# Laboratory Calibration of the Polarimetric Assembly of the SCORE/UVCI Sounding Coronagraph

**INAF - Osservatorio Astronomico di Torino**

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**ACHRONIM LIST**

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| KPOL | K-Corona Polarimeter |
| LCVR | Liquid Crystal Variable Retarder |
| SCORE | Sounding-rocket Coronagraphic Experiment |
| UVCI | Ultra violet and Visible Coronographic Imager |

# 1. INTRODUCTION

This report describes the calibration activity of the flight model polarimeter KPol of the SCORE/UVCI sounding rocket coronagraph, carried on in OATo laboratories in the period October-December 2007. The results are shown and shortly discussed. The KPol polarimeter assembly is based on a Liquid Crystal Variable Retardance plate, LCVR, in which the retardance is modified by varying an applied voltage. A fixed achromatic Quarter Wave plate is mounted with its fast axis forming a 45[deg] angle with the LCVR fast axis, in a rotator configuration: the polarization axis of the incoming linearly polarized coronal radiation is rotated by half of the LCVR retardance. After that, a fixed Linear Polarizer acts as an analyzer. A more detailed description of the SCORE/UVCI polarimeter can be found in Fineschi *et al.* (2005). The main purpose of the calibration activity is to characterize the polarimeter response, i.e. the rotation angle, at different voltages and wavelengths.

# 2. LABORATORY SETUP FOR KPOL CALIBRATION

The laboratory setup consists of a halogen light source and a monochromator, selecting the wavelength of the output radiation in a band of about 23[A], which goes into a box ensuring the light tightness and containing the KPol polarimetric components. Inside the box a linear polarizer defines the polarization axis of the input radiation, which is then rotated by a half wave plate, in order to obtain a modulation curve, after passing through the KPol and a linear polarizer acting as an analizer. Owing to the low light levels a PMT has been used as a detector. The stability of the source has been monitored by a second detection channel, in which a photodiode is fed by a beam splitter put after the input linear polarizer.

# 3.MUELLER MATRIX DESCRIPTION

A generic polarized radiation can be described with its Stokes vector:

$$S=\begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix}$$

where:

I = total intensity

Q = difference between the horizontal and vertical linearly polarized components

U = difference between the linearly polarized components oriented at ±45°

V = difference between the right and left circularly polarized components.

Given an input Stokes vector, describing the input linearly polarized radiation with orientation $\phi_0$

$$S_{in}=\begin{pmatrix} I_{in} & Q_{in} & U_{in} & 0 \end{pmatrix}=I_{in}\begin{pmatrix} 1 & \cos(2\varphi_0) & \sin(2\varphi_0) & 0 \end{pmatrix}$$

the action of the polarimeter and the laboratory setup can be described by using the Mueller matrix formalism as follows:

$$S_{out}(\lambda)=P\times L(\delta,\lambda)\times Q\times S_{in}$$

with $P$, $L$ and $Q$ describing the Linear Polarizer analyzer, the LCVR plate, the Quarter Wave respectively. The Half Wave plate rotates the polarization axis of the radiation coming from the input Liner Polarizer, which defines the setup reference direction, so giving the initial phase $\phi_0$ of the vector $S_{in}$ .

The Linear Polarizer Mueller matrix is:

$$P=\frac{1}{2}\begin{pmatrix}1 & 1 & 0 & 0\\ 1 & 1 & 0 & 0\\ 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0\end{pmatrix}$$

