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Imaging polarimeter for the 2.6 m Shajn telescope. Technical considerations and draft specifications

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ABSTRACT

Broadband polarimetry has been a substantial part of observing programs at the CrAO's 2.6 m Shajn telescope, resulting in a number of impactful results. Currently, an instrument filling this role on the telescope is the multichannel fast modulation polarimeter NEOPOL. The constraints of its design, namely the use of photomultiplier tubes (PMTs) as light detectors, leaves many potentially interesting objects and phenomena beyond reach. In this paper, we present a case for the development of the new instrument for imaging polarimetry and consider some principal considerations concerning its design and specifications. As an optimal solution, we propose a specialized imaging device (as opposed to a versatile imager-spectrograph-polarimeter instrument) in the primary focus, based on the existing GE ELSE 2K × 2K CCD camera.

Key words: telescopes, instruments, polarimetry

1 Introduction

Optical broadband polarimetry is an important and somewhat underestimated technique allowing in many cases for an estimate of details and parameters unresolved with other techniques for systems with a substantial role of scattering, reflection, and polarization-dependent absorption of light, including close binaries, protoplanetary disks, interstellar medium, and the Solar system objects. Polarimetric techniques may be arranged as a spectrum of capabilities, from the most effective in the sense of their ability to reach reasonable signal-to-noise ratio quickly, even for faint objects, to the most precise in the sense of their ability to reach extremely low measurement errors when the photon noise is not a limit, i.e., for relatively bright objects. The reason for this state of the field is intrinsically contradictory requirements of maximal efficiency and maximal accuracy. The highest accuracy is achieved with fast modulation techniques (Hough et al., 2003), while maximal efficiency requires the low-noise slow-scan CCD detectors, which do not support high readout frequency. Another accuracy-limiting factor for many CCD-based instruments is the difficulty in precise flat-field calibration.

The NEOPOL instrument[1], currently operated at the 2.6 m Shajn telescope (ZTSh), is an instrument at the high-precision and low-efficiency end of the spectrum of capabilities. The use of single-channel PMT detectors requires separate measurements of an object and sky background through a relatively large "physical" aperture, making observations of targets with a low object to sky contrast rather inefficient. The practical limiting magnitude for this instrument is about 17^m. Another obvious drawback is the absence of any spatial resolution, limiting the choice of targets to mostly point sources. To address this imbalance of polarimetric capabilities, we propose to develop a specialized high-efficiency imaging CCD-based polarimeter and consider available options concerning its design and specifications.

Basic requirements for the new instruments are as follows:

1. The complementarity with the existing NEOPOL instrument. The new device does not have to provide polarimetric accuracy higher than 0.1% (here and below we mean the measurement of the degree of linear polarization, fully polarized being 100%) in the situations when the errors are not limited by the photon noise. It should have high efficiency for faint objects, providing errors of 0.5%, and the realistic integration time of about an hour for objects with $R \sim 19^m$.
2. Simplicity of design, maximal use of inexpensive, commercially available optical components.
3. Imaging ability with independent measurement of the polarization parameters in each pixel for extended targets (comets, reflective nebulae) within the $\sim 2'$ field, using a single exposure to measure each of the Stokes parameters.

[1] https://www.craocrimea.ru/images/ckp/circular_ZTSh.pdf

4. Back-illuminated, cooled science-grade CCD detector, optimally the GE ELSE 2K × 2K CCD camera with a 13.5μ pixel.

2 Design choices

The new instrument may be installed either in the primary focus (1:3.8) or in the Cassegrain focus (1:16) of the telescope. The primary focus is an obvious choice regarding efficiency, and the only constraint is a limit of 0.5 m for the instrument's outer diameter.

