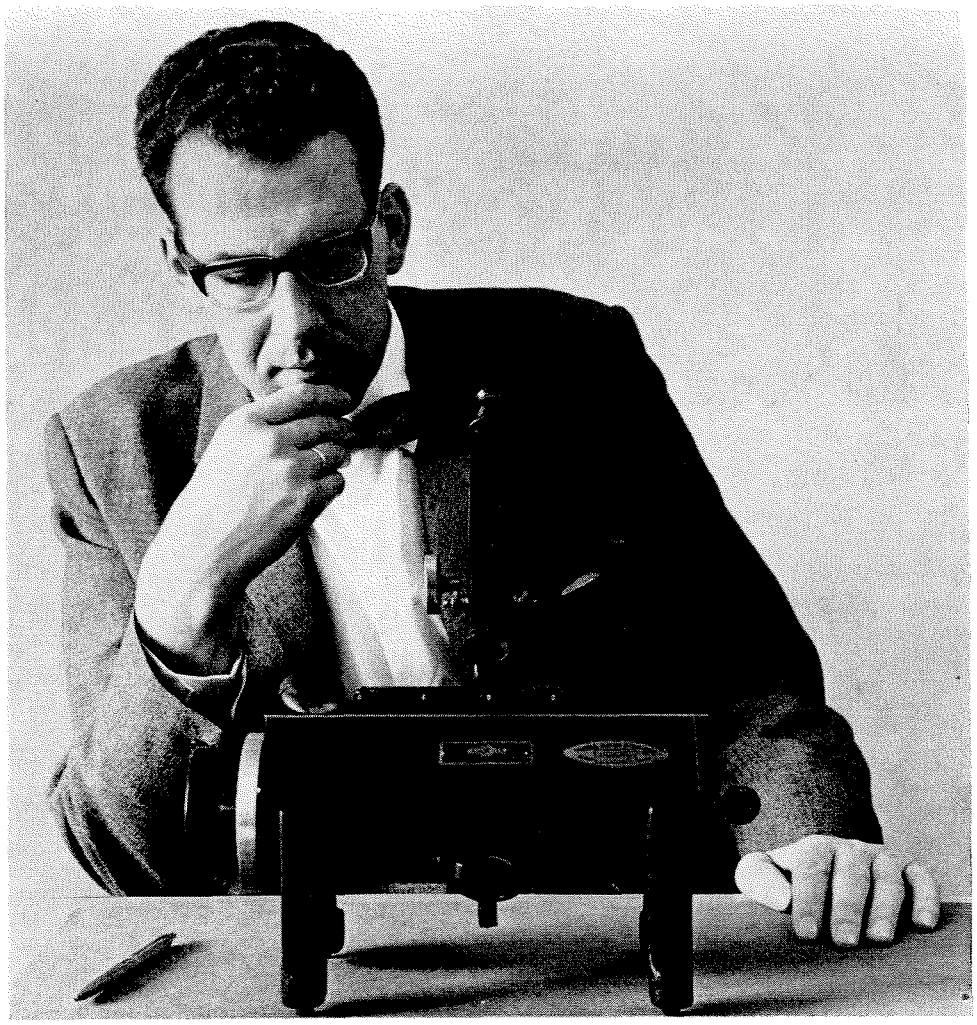


Maarten Schmidt, professor of astronomy at Caltech and staff member of the Mount Wilson and Palomar Observatories, uses a microscope to measure wavelengths in photographic spectra.

