HIGH RESOLUTION IMAGERY AND SLITLESS SPECTROSCOPY AT THE PRIME FOCUS OF THE CFH TELESCOPE

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ABSTRACT: Direct photographic work over a large field (1°) at the prime focus of the classical Canada-France-Hawaii 3.6m telescope has been achieved with a very good image quality (less than 0.5" FWHM). The basic characteristics of the Wide-Field Corrector are presented. Our Wynne Corrector was in fact redesigned to have the last optical surface flat so that a transmission grating could be replicated thereon. This arrangement with only three optical elements locates the gratings at a maximum distance from the focal surface resulting in improved resolution over a one degree field. The C.F.H.T. grating-plus-lens, or "grens" has a brightness limit which is fainter than the Palomar Sky Survey.

1. WIDE-FIELD, HIGH RESOLUTION DIRECT IMAGERY AT PRIME FOCUS

The design of the Wide-Field Corrector (WFC) of the 3.6m C.F.H. telescope, which has a paraboloidal primary mirror, is based on a three-lens formula originally devised and proposed by Wynne (1974). Before this break-through by Wynne, which required intervention in the computer optimization process, Ritchey-Chrétian telescopes, then at the height of astronomical fashion, needed fewer elements than classical telescopes like the C.F.H.T. Demands to change the C.F.H.T. to an R-C design were successfully resisted by Odgers who was the first Associate Director of the C.F.H.T. Corp. (from April 1973 to Sept. 1980). The first design of the C.F.H.T. corrector, also done by Wynne, was subsequently modified slightly by Richardson (1979) in order to make the last surface of the third lens flat. The theoretical resolution is excellent, as can be judged from the spot diagrams, Figure 1. This resolution along with the natural conditions on Mauna Kea and the technical performances of the telescope allow direct imaging over a large field (1°) with high resolution.

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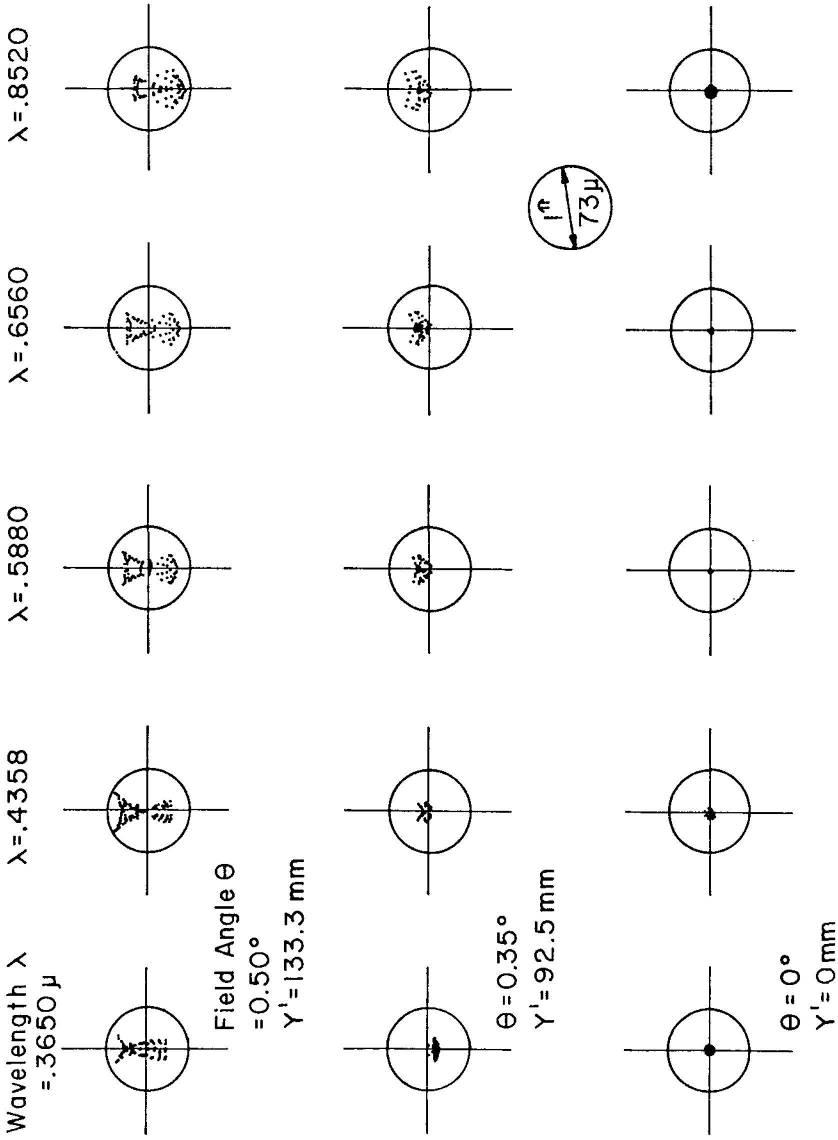

