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A SIMPLE OBJECTIVE TRANSMISSION GRATING FOR THE PALOMAR 48-INCH SCHMIDT

ARTHUR H. VAUGHAN, JR.
Hale Observatories
Carnegie Institution of Washington
California Institute of Technology

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The properties and possible applications of amplitude gratings which consist of alternate transparent and opaque stripes ruled on thin transparent plastic film are described and illustrated.

I. Introduction

The purpose of this report is to describe the properties and possible applications of crude objective gratings for coarse classification of spectra with a large Schmidt telescope. Some time ago, it was noticed that the thinnest commercially available grades of transparent Mylar polyester film* possess a remarkable optical uniformity, such that a single flat layer of the film stretched and mounted in front of a telescope objective would not degrade the images by more than 1″ to 2″, which is the limiting star-image size on the Palomar 48-inch Schmidt. The film is, moreover, sufficiently strong and durable that large pieces can be so mounted, without the need of a rigid glass backing. The possibility of producing simple, unblazed, amplitude gratings with this material was therefore investigated. Previous experiments concerned with the development of blazed or "echellette"-type objective gratings have been reported by Zwicky (1941, 1957).

II. The Gratings

Amplitude gratings, consisting of alternate transparent and opaque stripes of about 3 lines/mm, were ruled with opaque ink in the form of a screw thread or helix on ¼-mil (= 6 micron) Mylar film, the latter being fixed upon the surface of a cylinder in a lathe. The ruled film is then spread flat, stretched by a slight amount as uniformly as possible, and cemented to a lightweight aluminum hoop for mounting in front of the telescope. Initial tests showed

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*Produced by E. I. Du Pont de Nemours Company (Inc.).

that in order not to sacrifice spectral resolution it would be necessary to put the rulings at right angles to a predominantly linear pattern of thickness variations ($\sim$ 10%) that seem to be characteristic of Mylar and are the primary cause of wave-front distortion for normally incident light. The ruling was done by means of a draftsman's ruling pen equipped with an ink reservoir. The standard pen blades can be selected or lapped to produce a line of any desired width greater than about 0.1 mm. With care to eliminate dust, fingerprints, and electrostatic effects, nearly flawless amplitude gratings can be mass-produced in this way.

It is shown in standard optics textbooks (cf., Ditchburn 1963) that in an amplitude grating the monochromatic intensity of a principal maximum of order m is given by

$$I_m = I_0 \frac{\sin^2(\pi ma/d)}{(\pi ma/d)^2} \tag{1}$$

where a is the width of the transparent slits in the grating and d is their separation. The *efficiency* E_1, defined as the ratio of the energy transmitted in *one* of the two spectra of order $m = 1$ to the total transmitted energy, at a given wavelength, is evidently

$$E_1 = \frac{I_1}{I_0 + 2 \sum_{m=1}^{n} I_m} \quad , \qquad n \rightarrow \infty \quad . \tag{2}$$

From equation (1), it is seen that the intensities of all even orders are zero if $a/d = 0.5$. (There is no value of a/d, other than 0 or 1, for which all odd orders vanish.) A plot of E_1 vs. a/d, calculated to $n = 100$ from equation (2), in Figure 1 (A), shows that the first-order efficiency has a maximum value of about 23 percent when $a/d \approx 0.37$. Since it is also desirable not only to achieve the best available efficiency, but to reduce the intensities of extraneous second-order spectra as well, a compromise of $a/d \approx 0.45$ has been adopted.* In Figure 1 (B) we plot the resulting theoretical limiting magnitude for unwidened spectra as a function of spectrum length (= bandwidth ÷ dispersion) for the 48-inch; a limiting magnitude of 21 and image size of 0.03 mm for this telescope without the grating has been assumed (Bowen 1962).

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*The ratio a/d is also, obviously, the average transmittance.

