KFPA Pipeline Calibration and Mapping Procedures for Observations on 2009 November 27

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Abstract

This document describes the observations made with the GBT towards galactic radio source W49. We summarize the observations and present a series of data calibration imaging steps to produce a set of four images of this region, attempting to detect a variety of molecular species. These observations were made using the dual feed, dual polarization GBT high K-band (22 to 26 GHz) system, for spectral line observations of molecular transistions of NH_3 $1-1$, $2-2$, $3-3$, H_2O and CH_3OH. These observations were made in preparation for KFPA commissioning. Poor weather prevented us from achieving all the test goals, but a number of valuable lessons from this session are discussed. We summarize GBTIDL scripts that allow nearly completely automatic calibration of dual beam observations. We also outline requirements for improved "Sub-mapping" procedures, to facilitate efficiency when mapping large angular regions or observations interrupted for adverse weather.

This document contains a description of the major steps of the calibration and mapping process and documents the RMS noise and and Signal-Noise-Ratio achieved for the method of "Noise Diode Calibration". In addition to test observations of W49, these calibration routines have been tested on wide bandwidth line searches for neutral hydrogen clouds near galaxy NGC 784.

Later documents will compare different methods of calibration, but the implementation of these alternate methods will not significantly change our approach to pipeline calibration and imaging.

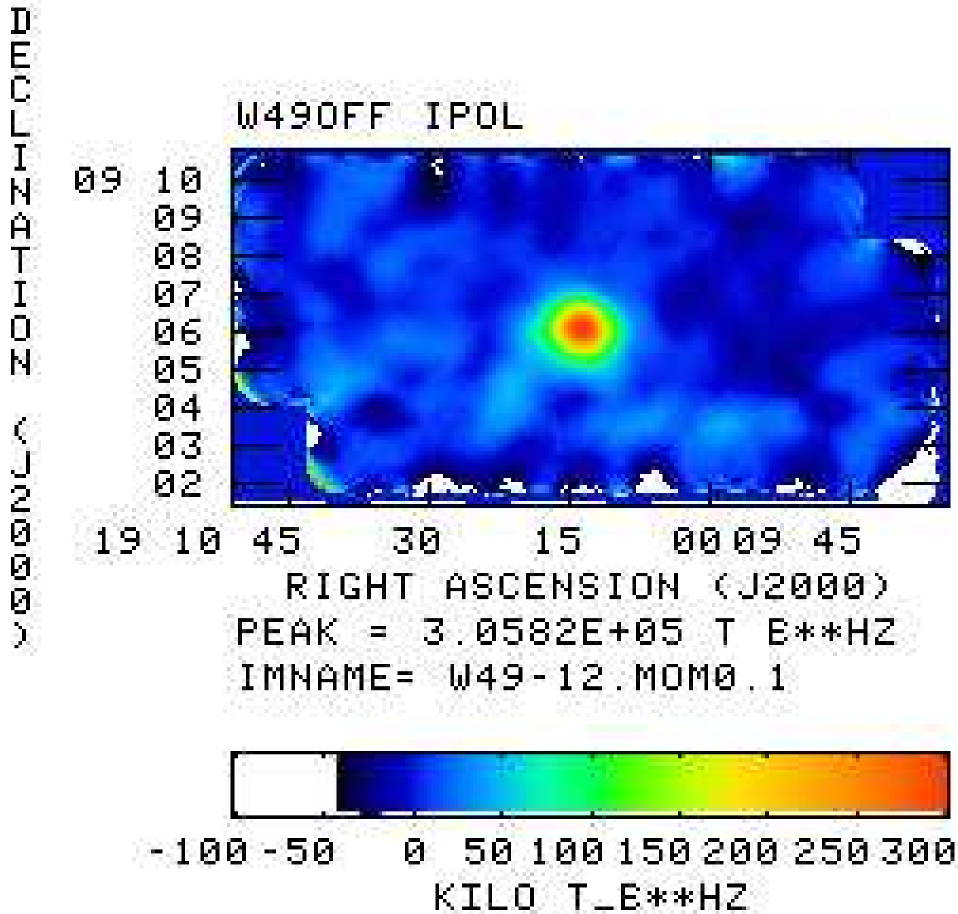


Figure 1: Image produced from the two beam, NH_3 $3-3$, observation of W49. The region of peak emission was imaged with both beams.

1 Test Goals

The purpose of these tests were to prepare for commissioning of the the 7 pixel GBT K-band focal plane array. The KFPA will be normally be used in a rapid scan and dump of spectra mode, so we focused on mapping observations with the maximum spectrometer dump rate. These particular observations were intended to compare mapping and calibration methods for three observing methods, 1) position switched, 2) position switched without winking cal and 3) frequency switched. We intended to make small maps of a point source, 3C286, and a larger map of a known spectral line source, W49. The point source maps were to be 8' square and the spectral line maps were to be 15' square. Astrid scripts were prepared for these observing methods, but only the position switched scripts were used. Poor weather allowed us to complete only part of the position switched observations. We attempted a beam map of point source 3C286, but we were stopped for high winds. After the winds, snow accumulation required pointing the telescope at lower elevations and we immediately moved to W49.

Only the position switched data were obtained during these tests, and future observations must be scheduled to perform the frequency switched tests. Data were obtained to allow position switched and noise-diode calibration. In this document, we describe only the noise diode calibration method. The conversion and imaging steps described here are applicable to all calibration methods. We intend to separately perform position switched calibration and compare the calibration accuracy and spectral baseline flatness in a separate memo.

