The activity of the ST-ECF has so far been devoted to the preparation of an implementation-development plan, to the recruting of personnel and to the definition of the Host System (High Level Command Language) within which the ST application software will run. The latter point is of great importance to European users and we are therefore aiming at a thorough, albeit quick solution. The problem will be discussed with those responsible for the major European Centres and Networks in forthcoming meetings and workshops and details on the matter will be published in the first issue of the ST-ECF Newsletter.

I would like to conclude this first, short information note on the ST-ECF by saying that we will be happy to answer any questions you may have on our activity and we look forward to your suggestions and comments. Please do not hesitate to contact us: our extensions at ESO are 290/291 (P. Benvenuti) and 287 (R. Albrecht).

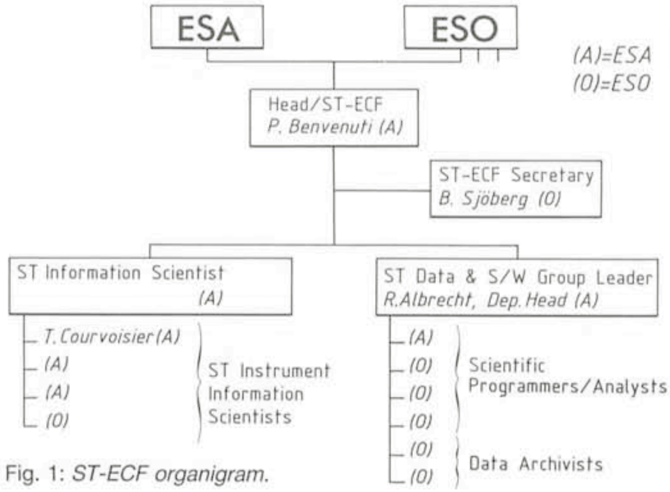

Fig. 1: *ST-ECF organigram.*

Progress in High Resolution Spectroscopy Using a Fibreoptic Coudé Link

G. Lund, ESO, and R. Ferlet, Institut d'Astrophysique, Paris

Experiments with a prototype 40 m optical fibre link between the 3.6 m telescope and the CES have already been described in the *Messenger* No. 31, and by Lund and Enard (1983). Further tests of this system, carried out in February 1984 using slightly different optical fibres and a highly efficient image-slicer, have confirmed the usefulness of a fibre link as an alternative to a 4-mirror coudé train. Gains in sensitivity typically of the order of 1.5 magnitudes in comparison with the classical CAT-slit-CES combination were obtained, thus permitting for the first time good spectra of 11th magnitude objects to be achieved with a resolution of 80,000.

New Fibre and Image Slicer

The new fibre link differs from the prototype tested in November 1982 only in the types of fibre and image-slicer used; two similar fibres, types QSF 133/200 AS and QSF 133/200 ASW, were tested at several wavelengths between 3900 Å and 10025 Å. These fibres were selected for their high purity silica composition, for their expected optimal transmission at respectively "red" and "blue" wavelengths, for their high degree of beam aperture conservation and for their core diameter of 133 μm which corresponds to 2.6 arcsec on the sky at the 3.6 m telescope prime focus.

When projected onto the image-slicer, the 10.5 times magnified image of the fibre output end is divided into four slices as shown in Fig. 1. The total height of the reassembled slices just matches that of the Reticon pixels. This arrangement is achieved by designing the image-slicer so as to provide a slice width of around 350 μm, corresponding to a spectroscopic resolution of 83,000 at 5000 Å. The use of a fibre larger than 133 μm would necessarily imply a loss either in resolution, or in geometrical efficiency at the detector. In preparation for the future commissioning of a new short (F/2.5) camera + CCD detector at the CES, a larger 200 μm core fibre was installed simultaneously with the other two. Although this new mode of operation will limit the spectral resolution to 35,000, the use of a larger fibre will not only enable a larger (4 arcsec) effective sky diaphragm to be employed, but will also improve the overall system transmission by around 15%.