The Mueller matrix for a generic plate with retardance $\delta$ and fast axis orientation $\phi$, is:

$$M=\begin{pmatrix}1 & 0 & 0 & 0\\ 0 & C_2^2+S_2^2\cos\delta & S_2C_2(1-\cos\delta) & -S_2\sin\delta\\ 0 & S_2C_2(1-\cos\delta) & S_2^2+C_2^2\cos\delta & C_2\sin\delta\\ 0 & S_2\sin\delta & -C_2\sin\delta & \cos\delta\end{pmatrix}$$

where

$$S_2=\sin(2\phi) \qquad C_2=\cos(2\phi)$$

The LCVR, with fast axis orientation $\phi$=–45[deg] with respect to the reference direction (we assume that the angle is positive counter clock wise looking towards the light source) has:

$$S_2=-1\ ,\quad C_2=0$$

while the Quarter Wave plate with fast axis at 0[deg]

$$S_2=0,\quad C_2=1\ ,\qquad \sin\delta=1,\qquad \cos\delta=0$$

Hence

$$Q=\begin{pmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 1\\ 0 & 0 & -1 & 0\end{pmatrix},\qquad L(\delta,\lambda)=\begin{pmatrix}1 & 0 & 0 & 0\\ 0 & \cos\delta_\lambda & 0 & \sin\delta_\lambda\\ 0 & 0 & 1 & 0\\ 0 & -\sin\delta_\lambda & 0 & \cos\delta_\lambda\end{pmatrix}$$

The output Stokes vector is given by:

$$S_{out}(\lambda)=\frac{1}{2}I_{in}\begin{pmatrix}1 & 1 & 0 & 0\\ 1 & 1 & 0 & 0\\ 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0\end{pmatrix}\times\begin{pmatrix}1 & 0 & 0 & 0\\ 0 & \cos\delta_\lambda & 0 & \sin\delta_\lambda\\ 0 & 0 & 1 & 0\\ 0 & -\sin\delta_\lambda & 0 & \cos\delta_\lambda\end{pmatrix}\times\begin{pmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 1\\ 0 & 0 & -1 & 0\end{pmatrix}\times\begin{pmatrix}1\\ \cos(2\varphi_0)\\ \sin(2\varphi_0)\\ 0\end{pmatrix}$$

$$S_{out}(\lambda)=\frac{1}{2}I_{in}\begin{pmatrix}1+\cos(2\varphi_0)\cos\delta_\lambda-\sin(2\varphi_0)\sin\delta_\lambda\\ 1+\cos(2\varphi_0)\cos\delta_\lambda-\sin(2\varphi_0)\sin\delta_\lambda\\ 0\\ 0\end{pmatrix}$$

The measured signal at the detector is then:

$$I_{out}(\lambda)=\frac{1}{2}I_{in}\{1+\cos[2(\varphi_0+\rho_\lambda)]\}$$

where $\rho_\lambda=1/2\delta_\lambda$ is the rotation angle of the polarized radiation after passing through the polarimeter. The KPol rotation angle $\rho_\lambda$ for different applied voltages and wavelengths is obtained with a least square fit of the modulation curves with the function $I_{out}(\lambda)$ .

## 4. DATA AND RESULTS

The data have been acquired according to the following scheme. After selecting a wavelength and a voltage, intensity measurements have taken for different polarization axis directions, by rotating the Half Wave plate, so obtaining a modulation curve. The Half Wave position angles are:

0, 10, 20, 30, 40, 43, 45, 47, 50, 60, 70, 80, 87, 90, 93, 100, 110, 120, 130, 133, 135, 137, 140, 150, 160, 170, 178, 180[deg]

The LCVR voltages have been selected to cover the entire operating range of the plate (0-10000[mV]), trying to better resolve the interval with maximum dynamics of retardance variation (2000-6000[mV]):

0, 1000, 2000, 2500, 2700, 3000, 3500, 4000, 4500, 5000, 5400, 6000, 8000,10000[mV]

The polarimeter KPol operates in the visible band, and the wavelengths at which characterize the polarimeter have been selected as follows:

450, 500, 530, 550, 570, 600[nm].

Measurements have been taken at the monochromator zero order, to estimate the loss of contrast in the modulation curves due to the LCVR chromaticity.

