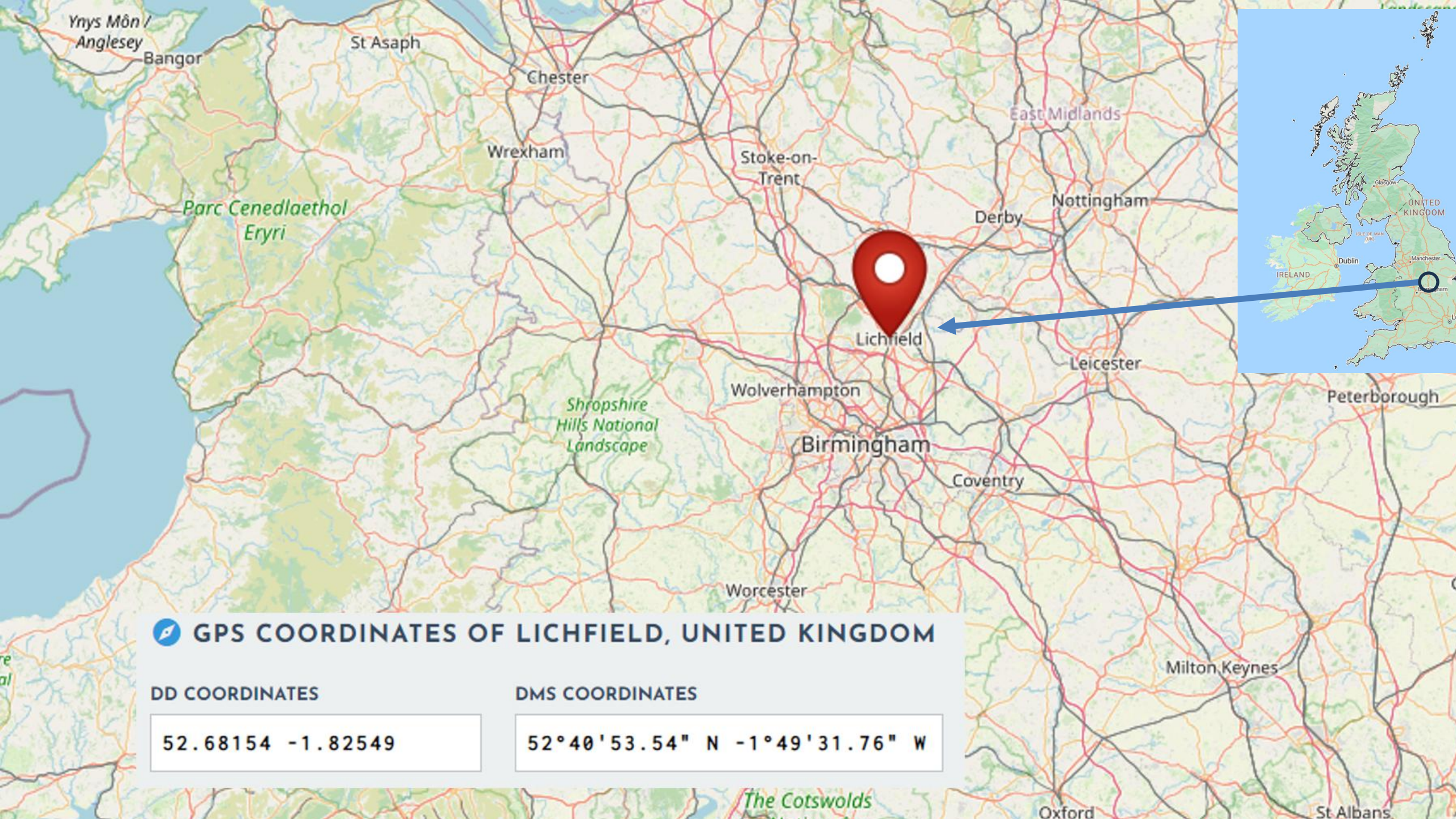

Lichfield Radio Observatory (LRO)
Dr Andrew Thornett, M6THO
www.astronomy.network
www.astronomy.me.uk
Mapping Milky Way in 3D & 4D using small backyard radio telescope
LRO in the Snow
Lichfield, England, UK



GPS COORDINATES OF LICHFIELD, UNITED KINGDOM

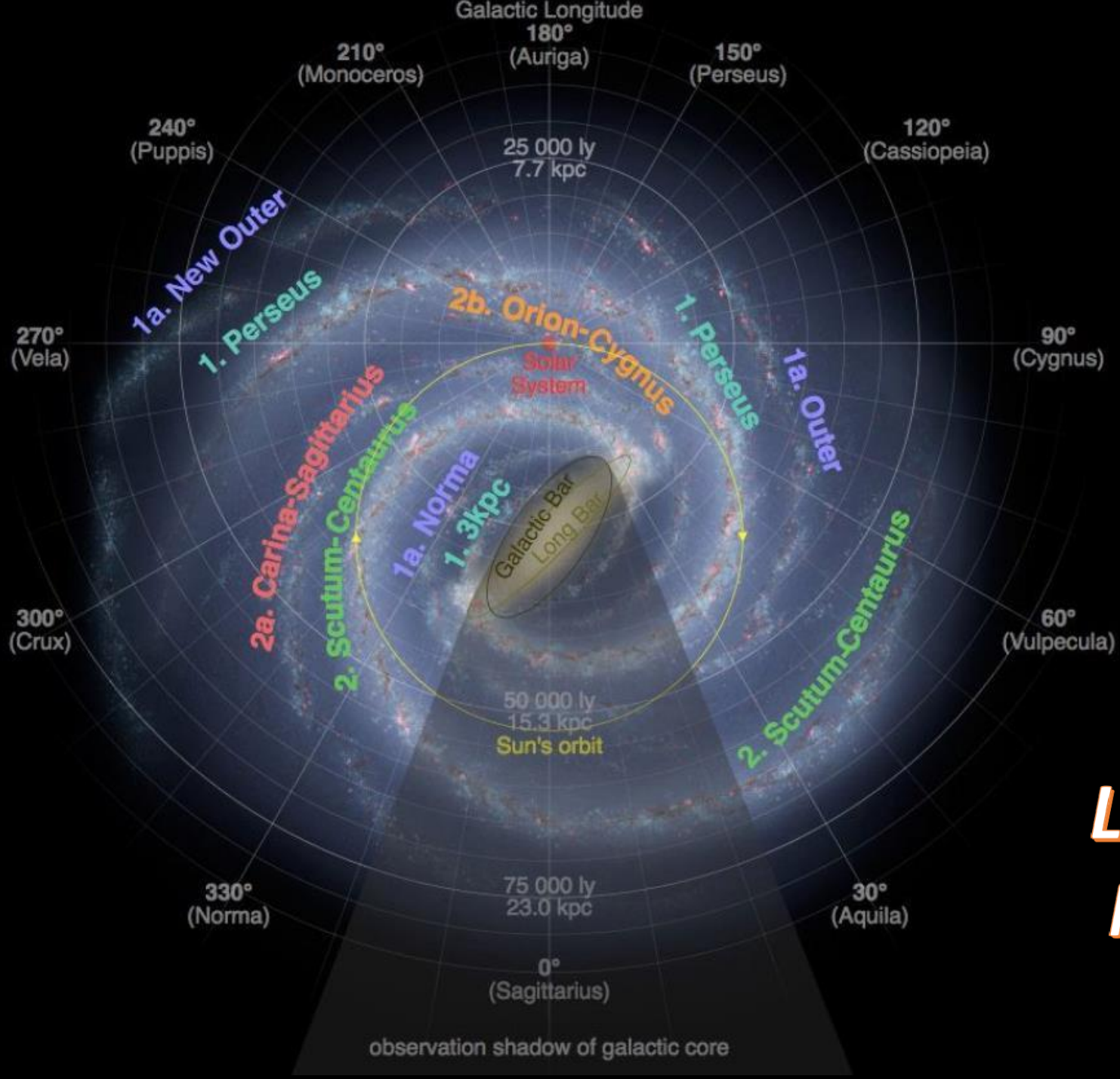
DD COORDINATES

52.68154 -1.82549

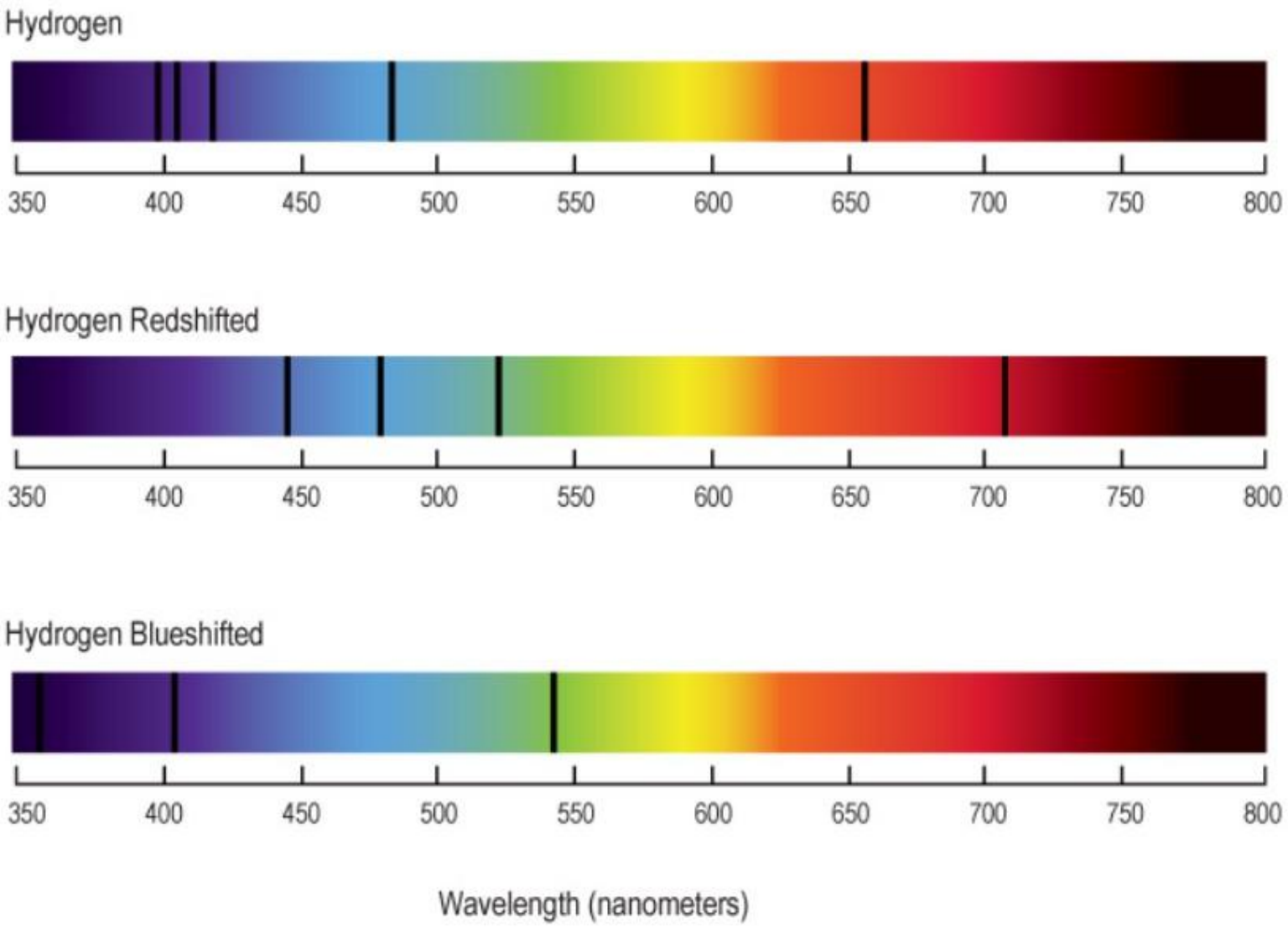
DMS COORDINATES

52°40'53.54" N -1°49'31.76" W


Looking from top down
Our Sun
Hydrogen Line 1420.405 Mhz

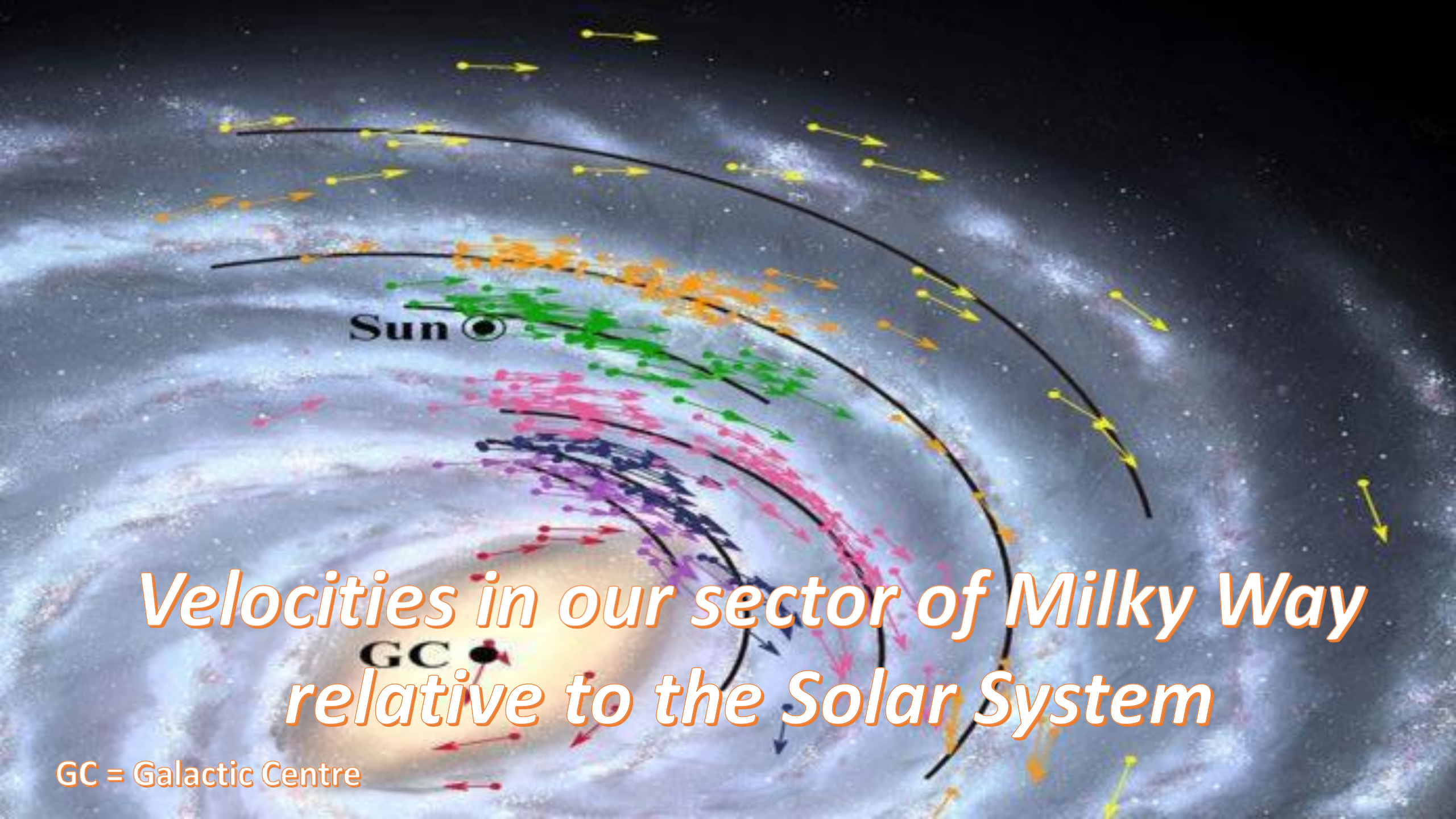


Looking down on Milky Way from outside



Doppler Shift

Red-shifted is moving away from us



Velocities in our sector of Milky Way relative to the Solar System

GC = Galactic Centre

Detecting molecular hydrogen line in Milky Way can now be achieved easily and cheaply

- Milky Way hydrogen detection used to be expensive but can now be achieved with very cheap equipment from Amazon/elsewhere, using Software Defined Radio (SDRs) and hydrogen line filter/pre-amp, and satellite dish/other aerial.
- The Society of Amateur Radio Astronomers (USA/"SARA") has produced a project called "Scope in a Box", which led me start hydrogen-line radio astronomy.

practical and easier to buy off the shelf is something Like this – Nooelec 1.4GHz grid antenna