Section §2 describes the observations and §3 describes the calibration process. Section §4 describes the conversion from GBTIDL `keep` format to AIPS input format. Section §5 describes the commands used in AIPS to examine and image the observations. Section §6 lists recommendations to ASTRID that will facilitate mapping large regions and also maps interrupted for adverse weather. Section 7 summarizes the test results.

Appendix A describes the highest level GBTIDL calibration procedure. Appendix B describes the noise diode calibration procedure. Appendix C is an observing log, to facilitate others to compare reduction processes. Appendix D lists an AIPS `runfile` to aid in configuring the AIPS imaging routines.

2 Observations

This document summarizes Mapping Test observations made with the GBT on November 27, 2009 and the current 22 to 26 GHz receiver system. The observations were made immediately after the Thanksgiving holiday shutdown, an NRAO holiday. Kevin Gum first moved the telescope slowly in Azimuth to condition the grease and bearing oil before the observations.

Beams 3 and 4 were configured for four spectral bands, each with dual polarization and 50 MHz bandwidth. This is the same spectrometer configuration that will normally be used for the KFPA, 7 beam configuration. These observations tested the capability of the spectrometer to dump multiple spectra at high rates.

The spectrometer was first configured for 0.5 second integrations, but we were unable to take data with the spectrometer in this mode.[1] We changed to 1 second integrations with winking cal, toggling at a rate of 20 Hz.

The four spectral bands were configured for four groups of lines. The NH_3 1-1 and $2-2$ were in the first spectral band. The second spectral band was configured for H_2O. The third spectral band was configured for CH_3OH and $CCCS$, and the fourth spectral band was configured for NH_3 $3-3$.

The data were archived under project T_09NOV27, and consisted of 130 scans taken in the interval between 14:00 and 18:08 UTC. Sources 3C286, J1856+06, and the region surrounding W49 were observed.

[1] During a maintenance period the spectrometer configurations will be more fully tested with shorter integrations and non-winking cal signals.

2.1 K-Band Mapping Sequence

The K-Band mapping parameters are set by the beam size and the sampling rate of the GBT spectrometer. The fastest demonstrated spectrometer dump rate is 1.0 for Cal On/Off observations for 16 spectral bands. The GBT FWHM beam at 22 GHz is 33" , and for optimum sampling the sky every 1/3 of a beam or approximately every 10" in the along telescope motion direction. For these observing parameters, the telescope moves at a rate of 10'/minute. Because the sky will be repeatedly observed with all beams, it is sufficient to space the scans of observations by 1/2 beam. For a square image with 15' sides, the observing time is 90 seconds per scan and 60 scans are required. For a 15' square map, the total observing time is 90 minutes, plus point, focus and calibration time. This duration is too long to expect reliable focus and pointing offsets, without periodic peak and focus observations.

For the purposes of these tests, the 15' map was divided into three equal sections, offset in declination. Before and after each observation a reference location was observed in spectral line mode.

The requirement of halting mapping for point and focus checks, combined with weather stoppage resulted in fairly poor observing efficiency.

3 Calibration Steps

The observations were reduced with GBTIDL procedures. These procedures were built on exiting procedures. The procedures are described in the appendix and summarized here.

`w49` The main procedure in the data reduction script is a fairly short script that complies the required procedures and specifies the scans to be used for reference calculations.

`calBand` Main computational procedure processes all observations of one spectral band. The procedure calls sub procedures to compute calibration spectra for both polarizations.

`getRef` Compute the reference spectrum and the average, smoothed Cal-On - Cal-Off spectra for each beam, polarization and frequency band (molecular line).

`scaleRef` Perform the initial scaling and smoothing operations on the reference and calibration spectra. The outputs of this procedure are a pair of "data containers" fully describing the spectra.

`calScanInt` Procedure to fully calibrate a scan, separately processing each integration and interpolating the reference spectra. This procedure uses the outputs of `scaleRef`. The model sky contribution to the system temperature is subtracted from the spectra.

The calibration routines generate an output file containing one or more polarizations, but from only 1 GBT beam. For this example, processing of the

23870 MHz observations from the third of four beams of the GBT K-band feed, the calibrated W49 data have name: `TCal_NH3_W49_3_51_82_23870.fits` These files are given names with the following parts:

`Calibration Type` Method of calibrating the Spectrum. In this case the calibration is performed only using the difference of the Noise Diode Cal-On - Cal-Off values.

`Molecule` The name of one molecule in the spectrum.

`Source` Source name for the first scan in the observation.

`Beam` The beam of the observation. In this case beams 3 and 4 (range 1 to N).

`First Scan` First scan number processed.

`Last Scan` Last scan number processed.

`Center Freq.` Center frequency of this frequency band (MHz).

Before proceeding further, we must point out that all calibration of Radio Astronomy data depends on some method for removing the receiver contribution to the system temperature and the spectral baseline shape. In many cases, an off source position can be found, where it is reasonable to assume there is no source contributing to the measured spectra. This `reference` position may be subtracted from the observation to yield a good estimate of the spectral properties of the science target spectrum. However for some spectral lines, such as H_I, there is no emission free off location. Also since the GBT is remarkably sensitive, there is also almost no location free of a background source, so there is always some contribution to the spectral baseline from the integrated collection of faint background sources.

Combined with an interest in attempting calibration from first principles, here we have focused on noise diode only calibration. The system contribution is still present in this reduction technique, and in the next step the system contribution is removed by assuming that most of the spectral baseline is free of line emission, and the baseline is removed using a median filter baseline (See Langston and Turner 2007, *Ap. J.*, **658**, 455 for more details on the median filter baseline removal process).