**Rotation curve at 450[nm]**

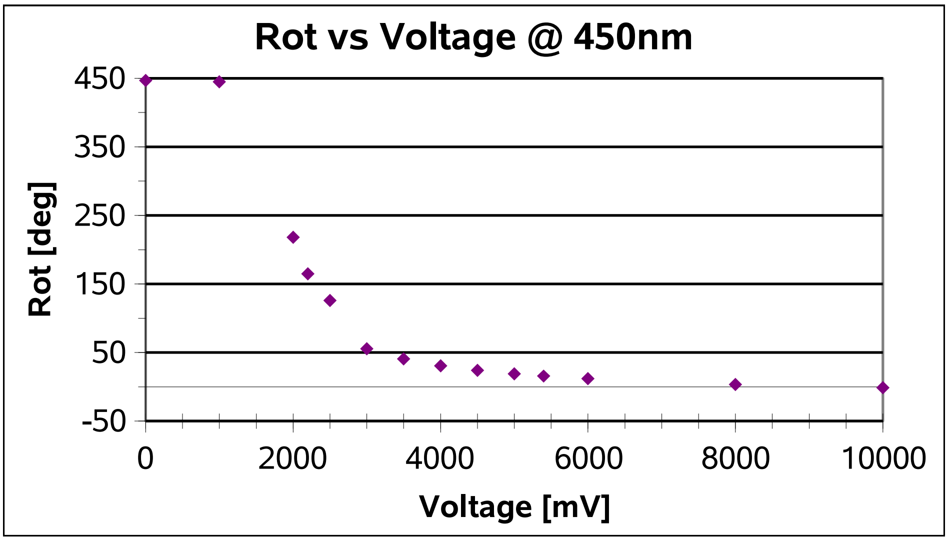


**Figura 1**

**Rotation curve at 500[nm]**

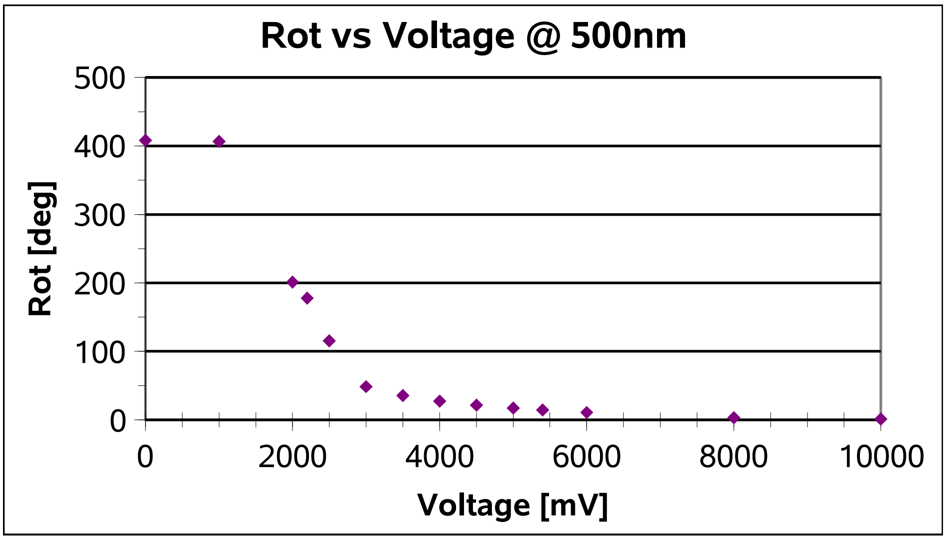


Figura 2

**Rotation curve at 530[nm]**

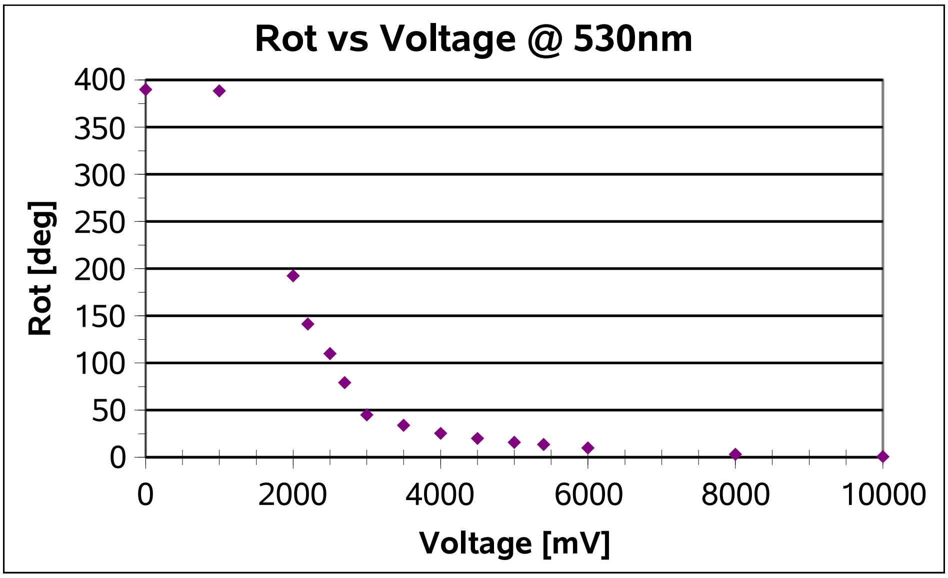


Figura 3

**Rotation curve at 550[nm]**

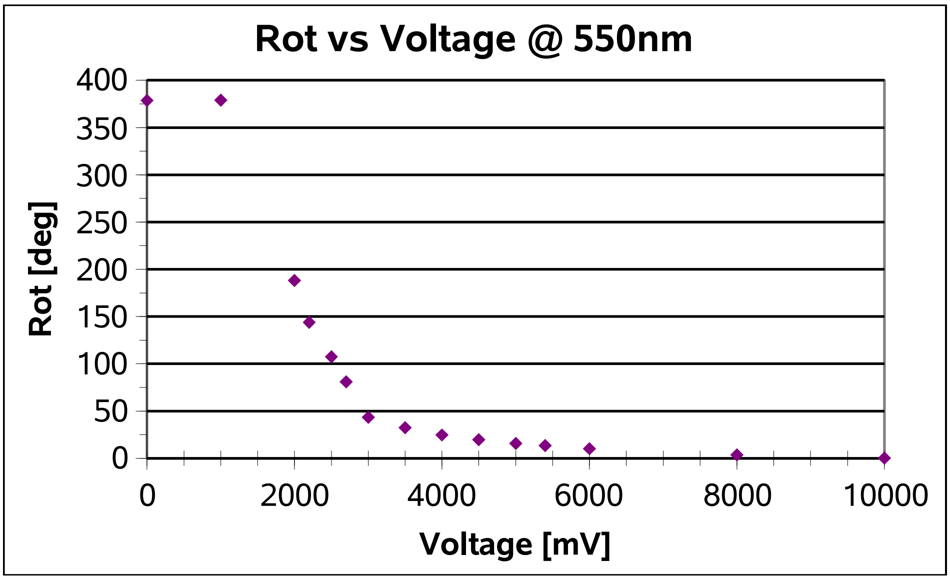


Figura 4

**Rotation curve at 570[nm]**

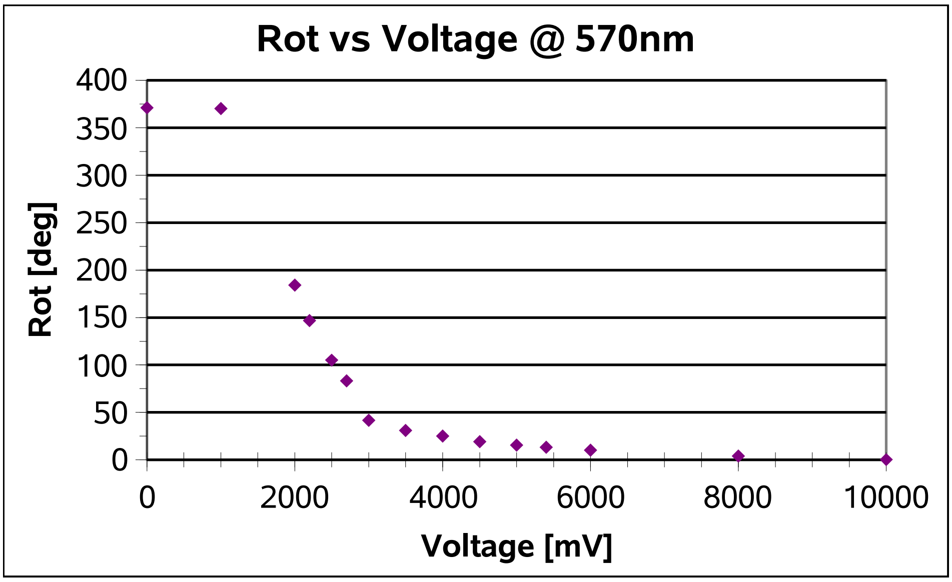


Figura 5

