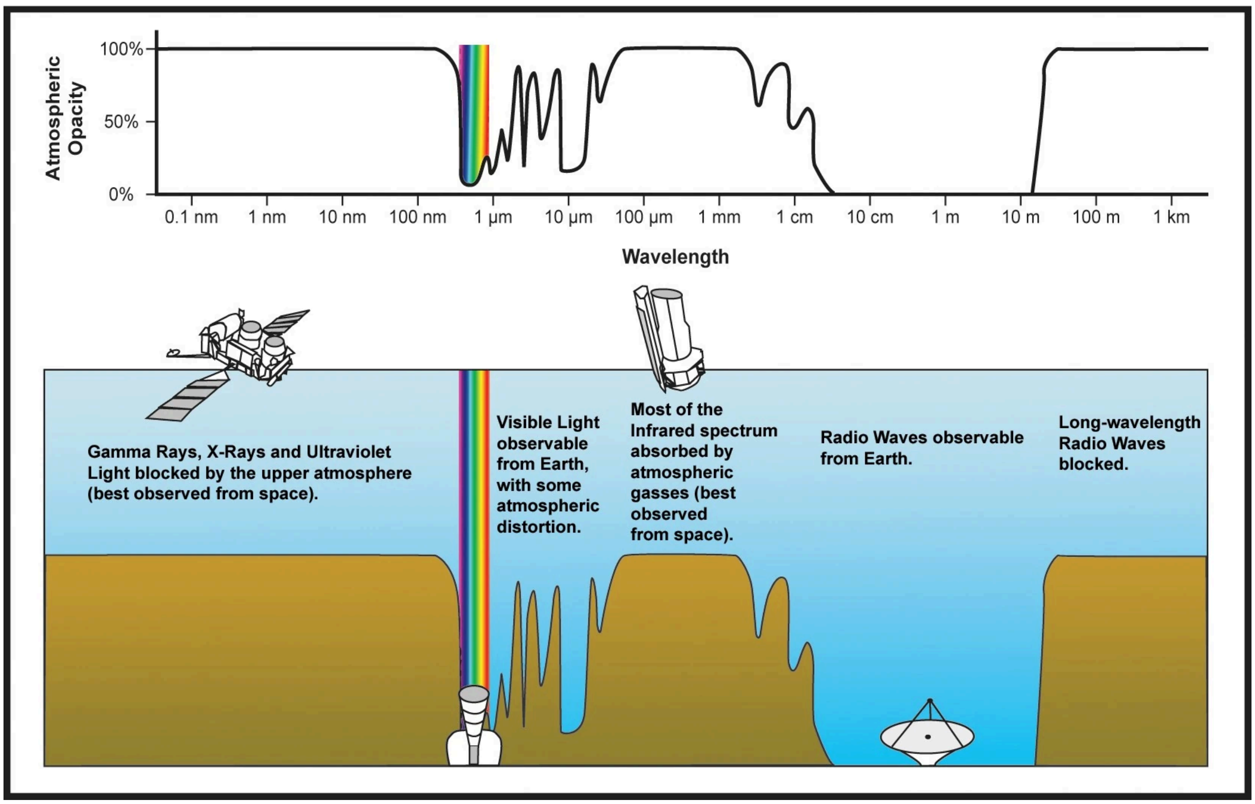
Hydrogen Line Radio Astronomy

Introduction

Radio telescopes have played a major role in modern observational astronomy. They have many advantages compared to other telescopes. The Earth's atmosphere is transparent to a large region of the electromagnetic spectrum from around 1 cm to 10 m, which allows radio waves of these wavelengths to be observed from telescopes on Earth. This contrasts with higher-energy light, which must be observed from space telescopes. In addition, radio telescopes, unlike optical telescopes, can operate at all times of day and in any weather.



Given this range of observable wavelengths, the 21 cm line, an emission line associated with the spin-flip transition of a neutral hydrogen atom, plays an important role in radio astronomy.

A neutral hydrogen atom consists of a proton and an electron, whose spins may be parallel (aligned) or antiparallel. Due to the interactions of their magnetic dipole moments, the parallel state has a slightly higher energy than the antiparallel state. Therefore, when a hydrogen atom is in the parallel state, the electron may flip its spin and emit a photon.

