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Scales of Seeing.

A. E. DOUGLASS.

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SCALES OF SEEING.*

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FOR POPULAR ASTRONOMY.

When it is reported that the seeing at a locality is good or bad, we have gained no precise information in regard to the atmosphere unless we thoroughly know the place referred to or perfectly acquainted with the observer who makes the statement and his class of work. When we see the record of an observation accompanied by a numerical note of the seeing as if to confirm its validity, we are apt to forget that such an addition may give little confirmation to the minds of other astronomers because in most cases the quality of the seeing is judged from the objects seen and then the figure is quoted to confirm them; it is simply arguing in a circle. The seeing as usually quoted is merely an indication of the confidence the observer has in his own work. Everyone knows that suspicion may become certainty through improved seeing and that the true quality of the seeing is a weight which can be assigned to the observation and enable others to judge of its value; but when each observer quotes his own arbitrary scale, such weighting is nearly worthless. In order to convey information the seeing has to be described minutely, or referred to a standard scale.

In almost every case the scale of seeing is confessedly derived from the observer's experience, and as the average range of seeing to which he has become accustomed is dependent upon his latitude, the nearness of mountains or oceans, presence of snow, elevation above sea level, upon the character of the work undertaken, the average altitude of the celestial body above the horizon

* Second paper on the subject of Atmosphere and Observatory Sites. The first paper entitled, "Atmosphere, Telescope and Observer," appeared in POPULAR ASTRONOMY for June 1897. The present paper was almost completed in July of that year but owing to my absence from the Observatory and the loss by fire of Mr. Drew's observations on seeing at different zenith distances and comparisons of aperture, it has had to wait for me to make a new set of observations.

and upon the aperture of the lens, his scale is not likely to be general in any sense. For these reasons I advocate in this paper the use of a standard scale of seeing and give some of its variations under certain conditions of aperture and zenith distance.

The Standard Scale.

The standard stellar scale is due to Professor W. H. Pickering who completed it in nearly its present form at Arequipa in 1891.

Under date of December 9 of that year the following was published in the *Nachrichten* No. 3079, (his scale numbers 3, 4 and 5 have been changed to 6, 8 and 10 and other slight alterations made):

"Under good conditions the brighter stars are surrounded with numerous diffraction rings:—

Seeing 6 indicates that the rings are broken and impossible to count.
Seeing 8 indicates that although in motion, the rings are complete and may be counted and that the central point of light is readily separable from the inner ring.
Seeing 10 indicates that each ring is perfect and immovable."

This scale was derived from the use of a 13-inch instrument. It was given to me in a more complete form when I first went to Arizona to test proposed sites for the Observatory. Later on, and now nearly four years ago, but after it was discovered that the seeing on Mars was not the same for micrometer measurement as for drawing detail, it was proposed to adopt a scale of seeing which would include two figures in every case, one in regard to the steadiness of the limb and the other depending on the amount of detail. This was, in fact, in use for some time and from that very use suggested a still more detailed method of recording the seeing which consisted in the record of many figures each one describing the amplitude of some vibration exhibited by the planet. This is undoubtedly the most perfect form of recording the seeing but it is very difficult and can hardly be made practical as yet. The most important motions were those called "total confusion" and "bodily motion." The first was the width through which the limb was indeterminate; it measured the extinction of fine detail. The other was the swaying motion of the whole planet in the field; which is a decided obstacle in good micrometer work. This is essentially the same as the limb and detail method but in this case the figures represented direct estimates of the amount of these two motions expressed in tenths of seconds of arc. The objection to both of these methods is their complication, and to the latter, the necessity for having a measuring instrument and a long focus telescope and high power.

The standard scale here adopted, depends upon the perfection of the image of any bright star as seen in a telescope of six-inch aperture, apart from any defects caused by the lens or its adjustment. In making the observation the name of the star should be recorded, and also its zenith distance and brightness; its brightness however is really of little importance except that if a star is faint it is harder to judge of the seeing by it; there is no difference in the figure of the seeing. But the zenith distance is almost as important as the seeing itself because the seeing varies rapidly with this distance.

STANDARD SCALE OF SEEING.

0. Disk and rings in one confused mass, violent motion, image greatly enlarged (for example to twice the diameter of the third ring) and varying in size.
2. Disk and rings in one confused mass, constant motion, no increase in size.
4. Disk well defined, no evidence of rings.
6. Disk well defined, rings broken into dots and lines but still traceable.
8. Disk well defined, rings complete but moving.
10. Disk well defined, rings motionless.

