ON THE CAUSE OF STAR-STREAMING

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ABSTRACT

Assuming tentatively a law for the velocity-distribution in the big stellar universe, the possibility of radial stream-motions due to encounters of stars with vast local accumulations of matter is shown.

In a note on the distances of the cluster-type variables[1] it was suggested that the star-streaming discovered by Kapteyn, the phenomenon of "two star-streams," may be a consequence of the characteristic distribution of high-velocity vectors in our neighborhood of space. This gets special support by the flagrant fact that the line combining the true vertices of the two star-streams is almost exactly at right angles to the direction of the asymmetrical drift of the high-velocity stars. The recent papers by Strömberg[2] bearing on the phenomena associated with very high velocities may make it worth while to consider the matter more in detail.

It was assumed in the paper mentioned that part of the spreading of the high-velocity vectors in the galactic plane at right angles to the asymmetrical drift is due to encounters of the stars in question with the large clouds of stars and nebulosity constituting our "local system," which we may simply identify with the "Kapteyn universe." The ordinary star-streaming should be due to stars of smaller velocity falling in toward the local system, subject to the same gravitational forces and therefore suffering still greater deviations from their original paths, to such an extent that they may, at least for a long time, be counted as members of the local system.

A rough representation of the distribution of projections of stellar velocities on the galactic plane (including the high velocities) may be given by the formula

$$N = A e^{-h(u^2+v^2)} du dv \,, \tag{1}$$

with the restriction

$$v < -\frac{u^2}{2p} \,. \tag{1a}$$

[1] *Astrophysical Journal*, **59**, 37, 1924.

[2] Mt. Wilson Communications, No. 84; *National Academy Proceedings*, **9**, 312, 1923. Mt. Wilson Contributions, No. 275; *Astrophysical Journal*, **59**, 228, 1924.

A, h, and p are constants; u, v, are the components of the velocities; N, the number of velocity-vectors within the element $dudv$. Here the axis of v is directed opposite to the direction of the asymmetrical drift of high velocities. The velocities of a certain size are thus assumed to be distributed uniformly within the parabola $u^2 = -2pv$.[1] The dispersion of the w-component in the directions of the galactic poles is known to be smaller than the dispersion in u. This circumstance may be due to the scattering influence of the local system in the way developed below; outside of the local system and similar aggregations of matter we may assume the dispersions in u and w to be equal, and the conditions for a steady state of motion, including motion of rotation around an axis of symmetry[2] of the big stellar system, to be satisfied. The axis of u should then point toward this center, which seems to be at least approximately the case. The u-direction lies, in fact, only about 20° toward increasing galactic longitude from the direction toward the center of the system of globular clusters according to Shapley.

The reason why the scattering power of the local system should work more strongly in the u- than in the w-component of the velocity is simply the concentration of the stars toward the galactic plane. A much larger number of stars will be scattered sideways parallel to the galactic plane than at right angles to it.

Allowing for this effect of spreading by the local system, we may assume tentatively that at a point far away from local irregularities and density-gradients the inequality (1a) should be replaced by

$$v < -|u| ; \tag{1b}$$

and we assume that, in harmony with the conditions for a steady state of motion of the big stellar system, the dispersions in u and w are the same at such a point.

The permanent members of the local system, which we may suppose form a "nucleus" of the system with small internal motions, may be considered represented by a single unit at the velocity $u=0$, $v=0$. The expressions (1) and (1b) thus represent only those

[1] This accounts approximately for the relation between dispersion and asymmetrical drift found by Strömberg.

[2] Cf. Jeans, *Monthly Notices of the Royal Astronomical Society*, **76**, 81, 1915.

stars which are free to move outside of the local system, and this is the reason for the sharp point at $u=0$, $v=0$, following from the restrictive assumption (1*b*). The form chosen for this expression is, in other respects, not essential, as long as we do not know more about the dynamics of the big system.

The expressions (1) and (1*b*) may be interpreted physically on a still wider basis in the following way. The velocity $u=0$, $v=0$, represents a purely orbital motion of a system around the center of the big system, with internal motions. We may assume that the purely Milky Way clouds, or more strictly their nuclei, which evidently form a very flattened system, are represented by this velocity. Our local system has then to be identified simply as a Milky Way cloud. With decreasing orbital motion the internal dispersion of the velocities increases, and the stars can no longer belong permanently to the clouds, but move freely as members of the bigger system. There seems to be a continuous transition from the state of motion of the Milky Way clouds to that of the system of globular clusters. Judged from the results for the motion of the spiral nebulae, and from the flattened form of the last-mentioned system, this system must probably be supposed to have a general motion of rotation also.

