KFPA Observer's Guide

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— DRAFT —
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1 Purpose of this Document

This Observer's Guide describes steps necessary to plan, observe, calibrate and image set of GBT 7 pixel K-Band Focal Plane Array (KFPA) observations. By making the reference observations in a consistent manner relative to the mapping observations, the calibration `Pipeline` will be more efficiently used. The planning steps are relatively simple and are implemented as a sequence of `Astrid` observing blocks. This document compliments the GBT observers guide (T. Minter et al. http://www.gb.nrao.edu/gbtprops/obsman/GBTog.pdf).

In this document we focus on the steps that must be taken to successfully observe in the modes required to achieve the KFPA top science priority goals. The top priority science goals were defined in a series of meeting preceding development of the 7 pixel K band. The science goals are summarized in a document entitled Science Case for a K-Band Focal Plane Array for the Green Bank Telescope by Larry Morgan, D.J. Pisano, Jay Lockman, James Di Francesco, Jeff Wagg, and Jurgen Ott and dated September 2007

This guide refer's to calibration techniques in the document it KFPA `Pipeline` Position Switched Calibration Methods, by Glen Langston. This document also refers to *Calibration of GBT Spectral Line Data in GBTIDL v2.1* by Jim Braatz and dated October 30, 2009. We also reference a similar document, *Calibration of spectral line data at the IRAM 30m radio telescope*, by C. Kramer and dated January 24, 1997.

These documents are available as links off of the main KFPA wiki page:

https://safe.nrao.edu/wiki/bin/view/Kbandfpa/

This document summarizes the KFPA key science goals (§2) as a basis for the approach taken in the design of the observing sequence (§3). The `Pipeline` calibration and imaging steps (§5). We conclude with an example observation of Galactic Star forming region W51 including the complete reduction of the observation producing images of the NH_3 (1,1) and (2,2) lines. Using these observations the example temperature map is produced.

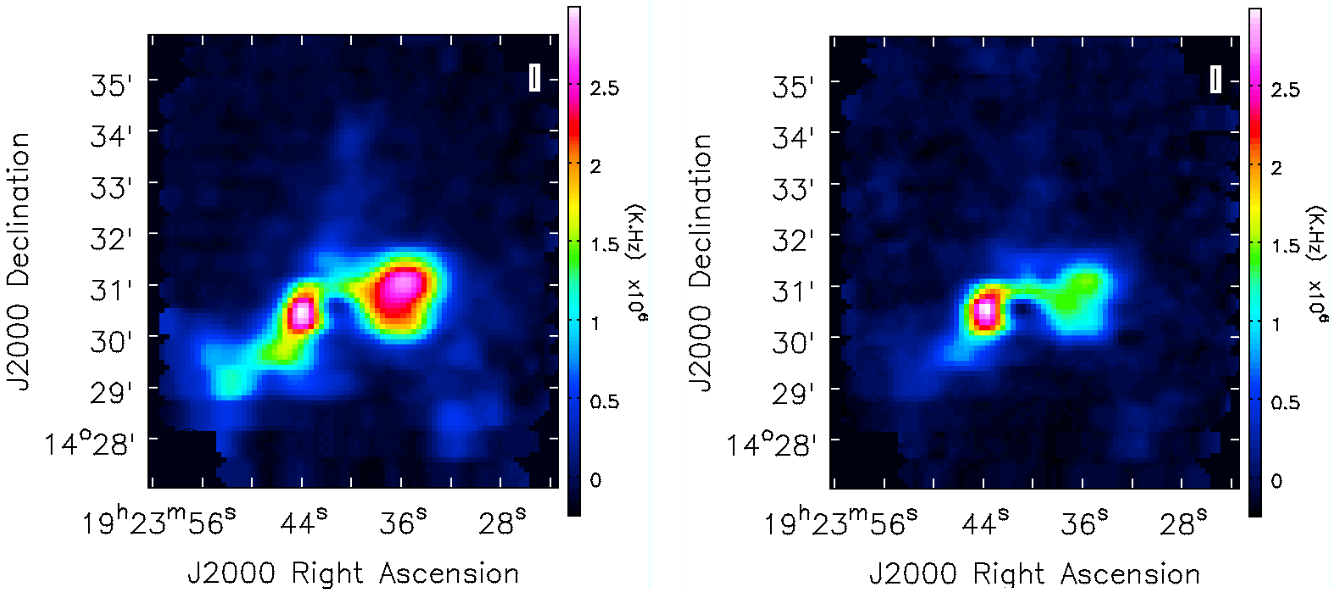


Figure 1: `Pipeline` Calibrated and imaged W51 NH_3 (1,1) (left) and (2,2) (right) transitions, from `RaLongMap` observations made during commissioning session TKFPA_29, in September 2010.

