A NEW THEORY OF THE MILKY WAY.

By C. EASTON.

§ 1. MY investigations on the apparent distribution of the stars in a part of the Milky Way, undertaken several years ago and published in the ASTROPHYSICAL JOURNAL, Vol. I, No. 3, March 1895,[1] seemed to indicate that it has a roughly annular structure. However, at the end of these articles I pointed out that there is nothing to prove that all parts of such a hypothetical ring — evidently very irregular in its details — are at the same distance from our Sun, nor even that it is a closed ring, independent of the central part of the galactic system. Moreover, Professor Seeliger, in an exhaustive discussion on the distribution of stars in space,[2] remarks that the conclusions reached in these articles do not necessarily apply to the entire Milky Way; he also thinks that the stellar accumulations of the Milky Way in different directions are probably at different distances.

I now propose to show that the annular theory of the Milky Way is in reality incompatible with the present state of our knowledge of the galactic phenomenon, and as there is little reason to hope that the great problem of the constitution of the visible universe will be definitively solved in the near future, I have added certain general considerations which seem to lead to a new theory of the structure of the Milky Way in space.

§ 2. If we assume that the actual form of the Milky Way corresponds with its apparent form: that of a ring surrounding us on all sides — what position must then be assigned to the Sun?

It does not seem to be situated near the center of the ring. In fact, a single glance at the Milky Way on a clear evening

[1] *Cf. A. N.*, **137**, No. 3270.

[2] "Betrachtungen über die räumliche Vertheilung der Fixsterne." *Abh. d. k. bayer. Akademie d. Wiss.*, II Cl., XIX. Bd., III. Abth., 1898.

in August or September reveals a peculiarity which has apparently been given less importance than it merits: the great superiority in brightness of the Milky Way near *Aquila* as compared with that near *Monoceros*. It may be inferred from this that in general the stars are more numerous near the XVIIIth hour than near the VIth hour of right ascension.[1]

This unequal distribution of the stars of the Milky Way, not only in detail, but also for the two halves of the zone as compared with each other, when it is represented as divided along a line through *Crux* and *Cassiopeia*, is still more striking in the results of stellar gauges and enumerations. The mean result of William Herschel's gauges in the region of *Aquila* is 161.5 stars; in that of *Monoceros*, 82.5 stars. Similarly, Celoria, systematically counting the stars to about the eleventh magnitude in an equatorial band six degrees wide, has found 58,883 stars in the half of this band which is traversed by the Milky Way near XVIII^{h}, and only 43,822 in the opposite half.[2]

William Herschel's gauges and Celoria's enumerations include regions of very different areas and embrace very diverse stellar magnitudes; for this reason alone it is almost inadmissible that the divergence indicated can be the effect of a chance accumulation of stellar condensations near the constellation *Aquila*. Furthermore, the aspect of the sky, and the charts of the Milky Way where account has been taken of the general distribution of the galactic light in the various parts of the zone, seem to indicate a certain measure of gradation in the brightness. Encke, in his criticism of Struve's theory,[3] insists that if such a supposition is made—eccentric position of the Sun—values should be given for the stellar density intermediate between the maximum and minimum density; these values must then agree with a quantity determined by the eccentricity.

[1] *Cf.* PLASSMANN, *Mittheilungen der V. A. P.*, III, 1893, Berlin, Dümmler, 1893, p. 102; Easton, *Verslagen d. Kon. Akademie, Amsterdam*, 1897–8, p. 383.

[2] F. G. W. STRUVE, *Études d'astronomie stellaire*, 1847, note 75; G. Celoria, "Sopra alcuni scandagli del cielo," *Pubbl. del R. Osserv. di Brera*, **13**, 18.

[3] *A. N.*, **26**, 622.

The observations at our disposal at the present time are certainly not sufficiently numerous to permit such an investigation to be undertaken, and it is to be feared that the marked irregularities of a purely local character, in the structure and brightness of the Milky Way, will always stand in its way; but we may at least endeavor to indicate the principal features of the distribution of brightness in the Milky Way.

In his *Uranométrie générale*, Houzeau has enumerated thirty-three bright spots and regions of the Milky Way; he has also estimated their brightness. Although his method (indicated on page 15 of this work) cannot give results of great precision, we may certainly regard as "fairly bright" the spots which he estimates as of magnitude 5–6, and as "bright" those which he estimates as 5 or 4–5. By dividing the entire Milky Way into halves by a line passing through *Crux* and *Cassiopeia*, I find in the half which contains *Monoceros* four or five fairly bright spots and not a single bright spot; in the half which contains *Aquila* I find seven or eight fairly bright spots and seven bright spots. The conclusion is the same as for the gauges of Herschel and Celoria.

Considering only the zone comprised between $-45°$ and $+45°$ I find two fairly bright spots and no bright spot near VI^h, as against six fairly bright spots and five bright spots near $XVIII^h$.

It follows that these apparent accumulations are comparatively most numerous in the region of *Aquila*, between $-45°$ and $+45°$, and that they are least numerous in the opposite zone, near *Monoceros*. From this point of view these two zones, each embracing a quarter of the circumference, are in the ratio of 5.5 to 1, while for the corresponding *halves* of the Milky Way, the ratio is 2.8 to 1. On my chart of the Milky Way it may be seen that the general brightness of the Milky Way diminishes pretty gradually from *Cygnus* to *Cassiopeia;* the same thing occurs between *Ara* and *Navis* in the southern hemisphere. But the gradation is very incomplete: between α *Persei* and α *Aurigae*, for example, the brightness of the Milky Way is much less marked than between α and θ *Aurigae*.

Gould remarks (*Uranometria Argentina*, p. 370) in speaking of the Milky Way in the southern hemisphere: "Its brightest portion is unquestionably in *Sagittarius*, that in *Carina* being slightly inferior to this as regards intrinsic brilliancy, although far more magnificent and impressive on account of the great number of bright stars with which it is spangled."

After having indicated this characteristic feature in the general distribution of brightness in the Milky Way, we may attack the problem from a different side.

§ 3. It is easy to imagine the aspect of the heavens, for each of the typical positions which may be assigned to the Sun, from the interior of the Milky Way considered as a stellar ring.

