SIDEREAL ASTRONOMY: OLD AND NEW.*

I. THE DATA IT HAS COLLECTED.

WHEN did astronomy have its beginnings on the earth? There have been many learned attempts to answer this question. They all have led to the conclusion that long before the historic period there was a large common stock of knowledge; so large, in fact, that one distinguished writer finds it simplest to ascribe the origin of astronomy to the teaching of an extinct race: "Ce peuple ancien qui nous à tout appris — excepté son nom et son existence," his commentator adds.

Astronomy is older than the first records of any nation. In order that the records might exist, it was first necessary to divide the years and times by astronomical observations. On the other hand, I believe the travelers of to-day have found no tribe so degraded as to be without some knowledge of the sort.

It is extremely doubtful if animals notice special celestial bodies. Birds seem to be inspired by the approach of day and not by the actual presence of the sun. It is a question whether dogs "bay the moon" or only the moon's light. A friend maintains that her King Charles spaniel watched the progress of an occultation of Venus by the crescent moon with the most vivid interest. This is the only case which I have been able to collect in which the attention of animals has been even supposed to have been held by a celestial phenomenon. The actions of the most ignorant savages during a total solar eclipse, compared with those of animals, throw much light on the question of whereabouts in the scale of intelligence the attention begins to be directed to extra-terrestrial occurrences. The savages are appalled by the disappearance of the sun itself, while animals seem to be concerned with the advent of darkness simply.

I am told that the Eskimos of Smith's Sound have *names* for a score or more of stars, and that their long sledge-journeys are safely made by the guidance of these stars alone. I have myself seen a Polynesian islander embark in a canoe, without compass or chart, bound for an island three days' sail distant. His course would need to be so accurately laid that at the end of his three days he should find himself within four or five miles of his haven; if he passed the low coral island at a greater distance, it could not be seen from his frail craft. There can be little doubt but that he used the sun by day and the stars by night to hold his course direct.

There must have been centuries during which such knowledge was passed from man to man by word of mouth, woven into tales and learned as a part of the lore of the sailor, the hunter, or the tiller of the soil. No one can say how early this knowledge of the sky was put into the formal shape of maps, globes, or catalogues. Eudoxus is said to have constructed a celestial globe B. C. 366. Globes would naturally precede maps, and maps mere lists or catalogues.

The prototype of all sidereal catalogues is the *Almagest* of Ptolemy (A. D. 150), which includes not only the observations of Ptolemy, but those of the great Hipparchus (B. C. 127). It contains the description of 1022 stars, their positions, and their brightness. Here we meet for the first time the name *magnitude* of a star. Ptolemy divides all the stars into magnitudes — degrees of brightness. Sirius, Capella, are of the first magnitude; the faintest stars visible to the eye are of the sixth. But Ptolemy has gone further, and divides each magnitude into three parts. The moderns divide each class into ten parts, that is, decimally.

SCALE OF MAGNITUDES.

IN assigning magnitudes in this way, we have unconsciously adopted a scale. A star of the third magnitude is brighter than one of the fourth. How much brighter? Sirius and the brightest stars are about one hundred times more brilliant than the very faintest stars which can be seen with the naked eye. In general a star of any magnitude, as fifth, is four-tenths as bright as the star of the next brighter magnitude, as fourth. Ten fifth-magnitude stars taken together are as bright as four fourth-magnitude stars, and so on. This relation between the brightness of stars of consecutive magnitudes gives us a means of computing the total amount of light received from stars. For example, there are ten stars in our sky as bright as the brilliant star Vega, or Alpha Lyræ, which we see in our zenith during the summer months. The collective light of these ten first-magnitude

* This article contains only a reference to the important advances in sidereal astronomy which have been made by the aid of photography during the past two years.

stars is ten times that of Vega. The 37 second-magnitude stars are together 7.4 times as bright as Vega; the 128 third-magnitude stars are 10.2 times as bright; and so on down to the 4328 sixth-magnitude stars, which, taken together, are 22.1 times as bright. Taking all the stars visible to us without a telescope and adding their brilliancy, we find that all the naked-eye stars give us a light 67.6 times as bright as that from Vega. Now the stars of the seventh and eighth magnitudes have been counted; there are 13,593 of the seventh, 57,960 of the eighth, and they too send light to us, although they are individually invisible. All the seventh-magnitude stars taken together give us 27.8 times as much light as Vega, and the eighth give us 47.4 as much; so that we have from both of these classes 75.2 times the light of Vega; that is, actually more light comes to us from stars so faint as to be individually invisible than from the less numerous and brighter stars that we see with the naked eye. We may recollect that more than half of the light of a star-lit night comes from the collective luster of stars, each of which is totally invisible except in the telescope.

METHODS OF NAMING THE STARS.

IN Ptolemy's *Almagest*, and for fifteen centuries later, there were two and but two ways of designating a particular star. Some few of the brighter stars had special names.

By far the greater number were described by their situation in their constellation. The brightest star in Taurus was the eye of the Bull, and so for others, as the belt and sword of Orion. This was all very well for the brighter stars, and it did not require that the boundaries of the constellations should be very accurately fixed. There was no mistaking Regulus, Cor Leonis — the heart of the lion. But when we come to the small pairs of stars which make the paws of the Great Bear, or to some of the stars in the windings of Serpens, then it is evident that Ptolemy must have had accurately bounded constellations laid down on charts or globes. Not a single ancient globe or chart has come down to us. The oldest extant are but Arabian copies of the tenth century.

Where, then, do we derive our figures of the constellations? If any one of my readers will ask some astronomical friend to show him a copy of Flamsteed's *Atlas Cœlestis* he will see the beautiful and spirited drawings of the constellation figures, and be charmed and delighted with their vigor and character. Who could have drawn these outlines, instinct with life? Who of the ancients knew the whole character of the timid hare, or who could draw Andromeda, and put a modern resignation in her chained despair? These figures were drawn by a master indeed, for they are from the hand of Albert Dürer himself. If we follow the history of how he came to make them for an edition of Ptolemy, and think of him patiently fitting his marvelously free outlines to match the stars in the sky and the crabbed descriptions in Ptolemy's book, the pleasure does not diminish. About 1603 Bayer introduced the practice of designating the brighter stars of each constellation by the letters of the Greek alphabet, so that Cor Leonis or Regulus became α Leonis; Aldebaran became α Tauri, and so on. As the number of the well-determined stars has vastly increased, the practice of referring to them by their numbers in some well-known catalogue has come into vogue; so that α Leonis, for example, might be known as Bradley, 1406, from its number in Bradley's catalogue; or as Lalande, 19,755, and so on. It is not to be denied that astronomical nomenclature in this direction could be greatly improved.

URANOMETRIES.

THE word *Uranometry* has received a limited technical meaning in astronomy. It is used to denote a description of the fixed stars which are visible to the naked eye only. The description of each star places it in its proper constellation, assigns its latitude and longitude, and gives its brightness or magnitude. Variable stars, which change their brightness periodically,— and there are many such,— are treated separately.

Ptolemy's *Almagest* (1022 stars) was an incomplete uranometry, since there were more than 3000 stars visible to him. Al-Sûfi's revision of it, in the tenth century, added no stars, but simply revised the magnitudes given by Ptolemy. Bayer (1603) gave 1200 stars. None of the very important works of Flamsteed (1753), Harris (1725), Wollaston (1811), Harding (1822), were complete. That is, no one gave every star down to a certain brightness. It was reserved for Argelander (1843) to give in the *Uranometria Nova* the position of brightness of every star visible to the naked eye at Bonn. This was a picture of the sky; changes could no longer occur without detection. This work gave the places of 3256 stars, from first to sixth magnitudes, and very careful eye-estimates of their magnitudes. Argelander's work has been repeated by Heis (1872). The southern sky has been treated in the same way by Dr. Gould, in the *Uranometria Argentina* (1879), containing 6694 southern and 991 northern stars, of magnitudes between the first and seventh. Houzeau, during a residence in Jamaica, made a uranometry which embraces every star in both hemispheres, and which has a special value owing to the fact that the estimates of magnitude were all made by a single person.

We have, then, a complete picture of our sky, as seen with the naked eye, based on eye-estimates of the brightness of the stars. It should be said that the magnitudes so determined are extremely accurate, approaching closely to the exactness which can be reached with the best photometers, or instruments for measuring the relative brightness of stars.

THE HARVARD PHOTOMETRY.

