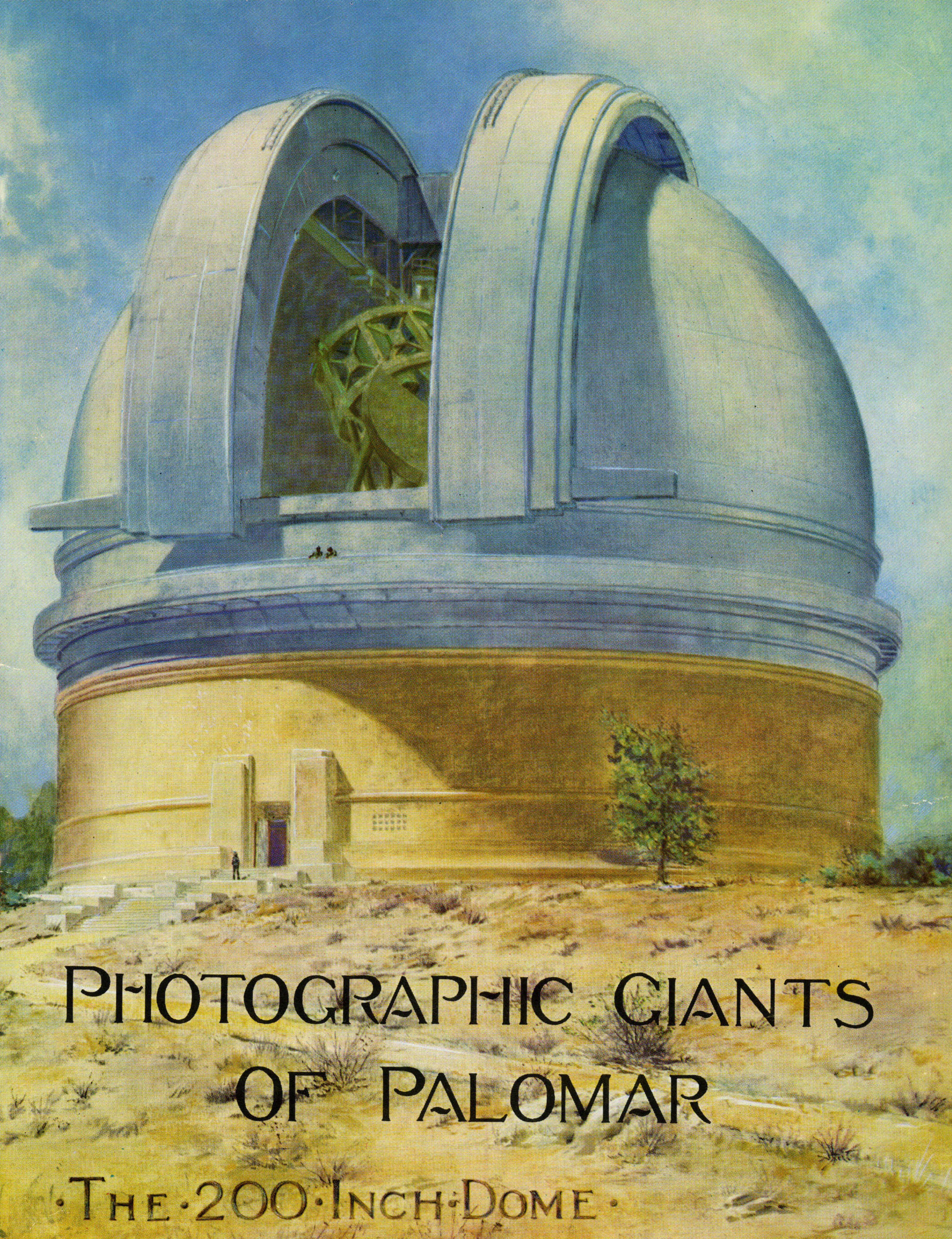

PHOTOGRAPHIC GIANTS OF PALOMAR

·THE·200·INCH·DOME·

THE FRONT COVER

Several years were spent observing with small telescopes at numerous sites to determine which one offered the best "seeing." The Palomar site was chosen not only because it offered the best astronomically, but also because it is located far enough from large cities to be practically unaffected by their scattered sky light. The site is located on a comparatively flat area on Palomar Mountain at an elevation of 5600 feet.

The dome is 137 feet in diameter and consists of a double wall with a four-foot air space between. Air may be circulated in this space so that the daytime temperature of the interior of the dome may be kept as near as possible to the observing night-time temperature. The lower part of the dome contains two floor levels built around the stationary base frame of the telescope. On the lower floor are the photographic dark rooms, offices, laboratories, lounge, library, midnight kitchenette, and air conditioning machinery. On the mezzanine floor are the switchboards, motor-generator sets, control panels for the elevators, and the oil pumping system. The upper, rotating part of the dome is made of 3⁄8-inch steel plates welded over a steel framework and weighs 1,000 tons. It rotates on 32 four-wheeled trucks riding on carefully ground circular tracks, and is driven by four rubber-tired friction wheels each of which is driven by a five-horsepower motor. The dome is provided with a split shutter which allows a clear opening of 30 feet.

Incidentally, and by pure coincidence, the dome is nearly the same size and shape as the Pantheon at Rome. However, the Pantheon has walls of stone 20 feet thick.

The public is taken through the main entrance and up a spiral stairway, to the main floor for viewing the telescope. Visitors are restricted to a glassed-in enclosure to prevent their body heat from disturbing the temperature of the interior of the dome.

PHOTOGRAPHIC GIANTS OF PALOMAR

by

JAMES S. FASSERO

Astrophysics, California Institute of Technology

Drawings by

DR. R. W. PORTER

Astrophysics, California Institute of Technology

WESTERNLORE PRESS

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FOREWORD

By DR. MAX MASON
Chairman of the Observatory Council

GEORGE ELLERY HALE, that great astronomer and statesman of science, conceived the project of building a telescope of two hundred inch aperture. Funds for the construction were given to the California Institute of Technology by the Rockefeller Boards.

The staff of the Mount Wilson Observatory of the Carnegie Institution of Washington joined with the scientists and engineers of the California Institute of Technology in directing the long task of scientific study and precise engineering.

The great telescope is a light gathering instrument—a fast telescopic camera. It will be used photographically, not visually, to study faint and distant nebulæ, those universes of suns, and to analyze into high detail the nature of the light received from stars and planets, to penetrate farther into the distant reaches of space, photographing over hours of exposure time the remote members of the cosmos.

First, then, more knowledge of the make-up of the cosmos. But there is another phase of modern astronomy. All science today is really one—its field the study of the electrical constitution and the behavior of the elements. We study this in terrestrial laboratories. But in the stars, and in inter-stellar space, matter exists under conditions which we cannot reproduce on earth. We cannot reproduce the enormous temperatures and pressures within the suns. Nor can we pump out the gas of a vacuum tube to have matter in as rarefied and attenuated a form as exists in interstellar space. The astrophysicist analyzes the light received from the suns and the effect on it of the attenuated gas in space and so uses the whole of the cosmos as a laboratory to learn of nature's laws.

Man wants to know and nothing will stop him. We grope dimly through our ignorance, driven by an insatiable curiosity inherited from our simian ancestors. We feel that we are a part of an all-embracing unity. We have learned that all matter is alive, sending energy, the source of life, back and forth through space, and that we, organic life in evolution, are a part of the great orderly universe. Our knowledge is in its infancy, but we press rapidly forward, learning of the make-up of the cosmos, the evolution of the stars as they are born, mature and age, the life history of whole universes of suns, and the laws of behavior of the very matter which makes the bodies which our minds and spirits inhabit. We seek nothing less than clues to the great mystery of existence, and knowledge to gain conscious control of man's evolution.

THE ARTIST

Dr. Russell W. Porter, well known to amateur telescope makers the world over, made this fine collection of drawings possible by his ability to faithfully portray mechanical objects in perspective. With pencil and paper he was able to "cut away" sections of the telescope to show the inside details; something which cannot be done with a camera. His artistic and mechanical abilities have combined to produce a set of drawings which have proved of indispensable value not only to the laymen but to all those who already are familiar with the instruments. Dr. Porter is shown here with the observatory's portable 8-inch f-1 Schmidt camera, which he designed.

Maxfield Parrish, celebrated fellow artist, has this to say of the Porter drawings: "If these drawings had been made from the telescope and its machinery after it had been erected they would have been of exceptional excellence, giving an uncanny sense of reality, with shadows accurately cast and well nigh perfect perspective; but to think that any artist had his pictorial imagination in such working order as to construct these pictures with no other material data than blue prints of plans and elevation of the various intricate forms—is simply beyond belief.

"These drawing should be in a government museum of standards, in a glass case, along with the platinum pound weight, yard stick, etc., to show the world and what comes after just what a mechanical drawing should be.

"Not only that, but the rendering is a work of art, exact and lifelike, and done with a delightful freedom of technique.

"I doubt if there are drawings anywhere which can in any way compare with these for perfection in showing what a stupendous piece of machinery is going to look like when finished. . . . Their creation should be world news."

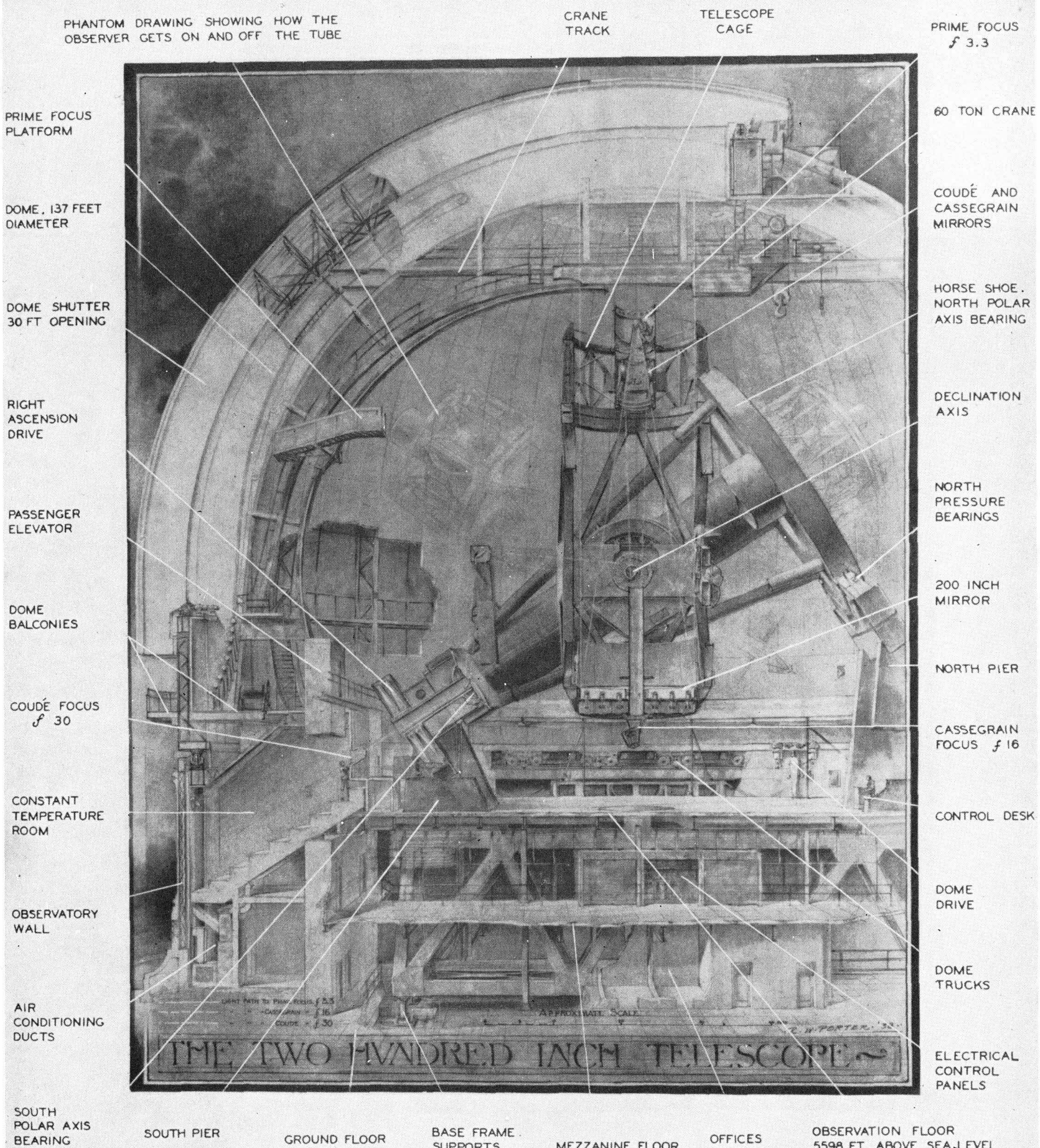
KEY DRAWING

A MERIDIAN section through the telescope and dome, looking west. This drawing, with marginal references, will enable one to locate and identify the various parts of the instrument shown in more detail in other drawings. The vertical member in the center of the picture is the telescope tube, which weighs 150 tons. The whole mounting weighs 500 tons.

Indicated by faint white lines, parallel light from a celestial object is shown being reflected from the 200-inch mirror and converging near the top of tube at the prime focus (f-3.3). A photograph of the object may be made at this point by the astronomer, who rides in the telescope during the exposure.

If a larger image is required, a Cassegrain mirror is swung into place just below the prime focus, and the light is reflected back down the tube and through a hole in the 200-inch mirror to the Cassegrain focus (f-16). At this point a direct photograph may be made, or as is usually done, a spectrogram taken. To accomplish this, an instrument called the spectrograph is placed at this focus of the telescope, and the light from the celestial object, in passing through it, is separated into all the colors of the rainbow. These colors are crossed by dark lines. It is by the careful study of these lines that the astronomers are able to learn so much about the nebulæ and stars, even though they are unimaginable distances away. By studying the position of the lines, their combination, intensity, whether the lines are single or multiple, etc., the astronomers learn not only what the particular star is made of, but under what temperature, pressure, magnetic field, etc., the various elements exist. In short, almost everything we know about stars and distant nebulæ is revealed by the lines in their spectra.

If a still larger image is desired, the Cassegrain mirror is replaced by a coudé mirror which reflects the light to an optical flat (see page 18) at the declination axis (center of picture) which in turn reflects the beam down the polar axis and into the constant temperature room. Coudé focus in this room is f-30, which means the telescope now has an equivalent focal length of 30 times the big mirror's diameter, or 6,000 inches.

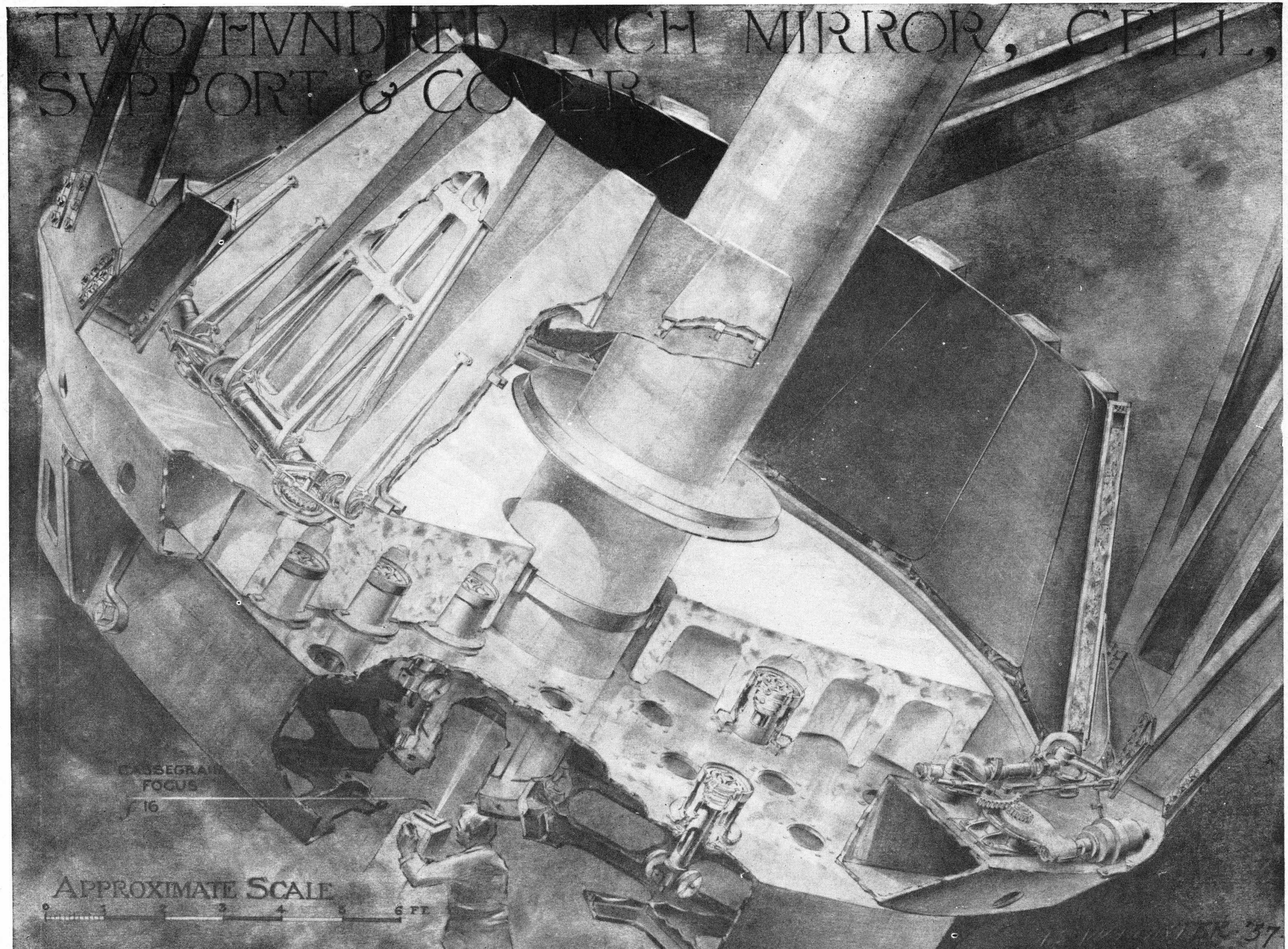


PHANTOM DRAWING SHOWING HOW THE OBSERVER GETS ON AND OFF THE TUBE
CRANE TRACK
TELESCOPE CAGE
PRIME FOCUS ƒ 3.3
PRIME FOCUS PLATFORM
60 TON CRANE
DOME, 137 FEET DIAMETER
COUDÉ AND CASSEGRAIN MIRRORS
DOME SHUTTER 30 FT OPENING
HORSE SHOE. NORTH POLAR AXIS BEARING
RIGHT ASCENSION DRIVE
DECLINATION AXIS
PASSENGER ELEVATOR
NORTH PRESSURE BEARINGS
DOME BALCONIES
200 INCH MIRROR
NORTH PIER
COUDÉ FOCUS ƒ 30
CASSEGRAIN FOCUS ƒ 16
CONSTANT TEMPERATURE ROOM
CONTROL DESK
OBSERVATORY WALL
DOME DRIVE
DOME TRUCKS
AIR CONDITIONING DUCTS
APPROXIMATE SCALE
THE TWO HVNDRED INCH TELESCOPE
ELECTRICAL CONTROL PANELS
SOUTH POLAR AXIS BEARING
SOUTH PIER
GROUND FLOOR
BASE FRAME SUPPORTS
MEZZANINE FLOOR
OFFICES
OBSERVATION FLOOR 5598 FT ABOVE SEA LEVEL

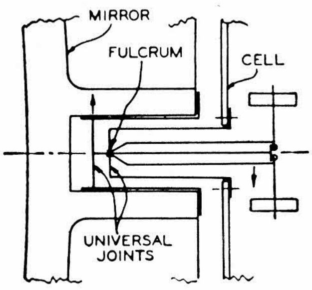
THE 200-INCH MIRROR

THE finished mirror is 200 inches in diameter, about two feet thick and weighs 14¾ tons. To support such a large piece of glass at any angle of inclination and without distortion presented a difficult problem. The mirror was cast with a solid face backed with a honeycomb rib pattern. This pattern made possible 36 points for support. At these points holes were bored from the back into the glass to its center of gravity. In these holes were installed 36 ball-bearing lever systems, so that each unit would exactly balance the amount of glass surrounding it. This drawing shows the mirror and cell cut away to reveal some of the supports. The drawing on the following page shows one of these supports in detail.

