# A Brief History of the Astrophysical Research Consortium (ARC) and the Apache Point Observatory (APO)

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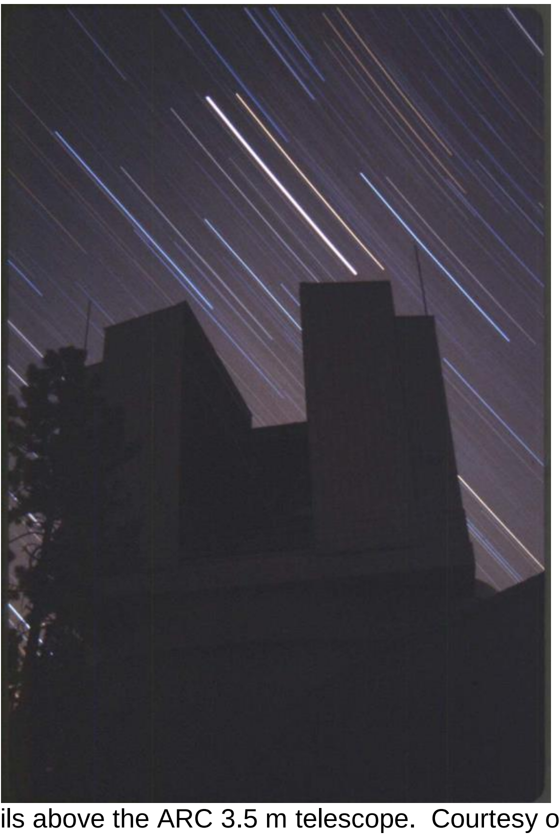

Star trails above the ARC 3.5 m telescope.  Courtesy of ARC.

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## Abstract

This history of the Astrophysical Research Consortium (ARC) and Apache Point Observatory (APO) describes why and how ARC formed, the vision for APO, and the technology used to implement that vision. In particular, it examines the building of the low cost, lightweight, f/1.75, ARC 3.5 m telescope with its experimental Roger Angel mirror 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 APO are noted. The content for this paper is based on interviews with key people, documents in ARC business files, and published papers and reports, such as the annual reports by astronomy departments.

## 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" telescope at the California Institute of Technology's Palomar Observatory and the 100" Hooker telescope at the Carnegie Institute of Washington's Mt. Wilson Observatory or even the University of California's 3 m 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 October 28, 1957 to create and manage a national U.S. optical observatory available to all U.S. 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 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, University of Chicago, University of Washington, and Washington State University formed the Astrophysical Research Consortium (ARC) in 1984 to create an observatory that provided telescope time to each member university based on its investment (ARC 1984). Figure 1 shows the Apache Point Observatory built by the consortium. The costs for the biggest and best tools have grown so much today that almost every telescope project is a cooperative effort. Modest ones require a small group of institutions like ARC and ambitious ones require the cooperation of nations. Today's models of cooperation rely on the pioneering steps by groups like 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.

**Figure 1 - The Apache Point Observatory today, including from left to right the Sloan Digital Sky Survey (SDSS) 2.5 m, the SDSS 0.6 m, the New Mexico State University 1.0 m (hidden by a tree), and the ARC 3.5 m telescopes. Courtesy of ARC.**

## Paths to an observatory

Prior to the formation of ARC in 1984 none of the consortium members had telescopes greater than 1.0 m and their observatory locations were not ideal. In general a common desire to gain access to a larger telescope in a better location brought these universities together, but it was a long and bumpy road even to get started. They each have their own path, but, since the astronomers at the University of Washington initiated the process, starting with their story provides the best illustration of how this group eventually formed.

### *University of Washington (UW)*

In 1965 UW decided to expand its Astronomy Department and hired Paul Hodge and George Wallerstein (both from the University of California at Berkeley) to join Theodor Jacobsen, the sole UW astronomer since 1928. As observers used to access to excellent telescopes, Hodge and Wallerstein soon began to plan for an observatory and that first year hired Ed Mannery to help with site selection and optics design. They quickly realized, though, they needed a better location than available in Washington State, they needed a larger resource base to fund the telescope (especially since state funds would be hard to get for an out-of-state project), and they needed a partnership with other astronomy departments because their small, but growing faculty would underutilize and have difficulty managing a large facility (Wallerstein 2004).

As early as October 1965 the UW Regents authorized construction of a large telescope using external (Vs 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 NSF was channeled to other projects, like the national observatory at Kitt Peak (Wallerstein 2004). In the meantime, in 1971 UW built a small observatory on Manastash Ridge in central Washington that initially housed a 16" telescope, but was replaced a year later with a 30" telescope (Wallerstein 2004). 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, UW ranked second in allocation of time among all U.S. institutions and ranked first in per capita allocation. Although UW got a lot of time, the constraints were growing as the demand increased and NSF funding for Kitt Peak did not keep pace. Three-quarters of all requests for time were denied. Programs like the one at UW were in a difficult position, because they could not assume access for their astronomers and graduate students as the department expanded (Balick 1981). They still needed to build a large telescope.

In 1975, when Mr. Alex Kane died and left an estate worth $250,000 for the purpose of building a telescope, UW finally had startup funds for a major telescope project. Kane, from Ashland, Oregon, first offered the money to Oregon State University, but they told him they were not interested in building a telescope. UW did not make that mistake, because the fundraising office knew of the Astronomy Department's ambitions. Even with secure funding, finding a partner was not easy. UW talked with Stanford 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" telescope from the University of Vienna and partnering with them to build an observatory for it. In addition to the mediocre optics and awkward mount, the mirror was just too small for the effort (Wallerstein 2004). Things changed in 1978/79 when Professor Bruce Balick began exploring a partnership with Howard University, New Mexico State University (NMSU), and Washington State University (WSU).

Balick 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 UW to build a telescope. The ideas for the new telescope came from the Kitt Peak Advanced Development Program and from radio astronomy. Balick's background in radio astronomy led him to invite Sebastian Von Hoerner and Wun Yuen Wong from the National Radio

Astronomy Observatory in Greenbank, West Virginia to visit Seattle for a week to help explore different approaches to optical telescope design by applying techniques from radio telescopes (Balick 2004).

What emerged from the brainstorming with new partners at Howard, NMSU and WSU and from the gathering of ideas from Kitt Peak and Greenbank was a well-developed concept for a lightweight, 2 m mirror only 6 cm thick with a support structure 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 approach meant lower thermal noise and lower cost. Overall dimensions were half and the weight was 10 - 20% of a traditional scope of similar aperture, so a small and inexpensive building was possible. Instead of placing an instrument in the standard position behind the mirror causing load flexure during use and costly equipment changes when a new instrument was needed, up to four instruments could remain attached to the sturdy telescope mount. The incoming beam could then be redirected to the selected instrument. The group even found a cost-effective site at Sunspot, NM on the Sacramento Peak campus of the National Solar Observatory. It has excellent seeing, on a par with any mainland site, and is close to support facilities, an airport and 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, UW astronomers had good reason to be optimistic as they anticipated using their 40% share in a world-class telescope that would also attract more 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 (Balick 1981). In particular, Malcolm Stamper, President of Boeing and a friend of the University, was very supportive (Balick 2004). Both Wallerstein and Balick 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.

