A BRIEF HISTORY OF THE ASTROPHYSICAL RESEARCH CONSORTIUM AND THE APACHE POINT OBSERVATORY

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Abstract: This history of the Astrophysical Research Consortium (ARC) and the Apache Point Observatory (APO) describes why and how the ARC was formed, the vision for the APO, and the technology used to implement that vision. In particular, it examines the building of a low cost, lightweight, f/1.75, 3.5 meter telescope with an experimental mirror cast at the Steward Observatory Mirror Lab, and key features of remote observing, rapid instrument change and flexible scheduling. The organizational challenge of unifying distinct institutions and their astronomy programs, and the difficulty of gathering funds for this venture, are also explored. Key scientific results and achievements using the APO are noted. This paper is based on interviews with key personnel, documents in the ARC business files, and published papers and reports (including astronomy department annual reports).

Keywords: history, astronomy, Apache Point Observatory, remote observing, spincast mirror

1 INTRODUCTION

Like most human endeavor, astronomy depends on bigger and better tools to break through the frontiers of discovery and ensure the advancement of our knowledge. By the 1950’s in the United States the biggest and best astronomy tools were concentrated in a handful of universities, guaranteeing the astronomers associated with them the best opportunities for new discoveries. Although there were a number of fine observatories supporting excellent astronomy programs, it was hard to compete with the Hale 200-inch telescope at the California Institute of Technology’s Palomar Observatory and the 100-inch Hooker Telescope at the Carnegie Institute of Washington’s Mt. Wilson Observatory or even the University of California’s 3-meter reflector at the Lick Observatory, which began operation in 1960. The size of their departments and their ability to raise private funds ensured their continued leadership in the ever more expensive world of bigger and better telescopes (McCray, 2004).

With National Science Foundation (NSF) support and encouragement, a number of institutions in the United States formed the Association of Universities for Research in Astronomy (AURA) on 28 October 1957 to create and manage a national US optical observatory available to all US scientists based on the scientific merits of their proposals (Edmondson, 1997). Government funding made excellent telescopes available to astronomers with good research ideas, who would not otherwise have access to the equipment needed. Although serving an important need, the AURA national observatories do not adequately support the needs of a university astronomy department to implement long-term observing programs (York, 2004) that strengthen the department by attracting top faculty, graduate students, and post-docs.

Desirous of a first-class observatory for long-term programs, yet recognizing that none of them individually could fund or fully utilize it (Wallerstein, 2004), New Mexico State University, Princeton University, the University of Chicago, the University of Washington, and Washington State University formed the Astrophysical Research Consortium (ARC) in 1984 in order to create an observatory that would provide telescope time to each member university based on its investment (ARC Agreement, 1984). Figure 1 shows the Apache Point Observatory, which was ultimately built by the consortium. The cost of the biggest and best astronomical instrumentation has grown so much that today almost every new telescope project is a cooperative effort. Modest ones require a small group of institutions like ARC, while ambitious ones might require the cooperation of nations. Today’s models of cooperation rely on the pioneering steps by groups like the ARC, where each institution’s individual needs, dreams, and ambitions have been accommodated and unified into a single vision. How they came together, how they worked together, and what they created provide insights into the science and technology of astronomy today, the business of astronomy today, and the human effort required to implement a vision.

2 THE LONG PATH TO AN OBSERVATORY

Prior to the formation of the ARC in 1984 none of the consortium members had telescopes with apertures exceeding 1.0-meter, and their observatory locations were not ideal. In general, a common desire to gain access to a larger telescope in a better site brought these universities together, but it was a long and bumpy road even to get started. Since the astronomers at the University of Washington initiated the process, starting with their story provides the best illustration of how this group was eventually formed.

2.1 University of Washington (UW)

In 1965 the UW decided to expand its Astronomy Department and hired Paul Hodge and George Wallerstein (both from the University of California at...
Jim Peterson and Glenn Mackie

Berkeley) to join Theodor Jacobsen, the sole UW astronomer since 1928. As observers used to accessing excellent telescopes, Hodge and Wallerstein soon began to plan for an observatory and that first year they hired Ed Mannery to help with site selection and optical design. Three issues soon became apparent. Firstly, Washington State did not offer a suitable site for an outstanding observatory. Secondly, funding for the telescope required a larger resource base, especially since State funds would be hard to get for an out-of-State project. Finally, they needed a partnership with other astronomy departments because their small, but growing faculty would underutilize and have difficulty funding and operating a large facility (Wallerstein, 2004).

As early as October 1965 the UW Regents authorized construction of a large telescope using external (versus State) funds. Although Professors Wallerstein and Hodge entered into discussions with many potential partners in the following ten years, including the Jet Propulsion Lab and the University of Wisconsin at Madison, private funding at UW and the other institutions had not been secured and Federal funding from the NSF was channeled to other projects, like the National Observatory at Kitt Peak (ibid.). In the meantime, in 1971 the UW built a small observatory on Manastash Ridge in central Washington State that initially housed a 16-inch telescope, but was replaced a year later with a 30-inch telescope (ibid.). Additionally, as the Department continued to grow, its many observers came to rely heavily on the National Optical Astronomy Observatory facilities at Kitt Peak in Arizona and Cerro Tololo in Chile. By 1981, the UW ranked second in allocation of time among all US institutions and ranked first in per-capita allocation. Although the UW obtained a lot of observing time, the constraints were growing as the demand increased and NSF funding for Kitt Peak failed to keep pace. Three-quarters of all requests for time were denied, and programs like the one at the UW were in a difficult position as the growing team of astronomers and graduate students at the University realized that they no longer rely on gaining access to NOAO facilities (Balick, 1981). They needed their own large telescope.

In 1975 Mr Alex Kane died and left an estate worth $250,000 for the purpose of building a telescope, so the UW finally had startup funds for a major telescope project. Kane, from Ashland, Oregon, had first offered the money to Oregon State University, but they told him they were not interested; the UW did not make the same mistake. But even with secure funding, finding a partner was not easy. The UW talked with Stanford University about locating a telescope on Mauna Kea in Hawaii, but Stanford could not justify the project without hiring four additional faculty members, so they dropped out of the discussion. Another possibility was acquiring a 40-inch telescope from the University of Vienna and partnering with them to build an observatory on Mauna Kea for it. In addition to the mediocre optics and awkward mount, the mirror was just too small (Wallerstein, 2004). The situation changed in 1978-1979 when Professor Bruce Balick began exploring a partnership with Howard University, New Mexico State University (NMSU), and Washington State University (WSU).

Figure 1: The Apache Point Observatory in 2000, including from left to right the Sloan Digital Sky Survey (SDSS) 2.5 meter, the SDSS 0.6 meter, the New Mexico State University 1.0 meter (hidden by a tree), and the ARC 3.5 meter telescopes (courtesy of ARC, photo by Dan Long, 2000).
Jim Peterson and Glenn Mackie  

The ARC and the Apache Point Observatory

Baliick had been presenting ideas for an advanced technology telescope to groups around the country; that, through personal and professional contacts, he heard might be interested in joining with the UW to build a telescope. The initial ideas for the new telescope came from the Kitt Peak Advanced Development Program and from radio astronomy. Baliick’s background in radio astronomy led him to invite Sebastian Von Hoerner and then Yung Wong from the National Radio Astronomy Observatory in Greenbank, West Virginia, to visit Seattle for a week to help explore novel, low-cost, intensively-engineered approaches to optical telescope design by applying techniques from radio telescopes (Balick, 2004).

What emerged through the brainstorming with new partners at Howard, the NMSU and the WSU, and through the gathering of ideas from Kitt Peak and Greenbank, was a well-developed concept for a lightweight, 2-meter mirror only 6 centimeters thick, with a support that would use tube structure members on an altazimuth mount with a servo control system driven by computer for precision pointing. The lower mass of this structure meant lower thermal noise and lower cost. Overall dimensions were only half and the weight was just 10-20% of a traditional telescope of similar aperture, so a small and inexpensive building was possible. Instead of placing an instrument in the standard position behind the mirror, which causes load flexure during use and costly equipment changes when a new instrument is needed, up to four instruments could remain attached to the sturdy telescope mount. The incoming beam could then be redirected to the appropriate instrument. The group even found a cost-effective site at Sunspot, New Mexico, near the Sacramento Peak campus of the National Solar Observatory in a region officially protected for astronomical use. It had excellent seeing, on a par with any mainland site, and was close to support facilities, an airport and the NMSU. The overall project cost was estimated at $3.6 million, with a 15% error margin (Balick, 1981).

