ESO 16 METRE VERY LARGE TELESCOPE

Instrument Matching in Spectroscopy and Direct Imaging

Daniel Enard

European Southern Observatory, Karl-Schwarzschild-Str. 2,
D-8046 Garching bei München, FRG

Introduction

Preliminary feasibility studies have been carried out in the framework of the ESO VLT project which have permitted the evaluation of several possible approaches to the instrument matching problem. This paper briefly discusses the detector long term perspective, recalls the main scaling laws and attempt to provide some quantitative analysis of spatial performance of instrumentation in a few typical cases. Field slicing technique is proposed as a potential solution to solve detector matching problems.

1. Detector considerations

The choice of a detector is not a trivial matter and depends basically on the application. Factors such as telescope size, field of view, spectral bandpass and wavelength are determinant. The main difference between CCDs and photon counting systems - to which one limits this discussion - is that the CCD has generally a better responsive quantum efficiency than the PCS, but has a small but finite read-out noise whereas the PCS is limited only by photon noise.

Fig.1 (taken from a paper by M. Cullum) (1) shows the typical limit for which the 2 systems have equivalent performance; 2 values of the CCD read-out noise, typical of present day detectors are considered. The signal-to-noise ratio is calculated for the total photon signal which includes the sky contribution. For situations in which the dark current is comparable to other noise sources, or dominant, such as for medium and high dispersion spectroscopy, the curves are modified slightly compared to the no-dark case as indicated by the dashed curves.

Proceedings of the IAU Colloquium No. 79: "Very Large Telescopes, their Instrumentation and Programs", Garching, April 9–12, 1984.

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

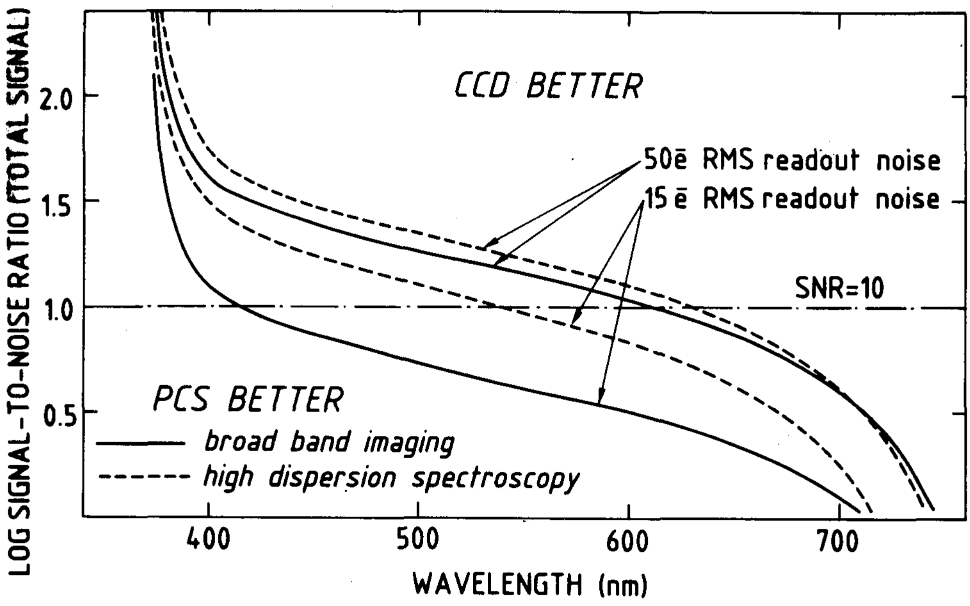


Fig. 1 Signal to noise ratio for equivalent CCD and PCS performance

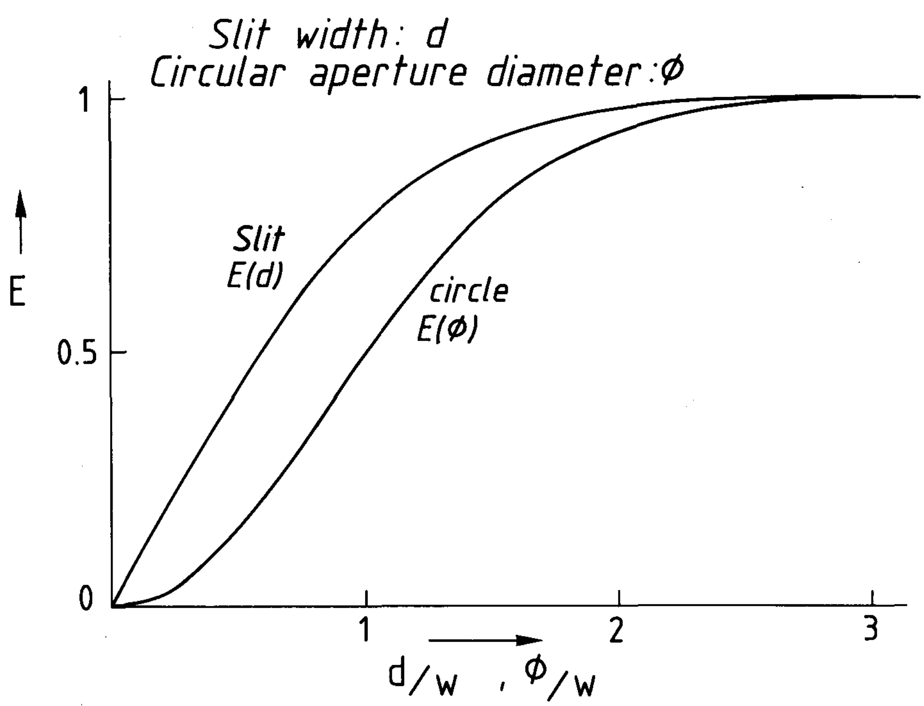


Fig. 2 Energy passed by an aperture for a Gaussian point spread function of FWHM : W

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

In this case, however, the result is dependent on the telescope focal length and the integration time. The curves shown have been calculated assuming an 8 meter telescope with F/2.0 final imaging and a 1 hour integration. Longer integration times and focal lengths would accentuate this shift from the no-dark situation even more.

In the example shown it can be seen that at 50e- read-out noise the difference between the solid and dashed curves is small. At 15e-, the PCS is better shortward of the V-band only.

Signal-to-noise ratios less than 10 on the total signal would only rarely be encountered in the majority of observing programmes, and so the general conclusion at this stage is that for most applications, the CCD would be the preferred detector.

This conclusion is further reinforced if one considers the trends in CCD performance. Read-out-noise values in the range of 5 to 10 electrons are already obtained and recently ways have been found to boost CCD U.V. response (2).

There are other practical effects that have also to be considered. With PCS, the counting rate is limited typically to about 10^6 detected photons/sec for the total detector area. This sets a limit to the brightness of objects which can be observed and also leads to very long calibration procedures. With a CCD, the accuracy is generally limited by more treacherous effects, such as sky substraction problems and residual non-uniformities which are not completely stable and not fully understood. This explains why even with great care and using complex reduction procedures it is hardly possible today to improve the photometric accuracy much below the 0.5% level. In a long term perspective, however, there are hopes of reducing these effects either by a better understanding - hence better control - of the instabilities or to circumvent them by applying artful techniques, an example of which is the drift-scan technique (3).

