# IMPLEMENTATION AND USE OF WIDE FIELDS IN FUTURE VERY LARGE TELESCOPES

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## ABSTRACT

The full potential of the next generation of larger telescopes will be realized only if they have well instrumented large fields of view. Scientific problems for which very large ground-based optical telescopes will be of most value often will need surveys to very deep limits with imaging and slitless spectroscopy, followed by spectroscopy of faint objects taken many at once over the field. Improved instruments and detectors for this purpose are being developed. Remotely positioned fibers allow the coupling of light from many objects in the field to the spectrograph slit. CCD arrays, operated in the TDI or drift scan mode, will make large area detectors of high efficiency that may supercede photographic plates. An ideal telescope optical design should be based on a fast parabolic primary, have a field of at least 1° with achromatic images $< 0.25$ arcseconds and have provision for dispersive elements to be used for slitless spectroscopy and compensation of atmospheric dispersion over the full field. A good solution for a general purpose telescope that can satisfy these needs is given by a three element refractive corrector at a fast Cassegrain focus. A specialized telescope dedicated to sky surveys, with better image quality and higher throughput than presently available, might be built as a scaled up Schmidt with very large photographic plates. Better performance in most areas should be obtained with a large CCD mosaic detector operated in the drift scan mode at a telescope with a 2-mirror reflecting corrector.

## 1. INTRODUCTION

Telescopes with apertures considerably larger than 4m diameter are being planned by a number of groups in the U.S.A. and elsewhere. A new generation of 8m class instruments, some making use of single glass honeycomb mirrors and alt-azimuth mounts, can be expected. One or two instruments with multiple primary mirror elements to achieve even larger area are planned, such as the US NNTT and ESO's VLT. The new telescopes should be built to realize the best quality imaging possible

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through the atmosphere and to match the most efficient detectors and instruments. In this paper we will consider the wide field capability that is needed and can be realized in these telescopes, and also future types of specialized survey instruments that will best support them.

Spectroscopy of faint objects will be one of the major tasks for the largest telescopes, and it is for this work that a wide field is most valuable. Even with a very large telescope, a long time is required to obtain spectra of objects at or below the sky limit, but recently techniques have been developed to obtain aperture or slit spectra of dozens of objects at once, taken from all over the field of view. This goes to the heart of a science in which no experiments are possible, but understanding has to be built up from observations of many objects.

In addition to slit spectroscopy of multiple objects, a wide field is valuable for slitless spectroscopy and for direct imaging. Most of the present generation of 4m telescopes take advantage of wide field prime focus correctors with photographic plates to make low resolution grism surveys. An interesting aspect of slitless spectroscopy is that the large telescope acts efficiently as its own survey instrument. The limiting magnitude for low resolution spectra projected against the sky background is similar to that of higher resolution spectra obtained through multiple apertures in the focal plane.

Direct imaging remains an area where very large telescopes will have an important role and should exploit the best seeing. With an 8m telescope the sky signal in photometric bands is about 1000 photon/sec from one square arcsecond. When the seeing is excellent, sampling with pixels of 0.1 - 0.15 arcseconds is desirable. Mapping to 1% of the night sky in these pixels will thus still require long exposures with the best detectors.

What field of view should we strive for in a telescope to be used in these ways? No hard and fast answer is possible, because of the great diversity of programs undertaken with optical telescopes. However, once it is accepted that equipment for identifying and simultaneous spectroscopy of many objects, of order 100 at a time, will be used, then there is considerable advantage in having the widest possible field. Consider the study of gravitationally bound systems, such as open and globular clusters, dwarf galaxies, galaxies and clusters of galaxies. The nearest examples of all these types, those that can be studied in the most detail, have a diameter of a degree or considerably more. It is clearly advantageous if entire systems can be studied in one or only a few fields of multiobject spectroscopy.