Figure 1. C.F.H.T. Wide-field corrector spot diagrams

Very often the observers looking through the eyepiece report images better than 0.5" during the exposures. This is confirmed by trailed plates obtained with the telescope locked at zenith position. These plates show images around 0.3 - 0.4 arcseconds. On hundreds of astronomical plates, after reduction and calibration, the stellar images have a full width at half maximum less than 1 arcsecond, and 0.7 arcsec resolution plates (Nieto and Lelièvre, 1981a) enabled a new description of the M87 jet (Figure 2; Nieto and Lelièvre, 1981b) and fine study of the central part of NGC 2903 where 25 knots can be detected instead of the 6 previously known.

The glass is BK7 with extended UV transmission of 93% at 3800 Å, 83% at 3500 Å, 43% at 3300 Å, and 21% at 3200 Å.

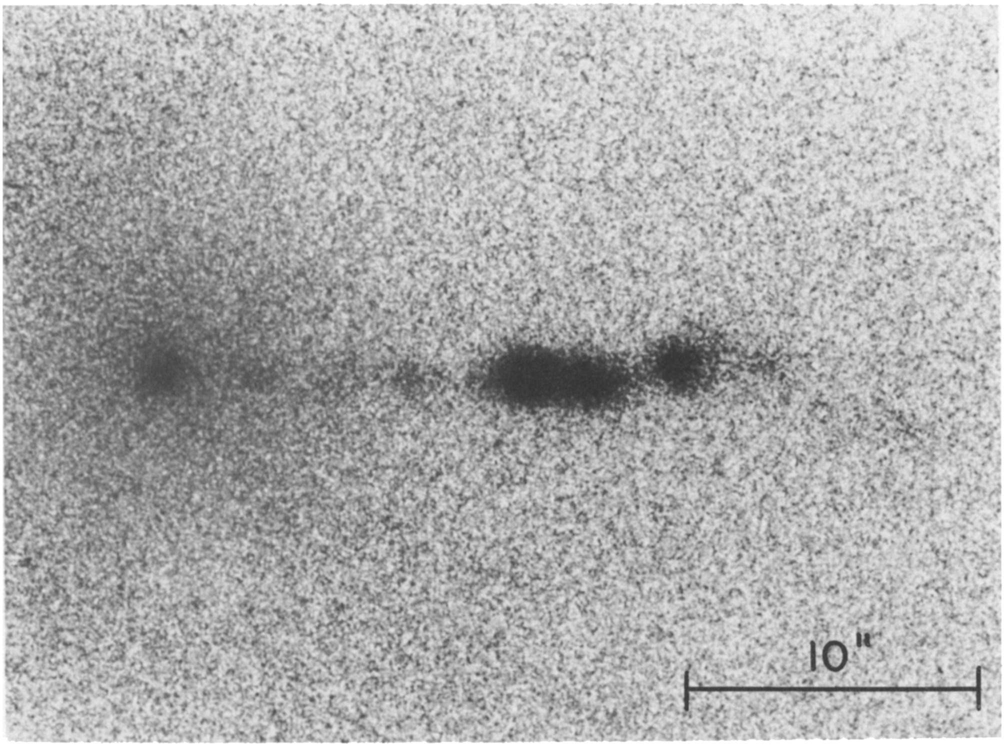

Figure 2. Nucleus and jet of M87 through BG385 filter, 3 min exposure, with wide-field corrector on IIaO plates. Resolution, after reduction is 0.7 arcsec.

