Researches on Galaxies at the Harvard Observatory.

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AMONG the many attempts of mankind to survey the universe, astronomy is almost unique in its combination of sweeping fields and sharp limitations. It reaches further into space than any other science; and it finds the demands of space and time more binding. Vast distances and dimensions are involved; processes are exceedingly slow, in terms familiar to man. The result is a constant challenge to man's ingenuity to devise techniques and to interpret observations.

Some of the problems that confront us when we examine our own galaxy, the Milky Way, also need solving when we study the distant universes that make up the rest of the Cosmos. Questions of size and structure, of dynamical conditions, are the same. There is the same analysis of the population of our own and other galaxies near enough to be examined in detail—stars and star clusters, gaseous nebulæ, stars that vary in light. (It may be pointed out that the terms "galaxy" and "nebula" are frequently used interchangeably to mean a great organization of stars. But since the word "nebula" is also used for the bright or dark clouds of gas or dust particles which are characteristic elements in many galaxies, we shall use the term "galaxy" mainly in the following account.)

Because we are involved in the midst of the Milky Way system, and at a great distance from all the others, there are many problems that arise only when we look beyond the Home Galaxy. The most essential problems deal with the general structure of the Metagalaxy, as the system of all such organisations of stars is called. What is the nature of the Cosmos? How many, and of what kinds, are the elements it comprises, and how are they disposed throughout space and time?

Again, we can study some of the distant galaxies to greater advantage than we can examine our own system. It is extremely difficult to obtain information about the Milky Way as a whole. We are not sure whether it is a single spiral or a group of smaller galaxies or an irregular system. The presence of absorption, the crowding of stars, the difficulties of obtaining perspective, throw us into confusion and uncertainty. But the other galaxies are observable from the outside. In some of the nearer ones, such as the Andromeda Nebula and the Magellanic Clouds, we can even study individual stars and clusters and gaseous nebulæ. Thus we are much more likely to learn what a typical galaxy is like by leaving the Milky Way, and exploring the neighbouring systems.

(1) One of the most fruitful sources of information about the structure and contents of an individual galaxy is the pair of systems lying close to the Milky Way, and probably functioning as its satellites. The Large and the Small Magellanic Clouds are much closer to us than any other external system—they are not a hundred thousand light years distant. Even a small telescope reveals something of their nature. Larger instruments show plainly many thousands of their stars, and other conspicuous features. At the Harvard Observatory a number of studies have been directed to the analysis of the Clouds as typical galaxies. Some of them are here briefly mentioned:

(*a*) The Clouds have been the source of considerable material on variable stars, which furnish the yardstick for measuring great distances. Over three thousand of these fluctuating stars are now known in the two Magellanic Clouds.

(*b*) A number of globular clusters found on the borders of each of the Clouds in the past two years have increased their recognised diameters considerably. The Large Cloud is now known to be about eighteen thousand light years across, and the Small Cloud about twelve thousand.

(*c*) Spectrographs of the brightest stars in the two Clouds are being taken with the 60-inch telescope. They will yield definite values of the radial velocities, and possibly information on the rotations of the Clouds—valuable material for the study of the dynamics of a galaxy.

(2) A recently developed type of analysis which is being extensively used at the Harvard Observatory on the brighter galaxies is the method of densitometer measures. Photo-tracings across the images of nebulæ are made which indicate the distribution of intensity of light. Thus two phenomena can be examined with considerable accuracy—the diameter of the object and the changes in density of luminous matter across its

surface. Diameters have been measured on many photographs, and the results show that the galaxies are very much larger than they had been believed to be. The outer extensions are much fainter than the central regions, and therefore not visible to the eye in examining photographic plates. The results are of inestimable importance in dealing with many problems of galactic structure —primarily, for example, the heretofore unexplained disparity between the two principal types of galaxies, spiral and spheroidal objects. The latter, an almost featureless type of galaxy, had been estimated as much smaller than the spiral form; but the densitometer measures indicate that the diameters of the spheroidals are increased by the faint extensions more than are those of the spirals. Thus an apparent discrepancy in the workings of nature has been to a large extent removed by our increased knowledge of the phenomena.

(3) The distribution of the galaxies on the celestial sphere and their distribution through volumes of space are of primary importance in a study of the Metagalaxy. In order to get complete knowledge of such distribution, large regions of the sky should be examined, so that the accidents attendant on small samplings will be obviated. For this purpose the Harvard Observatory is using at both the Northern and the Southern Stations telescopes which combine a fairly large field with space-penetrating power. On a single photograph there is covered an area of thirty-five square degrees of the sky; and nebulæ to the eighteenth magnitude—which means, roughly, to a distance of seventy five million light years—can be recorded in an exposure of three hours. Thus, with a reasonably small number of photographs taken on adjoining regions, several hundreds of square degrees are examined as a unit.

