Table-top Radio Telescope (TTRT)

Build instructions and driver software

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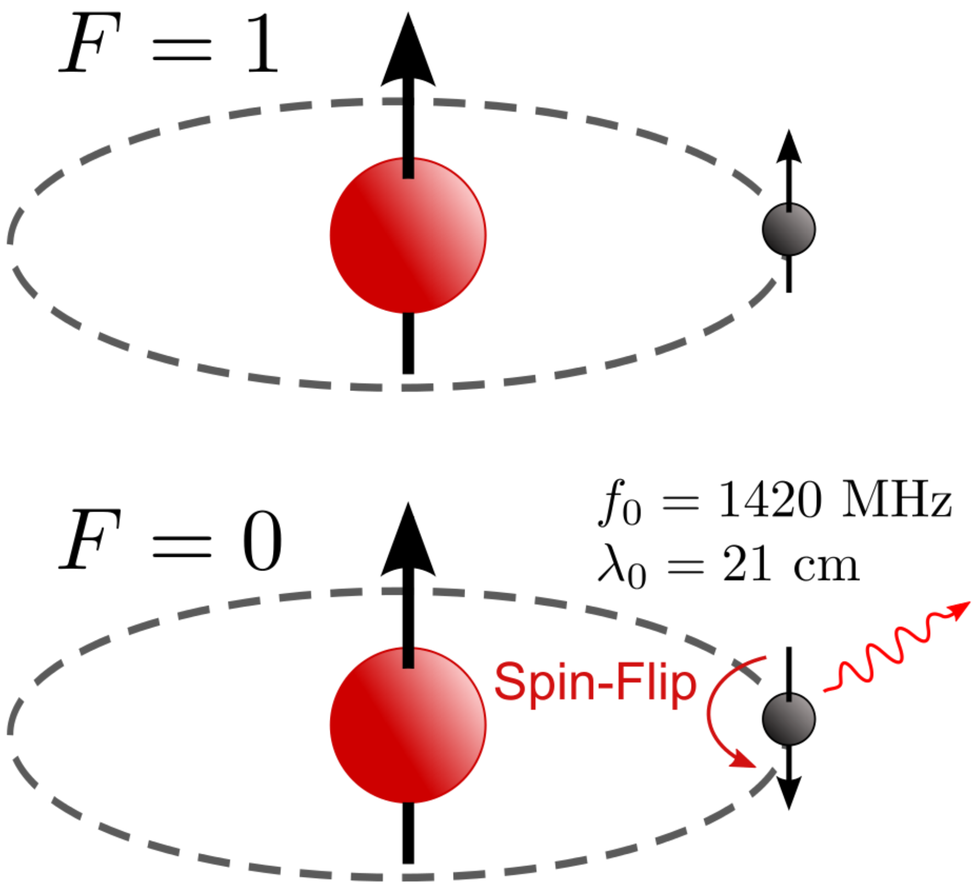
Introduction

- The Hydrogen atom is composed of two particles: the positively charged proton and negatively charged electron. These particles have some angular momentum referred to as ‘spin’, and most of the time the proton and electron ‘spin’ in the same direction within a hydrogen atom.

- However, it is possible for the spin of the electron to ‘flip’ and spin in the opposite direction to its proton – usually due to collisions with other atoms. When this happens, the atom gains a tiny amount of extra energy which radiates in the form of low-energy photons.

- These released photons radiate at around 1,420 MHz (that is, at radio frequencies), which have a corresponding wavelength of 21cm. Photons can penetrate clouds of interstellar dust that obscure optical telescopes’ views of the distant regions of our galaxy.

- When 21cm radiation was discovered in 1951, astronomers began using it to ‘peer through’ interstellar dust clouds and map the Milky Way’s spiral arms by determining where hydrogen was concentrated. The TTRT enables amateur astronomers to perform the same technique, and generate a characteristic ‘spike’ at around 1,420 MHz



Shopping list

- Software defined radio (SDR)
- Turns your computer into a radio receiver capable of detecting most RF signals
- Low noise amplifier
- Designed for hydrogen line detection and similar 21cm band experimentation
- RF amplifier
- Magnifies weak radio frequency signal
- SMA coaxial cables (male)
- Short lead connects low noise amplifier output to software defined radio. Long lead connects coaxial panel mount to RF input

Shopping list

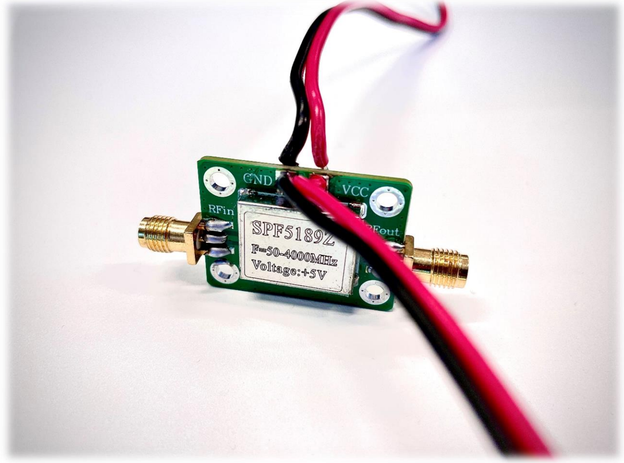
- Brass tube
- 100mm length, 3mm diameter and 0.5mm wall thickness
- SMA coaxial panel mount
- Fixes brass tube within cantenna and connects to coaxial cable
- DC Pigtail cables
- One male and one female connector solders to RF amplifier to adjoin power supply and low noise amplifier
- SMA coaxial adapter and terminator
- Adapter connects RF amplifier output to low noise amplifier input. Terminator connects to long coaxial lead during system baseline check

