Telescopes from Afar

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Abstract

Fully robotic telescopes at the Fairborn Observatory, which began operation in 1983, have been in continuous operation for a quarter century. Although initially confined to smaller telescopes, automation and remote access have now spread to the largest telescopes. Due to the high cost of transportation, many large telescopes, such as Keck, are now being operated remotely by astronomers in real time. Others, such as the Canada-France-Hawaii telescope, are being operated autonomously without any onsite staff. A recent conference, *Telescopes from Afar,* allowed a contrast to be made between early automation and remote access developments at the Fairborn Observatory and the current state-of-the-art in these areas for both small and large telescopes, as well as consideration of a recent development—networks of small automated telescopes.

1. Introduction

For most of the past four centuries astronomers have observed through their telescopes in person. For several hundred years this was eyeball-at-the-eyepiece observations until, gradually, film cameras were employed to accumulate photons over much longer time intervals than was possible with human eyes. Now CCD cameras, with their superior quantum efficiency, have recently replaced film cameras. For most scientific observations, visual astronomy is now a thing of the past.

Until the last century, not only were astronomers present in person with their telescopes but telescopes were located at universities or the astronomer's residence—rarely ideal locations from the viewpoint of weather, seeing, or light pollution. Beginning with observatories in the western United States—such as Lick, Lowell, and Mt. Wilson—telescopes were increasingly placed at locations chosen for their clear weather, dark skies, and superior seeing. This ushered in the modern era of giant mountaintop telescopes. Observational astronomers either traveled to these mountaintop observatories, spending their nights in freezing cold domes, or they hired on-site observers to make the observations for them.

With the advent of microcomputers, telescopes were increasingly brought under computer control, not only allowing in-person observers to control telescopes from nearby warm rooms but also allowing microcomputers to completely control telescopes and entire observatories on their own. As Internet bandwidths increased, real-time human telescope control from remote "virtual warm rooms" became possible. Although some astronomers still travel to remote mountaintop observatories to obtain their data in person, this task has, increasingly, been either delegated to automated systems or conducted remotely by astronomers located at low elevation base camps or at university campuses thousands of miles away.

We have now entered the era of "Telescopes from Afar." This era began with small, fully robotic, autonomous telescopes making photometric observations. Prior to powerful microcomputers and wide Internet bandwidths, differential aperture photometry with small telescopes was the least demanding to automate. Thus it is not surprising that early developments arose in this area. Real-time remote access and observational modes beyond simple differential photometry became possible as microcomputers became more powerful, CCD cameras appeared on the scene, and Internet bandwidths increased by orders of magnitude,. The observational revolution that began with small telescopes is now spreading to ever larger telescopes.

2. The Telescopes from Afar Conference

For about a dozen years (1979-1991) I participated, along with Louis Boyd and many others, in the development of autonomous robotic telescopes and then remote access to these telescopes via the Internet. When I retired, now some two decades ago, I moved on to my other interests. These included cosmic evolution (the synthesis of physical, biological, and cultural evolution), teaching astronomy, and travel to various places—New Zealand being a favorite. Of course the development of robotic and remotely accessed telescopes continued at a rapid pace without my participation. Recently I became curious to learn how these developments had fared over the past two decades. I figured one way to satisfy my curiosity was to organize a conference on robotic observatories.

Since I spend winters in Hawaii, I thought a good place to hold such a conference was on the Big Island so that attendees could not only visit the telescopes on Mauna Kea but take a winter break on the sunny beaches north of Kona. Lacking a current knowledge on robotic telescopes, I enlisted the help of Josh Walawender at the University of Hawaii's Institute for Astronomy. Josh was automating two small telescopes on Mauna Loa. Together, we visited Sarah Gajadhar, the Project Engineer developing remote access and automation of the 3.5-meter Canada-France-Hawaii Telescope (CFHT) on Mauna Kea. We three decided to co-chair the conference. Sarah took the lead with strong support from the CFHT's Director, Christian Veillet, and the CFHT staff.

The conference, *Telescopes from Afar,* was held at the Waikoloa Beach Marriott February 28-March 4, 2011. The conference featured 42 talks, 32 posters, and well over 100 attendees, including representatives from most of the major observatories around the world. The conference's PowerPoint talk slides and written papers are available at www.tra.cfht.hawaii.edu.

Figure 1. Telescope from Afar attendees gather on the lawn at the Waikoloa Beach Marriott.

Rather than attempting to summarize the *Telescopes from Afar* conference, I will provide a personal perspective on the early days of automation and remote access at the Fairborn Observatory, and then consider how, some two decades later, these areas have progressed—providing a few examples from the conference. I will close with a brief discussion of networks, something we only dreamed about in the early days.

