A PORTABLE, LOW-COST HYDROGEN 21 cm (1.42 GHz)

RADIO TELESCOPE PROJECT

FOR BOTH DAY AND NIGHT ASTRONOMY

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INTRODUCTION

For me, it began as a simple quest to see if ultra-high frequency (UHF) ham radio antennas could receive solar noise. After a few months of Internet searches, I found information on small radio telescopes. The construction, data collection, and analysis described here is within the ability of a motivated middle or high school student, with help, and the equipment described here can certainly be the basis for investigations from casual to advanced.

This project has exceeded my expectations. The system can actually receive and record the hydrogen 21 cm emission spectra of the Milky Way. One can measure the relative RF (radio-frequency) intensities of the clouds and the Doppler effect frequency shifts from different regions. The data can be used to calculate and plot hydrogen cloud velocities relative to Earth.

The cost is under $300, and the entire electronics package can be purchased from one source. The software is free, and the mounting can be as simple as a vertical pole in the ground. Data is acquired by positioning the antenna at a chosen sky location and then capturing hours of data as the sky drifts by.

IMPORTANCE OF HYDROGEN 21 cm ASTRONOMY

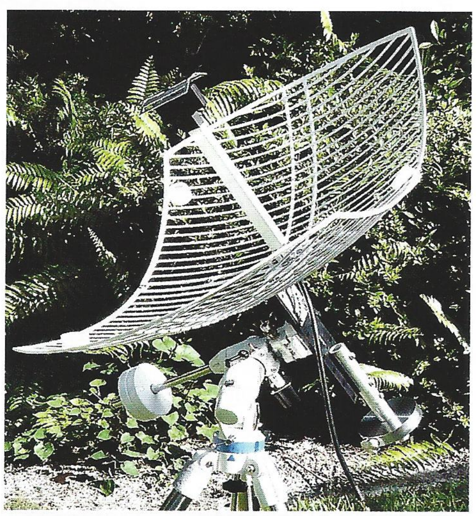
Hydrogen is the most abundant element in our universe, and there are huge clouds of neutral hydrogen left over from star formation. Mapping this neutral hydrogen using the RF radiation it emits can provide an accurate view of the shape of our Galaxy. The radiation comes from hydrogen's transition between two levels of its ground state, called the spin-flip transition. The state with parallel proton and electron spins is slightly higher in energy, so when the electron's spin flips, it releases that energy as photon at a very specific frequency: 1420.405751 MHz. It is a low energy, but there's lots of hydrogen.

The main frequency bands used in radio astronomy, including the 21 cm line of neutral hydrogen, have been protected by international agreement. "Protected" means that these frequencies are provided special treatment by governing organizations to keep them clear of harmful interference from human activity; no transmission is allowed in this particular band.

The Scope in a Box complete system is available for $295 from radio-astronomy.org/node/366

WHAT CAN BE DONE WITH A SMALL RADIO TELESCOPE

In this article I describe how to create a map and animations of the relative densities and velocities of neutral hydrogen clouds in the Milky Way, an interesting, ongoing project.



The parabolic reflector mounted on a telescope mount.

The parabolic antenna and electronics can detect the 21 cm RF emission of hydrogen within the Milky Way and measure and quantify its relative amplitude and velocity. I began constructing this system in August 2021. I used an existing Celestron CG-4 mount to make positioning easy. It is portable and I've had it set up several times for small outings.

The Scope in a Box project is offered by SARA, the Society of Amateur Radio Astronomers, and contains everything required to get started. It is a great way to begin; you know it will work out of the box, and then you can get creative.

SYSTEM DESCRIPTION

❶ A parabolic reflector acts like an optical mirror, capturing and focusing electromagnetic energy. Instead of visible light energy being focused to an eyepiece or digital camera, the radio frequency energy is focused on a small antenna.

❷ The RF energy is transferred to a Nooelec SAWbird H1 module which consists of a pre-amplifier, a filter to remove unwanted frequencies, and a final gain amplifier.

❸ The RF output is passed to a software-defined radio (SDR) Module. An SDR is a radio receiver whose functions are primarily implemented and controlled by a software program. The analog RF data are processed and converted to a digital format via an analog-to-digital converter (ADC) within the SDR module. Its output to the PC is a stream of digital amplitude and phase information that represents the original RF signal.