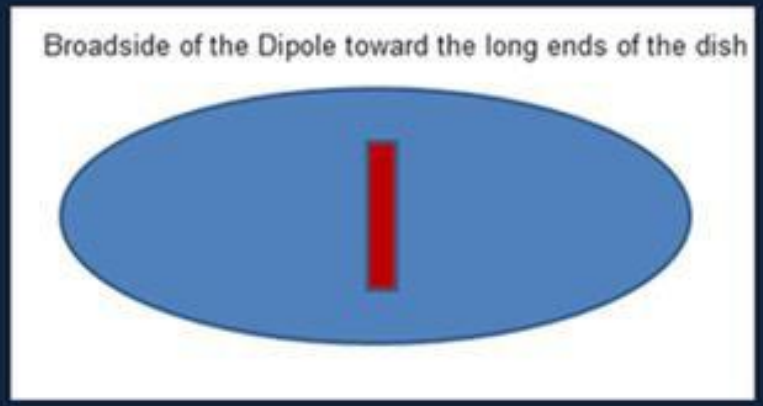
PARABOLIC MESH ANTENNA

Aerials & Mounts

How to orientate mesh aerial

From Alex Pettit

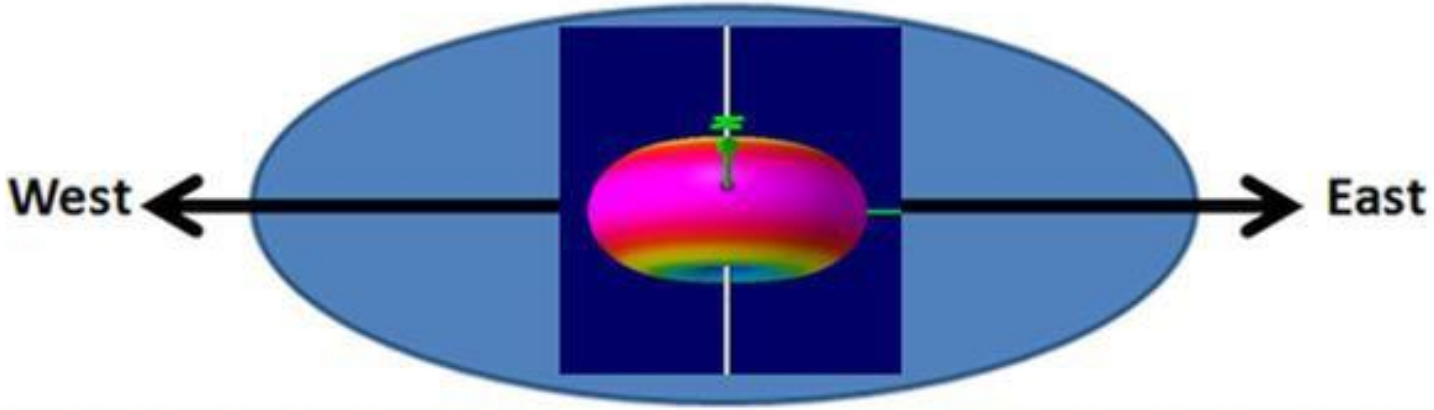
Para Grid WiFi Dish

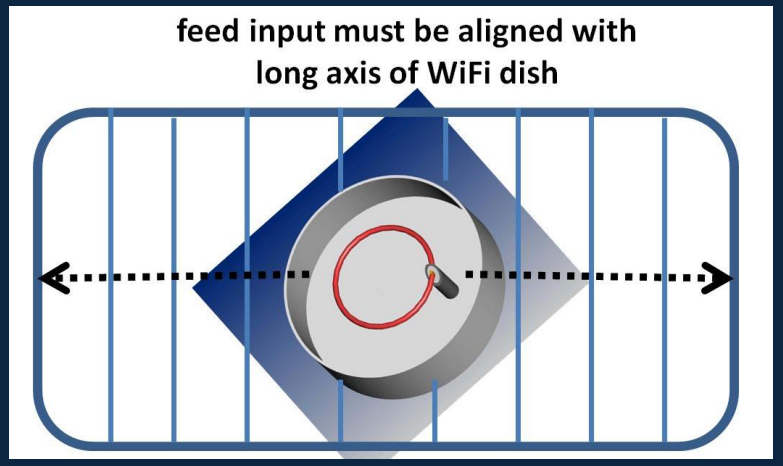


WiFi 100cmx60cm Para-grid Orientation

Recall that beam-width is inversely proportional to dish size.

For optimal angular resolution of H1 drift scans, align the **1m side E<>W**





Ptarmigan Triffid Band 3 Ex-Military Dipole Array (UK)

Homemade simple wooden mount

Box containing mini-PC, SDR & SAWBird H1 LNA


Elevation altered here
Homemade wooden manual telescope mount so that altitude can be varied

Filters, amplifiers and radios

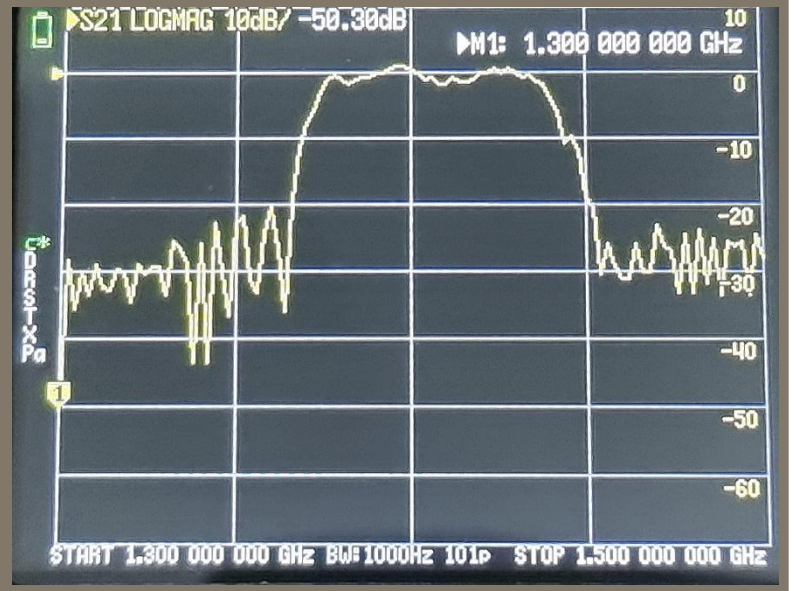
Nooelec SAWBird H1 LNA – cheap and effective

Software-defined radio (SDR)
I personally use RTL-SDR Blog V3

Testing Nooelec SAWBird H1 LNAs for consistency & performance

Using NanoVNA to test each SAWBird

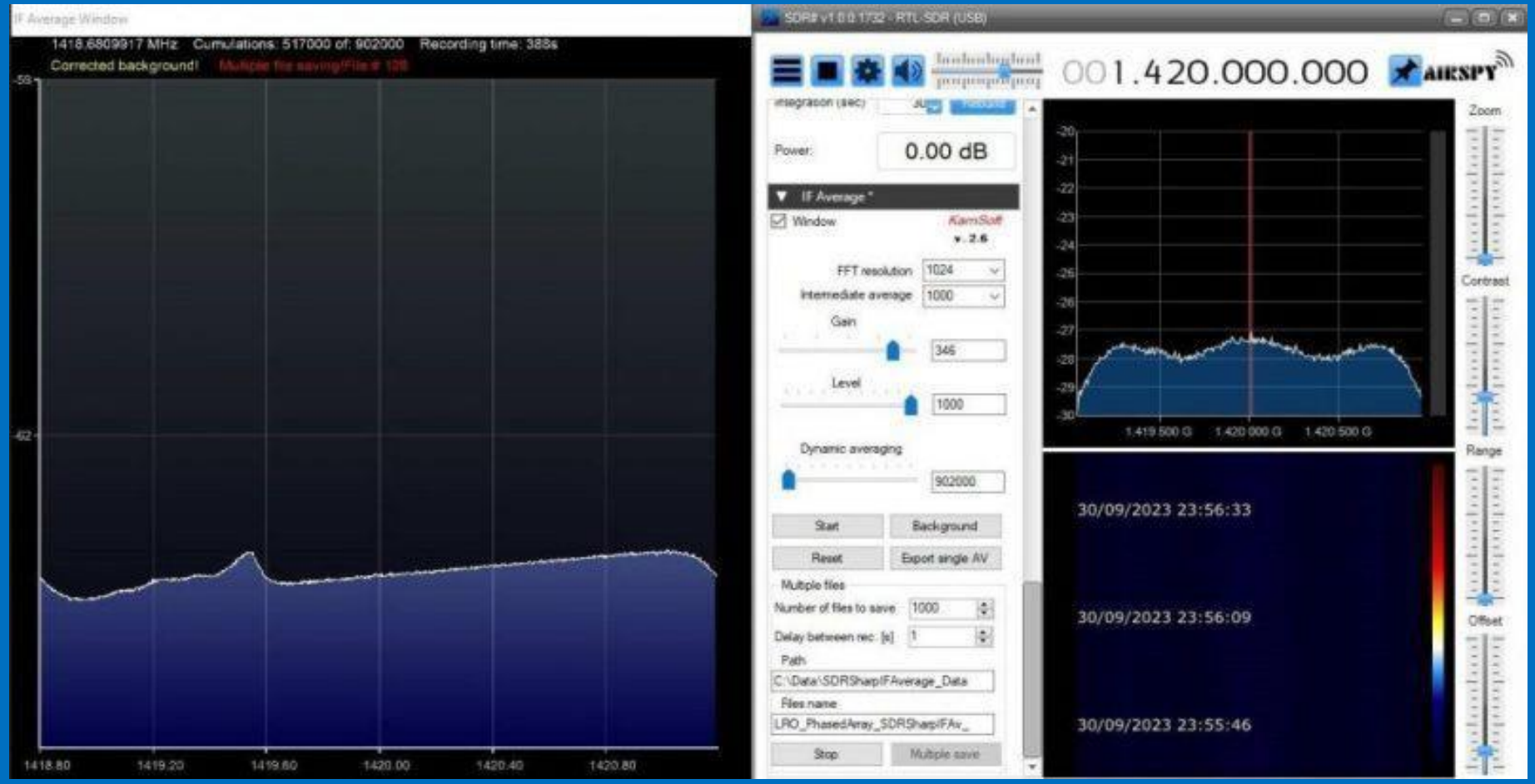
Different SAWBirds



Effect of adding Chinese 1400-1427 MHz cavity filter

Software

SDR Sharp with IF Average Plugin



My preferred software:

ezRA - Easy Radio Astronomy
Free 1420 MHz Galactic hydrogen
data collection and analysis
https://github.com/tedcline/ezRA
Windows and Linux

ezRA software is great for collecting and processing data and mapping it over known background of radio sources in Milky Way

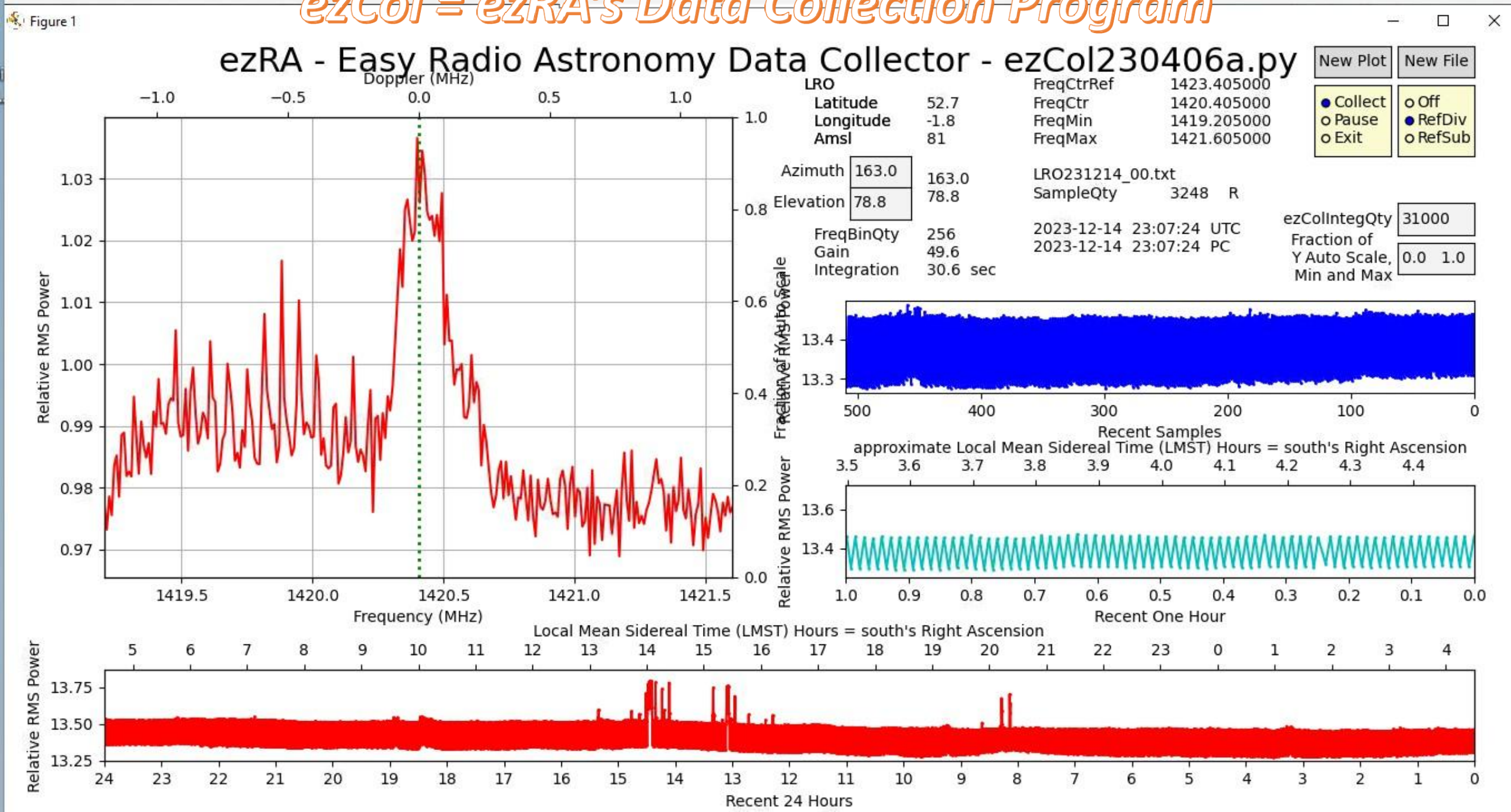
(Has own collection program, alternative to SDR# IFAverage Plug-In to collect data)

ezRA will also process SDR# data

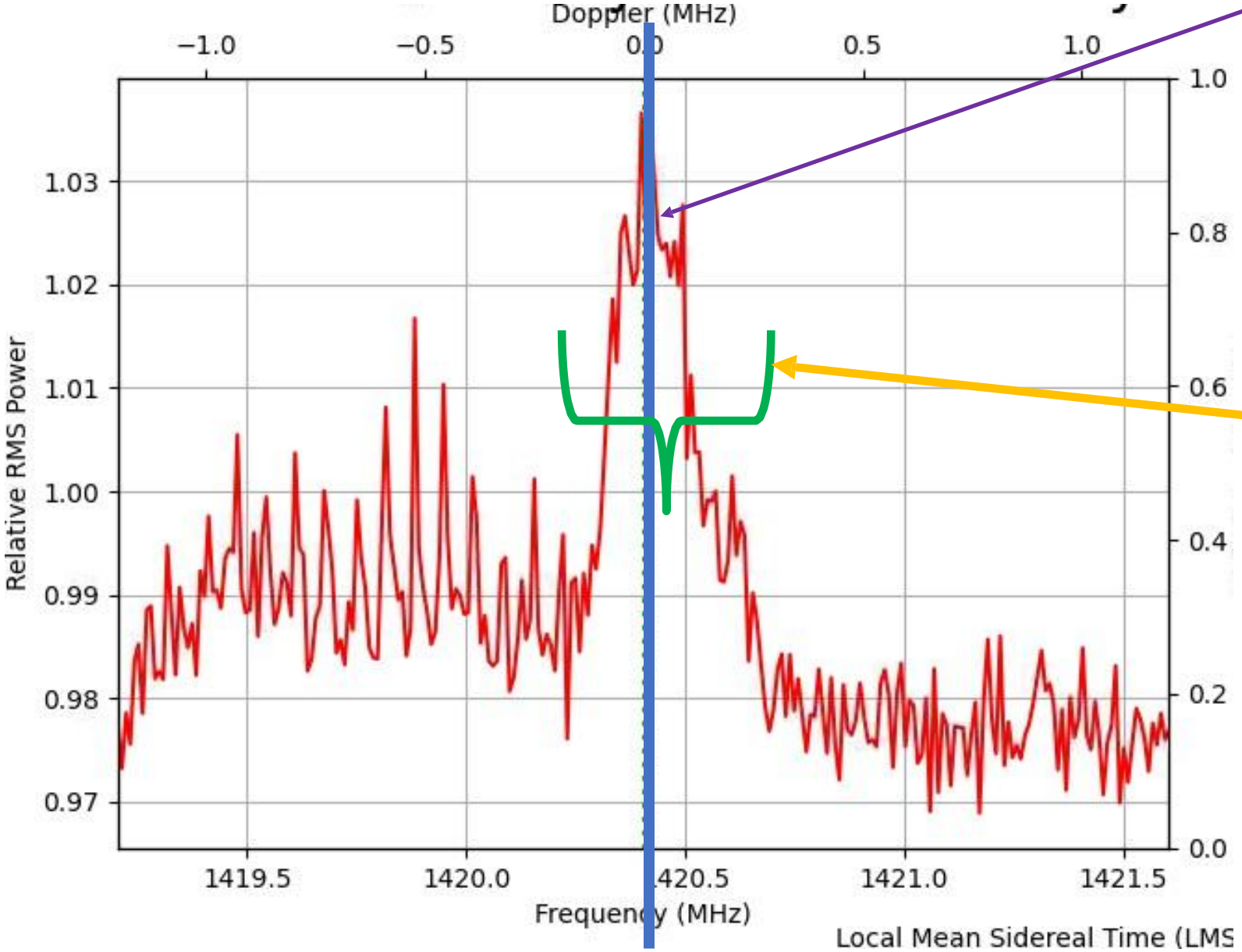
LRO-PharmiganArray (LRO-LAP-03) - RealVNC Viewer

