FOCAL REDUCER TECHNIQUES FOR DIRECT IMAGING AND FIELD SPECTROSCOPY WITH LARGE TELESCOPES*

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ABSTRACT

To exploit the full effectiveness of large ground based telescopes, the focal reducer technique can be applied very adequately. We review recent Hoher List observatory developments of observing techniques for direct imaging, field spectroscopy with multi-slit and masking methods for background supression and double-grism arrangements (heliometer principle)for absolute radial velocity determinations with a focal reducer field spectrograph.

INTRODUCTION

The effectiveness of present day and future large telescopes depends beside their optical performance and light throughput on the available size and detective quantum efficiency of the panoramic detectors available for direct imaging or for the backend auxiliary instrumentation.

For direct imaging with a telescope of aperture A, f-number Ω = f/A and a detector size d (linear diameter), the angular diameter of the useful field 2ϕ is given by

$$2\phi \approx \frac{d}{\Omega \cdot A} \quad \text{radian} \qquad (1).$$

As for all modern panoramic detectors in contrast to the 'old' photographic emulsion d does not exceed a few centimeters, the diameter of the useful field is much smaller than the field of view of the telescope, which can be as large as 1^{o} in RC-telescopes. For example, a 2x2 cm CCD attached to the RC focus of the 3.6 m telescope (Ω = 8) yields a field of 2.5 arcmin angular diameter. For

* Dedicated to Professor Dr.Ch.Fehrenbach on the occasion of his 70^{th} birthday, 1984 April 29

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

https://doi.org/10.1017/S0252921100108681 Published online by Cambridge University Press

even larger telescopes the field is accordingly smaller: The usable angular field decreases inversely with the aperture of the telescope for a fixed Ω. Therefore it is essential to design auxiliary equipment, which reduces the focal length of the telescope and thus Ω.

There are additional reasons for the use of focal reducer (FR) systems, especially in connection with RC-telescopes with $\Omega \geq 8$: The influence of the seeing is lowered and field spectroscopy with a collimated beam is possible.

B.Schmidt seems to be the first who designed a FR (quoted by Hellerich 1938). In an afocal arrangement FRs were used by Courtès (1951, 1960) and Meinel (1956) for direct imaging in narrow spectral bands. Especially for Fabry-Perot interferometry Courtès and collaborators (Boulesteix et al. 1974) advocated the design of FR systems for large telescopes.

This last mentioned application leads to a further need for FRs: Some optical parts (e.g. Fabry-Perot etalons, optics for polarimetry) are not available in any size. FRs allow to use very small optical devices in a collimated beam even with very large telescopes.

MATCHING DETECTORS BY FOCAL REDUCERS

As an example for the principal layout we show in Figure 1 the FR, which is used at the 106 cm Cassegrain reflector of Hoher List Observatory (Kellner eyepiece principle). To our experience there

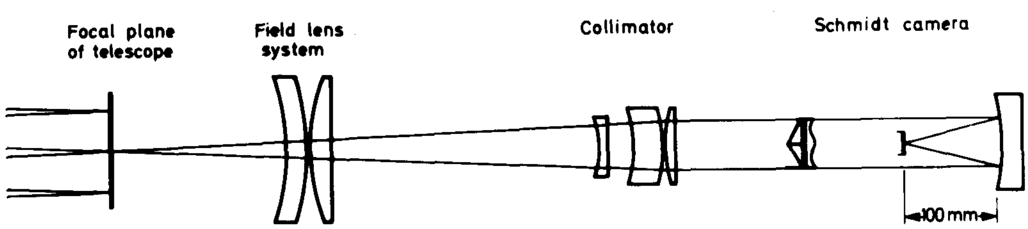

Figure 1: Optical arrangement of the focal reducer of the Hoher List Observatory

are several demands to be fulfilled (Geyer et al.1979,1981; Nelles et al.1981) for a FR suitable for direct imaging as well as for field spectroscopy:

a) The telescope's focal plane must be easily accessible for the

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application of the multi-diaphragm masking technique, which is important for the sky background supression as well as for the determination of the distortion constants for radial velocity work.

b) The distance between the last optical surface and the exit pupil of the system has to be large enough for the installation of dispersing elements (e.g. grisms, Fabry-Perot etalons). The diameter of the collimated beam should be not larger than 10 cm.

c) The focal reduction factor is given by Ω of the telescope and the f-number of the camera, which should be smaller than 3.

