We present the optical polarization of the Crab pulsar and its environment based on ~14 hours (selected out of 25 hours) of observations with the high-speed photo-polarimeter OPTIMA at the 2.5 m Nordic Optical Telescope (NOT). Time resolution as short as 10 μsec and high statistics allow the derivation of details in the degree and angle of linear polarization never before resolved. The phase resolved optical polarization shows surprising correlations ("bends") in the degree and angle of polarization with the phase structure at radio wavelengths. This subtle connection between presumed coherent and non-coherent emissions, which have also been detected between the giant radio pulses and the optical intensity of Crab [6], will require more elaborate theoretical models than those currently available in the literature (e.g. [1,2,6,7]). The cases of polarized pulsars (and e.g. blazars) show that mapping optical polarization could serve as a tool to identify counterparts for unidentified GLAST sources.

Comparison of the results obtained by Smith et al. 1988 (left) and this work (right). From top to bottom: the intensity, position angle, polarization degree, and the Stokes parameters Q, U plotted as a function of a linear polarized vector diagram as a function of the pulsar phase. There are 250 bins per cycle in both cases, the only difference is that for clarity we show two periods. As a DC component Smith et al. took 50 out of 250 bins, whereas we took only 7% of the rotational period (phase range: 0.78-0.84 indicated by a dashed region).

Polarization characteristics, l and p for both Crab pulsar peaks; left and right column is for the IP and MP, respectively. The upper two rows show the polarization before DC (θ = 118.9°, p=30%) subtraction, the lower two rows after this subtraction. Black dashed lines indicates the optical maximum phases of the peaks, blue dotted line indicates the radio phase. Red dashed horizontal line shows the θ = 118.9°. For clarity the optical light curve of the Crab pulsar is over plotted (black solid-line).

A rotating polarization filter covered the complete aperture and was binned into 180 phase bins (linear polarizers). Data analysis followed the method introduced by [10] using "The Case of n Polarizers".

The optical emission from the Crab pulsar is highly polarised, especially in the bridge and the "off-pulse" phases. The l and p of linear polarization as a function of rotation phase show well determined properties:

a) the polarisation characteristics of both, the MP and the IP, components are very similar;
b) the polarisation degree is minimal at the phases of maximum radio intensity; therefore, it is NOT aligned with the optical peak;
c) there is a well defined bump in polarization degree on the rising flank of MP;
d) there is an indication of such a bump also for IP (especially after the DC subtraction);
e) the polarization angle swings through a large angle in both peaks: after subtraction of an assumed constant polarization component, the angle swing is 130° and 100° for MP and IP, respectively.

Theoretical models, like the two-foil caustic model [1] or the striped pulsar wind model [6] are able to reproduce (qualitatively, at least) some of these properties, e.g. (a) and (e). However, full explanation of the properties (a) to (e) will require more detailed models to be developed. Detailed presentation and discussion of these results will be given elsewhere (Słówikowska et al. in preparation).

Phase averaged polarization of optical Pulses:
Pulsars and other high-energy sources are expected to show polarization since their emission characteristics are often highly anisotropic. The figure [([11] and Dysk private comm.)shows the phase averaged polarization for a simplified outer gap model [11] for different viewing angles and intrinsic degrees of polarization and the observed polarization of the brightest optical pulsars. Detection of polarized objects in the field of unidentified γ-ray sources could be a valuable tracer to aid identification.

References:
A. Słówikowska thanks Bronislaw Rudak and Janis Dulk for very fruitful discussions. She acknowledges support from the EU grant MTKD-CT-2005 019680 and a DAAD scholarship. We are grateful to Fritz Schrey (MPE) and the NOT team for their help during the observations. NOT is operated jointly by Denmark, Finland, Iceland, Norway, and Sweden in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias.