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ROYAL SIGNALS & RADAR ESTABLISHMENT

A REVIEW OF FOCAL REDUCER INTERFEROMETER SYSTEMS

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SUMMARY

This paper reviews the development of focal reducer imaging systems for use with interferometers and telescopes. Some less widely known designs are also discussed, these are based on the work of the author in the 1970s, while at the Royal Observatory, Edinburgh and at the University of Manchester. Interest in this type of optical system has come about particularly with the development of image intensifiers and electronic detector arrays such as CCDs. These designs are of interest wherever image reduction is required.

S80/59

1.1, Introduction: design considerations

The purpose of a focal reducer is to re-image on a reduced scale as much of the telecope field as possible onto the detector plane. The detector maybe photographic film or more likely an image intensifier or CCD device. The reduction in F-ratio gives a considerable speed gain and a consequent shortening of exposure time for faint objects. This kind of system is useful for modern electronic detector arrays with their limited sensitive areas. The reducer will give a consequent larger field of view. Some designs of reducer camera also include a collimated beam section which enables the system to be used as a narrow band filter camera, or if a diffraction grating is included, it can be used a low resolution spectrographic camera. The first focal reducers built were unsuitable for use with image tubes due to the focus being of the Schmidt type. This is a little inaccessable and the obscuration by the detector would be unacceptable; there is no problem with CCD arrays in this respect accept that the whole optics may need to be placed in a cryostat dewar if the detector has to be cooled. A number of reducer cameras of the Schmidt type have been used for narrow band interference filter work on diffuse nebulae, and other extended sources of $H\alpha$ radiation. The first designs were used with photographic film rather than II tubes in order to obtain a very fast wide field system. Fig.1 shows some short focal length cameras designed by Prof. Wynne and this work has opened up some interesting designs.

1.2, Comparisons

A comparison is sometimes made between focal reducers and the photographic performance of the prime focus of a large telescope (typically F/3) using a Ross corrector or similar device. The focal reducers built previously have had field size and image quality usually inferior to a well corrected prime focus, but this must be compared with the reducer advantage of greater speed, accessability, and a possible collimated beam section for spectrographic use.

Another competitor to the reducer camera is the Schmidt camera, which can be equipped with an objective prism, results using such a device are described later. Traditionally very wide field work (1° to 4°) has been carried out with Schmidt or Baker cameras, eg. satellite trajectory photographs, while the reducer camera offers an alternative intermediary field of view ($1/4^\circ$ to $1/3^\circ$) - see also Fig. 2 - most suited for nebula and cluster photography.

Design Constraints

The principal problems of designing a reducer camera as mentioned lie in the demands of small entrance and exit F-ratios. This is often coupled with a demand for broad working wavelength range which is near impossible for most lens type systems. An all reflecting system is highly desirable for its lack of chromatic aberration, and by careful design, other aberrations can be kept to a minimum, for example the use of confocal paraboloids in the collimator. The problem with such arrangements is the unacceptable self-obscuration of the mirrors, and only cases where the collimated beam section is of much larger diameter than the telecope field (eg. in the Meaburn et al. system, Fig.3) is this of minor consequence. This is also the disadvantage of the Wynne type cameras, but there it is not so serious. The Wynne spectrographic cameras suffer from astigmatism, which may or may not be a problem according to the system; for slit spectra the astigmatism may be aligned normal to the axis of dispersion, but in a filter camera this is not possible.

2, A review of the literature

The first plans for a focal-reduction system appears to have arisen from work on thin film narrow band interference filters and Fabry-Perot interferometers used for the study of nebula emission in the early 1950s. Work in this field was limited by the trade off between illumination of the photographic plate and the degree of collimation of the light at the telescope focal plane. The constraint with filter cameras is that a small F-ratio (less than 2) is required on the photographic plate or detector, but a large F-ratio (F greater than 5) is neededed at the filter to avoid much broadening and shift to the red of the passband.

2.1, First designs

The first references to focal reduction systems are in the early 1950s; G.Courtes of the Haute Provence Observatory considered such a system consisting of a field lens, collimator and fast focal-ratio photographic objective. Up to this time filters had been placed at the focal plane of only large F-ratio telescopes as restricted by passband broadening. A focal reduction system could be used to reduce the F-ratio from the focal plane to the detector. Alternatively, by inclusion of a collimator, space allowing, it was possible to place the filter or Fabry-Perot etalon in the collimated beam, dispensing with the limitation of a poor F-ratio at the focal plane incurred by passband broadening and shift. The practical problems of designing such an instrument are considerable. Reference to discussions about such an instrument can be found by J. Ring in 1955 and 1958 and Courtes in 1955.

Several focal reducers have now been built and used, mostly for imaging interferometers. The most recent well known scanning Fabry-Perot imaging interferometer system is TAURUS on the I.N.T., which superceeds the authors contributions to the field.

