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THIRD SERIES.

MATH.-PHYS. VOL. I, No. 7.

The Apparent Projection of Stars upon the bright Limb of the Moon at Occultation, and Similar Phenomena at Total Solar Eclipses, Transits of Venus and Mercury, Etc., Etc.

BY

GEORGE DAVIDSON, PH.D., SC.D.

Issued December 1, 1900.

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THE APPARENT PROJECTION OF STARS UPON THE BRIGHT LIMB OF THE MOON AT OCCULTATION, AND SIMILAR PHENOMENA AT TOTAL SOLAR ECLIPSES, TRANSITS OF VENUS AND MERCURY, Etc., Etc.

BY GEORGE DAVIDSON, PH.D, SC.D.

Read before the California Academy of Sciences, August 9, 1897.

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 November 15, 1900.

Introduction.

This paper is prompted mainly by the many references made by astronomers and astronomical publications to "Baily's Beads" in cases of total solar eclipses; to the "black drop" and "ligament" in transits of Mercury and Venus over the Sun's disc; to the projection of a star upon the bright body of the Moon at immersion or emersion of occultation; to stars and the satellites of Jupiter seen through the limb or body of that planet at occultation; to planets surrounded by an atmosphere of great depth; and to empirical corrections to the semidiameters of the Sun and Moon at meridian transits.

We have lately examined the reports of the observers of the transits of Venus in 1874 and 1882; of the transits of Mercury since 1878, and the reports of the total solar eclipses since 1860; and we are amazed at the crude and apparently indigested explanations given for certain appearances attending the phenomena. There would seem to have been a desire to seek explanations in some obscure cause or causes—such as the poor character of the objective used, the lack of sharpness in the limbs of the planets (owing to their possessing an atmosphere), diffraction, telescopic and occular irradiation, astigmatism, "sympathetic attraction," etc.

These explanations are very unsatisfactory, and the experienced observer, who has observed occultations of stars by the Moon or by Jupiter, meridian transits of the Moon, transits of Mercury and Venus across the Sun's disc, and total solar eclipses in a serene atmosphere, knows that the outlines of the planets, the Moon, and the Sun are remarkably sharp and steady, even under high magnifying power; that the observations made under such conditions are satisfactory; and that there are no extraordinary phenomena present.

In such an atmosphere the spurious disc of a star, large or small, moves along the horizontal thread of the Meridian Circle, or the Zenith Telescope, so steadily that the error of observation should not exceed one-tenth of a second of arc. And the double-star observer certainly expects his measures of distance to differ little from that amount. In the telescope the diffraction rings of the stars are beautifully delicate. On a quiet night the stars appear, to the normal eye, fixed on the sky like minute dots of light, without a sign of twinkling or irradiation, and the intensity of the light of each star, large or small, is continuous.

The observer knows that in an atmosphere which is remarkably unsteady, when every star to the naked eye is dancing madly, the smallest stars have disappeared, the smaller ones appear and disappear spasmodically, and the larger ones near the horizon rapidly change color, and even the planets have much irradiation and are blinking; the star in the instrument has lost its diffraction rings, the spurious disc is broken up, and the confused mass jumps wildly across the micrometer thread and frequently expands into a nebulous film many seconds in diameter. We have measured such an apparition of Polaris forty-seven seconds in diameter.

"Burnham has remarked that an object-glass of six inches will one night show the companion of Sirius perfectly; on the next night, just as good in every respect, so far as one can tell with the unaided eye, the largest telescope in the world will show no more trace of the small star than if it had been blotted out of existence." (Webb's "Celestial Objects.")

With a serene atmosphere the transit observer is certain of his times. With a disturbed atmosphere he can make only an unsatisfactory estimate by eye and ear, and a still less reliable one by the chronograph.

In the course of fifty-four years' experience as an observer, largely in the field, we have encountered a range of physical conditions that falls to the lot of very few. We have made astronomical and geodetic observations in all climates, at all seasons, from the low ocean coast to elevations reaching 12,566 feet, and with instruments of precision of various character. Our latest astronomical observations were made in perhaps the worst locality possible. The peninsula of San Francisco near the Golden Gate is unique for general unsteadiness of the atmosphere, yet marked on rare occasions by some supreme exhibitions of quietness.

Geodetic Observations in the Sierra Nevada.

In the high Sierras of eastern California, from 7,250 to 10,430 feet elevation, after a great southeast storm with clearing weather in the night, a strong wind from the northwest, and a wonderfully pellucid sky and steady atmosphere to windward that gave astonishing clearness, sharpness, steadiness and apparent nearness to all objects, we have, at the greater elevation, seen star-like heliotrope images with the naked eye, at stations 120, 130, 140 and 160 miles distant to the west and northwest, whence the cold, keen wind was blowing. At this station, with the whole range covered with snow, the mountain face was precipitous for 1,356 feet to the north. To the southeastward and eastward, over the very deep valley of the Mokelumne River, directly under us, subject to the Sun's early warmth, the atmosphere became excessively disturbed and the heliotrope images in that direction were not visible to the eye at distances of forty miles. In the telescope the former images were steady, round, and so minute that the micrometer thread nearly covered them; the latter images were very diffuse, irregular and unsteady, and ranged from twenty seconds to thirty seconds in diameter. In the first case the pointing was quickly and satisfactorily made; in the second the pointings were unsatisfactory, even with half a dozen occular pointings as checks.

Visibility of Jupiter's Satellites.

In astronomical work we have observed the Sun, Moon, planets and stars when the Sun was serenely steady; and at night not a star twinkled to the naked eye, and no irradiation was visible to Jupiter. Half a dozen times in our experience we have been able to distinguish with the naked

+ See Sabine's translation of Admiral Wrangell's Narrative of the Polar Sea &c., 1844, p 368

eye[1] two of Jupiter's satellites, when close together, as one; and at one mountain station (3,200 feet elevation) all the members of our party witnessed a similar phenomenon. Very curiously, that evening was slightly hazy, and very faint stars were not visible; but the atmosphere was remarkably steady. Under atmospheric condition of supreme quietness we have placed eleven stars in the Pleiades.

+ The visibility of Jupiter's satellites by the naked eye has generally been received with much doubt. Humboldt, in his Cosmos, has related a well authenticated case, but we can come to our own observers for confirmation. At the time of the total solar eclipse of August, 1878, one of the United States Naval Observatory observers in Colorado saw with the naked eye three satellites of Jupiter separately — two very distinctly and one less so. The atmosphere was supremely serene, and the station (Idaho Springs) 7,548 feet above the sea. Two other persons, not observers, also witnessed the phenomenon. In 1874 the Professor and his colleagues had doubted my seeing even two satellites close together as one. Eastman

Conditions of Steadiness and Unsteadiness of the Atmosphere.

Under similar atmospheric conditions the limbs of the Sun, Moon and planets are sharply defined and remarkably steady; the Sun-spots are beautifully distinct and their changes of form readily followed; the irregularities of the outline of the Moon are unmistakable; the spurious discs of the stars are encircled by delicate diffraction rings, and the overlapping spurious discs of very close double stars present new forms. Under conditions of supreme steadiness of the atmosphere, we believe that an observer with keen eyesight should see, with unassisted vision, the larger satellites of Jupiter, when favorably located, and from ten to twelve stars in the Pleiades. Either is a severe and unique test of steadiness and eyesight. In these periods of great steadiness the observer aches for finer micrometers, higher power, and more stable instruments.

[1] Except with spectacles for short-sightedness.

When the steadiness of the atmosphere begins to break, the images of the Sun, Moon and planets exhibit occasional tremors or shiverings; and even when this vibratory movement has become nearly continuous, but not rapid, the actual and apparently more condensed outline of the image can be selected for measures of precision in moments of quietude. As the unsteadiness of the atmosphere increases, the vibration of the limbs increases in rapidity and amplitude until there is finally created a blurred outline of Sun, Moon or planet, which necessarily presents an increased diameter of the object. The stars are similarly affected; with the first signs of unsteadiness in the atmosphere the diffraction rings are broken, and disappear as the unsteadiness increases; the spurious disc is broken into pieces; its march is peculiar, in presenting one fragment after another with more or less frequency, but may continue with a waltzing movement until the unsteadiness has increased and the spurious disc is without form, dilated, jumping wildly in every direction, and a wretched object for observation.

