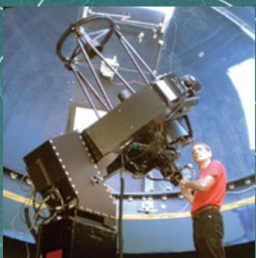
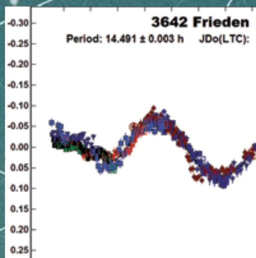
Gerald R. Hubbell · Richard J. Williams
Linda M. Billard

Remote Observatories for Amateur Astronomers





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Foreword I

by Scott W. Roberts

The purpose of an astronomical observatory is to contain the instrumentation that allows astronomers to observe and make measurements of the cosmos. They are often built—sometimes at great cost—in places that are the most optimum for the best observations, with today's observatories located both on land and in space for the use of professional and amateur astronomers. At the very least, observatories are built to make repeatable observations routine and convenient. In fact, some specialized observations can only be made from particular observatories with very specific equipment and/or locations.

Upon reading this book, you might feel that the advanced technologies we professional and amateur astronomers use every day to make and record scientific observations have reached new, unprecedented heights. And yet most certainly, many more peaks of innovation and discovery will be conquered at a pace that perhaps will leave even us—who are now quite accustomed to the breakneck pace of technology and our nearly continuous new discoveries about the universe we live in—uncomfortably numb.

We know that astronomical observatories were developed at least 10,000 years ago. And we could perhaps infer from what we are learning about humanity that the development leading to the building of Zorats Karer (in present-day Armenia), built in the sixth millennium BC, and Stonehenge, built in the second millennium BC more than 2600 miles away, that there are probably other ancient observatories yet to be discovered.

You could argue that without observatories, humanity might not have survived at all. Without accurate determinations of the changes of the seasons, accurate calendars to segment our orbits around the Sun, and accuracy of segmenting a single day, humanity might have been utterly lost and defenseless against the ravages of nature and perhaps even each other. The permanent placement of astronomical instrumentation in observatories allows repeatable and reliable measurements of the Sun, the planets, and the stars. Observatories are centers of higher learning, providing a stage for scientists from which they can disseminate the collected data and what has been learned from it to the scientific community and to the public at large.

Indeed, observatories are the vehicles that we developed to help us navigate and advance civilization and are as important to humanity as any invention that we have ever created. And today, all of the elements required to make a cutting-edge, high-technology, computer-controlled telescope and observatory system operated from anywhere on the planet through the Internet are within reach of dedicated amateur astronomers. What has been missing is a comprehensive guide for putting it all together.

Remote Observatories for Amateur Astronomers: Using High-Powered Telescopes from Home, written by Jerry Hubbell, Rich Williams, and Linda Billard, is a unique contribution centering on computer-controlled private observatories owned by amateur astronomers and commercialized professional–amateur observatories where observing time to collect data can be purchased. The methodical approach to operating a modern computer-controlled observatory and the discipline of critical thinking in pursuit of developing an astronomical imaging system (AIS) make this book a perfect companion to Hubbell's first book, *Scientific Astrophotography: How Amateurs Can Generate and Use Professional Imaging Data* and is available from the same publisher.

Until the development of this book, trying to piece together all of the necessary elements and processes that make up a remotely operated observatory was daunting. The authors and contributors have provided, in this single publication, a wealth of information gained from years of experience that will save you considerable money and countless hours in trying to develop such an observatory.

In these pages, you will be guided step-by-step through developing your observing plan design basis (OPDP), which will drive the selection of equipment to build the observatory. You'll also learn the discipline of "defense-in-depth and diversity" to maximize up-time and mitigate the possibility of a catastrophic failure while you are operating the observatory, possibly from a great distance, through your computer.

This book will make you take a hard look at the associated costs of making observations from a remote observatory. You will be able to weigh the pros and cons of building your own observatory versus buying observing time from a commercial facility. After careful consideration, you may find that your observing plan can be optimized by blending data collection from your own private observatory and a commercial observatory.

Amateur astronomers who understand how to properly collect and reduce science data can open up chances for themselves to access large telescopes and interact in the professional astronomy community. It should also be pointed out that there even are opportunities (albeit rare) for amateurs to be granted time on professional observatories. For example, in 1992, observing submissions from six amateur astronomers were selected by the Space Telescope Science Institute (STScI) that were carried out on the Hubble Space Telescope. The last section of this book presents an array of examples of work done by amateurs, professionals, and educators using remotely controlled observatories to achieve their observing goals. There is abundant inspiration there for you.

If you follow the methods and processes laid out in this book and choose to build your own remotely operated observatory or become a regular user of one of the commercial networks, you will not only join an elite group of advanced astronomers who make regular submissions to science but also become a member of an ancient fraternity. Your high-technology observatory will contain a "high-powered telescope" no matter how large it is, and from the comfort of home, you can actively contribute to the work that started in pre-history to help uncover the secrets of the cosmos.

