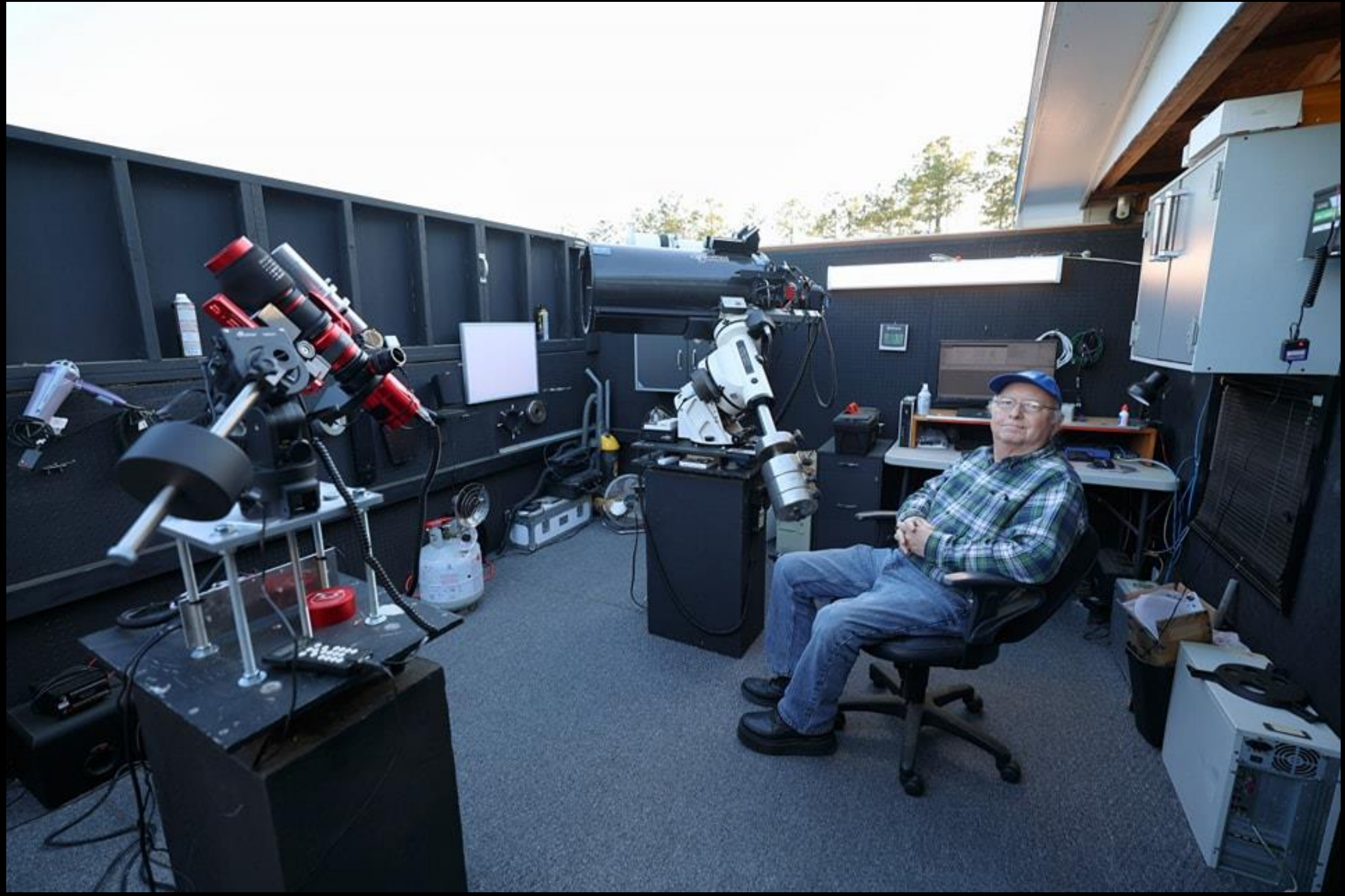
# Amateur Radio Astronomy

Initial Steps…

Hap Griffin / ImagingInfinity

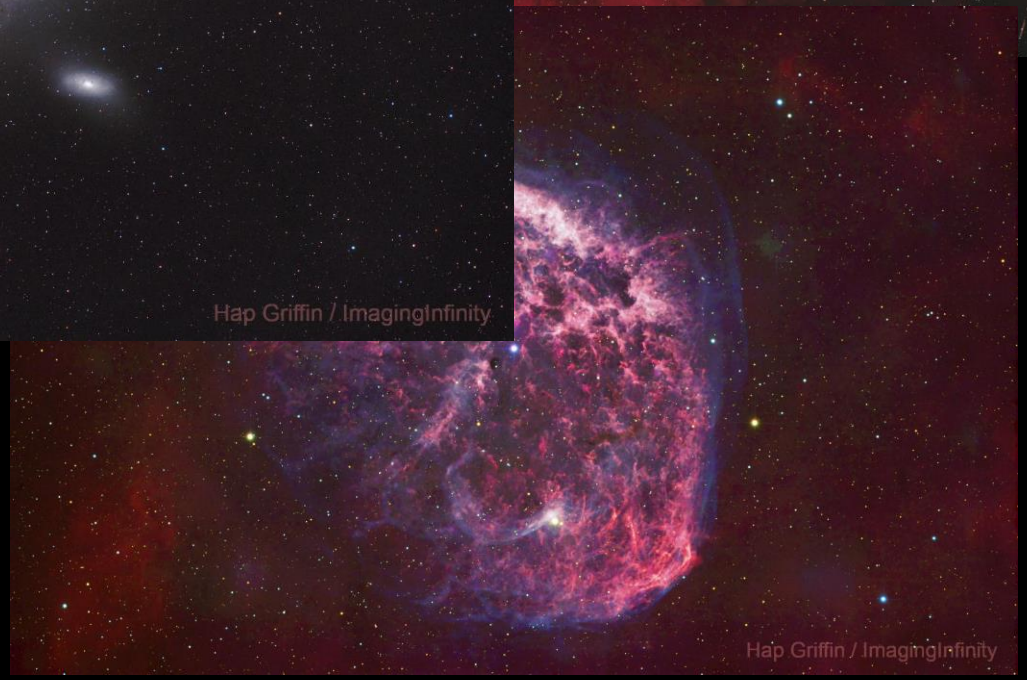
May 2025




/ ImagingInfinity


Hap Griffin / ImagingInfinity


Hap Griffin / ImagingInfinity

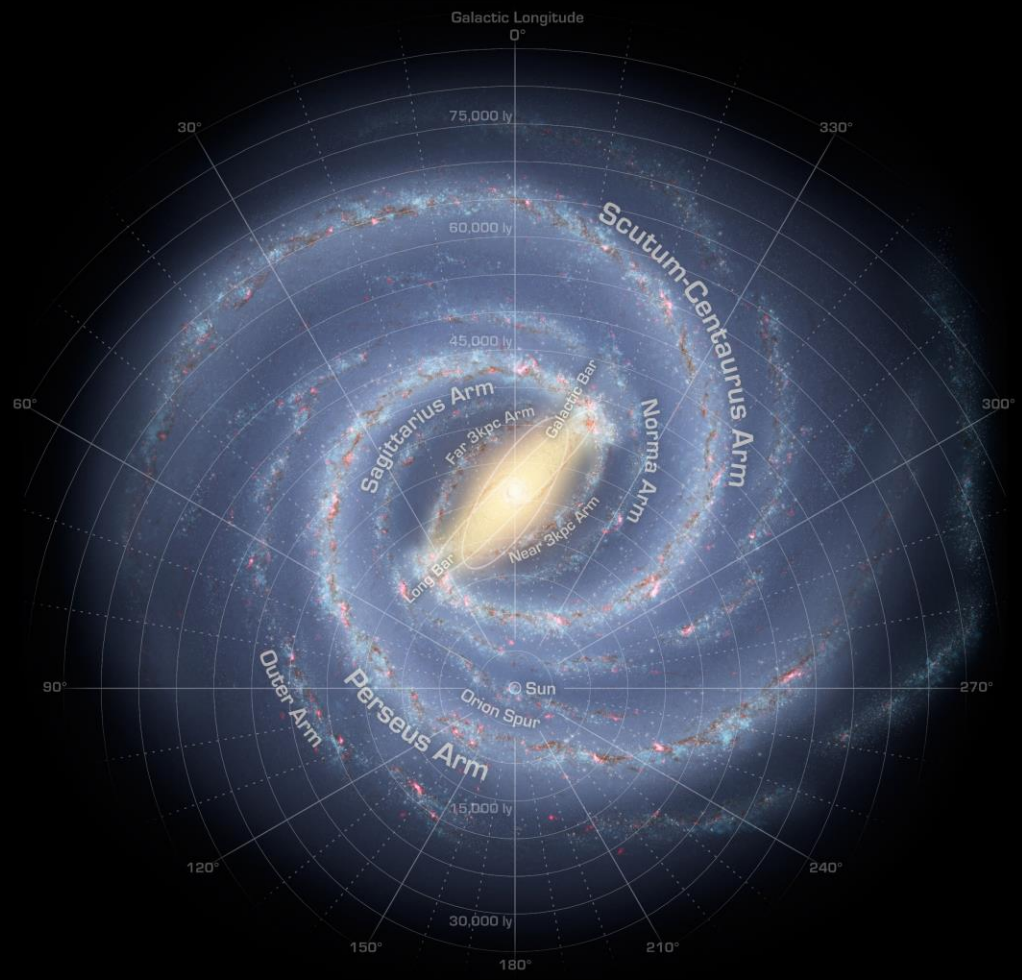

Hap Griffin / ImagingInfinity


Nikon
3


ULA

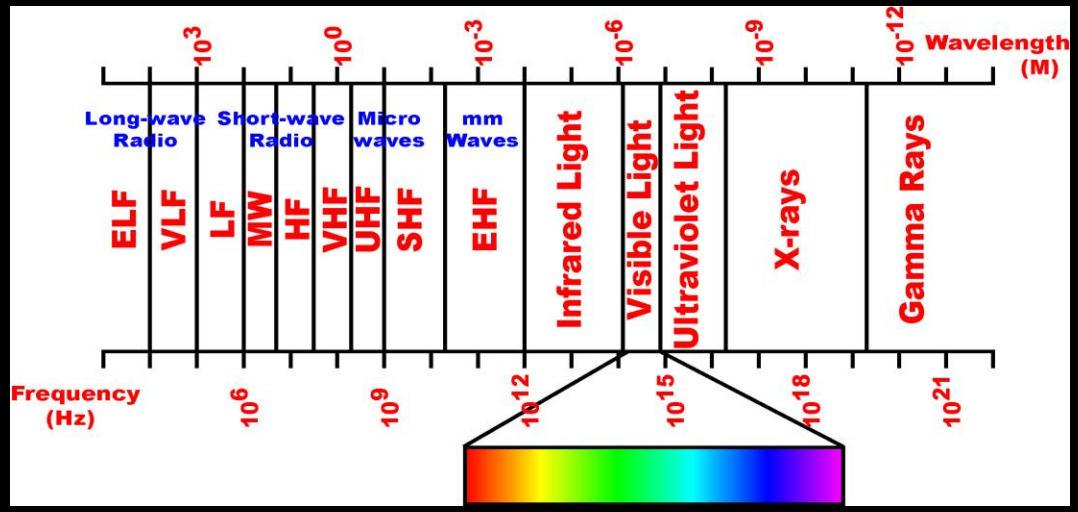

SA-2X6-016-102-12
CDR1
CDR2

?


Galactic Longitude
0°
30°
330°
60°
300°
90°
270°
120°
240°
150°
210°
180°
75,000 ly
60,000 ly
45,000 ly
30,000 ly
15,000 ly
Scutum-Centaurus Arm
Sagittarius Arm
Norma Arm
Perseus Arm
Outer Arm
Far 3kpc Arm
Near 3kpc Arm
Galactic Bar
Long Bar
Sun
Orion Spur

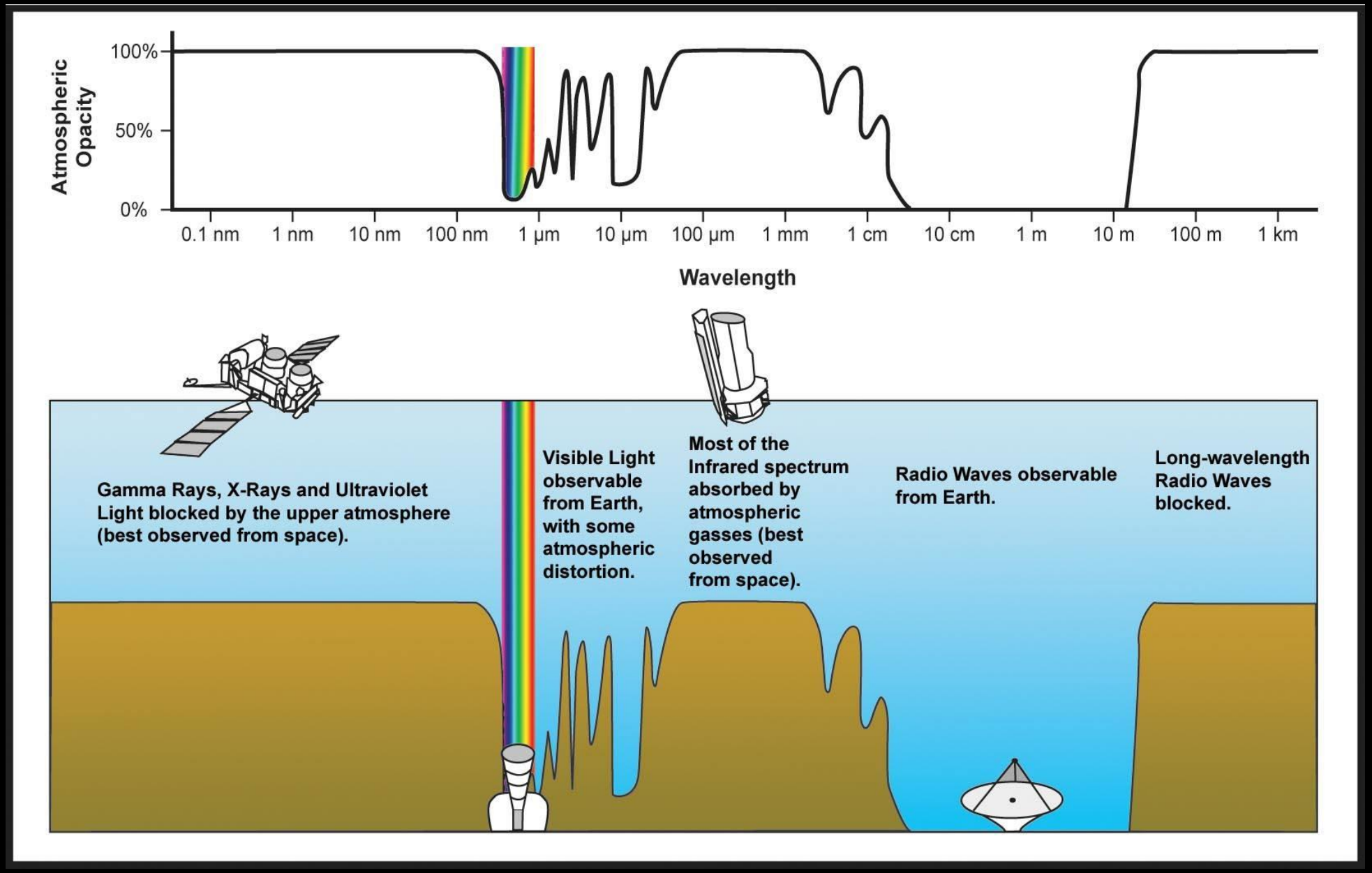
# Radio Astronomy

- Astronomical objects emit radiation across the full electromagnetic spectrum (Light, Infra-red, UV, X-Rays and Radio Waves). Using optical telescopes and cameras reveals only a small fraction of the information that is there.




- The objects may be stars, planets, or diffuse matter such as gas clouds and dust
- Electromagnetic radiation can be generated by
  - Charged particles being accelerated by magnetic fields
  - Energy transitions in atoms
  - Black Body radiation

# Atmospheric Absorption of Electromagnetic Spectrum



Limitation of Angular Resolution in Any Telescope is Proportional to Wavelength / Aperture

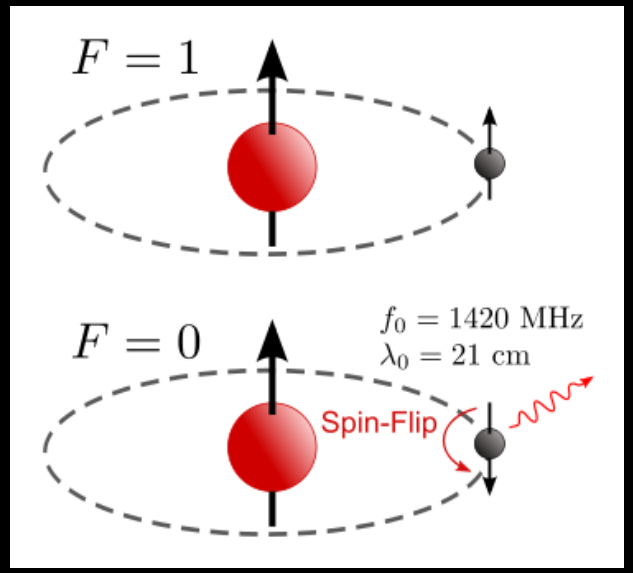
$$\Theta \propto \lambda / D$$

# Protected Frequencies for Radio Astronomy Worldwide

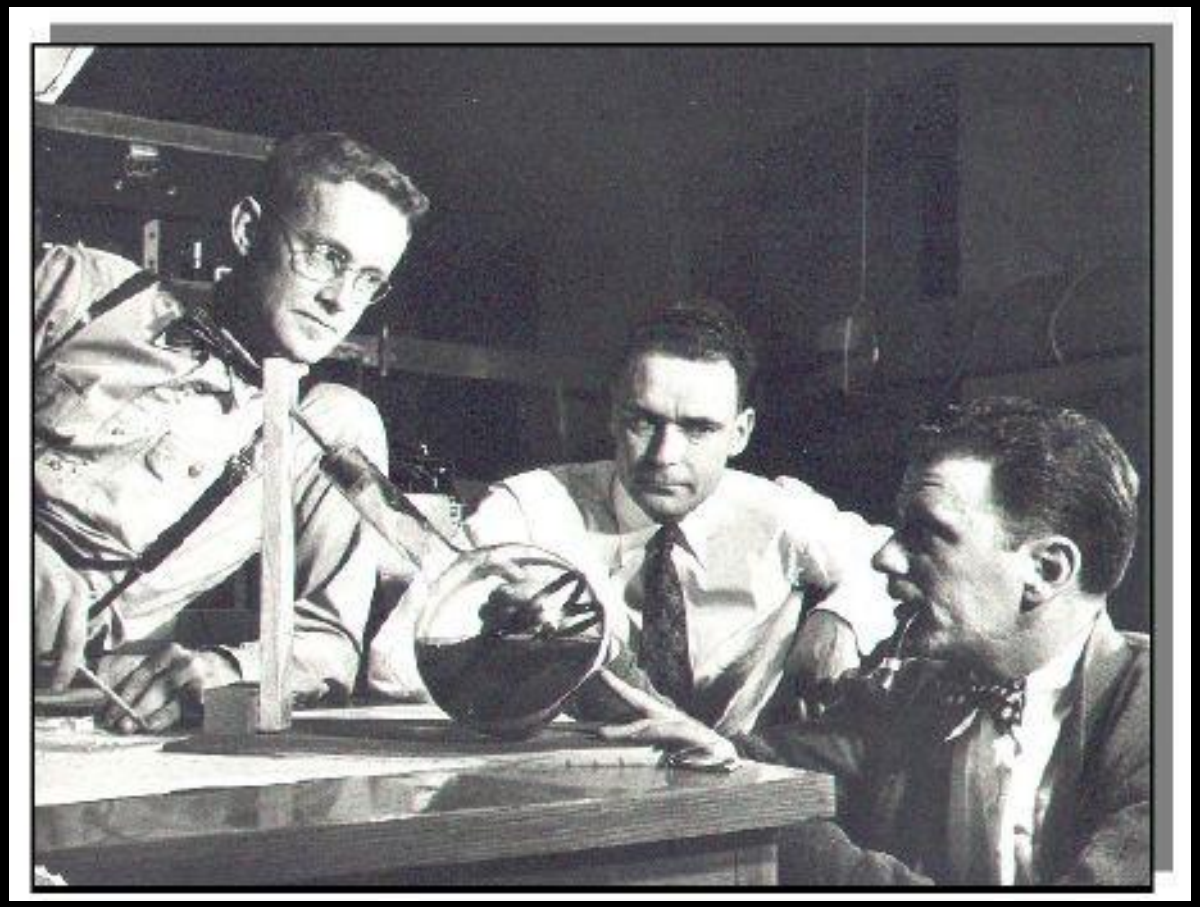
| Substance | Rest Frequency | Protected Segment |
|---|---|---|
| Deuterium (DI) | 327.3840 MHz | 327.0 - 327.7 MHz |
| Neutral Hydrogen (HI) | 1420.406 MHz | 1370.0 - 1427.0 MHz |
| Hydroxyl radical (OH) | 1612.231 MHz | 1606.8 - 1613.8 MHz |
| Hydroxyl radical (OH) | 1665.402 MHz | 1659.8 - 1667.1 MHz |
| Hydroxyl radical (OH) | 1667.359 MHz | 1661.8 - 1669.0 MHz |
| Hydroxyl radical (OH) | 1720.530 MHz | 1714.8 - 1722.2 MHz |
| Methyladyne (CH) | 3263.794 MHz | 3252.9 - 3267.1 MHz |
| Methyladyne (CH) | 3335.481 MHz | 3324.4 - 3338.8 MHz |
| Methyladyne (CH) | 3349.193 MHz | 3338.0 - 3352.5 MHz |
| Formaldehyde (H2CO) | 4829.660 MHz | 4813.6 - 4834.5 MHz |
| Methanol (CH2OH) | 6668.518 MHz | 6661.8 - 6675.2 MHz |
| Ionized Helium Isotope (3HeII) | 8665.650 MHz | 8660.0 - 8670.0 MHz |

