Bio-Inspired Optical Imaging and Sensing

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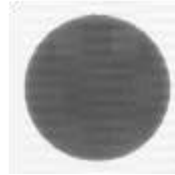
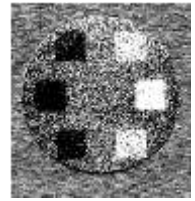
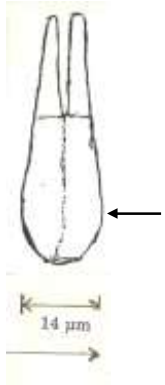
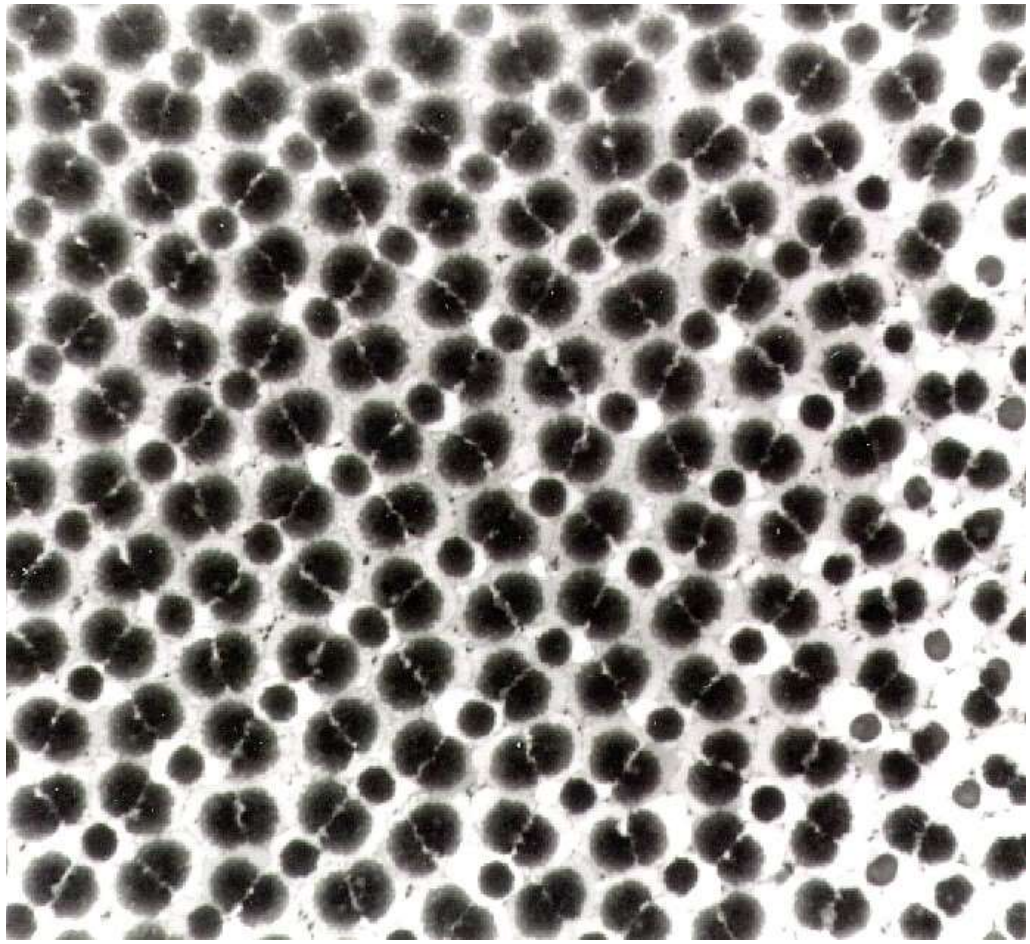
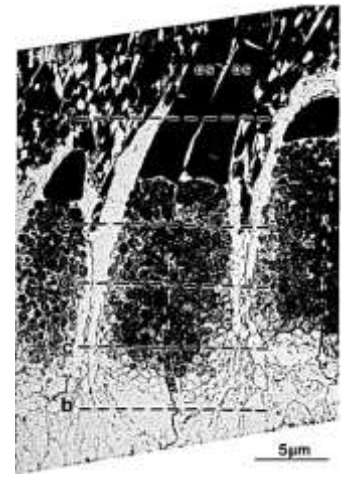
November 3, 2017



