

BUILDING THE SYSTEM: A PHASED PLAN TO ADDRESS THE RESTAR RECOMMENDATIONS AND PRIORITIES

Executive Summary

This white paper presents NOAO's plan to significantly improve the quality and quantity of open-access capabilities on 2-5 meter telescopes. It is driven by the need expressed by the Senior Review report, and detailed by the ReSTAR report, to provide access to a balanced suite of high-performance instruments on telescopes of all apertures. Based on the priorities given in the ReSTAR report, the program presented here would develop state-of-the-art optical and near-IR spectrographs for telescopes that provide open access; it would add nights available to the community by partnerships with two of the most capable private telescopes; and it would strengthen the infrastructure of this part of the ground-based O/IR system so that these and other telescopes could continue to provide safe, reliable, and effective access.

The approach to be taken maximizes the involvement of the broad community, by engaging them to participate in guiding the program and to undertake most of the development and fabrication work. A number of design and development studies are also planned for this three-year phase, the first of three, which will identify the best projects and partners for the future phases.

The Problem

The community that NOAO serves is diverse. Some fraction enjoys preferred access to non-federal facilities. Some fraction depends on open-access facilities. Some researchers work in large teams that use a wide range of different types of capabilities at many different facilities for complex or multiple projects. Some work individually or in small groups and do one project at a time. Some can see how their research interests demand the development of future large telescopes. Some are interested in solving problems that demand continued, reliable access to stable instrumentation on smaller telescopes.

As a consequence of this diversity of interests and needs, the community must have access to a balanced system of facilities. NOAO's strategic choices must weigh cost and benefit, and avoid being dominated by either end of the scale. Moreover, limited resources mean that tough decisions must be made. The recent NSF Senior Review, which solicited general input from the broad community, found that the consensus was that NOAO had moved too far from the support and improvement of the existing facilities towards the development of the next generation. It asked for a renewal of the infrastructure at the existing facilities and an upgrading of the capabilities on smaller telescopes to modern, high-performance standards.

NOAO began at once to redirect resources towards the facilities on Kitt Peak and Cerro Tololo. A limited amount of improvement was begun using only the funding within the NOAO budget in FY07. As an indication of acknowledgement and support for the

Senior Review recommendations, NSF/AST requested an increase of \$2.3M for NOAO in FY08 and described a budget envelope for the next five year period that would remain at a level consistent with making those improvements. However, the federal budget for FY08 ended with a bill that specified flat funding for the NSF, and so that infrastructure renewal is currently able to proceed at only a minimal pace.

The ReSTAR Process

In order to demonstrate a commitment to restore the balance in its efforts, NOAO convened a committee called ReSTAR, Renewing Small Telescopes for Astronomical Research. Chaired by Katy Pilachowski from Indiana University, this committee was charged to solicit community input on the desired capabilities that were needed on telescopes less than 6.5m in aperture. Over a period of nine months, the ReSTAR committee met four times. They solicited and received a great deal of input from astronomers at all stages in their careers and at all types of institutions about their use of telescopes in this size range. The records of the committee, including membership, meeting notes, and final report can be found on the ReSTAR page on the NOAO web site (<http://www.noao.edu>).

The report of the ReSTAR committee lays out a compelling case for the continuing use of telescopes in the aperture range 2-5 meters. It includes a comprehensive scientific justification, discussion of the ways that these telescopes are used, and how they should evolve in the future to retain that usefulness. The report makes clear that, unlike, for example, the analogy of accelerators for the particle physics community, there is much forefront astronomical research that can be done more cost-effectively – and, in some cases, better – on smaller telescopes. Some of this research consists of preliminary steps that then proceed to larger telescopes, but much of it is self-contained and complete.

The 2-5 meter aperture telescopes are only one part of the system. Following the completion of the ReSTAR report, NOAO has initiated a similar study, ALTAIR, Access to Large Telescopes for Astronomical Instruction and Research, to look at the desired capabilities on 6.5-10 meter telescopes. The study should be completed in early 2009. Ultimately, the various parts of the system, including the mid-size, large, and extremely large telescopes must be maintained in balance. Hopefully, this will be done by building each of these parts up to the level required by considering the needs of the community. Tradeoffs in investments among the different elements of the system should be made by the National Science Foundation, which has responsibility for maintaining this balance among all the astronomical resources that they fund.

