The evolution of worlds

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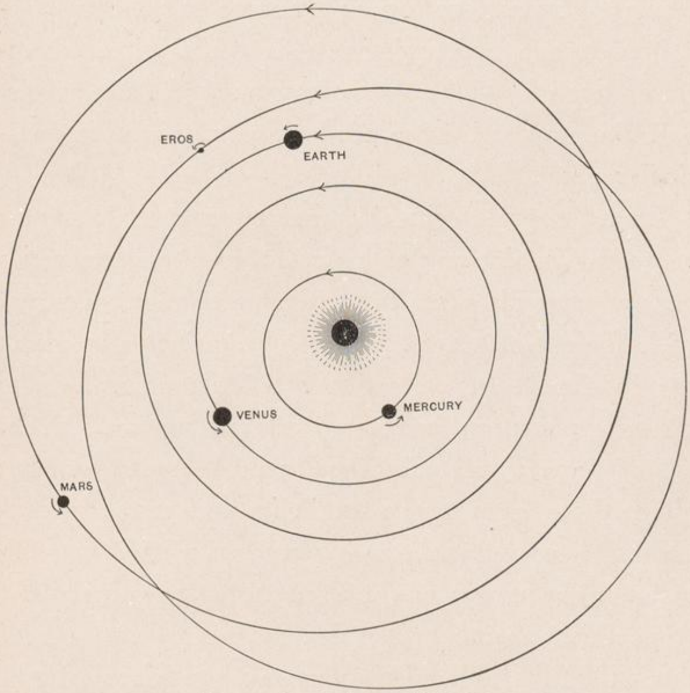
Chapter III.

CHAPTER III

THE INNER PLANETS

WHEN we recall that the Ptolemaic system of the universe was once taught side by side with the Copernican at Harvard and at Yale, we are impressed, not so much with the age of our universities, as with the youth of modern astronomy and with the extraordinary vitality of old ideas. That the Ptolemaic system in its fundamental principle was antiquated at the start, the older Greeks having had juster conceptions, does not lessen our wonder at its tenacity. But the fact helps us to understand why so much fossil error holds its ground in many astronomic text-books to-day. That stale intellectual bread is deemed better for the digestion of the young, is one reason why it often seems to them so dry.

Before entering upon the problem of the genesis and career of a world, it is essential to have acquaintance with the data upon which our deductions are to rest. To set forth, therefore, what is known of the several planets of our solar system, is a necessary preliminary to any understanding of how they came to be or whither they are tending; and as our knowledge has been vitally affected by modern discoveries about them, it is imperative that this exposition of the facts should be as near as possible abreast of the research itself. I shall, therefore, give the reader



Orbits of the Inner Planets.

in this chapter a bird's-eye view of the present state of planetary astronomy, which he will find almost a different part of speech from what it was thirty years ago. It is not so much in our knowledge of their paths as of their persons that our acquaintance with the planets has been improved. And this knowledge it is which has made possible our study of their evolution as worlds.

Could we get a cosmic view of the solar system by leaving the world we live on for some suitable vantage-point in space, two attributes of it would impose themselves upon us — the general symmetry of the whole, and the impressively graded proportions of its particular parts.

Round a great central globular mass, the Sun, far exceeding in size any of his attendants, circle a series of bodies at distances from him quite vast, compared with their dimensions. These, his principal planets, are in their turn centres to satellite systems of like character, but on a correspondingly reduced scale. All of them travel substantially in one plane, a fact giving the system thus seen in its entirety a remarkably level appearance, as of an ideal surface passing through the centre of the Sun. Departing somewhat from this general uniformity in their directions of motion, and also deviating more from circularity in their paths, some much smaller bodies, a certain distance out, dart now up now down across it at different angles and from all the points of the compass, agreeing with the others only in having the centre of the Sun their seemingly never attained goal of endeavor. These bodies are the asteroids. Surrounding the whole, and even penetrating within its orderly precincts, a third class would be visible which might be described for size as cosmic dust, and for display as heavenly pyrotechnics. Coming from all parts of space indifferently they would seem to seek the Sun in almost straight lines, bow to him in circuit, and then depart whence they came. For in such long ellipses do they journey that these seem to be parabolas. These visitants are the comets and their associates the meteor streams.

Although for purposes of discrimination we have labelled the several classes apart, an essential fact about the whole company is to be noted: that no hard and fast line can be drawn separating the several constituents from one another. In size the members of the one class merge insensibly into the other. Some of the planets are hardly larger than some of the satellites; some of the satellites than some of the asteroids; some of the asteroids than comets and shooting stars. In path, too, we find every gradation from almost perfect circularity like the orbits of Io and Europa to the very threshold of where one step more would cease to leave the body a member of the Sun's family by turning its ellipse into an hyperbola. Finally, in inclination we have every angle of departure from orthodox platitude to unconforming uprightness. This point, that heavenly bodies, like terrestrial ones, show all possible grades of indistinction, is kin to that specific generalization by which Darwin revolutionized zoölogy a generation ago. It is as fundamental to planets as to plants. For it shows that the whole solar system is evolutionarily one.

