

APPLICATION OF IMAGING POLARIMETRY IN THE STUDY OF ANIMAL POLARIZATION VISION

Vikings, Zebras, Polarized Light Pollution and Polarization Insect Traps

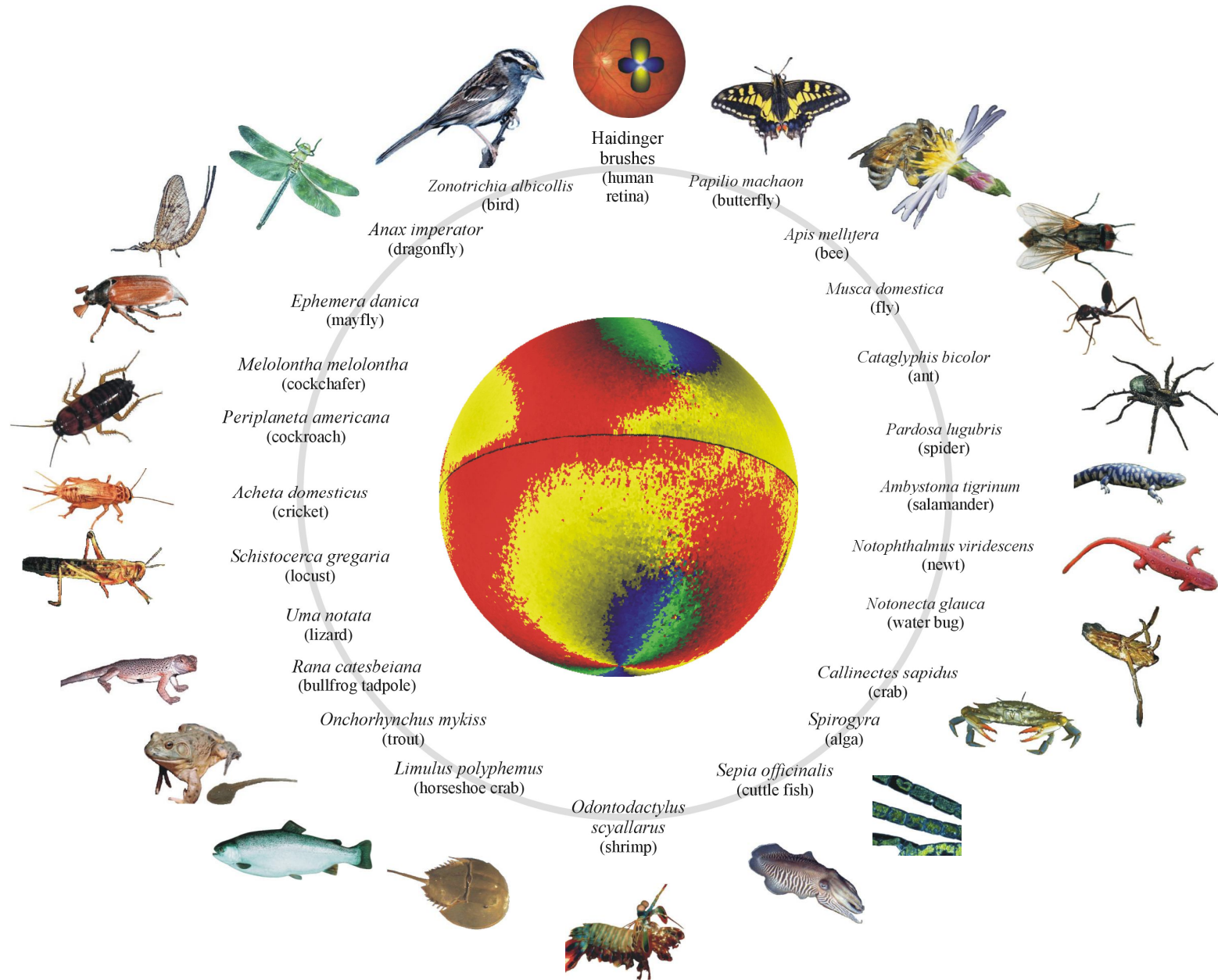
Gábor Horváth

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Department of Biological Physics,
Physical Institute,
Eötvös University, Budapest, Hungary,
gh@arago.elte.hu, <http://arago.elte.hu>

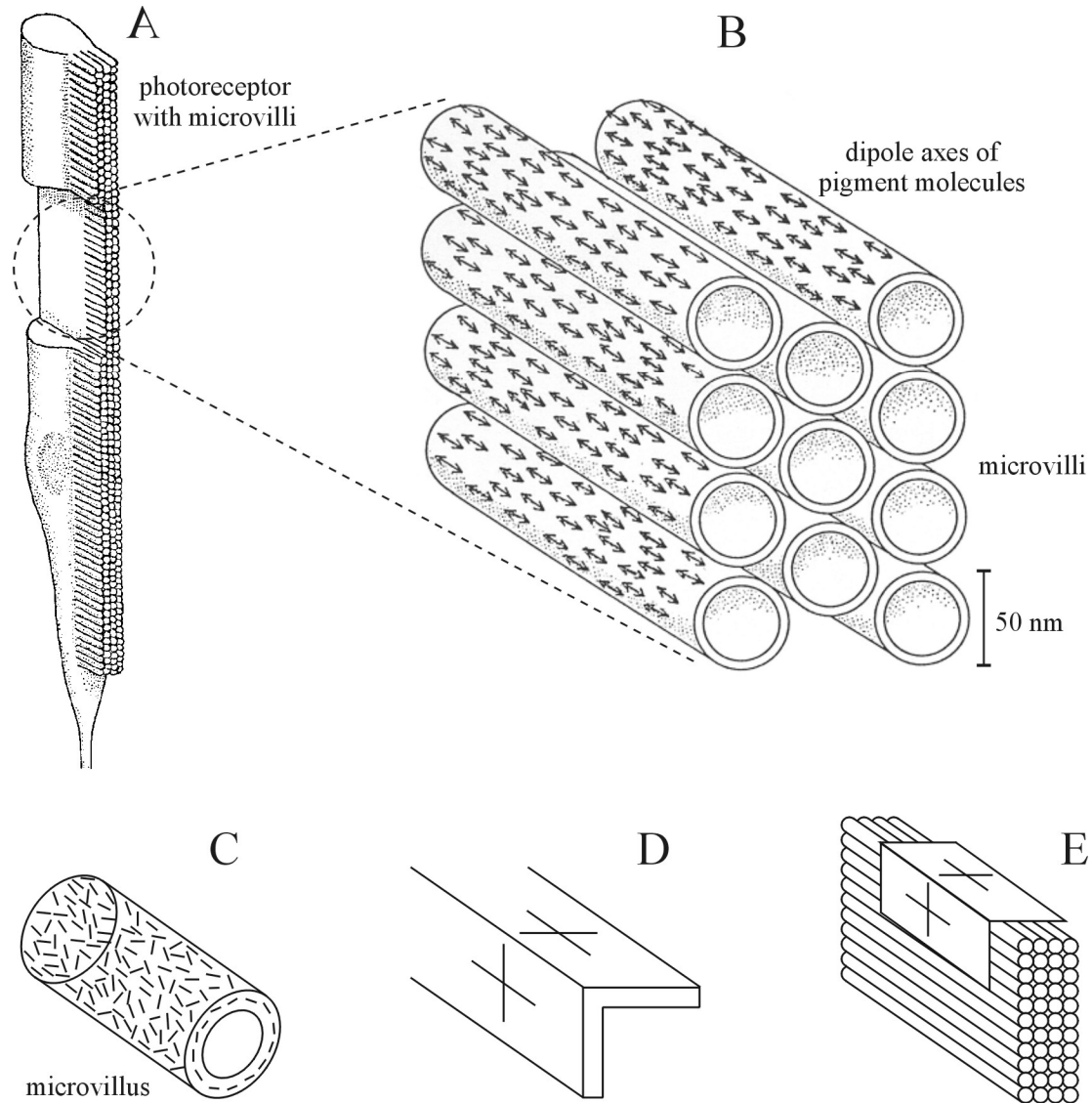


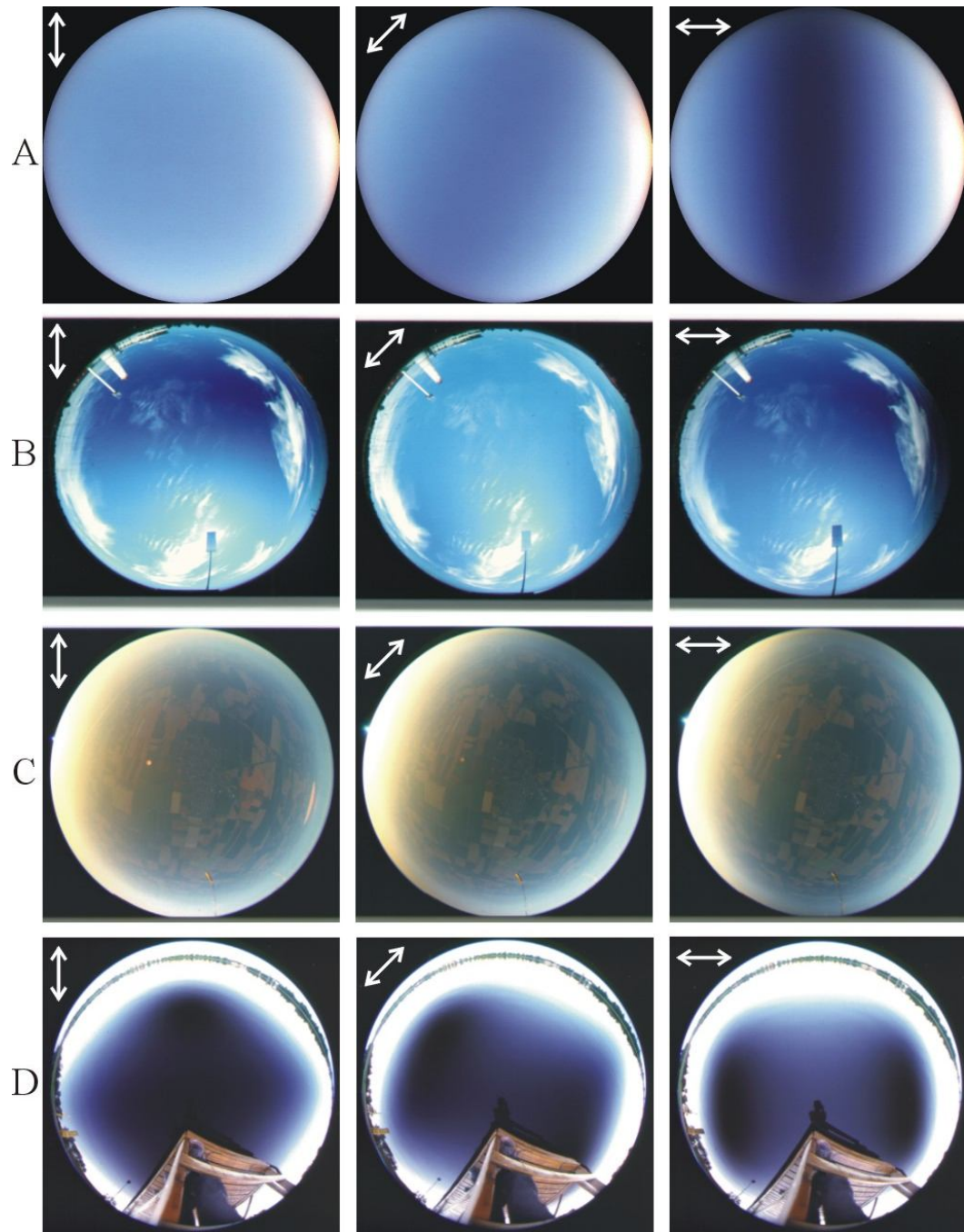
(1) Animal polarization vision and imaging polarimetry

Polarization-sensitive animals



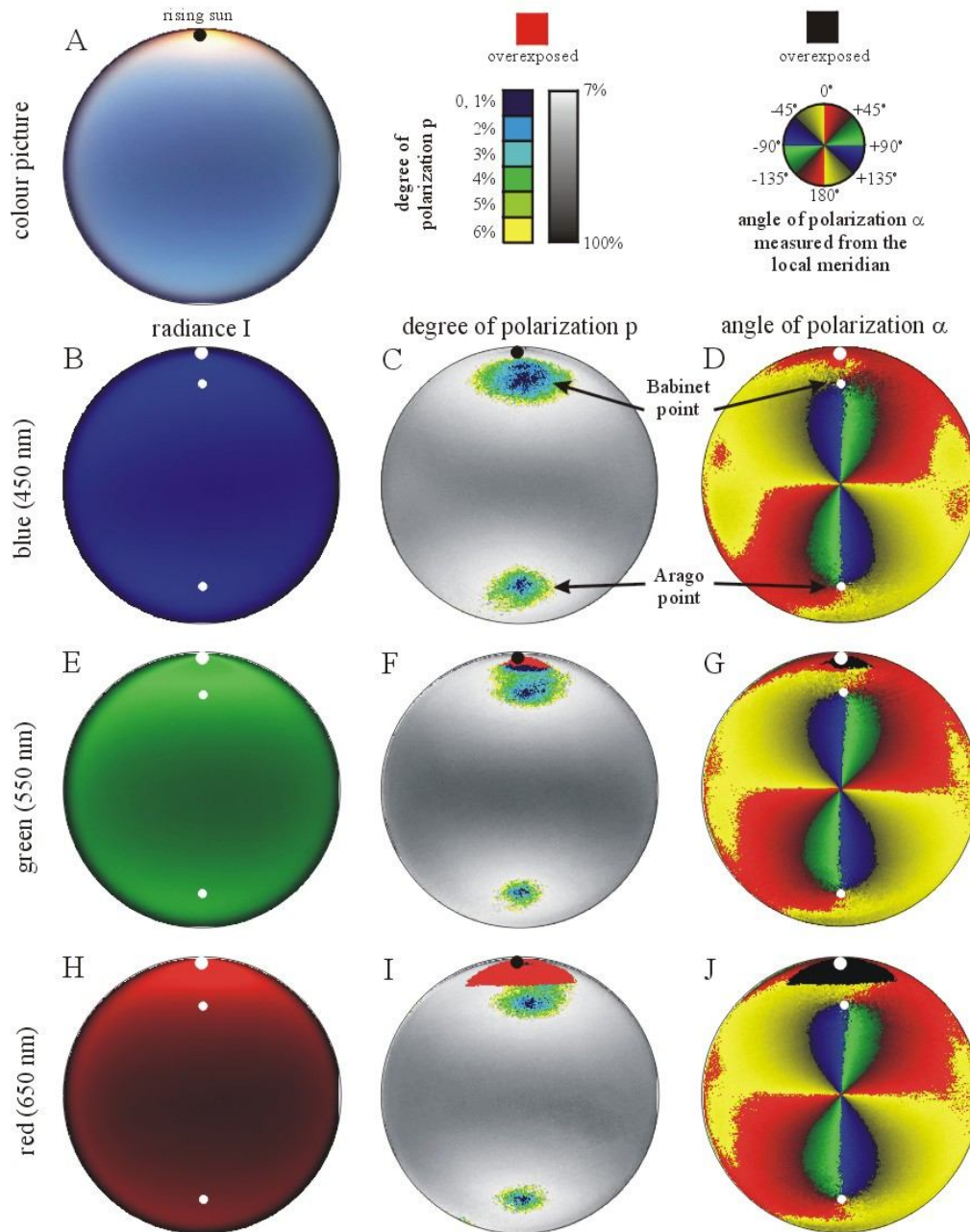
Polarization-sensitive photoreceptors in insect eyes





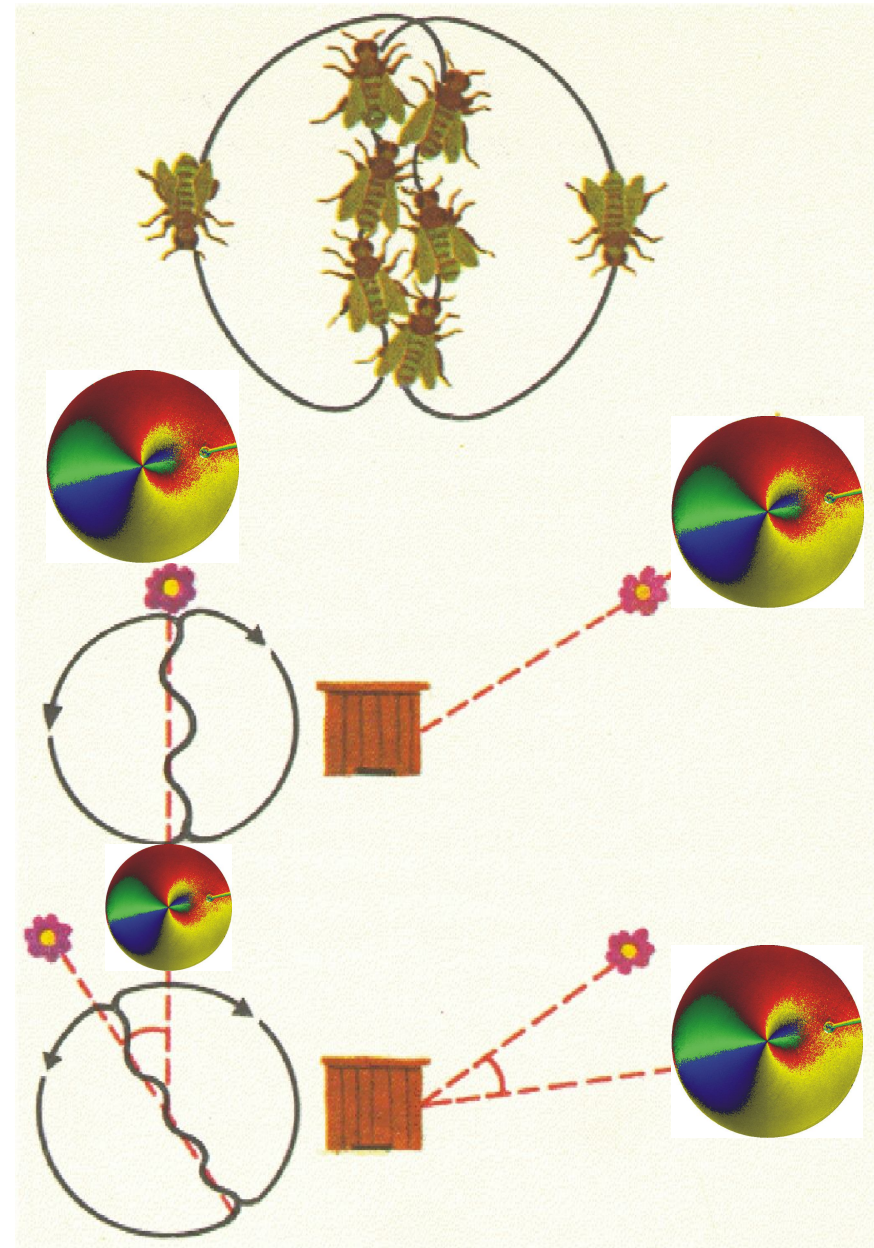
The linearly polarized world around us through a 180° field-of-view fisheye lens