The ReSTAR Recommendations and Priorities

The recommendations within the ReSTAR report include justification and detail. In order to develop a viable plan that flows from the report, we summarize the most important points made in the recommendations as follows:

- The suite of telescopes that provide open-access (access by peer review independent of institutional affiliation) should be instrumented with modern, high-performance instrumentation. Generally, the most fundamental capabilities should be available on the federally funded telescopes that provide most of the open-access time; more specialized instruments are suitable for non-federal facilities that are able to offer smaller amounts of time to the community.
- The number of nights needed on telescopes in this aperture range should be determined by monitoring the community demand. However, several approaches to estimate this need predict that an increase of 2-3 times the current supply may be justified.
- Priority for development of this system, and for addressing the suite of recommendations should go first to assure that the existing telescopes are safe, reliable, and efficient; second that instrumentation is competitive and effective, and third that an appropriate level of access exists.
- Future development should work towards integration of capabilities for time-domain studies, and then, exploration of optical interferometry and adaptive optics.
- All facilities that provide access to the community should be held to high standards of efficiency, reliability, performance, documentation, usability, and data quality.

At a greater level of detail, the report also presents priorities for capabilities, based on the community input. The community priority near-term needs for capabilities on telescopes of this size (without regard for what may be currently available or planned) are:

1. Wide-field, broad-band optical imaging
2. Moderate resolution optical spectroscopy
3. Near-IR (1-5 micron) imaging
4. Moderate resolution near-IR (1-5 micron) spectroscopy
5. High-resolution (10,000<R<50,000) optical spectroscopy
6. Wide-field narrow-band optical imaging
7. High spatial resolution IR imaging

A number of other capabilities follow, at lower priority.

The committee noted that "...spectroscopy should receive the highest priority for new instrumentation, since instrumentation for imaging is in a somewhat better state."

Principles and Constraints for the Implementation Plan

In order to develop a plan that moves us measurably towards the goals of the ReSTAR report, but fits within sensible constraints on budgets and other resources, the following principles have been adopted. These often represent choices based on other NOAO goals or considerations of particular capabilities that might actually be available.

- 1) The program will be structured as three consecutive phases, each three years in length. This allows moderate-scale instruments to be completed during a single phase, while studies and design work are going on to prepare for fabrication in the following phase. Three such phases, sized to a funding level of a few million dollars per year (approximately \$10M per phase) will allow significant progress towards a system that addresses the needs expressed in the ReSTAR survey input.
- 2) Much of the work will be done in partnership with community groups. Indeed, apart from generating access and instruments for the community, NOAO sees the overall strengthening of the technical capability of the community as a desirable goal. Thus, the model will be to engage external groups to do much of the design and fabrication of new instruments. NOAO will provide scientific and technical oversight of these efforts throughout, and, when appropriate, will take responsibility for integration and commissioning of new instruments.
- 3) Over the past years, NOAO has developed a number of partnerships, either to build instruments (University of Maryland, Dark Energy Consortium) or to provide resources to support operations (Clemson University, University of Illinois). While these partnerships bring more (and sometimes different) resources to bear, they have reduced the amount of telescope time available to the rest of the community. We will continue to explore partnerships, but the preference will be for arrangements where little or no open-access NOAO telescope time is traded to partners.
- 4) In order to more easily engage external groups and to minimize lead time and cost, our initial approach for developing a new capability will be to survey the community and see whether there is an existing instrument design or approach that can be adapted to provide an effective solution. In many cases, groups that have already built good instruments will be approached to capitalize on their existing experience.
- 5) While the first phase can only move forward at an acceptable pace with pre-selected partners, it is desirable to draw more participants into this activity. During each phase of the program we will be identifying partners for the next phase. We will make these opportunities widely known, though we will generally be looking for specific capabilities. Our strategy is to maintain the capability to do high-level design and final integration of instruments in-house, while engaging smaller instrumentation groups, which might have the ability to design and fabricate subsystems of instruments.