By 1981, armed with a well-conceived proposal and partners in the venture, the UW astronomers had good reason to be optimistic as they anticipated using their 40% share in a world-class telescope that would also attract other grants. They still needed approval from their own administration for the $1.44 million UW share in the project, but to help sway the argument they had already secured a sizable portion of the needed funds, including $300K from the Kane Estate (earning interest), $200K from UW matching funds, $100K from a Boeing pledge, and $100K from a Kenilworth Foundation pledge (ibid.). In particular, Malcolm Stamper, President of Boeing and a friend of the University, was very supportive (Balick, 2004). Both Wallerstein and Baliick were ready to increase the fundraising effort, once approval was gained. In the meantime, their partners also enthusiastically pursued approval and funding for the project.

2.2 New Mexico State University (NMSU)

In the fall of 1978, the NMSU Astronomy Department had six regular faculty members and two emeritus, including Professor Clyde Tombaugh, the discoverer of Pluto (New Mexico State University, 1979). With a size similar to UW and also a heavy user of Kitt Peak, the Department recognized that to support faculty and graduate student research programs they needed to secure access to a 2+ meter class telescope. They could no longer rely on national facilities to meet their needs. Although they originally planned on building their own telescope and had actually been exploring sites, the advantages of a partnership that brought more resources and more personnel support convinced the NMSU to join with the UW (Anderson, 2004). The UW brought telescope-engineering expertise and the NMSU had site management capability.

Initially the NMSU thought they could contribute $500K in cash and provide a site and an empty operations building (the former NMSU Cosmic Ray Lab about three miles north of Sunspot) to meet a $900K commitment for 25% participation, but the partners decided that the Sunspot site was better and it was free (Balick, 1981). Actually, the NMSU had considered the Sacramento Peak area for a telescope as early as the 1960s and Professor Kurt Anderson had extensive meteorological data acquired by others since the 1950s, so the choice was supported scientifically (Anderson, 2004). As it stood in July 1981, the NMSU committed to $576K for a 16% share, but held out hope that it might raise more funds to buy a 25% share.

2.3 Washington State University (WSU)

Although the WSU had a small astronomy program with only two observers, Professors Tom Lutz and Julie Lutz, the UW invited them to join. The astronomers at both schools knew and liked each other and had collaborated in the past at both Kitt Peak and Manastash Ridge. Both groups realized the political advantage of the two Washington State research institutions working together to create a state-wide resource, even though that resource would likely be located in New Mexico. The WSU’s astronomy program was part of the Mathematics Department at that time and had no specific plans to grow, but its observers would get a tremendous resource. The WSU could not add personnel expertise, but they could contribute modest funding for a small share of observing time, and they also agreed to help out where they could. For a 5% share, the WSU’s commitment was $180K, and an initial part of the funding came from both the Graduate School and the School of Arts and Sciences (Lutz, 2004).

2.4 Howard University

In the late 1970s Professor Ben Peery moved from Indiana University to Howard University in Washington (D.C.) to start an astronomy program. Baliick contacted Peery in hopes that Howard University might have an interest in a telescope project, since this would certainly help grow their new program. Peery was Howard University’s only astronomer at the time and a member of the Physics Department, and he responded to his University’s call for proposals to improve the graduate programs by suggesting that they buy a 30% share in the partnership with the UW, NMSU and WSU to build a new observatory. University officials liked the idea, and agreed to provide $1,08 million in funding if Congress would approve the budget. Howard University is funded directly by the U.S. Congress, and it had to convince Congress to support the project with an appropriation in the line item that funds them. Because it had such a small Department, Howard University, like the WSU,
would only contribute money, not expertise (Anderson, 2004; Wallerstein, 2004).

By August 1981 the presidents of the UW, Howard University, the NMSU and the WSU had given tentative approval for the project and the UW attorney general was drawing up the actual agreement. The astronomers had even found a 2-meter mirror blank made of Cervit for $35,000. A new one would be $500K. It was available from Norman C. Cole of Tucson, who would also figure and polish it for $160K (Balick, 1981). Throughout the rest of the year an optimistic group waited for approval of Howard University’s funding, the last roadblock. They even pooled money for a celebratory bottle of champagne. Alas, Howard University’s request to Congress was mistakenly excluded from President Reagan’s budget, and it never resurfaced. Although the University maintained an active role until the end, it had to drop out in early 1982 (Anderson, 2004). The project was then in jeopardy, and it might never have gotten back on track were it not for a timely disappointment experienced by Princeton University.

2.5 Princeton University

In the late 1970s Princeton University submitted a proposal to manage Hubble Space Telescope (HST) data acquisition and reduction. This included a $1 million endowment for postdoctoral positions associated with the project, if the University won the contract. In January 1981 Princeton heard that they had not been selected, nor did they get approval to build the wide field camera for the HST. With balloon experiments winding down and an unsuccessful bid to enter space-based astronomy, the Astronomy Department decided to focus on ground-based astronomy, which pleased Professors Jim Gunn and Ed Turner, two observational astronomers who had recently joined the faculty (Gunn, 2004; Wallerstein, 2004).

Although Princeton University was not selected for the HST projects, the $1 million donation was still available to them. During a research-related visit to Princeton in early 1982, Wallerstein happened to mention that the UW was forming a consortium to build a 2.5-meter telescope and that Princeton’s $1 million would buy a substantial share of telescope time. Notice, incidentally, that with the passage of time the mirror size continued to creep upwards in order to keep the telescope competitive (Wallerstein, 2004)! Professor Jerry Ostriker was Chairman of the Astronomy Department at that time and he liked the idea. He had hoped to build a much larger telescope, but realized that Princeton University did not have funding for it, so he asked Professor Don York to investigate participation in the UW project. Even though York moved to the University of Chicago soon after evaluating the consortium idea, Princeton University remained interested, but only at a $500K level (York, 2004). In addition, they lobbied for a larger telescope. Gunn felt that a 2- or 2.5-meter telescope would not give the consortium a leading edge in aperture and he insisted on a mirror of at least 3-meter and with a wide field of view. At a Departmental meeting Gunn showed that a 3.5-meter mirror located in a good seeing location would perform as well as the Hale 200-inch telescope that he frequently used. Meanwhile, a telescope with that aperture would be the second largest university-owned optical telescope. Princeton University brought prestige, money and expertise to the project, and Gunn agreed to build a dual imaging spectrograph for it (Gunn, 2004; Wallerstein, 2004).

Now that the consortium expected to build a larger 3-meter, wide field, advanced design telescope, Balick, Ed Mannery and Walt Szigmund (from the UW’s telescope engineering group) spent the remainder of 1982 working with Princeton University, the NMSU and the WSU on optical concepts that would deliver a 1’ field of view with 0.2 arcsecond image quality (NMSU, 1983; UW, 1983). Moving up to a larger mirror increased costs, yet currently-planned contributions from the associated Universities did not even cover a smaller telescope. Clearly, another partner was needed.

2.6 The University of Chicago

The University of Chicago has a long association with astronomy and astrophysics, and its Yerkes Observatory features the world’s largest refractor. From 1932 to 1962, the Astronomy Department also managed the MacDonald Observatory in Texas, which gave them access to the 2.1-meter Otto Struve Telescope. By 1982, though, access to newer and larger telescopes was more difficult, so the Department formulated a strategy to build instruments and trade their use off for observing time on large telescopes. In the fall 1982 Don York moved from Princeton University to the Astronomy Department at Chicago. Early in that academic year the Dean, Dr Stuart Rice, attended a Departmental meeting and suggested they build a large telescope (York, 2004). At this time Rice happened to be on the National Science Board, the National Science Foundation’s (NSF) governing body, which had control over its budget and plans. In July 1982 he received a letter from Dr Leo Goldberg, a long-time leader of AURA and Kitt Peak, which discussed the issues of funding national ground-based telescopes, space telescopes, and private university telescopes. Goldberg suggested that perhaps the space telescopes should be the national telescopes and that the NSF should go ahead and fund other ground-based projects (McCray, 2004). This may have emboldened Rice to encourage the Astronomy Department to ‘think big’. Fortunately, York had just explored this topic for Princeton University, and he was still enthusiastic about the UW-led consortium. He therefore had just the solution for the University of Chicago, and they decided to sign up for a share equal to the UW’s. The team was formed; now they had to get started.

