a scientist and his hobby

REFLECTIONS

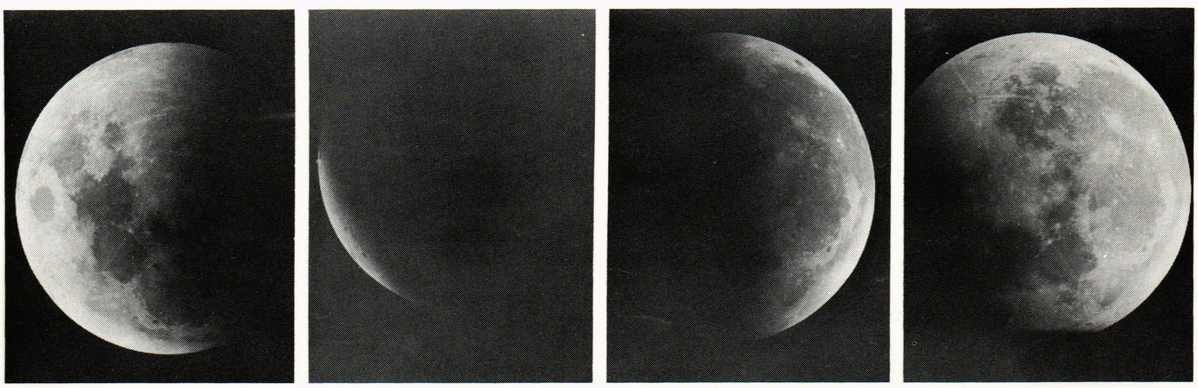
On a cold, late evening last January, I called to my younger son to come in from his "observatory" in the front yard. His reply—that it was neither too cold nor too late, and that school tomorrow was much less important than Jupiter's moons in transit now—set me to thinking. Time had now closed its full circle since his grandfather, too, had turned resignedly from a son whose inner clock ran on telescope time.

I could not help but muse awhile on the properties of this optic tube that bends light just so; that shows so clearly what young and old scarcely can believe to exist; that, itself a purely physical tool, enlarges man's concepts of his origin, nature, and destiny; that presents to the eye only events that are already past, yet with such precision and conviction that on its word I was one day to travel halfway around the world for a date with sun, moon, and a bench mark. Which is by way of saying that by suitable choice within the full scope of such a hobby, all ranges of ages, skills, and interests can find expression—from occasional diversion up to several lifetimes of serious activity.

Irvin H. Schroader, Assistant Supervisor of the Satellite Design Group, is a member of the American Physical Society and of the American Association for the Advancement of Science.

Suppose one takes a hobby point of view perhaps best described as opportunist, a sort of balance of one's resources of age, interest, and skill. In my own case, I chose early to combine library resources with an attempt to develop manual skills. My early attempts to read widely in the locally available literature on astronomy soon required supporting study into the disciplines of physics and mathematics, and this led to a career as a physicist. To this day, continued efforts to keep abreast of some of the major developments in astronomy serve a double purpose, since many recent advances in physics are involved.

My limited purse, on the other hand, led inevitably to the attempt to build or improvise instruments. And there are few who, having done so, will not put their efforts to practical use. Whether simple star gazing or attempting to photograph an astral body, holding "telescope night" for a scout troop or taking off on an eclipse expedition, a substantial reward accrues. Each success carries with it a sense of personal achievement; the inevitable imperfections only whet the appetite for another try, better planned next time if time allows.



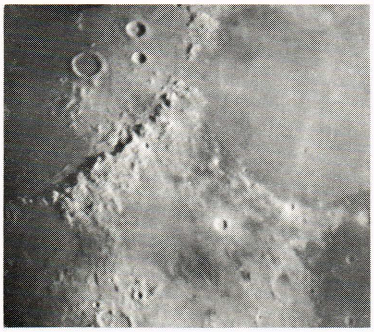
Eclipse of the moon, September 25-26, 1950. The four views were selected from a series taken as the moon moved through the earth's shadow. They were photographed by mounting a 35-mm camera, with lens removed, at the prime focus of a reflecting, 112-inch-focal-length telescope; that is, so that the telescope focused a sharp image directly on the film. The exposure was determined experimentally by considering the moon to be a chunk of grayish rock illuminated by the sun.

