Challenges in Developing an Amateur Radio Astronomy Database (Version 2/19/2018)

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A citizen science database is always a great idea. For those who collect the data, it is a rewarding learning experience, and it keeps observers returning and fulfilled to contribute more data to scientific endeavors. For those who use the data, it provides data that the professional community may not have had the time to collect. Joining the Society of Amateur Radio Astronomers (SARA) in 2012 was my first introduction to radio astronomy, even though I had an interest in optical astronomy since youth. As a relatively new organization, SARA offered a lot of opportunities to volunteers who wanted to help develop a long-term strategic vision for the organization. When I was elected as a Director in 2014, I saw great potential in SARA hosting a radio astronomy database much like those of other national amateur astronomy organizations hosting databases for their specialties. I set it as one of my goals and personal learning experiences. After all, radio astronomy is far more complicated than optical astronomy, and it would only be beneficial to attempt it. In 4 years, I learned a lot and realized I needed to trim my enthusiasm as to the structure of this database.

New amateur radio astronomers will need to clear a few hurdles before they can feel comfortable about long term radio observations, whether with a RASDR set-up or any other radio telescope. Developing a radio astronomy observation program and database is a great learning project. There are a few key items that should be included in any radio observation program for amateurs or students:

1. Targets to observe
2. Methodology for proper interpretation of data
3. Quality control
4. Optimization of the radio telescope settings for target observations
5. Raw data and its processing
6. The database for submission of observations

Radio astronomy, like its optical counterpart, can vary greatly in level of ease and sophistication for the amateur. Generally, it is more difficult to master than optical astronomy, thanks in part to a relative scarcity of instructional materials. When I joined SARA, and attended my first annual conference in 2013, I did not know much about the radio astronomy. I was pleased to have found the SARA website and that radio astronomy was available to the amateur. I found SARA members to be a very friendly and encouraging bunch, and there were opportunities to explore radio astronomy at every level of knowledge. This suited me fine as a beginner. One of my projects as a Director was the creation of the SARA Sections. This too was a learning tool that helped define the categories of radio astronomy for newcomers like myself. After the initial website set up, and a gathering of a SARA section team, section coordinators were appointed to the SARA sections.

The SARA Sections has the goal of providing a vision and process to help SARA enhance itself in the near, intermediate, and long-term future. It is hoped that by incorporating a sectional basis to the activities performed by SARA, that many organizational pursuits will have a structure to fulfill themselves. Goals include, but are not limited to, strategic planning, standardized data collection, methodologies and protocols, and member empowerment via section coordinators and assistant coordinators.

Unlike the many fantastic optical observing programs found at the Astronomical League, a radio observing program was easier said than done, especially geared to novices like myself. Some external radio observing programs do exist. However, I wanted to create a citizen science observation program that is SARA centric and collects data, thereby positioning SARA as a more substantive organization among professional astronomers. In radio astronomy four ingredients are needed to observe: a receiver, an antenna, an output device, and a target. While this article begins a program, it final structure has yet to be determine because of numerous difficulties. There are far too many variables associated with different types of radio telescopes, their signal to noise ratios, the targets involved, and how the data are captured and stored in a database. Let’s look at each one of these.

There are amateur radio astronomy programs to collect data, but they are not SARA owned, although SARA is associated with them. SuperSID allows amateurs to submit data to Stanford University. Radio Jove observers can send data to NASA. Finally, applications for SDR include radio meteors observations.

For this new proposed database, I initially focused on the observation of variable radio sources. This idea evolved with time, and a feasible proposition would start with the tracking of Cas A. Dr. Dan Reichart demonstrated that this is possible for amateurs. His paper is found at: http://www.gb.nrao.edu/20m/projdocs20m/FadingofCassA_MN469p1299_2017.pdf. While Cas A would be the initial target because of its relative ease, the list of targets could expand as collective amateur experience is achieved.

Following a proper methodology and quality control are important for ensuring observational results make sense. A poor methodology is not necessarily obvious, because a radio telescope will provide data nonetheless. Because the results are data based and not visual, it's always a matter of what the data actually are. Is there interference? Is there noise? Is the target resolved? Are the measured results acceptable for a database? On top of this, there are more factors to consider that are dependent on the receiver, antenna, and type of target. These many variables make radio astronomy very challenging. It's therefore not simple to list a methodology that covers everything an observer will need to know. However, let's attempt to provide an example. A large radio telescope that is available for amateur use is the 20m Green Bank Observatory dish offered through Skynet. Use is simple and it has a basic manual. It provides a great educational introduction to the novice observer. If one starts dissecting the results from this radio telescope, experimenting with input parameter adjustments, and asking a lot of questions on the quality of the data, one realizes the observational results are often not what one original thought. For example, point the 20-meter dish anywhere in the sky with any set of parameters centered on the hydrogen line, and one will get a hydrogen line result. An observer, who targets a galaxy for example, is initially thrilled because a hydrogen peak is captured. That observer, if a beginner, probably does not realize ubiquitous interstellar hydrogen and instrument noise were captured and probably drowned any signal from the targeted galaxy.