A second general class of observation is of randomly distributed objects, such as the local disc stellar population, halo stars, distant galaxies and quasars. There is no natural angular scale for studying these objects, but there is a relationship between number in a given field and apparent magnitude. Suppose one wishes to study many iso-

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tropically distributed objects of certain luminosity and the telescope is to be equipped to take a certain number of objects at once from a field of angular diameter $\theta$. The apparent magnitude that must be reached then varies as $10/3 \log\theta$, thus a doubling of the field diameter allows one to work almost exactly 1 magnitude brighter. At cosmological distances this simple relationship breaks down due to the effects of redshift, evolution and geometry, and each type of object must be treated explicitly. Thus, for bright quasars the number density increases much more strongly with magnitude than would be expected for an isotropic distribution. But by 21st magnitude, where the density is ~ 100/square degree, the rate of increase is not very different from the isotropic case above.

Our conclusion from these considerations is that the highest scientific productivity of very large telescopes operating in the optical spectrum will be achieved by giving them the widest possible fields of view. The actual size to be built turns on the practicality of making instruments and detectors for large fields, optical design solutions with the required image quality and scale, and compatibility of wide field use with other applications, particularly in the thermal infrared.

## 2. INSTRUMENTS AND DETECTORS

Aperture or slit spectra of multiple objects in the field are currently obtained either by making a drilled aperture plate at the spectrograph entrance, or relaying light from the focal plane to the spectrograph entrance with fibers. Aperture plates are the easier to implement and have been used at the Mayall and Hale telescopes (Dressler and Gunn 1983). However, the method cannot be adapted to large fields and is restricted to fairly low dispersion. Fiber coupling, in use at the Steward Observatory and AAT telescopes, overcomes these limitations and is the method of choice for very large telescopes.

A fiber is located at the position of each object in the focal plane, and all the fibers are brought into a line at the entrance slit of the spectrograph. In this way a detector with 1000 x 1000 large pixels can record linear spectra of moderate dispersion of around 100 objects at once. Higher dispersion spectra require large numbers of pixels in the form of mosaic detectors in a single large spectrograph, or multiple smaller spectrographs each handling a subset of the total number of spectra. Existing multiple fiber instruments use plates with drilled holes to locate fibers correctly in the focal plane (Hill *et al.* 1980, Gray 1983). The next generation will incoporate some type of mechanism so fibers can be remotely positioned under computer control (Hill, Angel and Scott 1983). This is not only a convenience; fibers in a permanent set can be prepared with more care, and equipped with microlenses to allow the most efficient coupling.

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Two telescope requirements for getting the most out of multi-fiber spectroscopy are as follows. First, the images should be achromatic. Most current wide field correctors were designed for imaging in photometric bands, when refocusing from band-to-band is not a serious defect. However, if silicon detectors covering 0.3 - 1μ are used in the spectrograph, this range of wavelengths should all come to a sharp focus in the same plane. Second, assuming the seeing is good and the corrector is achromatic, the spread of the image from dispersion in the atmosphere will be quite pronounced, even for objects well above the horizon. A system that incorporates prism elements to balance out atmospheric dispersion is thus very desirable, so that small round apertures with the maximum sky rejection can be used.

One aspect that is not critical for fiber spectroscopy is scale or focal ratio. With the aid of microlenses, which can be contacted to a fiber end with no loss, efficient coupling can be made to fast or slow foci (Hill, Angel and Richardson 1983). Another point is that there is no special difficulty in instrumenting very large fields with fibers, particularly if the fibers are remotely postioned. For Schmidt size fields with fixed fibers, differential refraction during the exposure is significant (Watson 1983), but remote positioning allows correction to be made during an exposure. A practical consideration is the need for access around the field for remotely positioned fibers. Optical designs like the Schmidt or Paul have 'trapped' foci, with little room for actuators unless folding mirrors are used.

Turning our attention to slitless spectroscopy and imaging, the big question is the detector to be used for large telescopes. In the best seeing, when images of 1/3 arcsecond can be recorded, pixel sizes of 0.1 - 0.15 arcseconds should be used, i.e., ~ $10^9$ per square degree. The ideal detector would combine the large area and convenience of photographic plates with the linearity, dynamic range and high sensitivity of CCDs. Many CCDs used together are needed, or more sensitive emulsions. In fact, we can anticipate that both may be available within the next decade, the time scale for development of the new big telescopes.

