SECTION II:

SPECTROGRAPHS AND SPECTROMETERS

MULTI-ORDER FORMATS TO INCREASE THE VERSATILITY OF CASSEGRAIN SPECTROGRAPHS

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ABSTRACT: "Grism" and compound prism cross-dispersers have been pro-
posed for the new Cassegrain spectrograph of the 2.5m telescope at La
Palma. The RGO image-tube spectrograph has been fitted with a grism
to provide us with experience in designing layouts, operating the equip-
ment and handling the data.

Instrument design for large telescopes frequently starts out with
the astronomical community being undecided upon whether to choose
single purpose systems which may be exceptionally efficient for special-
ised applications or try to find efficient layouts with multiple options
to provide more versatile equipment.

In 1977, during the initial stages of the design of the new Casse-
grain spectrograph for the 2.5m Isaac Newton Telescope on La Palma,
proposals were made to include cross-dispersion facilities for both
low- and intermediate-dispersion spectroscopy. By that time it had
already been agreed that the system should be capable of operating with
a long slit (4 arc min), which would therefore allow room in the image
format for a few orders to be recorded with modest separations.

The spectrograph is a flat-bed arrangement, having two folded
"short Schmidt" cameras (Wynne (1977)) of 23.5cm and 50.0cm focal
length. At RGO, in 1977, Morris made a study of the geometry of the
system to obtain optimum throughput; the resulting layout is shown in
Fig. 1. Dispersions from 130 A mm^{-1} to 7 A mm^{-1} are available in the
standard mode, but spectral coverage is incomplete at intermediate
dispersions because of limited field size, and at low dispersion over-
lapping orders prevent full use of the detectable wavelength range.

The two spectrograph cameras are designed for use with interchange-
able gratings, working at attitudes which produce a modest range of
anamorphic magnification. Substitution of a very high blaze angle
echelle grating to obtain the multi-order format would therefore not
be acceptable, so a variety of low ruling frequency gratings have been

GRATING 100 x 125

235 CAMERA

35° 25°

30°

DETECTOR

500 CAMERA

25°

OPTIONAL
X-DISPERSER

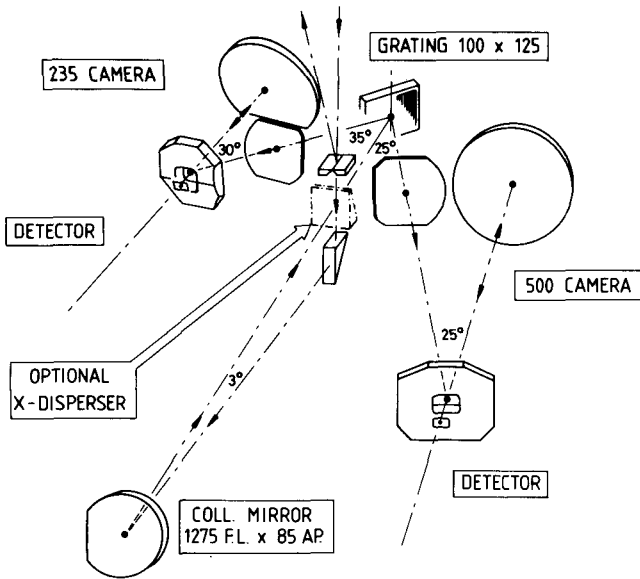3°

DETECTOR

COLL. MIRROR
1275 F.L. x 85 AP.

Figure 1. Arrangement of optical components in the Cassegrain
spectrograph for the 2.5m INT at La Palma. The instrument is mounted
on the acquisition and guiding unit at f/15 focus. Camera focal lengths
are 23.5cm and 50cm respectively, and the design is based on an 85cm
collimator beam diameter.

