma-separated scaling factor applied to each feed
                        and polarization in the order 0L,0R,1L,1R,etc. This
                        option only applies to KFPA. All 14 beam scale values
                        required as input.
  -t ZENITHTAU, --zenith-opacity ZENITHTAU
                        zenith opacity value (tau_z). Default: determined from
                        GB weather prediction tools.
  --smoothing-kernel-size SMOOTHING_KERNEL
                        boxcar kernel size for reference spectrum smoothing. A
                        value <= 1 means no smoothing. Default: 3

Output:
  -v VERBOSE, --verbose VERBOSE
                        set the verbosity level-- 0-1:none, 2:errors only,
                        3:+warnings, 4(default):+user info, 5:+debug
  --clobber             Overwrites existing output files if set.
  --keep-temporary-files
                        If set, do not remove intermediate aips.fits imaging

Use @filename.par as a command line parameter to use options from a file. Any
options set on the command line will override whatever is stored in the file.
Pipeline version: 1.3
```

Advanced Operation of the Pipeline

Basic usage of the *gbtpipeline* command, as described above, should meet the data reduction needs of many projects. Sometimes, however, you may need to customize the mapping results or take advantage of certain features that are not available from the standard *gbtpipeline* parameters. In this case, you can run any stage of the pipeline separately, customizing the results at each stage.

Calibration

The first stage of the pipeline calibrates the data and creates an SDFITS file for each sampler in the backend. You can halt the *gbtpipeline* process after calibration by specifying the command-line option "--imaging-off".

As an alternative to using the pipeline for calibration, you may use GBTIDL to produce the SDFITS files. GBTIDL gives you detailed control of the calibration on an integration-by-integration basis. The SDFITS file that you generate must contain one record for each integration in the map, and each record should contain a calibrated spectrum. You can either create one SDFITS file with all the data, or multiple SDFITS files containing partial data sets (for example, separating feeds into separate SDFITS files for individual processing). Separate SDFITS files are easily combined for gridding in a later step.

Flagging Data

There are currently some restrictions on how data flagging must be accomplished with the pipeline. There is no intrinsic flagging for RFI that can affect maps observed at lower frequencies. If you have data that has RFI in some channels, or other defects that you would like to flag, you will probably want to process your data in GBTIDL for calibration or just for the data correction.

GBTIDL documentation can be found here: http://gbtidl.nrao.edu/

KFPA Influence

The pipeline was developed primarily to support KFPA observations, but it works well with maps observed with other receivers. It is important, though, to be aware that certain pipeline features are not optimized for other receivers. For example, calibration defaults are tuned to sensible values for the KFPA. Calibration parameters can be set with command-line options.

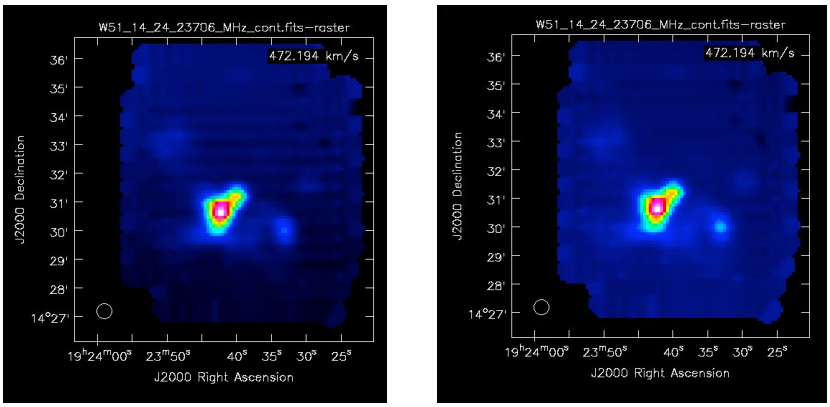
Reference Channel Smoothing