UP to 1877, when Professor Pickering became director of the Harvard University Observatory, there was no single observatory devoted to photometry as a chief end. The important works of this nature had been done as a part of other duties. Professor Pickering turned the whole strength of the observatory in this direction, and by means of new methods and new instruments he and his assistants have just completed a work of the first importance— the *Harvard Photometry*. It contains the positions and the measured brightness of 4260 stars visible at Cambridge, together with a comparison with the magnitudes of all other observers. The actual number of single observations is 95,000. Each one of these consists in a direct photometric comparison of the relative brightness of a star with one of the polar stars. The polar stars are always visible; the stars to be measured were taken as they crossed the meridian; and these direct measures, suitably combined, give the relative brightness of each of the stars of the list. We have now a sure basis for all future work, and a perfect picture of the sky at this time.

THE NUMBER OF THE STARS.

THE total number of stars one can see will depend very largely upon the clearness of the atmosphere and the keenness of the eye. There are in the whole celestial sphere about 6000 stars visible to an ordinarily good eye. Of these, however, we can never see more than a fraction at any one time, because a half of the sphere is always below the horizon. If we could see a star in the horizon as easily as in the zenith, a half of the whole number, or 3000, would be visible on any clear night. But stars near the horizon are seen through so great a thickness of atmosphere as greatly to obscure their light, and only the brightest ones can there be seen. As a result of this obscuration, it is not likely that more than 2000 stars can ever be taken in at a single view by any ordinary eye. About 2000 other stars are so near the South Pole that they never rise in our latitudes. Hence, out of 6000 supposed to be visible, only 4000 ever come within the range of our vision, unless we make a journey towards the equator.

As telescopic power is increased, we still find stars of fainter and fainter light. But the number cannot go on increasing forever in the same ratio as with the brighter magnitudes, because, if it did, the whole sky would be a blaze of starlight. If telescopes with powers far exceeding our present ones were made, they would no doubt show new stars of the twentieth and twenty-first, etc., magnitudes. But it is highly probable that the number of such successive orders of stars would not increase in the same ratio as is observed in the eighth, ninth, and tenth magnitudes, for example. The enormous labor of estimating the number of stars of such classes will long prevent the accumulation of statistics on this question; but this much is certain, that in special regions of the sky, which have been searchingly examined by various telescopes of successively increasing apertures, the number of new stars found is by no means in proportion to the increased instrumental power. If this is found to be true elsewhere, the conclusion may be that, after all, the stellar system can be experimentally shown to be of finite extent and to contain only a finite number of stars. In the whole sky an eye of average power will see about 6000 stars, as I have just said. With a telescope this number is greatly increased, and the most powerful telescopes of modern times will show more than 60,000,000 stars. Of this number, not one out of one hundred has ever been catalogued at all.

In Argelander's *Durchmusterung* of the stars of the northern heavens, there are recorded as belonging to the northern hemisphere:

10	stars	between the	1.0	magnitude	and the	1.9	magnitude.
37	"	"	2.0	"	"	2.9	"
128	"	"	3.0	"	"	3.9	"
310	"	"	4.0	"	"	4.9	"
1,016	"	"	5.0	"	"	5.9	"
4,328	"	"	6.0	"	"	6.9	"
13,593	"	"	7.0	"	"	7.9	"
57,960	"	"	8.0	"	"	8.9	"
237,544	"	"	9.0	"	"	9.5	"

In all 314,926 stars, from the first to the 9½ magnitudes, are contained in the northern sky; or about 600,000 in both hemispheres. All of these can be seen with a 3-inch object-glass.

THE CHARTS OF THE BERLIN ACADEMY.

IN 1824 Bessel wrote to the Academy of Berlin somewhat as follows:

> It is of the highest astronomical interest that every fixed star in the sky should be known, and its position fixed. Completeness in this task is unattainable; but when we once have maps of all the stars down to a

certain magnitude, then the object will be attained. The limit I set is at those stars which can just be plainly seen in one of Fraunhofer's excellent comet-seekers; * that is, at about the ninth or tenth magnitude.

Bessel then gives briefly the reasons why such a complete list would be valuable, in addition to its importance as a finished picture of the sky so far as it went; and continues:

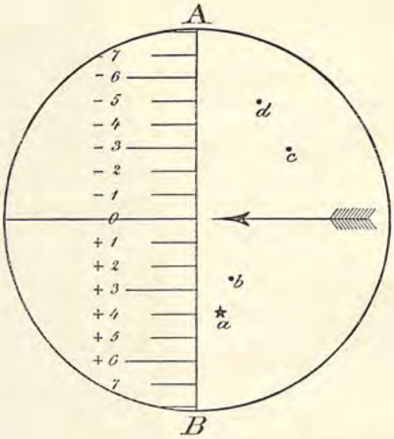
For all these reasons I have often expressed my hope that we might have such a complete list, if even over only a portion of the sky; and I think the time of an astronomer, and of an observatory, could not be better spent than in aiding a systematic attempt to carry out this plan. I myself designed the instruments of the Koenigsberg Observatory for such a purpose, and since 1821 I have observed as many as possible of the stars from 15° north to 15° south of the equator. In all there are 36,000 observations of 32,000 stars. If the stars are equally numerous over the whole sky, there are 125,000 such. I am about to carry on these zones up to 45° from the equator.

With this introduction Bessel unfolds his plan, which was to have 24 astronomers join in an undertaking to make the 24 separate charts required to extend round the whole 24 hours, and in width over the 30° from 15° north to 15° south of the equator. He himself made a small chart as a beginning, "to break the path," and as a model. The Academy welcomed Bessel's plan, and the work began in 1825.

The first two charts were received in 1828, and the work on the others continued slowly. One of these charts has a great history. It had been engraved but not yet distributed, and was lying in the Berlin Observatory for examination. On the evening of September 23, 1846, Le Verrier's letter, giving the place of a new planet, Neptune, was received in Berlin. The planet had never been seen, but its existence had been predicted from the otherwise inexplicable motions of Uranus. The predicted place of the planet fell within the limit of the lately finished chart, which was taken to the telescope. In very truth there was an eighth-magnitude star in the sky which was not on the chart. This star was in motion; it had the planetary light and disc; it was, in fact, Neptune. The proposal of Bessel had borne splendid fruit. Besides this major planet, many of the minor planets (asteroids) were discovered by these maps. Finally, in 1859, thirty-five years after Bessel's letter, this series was finished. But before it was finished a greater undertaking was begun, of which we must give a short account. One thing must be continually kept in sight. Every one of the systematic *Durchmusterungen*, as the Germans say,—we have no word for them,—is the direct outcome of Bessel's original proposition.

ARGELANDER'S "DURCHMUSTERUNG."

ARGELANDER was Bessel's pupil. In the great zones of Koenigsberg, Bessel had pointed the telescope on the stars as they passed, and Argelander read the verniers which showed their position. Finally Argelander had an observatory of his own at Bonn, and his two young assistants, Drs. Krueger and Schoenfeld, were all to him that he had been to Bessel. The years 1852 to 1862 were spent in the tremendous task of observing every star plainly visible in such a comet-seeker as we have described, over more than half of the whole heavens. The telescope was pointed and fixed in position. The time of the passage of every star over a wire in the field of view was noted; the part of the wire crossed by the star was also noted, and finally the brightness of the star.



The circle shows the field of view of the telescope. Half of it is covered with a thin plate of glass with a scale painted on it: *a*, *b*, *c*, *d* are stars moving in the direction of the arrow. The telescope itself is fixed. As each one comes to the edge, A B, the time is noted to the nearest half of a second. The division of the scale is also noted where each star touches it (+ 4, for *a*, − 5, for *d*). Finally the brightness in magnitudes is recorded (*a*, 8th mag.; *d*, 9.3 mag.). The observer at the telescope records the magnitude and the scale. The time is called out by him and noted by an assistant on a chronometer.

Not counting the time for the computations, the observations alone lasted seven years and one month. 1797 hours were spent in observing the comet-seeker zones, on 625 nights; and 227 other nights were used in part or wholly in revision zones to correct errors of one nature or another, or to solve doubts.

