A "single-shot" optical linear polarimeter for asteroids studies

C. Pernechele[1], L. Abe[3], P. Bendjoya[3],
A. Cellino[2], G. Massone[2], J. P. Rivet[3], P. Tanga[2]

[1]National Institute for Astrophysics, Astronomical Observatory of Padova, Italy.
[2]National Institute for Astrophysics, Astronomical Observatory of Torino, Italy.
[3]Laboratoire Lagrange, UMR7293, Université de Nice Sophia-Antipolis, CNRS,
Observatoire de la Côte d'Azur, France.

ABSTRACT

Polarimetric studies of minor Solar System bodies are useful to access physical parameters, such as albedo and diameter, which are both important and difficult to derive by other techniques. Current activities in this field are limited since most instruments adopted in recent observing campaigns involve photomultipliers detectors. These sensors are suitable for observations of objects with fast polarization variations, but usually suffer from low quantum efficiency. This severely limits the number of accessible targets. For asteroids, the polarization evolves slowly enough to allow more sensitive albeit slower detectors (CCD-based polarimeters). However, polarimetric measurement accuracy may be hampered with usual "sequential" polarimeters. Indeed, retarder plate swapping time, readout and exposure time add up. Consequently, the time laps between complementary polarization measurements (some minutes) may be non-negligible in some cases, compared to the evolution time of the polarization parameters. Moreover, polarimetric accuracy may also be limited by airmass variations between complementary exposures.

We are developing a new "single-shot" CCD polarimeter based on a "double-Wollaston" configuration already described in literature [9][10]. This allows simultaneous acquisition of the three Stokes parameters I, Q, U without any moving parts. So, the linear polarization degree can be measured accurately, even for targets with fast polarization and/or airmass variations. Presently, the polarization analyzer is in calibration phase, and will be installed soon at the F/12.5 Cassegrain focus of the West telescope at the "*Centre Pédagogique Planète et Univers*" facility (C2PU, Observatoire de la Côte d'Azur, Plateau de Calern, France).

Keywords: Polarimetry, Asteroids, Astronomical Instruments.

1. INTRODUCTION

Modern astrophysical techniques, particularly imaging and low resolution spectroscopy, have required high flexibility in instrumentation design. As a result, a typical multi-purpose camera involves a focal reducer, with re-imaging of the telescope pupil. This configuration allows a straightforward implementation of polarimetric and spectro-polarimetric modes by inserting a Wollaston prism near the pupil plane. In order to determine the Q and U components of the Stokes vector, it is necessary to take at least two different measurements with the polarization axis rotated of 45°. Thus, the typical configuration incorporates also a rotating $\lambda/2$ retarder plate inserted before the Wollaston prism. The time needed to swap from one orientation of the retarder plate to the other, adding up to the readout and exposure times, is likely to introduce a bias in the polarization measurements This is the case for astrophysical objects with rapid polarization variations, or when the sky transparency varies under non-optimal atmospheric conditions. Simultaneous measurement of Stokes parameters is important in many fields of astronomical research, including asteroids [1-5] and Gamma ray burst polarimetry [6]. A good review on modern VIS and NIR polarimetry is described by Hugh [7].

A former study on the potentiality of a polarimeter able to record more than two Stokes parameters simultaneously has been described by Geyer [8]. A Wollaston analyzer, in a double wedge configuration, has been described by Oliva [9], and realized by Pernechele et al. [10].

Ground-based and Airborne Instrumentation for Astronomy IV, edited by Ian S. McLean, Suzanne K. Ramsay,
Hideki Takami, Proc. of SPIE Vol. 8446, 84462H · © 2012 SPIE · CCC code: 0277-786X/12/$18 · doi: 10.1117/12.925933

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 05/14/2015 Terms of Use: http://spiedl.org/terms

We have designed, and are currently building such a double Wollaston polarimeter, optimized for the F/12.5 Cassegrain focus of the C2PU "West" telescope of the Observatoire de la Côte d'Azur (OCA), located on the plateau of Calern in France (latitude: 43º 45' 13" North, longitude: 6º 55' 23" East, altitude 1270 m). This 1 meter telescope is part of a facility (C2PU) involving two 1 meter telescopes dedicated to both research and educational activities (and combining the two aspects). The "West" telescope consists in a primary F/3 focus for wide field imaging, and an F/12.5 Cassegrain focus (interchangeable configurations) which will host the polarimeter. The "East" telescope will have an F/30 coudé focus.