With each number should be given the average amount of bodily motion, thus indicating the effect of air waves too large to otherwise affect the form of the stellar image in a 6-inch telescope.

I anticipate that in most countries this standard scale will be found satisfactory in use. In my own experience in regions of comparatively good seeing, numbers 0, 2 and 4 are the most readily distinguished, that is, the most constant in a given observation for seeing. Numbers 4, 6, 8 and 10 are apt to change quickly from one to another. On perhaps the majority of occasions the seeing has included 4, 6 and 8 and the final figure must be obtained from the proportionate amount of these. The seeing is best expressed by recording the observed amount of each, which shows at once what instants of good seeing are likely to be obtained. For practical purposes one should at least be able to obtain from the record both the range and the mean value. In order to get a satisfactory idea of the seeing it is well to make quite a number of records at short intervals so that the mean will be tolerably exact. It is by no means necessary to strive for great exactness in each estimate. The seeing (in our experience) varies considerably in long intervals, from ten minutes to several hours. A little experience will show how far such changes are likely to restrict the application of the recorded figure.

There are rare cases more easily predicted from theory than from experience for which the mere record of the form of the stellar image is wholly inadequate; in such cases a record of the motions of the image is essential. They arise from the use of very big lenses. Throughout the observations which I have made upon the currents in the atmosphere, in instruments of 18 and 24 inches, the maximum distance from crest to crest, so to speak, of the air waves has been about five inches. So that waves up to nearly this size seen in either large or small glasses will not be too large for a six-inch aperture and will affect the appearance of the image.

Nevertheless waves larger than six inches sometimes exist and doubtless usually have escaped notice because when the waves reach a size equal to one-third or one-half the diameter of the lens they become difficult to see. So with different combination of waves, the following results will be noticed: With merely a set of waves of less than six inches, the confusion and loss of planetary detail will be similar in a 6-inch and, let us say, a 30-inch telescope; a star-image will have form 2 without bodily motion in a 30-inch and any form from 2 up, in a 6-inch depending on the actual size of the waves. If the waves are above one and one-half inches there will probably be some bodily motion; the planetary detail also will improve with coarser waves.

As the waves increase from six to thirty inches there will be no change in the amount of detail seen in a six inch lens but both the detail and the stellar image will steadily improve in a 30-inch. But the stellar image in the 6-inch will have merely a bodily motion and will show no change while the waves are becoming coarser and will therefore fail to indicate these changes which are of great importance to the large lens. For this reason the bodily motion should always be recorded when the seeing is above 7 in the standard 6-inch lens. Most unfortunately for astronomers these coarse waves are very rare and when they do occur their good qualities are rendered useless by the presence of sets of fine waves which spoil the seeing.

The practical use in knowing of their presence is that when they do exist diaphragms may be advantageous on large instruments, because if the coarse waves are not too much smaller than the large lens, a large aperture diaphragm may remove their bad effects upon fine detail without greatly reducing the light. The best indication of their presence is a perfect image showing large bodily motion or a twinkling of the disk in a 6-inch telescope. A flowing over of the central disk onto the rings is probably another indication of them.

Effect of Different Apertures on the Standard Scale.

On applying Pickering's scale for a 13-inch telescope continuously to a 6-inch telescope, early in 1894, I found that the gradations of the form of the Image I saw, were somewhat different. In the scale given above for a 13-inch (the scale which Professor Pickering handed me for use in Arizona) the confusion of the disk with the inner ring supplies the distinction between 6 and 8, but in the 6-inch which I had with me the disk ceased to be confused with the rings before the rings themselves became distinguishable, and this has been the almost constant experience since. Once or twice, late in the afternoon when the seeing was about to become exceptionally good I have seen the rings finely distinct in the 6-inch, and the disc now and then suddenly extend itself in some direction over upon them. If we find that this usually is associated with good seeing, it will be very important to hunt out all the places in the world where it occurs.

But while the perfection or universality of the scale may possibly be affected by certain changes in the character of the atmospheric currents it certainly does change markedly with alteration in the aperture of the lens. Not only is the figure denoting the seeing different but the very scale itself is altered. I was forced to this conclusion by observing that in an 18-inch, the pure form 4 on the 6-inch scale never occurred and that 6 was very rare; the seeing usually jumped from 2 to 8 or 8 to 2, while in the 24-inch the denoting of gradations by the state of the rings is almost impossible.