downwelling skylight measured on the ground at sunrise

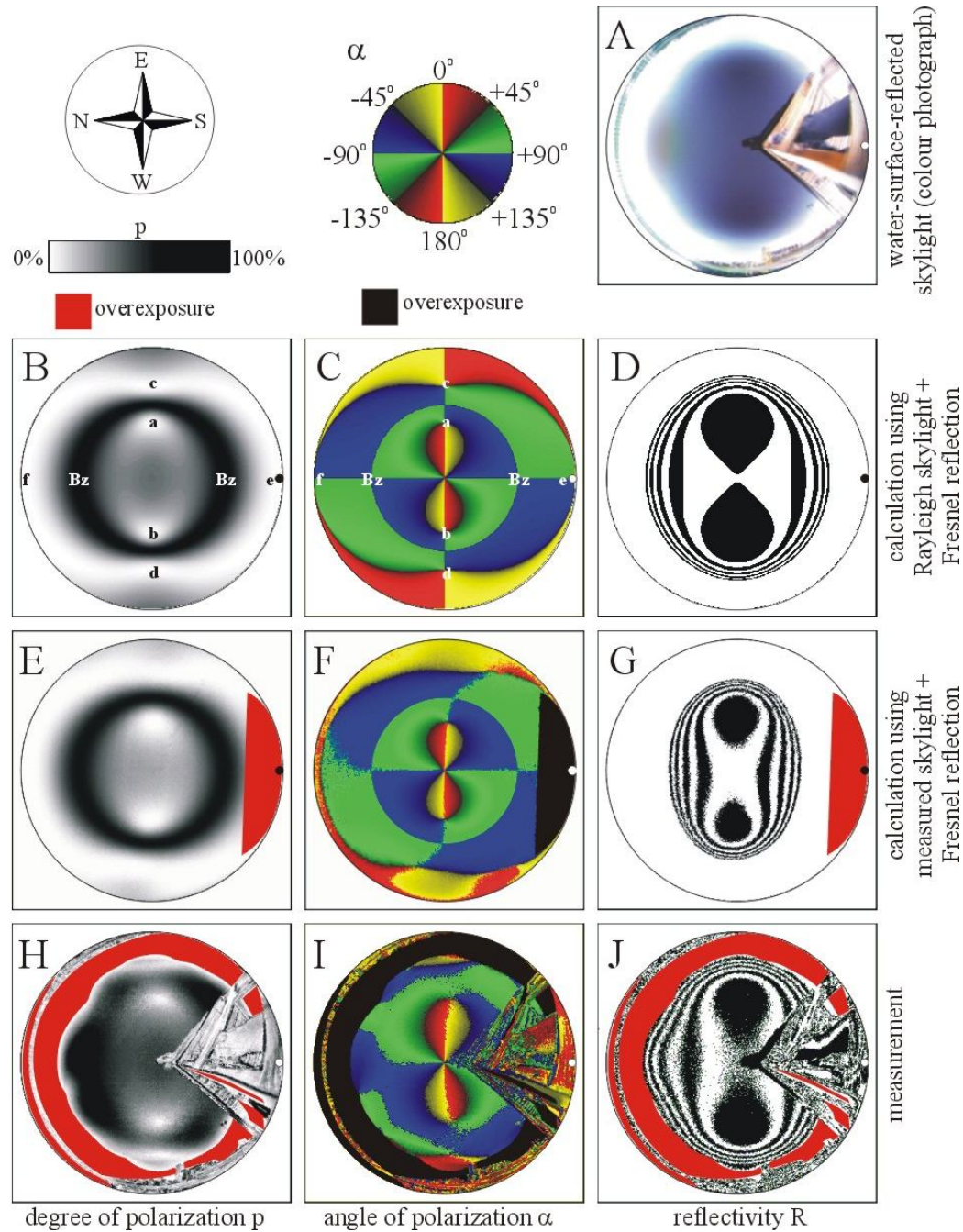


The Arago and Babinet neutral points

Orientation of honeybees (*Apis mellifera*) by sky polarization

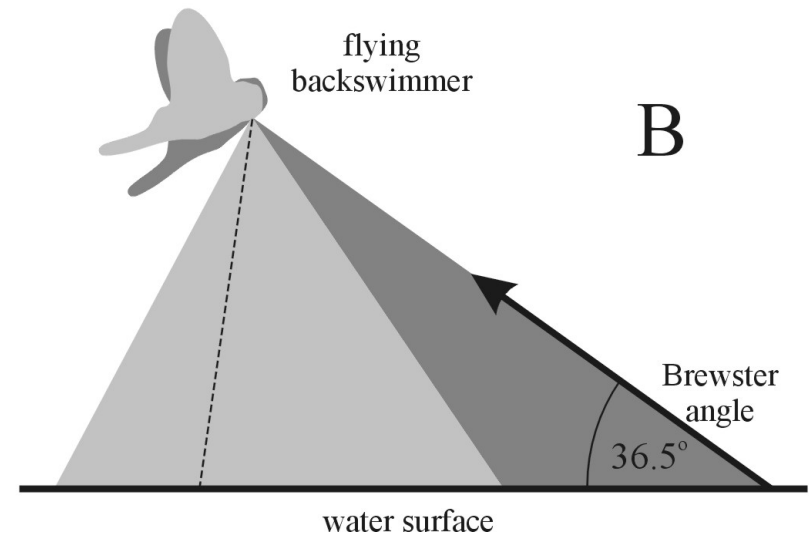
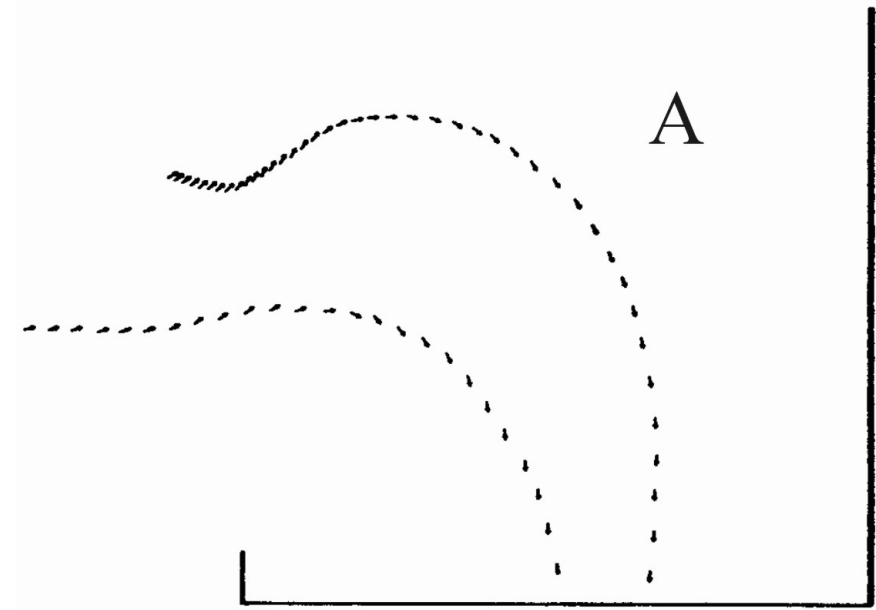


WATER-SURFACE-REFLECTED SKYLIGHT



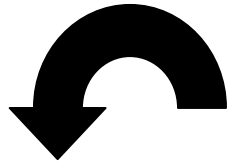
Reflection-polarization patterns of water surfaces

Polarotactic water detection of aquatic insects



Circularly polarizing exocuticle of metallic shiny scarab beetles

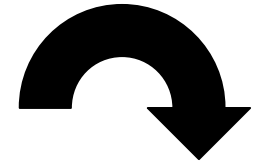
Cetoniischema jousselini



through a left circular polarizer



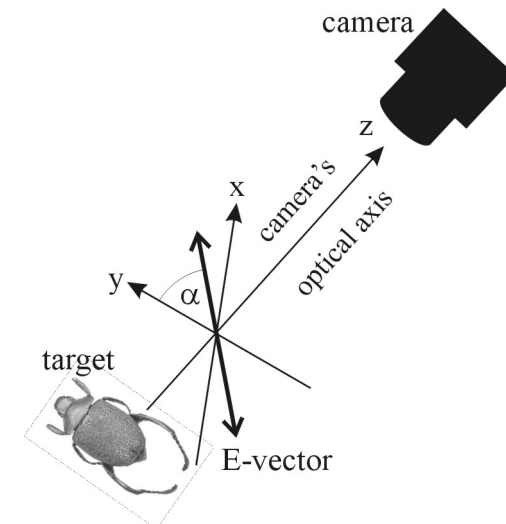
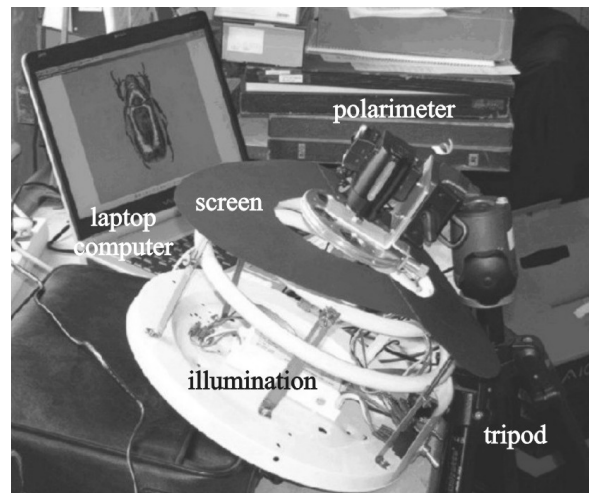
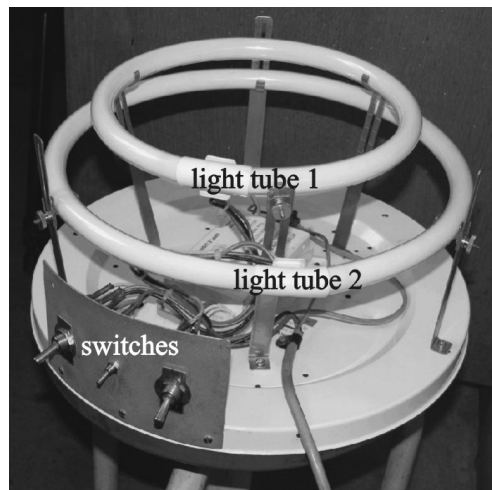
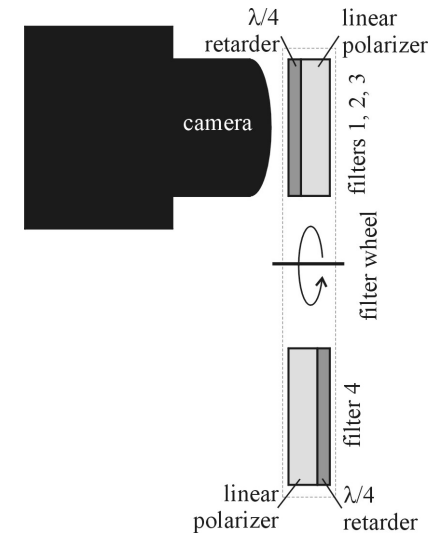
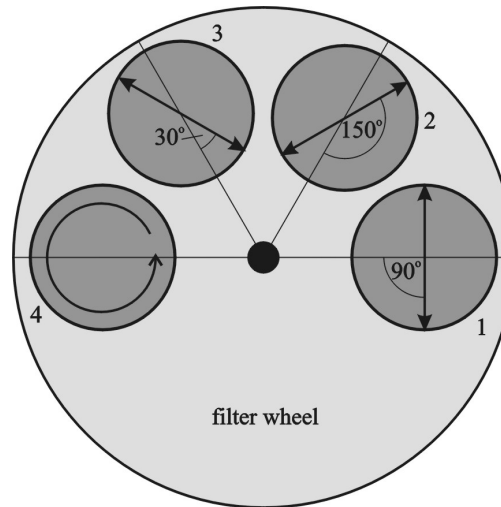
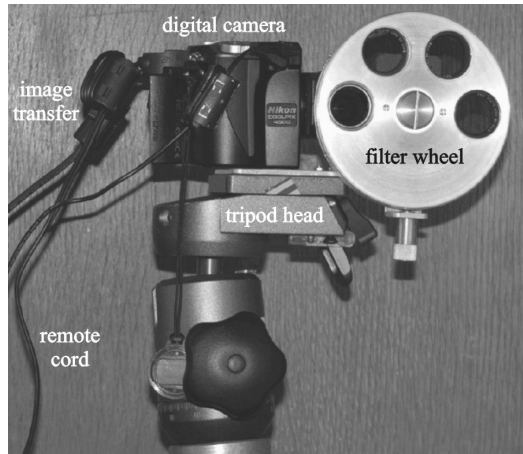
with the naked eye



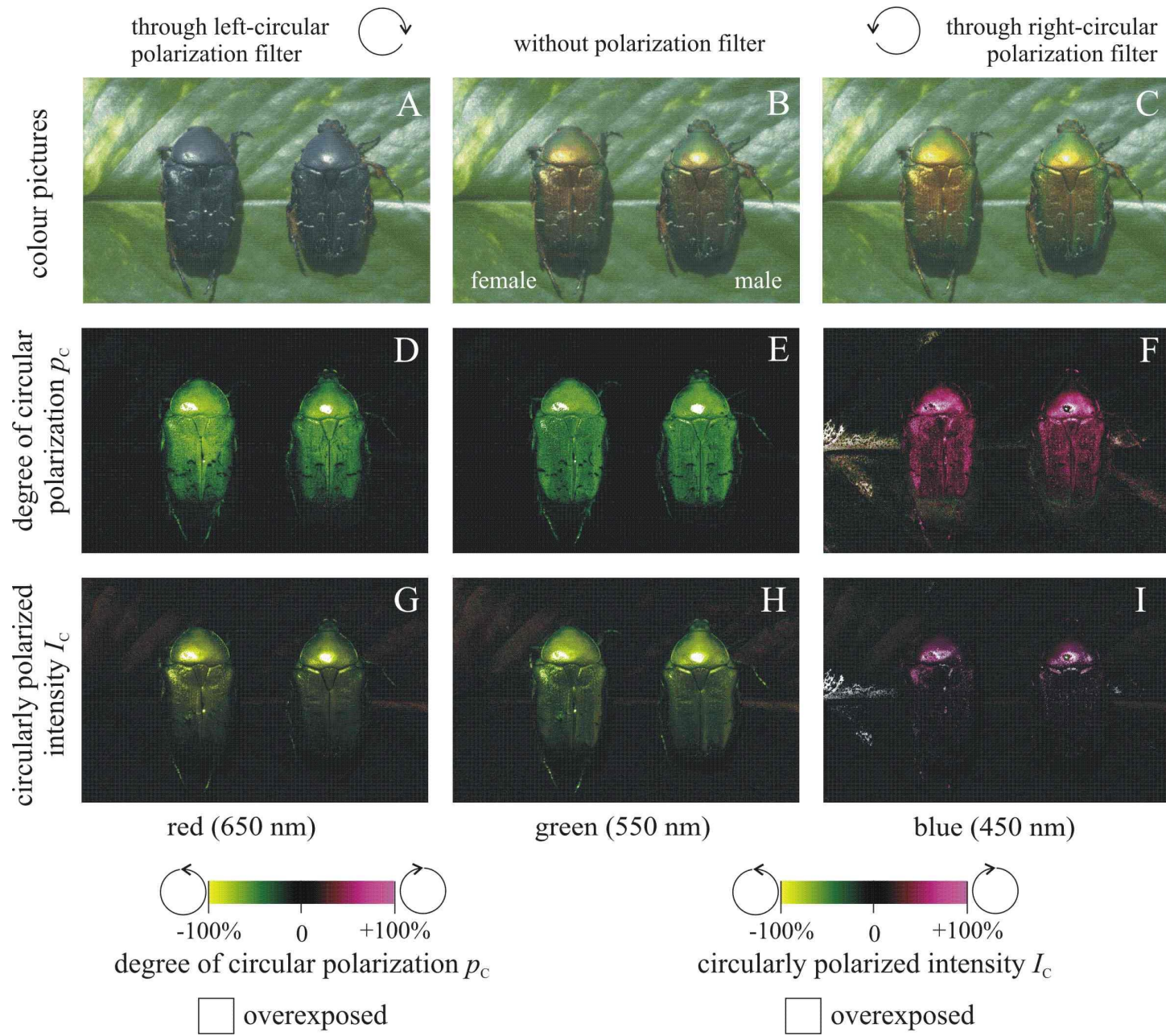
through a right circular polarizer



Circular-linear imaging polarimetry

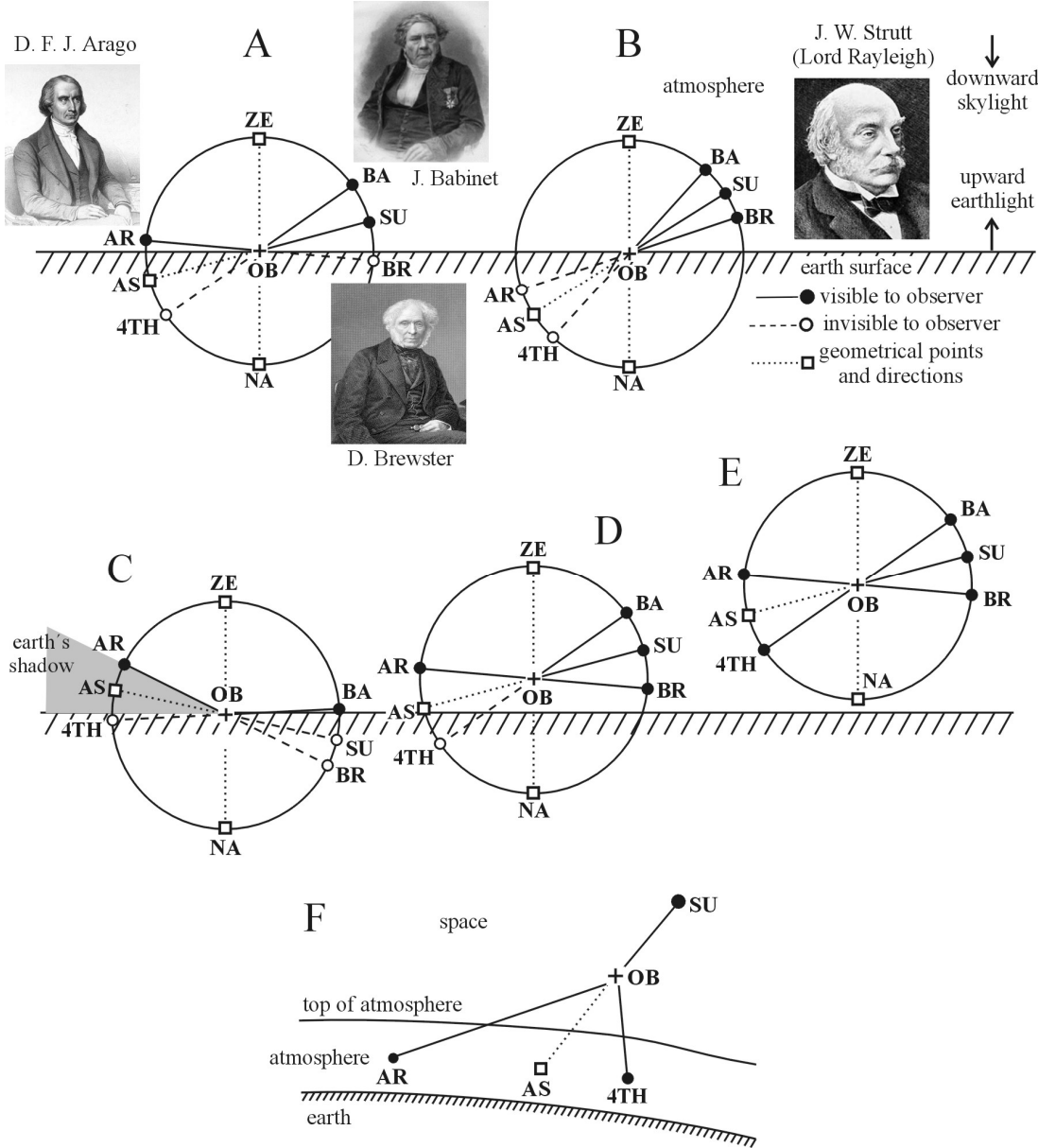


Circular polarization patterns of rose chafers (*Cetonia aurata*)

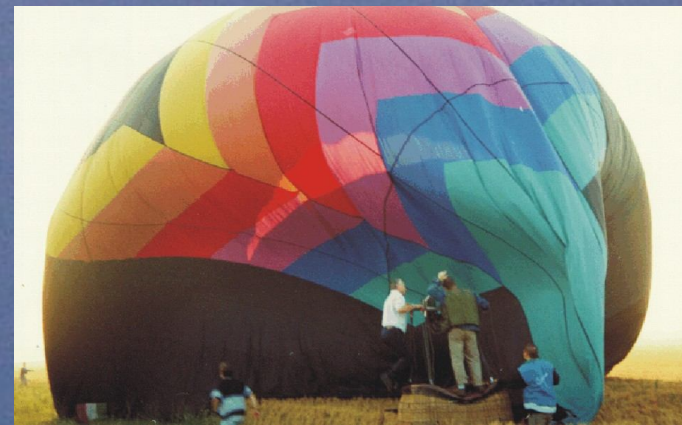
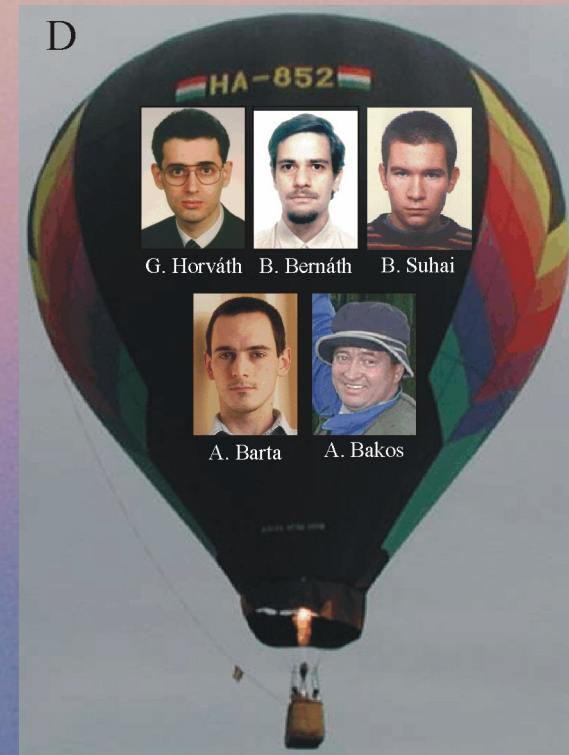