By default, the pipeline applies boxcar smoothing to reference spectra prior to calibration. This is an effective technique for improving signal-to-noise in the calibrated spectra. However, it can strongly emphasize birdies and other defects in the spectra, so in some instances it may be better to turn this option off. The smoothing kernel size has a default of 3 channels, and is controlled with the "--smoothing-kernel-size" parameter. To turn off smoothing, set "--smoothing-kernel-size=0".

Sky Brightness Correction

Total power position-switched mapping observations should include observations of a reference position immediately before and (optionally) after the mapping scans. The reference observation may take place at an elevation that is not necessarily representative of the mapping scan elevations. Moreover, if the reference observations take place many minutes apart, changes in the weather conditions can lead to a poor match between the signal (map) scans and the reference scans. If the calibration does not correct for these effects, maps can have artifacts in the form of stripes and a north-south gradient in the calibrated power. The pipeline includes, by default, a correction for this effect. The effect is particularly important at weather-sensitive frequencies (e.g. K-band and above) and it is pronounced for observations that use only a single reference observation. The correction can be turned off with the "--no-sky-brightness-correction" option.

Without the correction: *With* the correction.



K-band observation of W51 molecular cloud.

T_{cal} scaling for KFPA

The calibration temperatures (T_{cal}) of noise diodes used in GBT receivers are measured periodically by the observatory, and applied to the data during

calibration. These calibration temperatures can drift over time, leading to uncertainties in the measured flux scale. To correct for this scaling offset, the pipeline allows you to set per-beam adjustments at the command line (--beam-scaling). Each of the beam-scaling values (one for each feed and polarization pair) acts as a scaling factor on the observatory-measured T_{cal} values. If you wish to apply these calibration corrections, you should measure the beam-scaling factors by observing a calibrator during your observations. Typically, this is done in one of two ways:

1) Pointing each of the beams at a known flux calibrator source.
2) Observing an extended source with a known flux (e.g. the moon), using all beams.

You should consult your GBT project friend to determine the best calibration strategy.

By default, the pipeline does not apply any scaling factor to the beams. If you do measure and apply a beam-scaling factor, note that the pipeline nevertheless records the observatory-measured T_{cal} values in the output SDFITS spectra.

At the moment, the pipeline only applies corrections for the KFPA. Future releases will allow corrections for other GBT receivers.

Imaging

The imaging step of the pipeline is handled by the *gbtgridder* tool. The *gbtgridder* has a number of options that can be set by the user. Below is a listing of usage options. You can see these by typing "`gbtgridder`" at the command line. One thing to note when creating a large map is the gridder is limited to the amount of memory available on the machine. As a general rule, you should **use a machine with three times as much memory as the size of your map** to be available when running the gridder**.** The largest map that can be made on `arcturus` is approximately 44 GB (as `arcturus` has a maximum of 132 GB of available memory).