Below may be found a summary of the actual observations on comparison of scales and apertures. In parallel columns the corresponding figure in each scale for a given condition of the air is indicated by being on the same horizontal line. This is somewhat uncertain with regard to the 13-inch and the 18-inch but in the other cases is the mean result of direct comparisons.

The numbers in parentheses at the right of the seeing number indicates the number of direct comparisons with the 6-inch.

Eye. ¼-inch	1.6-inch	4-inch	6-inch	13-inch	18-inch	24-inch
1.7 (4) 33 twinkles in 10 sec.	7 (2) Disk well defined, rings not quite complete.	0 to 2 See paragraph foll. table.	0.0 Enlarged Mass	0 Enlarged mass	0 Enlarged mass	0 Enlarged mass
2.6 (6) 26 twink. in 10 sec.	9 (2) Image complete, rings not perfectly quiet.	3	1.0 Enlarging Mass	1 Enlarging mass	0	0
3.6 (4) 19 twink. in 10 sec.	9.4 (3) Perfect and rings nearly quiet.	3.8 (1) Bod. Mot. 7''.9	2.0	2	1	0

TABLE CONTINUED.

Eye. ¼-inch	1.6-Inch	4-inch	6-inch	13-inch	18-inch	24-inch
4.5 (4) 15 twink. in 10 sec.	10 (1) Image now shows only bodily motion no relative motion in its parts.	4.7 (1) Bod. Mot. 4''.0	3.0 Centralized Mass	3 Centralized mass	1	1 Enlarging mass
5.4 (7) 12 twink. in 10 sec.	10 (2)	5.6 (2) Bod. Mot. 2''.5	4.0 Disk perfect; rings confused	3	2 Confused mass	1
6.4 (9) 9 twink. in 10 sec.	10 (2)	6.3 (2) Bod. Mot. 1''.8	5.0 Disk perfect, rings rudimentary	3 and 5 Centralized mass, rings rudimentary	3 Centralized mass	2 Confused mass
7.2 (10) 6 twink. in 10 sec.	10 (2)	7.2 (1) Bod. Mot. 1''.3	6.0 Disk perfect, rings traceable	3 to 4, and 6 Disk traceable, rings traceable.	3 and 5 Centralized mass, rings rudimentary	2 to 3 (3) Rare centralization.
8.2 (11) 3 twink. in 10 sec.	10 (4)	8.0 (4) Bod. Mot. 1''.1	7.0 Disk perfect, rings not quite complete	3 to 4, and 6	3 to 4, and 6 Disk traceable, rings tracable.	2, 3 and 5 (3) Some centralization, rings rudimentary.
9.0 (2) 1 twink. in 10 sec.	10 (1)	8.8 (1) Bod. Mot. 1''.0	8.0 Disk perfect, rings complete but moving.	3 to 4, and 7 Disk traceable, rings not quite complete.	3 to 4, and 6	3 and 5 Centralized mass, rings rudimentary.
9.5 ½ twink. in 10 sec.	10	9.3	9.0 Disk perfect, rings complete and nearly quiet.	8 Disk perfect, rings complete but moving.	3 to 4, and 7 Disk traceable, rings not quite complete.	3 and 6 (1) Strong centralization, rings traceable.
10 No twink. in 10 sec.	10	10	10 0 Image perfect, no relative motion of parts.	9 and 10 Image perfect, little or no relative motion of parts.	8 and 10 Image more or less perfect, decreasing motion of parts.	4 to 10, 7 to 10 Image improving until perfect.

The columns above give the comparison of apertures reduced to uniformity; the actual results were plotted on squared paper and the values of the mean continuous curve were entered in the table. The only alterations from the observed values of any importance occur in the columns for the eye and the 4-inch; in fact these were the only ones that required actual plotting to get the mean values. The observed values for these apertures were as follows:

6-inch.	Eye.	4-inch.		″
0.0	1.5			
1.0	2.5			
2.0	4.0	3	Bodily Motion	7.9
3.0	4.5	5	" "	3.4
4.0	4.7	6.0	" "	2.8
5.0	6.4	6.5	" "	2.2
6.0	7.8	7	" "	1.1
7.0	8.2	7.8	" "	1.5
8.0	8.5	9	" "	0.9
9.0				
10.0				

The differences between these scales are described in more detail in the following paragraphs, and the causes of many of them are explained. The differences occur in the form of this image, the amount and velocity of its motions and its variations in brilliancy, or twinkling.