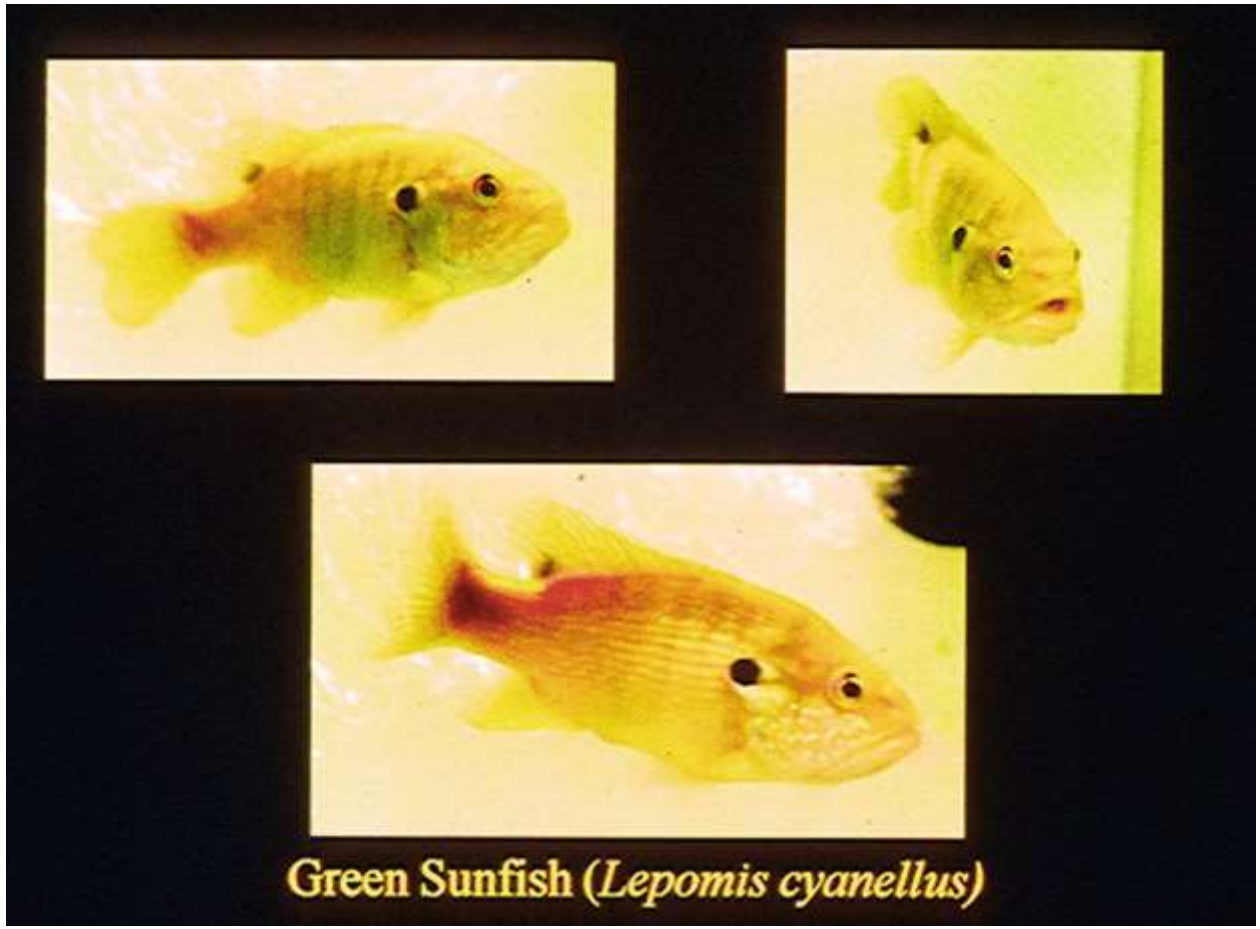








M. Rowe, N. Engheta, S. Easter, E. N. Pugh, J. Opt. Soc. Am, A, Vol. 11 (1994)


Green Sunfish (*Lepomis cyanellus*)

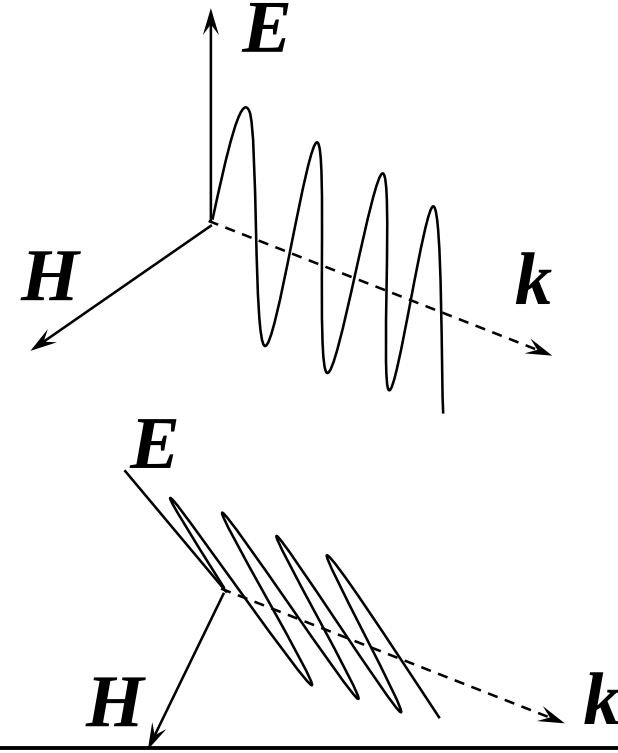
Polarization Information

- *EM/Optical waves have 3 physical characteristics*

Intensity ——— *I*

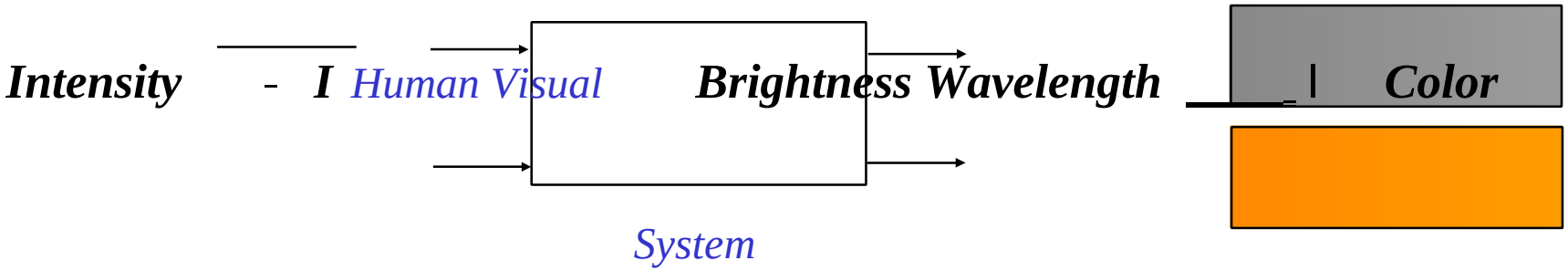
Wavelength |

Polarization —— *Vector E*

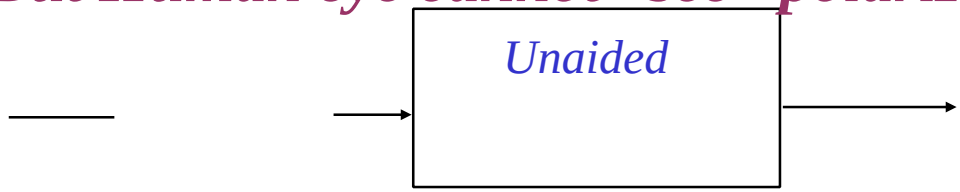


Human Eye is "Polarization-Blind"

- *Human eyes can gather information from "Intensity" and "Wavelength" of light and encode them as "Brightness" and "Color"*