Our instrument, called "CAPS" for "Calern Asteroids Polarimetric Survey", will be able to simultaneously produce polarized images at 0°, 45°, 90° and 135°. In that way, the I, Q, U Stokes parameters will be simultaneously measured. This is particularly well suited for studies aimed at monitoring the variation of the degree of linear polarization of asteroids light at visible wavelength for varying observing circumstances (in particular for different values of the so-called phase angle, namely the angle between the directions to the Sun and to the observer as seen by the target body). The resulting phase *vs.* polarization curves can be used to derive reliable estimates of the geometric albedo of the objects.

2. OPTICAL DESIGN

The "West" telescope of C2PU has a Cassegrain design with a primary diameter (entrance pupil) of 1 meter, working at an F/12.5 relative aperture. The focal extraction is 655.4 mm and the scale is 16.5 arcsec/mm.

The concept driving the design of the polarization analyzer is to simultaneously obtain four images or spectra of the same field, respectively containing the information of the polarization at 0°, 45°, 90° and 135°. Details on designing optical parameters of a Wedge Double Wollaston instrument are described in Pernechele et al. [3]. The final parameters of the focal reducer for the CAPS instrument are: a focal reduction of 0.5×, which means a final scale of 32 arcsec/mm (the pixel size of the CCD is 13 µm). The derived plate scale is then 0.42 arcsec/px. The working wavelength ranges from 0.5 µm to 0.75 µm (V and R bands). The field of view (FoV) is 4.8' × 54" on sky. The gap between the four images of the same field on CCD is 30 px (0.4 mm).

The layout from ray tracing code (Zemax) is depicted in the next figure

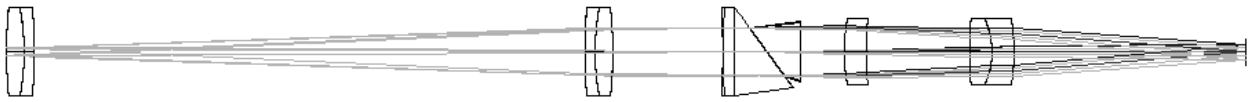


Figure 1: Sketch of the polarization analyser.

The focal reducer comprises (from upstream to downstream):

1. A rectangular 18 mm × 3.4 mm (4.8' × 54") field stop placed in the telescope's focal plane, to limit the field of view and prevent the four images of the field to overlap (not represented in Figure 1).
2. A field lens (an achromatic doublet).
3. A collimator lens (an achromatic doublet).
4. A re-imaged pupil plane, where the double Wollaston is located.
5. A camera, of 130 mm in foal length, composed by a singlet and a doublet.
6. A CCD sensor.

The pupil dimension, where the double Wollaston is placed, is about 24 mm in diameter: it is the "heart" of the instrument. The angle of the front wedge is driven by the camera focal length which in turn is fixed by the sampling requirements (seeing limited in the present case). In the case study, with the parameters indicated above, the angle of the front wedge is 1.4 degree. The internal angle between the two prisms is 54º (see Figure 2). The Wollaston produces 4 strip-shaped images of the same field in the focal plane, according to Pernechele et al. [10], as sketched in the figure 3, left panel. Each strip contains the proper polarized component (0°, 90°, +45°, -45°). The strips are approximately

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 05/14/2015 Terms of Use: http://spiedl.org/terms

1.7 mm × 9 mm wide (54" × 4.8') each. The sides of the rectangular area formed by the four strips plus gaps are about 7.0×9 mm^2.

