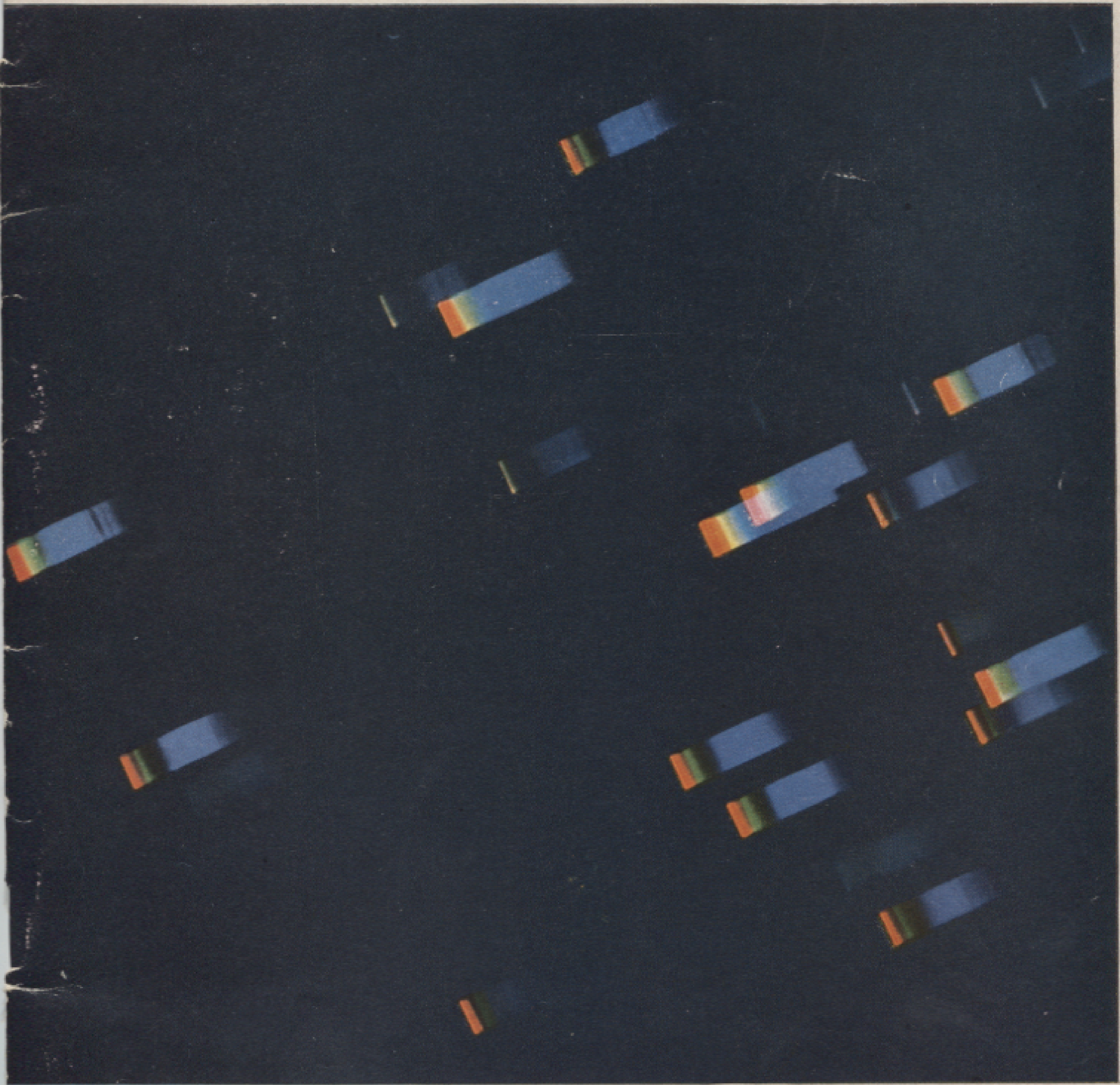
SCIENTIFIC AMERICAN



SPECTRA OF STARS

FIFTY CENTS
75 CENTS OUTSIDE THE AMERICAS

December 1950

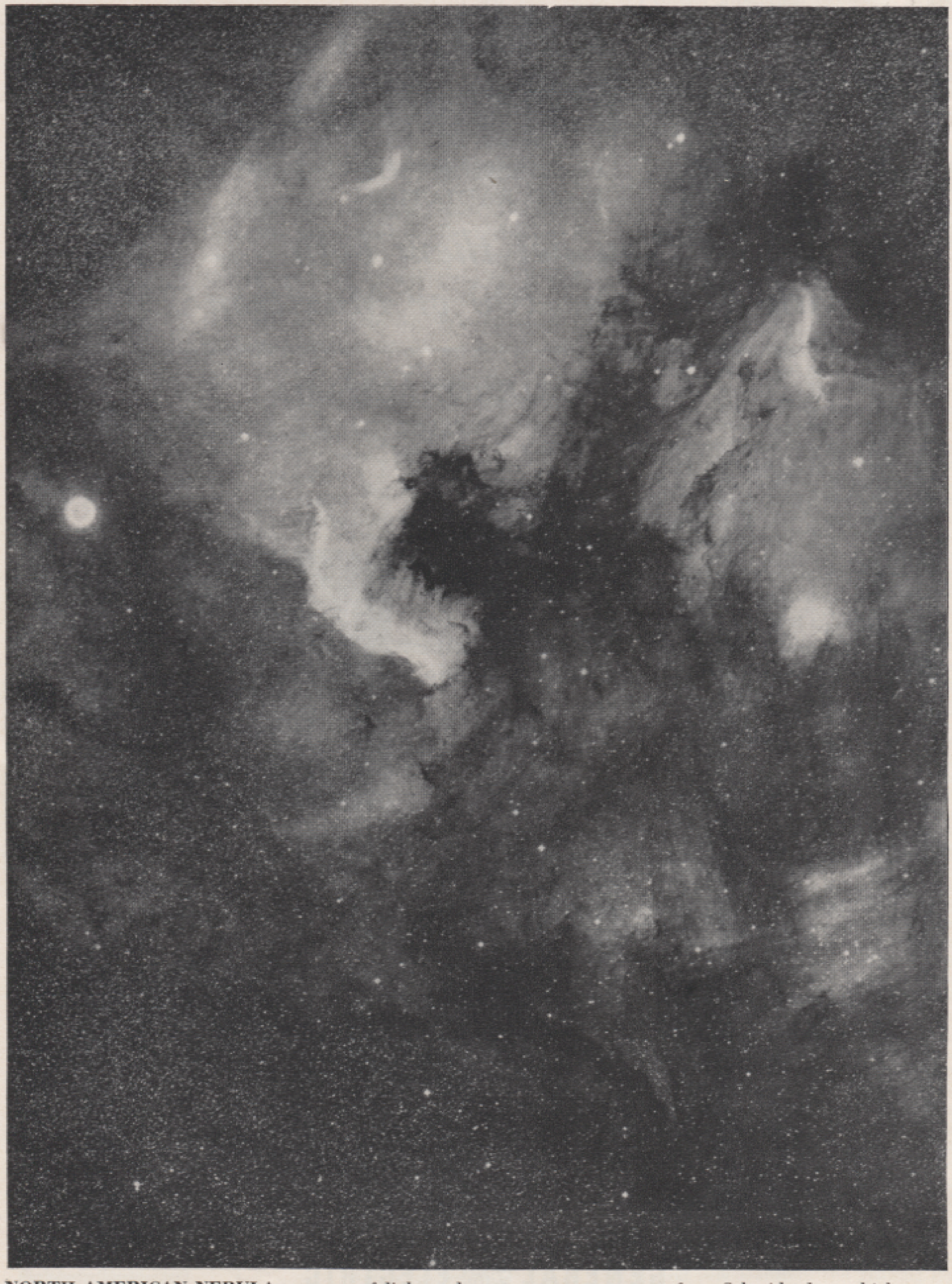
SCIENTIFIC AMERICAN

Established 1845

CONTENTS FOR DECEMBER 1950 VOL. 183, NO. 6

ARTICLES

DEPARTMENTS



NORTH AMERICAN NEBULA, an area of light and dark nebulosity in Cygnus, is shown in unprecedented detail by a photograph from the 48-inch Schmidt. This represents a quarter of one Schmidt plate, which covers 44 square degrees. Photograph copyright National Geographic Society-Palomar Observatory Sky Survey.

THE BIG SCHMIDT

The wide, sharp field of the 48-inch telescope, now engaged in a survey of the entire sky visible from Palomar Mountain, complements the deep but narrow view of the great 200-inch

by Albert G. Wilson

THERE was a time when the only instruments an astronomer needed in the practice of his profession were a conventional telescope and a good clock. Today the problems astronomy is tackling are so intricate and diverse that an astronomer who set out to investigate them armed only with a traditional telescope would be a little like a naturalist setting out to collect whales and microbes with a butterfly net. The modern astronomer, concerned with such matters as the method of energy generation in stars, the relative abundances of the chemical elements in the universe and the distribution in space of fantastically far-off galaxies, requires a large array of special instruments, each designed for a particular purpose. His equipment nowadays includes such devices as photoelectric photometers, radio "telescopes," high-altitude rockets and devices for producing artificial eclipses of the sun. And the evolution of the optical telescope itself has produced a number of highly specialized forms.