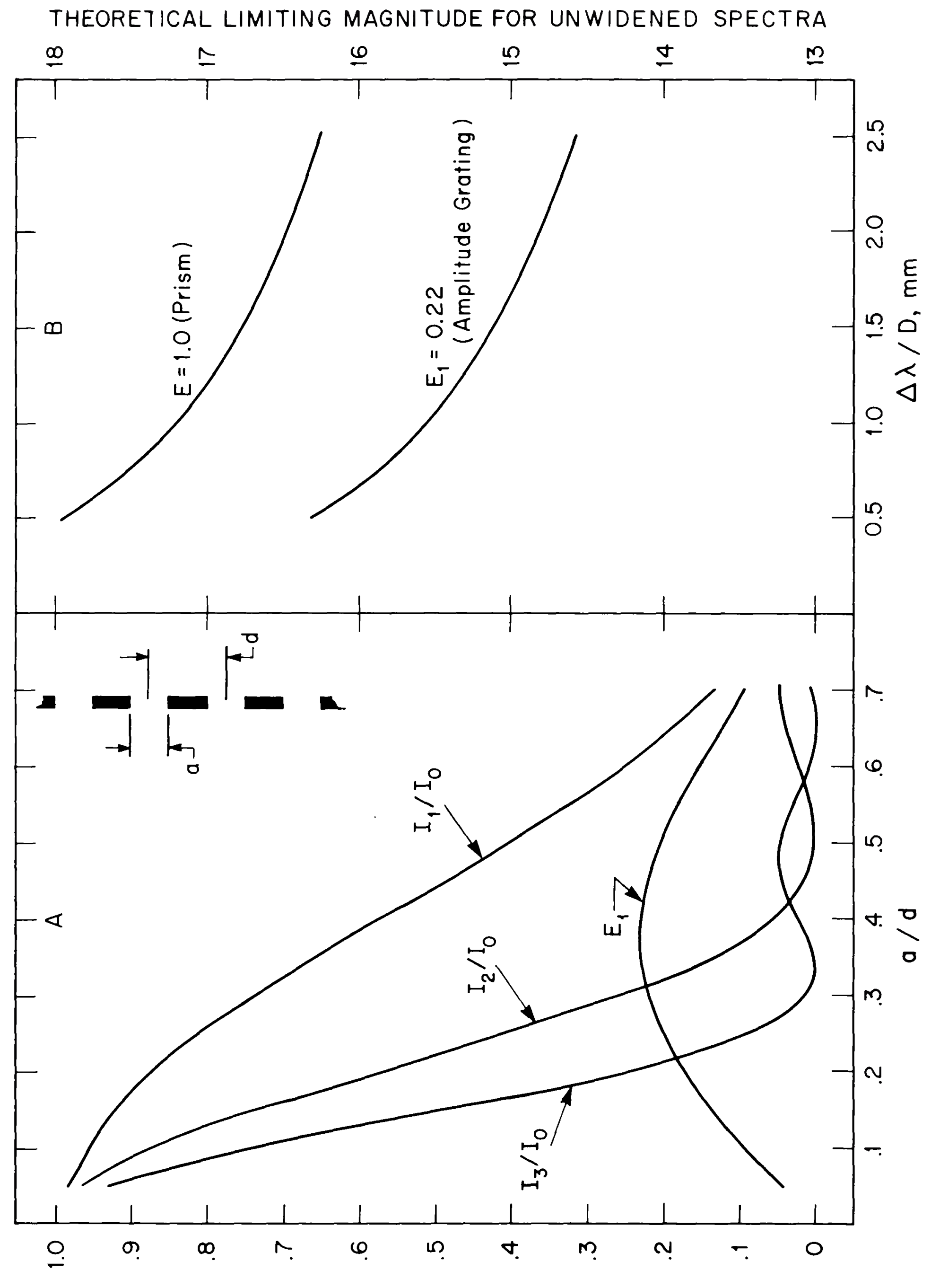

FIG. 1.—Properties of amplitude gratings. (A) Variation of intensities of the three lowest orders and the first-order efficiency vs. fractional transparent area. (B) Theoretical limiting magnitudes for unwidened spectra, 48-inch Schmidt, vs. spectrum length.

