Experiment Report

Galactic HI Experiment with Horn Antenna

RAWS 2023 Group 1 :
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1 Aim and Motivation

The aim of the experiment is to detect the galactic H1 emission through the calculation of temperature and velocities with respect to local standard of rest of celestial bodies along the galactic equator by using a horn antenna.

Hydrogen is the most abundant element in the universe and therefore the hydrogen line is a very important line in radio astronomy. The 21 cm hydrogen line is a spectral line emitted by atomic hydrogen. The proton and the electron in the hydrogen atom can have a parallel (higher energy) or an anti-parallel (lower energy) spin configuration. The photon emitted when an atom transits from high energy to low energy configuration, its frequency is approximately 1420.4057 MHz or 21.1 cm.

A horn antenna is a high performance, high gain and low noise antenna and is superior to the parabolic dish antenna in terms of noise performance.

For this experiment, the horn antenna is connected to Low Noise Amplifiers and a Bandpass Filter. The output of the bandpass filter is made to pass through a coaxial cable which is connected to the SDR on the system.

Using this setup, first we find out the temperature of the celestial bodies on the galactic equator by plotting the power against the frequency and after we calibrate the velocities wrt the local standard of rest, we plot the temperatures against the velocities and fit them with gaussians to find out the number of sources of H1 line emissions.

2 Procedure

1. Assembly: We connect the LNAs then the filter with connectors, and connect this assembly to the antenna. Then connect the long 10 m RG58 or LMR400 coaxial cable to the filter, and connect the other end of the cable to the receiver, with right adopters and plug the receiver to the computer. LNA power cables connected to the battery and turned on.

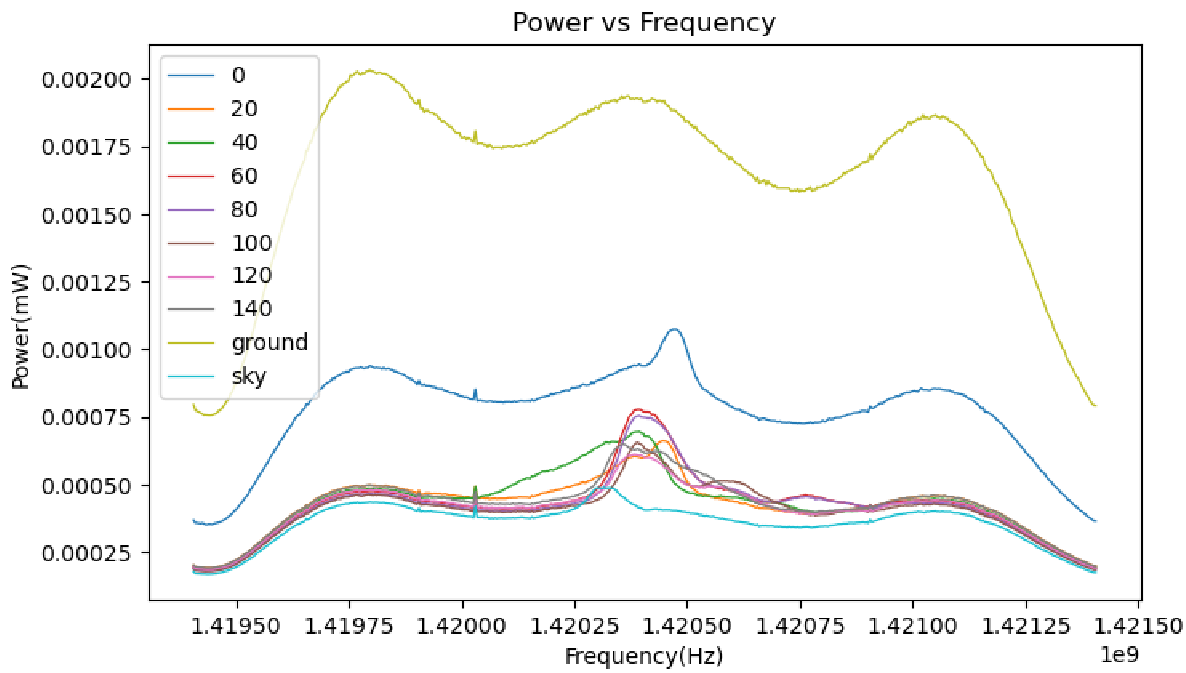
2. SDR: A software-defined radio (SDR) is a communication system designed in software, with components like the rtl-sdr dongle capable of turning it into an SDR. The dongle provides raw digital samples for computer interpretation and processing, allowing for FM demodulation entirely in software. The dongle has an 8-bit analog to digital converter with IQ sampling and can be tuned to frequencies ranging from 24 MHz to 1766 MHz.

