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FLAGS - A Fibre Linked Astronomical Grating Spectrograph

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Abstract. The design and construction of a fibre - linked grating spectrograph, developed for astronomical studies, is described here. The spectrograph has a resolving power of about 10,000 over the visible region (4000 - 7000 Å). We have used optical fibres to guide light from the telescope to the spectrograph. Some preliminary results, demonstrating the performance of the instrument, are presented.

Key words : grating spectrograph, optical fibre

1. Introduction

We describe in this paper, a high-resolution grating spectrograph which has been developed for astronomical studies in the visible region. The spectrograph has been specifically designed for use on the 1.2 m Mount Abu telescope. It has an f/10 optics of 1.5m focal length. Due to this it is not directly coupled to the Cassegrain end of the telescope. Instead, it is kept in the adjoining Coude room, and light from the telescope is guided to it through an optical fibre. The spectrograph has been built completely in-house at P.R.L., except for the bought-out items like the holographic grating, optical fibre etc. The instrument has been tested on the 1.2m Mount Abu telescope and found to perform to its designed specifications.

2. Optical configuration and lay-out

The optical configuration of the instrument is shown in Figure 1. It consists of mainly two parts i) the pre-spectrograph optics unit, and ii) the spectrograph proper. These are described in details below :

2.1 Pre-spectograph Optics Unit

This unit is designed to perform the following functions : object acquisition, focussing and centering of the stellar image on the optical fibre and finally enabling manual or auto guiding during extended exposures. It is attached at the Cassegrain plate of the telescope.