A simulation of the optical performances for the complete optical train of the CAPS polarimeter has been done using a commercial ray tracing software (Zemax). The spot diagrams for images formed in the four corners for each of the four strips in the final focal plane are shown in Figure 3, right panel. The left panel specifies the geometry of the strips. The depicted square area is 10 mm wide.

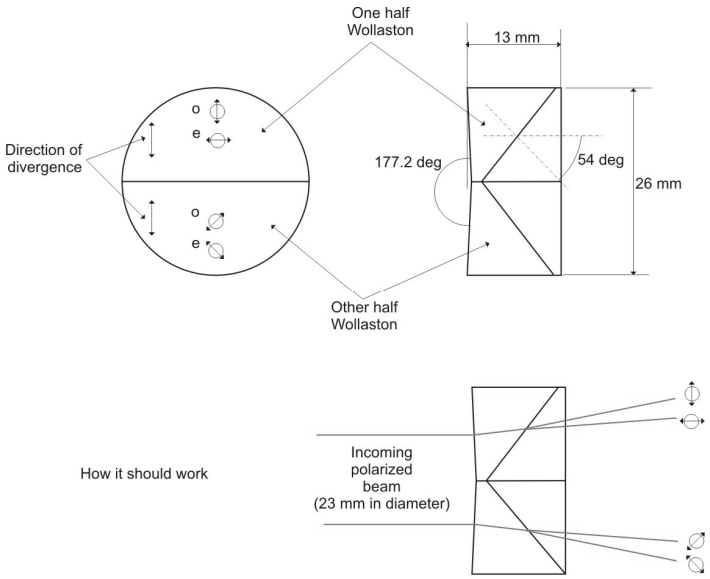


Figure 2: The double Wollaston parameters for the CAPS polarimeter.

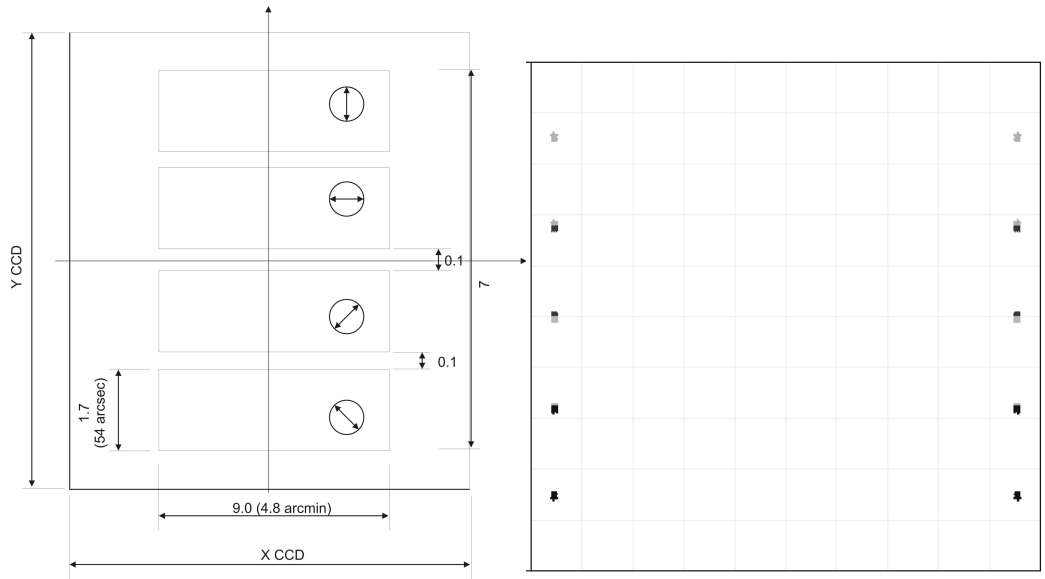


Figure 3: The focal plane of the CAPS polarimeter (left panel not to scale), showing the arrangement of the four strips with the four polarization states.