Similar conditions are exhibited by geodetic signals of all classes. In a serene atmosphere poles are seen very steady as fine, sharp images, sometimes finer than the micrometer threads. When this atmosphere is disturbed, tremors or shiverings carry the images to right or left one or more diameters, and the observer selects moments of quietude for first-class observations; finally, as the unsteadiness of the atmosphere increases, the images become large, confused, blurred and faint, and observations are difficult to make and unsatisfactory. In the quiet atmosphere, white poles five feet long and four and six-tenths inches in diameter, projected upon a dark background, have been seen with the naked eye at distances of four and one-half miles across water. In times of great unsteadiness and equally clear atmosphere they are difficult to see in the telescope.

Heliotrope images behave precisely as those of the stars. On a certain line of the main triangulation of the Pacific Coast, where plains, several mountain ridges and intervening valleys were crossed by the line of sight, and where the cold ocean air sweeping through the Karquinez Strait added ten-fold confusion, the heliotrope image from Mt. Diablo, distant forty-five miles, was seen in the telescope like the waving flame from the stack of a smelting furnace. Sometimes the image exceeded sixty seconds in irregular diameter, and its horizontal direction was very abnormal. This condition lasted for many days. When the air became of more uniform temperature the image was small, star-like, and steady, and its direction normal.

In the remarkably quiet atmosphere of the mountains, before sunset, with a pure sky for a background, we once saw, with the two and one-eighth inches objective of the theodolite, the observer leave his station, which was thirty-three miles distant from Mt. Tamalpais. With a salmon-colored sky in the west, and the atmosphere remarkably clear and steady, Superintendent Bache observed upon the signal-pole of Mt. Wachusett, distant sixty-one miles. The image was nearly as dark and sharp as the cross-threads.

In winter, at great elevation, we once saw, with a three-inch objective, just after sunrise, with a serene atmosphere, the heliotroper projected against a snow background at a distance of fifty-one miles. From Mt. Diablo, 3,849 feet elevation, with the same size objective, just before sunrise, in a perfectly quiet atmosphere, when the crest-line of the Sierra Nevada was projected like a dark-blue saw against the warm eastern sky, and apparently only thirty or forty miles distant, we saw upon several mornings the observing hut on the pinnacle of Mt. Conness. The hut was six feet wide by seven and a half feet high, and the distance one hundred and forty-three miles; the width therefore subtended 1″.64. After the hut had been cut down to about four feet we still made it out upon an extraordinarily clear and steady morning. On account of the distance and great height of Mt. Conness (12,566 feet) the Sun rose to the heliotroper about eight minutes earlier than to Mt. Diablo. The sharpness and steadiness of Mt. Conness were supreme, and the image of the heliotrope was like a minute star; but so soon as the Sun's rays struck the eastern flank of Mt.

Diablo the atmosphere around the observing station became so unsteady that observations were made with difficulty and little satisfaction.

We had a similar experience at the transit of Venus, Station Cerro Roblero, in New Mexico, in 1882. Before sunrise the atmosphere was so serene that we could see, with the five-inch equatorial, the small branches of the scant scrub growth on the dark, sharp, blue crest-line of the Organ Mountains, twenty miles distant. Immediately after sunrise the suddenly heated air, rising up the steep slope of the Cerro Roblero, just in front of the observatory, caused great waves of disturbed air to obliterate the branches of the brush and to exhibit the border of the Sun as a remarkably confused outline. The direction of these waves was very marked. At the time of the first contact of the images of Venus and the Sun the observations were made with difficulty and doubt, and micrometer measures were almost impracticable. The station was about 5,676 feet above the sea, and 1,655 feet above the Rio Grande and the Jornado del Muerte.

We have been thus prolix in order to indicate that the principal disturbance exhibited in the telescope, as well as to the unassisted eye, is in the immediate vicinity of the observing station. At trigonometrical stations, in disturbed conditions of the air, the confused and unsteady image of a heliotrope will exhibit a movement of 5″ to 15″ of arc. The observer could not see such movement if it took place rapidly at the distant station. If the heliotrope image at Mt. Conness were moved bodily sideways forty-four inches, the observer at Mt. Diablo would see it change only one second in amplitude, supposing the movement were slow and therefore capable of cognizance, instead of being very rapid and not then capable of detection. This exhibition of the locally disturbed atmosphere at the observing station can be readily produced artificially.

At Round Top station, in the Sierra Nevada, 10,435 feet elevation, we counted forty-seven forest fires that arose on the flanks of the forested mountains over which we were observing. The smoke gradually filled the Sacramento Valley to a height of 10,000 feet, and obscured the outline of the Coast Range Mountains; but we observed the heliotropes through this irregularly heated atmosphere with little difficulty, and at the close of the operations the probable error of a direction was only seven hundredths of a second of arc.

Besides the disturbance of the outer atmosphere near the observer, there is another source of disturbance in the air within the tubes of the great telescopes, especially in sunlight observations or at the sudden change of temperature at sunset. This is visibly exhibited in the blurred, unsteady and confused outline of the Sun and the Sun-spots projected upon the ground-glass plate of the horizontal heliograph tubeless telescope of forty-feet focus. In the transit of Venus of 1882 the image of the Sun at Cerro Roblero was projected through a forty-feet tin tube of large diameter, and was much blurred; but this was largely corrected when the tube was covered with a wooden roof not in contact.

Professor A. E. Douglass, of the Lowell Observatory, has shown that the waves of the disturbed atmosphere outside and inside of the large telescope tubes are distinctly visible to the naked eye when it is placed in the focus of the objective, as in the Foucault test. And even more than one series of such waves of disturbance at different distances and moving in different directions is not infrequent.

It is well known that to obtain the best results with the great telescopes it is imperative that the air inside the dome and inside the telescope tube shall have the temperature of the outside atmosphere.

At Arequipa, Peru, the Harvard Observatory was situated close to the valley of a mountain stream or arroyo, down which, on clear nights, a swift stream of cold air descends. Whenever this cold stream overflowed the banks and enveloped the observatory, and rose to the height of the objective, the seeing was immediately ruined for the rest of the night. In such circumstances, if the eye-piece of the telescope was removed and the eye placed in the focus, fine parallel, dark

Hot air. Edwin Arnold's "Light of Asia" Boston 1880. p 112.
— when the land Shimmered with heat, and walls and temples danced In the reeking air.

lines could be seen moving swiftly lengthwise across the illuminated lens in the direction of the wind.[1]

At San Francisco, in the strong "wind gap" of the Golden Gate, it sometimes happens at sunset, after a calm, moderate day, that star images are disc-like and steady; in a few minutes the westerly wind rises and brings in the fog-chilled air from the ocean, with flying patches of fog overhead, and the star images at once become diffused and nebulous, with an unsteadiness reaching an amplitude of 5″ to 10″ of arc.

Large volumes of air, each of different but uniform temperature, projected across a line of sight at a great distance from the observer, do not necessarily produce abnormal images of a star or heliotrope; they seem to act as prisms, and deflect the line of light so as to exhibit abnormal horizontal or vertical refraction without any marked unsteadiness. Along the face of a great mountain wall we have measured a slow change of azimuth of a signal amounting to 65″ of arc, due to the gradual rising of the morning temperature of the calm (no wind) air immediately adjacent to the eastern rocky face of Mt. Constitution.

There are so many conditions conspiring to a disturbed atmosphere that it necessarily acts in various ways difficult to predict. Where there are regular, irregular or confused atmospheric waves moving at different distances from the objective, and in different directions, they necessarily give different images of the star at different foci, and at each change they bodily shift the image near the focus, and also change its form. Professor Douglass' observations are very instructive in this matter.

When volumes of unusually heated air pass over the objective they may act as a species of air lens which suddenly and irregularly spreads out the image of the star at the focus; but no change of focus will bring the image to condensation. This we first experienced at Point Concepcion in 1850, where the perceptibly hot volumes of air from

[1] Douglass, "The American Meteorological Journal," March, 1895, p. 395.

Atmospheric Surface waves. The Weather Review Aug 20, pap 250.

the higher gulches were driven over the observatory by an incoming cold north wind from the Sierra Santa Inez.

