ezRA - Easy Radio Astronomy – Tour

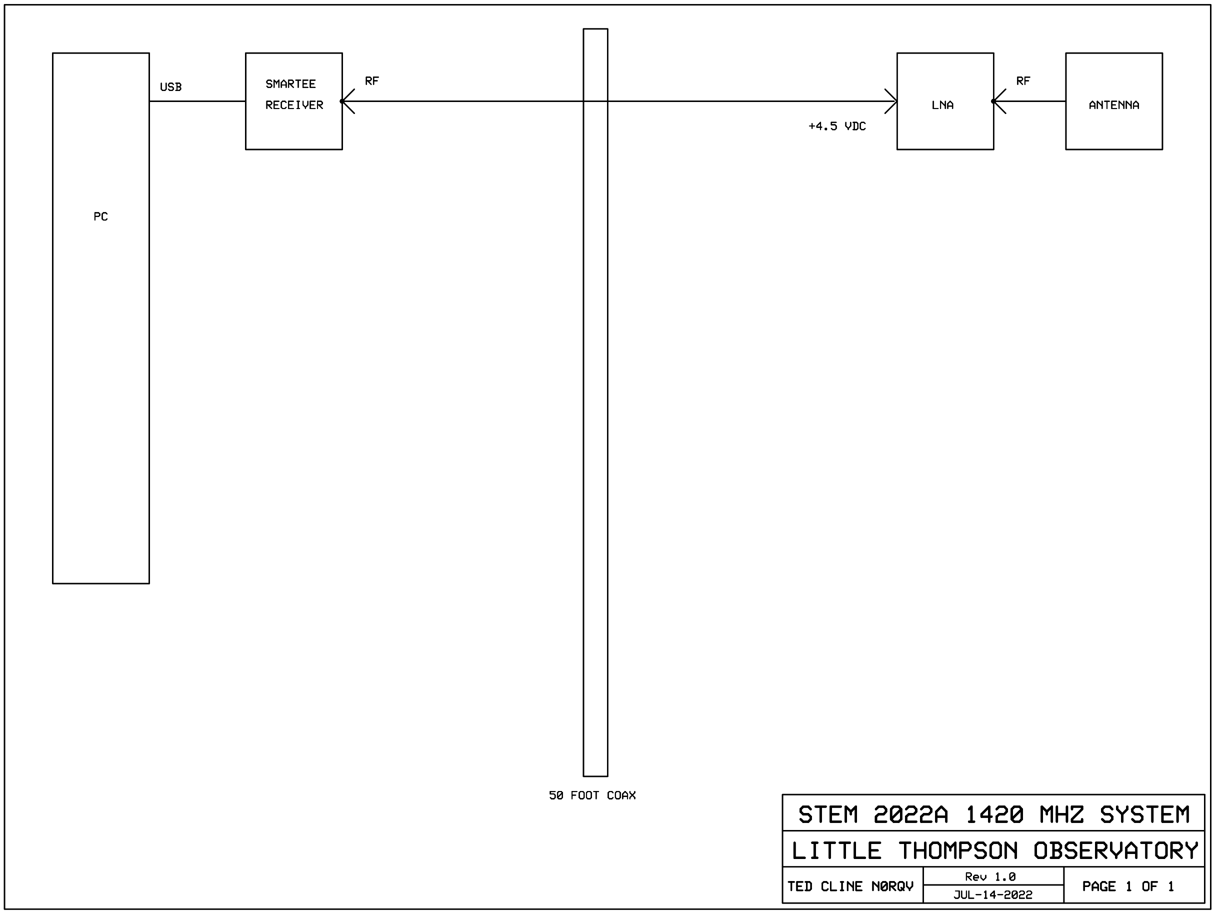
- Sep-30-2022

The ezRA Easy Radio Astronomy set of programs are free PC tools to help explore Radio Astronomy. The programs run on the Python3 programming language, on Windows and Linux.

Here is quick tour of what ezRA can do.

COLlect Radio Data into Files, with ezCol

First, hook up some hardware to receive 1420 MHz radio signals from the sky.



Above shows the radio signal data flow, from the top right,
from a suitable antenna,
to a Low Noise Amplifier (LNA),
to a coaxial cable (coax),
to a USB Software Defined Radio (SDR) receiver,
by USB to a Windows or Linux PC.

This LNA has the advantage of including a filter to pass primarily 1420 MHz signals,
https://www.nooelec.com/store/sdr/sdr-addons/sawbird/sawbird-h1-barebones.html

Simple TV RG-6 Coaxial Cable has worked well.

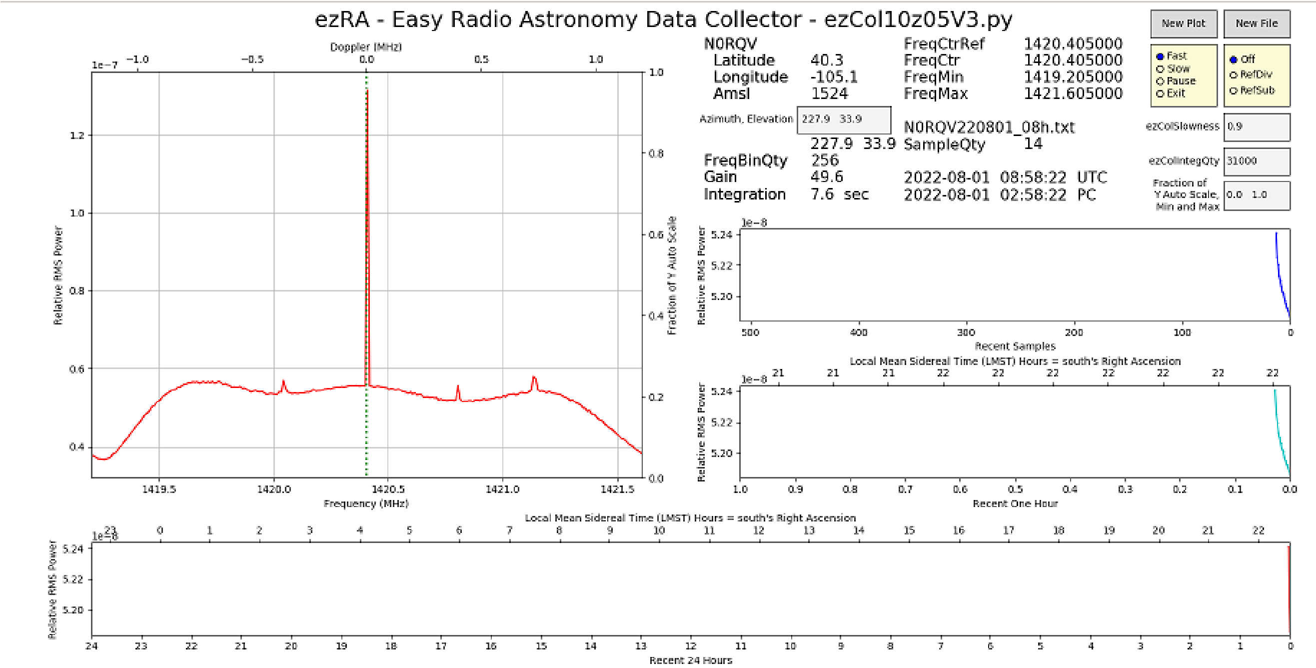
This “SMArTee” USB Software Defined Radio (SDR) receiver can provide 4.5 volts DC down the coax cable to power the LNA,
https://www.nooelec.com/store/sdr/sdr-receivers/smart/nesdr-smartee-sdr.html

“A suitable antenna” might be as simple as this 11-Element “Straw” Yagi on a PVC pipe,

or this 3-Sided Corner Reflector (made from foiled expanded polystyrene board insulation),

Usually, bigger antennas cost more, but they do provide more information.