❹ Via a USB cable, the SDR is controlled by SDR# (SDR Sharp) software running on the PC.

❺ An Airspy SDR# control program sets parameters within the SDR such as sample rate, center frequency, resolution, and bandwidth. These functions allow a specific frequency to be "tuned in" like a radio station. In the PC, the digital data is converted to a frequency spectrum and displayed. And, like a normal radio, the sound of the hydrogen RF signal is also output as an audio signal. It sounds like a hiss.

❻ Since the hydrogen signal amplitude is so small, thousands of averages must be combined to create a smooth plot. An IF Average plug-in program performs this function.

❼ The software creates and stores ASCII text files for further analysis. Typical files are from 30 seconds to 5 minutes of data averaging.

An equatorial telescope mount is convenient for pointing the antenna to a specific area. The mount is not tracking. A quick compass alignment allows use of the right ascension and declination setting circles. Since the antenna's beam-width is about 10 degrees, alignment is not overly critical. Another option is to use a vertical pole and adjust the antenna using the supplied clamp.

The optional ($11) but recommended heat sink shown above provides cooling for the SAWbird and SDR and a place to securely mount the components. Keep the connection between the antenna and SAWbird short because cable losses are high at these frequencies.

EXAMPLES OF RESULTS

Chart 1 shows data from a single sample of emissions from the Milky Way. The processing software saves a two-column table of frequency and amplitude. These data can be plotted as shown using a spreadsheet program.

Chart 2 shows data from twenty-five 5-minute intervals. There is a distinct change in the spectral frequency content as the sky drifts by. That equates to a right ascension shift of only 1.25 degrees per plot – good resolution for such a small parabolic reflector.

Chart 3 Shows Doppler redshift velocity calculations. In chart 2, you can see a left bias in the data: a significant portion of the data is at frequencies less than 1420.405751 MHz. This lower-frequency content is due to the Doppler shift caused by this area of our galaxy moving away from Earth: a redshift. The frequency shift can be converted to an actual velocity with the following redshift equation

$$V = \frac{\left(HI - F_{measured}\right)}{F_{measured}} * c$$

where HI = 1420.405751 MHz (non-moving spin-flip frequency); c = speed of light, 299,792 km/sec; $F_{measured}$ = Measured frequency, from spreadsheet.

Neutral hydrogen (H I) RF emission is redshifted – shifted to a lower frequency – when that area of the galaxy is moving away from Earth: the speed of light is constant, but the frequency decreases as the RF signal gets "stretched" by the velocity as the hydrogen moves away from us. Conversely, when hydrogen clouds move towards the Earth, the frequency increases as the light is blueshifted: the RF signal gets "compressed" and thus the frequency increases.

