Fostering Collaborations with the Amateur Radio Community

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Abstract

The amateur radio community is a global, highly engaged, and technical community with an intense interest in space weather, its underlying physics, and how it impacts radio communications. Over the past century, the amateur radio community has made significant contributions to ionospheric, space, and atmospheric science and it continues to innovate and contribute today. This community is ideally suited to collaborate with professional heliophysics researchers. In this white paper, we make recommendations to foster and further develop this relationship for community benefit. Our recommendations are based on experience with the Ham Radio Science Citizen Investigation organization (HamSCI, hamsci.org), a citizen science project established in 2015 for this purpose. We recommend allocating resources for amateur radio citizen science research projects and activities, developing amateur radio research and educational activities in collaboration with leading organizations within the amateur radio community, facilitating communication and collegiality between professional researchers and amateurs, and ensuring that proposed projects are of a mutual benefit to both the professional research and amateur radio communities.

1 Introduction

Today's technology is critically dependent on understanding space weather and its underlying physics. Operators of spacecraft and terrestrial power grids, users of satellite communications and precision satellite location and timing services, and those who rely on over-the-horizon radio communications know well the perils of space weather. Although individuals are shielded from most of space weather's direct effects, the amateur (ham) radio community (Figure 1) has a first-hand appreciation of its effects. The focus of their hobby is making successful communications over a broad spectrum of radio frequencies, including those propagating through the ionosphere enabling long distance, over-the-horizon communications. These communications are highly space weather dependent due to the tight coupling of the ionosphere to inputs from the Sun, magnetosphere, and neutral atmosphere. Consequently, amateurs spend a tremendous amount of time and effort to understand space weather and its underlying science. This interest makes the amateur radio community ideal partners in heliophysics citizen science.

As Solar Cycle 25 ramps up, it is critical to develop tools to measure the space environment to drive scientific advances and operational systems. While many excellent, professional ionospheric research facilities exist, the geospace system is so vast that these resources are insufficient. By fostering collaborations with the amateur radio community, new avenues for scientific advancement become possible. In this white paper, we make recommendations to foster a relationship between professional scientists and the amateur radio community based

Figure 1: The amateur (ham) radio community comprises over 770,000 licensees in the United States and over 3 million worldwide. Amateurs share a common interest in radio, and often in radio science and engineering, making them ideal partners in heliophysics citizen science. Amateur radio stations range from modest, portable stations as demonstrated in (a) and (b) by members of the W3USR University of Scranton Amateur Radio Club, to the large multi-operator multi-radio superstations such as K3LR (West Middlesex, PA) depicted in (c) and (d). K3LR photos courtesy of Tim Duffy (http://www.k3lr.com/Photos/).

on experience gained in operating the Ham Radio Science Citizen Investigation (HamSCI, hamsci.org), a citizen science project established in 2015 for this purpose. Current technical and scientific capabilities of the global amateur radio community and the role they play in the advancing heliophysics are described in a companion white paper, Frissell et al. [19].

2 Amateur Radio as a Community for Citizen Science

2.1 The Amateur Radio Community

Amateur radio is a non-commercial radio service with over 770,000 US licensed operators [10] and over 3 million licensed worldwide. They are an ideal community for a heliophysics citizen science partnership. Amateurs can be any age and range in experience from novice to those with advanced STEM degrees. Each amateur is required to hold an amateur radio license issued by a national government. The licensing process ensures that each licensee demonstrates an appropriate level of knowledge in the fields of radio science, electrical engineering, and amateur radio rules and practice.

Globally, amateur radio is represented by the International Amateur Radio Union (IARU, iaru.org). The IARU is an international nongovernmental organization comprised of 172 member national societies, each representing a particular country. Member societies include the US American Radio Relay League (ARRL, arrl.org), the Radio Society of Great Britain (RSGB, rsgb.org), Radio Amateurs of Canada (RAC, rac.ca), the Japan Amateur Radio League (JARL, jarl.org). Each society engages with their country's amateurs through Internet platforms, membership journals, and local radio club affiliations. The IARU societies, independent publishers, websites, e-mail groups, social media sites, podcasts, "hamfests", equipment manufacturers, and special interest amateur radio organizations together form an infrastructure for engaging, coordinating, and promoting amateur radio around the world.