Public attention has focused mainly on Palomar Mountain's giant 200-inch telescope. Not many people realize that the 200-inch is a specialist of a kind. It looks a billion light-years into space, but it gives us only a gimlet-eyed view; what it gains in penetration it loses in breadth of vision. Looking through such a telescope is like looking into a ball park through a nail hole in the fence.

The 200-inch is the culmination of the main line of development in classical telescopes. We have been building ever larger and more powerful instruments, reaching farther and farther into space but steadily narrowing our view. As a result we have in a sense been seeing less and less of the sky as a whole. At the farthest range of our more powerful telescopes less than two per cent of the sky has been photographed so far. Our present picture of the universe is based on a few long thin views of these remote regions and on what we know about the regions near us.

Obviously to get a comprehensive view of the universe we need a new type of telescope that can look both far and wide at the same time. The best answer to this need has been found in the large Schmidt-type photographic telescope. By an ingenious combination of mirror and lens it can photograph the sky at once to great depths and over a wide field. This article will describe the largest instrument of this type now in existence—the 48-inch Schmidt on Palomar Mountain.

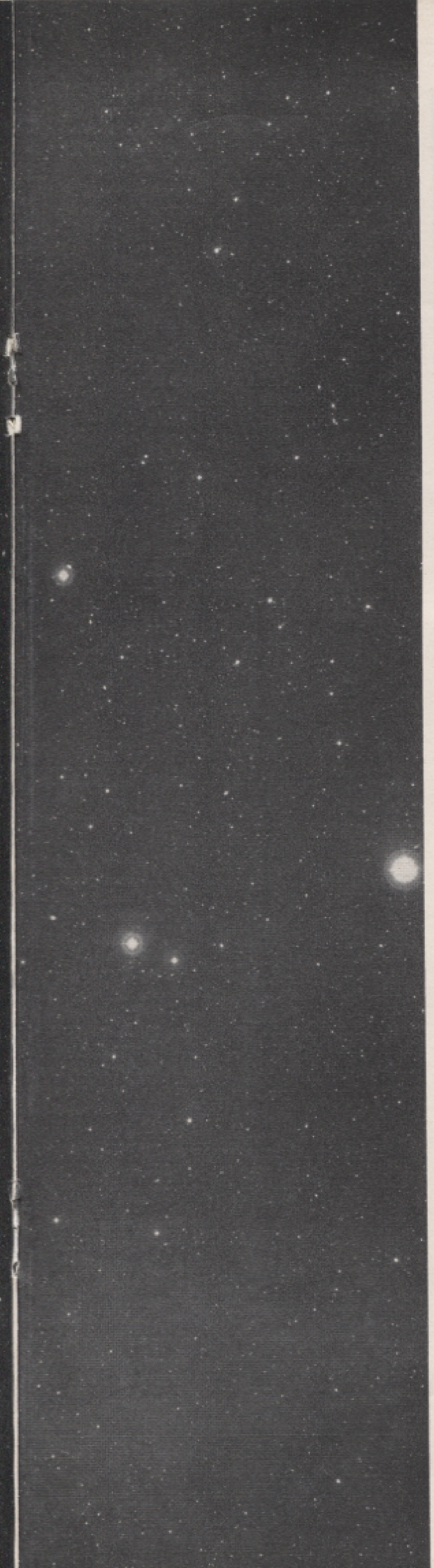
Aberrations

The main problem in designing a telescope to provide a wide field of view is to get rid of the optical aberrations or interferences with the quality of the image that are inherent in reflectors and refractors. One of these aberrations goes by the name of chromatism. It occurs in all lenses, and it is caused by the fact that the refracting lens splits the transmitted light slightly into its spectrum of wavelengths, thereby producing a colored fringe that makes the image fuzzy. Another fault, common to both lenses and mirrors, is spherical aberration, arising from the fact that the different zones of even a perfect spherical lens or mirror focus the light falling on them at different points; the result again is a hazy image. Other serious aberrations are astigmatism and coma. These defects, which affect only off-axis rays, are caused by unequal magnification of the different zones and become more serious as the angle of the ray with the axis increases, *i.e.*, toward the edges of the picture.