by Graham Berry

Extending the Frontiers of Space

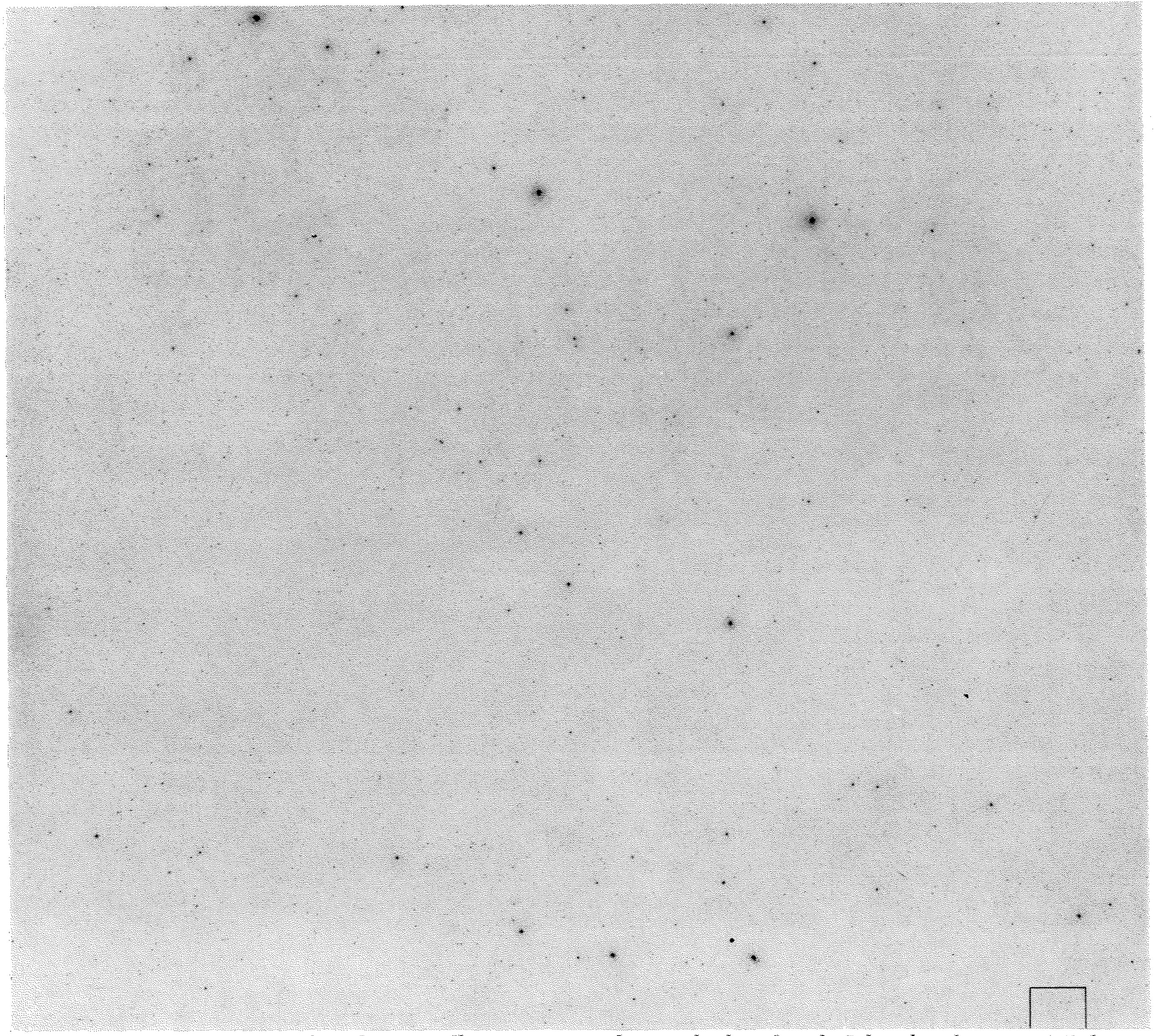
Maarten Schmidt, professor of astronomy at Caltech, and staff member of the Mount Wilson and Palomar Observatories, has found that five quasi-stellar radio sources are farther away than any other known object in the universe. The discovery is described by the Observatories as a breakthrough in determining relative cosmological distances.