3. Early Automation and Remote Access at the Fairborn Observatory

In 1979 I founded the Fairborn Observatory and began making photometric measurements of variable stars. From the outset I used a small microcomputer, the Radio Shack TRS-80, to reduce the observations (Genet 1980, Hall and Genet 1981). Soon I was able to log data from the photometer directly into the TRS-80. I then added TRS-80 control of the filter wheel via a small stepper motor, and instructions to the observer via a remote monitor. A remote keypad allowed me, as the observer, to key in responses (Genet 1982).

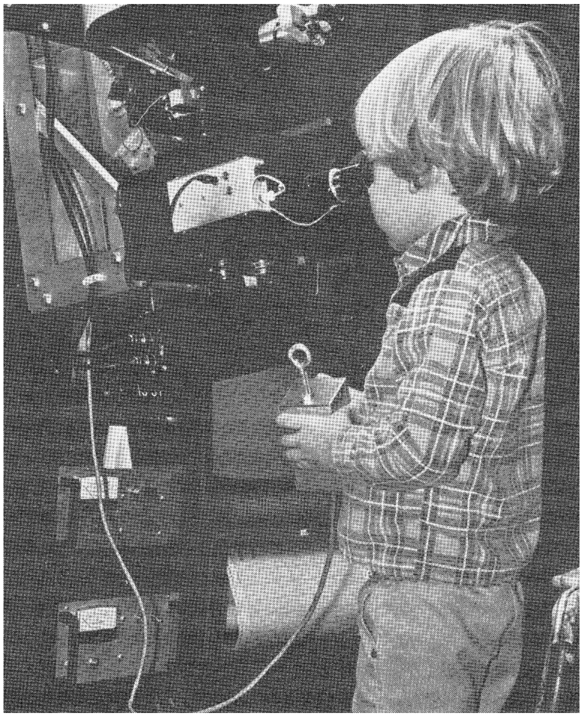

Figure 2. Russ Jr. (1979) centers a star at the Fairborn Observatory's first telescope. The UBV photometer, DC amplifier, high voltage power supply, and strip chart recorder are visible.

As the observational process was repetitive, boring, and kept me up at night, I decided that the remaining steps—finding and centering stars—should be automated so I could get a good night's sleep.

In 1981, during a visit to Arizona, an amateur astronomer, Jeff Hopkins, kindly introduced me to a number of Phoenix-area photometrists, including Louis Boyd. Lou had been helping Richard and Helen Lines with photoelectric equipment at their observatory in Mayer, Arizona. Richard operated the telescope, while Helen recorded the observations. Lou kept suggesting how various portions of the process could be automated.

Figure 3. A Radio Shack TRS-80 microcomputer) was used for data reduction. Also shown are a thermal printer, modem, and (upper left) a floppy drive.

Content with their smooth two-person manual operation, Helen told Lou that they were not interested. If Lou wanted an automated system he should go build his own, which Lou immediately set out to do. Having a common goal of full automation, Lou and I joined forces under the rubric of the Fairborn Observatory (east and west).

What we developed was simple low-cost automatic photoelectric telescopes (APTs) that did not even have (expensive for us) position encoders. Each axis was driven by a stepper motor under computer control. The photometer not only measured the brightness of stars but, via the Hunt and Lock routines we devised, was able to find and center stars (Genet and Boyd 1984).

A symmetrical sequence that involved 10 slews and some 33 individual 10-second observations was made of the variable, comparison, and check stars and a sky background in a "group" to obtain differential photometric magnitudes in three colors. The entire sequence, which involved hundreds of small telescope movements, took about 11 minutes to complete (Boyd, Genet, and Hall 1985).

In a typical winter night, about 50 groups could be observed, involving the finding and centering of over 400 stars and many thousands of small movements. The two initial Fairborn Observatory robotic telescopes (the Phoenix 10 and Fairborn 10) continued to operate for over two decades, each finding and centering about 3 million stars and making over 8 million 10-second integrations.

Initial automatic operation was achieved at the Fairborn Observatory (west) in October 1983 with Lou's Phoenix 10 telescope, located in his backyard in Phoenix, Arizona. I achieved automatic operation at Fairborn Observatory (east) some six months later with the Fairborn 10. Details were provided in my book with Mark Trueblood, *Microcomputer Control of Telescopes* (Trueblood and Genet 1985).

Figure 4. Russ, Lou, and the Phoenix 10 robotic telescope pose before its first full night of automatic operation on October 13, 1983.

