Astro2020 APC White Paper | State of the Profession Consideration

The Role of National Observatories in Professional Astronomy Training

Brief Description [350 character limit]: Observatories are where textbook learning confronts reality. Observatories train astronomers how to interpret data and push the limits of what is possible with current telescopes, critical skills for the advancement of astronomical research. We must commit to investing in observatory training programs to ensure future success.

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1. **Key Issue**

Every generation of astronomers needs instrumentalists and highly trained observers to ensure the instruments provide the highest quality data possible, plan the next generation of telescopes and instrumentation, and push the limits of existing instruments to explore new scientific realms. The 2010 Decadal Survey (NRCl 2010) noted that technology development is "the engine that powers advances in science", and the 2006 Building a Better NASA Workforce report (SSB 2006) notes that "… there is ultimately no substitute for hands-on training." Yet, as noted in the 2015 OIR Report (NRC 2015), "students are increasingly removed from instrument operation and data acquisition." Clearly, it is vital the U.S. astronomy community retains programs which provide hands-on training in observation and all aspects of instrumentation development.

Historically observatories have been the training ground for both observers and instrumentalists. Yet here, too, the opportunities for hands-on training are shrinking. A few universities around the country have access to private, research grade, telescopes that can provide the training grounds desired, but the number of such opportunities is limited to only those students at the privileged universities. National observatories are open to students and researchers from all backgrounds and have numerous student training programs offered annually, from observation and data reduction training schools to student summer research programs and pre– and post-doctoral employment opportunities[1]. However many of the new national instruments are exquisitely complicated, putting the detailed understanding of the instruments and data reduction into data reduction pipelines and analysts trained to look for known problems. While providing excellent, readily-published science, these instruments are both limited in their accessibility by students and do not allow for the type of opportunities needed to ensure train the next generation of expert observers and instrumentalists.

The result of the decreasing opportunities for hands-on training at world class facilities is felt by the astronomical community in a number of ways. First, as the pool of astronomers with detailed instrumentation knowledge decreases, the probability of a given astronomer knowing an instrument expert in a given field also decreases. As a result, astronomers' understanding of the data received through observation and the data reduction pipelines becomes more limited. To produce excellent science, astronomers need the ability to understand the fundamental principles behind their data, and to recognize how the instrumentation and data reduction routines used affect their scientific goals. Additionally, and of at least equal importance, is that without sufficient training programs, the next generation of telescopes and instruments, such as those proposed in the Astro2020 process, will lack the expertise to be constructed, as it is becoming increasingly difficult to find scientists and engineers trained in the necessary skills to plan, construct, test, and calibrate these new instruments. Finally, national facilities provide

[1] see, e.g. https://greenbankobservatory.org/education/student-research.

access for all students and professional astronomers, regardless of their institutional affiliation, providing the education and competitive data required for career advancement.

Observatories are where textbook learning confronts reality. Training the next generation of astronomers how to not only interpret data, but to push the limits of what is possible with current telescopes is critical for the advancement of astronomical research. With commitment to and investment in observatory training programs, the state of our profession will be strengthened for the next generation of scientists and engineers.

Here we look at three aspects of the necessary training: observational training (§2), professional advancement (§3), and flexible instrument and software experimentation at observatories (§4). We also highlight some current programs addressing these issues (§5) and help lay out a path for ensuring the future of these activities (§6).

2. Observational Training

The scientific process requires scientists to understand their data, which, for astronomers, requires a good comprehension of the data acquisition and reduction, process - not only how the data is taken and reduced, but also importantly the physics and logic behind the process. Without this knowledge, understanding of the data is incomplete and can result in inaccurate or even erroneous conclusions. Small observatories, such as those provided at most colleges and universities around the country, provide an excellent foundation for this training. A 12" optical telescope with a CCD camera and small software-defined (or similar) radio telescope can introduce basic observational techniques and are an excellent foundation for student education and experimentation.

Cutting edge research, though, often requires more than a basic knowledge of the data received. Delving deeply into data requires fully understanding the physical, instrumental, weather, and data reduction algorithm effects. Additionally, when instruments are pushed near their limits, technological and software flaws that otherwise would have remained hidden are often exposed. Only someone with an extensive understanding of the acquired data and instrumentation used can both understand and work through such flaws.

