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Asteroid polarimetry : validation run on the CAPS polarimeter

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Abstract

Polarimetric study of atmospherless bodies is a powerful tool to determine their physical properties (albedo, diameter) [1]. The "Calern Asteroids Polarimetric Survey" polarimeter has been designed for this purpose. It is a "single shot" CCD polarimeter based on a "double-Wollaston" configuration [3, 4]. This allows to measure simultaneously the three Stokes parameters *I*, *Q* and *U* without any moving parts. This instrument has been designed for the F/12.5 Cassegrain focus of the 1 meter West telescope of the "Centre Pédagogique Planète et Univers" facility (C2PU, Observatoire de la Côte d'Azur, Plateau de Calern, France). We present in this talk the first calibration and measurements made with CAPS. The results show that the instrument remained stable with a precision of 10^{-4} during the whole observing campaign (two months). We also present the very first polarimetric measurements on 30 main belt asteroids, in good agreement with previously published results.

1. Introduction

Usually, the degree of polarization for an asteroid is defined as the flux difference between the lights scattered with polarizations perpendicular and parallel to the scattering plane (normalized to their sum) :

$$P_{\mathrm{r}} = \frac{I_{\perp} - I_{\parallel}}{I_{\perp} + I_{\parallel}}. \qquad (1)$$

It is well known that the degree of polarization depends on the phase angle, *i.e.* on the angle between the Sun and the observer, as seen from the object.

For asteroids, the morphology of the "degree of polarization *vs* phase" curve $P_r = f(\alpha)$ has some general properties which are mainly dependent on their albedo. A feature common to all asteroids is a "negative polarization branch" for small phase angles (the polarization parallel to the scattering plane exceeds the polarization in the perpendicular direction). The transition from negative to positive polarization occurs for a critical value of the phase angle called the "inversion angle". For most asteroids this inversion angle has a relatively small value, around 20°.

The CAPS (Calern Asteroid Polarimetric Survey) is a new polarimeter dedicated to the observation of asteroids. This instrument aims at producing high quality "degree of polarization *vs* phase" curves for relatively bright asteroids (magnitude smaller than 16). One of CAPS major science case is to improve our knowledge about the relation between the polarization and the albedo [1]. In this context an interesting family of asteroids is the recently identified "Barbarian" family which display unusual polarimetric features [2].

2. Instrument description

The CAPS polarimeter is installed at the Cassegrain focus of the "Omicron" (West) telescope of the C2PU facility (Calern plateau, Observatoire de la Côte d'Azur, France; UAI code : 010). This telescope has an entrance pupil of 1.04 meter. For the Cassagrain focus, this leads to an aperture ratio of $F/12.5$. CAPS has been designed so as to allow simultaneous measurement of four polarization states (0°, 45°, 90°, and 135° *w.r.t.* the instrument's reference plane) on a single CCD frame. This is done by a double Wollaston prism [3, 4]. The common edge of those two Wollaston prisms subdivides an intermediate pupil image into two parts of equal surfaces. Each Wollaston prism splits the incoming light into two beams with complementary polarization states. The upper Wollaston prism separates polarizations 0° and 90°. The lower one separates polarizations 45° and 135°. Con-

sequently, four replicas of the same field of view are formed at the surface of the CCD sensor which correspond to the four polarization states.

3. Data reduction

After dark frame subtraction, a standard aperture photometry algorithm is applied separately to the four images of the same source. This yields the four polarized fluxes I_0, I_{90}, I_{45}, and I_{135} for the target. The Stokes parameters q and u are then computed according to their standard definitions :

$$q = \frac{I_0 - I_{90}}{I_0 + I_{90}}, \qquad u = \frac{I_{45} - I_{135}}{I_{45} + I_{135}} \tag{2}$$

Finally, the total polarization P and the polarization angle θ *w.r.t.* the instrument's reference direction are computed as follows :

$$P = \sqrt{q^2 + u^2}, \qquad \theta = \frac{1}{2} \arctan\left(\frac{q}{u}\right) \tag{3}$$

4. Observations

In the early 2015, a series of polarimetric standard calibration stars have been observed. These observations were used to calibrate the instrumental polarization and to measure the angular bias between the instrument's reference direction and the on-sky North direction (usually taken as the angular zero direction for on-sky polarization measurements). Repeating these observations on several polarimetric standard stars leads to an estimate of our measurements repeatability.

The optical components of the telescope and of the CAPS instrument are likely to introduce polarization biases. Those effects can be calibrated by the observation of a series of unpolarized standard stars. Since these stars are supposed to be unpolarized, any measured polarization is assumed to be due to these biases

The measurements on 17 unpolarized standard stars during 8 different nights shows a median instrumental polarization for the V band :

$$q_V(\%) = 3.82 \pm 0.018, \quad u_V(\%) = 0.27 \pm 0.007 \tag{4}$$

and for the R band :

$$q_R(\%) = 3.61 \pm 0.011, \quad u_R(\%) = 0.30 \pm 0.017 \tag{5}$$

where q and u are the reduced Stokes parameters (i.e. $q = Q/I$ and $u = U/I$).

The standard polarized stars are used to calibrate the angular bias between the instrument's zero direction and the on-sky North direction and to check if the instrumental component of the polarization are correctly subtracted. The measurements on 5 polarized standard stars during 5 different nights show that the CAPS instrument is rotated by $0.4^\circ \pm 0.4^\circ$ respectively with the IAU convention for the zero direction of polarization. The average difference between previously published polarization for these stars and the polarization found by CAPS after removing the instrumental component differ by $1.7 \times 10^{-4} \pm 2.7 \times 10^{-4}$

5. Results on asteroids

The CAPS instrument is dedicated to the observation of asteroids. Consequently, the full validation of the instrument requires observing asteroids for which the polarization *vs* phase relationship is well known. We have observed 30 asteroids during 8 nights. The results show that the polarization found is in agreement with the previously published measures.

6. Summary and Conclusions

The CAPS (Calern Asteroid Polarimetric Survey) instrument has been intensively tested during a two months validation run. The results show that the CAPS instrument provide reliable polarimetric measurements. In the meantime, the observation of standard polarimetric stars allowed us to test the instrument stabilibity, which is on the order of 10^{-4}.

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