The object is to show how the actual distribution of velocities can be derived from a distribution of velocities of the type represented by relations (1), (1*b*).

Let x, y, be co-ordinates in the galactic plane such that

$$u=\frac{dx}{dt}\,, \qquad v=\frac{dy}{dt}\,,$$

with the origin at the center of the scattering mass M (Fig. 1). Let, further, P be a point on the negative side of the y-axis at the distance $\bar{y}$ from M. We assume that very far from M and P the distribution of velocities is of the form (1), (1*b*), without further stream motion, only with the inclusion of a potential term due to M in the exponential, thus

$$\left.\begin{aligned} &N=Ae^{-h(u^2+v^2-2\Omega)}du\,dv\,,\\ &v<-|u|\,. \end{aligned}\right\} \qquad (2)$$

Consider a velocity-vector moving originally, very far from M, parallel to the y-axis with the velocity V', and with the abscissa x'. In order that the velocity shall pass through P, it is easily shown that we must have

$$a(e^2-1)=2\bar{y}\ ,$$

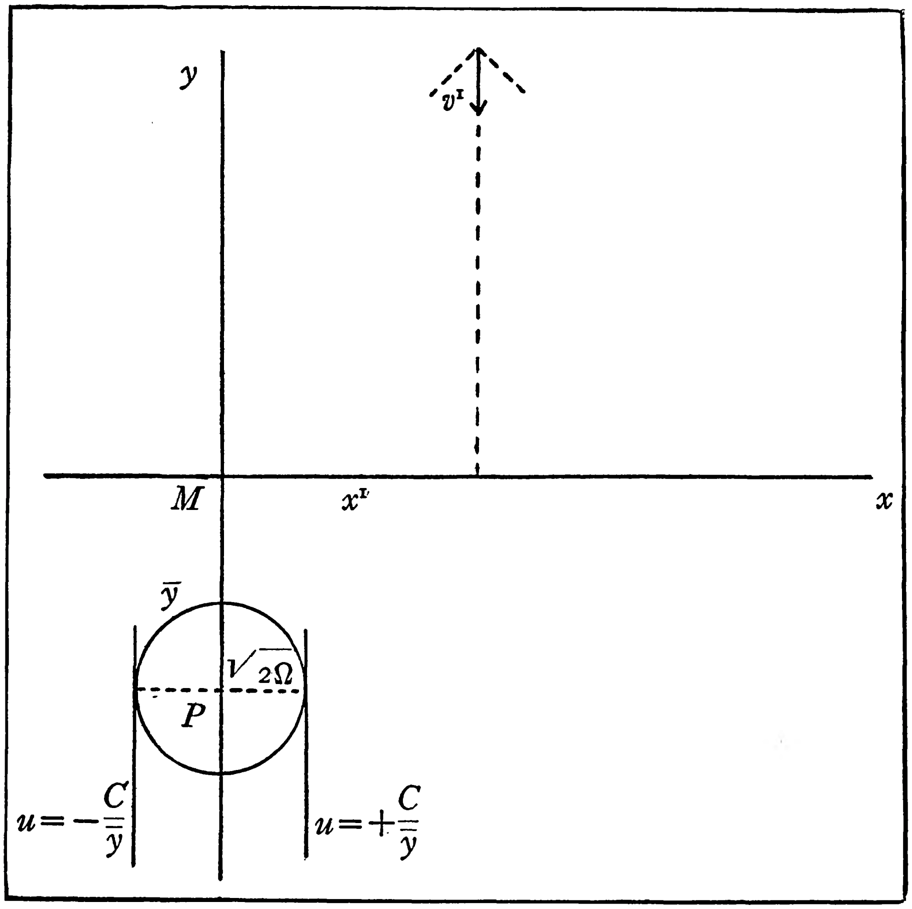

FIG. 1

where a is the semi-axis, e the eccentricity of the hyperbolic orbit around M. Now we have

$$xv-yu=-V'x'=\pm\sqrt{GMa(e^2-1)}\ ,$$

where G is the constant of gravitation, thus

$$xv-yu=\pm\sqrt{2GM\bar{y}}=C=const.\ , \tag{3}$$

independently of the eccentricity of the orbit. For velocities V' of other directions, with components u', v', but obeying the condition $v' < -|u'|$, the angular momentum necessary for passage through the point P will vary with the eccentricity of the orbit, but only to a comparatively slight extent. Another reason for non-compliance with the relation (3) will be found in disturbances of the star on its way by the gravitational action of other masses than M.

