Listening of the Galaxy with a Wire

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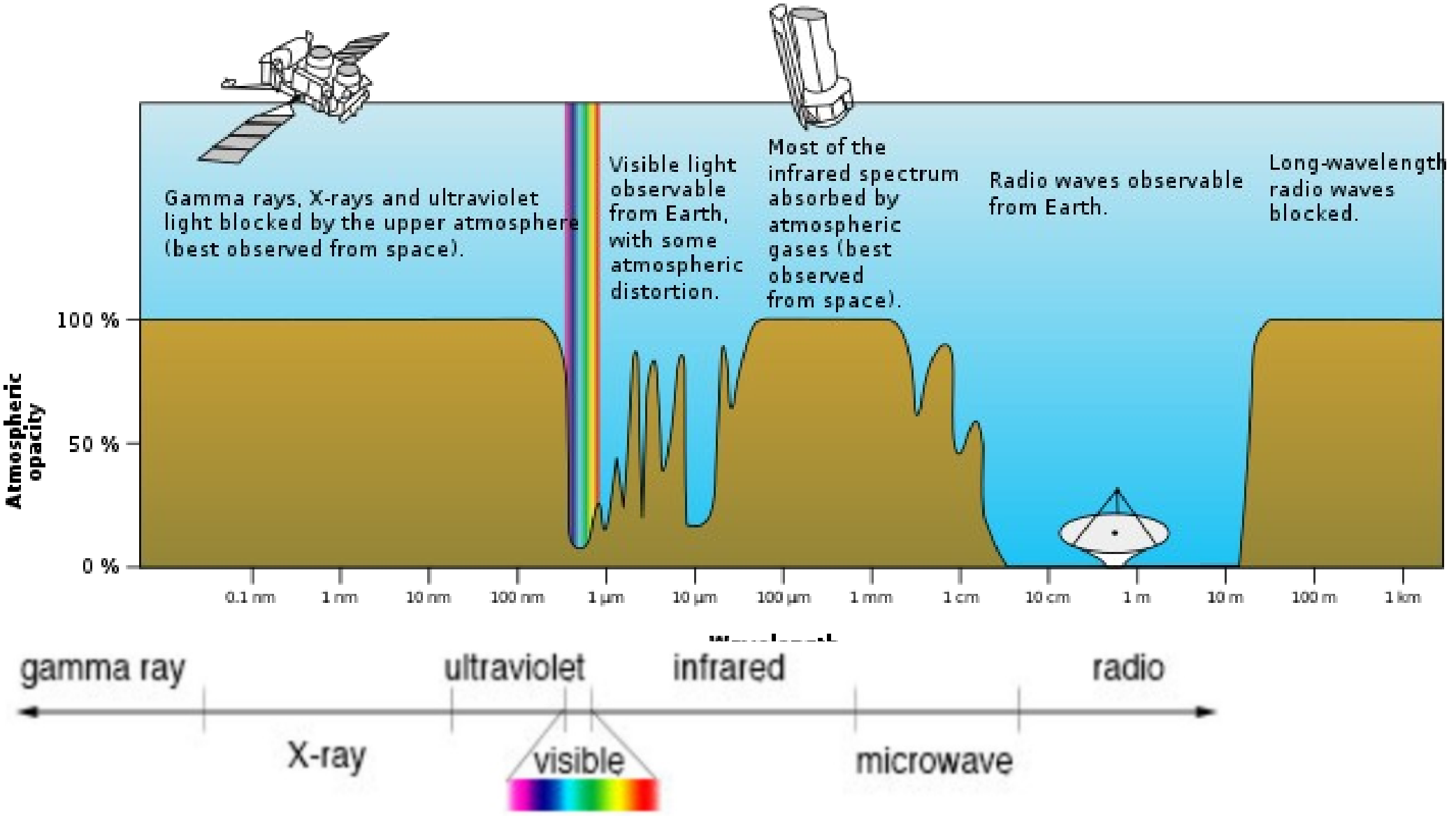
Outline

- Introduction
- Softvare defined radio (SDR)
- Amateur radio telescopes
- Projects for small radio telescopes
- Summary

