Apache Point Observatory : Facilities, Operations, and Partnerships

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Several recent studies, in particular NSF's Senior Review and NOAO's RESTAR reports have emphasized the continuing importance of small and medium sized optical/IR telescopes to the success of ground-based astronomy. In addition to the nationally funded and operated facilities, a substantial role in providing this capability has been played by private observatories and joint national/private facilities. Here we describe the facilities at the Apache Point Observatory (APO), operated by the Astrophysical Research Consortium (ARC). What started out as a single project to build a large (at the time) 3.5m telescope, has since resulted in a facility with 4 telescopes, including one of the most productive ground-based survey telescopes ever built, the Sloan Foundation 2.5m telescope, which has provided the data for the Sloan Digital Sky Survey (SDSS) and its successors. Some of the facilities at APO are fully privately operated (e.g., the ARC 3.5m telescope), while the SDSS project is funded by a combination of national, international, foundation, and private funds. We discuss the facilities, operation, and funding of the APO facilities. For the 3.5m, the principal advantages include low operating costs, rapid instrument changes, and flexible scheduling. APO also pioneered the use of routine remote observing on its 3.5m telescope, a cornerstone of its current operations model. SDSS has been a ground-breaking survey project, but we also discuss the challenges in the fund-raising for the SDSS project, notably the complexity in obtaining and aligning national, foundation, and private funds on critical deadline scales. We encourage the Decadal Survey Committees to consider the advantages offered by facilities such as APO as opportunities in realizing the future needs for small and medium-sized telescopes and for large survey projects.

1 Site and facility overview

Apache Point Observatory (APO) is an optical/near-IR astronomical facility located at an elevation of 2800m in the Sacramento Mountains of southern New Mexico. APO occupies approximately 8 acres under special use permit with the United States Forest Service. It is presently home to four astronomical telescopes: the ARC 3.5m telescope, the Sloan Foundation 2.5m telescope, the NMSU 1.0m telescope, and the ARCSAT 0.5m telescope. It also has basic infrastructure to support the operation of these telescopes: operations buildings, a small machine shop, high speed internet connectivity, observing support instrumentation, and dormitories.

The weather at the site is fairly typical for a continental astronomical site in the US Southwest. Averaged over a long period, night-time observations can be made roughly 65% of the time, with about 25% of the total time providing photometric condititions. The site seeing is about 0.9 arcsec median, with a tail reaching down to 0.5 arcsec; as expected, better seeing is observed at longer wavelengths. The site provides dark skies, which have been protected by dark-skies ordinances and legislation. It is a relatively dry site for its elevation.

The observatory is managed by the Astrophysical Research Corporation (ARC), a non-profit association of a group of eight institutions, although funding for the SDSS project(s) has been provided by a significantly broader group. The observatory is operated through New Mexico State University, which employs many of the observatory staff. The observatory staff comprises 28 people, which include a site manager, technical specialists, and observing specialists who enable the observing modes of the observatory.

2 Individual telescopes and their operation

2.1 ARC 3.5m telescope

The ARC 3.5m is a lightweight alt-az telescope. It was the project that motivated the development of the site, and began operation in the early 1990s. The telescope was designed to provide a versatile general observatory for use by a wide range of astronomers at the member institutions. The original design had a goal of providing rapid access to a variety of instruments by providing multiple instruments mounted at different ports and quickly accessible by adjustment of the tertiary mirror. Due to the need for field derotators and guiding capability, most of the instruments to date have been placed at the two Nasmyth ports (NA1 and NA2) of the telescope, but other ports are starting to come into use.

The NA1 port permanently hosts the ARC echelle spectrograph, which provides R$\sim$32000 spectroscopy across the entire bandpass from near the atmospheric cutoff in the blue to the CCD cutoff in the red in a single exposure. Other facility instruments that share the NA2 port include SPIcam, a small field direct imaging camera, DIS, a long slit two-channel spectrograph, NIC-FPS, an infrared imaging camera (also designed to eventually allow NIR Fabry-

Perot observations), Triplespec, a NIR spectrograph, and Agile, a high speed visible camera. The telescope is also the home of some specialty instruments: APOLLO, a high precision lunar ranging experiment, and the GFP, an optical Fabry-Perot instrument built by personnel at the Goddard Space Flight Center. The telescope has also hosted a variety of visitor instruments over the years.

