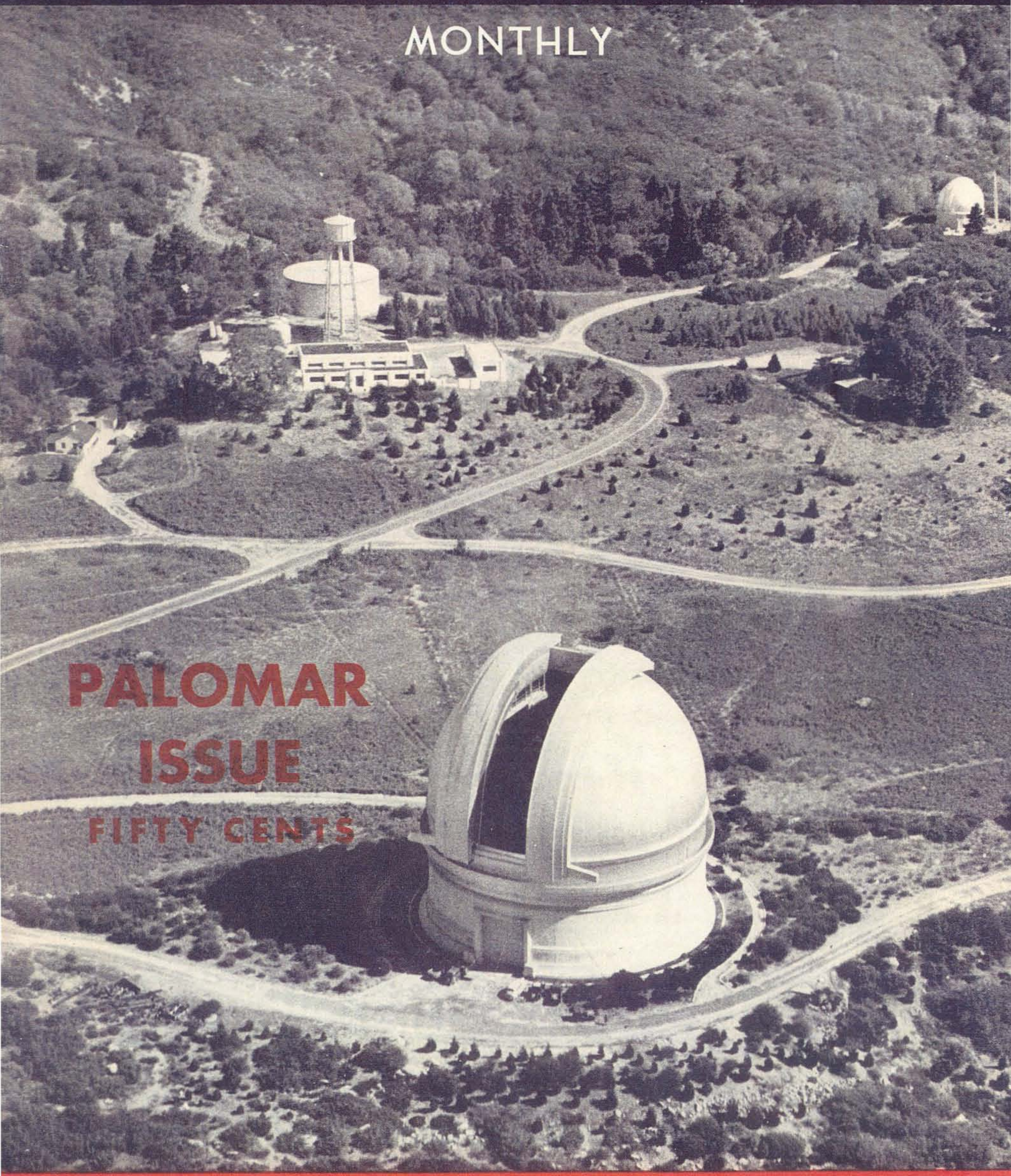
ENGINEERING AND SCIENCE

MONTHLY

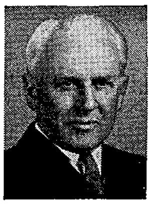


PALOMAR ISSUE

FIFTY CENTS

THE MEN

TO supplement this record, some of the men prominent in the planning, building, administration, and operating of the joint project are presented in this issue. Besides eleven introduced in the following pages, two of the most able administrators concerned with the over-all observatory planning are **mentioned** here.



Robert A. Millikan, who retired in 1946 as chairman of Caltech's Executive Council, was an original member of the Observatory Council, established in 1928. Now chiefly engaged in research and writing, Dr. Millikan has been with the California Institute since 1921, when he left his position as professor of physics at the University of Chicago. A native of Iowa, Dr. Millikan received his A.B. degree from Oberlin College in 1891, his Ph.D. from Columbia University in 1895, and took advanced study at Berlin and Gottingen.

Some of the other early workers are **Dr. John A. Anderson,** with the story of the 200-inch mirror on page 9; **Dr. Edwin P. Hubble** of "red shift" fame, on page 23; and **Dr. Ira S. Bowen,** ex-officio chairman of the Observatory Committee, page 27. **Max Mason,** on page 29, has seen the Palomar Project from two sides. **Russell W. Porter,** idea man extraordinary, has a message for amateur astronomers on page 32.

Two other men, **Byron Hill,** on page 19 with the story of the installation, and **Bruce Rule,** who wrote the page 16 story on engineering, joined the Project soon after graduating from Caltech. Optician **Marcus Brown** came by way of Mt. Wilson, where he worked as a truck driver 25 years ago.

Most recent addition to the astrophysics staff is **Jesse L. Greenstein,** who will conduct Caltech's new teaching program.

Two years ago Caltech inaugurated as President **Dr Lee A. DuBridge,** who gave the dedication speech at the June 3 ceremony on Palomar Mountain, reported on page 7. Dr. DuBridge studied at Cornell College, Iowa and the University of Wisconsin where he received the Ph.D. degree in 1926. After two years of research at Caltech, he went to Washington University in St. Louis, and then to the University of Rochester in 1934. Chosen in 1940 to head M.I.T.'s Radiation Laboratory, he served as director until his return to Rochester in February 1946. In April of that year, Dr. DuBridge was called to the presidency of the California Institute.

ENGINEERING AND SCIENCE

Monthly

The Truth Shall Make You Free

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ENGINEERING AND SCIENCE MONTHLY

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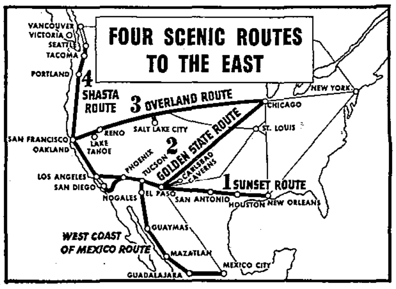
The Main Line

JUNE, 1948



THE TIME HAS come when alumni magazine editors and staffs get ready to close down for summer vacations. A logical move, this—seeing as how campus activity is nil, and a too-big percentage of alumni newsmakers (class secretaries, reporters, et al) are setting forth on summer holidays. So, a suggestion: the time has come for you, too, to start planning a summer vacation.

Have you decided on where, how and when you are going? We have some suggestions for you—four routes-worth of them. We sum up these suggestions (capsule them) thus: "Go one way, return another, see twice as much en route." Expanded slightly, here's our story:

Southern Pacific is the only railroad with four routes East from the Pacific Coast. You can dream up *six* completely different roundtrip expeditions East via S.P.—and experience practically every scenic thrill America has to offer. (And if you want an extra portion of any of the thrills, you can stop over anywhere en route.)

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(P.S.: West Coast of Mexico Route, too—*si quere viajar a* Mexico City.)

There's lots more to the story of vacations via S.P. We couldn't possibly give it all here—even as a serial. So look what we've put at the bottom of the column: a coupon, with lots of space for you to let us know what *you'd* like to know re S.P. vacationing. Fill it out, drop it in the mail, and we'll send back—posthaste—just the information you require. There's no obligation, of course—but do it now, because time is of the essence in vacation planning.

DOES YOUR BUDGET threaten to ball-and-chain you to an at-home vacation? We've got some thoughts on how to fit a trip to your purse—three to be precise. They are, from left to right:

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Index to Advertisers

COVER CAPTION

The dome of the 200-inch Hale Telescope, looking northeast. Behind the dome is "Utility hill" with power plant, shops, and water storage. To the right is the 48-inch Schmidt Telescope dome.

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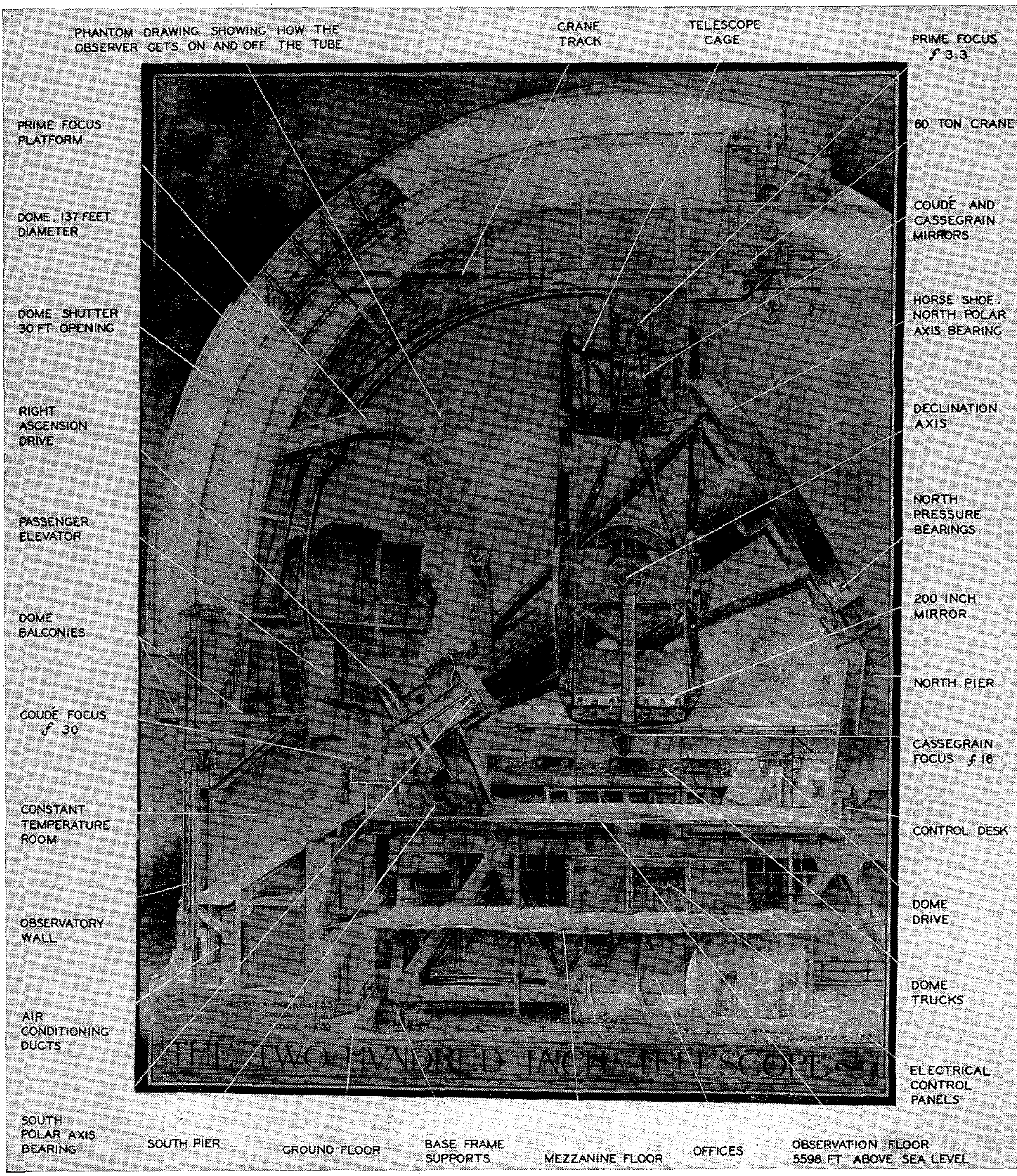

THE 200-INCH HALE TELESCOPE

A cross-section through the telescope and dome looking west. Faint white lines show the path of parallel light from a star to the 200-inch mirror and its subsequent reflection by auxiliary mirrors to photographic plates at the three foci. Actually, of course, only one focus can be used at a time.

The most direct path is to the f 3.3 prime focus. Light may also be intercepted by the Coudé convex mirror immediately below the prime focus cage. From there it converges to a diagonal flat mirror on the declination axis from which it passes to the f 30 Coudé focus through the hollow south polar axis. A third focus, the f 16 Cassegrain, is achieved by tilting the flat mirror out of the way and passing the light through the central hole in the 200-inch mirror. Drawing by R. W. Porter.

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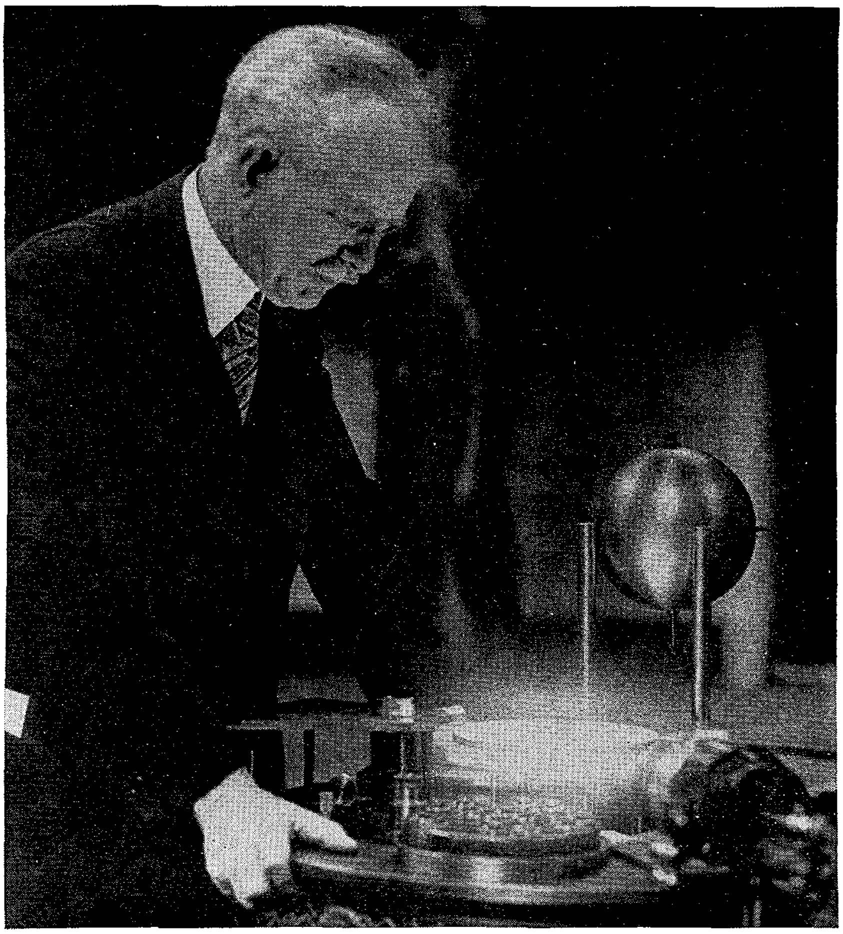
PALOMAR -- Dedication of the Observatory

By LEE A. DUBRIDGE



GEORGE ELLERY HALE
1868 1938

IT is not often in the history of science or of mankind that a group of men and women have such a high privilege as we have in dedicating to the service of man this magnificent and significant scientific instrument.

Since long before the dawn of history man has gazed wonderingly and thoughtfully at the heavens. Since the time of Galileo he has been able to study the heavenly bodies ever more searchingly and more precisely with ever finer and more precise instruments. While these instruments have vastly increased man's understanding of the universe, each new advance has raised new questions. A 60-inch telescope raised problems that only a 100-inch instrument could answer, the 100-inch called for a 200-inch. How much farther this quest will lead no one can foretell. But the great telescope before us here marks the culmination of over 200 years of astronomical research, and for generations to come it will be a key instrument in man's search for new knowledge.

It is with great pride that the California Institute of Technology formally dedicates this great observatory to the service of science and of mankind. We cannot know what new knowledge will accrue as a result of the work that goes on in coming years on this mountain top. But it is certain that new knowledge will come which will lead men a few steps farther along the road toward a more perfect understanding of this great universe.

It was almost precisely 20 years ago to the day that the 200-inch telescope project was assured. In June, 1928, the International Education Board voted to give six million dollars to the California Institute for the purpose of building this instrument and all the other facilities necessary for its construction and operation.

But it was long before 1928 that the idea of the telescope was born in the minds of George Ellery Hale and some of his associates. Soon after the 100-inch telescope on Mount Wilson was put into successful operation in 1917, Dr. Hale saw that an even larger telescope was both feasible and desirable, and as early as 1923 he put forth this idea in a paper he published in the magazine **Popular Astronomy.** As the work with the 100-inch telescope developed it became more and more clear to those who worked with it that a still greater instrument must some day be built. Dr. Hale and his colleagues talked over the possibilities among themselves and with other astronomers all over the world, discussing methods of mounting, methods of fabricating glass or fused quartz or metal mirrors, the requirements of a desirable site and dozens of other technical problems. By 1927 Drs. Hale, Adams, Pease, Hubble, and the other members of the staff of Mount Wilson had the broad outlines of a large telescope project in mind and an article outlining the purposes and possibilities of such an instrument was written by Dr. Hale for **Harper's Monthly,** appearing in the spring of 1928. That article did not fix a size for the mirror but mentioned that Dr. Pease had sketched a mount for a mirror 25 feet or 300 inches in diameter.

Before the article appeared, however, Dr. Hale on February 14, 1928 wrote to Dr. Wickliffe Rose, then president of the General Education Board, sending a proof copy of the **Harper's** article and inquiring as to the possible interest of the Rockefeller Boards. Given an encouraging reply he went at once to New York to discuss the matter, and within a few weeks the dream had been reduced to the form of a definite proposal for a 200-inch instrument. On June 12, 1928 Dr. Hale was informed that the International Education Board had voted a grant of six million dollars to the California Institute to finance the project. The Institute in turn had agreed to undertake the project, to cooperate with the Mount Wilson staff and to finance the operation of the Observatory after it was complete. Dr. Hale was asked to serve as Chairman of the Observatory Council which was to supervise the whole project, with Dr. Millikan, Dr. A. A. Noyes, and Mr. H. M. Robinson as the other members.

And so began what was to become one of man's greatest scientific enterprises. Unfortunately, Dr. Hale did not live to see it completed; but for 10 years from 1928 until his death in 1938, Dr. Hale gave all his energy to this task. His vision and leadership were decisive factors during those critical years and this great Observatory stands today as a monument to that great scientist.

On May 10, 1948, the Board of Trustees of the California Institute of Technology unanimously adopted the following resolution, which I herewith announce for the first time:

"The Board of Trustees of the California Institute of Technology hereby resolve that the 200-inch telescope of the Palomar Mountain Observatory shall hereafter be known as

THE HALE TELESCOPE

By this action the Board of Trustees seeks to recognize the great achievements of Dr. George Ellery Hale (1868-1938) who served as Director of the Mount Wilson Observatory from 1904 to 1923, who served as a member of the Board of Trustees of the California Institute from 1907 to 1938, who originated the bold conception of the 200-inch telescope and whose brilliant leadership has made possible its design and construction. As this great instrument probes the secrets of the universe, it is fitting that it should stand also in memory of the great scientist and the great leader who contributed so brilliantly to the science of astronomy and who served so ably his community and his nation.