3 FORMATION OF THE ARC

Acquiring telescope time on a first-class telescope brought these institutions together, so equally distributing the time and designing an effective form of governance was the first major administrative hurdle. Professor Bruce Margon, the UW Astronomy Department Chair at the time, took on this difficult task, and he and Don Baldwin (the UW Assistant Provost for Research) shepherded the process of gaining agreement while at the same time building an atmosphere of trust and mutual respect. It took most of 1983, but the Consortium Agreement signed by all members by 26 January 1984 and effective from 1 January, spells out
the obligations of each member and allocates telescope
time to each institution based on its contribution (ARC,
1984). The available observing time, after removing
small allocations for engineering developments and
Director’s discretionary time, breaks down as follows:
the UW 31.75%, NMSU 31.25%, the University of Chicago 31.25%,
and the WSU 6.25%. In addition, the Board of Governors
included two representatives from each university—one
scientist and one administrator/business person (York, et al., 1984).
At a summer 1983 meeting at WSU, Julie Lutz proposed “Astrophysical Research
Consortium” as the name for the new organization and
this was agreed to (Lutz, 2004). The ARC was
incorporated as a non-profit entity in Washington State
on 26 June 1984 (UW, 1985), and it received non-profit status from the IRS on 25 October 1984 (BOG,
1984b).

Project progress also continued in 1983 with the
final selection of the Sacramento Peak site near
Sunspot, selection of a 3.5-meter mirror, and develop­
ment of detailed concepts and budgets for the tele­
scope, enclosure and site. The Sacramento Peak site
had been tentatively selected early on because a year­
long monitoring program indicated that median seeing
approached one arcsecond (Beckers, 1979); it involved
low costs; and the National Solar Observatory wel­
comed and supported the ARC as a neighbor. Never­theless, NMSU’s President I. Sanders continued
site testing there, at the Cosmic Ray site nearby, and
at South Baldy near Soccoro, the NMSU Blue
Mesa Observatory site, and at the Cloudcroft (New
Mexico) 48-inch telescope Air Force site. M. Walker
from the Lick Observatory consulted with Sanders and
helped him use his site evaluation methods and a
The Sunspot site tested positively, and the consortium
members discussed naming it Apache Point. In re­
searching the use of this name, Anderson (1983)
determined that calling it Apache Point would not
offend anyone, and that nothing else in New Mexico
was using that name. Actual final approval to use the
site came on 17 April 1985 when the Forest Service
signed a use permit for Apache Point (Margon, 1985a).
The story of the mirror and the observatory designs
will be told later in this paper.

In 1984, with the ARC formed, the group could
elect officers, make appointments, and actually begin
spending their contributed resources to build their
dream. In the first meeting, on 20 January, the Board
of Governors voted Margon as the Chair and Baldwin
as the Secretary/Treasurer of the ARC. In addition,
York was appointed Director of the Observatory,
Anderson was appointed Associate Director for the
Site, Balick became Associate Director for the Tele­
scope and Doyal A. (Al) Harper of Chicago became
Associate Director for Instruments (BOG, 1984a;
NMSU, 1985; UC, 1985; UW, 1985). Appendix I lists
everyone who has served on the ARC Board of
Governors. Interestingly, at its next meeting, in Octo­
er, the Board decided that no outside oversight
would be needed for the project (BOG, 1984b), even
though by early 1984 the overall cost had already
grown to a projected $10 million (as illustrated by the
figures in Table 1).

### Table 1: Project expenditure and sources of funds (after York,
et al., 1984)

<table>
<thead>
<tr>
<th>Expenditure</th>
<th>$8.8 Million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faculty costs for which member institutions are not charging overhead</td>
<td>$1.2 Million</td>
</tr>
<tr>
<td>Total</td>
<td>$10.0 Million</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sources of Revenue</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Provided by the ARC using non-Federal funds</td>
<td>$3.2 Million</td>
</tr>
<tr>
<td>From member institutions</td>
<td>$1.2 Million</td>
</tr>
<tr>
<td>Requested from the NSF</td>
<td>$5.6 Million</td>
</tr>
<tr>
<td>Total</td>
<td>$10.0 Million</td>
</tr>
</tbody>
</table>

### 3.1 Fundraising

Obviously, the ARC expected to get significant sup­
port from the NSF. Funds provided by the ARC came
from State sources and private donations to the
member institutions, as described earlier. The NMSU,
for example, got $800,000 of its share through an
award of State bond funds set aside for graduate
programs. The consortium’s well-conceived proposal
helped the Astronomy Department win a sizeable
portion of the $5 million available to all of the NMSU
departments (Anderson, 2004). Member institutions
continued to look for sources to fund their individual
membership dues and developed a plan for the ARC to
approach national organizations for funds that would
reduce dues on a pro-rata share basis (BOG, 1984a).

Although individual members met with success, the
coordinated effort from the ARC did not. A $100K
donation from the Perkins Fund solicited by Princeton
University on behalf of the ARC was at first thought
to be a gift to the ARC and as agreed the funds would be
used to reduce all member dues (Margon, 1985b).
However, when Princeton University actually received
the money they discovered that the Perkins Fund
trustees had voted to donate it to University itself
and not the ARC (Eggers, 1985). Despite the ARC’s
difficulty in raising private funds, it met with huge
success in winning NSF funding.

Obtaining NSF funding, and the challenges of man­
egaging cash flow until the funding was received,
occupied a large portion of the Board’s efforts. Once
the ARC was formed, proposed budgets for 1984 of
$1,010,854 and for 1985 of $4,007,005 were put in
place so that the engineering and construction teams
could start designing and building the telescope and
buildings, and could complete site preparation, such
as roads and power (BOG, 1984b). Quarterly invoices
to members for contributions provided the cash for
expenses prior to NSF funding, which was anticipated
to cover the 1985 budget. With rising costs, tough
decisions had to be made, such as eliminating an
aluminizing facility at the Observatory—but only after
confirmation that Kitt Peak would be able to provide
optical coating services at a reasonable cost (Jeffries,
1984).

### 3.2 The NSF Proposal

The process to win NSF funding began early in 1983
when proposal-writing started. On 1 September of that
year consortium members sent a letter to Dr Laura
Bautz and Dr Francis Johnson at NSF telling them the
Universities had agreed to create the ARC and planned
to ask NSF for a grant of about $3.75 million. They
anticipated submitting the proposal by the end of 1983 (BOG, 1983). Manney, Siegmund and others worked with experienced fabricators to prepare a detailed concept design they called the ‘Blue Book’, which provided the basis for cost estimates, schedules, milestones, and specifications that were incorporated into the NSF proposal. By the time the request was actually submitted, on 15 May 1984, the amount had risen to $5.565 million. Donald G. York, Kurt O. Anderson, Bruce O. Balick, James E. Gunn, Doyal A. Harper, and Thomas O. Lutz signed the document, which became NSF proposal number AST-8414829 (York, et al., 1984).

After optimistically commencing work on the project and submitting the NSF proposal in early 1984, the reality of the challenge loomed by the end of the year. In a letter Margon sent to the Board on 31 December he bluntly stated that NSF money in 1985 was unlikely and that the ARC would have to spend carefully, while trying to move forward. He also cautioned to be careful when talking about the status of the NSF grant, in order to maintain fundraising momentum (Margon, 1984). By May 1985 he expressed some confidence in NSF approval and even expected a peer review date to be set shortly, but he had to counter some criticism of how aggressive York was being with NSF, by assuring the Board that York was doing a great job (Margon, 1985a). In early June the ARC implemented a project slowdown with a reduction of the calendar year 1985 budget from $4 million to $1.6 million (Baldwin, 1985b). Later that month NSF asked York to respond to a straw man budget that would give the full $5.6 million over several years, causing optimism to rise, even though no grant could be given before an in-person peer review, a date for which had yet to be set. Margon suggested communicating in a positive, but restrained manner, even though a stronger statement would help fundraising. He did not want to embarrass the NSF or cause competing projects to lobby harder for their projects before the ARC received approval (Margon, 1985c).