We have seen at this meeting the continuing strength of photographic methods, particularly when the most sensitive plates are analyzed with the new generation of high speed microdensitometers. The primary deficiency of photography is its low detective quantum efficiency (DQE), currently ~ 2% for the best hypersensitized IIIaJ plates. However, advances in speed continue to be made, with Kodak's new T grains holding the promise of a factor two increase in DQE for astronomical plates (Millikan 1984). The large plate scale of very big telescopes may allow still further advances, since larger grains can be tolerated. Presently a focal ratio of f/3 is considered ideal for photography, yielding optimum exposure for sky limited images in about an hour. Future increases in emulsion speed should allow for somewhat slower foci or shorter exposures.

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Charge coupled devices (CCDs) offer higher efficiency, linearity and dynamic range than photographic plates, with near unity DQE over a wide spectral range obtained in the best devices. Single devices are now widely used for imaging relatively small fields. Two techniques are now being developed to realize wide field coverage with CCDs: the deployment of many devices in a mosaic and the drift scan method. The wide field camera on space telescope uses four devices to sample a 2.6 arcminute square field with 0.1 arcsecond pixels. A similar configuration has just been developed at Palomar with 0.3" sampling over a 8' square field (Gunn, Westphal and Danielson 1983). In the drift scan or TDI method, the CCD is clocked slowly and continuously as the star field moves in synchronization with the charge image across the face of the chip. The deepest optical images yet made, reaching 26th magnitude in R, have been made this way (McKay 1983). Wide field surveys are also now being undertaken by this method. McGraw et al. (1982) describe a 1.8m transit instrument which will use two CCDs to scan a strip 8 arcminutes wide, of area 20 square degrees per night, to about the same limiting magnitude as a IIIaJ Schmidt plate.

The advantages of the TDI method are that seamless large area images can be realized from a mosaic of separated small devices, and that

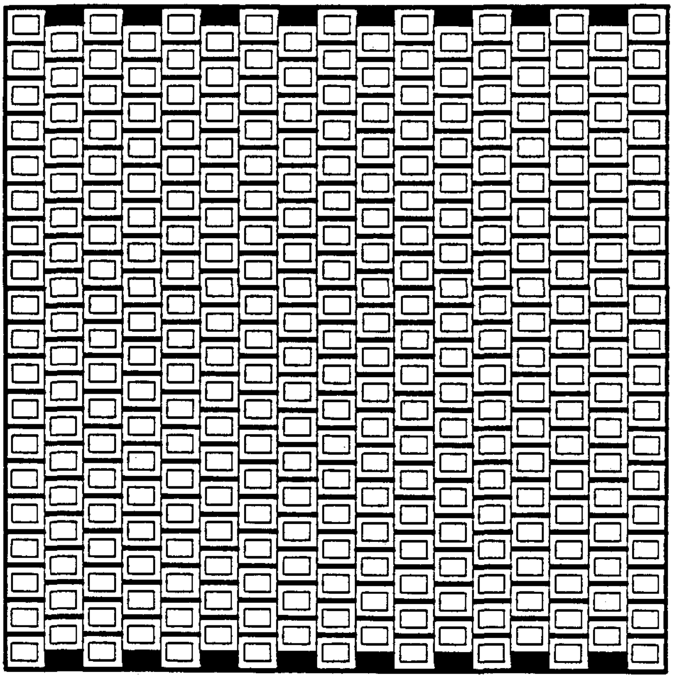

Figure 1. A possible configuration of CCDs of aspect ratio 2:3, suitable for drift scan imaging of a large field. The vertical repeat spacing is just less than twice the height of the active area, so that a horizontal scan leaves no gaps.

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flat fielding becomes a fairly tractable one dimensional problem. A mosaic configuration suitable for TDI imaging of large fields is shown in Figure 1. The devices here are packed with a filling factor of 1/3. The DQE of such an array would thus be about 25%, if the individual device quantum efficiency is 75%. If devices are used in this way, there may be no compelling advantage in using very large individual chips. In some ways it is better for them not to be too large. If the telescope is drifted across the star field, image distortion will result in blurring if the individual devices are too large.