We may then distinguish the five following cases:

a. The Sun occupies the center of the ring. In this case the Milky Way will appear as a more or less irregular luminous band, in which the irregularities in the distribution of the stars (dark and bright spots, richness in bright stars, unequal width of the zone) are not grouped systematically with reference to any given point of the circumference.

b. The Sun occupies an eccentric position.—The brightness of the Milky Way is less marked near 180° than near 0°, rapidly increases up to a point beyond 90° (270°), then more gradually or insensibly to about 0°. Between 180° and 90° there are many bright stars; these become less numerous as the zero point is approached. The width of the Milky Way is greater near 180° than near 90° (Fig. 1).

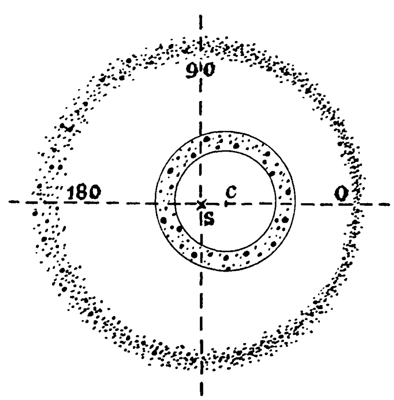


FIG. 1.

c. The Sun is situated on the inner edge of the ring.—The difference in the width of the Milky Way near 0° and near 180° is much more marked; the maximum of faint stars occurs between 0° and 90°, that of the bright stars at about 90°. Near 180° the Milky Way is very broad, vague, and very faint; whether the galactic light in this part of the sky is still even perceptible will depend on the thickness of the ring (Fig. 2).

d. The Sun is situated in the body of the ring.—Towards 180° no trace of the Milky Way will be visible, nor will the bright stars be very numerous in that region. Between 180° and 90° a faint galactic glow commences to appear, which increases pretty rapidly toward 90°; the bright stars also become more numerous and are seen in greater number beyond 90°. At first scattered, between 180° and 90°, over nearly a semi-circumference, the galactic glow grows narrower and narrower, becoming at the same time more brilliant, and the brightness attains its maximum between 90° and 0°. The Milky Way is narrowest near 0° (Fig. 3).

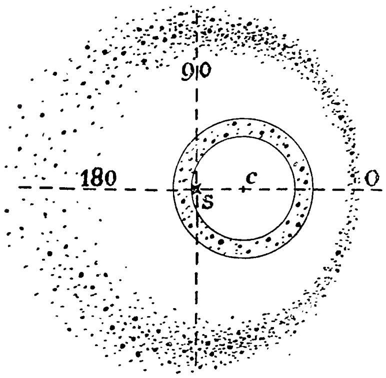


FIG. 2.

e. The Sun is situated on the outer edge of the ring.—The phenomenon which I have just described under *d* can hardly be called "Milky Way," but in this last case (*e*) nothing is seen but a spindle-shaped nebulous glow occupying less than half a great circle, with a long and narrow condensation. An immense mass of stars, of a somewhat nebulous appearance, and an empty sky surrounding them.

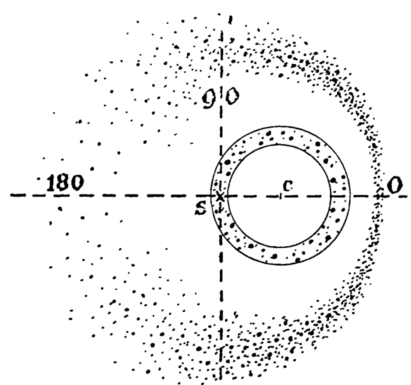


FIG. 3.

§ 4. The general aspect of the Milky Way, as it appears to us, and the result of stellar gauges and enumerations to which reference has already been made, would correspond very well with case *b* if it were not for an important exception regarding the *width* of the zone.

The limits of the Milky Way are so vague that it is impossible to measure the width exactly on the drawings. According to the charts by Boeddicker and myself, the Milky Way is a little wider near *Monoceros* than near *Aquila*, taking into account the separate branches; according to Gould's chart, on the contrary, it is a little wider near XVIII^h.[1] However this may be, in the theory of a galactic ring one would expect to find a very striking difference *in width*, as the difference between the *brightness* of the opposite regions is so evident.

But we possess a surer means of measuring the width of the Milky Way, independently of the optical phenomenon, *i. e.*, the width of the zone where the stellar density is higher than the average. In discussing the results of his stellar enumerations, Celoria (*loc. cit.*, tav. V.) gives diagrams of the stellar density in an equatorial zone 6° wide, (1) for the stars of Argelander's *Durchmusterung*, (2) for the stars to about the eleventh magnitude, counted at Milan, (3) for the stars comprised in W. Herschel's gauges between +20° and −20°, corresponding to Celoria's zone. By measuring the horizontal projection of the curves which rise above the mean, the following results are obtained:

a. When only the stars of the *DM.* are considered (magnitude about 0–9.5), the Milky Way is about 5° wider near VI^h than near XVIII^h.

b. For Celoria's stars, on the contrary (magnitude about 0–11), the Milky Way is about 18° wider near XVIII^h than near VI^h.

c. The gauges of W. Herschel (magnitude 0–14?) similarly indicate that the Milky Way is about 4° or 5° wider near XVIII^h than near VI^h.

Thus, *for the faint stars taken as a whole, the Milky Way is widest in its brightest part*, and at least for Herschel's gauges, this certainly cannot be explained by local causes.

This result is evidently not in harmony with case *b*, § 3, which is nevertheless the only supposition that seems to correspond with the appearance of the sky and the result of the star gauges,

[1] BOEDDICKER, *The Milky Way*, London, Longmans, and New York, Scribner, 1892; Easton, *La Voie lactée*, Paris, Gauthier-Villars, 1893; Gould, *Uranometria Argentina*, 1879.

in the theory of an annular Milky Way. This theory thus leads us to the following dilemma: the galactic ring is a ring the chance irregularities of which are markedly, one might even say systematically, grouped with reference to a certain part of the circumference—which is extremely improbable—or else it broadens considerably in one half of the circumference, which appears no more probable.[1]

§ 5. May it not be that the anomaly which we have just noted in the width of the Milky Way near XVIII^{h}, as compared with the opposite part of the zone, is due to the fact that the ring is really double, over nearly one half of its circumference, as it is shown in the old drawings of the Milky Way?