4 Conversion to `AIPS` Input Format

After completing the calibration process, the data are converted into another data format compatible with the AIPS package. The program `idlToSdfits`, written by Glen Langston, is used to convert the GBTIDL "keep" format files into the AIPS format. The program has a variety of control parameters, which allow data flagging, data selection, averaging of channels and subtraction of a median baseline.

The program `idlToSdfits` takes as input the calibrated spectra and produces an `AIPS` "Single Dish Fits" format file, which is different that the GBT format. The program gives this file the extension `".sdf"`. By default, the program gives the output file a name similar to the input file. The program also produces a .tex summary of the observation and a tabulation of the RMS noise in all spectra (.noi). The high level GBTIDL procedure automatically calls idlToSdfits at the end of calibration.

The selection of the spectra are selected and the spectral baseline removed by a call from GBTIDL to a procedure toaips. This procedure accesses the output GBTIDL file name (!g.line_fileout_name) and converts this output into the required AIPS input format.

5 AIPS Processing

The AIPS program is used to produce images for the observer. This process involves several steps. Each AIPS task has a number of input arguments. Generally, the AIPS default values are good for most tasks, so if uncertain about any value, try to set it to the default value. The default values are generally zeros or blank strings (”).

Each task has one or more input and output files. AIPS also has the concept of input DISKS which can be thought of as different output directories. More information on AIPS can be found at *http://www.nrao.edu/aips/*

5.1 Loading data into AIPS: UVLOD

The data are first loaded into AIPS using the AIPS task UVLOD. The most important input items are listed below.

DATAIN Ascii string specifying the data location and file name. Often the AIPS data are placed in the directory were AIPS is started. The current directory has a symbolic name PWD. In the case of the W49 example, the input file name is PWD:W49_3_5_82_23870.sdf.

DOUVCOMP The AIPS data is compressed by default, but single dish data must not be compressed, so always use DOUVCOMP = -1.

After loading the observations from several beams, the data must be merged using the task DBCON. This task only allows two inputs, so the task must be run repeatedly to merge all beams. Remember to give the input data equal weight by setting the AIPS parameter (REWEIGHT=0.

5.2 Mapping Parameters: SDIMG

The AIPS mapping task, SDIMG, has a larger number of input parameters. The critical ones are listed below:

BCHAN Beginning channel, usually BCHAN=0, is a good default, but can potentially generate a large amount of unused image planes.

ECHAN Same as for BCHAN

`CELLSIZE` Size of individual image pixels. The `CELLSIZE` is a two dimensional value, but usually the pixels are square. A good rule of thumb is to set the `CELLSIZE` to 1/3 to 1/5 the GBT beam size at the center frequency. For comparing observations of lines at several frequencies it is convenient to make all images with the same cell size and image size. AIPS has the capability of creating procedures for repeating tedious operations. Several AIPS procedures are listed in Appendix D for setting the proper values for the imaging convolution step.

For the NH_3 $1-1$ transition at 23,694.506 MHz, the GBT FWHM beam size is 32.1". Setting `CELLSIZE=5` yields a reasonable image.

`IMSIZE` Image size in pixels. The product of image size and `CELLSIZE` in (arc-seconds per pixel) and should be slightly larger than the region mapped.

`XTYPE` The convolving function for placing spectra into the image grid. The currently favored convolution type is `XTYPE = -16`, indicating a circular convolution shape that is the product of the first order Bessel function multiplied by an exponential. The convolution function is given in the equation below for angular offset θ:

$$f(\theta) = e^{-[\theta/Xparm(3)]^{Xparm(4)}} \; Bessel_{J=1}(\theta/Xparm(2))/(\theta/Xparm(2))$$

`XPARM` The convolving function $f(\theta)$ has three parameters that are specified in units of arc-seconds, and the forth parameter, the exponential exponent, is always 2. These convolving function parameters are set relative to the single dish beam size and may conveniently set using an equation in AIPS. An AIPS procedure `SETCONV` is listed in appendix D, to aid in the setup. This procedure is summarized here. First an AIPS variable, `BMAJ`, is defined by an equation to be approximately the GBT beam size (in arc seconds) at the rest frequency of the line. All other parameters in the convolution function are multiples of this value:
`XPARM = BMAJ, BMAJ*1.55, BMAJ*2.55, 2`

The first `XPARM` argument is the angular size of the convolving function. The inquisitive observer can get more `AIPS` help on this topic by typing `HELP UV6TYPE`.

`REWEIGHT` The data of low significance may be flagged using the `REWEIGHT` parameter, but usually this produces unsatisfactory results. To avoid this, use `REWEIGHT = 0, 1E-12`. (Remember to set this value back to zero before running `UVLOD` again!, or the second data set will have insignificant weight).

`OPTYPE` The project on coordinates onto a rectangular grid is controlled by this parameter. For large single dish fields, setting `OPTYPE = '-GLS'` produces a rectangular image.

5.3 Examining the Image: TVLOD, TVPS, TVLAB, TVWED, TVWLAB

To load images for examination, list the AIPS image catalog (MCAT) and select the image (GETN ??), where ?? is the number of the image. First set the pixel range to all values, PIXRA = 0 and load the image TVLOD. To label the image, type TVLAB and show a color wedge type TVWED. To label the color wedge type TVWLAB and then to adjust the colors type TVPS and use the mouse and keyboard letters A, B, C and D to adjust the color range.

