Amateur Radio Astronomy

Presented by:

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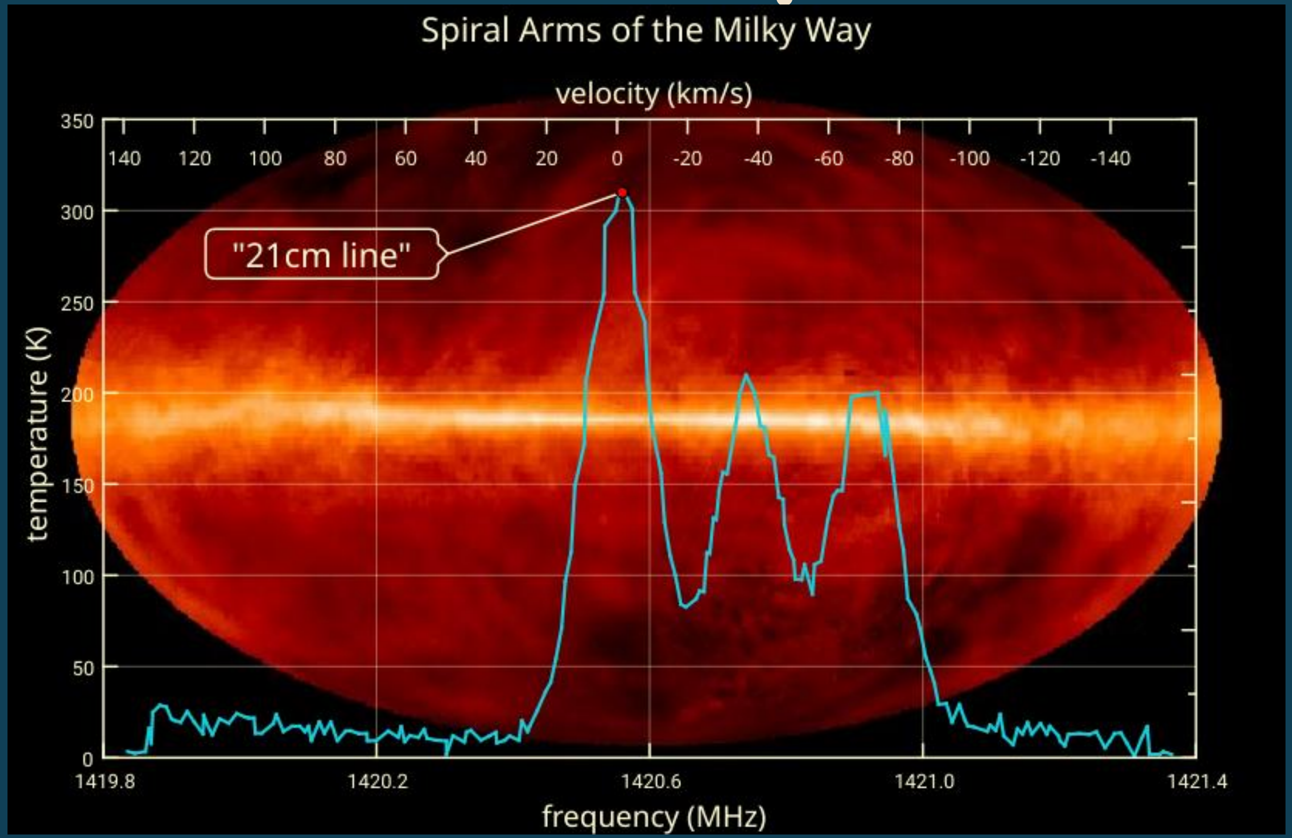
Our Project

- We built an **amateur radio telescope** horn antenna using easily available materials and RF equipment, **that can detect neutral hydrogen radio emissions at 1420.4MHz.**

Why hydrogen line?

- Hydrogen line systems offer a low barrier of entry
  - Easy to build, relatively cheap
- Educational! Provides educational opportunities in:
  - Radio astronomy and astrophysics fundamentals
  - Antenna design and fabrication
  - RF front end design
  - Lots of further development pathways to larger and more sensitive equipment (e.g. larger antenna, more sensitive electronics, dual antenna interferometry)



The Fullness of Space by Gareth Wynn-William, https://books.google.com.sg/books?id=wjxrloC2gyMC&pg=PA36&redir_esc=y#v=onepage&q&f=false
https://www.gb.nrao.edu/fgdocs/HI21cm/21cm.html

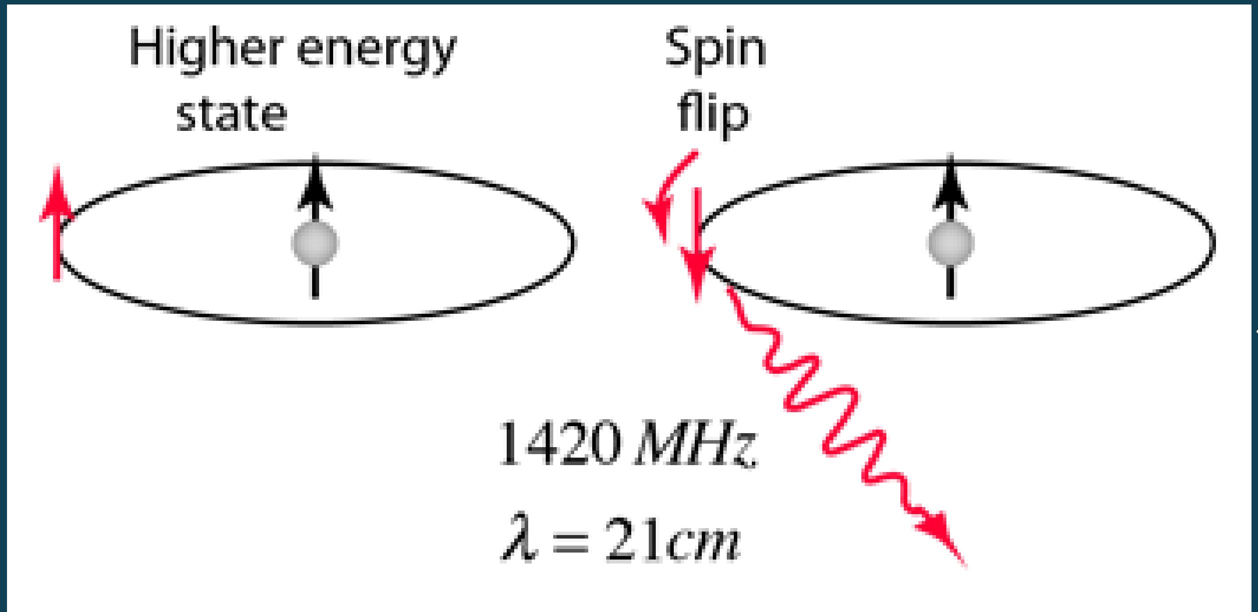
Working Principles (Part 1)

Hydrogen Line Emissions – The 21cm Line

Planck-Einstein relation $E = hf$

When hydrogen atom undergoes a spin-flip transition, it emits a photon with λ=21.1cm, or f=1420.4MHz.

- Massive clouds of hydrogen in space will emit numerous photons
- Low frequency/Long wavelength photons can penetrate clouds of cosmic dust that blocks visible light



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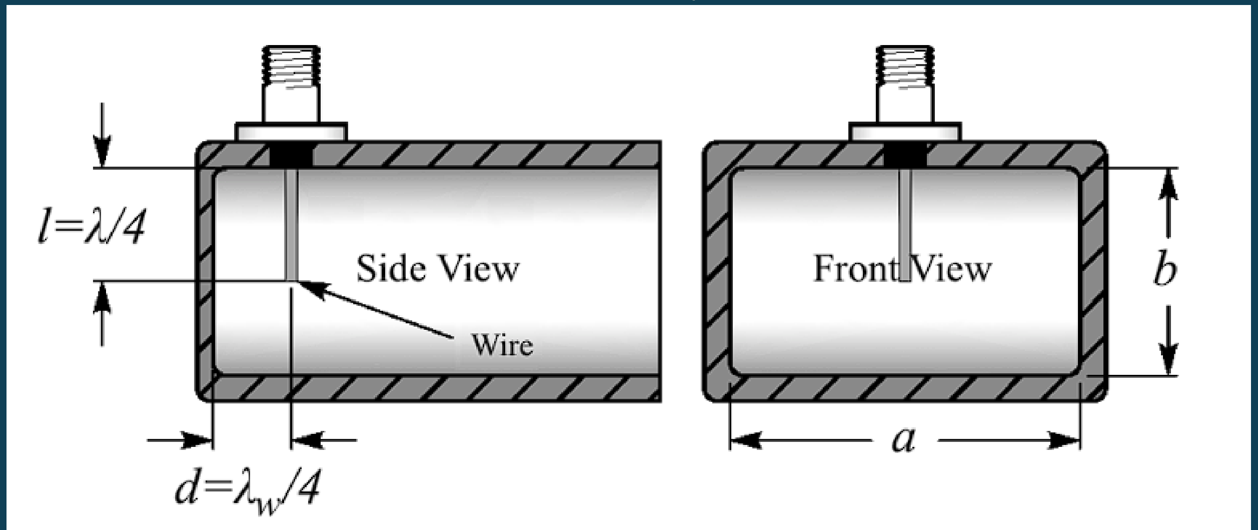
Working Principles (Part 2)

Probe feed size

Actual antenna is designed to be quarter wavelength, so the probe antenna length *l* needs to be:

- $l = \frac{\lambda}{4} = \frac{0.212}{4} = \mathbf{0.053m}$



Waveguide dimensions

Cut-off λ of rectangular waveguides in *a* dimension [1]

$$\lambda_{c,a} = 2a = \mathbf{0.168} * 2 = 0.336$$

$$v_{c,a} = 891.927\ MHz$$

<u>Waveguide is a high pass filter.</u>

Optimal frequency to minimise dispersion = 1.25x & 1.9x the cut-off [2]

Lower frequency $v_{o,l}$ = 1114.91 MHz

Higher frequency $v_{o,h}$ = 1694.66 MHz

Cut-off λ of rectangular waveguides in *b* dimension

$$\lambda_{c,b} = 2b = \mathbf{0.105} * 2 = 0.210$$

$$v_{c,b} = 1427.16\ MHz$$

[1]: https://www.ece.mcmaster.ca/faculty/nikolova/antenna_dload/current_lectures/LectureNotesAntennas_Nikolova.pdf
[2]: https://science.nrao.edu/opportunities/courses/era/