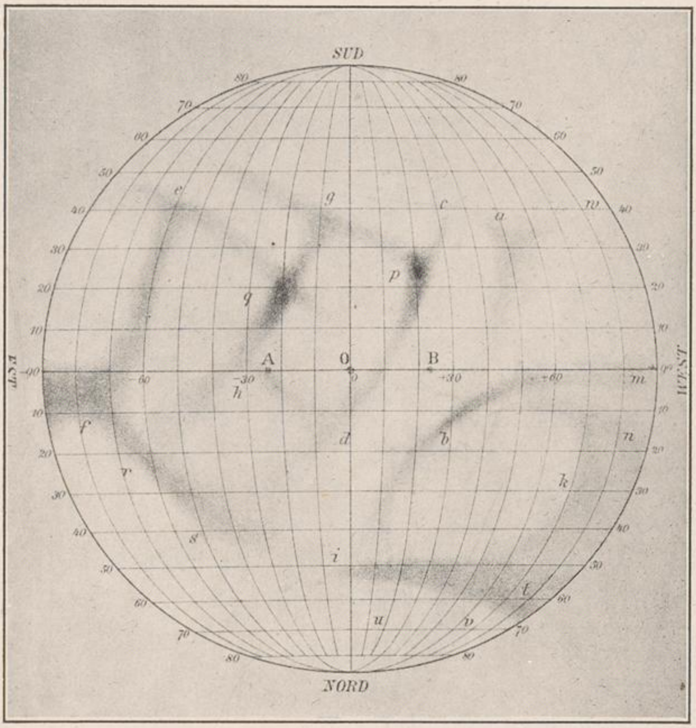
A second point to be noticed in passing is that undue inclination and excessive eccentricity go together. The bodies that have their paths least circular have them, as a rule, the most atilt. And with these two qualities goes lack of size. It is the smallest bodies that deviate most from the general consensus of the system. With so much by way of generic preface, the pregnancy of which will become apparent as we proceed, we come now to particular consideration of its members in turn.

Nearest to the Sun of all the planets comes Mercury. So close is he to that luminary, and so far within the orbit of the earth, that he is not a very common object to the unaided eye. Copernicus is said never to have seen him, owing, doubtless, to the mists of the Vistula. By knowing when to look, however, he may be seen for a few days early in the spring in the west after sunset, or before sunrise in the east in autumn. He is then conspicuous, being about as bright as Capella, for which star or Arcturus he is easily mistaken by one not familiar with the constellations.

His mean distance from the Sun is thirty-six million miles, but so eccentric is his orbit, the most so of any of the principal planets, that he is at times half as far off again as at others. Even his orbital behavior is the least understood of any in the solar system. His orbit swings round at a rate which so far has defied analysis. It may be a case of reflected perturbation, one, that is, of which the indirect effect from another body becomes more perceptible than would be the direct effect on the body itself. As yet it baffles geometers.

As to his person, our ignorance until lately was profound. It is only recently that such fundamental facts about him as his size, his mass, and his density have been reached with any approach to precision. This was because he so closely hugs the Sun that observations upon his full, or nearly full, disk had never been attempted. When I say that his volume was not known to within a third of its amount, his mass not closer than one-half, while his received density was nearly double what we now have reason to suppose the fact, some idea of the depth of our nescience may be imagined. This, of course, did not prevent text-books from confidently misinstructing youth, or Nautical Almanacs from misguiding computers with figures that thus almost achieved immortality, so long had they passed current in spite of lacking that perfection which is usually assigned as its warrant.

Schiaparelli first put astronomy on the right track. By attempting daylight observations of the planet, not



Sulla Rotazione di Mercurio — Di G. V. Schiaparelli.

toward night, but actually at midday, he made some remarkable discoveries, and though he did not detect the hitherto erroneous values of the volume, the mass, or the density, his method of observation paved the way for their ascertainment. What he sought, and found, was evidence of markings upon the disk by which the planet's time of rotation might be determined. Up to then, Schroeter's value of about twenty-four hours had been accepted, on very slender evidence indeed, and passed into all the books. But when the planet came to be observed by noon, very definite markings stood out on its face, which showed its rotation to take place, not in twenty-four hours, but in eighty-eight days. By a persistence equal to his able choice of observing time, he established this beyond dispute. He proved the revolutionizing fact that Mercury's periods of rotation and of revolution were the same.

He detected, too, the evidence in the position of the markings of the planet's great libratory swing due to the eccentricity of its orbit, a result as remarkable as a feat of observation as it was conclusive as a proof.

If Schiaparelli had never done any other astronomical work, this study of Mercury would have placed him as the first observer of his day. For the observations are so difficult that the planet not only baffled all his predecessors, but has foiled many since who are credited with being observers of eminence.

In 1896 the study of Mercury was taken up at the Lowell Observatory in Arizona along the same lines that had proved so successful with Schiaparelli, but without using his observations as guide. Indeed, his papers had not then been read there. The two conclusions were, therefore, independent of one another.

The outcome was a complete corroboration and an extension of Schiaparelli's work. We shall begin with the consideration of the most fundamental point. In the clear and steady air of Flagstaff, permitting of measurement of his disk up to within a few degrees of the Sun, Mercury was found to be much larger than previously thought.

Instead of a diameter of three thousand miles he proved to have one of thirty-four hundred, making his volume nearly half as large again as had been credited him. These measures bore intrinsic evidence of their trustworthiness in an interesting manner, and at the same time produced internal testimony that accounted for the smallness of previous determinations. Measures heretofore had been made, usually if not invariably, either when the planet transited the Sun or when it exhibited a pronounced phase. Now in both these cases the planet looks smaller than it is. In the first case this is due to irradiation, the surrounding disk of the Sun encroaching both to the eye and to the camera upon the silhouette of Mercury. And this inevitable effect had not been allowed for in the measures. In the second case the horns of the planet never seem to extend quite to their true position. This was rendered evident by the Flagstaff series of measures, which began when the planet was a half-moon and continued till it was almost full. As it did so, the values for the diameter steadily increased, even after irradiation was allowed for, although this against the brilliant background of the noonday sky must have been exceeding small, and tended in part to be diminished as the planet attained the full, because of its consequent nearing of the Sun. The measures thus explained themselves and vouched for their own accuracy.*