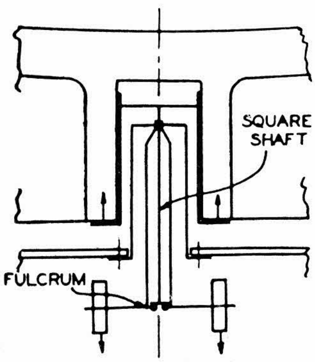
The mirror cover is shown partly closed. The leaves of the cover are so arranged that they form a circular opening, thus acting as an iris diaphragm to stop the mirror down to whatever aperture is desired. The leaves are filled with aluminum foil insulation and are operated by two ½-horsepower motors. The 40-inch hole in the center of the mirror is shown, filled with a coudé support tube on which the coudé flat mirror is clamped when in use. (See page 19.) When this flat is lifted out of the way, light passes through the coudé support tube and forms an image at the Cassegrain focus (f-16) shown below the cell. (f-16 means that at this point the telescope has a focal length of 16 times the diameter of the mirror, or 3,200 inches.) At this focal length the image of the moon would be about 29 inches in diameter.


TWO HUNDRED INCH MIRROR, CELL, SUPPORT & COVER
CASSEGRAIN FOCUS
f 16
APPROXIMATE SCALE
0 1 2 3 4 5 6 FT

MIRROR SUPPORTS

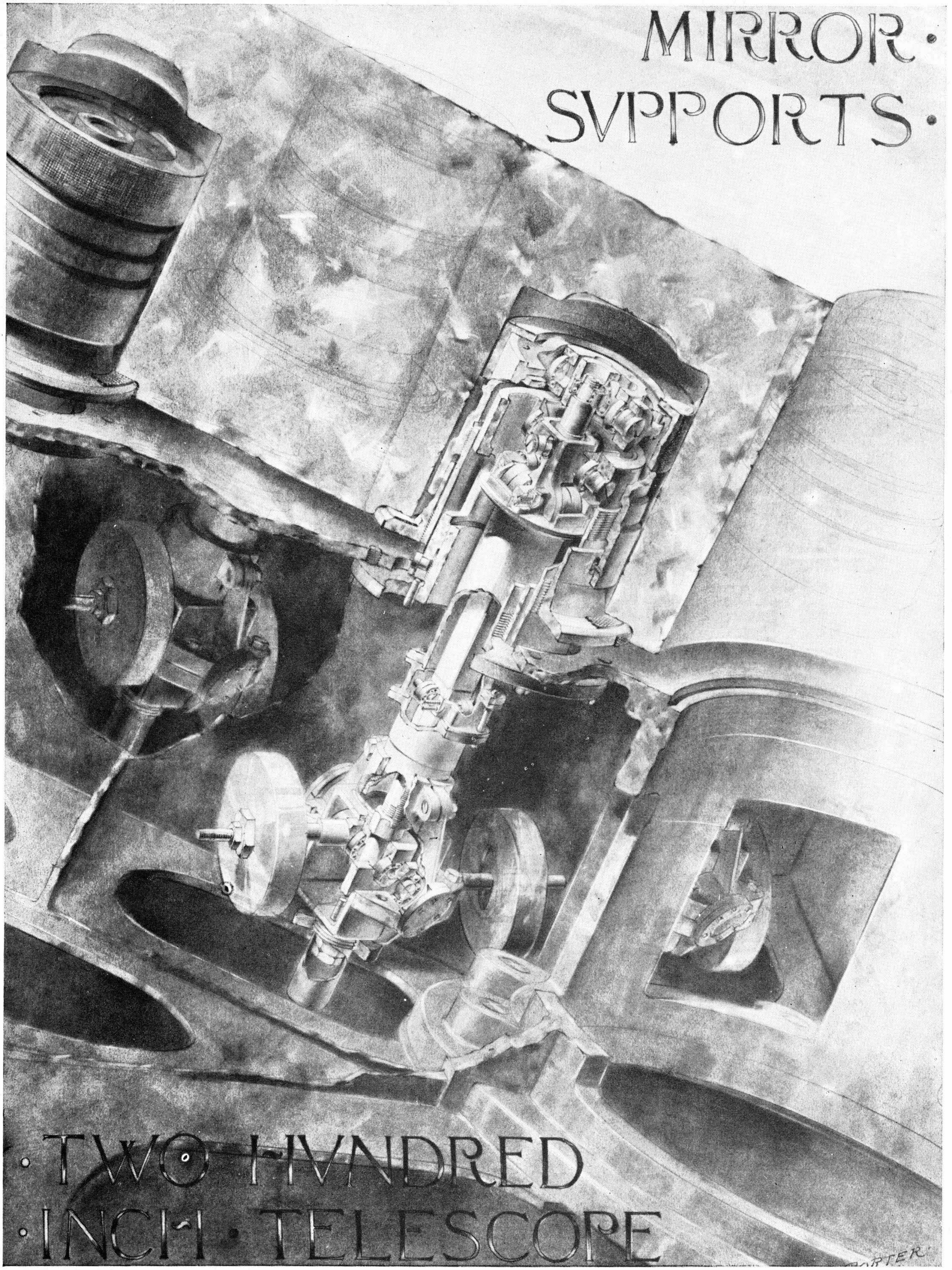


MIRROR VERTICAL



MIRROR HORIZONTAL

THIS is a close-up of one of the 36 mirror supports. The mirror is shown in section in the upper part of the drawing, with the support reaching in to its center of gravity. The cut-away metal section from the center of the drawing down is the mirror cell or the bottom of the telescope tube. The support is shown bolted to this cell, and the fulcrum of the lever system is located above the large rollers shown a few inches inside the glass. This is the fulcrum about which the mirror is balanced when it is on edge, as shown in the first diagram at the left. When the mirror is horizontal, its weight is transferred by the square shaft, through the hollow stem, to the lead counterweights below. These counterweights, working on eccentrics, lift up against the mirror, as may be seen in the second diagram. When the mirror is tilted, the proper combination of these two systems works together to exactly balance the glass at any angle of inclination. To minimize friction, all pivots and guides are on ball bearings.

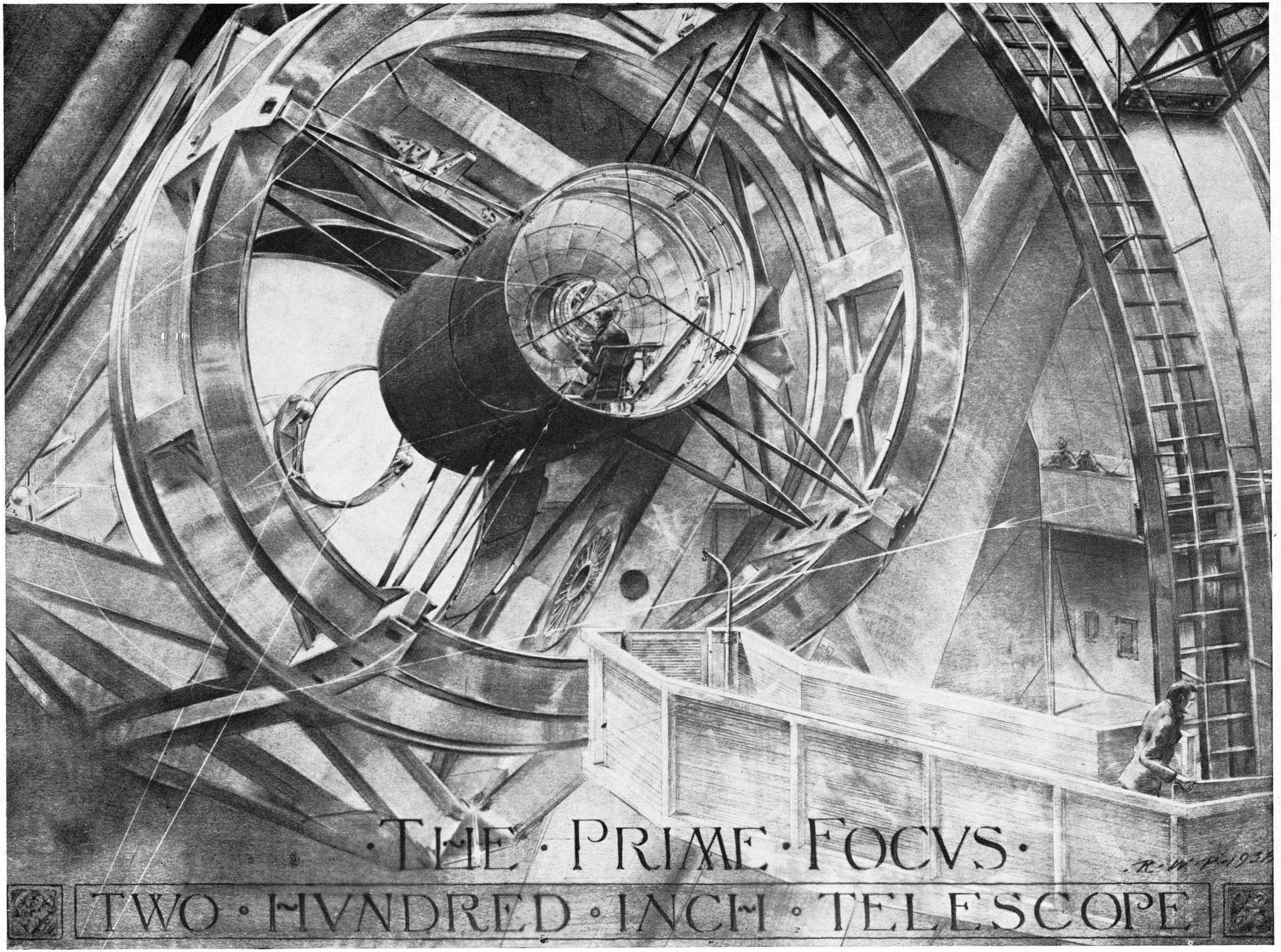

MIRROR ·
SVPPORTS ·
· TWO · HVNDRED
· INCH · TELESCOPE

PRIME FOCUS CAGE AND PLATFORM

This is a view of the telescope looked at almost "head on" from a point just outside the dome. The tube has been lowered until it is nearly horizontal. An astronomer is shown guiding the plate at the prime focus (near the center of the drawing). The bright elliptical object below him and to the left is the coudé flat, which is lifted out of the way when the astronomer is working at the prime focus. The large circular bright object, partially visible at bottom of the tube, is the 200-inch mirror.

In the right foreground is the prime focus platform or elevator. It runs up and down on a curved track attached to the dome, at the side of the shutter opening. Therefore, by rotating the dome and running the elevator up the curved track, the astronomer can get himself and his instruments to the prime focus station in the telescope, no matter where it may be pointing The curved track is so designed with gearing, that the platform remains level and just clears the telescope in any position. When the telescope is vertical, the astronomer is nearly seventy feet above the main floor. The steps at the right lead to the cab of the 60-ton crane at the top of the dome.

Due to the 40-inch hole already in the 200-inch mirror, this mirror and prime focus cage cut off only nine percent of the reflected light that would otherwise be available. The supports for this cage are ⅝ inches thick and are called knife-edges. Their light interference is negligible. (See also page 13.)

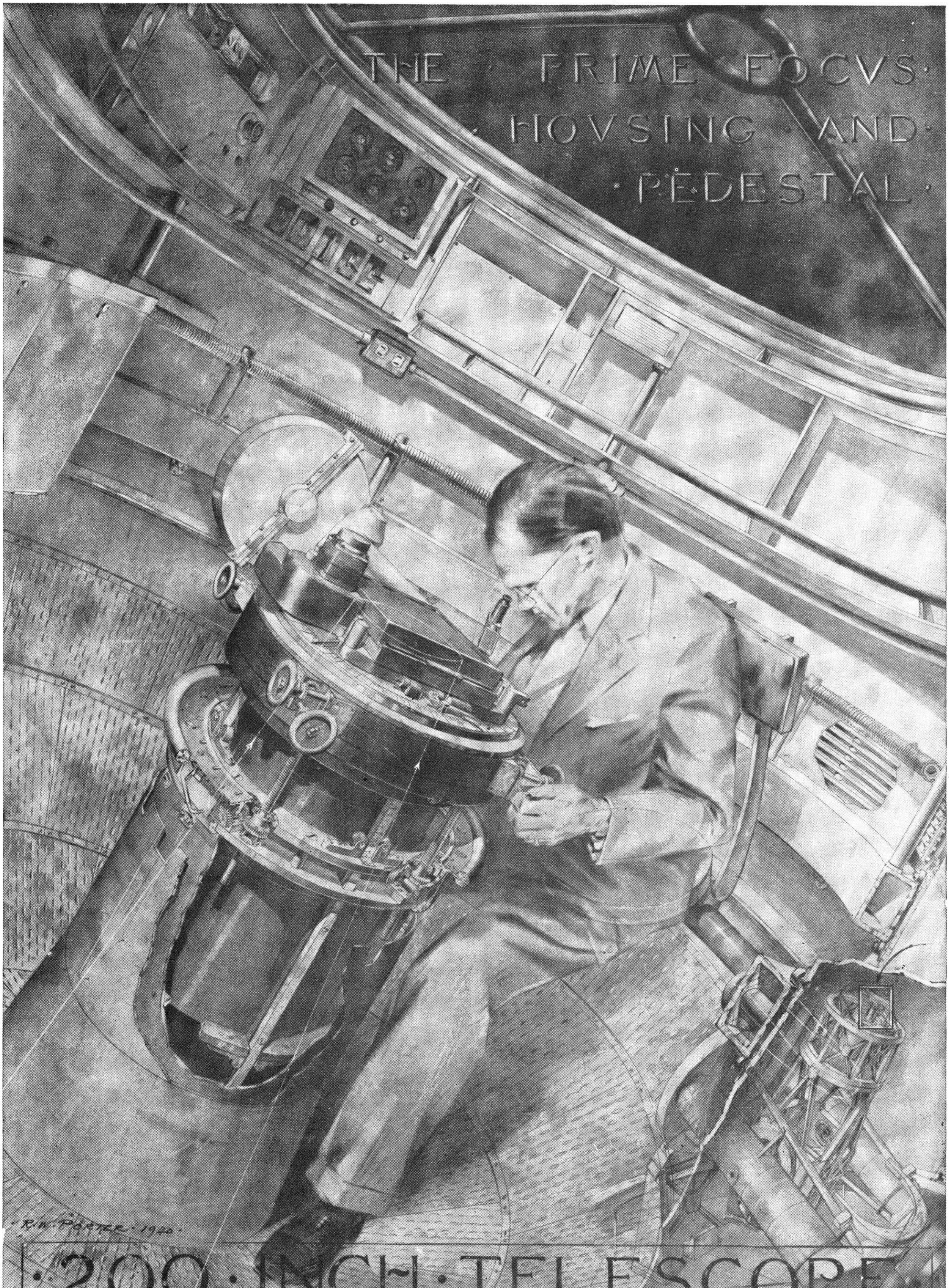

·THE·PRIME·FOCVS·
TWO·HVNDRED·INCH·TELESCOPE

PRIME FOCUS

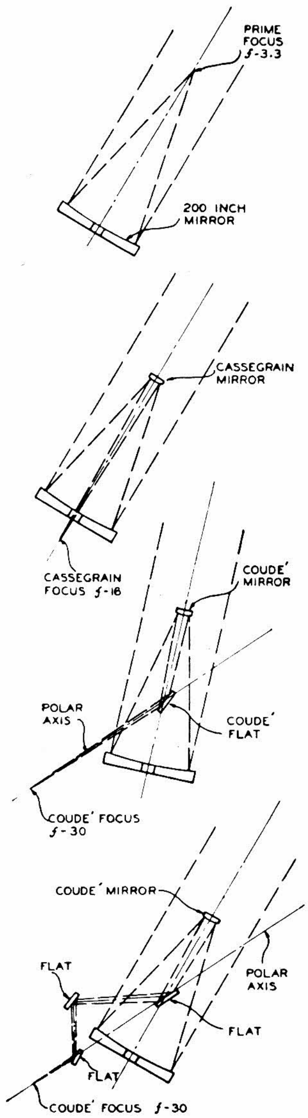
This is a close-up view of the astronomer guiding at the prime focus. The miniature sketch in the lower right-hand corner shows the location of this view with respect to the whole telescope. Usually the light is reflected out to the side of a telescope by a diagonal mirror at a point called the Newtonian focus, but the 200-inch instrument was considered large enough to allow the astronomer to ride within a cage at the top end of the tube, thus eliminating the extra reflection of the diagonal. The image is formed at the photographic plate directly after reflection from the 200-inch mirror.

We mentioned above that the astronomer is guiding. What do we mean by guiding a telescope? As you probably know, the stars appear to move across the sky due to the rotation of the Earth. Since a single exposure is often several hours long, the telescope is provided with a drive to follow this apparent motion as closely as possible. This would be relatively simple if it were not for the atmosphere surrounding the Earth. A ray of light from empty space is refracted or bent slightly as it passes through our atmosphere. Our atmosphere is never steady. Its temperature, pressure and motion are constantly changing, which, incidentally, is what causes stars to twinkle. This refraction, due to the atmosphere, combined with deflections of the instrument, etc., causes the images of the stars to drift slightly on the photographic plate. This, of course, would cause the picture to blur. To offset this motion the astronomer sets the cross hair of a microscope on a star beside his plate. Throughout the exposure he peers into the microscope and if the star tends to drift from the center of the cross hair, he moves the plate to follow it by turning the wheels as shown in the drawing. Thus the images of the stars are kept stationary with respect to the photographic plate.

At the top of the drawing are two sets of dials which indicate the point in the sky at which the telescope is directed. The chair tilts and may also be rolled around the inside of the tube, so that the astronomer is always in a comfortable position with respect to the plate holder while the telescope moves.


THE · PRIME · FOCVS ·
· HOVSING · AND ·
· PEDESTAL ·
· R.W. PORTER · 1940 ·
· 200 · INCH · TELESCOPE ·

CASSEGRAIN AND COUDÉ MIRRORS



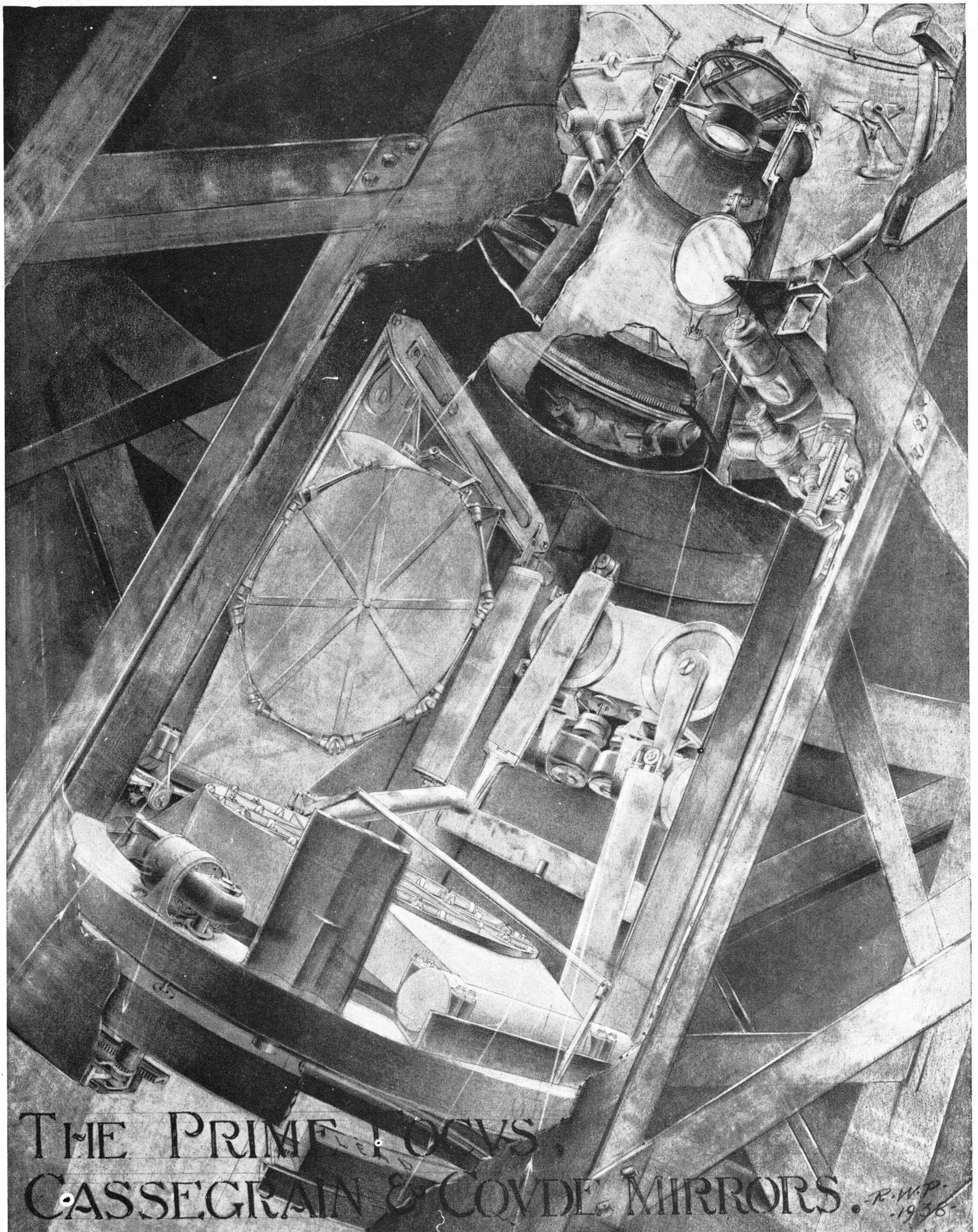
NEAR the upper right-hand corner of this drawing may be seen the rectangular photographic plate at the prime focus. Images formed by a parabolic mirror are sharp only on or near the center of the optical axis. However, with a slight sacrifice of definition at the center, a lens may be made which will increase the size of the useful field, thus allowing a larger photograph to be made. These lenses may be seen just below the plate.