The history of telescopes is largely a history of the various devices used to remove aberrations. In the early telescopes, which were mainly refractors, chromatism was mitigated by using lenses with a very large focal length; this reduces the effects of differences in refraction of the various wavelengths. A telescope with a large focal length is, however, unwieldy. Later it was discovered that two or more lenses with different refractive indices could be used in combination to correct the color defects.

The largest modern telescopes are all reflectors, so chromatism is not a problem. But the large reflectors must still contend with the other aberrations. Spherical aberration is usually overcome by making the curve of the primary mirror a parabola rather than truly spherical. A parabolic reflector, however, possesses the off-axis aberrations, and it is these, principally the coma, which cause the trouble today. They are the principal reason why the modern large reflecting telescopes, though mighty in light-gathering power and ability to penetrate to great depths of space, have so narrow a field.

Several solutions have been proposed for the removal of the off-axis defects.



CLUSTER OF GALAXIES in Coma Berenices is photographed by both the 48-inch Schmidt (*left*) and the 200-inch (*above*). The three bright objects in the 200-inch plate, which shows the heart of the cluster, appear in the center of the Schmidt plate. On this one Schmidt plate some 8,000 galaxies have been counted, of which about a tenth belong to the cluster itself. The cluster is about 45 million light-years away; the large galaxy at the lower left on the Schmidt plate is three or four million light-years away. Note the sharpness of the images that are near the edge of the Schmidt plate and the distortion of the images that are near the edge of the 200-inch plate.

Small gains in the size of the field can be obtained by introducing a correcting lens near the focus; in the 200-inch such a lense increases the usable field from 2 minutes of arc to about 15 minutes (a quarter of a degree) of arc. Other systems, using two mirrors to free images of spherical aberration and coma, have made possible still larger fields. But the most radical and also the most successful design is that of the late Bernhard Schmidt of the Hamburg-Bergedorf Observatory in Germany.

Schmidt's Idea

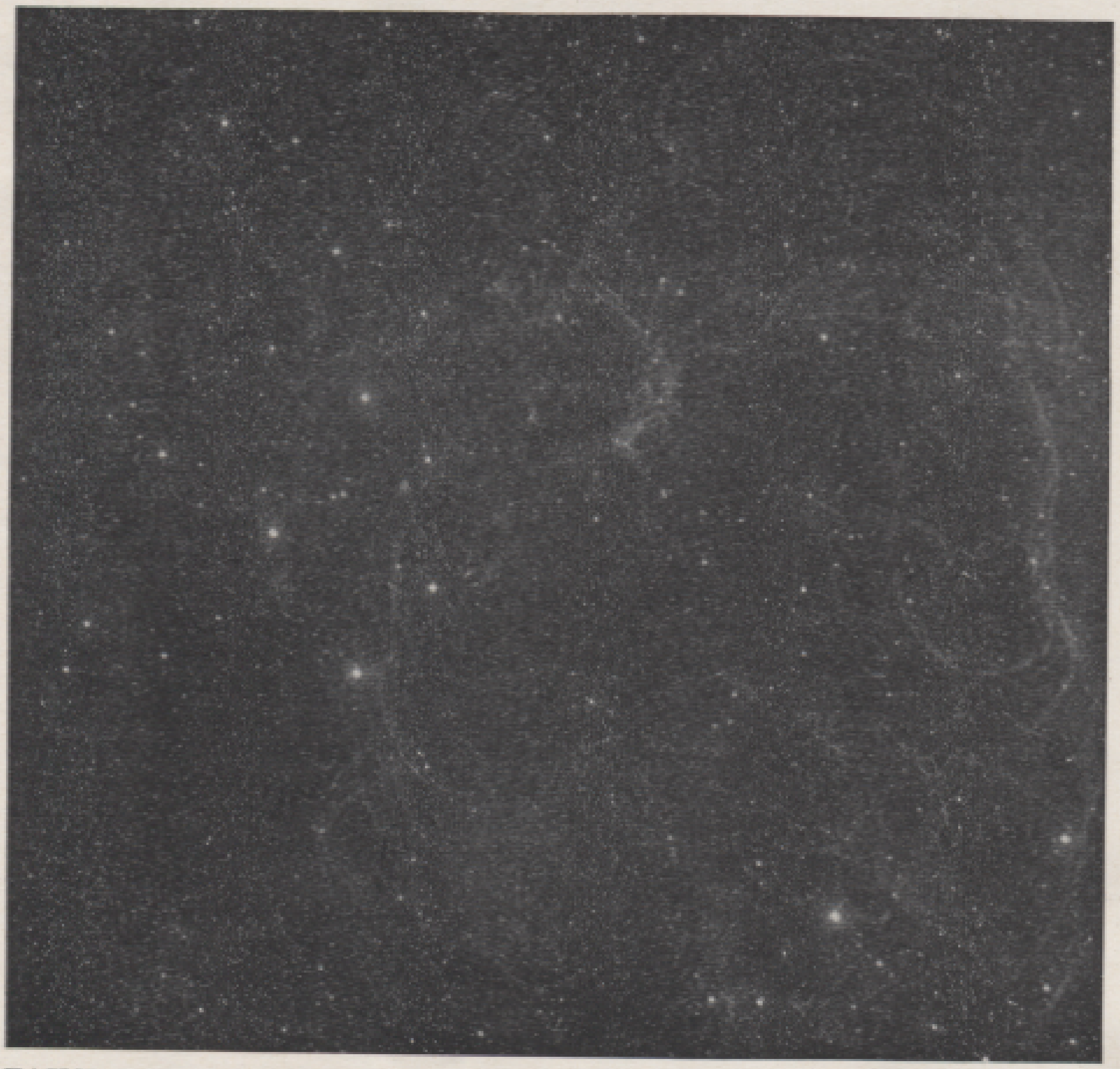
To rid the optical system of off-axis aberrations, Schmidt resorted to a revolutionary remedy: he did away with the axis. He decided to use a spherical mirror, because a sphere has no axis and no off-axis aberrations, and to try to solve the problem of spherical aberrations in a new way. He conceived the idea of altering the direction of the incident rays *before* they reached the spherical mirror in such a manner that after reflection they would be brought to the same focus by all zones. To effect this Schmidt designed a lens, properly called a correcting plate, which he placed out in front at the center of curvature of the mirror. This combination lens-mirror design removes both spherical aberration and coma and provides images of excellent definition over fields several degrees in diameter. Schmidt's system has the further advantage that it can be built with photographic speeds faster than $f/1$.