Earth atmosphere and observations

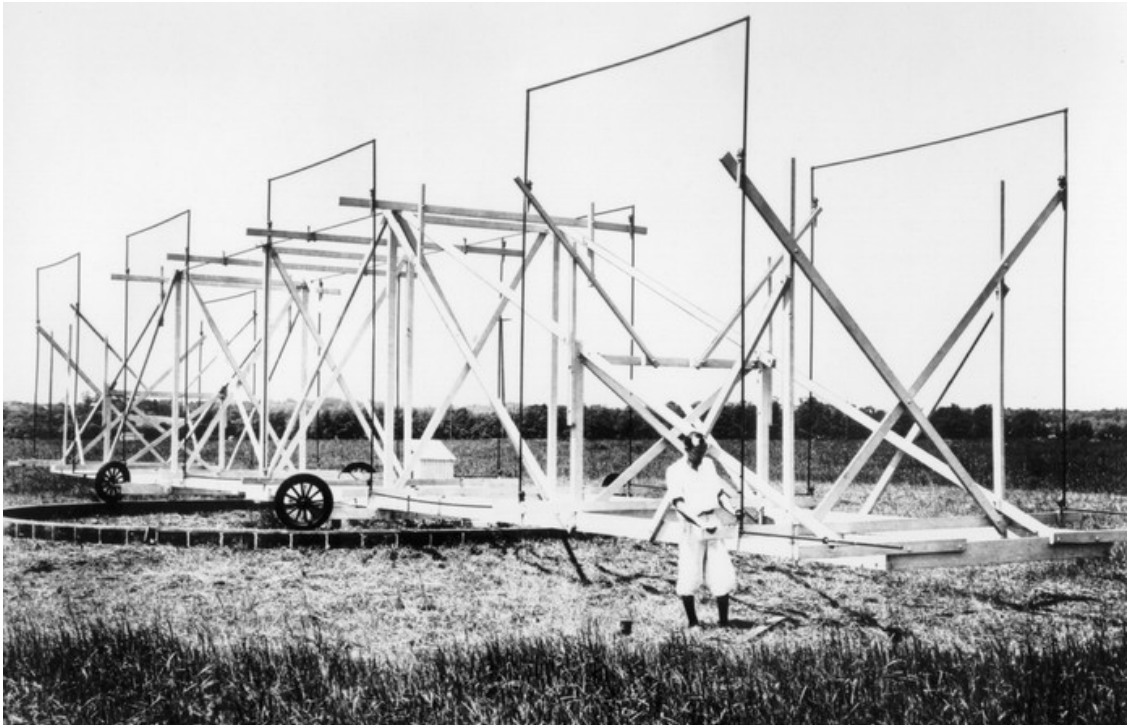


•Earth atmosphere is opaque for large part of the electromagnetic spectrum.

Radio-astronomy, beginning

Serious development of radio astronomy started after the WWII, with the availability of the post-war technical advances, especially thanks to the development of radar.

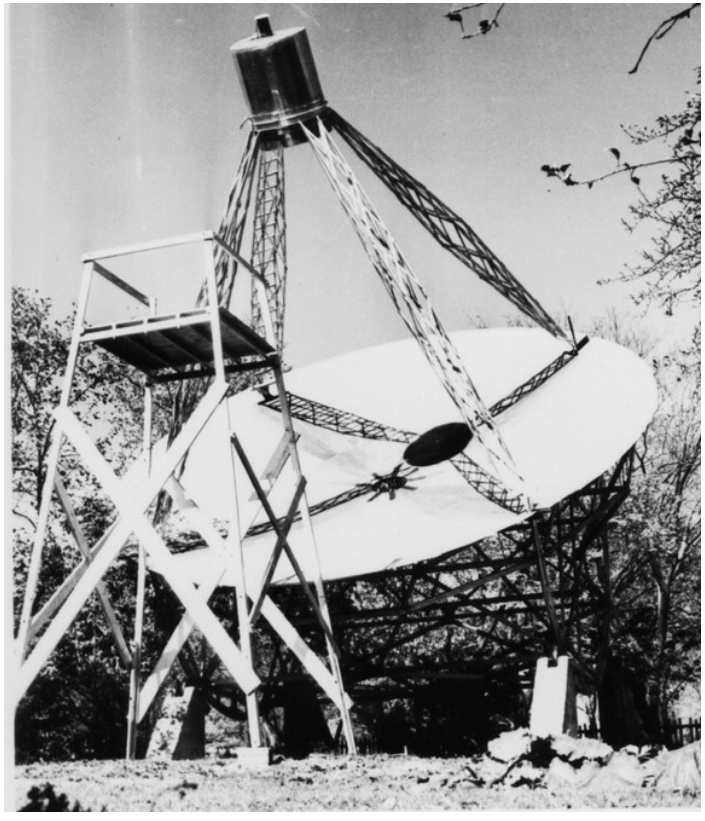
- Previous measurements in 19th ct. were made to register the expected electromagnetic radiation from the Sun, immediately after Hertz's discovery of the electromagnetic waves in 1888. Oliver Lodge from Liverpool, 1895. tried, but could not find anything except-already then!-disturbances from the electric tram and electric devices. He concluded that new measurements are needed, away from the city radio noise.
- The real pioneer or the radio-astronomy was Karl Jansky. 1 Jansky=1Jy=10^{-26} W/(m^2 Hz) is today the unit of spectral density of the energy flux of the electromagnetic waves in radio band (above wavelength of 3 m). Notice a very small number, 10^{-26} Watts per m^2, Sun radiation through a window is 1.36 kW/m^2.



Radio-astronomy, first amateur radio-telescope

Grote Reber, a radio-technician and radio-amateur, but also an amateur astronom, who joined his two hobbies and in 1937, constructed the first parabolic radio telecope (9 m diameter, see below) in his backyard. For about a decade he was the only world's radio-astronomer! He created the first radio-maps of the radio sky.

- At first he tried at 3300MHz, nothing, also nothing at 900 MHz, but at 1300 MHz he manged to measure and finally confirm Jansky-s results about noise coming from far behind the Solar system.
- At that time we still did not know what mechanism produces the radio signal from the Universe. Today we know it is the synchrotron radiation, produced when relativistic electrons move in the magnetic field.



- The first observation of a neutral hydrogen line from the Galaxy was 25.03.1951 by Purcell & Ewen at Harvard University in USA, with a horn antenna.
- The first pulsar was discovered in 1967.