Explore Scientific, LLC
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Scott W. Roberts

Foreword II—A Historical Perspective

by Russell M. Genet, Ph.D.

The Fairborn Observatory: An Early Remote Observatory

In the past three and a half decades, since I first became involved with remote observatories, the use of remote, unmanned telescopes at fully automated observatories has advanced from a very rare approach for making astronomical observations to an increasingly dominant mode for observation among both professional and amateur astronomers. I am very pleased to see this timely book being published on the topic.

I highly recommend this book to readers because it not only covers the knowledge needed to become an informed user of existing remote observatories but also describes what you need to know to develop your own remote observatory. This book draws on more than two decades of remote observatory operation and networking by coauthor Richard Williams as he developed the Sierra Stars Observatory Network (SSON) into the world-class network it is today. This book is the ideal follow-on to coauthor Jerry Hubbell's book *Scientific Astrophotography* (Springer 2012).

As both a research astronomer and educator, I have a keen interest in involving my students in astronomical research. My Astronomy Research Seminar, offered through Cuesta College, provides both undergraduate and high school student teams an opportunity to plan, conduct, write up, and present a modest-scale, original research project within the constraints of a single semester. Our hybrid in-person/online spring 2015 seminar featured teams from ten schools: six in California, two in Hawaii, and one each in Arizona and Pennsylvania. Local volunteer assistant instructors, primarily high school science teachers, frequently met with the students in person, while I met with them online for instruction and student-team presentations.

It was vital that the teams made their observations early in the semester so they would have sufficient time for analysis and, more especially, for writing and rewriting their papers, which were submitted for publication by the end of the semester. Remote access observatories were the key to obtaining timely, high-quality, hassle-free observations for many of my student teams.

If, like my students, you would like to try your hand at scientific research or would just like to take photographs of the many fascinating objects in the night sky, an excellent and very affordable way to get started is to use remote observatories. This book, with its many practical examples, can be your guide.

Early Remote Observatories

I was asked by the authors of this book to provide a personal, historic introduction to remote observatories. For those interested in reading additional historic details, two classic books on the topic are still available on Amazon at low cost and are still helpful reads: *Microcomputer Control of Telescopes* (Trueblood and Genet, 1985) and *Robotic Observatories* (Genet and Hayes, 1989).

Before recounting my own involvement with robotic telescopes and observatories starting in the late 1970s—the early days of the Fairborn Observatory—it is appropriate to mention two earlier efforts in the 1960s that were, in essence, a space race between the National Science Foundation (NSF) and National Aeronautics and Space Administration (NASA). Which agency, by establishing the feasibility of robotic telescopes on the ground, would lead the way to robotic telescopes in space?

NSF purchased a 1.5-m Boller and Chivens® telescope that it located at Kitt Peak National Observatory in southern Arizona. The telescope was controlled by a mainframe computer located 40 miles away in Tucson. Automation was achieved, but reportedly for just one night. A mainframe computer was simply not a viable approach for controlling a remote observatory. The telescope was soon converted to manual operation, serving for decades as a workhorse near-infrared telescope. Recently, in a slightly ironic twist, it has been converted back to automatic operation, this time with a nearby microcomputer controlling the telescope. It might be noted that Sterling Colgate also developed a remote telescope to search for supernovae. The telescope, located on a dark-site mountaintop in New Mexico, was connected by a microwave link to a mainframe computer on the campus of New Mexico Institute of Mining and Technology, located in Socorro. It encountered the same sort of difficulties as the NSF telescope.

Art Code and his colleagues at the University of Wisconsin helped pioneer the path toward space telescopes with a modest 8-in. telescope located in a totally robotic observatory controlled from a nearby minicomputer, a PDP 8. While they were able to maintain fully automatic operation for several nights in a row without human intervention, the telescope was eventually shut down, although its space counterparts paved the way toward larger space telescopes.

With the arrival of microcomputers in the late 1970s and early 1980s, many robotic telescope developmental efforts were launched. Most were short-lived, but a few, such as the Fairborn Observatory telescopes and the Carlsbad Meridian Telescope, have continued operation to the present. Telescopes at the Fairborn Observatory began robotic operation in 1983 and remote access operation in 1987. The Carlsbad Telescope began robotic operation in 1984 and remote access operation in 1997.

The Founding of the Fairborn Observatory

In 1978, while attending graduate school on a full scholarship at the Air Force Institute of Technology (located at Wright-Patterson Air Force Base near Dayton, OH), I decided, on the side, to conduct some scientific research from my backyard that was both publishable and affordable. I quickly homed in on astronomical research and looked at every paper for the past 5 years that had been published in the *Astronomical Journal*. Not being a theoretician, I searched for papers about projects for which I felt I could make similar observations from my backyard (I lived a few miles from the small town of Fairborn, OH) with a telescope and instrumentation I could build myself. Somewhat surprisingly, there were 30 papers that fell into this category. Of these, 28 were photoelectric photometry observations of variable stars, primarily made by various observers using one of two 16-in. telescopes then at Kitt Peak National Observatory in Arizona.

