THE FAINT OBJECT CAMERA

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Introduction :

The Space Telescope (S T) is one of the most exciting projects presently planned in space astronomy. It will make a considerable contribution to astronomical research throughout the rest of this century. The high resolution 2.4 m telescope will be placed in orbit probably in 1985 by the Space Shuttle and will provide an astronomical capability unattainable by the ground-based telescopes.

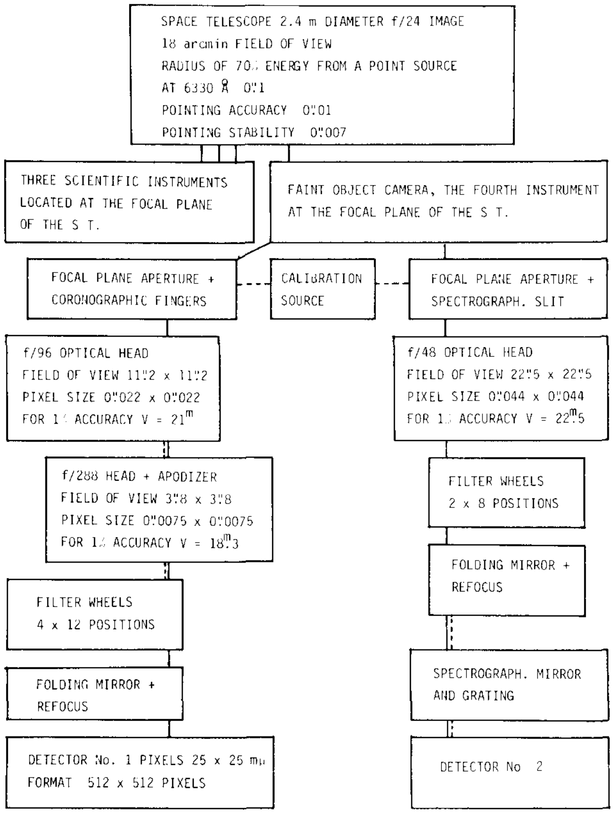
The European Space Agency decided to participate in this NASA programme in 1976. ESA´s part in the programme includes the production of a major subsystem (the solar arrays and associated mechanisms), the building of the Faint Object Camera, and future participation in the operational activities and in the running of the Space Telescope Science Institute.

The Faint Object Camera (Macchetto et al. 1980) will fully exploit the resolution capability of the S T on the very faintest detectable objects over a broad wavelength range. A large number of filters, objective prisms and polarizers, a choice of coronographic masks, and a variety of scan formats extend the scientific versatility of the direct imaging mode. In addition, the Faint Object Camera provides the unique facility of long-slit spectrography to space Telescope observers.

The FOC is one of the four axial scientific instruments located at the focal plane of the ST. Its design is modular and allows for interchange with the other axial scientific instruments; this ensures that removal and reinstallation can be achieved in-orbit by a suited astronaut. The total weight of the FOC is about 318 kg and the average power consumption over a 95 min orbit will be less than 140 W.

The FOC contains two complete and independent cameras - f/96 and f/48 - each with its own optical path and detector system, see the optical block diagram. The baseline mode at f/96 is matched to the resolution performance of the ST, in fact oversampling its point spread function in the visual and red region of the detector wavelength response. More precisely, the f/96 detector fulfils the Byquist sampling criterion for wavelengths longer than 300 nm, having at least 4 pixels within the first dark ring of the Airy pattern. At shorter wavelengths, further improvement in the resolution can be achieved by inserting a compact Cassegrain assembly into the f/96 optical path providing an f/288 very high resolution mode.

https://doi.org/10.1017/S0252921100010125 Published online by Cambridge University Press



FOC optical block diagram.

A coronographic facility is also provided for the observation of faint objects or extended structure near bright sources. The second mode at f/48 gives lower resolution but a field of view four times larger in area. It includes a spectrographic facility which provides the unique feature of long-slit spectroscopy to ST users.