- *But Human eye cannot "see" polarization vector*

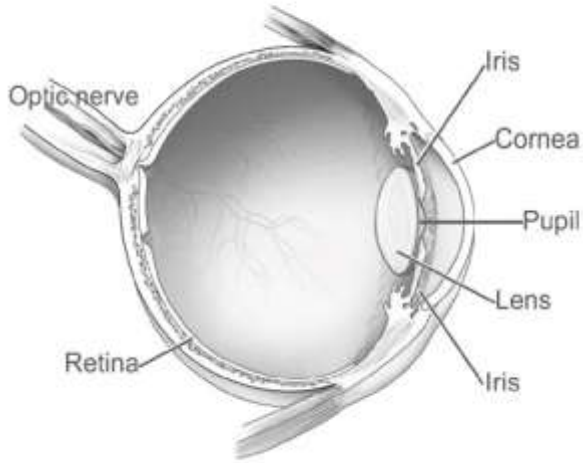


Polarization ***-Vector E*** *Human Visual System* ***No Information***

Some Animal Species Can "see" Polarization

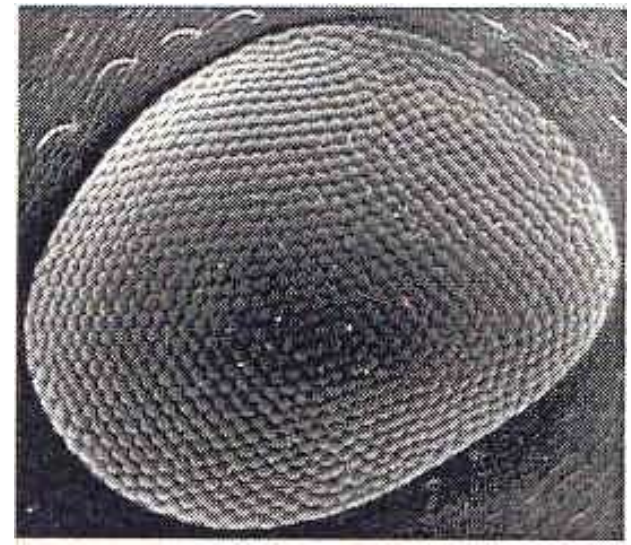
- *Biologists and zoologists have discovered polarization sensitivity of visual systems of certain species*
  - *Honey Bee,*
  - *Desert Ant,*
  - *Flying water bug*
  - *Octopus*
  - *Cricket*
  - *Cuttlefish*
  - *Mantis shrimp*
  - *Crustaceans*
  - *…….*
  - *……..*

Eyes



Human Eye

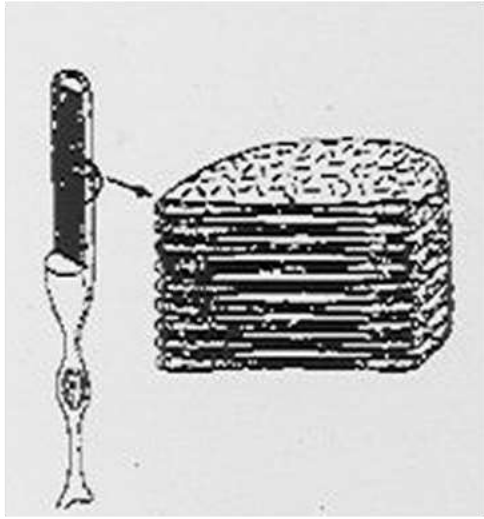
Credit: National Eye Institute, NIH



Compound Eye

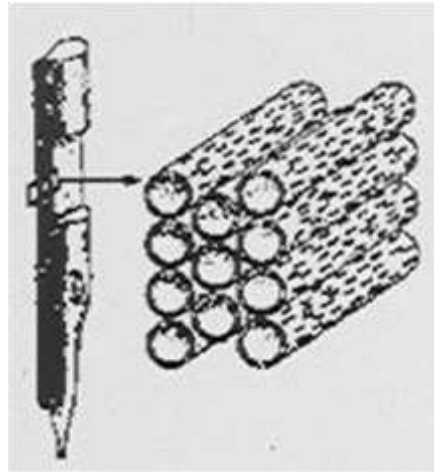
R. Wehner et al., J. Exp. Biol., 199, 129 (1996)

Receptors



Human Retinal Rod

From: Rudiger Wehner, Scientific American, Vol. 235, pp.106-114 (1976)