ezCol = ezRA's Data Collection Program

Figure 1



An example of a detection of the hydrogen line

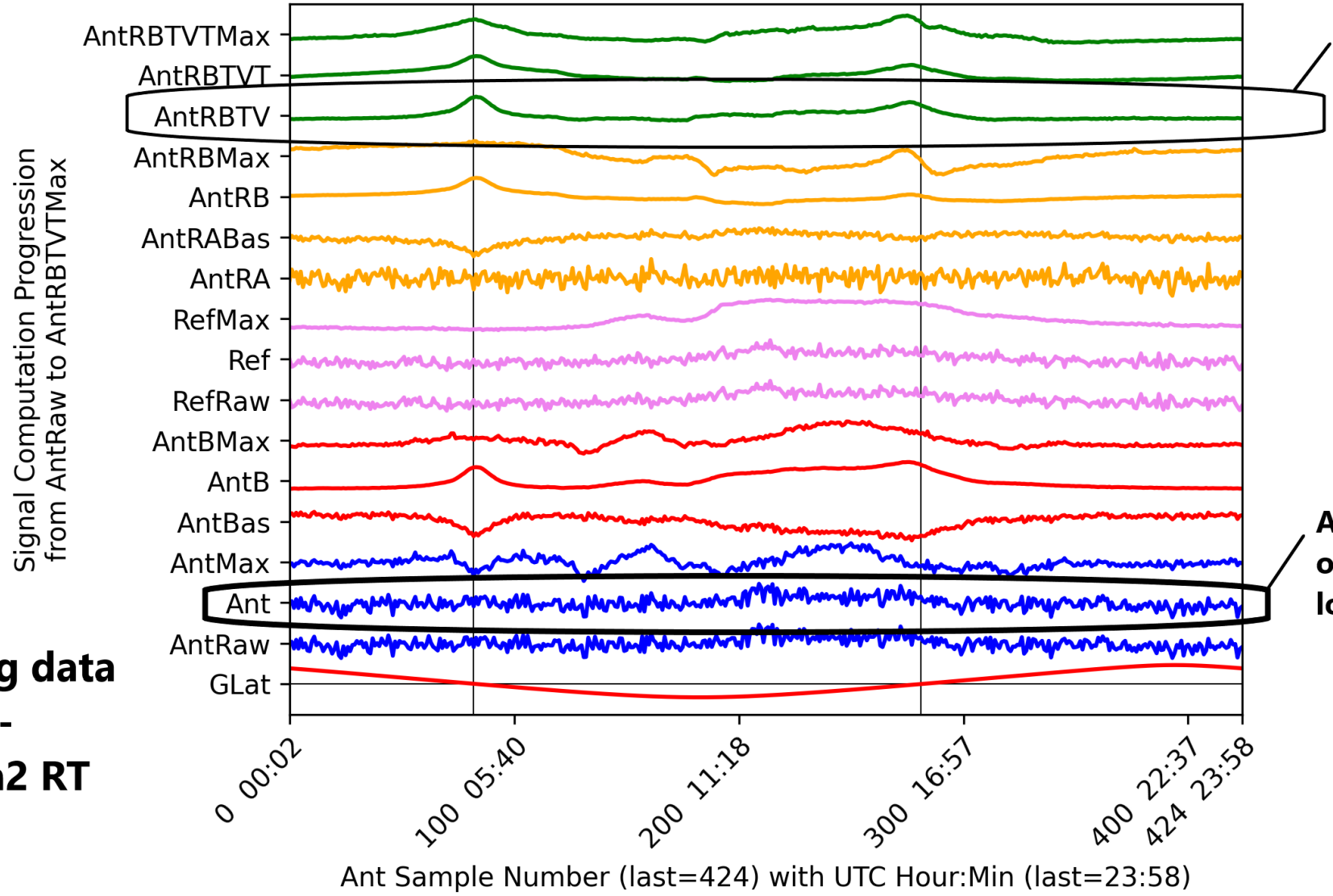


Frequency of hydrogen 1420.405MHz

Range of frequencies For hydrogen representing Doppler shift and hence differences in Velocity

Removing noise using ezRA

LRO-H2(SCRT)_El_48-00_Az_178_250430_00.txt LRO-H2_WoodenCantennaSupports_Az_178_ (ezCon241024a.py)



Signal after processing in ezRA including use of reference samples - effectively removes lot of noise to show peaks where aerial/antenna goes through hydrogen clouds of plane of Milky Way Galaxy (black vertical lines)