A critical design parameter in using CCD arrays for imaging is to match the pixel size and image scale. Present devices used for astronomy have pixels in the range 15 - 30µ. Taking 22µ as representative, we find for sampling at 0.1 arcseconds a focal length of 45.4m is needed, for 0.15 arc seconds, 30.3m. Thus a 7.5m telesope should operate in the range f/4 - f/6. Another critical parameter is device cost. The present cost for premium quality devices in unit quantity is approximately 1¢/pixel. At this price enough devices for a $10^9$ pixel array with 1/3 filling factor would cost $3M, and a detector system with resolution comparable to that of a Schmidt plate would then be comparable in cost to the large primary mirror that feeds it. We can anticipate improved yield and technology over the next few years may result in an order of magnitude reduction in cost, making the cost of large arrays not disproportionate, even for smaller telescopes.

A concern commonly expressed at the prospect of large CCD arrays is difficulty of data handling and reduction. The spectacular results reported at this meeting by the Edinburgh and Cambridge groups should help allay some of these fears. Digital processing of full Schmidt plates, ~ $10^9$ pixels, is already now being successfully undertaken with modest sized computers and tape data storage. When the new large telecopes are operating we can expect more powerful computers will be readily available, and also, as Grosbol (1984) has pointed out here, low cost laser disc storage of data.

If, as we can hope, the exposure and recording of large electronic images becomes manageable and routine, then the possibility arises for serendipitous imaging. When a single object is scheduled for extensive spectroscopic or polarimetric study, the surrounding field can be recorded and used for other projects. As an example, for many cosmological studies the exact area covered is not as important as the quality and depth of images. In conditions of good seeing, the serendipity mode will be of special value.

One final aspect to be considered in optical design is provision for the dispersing elements. Correction for atmospheric dispersion requires a way to disperse each object in the field by an amount equal to that produced by the atmosphere, but in the opposite direction. Dependence on an wavelength must be the same as the atmosphere's and with magnitude proportional to the tangent of zenith distance. Systems to make such corrections have been built for speckle interferometry,

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and make use of a pair of counter-rotating prisms. Slitless spectra will in general require higher dispersion, either by prism or grism elements. Both functions should be accomplished with elements that are a small fraction of the primary diameter, if they are to be practical for very large telescopes.

## 3. OPTICAL DESIGNS FOR LARGE TELESCOPES

From the discussion above, it would appear that electronic or photographic detectors can be realized for fields of at least 1°, and that multiobject fiber systems could be made for even larger fields. Ideally, the wide field should be achieved with a primary mirror that is rather fast, f/2 or faster, to keep down telescope length and enclosure size. Also, if the telescope is to be reconfigured for operation in the infrared, it is valuable to have a parabolic or nearly parabolic primary figure, so that small Cassegrain secondaries will give an acceptable field of view at long focal ratio and without refractive correctors. A summary of the reqirements to be met by an ideal optical system is given in Table 1:

**Table 1.**

| | |
|---|---|
| field of view | 1° or more |
| aberration | $\lesssim$ 0.15 arcseconds |
| achromatism | over range 0.3 - 1μ |
| correction for atmospheric dispersion | |
| dispersion for slitless spectroscopy (prism and/or grism) | |
| scale | 4.5 - 7 arcseconds/mm |
| primary figure | $\lesssim$ f/2, parabolic |

These are tough specifications, not met by any existing telescope. The two designs that come closest, and that we can take as points of departure, are the Dupont 2.5m telescope, a Ritchey Chretien that achieves a 2° field at f/7.5 with a single element Gascoigne corrector (Bowen and Vaughan 1973a) and the CFHT prime focus corrector, 1° at f/4.2 (Fouéré *et al.* 1982).

The general idea of Ritchey Chretien optics is to get a wide field of good resolution by using two reflecting surfaces to maximum advantage, requiring the primary to be hyperbolic instead of parabolic. A refractive element can then be used to fine tune the image, to flatten the field or reduce astigmatism to get more field. This approach has several deficiencies. Firstly, if a reasonably fast focus is required,

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$F \overset{\sim}{<} 6$, then the primary figure departs quite strongly from a parabola. Secondly, the insertion of a single refractive corrector element compromises achromaticity. In the Dupont telescope, for example, the corrector has to be repositioned to correct different wavelength bands. Thirdly, the introduction of glass prism or grism elements for either dispersion correction or slitless spectroscopy will cause some aberration, especially at the faster focal ratios (Bowen and Vaughan 1973b).

