THE SIZE OF THE UNIVERSE

Research reveals that the range of the 200-inch Palomar telescope is about twice as great as we had thought

IN RECENT YEARS, it has become increasingly apparent that there were discrepancies between the different methods astronomers used for measuring distances. Research done with the 200-inch Palomar telescope has now resolved these discrepancies—and revealed that the observable universe is about twice as large as we had supposed it was before.

This discovery was made by Dr. Walter Baade, staff member of the Mount Wilson and Palomar Observatories, as a consequence of a remeasurement of the distance to the great spiral nebula in the constellation of Andromeda. This distance is a yardstick used in measuring the distances of all more remote objects.

Dr. Baade's findings indicate that the astronomical distance scale was in error by a factor of about two, and further research is expected to refine this figure. Corrections by a factor of two would mean that:

1. The limit of the *observable* universe—as expressed by the range of the 200-inch telescope—has doubled. That range is now about 2,000 million light years. Distance of the Andromeda nebula, one of the nearest to us, has doubled to about 1½ million light years.

2. All the inhabitants of outer space—everything beyond our own galaxy, the Milky Way—are twice as far from us and twice as large as hitherto believed. However, the dimensions of the Milky Way are not affected. These facts remove a discrepancy of long standing—namely, that our galaxy formerly appeared to be twice as big as the biggest extragalactic nebulae which were found in the universe. With the new data, our galaxy is still among the giants, but it is no longer larger than any other.

3. The volume of the *observable* universe—that sphere of space which can be scanned with the 200-inch telescope—has increased eightfold because its calculated radius has doubled.

4. The expanding universe—outgrowth of the generally accepted interpretation of red-shifts in the light from distant extragalactic nebulae as velocity shifts—is expanding at half the previously accepted rate. The rule of thumb must now be that for every million light years of distance, the speed of expansion is increased 50 miles per second instead of 100.

5. Estimated age of the universe—based on the expansion interpretation of red-shifts—is twice as great. This age represents the span of time since all the great objects in space hurtled away from a common origin, some of them at great speed and some at lesser. The figure now stands at about 4,000 million years instead of the previously estimated 2,000 million years. This

THREE TELESCOPES

—— Three eyes on the universe

48-inch Schmidt telescope photograph of the Andromeda nebula. Remeasurement of the distance to this nebula led to corrections in the astronomical distance scale.

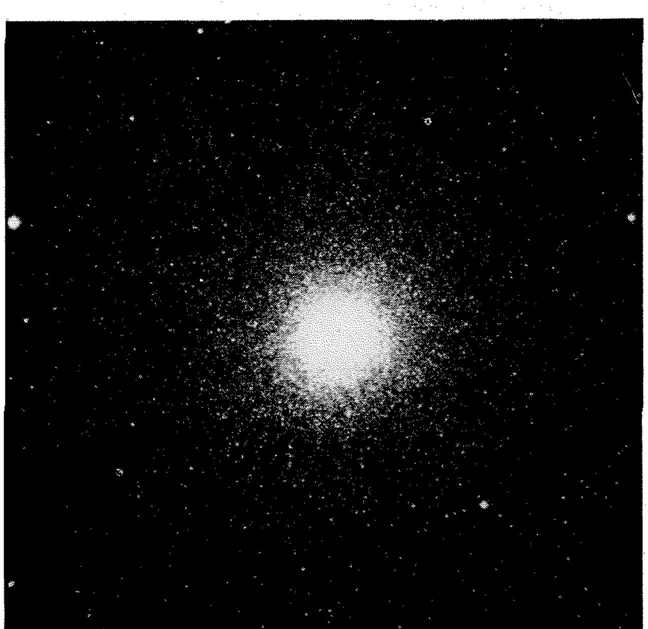
revision eliminates a disturbing disagreement with physicists' estimates—based on the rate of radioactive decay of uranium and thorium—that the earth itself (not the universe as a whole) was created 2,000 to 3,500 million years ago.

The beacons astronomers use to find the distances of far-off stellar systems are Cepheid variables. These are pulsating stars which periodically brighten and dim. Their periods of pulsation range from less than a day to about 50 days and correspond to their inherent brightness ("absolute magnitude"). Astronomers use these absolute magnitudes to calculate distances.

It is now clear that the errors in the astronomical yardstick crept in with the assumption that *all* Cepheids with the same period of pulsation were equally bright. Dr. Baade has shown that they are not. Rather, there are actually two types of Cepheids, one fainter than the other, even though both pulsate identically. Distances calculated on the basis of the old period-luminosity relationship are therefore wrong.

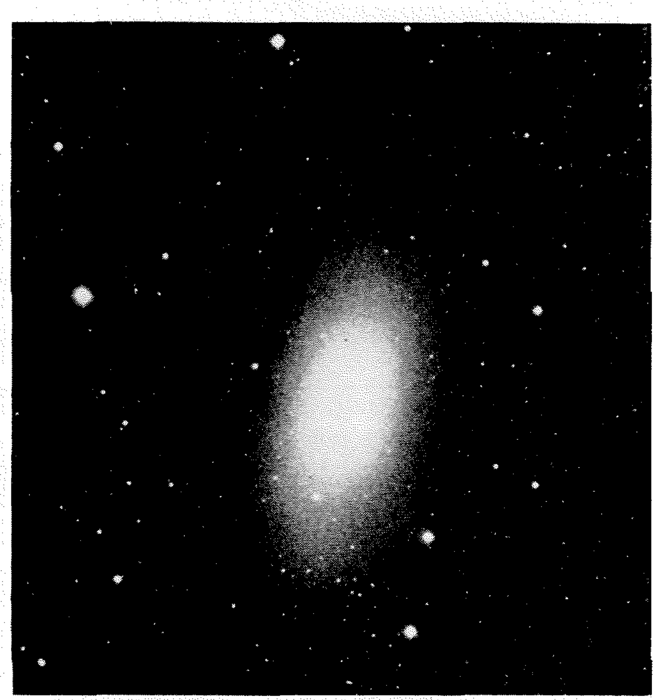
These errors were not apparent until Dr. Baade recognized that there are two kinds of stellar populations in galaxies, each with its own distance indicators.