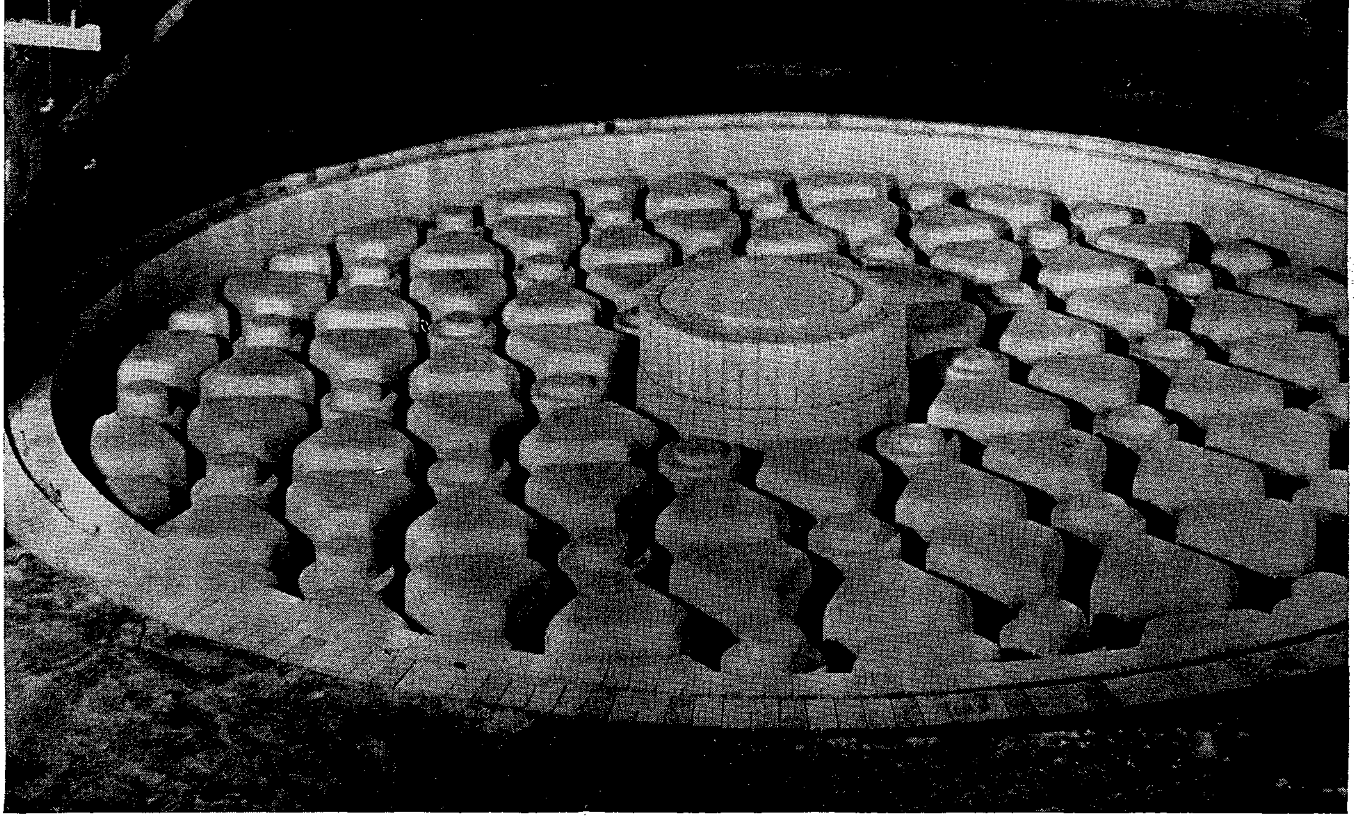
"The Board of Trustees further directs that a suitable plaque in Dr. Hale's honor be permanently installed in the Observatory and that an engrossed certified copy of this resolution be presented to Mrs. Hale."

No one would have predicted in June 1928 that the completion of this great instrument would not be accomplished for 20 years. No one could have foreseen the stupendous difficulties to be overcome nor the devastating World War which caused an additional four-year delay.

But the difficulties were overcome. Those who laid the plans planned well. Those who carried them out performed superbly.

Unfortunately, it is impossible at this time to pay adequate tribute to the hundreds of men who have contributed to this great enterprise. I should like, however, to mention briefly at this time the names of four men who have been closely associated with the project almost since its inception. One is Dr. Max Mason, who in 1936 succeeded Dr. Hale as Chairman of the Observatory Council and who had previously aided the project as President of the Rockefeller Foundation. A second is Dr. John A. Anderson, who, as Executive Officer of the Observatory Council from 1928 to date, has had the task of supervising the painstaking grinding, polishing and testing of the surface of the 15-ton disk of Pyrex glass to its present degree of perfection. Another is one who has contributed immeasurably to the realization of the plan, cooperating as Director of the Mount Wilson Observatory from 1923 to his retirement in 1946, Dr. Walter S. Adams. The plan was conceived and largely executed by his staff at Mount Wilson, and for 20 years, Dr. Adams' knowledge and abilities, his unstinting collaboration, and his kindly wisdom have been decisive is the success of the work. Finally, no history of this project would be complete

(Continued on page 15)



Mold for the 200-inch disk, showing cores for center hole, support holes, and triangular openings between ribs. Corning Glass Works photograph.

THE 200-INCH MIRROR

THE PRESENT 200-inch mirror took shape in a New York conference early in 1932. Members of Caltech's Observatory Council, the Corning Glass Works, the Rockefeller General Education Board, and the Carnegie Foundation met to discuss a second attempt at producing a 17-foot disk. The General Electric Company had experimented with fused quartz for more than two years since the International Education Board promised six million dollars for the project, but the work was discontinued owing to slow progress and great cost. The Observatory Council then turned to "Pyrex", a low expansion glass produced at Corning.

In order to gain the necessary rigidity, a 200-inch disk of Pyrex would have to be 30 inches thick and would weigh 40 tons. And if the mirror blank could be cast, there was ahead of the structural engineers the tremendous task of producing a mounting that would carry this weight—almost astronomical itself in dimensions.

In discussing ways of lightening the mirror a suggestion, simple, but radically different from contemporary telescope practice, was made: Design the disk with a thin face supported on a ribbed back. The more the conference considered this construction, the more they were taken with the idea. Not only would it lighten the mirror considerably, but the ribbed back would also provide pockets for a counterbalanced type of support designed by Francis Pease of the Mt. Wilson Observatory staff. Besides, the thinness of the reflecting surface would permit a rapid adjustment to changes in temperature with consequent greatly reduced distortion caused by uneven heating and cooling.

This plan was carried out, and now almost all large telescope mirrors are cast with ribbed backs.

The Observatory Council's program for Corning was to order glass disks of increasing larger size, starting with one of 26-inch diameter. Most of these were to be used as auxiliary equipment in the telescope.

Difficulties were ironed out one by one as they arose. The method of attaching cores to the mold floor in order to produce the ribbed back evolved from cement, to dowel pins, to steel bolts. Cores floating to the top of the molten glass spoiled three pourings. In one case, the casting was rendered usable by fishing

John A. Anderson

Dr. John A. Anderson, executive officer of C.I.T.'s Observatory Council, has served in that capacity throughout the entire development of the Palomar project since 1928. He was active at the Mt. Wilson Observatory from 1916 to 1943, and has done extensive research in the fields of spectroscopy, ruled gratings, and seismometry. The 200-inch mirror was ground, polished, and figured under his direction.

A graduate of Valparaiso College, Indiana, in 1900, and holder of the Ph.D. degree from Johns Hopkins University (1907), Anderson was instructor and associate professor of astronomy at the University from 1909 to 1916. During World War I he worked at Caltech on a supersonic anti-submarine project, and has participated in two U. S. Naval eclipse expeditions, one to Spain in 1905 and another to Sumatra in 1926.

Dr. Anderson was awarded the Howard Potts Medal by the Franklin Institute in 1927 and is a member of the American Chemical Society, the A.A.A.S., the National Academy of Sciences, the American Physical Society, the Seismological Society of America, the Geophysicists Union, the Optical Society of America, and the Astronomical Society of the Pacific.

Pouring the 200-inch disk. Glass was ladled into the mold through three such openings. Corning Glass Works photograph.

cores out of the molten surface and grinding solid sections left in the back to the symmetry of the molded pattern.

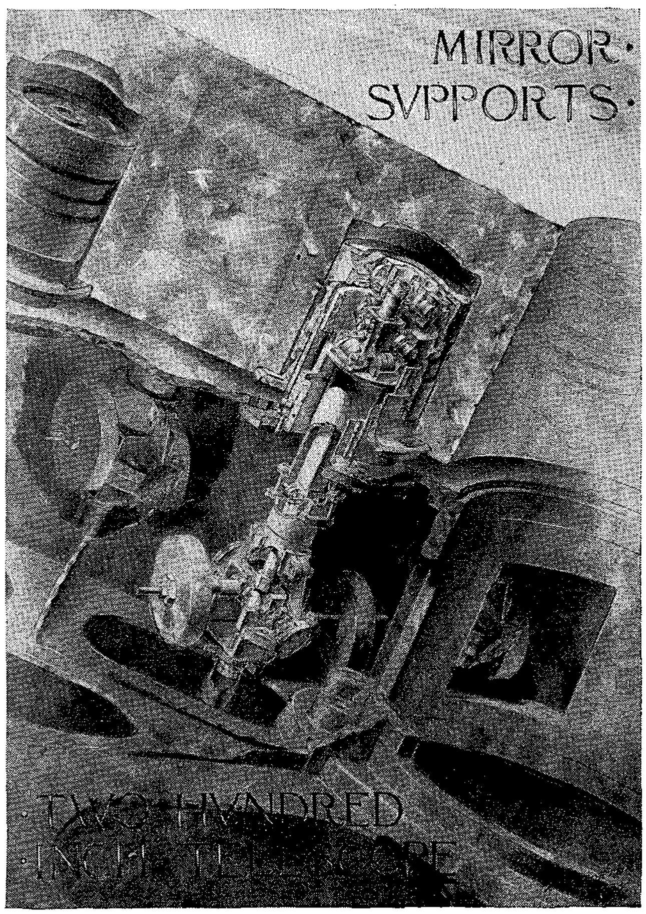
This trouble with cores was chiefly caused by the tremendous heat needed. Starting with the third mirror, one 60 inches in diameter, a furnace over the mold was required, as the molten glass had been found to solidify before filling all of the channels between the cores.

Everything was in readiness in February 1934 for the pouring of the 200-inch. Cores, 114 in all, had been bolted into place, and the brick furnace was keeping a heat of 2400° F concentrated over the mold. Pouring commenced, was half completed, when a core appeared on the surface of the glass lake inside the furnace. Three altogether rose, their retaining bolts having burned through in the great heat, but workers were able to break them into smaller pieces. The pourers finished their work, but Corning engineers had already made up their minds to try again.

The first disk was an excellent subject for experimentation. Corning cooled it at ten times the calculated rate, and on checking, found internal strains of exactly ten times those desired. With their calculations verified, the glass men drilled out the pieces of core and reheated the disk until the face became smooth again.

In December another disk was poured without a hitch. The mold had cores held in place by bolts of chrome nickel steel and cooled by an air circulating system. The disk was placed in the annealer to "soak" for two months at constant temperature, and then cool for eight more.

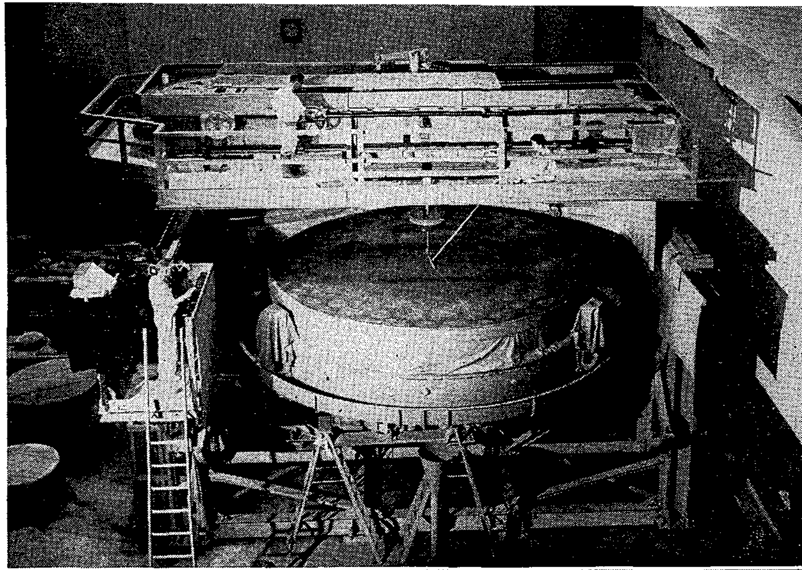
The next summer, with three months of cooling at the rate of one and one-half degrees Fahrenheit per day left, the nearby Chemung river flooded. The annealer was on the second floor of the laboratory, but the electrical equipment was on the ground floor. For a day and a half Corning men slaved to build a protecting dike, but in the end the current was shut off. Three days the great disk bled its heat away until the electrical equipment could be moved to the second floor. It was finally hooked up and

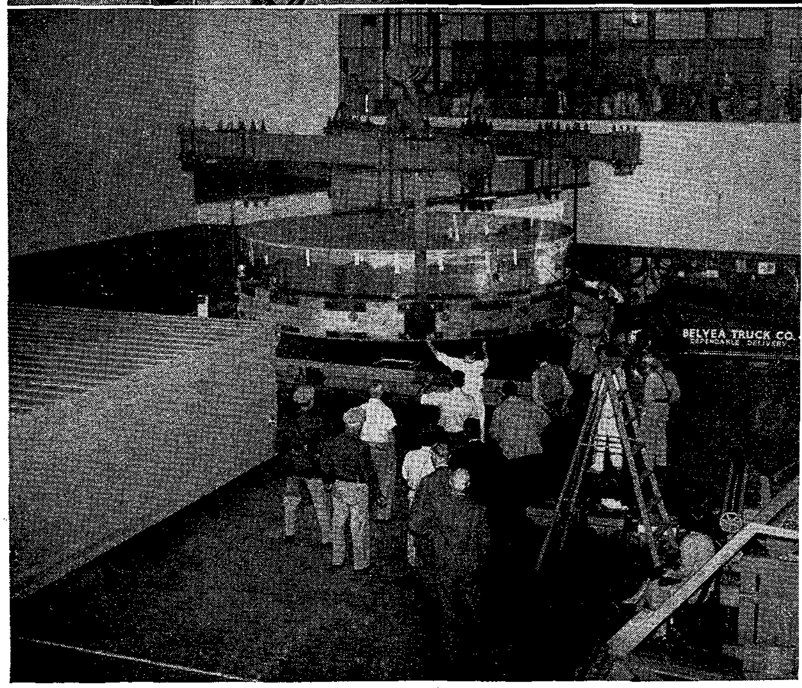


There are 36 supports identical to the ones shown here. Each is made up of over 1000 parts, comprising a series of gimbals and compound levers designed so that each support carries its share of the glass above it, no matter what inclination the mirror has to gravity. Drawing by R. W. Porter.

UPPER: Polishing the 200-inch mirror in the optical shop. The man at right on the bridge stirs the rouge-and-water compound and keeps it at the point of contact between the tool and the mirror.

***LOWER:* Loading the 200-inch mirror *in* the optical shop. This photograph shows the shop's observation gallery at the south end. To the left is the box which was placed over the mirror on its trip to Palomar Mountain.**





the annealing continued for the last three months.

No strains appeared when the annealer was opened. Across the country the disk was sent, arriving in Pasadena on Easter morning, 1936.

In the optical shop at Caltech the mirror was placed face down on an especially designed machine where its lower surface was ground smooth. Next came the face. After it was entirely trued up, 36 holes for the mirror supports were ground out.

Then came the grinding of a spherical surface, followed by polishing. These operations, as well as the original truing-up, were conducted on a turntable held high above the shop floor on a heavy iron frame. Underneath were motors and driving linkages which not only rotated the mirror but also tilted it to a vertical position for testing. Above the turntable was a heavy horizontal beam, called the bridge, which moved back and forth on wheels. This bridge supported a carriage, also on wheels, which held a vertical shaft for the grinding tool. In operation the disk on its table was rotated about once every 80 seconds, the tool turned faster and was moved over the surface by the bridge and carriage. The motors driving these parts were linked together so that the tool could be made to trace any kind of a pattern desired and hence distribute the grinding evenly over the whole surface of the disk.

For grinding and polishing, tools of 12 to 200 inches in diameter were constructed. These were faced with Pyrex blocks, used uncovered for grinding, and surfaced with a special pitch for polishing. Thirty-one tons of grinding and polishing compounds were used, ranging from carborundum to a very fine grade of rouge.

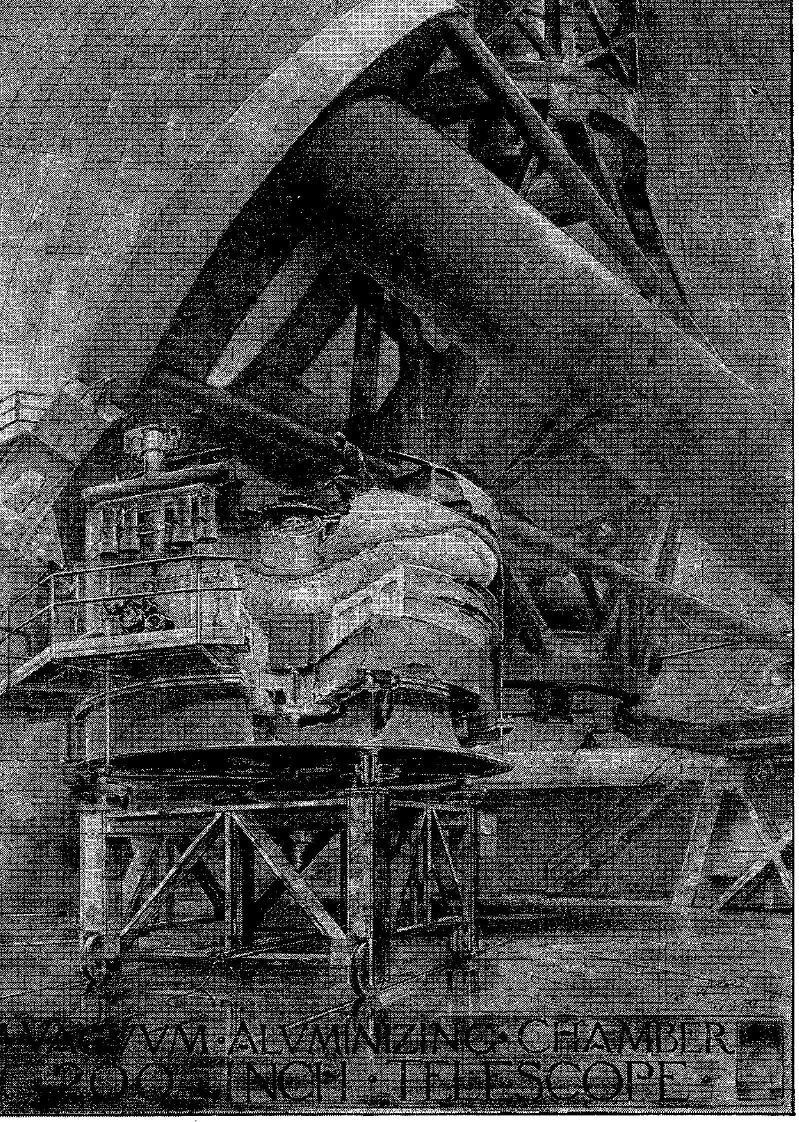
For rough polishing the 200-inch tool was used, with 1964 glass blocks surfaced with a compound concocted of resin, paraffin, and cylinder oil. Each pad was divided by channels into squares roughly one inch on a side, so that the 200-inch lap finally became a mosaic of 8000 facets with innumerable little canals for the polishing compound to run through.

In 1942, with polishing well under way, optical requirements for war work closed in, and the mirror was covered and left on its grinding machine. The crew spent three and a half years making mirrors, prisms, and other optical devices for the armed forces. In December 1945 polishing of the disk was resumed.

The work slowed down from 1946 to 1947. More and more time was spent in testing, and less and less in polishing. On October 3, 1947, the polishing was declared finished. By all of the routine tests used from the beginning, the mirror's parabolic surface was accurate to within two one-millionths of an inch—one-tenth of a wave length of light. Dr. John A. Anderson and his staff devised new testing methods. These new methods confirmed the accuracy of previous ones. The mirror was ready; and five and a quarter tons lighter than when it entered the optical shop.

November 18, 1947, saw the next high point in the mirror's career. The huge disk in its cell had been lifted off the grinding machine and lowered onto a trailer. At 3:30 in the morning State Highway Patrol officers gave the signal, and the tractor and trailer, convoyed by a spare tractor unit, another truck for spare parts, and innumerable reporters and cameramen, started the 160-mile trip to the Palomar Observatory. Road blocks were set up on some sections of the route, bridges received additional shoring, and the trailer had on one occasion 16 extra wheels mounted in order to distribute its 35-ton weight more evenly over a suspect bridge.

