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A CONCAVE GRATING CASSEGRAIN SPECTROGRAPH PROJECT

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Resumen : Se presenta el proyecto de un espectrógrafo Cassegrain con red cóncava . Los principales parámetros son estimados y comparados con el espectrógrafo de red plana de que se dispone actualmente.

Abstract : A concave grating Cassegrain spectrograph project is reported. The mean parameters are obtained and compared with the plane grating spectroghaph now operating in L.N.A.

Key words: INSTRUMENTS — SPECTROSCOPY

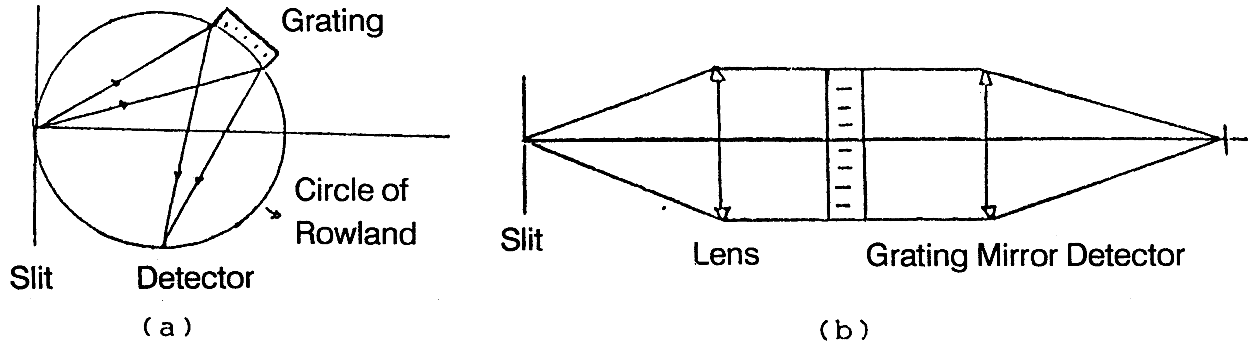
1. Introduction :

The Laboratorio Nacional de Astrofisica (L.N.A.) located at Pico dos Dias mount in the state of Minas Gerais - Brazil, presently disposes of a Boller & Chivens model 26767 single plane grating Cassegrain spectrograph.

The multiplicity of the avaliable solid state detectors, conducted us to project a second Cassegrain spectrograph to operate in association with the 1.60 m telescope of the L.N.A., attempting to improve on the performance of the existing instrument. The new spectrograph will be equiped with a concave grating , marked in a classical way with the entrance beam width equal to f/10.

The equipment will be available with a system to swap the slit for different requirements. It will also possess, as calibration aid, a variable source for continuous spectrum as well as a source for line spectrum. A microcomputer is in charge of the control of the lamps calibration operation and of the detector activity; it controls also the setup of the entrance slit directions.

One advantage in using a concave grating as scattering device consists in the possibility of the reduction of the instruments size. That is, the focusing characteristics of the concave grating make possible to avoid the use of lenses or focusing mirrors. The reduction of its size limits the mechanical flexure (the linear amount of flexure varies as the square of the size, provided that all dimensions, including the thickness of all members, are increased proportionally), and the elimination of some optical components, diminishes the loss due to absortion and reflexion [2].



(a) (b)

Fig. 1 - Diagram of the plane gràting (a) and the concave grating (b) spectrograph.

In 1882, H. A. Rowland [3] showed that when marking a grating on the surface of a spherical, concave mirror, a grating is formed being itself the scattering and the focusing element. The slit, the grating and the focused spectrum are located inside a circle, the circle of Rowland. However, it is possible to use other configurations as well. These are given by the following expressions (or by expressions derived from them):

Grating expression ➜ $\sin\alpha \pm \sin\beta = \pm\frac{m\lambda}{d}$

Distance expression ➜ $\frac{\cos^2\alpha}{r} + \frac{\cos^2\beta}{r_1} = \left[\frac{\cos\alpha + \cos\beta}{R}\right]$

Where :

α and β	are the angles of incidence and difraction respectively;
d	is the period of the grating (equal to the width of two strips)
λ	is the wave length;
r e r_1	are the slit-grating and grating-detector distances respectively;
R	is the radius of curvature of the grating;
±m	is the spectrum order.