The `Pipeline` automates calibration of spectral line mapping observations and automatically produces an image cube from a calibrated spectra of a single observing session. The GBT Pipeline is designed to calibrate and image any GBT mapping project, as well as new mapping projects tailored for the K-band Focal Plane Array. If all required `Pipeline` scan annotations are supplied during the `Astrid` observing session (§A), the `Pipeline` will completely calibrate and image (§B) the observations. The product of KFPA mapping observation is shown in (Figure 1).

2 Calibration Strategies for Key Science Goals

Three high priority science goals for the focal plane array are identified in the document by Morgan et al. (1997).

We plan continued refinements in the `Pipeline` to yield optimum results for specific types of observations. Because the primary molecular line target is Ammonia NH_3 for the key science drivers, we have refined the analysis for the (1-1) and (2-2) transitions.

The primary science targets described in this document are:

Star Assembly These observations of NH_3 in star forming regions are made toward cold regions of the galaxy, where the spectral lines are narrow. For these type of observations frequency switched calibration is applied.

Turbulence in the ISM Turbulence in the ISM will be measured by the structure, line widths and temperatures of the gas in the ISM containing NH_3. In this case the emitting regions can occur over a wide range of velocities, so that position switch calibration is required. If the emitting region is isolated and cold, the observations may also be carried out in frequency switched mode.

High Redshift Groups The distribution of high redshift galaxy groups will be studied by observations of the CO lines redshifted into the KFPA band. In this case the lines will be wide and confusion may be a problem. These observations will be carried out in position switched modes. If there is extensive faint molecular emission, these projects may also be studied using the noise diode calibrated mode.

The `Pipeline` provides as accurate as possible calibration as can be accomplished without making additional observations to determine the atmospheric opacity and telescope efficiency. The pipeline uses real-time weather monitor data to estimate the atmospheric opacity and the latest GBT structural models to estimate the telescope efficiency. In the appendix, we note additional observations that the observer could include to determine these intensity scale factors more accurately.

Frequency switched and position switched calibration methods share many common features, and the differences are emphasized in the next two sub-sections.

3 The Structure of GBT Spectral Line Observations

In this section we describe the structure of GBT spectral line observations and the resulting data products. GBT spectral line observations are specified using `Astrid` observing procedures listed below. Each procedure is used to command a sequence of one or more scans, with two or four phases per integration. For example, total power, position switched observations require two scans: one for the "on source" position and one for the "off source" position. Typically the noise calibration diode will be winking on and off during these observations. The backend will synchronously detect the calibration noise diode state, and sort the data according.

Observers wishing to use the KFPA pipeline should use one of the GBT "standard mapping modes" for spectral line observations. There are four standard mapping blocks (or modes) are:

RaLongMap Scan the telescope along lines of constant RA or Longitude to observe a rectangular region. The region is uniformly sampled.

DecLatMap Scan the telescope along lines of constant Dec or Latitude to observe a rectangular region. The region is uniformly sampled.

Daisy Scan the telescope in a multi-petal shaped patter to observe a circular region. The center of the region observed is more frequently sampled, yielding a higher SNR in the middle of the image than at the edges.

PointMap Map a region by moving to selected locations and observing without moving the telescope.

For frequency switched observations the reference spectra are obtained simultaneously with the signal spectra. For position switched maps, the Pipeline must identify reference spectra, so that the receiver and sky contributions to the observations may be calibrated. By default, the Pipeline assumes scans defined as "off-source" are made before and after a mapping observation. If no off-source observations are made, the Pipeline will use the average of first and last scans of the image as the two reference scans. Beam switched observations are not supported by the Pipeline.

No matter which observing procedure is used, each scan may have data for multiple IF's (i.e. spectral windows), multiple polarizations, and multiple integrations. Most observations collect two polarizations, either LL and RR (circular) or XX and YY (linear).

