Subject: Observing Steps to Make Your Galactic Map Spectra Data Overview
Memo: 19, revision 1
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Summary: Examples of data from 10 minutes of observing with a home built radio telescope. The data (ASCII) format is shown, along with a description of programs to plot raw, calibrated and mapped spectra.

This memo gives the Science Aficionado an opportunity to understand and play with the observing data format, from observations with a sensitive home-built radio telescope. This guide prepares the Aficionados to see the galaxy with their own radio telescopes.

File Format

The spectra recorded by the program NSF_watch (watch.py) are written in a very simple ASCII format. These files can be processed with text editors and also plotted by most plotting programs. I started using a free program, **gnuplot,** and slowly switched to my own programs, written in python The file names are created from the date and time of the observation. The Time Zone used is Universal Time Coordinated (UTC), which is Greenwich England time. UTC time is used by all Astronomical Observatories, and since you're operating an important one in your own back yard, your computer uses UTC for radio astronomy observations.

The file names all end **.ast** if they are observations of the sky and **.hot** if they are observations of the ground. This is mostly for the astronomer's convenience of figuring out which observations have associated calibration data. As described in LightWork Memo 1 the astronomical observations are calibrated by a comparison of the intensity measured by looking at the ground, with a known temperature (usually assumed to be 295K).

File header values

A goal astronomers have for saving observations is doing so in a manner that allows others to use your observations and also to check your observations. In addition, after a short time the astronomers may forget how the observations were performed, so putting notes in the data files are a great help. **Figure 1** shows the first few lines of the astronomy file **2017-07-31T20_00_12.ast.** From the file name you can tell the observation was made on July 31, 2017 at 20:00:02 UTC. You can also tell the telescope elevation was greater than 0 degrees, because it is an **.ast** file. The elevation angle is the angle above the ground the telescope was pointing. If the telescope is pointing straight up the elevation is 90. If the telescope is pointing at the horizon, the elevation angle is zero. If the elevation is less than zero the telescope is pointing at the ground.

The recorded spectra are averages of many many observations. In the example ,**Figure 1** shows spectrum is the result of the average of **Count = 247,911** observations, taken over a **Duration = 30.22** seconds. The telescope was pointed south (**Azimuth = 180.0** degrees) and the telescope was pointed up at **Elevation = 50.0** degrees. The location of the telescope on the surface of the Earth is given by the site Longitude (**TELLON**) and Latitude (**TELLAT**). The astronomer must find these for themselves, usually by looking at Google Maps.

The file header keyword meanings are described in the Appendix of this memo.

```
# File: 2017-07-31T20_00_12.ast
# cylinder horn + 1 TAMPs+1 filters; Green Bank- rotated horn 180
# GAINS      = 14.0; 11.0; 11.0
# Count      = 247911
# CenterFreq= 1419500000.0
# Bandwidth = 10000000.0
# Duration  = 30.224482
# DeltaX     = 9765.625
# NCHAN      = 1024
# UTC        = 2017-07-31 20:00:12.509278
# LST        = 11:19:21.890
# AZ         = 180.0
# EL         = 50.0
# TELLON     = -79:50:22.920
# TELLAT     = +38:25:59.160
# RA         = 11:17:35.490
# DEC        = -01:23:22.500
# GALLON     = 260:47:00.40
# GALLAT     = +53:37:15.90
# ALT_SUN    = +50:46:32.5
# AZ_SUN     = +249:45:06.8
# AST_VERS   = 02.01
0000 1414504882 1.85452e-08
0001 1414514648 3.05109e-08
0002 1414524414 3.36106e-08
0003 1414534179 3.56903e-08
```

