NAIC/NRAO Single Dish Summer School
Hands-On Project

HI Emission in Extended Galaxies

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CHECKLIST

Before beginning observations for this project, you should:

- Read this document and (at the least) skim through the appendices
- Have an understanding as to what your calibrators will be
- Have discussed, and come to a consensus, with your group as to what your correlator (backend) set-up will be
- Have a reasonable idea of what will you need to do to complete your observations
- Know what time you are expected to be in the control room
- Bring this write-up, your list of sources, something to write with, and paper to the observing session

1. Introduction

This project is designed to demonstrate the fundamentals of spectral line observing. We will observe galaxies at HI (in emission). Additionally, you will have to calibrate the pointing of the telescope and determine the telescope's gain. All spectral line observations will be made with the position switching technique. Position switching is the technique of observing first the blank sky and second the position of interest. The blank sky observation is used to remove atmospheric and systematic telescope noise, and a position should be picked for the blank sky observations so that the same part of the dish (the same az and za) is used for both observations.

2. The Sources

The sources for this observing were chosen in advance. All sources had the following requirements:

- First, a source has to be observable by the GBT during the time we are observing. The approximate LST of our observations is 21:40 – 00:40.
- Second, the sources needed to be bright enough to be readily detected by the GBT. This means a minimum peak density of ∼10-20 mJy.
- Third, there could not be any RFI (Radio Frequency Interference) at the frequency at which the source lies. The easiest means for finding out this information is though the RFI web page at http://www.gb.nrao.edu/ glangsto/rfi/lband/.

3. Front-End

For this project you will be using the L-band (1-2 GHz) receiver. Details on this receiver are given in Table 1.

Table 1. Details of the 1-2GHz Receiver

Name and Number:	L-band (1–2 GHz)
Frequency Coverage:	1.15 – 1.73 GHz
Measured Sensitivity:	∼ 3 K/Jy
Measured System Temp:	∼ 20K
Native Polarization:	Linear
Beam Size (at 1415 MHz):	∼9 arcmin

4. Backend Set-up

You need to decide the both the backend set-up you desire for your observations. This involves deciding what bandwidth and resolution you desire, as well as how you would like the banks set-up. Note that since you have four banks to play with, you have considerable freedom in this regard. The bandwidth chosen should be wide enough to insure your data gets through, but no wider than necessary. Table 1 lists the available bandwidths, resolutions, etc.

5. Blank Sky Observation

The unique geometry of the GBT prevents most reflection from sources both inside and outside the beam However, the blank-sky (off-source) observations should not be 'randomly' chosen. Instead we force the off source observation to trace the same pattern across the dish as the on source observation. That is, we observe as close to the same azimuth and zenith angles for the on source and the off source observations. This means that a five minute on source observation will have its off source observation taken at the same declination but at an RA position which is five minutes in time later than that of the source. In this way the same azimuth and zenith angle positions are traced for both the on and off source observations. (Remember – 1 minute in time equals approximately 15 minutes in the sky.)

Potential Problems: The off source observation is supposed to be a blank sky observation. This means you need to be sure the sky area which will be used for this observation does not contain any significant continuum sources or any other galaxies. If continuum, or another galaxy, is present at the location of your off source observation, you need to reconsider your observing strategy (i.e. choose another source, choose a different integration time, or just try moving to a slightly different spot on the sky). A great resource for determining the location on continuum near your object is the Northern VLA Sky Survey (NVSS), available on-line through *http://www.cv.nrao.edu/~jcondon/nvss.html* (For the purpose of this project the postage stamp server is good tool.) To search an area of sky for other galaxies, the NASA Extra-galactic Database (NED) at *http://nedwww.ipac.caltech.edu* has a "near position" search that is very complete.

6. System Temperature

Receiver temperatures are obtained at Green Bank through observations of noise diodes with known (pre-measured) temperatures. Typically, the noise diode is fired every 0.5s during observations. This information is then taken from the data using the following prescription (see the summer school lectures for further details):

$$\mathrm{T_{cal}} \ = \ \mathrm{T_{calon}} - \mathrm{T_{caloff}}/(\mathrm{T_{caloff}})$$

7. Telescope Gain

Like all astronomical observations, one of the most important steps in spectral line observing is converting your observations from local units (e.g. a local temperature) into universal units. For HI observations a typical unit of measurement is the Jansky (Jy). Janskies are units of flux density, with 1 Jy = 10^{-23} ergs cm^{-2} s^{-1} Hz^{-1}. Conversion from measured source temperatures (what you have, after taking T_{sys} into account) into Janskies (what you want), is done through observing a number of sources with well established fluxes, and then determining a conversion between measured temperature and flux density. This conversion factor is known as the telescope gain. (Technically, telescope gain is simply the telescope response to a point source. Here, we express the gain in terms on antenna temperature due to a point source of flux density 1Jy which lies in the center of the beam. With this definition, then, the gain is in units of K/Jy).