Then came a curious bit of unexpected proof to corroborate them. In his "Astronomical Constants,"† published but a short time before, Newcomb had detected a systematic error in the right ascensions of Mercury which he was not able to explain. By diligent mousing that eminent computer had discovered that Mercury was registered by observers too far from the Sun on whichever side of him it happened to be, and in proportion roughly not to its distance off but to the phase the planet exhibited. When the disk was a crescent the discrepancy between observation and theory was large, and thence decreased as the planet passed to the full. He suspected the cause, and would have found it had he not considered the diametral measures of the planet too well assured to permit of doubt. As it was, he neglected a factor which has

* New Observations of the Planet Mercury, *Memoirs Amer. Acad.* 1897. Vol. XII, No. 4.

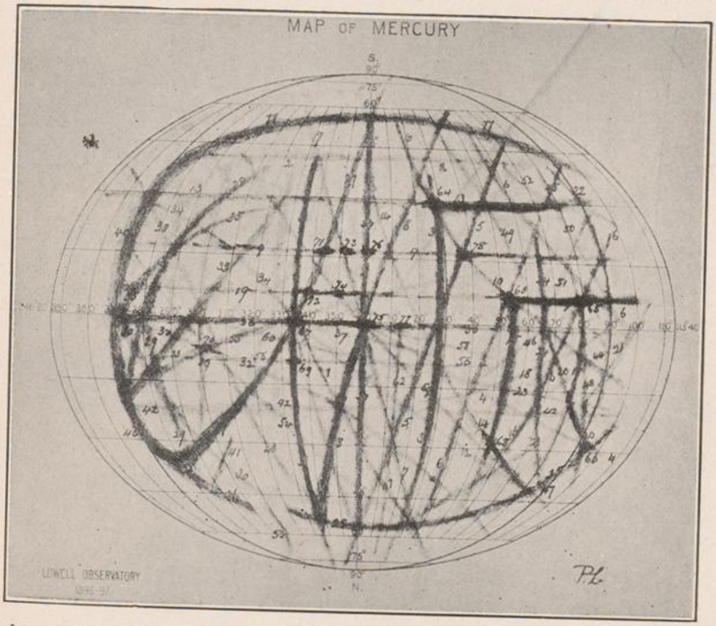
† "Astronomical Constants," 1895, pp. 67, 68.

vitiated almost all the observations made on the planets up to within a few years, the correction for irradiation. This was the case here. The received measures, beginning with Bradley and ending with Todd, had almost without exception been made in transit, and, as no regard had been paid to the contracting effect of irradiation, had been invalidated in consequence. The new method supplied almost exactly the amount needed to explain the right ascensions, a second of arc, and in precise accordance with the place which the discrepancy demanded.

About the mass there has been, and still is, great uncertainty. This is because it can only be found from the perturbing effect it has on Venus, the Earth, or Encke's comet. Modern determinations, however, are smaller than the older ones; thus Backlund in 1894 got from the effect on Encke's comet only one-half the mass that Encke had, fifty-three years before. Probably the most reliable information comes from Venus, which Tisserand found to give for Mercury $\frac{1}{7100000}$ of the mass of the Sun, or $\frac{1}{21}$ of the mass of the Earth. If we take $\frac{1}{7000000}$ as the nearest round number, we find the planet's density to be 0.66 that of the Earth.

The same observations that disclosed at Flagstaff the planet's size revealed a set of markings on his face so definite as to make the rotation period unmistakable.

It takes place, as Schiaparelli found, in eighty-eight days, or the time of the planet's revolution round the Sun. The markings disclosed the fact, as Schiaparelli had also discovered, in a most interesting manner, for



the ellipticity of the planet's orbit stood reflected in the swing of the markings across the face of the disk, a definiteness in the proof of a really surprising kind. What this means we shall see in a subsequent chapter when we take up the mechanical problem of the tides. Another result that issued from the positions of the markings was the determination of the planet's pole. Except for the libration above noticed, the markings kept an invariable longitudinal position upon the illuminated disk, showing that the planet turned always the same face to the Sun; but latitudinally a difference was noticeable between their place in October–November, 1896, and in February–March, 1897, the latter being 4° farther north. Now this is just what the orbital position should have caused, if the pole stood vertically to it. Thus a difference of 4° from perpendicularity should have been discernible, had it existed,—a very small amount in such a determination. We may, therefore, conclude that the axis stands plumb to the orbit, and this is what theory demands.

The state of things this introduces to us upon that other world is to our ideas exceeding strange. It is not so much the slowness of the diurnal spin, eighty-eight times as long as our own, which is surprising, as the fact that this makes its day infinite in length. Two antipodal hemispheres divide the planet, the one of which frizzles under eternal sun, the other freezes amid everlasting night. The Sun does not, indeed, stand stock-still in the sky, but nods like some huge pendulum to and fro along a parallel of latitude. In consequence of libration the two great domains of day and night are sundered by a strip of debatable ground $23\frac{1}{2}$° in breadth on either side, upon which the Sun alternately rises and sets. Here there is a true day, eighty-eight of our days in length from one sunrise to the next. But its day and night are not apportioned alike. The eastern strip has its daylight briefer than its starlight hours; the western has them longer. Nor are different portions of the strips similarly circumstanced in their sunward regard. Only the edge next perpetual day has anything approaching an equal distribution of sunlight and shade. The farther one just peeps at the Sun for a moment every eighty-eight days, and then sinks back again into obscurity.