It is sometimes reported that stars become very unsteady in a strong wind; yet we have determined micrometer values by observations upon a close circumpolar star during a fierce "norther." In geodetic observations between Mt. Diablo and Mt. Conness, on a line of 143 miles across the Sacramento Valley, we witnessed a strong norther blowing down the valley and carrying vast quantities of dust across the line of sight; but the wind did not reach the observing station on the first day, when the heliotrope image was fairly good, but was moved bodily by horizontal refraction two or more seconds of arc from the normal direction.

Observed Occultations of Red Stars at the Bright Limb of the Moon.

Referring now more particularly to the details of some astronomical observations, we give a few instances from our experience and that of others.

On September 18, 1848, about seven and one-half hours in the morning, we observed the occultation of *a* Tauri by the bright limb of the Moon, using a telescope of probably two and one-half inches aperture and moderate power. The red star touched the bright limb, and we noted the time mentally, because it did not instantly disappear. We continued the watch until the star was unmistakably *within the apparent limb*, when it disappeared instantly, about two and a half seconds after the first apparent contact. We at once submitted the case to our chief, R. H. Fauntleroy, who said the disappearance was the true time of the occultation, but he gave no explanation of the phenomenon. We then submitted the observation to the Superintendent of the United States Coast Survey, Professor A. D. Bache, who wrote to the Royal Astronomer (Airy) on the subject. The reply was that he personally had never observed the phenomenon, but there were similar cases on record. He gave no explanation.

ce "Outlines of astronomy", J. F. W. Herschel, Philadelphia
860, p 219+. "There is an optical illusion of a very strange
nd unaccountable nature which has often been remarked
i occultations," &c &c.

Stars on limb of Moon, from Cape of Good Hope Obsy. Annals Vol II - part III Occultations 1881-95 many examples.

In the trigonometrical survey of Admiralty Inlet and Puget Sound, during the approach of a southeast storm which finally brought up dense clouds, a heavy squall and rain, we observed *a* Scorpii (April 22, 1856,) with a three-inch Fraunhofer telescope and astronomical eye-piece, power about 70. The disappearance of the star was behind the bright limb, and the record states that "the time denotes the instant of the disappearance of the star *after it had been projected* upon the body of the Moon for about two and one-half seconds, certainly not less. The ruddy color of the star showed distinctly upon the body of the Moon, and the instant of disappearance was as accurately noted as if it had disappeared behind the dark limb. Having once before observed the same phenomenon, we were fully prepared for it."

In November, 1886, we presented a paper to the California Academy of Sciences upon the occultation of *a* Tauri on the twelfth of November. Three instruments were used at the disappearance: two three-inch Fraunhofers, power 100, and a two-inch, power 55. The atmosphere was clear and moderately steady, the stars showed signs of unsteadiness, and the Moon's border appeared reasonably sharp. The telescopes were not large enough for such observations, but an intervening house prevented the use of the six and four-tenths inches Equatorial.

The star was visible to the unassisted eye to within four minutes of contact. When it was a few seconds from the Moon's bright limb the star became invisible in the two-inch telescope. In the three-inch Fraunhofers the star did not disappear when it touched the apparent limb of the Moon, but continued to move upon the disc until it was fully one and one-half times the diameter of its spurious disc on the Moon, when it disappeared with the instantaneity of such phenomena. The star grew somewhat difficult to see after it entered upon the factitious limb, but its reddish hue left no doubt in the minds of the two observers, who differed 0.07 second in the time of its disappearance. They estimated that it was three seconds of time on the limb. At

Loewy & Puiseux. Recent Progress &c. Photos Lunar Surface. See Smithsonian Inst. Rep. 1898 p 105-121. Impossible to eliminate effects due to the undulations of the Atmos &c.

Ast. Jour. Vol VI. No 128 p. 57-63. a/c of 160 occultations of the Pleiades at 39 stations fr Aug 12/57 to Nov 20/58. Several cases of bad atmosphere &c.

emersion from behind the narrow, dark edge of the Moon (which was one day past the full) the 6.4-inch Equatorial noted the reappearance 0.17 second earlier than the two three-inch telescopes.

At the Chabot Observatory, thirty-six seconds of time east of the Davidson Observatory, the observer used the Clark eight-inch Equatorial for the same occultation. The atmospheric conditions were nearly the same as mentioned. The star advanced upon the apparent limb of the Moon, but not so far as above mentioned, and some of the apparent rays of the star projected outside the Moon's border.

On March 29, 1887, we observed the immersion of *α* Tauri at the dark limb, and the emersion at the bright limb; the former by daylight, and the ash-gray limb not visible. The disappearance was instantaneous. At reappearance the Moon's limb was blurred and very unsteady, and the star reappeared upon this blurred bright image inside of the outermost limit, which was very fuzzy and decreasing in brightness outward. The star was not so bright as anticipated, but its almost sparkling red color left no doubt whatever in our mind as to the nearest tenth of a second of the epoch. The star left the limb in two and one-half or three seconds, when it appeared much brighter. At emersion a power of 250 was employed.

We do not mention the hundred and more occultations which we have observed when the above phenomenon was not present, or when the smallness and whiteness of the star may have prevented its detection.

Other Observed Occultations of the Stars by the Moon, and of Stars and Satellites by Jupiter.

In 1890, the Astronomer Royal called the attention of the Royal Astronomical Society to the occultations of *ζ* Tauri (3.0 magn.) that presented matter of "interest" to observers and astronomers. On September 16, 1889, Mr. Turner, of the Greenwich Observatory, observed the occultation of the same star by the bright limb of the Moon with

"Aldebaran: ... It frequently suffers occultation of the moon, when the ascending node is in Virgo, and exhibits the phenomenon of projection on the moon's disk." Dict. of Sci Terms, by Richard D. Hoblyn (A.M. Oxon) N. York, D. Appleton & Co. 1850. p 14.

the Lassell Reflector of thirty-four inches, and Mr. Lewis with a refractor of three and three-fourths inches. Mr. Turner noted: "No projection; disappeared instantaneously at bright limb." Mr. Lewis noted that "the star touched the limb of the Moon five seconds before the observation, and was slightly inside the limb." It appeared "as a brilliant spot in the Moon, and disappeared suddenly at the time given above." In the same number of the "Observatory" where this report is made Mr. Ranyard says that "in the case of Jupiter there are instances * * * where one or two stars have apparently been seen through the limb of the planet. There are such a number of these observations that we cannot doubt the planets have not a sharp limb; they seem to be surrounded by an atmosphere of great depth, or rather a gaseous envelope, in which clouds or dusty matter float in irregular masses." This is an extraordinary statement, and, in our judgment, based upon a misconception of the cause of these phenomena.

The outline of any cloud system at such enormous distances from the Earth as Mars, Jupiter and Saturn would subtend so minute an angle that the outline of the planet would necessarily appear sharp, even if the assumed cloud were irregularly distributed. The Sun's outline appears remarkably sharp when our atmosphere is steady, and yet we know that extraordinary disturbances of the solar surface, far beyond our experience, are constantly taking place.

On May 10, 1895, Mr. John Tebbutt observed the occultation of Antares at Windsor, New South Wales. The steadiness and definition of objects were reported very satisfactory. The instrument was an eight-inch objective, with a magn. power of 74, and "Antares, quite brilliant to the last moment, was closely watched till it came into contact with the bright limb; but then, instead of instantly disappearing, it seemed to cut its way into the disc during two or three seconds, and vanished instantaneously. The reappearance of Antares (62 1-3 minutes) later at the dark limb was remarkably instantaneous." It should be noted however, that the observer was not looking at the spot where the star reappeared, and thereby lost the earlier reappearance of the well-known companion; and at any rate he could not have seen the star reappear with sudden brightness unless the dark limb was undisturbed. The same occultation was observed at Waverly, Sydney, by Walter F. Gale, under fairly good conditions and thick haze. With a six and a quarter-inch objective and magn. power 140 "the disappearance was instantaneous at a notch formed in the Moon's limb by two peaks." This description of the point of ingress indicates that the limb of the Moon was steady and sharp.

The same occultation was also observed at Warrickville, near Sydney, by C. J. Merfield, with a seven and a half-inch reflector, with power 170. "The definition was fair, although hazy at the time of disappearance, which was not instantaneous, as is usual."