The first to be described is that of A.B.Meinel in 1956 (Fig. 5), built for use with the Yerkes 42 ins. (1m) refractor and McDonald 82 ins. (2.1m) telecopes. The second is that of G.Courtes. It was described in 1960 (though built in the early 1950s, Fig. 4a) after successful use in an HII region survey in Ha emission, taken with the 1.95m. Haute Provence telescope. The instrument of A.B.Meinel consisted of a 165mm F/2 field lens, a Tessar collimator and F/2 Leica Surmicron Lens and of 0.5m. total length. Here the field is limited by the size of the field lens. Such a system can be designed to correct some of the aberration in the focal plane but here it was not necessary at the Cassegrain focus; according to Meinel the final resolution was still atmospheric limited. The increase in photographic speed at the Cassegrain F/13.5 focus using interference filters is considerable (proportional to the square of the F-ratio advantage). This enabled sky background limitation to be reached with a 1 hour exposure using 103a-E plates and an RG2 filter. The disadvantage of using commercially available components is in its lack of flexibility of and optical performance limitation. This instrument was designed for photography of nebulae with interference filters. The space between collimator and camera does not allow introduction of any dispersive element or any optical device thicker than an interference filter. The system is also strongly u-v light absorbing.

2.2, Purpose-built designs

The focal reduction system, of G.Courtes was designed for use at the F/5 Newtonian focus of the Hautes Provence 9.95m telescope, such that some of the aberrations from the primary mirror were substantially reduced. An F/2.5 100 mm dia. field lens was used with a 60 mm dia. collimator (fig. 4a). A small F-ratio of the focal plane gives rise to more difficult design problems, and as the final camera F-ratio is the determining factor in the speed advantage of the system, an F/1 camera was necessary. The space between collimator and camera does allow the introduction into the light path of a Fabry-Perot interferometer, but the difficulty in designing an F/1 camera lens with a sufficiently large field of view led to a Schmidt-type camera system. The problem of the severe central obscuration in this instrument limits it to purely photographic use (it could not be used with image tubes or photomultipliers).

There is a considerable gain in photographic contrast of emission-line to sky background using a narrow transmission band produced by a Fabry-Perot interferometer over that from a narrow band filter. For example, when looking at a narrow emission line (eg.$H\alpha$), which for nebula work is important. This, together with the gain in photographic speed over that of the Newtonian focus and the increase in definition, has made this instrument very worthwhile. The resulting HII survey shows many previously undetected nebulous regions and some very accurate radial velocity measurements made from the same negative in different parts of such a nebula. There are several references to this work of Courtes and its development, in particular for mapping the spiral structure of the galaxy (Courtes, 1960, 1964, 1966, 1968). In the 1964 paper of Courtes, several arrangements are considered for the use of dispersive or interferometric elements with a focal reducer. An instrument is described for obtaining simultaneously the radial velocities of multiple emission knots in galaxies. In this case, a filter and Fabry-Perot etalon is placed just before the focal plane, and interference fringes are formed as rings in the subsequent converging beam, after the focal plane, just before the focal reducuer field lens. Then the fringe system of one order from all points in the focal plane or field may be imaged onto the focal reducer camera focal plane (like a narrow band filter photograph).

Another system is suggested for the study of complex extended sources. Here a tilted Fabry-Perot etalon is placed after the collimator of a focal reducer. Hence rather than seeing an interference ring system in the focal plane of the camera superimposed on the field, we see an arcuate fringe system over the field. This would form a more preferable basis for the radial velocity study of an extended complex source.

Another suggestion of Courtes is for a combination of narrow band $H\alpha$ filter and a diffraction grating placed after the focal reducer collimator. An H lamp iluminates calibration slits in the telescope focal plane. In zero order a monochromatic image is seen, while in first order a field image is seen distorted by dispersion and Doppler-shift; radial velocities may be determined by measurement of the relative position of an HII region on each plate as compared to that of the calibration slits.

Courtes´ paper also discusssed the use of a transmission diffraction grating as an alternate arrangement to measure radial velocities in the emission knots in galaxies; here calibration slits are placed in the focal plane of the telescope, and the grating is placed in the collimated beam. It would be preferable to use a Carpenter´s zero deviation grating or a Fehrenbach zero deviation prism for this purpose, and such a device could be used for spectral classification of faint stars or for emission line star searches. G.Courtes has also proposed a design for a focal reducer for the E.S.O. 3.6m. Ritchey-Chretien telescope (Fig. 4b). He uses a Schmidt camera of 15 cm. aperture and 19.5deg. field in all, covering 50 min.arc at F/1.

2.3, Alternative designs

Two focal reducers have been built as described by J. Meaburn and proposed by J. Ring and N. Woolf in 1958 (Astro. Space Sci. 1968). By using a parabolic collimating mirror and camera mirror after the focal plane, the system has the advantage that confocal paraboloids tend to cancel out aberrations (only astigmatism remains if focal lengths are equal). One such instrument was used at the prime focus of the 1.1m (43 ins.) F/3.2 Pic-du-Midi reflector by J.Meaburn. He used a 152 mm F/1 Schmidt camera and a 35A. bandwidth Hα filter and a 490mm focal length collimator, in all covering 6.5 of sky with 7 arcsec resolution at the edges (see Fig. 3). For the 1.9m. (74 ins) F/4.9 Kottamia reflector, a 176mm diameter F/1 Schmidt camera was proposed. It used a 367 mm focal length paraboloid, with a useful field of 0.25deg. for a resolution of 4 acrsec. Collimation is effective to 3deg. off the principle axis for the 76 mm Schmidt objective, and may be used with 104Å. passband filters. The flat obstructs 25% of the light of which 10% is anyway obstructed by the film holder.

