TRANSIT TELESCOPE DESIGNS OPTIMIZED FOR MULTIPLE OBJECT SPECTROSCOPY WITH FIBERS

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Instruments to study simultaneously the spectra of many objects in the field of view of a telescope can be made with the aid of fused silica fibers. The spectrograph at the 2.3m telescope of the University of Arizona has been modified for such operation, and is used routinely to investigate the dynamics of clusters of galaxies (Hill et al. 1981). The system presently in use locates up to 40 fibers in the telescope's Cassegrain focal plane, with the aid of plates previously drilled with holes in the configuration of the objects to be studied. Each field must be set up by hand by inserting fibers into a hole plate. An obvious improvement to this method would be to mount each fiber on a mechanical actuator, so new field configurations can be set up by remote control. It is our intention to make such a system with 32 fibers for the 2.3m telescope, over the next two years.

We have considered how the multi-fiber technique can best be used to obtain spectra of the many faint objects identified by deep transit survey instruments and new space and radio telescopes. A transit survey such as that planned by McGraw et al. (1980), with CCDs at the focus of a 2m transit telescope, will identify objects down to 24th magnitude, and down to 22nd magnitude will give very complete data on variability and optical energy distribution. A telescope with much larger aperture is required for spectroscopic follow up. We argue that large telescopes dedicated to this type of work can be made and operated for only a fraction of the cost of a general purpose telescope.

The thinking is as follows. Any type of automated multiple fiber system requires mechanisms to position many fibers in two dimensions, within the field of the telescope. If the telescope were fixed in position, the same mechanisms could be used to track objects of interest as they move through the field at sidereal rate. Imagine for example a Schmidt telescope with a 6° field of view fixed to point at the zenith and equipped with tracking fibers. Each object could be tracked for nearly half an hour (depending on latitude). Assuming a CCD detector with very low noise were available for the spectrograph, sky limited spectra could be obtained at moderate resolution with a telescope of