The in-person peer review took place on 23 October 1985. York and Margon prepared the agenda and Anderson, Baldwin, Gunn, Harper, T. Lutz, Manney, and Siegmund also attended. Dr Roger Angel of the Steward Observatory Mirror Lab came as a guest of the ARC. The NSF representatives were Wayne Van Citters (Program Officer) and Laura Bautz (Division Director). The peers were Jerry Nelson (University of California, Berkeley), Steve Beckwith (Cornell University), Bob Toll (University of Texas), and Mike Mumma (NASA, Goddard). Luckily, the peers were well known to the ARC scientists, both professionally and personally. Margon reported to the Board that the review went well and that the attendees were able to answer every question confidently and clearly. Some minor follow-up questions were expected, but none ever came. Van Citters let Margon know that the NSF could take no final action on the request until the FY86 budget was in place and that the straw man budget of $5.6 million was possible but difficult (Margon, 1985d, 1985e).

As 1985 ended, the Board hoped that the NSF money would become available in February or March, but it realized that it would still have to request first quarter 1986 dues from the members, to ensure that funds would be available to maintain progress on the telescope and the enclosure. The telescope fabrication contract with L & F Industries of Los Angeles had a delay clause in it that could be activated beginning 28 February in exchange for a modest fee, but by mid-1986 the ARC would have to dismantle the project and lay-off people if no NSF funding came through (Margon, 1985e). Baldwin presented some 1986 budget alternatives at the 10 December 1985 Board meeting, and these included a new project total estimate of $9,556,515, not including in-kind contributions of at least $1.2 million. The Board decided to continue to work for a February 1988 goal for project completion, but put the L & F contract on hold as of 1 February 1986, unless otherwise approved by the Board (BOG, 1985).

On 5 February 1986 Margon sent a letter to the Board informing them that the NSF had asked the ARC to consider a revised budget with a total of $3.3 million. If the ARC agreed, the proposal would go to the National Science Board in April or May. Given this funding situation, Margon (1986a) outlined some possible options, such as cutting expenses by delaying instruments; increasing member dues; adding new partners; and asking the NSF to grant funds far into future, then taking a loan against the future funds. On a conference call with Board members on 14 February, Margon expressed delight with the grant, because it would be the largest ever by the astronomy program at the NSF. Furthermore, it would be done in the face of Gramm-Rudman restrictions passed by Congress on 11 December 1985 to cut spending through 1990 in order to reduce the Federal deficit. During the conference call the Board discussed, but did not decide on Margon’s options. They agreed to accept the revised budget, but decided to ask for more. In addition, they decided to have L & F move forward on the telescope, because its fabrication was at a critical stage and they felt confident that the grant would be approved (BOG, 1986a).

The NSF agreed to give $450K more, but on condition that the ARC come up with a further $750K itself, which would guarantee completion of the telescope (but without any instruments). Margon suggested approaching member administrations asking for the additional $2.05 million not granted by the NSF, but ‘begging’ immediately for the $750K. The UW and University of Chicago portions were $232.5K, Princeton University and the NMSU needed to ask for $120K and the WSU share was $45K (Margon, 1986b). By 21 March all the institutions had guaranteed the $750K (Margon, 1986c). Recognizing that a telescope without instruments was useless, York then suggested that the University of Chicago finish its two main instruments and charge the ARC later, and he also proposed that the ARC trade time for instruments (York, 1986). At its 6-7 May 1986 meeting, the Board agreed to the suggestion to swap observing time (prorated from all members) for instruments, noting that any arrangement should have a 2-3 year lifetime and be renewable. Members were instructed to explore this idea with their Departments. Also, given the budget restraints of a likely lower grant from the NSF, only the échelle spectograph, the 2-m camera and a makeshift CCD camera should be finished. The minutes state, “These are not scientific choices, but the affordable ones given the cost, current investment in these instruments and their progress.” (BOG, 1986b).
On 11 July 1986 the NSF granted the ARC $3.74 million, with $890,000 paid in 1986 and $950,000 to be paid in 1988, 1989 and 1990 (NSF, 1986). Interestingly, the amount received matched the expectations set in the September 1983 letter. This was a big win that assured completion of the Observatory as it was then envisaged (see Figure 2), but the one-year delay put the project behind schedule, even though the Board astutely funded critical path items. The key reasons for winning the grant were that it was a well-conceived proposal based upon Astronomy Survey Committee recommendations; it introduced advanced technology features; and it provided an opportunity to test new mirror fabrication processes to be used in a more ambitious project backed by the NSF. All three of these topics are discussed in more detail in the next section, which looks at the science and institutional goals that drove the Observatory design, as well as the actual design features.

4 THE APO DESIGN

The institutional goals, as noted earlier, were to provide abundant telescope time to faculty and students; enable long-term research; and build strong Astronomy Departments that attract top people and grant dollars. These goals called for a world-class facility with a telescope of competitive aperture. The scientific research conducted by the member institutions covered the full range of astronomy and astrophysics, from planets and asteroids to the most distant galaxies and difficult cosmological issues. The science perspective, therefore, called for a general-purpose design that could easily accommodate and adapt to a variety of uses. In addition, the US astronomy community, through its Astronomy Survey Committee process, identified a number of priorities for the 1980s that were important to the ARC astronomers. In particular, on page 16 in Section 4 the Committee report it suggests

... the construction of an optical/infrared telescope in the 2.5 meter class for observing: transient phenomena, long-term survey and surveillance programs, provide ground-based support for space astronomy, and permit development of instrumentation under realistic observing conditions. The committee particularly encourages federal assistance for those projects that will also receive significant non-federal funding for construction and operation. (Astronomy Survey Committee, 1983).

The NSF proposal described 49 planned projects by the faculty at member institutions and these covered QSOs, the intergalactic medium, galaxies, and the Galaxy. Some examples of projects listed are: a redshift survey of a complete sample of distant galaxies; studies of light curves of a variety of astronomical objects; high-resolution studies of intergalactic and interstellar absorption; measurements of the velocity dispersion of stars in galaxies; and the determination of abundances in stars. These projects needed extensive telescope time, but this was not available at any public facility or on the telescopes then owned by member institutions (York, et al., 1984). The projects listed in the NSF proposal only represented a small number of what was contemplated (Gunn, 2004). Astronomers hoped for an easily-rescheduled telescope that could be operated remotely, because they wanted to be able to match projects to seeing conditions; respond to transient events, like supernovae, which had to be observed within hours of discovery; and follow up on opportunities identified by the Hubble Space Telescope and other space telescopes. Remote observing would enable rapid response without the need for travel, saving both time and money, and it would also increases opportunities for student access—even by undergraduates.

Figure 2: A 1986 concept drawing of Apache Point Observatory (courtesy of ARC, drawing by Kent Blair, 1986).
Key design features developed by the original consortium with Howard University back in 1981 carried through in the design submitted to the NSF that was eventually built: a lightweight mirror; a low-cost enclosure; a remote observing capability; and rapid instrument changes. In 1983 and 1984 Balick and the UW engineering group worked with the new consortium, which now included scientists from Princeton University and the University of Chicago, to create a new conceptual design based on a 3.5-meter mirror. They wanted to design the optics, structure, and dome so that performance would only be limited by seeing on the best nights. In addition, the consortium decided to build instruments that would accommodate a wide range of astrophysical projects; provide for rapid observing program changes, including instrument changes to enable large routine surveys, programs that use sporadic transient events; and also let astronomers work that only needs small portions of a night (PU, 1985).

