Publications of the Astronomical Society of the Pacific, **113**:436–438, 2001 April

A Coronagraph with a Variable-Diameter Occulting Disk

P. Bourget, C. H. Veiga, and R. Vieira Martins

Observatório Nacional, Rua General José Cristino 77, 20921-400 Rio de Janeiro, Brazil; pierre@on.br, cave@on.br, rvm@on.br

Received 2000 December 8; accepted 2001 January 11

ABSTRACT. In order to optimize the occulting process of a classical Lyot coronagraph for imaging faint satellites next to Jovian planets, we designed a coronagraph with a variable-diameter occulting disk (Hg mask). We present the description of the Hg-mask coronagraph developed at the Observatório Nacional, Rio de Janeiro, and the imaging test on Neptune's satellite Proteus.

1. INTRODUCTION

The observation of faint astronomical objects very close to a bright source is limited by scattered light. Whereas a Lyot coronagraph can reduce the amount of light scattered from the bright object and prevent the saturation of the detector (Lyot 1939), the remaining scattered light still needs to be reduced for an efficient detection of objects close to bright sources. The scattering process is a consequence of the entire optical path: atmospheric turbulence, diffraction by the telescope aperture, and surface roughness of optical elements (Roddier & Roddier 1997).

The Lyot coronagraph reimages the telescopic focal plane onto the CCD. On the focal plane of the telescope, the occulting disk masks the central core and the first three or four rings in the Airy diffraction pattern of the bright source. The diffraction from the occulting disk is another source of scattered light which can be critical with a Lyot mask covering only the core of the bright object. Without adaptive optics, the Earth's atmosphere induces scattered light in the wings of the seeing disk, and its variation depends on the atmospheric turbulence. Here we use a variable-diameter Lyot mask which permits the optimization of the occultation.

2. THE CORONAGRAPH

This instrument is a Lyot coronagraph (Lyot 1939) and was designed with the astrometric purpose of imaging faint satellites next to Jovian planets. The coronagraph accepts an incoming beam of focal ratio f/8 or greater. The optical design gives a 1.24:1 magnification. The detector is an Hi-SIS 44 (CCD Kodak KAF 1600 grade 1, with antiblooming).

The occulting disk is on the plane surface of a plane-convex field lens where the telescopic focal plane is located. The field lens images the telescope structure. The image of the entrance pupil is limited by a diaphragm to reduce the diffraction light. This diaphragm is an iris type for fine adjustment to the telescope and to the observational conditions. A five-element optics placed behind this diaphragm finally reimages the focal plane of the telescope onto the CCD. A filter wheel is placed before the shutter and the detector. An optical layout of the coronagraph is shown in Figure 1 (the coronagraph is shown in Fig. 2). To avoid the diffraction spikes of the secondary support structure in the telescopic focal plane, we place a mask with circular apertures on the entrance pupil (Veillet & Ratier 1980).

2.1. The Occulting Disk

The occulting disk diameter depends on the planet apparent diameter, seeing conditions, and source brightness. For optimization of this occultation, we developed a Lyot mask with a variable diameter (Hg mask). This mask is a compressed drop of mercury located in the telescopic focal plane (Fig. 3). The potential function of surface tension (naturally minimum) produces a toric-free surface which projects on the focal plane as a perfect disk. In order to modify the disk diameter, we change the position of the optical window compressing the mercury drop on the field lens. This change of position is primarily realized by a mechanical translation actuated by a stepper motor. The fine motion is controlled by piezoelectric devices. We used three ceramic bi-morph elements placed together in the same plane with each element consisting of a 120° circular arc. These elements stick to the optical window and its support with an elastic glue in order to permit the adjustment of the parallelism between the field lens and the optical window. The precision control of the Lyot mask diameter is about 1 μm. As a consequence of its small size, the drop of mercury is completely adherent to the field lens and to the optical window. The effect of gravity is negligible in comparison with the surface tension. Occultation is a three-dimensional process near the focal plane. The converging beam is progressively occulted on the field of the bright object by the toric-free surface of mercury.