FR systems also allow the better matching of panoramic detectors: The signal to noise ratio at the exit of a 'threshold free' detector is given for ground-based monochromatic observations by

$$(S/N)_{ex} = \frac{\frac{\pi}{4}\cdot B_*(m)\cdot A^2\cdot o\cdot q\cdot t^{1/2}}{(\frac{\pi}{4}\cdot A^2\cdot o\cdot q\cdot (B_*(m) + \pi\cdot L\cdot (\frac{R}{f})^2) + b)^{1/2}} \qquad (2).$$

Here are: $B_*(m)$ the illuminance of a star of apparent magnitude $m(\lambda)$, $L(\lambda)$ the luminance of the night sky, $o(\lambda)$ the transmission of the optical system (including the atmospheric transmission), f the effective focal length of the system, R the linear diameter of the picture element, $q(\lambda)$ the quantum efficiency of the detector, b the dark events (dark emission, read-out noise) of the detector, and t the integration time.

Neglecting diffraction and optical errors, R is given for ground-based observations by

$$R = (r^2 + \beta^2 f^2)^{1/2} \qquad (3).$$

Here r is the detector resolution defined by the modulation transfer function and β the seeing angle. Thus the best $(S/N)_{ex}$ is achieved in the detector resolution case $\beta\cdot f \leq r$, which clearly demonstrates the need of focal reduction.

In the case of a 'threshold' detector (e.g. photographic emulsion) a certain number of quanta per pixel is necessary to give a minimum response. In the case of astronomical observations the night sky produces these number of quanta in an optimum integration time t_o, which is given by

$$t_o = \frac{n_o\cdot \Omega_e^2}{\pi\cdot L} \qquad (4).$$

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Here Ω_e is the effective f-number.

At the limit, where

$$B_*(m) < \pi \cdot L \cdot (\frac{R}{f})^2 \quad (5)$$

equations (2) and (4) lead to the apparent paradoxon that S/N depends on f and R only.

FIELD SPECTROSCOPY

Slitless spectroscopy within the accessible field of the telescope can easily be carried out with a FR by inserting a dispersing element in the parallel path of rays at the position of its exit pupil (= entrance pupil of the camera). Beside of Fabry-Perot etalons, we use direct vision grisms (Geyer et al. 1980).

At a first glance, such a slitless spectrograph seems to have all the disadvantages of a classical objective prism camera, namely seeing dependent resolution, sky background limitation, overlapping of spectra and the impossibility of carrying out absolute radial velocity observations.

Some of these disadvantages can be avoided or reduced by the following methods with FR-systems:

a) The effective focal length of the whole system should be short enough to approach the detector limited case. This lowers the linear diameter of the seeing disk and improves the spectral resolution $\delta\lambda$ for a given reciprocal linear dispersion D:

$$\delta\lambda = R \cdot D \quad (6).$$

b) Absolute radial velocity measurements can be obtained by the 'double grating prism' method (Nelles 1978, 1981), which is based on the heliometer principle: It consists of two identical grisms in a roof-like arrangement. Such a bi-grism yields a reversed pair of spectra simultaneously for each point source. Guiding errors, temperature and optical alignement effects, which are responsible that only relative radial velocities can be determined by the classical Pickering-Fehrenbach method with slitless spectrographs, are cancelled (Nelles 1983; see Figure 2).

c) An improvement of the limiting magnitude as well as the elimination of the overlapping problem can be achieved by the use of the multiple diaphragm technique (Geyer and Schmidt 1976). The sky background can be reduced by a factor of 100, shifting the limiting mag-

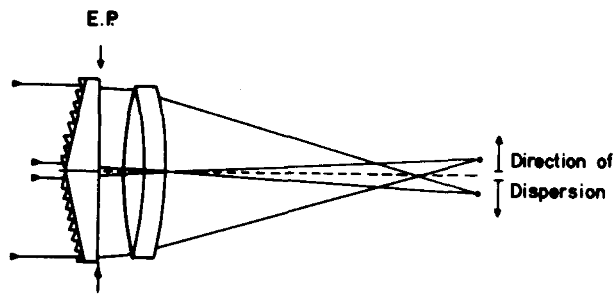

Figure 2: Bi-grism principle for absolute radial velocity determinations with slitless field spectrographs.