Largest radio-telescopes

End of 2020. we saw a crash of the Arecibo telescope at Puerto Rico, which at 1000 feets (305 m) was sinc 1963 the world's largest Only in 2016. godine FAST (Five-Hundred-Meter Aperture Spherical Telescope) telescope in China took over with its 500 diameter. FAST can not work as a radar, so it can not be used for mapping of the planetary surfaces.

ARECIBO

FAST

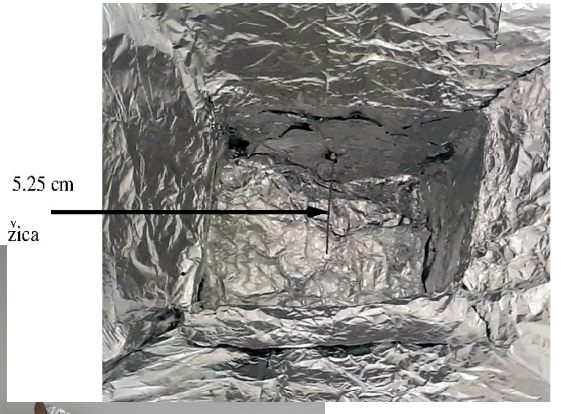
Future of radio-astronomy

- Measuring of the electromagnetic radiation below 100 MHz iz problematic, because of the noise from the surrounding devices, which is much, much stronger. Below 30 MHz, because of absorption in the Earth atmosphere, it is hopeless. Redshifted emission from the Big Bang comes to us at this band, with signal 100 000 times weaker than the signals from our own Galaxy, so measurement is very demanding.
- The era of space radio-telescopes is not yet started, and already has to worry about pollution: the best position, and unique in Solar System, because it gives the protection of the whole Moon, is the dark side of the Moon. And it is not to be any more dark in radio very soon. On Earth, the largest dedicated area without electromagnetic radiation is Murchison Widefield Array in West Australia, with radius of about 500 km.
- Chang-4, a Chinese lander from 2019 put a small radio telescope there, but it was more a show-off than a cosmological measurement device, since the probe's electromagnetic noise destroyed any chance for measurement. One has to turn off all the unnecessary electronics, and know well the noise produced by the used equipment, to be able to subtract it from a weak signal.
- NASA plans LuSee-Night mission, which would put two 3-m dipole antenna in a cross shape, to measure a Cosmic Dawn, with the info on first stars in the Universe.

Listening of the Universe with a wire: amateur radio-astronomy

At the end of 1980-ies in my secondary (technical) school in North Croatia I had a vague idea of making a radio telescope, but then it would be impossible because of prices and also the components would be hard to find. Thanks to the development of SDR (Software Defined Radio), today it is easily doable. The concept of SDR is invented in 1980-ies, but only about 10 years ago engineers realized that one can use the omnipresent satellite antenna receiver for TV as a receiver at the whole radio spectrum. The price of the equipment began a free fall. Today one can buy such a receiver for 15 EUR and a Low Noise Amplifier for about 30 EUR. Add a coaxial cable and...voila! Last winter I made a horn antenna from a cardboard and wrapped it in a kitchen alu-foil, and this is actually the first Croatian radio telescope, almost 100 years after Jansky! You, and anyone interested, can, and should,

do it at home!



Software defined radio

•After the WWII radio-astronomy was in the domain of experienced radio-technicians. Also, often the information and equipment was classified (radar!), and too expensive for private persons or amateur associations.

•In 1982., in the labs of Ulrich L. Rhode in RCA the first SDR was developed, with the COSMAC (Complementary Symmetry Monolithic Array Computer) integrated circuit.

•Predecessor of the Raytheon company in the USA introduced the term “software radio” for a digital receiver, where the analog detectors, mixers, filters, amplifiers and (de)modulators of the radio device is taken over by software. It performs mathematical operations on the digitalized signal with help of a computer, instead of using analog hardware.

•Mass production of the integrated circuits like RTL2832U for TV receivers kick-started, with the new Millenium, development of the ham-radio amateur use of SDR, and spread today to other fields, and also amateur radio-astronomy. There are yearly conventions in the USA, where people show-off their equipment, which is not shy of a modest professional equipment.

•Amateur observations of our Galaxy, Sun, Jupiter and pulsars are performed today. Even the molecular clouds! One can also do interferometry.

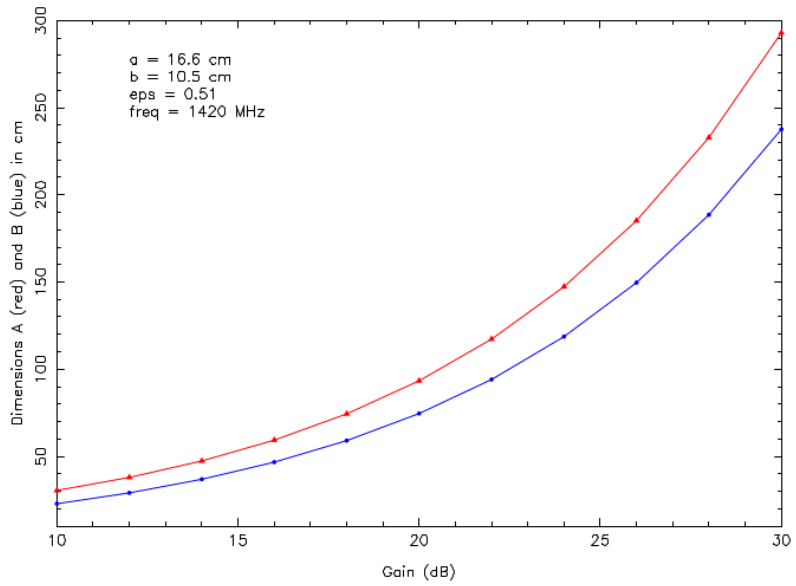
•The next generation of radio-astronomers can really start with hands-on experience at the elementary or secondary school level, experimenting and learning the observational techniques.