The two types of calibration reference methods are supported by the KFPA pipeline, *1)* position switched and *2)* frequency switched. Position switched and frequency switched calibration are described in detail.

Region A region is the entire area to be mapped in order to achieve the science goal of the project. Observations of a region are carried out over several different observing sessions, on different dates.

Session An observing session is carried out on a specific date for a continuous period. The sessions will include pointing and focus scans before mapping blocks.

Block A mapping block is the observation unit that is completely processed by the `Pipeline` . For position switched observations, a block includes reference position scans before and after a sequence of mapping scans.

Scan A GBT scan consists of commands to move the telescope in a specific manner, while collecting spectral integrations, averaged over short times. A scan is typically has a few minutes duration.

Integrations The data from a GBT integration is a complete set of spectra for all switching states, all spectral bands and all polarizations, for one time period. An integration duration is typically a few seconds. These data are appended into a set of FITS files for each scan.

The `Pipeline` will completely calibrate and image a *block* of scans. After all observations of a *region* are complete, the observer will use `Pipeline` tools to merge all calibrated spectra and produce the final image of the regions.

A scan is composed of spectral integrations. An integration is the smallest data unit that can be calibrated to either a temperature or flux density scale. Each integration is subdivided into a number of "phases", with the number of phases per integration being determined by the observing procedure used. Each phase has a unique set of parameters describing whether the data represents the "signal" or "reference" and describing whether the noise tube calibrator is on or off (cal_on or cal_off). For position-switched observations the signal and reference data are taken from different positions on the sky. For frequency-switched observations, the signal and reference data are taken with different center frequency settings. Beam-switched observations are not supported by the `Pipeline` .

The `Pipeline` can reduce a wide variety of GBT data, including archive data from observations with other receivers. However the downstream imaging scripts make assumptions concerning the organization of calibrated data, which yield unpredictable images. The primary goal of the `Pipeline` is reliable calibration, and the observer may override the default imaging steps of the processing, using standard imaging packages, such as `AIPS` or `CASA`.

Figure 1 shows example images produced using the KFPA `Pipeline` . The observing session is described at:

https://safe.nrao.edu/wiki/bin/view/Kbandfpa/ObserverGuide

4 Components of a Mapping Block

The observer must configure the GBT for the spectral line frequencies of interest and then describe the mapping motions to achieve the region coverage and signal to noise ratio required for their science targets.

Continuum Config, The observer must configure the GBT for continuum observations before point and focus scans.

Point+Focus Point and focus observations must be made before each KFPA mapping block. This is required to get optimum telescope efficiency. Typically, under normal weather conditions, the observer should schedule point and focus observations every one to two hours.

Spectral Config, The observer will configure the GBT for the required mapping spectral line configuration using the GBT `configuration tool` and `Astrid` scripts.

Test Line Generally the observer will configure the GBT of spectral line observations, then observe a strong line source, using the `Astrid Track` procedure. The If the test source is sufficiently close on the sky to the target region, this On/O observation can be used as the first position switched reference observation.

Begin Reference Obs For position switched observations, the observer should choose an emission free region at nearly the same elevation as the target region. This spectral line observation is required for `Pipeline` position switched calibration, but is not required for frequency switched observations.

Region Mapping The observer will select the appropriate shaped mapping command and calculate the number of observing scans that can be completed with the allotted time. The region mapping scans should have a duration of no longer than 1 hour, to allow reasonably frequency point and focus observations.

End Reference Obs For position switched calibration, the observer should schedule a second spectral line observation of the reference location. observations.

5 gbtpipeline

The `Pipeline` runs automatically during observations, and will select scans for calibration and imaging. The `Pipeline` may also be initiated by the observer, so that they may adjust the calibration input parameters for their science goals.