The image-slicer tested in the recent tests is of the "Modified Bowen-Walraven" type, to which our attention was first drawn by Tom Gregory at La Silla in 1982. The slicer, as depicted in Fig. 1, consists of 3 optically polished and molecularly adhered silica elements in which the incident light is either directly transmitted, or totally internally reflected until it reaches the exit condition at the other side of the slicer. If the slicer is carefully made, transmission losses (excepting Fresnel reflections at the input and output faces) can be as low as

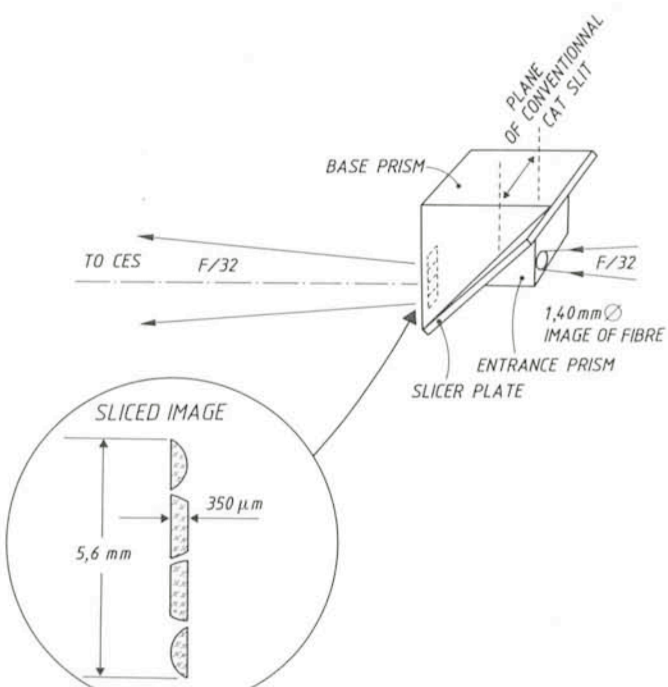

Fig. 1: *Modified Bowen-Walraven Image-Slicer at the input to the ESO high resolution CES. The slicer matches the 10.5 times magnified image of the output end of an optical fibre to the rectangular configuration of the Reticon detector pixels.*

4 %. The slicer acts similarly to a thick parallel plate, in which the first slice of the input spot is transmitted directly and the remainder of the spot is transmitted in translated slices of which the nth undergoes 2 (n-1) internal reflections. Experience has shown that this image-slicer is relatively easy to install, particularly since the fibre output end is immobile and can be conveniently fed with a white calibration source for daytime alignment of the slicer.

Photometric Comparison of the CAT with the 3.6 m Telescope + Fibre Link

Despite many foreseen difficulties involved in the photometric comparison of spectra obtained via the CAT with those derived by means of the fibre link, such measurements were nevertheless attempted during the first part of the recent test period. Since an effective slit width of 350 μm was imposed by the nature of the image-slicer, the CAT was used with a slit setting of the same value in order to achieve an identical resolution in both sets of observations. Spectra were thus recorded, sequentially, from the CAT and then from each of the two fibres, at ten different wavelengths using the bright stars δ^2 Vel, α Vir, and S Car. These stars were selected for their essentially smooth continuous spectrum at the chosen wavelengths and, in addition, in the case of S Car, for reasons of astronomical interest.

The read-out noise corrected, raw spectra obtained from both telescopes were reduced together in the same way; the relative gain γ (λ) of the fibre link + 3,6 m over the CAT is defined as the ratio of these reduced spectra. These values are plotted in Fig. 2, together with a curve (solid line) representing the theoretical gain if the fibre alone were to contribute to the system losses. The effective efficiency (righthand ordinate) corresponding to these curves is determined simply by dividing the gain (given by the lefthand ordinate) by the ratio of the collecting areas of the two telescopes (taking into account the reflection efficiencies of 0.90 and 0.98 for the two additional mirrors present in the CAT coudé train, and allowing for the central obstructions of respectively 1.58 m and 0.47 m for the 3.6 m and 1.4 m (CAT) telescopes). This factor is equal to 6.82 (2.1 magnitudes).

Tentative Time-table of Council Sessions and Committee Meetings in 1984

October 8	Scientific Technical Committee, Chile
November 13–14	Finance Committee
November 27–28	Observing Programmes Committee
November 28	Committee of Council
November 29–30	Council

All meetings will take place at ESO in Garching unless stated otherwise.