Without hesitation, I ordered a set of 10-in. Cassegrain mirrors from Coulter Optical, two large-diameter worm gear sets from Tom Mathis (I was his first customer), and other items for the telescope. I constructed my photoelectric photometer from hobby plywood. It featured a diaphragm wheel, a filter wheel, a back-viewing microscope with retractable mirror, illumination of the back of the diaphragm that could be switched off when not in use, and an RCA® 1P21 photomultiplier. Rounding out the instrumentation was a high-voltage DC power supply that I built myself, a strip chart recorder, and a Hallicrafters shortwave receiver. Knowing that data reduction would be tedious (I am somewhat dyslexic when it comes to arithmetic), I purchased a Radio Shack® TRS-80 in early 1979.

Concrete was poured for the Fairborn Observatory's pier right after the spring thaw in 1979, and the first papers were sent off for publication that summer. Most all of the early observations were of RS CVn binary stars as part of a program coordinated by the late Douglas Hall at Vanderbilt Observatory. These binaries had large, dark, star spots on one hemisphere that produced light curves that changed over time as the large spots changed their locations.

Wishing to meet Doug Hall and other photometrists in person, I organized a June 1980 mini-conference that was held at the Dayton Museum of Natural History in Ohio. Doug stayed with me for a couple of days after the conference, and we

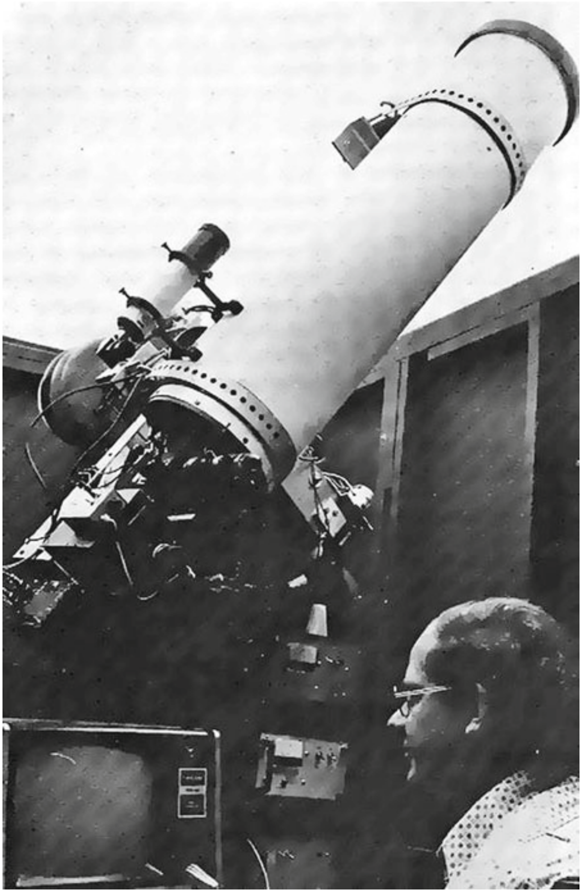

Fig. F1 Telescope, photometer, and Radio Shack® TRS-80 microcomputer at the Fairborn Observatory in 1979

launched the International Amateur-Professional Photoelectric Photometry (IAPPP) organization and its quarterly publication, the *IAPPP Communications*.

One good meeting deserved another, so I initiated a West Coast meeting in California that we called IAPPP West, and although I was unable to attend in person, the meeting took place and has been held annually for some 33 years, appropriately changing its name from the somewhat cumbersome IAPPP West to the much more informative Society for Astronomical Sciences. Back East, our next two IAPPP meetings were concerned with the use of microcomputers and resulted in two books, *Microcomputers in Astronomy I* and *Microcomputers in Astronomy II*, occasionally still available on Amazon. Doug Hall and I collaborated on a book, *Photoelectric Photometry of Variable Stars: A Guide for Smaller Observatories*. We were only slightly ahead of Arne Henden and Ronald Kaitchuck's masterful book, *Photoelectric Photometry*. Both books are still in print, although my book with Doug Hall was issued as a second edition.

Measuring strip chart traces of variable star observations was time-consuming and tedious, so I wired up an analog-to-digital converter to directly record the observations. Because the TRS-80 was not up to reliable operation in an observatory environment, I left it in my study and accessed it by a remote keypad and remote monitor. Soon a stepper motor was added to change the filter wheel. A good friend of mine, Johnathan Titus, author of the historic 1975 *Popular Electronics* article on how to build a microcomputer, asked me to write a book in 1982 entitled *Real-Time Control with the TRS-80*. As far as we know, it was the first published book on real-time control with microcomputers.