Structure of the Program and Goals for Phase 1

As stated above, each phase will include some projects carried to completion and some that are limited to studies and design work. For Phase 1, given the relatively strong state of optical and IR imaging capabilities (NEWFIRM, ODI, Dark Energy Camera), the focus of the instrumentation efforts will be on spectroscopy. In particular, we note that open-access optical spectroscopy at the 4m level is limited to the quite old RC (medium-resolution) and echelle (high-resolution) spectrographs on the Mayall and Blanco telescopes (technically, the echelle is no longer offered on the Blanco), and the just-delivered Goodman spectrograph on the SOAR telescope, which has limited access by the broad community. Additional capability is offered by the moderately old Hydra multi-object spectrographs on the WIYN and Blanco telescopes¹, though this capability (wide-field multi-object) was categorized separately in the ReSTAR study and ranked at a lower priority. Similarly, the medium-resolution near-IR spectroscopic capability is limited to Flamingos and IRMOS on the Mayall and OSIRIS on SOAR, all of which are essentially visitor instruments. It should also be mentioned that a near-IR spectroscopic instrument, SPEX, is available on the IRTF, and that a new high-dispersion near-IR spectrograph is planned for that telescope.

Our desire is to both upgrade these three critical capabilities, medium-dispersion optical and near-IR spectroscopy and high-dispersion optical spectroscopy, with modern high-performance instrumentation and increase the amount of time available with it. Thus, we have identified three instruments and two facility partnerships to achieve these goals. Note that all three of the proposed instruments capitalize on design work done previously by external (to NOAO) groups, and, for one instrument, TripleSpec, we can build a close copy of the version built for the Hale 5m telescope. Thus, there is little risk associated with these designs, and there are obvious partners with relevant experience. Two of the instruments are for NOAO telescopes; the third is for a partnered facility.

In addition to the new instruments, we have initiated discussions with two facilities about partnerships that would offer additional access to high-quality optical and IR spectroscopy to the broad community. These are the Discovery Channel Telescope, a 4.2m aperture telescope under construction just south of Flagstaff by Lowell Observatory, and the Hale 5m telescope at Palomar Observatory. We also note that time trades may be possible to provide better balance among the capabilities or to gain access to capabilities that are more specialized – for example, time on the Blanco 4-meter telescope with its wide field imaging capability for time on the Anglo-Australian telescope, with its wide field multi-object spectrograph, AAOmega.

A critical piece of the first phase of the program is the design and development work for projects in future phases. Four such studies are envisioned. The first two are aimed at the need for capabilities to support time-domain research. For these, we will leverage the work done by the Las Cumbres Global Telescope Network, with whom we have been discussing a partnership agreement. One study will have the goal of understanding how

¹ The bench spectrograph on the WIYN version of HYDRA has been significantly upgraded in recent years with improved gratings, detector, and optics.

to provide an effective interface between the community and such capabilities. The second will be design and site analysis work prior to building two new 2m telescopes to enlarge the LCOGT network in longitude and provide additional 2m access for the broad community. Finally, we will initiate studies of optical interferometry and adaptive optics as they relate to facilities in this aperture range. These studies will depend on community participation – both in order to define the specific goals of the studies and to carry them out.

Finally, we note that all of this improvement and enlargement depends on a strengthening of the infrastructure of the observatories and telescopes. While NOAO has been able to make a modest start of this, the funds that were promised to support this renewal have not been forthcoming. Therefore, we include as a part of the ReSTAR implementation program funds to ensure that the very highest priority of the recommendations – the safe, reliable, and efficient operation of the facilities – is addressed.

Below we describe each project within the first phase of the program.