The Influence of Seeing

Although the above figure was used to calibrate the efficiency ordinate in Fig. 2, it should be remembered that this

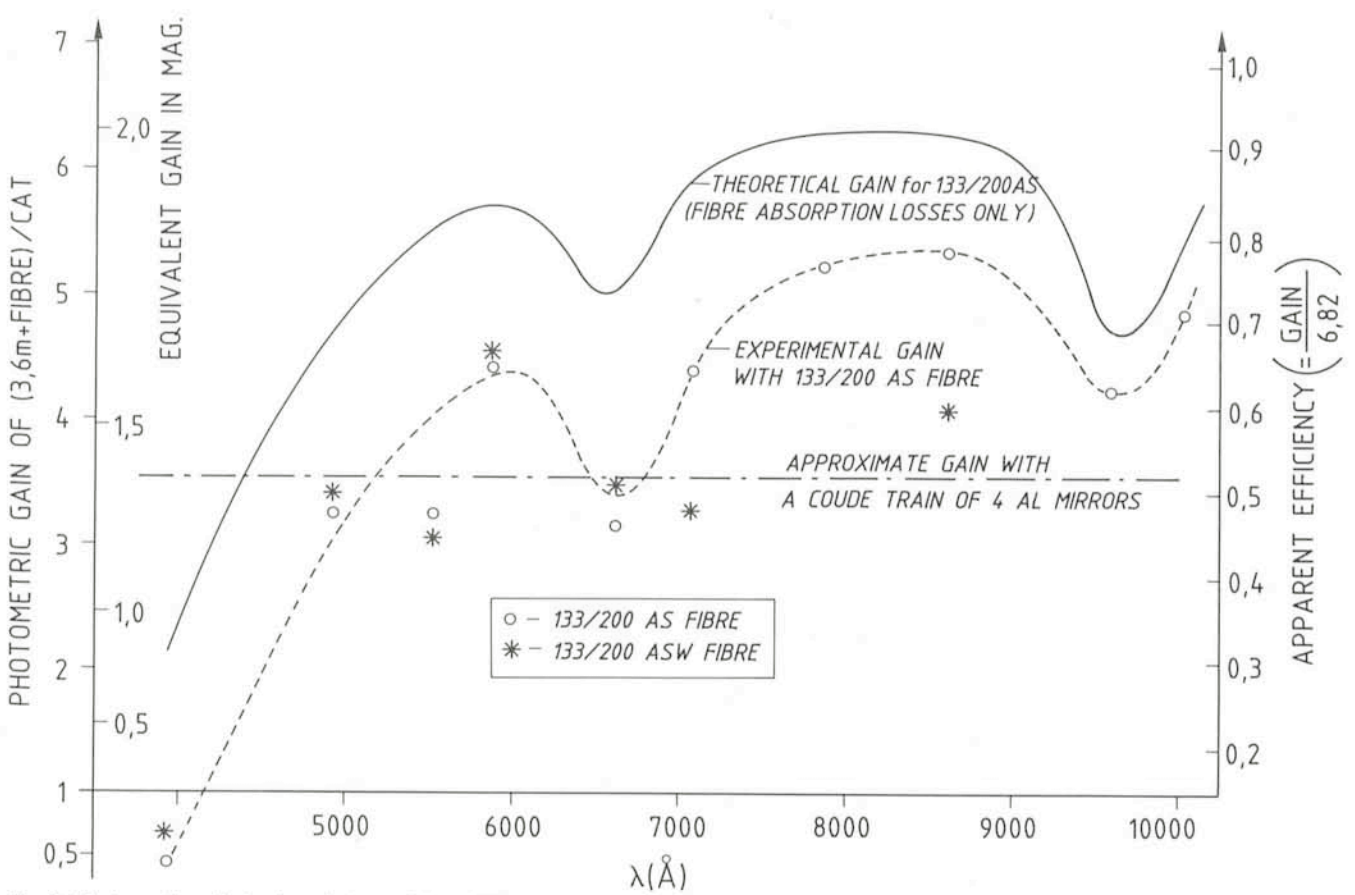

Fig. 2: *Photometric gain (and equivalent efficiency) for the 3.6 m telescope + optical fibre link, when compared with the CAT. The experimental points (including a dotted-line interpolation for the AS fibre) are compared with the theoretical transmission efficiency of the AS fibre alone. The difference between the two curves is accountable mainly from the combined efficiencies of the optical beam transfer elements (Fig. 3), equal to around 71 %. The gain to be expected from a conventional coudé mirror train is also indicated.*

calibration is somewhat arbitrary in the sense that it is seeing dependent, and assumes perfect guiding. Neither of these factors could be measured during the tests, and it is furthermore likely that the CAT seeing is better than that in the dome of the 3.6 m telescope. Both are certainly variable with time. If the assumption is made that both telescopes *do* have the same seeing, one can calculate (for an assumed Gaussian seeing profile) the relative geometrical efficiency of the 2.6 arcsec circular fibre sky diaphragm compared with that of the 1.64 arcsec (350 μm) slit (assumed to be infinitely long) used with the CAT. This ratio is a function of seeing, but remains very close to unity for seeing conditions better than 2.3 arcsec.