The transition from day to night is equally instantaneous and profound. For little or no twilight here prolongs the light; since the air, if there be any at all, is too thin to bend it to service round the edge to illuminate the night. When the libratory Sun sets, darkness like a mantle falls swiftly over the face of the ground. No evidence of atmosphere has ever been perceived, and theory informs that it should be nearly, if not wholly, absent.

In consequence of the rigid uprightness of the planet's axis, seasons do not exist. Their nearest simulacrum comes from the seeming dilatation of the Sun during half the year, and its apparent contraction during the other half. It expands so much between its January and its July as to receive more heat in the ratio of nine to four. A seasonless, dayless, and almost yearless planet, it is better to look at than to look from; but its study opens our eyes to the great diversity which even one of our nearest neighbors exhibits from what we take as matters of course on Earth.

That what we take offhand to be purely astronomic phenomena should turn out to be so essentially of the particular world, worldly, clarifies vision of what these really are, and how dependent on and interwoven with everyday life astronomy is. Or, we may consider it turned about and realize how purely astronomic relations, such abstract mechanical matters as rotations and revolutions, result in completely changing the very face and character of the globe concerned. Mercury to-day stares forever at the Sun. The markings we see have stereotyped this stare to its inevitable result. For they seem to mark a globe sun-cracked. At such a condition the curious crisscross of dark, irregular lines certainly hints, accentuated and perfected as it is by a bounding curve where the mean sunward side terminates to the enclosing them as by the carapace of a tortoise. Though they cannot probably be actual cracks, however much they may resemble such, yet they may well owe their existence to that fundamental cause.

In color the planet is ghastly white; of that wan hue that suggests a body from which all life has fled. Far whiter than Venus in point of fact, the rosy tint with which it sparkles in the sunset glow is all borrowed of the dying day and vanishes when the planet is looked at in the uncompromising light of noon. Seen close together once at Flagstaff it was possible directly to compare the two; when Mercury, although lit by the Sun two and a half times as brilliantly as Venus, was, surface for surface, more than twice as faint. Müller has found its intrinsic brightness about that of our Moon, which in some respects it resembles, though it apparently departs widely from any similarity in others. The bleached bones of a world; that is what Mercury seems to be.

Venus comes next in order outward from the Sun. To us her incomparable beauty is partly the result of propinquity: nearness to ourselves and nearness to the Sun. Relatively so close is she to both that she does not need the Sun's withdrawal to appear, but may nearly always be seen in the daytime in clear air if one knows where to look for her. Situate about seven-tenths of our own distance from our common giver of light and heat, she gets about double the amount that falls to our lot, so that her surface is proportionately brilliantly illuminated. Being also relatively near us, she displays a correspondingly large surface.

But though part of her lustre is due to her position, a part is her own. Direct visual observation, as we remarked above, shows her intrinsic brightness to be more than five times that of Mercury, square mile to square mile of surface for the two. Now this has been determined very carefully photometrically by Müller at Potsdam. The result of his inquiry was to indicate that Mercury shines with 0.17 of absolute reflection, Venus with 0.92. So high a value has seemed to many astronomers impossible, because so far surpassing that which has tacitly been taken as the *ne plus ultra* of planetary brightness, that of cloud, 0.72.

Now, one of the direct outcomes of the study of Venus at the Lowell Observatory was an explanation of this seemingly incredible phenomenon. When the planet came to be critically examined there under conditions of seeing which permitted discovery, markings very faint, but nevertheless assurable, stood presented on the planet's face. These markings, of which we shall have more to say in a moment, had this of pertinency to our present point, that they kept an invariable position to one another. They thus betrayed themselves to be surface features. Furthermore, their dimness was as invariable an attribute of them as their place. They were not obscured on some occasions and revealed at others, but stayed, so far as one might judge, permanently the same. They were thus neither clouds themselves nor subject to the caprice of cloud.

The old idea that Venus was a cloud-wrapped planet and owed her splendor to this envelope, vanished literally into thin air.

It is precisely because she is not cloud-covered that her lustre is so great. She "clothes herself with light as with a garment" by a physical process of some interest. As becomes the Mother of the Loves, this is gauze of the most attenuated character, and yet a wonderful heightener of effect. For it consists solely of the atmosphere that compasses her about. It is well known that a substance when comminuted reflects much more light than when condensed into a solid state. Now an atmosphere is itself such a comminuted affair, and, furthermore, holds in suspension a variety of dust. This would particularly be the case with the atmosphere of Venus, as we shall have reason to see when we consider the conditions upon that planet made evident by study of its surface markings. To her atmosphere, then, she owes four-fifths or more of her brilliancy. And this stands corroborated by the low albedo of both Mercury and the Moon, which have no atmosphere, and by the intermediate lustre of Mars, which has some, but little.*