2. LOW DISPERSION, SLITLESS SPECTROGRAPHY AT PRIME FOCUS

Toraldo di Francia (1949) showed that a grating in a converging beam produced coma, which could be eliminated by the opposite coma produced by locating the grating off the axis of a parabolic primary mirror; however, this arrangement is not suitable for wide-field work.

Hoag and Schroeder (1970) used a transmission grating in the converging beam of a telescope to do low dispersion, slitless multi-object spectroscopy at a long focal ratio where coma compensation was not necessary. For use at higher dispersions (or shorter, i.e. faster, focal ratios) Bowen and Vaughan (1973) used a weak prism for the blank of the grating (i.e. "grism"). The coma introduced by the prism and the grating balance each other.

The first use at a prime focus was the grism at the K.P.N.O. 4-meter telescope described by Buchroeder (1974). The grating and prism are separate and the prism is tilted to reduce astigmatism. Its five optical elements allow multi-object spectra over a half degree field.

At C.F.H.T., the slitless spectrograph system is called a grens because the grating is replicated on the last surface of the third lens of the corrector which is flat. This last lens is wedged with a very small angle for coma compensation. The optical layout, first suggested and evaluated by Richardson, is shown in Figure 3 (such a modified type of Wynne corrector with a flat final surface has recently been optimized by Harmer at the Royal Greenwich Observatory for the 2.5 metre classical telescope for the La Palma Observatory and thus will be capable of operation as a grens).

We have three interchangeable last elements for

- Direct Imagery
- Slitless spectrography at 2000 Å/mm
- Slitless spectrography at 1000 Å/mm

The interchange takes a few minutes.

Buchroeder (1974) has shown that for a fixed distance from focus, the coma introduced by a grating in a convergent beam varies linearly with reciprocal groove spacing, while astigmatism varies as the square of the reciprocal groove spacing. Therefore for a fixed Reciprocal Linear Dispersion (R.L.D. in Å/mm), aberrations will be kept to a minimum if the grating is located as far as possible from the focal plane. In our case, with the long back focal distance of the WFC (223mm) it is possible to obtain a R.L.D. of 1000 Å/mm by a rather coarse transmission grating (44 g/mm) directly replicated onto the lens.

		Green	Blue
Dispersion	=	2000 Å/mm	1000 Å/mm
Blaze	=	5000 Å (3500/8500 Å)	4300 Å (3500/6000 Å)
A Wedge	=	.68° ± .05°	1.11° ± .05°
α Tilt	=	.22° ± .02°	.39° ± .02°