If a design is to take advantage of the inherent achromaticity and good correction of reflecting optics, it would seem that a three-mirror system should be used. Wide field corection can be achieved without the need for any refractive element. If the primary and secondary together are made afocal, then dispersing elements can be introduced between the secondary and tertiary without compromising aberrations or achromaticity. The third element and focal surface must be tilted if there is deviation.

An early analytic solution for a two-mirror corrector with a parabolic primary yielding extremely low aberrations was given by Paul (1935), an example of which is shown in Figure 3a below. Even with a primary of focal ratio f/1, an optimized design described by Angel, Woolf and Epps (1982) gave 0.2 arcsecond images over a 1° field. The Paul configuration being built for McGraw's transit telescope has a 1.8m f/2.2 primary, and a 1° field of view. It will incorporate for slitless spectroscopy a zero deviation prism whose diameter is 1/3 that of the primary.

A disadvantage for general purpose telescopes is the inconvenience of the focal position, half way up the tube with very little room for instruments. A scheme was devised by Woolf *et al.* (1982), to access the focus with multifiber probes but is not simple and the field is limited to 40' by obscuration. A modification of the three-mirror design to produce an accessible focus just above the secondary has been developed by Epps and Takeda (1983). In this case though, the primary must be hyperbolic if high quality imaging is to be realized, and again the field is limited by obscuration. The most practical design for a versatile 3 element system, given by Epps (1983a), places the tertiary mirror behind the primary, and the focus a little above the primary vertex. A steering mirror gives several accessible focal stations below the primary.

Central obscuration is the dominant problem in three-reflector systems. Aberrations at wide field angles can be very well controlled, but a solution for a big telescope that gives a full 1° field and acceptable obscuration requires large auxiliary optics and will be somewhat inconvenient for access and reconfiguring with low IR background.

Let us return then to the prime focus type of solution, in which wide field achromatic imaging relies heavily on the use of refractive elements, and the particular primary figure is not very important. The

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idea that three refractive elements of the same material could be used to obtain achromatic correction, originally recognized by Sampson (1913), was realized in the wide field correctors designed for both hyperbolic and parabolic primaries (Wynne 1968, Faulde and Wilson 1973). The recent CFHT corrector of Wynne and Richardson (Fouéré et al. 1982) gives high quality images over a wide field. Operating at the prime focus of an f/3.78 parabola, it yields an unvignetted field of 46' at focal ratio f/4.20, with images better than 0.7" over a total field of 55'. It incorporates a grens as part of the interchangeable third corrector element, allowing slitless spectroscopy over the full field with high image quality. The CFHT system comes close to achieving many of the features of Table 1, including a parabolic figure on the primary, but fails in that the primary is rather slow (f/3.8). What happens if we use a three-element corrector with an f/2 or faster primary? This question is now being studied by Epps for the California group. It appears at the present time that, even with the field restricted to 30 arcminutes, good images over the full optical range need two alternative corrector configurations, with refocusing of different broad wavelength bands (Epps 1983a). The question of dispersion over the field is unresolved, but aberrations produced by prisms and grisms in the fast beam may be a problem, especially if good images are to be preserved.

If correction at a fast prime focus cannot meet our needs, a more favorable approach is to use multi-element refractive correctors at a Cassegrain focus derived from a fast primary. Wynne (1973, 1983) has shown that even two element correctors can give remarkably good performance over a 1° field. Three element correctors are potentially even more powerful, and indeed a recent solution by Epps, Angel and Anderson (1983) described below satisfies all the requirements of Table 1. Starting with an f/2 primary, a relatively fast classical Cassegrain focus, f/5.3, is formed by a secondary with about 1/3 the primary diameter. The focus could be used as is for small field work, but aberrations outside a 5 arcminute field become larger than an arcsecond. Coma is the same as for an f/5.3 parabola, astigmatism is greater. Correction of this focus is made with three fused silica elements, optimized to give minimum aberration over the wavelength range 0.33 to 1μ and over a 1° field. The design, which has a flat focal plane at f/6, was made with the inclusion of counter rotating zero deviation prisms placed after the second element, where the beam is narrowest and has least divergence. These prism elements are of FK5 and LLF2 glass, a pair that matches atmospheric dispersion quite well, and allows transmission down to 3300Å.

