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THE NATIONAL GEOGRAPHIC SOCIETY PALOMAR OBSERVATORY SKY SURVEY

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Today, some three years after the completion of the National Geographic Society—Palomar Oberv-atory Sky Survey, we can only begin to evaluate its accomplishments. Many papers have already appeared in the technical journals describing research carried out either partially or completely with the aid of the Survey or of the *Atlas* that has been reproduced from it. But it will be many decades, perhaps over a century, before the Survey has finally spent its usefulness.

The vast undertaking of photographing the sky could be completed in only seven years because of the remarkable features of the 48-inch Schmidt telescope on Palomar Mountain, which can cover an area of the sky 6.6 degrees square—about the size of the bowl of the Big Dipper—on a single 14 by 14-inch photographic plate. On a photograph exposed with the telescope until the faint light of the night sky begins to fog the emulsion, images are recorded of stars of the 21st magnitude—fainter than can be reached with any but a very few large telescopes. Furthermore, the Schmidt's ten-foot focal length and its excellent image quality combine to produce photographs of fairly large scale (about two inches per degree) upon which fainter stars

and finer details can be resolved than with any other wide-angle telescopic camera.

Although certain larger instruments, such as the great reflectors on Palomar, on Mount Wilson, and at the Lick Observatory can probe deeper into space, they have very small fields of view—less than the size of the moon—and a complete sky survey with one of these telescopes would require at least ten thousand years!

When the 48-inch Schmidt was completed in 1949, many astronomers were anxious to use it for their various research programs. It was decided then that the first major project for the Schmidt should be to photograph the entire sky in order to produce the most comprehensive sky survey yet conceived. It was further decided that the survey photographs should be reproduced and that first-quality photographic copies be made available to all interested research institutions and individuals. In this way the needs of many astronomers the world over could be met at one stroke!

Fortunately, a sponsor was available for such an expensive venture. The National Geographic Society, long noted for its support of geographical exploration, agreed to finance this "exploration of the farthest reaches of space." The program was launched, and became officially known as the National Geographic Society—Palomar Observatory Sky Survey.

About three-quarters of the sky can be adequately photographed from Palomar—all except a zone within about sixty degrees of the South Celestial Pole. This northern three-quarters of the sky (down to declination—27°) was divided into 879 fields, each 6 degrees on a side. Each field was photographed twice in immediate succession, once on a blue-sensitive and once on a red-sensitive

photographic emulsion. The exposure times were long enough to reach the faintest stars that could be recorded—usually about ten minutes for the blue plates and about forty-five minutes for the red.

By photographing the sky in two different spectral regions (blue and red) the colors of stars and other objects can be determined. A star that is intrinsically blue will make a larger image on the blue plate than on the red and *vice versa.* The color of a star, in turn, gives an indication of its temperature.

To obtain the total of 1758 red and blue photographs of good enough quality to use for astronomical research, over 4000 individual plates had to be exposed, each of which was carefully scrutinized for image quality, emulsion flaws, or other defects. From those plates that were finally deemed acceptable, photographic reproductions have been made and distributed as the *National Geographic Society—Palomar Observatory Sky Atlas* to more than a hundred institutions throughout the world.

During preliminary inspection of the plates, much of the cream could be skimmed from the wealth of new material provided by the Sky Survey. Now, as time has permitted more detailed inspections of the original negatives, and as the *Atlas* copies have been made available to many individuals, far more data are being gleaned from the Survey, yielding information about phenomena that range in distance from the outer atmosphere of the earth to the farthest observable reaches of space.

Meteorites, burning up as they plunge into the earth's atmosphere, frequently produce flashes of light streaking across the sky. The Survey photographs reveal trails of hundreds of such meteors

that happened to cross the field of view of the telescope during an exposure. Many of these meteors belong to showers that are produced when the earth periodically passes through belts of meteoritic material. A few of the meteor trails are very bright, indicating the passing of "fireballs" or "bolides." Harvard astronomers have measured the widths of some of the meteor trails on the Survey plates to obtain information about the size of meteors themselves.

The moon had to be avoided in the Survey, for when it is above the horizon the sky is too bright to expose long enough to reach the faintest stars. As a rule, the planets were avoided also; the image of a planet on a Survey plate would appear so bright that it would obscure much detail in the sky beyond the planet. On at least one occasion, however, there was a "slip up." One of the Mount Wilson astronomers was inspecting a Survey plate when he found what appeared to be a sixth-magnitude star that was not on any star chart. "It must be a nova," he thought, "a sixth-magnitude nova that everyone missed!" He duly reported it to the Harvard College Observatory (clearing house for such objects) only to be informed that it was the planet Uranus!

