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Several Possible Designs for BFOSC

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Abstract. Various optical solutions are presented for the Beijing Faint Object Spectrograph and Camera of Beijing Astrophysical Observatory 2.16 m telescope. They are based either on dioptric or catoptric designs including an adaptation of the existing Cassegrain spectrograph.

1. Introduction

Multi-mode Multi-slit spectrographs are very important for improving the overall efficiency of modern large telescopes. Main idea are to have large field of view (FOV), many choices of the focal plane slit plates, many choices of spectral resolving power and to incorporate direct imaging. There are by now many such instruments used in different observatories. Most of them are small beam size dioptric systems combined with grisms. Among them the EFOSC1 and EFOSC2 are very famous.

BFOSC means Beijing astronomical observatory Faint Objects Spectrograph and Camera. The original idea was to copy EFOSC1 or EFOSC2 after some Chinese astronomers had some experiences in ESO. But after discussion, we found that a direct copy is not always the best choice. Then we asked for some help from the ESO engineers to re-design EFOSC for our 2.16 meter telescope. This may be a good choice,but leads to a too long and too heavy device for our telescope. The heaviest part being at the far end, this would cause larger flexure. That is why this kind of small beam size instruments is so heavy. Here we will discuss several other possibilities.

2. The reform of the original Cassegrain Spectrograph

It is a reflection grating spectrograph with beam size 75 mm, but the focal ratio of the collimator is f/8 rather than f/9 for the telescope. We can add a doublet with focal length 331 mm, clear aperture 25 mm at 41.4 mm in the front of the original focal plane and the f ratio of the light beam coming from the telescope becomes f/8 with the new focal plane at 36.8 mm after the lens. This lens will also give a pupil of the primary of the telescope at a distance of 336.78 mm. The size of the pupil is 37.5 mm. The collimator re-images this pupil on the grating with a size of 75 mm. With this arrangement the field of view (FOV) can be as large as 4 arc-minutes on the sky. The grating ruled area is 80x110 mm^2. It may be changed easily. For direct imaging we can use a plane mirror instead of the grating. The optical system is shown on fig. 1. The camera is a lens system or a Schmidt-Cassegrain type with focal length of 150 mm. The weight including the CCD dewar is about 60 kg, much lighter than the 200 kg of EFOSCs.

3. The Reflective version of BFOSC

As shown in Fig. 2, we use a focal plane field lens to make a pupil of primary of the telescope on a small 45° folding mirror so that we can use an on-axis parabolic mirror as main collimator and re-image this pupil on the grating with size 75 mm. The FOV of the collimator is mainly limited by the coma. If we choose 30" as a limit and the F_c as the focal ratio of the camera, P as the pixel size of the detector, for a telescope with diameter of D_T and focal ratio of F_T combined with a spectrograph, the FOV θ_T is:

$$\theta_T = K\frac{12F_T^2P}{D_TF_C}$$

For D=2160 mm, $P = 0.024mm$, $F_T = 9$, $F_c = 3.33$, K=1.5, we have θ_T=15.27' which is already larger than that of most systems. This 30" coma will give to the collimated light beam a focal ratio of 6.875 in the edge of the field which is large enough for keeping a spectral resolving power R much smaller than 10^6 (according to I.S. Bowen, when a grating is in convergent or divergent beam R$\leq$ $5.33f^2$, with f the focal ratio of the light beam). Of course it also puts some limitations on the focal length of the camera. If we use a Tek 1024 CCD with a pixel size 24μ, taking 2p as resolved element, the image size caused by this coma must be kept smaller than 1.5p (36μ), so the camera focal length must be shorter than 260 mm. To keep the obstruction caused by the folding mirror smaller than the secondary of the telescope, the beam size cannot be too small for a reasonably large folding mirror. Another solution is shown in Fig. 3.

We use a reflection grating instead of the grism. This leads to shorten the length of the instrument down to half the original one and the total weight will also be much lighter. Another advantage is that there is a much larger choice for gratings than for grisms and the former are easier to get in China at much lower prices. Therefore the change is easier to keep the highest efficiency. We also can use pure reflection system except a thin field lens very close to the focal plane of the telescope. The camera will be a reflection Schmidt type with deformed grating surface as image corrector. The grating is a normal replica with thin blank so that it is easy to get enough deformation with a simple active optical system in the rear side. This can work both in open loop or closed loop as we like. Many gratings with different ruling and blaze angle are fixed on different surface of a rotating wheel for choice, including a plane mirror for direct imaging. The active optical system is in the center of the wheel and will not rotate when the wheel rotates for grating change. This kind of arrangement will be much shorter, lighter and cheaper. The light efficiency will also be higher than that of a dioptric system, especially at short wavelengths.

The focal length of the camera is 250 mm. To avoid the obstruction we use a part of the 210 mm corrector as grating and a part of the 300 mm spherical mirror as reflector. The FOV is 6° for a diameter of 24.5 mm and is about 8° for the square Tek 1024 CCD. The aberration is small enough. If α is the angle between the collimated beam and the axis of the corrector plate of the camera, the real aperture of the corrector to be used is $d_\alpha = d/\cos\alpha$. With one grating as an echelle with blaze angle of 35°, ruling density 100/mm, the largest α is 42°, and the largest size of the grating is 95 mm. The largest residual spherical aberration is

$$2\rho=0.012\omega(0.75\alpha+\omega)\mathrm{f}/F_c^3=6\mu$$

here f is the focal length of the camera, ω is the FOV of the camera.
In Table 1 we give out the comparison between all those different systems.