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 05/14/2015 Terms of Use: http://spiedl.org/terms

In Figure 4, the "ensquared" energy (percentage of the total energy found within a centroid-centered square area, as a function of the square half-side) on the focal plane of the polarimeter is shown. The top panel shows the performances for points close to the optical axis (two central strips), while the bottom one shows those for the external strips. As expected, far-from-axis images depart more severely from diffraction-limited performances. This is mainly due to the chromatism induced by the dispersion of Wollaston prism. The diffraction-limit curve is displayed for reference.

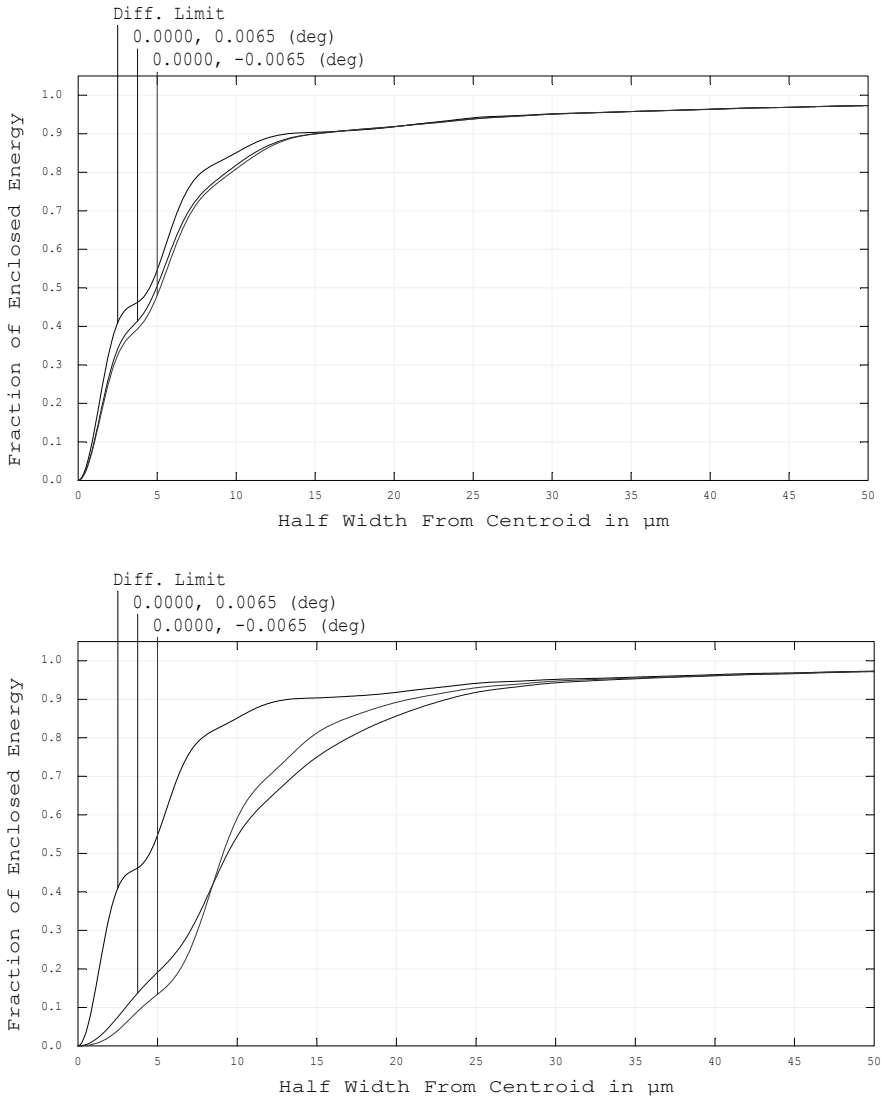


Figure 4: "Ensquared" energy for the two central strips (top panel) and the two external ones (bottom panel). The latter shows a worst performance due to the chromatic dispersion of the polarizer.

