A CORONOGRAPHIC MODE FOR LARGE TELESCOPES

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ABSTRACT: The study and efficiency test of the optics of the Space Telescope Faint Object Camera carried out at the Laboratoire d'Astronomie Spatiale, led the authors to design a similar coronographic mode for large ground based telescopes. Adaptation of this design to the Mount Chiran 1 meter and E.S.O. 3.6 meter Ritchey-Chrétien telescopes has given new levels of performance in the detection of faint features in stellar and planetary observations.

INTRODUCTION

It is well known that reflecting telescopes suffer from scattered light which limits the detection of faint objects close to bright ones. Strong diffraction branches are always produced by the spider arms. Light diffracted by the edges of the two mirrors further enhances the brightness of the background. To reduce this stray light, the coronographic technique invented by Lyot in 1931 must be used. We have implemented this technique for two applications:

i) the Faint Object Camera (F.O.C.) of the Space Telescope (S.T.) (Courtes et al., 1981) for which an extensive laboratory simulation has been performed by Saisse and Mauron (Mauron, 1979).

ii) a "planetary" coronograph being used as a focal instrument for large ground-based telescopes.

CORONOGRAPHY WITH THE SPACE TELESCOPE

The high resolution of the Space Telescope, expected to be diffraction limited, the absence of atmosphere and consequently of seeing and sky scattering, will allow observations of faint structures close to a bright starlike object. A well known goal is the detection of a planet near a star, where the luminosity ratio could be about 10^{-9} at a distance of 1 arcsec. But many other objects can be considered, such as the coronae of Wolf-Rayet or redgiant stars, the proximity of bright nuclei of galaxies, or the surrounding nebulosities of quasars.

C. M. Humphries (ed.), Instrumentation for Astronomy with Large Optical Telescopes, 73–78.

In such observations, one must avoid saturation or damage of the detector, and also reduce the stray-light produced inside the telescope mainly by two phenomena for the small field of view to be considered here (about 2 arcsec around the bright source):

- First, the diffraction by the edges of the obstructed aperture, giving an average relative intensity of 10^{-5} at a radial distance of 1 arcsec in the visible. This edge effect can be reduced with a coronographic Lyot-type system, as shown by Bonneau et al. (1975).

- Second, the scattering from middle-scale wavefront errors given by the Space Telescope mirrors. According to a statistical model by KenKnight (1977), it could be an order of magnitude stronger than the edge effect, but the model is severe and this should be considered as an upper limit.

A Lyot-type system will be implemented in the Faint Object Camera. It is composed of 2 removable masks inserted in the f/96 imaging mode: a 0.6 arcsec diameter focal mask occulting the Airy pattern up to the third ring at ST focus, and a Lyot apodizer stopping in a relayed pupil plane the residual diffracted light. Of course, for field sources, the Lyot stop acts as the aperture diaphragm and diffracts as usual; the energy loss was lower than 20% for any of the following cases.

To realize the expected performance of this device, we have set up an experimental simulation; an illuminated pinhole simulates a star; internal reflections in a glass cube give satellites $1.3\ 10^{-3}$ and $2.0\ 10^{-6}$ in relative intensity. Diffusion by the cube was checked afterwards to be negligible. A common 200mm focal length cemented doublet is diaphragmed at f/24 by a 0.37mm diameter obstructed pupil. It gives a good diffraction pattern whose size defines the scale in seconds of arc as it will be at the ST focus. Two spherical mirrors magnify the image to a f/96 aperture with diffraction limited resolution. Both focal occulter and Lyot apodizer can be inserted in the beam.

Figure 1 illustrates the efficiency of the Lyot post-focus coronograph. The diffracted light intensity is reduced by a factor of 10 to 15 over the whole field. The 2.10^{-6} satellite image is on the right, and its first diffraction ring of approximately 2.10^{-7} relative intensity (16.7 magnitudes) can be seen; 1 arcsec to the left, and half way between the 2.10^{-6} satellite and the center, the $1.3\ 10^{-3}$ satellite saturates the emulsion and can be identified by its spider diffraction spikes.

In conclusion, the performance of the coronographic system in the Faint Object Camera will depend strongly on the optical quality of the Space Telescope. In the best conditions, it can reduce the stray diffracted light by a factor 50 (4.2 mag.) and allows by direct imaging the detection of 2.10^{-7} (16.7 mag.) relative intensity features at an angular separation of 1 arc second from a bright starlike object (Fig. 1). The detection limit of F.O.C. being $m_V = 29$, the coronograph should be useful for bright sources to $m_V = 17$.