For seeing worse than this value the fibre becomes comparatively less efficient than the slit, with a change equal to −15 % per arcsec of seeing in excess of 2.3 arcsec. It is therefore likely for the seeing to have played a significant role in the comparative measurements if it was different at each telescope, or if it was the same at both telescopes but greater than 3 arcsec. The seeing factor, coupled with the unknown loss in photons due to guiding errors, is thought to account for the scatter in some of the data points in Fig. 2.

In Fig. 3 the coudé fibre link is schematically represented, including all of the optical elements involved in the beam transfer. Each element is associated with a figure indicating its estimated efficiency. With the exception of the absorption losses in the fibre itself, the combined losses due to Fresnel reflections and partial beam divergence beyond F/3 provide an efficiency of 71 %. Although this figure should account for the disparity between the full and dashed curves in Fig. 2, which it does quite well up to 7000 Å, the near-infrared performance of the link apears to have been better than expected. As already mentioned above, poor guiding of the CAT (which is generally less stable than the 3.6 m) could improve the apparent fibre link efficiency, whereas a strong increase in turbulence would have the opposite effect. Although these variables remain unknown, the dotted curve of Fig. 2 provides a reasonable estimate of the wavelength-dependent gain which can be expected from the 3.6 m + fibre link under *real* observing conditions.

Important Astronomical Results

For two years ESO has been operating the CES high resolution spectrograph together with the dedicated 1.4 m Coudé Auxiliary Telescope (CAT) using an echelle grating and a cooled Reticon detector. The spectrograph is optimized for a resolving power of $R = 10^5$, corresponding to an entrance slit equivalent to nearly 1 arcsec on the sky. When the spectrograph is used under these conditions, an object cannot be observed with an adequate S/N ratio if it is fainter than about the 9th magnitude. The availability of a fibre link from the larger collecting area of the 3.6 m telescope thus opened up the possibility of observing fainter objects, up to the 11th magnitude at very high resolution. On the other hand, for the observation of much brighter objects exhibiting rapid line profile variations and requiring very high S/N ratios (~400), a considerable gain in time resolution can be achieved with the fibre link. This could be very useful for the study of non-radial (high order) stellar pulsations.

In Fig. 4 we present an example of very promising spectra obtained at La Silla during the recent fibre link tests. The two LMC stars R127 and R128 were observed with integration times of respectively 6,000 and 9,000 seconds, with a measured spectral resolution of 70,000. These spectra, obtained in the Na I D line region, are the best so far obtained (in terms of S/N ratio), for 10.5 magnitude stars at such high resolution.

It has been possible to distinguish a number of interesting features, which have been appropriately labelled in the figure. Among these, the following seem worthy of a brief description;

– A feature corresponding to low velocity galactic gas is resolved into two components separated by 15 km sec^{-1}.

