

Astro2020 APC White Paper

University–Based Radio Astronomy

Thematic Area: Ground–Based Radio Astronomy

Aspects of the state of the profession in radio astronomy are discussed. The paper is probably most relevant to the panel on ground–based radio astronomy.

Principal Author:

Name: Jens Kauffmann

Institution: Haystack Observatory, Massachusetts Institute of Technology, Westford, MA 01886

Email: jens.kauffmann@mit.edu

Phone: 617–715–5502

Abstract: Funding for radio observatories at universities has decreased substantially since 2013. This limits the ability of the US–based community to train junior astronomers, perform astrophysical research, and build instruments. Changes to the MSIP scheme, embedding of university groups in major projects, and a new NSF center could address these issues.

1 Introduction

The evolution of funding programs shapes the evolution of research fields. This is in particular true for the university-based research community in the radio, millimeter, and submillimeter (RMS) domain. In previous decades, support by a dedicated funding line enabled the operation of numerous observatories inside the US. This university-led facility landscape allowed the RMS community in the US to conceive and deliver engineering marvels like the Atacama Large Millimeter Array (ALMA). Today, the observatory system created through previous focused RMS funding still enables momentous scientific breakthroughs, like the first resolved image of a Black Hole’s photon ring by the Event Horizon Telescope (EHT).

This once diverse and vibrant university-based RMS community is now strained by changes in NSF funding schemes. Put briefly, the funding rate for general-purpose RMS observatories that are tied to universities has decreased substantially. Some of these changes reflect the rise of highly productive national-level research facilities in the RMS domain, such as ALMA, the Very Large Array (VLA), Green Bank Observatory (GBO), and the Long Baseline Observatory (LBO). It was natural and appropriate that the NSF initialed restructuring of funding lines for the RMS community. However, the national-level facilities fail to provide critical opportunities for hands-on training, instrument development, and fast response to changes in the scientific landscape that can be delivered by agile and accessible university-tied observatories. The NSF recognizes these issues in discussions, but the agency needs guidance on how to respond to this situation, given external constraints.

This white paper is structured as follows. Section 2 quantifies the reduction in funding for the development and operation of university-based observatories in the RMS domain. The impact of this reduction in funding is examined in Sec. 3. Suggestions for a strategic plan to improve the situation for university-based work in the RMS field are provided in Sec. 4.

2 Key Issue: Reduced University-tied RMS Funding

2.1 Key Facts

The RMS community depends on large, complex, and therefore costly facilities. Starting in 1991, the NSF therefore provided dedicated grants for university-based RMS work. This University Radio Observatories Program (URO) disbursed funding at an averaged rate of \$8.8M yr⁻¹ (Sec. 2.2). The Astro2010 Panel on Radio, Millimeter, and Submillimeter Astronomy from the Ground endorsed an increase in this funding rate by \$2M yr⁻¹. The URO program was, however, terminated in 2013. It was in part replaced by elements within the Mid-Scale Innovations Program (MSIP). So far, the MSIP program (with a total award rate of \$25M yr⁻¹) awards funding at a rate \$2.8M yr⁻¹ to projects that resemble those originally enabled by the URO program (Sec. 2.2). This represents a substantial decrease in the funding available for university-led work in the RMS domain. Further, 51% of the funding in these URO-like MSIP awards benefits national-level observatories, and thus does not fully support the university-tied observatory landscape.

2.2 Financial Details of the URO and MSIP Schemes

The URO program ([search NSF element code 1211](#) for a list of projects) awarded \$184M between December of 1991 and September 2012, i.e., over a period of about 21 yr. This corresponds to $\$8.8\text{M yr}^{-1}$. The median award was \$2.1M.

The MSIP with elements replacing the URO program granted first awards in 2014 (see Sec. 3.1 for program details). This revised MSIP ([search NSF element code 1257 for a list of awards after 2014](#); funding for the Large Hadron Collider [LHC] should be ignored) awarded \$128M over the past five years to programs throughout all wavelength domains. This corresponds to an award rate of $\$25\text{M yr}^{-1}$, with median grant sizes of \$4.4M. Out of 24 awards, 15 were made in the RMS domain. However, as we explain in Sec. 3.1, only 4 of these awards are broadly consistent with the original goals of the URO program, i.e., the creation of an accessible, agile, and flexible university-tied observatory system. These initiatives (see Sec. 3.1) were awarded \$14M over the past five years.

This effectively yields an award rate of $\$2.8\text{M yr}^{-1}$ for URO-like efforts within the MSIP. This funding is, however, not exclusively used to improve university-led facilities. A total of 51% of the URO-like MSIP funding is spent on programs delivering hardware to the GBT and Arecibo Observatory.