First, in regard to the form of the image. In a small telescope, as the seeing improves, the confused mass quickly becomes centralized and the disk appears distinct and separate from the constantly moving globules surrounding it. From these the rings subsequently emerge, first showing rudiments, then traceable, finally complete though still in motion. With a large aperture the centralization is not so rapid. In the confused moving mass rudiments of ring begin to float around a slightly brighter center. The center grows brighter and the rings become traceable but the disk does not appear until the rings are complete though still moving.

This difference I explain in the following way. The disk is illuminated by the whole lens, whether large or small; consequently in the case of a large lens, compared with which the "waves" in the air are sure to be small, the lens becomes divided, as it were, into many pieces and the disk becomes split up, distorted, refracted, that is, misplaced, and probably enlarged. So with a big lense the state of the air has to be very much better than with a small one for centralization or disk to become evident. But in the case of the rings, a portion of a ring large enough to be called a rudiment or even if it is so large that the ring may be called traceable, receives light from only a certain proportion of the lens. So as we change from a small to a large lens the increase of area illuminating the portion of the ring is not so great as that illuminating the disk, and therefore the portion of ring is by that much less likely to be split up into smaller pieces, distorted, refracted or enlarged by the air waves. With an aperture therefore very large in proportion to the mean size of the currents the rings, as the seeing improves, must begin to form before the disk tends to separate from them.

This theory explains why it happens that in a lens much larger than the atmospheric waves the rings begin to form before the disk but it does not explain why, when the lens is the same size as or little larger than the waves, the disk actually forms before the rings become rudimentary. I think this must be due to some relation between the angular size of the disk and the mean refractive power of the waves.

It is almost needless to add that this difference between apertures was discovered in 1894 but the explanation has been worked out only for the present paper.

Quantitative Relation Between Size of Waves, Aperture and Form of Stellar Image.

From observations begun in September 1894 I can go even into the quantitative relation between size of waves, aperture and scale. Atmospheric waves smaller than two-thirds of an inch or larger than four inches are very rare. Of those between these limits there is almost always present a set of waves over one inch apart; they are almost free from noticeable variations throughout considerable intervals in a given evening, if not for the whole night. There is usually also a very variable set of waves of less than one inch in size; they appear and disappear, come in sheets like the rippled surface of falling water, or they come slowly, with twists and turns and squirming. When the latter are visible and conspicuous they divide the lens into many minute elements and destroy the character of the image in the 24-inch and 6-inch but they have very little if any effect on the 1.6-inch. When these fine waves are absent or faint the spurious disk in the 6-inch may become good, but I never have seen it good in the 24-inch although the rings become quite traceable. I therefore draw the conclusion that when the waves are roughly greater than one-half of the lens in size they have little or no effect on the image; when they are less than one-half they begin to destroy the disk and when they are one-sixth or one-eighth or less they destroy the rings. The amount of damage to disk and rings is always of course directly proportioned to their conspicuousness; if they are sufficiently faint they may have no effect.

The measures of bodily motion in the 6-inch, 4-inch and 1.6-inch, tabulated on a subsequent page, show about the same motion in the smaller instrument for the same condition of the air, which is contrary to the theory explained in a former paper. This may be due to error of measurement because the motions were estimated by comparisons with the spurious disk whose diameter is inversely proportional to the aperture (but I suspect not the same in a very long focus)* and whose linear motions are proportioned to the focal length. Therefore with a small telescope its size is increased while its motion apparently becomes less. So on turning from a larger instrument one is liable to underestimate the amount of vibration.

It is possible, however, that this is not a complete explanation.

* A micrometric investigation of this subject will be published in a subsequent paper. From measures thus far made it appears that when the focus is extremely long in comparison with the aperture, the dimensions of the diffraction pattern agrees much more closely with theory (see Encyclopædia Brittanica, *subject*, Wave Theory) than in the usual ratio of focal length and aperture, for which Dawes' results, quoted in Young's Astronomy, are sufficiently accurate.

It is probable that the theory itself should be amplified and made to read in this way: Where the lens is very large in comparison with the atmospheric waves reducing the aperture will decrease the total confusion of detail, improve a stellar image and increase the bodily motion: but when the lens is only four or five times the size of the waves, reduction of aperture will probably decrease the confusion of detail, will certainly improve a stellar image but will have no marked effect on the bodily motions.

The motions in the smaller instrument are much slower than in the large. The explanation, which I have verified by trying the effect of diaphragms on the 24-inch telescope, is that the rapid dancing motion seen in the six-inch consists of a large slow motion with a very rapid vibratory motion superposed on it, giving a general effect of rapid motion, and that the latter is too fine to be visible in the small aperture and short focus of the little telescope.