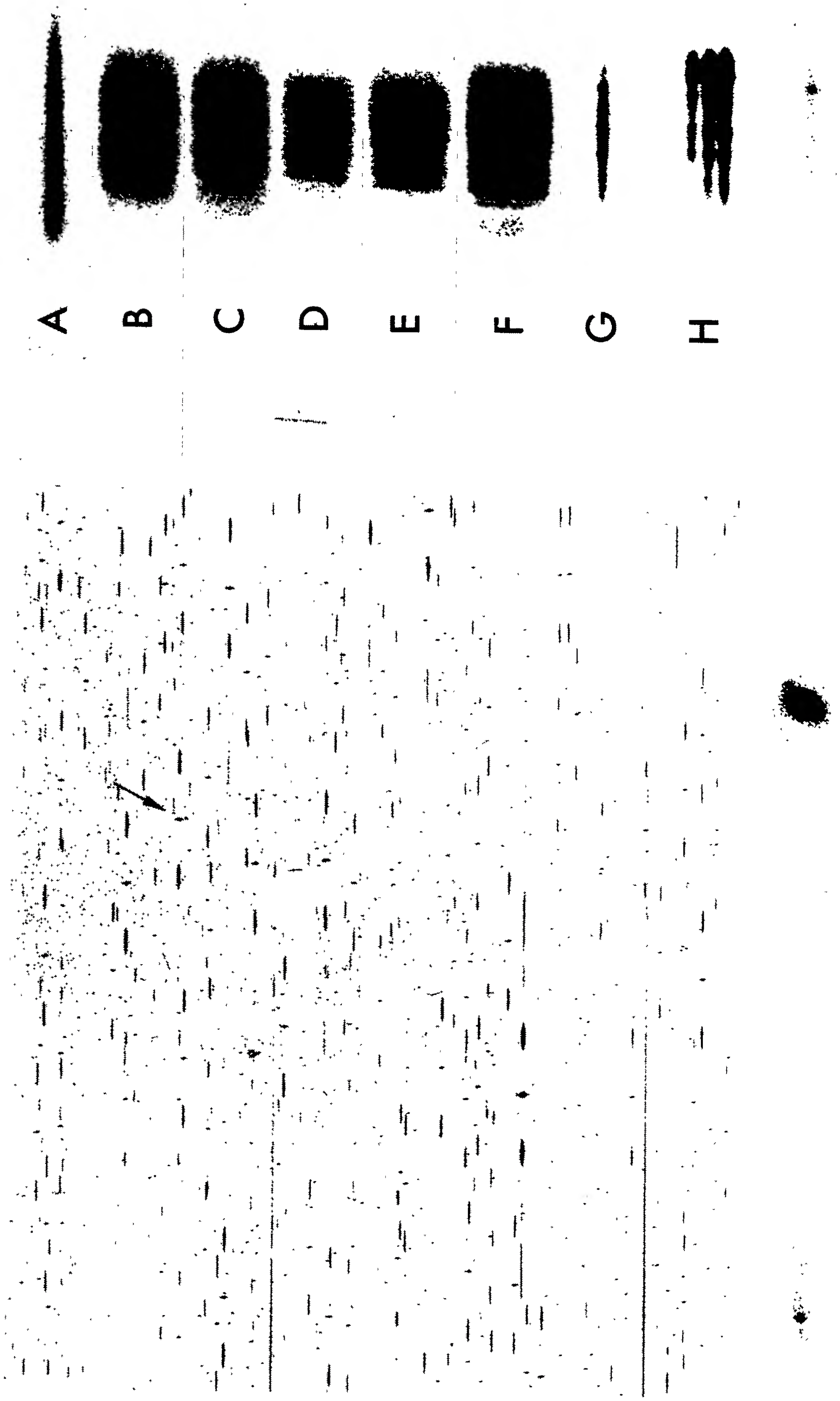
A
B
C
D
E
F
G
H

PLATE I

Objective-grating spectra, Palomar 48-inch Schmidt, original dispersion 1104 Å/mm, plate scale 67″/mm. *Upper left:* Field in Ursa Major. Arrow indicates the zero-order image of GD-299 (sd0, $m_{pg} = 12.0$). First-order spectra are seen on either side. Photographed on Kodak IIa-O emulsion with no filter, unwidened. The spectra cover approximately the range $\lambda\lambda$ 3400-5200. Sky fog density ≈ 0.5. Note slight elongation of central images perpendicular to dispersion, caused by irregularities in the Mylar as described in the text. *Upper right;* Enlargements of first-order spectra. (A) HZ 44, sd08p, unwidened, poor seeing; (B) HD 71297, dF0; (C) HD 70958, dF2; (D) HD 70937, dF4, streak at left is the trailed zero-order image of another star; (E) HD 82635, gG6; (F) HD 82885, dK0; (G) BQ Gem, gM4, unwidened; (H) R Lyn, S3.9e, unwidened, Kodak 103a-F emulsion and Wratten No. 16 filter, spectral range $\lambda\lambda$ 5200-6700. *Bottom:* NGC 1068, Seyfert galaxy, unwidened exposure, Kodak 103a-F emulsion and Wratten No. 16 filter, showing Hα emission. Nuclear Hα images are about twice the diameter of limiting zero-order star images on this plate, i.e., they are resolved.

III. Experimental Results and Conclusions

For the present experiments, conducted in February, March, and April 1970, the 48-inch was equipped with a mosaic of four Mylar gratings, each 18 inches in diameter, of 2.95 lines/mm, all having been ruled and mounted in one day with the aim of making them as nearly alike as possible. The gratings were aligned with rulings parallel, by means of the Moiré fringes produced by a fifth test-grating. The mosaic produces a linear dispersion of 1104 Å/mm. Plate I shows examples of some of the spectra obtained (both widened and unwidened, on Kodak IIa–O and 103a–F emulsions) illustrating the image quality obtained under good seeing conditions.

With baked IIa–O emulsion and no filter, a one-hour exposure is required to reach the optimum sky fog density of about 0.8. Unwidened first-order stellar spectra can be detected at approximately the expected magnitude limit of 15^m or slightly fainter. However, the practical magnitude limit for a complete visual assessment of the spectra is about one magnitude brighter, or $V \sim 14^m$ for continuous spectra. Only the strongest spectral features, including the hydrogen lines in A dwarfs, can be seen in the unwidened spectra. The spectra can