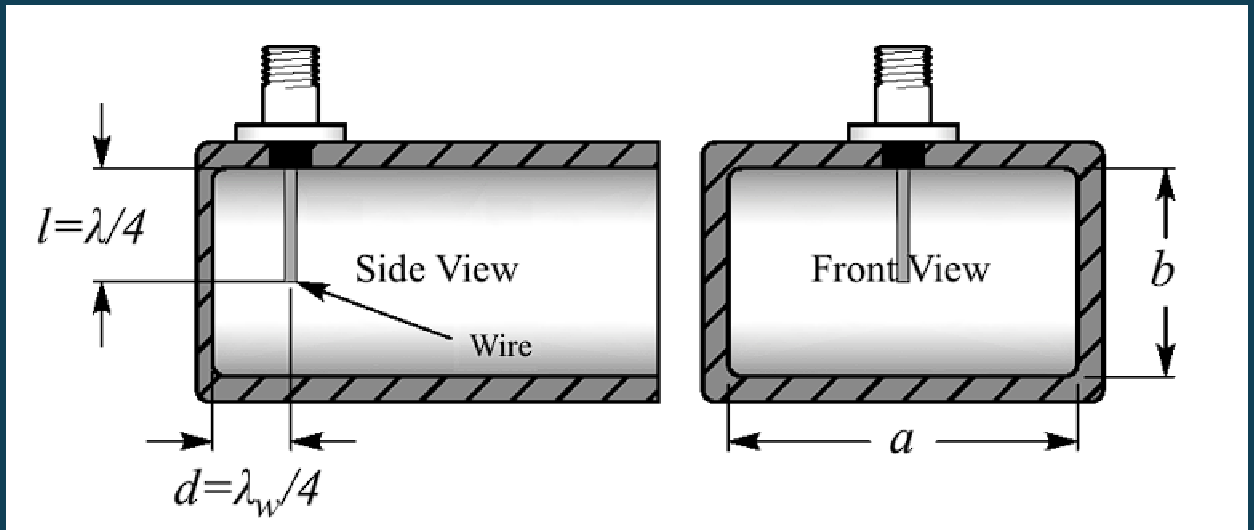
Probe feed position

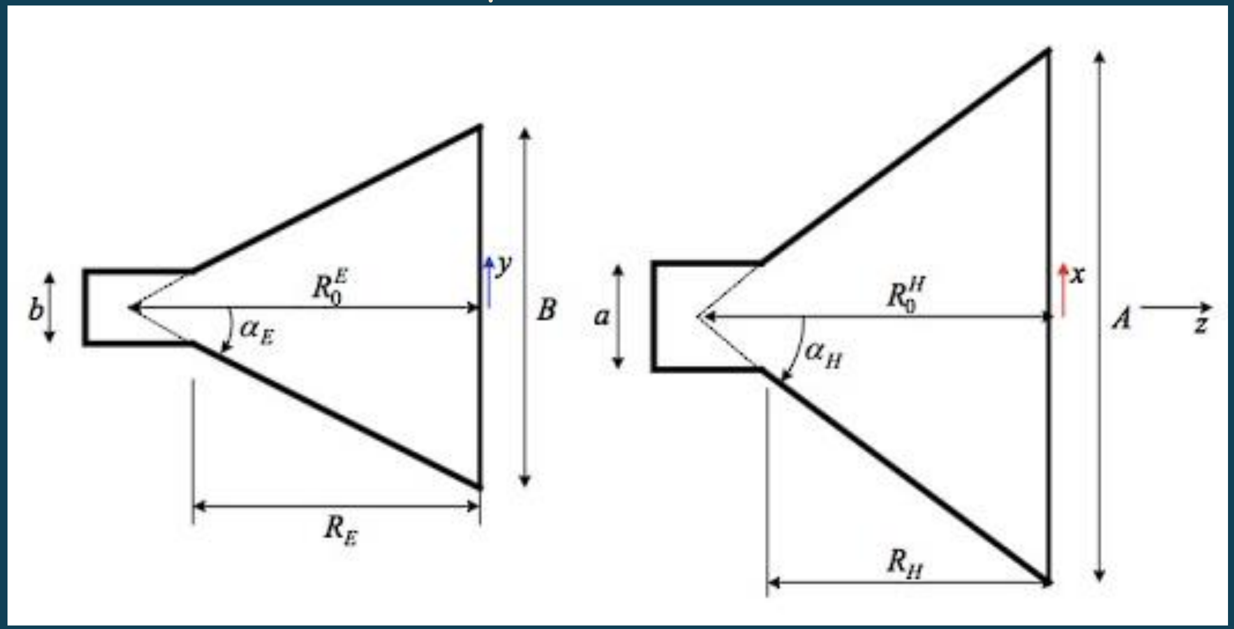
$$\lambda_W = \frac{c}{v}\left[1-\left(\frac{v_c}{c}\right)^2\right]^{-\frac{1}{2}}$$

$$= \frac{299\ 702\ 547}{1420.4*10^6}\left[1-\left(\frac{891.9*10^6}{1420.4*10^6}\right)^2\right]^{-\frac{1}{2}}$$

$$= 0.271\ (3sf)$$

$$d = \frac{\lambda_W}{4} = \mathbf{0.0678}\ (3sf)$$





Antenna dimensions (size of horn)

Set A = **0.6m**

$$B = \frac{1}{2}\left(b + \sqrt{b^2 + \frac{8A(A-a)}{3}}\right)$$

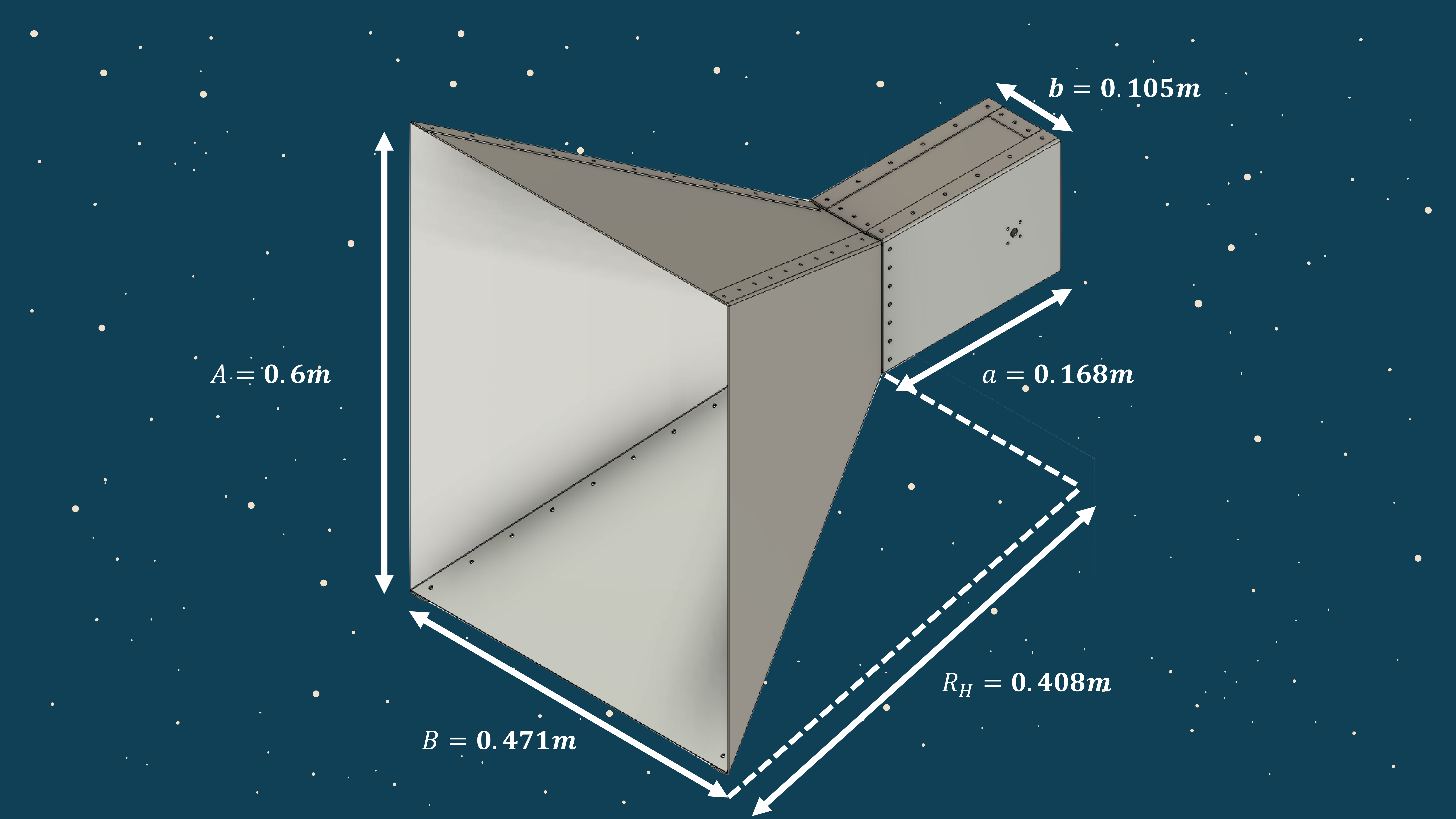
$$B = \frac{1}{2}(0.105 + \sqrt{0.105^2 + \frac{8(0.6)(0.6-0.168)}{3}}$$

$$B = \mathbf{0.471m}$$

$$R_H = \frac{A(A-a)}{3\lambda}$$

$$R_H = \frac{0.6(0.6-0.168)}{3(0.212)}$$

$$R_H = \mathbf{0.408m}$$

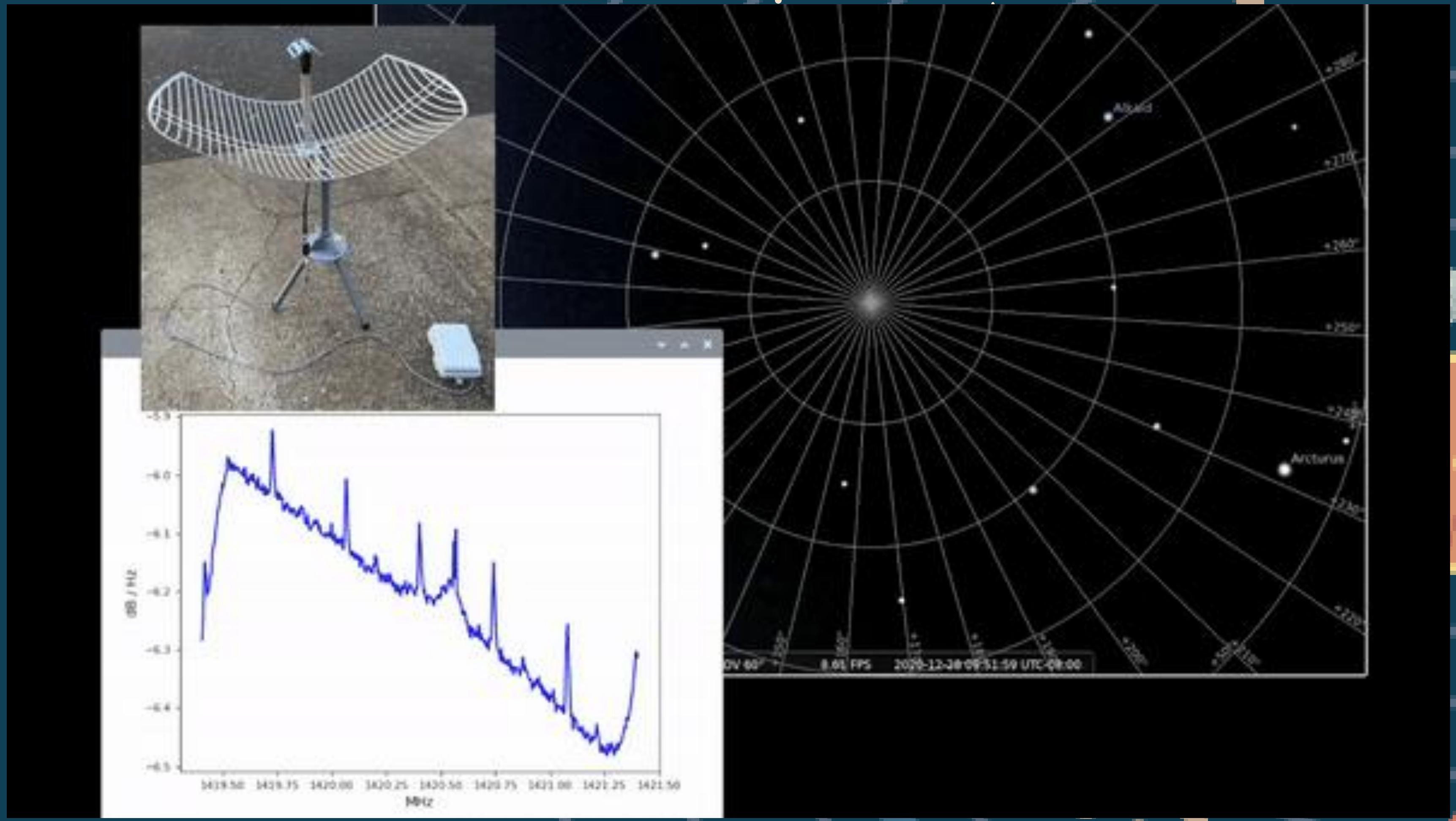


$b = 0.105m$
$A = 0.6m$
$a = 0.168m$
$R_H = 0.408m$
$B = 0.471m$

Working Principles (Part 3)

What can this system achieve?