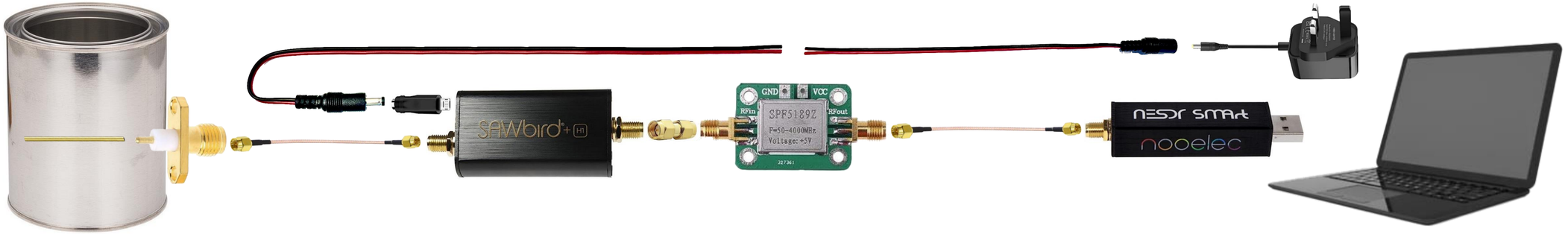
Shopping list

- DC power supply and connector kit
- Connects female pigtail cable to plug socket. Use included Micro USB to connect other male pigtail to low noise amplifier
- A metal paint tin or similar
- 160mm in diameter to house brass tube antenna and form base of cone horn
- Cardboard
- When laid flat it must have these dimensions
- Tin foil
- To apply to the inside of the cardboard cone horn

Construction (not to scale)

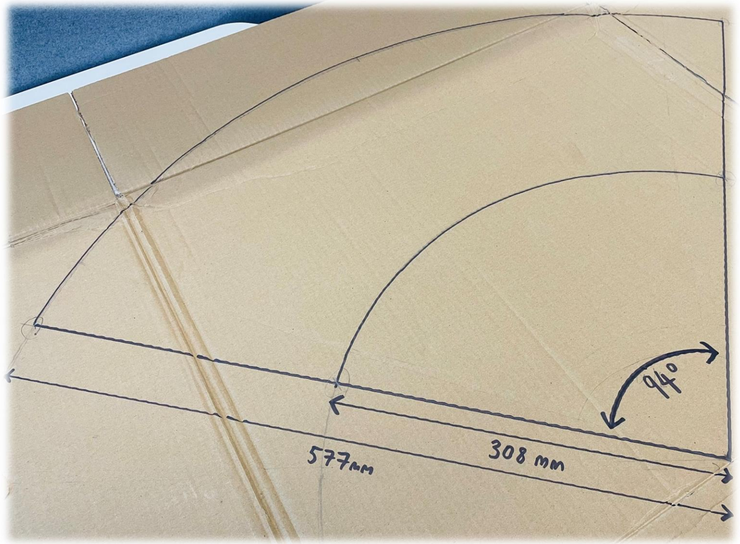
- Connect software defined radio to low noise amplifier output with short coaxial cable
- Connect low noise amplifier input into:
  - RF amplifier output with SMA coaxial adapter, and
  - Male DC pigtail cable using micro USB adapter
- Connect RF amplifier input into SMA coaxial panel mount with long coaxial cable
- Solder pigtails: black to GND, red to VCC
- Fix centre of coaxial panel mount 85mm from can base. Trim brass tube to 47mm and solder onto coaxial wire as pictured