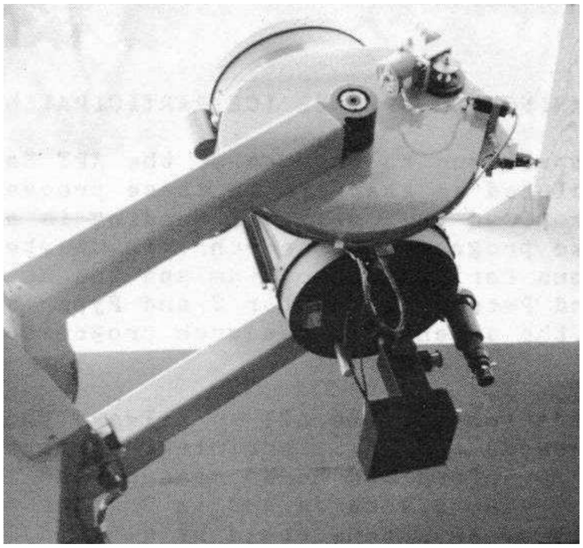

Figure 5. Russ assembled the Fairborn 10 robotic telescope from a DFM Engineering mount, Meade 10-inch Schmidt Cassegrain optics, and an Optec SSP-4 VRI photometer.

In 1985, I attended the winter meeting of the American Astronomical Society held that year in Tucson, Arizona. One afternoon during the meeting, Sallie Baliunas—an astronomer at the Harvard-Smithsonian Center for Astrophysics—took Lou and me on a tour of the Smithsonian Astrophysical Observatory and the Multiple Mirror Telescope, both on Mt. Hopkins south of Tucson, about half way to the Mexican border. We fatefully drove past an unused roll-off-roof building that Sallie explained to us had been used for satellite tracking with a laser ranger and a Backer Nunn camera.

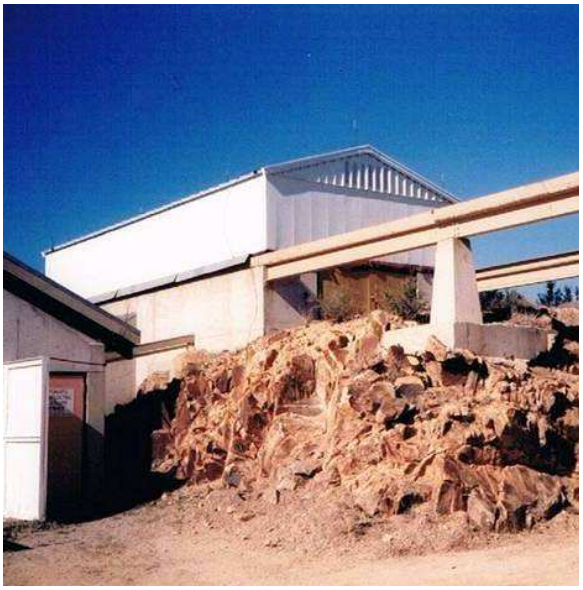

Figure 6. Located at 8010 feet elevation on the top of a ridge between the Multiple Mirror Telescope and the Fred L. Whipple Observatory, the Fairborn Observatory telescopes were housed in a roll-off roof.

A few months later I visited David Latham, the Director of the Smithsonian Astrophysical Observatory. We agreed that the unused satellite tracking station would make an excellent home for our robotic telescopes. A ten year agreement was drafted that defined the Automatic Photoelectric Telescope (APT) Service, a joint undertaking by the Fairborn Observatory and the Smithsonian Astrophysical Observatory (Boyd, Genet, and Hall 1986, Genet *et al* 1987).

The Smithsonian Institution would provide the facilities, utilities, and use of 4-wheel drive vehicles to negotiate the steep dirt access road. The Fairborn Observatory would provide and operate the robotic telescopes. My Fairborn 10 telescope, moved to Arizona from Ohio, would be devoted to Sallie Baliunus' solar-type star research program to provide photometric VRI measurements to compliment her spectroscopic observations being made with the historic 60-inch telescope on Mt. Wilson.

When Dave notified us that the Secretary of the Smithsonian Institution had approved the agreement, Lou and I had my Fairborn 10 robotic telescope bolted down to the floor of the observatory in less than 24 hours. Soon we moved the laser ranger out of the way and also bolted Lou's Phoenix 10 telescope to the floor.

After I gave a talk on our robotic telescopes to the Astronomy Division at the National Science Foundation, they suggested we submit a proposal for a third robotic telescope. We teamed up with Doug Hall to propose a 16-inch telescope that was soon built by DFM Engineering. The Fairborn Observatory provided the control system.