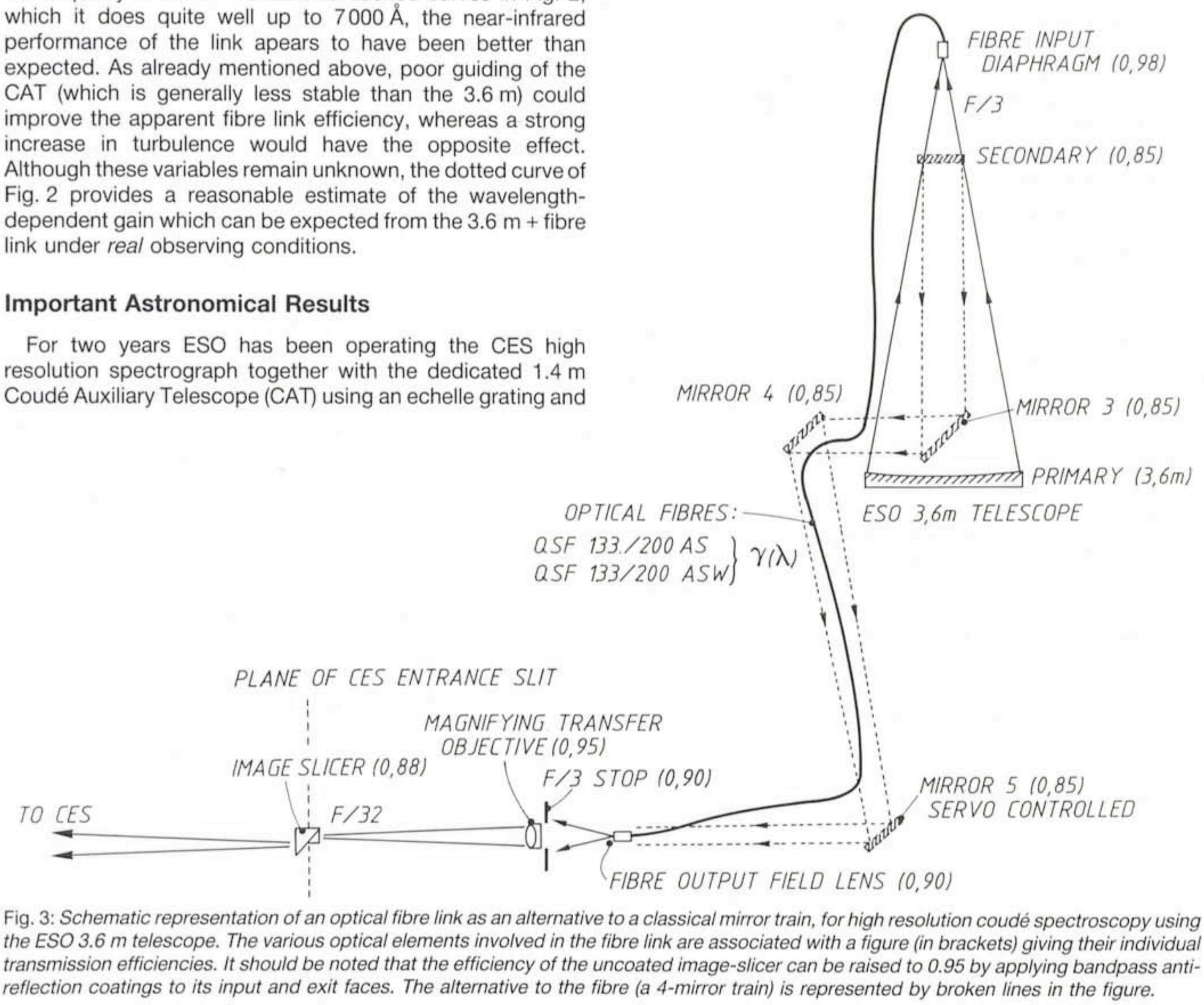

Fig. 3: *Schematic representation of an optical fibre link as an alternative to a classical mirror train, for high resolution coudé spectroscopy using the ESO 3.6 m telescope. The various optical elements involved in the fibre link are associated with a figure (in brackets) giving their individual transmission efficiencies. It should be noted that the efficiency of the uncoated image-slicer can be raised to 0.95 by applying bandpass anti-reflection coatings to its input and exit faces. The alternative to the fibre (a 4-mirror train) is represented by broken lines in the figure.*

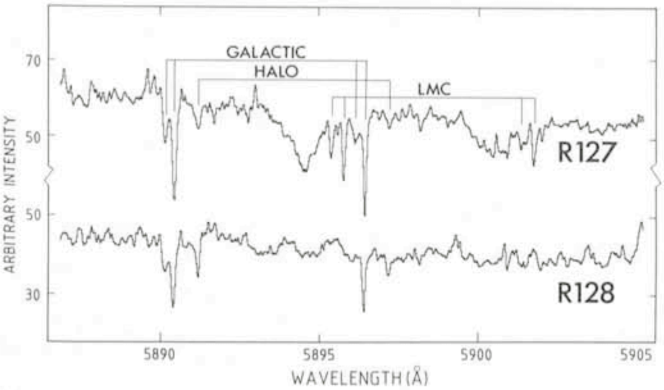

Fig. 4: *Interstellar Na I D line absorption towards R 127 and R 128 in the Large Magellanic Cloud (v ≃ 10.5; R ≃ 70,000). Note that the ordinate is broken in order to separate the two spectra. R 127 was recently discovered to be an S Dor variable which loses enormous amounts of matter. The broad Na I D line absorption features, which are seen to be slightly blue-shifted with respect to the LMC interstellar velocities, could provide evidence of an old, cool, ejected shell. All narrow absorption features above the noise level, other than those which are labelled, are due to telluric water vapour.*

– Two clearly visible Na I D components are detected in R127 at the system velocity of the LMC (~ +280 km sec^{-1}), whereas they are only marginally visible in R128. Although these stars are apparently very close in the sky, R128 may in fact be located near to the front of the Large Cloud.