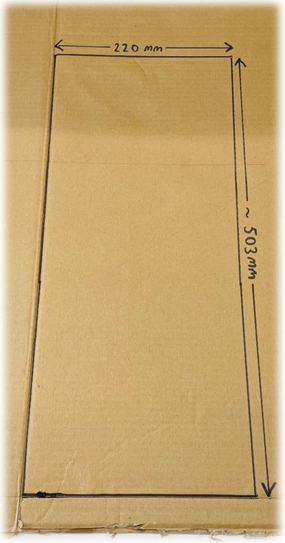


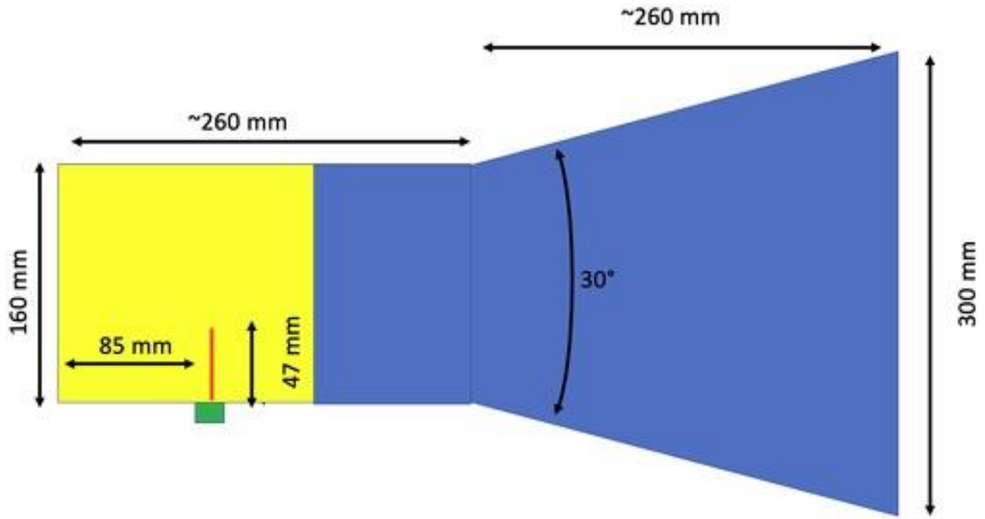


Construction – cone horn

- From a point on cardboard, draw straight line 577mm long. Mark a shorter measurement on the line of 308mm
- Draw a second 577mm line from point at angle of 94º. Again, marking a shorter measurement of 308mm
- With a pen tied around some string, hold finger on point and draw an arc connecting the 308mm measurements. Draw a second arc connecting the 577mm measurements
- Cut out shape, back with tinfoil and fix either end together to make cone
- For collar: wrap second piece of cardboard 220mm wide around outside of can between coaxial mount and can opening. Cut to desired length for snug fit. It should be around 503mm
- Back with tinfoil, fix to cone and slide along can to achieve around 260mm straight length