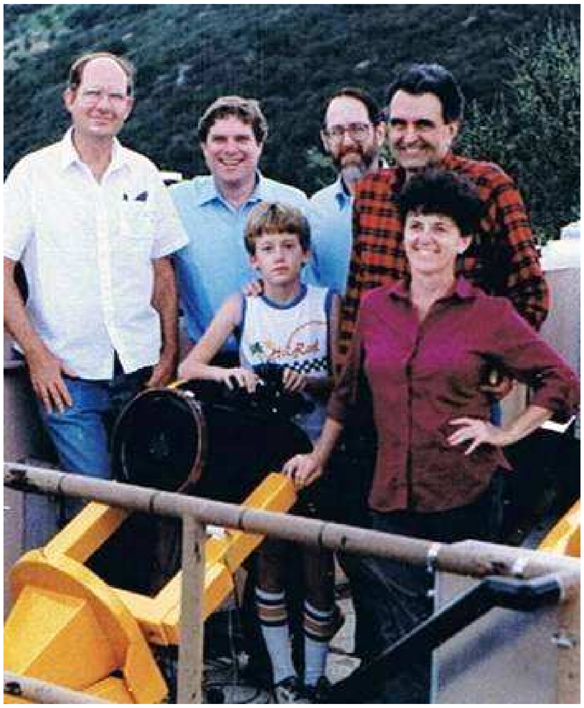

Figure 7. Russ' Fairborn 10 robotic telescope was the first to be installed at the Automatic Photoelectric Telescope (APT) Service on Mt. Hopkins in 1985. Left to right (back row): Russ, Don Hayes, Doug Hall, and Ken Kissell. Front row Russ Jr. and Judith Kissell.

For over a year Lou and I spent most of our weekends and vacations on Mt. Hopkins. We operated the robotic telescopes while we were there and worked on automating the observatory itself so we would not have to continue making the long, four-hour drive from Phoenix to our observatory. We designed and built the weather sensors ourselves, modified the northern wall of the observatory to tilt down—thus giving our telescopes access to the northern skies—and installed a large bank of batteries in our control room to power the closure of the five-ton roof when commercial power failed (which was not unusual).

A microcomputer was dedicated to reading the weather sensors, checking the roof and telescope's limit switches, controlling the roll-off roof and tilt-down wall, and authorizing the robotic telescopes to observe or commanding them to park. The observatory control computer also kept a log of the commands it issued, weather sensor readings, and the status of each telescope.

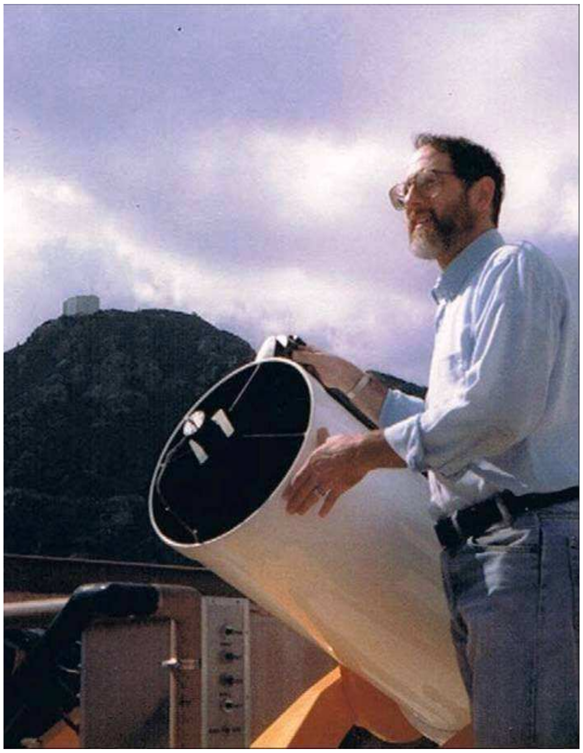

Figure 8. The Vanderbilt 16 (shown with Doug Hall) was funded by the National Science Foundation. The Multiple Mirror Telescope can be seen in the background.

While our telescopes normally operated reliably, not really knowing what was happening at our observatory began to drive us nuts! To reduce our worries, we devised what we called a "Morning Report." Every morning, after the observatory control computer had parked the telescopes and closed the roof, it initiated an Internet call to us and downloaded a summary of the previous night's operation in terms of weather, observatory control commands, and how successful each telescope had been in making its observations.

By 1987 we had a smooth running operation. Once a list of program stars (and the attendant comparison stars, check stars, and sky locations that formed a group) was loaded on a telescope along with group observational priorities, whether or not they should be observed with respect to the moon being up, etc., the telescope would itself choose the groups to observe. Various rules such as "first to set in the west" and "nearest the meridian" could be associated with each group; thus this was not a rigid observational sequence list but rather a quasi "artificial intelligence" approach (although the "intelligence" of the telescopes was limited by the slow speed and small size of our computers).

Loading new stars only infrequently and letting the "AI" program manage observations worked well for relatively fixed observing programs such as Sallie Baliunus' solar-type stars on my Fairborn 10, or Greg Henry and Doug Hall's spotted eclipsing binary program on the Vanderbilt 16. It did not work so well on Lou Boyd's Phoenix 10 telescope which had a mix of often short-duration observational requests from multiple observers in our "rent-a-star" program where groups (33 separate observations taking a total of about 11 minutes) were observed for $2 per group.