### *New Mexico State University (NMSU)*

In fall 1978, the NMSU Astronomy Department had six regular faculty members and two emeritus, including Professor Clyde Tombaugh the discoverer of Pluto (NMSU 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+ m 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 NMSU to join with UW (Anderson 2004). UW brought telescope-engineering expertise and NMSU had site management capability.

Initially NMSU thought they could contribute $500K in cash and provide a site and an operations building 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, NMSU had considered the Sacramento Peak area for a telescope as early as the 1960's and Professor Kurt Anderson had extensive meteorological data acquired by others since the 1950's, so the choice was supported scientifically (Anderson 2004). As it stood in July 1981, NMSU committed to $576K for a 16% share, but held out hope that it might raise more funds to buy a 25% share.

### *Washington State University (WSU)*

Although WSU had a small astronomy program with only two observers, Professors Tom Lutz and Julie Lutz, 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 state research institutions working together to create a statewide resource, even though that resource would likely be located in New Mexico. 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. WSU could not add personnel expertise, but they could contribute a small share of money for a small share of observing time and agreed to help out where they could. For a 5% share, 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).

### *Howard University*

In the late 1970's Professor Ben Peery moved from Indiana University to Howard University in Washington, D.C. to start an astronomy program. Balick contacted Peery in hopes that Howard might have an interest in a telescope project that would certainly help grow the new program. Peery, Howard's only astronomer at the time and a member of the Physics Department responded to his University's call for proposals to improve graduate programs with a proposal to buy a 30% share in the partnership with UW, NMSU and WSU to build an observatory. University officials liked it and agreed to $1.08 million in funding if Congress approved the budget. Howard is funded directly by the U.S. Congress and 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, like WSU, would contribute money, not expertise (Wallerstein 2004; Anderson 2004).

By August 1981 the presidents of UW, Howard, NMSU, and 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 m 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's funding, the last roadblock. They even pooled money for a celebratory bottle of champagne. Alas, Howard's request to Congress was mistakenly excluded from President Reagan's budget and it never resurfaced. Although Howard maintained an active role until the end, it had to drop out in early 1982 (Anderson 2004). The project was in jeopardy and, if it were not for a timely disappointment at Princeton, might never have gotten back on track.

### *Princeton University*

In the late 1970's Princeton had submitted a proposal to manage Hubble Space Telescope data acquisition and reduction that included a $1 million endowment for postdoctoral positions for the project, if Princeton was selected. In January 1981, Princeton did not get selected, nor did it get approval to build the wide field camera. With balloon experiments winding down and an unsuccessful bid to enter space-based astronomy, the department decided to get involved in ground-based astronomy, which pleased Professors Jim Gunn and Ed Turner, both observational astronomers, who had recently joined the department (Gunn 2004; Wallerstein 2004). Although Princeton was not selected, the donation was still available to them. Wallerstein, on an early 1982 visit with Professor Edward Jenkins to discuss an ongoing research project, happened to mention that UW was forming a consortium to build a 2.5 m telescope and that Princeton's $1 million would buy a substantial share of the telescope time. Notice that as time went on, the mirror size crept up to keep it competitive (Wallerstein 2004). Professor Jerry Ostriker, chairman of the department at that time, liked the idea. He had been hoping to build a much larger telescope, but realized Princeton did not have the funds for it. He asked Professor Don York to investigate participation in the project. Soon after, York moved to the University of Chicago, but Princeton remained interested, although now only at a $500K level (York 2004). In addition, they lobbied for a larger telescope. Gunn felt that a 2 to 2.5 meter telescope would not give the consortium a leading edge in aperture. He insisted on a mirror of 3 m or better with a wide field of view. Princeton brought prestige, money, and expertise to the project. Gunn had agreed to build a double imaging spectrograph (Gunn 2004; Wallerstein 2004).

Now that the consortium expected to build a larger 3 m, wide field advanced design telescope, Balick, Ed Mannery and Walt Siegmund (of the UW's telescope engineering group) spent the remainder of 1982 working with Princeton, NMSU and WSU on 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 universities did not even cover a smaller telescope. Another partner was needed.

### *University of Chicago*

Astronomy and astrophysics at Chicago had a long history and a fine observatory with the world's largest refractor, the 40" at its Yerkes Observatory, shown in

Figure 2. From 1932 to 1962, the department also managed the MacDonald Observatory in Texas, which gave them access to the 2.1 m Otto Struve telescope. By 1982, though, access to newer and larger telescopes was more difficult, so the faculty formulated a strategy to build instruments and trade use of the instruments for time on large telescopes. In fall 1982 York moved from Princeton to Chicago. Early in that academic year the Dean, Dr. Stuart Rice, attended a department meeting and suggested they build a big telescope (York 2004). Interestingly, at this time Rice was on the National Science Board, the National Science Foundation's (NSF) governing body, which had control over its budget and plans. In July 1982 Rice received a letter from Dr. Leo Goldberg, a long-time leader of AURA and Kitt Peak, which described 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 NSF should go ahead and fund other ground-based projects (McCray 2004). This may have emboldened Rice to encourage the astronomy faculty to think big. Fortunately, having just explored this topic for Princeton and still enthusiastic about the UW-led consortium, York had just the solution and Chicago signed up for a share equal to UW's. The team was formed, now they had to get started.

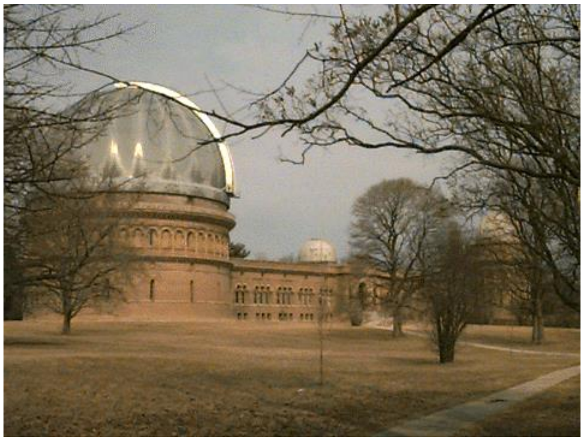

**Figure 2 - Yerkes Observatory. Courtesy of Yerkes Observatory, University of Chicago.**

### Formation of ARC

Acquiring telescope time on a first-class telescope brought these institutions together, so equitably divvying it up and designing an effective form of governance was the first major administrative hurdle. Professor Bruce Margon, UW Astronomy Department Chair at the time, took on this difficult task and sheparded, along with Mr. Don Baldwin, UW Assistant Provost for Research, the process of gaining agreement while also building an atmosphere of trust and mutual respect. It took most of 1983, but the Consortium Agreement signed by all members by January 26, 1984 and effective January 1, 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 a small amount for engineering time and director discretionary time breaks down as follows: UW 31.25%, Chicago 31.25%, NMSU 15.625%, Princeton 15.625%, and WSU 6.25%. In addition, the Board of Governors has 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 the others present agreed (Lutz 2004). Astrophysical