Another difference is that the image from the smaller apertures is very apt to twinkle. At its worst the field is full of light and together with the image twinkles violently. As the seeing improves the disc first becomes steady—this is because it receives light from a greater area than equivalent portions of the rings, and the greater the area the less the twinkling as explained in a former publication on this subject early in 1895—and then the rings cease their changes of brilliancy and finally the field becomes quiet. The field light seems to be due to some certain state of air, for on some nights it is not visible in the 1.6-inch at any altitude and at other times it may even be seen in the 24-inch at low altitudes. It is very likely due to some fine current of great refractive power or to haze.

One more scale is mentioned above and therefore should receive notice here. It is the scale of twinkling. In forming this scale in practice, I first observed the extremes and then gradually applied numbers from 1 to 9 to be intermediate variations. Finally I applied Dr. See's admirable idea of counting the number of "twinkles" in ten seconds. I found that on my scale previously formed the following numbers represented the average:

Twinkling.	Seeing.	Average Number of Twinkles. Observed.	Adopted.
0	10		
1	9	1	1
2	8	4	4
3	7	8	7
4	6	8	10
5	5		13
6	4	14	17
7	3	23	23
8	2	30	30
9	1		40
10	0		

In the above table the number of twinkles includes both big and little. The small ones were estimated to be a loss of 5 to 15% of light and the big ones, from 20 to 70% and sometimes also a seeming complete disappearance. Only very bright stars should be used in estimating the twinkling as its violence seems much reduced on fainter stars on account of the greater difficulty in observing the smaller absolute changes. And in estimating the character of the night stars in the zenith only should be observed.

It will be noticed that the figures in the naked eye scale derived from the twinkling of stars, are almost exactly the same as those in the 4-inch telescope for the same condition of the air in the line of sight. It may be stated in general that if at any time a naked eye scale is formed independently and developed by practice, the aperture of a telescope which will give the same figure for the seeing under normal variations of seeing as found on the naked eye scale, may be taken as a quantitative measure of the average seeing at that place.

The researches which I have made upon this subject of atmospheric waves in the last four years enable me to summarize approximately the relation between aperture and seeing, or character of a stellar image, as follows:

Waves must be at least twice the diameter of the lens to produce twinkling.

Waves larger than the lens, down to $\frac{1}{3}$ of lens	produce bodily motion,	do not destroy disk,	do not destroy rings.
Waves $\frac{1}{3}$ to $\frac{1}{5}$ of lens	produce bodily motion,	destroy disk (but less so as the angular size of the disk is increased),	do not destroy rings.
Waves $\frac{1}{5}$ to $\frac{1}{8}$ of lens	do not produce bodily motion,	destroy disk,	do not destroy rings.
Waves less than $\frac{1}{8}$ of lens	do not produce bodily motion,	destroy disk,	destroy rings.

The visibility of fine planetary detail is more or less coexistant with the disk and rings.

Expressed in another way the above table becomes as follows:

Twinkling ceases when the waves become as small as twice the diameter of the lens; the disk is lost with waves one-third the size of the lens, or smaller; bodily motion is lost when the waves get as small as one-fifth of the lens and the rings disappear when the waves are one-eighth or smaller. The amount of destruction to the disk and rings depends always on the conspicuousness, that is, the refractive power of the waves.

The Dependence of Seeing on Zenith Distance.

In March and April 1894, I made tests of the atmosphere at different points in Arizona varying in elevation above sea level from 1100 to 8200 feet. The observations were 186 in number, 134 of these being means of ten readings; the means below include eighty-seven measures made at Tombstone, Tucson or Tempe, near Phoenix, at altitudes respectively of 4630, 2770 and 1360 feet, on eleven nights in all; twenty-nine, made at Prescott in three nights and sixty-one made at Flagstaff on twenty-one nights. The two latter were from elevations of 5700 and 6900 to 8200 feet respectively.

OBSERVATIONS IN 1894.