It was time-consuming to keep up with the changing requests and interface with the multiple Phoenix 10 users. We did, after all, have an observatory to run, not to mention fulltime jobs. This difficulty was resolved by assigning a "Principal Astronomer" (PA) to each telescope. Mike Seeds kindly volunteered to be the PA for the troublesome Phoenix 10 telescope. He handled the interface with all of its many users, resolved observational conflicts, provided us now and then with a consolidated observational program, provided the multiple users with uniform data reduction, kept an eye on the quality of the data, and collected the modest $2 fee for each group successfully observed (Seeds 1989, 1992).

This worked well indeed, and every telescope from then on was always assigned to a single PA. Mike was the PA for the Phoenix 10 for over two decades, serving dozens of users, including many students—a major contribution to science, education, and automated astronomy.

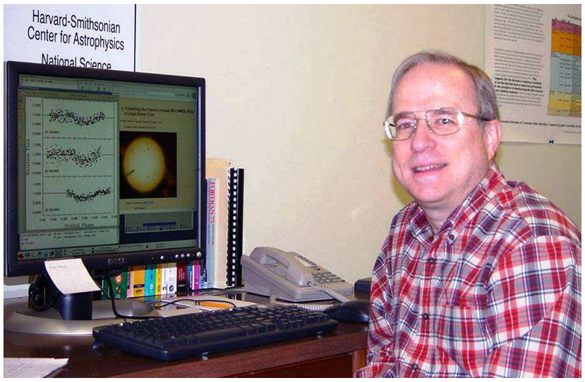

Figure 9. The robotic telescopes at the Fairborn Observatory on Mt. Hopkins were managed remotely by Principle Astronomers (PAs). Greg, who has managed multiple remote telescopes at the Fairborn Observatory for over a quarter of a century, is the planet's most experienced user of robotic telescopes.

Four times a year we mailed a floppy disk with a quarter's worth of data to each PA. We were always concerned that some equipment degradation that subtly ruined the data would not be discovered until the PA reduced the data.

While this never happened, it did inspire us to devise a procedure and high level language—the Automatic Telescope Instruction Set (ATIS)—that allowed the PAs to send in observational programs via the Internet. Each morning after observatory shut down, the previous night's observations were automatically sent to them, also via the Internet, for immediate reduction if they so desired (Boyd *et al* 1993, Henry and Hall1993, and Henry 1996). Bandwidth requirements for aperture differential photometry were modest (unlike imaging observations), and were readily handled by the Internet in its early days.

Although the precision of our automated photometry was good, it was not as good as the very best manual photometry such as that produced by Wes Lockwood at Lowell Observatory. Not to be outdone by mere human observers, I organized two workshops on "Precision Automated Photometry." Under the guidance of Andy Young, a photometry expert at California State University, San Diego, we thoroughly discussed all the possible errors that might affect the precision and accuracy of differential photometric measurements. We then considered how we might minimize these error sources through photometer design, automated observations of standard stars throughout the night, and automated but human-monitored quality control analysis (Young *et al* 1990 and 1991). Lou Boyd designed a precision photometer, and Greg Henry and Lou developed the quality control procedures and analysis program (Henry 1999). The result was photometry of the highest precision and accuracy—better than what human observers could produce.

As word of our successful operation spread, additional telescopes were funded by the National Science Foundation and others. We designed a compact 0.8-meter (32-inch) telescope specifically for automated photometry. We were able, after the Backer Nunn camera had been removed, to "shoehorn" four of these 0.8-meter telescopes within the remaining space under our roll-off roof. These telescopes were so close together that they had to be "networked" so they would not run into one another. They followed a simple "first into common space gets to complete its observations" rule.

Annual winter conferences at the Lazy K-Bar Ranch near Tucson, summer workshops, many papers, and nine books spread the word on what could be done via full automation and remote access. My book *Robotic Observatories* with Donald Hayes (Genet and Hayes 1989) provided a fitting close to this early development era and also considered future possibilities (quite prophetically as it turned out).

When the ten-year agreement between the Fairborn Observatory and the Smithsonian Institution expired, I retired and Lou moved the observatory to Camp Washington, a remote dark site just five miles north of the Mexican border (Eaton, Boyd, and Henry 1996). The original telescopes, such as the Four College APT, continued their operation (Adelman *et al* 2001).

Figure 10. The three original robotic telescopes at the rear of the Fairborn Observatory are almost obscured by the four 0.8-meter telescopes that were subsequently added—completely filling up the available space. These seven robotic telescopes observed together harmoniously every clear night on Mt. Hopkins for many years.

No longer constrained by the limited space on Mt. Hopkins, the observatory began to grow. Lou designed a new generation of 0.8-meter photometric telescopes and four of these telescopes were brought into operation at the Fairborn Observatory, including Wolfgang and Amadeus, the University of Vienna's twin automatic telescopes (Strassmeier *et al* 1997).

Figure 11. After 10 years on Mt. Hopkins, the Fairborn Observatory purchased remote dark sky property south of Mt. Hopkins, just 5 miles north of the Mexican border. Some 11 robotic telescopes operate there every clear night.

