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COMMUNICATIONS FROM THE ASTRONOMICAL INSTITUTE AT AMSTERDAM.

On the possible existence of large attracting masses in the centre of the galactic system,

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From the periodic variation of the mean radial velocities of distant stars with the galactic longitude J. H. OORT derived (*B. A. N.* **120**) that these stars and the sun are describing orbits around a large attracting mass, situated in the same direction of 325° galactic longitude, where SHAPLEY found the centre of the system of globular clusters. The distance was found to be 6000 parsecs and the mass 8×10^{10} times the mass of the sun. The question is raised by OORT why we do not perceive anything of these masses. There are, however, many indications that the largest agglomerations of stars of the Galactic System are situated just in this direction. The brightness of the Galaxy, notwithstanding its irregularities, shows a strong periodicity with galactic longitude. Between 290° and 360° are situated the brightest patches of the Milky Way (Norma, Scorpius, Sagittarius, Scutum); next to them come the less bright parts in Cygnus (30°—50°) and Carina (250°—270°), while from both the brightness decreases to a minimum in Perseus (110° to 130°). And at λ 330°, nearly the direction of the centre, we find the brightest star cloud of the whole Galaxy, between γ, δ, λ and X Sagittarii. Thus it may be of interest to see whether these star clouds may provide the central masses required.

The number of stars in this Sagittarius cloud may be deduced from counts, made by S. I. BAILEY on a number of plates of different exposures, from 1^s to 6^h (*Harvard Circ.* **242**). The limiting magnitudes have been determined from the Harvard Standard Regions. BAILY gives in his Table II N, the number of stars on a square degree, for different limiting magnitudes m. Making a diagram of log N as a function of m, we find a regular curve, showing a steeper ascent below 13^m, and then diminishing its slope again below 16^m. From this curve the values of log N for whole numbers of m were derived (*cf.* Table I) and from them the values of $A_{m+\frac{1}{2}} = N_{m+1} - N_m$, the number of stars of each magnitude. Subtracting A_0, the same number for the average galaxy (from *Groningen Publ.* **27**. Table IV, smoothed), the remaining $A_1 = A - A_0$ may represent the stars belonging to the cloud proper.

TABLE I.
NUMBER OF STARS IN THE SAGITTARIUS CLOUD.

m	log N	log A	log L	L	log A_0	log A_1	log A_1 comp.
10.0	1.11						
		1.32	7.12	0.0013	1.21	0.68	0.00
11.0	1.53						
		1.69	7.09	12	1.61	0.93	0.88
12.0	1.92						
		2.10	7.10	13	1.98	1.48	1.75
13.0	2.32						
		2.70	7.30	20	2.32	2.46	2.52
14.0	2.85						
		3.48	7.68	48	2.63	3.41	3.23
15.0	3.57						
		4.00	7.80	64	2.91	3.97	3.86
16.0	4.14						
		4.21	7.61	41	3.16	4.17	4.42
17.0	4.48						
		4.30	7.30	20	3.39	4.24	4.90
18.0	4.70						
		4.06	6.66	05	3.60	3.84	5.33
19.0	4.79						
				0.024			

Probably, however, the numbers counted by BAILEY for the fainter classes are too small at an increasing rate. Computing the combined brightness $L_{m+\frac{1}{2}} = A_{m+\frac{1}{2}} \times 0.4^{m+\frac{1}{2}}$ (5th column in Table 1) we find the total brightness 0.024 (stars $0^m.0$ per sq. degree). This is much too small for such a bright patch of light. For steps 1, 3, 5 of the scale used in my Northern Milky Way research (*Annalen Leiden* XI, **3**) I derived from the measures of VAN RHIJN a surface brightness 0.017, 0.031, 0.048 (*Astr. Nachr.* **214**, 391); on the same scale the place of the field counted (between γ and δ Sagittarii on the edge of the cloud) is estimated 6—7, thus its surface brightness is certainly above 0.05. In order to get this amount we must assume that from the 17th magnitude downward the numbers are too small, probably by the crowding of stars in the plates of longest exposure, or perhaps also by the scale of magnitudes being in error.

