AN INTEGRAL FIELD SPECTROGRAPH (IFS) FOR LARGE TELESCOPES

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ABSTRACT: A combination of an array of small lenses together with fibre optics can be used to produce a high transmission spectrograph which can record the spectra of many image elements simultaneously. Such a design may play an important role in ground based observations preparing for the NASA-ESA Space Telescope programmes.

Future programmes for the 2.4m Space Telescope (angular resolution 0.1 arc second) require supporting spectroscopic observations made at the highest angular resolution (1 arc second or better) attainable with large aperture, ground based telescopes. A study of the Faint Object Camera of the Space Telescope (Courtès et al., 1981) convinced us that preliminary spectrographic explorations of 20 arc second fields would be a necessary preparation for the space observations. The new spectrograph design proposed in this paper enables one to obtain in one exposure simultaneous spectra of an array of 1 x 1 $arcsec^2$ image elements.

The image at the Cassegrain focus of a telescope can be enlarged by auxiliary optics and projected on a multi-square shaped lens array (Figure 1). Each lens gives at its focus an image of the entrance pupil of the telescope and any beam collected by the front surface of one of the lenses forms an exit pupil which can be considered as equivalent to that from the slit of a spectrograph. The focal ratio of the collimator of this spectrograph should be equal to the diagonal focal ratio of the square shaped lens. All beams coming from the matrix of exit pupils are collected by the field lens of a focal reducer (Courtès, 1952) equipped with a normal field prism (Chopinet et al., 1958) or a Carpenter prism-grating (Courtès, 1964; Courtès, 1980). Figure 1 shows the optical arrangement and the geometry of the multiple spectra obtained at the detector.

Another solution, proposed by Lachièze-Ray (1980) and Vanderriest (1980) selects the image elements with fibre optics (see also the paper by Angel in these Proceedings). The properties of fibre optics are being constantly improved due to their growing use in telecommunications

C. M. Humphries (ed.), Instrumentation for Astronomy with Large Optical Telescopes, 123–128.

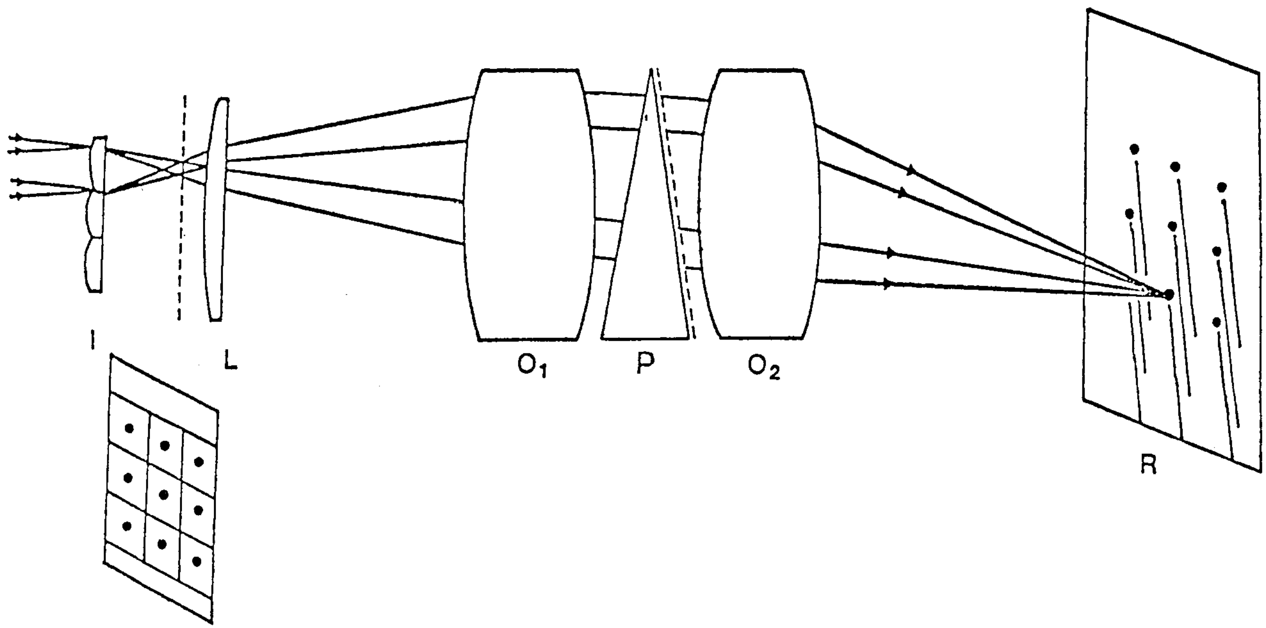

Figure 1. Integral Field Spectrograph: The array of lenses I is placed in the telescope focal plane and produces a chequer pattern of exit pupils; the focal reducer LO_1O_2, equipped with a Carpenter prism-grating P, gives a two-dimensional distribution of the spectra corresponding to each pupil.