2. The "ideal" grating :

As the necessary rigity for spectrographs requires dimensions up to 100 or 150 cm, the value of r was chosen as 70 cm and a spectral range of 5000 Å, in the interval of 3600-8600 Å, was fixed.

The value of the incident angle α was then calculated for the central wave length (λ_c) by using the following expression; the sum ($\alpha+\beta$) was fixed for a 45° angle :

$$\sin\left[\frac{\alpha - \beta}{2}\right] = \frac{m\lambda}{2d} \sec\left[\frac{\alpha + \beta}{2}\right]$$

Suppose that an ideal situation is the one in which each detectors pixel will contain a monocromatic image of the slit.

The optimized image of a star in the slit has a typical angular dimension of 2" and the scale of the telescope to be employed is 13"/mm. Thus, we obtain for the stellar diameter in the telescope focus the value

$$\frac{2''}{13''/\mathrm{mm}} = 153.8\ \mu\ .$$

However, one pixel in the available detectors corresponds to 25μ and as it has a total of 1000 pixels, the linear length of the spectrum must be 25 mm. Thus, the desired amplification of the slit image in the spectrum will be of the order of

$$\frac{153}{25}\ \mu = 6.2\ .$$

On the other hand, it is possible to show that the amplification is approximately equal to the ratio of the slit-grating distance over the grating-detector distance.

Therefore, keeping unaltered the pre-fixed contraints and varying the number of lines and the curvature radius of the grating, we can determine the detector that better fits the ideal situation.

3 . The parameters of the grating and spectrograph :

Once determined the ideal grating as explained above, we computed its astigmatism, coma, curvature of lines, spherical aberration and high order aberrations. This computation was carried out using the Beutler aproximation for the light path [1].

In the figure below the light issuing from point A intercepts the surface of the grating in point P and is diffracted toward the point B. The origin of the cartesian system x,y,z was placed at the middle of the grating surface with axis x normal to the grating.

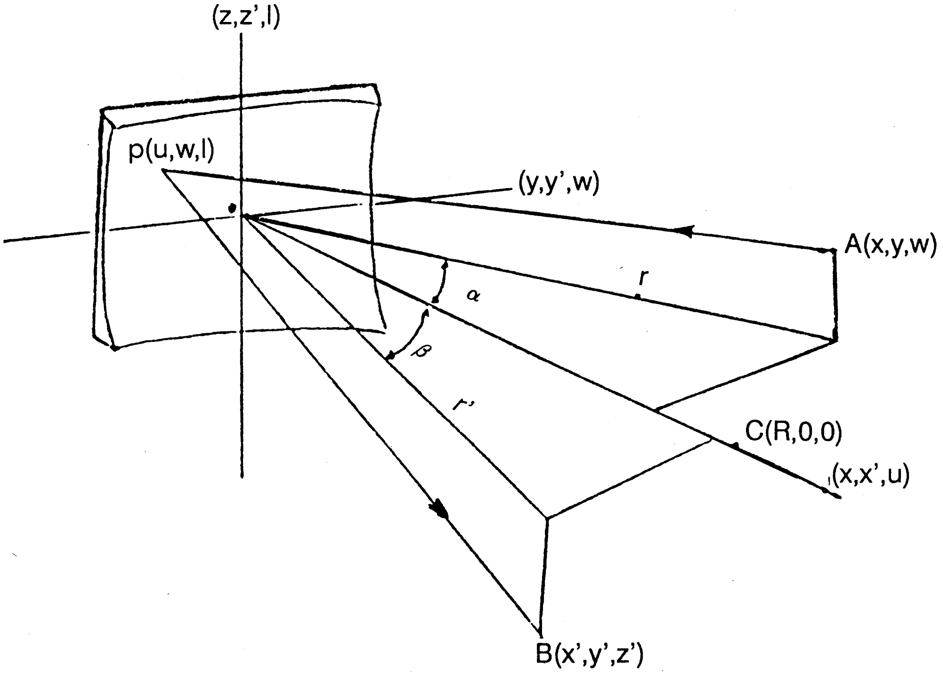


Fig. 2 - Image formation by a concave grating.