Then install the ezRA software on the PC, and run its ezCol program to control the receiver and collect the radio data into computer .txt files,



ezCol creates ezRA frequency spectrum data .txt files. Each data sample might represent thousands of readings integrated together, to write one file sample every 5 to 300 seconds . Each file sample provides one line of 256 to perhaps 4096 values of one frequency spectrum. These simple .txt data files are human-readable and can be studied with a spreadsheet program like Excel or the free LibreOffice Calc. A data file's text will start something like this:

```
from ezCol220826a.py
lat 40.4 long -105.1 amsl 1554.0 name N0RQV8
freqMin 1419.2 freqMax 1421.6 freqBinQty 256
az 227.9 el 38.9
# times are in UTC
2022-09-25T00:00:06 206.197 206.197 207.678 209.662 213.395 …
```

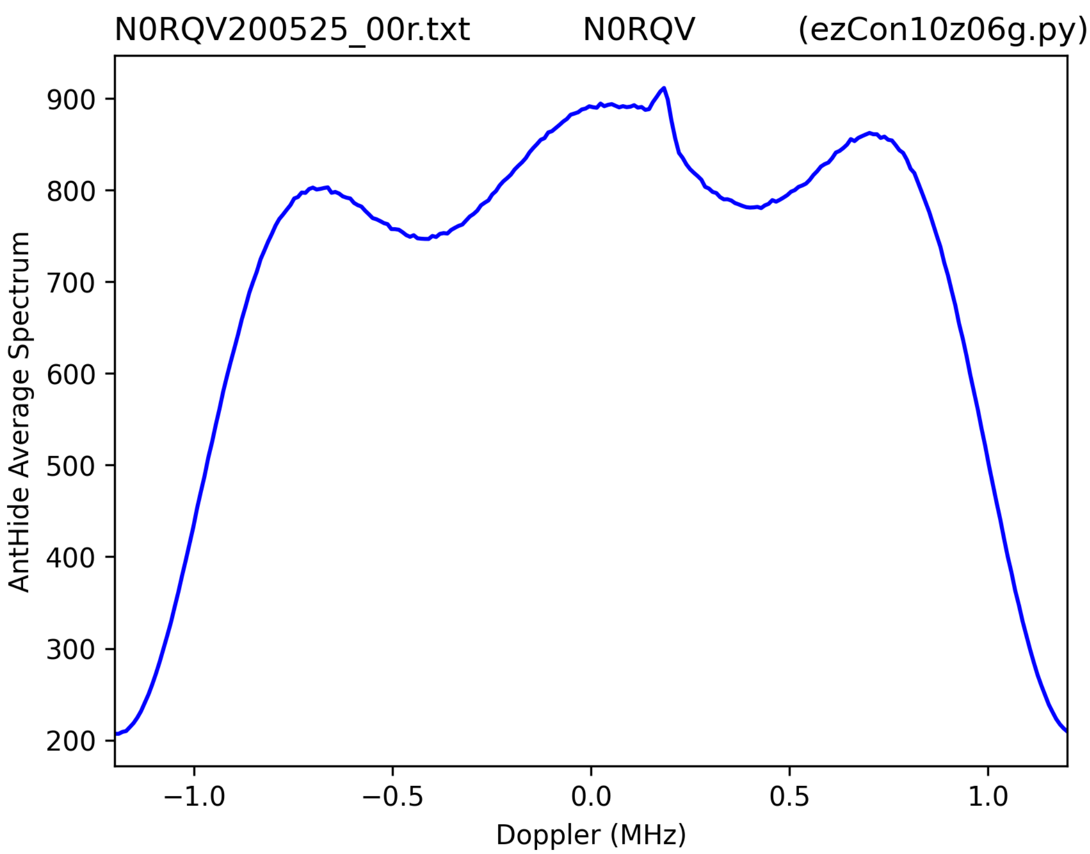
That last line is long, with at least 257 words, with lots of numbers. Presented here, the end of the first sample is trimmed off. Many long one-line samples would follow. A new data file is automatically started at the start of each new Coordinated Universal Time (UTC) day. Full-day 256-frequency data files are about 24 Mbytes.

The ezRA programs mostly analyze these data files, and create lots of plot files to study.

CONdense Data .txt Files, with ezCon

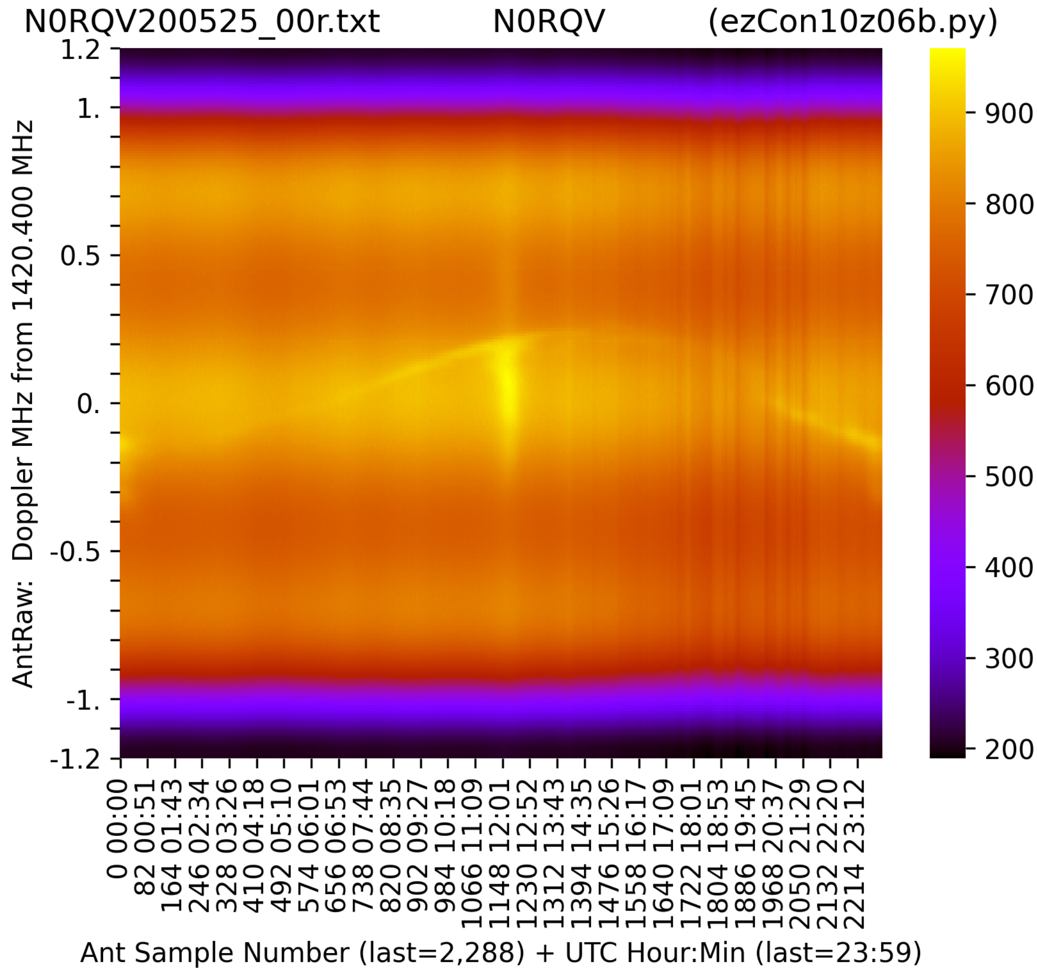
The ezCon program reads those .txt data files, extracts the hydrogen emission information, and writes out that improved data into one smaller .ezb condensed data file, and perhaps one GALaxy *Gal.npz data file. Along the way, ezCon creates lots of plot files, to inspect and study the data.