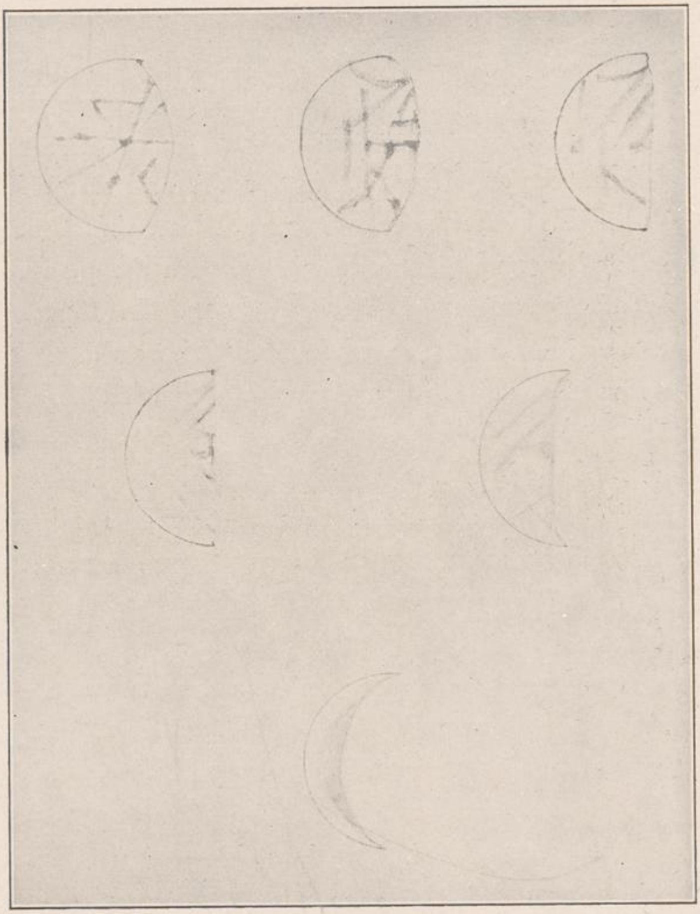
The rotation time of Venus, the determination, that is, of the planet's day, is one of the fundamental astronomical acquisitions of recent years. For upon it

* *Astr. Nach.* No. 3406. Monthly Notices R. A. S., March, 1897.

turns our whole knowledge of the planet's physical condition. More than this, it adds something which must be reckoned with in the framing of any cosmogony. It is not a question of academic accuracy merely, of a little more or a little less in actual duration, but one which carries in its train a completely new outlook on Venus and sheds a valuable sidelight upon the history of our whole planetary system.

Unconsciously influenced, one is inclined to think, by terrestrial analogies, astronomers for more than a couple of centuries, ever since the time of the first Cassini in 1666, deemed the day of Venus to be just under twenty-four hours in length. So well attested was its determination, and so precisely figured to the minute, that it imposed itself upon text-books which stated it as an acquired fact down to the last second. Nevertheless, Schiaparelli was not so sure, and proceeded to look into the matter. He first looked for himself, and then looked up all the old observations. His chief observational departure was observing by day as near to noon as possible; because then the planet was highest, to say nothing of the taking off from its glare by the more brilliant sky. From certain dark markings around two bright spots near the southern cusp, of one of which spots the detection dates from the time of Schroeter, and from a long, dark streak stretching thence well down the disk, he convinced himself that no such period as twenty-four hours could possibly be correct, inasmuch as whenever he looked, the markings were always there. His notes read, "Same appearance as yesterday," day after day, until he would really have saved ink and penmanship had he had the phrase cut into a die and stamped. He concluded that the rotation was at least six months long, and was probably synchronous with the planet's time of revolution. This was in 1889. In 1895 he became still more sure, and showed how the older observations were really compatible with what he had found.

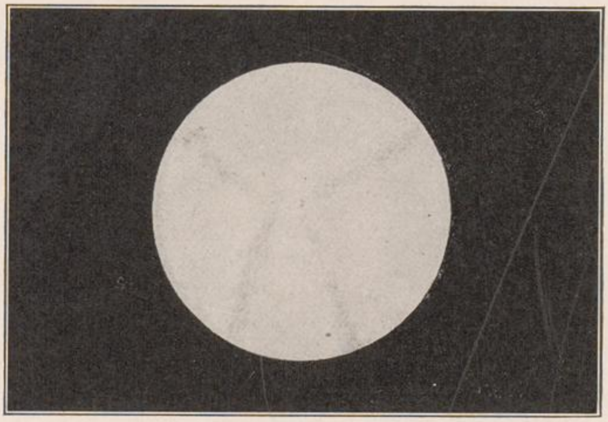
In 1896 the subject was taken up at Flagstaff. Very soon it became evident there that markings existed on the disk, most noticeable as fingerlike streaks pointing in from the terminator, faint but unmistakable from the identity of their successive presentation. Schroeter's projection near the south cusp was also clearly discernible as well as two others, one in mid-terminator, one near the northern cusp. Schiaparelli's dark markings also came out, developing into a sort of collar round the southern pole. Other spots and streaks also were discernible, and all proved permanent in place. By watching them assiduously it was possible to note that no change in position occurred in them, first through an interval of five hours, then through one of days, then of weeks. Care was taken to guard against illusion. It thus became evident



VENUS. OCTOBER, 1896–MARCH, 1897 — DRAWINGS BY DR. LOWELL.

that they bore always the same relation to the illuminated portion of the disk. This illuminated part, then, never changed. In other words, the planet turned always the same face to the Sun. The fact lay beyond a doubt, though of course not beyond a doubter.*

The years that have passed since these observations were made have brought corroboration of them. Sev-



VENUS. APRIL 12, 1909, 3H 26M–4H 22M — BY DR. LOWELL.

eral observers at Flagstaff have seen and drawn them and added discoveries of their own, among whom are especially to be mentioned, of the observatory staff: Miss Leonard, Dr. Slipher, and Mr. E. C. Slipher.†