Figure 1: Example NSF_watch data file named 2017-07-31T20_00_12.ast. *The header lines all have a # symbol so that plotting programs will ignore these lines. The first line is always the file name and the second line is an astronomer comment. The remaining header lines have **Keyword = Value** format. After the header, the spectra (data) values are listed. The three data columns are channel number, frequency (Hz) and intensity in count units. In this example there are 1024 data lines.*

```
ESMU.local{glangsto}213: pwd
/Users/glangsto/Desktop/Research/data-17Jul31
ESMU.local{glangsto}214: !ls
ls -lt *31T20_0*
-rw-r--r--  1 glangsto  staff  29162 Jul 31 16:10 2017-07-31T20_09_57.ast
-rw-r--r--  1 glangsto  staff  29174 Jul 31 16:09 2017-07-31T20_09_27.ast
-rw-r--r--  1 glangsto  staff  29169 Jul 31 16:09 2017-07-31T20_08_57.ast
-rw-r--r--  1 glangsto  staff  29167 Jul 31 16:08 2017-07-31T20_08_27.ast
-rw-r--r--  1 glangsto  staff  29152 Jul 31 16:08 2017-07-31T20_07_57.ast
-rw-r--r--  1 glangsto  staff  29178 Jul 31 16:05 2017-07-31T20_05_17.hot
-rw-r--r--  1 glangsto  staff  29163 Jul 31 16:05 2017-07-31T20_04_47.hot
-rw-r--r--  1 glangsto  staff  29145 Jul 31 16:04 2017-07-31T20_04_17.hot
-rw-r--r--  1 glangsto  staff  29171 Jul 31 16:03 2017-07-31T20_03_12.ast
-rw-r--r--  1 glangsto  staff  29175 Jul 31 16:02 2017-07-31T20_02_42.ast
-rw-r--r--  1 glangsto  staff  29170 Jul 31 16:02 2017-07-31T20_02_12.ast
-rw-r--r--  1 glangsto  staff  29164 Jul 31 16:01 2017-07-31T20_01_42.ast
-rw-r--r--  1 glangsto  staff  29155 Jul 31 16:01 2017-07-31T20_01_12.ast
-rw-r--r--  1 glangsto  staff  29183 Jul 31 16:00 2017-07-31T20_00_42.ast
-rw-r--r--  1 glangsto  staff  29187 Jul 31 16:00 2017-07-31T20_00_12.ast
```

Figure 2: List of files from a 10 Minute Mapping Observation. *The programs used in this example run from the Linux/Mac command/terminal line. This example shows the command **pwd**, to show the current directory, the **ls -lt *31T20_0*** command to list all files take with ten minutes of July 31, 2017 after 4:00 PM (16:00). In this example data were recorded every 30 second and there are 15 files. Of these files, 3 are **.hot.***