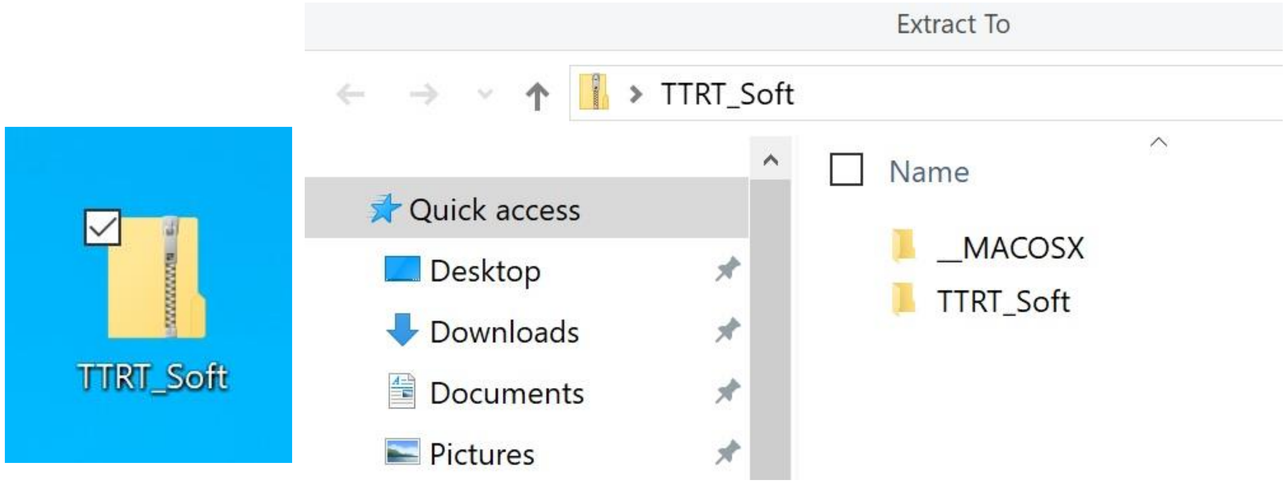


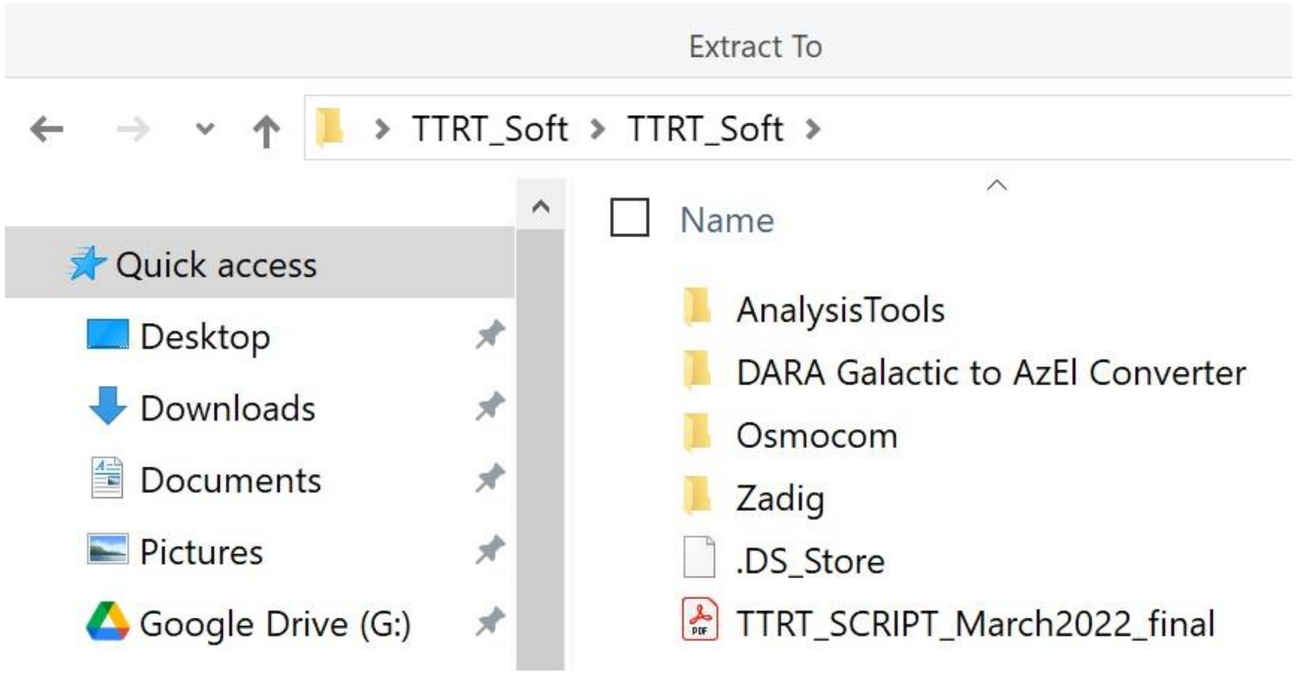
Star chart app

- You should now have a finished cone horn that looks like this:
- Next, download a star chart app for your smartphone
- Find the Milky Way and point the antenna toward it (roughly aligning it by eye is sufficient)
- Pointing towards the galactic centre, *illustrated right*, will produce the best results

Download TTRT Software

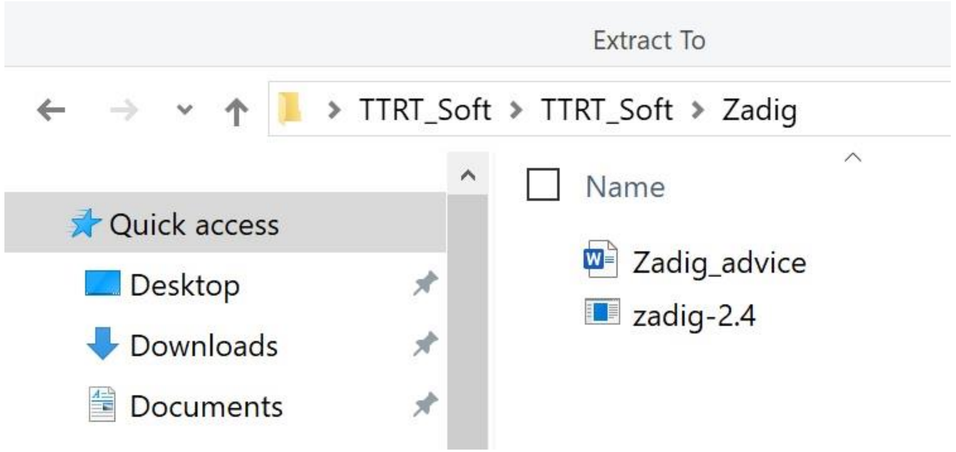
- Download driver software here.
- Select the appropriate file for your operating system – OS or Windows – to unpack the sub folders, *pictured top right*
- Inside are several files used for an earlier version of the TTRT, *pictured below right*. You won't need all these, but advanced users may be interested in the PDF, which describes the earlier interface and underlying physics of HI observations in more detail