Ray tracing of the design at different field angles and wavelengths, from 0.33μ to 1μ with no refocusing, shows spot diagrams mostly having 100% of the rays within 0.25 arcseconds (Figure 2). Only the spots of extreme wavelengths at the edge of the field fall outside this limit. The prisms introduce no significant additional aberration, and compensate up to 60° zenith distance, reducing atmospheric dispersion over the full wavelength range by an order of magnitude, more for

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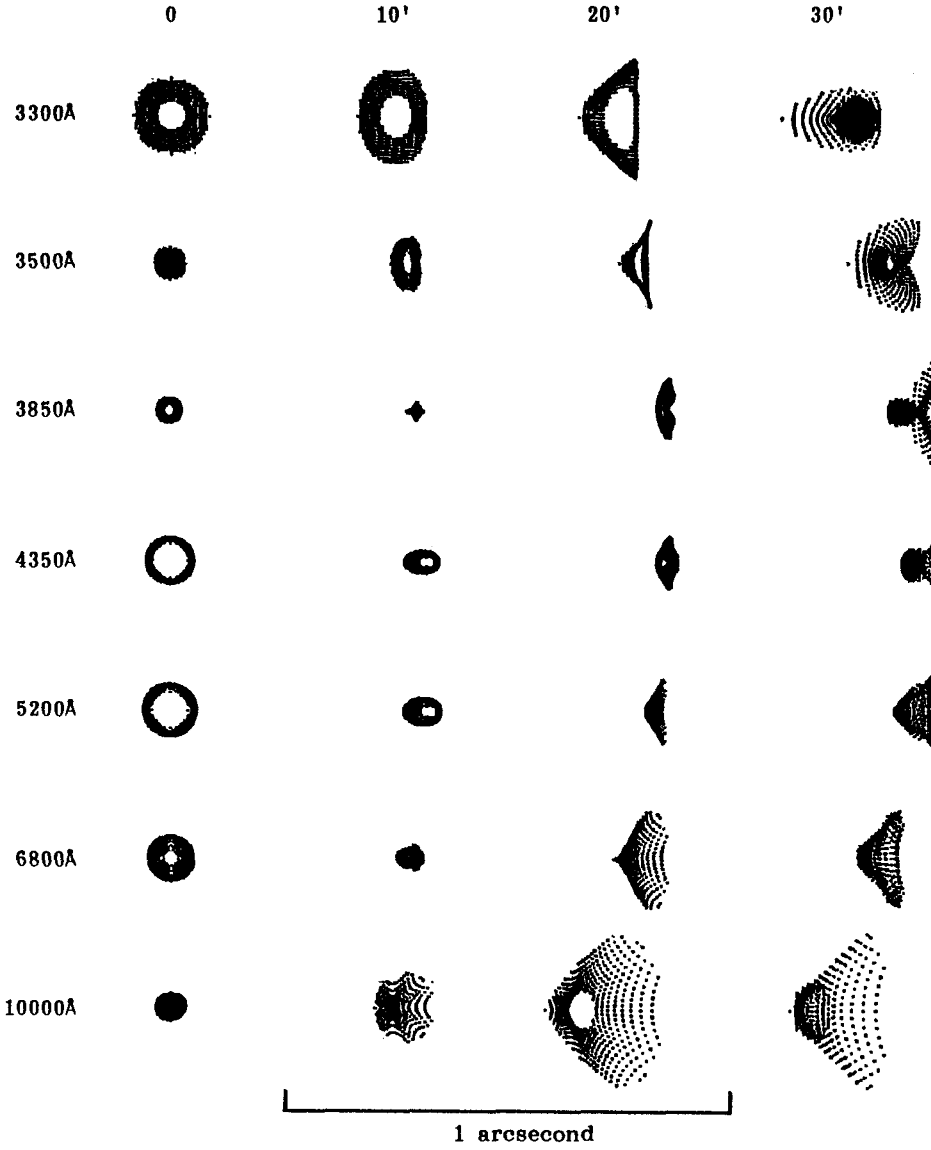

Figure 2. Spot diagrams for the corrected Cassegrain focus of Epps, Angel and Anderson (1983), all computed for the same flat focal plane. The horizontal registration is accurate, showing the small residual chromatic difference of magnification. Summed over all wavelengths, 0.33μ-1μ, 100% of the energy lies in a 0.17 arcsecond circle on axis, within 0.29 arcsecond at 20' radius and 0.46 arcseconds at the edge of the 1° diameter flat field. Atmospheric dispersion over this wavelength range is 4 arcseconds at 60° zenith distance, and can be reduced to 0.4 arcseconds by the prisms built into the corrector. On the scale of this drawing, the field diameter is 200m.