```
usage: gbtgridder.py [-h] [-c CHANNELS] [-a AVERAGE] [-s SCANS] [-m MAXTSYS]
                     [-z MINTSYS] [--clobber] [-k {gauss,gaussbessel,nearest}]
                     [-o OUTPUT] [--mapcenter LONG LAT] [--size X Y]
                     [--pixelwidth PIXELWIDTH] [--restfreq RESTFREQ]
                     [-p {SFL,TAN}] [--clonecube CLONECUBE] [--noweight]
                     [--noline] [--nocont] [-v VERBOSE] [-V]
                     SDFITSfiles [SDFITSfiles ...]

positional arguments:
  SDFITSfiles           The calibrated SDFITS files to use.

optional arguments:
  -h, --help            show this help message and exit
  -c CHANNELS, --channels CHANNELS
                        Optional channel range to use. '<start>:<end>'
                        counting from 0.
  -a AVERAGE, --average AVERAGE
```

```
                        Optionally average channels, keeping only
                        nchan/naverage channels
  -s SCANS, --scans SCANS
                        Only use data from these scans. comma separated list
                        or <start>:<end> range syntax or combination of both
  -m MAXTSYS, --maxtsys MAXTSYS
                        max Tsys value to use
  -z MINTSYS, --mintsys MINTSYS
                        min Tsys value to use
  --clobber             Overwrites existing output files if set.
  -k {gauss,gaussbessel,nearest}, --kernel {gauss,gaussbessel,nearest}
                        gridding kernel, default is gauss
  -o OUTPUT, --output OUTPUT
                        root output name, instead of source and rest frequency
  --mapcenter LONG LAT  Map center in longitude and latitude of coordinate
                        type used in data (RA/DEC, Galactic, etc) (degrees)
  --size X Y            Image X,Y size (pixels)
  --pixelwidth PIXELWIDTH
                        Image pixel width on sky (arcsec)
  --restfreq RESTFREQ   Rest frequency (MHz)
  -p {SFL,TAN}, --proj {SFL,TAN}
                        Projection to use for the spatial axes, default is SFL
  --clonecube CLONECUBE
                        A FITS cube to use to set the image size and WCS
                        parameters in the spatial dimensions. The cube must
                        have the same axes produced here, the spatial axes
                        must be of the same type as found in the data to be
                        gridded, and the projection used in the cube must be
                        either TAN, SFL, or GLS [which is equivalent to SFL].
                        Default is to construct the output cube using values
                        appropriate for gridding all of the input data. Use of
                        --clonecube overrides any use of --size, --pixelwidth,
                        --mapcenter and --proj arguments.
  --noweight            Set this to turn off production of the output weight
                        cube
  --noline              Set this to turn off prodution of the output line cube
  --nocont              Set this to turn off prodution of the output 'cont'
                        image
  -v VERBOSE, --verbose VERBOSE
                        set the verbosity level-- 0-1:none, 2:errors only,
                        3:+warnings, 4(default):+user info, 5:+debug
  -V, --version         show program's version number and exit

gbtgridder version: 0.5
```

Optimal Observing Configuration for the Mapping Pipeline

Previous examples demonstrated how you could specify mapping scans and reference scans for the pipeline's calibration sequence. By specifying mapping and reference scans explicitly in this manner, you have direct control over the calibration process. An alternative is to allow the pipeline to determine mapping and reference scans automatically. If you do not specify scan ranges at the command line, the pipeline will examine the entire input data file and attempt to process each mapping observation it encounters there. The pipeline looks at the observing sequence and uses header information to try to identify reference scans with mapping scans.

The following sample astrid script demonstrates a KFPA observing sequence. The pipeline can properly calibrate observations from this sequence without the need to identify mapping and reference scans in the parameter list.

```
# Example Astrid script demonstrating KFPA Mapping for use with pipeline
# We assume that the telescope has been configured prior to running this script

# Identify the source catalog
Catalog("/home/userid/mycatalog.cat")

target = "W51"  # define mapping target
off = "W51-Off" # define a map reference location, with no emission

Slew(target)

Balance()
# Check the levels are correct
Break("Check Balance")

#perform a total power observation at the reference location
Track( off, None, 30.0, "1")

#Map
RALongMap( target,
           Offset("Galactic", 0.33, 0.0), # This is a galactic coordinate map
           Offset("Galactic", 0.0, 0.10),
           Offset("Galactic", 0.0, 0.008),
           140.0, "1")

#perform the final total power reference obs
Track( off, None, 30.0, "1")
```

The pipeline command to image such an observation is simply:

```
gbtpipeline –i my_sample_data.fits
```

Pipeline Development and Help

The pipeline is a stable software product. As of October 1, 2016 it is only being developed at a minimal maintenance level. The pipeline developers are Joe Masters (jmasters@nrao.edu), Bob Garwood (bgarwood@nrao.edu) and Jim Braatz (jbraatz@nrao.edu).

You can get help on pipeline-related issues by using the NRAO Helpdesk. https://help.nrao.edu

The pipeline team uses a mailing list (gbtpipeline-announce@nrao.edu) to keep pipeline users abreast of news and developments. Ask Joe to be on it!

Appendix 1: Calibration Equations

The pipeline uses the following set of equations for calibration.

Calibration temperature

$$T_{cal} = T_{cal}^{lab} \times F$$

where T_{cal}^{lab} is the lab-measured calibration temperature and F is the a scaling factor, usually determined by calibration scans on a source with a known flux. A scaling factor, F, is a user-provided correction factor determined for each beam (i.e. for each unique feed and polarization pair). F defaults to the value 1 for all feeds. The T_{cal} values in the input and output SDFITS files are the lab-measured values.

System temperature

$$T_{sys} = T_{cal} \times \frac{\langle ref80_{caloff} \rangle}{\langle ref80_{calon} \rangle - \langle ref80_{caloff} \rangle} + \frac{T_{cal}}{2}$$

In order to minimize edge effects in calculating system temperature, 10% of the channels at each edge are eliminated. The notation *ref80* refers to the central 80% of the reference data. The angle brackets represent averaging over channels. A single calibration temperature (T_{cal}) is applied for the entire bandpass, averaged over the frequencies observed.

Antenna temperature

$$T_a(v) = T_{sys}^{ref} \times \frac{sig(v) - ref(v)}{ref(v)}$$

where $sig = \frac{1}{2}(sig_{calon} + sig_{caloff})$, $ref = \frac{1}{2}(ref_{calon} + ref_{caloff})$ and the calculation is done on a channel-by-channel basis. The notation T_{sys}^{ref} indicates that the system temperature calculation comes from the reference data, when the telescope is off source (position switching) or off frequency (frequency switching).

Corrected antenna temperature

$$T_a^* = (T_a - T_{corr}^{sky}) \times \frac{e^{\frac{\tau_0}{\sin el}}}{\eta_l}$$

where T_{corr}^{sky} is the correction for sky brightness variation between the reference and current integration, $e^{\frac{\tau_0}{\sin el}}$ is the elevation-adjusted atmospheric opacity and η_l is the correction factor for rear-spillover, ohmic loss and blockage efficiency. The zenith opacity (τ_0) is determined at every integration from weather modeling code provided by Ron Maddalena.

Main beam brightness

$$T_{MB} = \frac{T_a^*}{\eta_B}$$

where η_B is the main beam efficiency. For the KFPA on the GBT, $\eta_B = 1.28\ \eta_A$.

Flux density (Jy)

$$S_\nu = \frac{T_a^*}{2.85 \times \eta_A}$$

where η_A is the (frequency-dependent) aperture efficiency.

Appendix 2: AIPS as an alternate imaging path

The *gbtgridder* should support the needs of the vast majority of pipeline users. However, AIPS can also be used for imaging your data with the help of some scripts developed by the Green Bank pipeline team.

To use the pipeline AIPS imaging scripts, you must be in the "aipsuser" unix group. You can check whether you are a member by typing "groups" at the command line. If "aipsuser" is not listed, contact the GB helpdesk to have GB computing add you to the group. The NRAO helpdesk is accessible at: http://help.nrao.edu

AIPS can be used to image the pipeline-calibrated (or GBTIDL-calibrated) spectra.

1. First you must run the *sdfToAips* program to convert the SDFITS files into a FITS format that can be read by AIPS.
2. Next, use the *aipspy* imaging scripts to combine and grid these calibrated data and produce the output data cubes.

Step 1: File Conversion

With an SDFITS file in hand, you must convert the file to an AIPS-compatible format using the utility program *idlToSdfits*. A typical execution will look like:

```
% sdfToAips myfile.fits –o myfile.aips.fits
```

The *sdfToAips* program has a host of additional options that can be examined by typing "`sdfToAips`" at the linux prompt, with no parameters.

The product of this step is one "AIPS FITS" file for each calibrated SDFITS input.

Step 2: Combining Data and Imaging

The third step is to combine and image the "AIPS FITS" files generated in Step 1 using AIPS. We access the AIPS imaging routines using a python interface. Here we describe that process.

aipspy scripts: The pipeline includes a utility program called *aipspy* that runs ParselTongue scripts in AIPS. To use ParselTongue scripts, you need to know the AIPS ID used on your behalf by the pipeline. Get the ID (which is just a number) from the linux prompt using:

```
% id –u
```

There are several *aipspy* scripts in the standard gbtpipeline distribution. Two important scripts are:

1. load.py : Load one or multiple data files into AIPS in advance of mapping
2. image.py : Map data in AIPS

So, you map the data by executing the following two linux commands:

```
% aipspy /home/gbtpipeline/release/load.py <aipsid> <file1.aips.fits>
[<file2.aips.fits>]
% aipspy /home/gbtpipeline/release/image.py <aipsid>
```

The result of these commands is three FITS files, one with the full image data cube, one with a "continuum" map, and one with a spectral line map.

The "load" step must be executed prior to the "image" step, and you should use only one "load" to combine all of your AIPS FITS files intended for the map. You can specify as many files as you need, when running the "load" step. These will be combined prior to imaging. You can get online help for either of these commands as follows:

```
% aipspy /home/gbtpipeline/release/load.py -h
% aipspy /home/gbtpipeline/release/image.py -h
```

The image script allows you to average channels prior to imaging, specify the center position of the map in RA and DEC, specify the size of the map in pixels, and specify the rest frequency of the line observed.

AIPS Imaging Examples

Here we give several common examples of pipeline use.

Example: Combining Data from Multiple Maps

Suppose you have several data sets from independent executions of your GBT mapping observation. You can combine and map the data using the following steps.

First run the pipeline on each of the maps separately, specifying the "--imaging-off" option. Each execution will generate a set of SDFITS files.