An AIPS procedure TVLOOP is listed in Appendix D, which is convenient for rapidly viewing selected channels of the resulting image.

5.4 Spectrum of an Image Region: ISPEC

After producing the map, the spectral properties of a region may be examined using AIPS task ISPEC. Generally ISPEC is used several times to select the region of interest. First select the image to examine, load it on the AIPS TV, using TVLOD and adjust the colors using TVPS. After setting the color range to show the noise and regions with emission, use TVWIN to select a large region, avoiding the partially mapped regions. Then set the display to the AIPS TV (tt DOTV=1) and do not print out the values (DOCRT=0). Set the axis value to channels (pixels) LTYPE=6, so that the when running ISPEC, the channels containing emission can be selected for production of a moment map.

5.5 Switching Frequency/Velocity 3rd Dimension

The GBTIDL calibration has transfered the rest frequency of this observation to the file header. With that information, AIPS can transform between velocity and frequency on the 3rd axis. The AIPS verb ALTSW switches between these two options. Running ALTSW a second time switches back to the original display option.

5.6 Image of Molecular distribution: TRANS and MOMNT

Often the observer will need to view the distribution of a particular molecular transition over all velocity ranges. Two AIPS tasks are required to accomplish this. The first is TRANS which is used to re-organize the image from RA, Dec, Frequency order to Frequency, RA, Dec order. This new order is specified by the argument TRANSCOD = '312'. At the same time, the image planes containing emission may be selected using the Bottom Left Corner (BLC) and Top Right Corner (TRC) arguments. The task will run much faster if only the required channels are selected, so set the BLC(3) and TRC(3) values to the start and stop channels with line emission.

After transforming the image, an new TRANS image is produced. Select this image for input to MOMNT, using GETN ??. If only the total intensity image is required, set the output class to OUTCL = '0', and to include all values in the selected region `ICUT= 0`. Produce the total intensity image by commanding `GO MOMNT`. Find the new image (`MCAT`), select it (`GETN ??`) and display it (`PIXRA 0; TBLC 0; TTRC 0; TVLOD`)

5.7 Measure Image properties: `JMFIT`

The source structure and integrated intensity is measured using `JMFIT`, but first the telescope resolution must be described in the image header. Above, the AIPS procedure `GBTBEAM` is listed. `GBTBEAM` will set this information in the AIPS image header. The value is approximate, as the mapping method can reduce the effective angular resolution of the observations. The most precise method of determining the angular resolution is mapping a point calibration source in the manner identical that used for making the science observation.

After setting the beam size, the angular region to be fit is selected with AIPS verb `TVWIN`. The number of iterations of the fitting should be large, `NITER=1000`. The number of gaussian components to fit depends on the source structure. For a single component set tt NGAUS = 1. To fit position, width and intensity set `DOPOS = 1; DOMAX = 1; DOWID = 1`. Don't display the values on the terminal (`DOCRT=0`).

6 Observation Support Recommendations

One important result of these tests is the identification of requirements for improving the ASTRID mapping bookkeeping to increase observer efficiency for restarting suspended map observations.

6.1 ASTRID Script Improvements for Mapping

Below are items that would be beneficial for future mapping procedures. The goal of these changes is to more optimally complete sections of maps with appropriate calibration, and booking log that facilitates restarting the maps.

- Observing procedures should track interval between point and focus observations.
- Mapping procedures should automatically suspend mapping, then perform point, focus and calibration.
- Mapping procedures should resume mapping scans automatically after suspending mapping for calibration or weather.
- Mapping procedures should track remaining observing time and perform the final calibration observations just before the end of observing sessions.

6.2 Save/Restore Configurations

The current configuration tool does a good job of completely setting up the GBT RF/LO/IF/Data acquisition systems. A second valuable feature that should be added to the configuration tool is restoring a previous GBT configuration, from a previous mapping session. Having consistent gain (attenuator) settings would be valuable for checking gain stability and be potentially valuable for a more consistent calibration of a set of sub-images of a larger image.

6.3 Expanded Spectrometer Bands

Many molecular clouds exhibit numerous strong spectral lines, but the current GBT spectrometer can only be configured to fully observe one spectral band with all beams. Frequently the science goal for mapping, will be aimed at weaker lines. It will be valuable to configure the 8th pair of IF bands for a single beam and set up for observations of a stronger molecular line. In addition, the GBT should also be configured to allow observations of a third molecular line, by use of the GUPPI design. The GUPPI design would be valuable for galactic chemistry observations if it can be configured for sufficient spectral resolution and the output spectral line data can be quickly averaged and reduced in the existing spectral line systems.

After completing the initial implementation of the GUPPI spectrometer, additional capability can be implemented incrementally, as more funds for hardware becomes available.