The Harvard survey of galaxies to the eighteenth magnitude has so far revealed on photographic plates some hundred thousand previously unknown galaxies, in both the southern and the northern skies. One significant fact that appears is the unevenness of their distribution. Although in many regions they appear with average frequency, in others they are surprisingly scarce; and in still others, more surprising, there are very great concentrations. In the south, for instance, in the neighbourhood of the constellation Horologium, is a very extensive area of extraordinary richness. Here the galaxies seem to form a great stream, or cloud, many times more dense than the average. Within this Metagalactic Cloud of universes are several small spots of extreme density—spots in which the frequency is a hundred times the normal. Such clusters of galaxies are found scattered over the sky. They cover, to be sure, only a small portion of the entire sphere; but no description of the Universe, or theory about it, can be complete that does not take into consideration these irregularities in the cosmic scheme.

(4) Clusters of galaxies are of interest not only for the rôle they play in the structure of the Metagalaxy. They also provide an opportunity for the study of relative sizes and brightnesses of individual members. All objects within a cluster may be considered as being at the same distance from us. Thus the variations in diameter and brightness can be taken as absolute differences. A study of twenty-five groups of galaxies, ranging in population from less than a dozen to several hundred, has been published by Dr. Shapley. About a score of clusters of galaxies discovered on Harvard plates are as yet unpublished. A programme is now being carried on at the Southern Station for the analysis of some of these groups with the 60-inch reflector which will yield large-scale photographs for detailed study of their members. It will also bring more complete knowledge about the numbers and magnitudes of individuals in the clusters.

(5) Still another aspect of the studies of galaxies at Harvard, while being a part of the attack on the outer Cosmos, has a direct bearing also on the analysis of our Milky Way system. This is the examination of regions lying close to the plane of the Milky Way which are rich in external galaxies. The heavy obscuring material in the central plane of the Milky Way has a two-fold effect. It hides the distant galaxies in the line of sight, and also makes it extremely difficult to measure the Milky Way itself. Stars near the centre of our system are dimmed by this nebulosity; and therefore when the attempt is made to judge their distances by using measures of their apparant brightness, the results are false. For the absorption makes the stars seem fainter, and thus more distant, than they really are. Any measurement of the size of our galaxy must be corrected for the effect of the interpenetrating material among the Milky Way stars.

Dr. Shapley has pointed out that in places along the plane of the Milky Way where the obscuring material is very thin, or even absent, there is little or nothing to hide the systems lying beyond. On a number of plates covering these areas galaxies have been found in normal abundance, as they would be in high latitudes where the obscuration does not occur. Dr. Shapley has used the presence in these low-lying regions of numerous galaxies as an indication of freedom from obscuring matter in our own system. He has studied variable stars in these areas in the Milky Way, which he can use safely as distance-indicators, without fear of false estimates of their brightness. The small amount of obscuration that may occur can be easily corrected for. In one region almost directly in the line to the center of the Milky Way he has found such freedom, and a study of periodic variables discovered there has shown more than a hundred stars which must lie far beyond the center itself. This is the first certain penetration into the far side of the Milky Way, and stars are now known which are further beyond the center than we are on this side of it. The research is of great importance, both in furthering our knowledge of the size of the Home Galaxy and in analysing more exactly than heretofore the structure of the dark material within it.

An open spiral, showing spiral arms, condensations of stars, and obscuring material among the arms.

N. G. C. 5236 (Messier 83).

Position : R. A. = $13^h\ 34^m{\cdot}3$, Dec. = $-29°\ 57'$.

(This picture was taken with the 60-inch reflector of the Harvard Observatory at the Southern Station, Bloemfontein, South Africa, by Dr. J. S. Paraskevopoulos.)

The studies listed above represent some of the explorations that are designed to give a consistent and detailed picture of the Metagalaxy. Limitations of space have made it necessary to omit discussion of other allied programs now being carried on at Harvard. There is, for instance, a study supplementing the earlier work on the galaxies brighter than the thirteenth magnitude over the entire sky. The new work goes to the fifteenth magnitude, and thus augments knowledge of the "inner Metagalaxy". There is also the investigation of variable stars in our own system in high latitudes, which outlines the Milky Way in its minor diameter. Such problems necessarily entail a great deal of laborious routine, and can bring final results only after some years of continued research.

The past decade or two have seen the opening of many doors into the outer world. The present time and the coming decades will bring observational material by which we can fill out the picture of what lies beyond the Milky Way.