Antenna reading over 24 hrs showing lots of noise

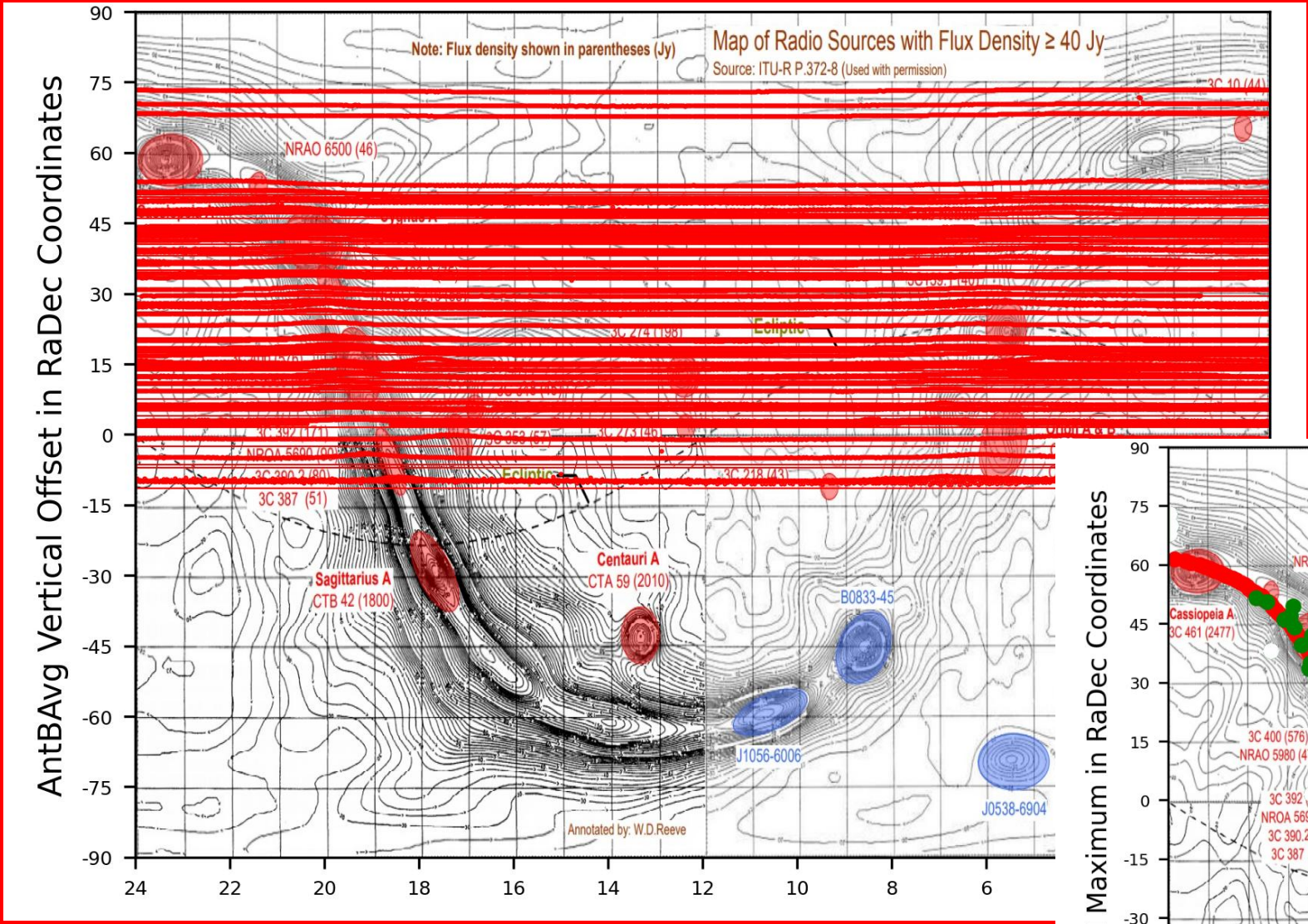
Processing data from LRO-Hydrogen2 RT

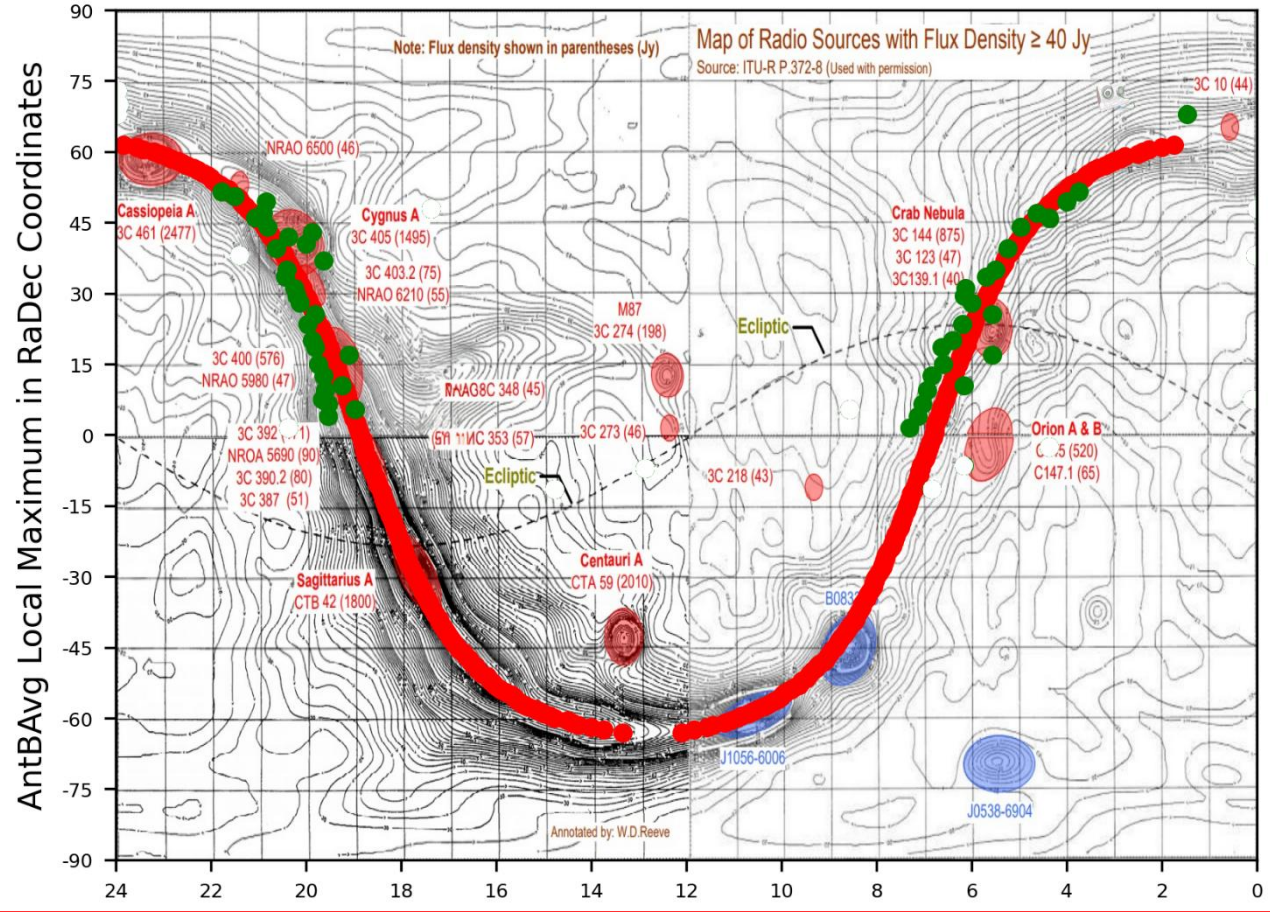
LRO-H2
150cm solar cooker

LRO-H3:
The Alex Pettit 21cm Patch Yagi Antenna

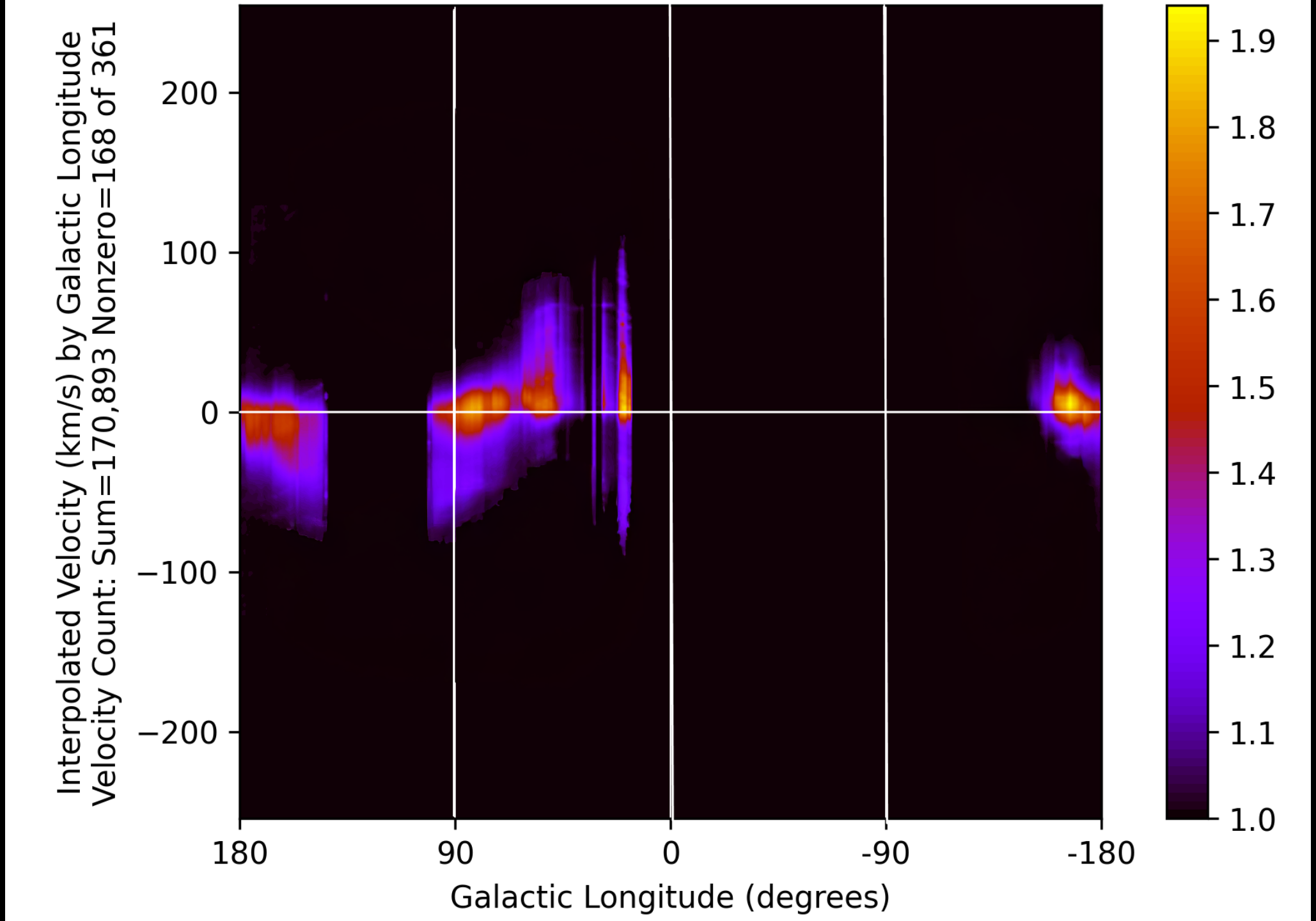
- *Small*
- *Light*
- *Efficient*

Survey sky coverage

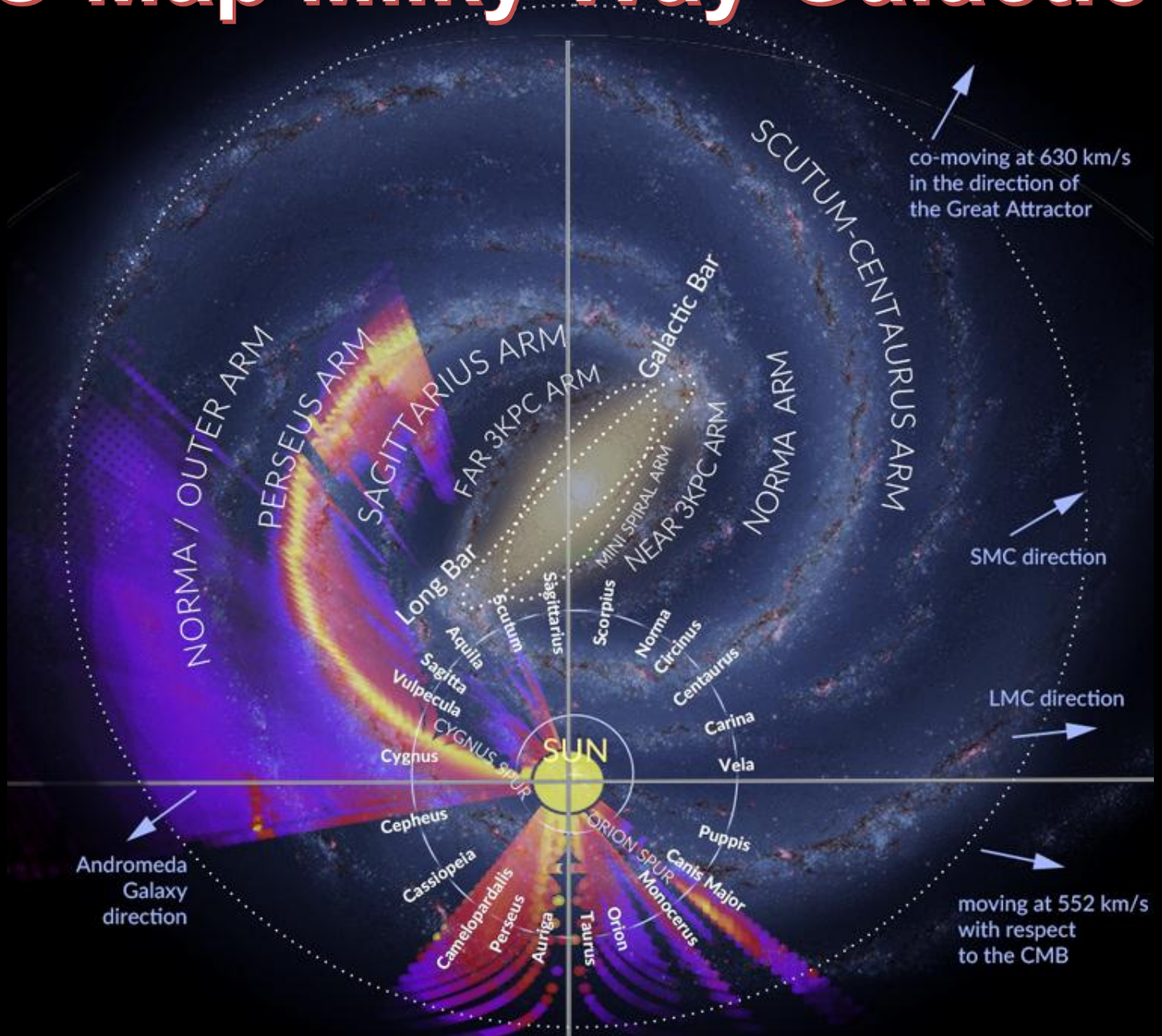




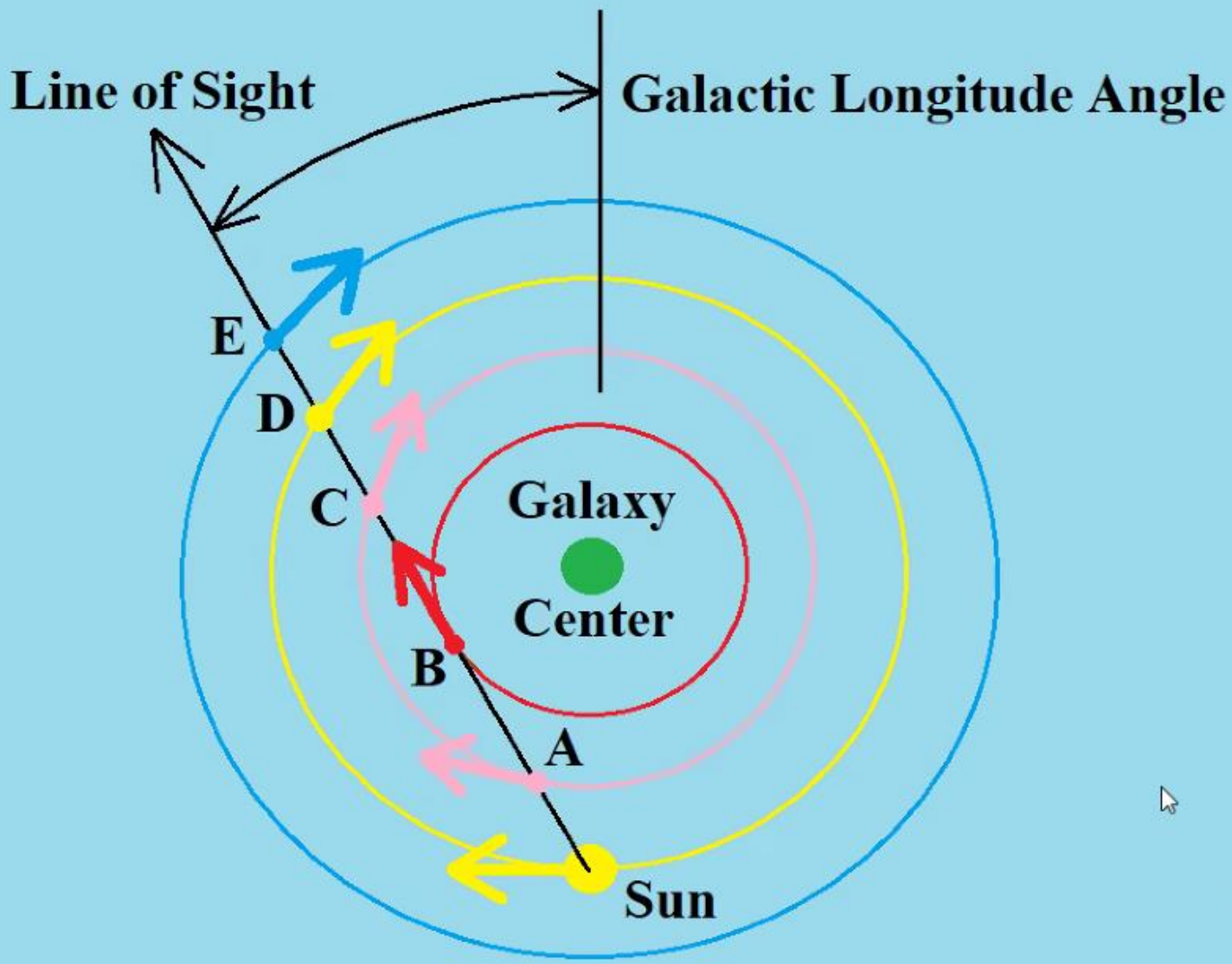
Combined results of all three H-line telescopes start- 17/8/2025


Interpolated Velocity (km/s) by Galactic Longitude
Velocity Count: Sum=170,893 Nonzero=168 of 361
200
100
0
−100
−200
180
90
0
-90
-180
Galactic Longitude (degrees)
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0

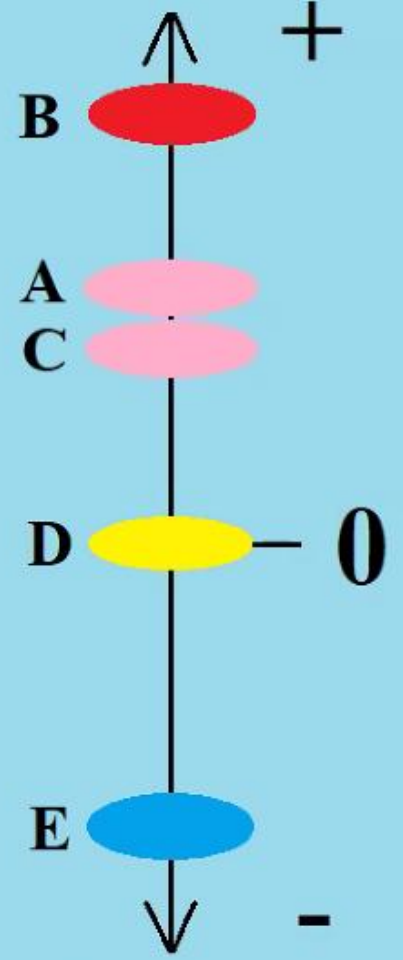
LRO Map Milky Way Galactic Arms



Measure Velocity Difference



Receding Velocity



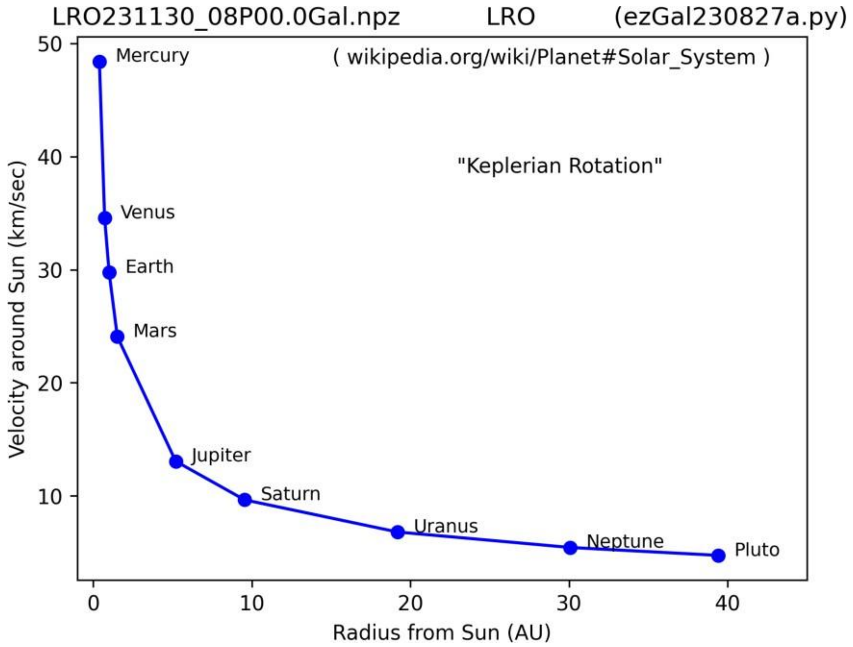
Approaching Velocity

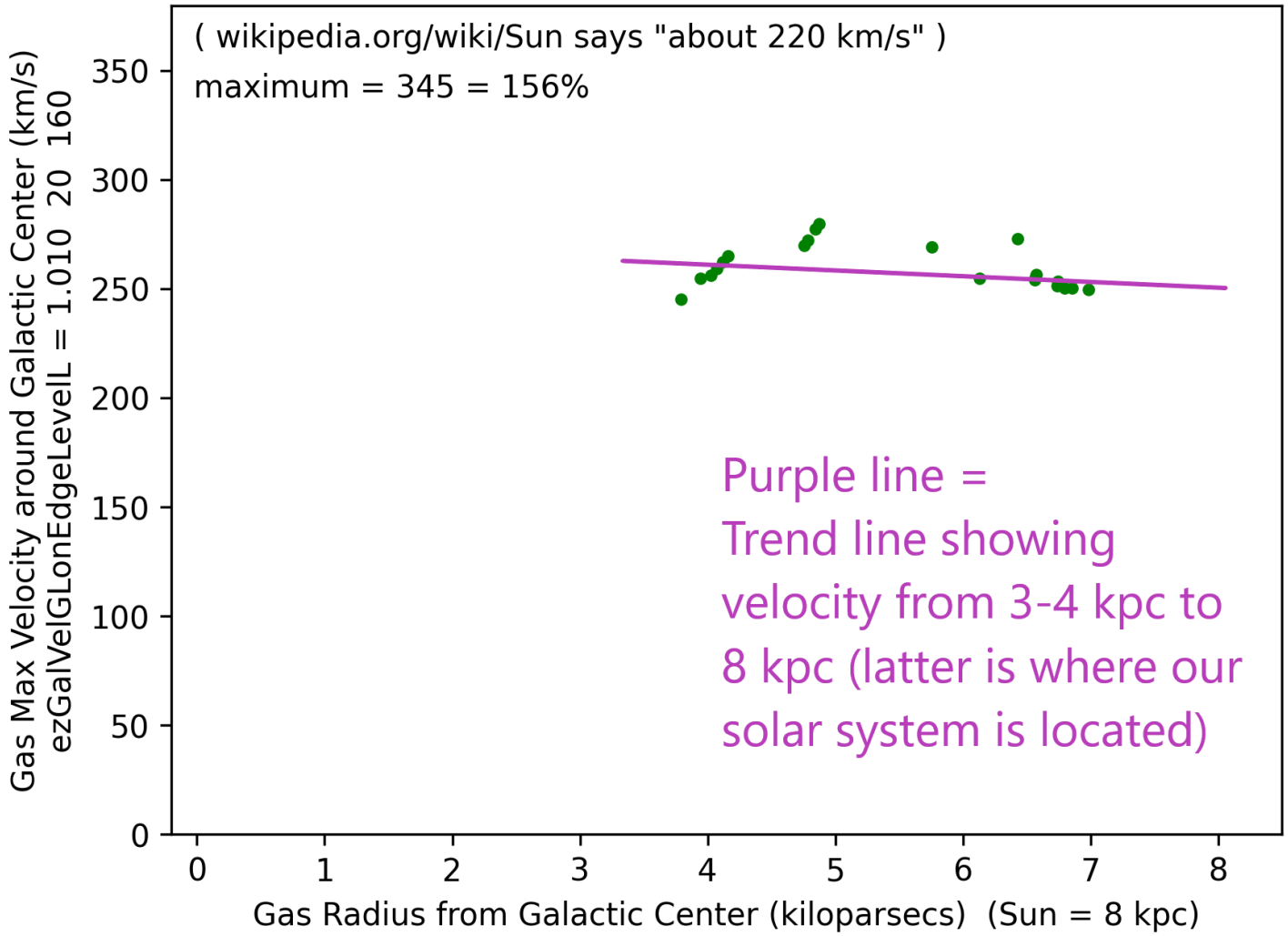
Simulation of galactic rotation WITHOUT Dark Matter (Left) vs WITH dark matter (Right); From Wikipedia

0:00 / 0:15

Dark Matter – galactic rotation curve from my data

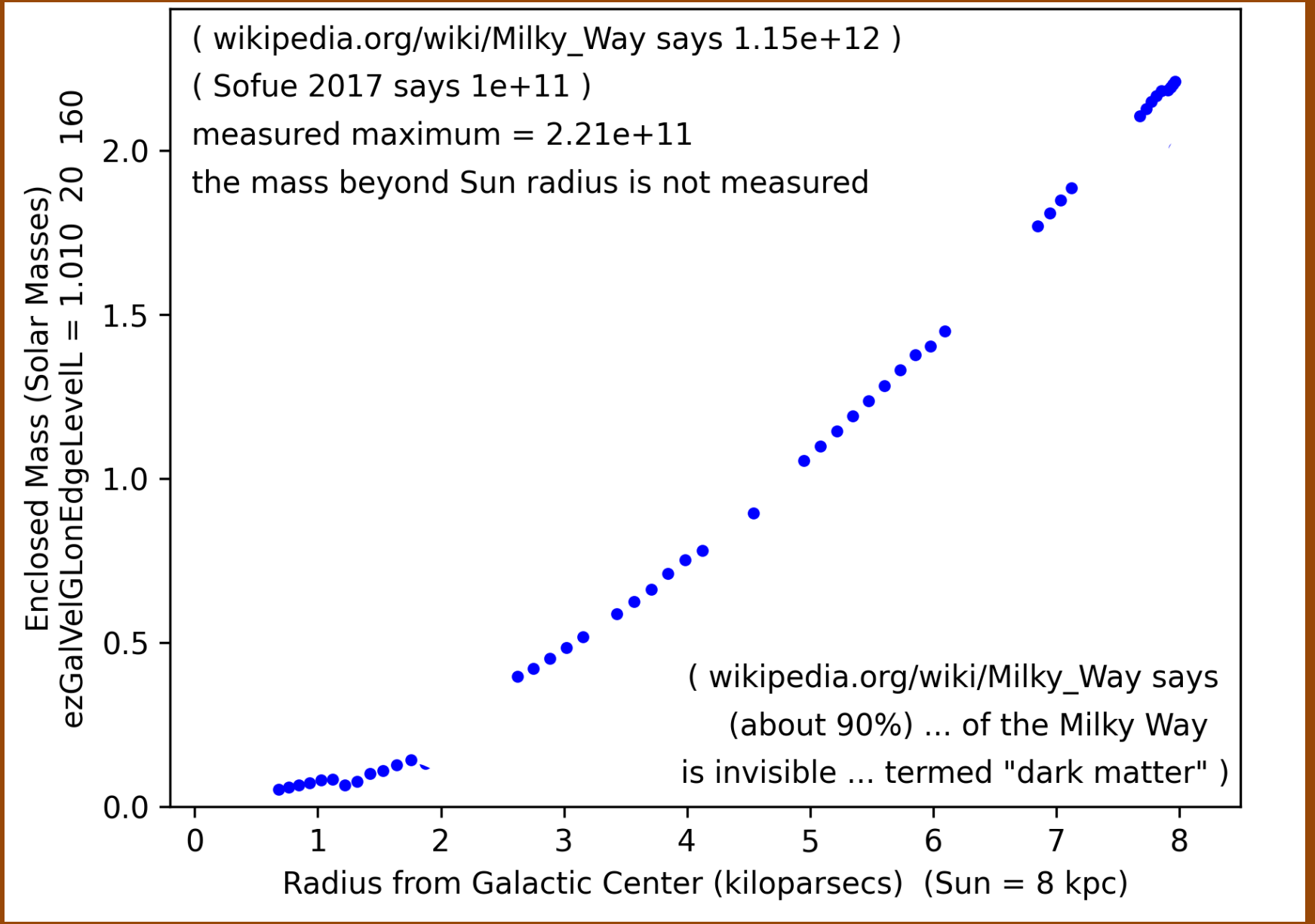
Below is typical Keplarian Rotation Curve which would be expected without dark matter, on right my data (ezRA suite/Pharmigan array)