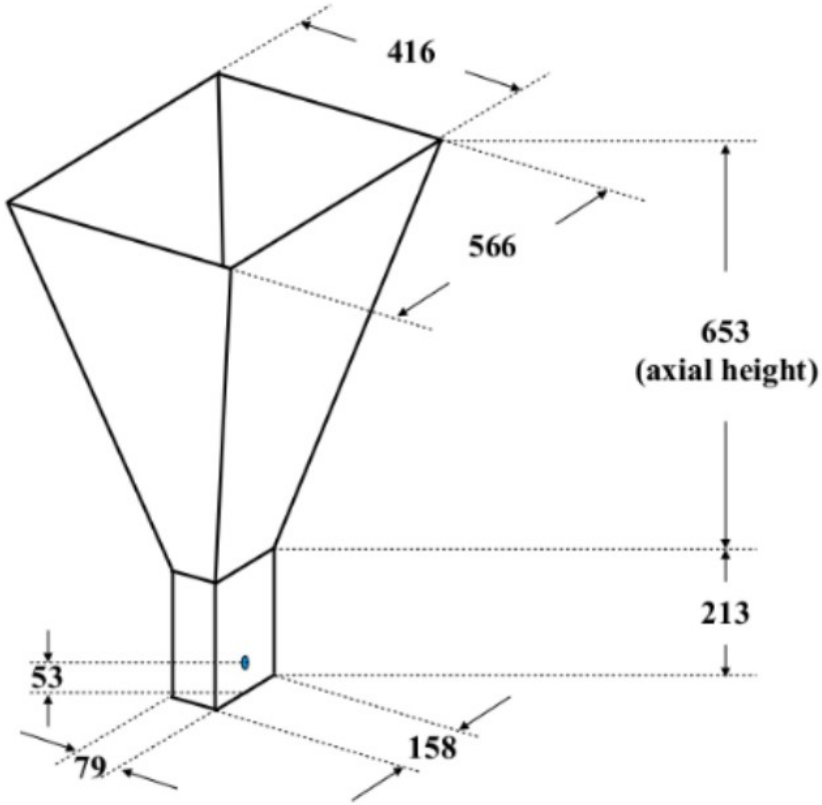
Horn antenna-waveguide dimensions

•The first goal is 21 cm, neutral Hydrogen line from our Galaxy, made by spontaneous transition of hydrogen atom from an excited state with parallel spins, to the neutral state with anti-parallel electron spins. It is a convenient task, since there is no need for a precise direction: our Galactic disk is a constant source.

•A horn antenna is chosen bacause of its superior sensitivity. Also, it provdes the best shielding from surrounding noise, an important factor if we wish to use it in schools, which are usually in or near the city.

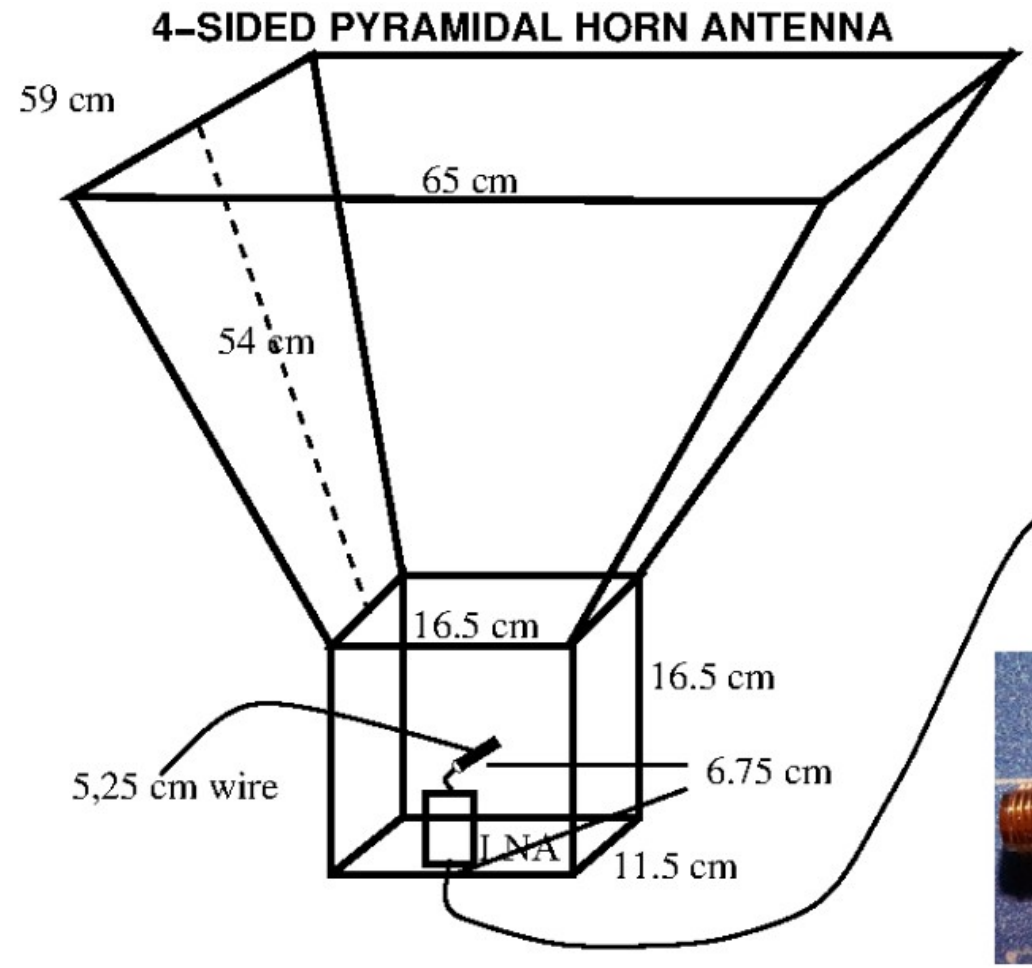
•Dimensions of the optimized horn antenna, to have the largest sensitivity, are readable from the graph below, and I show an example of the finished antenna - made by Piotr Łukasiak, craftsman in CAMK Warsaw, from a scrap advertisement board he found in the storage of CAMK.