The linux command `gbtpipeline` is used to initiate the calibration part of the `Pipeline` reduction. The `gbtpipeline` has a number of arguments. Help is provided if `gbtpipeline` is called without arguments:

```
gbtpipeline
Usage: gbt_pipeline [options]

Options:
  -h, --help            show this help message and exit
  -i FILE, --infile=FILE
                        SDFITS file name containing map scans
  -b SCAN, --begin-scan=SCAN
                        beginning map scan number
  -e SCAN, --end-scan=SCAN
                        ending map scan number
  -u UNITS, --units=UNITS
                        calibration units
  -d DIR, --sdfits-dir=DIR
                        SDFITS input directory; used if infile option is not
                        usable
  --refscan1=SCAN       first reference scan
  --refscan2=SCAN       second reference scan
  --all-scans-as-ref    use all scans as reference?
  -s SAMPLER, --sampler=SAMPLER
```

```
                        comma-separated sampler(s) to process
  -a AVERAGE, --average=AVERAGE
                        averge the spectra over N channels (idlToSdfits)
  --spillover-factor=SPILLOVER
                        rear spillover factor (eta-l)
  --apperture-efficiency=APERTURE_EFF
                        aperture efficiency for freq.=0 (eta-A)
  --gain-coefficients=GAINCOEFFS
                        comma-separated gain coefficients
  -v N, --verbose=N     set the verbosity level
  --nodisplay           will not attempt to use the display
```

5.1 Flagging

After each of the KFPA beams, polarizations and spectral bands are calibrated to the required standard, the spectral line data are converted to the format require for imaging. This format is the same independent of the type of calibration applied (either position or frequency switched).

During the conversion process, the data may be flagged for system temperatures out of range. This feature was used extensively to flag one polarization of beam 5. An amplifier in beam 5 had failed, so no valid signals were obtained. Using the calibration process above yielded average system temperatures out of the nominal range 40 to 250 Kelvin. By flagging all system temperatures out this range, the invalid beam 5 data were flagged.

No RFI was noticed during the KFPA commissioning observations, so data flagging was not important. Extending the `Pipeline` to lower frequencies will require flagging utilities.

6 Imaging

The `Pipeline` uses the `ParselTongue` scripts to control AIPS tasks which produce images of the combined spectral data. The `Pipeline` automatically images `blocks` of image scans. The observer must keep track of the calibrated spectra obtained on different dates and merge them to produce the final calibrated image. The observer may update a `ParselTongue` script to customize the AIPS imaging parameters appropriate for their science goals.

The documentation is available on the web at:
http://www.radionet-eu.org/rnwiki/ParselTongue

AIPS provides tools for baseline subtraction of the image cubes. For specific observing configurations, such as $NH3$ 1-1 and 2-2 observations, special scripts facilitate baseline subtraction and computation of integrated line intensity maps.

The observer will often use `ParselTongue` to combine all mapping blocks into images of specific regions, and adjust the mapping parameters for their science goals.

References

Mauersberger, R., Henkel, C., & Wilson, T. L. 1987, *A & Ap.*, 173, 352

Mauersberger, R., Wilson, T. L., Walmsley, C. M., Henkel, C., & Batrla, W. 1985, *A & Ap.*, 146, 168

