## NSF Science Across Virtual Institutes White Paper:

## International Advanced Community Collaboration to Enhance

## Spectrum Sharing

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## Executive Summary

Radio astronomy in the coming decade is poised for revolutionary advances and exciting discoveries. While radio telescopes become continually more powerful, unwanted signals – radio frequency interference (RFI) – becomes ever more common. This problem is experienced by radio astronomy observatories the world over, but it is not unique to radio astronomy. Interference between radio signals has a negative impact on all technologies which utilize the radio spectrum. To aid in counteracting the problems associated with increased use of the radio spectrum, we propose an **A**dvanced **C**ommunity **C**ollaboration to **E**nhance **S**pectrum **S**haring (ACCESS) with the objectives of: (1) assessing the potential impact of proposed new active radio services on existing users, (2) leading new international research in the area of RFI mitigation; (3) enabling knowledge sharing and cross-fertilization among the partner institutes; and (4) working with university and industry-based researchers to transition current experimental techniques into readily accessible, broadly usable, applications.

## Radio Astronomy and Radio Frequency Interference

Radio astronomy is an incredibly important area of astronomical research, in part because observations can be carried out from the ground, making it possible to build versatile, technologically advanced instruments with which to investigate celestial phenomena.

But technology is a sword that cuts both ways in radio astronomy: the proliferation of ground and space-based communication technologies create radio frequency interference (RFI) that can effectively blind radio telescopes at many frequencies. The influence of RFI on a radio astronomy measurement ranges from total disruption by saturation of the radio receiver to very subtle distortions of the data. Sources of RFI include commercial broadcast services, wireless devices, radar, satellite transponders, and many others.

Three factors provide powerful motivations to develop new methods to mitigate RFI: (1) the explosion of wireless communications services and consequent increase in the number of RFI sources, (2) growth in the number of astronomical observations that are made outside protected radio astronomy bands, and (3) an increase in the sophistication of signal processing hardware and algorithms, which allows scientific usage of data that would otherwise be discarded.

## Science Drivers

Improved RFI mitigation techniques will impact a wide range of astronomical research. Here we list examples where improved RFI mitigation will enable three scientific priorities outlined in the Astro2010 Decadal Survey.

**The Epoch of Reionization and Cosmology - The Redshifted HI 21cm Line:**  Hydrogen is the most abundant element in the Universe, and its study, through radio observations of the 21cm neutral hydrogen line reveals the evolution of the Universe from diffuse gas to galaxies. While the rest frequency of the neutral hydrogen line falls in a protected part of the radio spectrum, the signals from distant objects are redshifted into some of the most interference prone frequencies, compromising important science. Observations of the redshifted 21cm line are expected to provide a sensitive probe of galaxy evolution and cosmic dark energy, and will revolutionize our knowledge of the epoch of reionization (Morales and Wyithe, 2010). Advances in RFI mitigation are required to make progress in these frontiers of observational cosmology.

**Gravitational Wave Astronomy - Pulsar Timing:** Gravitational radiation is a prediction of Einstein’s Theory of General Relativity, but has not yet been directly observed. Millisecond pulsars can be used to detect gravitational waves via high precision timing (Hobbs et al. 2010). The precision of pulsar measurements is related to the available bandwidth, and can be increased substantially if RFI suppression can be achieved.

**Time Domain Astronomy - Radio Transients:** The Astro2010 Decadal Survey identified the dynamic sky as a research area ripe for discovery. Astronomical transient sources (see e.g. Lazio et al. 2009) include flaring brown dwarfs, bursting and transient magnetars, fading afterglows from short-duration gamma-ray bursts, a mysterious burster at the Galactic Center, a new population of sub-relativistic supernova, and tidal disruption of stars passing near super-massive black holes. Because RFI can mask or mimic the transient radio signals, mitigation and excision techniques are crucial for these studies.

## RFI Mitigation Approaches

Two traditional methods exist to mitigate RFI – prohibition of emissions within a defined frequency range and/or geographical region (radio quiet zones) and excision of the RFI signal(s) within radio astronomy data. Radio quiet zones are simple in concept but complex to manage, as they can place undue economic and social burdens on the persons living within the zones. Excision also has limitations, as astronomical observations require ever wider bandwidths and sensitivities, and corrupted frequency bands contain valuable scientific information.

As described below, to maximize use of the radio spectrum, the virtual institute will focus on both areas of RFI mitigation. Radio quiet zone studies will focus on the understanding of signal propagation and summation, areas of strong interest internationally to radio astronomers, but also of high interest to all users of the wireless spectrum. Excision studies will initially be focused on the development of new tools to identify RFI and to excise the RFI from the data using FPGA technologies. The proposed work will also feature study of a third promising tactic: active RFI mitigation.

## International Advanced Community Collaboration to Enhance Spectrum Sharing

Although the problems described above are experienced by all Radio Astronomy Observatories, the resources available to each individual observatory are limited. Given recent technological advances and the accelerating rise of RFI problems, there is strong motivation for creation of an international partnership that would share resources and leverage the current work across the partnership as a whole.

We propose an International AdvancedCommunity Collaboration to Enhance Spectrum Sharing (ACCESS) will be a new virtual institute with the goals of:

* Assessing the potential impact of proposed new active radio services on existing usage;
* Leading new international research in the area of RFI mitigation;
* Leveraging existing investments in NSF-funded radio observatories and increasing the productivity of these investments;
* Enabling knowledge sharing and cross-fertilization among the partner institutes;
* Working with university-based researchers to transition current experimental techniques into readily accessible applications;
* Providing co-mentoring of students.