- ✓ **Tier 1: Produce spectrographs of the hydrogen line**
- ✓ Tier 2: Mapping galactic hydrogen intensity
- ✓ Tier 3: Determine the velocity of rotation of the Milky Way vs distance away from us



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Presence of Hydrogen emissions!

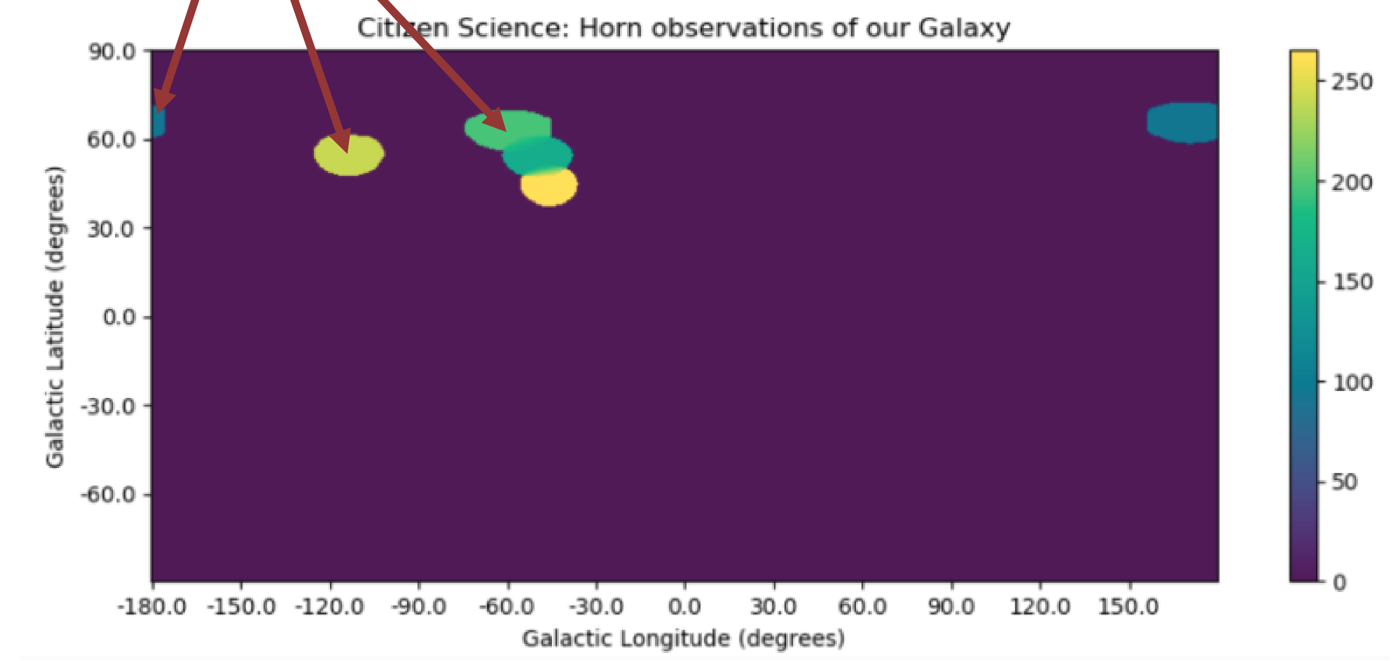

Figure 6: Integrated Intensity Map (Kelvins-km/sec) on a Galactic Longitude, Latitude Map. This is a whole sky map with X axis of Galactic Longitude and Y axis is the Galactic Latitude. The color indicates the signal strength.

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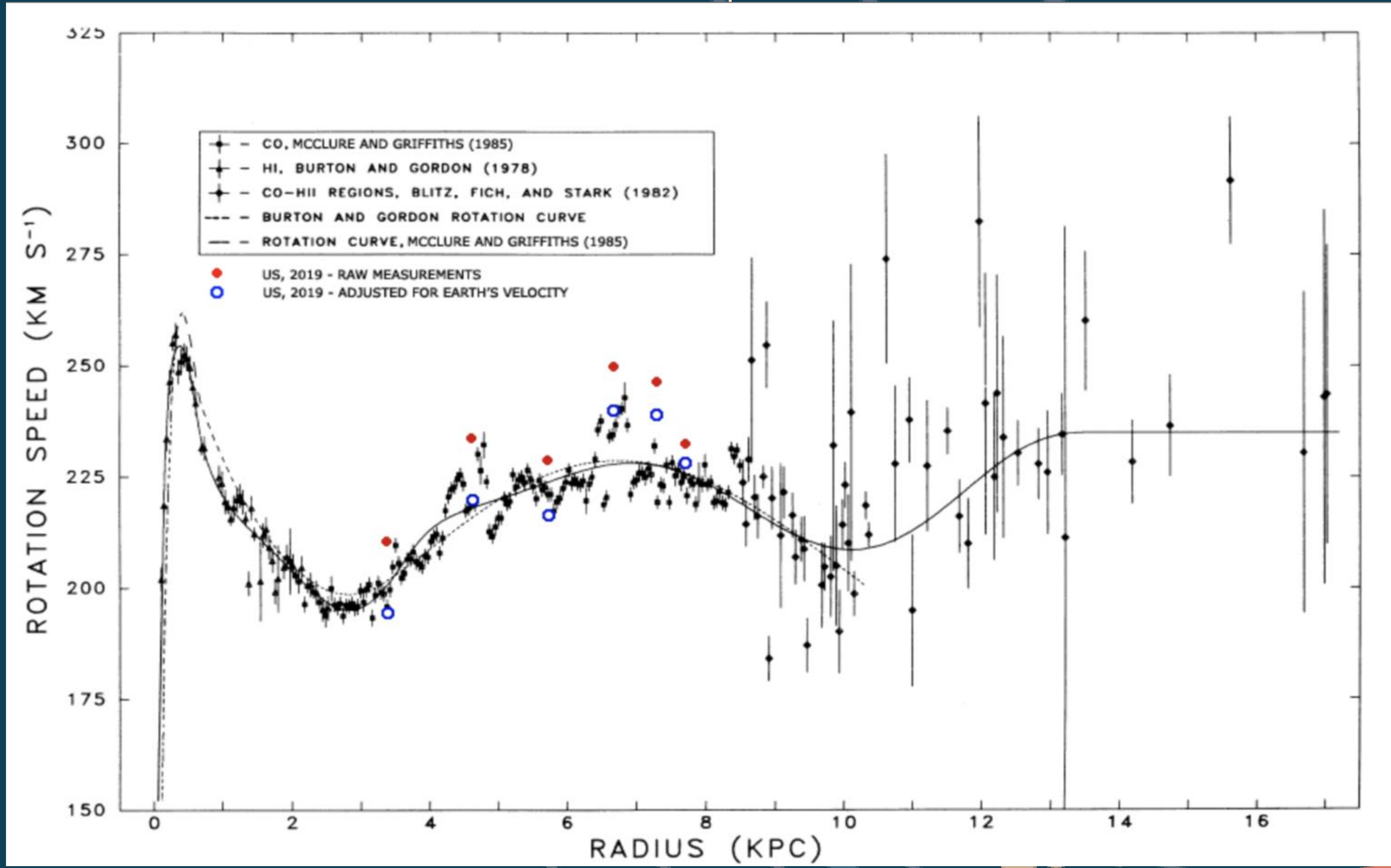
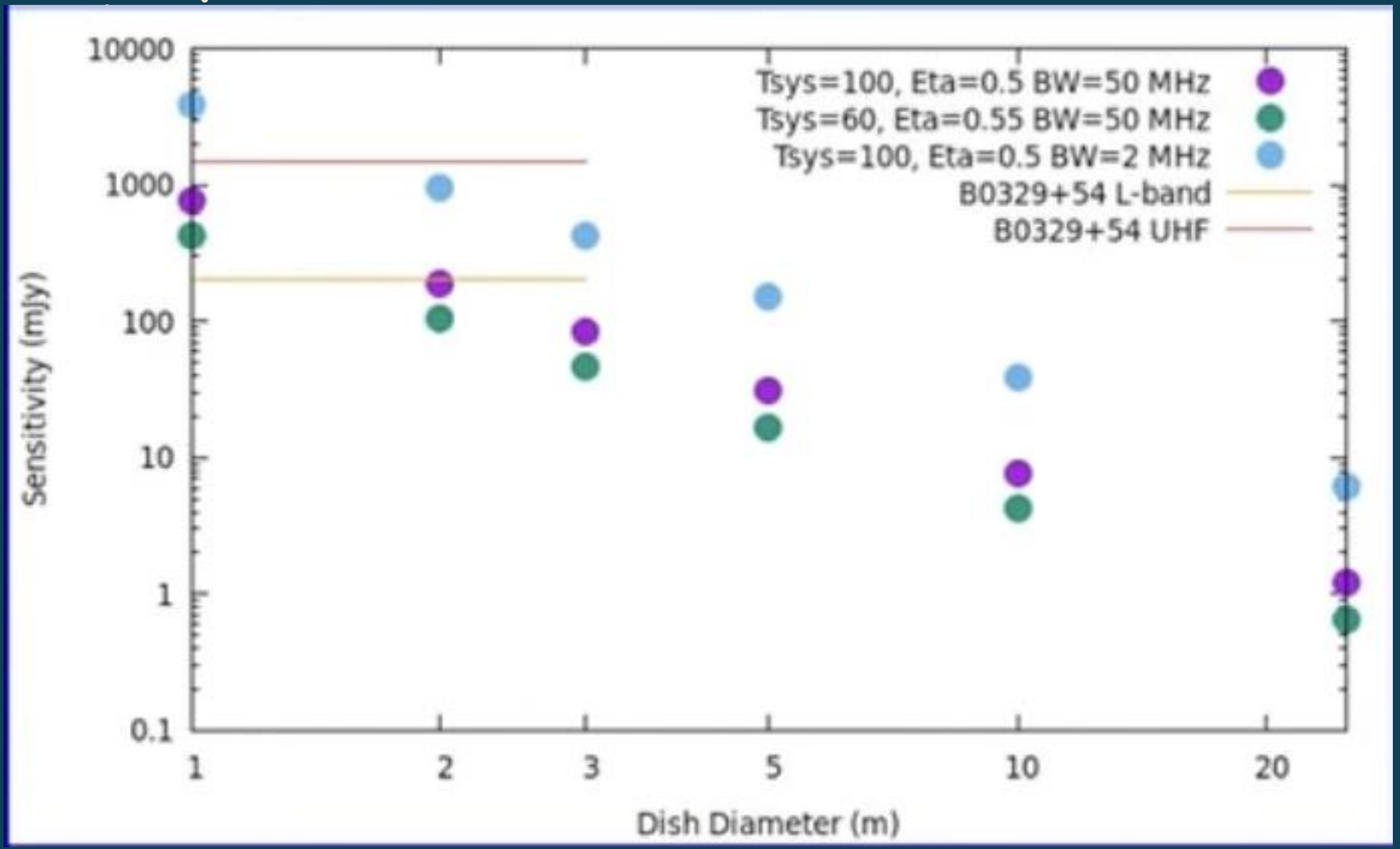


Working Principles (Part 4)

What can't this system do?