On arrival at the Observatory, the mirror was placed in an aluminizing tank, built as a permanent fixture on the observing floor. In this tank, under conditions of high vacuum, pure aluminum was vaporized off tungsten heating coils and condensed on the polished surface. The even coating thus formed is about two molecules thick—less than one-millionth of an inch. This was the reflecting surface. The glass, into which

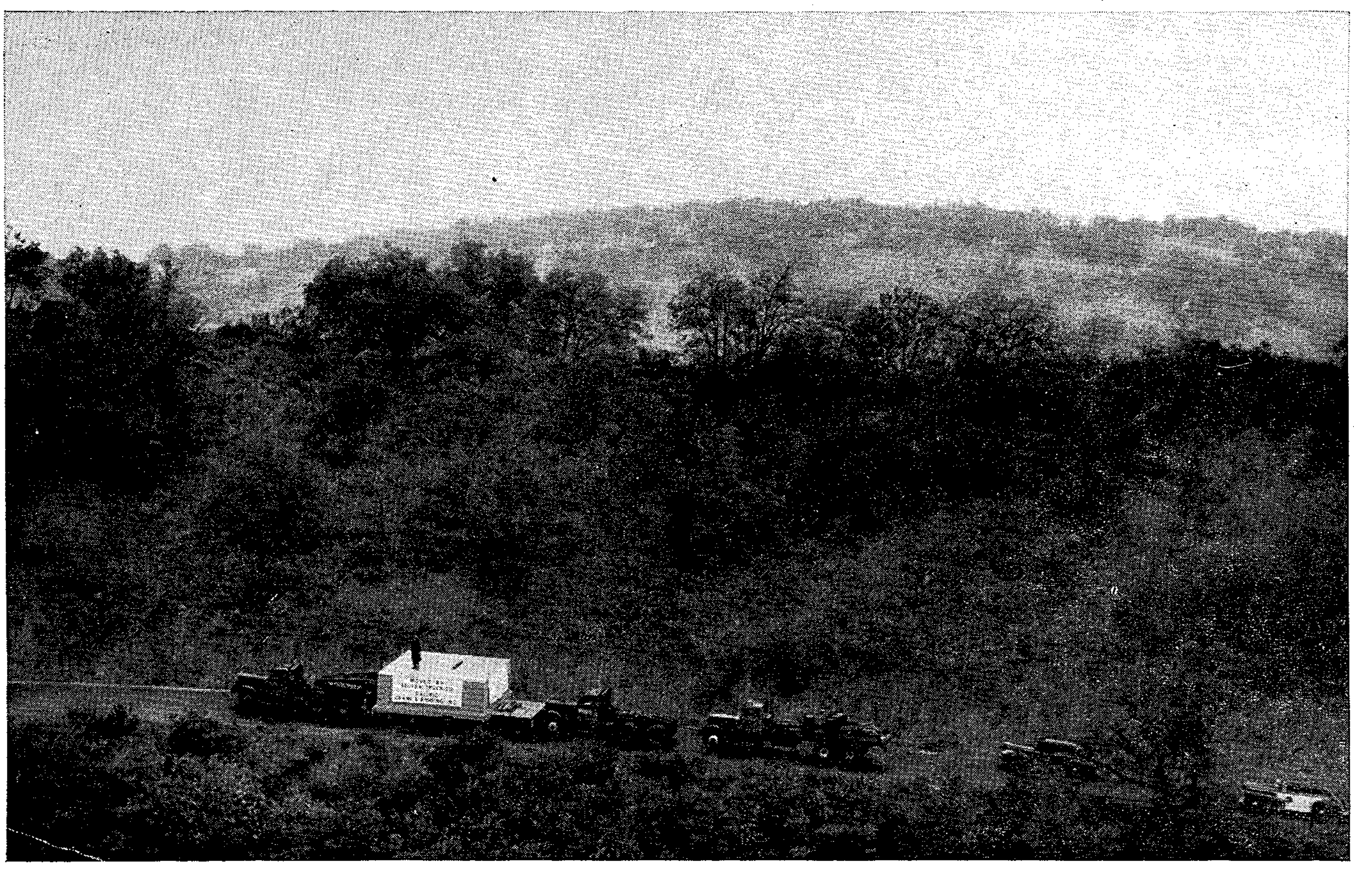


The aluminizing chamber is mounted on rails, so that it may be moved directly underneath the telescope. On the left are vacuum pumps. Pieces of aluminum wire are hung from tungsten coils inside the chamber, and vaporized in vacuum. Their temperature and position has been so computed as to place a layer of aluminum one or two molecules thick evenly over the surface of the 200-inch mirror. Each aluminizing is expected to last for about ten years. Drawing by R. W. Porter.

eleven years of work had gone, became backing for the mirror.

In December 1947 the first stars were seen reflected in the mirror. There was nothing spectacular about the "first look". Dr. Anderson used a small reading glass for an eye piece and peered into the big mirror. Asked what he saw, his noncommital answer was, "Oh, some stars." Marcus Brown, in charge of the optical shop and the actual mechanics of grinding and polishing from the beginning, was also there, as were Dr. Bowen, Dr. Hubble, Bruce Rule, and a few others.

Since that night, periodic photographs have been taken for the purpose of obtaining test data on how both the mirror and telescope react under working conditions. These tests will continue for some time yet as necessary adjustments are made, auxiliary mirrors installed, and other equipment completed.



Three trucks carring the mirror up Palomar Mountain. In spite of very poor visibility and road conditions, the trip was completed safely seven hours ahead of schedule. Photograph by Edna Sommer.

SHOPS AT CALTECH

WITH the decision made in 1928 to attempt a 200-inch telescope, past experience indicated the necessity of constructing special shops for finishing work on the mirror and development and fabrication of auxiliary apparatus for the project. Following the plan so successful at Yerkes and Mt. Wilson, Dr. Hale planned his third observatory with shops as an integral part of the project. The instrument shop, completed in 1931, and the optical shop, in 1933, were financed with funds from the Rockefeller grants.

INSTRUMENT SHOP

First to be built was the instrument shop, a one-story structure 70 feet by 197 feet, with a mezzanine floor for engineering offices and drafting rooms. The building is lighted by windows on the north and south sides, and through inclined "sawtooth" skylights.

A crane, normally equipped for five-ton capacity, but which can be rigged to carry considerably heavier loads, runs the entire length of the shop. All of the heaviest machinery is located in the central bay, where it is directly accessible by the crane. This location serves a two-fold purpose, permitting the crane to carry work to and from the machines, and also facilitating the dismantling of the machines themselves for overhauling.

Nearly all apparatus for the Palomar project, from the 10-ton gears cut for the telescope's right ascension and declination movements down to the smallest instrument part, has been manufactured here on the Institute campus. In a large woodshop for patternmaking, located in the southwest corner of the instrument shop, patterns for castings ranging in size from the great 14-foot gears just mentioned have been turned out. In most cases, actual casting was the only operation carried on outside the shop.

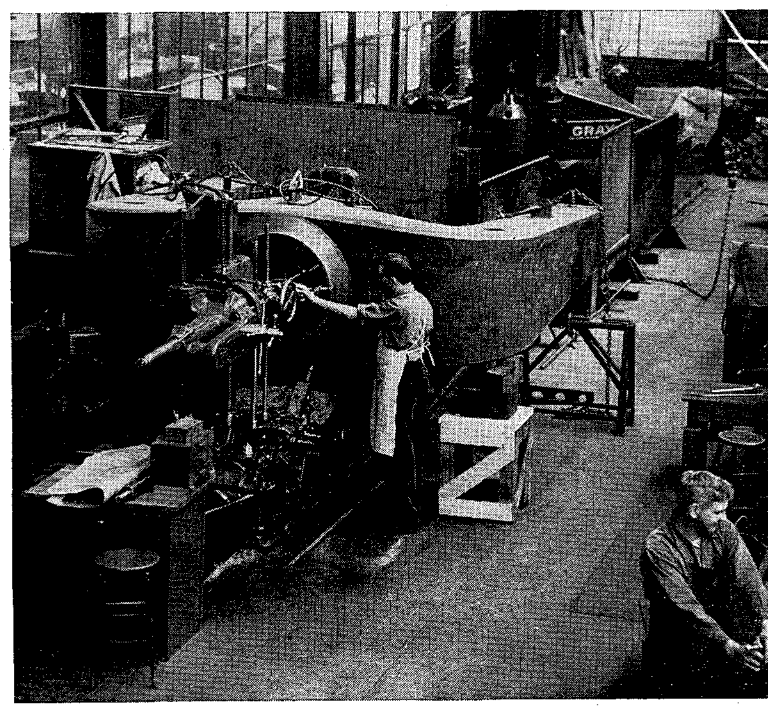
Opposite the pattern shop is the welding department, which also contains several heat-treating furnaces for hardening and annealing. One of the largest jobs done recently in this department was the fabrication of the 5½-ton fork mounting for the 48-inch Schmidt telescope from steel plates.

Since the shop's inception in 1930, its facilities have been used for a wide variety of work. Construction of all control cabinets, desks, and electrical test facilities, adaption of stock electrical parts and instruments to specialized telescope control, and installation and servicing of the short-wave radio formerly used for communication with the Observatory have been part of the shop crew's activities. In addition, all of the machinery for the optical laboratory, varying from the mechanism for grinding a 36-inch mirror to a machine for finishing the 200-inch, has been built in the instrument shop.

During the war when construction on the 200-inch project was suspended, the shop turned to Navy-sponsored work for the Institute. The usual complement of 24 workers was expanded to 70 to carry on rocket and torpedo research and development.

One of the most interesting jobs to be done in the shop was the machining of the three 14-foot gears for the 200-inch telescope right ascension and declination drives. These gears, each weighing ten tons and containing 720 teeth, were cut to an overall tolerance of one ten-thousandth of an inch. To cut the three gears required two and one-half years. And to achieve the degree of precision required, work was carried on inside a specially constructed, air-conditioned room maintained at constant temperature between 74° and 76° F.

The shop building also houses a complete electrical department. Chief electrician is Jerry Dowd, who joined the Mt. Wilson project as a truck driver in 1907, switching to the 200-inch job in 1930 when the shop went into operation. All electric equipment was built under his direction and was wired and tested under the same roof before being installed.



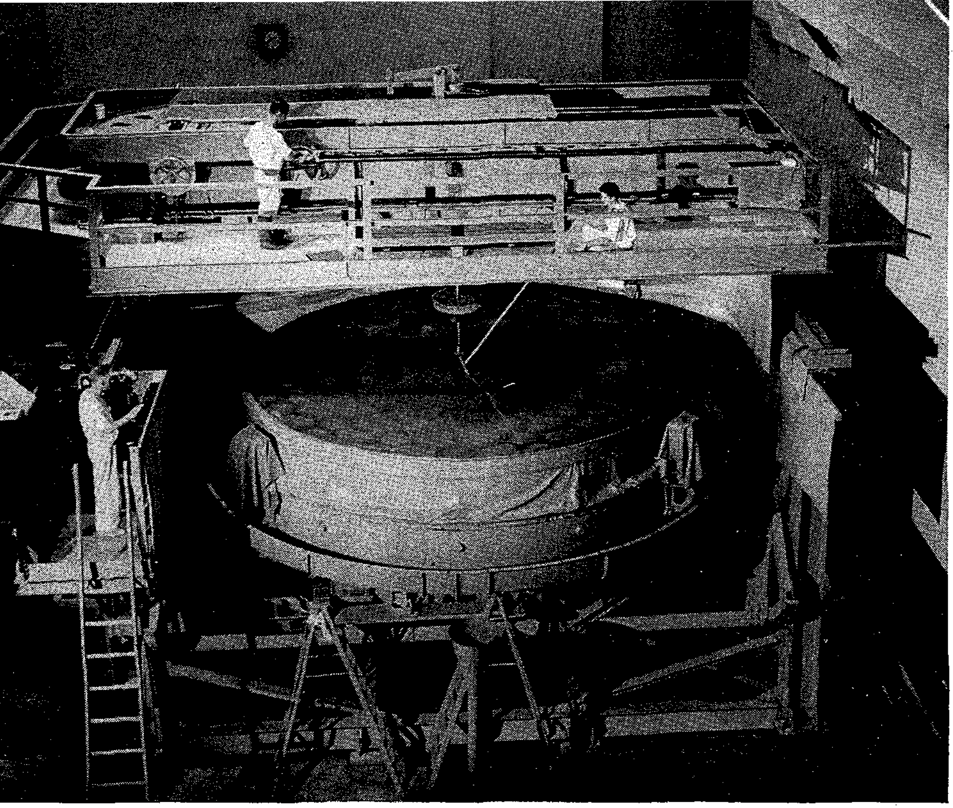
The 48-inch Schmidt telescope fork on the Lucas boring mill in the instrument shop. In this photograph, looking west, the pattern shop is to the left.

OPTICAL SHOP

One of the most important factors that had to be considered in designing the optical shop was its 17-foot scale. Facilities for the grinding and testing of the big mirror were all-important, although the shop would be used only for small auxiliary mirrors and testing after the 200-inch was moved to Palomar.

Completed plans provided for one large room, 52½ feet wide, 165 feet long, and 48 feet from floor to ceiling. The floor is of reinforced concrete divided into sections, each section completely isolated from the walls and adjacent sections to absorb earth disturbances. In turn, each section is floated on three inches of cork for insulation. The walls and roof are similarly of reinforced concrete and lined inside with cork.

For air conditioning a large blower is installed in the attic. This blower has a capacity of 12,000 cubic



Looking north in the optical shop. The 200-inch mirror is being given its final polishing. This scene was the usual one during polishing operations from the observation gallery at the south end of the shop.

feet per minute, and is equipped with facilities for washing the dust from the air as it enters the building and for maintaining a constant relative humidity.

Unlike the instrument shop, the optical shop has no windows connecting with the outside. Instead, constant illumination is provided by lights in the ceiling which are insulated from the room by heat-absorbent glass.

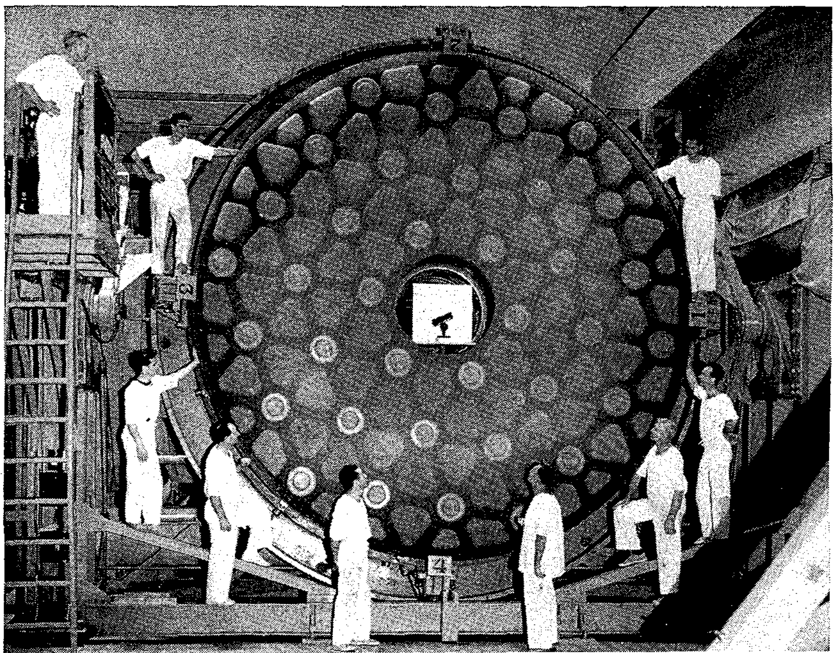
For handling the mirror and moving necessary equipment, there is a 50-ton overhead crane capable of traveling the entire length of the room. At the south end of the room a glass-enclosed, insulated observation gallery has been constructed which is open to the public on work days.

Entrance to the large room is provided by two huge doors having a clearance of 23 by 23 feet. On the west side of the building are two floors of smaller rooms where the auxiliary mirrors were made. The entire building is equipped with hot and cold water, gas, and alternating and direct current electricity.

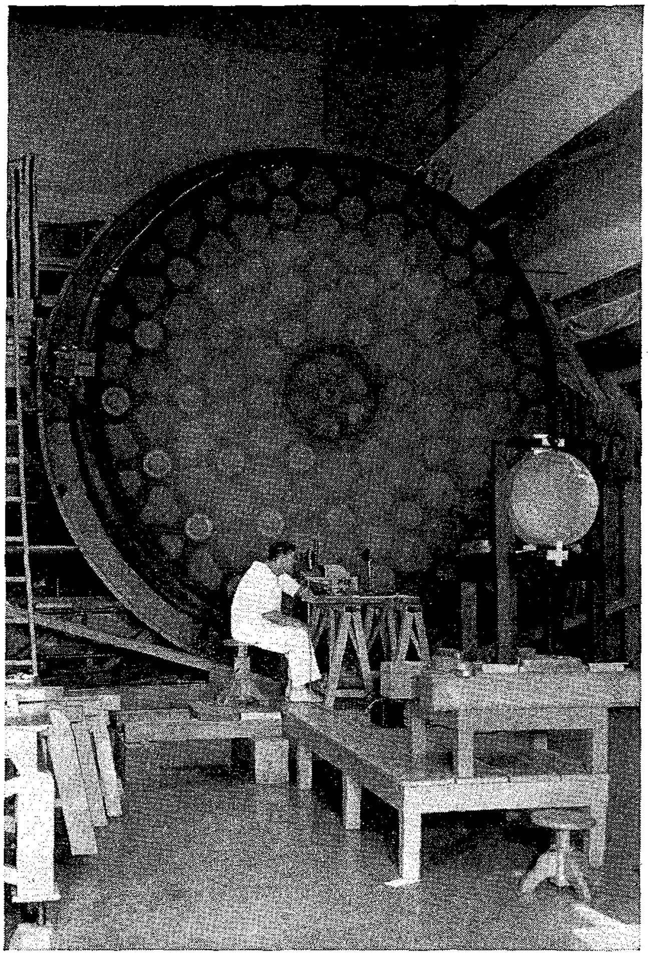
The most important piece of equipment in the shop has been the 200-inch grinding and polishing machine. This machine weighs 160 tons, and has a width of 30 feet, length of 36 feet, and height of 26 feet. At its front end is a turntable 17¼ feet in diameter for carrying the mirror, while the grinding and polishing tools are driven over the Pyrex surface by a bridge-and-trolley unit which comprises the machine's upper structure. Second of the mechanisms is a 120-inch machine of the same general construction on a smaller scale. There are also 60-inch, 48-inch, and 36-inch machines, of "beam" type construction. Other equipment includes stands for mounting the smaller mirrors and Foucault knife-edge sets for testing.

Various grinding and polishing tools were used on the mirror, ranging from the full size 200-inch tool to ones just a few inches in diameter. Some tools were fabricated from thin sheet metal, others of cast iron or aluminum, the material used depending on the requirement for the particular operation.

The principal procedure followed in facing the grinding tools was to cement on ceramic or glass blocks which could be replaced when worn out. For the polishing operation, blocks of pitch replaced the grinding blocks. Abrasives used for grinding were composed of silicon carbide or aluminum oxide mixed



The finished mirror shortly before it was taken out of the optical shop and trucked up Palomar Mountain. The 40-inch center plug has been removed, and in its place is a replica of Newton's telescope, with which he discovered the moons of Jupiter. Marcus Brown, optician in charge, is at center right. Photograph by E. R Hoge.



Marcus Brown checking for parabolic accuracy near the end of the polishing. The 200-inch disk has been turned to a vertical position on the grinding and polishing machine for testing.

with water. Iron oxide (rouge) mixed with water also was used for polishing. To prevent scratching the surface of the mirror, a constant program of sweeping and mopping was carried on, and when changing from one grade of abrasive to the next, even the walls of the room were thoroughly washed. For protection against foreign particles, particularly metal chips, which would mar the mirror's surface, workmen were required to leave their street shoes outside the large room. Rubber soled shoes and uniforms were provided to replace their street clothes, and as an added precaution, a magnetic sweeper was kept in constant operation on the floor.

Marcus H. Brown

Marcus H. Brown, in charge of the Institute's optical shop, has been the man directly supervising the grinding operation of the 200-inch mirror. From 1936 to 1947, except for the interruption of the war years when endeavors were turned to government research, Brown and his crew of 21 men executed the precision task of smoothing the Pyrex surface to Dr. Anderson's requirements.

First taken in to Mt. Wilson's optical shop in 1928, Brown had no training as an optician until that time. Doing odd jobs in the laboratory shops, he showed such interest in optics that he eventually was given a chance to work with the men who had ground the 100-inch Hooker telescope mirror. His training and experience under them, combined with intensive study on his own, led to his appointment in 1931 by Dr. Anderson as optician in charge of the grinding of the 200-inch.

From 1932 to 1936, Brown completed the organization of the optical shop, selected his crew, and made preparations for the arrival of the mirror. Many of the tools and procedures used in the grinding and polishing were developed by him during this preparatory period.

When he supervised the packing of the finished mirror for its trip to the Observatory on Palomar Mountain in November 1947, Brown was the only man who had stayed with the 200-inch disk since it was brought into the shop in 1936.

Dedication of the Observatory

(Continued from page 8)

without a long section devoted to the part played by Dr. Robert A. Millikan, who so wisely led the California Institute through all the years until 1945. He has been a member of the Observatory Council from the beginning. He and Dr. Hale and others discussed the plan exhaustively from the start. It was Dr. Millikan who boldly pledged the Institute to assume responsibility for the enterprise including financial responsibility for its operation.

