vice versa, depending on the thermal condition of the atmosphere and on the effects of the internal friction of the fluid. The presence of water vapor in the air complicates the problem; for the slightest difference in humidity with the least change in density or temperature of adjacent portions must cause circulation and a readjustment of the thermal equilibrium of those portions; and I suspect that in these inevitable inequalities of pressure or temperature will be found the explanation of the incessant agitation of the waves as the large currents move rapidly along. The importance of these phenomena as atmospheric movements affecting all astronomical work, aside from their high meteorological interest, is such as to justify a prolonged and critical study under the best conditions. Until this is done some of the effects may remain obscure; yet it seems fairly certain that the general character of the disturbances are as here indicated, and I have ventured to submit these considerations in the hope that they may be of interest to other observers.

Lowell Observatory, Flagstaff, Arizona, 1897 Aug. 23.

Explanation of the plate.

Fig. 1 represents a frequent form of the waves when the wind is very high; definition generally very bad.

Fig. 2 represents moderate sized waves; definition generally very fair.

Fig. 3 represents very large waves; definition generally bad.

Fig. 4 represents cross currents; definition depends on the character of the waves, but is frequently bad.

Fig. 5 represents very fine waves moving in all directions, characteristic of very hot, dry weather; definition generally bad.

Fig. 6 represents very fine seeing, only slight traces of gently moving waves.

In theoretically perfect seeing there should be no trace of any atmospheric movement whatever.

T. J. J. See.

On the Cause of the Scintillation of the Fixed Stars.

By *T. J. J. See.*

Recent studies of the air waves visible in telescopes have led me to connect these aerial agitations with the scintillation of the fixed stars. These undulatory phenomena have not been considered by previous investigators, and it seems probable that they constitute the true cause of stellar scintillation, which has heretofore been somewhat obscure. The air waves having been sufficiently described in previous papers, we may here consider the effect of such waves upon the images of telescopes of various apertures. In the case of the naked eye, the aperture from which the light is gathered is about 2 millimetres in diameter, and hence any intercepting wave which might turn the light of the star to one side by this amount would cause the star to twinkle suddenly; or if it did not wholly disappear, the wave would at least disperse the light into a spectrum and the eye would recognize a change in brightness and a rapid succession of spectral colors. The action of a wave is essentially similar to that of a lens, for it must always distort the luminous wave-front; but it would seldom happen that the eye would be in the focus of the wave (if indeed there be any exact focus), and hence while there would be incessant fluctuation in brightness as the waves pass before the eye, there would also be a rapid succession of colors. If we consider one wave, which we may imagine of the form of a double convex lens, the eye being supposed between the wave and its principal focus, it is clear that as the wave intercepted the light of the star the eye would first encounter a spectrum running from the red to the blue; as the centre of the wave passed, the colors would change gradually again in the reverse order. This is essentially the phenomenon observed in ordinary naked-eye scintillation. In practice it would rarely happen that a simple perfect wave such as we have supposed would pass before the eye, but it is easy to

see that however complicated and antagonistic the actual waves might be, the appearance at certain irregular intervals would be essentially that here described. If in the small area covering the pupil the rays from different waves or different parts of the same wave should interfere (as must occasionally happen) there would be total momentary extinction of the star. When the interference did not amount to extinction there would be a sudden diminution and then an increase in brightness, with a play of successive colors. If the waves happened to be conspicuous, the scintillation would be correspondingly marked. We have seen that the length of the waves vary from 1 to 20 centimetres (occasionally the length even surpasses 40 centimetres), and hence with a finite velocity of atmospheric movement there would be a certain time elapsing between the succession of colors from the different portions of the wave, the interval depending on the velocity of the current and the size of the wave. If the simple waves are superposed into compound waves, this interval might be lengthened or shortened to any corresponding degree. In case the intervals became too short, the eye would be unable to perceive anything but a blurring impression. At other instants more widely separated the flashes would be clear and distinct, as is frequently observed, and especially when the waves are large and conspicuous.

I have recently compared the scintillation in telescopes of apertures 2.54; 5.18; 10.16; 15.24; 61.0 centimetres, with the following general results:

1) When the waves are conspicuous and violent, the scintillation is marked both to the naked eye and in the smaller telescopes.

2) When the waves are small there is no proper scintillation in the larger telescopes, though parts of the

image undergo considerable motion and dispersion of color; yet scintillation continues in the telescopes of small aperture, and is always noticeable with the naked eye.