"We know now," he said, "that Cepheids of one type



Cepheid variables — pulsating stars which periodically brighten and dim — are the beacons astronomers use to find the distances of far-off stellar systems. A check of the luminosities of Type II Cepheids in the globular cluster Messier 3, shown at left, played an important role in Baade's revision of the astronomical distance scale.

100-inch telescope photograph of the lower area of the Andromeda nebula. Baade's work with this telescope led to his discovery that there are two stellar populations.



200-inch photograph of Andromeda satellite shown at upper right of picture on p. 10. Work with this telescope proved all previous extragalactic distances wrong.

were used for the distances and dimensions of our own galaxy, while Cepheids of an entirely different type were used for distances outside our galaxy.

"The second group of distance indicators had been wrongly calibrated. This we learned from observations of the Andromeda nebula, its satellites, and globular clusters in the Milky Way. We found all extragalactic distances were in error."

Dr. Baade has been assisted in his research by Allan R. Sandage, staff member of the Mount Wilson and Palomar Observatories, who is to receive the Ph.D. degree from Caltech this June.

Their present work grew out of Dr. Baade's discovery of the two stellar populations during the second world war. Astronomers have hailed that discovery as one of the greatest contributions to our understanding of the universe in recent years.

Using red-sensitive plates, Dr. Baade was able to resolve the central portion of the great Andromeda nebula into stars with the 100-inch telescope on Mount Wilson. This feat had never before been accomplished. This and associated work pursued in great detail by Dr. Baade led him to the discovery of two stellar populations, which he dubbed Populations I and II.

The brightest members of Population I are very hot blue stars, more than 100,000 times brighter than our sun. In contrast, the brightest members of Population II are red stars, only 1,000 times brighter than our sun. If they were side by side, at the same distance from us, the brightest Population I stars would be 100 times more luminous than the brightest of Population II.

Ever since the two stellar populations were recognized, there have been strong reasons to suspect that the pulsating Cepheid variables, although present in both populations, really represented two different species and hence each group of Cepheids had to be calibrated independently.

Dr. Baade has found that the two types do indeed differ. Type I Cepheids (of Population I) steadily brighten and dim. Type II Cepheids (of Population II) brighten, dim a bit, level off and then dim a great deal more before they repeat the process. Although both types include stars whose repeated periods of brightening and dimming range from about two days to fifty, there is another important difference:

Cepheids with periods shorter than one day exist only in Population II, and are exceedingly abundant. These are the cluster-type variables, named for the globular star clusters of our galaxy in which they were first found in quantity. They also are found outside our galaxy.

The two stellar populations exist side by side in the great Andromeda nebula. Population I stars are in the spiral arms and Population II in the central region and between the spiral arms.

The first definite experimental indication of error in the distance indicators came more than two years ago when Dr. Baade tried to find the short-period, cluster-type variables of Population II in the Andromeda nebula.

They should have been visible on 200-inch plates because their median absolute magnitude placed them at apparent magnitude 22.4—one-tenth magnitude brighter than the faintest object the 200-inch can photograph.

They were not visible, however. In fact, only the brightest stars of Population II—which are 1½ magnitudes (or four times) brighter than its cluster-type

Dr. Walter Baade, staff member of the Mount Wilson and Palomar Observatories

variables—were visible, and barely so. Either the cluster-type variables were fainter than had hitherto been supposed—or else the Andromeda nebula was farther away than we thought.

To settle the question, the 200-inch telescope was used to check the luminosities of cluster-type variables in the globular cluster Messier 3 by comparing them directly with stars of solar brightness. This check showed that the accepted luminosity for these Type II variables was correct within about one-quarter magnitude.

This meant, Dr. Baade said, that the calibration of Cepheids of Population II was essentially correct and that the $1\frac{1}{2}$ magnitude error which appeared in the Andromeda work had to be attributed essentially to Type I Cepheids.

These latter had formed the basis for distance determinations on the Andromeda nebula and other extragalactic nebulae, so that when their luminosities are increased by $1\frac{1}{2}$ magnitudes, all the distances and dimensions of extragalactic nebulae have to be increased by a factor of two.

Dr. A. D. Thackeray at the Radcliffe Observatory in Pretoria, South Africa, has found the same discrepancy in the calibration of cluster-type variables in the Small Magellanic Cloud, an extragalactic nebula visible only in the southern hemisphere. The cluster-type variables were expected at apparent magnitude 17.5, but he actually found them at magnitude 19.0—again a difference of $1\frac{1}{2}$ magnitudes. This was the first striking confirmation of the Palomar findings.

Corroboration also came from Dr. Henri Mineur, director of the French Institute of Astrophysics in a recent note to the Paris Academy. The once-puzzling calibration which he reported in 1944, he pointed out, is now understandable in view of the Palomar findings. That calibration agrees with Dr. Baade's, said Mineur, when he allows for the fact that it involves two different distance indicators which correspond to the two sorts of stellar population.