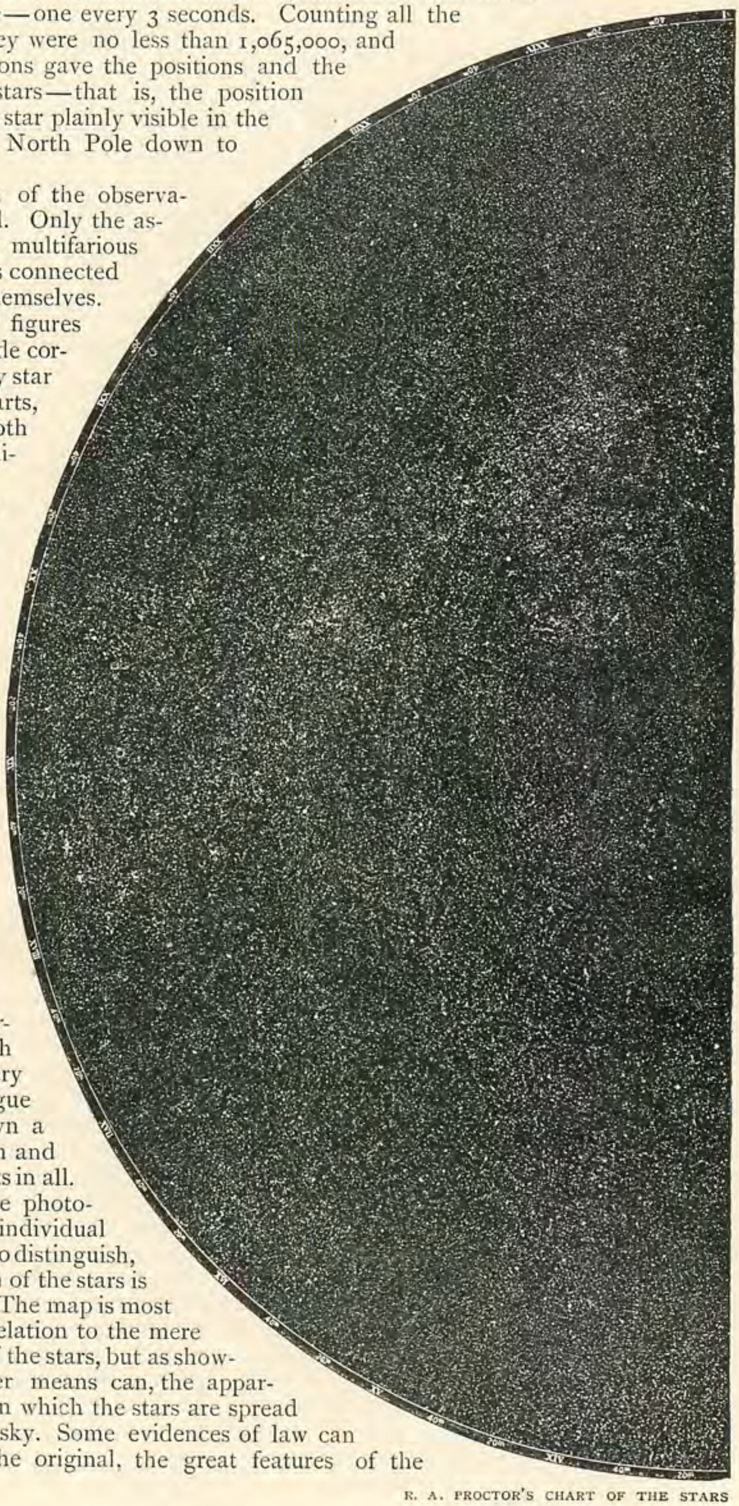
* A telescope with about 3 inches aperture, magnifying 10 times.

In the comet-seeker zones 850,000 single observations were made, or on the average 473 stars per hour, or 8 per minute. In specially rich parts of the Milky Way more than 16 stars per minute were often observed, and the richest zone had 1226 stars in the hour, or 20½ per minute—one every 3 seconds. Counting all the observations together they were no less than 1,065,000, and this million of observations gave the positions and the brightness of 324,198 stars—that is, the position and brightness of every star plainly visible in the telescope used, from the North Pole down to 2° south of the equator.

The very enumeration of the observations makes one fatigued. Only the astronomer can know the multifarious nature of the calculations connected with the observations themselves. Millions on millions of figures had to be made, and made correctly; and, finally, every star had to be engraved on charts, and engraved correctly both as to position and magnitude.

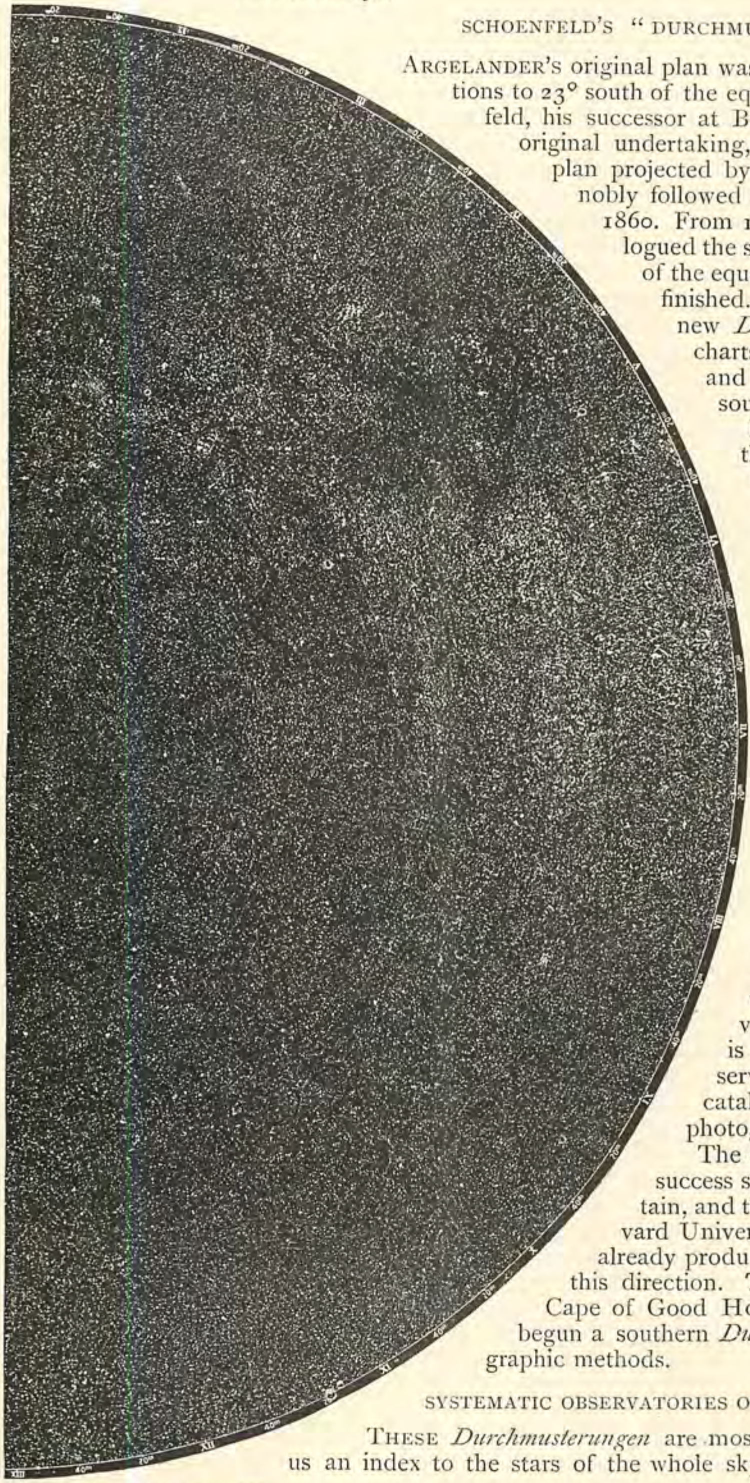
How this work could have been finished in ten years, one does not see. That Argelander and his two assistants had the courage to persevere in this tremendous task is itself a marvel. But the work is done, is printed, and is in daily use by scores of astronomers. Its value will never be less. It will remain forever as a picture of the sky, available for every purpose.

Mr. Proctor has done a very useful work in representing the results of Argelander's *Durchmusterung* in a single chart, which is here reproduced. For every star in Argelander's catalogue Mr. Proctor has laid down a dot, correct as to position and magnitude—324,198 dots in all. The resulting map is here photographed down so that the individual dots are, in general, hard to distinguish, but the law of aggregation of the stars is all the better brought out. The map is most interesting, not only in relation to the mere positions and brilliancy of the stars, but as showing, better than any other means can, the apparently capricious manner in which the stars are spread over the surface of the sky. Some evidences of law can be made out, and, in the original, the great features of the



R. A. PROCTOR'S CHART OF THE STARS

Milky Way come forth in a most striking manner. It must be remembered that this map contains, besides the stars visible to the naked eye, all those visible in an ordinary three-inch telescope.



OF THE NORTHERN HEMISPHERE.

SCHOENFELD'S "DURCHMUSTERUNG."

ARGELANDER'S original plan was to extend his observations to 23° south of the equator. Professor Schoenfeld, his successor at Bonn, and his aid in the original undertaking, in 1885 completed the plan projected by Bessel in 1824, and so nobly followed at Bonn from 1852 to 1860. From 1876 to 1884 he has catalogued the stars from 2° to 23° south of the equator, and the work is just finished. Soon we shall have this new *Durchmusterung*, with its charts, showing the position and brightness of 133,658 southern stars.

It is most desirable that this enumeration should be extended over the whole southern sky. So long ago as 1866 the work was begun in the Southern Hemisphere, but apparently it was abandoned, though there is reason to believe that the observatory of the Argentine Republic at Cordoba may begin anew. Professor Stone, at Cincinnati, has partly completed the zone between 23° and 31° (south).