Early Automation

Making fully manual variable star photometry observations is repetitive, tedious, and boring. It consists of centering the same variable star, comparison, and check stars (and their sky backgrounds), over and over again in various filters. Strip chart recorder on, strip chart recorder off. Note the time. The observations went on and on, hour after hour. Partially computerizing the process by having a microcomputer directly record the data, change the filter wheel, and prompt me what to do next made the process easier and less error prone, but actually increased the boredom. Partial automation naturally increased the desire for full automation. Let the microcomputer do the complete job so we humans could sleep at night!

A photometrist friend of mine, Jeff Hopkins, mentioned that a friend of his, Louis Boyd, had similar thoughts of full automation of photoelectric photometry and kindly arranged for us to meet at Jeff's house during one of my trips to Arizona. Lou and I immediately hit it off, and we decided to join forces as the Fairborn Observatory East (my observatory in Ohio) and Fairborn Observatory West (Lou's observatory in Phoenix).

Lou's telescope was a very clever, home-brew contraption that used large aluminum disks (from an early mainframe computer disk drive) and bicycle chains for moving his telescope, and a single-board computer with a Motorola® 6809 processor for control. The computer had 64 K of RAM, but after loading the OS9 operating system and Basic09 language, there was only 18 K of RAM left for our control program. I went to Arizona for the first night of automatic operation of Lou's "Phoenix-10" telescope on October 13, 1983. We watched the telescope do its thing for a couple of hours and then went to bed. That first night, the Phoenix 10 made some 600 photometric measurements—finding, centering, and measuring stellar magnitudes in all three Johnson UBV color bands.

Some 6 months later, our second robotic telescope was in operation at my Fairborn Observatory East. The Fairborn-10's mount was donated by Frank Melsheimer at DFM Engineering®. It was the prototype of his line of mounts for smaller DFM telescopes. The 10-in. Schmidt-Cassegrain optical tube assembly was

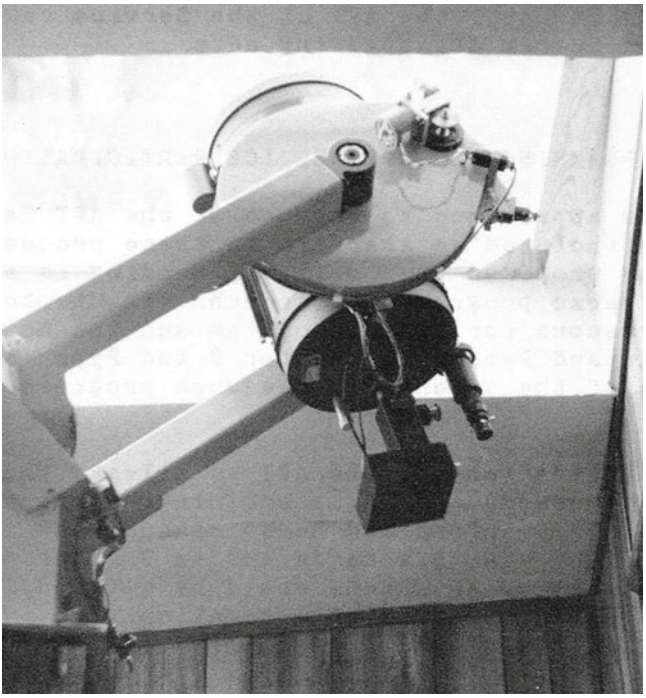

Fig. F2 The Fairborn-10 automatic telescope. It began operation in the spring of 1984

donated by John Diebold, President of Meade®, while the photometer, an Optec® SSP-3, was donated by Jerry Persha. Lou Boyd kindly wire-wrapped the control board.

In the days before CCD cameras, our early robotic telescopes used their permanently mounted aperture photometers to locate a star (our mounts were not very precise in their pointing), center the star in a diaphragm, and, finally, measure the stars' brightness in various color bands. The stars were located by way of a square spiral search.

Once a star was located, it was centered by making four offset measurements and from these determining which direction the center must be. Successive iterations brought the star sufficiently close to the center of the diaphragm. Once centered, the first of a symmetrical sequence of some 33 separate observations was made that, over the course of about 11 min, yielded differential photometric magnitudes in three color bands.

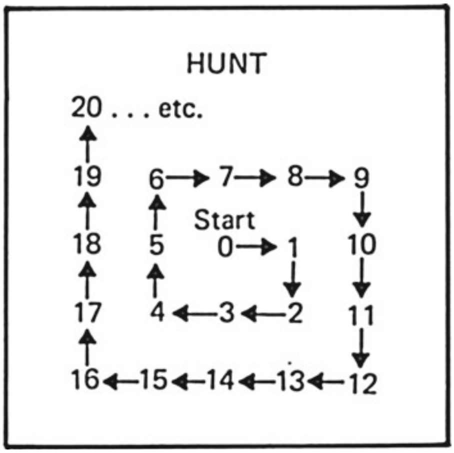

Fig. F3 The square spiral search routine used to locate stars

The Automatic Photoelectric Telescope Service

I attended the winter meeting of the American Astronomical Society (AAS) in Tucson in 1984. Dressed in shorts and a T-shirt, I called my wife back in Ohio every day. She was contending with −20 °F weather and freezing pipes. How about moving to Arizona, I suggested? Ohio, I had already concluded, was not a good location for robotic telescopes, and the government laboratory at Wright-Patterson Air Force Base where I was a research supervisor had a division in Mesa, AZ.