Each sample read from a .txt data has a date and time, with a long list of frequency spectrum values. One set of bright values from sample number 1066 might plot like this,



Note the sharp spike of hydrogen emission just to the right of center. Hydrogen is commonly seen in the middle frequencies, near the center 1420.405 MHz.

If we take that above blue trace of sample 1066, rotate it 90 degrees counterclockwise to a vertical line (with the low frequencies on the bottom), and place it side by side with the other vertical line samples in order of increasing sample number (usually displaying increasing time), and represent each sample's larger values as brighter colors, we get a 3-dimensional heatmap of all 2,288 antenna samples, like this AntRaw plot,

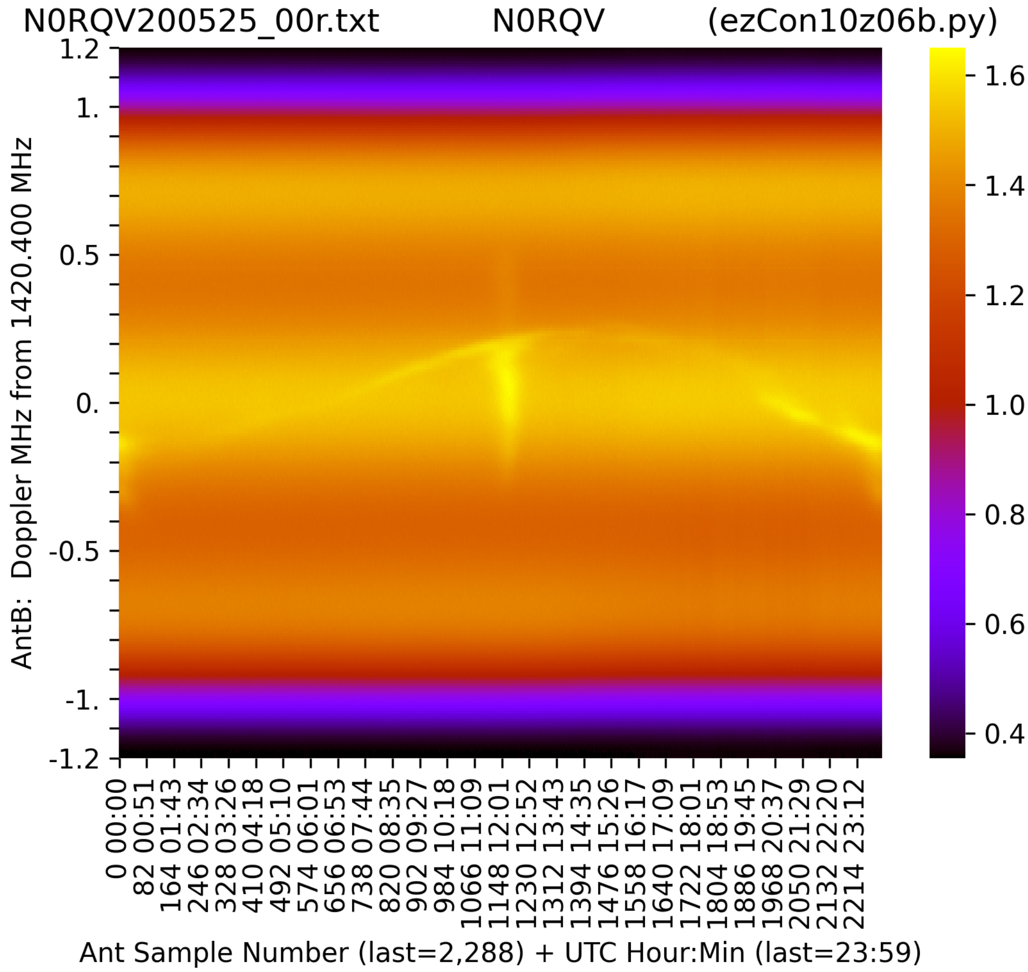


Horizontally, across the center frequencies, we can see a faint sinusoidal wave, in brighter yellow. That is the weak 1420 MHz emission from Galactic hydrogen,

