HIGH RESOLUTION EUV & SOFT X-RAY SPECTROMETERS USING VARIABLE GROOVE SPACINGS

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Introduction

Spectroscopic analysis is a powerful technique for the diagnosis of temperatures and compositions of astrophysical plasmas. The EUV (100-1000Å) and soft x-ray (10-100Å) bands contain hundreds of potentially useful diagnostic lines. Unfortunately, traditional types of grating spectrometer become inefficient or unwieldy when adapted to stellar spectroscopy onboard a spacecraft. At grazing incidence, the required length of a high-resolution plane-grating spectrometer can easily exceed the length of the telescope feeding it. For these reasons, we have systematically explored ways to introduce a reflection grating into the converging beam formed by a given objective optical system ahead of its first focus. A spectrometer of this type results in an optical train no longer than the telescope's existing prime-focus beam.

Varied-Groove-Spacing Gratings

If placed in a converging beam, the linear dispersion of a conventional uniformly-ruled plane reflection grating will vary from point to point over the entrance pupil of the beam. By varying the groove spacing over the face of the grating to satisfy the local grating equation at a given order, wavelength, and dispersion, this problem can be enormously reduced[1]. The general arrangement is shown in Figure 1, below.

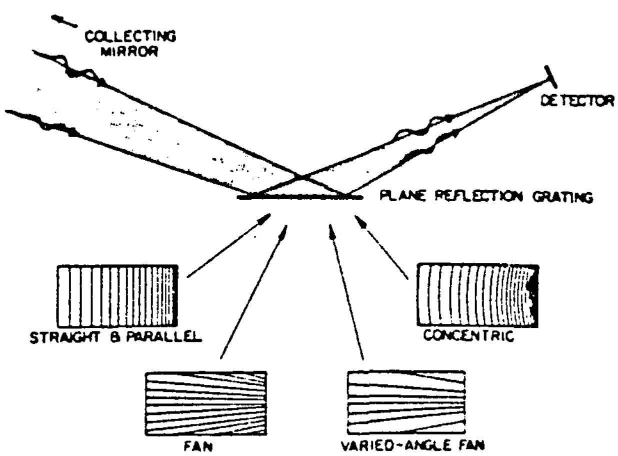

Figure 1.

Plane reflection gratings in converging light can be designed with a variety of groove illumination schemes and groove plans.

One important configuration is the in-plane mount, in which the incident and diffracted rays are approximately perpendicular to the grooves. The in-plane mount produces a straight linear spectrum and also offers the highest possible linear dispersion for a given spectral order. We have investigated a series of in-plane gratings with the goal of establishing

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their performance in the areas of spectral resolution, throughput, and imaging (the ability to concentrate light in the direction perpendicular to the dispersion.)

Figure 2 is a set of spot diagrams illustrating the performance of four in-plane gratings having grooves optimally spaced for one wavelength, λ304Å, in the -1 order. The straight grooves (Figure 2a) and concentric grooves (2d) can be ruled by mechanical techniques. The hyperbolic groove plans, in contrast, must be created interferometrically. Figures 2b and 2c differ in their choice of recording wavelength, with (2c) being made practical[2] by the availability of argon ion lasers.