Professor Young, in his "General Astronomy" (p. 246), refers to the projection of a star on the Moon's dark limb in the following paragraph: "In some cases observers have reported that a star, instead of disappearing instantaneously when struck by the Moon's limb (faintly visible by earth-shine), has appeared to cling to the limb for a second or two before vanishing, and in a few instances they have even reported it as having reappeared and disappeared a second time, as if it had been for a moment visible through a rift in the Moon's crust. Some of these anomalous phenomena have been explained by the subsequent discovery that the star was double, or had a faint companion." No further explanation is attempted. We have purposely watched stars occulted at the ash-gray limb of the Moon, but have never been able to see a sufficiently bright and defined limb to note whether it was invaded by the star before its sudden disappearance.

In the publications of the Astronomical Society of the Pacific for November 30, 1889, Professor Barnard, of the Lick Observatory, says that "at a number of occultations of the satellites [of Jupiter] I watched carefully for any evidences of their being seen through the edges of the

The planet Venus projected upon the ash grey limb of the moon at occultation. See Astro. Journ. Vol IV. No 12. Whole number 84, p. 95. Cambridge 1855, May 26.

planet, but saw nothing of the kind. Professor Holden informs me, however, that with the thirty-six-inch Equatorial the whole disc of a satellite has been visible within the planet's atmosphere at every occultation he has observed." In the "Astronomical Journal," volume VIII, page 64, there is a record by these observers of the occultation of 47 Libræ (6.4 magn.) by Jupiter, on June 9, 1888. With the thirty-six-inch objective and power 672, the images were below the average of good seeing. Director Holden reports that "the star entered the limb and was seen bisected" at 1^m 30^s after it had touched the outer edge. "The entire image of the star was seen, inside as well as outside the limb, being easily distinguishable from the planet's surface by its brilliancy and peculiar color." In 2^m 35^s "the star was entirely inside the limb, but still visible. For the next ten seconds the star was alternately visible and invisible, and the planet's limb was quite unsteady." In 2^m 51^s from the star's first touching the limb it was certainly gone. Professor Barnard observed the same occultation with the twelve-inch objective, reduced to eight inches because "the images were too unsteady with the full aperture" (magn. power 240). He noted the time of "contact of the following edge of the star with the preceding limb" of Jupiter. At 1^m 12^s after, he star was partly on the limb; at 1^m 51^s the star was seen by glimpses to that epoch, and three seconds later it had certainly disappeared when it had advanced about three-quarters of its disc within the limb. On the usual scale of seeing, the conditions were below the average; but even when the star had encroached on the limb the disc was small, round and bright, and as clearly defined as that of a satellite entering transit. No certain diminution of its light was observed.

Professor Barnard makes no allusion to the color of the star, and as its spectrum is recorded as that of the first type, there seems no reason why the first mentioned observer should attribute a "peculiar color" to it.

Under date of April, 1894, Professor Barnard thinks "astronomers should reject the idea that the satellites of Jupiter can be seen through his limb"; since, under good conditions, with the Lick thirty-six-inch objective, "the limb of Jupiter has appeared perfectly opaque, as in all my previous observations with smaller telescopes." But he makes no reference to the character of the factitious limb of the planet in unfavorable conditions of the atmosphere.

At Melbourne, September 14, 1879, the occultation of 64 Aquarii (6.9 magn.) by Jupiter was watched in the great reflector. The star was thirty-five seconds in disappearing, and remained visible ten seconds longer as a speck of light seen through ground glass. This speck "also disappeared gradually." Proctor says the observers personally assured him the phenomenon was not due to irradiation.

In 1878, at the Adelaide Observatory, two observers (Messrs. Todd and Ringwood) saw the occultations of satellites I, II and III upon certain occasions "within the disc of the planet" at disappearance, and once at reappearance. "In every other case the occultation was perfect at the limb." This latter sentence was not quoted by Proctor.

Dr. E. C. Pickering, Director of Harvard Observatory, has described an occultation of D. M., 23° 1087 (7.3 magn.), by Jupiter, April 14, 1883. He used the fifteen-inch objective, with achromatic eye-piece, power 400. "For a period of about ten minutes after disappearance was observed, the star is recorded as 'suspected.' The record states that for some time previous to final disappearance 'the star alternately disappeared and reappeared without cause; seeing pretty good and uniform throughout.' At the reappearance, the limb of the planet was watched continuously for forty-nine seconds, at the beginning of which the star was not visible, and at the end of which it was distinctly seen, remaining visible thereafter."

In our experience in observing Jupiter, we have never seen the border sharply defined when using powers of 500, but atmospheric conditions have never been supremely good at the times of observation. In observing the occultation of Jupiter's satellites through an unsteady atmosphere, our fellow-observer, with a smaller telescope and objective of two and one-half or three inches, lost the satellite much sooner than we observed its disappearance in the 6.4-inch Clark Equatorial, when we followed it into the factitious limb; and with a disturbed atmosphere this advantage should always pertain to the larger objective and higher power.

Numerous observers might be quoted who have seen stars and satellites projected within the apparent limb of Jupiter at occultation. Some of the details are rather startling, and perhaps the most notable is that by Admiral Smyth, in 1828, supported in part by two other observers at stations a few miles distant. The satellite II remained for some minutes projected upon the apparent edge of the planet, and thirteen minutes afterwards it was outside of the disc; then it remained visible four minutes and "suddenly vanished." If the observers had been experts, observing with instrumental means adequate to give sufficient light, definition, and size to the images — noting the times with accuracy, and fully recognizing the effect of the locally disturbed atmosphere — we are satisfied that some satisfactory explanation would have been reached.

Such details as these, and others upon different occasions, are rather astonishing. Such remarkable conditions must be due to imperfect instrumentation, to inexperience, to weariness or lack of quick and positive accommodation of the eye, to erroneous estimates of small intervals of time, to extraordinarily abnormal conditions of the atmosphere, to intervals of unconscious cerebration, or to gross mistakes. It was from the abnormal observations at Melbourne that Proctor undertook to deduce the depth of Jupiter's atmosphere, and concluded that the star 64 Aquarii was seen through a range of 10,000 miles of atmosphere below a depth of 300 miles.

We may here mention incidentally that for many years we have been on the outlook for Saturn and his ring system to occult some star of moderate magnitude; but the phenomenon has not occurred in our experience. We were anxious to learn how the ring system would treat the star.

Similar Phenomena at Total Solar Eclipses.

Many reports of observations of total solar eclipses and transits of Venus and of Mercury over the Sun's disc are painfully discordant, misleading and uninstructive. They betray inexperience and lack of knowledge of the local physical disabilities that may present themselves. It would almost appear as if those who had the least experience were the most authoritative in their opinions. And certainly, when the results are published, there is little or no discrimination made in assigning proper weights to them. Some observers make no mention of their defective eyesight, and we have personally known observers, quoted as authority, that should never have been trusted to attempt any observation of precision.

The elaborate reports of the total solar eclipse of 1869, in the United States, by many observers in different localities, are quite instructive in the unconscious exhibition of contradictory statements and inappropriate adjectives. Two observers at the same station reported directly opposite conditions of the steadiness of the limbs of the Sun and Moon. One said they were defined with the utmost clearness; another sent us drawings to explain his statement that they were "boiling excessively." And yet the observer who reported steadiness was in doubt twelve seconds of the time of contact, and took the mean of his limits of doubt. And it is evident that the many observers had different conceptions of what constituted the phenomenon of "Baily's beads." Some looked for, and evidently expected, the exhibition as a necessary and normal physical condition. The tabulated descriptions of the phenomena at totality range wildly; we find recorded: "no trace of Baily's beads;" "the phenomenon of Baily's beads lasted but a few moments;" "Baily's beads beautifully distinct and spreading over an arc of 30°;" "Baily's beads were seen fifteen seconds or more; they were long and thin, moved with the moon, and were unquestionably the effect of the irregularities of the Moon's contour exaggerated by

...lt of light around the Moon brighter than any other part of the Sun xx Baily's Beads distinctly seen x x. assigned to mirage Prof. Alexander on the total Eclipse of the ☉ at Labrador July 18, 1860.

irradiation." One observer has given detailed drawings of the form of the "beads," and exhibits them with mechanical precision and hardness; as a matter of fact he was not a draughtsman nor a skilled observer, and yet his name carried great weight. C. A. Schott

Similar Phenomena at Transits of Venus and Mercury across the Sun's Disc.