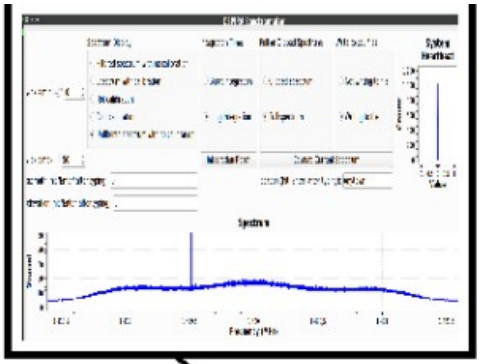




Horn antenna and other hardware 1

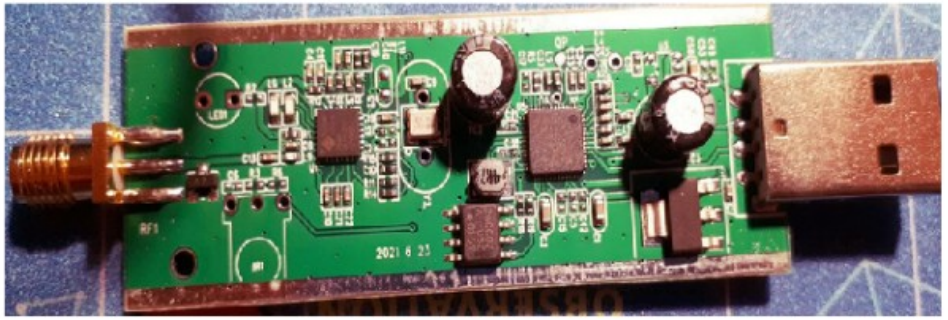
•My kitchen prototype was made of a cardboard and aluminum foil. We need a waveguide for λ = 21.206 cm (1420.406 MHz), the needed precision is of the order of centimeter, so it does not have to be a high-precision work, more important is the quality of the connections. Below is the sketch of a my configuration:





Computer with GNUradio/Pothos Flow and spectra analyzing software

RTL SDR dongle (receiver)



