2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

Open Source Radio Telescopes: Astronomy Projects for Students, Teachers, and Amateurs

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Abstract

The Open Source Radio Telescopes (OSRT) project is a budding endeavour to provide educational activities for primary and secondary school students and introduce them to science and technology through basic radio astronomy projects, as well as provide a repository for like-minded projects. There are two projects currently on the website: a horn antenna specialized for detecting the 21cm neutral hydrogen line of the Milky Way galaxy, and a loop antenna built to detect Sudden Ionospheric Disturbances (SID's) caused by solar flares and high-energy phenomena in the upper atmosphere. The OSRT website has instructions for building and operating both antennas (http://opensourceradiotelescopes.org/). GNU Radio software is used to interpret and display the data for each antenna, and both are successful at either mapping the Milky Way galaxy across the sky or detecting ionospheric disturbances, respectively. Both projects are well-suited for lab classes or workshop activities and aim to foster an interest in STEM among students.

1. Introduction

As industry grade electronics have become cheaper in recent years, it is easier for members of the general public to access these electronics, especially components used in the construction of radio telescopes. To aid in this process, we have created the Open Source Radio Telescopes Project (OSRT), which is a collection of radio astronomy citizen science projects geared towards primary/secondary school students, teachers, and any other interested members of the general public. These projects aim to foster an interest in the science, technology, engineering and math (STEM) fields and provide an introduction to basic radio astronomy principles. Over time, many OSRT builders may contribute back to the collection with their own designs and project ideas, and the website will be a repository for these contributions and discussions.

There are two types of antenna projects currently available. The first project horn antenna in the style of the Ewen-Purcell horn of 1951 [1] that picks up the 1420MHz signal of the neutral hydrogen gas that floods the Milky Way galaxy. By aiming this telescope at different areas of the sky and measuring its response, one can effectively map the radio Milky Way galaxy as seen from Earth.

The second project available from OSRT is a loop antenna tuned to a frequency of 24khz. It is roughly one half meter in diameter and measures the signal strength of VLF submarine communication signals in order to indirectly detect signs of ionospheric disturbances due to solar activity.

2. Neutral Hydrogen Antenna

The neutral hydrogen antenna is built to capture the 21cm/1420Mhz line of neutral hydrogen, with the aim of mapping the cool gas of the Milky Way. With the advent of inexpensive radio electronics, it is possible for the general public to afford to build a functioning radio antenna that is sensitive enough to detect the neutral hydrogen in the Milky Way. As documented on the website, the construction and usage of the telescope is designed as a project for students in primary or secondary school and their teachers that serves as an introduction to radio astronomy and to pique interest in STEM fields. Several prototypes have been built by the organizers and contributors to OSRT, as well as several other models by first generation undergraduate students from the First2Network (https://first2network.org/) and primary school teachers taking part in a DSPiRA research experience for teachers (http://wvurail.org/dspira/). There are several different models of the 21cm horn documented on the OSRT website, as well as the electronic systems used for converting the electromagnetic signals into data.

2.1 Construction

As of January 2018, there are three different neutral hydrogen antenna designs on the OSRT website. One design is shown in Figure 1. While each has a unique construction, the basic design allows the horn to balance on a base such that its elevation, or the angle between the telescope beam and the horizon can be changed at will. Depending on the construction, the base can either be picked up and repositioned or twisted to act as an azimuth angle.

The feed horn is made of a lightweight styrofoam with a radio-reflective coating to funnel the electromagnetic signals from the sky into the waveguide and copper wire antenna. The size of the opening of the feed horn is 3ft x 4ft, and the cross-sectional size of the waveguide is 3in x 6in, an optimal size for transmitting electromagnetic waves with wavelengths of 21cm. Simulations were done by Steve White of Green Bank Observatory to determine the optimal length of the copper wire antenna inside the waveguide, which is roughly 5cm.

The copper wire feeds directly into a series of two low noise amplifiers and L-band filters, which amplify the signal and reduce out-of-band interference. The radio signal then travels through a ‘bias-tee’ which splits the signal from the power supply to the amplifiers. The signal is sent via a coaxial cable to a SDR device which digitizes the signal and sends it to a computer via a USB connection.

In total, all of the materials for the construction of our HI antenna cost less than $300 USD. There are plans and attempts to bring the cost down to $100 USD or less in the future.

2.2 Software and Performance

The data is visualized and recorded by modified GNU Radio python code. The software allows a ‘hot’ measurement of the ground and a ‘cold’ measurement of radio-quiet sky to be saved, which allows for calibration of the antenna. The scans are saved as text files that contain scan metadata and the power for each frequency channel.

The various neutral hydrogen horn designs have typical system temperatures ranging from 100K - 200K. The beam size for the feed horn is roughly seven degrees. With these characteristics, it can take on the order of one week to create a reasonably full sky map of neutral hydrogen, as seen in Figure 2.

3. Small Loop Antenna

The small loop antenna monitors the signal strength of Very Low Frequency (VLF) radio stations from submarine communication transmitters in order to detect Sudden Ionospheric Disturbances (SIDs). VLF waves produced on Earth are prevented from escaping into space by reflecting off of the ionosphere, a region of the Earth's atmosphere that is ionized by high-energy particles. Any increase in ionization (due to solar activity or other phenomena) causes the VLF signal to bounce off the lower D-Region of the ionosphere instead of the higher E or F-Regions as it normally does, which we detect as an increase in the strength of the signal. So, by monitoring changes in the strength of the signal from a submarine station over time, we can figure out when solar activity has occurred.