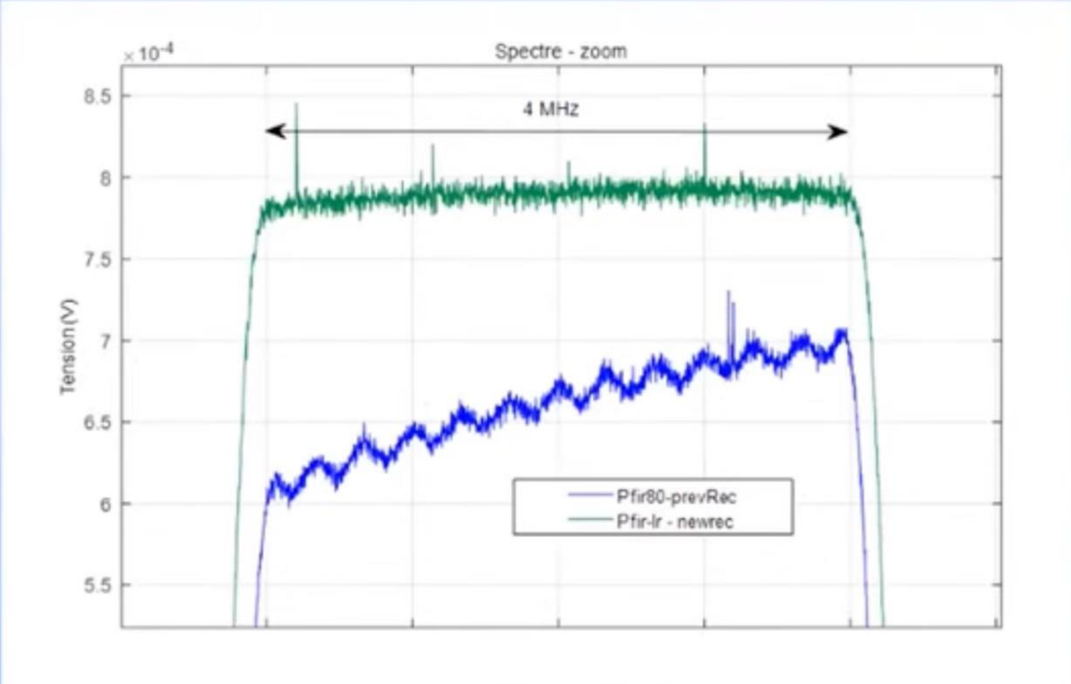
- **Do <u>pulsar detection</u> due to small size of telescope (limited by waterjet size)**
  - Pulsar detection requires minimally ø=0.8m antenna, or optimally ø=1.6m. Alternatively, signals from multiple antennas can be averaged
  - Very long time needed (1 week!)
- Observe <u>extragalactic hydrogen clouds</u> (e.g. Supernova remnants, Star formation regions)
- <u>Interferometry and synthetic apertures</u> requires at least 2 antennas and 2 RF frontends which falls outside the budget and time constraints

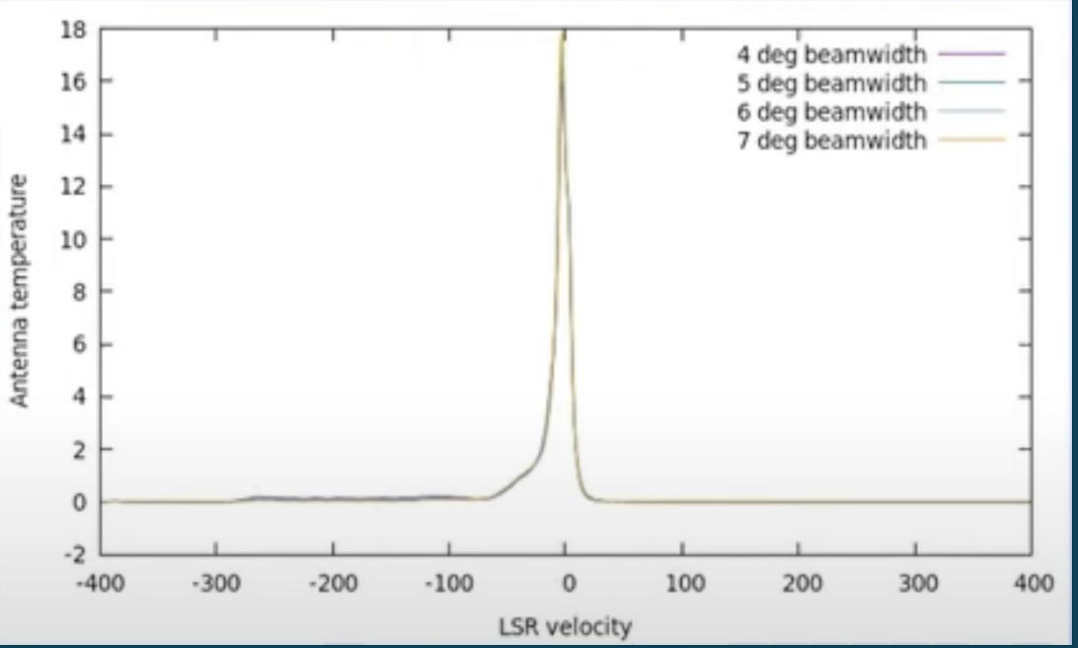


Working Principles (Part 4)

What can't this system do?

- Do pulsar detection due to small size of telescope (limited by waterjet size)
- **Observe extragalactic hydrogen clouds (e.g. Supernova remnants, Star formation regions)**
  - Emissions are extremely weak, and system needs to have extremely good spectral flatness
- Interferometry and synthetic apertures requires at least 2 antennas and 2 RF frontends which falls outside the budget and time constraints





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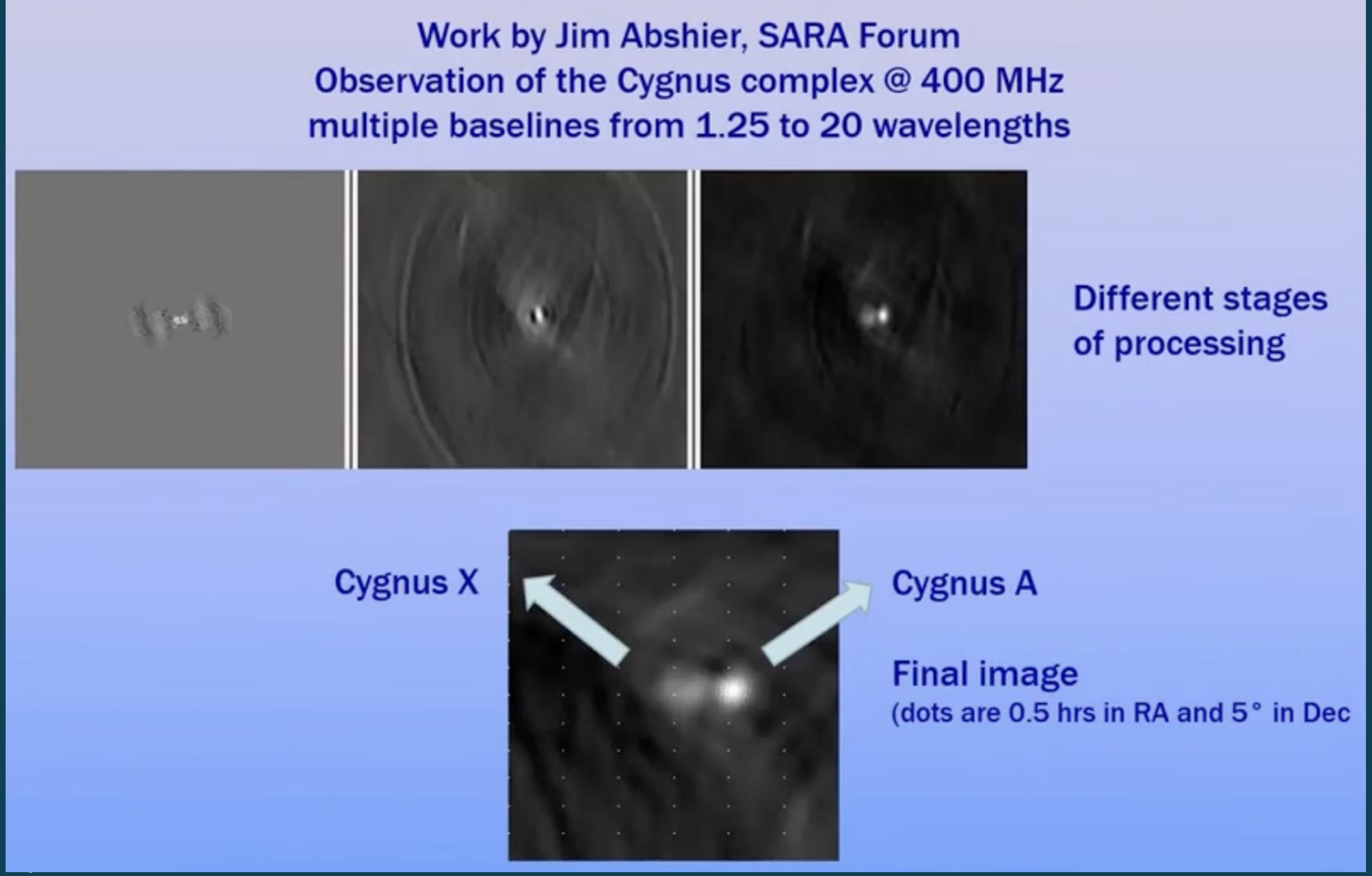
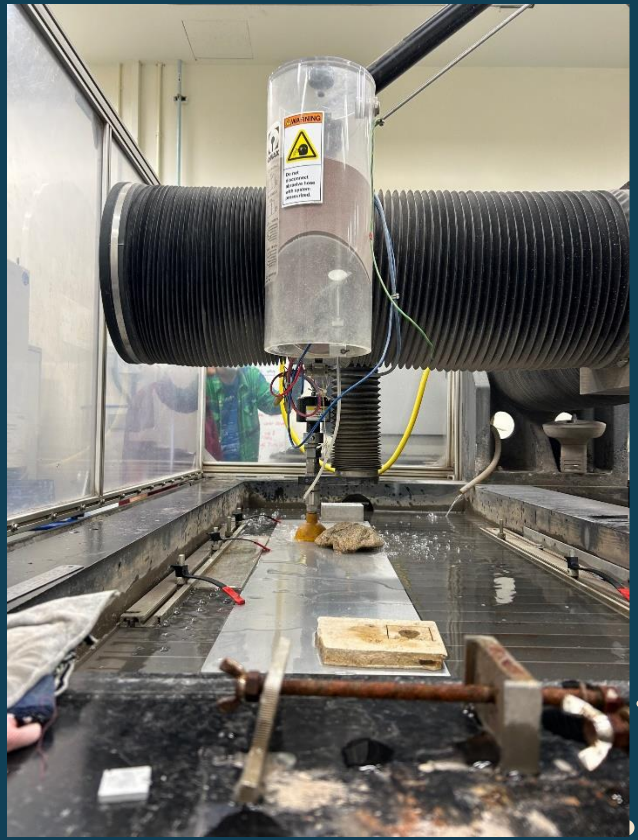
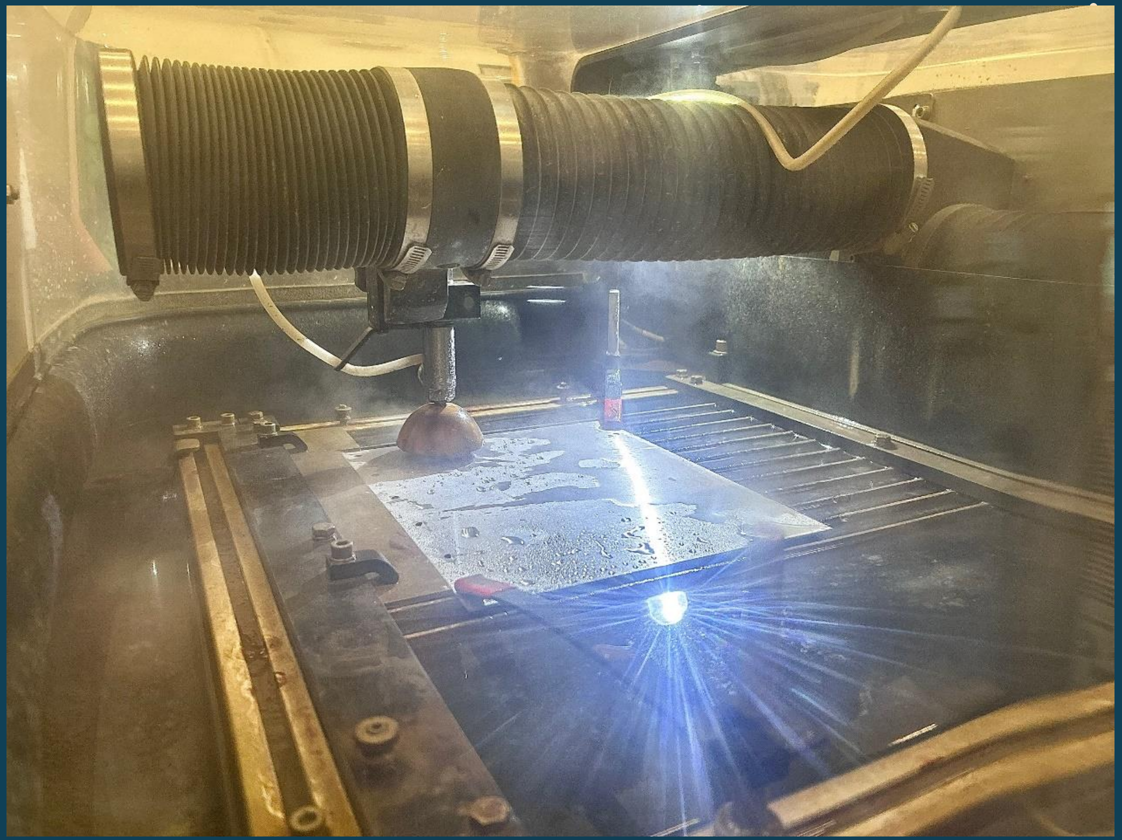
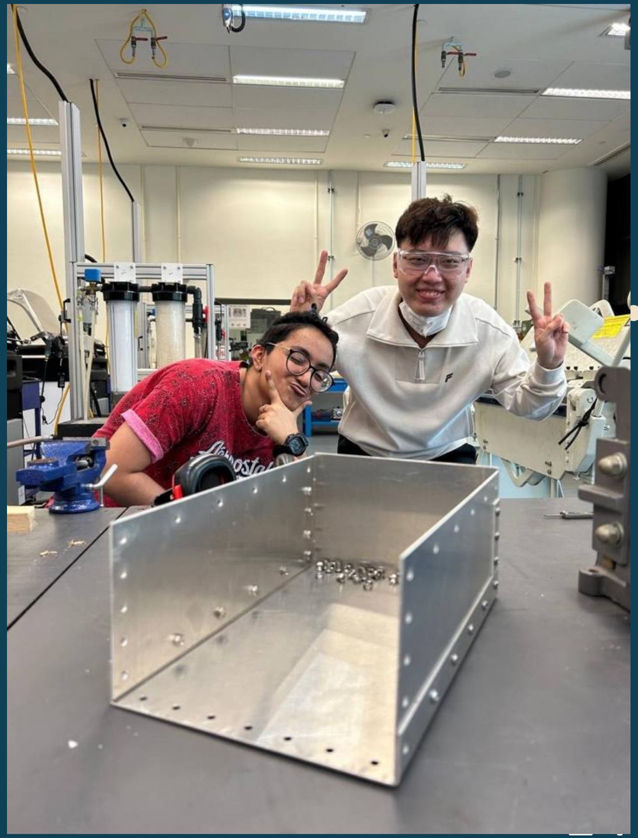