J.Meaburn's paper points out the advantage of a mirror collimator as opposed to a lens, comparing the mirror systems 20% light loss with a 40% loss for a 10deg. field lens. This becomes 20% for a limited wavelength range if the lens is optically coated, although here a lens could cope with larger fields.

Photographs were taken of the Cygnus loops in Hα, as were very wide field photographs of Ha emission associated with the nebulous arcs. Here he used a 150mm Schmidt F/1 camera with a 10deg. field. Another system described is a system with a 30deg. field, using a 178 mm focal length Aero-Ektar lens, and a double field lens in its focal plane. In turn this images the objective lens onto the corrector plate of the Schmidt camera. There is also a design for a wide field filter camera (Fig. 2).

Designs for use with II tubes

More recently Monnet and others at the Haute Provence Observatory built and used a focal reducer system similar to the Courtes design. This was for HII region study in other galaxies using the 200" Mt. Palomar telescope.

Some design work has been carried out for a 3.5m. E.S.O. telescope by Wilson (Fig. 6). Three designs were considered :-

1) a lens system without intermediate image taking F/8 to F/3.
2) a lens system with intermediate image taking - F/8 to F/3 (i.e. pre-focal plane) (Figs. 3 and 4)
3) a mirror system taking F/8 to F/1.7.

The first system requires 5 lenses including a very large field lens of about 0.65mm, for a +/-0.45° field and 1.3m total length and is considered impractical. The second requires seven lenses, the largest is of 0.42 m dia. and has inferior quality, and so is unsuited for reduction of a large image. This latter case is similar to the successful Meinel and Wilkinson design previously discussed, using a thick field lens, 4 collimator lenses, and six lenses in the camera but with internal camera aperture stop. The third system is similar to that of Courtes, but here a corrector is placed in front of the intermediate image, which gives independant control of astigmatism and transverse colour without affecting aperture aberrations. Spot diagrams have been made for this system when used with a Schmidt camera and then with a doublet corrector, a Bouwers-Maksutov camera and Hawkins-Linfoot camera, also with a Baker-2 meniscus plate camera and Baker camera with field mirrors instead of lenses. The general conclusions is that the more optical elements, the better the image quality. The possibility of different combinations of lenses and mirrors, some aspheric, appears endless; however aspheric lenses are difficult to align. This instrument does not, however, provide a facility for dispersive elements (no collimator space), and the camera suffers self-obstruction so is unsuited for use with photomultipliers or image tubes.

Most of these systems described incorporate a collimator and collimated beam in which a dispersing element is placed giving rise to a spectogram or interferogram in the reduced image plane. There are several papers concerned with prisms and gratings used in collimated or uncollimated beams. A thorough review of zero deviation objective prisms used for radial velocity measurment is given by C.H.Fehrenbach (Chapter 1 4 of Advance Astron. Astrop.) where a mathematical treatment is given of the normal field prism reversal method of line shift measurement and its limitations. Murty has given a detailed study of the behaviour of dispersive elements in converging and diverging beams.

The performance of a non-deviating triplet objective prism in a converging light beam has also been studied by K.Serowki, giving details of aberrations and light loss.

S.C.B.Gascoigne has written two surveys of the progress of astronomical optics design (1968, 1973) where the focal reducers of Meinel, Courtes and Wilson are discussed, pointing out the difficulties in the camera lens design.

3.1, Two recent reducer camera designs

The two instruments briefly discussed here result from the work at the Royal Observatory Edinburgh (1974, 1975) and at the University of Manchester (1976-1978). The former instrument was a design proposal as a result of a two year design study for a multi object spectograph (M.O.S.) facility on the Anglo Australian Telescope (A.A.T.). PILOT 8 and PILOT 18 contain a proposal to design and construct an A.A.T. M.O.S. using a low dispersion focal reducer system capable of giving simultaneous multi-spectra of all images over an extended field of view. Although conceived as a general user instrument with a collimated beam space suited to various dispersive elements, it was primarily designed for the simultaneous acquisition of spectra of clusters of faint galaxies. Radial velocity measurements would be made from observations of broad spectral features such as the near u-v H and K lines or the Balmer discontinuity.

The primary specification of this instrument was for a broad spectral response from 0.35μm to 0.67μm with optical performance between 0.37um and 0.5um. The spectral resolution was 0.3nm at 10nm/mm dispersion for an F/8 20arcmin. field and using an image tube. Dispersion was achieved with a 600 lines/mm diffraction grating placed in a 100mm diameter collimated beam. A 1 hour exposure should reach B.magnitude 18 with this specification providing a focal plane mask or fibre optic feeds are used to select the objects of interest. This also defines the resolution and reduces the sky background radiation to reduce film fogging.

Details of this instrument can be found in the R.O.E./S.R.C. reports (Baddiley ROE 1974, 1975). As a result of work done on this project by Baddiley, C.Wynne of I.C.S.T. and D.Brown of Grubb Parsons, a design was proposed that would meet thses specifications. The final proposal involved a rearrangement of the traditional field lens and collimator lens system into more equi-spaced components, with a modified Wynne camera design (Fig. 7). The instrument proposed used folded optics and would operate at the F/8 Ritchey Cretien A.A.T. focus, and should usually give seeing limited resolution.