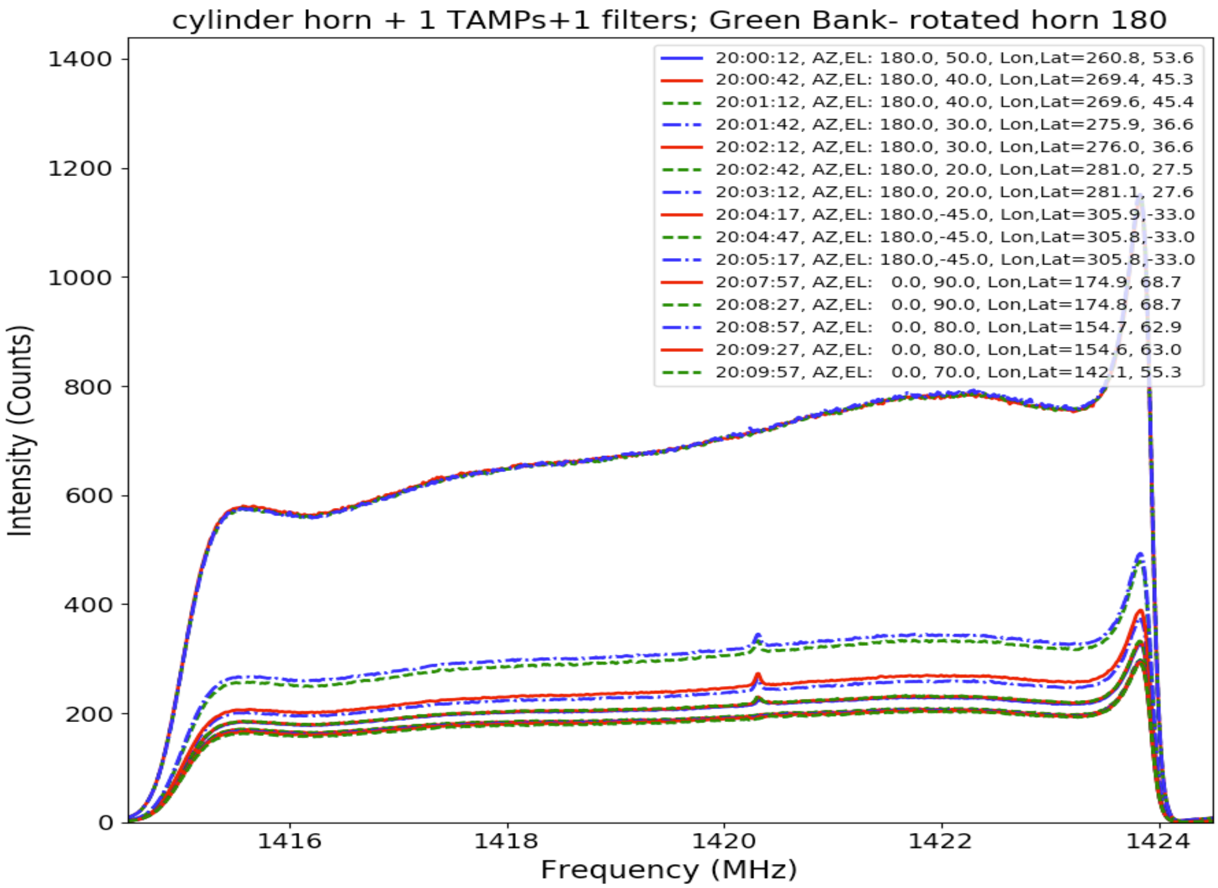

Figure 3: Plot of Raw Intensity (counts) versus Frequency in MHz for the files from a 10 Minute Mapping Observation. *These curves are not yet calibrated, so intensity is in units of data counts.The top most plots show the 3* ***.hot*** *files, which are plotted one on top of the other. The lowest lines show the low intensities seen at high elevations. The little peak at 1420.4 MHz is galactic hydrogen, which is clearly visible in these observations. Each of these observations is only 30 seconds long.*

Figure 2 lists a few Linux commands to used to find some data for processing. To see the name of the current directory you are "in" in Linux, type **pwd** (print working directory). To change directory type **cd data-17Jul31**, etc. Find a Linux tutorial on line to learn the basic commands.

With a previous command I'd found the latest calibration (**.hot**) file (i.e. **ls *.hot**). The calibration is most accurate if the observations are taken close to the same time as the calibration files. It is easiest to test data processing with a few files. These files were taken as a part of some mapping observations with our horn, so are taken at a variety of elevations.

The command to list at all files within 10 minutes of the 31st of the month at 20 hours 0 minutes UTC is: **ls -lt *31T20_0*** Note that there are three **.hot** files in the middle of this time range. After finding these files use the plot raw files command **R**.

The output of the command: **R *31T20_0*** is shown in **Figure 3.** **Figure 3** is a plot of raw spectral intensity in units of counts, versus frequency of the observation. The top most curves show the high intensity the horn measures when looking at the ground. The signal intensity is lowest when looking at high elevation. The telescope is working properly, and high sensitivity,