# of a TELESCOPE MAKER

I. H. Schroader

Grinding the Telescope Mirror

To illustrate, I recall standing inside the darkened dome that shelters the 100-inch telescope on Mt. Wilson,



Section of the moon at first quarter, taken by the same technique as that used in the September 25-26, 1950, moon-eclipse series. The shadows cast by mountain ranges and crater walls cause the surface features to stand out in bold relief. The mountain range is the Lunar Apennines, and the largest crater is named for Archimedes.

wishing for a look through the giant instrument. However, since the staff astronomers themselves seldom observed visually, luck was not with me. With better fortune sometime later, two nights spent at Lick Observatory provided opportunity for magnificent observations of Mars, Jupiter, and Saturn that might have ended all satisfaction with smaller instruments had not the element of personal achievement counted so heavily.

So I made a telescope of my own by the following process, based mainly on simple principles and hard work. Take two round disks of Pyrex glass, say 6 inches in diameter by 1 inch thick, and grind them together with coarse carborundum grains between. The upper disk, when stroked back and forth over the lower, tends to wear to a smooth concave surface if moved in all possible directions. The rough surface resulting is then made smoother by several hours of grinding with successively finer grades of abrasive.

At this point, further progress toward a smoother surface requires polishing by rubbing the upper concave disk over a rouge-saturated layer of pitch. Some hours later, the surface of the glass will become beautifully smooth and free of pits and scratches if cleanliness is carefully observed.

So far, work; from here on the emphasis is on minimum work with maximum skill, for the contour of the surface of the glass must be carefully modified so that it assumes the form of a paraboloid of revolution (a distorted pattern of stroking the upper disk over its pitch lap is employed, so that more glass is polished away in the center area of the disk). For the tyro, give or take 5 millionths of an inch is near enough to perfection. The final step requires that an extremely thin layer of aluminum be evaporated over the glass surface to render it highly reflective. When assembled in a tube, the curved mirror surface will then reflect light rays from a star to form a real image that can be further enlarged by a magnifying eyepiece.

The first look through one's own creation is a never-to-be-forgotten experience. Thousands of amateurs of all ages have completed successful instruments, thanks in large measure to the guidance of such men as the late Russell Porter and Albert Ingalls, and principally to the sponsorship of *Scientific American* magazine.

Perfecting the Mirror

The working of glass is still largely empirical—more art than science in its dependence on personal skill. The mounting of the optics to form a completed telescope can be kept very simple unless the amateur decides to take a turn at fine machine work. One of my own particular interests has been in perfecting the paraboloidal surface on a mirror and measuring it with high accuracy. This is a project that consumes large amounts of time and little money—a good combination for a hobby.

Surprisingly enough, the mirror surface can be measured for deviation from the desired paraboloid within, say, 2 millionths of an inch by illuminating it with an artificial star—an illuminated pinhole of light aimed to strike the average center of curvature of the mirror surface. The mirror will

Comet Arend-Roland, taken with a 35-mm camera attached to a 6-inch telescope. The telescope was mounted so that it could be moved to follow the motion of the comet.

reflect the incident light back to a somewhat distorted image of the pinhole. So simple a device as a razor blade can then be used (by slicing the light, so to speak) to locate the point where rays of light from any small selected area on the mirror come to a focus. Eye and mind can soon be educated to "see" the contour of the glass surface, with deviations from a perfect spheroid as small as a fraction of a millionth of an inch standing out in bold relief under test. A combination of measurement and simple calculation leads to a knowledge of the actual mirror surface contour, which can then be corrected toward perfection by always polishing off the high places. This method of testing bears the name of its inventor, Leon Foucault.[1]

By a combination of the mathematics that describes in detail how a paraboloid reflects light and an ingenious use of fine wire for examining the reflected image of an illuminated slit, Enrique Gaviola devised a "caustic test" for determining mirror accuracy. This method depends, for its high degree of accuracy, upon the uniform diffraction of light around a fine wire. The position of the wire must be known accurately as observations are made to measure surface inaccuracies as small as $\frac{1}{100}$ of the wavelength of light (about $\frac{1}{5}$ of a millionth of an inch).

