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THE MAGELLANIC CLOUDS

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Fig. 1.—The Magellanic Clouds. Just above the Small Cloud is the globular cluster 47 Toucanae. Leica photo by G. de Vaucouleurs, exposure 2 hours on red-sensitive film 103a-E.

Nubecula Minor and Nubecula Major, as the Magellanic Clouds were called in the sixteenth century, are conspicuous circumpolar objects in the southern sky, always above the horizon south of the Tropic of Capricorn. The distance between them is 20°, about the same as the total length of the Little Dipper at the north pole. Although the south celestial pole is not marked by a bright star, as the north pole is by Polaris, it can be located one-third of the way from the Small Magellanic Cloud toward Gamma Crucis at the head of the Southern Cross (Fig. 2). Both of the Magellanic Clouds cover large areas of the sky and are much more brilliant than the great Andromeda Nebula or the brightest globular star clusters. They are so large and so bright that even to the naked eye their galactic nature is apparent from their resemblance to the dense clouds that lie along the Milky Way from the Northern to the Southern Cross.

In early times they were thought to be detached portions of the Milky Way, but now, in consideration of their high galactic latitude of 45° and their great distance far beyond the confines of our Galaxy, it is clear that they are peculiar extragalactic systems.

Visually or on short-exposure photographs, they appear as irregular nebulae with diameters of about 4° and 7°, respectively. On long exposures at Harvard's Boyden Station in South Africa, H. Shapley and his collaborators found that their diameters were nearly twice as large. Recent studies with increased photographic contrast have indicated that their dimensions are still greater and measures with the radio telescopes at Sydney, Australia, point toward diameters of at least 12° and 20°.