Fabrication

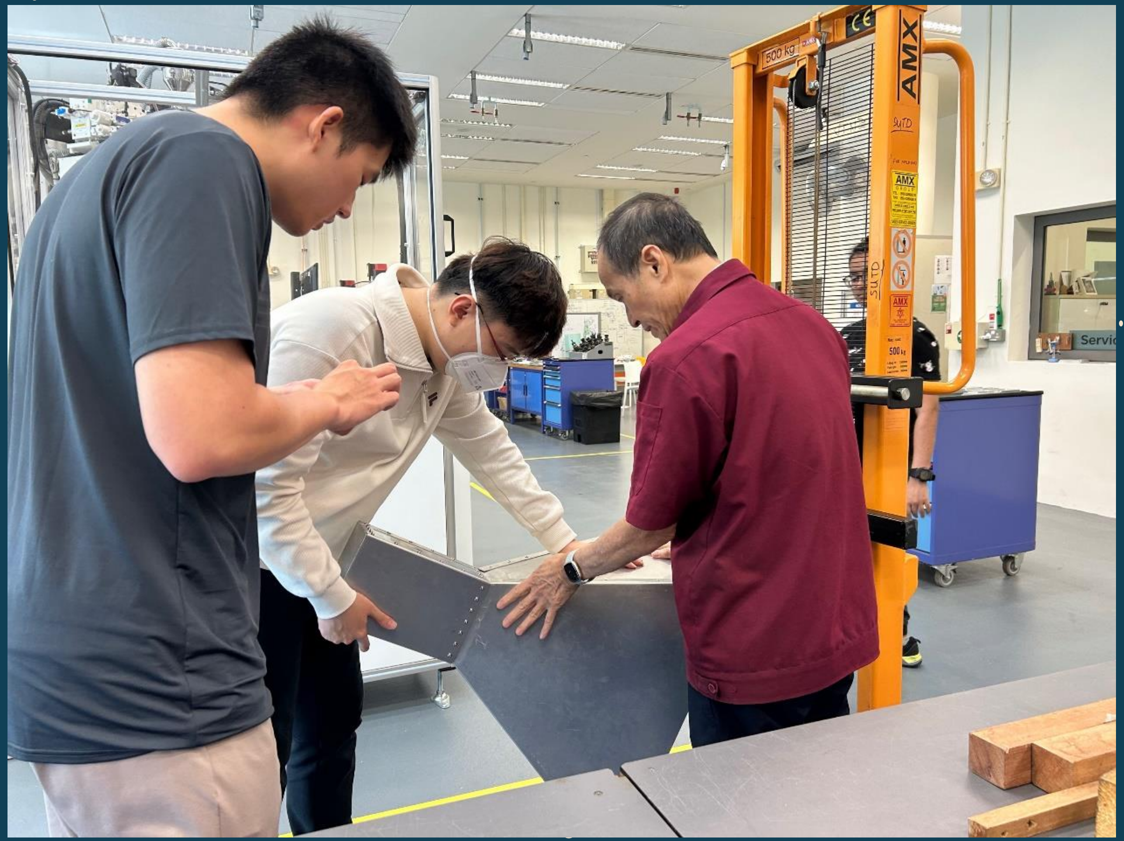






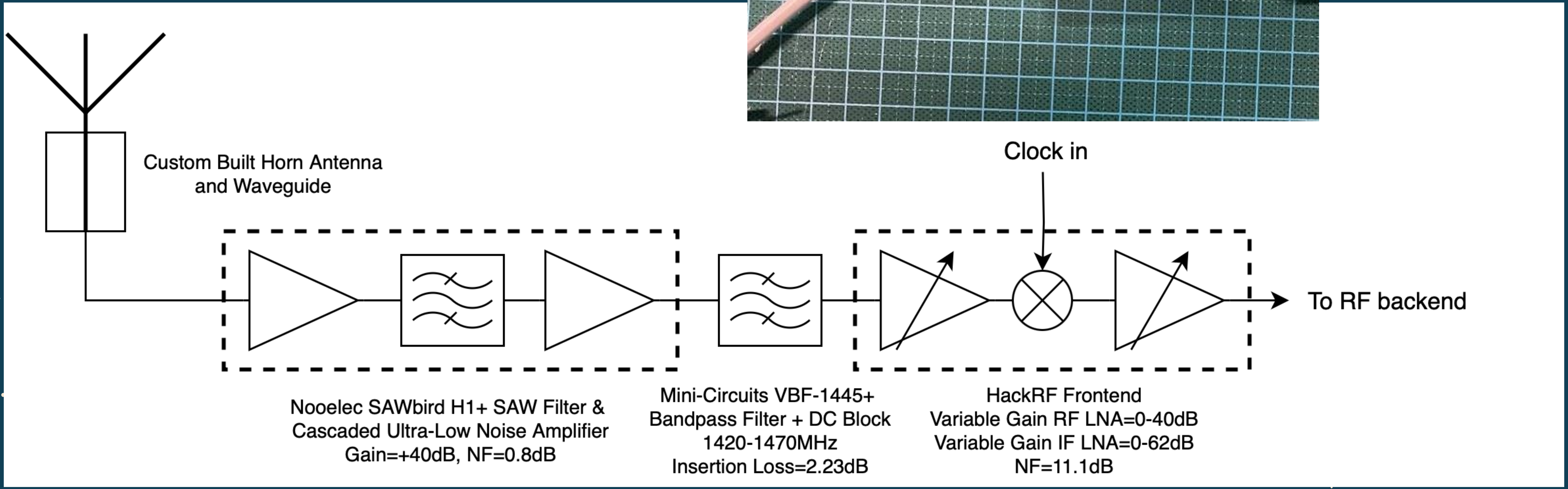
Fabrication





- Sheet metal bending was difficult due to specified angles (80, 27 and 23.5 degrees)
- Little margin for error for hole positions


Fabrication



Note that the HackRF frontend portion is greatly simplified to fit in this diagram.