examined for free spectral range and efficiency characteristics when
used in higher orders than usual. Estimates of efficiencies supplied
by the grating manufacturers looked encouraging, so prime dispersers
were selected from ordinary reflection gratings. Both grating and
prism cross-dispersion were proposed, but since the mechanical arrange-
ment of the spectrograph is fixed, the former had to be a transmission
grating-prism ("grism"), whilst the latter had to produce dispersion
without deviation. In each case, the effect of introducing the cross
dispersion had to be controlled to a level where performance of the
imaging optics remained satisfactory. Other criteria affecting the
combinations chosen relate to the type of detector used, its associated
memory size and dimensions of individual elements. In the case of
photographic plates or image tubes the entire image format can be
recorded at full resolution over the whole field. The INT spectrograph
will be fitted with the UCL Image Photon Counting System (Boksenberg
(1972)) so the external memory size and element sizes will govern the
amount of recordable spectrum.

At the time the scheme was proposed, the IPCS external memory
could accommodate 192K pixels, and several possible layouts were drawn
up for grism cross-dispersion including 35–70 A mm^{-1} 3500–7000A in 5

orders and 8-11 A mm^{-1} 3600 A-5200 A in 7 orders, as examples of what might be achieved with maximum resolution and minimum wavelength over-lap. Neither of these formats fills the available image areas of 30mm x 8mm and 30mm x 16mm. It may now be possible for the IPCS to be upgraded to 512K pixels (as it is at the Anglo-Australian Telescope), allowing more orders to be recorded at larger separation, and permitting wider spectral coverage at the higher dispersions. Consequently the final choice of combinations of prime and cross-dispersers has been deferred, pending this decision.

The other proposal, a compound prism producing dispersion without deviation, seemed suitable only for the low dispersion option as an alternative to an order-sorting filter which would remove overlapping wavelengths altogether. Mounting requirements constrain the prism thickness, as does the need to maintain image quality in the camera; an order-centre separation equivalent to 20 arc sec can be achieved between first and second orders of the prime disperser (8000 A-4000 A) using a prism of UBK7 (12.6°) and LF5 (11.1°). In the grism cross-dispersion formats, spectra are essentially straight, but spectrum curvature is significant in the prism system. The deviation is 1.8mm over a 30mm field from 3000 A-7000 A, and adds to the vital need for versatile data reduction software.

Agreement having been reached on the principles of these schemes, an experiment was devised to introduce a cross-dispersing grism into the RGO image tube spectrograph, comparing the predicted performance with results of laboratory and astronomical observations.

Palmer and Milsom (1972) have described the spectrograph, in which a Cassegrain collimator feeds a reflection grating, and the imaging system (Wynne (1971)) is an f/1.4 semi-solid Maksutov-Cassegrain camera. The form of the collimator and layout of the instrument lead to problems in pupil imagery if any significant field along the slit is required (Harmer (1974)); a field lens has now been added below the slit to allow slit lengths up to 2cm to be used. Originally, the system was designed only for on-axis work. It is perhaps a happy accident, therefore, that the camera has a circular secondary mirror and can thus be used with a sizeable field across the usual direction of dispersion. The camera is designed to have a 20mm diameter field.

Fig. 2 shows the grism in position. Optical tolerance of the camera unit to the presence of the grism, and mechanical constraints on prism thickness have put practical limits on the working field size of about 13mm in the direction of cross-dispersion. On the basis of likely grating efficiencies and resulting spectrum formats, standard gratings were selected from the Bausch and Lomb catalogue:-
    Reflection grating 35-53-17-860, 150 g mm^{-1}, λb 4.0μm
    Transmission grating 35-54-15-760, 150 g mm^{-1}, λb 5750A,
        replicated on the hypotenuse of a 9.25° BK7 prism.
The prime disperser was chosen to cover 3500 A-7500 A in 5 orders, with dispersions 40-80 A mm^{-1}. Sufficient cross dispersion was
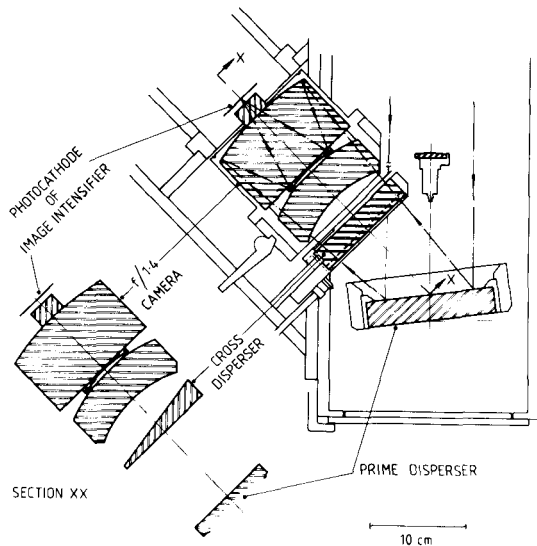
Figure 2. The position of the cross-disperser in the RGO image tube
spectrograph is shown here, with the prime disperser at its working
attitude, indicating the modest change in beam diameter due to this
grating. Obstruction of the down-coming collimated beam can be
alleviated by lifting the entire camera unit; the engineering was
not done during the testing phase.

