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THE PROFILE OF A STAR IMAGE

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Various data are assembled to construct the profile of a star image, from its central peak out to a radius of six degrees. The profile has a central core, an exponential drop, and an extended inverse-square aureole. The origin of its shape is not well understood.

Key word: star image profile

The telescopic image of a star is much larger than the theoretical diffraction pattern of the objective. Its profile is determined by various phenomena of atmospheric refraction and both atmospheric and instrumental diffraction and scattering. Although several partial profiles are available in the astronomical literature (van de Hulst 1952; de Vaucouleurs 1948, 1958; King and Hinrichs 1967; Moffat 1969), a complete star-image profile seems to be lacking. Data are therefore collected in the present paper.

In Figure 1 is given a composite profile of a star image. The ordinate, as given by the left-hand scale, is the surface brightness in the image of a star of magnitude zero, stated as a magnitude per square second of arc. The data come from four sources, as follow.

(1) The points at smallest values of r come from microphotometer tracings of three star images on a blue-sensitive plate taken in good seeing at the Cassegrain focus of the Mount Wilson 60-inch reflector. On this large-scale plate the smallest star images are more than 100 microns in diameter, while the tracing was done with a 30-micron spot. Sensitometer spots were used to reduce the tracings to an intensity scale and subtract the sky brightness. The three curves were scaled to a common intensity and combined, and the resulting curve was then normalized by performing a numerical integration of the brightness distribution.

(2) Points covering a large range of r were derived by measuring the diameters of star images on the blue reproductions of the National Geographic-Palomar Observatory Sky Survey (POSS). The diameters were measured by eye with hand-held reticle magnifiers, with every effort made to measure all diameters at the same level of image blackening. The intensity corresponding to this degree of blackening was estimated by measuring diameters in the same way for two elliptical galaxies. Their profiles had been determined photographically by the writer in the course of a galaxy-photometry project for which results will be published elsewhere. The fainter stars measured on the POSS are those of the north polar sequence, while the brighter stars are in various other parts of the sky. The brightest is Sirius.

(3) The straight line is taken from de Vaucouleurs (1958), whose data fit the line so well that it would be superfluous to plot the individual points. The outer two-thirds of his line comes from his own blue photoelectric measures on a second-magnitude star and on Jupiter, while the inner third results from his rediscussion of data by Redman and Shirley (1938).

(4) The two outermost points come from a summary by van de Hulst (1952) of various measurements of the brightness of clear sky near the sun. These data have been reduced in Figure 1 to the same zero point as the other data.

The data presented here, from quite diverse sources, have all been normalized to represent a star of a single magnitude, but no other adjustment has been made to fit them together. The agreement is striking. No doubt a closer examination will disclose differences that depend on the instrument and its condition, the site, and the weather; but the curve in Figure 1 should serve as a first approximation to star-image profiles in general.

The basic profile has three parts. In the center is a nearly uniform disk, which is surrounded by a region of steeply falling brightness. In this one

