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CanariCam-Polarimetry: A Dual-Beam 10 μm Polarimeter for the GTC

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Abstract. The advent of large (≥8m) telescopes, along with the new breed of mid-IR instrumentation, has opened a new window to diffraction-limited polarimetry. CanariCam, nearing completion at the University of Florida for the 10m GranTeCan, offers for the first time in the mid-IR, a dual-beam polarimetry mode. We discuss the design of CanariCam and the expected performance.

1. Introduction

Polarimetry is a photon-hungry application which, for this reason and the vector nature of polarization, is greatly facilitated through observations on the largest available telescopes that also have the highest spatial resolution. Polarimeters that operate at optical and near-IR wavelengths have been available for several years, but the availability of polarimeters that operate at mid-IR wavelengths is rare. Those mid-IR instruments that do have polarimetry options, such as MICHELLE on Gemini-N, TIMMI2 (Käufl et al. 2003) on the ESO 3.6m and TNTCAM (Klebe, Stencel, & Theil 1998), make use of wire grid polarizers, giving reduced accuracy, and lower observing efficency (for compact objects) than is possible with the dual-beam systems commonly used at shorter wavelengths.

At optical and near-IR wavelengths, polarization flux typically arises from scattering, transmission through aligned dust grains (dichroism) or synchrotron radiation. At mid-IR wavelengths, the amount of scattered flux is considerably lower compared to shorter wavelengths and transmission through or emission from aligned dust grains is common (Hough & Aitken, 2003). Absorption produces polarization with the E-vector parallel to the grain short axis and hence parallel to the local magnetic field, whereas polarized emission is perpendicular to the local field. Along a given line of sight, both mechanisms may contribute to the measured polarization, and if the grain alignment twists along that line of sight then a change in PA with wavelength will occur.

CanariCam is a 10 μm multimode instrument currently nearing completion at the University of Florida (Telesco et al. 2003). It is being developed as the GranTeCan's first light mid-IR instrument, offering diffraction-limited imaging, spectroscopy, dual-beam polarimetry and coronography as well as two engineering modes (window and pupil imaging). The instrument makes use of a 320×240 pixel Raytheon Silicon BIB detector, offering excellent sensitivity at the two mid-IR windows of N (∼7.5-13.5 μm) and Q (∼16-26 μm), and is the next generation of the recently commissioned Gemini South facility instrument, T-ReCS (Telesco et al. 1998). Dual-beam polarimetry will be offered as a standard observing mode, the first time in any facility instrument for a large (≥8m) telescope. We discuss the implementation of polarimetry in CanariCam in section 2, the expected performance in section 3 and conclude in section 4.

2. Implementation of CanariCam-Polarimetry

2.1. CanariCam Design Overview

Excluding entrance windows, filters, polarimetry and coronography components, CanariCam is an all-reflective system in the science modes. The reflective design is achromatic and minimizes scattering and therefore, straylight. The following description refers to the layout shown in Figure 1. Images of the astronomy field are located at positions designated I0 (telescope focal plane), I1, (spectroscopic slit) and I2 (detector). Images of the entrance pupil are located at positions designated P1 (Lyot stop) and P2 (diffraction grating).