A recognition of the enormous advantages which photography would have over ordinary visual methods of charting is now leading several observatories to attempt the cataloguing of stars from photographic negatives.

The difficulties are many, but success seems to be tolerably certain, and the observatories of Harvard University and of Paris have already produced wonderful results in this direction. The observatory of the Cape of Good Hope, also, has seriously begun a southern *Durchmusterung* by photographic methods.

SYSTEMATIC OBSERVATORIES OF THE STARS IN ZONES.

THESE *Durchmusterungen* are most important. They give us an index to the stars of the whole sky. But it is clear that the positions of the separate stars cannot be accurate when so many as eight or ten per minute are observed. What the astronomer wants is the *accurate* position of a star—its latitude and longitude, as it were. We shall see how much pains is necessary to fix the position of a single star with real precision. Scores of observations are needed, and each observation requires at least five minutes to make and an hour to calculate. When we say that many thousand stars have their positions known with this high precision, we shall be giving a feeble idea of the amount of labor devoted to this question.

But it is impossible to fix the position of every one of the 600,000 stars of the *Durchmusterungen* with this last degree of precision, and yet it is important to know very closely the place of each star. The positions of all faint comets, of asteroids, etc., are known by referring them to neighboring stars. We must know the positions of these stars. These positions are determined by a special kind of observations—zone observations, so called. A telescope is fixed in the meridian so that it can only move north and south. A divided circle is attached to this, the indications of which give the altitude of the stars seen in the field. One observer at the telescope moves it slowly up and down until some star enters the field. The motion is stopped. The transit of the star is observed over spider lines stretched in the field, while a second observer reads the altitude of this star from the divided circle. In this way it is possible to obtain very accurate positions, and by confining the work to a narrow zone the observations are increased as to number, and the subsequent computations are much simplified.

Before the days of the Berlin charts, or of the *Durchmusterung*, Lalande in Paris (1790) had fixed the places of more than 50,000 stars in this way, and the Abbé Lacaille (1751) had made a special expedition to the Cape of Good Hope to determine the places of 9766 southern stars. Bessel took up the same research in the years 1821–33, and his results are given in two magnificent catalogues, which include 62,000 of the most important stars from 15° south to 45° north of the equator. He made 75,011 single observations, employing 868 hours in observing alone. That is, about 84 stars per hour were observed. Argelander read the altitudes of the stars from the circle while Bessel observed their transits. One of Argelander's first works, when he took charge of the observatory at Bonn, was to continue this series of zones from 45° up to 80° north of the equator—that is, to within 10° of the Pole. In this region he made 26,424 observations of 22,000 stars, or 83 stars per hour. Not content with this extension of Bessel's zones to the north, Argelander next began a series of southern zones from 15° to 31° south of the equator. This task he also completed, with 23,250 observations of 17,600 stars, or 83 stars per hour.

Bessel and Argelander alone had pushed their zones from 31° south to 80° north of the equator, making nearly 125,000 separate observations and fixing the positions of 101,600 stars. We have no space to speak of the 38,000 observations made at the Naval Observatory in Washington in the years 1846–49, or of the zones observed by Lieutenant Gilliss, of our navy, in Chili (1850), which covered the region for 25° round the South Pole (27,000 stars). It is most unfortunate for the credit of American astronomers, as well as for the good of the science, that these collections are not yet suitably published.

One would think that the 100,000 stars of Bessel and Argelander would have been sufficient for the needs of astronomy. But the German Astronomical Society, at its meeting in Bonn in 1867, deliberately resolved upon the task of accurately determining the position of *every* star as bright as the ninth magnitude contained in Argelander's *Durchmusterung*.

The veteran Argelander presided at this meeting, and it is curious to note how serious the undertaking appeared to be to him. No one knew better how gigantic a task it was. The plan was well laid. A set of 539 very well determined stars was assumed as fundamental, and the society resolved that the position of the stars to be determined should be referred to these. The sky was cut up into zones five degrees wide, and various observatories undertook to finish one or more of these zones. The Polar Zone (90° to 80° north of the equator) had lately been completed by Carrington, in England, and did not need revision.

The observatories of Kazan (80°–75°), Dorpat (75°–70°), Christiania (70°–65°), Helsingfors (65°–55°), Harvard University (55°–50°), Bonn (50°–40°), Lund (40°–35°), Leyden (35°–30°), Cambridge, England (30°–25°), Berlin (25°–15°), Leipzig (15°–5°), Albany (5°–1°), Nikolaief (1° to 2° south), joined in the work, and to-day it is nearly completed.

But this is only a beginning. Schoenfeld's *Durchmusterung* to 23° south will soon be printed, and it is the intention of the German Astronomical Society to push the zones to this point, to join on to the great series of southern zones printed by our countryman Dr. B. A. Gould, at the National Observatory of the Argentine Republic. Dr. Gould is himself a pupil of Argelander, and his magnificent work may be fairly called an outcome of the spirit of Bessel, the master. 105,000 observations of some 73,000 stars, from 23° south to 65° south of the equator, have been printed by Dr. Gould as part of the results of fourteen years' labor in a foreign country. Thus from the North to the South poles the labors of Carrington, Argelander, Bessel, Gould, and Gilliss * have given us an almost complete catalogue of accurate positions of nearly all the principal stars. Besides this we shall shortly have the region from 80° north to 2° south completely re-observed, and by 1900 the region to 23° south will be done also.

SPECIAL CATALOGUES OF STARS.

BESIDES these gigantic undertakings there have been scores of separate catalogues pretending to greater precision even, the very names of which we cannot mention. The observatories of Greenwich, Oxford, Edinburg, Paris, Poltava, Dorpat, Bonn, Berlin, Palermo, Washington, Harvard University, Melbourne, Cape of Good Hope, and many others have issued such accurate collections.

It is also necessary to say that a certain small number of stars — several thousands — have had their positions and motions determined with extreme precision; and of these again, a few hundreds of the brightest stars have been observed for so long, and for so many times, that their resulting positions are now almost as accurate as they can be made, and their motions so well known as to admit of very little improvement by the work of the next generation. These are our fundamental stars, so called.

Such, then, are our data: a few hundred stars determined with the last degree of precision, a few thousand nearly as well, two hundred thousand with considerable accuracy, and nearly a half a million separate stars known by the approximate positions of the *Durchmusterungen*, or additional to these from the southern zones. We can add to these too the two hundred thousand or more stars laid down in the ecliptic charts of Paris, Vienna, and Clinton (New York), which serve as nets to catch the minor planets just now, but which have an incalculable value as accurate pictures of the sky at a given instant.

* Two Germans, one Englishman, two Americans.

The brightness of some 10,000 stars is very accurately known, and that of nearly half a million has been very approximately fixed. Lastly, the distances of some fifteen of the brighter stars from the earth are known with tolerable certainty, and that of a few more with a good degree of approximation.

These are the materials available — mighty monuments to human ingenuity, skill, patience, devotion. But what further problems will they solve for us? What far-reaching conclusions can be drawn? In a succeeding article I will try to show to what results a combination of the data so painfully accumulated may lead, and what conclusions may safely be drawn even now.

The science of the positions and the motions of the stars is not so young as that other science so well described by Professor Langley in his admirable articles on "The New Astronomy" (THE CENTURY for September, October, December, 1884, and March, 1885), but it has its modern period as well as the historical one which has been here set forth. The old astronomy has set itself to solve such problems as these: What is the rate at which the whole solar system is moving on through space? What are the distances and what are the masses of the stars? What is the shape of the stellar cluster to which our sun belongs? Are the stars in general broken up into subordinate universes? or do they, as a whole, form one mighty system, with one common motion?

Some of these and other such questions are answered; some seem almost unanswerable; some are still in the way of solution.

Edward S. Holden.

STILL DAYS AND STORMY.

YESTERDAY the wind blew
Down the garden walks:
Marigolds, the day through,
Trembled on their stalks.

But to-day the wind 's dead,
Marigolds are still:
Miss they what the wind said,
Do they take it ill?

