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# "NONOBJECTIVE" GRATINGS

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The aberrations that limit the use of a transmission grating in the converging beam of a telescope can be partially compensated and the performance significantly improved if the grating is combined with a low-angle prism. A description is given of such a device which will yield spectra at dispersions of 320 Å to 1280 Å $mm^{-1}$ of objects over a field of 150 × 200 mm (1°.2 × 1°.6) for the 40-inch $f/7$ telescope of the Las Campanas Observatory. At 320 Å $mm^{-1}$ the line broadening by aberrations reaches a maximum of just over one arc second at the ends of the 3500 Å to 7000 Å range.

*Key words:* instrumentation — spectrograph — "nonobjective" grating — optics

Hoag and Schroeder (1970) have described the use of a transmission grating in the converging beam of a telescope to obtain the spectra of all stars in the field. The chief limitations on this procedure are the coma, astigmatism, and field curvature introduced by the grating. Thus, as they point out, with a grating mounted normal to the optic axis the comatic image has a size $3\ell/8f^2$, in which $\ell$ is the distance of a point in the spectrum from the zero-order image and $f$ is the focal ratio of the telescope. For both the telescope on which they used the grating and the one for which we plan to mount a similar device, the focal ratio is 7.5 or 7.0. The comatic images therefore have a size of about $\ell/140$. The plate scales of both instruments are about 1 arc second = 0.035 mm. If the comatic image is not to exceed the "seeing" image under good conditions it is evident that the distance from the zero order to the long wavelength end of the spectrum should not exceed about 5 mm. Dispersions are therefore limited by coma to about 1000 Å $mm^{-1}$ for the blue and to 1400 Å $mm^{-1}$ if the red region is to be recorded.

Also, the sagittal image surface on which the band of the continuous spectrum is focused has a radius of curvature equal to the distance from the grating to the focus, while the tangential surface on which the images of spectrum lines are formed has a radius of only a third this distance. At large distances from the zero order, therefore, spectrum lines are brought to focus well above the plane of the plate.

Consideration has therefore been given to the possibility of reducing these aberrations in order to permit the use of higher dispersions.

### Coma

While it does not appear possible by any simple means to change the basic formula for the coma produced by a grating, it is feasible to shift the point of zero coma to any point in the spectrum, normally the center of the range to be observed, by combining the grating with a low-angle prism. The prism preceeds the grating and is oriented so that it deflects a ray in the direction opposite to the deflection produced by the grating. The wedge angle of the prism, $\tau$, to be used for this purpose is given by

$$\sin \tau = \lambda_0 n/d(n^2 - 1)$$

in which $\lambda_0$ is the wavelength at the center of the range, $d$ is the grating space, and $n$ is the refractive index of the prism material. Since, in the case of the telescopes under discussion, images of one second or smaller will be formed out to 5 mm on either side of the zero-coma wavelength, dispersions of 350 Å $mm^{-1}$ may be used over the range from 3500 Å to 7000 Å. Even higher dispersions can be used in case a shorter wavelength range is sufficient.

The introduction of the prism makes it necessary to tilt the photographic plate through the angle $\lambda_0/(n + 1)d$ radians from a plane normal to the optic axis of the telescope.

To avoid extra reflections it is desirable to

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replicate the grating layer directly on the second surface of the prism, or at least to cement the elements together if a separate grating blank is used.

It should be noted that Murty (1962) suggested the use of a prism to compensate for the coma of a reflection grating in converging light, and applied the principle to spectrometer and monochromator design.

## Field Curvature and Astigmatism

By rotating the grating through a small angle about an axis parallel to the rulings it is possible to bring any two spectrum lines into focus in the plane of the tilted plate. The two wavelengths, $\lambda_1$ and $\lambda_2$, normally would be those at the ends of the spectral range being observed. The angle of tilt, $\psi$, of the grating (and of the second surface of the prism, in which the grating lies), is then given by

$$\sin \psi = \frac{(-3n^2 + 3n - 2)\lambda_0 \delta n/d(n^2 - 1)^2 + 2(\lambda_2 - \lambda_1)/d(n + 1) - Td\delta n/L\lambda_0 n^2}{2(\lambda_2 - \lambda_1)/\lambda_0 - 2(n + 1/n)\delta n/(n^2 - 1)} ,$$

in which $\delta n$ is the difference in the indices at $\lambda_2$ and $\lambda_1$ and has the opposite sign from $\lambda_2 - \lambda_1$, and $n$ is the average of these indices. $T$ is the total thickness of the wedge at its midpoint, and $L$ is the distance from the grating to the photographic plate. Additional tilt would be required to correct for any change in focal length of the telescope with wavelength.