While many of the instruments share the same port, the observatory still allows great flexibility in instrument availability, because all of the NA2 instruments are kept cold and connected on the observatory floor, and can be swapped onto the telescope by a single person during the night within about 15 minutes. The tertiary mirror can be rotated to the other ports in under two minutes, so all instruments are available on short notice.

Recently, additional ports have started to be used. The APOLLO project is mounted at a dedicated port, as is a Shack-Hartmann camera used for optical alignment. A new rotator has been built that will allow AGILE to be permanently mounted on its own port in the near future. Upgrades to the telescope drive and encoder system are in progress which may improve tracking sufficiently to allow other ports to be used for long-exposure imaging without independent guiders.

The flexibility in instrument availability has led to a scheduling mode where the telescope is generally operated in half-night blocks, often with a quick instrument change in the middle of the night. The ability for rapid instrument changes also allows a wide range of monitoring programs to take place, which might only use 1-2 hours per night over a large number of nights (for example, planetary monitoring programs, and the APOLLO lunar ranging observations). The quick instrument changes also enable target of opportunity observations, either of short events that are known in advance, or for followup of transient objects, without a severe impact on the normal science programs.

Almost all of the observing on the telescope is done remotely by observers at the individual member institutions. The on-site observing specialists are responsible for the health and safety of the telescope; they make all decisions about weather and control the opening and closing of the dome. While they also provide a invaluable resource about efficient telescope and instrument operation and performance, the entire operation of the telescope – slewing, instrument configuration, and exposure management – can be controlled by the remote observers. This has been made possible by custom software; the current software, TUI, runs on a wide range of computer platforms and is very flexible.

The remote observing is extremely popular. Most observers appreciate the flexibility and time and cost savings (at least, at the PI level) that this mode allows. While some observers prefer longer dedicated runs, such time allocations can always be requested, and often scheduled, within the operating framework.

The telescope has low downtime, about 1% unscheduled, and 12% scheduled. The low amount of unscheduled downtime is achieved by using the scheduled downtime to continuously monitor and improve telescope performance, and also because of the instrument flexibility; if one instrument has any problems, a different instrument can quickly be mounted and used.

The budget for the telescope is roughly $1.6M per year, placing it relatively low in cost for a telescope of this aperture; costs are shared by the ARC institutions in proportion to their share of the telescope time. Sharing personnel costs between the 3.5m and the 2.5m telescopes allows cost savings for both projects. Of the total budget, about $350K per year is allocated to a capital improvements fund (CIF), which allows for improvements and upgrades; some examples of CIF usage include baffling improvements, telescope drive upgrades, and some basic instrument upgrades (new gratings, detectors, etc.). No separate funds are budgeted for new instrument construction, although nothing prevents CIF funding from being used for this; new instruments generally require external funding, and have mostly been achieved through the buy-in costs for new partners. Observatory funding does not support scientific analysis or data data reduction, nor does it support data archiving.

Scientifically, astronomers at the partner institutions have continually requested that the observatory be general purpose and work on a very broad range of scientific topics, rather than specialize on a few dedicated projects. Time is allocated at the institutional level, with each institution getting a share of time proportional to their contribution to the budget. The institutional shares are all scheduled together at the observatory level by the director. Of course, astronomers at the different institutions are free to communicate and collaborate, and this has resulted in several larger projects being done that obtain larger shares of telescope time via contributions from multiple institutions: the biggest example of this was for spectroscopic followup of the SDSS-II supernova survey.

Many of the scientific projects use the 3.5m to complement other observations, either for followup of objects identified by other surveys (SDSS is one of the most significant contributors here), or for setup observations on larger telescopes. The telescope has also been used on numerous occasions to contribute to worldwide observing campaigns, e.g., on planetary targets, and for multiwavelength simultaneous observations with satellites.

Many of the member institutions also value the 3.5m as a resource for training and student thesis projects. Graduate and undergraduate courses at several institutions include trips to the site for hands-on training, and many student thesis projects have been enabled by the ready access to the telescope and its remote capability.

Several years ago, a Futures Committee was put together by ARC to provide a report on the progress of the observatory and to provide guidance on future directions. Overall, the committee found that scientists at the member institions were satisfied with the current use patterns of the telescope and did not wish to see major changes.