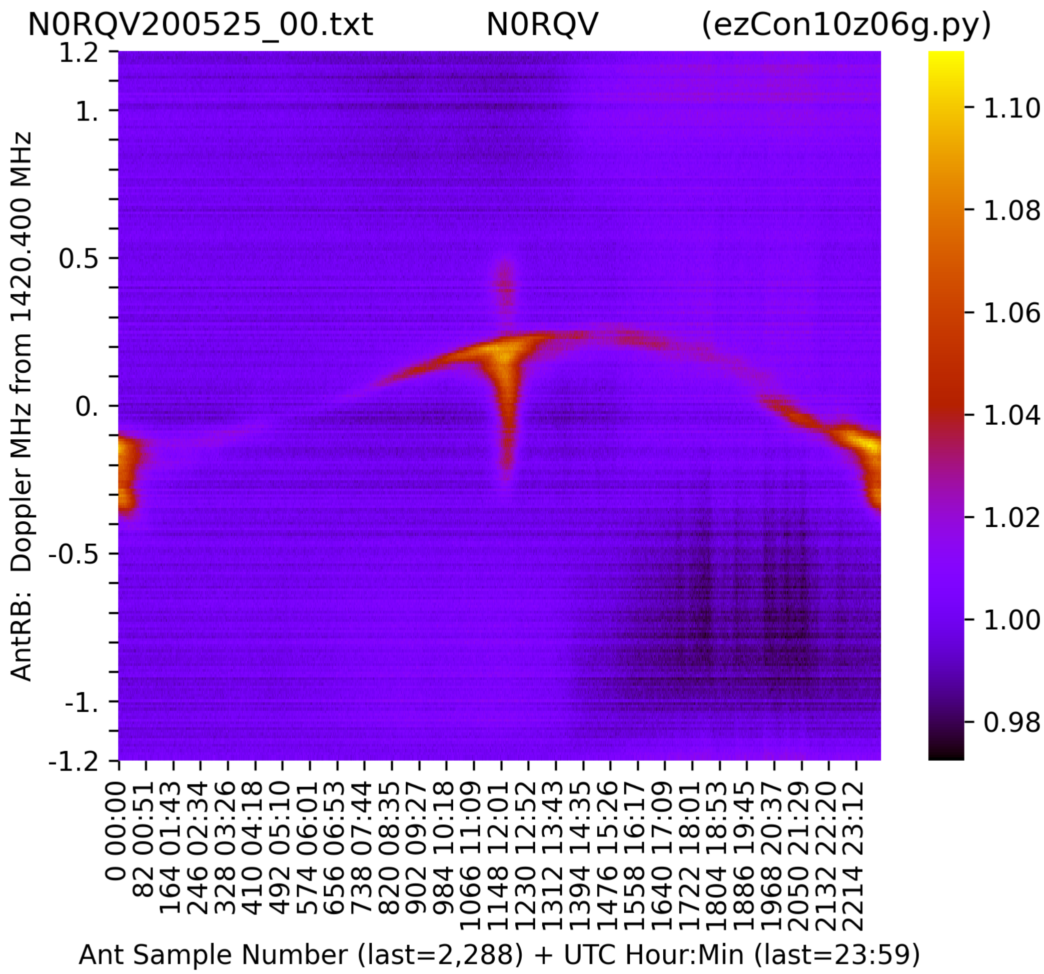
https://en.wikipedia.org/wiki/Hydrogen_line

Here, the brighter hydrogen wobbles in frequency, about once each 24 hours. The earth travels around the Sun. Sometimes the radio antenna is observing from the "front" of the earth and is facing forward (like looking out a moving car's front windshield). Maybe 12 hours later, the earth has rotated, and the antenna is observing from the "back" of the earth (like looking out the car's rear window). This wobble in frequency is due to that change in antenna velocity through space, and the Doppler Effect,

https://en.wikipedia.org/wiki/Doppler_effect ezCon can do some signal processing, to reduce those vertical curtains on the right, and improve the contrast of the hydrogen emission, to achieve the “AntB” signal,



Sample number 500 above, seems to have little hydrogen emission. ezCon can compare each Antenna sample to that quiet Antenna sample 500 (a Dicke Reference), to improve the contrast of the hydrogen emission, to achieve the "AntRB" signal with one Reference,



Likewise, in modern astronomical optical digital imaging, sky images are compared to dull Light Frames (and Dark Frames, and Flat Frames) to help the computer post-processing, to improve the results.

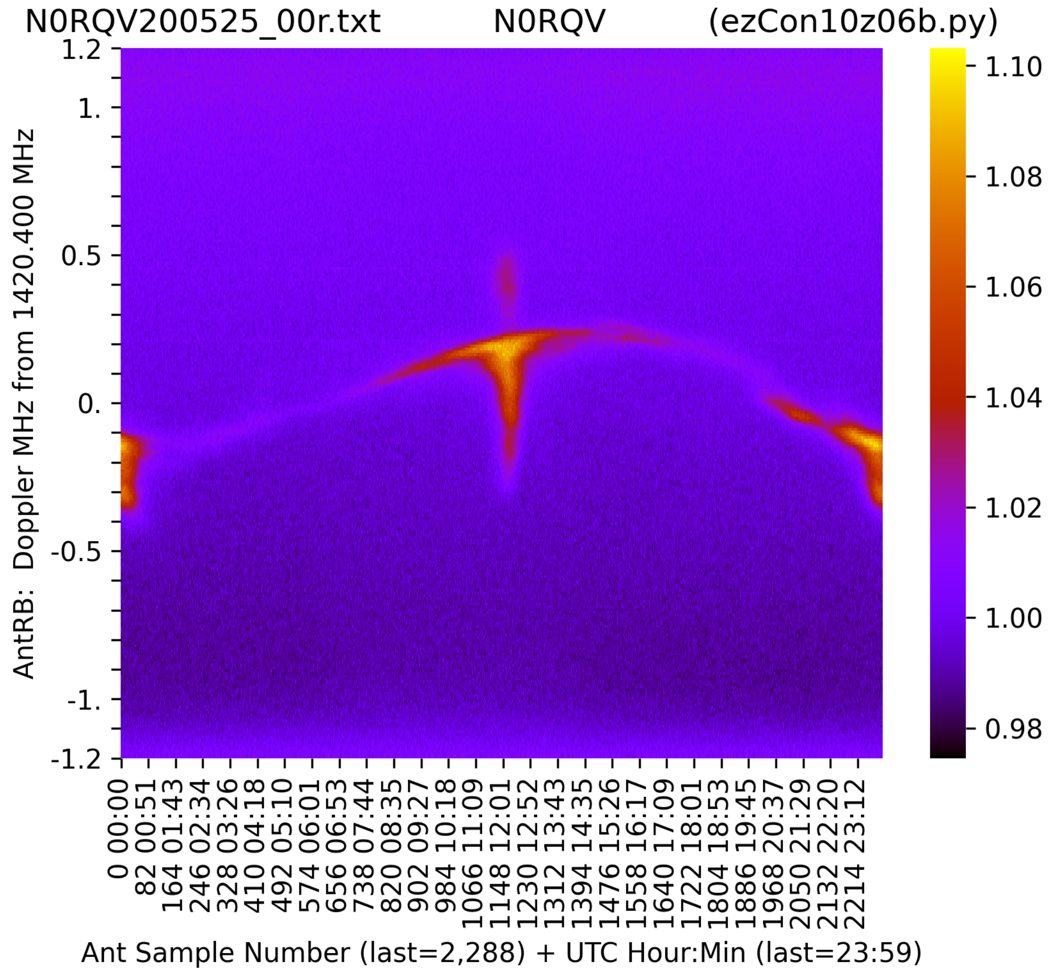
https://en.wikipedia.org/wiki/Robert_H._Dicke

http://setileague.org/askdr/dicke.htm

ezCon can control the frequencies sampled, to periodically sample a Reference frequency.

ezCon can control external hardware relays, to periodically sample a Reference resistor.