## Proposed Research Areas

The precise research areas to be investigated will change as the institute matures. To start, though, the areas of focus include:

**Identification and mitigation of RFI:** A number of possibilities exist to provide improved excision techniques for RFI. The institute will initially focus on two of these areas – active RFI mitigation through active cancellation and signal identification through the use of neural networks.

Active RFI cancellation is a very promising tactic for elimination of unknown and unwanted signals from spectral data. Strategies such as spatial filtering, null steering, and adaptive temporal filtering using fast field programmable gate arrays (FPGA), graphic processor units (GPU), and cluster-based hardware would have immense value in dealing with the growing challenge of RFI (ITU-R RA.2126). Recently published results demonstrate deeper interference nulling with antenna arrays than has previously been achieved. These methods are very encouraging and will be considered for adoption in both phased array feeds and synthesis imaging arrays (see e.g. Landon et al 2012).

Another means for more effectively identifying signals and efficiently removing RFI from radio data is through the application of neural network classification. Neural network classification, combined with FPGA and GPU technologies offers the possibility of ready signal identification and removal and offers the possibility of exceptionally clean resultant spectral bands.

**Improved propagation and summation models:** Understanding signal propagation and summation of multiple signals is extremely important both to the management of radio quiet zones but also to all users of the radio spectrum. Propagation model study research will focus on the improvement of propagation models in the real world environment (accurately shaped hills and other obstacles, inclusion of trees and plant life, etc.). Signal summation studies will work to improve our understanding of the summation of like signals such as from multiple cellular phone towers, wireless modem points, and so on.

## Broader Impact

The Virtual Institute will focus on areas of interest outside the realms of radio astronomy. Specifically, the institute’s research will be of interest to communities which take advantage of passive and remote sensing as well as terrestrial and satellite communications. Passive remote sensing shares many similarities with radio astronomy; it is receive only, and the received signals are weak and spread through-out the electromagnetic spectrum. Many of the techniques developed for radio astronomy are therefore directly applicable to remote sensing. Improved interference mitigation technologies may also benefit terrestrial and satellite communications applications in crowded bands (for example identification of radio spectrum “white spaces” using spectral kurtosis estimators). The loss of signal strength on a communications path that travels over terrain is currently unknowable, yet there are a number of users – commercial and military – who really need this information, for example military patrols heading into unknown territory who need to stay in constant communication and military spectrum planners trying to avoid friendly radio interference over a given land region. Improved propagation models will be applicable here.

Participation in the Virtual Institute will train university undergraduates and graduate students in relevant disciplines and skills, and the institute will foster collaborative relationships between U.S. and international researchers that will become valuable in future international astronomical instrumentation development efforts.

High school students will contribute to the progress of ACCESS through a citizen science project in which they analyze radio astronomy data for the purpose of characterizing and classifying RFI, producing a rich database which can be used to develop neural network classification models. We will model this effort on the successful Pulsar Search Collaboratory (NSF #0737641).

These examples do not cover the full range of ACCESS impact. The institute will be open to industry partners and the intent is to have one industry consultant within the management structure, to ensure that needs of the broader community are considered within the research fields.

## Potential Partners and Management Structure

Initially, we will identify a few key partners from radio observatories around the world and research universities in the US who, through their missions and research foci, bring expertise to the problems ACCESS will address. We are currently engaged in discussions with Brigham Young University, Virginia Tech and radio astronomy observatories in South Africa (South African SKA Project Office), Australia (Australia Telescope National Facility), and the Netherlands (Low Frequency Array). The final members of the Virtual Institute and will be identified in the final proposal where we will discuss how each groups’ goals are enhanced by the collaboration, and the critical specialties each group brings to the institute.

As the institute’s productivity becomes well known in the research community, we can expect other groups to join the collaboration.

We will model the management structure of ACCESS after that of the very successful CASPER consortium which was formed to advance low cost, rapid development instrumentation for Radio Telescopes (NSF **#0619596).** At the start of the collaboration we will create a charter in which the partners establish well-articulated problems to be solved, and delineate the work effort. A board of directors will be created, with each partner institute nominating one representative, as well as a representative from industry. The board will meet initially to determine the priorities of each groups’ efforts and, thereafter, annually to adjust those goals. The board of directors will provide guidance as to what is required for a group to join as well as the maximum number of groups the institute can successfully coordinate. A program manager will be appointed to execute the board’s goals by managing the day-to-day collaborations between all ACCESS partners, provide and administer collaboration tools for sharing results, distribute RFI databases, schedule and chair virtual meetings, ensure publication of results, and so on. Finally, a yearly workshop will be held to focus efforts and allow collaborators to gather and exchange ideas and report progress.

The U.S. components of ACCESS that will be covered by the NSF are:

* A post-doc (at 50%) and a junior digital engineer, situated at NRAO (GB), who will research and implement RFI excision techniques using existing FPGA platforms. (The post-doc will have 50% of his or her time for individual research.)
* One to two graduate students, at a partner university, to work with the NRAO team members and participate in 1-3 months exchange programs with foreign partner institutions.
* A program manager to coordinate the work at all SAVI sites.
* Funding for one to two annual workshops, open to the general research community and not just ACCESS collaborators, to discuss RFI mitigation issues and share results.
* A web portal to coordinate and provide services and content to the consortium.
* Modest opportunities for researchers to spend time at the site of their international collaborators.
* Face-to-face and virtual meetings for disseminating progress as well as a forum for discussing broader impact and RFI mitigation work.

## References

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