The most distant of the five objects, 3C-9, is so remote that it appears to be receding from the earth at 80 percent of the velocity of light – 149,000 miles a second. Under the expanding universe theory, the faster an object recedes from the earth, the farther away it is.

"The light we now see from 3C-9 left it many billions of years ago, before the sun and the earth were born and when the expanding universe was only a third as large as it is today," says Dr. Schmidt. "It started from 3C-9 only a few billion years after the universe was born." The universe is considered to be ten to fifteen billion years old.

Although all five quasi-stellars are many billions of light years away, their exact distances cannot be stated because that would require accurate knowledge of the evolution of the universe. What we have are their relative distances.

As is true of other objects far beyond our Milky Way Galaxy, their relative distances are inferred from their red shifts. The greater the red shift of its spectrum, the farther away an object is believed to be. However, the relationship of red shift to distance is still uncertain for objects that are more than a billion light years away. At such distances the un-



A negative print of a star field in the constellation Pisces, taken with the 48-inch Schmidt telescope at Palomar. The area marked at the lower right is enlarged in the photograph on the opposite page.

known geometry of the universe may affect this relationship. It is hoped that these uncertainties will be resolved by studying the red shifts, brightnesses, and sizes of many more quasi-stellars.

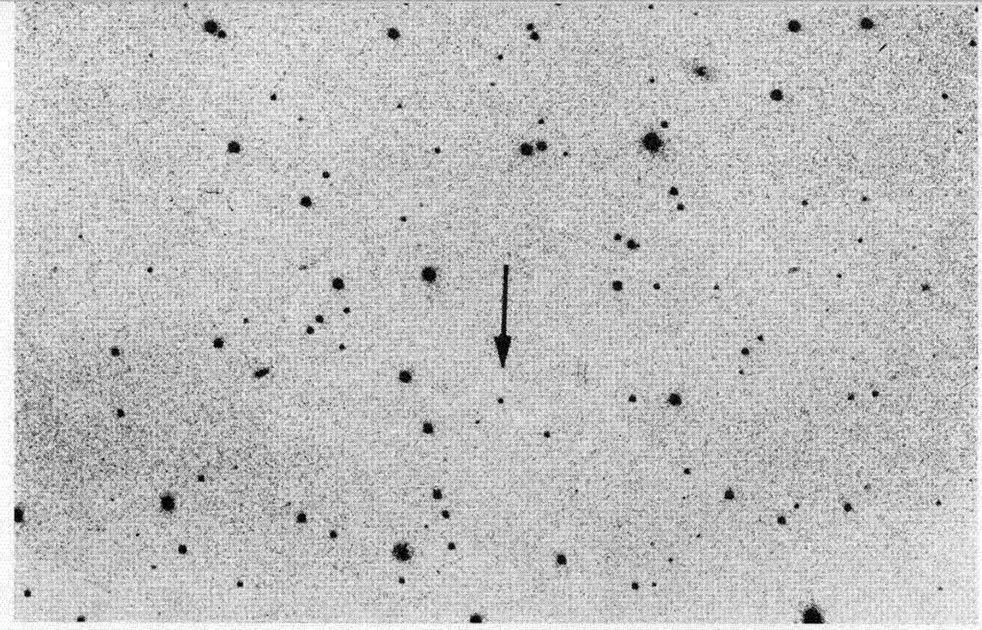
Previous to this announcement, red shifts had been obtained for four quasi-stellars. Dr. Schmidt obtained three of them. The largest was that of 3C-147, whose red shift corresponds to a recession rate of 76,000 miles a second. For such large red shifts, the corresponding velocities are computed according to Einstein's special theory of relativity proposed in 1905.

The five new red shifts which the astronomer has obtained are for the following five quasi-stellars and correspond to the following recession rates: 3C-254—93,000 miles a second; 3C-245—113,000 miles a second; CTA-102—114,000 miles a second; 3C-287—115,000 miles a second; and 3C-9—149,000 miles a second. The "3C" designation indicates a listing in the third Cambridge catalog of radio sources. The "CTA" prefix indicates inclusion in the "Caltech List A" of radio objects.