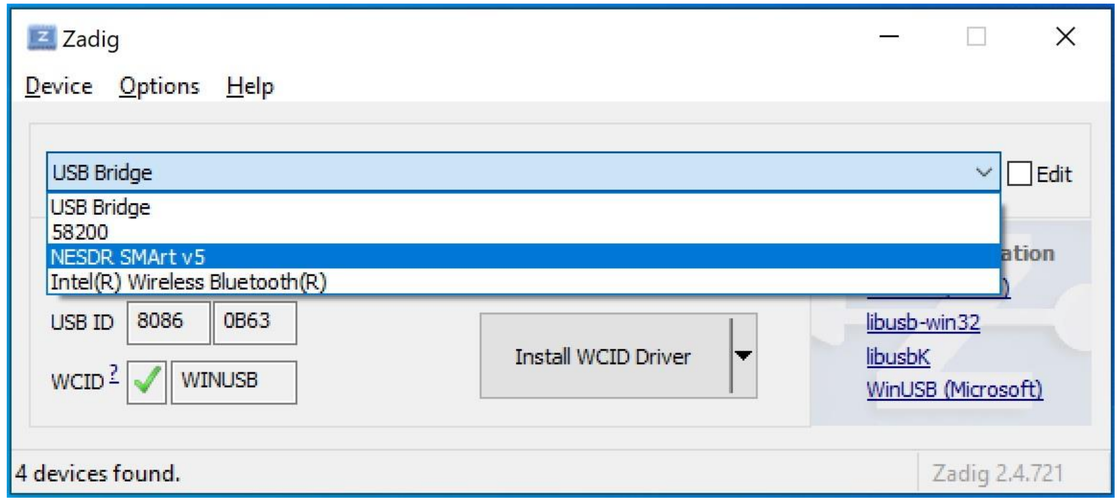


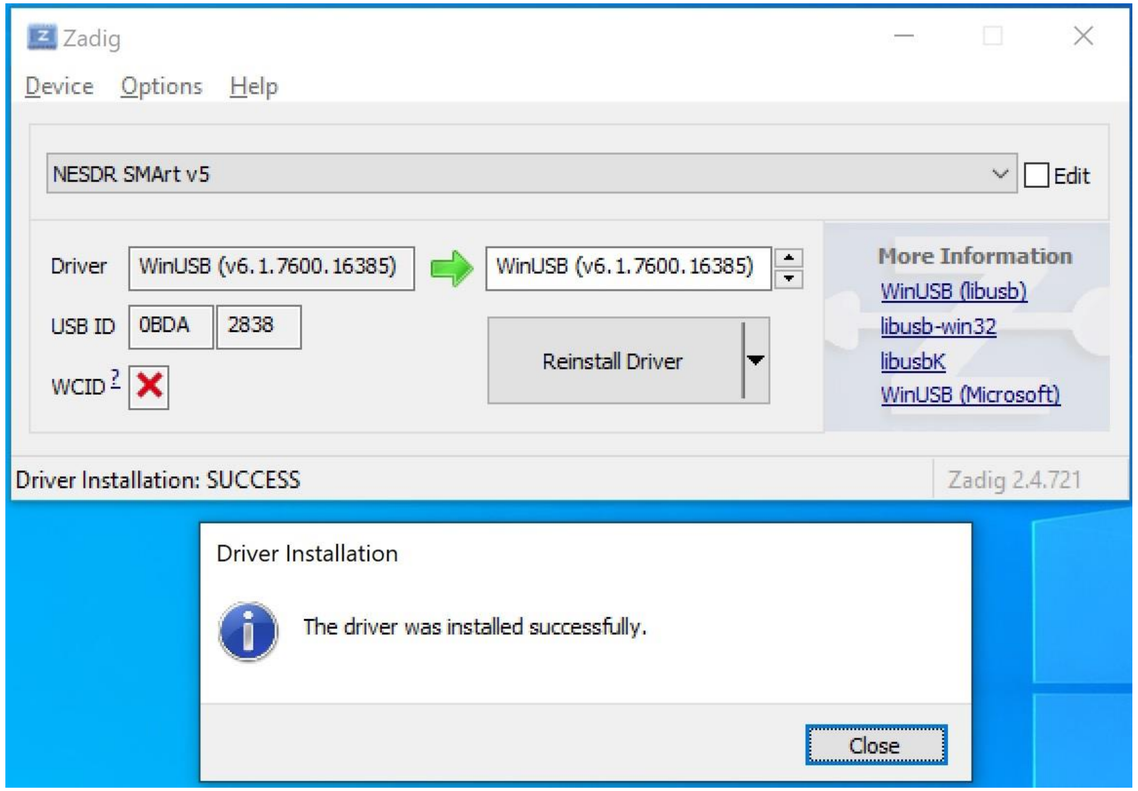


Zadig – driver for SDR

- Plug software defined radio (SDR) into computer
- Open Zadig folder and then Zadig-2.4, *pictured top right*
- When open, click ‘list all devices’ from the options tab and select NESDR SMArt v5 from the drop-down menu, *pictured below*
- Click ‘install driver’. After a period, your driver will be installed, *pictured below right*