Figure 1. Neutral Hydrogen horn antenna taking a hot load measurement of the ground near the Green Bank Telescope.

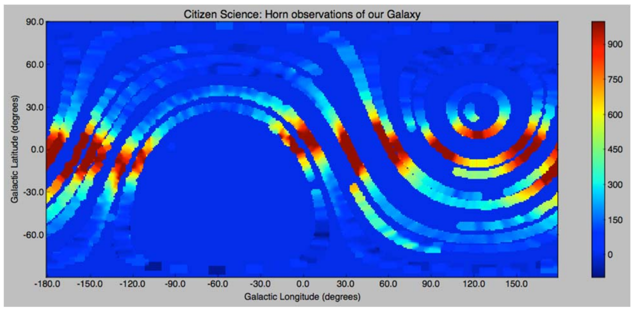

Figure 2. Results of many days of neutral Hydrogen mapping of the Milky Way plotted by galactic coordinates. The galaxy appears as the straight horizontal red area.

3.1 Construction

Constructing the loop antenna is very simple. As seen in Figure 3, The loop antenna consists of several turns of magnet wire wound around a wooden cross frame approximately one half meter in diameter, and supported by a base. The magnetic field of the VLF radiation induces a voltage in the wire loops, which is amplified, upconverted in frequency, and sent to an RTL-SDR dongle, which acts as an analog to digital converter.

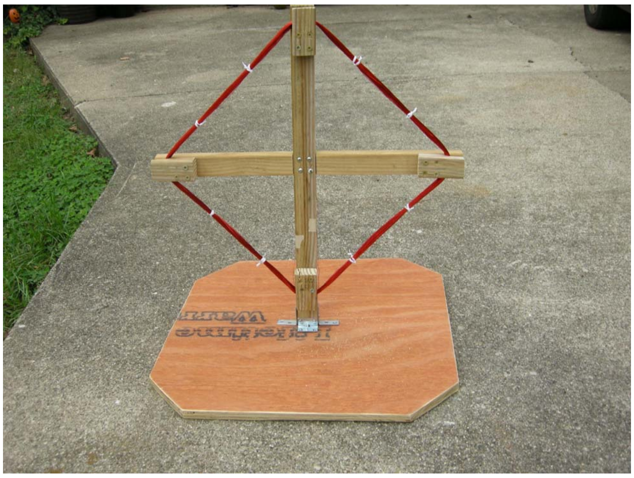

Figure 3. The loop antenna.

3.2 Software and Performance

A program created by the GNU Radio Companion processes samples from the RTL-SDR dongle and creates a data file. A secondary Python program then reads this data file and creates an 8192-channel frequency plot (with a channel width of 244 Hz) and a separate time series plot showing how the intensity of the VLF signal changes over time. By recording the signal from the small loop antenna for several hours at a time and analyzing the resulting time series plot, it is possible to identify features in the data such as significant dips in intensity near sunrise and sunset (due to effects of the Sun's angle to the atmosphere) and, in rare but rewarding cases, large spikes in signal strength caused by solar weather. In fact, the antenna setup described above successfully detected intensity spikes during a period of high solar activity in September of 2017, as seen in Figure 4. The ease and low cost (<$100) of constructing a Small Loop Antenna, along with the ability to detect exciting astronomical occurrences such as solar flares, makes this an ideal project for students of any age range.

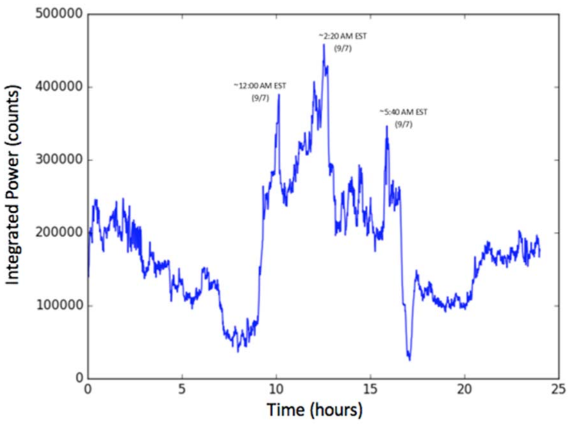

Figure 4. Spikes in intensity captured by the loop antenna in September 2017. These spikes correspond with ionospheric disturbances.

4. Conclusion

Open Source Radio Telescopes aims to promote interest in STEM through a collection of citizen science radio astronomy projects. There are currently two projects available on the website, geared towards primary and secondary school students and teachers: a horn antenna that detects the 1420MHz line of neutral hydrogen, and a loop antenna that can pick up 24kHz ionospheric disturbances. Both projects use GNU Radio based programs to display and analyze the data. The materials for each project are relatively affordable.

The OSRT website and wiki aims to serve as a repository of crowd-sourced like-minded radio astronomy projects submitted by users. We also aim to host discussions on the projects on the wiki, specifically improvements made on the effectiveness or cost of the projects, and feedback from groups that have used the designs to build their own radio antennas. These citizen science projects will inspire interest in STEM fields through the hook of radio astronomy and help develop a scientifically literate society.

5. Acknowledgements

Many thanks go to the following Green Bank Observatory employees: Steve White for his electrical engineering expertise, Sue Ann Heatherly and Sophie Knudsen of the E/PO department for providing the funds for the neutral hydrogen antenna and facilitating the first few outreach events. Thanks to Kevin Bandura of West Virginia University for providing electrical engineering experience and organizing the DSPiRA workshop.

6. References

1. "Observation of a Line in the Galactic Radio Spectrum." H.I. Ewen and E.M. Purcell, *Nature* 168: 356, 1951