Analysis of photonic structures in beetles using Mueller-matrix data

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Since one hundred years it is known that some scarab beetles reflect elliptically polarized light as demonstrated by Michelson (Phil. Mag. 21(1911)544) for the beetle *Chrysina resplendens*. The handedness of the polarization is in a majority of cases left-handed but also right-handed polarization has been found. The polarization and color effects are generated in the outer part of the exoskeleton, the so called cuticle. Our objective is here to demonstrate that structural parameters and materials optical functions of these photonic structures can be extracted by advanced modeling of spectral multi-angle Mueller-matrix data recorded from beetle cuticles.

A dual rotating compensator ellipsometer (RC2, J. A. Woollam Co., Inc.) is used to record normalized Mueller-matrix elements m_{ij} (i,j=1..4) in the spectral range 300 – 900 nm at angles of incidence in the range 20-75º. All measurements are performed on the scutellum (a small triangular part on the dorsal side of the beetles) with focusing optics resulting in a spot size of the order of 0.05-0.1 mm. The software CompleteEASE (J. A. Woollam Co., Inc.) is used for regression analysis. Analysis of data measured on *Cetonia aurata* will be presented in detail and data from other beetles in the Cetoniinae and Rutelinae subfamilies will be briefly discussed.

A contour plot of Mueller-matrix data measured on *Cetonia aurata* (insert) is shown below. This beetle has a metallic shine and if illuminated with unpolarized white light it reflects left-handed polarized green light as revealed by the non-zero Mueller-matrix elements m_{14} and m_{41} in the green spectral region for angles of incidence below about 45º. This is detailed in the graph to the right which shows a spectrum for Mueller-matrix element m_{41} at 20º as well as fitted model data. The model used for the chiral nanostructure is based on a twisted lamella structure, also called Bouligand structure. Given the complexity of the nanostructure, an excellent model fit is achieved. The obtained model parameters are the spectral variation of the refractive index of the birefringent lamellas and the pitch. Limitations and development of the model will be discussed as well as its applicability to more complex beetle cuticle structures.

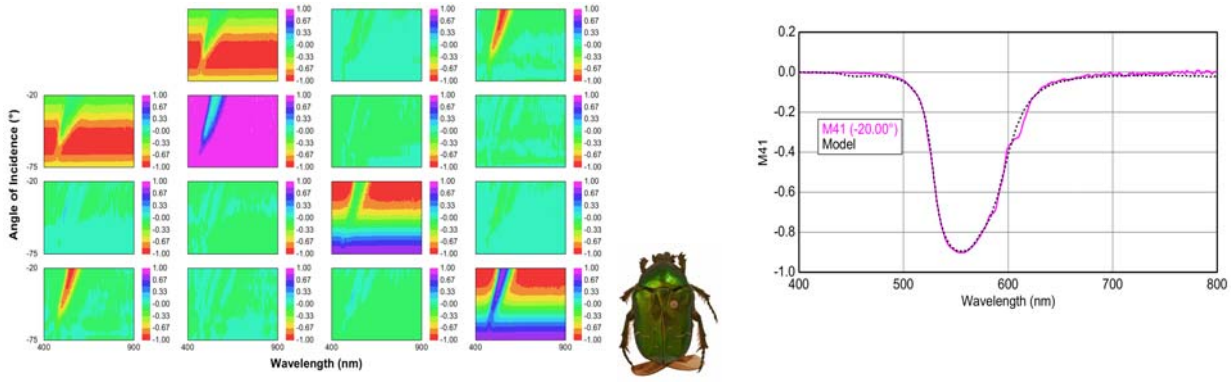

Figure. Left: Mueller-matrix data versus wavelength and angle of incidence on *Cetonia aurata*. Each panel shows m_{ij}, where i and j correspond to the row and column, respectively. Right: Experimental and model-generated m_{41} at an angle of incidence of 20º.

In addition, Mueller-matrix spectra are very rich in information about reflection properties and allow parameterization of polarization parameters of the reflected light, e.g. in terms of azimuth and ellipticity of the polarization ellipse and the degree of polarization (see abstract by Järrendahl).