The second system mentioned here is that of the Baddiley-Meaburn focal reducer camera. This instrument is primarily designed for use on large telescopes with an F/15 to F/18 focus, and uses a 50 mm diameter pressure scanned Fabry-Perot etalon in a collimated beam section with one lens as a window, and will give very high resolution spectrograms ($d\lambda \sim 0.01$nm) of nebulae in Hα (656nm), [OI] (630nm) and [NII] (685nm) and includes acquisition facilities. It has two beams with a dichroic beam splitter equally splitting around 500nm placed between the 140mm dia. field lens and the F/15 Tessar collimators. The large input F-ratio and more limited field of view (typically 10 acrmins) reduces the design contraints on the collimator and camera, and so here two F/3.8 178mm Aero-Ektar cameras are used together with cooled image tubes (Westinghouse type, ref. Johnson et al 1978). The expected resolution when used simply as a filter camera without F.P. etalon is ~ 3.3nm.at Hα.

3.2, Alternative grating system

A similarly designed reducer camera could be operated as a multi-object spectograph if used with a suitable grism (prism combined with a grating) or diffraction grating. The nature of the mechanical layout prevents the system being used off axis and so only low dispersions can be acheived in this mode. A Fehrenbach (Fehrenbach, Serowski) non-deviating prism gives too low a dispersion for a reasonable prism angle.

Using the same design parameter as before, a prism angle of 28 gives a spectral resolution of 3 nm with the same image tube, or 100 nm/mm dispersion. A transmission diffraction grating will give a reduced working field depending on the dispersion. A 112 line/mm grating will give first order spectra with 500 nm displaced by 10 nm from centre (without the grating). In second order this is 20nm, which would render over 2deg. of the area useable (the field radius is approximately 17 mm).

The first order dispersion is 50 nm/mm and the spectral resolution is then 1.5nm. Such a grating can be blase-angle optimised; the highest transmission occurs when the grating is tilted equally to the incident and transmitted beans (Murty). If higher dispersion gratings are used, then the camera must be tilted off-axis in the direction of dispersion and the loss of a zero reference will prevent absolute calibration.

As has been found with the U.K. Schmidt objective prism, (Nandy et al. 1977) useful work can be done using low dispersions. The U.K. Schmidt objective prism produces a dispersion of 248nm/mm at $H\alpha$ and 352nm/mm at $H\beta$ (spectra in a 1 hour exposure at band B on magnitude 19.5 stars. At this resolution hydrogen lines in class A stars can be seen, with other features visible in later type stars in the spectral range 350 nm to 500 nm. Redshifts of galaxies may be determined from the position of the 400 nm discontinuity. This technique is reported by Nandy et al (1977) and Cooke et al (1977); the latter used the Curtis Schmidt telescope of the Cerro Tololo Inter-American Observatory with an objective prism. This prism gives a despersion of 140nm/mm at H . The method uses the photographic emulsion cut off wavelength as a standard of reference, which is determined by fitting a dispersion curve of stars of defined line blends and using the available prism dispersion curve (λ 536nm.+/-3nm). The 400 nm feature is common to elliptical galaxies and should be seen in spirals as far as type Sb. Redshifted galaxies have been determined in this way to z=0.02 at Bmag.~17.5, over 1.4deg. of sky.

Adoption of this technique to the reducer camera on a 2 meter telescope using a transmission grating would be of particular interest. An estimate of the transmission of the optics suggests that unwidened spectra of galaxies at Vmagnitude 18 could be obtained in a 1 hour exposure, with a sky background fog of magnitude 20 without using a focal plane mask. Use of a focal plane mask should improve the sky fog limit by approximately 2 magnitudes. There are on average about 3 galaxies to a Vmagnitude 18 limit in any 12 acrmin. field, and a considerably larger number in a cluster.

4.1, Recent designs for use with image photon counting systems and detector arrays

Since this review was complied, focal reducer systems have become more common place, that of note is the I.N.T. TAURUS scanning imaging F.P. interferometer system (K.Taylor et al.). An imaging collimator-less spectrograph has also been designed and built for use with CCD arrays. (Wynne et al). It uses the cryostat window as an op tical element and has a cold finger to the CCD placed at a Schmidt focus. Many observatories are experimenting with glass fibre optical feeds from the telescope focal plane to a slit spectrograph.

5, Conclusion

This review has presented the reader with an outline of the design and use over the years of focal reducer systems for telescopes. The results obtainable with such instruments rival if not better those obtained by other means. They rival prime focus filter photography, or Schmidt camera filter photography, or objective prism spectography, but are more convenient to use. For some particular research projects as mentioned, such instruments are ideal, portable versions being particularly advantageous for use on remote and ill equipped telescopes.

The smaller instruments described are inexpensive to make and such specialist instruments can offer a valuable contribution to observational astronomy. The increasing use of CCD arrays in astronomy necessitates the use of such reduction systems for wide and intermediary field photography. Reducer camera systems clearly have an active role to play.

References

1, Baddiley, C.J., 1974 Anglo Australian Telescope Multi-Object Spectrograph Design Specification, Report (R.O.E./S.R.C.)