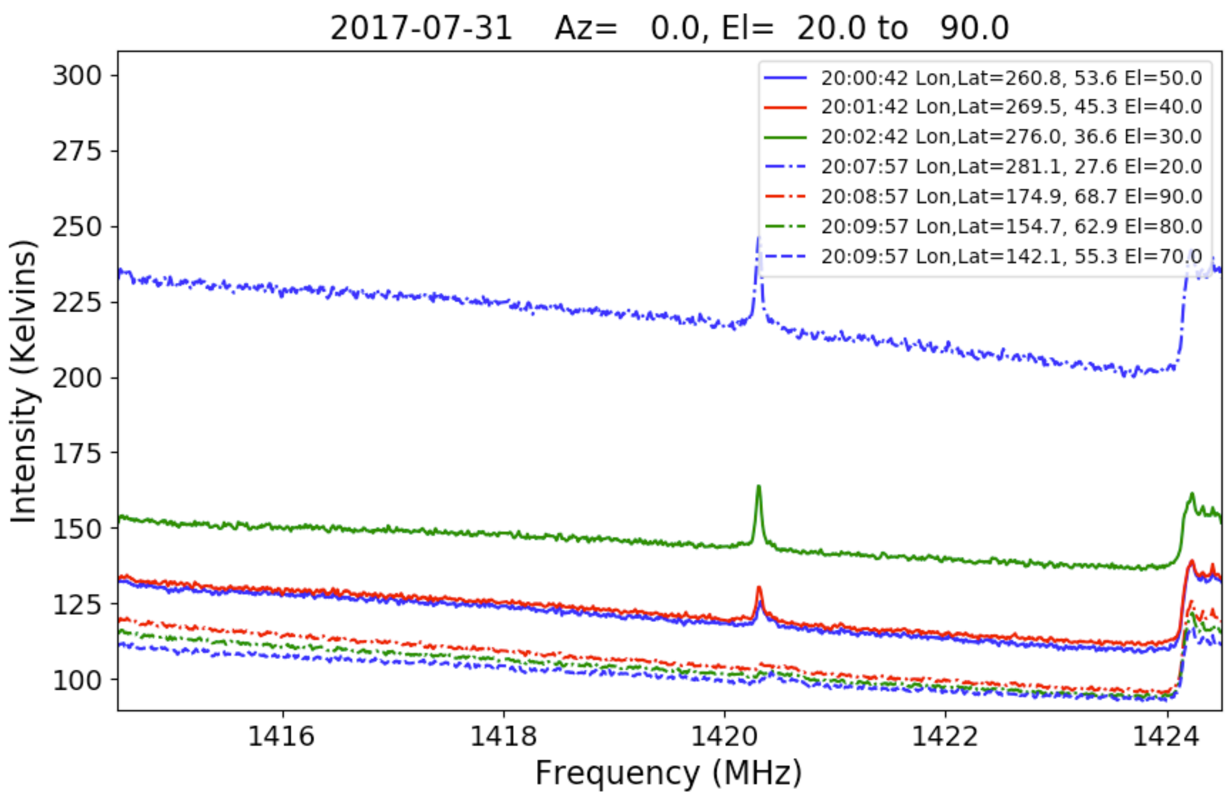

Figure 4: Plot of calibrated Intensity (Kelvins) versus Frequency in MHz for the same data shown in Figure 3. *The **.hot** load observations are used to calibrate average of the data taken at each elevation. The top most plots show the observation at 20 degrees elevation. The lowest three plots are from 70, 80 and 90 degrees, where the telescope is not effected by the ground temperature. The other plots have less ground contribution at higher elevations..The peaks at 1420.4 MHz, of galactic hydrogen, are more clearly visible.*

when the .**hot** plots are 3 or 4 times stronger than the high elevation (**.ast**) plots. Note that the counts are higher for observations at lower elevations, because the horn partially sees the **ho**t ground.

The overall shape of the curves in **Figure 3** are due to filters in the software defined radio (SDR) sampler. In this case we used the 10 MHz bandwidth AIRSPY revision 2 sampler. In order to have good spectra in the middle of this 10 MHz band, the AIRSPY has a filter that rejects almost all signals outside of the 10 MHz window and the signals go to zero about 0.5 before the edge of the band. This is a very good feature for observing galactic hydrogen at high sensitivity.

The next step in examining the observations is a simple temperature calibration, done as is described in LightWork Memo 1. **Figure 4** shows the calibration of the spectra using the average of the hot load spectra as a reference. Our goal of studying the Galaxy through observations of hydrogen is much easier after calibration. Galactic structure is clearly seen. It happens that the observations at low elevation, 20 degrees, were closer to the galactic plane, so hydrogen signal is much stronger.