3. Professional Advancement

Advancement within an observational research career requires access to research-grade instruments and data products. However, the faintness and/or high resolution required for many astronomical datasets requires large apertures and expensive telescopes. While some colleges and universities around the country have at least partial ownership of one or more large aperture telescope, far more institutions cannot afford the cost or upkeep of such an instrument. As a result, national observatories are required if the astronomy community wishes to ensure equal access to all astronomers, regardless of their institutional affiliation. Open access to first class research telescopes also greatly grows the diversity of the astronomy community by allowing

students and professors at smaller colleges, including primarily teaching colleges and minority-focused institutions, to compete equally for telescope time and data.

Similarly, internships such as the Research Experience for Undergraduates (REU) and similar programs for undergraduate and graduate students serve as another bridge for students into observational astronomy, particularly again for those students at smaller institutions.

For professional astronomers working at primarily undergraduate-serving institutions, observatories act as a bridge to continued education opportunities and as a way for professors to stay engaged in current research.

4. Instrument and Software Experimentation

The institutional knowledge of designing and operating world-class telescopes is never more than one generation of astronomers and engineers away from obscurity. If the U.S. wishes to remain at the forefront of astronomical research it must have the expertise to design, build, test, operate and improve the next generation of instruments and data products. Doing so requires a trained and experienced staff of many scientists and engineers of all specialties (software, microwave, digital, etc.).

The largest astronomical observatories have necessarily rigid operations. This allows heavily oversubscribed instruments to have efficiently planned schedules. These observatories also typically have well tested and readily available data reduction pipelines, resulting in the scientific community having ready access to the telescopes' advanced scientific data without requiring high level of instrument-specific training to use the data.

However, while the "black box" nature of the data coming from many of the national facilities means their scientific data products are readily available to the wide scientific community, it also means these facilities are not good training grounds for students nor are they good locations to deploy experimental student or university-led instruments and software. Operator run observing has become a necessity for many observatories, where complicated electronics require a level of specialized technical expertise that is impractical for the average user to master. For all its benefits, this method of observing does not empower students or professionals to understand the full path of a photon as it travels from an astronomical source to a spectra or image in a FITS file.

5. Existing Programs and Facilities

As mentioned above, national facilities play an important role in the hands-on training of astronomers and engineers, and they must continue to provide hands-on training opportunities to as many observational astronomers as possible. As mentioned above, national facilities play an important role in the hands-on training of astronomers and engineers, and must continue to provide hands-on training opportunities to as many observational astronomers as possible. The facilities being commissioned over the next decade and proposed for as part of the decadal

Table 1. List of training programs available to astronomers using the Green Bank Telescope.

Name	**Frequency**	**Professional Level**	**Average # Trained Annually**
Single Dish Training Workshop	Annual	Graduate/Post-graduate	30
Observer Training School	2x/year	Graduate/Post-graduate	40-50
Undergraduate School	Annual	Undergraduate	30
Summer Student Program	Annual	Undergraduate/Graduate	10-15
Post-Doctoral Program	Annual	Post-graduate	2-3
On-site Training	As needed	Graduate/Post-graduate	30-50
Co-op/Internships	Annual	Undergraduate/Graduate	1-3
Instrument Development	Ongoing	Graduate/Post-graduate	3-10
NANOGrav Training*	Annual	Undergraduate/Graduate	30
ALFALFA Undergraduate workshop**	Annual	Undergraduate	43
College-based courses***	Annual	Undergraduate/Graduate	20-100

* Workshop organized and run by the NANOGrav Team
** Workshop organized and run by the Undergraduate ALFALFA team
*** Organized by individual colleges annually

Table 2. List of training programs available to astronomers with the NRAO.