2, Cooke,J.A., Emerson,P., Nandy,K.,Reddish,V.C.,Smith,M.G., 1977,

3, Mon.Not.R.Astr.Soc., 178, 687

4, Courtes, G., c.r. le Bd.Seanc Acad.Sci.Paris, 234, 506, 2424

5, Courtes, G., Ann.d'Astrop, 23, No. 2, 115

6, Courtes, G., Ann.d'Astroph., 31, No. 1, 63

7, Courtes, G., 1964, Astron.J., 69, No 5, 325

8, Courtes, G., 1966, App. Optics, 5, No. 9, 1349

9, Courtes, G., 1972, Vistas Astron. 14, 81

10, Fehrenbach, C.H., Advance Astron. Astrop., 4c, 1

11, Gascoigne, S.C.B., 1986, Q. Jl R.Ast.Soc., 9, 98-115

12, Gascoigne, S.C.B., 1973, App.Optics, 12, 1419

13, Johnson, P.G., Kaye, A.C., Meaburn, J., 1978, App.Optics, 17, 442

14, Meaburn, J., Ring, J., Woolf, 1958, Astrophys.Space Sci., 196

15, Meinel, A.B., 1956, Ap. J., 124, 652

16, Monnet. C., Private Communication

17, Murty, M.V.K., J.O.S.A., 527, 768

18, Nandy, K., Reddish, V.C., Trittin, K.P., Cooke, J.A., Emerson, D., 1977, Mon.Not.R.Ast.Soc.,178,63

19, Reddish, V.C., PILOT 8 Report

20, Reddish, V.C., PILOT 18 Report

21, Ring, J., Courtes, G., 1955, Astronomical Optics Coll., Manchester

22, Ring, J., 1958, J.de Physique, 19, Coll., Bellevue

23, Serkowski, K., The Observatory, 87, 961, 259

24, Serkowski, K., Private Communication

25, Taylor, K., Mon.Not.R.Astr.Soc.,

26, Wynne, C.G., 1972, Mon.Not.R.Astr.Soc., 157, 403

27, Wynne, C.G., 1972, Auxiliary Instrumentation for Large Telescopes Conference, CERN/ESO

Legenas to the Figures

Figure 1

Catadioptic type short focal length cameras as stages of development of the Wynne Schmidt-Cassegrain spectograph camera.

Figure 2

A wide field reducer camera of J. Meaburn

Figure 3

A focal reducer of Meaburn, Ring and Woolf. a, primary of telescope; b, collimator; c, filter; d, camera.

Figure 4(upper)

The focal reducer optical design of G. Courtes for the 1.93 m. Telescope of the Observatoire de Haute Provence. a, telescope focal plane and field lens; b, collimator; c, camera.

Figure 4b (lower)

A proposed focal reducer optical design of G.Courtes for the 3.6m Ritchey Chretien telescope. a, telescope focal plane and field lens; b, collimator; c, camera.

Figure 5

The focal reducer of A.B. Meinel, 1956 a, telescope focal plane and field lens; b, collimator; c, filter; d, camera with accessible focal plane

Figure 6

A focal reducer design proposal of Wilson for the E.S.O. 3.5 m. telescope. This is one of several alternative designs and includes here an intermediate image and a +/-0.45 degree field (but no collimation). a, telescope not to scale; b, telescope focal plane and fieldlens; c, reduction optics; d, field flattener and reducer focal plane.

Figure 7

The suggested optical design for an F/8 A.A.T. Multi-object spectrograph (R.O.E. 1975) a, alignment and test source location s, field stop at F/8 telescope focal plane up beam of the diagonal flat; b, field available for guiding; c, folding axis of sliding diagonal flat, finder eyepiece located below, guide eyepieces located up beam; d, field lens; e, folding mirror; f, collimator; g, diffraction grating; h, reduction camera; j, reduced field plane shown in first order; k, location of image tube; m, A.A.T. guide box.

Figure 8

The layout of the F/15 Baddiley-Meaburn focal reducer (plan). a, calibration lamps; b, diffuse screen; a, telescope beam F/15; b, telescope focal plane and field lens; c, diagonal flat on slide; d, guider unit; e, dichroic beam slitter; f, collimator lens; g, pressure chamber; h, interference filter and F.P. etalon; j, camera lens; k, shutter; m, reduced field image plane location of image tube; n, baseplate.

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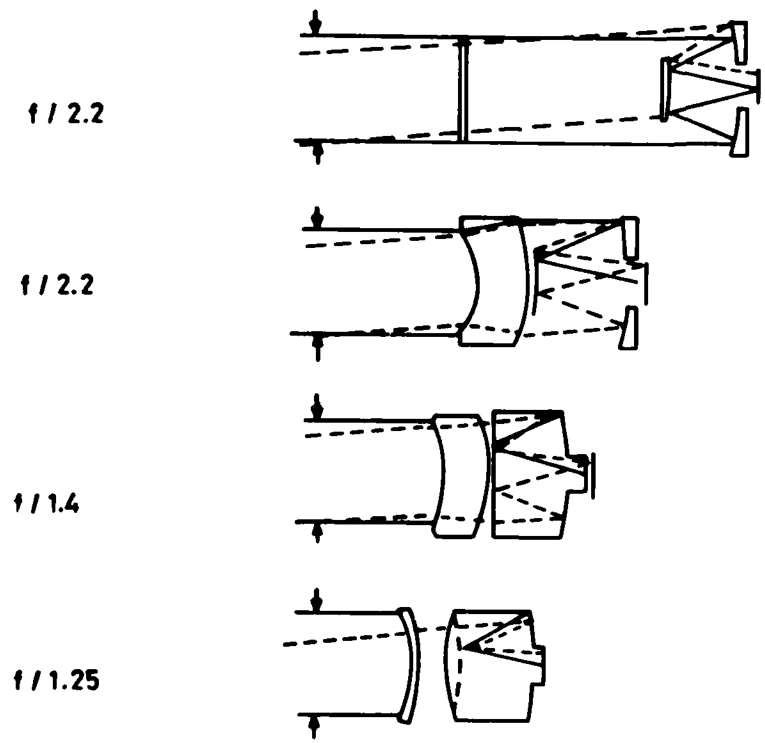