A good calibration source is a point source with a strong, non variable flux. For L band observations (the regime in which HI observations are done), this means you want a source which is considerably smaller than the $9'$ size of the beam. Additionally, the flux should be at least 20-30 mJy but not larger than a 100 Janskies or so, or you will exceed the dynamic range of the telescope. A list of possible flux calibrators is given in Appendix I.

As no dish is perfect, it is a good idea to observe a calibrator as close to your source(s) of interest as possible. However, with the GBT it should be noted that it is more important to get a reliable calibration source than to worry overly about the source's proximity to the objects of interest. Once you've chosen your calibrator source(s), you should then perform one or to observations on that source (using the same position-switching technique). This then can be reduced to determine your gain:

$$\mathrm{Gain} = (\mathrm{T_{onsource}} - \mathrm{T_{offsource}})/\mathrm{T_{offsource}} \times 1/\mathrm{Flux_{calibrator}}$$

where the calibrator flux is determined from the literature.

8. Putting it all together – Data Calibration

Once all your observations have been taken, its time to sit down and analyze your data. Rather than tie you down with a particular data reduction scheme, here I just describe the basic method which needs to be applied to your data. When you are at the GBT, we will reduce the spectra you took into just ascii files with channel number, frequency, and power in each column. A more detailed description of the calibration steps is included in 'Notes Relevant to Spectral-Line Calibration" by C. Salter, which is included in this hand-out.

The first step in your data reduction is to remove the background noise from your data. For position switching, this is done using the off source observations taken during your observing run. Removing background noise from your source involves subtracting out the contributions due to the receiver, extraneous noise from the ground due to spillover, vignetting, etc, atmospheric noise, and background radiation (e.g. the galactic background emission and the Cosmic Background

Radiation). Conveniently, all of this is readily done by simply subtracting your of source observation from your on source observation. You also need to: add or average all the individual scans for a given observation (or the individual (on-off)/off observations) and convert the value of temperature into Janskies. Again, take a look at the lecture by O'Neil in the Summer School book to get more info on this process.

9. Converting your Data into Useful Numbers

Once you've successfully calibrated your data, you need to turn your spectra into useful (publishable) facts – HI mass, velocity widths, etc. Fortunately, this step is extremely easy. Using your favorite data reduction software, you need to (a) sum all the relevant data (if you haven't already); (b) perform a baseline subtraction on your data; (c) integrate the total flux of the galaxy (to obtain the flux and, ultimately, the total HI gas mass), and (d) fit Gaussian(s) to your spectra to obtain the central velocity and the FWHM at 50% and 20% of the Gaussians (that is, obtain the velocity widths).

Baseline Subtraction: The region chosen for your baseline subtraction should be large enough that sufficient channels are available to get a reasonable fit, yet small enough that the baseline you are fitting will be accurate for the spectral line in which you are interested. Typically, this means no more than a few hundred channels on either side of the spectral line, and sometimes much less (depending, of course, on the width of the observed line). The other factor to consider when fitting a baseline is that you do not want to over- or under-compensate for the true baseline. The correlator at the GBT is fairly good, for many reasons, including the fact that it gives remarkably flat baselines. As a result, assuming you choose a baseline which is limited to the region reasonably near your observed line, the baseline which you fit to your data should not be of order larger than two.

Determining the HI mass: First, as already mentioned, you need to use you favorite data reduction program to integrate and obtain the total flux of your source. When performing this integration, you want to be sure that your y-axis (or intensity) is in units of Janskies, and your x-axis is in terms of velocity. The flux you obtain will then be in the very useful units of Jy km s^{-1}. This can be converted to, i.e.total gas mass (in units of $M_\odot$) through the conversion:

$$M(HI) \;=\; 2.356\times10^5 \;\times\; \left[D(Mpc)^2\right] \;\times\; \int (Jy\; km\; s^{-1})\;\; M_\odot$$

where $\int$ is the measured flux of your source and D is the distance to your object in Mpc (for distant objects – objects where v$_{sys}$ is considerable larger than v$_{random}$ – a reasonable distance estimate is D=v(km s^{-1})/H$_0$(km s^{-1} Mpc^{-1})).