3) When the length of the wave surpasses the aperture of the telescope there is always some scintillation; while if the waves are shorter than the diameter of the objective, only partial scintillation or none at all can be perceived.

4) We have never seen any distinct scintillation in the 61.0 centimetre refractor, although on a few occasions when the waves were large and conspicuous the image of a star displayed considerable motion, and more than usual fluctuation of color.

5) The intensity of the scintillation is a function of the altitude of the star above the horizon. This may be explained by the fact that low down the numerous successive waves superposed in the line of vision frequently act as combined waves and thus increase the visible effects upon the star's brightness, position and color.

6) To connect the waves directly with the scintillation in such a way as to leave no doubt of the cause of the phenomena, I have on several occasions counted by careful watching the number of flashes in ten seconds, the time signals being taken by Mr. Cogshall; in this way we have found that the number of flashes is sensibly the same for all altitudes higher than 30° . Having thus fixed the rate of scintillation, we then examined without delay the number of violent wave agitations noticed to pass the field of the great telescope; and it was found that the number of large waves passing the objective was sensibly the same as the number of flashes observed with the naked eye. This number on the average was about 22 for ten seconds. Our counts on α Scorpii, α Bootis, α Lyrae, and α Ursae Majoris at 17^h sidereal time, showed that the number of flashes in different parts of the sky was sensibly the same; so that the direction of the currents relative to the observer seem to have very little to do with the twinkling. It was remarked that sometimes as many as four flashes would occur within one second, while at other times only one could be perceived; only such flashes and waves being taken account of as were recognized with certainty.

7) It seems incorrect to state that the refraction proper varies from moment to moment. It varies gradually from hour to hour owing to continuous fluctuation of the barometric pressure, temperature and humidity; but the small momentary changes in the apparent position of a star are like those which affect the shape of the image and disperse the colors, and are to be attributed solely to the momentary combinations of air waves which intercept the light of the star.

8) When the flow of the currents is exceedingly gentle and smooth, and the atmospheric waves are practically absent, scintillation ought almost to cease; and we have actually confirmed this inference by observation, though even in the best localities these intervals of calm are rare and of short duration. Humboldt mentions the stillness of the stars and

the almost total absence of conspicuous scintillation in the plains of Peru (Cosmos, vol. III p. 103, Bohn's Translation). The good seeing at the Harvard Station near Arequipa may be regarded as another confirmation of this result in our own time, from a somewhat different point of view.

In the Philosophical Magazine for July 1893,*) Lord Raleigh has very fully considered the theories of scintillation held by previous writers, and given at considerable length the analysis for the effects of refraction on the path of the light through the atmosphere. He intimates that the true cause of the scintillation is obscure, in this language: »One of the principal outstanding difficulties in the theory of scintillation is to see how the transition from one index to another in an atmospheric irregularity can be sufficiently sudden. The fact that the various parts of a not too small object glass are diversely affected seems to prove that the transition in question does not occupy many centimetres. Now whether the irregularity be due to temperature or moisture, we should expect that a transition, however abrupt at first, would after a few minutes or hours be eased off to a greater degree than would accord with the above estimate. Perhaps the abruptness of transition is, as it were, continually renewed by the coming into contact of fresh portions of light and dense air as the ascending and descending streams proceed in their courses. The speculations and experiments of Jevons on the cirrus form of cloud (Phil. Mag. XIV p. 22, 1857) may find some application here. A preliminary question requiring attention is as to the origin of the irregularities which cause scintillation.«

Lord Raleigh concludes that the present state of Meteorology does not explain the origin or character of the irregularities to which scintillation is due. It is clear from the discussion above, and from the descriptions of the air waves published by Mr. Douglass†) and the writer, that the atmospheric irregularities which cause scintillation are at last recognized; it is not yet quite clear how these waves are maintained though the suggestions advanced in the accompanying paper seem plausible.

Lord Raleigh attaches considerable importance to the dispersive action of the atmosphere upon the red and blue rays, which are thus separated and made to pursue different paths in the vertical plane. I conceive this dispersion to have a bearing on the scintillation only in this way: That when the rays of the star are thus separated, the red being above the blue, it is perhaps easier for a chance combination of the waves to still further separate the extremes of the spectrum, or to extinguish one part while the other part remains, and thus produce a change in color or a variation in brightness.

On the wave-theory it is easy to account for the sudden transition from one phase to another, and for all the general phenomena considered by previous observers. The spectroscopic observations of Respighi quoted by Raleigh also find complete explanation, as do also the relation of the phenomena to altitude and to aperture of telescope. It is needless to add that this theory accounts perfectly for

*) Reprinted in Astronomy and Astrophysics, Nov. and Dec. 1893.