On the other hand, there are some disadvantages to the Schmidt system. One is that the picture is not focused on a flat plane but on a spherical surface. This means that the photographic plate must be bent to a spherical surface or that a third optical element must be introduced into the system to flatten the field. Further, the focal surface, where the photographic plate must be placed, is located about halfway between the mirror and the correcting plate—a not readily accessible position. In large Schmidts the problem of loading and unloading the plates can become a serious one. But all of these disadvantages are of little weight when compared with the great advantages of excellent definition, wide field and high speed.

It was the amateur astronomers who did much of the pioneering work with Schmidt cameras. Partly because of their valuable experiments on a small scale, it was soon realized that a Schmidt camera of large dimensions would be the ideal answer to the need for a wide-angle camera capable of photographing faint objects.

How large a camera of this type was it feasible to build? Schmidt's first camera, built in 1930, was an $f/1.74$ system with a 14-inch correcting plate and a

DWARF GALAXY near our own was discovered by the Schmidt. The galaxy is a very faint patch to the right of the bright star Regulus. Photograph copyright National Geographic Society-Palomar Observatory Sky Survey.



FAINT NEBULOSITY left by a supernova also was found by the Schmidt. The nebulosity is too large to be appreciated by the 200-inch. Photograph copyright National Geographic Society-Palomar Observatory Sky Survey.

17-inch mirror. North American observatories began to construct larger and larger models: the Palomar Observatory had one built with an 18-inch correcting plate and 26-inch mirror (18/26), the Warner and Swasey Observatory in Cleveland a 24/36, the Harvard College Observatory a 24/33, the Mexican National Astrophysical Observatory a 26/30. But it seemed that Schmidts much beyond this size might not be feasible.

There was no problem about getting a large mirror; successful mirrors with diameters up to 100 inches had been built. The trouble lay in increasing the size of the correcting plate. The Schmidt correcting plate, unlike a conventional lens, is very thin; on the average it has a thickness of the order of only one fiftieth of its diameter. Consequently as it is increased in size the elastic bending of the thin plate may become appreciable. Fortunately, however, the optical system is relatively insensitive to such deflections, and it is even possible to support the correcting plate at its center, so this factor is not a serious limitation on the plate's size. More serious is the fact that the correcting plate, like all lenses, is subject to chromatic aberration. It is possible, of course, to achromatize the system by employing two plates of different indices of refraction. But in large sizes this might be very difficult.

The Building of the 48-Inch

In 1938 the Observatory Council of the California Institute of Technology, the group responsible for the design and construction of the 200-inch telescope and its auxiliaries, decided that a large Schmidt-type camera would make an excellent auxiliary for the 200-inch. It was decided to build as large a Schmidt as could feasibly be constructed without the necessity of revolutionary modifications to overcome chromatism. Calculations showed that an *f*/2.5 camera with a 48-inch conventional correcting plate and 72-inch mirror would not introduce objectionable chromatism. In 1939 construction was begun on such a Schmidt for the Palomar Observatory.