Research Consortium incorporated as a non-profit in Washington State on June 26, 1984 (UW 1985), and received non-profit status from the IRS on October 25, 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 m mirror, and development of detailed concepts and budgets for the telescope, enclosure and site. Although the Sacramento Peak site had been tentatively selected early on, because it seemed to have excellent seeing and it definitely had low costs, NMSU's Professor W. L. Sanders continued site testing there and at an old cosmic ray site nearby, at South Baldy near Soccoro, at the NMSU Blue Mesa Observatory site, and at the Cloudcroft, NM 48" Air Force site. M. Walker of the Lick Observatory consulted with Sanders and helped him use his site evaluation methods and a Walker-type telescope (NMSU 1981, 1982, 1983). The site tested positively and the consortium members decided to name it Apache Point. After researching the use of this name, Anderson determined that calling it Apache Point should not offend anyone and nothing else in New Mexico was using that name (Anderson 1983). Actual final approval to use the site came on April 17, 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 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 January 20th the Board of Governors voted Margon the Chair of ARC and Baldwin the Secretary/Treasurer. In addition, York was appointed Director of the Observatory, Anderson was appointed Associate Director for the Site, Balick became Associate Director for the Telescope and Doyal A. (Al) Harper of Chicago became Associate Director for Instruments (BOG 1984a; NMSU 1985; UC 1985; UW 1985). Appendix A lists everyone who has served on the ARC Board of Governors. Interestingly, at its next meeting in October 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 following budget:

| | | |
|---|---|---|
| Expenses | | |
| $8.8 Million | | |
| $1.2 Million | | Faculty costs for which member institutions are not charging overhead |
| Total | $10 Million | |
| | | |
| Revenues | | |
| $3.2 Million | | Provided by ARC using non-federal funds |
| $1.2 Million | | From member institutions |
| $5.6 Million | | Requested from NSF |
| Total | $10 Million | |

**Figure 3 - Project expenses and sources of funds (York et al. 1984)**

### *Fundraising*

Obviously, ARC expected to get significant support from NSF. Funds provided by ARC came from state sources and private donations to the member institutions as described earlier. 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 $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 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 ARC did not. A $100K donation from the Perkins Fund solicited by Princeton on behalf of ARC was at first thought to be a gift to ARC and as agreed the funds would be used to reduce all member dues (Margon 1985b). However, when Princeton actually received the money they discovered that the Perkins Fund trustees had voted to donate it to Princeton and not ARC (Eggers 1985). Despite ARC's difficulty in raising private funds, it met with huge success winning NSF funding.

Obtaining NSF funding and the challenges of managing cash flow until the funding was received occupied a large portion of the Board's efforts. Once ARC formed, proposed budgets for 1984 of $1,010,854 and 1985 $4,007,005 were put in place to get a marching army started to design and build the telescope and buildings and 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 decision had to be made, such as eliminating an aluminizing facility at the observatory after confirming that Kitt Peak would be able to provide optical coating services at a reasonable cost (Jefferies 1984).

### *NSF Proposal*

The process to win NSF funding began early in 1983 when proposal writing started. On September 1 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 ARC and planned to ask NSF for a grant in the range of $3.75 million. They anticipated submitting the proposal by the end of 1983 (BOG 1983). By the time the request was actually submitted on May 15, 1984, the amount had grown 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 December 31 he bluntly stated that NSF money in 1985 was unlikely and that 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 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 gives 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, which had not been set yet. Margon suggested communicating positive, but indirect signs, even though a stronger statement would help fundraising. He did not want to embarrass NSF or cause competing projects to lobby harder for their projects before ARC received approval (Margon 1985c).

The in-person peer review took place on October 23, 1985. York and Margon prepared the agenda and Anderson, Baldwin, Gunn, Harper, Lutz, Mannery, and Siegmund also attended. Dr. Roger Angel of the Steward Observatory Mirror Lab came as a guest of ARC. NSF representatives were Wayne Van Citters, Program Officer, Morris Aizenman, his boss, and Laura Bautz, Division Director. The peers were Jerry Nelson (UC Berkeley), Steve Beckwith (Cornell), Bob Tull (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 it went well and 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 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 realized it would have to request Q1 1986 dues from the members hoping that NSF money would be available by February or March, because funds were needed to keep the telescope and enclosure going. The telescope fabrication contract with L & F Industries of Los Angeles had a delay clause in it that could be activated beginning Feb 28 in exchange for a modest fee, but by mid-1986 ARC would have to dismantle the project and lay-off people, if no funding came through (Margon 1985e). Baldwin presented some 1986 budget alternatives at the December 10th Board meeting that 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 February 1, 1986, unless otherwise approved by the Board (BOG 1985).

On February 5, 1986 Margon sent a letter to the Board informing them that NSF asked ARC to consider a revised budget with a total of $3.3 million If ARC agreed the proposal would go to the National Science Board in April or May.

Given this funding situation Margon outlined some possible options, such as, cutting expenses by delaying instruments, increasing member dues, adding new partners, and asking NSF to grant funds far into future, then taking a loan against the future funds (Margon 1986a). On a conference call with Board members on February 14, Margon expressed delight with the grant, because it would be the largest ever by the astronomy program at NSF and it would be done in the face of Gramm-Rudman restrictions passed by Congress December 11, 1985 to cut spending through 1990 to reduce the federal deficit. On the call the Board discussed, but did not vote 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 on the critical path and they felt confident that the grant would happen (BOG 1986a).

NSF agreed to give $450K more, but insisted that ARC had to come up with another $750K to guarantee completion of the telescope (without instruments) to get any NSF money. Margon suggested approaching member administrations asking for the additional $2.05 million not granted by NSF, but "begging" for $750K now. UW and Chicago portions were $232.5K, Princeton and NMSU needed to ask for $120K and WSU's share was $45K (Margon 1986b). By March 21 all the institutions had guaranteed the $750K (Margon 1986c). Recognizing that a telescope without instruments was useless, York proposed that Chicago finish its two main instruments and charge ARC later and he proposed that ARC trade time for instruments (York 1986). At its May 6 - 7, 1986 meeting, the Board agreed with the suggestion to swap observing time (pro-rated 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 NSF, only the echelle spectrograph, the 2μ camera and a makeshift CCD camera could 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).