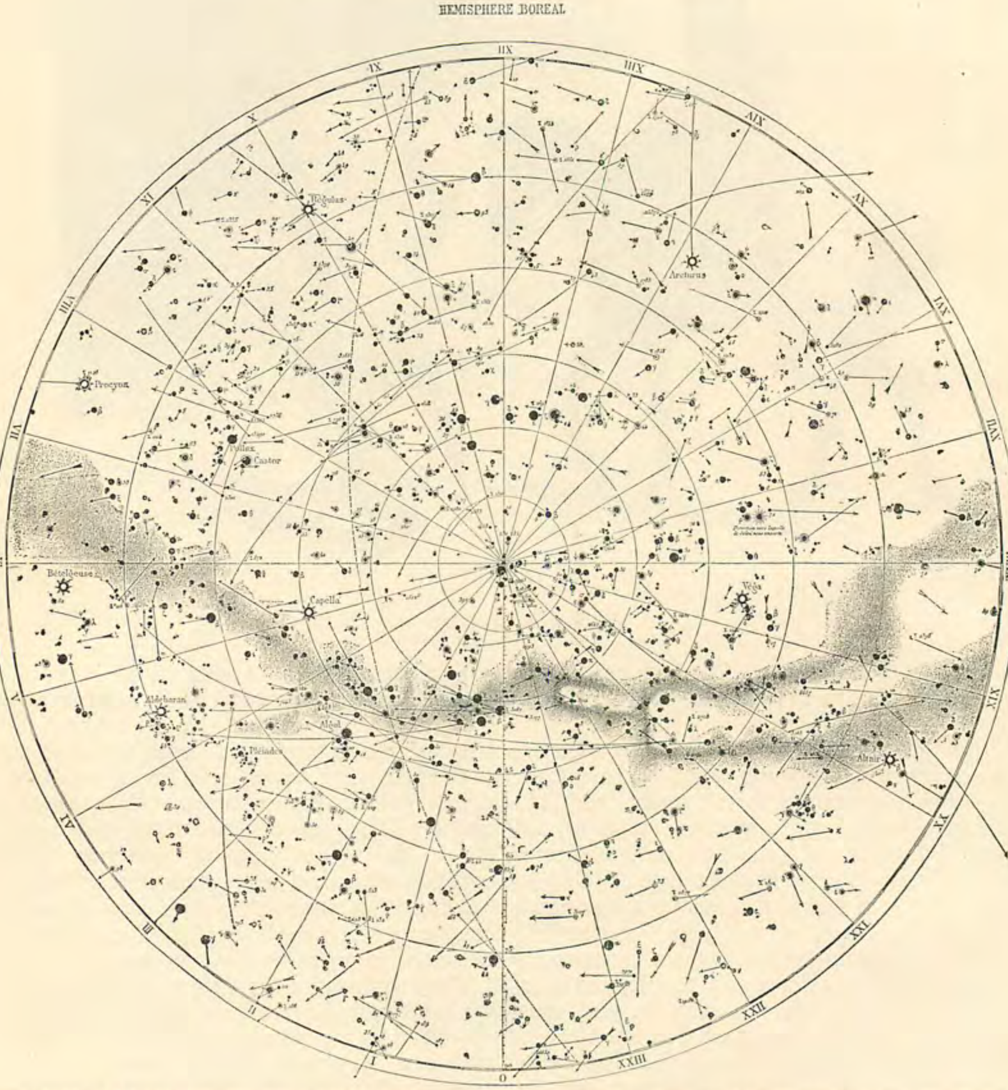
Yesterday my love stood
Hearkening to me;
Fair flower of womanhood,
All a-tremble she.

But to-day she 's sad, still,
Makes no true-love sign:
Is her lover to her will,
Is she yet mine?

Richard E. Burton.

SIDEREAL ASTRONOMY: OLD AND NEW.

II. THE RESULTS THAT IT HAS ATTAINED.



FLAMMARION'S CHART, SHOWING THE SECULAR MOVEMENTS OF THE STARS AND THE STELLAR SYSTEM OF THE NORTHERN HEMISPHERE. (FROM "ATLAS CÉLESTE," BY PERMISSION OF GAUTIER VILLIERS.)

IN the preceding article we collected the data which the ancient and the modern astronomy has placed at our disposition. We saw that a few hundred of the stars have their positions fixed with the last degree of precision; a few thousand are known nearly as well; half a million have their places approximately known, and half of these last are tolerably well determined. The brightness of some 10,000 stars is well known, while the brightness of nearly half a million is known with fair approximation. The distances of a few stars (about fifteen) are known with precision; the distances of a few more are approximately known.

These are the data which have been amassed by the observing astronomers of the modern period, beginning with Bradley (1750). In the present paper we are to see some of the general conclusions which may be drawn from these data. What are the distances, what are the dimensions, of the stars? What is the orbit in which our sun, with its group of planets, is traveling? What stars are our nearest neighbors and traveling with us? Are stars in general aggregated into systems of comparatively small size, or are the stars as a whole collected into one vast system, bound together by a common bond, and endowed with a common motion?

The stellar universe, as we see it at any moment, is quite complete. Change does not seem to belong to the region of fixed stars. Yet every one of the millions of observations has been made to fix a position so accurately that the slow changes which must be going on may not escape us; so that the laws of these changes can be formulated. If we know that a star retains its position invariably, if we know positively that its brightness and color remain the same, it becomes for these very reasons a most useful standard of reference, but it does not, as yet, help us to solve the problem of the stellar universe. We must seek a clue elsewhere, among the stars where changes are manifest, so that the unknown laws of these changes may be unfolded.

PROPER MOTIONS OF STARS.

As we said, nothing appears to be more invariable or unalterable than the region of the fixed stars, and, in a general sense, nothing is more so. But when we come to a closer view all is change there as well as elsewhere.

Since Rome was built the apparent situation of Sirius has changed more than a diameter of the moon, Arcturus has moved more than three such angular diameters, and so with other stars.

If gravitation is truly universal, if all the stars are bound together in one system by this law, as we believe, then no star can move without affecting every other. As one moves all must move. The real motion of any star is along some line or curve; we see this real motion projected on the ground of the heavens as an apparent change of its latitude and longitude. Knowing the latitude and longitude of the star now by observation, we may compare these with the positions of twenty, fifty, or a hundred years ago. It is possible to allow by calculation for every one of the complex changes produced in the apparent position of a star by every cause not in the star itself. Each one of the several observations, when so reduced to a common epoch, should give the same position, except for the small and unavoidable errors of observation and the proper motion of the stars.

For example, here are the observations made by Dr. Gould in the last twelve years on a southern star, all reduced to what they would have been if made on January 1, 1875:

Year of Observation.	*Right Ascension.*	*South Declination.*
1873	$23^h\ 58'\ 0.92^s$	$37^\circ\ 58'\ 13.9''$
1876	2.19^s	$20.9''$
1881	4.63^s	$34.1''$
1885	6.60^s	$42.0''$

These do not agree. They ought not to differ by more than 0.20^s or $3''$* if the star were at rest. If we assume that the star is moving in right ascension by 0.482^s and in declination by $2.45''$ yearly, and apply these numbers, the positions will harmonize.

1873 is two years before 1875, and we add twice 0.482^s and twice $2.45''$; and subtract for the other intervals. The observations thus corrected give

For 1873	$23^h\ 58'\ 1.88^s$	$37^\circ\ 58'\ 18.8''$
1876	1.71^s	$18.4''$
1881	1.74^s	$19.4''$
1885	1.78^s	$17.5''$

and are harmonious within the errors of observation. If we assume that this star is as near to the earth as the very nearest of all the stars, it is certainly moving no less than 600,000,000 miles per year. Yet it will require more than 3000 years for it to move from its present place by so much as one diameter of the moon.

The calculation that has been outlined here for one star has been performed for several thousands of the better known stars, especially for the 3222 stars which were most carefully determined by Bradley in 1750. For each one of these the proper motion has been determined with the greatest nicety. The results at first sight are interesting only in a very special way. No. 1, for example, may be moving $21''$ in a century along a path inclined by 10° to the equator. No. 2 moves $44''$ in a century along another path inclined by another angle, and so on to No. 3222. Here seem to be 3000 isolated facts, each one useful in its narrow relations, but each having no connection with any other.

Let us suppose for a moment that the sun, with the solar system, and the earth, our point of view, are moving onward in space, and imagine how such a motion would affect the appearance of a universe of stars scattered all about us. If the sun alone has a motion, all the stars towards which we are moving will appear to be retreating *en masse* from the point in the sky towards which our course is directed. The nearer stars will move most rapidly; those more distant, less so.

In the same way the stars from which we are retreating will appear to crowd together

* Errors of observation of this magnitude may exist.

and approach each other. It is as if one were riding on the rear of a railroad train and watching the rails over which one had just passed. As one recedes from any point the rails at that point seem to come nearer and nearer together. If we were passing through a forest we should see the trunks of the trees from which we were going apparently moving nearer and nearer to each other, while those at the sides would retain their distance apart and those in front would be moving wider and wider apart.

Here is a case in which we are sensible of our own motion and observe the effects of that motion in the positions of the fixed objects about us. We may turn the question about, and inquire whether the observed motions of the stars indicate any real motion of our own.

