

Facilities, Equipment, and Other Resources

1 Green Bank Observatory

The Green Bank Observatory (GBO) is a Federally-Funded Research and Development Center whose mission is to enable forefront research into the radio universe by providing world-leading telescopes, instrumentation and expertise, training to the next generation of scientists and engineers, and by promoting astronomy to foster a more scientifically literate society.

GBO operates the Robert C. Byrd Green Bank Telescope (GBT), the world's largest fully steerable telescope. The GBT provides nearly continuous frequency coverage from 0.3–116 GHz and a diverse suite of instruments, including two CASPER-based digital spectrometers with spectral line and pulsar observing modes. GBO also operates a number of additional research-class telescopes, including a 20-m telescope equipped with a ROACH1-based digital back-end that has been used to prototype real-time radio frequency interference (RFI) techniques.

1.1 Digital Electronics Group

GBO digital engineers have over 40 years combined experience designing, building, testing, deploying, and operating world-leading instruments for radio astronomy. This includes expertise in the design of low-power and low-noise electronics and the Xilinx Vivado tool flow for complex firmware design. Our group has also become active in designing and implementing real-time RFI excision algorithms in firmware, and have recently completed the first real-time CASPER-based system for mitigating impulsive RFI such as airport RADAR.

An undergraduate funded by this project will be co-mentored by the digital electronics group and the PI.

1.2 Radio Quiet Zones

GBO is located in the heart of the 13,000 square-mile National Radio Quiet Zone (NRQZ) and the West Virginia Radio Astronomy Zone (WVRAZ). The NRQZ was established by the Federal Communications Commission and the Interdepartment Radio Advisory Committee in 1958 to minimize possible harmful interference to the National Radio Astronomy Observatory in Green Bank, WV (now GBO) and the radio receiving facilities for the United States Navy in Sugar Grove, WV. The NRQZ provides regulatory protection by requiring coordination between GBO and all new or modified, permanent, fixed, licensed transmitters inside the NRQZ, as specified for federal transmitters by NTIA manual section 8.3.9 and for non-federal transmitters by the FCC in 47 CFR section 1.924. The NRQZ office at GBO ensures that the power flux density of transmitters within the zone does not exceed certain frequency-dependent thresholds, and works with stakeholders to mitigate any non-compliant devices. Mitigation methods include the use of directional antennas, locating transmitters to areas that provide terrain shielding, or selecting a different frequency where the transmitter power is within limits.

The WVRAZ provides stricter protection within a more limited geographic area. Within two miles of GBO all electrical devices that interfere with the operation of GBO are prohibited. This includes the use of wireless internet, Bluetooth, and broadband transmitters such as microwave ovens, to name but a few. Between a two-mile and ten-mile radius from GBO, strict power dissipation requirements are in place.

The NRQZ and WVRAZ are a unique and invaluable resource for GBO, but cannot protect against all forms of interference. Notable exceptions are the growing use of car RADAR collision avoidance systems, aircraft, and communications satellites. This necessitates observing systems that produce high-quality data in the presence of RFI, such as the one we will build as part of this project.

1.3 Anechoic Test Chamber

A shielded anechoic chamber measuring $15' \times 15' \times 37'$ is located in the Jansky Laboratory at GBO. The chamber serves as both a far-field antenna test range and evaluation suite for new equipment to ensure compliance with limits on self-generated RFI. The GBO Interference Protection Group evaluates all equipment

and devises mitigation techniques as needed. The anechoic chamber will be used to evaluate all hardware developed as part of this project, including all equipment that will be installed near the GBT radio receivers.

1.4 Machine Shop

GBO operates a full machine shop that can build custom fabricated parts as needed. We do not anticipate heavy use of the machine shop for this project, but could rely on it to build RFI-shielded casings for the electronics that will be placed in the GBT receiver and equipment rooms.

1.5 Education and Public Outreach

GBO has a nationally recognized, fully-developed education and public outreach program. The Green Bank Science Center hosts over 50,000 visitors each year. Over 3,000 students annually take part in various on-site educational programs. GBO has a variety of long- and short-term housing, including a dormitory that sleeps up to 60 students (which will be used for the two-week internship) and on-site housing for summer research students (which will be used for the undergraduate student supported by this proposal). GBO is a member of the NSF-INCLUDES Alliance First 2 Network.

1.6 Project Management

GBO has established budget management, project management, and systems engineering processes developed in adherence with the NSF's requirements as per its Large Facilities Manual (NSF 17-066, March 2017). The GBO team includes an experienced and credentialed program management and systems engineering professional who will coordinate, track, and report on activities from a project and programmatic view. Scope, schedule, costs, and risks will be managed using GBO standard operating procedures.

2 The University of California, Berkeley

GBO staff will work in collaboration with UCB's Collaboration for Astronomy Signal Processing and Electronics (CASPER). The primary goal of CASPER is to streamline and simplify the design flow of radio astronomy instrumentation by promoting design reuse through the development of platform-independent, open-source hardware and software. CASPER's aim is to couple the real-time streaming performance of application-specific hardware with the design simplicity of general-purpose software. By providing parameterized, platform-independent "gateway" libraries that run on reconfigurable, modular hardware building blocks, we abstract away low-level implementation details and allow astronomers to rapidly design and deploy new instruments.

Dan Werthimer is the director of the UCB SETI program and CASPER. Werthimer is also associate director of the Berkeley Wireless Research Center. Werthimer will provide local mentoring to a UCB undergraduate student.

Jack Hickish is a staff researcher in UCB's Radio Astronomy Lab. Hickish will develop CASPER blocks for interfacing with peripherals through 100-GbE and PCIe.

Both Werthimer and Hickish will act as unfunded collaborators and technical advisers to the GBO digital engineering team.