Design of TFOSC Compatible Polarimeter for Polarimetric Observations

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Abstract— This study proposes a design steps of a TFOSC focal plane instrument compatible optical polarimeter in order to investigate the physical parameters of targets (such as albedo, diameter, taxonomy of asteroids, porosity) based on the polarization properties of light. Images captured with Polarimeter will be reduced for the atmospheric effect and device errors. The light impinging on WeDoWo prism is divided into four different images which is polarized at 0, 45, 90, 135 degrees and used to determine Stokes' parameters of electromagnetic waves. WeDoWo prism has been designed by using commercial optical design software named ZEMAX, it is 40 mm in diameter and has a thickness of 20 mm.

1. INTRODUCTION

Aim of this study is to design a TFOSC (TUBITAK National Observatory "TUG" Faint Object Spectrograph and Camera) focal plane instrument compatible polarimeter and investigate the physical parameters of targeted asteroids (such as albedo, diameter, taxonomy of asteroids, porosity) based on the polarization properties of light by using this polarimeter which will be designed.

Polarized light can provide additional information about the scene that cannot be obtained directly from the intensity or spectral images. Rather than treating the optical field as scalar, polarization images seek to obtain the vector nature of the optical field from the scene [1].

Instrumental base of 1.5 m Russian-Turkish telescope RTT150 makes it possible to carry out practically whole kind of astrophysical observations in the visible range. Until recently the observational complex included light detectors for high positional and photometric CCD observations, fast photometry, and for obtaining low and high resolution spectra. During the last observation campaign of PHA Apophis close approach, we are faced with lack of spectroscopic observations to determine the taxonomy class of asteroids with visual magnitude fainter than 16 m, due to the requirement of extremely long observational time. In addition to spectroscopic method for taxonomy determination, polarimetric method should also be employed. We present design of a polarimeter for RTT150 for simultaneous imaging of celestial sources on polarization planes on the base of WeDoWo (Wedge Double Wollaston) [2]. The accuracy and magnitude limits are discussed. The designed polarimeter may be used for not only asteroid observations but also for astrophysical sources like SN (Super Nova), AGN (Active Galactic Nuclei) and so on. Thus, the polarimeter integration to the RTT150 telescope increases its capabilities in ground-based observational support of present and future astrophysical space missions (GAIA "Global Astrometric Interferometer for Astrophysics", SRG "Spectrum-Rontgen-Gamma").

In this paper, we propose a Wollaston-based optical prism design principles, and images will be gathered by means of CCD. First measurement results will be presented in the conference.

2. WEDGE DOUBLE WOLLASTON (WEDOWO) PRISM

WeDoWo prism is one of the methods used for determining the celestial body originated light polarization rate throughout the world wide observatories. The light impinging on WeDoWo prism is divided into four different images which is polarized at 0, 45, 90, 135 degrees and used to determine Stokes' parameters of electromagnetic waves. First three elements of Stokes' vector can be determined without needing neither simultaneously obtained light component that have $\lambda/2$ variation nor other moving components [2]. To evaluate optical performance of WeDoWo prism parameters, a commercial optical design software called ZEMAX was used [4]. A space between collimator and camera allows integrating our new polarimeter to the system without any distortion, and by this way it allows to investigate asteroids whose taxonomy class faint less than 16th magnitude and diameter of 300 m.

Since images will be captured simultaneously with this Polarimeter, the atmospheric effect and device errors will be reduced. TFOSC which is a multi-functional device allows both photometry and spectroscopy at the moments. After designed Polarimeter is integrated to TFOSC, the transition between the three methods will take place fast and optionally according to the observing sources.

3. THEORY OF POLARIZATION

A light is an electromagnetic wave whose polarization characteristics can be completely represented by its Stokes vector (I, Q, U, V) [3]. The Stokes parameters are a set of values that describe the polarization state of electromagnetic radiation. They were defined by George Gabriel Stokes in 1852, as a mathematically convenient alternative to the more common description of incoherent or partially polarized radiation in terms of its total intensity (I), (fractional) degree of polarization (p), and the shape parameters of the polarization ellipse.