11 nights. 2700 feet. Mean elevation.			3 nights. 5700 feet. Mean elevation.			21 nights. 7400 feet. Mean elevation.		
Z. D.	Seeing.	No. Obs'ns	Z. D.	Seeing.	No Obs'ns.	Z. D.	Seeing.	No. Obs'ns.
16	7.3	7	14	6.4	4	19	6.1	3
24	6.1	40	23	5.8	6	25	6.6	33
34	5.8	18	33	6.0	10	32	7.2	12
44	5.9	10	45	6.2	4	43	6.1	7
53	4.9	7	55	2.0	3	55	7.5	2
64	4.6	5	60	4.1	2	64	6 0	4

Upon plotting these curves and comparing them with the normal Flagstaff curve given below, it will appear that the curve for the lowest elevation is, so far as it goes, almost identical with the normal, save that it begins at the zenith at about 6.7 instead of 7.0. This difference in favor of Flagstaff is probably too small since the normal curve was made in November, December and January, months usually worse than March and April the time of observation in southern Arizona. The normal curve therefore probably should begin at a point somewhat higher on the scale than 7.0. The observations made at Flagstaff in 1894 will do this if the poorer observations are discarded, the poorer observations being those in which the least range of zenith distance was observed. This correction brings the zenith seeing at Flagstaff up to 7.5 at closely the same season of the year when it was about 6.7 at Tombstone, Tucson and Tempe, and about 5.8 at Prescott.

The curve for Prescott is of a different character. The fact that the general seeing was poorer was easily explained as being due to the Bradshaw Mountains to the south and west of the city, and will be more fully discussed in a subsequent paper. But the average seeing was nearly constant out to zenith distance 45° and then fell off very rapidly.

In November and December, 1897, and in January of 1898, one or more series of observations was made on eighteen different nights usually for the special purpose of measuring the dependence of seeing on zenith distance. The results therefore are harmonious and instructive.

Upon constructing a curve for each night on which the series was sufficiently complete, three distinct types of curve appeared. In the first the seeing falls off at once on leaving the zenith; its decrease is almost proportional to the angular zenith distance. Such a curve was in one case obtained when the sky was covered with haze. The second type, which I call the normal, descends from, say, 8 to 7 in the first 30° and from 7 to 5 in the second. The third type shows no deterioration in seeing out to 45° or 50° and sometimes to about 70°, and then drops very rapidly. This I call the Prescott curve because it is precisely like the curve obtained there in 1894. It seems to have occurred chiefly when the atmospheric waves were especially coarse and conspicuous.

The whole collection of over one hundred and fifty complete estimates of seeing has also been arranged with reference to the value of seeing at the zenith for each night, or for each known alteration in the local conditions. It appears that the mean curve is of the same general form when the zenith seeing is 8, 7, 6, 5 and 2. Observations were made on one evening in the valley below the observatory where the zenith seeing was 0. In the tables below the means of all the observations in the 6-inch at the observatory are given, together with the results when the zenith seeing for the 6-inch was 0 and the means for the 4-inch. The mean vibratory motion of the image is given also both for the 6-inch and 4-inch, and finally the mean bodily motion of the image for each point on the 6-inch scale of seeing in each telescope and in the 1.6-inch finder. The values for the latter are somewhat uncertain owing to the difficulties of observation before mentioned.

6-inch observed means.				Continuous curve derived from preceding.		
Z. D.	Seeing.	Motion. ″	No. Obs'ns.	Z. D.	Seeing.	Motion, ″
6	7.6	1.0	11	0	7.0	1.0
14	6.8	1.1	12	10	6.9	1.1
25	6.0	1.5	9	20	6.7	1.3
35	6.2	1.4	13	30	6.4	1.4
44	6.0	1.9	17	40	6.1	1.6
55	5.6	1.6	15	50	5.7	1.8
65	4.5	2.5	17	60	5.1	2.2
74	3.6	4.4	14	70	4.2	3.5
83	1.2	6.5	17	80	2.2	5.7
				8.5	0.0	7.2

6-inch; observed zenith seeing 0.

Z. D.	Seeing.	Remarks.	Motion. ″	No. Obs'ns.
6	0	halo	3.8	1
22	0	halo	4.5	2
30	1.		5.2	1
45	—1	field hazy	6.8	1
58	0—		5.2	1
68	—1	halo and field full of light	7.5	1

4-inch; observed means.

Z. D.	Seeing.	Motion. ″	No.Obs'ns.
5	7.5	1.5	3
12	7.3	0.9	3
20			
34	6.8	1.1	4
46	6.6	1.2	4
54	6.2	1.8	3
62	6.0	1.7	1
74	2.8	4.5	4
82	1.5	6.8	2

SEEING AND BODILY MOTION.