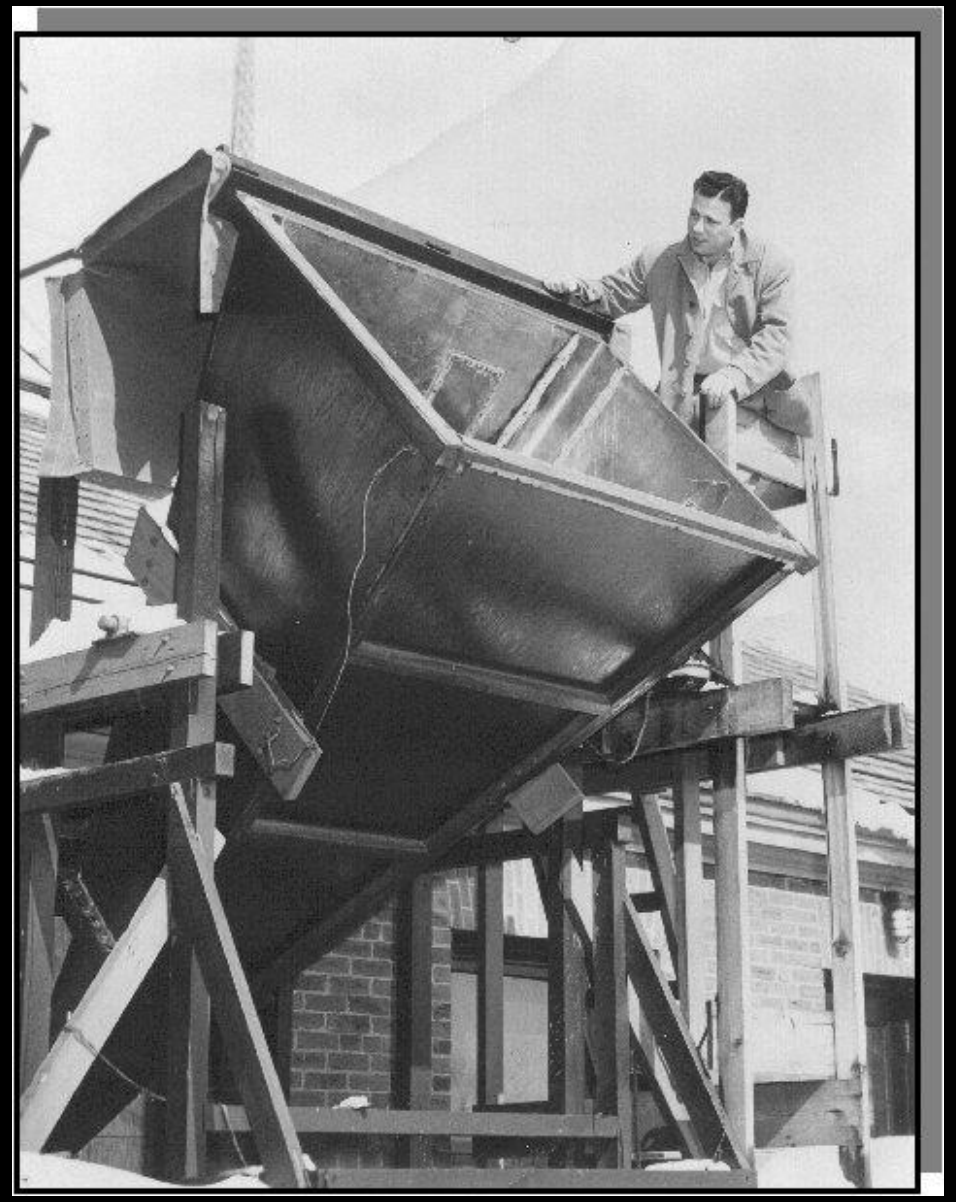
# The Hydrogen Hyperfine Energy Transition

- In any single atom of hydrogen, on average once in every 10 million years, the electron spontaneously flips its spin to be opposite of the proton.
- This state has a slightly lower total energy than the normal state and thus the atom emits a photon of energy at a wavelength of 21 centimeters, or a frequency of 1420.405750 Mhz
- In a large number of H atoms (i.e. a hydrogen cloud or galaxy arm) the emission forms a continuous radio signal

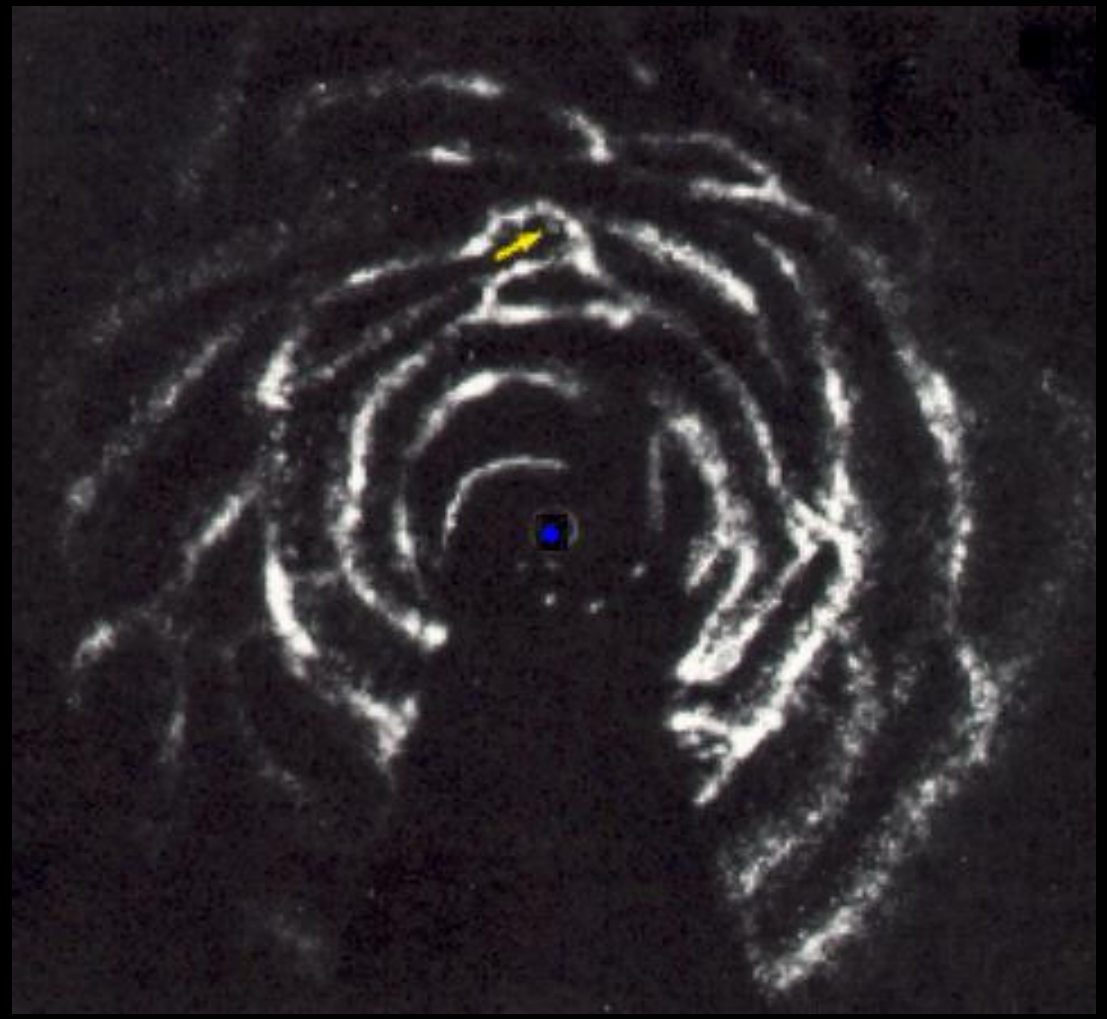


# Discovery of The Hydrogen Hyperfine Energy Transition





# Early Maps of Milky Way Galaxy Plotted from Hydrogen Data



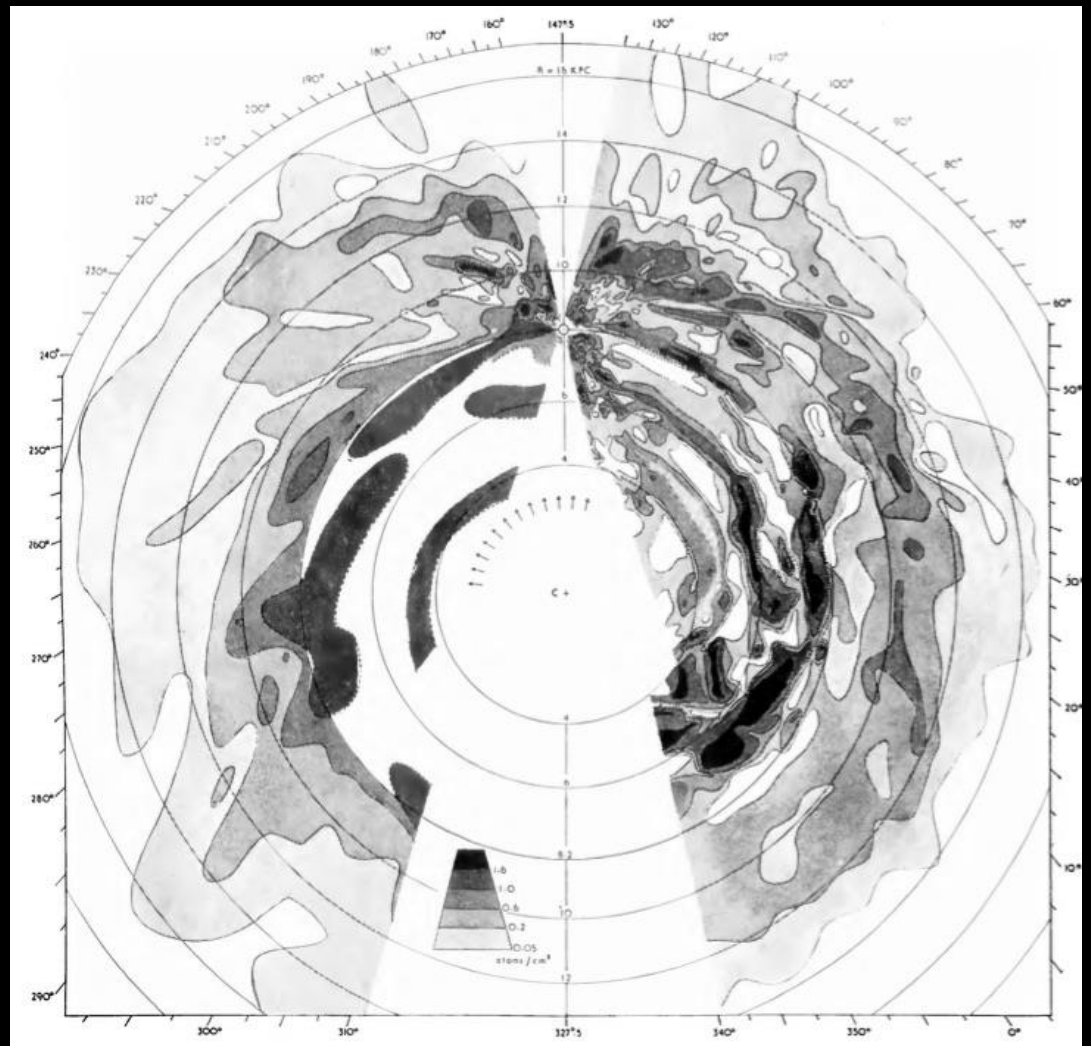
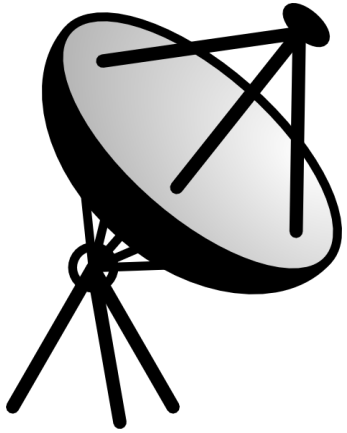


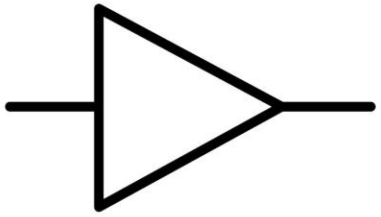
FIG. 4.—*Distribution of neutral hydrogen in the Galactic System. The maximum densities in the z-direction are projected on the galactic plane, and contours are drawn through the points.*

My original radio telescope antenna…a modified WiFi parabolic antenna approximately 1 meter in its largest dimension.  Even with a beam width of 14 degrees and low capture area, the “hydrogen line” was clearly detected along with basic Doppler frequency shifts due to relative motion within the galaxy.

# Homemade 21 cm Radiotelescope

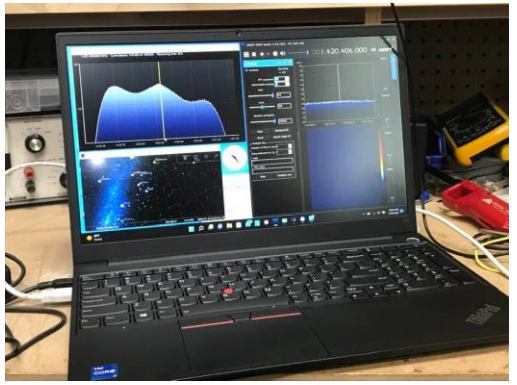


Modified WiFi Antenna



LNA (40 dB Gain) w/ 1420 MHz Bandpass Filter


Software Defined Receiver (RTL SDR)



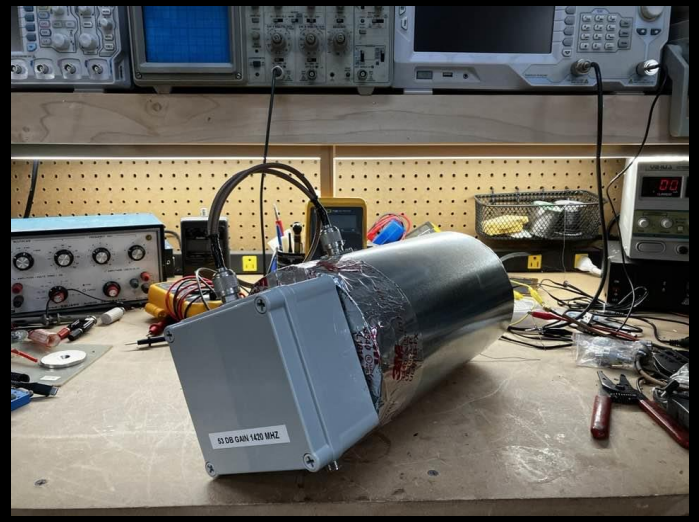
Laptop PC with SDR # Software, Stellarium

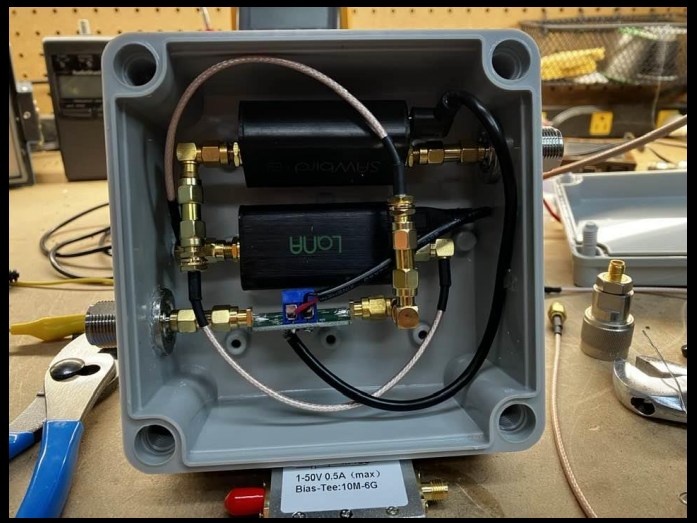
# The Challenge

- Radio Astronomy signals are WEAK!
- Unit of measure is the Jansky = $10^{-26}$W $m^{-2}$ $Hz^{-1}$ = -204 dBm $m^{-2}$ $Hz^{-1}$
- Cell phone (1 watt) from surface of Moon = 1 Jy
- (Quiet) Sun @ 1.420 GHz = 500,000 Jy
- Strongest Milky Way sources = 2000 Jy