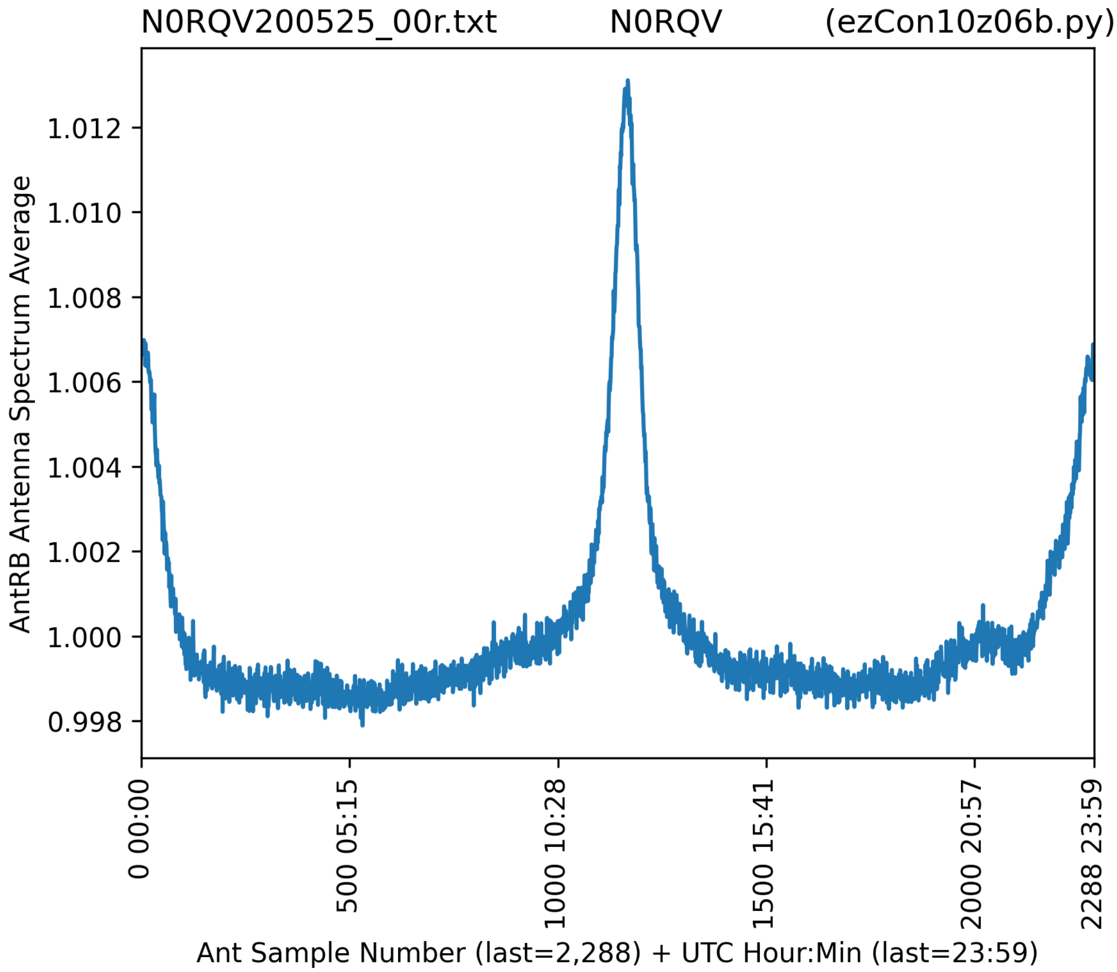
ezCon can compare each Antenna sample to the last Reference sample (a Dicke Reference), here a sample of a quiet resistor, to further improve the contrast of the hydrogen emission, to achieve the AntRB signal with many References,



That hydrogen signal's sinusoidal frequency wobble due to the earth's movement, can be calculated and removed. Then the true relative velocity of the Galactic hydrogen can be measured.

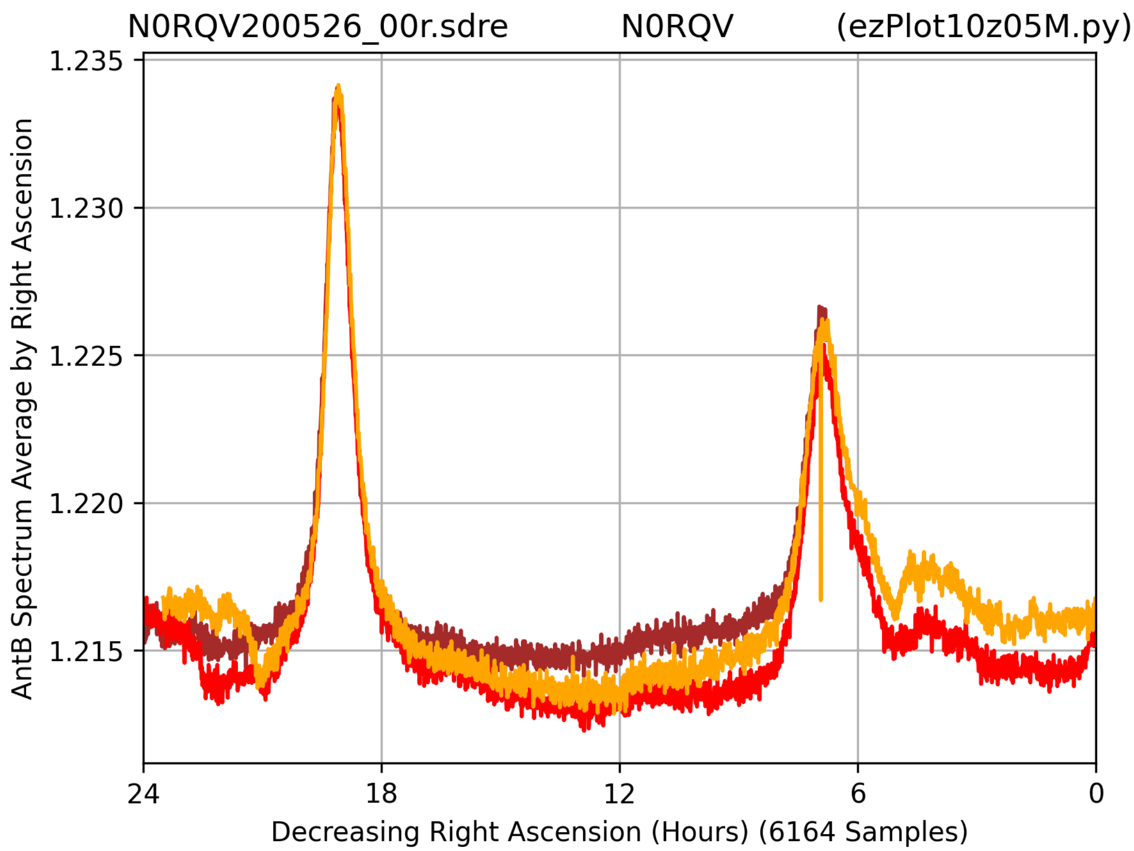
ezCon records the Antenna sample spectra collected during Galactic plane crossings (if any) in a *Gal.npz condensed data file. The ezGal program can later analyze the collected *Gal.npz data files.

ezCon can plot the average of each of those vertical line samples, on the previous AntRB heatmap plot,



