SEEING EFFECTS ON OCCULTATION CURVES

A. T. YOUNG

Jet Propulsion Laboratory, California Institute of Technology, Calif., U.S.A.

'Seeing' affects the light-curve of a stellar occultation by the Moon in two ways: the diffraction pattern on the ground is *smeared out* by atmospheric turbulence, and the pattern also suffers *random displacements*. These effects are analogous to the familiar *image blur* and *image motion*, respectively. However, there is a major difference between ordinary astronomical seeing and the effect on the lunar diffraction pattern: the former is the seeing looking up at the sky from the bottom of the atmosphere, but the latter corresponds to the seeing looking down through the atmosphere at the surface of the Earth.

This downward-looking seeing is of concern to people engaged in aerial photography and satellite reconnaissance, and has been studied theoretically from this point of view [1, 2]. It also enters into the theory of stellar scintillation [3–5], because the seeing blurs out the scintillation shadow pattern just as it blurs out the occultation diffraction pattern.

The theoretical studies of Fried [1] and Hulett [2] indicate that the linear size of the downward-looking seeing disk on the ground grows nearly linearly with height above the ground; that is, the *angular* size of this seeing disk is nearly constant, up to heights of some tens of kilometers. Because of this constant *angular* size, the effect on scintillation is to make a star scintillate like a planet of small angular diameter [3]. For vertical propagation, Fried's values [1] give an angular size near 1.0 sec of arc; Hulett's revision [2] of Fried's work gives about 0.05 sec. The scintillation data [3, 5] give values on the order of 0.2–0.4 sec of arc, depending on the adopted scale height of the atmospheric turbulence. This corresponds to a linear blur on the ground of about 2 cm, if we assume the seeing levels off at 10–20 km heights; Fried's limiting value was about 5 cm and Hulett's was 1.5 cm. Thus all these studies agree that the blur amounts to a few centimeters for a star in the zenith.

The variation of angular seeing with zenith distance is usually supposed to be $(\sec z)^{1/2}$. Irwin [6] found an exponent closer to 0.4; on the other hand, Fried's theory [7] leads to an exponent of 0.6. In any case, the square-root law is not far from the truth. However, the *linear* size of the blur is the product of the angular blur and the slant range, which is proportional to air mass. Thus the *linear* blur must grow approximately as $(\sec z)^{3/2}$.

The scintillation noise amplitude also grows approximately as the $\frac{3}{2}$ power of the zenith distance for moderately large apertures [4]. This rapid increase in scintillation noise makes observations unattractive at sec z greater than about 2, where $(\sec z)^{3/2} = 2.8$. Thus, for most observations, the seeing blur will not exceed 8–10 cm. To a crude approximation, we may regard the effect of seeing as increasing the telescope aperture by this amount. In general, the photon and scintillation noise require the

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use of apertures some tens of centimeters in diameter at least, so the additional seeing blur of a few centimeters is negligible.

The above estimates include the effects of both instantaneous blur and image motion or distortion. The latter effect causes phase distortion by randomly displacing the fringes on the ground. However, it is a relatively minor effect in actual practice, because the Moon's motion sweeps the pattern across the telescope aperture at a much higher rate than the wind speed; thus the entire fringe pattern is recorded before the motion of the atmosphere can change the displacement appreciably at the telescope.

The limitation on angular resolution imposed by this seeing effect is readily calculated from the following consideration. In principle, the Fresnel diffraction pattern of the Moon's shadow contains the same angular information on the source as could be obtained from a diffraction-limited telescope aperture the size of the Moon. As the Moon subtends $\frac{1}{100}$ of a radian, the finest fringes in the pattern are about 100 wavelengths (say 50 μ) across; at the distance of the Moon this subtends an angle just over 10^{-13} rad or about 3×10^{-8} sec of arc (a similar figure is given by $\lambda / D_{\mathrm{Moon}}$). However, the seeing blurs out all fringes smaller than a few centimeters across; at the distance of the Moon, this distance subtends about 10^{-10} rad (2×10^{-5} sec of arc), and this is the seeing-limited resolution that can be extracted from occultation data.

As a practical matter, we cannot expect to see fringes as fine as 10 cm, for these have a visibility of only one or two percent, even for a point source. Thus the seeing only wipes out fringes too small to be observed anyway.

We may safely regard seeing effects as negligible.

References

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