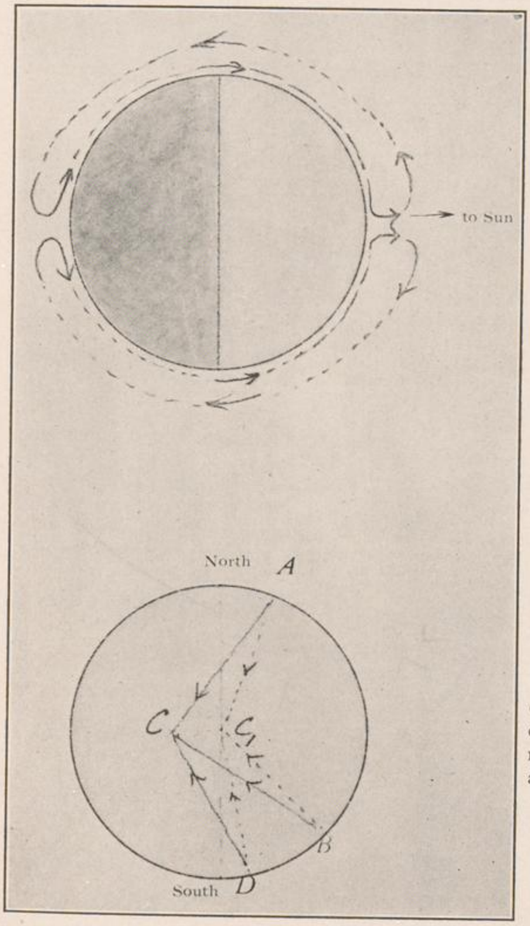
In character these markings were peculiar and distinctive. In addition to some of more ordinary char-

* Monthly notices R. A. S., March, 1897.

† Lowell Observatory Bulletin 6.

acter were a set of spokelike streaks which started from the planet's periphery and ran inwards to a point not very distant from the centre. The spokes started well-defined and broad at the edge, dwindling and growing fainter as they proceeded, requiring the best of definition for their following to their central hub.

The peculiar symmetry thus displayed, a symmetry associated with the planet's sunrise and sunset line, or, strictly speaking, what would be such did the Sun for Venus ever rise or set, would seem inexplicable, except for that very association. When we reflect, however, upon what this means, a very potent cause for them becomes apparent, so potent that surprise is turned into appreciation that nothing else could well exist. That Venus turns on her axis in the same time that she revolves about the Sun, in consequence of which she turns always the same face to him, must cause a state of things of which we can form but faint conception, from any earthly analogy. One face baked for countless æons, and still baking, backed by one chilled by everlasting night, while both are still surrounded by air, must produce indraughts from the cold to the hot side of tremendous power. A funnel-like rise must take place in the centre of the illuminated hemisphere, and the partial vacuum thus formed would be filled by air drawn from its periphery, which, in its turn, would draw from the regions of the night side. Such winds would sweep the sur-



I
Showing convection currents in the planet's atmosphere.

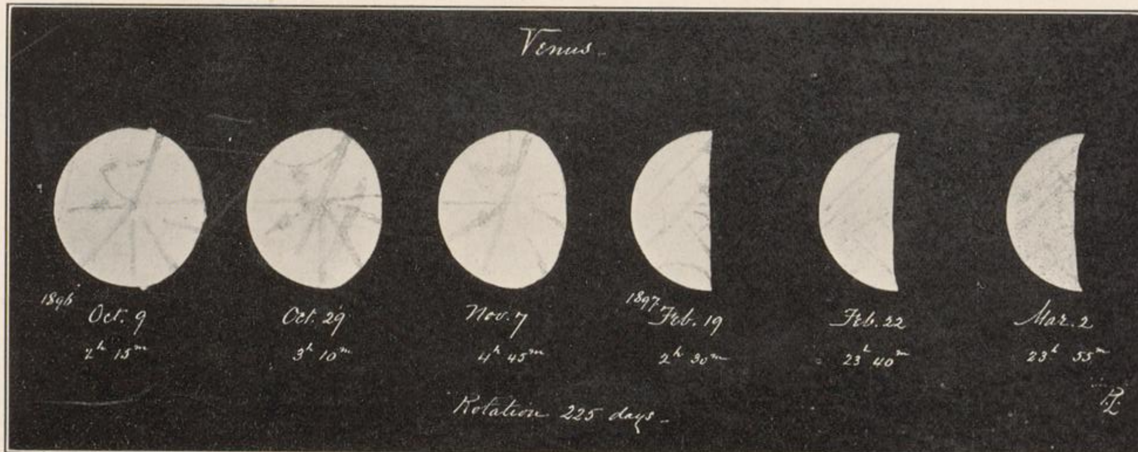
II
Showing shift in central barometric depression due to rotation of the planet affecting the winds.

VENUS.

face as they entered, becoming less superficial as they advanced, and the marks of their inrush might well be discernible even at the distance we are off. Deltas of such inroad would thus seam the bounding circle of light and shade.

Another result of the aërial circulation would be the removal of all moisture from the sunward face, and its depositing in the form of ice upon the night one. For the heated air would be able to carry much water in suspension, which, on cooling, after it had reached the dark hemisphere would unload it there. In the low temperature there prevailing, this moisture would all be frozen, and so largely estopped from return. This process continuing for ages would finally deplete one side of all its water to heap it up in the form of ice upon the other.

Now it is not a little odd that a phenomenon has been observed upon Venus which seems to display just this state of things. Many observers have noted an ashen light on the dark side of her disk. Some have tried to account for it as Earth shine, the same earth-reflected light that makes dimly visible the old moon in the new moon's arms. But the Earth is too far away from Venus to permit of any such effect; nor is there any other body that could thus relieve its night. But if the night hemisphere of Venus be one vast polar sheet, we have there a substance able to mirror the stars to a ghostlike gleam which might be discernible even from our distant post.