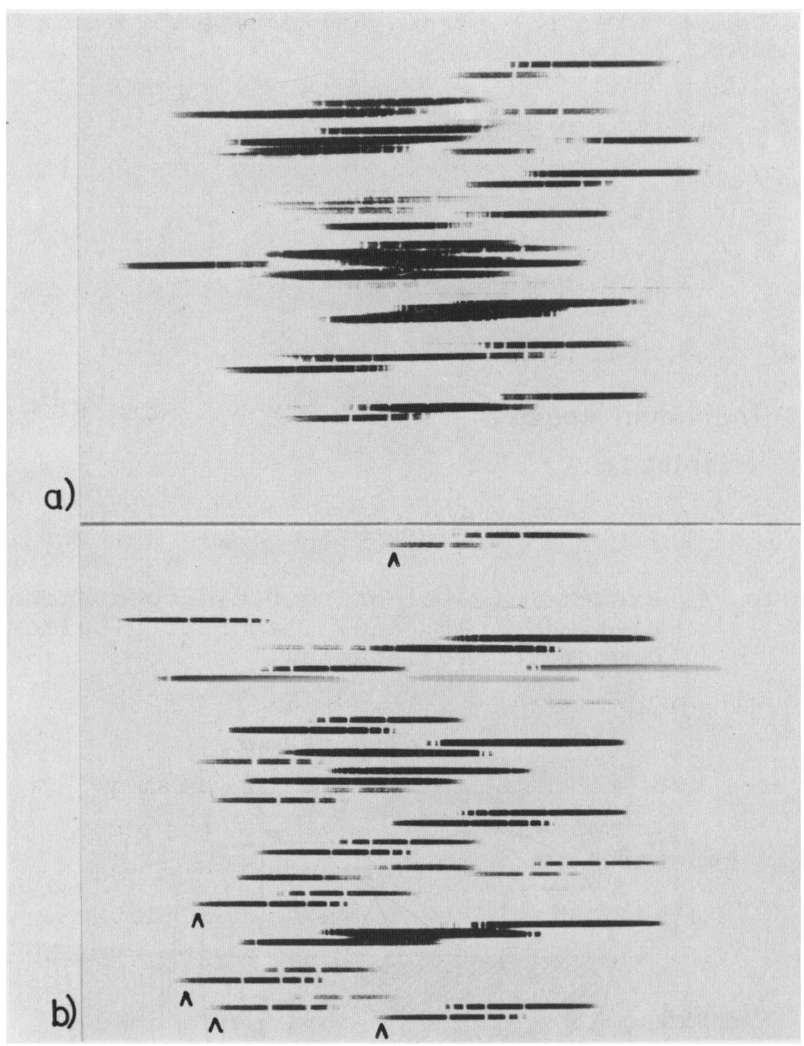

Figure 3: Field spectrogram of NGC 2287 without (a) and with focal plane diaphragm. A double grating prism with 400 grooves/mm was used (217 Å/mm with a f=100mm camera). The spectra of fainter objects not visible in the unmasked exposure are marked by arrowheads.

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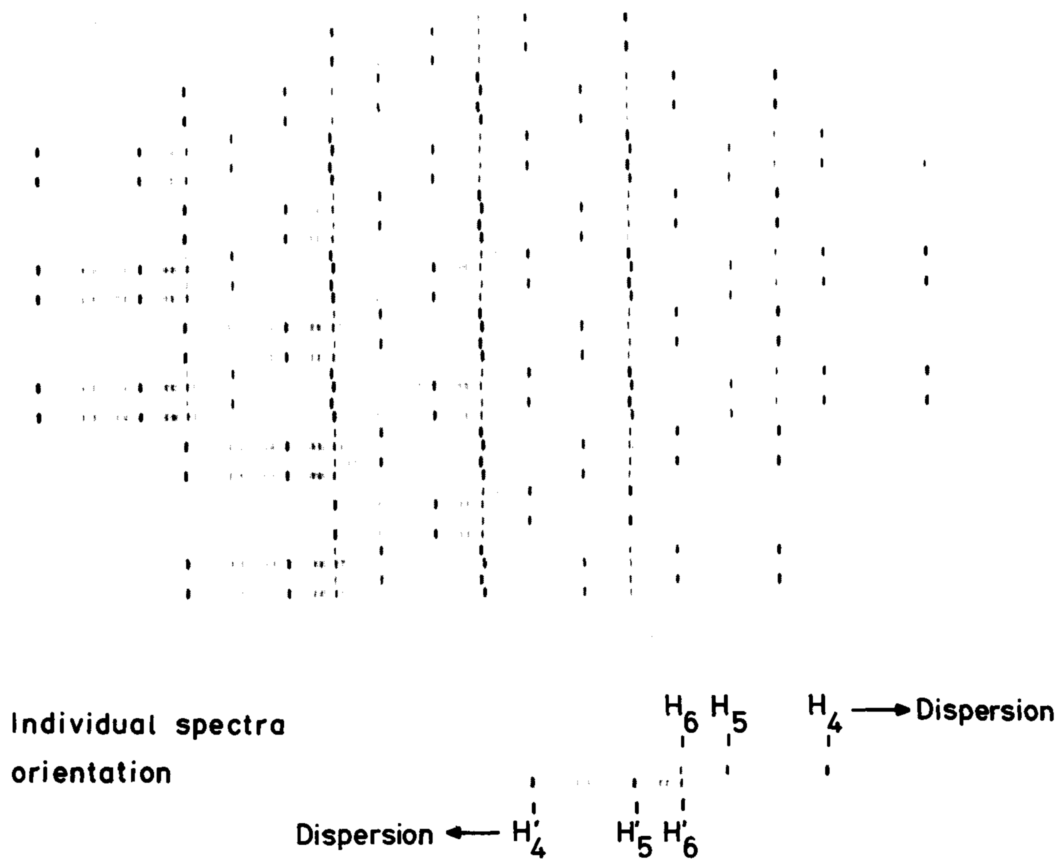