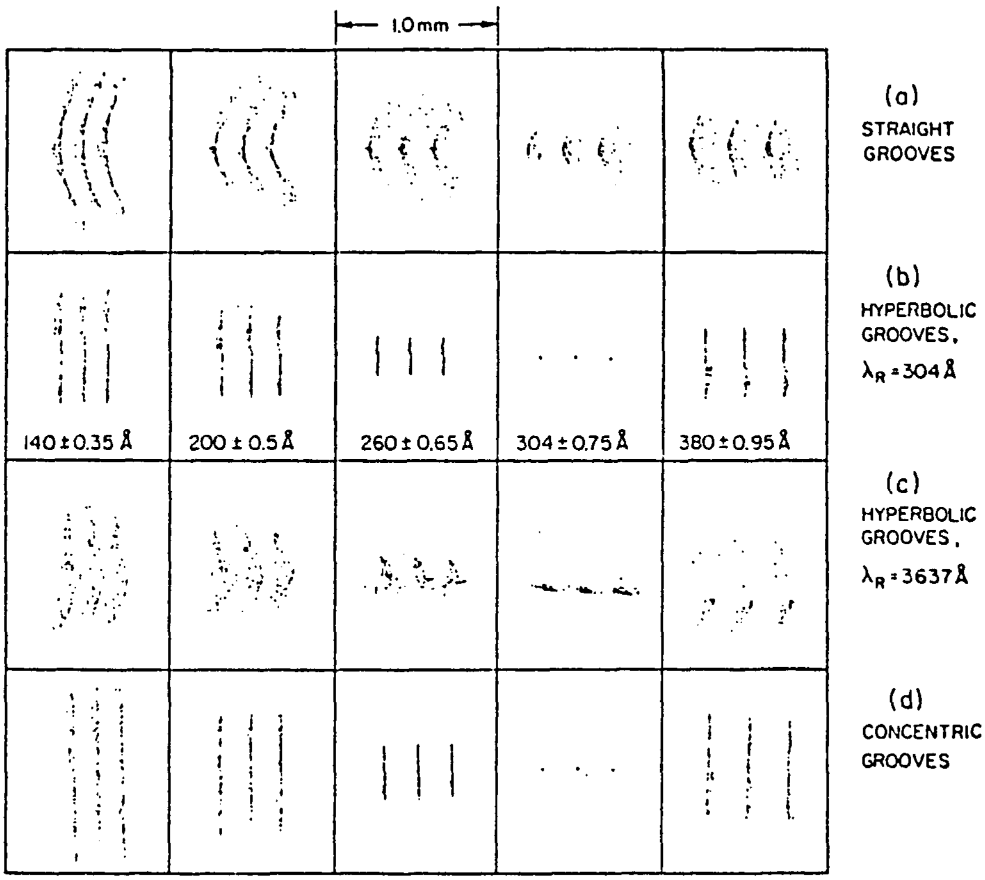

Figure 2. Performance of four in-plane grating designs using straight and curved grooves. The line separations shown are $\lambda/\Delta\lambda$ = 400, a design goal for the EUVE mission.

For comparison, each of these designs was chosen to intercept an f/6 × f/22 beam from a portion of the spectroscopy telescope[3] beam on the Extreme Ultraviolet Explorer mission[4]. The spectrometers traced here have a beam focal length of 136 cm, a distance separating the grating center from the focus equal to 48.5 cm, and a central groove spacing of 8294Å. The dispersion is 0.2 mm/Å at the detector. In all cases, the performance was optimized at λ304Å. These ray traces indicate that any of these ruling techniques can be effective for achieving the desired spectral resolution (~400) and that if other causes of blur were not factors, the concentric groove design would be able to do considerably better than this figure.

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An alternative geometry is the out-of-plane "conical diffraction"[5,6,7] mount. In spectrometers of this kind, the incident and diffracted beams lie nearly parallel to the grooves. The grooves can remain fully illuminated even at grazing incidence, and high efficiency can consequently be obtained even at the very shortest wavelengths of interest. However, as the glancing angle is made small, only a small component of the incident wave vector is perpendicular to the groove direction, so a small dispersion is obtained for a given groove spacing. Two other complications are that the spectrum is formed along a circular arc, and that a circular "point" object becomes highly elongated upon undergoing conical diffraction. Both of these effects can lead to extreme requirements in the area of detector performance required to record high resolution spectra.

To adapt the extreme out-of-plane mount to converging-beam illumination, it is necessary to arrange for the grooves to converge. The resulting gratings resemble oriental fans; the groove spacing is proportional to the distance from a ruling focus[1] or "hub"[8]. In Figure 3, we present ray traces of a grating of this kind, for three mounting configurations. The wavelengths chosen for these traces are separated by $\lambda/\Delta\lambda = 100$. These traces assume a flat focal surface, for which wavelength aberrations grow rapidly away from the optimized wavelength (here, 150Å). However, by the use of a curved focal surface, maximum wavelength resolution (as in panels 3i and 3n) can be enforced over the entire spectrum.[9]