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

The limited size of CCDs is a serious problem. Though relatively large PCS can be envisaged - it basically depends on the availability of large image intensifiers - it does not appear very easy to but several CCDs so as to make a large array. Larger CCDs may be developed but it is unlikely that solid state detectors much larger than 50 mm diagonal will ever be produced. The trend is rather to increase the resolution by reducing the pixel size, and keeping the overall dimensions small.

In conclusion, there is little doubt that in 10 years time the CCD will be a nearly ideal detector and will be preferred to photon counting for most applications. However, there is only moderate hope of significantly increasing the size of present day CCDs. This will be a major problem to be faced in matching instrumentation to large telescopes.

2. Imaging capacity of a telescope-instrument system

2.1 Image entropy

In the following we only consider the case of a 2D detector defined by X, Y, number of pixels in both directions and Δp the pixel interspacing. Pixels are assumed to be square.

The total number of independent image elements the system is capable of recording is:

$$H = \frac{S}{da} = \frac{X\ Y\ \Delta p^2}{D^2\ N^2\ d\alpha\ \ d\beta} \qquad (1)$$

S is the detector area, D the telescope diameter, N the equivalent relative aperture of the telescope and $d\alpha$, $d\beta$, da are respectively the angular dimensions and area of the image element as determined either by the seeing or by an intermediate aperture as, for example, in spectroscopy. It is assumed that the elementary image element is uniformly illuminated and that the image is not undersampled, i.e.

$$D\ N\ d\alpha \text{ or } D\ N\ d\beta \geqq 2\ \Delta p$$

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

H can be named "image entropy" of the system, by analogy with the signal entropy often used in information theory (4) and which would be in our case:

$$\frac{X\ Y\ \Delta p^2}{D^2\ N^2\ d\alpha\ \ d\beta} \cdot \log_2 \left(1 + \frac{S}{N}\right)$$

It is the minimum number of bits necessary to numerically code the image, where S/N is the available signal to noise ratio.

The "image entropy" is an adequate quantity to determine the field performance of a system.

a) Direct imaging

$d\alpha = d\beta$ = seeing disc angular diameter, H is the number of elements in the picture and $H \cdot d\alpha^2$ is the two-dimensional field of view.

b) Stellar spectroscopy

The spectral coverage is $\Delta\lambda = H\ d\lambda$ where $d\lambda$ is the spectral resolution.

c) 2D spectroscopy (long slit)

The spectral coverage is $\Delta\lambda = \frac{H\ d\lambda}{k}$

where k is the number of independent image elements observed simultaneously.

The image entropy is theoretically independent of the way the information is collected. For instance, image slicers - simply because they don't escape the Lagrange law - do not modify the entropy as long as they are perfectly adapted to the prevailing conditions. This is seldom the case in practice and it must be recognised that design constraints and compromises that could be necessary in order to adapt a particular instrument and detector to a specific telescope, will in general degrade the entropy.

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

As an example, let us consider the case of a cross-dispersed echelle spectrogram. The peculiar shape of the individual orders as well as the necessary separation will usually necessitate a loss of useful detector area of 50%.

Another interesting example is the case of MMTs, or optically combined arrays, or more generally of any unfilled aperture. For point-like object spectroscopy the beams may be combined using a multi-prism combiner that would superpose the different pupils. If perfectly matched to the seeing conditions the entropy is the same as that of a single telescope of same collecting area.

If the different images are simply superposed the image scale is again determined by equation (1), but D is then the diameter of the overall aperture. In case of an MMT made of 4 mirrors of diameter Do, the necessary spacing between the mirrors will give D~4•Do whereas the single dish telescope of equivalent collecting area has a diameter of 2 Do. Therefore the entropy in that case is 4 times less than for an equivalent single dish, and for identical spatial performance a detector 4 times larger is needed. This is the reason why very large MMTs or arrays are ill adapted to imaging at a combined focus. Independent observation at each telescope and subsequent data co-adding would, on the contrary (and assuming perfect detectors), give a performance identical to that of a single dish.

H being inversely proportional to the square of the telescope diameter and to the square of the seeing disc dimension, it results clearly that, with equal seeing conditions, pixel size and detector dimension, a VLT will yield much less spatial information than a smaller telescope, especially as the aperture is unfilled. This is an important conclusion to remember when setting the scientific objectives of a VLT.

2.2 Matching the instrument aperture to the object

The instrument aperture is usually a slit but may also be circular, as in the case of a fiber optic pick-up. Fig.2 shows the amount of energy passed by these 2 types of aperture for a purely Gaussian star profile, of FWHM w. To collect 90% of the light, a slit must have a width of 1.4