Figure 4: Example of a bi-grism field spectrogram with the multiple slit diaphragm and a laboratory Balmer lamp for field distortion calibration.

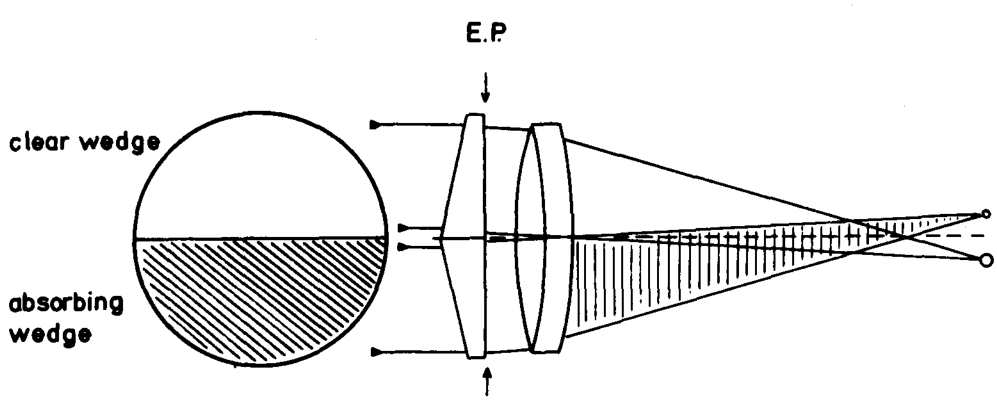

Figure 5: Double wedge principle for autocalibration of panoramic detectors in a focal reducer arrangement.

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nitude by 5 mag. to fainter ones (for details see Geyer et al. 1979). The sky background supression is demonstrated in Figure 3.

With such a FR field spectrograph at a 1 m telescope we obtained absolute radial velocities of late B to G type stars with an accuracy of ± 6 km/s down to an apparent magnitude of $13\overset{m}{.}5$ using a reciprocal linear dispersion of 217 Å/mm. With a single exposure pairs of spectra of up to 40 stars can be obtained in the 25 arcmin field of the telescope.

The bi-grism in its simplest form is not distortion free. We nevertheless are able to determine the field errors in a very simple way: A multiple-slit diaphragm at the position of the telescope focal plane is illuminated by a laboratory spectral lamp. The resulting pairs of spectra are well distributed over the whole field. From these spectrograms we derive the field coefficients of the distortion. Such a field spectrogram of a Balmer lamp is shown in Figure 4.

DIRECT IMAGING

In the application of FRs for direct imaging we restrict ourselves to the discussion of the advantages which can be achieved for the autocalibration of detectors for stellar photometry: As in the case of bi-grisms, again, the heliometer principle is applied by the use of a double-wedge (Lentes 1981), of which one half is covered by a neutral absorbing filter. First redults show that photographic scales free from systematic errors can be obtained for broad and narrow band photometry over more than 7^m (Geyer 1984). A schematic sketch is shown in Figure 5.

Finally, some critical remarks have to be made on the application of the double image principle: The double wedge as well as the Pickering-Racine wedge method are based on the dividing of the camera entrance pupil. It must be made sure that the point spread function of the primary and secondary images become identical. If this condition is not completely fulfilled, systematic effects are introduced (see e.g. Blanco 1982).

In the case of a Schmidt camera with exactly halved entrance pupil the silhouetting by the plate holder over its field yields also non-symmetrical images. This can be avoided by a central stop at the corrector lens (Figure 6) or by an 'out of axis' Schmidt camera system (Figure 7).