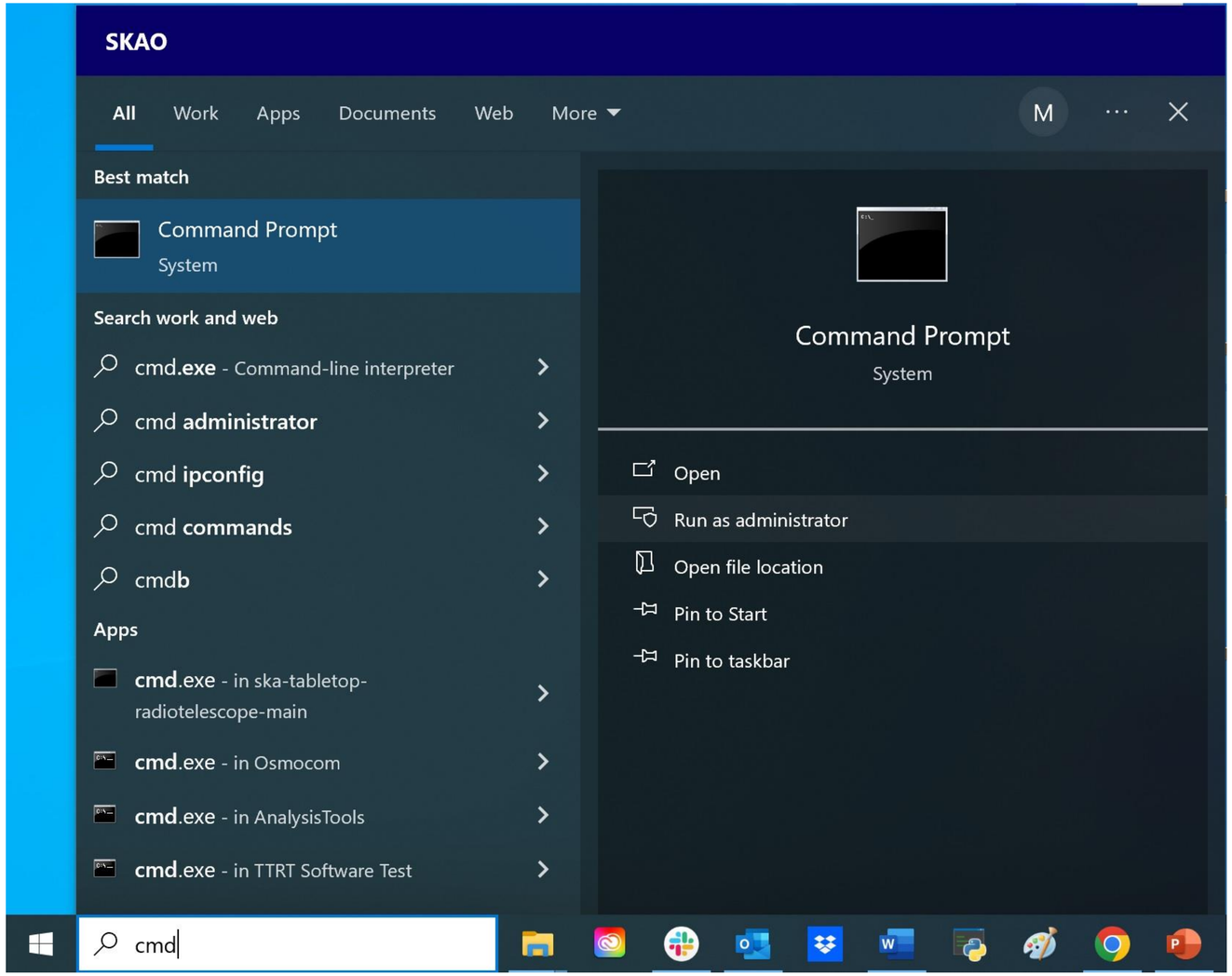






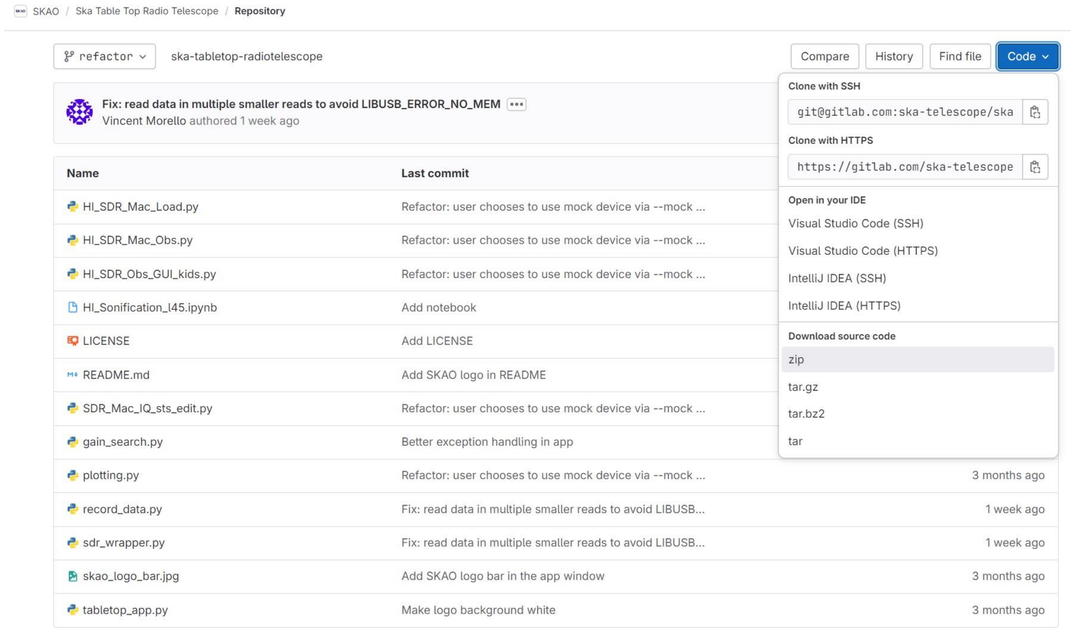
Python

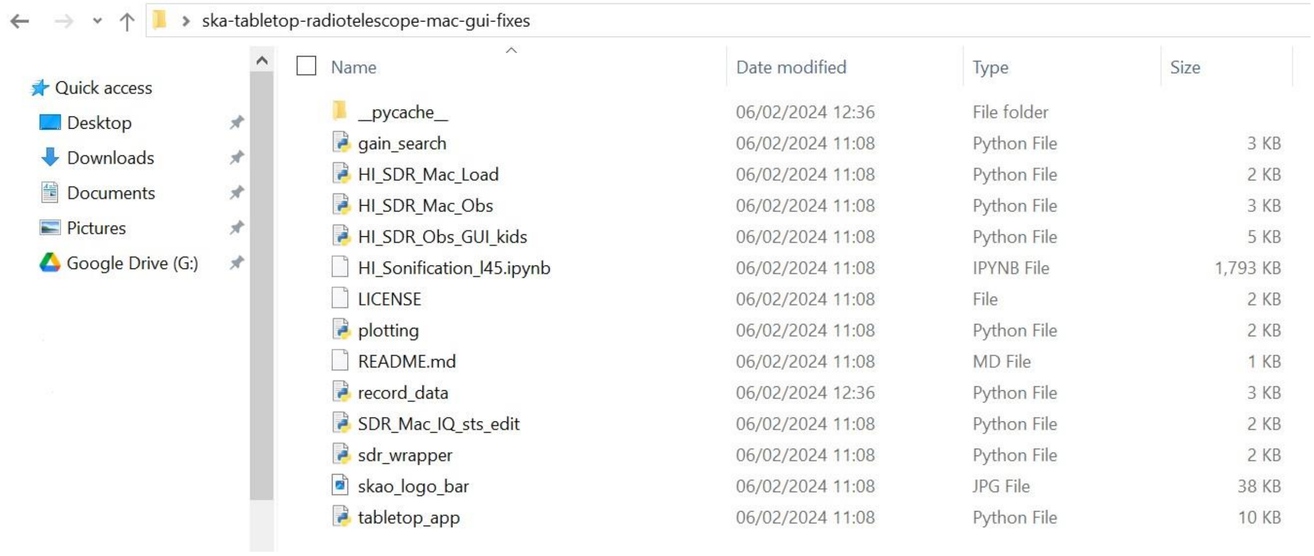
- The SKAO TTRT interface runs on a programming language called Python
- Download Python here
- Find Command Prompt by typing ‘CMD’ into search bar and open with ‘run as administrator’
- Type ‘python’ and click return
- We now need to install SciPy, a scientific computing module for Python, and matplotlib, a graphing module. To do this type:
- **pip install matplotlib scipy**
- Next, we install pyrtlsdr, a module for operating the SDR. To do this type:
- **pip install --upgrade pyrtlsdr[lib]**



SKAO observation interface

- Install the SKAO TTRT interface as a Zip folder from GitLab here. *Pictured top right.*