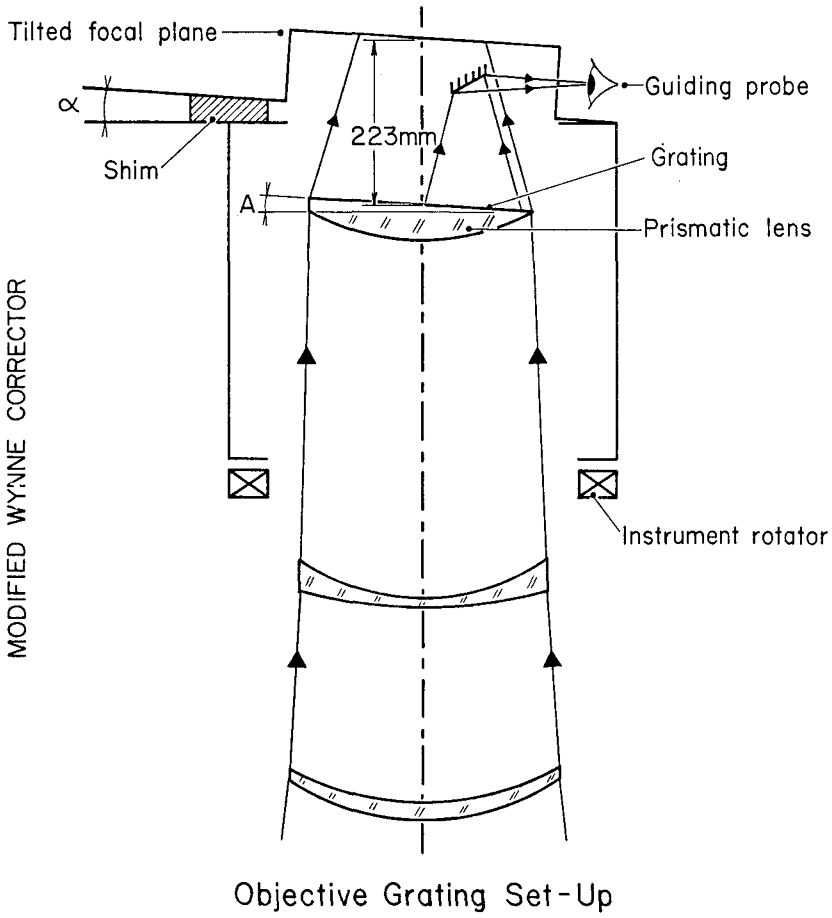

Figure 3. Slitless spectrograph system incorporating GRENS.

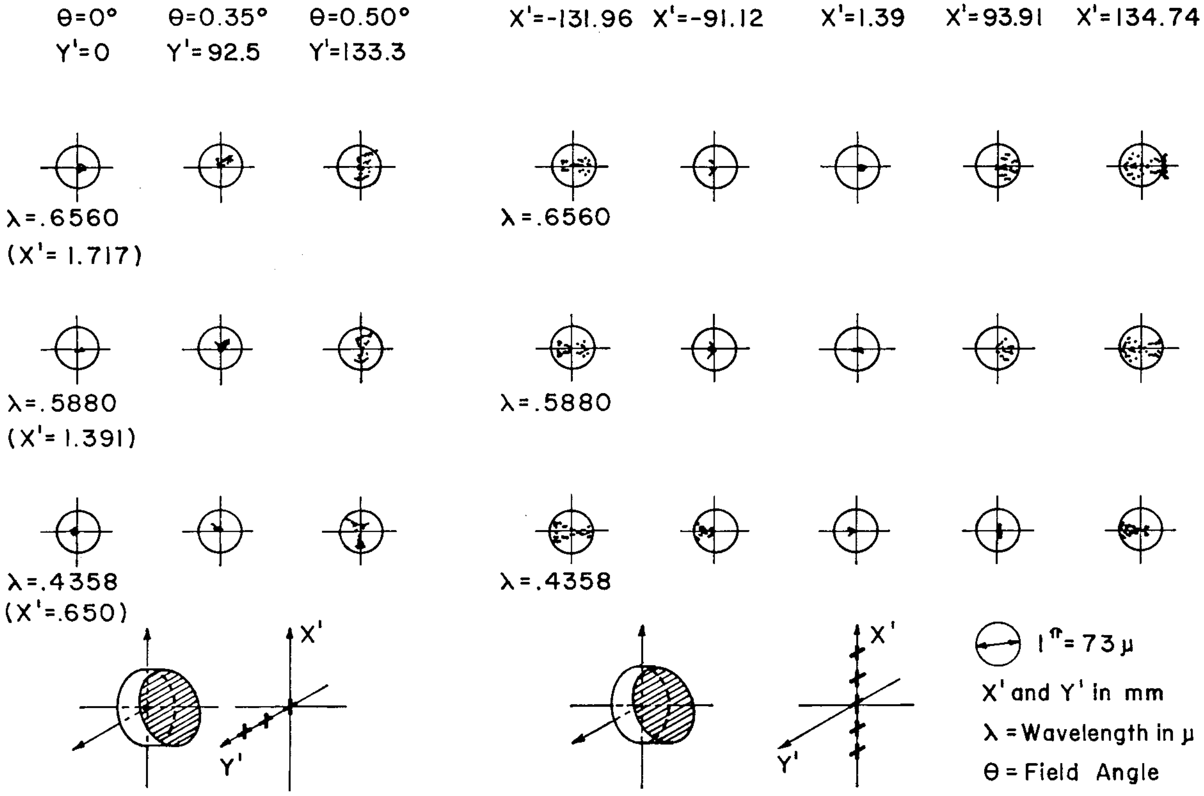

Figure 4. Spot diagram for C.F.H.T. 2000 Å/mm grens (21g/mm)

Thus, the optical quality is indeed very good over a 1° field. No correction for astigmatism is required with the grens as can be deduced from Figure 4. It shows a ray-trace spot diagram for the 2000 Å/mm grens; usually the monochromatic images are located well within a 1" diameter circle. The blue grens, 1000 Å/mm, has somewhat lower resolution but is satisfactory.