Seeing in 6-inch.	Motion in 6 inch. Obs'd Means ″	No. Obs'ns	Derived Means ″	4-inch. Obs'd Means ″	No. Obsn's	Derived Means ″	1.6-inch. Obs'd Means ″	No. Obsn's	Derived Means ″
0	8.8	9	8.8	7.9	2	7.9	4.2	2	4.7(?)
1	5.9	9	6.2	4.8	6	5.3	3.2	2	4.7(?)
2	4.6	15	4.5	6.4	3	3.7	4.7	3	4.7
3	3.0	7	3.2	3.4	4	2.5	3.4	1	3.5
4	2.2	17	2.3	2.0	4	1.7	2.8	2	2.6
5	1.8	14	1.7	1.5	9	1.4	2.2	2	1.9
6	1.4	25	1.3	1.5	14	1.2	1.1	1	1.5
7	1.2	33	1.0	1.1	18	1.0	1.5	4	1.2
8	0.9	22	0.7	0.9	1	0.9	0.9	1	1.0
9	0.4	1	0.6			0.8			1.0
10			0.5			0.8			1.0

The apparent non-fulfillment of theory in the lack of marked increase of bodily motion in the smaller instrument has been discussed in a preceding page.

It would be very desirable to get similar series at sea-level in order to make comparisons with these. In fact such an investigation carried on at each large Observatory would, I fancy, be a revelation to many astronomers.

SPECIAL SCALES.

The primary basis of all special scales is the average range of seeing during the hours of actual or attempted work. To these various observed states of seeing the figures from 2 to 8 are naturally applied, leaving a number or two at each end to meet conditions rarely experienced. So, two results occur; first, as each place has its normal set of conditions it follows that different scales made at the same Observatory, will usually agree upon the figure for the seeing at any time and thus be largely interchangeable, so far as the class of work is at all similar in its requirements. Let me give an example. In our Flagstaff work Dr. See, using his scale on double stars, and I, using mine on Jupiter's satellites, record usually the very same figure; that is because we are both working only near the limits of vision. On leaving work, for instance he has often named the quality of seeing on his scale, and upon turning to the satellites I have exactly confirmed it. But the actual seeing denoted by the same figure, if in the lower part of the scale, is different; for his work is nearly always at low altitude and mine at high so that when I turn to his region of the sky I record a figure about two points below his for the same region. As the figures become higher in the scale and rarer in occurrence this absolute difference grows less and finally disappears. So our scales although agreeing, usually denote different seeing.

But if some one at the same place were taking meridian transits, or similar observations, his range of available seeing would be much greater; he could work under some conditions that would be prohibitory to us and his scale would be less rigid. So I say that for similar requirements scales at one Observatory will be almost exactly the same in figure, though they may not be at all the same in absolute value.

The second point follows from what has been said above, and is this: that the scale in use at a place, when expressed carefully in terms of the standard scale, becomes an index of the average character of the seeing in that place. This I have never tried but it is a logical conclusion. If, therefore, we can obtain from each Observatory merely the value of their figures of seeing expressed in the standard scale, we shall have a means of comparing directly the character of the atmosphere in different parts of the world and can draw inferences which will be of vast value in the selection of sites for future Observatories.

It is evident that a planet cannot be used in a standard scale because the seeing varies with the apparent size of the disc and of the detail upon it. Such scales however are in constant use because it is difficult to turn the telescope on anything standard like a bright star when one is very busy with planetary work. The proper method is to make a special comparison between the adopted scale after it has become well fixed and constant, and the standard. Some examples of special scales, three planetary and one stellar, in use at our own Observatory, are here given:

Scale on Mars, 10″ to 18″ in Diameter, 24-inch Telescope.

	(By Mr. Lowell.)	(By Mr. Douglass.)
0.	Image void of contour or detail.	Planet a blur, increased greatly in size, no detail.
1.	Limb moving, polar caps and dark areas alone recognizable, latter unstable.	Limb very bad, indefinite through 1″, seas visible and possibly whitening at poles.
2.	Limb steady, dark areas tolerably so, uncertain glimpses of canals.	Limb very bad, indefinite through ½″, first canals visible, as Ganges, Agathadaemon and Chrysorrhoas.
3.	Coarser canals as streaks; double canals as very broad ones.	Forked bay a little difficult.
4.	Coarser canals evident; double canals suspected.	Forked bay distinct.
5.	Coast lines absolutely sharp.	Outline of Sinus Sabaeus fairly dis-

6. Oases visible.
7. Finer detail tolerably distinct.
8. Double canals perfectly distinct.
9. All detail approaches steel engraving.
10. Image absolutely steady throughout.

tinct.

6. Glimpse Phison and Euphrates.
7. Phison and Euphrates distinct.
8. Glimpse Daix.
9. Daix Distinct.
10. Daix and oases and other canals perfectly distinct.