To these four men I have named and to the multitude of others who made outstanding contributions we all join in tribute. This Observatory stands as a monument to their collective efforts. And it is a living monument. For from this Observatory will flow down through the ages the one indestructable thing that mankind achieves—new knowledge, new understanding.

As is known, the Board of Trustees of the California Institute of Technology and the Carnegie Institution of Washington some time ago agreed mutually that the Palomar Observatory and the Mount Wilson Observatory should operate cooperatively as one, under single management, with mutual sharing of facilities and staff. I wish only to emphasize that the California Institute has entered into this cooperative arrangement with greatest enthusiasm. In dedicating this Observatory, we dedicate it as one part of the Combined Observatories. We pledge ourselves to work in fullest collaboration with the Carnegie Institution as we devote our combined facilities to the service of science. We deeply appreciate the collaboration of Dr. Bush and the other officers and trustees of the Carnegie Institution. We and they are fully aware that in combining talents and facilities in this way we are creating in Southern California the mightiest astronomical center the world has ever seen or is likely ever to see. The California Institute assumes its share in this joint enterprise with pride, but also with humility and a deep sense of our responsibility.

The word "dedicate" in the English language means to set apart by a promise. It is essentially synonymous with consecrate, which means to make holy by a special act. The word has more than a formal or material significance. It carries also a spiritual implication. It is in this sense actually that we do today set aside this temple of learning and promise that it shall be devoted henceforth to deepening man's intellectual and spiritual understanding.

Engineering Aspects of the 200-Inch Telescope

By BRUCE RULE

THE principal features of the Palomar 200-inch Telescope are well known and are of considerable general interest, not only because of the huge size required to accomodate the largest reflector made, but also because of the engineering aspects involved in achieving the unprecedented accuracy and coordination of precise mechanisms. Most of the exacting engineering objectives have been accomplished by modifications of conventional methods or by development of new techniques to meet special conditions.

ADVANTAGES OF THE 200-INCH TELESCOPE

Briefly, the function of the Palomar 200-inch Telescope is to collect light from celestial objects and concentrate it at the prime focus, or, by a series of additional reflections from auxiliary mirrors, to bring the light to other focal points both on and off the telescope. The major advantages of the 200-inch telescope over other large instruments in existence are:

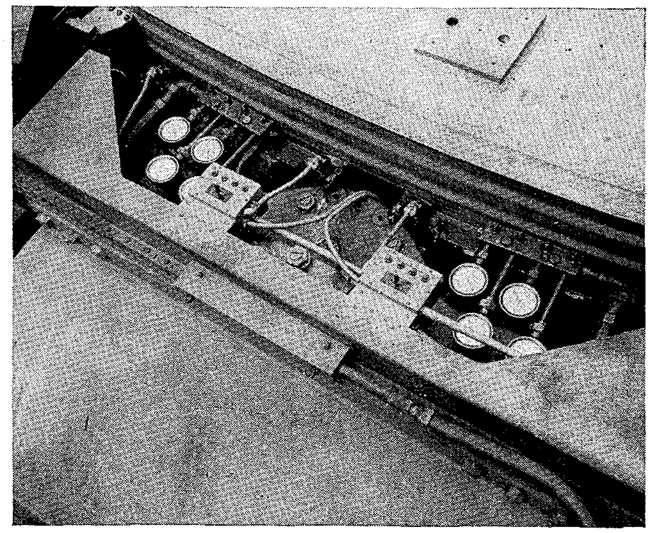
1) its considerably larger light-gathering capacity, permitting reduction in time of exposures and the photographing of more distant objects;

2) its design, permitting astronomical work directly on the telescope at the prime focus, thus avoiding the loss of light through additional reflections;

3) its flexibility by remotely operated auxiliary mirror combinations;

4) its automatically corrected drive and setting controls, which relieve the observers of unnecessary tasks and save time.

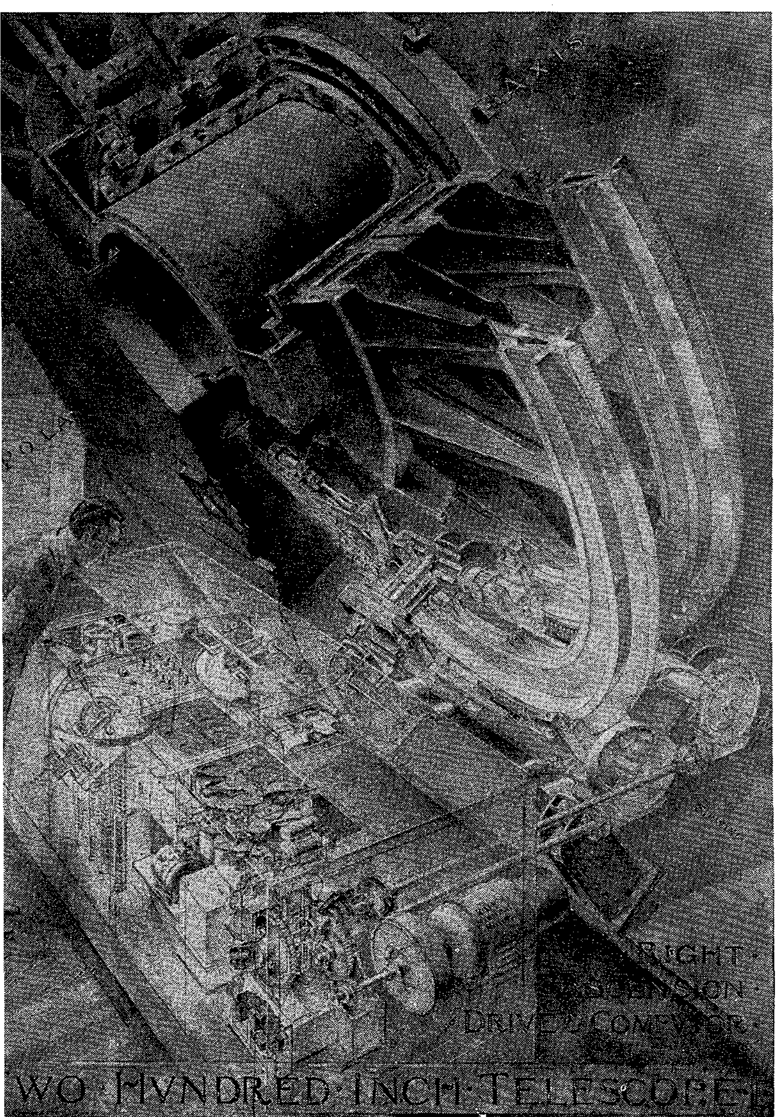
To realize the optical advantages of the 200-inch telescope, the application of many mechanical, structural, and electrical devices has been made to obtain the required coordination of the many precise auxiliary mechanisms.



North oil pad bearing and film gauges.

THE MOUNTING

The mirror is now supported in its 530-ton mounting within the 137-foot-diameter welded and insulated dome, so that it can be directed with minimum effort toward any point of the celestial hemisphere and moved automatically and continually to follow the apparent motion of the stars, due to the earth's rotation. The angular rate of motion of any telescope

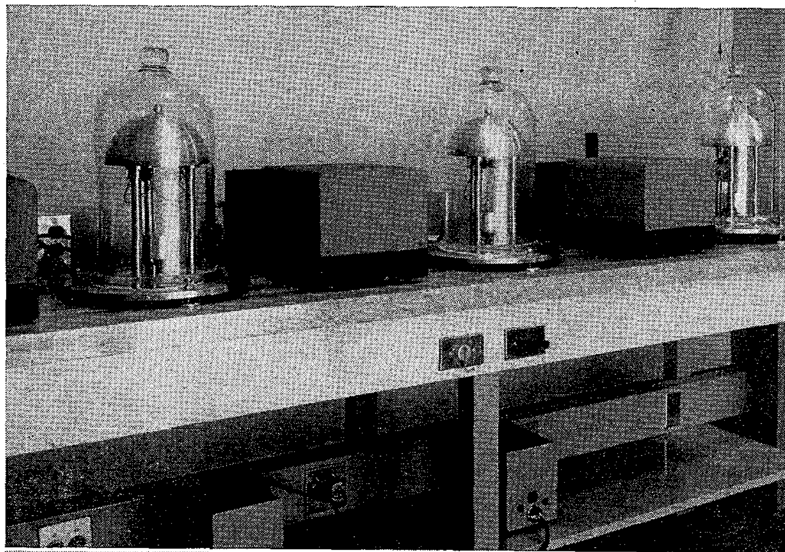


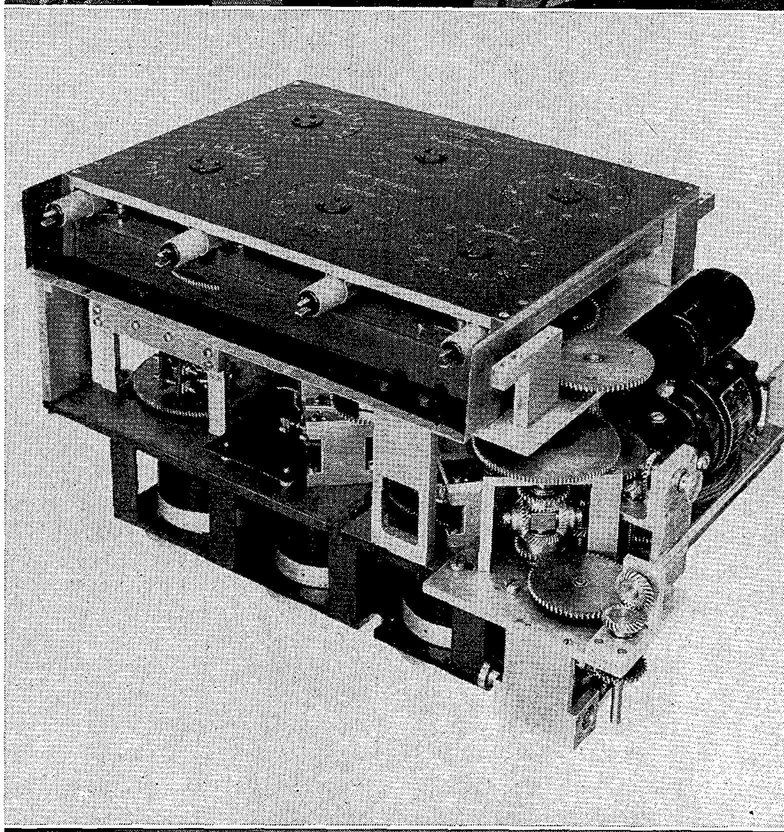
Two 14-foot worm wheels drive the telescope in right ascension. The upper one, for "tracking", turns at celestial rate, just fast enough to keep the telescope on its objective, while the photographic plate is being exposed. The lower "slewing" gear permits fast turning of the instrument. The computor below compensates for atmospheric conditions and flexure of the telescope. Drawing by R. W. Porter.

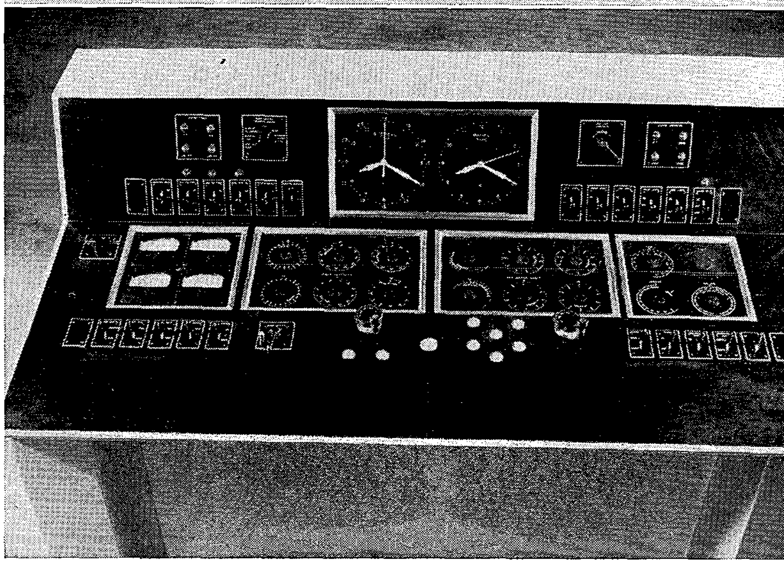
UPPER: Vibrating wire time standard eqipment.

CENTER: Right ascension indicator and sidereal time unit.

LOWER: Main 200-inch control desk.







in "unwinding" the earth's rotation is not uniform, but, nevertheless, very exact and requires compensation for the apparent motion of the star image. This star image must remain stationary on the photographic plate, or the spectrograph slit, for the entire period of exposure, which may be for several hours. The drive at celestial rate is by means of a synchronous motor supplied with power from an accurate yet variable vibrating wire frequency standard. This is in contrast to the usual mechanical governor-type of drive for telescopes. Variation in drive rate as determined by mechanical computers automatically adjusts the frequency of the standard to provide the proper rate.

The weight and size of the telescope mounting are not overwhelming, compared with modern structures, but the high optical and drive accuracy required makes the problem unusual. For example, while a comparable structure may safely deflect several inches under load, the telescope tube must not deform in any position more than 1/16 inch, and must operate in such a way that the optics remain collimated with the face of the mirror held perfect to within two-millionths of an inch.

ENGINEERING REQUIREMENTS

The engineering requirements were determined largely by the optical accuracy necessary. Not only is each mirror mounted on the structure to prevent rotation with respect to other mirrors, but each support system is gravity compensating yet rigidly defined in all positions. The aperture ratio of f 3.3 set severe mechanical alignment tolerances since mounting and instrument equipment is large in size, but deflections tolerable are less than for most smaller telescopes. Not only are "dead weight" deflections important, but also secondary effects such as torsion, temperature, unbalance, vibration, and driving friction torques. One of the early questions of overcoming the obvious enormous friction that 530 tons would create on the polar axis bearings was resolved by the use of forced feed oil film at pads of the north and south bearings, which reduced the friction torque a thousand times over that possible with a roller bearing system, besides permitting the yoke to be driven from one end without requiring excessive torsion in the yoke structure.

Other factors of design were dictated by the operating and control requirements. Because of the size and location, most mechanisms must be remotely operated and self-aligning with servo follow-up or indicating systems where motions are required. The controls are centralized at various stations where of necessity operations are carried on in complete darkness during

(Continued on page 30)

THE PALOMAR STORY

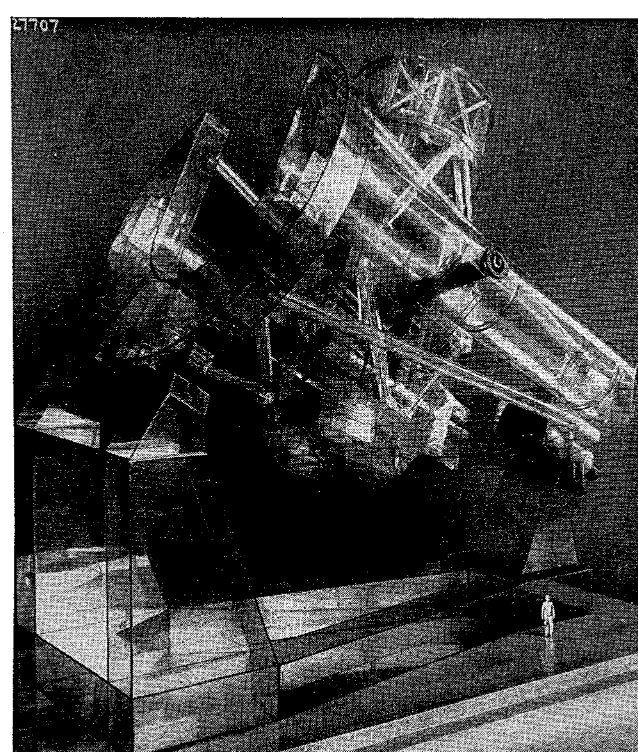
AFTER decision was finally reached to attempt a telescope larger than the 100-inch Hooker, it was necessary to decide on the exact size. The three problems of cost, construction, and transportation were the limiting factors. First consideration was given to a 300-inch reflector, until a survey showed that it would be impossible to transport such a mirror by any existing means and would necessitate building the disk on the observatory site. It was finally decided that 200 inches was the maximum size feasible. Dr. George Ellery Hale, who was fathering the project, estimated a construction cost of six million dollars and set about locating such a sum. Dr. Wickliffe Rose, president of the General Education Board of the Rockefeller Foundation, had shown interest in Hale's project, and in 1928 pledged the necessary amount to the California Institute of Technology. It was agreed with the Carnegie Institution that its Mt. Wilson staff would be available for consultation, and the facilities of the Observatory and Caltech would combine to produce the new telescope. Futher endowments from other sources guaranteed sufficient funds to carry the cost of operations at least for a time after construction, and the Observatory Council turned its attention to organization and actual building details.

Forming the Council in the beginning were Dr. Robert A. Millikan, chairman of the California Institute's Executive Council, Dr. Alfred A Noyes, professor of chemistry, Henry M. Robinson, chairman of the Security First National Bank of Los Angeles, and Dr. Hale. In an advisory capacity were top scientists in America and Europe, including astronomers from every American observatory. As executive head of the project, Hale named Dr. John A. Anderson, Mt. Wilson's chief optical expert for the previous 15 years. Russell W. Porter was brought West to design facilities for developing the new observatory, including Caltech's Astrophysical Laboratory.

The problems of casting a 200-inch mirror were first taken on by General Electric, where Professor Elihu Thompson experimented with a disk of fused quartz. The excessive cost of working with this material led the Council to reject it in favor of a Pyrex casting. This work was done by Corning Glass Works under the direction of Dr. George McCauley. After his own share of difficulties and near-failures, McCauley's task was completed in 1935, and the disk was carefully packed and shipped by rail to the optical shop at the California Institute for grinding and polishing.

When it was assured that the mirror would be cast successfully, other construction problems had to be met. One was the choice between a fork- and yoke-type mounting for the 55-foot telescope tube. The former would permit the instrument an unhampered view of any part of the sky, but at the same time it would be required to support the 125-ton tube in the middle, placing tremendous stresses on the arms of the fork and bearings. The yoke mounting alternative, on the other hand, would give the required rigidity but at the same time, as was the case with the 100-inch Hooker at Mt. Wilson, would stop the telescope 34° short of sighting on the Polar Star. In working out a compromise between these two designs, a third type was evolved which eventually solved both problems. With a basic yoke-type design, the new plan used a 46-foot horseshoe-shaped bearing at the north end of the yoke, which permitted full declination of the telescope tube.

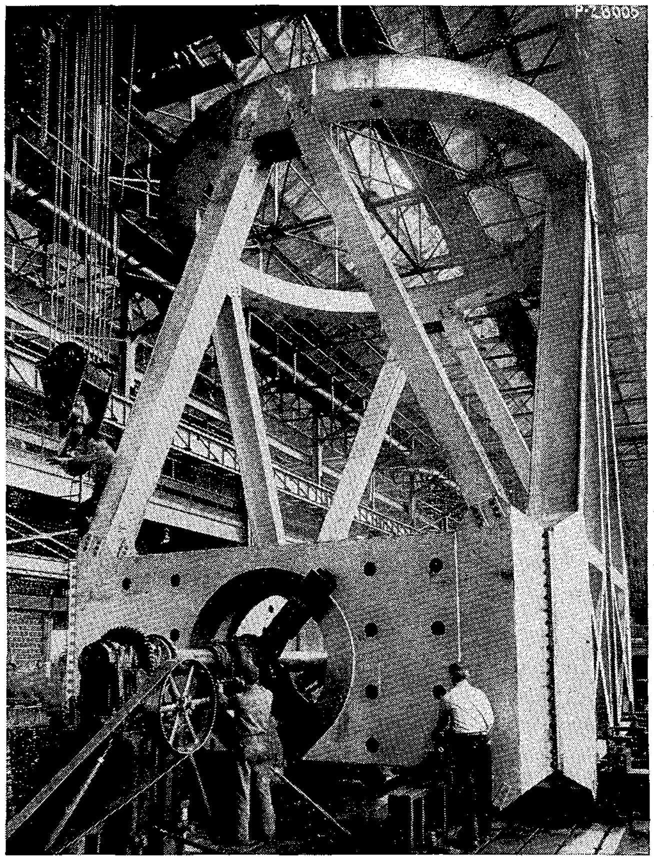
After settling on the design there arose the problem of actual construction. The telescope mounting, with the observer's cage and auxiliary fixtures, was to weigh 125 tons. The yoke with its horseshoe bearing would weigh some 300 tons, and the combination had to be so mounted that it could be turned as nearly without friction as possible. Westinghouse Electric Corporation was given the contract, and four of its leading engineers, Hodgkinson, Ormondroyd, Froebel, and Kroon, took on the problem. As a check for paper calculations, a one thirty-second-inch scale working model was constructed of celluloid, and deflec-



Completed plastic model of the 200-inch telescope, 1/32 actual size. The model, cemented together with acetone applied with a hypodermic needle, was built to test utility of design and points of stress. Places of strain were revealed by use of polarized light. Westinghouse photograph.

tions and distortions expected in the telescope mount were tested with ultra-sensitive micrometers electrically connected to a microammeter.