Many popular amateur radio activities are directly affected by space weather because they rely on signals that are refracted back to Earth by the ionosphere (Figure 2a). Indeed, these space weather impacts are part of the allure of the hobby as many amateurs enjoy the challenge of space weather prediction. A goal of many amateurs is to make contact with distant

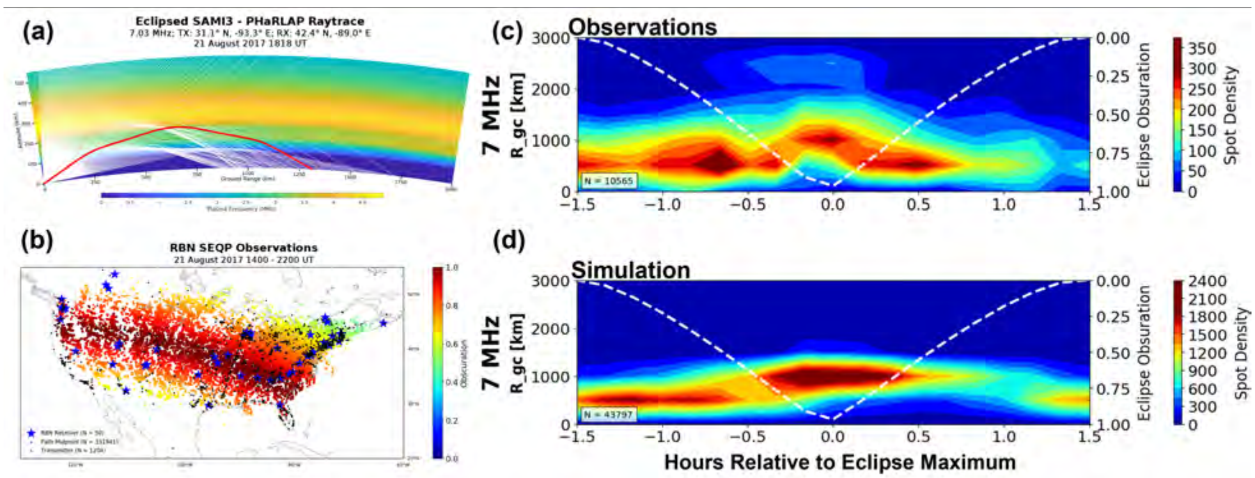

Figure 2: Solar Eclipse QSO Party Results from Frissell et al. [16]. (a) 7 MHz ray trace through eclipsed SAMI3 ionosphere along the dashed line path from south to north shown in (b). (b) Map of ham radio HF observation locations; black dots are transmitters (TX), blue stars are RBN receivers (RX), and TX-RX midpoints are dots color coded by maximum eclipse obscuration at that location. (c) Observations of the 7 MHz amateur radio band as a function of time relative to eclipse maximum, showing that the communication distance extends as ionospheric electron densities decrease during the eclipse. (d) Simulation of (c) using the PHaRLAP ionospheric raytracing library [3] and an eclipsed version of the first-principles SAMI3 ionospheric model [29]. Data-model comparisons such as this are a powerful method for linking amateur radio observations to physical understanding.

stations (DXing), often in spite of poor space weather conditions. Amateurs also enjoy contesting, where they amass points by contacting as many other stations and locations as possible. In both DXing and contesting, amateurs can win with certificates, awards, and public recognition. Serious DXers and contesters build elaborate stations and antenna systems (Figures 1c and 1d) and actively study radio propagation and space weather [e.g., 32, 34, 9]. To effectively fulfill their duties, amateurs engaged in public service and emergency communications also need to understand space weather and its effects on radio propagation.

2.2 Amateur Radio and Scientific Discovery

Since its beginning in 1912, the US amateur radio service has made significant contributions to radio technology and the understanding of radio science. In the 1920s, radio propagation experiments known as the trans-Atlantic tests were coordinated by the ARRL and the RSGB. The experiments led to a greatly improved understanding of the ionosphere and directly contributed to the development of the field of atmospheric science [52]. FCC rules require that this work continue today: Part 97 of the FCC rules states that a primary purpose of the amateur radio service is the "Continuation and extension of the amateur's proven ability to contribute to the advancement of the radio art." Recent advances in the fields of computing and software defined radio provide potent and novel opportunities to meet this mandate.