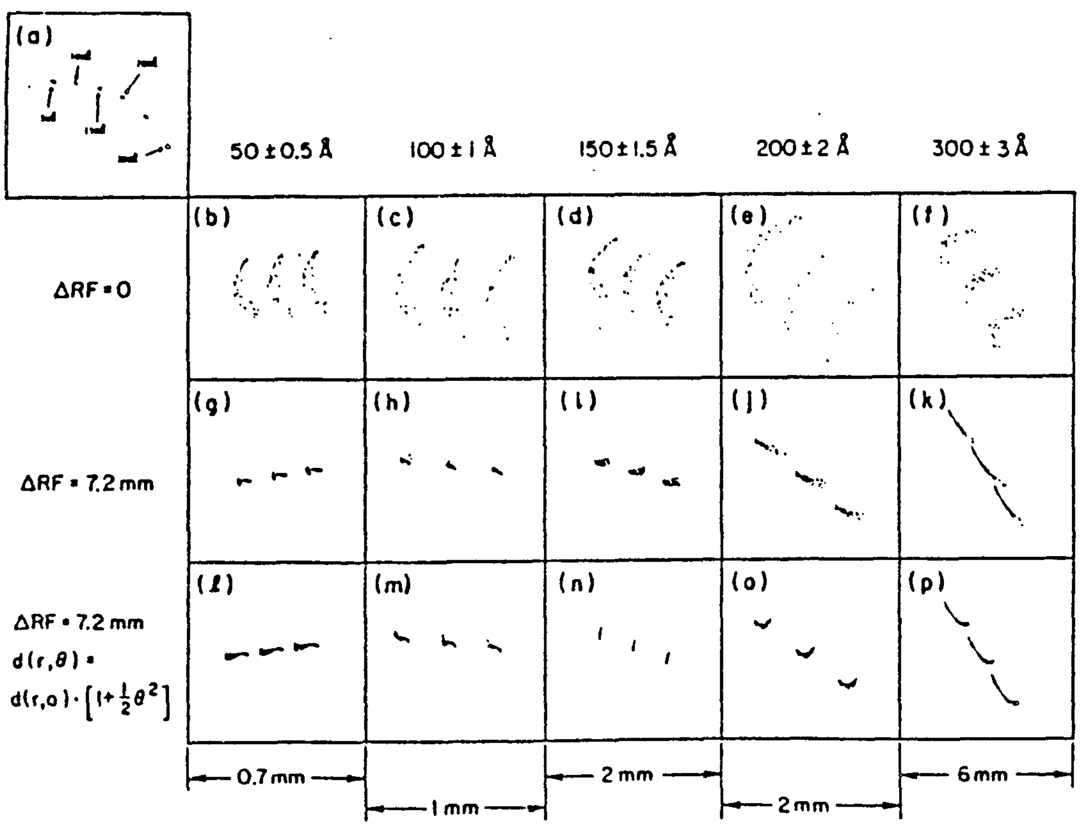

Figure 3. Oriental fan spectra. Here (a) is the gross wavelength map; ΔRF=displacement between image plane and ruling focus; (b)-(f) have ΔRF=0; (g)-(k) have ruling focus optimized 7.2mm behind focal plane; (l)-(p) have also an optimized angular variation in groove spacing.

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After comparing the detailed characteristics of the in-plane and out-of-plane mounts, we have selected the in-plane mount for use in the spectroscopy experiment of the EUVE mission. In addition, we are developing a set of concentric-groove gratings for soft x-ray spectroscopy as one candidate instrument for the the AXAF mission. Each grating will accept about 20% of the converging beam from the AXAF objective, and provide useful throughput over a 2:1 wavelength band in the $\lambda\lambda$10-100Å region. The spectral resolution will be on the order of $\lambda/\Delta\lambda \sim 3000$ in each band.

Finally we mention that a high-dispersion concentric-groove grating can be combined with the oriental fan grating to form an echelle spectrometer well suited for feeding a two dimensional format detector. Such a combination offers high throughput and extremely high spectral resolution (~40000) over the $\lambda\lambda$900-1200Å wavelength range, and could form the basis of a spectrometer applicable to the Columbus mission. Figure 4 illustrates such an echelle spectrometer fed by a novel grazing incidence telescope[10] that allows a field-limiting aperture to be placed between primary and secondary.

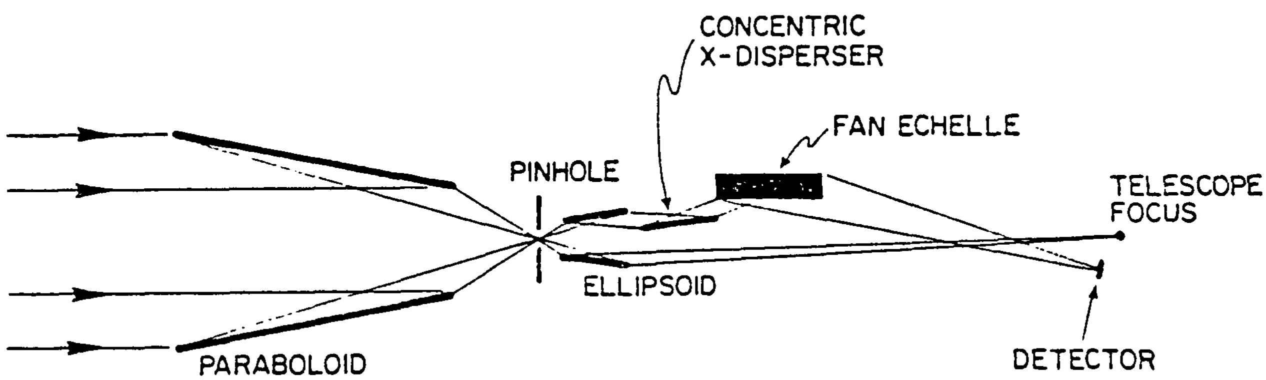

Figure 4. A grazing incidence telescope incorporating a slit feeds a grazing incidence echelle spectrometer; the combination offers high resolution and high throughput.

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