The first diagram at the left shows the path of the light beam when the prime focus is used. The image of the moon at this point would be six inches in diameter.

As mentioned earlier, the telescope is not restricted to this one focal length. By intercepting the light with a small convex mirror near the top of the tube, as shown in the second sketch, the light is reflected down through the hole in the 200-inch mirror to the f-16 Cassegrain focus. The equivalent focal length of this combination is 3,200 inches, and the image of the moon would be about 29 inches in diameter.

If a still larger image is desired, the coudé mirror is mechanically lowered in place, and the light is reflected to a flat coudé diagonal which in turn reflects it down the polar axis to the coudé focus as shown in the third sketch. The image of the moon at this point will have a diameter of over 54 inches. The equivalent focal length is 6,000 inches or 500 feet.

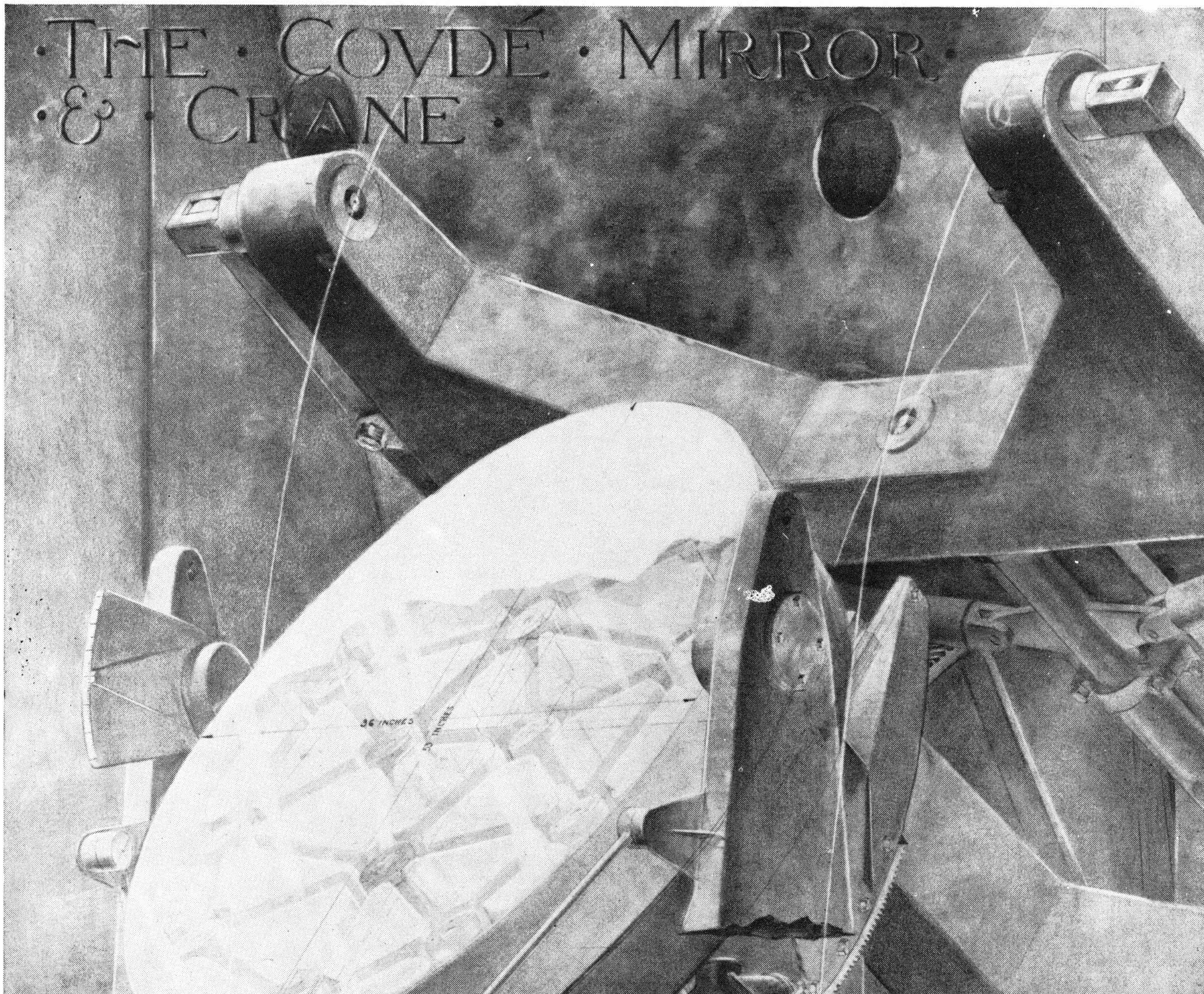
There are certain regions in the northern sky where this combination will not be able to reach due to the interference of the 200-inch mirror with the beam of light going down the polar axis. Therefore, for observations near the north celestial pole, the so-called five-mirror system may be used as shown in the last diagram. The focal ratio still remains at f-30


THE PRIME FOCUS,
CASSEGRAIN & COUDE MIRRORS.
TWO HUNDRED INCH TELESCOPE
R.W.P.
1938

COUDÉ DIAGONAL MIRROR

THIS is a close-up of the coudé diagonal mentioned on the preceding page. The mirror is elliptical, measuring 36 x 53 inches, and its surface is an optical flat. The drawing shows the upper part of the glass coated with a thin film of aluminum while the lower part shows the polished glass surface through which may be seen the ribbed structure of the back. When in operation the whole surface of the mirror as well as all the other mirrors in the telescope, have a thin, even aluminum coat. It is because of the elbow-like bending of the rays of light by this mirror that the system gets its name. "Coudé" is a French word meaning "elbow." This mirror is driven half as fast as the telescope in declination, so that the image down in the coudé room remains fixed. Declination is the astronomer's term used to denote the motion of the telescope in the north and south direction.

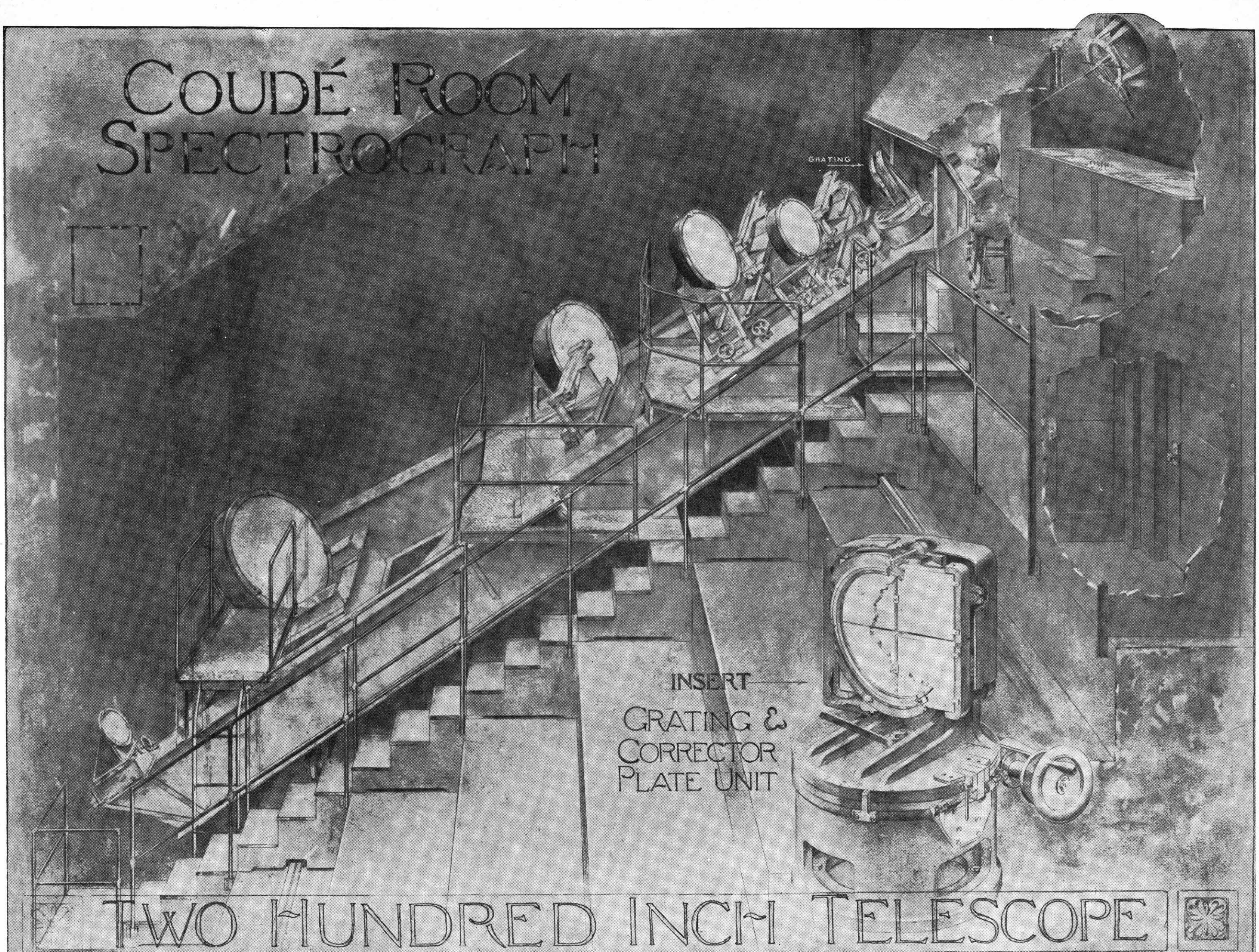
When the coudé focus is not in use, it is desirable to have this mirror out of the way. For this purpose a crane, pivoted against the north wall of the tube, descends to the bottom of the mounting and grips the mechanism on both sides. The mounting automatically releases itself from its support, and the whole unit is lifted out of the way, against the side of the telescope tube. When the mirror is desired back in place, the sequence is automatically repeated in the reverse order. The movements of these units are compensated for by the shifting of weights on the tube, so that the telescope remains balanced at all times.


·THE·COVDÉ·MIRROR·
·&·CRANE·
36 INCHES
APPROXIMATE·SCALE·
R·W·PORTER
·TWO·HVNDRED·INCH·TELESCOPE·

COUDÉ SPECTROGRAPH

AT THE south end of the telescope is the totally enclosed coudé spectrograph room. An astronomer can be seen in the upper right corner of the drawing examining the image at the coudé focus. Here the light of the object under study passes through a narrow slit and travels down the polar axis to a 12-inch mirror at the lower left corner of the drawing. This mirror reflects the light back as a parallel beam which falls on the grating just behind the slit. The grating separates the light into all the colors of the spectrum and reflects it back into one of four Schmidt cameras seen in the drawing. The grating required here is one having a ruled area twelve inches square. A satisfactory grating of this size has not yet been ruled, so this had to be made up of four six-inch gratings optically aligned as shown in the inset. The present gratings are ruled with 10,000 lines per inch on an aluminum coating which has been evaporated on an optically flat glass blank. The grating may be changed to another of different groove-form if it is desirable to concentrate the light in a given order of the spectrum.

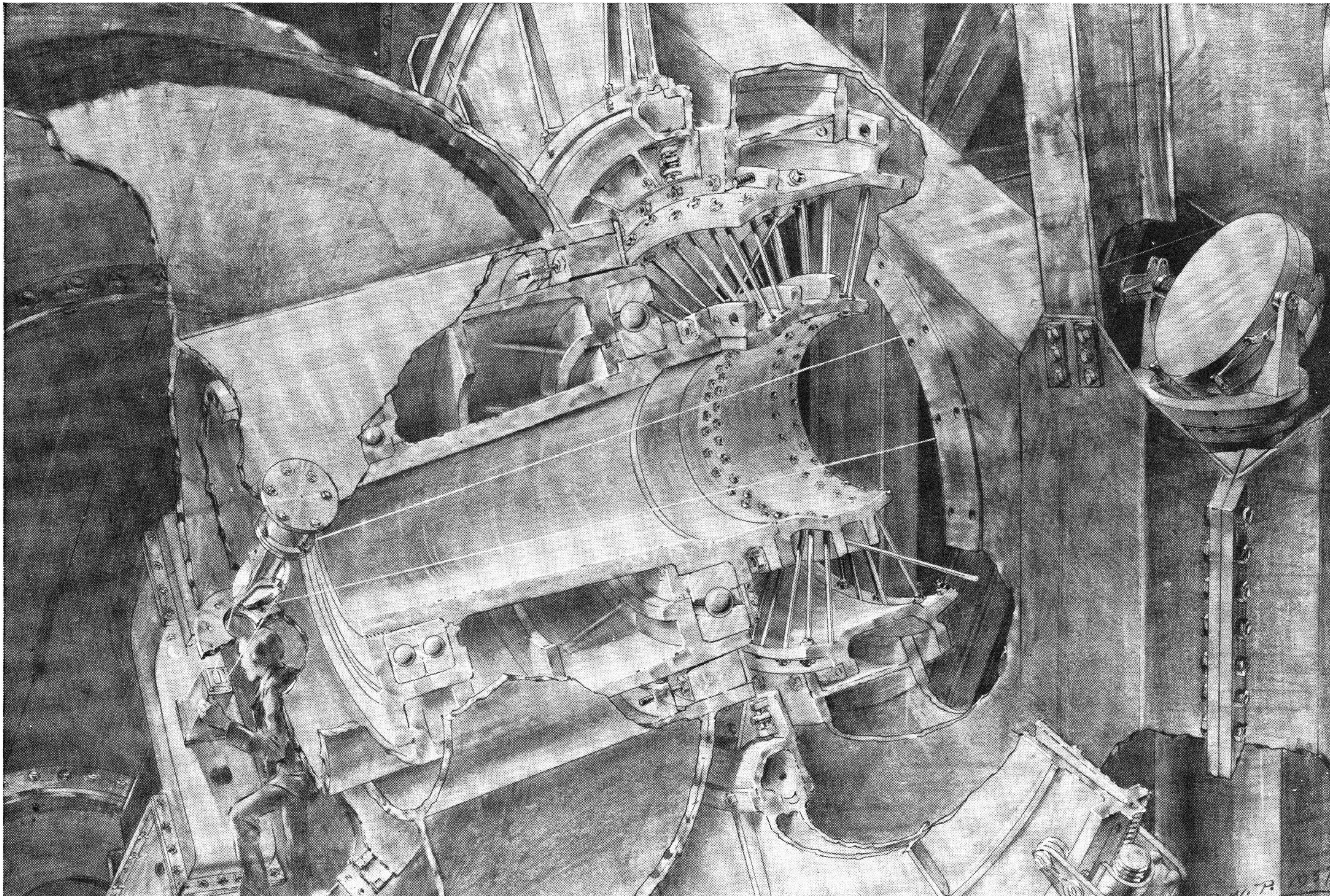
The four Schmidt cameras have mirrors ranging from 20-inch to 48-inch diameter and they photograph the spectrum on plates ranging from one inch by six inches to one inch by twenty-two inches. The correction plate for the Schmidt cameras is placed directly in front of the grating.


COUDÉ ROOM
SPECTROGRAPH
GRATING
INSERT
GRATING &
CORRECTOR
PLATE UNIT
TWO HUNDRED INCH TELESCOPE

EAST DECLINATION TRUNNION

As MENTIONED previously, the main tube of the telescope is mounted to rotate in the north and south direction on two large declination bearings. This drawing shows the one on the east side of the tube. Large ball bearings are shown in section around the hollow spindle. The spindle is fastened to the tube by two rows of steel rods similar to bicycle spokes. These were used to incorporate enough flexibility to eliminate binding due to deflections of the mounting as the telescope moves to follow the stars. The direction of flexure was controlled by the selection of the proper angle between the two rows of spokes.

This drawing also shows one of the future observation stations not previously mentioned. It has the same aperture (f-16) as the Cassegrain station at the bottom of the telescope tube, but in this case it is located in the middle of the east ten-foot tubular girder. For this station the coudé flat mirror is used. It is turned so that it reflects the light through the hollow declination spindle to a small flat mirror in the tubular girder. The small flat mirror reflects the light down the tube to the focal point; where, in this case, is located the slit of a spectrograph. Access to this station is by means of steps within the tubular girder shown on page 30.



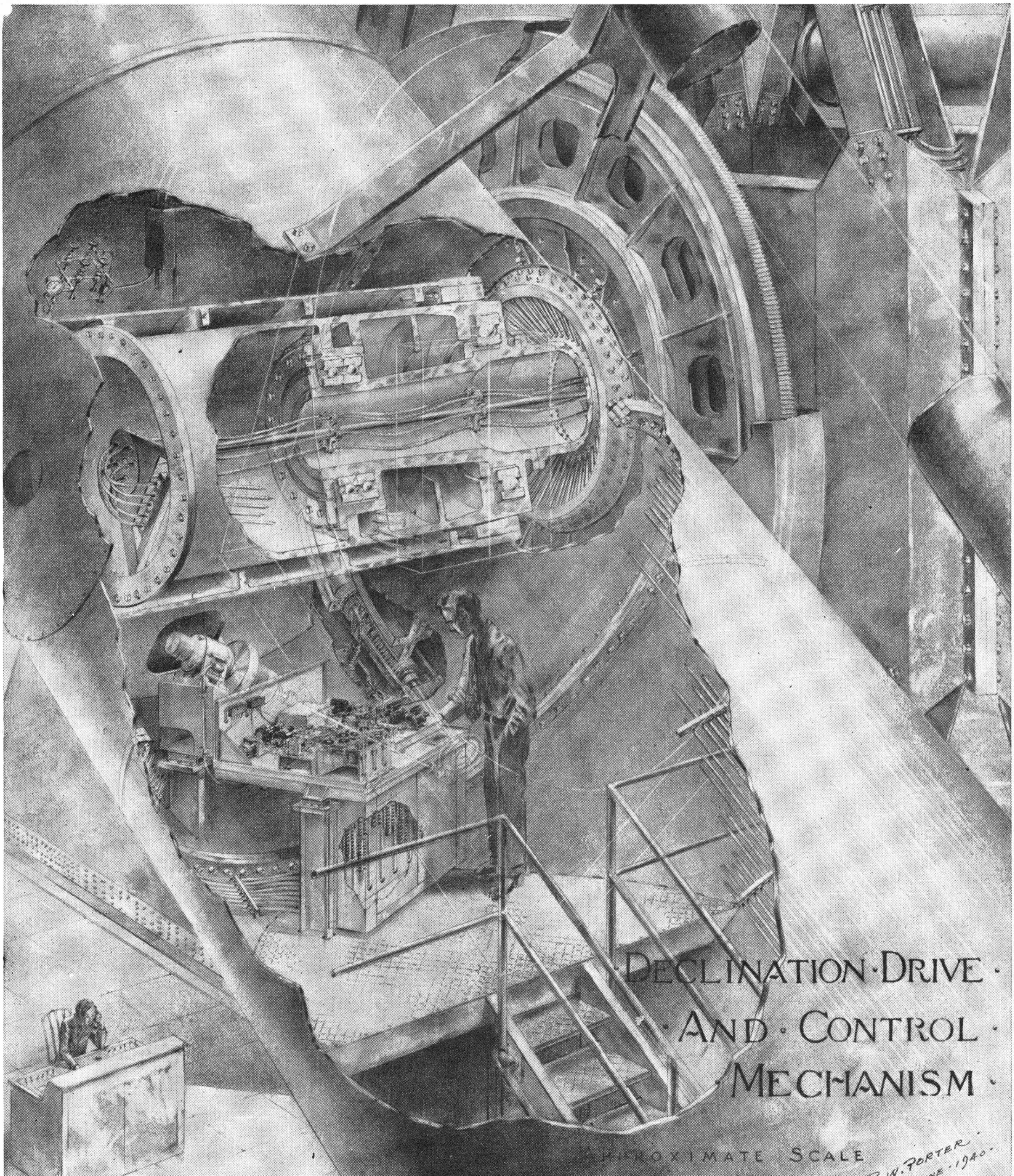
CVTAWAY DRAWING OF DECLINATION TRVNNION, 200 INCH TELESCOPE

WEST DECLINATION TRUNNION

IN THIS drawing the west ten-foot tubular girder is cut away to show the mechanism for driving the telescope in declination (north and south direction). Near the upper right-hand corner is the 10-ton 14-foot worm gear, bolted directly to the telescope tube. It is connected to the hollow spindle through "bicycle spokes" similar to those on the east side as described on the preceding page. Here the spindle is hollow to allow electric cables to go to the telescope tube. The fastest rotational speed of the telescope (slewing speed) is 45 degrees of arc per minute. For this motion a one-horsepower motor is used. This motor is shown at an angle to the table at left center of the drawing. A large flywheel is provided so that the driving mechanism will not slow down too fast in comparison with the telescope and cause undue strain on the teeth of the large gear.