3 Overview of Impact on the Field

It is hard to broadly capture the implications of a funding line on the research community. Here we instead focus on selected well-documented examples that outline how the URO critically advanced work in education (Sec. 3.2), astronomical instrumentation (Sec. 3.3), and astronomical research (Sec. 3.4). These examples are complemented by lists of issues that affect the RMS community today. To start, Sec. 3.1 outlines the differences between the URO and MSIP schemes relevant for this discussion. Section. 3.5 rounds the discussion off by examining how modest general-purpose observatories in the RMS domain fit into an observatory landscape that is increasingly dominated by large and capable international observatories (e.g., ALMA) and small, focused, and ambitious experiments.

3.1 Background: Difference between the URO and MSIP Schemes

The NSF maintains several funding programs that permit development and operation of ground-based astronomical observatories. These programs support all wavelength domains in astronomy. The URO program therefore made a difference for the RMS community during past decades. [NSF Solicitation 11-529](#) describes the last incarnation of URO program. It recognizes the need to “support university-based radio astronomy at funding levels above those normally considered appropriate for individual investigator research grants”. The particular focus of the scheme is stated as follows.

The emphasis of the program is to maintain a presence for radio astronomy in the university environment, in order to foster innovation and train upcoming generations of students in the field. UROs also provide research opportunities of scope and risk not typically available at the National Centers.

The URO program provides funding for telescope operations and for equipment development. It also provides partial or full salary support for research faculty, engineers, and technicians; partial summer salary for teaching faculty; and stipend support for both graduate and undergraduate students. [...]

UROs funded by NSF are expected to provide the general astronomical community with access to between one-third and one-half of available telescope observing time. For a telescope that operates primarily in survey or campaign mode, equivalent value must be provided to the general community and detailed in the proposal.

A [search for NSF program element 1211](#) delivers a list of facilities that received support from the URO program. During its last decade (i.e., 2003–2013), the URO framework awarded funding to the Combined Array for Research in Millimeter-wave Astronomy (CARMA; a 23–element radio interferometer), the Caltech Submillimeter Observatory (CSO; a 10m–antenna), the Five College Radio Astronomy Observatory (FCRAO; a 14m–antenna), the Allen Telescope Array (ATA; a 350–element interferometer), the Murchison Widefield Array (MWA; a low–frequency dipole array), the Arizona Radio Observatory (ARO; one 10m–antenna, and one 12m–antenna), and the LWA (a low–frequency dipole array). These are general–purpose observatories that supported a wide variety of small and large programs driven by guest observers.

The revision of the URO program was not a consequence of an unsatisfactory performance of the funding scheme program, as we discuss in Secs. 3.2–3.4. It is more appropriate to consider the termination of the URO funding line as a response to external funding pressures and the general evolution of observatories towards national–scale facilities.

The current goals of the MSIP are documented in [NSF Solicitation 17–592](#). The overall aim is stated as follows.

The MSIP is designed to fill the need for a well–defined budgetary and competitive selection process to support astronomical projects of intermediate to large cost [...]. This solicitation fills part of the mid-scale gap, from \$4M to \$30M.

The only specific statement concerning the RMS domain is that “proposals formerly directed toward the now-discontinued URO program [...] must now be submitted to the MSIP.” In particular, the preservation of a diverse university–based RMS community is not a stated goal of the MSIP. It is true that the MSIP has a strong track record in supporting RMS–focussed work. Since 2014, when URO–like program elements were subsumed within the MSIP, the MSIP made 24 awards, out of which 15 benefited 13 observatories in the RMS domain. This includes HERA, ACTPol, EHT, NANOGrav, POLARBEAR/Simons Array, CLASS, DSA, BICEP, and the SPT. However, these projects should rather be considered ‘experiments’, i.e., they target a very narrow science goal in a highly focused fashion. *The awards are not designed to create accessible, multi–purpose observatories.*

Only four efforts pursue goals that would have been broadly consistent with the aims of the URO program, i.e., they enable guest observers to execute their own research projects. These are projects delivering the TolTEC camera on the Large Millimeter Telescope (LMT), the ALPACA camera for the Arecibo Telescope, operation and development of the long wavelength Array (LWA), and dish improvements to the Green Bank Telescope (GBT). Only two of these awards support observatories with a strong university–level involvement

in operations, i.e., the LMT and LWA. MSIP awards on URO-like projects thus only partly support the diversity of university-based RMS work.