Study Condensed Data .ezb Files, with ezPlot

Using .ezb condensed data files from ezCon, the ezPlot program can plot the signals against their calculated Right Ascensions,

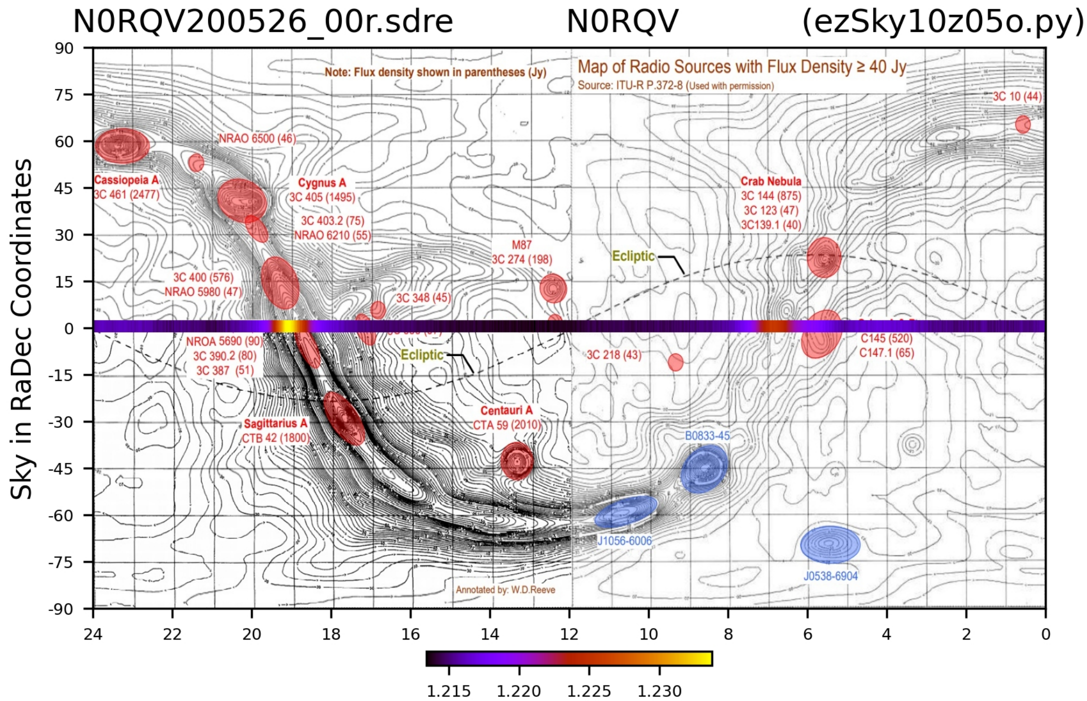


The above data comes from most of 3 consecutive UTC days, shown as brown, red, and orange traces, advancing to the left.

Combining many collected .ezb files, reduces random noise, and improves the plotted signal.

Plot the Radio SKY, with ezSky

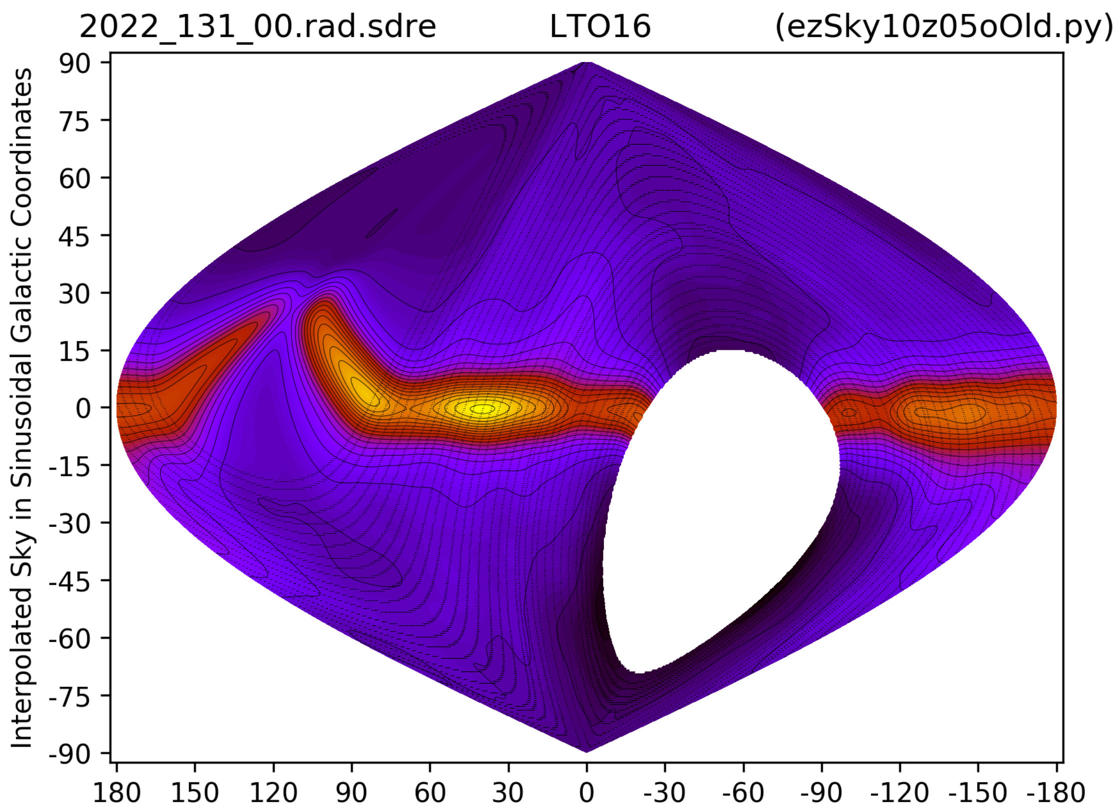
Again, using those .ezb condensed data files from ezCon, the ezSky program can plot the processed signals against their calculated Right Ascension and Declination sky coordinates,



Note the two bumps of signal show up as brighter spots on the horizontal trace, and the brighter spots fairly align with the wavy Galaxy plane background. The bright spots may not align with the Galaxy if data timestamps, or antenna location, or antenna bearing were wrong. The whole horizontal trace might be shifted to the left or right, or up or down.

Raising the antenna's elevation angle, and then collecting data from another 24-hour drift-scan, would create another .ezb condensed data file, to provide a similar, but higher horizontal declination trace across the plotted sky. By plotting all the collected .ezb files together, we begin to plot the 1420 MHz radio sky.

https://en.wikipedia.org/wiki/Astronomical_coordinate_systems ezSky will also plot your many .ezb files using Galactic coordinates,



ezSky optionally adds a thin black line along the path of each drift-scan. The upper left is incomplete, it needs more north data drift-scans near Polaris. The lower right white egg indicates where the earth blocks the sky, for this antenna location on earth.