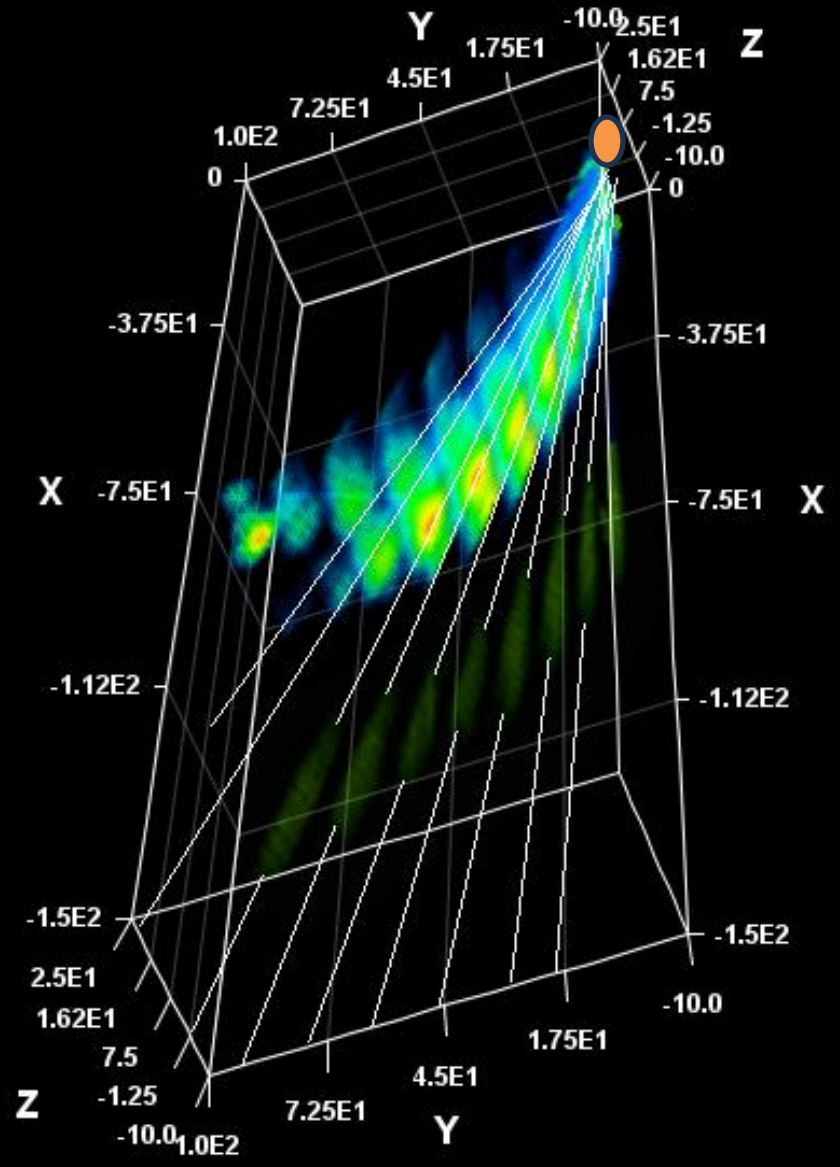


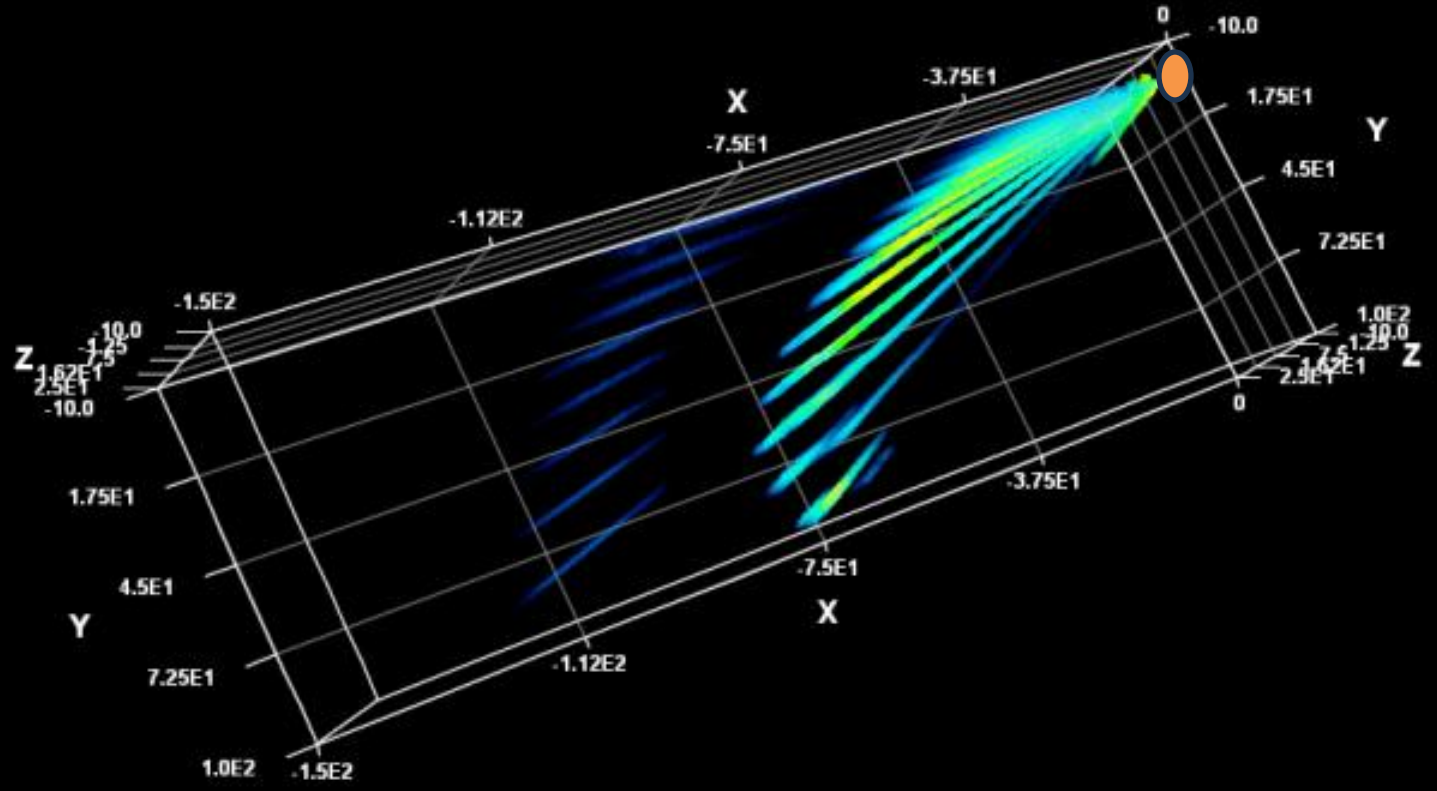
Purple line =
Trend line showing velocity from 3-4 kpc to 8 kpc (latter is where our solar system is located)

Enclosed Milky Way galactic mass



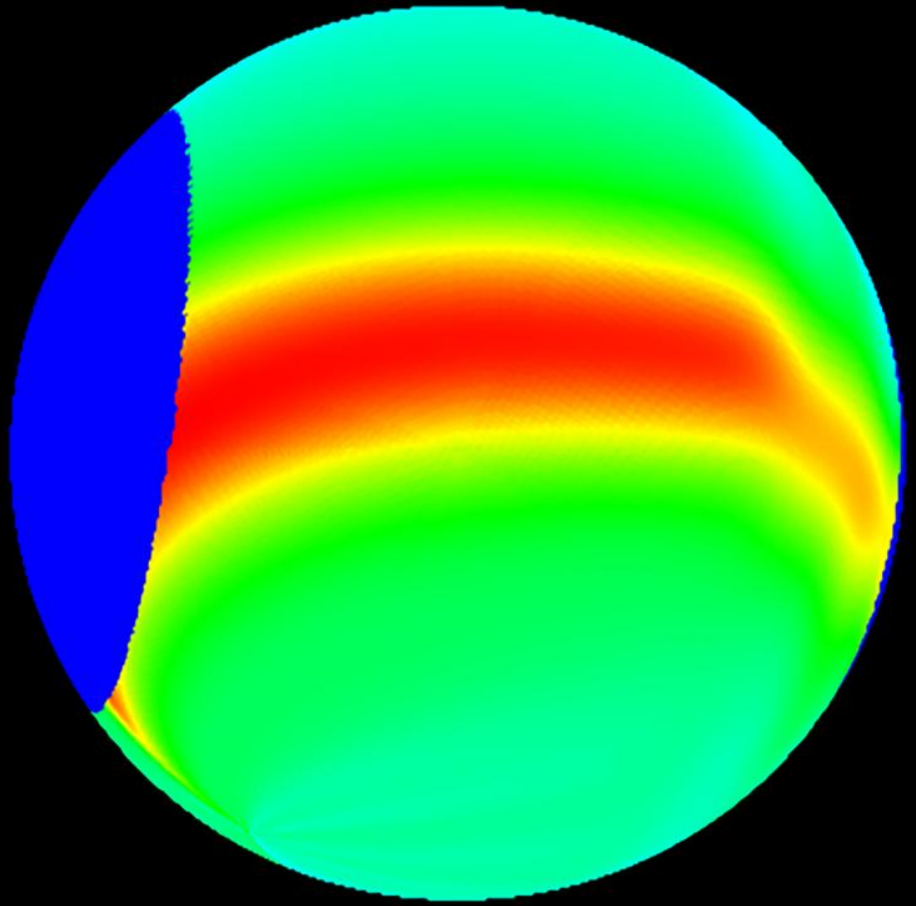
Plotting Milky Way Hydrogen Data in 3 spatial dimensions Using data from LRO-H1 (Ptarmigan Array)