3.2 Impact on Education and Training in the RMS Domain

URO Program Successes: Graduate Students and Postdoctoral Fellows

The [Astro2010 Panel on Radio, Millimeter, and Submillimeter Astronomy from the Ground \(Astro2010 RMS Panel\)](#) estimated that about 160 graduate students and 100 postdoctoral fellows were trained at URO-supported facilities during the 2000–2010 time frame. The observatories of the URO program offered junior scientists a very wide range of activities to get involved with the RMS domain. Many students and postdoctoral fellows used facilities in the URO program to obtain data for their work, either via competed proposals or archival work. A substantial number of people used the opportunities created by the URO program to gain hands-on experiences with complex telescopes and their receivers and backends at levels well beyond what streamlined national-level observatories can offer. Some individuals also helped to build, maintain, and develop the observatories via technical work.

Current Issues

The lack of accessible university-level observatories resulting from the termination of the URO program creates large gaps in the ability of the US-based RMS community to train the next generation of astronomers.

- It is very difficult for junior scientists to be exposed to the full scientific discovery process, consisting of the iteration between observation, analysis, theoretical interpretation, and further observations. First, time allocation on national-level observatories has become very competitive, thus making it hard for junior scientists to execute self-conceived projects. Second, the period between proposal submission and data delivery can exceed a year on facilities like ALMA, which becomes a substantial fraction of the duration of a student project or postdoctoral fellowship. The existing university-operated observatories can only partly address these issues, since these facilities are primarily focused experiments that are not open to general proposals from US-based observers. The URO program, by contrast, enabled low-threshold access to telescopes that were able to deliver data within a few months of project conception.
- Junior astronomers have limited chances to receive hands-on training at telescopes in the RMS domain, unless they are directly involved with observatories operating as experiments. A large fraction of the astronomers being trained today will only learn how to generate observing scripts for observatories, and how to reduce the resulting data (which is typically pre-screened for flaws by observatory staff). This approach results in substantial scientific discoveries, but it fails to provide a well-rounded education. In particular, the lack of immediate exposure to unrefined data and the guts of telescope operations cultivates a mindset that treats observatories as black boxes. The URO-supported facilities, by contrast, enabled visiting students to be in full control of complex telescope hardware even if their projects were not focused on technology.

- A secondary issue is that the decline of direct telescope access in the RMS domain also has an impact on faculty hires: excluding instrumentalists, hands-on experience becomes less of an asset for university professors. This means that even the persons training the next generation of astronomers might have increasing difficulties to convey the basic working principles of radio telescopes, given a lack of personal experience. This was different when educators and their students were working with URO-supported facilities.

In summary, it would be important to enable fast and low-threshold access to hands-on telescope experiences. Expansions of remote observing programs cannot deliver this.

3.3 Impact on Instrument and Facility Development

URO Program Successes: Enabling ALMA and NRAO Facilities

The partner institutions of the Combined Array for Research in Millimeterwave Astronomy (CARMA) analyzed the impact of their facility on ALMA and NRAO in 2015 (priv. comm.). They researched the number of ALMA and NRAO staff members had been trained at CARMA, as well as the interferometers operated by the Owens Valley Radio Observatory (OVRO) and the Berkeley-Illinois-Maryland Association (BIMA) that were merged into CARMA. In 2015, these staff members included the North American Project Scientist for ALMA, the Canadian Project Scientist, the European Project Scientist, the previous ALMA Commissioning and Science Verification Lead and ALMA Deputy Director, the ALMA Commissioning Science Verification Lead, the previous NRAO Director, and the current NRAO director. At least 10 of the staff members working at the North American ALMA Science Center, the VLA, and the GBT in 2015 did their graduate or postdoctoral training at CARMA, BIMA, or OVRO.

While the impact of CARMA on ALMA and NRAO is documented particularly well, it is obvious that other URO-supported facilities played a similar role in conducting the groundwork that enabled ALMA. The [Astro2010 RMS Panel](#) further highlighted that the URO program delivered numerous technologies that are now in use at ALMA.

Current Issues

These examples introduce the challenges now faced by the US-based RMS community, given the termination of the URO program.

- It has become very difficult to test new hardware that enables future major advances in science and technology. To do so, instrument developers need straightforward low-threshold access to telescopes. These telescopes should ideally be relatively simple, so that receiver issues can be separated from unexpected telescope behavior (e.g., an issue at the GBO at ~ 100 GHz frequency). Some projects require invasive and sometimes time-intensive access to telescopes (e.g., to make physical space for receivers, and to modify drive systems for particular observing modes). This is largely impossible at national-level observatories, while the small and simple telescopes of the URO program provided all of this.