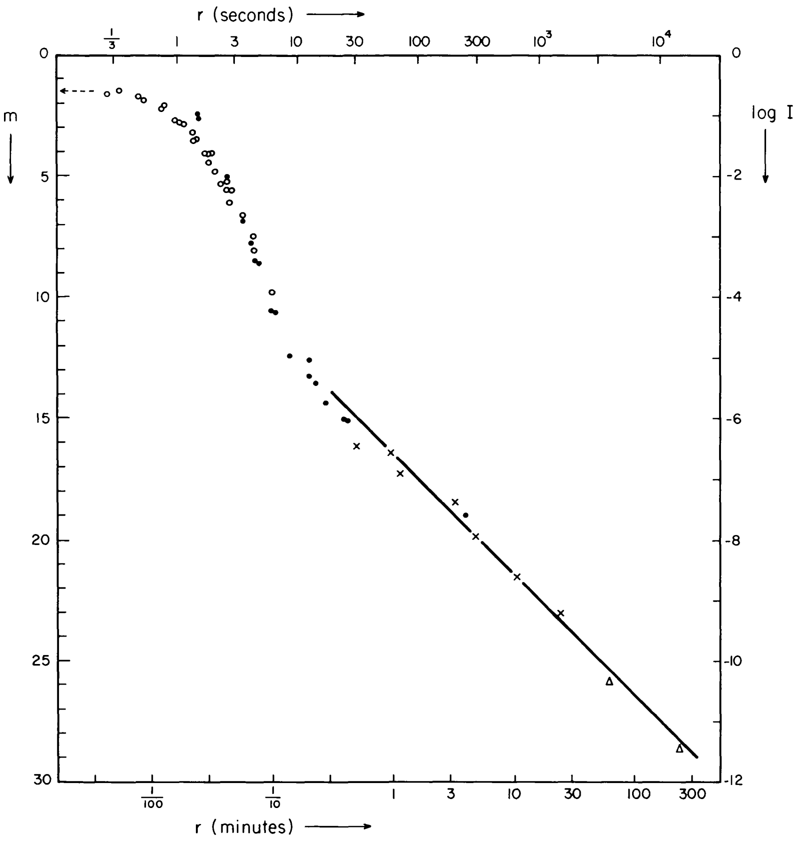

FIG. 1 — Surface brightness, in magnitude per square second, in the image of a star of magnitude zero. Open circles are derived from 60-inch Cassegrain images, closed circles from diameters of NPS stars on the Palomar Observatory Sky Survey (POSS), and crosses from other stars on POSS. Straight line is inverse-square law found by de Vaucouleurs. Triangles are from sky brightness near the sun.

respect the profile clearly depends on the circumstances, for the smallness of this disk determines the resolving power of the telescope; the size of the disk expresses seeing, telescope aberrations, etc. (In Figure 1 the two highest POSS points are probably an example of this variation since they are at a radius comparable to the resolving power of the 48-inch Schmidt plates.) The seeing disk and the initial turndown of the profile are well represented by a Gaussian curve, but over this small range of brightness many other formulas would represent the profile equally well. A steep drop follows, but it is not as steep as the fall-off of a Gaussian curve. An exponential drop represents this part of the curve quite closely. Finally the slope moderates abruptly into an inverse-square law that is closely followed over a factor of 1000 in angular distance. Integration shows that the inverse-square halo, which has sometimes been called the aureole, contains about five percent of the star's light.

The physical origin of these separate parts of the profile is not clear. Theories of atmospheric seeing exist (Stock and Keller 1960) but they do not seem to predict the mathematical shape of any except the small Gaussian part of the curve. On small-scale plates an exponential drop can be due to scattering of light in the photographic emulsion (Moffat 1969), but such scattering has far too short a range to explain the exponential part of the profiles of images made at the Cassegrain focus of the 60-inch reflector. The long inverse-square slope of the aureole is a particular puzzle. Van de Hulst (1952) suggests scattering by small atmospheric particles or small scratches in the telescope, but it seems implausible that the size distribution would be such as to give exactly a -2 power.

The extended profile of a star image is of importance for double-star observers and observers of planetary satellites, for whom it is a nuisance; but it is a benefit for photographic photometry of stars, which the law of image growth makes possible. An iris photometer is basically an image-diameter gauge, and indeed attempts have been made to predict calibration curves (Moffat

1969) and even to determine magnitudes by direct linear measures of image diameters (Perek 1958; Pěkný 1958; Bajcar 1960). For such applications it is clearly desirable to investigate the dependence of the image profile on observing conditions and to understand its fundamental origin.

REFERENCES

Bajcar, R. 1960, *B.A.C.* **11**, 204.

Hulst, H. C. van de. 1952, in *The Atmospheres of the Earth and Planets,* rev. ed., G. P. Kuiper, ed. (Chicago: University of Chicago Press) p. 69.

King, I. R., and Hinrichs, E. L. 1967, *Pub. A.S.P.* **79**, 226.

Moffat, A. F. J. 1969, *Astr. and Ap.* **3**, 455.

Pěkný, Z. 1958, *B.A.C.* **9**, 164.

Perek, L. 1958, *B.A.C.* **9**, 39.

Redman, R. O., and Shirley, E. G. 1938, *M.N.R.A.S.* **98**, 613.

Stock, J., and Keller, G. 1960, in *Telescopes,* G. P. Kuiper and B. M. Middlehurst, eds. (Chicago: University of Chicago Press), p. 138.

Vaucouleurs, G. de 1948, *Ann. d'Ap.* **11**, 247.

—— 1958, *Ap. J.* **128**, 465 (Appendix II).