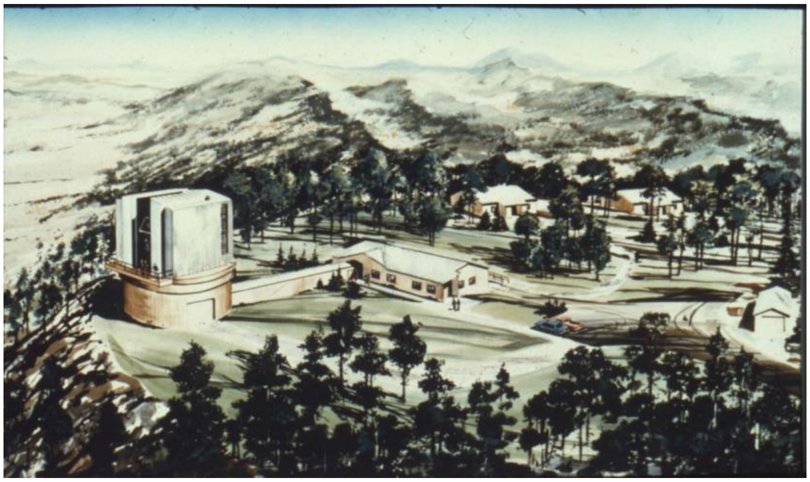

**Figure 4 - 1986 concept drawing of Apache Point Observatory. Courtesy of ARC.**

On July 11, 1986 NSF granted ARC $3.74 million with $890,000 paid in 1986 and $950,000 to be paid 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 imagined in Figure 4, 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 on 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 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.

## APO Design

The institutional goals, as noted earlier, are 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 call for a world-class facility with a telescope of competitive aperture. The science research conducted by the member institutions covers the full range of astronomy and astrophysics from planets and asteroids to the most distant galaxies and difficult cosmological questions. The science perspective, then, calls for a general-purpose design that can easily accommodate and adapt to a variety of uses. In addition, the U.S. astronomy community through its Astronomy Survey Committee process identified a number of priorities for the 1980's that were important to ARC astronomers. In particular, in section 4 on page 16 the report

> "… suggests the construction of an optical/infrared telescope in the 2 - 5 m 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." (N/A 1983)

The NSF proposal described, in 100 pages of detail, 49 planned projects by the faculty at member institutions that cover QSO's and the intergalactic medium, galaxies, and the Galaxy. Example projects are redshift determination 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, measuring the velocity dispersion of the stars in galaxies, and the determination of abundances in stars. These projects need ample telescope time that was not available at any public facility and not possible with the telescopes owned by member institutions at that time (York et al. 1984). The projects listed in the NSF proposal represented a small number of what was contemplated and many projects had not even been thought of yet (Gunn 2004). Astronomers hoped for an easily rescheduled telescope, because they wanted to be able to match projects to seeing conditions, they wanted to be able to respond to transient events like supernovae, which must be observed within hours, and they wanted to be able to follow-up on opportunities identified by the Hubble Space Telescope and other space telescopes.

Key design features developed by the original consortium with Howard back in 1981 carried through in the design submitted to NSF that was eventually built: lightweight mirror, low-cost enclosure, remote observing, and rapid instrument changes. In 1983 and 1984 Balick and the UW engineering group worked with the new consortium, now including scientists from Princeton and Chicago, to create a new conceptual design based on a 3.5 m mirror. They wanted to design the optics, structure, and dome so performance is only limited by seeing on the best nights. They needed to build instruments for a wide range of problems and provide rapid observing program changes, including instrument changes, to enable large routine surveys, programs that use sporadic really excellent conditions, and variable search work that only need small portions of a night (PU 1985). Remote observing was available at other observatories. 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 around a long time, if an astronomer wished to relinquish observing to another. The goal for APO was convenient and simple control of all aspects of the telescope and instruments by the astronomer him/herself. The real innovation, though, was flexible scheduling and timesharing, which allowed multiple observers to share a night instead of traditional schemes where one observer had a whole night or several in a row, even though the whole night was not required for the research (Mannery 2004).

### *Mirror*

Detailed specifications for the telescope and enclosure start with the 3.5 m, f/1.75, lightweight mirror. With the short focal length primary mirror, the overall telescope structure can be shorter and lighter and less mass in the mirror and telescope reduces noise from thermal heat. The secondary mirror gives a final focal length of f/10, but it is removable and can be swapped with an optional longer secondary (f/35) that is available for observations in the infrared. The flat tertiary mirror can be oriented to point the beam towards selected instruments that are already mounted and available. The optics follow a modified Ritchey-Chrétien design giving a 1/2° field of view and images smaller than 0.1 arcsecond. The Steward Observatory Mirror Lab was contracted to supply the primary and secondary mirrors (York et al. 1984).

In early 1983 Gunn heard of an opportunity to get an experimental mirror for free and sent word to Balick for follow-up. From 1980 to 1983 Roger Angel researched and developed a process for spin casting short focal length mirrors that grew into the Steward Observatory Mirror Lab located on the University of Arizona campus, eventually in a large space built under the bleachers of the football stadium. He wanted to create a production process for low-cost, lightweight mirrors. Angel's goal was to cast an 8 m mirror for a nationally funded new technology telescope. NSF had funded some of his effort and supported the plan for a large telescope. However, Angel needed to successfully cast smaller mirrors on his way to an 8 m one. He planned to cast a 1.8 m mirror in 1983 and expected to complete a 3.5 m mirror in 1986 and after that a 6.5 m one (McCray

2004). NSF funded the 3.5 m mirror in a separate grant to the Mirror Lab, but both Angel and NSF wanted the mirror used in an observing environment that would provide valuable feedback to the casting process before an 8 m mirror was attempted. Therefore, the mirror was available for free to the group with the best plans to use it (Hill 1988). Balick responded quickly, since ARC plans were already well under way. They had the best plans for the mirror; they were willing to take the risk on an experimental mirror; and they agreed to conduct tests of it.

After selection of the Angel 3.5 m mirror 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 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 (Anderson 1983).

### *Telescope*

The broad features of the telescope, shown in figure 5, did not change much from the 1981 version described earlier. Of course, it would be larger with a 3.5 m mirror, instead of the 2 m one, and more than four instrument locations fit on the larger mirror weldment. Still the moving mass was only about 30 tons, which is about 1/5 the weight of the conventionally designed Lick 3 m reflector (PU 1985). Engineers designed the telescope for 0.3-arcsecond image quality with wind speeds less than 20 mph and 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, Siegmund, & Hull 1986).