# Typical Amateur Radiotelescope Antennas

# My Current 1.8 meter Radiotelescope Antenna

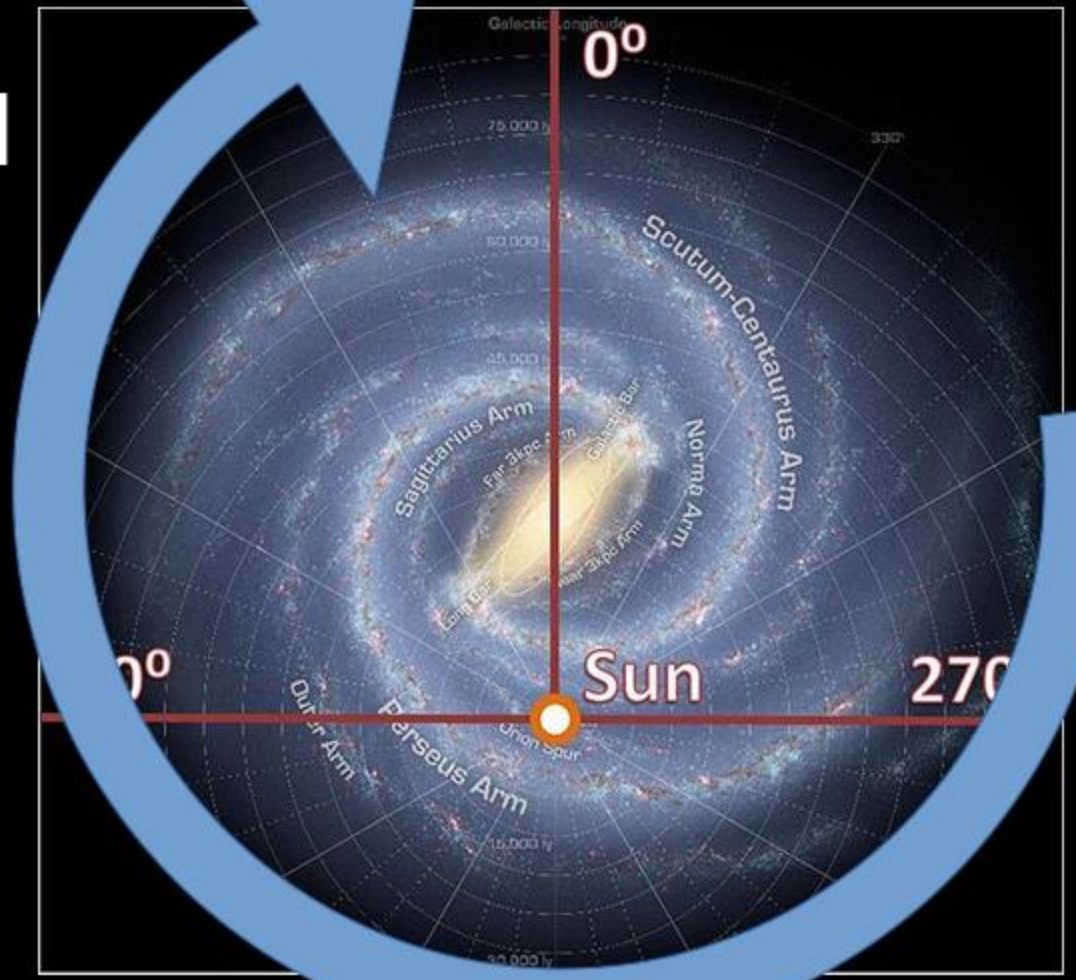

63 DB GAIN 1420 MHZ


1-50V 0.5A（max）
Bias-Tee:10M-6G

# Geography of Our Galaxy

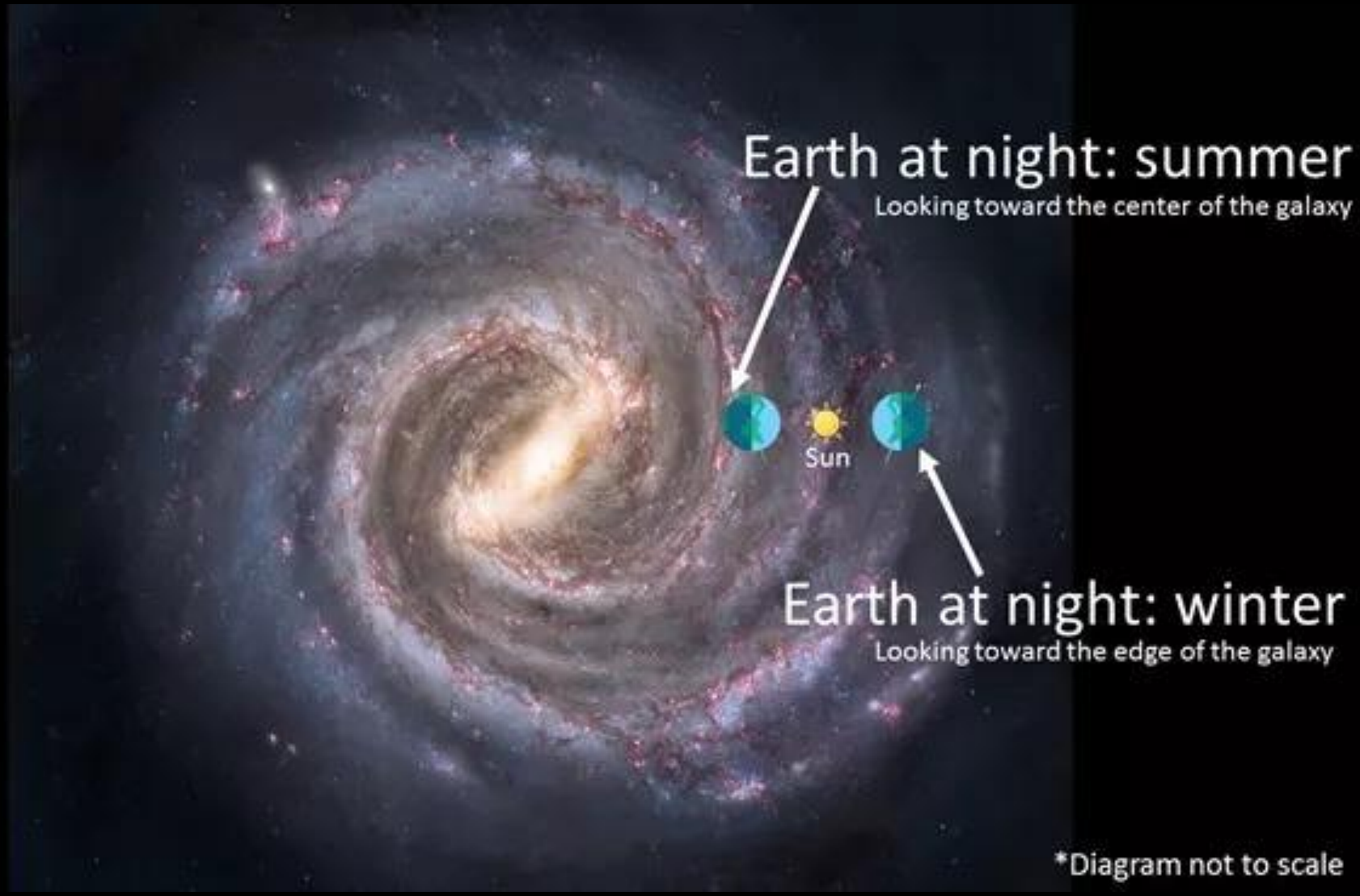
Quadrant I

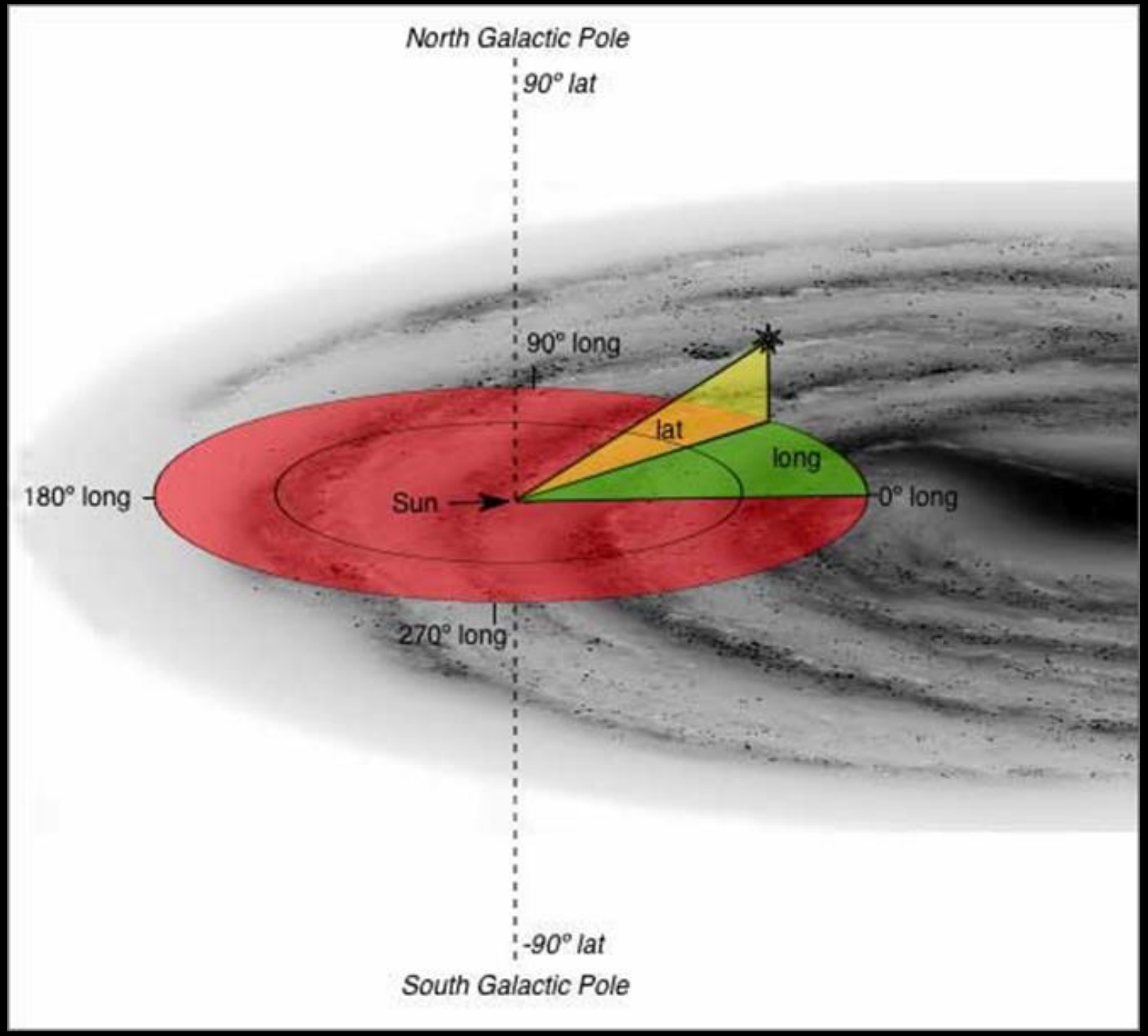
IV

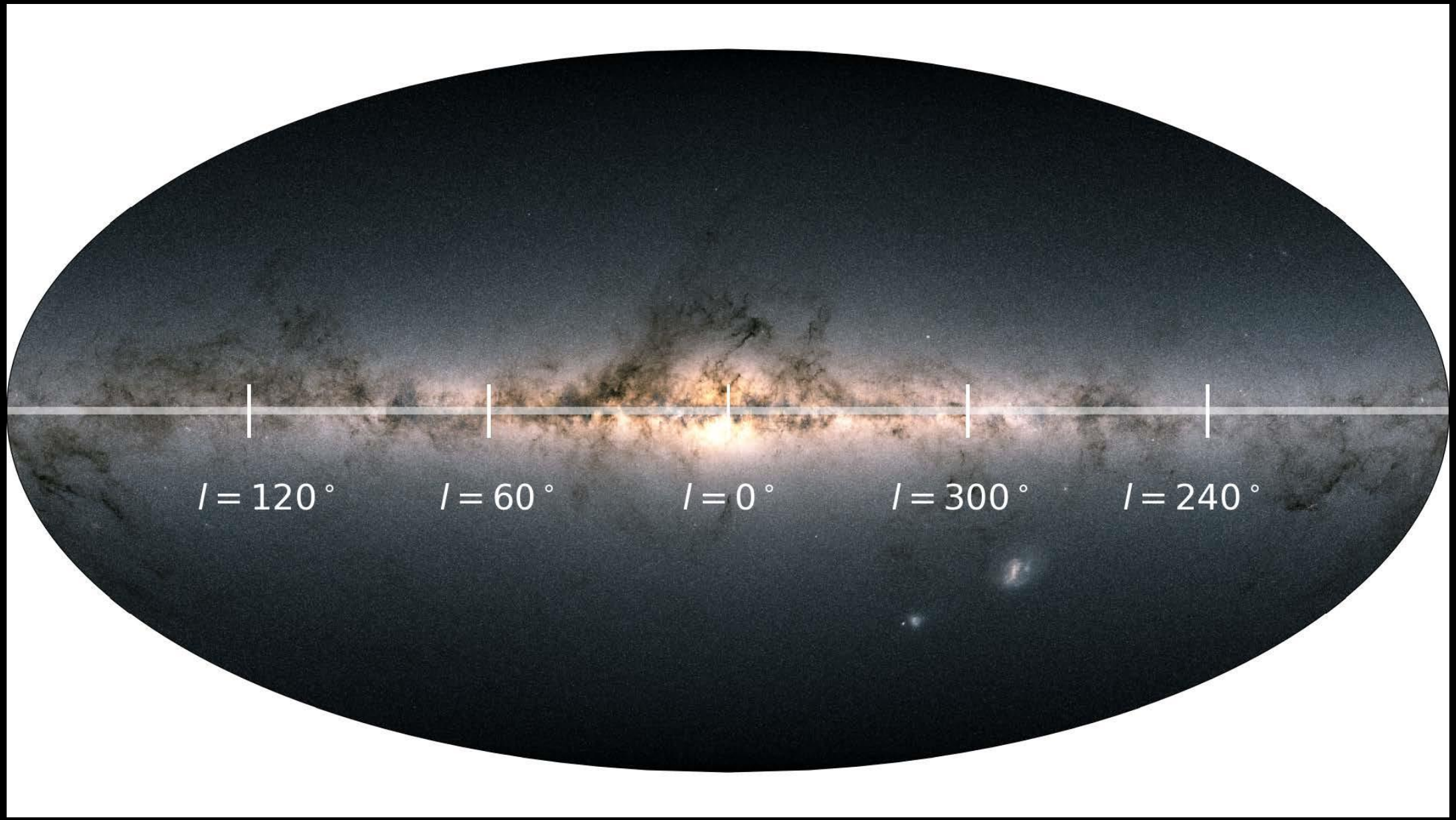


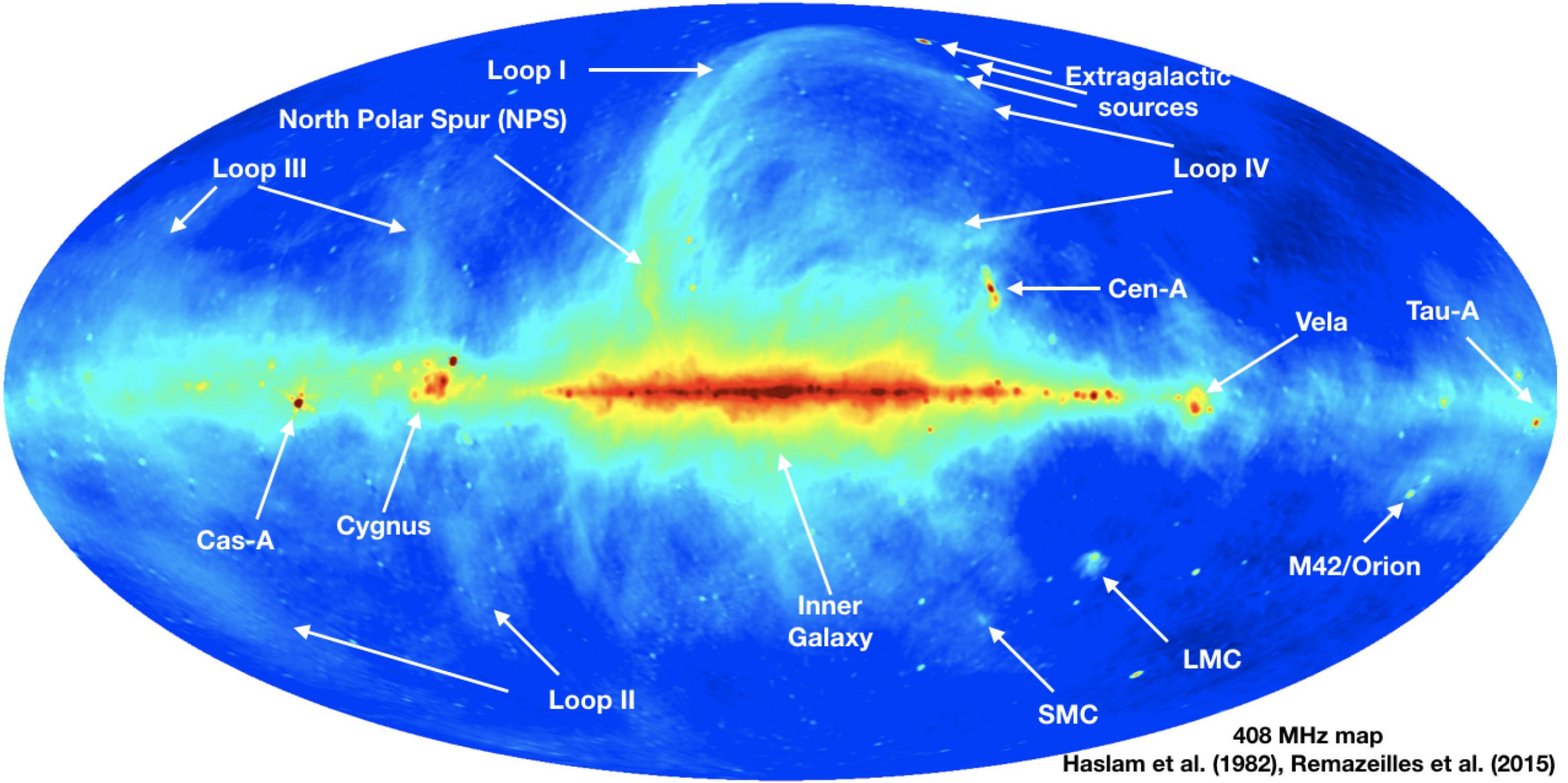

II

III


Earth at night: summer
Looking toward the center of the galaxy
Sun
Earth at night: winter
Looking toward the edge of the galaxy
*Diagram not to scale

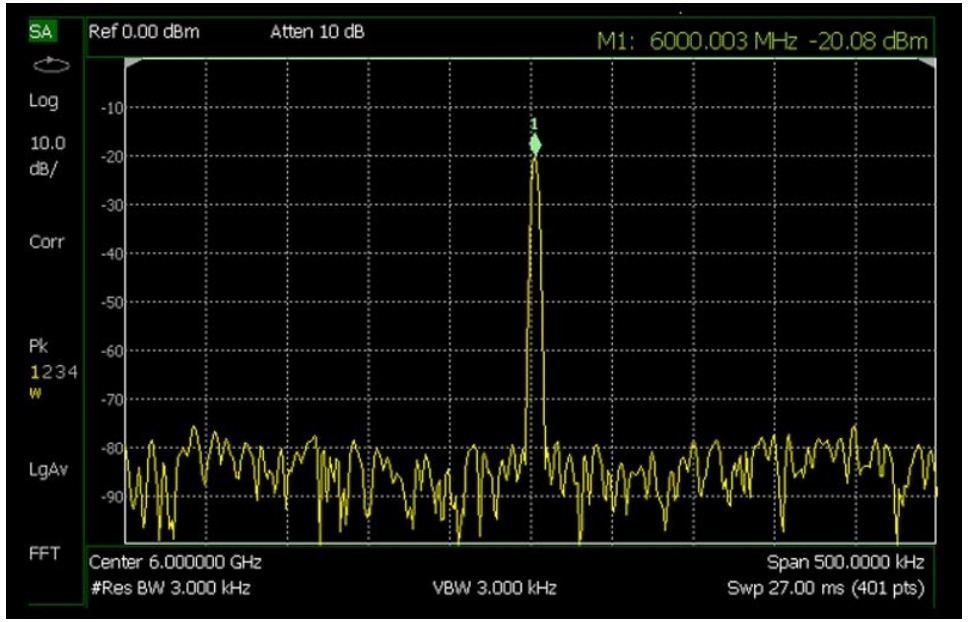

North Galactic Pole
90° lat
90° long
lat
long
180° long
Sun
0° long
270° long
-90° lat
South Galactic Pole