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

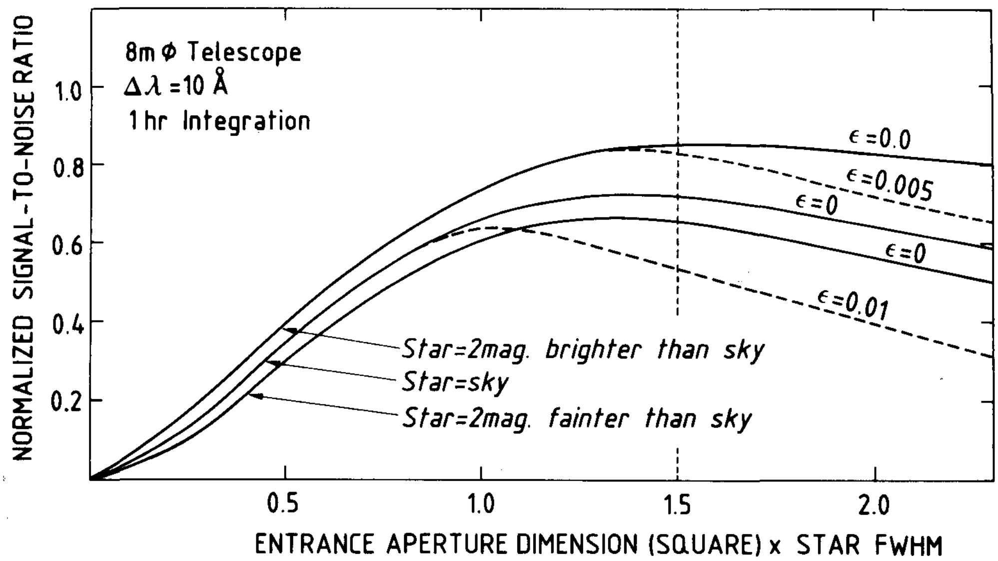


Fig. 3 Signal to noise ratio and spectrograph aperture

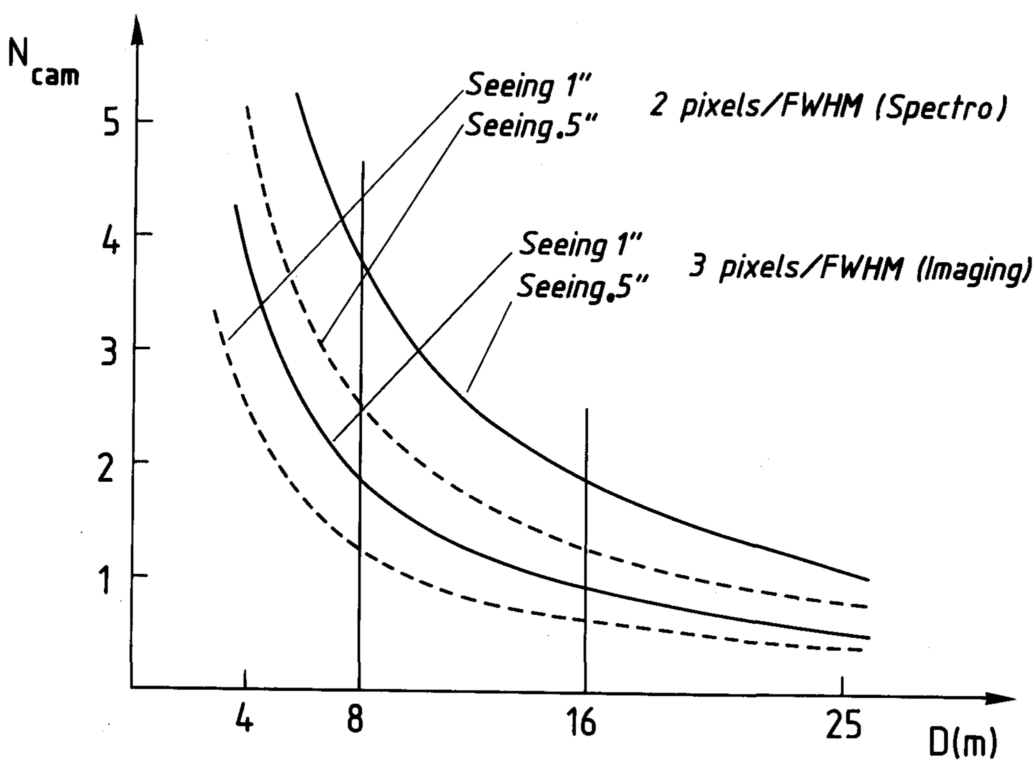


Fig. 4 Camera/Telescope relative aperture for various seeing conditions and a match of 2 and 3 pixels/image element

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

x w and a circular aperture must have a diameter 1.8 x w. When the sky background has to be considered the situation is different since the larger the aperture, the more sky pollution; there is an optimum which is shown by Fig.3 [M. Cullum (1)] for different cases. When the calibration accuracy sets the limit, the maximum is obtained for a smaller aperture.

In practice, whenever an intermediate aperture is used, it should be between 1 and 1.5 times the seeing disc as defined by its FWHM. If one also considers possible pointing and tracking errors, a larger aperture may have to be used. This is an important result since many instrumental analyses only consider an aperture equal to the FWHM of the seeing profile. This leads either to overly optimistic conclusions or to a considerable loss of efficiency. In what follows, we generally consider apertures equal to 1.5 x FWHM.

2.3 Pixel matching

This is a long debated issue for which there is no clear cut conclusion, despite some efforts to find an objective answer (5).

The problem lies basically with the fact that astronomical requirements are not always the same and that sooner or later it becomes necessary to trade-off photometric accuracy against spatial resolution: that is to say that the answer basically depends on the final objective, observing conditions and to some extent on personal bias. Nevertheless, it is relatively easy to define mean and generally accepted values based on current experience. In direct imaging as well as in spectroscopy it is generally accepted in accordance with the sampling theorem that a scale of 2 pixels per FWHM of the image profile is adequate. A slight aliasing may occur because the image power spectrum has wings extending beyond the Nyquist frequency, but this has never be found to be a real problem in astronomy. In order to improve the S/N it should be possible to slightly undersample but the tendency is often the opposite using about 3 pixels/FWHM. This is explained by the fact that detectors are not always as perfect as assumed in theoretical calculations, and a moderate oversampling and hence redundancy helps in reducing the influence of local effects such as defective pixels, spurious spikes, cosmic ray events, cross-talk etc. In spectroscopy and with an intermediate aperture of 1.5 x FWHM the same oversampling leads to a scale of 2 pixels per FWHM of the star image.

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

The conclusion is that for direct imaging with no intermediate aperture the scale should be about 3 pixels/FWHM of seeing disc whereas with an intermediate aperture it should rather be 2.

Fig. 4 shows the relative aperture of the telescope (or of the camera) to be used in those 2 cases and for two values of seeing. The pixel size is 25 μm which corresponds to most present day detectors. Indeed, the pixel binning facility offered by CCDs can be used to create artificially larger pixels and then relax the requirements on relative aperture. This, however, will affect the field of view which, to be maintained, will necessitate larger detectors. This is not without drawbacks since the dark current increases with the detector area as well as the number of cosmic ray events.

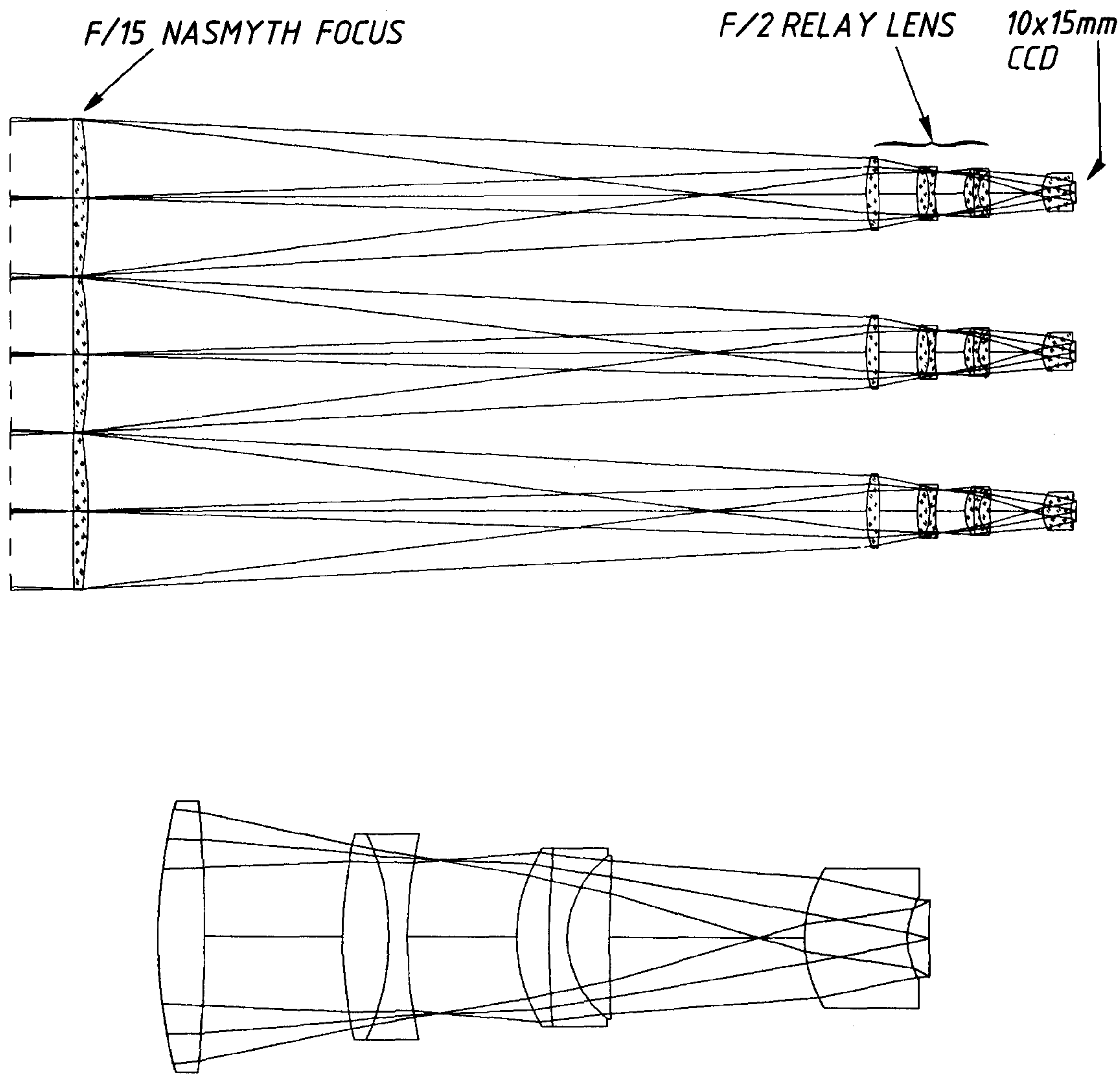
It seems difficult to correctly match telescopes larger than 8-10 m to modern detectors without facing either tremendous optical problems in designing ultra fast cameras or correctors, or expanding the detector area. The field slicing technique described below may, however, help to solve that problem.