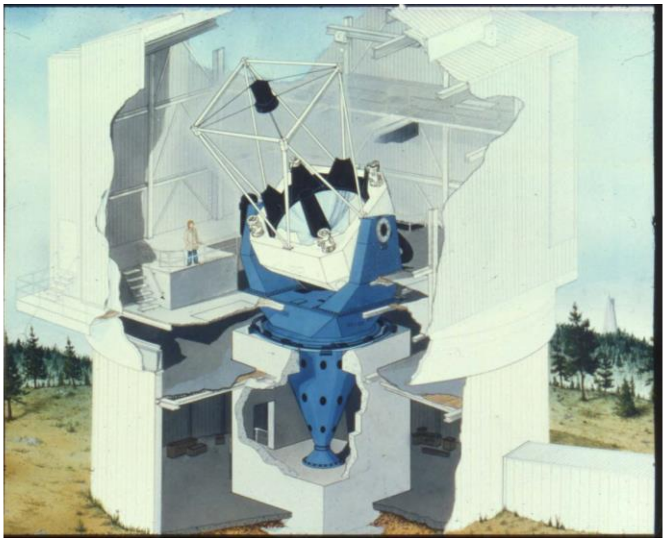

**Figure 5 - Cutaway view of the ARC 3.5 m telescope. Drawing by T. Asa Bullock, L & F Industries. Courtesy of ARC.**

The NSF proposal had 7 possible mounted instruments, by 1988 there were 9 slots - 2 at Nasmyth and 7 at 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 needed. A fourth mirror in the corners directs the beam to the top or retracts to let it pass to the corner port.

Plans called for one Nasmyth port to be permanently reserved for a large echelle spectrograph, while the other could have an instrument change accomplished in under 15 minutes by one person. A cart containing the new instrument made it easy to roll it into place. Since all the mounted detectors are continuously powered and ready to be used changing to one of these is expected to take no more than 5 minutes (Balick 1988).

*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):

- Echelle spectrograph with resolving powers ($\lambda/\Delta\lambda$) of 50K, 5K, and < 500
- Fabry-Perot narrow band spectrograph with imaging capability
- Direct cameras for photographic and CCD imaging
- Cooled IR/optical bench for a variety of IR sensors
- Photo-electric photometer
- Ronchi astrometry machine

As noted above, by the time of the NSF grant approval in 1986, most of these were put on hold until funding was available.

*Enclosure*

The fast primary mirror and altazimuth mount allowed a compact barn-like enclosure modeled after the Multiple-Mirror Telescope at Mt. Hopkins, owned by the Smithsonian Institution and the University of Arizona and dedicated in 1979 (NMSU 1985). Figure 6 demonstrates the size and, therefore, cost differences between this new design and conventional designs. The cube building opens wide 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 5). 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 exhausting the warm air through the covered walkway and 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 & Comfort 1986). The enclosure design supports the best possible seeing.

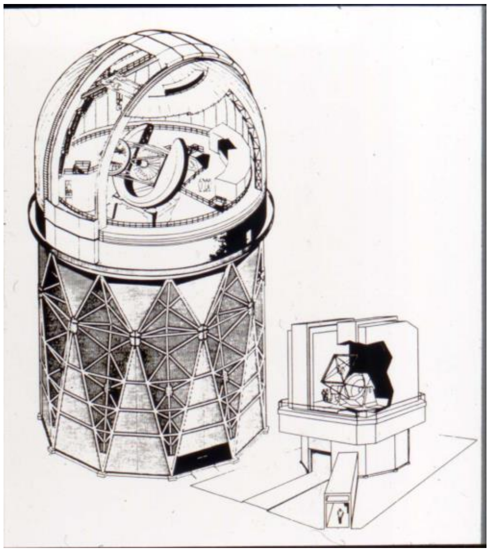

**Figure 6 - Size comparison between Mayall 4 m at Kitt Peak and ARC 3.5 m. Courtesy of ARC.**

## Building APO

After a period of intense design through 1984 and into 1985, ARC had solid plans for the site, the buildings, the telescope, the enclosure, and the instruments. Once the Forest Service granted the use permit, construction commenced in 1985 with the clearing of the site and the completion of the road (NMSU 1986), but major work was delayed until NSF funding came through. The building of APO went smoothly with few problems, except for long and costly delays in the delivery of the mirror and some instruments. David Nordfors of Seattle designed the telescope enclosure (shown under construction in Figure 7), which follows telescope design by six months, so the telescope design drives enclosure design and not visa 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 detail design of the telescope parts and then construct the telescope (Margon 1985f). Mesilla Valley Construction (Las Cruces) built the site buildings and infrastructure, Otero County Electrical Cooperative (Cloudcroft) put in the power lines and Sunshine Services (El Paso) did the roads (Anderson 2004). By November 1, 1987 contractors completed the telescope, enclosure, and support buildings and, after acceptance, ARC occupied the site in January 1988.

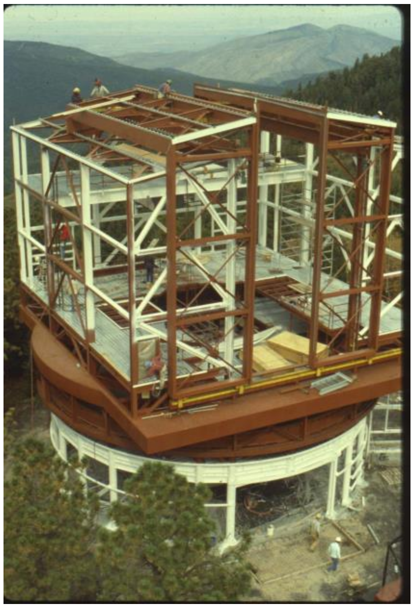

**Figure 7 - 3.5 m telescope enclosure under construction. Courtesy of ARC.**

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

### *Mirror Delay*

The real frustration came from the delay in the mirror. The NSF funding problem was only the first delay in a long wait. ARC originally expected the Mirror Lab to deliver the mirror in August 1985 with first light in 1987 (York et al. 1984). After signing a contract with the University of Arizona (operator of the Steward

Observatory Mirror Lab) for the 3.5 m mirror in August 1986, ARC scheduled first light for February 1988 (UC 1987). From then until mirror casting actually started in April 1988, ARC expected the casting to start at any time. Bulletin of the American Astronomical Society Annual Reports by the member institutions from 1985 through 1988 (sadly) give continually later dates. The process for casting the mirror was complicated and it had not been done before. The Mirror Lab cast its first mirrors in April and August of 1983. These were 1.8 m mirrors for the University of Calgary and the National Optical Astronomy Observatory (NOAO) done in a non-rotating furnace. In March 1985 it cast its next mirror and the first using a rotating furnace, a 1.8 m 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 a 1.2 m mirror for the Smithsonian Astrophysical Observatory cast in November 1987. Casting for the ARC 3.5 m 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 Ohara Corporation of Japan, were placed on top of the mold and melted by heating up the furnace (Lampis 2000). After about a month of heating 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 about 8.5 revolutions per minute. After 20 hours engineers peeked inside the furnace to check progress and then stopped the spinning about 13 hours after that, when the mirror was cool enough to hold its shape. It took another six weeks for the mirror to anneal (cool and temper). Figure 8 shows ARC and Mirror Lab personnel inspecting the just cooled mirror on June 27, 1988. After inspection, engineers used water jets to wash the mold material out of the mirror. Then they cleaned it up and delivered it (McCoy 1988).