In our observations of the transit of Venus, December 1882, at Cerro Roblero, New Mexico, 5,676 feet above the sea, and 1,655 feet above the Rio Grande del Norte and the great arid plain of the Jornado del Muerte, there were, towards the close, occasional tremors or shiverings of the borders of the discs of the Sun and planet from slight tremulousness of our atmosphere; but the eye was not confused, as would have been the case if the discs had continued ill-defined and unsteady by excessive vibration. In the first case the eye could and did select its opportunity for micrometric measurements. But at this very period the assistant astronomer in charge of the photographic exposures reported the results unfavorably affected by this slight unsteadiness. It was a case where the eye selected a moment of steadiness, but the mechanical movement of the photographic shutter permitted no selection. The unsteadiness of the atmosphere at the time between the third and fourth contacts permitted a beautiful and unique exhibition of the fine, white, faint, crescent of coronal light apparently surrounding part of the disc of Venus as an illuminated atmosphere. The crescent was long, extremely thin, white, and as fine, sharp and regular as if cut by the finest graver; and we watched it die away in excessive minuteness. We made drawings of the exhibition. Another observer of this beautiful phase of the transit at a different station saw a similar phenomenon "shortly after the first external contact, when the limb of the planet was 'boiling,'" and "it was difficult to be certain whether it lay within or without the planet's contour * * * but it certainly appeared to extend at any rate within the circumference; and indeed it presented the appearance of 'Baily's beads' at the time of a total solar eclipse. Its whole depth was one-fourth of the planetary radius"; and the published drawing showed the broader part of the coronal light partly inside the planet's circumference when the planet was half on the Sun's disc. Astr. Nach. 2,481. Here we have exhibitions of the same or a similar phenomenon at the same transit under widely different atmospheric conditions; and the first is surely to be taken as better representing the true or normal phase of the phenomenon, and the latter is to be reckoned as abnormal and misunderstood.

This phenomenon of the so-called "atmosphere of Venus," though not connected with the disturbance of our atmosphere, is thus seen to be affected by it just as much as the outline of Sun or planet. Mouchez has called it the "pâle auréole * * * to be attributed in part to the atmosphere of the Sun rendered visible by contrast, and also in part by the atmosphere of Venus." Heraud and Bonify designated it as the "filet lumineuse;" and Airy says this "penumbra must, of course, be considered a part of Venus;" and elsewhere he says "the partial illumination of the atmosphere of Venus introduces difficulties of observation" etc. One observer says that this ring of light around Venus enabled him to see the planet twenty-four minutes before contact. One of our astronomers who had witnessed the transits of Venus of 1874 and 1882 asserts that "there seems to be absolutely no way of escaping from a new difficulty—the planet's atmosphere causes it to be surrounded by a luminous ring—as it enters upon the Sun's disc, and thus renders the time of contact uncertain by at least five or six seconds." Another admits "the disturbance of the image by irregular refraction in the Earth's atmosphere," but declares that "we must look to the chief cause of the great discordances" of the times of contact of Venus and the Sun, "in the atmosphere which surrounds Venus." And he further says, that "the cruel manner in which all the phenomenon are modified by the atmosphere of Venus is not easy to explain." Another declares "the planet was surrounded by a ring of light, as bright as the Sun, that pushed the edge away from it; and no actual contact could be observed." And yet there was no black drop, no ligament and no distortion reported by the observer.

It is admitted that there is no atmosphere enveloping the Moon, and yet Royal Astronomer Stone at the Cape of Good Hope observed the outline of the Moon projected against the Sun's corona five minutes and eight seconds before the total phase of a solar eclipse. We reported a very faint exhibition of this phenomenon January 11th, 1880. If the corona of the Sun is the visible arc of illumination in this case through contrast, we are entirely justified in assuming it to be the agent of illumination at the circumference of Venus; and on account of the irregularity and inequality of the brightest parts of the corona, it may be seen at one part of the planet's circumference and not at another, or it may be seen all around the planet. A critical examination of the reports clearly demonstrates that this faint illumination on the border of the dark body of the planet is seen as (1) part of a circumference; (2) at different parts of the circumference; (3) of varying breadth at different points of its length by the same observer; (4) as wholly encircling the planet. If it were the atmosphere of Venus it would be uniform and continuous, unless a Venus cloud system interfered irregularly. Professor Young says (p. 159) that at a total solar eclipse there is "not any ring of light running out on the edge of the Moon like that which encircles the disc of Venus at the time of the transit."

With a slight digression, we mention one or two vagaries of observers of the transits of Mercury.

At one of the recent transits where the observers were side by side, one reported the "definition of Mercury sharp and steady," and the "limb of the Sun undulating," as if the two objects were unequally affected. The other observer described the "limbs of the Sun and Mercury loosely connected by a patch of haziness oscillating between them;" and at another phase the "undulations of the Sun's limb occasionally reached Mercury;" leaving the inference that the planet was steady. At yet another station the "planet appeared with rippling fiery and black balls chasing each other between the planet and the Sun." In the transit of 1878 one observer "was surprised at the absence of glare and tremor; and the edge of the Sun's disc was clearly defined and remarkably steady with the exception of a few notches and scratches."

We had been fortunate in our observations of the two transits of Venus, and of several transits of Mercury, never to have seen an exhibition of "black drop" or "ligament," except at the transit of Mercury in 1891, when the atmospheric conditions of San Francisco were very unfavorable although the sky was clear; the limbs of the Sun and planet were both spurious or factitious on account of excessive vibration; and the observation was necessarily difficult and doubtful. Under such adverse conditions the observation may be very wild, or it may turn out very good; but certainly the observer cannot assign much weight to the epoch noted.

Instructions for Observing the Transit of Venus.

In re-examining the large number of reports of the transits of Venus of 1874 and 1882, we have gathered forty or fifty expressions of the observers in their endeavors to describe the phenomenon usually known as "black drop," "ligament," or "filament."

This need hardly be wondered at. The British Instructions of 1882 assert that the phenomena seen by most observers near the time of contact are of a complex character, and extend over considerable intervals of time. These instructions surely conveyed the impression that these complex phenomena were the normal physical conditions. They added confusion to previous descriptions by mention of the "light of the cusps;" and evidently regarded the exhibition of haze, or ligament, as "the glimmering of the light of the 'auréole,' 'penumbra', or 'sunlight' refracted through the atmosphere of Venus across the dark space between the cusps." And further, if a "pure geometrical contact" (which is the only line that can be given for contact) is frustrated by haze, shadow, ligament, or black drop, then the last marked discontinuity of the illumination of the Sun near the point of contact is the epoch to be recorded if it "is distinctly recognized as independent of mere atmospheric tremor."

The American Instructions were mainly based upon the appearances of 1769; and declared the "atmosphere of Venus clearly illuminated." They refer to the difficulty of observing the moment of tangency on account of imperfection of vision, irradiation produced by the Earth's atmosphere, and imperfections in the telescope; and then mention the difficulties to be expected by atmospheric undulation.

One of our eminent astronomers accepts the explanation of Lalande, that the phenomenon of "black drop," etc., is caused by irradiation at the bright object; and that this irradiation arises from a number of causes, imperfections of the eye, imperfections of the telescope, and the softening effect of the atmosphere upon a celestial object when seen near the horizon. He likens it to a narrow and less bright false edge around the bright object; and says that this band will appear narrower the better the telescope and the steadier the atmosphere. He furthermore says that in the observations of the transit of Venus of 1874, with the improved instruments, very few of the experienced observers noticed any distortion at all. Later on he adds that "in the varied forms presented 'when the air is not still,' we recognize all the peculiar appearances described by the observers of 1769." In 1874 the Mexican observers at Yokohama reported to us a decided exhibition of "black drop."

Colonel Tennant has remarked of the black drop phenomenon, "there is no doubt in my mind that the outer part of the Sun is never free from the result of outstanding astigmatism." We have astigmatism of the human eye, and astigmatism of the telescopic objective and ocular, but we do not understand to which he applies the term, if to either of them. And one of our best astronomers, in reviewing the physical and other conditions of the 1761, 1769 and 1874 transits, summed up his deductions by saying that "the black drop, and the atmospheres of Venus and the Earth, had again produced a series of complicated phenomena extending over many seconds of time."

Curious Descriptions of the Phenomena.