3. Instrument matching - The imaging case

It has already been shown (2.1) that imaging at the combined focus of any unfilled aperture (MMT or array) leads to considerable loss of imaging capacity and is not the optimum way to use a VLT. We therefore limit the following discussion to the case of conventionally filled apertures.

The obvious requirement for direct imaging is a large field, thus a large detector area and a fast focus. As said before, it is unlikely that CCDs large enough to cover the 5 to 20 arcminute field of view that would be desirable, will ever be available. Two possible solutions to this problem would be either to use butted CCDs or field slicing techniques. The development of 2D arrays of butted CCDs is by no means impossible but would certainly imply a major technical development; it is however the only practicable solution for work at a prime focus. The second approach, field-slicing is more adapted to a slow focus such as a Cassegrain or Nasmyth. The two options are therefore discussed separately.

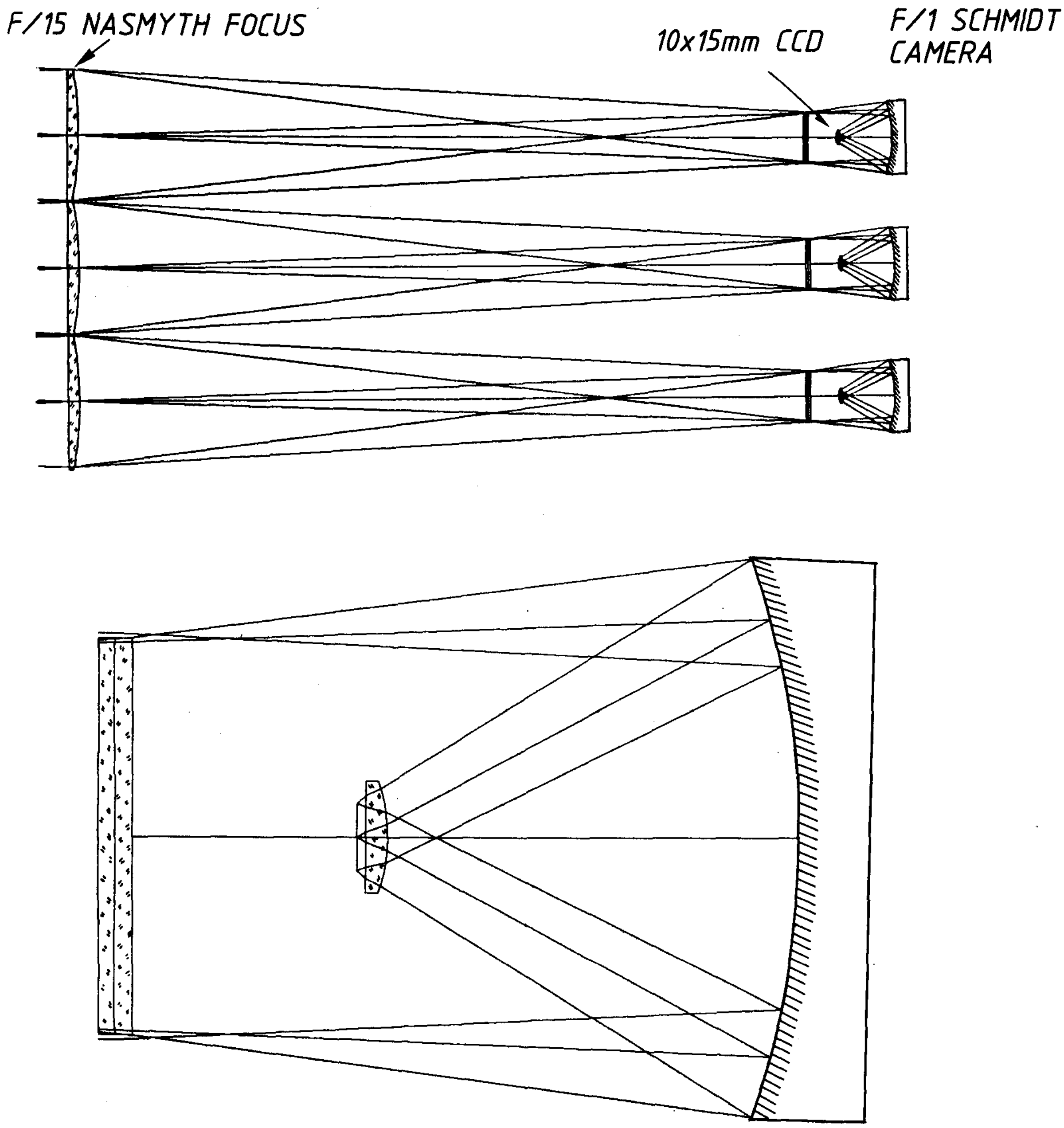
https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press



LARGE FIELD IMAGING AT NASMYTH FOCUS USING THE FIELD SLICING TECHNIQUE (F/2)

Fig. 5

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press



LARGE FIELD IMAGING AT NASMYTH FOCUS USING THE FIELD SLICING TECHNIQUE (F/1)

Fig.6

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

3.1 Prime focus

As shown on Fig.4, the relative aperture should ideally be F/2 for an 8 m telescope and F/1 for a 16 m. Large field dioptric correctors for an F/2 telescope are feasible and several designs have already been proposed (6) (7); if a suitable detector becomes available, it should be possible to work at the P.F. up to 8 m telescope size despite the fact that any P.F. corrector for such a telescope size will be extremely bulky and difficult to operate. This is much more doubtful for larger telescopes that will necessitate extremely fast correctors (or correctors/reducers) which would consist of a complex combination of aspheric mirrors.

In this case and whatever type of coatings may be available in the future, the efficiency would be similar to that obtained at a Nasmyth with a focal reducer. For fast F/ratios the technique of field slicing described subsequently looks more attractive.