Determining v$_{sys}$, v$_{50}$ and v$_{20}$: Both the systematic velocity and the velocity widths of HI absorption and emission lines are typically obtained by fitting one or two Gaussians to the absorption/emission spectra (the number of Gaussians is chosen base on whether the spectra shows a one or two 'horned' profile). The systematic velocity is then the velocity at the peak of the Gaussian (or the center of the peaks of the two Gaussians). V_{20} and v_{50} are the velocity width at 20% and 50% of the Gaussian peak(s).

When no line is seen (setting upper limits): If no line is detected during your observation, it is still useful to obtain an upper limit to the flux density of your object.

In order to set flux limits you first need to decide on what a likely velocity width (v_{20}) for your object is. The easiest means to do this is to go to the literature and determine common velocity widths for similar objects. When choosing the velocity width to assume for your (undetected) source, remember that you are setting *upper* limits on the flux and mass. This means that you should not choose a small velocity width simply because it gives an impressively low flux limit. Instead, if anything, you should err on the side of overestimating your object's velocity width.

Once you've decided on a reasonable velocity width, you can determine your flux, and mass, upper limits. There are two common methods for setting these limits. In the first method, you need only to determine the r.m.s. noise of the region in your spectra which should contain the line of interest. Your flux upper limit would then be $< \# \, \sigma > \times \sigma_{rms} \times v_{20}$, where $< \# \, \sigma >$ represents the signal-to-noise level, in number of σ_{rms}, at which you would expect to see your spectral line. (This is typically of order 3 or higher.) You can now convert that flux upper limit to a mass limit via the conversion equation given earlier.

The other common method for determining upper flux limits for non-detections is by integrating the noise over the region where your source should lie. This gives you a 1σ upper limit to you flux. If there is any non-linear components to your baseline, this method will provide a more realistic (albeit higher) flux limit.

One final note in this discussion is the possibility that you do not know the exact red shift of your source. If you know an approximate velocity, or a range, you can apply either of the above techniques repeatedly across the velocity range of interest, and then use the highest value as your flux upper limit. If, though, you have no idea what the red shift of your source is, you are probably best off just reporting your r.m.s. values.

APPENDICES

Table A-1. Possible HI Emission Sources

Object Name	**RA** (J2000)	**Dec** (J2000)	$\mathbf{v}_{rad}$ (km/s)	**Type**	$\mathbf{D}_{opt}$	$\mathbf{D}_{HI}$
UGC 11651	20:57:15.3	25:58:13	1525	Sdm	3.1'	6'
UGC 11707	21:14:31.8	26:44:05	905	SAdm	3.6'	7'
NGC 07013	21:03:33.6	29:53:51	779	SA(r)0/a	4.0'	5'
UGC 12281	22:59:12.8	13:36:24	2568	Sd	3.44'	7'

Table A-2. List of Potential Flux Calibrators

Name	**RA** (B1950)	**Dec** (B1950)	**Flux (1420)** (Jy)	**Size**	**Variable?**
B0300+162	03 00 26.9	16 15 04	2.73	$<10''$	N
B0316+162	03 16 09.1	16 17 41	7.79	$<10''$	N
B0333+321	03 33 22.4	32 08 36	3.35	$<10''$	Y
B0428+205	04 28 06.86	20 31 09.2	3.86	$<10''$	N
B0453+227	04 53 42.17	22 44 41.7	3.21	$<10''$	N
B0500+019	05 00 45.18	01 58 54.7	2.30	$<10''$	N
B0518+165	05 18 16.53	16 35 26.8	8.09	$<10''$	N
B0521+281	05 21 14.4	28 09 50	1.77	$\sim2.1'$	N
B0640+233	06 40 04.9	23 22 10	2.64	$<10''$	N
B0711+356	07 11 05.62	35 39 52.5	1.83	$<10''$	Y
B2041+170	20 41 59.4	17 00 00	0.66	$<10''$	N
B2153+377	21 53 45.52	37 46 13.9	6.81	$<10''$	N
B2209+080	22 09 32.2	08 04 25	1.69	$<10''$	N
B2210+016	22 10 05.17	01 37 59.4	2.84	$<10''$	N
B2223+210	22 23 14.8	21 02 50	1.97	$<10''$	Y
B2247+140	22 47 56.33	14 03 56.7	2.13	$<10''$	N
B2249+185	22 49 07.7	18 32 44	1.72	$<10''$	N
B2251+158	22 51 29.5	15 52 54	13.2	$<10''$	Y
B2314+038	23 14 02.27	03 48 55.2	4.51	$<10''$	N
B2338+132	23 38 00.9	13 16 23	1.78	$<10''$	N