The wavelength of the emitted photon can be calculated. For a photon with frequency ν and wavelength λ, we have

$$E = h\nu$$

$$c = \lambda\nu$$

where h is the Planck constant. The energy difference between the two states is

$$\Delta E = 5.87433\ \mu\text{eV}$$

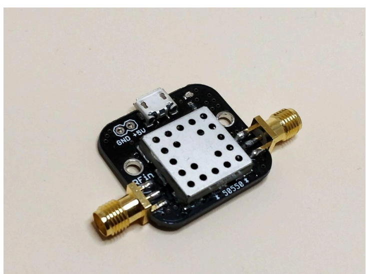
Therefore

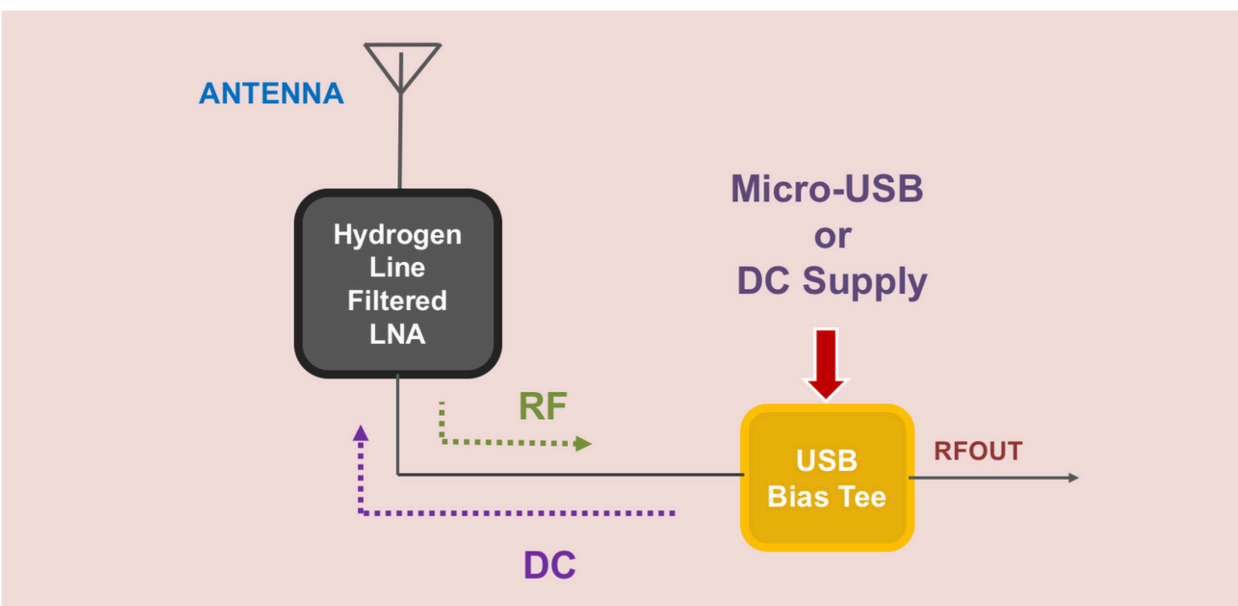
$$\lambda = \frac{c}{\nu} = \frac{hc}{E}$$
$$h \sim 4.13567 * 10^{-15}\text{eV s}$$
$$c \sim 3 * 10^{8}\text{m/s}$$
$$\implies \boxed{\lambda \sim 21.106\text{ cm}}$$
$$\implies \nu \sim 1420.405\text{ MHz}$$