For the ray APB, the light path function can be represented by :

$$\overline{F} = \langle \overline{AP} \rangle + \langle \overline{PB} \rangle \ .$$

The terms $\langle \overline{AP} \rangle$ and $\langle \overline{PB} \rangle$ in the above relation were expressed by Beutler in the form :

$$\langle \overline{AP} \rangle = F_1 + F_2 + F_3 + \ldots$$

$$\langle \overline{PB} \rangle = F'_1 + F'_2 + F'_3 + \ldots$$

here, each pair of terms an has individual physical meaning, either as regards the image formation or its imperfections. The first two pairs $(F_1 + F'_1)$ and $(F_2 + F'_2)$ give the condition for the image formation, The meaning of the others are :

$F_3 + F'_3$ → Astigmatism

$F_4 + F'_4$ → Coma and curvature of lines

$F_5 + F'_5$ → Spherical aberration

$F_7 + F'_7$ → High order aberration

These terms are given by :

$$F_3 = \frac{1}{2}\, l^2 \left[\frac{1}{r} - \frac{\cos\alpha}{R}\right] - \frac{lz}{r} + \frac{z^2}{2r} \;;$$

$$F_4 = \frac{1}{2}\, l^2\, \frac{w\ \mathrm{sen}\alpha}{r} \left[\frac{1}{r} - \frac{\cos\alpha}{R}\right] + \frac{w\ \mathrm{sen}\alpha}{2r^2}\left(-2lz + z^2\right) \;;$$

$$F_5 = \left(\frac{w^2 + l^2}{8R^2}\right)^2 \left[\frac{1}{r} - \frac{\cos\alpha}{R}\right] \;;$$

$$F_7 = \left(\frac{w^2 + l^2}{8R^2}\right)^2 \frac{w\ \mathrm{sen}\alpha}{r} \left[\frac{1}{r} - \frac{\cos\alpha}{R}\right] \;;$$

And similarly for the terms of the diffracted beam, F'_3, F'_4, F'_5 and F'_7, with the changes : $(r,z,\alpha) \rightarrow (r',z',\beta)$.

In addition to these calculations, further important parameters which determine the suitability of any spectrograph, in a given observational program, were obtained . They are described as [4] :

Reciprocal linear dispertion → $\frac{\partial\lambda}{\partial x} = \frac{d\cos\beta}{r_1}$

Spectral purity → $\partial\lambda = \frac{Lf}{r\ \frac{d\beta}{d\lambda}}$; $\frac{d\beta}{d\lambda} = \frac{m}{d\cos\beta}$

Spectral resolution → $R = \frac{\lambda}{\partial\lambda}$

Throughput → $T = \mathrm{Area}\ \cos\beta\ \frac{Lf\ Af}{r^2}$

Spectrograph speed → $V \propto \mathrm{Area}\ \cos\beta \left(\frac{r_1}{r}\right) \frac{\partial\lambda}{\partial x} \frac{1}{L_f}$

Anamorphic magnification → $Aa = \frac{\cos\alpha}{\cos\beta}$

Where :

(Lf, Af) are the dimensions of the grating ; and
Area is, accordingly, the area of the grating with dimentions (Lf, Af).

These values allow us to compare with the ones of the plane grating Cassegrain spectrograph of the L.N.A. as can be seen in table 1. Such parameters were considered as highly satisfactory concerning the construction of a new instrument for low dispersion spectroscopic work.

4 . Conclusions and projects :

An inconvenience of the found solution, that is intrinsic to all concave grating spectrographs, is the high spectrum curvature. Its correction using optical fibres is not feasible in our case, due to the structure and position of the detector focusing. Instead we will use a lens system in order to reduce that curvature to a consistent value within the desired solution.

SPECTROGRAPH	L. N. A.	IDEAL
Nº Lines	300	400
Radium Grat. (mm)	∞	200
Radium Spec. (mm)	∞	52.9 + 1.3
r (mm)	675	700
r_1 (mm)	152.4	115.4
Lf (mm)	0.2	0.2
Af (mm)	1.0	1.0
Lr (mm)	50	78.6
Ar (mm)	50	68
$\alpha + \beta$ (grau)	50	45
$\lambda_{central}$ (Å)	6100	6100
λ_{blase} (Å)	5000	4255.6
CARACTERISTICS PARAMETERS		
$\frac{\partial\lambda}{\partial x}$ (Å/mm)	206.5	209.3
$\partial\lambda$ (Å)	9.3	6.9
R	655.9	883.8
T (mm)Sr ^{2}	0.0009	0.0017
V (erg*cte/cm^{4} s)	55.5	134.5
Aa	0.91	0.90

Table 1 : The plane and concave grating comparison.

5 . References :

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