**(2) First observation of the 4th neutral polarization point
in the atmosphere from a hot air balloon**

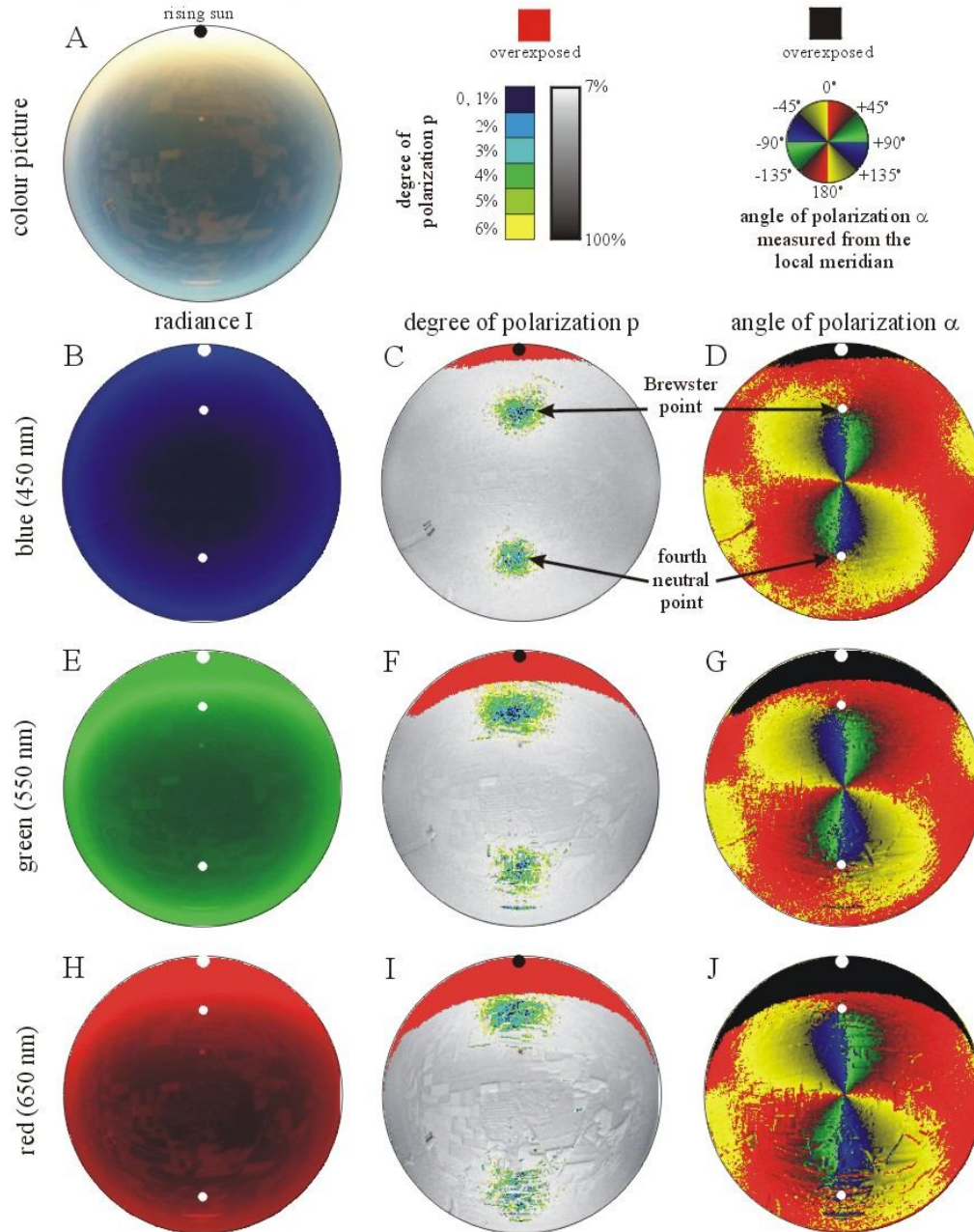
The three neutral points of the sky observable from the ground



Hunting the last (4th) neutral point from a hot air balloon

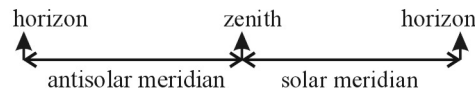
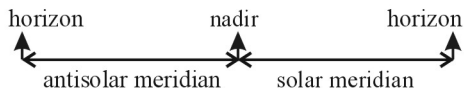
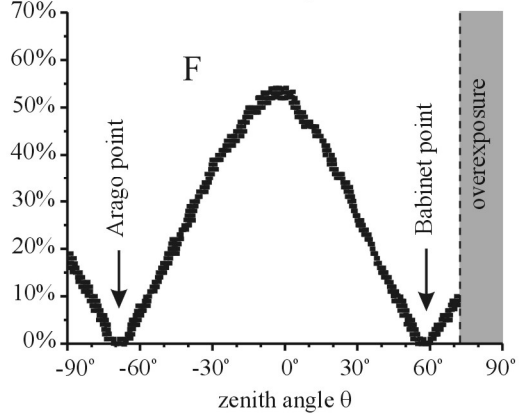
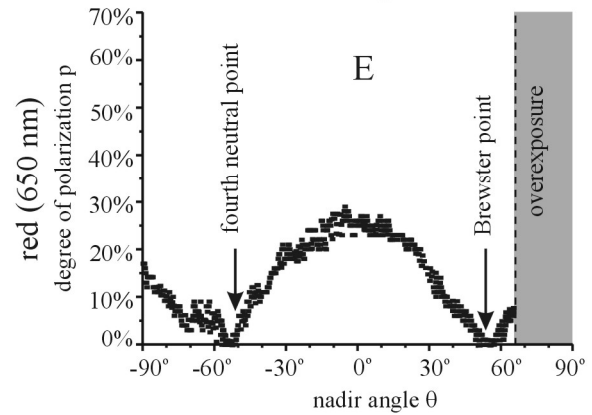
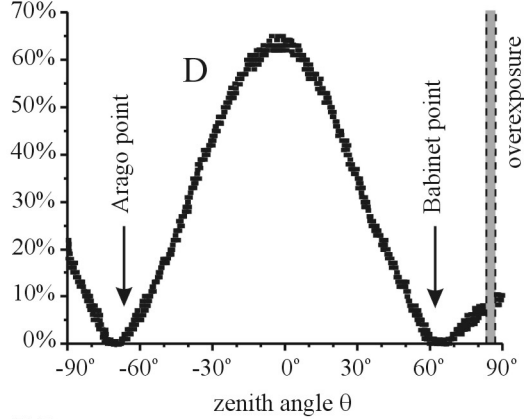
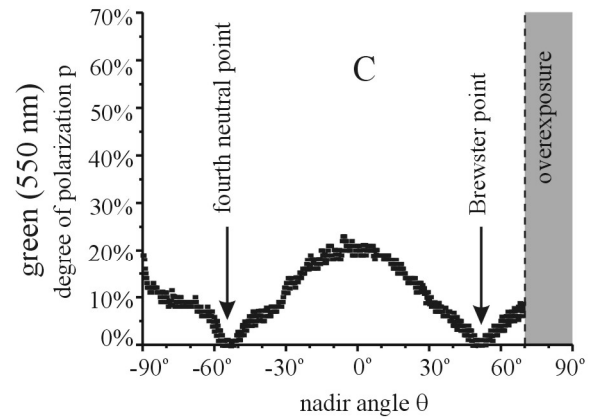
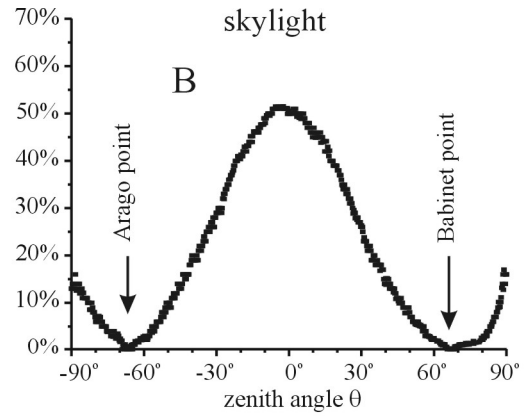
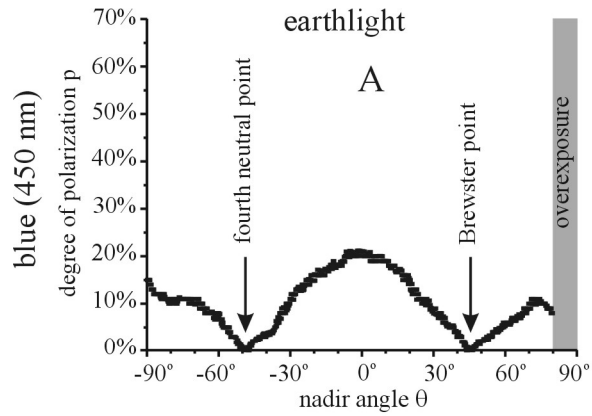


upwelling earthlight measured from balloon at an altitude of 3500 m

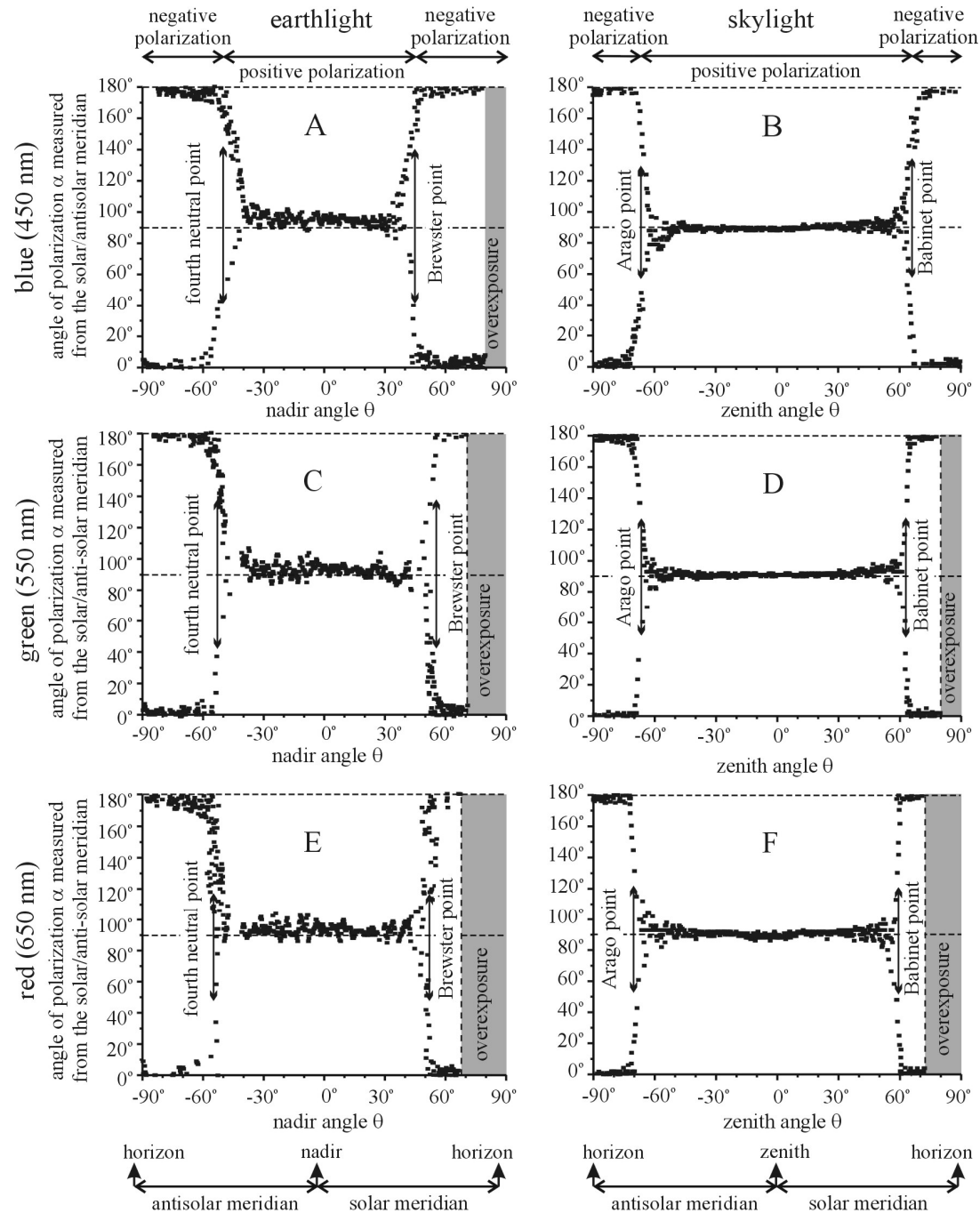


The Brewster and the 4th neutral points

Neutral points in the graphs of the degree of linear polarization of skylight and earthlight

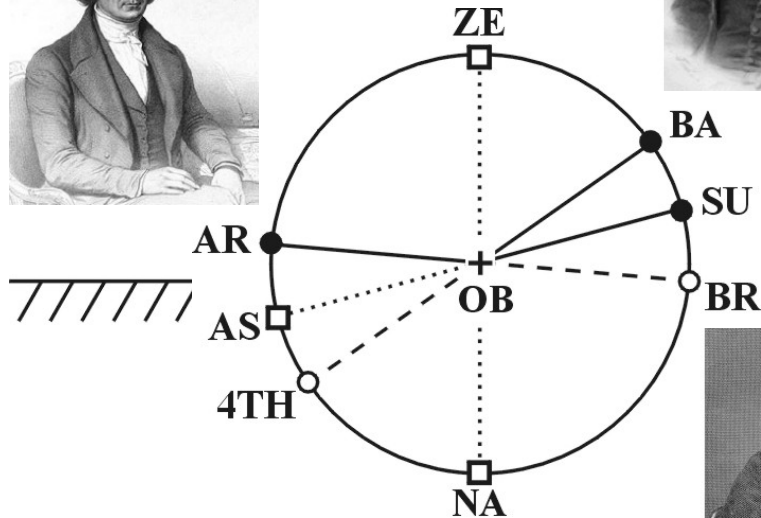


Neutral points in the graphs of the angle of polarization of skylight and earthlight



All four neutral points in the atmosphere

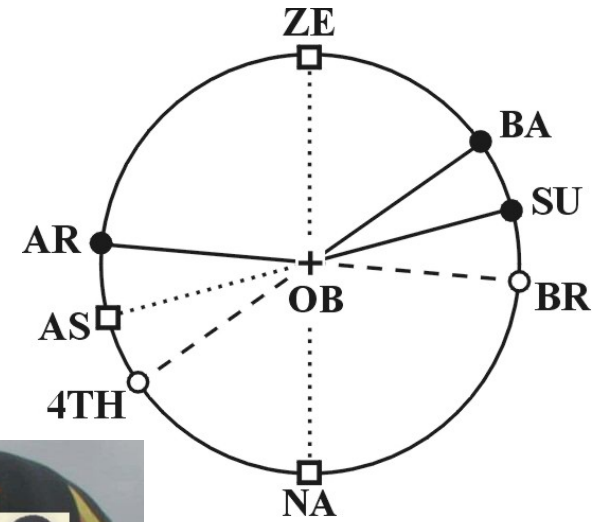
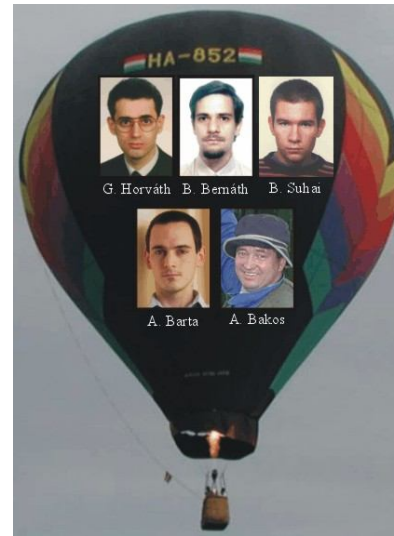
Jean Arago
1809



Jacques Babinet
1840



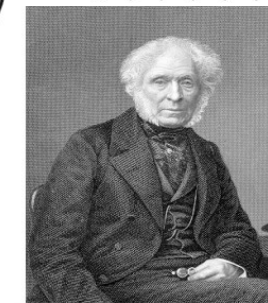
2001



atmosphere

earth surface

- visible to observer
- - - ○ invisible to observer
- □ geometrical points and directions



David Brewster
1842

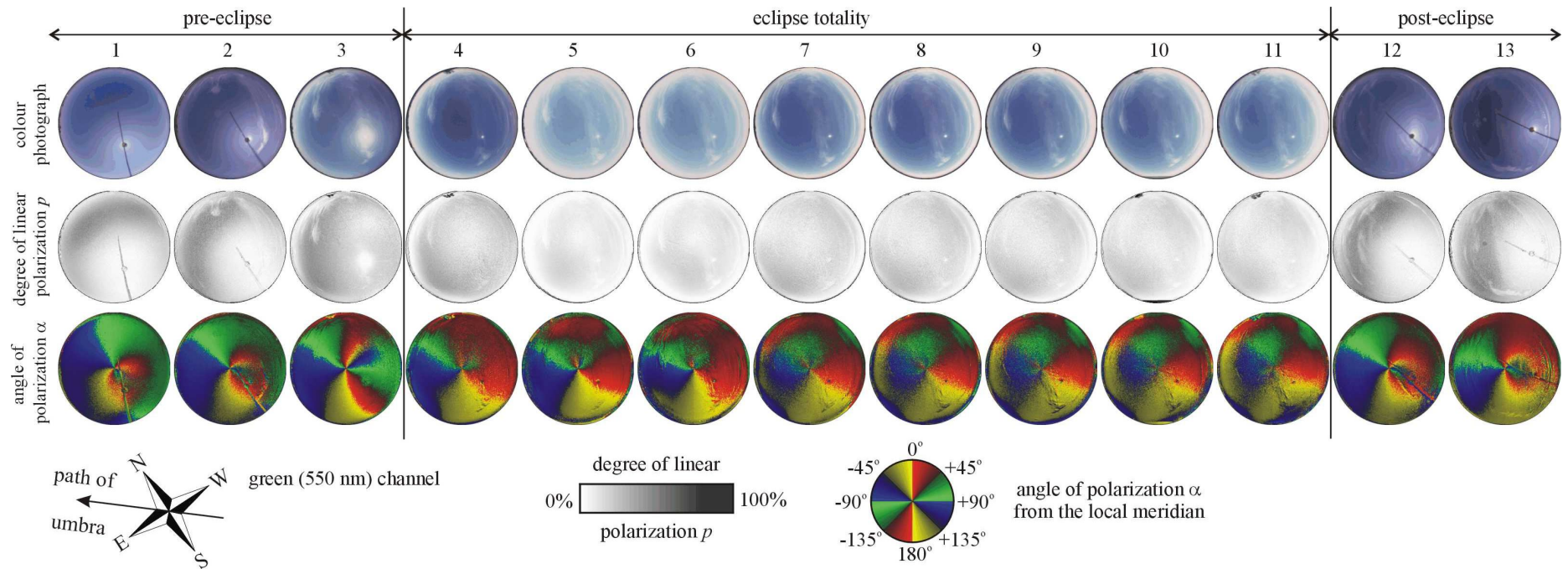
**(3) Spatio-temporal change of the celestial polarization pattern
during total solar eclipses**

Polarized and unpolarized points of the eclipsed sky

Total solar eclipse in Turkey on 29 March 2006



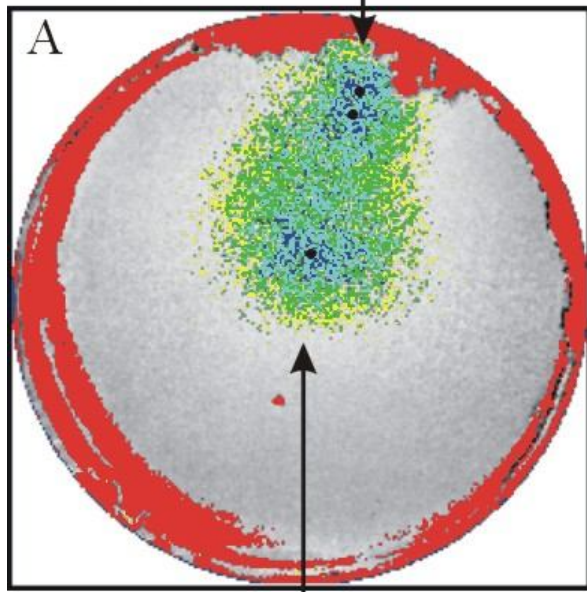
Celestial polarization patterns during a total solar eclipse



Neutral points in the patterns of the degree of polarization of an eclipsed sky

12:51:34 450 nm (blue)

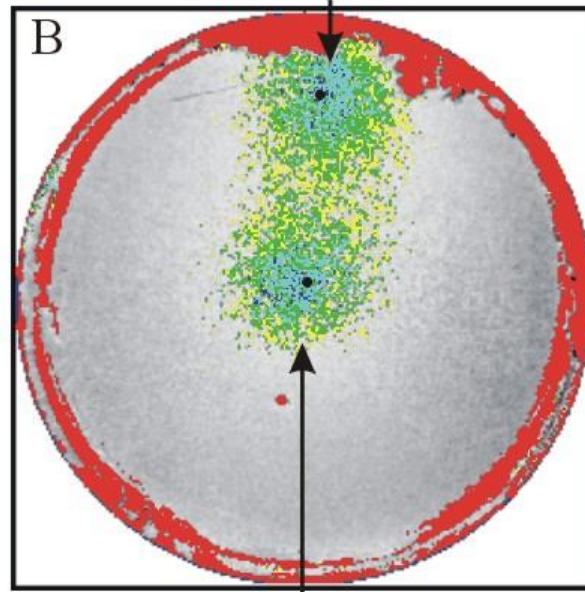
two neutral points N1 of type-1 near the horizon



neutral point N2 of type-2 near the zenith

12:52:00 450 nm (blue)

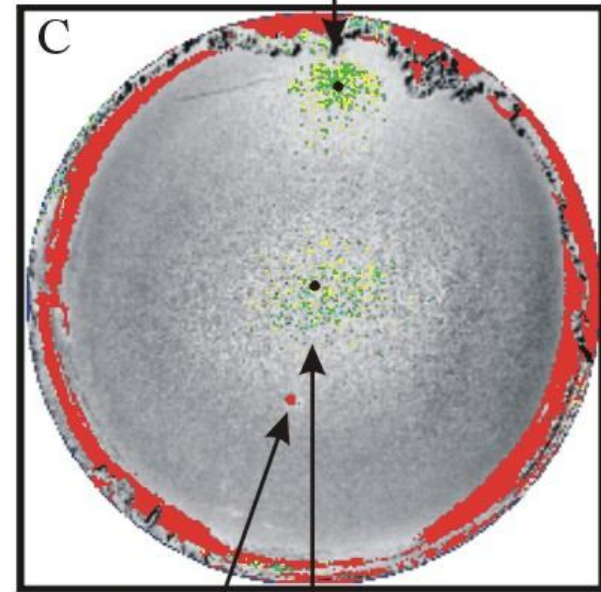
neutral point N3 of type-3 near the horizon