Over a period of several years, I worked with the late A. G. Ingalls, a *Scientific American* staff editor, on ways of developing this technique so that it could be used by amateurs. Of particular interest, the instrument for moving the wire with a precision of, say, 200 millionths of an inch had to be designed with the limited shop facilities of even the advanced amateur in mind. In simple terms, a form of construction that depended on the assembly of readily available materials had to be used. Careful adherence to the principles of geometric design virtually assures required accuracy.

This effort brought success of several kinds. First, several test instruments were constructed and tested, using only hand tools and inexpensive, commercially available components; these proved to have the required accuracy when compared with precise measuring screws. Second, the test instruments and methods have been used repeatedly, with a high degree of success, by a number of interested telescope makers. Third, I completed a chapter in *Amateur Telescope Making*[2] describing the test in detail.

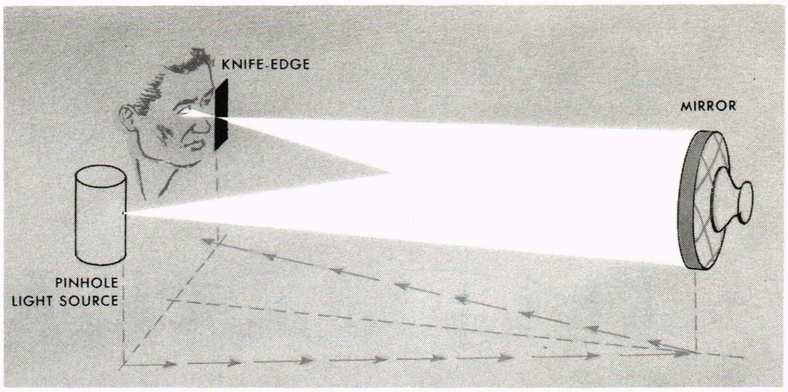


Illustration of the Foucault test setup for determining precision of mirrors during polishing.

A major undertaking in mirror making is the task of working a disk of glass to achieve a surface contour so close to that of a perfect paraboloid that testing errors become important in stating the accuracy achieved. It is evident that glass can only be *removed*, so the worker must continually think in terms of an imaginary surface lying principally just under the actual glass surface. As the real and imaginary surfaces approach each other within less than a millionth of an inch, the work of wearing away the high areas must approach the vanishing point, perhaps $\frac{1}{100}$ of a millionth of an inch of glass removed per stroke. At this stage the emotional outlook of art, the rational viewpoint of science, and the empirical basis of technology blend in almost exquisite form to force completion before the anguish becomes unbearable. I have succeeded on surfaces as large as 12 inches in diameter, less well on larger surfaces. In defense of such painstaking effort, it must be realized that the constant turmoil of the earth's atmosphere will often blur the finer details of even the most marvelous image—of Mars, for example. However, the chance-of-a-lifetime critical moment on an almost perfect night can be lost forever because of some minor imperfection in the equipment.

Photography and Astronomy

To be continually attractive, a hobby must offer less demanding goals as well. With little talent for sketching, I have had only limited success in drawing what is seen through the eyepiece. On the other hand, photographing astronomical events and objects has proved to have very interesting possibilities. I have tried a variety of devices, from very simple lenses up to those in much more sophisticated cameras. Perhaps most interesting have been attempts to photograph the moon, planets, and comets, using the greater light-gathering capability and resolution of the largest available telescope. Here again it is easy to become absorbed in an attempt to develop techniques to the limit of perfection and then play games with atmospheric turbulence in the hope of catching the sharpest possible images.

Whatever the success achieved, it is an established fact that the eye and mind can better read through the atmospheric turbulence to catch and remember fine detail momentarily perceived than can the photographic image that averages its impression over the exposure interval. An amateur's carefully made 12-inch telescope directed at the moon or planets will show to the eye all that can be photographed through the largest telescopes with present cameras.

A Family Affair

There are times when nature contrives to schedule an event so fleeting or so magnificent that photographic coverage with the best equipment on

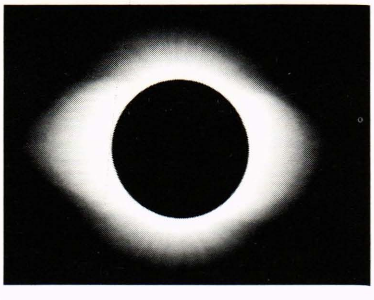
[1] A. G. Ingalls (ed.), *Amateur Telescope Making*, Scientific American Publishing Co. New York, 1933.