There are basically two types of imaging polarimeters:

1. The designs based on a Savart plate as a polarizer, introducing a relative linear shift of the O and E output rays. It may be installed in front of the focal plane without need for other optical elements, producing a "double" image at the focal plane. The benefit of this scheme is its simplicity. However, the linear shift of O and E images is limited by Savart plate's thickness and cannot be larger than 2 mm realistically, which is only 40″ at the ZTSh primary focus. This constrain either limits the instrument to point sources only, with the object to sky contrast deterioration by a factor of two, or requires the use of the focal plane mask(s) and a relay lens to form a "sliced" image. The latter scheme loses half of the image on the mask and requires at least two exposures to form a single full image.
2. The focal reducer scheme with a post-focal collimator, a Wollaston prism placed in the collimated beam, and a camera lens producing two images with reasonable separation on the detector.

The second scheme is obviously an optimal choice for our requirements. This scheme is very popular for the versatile spectrograph-imager instruments, e.g., SCORPIO (Afanasiev, Moiseev, 2011), which often have a polarimetric mode. An instrument of this kind might be useful at the ZTSh as well, but the spectroscopy mode significantly hardens requirements for the collimator and camera lenses. It also introduces at least two extra mechanical drives for dispersers and slits as well as a rather complicated pre-focal assembly with a range of precise guiding and calibration devices.

Unless spectral resolution of the spectroscopy mode is very modest, it also requires a diameter of the collimated beam in excess of that necessary for our narrow-field imager. Thus, the concept of a versatile "all-in-one" focal reducer contradicts our requirements concerning the use of low-cost available components. Polarization optical components (like a Wollaston prism) has a very sharp jump in cost for sizes larger than 20 mm, and this diameter of the collimated beam might not provide spectral resolution high enough for a versatile "all-in-one" instrument.

3 Conclusions

Thus, the optimal design for our requirements is a focal reducer in the primary focus, with a collimated beam diameter of about 20 mm, and a Wollaston prism as a polarization splitter.

The proposed specification is as follows:

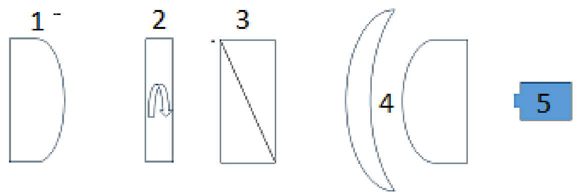

Fig. 1. Layout of the proposed optical scheme: 1 – collimator, 2 – waveplate (changeable), 3 – Wollaston prism, 4 – camera lens, 5 – CCD.

- Installation at the primary focus (1:3.8).
- Focal reducer layout (Fig. 1).
- A collimator diameter of 20 mm.
- A field of view (non-overlapping double image) of 1–3′, depending on the choice of the Wollaston separation angle.
- Remotely changeable, rotating quoterwave and halfwave superachromatic plates.
- A calcite Wollaston prism of 20–25 mm clear diameter.
- The Greateyes ELSE 2K × 2K 13.5μ CCD camera.
- The moving parts are the waveplate rotation drive, the waveplate changing linear drive, the filters wheel (not shown on the scheme).

The least straightforward design choice for this scheme is the characteristics of the Wollaston prism. The main tradeoff is between the useful field of view: the greater separation angle of the prism, the larger double image may be placed on the detector without overlap, and the degree of chromatic aberrations introduced by the prism, which depends on the separation angle. To some extent, the chromatic aberrations may be compensated by the custom design of the camera lens, as done in the NEOPOL instrument, but this means that the lens should be designed specifically to this goal and standard off-the-shelf lenses could not be used for this component. Another consideration is the degradation of polarization contrast due to oblique incidence on the Wollaston prism, but the incidence angle is less than 10° for the 3′ field of view.

References

Afanasiev V.L., Moiseev A.V., 2011. Baltic Astronomy, vol. 20, pp. 363–370.

Hough J.H., Lucas P.W., Bailey J.A., Tamura M., 2003. In S. Fineschi (Ed.), Polarimetry in Astronomy. SPIE, vol. 4843, pp. 517–523, doi:10.1117/12.458222.