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technology and the fibre ends can be arranged linearly to match the dimensions of a spectrograph slit. By combining these two methods, i.e. by using an array of lenses and fibre optics, an interesting new version of an integral field spectrograph (IFS) is obtained.

Thus the collecting area of the fibre optics can be increased by using them in series with a multi-lens array. The flux $\emptyset_1$ admitted at the front end of a fibre bundle is limited for two reasons:

(1) for a hexagonal distribution of fibres (Figure 2), $\emptyset_1$ is less than the incident flux $\emptyset_o$ and even in the most favourable case $\emptyset_1 = 0.89\emptyset_o$

(2) the diameter of the most efficient area is related to the type of fibre used but is always smaller (dotted circle in Fig. 2) than the fibre diameter (in the mode of reflection or refractive index variations). Other losses are due to defects of the circular contour of the fibres.

These geometric limitations result in a loss of efficiency, often reaching 0.4 which is unacceptably large for astrophysical applications. Another disadvantage is the unavoidably irregular alignment of the fibre bundle output giving uncertainties about the true positions of the images. On the other hand, the fibre cores have a near-perfect transmission for the short lengths (a few cm) used in this application.

Our new design has been proposed in order to avoid these losses in efficiency. The multi-square shaped lens array is located in the focal plane of the telescope and the dimensions of the lenses correspond to the angular resolution neeeded. For 1 arc second it is necessary, of course, to use an enlarger lens between the focus of the telescope and

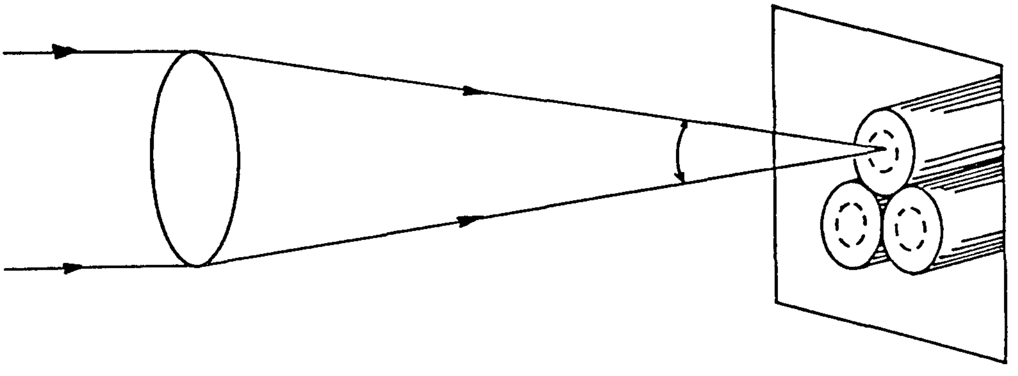

Figure 2. Hexagonal distribution of fibres; the zone of high efficiency at the entrance to each fibre is the core denoted by a dotted circle.