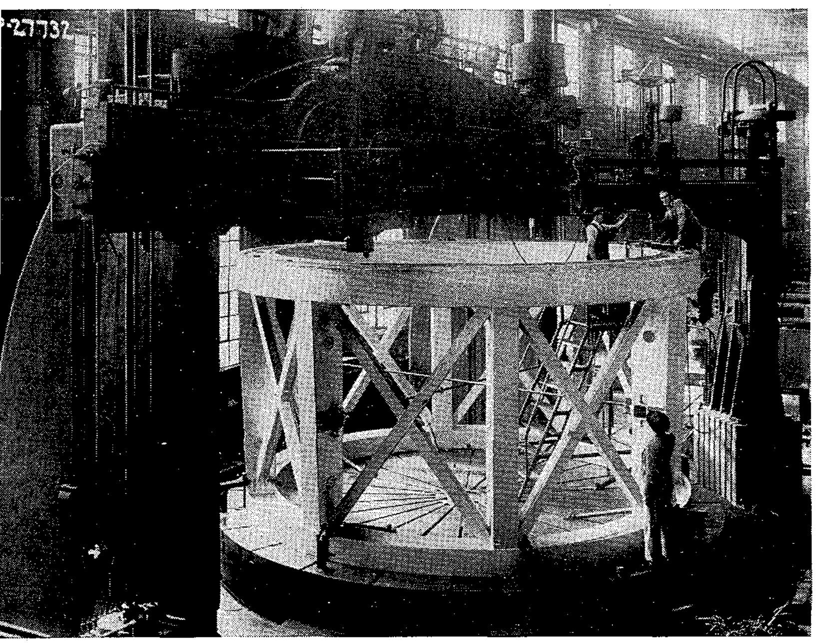
Most of the machining of the various parts was done on the regular tools in the Westinghouse turbine plant at Lester, Pennsylvania. However, the 46-foot horseshoe bearing had to be finished on a giant floor mill at Westinghouse's East Pittsburgh plant. And some pieces of the big telescope tube were so wide that a planer and a milling machine at Philadelphia had to be combined to achieve the necessary "reach".



A section of the 125-ton telescope tube under construction. Westinghouse photograph.

Annealing of the fabricated parts presented another problem. All major parts were electrically welded, a process involving localized heating and resulting in internal strains in the surrounding metal. In order to remove these stresses, a special annealing oven was built and the parts brought to a maximum temperature of 1200° F and slowly cooled to 300° before removal.

The bearings on which the million-pound telescope turns to scan any visible portion of the sky consist of the 46-foot horseshoe at the north end, and a seven-foot spherical bearing at the south end. To assure the desired accuracy, the use of roller bearings or mercury flotation was finally rejected in favor of an oil film bearing more commonly used in turbo-generators. By this device, a film of oil three thousandths of an inch thick is pumped under 300-pound pressure through orifices in four steel pads against which the bearing rests. The only frictional forces then to be overcome are the shearing forces created in the oil film itself—one six-hundredth of the friction caused by roller bearings. The seven-foot bearing at the south end was similarly floated on an oil film.



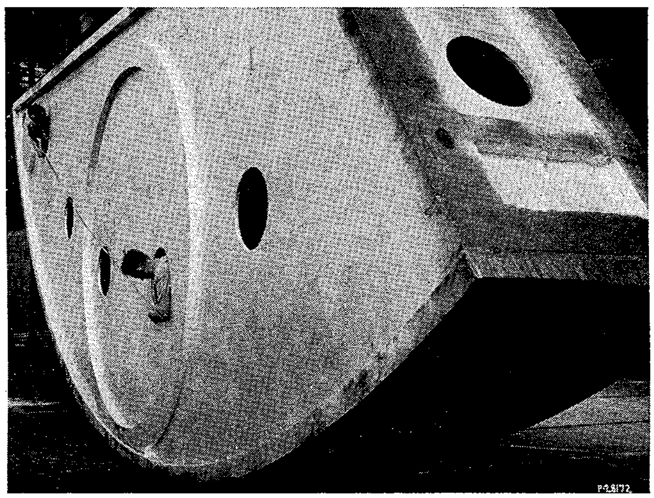
Milling the cage that forms the upper end of the tube of the 200-inch telescope, at the South Philadelphia Works of Westinghouse Corp. Westinghouse photograph.

The many phases of construction, both of the telescope framework itself and of structures and improvements at Palomar Mountain, were directed by Captain Clyde S. McDowell, borrowed from the Navy by Max Mason. "Captain Sandy" had been working at the New York Shipbuilding Company's plant in New Jersey when he was brought west to superintend construction work for the Observatory Council. Plans and specifications passed through his hands to be distributed to manufacturing concerns all over the country whose facilities could accomodate the big orders. For the telescope itself there was the 55-foot tube, designed by Mark Serrurier, the steel supporting cell for the mirror, and the yoke-and-horseshoe combination which supported the telescope. On the moun-

Byron Hill

Byron Hill, superintendent of construction for the 200-inch telescope, is the only man in these pages whose permanent address is Palomar Mountain. After graduating from C.I.T. as a Tau Bete civil engineer in 1925, Hill turned to concrete construction work. The City of Pasadena was one of his employers soon after graduation, and he continued to work in various engineering capacities when he joined the Buildings and Grounds Department at Caltech. In these years Hill also did consulting work on concrete construction in Pasadena. From 1933 to 1936 he was superintendent of inspections for the Metropolitan Water District, which was building the acqueduct to carry water from the Colorado River to Los Angeles. In 1936 he was appointed to his present position, and soon moved to Palomar Mountain where he is to day.

Engineers check the measurements of a finished "point", one of two such pieces forming part of the massive yoke of the 200-inch telescope mounting. Westinghouse photograph.

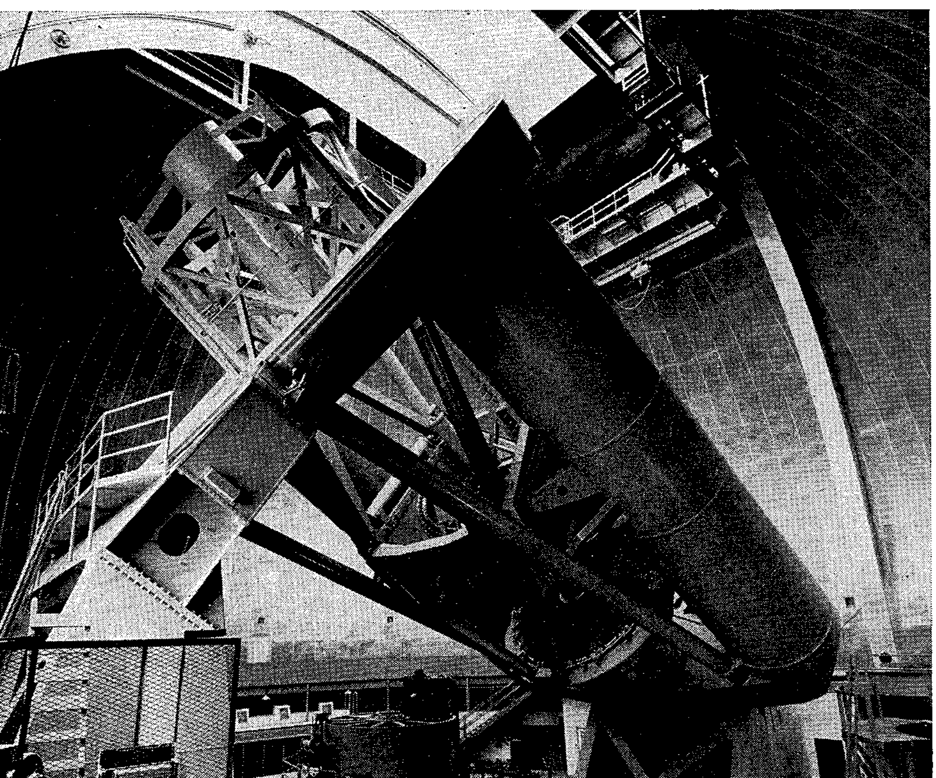


tain there had to be built the domes, the electric plant, housing for personnel, communication lines, and a road up the mountain sufficiently wide to permit trucking in of all the prefabricated parts.

In 1935, work began at Palomar Mountain. The next year Byron Hill became superintendent of construction there, and in the succeeding years the Palomar community gradually took shape. Besides the 137-foot dome for the 200-inch telescope, there are the 48-foot and 20-foot domes for the two smaller Schmidt telescopes. On Utility Hill are the power house, shops, and water tanks. For housing there is the two-story, 16-room Monastery for observers, and a number of cottages for staff and families. A dial phone system provides intercommunication between buildings on the mountain and outside lines afford regular telephone service. The paved road was built by State and San Diego County funds.

The Palomar location, considered almost 50 years ago before the Mt. Wilson site was chosen, affords astronomers perhaps the best seeing conditions in the Southwest. Numerous considerations influenced the choice of Palomar Mountain. First of all it was agreed that the telescope should be in a moderate latitude, where at least three-fourths of the sky is visible at some time of the year. Considerations of a southern hemisphere location were rejected since very little investigation of that sky has been done and the 200-inch was to be used primarily to further investigations already begun. It would have been more convenient to locate the new instrument on Table Mountain next to Mt. Wilson, but civilization was encroaching even on that remote spot and lights from the San Gabriel Valley were becoming more numerous each year, already clouding long exposures with the 100-inch. Besides, Table Mountain was on the edge of the unstable San Andreas Fault, and liable to be badly shaken in case of earthquake.

Dr. John Anderson and a number of Caltech students did a comprehensive survey of possible locations between Mono Lake in the Sierras and the Mexican border and Arizona, testing the seeing conditions from mountain peaks to desert flatlands. Their findings indicate that next to artificial light or earthquakes, the most serious interference for observers came from rising currents of hot air, encountered at mountain edges or on overheated desert sands. Their final choice is accessible over modern roads, is isolated from urban glare. The mountain is known to be a solid granite block, 25 miles deep, 30 miles long, and 10 miles wide—well protected from earth stresses. There are no near ledges or hot sands to provide heat wave interference. Still, the mountain is near enough to Mt. Wilson and Caltech so that staff members can alternate between the observatories, and Palomar equipment can be tested in Pasadena when necessary.



The Hale Telescope completed, showing tube at nearly full declination resting within the prongs of the horseshoe bearing. Weight of the entire structure is 530 tons. Photograph by E. R. Hoge.

Schmidt Cameras - Blazing the Trail

OVERSHADOWED by their big brother, the 200-inch, are the Schmidt Cameras atop Palomar Mountain. There are three of these—the small 8-inch, an 18-inch, and the 48-inch. The latter, like the Hale Telescope, is the largest of its kind in the world, and as a team these two will be unequalled by any other pair of astronomical tools in existence today.

Named for their inventor, Bernard Schmidt, an Estonian-born optician who did most of his work in Germany, these cameras are already playing a vital role in astronomical research.

The remarkableness of these instruments lies in the fact that they combine a large field of view with very high speed, or put another way, they are extremely fast wide-angle cameras.

The 18-inch Schmidt has been in operation for several years and to date its most important contribution to astronomy has been that of photographing supernovae, or exploding stars. Nearly twenty of these stars have been photographed by the 18-inch Schmidt. At the present time its program calls for making a photographic survey of our own milky way, a project for which such cameras are particularly suited.

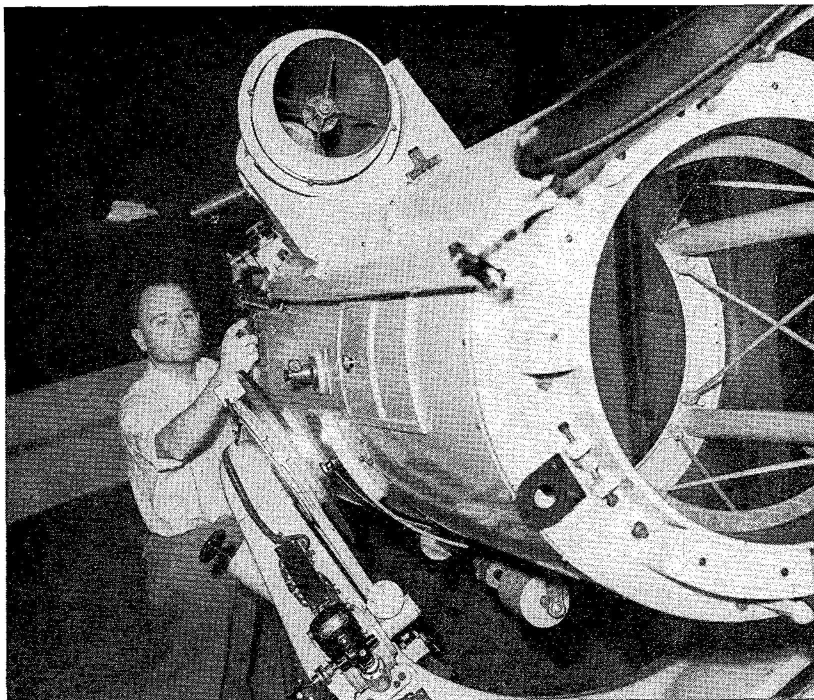
The 48-inch Schmidt in its initial program will be used for mapping of the entire skies as they can be observed in this hemisphere and it is estimated that this will require from two to three years to complete. Its principal advantage over the smaller 18-inch will be its ability to reach farther into space. It is from studies of photographs taken by the Big Schmidt, as it is commonly referred to, that astronomers using the 200-inch Hale will determine much of the work to be done with that telescope. This then, places the Schmidt in the position of acting more or less as a "scout" for the 200-inch—a sort of astronomical bird dog that locates the game after which the 200-inch as the hunter takes over to make the kill.

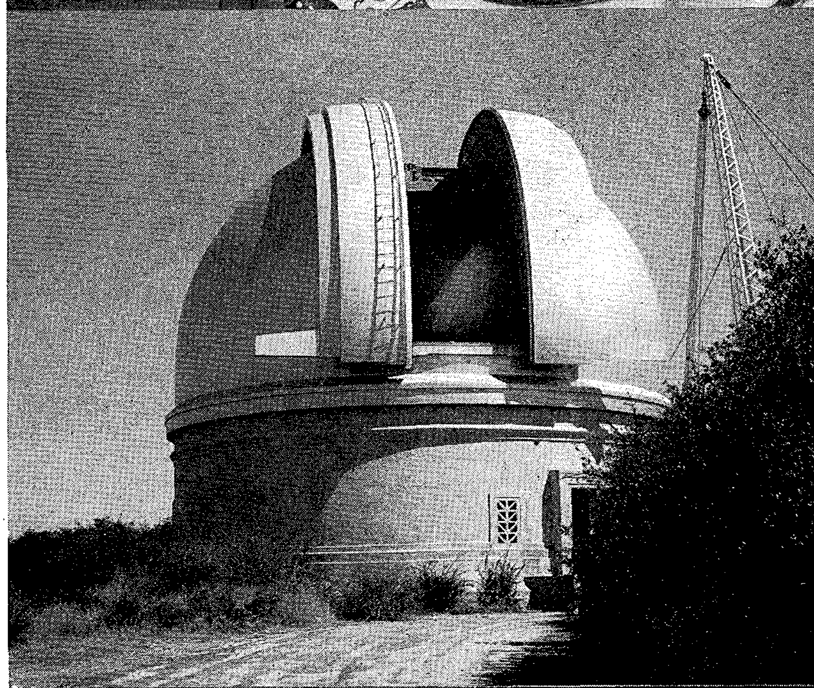
With a focal ratio of f 2.5 the Big Schmidt can cover an area of the sky nearly three thousand times greater than the 200-inch.

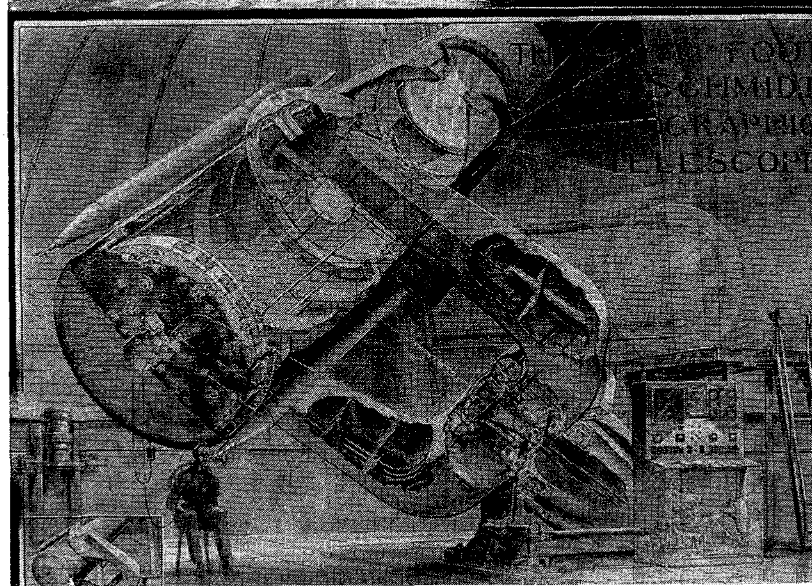
The principle by which the Schmidt camera functions is a relatively simple one. At the end of the tube which points to the sky is a correcting lens, the purpose of which is to bend incoming light rays from a star field so that they will strike the camera mirror, located at the other end of the tube, in such a manner that all rays will come to focus on a common plane. The photographic plate is located approximately midway between the mirror and the correction plate.

Two different size plates will be used in the 48-inch, one 10 x 10 inches and another 14 x 14 inches. Circular plates are used in the 18-inch but square ones will be used in the 48-inch so that a minimum of difficulty will be encountered in fitting plates together to obtain the sky map.

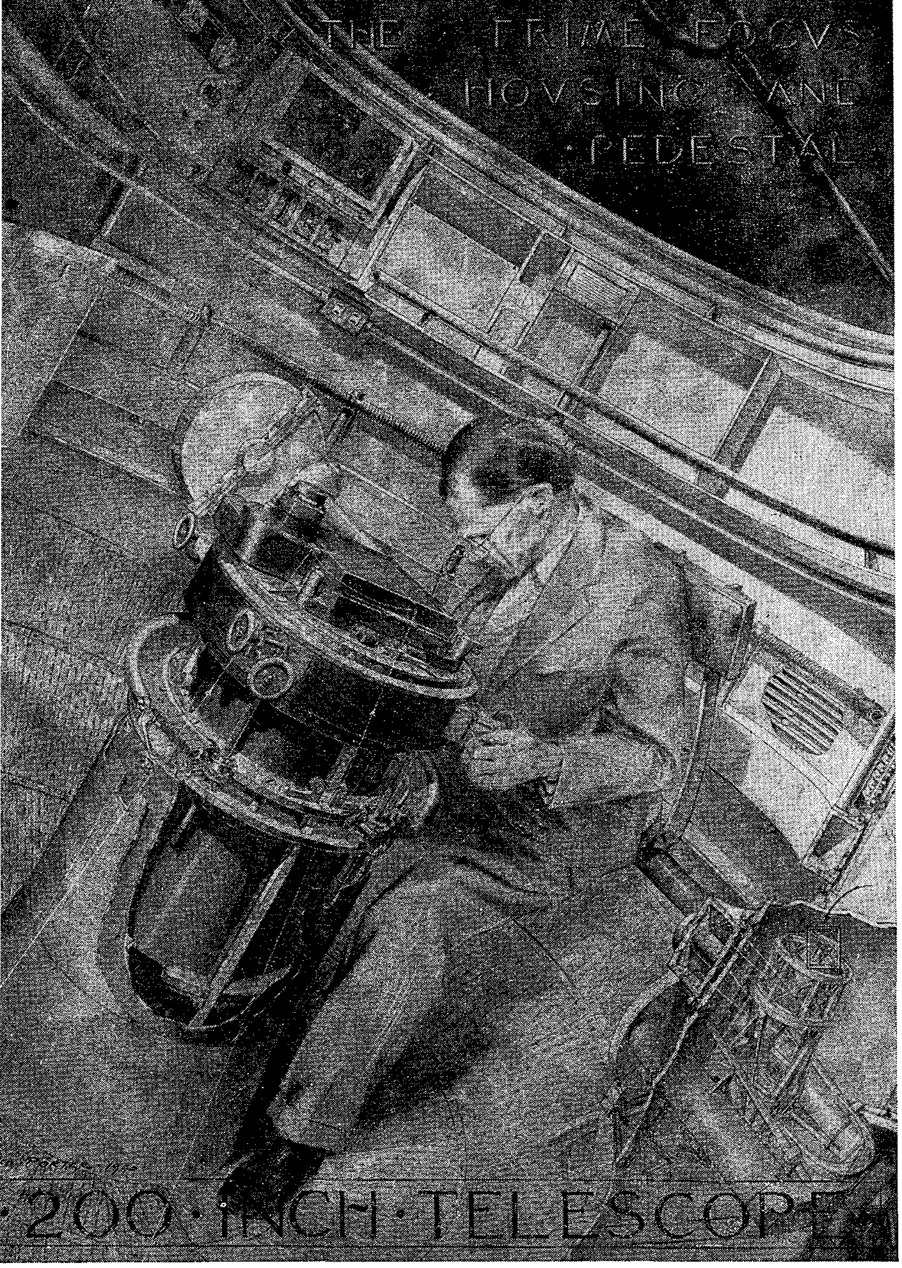
Although the Big Schmidt is nearly completed, it will not be finished and go into operation until after the 200-inch Hale begins its first research program.