At first sight it would seem strange that, for one of the halves of the ring, there should exist, not a division, but an actual duplication—for twice as many stars are counted on the "two branch" (*Aquila*) side as on the opposite side—and especially since the classic division of the galactic zone into two *distinct and separate* branches, between *Cygnus* and *Centaurus*, no more exists than the single band between *Cassiopeia*, *Monoceros*, and *Crux;* this follows from all the evidence of the modern charts and photographs of the Milky Way. On the one hand the northern (secondary) branch of the Milky Way is not a single and continuous stream, and the part between δ *Cygni* and γ *Ophiuchi* cannot be regarded as the continuation of the luminous regions toward *Scorpius* and δ *Ophiuchi;* and on the other hand the ramifications properly so-called seem to be even more numerous in the part which was formerly regarded as single than in the "double" part of the Milky Way.

With a little good will it is possible, however, to trace a zone, starting from ϵ *Cassiopeiae*, through γ and δ *Cygni*, ϵ *Aquilae*,

[1] Sir John Herschel (*Outlines of Astronomy*, § 788) assigned to the Sun an eccentric position in the Milky Way on the side nearest the southern parts of the zone, on account of their great brightness and their better defined boundaries. Proctor has followed the same reasoning for the construction of his spiral (*Monthly Notices*, **30**, 50). From what precedes one would infer, on the contrary, that the Sun is, in general, nearer the vague and faintly luminous parts of the Milky Way. Proctor's "spiral," moreover, explains none of the principal features of the galactic phenomenon, although it led its author to make interesting remarks.

θ Ophiuchi, and terminating at *α Centauri*, in which the galactic light is in general more brilliant than between this zone and the principal branch of the Milky Way. It is even possible to regard the faintly luminous streams between *ζ Persei*, *δ Orionis*, and *ε Canis Majoris* as the continuation of this "secondary" Milky Way, and also to connect it with "the belt of bright stars" of John Herschel and Gould, extending through *Taurus*, *Orion*, *Crux*, *Scorpius*, etc. We should thus have an indication of two principal planes, in which are grouped both the bright and the faint stars of the Milky Way.

It may be remarked that Celoria (*loc. cit.*, 42; *cf.* Gould, *loc. cit.*, 381) by a process of reasoning different from that which has led us to reject the theory of a single ring, reaches the conclusion that there exist *two galactic rings*, inclined to each other at an angle of 19° or 20°, one of which contains principally the fainter stars, the other the bright stars. Celoria is unable to decide whether these two rings coincide at the point where they appear to touch. The principal ring, composed particularly of faint stars (*i. e.*, distant stars, in Celoria's hypothesis) would be projected on the sphere in a great circle traversing *Sagitta*, *Auriga*, *Monoceros*, *Scutum;* the secondary ring would include the branch of the Milky Way in *Ophiuchus*, the branches in *Orion*, the *Hyades*, the *Pleiades*, and the belt of bright stars.

§ 6. Assuming that the belt of bright stars and the secondary branch of the Milky Way (which seems to be the cause of the incompatibility between the aspect of the Milky Way and the annular theory) are due to the same cause: the existence of a *secondary galactic ring*, it will be noticed that the belt and the secondary branch are, so to speak, complementary; the bright stars are numerous where the secondary Milky Way is very faint—*Taurus*, *Orion*, etc.—and, on the contrary, the belt of bright stars is almost wholly effaced where the secondary branch of the Milky Way is fairly bright—*Ophiuchus*, *Cygnus*. Thus, for this secondary galactic ring, the position of the Sun should correspond with case *c*, § 3—and hence the secondary ring must be *much smaller* than the principal ring—while this position will be intermediate between cases *b* and *a* so far as the principal ring is concerned.

If now we place the center of the secondary ring at some distance from the center of the principal ring, and outside of the principal plane, the Sun being near the line of intersection of the two planes *p I p'* (Fig. 4*a*), the *general features* of the galactic

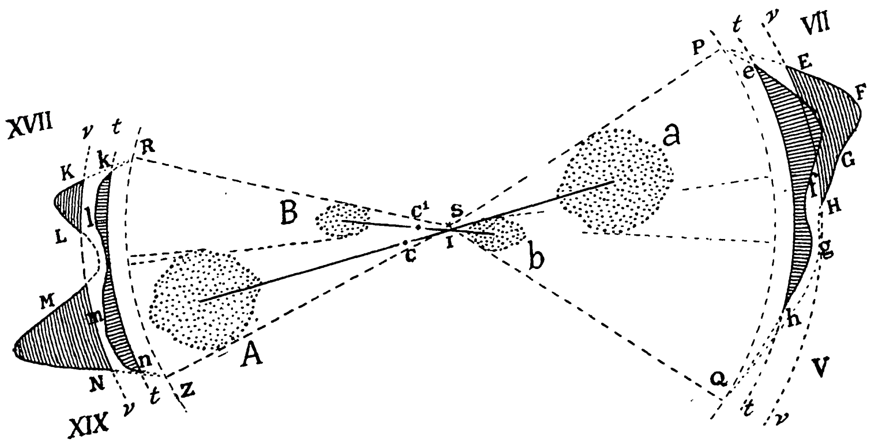


Fig. 4.

phenomenon are fairly well explained by what we may call Celoria's modified theory.