$l = 120^\circ$
$l = 60^\circ$
$l = 0^\circ$
$l = 300^\circ$
$l = 240^\circ$




408 MHz map
Haslam et al. (1982), Remazeilles et al. (2015)

# Pure Signal from Hydrogen with No Relative Motion

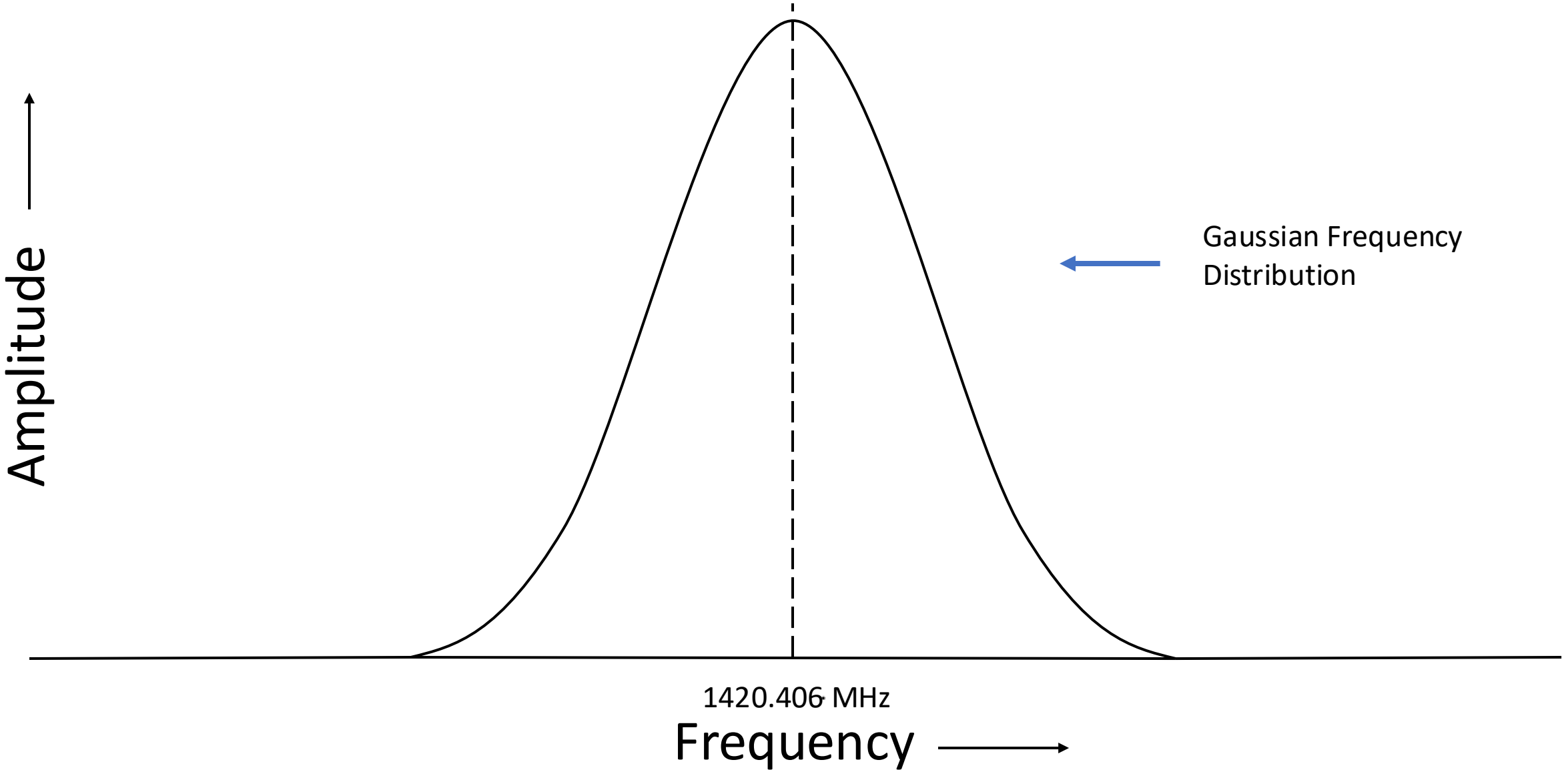



Amplitude →

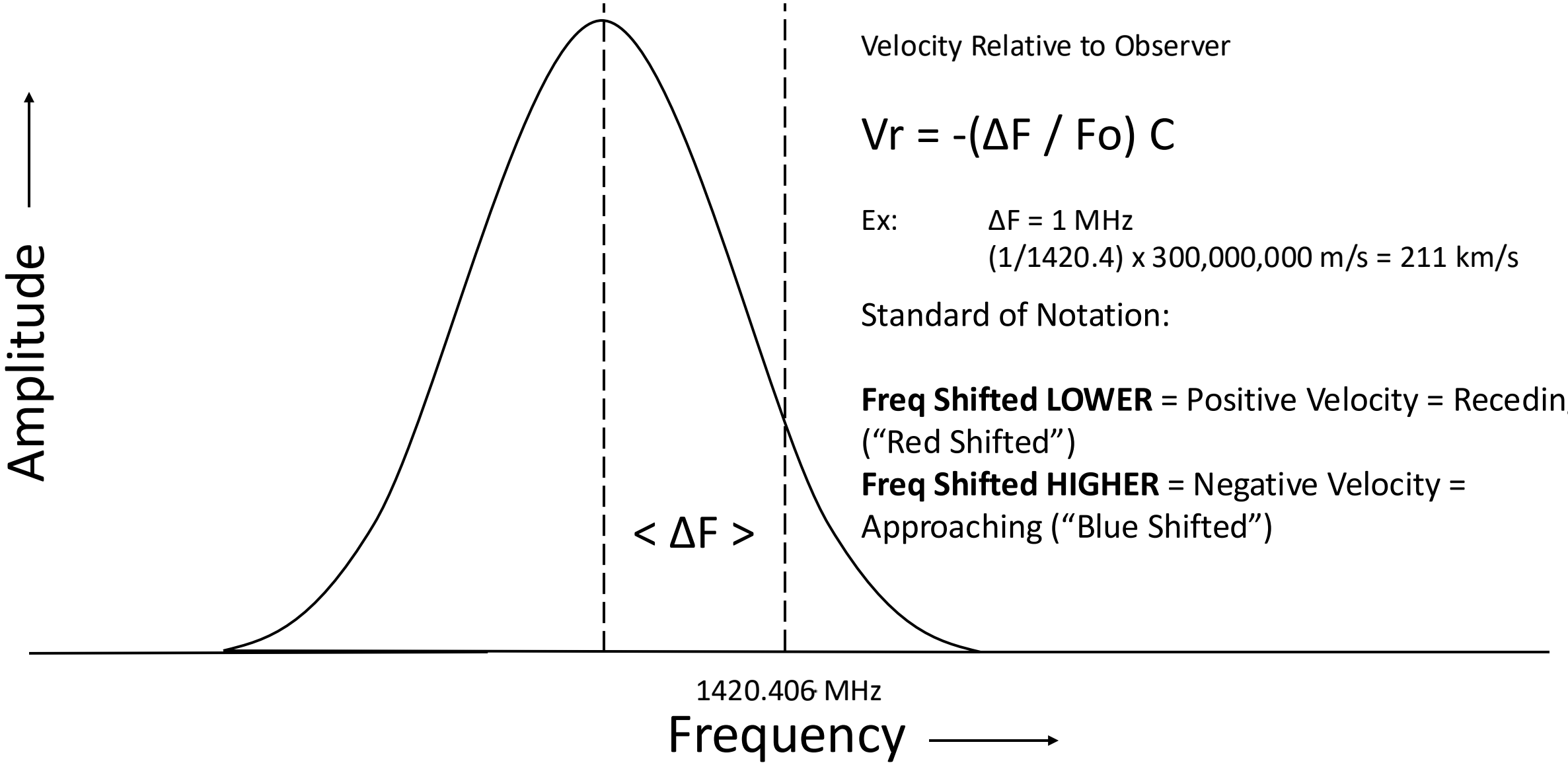
1420.406 MHz

Frequency →

# Doppler Shift From Random Movements Within Cloud Causes Spectrum Spreading



# Signal Doppler Shifted in Frequency Due to Relative Velocity




Velocity Relative to Observer

$$Vr = -(\Delta F / Fo)\, C$$

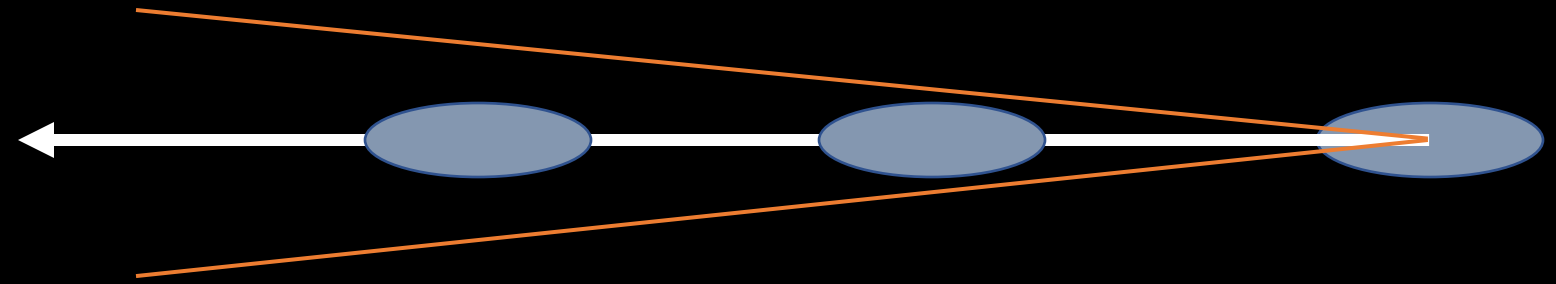
Ex: ΔF = 1 MHz
(1/1420.4) x 300,000,000 m/s = 211 km/s

Standard of Notation:

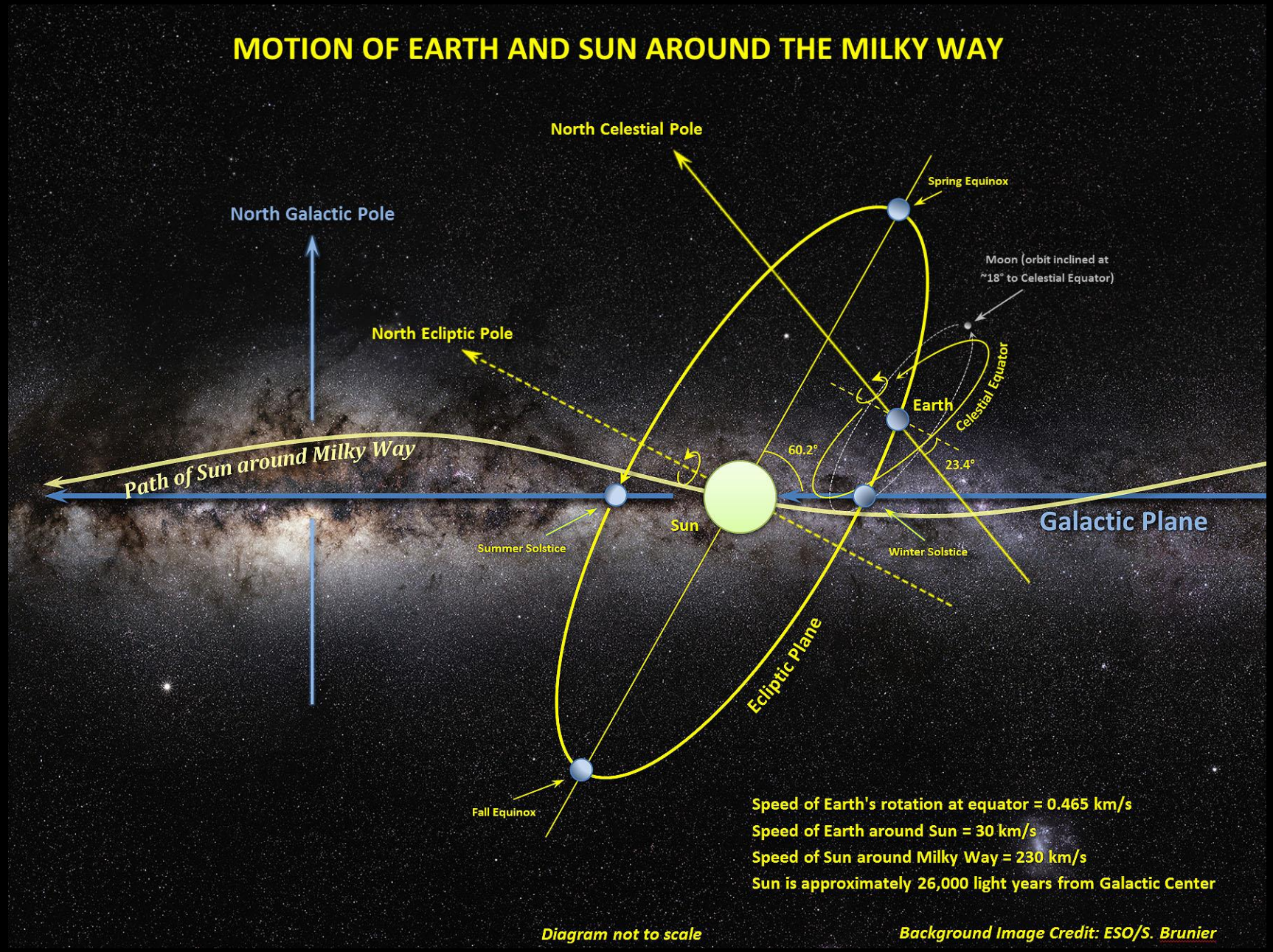
**Freq Shifted LOWER** = Positive Velocity = Receding ("Red Shifted")
**Freq Shifted HIGHER** = Negative Velocity = Approaching ("Blue Shifted")

# Looking Through Plane of the Galaxy (along equator)

Direction of Antenna along Galactic Equator



Each H cloud that we look through is a separate entity, each with its own Doppler Shift, each appearing as a hump in the spectrum graph at a different observed frequency. H clouds generally exist in galactic arms.




When measuring the velocity of a distant object, we need a Local Standard of Rest (LSR) as the reference. This has been defined as the volume encompassing a group of stars in the vicinity of the Sun.

But we are moving in several different directions, changing constantly, within the LSR.

# Correction for Velocity relative to Local Standard of Rest (VLSR)

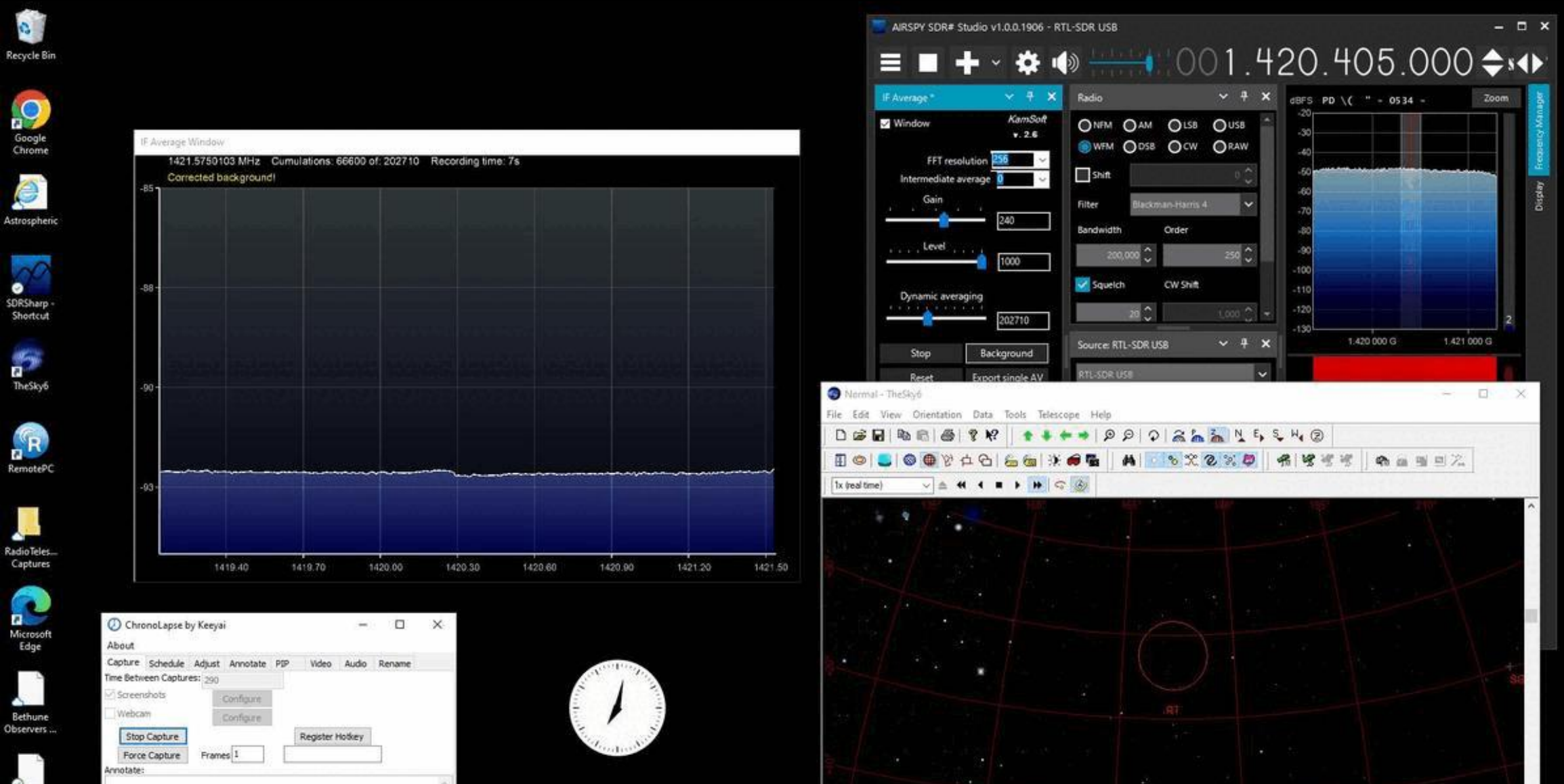
- The Local Standard of Rest is defined by a volume encompassing a group of the nearest stars.
- When measuring the velocity of an object within our galaxy, we must correct for our own motion within the LSR
- The correction equation for this takes into consideration the observatory's velocity due to Earth rotation, the Earth's orbit around the Sun, and the Sun's motion within the LSR
- The amount of correction is calculated to be the observatory's motion vector in the direction of observation

- The concept of a Local Standard of Rest is similar to riding on a roller coaster in an amusement park and trying to measure the velocity of a distant train. We want to measure the train's velocity relative to the amusement park (the local standard of rest)…NOT our roller coaster car, so we have to correct for the roller coaster car's instantaneous velocity vector in the direction of the train, which is constantly changing.

- There are calculators on the web for VLSR (THANKFULLY!)