If we suppose KAPTEYN's luminosity curve to apply to this cloud the number of the smaller stars may be computed by fitting the values log $A_1 = f(m)$ to the ascending branch of KAPTEYN's curve $n = \varphi(M)$ (*Aph. J.* **52**, 31). A good agreement is obtained (neglecting the last values) by identifying $m = 12$ with $M = -9.5$ (for $\pi = 1''.0$), and log $A_1 = 4.0$ with log $n = 8.4$ (per 1000 parsecs) (*Vide* colomn log A_1 comp. in Table 1). In this case the modulus of distance $\rho = 5 \log r$ becomes 21.5 (distance 20 000 parsecs) and the total number of stars (log $\Sigma n = 1.6$) becomes log $\Sigma' A = 4.0 + (1.6 - 8.4) = 7.2$; the total brightness of these stars is now 0.055 and by slight changes in the preceding values may be easily brought to any neighbouring amount. Taking the surface of the cloud 50 square degrees we find the total number of stars in the cloud 8×10^8. In the supposition of a mean mass equal to the sun's mass this is 100 times smaller than the mass supposed by OORT. The discrepancy is still larger, because this number of stars is obtained by assuming a distance three times larger than has been derived by OORT.

The connection between the dynamical action of a distant star cloud and its brightness may be deduced by assuming for the distribution of luminosities the formula of KAPTEYN and for the masses the mass-luminosity relation of EDDINGTON. Neglecting in the computation of masses the change of mean type for decreasing absolute magnitude, we find for the total mass per cubic parsec in the surroundings of the sun 0.027 times the sun's mass, for the number of stars 0.045 and for their total brightness 0.055 stars of absolute magnitude 0.0 ($\pi = 1''.0$); the average mass is 0.6 $\odot$, their average light 1.2 stars $0^m.0$, or equal to the sun (adopted $M = -0.2$). Because the apparent brightness of such a group of stars as well as their attraction vary inversely with r^2, we may express the result in this way that with an attraction 0.027 $\odot\, ps^{-2}$ corresponds an apparent brightness of 0.055 stars of magnitude 0.0. Of course this holds only if there is a KAPTEYN distribution of luminosities. If a cloud of stars consists chiefly of giants the attraction is much smaller. If there is a surplus of dwarf stars, as has been made probable by KIENLE, LUYTEN and others, the attraction is greater; but the factor probably will only amount to a few units, and the question whether there is a more considerable quantity of small dark bodies belongs to the theme of dark absorbing matter in space.

Applying this general result to the case of the Sagittarius cloud the apparent brightness $50 \times 0.06 = 3$ corresponds to $M/r^2 = 1.5$, which for $r = 20000$ gives $M = 6 \times 10^8$ (confirming the former evaluation), but for $r = 6000$ gives only $M = 5.5 \times 10^7$, more than 1000 times too small. If we take together all the star clouds and layers of stars which to us appear as galactic brightness, over a longitude of say 80° and a latitude of 20° and assume for them an average surface brightness 0.04 (thus attributing part of the fainter light to absorbing matter), then they have a total brightness $1600 \times 0.04 = 64$, corresponding to $M/r^2 = 31$ and (for $r = 6000$) to $M = 1.1 \times 10^9$, still 70 times too small. The deviation is too great to be removed by a surplus of small dwarf-stars to the KAPTEYN luminosity function. Thus we come to the conclusion that the visible stars of the galactic system cannot provide the required central attracting masses.

OORT mentions the possibility of absorbing nebulous matter obscuring the large star agglomerations responsible for the attraction. In this case, however, the unobscured Milky Way would have a brilliancy at least a hundred times greater than it has, and part of it would shine through the holes of the nebulae. But cannot the dark matter itself act as a part of the attracting masses? In the visual aspect of the Milky Way the dark absorbing nebulae have the same importance as the luminous star clouds. These nebulae, however, are situated at a small distance from the sun, 100—200 parsecs, and the volume of space they occupy is small compared with the more remote clouds. Moreover, since the absorption is probably due chiefly to dark particles, their masses are small. Absorbing nebulae at a distance of 6000 parsecs would appear only in the diminution of the number of faint stars, below the 14th magnitude; thus we have no observational evidence of them.

Another possibility lies in the existence of gaseous interstellar matter. EDDINGTON assumes in interstellar space a density 6×10^{-23}, for which there is one *Ca* atom per cm^3. A sphere of this gas with a diameter of 6000 parsecs $= 10^{22.27}$ centimeters would have a mass of 10^{11} times the sun's mass, far exceeding the collective mass of the luminous stars in the galaxy. The absorption of this gas by electron scattering (taking 2 electrons per cm^2, or $10^{22.57}$ electrons along the diameter of the sphere) would be 0.03 magnitudes, wholly unsignificant. If we may assume, that the interstellar gas is locally concentrated, and that such a concentration takes place around the centre of the galactic system or around the densest star clouds in these parts of space, it appears possible to find the required mass in this gaseous matter.