Results: Physical Setup

Results: Hot and Cold Calibration

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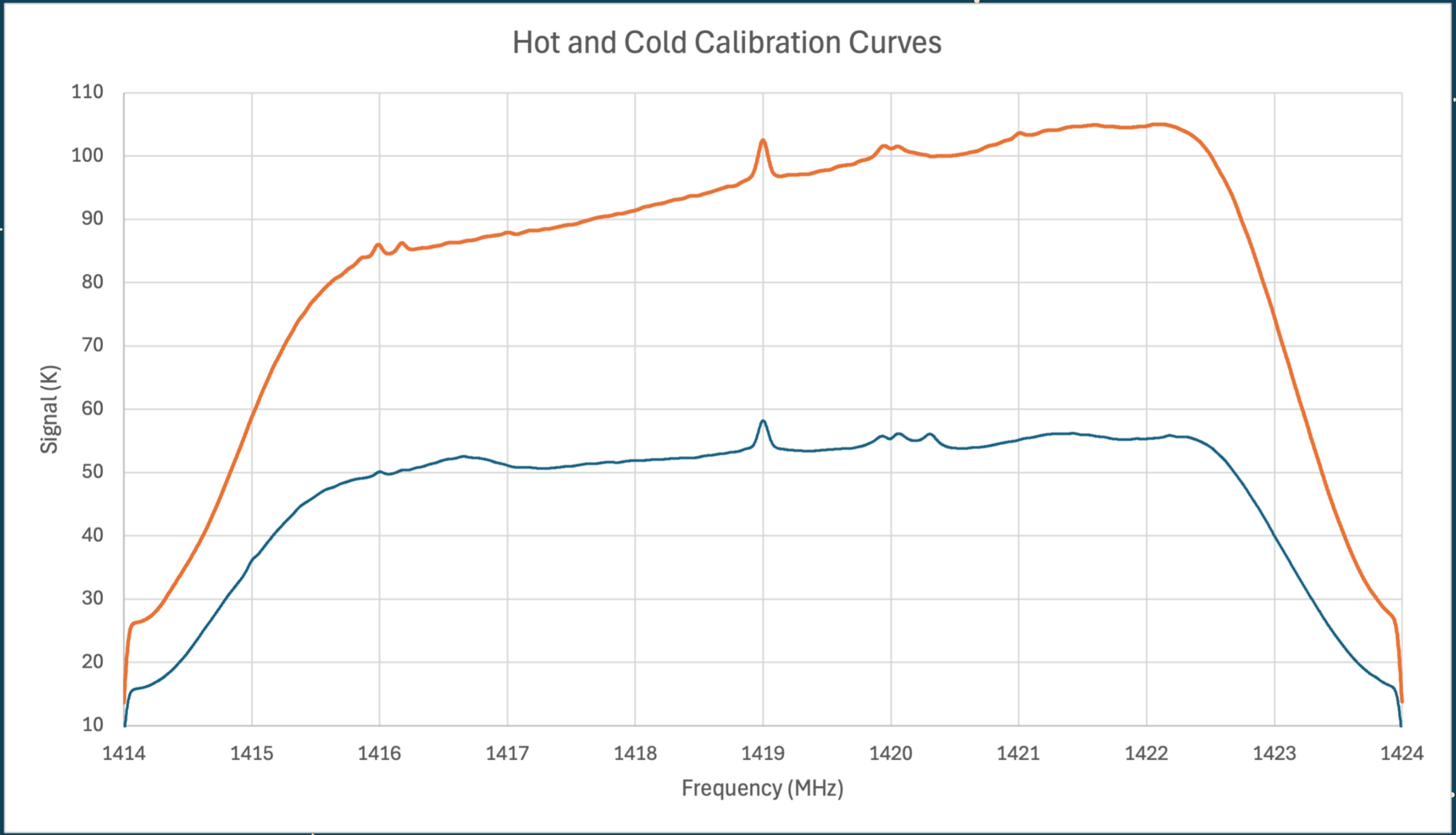
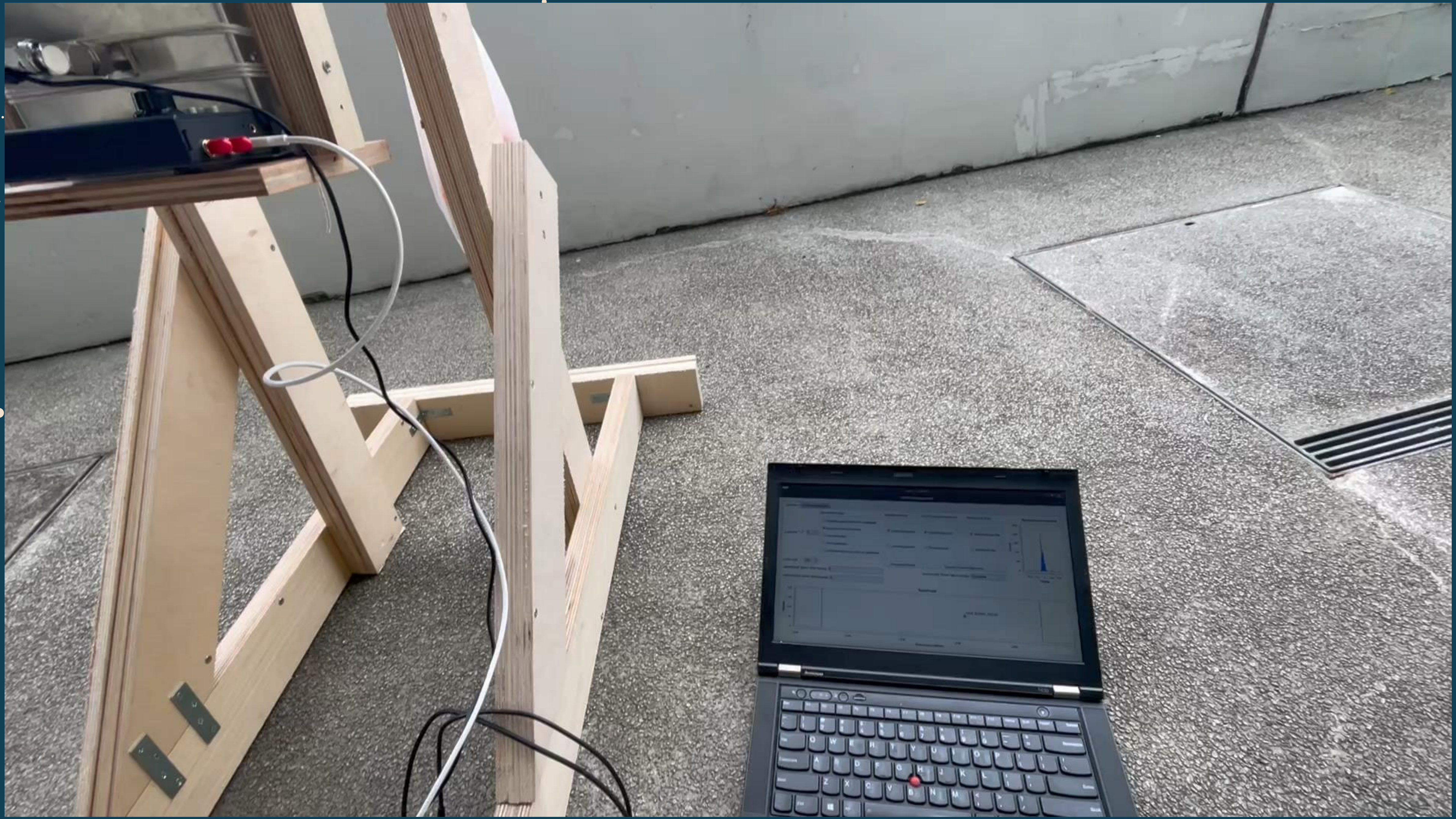


Results: First Light!!



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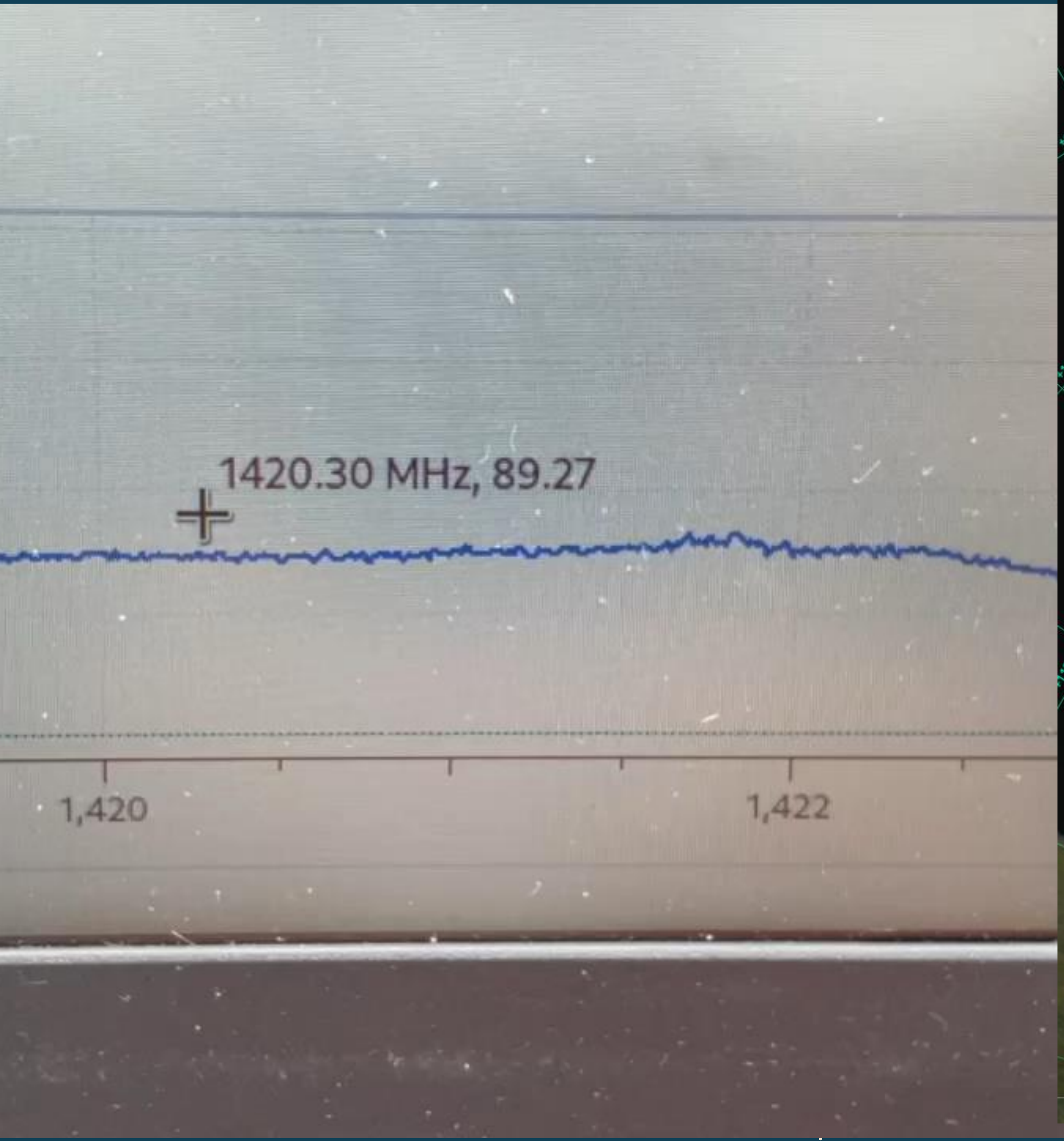
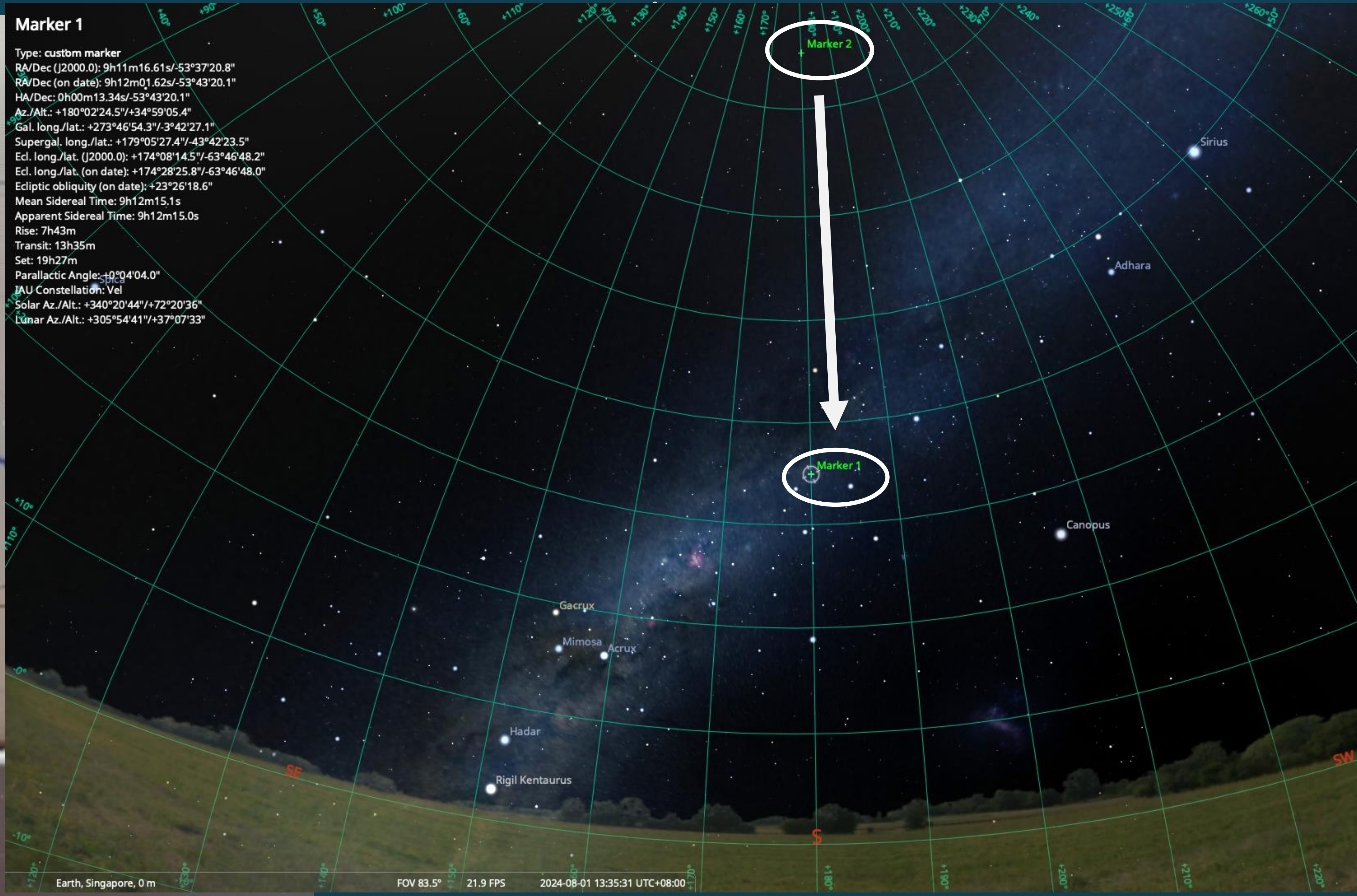
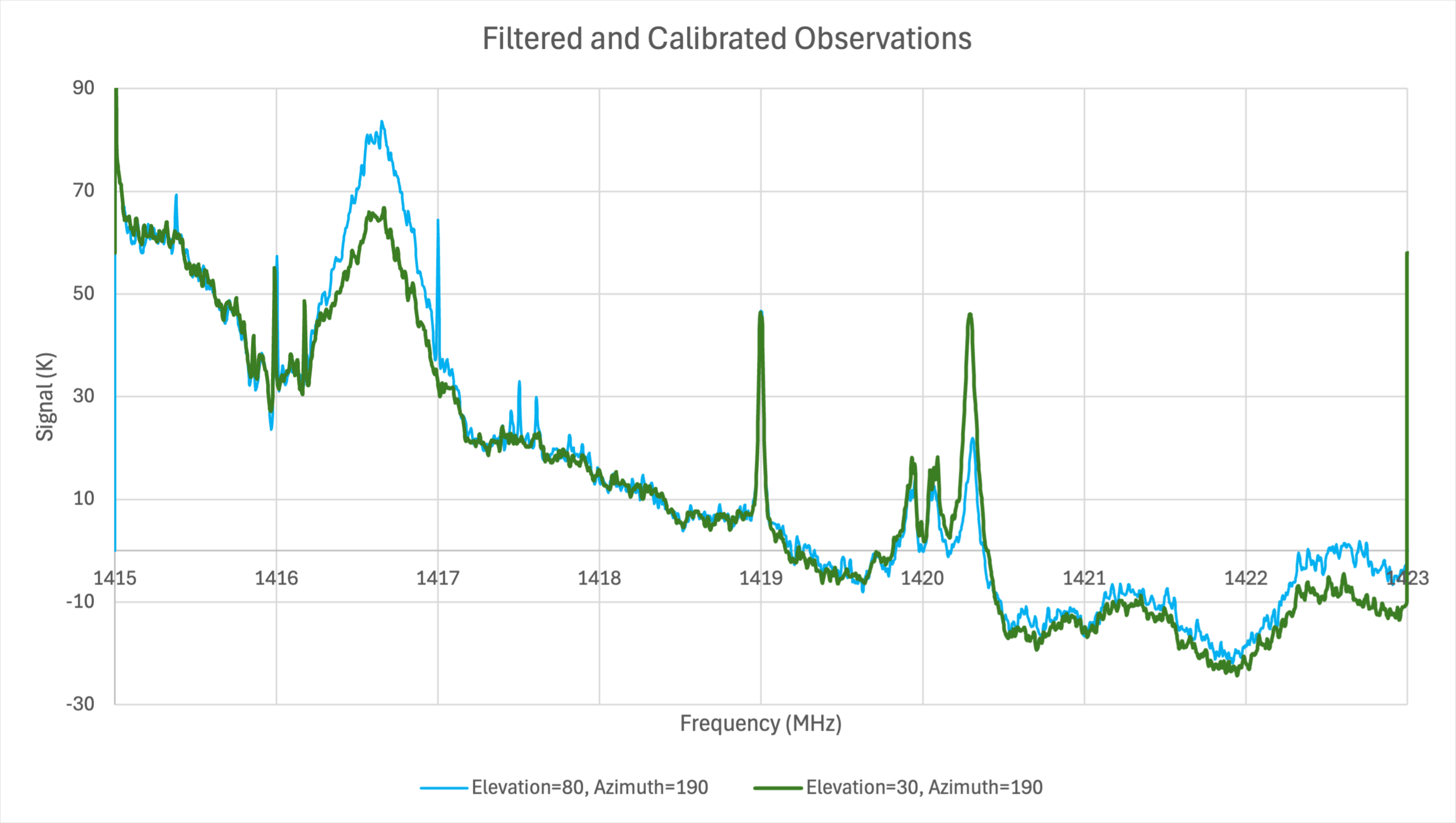