In cooperation with Tennessee State University, a 2-meter telescope and automated spectrograph was brought into operation (Eaton 2003). With the occasional help of Donald Epand who wrote new software, Lou not only has kept all 11 telescopes operating but, as time allows, is building five additional telescopes. Lou has also been working with Saul Adelman and others on an automated spectrophotometer (Adelman *et al* 2007).

Figure 12. The 2-meter telescope at the Fairborn Observatory is dedicated to spectroscopic observations via a fiber-fed spectrograph.

4. Automation and Remote Access at Smaller Observatories Today

An excellent example of a small modern, fully automated observatory is my good friend Tom Smith's 7100 foot elevation Dark Ridge Observatory in Weed, New Mexico. A fully automatic 14-inch Meade telescope has been used to observe interacting eclipsing binaries, visual double stars, and known exoplanet transits. The Sky and CCD Soft programs control the telescope and camera, while data reduction is accomplished via an Excel Visual Basic for Applications program written by Tom.

Two 8-inch f/3.6 ASA Astrographs are mounted together on a Paramount. These are being used for the AAVSO Photometric All Sky Survey (APASS) which will result in an all-sky photometric catalog for stars between 10th and 17th magnitude. The survey is using both Johnson and Sloan filters, thus tying these two systems together.

Figure 13. Tom Smith's Dark Ridge Observatory has two operational robotic telescopes. The twin astrograph is in the foreground and the 14-inch Meade is in the background (roof closed).

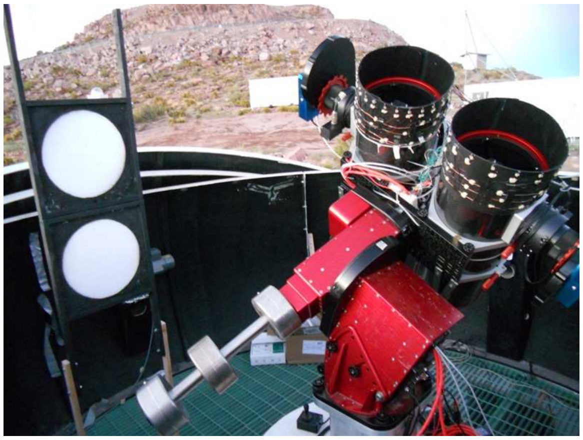

Figure 14. Tom installed the twin APASS system in Chile at the Cerro Tololo Inter-American Observatory.

The northern survey is being made from Tom's Dark Ridge Observatory, while the southern survey is being made from Cerro Tololo Inter-American Observatory (CTIO), borrowing one of the PROMPT clamshell structures. Tom assembled, debugged, and operated the system at Dark Ridge Observatory and then moved the equipment to Chile where he got it running again. He then set up a second, identical system at Dark Ridge Observatory. The APASS Catalog will be an all-sky secondary photometric standards catalog that will provide a uniform set of comparison and check stars for fields anywhere in the sky.

Another good example of a small, robotic telescope is Ohio State's dedicated MONitor for EXotransits (DEMONEX) 0.5-meter telescope located at Mark Trueblood's Winer Observatory in Sonoita, Arizona.

Figure 15. The 0.5-meter DEMONEX robotic telescope at the Winer Observatory observes exoplanet transits for Jason Eastman at Ohio State University.

This fully robotic telescope, which utilizes off-the-shelf components, was installed at Mark's existing telescope service, and has experienced very low operating and support costs. The project, managed by Jason Eastman at Ohio State University, has observed 59 different exoplanets. So far, the system has observed 328 primary transits and 201 secondary transits, and made 300 hours of out of transit observations. Small variations in transit timing allow additional planets in the systems to be inferred.

There are, of course, many other fine examples of small automated observatories. I chose these two as examples because they were both presented at the *Telescopes from Afar* conference.

5. Remote Access and Automation at Larger Observatories Today

With a huge investment in their remote mountaintop telescopes, large observatories are, understandably, somewhat reluctant to leave them entirely on their own without any humans present. However, real-time remote access is another story entirely. The high altitude of Mauna Kea (14,000 feet) can make in-person observations a bit fuzzy-headed, not to mention the time and expense of flying astronomers to Hawaii.

At the W. M. Keck Observatory, remote operation at their base facilities in Waimea, 32 km from the summit, was established early on, with an operating environment that mirrored that of the telescopes on the summit. Ten remote operating locations were then established in California, with two of them being dual control stations so both Keck telescopes could be operated simultaneously. Recently an additional station has been established at Swinburn University in Australia.

This has allowed Keck to continue their "classical scheduling" approach where the astronomers themselves make the observations, but without the need for them to actually fly to Hawaii and spend nights at 14,000 feet elevation. Interestingly, many astronomers still prefer to fly to Hawaii and observe from Waimea. This not only gives them a chance to interact with the Keck staff, but they are always assured a full uninterrupted daytime sleep—something they might not get at home.