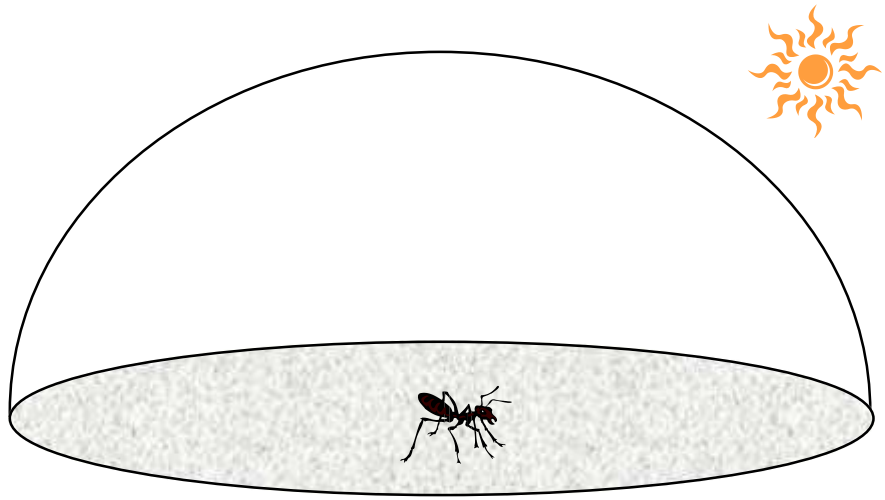


Insect Receptor

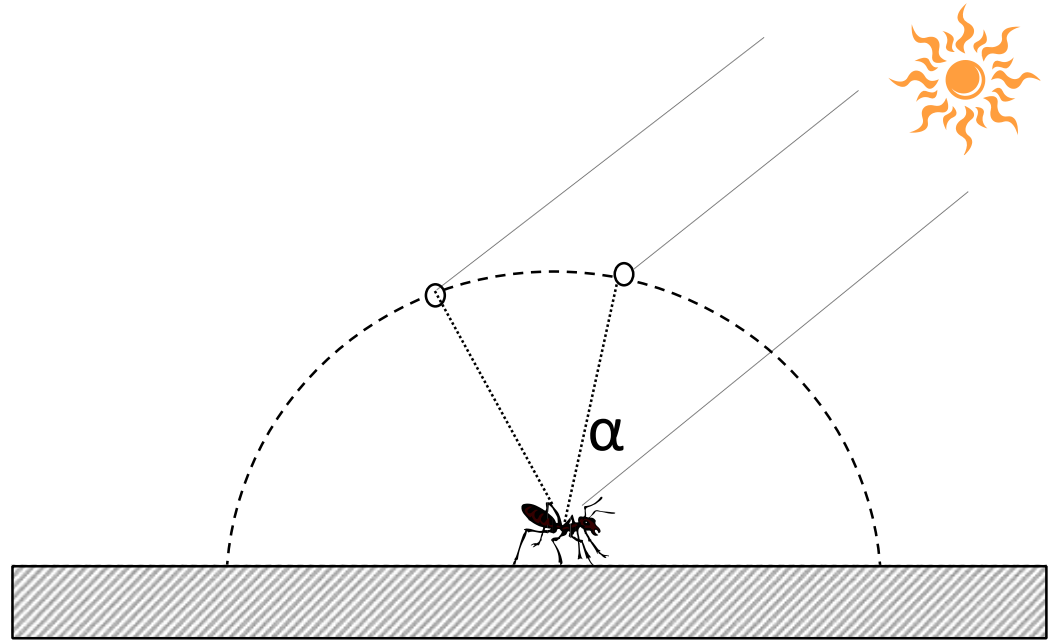
From: Rudiger Wehner, Scientific American, Vol. 235, pp.106-114 (1976)

Why Do These Species Use Polarization Sensitivity?

- ***Navigation***
  - ***Desert Ant and Honey bee use the polarization map of the sky for navigation as shown by R. Wehner and his group***

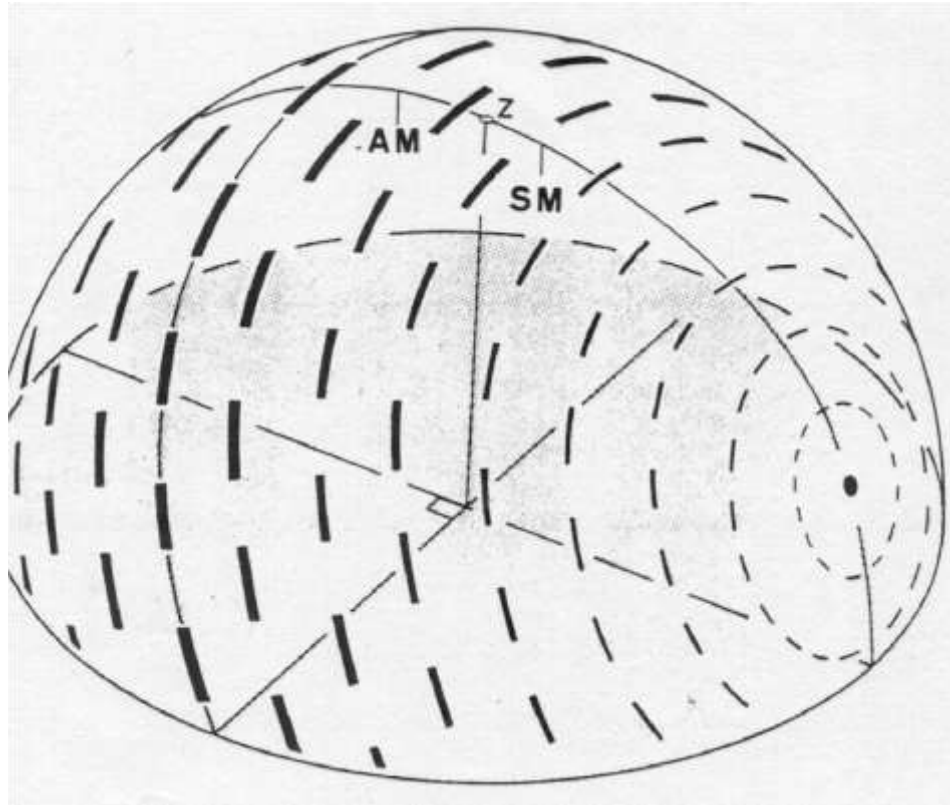


Light and Atmosphere



$$pp = \frac{\sin^2(\alpha)}{\cos^2(\alpha) + 1}_{\max}$$

Polarization Map of the Sky



From: R. Wehner, "Neurobiology of Polarization Vision," Trends in Neurosciences, vol. 12, pp. 353-359, 1989.

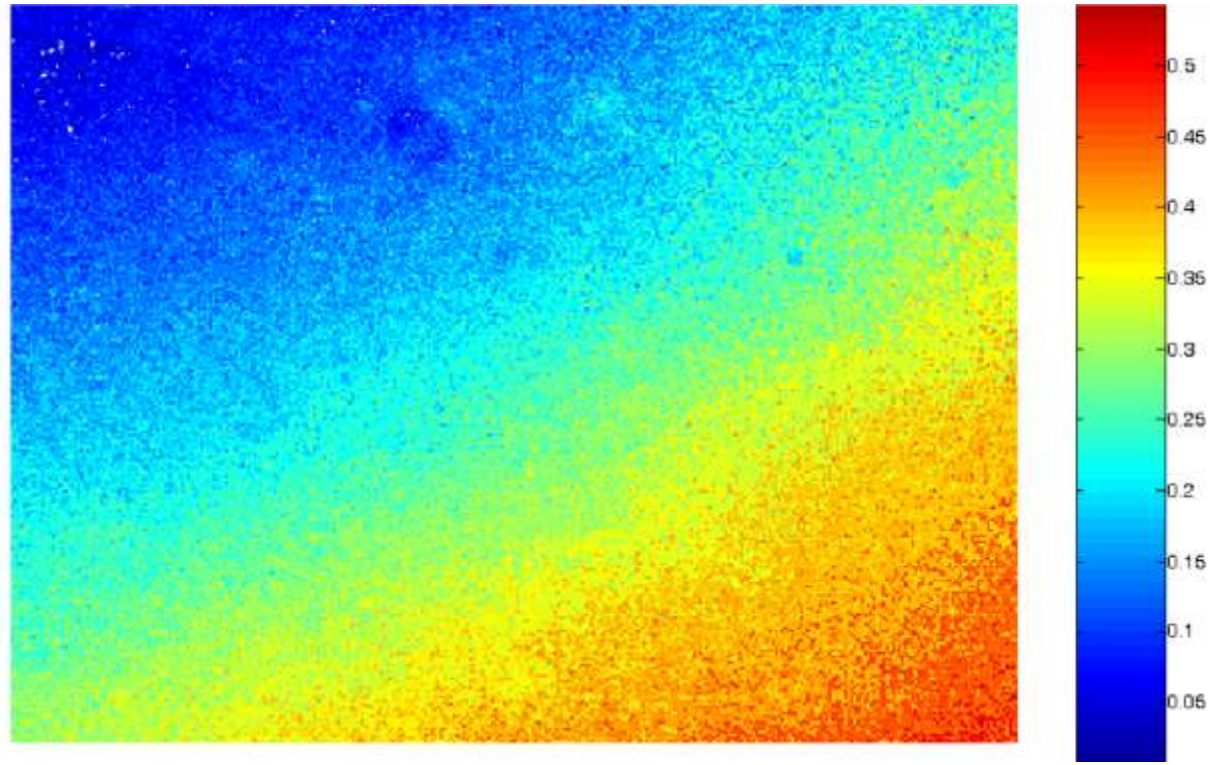
Polarization Map of the Sky (cont' d)