- Currently, the Sun is moving within the LSR:
  - A bit towards the galactic center
  - Around the galaxy a bit faster than the LSR
  - Northward out of the galactic plane (currently near the mid-plane)

# Antenna at 27 deg Elevation Due South – 1/30/2023 – 22 hours



# Things to Notice

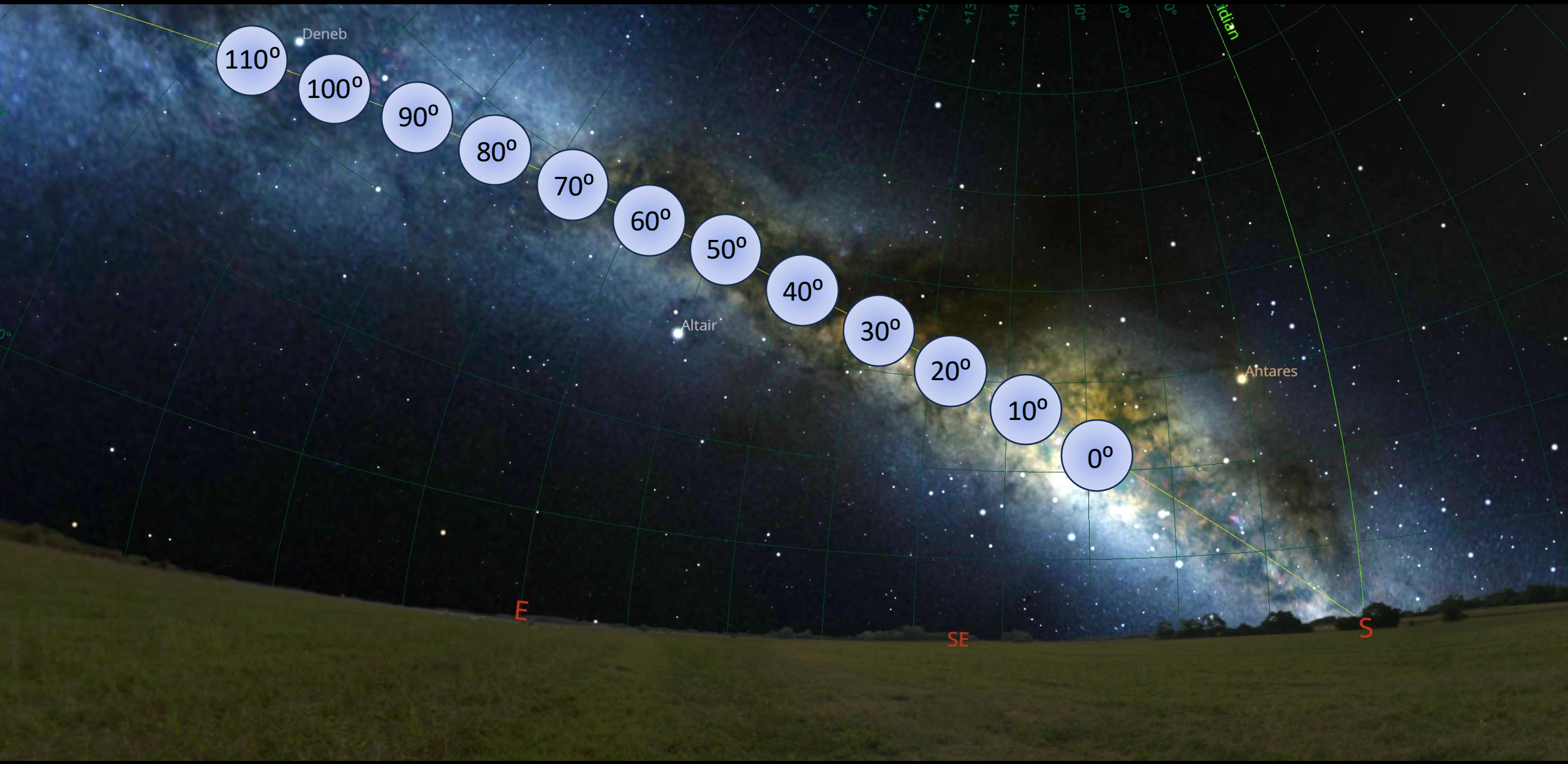
- When the MW comes into the antenna's beam, we see the hydrogen signal at 1420.406 MHz rise up about 1 dB above the noise.
- If everything were at rest and not moving, the signal would be a single, narrow frequency spike on the spectrum graph.
- The fact that the signal appears as a hump means that it is being spread in frequency by Doppler shift – components of the hydrogen cloud are moving both towards and away from us.
- The fact that there are multiple humps separated in frequency means that we are seeing multiple hydrogen clouds (arms) each with a different relative radial velocity.

# Preliminary Conclusions

- From this single, simple near 24 hour observation, we can deduce:

  - We are surrounded by hydrogen in distinct areas (clouds)
  - These clouds have different relative radial velocities to us
  - Within each cloud, the hydrogen is randomly distributed with motions both towards and away from us (Gaussian frequency distribution)
  - We see two completely different spectrum patterns approximately 12 hours apart, so our large scale environment is different in different directions
  - As the antenna is moved in galactic longitude, we see different spectrum patterns (i.e. non-uniform structure)

# My Procedure

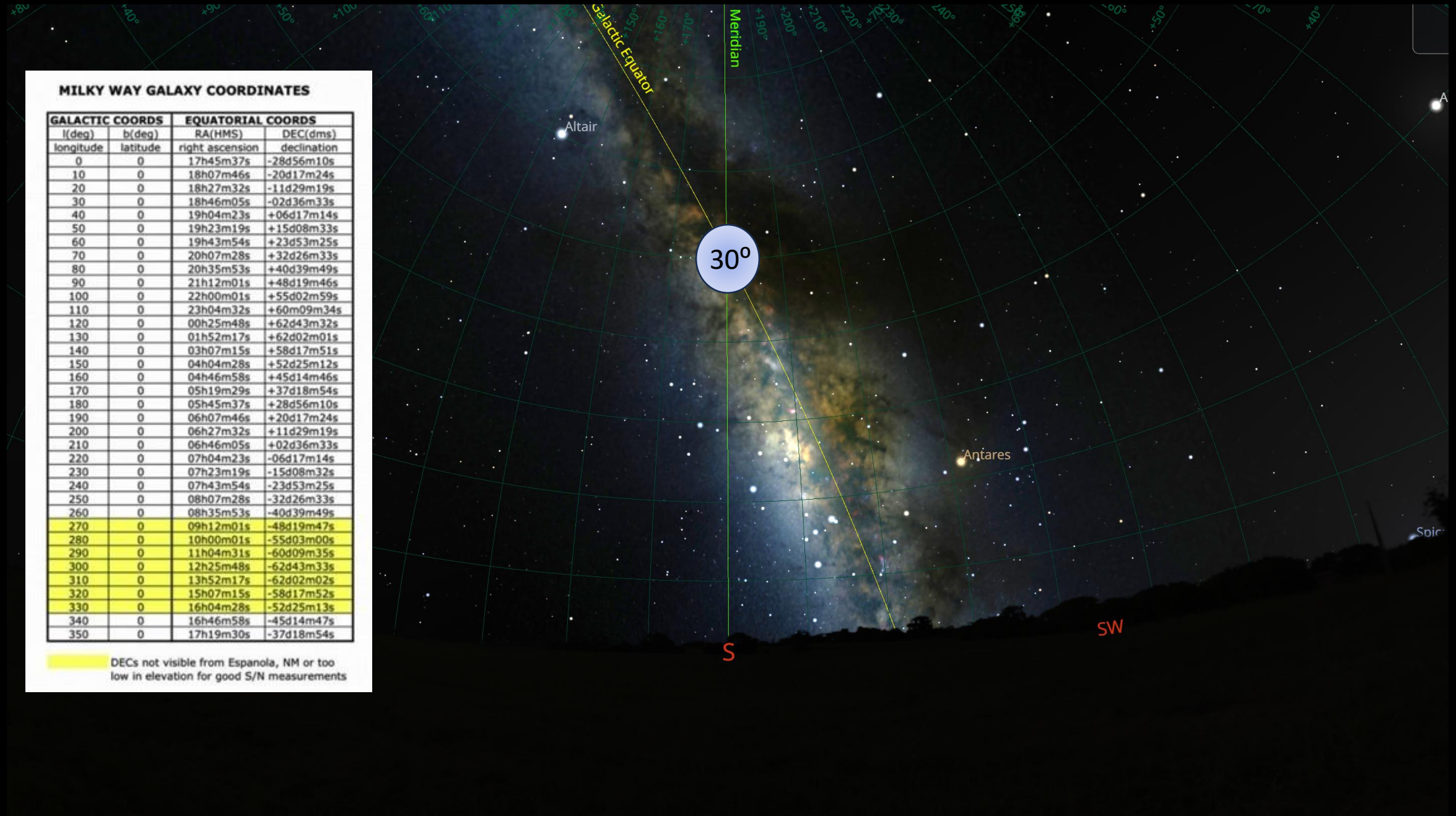


# My Procedure

**MILKY WAY GALAXY COORDINATES**

| GALACTIC COORDS | | EQUATORIAL COORDS | |
|---|---|---|---|
| l(deg) | b(deg) | RA(HMS) | DEC(dms) |
| longitude | latitude | right ascension | declination |
| 0 | 0 | 17h45m37s | -28d56m10s |
| 10 | 0 | 18h07m46s | -20d17m24s |
| 20 | 0 | 18h27m32s | -11d29m19s |
| 30 | 0 | 18h46m05s | -02d36m33s |
| 40 | 0 | 19h04m23s | +06d17m14s |
| 50 | 0 | 19h23m19s | +15d08m33s |
| 60 | 0 | 19h43m54s | +23d53m25s |
| 70 | 0 | 20h07m28s | +32d26m33s |
| 80 | 0 | 20h35m53s | +40d39m49s |
| 90 | 0 | 21h12m01s | +48d19m46s |
| 100 | 0 | 22h00m01s | +55d02m59s |
| 110 | 0 | 23h04m32s | +60m09m34s |
| 120 | 0 | 00h25m48s | +62d43m32s |
| 130 | 0 | 01h52m17s | +62d02m01s |
| 140 | 0 | 03h07m15s | +58d17m51s |
| 150 | 0 | 04h04m28s | +52d25m12s |
| 160 | 0 | 04h46m58s | +45d14m46s |
| 170 | 0 | 05h19m29s | +37d18m54s |
| 180 | 0 | 05h45m37s | +28d56m10s |
| 190 | 0 | 06h07m46s | +20d17m24s |
| 200 | 0 | 06h27m32s | +11d29m19s |
| 210 | 0 | 06h46m05s | +02d36m33s |
| 220 | 0 | 07h04m23s | -06d17m14s |
| 230 | 0 | 07h23m19s | -15d08m32s |
| 240 | 0 | 07h43m54s | -23d53m25s |
| 250 | 0 | 08h07m28s | -32d26m33s |
| 260 | 0 | 08h35m53s | -40d39m49s |
| 270 | 0 | 09h12m01s | -48d19m47s |
| 280 | 0 | 10h00m01s | -55d03m00s |
| 290 | 0 | 11h04m31s | -60d09m35s |
| 300 | 0 | 12h25m48s | -62d43m33s |
| 310 | 0 | 13h52m17s | -62d02m02s |
| 320 | 0 | 15h07m15s | -58d17m52s |
| 330 | 0 | 16h04m28s | -52d25m13s |
| 340 | 0 | 16h46m58s | -45d14m47s |
| 350 | 0 | 17h19m30s | -37d18m54s |

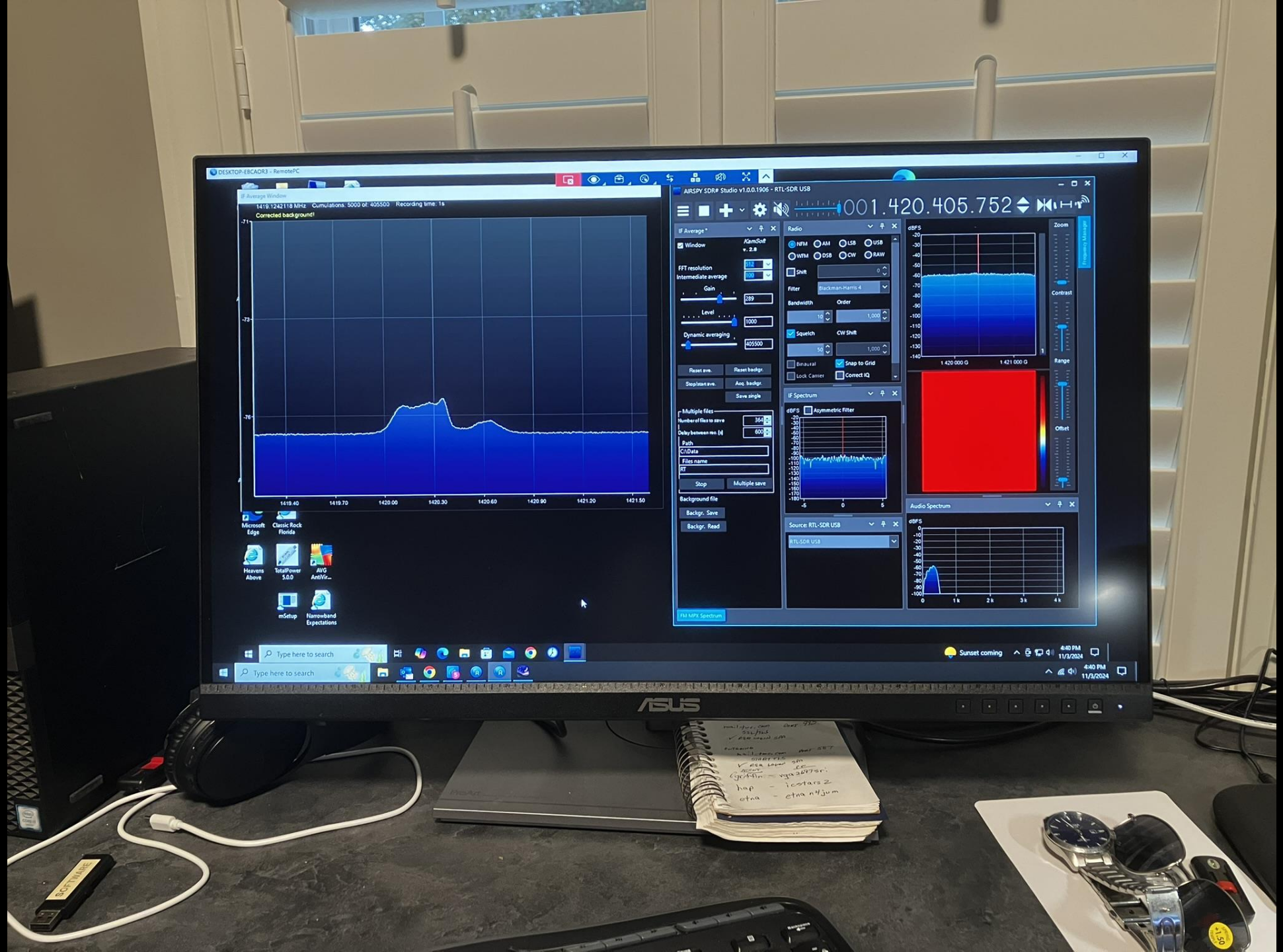
DECs not visible from Espanola, NM or too low in elevation for good S/N measurements



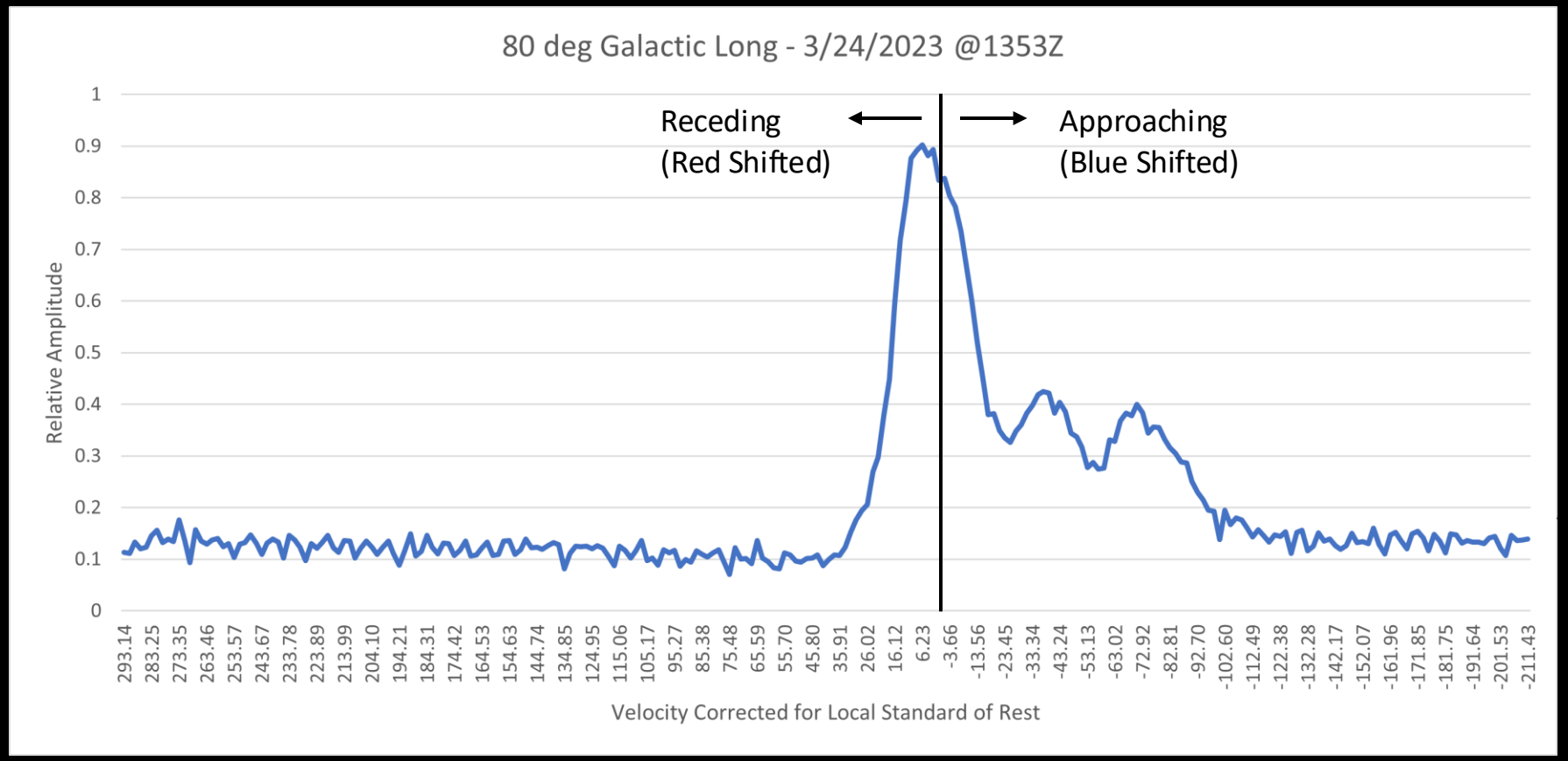
# My Procedure

- With the antenna aiming at southern (or northern) meridian, find time and elevation of galactic equator meridian crossing of chosen longitude with planetarium software (TheSky, Stellarium, etc)
- Capture the spectra at exactly the time of galactic equator crossing meridian
- Calculate observatory VSLR using online calculator at time of spectra capture
- Plug data into spreadsheet for record keeping and to generate spectrum graph corrected for VLSR
- Each antenna position will generate two galactic longitudes, approximately 12 hours apart