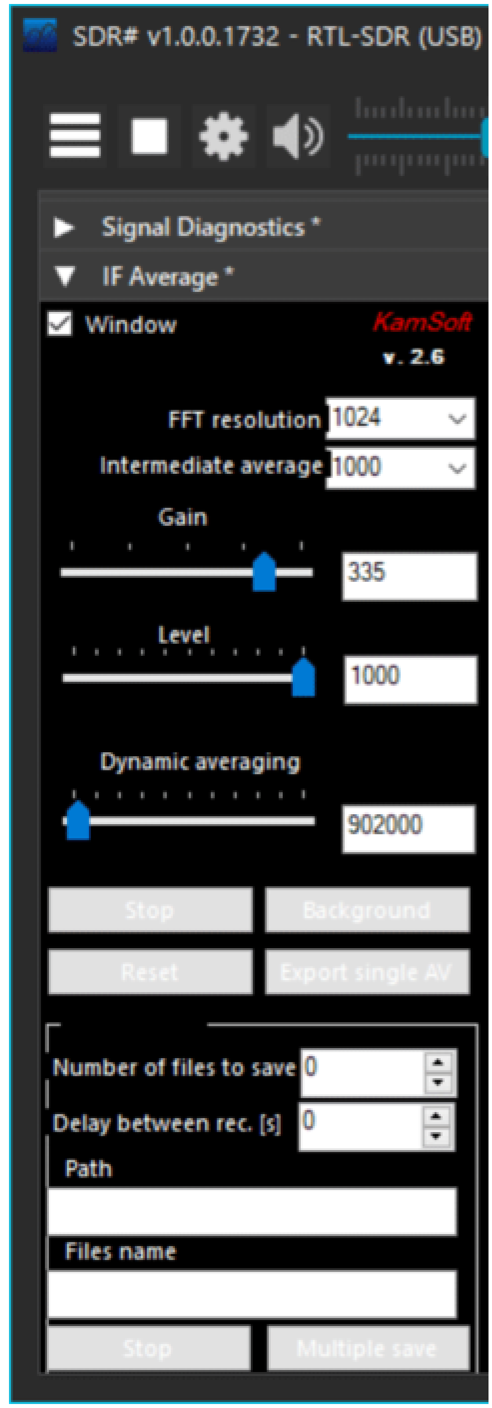
Thus, this emission line is known as the 21 cm line. This transition is very rare, with a transition rate of $2.9 * 10^{-15}$ Hz, but on astronomical scales, it is detectable. As the emitted photons are radio waves, a radio telescope is required. Our project was to assemble a radio telescope and detect this emission line by pointing the radio telescope toward the Milky Way.

Procedure

The setup uses a 2.4 Ghz 100 cm x 60 cm parabolic WiFi grid antenna, connected to a low noise amplifier, which is then connected to a usb flash drive via coaxial cables. This usb flash drive is an RTL-SDR flash drive that works specifically for radio and can be used with our SDR software running on a laptop. The low noise amplifier (LNA) is specifically made for 1420 Mhz hydrogen emission line detection, and helps reduce other background noise and man made signals. This LNA is also powered using a micro-USB connected to an outlet that provides it 5V.