To focus the plate, the astronomer can still use the knife edge test by cutting the 1st order image in the direction perpendicular to the dispersion. The guiding with the guide-probe behind the grating is generally possible on a zero order image with a star no fainter than B=10. The efficiency of the grating in the zero order is only 5% and this image is slightly dispersed by the prism (1 to 3 arcsec).

The efficiency at blaze angle is greater than 70% for both grenses. With good seeing and dark sky, very faint spectra can be recorded. Figure 5 shows a spectrum of an 18 mag. quasar in a 10 min. exposure with the 2000 Å/mm grens. Lyman α is well visible and leads to a redshift of 3.2. In two hours of exposure we can reach objects of magnitude 22 at 2000 Å/mm and 21 at 1000 Å/mm. Figure 6 shows a well exposed spectrum of a 21.2 magnitude quasar obtained with the 1000 Å/mm grens.

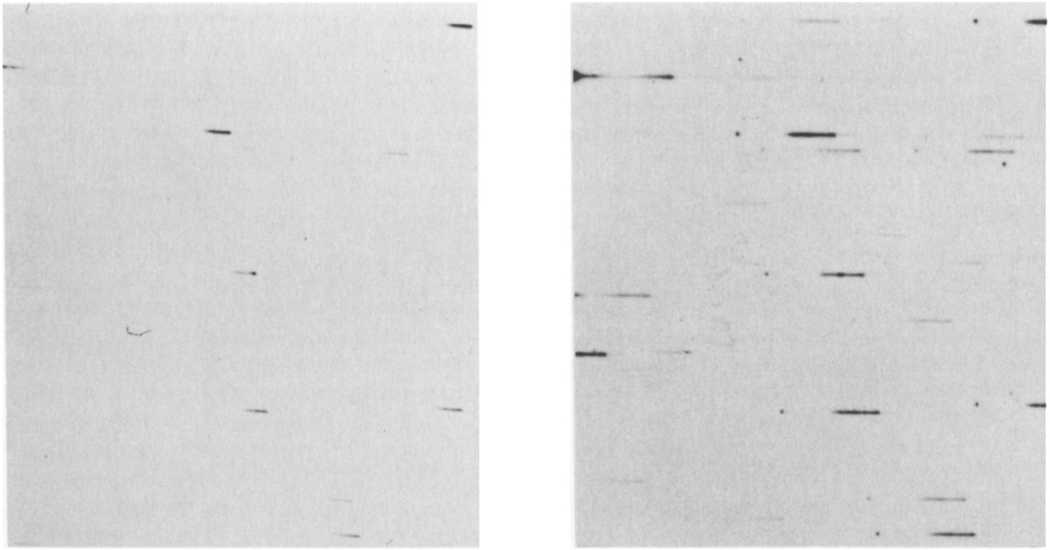

Figure 5. 18th magnitude quasar field obtained with the 2000 Å/mm grens; on the left is a 10 min exposure on IIIaJ while on the right, a 20 min exposure on IIIaF shows a spectrum in the range of 3500 to 7000 A.