In Fig. 4 let *c* and c^1 be the centers of the two galactic rings, whose equatorial sections are *A*, *a* and *B*, *b;* let *I* be the projection of the line of intersection of the two galactic planes, and *S* the position of the Sun; the angle *PSQ* will be greater than the angle *RSZ*. For the stars of the *DM.*, *a* and *b* unite to produce a density greater than the average near VI^h, because stars of various magnitudes are mingled together in the Milky Way, and because, consequently, there is also a surplus of bright stars near *a*, although the great majority of the stars at *a* (*i. e.*, of the outer galactic ring) escape observation, which nevertheless includes the greater part of the stars of *b*, the interior ring. All that is above the average density (theoretical Milky Way)[1] for the stars of the *DM.* is indicated by the curve *efgh*. But Herschel's

[1] The *optical* Milky Way, which is a rather complex and purely subjective phenomenon (*cf.* my *Milky Way*, Introduction, p. 12), thus resembles a theoretical Milky Way composed of a great number of telescopic stars fainter than magnitude 9.5.

gauges contain the greater part of the faint stars included in *a*, while in the direction of *b* the number of stars increases in a much less rapid proportion; in fact, hardly increases at all beyond a certain telescopic power. The Milky Way for Herschel's stars will be indicated by the curve *EFGH*, less extended than the curve *efgh*. Near XVIII^h, on the contrary, especially on account of the distance of *B* as compared with *b*, the stars of the interior ring contribute in an important degree toward the formation of the Milky Way, and this narrowing of the Milky Way in proportion as the number of telescopic stars increases will be less sensible; for the telescopic stars the Milky Way may be as broad as, or even broader than the zone near VI^h. The density of the Milky Way in the direction of XVIII^h will be greater on account of the greater distance; therefore it will also be more brilliant.

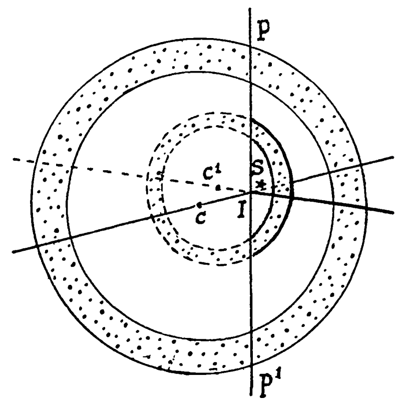


FIG. 4*a*.

The Sun cannot be very far from the line of intersection of these two principal planes of the Milky Way, which terminate in *Cassiopeia* and *Crux*, a distance of about 180°. This forces us to place the center of the secondary (interior) ring rather distant from the plane of the principal ring, which appears to be a weakness in this theory. If we could assume the existence of an actual condensation of stars in the direction of *B* (see Fig. 4), this would explain the brilliancy of the Milky Way in the direction of *Cygnus* and *Ophiuchus*, and we would be free to make the interior ring still smaller and to bring the center c^1 nearer the point *I*. We shall see in what follows that there in fact seems to be a plausible reason for making such an assumption.

§ 7. However, all that has been learned regarding the constitution of the Milky Way since the ingenious investigations of the Italian astronomer — more thorough studies of the Milky Way with the naked eye, structure of galactic clouds revealed by photography, etc.—forces us to admit that the Milky Way cannot be composed of two distinct, uninterrupted rings, as Celoria believed ("due anelli distinti, nè mai interrotti nel loro corso," *loc. cit.*, p. 41). In reality, the structure of the Milky Way, even in its principal features, must be much more complicated.

Nevertheless this fact does not require us to reject all the considerations set forth in the above paragraphs. On the contrary, although the irregularity of the Milky Way is evident enough so far as the details of the zone are concerned, and although the situation of our Sun makes it very difficult for us to discover a definitive arrangement of the stars and stellar groups which surround us on all sides in the plane of the Milky Way—there are nevertheless indications that regularity is not altogether lacking in the distribution of the galactic stars; evidence that, so to speak, our stellar system possesses a certain degree of organization.

Let us first pass in review these indications, and subsequently consider the modifications which can advantageously be made in the theory stated in § 6.

I need not here dwell upon the fact—first pointed out by William Herschel (although contradictory to his first hypothesis of the uniform distribution of all stars in space): the reality of the clustering tendency which is seen in certain parts of the heavens. While in certain regions of space the distances between stars are enormous and the stars are quite alone or grouped only in binary and triple systems, etc., there are other regions where the original matter has condensed in star clusters, and still others where accumulations of stars of different magnitudes occupy very extensive regions of celestial space. Bauschinger and Sidney Waters have pointed out the correlation between these last two phenomena, *i. e.*, that star clusters for the most part follow the ramifications of the Milky Way. The same is true, it would appear, of diffused nebulosities.

It nevertheless does not follow that there must exist an organic connection between the stellar groups of the Milky Way, nor that the stars which are clustered together, and those which are relatively isolated, should form two independent systems.

§ 9. If it is no longer possible to regard the stellar accumulations of the Milky Way, taken as a whole, as a ring, or even as two interlacing rings, the aspect of the Milky Way by no means excludes the existence of annular segments or of streams or strata of stars.

The majority of the stars seem to be grouped in two principal planes. This conclusion, developed in Celoria's investigations, is found in slightly different form in the writings of John Herschel and Gould ("belt of bright stars," "cluster of bright stars." *Cape Observations*, 1847, § 321; *Uran. Argent.*, 368). Ristenpart states that the principal plane of the Milky Way is not a broken plane, but is composed of two planes slightly inclined to each other.[1] Struve, who preferred a "broken plane," did not exclude the idea that "the most condensed layer of stars lies in two planes" (*Et. d'astr. stell.*, 1847, p. 82).

Such an arrangement of the greater part of the stars in two planes, slightly inclined to each other, would appear hardly compatible with the idea of a purely fortuitous distribution of the stars in the galactic layer.

§ 10. The aspect of the Milky Way does not correspond to the projection of agglomerations distributed by chance in space, which would rather produce series of superposed spots, for the most part condensed toward the center, and in general more numerous and more brilliant as the galactic equator is approached, without characteristic differences in the various portions of the zone.

On the contrary, in many parts of its course the Milky Way is composed principally of stellar beds or streams, frequently irregular, it is true, but of a character which differs essentially from the appearance which would be produced by the projection of irregular clusters situated at different distances (*cf.* the photographs of the regions surrounding *Crux*, *Scorpius*, ϵ *Cygni*, δ *Cephei*, etc.)

[1] *Veröffentl. grhz. Sternw. Karlsruhe*, 1892, p. 67.