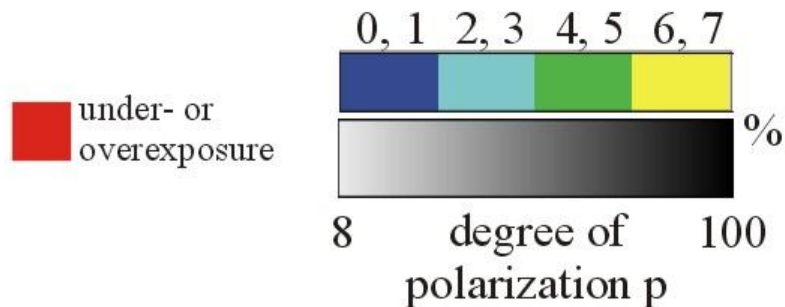
neutral point N2 of type-2 near the zenith

12:52:00 550 nm (green)

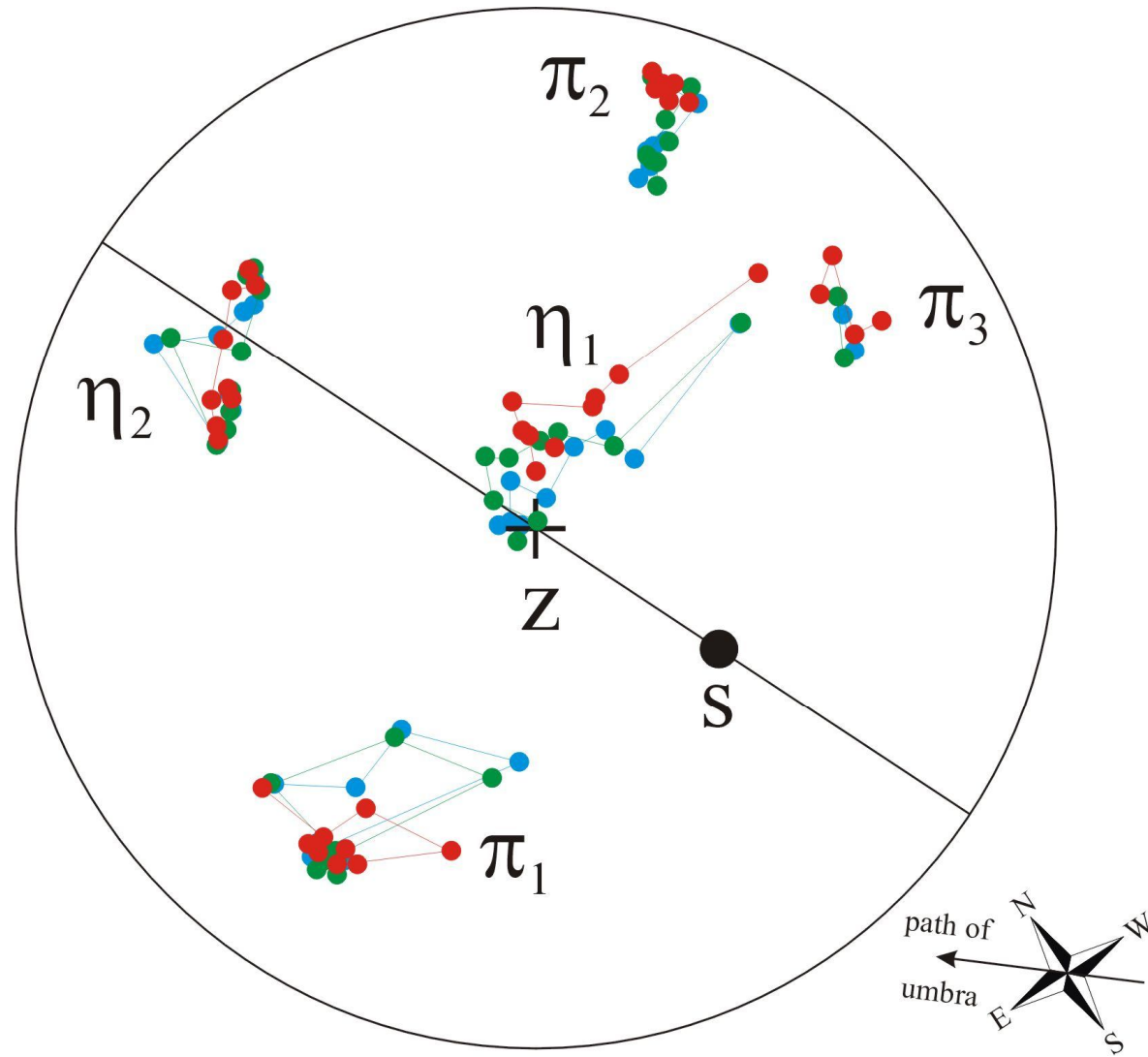
local minimum MH of p near the horizon



eclipsed sun local minimum MZ of p near the zenith

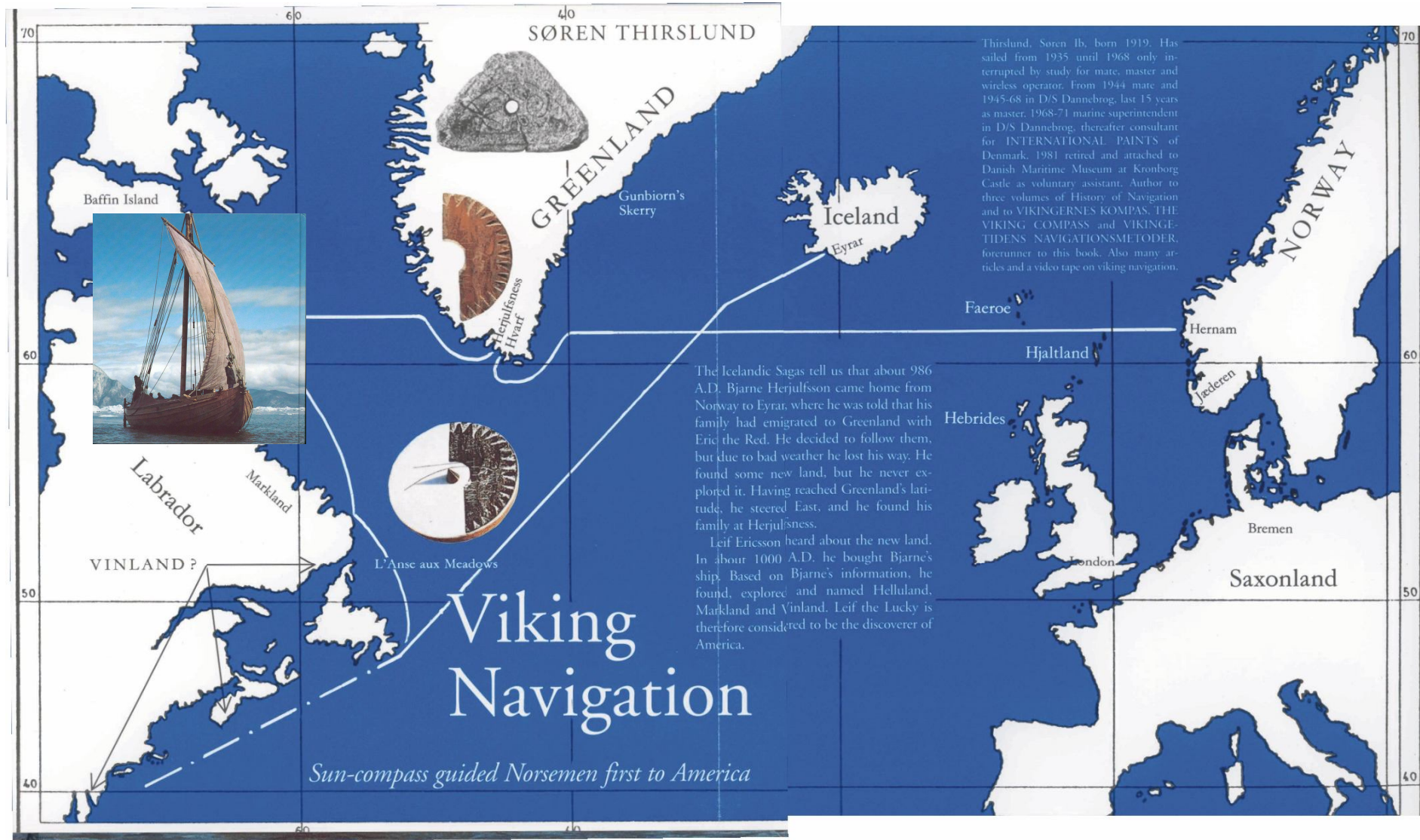


Unpolarized (η) and polarized (π) points of an eclipsed sky



(4) Imaging polarimetric study of the atmospheric optical prerequisites allowing polarimetric navigation by Viking seafarers

The sun-dial of Vikings



The enigmatic Viking sunstone as an analyzer of skylight polarization



cordierite

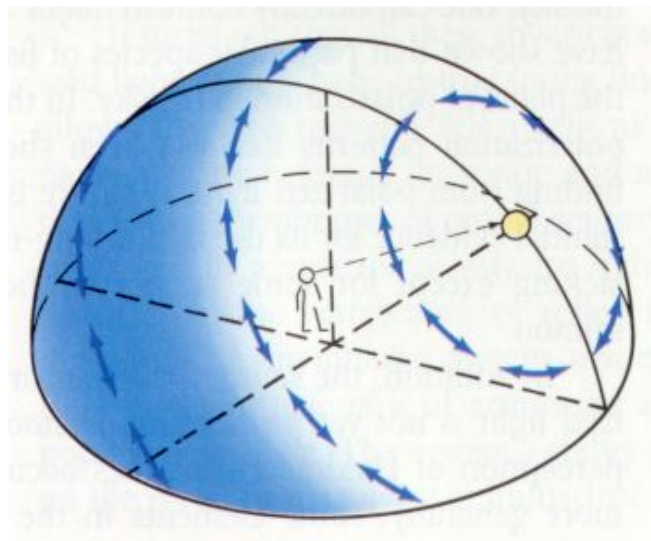
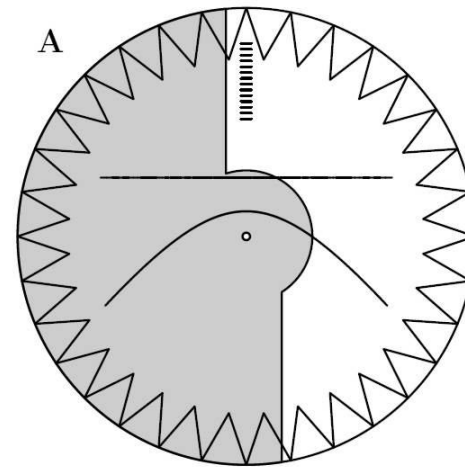


tourmaline



calcite

Hypothesis of the sky-polarimetric Viking navigation under foggy and cloudy conditions



Rayleigh pattern of sky polarization

Swedish Polar Research Secretariat

Beringia 2005 Leg 3

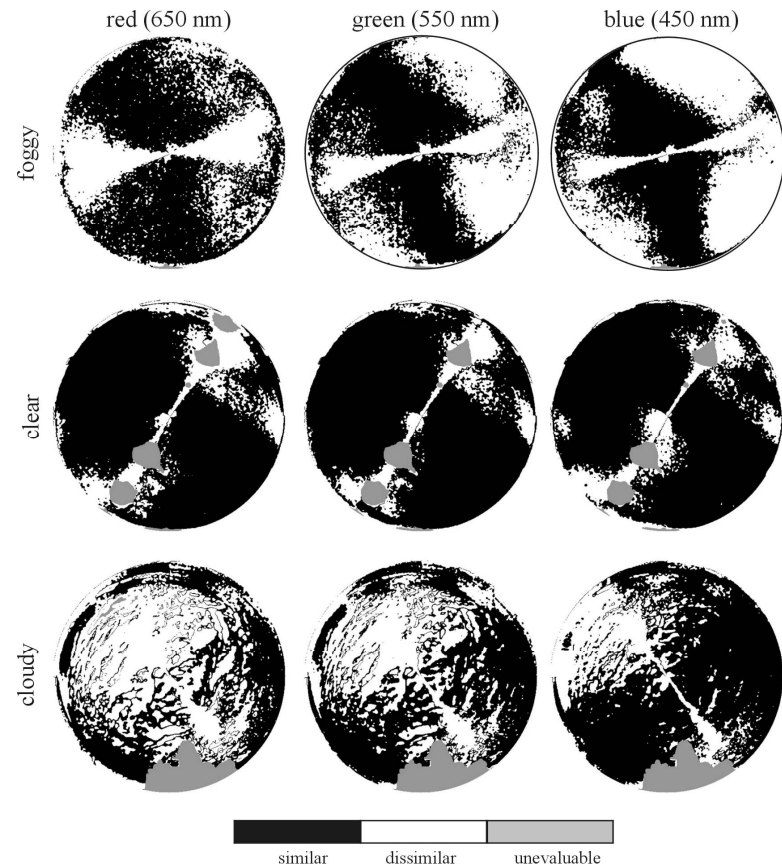
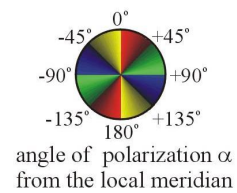
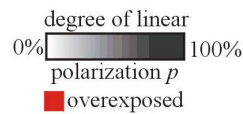
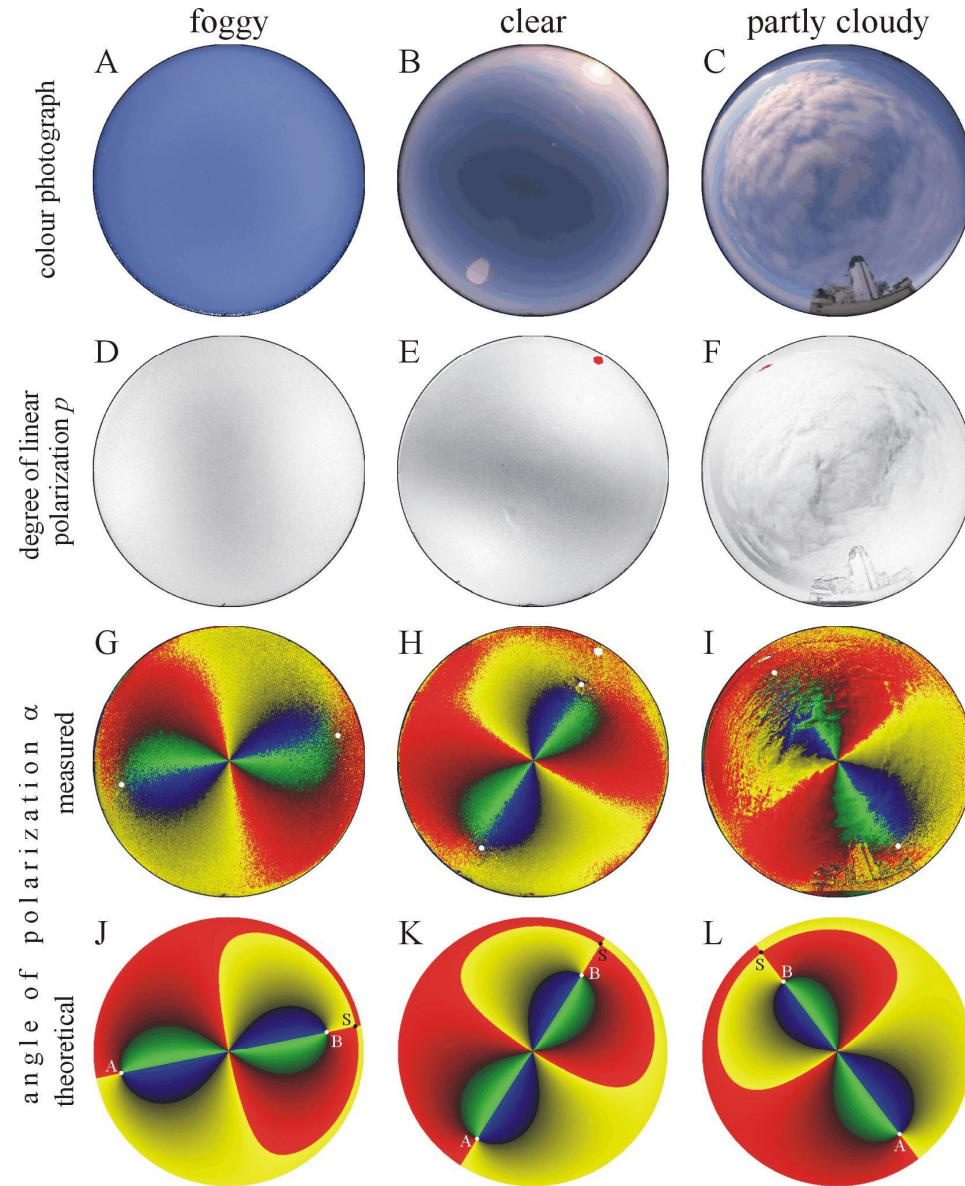


The collage features a central bathymetric map of the North Pole region, showing depths from 0 to -5000 meters. A red line indicates the expedition route. Surrounding the map are numerous small portraits of the expedition crew. Below the map is a yellow certificate of participation for Gabor Horvath, Expedition Leader, and T. Arnell, Oden Captain. The certificate is signed by A. Karlqvist and T. Arnell. The text on the certificate reads: "Beringia 2005", "Oden at the North Pole 12th September 2005", "Gabor Horvath", "Certificate of participation in Beringia 2005 Leg 3.", "A. Karlqvist", and "T. Arnell".

Full-sky imaging polarimetry on the Arctis

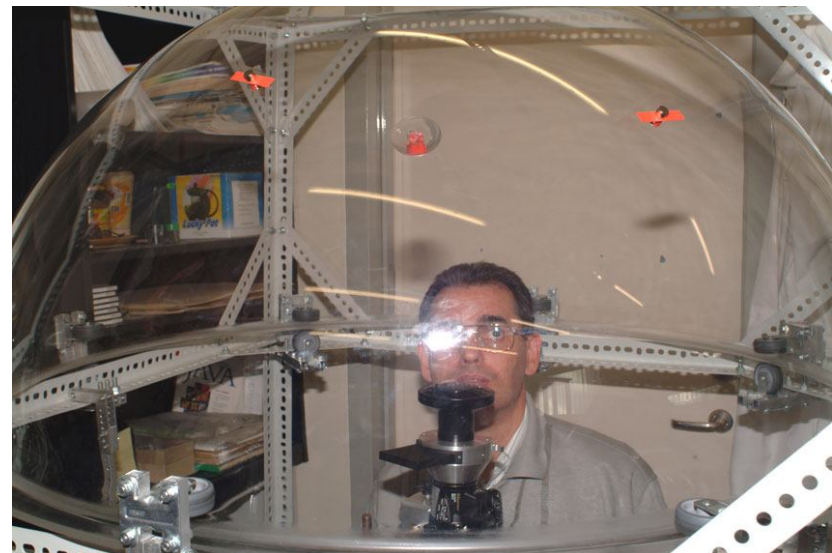
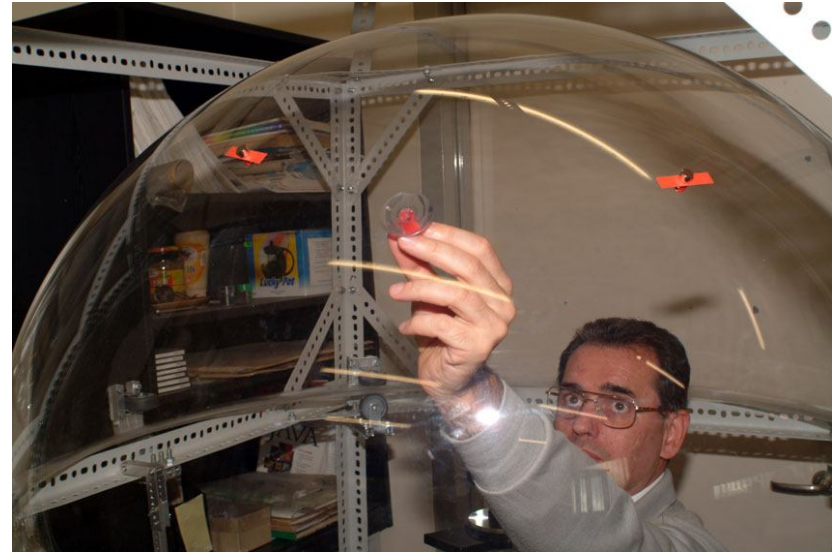


