Astronomy. — *"The proper motions of the globular clusters Messier 13, 56 and 2 and their internal motions."*. By ADRIAAN VAN MAANEN.

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In a previous paper the preliminary results were given of the proper motion of and in the globular cluster, Messier 13; these results were derived from two pairs of plates taken at the Cassegrain focus of the sixty-inch Mount Wilson reflector, taken with intervals of 9 and 11 years, respectively. The present paper discusses the results from two pairs of plates of Messier 56 and one pair of Messier 2, taken with intervals of 9, 11 and 11 years, respectively, at the Cassegrain-focus of the sixty-inch reflector (equivalent focal-length = 80 feet) and from one pair of plates each of Messier 13 and Messier 2, taken with intervals of 14 and 15 years, respectively, at the Newtonian focus of the same instrument (focal-length = 25 feet).

As two of the comparison stars used in the former communication showed a considerable proper motion and two other comparison stars used there could not be measured on the plates taken at the 25-foot focus plates, the former results were reduced with the exclusion of these four stars. The annual proper motion of the members of the clusters is thereby changed very little viz., 0″.0015 in each coordinate.

All plates were measured with the monocular arrangement of the stereo-comparator in four positions, with East, West, North, and South in the direction of the increasing readings of the micrometer screw.

In the case of the first measures of Messier 13, Dr. SHAPLEY had indicated which stars might be members of the cluster and which not. The comparison stars were selected from the latter, the selection being based on distance from the center, magnitude and color-index. For the later measures of Messier 13 and for those of Messier 2 and 56, no such data were available. Accordingly a limiting distance was adopted, outside of which it was assumed that no stars were members of the clusters. The cluster-stars were chosen well within these limits. It is, however, still possible that some of the comparison stars may belong to the cluster, and that some of the cluster-stars are in reality foreground or background stars; but the number, in either case, will probably be small and cannot disturb the mean motions very seriously.

The magnitudes of the stars measured in Messier 13 are due to Dr. SHAPLEY, except for 22 very faint stars measured on the 25-foot focus plates; these were estimated to be between the eighteenth and

nineteenth magnitudes. For Messier 56 the magnitudes were derived by Dr. PANNEKOEK and for Messier 2 by Mr. J. A. BROWN, to both of whom, together with Dr. SHAPLEY, I wish to express my sincere thanks for their kind cooperation.

From the proper motions found for the members of the clusters the following conclusions can be drawn:

A. The relative motion of the three clusters with respect to the mean motion of the comparison stars is:

$$\begin{aligned} &\text{Messier 13: } \mu_\alpha = +0''.0015; \quad \mu_\delta = +0''.0005 \\ &\text{Messier 56: } \mu_\alpha = -\ 0.0018; \quad \mu_\delta = +\ 0.0066 \\ &\text{Messier\ \ 2: } \mu_\alpha = +\ 0.0061; \quad \mu_\delta = +\ 0.0042. \end{aligned}$$

With the help of Table 26 of "Groningen Publications", N⁰. 29, we can compute the mean parallactic motions of the comparison stars and the corrections from relative to absolute motions of the clusters. These last are then:

$$\begin{aligned} &\text{Messier 13: } \mu_\alpha = +0''.0005; \quad \mu_\delta = +0''.0008 \\ &\text{Messier 56: } \mu_\alpha = -\ 0.0013; \quad \mu_\delta = +\ 0.0066 \\ &\text{Messier\ \ 2: } \mu_\alpha = +\ 0.0082; \quad \mu_\delta = +\ 0.0026. \end{aligned}$$

Although only three clusters are included in the discussion, it seems worth while to derive from these motions an indication of their mean parallax with the help of the relation between parallax, proper motion, and radial velocity. Using STRÖMBERG's recent value $\overline{V} = 329$ km/sec. for the mean radial velocity of the globular clusters, the result is: $\overline{\pi} = 0''.000061$, which compares favorably with the mean of the three parallaxes found by SHAPLEY, viz., $0''.000065$.

B. The proper motions of the probable members of the clusters were used to compute the probable errors of the motions; for this the deviations of the individual stars from the mean cluster motion were utilized. This gives an upper limit for the probable error, since the internal motions, while small, may still amount to a few thousandths of a second of arc, and further, some stars may have been included which are not members of the clusters. For the plates secured at the Cassegrain-focus we find that the probable error of an individual yearly μ_α or μ_δ derived from one pair of plates is $0''.0030$, for the plates secured at the Newtonian-focus, $0''.0044$; this can be expressed better as $\frac{0''.030}{n}$ and $\frac{0''.064}{n}$, respectively, if n is the interval in years.

C. In "Mount Wilson Contributions", N⁰. 129 [1]), PEASE and SHAPLEY have called attention to the asymmetry found in several globular clusters. While this asymmetry is extremely small, if not negligible, for Messier

[1]) Astrophysical Journal, **45**. 225, 1917.