[2] I. H. Schroader, "The Caustic Test," in *Amateur Telescope Making (Book Three)* A. G. Ingalls, ed., Kingsport Press, Inc. Kingsport, Tenn., 1953.

command at the time becomes an urgent necessity. Thus, an entirely new area of interest opened up for me several years ago.

A total eclipse of the sun always occurs somewhere else, and it almost demands a photograph to convince one of its reality since it is here and gone in seconds. Contrary to the impression so far given, amateur astronomy is not necessarily a lone-wolf operation. Early in 1954 I exchanged correspondence with Mr. L. A. Pommerening, Forest Supervisor of Chequamegon National Forest in Wisconsin, asking for permission to set up equipment to photograph the June 30 sunrise eclipse of that year. The forest would provide a pleasant camping vacation as well, but posed the difficulty of finding a clear shot at sunrise. Mr. Pommerening kindly provided a clear location at the base of Long Mile Fire Tower, which indeed proved perfect.

This kind of thing can become something of an adventure, with family, dog, and equipment to care for, along with mounting concern over losing everything to the weather at the appointed moment. My telescope, mounting, and camera were cleaned, set up, and adjusted in fine June weather, and in a cloud of flies that literally covered every square inch of exposed skin. It was impossible to kill them (two boxcar loads had just been imported to eat tent caterpillars), just grin and bear it while my family complained from behind mosquito netting. Seven hours before sunrise my German shepherd lost his challenge match with a porcupine; he was a pitiful sight for some hours as I removed quills and dressed his wounds



The Solar Corona, June 30, 1954 (from a Kodachrome original). The original was made by attaching a 35-mm camera to a small telescope, of 35-inch focal length, that was mounted and clock-driven to follow the sun.

by gasoline-lantern light. By then the day's thunderstorms went their way and left the atmosphere crystal clear for a never-to-be-forgotten 60 seconds of totality.

By careful pre-planning, I managed to squeeze into that interval six excellent exposures on Kodachrome film, ranging from $\frac{1}{30}$ second up to 15 seconds in duration, along with a quick look at the sun. The first exposure recorded the last thin crescent of the sun's photosphere—an instant before the moon completely blocked its blinding radiance—to reveal the fainter crimson chromosphere accented with hydrogen-gas prominences that exceeded five earth diameters in height. Stepwise increases in exposure enabled the limited dynamic range of Kodachrome to record, first, the chromosphere, then the relatively bright inner corona, with the longest exposure recording faint extensions of the corona extending outward several sun diameters before fading to the same brightness as the general sky illumination. Here again the eye proved vastly superior to film in resolution and dynamic range. In the 20 seconds remaining after exposing film, I was easily able to observe and remember, well beyond the camera's ability to record, both the magnificence of the phenomenon as a whole and the ray-like structure of the corona with its faint extension.

Even the best laid plans can go astray, however. The inevitable small detail overlooked showed up as a neat crescent-shaped hole in the camera's shutter, burned into the black cloth as the sun waxed large again. Fortunately, my exposures had already been made. In another way, I came close to complete failure not more than a minute before the total phase began. I had made no provision for shielding the telescope lens from the dew that inevitably forms as the temperature drops rapidly, leaving the glass cooler than the moist air. I knew that wiping the moisture away would be utterly useless, as it would quickly reform. What a welcome sight it was to watch the dew evaporate in the warmth provided by my Coleman lantern, which, by great good fortune, was still burning. Three hours later we left the site to the flies, gathering storm clouds, and a porcupine in a tree.

To the Far Corners of the Earth

Some months later, at lunch with Father Heyden, S.J., Director of Georgetown University Observatory, when he mentioned his need for help at a forthcoming eclipse, I literally leaped up to volunteer at a chance to go on a real eclipse expedition. This one had elements of travel, diplomacy, science, and adventure, along with a chance to make a useful contribution to geodesy. I was to be responsible for a team of five men to photograph a not-quite-total eclipse of the sun from a location in Ceylon. The carefully timed observations were to be combined with those of other groups spread out along the eclipse path in Africa and Asia in an attempt to interlock geodetic survey grids and perhaps to derive an improved radius of the earth.

A travel log filling a secretary's notebook twice over, hundreds of color slides, and some vivid memories remain as mementos of the trip. Among them, from my notebook, is the simple entry:

"Saturday, November 26—Al Kobar,"

followed by five blank pages. And thereby hangs a tale of East meets West with but slight understanding of each other.