Two other motors provide for setting and guiding. Setting speed (40 minutes of arc per minute of time) is used to bring the telescope slowly up to the object to be observed. Guiding speed (1½ minutes of arc per minute of time) is used to follow the object while the photographic plate is being exposed as described on page 14. A mechanism is also provided for moving the telescope at a very slow rate, either manually set or automatically controlled. This rate may be used to follow objects such as comets which may move in declination, or to correct apparent motions due to atmospheric refraction or deflections of the telescope mounting.

At the lower left, down on the observing floor, may be seen the main control desk, which is one of several stations from which the telescope may be controlled.

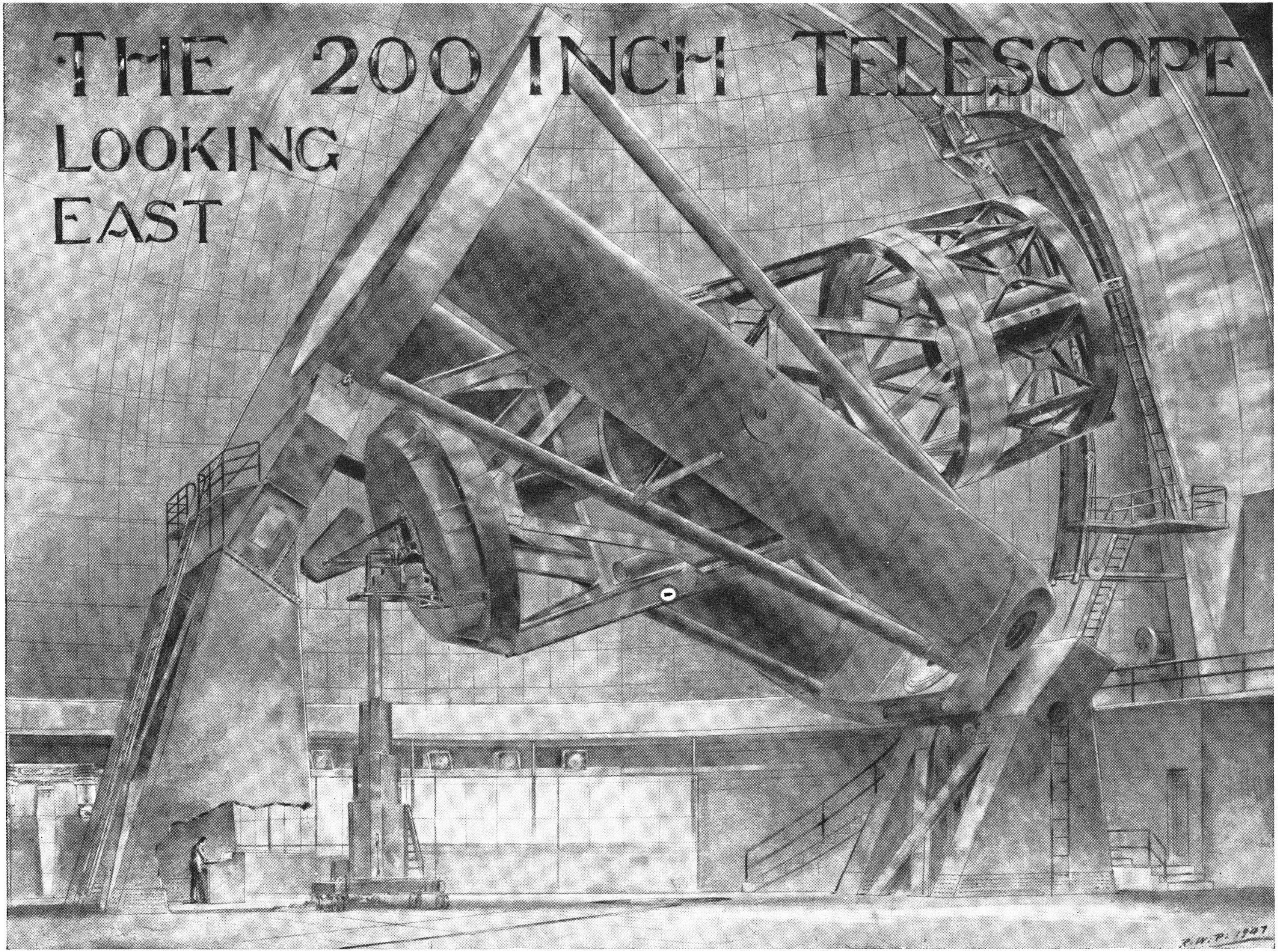


·200 · INCH · TELESCOPE·

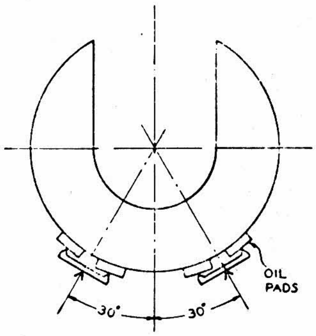
CASSEGRAIN FOCUS

This view of the telescope shows the astronomer at work at the Cassegrain focus. Bolted to the bottom of the tube is the Cassegrain spectrograph with which he is apparently making a spectrogram of a star low in the southern sky. As the telescope follows an object across the sky, it is evident that this station will vary considerably in position and in height from the observing floor. To enable the astronomer to follow his instrument, a four-wheeled truck is provided that is free to move anywhere on the floor and equipped with an elevating shaft. An observer's chair and controls are provided at the top of the shaft, so that the astronomer has complete control of direction and elevation.

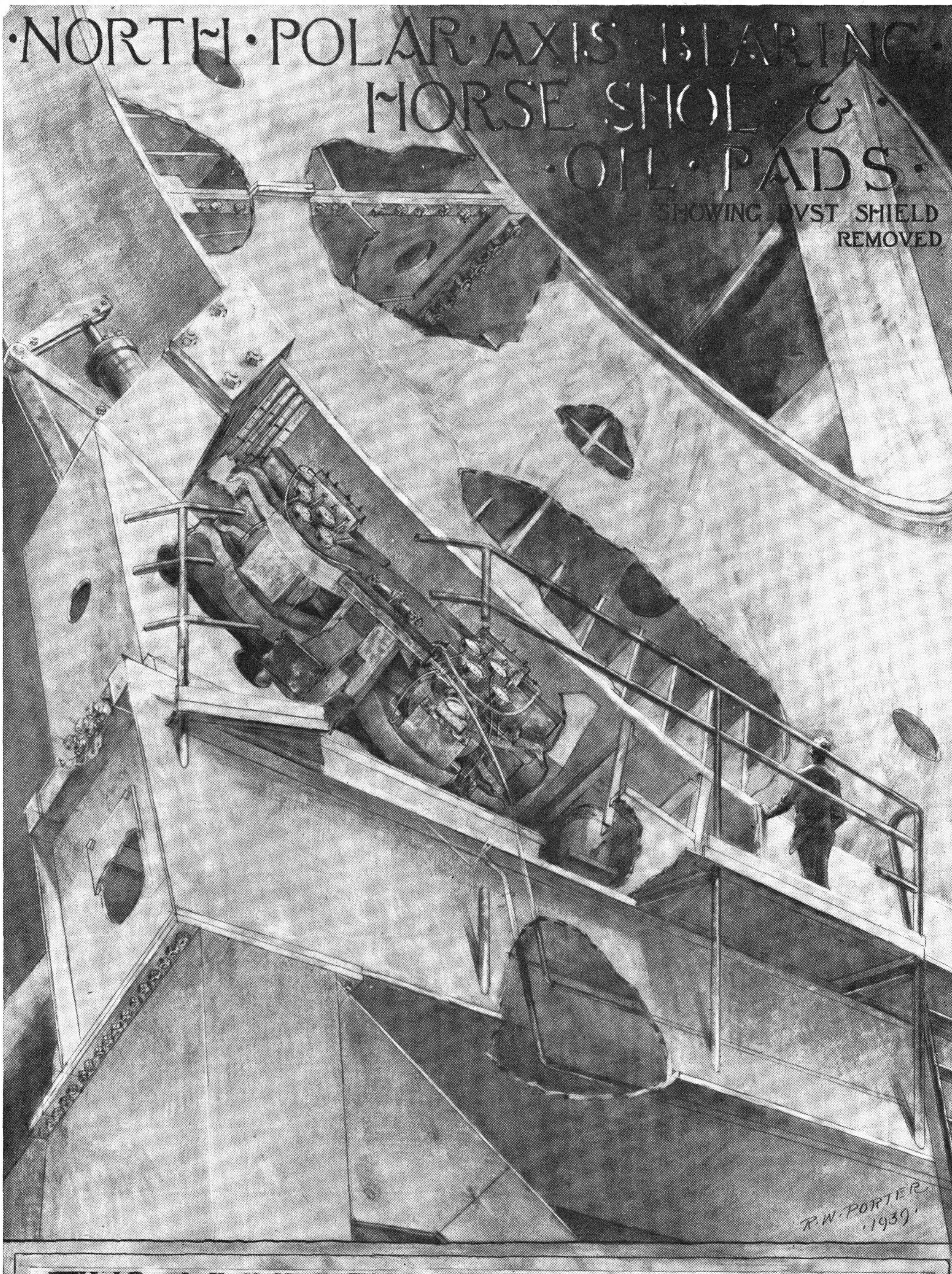
The North pier has been "cut away" to show the main control desk. In the background may be seen the visitor's gallery. This is a glassed-in room, to prevent the body heat of the visitors from disturbing the interior of the dome during the daytime. The curve of the mirror face is disturbed while it undergoes a change in temperature, therefore every attempt is made to keep the daytime temperature of the mirror nearly the same as the observing nighttime temperature. In the lower left-hand corner are shown two of the four five-horsepower motors used to rotate the dome by friction.


THE 200 INCH TELESCOPE
LOOKING
EAST
R.W.P. 1947

NORTH POLAR AXIS BEARING



THE North bearing of the telescope is in the form of a huge cylinder 46 feet in diameter. In order to allow the telescope to view the North regions of the heavens, a section of the cylinder had to be removed, so that it roughly resembles a horseshoe. To the astronomers and engineers of the project, it is known as the "horseshoe" bearing. It weighs 148 tons. Thirty degrees from each side of the center of the "horseshoe" is located a pair of 28-inch square pads. These pads are machined to fit the outer surface of the "horseshoe." and recessed in the center. Into this recess oil is pumped, until a sufficient pressure is reached (210 to 385 pounds per square inch) to lift the telescope from the pads. The oil then flows out all around the pads and returns to the pump. The thickness of the oil film is .003 to .005 inch. Each pad rests on knife-edges so that it can align itself to the face of the "horseshoe." Thus the telescope may be considered to be floating on oil. This type of bearing reduces the friction so much that, although the moving parts of the telescope weigh more than 500 tons, a small 1/12-horsepower motor is more than sufficient to drive the telescope at the sidereal rate of one revolution per day.


·NORTH·POLAR·AXIS·BEARING·
HORSE SHOE·&
·OIL·PADS·
SHOWING DUST SHIELD
REMOVED
R.W.PORTER
·1939·
·TWO·HUNDRED·INCH·TELESCOPE·

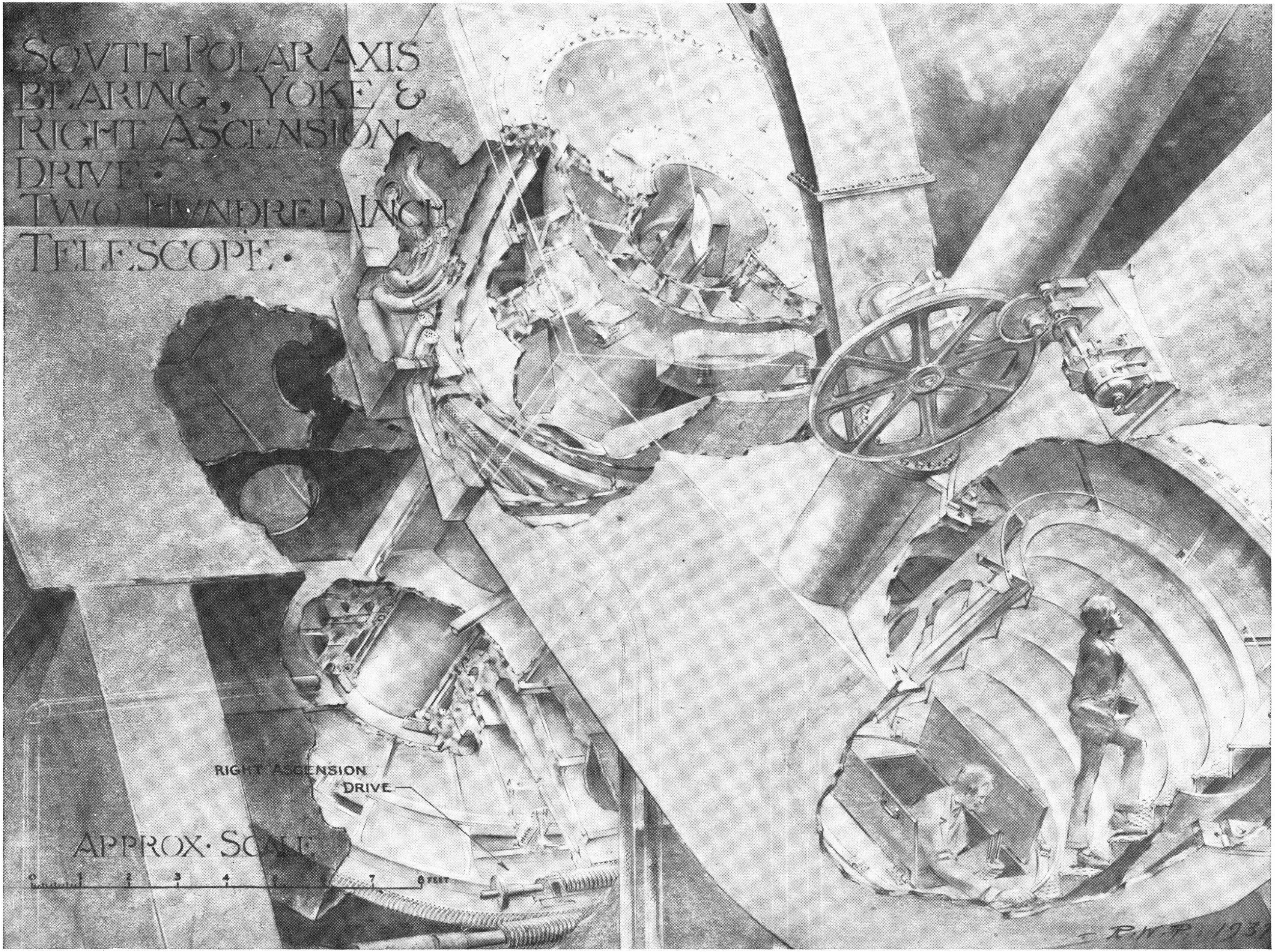
SOUTH POLAR AXIS BEARING

At the top center of this drawing the telescope yoke is cut away to show the spherical bearing at the south end of the mounting. At the center of the yoke, which supports the ten-foot tubular girders, is fastened an 84-inch diameter steel hemisphere. Against this hemisphere rest three spherically ground pads, two of which are shown near the center of the drawing. Oil is pumped to these pads until a sufficient pressure is reached to lift the telescope in a manner similar to that which takes place at the horseshoe bearing described on the preceding page.

Shown near the bottom of the drawing are the two right ascension worms and gears. As the telescope is lifted by the thickness of the oil film, the gears necessarily go with it. The worms, therefore, are not fastened to ground but, by a system of rollers and counterweights, are made to follow the face of the gear.

Near the lower right-hand corner, the mounting is cut away to show two astronomers ascending the cylindrical steps in the ten-foot girder. They are going to the observing station located at the declination axis inside the East cylindrical girder. (See page 22.)

Electrical control and power cables are shown near the center of the drawing. The motor and gears at the right are used to lift one of the coudé mirrors in place. (See page 16, lower sketch.)

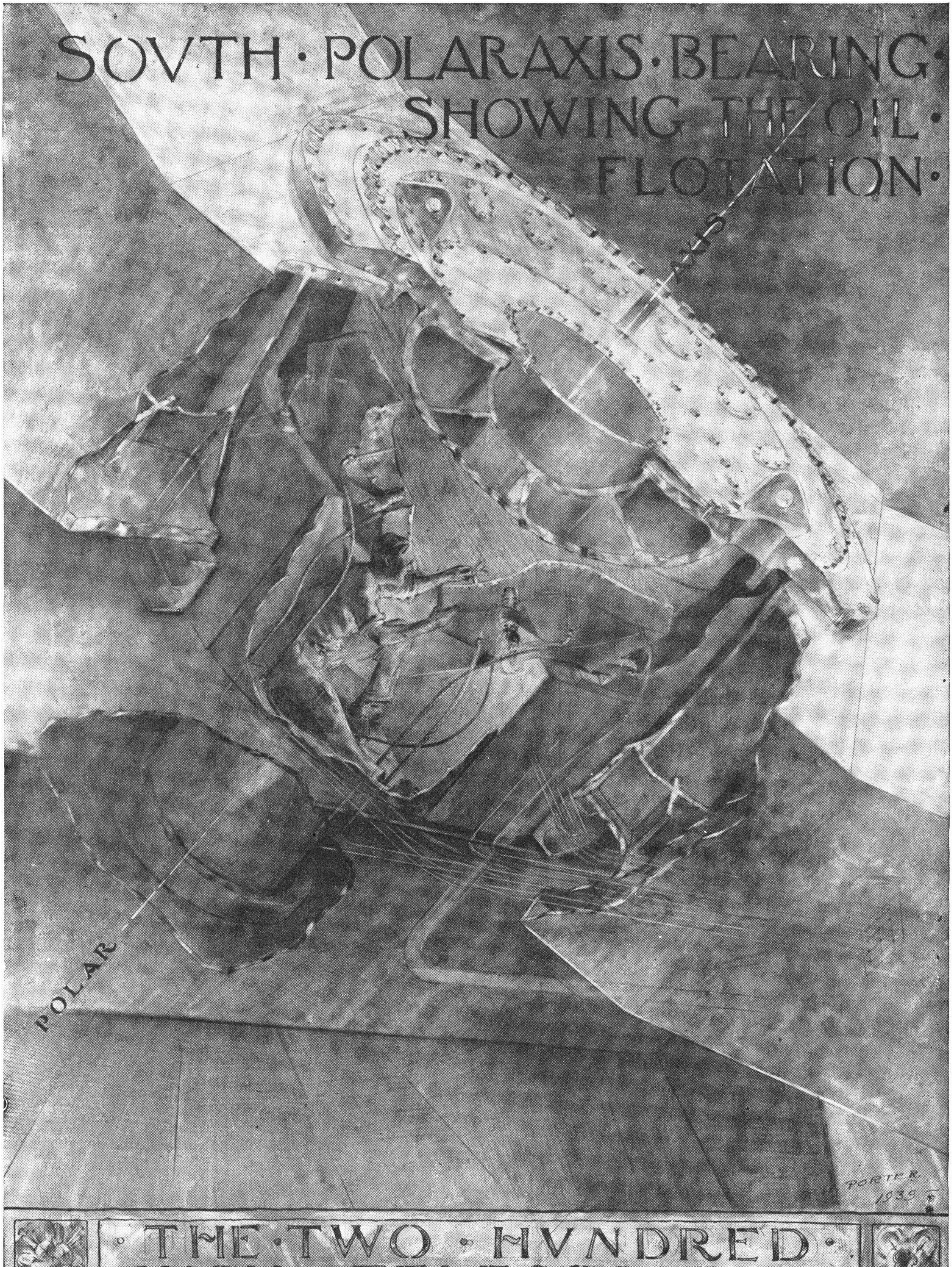


SOUTH POLAR AXIS
BEARING, YOKE &
RIGHT ASCENSION
DRIVE ·
TWO HUNDRED INCH
TELESCOPE ·
RIGHT ASCENSION
DRIVE
APPROX · SCALE
0 1 2 3 4 5 6 7 8 FEET
R.W.P. 1937

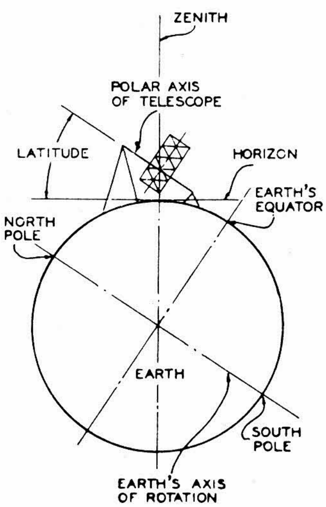
SOUTH POLAR AXIS BEARING *(Detailed)*

A CLOSE-UP of the 84-inch diameter steel hemisphere with the oil pads resting against it. The cutaway shows a thickness gage being used to test the thickness of the oil film, which will vary from three to five thousandths of an inch. The load supported by this bearing is about 342 tons.