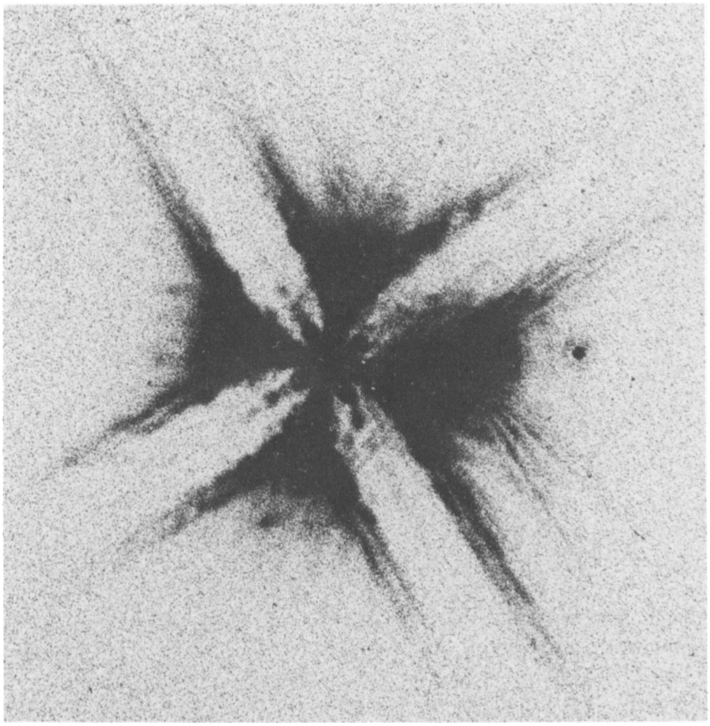

Fig. 1 Image of a point source given by the mock-up of the ST Faint Object Camera Coronograph, 5000-7000 Å; see text.

THE PLANETARY CORONOGRAPH

For ground-based observations, we have designed a focal instrument incorporating a coronograph essentially similar to those described by Larson and Reitsema (1979) and Dollfus and Brunier (1980).

A field lens is placed in the focal plane of the telescope and images the two Cassegrain mirrors and the spider onto a Lyot-type mask which blocks the light diffracted by the aperture and the spider arms. Behind the mask, a photographic objective projects the image of the focal plane onto a photographic plate. The coronographic mask which blocks the light of the planet is made of half a sphere of glass, cemented on the field lens. Its meridian plane is aluminized and slightly tilted so that the light from the planet is totally reflected at an angle of 20^{o} with respect to the optical axis and further directed to an eyepiece. This solution allows an accurate positioning and guiding without introducing additional scattering surfaces (e.g. a semi-reflecting plate) into the beam (Fig. 2).

With such an instrument properly adjusted, the remaining scattered light results from the mirrors of the telescope (dust, imperfect alumi-

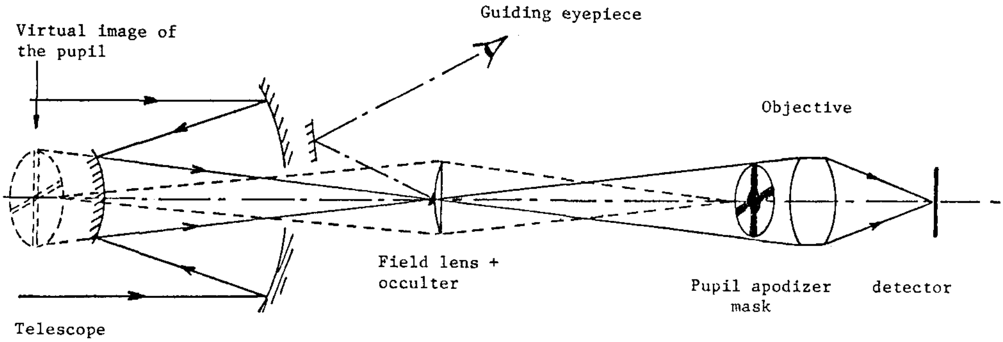

Fig. 2 The post-focus coronograph.

nium coating) and, to a much greater extent, from the seeing conditions. These were indeed the conditions experienced by the authors when observing under poor atmospheric circumstances, resulting in unfavourable seeing. All our observations were obtained with the 1 meter f/8 Chiran telescope of the high altitude station of the Haute Provence Observatory located in the French southern Alps at an altitude of 1800 meters.

We present in Figure 3, as an example, the observations on 15th March 1980 of a new satellite of Saturn, 1980 S10, discovered on 1 March 1980 by Laques and Lecacheux at OPM. On this date, the earth was exactly in the plane of the rings of the planet, a situation which occurs every 14 years. The exposure time was 30 min, with a IIIaJ plate, and aperture f/2. One can see the faint satellite 1980 S10 (Dione B), Titan, Tethys and the outer E ring extending on both sides. 32 photographs of varying exposure times ranging from 3 min. to 1 hour were taken between March 12 and 17, 1980. The plates used were IIIaJ nitrogen hyper-sensitized and 09802 Kodak plates.

This new satellite of Saturn is travelling in the orbit of Dione and leading it by 72°, close to the stable Lagrangian point L4. All our images of Dione B have a nebulous appearance. Although the seeing was not really good, this may suggest that this satellite is rather a clump of material from the external ring near the stable Lagrangian point.