Throughout the previous solar cycle, the amateur radio community has voluntarily built multiple networks that automatically monitor and log global amateur radio communications. These systems include the Reverse Beacon Network (RBN, reversebeacon.net), PSKReporter (pskreporter.info), and the Weak Signal Propagation Reporter Network (WSPRNet, wsprnet.org). Using amateur radio data, multiple peer-reviewed studies have been published. These include studies of the ionospheric impacts of solar flares and geomagnetic storms [17, 13, 51], traveling ionospheric disturbances (TIDs) [20], Sporadic E [8, 7], near vertical incidence skywave (NVIS) propagation [46, 47, 48, 51, 49, 50], greyline propagation [31], 160 m band propagation [45], solar eclipses [16], and plasma cutoff and single-mode fading [36]. The current technical capabilities of amateur radio community and future opportunities for scientific and operational advancement are detailed in the companion paper, Frissell et al. [19].

A distinct advantage to collaborating with the amateur community is the ability to leverage their expertise, resources, culture, and large numbers to find new solutions to scientific problems. For instance, Archer et al. [1] called upon amateur radio operators with expertise listening to complex signals in noise to help identify the best way to sonify magnetospheric ULF waves. Similarly, professional researchers joined forces with the amateur radio contesters to create a contest-like event called the Solar Eclipse QSO Party (SEQP) Frissell et al. [16]. The contest aided study of the ionospheric impacts of the 21 August 2017 Great American Total Solar Eclipse (Figure 2). The contest rules of the SEQP were designed to be as familiar to contesters as possible, but were optimized to provide MF and HF radio observations that would be useful for scientific analysis of ionospheric impacts. By teaming with the ARRL and contesting community for publicity and making the SEQP a fun operating event for amateurs, the SEQP saw tremendous participation and success [42, 41, 11]. It ran for a period of 8 hours during the day of the eclipse and generated over 2.5 million radio contacts. The observations formed the basis for Frissell et al. [16] (Figure 2).

3 Ham radio Science Citizen Investigation (HamSCI)

Following Frissell et al. [13] and in preparation for the 2017 SEQP, a team of amateur radio-research scientists identified the need to create an organization that would foster collaborations between the professional research and amateur radio communities. This led to the creation of HamSCI, the Ham radio Science Citizen Investigation [14, 15, 40]. HamSCI's objectives are to (1) advance scientific research and understanding through amateur radio activities, (2) encourage the development of new technologies to support this research, and (3) provide educational opportunities for the amateur community and the general public. Today, HamSCI has multiple projects supported by NSF and NASA and is recognized as an official NASA Citizen Science project. HamSCI is highly collaborative and structured such that it can promote multiple projects from different institutions, even projects led from within the amateur radio community [27]. This makes HamSCI extremely adaptable to any scale and ideally suited for novel and creative projects.

4 Exchange Between Amateur and Professional Communities

A key tenet of citizen science is the ability for amateurs and professionals to connect with each other and freely exchange ideas on an equal basis. A bi-directional exchange is particularly important, as the amateur and professional communities often have different but complementary skills, experience, and perspectives. For instance, an amateur might have excellent practical expertise in selecting the best operating frequencies and modes for effective communications under a variety of geophysical conditions; however, they may not have the necessary academic background to understand the underlying physics of why their choices are effective. Trained scientists may have extensive facility using different data sets to explain a particular phenomenon, but lack a practical understanding of how this impacts actual operations. An amateur may hear strange noises but not know what is interesting from a geophysical standpoint. A scientist may miss an important phenomenon due to limitations of the professional observing techniques being used.

HamSCI facilitates bi-directional communications in a variety of ways, including e-mail lists, weekly teleconferences, and the annual HamSCI workshop [25]. Currently, the HamSCI Google Group has over 600 global members, including amateurs and professionals. Many are members of both communities. The Google group allows anyone to post questions, announcements, or begin a discussion. While posting is open, moderators do monitor the group to ensure posts follow the HamSCI Community Participation Guidelines [24]. Similar idea exchanges occur on the multiple Zoom teleconferences held each week.

HamSCI also connects amateurs and professionals at in-person conferences. Since 2018, HamSCI has hosted an annual workshop for amateurs and professionals to meet and give presentations of mutual interest [26]. The HamSCI workshop is now a hybrid workshop, allowing for the benefits of an in-person meeting combined with the accessibility of a virtual workshop. The meeting is announced through multiple outlets that reach both amateur and professional audiences. Each year, leaders from both the amateur radio and professional communities are selected as invited speakers. In addition to its own meeting, HamSCI also participates in both professional and amateur conferences throughout the year. Professional conferences include the NSF Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) workshop and the Fall American Geophysical Union (AGU) meeting. Amateur radio conferences include the ARRL-TAPR Digital Communications Conference and the Dayton Hamvention. Research funding has been used to support the meeting travel of volunteers, students, and professionals. The regular participation by both amateurs and professionals at these meetings builds trust and facilitates collaboration between the groups.