West, 20 degrees from zenith, at 10:30 AM

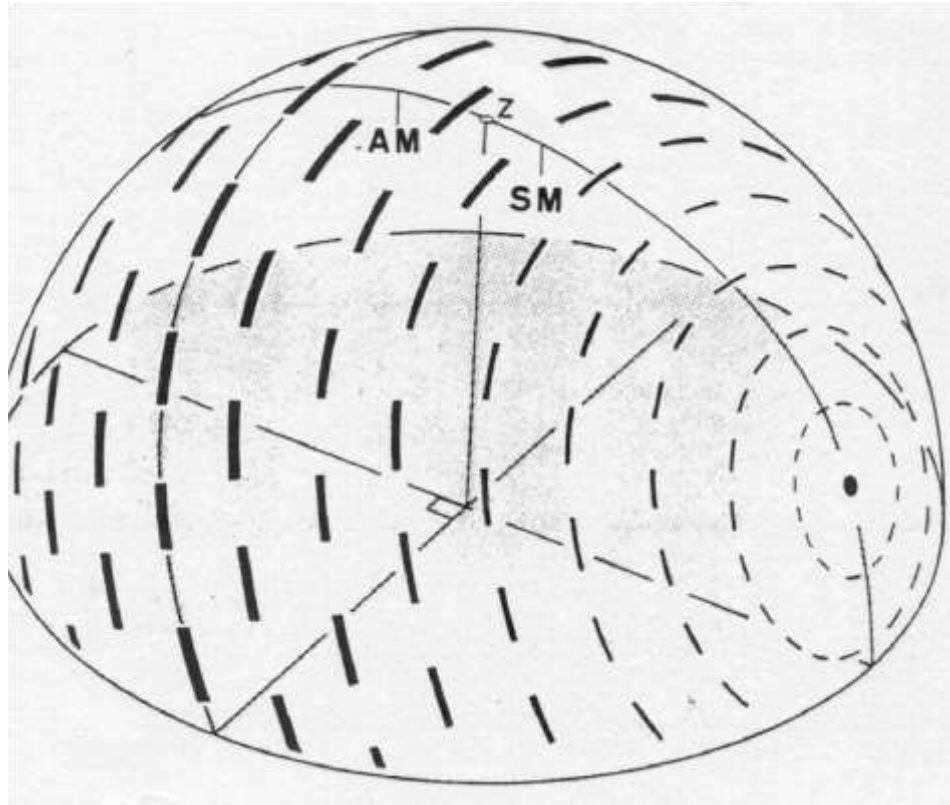
Polarization Map of the Sky (cont' d)