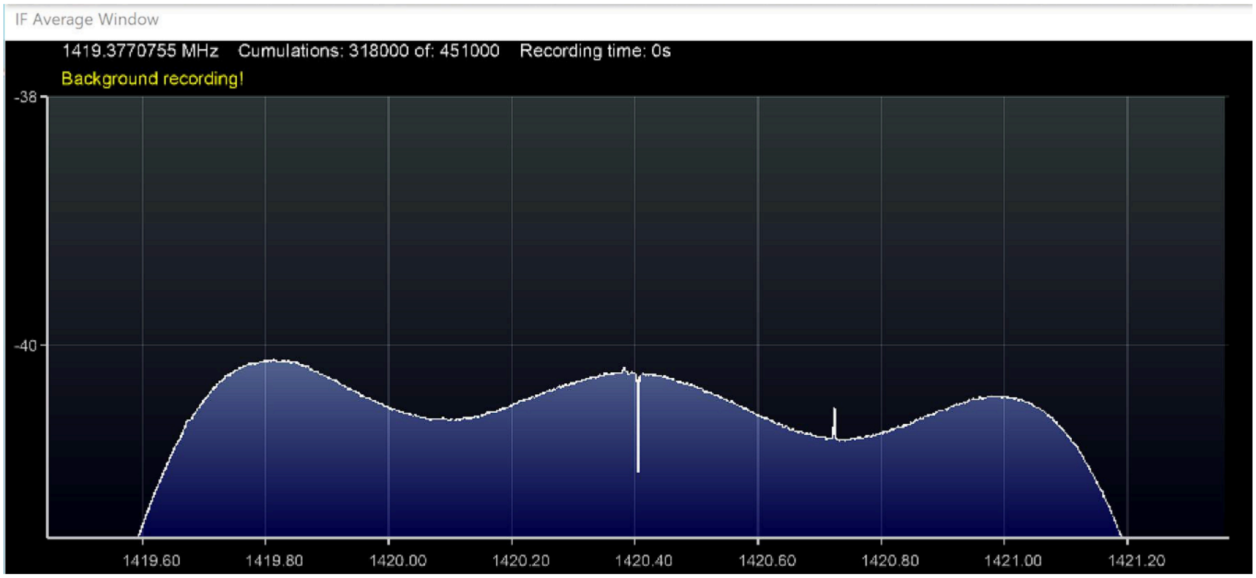






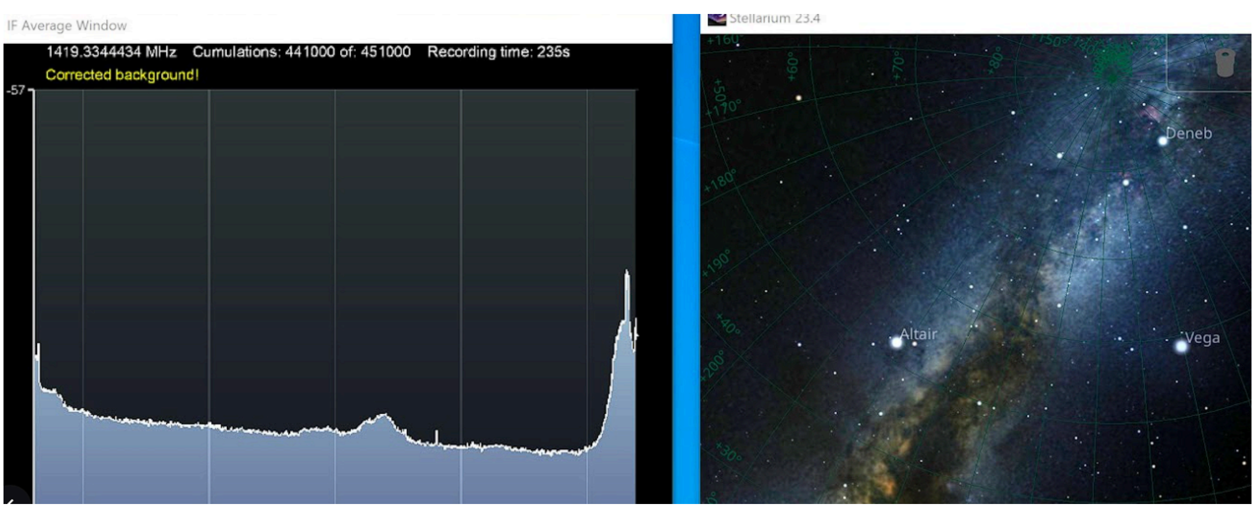
For compatibility reasons, we used a depreciated release of the SDR software, version 1.0.0.1732, along with a custom plugin called IF average. This plugin allows the user to plot an average of the spectrum that SDR detects from the antenna by using a fast fourier transform to signal data. This allows us to plot the signal over time and shows a better hydrogen emission line. For the settings within the SDR, we set bandwidth to 8000, the order to 1000, set the frequency to 1420.405 Mhz, turn on offset for higher gain (set slider to max), and then finally set sampling rate to 1.92 Msps. Then within the IF plugin, we set the FFT resolution to 1024, the intermediate average to 1000 (this shows many averages it will take a second), the gain to 350, and the Dynamic Averaging between 451000 to 902000. The level option can be changed according to the user to get the spectrum in view of the plot once observation begins, but first we must calibrate for the background.