3. Locate the source and point the antenna: Stellarium is a tool that allows users to determine the source location of stars in the galactic plane at a particular time. We choose a star closest to our required galactic longitude. We note the azimuth and elevation (and also RA and Declination) of the star and point the antenna. This process ensures accurate pointing information for sources in the galactic plane. We use a mobile phone and an application to turn the antenna to a particular source by changing it's azimuth and then it's elevation.

4. We then begin recording the data through the drivers and software, which stores data as a csv. Now we analyze the data.

3 Observations / Data

- We have all the data as a CSV, which is essentially Frequency vs Power data. The following plot concisely shows our observed data.



- The coordinates where we pointed our antennae are (all angles are in degrees):

Source	RA	Dec	Az	Alt
sky	336.9	5.7	148	75
0	266.5	-29.8	232	13
20	277.2	-12.1	244	29
40	286.6	6.6	261	44
60	296.7	24.2	286	55
80	308.7	41.3	321	58
100	330.8	55.3	355	53
120	6.9	63.3	17	41

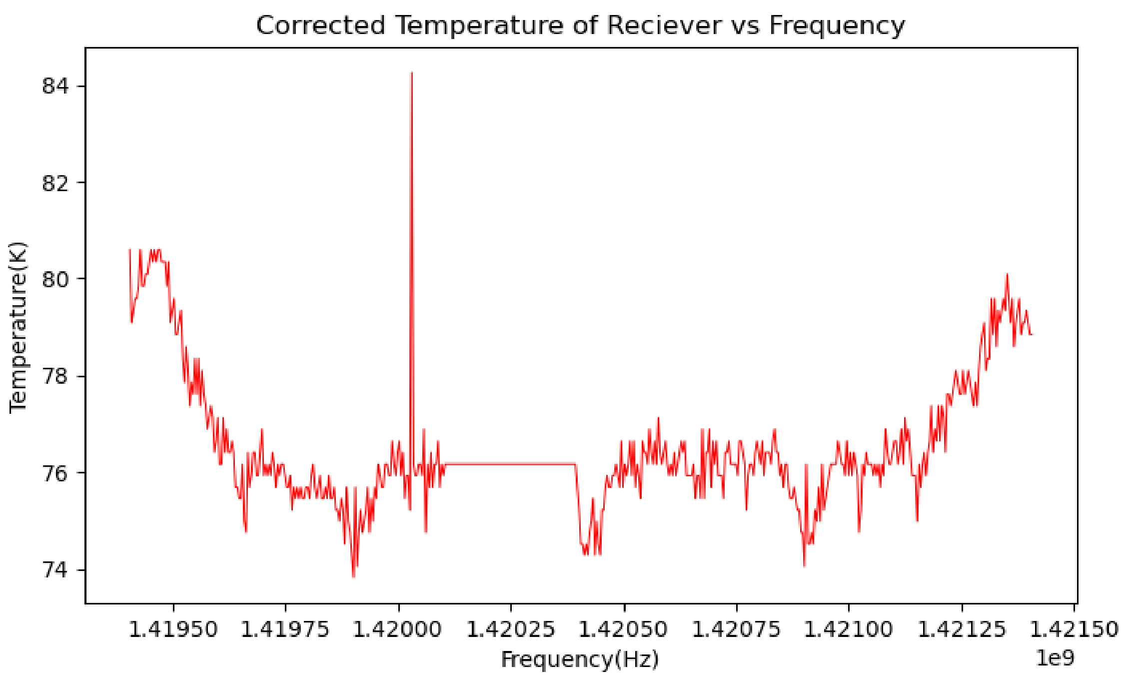
4 Analysis and Results

- Considering the nature of this experiment, we felt it would be suitable to combine the analysis and results section into one.
- We now analyze the data with the end goal of fitting gaussians to identify neutral hydrogen clouds in the galaxy.