3.2 Nasmyth or Cassegrain

Making a large field and very fast focal reducer is by no means easier than making an equivalent corrector for a prime focus, and the detector requirements remain identical. The technique of field slicing seems a promising alternative. Fig.5 and 6 show two typical designs working at F/2 with a fully dioptric relay lens and at F/1 with a finite conjugate Schmidt-type camera.

The Nasmyth image plane is sliced into elements corresponding to the individual detector field of view by an array of contiguous field lenses each of which images the telescope pupil separately onto the corresponding relay lens. The only condition is that the overall dimension of the relay system does not exceed the corresponding field dimension at the telescope focal plane. This is relatively easily obtained at a speed of about F/15.

There are immense advantage in using that technique:

- Small (existing) detectors can be used directly and no specific detector development is required.

- The field requirement on the optical system is considerably reduced making the design of fast relay systems with excellent performance possible. An F/1 equivalent aperture becomes quite a realistic goal.

- The individual focal reducers are small and easy to produce.

- Since each system works for a specific region of the telescope field it is possible to optimise each of them so as to compensate for the particular mean field aberration of the telescope, such as curvature and astigmatism.

- The system is modular and can be expanded. The limit is rather set by the amount of data to be manipulated and recorded.

4. Instrument matching - Spectroscopy

We voluntarily limit the scope of this paper to grating spectroscopy for this is the most critical application in terms of instrument matching. Other techniques, such as Fabry-Perot and FTS, have the same requirements as direct imaging and would not generate problems specific for a VLT.

Case of extended objects

We implicitly assume that the VLT will mainly be used to look at point-like objects for which the major problem is to match the slit width to the prevailing seeing. The reason for this is that a VLT cannot yield much gain for observation of extended objects. This is clearly shown by the following expression which gives the photon flux P passing through an entrance aperture $d\alpha$, $d\beta$; Bo and Bs are respectively the object and the sky relative brightnesses.

$$P = k\ D^2\ (Bo+Bs)\ d\alpha\ d\beta$$

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

For a given spatial resolution we still have

$$d\alpha = d\beta = \frac{n}{D}\frac{\Delta p}{N}$$

and $$P = k(Bo+Bs)\,\frac{n^2\Delta^2 p}{N^2}$$

the S/N per pixel is $$k\,\frac{\sqrt{(Bo+Bs)}}{N}$$

The ratio of object and sky contributions is indeed independent of the instrument and of the telescope size, and the total signal depends only on the pixel matching, and of the relative aperture of the camera which should be as fast as possible. These 2 parameters become more critical with a VLT, and it is clear that observation of extended objects should rather be achieved with smaller telescopes.

4.1 Slit width, resolution and grating requirements

With the symbols already defined and those shown by Fig.7, the projected slit width of a grating spectrograph is:

$$\ell p = \text{Ncam}\ D\ d\phi\ \frac{\cos i}{\cos i'} \qquad (2)$$

$d\phi$ is here the angular slit width projected on the sky. With the mean slit width value defined before (1.5 x FWHM) and for a 3 pixels match we have:

$$\ell p = 3\ \Delta p \text{ and } d\phi = 1.5\ d\alpha$$

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

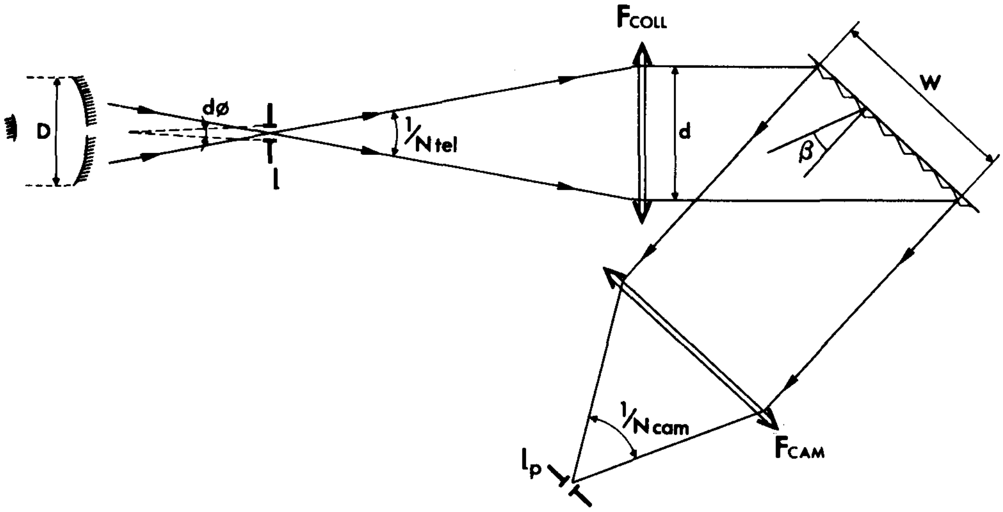


Fig. 7 Spectrograph schematics

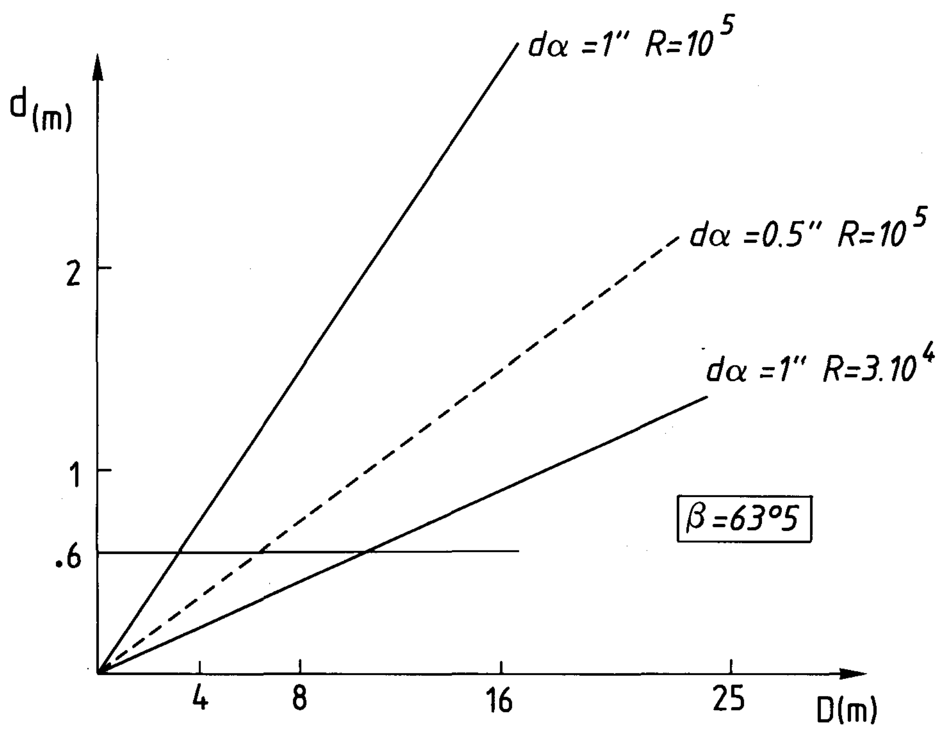


Fig. 8 Grating height versus telescope diameter (slit width is set 1.5xFWHM of seeing disc $d\alpha$)

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

therefore if $i \approx i'$ (Littrow mode):

$$N_{cam} = \frac{2}{D}\frac{\Delta\rho}{d\alpha} \qquad (3)$$

The camera aperture is given by Fig.4 for two values of seeing. For seeing values worse than 1" it becomes impossible to envisage fast enough cameras for telescope sizes beyond 8 m. It is clear then that image slicers, which shrink the image in the direction of the dispersion, remain the only possibility.