5 Education and Training

Education and training is critical to citizen science. It benefits the participant and is a requirement for good science. Amateur radio has a long tradition of providing training in electrical engineering, communications systems, antenna and information theory, space weather, and programming. Training starts with licensing (Section 2.1), but life-long education is strongly encouraged. Amateur radio topics are already aligned with heliophysics research needs. Citizen science collaborations with the amateur community should support and enhance existing training programs while adding new opportunities that delve even deeper into heliophysics.

Heliophysics education opportunities exist for collaboration with established providers of amateur radio educational content. The ARRL, other national radio societies, and independent publishers produce books and media for amateur radio education [e.g., 2, 6]. Programs such as the virtual Online Learning @ ARRL and the in-person ARRL Teacher's Institute on Wireless Technology are excellent programs that might develop citizen space science specific training materials. Societies such as the ARRL work with independent and school-affiliated amateur radio clubs across the country and can develop and distribute training materials and programs. Other groups with established radio educational programs include scouting [37, 30] and Youth on the Air [53]. Besides working with established groups, independent creation of education and training programs and materials is effective. Instructors can create courses that use amateur radio to introduce space physics, such as Reiff [38] at Rice University and Frissell et al. [21] at The University of Scranton. Amateur radio contests such as the ARRL School Club Roundup can be used to introduce space weather contests. Shortwave listening contests that make use of free, internet connected radios can be used by unlicensed participants [39].

Current school based learning emphasizes modeling concepts and investigations that follow UDL principles. Amateur radio offers an established, externally-supported and multi-faceted educational canon uniquely suited to supporting UDL goals. Amateur radio training naturally incorporates UDL because concepts are presented in multiple ways (mathematically, with a model, verbally, and in building or using a radio). This results in a highly accessible way to understand math, science, engineering, or even writing [4] for people who may fear these.

6 Driving Co-Design and Collaboration in Amateur Radio Science

Pandya and Dibner [35] provides a comprehensive resource for the design of citizen science projects to maximize broader impacts in the areas of learning and equity (*cf.* Sect. 7). HamSCI embraces a model of citizen science where volunteers are engaged in every stage of an investigation, from formulating questions to building tools and engaging in analysis. This concept of co-design is critical for participant engagement, project success, making the best use of skills and talents, and ensuring the project is beneficial to all involved. We note that in these collaborations all participants should be fully credited and have rights to use the materials and ideas they help develop. Open hardware [44] and open software [23] licenses are used for all projects. HamSCI volunteers are encouraged to set up ORCIDs, use callsigns as FAIR identifiers [43], and are given co-authorship or acknowledgment in papers and presentations.

As discussed in Sections 4 and 5, amateur radio operators generally have a powerful combination of advanced technical skills and strong avocational initiative, and are as such well-positioned to participate in hardware and software development. For instance, the NSF-funded HamSCI Personal Space Weather Station (PSWS) project is developing a network of novel ground-based instrumentation for ionospheric remote sensing that can be used by citizen scientists and professionals alike [5, 18, 22]. In developing the PSWS proposal, HamSCI joined forces with Tucson Amateur Packet Radio (TAPR, tapr.org), a volunteer amateur radio electrical engineering organization with a global presence and almost 40 years of experience.

A similar collaboration occurs when designing large-scale operating events that simultaneously serve as ionospheric experiments, such as the 2017 Solar Eclipse QSO Party (SEQP)

(Figure 2) [16]. Discussions between the professionals and amateurs occurred at the earliest stages of event planning, ensuring that the needs of both groups were met. This allowed for an event that was successful from both an amateur radio and scientific perspective. In light of the success of the 2017 SEQP, planning is now underway to hold similar events for the 2023 and 2024 American Solar Eclipses [12].

7 Diversity, Equity, and Inclusion

The current demographic landscape of the amateur radio community presents significant challenges and opportunities to increase diversity. Barriers to entry include exam and equipment costs, asymmetric mentorship opportunities, and a lack of support for some newcomers to the community. Demographic statistics are not readily available, but informal surveys and the authors' lived experience indicate that the population of active amateur radio operators is generally White, overwhelmingly male, and aging. Instances of implicit and explicit bias are common and expected for female, LGBTQ+ and BIPOC hams, leading to a "leaky pipeline" of talent within the hobby [28] and thereby reducing the pool of possible citizen science volunteers. The ARRL has signaled willingness to address current DEI issues [33].