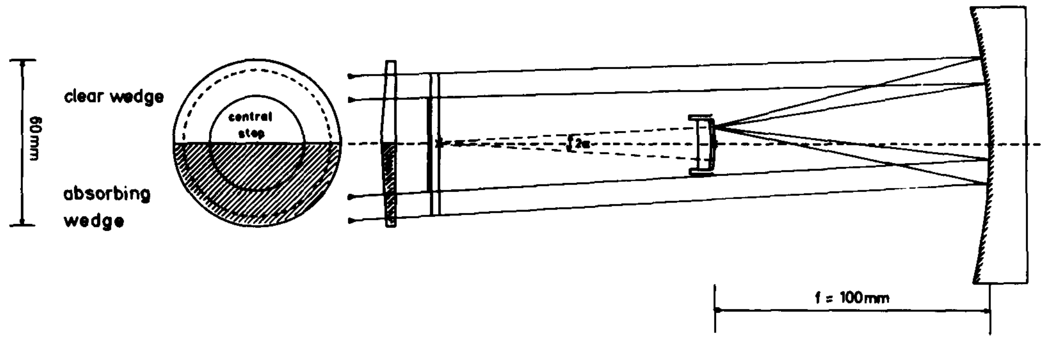

Figure 6: Vignetting free bi-prism Schmidt camera arrangement.

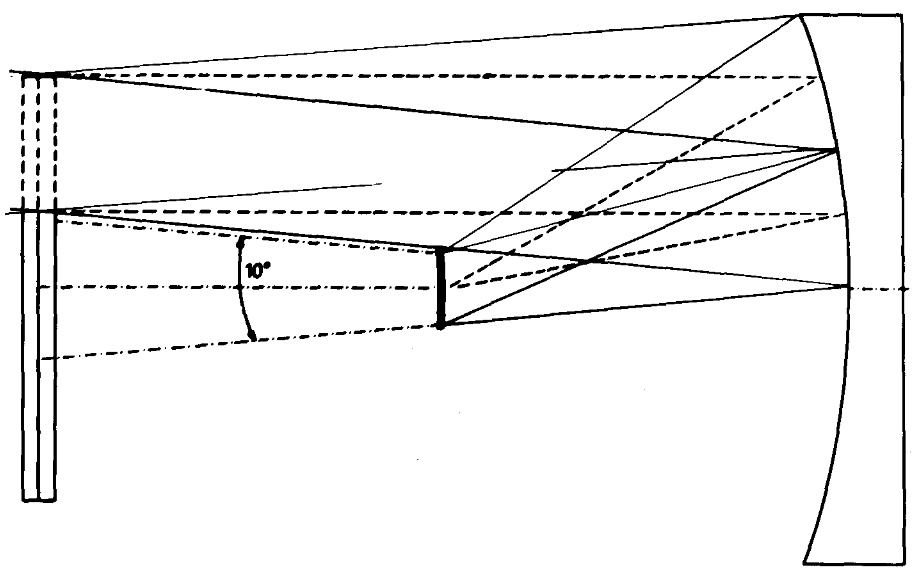

Figure 7: Basic principle of an out of axis Schmidt camera.

Thus for photometric autocalibration purposes the classical Kapteyn (1906) - Schwarzschild (1909) 'half filter method' is most favourable applied with a FR-system, as the 'half filter' is placed ideally in the telescope focal plane.

REFERENCES

Blanco,V.M.: 1982, Publ.Astr.Soc.Pac.94, 201

Boulesteix,J., Courtès,G., Laval,A., Monnet,A.: 1974, Proc. ESO/ SRC/CERN Conference on Research Programmes for New Large Telescopes

Courtès,G.: 1951, Publ.Obs.Haute Provence 2, No.19

Courtès,G.: 1960, Ann.Astrophys.23, 115

Geyer,E.H.: 1981, Mitt.Astron.Ges. Nr.54, 156

Geyer,E.H.: 1984, IUE Working Group Meeting on Photographic

https://doi.org/10.1017/S0252921100108681 Published online by Cambridge University Press

Problems
Geyer,E.H., Hoffmann,M., Nelles,B.: 1979, Astron.Astrophys.80, 248
Geyer,E.H., Schmidt,H.: 1976, Mitt.Astron.Ges. Nr.40, 125
Hellerich,J.: 1938, Mitt.Hamburger Sternwarte Nr.43, 179
Lentes,F.T.: 1981, Mitt.Astron.Ges. Nr.54, 181
Meinel,A.B.: 1956, Astrophys.J.124, 652
Nelles,B.: 1981, Mitt.Astron.Ges. Nr.54, 186
Nelles,B.: 1983, Doctor thesis, University Bonn
Nelles,B., Geyer,E.H.: 1981, Applied Optics 20, 660

https://doi.org/10.1017/S0252921100108681 Published online by Cambridge University Press