The Stokes parameters are linear with intensity, so the link between each pixel of the images and Stokes parameters can expresses with a matrix. If the images are perfectly 0, 45, 90, 135 degrees polarization, the Stokes parameters (in Eq. (1)) can be easily deduced [5]. $I^2 = Q^2 + U^2 + V^2$ (This only holds for 100% polarized waves). I is the total intensity, Q and U are linear polarization and V is circular polarization. V value for linear polarization is zero. The degree of linear polarization of such a light beam is defined as P_L in Eq. (2) and ϕ_L is defined in Eq. (3).

$$\vec{S} = \begin{bmatrix} I \\ Q \\ U \end{bmatrix} = \begin{bmatrix} I_{0^\circ} + I_{90^\circ}\ veya\ I_{45^\circ} + I_{135^\circ} \\ I_{0^\circ} - I_{90^\circ} \\ I_{45^\circ} - I_{135^\circ} \end{bmatrix} \tag{1}$$

I_{0°: the linearly polarized component along the horizontal axis,
I_{90°: the linearly polarized component along the vertical axis,
I_{45°: the linearly polarized component at 45°,
I_{135°: the linearly polarized component at −45°.

$$P_L = \frac{\sqrt{Q^2 + U^2}}{I} \tag{2}$$

$$\phi_L = \frac{1}{2} \arctan \frac{U}{Q} \tag{3}$$

As $P = 1$, the wave is totally polarized.
As $P = 0$, the wave is totally non-polarized.
If $0 < P < 1$, P represents the amount of beam polarization.

Figure 1 represents the WeDoWo schematics. Figure 1(a) is the schematic representation of WeDoWo device and ray-tracing. To prevent vignetting at the prisms interface the wedge angle is chosen to ensure that all rays (including those from the field edges) always travel above/below the optical axis. Middle one is the illustration of how this device creates four polarized images (at 0, 90, 45 and 135 degrees) of a stellar field. Right one is the illustration of how the WeDoWo creates four long slit polarized spectra (at 0, 90, 45 and 135 degrees) of two stars [2].

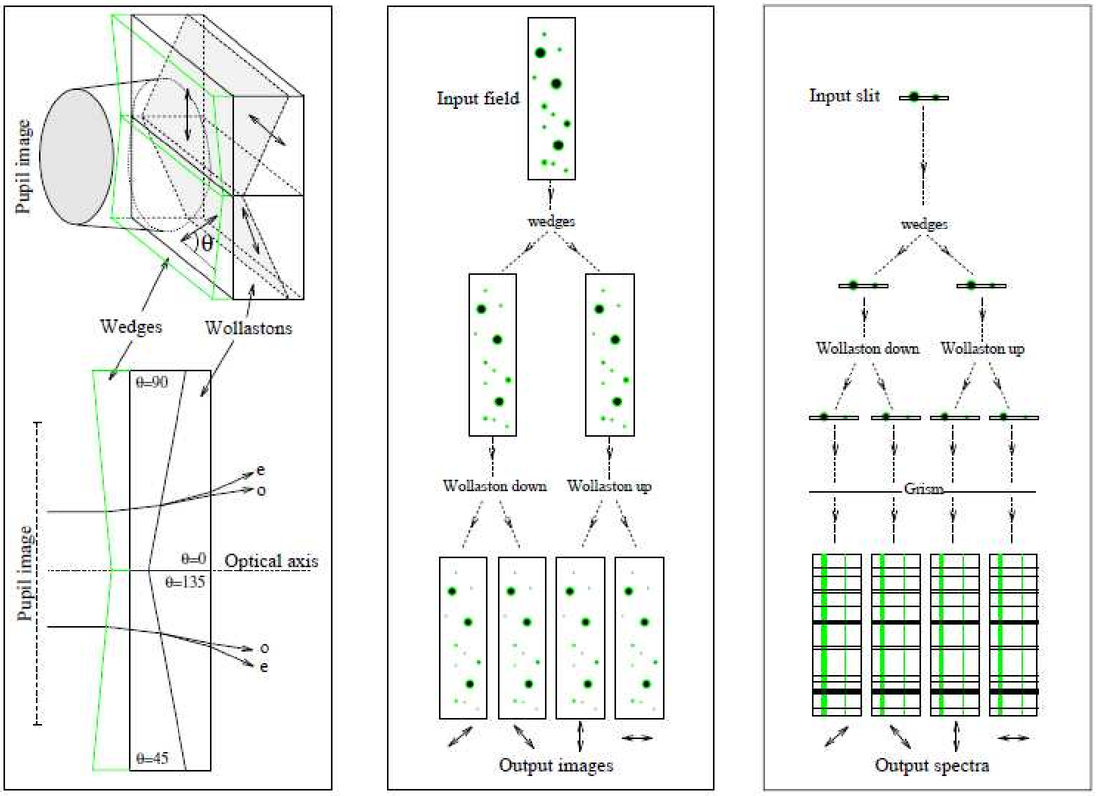
$$\left(\frac{\theta}{derece}\right) = 2.78 \left(\frac{\theta_{sky}}{100}\right) \left(\frac{D_{Tel}}{1\,\mathrm{m}}\right) \left(\frac{D_p}{1\,\mathrm{cm}}\right)^{-1} \tag{4}$$