7 Summary

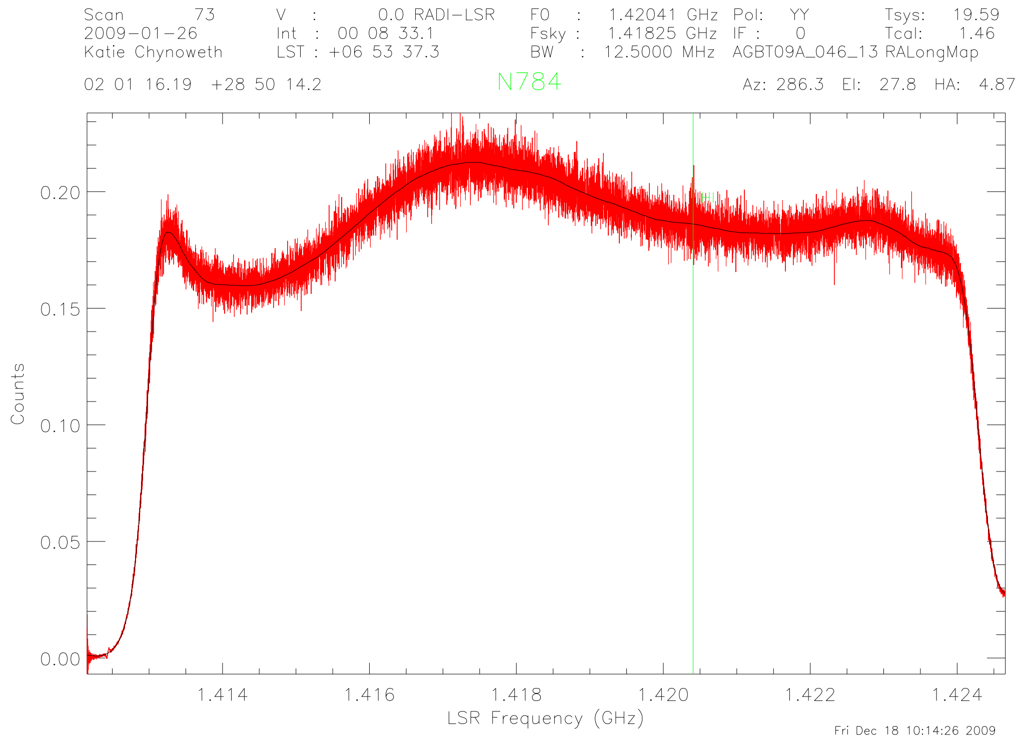
The position switched observations of W49 were carried out successfully, with the observations of a 15' map divided into three sections. All data were processed in a consistent manner with the calibration scripts. The full calibration processing time is significant for a 2 beam, 4 spectral band observation. The processing required almost 24 hours for these mapping observations. The pipeline processing can be significantly speeded if the calibration can be run on several processors simultaneously.

The time required for calibration, pointing and focus were underestimated and future tests should image smaller regions.

These data reduction scripts produce reasonable images of the observations. We show that the Cal-On - Cal-Off observing method can produce good spectral baselines, but only with a dynamic range of about 1 in 400, relative to the system temperature. This implies that spectral features fainter than 20K/400 $\sim$ 0.05K can not be reliable detected with this technique. Note that if the observer can accurately identify line - free regions, then AIPS can be used to fit a spectral baseline, after the imaging step. This allows fainter lines to be detected. Also note that frequently a final spectral baseline must be subtracted in the position switched and frequency switched calibration modes.

In a companion document, we describe the RMS noise found for position switched and frequency switched observations.

Future KFPA images can be produced using these methods, but a number of improvements to the starting and stopping of mapping image sub-sections would improve observer efficiency.



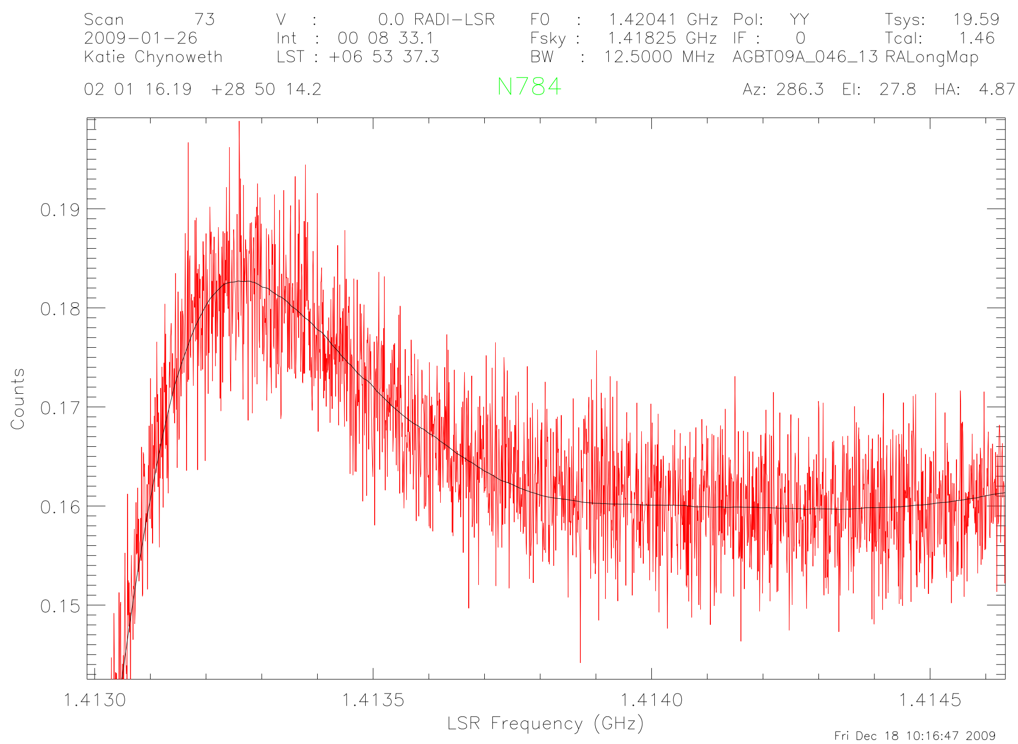


Figure 2: Band pass spectrum of the smoothed Cal-On - Cal-Off signals and model fit to the spectrum. Bottom, zoom in on particularly sharp cusp in the spectrum and the model fit.