Results: Calibrated Observations



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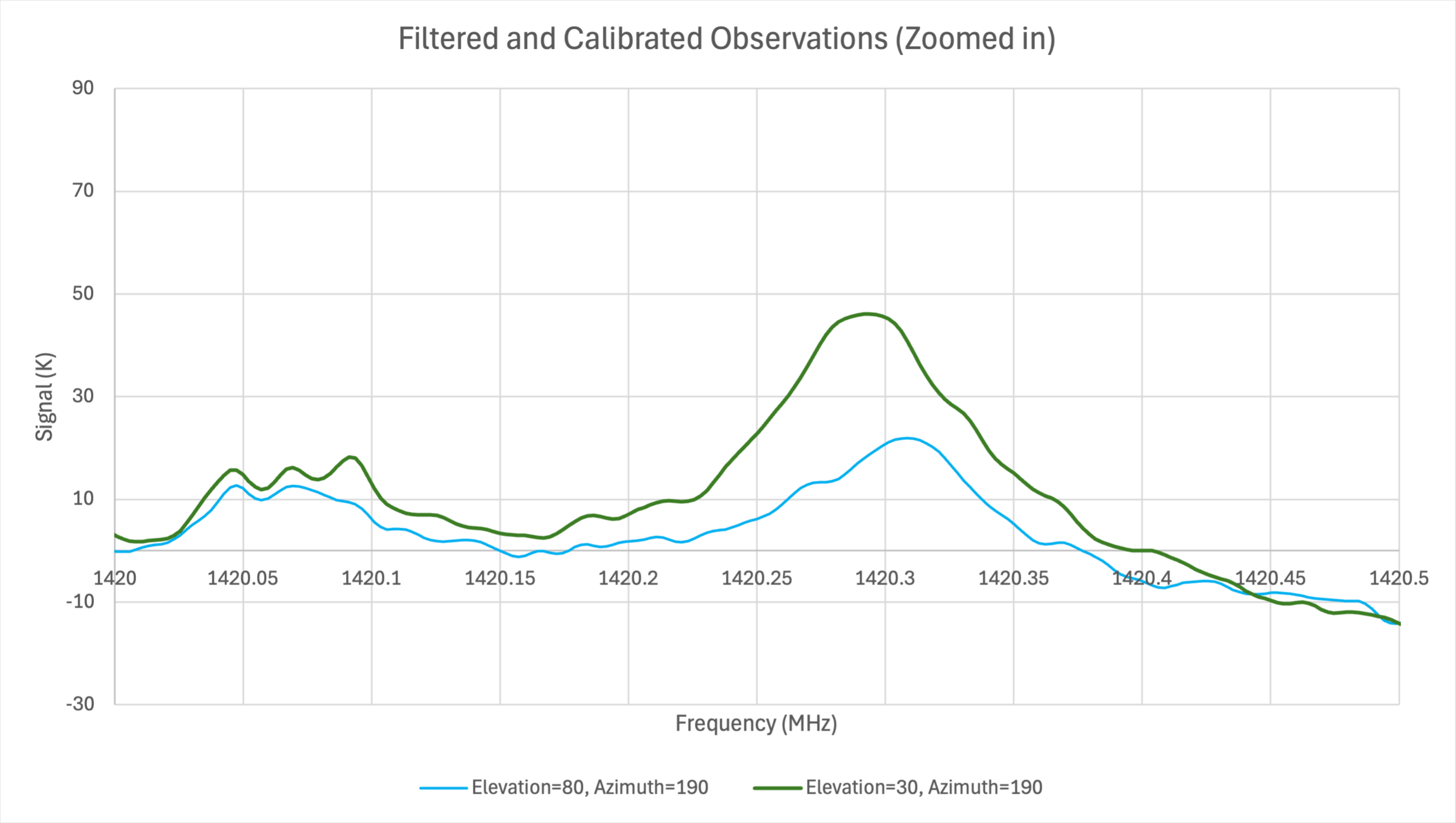


Discussion

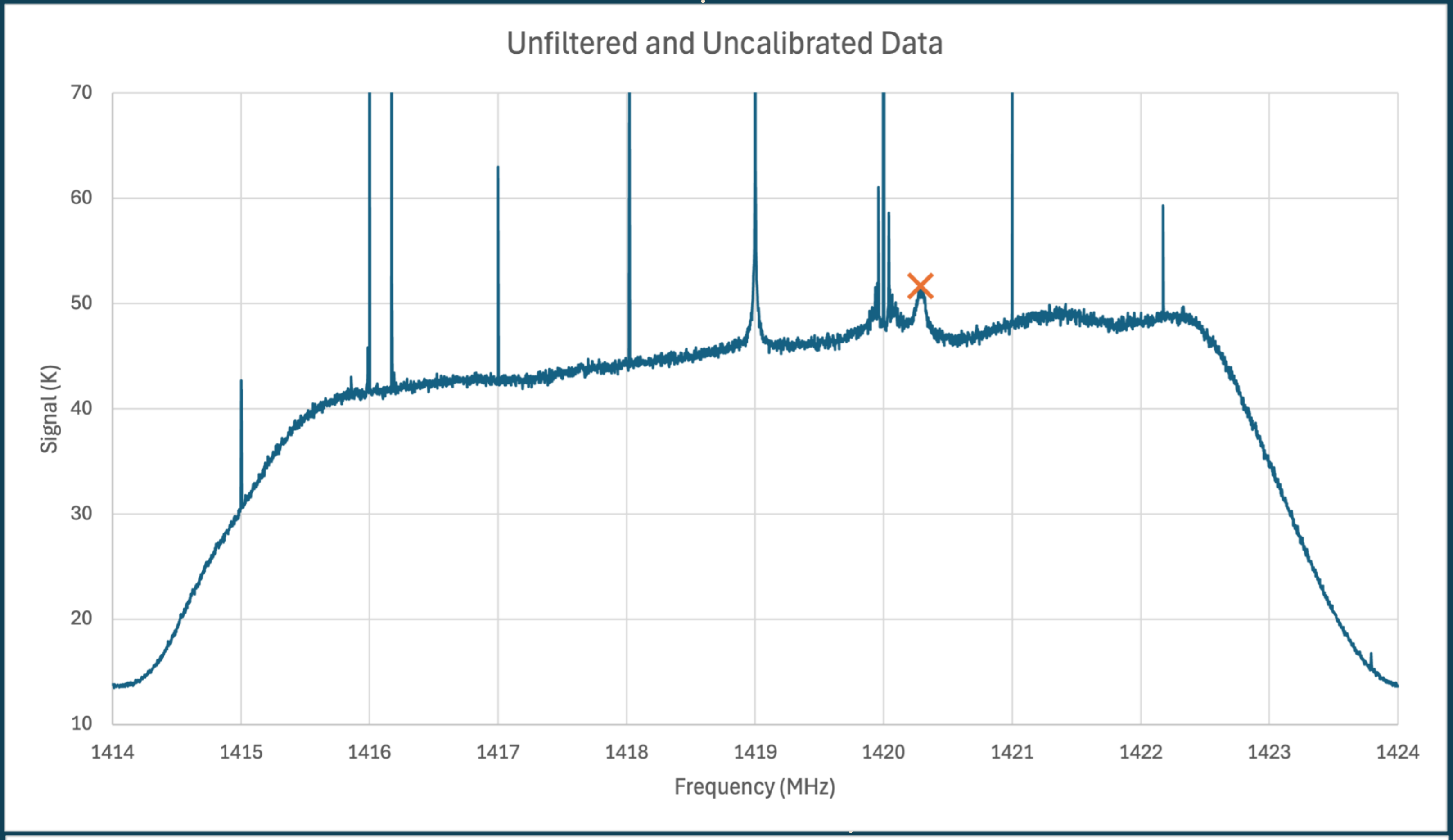
What did we get right?