56, they were able to derive "galactic planes" for both Messier 13 and 2. From the flattening of several of the clusters, as well as from theoretical reasons, we might expect the stars in the clusters to be moving in orbits parallel to the galactic planes, around the center of gravity, but according to Russell such motions should be less than 0″.001 per year even in the nearest of the clusters. The internal motions for the two clusters, Messier 13 and 2, were analyzed into components, parallel to and at right angles to these planes. In both cases the positive sign was used for motion in the directions southeast and away from the "galactic plane", respectively. The results are:

Messier 13

Two pairs of plates, 80-foot focus $\begin{cases} \bar{\mu}\,// = -\,0''.0004 \pm 0''.0003 \\ \bar{\mu}\perp = +\,0.0005 \pm 0.0003 \end{cases}$

One pair „ „ 25-foot „ $\begin{cases} \bar{\mu}\,// = -\,0.0001 \pm 0.0005 \\ \bar{\mu}\perp = -\,0.0008 \pm 0.0005 \end{cases}$

Messier 2

One pair of plates, 80-foot focus $\begin{cases} \bar{\mu}\,// = -\,0''.0003 \pm 0''.0002 \\ \bar{\mu}\perp = +\,0.0002 \pm 0.0002 \end{cases}$

One „ „ „ 25-foot „ $\begin{cases} \bar{\mu}\,// = +\,0.0004 \pm 0.0006 \\ \bar{\mu}\perp = -\,0.0004 \pm 0.0005. \end{cases}$

The dispersion of the motions in the direction parallel to and at right angles to the "galactic plane" is practically the same; this indicates that there is no pronounced motion parallel to the galactic planes.

D. The internal motions for all three clusters were finally analyzed into radial and tangential components, the positive sign being used for motion outward and in the direction **N E S W**.

A radial motion might be expected if the clusters were either expanding or contracting. For Messier 13 we find from the 80-foot focus plates the mean radial motion $+\,0''.0006 \pm 0''.0003$, and from the 25-foot focus plates $+\,0''.0013 \pm 0''.0005$; for Messier 56, $-\,0''.0002 \pm 0''.0005$; for Messier 2, $-\,0''.0004 \pm 0''.0003$ from the 80-foot focus plates and $+\,0''.0019 \pm 0''.0005$ from the 25-foot focus plates. While there is slight preponderance of the positive sign, indicating an expansion of the clusters, the amount is too small to draw any definite conclusions.

From *C* it follows that the motions resulting from a possible rotation of the clusters are small. Tangential components of the motions were derived therefore only because evidence of such motions had been found in the measures of spiral nebulae. The results for the clusters are:

Messier 13	two pairs of 80-foot focus plates:	$\bar{\mu}$rot. $= +0''.0001 \pm 0''.0003$
	one pair of 25-foot „ „ :	„ $= -0.0034 \pm 0.0004$
Messier 56	two pairs of 80-foot „ „ :	$\bar{\mu}$rot. $= -0''.0002 \pm 0''.0003$
Messier 2	one pair of 80-foot „ „ :	$\bar{\mu}$rot. $= +0''.0001 \pm 0''.0002$
	one pair of 25-foot „ „ :	„ $= -0.0026 \pm 0.0005$

In the mean, the tangential component for all the cluster plates taken at the 80-foot focus is exactly 0″.0000, while in the case of Messier 33, observed at that focus, an annual tangential component of 0″.0140 was found; for the cluster plates taken at the 25-foot focus the mean tangential component for Messier 13 and 2 is 0″.0030, while for seven spirals it is 0″.0184.

It has been thought that the large displacements in the spirals might be due to a difference in quality in the old and the new plates. In that case the annual motions derived would be smaller for pairs of plates with longer intervals, but the total displacements would be of the same order, and should be the same for both the clusters and the spirals. We find, however, that the total rotational displacement in the case of the 80-foot focus plates is 0″.070 for the spirals, 0″.000 for the clusters, and, in the case of the 25-foot focus plates, 0″.174 for the spirals, and 0″.044 for the clusters.

The length of exposure too cannot have caused the displacements in the spirals; for all the 80-foot focus plates for Messier 33, as well as for the clusters, these were about half an hour, except for Messier 2, where the exposure times were 15 and 20 minutes. The exposures for the 25-foot focus plates of the spirals ranged from one hour to eight hours, while for the clusters they were 100 minutes and five hours, respectively.

Since the comparison stars for the spirals are brighter, on the whole, than the nebular points measured, it has been suggested that the rotational displacements found in the spirals might be due to some obscure magnitude error. It was for this reason that several faint objects were measured on the plates of the clusters taken at the 25-foot focus. While no stars fainter than magnitude 16.5 could be measured on the plates taken at the 80-foot focus, the range in magnitude for the 25-foot focus plates was from 12.5 to the eighteenth or nineteenth magnitude for Messier 13, and from 10.3 to well below the seventeenth magnitude for Messier 2. No correlation whatsoever seems to exist between magnitude and tangential component.

The result of the investigation therefore is not only a further proof that the internal motions in the globular clusters are extremely small, but it is also a proof that the displacements found in the spiral nebulae cannot be due to any of the systematic errors discussed above.

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