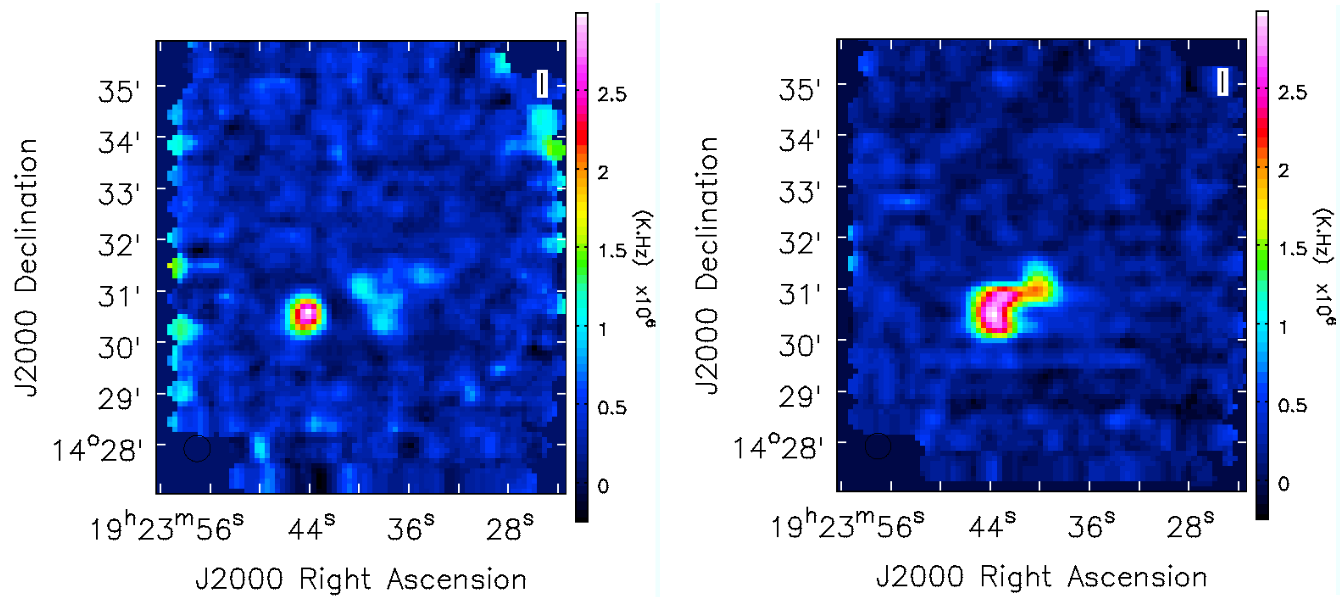


Figure 2: Calibrated and imaged W51 NH_3 4-4 (left) and 5-5 (right) transitions, from RaLongMap observations made during commissioning session TKFPA_30.

A Example W51 Mapping Block

We present an example test observation of W51, made during KFPA commissioning in September 2010. The KFPA commissioning `Astrid` scripts are kept in directory:
/home/astro-util/projects/TKFPA

In this directory are a number of scripts to configure the KFPA and GBT IF for DCR and Spectrometer observations. The latest scripts are identified on the KFPA `Pipeline` wiki page. The configuration scripts are changing dynamically, so are not described in detail here. All of the configuration scripts will be replaced by `configtool` changes to support the KFPA

The mapping techniques are more stable and an example is given below for a W51 position switched mapping observation. The example has the calibration components described in section 4.

```
#Map a region using the KFPA
#Assumes previous setup of the spectrometer configuration.
#HISTORY
# 10OCT06 GIL revised for pipeline keywords and comments

#First put in your sources
execfile("/home/astro-util/projects/TKFPA/sources.cat")

target = "W51"
offSource = "W51-OFF"
mapTarget="W51"

Slew( target)
Break("Balance IF-Rack and Spectrometer")
```

```
#First observe the target and reference again
#Guide Pipeline by annotating Scans
SetValues("ScanCoordinator",{"scanId":"Target"})
Track( target, None, 30.0, "1")
SetValues("ScanCoordinator",{"scanId":"Off"})
Track( offSource, None, 30.0, "1")

#at 20 GHz beam FWHM is 0.6' == 0.01 degree
#max K band rate is 8 mins for 1 degree if 1.0s/int
#make a 6' map = 0.10 degrees
SetValues("ScanCoordinator",{"scanId":"Map"})
RALongMap( mapTarget,
           Offset("J2000", 0.10,0.0),
           Offset("J2000", 0.0, 0.08),
           Offset("J2000", 0.0, 0.008),
           60.0, "1")

#Observe the target and reference again

SetValues("ScanCoordinator",{"scanId":"Target"})
Track( target, None, 30.0, "1")
SetValues("ScanCoordinator",{"scanId":"Off"})
Track( offSource, None, 30.0, "1")
SetValues("ScanCoordinator",{"scanId":"Unknown"})
```

B Example W51 Reduction

The `Pipeline` will automatically produce default images of GBT KPFA observations, however often the observer will frequently adjust the default imaging parameters to make the images overlap with observations.

The W51 astrid script was the basis for a number of observations with the KFPA in September 2010. Some of the observations are completely reduced using a set of scripts described below.

Command	Note
mkdir /home/scratch/$USER/pipeline	# Make a working directory
cd /home/scratch/$USER/pipeline	# Go to pipeline directory
cp /home/sandboxes/gbtpipeline/contrib/demoW51 .	# Copy a demo script
./demoW51	# Execute the script