Restricted remote observing was already available at other observatories using text-based commands to control a limited number of options. For example, the National Optical Astronomical Observatory at Kitt Peak had a remote tele-type terminal that could be used for observing. Of course, remote observing using the services of a staff observer had been available for a long time, if an astronomer wished to relinquish observing to a colleague. The goal for the APO was to be convenient and simple control of all aspects of the telescope and instruments by the astronomer himself. To accomplish this they would use a revolutionary graphical user interface built with Apple Macintosh computers, which would also include image feedback capability. The real innovation, though, was flexible scheduling and timesharing, which allowed multiple observers to share a night instead of the traditional scheme where one observer would be assigned a whole night or several nights in a row, even though the entire night was generally not required for the research (Mannery, 2004).

4.1 The Mirror

Detailed specifications for the telescope and enclosure start with the 3.5 meter, f/1.75, lightweight mirror. With a short focal length primary mirror, the overall telescope structure can be shorter and lighter, and the less massive mirror and telescope reduces noise from thermal heat. The APO secondary mirror gives a final focal length of f/10, but it is removable and can be replaced by an optional longer secondary (f/35) that is available for infrared observations. The flat tertiary mirror can be oriented to point the beam towards selected instruments that are already mounted and available. The optics follows a modified Ritchey-Chrétien design giving a 0.5° field of view and, theoretically, images smaller than 0.1 arcsecond when the optics are perfectly supported and aligned. The Steward Observatory Mirror Lab was contracted to supply the blank for the primary mirror, while the Hextek Corporation, a technology spin-off of the Steward Lab, would provide the blank secondary mirror (York, et al., 1984).

In early 1983 Roger Angel contacted the UW astronomers forming the new consortium to tell them of an opportunity to get an experimental mirror free of charge. From 1980 to 1983 Angel researched and developed a process for spin-casting short focal length mirrors. This grew into the Steward Observatory Mirror Lab at the University of Arizona campus, which was eventually located in a large space built under the bleachers of the local football stadium. Angel wanted to create a production process for low-cost, lightweight mirrors, and his ultimate goal was to cast an 8-meter mirror for a nationally-funded new technology telescope. The NSF had funded some of his efforts, and supported the plan for the large new telescope. However, Angel needed to successfully cast smaller mirrors on his way to the 8-meter one. He planned to cast a 1.8-meter mirror in 1983, expected to complete a 3.5-meter mirror in 1986, and follow this with one of 6.5 meters (McCray, 2004). The NSF funded the 3.5-meter mirror in a separate grant to the Mirror Lab, but both Angel and the NSF wanted the mirror used in an observing environment that would provide valuable feedback to the casting process before an 8-meter mirror was attempted. Therefore, the mirror was available free of charge to the group with the best plans to use it (Williams, 1988). The ARC consortium astronomers responded quickly, since their plans were already well developed. They claimed to have the best plans for the mirror; they were willing to risk using an experimental mirror, and they agreed to conduct thermal and optical tests after it was installed in the telescope.

After selection of the Angel 3.5-meter mirror the ARC's Scientific Steering Committee debated the desired focal length for it. The faster the better, since it would reduce the overall size of the telescope and the enclosure. Several argued for f/1.5, but in the end the Committee recommended an f/1.75 mirror as the safer choice, because they thought polishing and finishing an f/1.5 mirror would take too long (even with double shifts), require risky testing methodologies and be difficult to align (Anderson, 1983).

4.2 The Telescope

The broad features of the telescope, shown in Figure 3, did not change much from the 1981 version described earlier. Of course, it would be larger, with a 3.5-meter mirror instead of the 2-meter one, and more than four instrument locations fit on the larger mirror weldment. Still, the moving mass was only ~30 tons, which is about 20% of the weight of the conventionally-designed Lick Observatory 3-meter reflector (PU, 1985). Engineers designed the telescope for 0.3-arcsecond image quality with wind speeds less than 20 mph, absolute pointing to 1 arcsecond, and tracking to 0.2 arcseconds for up to 10 minutes (York, et al., 1984). Pneumatic pistons support the mirror and provide dynamic compensation for variable wind loading and gravity changes as a result of altitude angle changes. The support and ventilation systems are integrated so that support does not block ventilation (Mannery, 1986).

The NSF proposal had seven possible mounted instruments, but by 1988 there were nine slots. Two of these were at the Nasmyth and seven were at the bent Cassegrain foci, located on the edges and top of the weldment holding the primary mirror. Light is directed to a particular focus by a rotatable flat tertiary mirror. The tertiary mirror assembly is removable in
case a conventional cassegrain focus is ever required. Four mirrors located in two of the corners direct the beam to the top, or retract to let it pass to the corner ports. Plans called for one Nasmyth port to be permanently reserved for a large échelle spectrograph, while at the other an instrument change could be accomplished by just one person in less than 15 minutes. The new instrument was on a cart which could easily be rolled into place. Since all the mounted detectors are continuously powered and ready to be used, changing to one of these was expected to take no more than 5 minutes (Balick, 1988). With this design the nightly schedule could accommodate multiple users with a variety of observing needs. In addition, users could respond quickly to unexpected situations.

4.3 Associated Instruments

Obviously, a key design goal for instruments was ease of use in remote observing, in addition to meeting scientific goals. In early 1984 the instruments planned at first light were (York, et al., 1984):

- An échelle spectrograph with a resolving power (λ/Δλ) of 50K.
- A Fabry-Perot narrow-band spectrograph, with imaging capability.
- Direct cameras for photographic and CCD imaging.
- A cooled IR/optical bench for a variety of IR sensors.
- A photo-electric photometer.
- A Ronchi astrometry machine.

As noted above, by the time the NSF grant was approved in 1986, most of these were put on hold until funding was available. In fact, the photo-electric photometer and the Ronchi astrometry machine were never built.

4.4 The Enclosure

The fast primary mirror and altazimuth mount allowed a compact barn-like enclosure to be built. This was modelled on the enclosure used for the Multiple-Mirror Telescope at Mt. Hopkins, and was dedicated in 1979 (NMSU, 1985). Figure 4 demonstrates the size and, therefore, cost differences between this new design and conventional designs. The APO enclosure has a wide shutter and rotates with the telescope. In order to ensure the best seeing possible, the design goals call for the telescope and enclosure to cool quickly and remain isothermal with outside conditions (PU, 1985). Mounting the honeycombed mirror high on a pier above the structure lets airflow cool it more quickly (see Figure 3). To minimize heat production, observers and computers work from a separate operations building connected to the telescope enclosure by a covered walkway. Forced ventilation pulls outside air in, while the warm air is exhausting through the covered walkway, downwind of the telescope. Warm air is not allowed to cross the light path. Ventilation and airflow were modeled using dye, with an acrylic model of the enclosure placed in a water tunnel (Siegmund and Comfort, 1986). The enclosure design promotes the best possible seeing.
5 BUILDING THE APACHE POINT OBSERVATORY

After a period of intense design through 1984 and into 1985, the ARC had firm plans for the site, the buildings, the telescope, the enclosure and the instruments. After the Forest Service granted the use permit, construction commenced in 1985 with the clearing of the site and the completion of the access road (NMSU, 1986), but major work was delayed until the NSF funding came through. The building of the APO went smoothly with few problems, except for long and costly delays involving delivery of the mirror and some of the instruments. One of the on-site problems that did occur was when the primer used on the beams of the dome and the skin of the enclosure degraded in the harsh ultraviolet light at the site’s high altitude.

Although the entire structure had to be sandblasted and reprimed, the project got back on schedule and the costs were shared by the ARC and the contractors. David Nordfors of Seattle designed the telescope enclosure (shown under construction in Figure 5), which followed the telescope design by six months, so that the telescope design drove the enclosure design and not vice versa (Baldwin, 1985a). Leedshill-Herkenhoff of Santa Fe completed the design of the site improvements and other buildings by May 1985, and L & F Industries of Los Angeles was hired in July 1985 to complete the detailed design of the telescope parts and then construct the telescope (Margan, 1985f). Mesilla Valley Construction (Las Cruces) erected the site buildings and infrastructure, Otero County Electrical
Cooperative (Cloudcroft) put in the power lines and Sunshine Services (El Paso) constructed the roads (Anderson, 2004). By 1 November 1987 contractors completed the telescope, enclosure, and support buildings and, after formal acceptance, the ARC occupied the site from January 1988.