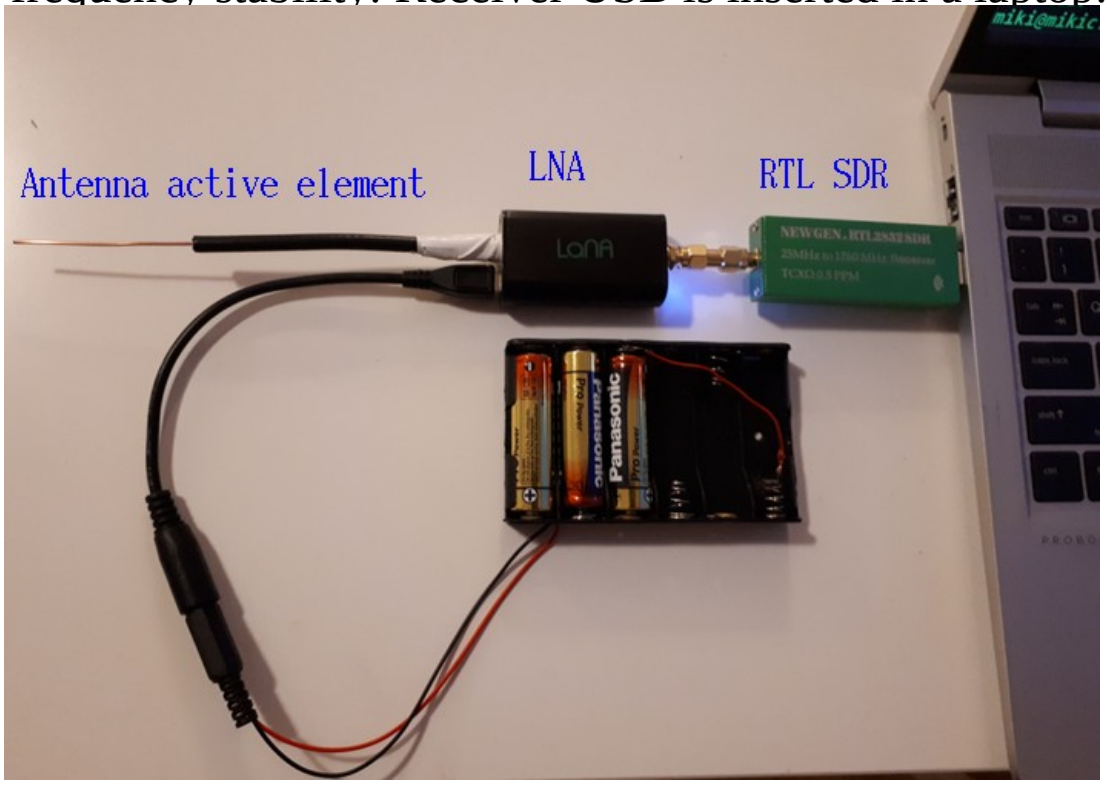
Horn antenna and hardware 2

We wish to make so called λ/4 antenna, so we need the antenna active element of 5.25 cm length. The easiest way is to take about 12 cm of the RG58U coax cable and carefully remove the 5.25 cm of its shielding. The active element should be inserted in the antenna, with ground (=shielding of the coax cable) connected to it-check with the standard multimeter, there should be a small but finite resistance.

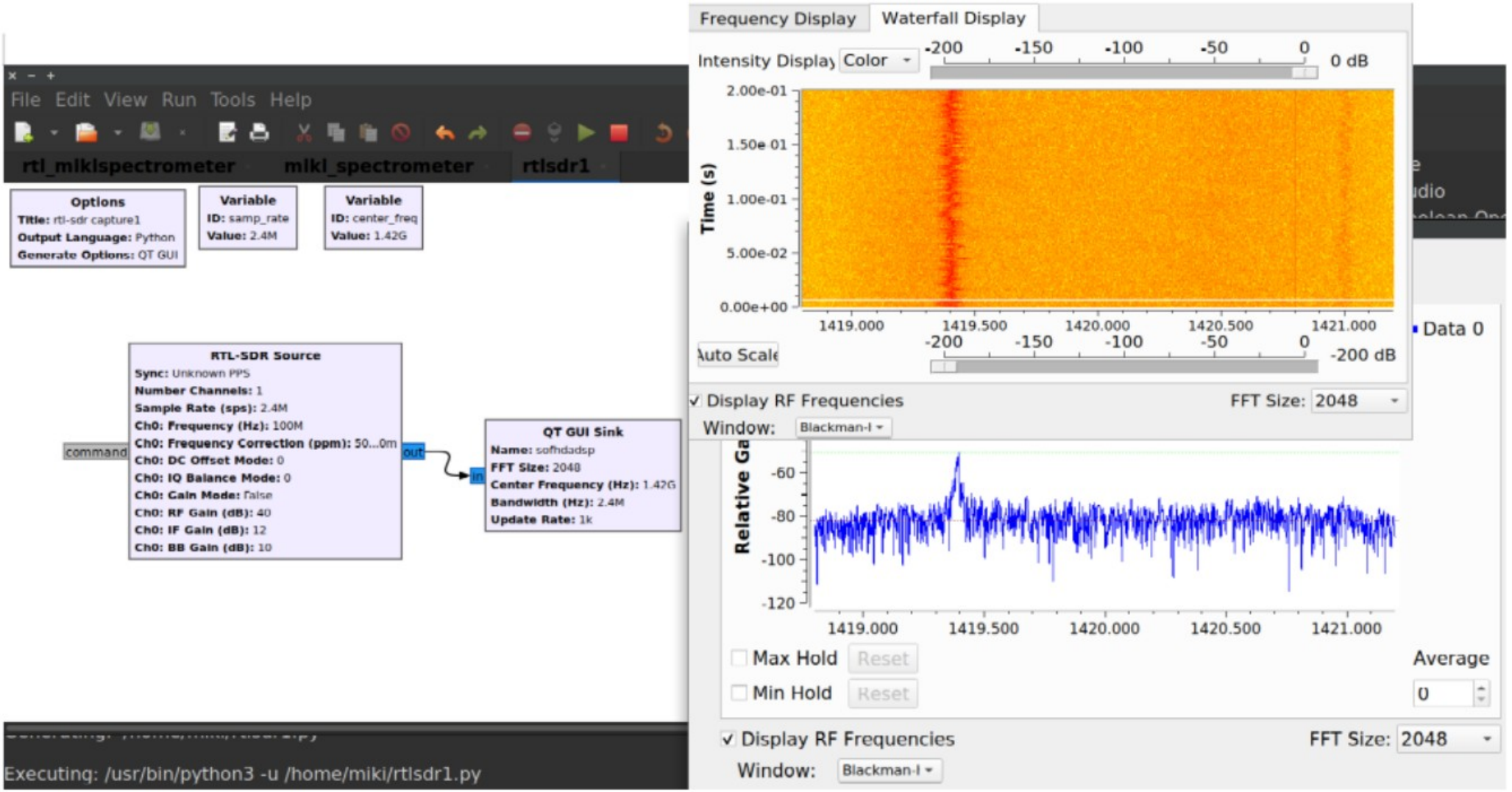
•The antenna should be connected to Low Noise Amplifier (LNA). I used NooElec Lana for the 20-4000 MHz band, with 4.5 V power (be careful when powering it from USB, as there is usually a lots of noise!) as close to the antenna as possible, because we do not want to introduce the noise before the LNA. Before and after the LNA one can use the additional filters.