Furthermore, it follows from even a superficial study of the aspect of the Milky Way that the constitution of the belt exhibits characteristic differences when extensive and widely separated parts are compared among themselves. Relatively uniform regions immediately follow flocculent regions; here series of spots are seen, there ramifications extending over enormous distances. As examples we may cite the Milky Way in *Sagittarius* and *Scutum*, in *Cygnus* and *Lacerta*, in *Cassiopeia* and *Perseus*.

It is also a remarkable fact that the gradation of the light in passing from the edges toward the middle of the belt is very different in different parts of the Milky Way. Thus, in the principal branch which passes through α *Aquilae*, the brightness decreases gradually from the inner edge toward the outer boundary, while in the secondary branch (from *Lupus* to *Camelopardus*) the luminosity is much more uniform. The region between γ *Sagittae* and ν, δ, and β *Cygni* is an exception: the principal branch here appears vague and dull, and a great bright spot extends from γ to β *Cygni*, encroaching a little on the dark interval.[1]

§ 11. In addition to these characteristic features there is the tendency to form streams and branches. Sir John Herschel, who was perfectly acquainted with the telescopic structure of the Milky Way, called attention to the fact that in the southern hemisphere he saw a series of star clusters distributed along a luminous band of the Milky Way, while no cluster was visible in the dark interval between the galactic branches.[2] He speaks elsewhere of fainter and less clearly defined streams and again of the tendency of the secondary streams to unite with the principal stream.[3]

Telescopic observation suggested to him still more precise ideas. "In some [regions], for instance," he remarks, "extremely minute stars, though never altogether wanting, occur in numbers so moderate as to lead us irresistibly to the conclusion that in

[1] GOULD, *loc. cit.*, 381; Easton, *Voie lactée*, Description, pp. 41, 47.

[2] J. HERSCHEL, *Cape Observations*, 1847, p. 387; *cf.* Sidney Waters, *Monthly Notices R. A. S.*, LIV.

[3] *Ibid.*, p. 386.

these regions we see *fairly through* the starry stratum, since it is impossible otherwise (supposing their light not intercepted) that the numbers of the smaller magnitudes should not go on continually increasing *ad infinitum*. . . . In other regions we are presented with the phenomenon of an almost uniform degree of brightness of the individual stars, accompanied with a very even distribution of them over the ground of the heavens, both the larger and the smaller magnitudes being strikingly deficient. In such cases it is equally impossible not to perceive that we are looking *through* a sheet of stars nearly of a size, and of no great thickness compared with the distance which separates them from us. Were it otherwise we should be driven to suppose the more distant stars uniformly the larger, so as to compensate by their greater intrinsic brightness for their greater distance, a supposition contrary to all probability. In others again, and that not infrequently, we are presented with a double phenomenon of the same kind, viz., a tissue as it were of large stars spread over another of very small ones, the intermediate magnitudes being wanting. The conclusion here seems equally evident that in such cases we look through two sidereal sheets separated by a starless interval."[1]

In several parts of the Milky Way one notices (not on the photographs, which are incomparable for the study of the structure of the details, but do not bring out the greater features of the galactic image) what Dr. Boeddicker calls "the tendency to duplication;" this tendency is particularly noticeable in *Cassiopeia* and *Perseus*.[2] It would seem very difficult to reconcile this phenomenon with the absence of all structure in the Milky Way.[3]

[1] *Outlines*, § 797.

[2] BOEDDICKER, *Monthly Notices R. A. S.*, L, No. 1; Easton, *Voie lactée*, Plate III and Description, p. 49.

[3] I cannot here enter into a discussion of the much disputed question of the reality of "star drifts" (Proctor), ellipses and wreaths (Holden), lines of stars (Ranyard, Backhouse), etc.

It is equally impossible in this necessarily limited discussion to consider the interesting investigations which treat of the relation of the galactic plane to the distribution of the various spectral types, Wolf-Rayet stars, new stars, etc., by Dunér, Pickering, McClean, Campbell, Kapteyn, and others, nor the investigations on the distribution of nebulæ, the constitution of the Magellanic clouds, etc.

§ 12. The dark spots and bands in the Milky Way particularly merit our attention. A well-known argument of Sir John Herschel is drawn from the fairly regular dark spots; "When we see, as in the coal-sack, a sharply-defined oval space free from stars, insulated in the midst of a uniform band of not much more than twice its breadth, it would seem much less probable that a conical or tubular hollow traverses the whole of a starry stratum, continuously extended from the eye outwards, than that a *distant* mass of comparatively moderate thickness should be simply perforated from side to side, or that an oval vacuity should be seen foreshortened in a *distant* foreshortened area, not really exceeding two or three times its own breadth."[1]

The "coal-sack" near the Southern Cross is better known, but is perhaps not more remarkable than certain other similar openings in the Milky Way. I cite in the first place the elliptical spot situated half way between *α Cygni* and *α Cephei.*[2] Notice also the curious little black spots, which so well produce the effect described by Herschel as an "oval vacuity," between *α* and *f Cygni*, on Max Wolf's photographs.[3] As opposed to Sir John Herschel's argument the objection has been raised that the proximity of the dark and bright spots in the Milky Way does not exclude the possibility that in this direction the cosmical matter may be greatly extended in the line of sight, since the probability of the existence of apertures in an accumulation of a limited number of stars does not depend upon the dimensions in the line of sight.[4] A popular objection would be that portions of the sky can always be seen through the foliage of a tree. I think there is a slight error in this interpretation of Sir John Herschel's idea. Two or three leaves form as much of a screen as a thousand leaves, while a thousand stars form a luminous accumulation as compared with a region where the

[1] *Outlines*, § 792.

[2] No. XVII of my catalogue; see also Heis, *Atlas coel. novus*, 1872, and *cf.* Oehl, in *Gruithuisen's Naturw. Astron. Jahrbuch*, IX, 1846.

[3] Reproduced in *Knowledge*, October and December 1891, in Schweiger-Lerchenfeld's *Atlas der Himmelskunde*, and elsewhere.