Figure .1 Catadioptic type short focal length cameras as stages of development of the Wynne Schmidt - Cassegrain spectograph camera:

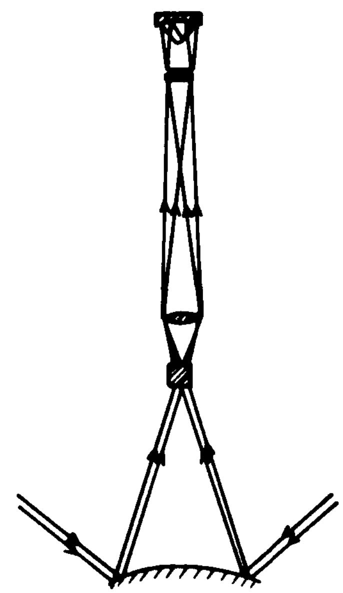

Figure . 2 A wide field reducer camera of J. Meaburn

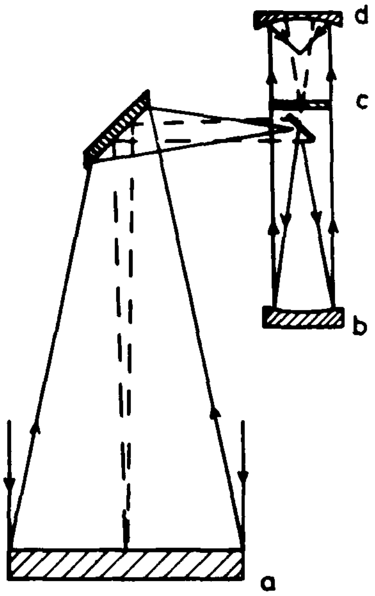

Figure.3 A focal reducer of Meaburn, Ring and Woolf. a, primary of telescope; b, collimator; c, filter; d, camera.

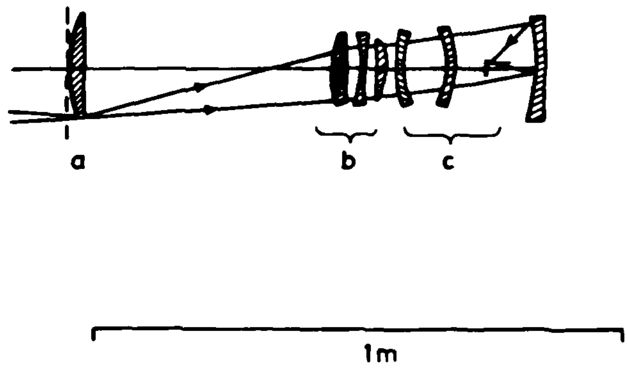

Figure 4 (upper) The Focal reducer optical design of G. Courtes for the 1.93m telescope of the observatoire de Haute Provence. a, Telescope focal plane and field lens; b, collimator c, camera.

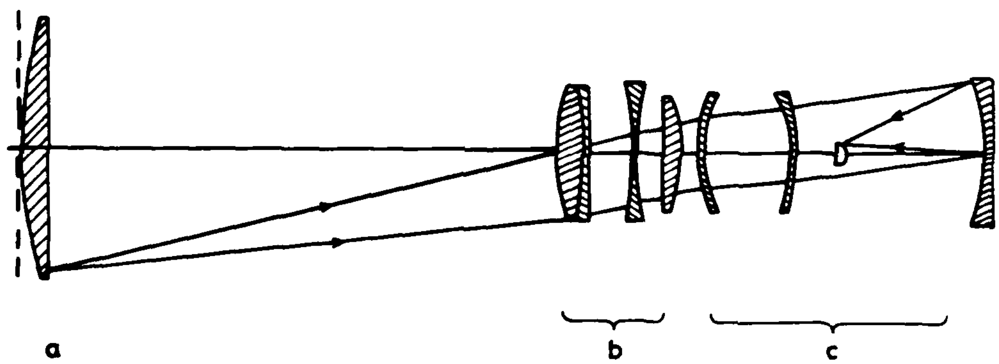

Figure 4b (lower) A proposed focal reducer optical design of G. Courtes for the 3.6m Ritchey Chretien telescope. a, Telescope focal plane and field lens; b, collimator; c, camera.