West, 20 degrees from zenith, at 10:30 AM

p

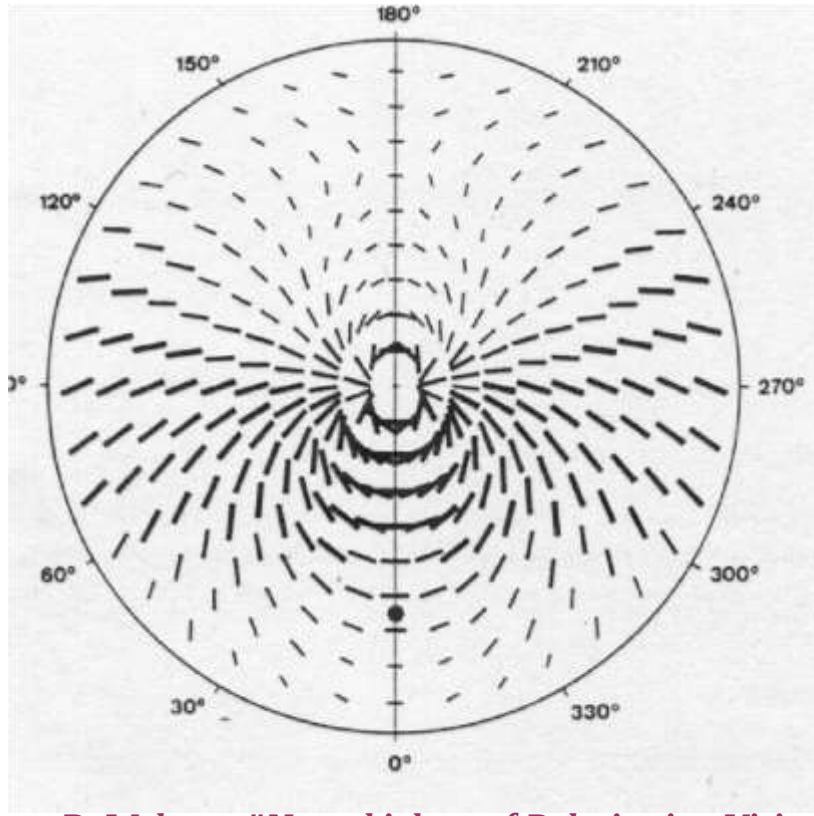


Polarization Map of the Sky



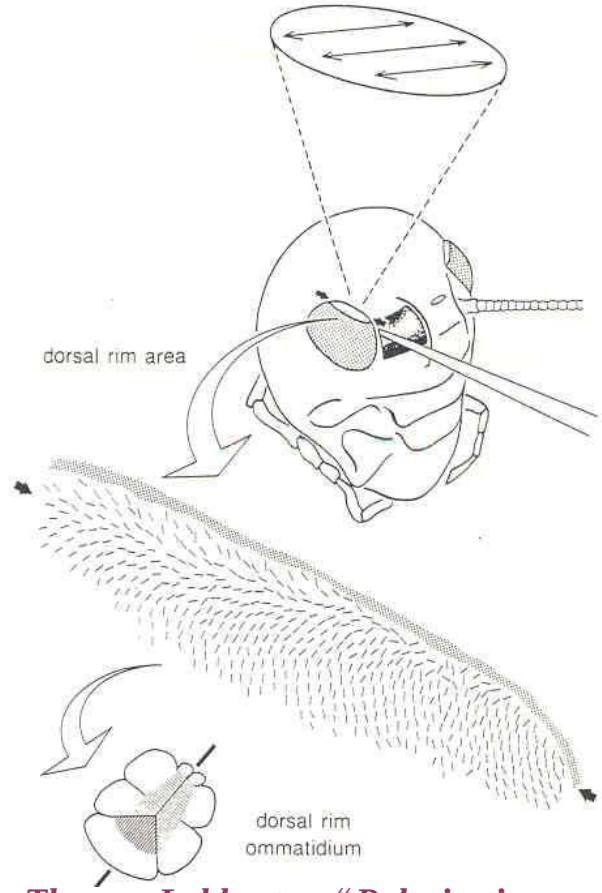
From: R. Wehner, "Neurobiology of Polarization Vision," Trends in Neurosciences, vol. 12, pp. 353-359, 1989.

Polarization Map of the Sky



From: R. Wehner, "Neurobiology of Polarization Vision," Trends in Neurosciences, vol. 12, pp. 353-359, 1989.

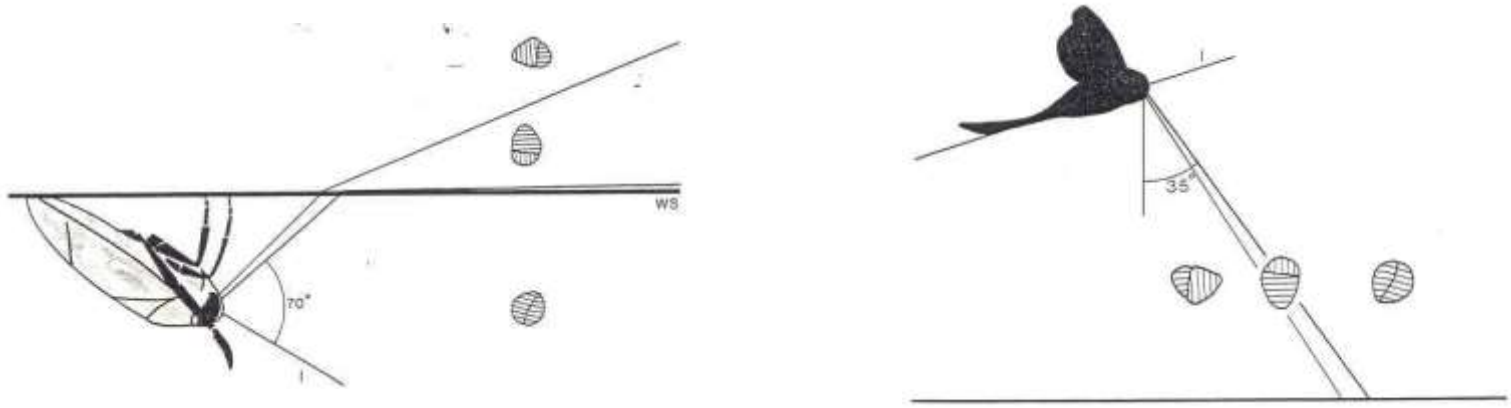
Polarization Vision in Insects



From: Thomas Labhart, "Polarization-opponent interneurons in the insect visual system", Nature, Vol. 331, p. 435, February 1988.

Why Do These Species Use Polarization Sensitivity?

- ***Enhancement of Target Detection and Recognition***
  - ***Water Surface Recognition by Flying Water Bugs, Notonecta glauca*** ***(Schwind, 1984)***



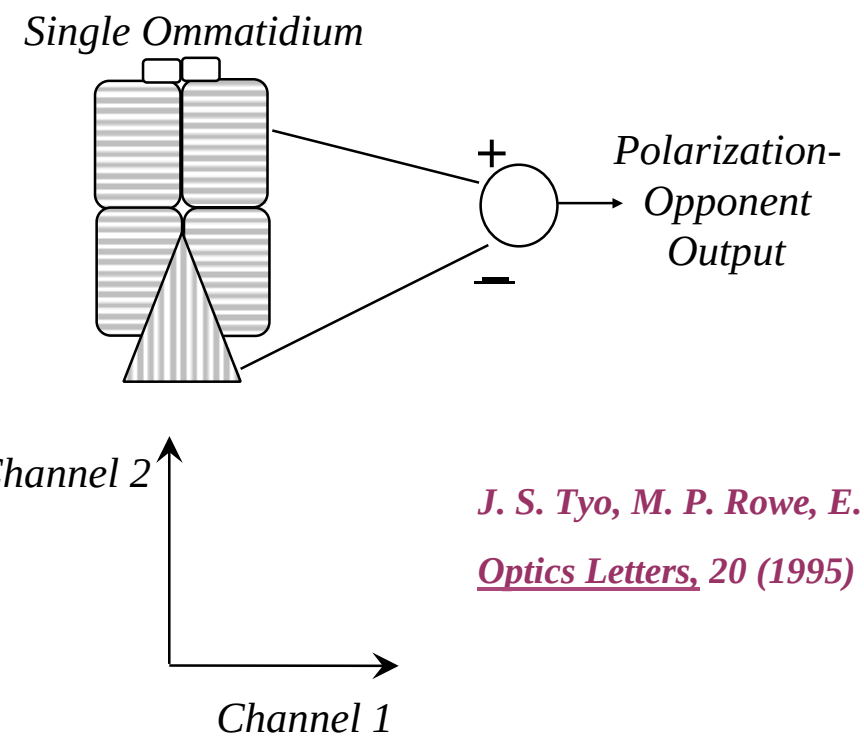
R. Schwind, Cell Tissue, 232, 53, (1983)