[4] SEELIGER, *loc. cit.*, 628.

stars are few, and it is precisely this relatively homogeneous character of regions surrounding the "coal-sacks" which suggests the idea of a perforated band. It is true that the limits of these dark spots are not so well defined as Herschel supposed them. (See the "coal-sack" on Russell's photographs and on those of Pickering in the publications of the Henry Draper Memorial); nevertheless, in my opinion, the degree of definition of the edges of these spots and the uniformity in brightness of the surrounding regions are sufficient to sustain Herschel's argument. It is a question of judgment. To take a definite case, it seems to me that the appearance of the regions surrounding the small black spots in the neighborhood of f^2 *Cygni* and θ *Ophiuchi* on the photographs of Wolf and Barnard can only be explained as due to actual holes in a comparatively thin layer of stars.

A similar argument is furnished by the dark bands and fissures in certain parts of the Milky Way. Maunder[1] has already pointed out that these dark lanes are most easily explained as actual openings in the star clouds of the Milky Way. But it is particularly in that part of the Milky Way lying on the boundaries of *Ophiuchus* and *Scorpius* that a magnificent photograph taken by Professor Barnard on June 21, 1895 reveals, between ω *Ophiuchi* and *Antares*, streams separated by dark intervals, which strongly suggest the existence of actual stellar strata, the thickness of which is small as compared with their distance from us (see Plate XI).[2]

§ 13. If the considerations developed in the preceding paragraphs render probable the existence of extensive but comparatively thin strata or streams of stars—which may be projected upon each other in certain parts of the Milky Way—there are also reasons to believe that the various portions of the Milky Way are not all at the same distance from us; reasons additional to those based upon the conclusions which may be drawn from Celoria's investigations (§§ 5 and 6).

[1] *Knowledge*, Feb. 1895, p. 37.

[2] See E. E. BARNARD, this JOURNAL, March 1899, on the very dark openings in the dark bands.

A minute study of the Milky Way in the southern hemisphere led Sir John Herschel to the conclusion that this part of the zone is composed of various portions situated at different distances (*Cape Observations*, § 321). In certain regions he believed that his telescope led his view across two stellar strata, separated by an interval void of stars. Elsewhere he describes the space revealed to him by his telescope as a cone filled with stars for a limitless distance in the line of sight. In this case, however, his reasoning would not appear to be well founded, as has already been indicated by Proctor.[1] But the argument based on the lateral branches of the Milky Way—in the northern hemisphere they are mentioned by Heis (*Draco*), Gould (*Orion*), Easton (*Auriga*, *Lynx*), and particularly by Boeddicker—would appear to have more weight: "Neither can we without obvious improbability refuse to admit that the long lateral offsets which at so many places quit the main stream and run out to great distances, are either planes seen edgeways, or the convexities of curved surfaces viewed tangentially, rather than cylindrical or columnar excrescences bristling up obliquely from the general level."[2]

It is evident that these lateral branches, which frequently extend to a considerable distance from the galactic equator, are in general much more easily explained by supposing that they extend on this side, and not beyond the principal branch of the Milky Way. Thus some portions of the Milky Way would be comparatively near us.

Another consideration, which is perhaps even more important, is the following. In certain parts of the Milky Way the galactic image, with its bright and dark spots, would appear to be outlined by the distribution of the stars of Argelander's last class.[3] On the other hand, Professor Seeliger has shown[4], by a comparison of the number of stars in the two *Durchmusterungen* with those of William and John Herschel's gauges, that this is not

[1] *Intellectual Observer*, August 1867. [2] *Outlines*, § 792.

[3] EASTON, *Verslagen Kon. Akademie Amsterdam*, 1894–5, p. 187.

[4] *Loc. cit.* 626.

the case for the whole galactic zone. However, there are some regions where even the naked-eye stars are evidently correlated with the distribution of the galactic light, as follows from a simple comparison of the Bonn charts with the most detailed photographs and charts of the Milky Way. I cite especially the luminous spot between α and *A Cygni*, and the northern part of the great spot $\gamma - \beta$ *Cygni*.[1] Unless we suppose gigantic stellar accumulations to exist at this point we are forced to admit that this part of the Milky Way is much nearer to us than the average.

Although it appears from the beautiful investigations of Professor J. C. Kapteyn[2] that the mean distance of stars of a given magnitude is much greater in the Milky Way than outside of this zone, the branches which start from the central part of the Milky Way and include the *Pleiades* and several bright stars in *Orion* seem also to support the conclusion that in certain parts of the Milky Way the small stars are at distances comparable with that of the bright stars.

§14. The galactic region in *Cygnus*, referred to in the preceding paragraph, is very remarkable and in fact quite exceptional as regards its brightness and its situation in the zone.

If we omit questions of detail, that which strikes us most forcibly in studying the aspect of the Milky Way in the northern hemisphere is the fact that the principal branch is exceedingly faint in *Perseus*, and that the secondary branch, very faint elsewhere, has a remarkably brilliant portion in *Cygnus*, between β and γ, about 90° from the sparse region in *Perseus*. These two characteristic features are evident not only in the distribution of stars of magnitudes 6–9.5[3] but even in the grouping of stars of magnitudes 0–6.[4]

The brilliant region between β and γ *Cygni* is connected—as the photographs abundantly attest—with a smaller but equally bright spot between α and *A* (68) *Cygni*, which in its turn is

[1] *Cf. Ast. Nach.*, No. 3270. [2] *Verslagen Kon. Akademie Amsterdam*, 1892–3.

[3] PLASSMANN, *loc. cit.*

[4] SCHIAPARELLI, "Sulla distribuzione," *Pubbl. Brera*, XXXIV, 1889.

connected with another less brilliant spot, between ρ and π *Cygni*, which is continued by a luminous stream, slightly inclined to the galactic equator, to a kind of knot near η and β *Cassiopeiae*, where the Milky Way divides; in part these branches lose their brightness rather abruptly at the altitude of γ *Persei*. Between *o Cygni*, *a Cephei* and η *Cassiopeiae* a much fainter zone extends, which shows a tendency to reunite with the principal branch.[1] Almost the entire region described here, with a few branches toward *Draco* and *Ursa Major*, and the fairly bright part between β *Cygni* and γ *Ophiuchi*, produce somewhat the impression of an immense appendage of the principal branch, with which the bright region between δ *Cephei* and *a Cygni* would appear to be closely connected; while the series of small luminous spots between γ *Sagittae* and *v Aquilae* do not seem to be independent of the luminous region north of β *Cygni*.