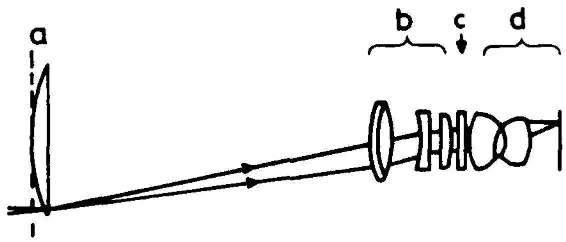

Figure 5. The focal reducer of A.B. Meinel, 1956
a, Telescope focal plane and field lens; b, collimator;
c, filter; d, camera with accessible focal plane

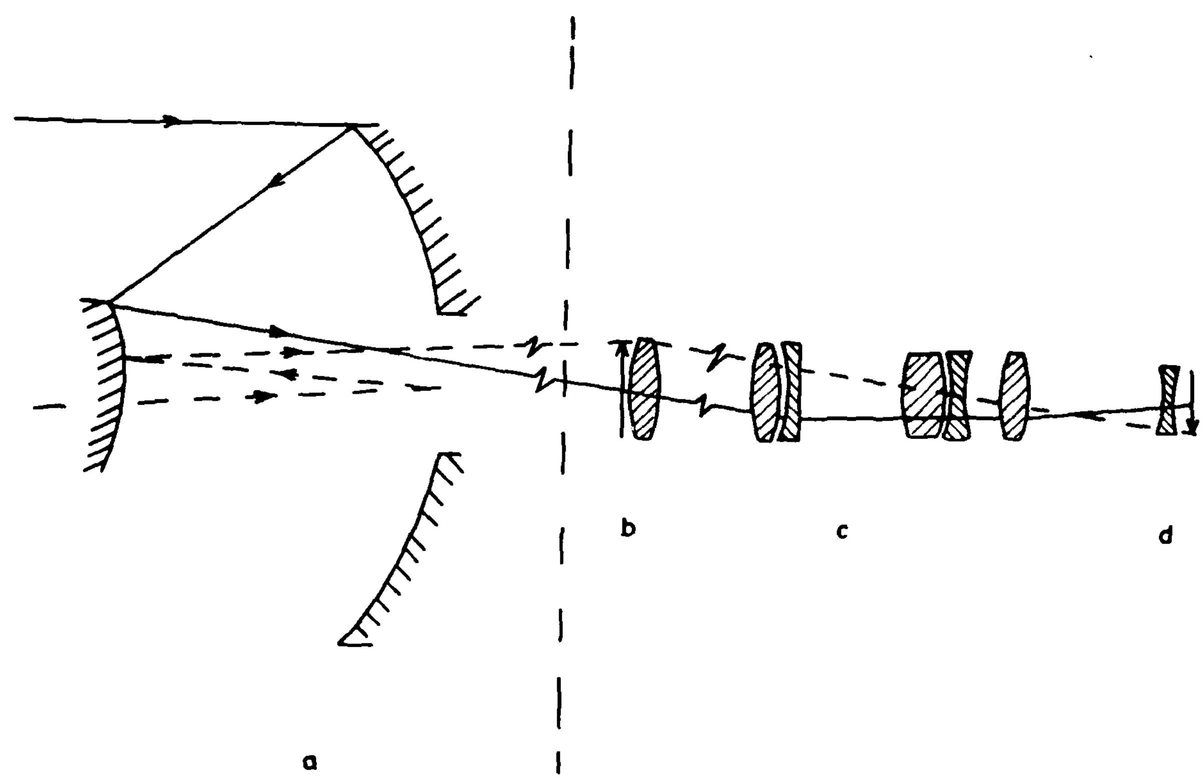

Figure.6 A focal reducer design proposal of Wilson for the E.S.O. 3.5m. telescope. This is one of several alternative designs and includes here an intermediate image and a +/- 0.45 degree field (but no collimation). a, Telescope not to scale; b, telescope focal plane and field lens; c, reduction optics; d, field flattener and reducer focal plane.

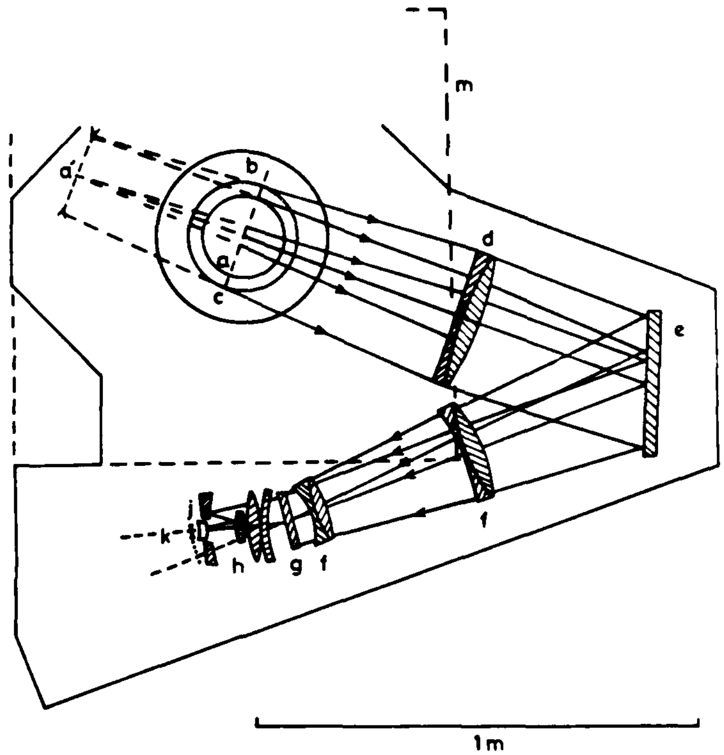

Figure.7 The suggested optical design for an F/8 A.A.T. Multi - object spectograph (R.O.E. 1975) a, Alignment and test source location s, field stop at F/8 telescope focal plane up beam of the diagonal flat; b, field available for guiding; c, folding axis of sliding diagonal flat, finder eyepiece located below, guide eyepieces located up beam; d, field lens; e, folding mirror; f, collimator; g, diffraction grating; h, reduction camera; j, reduced field plane shown in first order; k, location of image tube; m, A.A.T. guide box.