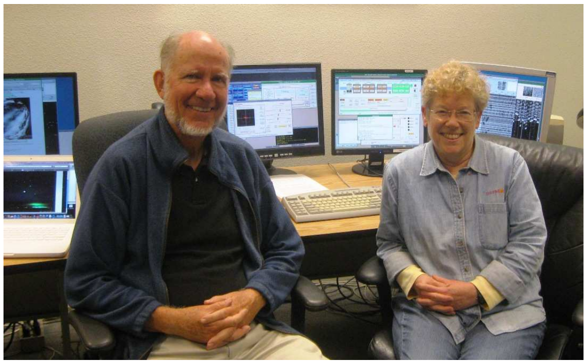

Figure 16. Russ and Sandra Faber (Chair of the Astronomy Department at the University of California, Santa Cruz and one of the originators of the Keck telescopes) discuss Keck remote control operation at the Keck headquarters in Waimea.

The Canada-France-Hawaii Telescope needed to reduce their operations and maintenance (O&M) budget. A significant cost for CFHT was maintaining two people at the telescope on the summit of Mauna Kea every night. Sarah Gajadhar, a systems engineer from Canada, was put in charge of a developmental program that would allow the telescope to be operated at night unattended, first with an operator on duty at the base camp and, eventually, with the telescope entirely on its own (but with an operator always on call).

CFHT had already fully implemented queue scheduling, where using astronomers submitted their observational programs well in advance and the actual observations were overseen by a staff astronomer at CFHT and a night telescope operator. This type of scheduling made it easier for them to move to an unattended telescope at night than it would have been for an observatory such as Keck that employed classical scheduling.

Figure 17. The remote controls for the Canada-France-Hawaii Telescope (also in Waimea) are now used to operate the telescope with no one actually at the telescope at night.

Somewhat similar to Keck, CFHT developed operating displays that mirrored those on the summit. What was different, however, was that CFHT had to install many additional sensors and displays that monitored the status of all the systems (and the weather) on the mountain and also allowed graceful shutdowns to be made of various systems.

6. Networks of Small Robotic Telescopes

During the early days we dreamed about and discussed networks of robotic telescopes. William Borucki and I proposed searching for exoplanet transits with a global network of robotic telescopes (Borucki and Genet 1992). Although we were unable to obtain funding for this network, Greg Henry, using a robotic telescope at the Fairborn Observatory, discovered the first transit of an exoplanet in 1999.

Greg was following up on systems known via radial velocity measurements to harbor an exoplanet. He wanted to see if their spatial alignment would also produce a transit. A number of earlier candidates had not revealed any such transit. Automated photometric measurements of HD 209458 at the Fairborn Observatory on the night of November 7, 1999, caught the first exoplanet transit just before the star disappeared into the western sky (Henry *et al* 2000).

While unable to obtain funding for a ground-based network of robotic telescopes, Bill did obtain funding for a single space-based telescope. Kepler, thanks to its beyond-the-atmosphere photometric precision, has now discovered hundreds of transiting exoplanets.

One of my favorite networks of small robotic telescopes is the AAVSOnet, which was briefed by Arne Henden, the Director of the American Association of Variable Strars, at the *Telescopes from Afar* conference. AAVSOnet is composed of 19 robotic telescopes ranging in aperture from 6 to 80 cm. The net's first telescope was installed in Sonoita, Arizona in 2005.

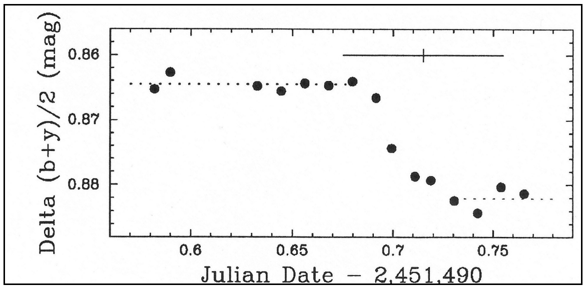

Figure 18. Greg Henry, with a robotic telescope at the Fairborn Observatory, observed the first transit of an exoplanet on the night of November 7, 1999. The ingress was caught, but the star was lost in the west before egress.

These telescopes are used by AAVSO staff for research and are available to all AAVSO members. The telescopes are engaged in long-term monitoring programs, yet can swing into action on targets of opportunity.

Figure 19. Tom Krajci and one of his AAVSOnet robotic telescopes. Tom has several similar telescopes at his home in Cloudcroft, New Mexico, at an elevation of over 9000 feet.

The AAVSOnet hardware is all commercial, relatively low cost, and off-the-shelf. While the telescopes are heterogeneous, the software is homogeneous. Telescopes are typically located on private property and kept in operation by an on-site volunteer.