UPPER: Dr Josef J. Johnson operating the 18-inch Schmidt telescope.
CENTER: The 48-inch Schmidt dome, looking east.
LOWER: The 48-inch Schmidt telescope. At the end of the tube is a 48-inch correcting plate, through which starlight passes to the 72-inch mirror. It is then reflected to the photographic plate at the focus (center). Drawing by R. W. Porter.



The Men at the Telescope

Astronomer seated in the prime focus cage at the top of the 55-foot-long telescope tube. His chair is adjustable so that he is comfortable while observing at any angle. Drawing by R. W. Porter.

HOW do astronomers work? How do they analyze and interpret the information they obtain with telescopes? What is this information they obtain by simply taking pictures of stars or of the spectra of stars? These are questions that people ask about astronomy, astronomers and telescopes such as the Hale 200-inch.

Generally, astronomers do not live in the immediate vicinity of great observatories. Rather, they live in the vicinity of the laboratories where work done at the observatory is analyzed and interpreted. This is entirely true of both the Palomar and Mt. Wilson Observatories. The astronomers who use these giant instruments live in Pasadena for it is there that the California Institute of Technology and Mt. Wilson laboratories are located. Only about 20 per cent of their working time is spent in observing—say three to six nights a lunar month.

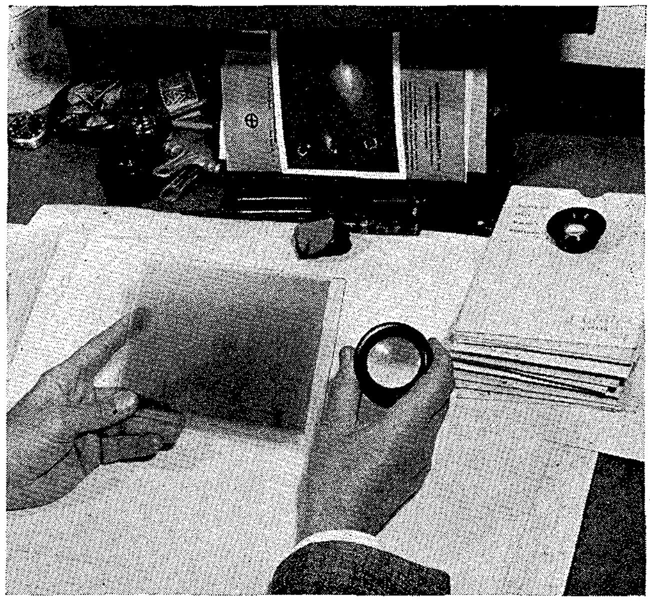
When at the observatory, astronomers live in quarters commonly referred to as "Monasteries". The Palomar Monastery, like all others, is designed for day, rather than night, rest. Each astronomer has his own room. Each window has thick black shades that can be drawn to keep the room in darkness during the day if desired. There is a modern kitchen and the astronomer takes his meals at the Monastery. It has a living room and library, dining room, and caretaker's quarters.

Astronomers observe according to the field in which they are interested. One might say there are "light of the moon" and "dark of the moon" astronomers. Those interested in photographing distant nebulae or stars must do their work in the dark of the moon when there is a minimum of light from other than the source they wish to study. In general, the dark of the moon period is devoted to direct photography, although some spectroscopic work may also be done then—particularly if it is concerned with nebulae.

Those interested in spectroscopic work are at the observatory during the light of the moon, for there are no direct photographs to be made, hence no worry about plates being fogged from unsought light sources. In fact, with bright stars such as Sirius and Arcturus, spectroscopic observation could be made in daylight. This, however, will never be done, since it would involve opening the dome during the day and consequently allowing it to heat up so that night observations would be delayed.

Two men are needed for observing—the astronomer and his assistant. The latter will be at the control desk on the observatory floor, the former at the prime or other focus. Assuming the astronomer is a "dark of the moon" observer, he will be working at the prime focus. He or his assistant will see to it that the huge

Preliminary examination of an exposed plate with a hand lens. Photograph by E. R. Hoge.



dome is opened as early in the evening as possible so that the inside temperature can become adjusted to that outside the dome. This is important since both the tube and mirror are affected by changes in temperature.

When ready to begin work, the astronomer rides the prime focus elevator to his observing station inside the upper end of the telescope tube. He takes with him a number of photographic plate holders, enough perhaps to last him through the night. He advises his assistant at the control desk by telephone or "talk-box" the coordinates of the nebulae he wishes to photograph. The assistant moves the necessary control desk dials to these predetermined positions, presses a button and the telescope moves to the desired position. With an eye-piece that magnifies, the observer looks into the mirror to make certain the telescope is pointed at the right object. Next, he sets the cross-hairs of his eye-piece on a guiding star just outside the field to be photographed, puts his photographic plate in place, and the exposure begins. From then until the exposure is completed, he keeps his eye on the guide star as the telescope follows it across the heavens. From time to time he may have to make adjustments, which he can do himself, in order to keep the big instrument on position.

Stars move from east to west as the earth rotates. The Palomar telescope is designed to compensate for this rotation, but even though its driving mechanism is of the highest precision possible, it is still not possible to get the high accuracy required to assure the sharpest image. Thus the need for occasional adjusting.

The work to be done, the quality of the "seeing", and other factors determine how long the observer will remain at his station. If he is taking several photographs of not too long exposure, it is probable that about midnight he will come down out of the telescope for coffee and sandwiches—and also to get warm. Observing at the prime focus during the winter months calls for heavy clothing. The temperature may be freezing or below.

A great deal, of course, depends upon the weather. Perhaps "seeing" will not become good enough to take pictures until 1 or 2 a.m.—perhaps not at all. Again, it may be good most of the night. When the astronomer goes to the observatory, he can never be certain as to how much productive observing he can do in the four or five days he will be there. Nights when the "seeing" is ideal are not plentiful. But it is on such nights, which he dares not miss, that he gets in his most important work. There may never be more than a dozen such nights in an entire year.

From such direct photographs, the astronomer can determine many things—the distance of the star from the earth, the distribution of objects in space, the brightness of such objects, etc.

This, however, is not enough information. The astronomer also wants to know of what these stars are composed, the abundance of their chemical elements, their temperatures, their density, etc. The astronomer whose field is spectroscopy then comes into the picture. By breaking down the light from a star into its colors or lines by use of glass prisms or gratings, he can obtain this information. It is already known that if, for instance, the light source is a solid one—say the filament of an incandescent

Edwin P. Hubble

Dr. Edwin P. Hubble has served as staff member of Mt. Wilson Observatory since 1919 and is now chairman of the committee formed in 1946 to study and formulate a long-range program of research for the combined observatories at Mt. Wilson and Palomar. Receiving his B.Sc. and Ph.D. degrees from the University of Chicago in 1910 and 1917 respectively, Hubble filled the interim as a Rhodes Scholar at Oxford from 1910 to 1913, as a practicing member of the bar in Kentucky in 1913 and 1914, and as research fellow at Yerkes Observatory from 1914 to 1917.

During the first World War, Dr. Hubble enlisted in the infantry, served in France, and attained the rank of major. At the war's end he returned to the study of astronomy, came to Mt. Wilson where he joined research leading to the controversial "red shift" discovery, and has been a member of the observatory organization, studying nebular photography, photometry, and spectroscopy.

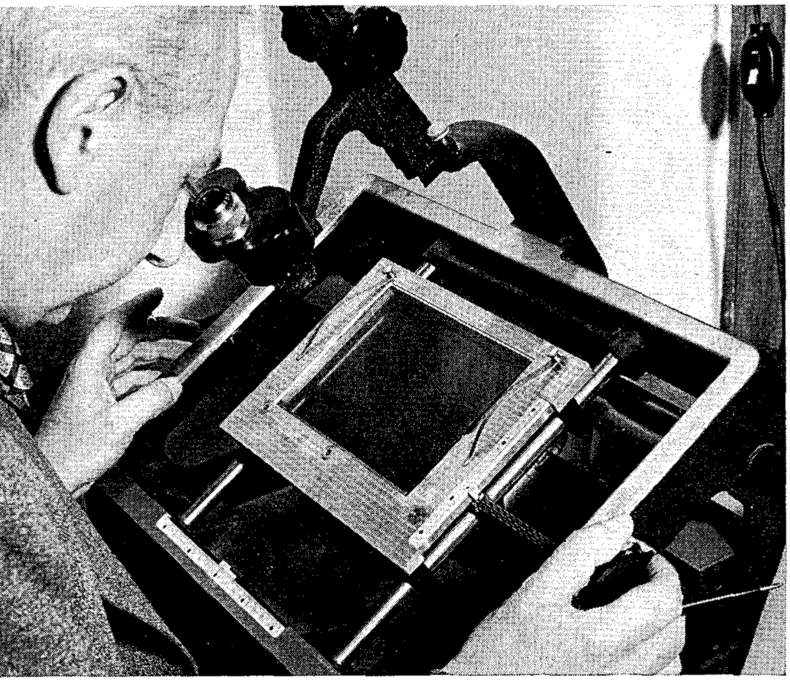
He has received honorary D.Sc. degrees from Oxford, Princeton, and Brussells, and holds an honorary LL.D. degree from Occidental. For his service as chief ballistician and director of supersonic wind tunnels at Aberdeen Proving Grounds, Md., in World War II, Hubble was awarded the Medal of Merit and has been retained as consultant at their research laboratory. He is a member of the National Academy of Sciences, the American Philosophical Society, the A.A.A.S., and the Astronomical Society of the Pacific. He holds honorary fellowships from England's Royal Astronomical Society and Vienna's Academy of Sciences.

Resident of San Marino, Calif., Dr. Hubble is also active in Southern California as a trustee of the Huntington Library and Art Galleries, member and past chairman of the Los Angeles Committee on Foreign Relations, and a member of the United World Federalists of California.

light—the spectrum is continuous and each color blends into the next, starting with red at one end and continuing through orange, yellow, green and blue to violet at the other end.

However, if the light source is a glowing gas—gas such as that used in a neon sign for example—the spectrum is broken up into a series of bright disconnected lines. In some instances, such as light from a filament shining through a gas, the same lines appear as black ones cutting across the continuous colors of the incandescent light.

The arrangement and number of these lines, regardless of whether they are dark or bright, are determined by the gaseous chemical elements in the source. Helium has one characteristic group of lines, hydrogen another, vaporized iron another, etc. Thus it is possible to determine accurately by spectroscopic analysis the presence of elements in a star source.



Dr. Walter Baade of the Mount Wilson Observatory examining a plate with a comparator. Photograph by E. R. Hoge.

Also, the brighter the line the greater the amount of this element, so by measurement of brightness and characteristic groups of lines, both the element and its quantity can be determined.

By comparing the relative brightness of red and blue parts of the spectrum, the astronomer can determine the temperature of the star. He can also determine the velocity at which the star is moving by comparing the shift in spectrum lines with those of the same element in the laboratory. So too, he can determine the pressure in the source star by studies of intensities of lines.

Thus, by all these means, the astronomer can learn a great deal about the makeup, size, distance, temperature and pressure of a star millions of light years away (a light year is the distance light, traveling at 186,000 miles per second, goes in one year).

In obtaining spectrum information, the astronomer uses a spectrograph. Here too he takes photographs and does not observe visually. Spectroscopic exposures may require an entire night, or even more than one night.

After photographs have been obtained, the astronomer returns to Pasadena and begins his laboratory analysis of what he has secured. These laboratories are equipped with many precision instruments designed to measure astronomical data obtained photographically. There are comparators which can measure the position of a star image or a spectrum line with an accuracy of a few thousandths of an inch. There are microphotometers for measuring the blackening of photographic images quantitatively to determine the brightness of the star or the strength of the spectrum line. This information can in turn be used to calculate the distance of the star or the amount of any given chemical element it may contain.

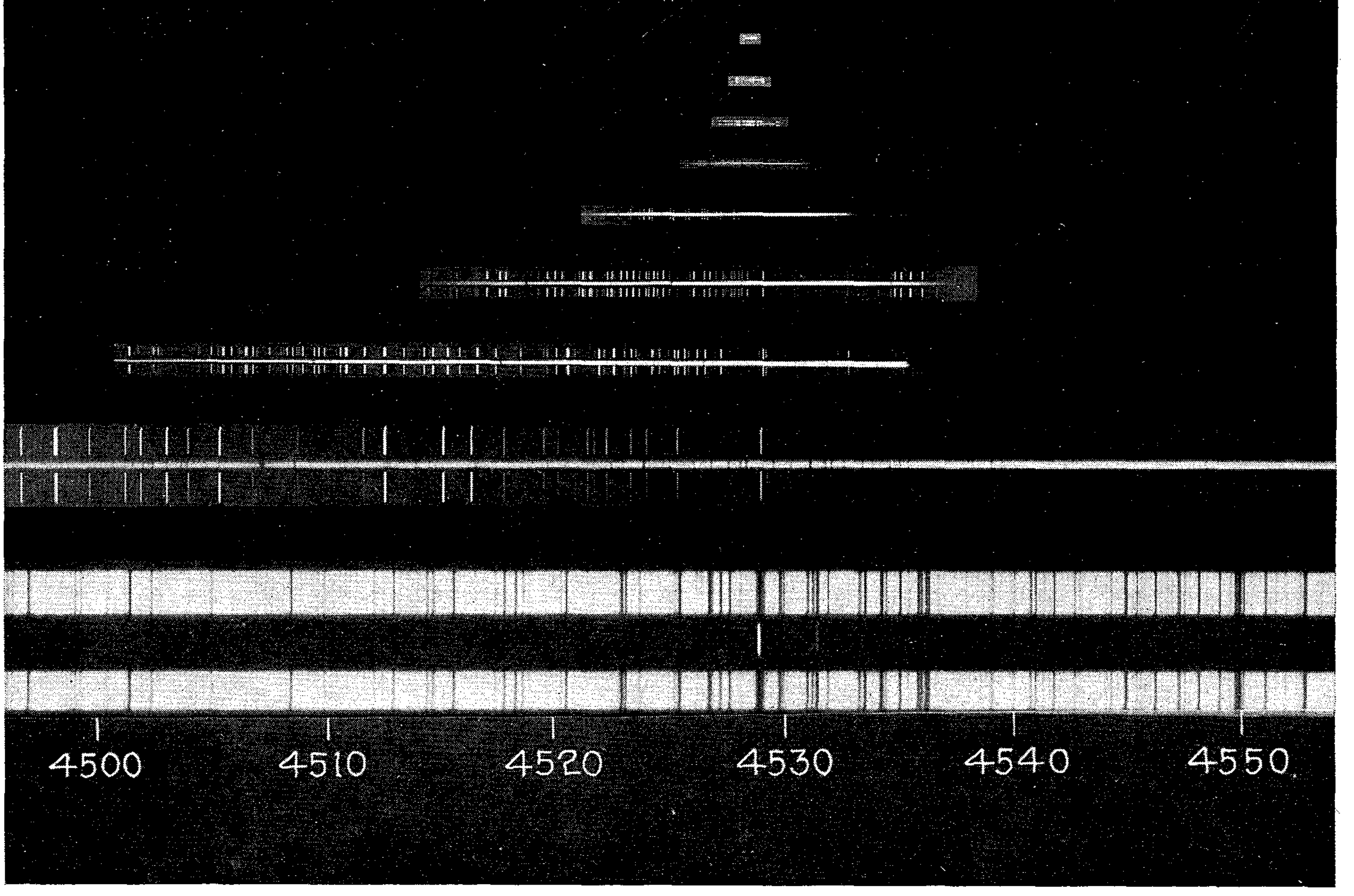
It may often take weeks, or even months of work in the laboratory to measure and interpret information obtained on photographic plates in a single night. Thus, between the time an observation is made and the determination of complete information about that particular photograph, there may be a lag of months. It is for such reasons that knowledge of new information about the universe obtained by the 200-inch telescope may not be announced for a year, perhaps years, after such data was actually recorded on a photographic plate.

PHOTOGRAPHING THE STARS

TODAY'S astronomer observes a photographic plate. In large observatories the visual observer has all but disappeared. At Mt. Wilson, in all of the solar and stellar records that are made, the only visual observations now taken are a drawing of the sun and a record of the magnetic field strength of sun spots. Except for the possible examination of a comet, it is very improbable that an astronomer at a large observatory will look through a telescope.

The many photographs exposed at an observatory are used not only for immediate scrutiny, but also for future reference. Of the over 50,000 taken since the Mt. Wilson Observatory commenced operation, a great number have been filed after only a cursory study. While stars that have been recorded by the 100-inch Hooker telescope may be traveling at a rate perhaps one-quarter the speed of light, the distances involved are so great that a wait of many years, perhaps 20 to 50, will be necessary before a shift can be measured. It is with this future comparison in mind that so many photographs have been taken.

Another of the advantages of photography is the accumulative property of photographic emulsions. A five-minute exposure will show all of the stars that



A display of stellar spectra taken with increasing dispersion from 835 Angstroms per mm to 0.7 Angstroms per mm. The spectra shown above are photographic prints or "positives". Actually the astronomer works almost exclusively with the original plate or "negative" as a matter of convenience.

can be seen with the naked eye. Some direct photographs are taken with exposures of several hours. And in spectroscopic work, analyzing light from the stars, cumulative exposures of 50 to 60 hours, taken on several successive nights, are not uncommon.

Once made, the photograph is there for all to see. Some of the drawbacks of visual observation are shown in the current controversy over the surface of the planet Mars, which may be cleared up with the use of the 200-inch Hale telescope. The surface of Mars has proved very difficult to photograph, owing to an enveloping atmosphere of carbon dioxide. Visual observers have varied considerably in their reports of observations of the red planet. Acceptance of the "canals" is by no means universal. It is for this reason that instantaneous photographs or "snapshots" of Mars, which may be possible with the great light-gathering properties of the 200-inch, will probably be included in its research program.

There are two main types of records made, direct photographs and spectrographic photographs. The direct observations show planets, stars and star clusters from our own galaxy, and extra-galactic or "spiral" nebulae, which are complete solar systems resembling our own. Spectrograms, analyzing light from the stars, give their chemical composition, velocities through space, and their distances from each other and from the earth. For physicists there is much to be learned from spectrograms, for the examinations of the universe show the same chemical elements that are present on the earth, but acted upon by conditions of pressure and temperature difficult to duplicate in the laboratory. Nevertheless, attempts are being made. There are fields of astronomy in which workers try to duplicate solar and stellar spectrograms by laboratory methods, gaining considerable insight into the conditions producing such a record.

For spectroscopic work, photographic plates from 8x10 inches in size down to as small as ¼ x1 inch are used, depending on how widely the light from a distant star can be spread out with a dispersion grating. A dispersion grating is a series of tiny scratches on a metal plate which, if sufficiently parallel and close enough together, will break up a beam of sunlight in much the same way as a prism, but with considerably greater dispersion.

Very important in the development of photography as an aid to astronomy has been the research work on emulsions by the Eastman Kodak Company and other firms. By perfecting plates sensitive to light over the whole range of the spectrum, especially red, photographic research has opened new vistas to spectroscopy. Responsible for much of this work is Dr. C. E. K. Mees, research director of Eastman, who told Dr. Hale: "If you build large telescopes, I'll make them larger yet with better plates!"