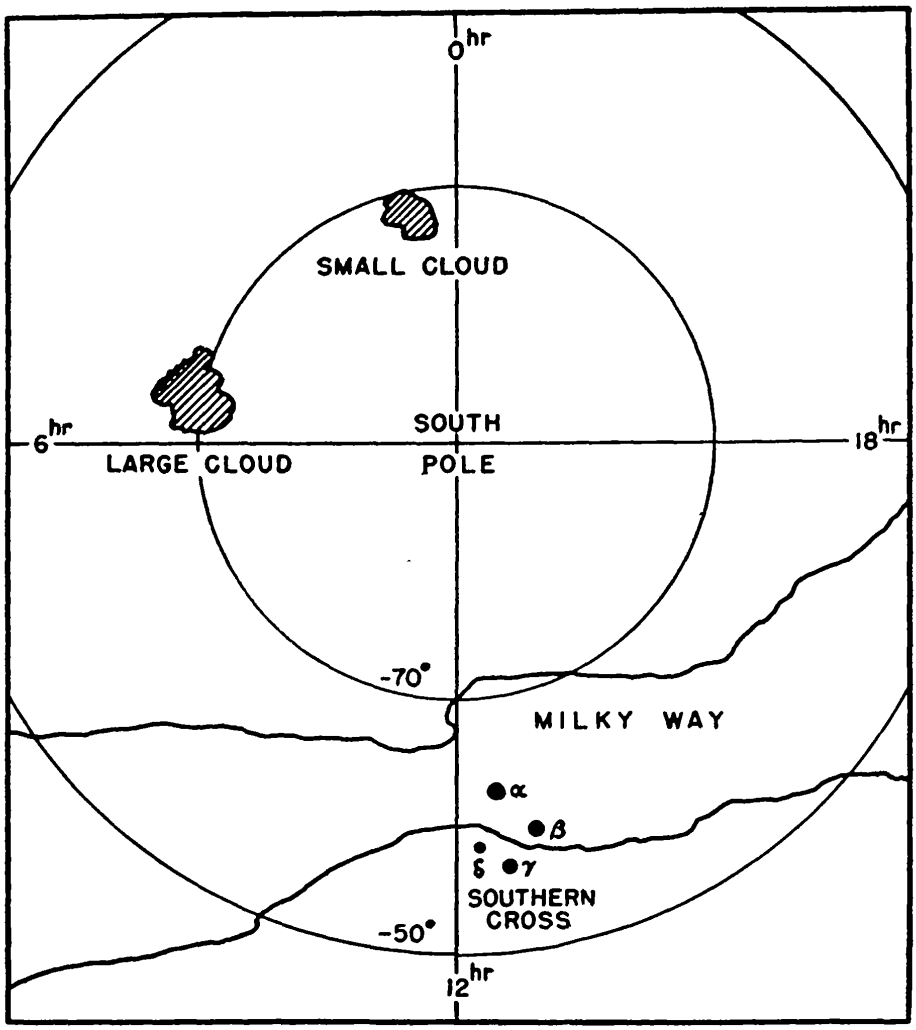

Fig. 2.—Region of the South Pole, showing the relative positions of the Magellanic Clouds, the Southern Cross, and the Milky Way.

The great astrophysical importance of the Clouds was first recognized in 1912 when Henrietta Leavitt at Harvard was studying the variable stars on plates taken at the original southern station at Arequipa, Peru. By arranging 25 classical Cepheids in the Small Cloud in order of increasing brightness at maximum light, she unexpectedly found that the

periods were also in order, increasing from 1 to 150 days. Since the stars in the Cloud are all at practically the same distance from us, Ejnar Hertzsprung derived within a few months a value for their distance by comparing their apparent magnitudes with those of Cepheids with similar periods in the sun's neighborhood, whose distances had been estimated from their apparent motions.

The *absolute magnitude* of a star is the apparent magnitude it would have if it were 32.6 light-years (10 parsecs) away from us. The difference between the apparent magnitude and the absolute magnitude is called the *distance modulus.* It is related in a simple way to the actual distance and is often used instead of the distance.

To determine the distance modulus of any distant system, a curve is constructed showing the relationship of periods to the median magnitude for all the Cepheids variables in the system. For nearby Cepheids, a similar period-luminosity curve is established. In the attempt to extend this curve, points were added for the very short-period cluster-type variables, like RR Lyrae. The two types of variables differ, however, and the curves should really be separated by a gap of 1.5 magnitudes since it is now clear that the classical Cepheids with periods of about 2 days are intrinsically about four times brighter than cluster variables with the same period. A third group of Cepheids, like W Virginis, is now recognized as being related to the cluster variables, although their periods are from 2 to 40 days. They have ranges in brightness smaller than those of the main Cepheids and their light-curves show a double or extended hump near maximum.

Although the relative distances of the galaxies can be determined in several ways, the absolute

values of these distances in light-years are derived primarily from the brightness of the Cepheid variables in them. If then all the so-called normal Cepheids in the external galaxies as well as those in our own galaxy are more luminous than previously believed, the distances of the galaxies are about twice as great as previously calculated.

In the Andromeda spiral galaxy, which is relatively close to us, even the faint cluster-type variables should have been within range of the 200-inch Hale telescope on Palomar Mountain, if they fitted onto the period-luminosity plot with the other Cepheids. Since Baade could not find any such short-period faint variables in the Andromeda nebula, they must be fainter than apparent magnitude 23 and either there are none in that galaxy or it must be farther away than given by the previous scale. Because it is unlikely that there are no short-period variables in the Andromeda nebula and because there were other reasons for suspecting that the normal long-period Cepheids were brighter than previously thought, the accepted scale of galactic distances has been increased. The revised value for the distance of the Andromeda galaxy is 1,500,000 light years.

Using similar arguments, the cluster variables in the Magellanic clouds should be fainter than the 18th magnitude. Last year Thackeray and Wesselink at Pretoria found 32 such variables in two globular clusters associated with the Large Cloud and 4 in one near the edge of the Small Cloud. Based on their brightness, the distances of the Clouds which had been previously estimated as 25 kiloparsecs were redetermined as 45 kiloparsecs (150,000 light-years). From photoelectric measures, Gascoigne and Kron in Australia showed also

that the globular clusters in the Clouds appear fainter than their counterparts in our Milky Way would at 25 kiloparsecs. At 45 kiloparsecs the observed magnitudes agree much better with those in our galaxy. Further evidence that the Clouds are really at the greater distance was added from Shapley's measures of total magnitudes of clusters on small-scale photographs.