Five of the telescopes belong to the Bright Star Monitor (BSM) program. These telescopes are 60-70 mm in aperture, and employ SBIG ST-8 cameras to monitor 2nd to 10th magnitude stars in BVRI. A complete system, all off-the-shelf, costs only $7,000, and individual donors are adding these telescopes to the BSM program on the AAVSOnet.

Last, but certainly not least, is the Las Cumbres Observatory Global Telescope Network (LCOGTnet). This network was envisioned years ago by Wayne Rosing and on his retirement from Google (Vice President), Wayne had the time and funding to turn his dream into reality.

To this end, Wayne established the Las Cumbres observatory with its headquarters and design and production facilities in Santa Barbara (Goleta), California. A staff of some 40 scientists, engineers, and technicians has developed the telescopes, instruments, software, and operational procedures that will populate and operate the network.

Figure 20. The assembly line for the 1-meter telescopes at the Las Cumbres Observatory in Santa Barbara, California. Over a dozen of these telescopes will be placed at sites around the world.

There are or will be network sites in Hawaii, Australia, South Africa, Spain, Chile, and Texas. Two 2 meter telescopes were acquired, but the 1-meter and 0.4-meter telescopes are being assembled in quantity at the Santa Barbara facility. After production, the telescopes, enclosures, and control electronics, etc., are completely assembled and tested out as a complete system in Santa Barbara. They are then disassembled and shipped out to one of the observing locations and reassembled.

The Las Cumbres Observatory Global Telescope Network has uniform, completely standardized telescopes, instruments, and software. With clusters of 1.0- and 0.4-meter telescopes at each of its sites spread around the globe, it will be able to provide constant, around the clock monitoring of many objects, and will also be able to respond in seconds to targets of opportunity. Without doubt, the Las Cumbres Observatory is raising small telescopes to new heights.

Figure 21. Pouring concrete for a 1-meter LCOGTnet telescope at the Cerro Tololo Inter-American Observatory in Chile.

7. Sage Advice

Louis Boyd, who began his effort to automate astronomy in the late 1970s and has continued on unabated to this day, kindly sent me, just before my talk at the *Telescopes from Afar* conference, a few words of advice for those interested in automating their operation.

“The main advantage of automation, as with automation of most things, comes at the point where the human is removed from the normal operating loop. Humans are very expensive compared to a computer and they're not good for even a 50% duty cycle long term. It takes at least two humans to run one non-automated telescope every night. Computers make far fewer stupid mistakes. I've never seen a dyslexic computer which swaps two digits in output data or entering coordinates. On the other hand a human is much better at recovering systems when something unexpected happens, like a rat chewing though a control cable.

“The operation of APTs at Fairborn is at the point where one human operates 11 telescopes at the observing end. It's still averaging about one human per telescope at the selection request preparation/data reduction/data analysis/collaboration/publishing end. Greg Henry is the only human I know who handles several telescopes with one person doing all those functions. He has automated it as much as is practical, but object selection, data analysis, collaboration, and publishing are still human labor intensive.

“I wouldn't separate remote monitoring from remote data retrieval. They both take similar bi-directional bandwidth. Data retrieval can be batched but few communications systems impose that limitation. The "morning report" is just part of the data retrieval. It has no function in the operating of the telescope though it's useful during data reduction.”

“The things which are most difficult to automate are:

- Site security. Some humans will steal or destroy anything which isn't closely watched. Automated cameras can watch such activity but can’t stop it.
- Telescope maintenance. Both simple cleaning and maintenance, and computer and instrument repair require a human with some skill. I've never seen one computer repair another other than by swapping.
- Building and grounds maintenance. If it wasn't for weather and "critters," this would not be a problem.
- Systems to support the human(s) who do the above. Humans need human oriented conveniences.
- Legal necessities (taxes, accounting, etc.). All the things any business requires. Most of those can be done off site unless there's only one human doing it all.”

“The actual automation of a telescope is fairly simple if and only if everything is thought out initially that the automation will have to accomplish. Necessary and sufficient weather monitoring is an essential part of an automated telescope. The more humans can be kept out of the process the simpler the software becomes. Getting humans out of an observatory building eliminates a lot of systems which are unnecessary for telescope operation. Displays, keyboards, lights, chairs, beds, toilets, sinks, refrigerators, microwaves, coffee pots and lights are not needed when only a computer runs a telescope. Unfortunately humans are needed for maintenance.”

8. Conclusion

Automated telescopes and remotely accessed observatories are now becoming commonplace, even ubiquitous. Their robotic efficiency, ability to be placed at ideal remote locations without incurring travel time and cost penalties, and their low operating and maintenance costs have been the keys to their continued success and proliferation. I leave the final word to Lou:

“As with all astronomy projects the capabilities of automated telescopes are restricted by funding and perceived value. There's really not a lot of difference conceptually in an automated telescope service and a laundromat. There's still some human effort to load and unload them and occasional maintenance. With either, a human isn't tied up running each machine and you get reasonably consistent results.”

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