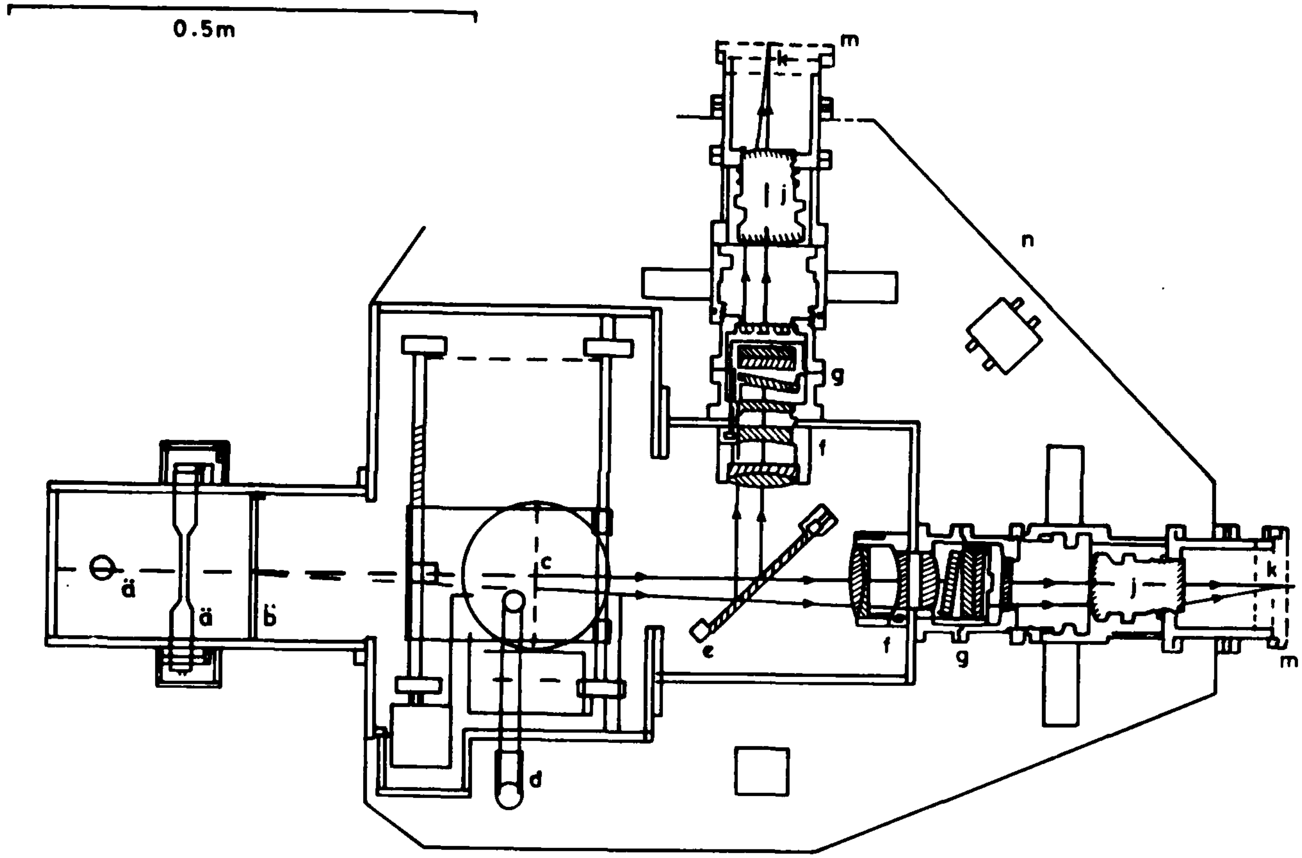

Figure. 8 The layout of the F/15 Baddiley - Meaburn focal reducer (plan). a, calibration lamps; b, diffuse screen; a, telescope beam F/15; b, telescope focal plane and field lens; c, diagonal flat on slide; d, guider unit; e, dichroic beam slitter; f, collimator lens; g, pressure chamber; h, interference filter and F. P. etalon; j, camera lens; k, shutter; m, reduced field image plane, location of image tube; n, baseplate.

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Abstract

This paper reviews the development of focal reducer imaging systems for use with interferometers and telescopes. Some less widely known designs are also discussed, these are based on the work of the author in the 1970s, while at the Royal Observatory, Edinburgh and at the University of Manchester. Interest in this type of optical system has come about particularly with the development of image intensifiers and electronic detector arrays such as CCDs. These designs are of interest wherever image reduction is required.

S80/48