OSMOS

This is a high-throughput (VPH grism), optical imaging spectrograph, being designed and built by the Ohio State University instrumentation group for the Hiltner 2.4m telescope at MDM observatory. Slightly redesigned for the Mayall or Blanco telescopes, it would match a 1 arcsec slit to 3 detector pixels and would offer resolutions from 500 to 5000 over the wavelength range 350-1000 nm on a 4K X 4K detector. Entrance apertures include 20 arcminute-long single slits or multi-aperture masks covering a 20 arcminute diameter circular field. An imaging mode is also available. More information about the design can be found on the Ohio State University astronomy department web site.

Design work would be led at OSU with participation from NOAO personnel. Fabrication would be split between OSU and NOAO, with NOAO providing the detector/controller package. If design work were initiated soon, a first copy could be available for the Mayall telescope by early 2011. If a decision to build two copies were made in advance, a second copy for the Blanco telescope could be completed by about 6 months later.

TripleSpec

This is a $R=3500$ (1.1 arcsec slit) cross-dispersed near-IR (JHK) spectrograph, of which three copies are being (or have been) built – for the Hale 5m, the ARC 3.5m, and the Keck 10m telescopes – by a collaboration that includes the University of Virginia, Cornell University, and Caltech. It provides continuous coverage from 0.95 to 2.46 microns through five orders. The maximum slit length is 43 arcseconds. The copies of this instrument for the ARC and Hale telescopes were delivered and commissioned in the first half of 2008. Information about the instrument design and performance can be found at the astronomy department web site of the University of Virginia.

We have had discussions with members of this team, and the Cornell University group has expressed interest in working with us on this instrument. We believe that this instrument could be completed for the Blanco telescope by early 2011. Placing this instrument on the Blanco provides capability balance north-south, given existing instruments and a proposed partnership discussed below.

An Optical Echelle Spectrograph for the DCT

One of the instruments of interest to the Lowell Observatory staff for the Discovery Channel Telescope (see below) is a high-dispersion ($R=60,000$) optical spectrograph. This capability is a natural fit for a telescope that will see a minority fraction of community access. Although an optical design for this spectrograph has been generated, it addresses a very limited range of problems. This is an opportunity to utilize the science identified by the ReSTAR survey for such an instrument, involve some of the people who would be users, and generate a design based on their requirements; this work is just getting underway and community input would be most helpful. This is also an opportunity to involve external instrumentation groups in the design and construction.

The Discovery Channel Telescope Partnership

The Discovery Channel Telescope is a 4.2m aperture telescope under construction by Lowell Observatory at a site about 40 miles south of Flagstaff, Arizona. First light is expected in 2010. The telescope has a prime focus with a planned wide-field corrector, and Nasmyth and Cassegrain ports. The site is dark, and the telescope will be operable remotely. A 30% share of the telescope has been proposed for NOAO by Lowell. NOAO would then have input into the policies and scientific operation of the telescope, including the instrument complement. As mentioned above, a high-resolution optical spectrograph would be an effective capability to place here, but subsequent options might include a near-IR spectrograph or a wide-field multi-object spectrograph.

The Palomar Hale 5m Telescope Partnership

With a relatively efficient optical spectrograph (Double Spectrograph) and the just-commissioned TripleSpec, the Hale 5m telescope could provide access to high-quality spectroscopic capabilities on at least an interim basis. Access to the same IR spectroscopic capability as will be provided on the Blanco telescope in the south provides commonality that should help NOAO to support community use. The Double Spectrograph has been recently upgraded and provides good throughput, broad wavelength coverage, resolutions from about 1500 to 40,000, and spectropolarimetric capability. Initial discussions suggest that approximately 50 nights per year might be available for community use starting in early 2010. There is mutual interest in improving the infrastructure of this system in the context of this partnership, including improving the efficiency of target acquisition and developing a robust data reduction pipeline.