Name	**Frequency**	**Professional Level**	**Average # Trained Annually**
Synthesis Imaging Workshop*	Every other year	Graduate/Post-graduate	75
VLA Data Reduction Workshop	Every 18 months	Graduate/Post-graduate	30
Community Days	Few times/year	Undergraduate/Graduate /Post-graduate	75-100
Student Observing Support Program	Annual	Graduate	20
REU Program	Annual	Undergraduate	10
Other Summer Research Programs (NAC, etc.)	Annual	Undergraduate	10-15
Jansky Post-Doctoral program	Annual	Post-graduate	5
Reber Doctoral Fellows	Annual	Graduate	7-10
Co-Op Students	Annual	Undergraduate	2
Engineering interns	Annual	Undergraduate	2
VLA/VLBA On-site Training	As needed	Graduate/Post-graduate	30
ALMA Ambassadors Program**	As needed	Graduate/Post-graduate	240
ALMA On-Site Training	As needed	Undergraduate/Graduate /Post-graduate	30
* Workshops held every other year, with 150 participants per workshop.			
** These workshops were led by 15 postdocs, trained by NRAO. There were 12 proposal preparation workshops in total, including 10 in the US and 2 in Chile. Of the 240 participants, 190 were in the US and 50 were in Chile.			

survey will need astronomers trained for this work. Here we provide a brief description of some programs and facilities open to all observers.

5.1 Green Bank Observatory

The Green Bank Observatory has seven research-class telescopes on site, however only one, the 100-m Green Bank Telescope, or GBT, is available for NSF-funded peer reviewed science. At present (2019), the GBT has approximately 60% of its time available for "open skies" astronomy, for about 3,900 hours annually across its 0.2 - 116 GHz frequency range.

The Green Bank Observatory runs a number of training programs for undergraduate through post-graduate students, as described in Table 1. The Observatory is also open for other organizations, universities, and colleges to run their own courses on site. An example of this is a recent radio astronomy course run by Quest University at the Observatory utilizing the site telescopes, facilities, and staff.

5.2 National Radio Astronomy Observatory

The National Radio Astronomy Observatory (NRAO) is the North American partner for the ALMA telescope and also runs the Very Large Array (VLA) and the Very Long Baseline Array (VLBA). ALMA has 37.5% of the telescope time for use by the North American and Taiwanese scientific communities for about 1600 hours each year. The VLBA has 50% of its time available (approximately 2,100 hours) as open skies science, while 100% of the VLA (4,700 hours, roughly) is open to the international astronomy community. NRAO's training for professional astronomers is listed in Table 2.

5.3 Gemini Observatory/National Optical Astronomy Observatory

Gemini Observatory operates the two 8.1-m optical telescopes, Gemini North and South. Both telescopes have a significant share of time available to open skies science, of order 1,800 - 1,900 hours annually on each instrument. Gemini typically has two science fellow positions (post-doctoral position; one per each site) open on an annual basis. The fellows are treated as science staff and trained to pursue the observatory-based career by learning different aspects of the science operation (observing duties, being part of the instrumentation programs, checking the data quality as a contact scientist, etc.). Gemini also offers several internship opportunities to both science and engineering undergraduate students, and to students interested in public outreach and astronomy education. Gemini's training programs are listed in Table 3.

Table 3. List of training programs available at Gemini Observatory

Name	**Frequency**	**Professional Level**	**Average # Trained Annually**
Gemini Science Fellowship	Annual	Post-graduate	2
Research/PIO/Engineering interns	As needed	Undergraduate/Post-graduate	8
Akamai internship	As needed	Undergraduates in Hawaii	1 or 2
iRex/Co-op program	Annual	Undergraduates in Canada	10

The National Optical Astronomy Observatory (NOAO) operates Cerro Tololo Interamerican Observatory and the Kitt Peak National Observatory. Combined, NOAO operates 8 optical telescopes ranging in size from 0.9m through 4.1m in diameter, and covering from 0.31 - 2.5 μm in wavelength. NOAO offers two post-doctoral positions hosted at NOAO North and South, and a Goldberg fellowship (5-year post-doctoral position) annually. The NOAO also offers travel awards to graduate students carrying out PhD thesis observations at Gemini, KPNO, CTIO, or private observatories through community-access programs.