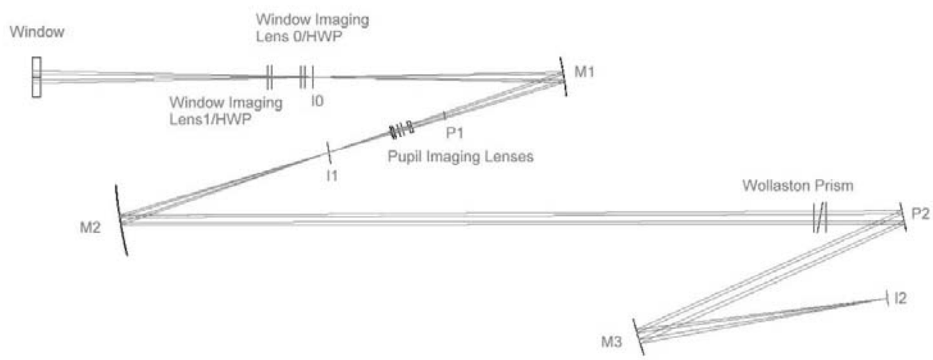

Figure 1. CanariCam unfolded optical layout

The telescope beam passes through the dewar entrance (pressure) window and is focused at I0 inside the dewar. Between the entrance window and I0, a lens assembly for the window-imaging mode can be inserted. A selection of aperture stops (including occulting masks for coronography) will be installed in a wheel at I0. After I0, the diverging beam is incident on the powered transfer mirror M1, which forms an image at P1 of the telescope pupil and an image at I1 of the telescope focal plane. Pupil stops are placed in a rotating assembly at P1, and a double filter wheel is very close to this position. The rotating pupil-stop assembly permits rotation of the complex pupil mask between integration sets in order to provide maximum throughput and straylight rejection. One can insert a dual-lens assembly between P1 and I1 in order to form an image of P1 at I1 (the pupil imaging mode). A slit wheel is located at I1 that contains an open position for all non-spectroscopy modes and several mask positions for spectroscopic slits. After I1, the beam is incident on the collimator M2, which forms a pupil image at P2, where the diffraction gratings (used for spectroscopy) and a flat mirror (for all other modes) are mounted on a turret. After P2, the

Figure 2. Completed half have retarders

beam is incident on the camera mirror M3, which images I1 onto the detector array. All optical components and associated mechanisms are attached to an optical bench. The optics and mechanisms are distributed on either side of the bench with a fold mirror to divert the beam through the bench.

The delivered plate scale is $0.08''$ per pixel, and is diffraction limited at all wavelengths ≥ 8 μm. The spectroscopic resolutions are R$\sim$140 and R$\sim$1100 at both 10 and 20 μm. In both polarimetric and coronographic modes these parameters are unchanged.

2.2. Half-Wave Retarders

A single half-wave retarder that provides good performance in both the N and Q atmospheric windows is currently unavailable. As a 'true' zero-order half-wave retarder would be extremely thin (less than a few tenths of a mm). Canari-Cam will use a compound zero-order plate which is constructed from two plates whose retardance differs by a half-wave and whose optical axes are orthogonal. To minimize thermal background, the half-wave retarders are installed inside CanariCam upstream of the telescope focal plane and prior to any reflections interior to the instrument to minimize instrumental polarization. A mechanism allows the half-wave retarders to be inserted into the science beam and subsequently rotated. A d-tent mechanism locks the retarders at canonical rotation angles ($0°$, $22.5°$, $45°$, and $67.5°$), although any angle maybe selected.

The half-wave retarders are made from sulphur-free CdSe (Figure 2), have a clear aperture of 30 mm and are oversized by several mm on each side to allow for positioning and anti-reflection (AR) coating runoff. The retarders have a combined thickness of $\sim$4 mm. They are mounted in a holder that holds the two retarders parallel to each other and perpendicular to the incident beam. The AR coating is designed to provide the highest throughput at 10.25 μm and at cryogenic temperatures ($\sim$10K), as shown in Figure 3. The introduction of the half-wave retarder in the converging beam causes a focus offset, which can be compensated by a $\sim$1mm change in telescope focus. Due to cost constraints,

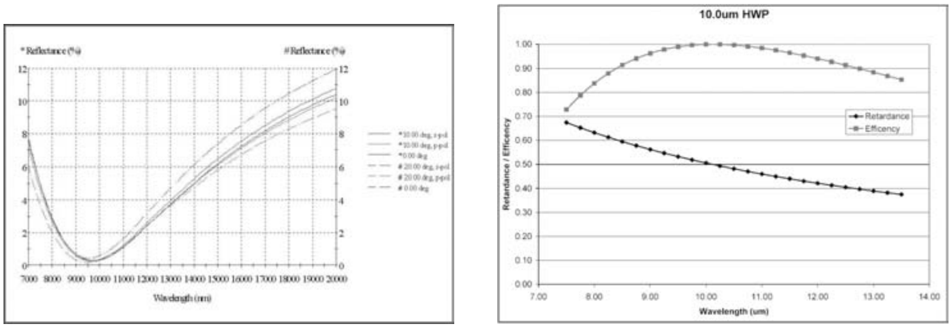

Figure 3. Left: AR coating wavelength response. Right: retardation and efficency versus wavelength.