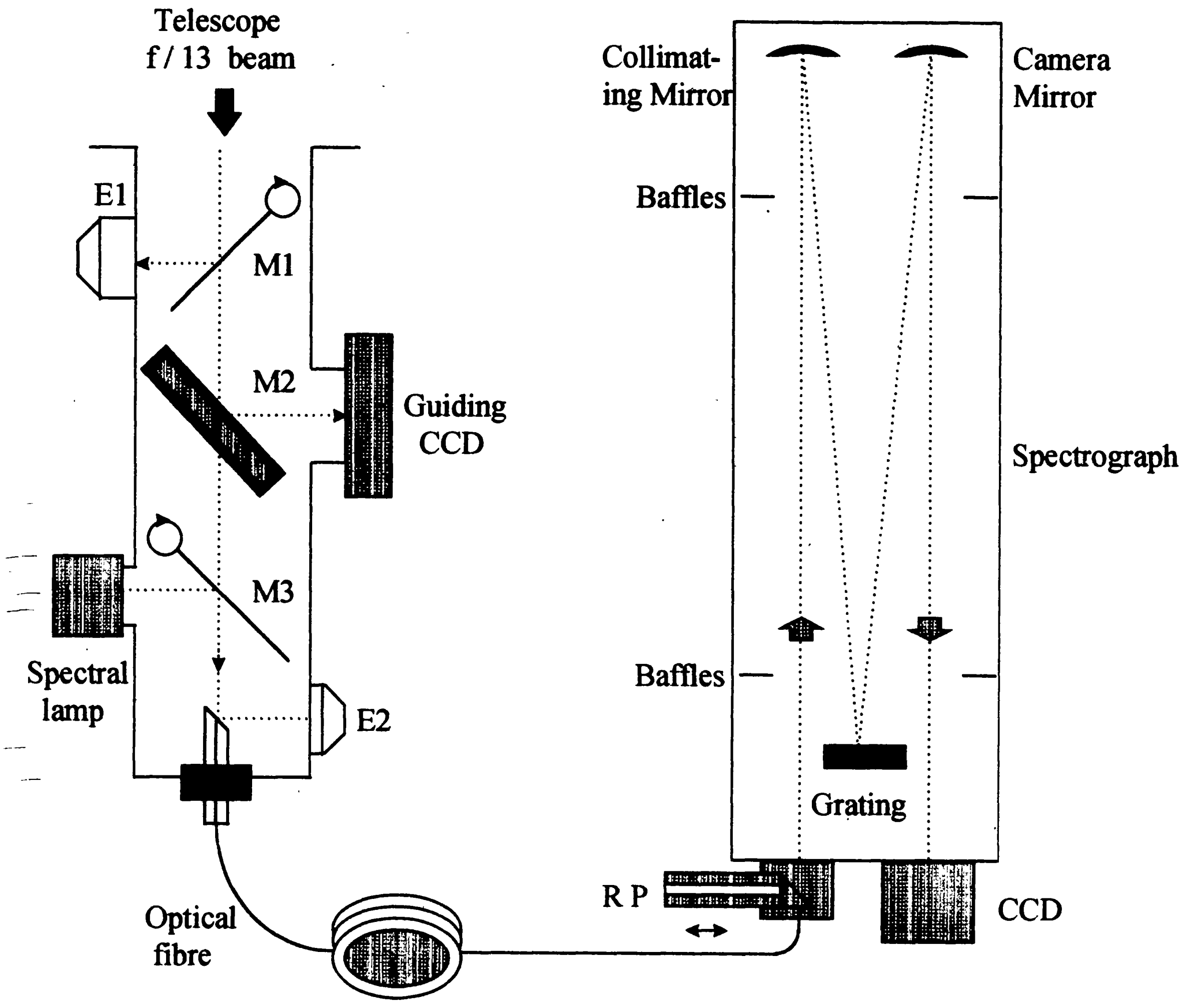

Figure 1. A schematic lay-out (not to scale) of the pre-spectrograph optics and the spctrograph : E1, E2 are eyepieces, M1, M3 are flip mirrors, M2 is the guiding mirror assembly and RP is a retractable prism (see text).

The f/13 beam from the telescope first encounters a 45 degree flip - mirror M1, which folds the beam into an eye-piece E1, thereby allowing the object to be acquired. Following the flip-mirror is another sliding mirror assembly M2 at 45 degrees, which is used for guiding. Mounted on the same mirror assembly is a carefully selected, imaging - quality glass flat with a $\lambda/4$ finish on both surfaces. The flat has an anti-reflection coating on one side to minimise reflection losses. The final transmission through it amounts to about 95 percent of the original intensity; the rest of the 5 percent of light can be used for on-source guiding. The guiding beam enters the guiding port (Figure 1), giving rise to two vertically displaced stellar images of differing intensities. The brighter of these, corresponding to the uncoated top surface of the flat, can be positioned on the cross-wires of an eyepiece with an illuminated reticle, and guiding can then be done manually. The positioning of the stellar image on the cross-wires of the guiding eyepiece, is accomplished by a Melles Griot X-Y positioning stage on which the eyepiece is mounted.

Alternatively, for guiding during longer exposures, the eyepiece is replaced by an ST-4 CCD camera (Santa Barbara Instruments Group) which serves as an auto guider. The difference in spatial position of the two stellar images, formed by the guiding flat, helps position only the brighter image on the guiding CCD. The choice between manual guiding and the auto-guiding CCD, depends largely on the brightness of the star being studied. We have been able to manually guide stars of and upto tenth magnitude. At this faintness the CCD has some difficulty in guiding satisfactorily.

An arrangement for off-axis guiding has also been made. In this, a mirror with a central hole is mounted on the same sliding mirror assembly M2, adjacent to the guiding flat. It allows the light from the object under study to pass through to the fibre, and off-axis stars can be picked up for guiding.

Following the above guiding optics, comes the optical fibre. We have chosen an optical fibre, type FIP 320385415, made by Polymicro Technologies (U.S.A) which has core/ cladding/ buffer dimensions of 320/385/415 microns and a transmission loss of 4 db/km at 800 nm. This particular fibre was chosen since the focal-ratio-degradation (FRD) properties of an almost identical fibre FLP 320385415, have been well-studied by Barden (1988). For an input f/13 beam (as is the case for us), the above fibre appears to transmit (by extrapolating Barden's data) about 80 percent light within an f/10 cone at the exit end. This suits the maximum possible f/10 acceptance angle of the spectrograph collimating mirror. A better matching of the spectrograph and the fibre output f-ratios can be done by using some additional input optics. The best, of course, would have been the availability of fibres having better FRD properties. Launching the star-light into the fibre core efficiently, poses some difficulty. If we consider the point spread function of a star, given the average seeing conditions at Mount Abu, to be Gaussian with a FWHM of 1.5 arc seconds, then the light of the star at a 2 sigma level (containing 95 percent or almost all the starlight) would be contained in an area of diameter of about 2.55 arc seconds. This would correspond to a spot size of about 200 microns at the Cassegrain focus, given a plate scale of 13 arc sec/mm there. This, as may be noted, is smaller than but comparable with the 320 micron diameter of the core of the fibre, and hence light has to be launched accurately into the fibre to prevent coupling losses. To achieve this, the fibre has been mounted in a brass ferrule, the end of which is cut at 45 degrees, polished and aluminized. The 45 degree face can be viewed, through a eyepiece E2, shown in Figure 1. The fibre tip and the star image can both be seen. The star image can then be positioned exactly on the fibre tip, by using the telescope hand-set or an XYZ positioning unit in which the ferrule is mounted. We have found the above arrangement of launching the starlight into the fibre to be quite satisfactory. Once the star is centered on the fibre, the auto guiding CCD can be put in track mode, or the star can be quickly centered on the cross-wires for manual guiding.