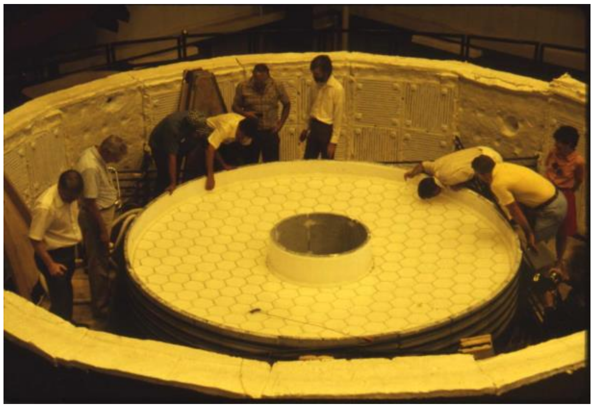

**Figure 8 - ARC 3.5 m mirror fresh out of the oven. Photo by E. Mannery. Courtesy of ARC.**

Spun mirrors have the short focal length desired by ARC and Roger Angel's other clients. Casting the ARC 3.5 m was a critical step in the Mirror Lab's progress to 8 m mirrors. Angel says problems were not with technology, but with inexperience in managing large projects. Handoff 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 delay of the mirror grew a beard and proclaimed, "when the beard comes off, the mirror has been delivered" (Erickson

1988). A happy York shown in Figure 9 gets his beard shaved off by Roger Angel. The 3.5 m mirror is in the background. Roger Angel, calling it a perfect 10, delivered the mirror on August 10, 1988 (Erickson 1988). On August 11 ARC moved the mirror to the optical shop of Norman C. Cole, Arizona Technologies, Inc., for generating and polishing (UC 1989). As it turns out, York should have waited to shave his beard.

Assuming it would take 18 months to polish and install the mirror, ARC astronomers now projected first light in early 1990 (Balick 1988). Because of the mirror delay, instrumentation and programming were also stretched out. Telescope and enclosure testing and shakedown, however, continued even without the mirror. During fall 1989 NOAO, the Magellan Project, Steward Observatory, NSF, and ARC collaborated on thermal control tests using a dummy honeycomb mirror segment. ARC agreed to these tests when it acquired the mirror for free. Scientists studied thermal control under operating conditions at APO through April 1990. The tests showed that thermal surface deformation would be less than 0.2 arcseconds in all but the worst nights (York 1991), validating plans for 8 m mirrors.

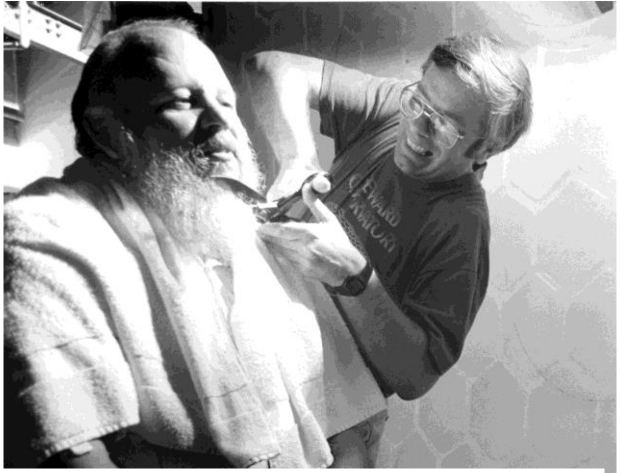

**Figure 9 - Roger Angel shaving Don York with the 3.5 m mirror in the background. Photo by E. Mannery. Courtesy of ARC.**

*Temporary Mirror*

An even more interesting test came from borrowing the University of Calgary's 1.8 m mirror, the first mirror made by the Mirror Lab. The idea for this came up in late1987 as the observatory construction ended and the mirror was still unpredictably delayed. It turns out Calgary had a mirror, but no telescope and ARC had a telescope without a mirror. In exchange for borrowing the mirror, ARC paid for it to be generated, polished, and aluminized. The mirror arrived on June 19, 1990 and was installed by March 1991 (N/A 1990; ARC 1992). 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 m primary mirror (UC 1991). Besides being used for an engineering shakedown and refinement of the software written to remotely control the telescope, enclosure, and instruments (ARC 1992), from February to October 20, 1992 full remote operation was carried out from the campuses of member institutions using a CCD camera, a guide camera, and an infrared imager. Observing with the mirror successfully tested key goals of rapid instrument change and a shared nightly schedule with observers from different campuses (ARC 1993). APO even had its first publishable results from observations of the cataclysmic variable HV Virginis by Szkody and Ingram (1992; Ingram & Szkody 1992; UW 1993). Turner tested the synoptic advantages of the telescope by capturing sixty light curves over three months of gravitationally lensed Q2237+0305 (PU 1985). Images with the 1.8 m mirror confirmed the expected good seeing of the site and the benefits of the enclosure design (ARC 1992).

*Delivery and Installation*

By early 1990 Norm Cole completed rough generation and began polishing the 3.5 m mirror. When the mirror was delivered to him in 1988, ARC scientists predicted the mirror would have seen first light by now. Cole had a small, but good shop. This project stretched his capabilities, though, because the curvature changes quite a bit from point to point on a short focal length mirror. When he was chosen, 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 m 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, 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 coated with aluminum at Kitt Peak on September 15, 1992 and arrived at APO on September 18, 1992. The process of installation began on October 20, 1992 (ARC 1993). The secondary, also cast by the Mirror Lab, was delivered to Optical Sciences Center in February 1992 and completed in January 1994. While waiting for the secondary and tertiary mirrors, the 3.5 was operated at prime focus with a simple detector to exercise and refine operations. Three-mirror first light happened on April 5, 1994 and the dedication of Apache Point Observatory was held on May 10, 1994 (ARC 1995).

**Figure 10 - The completed ARC 3.5 m telescope. Courtesy of ARC.**

*Dedication*

In early 1993 with the primary mirror on site, but still waiting for the secondary and tertiary mirrors, ARC set a date for the dedication. A rare annular solar eclipse would pass directly over Apache Point in just a little over a year. Although it would be a challenge to get ready, they had to do it (Gillespie 2004). The 3.5 m, the 14th largest telescope in the world at the time, was dedicated on May 10, 1994 before an invited group of about 300. The eclipse took place at 10:30 am, during which Don Jennings and Drake Deming, guests from Goddard Space Flight Center, imaged solar spectral lines with their 12-μ spectrometer. The telescope remained in operation until August as astronomers and students trained to use remote observing (ARC 1995).