only a 10 μm half-wave retarder will be available at the time of commissioning. The expected retardation and efficiency is shown in Figure 4.

A disadvantage of rotating waveplates is the potential for image wander on the detector array. A goal of $\leq$0.2 pixels was set that provides a wedge tolerance for the individual retarders of $\pm$0.01° and a tilt of $\leq$0.225°. Any residual image wander can be corrected for in real-time by offsetting the telescope for each retarder position.

Table 1. CanariCam Polarimetry Performance

Observational Parameter	Scenario 1	Scenario 2
Filter	N	N
Observational Efficency	33%	33%
Elapsed Telescope Time	3600 sec	3600 sec
Object	Point Source	Uniform surface brightness
Limiting Flux	60 mJy	82 mJy/square arcsec

2.3. Wollaston Analyzer

The analyzer for CanariCam is a Wollaston prism constructed from sulphur-free CdSe. It is located inside the cryostat on a mechanism to allow insertion into the science beam. It is placed in the collimated beam 100 mm upstream of the grating turret. The clear aperture of the front face of the Wollaston prism is 38$\times$33 mm, and is oversized by several mm on each side to allow for positioning and AR coating runoff. The height of the Wollaston prism is $\sim$9 mm, and each optical surface of the prism is AR coated, optimized to balance transmission of the ordinary (o) and extraordinary (e) rays (Figure 3). Adherence of the AR coating at cryogenic temperatures had been demonstrated through the use of CdSe witness samples.

A cut-angle of 10.3° provides a beam displacement of 1/8th of the array. For cut-angles $\geq$10.3° the image quality degrades significantly and a lower angle produces insufficient beam displacement. The birefringence across the N-band changes by 6.7%, leading to an image elongation of 42 mm, or $\sim$19% of the Airy disc diameter in the worst case (at the short wavelength cut-off of the filter).

2.4. Delivered Image Quality

Image quality in polarimetry mode during standard observing conditions will show no measurable degradation from that in direct imaging mode, after a $\sim$1 mm change in telescope focus. The final delivered image quality at a monochromatic wavelength of 10.5 μm has a Strehl ratio of 98%, but seeing, tracking etc., will typically dominate the final image quality. For broadband N imaging, the Strehl ratio falls to 81%, but again seeing, tracking etc. will typically limit the final image quality.

2.5. Polarimetric Focal Plane Masks and Calibration

To prevent overlapping the o and e rays, a focal plane mask is used. Although a single Wollaston prism can be used to cover the N and part of the Q band, two masks are needed to match the different separations of the e and o rays for each atmospheric window.

For measuring polarizing efficiency and checking that the polarimeter is operating nominally, an external KRS-5 wiregrid polarizer that produces a known degree of polarization can be inserted in to the beam. Alternatively, objects of known polarization can be observed.

3. Expected CanariCam Polarimetry Performance

In Table 1 we estimate the performance of CanariCam on GranTeCan. The quoted observing time (see Table 1) is for a final signal to noise ratio of 300:1, which provides an absolute uncertainty in the degree of polarization of 0.5%. The expected sensitivity places numerous active galaxies, young stellar sources and numerous other types of sources within the practical observational reach of CanariCam-Polarimetry.

4. Conclusions

CanariCam is projected to be completed at the University of Florida by early 2005. The GTC is currently projected to be completed and ready for instrument commissioning in late 2005. The combination of CanariCam and the GTC and the dual-beam nature of the polarimeter will permit highly accurate polarimetry across the N band atmospheric window.

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