We want to know the distribution in u, v, of fairly small velocities in the region around P. The number of stars of given u, v, having an angular momentum without regard to sign *slightly smaller* than $\sqrt{2GM\bar{y}}$, may be assumed to be proportional to

$$e^{-n[C^2-(xv-yu)^2]}\,, \tag{4}$$

where n is a constant, and thus the distribution of velocities at P (because the exponential in [2] is an integral of the motion) will be

$$\left.\begin{aligned} &N = A_1 e^{-h(u^2+v^2-2\Omega)+n\bar{y}^2u^2}dudv\,, \\ &v' < -|u'|\,, \qquad u^2+v^2 \geq 2\Omega\,, \quad |\bar{y}u| \leq C\,. \end{aligned}\right\} \tag{5}$$

The distribution of velocities will thus be represented by the velocity-ellipse (or hyperbola, if $n\bar{y}^2 > h$)

$$(h-n\bar{y}^2)u^2+hv^2=\text{const.}\,, \tag{6}$$

having its greatest elongation at right angles to the asymmetrical drift of the high velocities.

Velocities of a certain original direction excluded by the condition $v' < -|u'|$, having the constant angular momentum $\sqrt{2GM\bar{y}}$, can only pass close to P for a very limited range of the eccentricity of the orbit, and will pass in the direction of the positive y-axis, i.e., with $v > 0$. The restriction $v' < -|u'|$ may therefore be assumed to give at least the lower half of the velocity-ellipse (6), i.e., the half of the ellipse on one side of the major axis. Because n must be supposed to be of appreciable magnitude, the second restriction $u^2+v^2 \geq 2\Omega$ will practically have only two transverse streams in opposite directions along the major axis. The third condition $|\bar{y}u| \leq C$ will limit these stream-velocities to the velocity in the parabola with vertex at P.

If we consider velocities of angular momentum somewhat exceeding $\sqrt{2GM\bar{y}}$, the number of stars of given u, v, will be assumed proportional to

$$e^{-n[(xv-yu)^2-C^2]} ,$$

and the velocity-ellipse will be

$$(h+n\bar{y}^2)u^2+hv^2=\text{const.} , \tag{7}$$

with the restrictions

$$v'<-|u'| , \quad |\bar{y}u|>C ,$$

having the major axis parallel to the y-axis. The condition $v'<-|u'|$ will exclude the upper part of the ellipse. The remaining part will show transverse symmetrical star-streaming parallel with the x-axis, with a tendency to an asymmetrical drift in the direction of the negative y-axis along the lines $u=\pm C/\bar{y}$.

We must, however, make a special remark here. We have assumed the mass M to be a nucleus of high density, so that the force is everywhere proportional to r^{-2}. This will not be the case if M is an aggregation of stars or very thin nebulosity. Then we must assume that for a star passing through the attracting mass the attracting force decreases with decreasing r. The character of the asymmetrical drift will be somewhat different for this reason, because the stars passing near the origin on their way through P can have much smaller velocities than in the present theory.

In order to get quantitative estimations of the transverse star-streaming, we have to consider the two streams represented by the motions in opposite directions in the parabola with vertex at P.

The velocity V at P of a star moving in the parabola in question will be given by

$$V^2=GM\frac{2}{\bar{y}} .$$

Imagine a mass of ten million (10^7) solar masses in a sphere with radius 300 parsecs, which will give about one star of the mass of the sun in 10 cubic parsecs, a density which may be considered quite normal in an accumulation of stars. The velocity V at the boundary of the cluster will be 17 km per sec. The star-streaming at the boundary will be double this amount, thus, 34 km per sec.

If fairly isolated masses of the dimensions mentioned exist in the local system, there may be a star-streaming of the kind considered at several points of the local system, and this must in the course of time affect the velocity-distribution in the local system as a whole, as there will be no similar streaming in other directions.

In any event, if our conception of the local system has to be widened, in respect to the character of motion, to include the Milky Way clouds as a whole, it seems very possible that we may have to include in our consideration discrete accumulations of matter sufficient to produce a general transverse star-streaming of the observed magnitude.

The theory of Jeans,[1] attempting to interpret star-streaming as due to circular motion in both directions around the center of the local system, need not, of course, stand in absolute contradiction with the present considerations. From the point of view of that theory, the star-streaming considered here may be the ultimate cause of the rotations in opposite direction around the center of the local system. But if the observed star-streaming is supposed to be due entirely to such circular rotations, the coincidence of the line of the vertices with the normal to the direction of the asymmetrical drift of high velocities must be considered as a mere chance, due to the circumstance that the direction toward the center of the local system happens to coincide with the line of asymmetrical drift.

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[1] *Op. cit.*, **82**, 122, 1922.