It may be mentioned, that the optical fibre tip is at a distance of 48 cm from the telescope Cassegrain plate. As has been shown (Banerjee et al, 1997), this back focal distance falls well in the regime where the stellar image degradation due to spherical aberration is almost minimised. Finally, a flip - mirror M3, is incorporated in the pre-spectrograph optics. It permits light from a spectral lamp, to be focussed on the fibre tip for the purpose of calibrating spectra and checking instrument performance and stability.

2.2 The Spectrograph

The grating spectrograph has a conventional Czerny - Turner configuration. The spherical collimating and camera mirrors are of 1.5 m focal length and 15 cm diameter. They are mounted on kinematic mounts to enable the axial alignment of the various optical elements. Light enters the spectrograph from the fibre-tip, which is placed at the focal plane of the collimating mirror. The exact position of the focal plane was determined, by auto collimating the image of a slit onto itself via the collimating mirror and the grating kept in the zeroth order. Close to the fibre end, there is a small right angle prism RP (Figure 1), which can be put in and out of the path of the optical beam from the fibre. This retractable prism, which is mounted in a tube, permits viewing of the fibre-tip prior to taking the stellar spectrum, and thereby ensuring that star light has been launched efficiently into the fibre at the telescope end. Baffles have been placed inside the spectrograph, to minimise the problem of stray light.

At present, we are using a holographic grating manufactured by Jobin Yvon (France), with a line density of 2400 lines/mm. It is blazed for 4000 Å, under Littrow conditions, in the first order. The grating has been mounted at a distance of 231 mm from the slit / image plane, towards the collimator / camera mirror, to satisfy the requirements of a sufficiently large flat image field at the camera focal plane (for example, James and Sternberg, 1969). While this is not particularly significant for the single optical fibre in use now, it would be useful in future plans to go in for imaging spectroscopy by using a large bundle of fibres (for example, Vanderriest and Lemonnier, 1987). The linear dispersion on the camera focal plane is 1.77 Å/mm at 6000 Å. A thermo-electrically cooled CCD, using a Kodak KAF-1600 Grade I chip, serves as the detector. It is mounted on a precision translatory stage, and can be moved to determine the position of best focus at the camera- mirror focal plane. The CCD has a 1536 × 1024 pixel format, each pixel being 9 microns in size. The rms read-out noise is $8e^-$. The spectral dispersion across each pixel is typically 0.018 Å/ pixel. However, the achievable spectral resolution, is limited by the 320 micron size of the fibre core which, after considering a mean anamorphic magnification factor of 0.92 (Schroeder, 1987) ranges between 0.5 to 0.7 Å for wavelengths in the visible region. Thus, a resolving power of the order of 10,000 is achieved in the spectrograph.

Wavelength selection, or positioning of a desired wavelength on the CCD is achieved by rotating the grating. There are two arrangements for this, which work in tandem. Firstly, a stepper motor, giving 200 pulses per revolution, is coupled to the grating shaft through a 2-stage gear assembly with a 1000 : 1 reduction ratio. Therefore, each pulse of the stepper motor, essentially rotates the grating, by about 0.1 arc minutes in angle. Next, an optical encoder, is mounted directly on the grating - housing shaft (through a flexible-coupling to take care of mechanical misalignments), to read the position of the grating. The resolution of the encoder, which is 10000 pulses per revolution, has been multiplied electronically to four times this value, viz. 40,000. The output of the encoder can be read from a digital display on the electronics unit which controls the forward/backward movement of the stepper motor by the requisite amount. By measuring the number of pulses of the encoder required for different known wavelenghts, a calibration of the encoder pulses can be done. It may be noted that the resolution of the stepper-motor gear assembly combination is by itself higher than that of the encoder. However, the effect of back-lash in the gear wheels, does not ensure repeatability to the desired level, and the use of the encoder became necessary. This pertains only to wavelength selection. Finally, accurate wavelength calibration, however, is always done with a spectral lamp, before and after the actual measurements. This allows reliable radial velocities to be obtained, with an accuracy dependent on the pixel binning factor used on the CCD in the dispersion direction. Typically, for a binning factor of 4 pixels, the radial velocity can be determined with an accuracy of 3.5 km/s.