required to allow room for a comparison arc between orders, as image
tube and photographic plate would be used for recording the spectrum.
(The problem of inter-order separation still exists for the low-light-
level digital detectors because of the need to record a simultaneous
sky spectrum). Harmer (1977) has computed the optical performance of
the system and shown that, whilst some image degradation is to be
expected, the resolution is still within 30μm FWHM achieved by the
EMI image intensifier used as the detector. It is worth digressing
briefly at this stage to note a request received from Penston, then
at the AAT, to examine performance of grism cross-dispersion in the
Wynne (1972) f/1.6 camera of the RGO spectrograph (Palmer and Gietzen
(1972)). Harmer's results (1977) showed that this system, too, would
be tolerant to the introduction of a modest grism.

     Littrow blaze wavelengths of the gratings purchased differed
slightly from the catalogue values, being 3.68μm and 5850 A for
the prime and cross-dispersers respectively. The spectrum format
achieved by centering the pattern on the effective blaze wavelength
is shown in Fig. 3 and the principal lines marked are identified in
Table 1. The wavelength range is contained in the 5th to 9th orders
of the prime disperser; in the ultraviolet, the second order from
the grism appears and is stronger than the first order because of the

1.	7320/30 A [OII]	6.	4861 A Hβ
2.	6717/31 A [SII]	7.	4471 A HeI
3.	6548/63/84 A [NII], Hα, [NII]	8.	4340/63 A Hγ, [OIII]
4.	5876 A He I	9.	4101 A Hδ
5.	4959/5007 A [OIII]	10.	3969 A Hε
		11.	3727/9 A [OII]

Table 1.   Identification of principal emission lines attainable
with S20 response, shown in Figure 3.

transmission grating blaze characteristics. This is not ideal, and
arises here from the very limited choice of near-suitable catalogue
gratings. With S20 response, the effect is not serious because of
the small amount of extra cross-dispersion provided by the prism.
Lowne has kindly measured the efficiencies of the gratings, and his
results are shown in Fig. 4. Although the prime disperser is an
ordinary blazed grating used in fairly high orders, it is encouraging
to note that the peak efficiencies are comparable with those expected
from echelles.

Laboratory experiments carried out on the spectrograph during the
summer of 1978 included verification of the expected spectrum format,
2-D focus and tilt adjustment, examination of the ripple function
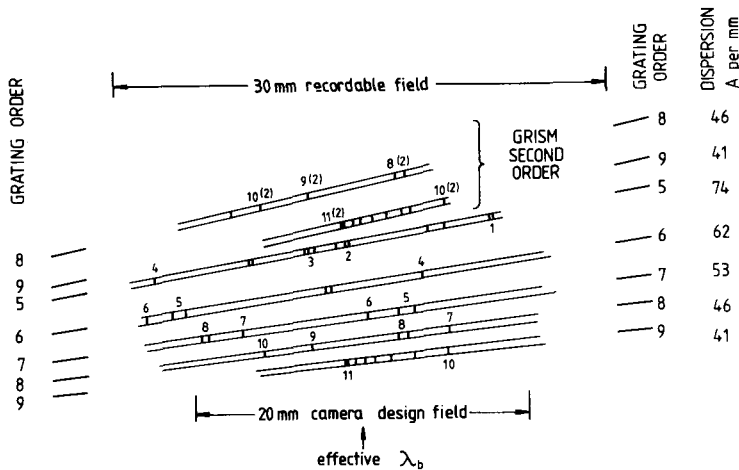