With much more speculation of similar import we should be prepared for the crude descriptions and attempted explanations given by the observers. They range from a 'Chinaman's hat' to a 'pear-shaped planet,' and are even stretched out to a 'gourd shape.' The descriptions and explanations by the same observer are sometimes curiously contradictory or vague, as: 'the limbs were boiling violently,' 'yet quite sharp and doubt only three or four seconds;' there was 'black drop' but 'no distortion;' 'no distortion' yet the 'limbs of the Sun and Moon were spinning;' 'interference lines;' 'Venus serrated;' 'the Sun's limb had lost its sharpness from the overlapping of Venus' atmosphere;' the 'shadow of contact;' from the overlapping of the two 'penumbras of imperfect definition;' and most remarkable and incomprehensible, 'the sympathetic attraction or assimilation' of the limbs of the Sun and the planet at the second contact but no 'mutual attraction' at the third.

In Egypt, in 1882, one observer paid particular attention to detect the black drop and could not see it; another observer at the same locality observed the black drop. The imagination would seem to have played a part in the observations. One observer saw Venus twenty-four minutes before contact; and near the first contact he saw "a distinct cone of shadow thrown away into space;" and his drawing is stronger and stranger than his description. In 1874 the chief astronomer of one of the foreign expeditions declared to us that the phenomenon was simply and solely a case of diffraction.

Errors of Observation.

It is therefore astonishing to note that under such adverse conditions for accurate observation the times of contacts are noted to tenths of seconds. As two seconds of time mark the apparent relative movement of the bodies about one-tenth of a second of arc, we need not wonder that some of the observers were not sure of the minute; and in one case an error of three minutes could not be fixed. This occasional and accidental distortion of the planet's disc in such transits had called for the determination of the epoch of the geometrical contact of the limbs of the images of the two bodies and for other appearances; but under such unfavorable conditions the judgment of the best observer may reasonably have been at fault, and his recorded epoch of contact very wild. This is shown by many illustrations of the distortion where the outlines of the "black drop" are drawn with a hardness and positiveness that are certainly uninstructive, and unsuggestive of the cause.

The difficulty of observation is made painfully manifest in the experiments at Washington early in 1874, when most of the observers practised upon an artificial transit of Venus to determine the times of the four contacts. The observations range from four seconds before the first contact to twenty-eight seconds after; and even at the second and third contacts, from twenty-one seconds before to seventeen seconds after the epochs. These extraordinary personal equations must surely have been due in part to inexperience, and mainly to the disturbed conditions of the atmosphere. And yet the mean value of a series of such observations was applied to the actual observations in the field upon the Sun and planet, to reduce them to a systematic series. Had these preliminary observations been made in a serene atmosphere, the apparent personal equations would have been brought to normal and reasonable limits, notwithstanding one observer declares that "the optical edge of a bright body is not, and in the nature of things, cannot be, absolutely sharp in the eye or in the telescope." The great discrepancies arose in large measure from the unsteadiness of the short line of intervening atmosphere near the ground; and we then related our experience at great elevations and over heated plains, and urged the occupation of elevated and isolated stations as the most effective means of avoiding an unsteady atmosphere in such costly and important observations.

Observations of Solar Eclipses under Different Atmospheric Conditions.

Professor Dr. Schaeberle of the Lick Observatory observed the total solar eclipse of October 9, 1893, at 6,600 feet elevation, on the western flank of the Andes in Chili. He was eminently successful in all his observations on account of the extreme steadiness of the atmosphere. The Sun's image, projected by the six-inch equatorial upon a white cardboard, looked "more like an engraving than an optical image." Aubertin, at the same station, said that during the eclipse "the atmosphere was absolutely pellucid"; he had had experience at Gibraltar in 1870.

Our experience in observing the above eclipse at San Francisco as a partial phase was the reverse of Professor Schaeberle's, but very instructive. We condense the report. The images of the Sun, and the micrometer thread were projected by the 6.4-inch equatorial upon a white sheet of paper. The apparent diameter of the Sun's image was about twenty-two inches. The atmosphere was unsteady, and the border of the Sun was confused and blurred, and lacked the solid or consistent brightness of the disc. This factitious border was about half a millimeter broad at the least. The solar spots were confused and their details were not distinguishable. As the time of first contact approached we watched the predicted point of contact, not for the first indentation of the Sun's disc, but for the first commingling or overlapping, so to speak, of the factitious image of the Moon's border with the factitious image of the Sun's border. There first appeared a very faint darkening of the confused and apparently expanded border of the Sun's limb. We noticed it when it was about three millimeters long; the disturbance of the limb was very great. The dark commingling or overlapping increased in length, breadth, and darkness; and at last changed to a line of blackness when the actual limb of the Moon's image touched upon the Sun's condensed, brighter and actual border. There was no hesitation in noting the time of this contact by several observers. At the time of the last contact, four of the observers watched the phenomenon. The borders of the two discs were more unsteady than at the first contact, and the reversed order of the first contact-appearances took place. A great mountain range of the Moon was the last to disappear. The two exhibitions were very instructive.

At the total solar eclipse of January 11, 1880, on the Sierra Santa Lucia, 6,100 feet above the sea, we observed the phenomenon under peculiar circumstances fully detailed in the official report. The atmosphere was beautifully serene after a prolonged and terrific storm of wind and snow. The limb of the Sun was not absolutely steady but exhibited occasional tremors or shiverings, and there was no disturbance of the limb at first contact. "The cusps were very sharp and clear, and whenever a tremor occurred on account of any slight atmospheric disturbance these cusps were apparently doubled." (At Oakland where the atmosphere was much disturbed the cusps appeared confused and blunted.) As totality approached, the crescent of the Sun was remarkably long and narrow on account of the slight difference of the apparent semi-diameters of the Sun (16′ 18″.1) and the Moon (16′ 23″.5). The last line of the crescent was 30° to 40° long before it broke. It exhibited no distortion from atmospheric disturbances except an occasional tremor or shivering. The cusps, before the crescent was reduced to a line, were remarkably sharp, curved points, as if cut by the finest graver. The breaking of this last thin line of sunlight was occasioned by the intrusion of the lunar mountains and the inequalities of outline. It presented the appearance of a line of bright dots and dashes, and black spaces. There was no wavy motion to interfere with this exhibition; whenever a bright spot or a line disappeared it was instantaneous, and gone forever. The moving dots of the "Baily's beads" were absolutely wanting. At the last contact of the eclipse the atmospheric conditions were wholly changed. The atmosphere was in a remarkable state of undulation and the limbs of the Moon and Sun were moving in great rapid waves, and the observation was unsatisfactory. The Sun set below the ocean horizon about ten minutes later and we should have expected a quiet atmosphere, but the warm Sun rays heating the air upon the steep, snow-covered ocean-side of the mountain mass caused rapid evaporation of the snow, and irregularly heated currents of air to flow over the station. At this eclipse we called attention to the less darkness of the sky adjacent to the advancing body of the Moon, due to contrast with coronal effects.

At the solar eclipse of October 30, 1883, we projected the images of the Sun and Moon upon a sheet of white paper, and studied the disturbed outline of both objects. The greatest obscuration occurred just before sunset, when the Moon was half way over the Sun's disc. Owing to the extreme refraction at this zenith distance, and the "exceedingly great boiling" of the borders of the two images, the "distortion of the cusps was striking and peculiar."

In contrast with these two exhibitions of great atmospheric unsteadiness, we introduce an experience approaching that of Professor Schaeberle's above mentioned.

We observed the total solar eclipse of August 7, 1879, on the Chilkaht River in Alaska, near the end of heavy, cloudy weather, when the atmosphere had become clear and steady. At the first contact "the limb of the Moon was very sharply defined, and the outline of the Sun was very steady and sharp." Just before totality "the crescent was very beautiful to the unassisted eye, and in the telescope." In the three-inch Fraunhofer, with moderate power, the "borders of the Sun and Moon were remarkably steady and very sharply defined. In twenty-four years of practice in observing we have rarely, if ever, seen them under such favorable circumstances. We observed them without any shade, and followed the Sun's border to the instant of disappearance. The bright, long, narrow crescent was sharply and regularly defined throughout; the extremities were clear-cut and pointed. As the width and length of the crescent decreased, this sharpness of outline and regularity of form were maintained until it became a fine line of *living* white; and, shortening rapidly, it disappeared as a very short, fine, distinct line, and not as a star at its disappearance. There was no breaking of this line into points or heads; no wave motion along it; no disturbance whatever of continuity or regularity of form."