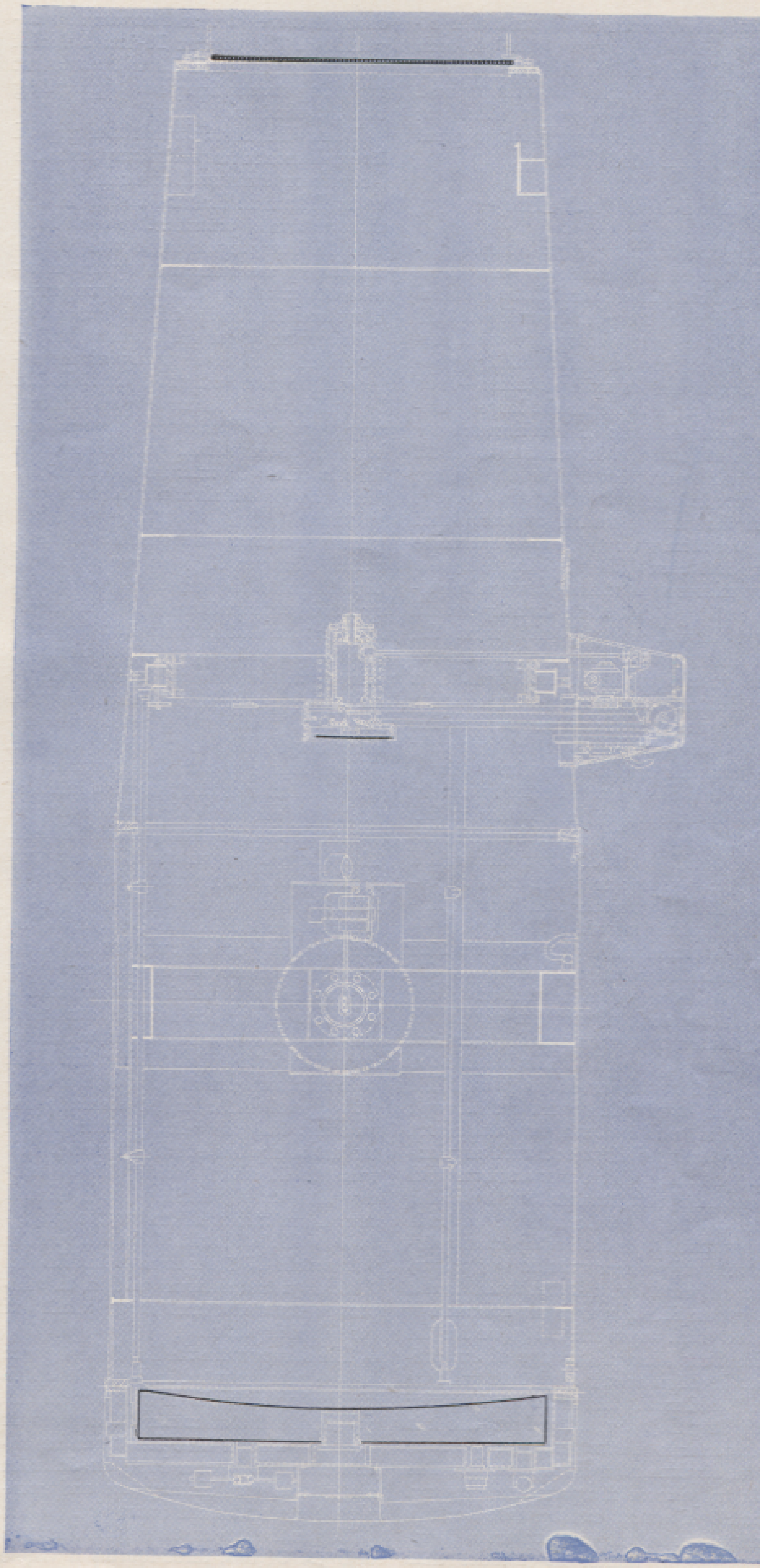
Overshadowed by its giant colleague, the 48-inch Schmidt attracted little attention. But its engineering and optics required the same sort of highly skilled techniques that were demanded for the 200-inch. The most exacting single item was the shaping of the large correcting plate. This pioneering piece of work was taken over by Don Hendrix of the Mount Wilson Observatory optical staff. Hendrix inspected a whole carload of plate glass before he found a piece sufficiently free of defects to make a useful blank for the correcting plate. He then devised tools and methods for grinding, polishing and testing the large plate and in only three months' working time succeeded in producing a correcting plate of excellent quality. Hendrix also shaped the spherical surface for the 72-inch Pyrex mirror. The remaining optical parts, including two 10-inch refractors used for guide telescopes, were made in the optical shops of the California Institute of Technology.