C. M. Humphries (ed.), Instrumentation for Astronomy with Large Optical Telescopes, 117–122.

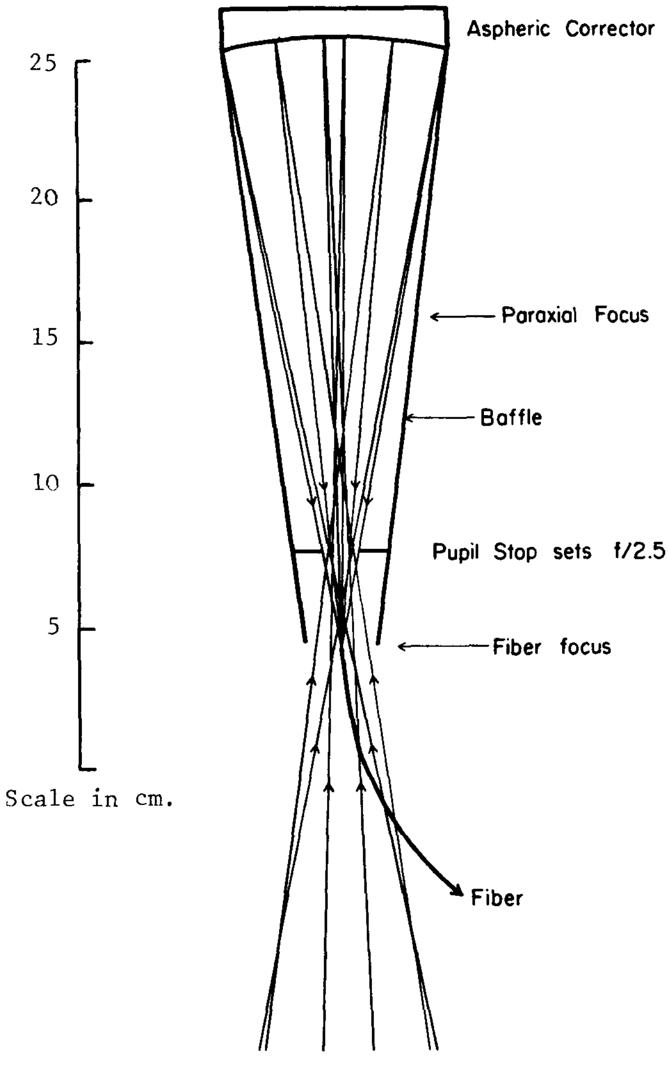

Figure 1. A single aspheric reflector to correct spherical aberration and form a stellar image on a fiber feed. The stop accepts a cone of f/2.5 from the spherical primary that may be considerably faster. The drawing is to scale for a primary mirror of 20m focal length.

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1 meter diameter. Signal to noise could be improved by co-adding data from many nights during the season for each program object. According to the sophistication of the fiber tracking mechanism, it might be possible to follow up to 100 objects simultaneously.

Markedly reduced building, housing and operating costs should be achieved with this type of telescope. There are no moving parts except in the focal plane instrument; the housing is small since the telescope sweeps out no volume; operation is automatic and proceeds according to a programmed sequence of objects through the night. One is tempted thus to consider telescopes much larger than normal Schmidts for this application. It may be practical to build up from sections a Schmidt corrector plate of very large dimensions. Support of the sections should not be difficult since it is not to be moved from a horizontal orientation. Figuring of the off axis aspheric surfaces could perhaps be achieved by the stress polishing method of Nelson and Lubliner (1980), or by methods involving diamond turning or diamond grinding and replication.

A different approach for very large aperture is to dispense with the corrector plate, and deal with telescope aberration near the focal plane. At first sight this might seem impractical, since corrected fields larger than a degree can be achieved only with great difficulty. However, for our purpose we can consider equipping each fiber with its own small corrector, which has only to bring to a sharp focus a single point on the sky. For such a system the primary should be spherical, allowing operation over a large field like the Arecibo radio telescope.

Clearly if many correctors are to be used at once each must be made as small as possible. A lower limit to their size is set by the blur circle at the paraxial focus, which has a diameter of $1/32F^3$ radians (F is the focal ratio of the cone accepted by the corrector). The simple corrector shown in Figure 1 is a concave aspheric mirror with a diameter $1/16F^3$, drawn to scale to accept and correct an F/2.5 beam. The field diameter obscured by the corrector in this case is 0.23°. Single element correctors of this type suffer from substantial coma, so the magnification of the image formed by extreme and paraxial rays is different by ± 30% from the mean. However, this does not seriously compromise the signal to noise that can be achieved for faint objects that are unresolved in presence of atmosphere turbulence.

To illustrate some of the features of the multiple corrector system, we show in Figure 2 a specific concept for a large telescope with 16 correctors moving over a field of view of 15°. The fixed primary is a spherical mirror of 20m focal length, square 18m on a side with rounded corners. It would be built up from smaller identical spherical mirrors supported by a stiff framework. The mirror is housed in a building 8m high with a cover in the form of a pitched roof. A laboratory for instruments to analyse light from the fibers is on the floor below the mirror.