be widened, with a corresponding loss in limiting magnitude. For some purposes the unwidened spectra are adequate, especially for discovery or classification of late M, S, and carbon stars, supernovae, and emission-line stars and galaxies. For stars with weak absorption features a large gain in information per spectrum is brought about by widening; in such cases a different dispersion might more nearly optimize the balance between information and limiting magnitude. In fact, our present dispersion was an arbitrary choice, and it is not necessarily ideal. The use of substantially lower dispersion in certain applications is discussed by Schulte (1956).

Plate I shows that our grating spectra compare not unfavorably in definition with those obtained at like dispersions by means of objective prisms on smaller telescopes (see, for example, Velghe 1957; Nassau and Velghe 1964). The presence of pairs of spectra in our case is potentially useful in providing a check for plate flaws or overlapping spectra or in establishing the wavelengths of features or even radial velocities.[*]

An obvious basic disadvantage of unblazed amplitude gratings is, needless to say, their reduced magnitude limit due to these multiple orders. The same magnitude limit at a given dispersion (although not the same large plate scale) could be reached by a telescope of half the focal length equipped with a blazed grating or a prism. Thus, the need continues for an objective dispersing device that can take full advantage of the largest existing or planned Schmidt telescopes. In the meantime, it appears that the present compromise solution will be adequate for some useful work. A limited survey program is in progress with it. The grating is also available for use by other observers on the 48-inch telescope.

I am indebted to Drs. G. W. Preston and I. S. Bowen for helpful and stimulating discussions. I thank Dr. J. Kristian and Mr. Dennis Palm for acquainting me with the use of the Palomar Schmidt telescope, members of the Mount Wilson Optical Shop for assistance in assembling the gratings, and Mr. Malcolm Riley for numerical calculations.

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[*] At 1104 Å/mm the measuring error is about ±400 km/sec which exceeds the velocity of escape from the Galaxy. Hence, the method is likely to succeed only for extragalactic objects with emission lines. For NGC 1068 it was found to yield excellent (~ 10%) agreement with published redshifts from slit spectra.