The APO, site works and infrastructure, were all completed on time and within budget, but while the Observatory had a telescope, it lacked the mirrors and some of the instruments. The initial delay in obtaining the 3.5-meter mirror arose from the funding problems, as the NSF did not grant the Mirror Lab its full funding request. Eventually, the ARC was asked to provide money for materials and labor (UC, 1988). The NSF's smaller grant to the ARC also constrained the project: the ARC had to increase member contributions by $1.5 million, pro-rated by share, from the original $3.95 million ($3.2 million, plus $750K more to get the NSF grant), because fundraising was slow and challenging. In struggling to find funds, the ARC decided not to build a second dormitory costing $116K, even though that was an excellent price (because it was cost-effective to build two dormitories at the same time). The ARC only had $54K, which the Board decided to reserve as a contingency fund, and they thought they might be able to use the AURA dormitories at the nearby National Solar Observatory if the need arose (Baldwin, 1987a; 1987b).

Figure 6: 3.5 meter telescope enclosure under construction in summer 1987 (courtesy of the ARC, photo by Dan Long, 1987).
5.1 The Mirror Delay

The real frustration came from the delay in the delivery of the mirror blank. The NSF funding problem was only the first delay of many. The ARC originally expected the Mirror Lab to deliver the mirror in August 1985, with first light scheduled in 1987 (York, et al., 1984), but after signing a contract for the 3.5-meter mirror with the University of Arizona (operator of the Steward Observatory Mirror Lab) in August 1986 they re-scheduled first light for February 1988 (UC, 1987). They expected the casting to start at any time, but further delays occurred and it only began in April 1988. Bulletin of the American Astronomical Society Annual Reports by the ARC member institutions from 1985 through 1988 give continually later dates for first light.

The process that was used to cast the mirror was complicated, and had not been tried before. The Mirror Lab only cast its first mirrors in April and August 1983. These were 1.8-meter mirrors for the University of Calgary and the National Optical Astronomy Observatory (NOAO), and they were done in a non-rotating furnace. In March 1985 the Lab cast its next mirror and the first using a rotating furnace. This was a 1.8-meter mirror for the Vatican Advanced Technology Telescope. The Mirror Lab then moved to its site under the stadium at the University of Arizona and built a larger rotating furnace. Its next mirror, from the new furnace, was 1.2 meters in aperture, for the Smithsonian Astrophysical Observatory, and this was cast in November 1987. Casting the ARC’s 3.5-meter mirror started in April 1988 (Lampis, 2000).

Prior to casting, engineers at the Mirror Lab built a mirror mold and placed it in the furnace. Casting began when five-pound chunks of borosilicate glass, known as ‘E6’ and supplied by the Ohara Corporation of Japan, were placed on top of the mold and melted by heating up the furnace (Lampis, 2000). After heating the glass to 1,170°C and maintaining it at that temperature for three hours, the glass melted into a honeycombed shape around the mold. The heat was then turned off and the spinning started, which gave the mirror its parabolic shape. Spinning reached a top speed of ~8.5 revolutions per minute. After twenty hours engineers peeked inside the furnace to check progress, and they stopped the spinning about thirteen hours later, when the mirror was cool enough to hold its shape. It took another six weeks for the mirror to anneal (cool and temper). Figure 6 shows ARC and Mirror Lab personnel inspecting the just-cooled mirror on 27 June 1988. After inspection, engineers used water jets to wash the mold material out of the mirror. They then cleaned it up and subsequently delivered it (McCoy, 1988).

Spun mirrors have the short focal length desired by the ARC and Roger Angel’s other clients. Casting the ARC 3.5-meter was a critical step in the Mirror Lab’s progress to 8-meter mirrors, and Angel said that the problems were not with technology but with their own inexperience in managing large projects. Handover from astronomers to engineers earlier in the production process might have helped (McCoy, 1988). In addition, better expectation management could have relieved growing customer frustration. Don York, sick of explaining the mirror delay, grew a beard and proclaimed: “When the beard comes off, the mirror has been delivered.” (Erickson, 1988). Figure 6 shows a happy York as Roger Angel shaves his beard off, with the completed 3.5-meter mirror in the background. The mirror was delivered on 10 August 1988, and Angel claimed it was a perfect 10 (ibid.). On 11 August the ARC moved the mirror to the optical shop of Norman C. Cole’s Arizona Technologies Inc., where it was polished (UC, 1989). As it turns out, York should have waited to shave his beard.
Assuming it would take eighteen months to polish and install the mirror, the ARC astronomers now projected first light in early 1990 (Balick, 1988). Because of situation regarding the mirror, there were also delays with instrumentation and programming. However, telescope and enclosure testing and shake-down continued, even without the mirror. During the fall of 1989 the NOAO, the Magellan Project, the Steward Observatory, the NSF, and the ARC all collaborated on thermal control tests using a dummy honeycomb mirror segment. The ARC agreed to these tests when it acquired the free mirror. Scientists studied thermal control under operating conditions at the APO through April 1990, and their tests showed that thermal surface deformation would produce image quality less than 0.2 arcseconds in all but the worst nights (York, 1991), thus validating plans for 8-meter mirrors.

5.2 The Temporary Mirror

An even more interesting test came when the ARC astronomers borrowed the University of Calgary's 1.8-meter mirror (the first made by the Mirror Lab). The idea for this emerged in late 1987 as Observatory construction ended but the mirror was still unpredictably delayed. It turns out that the University of Calgary had a mirror but no telescope, while the ARC had a telescope but no mirror. In exchange for borrowing the mirror, the ARC paid for it to be generated, polished, and aluminized. The mirror arrived on 19 June 1990 and was installed by March 1991 (ARC, 1992; Smith, 1990). It was installed with secondary and tertiary mirrors that gave an overall optical system of f/20, with a scale about the same as the final optical system planned for the 3.5-meter primary mirror (UC, 1991).

Besides being used for an engineering shake-down and refinement of the software written to remotely control the telescope, enclosure, and instruments (ARC, 1992), from February to 20 October 1992 full remote operation was carried out from the campuses of the ARC member institutions using a CCD camera, a guide camera, and an infrared imager. Observing with this mirror successfully tested key goals of rapid instrument change and a shared nightly schedule with observers from different campuses (ARC, 1993). The APO even produced its first publishable results, observations of the cataclysmic variable, HV Virginis (see Ingram and Szkody, 1992; Szkody and Ingram, 1992; UW, 1993). Turner tested the synoptic advantages of the telescope by capturing sixty light curves of the gravitationally-lensed quasar Q2237+0305 over a three month period (PU, 1985). Images with the 1.8-meter mirror confirmed the expected good seeing at the site and the benefits of the enclosure design (ARC, 1992).

5.3 Delivery and Installation

By early 1990 Norm Cole completed rough generation of the 3.5-meter mirror and began polishing it. When the mirror was delivered by Roger Angel in 1988, the ARC scientists predicted the mirror would have seen first light by this time. Cole had a small shop and was an experienced optical worker, but this project stretched his capabilities since the curvature changes significantly from point to point on a short focal length mirror. When he was chosen for the task, the ARC knew it might be a risk, but the only other vendors for this kind of work were very expensive. The Mirror Lab wanted to do the work, but they did not have the facility at the time (Mannery, 2004). By November 1990 the Board authorized a search for another vendor (BOG, 1990). In the meantime, Roger Angel, knowing that he had to develop faster, cheaper methods of polishing and measuring if he hoped to achieve his goal of producing inexpensive mirrors, had developed computer controlled polishing tools and had designed an interferometric measuring method. He offered to finish the 3.5-meter mirror if ARC would pay for the development costs of the testing methods, a risky proposition since those costs were only roughly known (Balick, 2004). In February 1992, after months of no progress on figuring the mirror, the ARC took the risk and moved the mirror to the Steward Observatory Mirror Lab. Mirror polishing and test evaluations were completed in August 1992, the mirror was aluminized at Kitt Peak on 15 September 1992, and it arrived at the APO three days later. The process of installation began on 20 October 1992 (ARC, 1993). The secondary, cast by the Hextek Corporation, was delivered to the Optical Sciences Center in February 1992 and completed in January 1994. While waiting for the secondary and tertiary mirrors, the 3.5-m mirror was operated at the prime focus with a simple detector, in order to exercise and refine operations. Three-mirror first light happened on 5 April 1994, and the dedication of the Apache Point Observatory was held on 10 May 1994 (ARC, 1995).