• From the LNA we can use a longer (few meters) SMA cable to RTL SDR receiverl I had a low quality Chinese clone NEWGEN.RTL2832SDR, 25MHz to 1760 MHz, with the integrated circuit R860 instead of the older R8232T, with a “Temperature Compensated Crystal Oscillator”

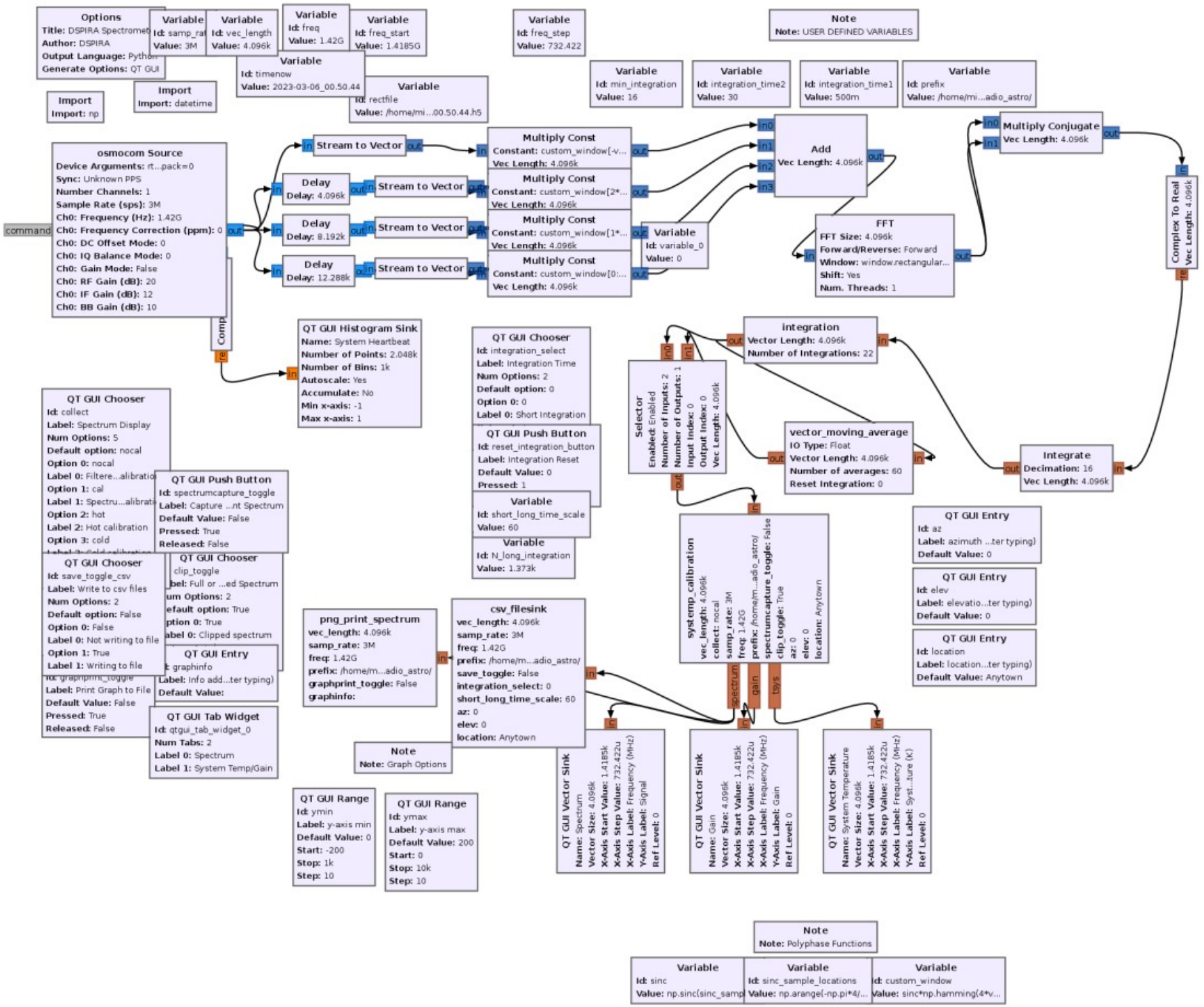
(TCXO) of 0.5 PPM frequency stability. Receiver USB is inserted in a laptop.