**Rotation curve at 600[nm]**

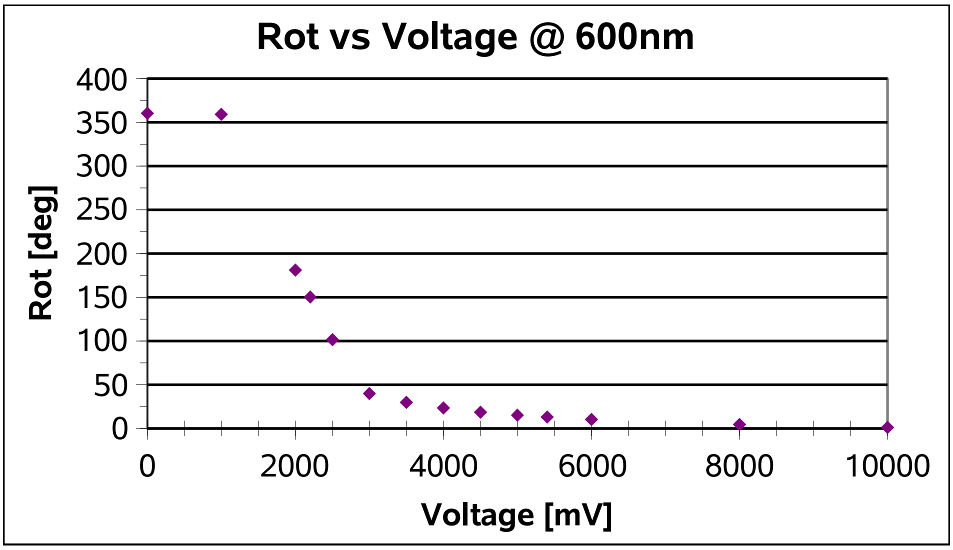


Figura 6

**Rotation curve in band 450-600[nm]**

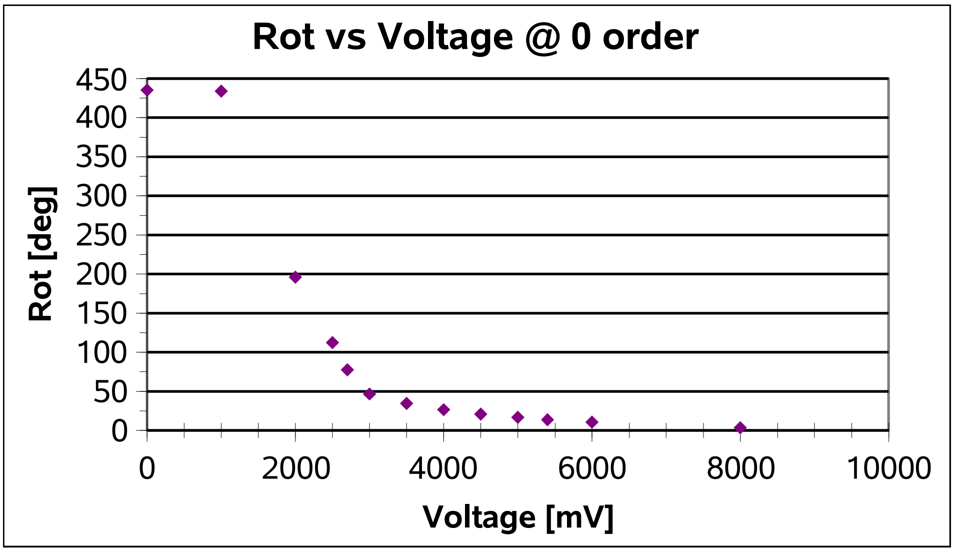


Figura 7

**Summary of data**

In the following Figure 8 results are collected together, in order to put in evidence the voltage interval in which the KPol gives the maximum dynamics, and the different rotation we get for a fixed plate voltage at different wavelengths. After a short plateau between 0 and 1000[mV], the