- In particular, receiver development projects (as well as scientific observing projects; Sec. 3.4) targeting very high frequencies require access to dry sites at altitudes well above 13,000 ft. No publicly accessible US-based telescope resides under such conditions. As a consequence, it is not possible to field experimental equipment for engineering work in a straightforward fashion. This substantially limits work in this wavelength domain by US-based institutions. During the URO program, the Caltech Submillimeter Observatory (CSO) and to some extent the Submillimeter Telescope (SMT), provided opportunities for such work.
- Likewise, given the termination of the URO program, also the manpower needed for operations and development of telescopes in the RMS domain finds few chances to get trained. As argued in Sec. 3.2, the URO-supported facilities provided ample of opportunities for education and maturation.

These considerations underline the need for straightforward access to facilities where intrusive and time-intensive engineering work can be performed if needed. At least one such facility should reside at high elevations (and have a precise surface) in order to enable observations at very high frequencies.

3.4 Impact on Astronomical Research

URO Program Successes: Resolving a Black Hole’s Photon Ring

In a [series of publications](#) released in spring of 2019, the Event Horizon Telescope (EHT) collaboration documented the [first resolved image of the photon ring around a Black Hole](#). The data used for this experiment were obtained in 2017, i.e., several years after the termination of the URO program. However, the EHT project would not exist in its current form without previous URO funding.

Specifically, the observations in 2017 included data from the SMT, which had in previous years in part been developed and maintained using URO funding. This represents direct impact of the URO program on the main results of the EHT. However, arguably more importantly, the URO program generated a network of easily accessible facilities that enabled the development of the EHT. Specifically, [CARMA, the SMT, and the CSO participated](#) in previous observations while being supported by the URO program. These observations lead up to the resolved images of the Black Hole in M87 that were released in 2019.

Current Issues

The lack of accessible observatories in the US now has consequences for the ability of the US-based community to pursue scientific experiments.

- The EHT project demonstrates the value of a network of general-purpose observatories that can be repurposed for relatively brief focused experiments that do not justify the building of new observatories. Today it would be very hard to launch a project like the EHT, because all observations might need to involve major international facilities starting from day one.

- More generally, easily accessible general-purpose observatories allow for a quick iteration between observations, theoretical experiments, and potentially the development of new instruments. The termination of the URO program complicates such work in the US, since opportunities for observations and technology development are now more closely tied to national-level observatories. The situation is particularly complicated at the highest frequencies, where no general-access facility exists.
- The reduced access to facilities in the RMS domain in particular limits the ability of the US-based community to fully exploit major national-level telescopes. To give one example, many current ALMA projects use the US-led [Bolocam Galactic Plane Survey](#) and the EU-led [ATLASGAL](#) survey of galactic dust emission as the basis for the generation of source lists. These are examples where small and agile university-based facilities were used to quickly conduct preliminary experiments that critically prepared the efficient use of limited observing time on major facilities.

The efficient access to agile facilities is thus also essential for the advancement of our understanding of the cosmos.

3.5 General-Purpose Facilities vs. ALMA and Experiments

One might wonder to what extent university-tied facilities of relatively small size still fit into today’s observatory landscape. This holds in particular at the high-frequency end of the RMS domain, where ALMA provides unprecedented observational capabilities. Sections 3.2–3.4 show that ALMA and URO-like facilities do not occupy the same parameter space in terms of training potential, science goals, and instrument technology. For the latter this is, for example, made evident by the thriving ecosystem of ‘experiments’ in the RMS domain. To give one example, modest single-dish telescopes substantially outperform ALMA if science requirements demand the mapping of large areas on the sky with limited angular resolution. General-purpose observatories are needed in addition to experiments as this greatly expands the pool of junior scientists to receive hands-on training, observers to acquire types of data not available from ALMA, and instrumentalists to test new hardware in an accessible environment.

4 Plausible Elements for a Strategic Plan

Section 2 shows that the underlying problem for the issues raised above is the reduced funding for university-level observatories with a general-purpose character in the RMS domain. Any increase over the current level of $\$2.8\text{M yr}^{-1}$ (of which half is not exclusively spent in a university environment; Sec. 2) would help. It would be most straightforward to reestablish the original URO program in its original form. This does, however, not necessarily fit well into today’s observatory landscape, which is increasingly dominated by large and incredibly capable international facilities.

Below we list more modest and modern options that would have an impact on general-purpose observatories at the university level. Given the large number of stake holders, and

numerous external constraints, it is not possible to deliver a comprehensive strategic plan at this point. It is, however, possible to list options that could become part of such a plan.