θ_{sky} (sky projected angles) is the slit length, D_{tel} is the telescope diameter and D_p is the diameter of the pupil image in Eq. (4). This values for RTT150, as indicated in Eq. (5).

$$\theta_{sky} = 60'', \quad D_{Tel} = 1.5\,\mathrm{m}, \quad D_p = 54\,\mathrm{mm} \tag{5}$$

Combined with Eqs. (1), (2) and [2] we have obtained Eq. (6);

$$\begin{aligned} \alpha &= 18.853 \\ \beta_1 &= 3.591 \\ \beta_2 &= 1.89 \end{aligned} \tag{6}$$



(a) (b) (c)

Figure 1: WeDoWo schematics [2].

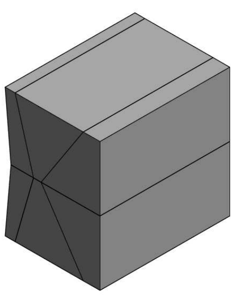


Figure 2: WeDoWo.

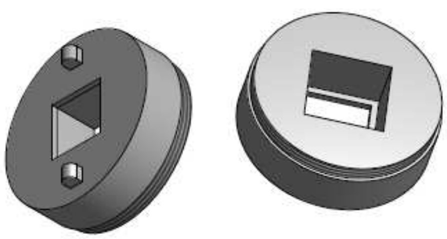


Figure 3: Mouth.

Figure 4: WeDoWo with mouth.

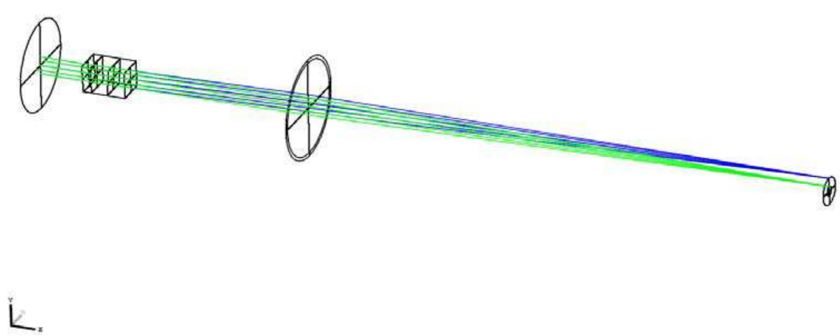


Figure 5: Wollaston birefringent sample with $CaCO_3$ material.

4. NEW OPTICAL DESIGN

We designed new WeDoWo polarimeter prism by using optical design software ZEMAX. The most convenient (and probably the cheapest) material for our design is $CaCO_3$ in visible wave length. A consequence of this choice is that the output images suffer by different lateral chromatism and the outer spectra are much more distorted than the inner one's [2]. Figure 2 shows designed wedged double Wollaston prism, Figure 3 shows its holder, and Figure 4 simulates the held WeDoWo. Figure 5 demonstrates the Wollaston briefringent sample with $CaCO_3$ material. These prisms were produced in St. Petersburg according to our design.

5. CONCLUSION

Designed optical polarimeter integrated to TUBITAK National Observatory TFOSC System will allow polarimetric observations with RTT150 telescope. Optical polarimeter design capability of Turkish scientists has increased by this study, and it is expected that there will be new designs for other aims for near future.

After fine tuning of system, it will be used by astronomers to observe asteroids as well as AGN, SN, pulsars, and so on.

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