Targeted efforts to welcome more women, young people, and underrepresented groups into the hobby will therefore have an outsize impact. The benefits of these efforts will be twofold: they will introduce to the participants a valuable technical skillset, while simultaneously growing the ranks of amateur radio operators to keep the community strong in the future. To do this, the science community must leverage best practices in diversity, equity and inclusion. The authors recommend a two-prong strategy: supporting amateur radio organizations to welcome diverse cohorts in training and exams, while also encouraging the inclusion of amateur radio in existing STEAM curricula of formal and informal programs with strong DEI components.

Further support may be needed to join and fit in the community. Amateur radio struggles with the Curse of Knowledge: a cognitive bias where an expert assumes something that they are intimately familiar with must be widely known and/or inherently easy. For instance, expert hams may assume that the math required (algebra level) for a basic amateur radio license is easy, but some people do in fact struggle with this greatly. Hams must be provided with some level of training in education and education theory, and encouraged to widen the circle of mentorship.

8 Giving Back to the Amateur Radio Community

All amateur radio citizen science projects need to address research questions and advance the scientific field, but it is also crucially important that the projects mutually benefit the amateur radio community as well. On an individual level, it is important that project participants receive appropriate acknowledgment, often in the form of co-authorship and/or acknowledgment in publications and presentations and the ability to retain intellectual property rights (at least in the open source sense) on ideas and designs. When data collection is involved, amateurs want feedback to know that their data has been received and is in fact being used. Interviews with HamSCI participants have indicated that web-based real-time displays of participant data are a particularly important way to provide this feedback. As new scientific discoveries are made or operational products are developed using amateur radio resources, those discoveries and products should be made available back to the amateur community in a way that is understandable and useful to them. Finally, it is important to actively listen to the amateur radio community to identify ways in which the scientific community can provide the greatest service to the amateurs.

9 Recommendations

- **Provide funding resources for amateur radio-based citizen science projects.** The amateur radio community is a highly technical, engaged community that has a proven track record of making substantial contributions to heliophysics science and technology. Support should include collaborative amateur radio-professional research projects, infrastructure for the collection, storage, and distribution of citizen science datasets and analytical tools, conferences and workshops that bring professionals and amateurs together in-person and virtually, and personnel support to help manage these projects.
- **Develop research and educational programs in collaboration with organizations already established in the amateur radio community.** Many organizations, including the ARRL, TAPR, CQ Communications, Scouts, and HamSCI are already have established means of engaging with the amateur radio community. By having citizen science projects collaborate with these groups, it is possible to engage broad participation.
- **Develop international collaborations to solve global-scale science problems.** Heliophysics problems extend beyond the regulatory boundaries of the United States. Scientific collaborations at a global level, coordinated with the help of the IARU and its member societies, should be established.
- **Recognize volunteers as colleagues that have important skills and insight.** Many amateurs have years of experience or even advanced degrees in fields relevant to Heliophysics research. Volunteers that do not are highly enthusiastic and are willing to learn. Volunteers should be respected and treated collegially.
- **Encourage attendance of amateur radio citizen scientists at professional conferences.** This could be done either through direct support and citizen science related discounted registration. This would encourage skilled and vested amateurs to foster relationships with scientists in a professional venue while allowing them to learn how scientific papers are written and presented.
- **Ensure open access to publications and software.** Requiring all publicly funded research to publish open access and encouraging the use of open source software for analysis will make research more accessible to citizen scientists.
- **Provide the citizen scientist routes to peer-reviewed publication.** Citizen scientists working on independent research projects may lack funding to cover publication fees or knowledge of how to properly analyze data and prepare a manuscript for a peer-reviewed journal. We recommend resources be allocated and policies be established to help citizen scientists clear these hurdles.
- **Ensure that collaborations have a clear benefit to the scientific and amateur radio communities.** All amateur radio citizen science projects needs to address research questions and advance the scientific field, but it is also important that the projects benefit the amateur radio community as well.
- **Encourage growth and diversity, equity, and inclusion in the amateur radio community.** Support amateur radio organizations to welcome diverse cohorts in training and exams, while also encouraging the inclusion of amateur radio in existing STEAM curricula with strong DEI components.

Acknowledgments: We are grateful to the amateur radio community who voluntarily produced the HF radio observations used in this paper, especially the operators of the RBN, PSKReporter, and WSPRNet. We thank NSF Grants AGS-2045755, AGS-2002278, AGS-1932997, & AGS-1932972 and NASA Grant 80NSSC21K1772.

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