The demo pipeline script, `demoW51`, runs in the NRAO GB Linux computing environment. The script initiates the `Pipeline` calibration and the runs two python scripts to produce image cubes and then integrates planes of the cube to produce images of the NH_3 (1,1) and (2,2) emission. Below is a listing of `demoW51`:

```
#!/bin/csh
#run the pipeline with arguments specified
#HISTORY
# 101020 GIL produce a temperature map
# 101013 GIL change default location of python code
# 101006 GIL complete execution of pipeline
# 100929 GIL try all w51 data on gbtpipeline
# 100325 GIL revised for existing SDFITS file

setenv pipehome /home/sandboxes/gbtpipeline
setenv gbtpipeline $pipehome/gbtpipeline
set you=‘whoami‘

#Use AIPS with a public number
setenv NUMBERS ‘$pipehome/contrib/aipsNumber $you‘
#Due to strange prompt issues, strip out last 5 digits only
setenv AIPSNUM ‘echo $NUMBERS | awk ’{print substr($0,length($0)-4,length($0))}’‘
echo ’---------------------------------------------------’
echo ’ Your (’$you’) pipeline AIPS number: ’$AIPSNUM
echo ’---------------------------------------------------’

#select NH3 (1,1) scans for this map
$gbtpipeline -i /home/sdfits/TKFPA_29/TKFPA_29.raw.acs.fits -b 14 -e 24 \
```

```
    --refscan1=13 --refscan2=26 --units='Tmb' -v 1 \
    --nodisplay
# --allmaps

########################## Set your imaging script name here
set image=imageW51.py

#Transfer the python/ParselTongue scripts to local
if (! -f "$image") then
  cp $pipehome/contrib/$image .
endif

set doImage=$pipehome/doImage
#Now produce the cube, continuum and baselined images
$doImage $image $AIPSNUM *.sdf

#Sum channels to compute Line integration
if (! -f "sumLine.py") then
  cp $pipehome/contrib/sumLine.py .
endif

#Sum line channels for W51 NH3 (1,1)
#v=60 km/sec, line FULL width 20 km/sec
$doImage sumLine.py $AIPSNUM W51-NH3-11 23694.506 60. 20.
casaviewer *NH3-11.fits &     #Look at NH3 (1,1) line output

#Next sum the NH3 (2,2) transition
$doImage sumLine.py $AIPSNUM W51-NH3-22 23722.6336 60. 20.
casaviewer *NH3-22.fits &     #Compare NH3 (2,2)

#Sum channels to compute Line integration
if (! -f "tempNH3_1122.py") then
  cp $pipehome/contrib/tempNH3_1122.py .
endif

#Produce a temperature map for source Velocity 60 km/sec, width 20 km/sec
$doImage tempNH3_1122.py $AIPSNUM W51 60. 10. .2
casaviewer W51*T_11_22.fits &     #Examine the temperature map
```

B.1 doImage

The gridding of spectra from the GBT is performed using AIPS. The first few steps of merging the spectra from different beams and polarizations are tedious,

but this has been greatly streamlined using a python scripting language, `Parsel Tongue` . This script is initiated with the `Pipeline doImage` command, in directory /home/sandboxes/gbtpipeline. These first imaging steps may be completed for any observation using the script `imageDefault.py`, which may be found in the directory:
/home/sandboxes/gbtpipeline/contrib

The `doImage` arguments are:

Script Python/ParselTongue script setting the AIPS parameters for the next image processing steps.

AIPS Number This `Pipeline` number is used to select a **SCRATCH** AIPS number for creating the images. It is critical that this number **NOT** be the observer's normal AIPS number as all data will be **DELETED**.

***.sdf** AIPS format Single Dish FITS (.sdf) files containing calibrated spectra with associated angular coordinates. Any number of files may be provided. These files will all be merged together and placed on a coordinate grid. Note that these *.sdf files must all have the same frequency axis properties (ie bandwidth, center frequency and number of channels).

The observer can be automatically assigned an AIPS Number using the following unix command:

/home/sandboxes/gbtpipeline/aipsNumber $USER

Use this AIPS Number for all remaining processing.