– An absorption feature of intermediate velocity (~ +60 km sec^{-1}) is apparent in both stars, which could plausibly be interpreted as being due to expanding shells surrounding the LMC, formed perhaps by the tidal action of the Milky Way on the Magellanic Clouds.

These interesting results should encourage further extragalactic research using high resolution spectroscopy.

Some candidates which would now be just accessible with the 3.6 m telescope + fibre link, and which could be of significant interest if observed at very high spectroscopic resolution, are:

– galaxies, for the investigation of the morphology and physical properties of halos;

– the Magellanic Clouds, for the analysis of less evolved Magellanic material whose abundances are close to the fundamental one, or for the determination of the optical depth of the Small Magellanic Cloud;

– the brightest quasars and Seyfert galaxies, for the study of their absorption line features;

– active galactic nuclei, for the investigation of the structure in their broad line-emitting regions.

With respect to the latter, a preliminary attempt was made during the fibre tests to observe the Hα emission line profile in the nucleus of the Seyfert 1 galaxy NGC 3783. The result of a three hour exposure is found to be most encouraging by virtue of the considerable number of emission features which are detected at various velocity displacements around the broad major Hα feature.

Conclusions

It has been demonstrated that in spite of its considerable length, a 40 m optical fibre can provide an attractive solution for the coudé spectrograph matching of a 4 m class telescope. The installation of such a system at the ESO 3.6 m telescope has enabled record sensitivities to be achieved in high resolution spectroscopy. The main additional benefits provided by the fibre link are the following:

– The onerous task of installing and aligning the alternative solution of a classical coudé 3-mirror train for which (as in the case of a telescope such as the ESO 3.6 m) a servo-driven mirror may be needed, is eliminated.

– Guiding of a star onto the fibre input face is more straightforward and less prone to instabilities than with a synchronously driven coudé arrangement.

– The immobility of the output end of the fibre facilitates the task of correctly aligning the beam onto the image slicer.

– The calibration lamps, which are fed through the fibre, enable all transmission anomalies of the optical system (except for that of the primary mirror), to be corrected for.

– The "image-scrambling" property of the fibre and the immobility of its output end ensure a spatially and temporally stable illumination of the spectrograph optics. This can be important for the accurate determination of radial velocities or profile equivalent widths.

The major drawback of the fibre link, as can be seen in Fig. 2, is its poor transmission at wavelengths below 4500 Å. At wavelengths above 5000 Å, however, the total link efficiency is slightly better than that of a normal coudé train of perfectly aligned uncoated aluminium mirrors (this would have a combined reflectivity of 52 %). On the other hand, a coudé train of interchangeable dielectrically coated mirrors could provide a highly efficient (90 %) alternative to a fibre link.

The scientific implications of the achievable improvement in limiting magnitude, when using a 4 m class telescope for high resolution spectroscopy, are discussed in the foregoing paragraph. Those areas in which important progress is likely to be made are:

– time-resolved analysis of rapidly varying features;

– the study of weak galactic and extragalactic objects (including bright quasars and Seyfert galaxies).

The potential for research in these areas should be further improved in the near future when the ESO CES is equipped with a short camera and a cooled CCD detector. Although this option will reduce the limiting resolution to around 35,000, an improvement in sensitivity in excess of two magnitudes is expected.

Future Use of the Fibre Link

Although the fibre link undoubtedly has several merits for high resolution faint object spectroscopy, its use will have to be limited to programmes of singular importance – owing to the necessary, but undesirable implication of assigning both the 3.6 m and the CAT telescopes to the observer. It is perhaps of interest to note that objects at very high declinations towards the south pole can only be observed from the 3.6 m telescope, since its dome vignettes the CAT at these declinations.

Acknowledgements

The work presented in this paper could not have been achieved without the individual contributions of many ESO staff members. In particular, we wish to thank Bernard Buzzoni and Gotthard Huster for their considerable assistance in the technical realization of this project. We extend our gratitude to Dietrich Baade, Denis Gillet and Eric Maurice for their contributions to the astronomical content of the report.

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