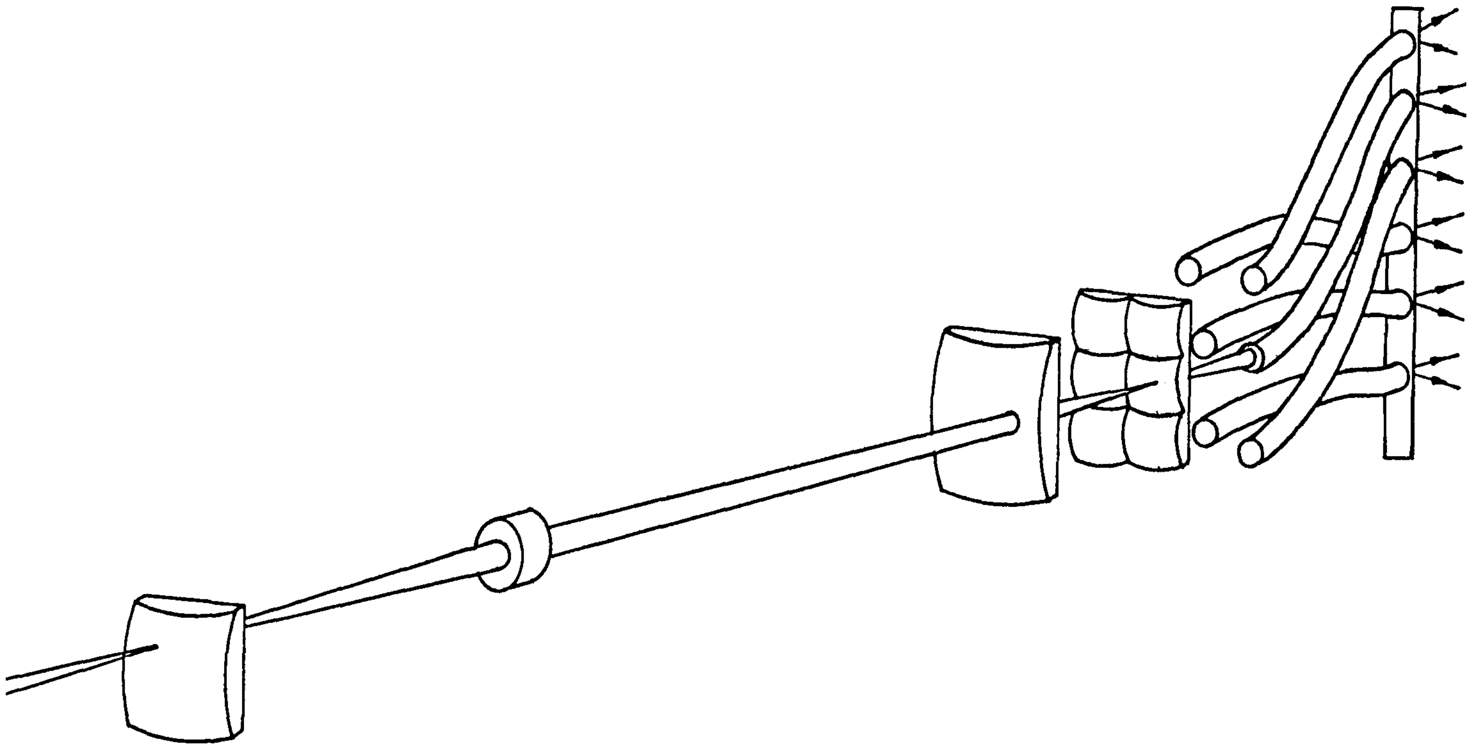

Figure 3. Integral Field Spectrograph (IFS) showing the application in which all image elements are transmitted to a spectrograph slit. The components shown are: the field lens in the focal plane of the telescope, the enlarging lens, the secondary field lens, the array of square shaped lenses, and the fibres going from the exit pupil to the slit.

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the plane of the lens array. Each lens then forms an exit pupil small enough to be collected by the core of each fibre so that all of the flux in the focal plane is transmitted by the fibres. One can choose various geometrical arrangements for the distribution of the ends of the fibres including the particular case where the fibres are aligned along the slit of a spectrograph. The arrangement of the system is shown in Figure 3.

The ability to obtain spectra of many image elements simultaneously is well suited to the range of two-dimensional detectors which are available nowadays and observations made recently (Vanderriest, 1980; Hill et al., 1980) using fibres adapted to a slit spectrograph are very promising. In practice, the focal ratio of the collimator should be larger (by about 0.1 radian) than the focal ratio of the telescope. In the case of the IFS, the focal ratio at the entrance of the fibres is the diagonal focal ratio of the square shaped lens.

We have recently produced an IFS for extragalactic studies having a dispersion of 60 Å/mm and a focal ratio of f/2. This solution is in fact very flexible and smaller or larger dispersions could be used equally well. The detector foreseen for the IFS is the "Laboratoire d'Astronomie Spatiale" photon counting TV camera (Cenalmor et al., 1978; see also Boulesteix et al., these Proceedings). Image processing can extract, at any wavelength, the photometric contours making this method one of the best and most widely applicable for obtaining monochromatic images of a given object (see other solutions given by Courtès, 1964).

For low resolution work, it is not necessary to use a spectrograph, and after expansion of the beams from the fibre bundle a simple post-focus, objective grating technique (Courtès, 1964) can provide a good two-dimensional display of the spectra of the image elements.

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