Figure 3.   The cross-dispersed spectrum format and positions of
principal emission lines attainable with an S20 photocathode. Line
identifications are in Table 1 and lines which also appear in the
grism second order are designated n (2). The spectrum height shown
corresponds to 300 μm at the detector (45 arc sec on the sky at
the Cassegrain focus of the RGO 36-inch telescope), and allows arc
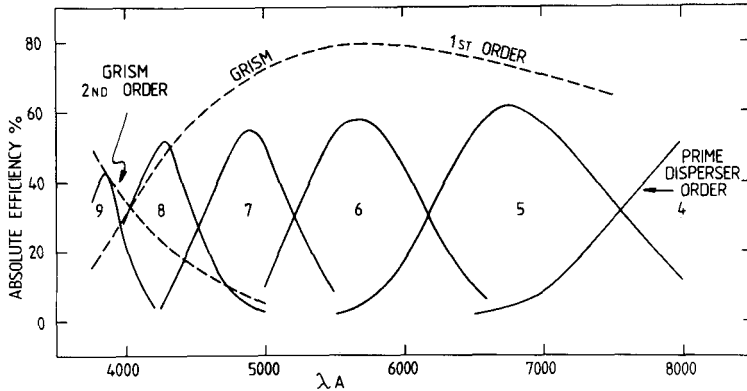spectra to be recorded between the orders.

Figure 4. Efficiencies of the prime disperser and transmission
grating as measured in the laboratory. These measurements also show
how the fairly long blaze wavelength of the transmission grating
makes the second order array from order 9 of the prime disperser
more prominent than the first order.

using white light spectra and tests of an external photometric
calibration system. The spectrograph is fitted with an EMI image
intensifier with phosphor output, the image being optically relayed
to a IIIaJ photographic plate; emulsion characteristics alone have
been used to determine the calibration curve.

Eventually, working equipment and clear skies coincided with an
allocation of 36-inch telescope time. During November 1979 and
January 1980 Worswick and I obtained observations of the spectro-
photometric standard stars HR 718 and HR 1544 (π^2 Ori) using a 5
arc sec slit width and broadening the spectra to 300μm (giving
room for comparison arcs) or 900μm (leaving orders just separated
in the ultraviolet). Exposure times were too short to obtain uniform
spectra using telescope trail, so the faster electronic trail was
used in preference to filters whose neutrality might be questionable.
Telescope trail was used with filters only to check illumination
with the spectrograph for long-slit observations.

The plates were scanned on a PDS microdensitometer and the data
reduced using a suite of computer programs developed at RGO by Burgess,
Hartley and Pike based on work originating from Kitt Peak National
Observatory. Intensity-calibrated tracings are produced order by
order, internally corrected for line slopes.

The standard star observations have been used to derive the
relative spectral response for the spectrograph/detector combination
and a more detailed account of procedure will appear in a text descri-
bing astrophysical results. Fig. 5(a) shows the relative efficiencies

