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ON THE LIMITS OF UNAIDED VISION

It is generally stated that stars of the sixth magnitude are as faint as can readily be seen by the unaided eye, though it is well known that under conditions of exceptional clearness favorably placed stars from a half to a whole magnitude fainter can be made out. That the sixth magnitude is, for all practical purposes, the boundary between the visible and the invisible for the unaided eye is well seen from a brief study of the faintest stars included in the various star catalogues and Uranometriæ devoted to naked-eye stars. The mean magnitude of the faintest stars included in Ptolemy's *Almagest* is 5.38 M. on the scale of the Harvard Photometric Durchmusterung (these averages are taken from H. C. O. Annals, Vol. XIV, Part II). In the case of Sûfi it is 5.64 M.

In the case of the more modern catalogues of naked-eye stars Argelander states in his introduction to the *Uranometria Nova*, "Ich habe hierbei die üblichen sechs Classen angenommen, indem ich die schwächsten meinem Auge noch erkennbaren Sterne zur sechsten Classe rechne. Mein Auge ist von mittlerer Schärfe; ein schwächeres wird die kleinern meiner Sterne sechster Grosse nicht sehen, ein schärferes hingegen manche erkennen, die mir unsichtbar blieben." A count (H. C. O. Annals, loc. cit.) of all the stars of his faintest class, the sixth, averages 5.74 M.

Heis, in his *Atlas Coelestis Novus*, includes over fourteen hundred more stars than did Argelander, and many of these are somewhat fainter than the faintest observed by Argelander. Heis's sixth magnitude averages 5.84 M. on the Harvard Scale and his faintest class, marked 6.7, averages 6.06 M. Houzeau in his *Uranométrie Générale* (*Annales de l'Observatoire Royal de Bruxelles*, T. I.) writes as follows of the limit of vision for his faintest class: "J'ai regardé comme appartenant à la 6^me grandeur (entière) ceux des astres qui, dans les circonstances ordinaires,

restaient visibles à peu près constamment; tandis que j'ai affecté du chiffre 6.7 ceux qui disparaissaient par intervalles." Houzeau's class 6.7 M. average 6.40 M. on the Harvard scale.

Gould, in the Introduction to the great *Uranometria Argentina*, page 6, writes, "A very large number of our faint stars had been noted by Lacaille as of the seventh magnitude, this being the lowest which he assigned to any star observed with his little telescope of half an inch aperture. Many of them were called 7.5 M. and some even 8 M. by Taylor, Lalande, and in the Brisbane catalogue; yet I was disinclined to believe that stars fainter than the magnitude 6.5, at the farthest, could really be seen with ease by the naked eye. Under this impression I had fixed upon 6.5 as the average limit when the sky was exceptionally favorable. . . . many circumstances having combined to throw doubt upon the correctness of these estimates, I entered upon an elaborate investigation of the matter by comparison of our values for faint stars with those given by other observers. . . . There now appears no room for doubt that, in the most favorable nights, stars of the 7.0 M. are easily seen at Cordoba by persons of ordinarily good vision; while in Albany I fixed upon 6.2 as the corresponding limit. Such nights are not frequent, it is true, but as the observatory is situated nearly 446 meters above the sea, the quantity of atmosphere above it is less, by more than its twentieth part, than that over the level of the ocean; while the atmosphere itself is, at certain times, of an exceptional transparency." That these conclusions are due only in very slight measure to an enhanced scale of star magnitudes is shown by the following comparison of the magnitudes from 6.0 to 7.4 with their mean magnitude on the Harvard scale.

Cordoba Magn.	Harvard Scale.
6.0	5.76
6.1	5.86
6.2	5.90
6.3	5.96
6.4	6.08
6.5	6.16
6.6	6.27
6.7	6.30
6.8	6.51
6.9	6.60
7.0	6.71
7.1	6.95
7.4	7.20

For the sake of comparison a similar table is given for those magnitudes of the Bonn Durchmusterung which are near the limit of visibility.

DM. Magn.	Harvard Scale.
6.0	5.85
6.5	5.81
6.8	6.32
7.0	6.39

Closely allied to the question of the faintest star visible to the naked eye is that of the ability to resolve close celestial objects. The quadruple ϵ Lyrae is a good example, as most normal eyes can see it double, its components being about three minutes of arc apart. Under this head come also the various cases, for the greater part unauthenticated, where persons claim to have seen Venus as a crescent or to have plotted the positions of the satellites of Jupiter with the unaided eye. These are rather due to the resolving power of the human eye, however, and are in the domain of physiological optics.