All the optical elements and both detectors are aupported on an optical bench, which is rigidly connected to the focal-plane structure of the ST. The optical bench is contained within the load-carrying structure which provides a light-tight enclosure. To meet the image stability requirements, the internal surfaces of the load-carrying structure which enclose the optical bench are actively thermally controlled with a stability of better than 0.5 ^{o}C.

The f/96 and f/48 optical relays consist of an aplanatic system. Beyond the aperture, the beam is relayed from a spherical concave primary mirror to an elliptical convex secondary mirror, which focusses the image onto the detectors first stage photocathode. The folding mirrors can be moved for in-flight refocussing. In the event of light overload, each focal plane aperture can be closed by a shutter in less than 0.2 s. With the shutter closed, a mirror behind it reflects the light from a calibration source into the optical path. Test interferograms show that the total wavefront distortion for the complete f/96 optical relay is less than $\lambda/15$ at 633 nm. The theoretical Rayleigh limit ($1.22\ \lambda/D$) for the angular resolution of the ST is 0.066 arcsec at 633 nm and 0.013 arcsec at 125 nm. The optical quality of the ST guarantees near diffraction limited performance at 633 nm; the FOC imaging at f/96 exploits this resolution capability. There is a resonable probability that near diffraction limited performance will be reached by the ST at shorter wavelengths but, even at wavelengths where the diffraction limit cannot be reached by the overall optical quality, the telescope optical aberrations will probably produce a stationary speckle pattern. Deconvolution of this pattern may then be possible, thereby yielding diffraction limited images at the shortest detectable wavelengths. To exploit this exceptional resolution capability, a facility for imaging at f/288 can be inserted into in the f/96 optical path, giving a pixel size of 0.007 arcsec (corresponding to the rms guiding error of ST): this is sufficient to sample the speckle pattern even at 125 nm.

Faint structure close to bright objects may be studied with a coronographic facility included in the f/96 relay. It consist of a fixed mask placed at the ST focal plane and of an apodizing mask located on the f/288 removable Cassegrain at the ST pupil. The focal plane mask contains two fingers 0.4 and 0.8 arcsec wide respectively, either of which can obscure the central spot and up to three Airy rings of the bright source depending on wavelength. The apodizing mask has been designed to remove the light scattered and diffracted by the ST secondary mirror and spider and by the three supporters of the ST primary mirror. Since the mechanisms are independent it is possible to use either one of the coronographic fingers alone at f/96 or the 0.8 arcsec coronographic finger and the apodizing mask at f/288, thus realising a Lyot type coronograph. The performance of this coronograph will depend strongly on the optical quality of the ST. Assuming this to be good, the coronograph will allow, by direct imaging, the detection of features 16.7 magnitudes fainter at an angular separation of 1 arcsec from a bright point object.

Binary Stars and the ST :

Modern speckle interferometric measurements with large ground based telescopes have been made til now for about 360 very suitable and also very close visual binaries. Position angles and separations can be determined very accurately this way. However, the brightness difference, which is essential for the astrophysical interpretation of the results, can only be estimated in a crude way due to problems inherent in the technique. Using the area scanner technique it is possible to measure the difference in brightness with high degree of accuracy of binaries as close as 0.5 arcsec (Rakos et al. 1981). Only the Space Telescope equipped with FOC will be able to carry out observations of significantly closer binaries with significantly greater magnitude difference and accuracy.

A substantial number of astrometric and spectroscopic single line binaries is known, where a single high precision observation will yield the separation and the brightness difference of the two components. This immediately would allow ground based observations to be converted into individual masses and luminosities, for example the stars 61 Cyg, 70 Oph, Barnards Star, Ross 614B, L 726-8, BD $20^{o}2465$, Ci 1244, Ci 2354 and many others.