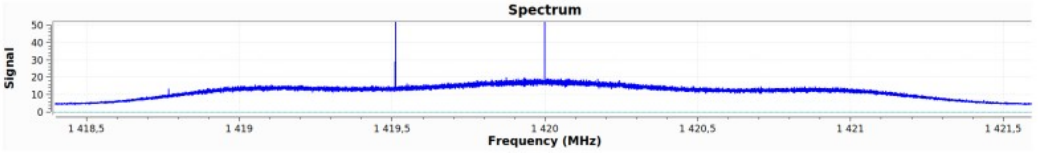
We use the Fast Fourier Transform (FFT) to analyze the separated channels. I used the DSPIRA gnuradio software (OpenLab, 2020). The simplest visualization scheme is shown below, and a complete, much more complicated one, in the next page:

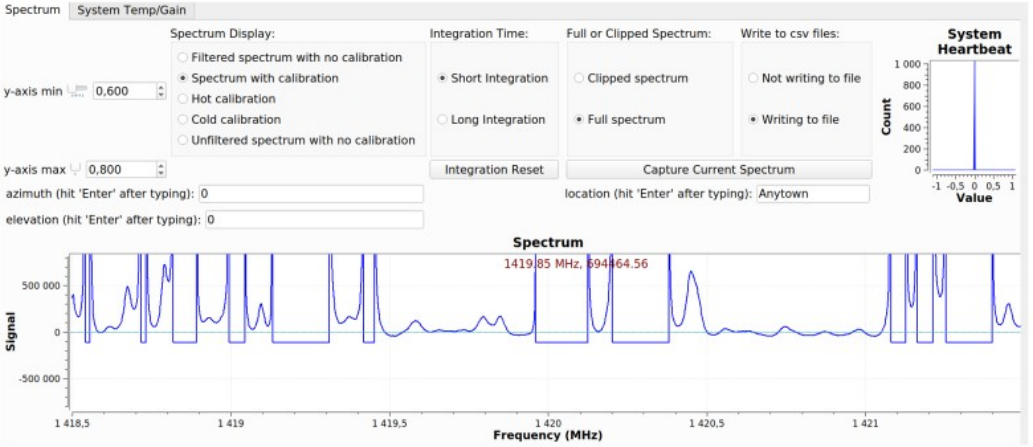


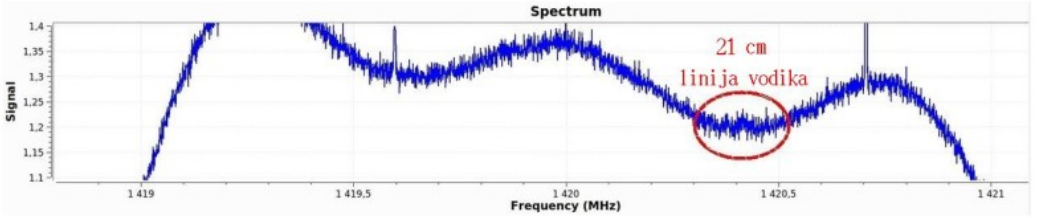
Signal analysis-DSPIRA software

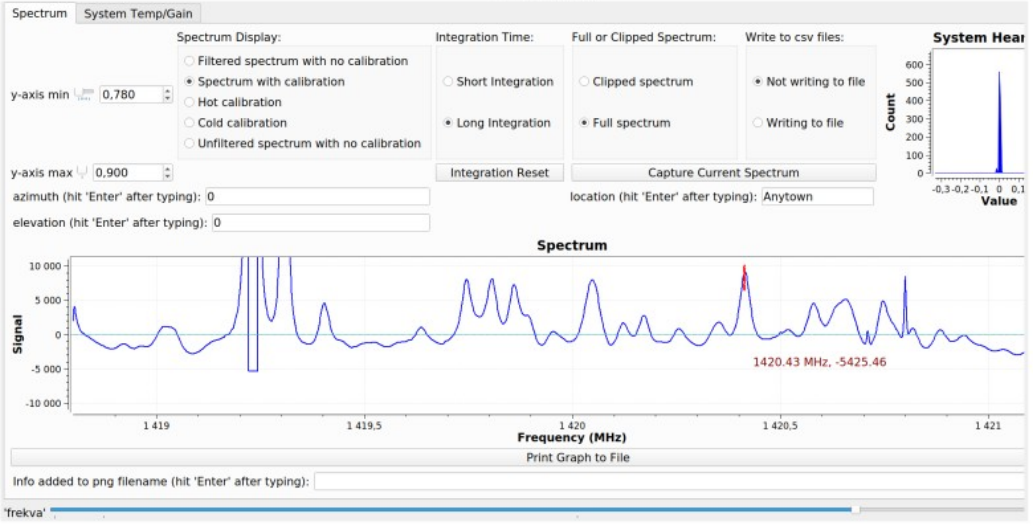


My first measurements at 1420 MHz without calibration and first attempts at calibration. The first successful registration of H1 line is shown below.









Signal analysis-location of the first objects

Part of the sky in Monoceros, between the Procyon and Sirius, where I measured the first H1 line. There are hydrogen clouds in our Galaxy, where the signal is the strongest.

Observational challenges

- Hydrogen clouds in the Galaxy
- Rotational curve of the Galaxy
- Sun
- Jupiter
- Pulsars
- Interferometry with 2 or more antennas.
- Interferometry from the water surface.

Summary

I presented a prototype of small radio telescope, using the software-defined radio (SDR)

•Such technology became available because of large production of devices for mobile communications and digital HF signals.

•A potential of use of such devices in regular education and STEM programs is very large and connects astronomy, mathematics, physics and informatics.

•Educators should be informed about such possibility and encouraged to use it at the various levels of education.

Enjoy the practical astronomy!

Two instruments which brought the largest joy in practical astronomy to me, during the 40 years of doing it. Both are of the dimensions of about half a meter.

Miljenko Čemeljić, CAMK Warsaw, July 21, 2023