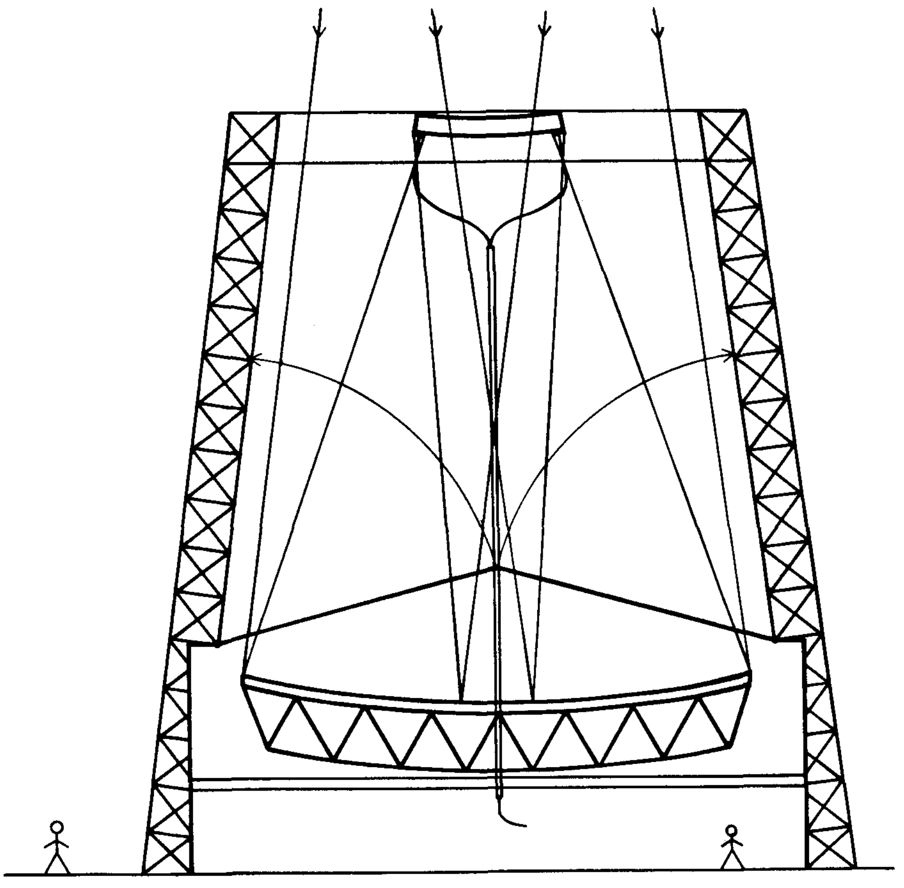

Figure 2. A multi-corrector telescope with fixed primary mirror. The large spherical mirror, 18m across, is in a housing with a roof that swings up on hinges. At the focal plane are 16 small fiber-feeding correctors, that can be set independently and tracked over a 15° field of view. The fibers are brought down a central pipe to the instrument lab below the primary mirror.

The focal surface assembly, about five meters square and supported from an open steel structure, is shown in detail in Figure 3. Sixteen correctors of the type shown in Figure 1 are arranged to move in groups of 4 over the spherical focal surface. The east-west rails have the geometry of lines of latitude on the focal sphere. Each corrector is on a carriage spanning two rails. The declination to be tracked by a corrector is set by driving it along its carriage, between the limits set by the rails. Sidereal motion is tracked for up to an hour driving the carriage along the rails. Fibers hanging from the correctors are passed down a central pipe to the instrument laboratory some 24 meters