3. INSTRUMENTAL SETUP

Figure 5 shows a sketch of the instrumental setup (casing, baffles and CCD camera not displayed). The optical component mounts are attached to an optical bench, which will be connected to the telescope's rotating output flange by an interface flange. The focal reducer incorporates a rectangular field stop and a field lens (achromatic doublet) in the same mount, a collimator (also an achromatic doublet) in a separate mount, and the camera lenses (a singlet and an

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 05/14/2015 Terms of Use: http://spiedl.org/terms

achromatic doublet) fitted inside a spacer tube. For a basic polarimetric mode, the double Wollaston analyzer is to be introduced on the optical axis, in the re-imaged pupil plane, between the collimator and the camera lenses assembly. All the optics and mounts have been realized by the LOBRE srl (Brescia, Italy) manufacturer. Images of the optical and mechanical parts are shown in Figure 6.

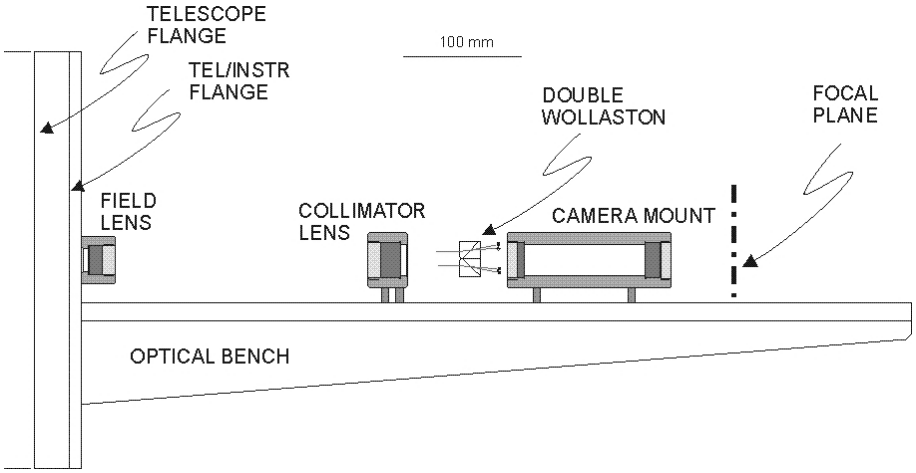


Figure 5: The setup of the focal reducer with the double Wollaston inserted.

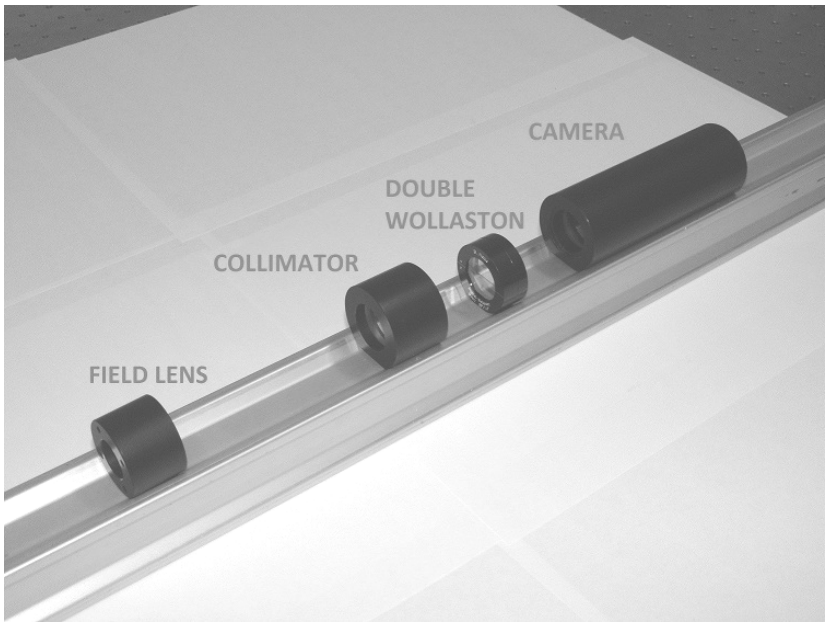


Figure 6: the polarimeter during the assembly phase.