The telescope itself was manufactured in the Caltech machine shops and set up on Palomar in a dome about a quarter of a mile east of the 200-inch. The Big Schmidt, as it is called, consists of a tube 20 feet long in a fork-type mounting which allows the telescope to sweep all parts of the sky from the pole to as far south as declination minus 45 degrees. The combined weight of the fork and tube is over 12 tons. This whole assembly moves on two-inch ball bearings in the polar axis. The tube, partly cylindrical and partly conical and made of 5/16-inch welded steel plate, looks like a large mortar. The telescope shutter consists of two rotating shells located inside the tube behind the correcting plate. This construction allows the correcting plate to be removed or auxiliaries to be mounted without removing the shutters. The mirror and its cell are mounted at the lower end of the tube and are kept at a constant distance from the focal surface, regardless of temperature fluctuations, by means of three floating metal-alloy rods.

The telescope does not have positioning circles but instead employs Selsyn indicators which take their signals from declination and right-ascension gears and transmit the position electrically to the control desk. Other electrical features include automatic limit switches which stop the telescope four degrees from the horizon, automatic control of the dome's rotation and automatic regulation of the wind-screen height. The telescope is driven by a 1/25th-horsepower synchronous motor.

Two sizes of photographic plates are used in the camera: 10 inches square and 14 inches square. Since the plates must be bent to a spherical surface with a radius of 120 inches, to conform to the curved focal surface, they have to be very thin—less than one millimeter in thickness. The delicate glass plates are tested by bending beforehand to make sure they will not break in the telescope.

Construction of the telescope was finally completed in the autumn of 1948. The first tests showed that the telescope was much better than its specifications called for: the usable aperture of the correcting plate was actually 49.5 inches instead of 48. On 14-inch photographic plates the images were found to possess excellent definition over the entire field of 44 square degrees. The telescope is so fast that with 103a-O emulsion it reaches its limiting magnitude of 20.3 in about 12 minutes. This limit corresponds to the brightness of an average



BLUEPRINT OF THE SCHMIDT shows its three principal elements in black. At the top of the tube is the correcting plate. At the bottom is the mirror. At the center are the photographic plate and its loading assembly.

galaxy at a distance of 300 million light-years; in other words, the 48-inch Schmidt can "see" about one third as far as the 200-inch itself. So finally here was available a telescope of excellent quality that could photograph to great depths over a wide field.

The Schmidt's Big Project

The question now arose: What assignment should this great new instrument tackle first? There are three general types of job it is especially well qualified to do. One is to photograph wide, extended objects that an ordinary telescope can only sample piecemeal—such objects, for example, as the large galactic clouds of dark or luminescent gas called nebulosities. It was known that a few nebulosities covered several square degrees in the sky. Preliminary surveys with the new Schmidt revealed that some of them were much more extensive than had been realized. Moreover, the new telescope disclosed new nebulosities so large that their identity would never have been suspected from the knothole views obtained with conventional telescopes. The Schmidt makes it possible to study the turbulence in these gas clouds as no other instrument could. Another type of large object that only the Schmidt can see anywhere nearly whole is a cluster of galaxies relatively close to us, such as the clusters in the constellations of Coma, Hydra and Virgo. It would take scores of plates with a reflector telescope to give the same coverage of these objects that four or five Schmidt plates afford.

The second kind of program for which the Schmidt is particularly suited is the statistical study of large numbers of objects. Statistical information about the distribution of stars in position, motion, brightness, color and so on is basic in the study of the structure of our galaxy. The Schmidt, used with various filter and emulsion combinations, can single out particular types of objects such as planetary nebulae and emission stars and chart their distribution. Similarly, for clues as to the structure of the universe the astronomer is interested in the distribution of systems outside our galaxy. This information will be made much more complete through the Schmidt.

The third appropriate big job for the Schmidt is a simple voyage of exploration. Its high speed combined with its wide field make this telescope ideal for patrolling the skies. Indeed, for this it is as superior to the conventional telescope as an airplane is to an automobile. The primary purpose of a patrol is discovery. The Big Schmidt can be used for two kinds of patrol. It can explore new regions out to fainter magnitudes than have been surveyed before; there it will undoubtedly discover many new faint objects. And it can rapidly resurvey parts of the sky already covered to detect changes there, *e.g.*, to discover new supernovae. The veteran 18-inch Schmidt on Palomar revealed 18 of these giant exploding stars in five years of patrolling certain galaxies.