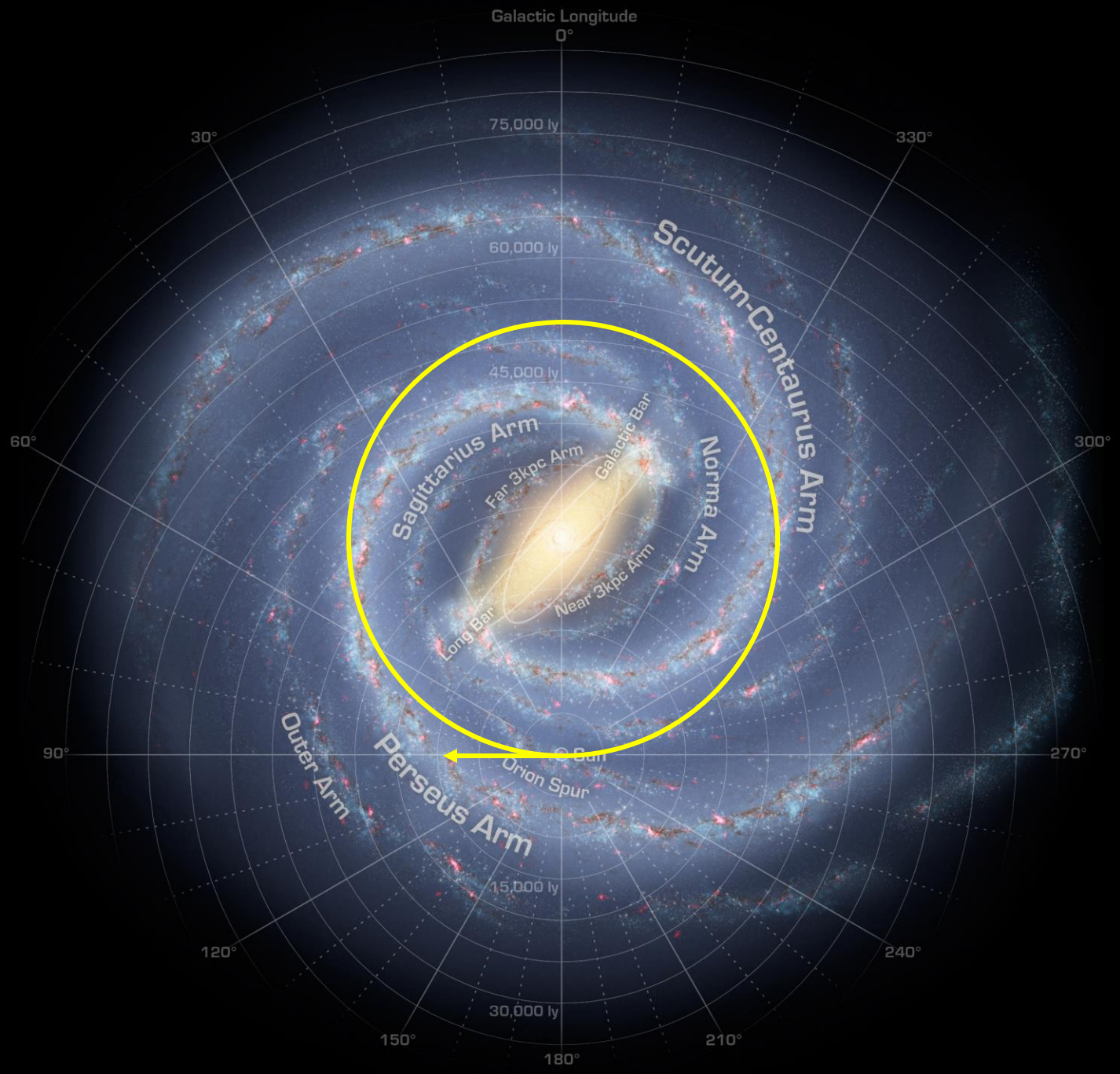

MeTV
RTMC
CLYDE TOMBAUGH AWARD
HAP GRIFFIN
DELL
DELL


DESKTOP-EBCAOR3 - RemotePC
IF Average Window
1419.1242118 MHz Cumulations: 5000 of: 405500 Recording time: 1s
Corrected background!
AIRSPY SDR# Studio v1.0.0.1906 - RTL-SDR USB
001.420.405.752
IF Average *
Window
KamSoft
v. 2.8
FFT resolution
Intermediate average
Gain
Level
Dynamic averaging
Reset ave.
Reset backgr.
Stop/start ave.
Acq. backgr.
Save single
Multiple files
Number of files to save
Delay between rec. [s]
Path
C:\Data
Files name
RT
Stop
Multiple save
Background file
Backgr. Save
Backgr. Read
Radio
NFM
AM
LSB
USB
WFM
DSB
CW
RAW
Shift
Filter
Blackman-Harris 4
Bandwidth
Order
Squelch
CW Shift
Binaural
Snap to Grid
Lock Carrier
Correct IQ
IF Spectrum
Asymmetric Filter
Source: RTL-SDR USB
RTL-SDR USB
Audio Spectrum
FM MPX Spectrum
Zoom
Contrast
Range
Offset
Microsoft Edge
Classic Rock Florida
Heavens Above
TotalPower 5.0.0
AVG AntiVir...
mSetup
Narrowband Expectations
Type here to search
Sunset coming
4:40 PM
11/3/2024
ASUS

# A Typical Spectrum Capture – From 80 deg Galactic Longitude




Frequency has been converted to relative velocity and corrected for VLSR (X axis)
Relative amplitude is along vertical Y axis
Rest frequency of hydrogen (1420.406 MHz) is shown as a vertical line at 0 velocity
Hydrogen cloud emissions show as humps each with a different relative velocity

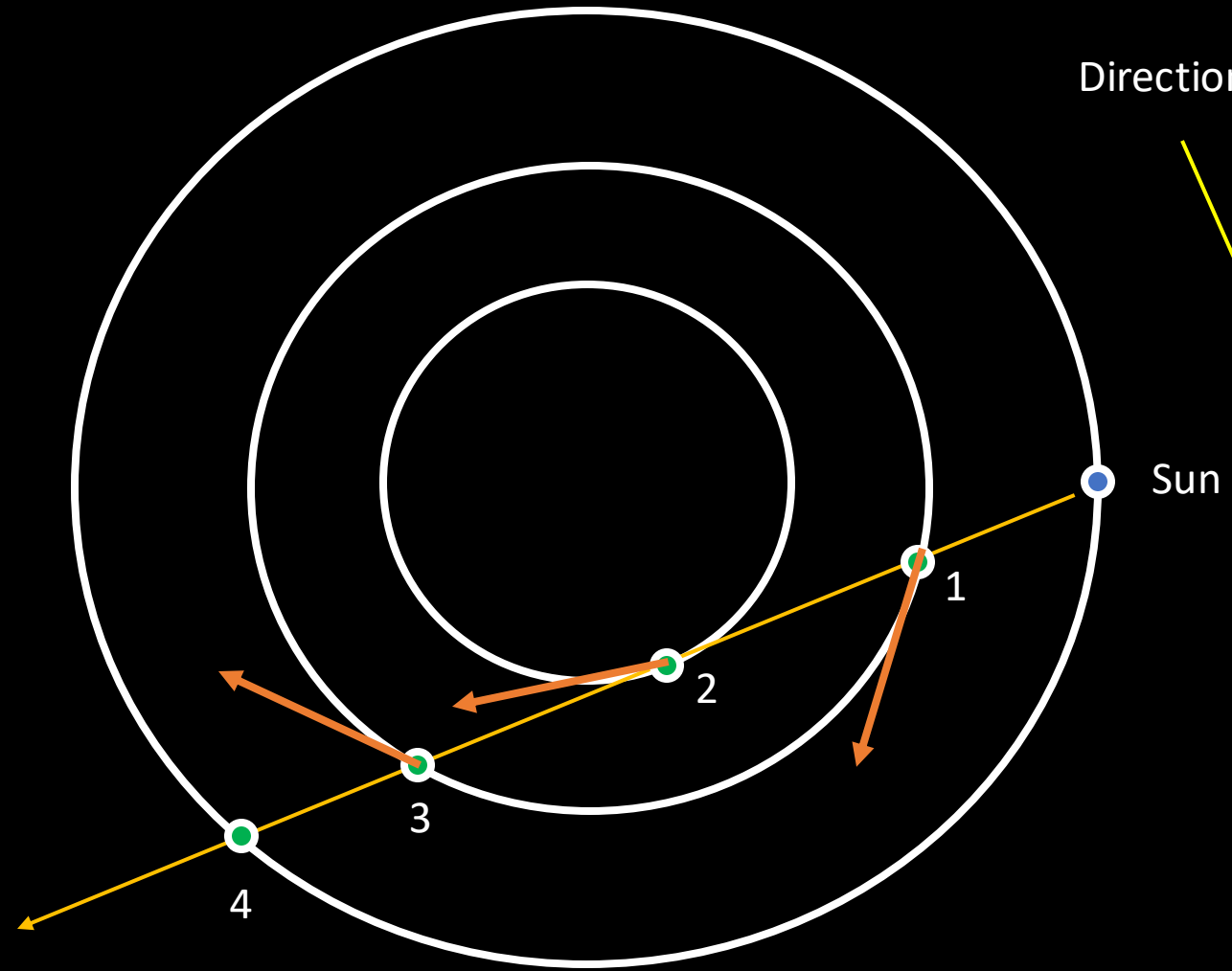



Our Sun and solar system orbits the galaxy at a speed of 828,000 km/hr, taking 230 million years to orbit once.

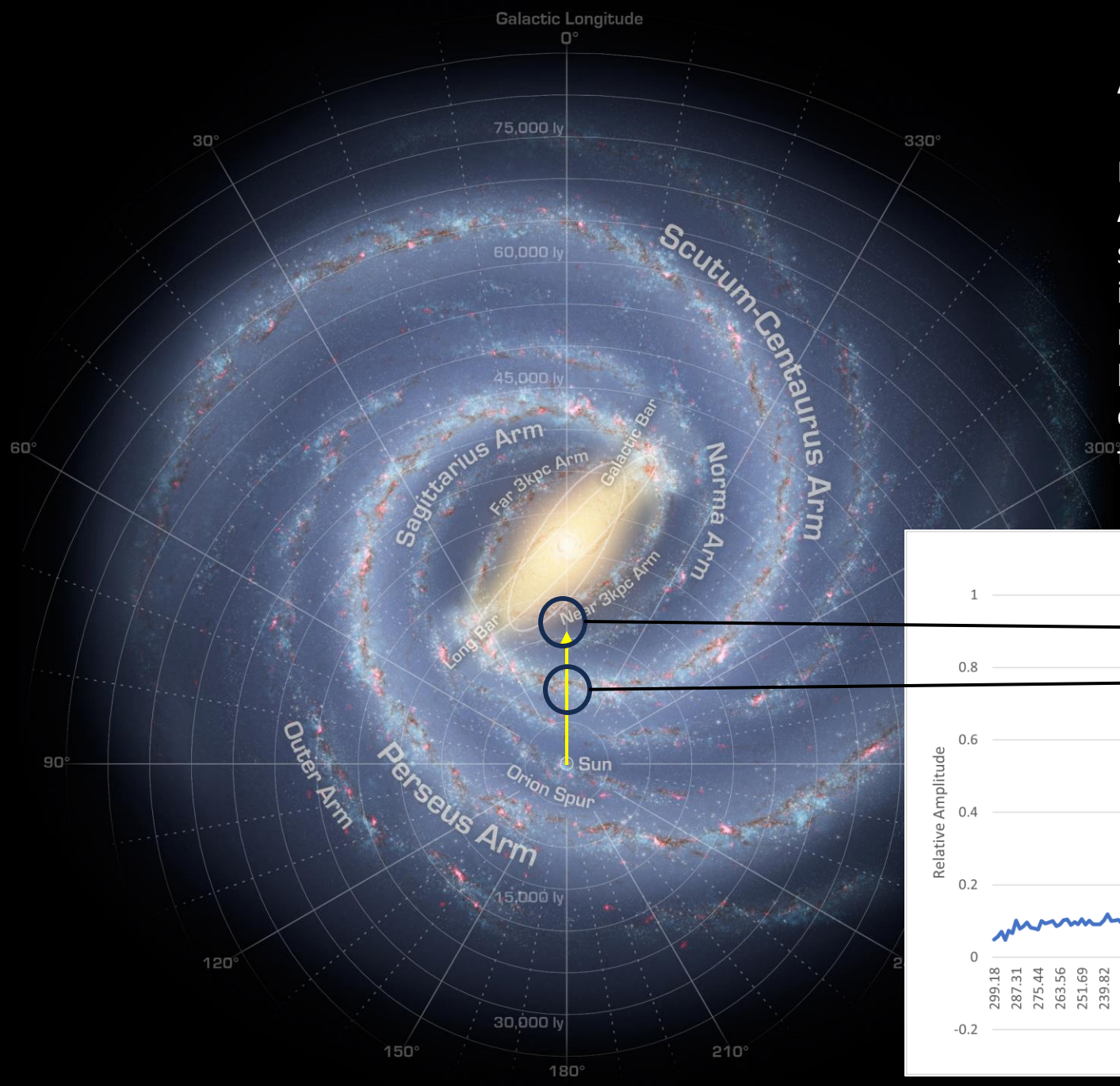
Galactic rotation basically follows Kepler's Law of Planetary Motion (*), therefore hydrogen clouds that orbit the galactic core in orbits internal to our orbit have higher orbital velocities. Those in orbits external to that of our Sun have slower orbital velocities.

Therefore: If an H cloud has a positive (red shifted) velocity, it has to lie inside of our orbit. If an H cloud has a negative (blue shifted) velocity, it has to lie outside of our orbit.

# Identification of H Clouds in Spiral Arms by Doppler Shift

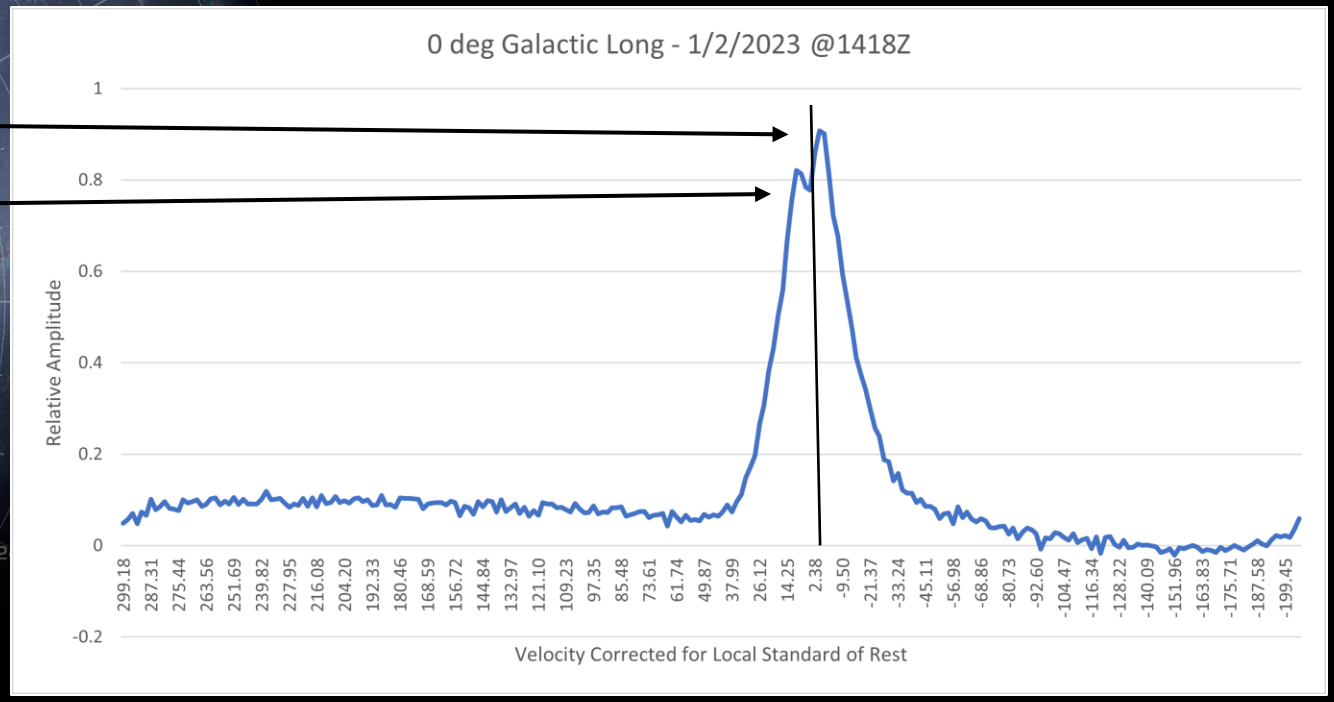



- Hydrogen clouds 1 and 3 have a net velocity AWAY from us and have a moderate positive (RED) shift
- Hydrogen cloud 2 has a faster net velocity AWAY from us and has a higher RED shift
- Hydrogen cloud 4 is in the same orbit as we are and thus is neither moving towards or away from us – very little RED or BLUE shift.



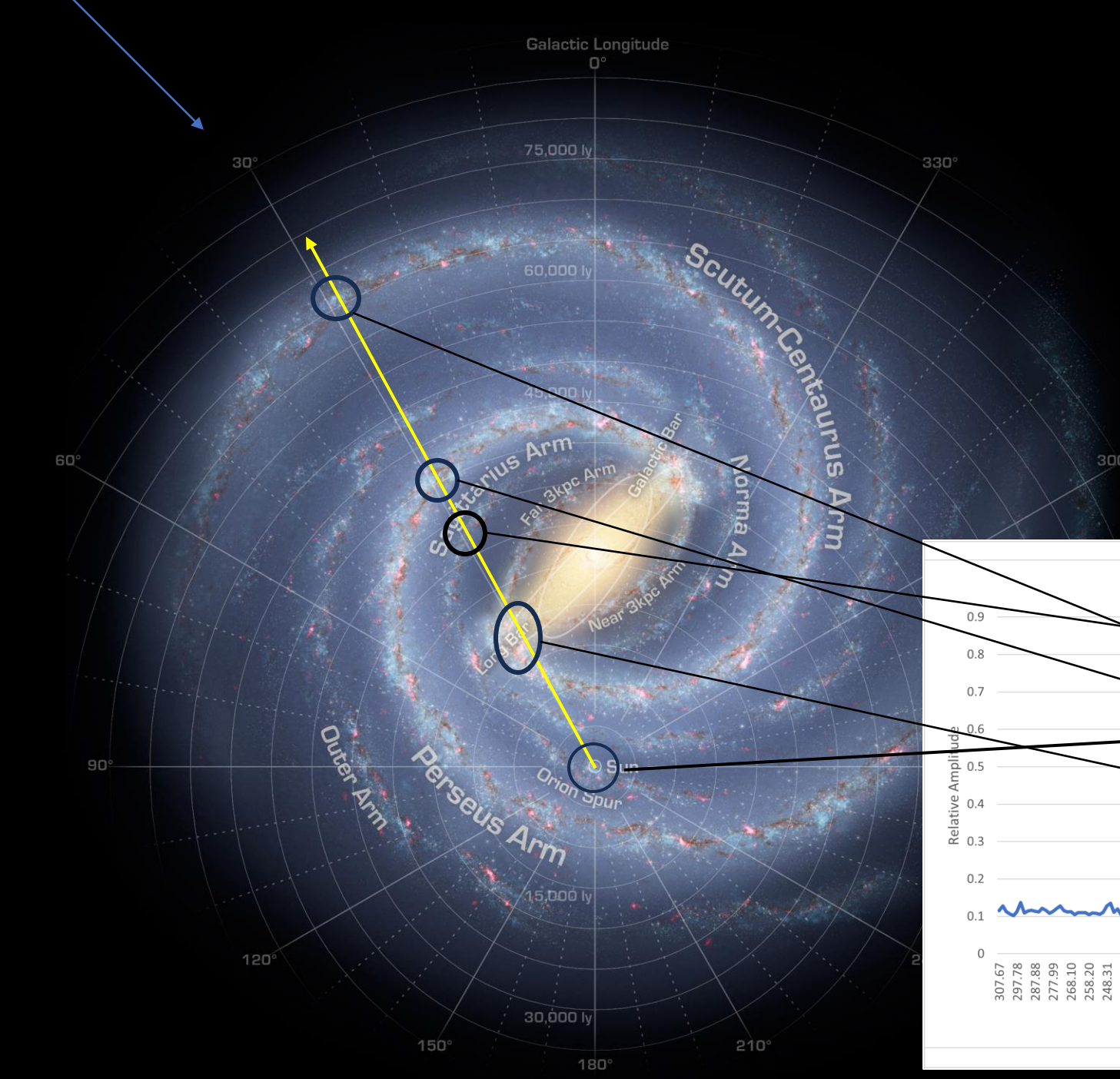

## Antenna aimed at 0 deg Galactic Longitude

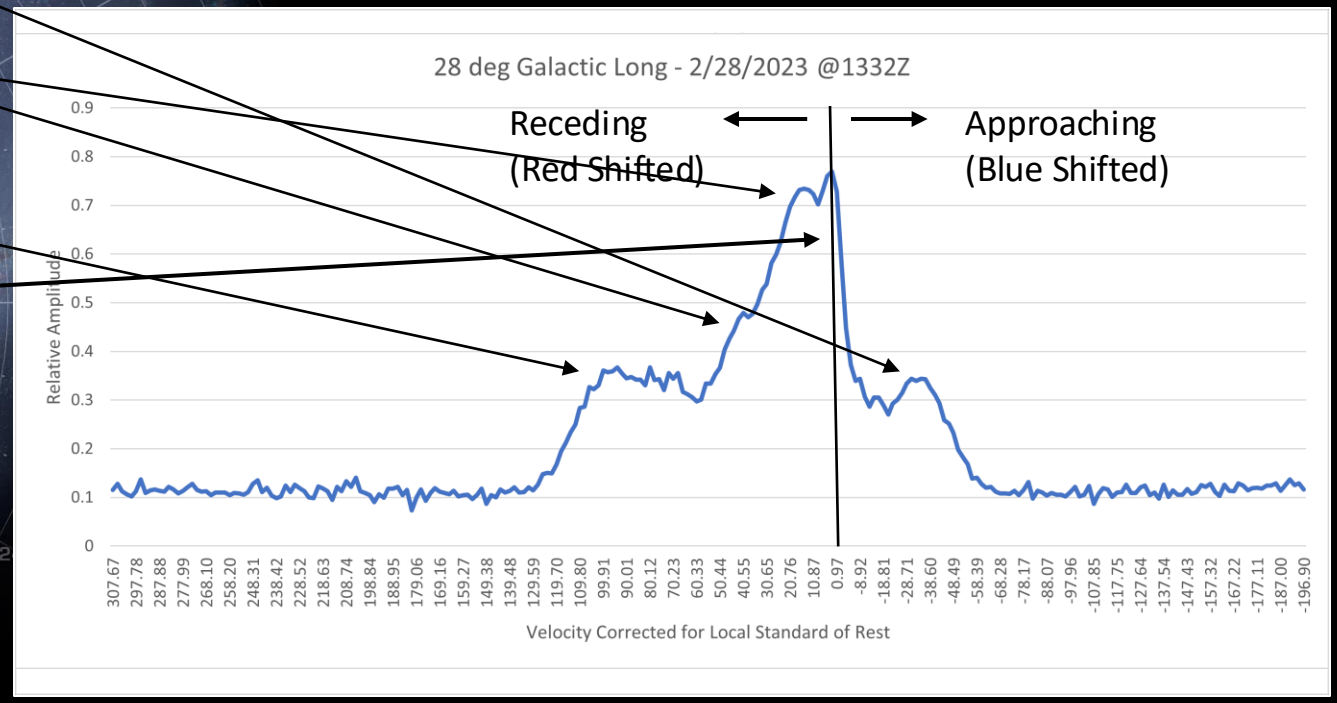
Looking through local environment, Scutum-Sagittarius Arm and Central Bar. Very little radial relative motion, so very little Doppler Shift. The two peaks can be identified since the angles do impart a small amount of radial velocity…the clouds in the Scutum-Centaurus Arm have a net receding motion (positive velocity) while the outer rim of the Central Bar has a small velocity towards us (negative).