Giving an oversubscription factor is complicated for projects with small institutional telescope shares because we have found, at many of the institutions, that people have adjusted their expectations for telescope allocation to allow several projects from each department to proceed at a given time, and adjust their telescope requests accordingly. Nonetheless, most of the institutions generally experience a 1.5-2x oversubscription rate.

2.2 Sloan Foundation 2.5m

The Sloan Foundation 2.5m telescope at APO is an alt-az telescope that was built for the Sloan Digital Sky Survey and is currently being used for SDSS-III. As a wide-field survey telescope, the Sloan telescope has entirely been used for large dedicated surveys. SDSS-I included imaging of the North Galactic cap and three southern strips with followup spectroscopy over all of these regions. SDSS-II included an extension (SEGUE) to lower galactic latitudes and to spectroscopic targets that enable more studies of the Milky Way, as well as a supernova search (SDSS-II SN) designed to populate the type Ia Hubble diagram at intermediate redshift. SDSS-I and II together imaged 45,000 total square degrees and 11,600 unique square degrees, revealing 360 million unique objects. The spectroscopic programs took spectra of 1.5 million targets over 9380 sq deg. All of these data were made public in scheduled releases during the course of the surveys, culminating in the final SDSS Data Release 7.

SDSS-III will perform four interleaved surveys in the period from July 2008 to June 2014:

- SEGUE-2 will obtain spectra of 140,000 stars in the outer halo of the Milky Way, continuing the successful SEGUE program from SDSS-II.
- The Baryon Oscillation Spectroscopic Survey (BOSS) will take over dark time in fall 2009 and conduct 5 years of observations to produce the world's largest galaxy redshift survey (1.5×10^6 galaxies), with the goal of producing a 1% measurement of the cosmic distance scale.
- The Multi-object APO Radial Velocity Exoplanet Large-area Survey (MARVELS) will search for planets around 10,000 stars.
- The APO Galaxy Evolution Explorer (APOGEE) will conduct high-resolution infrared (H band) spectroscopy of 100,000 stars to build a detailed chemical picture of all components of the Milky Way galaxy.

For SDSS-I and SDSS-II, there were two instruments on the 2.5m telescope:

- a 1.5 square degree camera that performs drift-scan imaging in 5 bands simultaneously, and
- a fiber-fed spectrograph with a 7 square degree field and 640 fibers feeding a pair of dual-beam R=1800 spectrographs.

SDSS-III began operations in July 2008 with these two instruments. The imaging camera will be retired in 2009 after completing a contiguous footprint in the southern galactic cap. For BOSS, the SDSS spectrograph will be upgraded to 1000 fibers, with new detectors and gratings approximately doubling the throughput. In addition, SDSS-III is constructing two new instruments:

- The University of Florida has built a 60-object dispersed fixed-delay interferometer for the multi-object planet search survey (MARVELS). A copy of this instrument is planned to expand the planet search to 120 stars simultaneously.

- The SDSS-III consortium is building a 300-fiber $R = 22,000$ H-band spectrograph at the University of Virginia for the APOGEE project. This will be the first multi-object high-resolution infrared spectrograph.

The telescope is operated by a staff of 9 dedicated APO observers with a day staff of 9.5 FTE keeping the facility at a high level of readiness. Scientists in the SDSS consortium have remained involved to provide more detailed engineering support of the telescope and instruments. All fiber operations are done with plug plates, which are drilled about 6 weeks before use and hand-plugged at APO. A set of 9 cartridges (soon to be upgraded to 16) allow exposures of order 1 hour in length. Quick-look reductions allow one to integrate to a given signal-to-noise ratio, rather than a fixed exposure time. All data flow off-site to dedicated imaging and spectroscopy pipelines, with the data products made available to the full collaboration. The data are then placed into a fully relational database (the Catalog Archive Server with its SkyServer front-end) and released on a roughly annual cadence.

We believe that the SDSS has dramatically proved the value of large homogeneous data sets and of large long-standing institutional collaborations. SDSS has been much more than a hardware facility: it has produced excellent data pipelines, data validation, data releases, and uniform operations model, all while cultivating a collaboration of users that remain connected to the hardware and software developers. The result has been a superb scientific legacy.

SDSS-III will continue this model with a consortium of 29+ member institutions. In addition to the institutional support, SDSS-III has received funding from the Sloan Foundation, National Science Foundation, and Department of Energy.