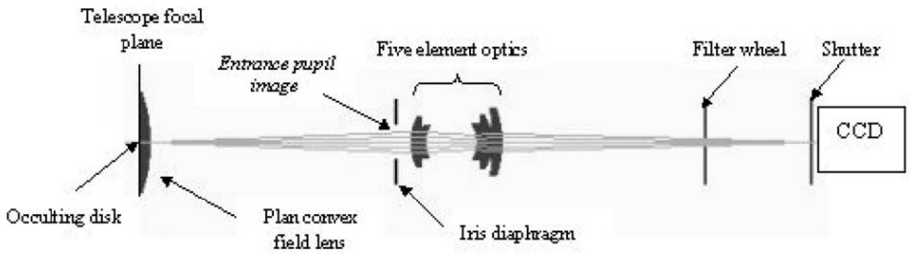

FIG. 1.—Optical configuration

3. PROTEUS IMAGING TEST

All the tests were made at the Cassegrain focus of the 1.6 m Ritchey-Chrétien reflector of the Laboratório Nacional de Astrofísica, Brazil (geographical longitude: $3^h02^m19^s$, latitude: $-22°32'04''$, and altitude: 1872 m). Proteus (Neptune VIII) was discovered from *Voyager* spacecraft images in 1989 (Smith 1989). Colas & Buil (1992) obtained the first Earth-based observation of this satellite with the 2.2 m telescope at the European Southern Observatory (La Silla, Chile). The detection process used the addition of frames to capture an image of the satellite. The motion of Proteus around Neptune had to be compensated for in this case. After the first ground-based adaptive optics observations of Neptune and Proteus (Roddier et al. 1997), the satellite has been observed only with adaptive optics. In our case, the Hg mask coronagraph provides a direct detection of Proteus with classical optics and with the size of the field determined by the CCD size. Figure 4 shows a raw image of Neptune and Proteus obtained with the coronagraph. When we compared this image with another taken in the same conditions but without the mask, Proteus is immersed in a saturated region because of the light from Neptune. In order to isolate the image of Proteus we fitted its image with a