Design Study for 2m Telescopes

Building two 2m telescopes would provide additional access for the community, but, more importantly, it would provide a critical extension of the Las Cumbres Observatory Global Telescope network (see below), and establish the community as a 50% partner in this longitudinally-distributed array. Adding modern 2m telescopes at or near our current facilities at Kitt Peak and Cerro Tololo to the existing telescopes at Haleakala, HI and Siding Spring, Australia would extend the network to span 140 degrees of longitude, permitting night-time observations for about 20 hours of any 24 hour period. Future development could complete the coverage with two more telescopes. All of the 2m telescopes would be instrumented with simple, identical instruments that would provide a standard set of capabilities – say, optical imaging and medium-resolution spectroscopy. The telescopes could be operated robotically, as they would be as part of the network, or they could be operated in a classical mode by visiting observers or remotely through a network interface.

The work to be done during this phase is to develop a design and costing for these telescopes and their instruments such that they will be compatible with the existing telescopes in the network. If appropriate, work to prepare the sites for these new telescopes could proceed with the expectation of funding in the next phase to begin construction.

Development of Concepts for Future Projects

1. Community support and capabilities for time-domain research – The most obvious and compelling type of research that will become much more important to the community in the next ten years is time-domain research. With Pan-STARRS beginning operation and LSST anticipating first light in 2014, there will soon be thousands of nightly discoveries of moving or changing objects. Follow-up observations of these will require the ability to dynamically schedule telescopes given priorities for targets-of-opportunity, rapid-response, and observations spaced to sample variations with a particular cadence. Even figuring out which objects to follow will require the development of software to interface with and filter the event announcement streams from these discovery facilities. NOAO has initiated discussions with the Las Cumbres Observatory Global Telescope (LCOGT; <http://lcogt.net/>) network foundation, who have announced plans to develop a world-wide array of telescopes between 0.4 and 2.0 meters to undertake observations that explore the time-domain. The first step is to develop a model for community time-domain research: What particular types of observations are needed, how should this capability be advertised, how are programs selected and time assigned, what processing is needed for the data, how should the data be distributed? All of these questions will be answered as prototype tools and mechanisms are developed to allow the community to access a small fraction of the LCOGT network.
2. Adaptive optics for 2-4m telescopes – The priority of most adaptive optics development programs has been systems for 8m-class telescopes. Both the ReSTAR committee and the recent 2008 AO Roadmap Update (found on the

AODP page of the NOAO web site) expressed interest in seeing the role of adaptive optics on mid-sized telescopes explored. Low-order systems might effectively improve efficiency of almost all capabilities by significantly improving image quality. The development of a low-cost, versatile system that could effectively feed existing instruments on existing telescopes might be a goal for this study.

3. Optical Interferometry – Arrays such as CHARA and MROI are extending the science reach of optical interferometry beyond the limited areas for which it has been used. At some point in the future, the community will have to address the desirability of developing an optical VLA. In the short term, however, as pointed out in the ReSTAR report, the existing facilities must become available and easily usable by a broad segment of the community, and the community must become aware of the potential of this type of observation. A study would target how to help the existing optical interferometric facilities develop the support infrastructure and tools to engage the community.

Renewing the Infrastructure

One of the underlying goals of the ReSTAR implementation program is to strengthen the infrastructure of the small and mid-sized part of the US ground-based O/IR system. This infrastructure begins with mountaintop utilities, includes technical support for modern instrumentation, and extends all the way to telescope performance, including image quality. This will make it possible for these telescopes to provide effective access and state-of-the-art capabilities to the community for as long as it is scientifically desirable. As recommended by the ReSTAR committee, the highest priority is to ensure safe, reliable, and efficient operation of the facilities already providing open access. Beyond this, it is attractive to bring in additional facilities, because this is a more cost-effective way of providing additional access, particularly to more specialized capabilities. Discussions with a large number of observatories that operate telescopes between 2 and 5 meters in aperture turned up a number of different operational hurdles before effective community access could be provided. These include number of support personnel, availability of data reduction software or documentation, aging or unreliable telescope control systems, and even mountaintop infrastructure.