Luckily, instruments were available. The dual imaging spectrograph (DIS) built by Jim Gunn took its first images in April, barely making the dedication. It has since become the observatory workhorse (York 2004; Anderson 2004). The near infrared spectrometer and imager built by Mark Hereld (Chicago) and a drift scan camera (DSC) built by Tim McKay at Fermi Lab were also being tested (ARC 1995). The echelle spectrograph turned out to be more difficult to make and had to be rebuilt, so it was unavailable, although it eventually returned and now performs above initial expectations (York 2004; Anderson 2004). In July, as part of a coordinated effort with other observatories, intense (up to 18 hours a day) observing of Comet Shoemaker-Levy 9's impact with Jupiter fully exercised the telescope (ARC 1995).

The new optics showed performance problems, however. Earlier tests with just the primary mirror installed beat performance expectations. Tests with all three mirrors did not and the problem was traced to zones on the secondary. 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. The ARC 3.5, shown in Figure 10, commenced full-time science observations in November 1994 (ARC 1995).

### Sloan Digital Sky Survey (SDSS)

At the time of the dedication, APO was home to three other telescopes: the NMSU 1.0 m telescope dedicated the same day, the SDSS 2.5 m telescope, and the SDSS 0.6 m telescope, both under construction at the time. SDSS is a very successful project led by ARC and located at APO. It deserves its own history, but will get a brief description here, because its roots reach early into ARC's history. In fact in May 1988 Rice, then interim Chair of ARC, sent a letter to Board members saying ARC needed a process to allocate and approve space for other telescopes at APO. York had sent a proposal to NSF for a dedicated 3.5 m telescope for a cosmology program and UW and Princeton were getting more serious in their desire for a 2.5 m telescope for a survey they started discussing in 1982 (Rice 1988). At the October 23 - 24, 1989 Board meeting the members discussed the 2.5 m 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 and Chicago (BOG 1989). IAS actually joined in December 1990, when ARC formed a subcommittee to investigate building the second telescope (UW 1991, 1992). In the fall 1991 this grew into an additional collaboration of ARC with other institutions that was funded by the Alfred P. Sloan Foundation and named the Sloan Digital Sky Survey (SDSS). John Hopkins University (JHU) joined the consortium in June 1992 to be part of SDSS. IAS and JHU joined ARC, but do not share in the time or expenses of the 3.5 m telescope (ARC 1994). UW did not join SDSS until 1994, even though it had a lead role in the project. NMSU joined in 2000, but WSU never joined SDSS. The SDSS telescope is dedicated to the survey, so membership in it gives access to the data, not telescope time. Although a number of other institutions from around the world have joined SDSS, they are not members of ARC. Today, the other members of SDSS are: 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 (MPIA), the Max-Planck-Institute for Astrophysics (MPA), University of Pittsburgh (Pitt), and the United States Naval Observatory (USNO) (N/A 2004). Appendix B 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 $3^o$ 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 as it drifts by. 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 universe. In addition, many other objects will be found, such as supernovae, brown dwarfs, and asteroids (PU 1994; ARC 1994). Originally, first light was expected in 1995 and the survey completed by 2001 (UC 1995). Major site improvements at APO for SDSS were completed in summer 1993 (UW 1994). Because of the challenges with the components individually and as an integrated package, the survey did not start until April 2000. By the time of its anticipated completion in June 2005, SDSS will have captured a wealth of observations and discoveries that will continue to contribute benefits for years.

## Celebrate Success

With SDSS in full operation and Apache Point providing ample observing time to astronomers and students, ARC celebrated its achievements on May 27, 2004, the 20th year of its existence and the 10-year anniversary of the dedication of the 3.5 m telescope. The accomplishments: creating a thriving organization, building a world-class observatory, and fulfilling its goals of building strong astronomy departments and doing great scientific work.

Organizationally, ARC proved sturdy enough to withstand the vicissitudes of long-term projects, the formation of a complex sub organization (i.e., SDSS), and even a membership change in July 2001, when WSU sold its share to the University of Colorado at Boulder. 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 UW a few years later. Without these two observational astronomers and ARC founders, the costs outweighed the benefits and WSU sold its share, smoothly transitioning participation to Colorado (Lutz 2004). For the other members, ARC and APO worked as planned. By the end of the second full year of operation in 1996, 200 astronomers and students had been certified to operate the telescope remotely (ARC 1997) and by 2004 members could say that having the 3.5 m telescope made their departments attractive to faculty, students, and grants (York 2004; Anderson 2004; Balick 2004). In particular, students benefit from it, because there is time available to them and they do not have to find ways to fund travel to an observatory. They can do their work remotely from home.

Astronomers and students do a variety of work at APO, producing results in a range of astronomy sub-disciplines. The anniversary celebration in 2004 included talks with topics like "APO Insights into Cataclysmic Variables", "Observations in Support of HST", and "A Decade of Planetary Science with the APO 3.5 m Telescope" (ARC 2004). A search for "Apache Point" on NASA's ADS server on September 14, 2004 resulted in 247 articles. 159 of them were selected when that search was limited by "3.5". Many projects at APO are multiwavelength and collaborative, which the ARC 3.5 m is very good at, but its contribution not specifically cited (Lutz 2004), for example asteroid detections as part of Spacewatch Projects or the impact of the comet into Jupiter mentioned earlier. Some do show up in published papers, though. Anderson was part of a large collaborative effort monitoring the temporal behavior of radio galaxy 3C390.3 obtaining images and spectra using the DIS on ARC 3.5 at 10-day intervals (O'Brien et al. 1998).

Flexible scheduling, both for unexpected opportunities and for long-term programs, separate APO from other facilities and give ARC astronomers a distinct benefit. Advantageous scheduling of the ARC 3.5 m enabled optical spectra collection along with International Ultraviolet Explorer data during the 43-day super outburst cycle of ER Uma (Szkody et al. 1996). Rapid instrument change made it possible to observe the optical afterglow of Gamma-ray Bursts (Margon et al. 1997). ARC astronomers can commit to long-term programs using APO that would be impossible to do competing for time in the telescope "marketplace". These kinds of projects yield important results. Turner and colleagues at Princeton and APO conducted a synoptic gravitational lens program consisting of 1/2-hour observations every other night that started later and later as the program progressed. Actually, the initial observations were done with the 1.8 m that resulted in a prediction of time delay for the 1996 image B light curve