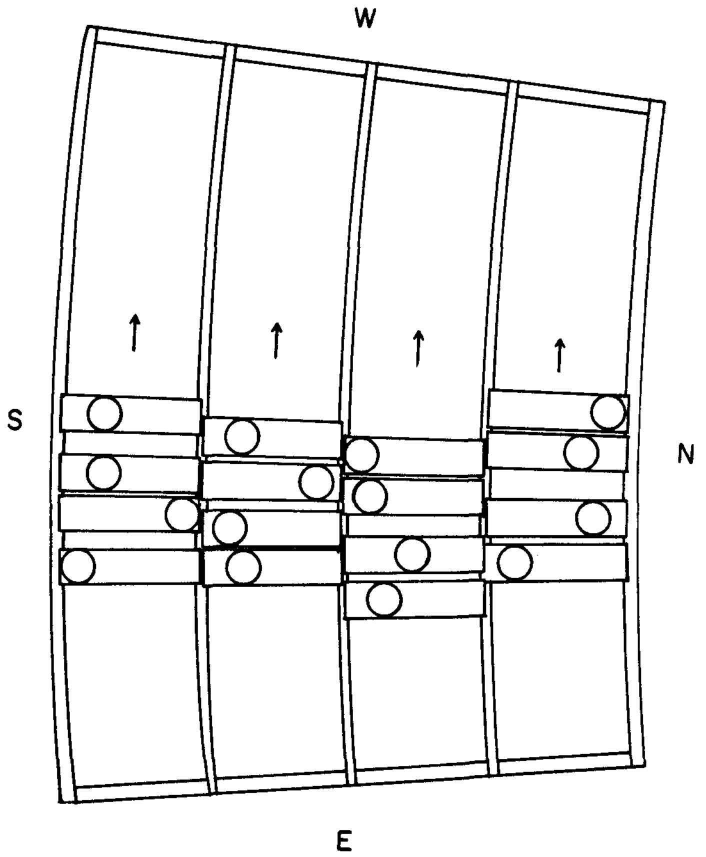

Figure 3. Detail of the focal surface assembly. Each corrector can be set in declination by motion along its carriage, and the carriages track along rails which are along lines of latitude in the spherical focal surface.

below. Transmission of plastic clad fused silica fibers falls off in the blue and ultraviolet, but is still quite useful. Angel et al. (1977) give for a 20m fiber transmission of 90% at 5000 A, 80% at 4000 Å and 70% at 3500 Å.

Figure 2 shows each fiber accepting light from 8m diameter at f/2.5. The fastest beam that could be accepted, with $1/32F^3 = 0.9^{\circ}$ (the diameter of the corrector in Figure 3), is f/1.25. Such fast correctors must match into fibers at slower f ratio. Vignetting with this 16m acceptance would be 20% at the 15° field edges.

In practice it would be advantageous to arrange a cluster of fibers at each focus, to accommodate the need to sample the sky and to act as an image slicer in poor seeing. The primary scale at 20m focal length is 10.3 arcsec/mm. Correcting from f/1.25 to f/2.5 this is decreased to approximately 5 arc-seconds/mm. Individual fibers of 100μm diameter would thus subtend 0.5 arc-seconds. A close packed array of some 40 fibers in a slit-like configuration 2 x 5 arc-seconds would be ideal. At the instrument lab, tracking and focus could be checked with the spatial information carried by the array. In a spectrograph operating at f/1.25 the spectra from the fibers, each 50μm wide at the camera focus, could be recorded individually by CCDs with 15μm pixels. Subsequent weighting and subtraction of these spectra in the computer would be used to optimize the signal to noise of the object-minus-sky spectrum, taking account of the seeing diameter. We note that for a 1-hour integration with CCDs of 10 electron RMS noise per 15μm pixel, individual fiber spectra integrated for 1-hour will be sky noise limited for resolving power $\lesssim 10^4$ (Angel, 1980).

The large primary mirror deserves some further discussion. Although not subject to gravitational distortion, it will be sensitive to thermal distortion. This can be minimized by making the surface and back up structure of materials with low coefficient of expansion, and of low thermal inertia. It should be maintained isothermal at the ambient air temperature to avoid image degradation from local convection as well as thermal figure distortion. To maintain sub-arcsecond image quality it will probably be necessary to sense image quality during the night and make corrections to the mirror surface. We would propose to install a knife edge test system with pupil imager on one of the carriages. Each section of the mirror would be supported by screw actuators, allowing corrections to be made when desired.

In conclusion, we believe that a multi-object wide field transit telescope holds promise for a very powerful instrument for spectroscopy from .3 to 2μm. It avoids many of the cost drivers of a steerable telescope, and may be the most cost effective way to address a wide range of current problems in astronomy. We have in mind the many statistical, dynamical and cosmological studies that are <u>not</u> compromised by having only a limited area of sky to look at, but are by the inability to get enough high quality spectra of faint objects. I am grateful to Nick Woolf and John McGraw for sharing their thoughts on this concept; also to Aden Meinel for pointing out a mistake in the preprint of this paper. This work is supported by NASA under grant NAGW-121.

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