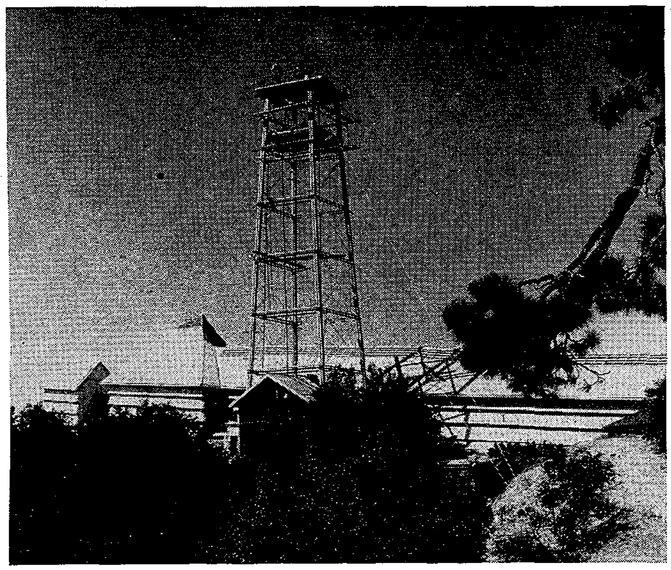
As far as direct photographs are concerned, those now taken at Mt. Wilson are of comparatively short exposure. Exposures of over a few hours are fogged by the lights of the San Gabriel Valley and nearby Los Angeles. The Palomar Mountain location of the Hale telescope will give astronomers black night in which to work.

Coming in the recording of light is research with the photo-electric cell. By expressing light as an electric current, the study of stars of variable magnitudes will be intensified. Hitherto it has been necessary to take countless photographs of a variable star and compare them, making necessary allowances for variations in "seeing". With the photo cell, a continous record may be kept, showing conclusively the variations and their rates of change.

Mount Wilson

WORK that resulted in the establishment of the Mt. Wilson Observatory began in the spring of 1903, when George Ellery Hale first set up a small coelostat and a portable four-inch refracting telescope on the mountain and began taking direct and spectroscopic photographs of the sun. The success of these experimental observations was such that the following year The Carnegie Institution gave Hale a $10,000 grant to move a solar telescope from Yerkes Observatory to Mt. Wilson on an expeditionary basis. Impressed with the results of this experiment, Carnegie made Mt. Wilson a full department of the Institution with an initial grant of $150,000, and started the Mt. Wilson Solar Observatory, as it was then known, on its way.

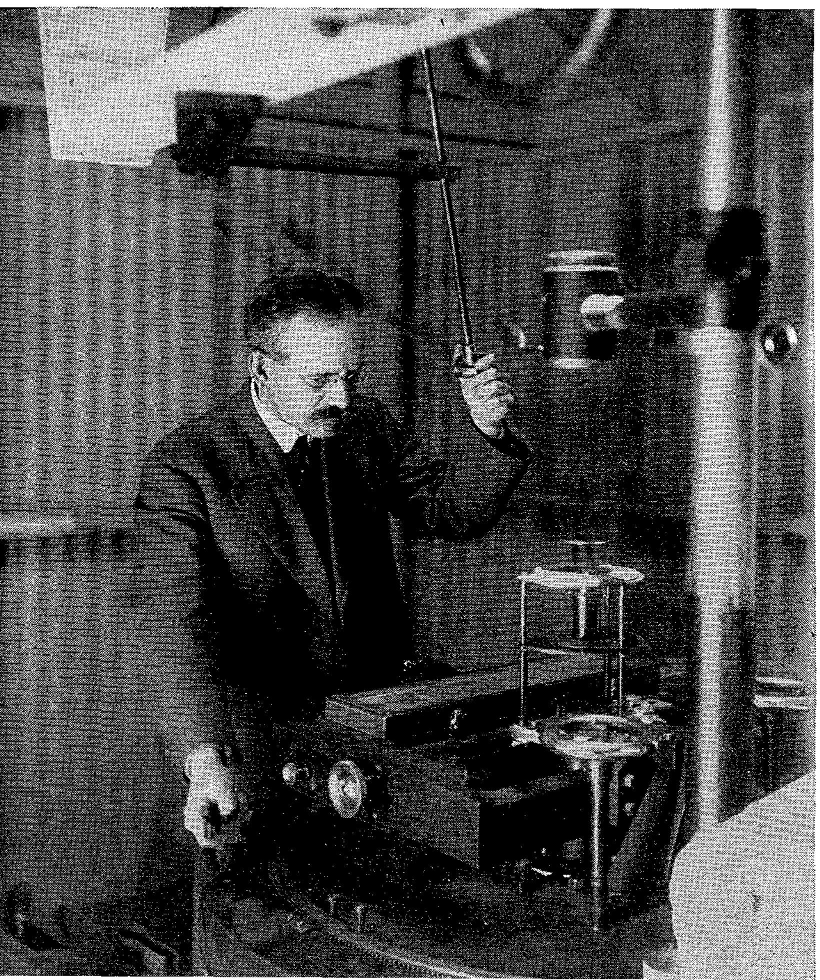
From Yerkes with the Snow telescope had come George Ritchey, Ferdinand Ellerman, and Walter Adams, and a short time later, Francis Pease. These men, with Hale, were the nucleus who took part in the establishment of the Mt. Wilson Observatory. Life on the mountain in the early days was itself in the nature of an experiment. The only lines of contact with the valley were an old, precipitous Indian trail which led up Little Santa Anita Canyon from the village of Sierra Madre, or a somewhat shorter, equally rugged "toll road", no more than two feet wide, which zigzagged up from the mouth of Eaton's Canyon in Altadena. Over one or the other of these trails, vital supplies, bulky equipment, and world-renowned astronomers had to be transported by mule or afoot to the mountain top.



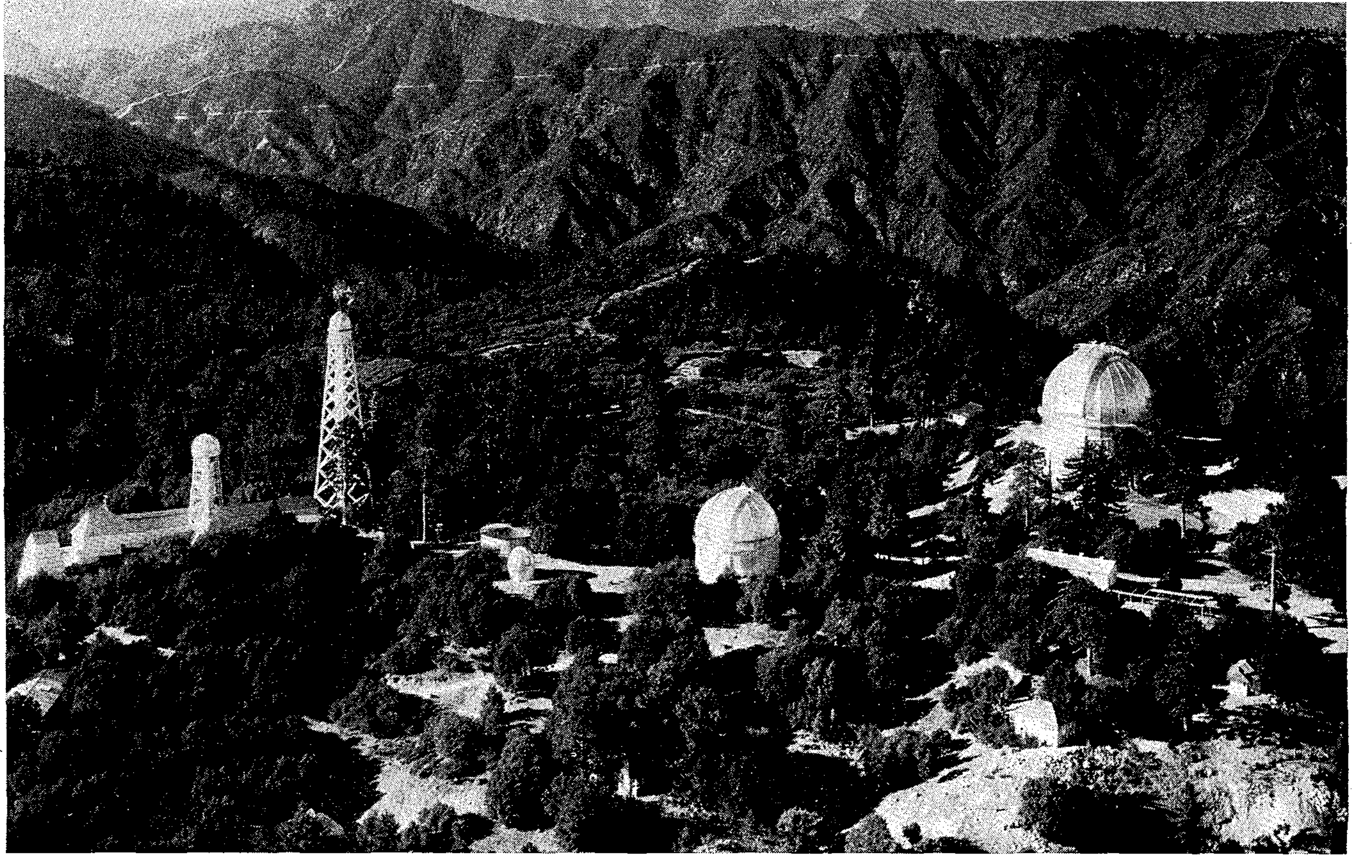
The 60-foot tower telescope at Mount Wilson as it looked in 1907. The horizontal shed behind it houses the Snow solar telescope. These same structures are seen at extreme left in the picture opposite.

When Hale first visited Mt. Wilson, the only building standing was a half-gone log cabin, called the "Casino", vestige of adventurous vacationers who had formerly visited the spot in the summer months. The Casino was soon patched and made waterproof, and living conditions were immensely improved with the construction of a huge granite fireplace. By December 1904, a residence known as the Monastery was completed to serve as living quarters for Mt. Wilson astronomers.

During the summer of 1904, plans went ahead for the design and construction of the building to house the Snow telescope. With the complete financing of the Mt. Wilson project assured by the Carnegie Institution, George Hale had a 60-inch glass disk, an earlier gift from his father, moved from Yerkes to optical shops which had been established in Pasadena. Ground and polished for two years under the direction of Ritchey, it was laboriously trucked up the mountainside on the toll road especially widened for the occasion from two feet to a spacious eight. The truck



Dr. George Ellery Hale observing the sun at the 60-foot tower telescope in 1907.



Aerial view of Mount Wilson today. At left, the 60-foot and 150-foot tower telescopes; behind them in long white shed, the Snow telescope. Center, the dome housing the 60-inch reflecting telescope. To its left the tiny dome housing the 6-inch refractor for visual observation. On the right is the dome of the 100-inch Hooker Telescope. Photograph by E. R. Hoge.

used in the process was a unique affair, having a gas engine connected to a dynamo which powered individual electric motors in each of the four wheels. Driver of the machine was Jerry Dowd, who became chief electrician for the Palomar project in 1930. The 60-inch, then the world's largest, was installed without mishap and went into service in 1908.

This was the point when stellar observation at Mt. Wilson began to take its place in importance beside solar investigation. While Adams, Pease, and others made spectrographic photographs, Frederick Seares worked with direct photographs at the main focus of the 60-inch, and in the first five years they made more than 4000 photographs. They began to reach conclusions which indicated a termination of our galaxy but at an undetermined distance. The 60-inch mirror was not big enough to answer the theory which it posed. Only an infinitesimal number of stars could be analyzed, and at a limited distance. It became increasingly evident that a larger instrument would be necessary to bring a greater number of more distant stars within range.

Then came an offer from John D. Hooker of Los Angeles, who had helped earlier to finance Hale's first work at Mt. Wilson, to build a 100-inch reflector. The uncertain task was taken on by the French glassworks at Saint Gobain, which had produced the 60-inch. Although bubbles seemed to mar each of the four disks poured, Hale finally had their first and best attempt sent to Pasadena for inspection. Stored for a time in the Santa Barbara Street shops, the surface was used as an assembly table for other instruments until a Carnegie Institution geophysicist looked it over and advised Hale to go ahead with the grinding. While Ritchey closeted himself with the glass for six years of polishing, Carnegie himself visited Mt. Wilson, showed intense interest in the work going on, and increased the Institution endowment with specific recommendation that the Mt. Wilson project be encouraged. In 1917 the 100-inch Hooker telescope was first used

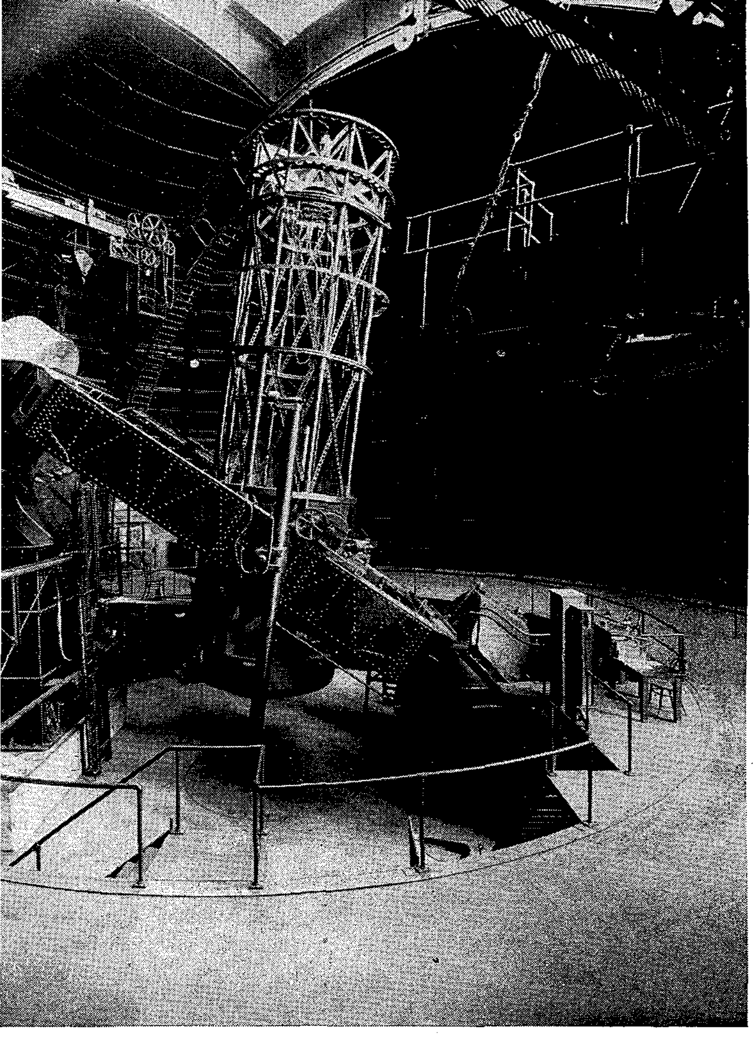
During the thirty years since, the 100-inch has been the center of a great cooperative effort by leading astronomers and physicists to reach farther out into the universe. Adams and his associates devised new methods of measuring the distances of stars; Harlow Shapley's studies gave an accurate idea of the extent of our galaxy; A. A. Michelson applied his interferometer to the 100-inch to measure stellar diameters; Edwin Hubble mapped "island universes" 900,000 light

Ira S. Bowen

Dr. Ira S. Bowen is Director of the Palomar and Mt. Wilson Observatories and at present is a research associate in astrophysics at the California Institute and chairman of the Observatory Committee.

Joining the Caltech faculty in 1921, Bowen served as a member of the faculty for 10 years, as instructor, assistant professor, and later associate professor in physics. He received his B.A. from Oberlin College in 1919 and a Ph.D. from the California Institute in 1926. Member of the Carnegie Institution, he was named Director of Mt. Wilson Observatory in 1946 and began service this year as ex officio chairman of the Observatory Committee of Mt. Wilson and Palomar. In 1938 he was also Morrison research associate at Lick Observatory, Mt. Hamilton.

In his work at Mt. Wilson, Bowen has been engaged in research in the division of stellar spectroscopy. Professional societies of which he is a member include the American Physical Society, American Astronomical Society, Astronomical Society of the Pacific, National Academy of Sciences, and the American Philosophical Society. Bowen is also holder of the Draper Medal from the National Academy of Sciences and the Franklin Institute's Howard N. Potts Medal.



The 100-inch Hooker Telescope, showing the interior of the dome, the Cassegrain observing platform, and the control panel, as seen from the west.

years away. In 1923, increasing ill health forced Hale to resign as director of Mt. Wilson, to be succeeded by Adams. While investigation went on with the 100-inch, Hale realized that the telescope's size still was inadequate. Again it led to questions which it could not answer. By 1928, he was seriously considering a mirror increased to "200 inches or, better still, to twenty-five feet."

As the idea took shape he interested the Rockefeller Foundation in the project; and it was finally agreed that the Foundation would finance the construction of the giant 200-inch through the California Institute of Technology, with the aid of the staff and facilities of Mt. Wilson.

With the development of the Astrophysical Observatory and Laboratory at Caltech, Mt. Wilson provided facilities for the testing of auxiliary instruments and attachments for the projected Palomar telescope. Thirty-six-inch and 60-inch grinding machines had already been made available to Caltech from the Mt. Wilson shops. The cooperative plan was continued as experimental correcting lenses were designed for the 60-inch and 100-inch reflectors to increase photographic ranges without altering the ratio of focal length to aperture. Successful experiments on the Mt. Wilson telescopes led to the design of correcting lenses for the Palomar instrument following the same plan. Similarly the Rayton lens to determine radial velocity of remote nebulae, the B.S.I.R.A. lens, and photo-electric amplifier have been perfected on the 100-inch and are expected to increase greatly the efficiency of the 200-inch telescope.

During this cooperative development, regular investigation at Mt. Wilson continued. Solar observation, Dr. Hale's specialty, has always been an important part of the Mt. Wilson program. In the early years, when it was known as the Mount Wilson Solar Observatory, there were three solar and only one stellar telescope. After the completion of the 100-inch reflector more attention was given to the stars and "solar" was dropped from the name though solar investigations have been continued as a major activity. Probably the most outstanding achievement in the study of the sun was the discovery of magnetic fields in sun spots by Dr. Hale in 1908. Investigation of this phenomenon has since been carried on almost exclusively at Mt. Wilson. The solar tower telescopes built in the early days of the observatory are in regular use today and are still the most powerful of their kind. The long series of solar photographs made almost daily at Mt. Wilson are a nearly complete record of the sun's activities for the last 40 years.

Another field of investigation carried on at Mt. Wilson has been a study of the materials composing the moon's surface and of the surface temperatures and atmospheric conditions of planets. Since the moon itself gives out no light but is merely a reflecting surface, it has been necessary to use the progress of the earth's shadow across the moon at total eclipse as a basis for testing the rate of surface cooling. Another method is to compare the polarization of light from the moon's face with that of known terrestrial materials. From these investigations, Mt. Wilson observers have concluded that the visible lunar surface is not exposed rock but rather a fine dust or sand, possibly volcanic. Using a vacuum thermocouple, the surface temperatures of planet areas have likewise been determined, the extremes on Mars, for example, being set at 60° and —40° F. Analysis of all but the outermost planets also has been made, by means of a spectroscope.

Mt. Wilson Observatory has continued to make extensive contributions to the study of the stars in our galaxy, establishing what is now the international scale of stellar brightness, and measuring the magnitudes of 70,000 faint stars. These observations have made important advances in the determination of the distribution of stars in our galaxy, the size of our stellar systems, and the eccentric position of the sun in it. The distances of some 400 stars of low luminosity located nearest to the sun have been measured trigonometrically, aiding in evolutionary studies and in plotting the distribution of stars in space. Study and classification of nebulae have led Mt. Wilson astronomers to conclusions concerning the nature of the composition of these nebulae, their location and numbers, and their relative distances. Spectroscopic observations of nebulae outside our galaxy have led to Hubble's "red shift" discovery and resulting "expanding universe" and other cosmological theories.

Administering Two Observatories

FROM THE DAY back in 1928 when the International Education Board granted to the California Institute of Technology $6,000,000 of Rockefeller funds with which to build the Palomar observatory and its 200-inch telescope, Southern California was destined to become the center of the greatest cooperative astronomical undertaking in all history. With the Mt. Wilson Observatory and its 100-inch and other telescopes already located here, it was the intention of the donors as well as the California Institute and the Carnegie Institution of Washington, D. C., which built and has always operated the Mt. Wilson Observatory, that these two observatories were to become essentially one in operation. Thus the Palomar project began as a cooperative one and continues as such.

In the beginning and throughout the construction period there was not only the greatest of cooperation betwen the two institutions, but they in turn received the same kind of cooperation from engineers, industries, manufacturers and others who played a vital part in bringing the new observatory into being.

With the funds assured in 1928, the first step taken by Dr. George Ellery Hale, father of both the Mt. Wilson and Palomar Observatories and member of the California Institute Board of Trustees, was that of setting up an Observatory Council. It was this Council, composed of representatives from Caltech and the Carnegie Institution, that has guided the mammoth undertaking to its present stage.

Following agreements reached some time ago between the two institutions, a unified plan of operation involving cooperation between the Carnegie Institution and the California Institute has now been put into effect. This plan is one which calls for operation of the world's two greatest observatories by a single director aided by an Observatory Committee composed of representatives of the two institutions.