The outline of the problem is here much as it presented itself to Sir William Herschel in 1782. The details are extremely complicated. It is certain that we are *not* passing along through space among a vast number of *fixed* stars. Each star has a motion peculiar to itself. It also is moving along a vast orbit, and this real motion of the star is evident to our instruments. Combined with the veritable motion of the star itself is the parallactic motion produced by the shifting of our point of view as the earth sweeps forward through space.

It is for analysis to separate the effects of these two motions and to determine what is the real direction and the real amount of the solar motion. The processes of the analysis cannot be given here, but fortunately it is easy to exhibit both the data and the results graphically. This has been well done by M. Flammarion in the figure that we copy.

The circle marked "Northern Hemisphere" gives the positions of those northern stars which are known to have a proper motion. The size of the dot representing each star gives the magnitude (*i. e.*, brilliancy) of the star. The arrows attached to the star represent the directions in which the stars move on the surface of the sky by their proper motions. The lengths of the arrows represent the velocities with which the stars move. At the time of making the map the stars are in the positions marked by the dots. At the end of 50,000 years they will be at the ends of their respective arrows.

Thus the data are all presented graphically. Notice what variety there is. Notice, too, the striking fact that some of the largest proper motions belong to some of the smallest stars. One would think that the brighter stars would be the nearer, and therefore that on the average they would have the larger proper motions. For evidence on this point I have compiled the little table which follows from Argelander's list of the 250 stars with the best known proper motions. I have chosen the fainter magnitude classes in order to get a sufficient number of stars:

77 stars between 6th and 7th magnitudes have a proper motion of 0.54″ yearly; 80 stars between 7th and 8th magnitudes have a proper motion of 0.56″ yearly; 58 stars between 8th and 9th magnitudes have a proper motion of 0.71″ yearly.

That is, the proper motions do not seem to diminish as the numerical magnitude diminishes.

But to return to the plate. In the middle of the triangle formed by the pole (center) of the Northern Hemisphere and the two points XVII and XVIII on the edge is a figure like the sun. That is the point towards which the sun is moving. It is in the constellation Hercules, not far from the bright star Vega, which is near our zenith in the summer sky. In the corresponding position on the map of the Southern Hemisphere, which we do not reproduce, is a similar point; it is the point from which we come. All over the map are arrows not attached to any stars. These show the direction and the velocity of that part of the proper motion due to the motion of the solar system alone. In general the arrows belonging to the stars should agree in length and in direction with these unattached arrows — and in general they do, for the latter were derived from computations based on the former. But there are many exceptional cases; and, at first glance, it is the exceptions which seem to be the rule.

There is no space to refer to special cases except in passing; but the reader should note a pair of stars marked 21,258 (of Lalande's Catalogue) and 1830 (of Groombridge's Catalogue). They were about 15° apart in 1880, and on the map they may be found about half way from the pole (center) to the edge, near the straight line marked IX. In 50,000 years one will be on the straight line VI, and the other near the straight line XIII, at the very edge. They will be more than 200 diameters of the moon apart then, while now they are not more than 30 such angular diameters. Proper motion alone will in time change the whole aspect of the sky.

So MUCH for the map. Analysis gives the same results in numbers. It declares that the apex of solar motion is in the right ascension 260° and in declination 36° north, which defines the point in Flammarion's map marked by the figure like the sun; and analysis further declares that the amount of the solar motion in one hundred years, if viewed from a point at the average distance of the 3222 Bradley stars, would be 5.05°.

If we know this average distance in miles, we can assign our own velocity in miles. With our best present knowledge, it follows that the sun, the earth, and the whole solar system are moving through space at the rate of

586,000,000	miles	per	year.
1,600,000	"	"	day.
67,000	"	"	hour.
18½	"	"	second.

The earth moves about the sun in its own orbit at about the same rate of 19 miles per second, while sun, earth, and orbit move along in space another 19 miles.

We can now go back to the stars themselves, and subtract from the observed proper motion of each star that portion (*motus parallacticus*) which is due to the motion of the solar system, and leave that portion which is due to the star's own motion (*motus peculiaris*).

Is there anything common to the truly proper motions of the stars? In the first place, it may be said that, so far as we know up to this time, these motions are, in general, not curved. They are practically straight lines. They have no common center. There is no great central body around which revolve the suns of all other systems. If there be such a body it will be many centuries before we shall know it; and we may say that, so far as our knowledge goes, there is none.

SYSTEMATIC MOTIONS OF THE FIXED STARS PARALLEL TO THE MILKY WAY.

BUT if we are obliged to consider the motions of all the stars to be practically in right lines, and not in closed orbits, there is no reason why we should not examine the question of whether the stars as a whole do not have some systematic motion — whether there is not among this variety some unity. The most natural hypothesis to start with is that the stars have a vast rotation in planes parallel to the Milky Way. We already have good data for examining this, and in a few years, when the zones of the *Astronomische Gesellschaft* are complete, much material will be added. Without some assumption of the sort, that the stars rotate in planes parallel to the Milky Way, it is hardly possible to explain the existence of the Milky Way itself. It would necessarily disintegrate more and more with the lapse of time, and it would be a pure accident that we happen to live at a time when this disintegration has not been accomplished. The investigation of this possible rotation has been carried out by two pupils of Professor Gyldén and of Professor Schoenfeld respectively. While the result in one case is fairly against the hypothesis of such a rotation, in the other it is somewhat in its favor. The doubt in the matter arises solely from the deficiency of the data, and this will soon be supplied. In the mean time it should be an answer to those objectors who ask what is the use of another new catalogue of stars, that this catalogue, and every other catalogue, goes a certain way towards providing the means for solving the very greatest problem that can be presented to the human mind by natural objects.

Look at the Milky Way stretching across the summer sky with the bright star Vega burning near it. Think that the few proper motions laboriously determined by Halley and Maskelyne enabled Herschel to announce that the sun, the earth, and every planet is moving towards a spot — near Vega — which he could point out. Think, too, that the smallest efforts of every faithful observer, the world over, go to the solution of the question, How do all these thousands of stars that I see move in space? Are they bound up with that Milky Way in one fate? Or is that permanent shining track, which seems unchanged since Job and the patriarchs looked upon it — is that doomed to destruction? The finger of analysis can point out the fate of those myriads of shining stars, and man becomes fit to live under their influence when his mind adds the beauty of law to the wayward beauty of their shining.

SPECTROSCOPIC PROPER MOTIONS — MOTIONS IN THE LINE OF SIGHT.

THE observation of a star's position is really nothing but the determination of the place where the line joining eye and star pierces the celestial sphere. The determination of its proper motion is nothing but the determination of the rate at which its apparent position changes. If a star is moving directly towards us, or directly away from us, its apparent place in the sky will remain unchanged. But we have in the spectroscope a means of measuring the motion of a star in the line of sight. The principle of the method is simple. The application of it is most difficult. Every one has noticed, in traveling upon an express train, the sudden clang of the bell of a train passing in the contrary direction; and how the note, the pitch, of the sound of this bell rapidly changes from high back to low again. Nothing is more certain than that the bell has but one essential pitch. Why, then, does it change? The engineer of the passing train hears his own bell giving always the same note, and this note is determined by the length of the sound waves that reach his ear. Suppose them to come at the rate of about 500 per second to him. He is always moving at the same rate as his bell. But to us in the other train the case is different. When the bell is just opposite us 500 waves come to us per second; when we are approaching the passing train more than 500 come to us (not only the 500 sent out by the bell, but those others which we meet by our velocity); as we leave the passing train, less than 500 waves overtake us per second. Hence the pitch (the number of waves per second) varies. The same thing happens in the case of light. In the spectrum of a star there are certain dark lines the presence of which is due to hydrogen in the star's atmosphere. If the star is at rest with respect to us, these lines are not displaced in its spectrum; a definite number of waves per second (say *A*) come to us from the spectrum on both sides of these lines. If the star is approaching us, more waves than *A* reach us; if the star is receding, fewer waves reach us. The pitch of the line, so to say, is altered; and the spectroscope can measure this change of pitch.

When this is done with respect to the principal stars the most interesting results follow.

Vega (Lyræ) is found to be approaching us at the rate of 75 kilometers per second, Pollux is approaching us at 67 kilometers, Arcturus at 70 kilometers, etc.; while Castor is receding from us 44 kilometers per second, Regulus is receding 33 kilometers, Procyon 74 kilometers, and so on. After years the aspect of our sky will change. We shall have new glories in the galaxy, and after thousands of years these again will leave us. There is ceaseless change here as everywhere.

No adequate idea of the delicacy of the measures upon which these results depend can be briefly given; but delicate and difficult as they are, we have evidence that they are to be trusted. The independent observations of Dr. Huggins, Dr. Vogel, and Mr. Maunder of Greenwich show a good agreement. It is hoped that the Princeton telescope in the skillful hands of Professor Young may contribute to our knowledge of stellar motions in the line of sight; and this is a research to which the large refractor of the Lick Observatory will be especially devoted. The consistency of the results reached by the three observers named above for the stars observed in common by them makes the one exceptional case extremely interesting.