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reduced bandwidth. Scaled for a 7.5m primary, the completely unvignetted field of 1° requires a secondary 2.48m of diameter and corrector elements of 1.19m, 0.86m and 0.97m. The field diameter is 0.8m and the scale is 222μ/arcsecond.

Epps' optimization of this f/6 system has given a solution that combines extraordinary achromaticity, image quality, spectral range and field size. The design is evolving. We plan next to try for a slightly faster final focus, explore the performance to 2μ and look at dispersive elements for slitless spectroscopy.

## 4. SPECIALIZED SURVEY INSTRUMENT

Our discussion so far has been restriced to the implementation of wide fields in very large general purpose telescopes. Now let us consider briefly two directions that might be taken by specialized survey instruments with larger aperture and better image quality than present day Schmidts. For survey instruments having the same spatial resolution, the time taken to survey a large area of sky to a given limiting magnitude inversely is proportional to $(A\Omega)_{eff}$, the product of telescope area, the field of view and the DQE of the detector. This figure of merit can be reexpressed as

$$(A\Omega)_{eff} = \pi a/4F^2 \times DQE$$

where a is the detector area and F is the telescope focal ratio. Its value for an f/2.5 Schmidt telescope with 35 cm square photographic plates is 3 $cm^2$, assuming a DQE of 2%.

In order to achieve higher spatial resolution and a higher figure of merit we consider the performance of a larger Schmidt with better emulsions, say a DQE of 4%. With a clear aperture of 2.5m, and operating at f/2.5 one could achieve spatial resolution of ~ 0.5 arcseconds, at least in moderately narrow wavelength bands and with moderately short exposures, so as to minimize variable distortion from differential refraction. The figure of merit would be 24 $cm^2$, assuming 70 cm square plates. The telescope tube would be 12.5m in length and a primary of ~ 4m diameter would be needed (Figure 3b). If the images are to be treated digitally and not to be degraded, the telescope would have to be operated in conjunction with a large plate scanner, having 0.25 arcsecond pixels (6μ).

As an alternative, we can consider a shorter, fatter telescope, a 6m f/2 primary in a three-mirror sytem, such as that shown in Figure 3a, operated with CCDs in the TDI mode. In order to be specific let us take hypothetical CCDs not unlike those widely used today, with a DQE of 75% and 400x600 pixels each 25μ square, subtending 1/4 arcsecond on the sky. It follows then that F at the corrected focus must be 3.44, and $(A\Omega)_{eff} = n \times .075\ cm^2$, where n is the number of CCDs operated in the focal plane. A figure of merit of 25 $cm^2$ requires the use of 330 chips. Packed with a filling factor of 1/3, the required field of view

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in the focal plane would be 1.1 square degrees. The array shown in Figure 1 represents this concept. It has 323 devices, and would measure 37 cm square.