Director of the combined observatories is Dr. Ira S. Bowen who has been director of Mt. Wilson since 1946. Caltech's representatives on this committee are Dr. Max Mason who replaced Dr. Hale upon the latter's death in 1938 as head of the Observatory Council; Dr. H. P. Robertson who has long been a member of the Observatory Committee; and Professor E. C. Watson, chairman of the Caltech division of physics, astrophysics, mathematics, and electrical engineering.

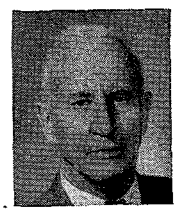
Carnegie Institution members of the committee are Dr. Ira S. Bowen, director of both the observatories, who will serve ex officio as committee chairman; Dr. Walter S. Adams, director of Mt. Wilson from 1923 to 1946, who served on the Observatory Council from its inception; and Dr. Edwin P. Hubble, Mt. Wilson astronomer, who has long been a member of the Policy Committee.

To these men then falls the responsibility for guiding the operation of this great combine for astronomical research. As they take over as an operating group, they face new problems that come to the fore only as Palomar goes into operation. They will plan a comprehensive research program that will utilize to the best advantage the facilities of both observatories—Mt. Wilson with its 100-inch and 60-inch telescopes, its solar instruments and other facilities, and Palomar with the new 200-inch telescope and the 18-inch and 48-inch Schmidt cameras.

To every astronomer and astrophysicist on the staffs of both institutions all of these facilities will be available.

The responsibility for financing of the two observatories will be shared by the two cooperating institutions with the Carnegie Institution retaining primary responsibility for Mt. Wilson operation and Caltech assuming Palomar expenses. An additional endowment of $4,000,000 to supplement the $1,000,000 already on hand is being sought by the Institute for this purpose. Until additional funds are available for enlarging the staff, present members of the Mt. Wilson and Caltech staffs will operate both observatories.

Max Mason



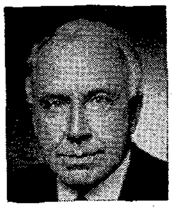
Max Mason is chairman of the Observatory Council and a member of the Institute's Board of Trustees. With a B. Litt. degree from the University of Wisconsin and Ph.D. from the University of Gottingen, Mason served as president of the University of Chicago from 1925-1928. He then became director of Natural Sciences for the Rockefeller Foundation and was Foundation president from 1929-1936.

During the last war Mason did work on water ballistics at Morris Dam, and was adviser on Army and Navy Air Corps research. Next year he will be in Claremont as Professor of Sciences at Claremont Men's College and Pomona College.

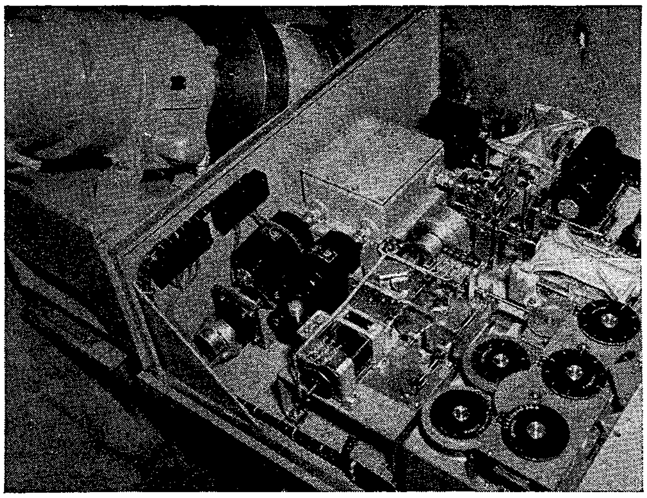
Vannevar Bush

Vannevar Bush, president of the Carnegie Institution of Washington, has combined administration and engineering successfully. Dr. Bush took his B.S. and M.S. degrees at Tufts, then continued electrical engineering studies at M.I.T. and Harvard, receiving the Eng.D. degree from the latter in 1916. Until joining the M.I.T. faculty in 1919, Bush worked for General Electric, the Navy, and taught at Tufts, during his graduate work and subsequently. He remained at M.I.T. until 1938, serving as vice-president and dean of engineering during his last six years. In 1939 he was named president of the Carnegie Institution. During the war Dr. Bush served as director of the O.S.R.D.

Raymond B. Fosdick



Raymond B. Fosdick, president of the Rockefeller Foundation and the General Education Board, is a lawyer turned administrator. A graduate of Princeton ('05), and the New York Law School ('08), Fosdick served in several administrative positions for New York City until 1913. He continued administrative and advisory work for the Government, the Rockefeller Foundation, and the League of Nations for seven years, then practiced law with Curtis, Fosdick, and Belknap until 1936. Fosdick, a member of the joint Army and Navy Committee on Welfare and Recreation, is holder of the DSM (U.S.), and a Commander of the Legion of Honor (France).



Declination drive unit in west tube of the Hale Telescope.

Engineering Aspects of the 200-Inch Telescope

(Continued from page 17)

exposures. Consequently operations must be reliable, simple, and safe. Mechanisms must function correctly under conditions of wide range of temperature, humidity, and position. Several driving speeds covering a range of 36,000 to one from fast slewing to correcting rates are provided with driving accuracy tolerances of 1/10 of seconds of arc per 5 seconds of time for celestial rates, to 5 seconds of arc accuracy for automatically setting the telescope to a selected field of view. The drive rates and setting control functions must eventually compensate for the residual structural deformations, periodic driving gear errors, errors due to atmospheric refraction, and other operations which are functions of hour angle (about the polar axis) and declination angle.

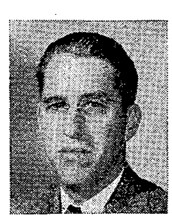
Since for the first time the observer will "ride" on the telescope, the usual graduated circles for reading declination angle and hour angle were modified to allow him to ascertain the telescope setting while working at the various stations. These and other conditions led to the adoption of a 68-Selsyn remote indicating system of high accuracy for position indicators at each observing station.

Coordinated with the telescope positions are the operations of other, auxiliary, equipment, such as the rotating dome, prime focus elevator, wind screen, hoists and moving platforms, each involving some unusual problems. These are examples of but a few of the many problems confronting the engineers.

To justify such an instrument, every moment of good "seeing" time must be used to its fullest extent in getting data with no time lost in set-up operations. Thus special attention has been directed to reducing the time necessary to change the auxiliary mirror combinations for working at different focal points. All auxiliary mirrors are permanently attached to the telescope and are swung into or out of position by means of motorized mechanisms remotely controlled. These operations extend the usable time of this large camera and give the flexibility desired for a wide range of uses to meet present and possible future astronomical problems. The choice of equipment and methods was determined by the criteria of telescope use for a long period of time but at low operating and maintenance cost.

With the finished and aluminized 200-inch disk in place at Palomar, the telescope appears complete. Its size, however, masks the remaining auxiliary instrument assemblies that are being installed within the structure. The mechanical drives and most of the auxiliary mirrors are now being operated and adjusted in the course of overall optical tests. When mirror adjustments and camera equipment are completed, preliminary operations will begin. Solutions of the unusual design and manufacturing problems encountered on this telescope project have required the close cooperation of engineers and scientists of the California Institute of Technology with many manufacturers who have made their facilities available, assisting in the accomplishment of Dr. George E. Hale's vision of twenty years ago. The Palomar telescopes will give mankind new concepts of the universe. The dedication, therefore, is a logical beginning further to satisfy man's quest for a small understanding of the evolution of our system, as well as a tribute to those scientists and engineers whose labor, experience, or encouragement made possible this instrument.

Bruce Rule



Bruce Rule, project engineer for the Palomar Observatory, has been working on the development of the 200-inch at the Institute since 1937. In addition to his work at Caltech he has been electrical and mechanical consulting engineer at the University of California's Lick Observatory, Mt. Hamilton, for the past year.

Prior to the war, Rule had considerable experience with services and industries in Southern California, including electrical testing with the Los Angeles Bureau of Power and Light, and as superintendent of the meter and testing division of light and power for the City of Vernon. He was engineering consultant for the Cooperative Development Co. of Los Angeles and the Hydril Corporation; and while an undergraduate in 1931 and 1932, helped in the Caltech Electrical Engineering Department on the design and construction of Institute buildings. In 1932 he received his Bachelor of Science degree from the California Institute.

From 1933 to 1938 he taught adult education classes in Los Angeles on radio theory and practice, electricity, sound, amateur radio, and vocational arts. In the war years Rule did research at Caltech on the development of anti-submarine devices, projectiles, and rockets, and worked on special contracts in connection with aerial cameras and optical instruments. In 1945 he received the Merit Award badge and Development Award for Exceptional Service from the U. S. Navy Bureau of Ordnance. He belongs to the American Institute of Electrical Engineers in Los Angeles and is a member of Sigma Xi and Tau Beta Pi honorary societies.

Graduate Work in Astrophysics at Caltech

PARALLELING the extensive research program planned for the combined Palomar-Mt. Wilson Observatories will be a program of training in astronomy and astrophysics at the California Institute of Technology. Designed primarily for Ph.D. candidates, this program will be superimposed upon the Institute's present thorough training in mathematics, physics, and chemistry, and will include an undergraduate option.

Combining with the Caltech faculty in this program will be many of the Mt. Wilson staff who will from time to time give seminars in the fields of their special interests. The Institute staff will be increased from time to time as the program is expanded.

A new addition this year to the astrophysics staff is Dr. Jesse L. Greenstein, now assistant professor of astrophysics at the Yerkes Observatory, the University of Chicago's famous astronomical center at Williams Bay, Wisconsin. Dr. Greenstein, who is also a research associate at the McDonald Observatory of the University of Texas, joined the Caltech faculty on July 1 as associate professor of astrophysics. He will conduct classes in astrophysics and have general supervision of the entire Institute training program in astrophysics.

Serving with him will be Dr. Fritz Zwicky, professor of astrophysics and who recently delivered the Halley Lecture at Oxford; Dr. Max Mason, Dr. Walter S. Adams, and Dr. Josef J. Johnson, research associates in astrophysics; Dr. Albert G. Wilson, research fellow in astrophysics; and Dr. Ira S. Bowen, director of both the Mt. Wilson and Palomar Observatories.

Not only are particular courses for both graduate and undergraduate work included in the curriculum, but special seminars such as the following will be offered from time to time during the school year by members of the Mt. Wilson Observatory staff and such Institute staff members as Drs. H. P. Robertson, Richard C. Tolman, Leverett Davis, Jr., and some of the theoretical nuclear physicists.

Applications of Nuclear Physics to Astronomy
The Sun and Planetary System
Sun Spots and the Solar Atmosphere
Zeeman Effect in Solar and Stellar Spectra
Classification of Stellar Spectra
Peculiar Stellar Spectra
Stellar Radial Velocities
Stellar Absolute Magnitudes
Microphotometry of Stellar Spectra
Spectra of Gaseous Nebulae
Structure of the Galaxy
Observational Cosmogony
Theoretical Cosmogony
Cosmic Rays

Jesse L. Greenstein

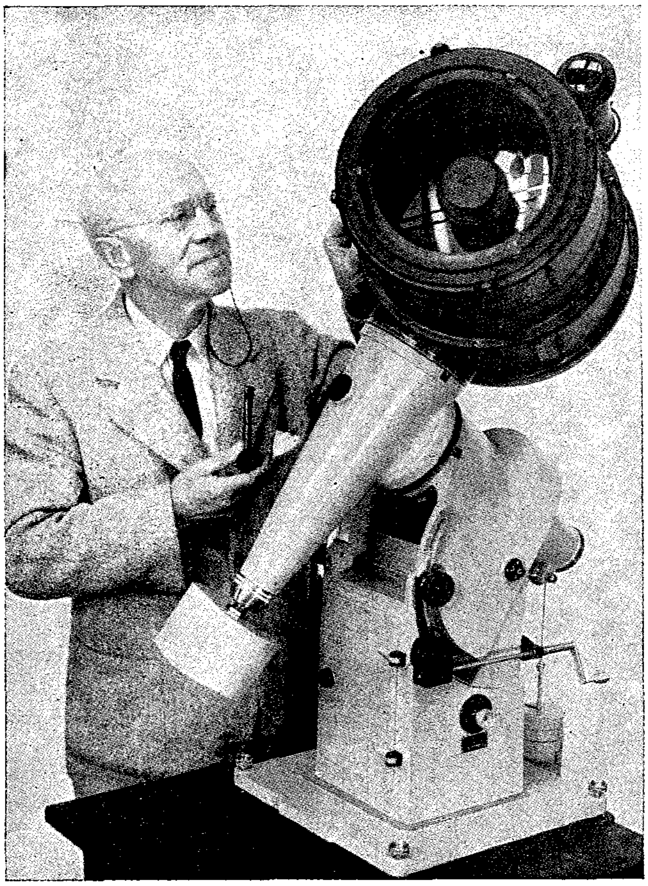
Dr. Jesse L. Greenstein, newly appointed associate professor of astrophysics who will supervise the Institute's training program in the field, has been engaged in research work at Yerkes Observatory and for the past six years has been on the faculty of the University of Chicago as assistant professor of astrophysics. Since 1946 he has also been in charge of a contract with Applied Physics Laboratory of Silver Springs, Md., for the development of spectrographic solar observation from V-2 and possibly other rockets.

Now 38, married, and father of two children, Dr. Greenstein was graduated from Harvard with an A.B. degree in 1929, an A.M. in 1930, and Ph.D. from the Harvard Observatory in 1937. During this period he had four years' experience in business finance and management and spent part of the time in research at Columbia University. Following this he was a National Research Council Fellow two years and instructor in the University of Chicago, stationed at Yerkes Observatory, from 1939 to 1942. Since that time, Greenstein has held the rank of assistant professor of astrophysics at Yerkes and has been a research associate at the McDonald Observatory of the University of Texas. In recent years he has spent about one-fourth of his time teaching graduate students at Yerkes Observatory and a small amount at the University of Chicago.

During the war, from 1942 to 1945, he was engaged in design and construction of military optical instruments under contract with the National Defense Research Council at Yerkes. Research has been his chief activity, with particular emphasis on the nature of interstellar matter and its intersection with the stars, observations of galactic nebulae and interpretation with reference to the nature of interstellar matter, the theory and practice of optical design, and interpretation of stellar spectra. In a phase of this last field of investigation, Greenstein spent a few weeks in Pasadena in 1945, working in collaboration with Drs. Walter Adams and Paul Merrill of the Mt. Wilson Observatory.

Greenstein is a member of Phi Beta Kappa; Fellow of the A.A.A.S., the Royal Astronomical Society, Astronomical Society of the Pacific, International Astronomical Union, Midwest Group of Astronomers (of which he is permanent secretary), and the American Astronomical Society.

From Russell W. Porter



Russell W. Porter, dean of amateur astronomers, and creator of six of the illustrations reproduced in this issue, is shown here with the Observatory's portable 8-inch f 1 Schmidt camera, which he designed. Photograph by James Fassero.

IT IS SUPRISING that the great astronomical observatories of California have not created a larger following of laymen to take a more active interest in this, our noblest of sciences. I am referring not to the dilettante, but to the seriously-inclined amateur as compared to the professionals themselves.

These so-called amateurs are far more numerous in the eastern states than here on the West Coast. There are literally thousands of enthusiasts east of the Mississippi who have made their telescopes with their own hands. They have formed groups in all the large cities, where they meet together to discuss the various theories of our universe and to compare notes on the great advancements and discoveries in astronomy.

Besides our preeminence in the number of observatories in the West, we also have the finest "seeing" conditions and the greatest number of clear nights. With the deserts so easily accessible for weekend trips, I wonder why more people do not take advantage of this opportunity to get away from the glaring street and neon lights. With a relatively small and inexpensive telescope they can easily explore the heavens in the clear and quiet of desert nights.

Since I was somewhat responsible for starting the amateur telescope-making hobby which has swept this country and Europe, I feel entitled to stress the pleasures that this movement has given to so many. There are people from all walks of life who have fallen victims to this indoor sport and have actually made powerful telescopes themselves that would have been the envy of Galileo and Newton. Some of them have turned professional, like the young Kansas farm boy named Clyde Tombaugh, who made his own telescope from parts of a discarded cream separator. What he saw through it so intrigued him that he asked for a job—any old job—at the Flagstaff Observatory in Arizona. As a result, he found Pluto, our most remote relative known at present in our solar system.

A few amateurs are putting their telescopes to useful work, such as watching variable stars, comets, and meteors, observations outside the more important programs of the large observatories.

As a matter of fact, our largest telescope today, at Palomar Mountain, is essentially a camera, and astronomers rarely will look through it. Instead, a moderate-size telescope of, say, twelve inches aperture, gives the inquisitive eye of the amateur about as much fine detail of the moon, or Mars as if he were looking through the 200-inch giant.

"Would-be astronomers" drop in often to see me. Many more write to me for help, and since they have dubbed me "father confessor," I answer them all conscientiously. I have never regretted the long hours devoted to helping these amateurs. The satisfaction of knowing that they are deriving keen enjoyment in better understanding the mechanism of the universe we live in is ample reward.

RUSSELL W. PORTER

Russell W. Porter, associate in optics and instrument design at the California Institute until his retirement a few years ago, is referred to as the "idea man" of the Palomar project. Porter's architectural drawings for the telescope, the observatory, and the equipment on the Palomar Mountain installation are to be found in this magazine and in nearly every publication concerned with the story of the 200-inch.

Widely known for his ingenuity in building his own telescopes from spare parts and for popularizing this hobby among amateur observers throughout the country, Porter was chosen in 1928 by Dr. George Ellery Hale to join the Institute staff and make preliminary sketches for the Astrophysical Laboratory at Caltech. Performing a variety of tasks on this project and the development of Palomar itself, some of Porter's most significant contributions have been in the translation of blueprint designs into three-dimensional drawings, and in the design of accessory equipment for the telescope and its mechanism.

Russell Porter received his undergraduate training at Norwich University, which has subsequently awarded him an honorary M.E. degree, and he was graduated from M.I.T. as an architect. After leaving Massachusetts Tech, as an architect, however, Porter turned first to Arctic exploration. He went as surveyor with the Cook expedition to West Greenland in 1894 and was with three Peary Relief expeditions, in 1896, 1897, and 1899. He was artist and surveyor with the Ziegler Polar Expeditions of 1901-02 and 1903-05, when he discovered a number of new islands and mapped more than 500 miles of new coastline.

As a side interest he turned to the design and construction of home-made telescopes, including one which he patented and put on the market. Despite his preoccupation with the vast Palomar project during the last 20 years, he is looked upon as patron saint by amateur astronomers the world over and still maintains a lively correspondence with them.

(Editor's note—On February 22, 1949, Russell Porter, 77, died of a heart attack, at his home in Pasadena.)

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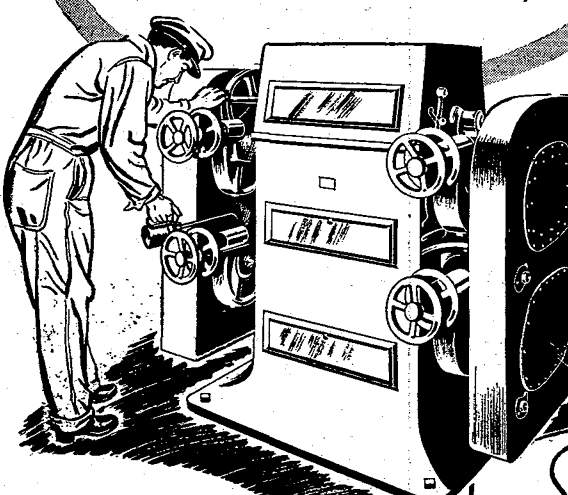
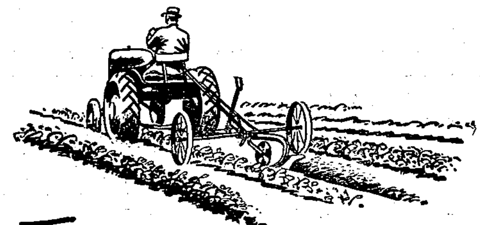
THE MARCH OF SCIENCE

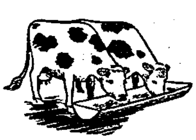
UNLOCKING SECRETS OF THE SOY BEAN..

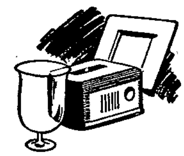


THE SOY BEAN, ONCE PLANTED ONLY AS A ROTATION CROP, WAS PLOWED UNDER TO INCREASE THE FERTILITY OF THE SOIL.



THEN SCIENCE DISCOVERED THAT SOY BEAN FLOUR IS WHOLESOME ...THE OIL MAKES GOOD PAINTS AND SALAD DRESSING...THE MEAL IS GOOD CATTLE FEED... THE FIBRE MAKES PLASTICS.. BUT FIRST EXTRACTION METHODS DIDN'T GET ALL THE OIL...ONLY PARTIALLY SEPARATED THE OTHER INGREDIENTS.





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