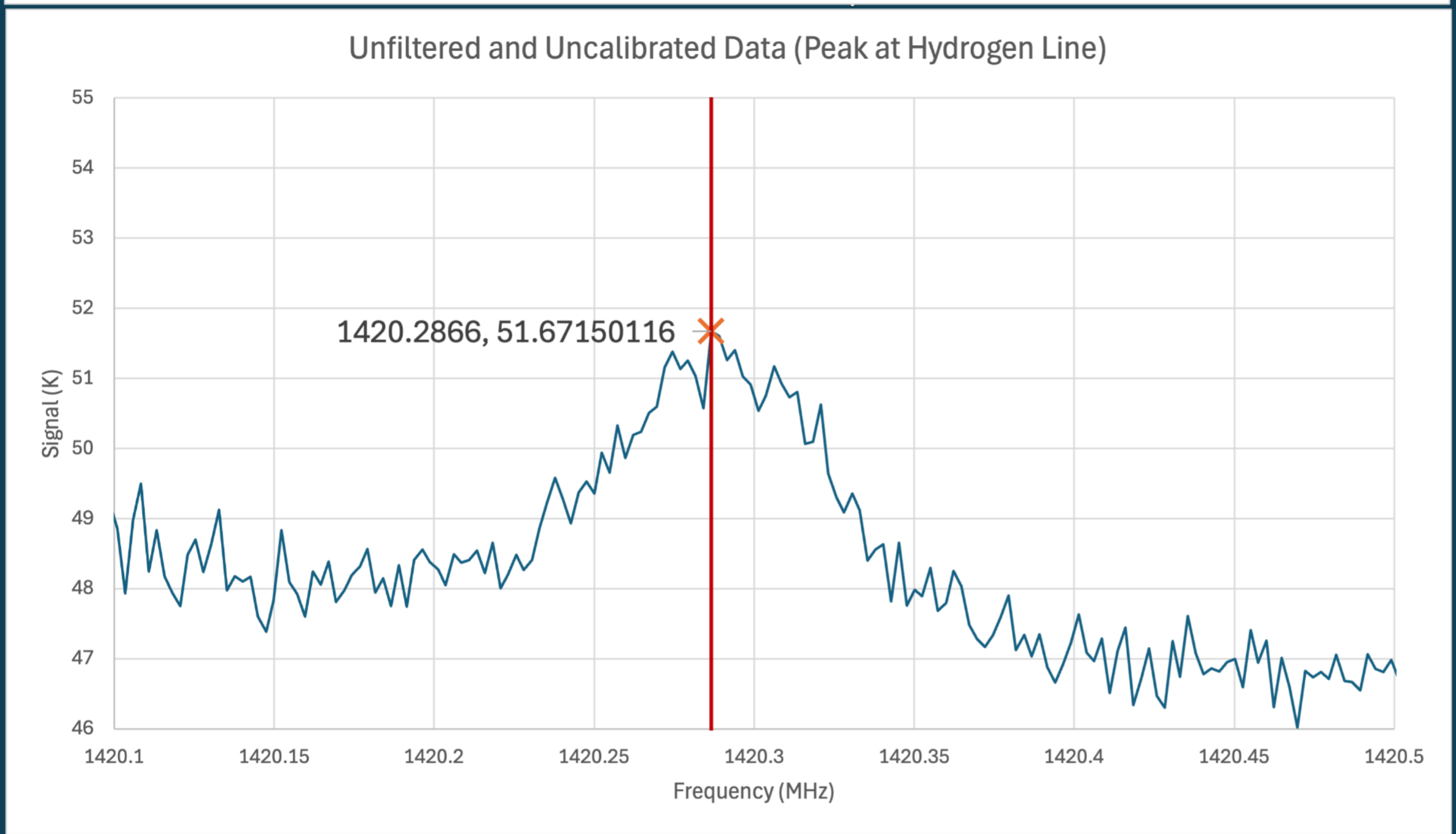
- ✓ Antenna fabrication:
  - ✓ The antenna was physically more robust compared to the original DSPIRA antenna.
  - ✓ More suited to mass production due to ease of manufacture for professional metalworking shops
- ✓ 1st Stage RF design: a good first stage design gives good leeway for future expansion

Discussion

What could be done better?

- ❖ The software defined radio
  - ➢ The clone HackRF One SDR has significant spurious signals due to shoddy workmanship (possibly inadequate EMI mitigation) and component quality
  - ➢ Significant frequency shift of -0.1MHz
  - ➢ Consider external high accuracy clock source to allow for accurate quantitative measurements (e.g. Doppler)

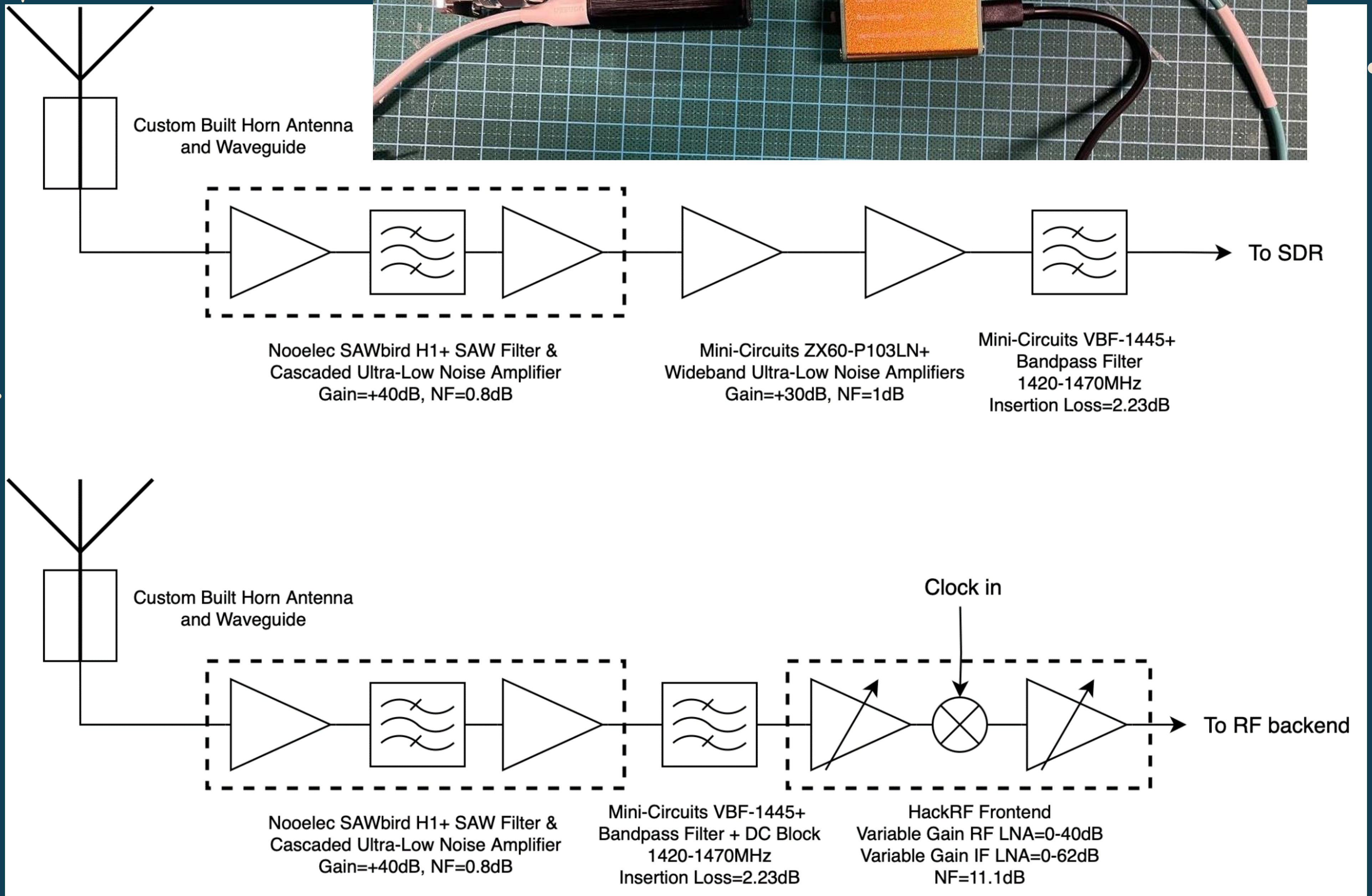




Discussion

What could be done better?

- Better RF design in 2nd stage
  - Since we accidentally burnt one LNA…the current setup is not ideal
  - Take advantage of LNAs that accept a DC bias voltage to reduce cabling



Discussion: Future Plans

1. Better radio components

As mentioned previously, better quality components helps with accuracy of the system

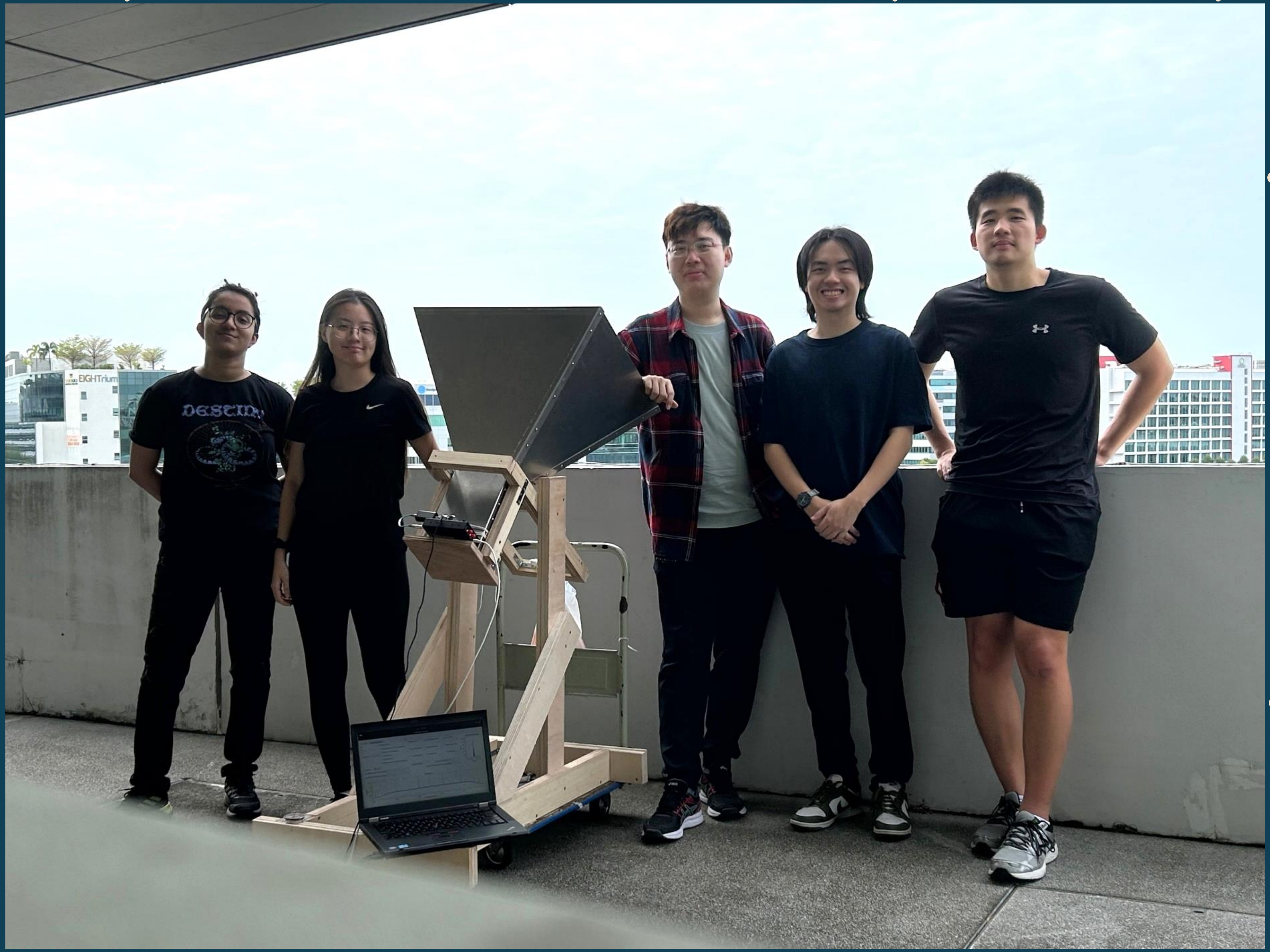
2. Education outreach?

Great potential for education outreach to secondary schools

3. Applied lab in SUTD’s 30.115 Digital Signal Processing?

In this project we are mainly focused on the radio segment, but there’s great potential in using this as an applied lab in DSP topics

Further Resources



Thank you