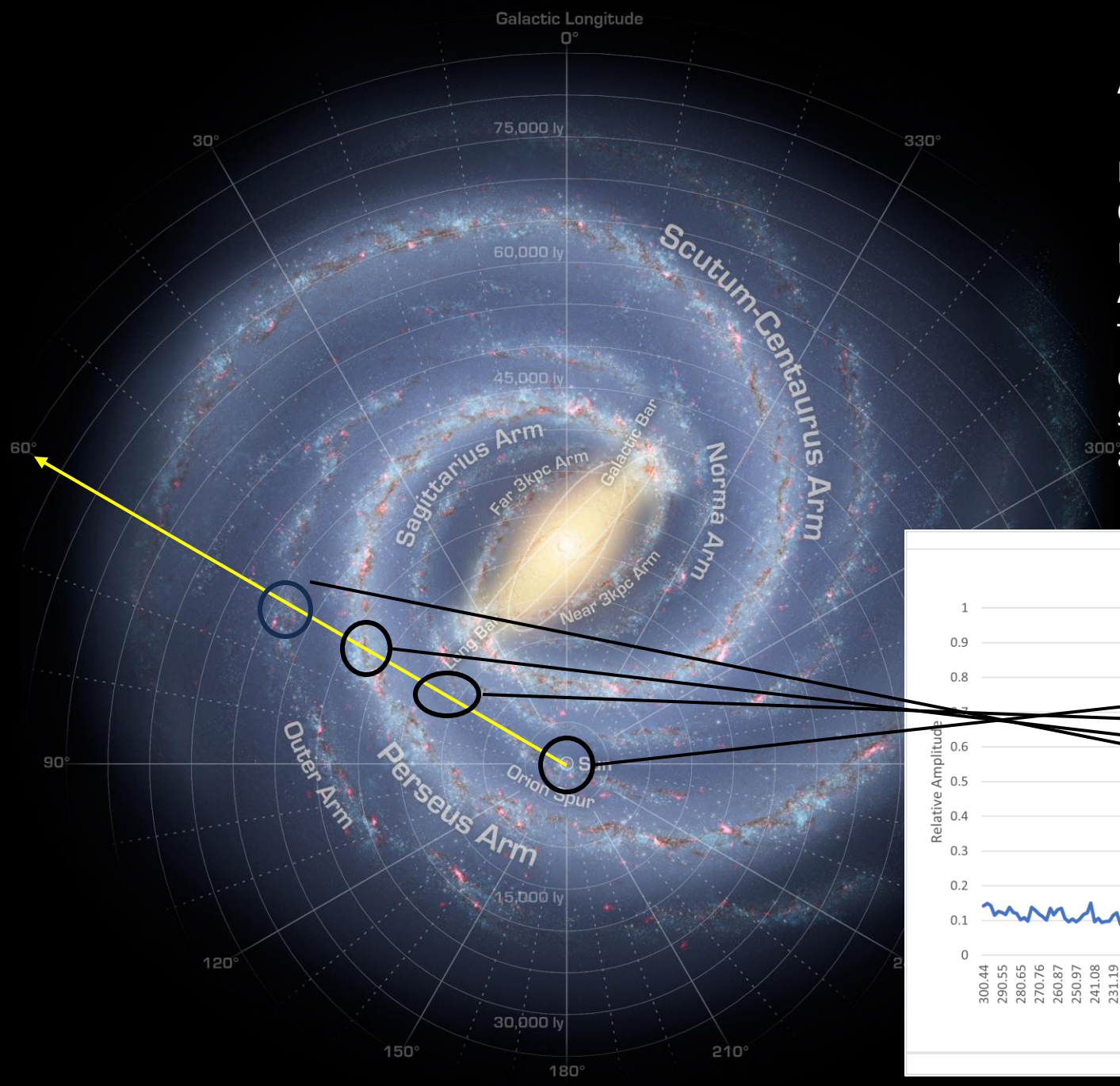


# Antenna aimed at 28 deg Galactic Longitude

Looking through local environment, Scutum-Centaurus Arm/Central Bar junction. We see a strong signal from the Local Environment with near 0 relative velocity. The end of the Central Bar is closer to the center than us, thus has a higher orbital velocity (positive) and is moving away from us. The Sagittarius and Perseus Arms in this direction are rotating slightly faster than us so have small positive velocities. The Scutum-Centaurus Arm on the far side is orbiting much slower (negative velocity) and we are "catching up" to it.

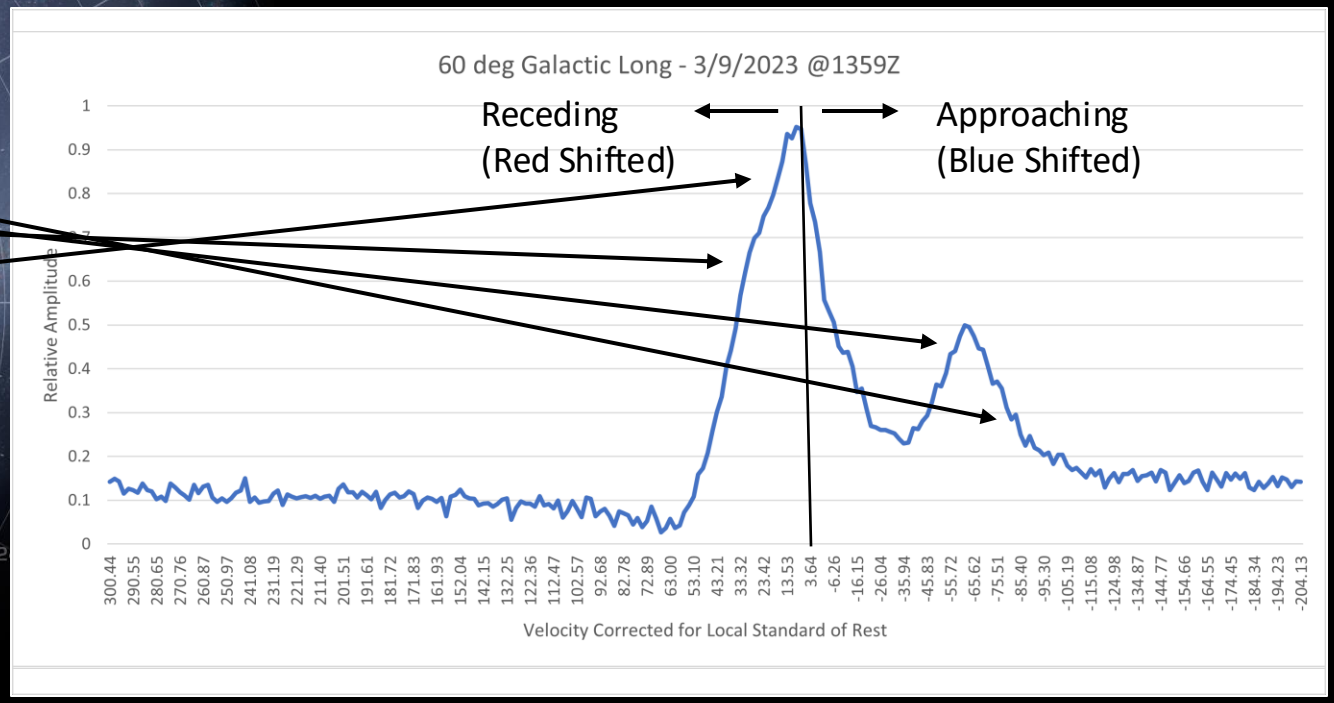




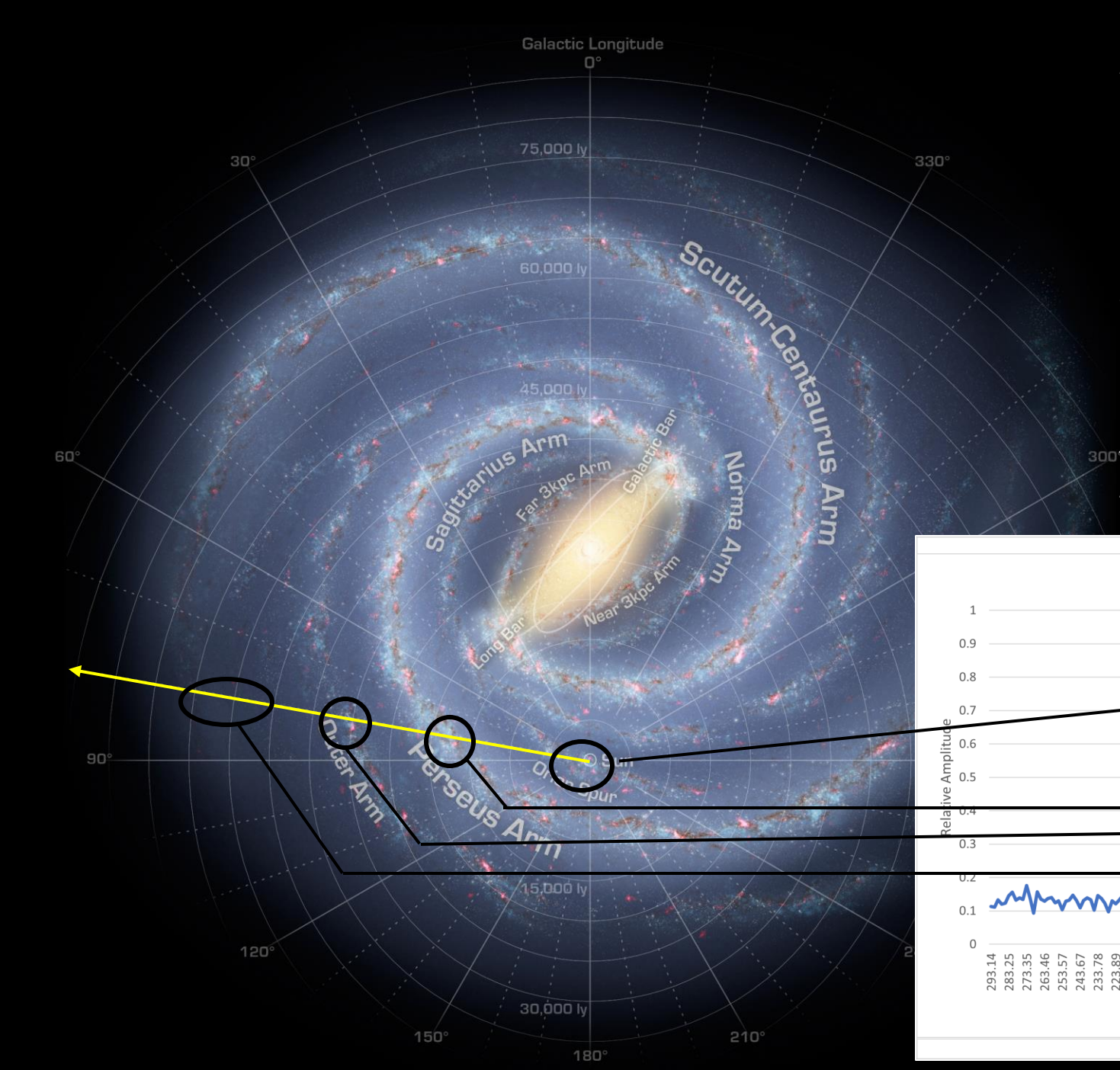

## Antenna aimed at 60 deg Galactic Longitude

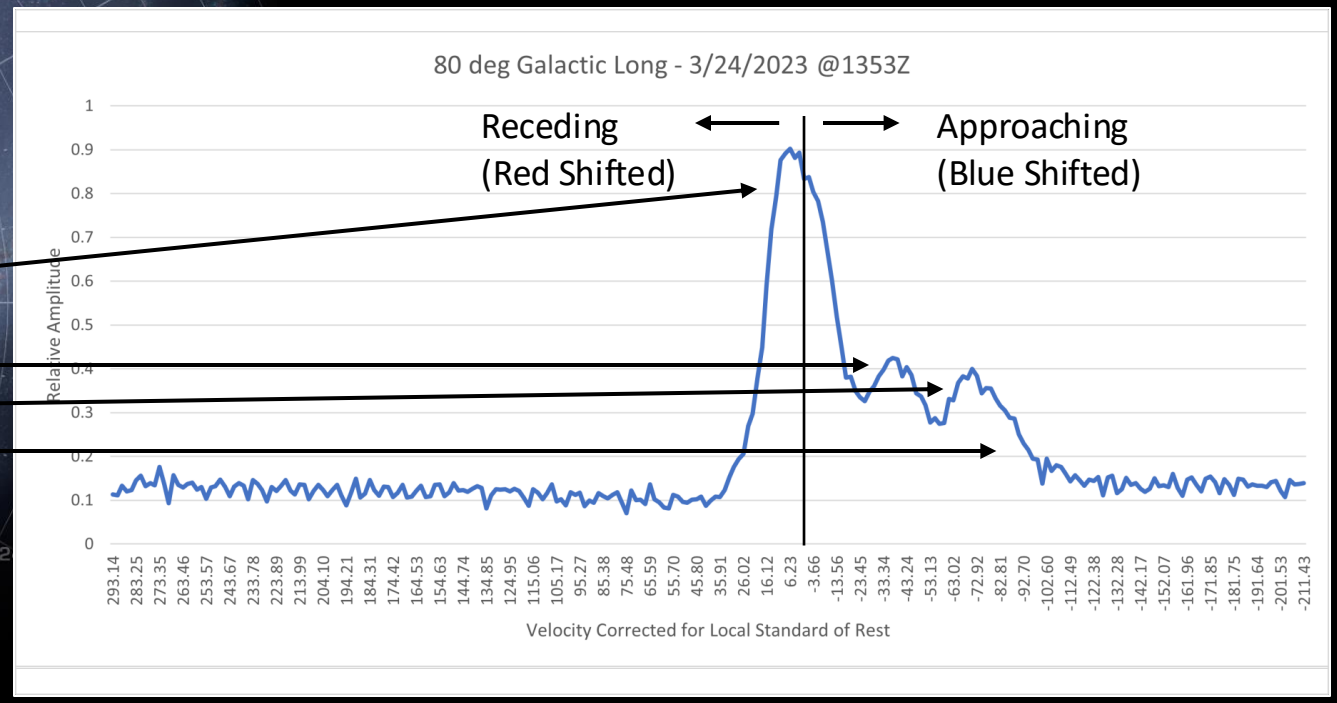
Looking through local environment, Perseus Arm, and Outer Arm beyond. We see strong signal from the Local Environment near 0 relative velocity, and the Perseus Arm at a negative velocity that we are approaching. The wide slope on the right side is likely from the distant Outer Arm. The wide left slope of the main signal with a higher positive velocity is likely from antenna spillover from the outer Central Bar.

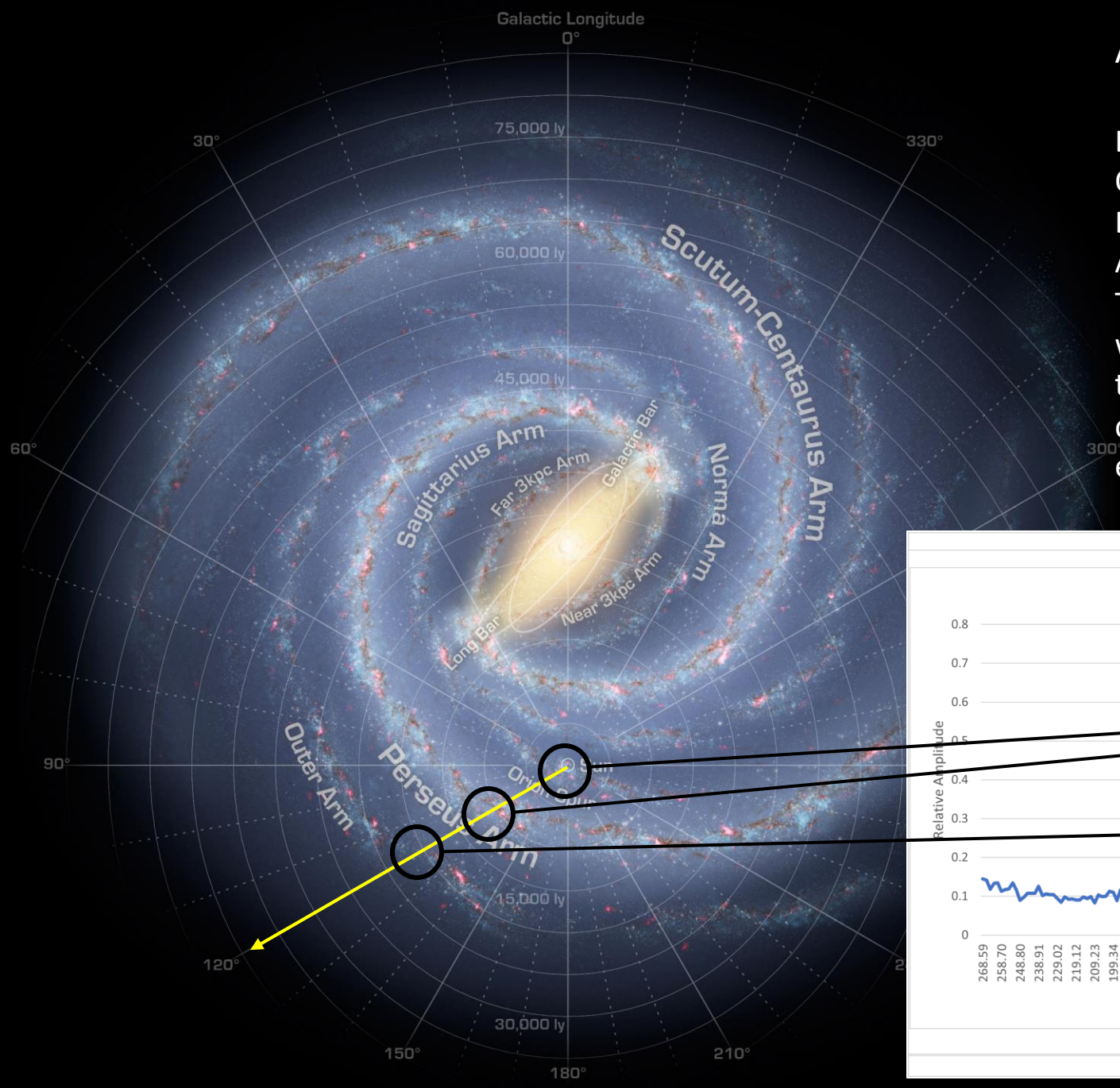


# Antenna aimed at 80 deg Galactic Longitude

Looking through local environment, Perseus Arm, and Outer Arm beyond. We see strong signal from the Local Environment near 0 relative velocity, which is widened by a positive contribution from the Orion Spur which we inhabit. The Perseus Arm is orbiting slower (negative), and the Outer Arm is orbiting slower still (more negative) and is closer at this angle so has a higher signal level than at lower angles of longitude. The wide slope at higher negative velocities is likely the thin outer veil of hydrogen in that direction.