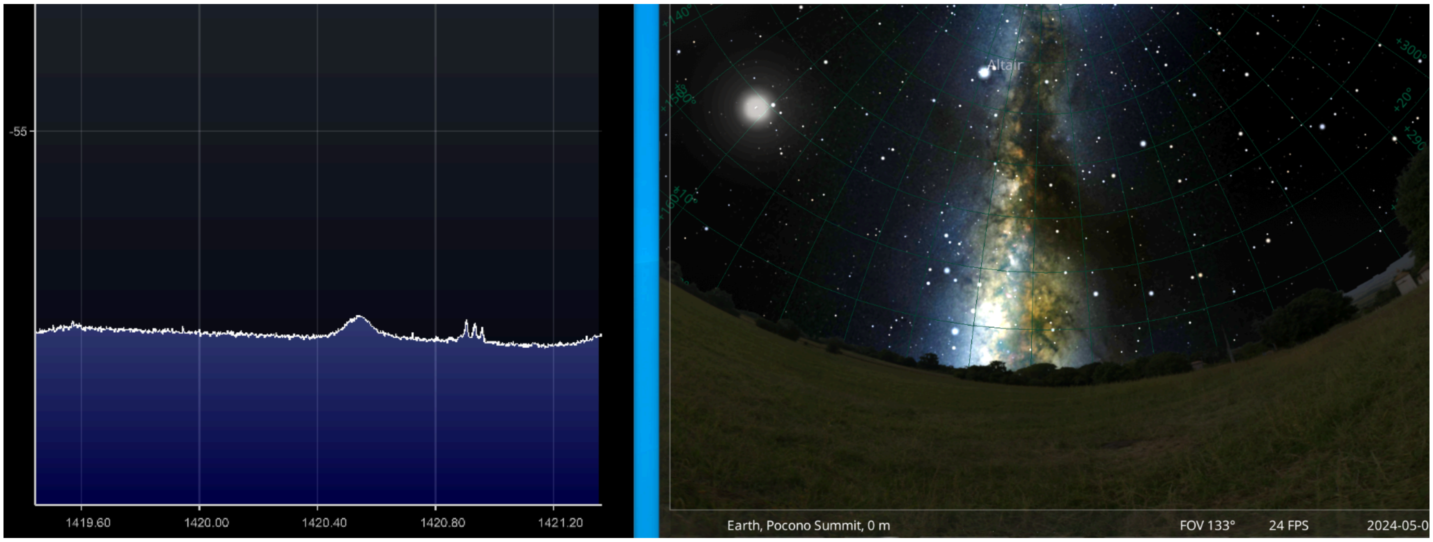
In order to calibrate, point the antenna upwards toward the zenith, but do not connect to the LNA yet. Have the RTL SDR usb plugged into the computer, and the LNA connected to the usd using coaxial and the LNA should also be connected to power via micro usb. Then within the SDR IF plugin window, check the “Window” option box, a plot should pop up, and then click on background (or acquire background), it should take 3-6 minutes. Once the background is complete, the plot will be in yellow text; corrected background. Without background correction, our signal looks like this;