The five of us from APL—C. T. Holliday, L. W. Fraser, L. W. Bennett, D. C. Small, and I—went by cab from Dhahran Air Force Base, Saudia, Arabia, to visit the small nearby Arab town of Al Kobar. We were wary with our cameras lest offense be taken by some devout Mohammedan who might involuntarily become accessory to the formation of an image, expressly forbidden as they read the Ten Commandments of Moses. Somehow we wandered too close to the residential area and shortly were on our way to the local police station under armed escort (a bayonet). There we were courteously seated, facing the police captain in western military uniform and several other personages in white robes. Their English vocabulary seemed to consist of the word "picture," and later also of "women," at which we then realized our predicament. My Arabic escaped me, and English protestations were in vain until Lorie Fraser, in an inspired moment, took up a slow chant—

Eclipse day, Ratmylana Airport, Ceylon. Clyde Holliday (left) and the author are at their operating stations. The remainder of the APL group are at stations in the tent to the right, and a group of interested Ceylonese form the background.

"*American - School - Professor - American - School - Professor. . . .*" A few minutes later the local high school teacher (English and algebra) arrived to solve the communications problem. Our penalty, as provided by law: turn in our film for local development (Kodachrome!) to verify the absence of feminine images, after which it would be returned. The police chief made this verification on the spot by pulling the film out of one spool. Just as I had said, no women.

Shooting the Eclipse

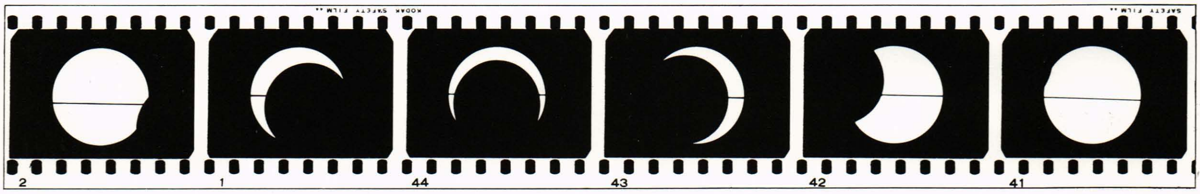
Three weeks before Christmas, 1955, we were registered in comfortable quarters at the Mt. Lavinia Hotel located near the capital city of Colombo, Ceylon. Clyde Holliday and I shared a room overlooking a fine beach. A few miles away, on the edge of the airport, a concrete pier had been poured to serve as a stable base for our telescopic camera. An insulated tent set up by the army of Ceylon proved its value twice over—as a shelter from the midday heat and from the frequent rains that characterize the transition period between one monsoon season and the next. There followed busy days of preparation; what hadn't been accomplished in the States had to be finished now, with masking tape and the like.

An important task was to place in operation a precision crystal-oscillator clock and a radio receiver, and to provide a standby generator in case of power failure. The clock had to be kept running at all cost, for upon its accuracy depended a major factor in the success of the expedition. Each day it was necessary to compare its time indication with that broadcast throughout the world by WWV and log the difference within a few thousandths of a second.

The task facing us was to photograph the sun well over 100 times during the eclipse, record accurately the instant in time when each exposure was made, and get the photographic negatives safely returned to Georgetown Observatory. A number of technical details had to be worked out on site. Very slow (low-sensitivity) glass plates were to be used rather than the more familiar film. Each plate had to be loaded into "old-fashioned" plate holders. This would have been easy in a darkroom with a safety light; in our case, however, the darkroom was a light-tight box about the size of an orange crate. Plate holders entered and left the box by a light-tight sliding trap door, while the operator's arms worked through light-tight sleeves. With only four plate holders on hand, the trick was to keep up a rate of one exposure every 30 seconds during the middle of the eclipse. Lorie Fraser's practiced hands made it with not a plate out of order.

Clyde Holliday struggled with development of the test plates, first in the tropical heat of an improvised darkroom in the hotel, but later in a cool darkroom at the University of Ceylon, through the kindness of Professor Mylvanagam, head of the Physics Department.