3. Instrument performance and discussion

The spectrograph was used for its first observational run in April 1998. Till date, we have had three observational campaigns with it on the 1.2m Mount Abu telescope. Its resolving power capability, was verified in the laboratory by using a narrow 100 micron slit illuminated by a Helium lamp. As can be seen in Figure 2, the two Helium lines at 5875.62 and 5875.97 Å (transitions between 2^3P - 3^3D levels) are well resolved.

Since one of the main programmes using this spectrograph is on Be stars, we show in Figures 3(a) and 3(b), the 6563 Å Hα emission line spectra from two Be stars, Khi Oph (m_v = 4.24) and Psi Per (m_v = 4.3). Note that Khi Oph shows the typical wine - bottle shaped profile observed in some Be stars, while Psi Per shows a large central absorption dip associated with the shell phenomenon. Our profiles compare well with those obtained by other observers (Hanuschik et. al, 1996, Andrillat and Fehrenbach, 1982), after taking into account the intrinsic temporal variation of lines profiles in these stars. So far, we have attempted and

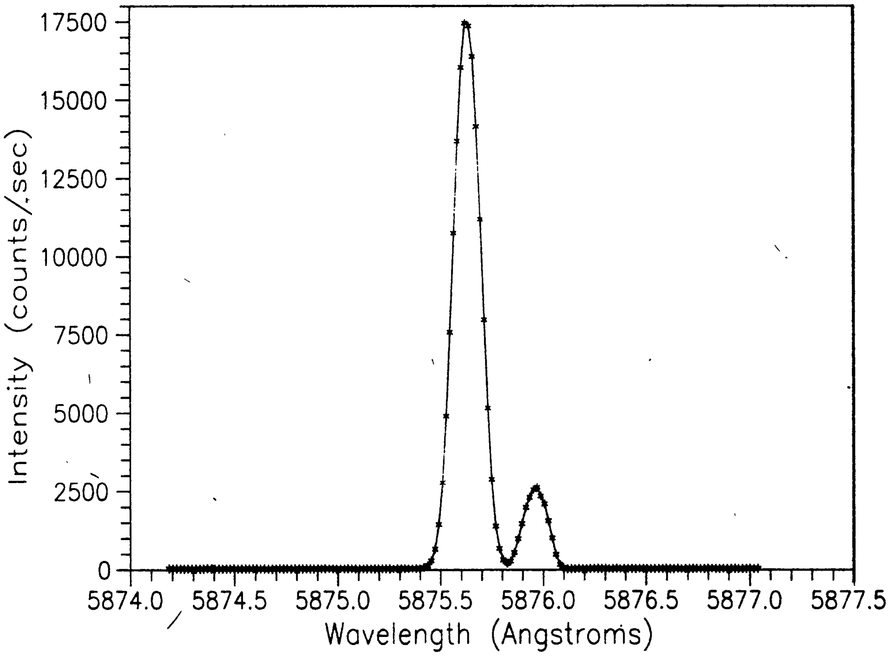

Figure 2. The resolved profiles of Helium lines at 5875.62 and 5875.97 Å are shown. The profiles were obtained by illuminating the spectrograph entrance slit, set at 100 microns, by a Helium spectral lamp.

obtained spectra of stars, upto m_v=8.0, with integration times of 10 minutes (for example the Herbig AeBe star AB Aur, m_v = 7.2). The main limitation on going for fainter objects, is the noise of the dark counts (0.1e⁻/pixel/sec at -20° C) of the thermoelectrically cooled CCD being used at present. It is planned, in the future, to replace the present detector with a liquid nitrogen cooled larger size CCD to enhance the instrument capability. The grating being used at present, is also slightly overfilled, and procurement of a larger grating is being planned. As mentioned earlier, it is also intended at a later stage, to go in for imaging spectroscopy, by replacing the single fibre by a bundle of fibres.