This drawing also shows the hollow polar axis shaft through which light passes to reach the coudé room. (See page 38.)


SOVTH · POLARAXIS · BEARING ·
SHOWING THE OIL ·
FLOTATION ·
AXIS
POLAR
PORTER
1939
THE · TWO · HVNDRED ·
INCH · TELESCOPE ·

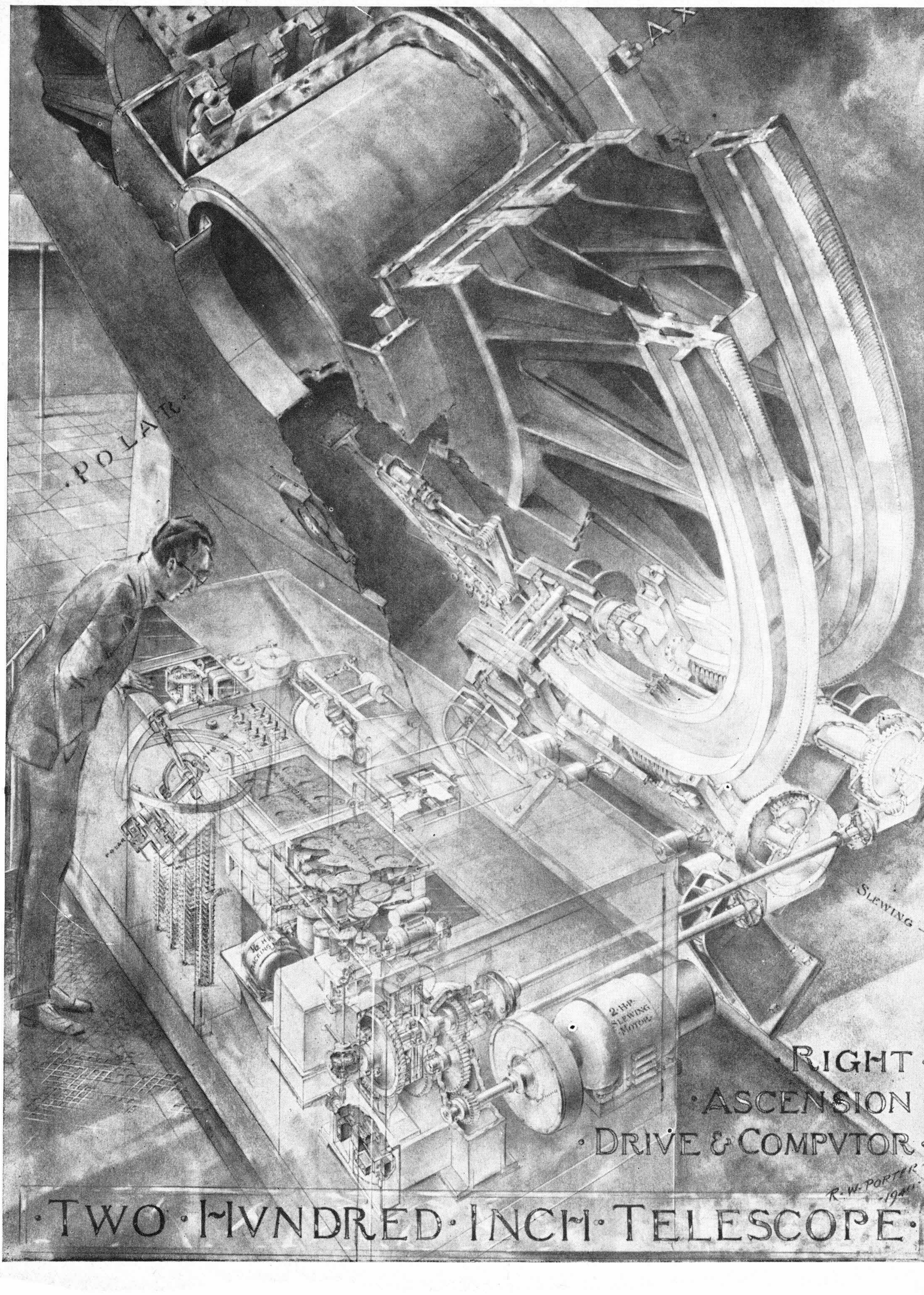
RIGHT ASCENSION DRIVE AND COMPUTER



Right ascension is the term used by astronomers to denote star positions. To reach these positions the telescope is rotated in hour angle, i.e., east and west, about its polar axis. This axis of rotation of the telescope is parallel to the axis of rotation of the earth and therefore varies with the latitude. At the equator the latitude is zero, and the polar axis of a telescope situated there would be horizontal to be parallel to the axis of rotation of the earth. If a telescope were situated exactly at the north pole, its axis of rotation would be vertical. At Palomar, the latitude of the observatory is 33° 21′20″; therefore the polar axis of the 200-inch telescope is tipped up by that angle as shown in the diagram.

The stars appear to travel across the sky, due to the rotation of the earth. The earth rotates from west to east, one revolution in 24 hours. Therefore to counteract this motion, the telescope must rotate from east to west, one revolution in 24 hours. This motion is known as "tracking." For this rate a 1/12-horsepower motor is used. After driving through the proper gearing, it drives the second large worm gear at the right, which moves the 500-ton telescope.

To move the telescope from one observation point to another, a higher speed is convenient. For this purpose a two-horsepower motor is needed, which drives the first large worm gear. This motion is called "slewing" and moves the telescope at the rate of one revolution in eight minutes. An automatic mechanism also is provided which slows down or speeds up the tracking motor to compensate for repeated errors such as atmospheric refraction, deflection of the mounting, etc. The instrument just in front of the operator is the automatic dome control mechanism, which keeps the opening in the dome always in front of the telescope.

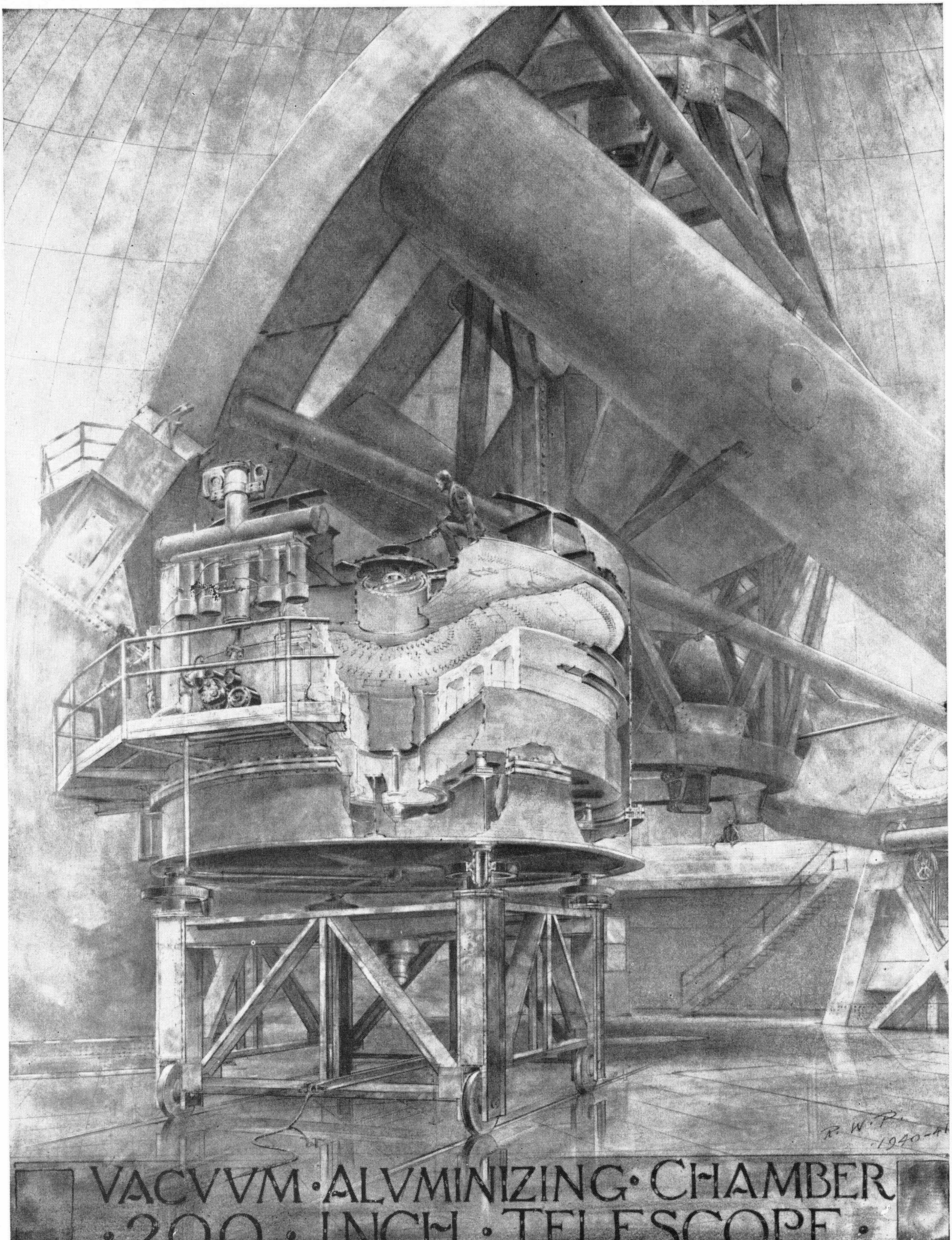

POLAR
SLEWING
2 HP SLEWING MOTOR
RIGHT ASCENSION DRIVE & COMPVTOR
R. W. PORTER 1941
TWO HVNDRED INCH TELESCOPE

ALUMINIZING BELL JAR

To REMOVE the 200-inch mirror for recoating its surface, a truck running on railroad rails is moved directly underneath the telescope. Jacks at the four corners lift the truck platform into contact with the mirror cell, and the bolts holding the cell to the tube are removed. The jacks are then lowered and the truck, cell and mirror are moved away from the mounting, so that the bell jar (hung from the crane above) may be lowered and bolted to the truck table.

The drawing shows the jar and parts of the mirror and cell cut away, exposing the tungsten coils suspended from the ceiling. On each coil are hung several pieces of aluminum wire. Each coil is energized individually from hand-controlled contacts above to evaporate the aluminum wire, which will condense evenly on the surface of the mirror. The evacuating pump system is shown on the left side of the jar. On completion, the different movements described above are reversed, and the mirror carefully returned to the telescope.

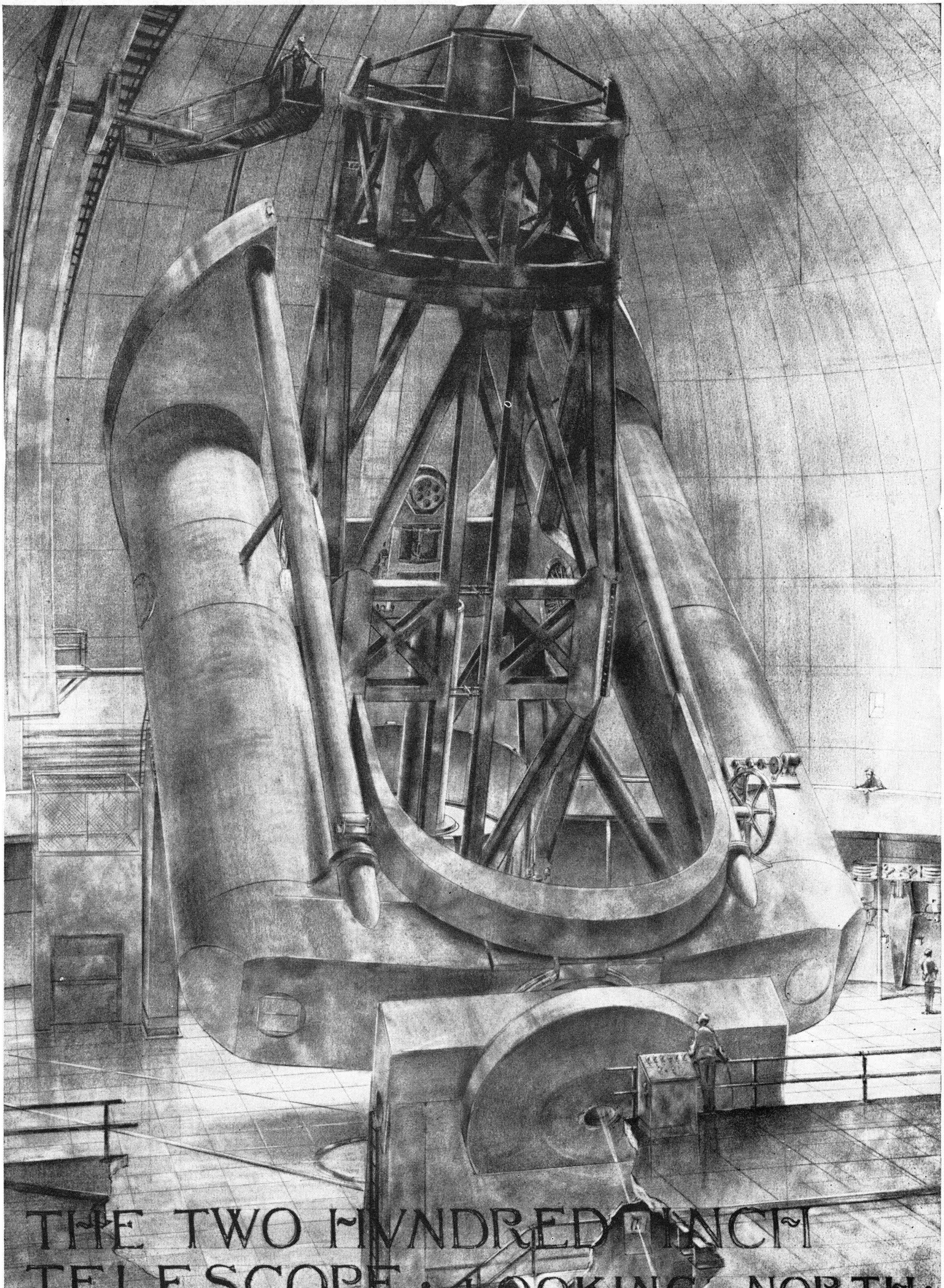
Aluminum is used as a reflecting surface because, for most wave lengths, it has a higher reflecting power than silver, and its loss of efficiency due to tarnish is much less than that of silver.


R. W. P.
1940-41
VACVVM · ALVMINIZING · CHAMBER
· 200 · INCH · TELESCOPE ·

LOOKING NORTH

The 200-inch telescope as it would appear to an observer situated some hundreds of feet south of the instrument. This view shows well the slit extending the length of the south wall of the telescope tube. This opening is required to permit the light beam from the coudé diagonal to reach the f-30 focus through the hollow south polar axis bearing, shown in the lower part of the drawing. The horseshoe-shaped member seen resting on the yoke carries a small mirror (not shown) that bypasses, or detours, the beam around the lower part of the telescope when pointing to areas close to the north pole of the heavens.

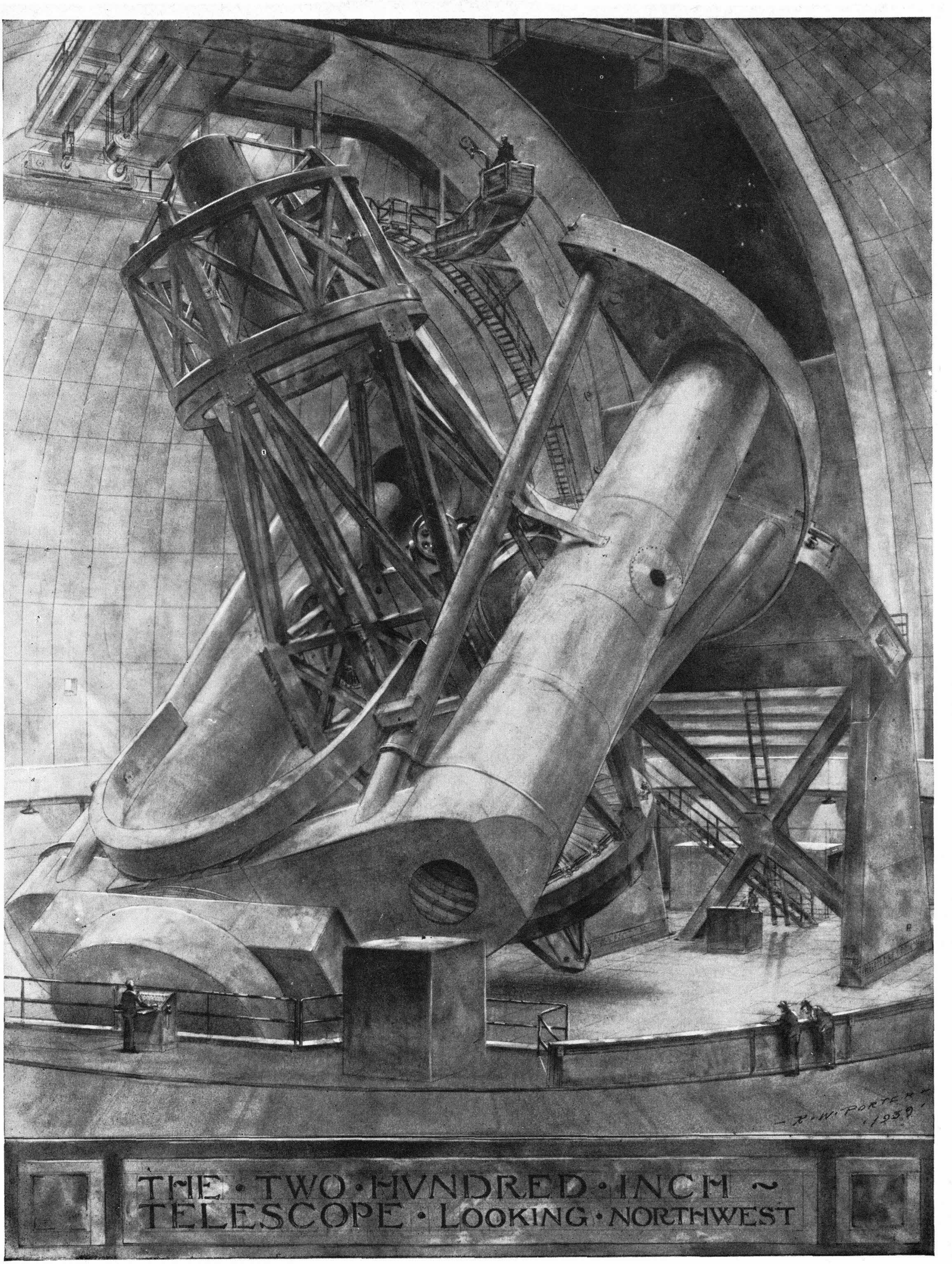
The cutaway near the bottom of the drawing shows the light beam coming down the polar axis into the coudé room.


THE TWO HUNDRED INCH
TELESCOPE · LOOKING NORTH ·
R. W. PORTER
1938

LOOKING NORTHWEST

Another view of the instrument looking northwest. The upper edge of the drawing shows a part of the 60-ton crane attached to the dome, and immediately below is seen the platform by means of which the astronomer may reach the prime focus cage in any position of the telescope.