†) After finishing this paper I find that Mr. Douglass has suggested a connection between scintillation and cross-currents (Popular Astronomy, June, 1897).

the absence of scintillation in the case of planets with large discs; for in this case the waves* are generally shorter than the angular diameter of the planet, and consequently cannot affect the light of the whole; so that the eye perceives no change comparable to that observed among the stars, though there must be scintillation of points on the surface. It is well known that when the seeing is bad the planetary image of Mars, for example, is frequently displaced by almost half its diameter, and sensible distortion of form is very common.

Lowell Observatory, Flagstaff, Arizona, 1897 Aug. 24.

This bodily displacement as well as the shifting of points on the surface, so frequently noticed by observers of planetary detail, is traceable to the action of air waves, which distort the luminous wave-front entering the telescope.

Thus while the wave-theory certainly assigns the true cause of the scintillation of the fixed stars, considerable observation is still needed for delineating the exact forms of the waves under all conditions and for investigating their effects upon the steadiness of stellar images.

T. F. F. See.

Researches on the Orbit of the New Binary β 395 = 82 Ceti = Cord. GC. 544.

By *T. F. F. See.*

On the morning of Aug. 18 while sweeping over the constellation Cetus, I recognized an extremely close and difficult object of about the sixth magnitude; though the pair was detected with the usual sweeping power of 500, it was only elongated and required a power of 1500 to divide the well defined images which are of the 6.5 and 6.6 magnitude, and both yellow. The appearance of this difficult object was such as to inspire the belief that the system was new; yet on comparing it with the extensive manuscript catalogue of every known double star within 75° of the south pole, which we have recently formed, I found that the star is β 395 = 82 Ceti = Cord. GC. 544:

$$\alpha = 0^h 32^m 9^s \quad \delta = -25^\circ 18' 37''.3 \quad (1900.0).$$

So great an orbital motion had intervened since the last published measures of 1891, that the whole aspect of the system had changed, and the former measures would ill have enabled us to identify the object; yet as there could be no doubt of the star being 82 Ceti, it became evident that we had discovered quite unexpectedly one of the most rapid of known binary systems. This striking double star was detected by Burnham with his celebrated six-inch Clark refractor in 1875; his estimates fixed the position as

$$1875.843 \quad 135^\circ \pm \quad 0''.5 \pm \quad 1n.$$

The following measures have been published by later observers, and I am not aware of any other observations to the present time.

t	θ_0	ϱ_0	n	Observer
1886.849	104.7	0''.65	2	Leavenworth
1888.89	109.6	0.67	3	Leavenworth
1889.988	111.4	0.88	2	Hall
1890.82	112.6	0.74	3	Burnham
1891.757	115.2	0.69	1	Leavenworth
1891.85	118.2	0.75	3	Burnham

Our measures with the Lowell 24 inch refractor are:

t	θ_0	ϱ_0	
1897.627	278.0	0''.22	Just separate with 1500
1897.627	279.3	0.22	
1897.671	277.3	0.24	Separation doubtful with 1000,
1897.671	278.1	0.20	[closer than β 883
1897.649	278.2	0.22	

By *Mr. Cogshall:*

t	θ_0	ϱ_0	
1897.671	269.7	0''.26	Smaller component precedes
1897.671	275.9	0.25	
1897.671	272.8	0.25	

From these measures, which were made under good conditions and certainly are affected by no appreciable errors, we see that the angular motion since 1891 has amounted to 160° , and that the radius vector has diminished from about $0''.70$ to $0''.22$. A comparison of Leavenworth's measures in 1886 with Hall's in 1889, and of the latter with the mean of Leavenworth's and Burnham's in 1891, shows a good conformity to the law of areas, and we are able to conclude that the motion is undoubtedly direct. Yet as the radius vector in the region then being described is long, the angular motion is slow; and in 1891 Burnham could merely say that the system is a binary in moderately slow motion. The measure just secured defines the character of the motion with a degree of precision which is truly extraordinary. Deriving the integral of areas

$$\frac{1}{2} \int_{t_1}^{t_2} \varrho^2 \frac{d\theta}{dt} dt$$

from the measures between 1886 and 1891 inclusive, and relying for distance upon the excellent measures secured by Hall in 1889, we find the area lying between the position for 1891, and that now occupied by the companion. As