Table 1. Comparison of EFOSC at 2.16m telescope with other BFOSCs

parameter	EFOSC1	EFOSC2	BFOSC1	BFOSC2	BFOSC3
collimator foc. length	320mm	320mm	360mm	675mm	675mm
beam size	35.56mm	35.56mm	40mm	75mm	75mm
camera f.	100mm	195mm	160mm	150mm	250mm
focal ratio	2.81	5.48	4.0	2.0	3.33
detector scale	34".00/mm	17".4/mm	23".87/mm	47".7/mm	28".00/mm
image quality	22μ	reasonable	35μ	35μ	$\leq 36\mu$
24μ size	0".82	0".42	0".57	1".14	0".69
2 pixel slit w.	1".64	0".84	1".14	2".28	1".37
Tek 1024 FOV	840" square	430"	584"	1167"	706"
λ range[a]	0.36-1μ	0.36-1μ	0.36-1μ	0.4-1μ	0.3-1.1μ
light eff.[a]	0.49-0.79	0.70-0.81	0.70-0.81	0.45-0.70	0.55-0.86

[a]for 2" slit width and 600l/mm grating first order

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Discussion

P. Atherton: Could you give us an estimate of the budget for this instrument (preferably in DM).

S.Y. Jiang: It is about 100,000 DM not including the TEK1024 thinned AR coated CCD which costs about US$ 65,000.

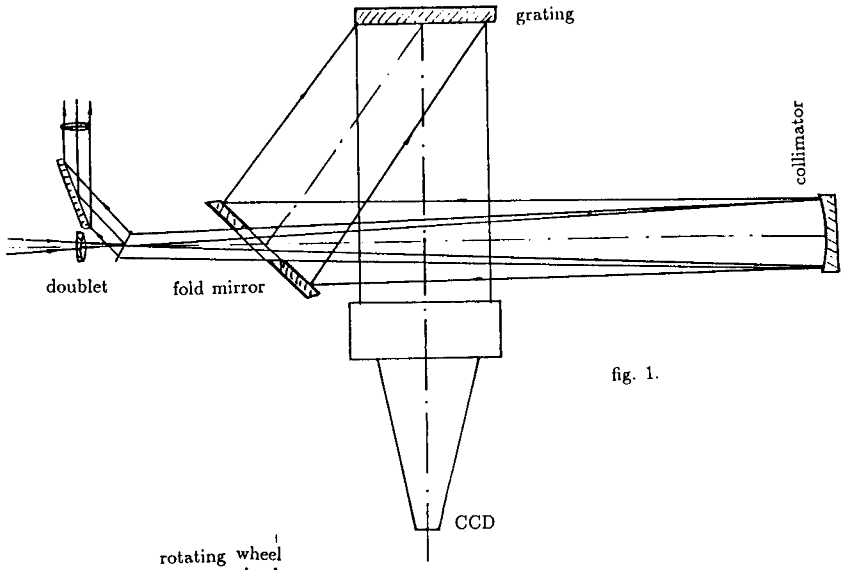

fig. 1.

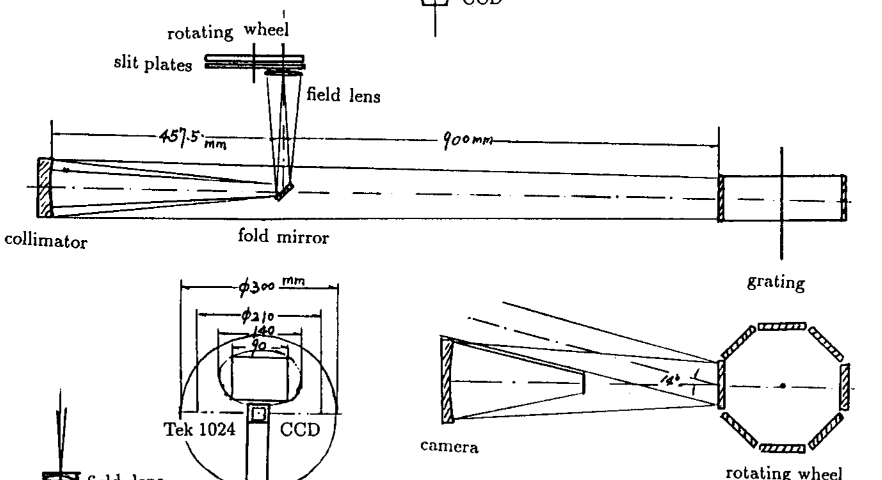

Fig. 2

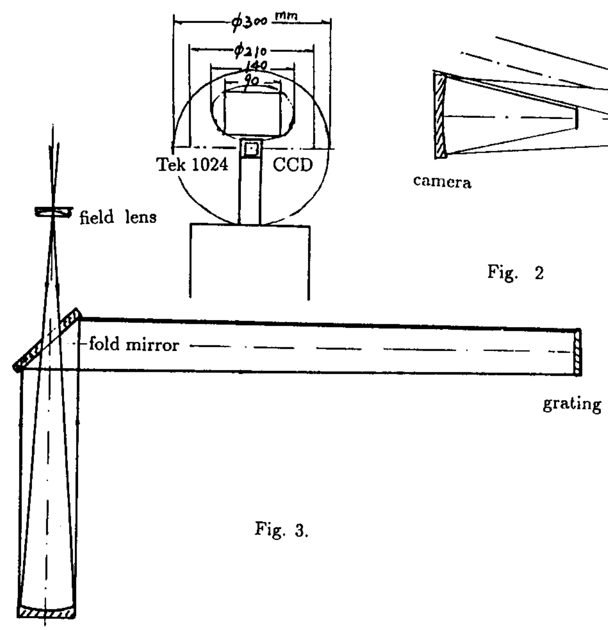

Fig. 3.

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