B.2 `sumLine.py`

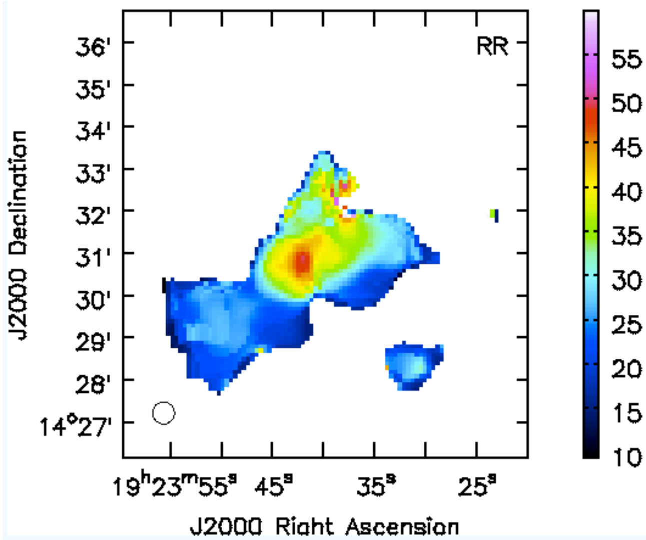
After producing the image cube and subtracting spectral baseline from the band edges, the channels contain molecular line emission are typically integrated, to measure source properties. This task can be accomplished using the script `sumLine.py`. The script also takes a number of arguments.

AIPS number This AIPS number should be the same number used in the previous step.

Line frequency Molecular Line rest frequency in Hz.

Source Velocity Source redshift velocity in km/sec.

Source Velocity Width Source velocity Full Width (km/sec)



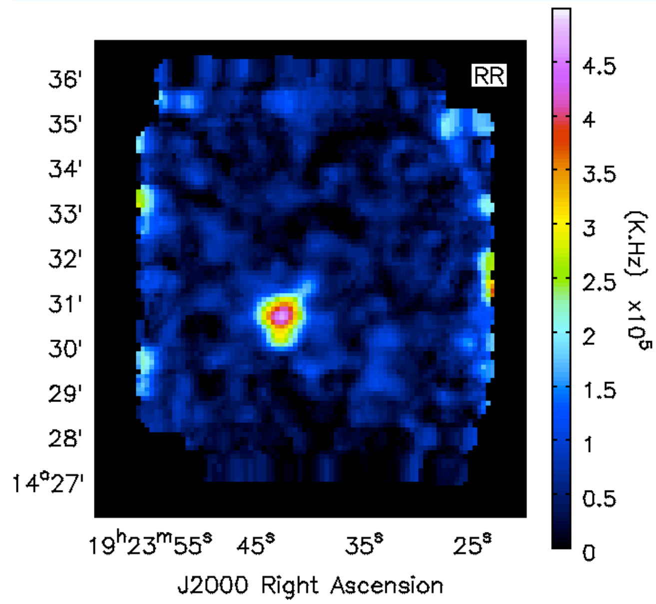


Figure 3: Rotational Temperature map of the W51 region based on the (1,1) and (2,2) measurements (left). The data used in the temperature fits were flagged if the intensities were less than 0.1 K. Only the central region, where the temperature variations are smooth, should be considered significant. The peak temperature is ~ 45 K. These values are consistent with the measurements of Mauersberger et al. (1985). Note that peak temperatures deduced from higher order transitions are significantly higher. Right shows the integrated $H\delta 109$ Recombination line showing the location of peak continuum intensity is close to the location of peak NH_3 temperature.

B.3 `tempNH3_1122.py`

The observer may wish to directly compute a source temperature map based on NH_3 (1,1) and (2,2) line observations. This task can be accomplished using the script `tempNH3_1122.py`. The script also takes a number of arguments.

AIPS number This AIPS number should be the same number used in the previous step.

Output Name The output name is the beginning part of the name of the FITS format image created by the script. The full output name will be `outputName_T_11_22.fits`