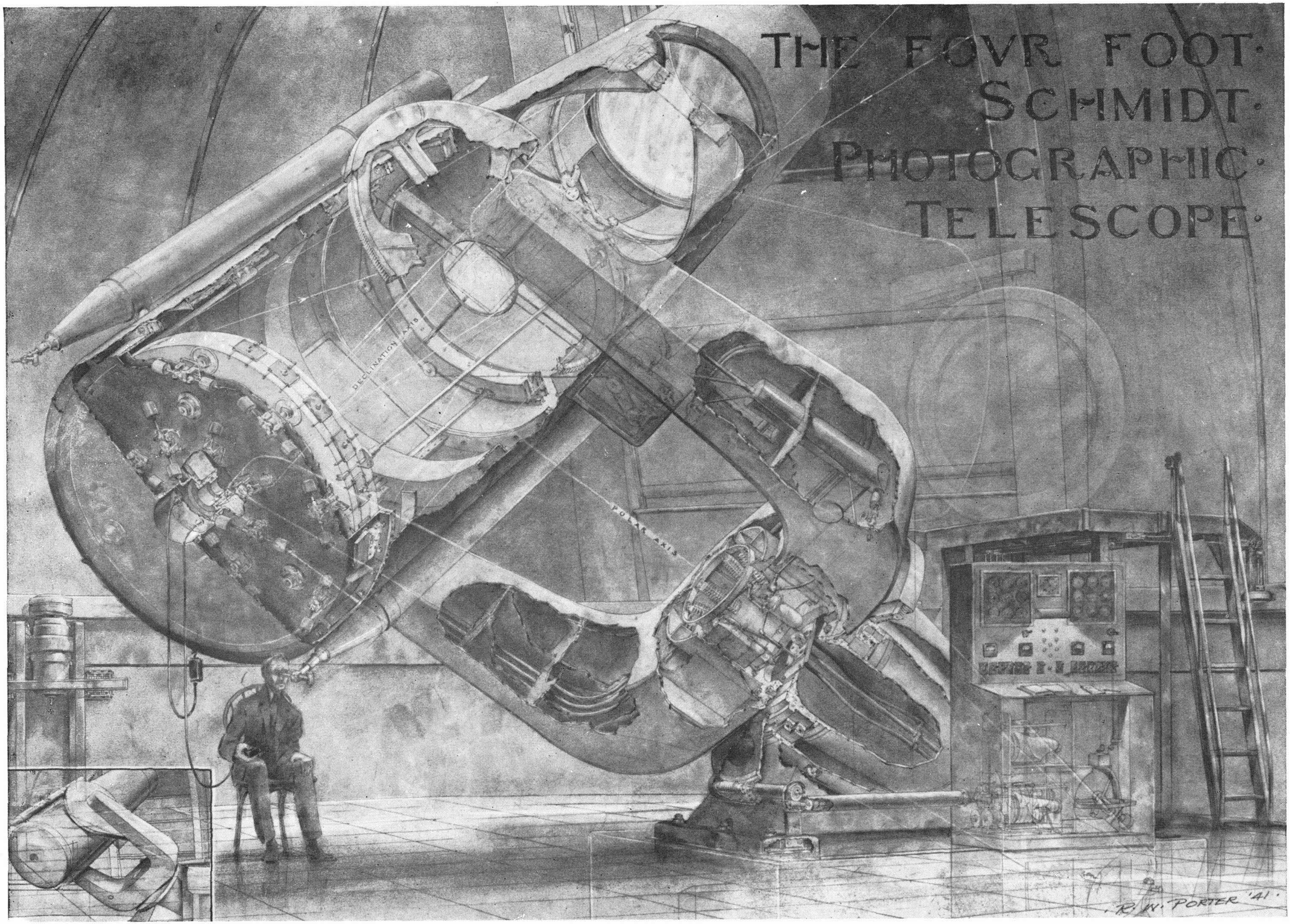
The operator at the lower left is standing at the mirror control "pulpit." Here are located the controls which operate the Cassegrain and coudé mirrors, depending at which focus the astronomer has decided to observe. The box structure in the foreground is the top of the passenger elevator shaft. In the background the canvas windscreen may be seen part way up the shutter opening.


R·W·PORTER
1939
THE·TWO·HUNDRED·INCH ~
TELESCOPE·LOOKING·NORTHWEST

THE 48-INCH SCHMIDT TELESCOPE

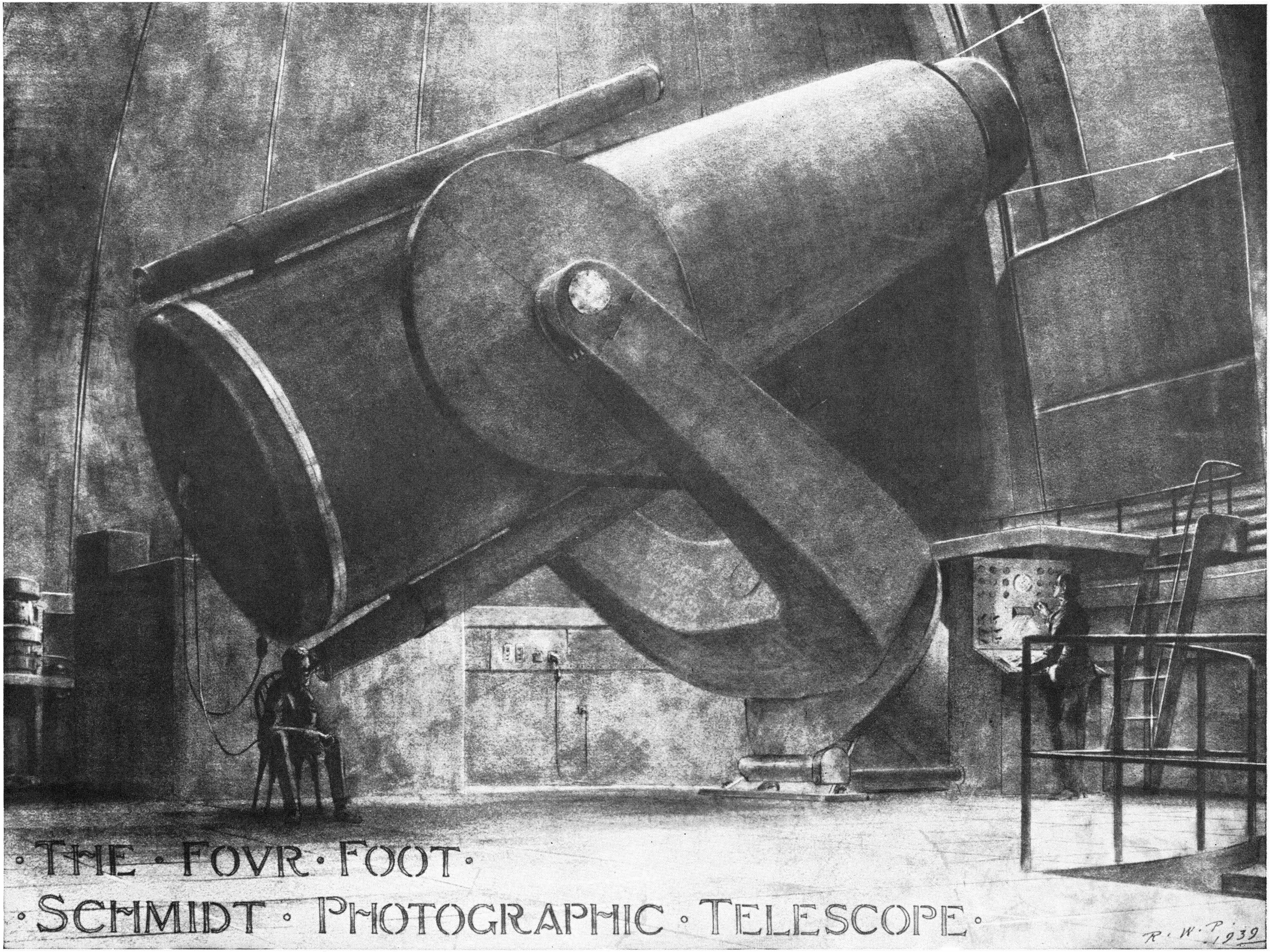
ONE of the chief advantages of the Schmidt telescope is that it covers a larger area of the sky compared to the ordinary reflecting telescope. Most large telescopes cannot cover more area of the sky than is occupied by the full moon. The 48-inch Schmidt on a single photograph can cover an area of the sky approximately equivalent to 250 full moons. Another advantage is its speed. The 48-inch operates at f-2.5, which makes it faster than the 100-inch (f-5) and the 200-inch (f-3.3), and therefore requires less exposure time. The disadvantage of the Schmidt, however, is its short focal length, which means that the images are smaller than those made by the larger telescopes.

The 48-inch Schmidt, as shown in the cutaway drawing, has a 72-inch mirror at the bottom of the tube. In order to cover a wide angle of the sky, the mirror must have a spherical surface. A spherical mirror, however, will not focus parallel light; therefore a correction is made before the light reaches the mirror. This is done by a 48-inch diameter, 3/8-inch thick "lens" or Schmidt plate, as it is called, at the top of the tube. The light is refracted or bent slightly as it passes through the glass, so that, after being reflected from the spherical mirror, it is brought to a sharp focus on a 14-inch square photographic plate halfway up the tube. The optics for the 48-inch Schmidt were ground and figured by Don Hendrix of the Mount Wilson Observatory. The focal length is 120.9 inches.


THE FOVR FOOT·
SCHMIDT·
PHOTOGRAPHIC·
TELESCOPE·
DECLINATION AXIS
POLAR AXIS
·R·W·PORTER '41·

FOLLOWING A STAR

THIS is an external view of the 48-inch Schmidt telescope showing the method of guiding the instrument. The astronomer is following a star through one of the 10-inch refractors. His assistant is at the control desk which houses the right ascension drive and the refraction correction instrument similar to the one used for the 200-inch telescope. The desk also contains the device which keeps the shutter opening of the dome always in front of the telescope. The canvas wind screen is shown part way up the shutter opening. The dome drive (1¾-horsepower) shown at the left is of the same type as that used on the 200-inch dome. The diameter of the dome is 45 feet. The moving part of the telescope weighs 20 tons and is driven at tracking rate by a 1/25-horsepower motor. For fast motion a 1/3-horsepower motor is used. The platform at the right is for installing a 48-inch grating in front of the Schmidt plate. This will cause every star image on the photographic plate to become a short spectrum of the star. The enclosure behind the astronomer is a photographic dark room.



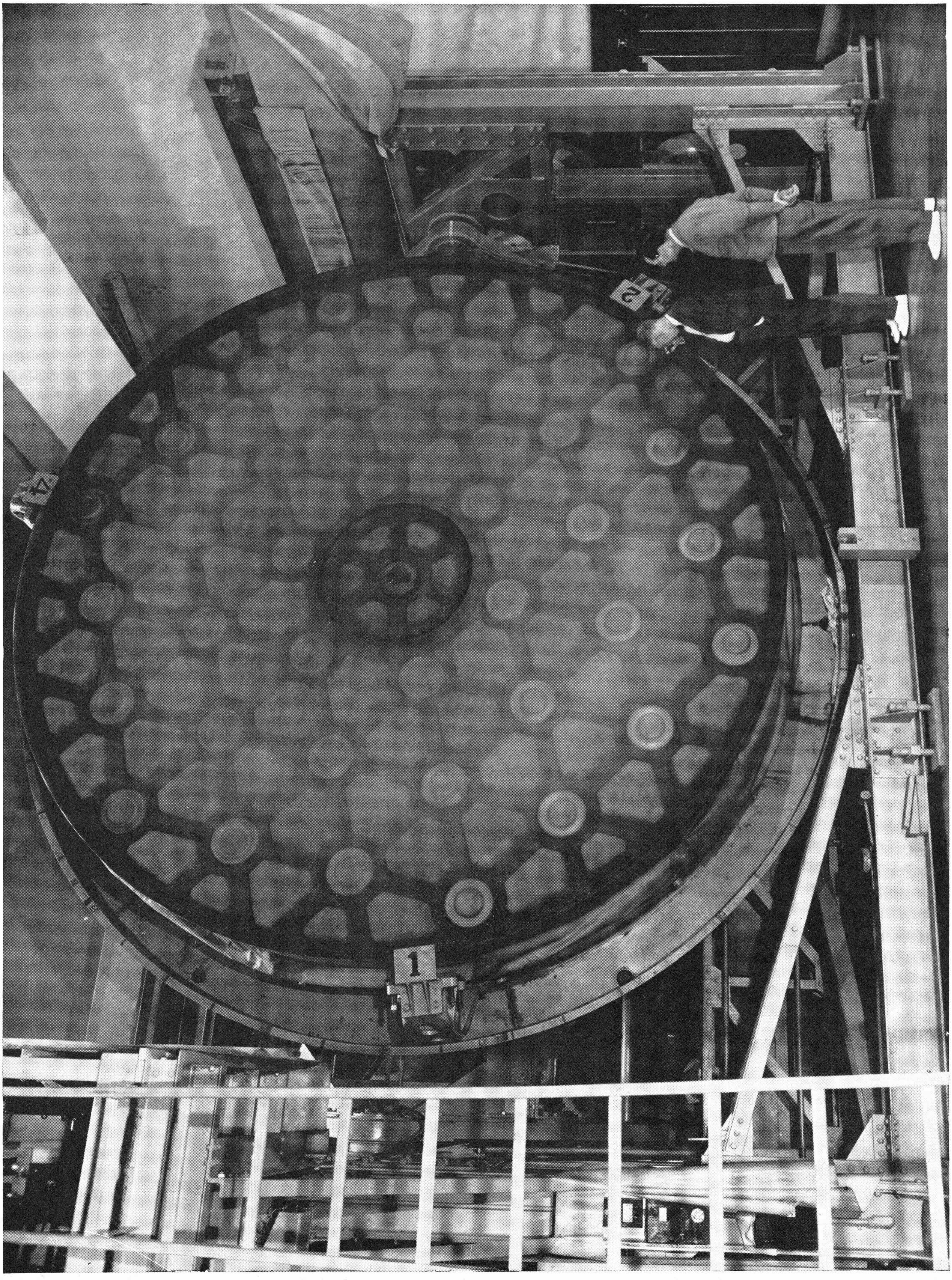
· THE · FOVR · FOOT ·
· SCHMIDT · PHOTOGRAPHIC · TELESCOPE ·
R · W · P. 1939

200-INCH MIRROR ON ITS GRINDING MACHINE

California Institute of Technology in Pasadena

THE mirror is shown tilted up to its testing position. The ribbed pattern of the back is visible through the polished surface. In this photograph, the curved surface is being examined by Dr. J. A. Anderson, who had the responsibility of guiding the polishing and "figuring" operations to such a delicate degree that the surface over the entire face of the mirror is within one or two millionths of an inch of a true paraboloid, with a focal length of 666 inches. Looking on behind him is Marcus H. Brown, director of the group of opticians who performed the exacting tasks.

The Pyrex mirror is about two feet thick at the edge and weighs 14¾ tons. It was cast with a ribbed back to allow it to adjust itself more quickly to night temperatures. In the center of the mirror is shown a 40-inch diameter Pyrex plug. It was cemented there only for the grinding and polishing operations and was removed before the mirror was placed in the telescope. The polished surface of the mirror is coated with a thin bright coating of pure aluminum as shown on page 37.


1
2
4

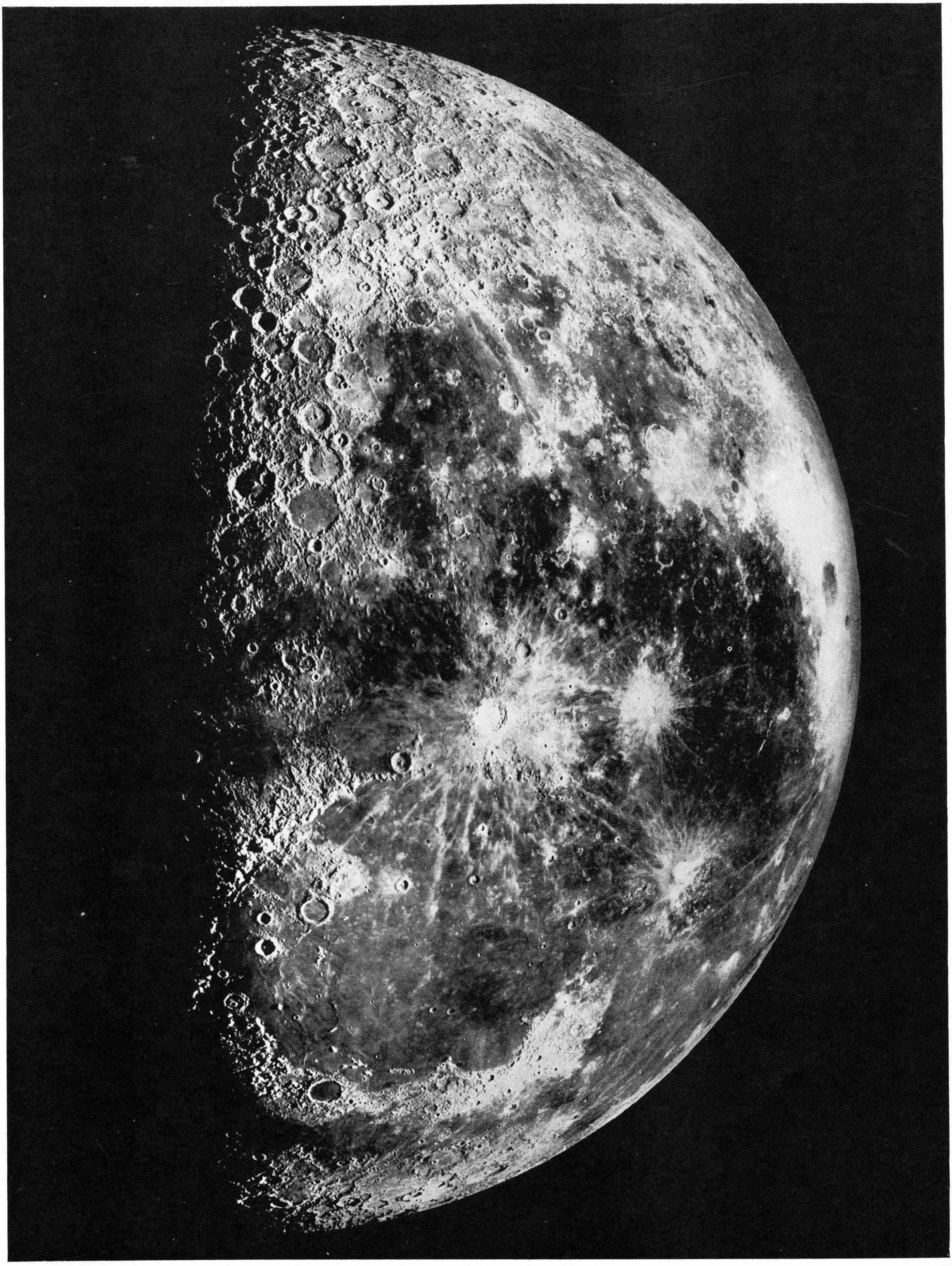
THE MOON

Photographed with the 100-Inch Reflector, Mt. Wilson Observatory

OUR nearest astronomical neighbor is the moon. It circles the earth once in a little over twenty-seven days in a path that is slightly elliptical. Therefore, its distance from us is not always the same: It varies from 222,000 to 252,000 miles. In its travels around the earth, the moon keeps the same side toward us all the time. Man will never see the other side of the moon unless he makes a trip around it in a space ship. If he were to land on the moon, he would find himself in a very strange and desolate land. The diameter of the moon is only 2,160 miles—a little over one-fourth that of the earth. Its gravitational force is one-sixth of ours, so that an object weighing six pounds on the earth would weigh only one pound on the moon. Because there is no air or water on the moon, there can be no vegetation. The moon is also a silent world since sound is carried to our ears by our atmosphere. Sound waves could, however, travel below the surface, through the structure of the moon itself.

The blanket of air around the earth not only carries sound but also protects us from the direct rays of the sun during the day and from the intense cold of outer space at night. Without such a blanket the temperature at the equator of the moon rises to 230 degrees Fahrenheit during its two-week long day. During its equally long night, it drops below 200 degrees Fahrenheit below zero.

When reference was made to an atmosphere on the moon, we had in mind one which is capable of supporting life, similar to that with which we are familiar here on earth. The presence of a very thin atmosphere, however, has been a subject of much controversy. Many observers have reported the presence of a slight fog on the floor of some of the craters during a lunar sunrise. This fog is reported to have obscured details on the floor, which came back into view when the fog was evaporated by the sun.