A Calibration Procedures for Mapping

This appendix describes in more detail the functions of the mapping procedures and points at the relevant new features of these procedures. Each mapping technique makes some assumptions concerning the data quality and system stability. The procedure methods which make these assumptions are high lighted.

A.1 Top Level Procedure Example: w49.pro

The GBTIDL mapping calibration procedures are all called by a single high level GBTIDL script. This script must be configured by the observer to select the scans for calibration and for computation of the reference spectra. The reference spectrum has two distinct functions. The first and foremost is for use in gain calibration of the observation. The second use is for subtracting of the electronics and sky contributions to the measure of the sky intensity. The gain calibration is always done by use of measurements of the injected noise diode signals and laboratory measurements (or astronomical observations) of the effective noise temperature of these noise diode values.

```
;IDL Procedure to calibrate map scans
;HISTORY
; 10JAN23 GIL use toaips to prepare data for AIPS imaging
; 10JAN22 GIL add code for selecting line emitting region
; 09DEC16 GIL break up sdfits call for clarity
; 09DEC15 GIL revised for tmc map
; 09DEC02 GIL revised for a 2x2 degree map
; 09NOV30 GIL initial version

@compilePipeline.pro

;The data can be loaded from inside idl, so that when the data are
;transformed to an sdfits file, they will be immediately calibrated
sdfitsStr = '/opt/local/bin/sdfits -fixbadlags -backends=acs'
;specify scan list, if all spectra are needed
scansList = ' '
;else specify only the desired scans
scansList = '-scans=49:83'
dataDir = '/home/archive/science-data/tape-0028/'
dataDir = '/home/gbtdata/'
projectName = 'T_09NOV27'
;From the Unix prompt type
sdfitsCmd = sdfitsStr + ' ' + scansList + ' ' + dataDir + projectName
;Tell observer what's being done
print, sdfitsCmd
; or spawn within IDL (uncomment the line below)
spawn, sdfitsCmd
```

```
mapDataName=projectName + '.raw.acs.fits'
filein,mapDataName

;now specify first and last scans, to guide mapping
firstScan=51
lastScan=82
refscans = [50,83]
;use all map scans as ref scans
allscans = indgen(1+lastScan-firstScan) + firstScan
refscans = allscans
print,allscans

; observation is for two feeds and two polarizations
nPol=2

; set velocity parameters for selecting relevant channels
vSource = 10.0        ; km/sec - defines center channel to select
vSourceWidth  = 10.0 ; km/sec - defines median filter width
vSourceBegin  = -30.0 ; km/sec - defines beginning channel to select
vSourceEnd    = 50.0 ; km/sec - defines endding channel to select
; The rest frequency frequencies guide the selection of data to be
; converted to AIPS format.   If no rest frequencies are provided,
; The rest frequencies in the observation header are used.
;            NH3 1-1 and 2-2, H2O,         CH3OH+CCCS,   NH3 3-3
restFreqHzs = [ 23694.5060D6, 22235.120D6, 23121.024D6,  23870.1296D6]
;below the line rest frequency for each band is set.
;There are many-many NH3 lines, so to set the velocity the strong line
;must be identified.

for iFeed = 0, 1 do begin $\
for iBand = 0, 3 do begin $\
  gettp,refScans[0], int=0, ifnum=iBand & $\
  calBand, allscans, refscans, iBand, iFeed, nPol & $\
  data_copy, !g.s[0], myDc & $\
;change rest frequency for computation of velocities in AIPS
  myDc.line_rest_frequency = restFreqHzs[iBand] & $\
;select channels and write the AIPS compatible data
  toaips,myDc,vSource,vSourceWidth,vSourceBegin,vSourceEnd & endfor&endfor
```