Immediately after the Tucson AAS meeting, Sallie Baliunas, an astronomer at the Harvard-Smithsonian Center for Astrophysics (CfA), took Lou Boyd, Doug Hall, and me on a tour of the telescopes on Mount Hopkins, south of Tucson. As we drove by a large roll-off-roof building, Lou asked about it and was told by Sallie that it was currently unused but was occupied by a laser ranger and Baker-Nunn camera that had been used in the past for satellite tracking. Lou insisted that we stop, and, although the building was locked, he paced out its dimensions.

Within months, I visited Dave Latham, the Director of the Smithsonian Observatory at CfA. We agreed that Lou and I could use the building on Mount Hopkins, along with utilities and use of Smithsonian Observatory vehicles, in exchange for devoting my Fairborn-10 telescope to making photometric measurements of solar-type stars for Sallie Baliuns to complement her spectroscopic observations on the 60-in. telescope on Mount Wilson. Together, these observations could establish "spot cycles" on other stars similar to our own solar cycle.

Not long after I moved to Arizona, I received a phone call from Dave Latham informing us that the Secretary of the Smithsonian Institution had approved a 10-year agreement for the Automatic Photoelectric Telescope Service, a joint

Fairborn Observatory–Smithsonian Institution operation with Lou and me supplying the telescopes and work, and the Smithsonian providing the building, utilities, and vehicles for navigating the long dirt road. The very next day, Lou and I drove to Mount Hopkins and bolted my Fairborn-10 telescope to the floor. Thus began the APT Service.

For more than a year, Lou and I spent many of our weekends and vacations on Mount Hopkins, automating the observatory itself. AC power on the mountain was not very reliable, so Lou, who was chief engineer for the telephone company, scrounged up an entire wall of batteries to provide us with the power we needed to close the massive roof when power failed. Weather sensors were devised, and Lou coded an observatory control computer to take charge of the observatory.

Finally, after much work, we arrived one weekend at the observatory, threw the switch to automatic, and let the observatory run on its own while keeping a careful eye on its operation. There were problems, of course, so these were fixed, and we tried it all over again the next weekend. This went on for several months until at last we had a number of weekends of fully automatic operation in a row without any problems. Somewhat nervously, we finally left the switch on "automatic," left the observatory running on its own, and drove back to the Phoenix area, a 4-h drive from Mount Hopkins.

It wasn't too many days before we received a call from one of the daytime crew members of the Multiple Mirror Telescope (MMT). "As I was driving by the APT Service, I noticed that your roof was rolling off, then rolling back on, then rolling off …" We asked a friend on the mountain to stop automatic operation. Once the software fix was made, the observatory was back in automatic operation again.

It was somewhat nerve wracking always wondering how our automatic telescopes were doing. We would often call down to our friends, the nighttime operators of the Smithsonian's 60-in. telescope just down the ridge from our APT Service, and ask them to walk up to our observatory and check on our automatic telescopes, now three in number. These frequent calls were somewhat disruptive, so Lou programmed our Observatory Control Computer to send us a "morning report" over the Internet that summarized the operation of each telescope as well as the observatory itself for the previous night.

These helpful morning reports usually informed us whether or not another weekend trip to Mount Hopkins was required, although there were occasional conflicting reports. Once, for several mornings in a row, the morning report illogically reported that the skies were clear but it was raining. A call to our friends on the mountain established that it had been clear all the time. We drove down, and an inspection of the rain detector revealed that a bird had used our sensor as a toilet facility.

Our observatory eventually settled down into routine, reliable operation, really cranking out the observations. My Fairborn-10 telescope observed solar-type stars for Sallie Baliunas. The newly acquired Vanderbilt-16, a DFM Engineering® telescope funded by NSF, was devoted to observations of RS CVn spotted binaries for Doug Hall. Lou Boyd's Phoenix-10 was devoted to the APT Service's "Rent-a-Star" program. For $2.00, we made UBV photometric observations (33 separate

Fig. F4 The original three robotic telescopes at the APT Service on Mt. Hopkins. *Left* to *right*: the Fairborn-10, the Phoenix-10, and the Vanderbilt-16

measurements spread over about 11 min) of a variable star, comparison, and check star (and associated backgrounds). Our Automatic Telescope Instruction Set (ATIS) was smart enough to decide what should be observed next, given the desired frequency of observation, number of past observations, location of the Moon, etc. If poor weather shut the observatory down for a few hours, once started up again, ATIS would carry on with its selections, always picking what was most appropriate to observe at any given time.