For the case in which the prism is fused silica and the range is from 3500 Å to 7000 Å the formula for the tilt reduces to

$$\sin \psi = 0.000225/d + 13.56Td/L$$

in which all lengths are in millimeters. The direction of tilt is such that the thicker end of the prism is nearer to the focus.

A small amount of astigmatism is present which lengthens the spectral lines (i.e. widens the spectrum) by $L\lambda^2/(n^2 - 1)d^2 f$ millimeters at the center of the observing range. To avoid excessive astigmatism it is obviously desirable to use coarse gratings at large distances from the focus. This also reduces field curvature.

In summary, by this procedure it is possible to produce a spectrum of length $5.33f^2$ times the diameter of the seeing image, in which the definition is not appreciably degraded below that set by the seeing. In other words, one can obtain a spectrum with $5.33f^2$ picture elements covering any specified range of wavelengths. Since the dispersion is proportional to the distance between the grating and the focus, and since the prism wedge angle is independent of this distance, one grating-prism combination can be used to provide a wide range of dispersions.

Attention should be called to the crowding of the field by other orders of spectra of bright stars that may result when a grating is used for slitless spectroscopy.

It may also be noted that in all telescopes having a paraboloid primary the coma of the telescope limits the diameter of the field in which the aberration is smaller than the seeing image to 10.67 $f^2$ times the diameter of the seeing image. This applies to both the prime and the Cassegrain foci if the corresponding value of $f$ is used. Unfortunately, the comatic aberrations of the telescope and of the grating as here used are in many cases additive, thus still further reducing the field. For wide field survey purposes, this prism-grating device will therefore find its chief application on the newer telescopes with Ritchey-Chrétien optics rather than on the older paraboloid type instruments.

Table I gives the specifications of the prism-grating combination that is planned for the 40-inch $f/7$ wide-field telescope of the Las Campanas Observatory. The performance of this system has been checked by means of a ray-tracing program (polypagos) for the effect of a grating. Figure 1 shows the spot diagrams of the images formed at the center and ends of the spectral range for the case of the highest dispersion, 320 Å mm$^{-1}$.

### REFERENCES

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TABLE I

PRISM-GRATING SPECIFICATIONS FOR THE LAS CAMPANAS OBSERVATORY 40-INCH TELESCOPE

| | |
|---|---|
| Wavelength range | λλ3500–7000 |
| Grating | Ruled area 154 × 206 mm, 75 lines $mm^{-1}$, first order blaze wavelength λ5700, replicated directly on prism. |
| Prism | Fused silica, wedge angle $\sin \tau = 0.0502$, midpoint thickness 20.0 mm. |
| Tilt of photographic plate | 0.0160 radian |

| Distance from grating to focus (mm) | Dispersion (Å $mm^{-1}$) | Tilt of grating Sin $\psi$ |
|---|---|---|
| 400 | 320 | 0.026 |
| 200 | 640 | 0.035 |
| 100 | 1280 | 0.053 |

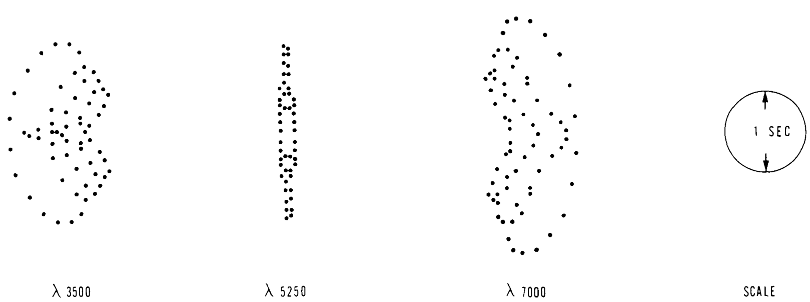


FIG. 1 — Computed monochromatic spot diagrams of images, Las Campanas 40-inch telescope with "nonobjective" grating-prism combination described in the text. Dispersion for the case shown is 320 Å $mm^{-1}$. Distances between images are not shown to scale.