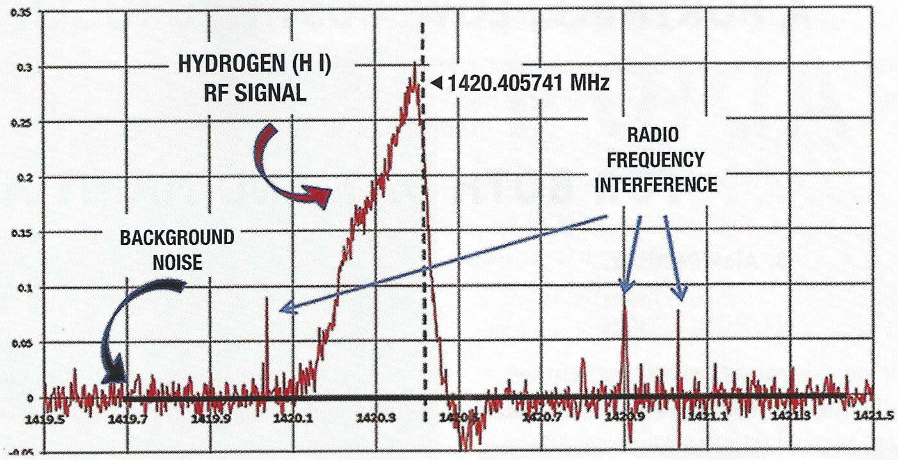


Chart 1: *Plot of single-sample data saved by processing software*

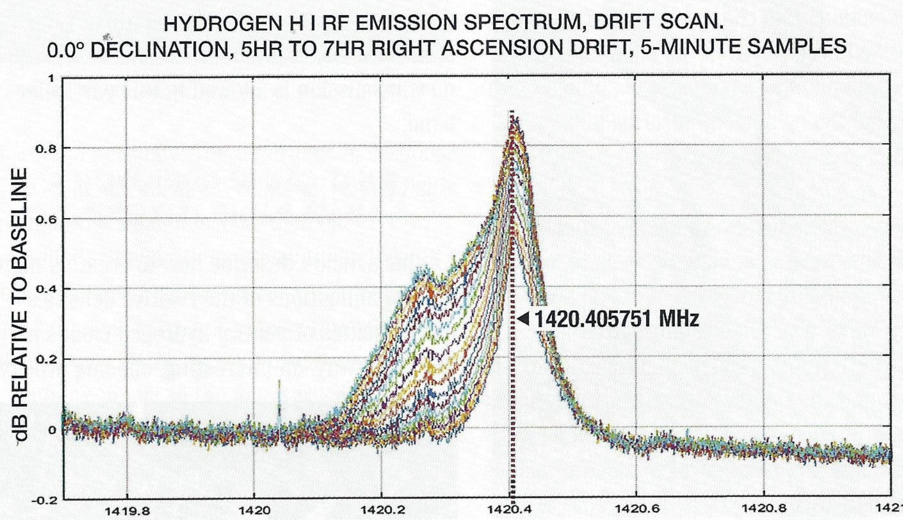


Chart 2: *Plot of multiple samples at 5-minute intervals*

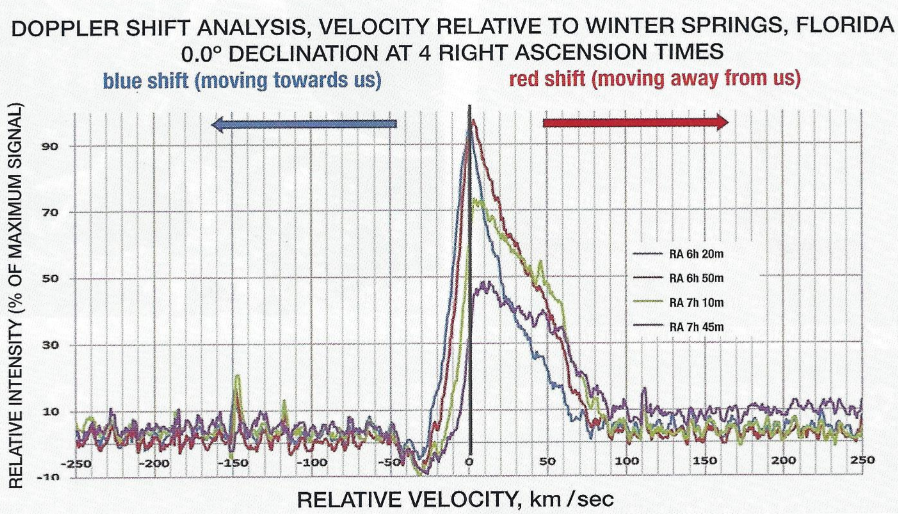


Chart 3: *Plot of relative velocity calculated with Microsoft Excel from Doppler shift, using the equation at left. The horizontal axis now shows relative velocity.*

FINAL NOTES

Radio-Frequency Interference (RFI): The receiving system is sensitive. If you have noise in the spectrum (generally sharp frequency spikes), try changing the position of the cables and the PC. Many items in a home can generate RFI: chargers, televisions, light dimmers. Try turning items on or off to help identify the source. Perhaps relocating the antenna will be the solution. Perfection is not required; the peaks can be photoshopped out of your plots.

Remote Operation: A normal USB cable is limited to about 15 feet. A convenient way to set up the antenna and electronics outside with the PC inside is to use a USB over Cat5 cable extender such as this one: *tinyurl.com/hubextender*. It uses a power supply at the PC end and will power both its USB hub unit and all USB radio telescope modules through a Cat5 cable. Cable and extender can be purchased for about $100. I have verified that the system works with a 75-foot cable. Do remember that none of the connectors or electronic modules are waterproof.