The grating angular dispersion is given by the expression:

$$\frac{di'}{d\lambda} = \frac{m}{a \cos i'}$$

and the spectrograph reciprocal linear dispersion can then be deduced as

$$\frac{d\lambda}{dy'} = \frac{a \cos i'}{m \, N_{cam} \, d} \qquad (4)$$

where d corresponds to the groove length, 1/a to the groove ruling frequency and m to the grating order. The turbulence-limited resolving power of the instrument is defined as:

$$R = \frac{\lambda}{d\lambda} = \frac{m\lambda}{a} \cdot \frac{d}{D \, d\phi \cos i} \qquad (5)$$

By introducing the effective grating width:

$$W = \frac{d}{\cos i}$$

$$R = \frac{m\lambda}{a} \cdot \frac{W}{D \, d\phi} \qquad (6)$$

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

In Littrow mode $i = i' = \beta$, the grating blaze angle, and it can be shown that:

$$R = \frac{2\ d\ \mathrm{Tan}\beta}{D\ d\phi} \qquad (7)$$

If we assume $d\phi = 1.5\ d\alpha$ we have:

$$R = \frac{4}{3}\frac{d\ \mathrm{Tg}\beta}{D\ d\alpha} \qquad (8)$$

Fig.8 gives the grating height d (or diameter of the collimated beam) versus telescope diameter for several resolution and seeing conditions and for a 63.5° blaze angle. It is clear that with a grating height limited to say 0.6 m, it is not possible to reach a very high resolution with telescopes larger than 8 m without the help of image slicers which would reduce $d\Phi$ and relax accordingly the requirement on d. Present day technology cannot provide gratings larger than 300 x 600 mm. However it is possible to assemble gratings in mosaics and monolithic holographic gratings could be produced in larger sizes. We believe nevertheless that a 600 mm x 1200 mm grating size (for 60° blaze) is close to the reasonable maximum on which we should base a spectrometer design.

For very high resolution or mediocre seeing conditions, image slicers become anyway mandatory. This is further strengthened by the following consideration: In spite of all the care that will be taken to obtain the best possible seeing with the new generation of telescopes, it is unrealistic to believe that sub-arcsecond seeing could be obtained for most of the observing time (at least it is unrealistic to base a telescope design on such an assumption). The question is therefore what to do during bad seeing periods? All observations on faint objects either imaging or spectroscopy will have to be restricted to excellent seeing periods because of sky background limitations, thus there are only two possibilities, either one closes the telescope, or one finds a way to use that time for work where the sky background is not the major limitation. Clearly it is our belief that instrumentation for high resolution spectroscopy, where the objects are typically brighter than the sky, should be designed for good as well as for poor seeing conditions. We strongly oppose over-optimistic views that assume exclusively excellent seeing conditions for a VLT.

4.2 First practical example: Echelle grating spectrometer

Table 1 illustrates different instrumental trade-offs which provide the same basic resolving power. A detector of 25 x 25 mm (1000 x 1000 pixels) has been assumed to determine the number of orders recorded and the ruling frequency.

The first instrument is optimized so that a direct coupling without image slicer could be possible under excellent seeing conditions. The grating utilises a classical blaze angle and should be a mosaic made out of at least 4 of the biggest gratings ever produced. The second instrument is half the size of the previous one. In order to keep the same resolution, the camera is a factor 2 slower and the angular slit width a factor 2 narrower. Consequently, the entropy and the spectral coverage are 4 times smaller. The third instrument would provide initially the same characteristics as the first one but is based on a more dispersive grating - in fact the most extreme blaze angle that has ever been produced. A factor of 2 in the grating area and in the optics diameter is gained which makes this solution very attractive, at least if the technical difficulties involved in producing such a grating do not outweigh its advantages.

The preferred mode of operation of an echelle is the cross-dispersion which permits recording a maximum of information on a 2D detector, but the requirements imposed on the cross-dispersing element are likely to cause major problems. A prism would hardly be able to provide sufficient dispersion, and a grating cross-dispersion would introduce an additional loss of about 40%.

The ruling frequency necessary to project one full order over a typical 25 mm detector length is about 18 mm^{-1}. This cannot be achieved for such extreme blaze angles; the coarsest grating ever produced (in small size) has a frequency of 33 mm^{-1}. It would imply that different orders will no longer overlap and the final spectrum will be discontinuous. The solution is to use larger detectors. The field slicing technique could here too be advantageously applied to match the detector size to the optical requirement. It could also be helpful to solve the cross-dispersion problem since smaller cross-dispersers could be used on the relay system beams.

Grating / Inst. Parameters	1: 63° Blaze 600 x 1200 mm	2: 63° Blaze 300 x 600 mm	3: 75° Blaze 300 x 1200 mm
Resolving power	66.000	66.000	66.000
Slit width (pixels)	3	3	3
Camera focal length	1200 mm	1200 mm	640 mm
Camera aperture	F/2	F/4	F/2.14
Angular slit width	1 arcsec	0.5 arcsec	0.87 arcsec
Slit length for 2 arcsec seeing	12 pixels	48	12
Dispersion	1 Å/mm	1 Å/mm	1 Å/mm
Number of orders recorded	20	5	17
Ruling frequency			
Ideally:	18 mm^{-1}	18 mm^{-1}	19.5 mm^{-1}
In practice:	> 33 mm^{-1}	> 33 mm^{-1}	> 53 mm^{-1}

Table 1

The remaining advantage of an echelle is the possibility to cover the full spectral range with only one single grating; however, the cross-dispersion might be the major difficulty especially as the beam dimension increase.

4.3 Example No 2

Instead of a coarse echelle grating one can use a single order grating working at a similar blaze angle and therefore with an identical dispersion. This solution has several advantages over a cross-dispersed grating:

- A continuous spectrum is directly obtained without further processing;

- No cross-dispersion is needed so that the optics could be relatively simple and more efficient;

- Monolithic holographic gratings can be produced in fairly large sizes and at very high ruling frequencies; their efficiency can be excellent (up to 80% absolute) under polarised light as indicated in the efficiency curves for an existing grating shown in Fig. 9.

- The use of concave gratings might further improve the system efficiency by decreasing the number of optical elements.

The disadvantage is that this solution needs a long detector and badly uses the potential 2D capability of optical systems, with the consequence that the optics become unnecessarily large. This can again be elegantly overcome by the field slicing technique as demonstrated by the following example which describes a proposed preliminary scheme for a high resolution spectrograph for the ESO VLT.