"A feature of the phenomenon of totality was the vivid impression that the dark body of the Moon stood out clearly and unmistakably in relief in the space between the observer and the coronal brightness around the obscured body of the Sun, and did not lie flat and upon it, as in a picture." This perspective effect resulted from the serenity of the atmosphere, the sharpness of the Moon's outline, and an impression that the dark Moon was very close to us.

Graphic Exhibitions of Unsteadiness.

If it were necessary to add graphic demonstration to the effect of the disturbed atmosphere already described, we have it in the photographs referred to in the following note by Warren de la Rue,[1] where he describes the method of photographing the Sun's disc, in a very small fraction of a second. He says, "So rapid is the delineation of the Sun's image that fragments of the limb, optically detached by the 'boil' of our atmosphere, are frequently depicted on the collodion, completely separated from the remainder of the Sun's disc; more frequently still from the same cause the contour of the Sun presents an undulating line." To this case can be added a photograph of the Sun taken at the Lick Observatory January 14, 1897; wherein the factitious limb is like a flocculent border of cotton or wool with ragged holes through the relatively faint, irregular outline

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[1] Proc. Brit. Assn. Adv't. Sci., Aberdeen, 1859, page 151.

of the disc; and several cloud-like areas actually detached. The breadth of the thin border is about 6″, and the whole factitious breadth must be more.

It seems a physical impossibility that we should be able to detect any irregularities of even a dense atmosphere at the border of the Sun. If that body were to decrease 45 miles in diameter, our instrumentation would not be able to measure it under present conditions. Much less could we detect it if there were actually rolling billows of the exterior matter of the Sun 45 miles high around its border. They would subtend but 0.1″ in height; a quantity covered by the finest spider thread in the telescope. Much less could we detect any changes of atmospheric conditions at the distances of Jupiter, Mars, Venus, or Mercury. Some great deep Sun spot just on the edge of the Sun would doubtless show a depression, but not any imaginable storm disturbance of the densest atmosphere, as we understand storms and waves.

Official Recognition of the Factitious Borders of the Moon and Sun.

In still further confirmation of the existence of the spurious limbs of the Moon and Sun under unfavorable atmospheric conditions, it is only necessary to appeal to the representative of astronomical authority in the American Ephemeris or Nautical Almanac. In that government publication an empirical correction of 2″.5 is applied to the Moon's semi-diameter in order to represent the observed value in meridian instruments. But this "constant is omitted in the computation of solar eclipses and occultations as due to telescopic and ocular irradiation" (p. 528, 1899). This 2″.5 of increased semi-diameter may represent the average measure of the factitious border, but certainly it is frequently much greater.

In many years of experience upon the Pacific Coast of the United States in observing lunar transits, we have learned to expect wild results when a markedly factitious bright limb of the Moon was observed, the resulting longitude being always affected as if the diameter of the Moon were too great. At times, when the vibration or undulation of the disc of the Moon was not rapid, the sharp, solid limb could be observed even with a faint, spurious, vibrating outline beyond it. In 1889-'90, during lunar transit observations for longitude at San Francisco, our party had a case of spurious disc from excessive diffusiveness, with a predicted error in the resulting longitude that was verified upon reduction. This clearly indicated that even the official empirical correction may frequently be too small; while in times of supreme steadiness of the atmosphere and resulting sharpness of the limb of the Moon, this correction is not required.

If this factitious diameter belongs to the Moon, the Sun is much more likely to carry a more pronounced factitious diameter, and every observer must have frequently watched its wildly boiling limb flaring and leaping across the threads or rolling forward like waves of flame along the horizontal thread. This factitious border is in effect tacitly acknowledged in the American Ephemeris above referred to, where "the adopted semi-diameter of the Sun at the Earth's mean distance is 16′ 02″. In the computations pertaining to eclipses, Bessel's semi-diameter 15′ 59″.788 has been adopted." It appears to us that the explanation in the American Ephemeris of the cause of the acknowledged spurious diameter of the Moon is erroneous.

Great Elevations for Observation.

Although our experience has led us to advocate the selection of great elevations for astronomical observations of precision and research, yet elevation alone is not a panacea. The locality must present other favorable orographical conditions. Unfavorable conditions are great gulches, cañons, or narrow valleys lying directly under a summit and leading to it. These gulches become filled with highly heated air during two or three days of clear, calm weather, and the first wind from below drives this heated air over the summit and spreads stars out into unsteady nebulous films; the the rings of Saturn become woolly girdles, the crape ring is invisible and the details of the belts of Jupiter are indistinguishable. And in such a location during daytime, observations of precision on the Sun are absolutely useless. The seeing upon a mountain peak may be generally good when there is no snow on the surface; and even remarkably good with snow, when the temperature is low and the wind is strong; but when the Sun shines and the temperature rises, and rapid evaporation takes place with light airs, the seeing becomes very bad. (Experience at 10,450 to 7,250 feet elevation.)

On Mt. Conness, in the Sierra Nevada (12,566 feet elevation), the geodetic heliotrope images were perfect until the afternoon Sun shone upon the 2,300 feet nearly vertical western face of that curious buttress; and then the uprising, irregularly warmed atmosphere caused the images to become unsteady. During the quieter moods of the atmosphere, we observed Polaris for azimuth in the middle of the day very satisfactorily with a telescope that would not show it in daytime at lower elevations or under less favorable conditions.

In 1872 we experimented in the Sierra Nevada at elevations from 7,200 to 9,500 feet with remarkable success; while another party of the United States Coast and Geodetic Survey sent for the same purpose to Sherman, 8,300 feet elevation, in the Rocky Mountains, had at times a very unsteady atmosphere. The Lick Observatory at Mount Hamilton, in the Diablo Range, at 4,209 feet elevation, is surrounded by unfavorable orographical conditions, especially for observations of precision in daytime.

It would appear that Newton attributed the apparent unsteadiness of celestial objects to the disturbance of our own atmosphere. "Telescopes," he writes, "cannot be formed so as to take away that confusion of rays which arises from the tremor of the atmosphere. The only remedy is a most serene and quiet air. Such as may perhaps be found on the tops of the highest mountains above the grosser clouds."

Precision Observations at Low Elevations.

And yet there are climatic conditions at comparatively low elevations, which are supremely favorable for observations of precision at night. The experience of the observers of the United States Coast and Geodetic Survey on the immense, elevated, arid plains from El Paso to San Diego is very instructive. During the hot cloudless days the atmosphere over the immediate surface of the parched earth was in violent unsteadiness, and the heliotrope images at even short distances flared out wildly like burning houses. They were the worst possible objects for observations of precision. After sunset the conditions were suddenly changed. With a cloudless sky and a minimum of aqueous vapor in the attenuated air (Barometer about 26 inches) radiation was quickly effective. The temperature fell many degrees in a short time, and the air became supremely quiet. The latitude telescope showed stars as minute discs with diffraction rings running along the micrometer thread with such extreme steadiness that it was impossible to be in doubt more than one-tenth of a second of arc in measurement; and in the transit instrument the star marched with absolute regularity across the reticule. It was an experience that an observer of over thirty years in the field declared he had never before enjoyed.

Per contra, on the low Yolo plains of the Sacramento Valley in California, we have had the azimuth signal-light (distance eleven miles), in a calm night, running wildly up and down the vertical thread of the theodolite through five minutes of arc, in an ever changing line of broken stars of the prismatic colors, and yet showing little or no horizontal motion. The range of height of this column of images was eighty-seven feet.

In the great Gangetic plains of India the night signals of the triangulation parties, when shown from towers of fifty feet elevation, frequently appeared as continuous columns of light sixty feet high.

In the triangulation of the western coast of Lower California by the United States Steamer "Thetis," the

The "azimuth" was observed at N. [illegible] S. Yolo; and the difference of direction of the line was of 0."04; noted as remarkable by [illegible].

observer informs us that the unsteadiness of the atmosphere and the irregularity of the refraction apparently lengthened the signal poles to a hundred feet and more; and the tripod supports were like great writhing snakes. Even upon some small low island in the ocean, where the climatic conditions are favorable, the atmosphere at night becomes very quiet and serene. From a vessel's deck we have watched the larger stars nearly reach the horizon with very little twinkling.