ReSTAR implementation funds would be used to identify those facilities for which such investment would provide the most benefit, priority going to those that are already providing community access. Beyond these, the opportunity to provide such access in exchange for resources to improve the ability to do it effectively would be widely advertised. Probably the greatest impact could be achieved by putting emphasis on the smaller telescopes in the 2-5 meter range; there are a number of such facilities that could provide access to effective capabilities if their operations and support levels were improved. A group comprising some external community members to advise on the desirability of particular capabilities and some internal (NOAO) members to advise on practicality of providing and supporting access would review responses. Preliminary,

informal discussions with some of the operators of these telescopes have indicated substantial interest in participating in a program such as this.

Overview of Phase 1

The plan for Phase 1 has been put together using rough estimates of the costs for the instruments, partnerships, and studies. No contingency has been included. The way in which we expect to manage the program is to establish clear priorities within the program to be used as guidance for making decisions. Each instrument will have formal design reviews (preliminary and critical) at which the expected cost to completion will be assessed. Decisions about whether to proceed will be made with the understanding that cost overruns (predicted or not) must be contained within the ReSTAR program. Guidance will be sought from several committees that provide oversight or advice including the NOAO Users committee, the AURA Observatory Council, and the NSF's Program Review Panel. In addition, we plan to reconvene the original ReSTAR committee periodically to provide a continuous community perspective.

The full suite of projects above – 2 copies of OSMOS, 1 copy of TripleSpec, the echelle spectrograph for the DCT, the partnerships that will provide access to the Hale 5m and the Discovery Channel Telescope, and the studies – all fit into a three year program that totals just under \$11M. The spend rate is fairly constant, though it ramps up slightly from the first year, allowing a start to be made using NOAO funds as soon as it is known that the program will be funded. The chart following the text shows phasing of the various components and gives an idea of the funding profile that will be needed to carry out this phase of the program.

If this first phase is completed as planned, the number of 4m telescope nights available via peer-review will increase by 150 nights per year, the equivalent of half of an additional telescope. Time recovered at the expiration of the current NOAO operations partnerships will further increase the total. The next generation of optical imagers will be deployed and in scientific use. The spectroscopic capabilities that were in the top 5 community-requested capabilities in the ReSTAR survey will be upgraded to be high-performance instruments. And studies of the capabilities needed beyond the workhorse instruments will have laid the groundwork for the next phase of building the ReSTAR system.

Future Phases

While Phase 1 is aimed at addressing the most pressing needs identified in the ReSTAR study, the subsequent phases will focus on (a) executing projects for which more design work or planning is needed, (b) building larger scale enhancements to the system that require more serious consideration of impacts, (c) adding capabilities that depend on or are driven by evolution of other parts of the system, and (d) using information gathered as the impact of the early phases becomes clearer. Obvious options include:

- Construction of the two 2m telescopes and instrumentation planned in phase 1 to support community participation in the Las Cumbres network for time-domain research
- New partnerships with other non-federal facilities, including optical interferometric arrays, to provide open-access time – particularly to capabilities that are considered essential to a smaller fraction of the community
- Continued infrastructure renewal to allow more widespread and diverse participation in the system
- Copies of successful instruments such as NEWFIRM, allowing us to provide more balanced access to important capabilities between the two hemispheres
- Additional instruments, in particular those addressing the next highest prioritized capabilities of the ReSTAR study
- Ultimately, consideration of a new, large (4-6.5m) telescope in the south – where options for adding significant access through other channels are limited. This possibility would require careful study and obviously would not fit into the funding profile we envision. A partnership such as WIYN or SOAR is one option.

We expect that this program will be somewhat dynamic – information will be gathered during each phase that will guide the program. Oversubscription rates and their histories will be monitored. Both ad hoc groups like ReSTAR and established groups that provide oversight will make arguments for revision of priorities and for the effectiveness of different strategies. Input from potential partners in the community will be solicited, including both instrumentation groups that would like to build instruments or subsystems and non-federal facilities that would like to participate in the open-access system.

We believe that the end product of this program will be a system that is more than just a set of facilities or capabilities. It will be strongly tied to the community of users and to the community of providers, and it will give a more coherent voice to the researchers and teachers who depend on the ground-based O/IR system.

ReSTAR Implementation Plan - Phase 1