The minor planets, or asteroids, on the other hand, have been photographed in great numbers. They can be recognized because they move in the sky during the exposure and produce short trails or "dashes" on the photographs. Doubtless many of the thousands of asteroid images on the Survey plates are of uncharted objects. Unfortunately, time has not permitted their detailed investigation. But much valuable material is there for the statistical study of these interesting little planets. On the other hand, close-approaching asteroids are of

special interest. Some come nearer to the earth than any other permanent object except the moon. Three close-approaching asteroids were discovered on the Sky Survey. One of them, named *Geographos* (the "geographer") in honor of the National Geographic Society, will pass within about three million miles of the earth in 1969. In the words of Dr. Samuel Herrick, "it is the closest-approaching asteroid 'in capitivity' that is, whose orbit is known and whose return we can predict." It is possible that an effort will be made to measure its distance accurately in 1969, to obtain a better determination of the scale of the solar system.

Thirteen new comets were discovered on the Survey. Mr. Robert G. Harrington, one of the observers, must come close to holding something of a record, having been the discoverer or co-discoverer of eight of them.

Because the Survey is in both red and blue light, it is possible to pick out those stars of extreme colors by comparing their images on the red and blue plates. Many very-blue stars have been found whose color indicates that they have high surface temperatures. These stars have very interesting characteristics and are important to the study of stellar evolution. Several are being investigated at the 200-inch telescope.

The Survey photographs reveal thousands of clusters and associations of stars, many of which have never been catalogued. Most interesting among them are thirteen new globular clusters. Three of them appear to be at distances beyond the farthest parts of our galaxy. They are probably "extra-galactic" star clusters.

Eighty-six new planetary nebulae were discovered bringing the total number of known planetaries to more than 600. The ones found on the Survey

are large and faint and thus escaped earlier detection. Planetary nebulae are so named because some bear superficial telescopic resemblance to planets. Actually they are shells of gas ejected from and expanding from extremely hot stars. Most of the large faint ones found on the Survey are probably at an advanced stage of evolution. They have expanded to large sizes, a majority of them exceeding two or three light years in diameter.

The space between the stars, although a high vacuum on our standards, is not completely empty. The sparse distribution of interstellar gas is sometimes set aglow by hot stars embedded in it. The Orion Nebula is a familiar example. The Sky Survey has revealed many new bright nebulae, and has shown that many of the well-known ones, like the Orion Nebula, are much more extensive than was formerly thought. The Survey has also disclosed much about the distribution of the microscopic solid grains of interstellar space, the cosmic "dust" that hides or dims stars that lie beyond it.

A few decades ago, our galaxy, with its hundred billion or so stars, star clusters, and nebulae, was believed to be the entire universe. By 1923, however, astronomers had learned that ours was but one of many galaxies of space. But only recently have we begun to realize the true distribution of galaxies, or of their range in sizes. We have found, for example, that "dwarf" galaxies, perhaps only a hundredth or less as massive as our own system, are more common than the giant galaxies (like ours and the Andromeda galaxy) that we can see to much greater distances, and hence have discovered more readily. Among the countless millions of galaxian images on the Survey photographs are many comparatively nearby dwarf systems. Four of them are members of the Local Group, a small

cluster of seventeen known galaxies to which our system and the Andromeda Galaxy belong.

Besides the Local Group, there are other clusters of galaxies. Before the Survey was begun, a few dozen such clusters were known. Some astronomers had expected that the Survey might turn up many more—perhaps even *hundreds*. But there are *tens of thousands* of recognizable groups and clusters of galaxies revealed on the Survey photographs! Investigations at the Lick Observatory have also shown that clustering of galaxies is far more common than had been supposed. It now seems possible that *all* galaxies belong to clusters.

Dr. Fritz Zwicky is engaged in the painstaking task of measuring positions of these galaxian clusters on the Survey plates, and he is preparing a large catalogue of galaxies and clusters. Several years ago, the writer published a catalogue of the 2712 richest of the clusters, that is, those clusters that have many hundreds of member galaxies each. An investigation by the writer of the distribution of those rich clusters has produced evidence that suggests that some of the clusters themselves may be clustered into still larger clusters—*clusters of clusters of galaxies!*

Among the clusters of galaxies found on the Sky Survey are the most distant objects known—billions of light years away. Some are now being investigated with the 200-inch telescope to study the "expanding universe," and to attempt to solve the problems of cosmology—to learn whether the apparent recession of galaxies is the result of a primeval "big boom," or whether the universe is undergoing "continuous creation," or if either theory is correct!

At observatories and laboratories throughout the world, the Sky Survey prints are being used to in-

vestigate astronomical problems—the distribution of stars, star clusters, nebulae, dark matter that may be forming into stars, to name but a few. The *Sky Atlas* and Survey will long be valuable, not only for the discovery of new objects and their detailed study, but for statistical studies of matter in space. Further, the Sky Survey serves as a standard reference—a master chart with which other photographs can be compared to detect changes in the sky, novae (exploding stars), variable stars, and moving objects. Finally, the *Sky Atlas* is a map of the sky, one that can be used like any road map, to help the astronomer find his way to objects too faint to see directly at the eyepiece of a telescope, and to aid him in planning his research program.