When the Big Schmidt had proved its excellence in its preliminary tests, the Observatory's research committee, headed by Edwin P. Hubble, met to discuss the question of priority. It was decided that the best way to begin was to take the bull by the horns; namely, to undertake one extremely ambitious program—a systematic survey of the *entire sky* visible from Palomar. Such a project would at once cover many of the research programs awaiting the Schmidt. Not only would it provide an exploratory patrol of the skies but it would collect the observational material needed for the study of extended celestial objects and of distributions of stars and galaxies.

The National Geographic Society, which for over 60 years has sponsored expeditions to far corners of the earth in quest of geographic and scientific knowledge, became interested in this proposed exploration of the heavens. It therefore undertook the financial sponsorship of the survey, and the ambitious program was made possible as a cooperative undertaking of the Society and the Mount Wilson and Palomar Observatories. It was decided that photographic prints of each field should be distributed at cost to interested institutions and individuals. The whole set of prints will be known as the National Geographic Society Palomar Sky Atlas.

Hubble, the scientific director of the project, has pointed out that the Atlas will serve as a record of the heavens at one epoch, will provide an invaluable reference library for a great number of astronomical research projects, and, most important, will give us the first good look at the universe around us out to the distance to which the largest telescopes are working. Only one photographic atlas of the entire sky has ever been made. This was the Franklin Adams Survey conducted over 40 years ago with a small camera that reached only to the magnitude of 17.5. The Big Schmidt reaches out to stars 15 times fainter. In addition there is a tremendous gain in the improved definition and image quality of the Schmidt plates.

The survey with the Big Schmidt was formally inaugurated in July, 1949. The present objective is to photograph the sky to declination minus 24 degrees. It is hoped that in time funds can be obtained to construct a duplicate Schmidt in the Southern Hemisphere and complete the map for the entire sky.

The entire sky contains 41,259 square degrees. Of this, three-fourths is visible from Palomar. One 14-inch photographic plate used in the 48-inch Schmidt covers over 40 square degrees. This means that the Schmidt, even with fields overlapping, can cover the whole visible sky with less than 1,000 plates. Assuming that each field can be photographed in approximately one hour, it should take only about four years to map the sky.

The Sky in Two Colors

Each field is photographed twice—once with a blue-sensitive emulsion and once with a red-sensitive emulsion. The two exposures are made in rapid sucession in order to obtain an accurate comparison of the sky in two colors. The two-color photography is in effect equivalent to a rough spectral analysis. Comparisons of starlight in the two colors provide what is known as the color index of the star. The color index provides a great deal of information about a star, since it indicates the star's spectral type and temperature. Colors of nebulosities are an aid in identifying the sources and mechanisms of their luminescence. Colors of extragalactic systems are helpful in identifying what kinds of stellar populations are present and aid in checking the remoteness of galaxies, for distant galaxies show considerable reddening because of the red shift. Colors also give a clue to the presence of obscuring material in interstellar space, because such material is more transparent to red light than to blue light. So in addition to the ordinary positional data available from a single photographic plate, the two color plates give appreciable physical data.

In its first few months the survey has already produced many interesting discoveries and accumulated much significant material. As expected, it has discovered new clusters of galaxies, new faint galaxies, new planetary nebulae, nebulosities, comets and asteroids. Some oddities and phenomena not yet explained have appeared. New information of possible cosmological significance has turned up, both on the distribution of extragalactic nebulae and on the density of matter in the universe. This material will be made available to astronomers everywhere in the near future. The process of systematic evaluation can then begin. It has been estimated that the Atlas as a whole will furnish so much information that astronomers will be kept busy for 50 years tabulating and interpreting it.

Great advances in scientific knowledge have been made either by the discovery of new objects or by looking at familiar objects in a new manner. The survey with the 48-inch Schmidt embodies both of these aspects. It may well prove to be one of the most significant astronomical endeavors of all time.

Albert G. Wilson is a member of the staff of the Mount Wilson and Palomar Observatories.

A RICH VARIETY OF OBJECTS is shown by the Schmidt's view of Scorpio. At lower right is the bright star Antares, embedded in a diffuse nebula that shines by reflected light. At left center is a nebula that shines by emitted light. At lower right and upper left are three globular clusters. At upper right are dark nebulae that blot out the stars in the background. Also on the plate are 30 asteroids too faint to show in this reproduction.