- We do all the analysis, except fitting gaussians, in python. We use the libraries numpy, scipy, matplotlib and pandas for the analysis. We use the origin software to fit gaussians.
- We convert Power units to Temperature units with the reference points of the sky and ground with reference temperatures of 5K and 300K respectively. The sky has contributions from the atmosphere and the CMB. We use $P = kT$ and also adjust the presence of the receiver temperature T_r with the following formula.

$$\frac{P_g}{P_{sky}} = \frac{T_g + T_r}{T_{sky} + T_r} \tag{4.1}$$

- We use 4.1 to obtain T_r as a function of f (frequency). Because the HI line is present almost in any direction, even though we ensured the sky observation was not in the galactic plane, T_r would carry a signature of the HI line. We manually replace that signature with a flat line as shown below. One can see a flat line around a frequency of 1.42025 GHz. We now use this corrected or adjusted T_r (also called T_{fit} in the experiment manual) for source calibration following 4.2

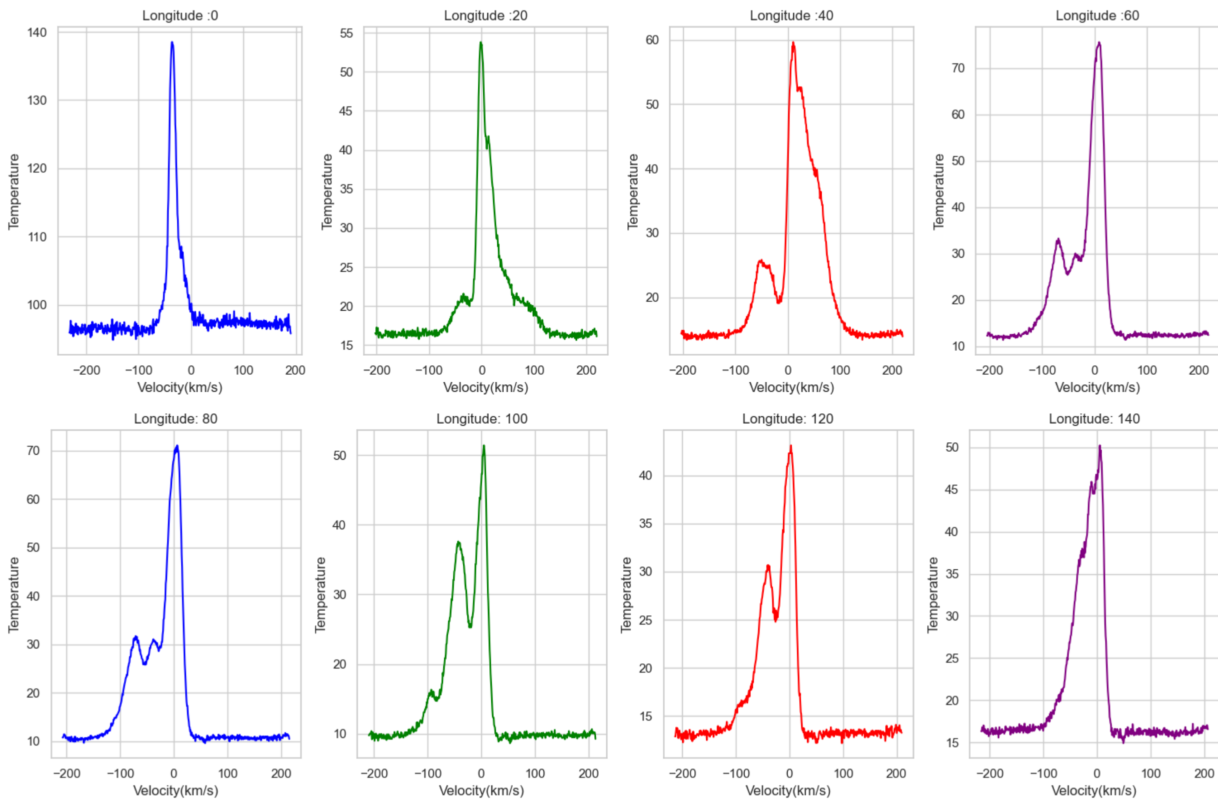


$$T_{source} = \frac{T_g + T_r}{P_g/P_{source}} - T_r \tag{4.2}$$

- Now we convert the frequency axis to velocity axis following 4.3 and the python code in the appendix of the experiment manual which accounts for peculiar velocity (including that due to rotation and revolution of Earth) of the Earth and the Sun. This has now shifted us into the LSR frame. LSR frame is the "local standard of rest" frame which follows the mean motion of all material that revolves around the galactic centre at a distance of around 8kpc (the distance of the sun from the galactic centre). This corresponds to a tangential velocity of roughly 220 km/s with the centre as the galactic centre.