Having set a preferred bright target (Cas A) for an amateur astronomical database, some observational guidelines regarding methodology, quality control, and output needs to be considered. The range of these parameters may vary a bit, but there are important considerations. With the Skynet 20m dish (http://www.gb.nrao.edu/20m/map20m_advice.html) one may consider:

- At least 60 seconds for galactic hydrogen and strong pulsars in track mode.
- About 300 seconds or more for hydrogen in nearby galaxies in On-Off mode with offset at 3-4 degrees or a few beamwidths.
- An integration time of 0.2 seconds and radius of 2-3 degrees (120-180 arcmin or 3-4 beamwidths) for a 4-petal daisy map with the 1.4 GHz receiver.
- A minimum of 3.5x3.5 degrees or 6x6 beamwidths for raster maps using a gap sweep of 1/10 beamwidth for enough detail, with integration time at 0.3 seconds.

Instrumental effects cause variations in the baseline that are often much larger than the signal that we want to measure. We need to find a way to observe with and without the source but without changing the instrumental effects. We usually accomplish this with either beam (position) switching or frequency switching. Position switching helps remove systematics in data. Total scan time per target could be 7 minutes, using an on-source/off-source data collection technique (i.e., 3 minutes on source, 1 minute to move back, 3 minutes off source). Consider at least 2 degrees in each of four directions, preferably with the OFF target being the blank sky observed over the same altitude and azimuth path traveled by the target (on source). Corrections could be needed for local environmental noise as well. The reduced spectrum is (ON-OFF)/OFF.

Proper integration time (signal to noise) selection helps spectral resolution. An averaging of data in observations is done by integrating over some integration time, integration greatly reduces receiver output fluctuations.

In the Skynet 20-meter dish observational results there are two traces for the two polarizations. Electron polarization is a property of electrons defined by the Pauli Exclusion Principle but simply described as up or down, or left and right. Radio telescopes are equipped with polarizing filters that distinguish between the two electron polarizations. The two polarizations that can be compared to identify RFI or averaged to improved signal for a non-polarized source. Skynet observational results also have two plots for upper and lower frequency bands. The second frequency switch allows comparisons for interference problem identification.

Regarding outputs from radio telescopes in general, the units used may not be the same. However, to compare results to published tables, the preferred output is in Jansky units. Hence some further raw data processing could be needed. The Skynet 20m dish uses counts. Counts are a measure of the intensity of a signal created by photons bouncing off the dish and into the receiver. This unit can be converted to a temperature (K) and subsequently to Janskys (intensity per unit area). To convert counts to Janskys, use the following equation:

$S = (2 \sigma T_A)/ A \eta_A$
Where:
S = Flux Density (Janskys)
σ = Stefan-Boltzman constant (1.38 x 10^{-23})
T_A = Average temperature (Left, Right polarization, in K)
η_A = Telescope Efficiency (elevation dependent, available on website)
A = Area of dish (available on Skynet website)

When analyzing data from the 20m radio telescope, you may need to import ASCII data into Excel and convert the given left and right intensities (in counts) to Kelvins or Janskys in order to conduct certain analyses. The intensities in the ASCII file are total intensities, meaning the object intensity and the system intensity. You need to subtract the system values for the left and right polarizations (which can be found in the corner of the 2D plot).

While the database is not yet built, we need initial observational data from the SARA community and others to help us develop it. While Skynet has data attached to it, we realize this is not the format many amateurs will use. Using one example target (Cas A) and multiple sets of data, we hope we have enough actual real inputs to better construct SARA templates that will be the basis of a future database. Data templates are posted on the SARA Sections website, and represent some first attempt on what to document, but additional detail is needed as to what should be collected and saved. Now consider saving a result in a database. Observations should be prepared as best as one can with as many parameters documented. It is realized that "perfection" will not happen immediately, nor one way of documentation is applicable to all observations. However, observational data can be evaluated on an ongoing basis and lessons learned incorporated into a database's set of instructions.

By constructing a good database, amateurs will begin to use it, both for storing data, as well as a benchmark to compare their data. A database is a central piece in any citizen science program. The advantages of citizen science are that it not only teaches, but also allows collection of data and ensures ongoing interest. We are also interested in developing tips to help new amateurs develop skills in using software used to collect the data. The software might include Python, ASCII files, gnu radio, or Radio sky-eyes.

The next steps are many. While the analytical section can post initial results on its website, the actual database needs to be created. I would suggest a Microsoft Access database, which offers the capability for comprehensive storage, and the ability for the largest number of people to understand for programming its ongoing development. Here's where you the reader can help. This effort always needs volunteers, and a set of ongoing activities is listed below. If you have skill sets and are interested in the following contact us.

1. Providing examples of observations (formats, programming, collected data, etc.).
2. Writing explanation of how the data was obtained or how the programming was created.
3. Programming for the database.

4. Collecting actual observation data.
5. Developing techniques for RASDR as a common use radio telescope system in coordination with the database.
6. Advising on the database expansion for other targets.
7. Providing raw data examples and showing how to process it with online programs (Python, GNU)
8. Consulting with stakeholders to expand the citizen science program.
9. Encouraging university student participation and projects related to this program.
10. Helping to populate the SARA section web pages for gaps in knowledge important for amateur radio astronomy observing.

This is a long-term multi-year project. What you contribute over a long period of times builds the SARA of tomorrow, and with it the field of amateur radio astronomy. If you are planning on attending the June 2018 SARA conference, I'll be demonstrating the Skynet 20 m dish and discussing the Cas A observation project further on the Sunday evening of the conference.