At this point, our biggest problem was implementing the changes in the observing program requested by the many astronomers using our telescopes and then distributing the observational results back to them. This problem was particularly severe for the Phoenix-10 Rent-a-Star telescope, which had many subscribers. We decided that each telescope should have a Principal Astronomer (PA). The PA would consolidate the observational requests from multiple users, make updates to the observing program, check the observations for quality, distribute the results to other astronomers, and, for the Phoenix-10 telescope, collect observational fees. Michael Seeds, at Franklin and Marshall College, was the first PA, boldly taking on the difficult Phoenix-10. Sallie Baliunas, at the CfA, was the PA for the Fairborn-10, while Greg Henry, at Tennessee State University (TSU), was the PA for the Vanderbilt-16, taking care of it for Doug Hall. PAs worked out well indeed, shifting the workload to those who were in the best position to handle it.

One final problem remained to be solved, and that was timeliness, both in terms of the inspection of the observational results to determine whether their quality remained high and in terms of making changes to the basic observing programs. Observational results were stored, untouched, on 3.5-in. floppy disks for 3 months. At the end of each quarter, a disk from each telescope, containing a quarter's worth of observations, was mailed to each PA, who reduced the data, checked its quality, and distributed the reduced results to other astronomers. The PAs also sent occasional observing program changes to us, which we loaded on their telescope.

We were always worried that sometime during the quarter, a subtle equipment fault would occur that could not be detected until the data were reduced. To speed up this process, we instituted remote access in 1987, perhaps the first such access to telescopes. Observational program change requests made by PAs over the Internet during the day would be honored that night. The night's observational results were automatically sent via the Internet every morning to each of the PAs so they could reduce the observations and check their quality.

Fairborn Observatory Expansion and Maturation

The IAPPP (East) annual summer conferences were moved to Arizona in 1985 and became mid-winter conferences that were held for many years at the Lazy K-Bar Guest Ranch near Tucson. These conferences were attended by an eclectic mix of professional and amateur astronomers. (Many of the amateurs were professional engineers or computer programmers.) The Lazy K-Bar conferences featured research and development talks, sunbathing around the pool, horseback riding in the desert, and annual pilgrimages to the growing collection of robotic telescopes at the Fairborn Observatory on nearby Mount Hopkins.

Many of the talks at these annual conferences were published in a series of books. A number of these books are still available at low cost on Amazon and provide insights into the early development of robotic telescopes and remotely accessed observatories. A film crew documented the development of robotic telescopes during a 3-day visit to the Fairborn Observatory that was aired on PBS as "The Perfect Stargazer."

The telescopes on Mount Hopkins were shut down every summer because of severe lightning during the monsoon season. However, the cool summer mountaintop environment was ideal for meetings, and a series of workshops were devoted to advancing robotic telescope and remote observatory technologies. During one of these workshops I made a scale model of a 0.8-m telescope, specifically intended for automated photometry. Soon a number of these telescopes, designed in detail by

Fig. F5 Four 0.8-m automatic telescopes on Mt. Hopkins. The three original telescopes are in the background

Lou Boyd, were manufactured by Rettig Machine in Redlands, CA. Four of these telescopes were installed at the Fairborn Observatory on Mount Hopkins.

A regular speaker at the Lazy K-Bar IAPPP conferences was Wes Lockwood, an astronomer from Lowell Observatory. Wes made highly precise photometric observations on a 21-in. telescope that were a cut above robotic telescope in terms of photometric precision. I figured that robotic telescopes should be able to make observations that were at least as precise as mere humans, so I organized and hosted two workshops devoted to figuring out how we could make much more precise automatic observations. The workshop attendees included Wes Lockwood, Bill Borucki from NASA Ames (who was working on making photometric observations precise enough to detect exoplanet transits), Andy Young from San Diego State University (who was an expert on sources of error in photomultiplier aperture photometers), Lou Boyd a seasoned instrument designer, myself, and a few others. Based on what Lou learned in these workshops, he designed a fully automated photometer that produced observations significantly more precise than the best manual observations.

Downloading each night's observations every morning made it possible for the PAs to institute daily quality checks on the observations. Greg Henry at TSU developed a semi-automatic quality check he used every morning to look for potential problems in the several telescopes for which he was the PA. At the first hint of a problem, Greg would contact Lou, who would immediately investigate and take corrective actions as appropriate.

In 1991, Bill Borucki and I proposed using a network of robotic telescopes equipped with high-precision photometers to detect exoplanet transits. There was little interest in this at the time—after all, we were not even sure there were any exoplanets, let alone transiting exoplanets—so the idea didn't go anywhere. However, Bill was already thinking about placing a high-precision automatic photometric telescope in space to search for exoplanets.