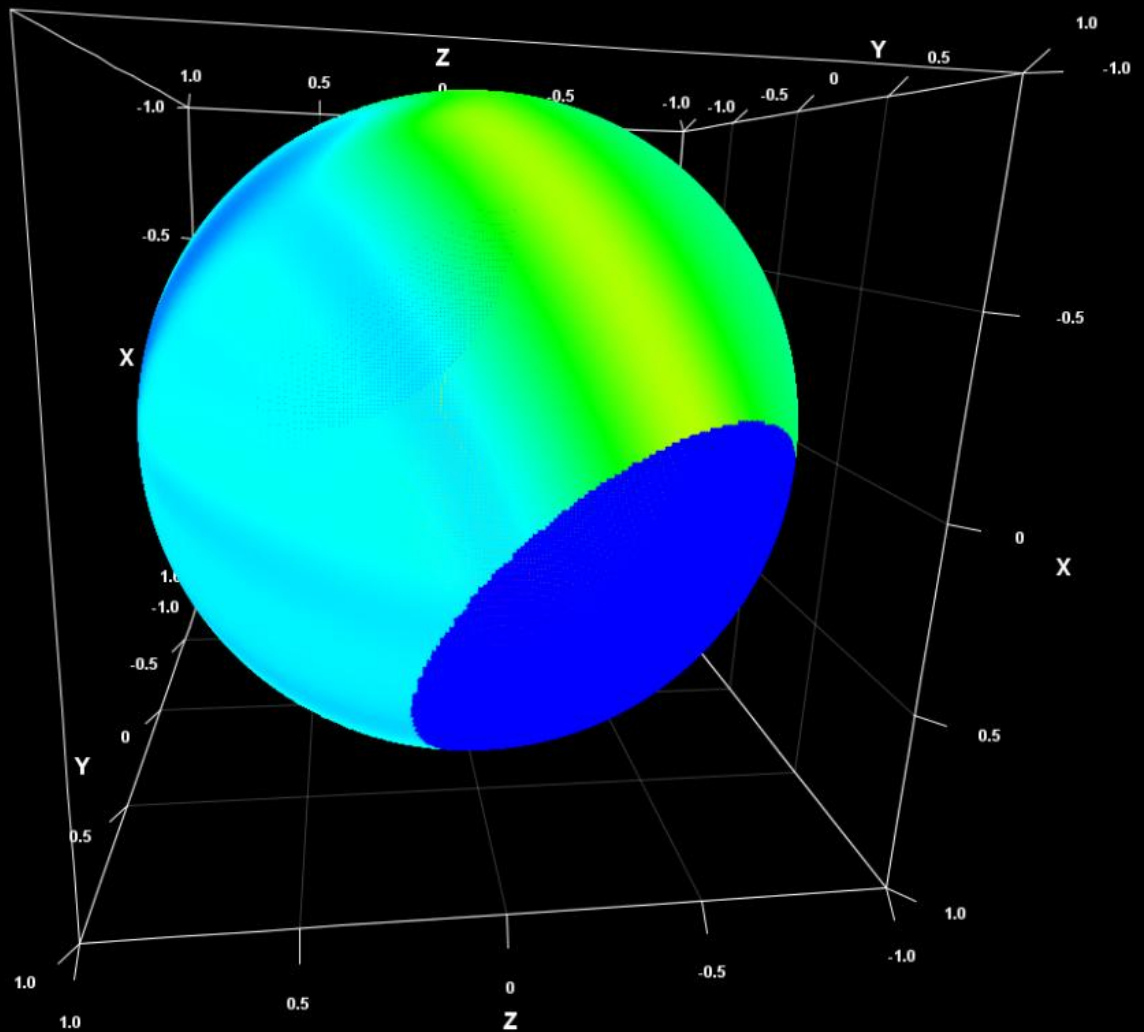


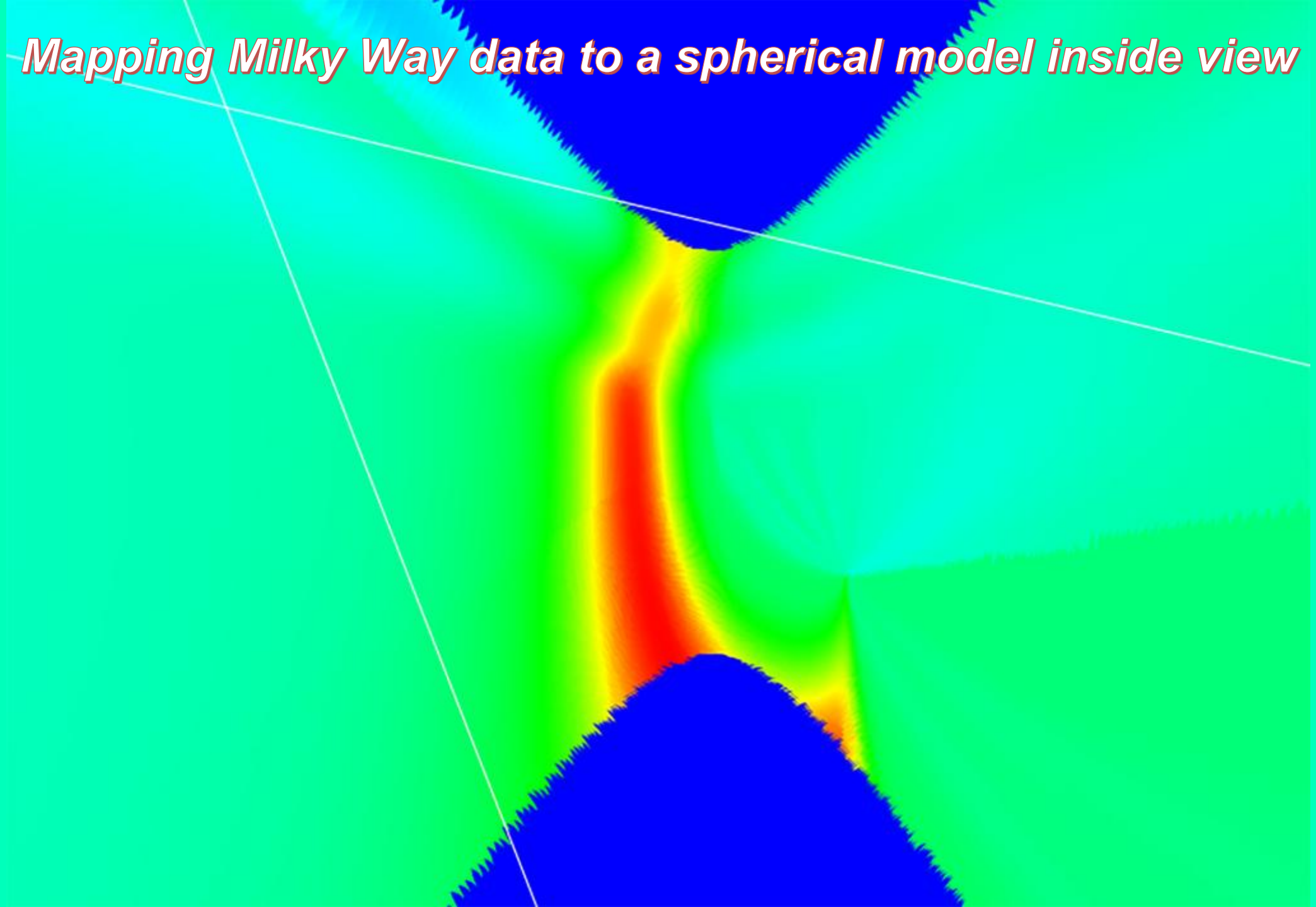


=location of our solar system

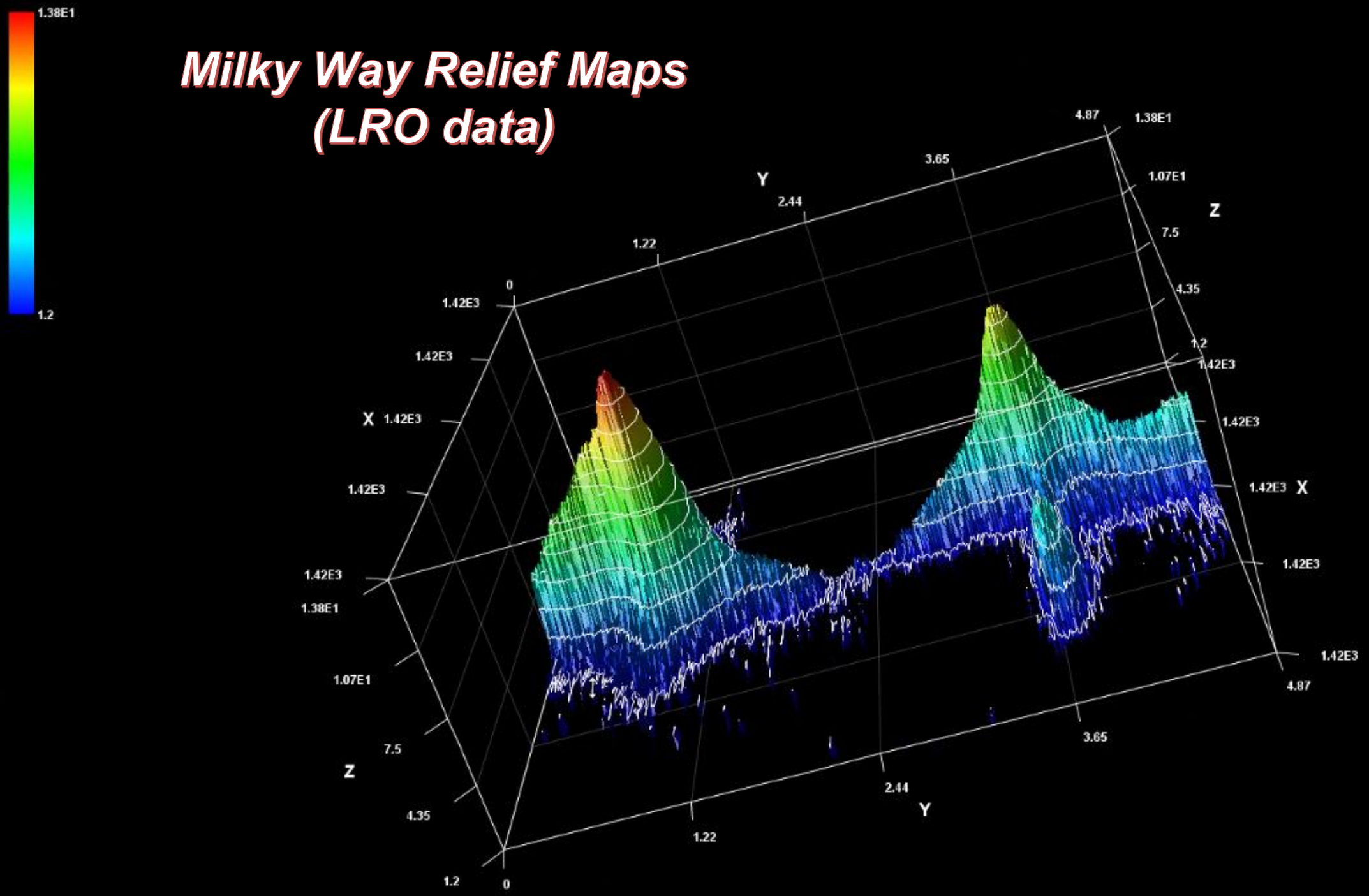
Mapping Milky Way data to a spherical model outside views

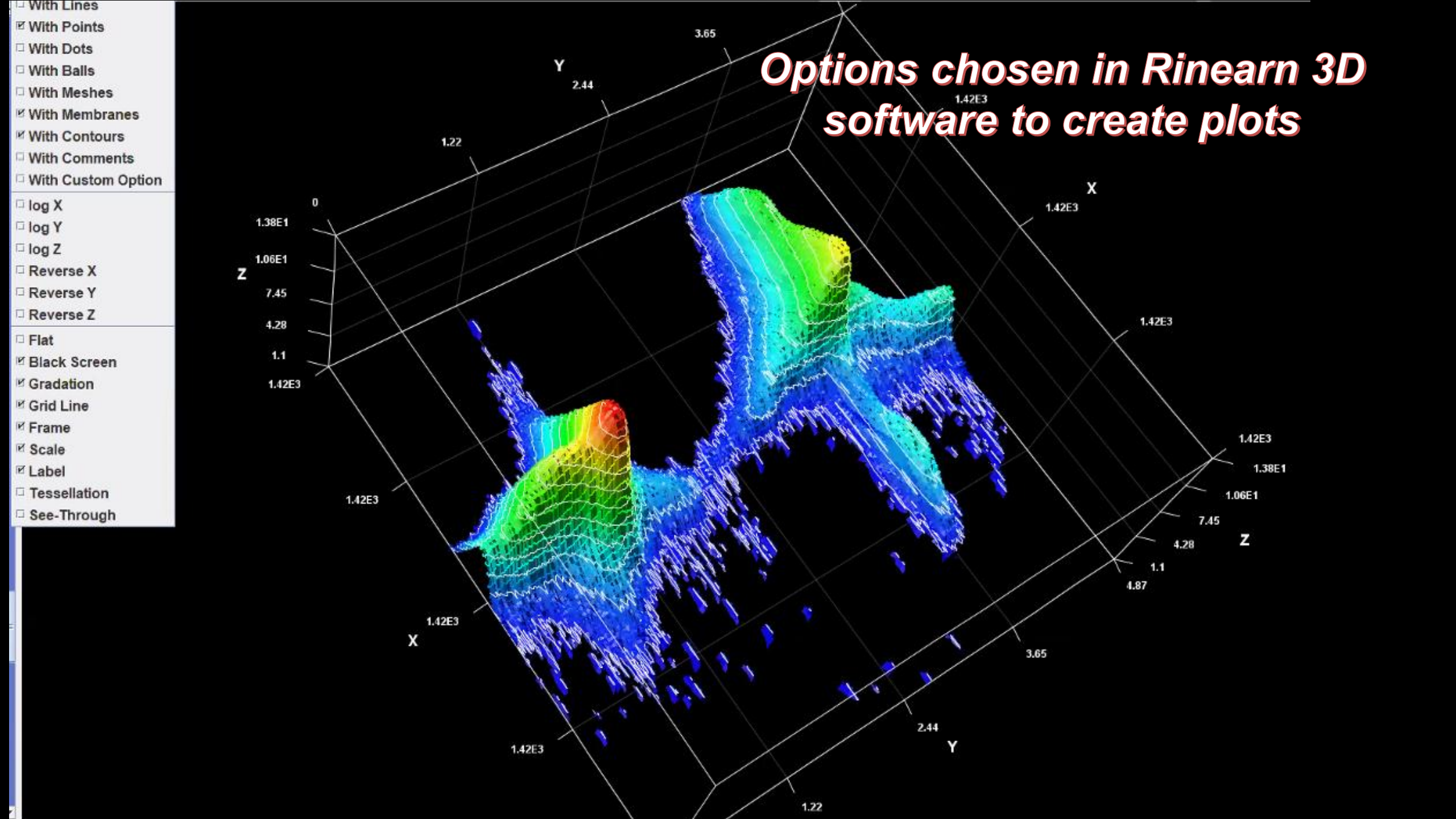


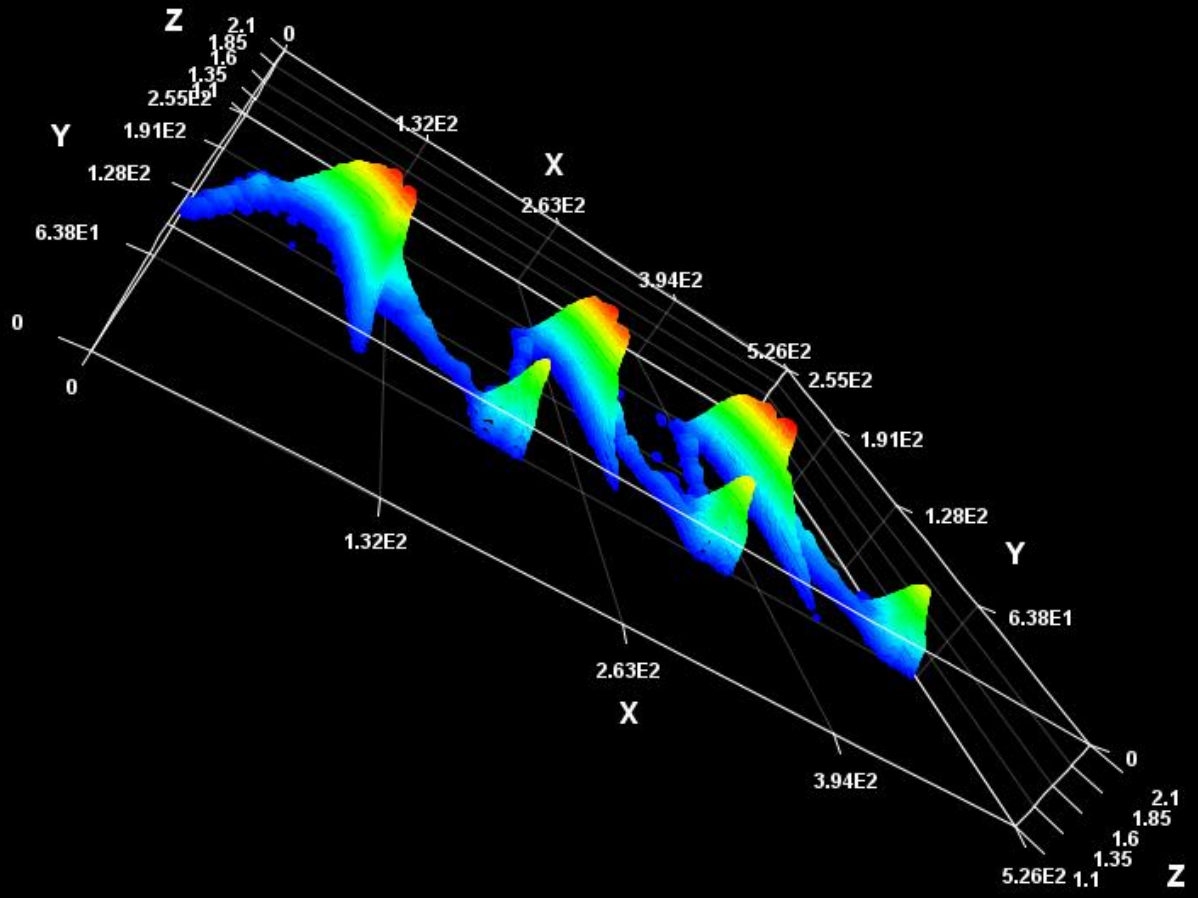


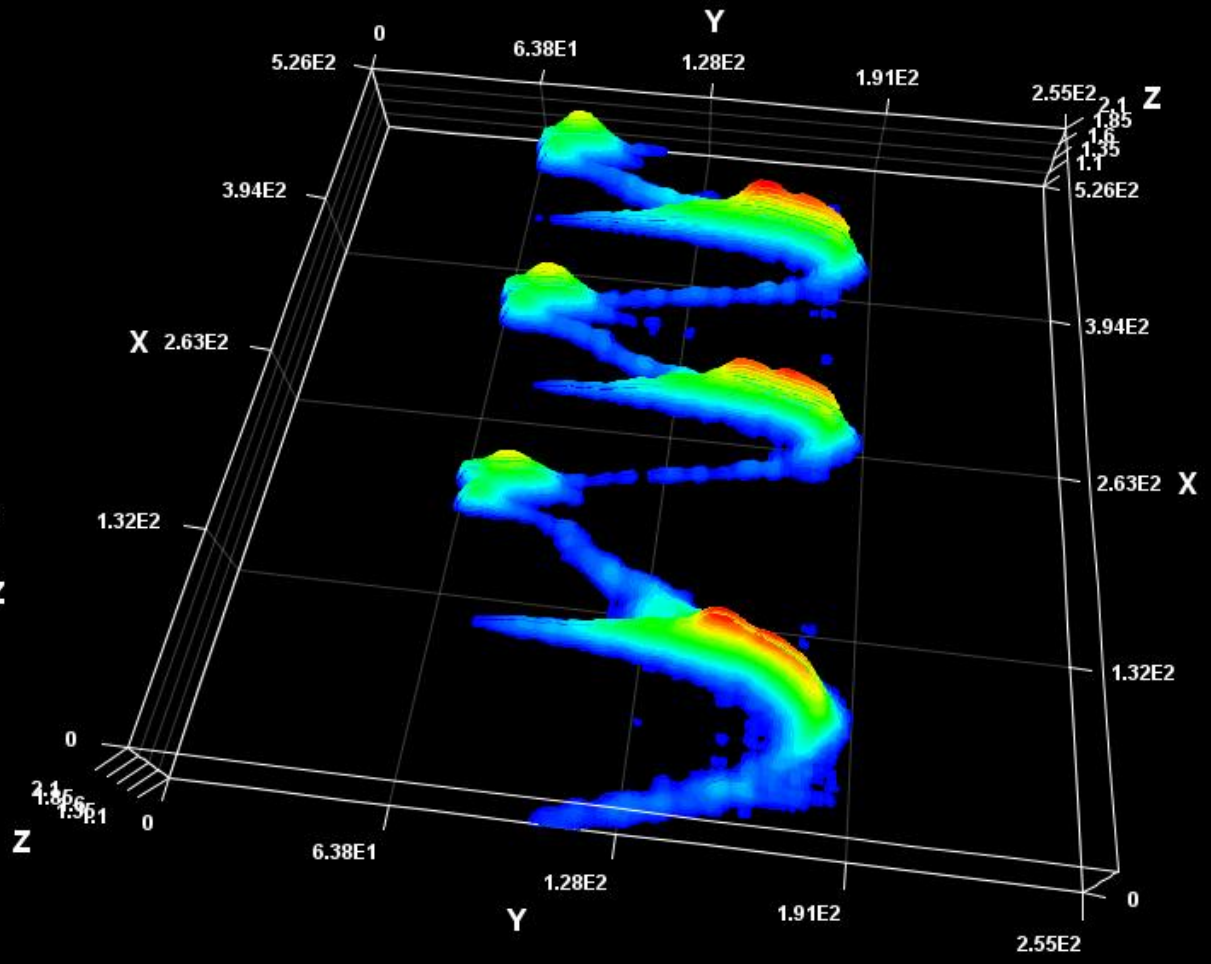

Mapping Milky Way data to a spherical model inside view

Milky Way Relief Maps (LRO data)

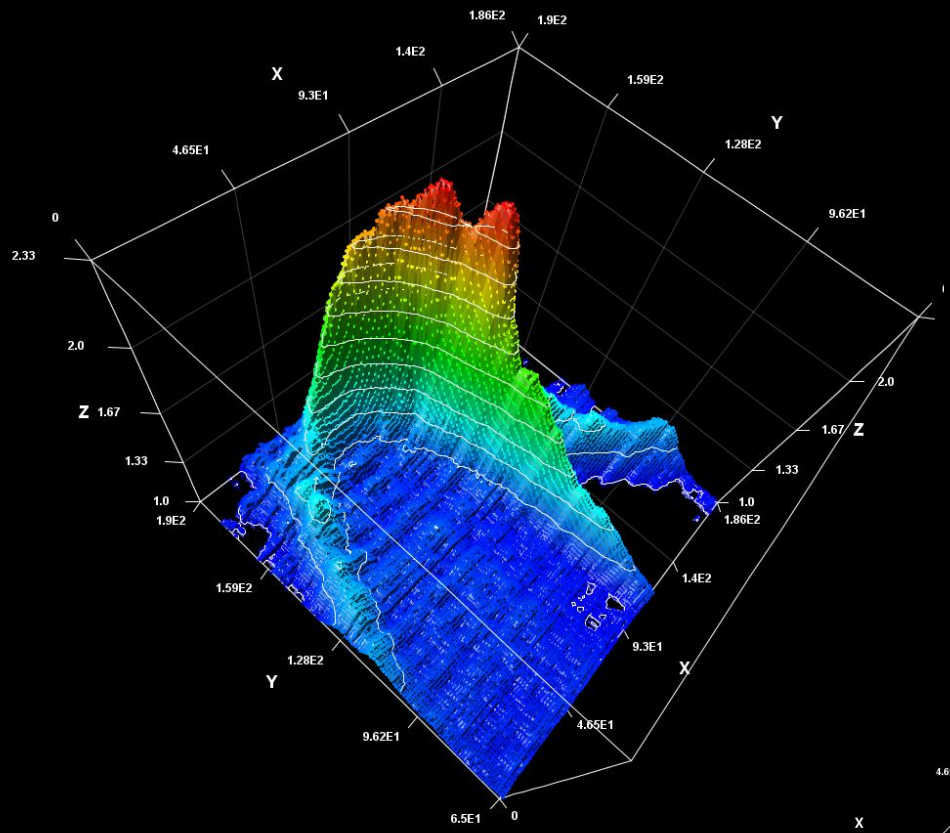


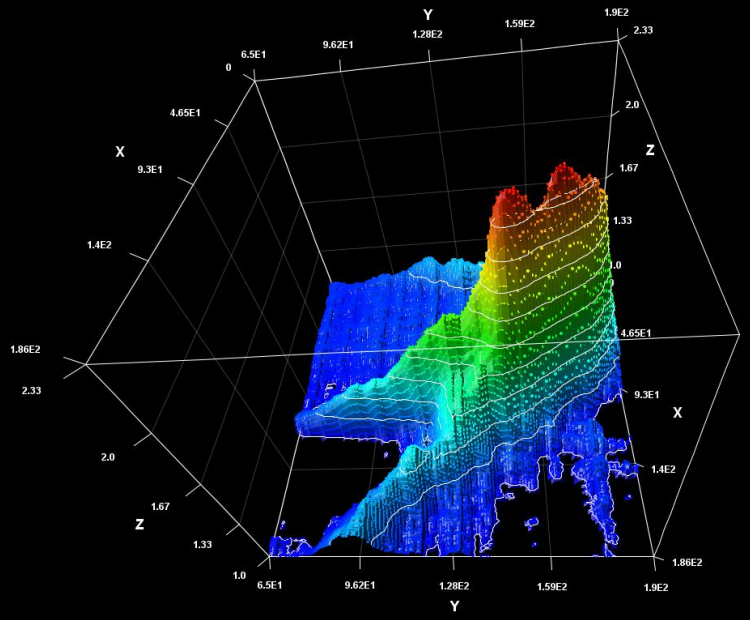

With Lines
With Points
With Dots
With Balls
With Meshes
With Membranes
With Contours
With Comments
With Custom Option
log X
log Y
log Z
Reverse X
Reverse Y
Reverse Z
Flat
Black Screen
Gradation
Grid Line
Frame
Scale
Label
Tessellation
See-Through
Options chosen in Rinearn 3D software to create plots
Y
3.65
2.44
1.22
0
X
1.42E3
Z
1.38E1
1.06E1
7.45
4.28
1.1
4.87