While SDSS-I, II, and III have all been examples of successful public-private partnerships, it is worth noting the challenges of the model. The telescope facility itself is supported purely by project funds, with no institutional guarantees. SDSS-II and III both survived multiple jeopardy in simultaneous funding proposals that led to only last-minute approvals for the project. Facilities depend on long-term stability of the staff and expertise, and for surveys this extends to the support of the data pipelines and even the preservation of a successful collaboration culture. There is an understandable tension between this need for long-term stability and the need for astronomical funding agencies to critically judge the success of ongoing efforts and make room for new starts. Getting many institutions and funding partners to start pulling in the same direction simultaneously requires a high level of responsiveness on the part of the agencies.

The Sloan 2.5m telescope is presently the US's leading facility for wide-field spectroscopy. The AAO 2dF/AAOmega instrument, AAO 6dF facility, and the new Chinese LAMOST facility are the other major world facilities. Overall, this represents a severe imbalance with present and near-term imaging facilities (e.g., SDSS, KPNO/CTIO Mosaic, CFHT Megacam, SuprimeCam, Palomar/Quest, LBT/LBC, PanSTARRS, Skymapper, WIYN ODI, Subaru/HSC; IRTF/UKIDDS, KPNO/NewFIRM, VISTA; GALEX; Spitzer and Spitzer warm mission, WISE; eRosita), particularly when one considers how time-consuming spectroscopy is in comparison to imaging. We believe that the world is and will be starved for wide-field spectroscopic platforms.

Whether the Sloan 2.5m facility continues to operate beyond 2014 will depend on identifying new funding, whether as part of a new survey consortium or as a more conventional user facility.

2.3 NMSU 1m

The NMSU 1.0m is an alt-az telescope that was built in the early 1990s. It has a direct imaging camera on one of the Nasmyth ports and a multi-bandpass single-channel photometer is under construction for the other Nasmyth port.

To maximize usage of the telescope, a robotic observation mode has been developed and is used extensively. Many of the projects done robotically involve monitoring of sources, for which the data reduction is relatively straightforward; automatic data reduction has also been developed for these applications. Some examples of these are monitoring programs of eclipsing binaries and cataclysmic variables. Another niche has been for programs requiring photometric calibration relative to standard stars around the sky; the robotic mode is flexible to allow for such programs to use the telescope when the weather conditions are adequate.

Support for the telescope is provided by NMSU at a base level of about $15K per year, which goes to basic infrastructure costs. No specific staff costs are pre-budgeted for the telescope; maintenence by APO staff is performed with a per-hour charge to NMSU and is subject to availability of the APO staff (the larger telescopes always have priority). Significant support is provided by NMSU faculty.

Work on the 1m has been supported by NSF's PREST program, in particular, for upgrades to improve reliability and performance and for construction of the multichannel photometer. As a condition for this support, a significant amount of time has been given to non-NMSU astronomers for scientific use. Although this time has been granted by informal arrangement, the usage has been scientifically productive.

2.4 ARC 0.5m

A 0.5m telescope is located at APO that was originally used for the photometric calibration of the SDSS survey; in the capacity it was known at the Photometric Telescope (PT). After SDSS-II, this need no longer existed, so the telescope has been turned over to the ARC community. The telescope is now referred to as ARCSAT, and is being operated on a trial basis as a community resource. Incidental costs are being provided by the 3.5m telescope budget but any improvements or significant maintanence or upgrades will require additional external funding; one such example, for the acquisition of a new detector, already exists. The telescope can be operated remotely but currently requires a small amount onsite assistance for opening, closing, and weather monitoring.

Plans are in progress to automate this, much the same way as the NMSU 1m telescope is now.

3 Governance

The Astrophysical Research Consortium (ARC) was founded in 1984 to construct and operate a 3.5m telescope at APO by five institutions: University of Washington, University of Chicago, New Mexico State University, Princeton University, and Washington State University. A consortium agreement and a set of by-laws constitute the core formal documents that have guided the governance of the facilities at APO extremely well since then. Various amendments to the agreement and the by-laws have been added over the years to reflect changes to the financial agreements, inclusion of new member institutions, re-distributions of telescope shares, etc. Since 1984, one of the founding institutions has withdrawn from ARC (Washington State University), while four institutions have joined (Institute for Advanced Study, Johns Hopkins University, University of Colorado, and University of Virginia). New ARC members are required to contribute a share of capital costs as well as ongoing operational contributions; several of the capital contributions have been in the form of new instruments, and this has represented an important mode of keeping instrumentation capabilities up to date. As institutional interests have evolved and new partners have been added, some of the fractional shares that each institution holds have been adjusted.