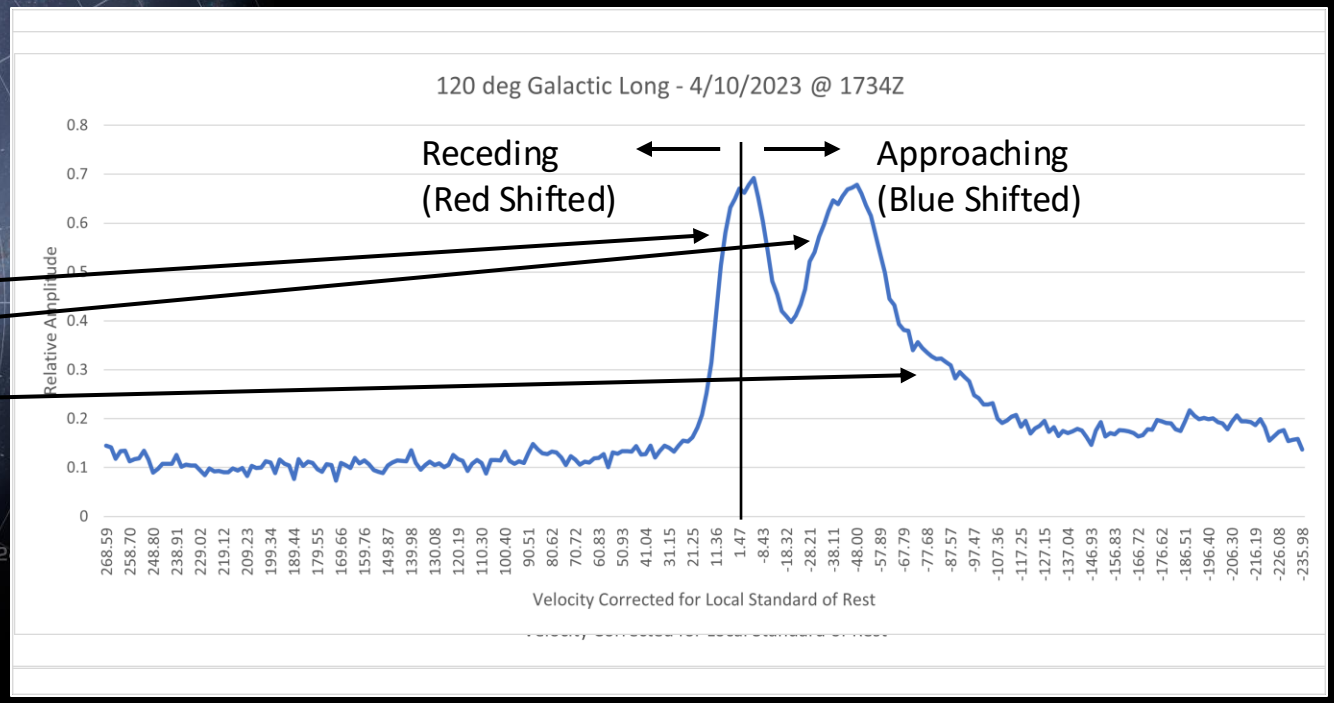


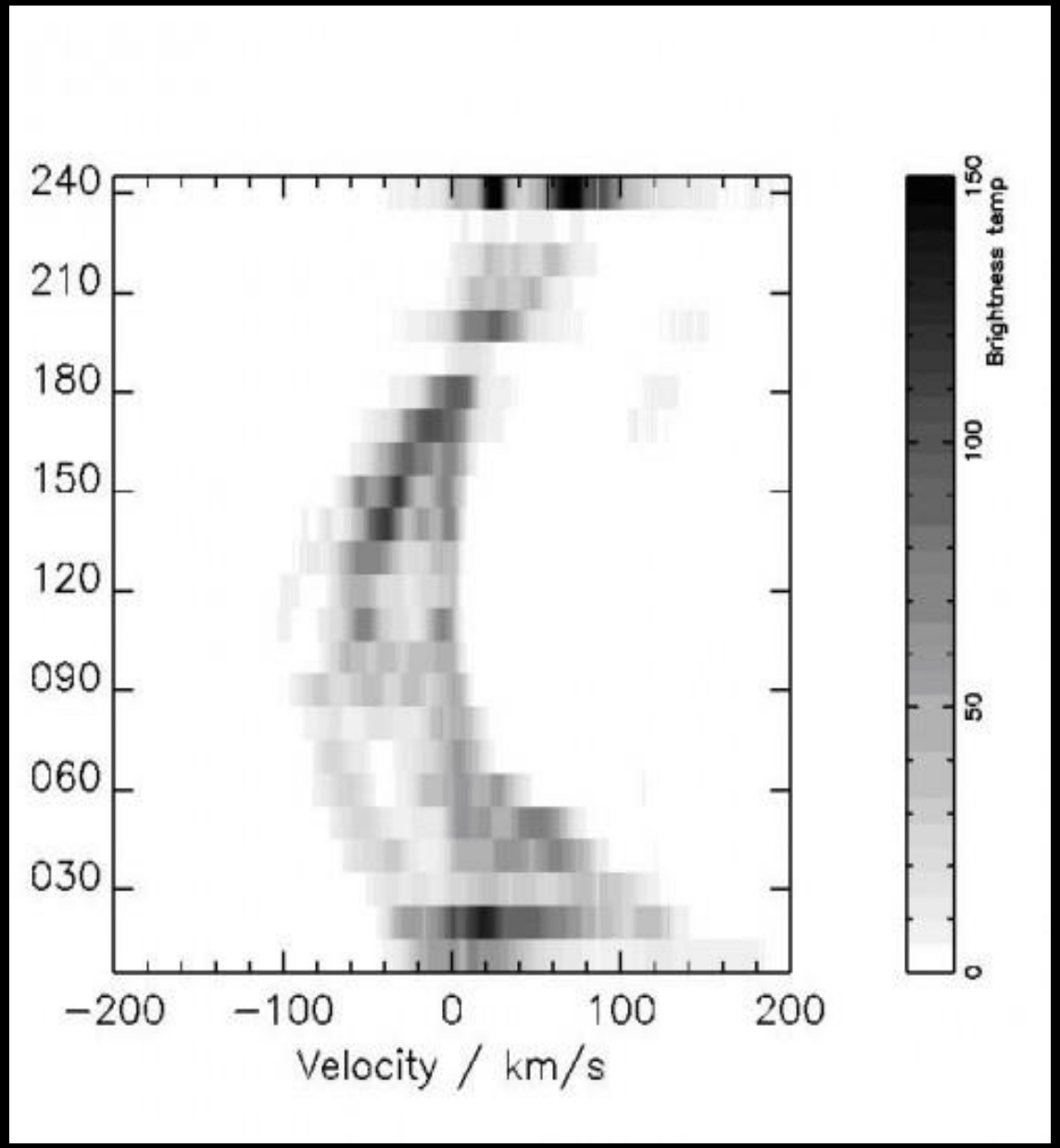





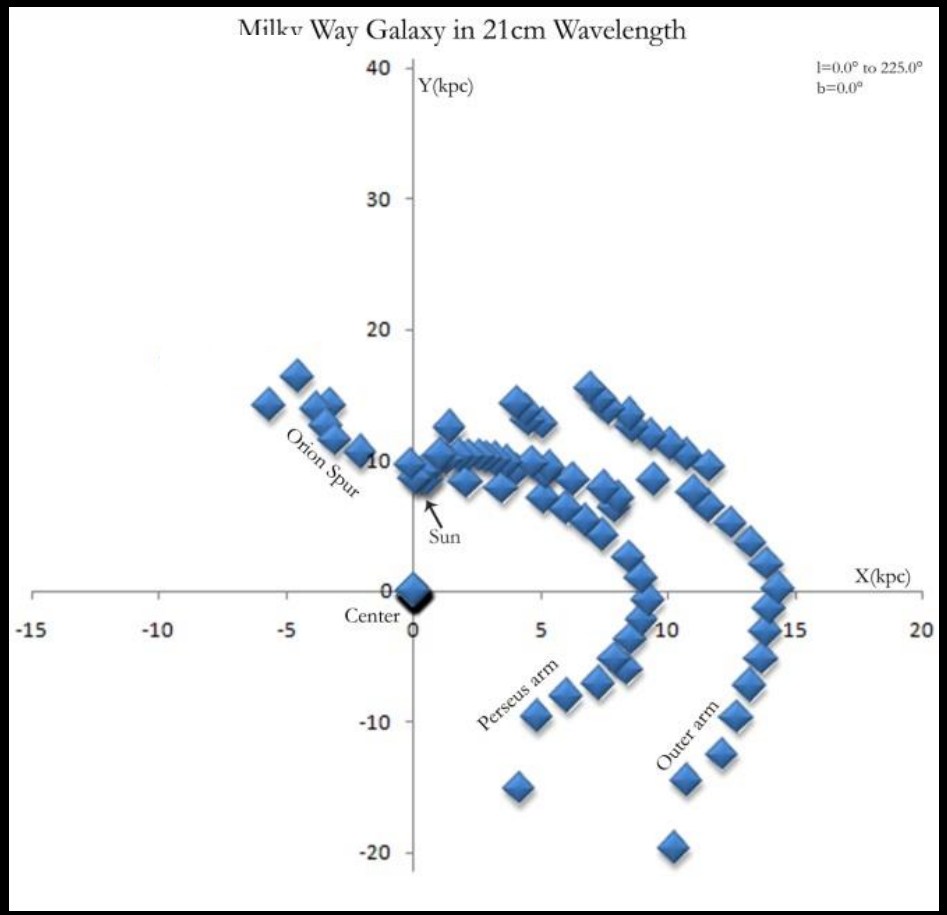

## Antenna aimed at 120 deg Galactic Longitude

Looking through local environment, Perseus Arm, and Outer Arm beyond. We see strong signal from the Local Environment near 0 relative velocity, and the Perseus Arm at a negative velocity that we are "outrunning". The Outer Arm is less dense at this angle and has a weaker amplitude but higher negative velocity signal than at lower angles of longitude. Note: All components lie at or outside of our orbit and thus have equal or slower (negative) orbital velocities than us.



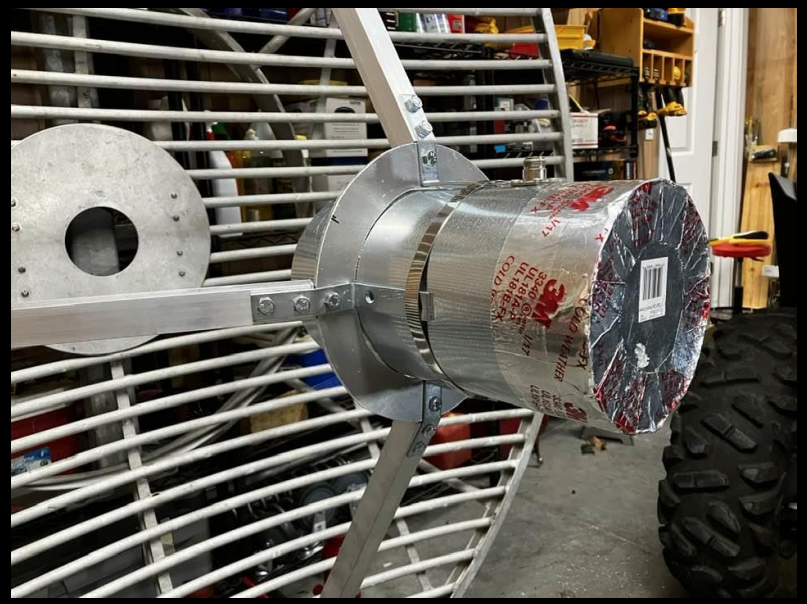


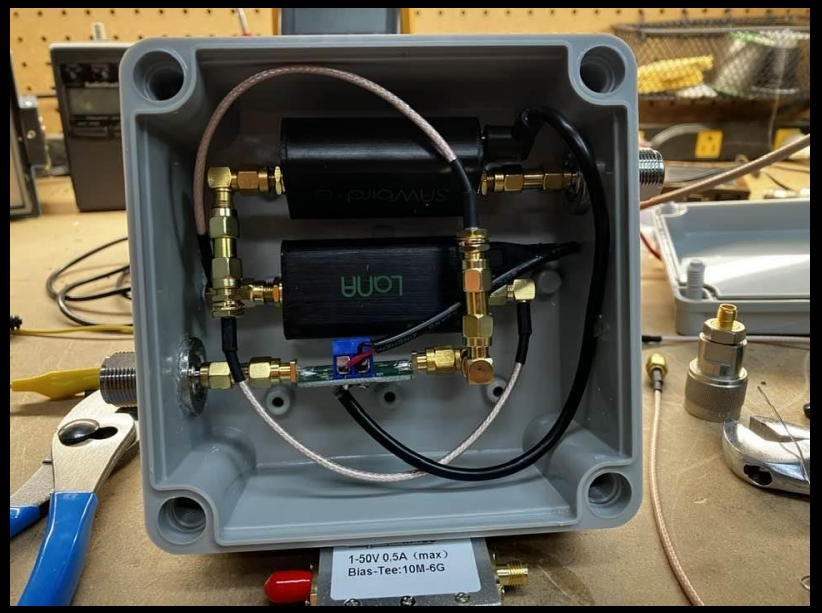

By using geometry and trigonometry along with a systematic survey of the Doppler Shifted signal components at various angles of galactic longitude, a spiral shape becomes apparent!



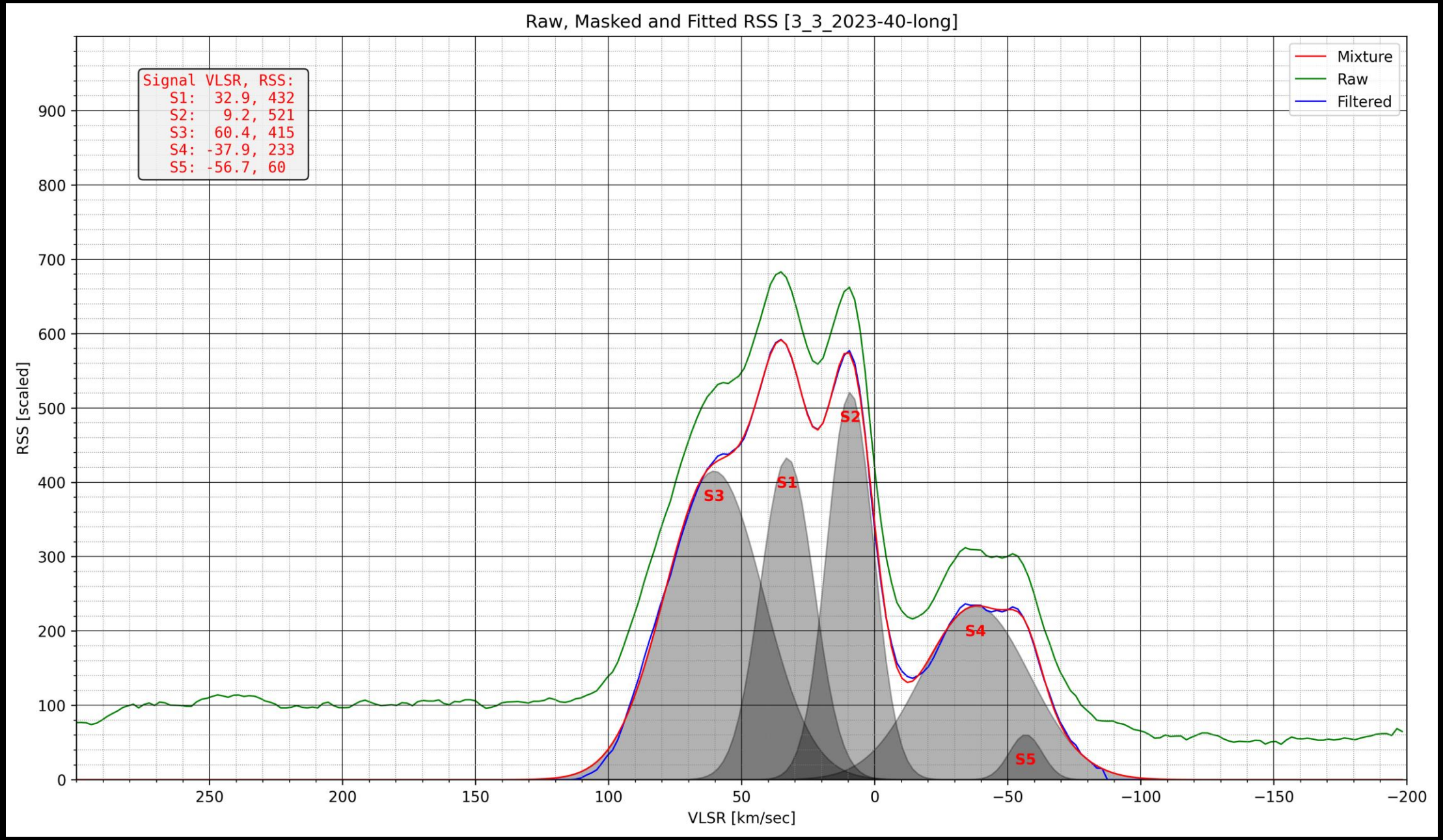
All of this together, if data is collected in a systematic directional study, reveals the spiral structure of our galaxy, even though it cannot be seen optically! Taken further, its rotational velocity, the Sun's orbital period, and even the mass of the galaxy can be deduced from these observations!

All with a small 1.8 meter salvaged antenna and a homemade feedhorn and receiver!






# Current Project – Developing Automated Data Analysis Routines



# Conclusions

- From these systematic measurements of the 21 cm wavelength radiation from hydrogen with a homemade radiotelescope, we can deduce:

  - We are surrounded by hydrogen in distinct areas – there is non-uniform structure around us
  - These areas have different relative radial velocities to us
  - Within each area, the hydrogen is randomly distributed with motions both towards and away from us (Gaussian frequency distribution)
  - We see different spectral patterns as we look at various points along the Milky Way
  - By plotting the radial velocities at the various angles across the Milky Way (along with a bit of math), a SPIRAL pattern emerges.
  - Moreover, the relative velocities vs distances from the core reveal the presence of invisible extra mass…DARK MATTER.

# Future Goals

- Exploring areas above and below galactic equator
- Detecting sun radio noise (wideband)
  - Detecting increase in noise during solar flares
  - Graphing noise change during a solar eclipse


- Detecting radio noise from Jupiter/Io interaction (20.5 MHz)

- Building an interferometer for detecting weaker radio emissions
  - Detecting High Velocity hydrogen clouds
  - Detecting the Andromeda (M31) and Triangulum (M33) Galaxies
  - Detecting Radio Sources, Pulsars, etc.

# Questions?