A CLOSE-UP OF THE MOON

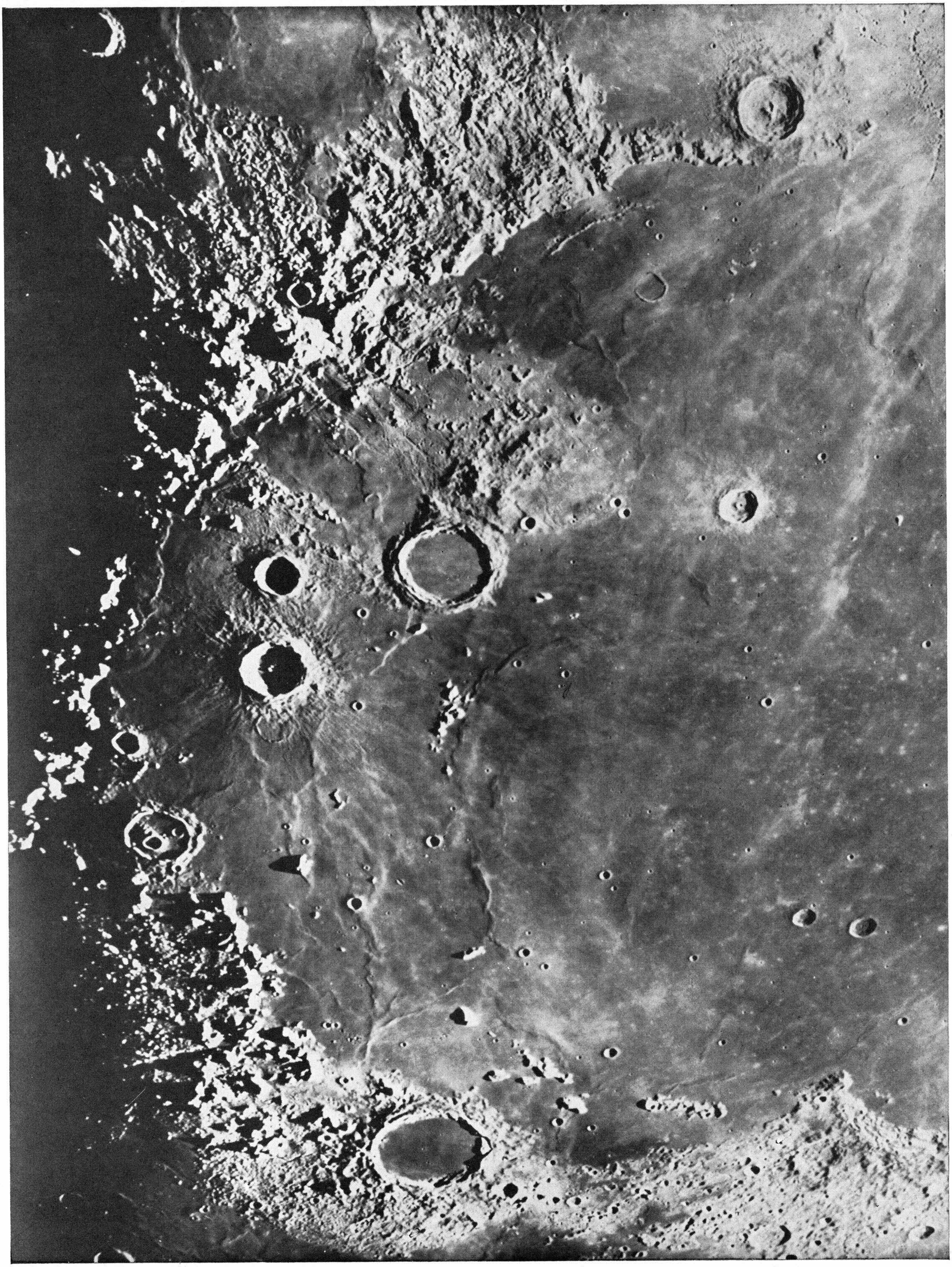
Photographed with the 100-Inch Reflector, Mt. Wilson Observatory

THE major part of this photograph is occupied by the 750-mile-long Mare Imbrium, largest of lunar plains. Bordering Mare Imbrium at the upper left, the moon's finest mountain range, is the Appennines, 400 miles long. This range contains peaks up to 20,000 feet high and ends at the crater Eratosthenes. This crater is about 38 miles in diameter and the lowest part of its floor is almost 9,000 feet below the surface outside. A mountain may be seen rising from its floor.

The large crater in the center of the photograph is Archimedes, 50 miles in diameter, with walls 4,000 feet above the interior plain. To the left of Archimedes is the deep crater Autolycus, about 25 miles in diameter, with walls 9,000 feet above the interior. Just below Autolycus is the crater Aristillus, about 35 miles in diameter, with walls rising to 11,000 feet on the left edge. In its center is a mountain with two of its peaks just catching the sunlight. About 100 miles below Aristillus is the lone mountain peak Piton, rising abruptly from Mare Imbrium to a height of 7,000 feet.

Heights of these mountains are obtained by a simple application of trigonometry. First the length of the shadow is carefully measured. Then, knowing the angle of the sun with the moon at that instant, trigonometry will solve the right-angle triangle, giving the height.

Bordering Mare Imbrium at the lower left, are the Lunar Alps, 180 miles long and containing peaks up to 12,000 feet high. The Alps end at the great walled plain of Plato, seen at the bottom of the photograph. Plato is 60 miles in diameter, and its walls rise to 3,500 feet above the interior.



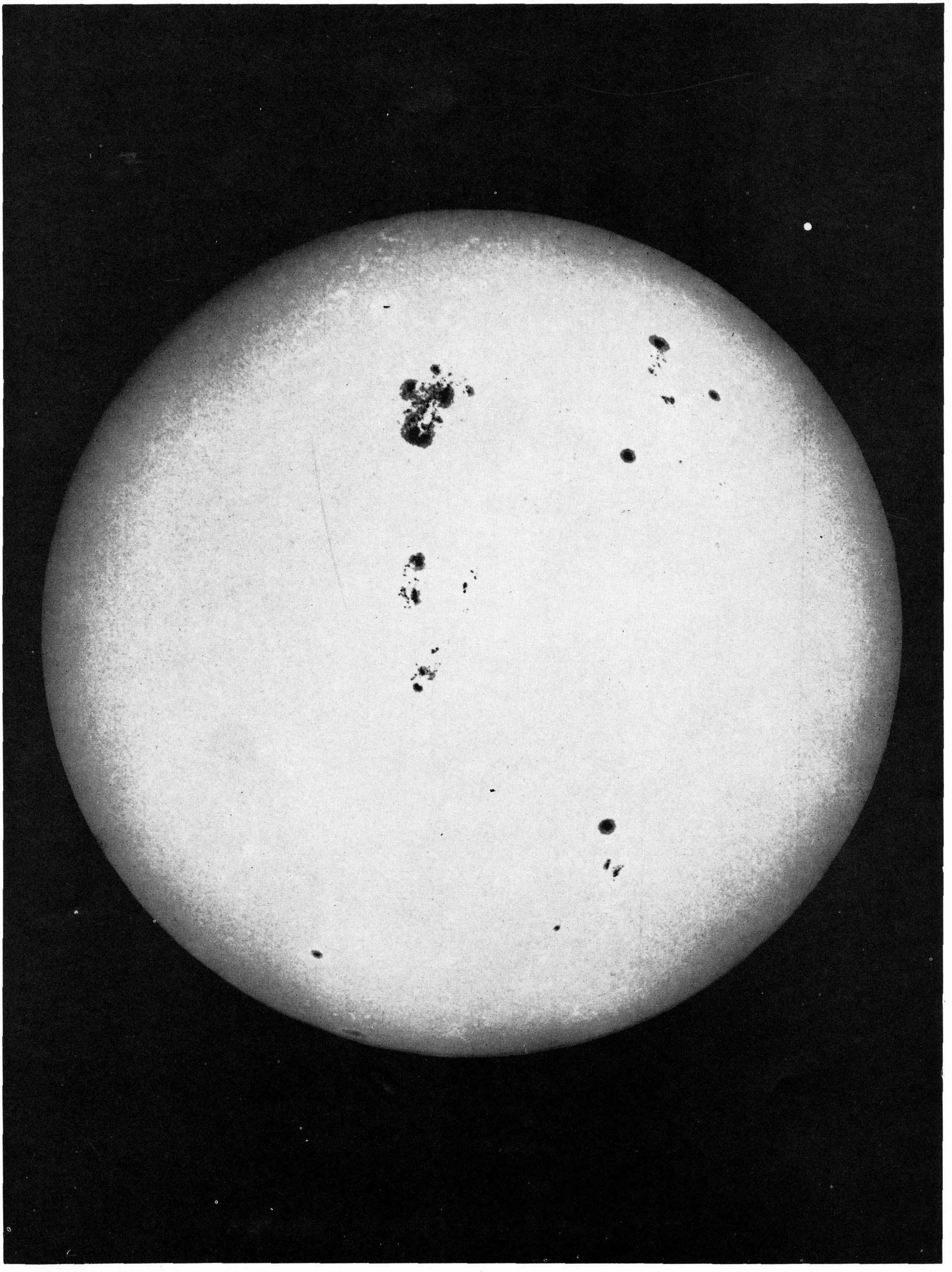
A DIRECT PHOTOGRAPH OF THE SUN

Made with the 60-Foot Tower Telescope, Mt. Wilson Observatory

Our sun is a star, and not a large one at that. Its effect upon the Earth is so much greater than that of other stars because, astronomically, the sun is very close to us. Its distance is about 93,000,000 miles. Because stars are so much farther, astronomers do not use the mile to denote their distances. Their unit is the light year, or the distance light travels in one year at the rate of approximately 186,000 miles per second. This distance amounts to the staggering total of 5,870 billion miles. At that rate it takes light about eight minutes to come to us from the sun, while it takes over four years to get here from our nearest star, Alpha Centauri.

When you go out on a dark night and look up at the stars, what you see are thousands of suns. Some of them are like our sun. A great many are larger and brighter. For example, the bright star, Betelgeuse, in the constellation of Orion, has a diameter of 215 million miles compared to that of 865,000 miles for our sun. In other words, if our sun were placed in the center of Betelgeuse, the orbit of the Earth would be engulfed within the giant star. It shines with a light equal to 1,600 of our suns, yet it appears only as a star because it is so far away that it takes light 210 years to reach us.

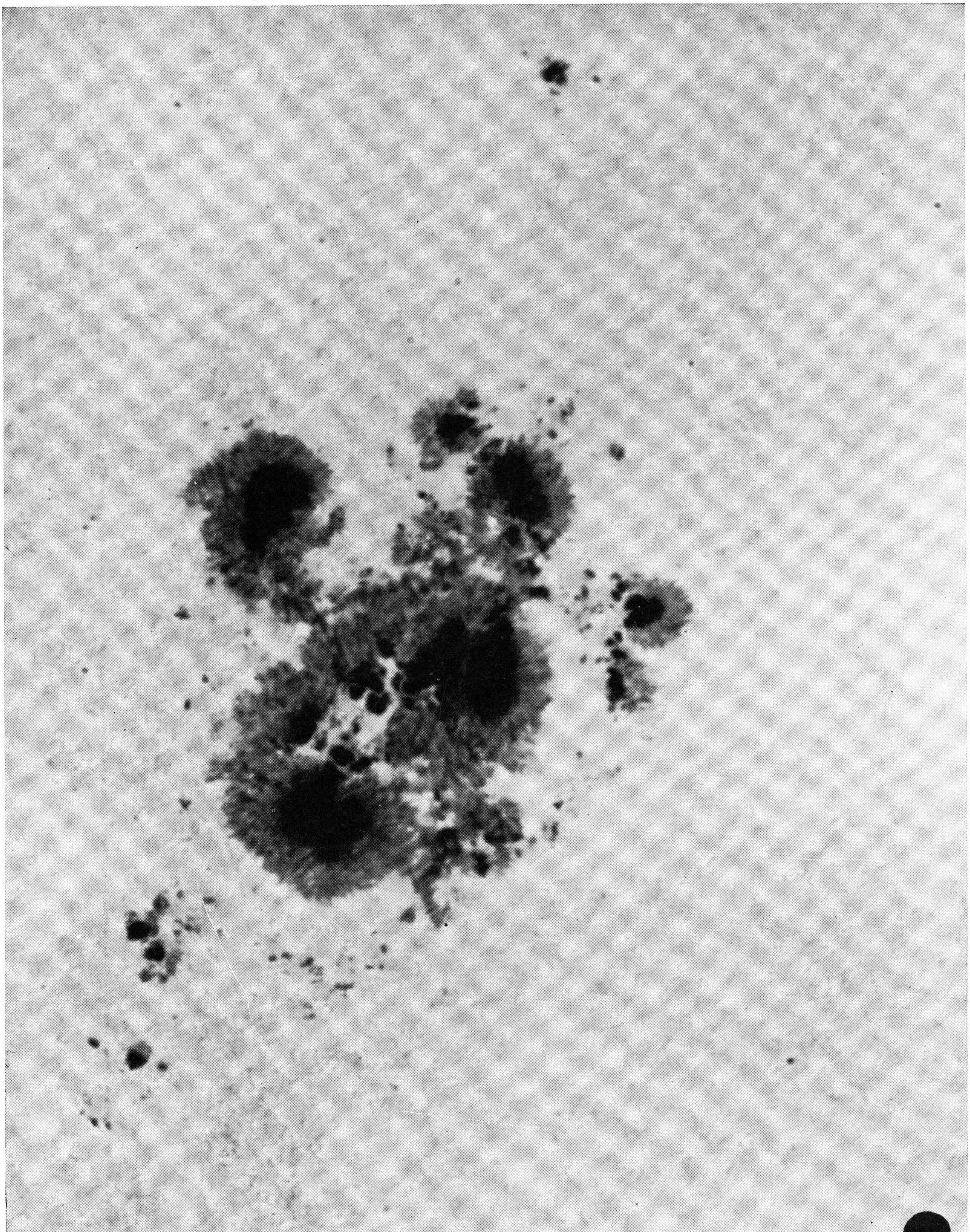
The surface or photosphere of our sun is about 10,000° F. It is made up of giant clouds of hot gas thousands of miles across. These clouds constantly rise to cool, and fall back, to be replaced by others. Spots that appear on the surface are constantly changing in size and number. They follow roughly a cycle from a maximum number to a minimum, with an average period of a little over 11 years from one maximum to another. This photograph shows the sun spot maximum of August 12, 1917. The white spot near the edge of the sun represents the Earth on the same scale.



SUN SPOTS CLOSE-UP

This is a close-up of a group of spots, shown on the preceding photograph. It was taken a few days earlier, on August 8, 1917. The central dark area, or umbra, of the spots may be as much as 2,000° C. cooler than the sun's surface. Spots are thought to be caused by disturbances below the surface, which cause the gas to spiral upwards like a giant cyclone. Due to the whirling motion, the gas expands and cools at the center. Spots may appear singly or in groups. The size of this group is indicated by the black dot at the bottom, which represents the Earth on the same scale.

Sun spots are accompanied by magnetic storms strong enough to affect the Earth. These storms are not to be confused with electrical storms such as lightning, but are disturbances which affect radio and telegraphic communications. The total amount of energy received by the Earth from the sun, however, is not affected very much by the sun spots. The amount of increase in energy due to sun spots is probably less than two per cent. However, the change may be large enough to produce slight overall weather variations on the Earth. The total amount of energy received by the Earth from the sun is staggering when compared to the amount which man is able to produce. If converted to units with which we are familiar, each square mile of the earth's surface receives over 4,000,000 horsepower. If all the energy received by the Earth were converted at the low rate of one cent per kilowatt hour, it would be worth more than $400,000,000 per second. This is only the amount received by the Earth. To find the total amount of energy radiated by the sun one would have to multiply this figure by more than 2,000 million.



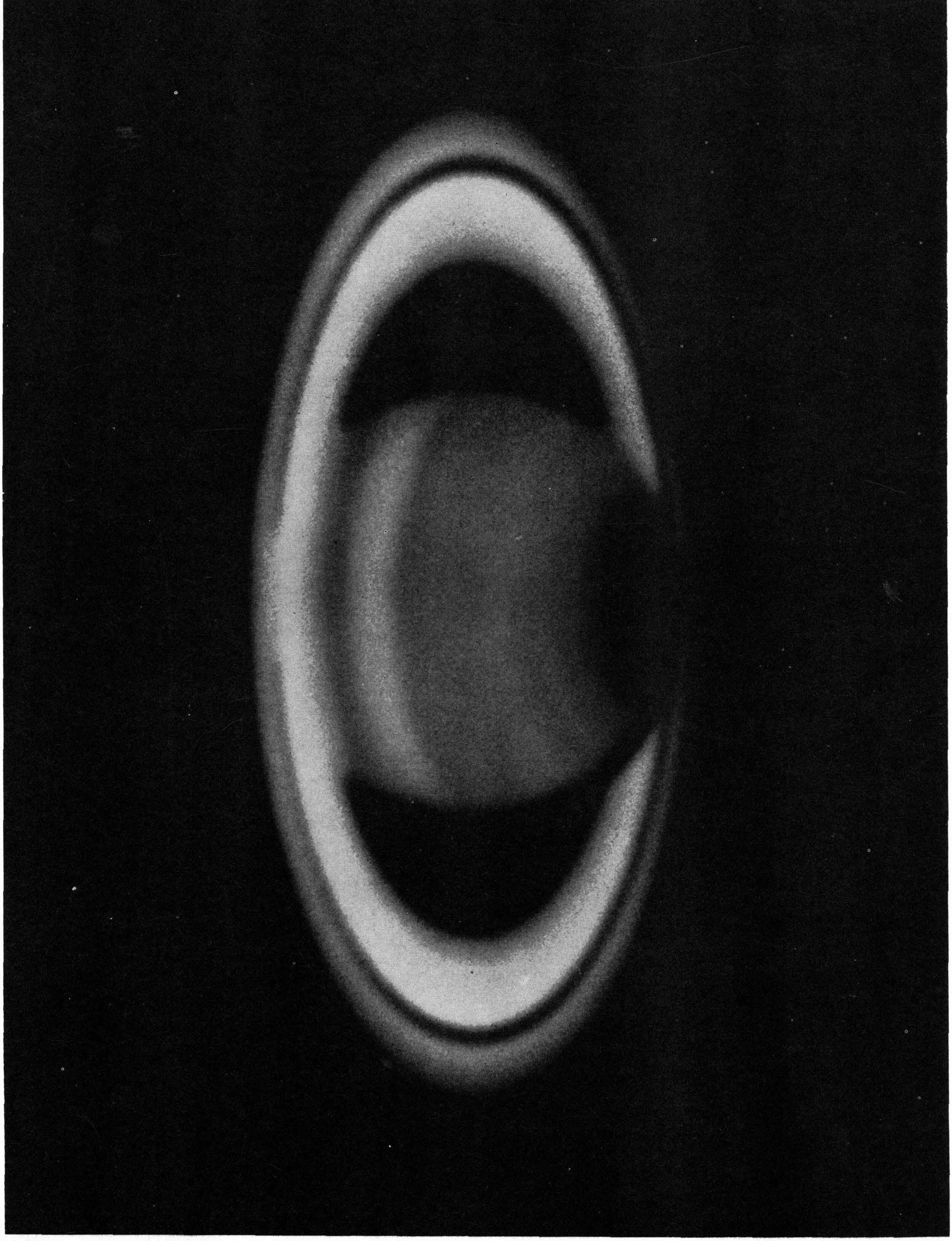
SATURN

Photographed with the 100-Inch Reflector, Mt. Wilson Observatory

SATURN is the second largest of all the planets. It has a mean diameter of 72,000 miles. Its average distance from the sun is 886,000,000 miles, but it travels in an elliptical path, so that this distance may vary as much as 100,000,000 miles. It takes 29½ of our years for Saturn to make one trip around the sun. Its day is only ten hours and fourteen minutes long. This rapid rotation causes a bulge at the equator so that the diameter through the poles is only 66,300 miles.

Saturn is constantly obscured by a layer of clouds, similar to those of Jupiter, except that they are more even in shade and less variable. At the equator we usually find a light yellowish band, while the pole is covered by dark greenish tinted clouds.

Saturn is the only planet surrounded by rings. At the equator of the planet are three distinct rings, concentric and in the same plane. The outer ring extends to a diameter of 171,000 miles, while the distance from the inside of the inner ring to the cloud surface of the planet is about 7,000 miles. The thickness of the rings is probably not over ten miles. If we were to construct a model of the rings, so that the thickness is represented by the thickness of a sheet of newspaper, the diameter would have to be over four feet. The rings are not solid. They are believed to be composed of small particles, all circling the planet like tiny moons.