I insist upon the exceptional position of this spot, or rather conglomeration of bright spots, between β and γ *Cygni*. It lies in the midst of a series of luminous spots and streams between *v Aquilae* (the series which commences in *Sagittarius* appears to be related to this one) and χ *Persei*, but it is the only one — with the possible exception of the spot at *a–A Cygni*, just on the galactic equator — which is not situated on the inner edge of the principal branch of the Milky Way, but in the secondary zone, not far from the galactic axis. This is, moreover, the only very bright region which occurs in the "secondary zone" (§5), and the only place where this zone is brighter than the principal branch.

This region between *A* (68) and β *Cygni* is richer in stars than any other zone in Argelander's *Durchmusterung*. As for the fainter stars, William Herschel found here one of the maxima of his gauges: 588 stars per telescopic field; Th. Epstein[2] counted near ϕ *Cygni* 600 stars to the eleventh or twelfth magnitude in an area which on an average would contain only 140.[3]

[1] EASTON, *Voie lactée;* Boeddicker, *Milky Way*. [2] See PLASSMANN, *loc. cit.*

[3] The estimate of the brightness of this region in Houzeau's *Uranométrie*, p. 17, is certainly too small.

In the southern hemisphere brighter spots occur, notably that in *Scutum* and near γ and μ *Sagittarii*. But the spot at β–γ *Cygni* is larger than all these others combined. Furthermore, the brightness of the southern region in *Sagittarius* is particularly striking, on account of the contrast between the small bright spots and the very dark regions which separate them; the great bright spot in *Cygnus*, on the contrary, has no definite boundaries and is surrounded by a rather luminous region of the Milky Way.

As for the very faint region in *Perseus*, it is remarkable in that it is situated northeast of the tortuous part of the Milky Way, which, in *Auriga*, deviates considerably from the galactic axis. It may also be remarked that the "zone of nebulae" on Sidney Waters' chart approaches the Milky Way at this same place.

§15. This brilliant and relatively independent region in *Cygnus* which, moreover, is certainly connected with the other parts of the Milky Way, occurs in a part of the sky where, in the provisional supposition made in paragraph 6, the explanation of the general features of the Milky Way would be much simplified if it were permissible to assume the existence of an important stellar condensation in this direction. On the other hand—though this is perhaps a chance coincidence—the center of the secondary accumulation of which our Sun is a part would be situated, according to Professor Kapteyn's investigations, not far from this region.[1]

May not the bright region in *Cygnus* be the *central accumulation of the Milky Way?* If this were the case the general features and many characteristic details of the galactic phenomenon might be easily explained.

Fig. 5 gives an approximate representation of the Milky Way between γ *Ophiuchi* and β *Cassiopeiae* (*cf.* my chart of the Milky Way, Plate IV). Fig. 6 is based upon the two rings of the provisional theory stated in §6. In order to simplify the drawing I have left unbroken the exterior ring $RR'R''$ (principal

[1] KAPTEYN, *Verslagen Kon. Akademie Amsterdam*, 1892–3, p. 129.

branch of the Milky Way) except the very faint part between R and R'' (*Perseus*). As for the interior ring, it must divide into at least three principal parts:

A, the bright part between γ *Ophiuchi* and *Cassiopeia*, considered as an appendage of the principal ring, in accordance with what has been stated in the preceding paragraph.

FIG. 5.

B, the secondary branch in *Serpens*, *Scorpius*, *Lupus;* closely related rather to the principal branch in this region than to the secondary branch in *Ophiuchus* (north of γ) and *Cygnus*.

C, the belt of bright stars, projected upon a very faint nebulosity.

Certain details between *Aquila* and *Cassiopeia*, the "luminous bridges" which are projected upon the "rift" between the two branches, etc., have been inserted from the galactic chart of this region (Fig. 5).

The representation of the Milky Way thus obtained curiously resembles the spiral nebulae, of which Dr. Isaac Roberts has given such beautiful photographs.[1] To facilitate the comparison I have sketched in Fig. 7 the principal features of the nebula *M. 74 Piscium*. It is unnecessary to remark that the distortion of the spiral in Fig. 6 is due to the preconceived idea of the two rings (in reality the cluster in *Cygnus*, and not the Sun, is at the center of the system).

From what precedes it follows, furthermore, that the convolutions of this "galactic spiral" would not be situated in a single plane, but principally in two planes forming an angle of about 20°.

[1] *A Selection of Photographs*, London, 1894.

It would be easy to push the comparison further[1] and to find in it a plausible explanation of many features of the galaxy. But I confine myself here to pointing out how easily this theory explains the luminous streams between the two branches of the Milky Way, in *Sagittarius* and *Cassiopeia;* the anomalous brightness of the secondary branch near *Cygnus;* the dark spaces surrounded by luminous streams between *α Cygni* and *β Cassiopeiae*, etc.; the "lateral offsets" of the Milky Way; the connection of the clusters and the bright stars in *Taurus* and *Orion* with the nebulosities related to the Milky Way; the very faint region in *Perseus*, etc.—while retaining the advantages offered by the annular segments. I wish to insist upon the fact that Fig. 6 *does not pretend to give an even approximate representation of the Milky Way*, seen from a point in space situated on its axis. It only indicates in a general way how the stellar accumulations of the Milky Way might be distributed so as to produce the galactic phenomenon, in its general structure and its principal details, as we observe it.

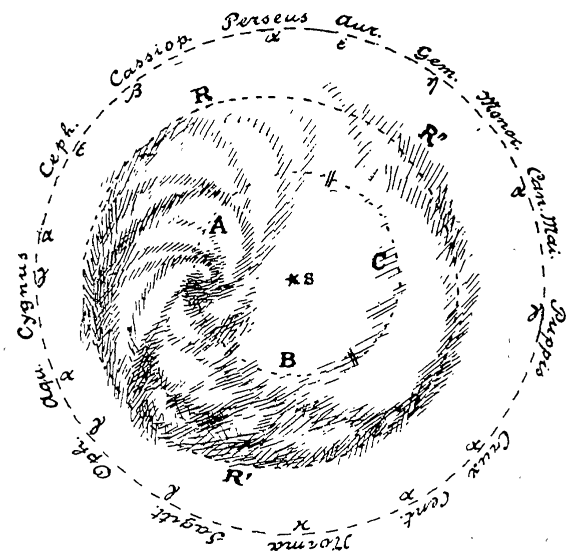


FIG. 6.