of the orders derived from two plates of HR 1544 taken at the same air
mass (1.6 air masses) and with exposures differing by a factor of two
so that intensities were obtained from different regions of the
photographic characteristic curve. Agreement between the two plates
is good, with an r.m.s. scatter in the points of about 5%; accuracy
of photometric photometry used is about 2% so the scatter is predomi-
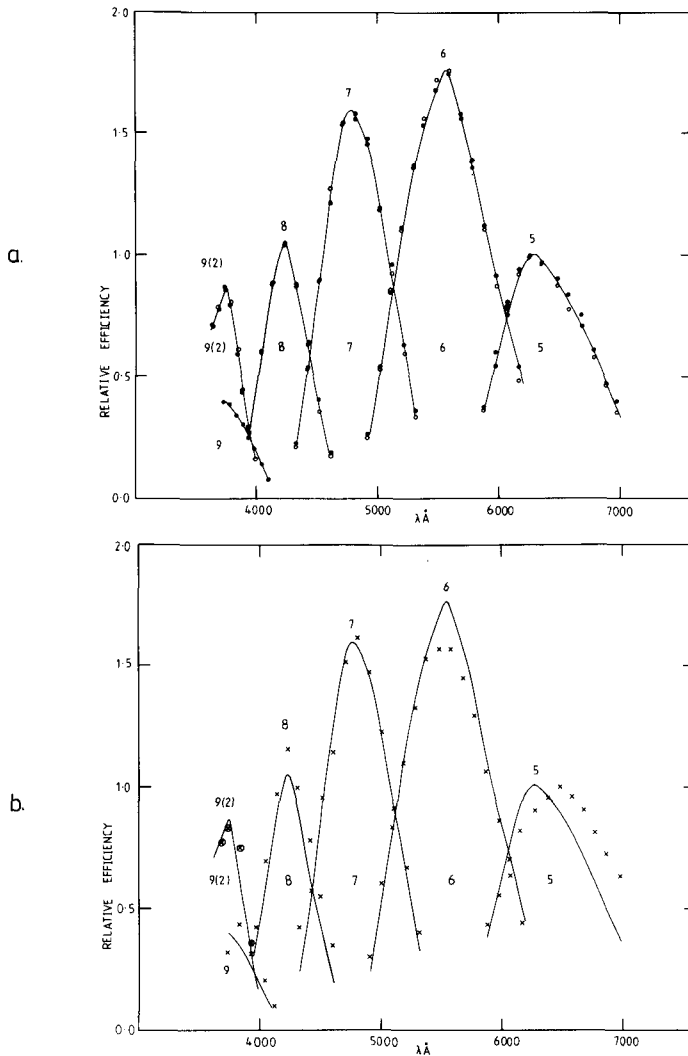

Figure 5(a). Relative efficiency of orders within the cross-dispersed
spectrum format, derived from spectra of HR 1544. Filled circles
represent measures from a two-minute exposure, open circles from a
one-minute exposure. (b) Comparison of predicted (points) and measured
(continuous curves) performance of the spectrograph.

nantly introduced by accuracy of the photographic photometry. A
comparison has been made of the performance achieved by the system
on the telescope with a "theoretical" efficiency derived from labora-
tory performance of the gratings and a "typical" S20 sensitivity
curve. The points obtained are plotted on the measured curves and
shown in Fig. 5(b). Disagreement in the red tail of order 5 is due
to a steeper red cut-off in this photocathode sensitivity compared
with a "typical" S20.

    These experiments have shown that it is feasible to use a standard
configuration spectrograph with a grism cross-disperser, provided both
optical and mechanical parameters are kept within reasonable limits.
The system has been used to obtain spectra across an ionisation front
in the Orion nebula, showing spatially resolved structure on a scale of
the order of 10 arc sec in which line intensity ratios change. These
data are being reduced through the computer programs described earlier,
but, experiments are also in progress to digitise the data as though
it had been obtained on a detector such as the IPCS and attempt to
handle it within STARLINK software in readiness for the data emerging
from the INT Cassegrain spectrograph.

    If this spectrum format is to be transferred into the realms of
silicon detectors there will be other problems to overcome. The
extended red response already available and the potential lowering of
the short wavelength cut-off will make it less attractive to use the
grism solution because of overlapping orders. Questions of acceptable
order separations and angular sizes of objects will undoubtedly affect
the use of prisms alone, as will any changes in mechanical operation
if the system is also required to function in a long-slit mode.
Experiments on the compound prism proposal have not been carried out,
but it is evident that the major problems here will be in extracting
and handling the data. Flat field calibration which spans this very
large wavelength range (3500 A-1μm) presents a significant problem
as well, and it remains to be seen whether the versatile or special
instrument becomes the solution to astronomical projects in the future.

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