- Save this folder to your desktop for ease.



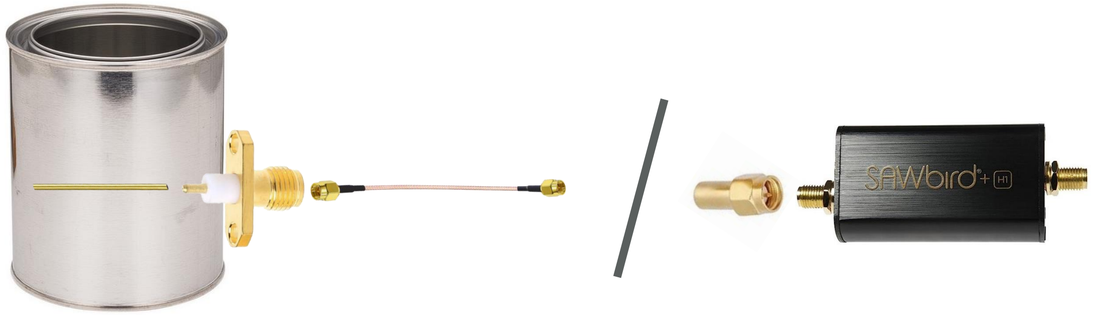


Operation - preparation

- Open Command Prompt from the folder by typing ‘cmd’ into the Windows address bar. Then type:

  python tabletop_app.py

- This will open the SKAO TTRT interface, *pictured top right*
- Temporarily disconnect cantenna from system by replacing SMA coaxial cable with SMA coaxial terminator, *illustrated below*
- Your system is now isolated from the cantenna and can be calibrated against background interference
- Click ‘prepare’. This will take around 15 seconds and display a result reading the optimum gain for your amplifier, *pictured below right*