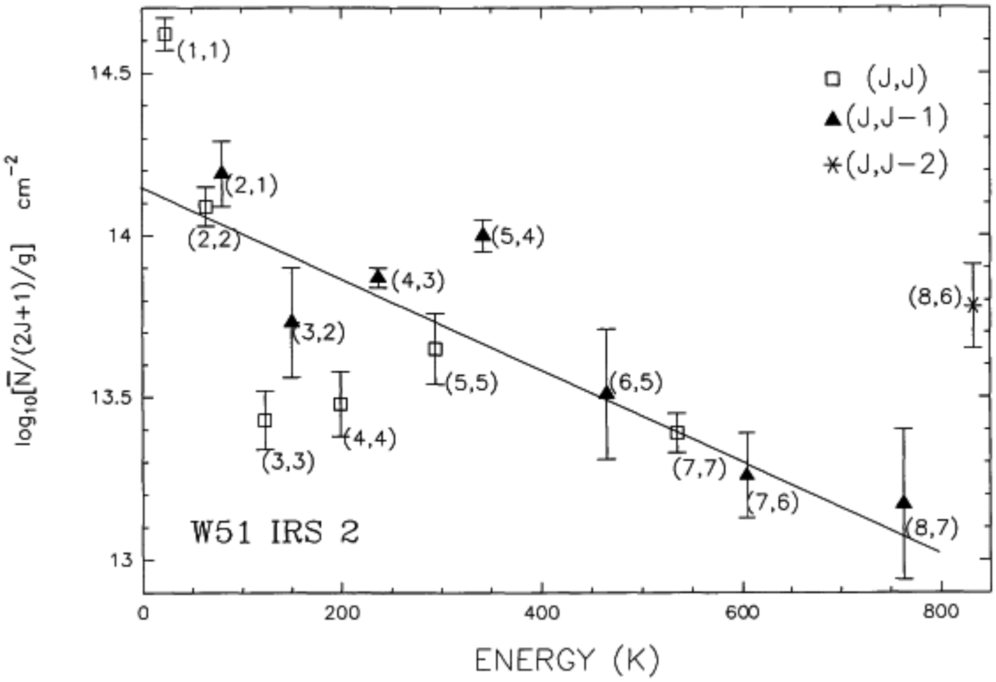
Source Velocity Source redshift velocity in km/sec.

Source Velocity Width Source velocity Full Width (km/sec)

Minimum Intensity Minimum intensity to use in integrating the line strengths. Increasing this value reduces the noise in the final output temperature map.

C Comparison with published Measurements of W51

We use the methods of Mauersberger et al. (1987) to measure the temperature of W51 IRS2.



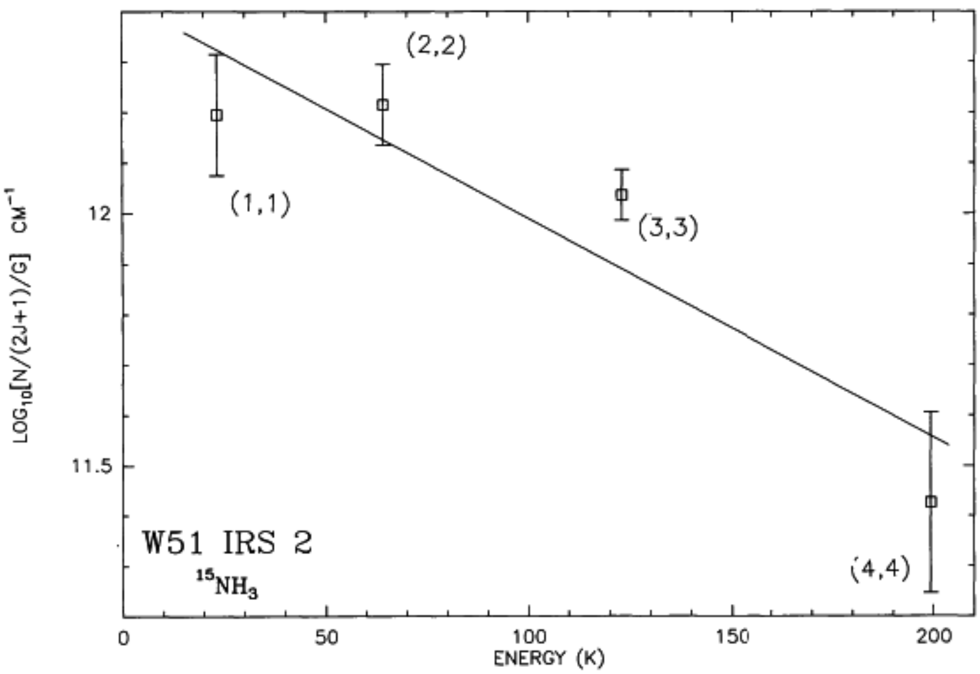


Figure 4: Boltzmann plot of observations by (Mauersberger et al. 1987) shown for comparision to the results obtained for the W51 commissioning observations. The upper plot shows $^{14}NH_3$ measurements with a line corresponding to $T_{rot} = 310 \pm 40$. The lower plot shows $^{15}NH_3$ measurements with a line corresponding to $T_{rot} = 95 \pm 10$.