In the endeavour to obtain as complete as possible a picture of the distribution of the masses of stars, the study of invisible or unobserved companions has played an increasing role in recent years. These investigations have been particularly important in revealing masses in the range between planetary objects and stars. Especially spectroscopic variables of $a \sin i$ greater than 6×10^{7} km are very suitable for such investigations. The problem of deriving the astrometric orbit is greatly simplified by the fact that the spectroscopic orbit already provides us with the period, the eccentricity, and the position of the star in the orbit. Thus, the solution merely requires the projection of an orbit of a given shape so as to best satisfy the astrometric data. A number of unresolved spectroscopic binaries of interest are the stars: 58 Per, V367 Cyg, B 1074, 70 Oph A, 12 Com, 31 Cyg, α U. Ma.

A similar effort should be invested observing certain eclipsing binaries as VV Ceph, ζ Aur, RZ Oph and AR Pav.

Beside the very close binaries there are a large number of close double stars with known orbital elements or with differently evolved companions. The age of the individual components of a binary system can be assumed to be the same, so observations of the brightness difference in the far ultraviolet in addition to the observations in UBV and Strömgren systems can be compared to theoretical models of the stellar structure in an independent way.

The search for low-mass planet-type bodies with masses below $0.06\ M_{\odot}$ gravitationally bound to the nearest stars has always attracted a great interest. Therefore any positive detection of such bodies would be of immediate consequences not only in Cosmogony and Stellar Evolution but even outside the astronomical discipline. This subject has been treated with a variety of arguments by many authors, and reference can be made to the following two fundamental papers: van de Kamp 1975; Lippincott 1978. Obviously, the practical problems of detection are of extremly difficult to solve, and great ingenuity has been spent to circumvent them; a recent review is given by Black (1980). Several indirect methods such as irregularities in the motions, or Doppler shifts offer good hopes for a not too future detection; for instance Baum has pointed out the possibilities opened by Hipparcos, the ESA Astrometry Satellite. However, direct imaging of the planet if feasible would provide not only evidence but also a fas superior information content. The difficulty is that the expected intensity ratio between primary and secondary is very high; for instance, a planet like Jupiter could be 20 magnitudes fainter than its Sun and at 1 arcsec from it viewed from 10 pc distance. Even the Space Telescope with its very good optical quality would not afford this detection, unless scattered light could be effectively removed by some auxiliary device. The matter of scattered light has been discussed for instance by KenKnight (1977) who shows that apodisation of the aperture of very well figured 2 m telescope permits the detection of an intensity ratio of 10^7 (17 magnitudes) at about 1 arcsec. An additional gain could be reached if the background of scattered light had a speckled pattern fixed in position on the focal plane, because than the difference between two different exposures with different roll angles of the telescope would enhance the planetary image. The conclusion is that an apodisation facility on the ST offers the best opportunity to carry out the planetary search in a direct, quick and effective way. This expectation is indeed fulfilled by the FOC with its coronograph. The experiment carried by Mauron (1979) using a simulated ST and the FOC coronographic facility has shown that a secondary image 16.7 mag fainter than the primary can be clearly resolved at 1 arcsec from it. If one recals that observations with ground telescopes seldom detect a 5 mag fainter companion at 1 arcsec, we see that imaging the nearest stars through the coronograph of the FOC can immediately confirm and expand the results of decades of painstaking astrometric work and extend the knowledge of the luminosity and of the mass functions of the heavenly bodies very low limits. A list of first priority targets for this search of unseen companions can be easily provided (e.g. van de Kamp, 1975).

Data Reduction Techniques:

The experience and the extensive software for the reduction of area scanner measurements of double stars can be used for the reduction of ST doub-

https://doi.org/10.1017/S0252921100010125 Published online by Cambridge University Press

le star observations. After correcting the FOC frames for photometric and geometric distortion, we can mathematically project the two-dimensional intensity distribution onto a plane parallel to the line of separation to obtain the typical one-dimensional area scanner intensity distribution. As long as we restrict ourselves to binary systems, this involves no loss of information, however it facilitates greatly the data handling problem. An interactive image processing system for the photometric and astrometric reduction of large two-dimensional frames is currently under development at the Institute for Astronomy in Vienna and of course at other places too.

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https://doi.org/10.1017/S0252921100010125 Published online by Cambridge University Press