These scales were gradually developed and afterwards written out independently of each other and as the appearances of a star in the six-inch telescope has only recently been adopted as a standard, direct comparisons between these and a standard are mostly lacking. Yet individual comparisons have been made though not always recorded, and it is believed that these scales conform closely to the standard when the diameter of Mars is over 12″. As the diameter grows less these scales become more rigid, that is, for the same condition of atmosphere, a lower figure applies. For instance when the diameter of Mars is 6″ the seeing will be recorded lower by about two points on this scale of ten. Any one thoroughly acquainted with work on Mars under good atmospheric conditions will perceive that these scales are nearly identical.

The writer's scale on the satellites of Jupiter, observed with a 24-inch telescope, is even more rigid. The satellites are so small that the seeing has to be extremely good in order to do any work on them.

After the scale of seeing became fixed and then had received many direct comparisons with the standard it became evident that it was formed directly from experience in that particular work and depended on the customary qualities of the seeing during periods when the general atmospheric conditions warranted at least a test of the atmosphere; that was by no means a mere question of clouds, for many clear nights passed with only the briefest glimpse through the instrument, experience having shown that under conditions then present work was impossible.

The scale on these satellites, or especially on the third whose diameter is 1″·6, is as follows:

Standard 3 or less.	1.	Greatly enlarged in size, to 3″ or over, no detail.
Standard 4.	2.	Limb very hazy, very rare glimpses of most conspicuous markings by using power 500.
Standard 6.	3.	Diameters possible but of little value, occasional glimpses of detail in power 500 but drawings very unreliable.
Standard 7.	4.	Satellite fairly steady and limb quite distinct; sure of coarse detail in 500 and uncertain glimpses in 750.
Standard 8.	5.	
Standard 8 or 9.	6.	Fine for diameters; detail very distinct in 500 and can be studied to advantage in 750.
Standard 10.	8.	Detail distinct in 750 (these are dark lines estimated to be 1/20 of a second in width).
	10.	(Never seen).

Even with the slight difference in the diameters and brightness of the satellites, there is a difference in this scale. When the third satellite shows the seeing to be between 3 and 5 on its scale, the fourth satellite, which is of the same size but decidedly darker, is usually one point higher on the scale; and the first and second, which are about 1″.0 and 0″.8 respectively, in diameter and a trifle brighter are about one point lower on the scale. In other parts of the scale they all agree.

It is very likely that in fixing this scale the figures in use on Mars were followed. Both for Mars and the satellites 4 is the turning point between profitable and unprofitable seeing; or at least between poor and good seeing, for with persistance seeing below 4 may become profitable.

Dr. See defines the scale for double star work used by himself and Mr. Cogshall in the 24-inch telescope as follows:

0. Light of the star spread all over the field, or expanding and contracting violently.

1. Image greatly agitated, expanding and contracting; perhaps on the average 5″ in diameter (for 6th mag. star,) rays and fringes from 5″ to 10″ long.

2. Image blurred, less motion, but numerous short fringes, no possibility of seeing a close unequal companion, say the 11th magnitude and distance 1″.5, for 6th magnitude star.

3. Image blurred, only slightly agitated but surrounded by short fringes; no sharp definition of the central part, and some faint light still diffused about the image.

4. Image still blurred, scarcely any diffused light or rays, but central disk indistinct.

5. Central disk fairly distinct, no diffused light, only very short fringes, but these moving constantly.

6. Central disk distinct, short fringes in gentle motion; easy to see an equal double separated by 0″.3.

7. Central disk sharp, fringes short and almost motionless; easy to see parallel fringes of an equal double separated by 0″.25.

8. Perfect central image; diffraction rings and fringes seen in gentle motion, will separate an equal double at a distance of 0″.25.

9. Diffraction fringes numerous and almost motionless; easy to see the closest double separable by the telescope (unless very unequal).

10. Diffraction rings and fringes perfect and motionless (never realized for any length of time).

I hope many astronomers will see the wisdom of comparing their special scales in constant use with the standard scale, now for the first time fully discussed, or of determining the mean value of the seeing at different zenith distances in terms of the standard scale or at least of discovering the aperture of a lens which by the form of its stellar image will give the same figure for the seeing as obtained from well-practiced observations of twinkling. And I hope thev will speedily publish such comparisons; for everyone will be interested in them because the excellence of any region in the most delicate astronomical work will thus be revealed with absolute impartiality.

LOWELL OBSERVATORY, Flagstaff, Arizona.
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