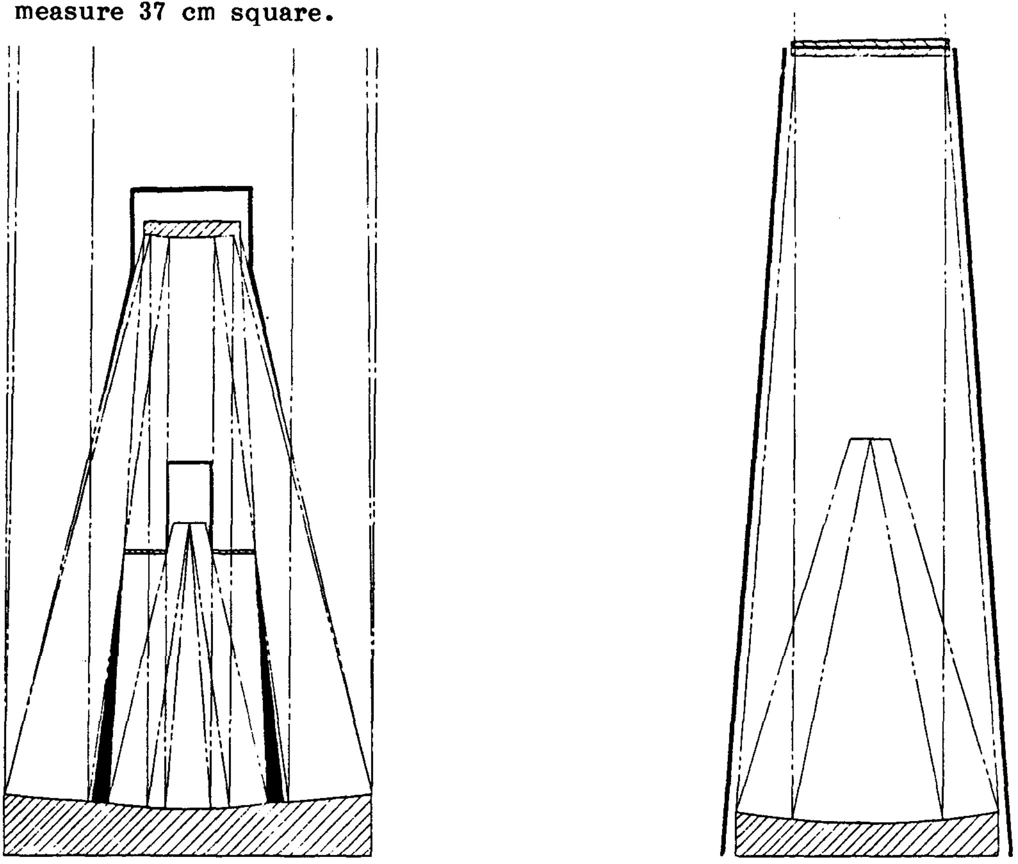

Figure 3. Two large survey telescopes drawn to the same scale, (a) shows a Paul 3 mirror telescope in which the f/2 primary and tertiary surfaces are figured on the same 6m blank (Arganbright 1983). The field is 1.45° diameter at f/3.44 and the image size ~ 0.1 arcseconds (Epps 1983b), (b) shows a classical Schmidt of 2.5m clear aperture with 8.5° diameter field at f/2.5.

The construction and operation of such a large detector array may seem prohibitively difficult but it should be contrasted with the construction and operation of appropriate dark room facilities and a plate scanner than can accurately scan $10^{10}$ 6μ pixels over a 70 cm plate in a reasonable period. The CCD approach offers linear data with high dynamic range and an immediate digital record. The Paul telescope has considerably better optics and wider spectral range (0.3 - 2.2μ). Its aperture is larger than the Schmidt's and it would be much more powerful for intensive study of restricted fields much less than 36 square degrees.

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## 5. SOME CONCLUSIONS

Perhaps the most important conclusion is that the need for wide fields of excellent imaging can be realized in optical designs based on fast primaries. Predictably though, the good optical solutions require relatively large auxiliary mirrors and lenses. This need should be of concern when telescopes with very large primary mirrors are contemplated, particularly if rapid reconfiguration of the telescope for low background IR operation is envisaged. A specific solution to this problem is offered by the MMT design reported by Lynds et al. (1983). Four 2.5m Cassegrain secondaries, which work with four 7.5m primaries as individual wide field telescopes, are mounted in a single large structure across the top of the telescope. When this structure is rotated by 45° the secondaries and their supports move out of the light path, to be replaced by small chopping secondaries and beam combining mirrors.

Another point we have considered is application of the above designs to telescopes in space. Paul optics are an obvious choice for wide field imaging, given their achromaticity and excellent images. However, the three element Cassegrain corrector has high enough performance to merit consideration for a larger ST successor that can do multiobject spectroscopy as well as imaging. Large and small field correctors could be used interchangeably at the same basic Cassegrain focus, to give either the wide field at 0.2 arcsecond resolution, or a smaller field at the diffraction limit.

Whether in space or on the ground, the problems of transmitting, recording, accessing and calibrating images each of $10^9$ pixels is formidable. Still more of a challenge is to use computers efficiently to help us digest all this information. As we plan and develop new very large telescopes with wide fields and the highest resolution, the experience gained from Schmidt telescopes will be invaluable.

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