4.1 Strategic Goals

Before spelling out specific actions, it is useful to detail the specific intent of these activities. The goal is to support observatories in the RMS domain that

- have a general-purpose character, thus befitting a large pool of students, observers, and instrumentalists,
- involve university-based groups in operations and maintenance of the facility, in order to cultivate relevant expertise outside of the national observatories,
- have lean management and approval processes that permit to swiftly adapt to changes in the scientific landscape, and
- ideally as a network cover a large geographic fraction of the US (i.e., more than one physical observatory), in order to make the observatories accessible.

These points in particular underline that current or even increased funding for focused experiments in the RMS domain do not alleviate the situation.

Note that the NSF does at the moment not possess a long-term strategy for the RMS community, and in particular none that highlights the role of university-tied observatories. Instead, the NSF awards funding in an exclusively reactive fashion, i.e., it responds to the proposals submitted via existing funding schemes. This is a reasonable approach that places a high weight on the case made by an individual proposal. This approach is, however, not suited well to address the multi-faceted issues currently encountered by the RMS community.

4.2 Strengthening of URO-like Elements within MSIP

The NSF stated (in a [“Department Chairs Presentation”](#)) that the MSIP pursued the explicit goal to preserve the URO program at some level within MSIP. It would be relatively straightforward to adapt future MSIP solicitations to fully represent this intention, with the goal to support observatories as spelled out in Sec. 4.1. It would be ideal to explicitly set funding aside for such a task. More realistic would be the an implementation via the inclusion of specific merit criteria. Note that such guidelines in MSIP solicitations, or other calls by the NSF, would de-facto establish a long-term strategy of the NSF for university-based observatories in the RMS domain that is now missing.

4.3 Embedding University-level Groups in Major RMS Projects

A variety of larger projects in the RMS domain are discussed in submissions to the Astro2020 Decadal Survey. This includes the following undertakings.

- The [the ngVLA project](#), which envisions to deploy ~ 200 antennas for operations at up to ~ 100 GHz across the US.

- An expanded version of the [EHT array](#), which seeks to establish new 6m-telescopes capable to observe at frequencies of several 10^2 GHz at multiple locations in the US.
- Increased public access to the [Large Millimeter Telescope Alfonso Serrano \(LMT\)](#), a 50m-telescope at an altitude of 15,000 ft in Mexico.
- Construction of the [Atacama Large-Aperture Submillimeter Telescope \(AtLAST\)](#), a telescope of 25–50 m size above ALMA at an altitude of up to 18,000 ft.

Provided one or several of these projects are realized, it would be possible to *deeply embed university-tied groups* in equipping, maintaining, and operating these facilities. Specifically, the role of universities should go beyond delivering instruments and maintenance services. Instead, to enable agile observatories cultivating a broad set of skills, university-based groups should be involved in as many aspects of observatory operations as possible.

The ngVLA and EHT projects, in particular, generate very interesting opportunities for work in the RMS domain throughout the US. Selected telescopes of these interferometers could be operated independently as single-dish telescopes or small interferometer arrays for some of the time. This would likely require modest modifications to the antennas and operating procedures, for example to enable the hosting of guest instruments, and thus slightly reduce the efficiency of the arrays. However, the benefit of this approach would be that several capable and flexible telescopes would become available in several locations in the US, and this would vitalize the university-based RMS community. Further, sharing of staff and facilities between universities, the ngVLA, or the EHT could reduce costs and improve the expertise levels at all involved observatories.

The LMT and AtLAST projects could provide university-tied groups with excellent opportunities for astronomical observations and instrumentation work in a very straightforward fashion. For this it would be important to devise management structures that permit involvement of and contributions from the full range of institutions in the US.

4.4 Creation of an NSF Center in the RMS Domain

The NSF maintains programs for the creation of centers focusing on specific aspects in science, technology, and engineering. A national center in the RMS domain that involves several universities and university-tied observatories throughout the US could deliver the following.

- A comprehensive US-wide network for the education of students and the mentoring of postdoctoral fellows active in the RMS domain.
- A comprehensive network of accessible university-tied observatories. This would substantially advance education in the RMS domain, enable high-impact astronomical research in fields where national-level observatories are too large or too slow to respond to a moving science landscape, and enable research into instrumentation that is needed to deliver new breakthroughs in astronomical research and technology.
- Funding covering fellowships for students and postdoctoral researchers, and support for the salaries of research staff, engineering staff, and faculty (in the summer), so that comprehensive work in astronomical research and instrumentation can be performed.

The idea of such a center is currently being explored by some people in the RMS community, including the author of this document. A more concrete plan for such a center is expected in fall.