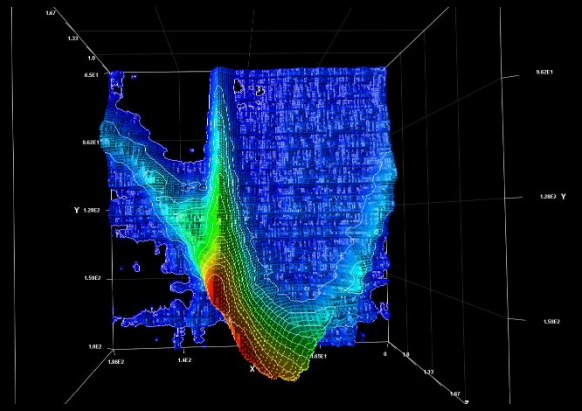


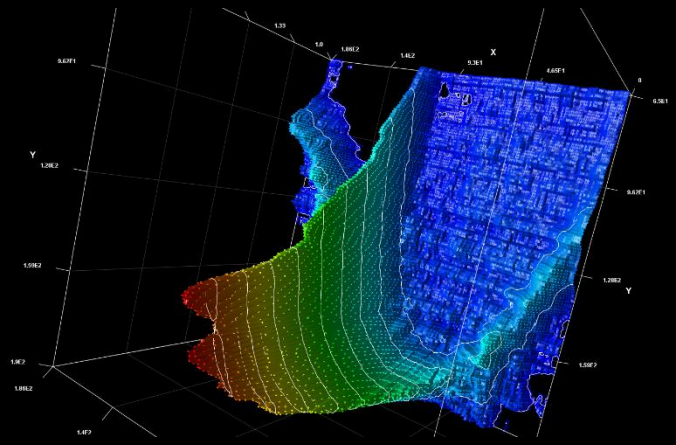


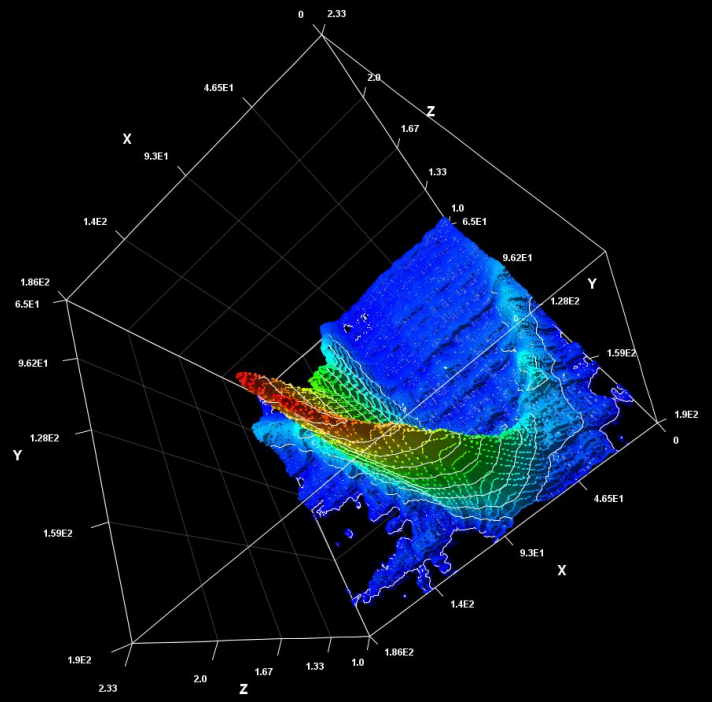
Over multiple days


X
Y
Z
1.86E2
1.9E2
1.4E2
1.59E2
1.28E2
9.62E1
9.3E1
4.65E1
6.5E1
0
2.33
2.0
1.67
1.33
1.0


Y
X
Z
1.9E2
1.59E2
1.28E2
9.62E1
6.5E1
0
4.65E1
9.3E1
1.4E2
1.86E2
2.33
2.0
1.67
1.33
1.0






X
Y
Z
0
2.33
4.65E1
9.3E1
1.4E2
1.86E2
6.5E1
9.62E1
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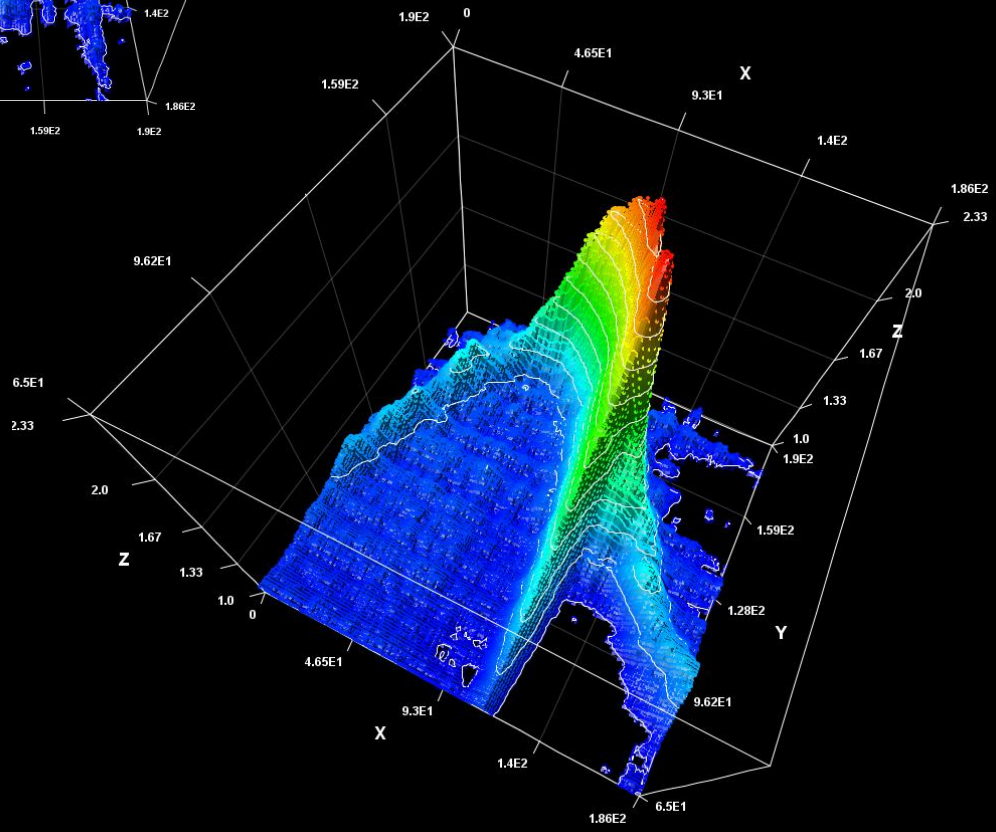
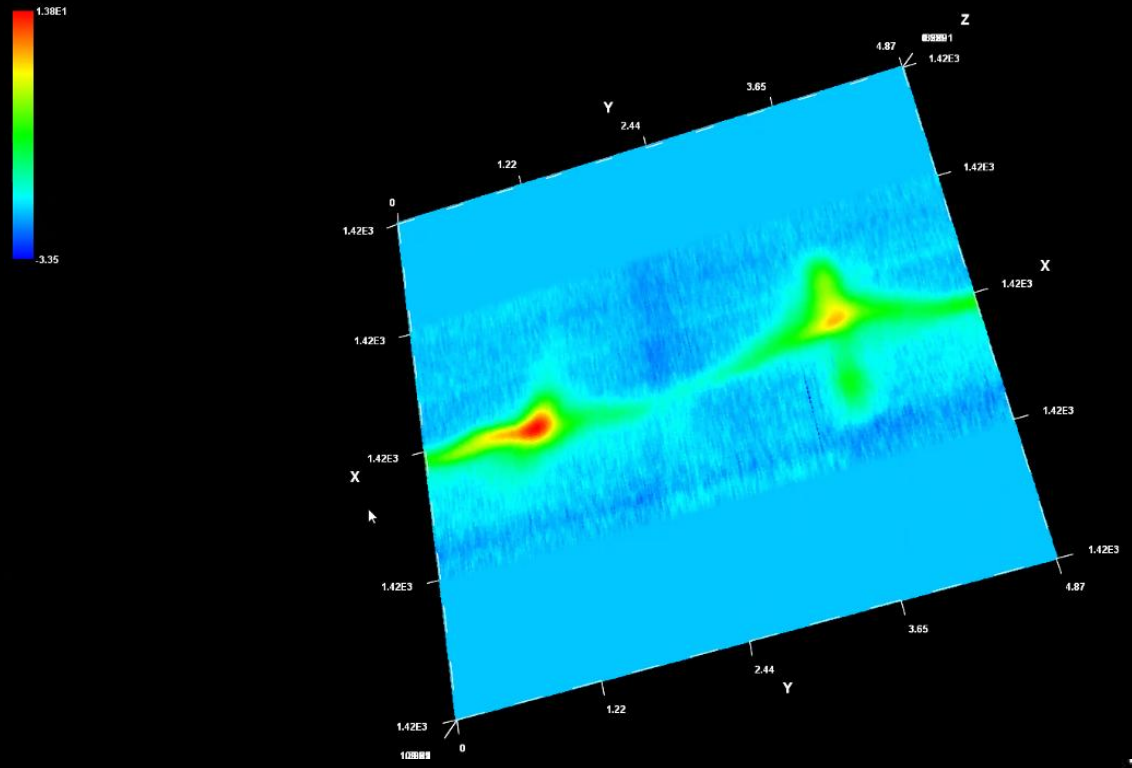
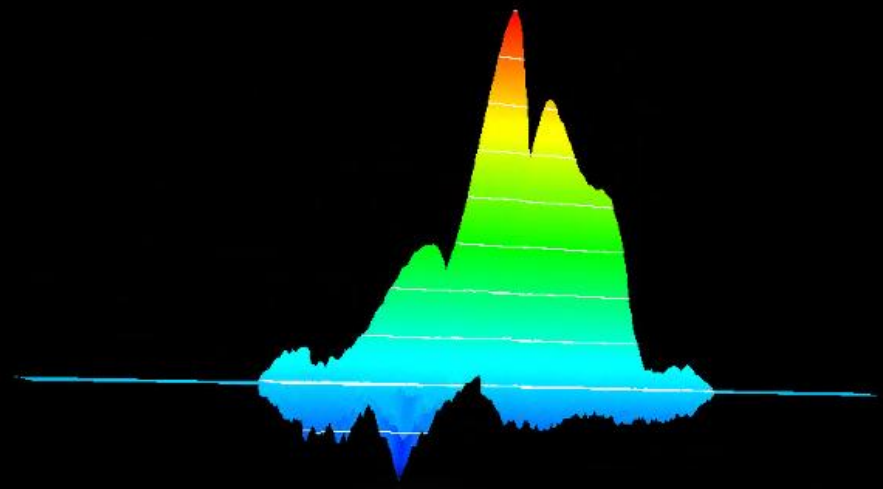
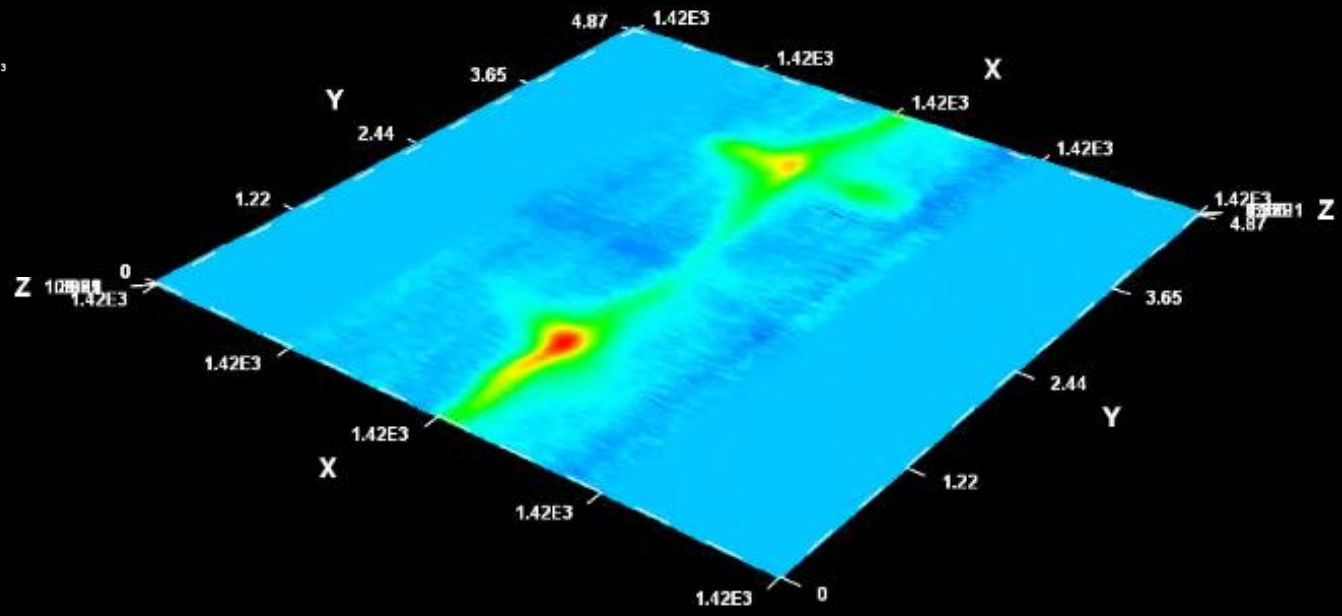
2.0
1.67
1.33
1.0


X
Y
Z
1.9E2
0
4.65E1
9.3E1
1.4E2
1.86E2
2.33
1.59E2
9.62E1
6.5E1
1.28E2
2.0
1.67
1.33
1.0

Flattening Milky Way Relief Map (LRO data)







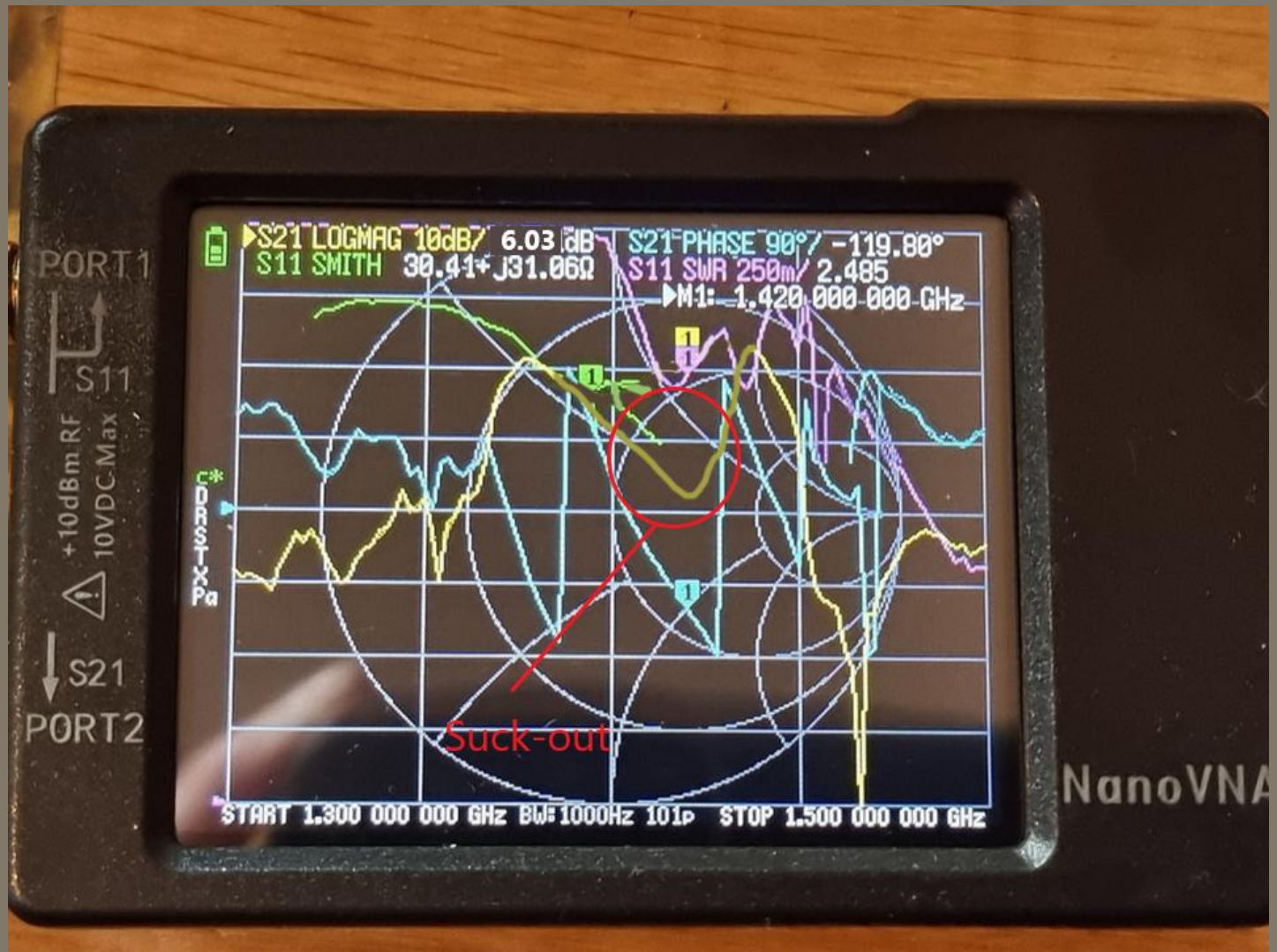
NanoVNA analysis LRO-H2(SCRT)

Problems with LRO-H2 RT performance that led to this analysis

- Very poor signal detection – hardly any hydrogen line.
- Surprise as adjacent to smaller LRO-H1(Ptarmigan Array) which was working.
- Similar arrangement to LRO-H1
  re: filters and receiver etc.