Polarization patterns of foggy, clear and cloudy skies

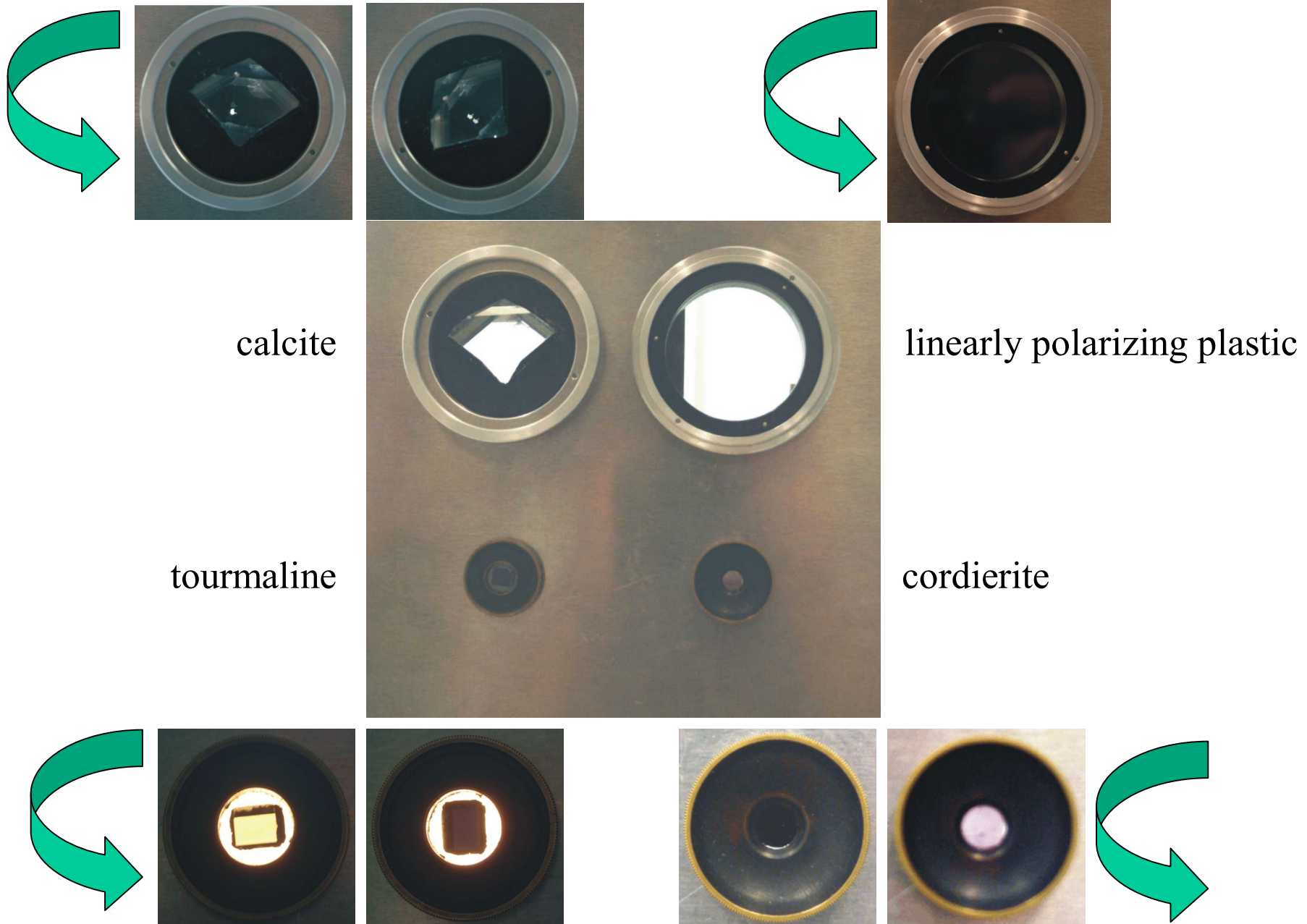


Regions (black) of foggy, clear, and cloudy skies suitable for polarimetric Viking navigation

Psychophysical laboratory experiments studying the accuracy of the different steps of polarimetric Viking navigation

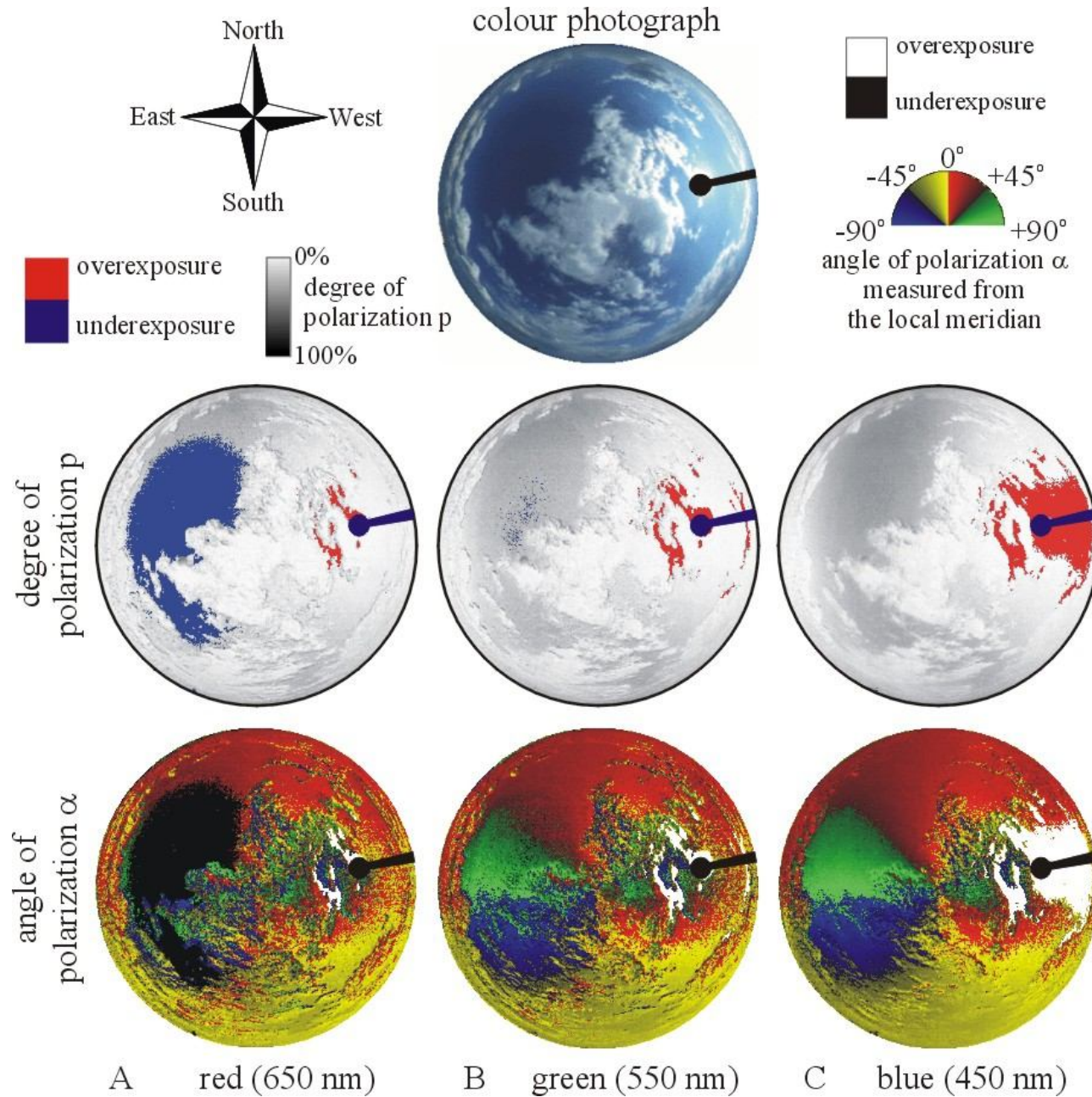


Dichroic crystals functioning as Viking sunstones

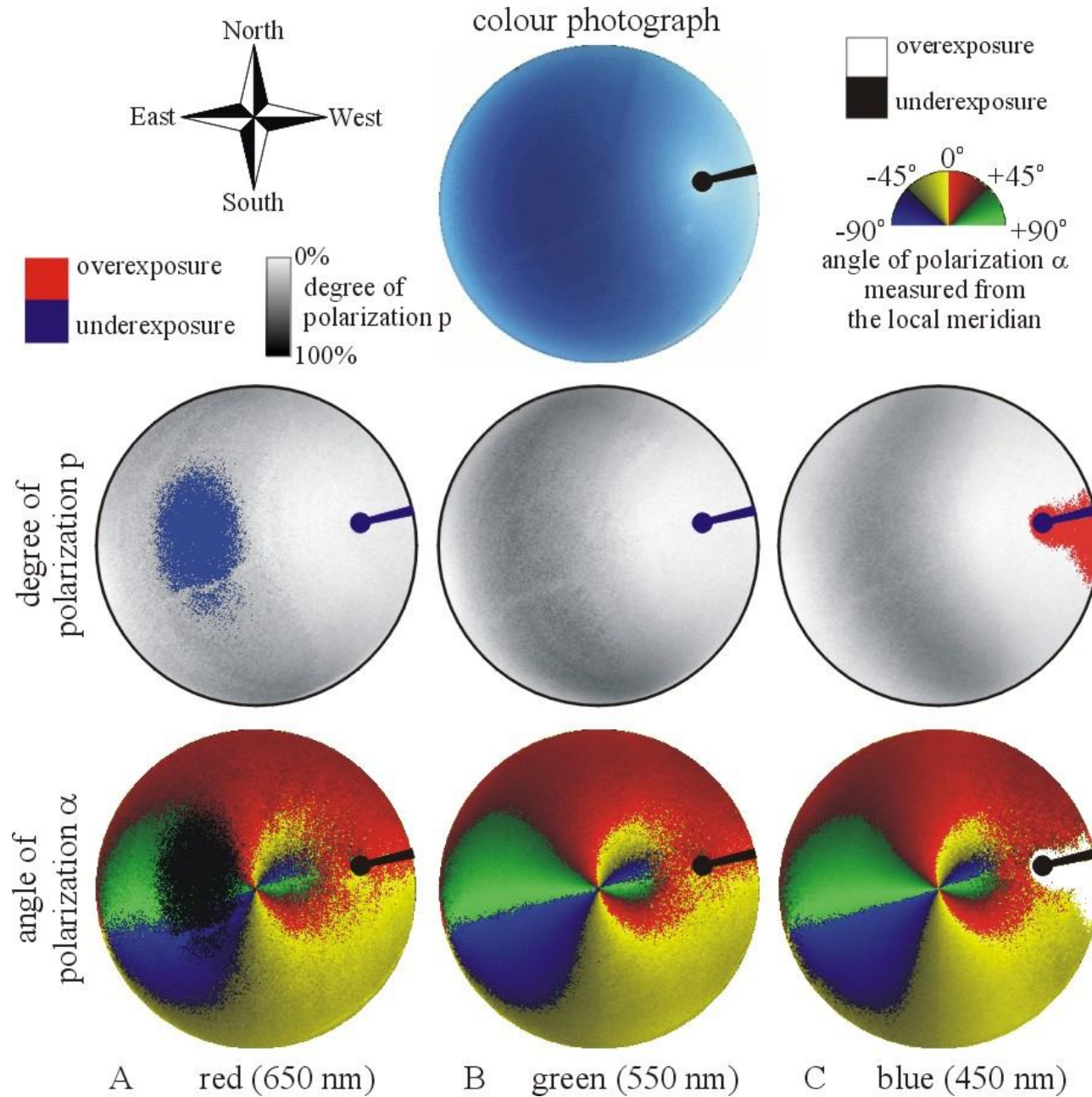


(5) Polarization cloud detection

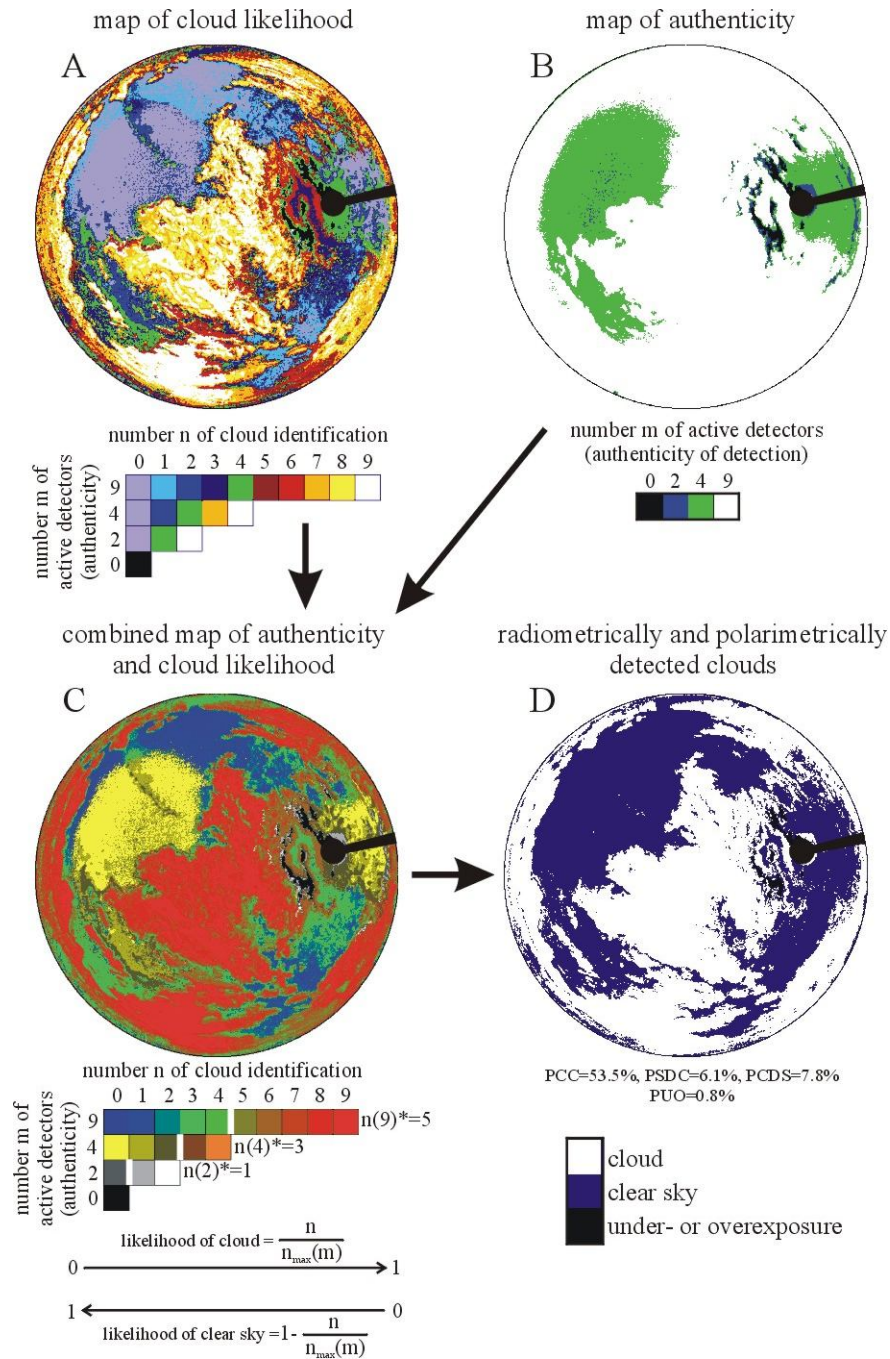
Polarimetric cloud detection



Polarimetric cloud detection



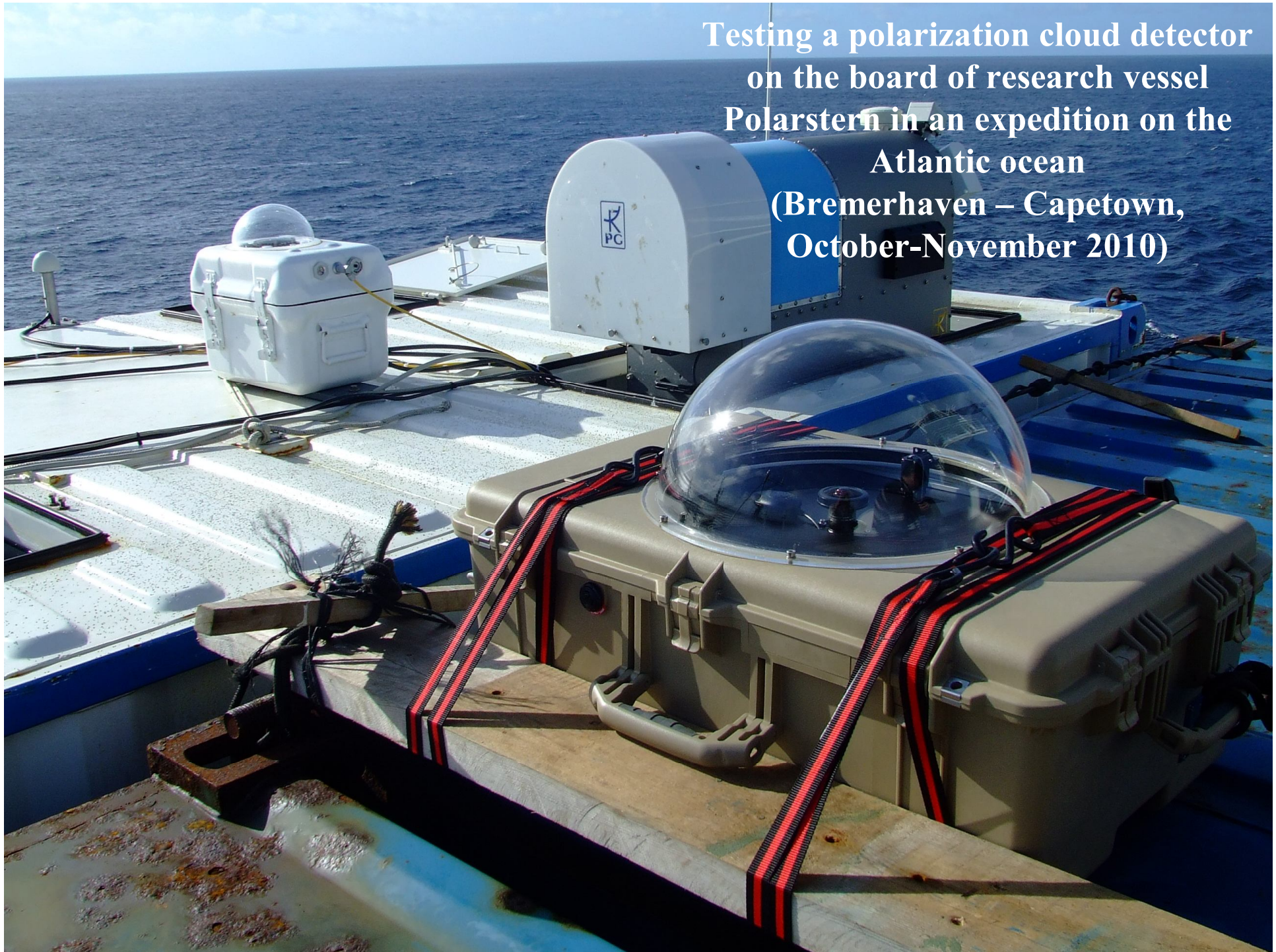
Polarimetric cloud detection



**Testing a polarization cloud detector
on the board of research vessel
Polarstern in an expedition on the
Atlantic ocean
(Bremerhaven – Capetown,
October-November 2010)**

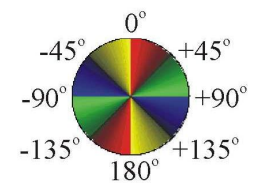
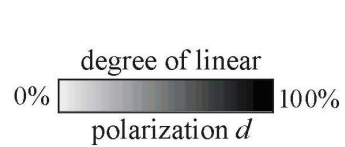
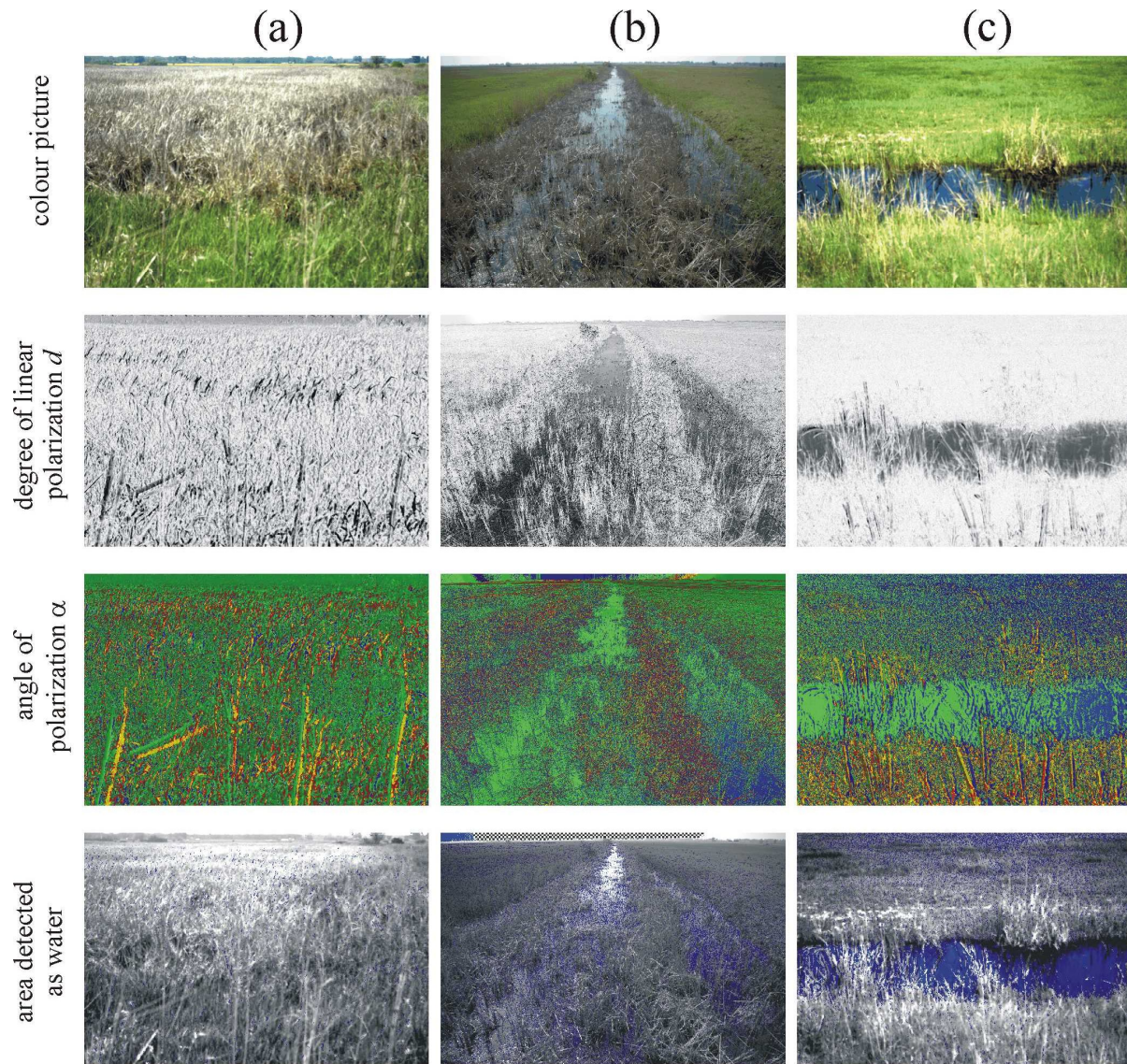