The ARC Board oversees and approves all operations budgets for activities at APO and elsewhere related to its projects. The ARC Board appoints the directors for the 3.5m telescope (currently, Suzanne Hawley, UW) and for the Sloan 2.5m telescope (currently, Daniel Eisenstein, UA), as well as an ARC administrator (currently, Mike Evans, UW). Each ARC member institution has two member representatives on the Board, typically one of whom is a scientist/faculty member, the other an administrator; this model has been very successful in keeping the engagement of administrators while at the same time providing for significant scientific input at the management level. Each Board member has one vote; only in the case of budget issues regarding the 3.5m telescope are the votes weighted according to institutional shares. The Board meets once per year in person and by telecon as needed.

The largest project at APO, the Sloan Digital Sky Survey which uses the Sloan 2.5m telescope at the site, was initiated after the formation of ARC. SDSS brought several new partners into ARC (IAS and Johns Hopkins University), while other new partners joined to gain access to the 3.5m telescope (University of Colorado and University of Virginia). Most, but not all, ARC member institutions are participating in SDSS. The SDSS projects have grown to include both ARC and non-ARC members with a total of 9 institutions for SDSS, 25 for SDSS-II, and 29 for SDSS-III to date. The SDSS project and its successors (SDSS-II, SDSS-III) are overseen by the Advisory Council (SDSS-AC) which has evolved to have one member representative from all the participating institutions (because of the larger number of institutions). The SDSS-AC is advisory to the ARC Board which holds final authority, although the ARC board has usually followed the recommendations from the SDSS-AC.

The two principal projects at APO (3.5m and SDSS) are governed in different ways related to the mode of operation and funding. The 3.5m operations are entirely funded by the ARC institutions in proportion to their ownership shares, on an ongoing yearly budget cycle. NSF funding obtained through peer reviewed grants was a critical part of the initial construction of the 3.5m and also for partial funding of some instrument upgrades and new instruments. The SDSS was developed as a fixed length project with a fully scoped observational program and the participating institutions joined to gain access to the data and contribute to the project. A similar mechanism has been in place for SDSS-II and SDSS-III. Funding agencies for the different phases of SDSS have included the Sloan Foundation, the National Science Foundation, the DOE, NASA, the Japanese Monbukagakusho, the Max Planck Society, the Higher Education Funding Council for England, and the participating institutions.

The governance structure of ARC has worked well. The original by-laws and agreement were developed with much insight by the late Donald Baldwin (UW), with contributions from Al Sinisgalli (Princeton), Stuart Rice (UC) and Jerry Ostriker (Princeton), and have stood the test of time extremely well. The ARC Board and SDSS-Advisory Council have faced many critical issues in the development of the projects. The governance has provided the mechanism to outline responsibilities and rights for the member institutions, while at the same time ensuring input from all involved.

4 Future of facility/site

The ARC institutions currently intend to operate APO through the next decade. As institutional priorities and resources evolve, there will likely continue to be some adjustment of telescope shares, and the possibility of new partners exists.

For the 3.5m, the challenge will be to maintain scientific competitiveness as a general purpose observatory (or to switch to a different mode) and to maintain state of the art instrumentation.

For the 2.5m, funding for SDSS-III will expire in 2014, after which new funding will need to be found, either for continuing to operate the telescope in survey mode, or to switch it over to a more conventional mode. We anticipate that the telescope will remain one of the world's most powerful wide-field spectroscopic facilities in 2014, well suited to further investigations of Galactic structure, exoplanet populations, or other fields amenable to highly multiplexed observations. The issue of continued operation of the 2.5m will have an impact on the other telescopes at the site because of the economy provided by using shared personnel.

Partnerships with other private or public entities are a possibility. The possibility of sharing facilities among different observatories has been brought up in informal discussions with other observatories (e.g., between APO and

WIYN); the idea would be to allow each to concentrate on particular instrument/observational capabilities (e.g., IR, wide-field, etc.) with shared usage to allow scientists access to all capabilities. The remote operation of the 3.5m may help to enable such cooperation and serve as a model for other observatories.

Finally, while no expansion plans currently exist, the site does have the capacity to house additional facilities.