Bio-Inspired Sensing and Imaging

- ***Bio-Inspired Techniques to Enhance Detection***
  - *Target detection and visibility enhancement in scattering media*
  - *Increase of detection depth in scattering media*
  - *Adaptive algorithms in bio-inspired pol imaging*
  - *Surface deformation and variation detection using pol imaging*
  - *Skin imaging*
  - *Shadow removal using polarization imaging*

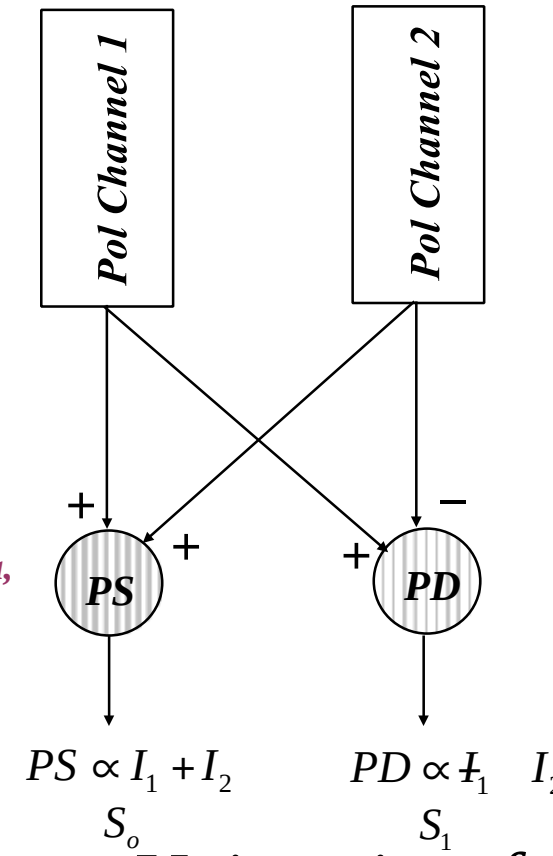
Bio-Inspiration in Imaging

- ***Enhancement of target detection and Improve Visibility in Scattering Media Using "polarization-difference imaging"***

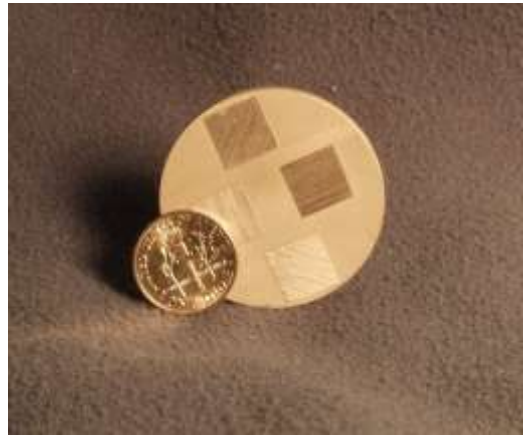


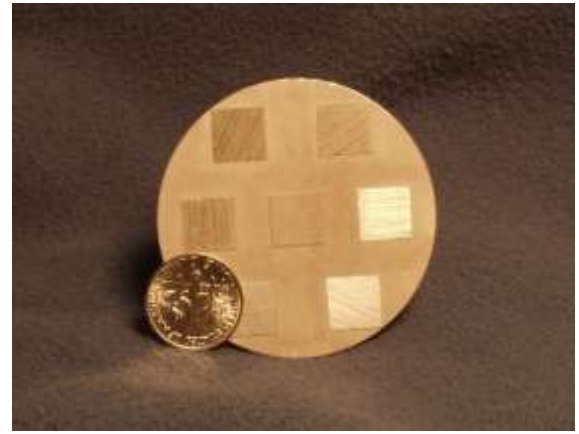
J. S. Tyo, M. P. Rowe, E. N. Pugh, N. Engheta,

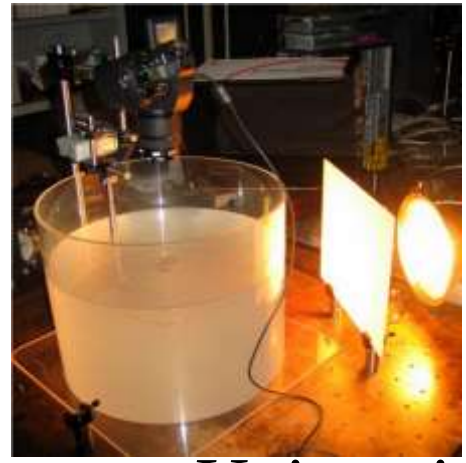
Optics Letters, 20 (1995)



Specially Designed Targets







J. S. Tyo, M. P. Rowe, E. N. Pugh, N. Engheta, Optics Letters, 20 (1995)

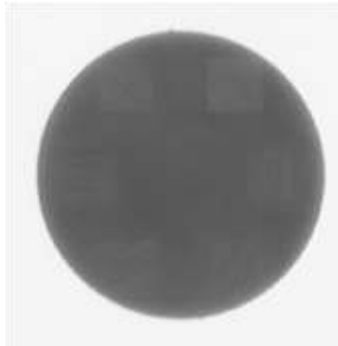
J. S. Tyo, M. P. Rowe, E. N. Pugh, N. Engheta, Applied Optics, 35 (1996)

J. S. Tyo, M. P. Rowe, E. N. Pugh, N. Engheta, J. Opt. Soc. Am. A, 15 (1998)

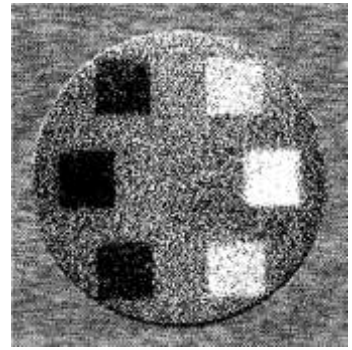
K. Yemelyanov, S.-S. Lin, E. N. Pugh, Jr., and N. Engheta, Applied Optics, 25 (2006)