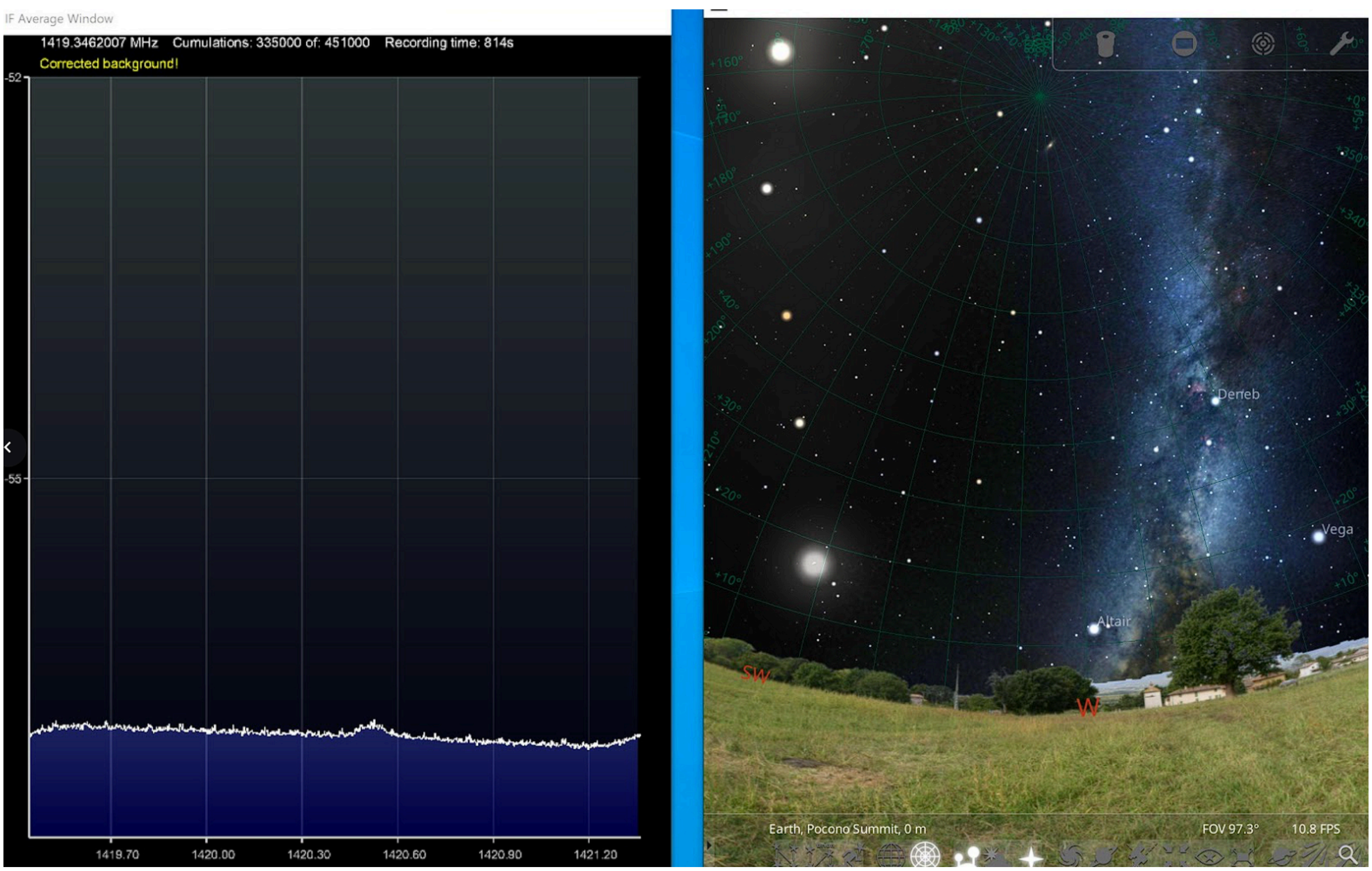


Immediately after a corrected background calibration, we should see a flat line, from there we can connect the LNA to the antenna pointing to the zenith. Using stellarium on the computer, we can track the Milky Way going across the zenith, and see how the hydrogen emission line changes. For our local coordinates, the best time to observe the Milky Way crossing the zenith was between 3 to 7 am, and using an automatic computer screen shot software, chronolapse, we took time lapse images of the IF average plot a few times every hour.

Results




-55
1419.60
1420.00
1420.40
1420.80
1421.20
Altair
Earth, Pocono Summit, 0 m
FOV 133°
24 FPS
2024-05-0


IF Average Window
1419.3462007 MHz Cumulations: 335000 of: 451000 Recording time: 814s
Corrected background!
-52
-55
1419.70
1420.00
1420.30
1420.60
1420.90
1421.20
Deneb
Vega
Altair
SW
W
Earth, Pocono Summit, 0 m
FOV 97.3°
10.8 FPS

Conclusion

We can see an approximately gaussian pulse around 1420.4-1420.6, which is the hydrogen emission line. It is important to note the hydrogen emission will take a gaussian shape, as most natural radio signals do, and sharp changes in the spectrum are man-made signals. We find such man made signals around 1420.8 Mhz, and some occasionally around 1421 Mhz which may actually come from the computers and usb electronics themselves.

After observing the IF average radio spectrum, we saw the gaussian pulse shift over the duration of the timelapse, as the Milky Way moved towards the zenith, crossed it, and then began setting in the late morning. This shift was due to the Doppler effect as the antenna was pointed towards the zenith during the timelapse, which the Milky Way was approaching at the beginning of our time lapse. Hypothetically, knowing the shift in frequency and the duration of the timelapse, one could calculate the apparent velocity of the Milky Way through our celestial sphere.

Resources:

https://groups.google.com/g/sara-list/c/vgZfbIg0d9k?pli=1

https://www.rtl-sdr.com/cheap-and-easy-hydrogen-line-radio-astronomy-with-a-rtl-sdr-wifi-parabolic-grid-dish-lna-and-sdrsharp/

https://16767887561855875192.googlegroups.com/attach/15bd5f223df41/SDR%23%20Paper.pdf?part=0.1&vt=ANaJVrFh9asNNd2g-9O82hs-hEbAC8VD44pHjshGtlS2Mpws2k3yrq__Q8xJfBfLyGqlhzqz3B0lnmfQYPP5o1FDMiJOGaZ2j7kab5r2yUaysOt4rIDVXXU