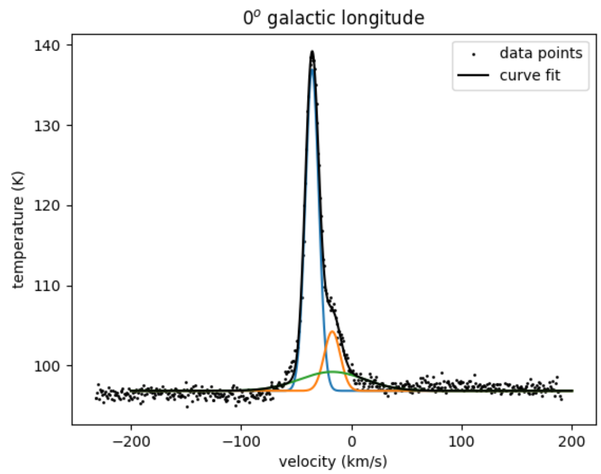
$$v = c\left(1 - \frac{f}{f_o}\right) \tag{4.3}$$

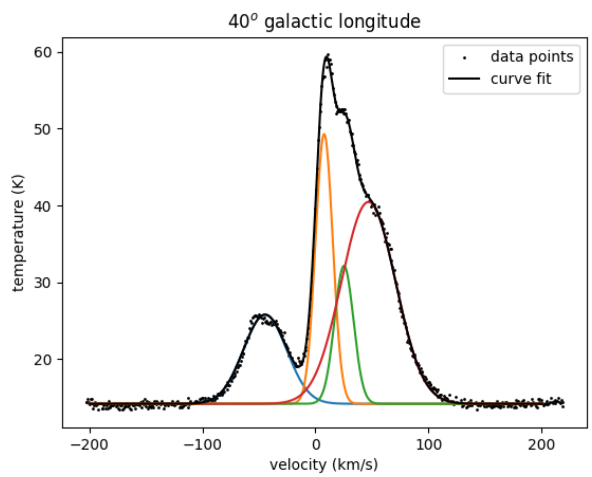
The following are the plots of each galactic longitude when we do the conversion of frequency to velocity, and do the velocity corrections as well.