Sirius, the brightest star in the sky, was naturally among the first to be observed. It has been followed from 1875 to 1885, ten years, with the results given below:

Year.	*No. of measures.*	*Motion, per second.*
1875–77	8	21.1 miles receding.
1877–78	8	23.0 " "
1879–80	10	15.1 " "
1880–81	4	11.3 " "
1881–82	22	2.1 " "
1882–83	18	4.7 " approaching.
1883–84	43	19.4 " "
1884–85	8	21.5 " "

Here we have well-marked evidence of a real change in the direction of the motion of Sirius, with respect to the earth, and it is based on spectroscopic observations alone. It happens also that it was known, from observations with the telescope, that Sirius was moving in an elliptic orbit, and hence necessarily approaching us at times, and at times receding from us. It will not require many more years to determine all the circumstances of this motion, of which we unexpectedly have a double proof.

PARALLAXES OF THE STARS.

THE ancients placed all the fixed stars on the inner surface of a vast sphere which turned about the earth's center once each day. They had absolutely no way of even guessing how far off this sphere might be. In 1618 Kepler's guess was 4,000,000 times as far as the sun; in 1698, Huyghens placed Sirius 28,000 times as far as the sun; in 1741, Picard showed that the errors of observation with the instruments of his time were as great as the parallaxes of the stars themselves, and that therefore the problem was indeterminate to him; in 1806, Delambre concluded that the same thing remained true, notwithstanding the improvements of the instruments in the meanwhile. It was not till 1836 that W. Struve and Bessel really determined the parallax, and hence the distance of two different stars α Lyræ and 61 Cygni.

It is familiar to all that the distances of even the nearest stars are not to be conceived when they are expressed in miles or familiar units. No star is so near to us as 200,000 times 93,000,000 of miles. We have to express these distances in terms of the time required for light to pass from star to earth. For 61 Cygni that time is 2377 days, or 6½ years. It was the elder Herschel who put these immense distances before us in the true light, by showing that if to-day the star were blotted out of existence its mild light would shine on for years, until the last ray that left it had finally ended its long journey and reached the earth, more than six years afterwards.

But all stars are not equally distant. The light from one star may be 10, from another 100, from another 1000 years old when it reaches us. We must no longer regard the study of the stars as a study of their contemporaneous existence. It is rather the ancient history of the universe which is exhibited to us by the vault of heaven. Assiduous observers have determined the parallaxes of about a score of stars. The first stars to be examined were either the brightest (as in the case of Vega), or those of large proper motion (as 61 Cygni). In general, the brightest stars should be the nearest, one would think, and yet the very largest parallaxes belong to the fainter stars. Similarly the star with the greatest proper motion has a very small parallax.

By treating all the certain data in various ways, Professor Gyldén has come to the conclusion that the average parallax of a star of the first magnitude is about 0.084″, or that the average distance of our brightest star is 160,000,000,000,000,000 miles. But to make farther steps in the problem of the "construction of the heavens," we must know more than the average parallax of the brightest stars. We must be able to assign the average parallax of stars of each order of magnitude, and this in both hemispheres.

This task is now undertaken for stars down to the fourth magnitude by two observers who have already distinguished themselves in this field — Dr. Gill, Royal Astronomer at the Cape of Good Hope, and Dr. Elkin, now at Yale University Observatory. These gentlemen have devoted their energies to this one problem, which will require perhaps ten years for its solution in the form that they have chosen for it. Dr. Ball, Royal Astronomer for Ireland, is systematically searching for stars of large parallax and incidentally proving many stars to have small parallax — a fact which it is just as important to know as its converse.

The next dozen years will show immense strides in our knowledge of the stellar distances of individual stars, and it may well be that some general relation between distance, brightness, and proper motion of situation in the sky will result from the great increase of data.

DISTANCES OF STARS OF EACH MAGNITUDE.

THE golden time for astronomers will come when the parallaxes of enough stars have been determined for them to be able to say that the distance of an average third, fourth, sixth, or tenth magnitude star is so many, or so many, times the sun's distance. That time has not yet come, nor will it have come even when the great work undertaken by Messrs. Gill and Elkin has been ended. There is no certain way of assigning the stellar distances but by measurements such as they are making. But it is a fair procedure to make certain assumptions as to stellar distances, to work out the logical consequences of these assumptions, and to compare these consequences with known facts. An agreement with the facts will, in some degree, support the assumptions. If we assume the stars to be of equal brilliancy one with another, we have one basis of computation. If we suppose them, further, to be equally distributed in space on the average, we have another basis. These conditions lead at once to the following table:

Magnitudes.	*Relative Distances.*
1	1.00
2	1.54
3	2.36
4	3.64
5	5.59
6	8.61
7	13.23
8	20.35

We can test these assumptions to some extent. If they are true, then the ratio of the actual number of stars of any brightness to the actual number of stars of the next lower grade of brightness, raised to the two-thirds power, should be 0.400. Using the stars of the sixth and seventh magnitudes, this number results 0.426; of the seventh and eighth, it results 0.4003, etc. The two hypotheses are in the main not far from correct, and therefore the relative distances above given are not very far wrong for stars down to the eighth magnitude. There is strong reason to believe that the fainter stars, from eleventh to fifteenth magnitudes, do not follow the same law. We have seen that the average distance of a first magnitude star is 160,000,000,000,000,000 miles. Multiply this by 20.35 and you have the best estimate now available of the distance of an eighth-magnitude star. It is inconceivable, but no more so than the first number. Light would require 600 years and more to reach us from such stars.

DISTRIBUTION OF THE STARS OVER THE SURFACE OF THE CELESTIAL SPHERE.

THE real question to be solved is, How are the stars distributed throughout solid space itself? To solve this question completely the distance of every star from the earth must be measured (which is a simple impossibility), or else we must find some law which connects the brightness, or the proper motion, or the position of a star with its distance. Suppose that 10 stars of each magnitude from the brightest down to the faintest are selected — say 150 or 160 in all — and that the parallax of each individual star is determined. This would be a tremendous labor in itself, and would require the work of several observers for a score of years. But suppose this work done. Suppose that the average distances of the ten stars of each group resulting from the measures were I, II, III, IV, V ———————— XIII, XIV, XV, XVI. Would any general relation exist between the magnitudes 1 ———— 16 and the corresponding distances I ———— XVI? From those measures that we already possess this is by no means sure. In fact, the evidence seems to be directly opposed to this conclusion. The average measured parallax of 5 first-magnitude stars is about 0.27″; of 3 fourth-magnitude stars about 0.13″; of 3 fifth-magnitude stars about 0.31″; of 7 sixth-magnitude stars about 0.21″. That is, the parallax does not seem materially to decrease as the brilliancy diminishes from the first to the sixth magnitude. If, instead of comparing the magnitudes with the distances, we compare the proper motions, there seems to be no evident agreement. The stars with the largest proper motions do not in general have the largest parallaxes (and hence the smallest distances). We have not enough determinations of parallax to decide whether the region of the sky in which a star is situated has any relation to its distance; so that for the present we are not sure that a series of measures so extensive even as the one we have imagined would solve the question of the relation between magnitude, or proper motion, and parallax. Such a series would go a great way towards deciding whether the question was solvable or not. It would add enormously to the very small number of certain facts bearing on the subject of the constitution of the stellar system. And it is to the great credit of this generation of astronomers that such a series has actually been begun (for stars of from first to fourth magnitudes) by Messrs. Gill and Elkin at the Cape of Good Hope and New Haven respectively, as has been mentioned already.

In the absence of real knowledge with regard to the distribution of the stars in space, much labor has been expended on the study of what we may call stellar statistics — the statistics of the distribution of the stars on the surface of the celestial vault. This distribution of the stars is known when once we have a map of their positions, which it is comparatively easy to make. Or a more rapid method of studying this distribution may be employed — that of *star gauging*, so called by Herschel, its inventor. This consists essentially in counting the number of stars visible in the field of the telescope as it is directed to various known portions of the sky. The mere number of stars visible at each pointing may be laid down on a map, like the soundings on a hydrographic chart. The data are easily gathered. How are they to be interpreted? We may briefly indicate one obvious method. Suppose that we have made such star gauges with telescopes of five different powers over the same areas in the sky. The largest telescope will show all the stars say down to and including the fifteenth magnitude; the next smaller those to the fourteenth; the next to the thirteenth, the twelfth, the eleventh (the actual distribution of the individual stars from first to tenth magnitudes is known by the *Durchmusterungen*). In any area the difference between all the *Durchmusterung* stars (from one to tenth magnitude) and the number seen in telescope I (the smallest of the five supposed) will give the number of the eleventh-magnitude stars in that region.