Figure 4 was created with the command: **T 300. *31T20_0***
This Temperate plot command indicates that data should be averaged for 300 seconds (5 minutes) or until the azimuth or elevation of the observations change. Since these were mapping observations, Sophie, Evan and Glen were moving the telescope every 30 seconds. They recorded data for one minute at each elevation. They stopped data recording to move the telescope to point at the ground then restarted. They then stopped observations and moved the telescope to point straight up. When moving only a few degrees, the kept recording while moving the telescope to save the time of stopping and starting observations.

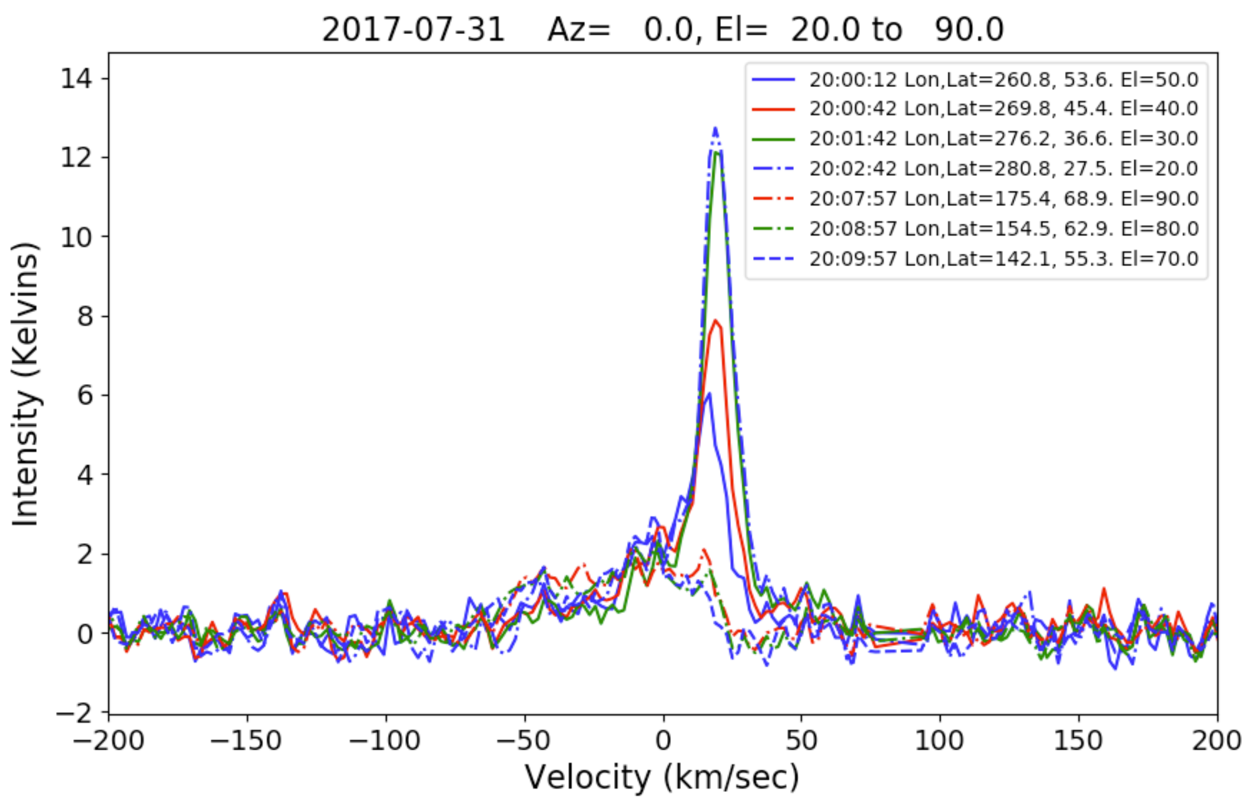

Figure 5: Plot of fully calibrated Intensity (Kelvins) versus Velocity in Kilometers per second for the same data shown in Figure 5. *A linear, "spectral baseline", is subtracted to bring all the spectra in line with zero intensity where no hydrogen is expected. As expected, little hydrogen is seen at high galactic latitudes. The peaks of galactic hydrogen, are even more clearly visible.*

Figure 5 shows calibrated intensity, in Kelvins, as a function of velocity of the hydrogen gas. A few features are noted. In these directions the velocity, 25 km/sec, is about the same for 20 and 30 degrees elevation, while at higher elevations the velocity id close to zero. These velocities are measured relative to the motion of the Earth. There is a flat part of all plots between 70 and 90 km/sec, where strong interference is flagged. This corresponds to the feature at 1420.0 MHz which is internal to the AIRSPY SDR.