Venus.
1896 Oct. 9
2h 15m
Oct. 29
3h 10m
Nov. 7
4h 45m
1897 Feb. 19
2h 30m
Feb. 22
23h 40m
Mar. 2
23h 55m
Rotation 225 days.
P.L.

Thus when we reason upon them we see that the peculiar markings of the planet lose their oddity, becoming the very pattern and prototype of what we should expect to view. Interpreted, they present us the picture of a plight more pitiable even than that of Mercury. For the nearly perfect circularity of Venus' orbit prevents even that slight change from everlasting sameness which the libration of Mercury's affords. To Venus the Sun stands substantially stock-still in the sky, — a fact which must prove highly reassuring to Ptolemaic astronomers there, if there be any still surviving from her past. No day, no seasons, practically no year, diversifies existence or records the flight of time. Monotony eternalized, — such is Venus' lot.

What visual observations have thus discovered of the rotation time of Venus, with all that follows from it, the spectroscope at Flagstaff has confirmed. At Dr. Slipher's hands, spectrograms of the planet have told the same tale as the markings. It was with special reference to this point that the spectrograph there was constructed, and the first object to which it was directed was Venus.*

The planet's rotation time was to be investigated by means of the motion it brought about in the line of sight. Visual observation, telescopically, reveals motion

* Lowell Observatory Bulletin No. 3.

thwart-wise by the displacement it produces in the field of view; spectroscopic observation discloses motion to or from the observer by the shift it causes in the spectral lines due to a stretching or shortening of their wave-lengths.

The spectroscope is an instrument for analyzing light. Ordinary light consists of light of various wave-lengths. By means of a prism or grating these are dispersed into a colored ribbon or band, the longer waves lying at the red end of the spectrum, as the ribbon is called, the shorter at the violet. Now the spectroscope is primarily such a prism or grating placed between the image and the observer, by means of which a series of colored images of the object are produced. In order that these may not overlap and so confuse one another, the light is allowed to enter the prism only through a narrow slit placed across the telescopic image of the object to be examined. Thus successive images of what is contained by the slit are presented arranged according to their wave-lengths. In practice the rays of light from the slit enter a small telescope called the collimator, and are there rendered parallel, in which condition they fall upon the prism. This spreads them out into the spectrum and another small telescope focusses them, each according to its kind, into a spectral image band which may then be viewed by the eye or caught upon a photographic plate.

Now, if an object be coming toward the observer, emitting or reflecting light as it does so, each wave-length of its spectrum will be shortened in proportion to the relative speed of its approach as compared with the speed of light, because each new wave is given out by so much nearer the observer and in reflection the body may also meet it. Reversely it will be lengthened if the object be receding from the observer or he from it. This would change the color of the object were it not that while each hue moves into the place of the next, like the guests at Alice's tea-party in Wonderland, some red rays pass off the visible spectrum, but new violet rays come up from the infra-violet and the spectrum is as complete as before. Fortunately, however, in all spectra are gaps where individual wave-lengths are absorbed or omitted, and these, the lines in the spectrum, tell the tale of shift. Now if a body be rotating, one side of it will be approaching the observer, while the opposite side is receding from him, and if the slit be placed perpendicular to the axis about which the spin takes place, each spectral line will appear not straight across the spectrum of the object, but skewed, the approaching side being tilted to the violet end, the receding side to the red.

This was to be the procedure adopted for the rotation of Venus. By placing the slit parallel to the ecliptic, or, more properly, to the orbit of Venus, which is practically the same thing, it found itself along what we have reason to suppose the equator of the planet. Even a considerable error on this point would make little difference in the rotational result. In order that there might be no question of illusion or personal bias, photographs instead of eye observations of the spectrum were made. For reference and check side by side with that of Venus were taken on either hand the spectra of iron, made by sparking a tube containing the vapor of that metal. The vapor, of course, had no motion with regard to the observer, and therefore its spectral lines could have no tilt, but must represent motional verticality.

Dr. Slipher chose his time astutely. He selected the occasion when Venus was passing through superior conjunction, or the point in her orbit as regards us directly beyond the sun. At first sight this might seem to be the worst as well as the most impracticable of epochs, inasmuch as the planet is then not only at her farthest from the Earth, but in a line with the Sun, and so drowned in his glare. But in point of fact any tilt of the spectral lines is then, owing to phase, twice what it is at elongation, and exceeds still more what it is when Venus has her greatest lustre.[3] In his purpose he was abetted by the Flagstaff air, which enabled the planet to be spectrographed much nearer the sun than would otherwise have been the case. He thus selected the best possible opportunity. To guard against any subsequent bias on the part of the examiner of the plates, after the spectroscope had taken a plate it was then reversed, and the process repeated on another one, the iron being sparked as before. What had been the right side of Venus with regard to the red end of the spectrum thus became the left one, and *vice versa.* In this manner, when the plates came to be measured for tilt, the measurer would have no indication from the spectrum itself which way the lines might be expected to tilt; he could, therefore, not be influenced either consciously or unconsciously in his decision.

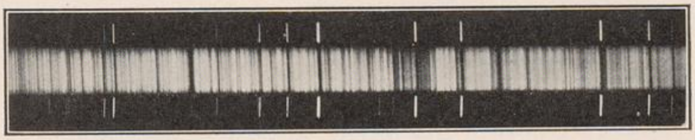
Eight plates with their comparison ferric spectra were thus secured; four with the spectroscope direct, four with it reversed. They were then shuffled, their numbers hidden, and given to Dr. Slipher to measure. The spectral lines told their own story, and without prompting. All the plates agreed within the margin

SPECTROGRAM OF VENUS, SHOWING ITS LONG DAY — V. M. SLIPHER, LOWELL OBSERVATORY, 1903.

of error accordant with their possible precision, a precision some thirty times that of Belopolski's experiment on the same lines, — a result not derogatory of that investigator, but merely illustrative of superior equipment. They showed conclusively that a rotation of anything like twenty-four hours was out of the question. They yielded, indeed, testimony to a negative rotation of three months, which, interpreted, means that so slow a spin as this was beyond their power to precise.