Techniques of loading plate holders at the telescope, guiding the telescope, etc., were worked out to perfect the routine. My experience with the burned shutter in 1954 emphasized the ever-present possibility of a slip-up due to inattention, momentary distraction, or even boredom with routine. As a drill, we photographed the setting sun on several evenings and developed the plates to assure our success. As we drilled, each man developed the habit of "talking out" each step of his chosen task, and listen-



Partial eclipse of the sun, from a series photographed in Ceylon.

ing at the same time, alert to act as prompter if any one should bypass a single important step.

We came to December 14 a well-drilled team. I recall wondering how foolish we would look to the local people gathered around if nothing should happen. Much to my relief, the eclipse arrived on time and passed without incident; perhaps the local Buddhist priest present in the group around us served as a stabilizing factor. We exposed 135 plates before the temperature drop literally brought down the curtain on the show clouds. After a few minutes of elation, the homeward-bound phase began, and it ended at home three shopping days before Christmas. It could have been much later, considering the date, for the transportation officer at Dhahran tried to send us the long way home to relieve pressure on his sector.

By the way, there was one technical failure I must confess—a shutter again. Half in jest I asked Clyde Holliday one day whether he had checked the shutter of the movie camera he was using. "No," he replied, "but it's the only thing around here we haven't checked!" The developed film proved once again, to our sorrow, that *everything* must be checked. Every frame of seven rolls was ruined.

With the technical mission accomplished, I cannot help but reminisce a bit about the personal impact of the trip. It was my first trip out of the country, save Canada. Over and over again I could only think in terms of how I would feel if my family had to live in such a way as we saw around us in many places. Often only a few steps separated youngsters without hope from those surrounded with every evidence of good living. Our senses eventually became saturated and numbed in the face of our utter inability to do anything about it.

Colombo is a beautiful city, with less that detracted from this beauty than in many an American city. A one-day trip to Kandy, the ancient capital city of Ceylon, seemed to confirm our impression of a clean, well-dressed, well-fed, and friendly people. Yet Ceylon in that December was in the midst of an election campaign, carrying with it many overtones of the problems a young nation faces as it develops in self-government—problems of race, language, and political philosophy that must be accommodated if a somewhat dependent economy is to survive.

It seemed not a little strange that as eclipse day neared, some degree of apprehension developed throughout the local population. They had lived through a total eclipse in the previous June, during which many of the people became genuinely fearful at the sun's apparent demise, and were impelled to restore its former vigor with appropriate ceremonies.

I was pleased to repay, in part, Professor Mylvanagam's favor by writing a letter to the University Dean on behalf of the Professor's assistant, Mr. P. A. S. Perera. Mr. Perera had assisted us with darkroom work at the University, made a modification to the plate-changing box that enabled us to change plates at a faster rate, and assisted at the site on eclipse day. The letter, I understood, would assist Mr. Perera in his application for an assistantship at Cambridge University.

New Fields to Conquer

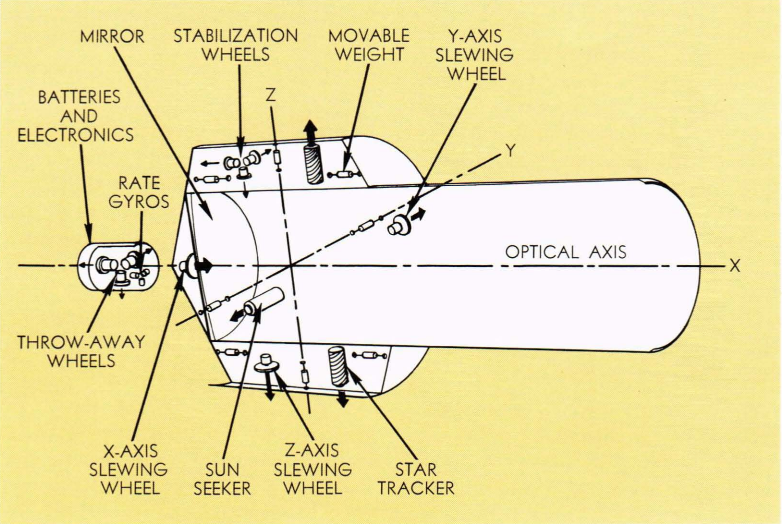
A few years later, and back on this side of the world again, other intensely interesting opportunities developed. Two of these have absorbed a major amount of my time at the professional level. These are the Orbiting Astronomical Observatory and the 60-foot-diameter radio telescope nearing completion at the APL Howard County site.