Testing a polarization cloud detector
on the board of research vessel
Polarstern in an expedition on the
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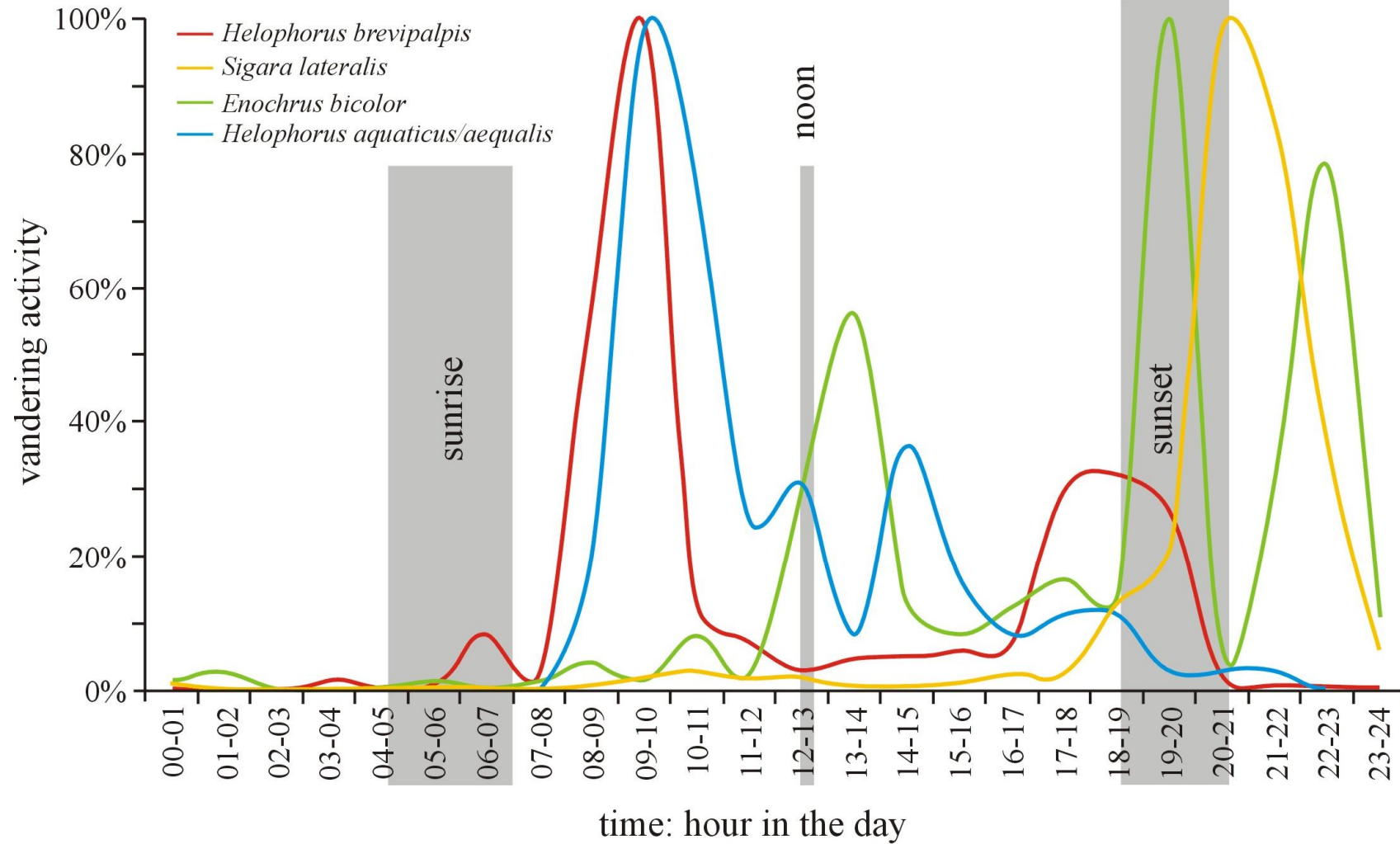
(6) Polarotactic water detection by aquatic insects

Reflection-polarization patterns of water surfaces

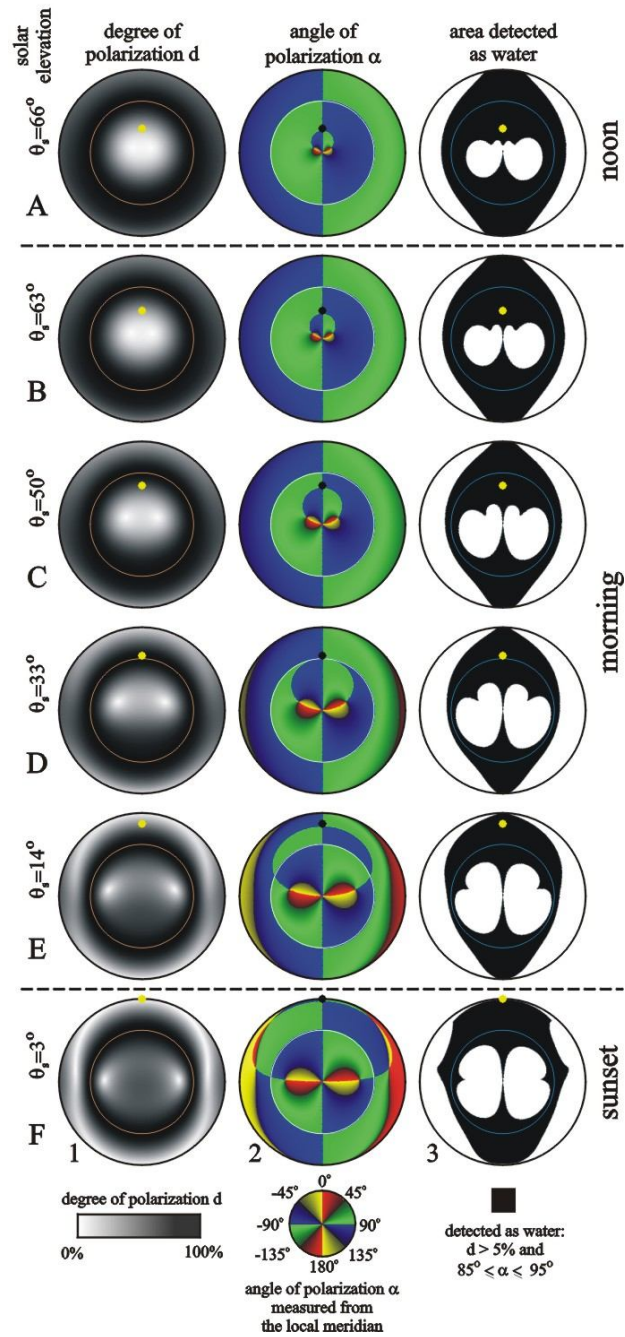


area detected polarotactically as water:
 $d > 5\%$
 $80^\circ < \alpha < 100^\circ$

Diel flight activity patterns of water-seeking aquatic insects

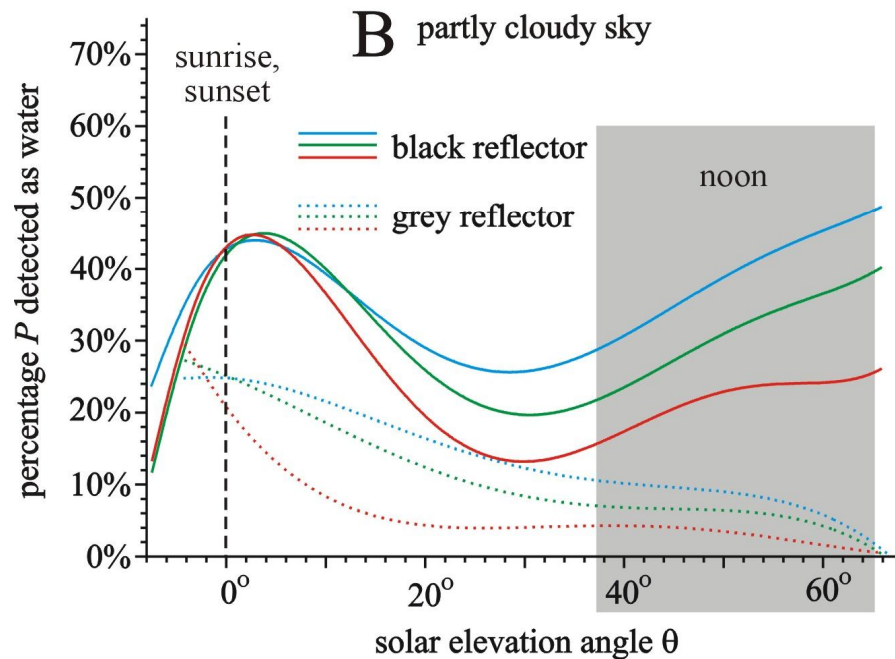
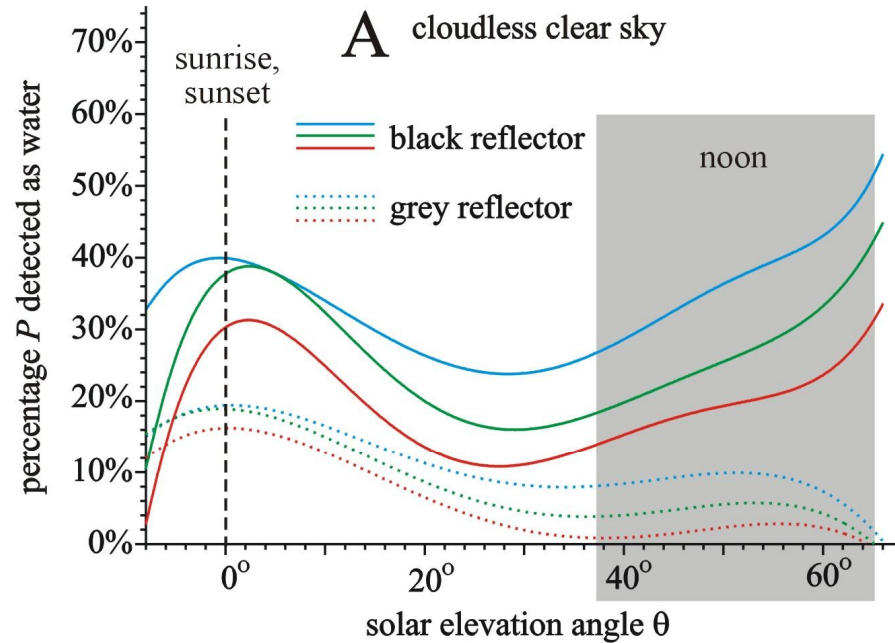


perfectly black reflector under clear Rayleigh skies



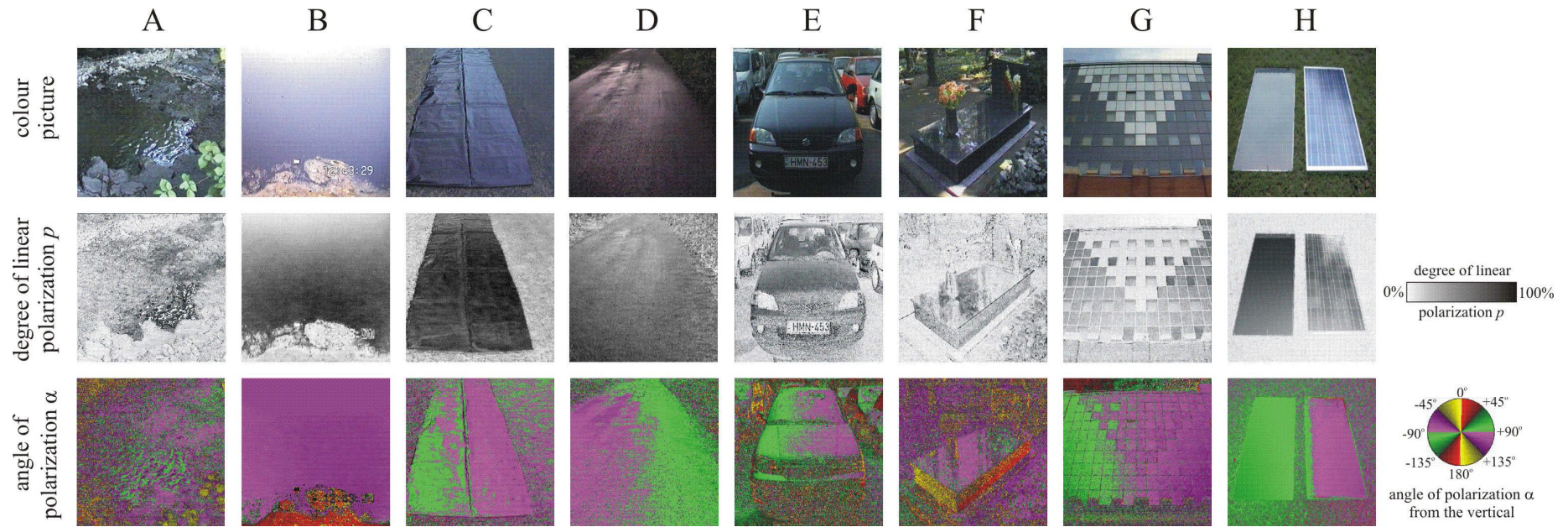
180° field-of-view reflection-polarization patterns of water surfaces

Percentage of the water surface detected as water by polarotactic aquatic insects versus the solar elevation

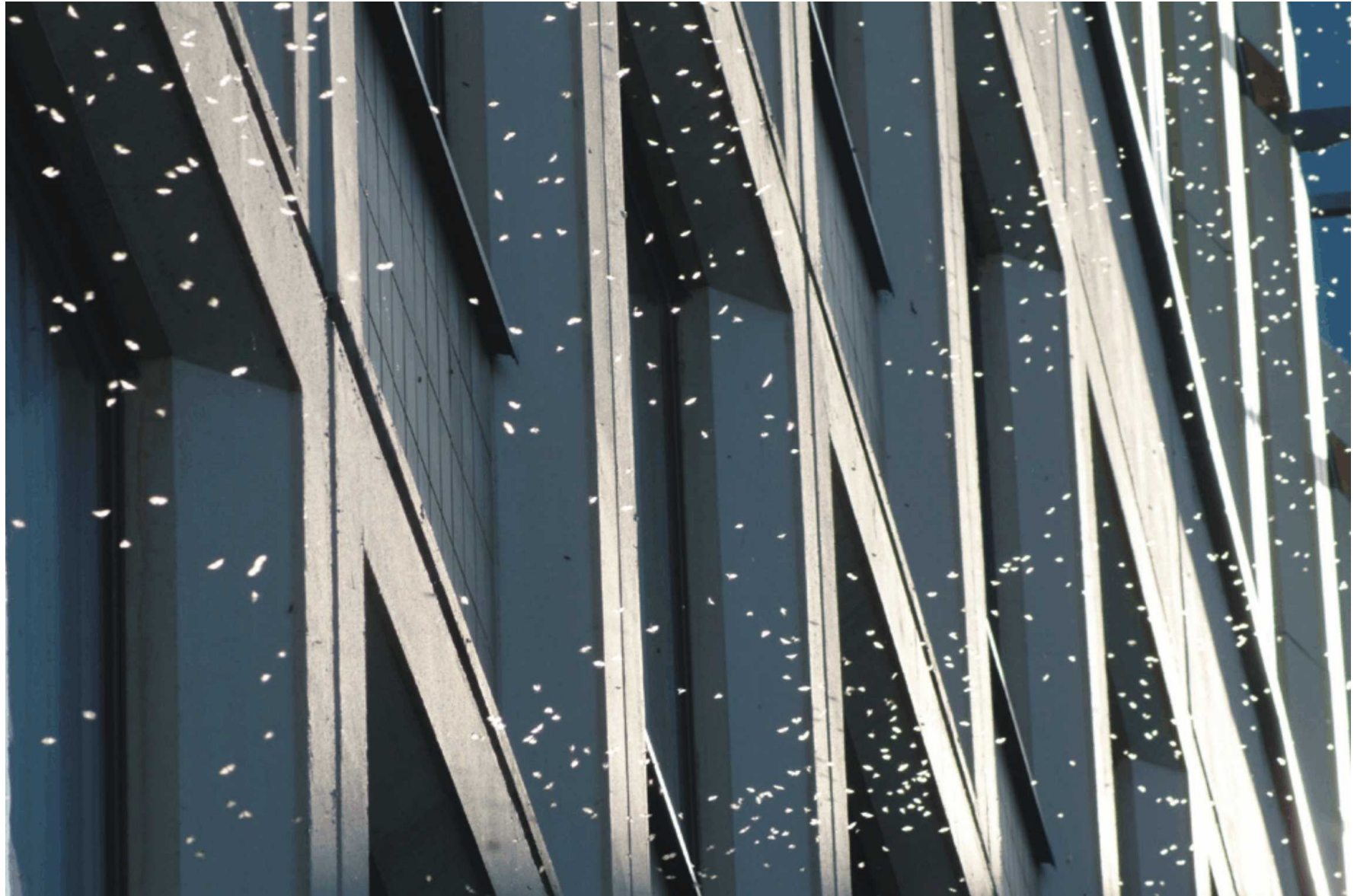


**(7) Polarized light pollution of highly polarizing,
shiny dark artificial surfaces**

Sources of polarized light pollution



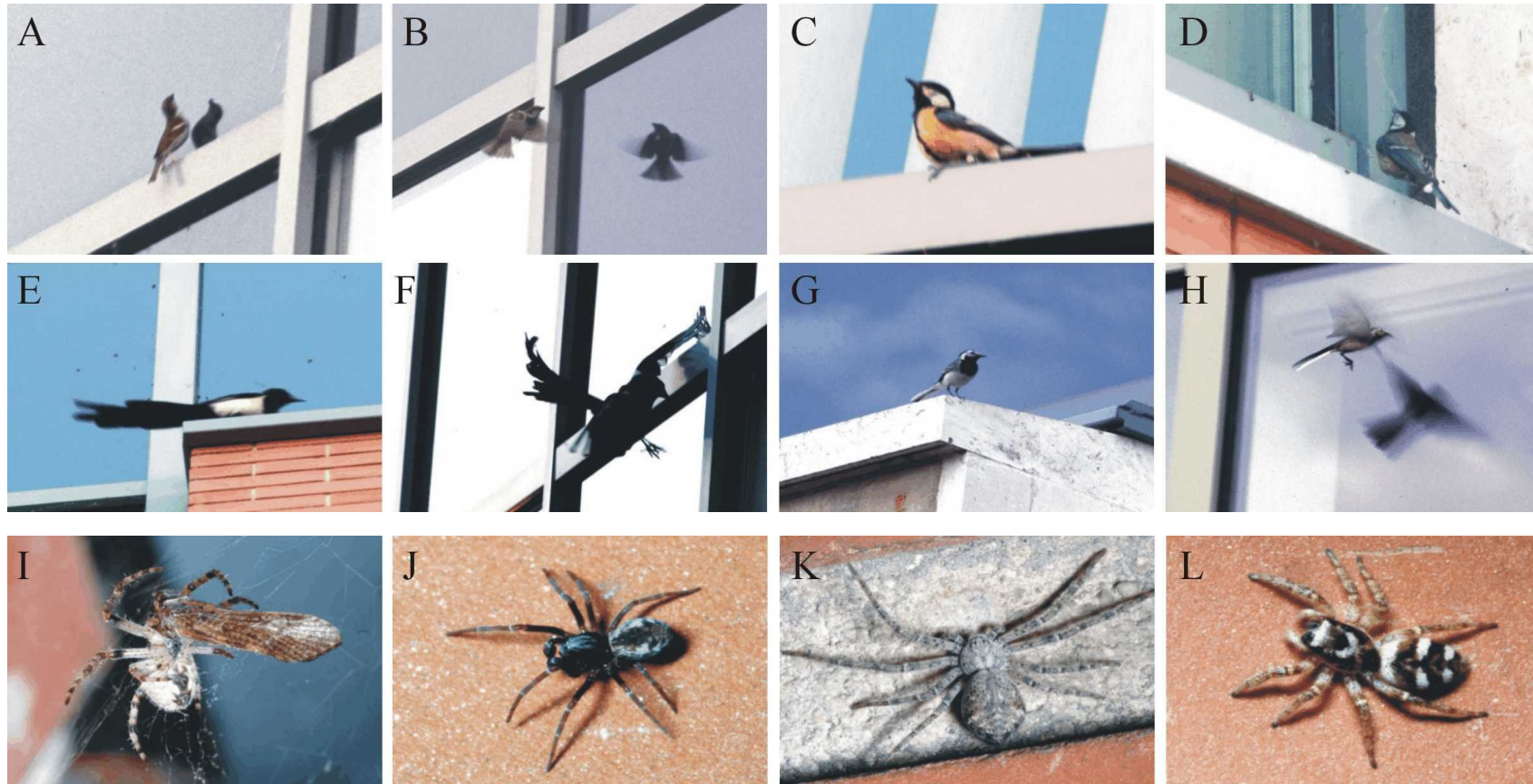
**Mass swarming of caddis flies (*Hydropsyche pellucidula*)
at vertical glass panes**