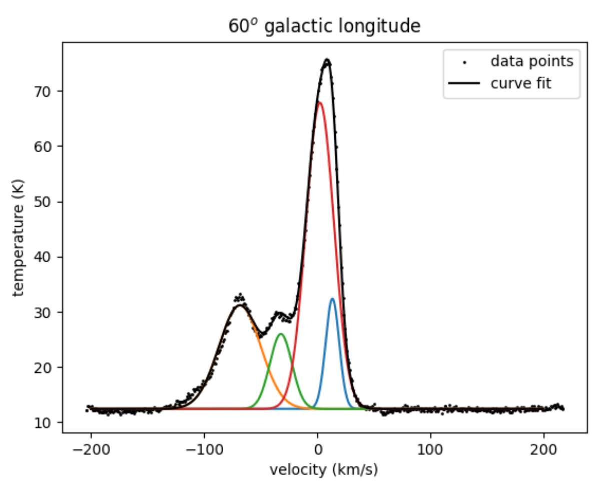


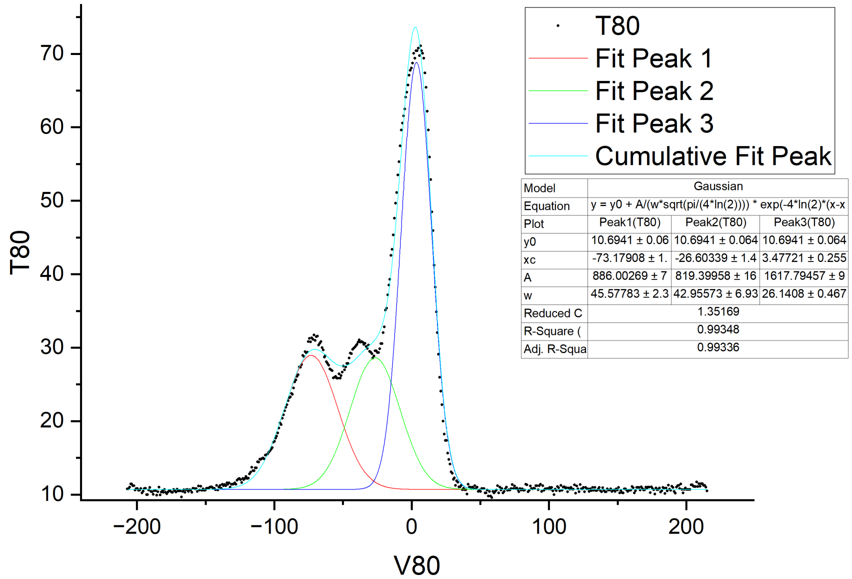
- Now, we fit gaussians to the above plots to locate HI clouds in the galaxy. The gaussians correspond to the 21cm line emitted by each neutral hydrogen cloud, and the x-axis value (velocity) would indicate whether the cloud is approaching the observer (now in LSR) or receding away from the observer. The following plots show the gaussians, and the residuals.

The gaussian curve fits (we include the parameters of the fit for one of the plots):

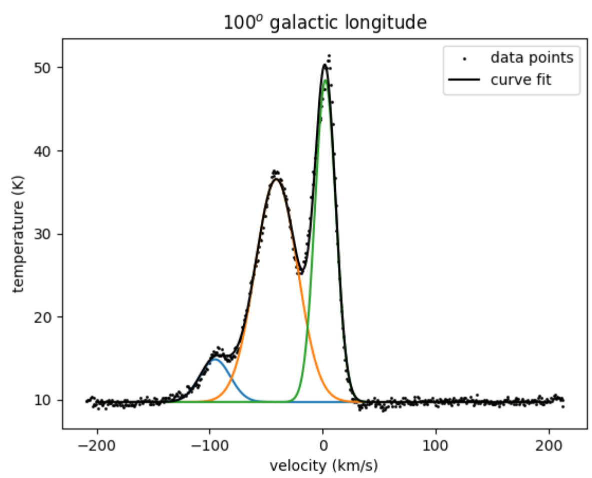

0^o galactic longitude
data points
curve fit
temperature (K)
velocity (km/s)

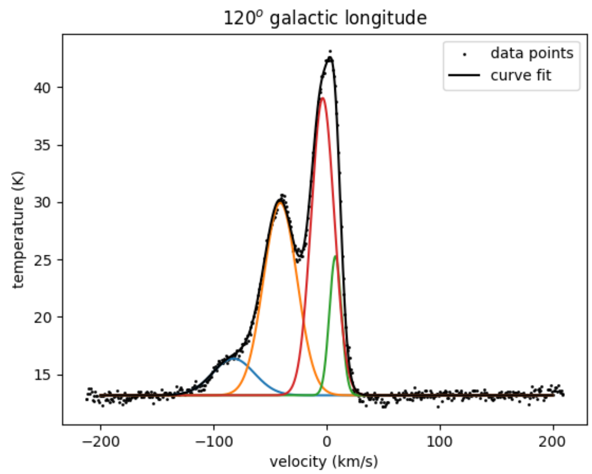

40^o galactic longitude
data points
curve fit
temperature (K)
velocity (km/s)

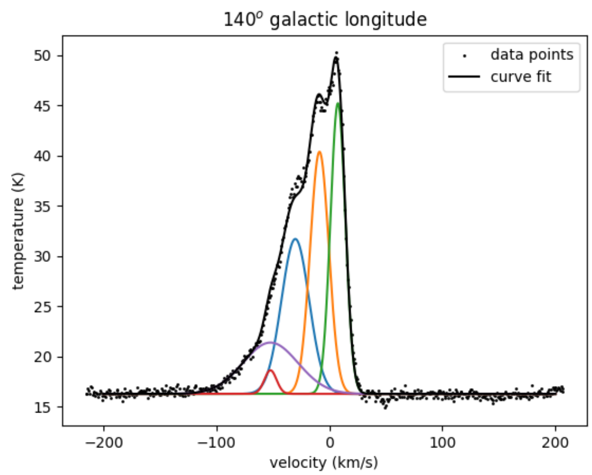

60^o galactic longitude
data points
curve fit
temperature (K)
velocity (km/s)