SWR 1.5 on LRO-H2 waveguide

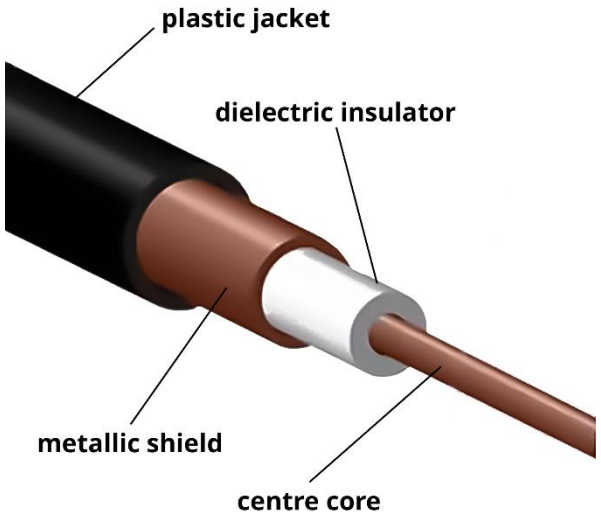
- My SAWBird (left) = S21 Logmax at 1420MHz = the response curve dips down to 6.03 db ➔ indicates “suck-out”
- Should be flat at anything up to +25dB on NanoVNA around 1420MHz



- Jason’s SAWBird (right) for comparison

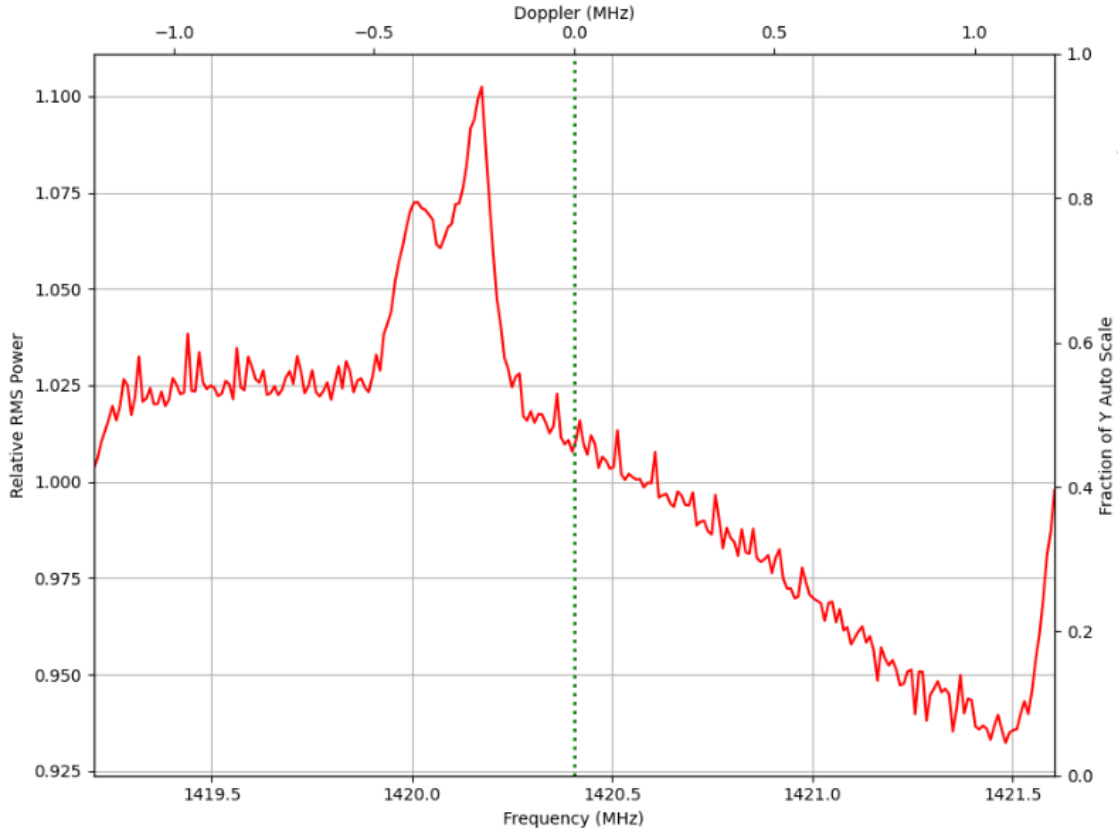
There are TWO types of SMA connectors!!!!

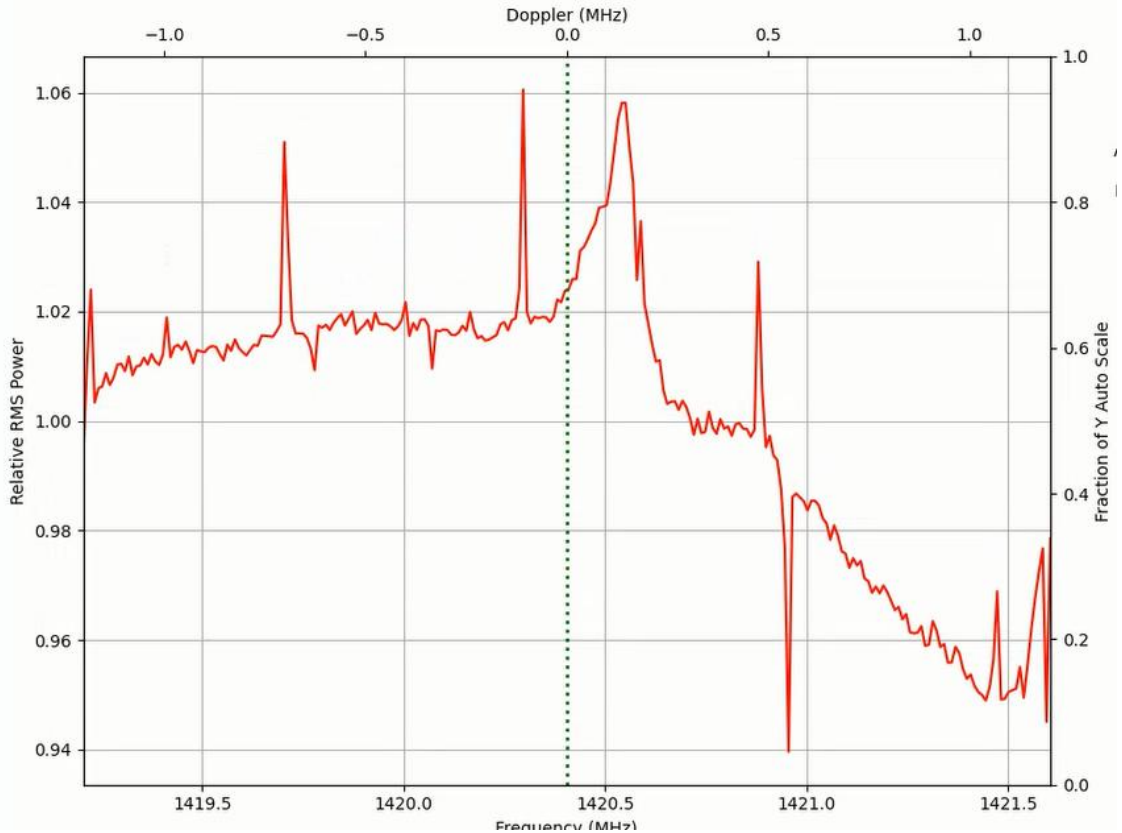
	SMA	RPSMA
Male		
Female		



Connector coax @ end male RP-SMA & connecting to female SMA so centre conductor not connected – as soon as added RP-SMA→SMA adapter into chain NanoVNA went from -32dB→-2dB

Output on ezRA's ezCol software from LRO-H2 post-sorting our adapter connectors & changing ref frequency to 1417MHz (to hit RFI there) – much better!!

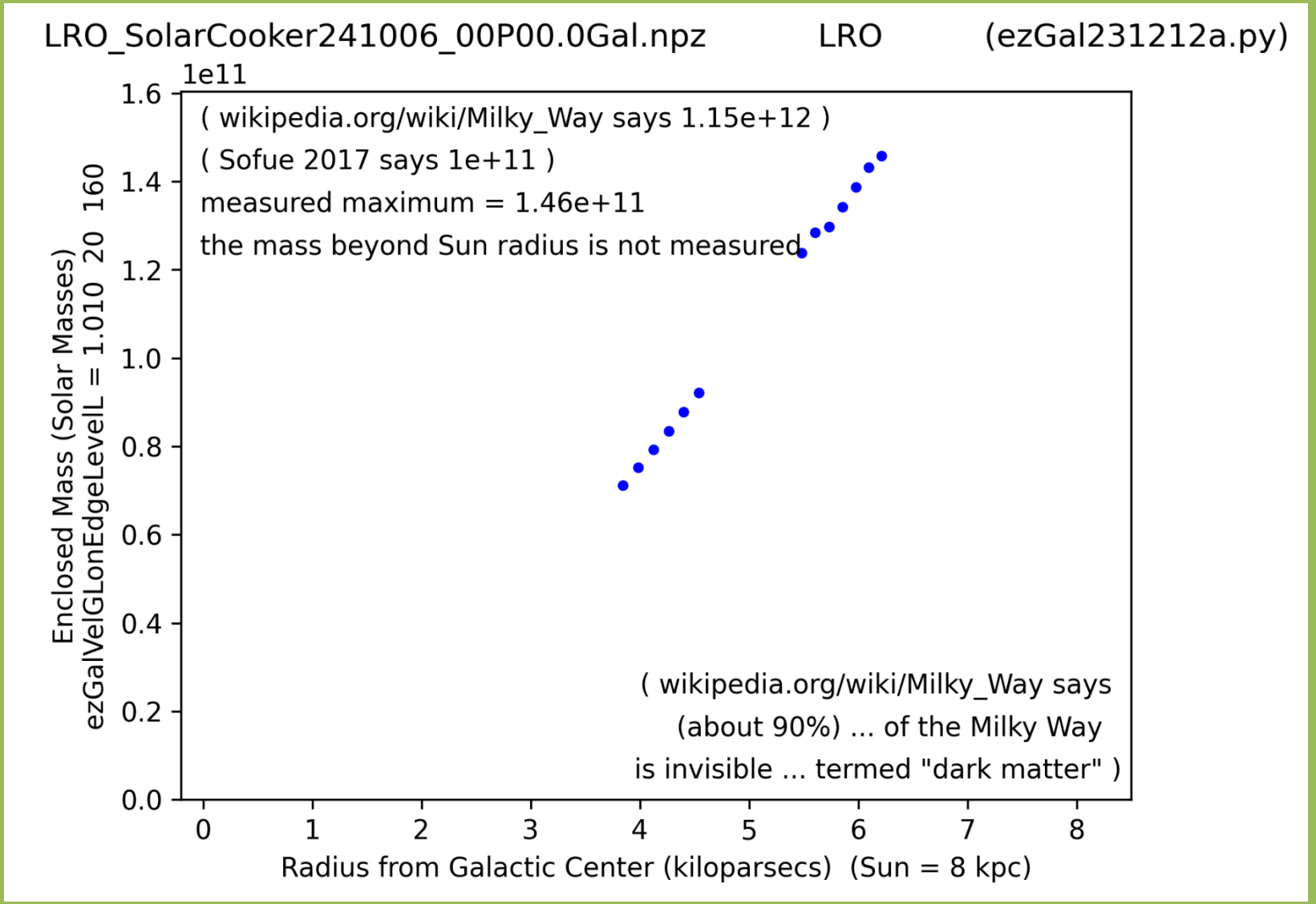




LRO-H2 Data Collection Timelapse after correcting issues.

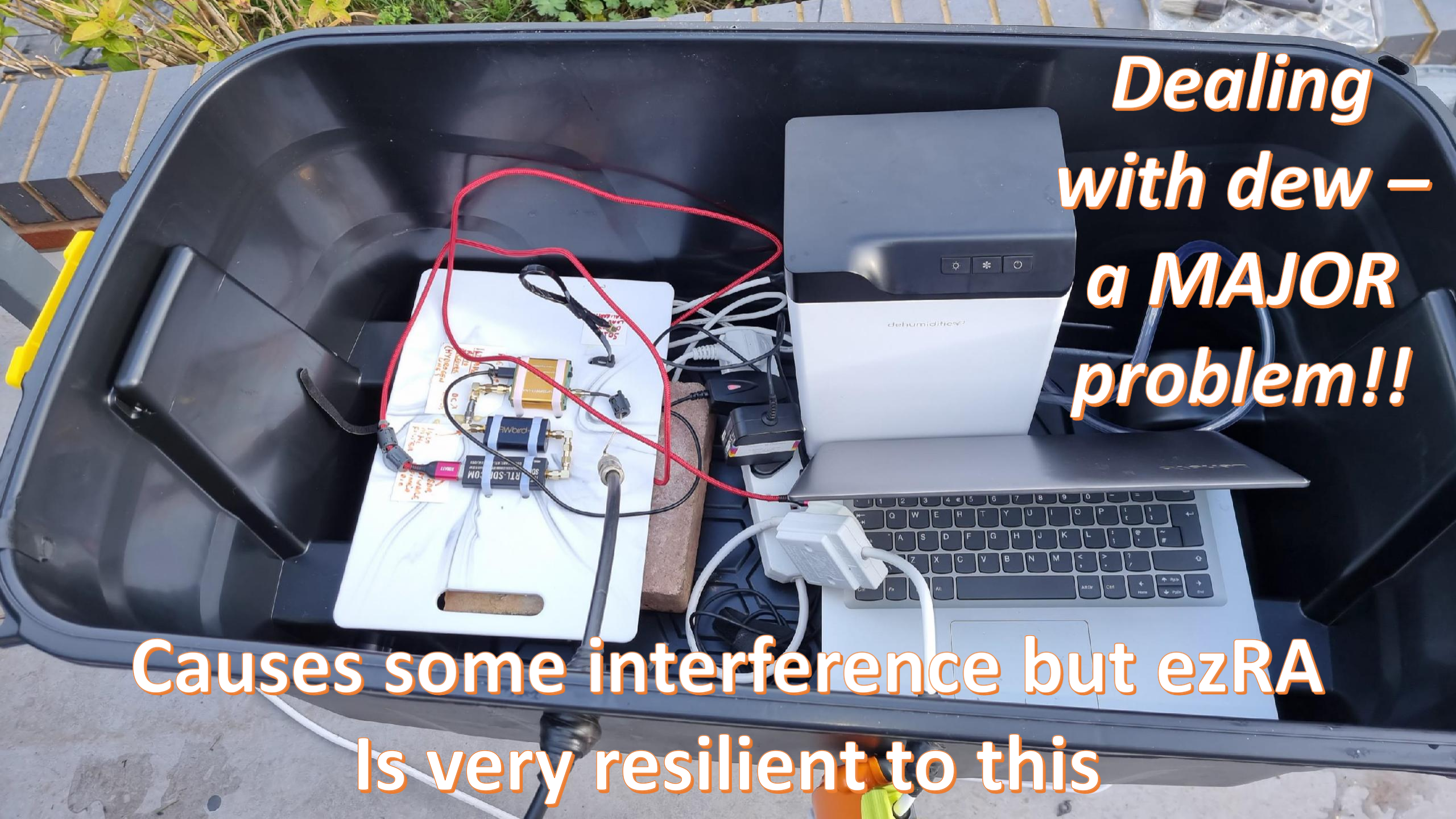
LRO-H2 Data Collection Timelapse after correcting issues.

Even on just two elevation points from this solar cooker dish allows some measurement of mass of Milky Way



Choosing a PC to record data – I chose Windows-based Mini-PC

- 2nd hand mini-PCs are very cheap - £85 buys off ebay Levono i5, 8GB RAM, 256GB SSD. A little extra increases RAM and SSD.
- RealVNC for remote connection – I opted for this rather than Remote Desktop as latter causes issues with audio inputs on remote computer – free RealVNC account gives three remote PCs per account – I now have three accounts!
- Raspberry Pis, Ardinos, Linux machines are all options too


Dealing with dew – a MAJOR problem!!
Causes some interference but ezRA
Is very resilient to this

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