Listing of the top level calibration script: w49.pro

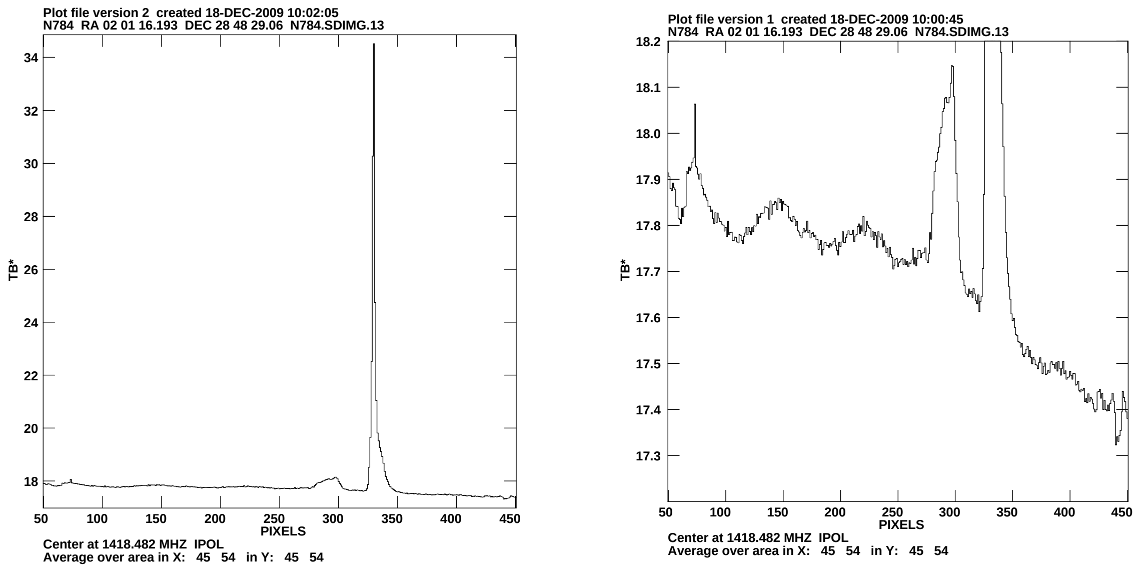


Figure 3: Spectrum of galaxy NGC 784 observed with the GBT by Katie Chynoweth and calibrated using the pipeline proceedurs. The spectrum at left shows the full range of intensities. The strongest line is emission from the Milky Way, and the second strongest line if NGC 784. The spectrum at right is identical to that on the left, except zoomed in on the spectral baseline. The galaxy NGC 784 is clearly visible, but there is significant spectra baseline wripple.

B Calibration Steps

The observations were calibrated using previously written GBTIDL scripts. The main script, `w49.pro` has a number of steps. These procedures are currently written by the observer. In the future, the pipeline will automatically generate these scripts and run them on a set of processors.

`sdfits` The main procedure will select relevant data from the GBT archive and place these data in a file for calibration. The linux program `sdfits` is called from inside IDL, so that calibration can start immediately after the data selection.

`Scan Selection` The calibration process requires identification of scans appropriate for gain (reference) calibration. The type of calibration determines the scans to be selected. For Noise Diode calibration, frequently all scans in a observation will be used. An exception is the case where the source to be observed is so strong that the noise diode measurements are adversely effected by the source. This is the case for the W49 water maser observations. In this example, two off source reference spectra are combined with the first and last map scans, to compute the reference Noise Diode spectra for each beam and polarization.

`Band Selection` This particular implementation of the calibration process separately calibrates each spectral line observed. This may be easily parallized so that different processors calibrate different bands. In the KFPA case, usually there will be only one band, but multiple beams. Potentially this script should be re-written to separately identify different beams for calibration.

`Calibration` The calibration process is completely performed by one of three calibration processes.

- `calBand` Calibration of the gain using only the noise diodes, but performs to subtraction of the receiver temperature contribution to the intensity values. The model atmospheric contribution to the spectra is removed.
- `calBandRef` (Signal - Reference)/Reference calibration of the observations. In this case a set of reference spectra are chosen which are free of line emission. After the amplitude calibration, the reference spectra is subtracted. The model atmospheric contribution to the spectra is removed, by tracking changes in the weather and antenna elevation between observations and the values at the time of reference spectrum observation.
- `calBandFS` Frequency Switched calibration of the observations. This technique requires no specification of the reference signal, to be subtracted from the observation, but does require specification of gain calibration observations.

B.1 High Level Noise Diode Calibration: `calBand`

The Noise Diode calibration method is implemented in GBTIDL script `calBand.pro` which computes a noise diode spectrum for each beam and polarization of the observations. Only one spectral band is processed per call.

C W49 Observing Log

Below is a list of the observations during the W49 test. Due to poor weather, we initially had trouble with the peak and focus observations, required a second set of peak and focus observations. Note that probably the "Relaxed Fit" option should be the default for Astrid for all KFPA observations.

The observations were suspended for high winds, then snow during the 3C286 Map interval. After the winds decreased, we elected to observe W49, which was at low elevation, so as to minimize snow accumulation.

```
StartStop Source Proc.  # RA-2000  Dec-2000   #   Sky  BandWidth
   Scan   Name            (hms)    (d'")    Data (MHz)(MHz)
==== /home/gbtdata/T_09NOV27/ ==== T_09NOV27 ==== Glen Langston ========
   1    4 3c286   Peak   4 13h31m08 30d30'31  576 22105  990 DCR 14:02:24
   5    5 3c286   Focus  1 13h31m08 30d30'33  294 22105  990 DCR 14:04:52
   6    9 3c286   Peak   4 13h31m08 30d30'31  576 22105  990 DCR 14:08:25
  10   10 3c286   Focus  1 13h31m08 30d30'33  294 22105  990 DCR 14:10:53
  11   14 3c286   Peak   4 13h31m08 30d30'32  576 22105  990 DCR 14:14:49
  15   18 3c286   Peak   4 13h31m08 30d30'32  576 22105  990 DCR 14:20:02
  19   19 3c286   Focus  1 13h31m08 30d30'33  294 22105  990 DCR 14:22:31
  20   21 3c286   Nod    2 13h31m08 30d30'33  122 22237   50 ACS 14:32:52
  22   23 3c286   Nod    2 13h31m08 30d30'33  122 22237   50 ACS 14:37:48
  24   25 3c286   Nod    2 13h31m08 30d30'33  124 22237   50 ACS 14:45:14
  26   27 3c286   Nod    2 13h31m08 30d30'33  124 22237   50 ACS 14:51:26
  28   28 3c286Off Track 1 13h35m00 30d30'33   62 22237   50 ACS 14:53:02
  29   41 3c286   RAMap  ! 13h31m01 30d28'33  770 23700 1280 DCR 14:56:08
  42   45 J1856+06 Peak  4 18h56m32  6d10'15  720 23700 1280 DCR 15:31:50
  46   46 J1856+06 Focus 1 18h56m32  6d10'17  294 23700 1280 DCR 15:34:08
  47   48 W49     Nod    2 19h10m13  9d06'13  122 22234   50 ACS 15:38:48
  49   50 W49     Nod    2 19h10m13  9d06'13  122 22234   50 ACS 15:42:15
  51   51 W49Off  Track  1 19h14m13  9d06'13   61 22234   50 ACS 15:43:44
  52   82 W49    RAMap  31 19h10m13  9d08'42 2821 22234   50 ACS 15:47:11
  83   83 W49Off  Track  1 19h14m13  9d06'13   61 22234   50 ACS 16:46:22
  84   87 J1856+06 Peak  4 18h56m32  6d10'15  576 23700 1280 DCR 16:49:00
  88   88 J1856+06 Focus 1 18h56m32  6d10'17  294 23700 1280 DCR 16:51:18
  89   90 W49     Nod    2 19h10m13  9d06'13  122 22234   50 ACS 16:55:28
  91   92 W49     Nod    2 19h10m13  9d06'13  122 22234   50 ACS 16:58:55
  93   93 W49Off  Track  1 19h14m13  9d06'13   61 22234   50 ACS 17:00:25
  94  124 W49+7   RAMap 31 19h10m13  9d15'42 2821 22234   50 ACS 17:03:54
 125  125 W49Off  Track  1 19h14m13  9d06'13   61 22234   50 ACS 18:03:10
 126  129 J1856+06 Peak  4 18h56m32  6d10'15  576 23700 1280 DCR 18:05:53
 130  130 J1856+06 Focus 1 18h56m32  6d10'17  294 23700 1280 DCR 18:08:14
```