The red shifts of the new quasi-stellars are so large that three spectral lines from the far ultraviolet are shifted into the visible part of the spectrum. One of these is the Lyman alpha line of hydrogen, which never before had been observed from a ground-based observatory.

Last month some Russian astronomers reported that one of the five new objects, CTA-102, emits a radio signal that varies in a 100-day cycle. A Moscow report said the variable signal might be evidence of a super civilization. However, Drs. Allan Sandage, staff member of the Mt. Wilson and Palomar Observatories, and John Wyndham, Caltech radio astronomer, said they believe the signal comes from a natural source. They had previously identified CTA-102 as a quasi-stellar. Dr. Schmidt's de-

Enlargement of the marked area in the photograph at the left shows the location of the quasi-stellar radio source 3C-9. Negative prints are used almost exclusively by astronomers because much more detail is visible and faint objects show up better.



termination of CTA-102's large red shift confirms their statement.

What are these mysterious quasi-stellars that have intrigued astronomers so much for the past three years? They used to be considered ordinary stars within our galaxy. In 1960 it was discovered that they emitted energy as radio waves as well as in the form of light. In 1963 Dr. Schmidt obtained a large red shift for one of them, 3C-273, which indicated that it was a very distant object, far beyond our galaxy.

With their large red shifts indicating great distances, it became evident that they must be very bright intrinsically, although, because they are so far away, they appear only as faint stars of 17th or 18th magnitude. Being up to 100 times brighter than an entire galaxy, they can be observed farther away than any other objects.

Although little is known about their structure and energy-producing mechanisms, several theories have been advanced to explain them. Currently, astronomers think a quasi-stellar is a distant object with a mass of at least 100 million suns. It is believed that its energy-producing core is surrounded by two cloud layers. The inner, visible layer is of luminous gas, the outer, optically-invisible layer consists of fast-moving electrons, emitting energy as radio signals as they spiral in a magnetic field.

The over-all information on the composition of these objects is meager. There are no indications that the composition of the extremely far away ones is different from that of other quasi-stellars. They are the oldest visible objects in the universe. They probably lived only a short time — perhaps a million years — as very bright quasi-stellar sources.

"When we have determined the red shifts for enough of them," says Dr. Schmidt, "they should become invaluable in studying the geometry and evolution of the universe. I believe the red shifts will be determined shortly for many of them because we now know what to look for."

The five new red shifts mark a breakthrough in spectroscopy — the astronomical technique which makes it possible to learn something of an object's composition, motions, and temperature, and to infer how far away it is.

Before spectroscopist Schmidt undertook the difficult, meticulous task of attempting to obtain a red shift for one of the objects, it already had been identified as a quasi-stellar source. Several radio and optical astronomers such as Drs. Wyndham and Sandage are currently engaged in identifying quasi-stellars.

The exact sky positions of radio sources are pinpointed at Caltech's Owens Valley Radio Observatory and at other such installations. Astronomers try to match these locations with star-like optical objects. If, in addition, considerable ultraviolet light is radiating from such a radio-optical source, then astronomers are virtually certain it is a quasi-stellar. More than 40 of them have been located. Now red shifts for a total of nine have been reported.

Obtaining red shifts is very difficult. So little of the quasi-stellar's ancient light reaches the earth that there isn't much left to split into a spectral pattern of lines, each line representing a specific wavelength of light. This must be done to obtain a red shift.

A grating mirror was used with the big 200-inch Palomar telescope to separate the light from these objects into its color components. The light was admitted through a slit and deflected from the mirror-grating into a camera. Exposures of four to five hours each were required to obtain the faint tracing on a photographic plate.

To make certain that the barely-observable trace marks represented actual spectral lines, Dr. Schmidt obtained at least four spectral photographs of each object. Two or more spectral lines were required on each spectrum to determine the red shift at all.