Welcome to the SKAO Tabletop Telescope App
Short instruction manual:
1. Prepare
2. Observe

Prepare | Observe | Clear | Exit
Status: Ready

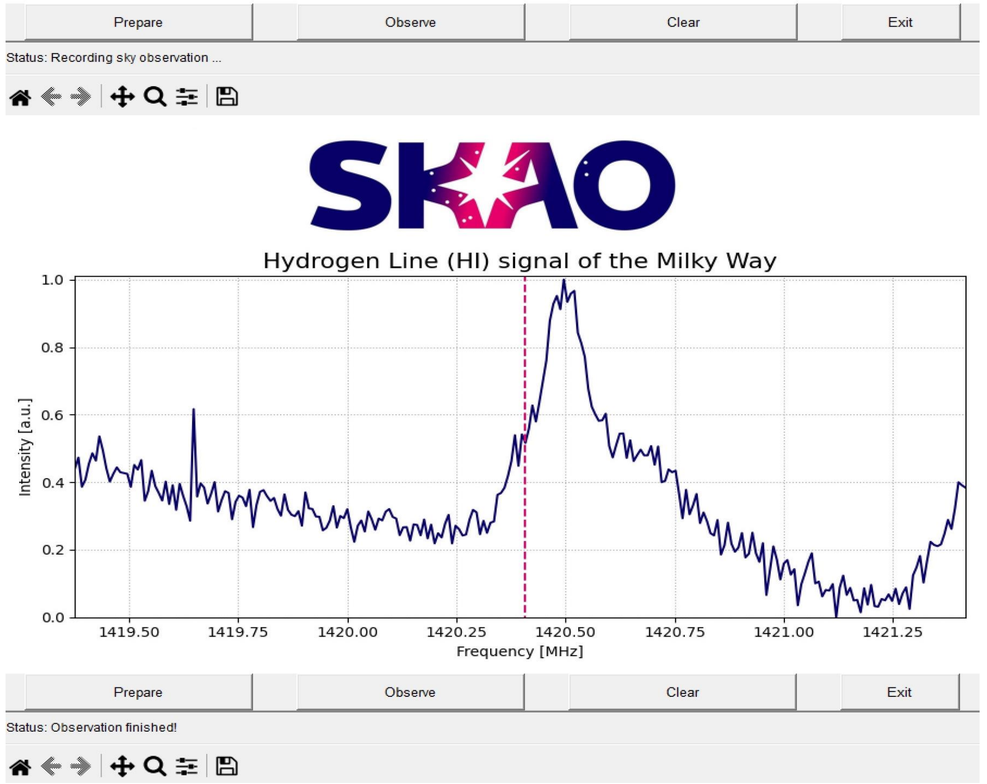
Preparation complete
Optimum Gain = 9.63
You can observe the Milky Way!
Remove RF termination and
Connect your antenna to the Sawbird HI

Prepare | Observe | Clear | Exit
Status: Preparation complete!

Operation - observation

- Remove terminator and reconnect SMA coaxial cable to the low noise amplifier. The cantenna is now re-attached and ready for observations, *illustrated below*
- Click ‘observe’ and the TTRT software will begin a 30 second observation cycle, *pictured top right*
- When complete, the TTRT software will display your observation of neutral galactic hydrogen, *pictured below right.* You can use the icons in the bottom left of the interface to explore your observation in detail, and save it to you computer

Sky observation in progress
This should take about 30 seconds ...
An interactive graph should appear at the end!



Explainer

- Congratulations, you just performed your first radio astronomy observation! What on earth just happened?!
- Somewhere in the galaxy – in roughly the direction you pointed the cone horn – low energy photons with a 21cm wavelength were released from a hydrogen atom following the ‘spin-flip’ of an electron relative to its proton (see slide 2). This ‘spin-flip’ to create neutral hydrogen is technically called a hyperfine transition. is an extremely rare event – any given hydrogen atom would have to wait around 10 million years for it to occur!
- However, because there’s so much hydrogen in the Universe (it accounts for around 75% of all known elements) and it is concentrated in galactic structures, then there will always be hyperfine transitions occurring for any line of sight through the Milky Way.
- The pink dotted line in the observation graph indicates neutral hydrogen’s exact frequency of 1,420.405752MHz. You may notice that the ‘spike’ in your observation is slightly misaligned with these dots. This is caused by the earth’s movement relative to the photons’ emission – both by the earth’s rotation and our rotation around the sun.
- The frequency will be very slightly lower (to the left of the pink dotted line) if the earth is moving away from the source, or very slighter higher (to the right of the dotted line) if the earth is moving towards. This is called doppler shift, and is comparable to how the sound waves from the siren of a passing emergency vehicle are received by an observer.
- When the siren is moving towards the observer, each successive cycle of its sound wave is emitted from a closer position; the time between cycles is reduced and frequency increased. As it passes and moves away, each cycle of the wave is emitted from a more distant position; the time between cycles is increased, and frequency reduced.

We recognise and acknowledge the Indigenous peoples and cultures that have traditionally lived on the lands on which our facilities are located.

SKAO

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