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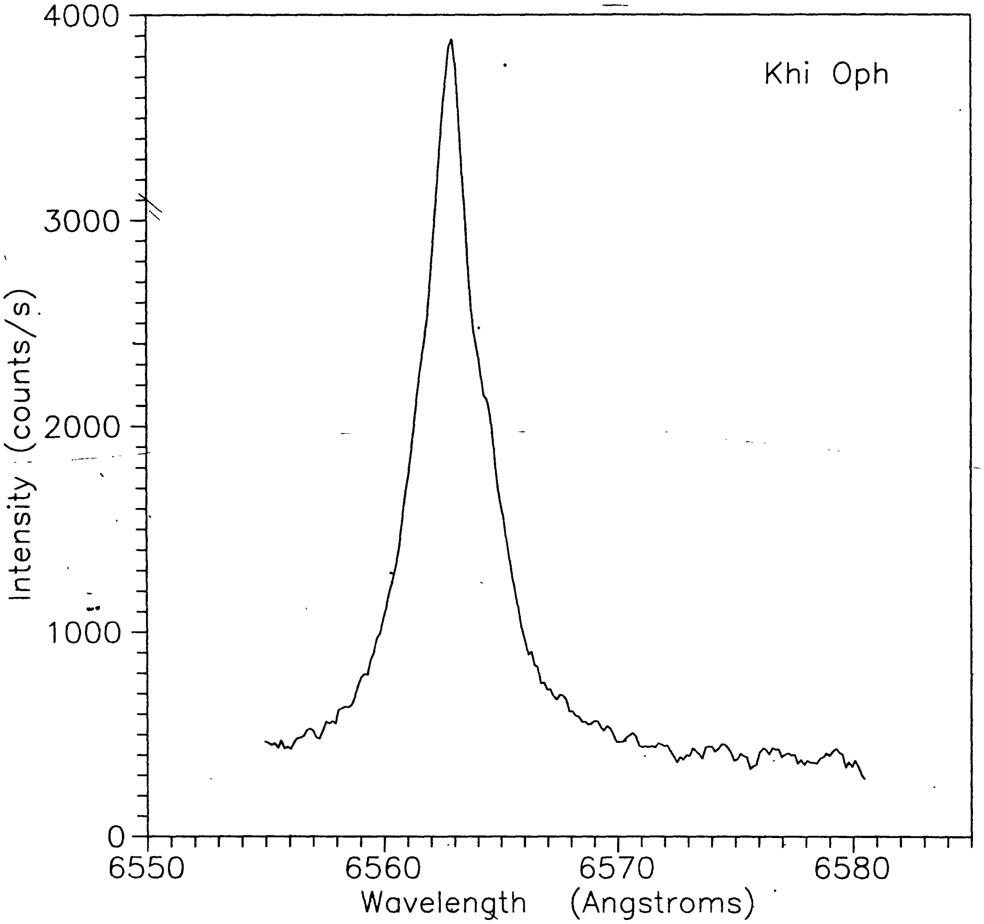

Figure 3(a). The 6563 Å Hα emission line spectrum from the Be star, Khi Oph. The wine-bottle shaped structure of the profile, sometimes observed in these stars, may be noted.

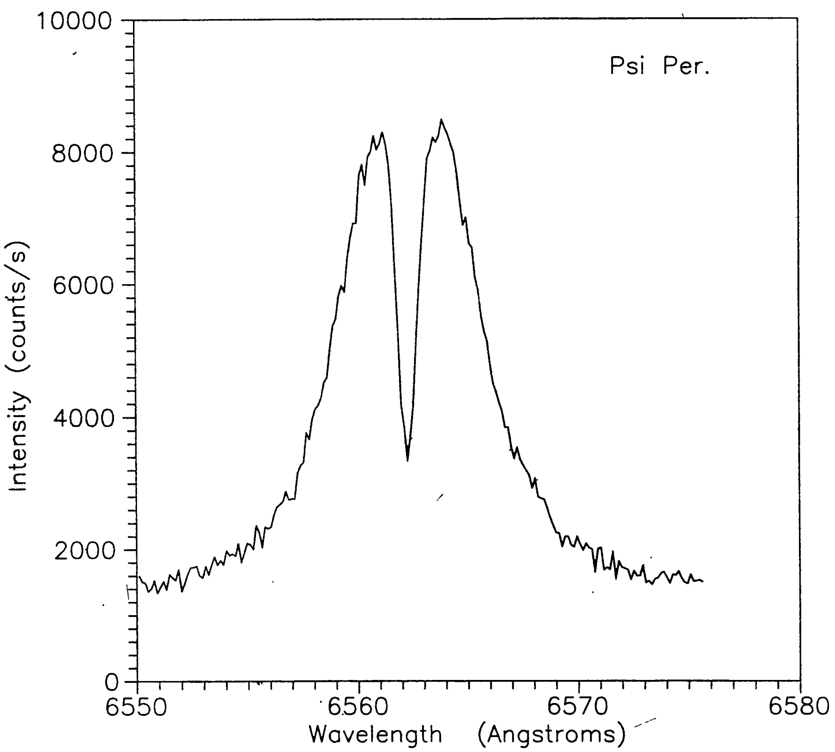

Figure 3(b). The 6563 Å Hα emission line spectrum from the Be star Psi Per.

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