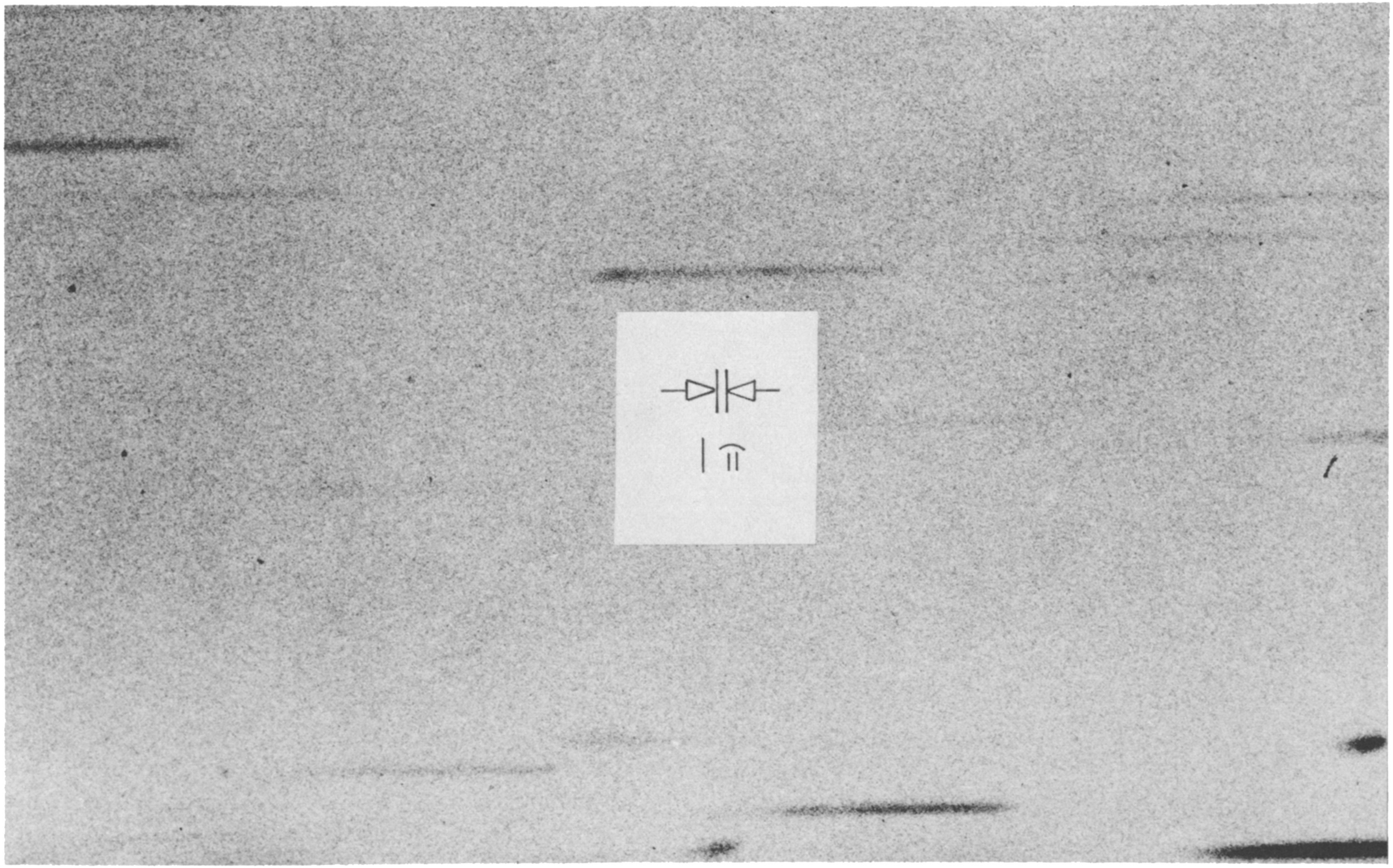

Figure 6. A 21.2 magnitude quasar, z=2, obtained by D. Crampton with 1000 Å/mm grens, 1hr exposure (IIIaJ). Wavelength increases to the right.

IIIaJ or IIIaF photographic plates are suitable for faint object slitless spectroscopy. The J plate gives a spectrum between 3300 Å (cut off by WFC) and 5600 Å with a rather smooth chromatic response but the IIIaF plate has strong variations of sensitivity according to the wavelength. On a IIIaF plate (Figure 5), for instance, each spectrum towards the red shows a strong increase of sensitivity around 6800 Å, giving an impression of an emission line being present. A red sensitive image tube does not have this problem.

In addition to the grenses, a grism will be operational soon, designed by Fouéré. The transmission grating is replicated on a separate wedge, mounted in the converging beam, in front of the focal plane. The R.L.D. will be adjustable anywhere between 1650 Å/mm and 2350 Å/mm by translating the wedge along the optical axis. It will be used with a 90mm ITT image tube. The S-20 photocathode of the tube along with the good efficiency of the grating in the red (blaze 7000 Å) should allow one to perform efficient slitless spectrography in the red region of the spectrum, over a 20" field. A red grens would have had higher efficiency and better resolution over a larger field, but its dispersion would not have been variable.

CONCLUSION

CFHT can provide, right now, together with the Wynne corrector, an elegant optical arrangement to obtain low dispersion spectra on faint objects. The brightness limit reached is fainter than the Palomar Sky Survey. In future, a large ITT image tube will be used with the grism and with the grenses. It is also planned to use an electronographic camera to increase the magnitude limit and the dynamics.

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