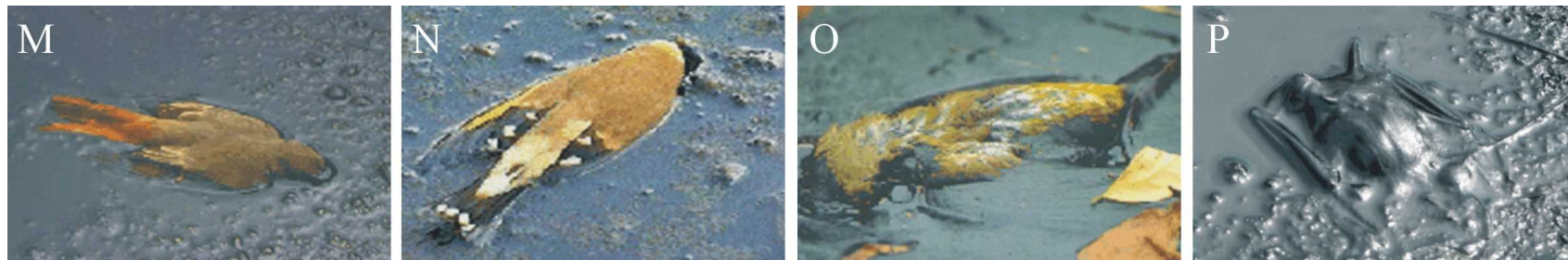
Victims of polarized light pollution



Beneficiaries of polarized light pollution



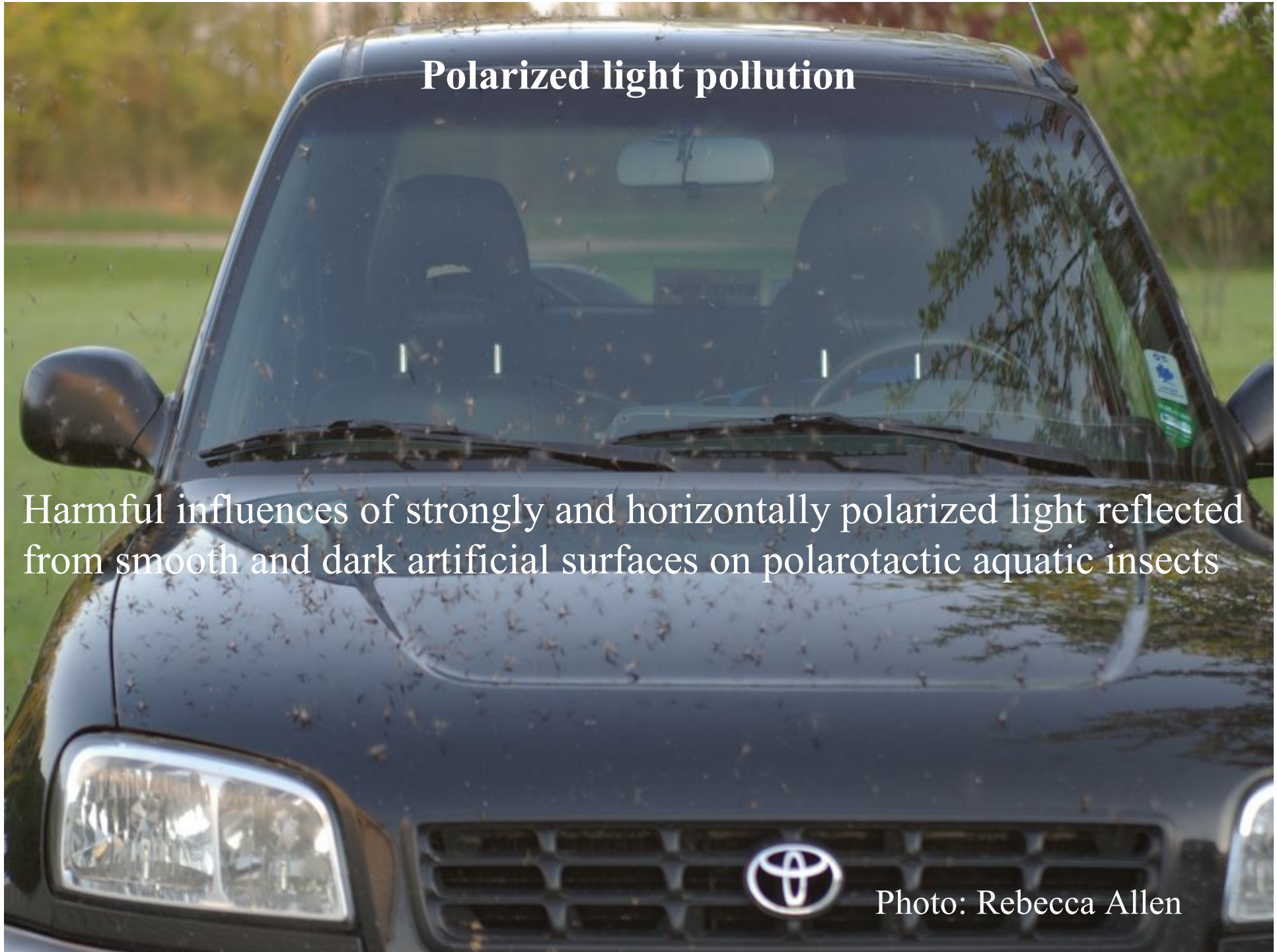
Beneficiaries/victims of polarized light pollution



Polarized light pollution

Harmful influences of strongly and horizontally polarized light reflected from smooth and dark artificial surfaces on polarotactic aquatic insects

Photo: Rebecca Allen

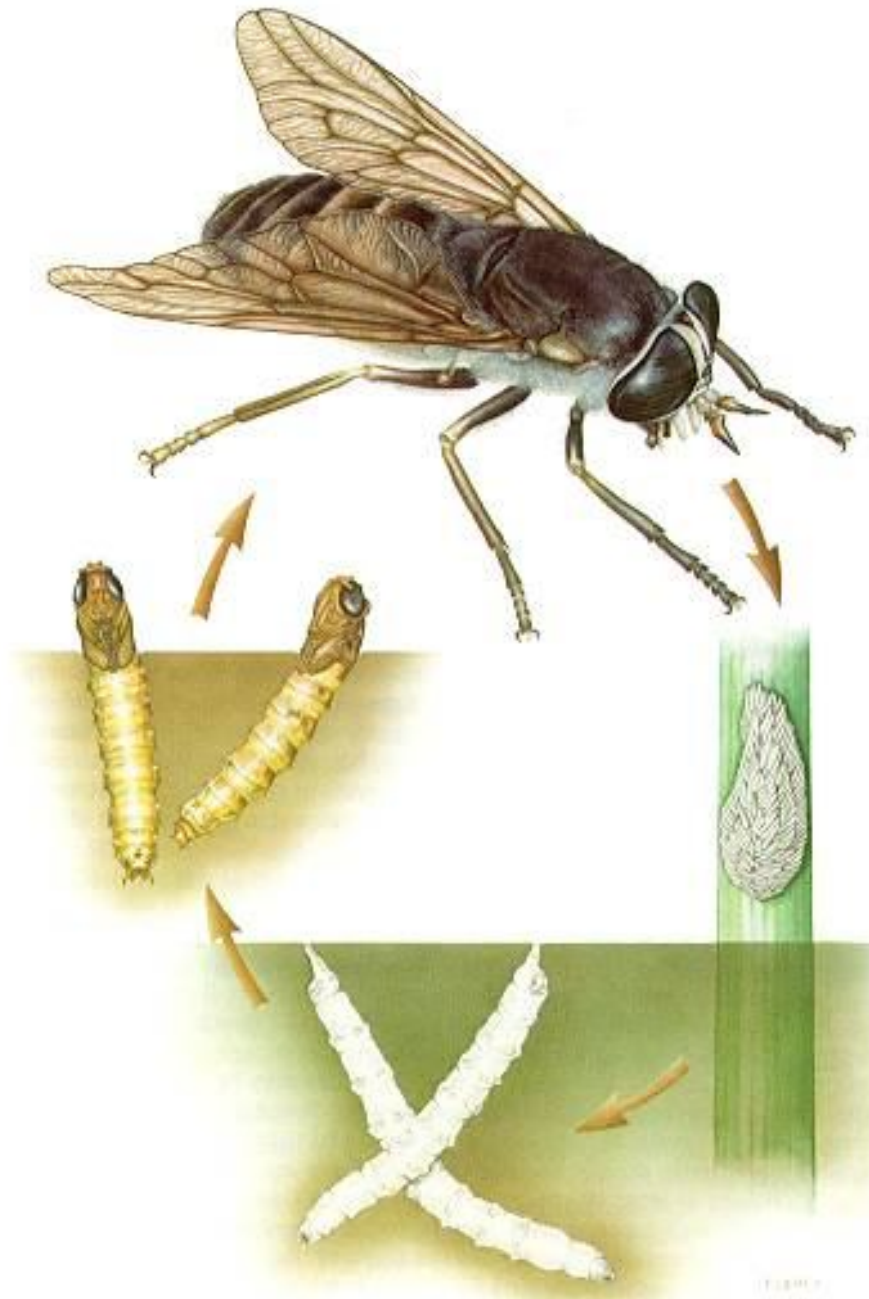


(8) Polarotactic tabanid flies find striped patterns with brightness and/or polarization modulation least attractive:

An advantage of zebra stripes

Tabanid-repelling zebra stripes as a natural tool to reduce polarized light pollution

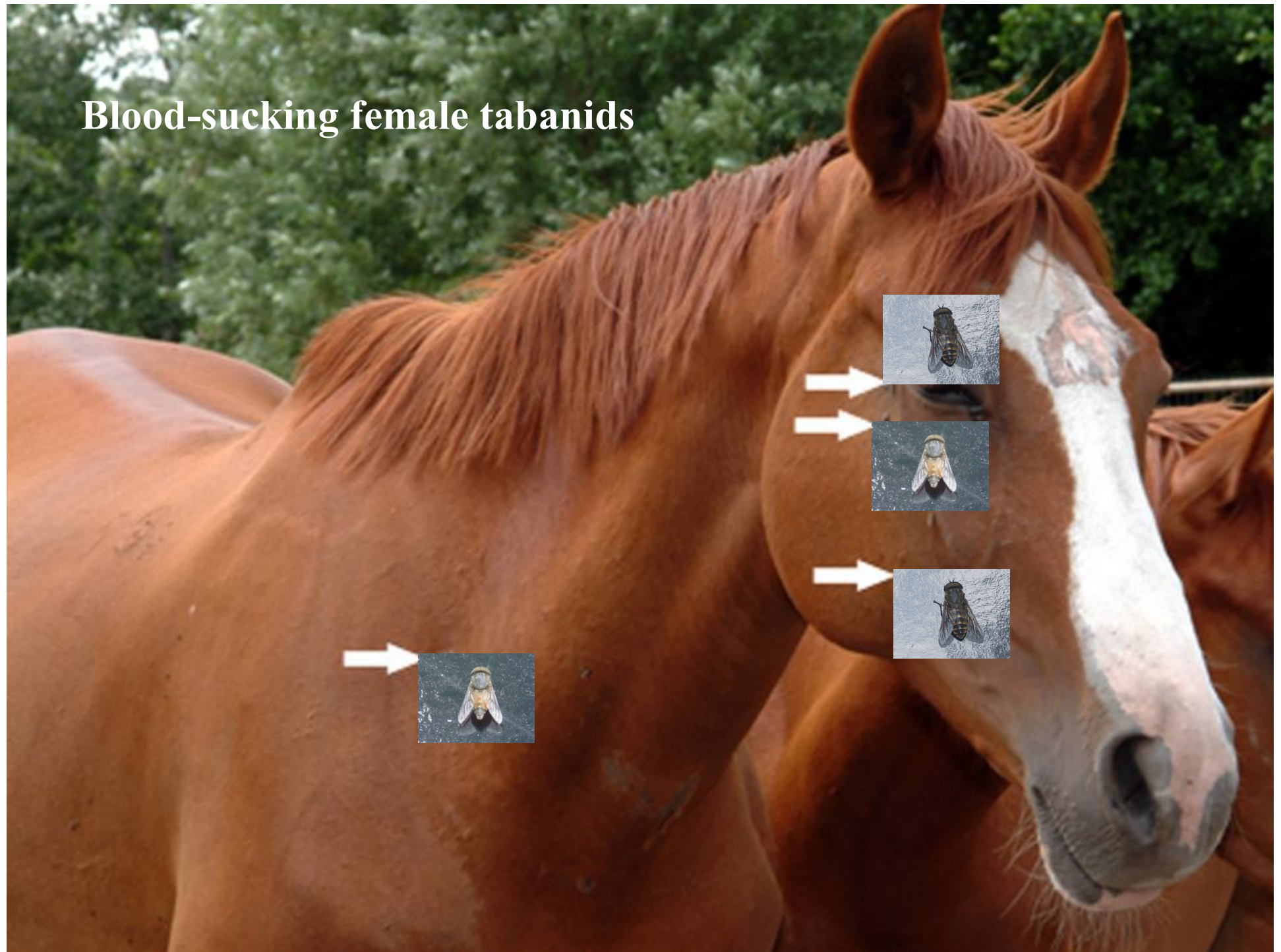
The life cycle of tabanid flies



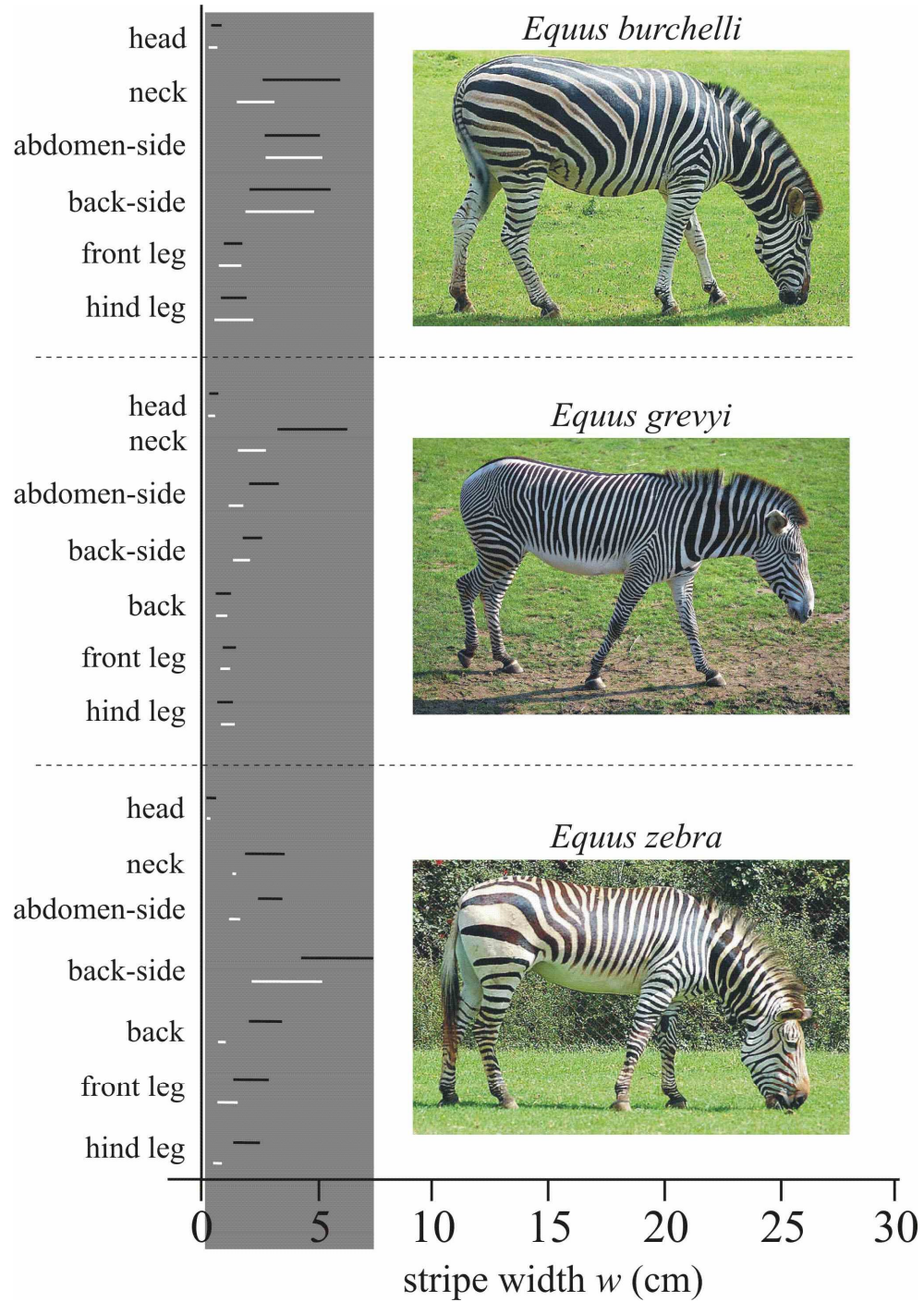
Functions of positive polarotaxis of tabanid flies