A portion of the difficulty in perceiving stars fainter than the sixth magnitude would undoubtedly be removed if in each trial the position of the star could be accurately known. Any one who has tried to pick up the planet Venus in the day time, or to see an object at the limit of visibility in a telescope, has experienced this and found that such an object seems to be comparatively easily seen when once found. If the eye is allowed to wander for an instant, however, it may be impossible to find the object again.

Another difficulty arises from the fact that the background of the sky is by no means perfectly dark; even in regions well removed from the Milky Way the diffused light of the sky is considerable. In the *Astrophysical Journal* for December, 1901, Professor Simon Newcomb has given the results of some visual attempts to determine the relative brightness of different parts of the sky. He finds here that the amount of light from a disk of non-galactic sky 12' in diameter is somewhat less than that given by a star of the eighth magnitude, and reaches the conclusion that were the light of the sky reduced to one-sixth of its normal brightness a star of magnitude 7.2 would be visible to his eye. These results have been confirmed by Dr. S. D. Townley, who last summer at the Lick

Observatory applied photographic methods to the solution of the same problem (*Pub. A.S.P.*, No. 88). His results indicate a slightly greater degree of brightness for the non-galactic sky. Compare also an article by G. J. Burns in the *Astrophysical Journal*, October, 1902.

At Professor Newcomb's suggestion Director Campbell has asked me to find my limit of naked-eye vision, having given as artificial aids the direction in which the object lies and the screening off of the light of the sky.

Two blackened screens were attached to the twelve-inch telescope at a distance apart of 178 inches. The rear screen was provided with an aperture half an inch in diameter. The screen at the object glass was pierced with apertures of half an inch and one inch, either of which could be used. Both of these apertures were at once found to be too large and the size of the screen too small, so that the light of the background of the sky interfered seriously with seeing objects at the limit of visibility. A larger screen having an aperture of about one quarter of an inch was substituted and gave satisfaction. The apertures were so aligned that when a star was seen centrally placed it would be found at the intersection of the cross-wires of the three-inch finder. A movement of two or three minutes of arc was sufficient to carry a star out of the field of view thus formed.

The following plan of observation was adopted: The telescope was clamped at the correct declination for the star selected. The telescope was then swept very slowly in right ascension with the eye at the aperture in the effort to pick up the star. When the star was seen through the apertures its position was noted in the finder, and if not more than a minute or two of arc from the intersection of the cross-wires the observation was considered successful. These trials were repeated a number of times for each star. In no case was a failure recorded for the brighter stars in the subjoined list. For the fainter stars occasional failures were experienced, generally when the eye was tired from the strain incurred in searching for these very faint objects.

Several stars in the region T Virginis were observed on three nights of which the first two were rather poor, the sky being somewhat hazy. On the third night, while the seeing was only fair as judged with the twelve-inch, the sky was very clear and a star of magnitude 6.53 was seen with the naked eye, unaided by the apertures. On the third evening several stars were observed as well in the region T Ursæ Majoris. The magnitudes of the brighter stars were taken from the Harvard Photometric Durchmusterung (HP.); in the case of the fainter stars from Hagen's *Atlas Stellarum Variabilium* (H.).

D.M.	1900		δ	Magn.
	α			
3219	12 ^h	4 ^m 7	- 4° 40'	7.31 HP.
3235		9.2	5 10	6.52 HP.
3332		10.0	6 42	7.42 HP.
3459		10.4	5 23	8.3 H.
3463		10.8	5 37	8.1 H.
3465		11.3	5 18	8.0 H.
3487		18.3	5 34	7.20 HP.
1413	12	34.8	+60 18	8.3 H.
1415		35.9	13	8.5 H.
1416		35.9	4	8.1 H.
1457		36.8	59 30	8.2 H.

NOTES.

Seen quite easily.
 Very easily seen through apertures. Could glimpse easily with the naked eye.
 Seen easily.
 Seen with considerable difficulty; perhaps one-fifth of trials failed.
 Seen without difficulty on last two nights.
 Seen easily on last two nights; with some difficulty on first.
 Seen easily.
 Seen with difficulty.
 Glimpsed at intervals; very doubtful.
 Seen; one or two failures.
 Seen.

During the past two years I have had occasion to measure photometrically stars of the fifteenth and sixteenth magnitudes. These faint objects were frequently at the extreme limit of perception with apertures of twenty-six and thirty-six inches respectively. I am inclined to think that the observation of stars of the eighth magnitude or slightly fainter is fully as difficult, and would be in fact impossible for the eye unaided by such helps as to direction of vision and screening off of all extraneous light as were afforded by the use of the apertures. The contrast between

the almost perfect darkness of the object-glass screen and the light of the sky immediately around it as seen through the rear aperture is very marked and it seems evident that, for the purpose of detecting stars so faint with the unaided eye, the screening off of the light of the sky is more important than the concentration of the vision in the definite direction afforded by the apertures.

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