5.4 Dedication

Early 1993, with the primary mirror on site but still awaiting the secondary and tertiary mirrors, the ARC set a date for the dedication. A rare annular solar eclipse would pass directly over Apache Point in just a little over one year. Although it would be a challenge to get ready on time, they could not miss this unique opportunity (Gillespie, 2004). The 3.5-meter reflector, the 14th largest optical telescope in the world at the time, was dedicated on 10 May 1994 before an invited audience of about 300 people. The eclipse took place
Jim Peterson and Glenn Mackie

at 10:30 am, during which Don Jennings and Drake Deming, guests from Goddard Space Flight Center, imaged solar spectral lines with their 12-μm spectrometer. The telescope remained in operation until August as the astronomers and students were trained to remote observing techniques (ARC, 1995).

Luckily, some instruments were available. The dual-imaging spectrograph (DIS) built by Jim Gunn (University of Chicago), and a drift scan camera (DSC) built by Tim McKay at Fermi Lab, were also tested (ARC, 1995). The échelle spectrograph turned out to be more difficult to make and had to be rebuilt, so it was unavailable, although it eventually was commissioned and now performs above initial expectations (Anderson, 2004). In July, as part of a coordinated effort with other observatories, intensive observing of Comet Shoemaker-Levy 9’s impact with Jupiter for up to 18 hours per day fully exercised the telescope (ARC, 1995).

The new optics exhibited performance problems, however. Earlier tests with just the primary mirror installed exceeded performance expectations, but tests with all three mirrors in place did not, and the problem was eventually traced to incorrectly-figured zones on the secondary mirror. In August the secondary was sent to Lick Observatory for measurements and then to Kodak for ion polishing. After re-measurement at Lick, the secondary was reinstalled in October with substantially improved image quality, but because it had too thin a faceplate to be successfully refigured, it still performed below expectations. The ARC’s completed 3.5-meter telescope is shown in Figure 8, and it commenced full-time science observations in November 1994 (ARC, 1995).

6 THE SLOAN DIGITAL SKY SURVEY (SDSS)

At the time of the dedication of the ARC’s 3.5-meter telescope, APO was home to three other telescopes: the NMSU 1.0-meter telescope dedicated the same day, the SDSS 2.5-meter telescope and the SDSS 0.6-meter telescope (both of which were under construction at the time). The Sloan Digital Sky Survey (SDSS) is a very successful project led by the ARC. It deserves its own history, but will get a brief description here, because its roots extend into the ARC’s early history.

In fact in May 1988, Rice, then interim Chair of the ARC, sent a letter to Board members saying that the ARC needed a process to allocate and approve space for other telescopes at the APO. York had sent a proposal to the NSF for a dedicated 3.5-meter telescope for a cosmology program, and the UW and Princeton University were getting more serious in their desire for a 2.5-meter telescope for a survey they started discussing in 1982 (York, 1988). At the 23-24 October 1989 Board meeting the members discussed the 2.5-meter survey project and admitted the Institute for Advanced Studies (IAS) as an ARC member for the purpose of doing the survey that, at that time, only included Princeton University and the University of Chicago (BOG, 1989). The IAS actually joined in December 1990, when the ARC formed a subcommittee to investigate building a second telescope (UC, 1991; 1992). In the fall of 1991 this grew into an additional collaboration of the ARC with other institutions that were funded by the Alfred P. Sloan Foundation to carry out the Sloan Digital Sky Survey. Johns Hopkins University (JHU) joined the consortium in June 1992 to be part of the SDSS. The IAS and JHU joined the ARC, but they do not share in the time or expenses of the 3.5-meter APO telescope (UC, 1994). The UW did not join the SDSS until 1994, even though it had a lead role in the project. The NMSU joined in 2000, but the WSU never joined the SDSS. The SDSS telescope is dedicated to the survey, so membership in it gives access to the data, but not to telescope time.

Figure 8: The completed ARC 3.5-meter telescope at APO in 2000 (courtesy of the ARC, photo by Dan Long, 2000).
Although other institutions from around the world have since joined SDSS, they are not members of ARC. Today, the other members of the SDSS are: the Fermi National Accelerator Laboratory (FNAL), the Japan Participation Group (JPG), the Korean Scientist Group (KSG), the Los Alamos National Laboratory (LANL), the Max-Planck-Institute for Astronomy (MPI), the Max-Planck-Institute for Astrophysics (MPA), University of Pittsburgh (Pitt) and the United States Naval Observatory (USNO) (see ARC, 2004a). Appendix 2 lists everyone who has served on the SDSS Advisory Council.

The SDSS telescope, software and instruments are tightly integrated to survey the North Galactic Polar Cap. The sophisticated design of the telescope gives about a 3° field of view and consistent images even out to the field edge, so that it works well with fiber-fed spectrographs. During excellent seeing, five-color imaging, with a limiting magnitude of 23 in R band, surveys the sky via drift-scans. These images are used to select galaxies and QSOs for spectroscopy with two fiber-fed spectrographs. A million redshifts will be obtained over a 5-year period to study the large-scale structure of the Universe. In many observations, other objects will be found, such as supernovae, brown dwarfs and asteroids (PU, 1994; UC, 1994). Originally it was expected that first light would occur in 1995 and the survey would be completed by 2001 (UC, 1995). Major site improvements at the APO associated with the SDSS were completed in the summer of 1993 (UW), but because of instrument problems the survey did not start until April 2000. The initial project formally ended in June 2005, when a 3-year extension project began (SDSS-II).

7 CELEBRATING SUCCESS

With the SDSS in full operation and the APO providing ample observing time to astronomers and students, the ARC celebrated its achievements on 27 May 2004, the twentieth year of its existence and the ten-year anniversary of the dedication of the 3.5-meter telescope. The accomplishments included creating a thriving organization, building a world-class observatory, and fulfilling the goals of developing strong astronomy departments and conducting important scientific work.

Organizational, the ARC proved sturdy enough to withstand the vicissitudes of long-term projects, the formation of a complex sub-organization (i.e. the SDSS), and even a membership change in July 2001 when the WSU sold its share to the University of Colorado (Boulder), which also agreed to build several new instruments. The WSU did not have an institutional commitment to grow its astronomy program, so it could not justify the cost nor fully use its plentiful telescope time—especially after Tom Lutz died in 1995 and Julie Lutz moved to the UW a few years later. Without these two observational astronomers and ARC founders, the costs outweighed the benefits and the WSU sold its share, smoothly transitioning participation to Colorado (Lutz, 2004). For the other members, the ARC and the APO worked as planned. By the end of the second full year of operation, in 1996, two hundred astronomers and students had been certified to operate the telescope remotely (ARC, 1997), and by 2004 the ARC members could say that having the 3.5-meter telescope made their departments attractive to faculty, students, and future grants (York, 2004; Anderson, 2004; Balick, 2004). In particular, students benefited from it: there was time available to them, and they did not have to find ways to fund travel to an observatory. They could do their work remotely.

Astronomers and students now do a variety of research work at the APO, and produce results in a range of astronomy sub-disciplines. The anniversary celebration in 2004 included papers with titles like “APO Insights into Cataclysmic Variables”, “Observations in Support of HST” and “A Decade of Planetary Science with the APO 3.5 meter Telescope” (ARC, 2004b). Meanwhile, a search for ‘Apache Point’ on NASA’s ADS server on 10 November 2005 resulted in 305 papers, 179 of which were selected when that search was limited by ‘3.5’. Many projects undertaken at the APO are multi-wavelength and collaborative, which the ARC 3.5 meter is very good at, but its contribution often is not specifically cited (see Lutz, 2004). Examples of these types of programs include asteroid detections (as part of Spacewatch Projects), or the impact of the Comet Shoemaker-Levy 9 on Jupiter, as mentioned earlier. Some of these collaborations do show up in published papers, though. Kurt Anderson, who was part of a large collaborative effort involved in monitoring the temporal behavior of radio galaxy 3C390.3, obtaining images and spectra using the DIS on the ARC 3.5 meter telescope at 10-day intervals (see O’Brien, 1998).