Then compare your Galactic coordinate plot to

https://irsa.ipac.caltech.edu/data/Planck/release_2/external-data/img/image036.png

(from https://irsa.ipac.caltech.edu/data/Planck/release_2/external-data/external_maps.html)

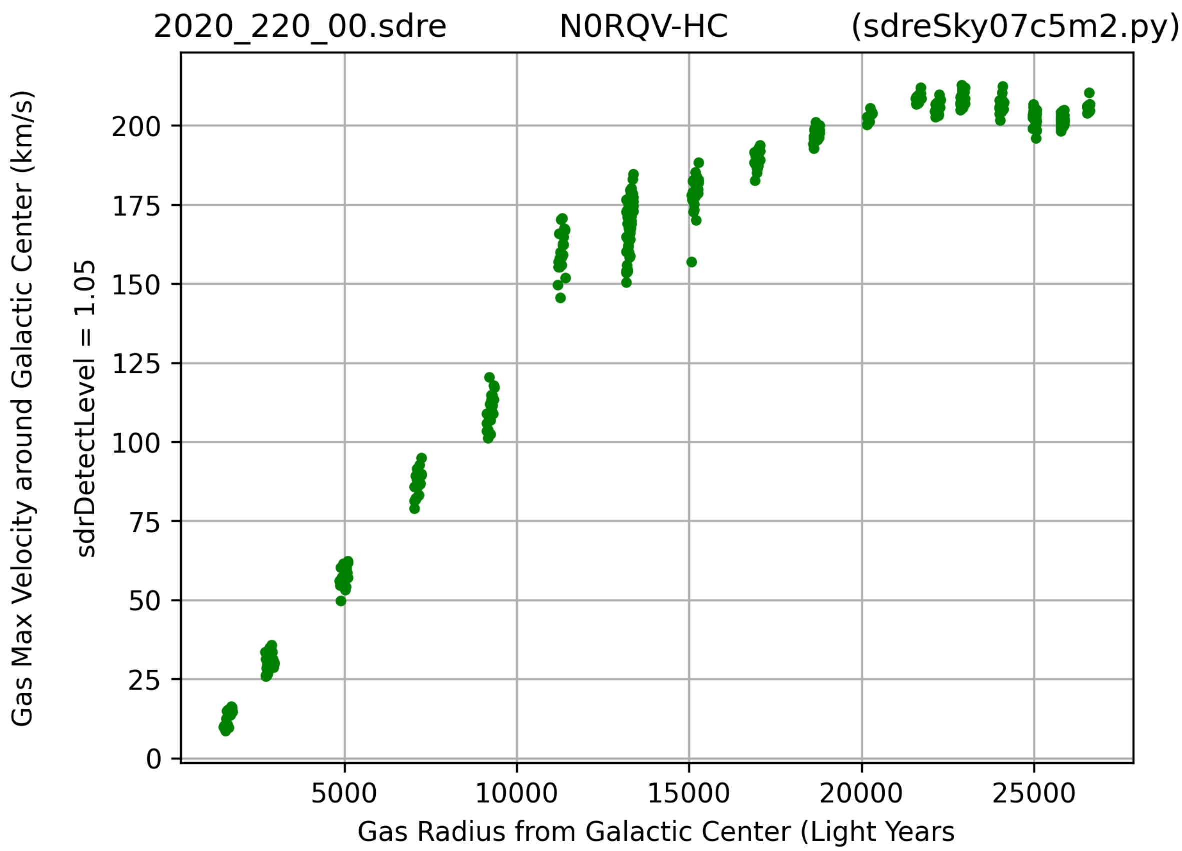
and note the same flare from center upwards.

Or compare to this cool Max Planck Society video (highlighting approaching gas to receding gas),

https://www.youtube.com/watch?v=Q2mgpsTFuV8&t=1s&ab_channel=MaxPlanckSociety

Explore GALactic Rotation and Arms, with ezGal

Using several *Gal.npz condensed data files from ezCon, the ezGal program can analyze the collected Galactic plane crossing spectra to plot the Galactic arm rotation against their Galactic radius,

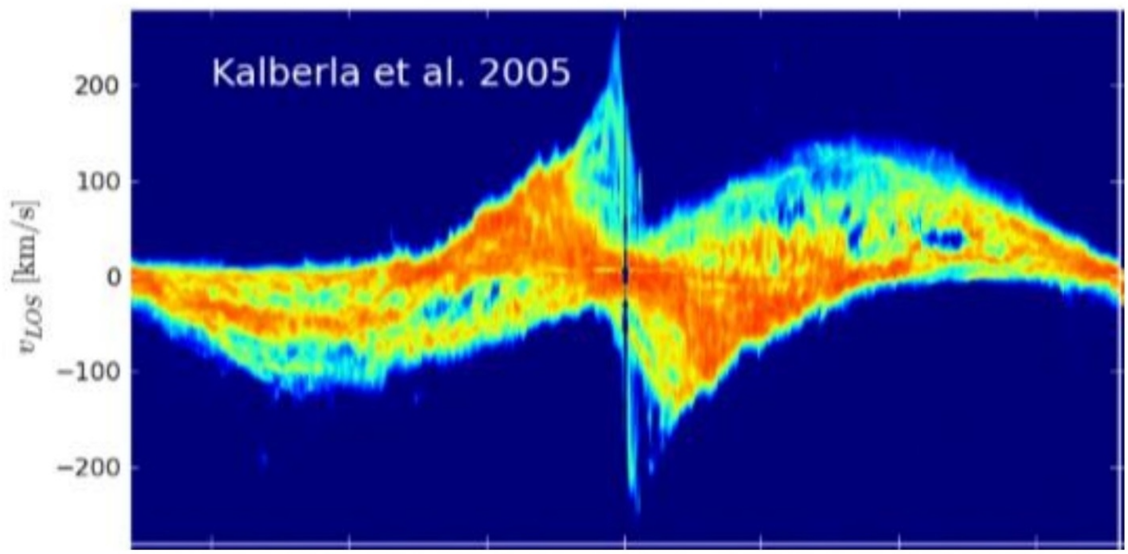


The Sun is 25,800 light-years from the Galactic Center.