5.4 Arecibo Observatory

The University of Central Florida (UCF), in alliance with Yang Enterprises Inc., and Universidad Metropolitana, currently operates the 305-m Arecibo radio telescope under cooperative agreement with NSF. Arecibo Observatory is the most sensitive radio telescope in the U.S. operating between 0.3-10 GHz, has incoherent scatter radar that allows studies of the atmosphere, and has a huge program dedicated to studying near-earth asteroids. All professional training programs conducted at the observatory benefit from this multi-disciplinary nature of the facility. By 2023 it is estimated only ~20% of Arecibo's time (roughly 1,000 hours or less) will be available for US astronomers, although it is currently unclear how much of that time will be available for general, open skies proposals and how much of that time will be open for general, semi-annual proposal calls.

The training programs at Arecibo include: REU which brings 7-8 undergraduates and 1-2 teachers for 8 weeks of training, NANOStars that involves undergraduate students in pulsar timing observations and gravitational wave research, the Arecibo Remote Command Center (ARCC) program that brings together high school, undergraduate, and graduate students to conduct pulsar and FRB search observations, ALFALFA/APPSS training including the Undergraduate ALFALFA Team, and the opportunity for undergraduate students in the UPR system to conduct Semester-long research projects on site. Starting 2018, UCF's Preeminent

Postdoctoral Program provides matching support for Arecibo-based postdocs funded via other grants. Arecibo Observatory is planning to collaborate with the Green Bank Observatory to join the Single Dish Training Schools. The ALFALFA Undergraduate Workshop, held annually in Green Bank, also provides training for observations and data access for the Arecibo telescope. Arecibo's training programs are listed in Table 4.

It should be noted that being based on the island of Puerto Rico, Arecibo's programs include a large minority participation and offer US students the exposure to unique recreational and cultural experiences during their professional training.

Table 4. List of training programs available to astronomers with the Arecibo Observatory.

Name	**Frequency**	**Professional level**	**Average # trained annually**
REU/RET program	Annual	Undergraduate/graduate	8-10
ARCC	Every semester	Undergraduate	6
NANOStars	Every semester	Undergraduate	20
ALFALFA/APPSS training	Annual	Undergraduate/graduate	43
Single dish training	Bi-annual	Graduate/postgraduate	30
Semester internships	As needed	Undergraduate/graduate	1-2
Postdoctoral program	Annual	Postgraduate	2-3

6. Concluding Statement/Funding Request

National observatories provide a vital resource for the training of professional astronomers and engineers. They provide telescope and data access to everyone within the United States, regardless of the size of her home institution, allowing for cutting-edge research possibilities for students and astronomers from a wide variety of backgrounds. Observatories teach astronomers how to not only interpret data, but how to push the limits of what is possible with current instruments and software. Finally, the national observatories provide the training necessary to develop the next generation of instrumentation, training which is critical to achieve the many plans described for the next decades of astronomical research.

Current programs at national observatories reach roughly 400-500 students and professionals annually. However if we wish to attract the best possible students to astronomy,

these programs need to grow, particularly at the undergraduate level, when many students are choosing their areas of interest in the STEM fields. Crucially, too, we need to grow the programs available to provide in-depth training opportunities, those opportunities which allow students to do more than gain a superficial understanding of instrumentation and software techniques but which develop the next generation of instrument builders.

To ensure provide the vital training, we need:

- Guaranteed access to the national facilities by all U.S. astronomers and astronomy students. This requires that all National Facilities have a significant amount of their time available for U.S. peer-reviewed ("open skies") science;
- Sufficient funding for the less operationally complex large, single-aperture telescopes to allow for continued training programs (and telescope time);
- Funding for training schools and workshops at all the national facilities, including covering the travel costs of the U.S. students attending the schools and workshops;
- Training grants for astronomers new to a facility to cover a visit of up to two weeks for an observing and/or data reduction run;
- Grants for sabbatical/summer visits for faculty to provide detailed training and/or instrumentation planning.
- Funding at the National Facilities to have sufficient staff to ensure all University built instruments can be successfully used on the National telescopes;
- Continue and further increase support for REU summer programs at all national facilities.

With commitment to and investment in observatory training programs, the state of our profession will be strengthened for the next generation of scientists and engineers.