For Dr. Slipher was at no less care to determine just what precision was possible in the case, although a speed corresponding to a spin of twenty-four hours on a globe the size of Venus is well known to be spectroscopically measurable. It would mean a motion toward us of one thousand miles an hour, or about a third of a mile a second. The tilt occasioned by this speed is well within the spectroscope's ability to disclose. Not content with this, however, by two special investigations, he proved the spectroscope's actual limits of performance to be far within the quantity concerned. One of them was the determination by the same means and in like manner of the rotation time of Mars, the length of that planet's day, which in other ways we know to the hundredth of a second, and which is $24^h\ 37^m\ 23^s.66$. Now Mars offers a test nearly twice as difficult as Venus, even supposing the apparent disks of the two the same, because his diameter being less in the proportion roughly of one-half, the actual speed of a particle at his edge is less for the same time of rotation in the like proportion, and it is only with the speed in miles, not in angular amount, that the spectroscope is concerned. Nevertheless, when a like number of plates were tried on him, they indicated on measurement a rotation time within an hour of the true. This corresponds to half an hour on Venus. We see, therefore, that had Venus' day been anywhere in the neighborhood of twenty-four hours, Dr. Slipher's investigation would have disclosed it to within thirty-one minutes.

This result was further borne out by a similar test made by him of Jupiter. Inasmuch as the diameter of



Spectrogram of Jupiter, giving the length of its day by the tilt of its spectral lines — V. M. Slipher, Lowell Observatory.

Jupiter is twelve times that of Venus, while the rotation time is $9^h\ 50^m.4$ at the equator, the precision attained on Venus should here have been about a minute. And this is what resulted. Slipher found the rotation time spectrographically $9^h\ 50^m$, or in accordance with the known facts, while previous determinations with the spectroscope had somehow fallen short of it.

The care at Flagstaff with which the possibility of error was sought to be excluded in this investigation of the length of Venus' day and the concordant precision in the results are worthy of notice. For it is by thus being particular and systematic that the accuracy of the determinations made there, in other lines besides this, has been secured.

In size, Venus of all the planets most nearly approaches the Earth. She is 7630 miles in diameter to the Earth's 7918. Her density, too, is but just inferior to ours. And she stands next us in place, closest in condition and constitution in the primal nebula. Yet in her present state she could hardly be more diverse. This shows us how dangerous it is to dogmatize upon what can or cannot be, and how enlightening beyond expectation often is prolonged and systematic study of the facts.

The next planet outward is our own abode. It is one of which most of us think we know considerable from experience and yet about which we often reason cosmically so ill. If we knew more, we should not deem ourselves nearly so unique. For we really differ from other members of our system not more than they do from one another. Much that appears to us fundamental is not so in fact. Thus many things which seem matters of course are merely accidents of size and position. Our very day and night upon which turn the habits of all animals and, even in a measure, those of plants, are, as we have seen, not the possession of our nearest of cosmic kin. Our seasons which both vegetally and vitally mean so much are absent next door. And so the list of our globe's peculiar attributes might be run through to the finding of diversity to our familiar ways at every turn. But, as we shall see later, these differences from one planet to the next are not only not incompatible with a certain oneness of the whole, but actually help to make the family relationship discoverable. Analogy alone is a dangerous guide, but analogy crossed with diversity is of all clews the most pregnant of understanding. The very fact that we can tell them apart when we see them together, as the Irishman remarked of two brothers he was in the habit of confusing, points to their brotherly relation.

Proceeding still further, we come to Mars at a mean distance of one hundred and forty-one million miles. Smaller than ourselves, his diameter is but a little over half the Earth's, or forty-two hundred miles, his mass one-ninth of ours, and his density about seven-tenths as much. Here, again, but in a different way, we find a planet unlike ourselves, and we know more about him than of any body outside the Earth and Moon. So much about him has been set forth elsewhere that it is enough to mention here that no oceans diversify his surface, no mountains relieve it, and but a thin air wraps it about, — an air containing water-vapor, but so clear that the surface itself is almost never veiled from view.

About the satellites Mars possesses, Deimos and Phobos, we may perhaps say a word, as recent knowledge concerning them exemplifies the care now taken to such ascertainment and the importance of considering factors often overlooked. Soon after they were discovered in 1877, they were measured photometrically, with the result of giving a diameter of six miles to Deimos and one of seven miles to Phobos, and these values unchallenged entered the text-books. When the satellites came to be critically considered at Flagstaff, it was found that these determinations were markedly in error, Phobos being very much the larger of the two, the actual values reaching nearer ten miles for Deimos and thirty-six for Phobos.

In getting the Flagstaff values, the size to the eye of the satellite was corrected for the background upon which it shone; for the background is all-important to the brilliancy of a star. In the case of a small star near a planet, the swamping glare of the planet is something like the inverse cube of its distance away. Furthermore, the Flagstaff observations indicated how the previous error had crept in. For before correction for the differing brilliancies of the field of view, the apparent size of the satellites judged by conspicuousness was about six to seven. The photometric values must have been taken just as they came out, no correction apparently having been made for the background. Now the background is a fundamental factor in all photometric determinations, a factor somewhat too important in this case to neglect, since it affected the result 2500 per cent.