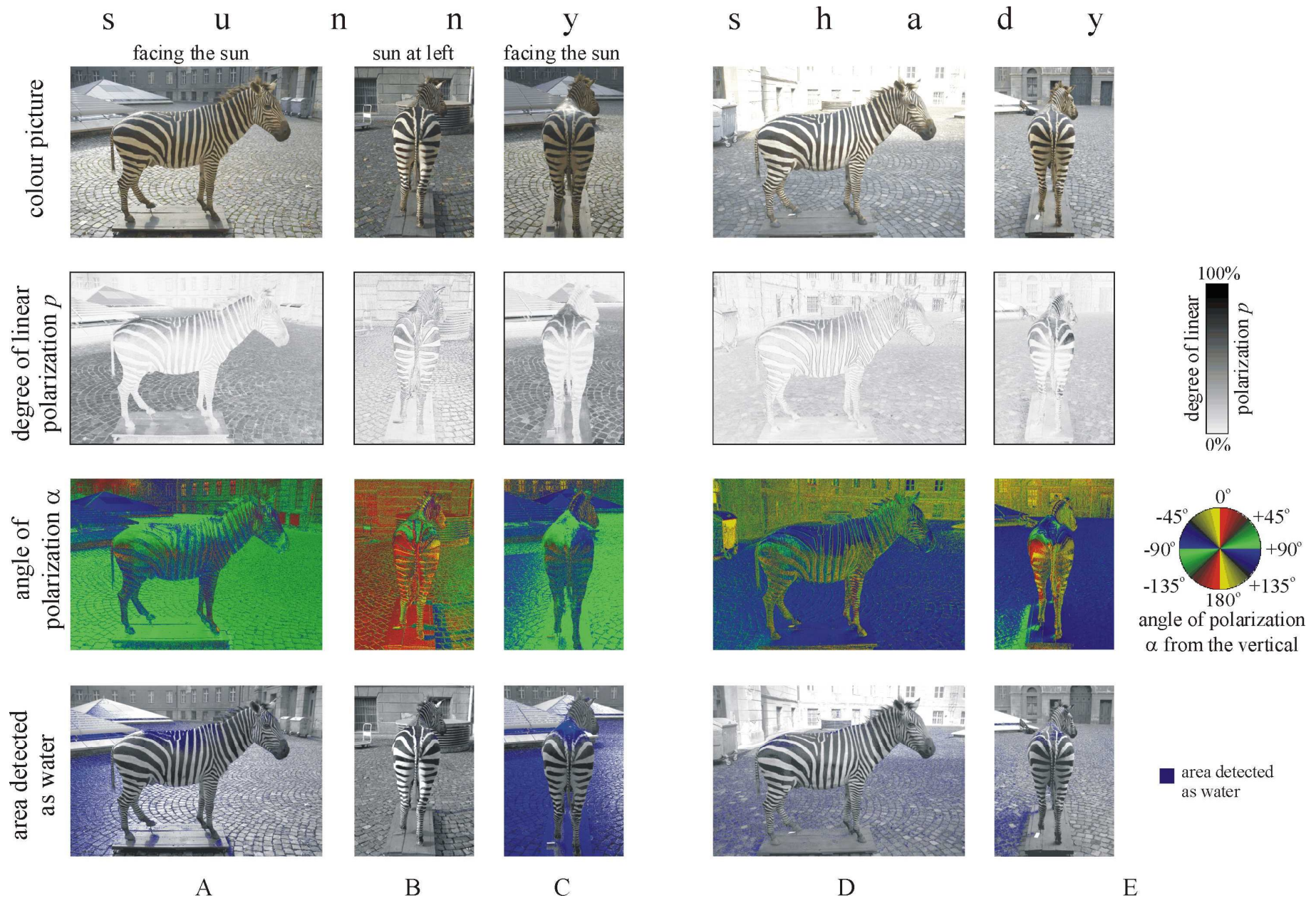
Blood-sucking female tabanids



Distribution of the stripe width on the body surface of zebras



Polarization patterns of zebras



Field experiments with striped test surfaces and polarotactic tabanids



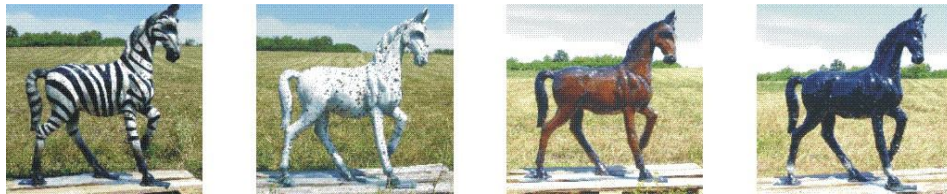
■ 1st experiment



● 2nd experiment



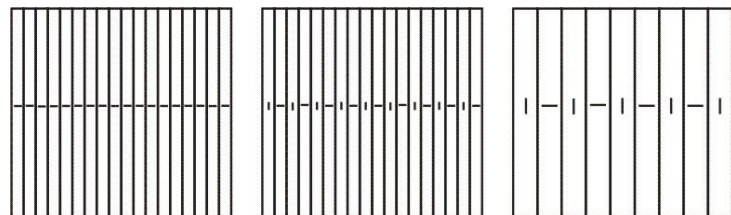
▲ 3rd experiment



--- 4th experiment



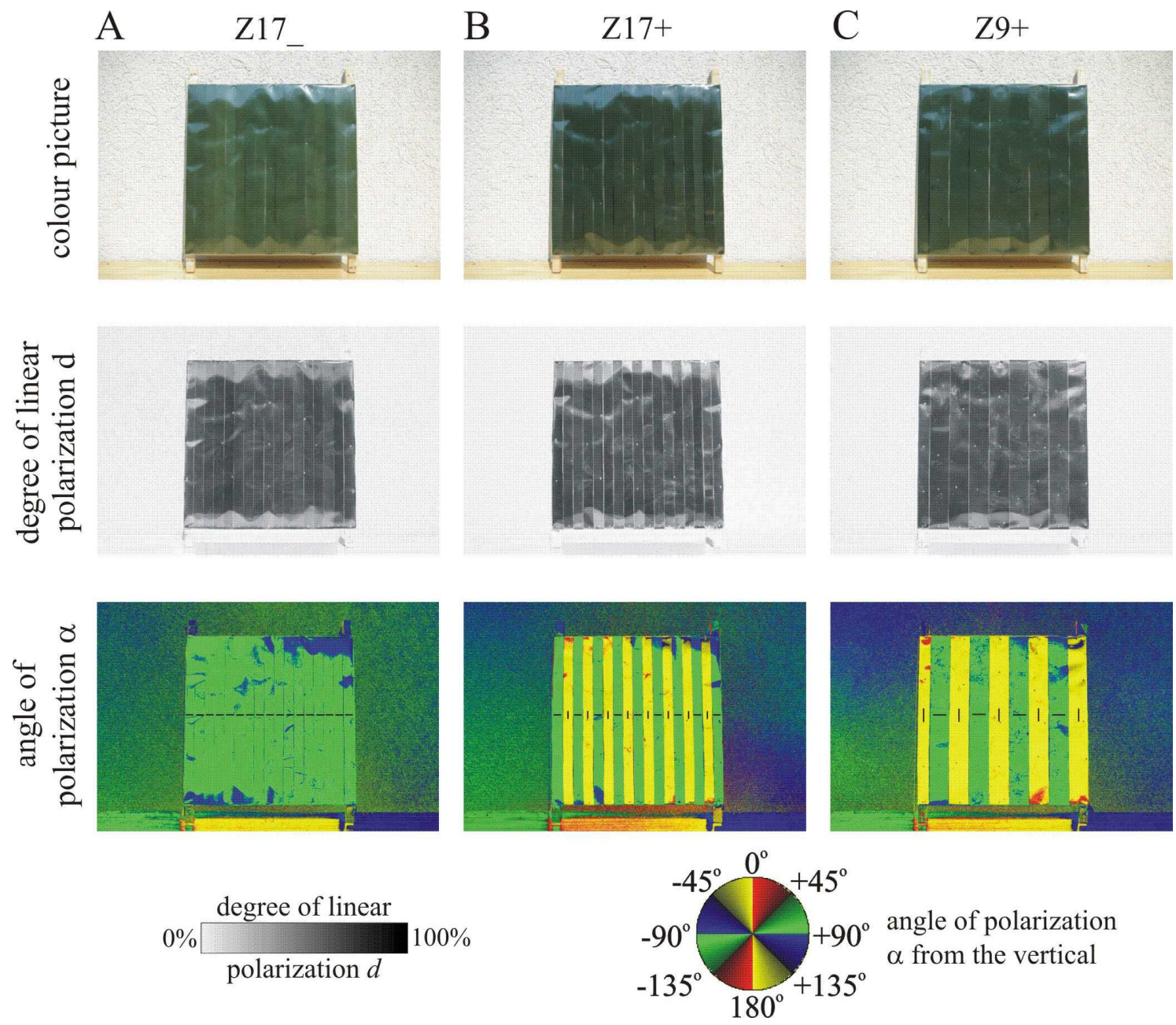
◆ 5th experiment



○ 6th experiment: horizontal test surfaces

□ 6th experiment: vertical test surfaces

Polarization-stripped test surfaces used in experiment 6



The ancient zebra was dark, its stripes have been developed only later



"I've already solved the Tabanid problem."

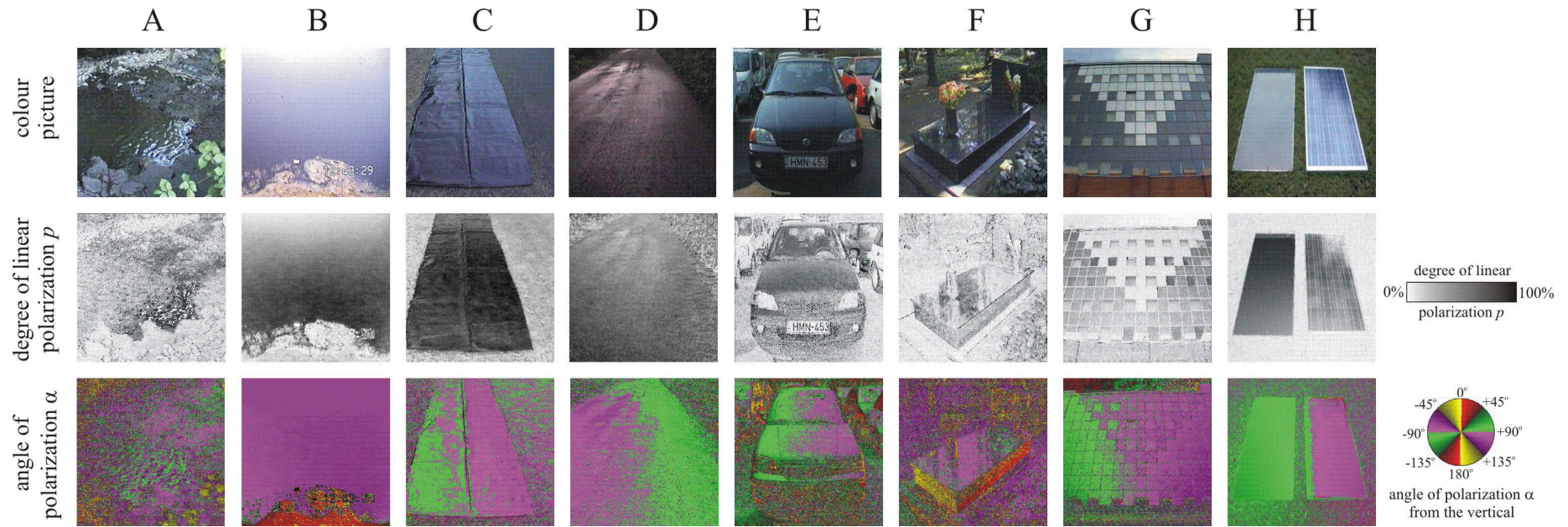
(9) Polarization tabanid traps

How polarotactic male and female tabanid flies can be perished by traps reflecting strongly linearly polarized light mimicking water surfaces or host animals

Discovery of polarotaxis in tabanid flies at black gravestones



Sources of polarized light pollution



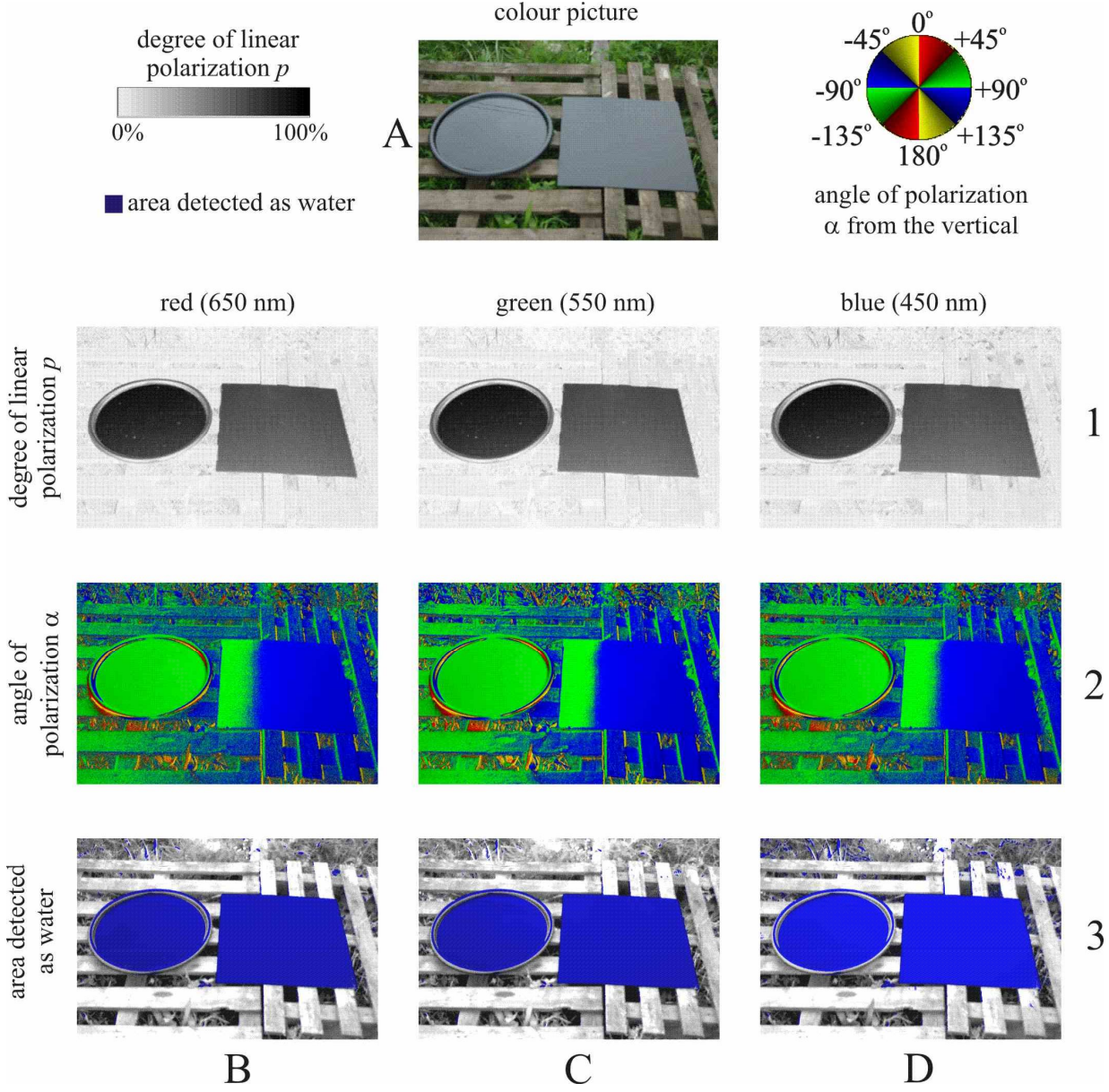
Sticky polarization tabanid trap



Liquid polarization tabanid trap



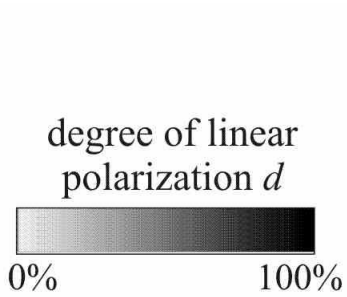
Reflection-polarization patterns of TabaNoid traps



Solar panel as polarization tabanid trap

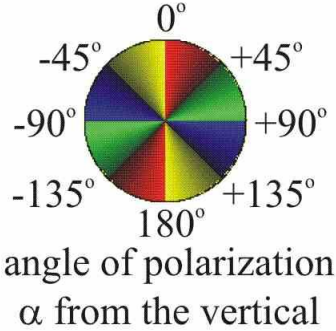


Reflection-polarization patterns of solar panels

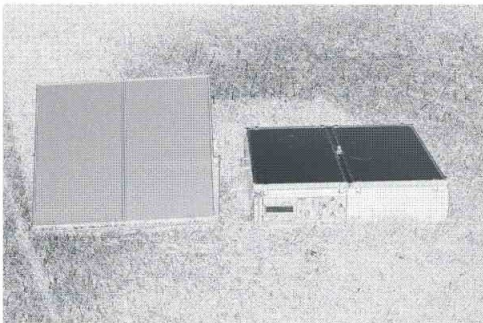
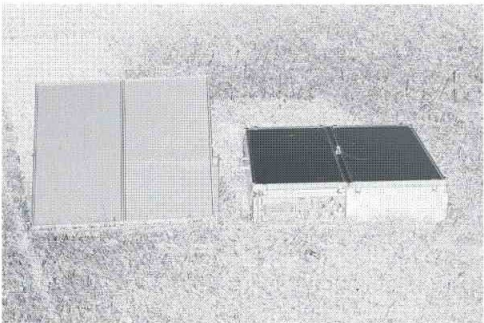
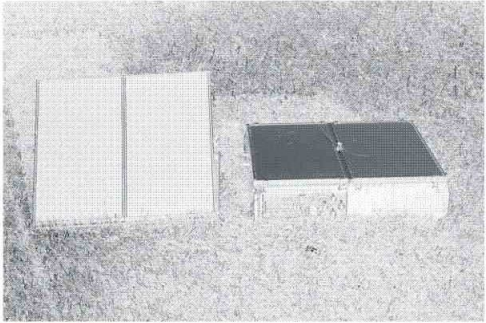


A

colour picture

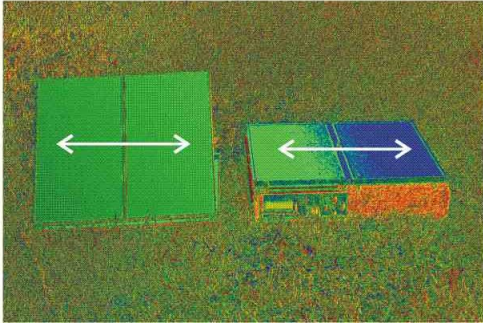
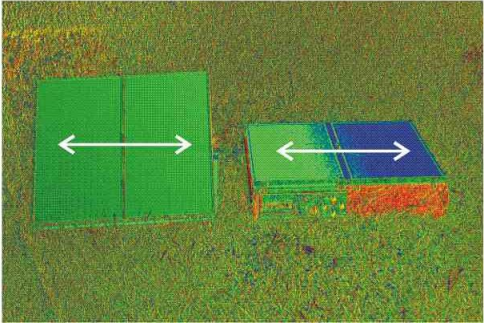
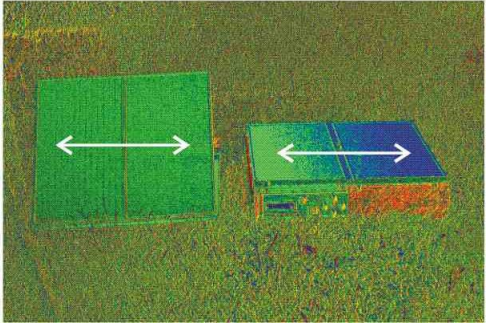


degree of linear polarization d



B

angle of polarization α



C

Research for the Development of TabaNOid Technology

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Project acronym: TabaNOid

TabaNOid

Grant type: Research for the Benefit of Small and Medium Enterprises

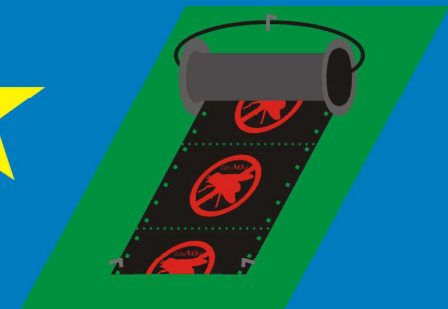
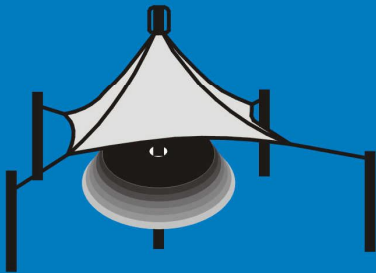
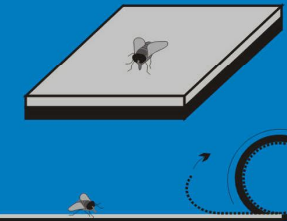
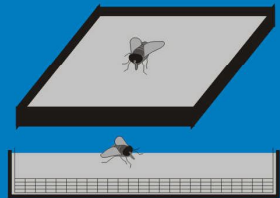
Title: Trap for the novel control of horse-flies on open-air fields

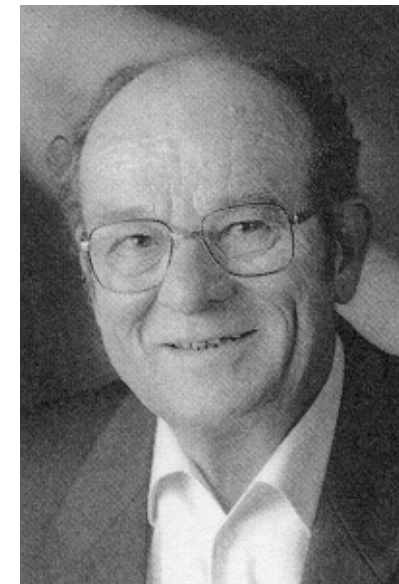
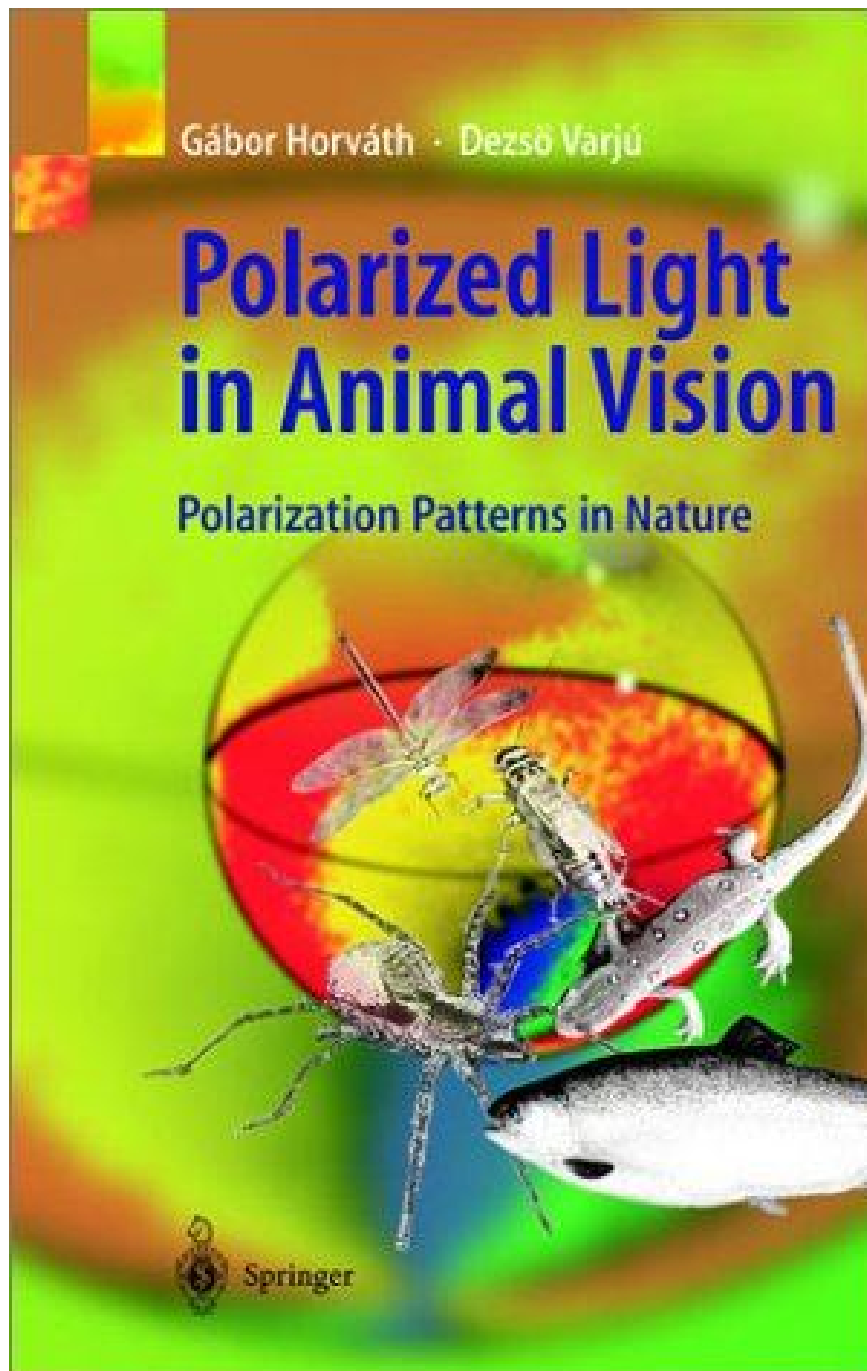
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THANK YOU FOR YOUR ATTENTION!