We also observed the Saturn outer (E) ring discovered by Feibelman in 1966. This ring appears highly heterogeneous (as studied on densitometric profiles) and extends to about 8.5 R_s. The radial structure shows a minimum near 3 R_s, a broad maximum between 3.5 and 4 R_s followed by an erratic decrease; it appears to vary with time.

Other observations have recently been performed at the ESO 3.6m telescope at La Silla with the additional use of a Perot-Fabry interferometer. The sodium cloud around Io was easily detected. In another application, circumstellar shells around red giant stars (e.g. αOri,

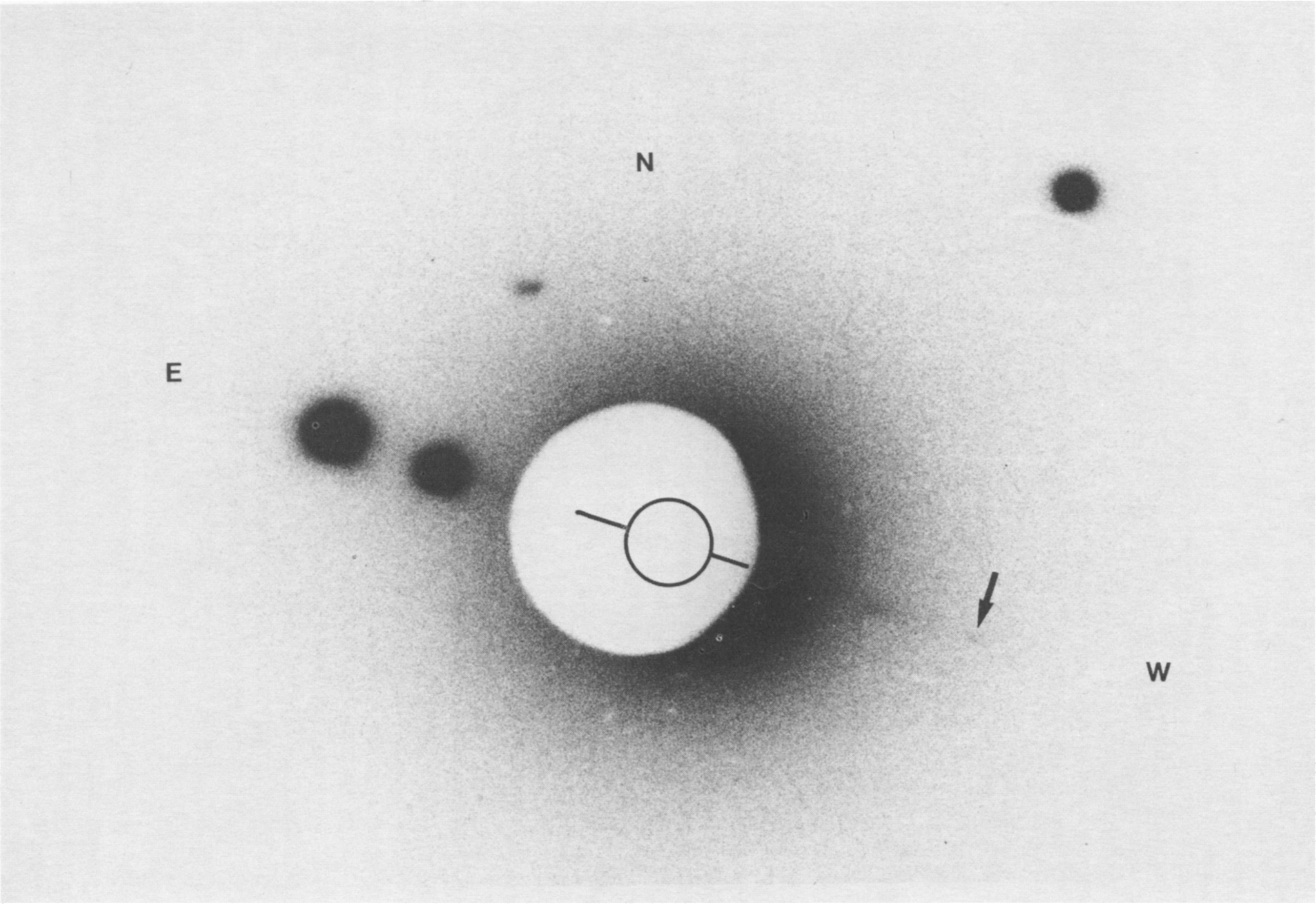

Fig. 3 Photograph taken on March 15, 1980 showing 1980 S10 ("Dione B"), arrowed, on the west side of Saturn; Titan and Tethys are seen on the east side. Note the outer (E) ring on both sides of the planet.

αSco) have been searched for. The results look promising and are presently being analysed.

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