Presently, the polarimeter is in the mounting and alignment phase, as shown in Figure 6.

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 05/14/2015 Terms of Use: http://spiedl.org/terms

4 . CONCLUSIONS

We are constructing a double Wollaston simultaneous polarization analyzer for the 1 meter "West" telescope of the C2PU facility (Observatoire de la Côte d'Azur, Calern plateau, France). The instrument will be able to measure three of the four Stokes parameters (U, V, B) simultaneously. With this instrument, we aim at measuring the linear polarization for celestial bodies with polarization variations which can be even moderately fast (some minutes). We expect that the study of the polarization properties of asteroids may take great advantages from this new instrument.

All optics, mounts and the optical bench have been realized and the instrument in presently in the mounting and alignment phase. The first 1 meter C2PU telescope is scheduled for first light in the second half of 2012.

ACKNOWLEDGEMENTS

The C2PU facility has been funded by the Observatoire de la Côte d'azur (OCA), the University of Nice-Sophia Antipolis (UNS), the General Council of the "Alpes Maritimes" district (CG06) and Collège de France.

The funds for the development of the polarimeter were provided by the Italian National Institute for Astrophysics (INAF), in the framework of 2010 PRIN contracts.

5. REFERENCES

1. Cellino A., Gil-Hutton R., Di Martino M., Bendjoya Ph., Belskaya I.N., Tedesco E.F., "Asteroid polarimetric observations using the Torino UBVRI photopolarimeter", Icarus, 179, 304 (2005).
2. Belskaya, I. N., Shkuratov, Y. G., Efimov, Y. S., Shakhovskoy, N. M., Gil-Hutton, R., Cellino, A., Zubko, E. S., Ovcharenko, A. A., Bondarenko, S. Y., Shevchenko, V. G., Fornasier, S., Barbieri, C., "The F-type asteroids with small inversion angles of polarization", Icarus, 178(1), pp 213-221, (2005).
3. Fornasier, S., Belskaya, I. N., Shkuratov, Y. G., Pernechele, C., Barbieri, C., Giro, E., Navasardyan, H., "Polarimetric survey of asteroids with the Asiago telescope", A&A, 455(1), pp 371-377, (2006).
4. Fujita, K., Itoh, Y., Mukai, T., "Development of simultaneous imaging polarimeter for asteroids", Adv in Space Research, 43(2), pp 325-327, (2009).
5. Belskaya, I. N., Fornasier, S., Krugly, Y. N., "Polarimetry and BVRI photometry of the potentially hazardous near-Earth Asteroid (23187) 2000 PN9", Icarus, 201(1), pp 167-171 (2009).
6. Kawabata, K. S., Nagae, O., Chiyonobu, S., Tanaka, H, Nakaya, H., Suzuki, M., Kamata, Y.,Miyazaki, S., Hiragi, K., Miyamoto, H., Yamanaka, M., Arai, A., Yamashita, T., Uemura, M., Ohsugi, T., Isogai, M., Ishitobi, Y., Sato, S., "Wide-field one-shot optical polarimeter: HOWPol", Proc. SPIE, 7014, pp. 144-154, (2008).
7. Hugh. J. H., "Polarimetry techniques at optical and infrared wavelengths", ASP conf. series, 343, 11 pages, (2005).
8. Geyer, E. H., Jockers, K., Kiselev, N. N., Chernova, G. P., Astroph. & Space science, 239, pp. 259-274, (1996).
9. Oliva, E., "Wedged double Wollaston, a device for single shot polarimetric measurements", *A&ASS*, **123**, pp. 589-592 (1997).
10. Pernechele, C., Giro, E., Fantinel, D., "Device for optical linear polarization measurements with a single exposure", Proc. SPIE, 4843, 156-163 (2003).

Downloaded From: http://proceedings.spiedigitallibrary.org/ on 05/14/2015 Terms of Use: http://spiedl.org/terms