Once the distances have been settled, one can interpret some structural features of the Clouds. Their diameters are of the order of 23,000 and 50,000 light-years, compared with about 100,000 for the Milky Way and nearly 130,000 for Andromeda. Based on the revised distances, the mean maximum absolute magnitude for the eight novae which have been recognized so far in the Magellanic Clouds agrees with the brightness which exploding stars attain in our own Galaxy. While the Small Cloud is more transparent and even with long exposures is clearly resolved into stars, the large Cloud contains tangled masses of unresolved nebulous material. Some evidence has been found for a faint spiral structure surrounding the central bright shaft of the Large Cloud. Slightly removed from this axis of symmetry is the 30 Doradus rosette, 400 parsecs in diameter, which is much brighter than the Great Orion Nebula. In addition to the bright emission lines contributed by the nebulous hydrogen, helium, and oxygen gases, dark absorption lines due to interstellar ionized calcium have been identified in the spectrum of the bright blue star in its nucleus. Also, photographs in Hα light have revealed many regions of ionized hydrogen up to 100 parsecs in diameter within the Large Cloud.

In a recent survey of radiation in the neutral

hydrogen line at 1420 megacycles with the 36-foot radio-telescope at Sydney, Kerr and Hindman have shown that the interstellar gas is coextensive with the stars in the Large Cloud, but more widespread and less centrally concentrated than are the stars in the Small Cloud. The profile of the observed emission line in all regions indicates complex turbulent motion of the gas. From both optical and radio studies emerges a general picture of the Magellanic Clouds, which emphasizes the differences between them. In the Large Cloud which is a flattened galaxy, gas and dust are intermixed with a stellar population like that found in the outer parts of spiral galaxies. Conditions there may correspond to an early stage of stellar evolution, where supergiant stars are probably still forming.

The Small Cloud contains a core of stars of a more mixed character, surrounded by a spheroidal cloud composed of gas, but very little dust, with a protuberance extending toward the more massive Large Cloud. Following the current ideas on the formation of stars (Leaflet No. 241), do we infer that the Small Cloud is older, and its supergiants already exhausted?

Although the Cepheids have been studied as extensively as photographic photometry would permit, other types of variables in the Clouds have merely been listed and await more detailed investigation. Many long-period and irregular variables have been recognized, but remarkably few novae; while the search for spectroscopic binaries has not yet begun. Eclipsing binaries are numerous; and one unique system, S Doradus, surpasses in brightness any other known star with the temporary exception of a few supervovae. Sergei Gaposchkin has interpreted from its light-curve, which showed

deep eclipses in 1890, 1930 and 1940, that it is a eclipsing binary and that each of the hot P Cygn type (expanding emission-shell) stars is as big a a sphere containing Saturn's orbit, radiating visibl light at 250,000 times the sun's rate of radiation The occurrence of highly luminous O and B star in our Milky Way system more than 1 kiloparse (3260 light years) from the central plane in galac tic latitude 45° is extremely unlikely, hence, it i necessary to conclude that these stars are not fore ground stars but true members of the Magellani Clouds. Since the hot supergiants closer to us ar all thickly veiled in interstellar dust toward th center of the Milky Way, this pair in the Magel lanic Clouds present an intriguing challenge fo study under more favorable conditions. The dis tances of these Clouds are better established thar are those for most distant bodies of our own Gal axy, where the amount of extinction by intervenin dust clouds is uncertain.

All of the southern observatories have now em barked on extensive programmes to increase ou knowledge of these nearby galaxies. One of th main handicaps, the lack of a consistent magnitud scale for faint stars, is being overcome by succes sive photoelectric comparisons in the northern equatorial, and southern regions of the celestia sphere.