Recapitulation of Phenomena at Observation.

These examples are a few of the many experiences in our geodetic and astronomical observations, and in the descriptive experiences of a few other observers. And yet from recent publications there appear to be many observers who do not understand the cause of the phenomena, and who seem to think there must be something occult and unexplainable. We have therefore felt constrained to repeat this explanation which we have held and announced for many years. It seems to cover every phase of the phenomena.

In the occultation of stars by the Moon, a spurious and factitious limb of the Moon can be formed only and solely by the unsteadiness of our atmosphere more immediately surrounding the station of the observer.

In a serene atmosphere, the outline of the Moon is so sharp and clear-cut that the mountains and valleys thereon are very distinctively exhibited, and will bear the largest magnifying power. When the atmosphere begins to change to unsteadiness, the sharp outline of the Moon (or other object) is first affected by tremors or shiverings, which are so infrequent that the observer is able to select the actual border and its features. As the unsteadiness of the atmosphere increases, the tremors increase in frequency and in amplitude, until the border of the Moon becomes a confused, blurred outline, in which no serrations can be detected. The early shiverings usually denote the direction of movement of the disturbed air. Under the atmospheric conditions of clearness and serenity, the apparently approaching image of the star is a beautiful, steady, minute disc with one or more delicate diffraction rings. The Moon's white and sharply defined border exhibits all its serrations and irregularities. As it approaches the star, the diffraction rings disappear in the increasing light in the field of view, but the disc remains; and at their visible contact the disappearance of even the largest and brightest star is absolutely instantaneous; and no observer can be in doubt of the epoch beyond the tenth of a second. Under such favorable atmospheric conditions, the image of the star never enters upon the visible limb of the Moon, no matter what the size of the objective or the magnifying power employed. And with such conditions, the reappearance of a star from the bright limb of the Moon will be instantaneous. If the star were apparently to make a near approach to the Moon along the dark north or south limb, where there are serrations, it might pass so close as to disappear behind the first mountain and reappear in the next valley (each phenomenon being absolutely instantaneous) to be swallowed up by the next mountain, or in its absence, to continue its visible course. We have heard (1846) the elder Bond describe such a phenomenon in his experience and it has happened once to ourselves. But when the atmosphere begins to change to unsteadiness, the star loses its diffraction rings, the nucleus is broken up and gradually diffused into a nebulous image, fuzzy and unsteady, with a brighter, irregular, dancing nucleus, or is spread out as a nebulous film as much as forty or fifty seconds of arc in diameter. This unsteadiness of the atmosphere throws the disc of the Moon into irregular vibrations or displacements of equal amplitude and duration, giving it a factitious border. With this disturbed and spurious limb the Moon approaches the diffused image of the star, both being in a state of great unsteadiness; but if the nucleus of the star be sufficiently large, bright, and colored, like Antares and Aldebaran, the impression of its image upon the retina of the eye is naturally more intense as an isolated spot than the image of the whitish, confused, spurious border of the Moon, even when the former is within the latter. The action of the eye is unconsciously selective, but a certain effort of selection is made under the less favorable condition when the star is small or white. There is no effort at selection needed to receive an impression of the Moon's limb, although the actual limb may doubtless be detected, under high powers, inside this factitious border. The impression of the image of the star is, therefore, continuous within the range of amplitude of the excursions of the disc of the Moon, but is instantly lost when the limit of this range of vibration is actually reached by the apparent nucleus of the equally unsteady star, and the true limb of the Moon occults it. With a large colored star all the phases of this phenomenon are unmistakable; with a large white star they may be somewhat in doubt, as in the case of 47 Libræ and other stars elsewhere quoted; with a small white star they will probably not be noted, especially in small telescopes with low power.

The exhibition of the phenomenon at the reappearance of a star on the blurred and factitious bright limb of the Moon should be in exactly the reverse order of the foregoing phenomenon of disappearance; and we have been fortunate in looking over our old record to find the original notes of the disappearance of Aldebaran behind the dark limb of the Moon, and its reappearance from the bright limb, on March 29, 1887, as elsewhere mentioned.

In this résumé we have confined ourselves to the exhibition of the normal and abnormal conditions in our atmosphere attending the phenomenon of occultations of stars by the bright limb of the Moon, or by Jupiter or any other planet, because the explanation virtually covers all associated phenomena in solar eclipses, lunar transits, transits of Venus and Mercury, and the vagaries of star images.

When our atmosphere is absolutely serene there is not and cannot be the slightest abnormal exhibition of form, size, march, or steadiness of images; or of doubt of instantaneity in the epochs observed. Under such a condition there would be no empirical corrections in the Nautical Almanac to the semidiameters of the Sun and Moon; and the diameters of the planets measured by different observers, and the right ascensions and delineations of the stars would be consistent within the instrumental and personal equations.

Other Important Results Affected.

There is another and very important class of astronomical results affected by these factitious borders of the Sun and planets and the unsteadiness of the stars.

Dr. Newcomb says that the observed right ascensions of the mean of the Sun's two limbs, relative to the fixed stars, are affected by personal errors for which no means of elimination have been tried. He suggests personal error and possibly the effect of the Sun on the telescope. To these causes should be added the larger effects of the disturbed and factitious limbs; and in cases of steadiness, to diffraction of the limb at the spider line. He elsewhere notes "very large errors, both accidental and systematic, to which observations of the Sun are liable;" and again he regards "the constant error in declination of the Sun as something peculiar to the observer and the instrument." In another place he says: "There is a remarkable systematic difference in the observed A. R. of Mercury, according as the planet is east or west of the Sun, and therefore according to the illuminated side. The sign of the result shows that the reduction to the center of the planet was apparently too small, and then it is of interest to learn according to what law this error changed as the planet moved around its relative orbit."

Furthermore, the hurtful effect of observing upon the outer limb of the factitious limb of the disturbed Moon can be shown in the determination of the parallactic inequality of the Moon from meridian observations. Dr. Newcomb says the method is peculiarly liable to systematic error, owing to the fact that observations have to be made on one limb of the Moon when the inequality is positive, and on the other limb when it is negative. Hence if we determine the inequality (125″.5) by the comparison of its extreme observed effects on the Moon's right ascension, any error in the adopted semidiameter will affect the result by its full amount. This suggests that this gravitational method of determining the Solar Parallax would be more accurately employed by observing occultations of stars large enough to be seen through the spurious bright limb of the Moon. Moreover, the observations themselves would afford some data for the elimination of the error depending upon a factitious limb.

Nearly all Measured Diameters Too Large.

In all instrumental observations for the right ascension of the Sun or Moon, and for their declination and diameter, it must be evident that the observer obtains accurate measures only when the disc of either body is sharply defined, devoid of tremor or unsteadiness, and unaffected by irregular and extraordinary refraction, without reckoning diffraction at the spider line, unknown instrumental errors, and peculiarities of observation. As these supreme conditions of steadiness are seldom obtained, it necessarily follows that the mean of any number of observations taken under different atmospheric conditions (say for example the diameter of the Sun, Moon, or planets) must be too large. The diameter can only be too small through error of observation, instrumental errors, diffraction of the spider line, or abnormal refraction.

With a disturbed atmosphere in observations for the determination of the right ascension of the Moon during the first half of a lunation, the observed A. R. of the limb will be too small and for the second half too large. Similar results will follow from observations of the I and II limbs of the Sun and planets. Therefore all published diameters of the Sun, Moon and planets derived directly from actual observations must be too large. Moreover, this presents a case where the mean of measured quantities is not the most probable value. The mean of all the minimum measures would be nearer the truth.

The amplitude of the excursions of the images of the Sun, Moon, and planets in a disturbed atmosphere is a variable quantity that can not be determined but should be avoided if practicable. To obtain the most trustworthy results in reasonable time, we need the fixed observatories located at points which conspire to give the best atmospheric conditions determined upon after systematic and exhaustive trial for special lines of research; the highest class of instrumentation; observers with ideal eyes (of which unfortunately there are very few); discrimination in the selection of proper times of observation; and a wise rejection of observations made under abnormal conditions.

Note. Since this paper was presented to the California Academy of Sciences, Professor A. E. Douglass of the Lowell Observatory at Flagstaff, Arizona, has published the second of his interesting papers upon "The Atmosphere, Telescope and Observer," and "Scales of Seeing." Pop. Astr. 1898.

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