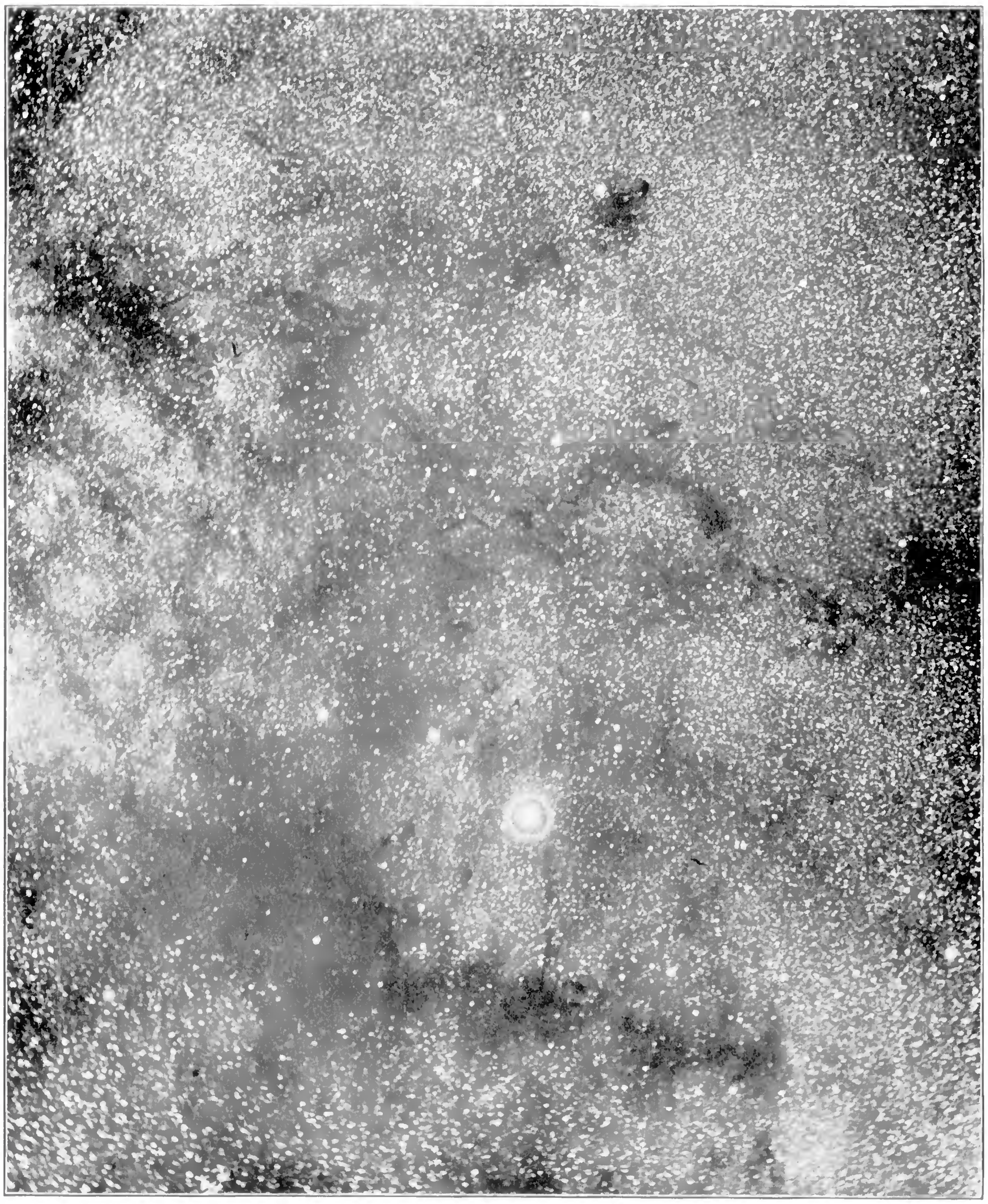
[1] Arguments based upon analogy are always dangerous. It is nevertheless permissible to point out here that the most recent observations and photographs show that the spiral is a much commoner form in the structure of nebulae than has hitherto been supposed. Only recently it has been recognized in the supposedly oval nebula of *Andromeda* (*cf.* Scheiner, *Astr. Nach.*, Bd. 148, No. 3549), and Professor J. E. Keeler sums up as follows the results of his investigations on the structure of nebulae (*Astr. Nach.*, Bd. 150, No. 3601): "If, then, numerous exceptions prove that spirality in nebulae is not a universal law, it may perhaps be regarded as the usual or normal accompaniment of contraction in cosmical masses. . . . ."

§16. It is possible that our Sun and the group of stars which, according to the investigations of Schiaparelli, Gould, and Kapteyn, form with it a secondary system in the great galactic system, may be only one of the clusters lost in the convolutions of the galactic spiral. But it seems to me simpler to suppose that what appears to be a "solar cluster" is the expression of the central condensation of the galactic system itself, composed for the most part of suns comparable with our own (and which would thus embrace most of the bright stars to the ninth or tenth magnitude). The distance of the galactic streams and convolutions would then be comparable with the distances of these stars, and there might even exist, at the boundaries of the system, a certain number of very large stars, further from us than most of the stars of the Milky Way. In the galactic convolutions or near them, there would be important stars, of enormous size, centers of stellar condensations exercising a preponderating attraction on the innumerable small stars of the zone, intermixed with nebulosity. Our Sun, lying eccentrically with reference to the convolutions of the Milky Way, would nevertheless not be far from the center of the central condensation of the system, which would be at the same time the central point of the galactic convolutions.

FIG. 7.

ROTTERDAM,
March 1900.

PLATE XI



PHOTOGRAPH OF THE MILKY WAY NEAR THE STAR *THETA OPHIUCHI*