4.4 Possible scheme for a high resolution spectrometer for the ESO VLT

The ESO VLT present concept is an array of four 8 m telescopes with optical beam recombination limited to a very narrow field. For the reasons already mentioned, the combined Coudé focus is not intended for imaging but rather for spectroscopy on point like sources, for which the beams can be arranged

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

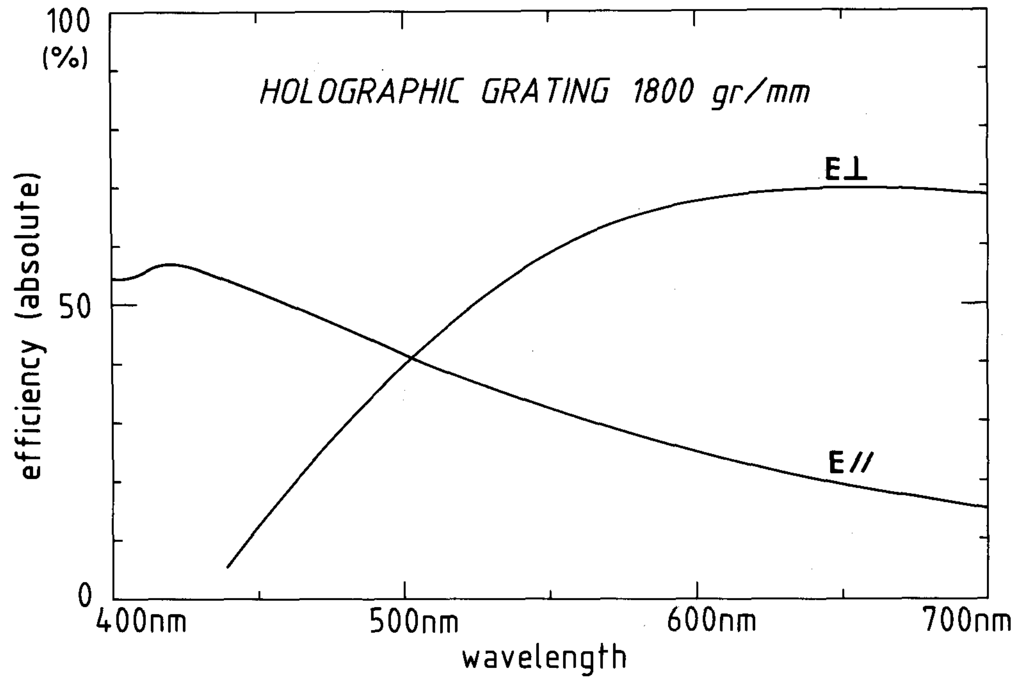


Fig. 9 Measured absolute efficiency of a commercial holo-grating

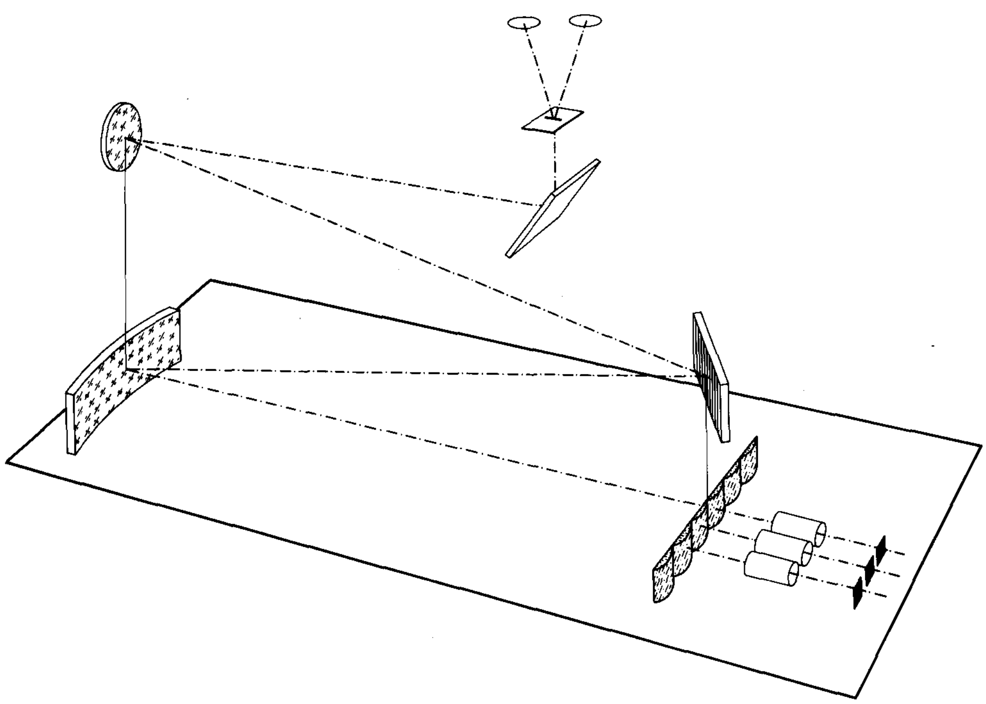


Fig. 10 Principle of a "multi" white pupil spectrometer using the field slicing technique

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

POSSIBLE CHARACTERISTICS OF A HIGH RESOLUTION SPECTROMETER FOR THE ESO 4 X 8 M VLT

2 separate instruments for optimum blue and red response.

SLIT FEED

- MMT-type prism beam combined.
- Polarising beam-splitter + $\lambda/2$ plate on one path.
- Modified Bowen-Walraven image slicers for seeing > 1.5 arcsec or R > 50.000.

SPECTROGRAPH

- First order plane (or concave) holographic grating
  600 x 1200 mm monoliths.
  45 $<\beta<$ 65°
  1800 to 3600 gr/mm
- "Multi White Pupil" arrangement with slicing of the intermediate spectrum and array of non-contiguous CCDs.

Relay system:	Schmidt for F/1
	Lens for F/2
Detectors:	8 existing CCDs 10 x 15 mm 25 µm pixel

PERFORMANCE

- R = 30.000 to 100.000.
- Without image slicer = - R = 32.000
  - $\frac{\Delta\lambda}{\lambda} = \frac{1}{30}$ (200 Å at λ = 6.000 Å)
  - Slit width 1.85"
- Limiting magnitude = R = 30.000 S/N = 50 m = 20

TABLE 2

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

so as to not loose any imaging capacity. Fig.10 shows the principle of a "quasi" one dimensional spectrometer using the field slicing technique and a monolithic holographic grating. The relay systems consist of Schmidt cameras working at F/1; relay lenses can also be used for smaller F/ratio. This arrangement illustrates the advantages of the field slicing technique: very fast camera, no detector limitation.

Fig.11 shows a possible slit-feed. The 4 telescope beams are combined together using a prism combiner. The polarising beam splitter can be of a Wollaston or Rochon type. The system is shown combined to a modified Bowen-Wallraven image slicer. This type of slicer has been recently successfully tried at La Silla. Owing to highly accurate optical manufacturing and to the use of molecular adherence to contact the pieces together, an efficiency of about 97% (neglecting Fresnel losses) has been obtained (8). The "polarising" beam splitting has an obvious drawback which is that it reduces by a factor of 2 the image entropy and necessitates a larger detector. As a by-product it also has the advantage of providing a Zeeman analyser.

Table 2 indicates possible characteristics for such an instrument.

Conclusions

The major problems to be faced when matching instruments to large telescopes are direct consequences of the larger linear scale: larger detectors, and faster optics are necessary.

The first conclusion is that, assuming identical detectors, a VLT will not be a great contender for smaller telescopes when the detector area sets the rate at which information is collected. This is a fundamental point to consider when setting scientific objectives for a VLT.