Alex Filippenko, at the University of California, Berkeley, had a keen interest in investigating the expansion of the universe by observing Type 1-a supernovae. The problem was finding these rare, transient supernovae. Alex figured that a robotic telescope would be a good way to find them. By taking images of many galaxies every night and comparing them with previous images, he hoped to see whether a bright supernova had shown up. Alex came to several of the Lazy K-Bar conferences, and arrangements were made to build one of the 0.8-m telescopes for him as the Katzman Automatic Imaging Telescope (KAIT). It was installed at Lick Observatory in California and held, for a number of years (late 1990s and early 2000s), the world's record for the number of supernovae discoveries. The knowledge gleaned from these Type 1-a supernovae observations was helpful in establishing the baseline for the interpretation of Type 1-a supernovae observations that led to the discovery of the runaway universe.

In the late 1990s, Geoff Marcy asked Greg Henry to use one of the 0.8-m automatic photoelectric telescopes at the Fairborn Observatory to look for potential exoplanet transits. While none had yet been observed, Geoff had a good feel for which of the exoplanets, discovered via small changes in the radial velocities of the parent stars, might produce a photometrically detectable transit. Greg Henry observed the first exoplanet transit in November 1999. David Charbonneau made simulation transit observations of the same exoplanet, and Dave's paper was published immediately following Greg's in the *Astrophysical Journal*.

At a number of the Lazy K-Bar IAPPP annual conferences, there were talks and discussions on the automation of spectroscopy. Eventually, Mike Busby at TSU obtained funding for a 2-m automatic spectroscopic telescope, which was located at the Fairborn Observatory in its new location in southern Arizona, just 5 mi north of the Mexican border. Currently, this telescope is equipped with very high-precision (just a few meters/second), fully automatic, fiber-fed spectrometers from TSU (Matthew Muttersburgh) and the University of Florida (Juan Gee).

Fig. F6 Two-meter automatic spectroscopic telescope at the Fairborn Observatory

The Fairborn and Other Remote Observatories Today

In the early 1990s, I retired from my job as a laboratory supervisor, after having worked for 33 years for the federal government and also having completed my term as the 52nd President of the Astronomical Society of the Pacific. I retired from the Fairborn Observatory, and Lou Boyd became its sole Director. I had greatly enjoyed my 15-year exploration of observational astronomy and robotic observatories, but felt the call to return to and continue my research, lectures, and courses on cosmic evolution, the grand synthesis of physical, biological, and cultural evolution. For those who might be interested, my book on this topic, available from Amazon, is *Humanity: The Chimpanzees Who Would Be Ants.*

Lou Boyd at the Fairborn Observatory and Greg Henry at TSU carried on just fine without me. The observatory continued to grow. Today, more than two decades after I retired, Lou continues to manage the Fairborn Observatory as a one-person

Fig. F7 The Fairborn Observatory now features some 14 automatic telescopes. The 2-m spectroscopic telescope can be seen in the background

operation, easily making it the most cost-efficient observatory on the planet. A dozen telescopes make observations every clear night. Greg continues as the planet's most experienced PA of robotic telescopes. He has authored or coauthored hundreds of papers with his many collaborators in the many research areas where automatic photometric and spectroscopic telescopes excel.

The approach of having multiple telescopes under one roof was picked up, early on, by Mark Trueblood at the Winer Observatory southeast of Tucson. His remote access Winer Observatory has been serving many astronomers for decades. A recent example of a collection of a dozen telescopes under one roof is demonstrated by iTelescope in Australia.

Individual telescopes were also automated, many inspired by my 1985 book with Mark Trueblood, *Microcomputer Control of Telescopes.* Sophisticated telescope control systems, such as the one made by Sidereal Technology®, became available off the shelf. High-performance telescope mounts also became off-the-shelf items, such as the Paramounts made by Software Bisque®, and complete robotic telescopes became available, such as the Corrected Dall-Kirkham telescopes made by PlaneWave Instruments®. Many of the ever-popular Schmidt-Cassegrain telescopes made by Celestron® and Meade® were also automated.

Controlling the telescopes, cameras, weather sensors, roofs, and all the other things that made up a complete remote observatory remained a difficult challenge until Bob Denny developed the Astronomer's Control Panel (ACP) and established the Astronomy Common Object Model (ASCOM) as a standard interface for astronomical devices managed by a personal computer. Starting in the early 2000s, Bob programed and then continuously refined his telescope and observatory control software for both remote real-time and fully automatic operation.

One of our early dreams was a network of robotic telescopes spread around the globe. A number of these networks have now been established, including the Sierra Stars Observatory Network (SSON) established by Rich Williams, one of the authors of this book. There are now many other networks, such as the AAVSOnet and the iTelescope.

The premier global network is the Los Cumbres Observatory Global Telescope (LCOGT) network, established by Wayne Rosing after he retired from Google® as its Vice President for Engineering. The LCOGT network has two 2-m telescopes (one on Haleakala on Maui, and one in Australia), ten 1-m telescopes (in Chile, South Africa, Texas, and elsewhere), and a dozen 0.5-m telescopes, collocated with the 1-m telescopes. This matched set of telescopes and instruments is controlled automatically from LCOGT headquarters in Goleta, CA (not far from Santa Barbara).