Mapping with an Aficionados Telescope

Finally, these few samples may be mapped using two more commands. The first produces a summary of the spectral computing of all the signals over the range expected for galactic hydrogen. This program is called **SUM** and is executed like **T and M: T**o map these observations first run the command: **SUM 300. *31T20_0***

This command averages all spectra until 300 seconds have past, or a new azimuth or elevation and writes one or more summary files for each hour of observations. Since these data were all taken within 10 minutes there is only one summary file.

```
ESMU.local{glangsto}261: ls *.sum
2017-07-31_20.sum
ESMU.local{glangsto}262:
ESMU.local{glangsto}262: GO GAL *.sum
```

The Grid Observation, GO, command produces either a galactic or RA-Dec map. In this example we produced a galactic map, shown in **Figure 6.**

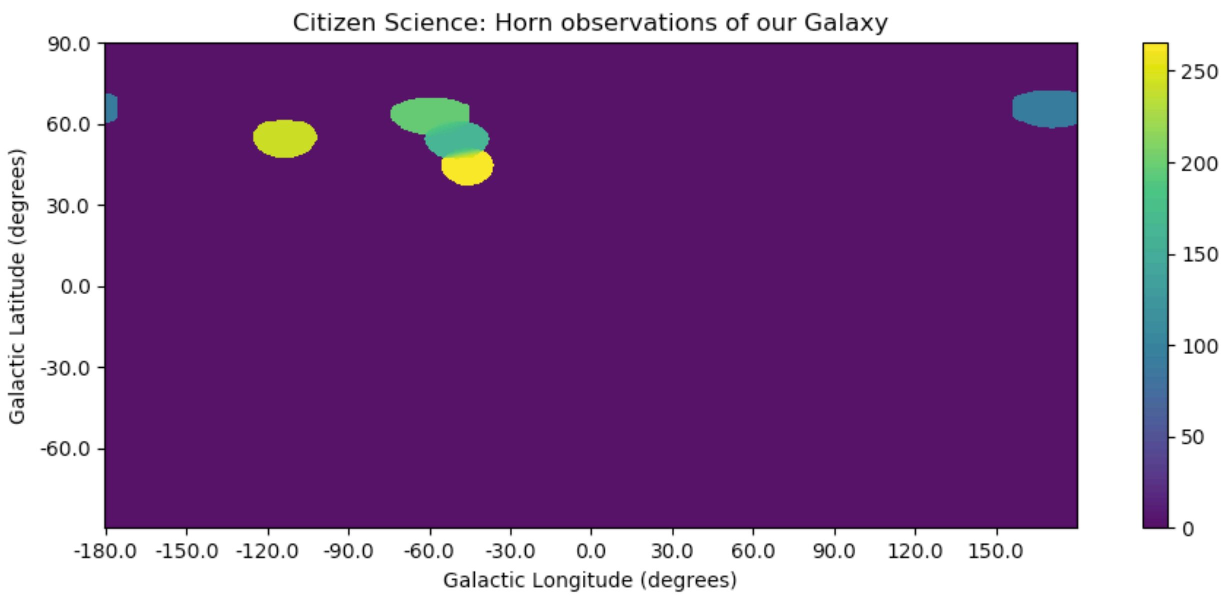

Figure 6: Integrated Intensity Map (Kelvins-km/sec) on a Galactic Longitude, Latitude Map. This is a whole sky map with X axis of Galactic Longitude and Y axis is the Galactic Latitude. The color indicates the signal strength.

Conclusion

With 10 minutes of observations with your sensitive radio telescope you can start to discover our galaxy. Give these commands a try with your own data!