THE DETERMINATION OF THE VIGNETTING FUNCTION OF A SCHMIDT TELESCOPE

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ABSTRACT

Observational and geometric approaches to the problem of determining the vignetting function are discussed. A simple technique for producing a "flat-field" is described, and the various uses of such a flat-field to investigate the photometric accuracy and sensitivity of different emulsions are discussed.

INTRODUCTION

A necessary compromise in the construction of many wide-angle Schmidt telescopes is the presence of weak vignetting in the outermost portions of the field. However, in order for the full area of wide-angle plates to be of value for such problems as number counts of galaxies, photographic photometry to the plate edge, etc., it is essential that the effect of vignetting is known quantitatively.

There are two simple approaches to this problem. The first is theoretical, and involves ray-tracing through the appropriate geometry of the telescope. The second is empirical, and necessitates the imaging of a "flat-field", extended source onto the focal plane. A third method, which requires the extraction of the stellar background from real sky plates (Campbell, 1982; Dawe, 1983), is fraught with difficulties, but may be used as a check on the other two.

GEOMETRICAL APPROACH

Any parallel, on-axis beam of light entering the telescope corrector will encounter obstructions within the tube, e.g. the plate-holder support and spider, sensitometers, cables, etc. These restrict the amount of light intercepted by the mirror and place an upper limit on the effective aperture of the telescope.

M. Capaccioli (ed.), Astronomy with Schmidt-Type Telescopes, 193–196.

An off-axis beam will encounter not only these obstructions but, if it exceeds a critical angle θ_c, will not be intercepted by the mirror over its entire cross-section. From a consideration of the geometry in Figure 1:

$$\theta_c=\arctan[(R-r)/2f] \qquad (1)$$

(For the UKST, $\theta_c=2^{\circ}\!.7$.) Thus, geometric optics predicts that the onset of vignetting is discontinous and that, for angles $\theta<\theta_c$, there should be no vignetting.

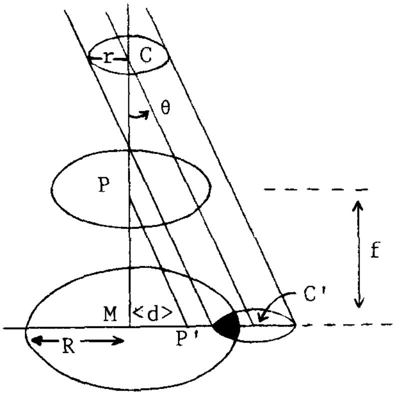

Figure 1. Vignetting geometry.

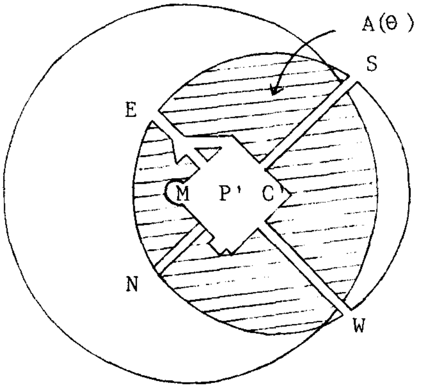

Figure 2. Mirror area intercepted.

A simple graphical method may be used to compute geometrical vignetting, making due allowance for internal obstructions and, in particular, asymmetric ones. On three separate pieces of tracing paper draw cross-sections of (1) the corrector, (2) the spider together with all associated equipment, and (3) the mirror, including the central hole if this exists. The vignetting, for a given angle θ, may now be derived by spacing the centres of the corrector and mirror sheets at equal and opposite distances, d, from the plateholder centre, P, where:

$$d=f\tan(\theta) \qquad (2)$$

The line passing through the three centres, M, P' and C', will define the position angle over which the vignetting function is being sought. Figure 2 shows the result for $\theta=3^{\circ}\!.8$ in the UKST, taken along a position angle of 45°. By definition, the equivalent magnitude change brought about by vignetting, is:

$$\Delta m(\theta)=-2.5\log[A(\theta)/A(0^{\circ})] \qquad (3)$$

where $A(\theta)$=mirror area intercepted by a beam at angle θ. This function is illustrated in Figure 3.