Noise Temperature: All objects with temperatures above absolute zero (–273°C, –460°F) radiate electromagnetic (EM) energy. This system will detect the RF portion of that energy coming from the ground, trees, buildings, and clouds, in addition to the intended 21 cm radiation of hydrogen. Try to keep the antenna away from buildings and trees, and preferably pointed upwards to minimize the EM energy from the ground. When clouds drift into the field of view, they will shift the background and signal levels upwards but have the overall effect of slightly reducing the signal-to-noise ratio.

IT'S EASY... TRY IT!

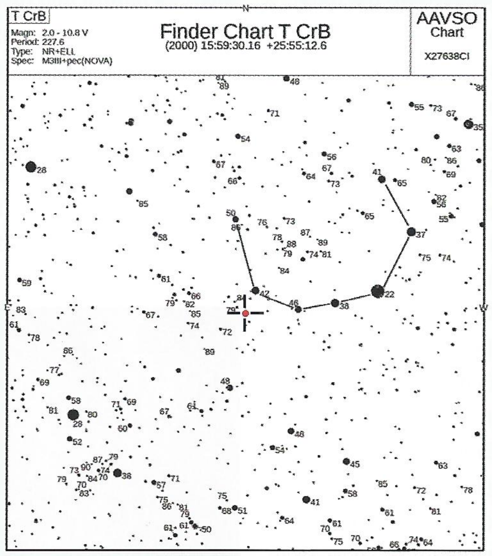
Don't get overwhelmed with the seeming complexity of this project. It's easy to set up the system to capture and display signals from vast, moving, swirling hydrogen clouds within the Milky Way. If it impresses you as much as it did me, it will create a motivation to learn more, and then you can delve into the technical details. The Scope in a Box and optional accessories can be purchased from *radio-astronomy.org/node/366* and detailed setup advice can be found at *tinyurl.com/radio-astro-setup*. ✶

Further Reading can be found at these sites: *radio-astronomy.org* • *ccera.ca* • *setileague.org/index.html* • *wvurail.org/dspira-lessons/tour.*

KEEP AN EYE ON THIS ONE

by Jamey Jenkins

For several years now I've practiced techniques of differential photometry, the goal being an avocation to embrace in my retirement years. Photometry is the scientific measurement of visible light (brightness variations). Having reached the retirement plateau, the first task has been to develop a list of stars I wish to follow on a regular basis. My current list consists of a collection of long-period variable (LPV) stars, three young stellar objects (YSOs), three recent novae, and the star T Coronae Borealis (T CrB). I upload my observations to the database of the American Association of Variable Star Observers (AAVSO).



T Coronae Borealis is the star found in the center of this 20° wide AAVSO field chart, marked with a red dot. Credit: AAVSO, modified by Reflector *staff.*

T Coronae Borealis, also known as the Blaze Star, is the nearest symbiotic recurrent nova. Symbiotic novae are slow irregular eruptive variable stars with nova-like outbursts. They are a binary star system in which a white dwarf accumulates matter from its red giant companion through the system's accretion disk. The accreted material is ignited thermonuclearly on the surface of the white dwarf and produces a nova eruption. Outbursts of T CrB were recorded in 1866 and 1946, hinting at a recurrent event time of approximately 80 years. Ordinarily this star shines near 10th magnitude, however, the 1866 outburst quickly reached magnitude 2.0 and in February 1946 it attained magnitude 3.0 overnight. Professional astronomers predict the next eruption to occur between 2023 and approximately 2026.

The "blue light" magnitude graph (below) by Bradley Schaefer, Louisiana State University, shows the 1946 eruption (red line) versus the recent 2020 AAVSO data as blue dots. Noteworthy is the similarity of the pre-outburst activity which began again around 2014–2015. Something is happening with T CrB, something that warrants keeping a watchful eye on this star. I suggest interested stargazers check out the field of T CrB each night they venture out, looking for a noticeable surge in brightness. The amateur astronomer Leslie Peltier recounted his misstep with this star in his classic book, *Starlight Nights,* after having faithfully watched it for many years. Peltier it seems opted to "call it a evening" on February 9, 1946, instead of checking out T CrB the night that it unexpectedly rose from its sleep, a once in a lifetime error that he regretted. Maybe we'll have to wait until 2026 for the next eruption but maybe not, as astronomy is always full of surprises. Here is one star worthy of your watchful eye, one guaranteed to put on a spectacular show! ✶

T Coronae Borealis, mag: about 9.8, R.A. 15h 59m 30s, Dec. +25° 55′ 12″