The second conclusion is that the instrumentation matching would give immense difficulties if only classical schemes are retained. The field slicing technique is capable of providing an adequate solution to the problem of detector matching for spectroscopy as well as for direct imaging.

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

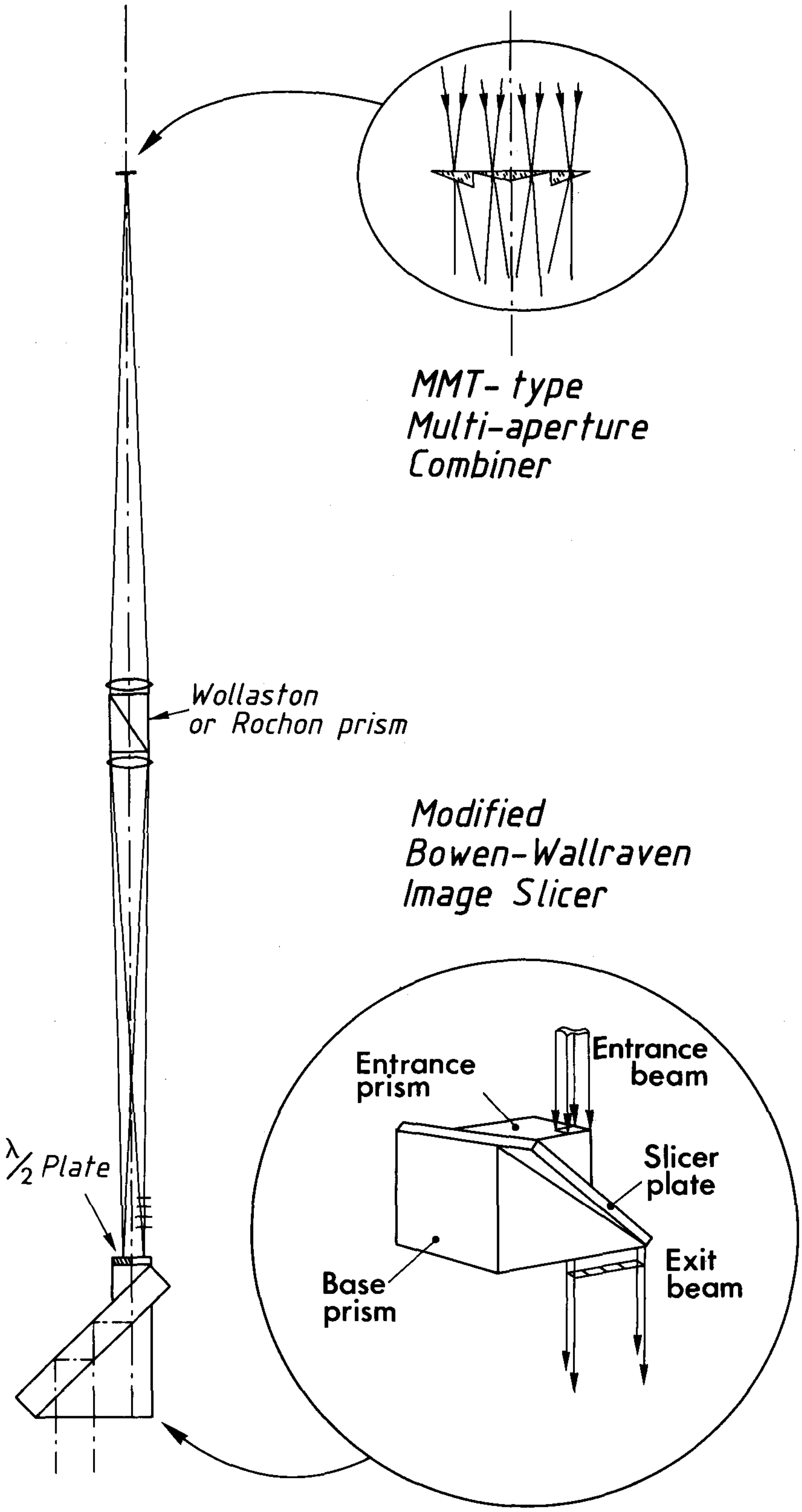


Fig. 11 POSSIBLE VLT COMBINED FOCUS ADAPTER FOR HIGH RESOLUTION HOLO-GRATING SPECTROGRAPH

https://doi.org/10.1017/S0252921100108589 Published online by Cambridge University Press

For direct imaging, and on the assumption that good coatings for the secondary and Nasmyth mirrors are available, the best solution would be field slicing at the Nasmyth focus. If only standard aluminium coatings are envisaged the prime focus remains the most efficient; however, imaging at the prime focus may lead to so many difficulties that even in that case, the Nasmyth may be preferred. In spectroscopy, field slicing can also be applied to almost any instrumental scheme, either echelle or classical grating spectroscopy.

The interest of field slicing is that it does not only help to solve the detector area problem but also helps to overcome the difficulty of building fast, very large, and wide field optics. This advantage alone would strongly tilt the balance in favour of a field slicing arrangement.

The important consequence of such a choice is that the development of very large detectors would not be of paramount importance thus allowing research efforts to be concentrated on the improvement of present day CCDs to give lower readout noise and dark current, better UV response and good signal charge transfer efficiency.

Finally, it should be concluded that even with present day technology, efficient high resolution spectroscopy with a VLT is possible. High resolution and high photometric accuracy on objects as faint as magnitude 20 can be contemplated and is certain to produce a crop of scientific results of great significance.

1) M. Cullum, Optical detectors and the VLT. ESO Workshop on ESO's VLT, Cargèse May 1983.

2) P.J. Hilvak, P.J. Henry, C.B. Pilcher, Proceedings of Instrumentation in Astronomy, London Sept.1983, SPIE Vol. 446

3) J.F. Wright, C.D. Mackay, Proceedings SPIE 290, p.160.

4) S. Goldman, Information theory, Dover Publ. New-York.

5) S.M. Faber, UC. TMT report. AV 61.

6) H. Richardson, Prime focus corrector lens for a 300" telescope.

7) B. Delabre, ESO internal communication.

8) B. Buzzoni, D. Enard, R. Ferlet, G. Lund, to be published in "The Messenger".

DISCUSSION

R.G. Tull: There was a paper published about 2 years ago (Applied Optics) comparing efficiencies of echelle and holographic grating spectrographs. The author found not only that the holographic grating spectrograph gave higher resolution but that the efficiency was up to 5 times as great. This was a surprising result and I have not seen any confirmation.

D. Enard: This seems surprising but neverless good news.

R. Bingham: I have also been looking at methods of correcting the polarization to suit the efficient mode of the grating, and I have a design for a monolithic device to do this, so it requires only two external optical surfaces.

D. Enard: We have not yet done any detailed analysis of the various ways to achieve our "polarizing image slicer" but there are certainly better methods than the one I have shown. Anyway, I would be interested to have more information about your design.

G. Courtès to D. Enard: The extended regions are uniform in brightness only at the first approximation. As soon as you have a bigger telescope you see fluctuations and morphological new details such as filaments, clumpy repartition, etc., in which some of the brightest areas are detected. Then a larger telescope permits to obtain spectrographic or interferometric data that a small telescope would have been unable to reach. In conclusion, extended sources need also VLT.