Flexible scheduling, both for unexpected opportunities and for long-term programs, separate the APO from other facilities and give the ARC astronomers a distinct benefit. Advantageous scheduling of the ARC 3.5 meter telescope enabled optical spectra to be obtained collection in conjunction with International Ultraviolet Explorer observations during the 43-day super-outburst cycle of ER UMa (Szkody, et al., 1996), and rapid instrument changes made it possible to observe the optical afterglow of gamma-ray bursts (Margon, et al., 1997). The ARC astronomers can commit to long-term programs using the APO that would be impossible to do by competing for time on other telescopes in the open ‘marketplace’. These kinds of projects yield important results. Turner and colleagues at Princeton used the APO to conduct a synoptic gravitational lens program consisting of half-hour observations every other night, starting later and later in the evening as the program progressed. Actually, the initial observations were done with the 1.8-meter, and these resulted in a time delay prediction for the 1996 B light curve of quasar 0957+561 (Kundic, et al., 1995). In 1996, the time delay was observed as predicted, allowing them to derive the Hubble Constant to a claimed accuracy of 10% (Kundic, et al., 1997). A graph from the later paper is reproduced here as Figure 9, and it shows the 1995 prediction and the 1996 observation. In yet another example, Professors Reiss, Diercks, Stubbs, and Hogan joined an international effort with the High-z Supernova Search Team to study and monitor high-redshift supernovae using the 3.5 meter telescope (UW, 1996).

The wide range of astronomical interests at ARC member institutions results in a variety of research programs. Greenawalt and Walterbos made the first detection of oxygen lines in a truly diffuse medium,
confirming the expected strength of [OII] and the weakness of [OIII] (Walterbos, 1996). Walter and Marley used the infrared camera to show evidence of substantial haze at the south pole Uranus, and were able to demonstrate that it had brightened in recent years (Walter, et al., 1996). Kibblewhite and his group at Chicago installed developmental adaptive optics instruments on the 3.5 meter telescope, including a laser beam for artificial sodium stars. Even though promising improvements in image size from 1 arcsecond to less than 0.2 arcseconds were recorded, indicating excellent progress, the system never became operational (Shi, et al., 1995; Larkin and Kibblewhite, 1998). After 1997, funding for the costly laser effort became too difficult to obtain. Interestingly, discussions between APO staff and local officials led to a national-level discussion involving several large observatories and Government agencies in a bid to develop guidelines for the safe use of laser-guided systems (ARC, 1997). Another laser project, the APOLLO-Apache Point Observatory Lunar Laser-ranging Operation, was used to test predictions of General Relativity using precise measurements of the Moon-Earth distance (see Strasburg, et al., 2002).}

Ultimately the continued success at the APO depends on the quality of the site, the telescopes and the instruments. The key functional design goals of remote observing—rapid instrument changes and flexible scheduling—have been achieved, are successful, and will remain fundamental to future plans. The site provides excellent seeing, as confirmed by continual and extensive monitoring. Between 1997 and 2000 the APO implemented an aggressive plan to improve telescope performance by replacing the secondary mirror (which had never quite met expectations), stiffening optical supports to reduce jitter, increasing baffling to reduce scattered light effects, and completing a host of other upgrades, such as new and updated instruments, new computers and rewritten software (ARC, 1998). In addition to an ongoing maintenance and upgrade program, the ARC is beginning to discuss future telescopes and instruments for the Apache Point Observatory. Don York, chair of a “Futures Committee”, not only sees the APO completing the large-scale surveys that are currently progress (such as SDSS II), but also initiating new ones. Survey follow-up can be done with current instrumentation, but his Committee will explore the construction of a 6-meter class experimental telescope (York, 2004).

B CONCLUSION

Despite delays in building the telescope, the ARC successfully completed a world-class facility for its members that served to strengthen their astronomy programs and accommodate the types of long-term projects that are so important to university astronomy departments.

The University of Washington initiated the effort to build a world-class university observatory in the USA, but at the same time the other universities were discussing the same thing so the messages conveyed by Wallerstein and Balick resonated with them. Committees led by Margon and Baldwin formed the Astrophysical Research Consortium (ARC), an organization that unified different member-interests and created a process for long-term cooperation. This new organization faced difficult challenges in funding and budgeting, but it eventually succeeded, and even went on to develop other ambitious projects desired by its members, such as the SDSS.

The construction of the ARC 3.5 meter telescope at the APO was driven by the goals of convenient remote observing, rapid instrument changes and flexible scheduling. Without the benefit of a dedicated project manager, Don York guided this project to a successful conclusion by overseeing the work which was distributed among all of the member institutions and a number of vendors (including Angel’s experimental mirror, which was vital to the telescope, yet contributed to its delay). Building the telescope exercised and developed the skills and talents of the astronomers at all of the ARC institutions. Anderson and NMSU faculty selected, prepared and manage the site. Gunn at Princeton, Harper at Chicago, and their various colleagues, built cutting-edge instruments that had to function in remote observing mode, and could be rapidly interchanged. Balick, Mannery, Siegmund and colleagues at the UW designed the advanced technology telescope and enclosure. After a long gestation

Some of the most exciting results at APO have come from the combination of SDSS and the ARC 3.5 meter. For example, the infrared camera on the ARC 3.5 meter, following up on SDSS commissioning data, found some of the highest redshift QSOs in the universe at the time (Fan, 1999) and the first field methane brown dwarf (Strauss, 1999). Further spectral analysis of the distant quasars with the ARC 3.5 meter telescope and at the Keck Observatory led ARC scientists to announce the detection of the Gunn-Peterson Trough at redshifts of z > 6 and evidence of reionization at z ~ 6 (Fan, 2000; Becker, 2001).
period, in 2005 the APO 3.5 meter telescope completed ten years service to the ARC. The first APO Director, Princeton's Ed Turner, took up duties in 1994, and he only stepped down on 1 January 2005. Suzanne Hawley from UW then replaced him, beginning a new era for the APO.

9 ACKNOWLEDGEMENTS
We would like to thank the following people for their advice and support: Mike Evans (Business Manager of the ARC) for overall guidance and provided information and access to archives; George Wallerstein (UW), for starting JP on this project, outlining the early history of the APO and 3.5 meter telescope, and commented on the manuscript; Bruce Balick (UW) for also reading and commenting on the manuscript; Bruce Gillespie (the APO) for making his 10-Year anniversary presentation available; and Peggy Fanning (UW's Office of Research), for providing information contained in the ARC's files. We are also grateful for the following for providing JP with insights and recollections relevant to this study, through face-to-face, telephone or e-mail interviews: Kurt Anderson (NMSU), Bruce Balick (UW); Jim Gunn (Princeton) Julie Lutz (UW); Ed Mason (UW), Ed Turner (Princeton) and Don York (Chicago). Nanette Peterson typed the transcripts of all of the interviews, while JP's wife and children provided moral support, and were so understanding when he was always so busy.

10 NOTES
1 US dollars are used throughout this paper.

11 REFERENCES


12 APPENDIX 1: MEMBERS OF THE ARC BOARD OF GOVERNORS, 1984 – 2005, LISTED BY INSTITUTION*

Note that only two members from each institution are on the board at any given time. The members are listed in the order they served from their institution.

<table>
<thead>
<tr>
<th>Princeton</th>
<th>Chicago</th>
<th>UW</th>
<th>NMSU</th>
<th>WSU</th>
<th>JHU</th>
<th>IAS</th>
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*Provided by Mike Evans, Astrophysical Research Consortium.
13 APPENDIX 2: MEMBERS OF THE SDSS ADVISORY COUNCIL, 1995 – 2005, BY INSTITUTION*

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*Provided by Mike Evans, Astrophysical Research Consortium

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