EMPIRICAL APPROACH

A "flat-field" source may be provided for a Schmidt optical system by placing a back-illuminated, diffuse screen in contact with the corrector. In its simplest form, this can be a linen sheet stretched tightly across the entrance aperture of the telescope. The sheet should be indirectly illuminated by another diffuse screen, which in turn is symmetrically illuminated by a low-wattage lamp. The warp and weft of the linen define a large number of pin-holes at the centre of curvature of the mirror. These act as Lambertian scatterers of the incident radiation, providing a near-uniform illumination of the focal plane.

To determine the intrinsic vignetting function, a short exposure plate is taken of the flat-field source, together with appropriate sensitometry to determine the characteristic curve of the emulsion. Measurements of the density, at a grid of points on the plate, are made with a densitometer and converted into measurements of relative intensity, as a function of position in the field.

In the case of the UKST, departures from circular symmetry lie below the available accuracy of density measurement (i.e. <0.01 equivalent magnitudes). This is consistent with the predictions of the geometrical approach. The empirical mean vignetting curve, averaged over a number of concentric zones corresponding to various values of θ, is also shown in Figure 3.

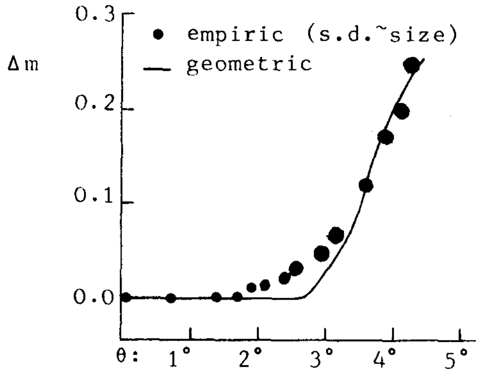

Figure 3. Vignetting function for UKST.

DISCUSSION

It is apparent, from Figure 3, that:

(a) the vignetting appears to commence at angles $<\theta_c (=2.^\circ7)$,

(b) although the two vignetting functions agree at the plate centre and edge, there is a zone, defined by $1\overset{\circ}{.}7<\Theta<3\overset{\circ}{.}5$, where the geometric and empirical curves deviate from one another by up to 0.03 equivalent magnitudes.

Experiments with KODAK plates show that something like 25% of the light incident on a plate is reflected or scattered back. A simple analysis of this scattering problem is not possible here, but considerations of the fraction of this light, returned to the focal plane by the corrector and screen, lead us to suppose that it could account for a difference of up to $0\overset{m}{.}07$ between the two curves. That the observed difference is much less than this, and only occurs over a restricted range of Θ, may arise from the complex scattering functions of the plate and corrector.

Unfortunately, because the presence of the diffuse screen is required for the "flat-field" approach and this also backscatters light, the resultant effective vignetting curve differs from that experienced by real-sky plates. However, the mean of the geometric and empirical curves is probably a fair approximation to the true effective vignetting curve. (For the UKST, it is known to be consistent with the vignetting, at the (Θ=2°) zone, derived from real-sky plates (Dawe et al., (1983)).

Once the vignetting function is known, it is then possible to investigate the intrinsic uniformity of photographic plates. This is particularly important for hypersensitized emulsions, which are known to lose sensitivity on exposure to moist air. Such studies have been carried out by Dawe and Metcalfe (1982), and Dawe et al. (loc.cit.), and have shown that point-to-point variations in the sensitivity of the IIIa-J emulsion lie below the range ±0.01 equivalent magnitudes, provided that it is kept in dry nitrogen. However, exposure to ambient air (even at a humidity as low as 45%) can increase this variation to ±0.04 equivalent magnitudes, as well as leading to larger-scale variations over substantial regions of the plate (typically 0.04 equivalent magnitudes over 2° on an UKST plate).

REFERENCES

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