D AIPS Utility for Imaging parameters

Imaging of GBT spectra in AIPS is relatively straightforward, however the setting the convolving function values to yield good results is slightly tricky. Below is a listing of an AIPS `runfile` to aid in setup of the inputs to AIPS task `SDIMG`.

The critical procedure `SETCONV`, below is run after all other inputs to the AIPS task `SDIMG` are set. This includes selecting the input spectra for the subsequent imaging process. The header of the input single dish data will be modified to include an estimate of the GBT beam size at the frequency of the molecular line.

To use these procedures, within AIPS one must first compile these procedures. to do this type

`RUN IDLTOSD`

at the AIPS command prompt.

Below is a listing of the `IDLTOSD.001` procedure for this date.

```
$ aips scripts transfer circular beam shape to map header
$ Allows imstat to return the correct intensities
$ HISTORY
$ 10JAN24 GIL add scripts for seting SDIMG convolution function

$ define some variables for procedures
PROC INITGBT
  SCALAR FREQMHZ, FWHM, BEAMSIZE, LAMBDACM
  SCALAR ISTART, IEND, PAUSEL
FINISH

$ Assume a "Circular Clean Beam"
$ INPUT beam size in arc-seconds
PROC CIRCULAR( X)
  keyword='BMAJ'   ; KEYVAL = X/3600., 0; PUTHEAD
  keyword='BMIN'   ; KEYVAL = X/3600., 0; PUTHEAD
  keyword='BPA'    ; KEYVAL = 0; PUTHEAD
  keyword='NITER'  ; KEYVAL = 1, 0; PUTHEAD
  RETURN
FINISH

$compute the GBT beam size expected for a GBT mapping
$observation.   This model assumes the data are sampled
$much faster than the time to cross a point source, so
$no source smearing correction for finite integration
$time is required.
PROC GBTBEAM
  keyword 'restfreq' ; gethead
  FREQMHZ = KEYVAL(1)*.000001
  LAMBDACM = 29979.245/FREQMHZ
```

```
  BEAMSIZE = 0.423*LAMBDACM*60.
  CIRCULAR( BEAMSIZE)
  KEYWORD 'BUNIT'; gethead
  KEYWORD 'BUNIT'; KEYSTR = KEYSTR !! '/BEAM'; puthead
$ need Jy/beam for IMSTAT to work
  KEYWORD 'BUNIT'; KEYSTR = 'Jy/BEAM'; puthead
  RETURN
FINISH

$setCONV() computes the appropriate convolution
$function for a GBT observation.   This function should
$be used after setting the CELLSIZE for SDIMG.
$The proceedure uses 5 arc second cellsize if cells is
$not set.
PROC SETCONV
  XTYPE = -16; YTYPE = -16
  GBTBEAM
  KEYWORD = 'BMAJ'; gethead
  BMAJ = KEYVAL(1)*3600.
  IF (CELLS(1) < 0.1) then cells = 5; END
  Y = BMAJ/CELLS(1)
  XPARM = BMAJ, 1.55*BMAJ, 2.55*BMAJ, 2, 0
  YPARM = XPARM
  RETURN
FINISH

$Fix a common spelling error
PROC TPYE(I)
  TYPE I
  RETURN
FINISH

$Fix a common spelling error
PROC TYEP(I)
  TYPE I
  RETURN
FINISH

$Fix another common spelling error
PROC GENT(I)
  GETN I
  RETURN
FINISH

$display a sequence of images on the TV
$Arguments are start and stop frequency channels
```

```
PROC TVLOOP(ISTART,IEND)
  FOR I=ISTART to IEND
    TBLC(3) = I; TVLOD; TVLAB
    PRINT I
$Just enter <CR> to continue
    IF (PAUSEL > 0) THEN READ X; END
  END
  RETURN
FINISH

$ set PAUSEL = 1 to wait between channels
$ set PAUSEL = 0 for no pause in display loop
PAUSEL = 0
```