```
gbtpipeline -i my_sample_data.fits -m 10:19 --refscan 9 --imaging-off
gbtpipeline -i my_sample_data.fits -m 21:30 --refscan 20 --imaging-off
```

Next create the aips files for each FITS file generated in the previous step:

```
sdfToAips file1.fits -o file1.aips.fits
sdfToAips file2.fits -o file2.aips.fits
```

Now combine the data using the *aipspy* command with load.py:

```
aipspy /home/gbtpipeline/release/load.py <aips_id> file1.aips.fits file2.aips.fits
```

Finally you can map the data using the *aipspy* command with image.py:

```
aipspy /home/gbtpipeline/release/image.py <aips_id>
```

Example: Mapping Pre-calibrated Data

Under certain circumstances, you may wish to calibrate and process your data in GBTIDL rather than calibrate with the pipeline. For example, the pipeline cannot currently calibrate W-band data, since observations with that receiver use a unique observing sequence for calibration. Or, you may need to perform specific calibration and processing steps, such as reducing the number of channels or fitting a complex spectral baseline. To process data such as this, you must first calibrate the data in GBTIDL and produce a "keep file" that has one record per beam, per integration in the map.

You can then grid the data with the following steps. First, convert the *keep* file to a FITS format (aips file) that can be read by the AIPS FITS reader:

```
% sdfToAips my_keep_file.fits -o my_aips_file.aips.fits
```

Next, load the data into AIPS with the *load.py* script:

```
% aipspy /home/gbtpipeline/release/load.py <aipsid> my_aips_file.aips.fits
```

And finally map the data with the *image.py* script:

```
% aipspy /home/gbtpipeline/release/image.py <aipsid>
```

Example: Reducing channels prior to mapping VEGAS data

Here is an example of how to reduce the number of channels in a data set prior to mapping. This example refers to a real sample VEGAS data set stored on the GB file system.

First calibrate the data with the pipeline:

```
% gbtpipeline -i /home/gbtpipeline/reference-data/TREG_140917.raw.vegas --imaging-off
```

Next reduce the number of channels:

```
% gbtidl
```

```
GBTIDL -> sdextract, 'W3OH_scan_140_145_window0_feed0_pol0.fits', 'reduced_pol0.fits',
startat=65000, endat=65999, boxwidth=10
GBTIDL -> sdextract, 'W3OH_scan_140_145_window0_feed0_pol1.fits', 'reduced_pol1.fits',
startat=65000, endat=65999, boxwidth=10
```

You can then grid the data with the following steps. First, convert the *keep* files to the AIPS FITS format:

```
% sdfToAips reduced_pol0.fits -o reduced0.aips.fits
% sdfToAips reduced_pol1.fits -o reduced1.aips.fits
```

Then load the data into AIPS with the *load.py* script:

```
% aipspy /home/gbtpipeline/release/load.py <aipsid> reduced0.aips.fits
reduced1.aips.fits
```

And finally map the data with the *image.py* script:

```
% aipspy /home/gbtpipeline/release/image.py <aipsid>
```

Example: Line Maps and Temperature from $NH_3(1,1)$ and $NH_3(2,2)$

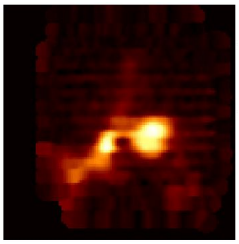
Here we give an example of using *aipspy* scripts to generate line maps and a temperature map from the NH_3 data. Glen Langston contributed the scripts. We make line maps by restricting the spectral channels used in the map to only those near the NH_3 line centers. We use sample data observed with the spectrometer.

Here are the commands to run on arcturus:

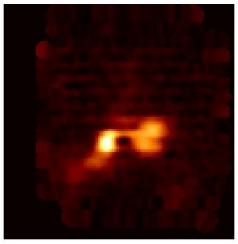
```
% gbtpipeline -i /home/gbtpipeline/reference-data/TKFPA_29/TKFPA_29.raw.acs.fits -m
14:24 --refscan 13 -a 3 -v 4