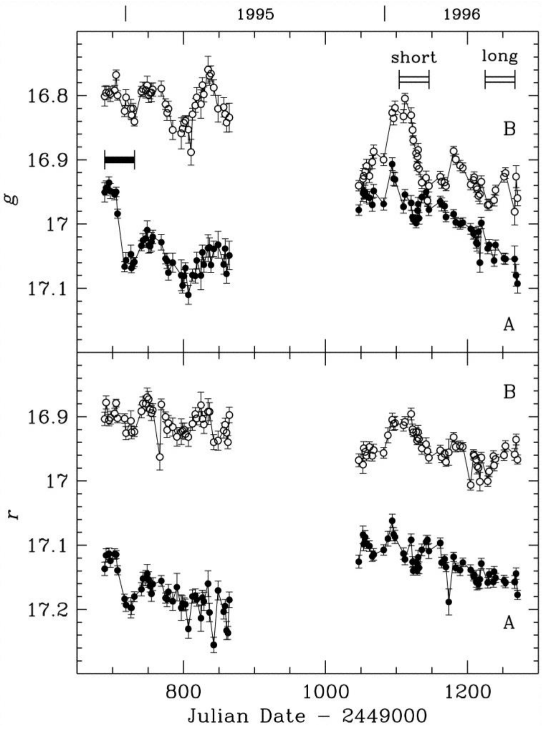

**Figure 11 - Observations and predictions of time delay for the gravitationally lensed quasar 0957+561 (Kundic, T. et al. 1997).**

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, Figure 11, shows the 1995 prediction and the 1996 observation. In another example, Professors Reiss, Diercks, Stubbs, and Hogan joined an international effort with the High-z Supernovae Search Team to study and monitor high redshift supernovae using the ARC 3.5 m (UW 1996).

The wide range of astronomer interests at member institutions results in a variety of research. Greenawalt and Walterbos made the first detection of oxygen lines in a truly diffuse medium, confirming the expected strength of O[II] and the weakness of O[III] (Walterbos, Greenawalt, & Braun 1996). Walter and Marley used the infrared camera to show evidence of substantial haze at Uranus's south pole and that it had brightened in recent years (Walter, Marley, & Baines, 1996). E. Kibblewhite and his group at Chicago installed developmental adaptive optics instruments on the ARC 3.5 m telescope, including a laser beam for artificial sodium stars. Promising results of image size improvement (from 1 arcsecond to less than 0.2 arcseconds) indicate good progress (Shi et al.1995; Larkin & Kibblewhite 1998). Interestingly, APO's work with local officials led to a national level discussion involving several large observatories and government agencies to develop guidelines for the safe use of laser guide systems (ARC 1997).

Some of the most exciting results at APO have come from the combination of SDSS and the ARC 3.5 m. For example, the infrared camera on the ARC 3.5 m, following up on SDSS commissioning data, found some of the highest redshift QSOs in the universe at the time (Fan et al. 1999) and the first field methane brown dwarf (Strauss et al. 1999). Further spectral analysis of the distant quasars with the ARC 3.5 m telescope and at the Keck Observatory led ARC scientists to announce the detection of a Gunn-Peterson Trough at redshifts of $z > 6$ and evidence of reionization at $z = 6$ (Fan et al. 2000; Becker et al. 2001).

Ultimately the continued success at 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 confirmed by continual and extensive monitoring. From 1997 to 2000 APO implemented an aggressive plan to improve telescope performance by replacing the secondary mirror, which never 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, ARC is beginning to discuss future telescopes and instruments for the Apache Point Observatory. Don York is heading a Futures Committee. He sees APO completing a number of large surveys that are in progress, such as SDSS and now SDSS II, but also initiating new ones. Survey follow-up can be done with the current equipment, but they will also explore building a 6 m class experimental telescope (York 2004). That member institutions look to ARC to provide for their future observing resources is a testament to its success.

## Conclusion

Despite bumps along the long road to build the Apache Point Observatory, ARC successfully completed a world-class telescope for its members that strengthens their astronomy programs and that contributes valuable scientific data and discoveries, advancing our knowledge of the universe. Bigger and better tools make a difference. Those built by the U.S. national observatory provide a valuable service that cannot be underestimated, but they do not easily accommodate long-term programs, so important to university astronomy departments.

The University of Washington initiated the effort to build a world-class observatory, but the other members were searching for the same thing, so Wallerstein and Balick's message resonated with them. Turning an idea into reality took the efforts and talents of all of the members. Early board members led by Margon and Baldwin formed the Astrophysical Research Consortium, a sturdy organization that unified different member interests and created a process for long-term cooperation. This new organization faced difficult challenges in funding and budgeting, nevertheless it succeeded and moved on to tackle other projects desired by its members, such as SDSS.

Building the observatory, though, demanded the most from these institutions. Of course observatories have been built before and ARC learned from those experiences, but an observatory does not follow a cookie-cutter design. It is a unique project. APO was driven by the goals of convenient remote observing, rapid instrument changes, and flexible scheduling. York guided this enormous project to a successful conclusion by managing work spread out among all of the member institutions and a number of vendors, including Angel's experimental mirror that was at once the central piece and the timing factor. Having the telescope helps member astronomy departments, but building it did, too, because it exercised and developed the skills and talents of astronomers at all of the institutions. Anderson and NMSU faculty selected, prepared and manage the site. Gunn at Princeton, Harper at Chicago and their colleagues built leading edge instruments that had to work with remote observing and rapid changes. Balick, Mannery, Siegmund and colleagues at UW designed the advanced technology telescope and enclosure. All of those who worked to create the consortium and build the observatory can feel immense pride and satisfaction for what is probably a once-in-a-career type accomplishment. It is unlikely that they will rest on their laurels, though, as they are already looking to the future.

## Acknowledgements

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## Appendix A - ARC Board of Governors 1984 - Current (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.

| Princeton | Chicago | UW | NMSU | WSU | JHU | IAS | UC-Boulder |
|---|---|---|---|---|---|---|---|
| Ostriker | Rice | Baldwin | Beebe | Lutz | Heckman | Bahcall | Peterson |
| Sinisgalli | Rosner | Margon | Darnall | Radziemski | Poehler | Rowe | Shull |
| Gunn | Schramm | Hogan | Burnes | Spitzer | | | Barker |
| Tremaine | Oxtoby | Kwiram | Casillas | Brown | | | Pampel |
| | Konigl | Balick | Adams | Miller | | | |
| | Turner | Irving | Dwyer | | | | |
| | Olinto | | Walterbos | | | | |
| | Fefferman | | Paap | | | | |
| | | | Czerniak | | | | |

*Provided by Mike Evans, ARC.

## Appendix B - SDSS Advisory Council 1995 - Current (by institution)*

| Chicago | Princeton | FNAL | IAS | JPG | JHU | USNO | UW |
|---|---|---|---|---|---|---|---|
| Rice | Ostriker | Peoples | Bahcall | Fukugita | Heckman | Johnston | Baldwin |
| Schramm | Sinisgalli | Nash | Rowe | Ikeuchi | Poehler | Pier | Margon |
| Rosner | Gunn | Kolb | | Okamura | Davidsen | | Hogan |
| Turner | Tremaine | Stanfield | | Sekiguchi | | | Parks |
| Oxtoby | | | | Ichikawa | | | Hawley |
| Fefferman | | | | Suto | | | Irving |

| NMSU | MP | Pitt | LANL |
|---|---|---|---|
| Walterbos | Rix | Jasnow | Press |
| | White | Turnshek | |

*Provided by Mike Evans, ARC