The Orbiting Astronomical Ob-

The author in a moment of relaxation, at Kandy, Ceylon.

servatory design study was made by a group of engineers and scientists at the Laboratory in cooperation with the NASA program for space astronomy. The conclusion of the study incorporated a telescope design best described by the accompanying illustration. Basically, it is a large reflecting telescope (up to four feet in diameter) to be placed in orbit by state-of-the-art rockets. Once in orbit, it would relay observations back to the ground control station by television and by telemeter. An important feature is the system of reaction wheels, which serve to move the telescope under ground-based control signals for aiming the telescope and for precision-tracking of an astronomical body under study.

Another requirement of this age is that of transmitting to and receiving



The orbiting telescope designed at APL, showing major control components.

signals from space. The Laboratory has invested in its future capability by installing a high-performance radio telescope, which consists of a 60-foot-diameter reflecting paraboloid with associated support, and aiming and driving mechanisms. I shall soon finish my present responsibility as problem sponsor and will then turn to its use. One of the most intriguing possibilities is its use for radio astronomy, a new field of astronomy based on the radar technology developed during World War II.

Maine, 1963

Much of this story was written while making preparations for eclipse day on Saturday, July 20, 1963, again at the request of Georgetown University. Our destination was Ellsworth, Maine.

My first responsibility was to repeat the Ceylon experiment, namely, to photograph the partial phases of the eclipse. Three Georgetown astronomy students collaborated on this project. The resulting plates were to be measured in a digital data-reducing machine at the observatory in order to define accurately the moon's position at mid-eclipse.

Results from two other experiments were to be compared, in an attempt to detect the errors that were characteristic of each. One of these experiments involved measuring the sun's waning and waxing light by means of a photometer, from which mid-eclipse time could then be determined. The other experiment was to photograph the sun's spectrum on movie film, starting a few seconds before the total phase. For a brief interval the resulting spectrum changes suddenly from absorption to emission —the flash spectrum—just as the sun's disk is covered by the moon.

My task being an old one, it went without incident right into the eclipse itself. Meanwhile, I helped Clyde Holliday and Lowell Bennett adjust the Georgetown cameras that they were to use to take black-and-white and color pictures of the sun.

Since I was not needed to operate the Georgetown camera for some ten minutes before and after the total phase, there would be time for pictures on my own of the most exciting

The author is seen on site at Ellsworth, Maine, adjusting the Questar telescope in preparation for photographing the total eclipse of July 20, 1963.

part of the event. For this purpose, a Questar telescope and camera, on loan from L. R. Sanford (APL), and the same camera and lens that were used in Wisconsin in 1954 were set up and checked out.

Friday dawned fair but ended cloudy, an ill omen. True to the weather reports, Saturday was the same. Both tension and cloud cover increased as groups sought shelter from the midday heat in order to smooth their working routines. Since there were only 45 seconds of totality available, every second had to count.

When first contact was announced, it was a thin black notch most noticeable on the five-inch-diameter image on the ground glass of Clyde Holliday's camera. A few shots were made on schedule, but then we began to expose plates whenever breaks in the clouds permitted, for a total of 13. By 5:30 PM it was obvious that only pure luck or a miracle would allow us a look at the total phase.

Our low spirits must have showed as groups wandered from their stations, but with only seconds to spare a sudden shout directed all eyes to the thinnest ghost of a crescent sun. Cameras were re-aimed and I made my first exposure on the last thread of the photosphere, for a fine "diamond ring." Six more exposures were crowded into the allotted time, along with a quick look through binoculars—and then it was over. Just as quickly, and almost as if planned, solid clouds ended all further observations.

I am often made curious by the viewpoint of persons who look with wonder through my telescope, and then ask, "Doesn't it make you feel utterly insignificant?" True, we are smaller than much of the universe and are possessed of less energy; but it is also true that we are larger than much of it and possessed of more energy. These factors, of course, count heavily in brute contests of will. But scientific man looks ever for new knowledge, for more effective ways to control, in man's behalf, the large forces of nature.

In such a contest, individual man possessed of rational mind and skilled hands can well afford to lay aside the arrogant pride associated with brute force in exchange for the ever-renewing personal satisfaction that comes with accomplishment of a useful result.