According to Newtonian physics, the curve should be decreasing down to the right, when the radius is greater than 10,000 light years. The observed curve supports the presence of invisible Galactic dark matter.

http://euhou.obspm.fr/public/Milky_Way_Rotation_A4.pdf

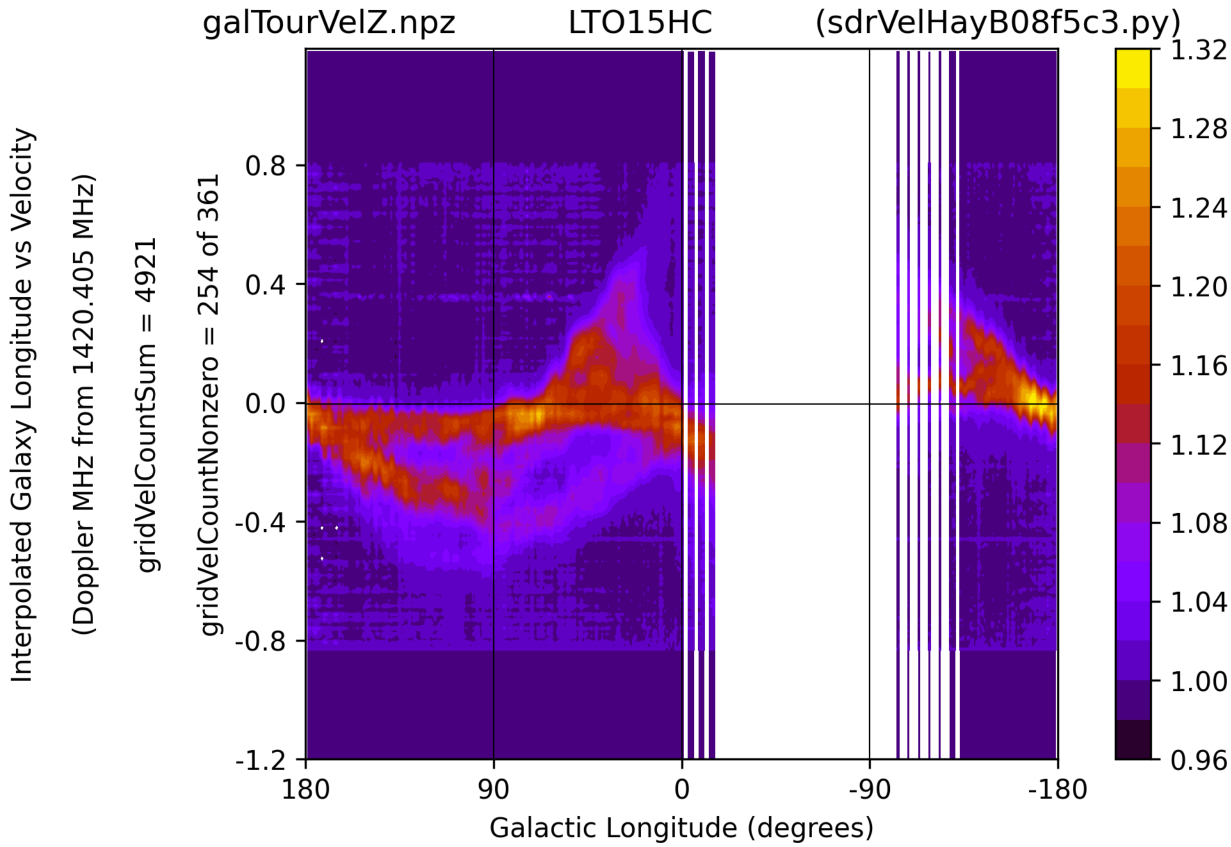
To explore the Galactic Arm location, start with the professional plots of Velocity vs Galactic Longitude,



https://arxiv.org/abs/1310.2852

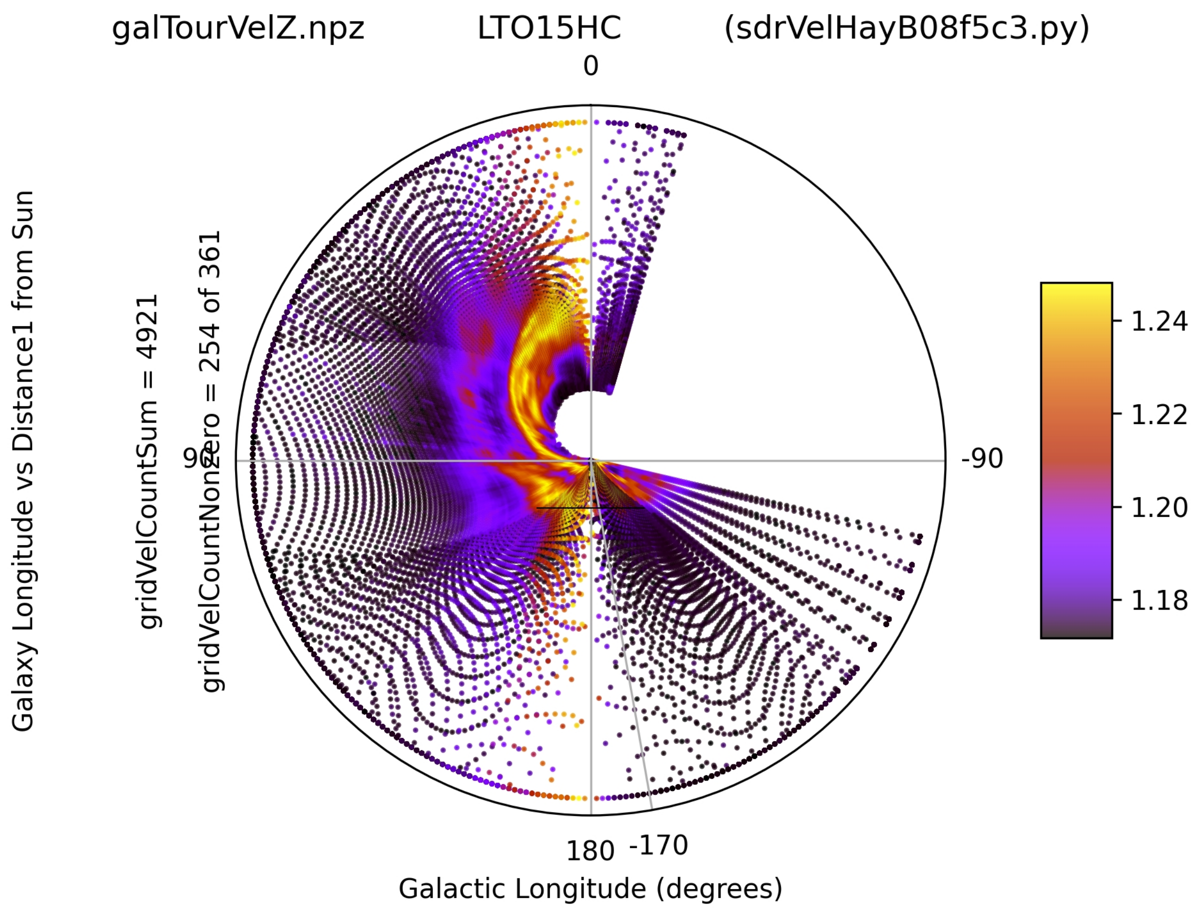
https://arxiv.org/abs/astro-ph/0009217

and compare them to the collected 15-time-minute vertical spectra of Galactic plane crossings, for each one-degree Galactic Longitude,



More data can still be collected, but there are some Galactic plane longitudes on the right that the antenna's northern location on earth can not see.

After a healthy dose of trigonometry, ezGal will try to plot the location of the Galactic Arms (centered on the Galactic Center),



Partial success, but ezGal needs more work.

ezRA plots many more files to explore.

What else should ezRA do ?

- Calculate Galactic mass ?