% aipspy /home/gbtpipeline/release/contrib/sumLine.py <aipsid> W51-NH3-11 23694.506 60.
20.
% aipspy /home/gbtpipeline/release/contrib/sumLine.py <aipsid> W51-NH3-22 23722.6336
60. 20.
% aipspy /home/gbtpipeline/release/contrib/tempNH3_1122.py <aipsid> W51 60. 10. .2
```

Here are example output images from the commands above:

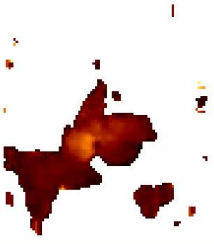
W51-NH3-11 map



W51-NH3-22 map



W51 temperature map



Remember you must replace <*aipsid*> with your unique ID. The first command is the pipeline mapping command we encountered already in our initial example. The second and third commands use the sumLine.py script to generate single-channel maps averaged through the line centers from the NH_3(1,1) and NH_3(2,2) lines. The parameters of the sumLine.py procedure are:

sumLine.py <aipsNumber> <fileName> <restFreq> <lineVel> <lineWid>

(1) <aipsNumber> : the AIPS ID
(2) <fileName> : a name for the output file
(3) <restFreq> : the rest frequency of the line in MHz
(4) <lineVel> : the line center velocity in km/s, and
(5) <lineWid> : the line FWHM in km/s.

The fourth command in the sequence generates the temperature map from the original line cube using the temp_NH3_1122.py script. The parameters for this command are:

tempNH3_1122.py <aipsNumber> <fileName> <restFreq> <lineVel> <cutOff>

(1) <aipsNumber> : the AIPS ID
(2) <filename> : a name for the output file
(3) <lineVel> : the line center velocity in km/s
(4) <lineWid> : the line width (FWHM) to average, and
(5) <cutOff> : the minimum line intensity to use in the line ratio (smaller values result in blanked pixels in the temperature map)

These python scripts are available in the */home/gbtpipeline/release/contrib* directory. Besides being useful in their own right, they also serve as good examples to help you develop your own scripts.

Subtracting Spectral Baselines

A typical GBT mapping observation uses short integration times per pixel (a few seconds), and the resulting spectral baselines are flat compared to the thermal noise. The pipeline therefore uses a very basic spectral baseline subtraction, implemented with the AIPS task *IMLIN* in the *image.py* script. The default behavior is to fit a DC baseline (polynomial of order 0) determined from the edges of the spectrum. Specifically, the baseline is fit to channels [0.04, 0.12]* nchan and [0.81,0.89]*nchan. You can modify this behavior by editing the *image.py* script directly. Follow these steps:

1. cd to the directory with your mapping data
2. copy /home/gbtpipeline/release/image.py to the current directory
3. edit image.py appropriately (search for the “imline” command)
4. re-run the pipeline with the “--imaging-off” option

5. run “aipspy /home/gbtpipeline/release/load.py <aipsid> <file.aips.fits>”
6. run “aipspy image.py <aipsid>” (note we are using the local copy of image.py)

A future upgrade to the pipeline will incorporate baseline-fitting parameters directly in the *gbtpipeline* command line.

For more detailed control over the baseline fitting and other aspects of the calibration and flagging, you can use GBTIDL to calibrate the data and use pipeline tools for “Steps” 1 and 2, that were discussed in the “AIPS” section above.

Cleaning Up Disk Space

The pipeline creates large data files, and may completely fill the available disk space if care is not taken to clean up unused files. You should remove all intermediate files that are not needed for additional processing. This includes “aips” files generated during the calibration of data, and AIPS files used in intermediate stages of gridding the data. A utility is available to clean up old AIPS files, and this should be run after each use of the pipeline.

```
% aipspy /home/gbtpipeline/release/tools/clear_AIPS_catalog.py <aips_id>
```

Recall that you can find your AIPS ID by the linux command “id –u”.

Note: All files stored under the AIPS ID used by the pipeline will be removed with this operation, so it is important that you not store any non-pipeline AIPS files under this AIPS ID.

Units in Image FITS files

AIPS, always writes BUNIT=Jy/Beam to the header of FITS image cubes regardless of the actual units specified in the calibration. Despite the header, the values in the image are correct. If you calibrated your data to units other than Janskys and wish to correct the header, you can use the unix tool *fv*, the *fthedit* procedure in IDL’s modfits.pro or the python package *pyfits*.