Great as are the difficulties in obtaining the spectral lines, they are small in comparison with those of interpreting them. Dr. Schmidt describes the problem as follows:

Interpreting spectral lines

A red shift is produced by a light source moving away from the observer, just as a blue shift is produced if the light source is approaching. The light waves from a receding source are stretched out, lengthened. The faster the object's motion away from the observer, the more its light waves are stretched and the greater the shift toward the redder end of the spectrum, where the light waves are the longest.

Sound waves are affected similarly by motion. A train's horn is higher in pitch as it approaches, because the sound waves are shortened, and lower as it recedes, when the sound waves are lengthened.

Now imagine a locomotive with ten horns on it, each with a different pitch. The tones of three horns, say, are too high in pitch for the human ear to detect (like the special dog whistles; dogs can hear tones that are higher than 20,000 cycles per second, but humans can't). If the train were moving away fast enough, the sound waves of the normally inaudible horns would be stretched out enough to move into the audible range. We would hear them.

This is what is happening in the spectra of the quasi-stellars. For instance, the wavelengths of the light from 3C-9 are three times longer than they would be if that quasi-stellar were at rest in relation to the earth. Each wavelength is represented by a spectral line which normally has a specific location in a spectrum. However, for 3C-9 a line normally located in a spectrum at 1,550 angstroms would, if the wavelength were thrice as long, be located at the 4,650-angstrom mark. An angstrom is equal to one 254-millionth of an inch. A wavelength that is 1,550 angstroms in length is too short to be visible on the earth's surface. That is because our atmosphere absorbs all wavelengths of less than 3,100 angstroms. However, a wavelength of light that is 4,650 angstroms long is visible as blue light.

In observing the two or more lines in the spectrum of a fast-receding quasi-stellar, Dr. Schmidt suspected that these lines represented wavelengths that normally are invisible. The problem then was to identify that quasi-stellar's spectral line pattern with part of the laboratory spectrum, which is made up of the prominent lines of the more abundant elements. Once the identification is made, the red shift follows from the difference in the wavelengths of the quasi-stellar line pattern and the laboratory line pattern.

For the nearest of the five new quasi-stellars, 3C-254, Dr. Schmidt obtained five spectral emission lines. The lines disclose two forms of neon (III and V), and one each of carbon III, magnesium II and oxygen II. The Roman numerals represent the degree to which the chemicals were ionized. Neon III denotes neon atoms with two fewer than a full complement of electrons. Neon V signifies neon atoms with four less than the full complement of electrons.

For the next most distant objects – 3C-245 and CTA-102 – the astronomer obtained the same two lines on each of their spectra – those of carbon III and magnesium II. The lines of CTA-102 were shifted a little more than those of 3C-245, indicating that CTA-102 was farther away.

In the spectrum of the second most distant of the five objects, 3C-287, Dr. Schmidt obtained three lines – the two that had been found for 3C-245 and CTA-102 (carbon III and magnesium II), plus another one, that of carbon IV. This is the first time that carbon IV's line has been obtained for an astronomical object. That is because the wavelength of its light normally is 1,550 angstroms – too short to be visible. However, in the spectrum of 3C-287 the wavelength has been red-shifted (lengthened) to 3,192 angstroms.

Getting the carbon IV line in 3C-287 was vital in obtaining a red shift for the most distant of the objects – 3C-9. Dr. Schmidt got two lines for 3C-9 – that of carbon IV and that of Lyman alpha. In 3C-9, the carbon IV line has been red-shifted to 4,668 angstroms, which is slightly more than three times its normal (at rest) wavelength of 1,550 angstroms.

A new method

In determining the red shifts for these five far-out objects, Dr. Schmidt has discovered the key to unlocking the red shifts of other quasi-stellar objects that may be even farther away. The key is this step-wise method of uncovering new spectral lines that never before have been visible because the wavelengths of their light were too short.