The difference between the counts by telescope I (which shows all stars down to and including the eleventh magnitude) and telescope II (which shows all to twelfth magnitude) will give the actual number of twelfth-magnitude stars. Combining the results of the telescopes II and III we should have the number of thirteenth-magnitude stars for this region, and so on for the fourteenth and fifteenth magnitudes. Thus the actual number of the stars of each magnitude in this area (and similarly for other areas) will be known. We may interpret these figures somewhat in this way. Take a map which shall have spaces on it for the whole sky, and devote this map to exhibiting the results of our gauges for the fifteenth-magnitude stars. Wherever there are 100 of these to the square degree lay on one tint of color; wherever there are 200, two tints; 300, three tints, and so on. The final map will exhibit to the eye the results of our gauges for the fifteenth-magnitude stars. Where the tint is deep, there are more stars; where it is light, fewer. Another such map must be made for the fourteenth-magnitude stars; another for the thirteenth, and so on. Now place these fifteen maps side by side before you, and it will be possible to obtain at once a number of definite conclusions. Here the stars that we call fifteenth and those that we call fourteenth are really connected together in space. Why? Because this long ray of many fifteenth-magnitude stars on one map is matched by this other long ray of just the same position and shape of the fourteenth-magnitude stars. The thirteenth, too, we will say, is similar. But the ninth, tenth, eleventh, and twelfth do not in their distribution at all resemble the fainter stars in this region, but they do resemble each other. In this way, passing from region to region, the general peculiarities of each region may be made out, and much light may be thrown on the vital question, How many magnitudes of stars exist at the same distance from us? Are the stars of the so-called ninth, tenth, eleventh magnitudes all really at the same distance from us, and are their differences in brightness simply due to differences in size, or are they really at different distances?

A large amount of evidence upon these fundamental points already exists, and more is being accumulated, and it appears possible that a skillful use of it may throw much light on the real question. The new photographic processes will be of immense importance for this investigation. We have not the space to go farther into this method of research, but we may just refer in passing to one interesting form of it. We have already elaborate maps of certain portions of the sky showing the position and magnitude of every star down to the thirteenth. These are the maps used for the discovery of asteroids. From each of these maps we can make thirteen others, each of which latter shall show the stars of one magnitude only. Now compare these thirteen derived maps, and see what the evidence is that the stars of any two magnitudes are connected or independent. This method is capable of bringing out most interesting conclusions when it is thoroughly carried out, as it has not yet been to any large degree. The local arrangements of stars can be adequately studied in this way; and it is not too much to expect that the typical forms of stellar systems — distorted by perspective, of course — may be exhibited here.

Suppose one typical form to be a circular ring, as it appears to be. The apparent dimensions of these rings may well give us a clue to the relative distances of the stars of which they are composed. The preliminary work of this kind which has been done at the Washburn Observatory appears to promise some definite results in this direction.

MASSES OF BINARY AND OTHER STARS.

THE binary systems are those composed of two stars which are connected with each other by a mutual gravitation. They revolve about a common center of gravity in orbits which can be calculated. In some few cases the parallax of these stars is known; and in every such case the sum of the masses of the two stars becomes known in terms of the mass of our own sun. It is especially noteworthy that in every known case the mass of the binary system is not very different from the mass of our own sun. That is to say, all the stars whose masses are known at all are such bodies as our sun is: they shine with light like his; they are of the same order of magnitude mass.

The term "hypothetical parallax" is applied to a parallax computed for a binary star on the supposition that the mass of the binary, although unknown, may be hypothetically assumed to be the same as the sun's mass. So far as we can judge, these hypothetical parallaxes must be provisionally accepted as essentially correct.

If we can assume that the intrinsic brilliancy of the fixed stars is the same for each star, which does not seem to be a very violent supposition, several interesting conclusions follow which can only be stated here.

If it be true that for the stars, taken one with another, a square mile of surface shines with an equal light for each star, then among stars of known distances some must be at least 270 times as great in diameter as others. This is about the proportion of the sun to Mercury. Also it follows that binary stars whose colors are alike must be composed of stars of like size; and also, that on the average the brightest star of any cluster is about four times as large as the smallest star of the cluster. No star is more than 200,000 times farther than the nearest fixed star. Other assumptions which might serve as a basis for computation will give other results; but for the present we have to content ourselves with some such assumption, and in the infinite variety of circumstances among the fixed stars choose that one as general which seems to be the most likely *a priori*, and which leads to results which agree with the facts of actual observation.

THE CLUSTER OF STARS TO WHICH OUR SUN BELONGS.

THE *Uranometria Nova* of Argelander gave the positions of the lucid stars of the northern sky, and it has been supplemented by the *Uranometria Argentina* of Dr. Gould, which covers the southern sky. With the stellar statistics of the whole sky before him Dr. Gould was in a position to draw some extremely interesting conclusions with respect to the arrangement of the brighter stars in space, and to the situation of our solar system in relation to them. The outline of his reasoning can be given here, but the numerical evidence upon which his conclusions are founded must be omitted. In the first place, it is fairly proved that in general the stars that are visible to the naked eye (the lucid stars) are distributed at approximately equal distances one from another, and that on the average they are of approximately equal brilliancy. If we make a table of the number of stars of each separate magnitude in the whole sky we shall find that there are proportionately many more of the brighter ones (from first to fourth magnitudes) than of the fainter (from fourth to seventh magnitudes). That is, there is an "unfailing and systematic excess of the observed number of the brighter stars." We cannot suppose, taking one star with another, that the difference between their apparent brightness arises simply from real difference in size, but we must conclude that the stars from the first to fourth magnitudes (some 500) are really nearer to us than the fainter stars. It therefore follows that these brighter stars form a system whose separation from that of those of the fainter stars is marked by the change of relative numerical frequency.

What, then, is the shape of this system? and have we any independent proof of its existence? Sir John Herschel and Dr. Gould have pointed out that there is in the sky a belt of brighter stars which is very nearly a great circle of the sphere. This belt is plainly marked, and it is inclined about 80° to the Milky Way, which it crosses near Cassiopea and the Southern Cross. Taking all the stars down to 4.0 magnitude Dr. Gould shows that they are more symmetrically arranged with reference to this belt than they are with reference to the Milky Way. In fact, the belt has 264 stars on one side of it and 263 on the other, while the corresponding numbers for the Milky Way are 245 and 282. From this and other reasons it is concluded that this belt contains brighter stars because it contains the nearest stars, and that this set of nearer and brighter stars is distinctively the cluster to which our sun belongs. Leaving out the brighter stars which may be accidentally projected among the true stars belonging to this cluster, Dr. Gould concludes that our sun belongs to a cluster of about 400 stars; that it lies in the principal plane of the cluster (since the belt of bright stars is a great, not a small circle); and that this solar cluster is independent of the vast congeries of stars which we call the Milky Way.

We know that the sun is moving in space. It becomes a question whether this motion is one common to the solar cluster and to the sun, or only the motion of the sun in the solar cluster. The motion has been determined on the supposition that the sun is moving and that its motion is not systematically shared by the stars which Dr. Gould assigns to the solar cluster. But a very important research will be to investigate the solar motion without employing these 400 stars as data.

In what has gone before I have tried to exhibit some of the main questions in purely Sidereal Astronomy; to show some of the more important results already reached, and especially to indicate the directions along which present researches are tending. It is impossible to give a complete view in this or in any other single branch of astronomy, for they are all indissolubly bound together.

The methods of the new astronomy have taught us that in the condition of the variable stars, where the intense glow has cooled to a red heat, we can see the future of our own sun as well as its past in the brilliant white and violet of the brightest and youngest stars. It requires the profound mathematical analysis of Gyldén to interpret his equations so as to explain to the new astronomy exactly how the phenomena of the rotation of variable stars produce the effects which are observed by its methods.

Professor Langley measures the light and heat of the moon by the new methods; Professor Darwin interprets the mathematical theory of the tides so as to trace back the origin of that heat to the remote time when the earth and moon formed one mass, and rotated in less than an eighth part of our present day. All the parts of the complex science are intimately connected, and no one can be separately treated without losing sight of many lines of research of the greatest promise and importance.

But I hope that enough has been said to show that the old astronomy is not idle; that it has its new side; and that its energies are addressed to the solution of tremendous problems of the highest significance. In broad terms, it seems to me to be the noble aim of the new astronomy to trace the life-history of an individual star, and of the old to show how all these single stars are bound together to make a universe. There is no antagonism in their objects. Each is incomplete without the other.

Edward S. Holden.

WAVES AND MIST.

THIS is the fancy that thrills through me
Like light through an open scroll:
The waves are the heart-throbs of the sea,
And the white mist is her soul.

William H. Hayne.