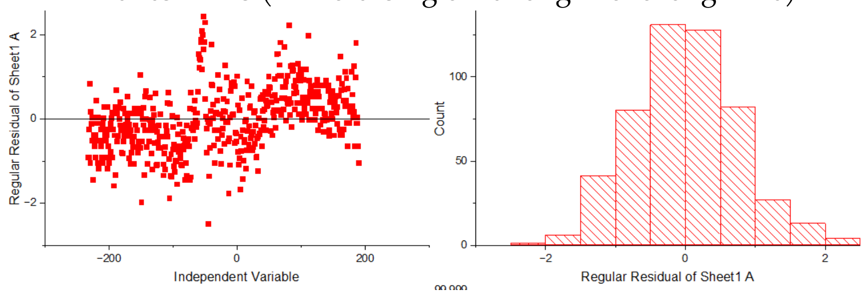
Model	Gaussian		
Equation	y = y0 + A/(w*sqrt(pi/(4*ln(2)))) * exp(-4*ln(2)*(x-x		
Plot	Peak1(T80)	Peak2(T80)	Peak3(T80)
y0	10.6941 ± 0.06	10.6941 ± 0.064	10.6941 ± 0.064
xc	-73.17908 ± 1.	-26.60339 ± 1.4	3.47721 ± 0.255
A	886.00269 ± 7	819.39958 ± 16	1617.79457 ± 9
w	45.57783 ± 2.3	42.95573 ± 6.93	26.1408 ± 0.467
Reduced C	1.35169		
R-Square (	0.99348		
Adj. R-Squa	0.99336		