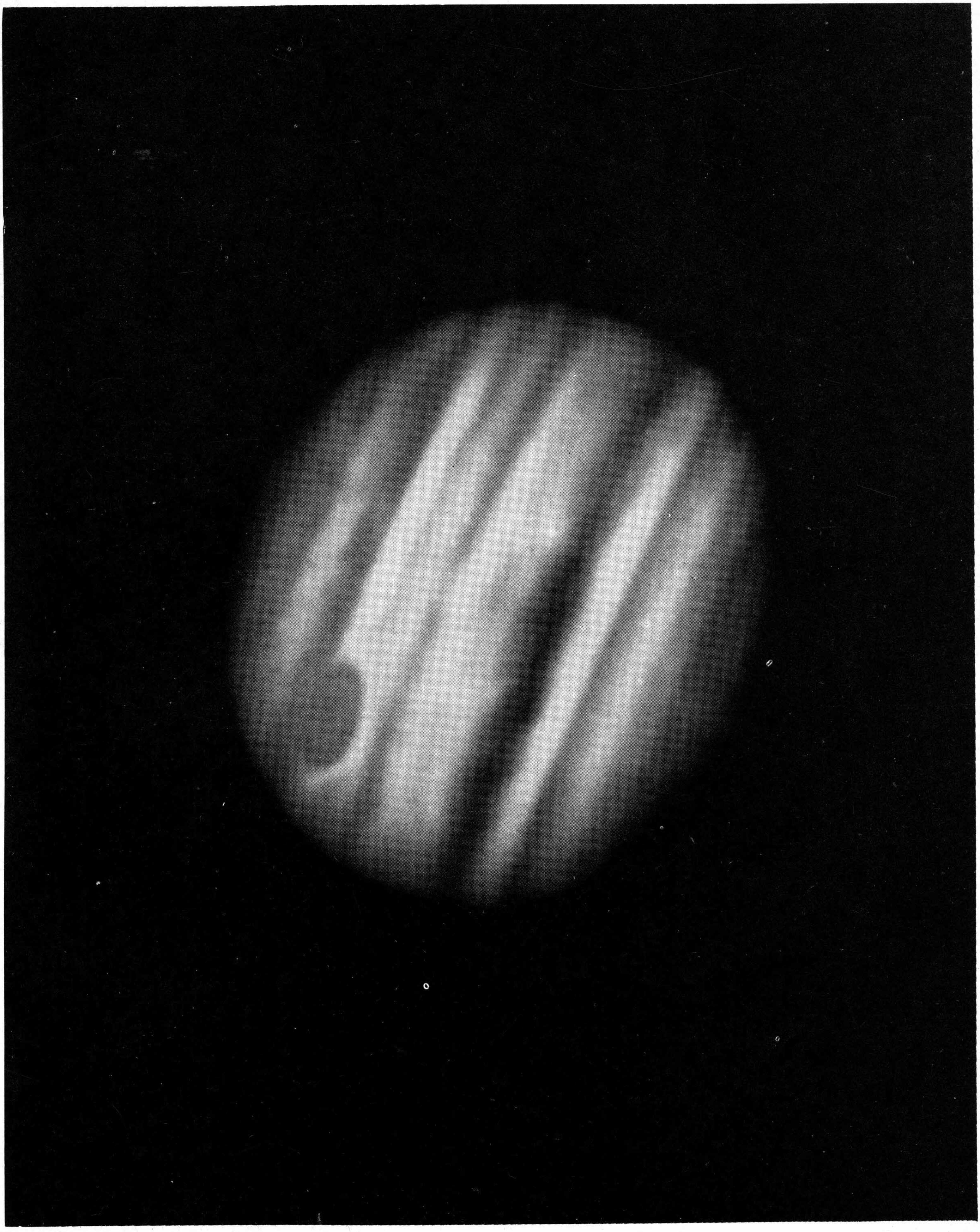
JUPITER

Photographed with the 200-Inch Telescope, Palomar Observatory

JUPITER is the largest planet in the solar system. In fact it is larger than all of the other planets put together. Its mean diameter is about 88,600 miles. Its average distance from the sun is about 483,000,000 miles, but it circles the sun in an elliptical path so that the distance may vary as much as 47,000,000 miles. Its year equals 11.8 earth years, but its day is shorter than that of any other planet. It is only 9 hours 55 minutes long. This fast rotation, coupled with its large diameter, creates a high centrifugal force at the equator, so that its diameter at the equator is 6000 miles longer than the diameter through the poles.

The markings we see on the planet are cloud bands and are therefore constantly changing. We have never been able to see the solid surface of Jupiter. There are markings visible to us however which are more permanent than the cloud bands. The most conspicuous is the great red spot, visible in the photograph as an elliptical darkened area. It was discovered in 1878 and was then measured as being 30,000 miles long and 7,000 miles wide. It has since become gradually less conspicuous and more round in shape.

Measurements have shown that nearly all radiation received from Jupiter is reflected sunlight, which would indicate the planet has very little internal heat. If such is the case, the surface temperature may be as low as —140° centigrade due to its great distance from the sun.



THE TRIFID NEBULA IN SAGITTARIUS

Photographed with the 200-Inch Telescope, Palomar Observatory

Our galaxy is estimated to contain approximately 100 billion stars, yet its overall dimensions are so large that the distance between the stars is measured in light years. The spiral arms of our galaxy extend more than 50,000 light years from the center. Our sun is but a small star in this multitude, about 30,000 light years from this center. Besides stars, our galaxy contains tremendous clouds of gas. Some are illuminated by bright stars nearby or within them, and some are dark and opaque, shutting off light from stars beyond. This photograph of the Trifid Nebula is an outstanding example of both kinds. The dark streaks are opaque nebulæ in front of the luminous material. It is 1900 light years away and about 16 light years in length. The energy to illuminate the bright part is furnished by a triple star within the nebula.

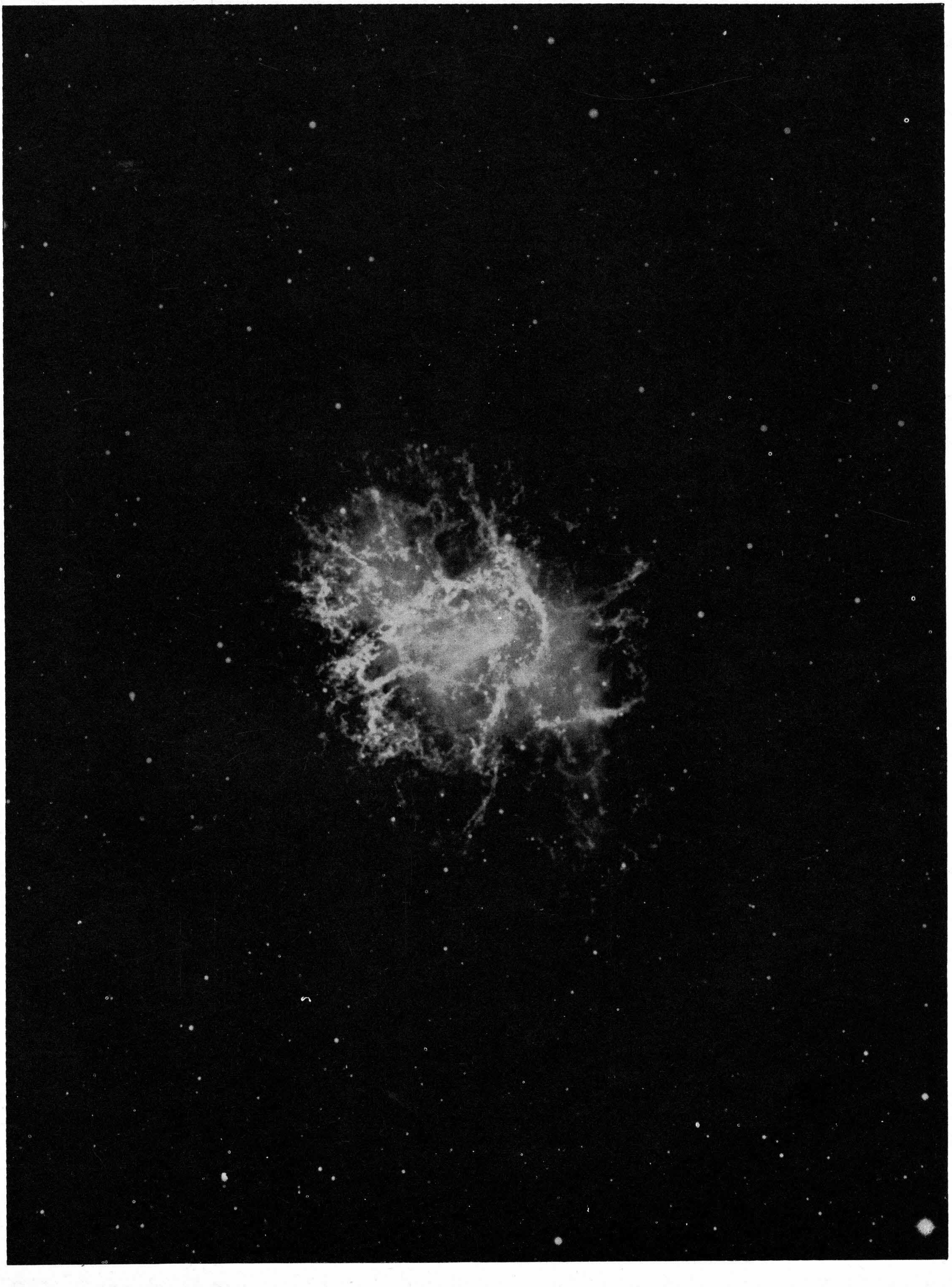
These objects when viewed through a telescope are observed to be a pale green, which is due to two green lines in their spectrum. Astronomers thought for a time they had discovered a new element, since the lines did not appear in the spectrum of any elements on Earth. They called it *Nebulium*. Later, however, Dr. Bowen, now director of the observatories on both Mt. Wilson and Palomar, proved that the lines were caused by the element oxygen under strange conditions of pressure and temperature. The pressure is so low we cannot attain it in our laboratories.

THE CRAB NEBULA, M-1

Photographed with the 200-Inch Telescope, Palomar Observatory

CERTAIN types of stars have been observed to undergo terrific atomic explosions which are known as "novae." These stars are usually hotter and more dense than the average. Some of them undergo repeated explosions, and others merely fluctuate in brightness. Some of these explosions are so violent that most of the material comprising the star are thrown out in all directions with such force that it never returns. It continues out into space in the form of a nebulous envelope, becoming thinner as it expands until it becomes too rarefied to be seen.

The crab nebula shown here is one of this type. Most of them appear more like elliptical discs, brighter at the rim. However, this one is more filamentary than the average. Astronomers have measured the velocity of expansion and found it to be over 800 miles per second or about 70 million miles per day. At this rate, calculations show that the explosion should have occurred about nine hundred years ago. Investigations revealed that the Chinese had recorded a new star at this point in the sky in 1054 A.D. It was reported as having appeared almost as bright as Jupiter. The crab nebula is about 4100 light years from the earth, which means that the explosion actually occurred about five thousand years ago.

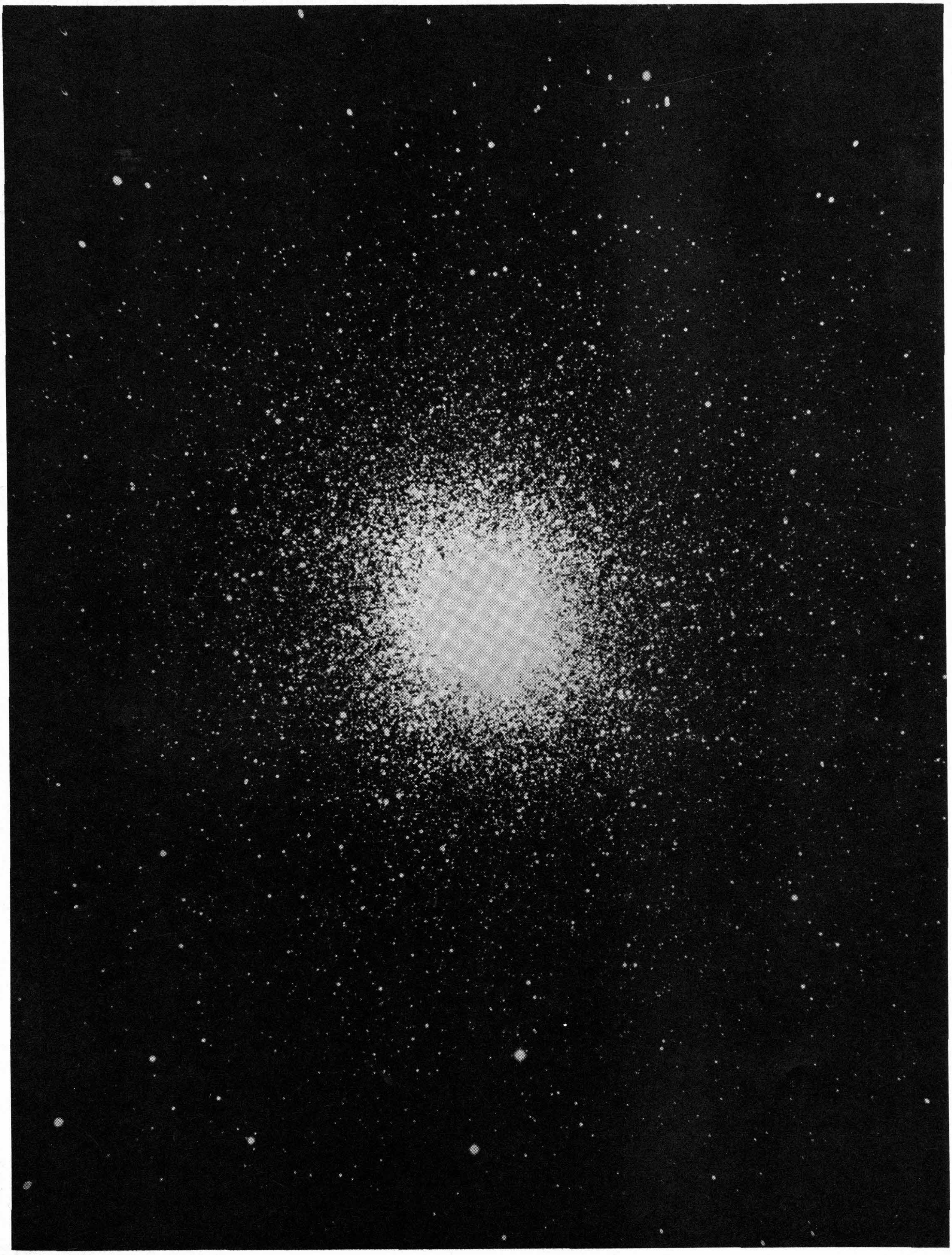


THE GREAT STAR CLUSTER IN HERCULES

Photographed with the 200-Inch Telescope, Palomar Observatory

SOMETIMES the stars in our galaxy are found concentrated into great clusters like the one shown here in the Constellation of Hercules. About 100 such globular clusters are known to exist. Their distances from the Earth vary from 21,000 light years to almost 100,000. The Hercules Cluster M-13 is about 36,000 light years distant, and just visible to the naked eye. At that distance our sun would be so faint it would hardly register on the photographic plate.

These clusters are about 100 light years in diameter and are estimated to contain at least 50,000 stars as bright as or brighter than our sun, and an unknown but presumably larger number of fainter ones. If we are to consider these clusters as part of our galaxy, which they seem to be, then we would establish the diameter of our spiral at more than 100,000 light years.



ANDROMEDA, M-31

Photographed with the 48-Inch Schmidt Telescope, Palomar Observatory

As we look from the earth we see stars in all directions for many thousands of light years outside our solar system. Sometimes they are gathered in clusters, but usually they are scattered at random. In some places the stars are surrounded by nebulous material—dust and gas—sometimes bright from starlight, and sometimes dark and opaque. Eventually, however, the stars begin to thin out until there are no more, and we are looking out beyond the limits of our galaxy into empty space.

If we look far enough, we see other galaxies similar to ours. Looking through the constellation of Andromeda, which is made up of stars in our own galaxy, and beyond for some 2,000,000 light years, we see the great spiral shown here. This is the nearest galaxy to us and it is believed to be somewhat similar to our own in appearance and size. It is more than 100,000 light years in diameter and is composed of the same types of stars and star dust that make up our own spiral. The two patches of light are companions belonging to the Andromeda galaxy, but the stars scattered rather uniformly over the entire plate belong to our own galaxy and are therefore much closer to us.

SPIRAL NEBULAE IN URSA MAJOR, M-81, N.G.C. 3031

Photographed with the 200-Inch Telescope, Palomar Observatory

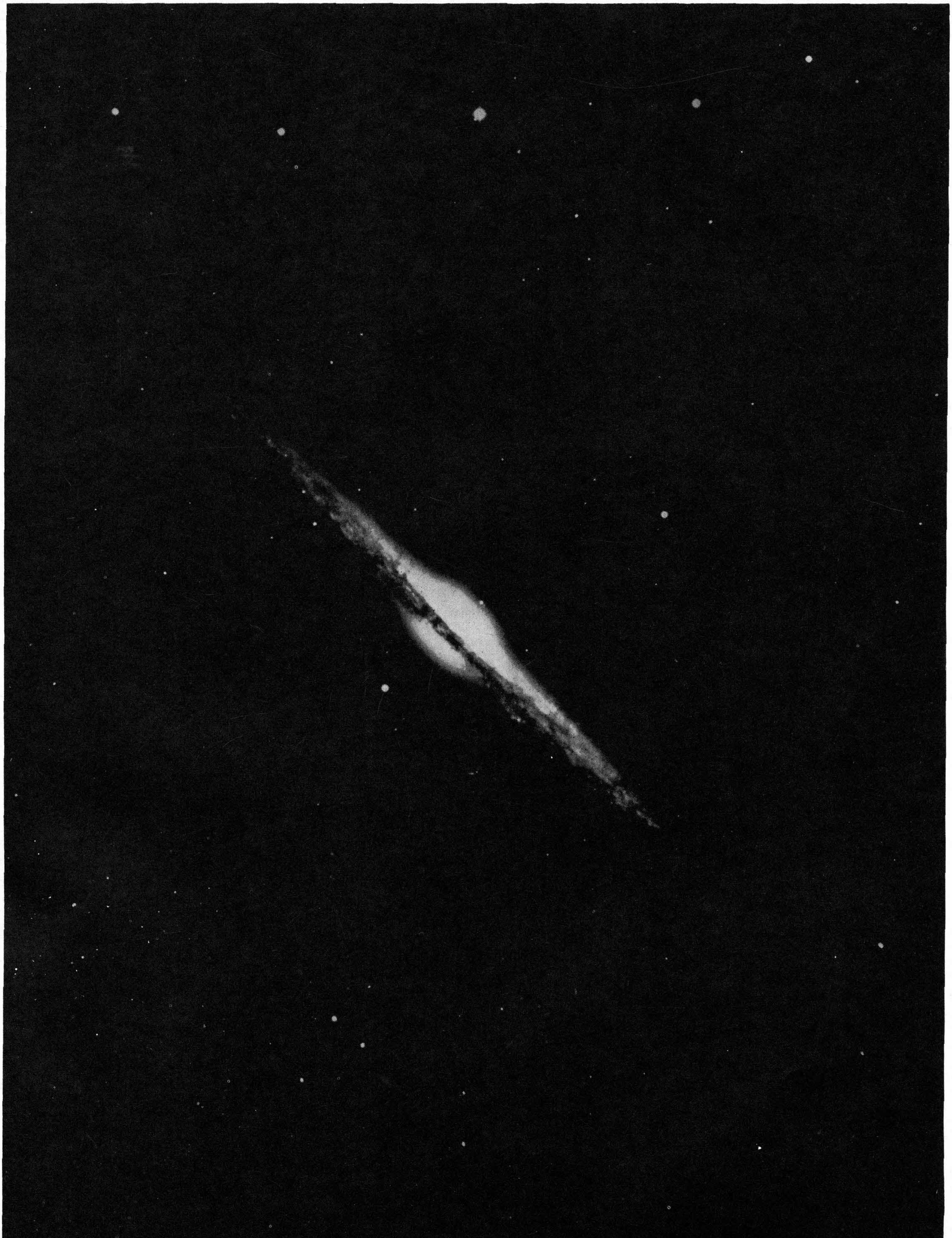
THESE objects were called nebulæ by early astronomers whose telescopes were too small to reveal their true nature. They are not nebulæ, but galaxies similar to ours. They may, of course, contain some nebulous material, but as a whole they are galaxies containing billions of stars. One-hundred million galaxies are estimated to exist within the reach of our present telescopes. They are separated on the average by two million light years of empty space.

M-81, shown here, is one of our next door neighbors, 8,000,000 light years away. A beam of light traveling approximately 186,000 miles per second would require 17,000 years to travel across this spiral, and then require another 8,000,000 years for its journey to the Earth. Therefore, as we look at this picture, we see it not as it is now, but as it looked 8,000,000 years ago. This is one of the spirals known to be rotating. Round spots dispersed over the entire photograph are images of stars in our own spiral and are much closer to us than M-81.

N.G.C. 4565

Photographed with the 200-Inch Telescope, Palomar Observatory

N.G.C. 4565 shows what the average spiral galaxy looks like when seen on edge. Galaxies are composed of billions of stars similar to our sun. They also contain tremendous gas and dust clouds. Some of these clouds are bright by the light and energy induced from nearby stars, while others are dark and opaque. This photograph of N.G.C. 4565 shows some of these dark clouds on the outer rim being silhouetted by the bright nucleus of stars. Its luminosity is equivalent to about 400 million suns. It is twenty million light years from the earth and is traveling away from us at the rate of 735 miles per second.



HORSE HEAD NEBULA IN ORION (See Back Cover)

Photographed with the 200-Inch Telescope, Palomar Observatory

THE term "empty space" is in reality a misnomer, since the space between stars is inhabited by vast clouds of dust and gas. The clouds are very thin: In fact, here on earth we would consider them a good vacuum. Their size is so large, however, that the total amount of dust and gas between the stars would probably weigh more than all of the stars put together.

The majority of these clouds are dark, and some are opaque. If a star happens to be in the cloud then it will appear as a bright object. If the star is a cool one, we will see the cloud by reflected light from the star. If the star is very hot, a great deal of energy will be radiated in the ultraviolet part of the spectrum. The absorption of this energy causes the cloud to fluoresce and radiate its own light.

The Horse Head Nebula is an example of dark and opaque cloud silhouetted by the bright cloud behind. Its distance from the earth is about 900 light years.