A few years ago, I became curious to learn about the present state of remote observatories. Because I spent every winter in Hawaii, the dry side of the Big Island seemed like a good place for a conference. I had not gotten very far in my organizational efforts when Christian Veillet, then the Director of the Canada-France-Hawaii Telescope (CFHT), volunteered to handle the conference's organization. The result was the *Telescopes from Afar* conference. Christian kindly invited me to give the first talk on the early history of robotic telescopes and observatories. Christian knew everyone, and some 150 astronomers from all over the world attended and reported on their uses of robotic telescopes and development of new capabilities.

Remote observatories have a bright future, opening up astronomy to a new and much larger generation of professional, amateur, and student observers. Machines and humans can and do work well together. I hope you enjoy reading this book as much as I have and will take advantage of the developments over the past several decades by the many pioneers of remote observatories.

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Preface

Book Organization and Purpose

Welcome to *Remote Observatories for Amateur Astronomers: Using High-Powered Telescopes from Home*. The idea for this book came about through discussions with Maury Solomon, Nora Rawn, and John Watson of Springer Books. Our objective was to create a follow-on book to *Scientific Astrophotography: How Amateurs Can Generate and Use Professional Imaging Data* that was not only timely but also provided significant new material to enable the amateur astronomer to expand his or her horizons and delve into the latest techniques and equipment available today.

It immediately became obvious to me that to provide the highest quality material, this new book would require the involvement of an expert in remote observatories; I had just the fellow in mind. Rich Williams is well-known throughout the astronomy community as a pioneer in designing, building, and operating remote observatories and operates the Sierra Stars Observatory Network (SSON). This network of state-of-the-art observatories was built in 2007 and has been in operation ever since.

I also realized that to provide you, the reader, with the quality reading experience you expect, an excellent editing job was paramount. In this regard, I asked the editor of my previous book, Linda Billard, to join the team to provide her expert skills and knowledge to meld the material that Rich and I would be delivering. This ensures the book speaks with “one voice,” avoiding the distractions that different authors’ writing styles can cause for readers. Linda has a wealth of experience in this regard, and I am very grateful for her work on this book.

This book, which is intended for those astronomers who are interested in learning all the details of designing, building, and operating a remote observatory, provides the resources to get you quickly up to speed on what is involved in building your own remotely operated observatory or working with an existing commercial remotely operated observatory service. This book provides a wealth of detail not only on the systems, subsystems, and components (SSC) that make up the remote observatory but also how to integrate those SSCs and operate the observatory in a professional manner.

In *Scientific Astrophotography*, I introduced the concept of an Astronomical Imaging System (AIS) to describe the design and function of the SSCs that provide data based on a specific observing program. In this new book, we expand on this concept and discuss how it may apply to your specific remote observatory design and to the various observing programs you want to run as the observatory director. This approach also offers insight for those astronomers who need to match their specific observing programs to the equipment provided by the remote observatory services available today to astronomers all over the world.

Having access to your own remote observatory is a significant milestone in the life of an astronomer whether you own it or rent it. It will make your life significantly easier in several ways, including not having to set up or tear down your AIS, being able to work in a comfortable environment, and efficiently taking advantage of those observing opportunities that quickly changing weather may have denied you in the past. Productivity goes up as frustration goes down, and your life as an astronomer becomes golden.

Using a commercial observatory service allows you to focus on your data rather than equipment issues and operations if that is your desire, and again boosts your productivity. These are advantages particularly valuable for astronomers involved in scientific observing programs. Providing accurate and timely observations to those scientific groups that accept them are key to developing a reputation as a professional-caliber astronomer, whether you are paid or not for your high-quality work.

It is my expectation that this book will be the definitive "go-to" book on remote observatories long into the future and will help astronomers—whether they are amateurs or professionals—who are looking to move to the next level in their astronomy "career."

Lake of the Woods Observatory MPC I24 Jerry Hubbell
Locust Grove, VA, USA
June 2015

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We would like to thank several amateur and professional astronomers for their contributions to Part III of this book, the case study section. Part III provides you, the reader, with a strong sense of what is possible when using a remote observatory and presents a wide variety of observing programs on which to model your own. Specifically, we would like to thank Adam Block, Roger Dymock, David Galbraith, Kevin Healy, Carl Hergenrother, Rob Matson, Patrick Miller, Robert Mutel, Kevin Paxson, David Pulley, Derek Smith, Americo (Eric) Watkins, and George Faillace for their valuable contributions to this book.

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Finally, we would like to thank Springer Books for this opportunity to create a book that we believe is needed at this time of great change in the industry to help amateurs keep abreast of the many new ways they can enjoy their hobby. We thank our Springer editor Nora Rawn for her support and understanding while assembling the manuscript; it is greatly appreciated.