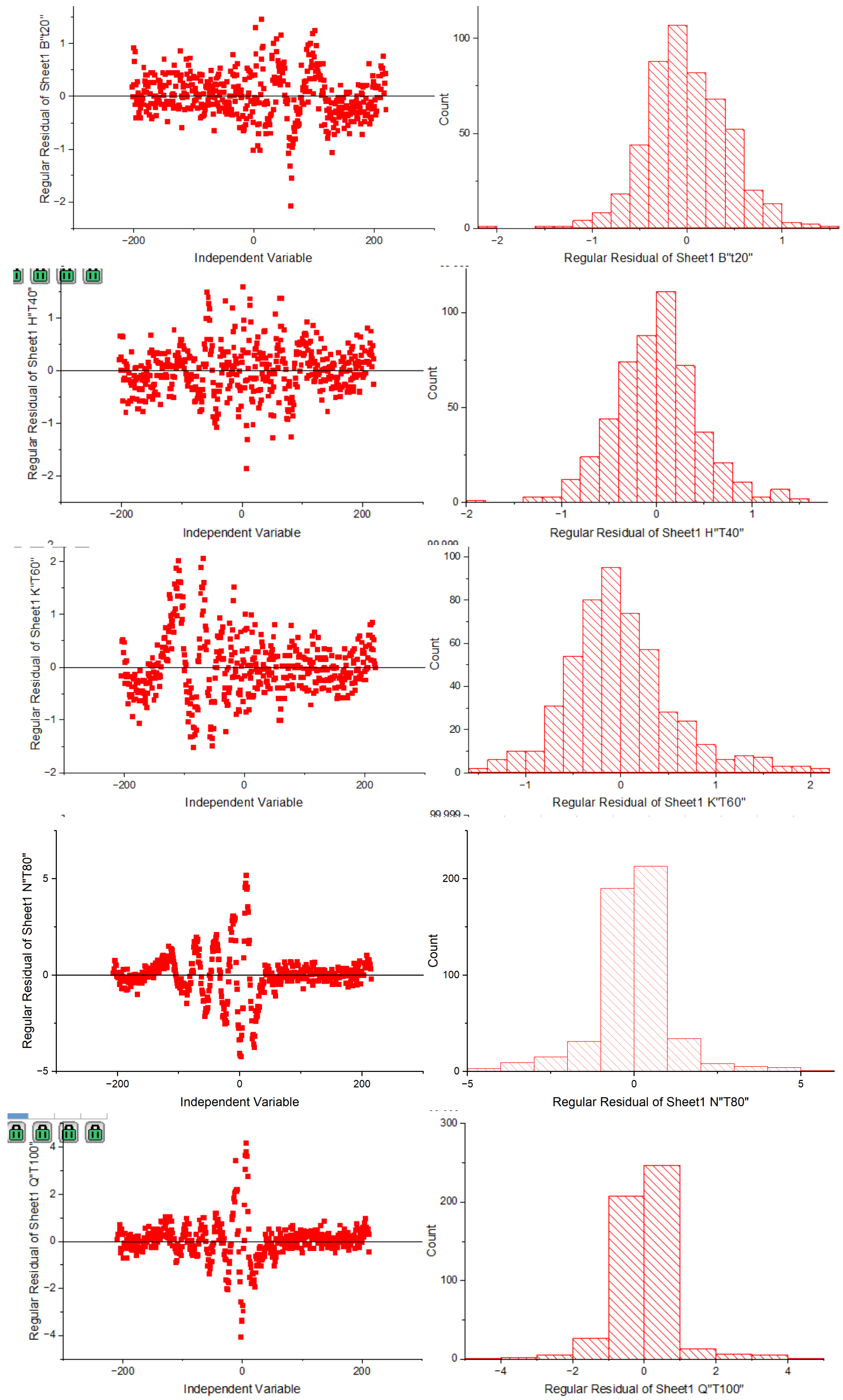


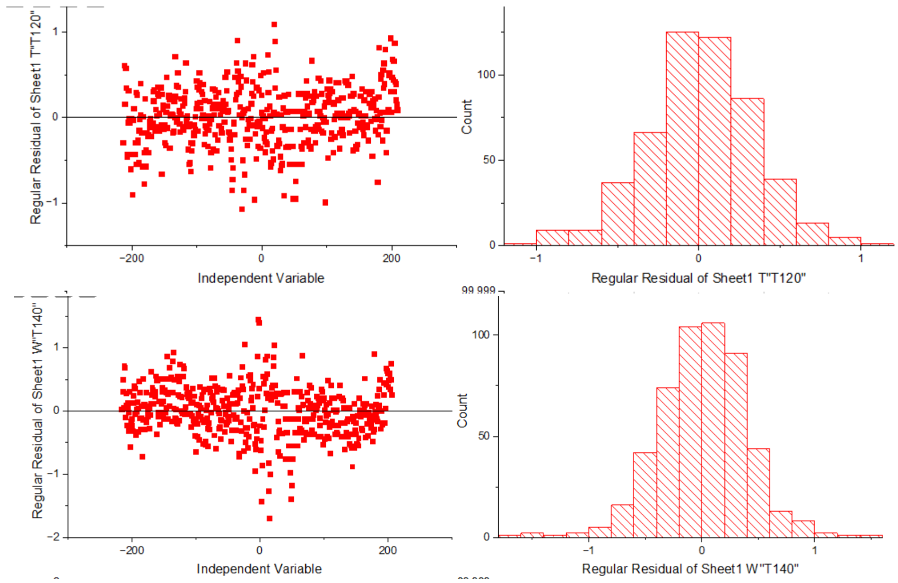




The residuals (in increasing order of galactic longitude):




Regular Residual of Sheet1 B"t20"
Independent Variable
Count
Regular Residual of Sheet1 B"t20"
Regular Residual of Sheet1 H"T40"
Independent Variable
Count
Regular Residual of Sheet1 H"T40"
Regular Residual of Sheet1 K"T60"
Independent Variable
Count
Regular Residual of Sheet1 K"T60"
Regular Residual of Sheet1 N"T80"
Independent Variable
Count
Regular Residual of Sheet1 N"T80"
Regular Residual of Sheet1 Q"T100"
Independent Variable
Count
Regular Residual of Sheet1 Q"T100"


Regular Residual of Sheet1 T"T120"
Independent Variable
Count
Regular Residual of Sheet1 T"T120"
Regular Residual of Sheet1 W"T140"
Independent Variable
Count
Regular Residual of Sheet1 W"T140"