rotation steeply decreases, reaching an asymptotic regime, starting from about 5000[mV]. The strongest chromaticity of the KPol plate is in the low voltages regime, from about 100[deg] @ 0[mV] to about 60[deg] @ 2000[mV] of rotation difference at different wavelengths, at a fixed voltage. Between 2000[mV] and 5000[V] the chromaticity is less severe and the variation of the rotation we get is about 180[deg], that is a reasonable operation interval, the measurement of the Q and U stokes parameters requiring determinations in an interval 135[deg] wide.

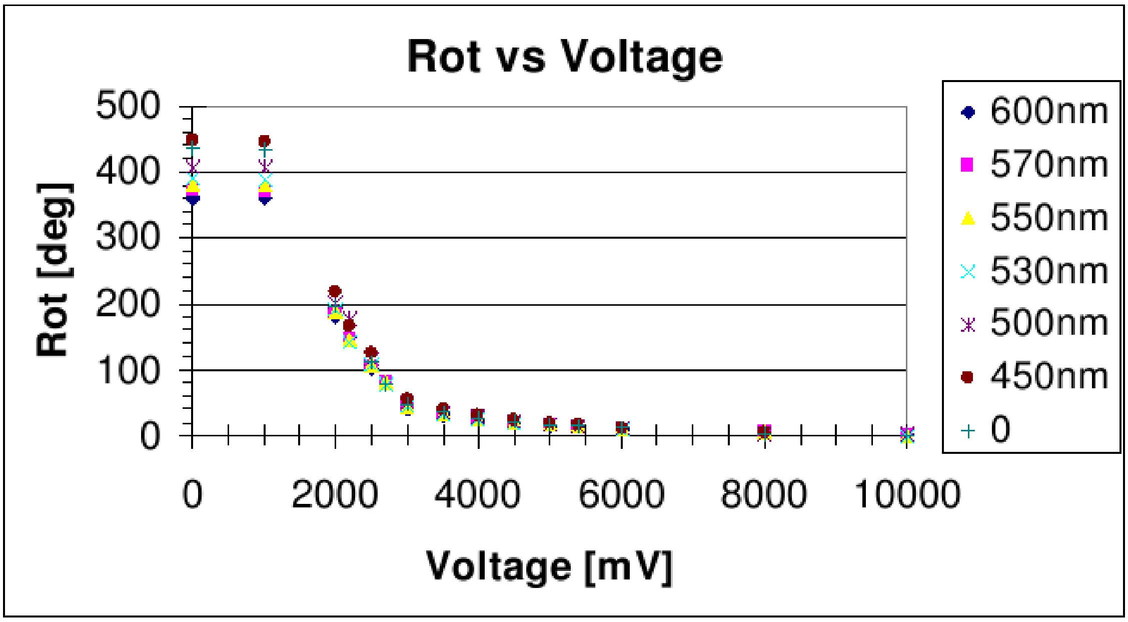


**Figura 8**

## BIBLIOGRAPHY

Fineschi S., Zangrilli L., Rossi G., *et al*., 2005, *KPol: liquid crystal polarimeter for K-corona observations from the SCORE coronagraph*, Solar Physics and Space Weather Instrumentation. Edited by Fineschi, Silvano; Viereck, Rodney A. Proceedings of the SPIE, Volume 5901, pp. 389-399.