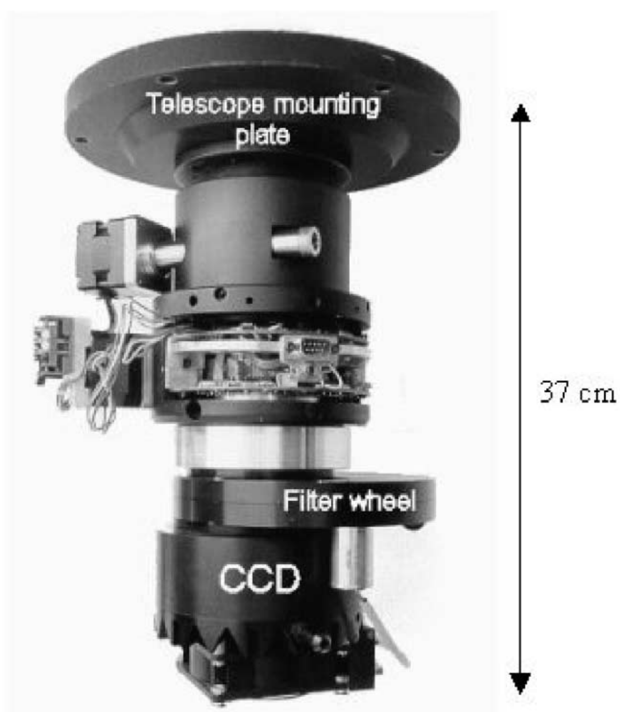

FIG. 2.—View of the coronagraph

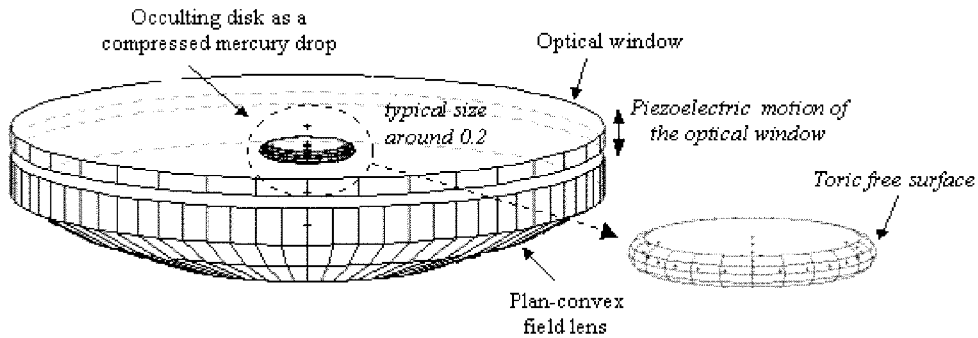

FIG. 3.—Occulting disk in the telescopic focal plane

bi-dimensional Gaussian function added to a second-degree polynomial. In this fitting the signal-to-noise ratio was 4. No procedure which combined several images was used. The positional measurements based on these observations will be submitted for publication.

We want to thank F. Colas and F. Sevre for their comments and suggestions and the Observatoire du Pic du Midi where the coronagraph prototype has also been tested by F. Colas, P. Bourget, and R. Vieira Martins. The authors thank the CNPq-Brazil for partial support of this work.

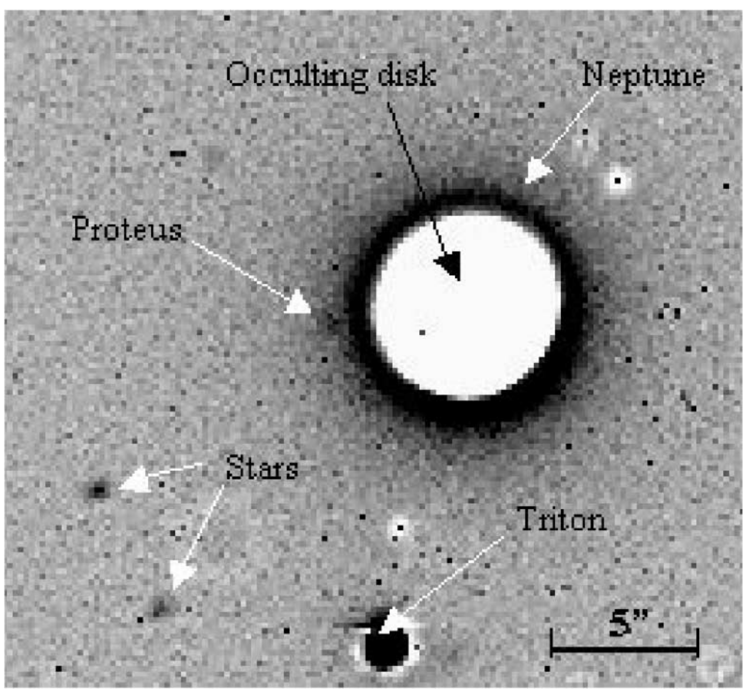

FIG. 4.—Image taken on 2000 October 12 at $23^h05^m39^s$ (UTC) with an exposure time of 10 minutes (no filter). Visual magnitudes are 7.9 for Neptune, 13.5 for Triton, and 20.3 for Proteus. The Neptune-Proteus distance is 5″. Observers: P. Bourget and C. H. Veiga.

REFERENCES

Colas, F., & Buil, C. 1992, A&A, 262, L13
Lyot, B. 1939, MNRAS, 99, 580
Roddier, F., & Roddier, C. 1997, PASP, 109, 815
Roddier, F., Roddier, C., Brahic, A., Dumas, C., Graves, J. E., Northcott, M. J., & Owen, T. 1997, Planet. Space Sci., 45, 1031
Smith, B. A. 1989, Science, 246, 142
Veillet, C., & Ratier, G. 1980, A&A, 89, 342