Polarization-Sum (PS) and Polarization-Difference (PD) Images

- ***Enhancement of target detection and Improve Visibility in Scattering Media Using "polarization-difference imaging"***



$$I_{PS} = I_{\parallel} + I_{\perp}$$



$$I_{PD} = I_{\parallel} - I_{\perp}$$

Linear Contrast Enhancement with T = 10 %

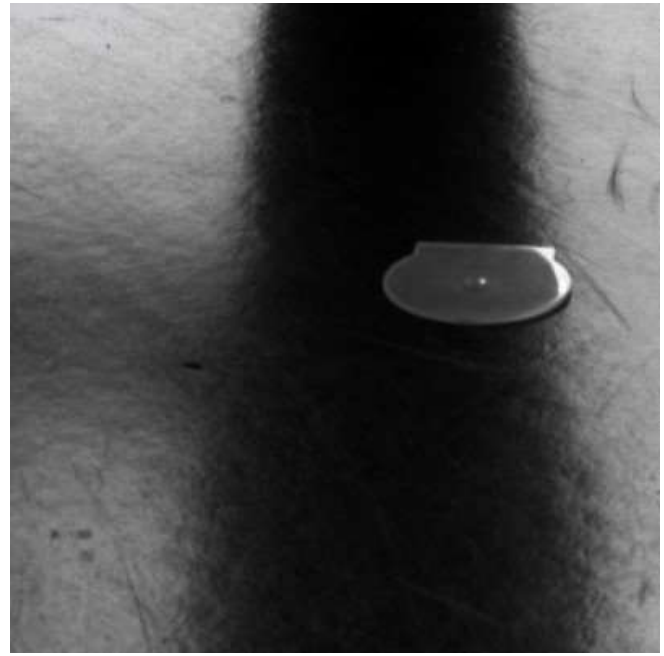
J. S. Tyo, M. P. Rowe, E. N. Pugh, N. Engheta, Optics Letters, 20 (1995)

K. Yemelyanov, S.-S. Lin, E. N. Pugh, Jr., and N. Engheta, Applied Optics, 25 (2006)

An Example

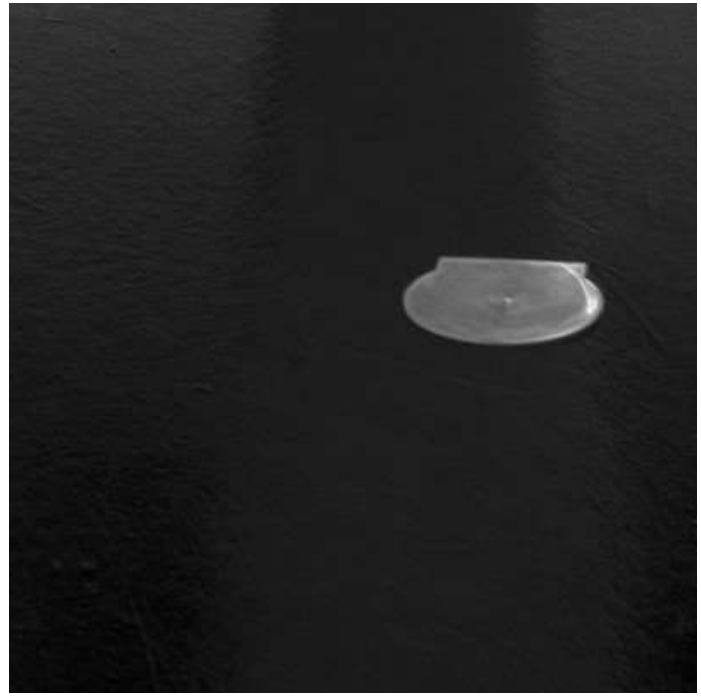
"Background"

"Target and Background"



K. Yemelyanov, S.-S. Lin, E. N. Pugh, Jr., and N. Engheta,Applied Optics, 25 (2006)

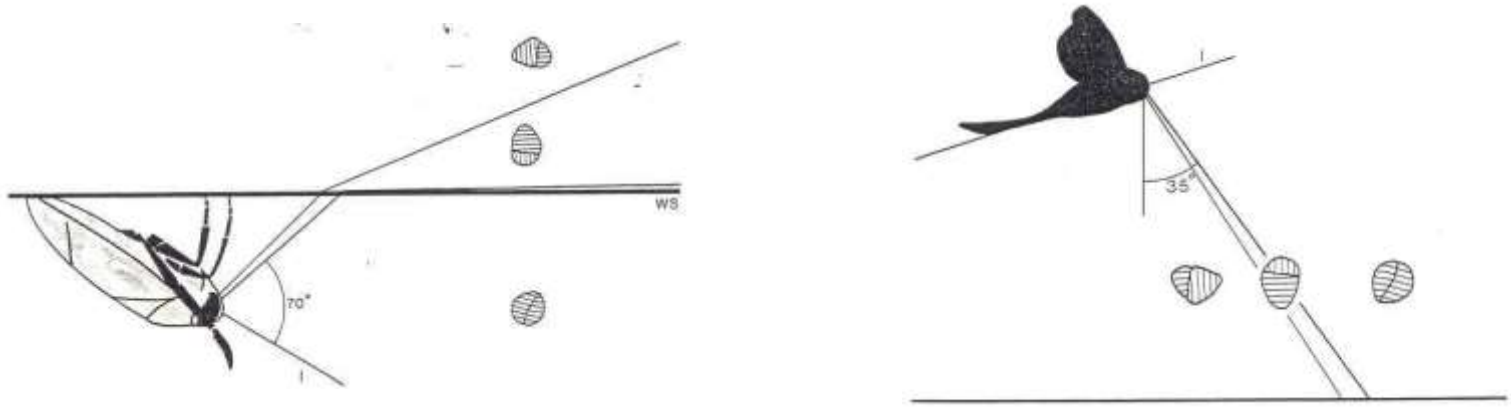
Adaptive Pol Imaging



K. Yemelyanov, S.-S. Lin, E. N. Pugh, Jr., and N. Engheta,Applied Optics, 25 (2006)

Surface Imaging

- ***Enhancement of Target Detection and Recognition***
  - ***Water Surface Recognition by Flying Water Bugs, Notonecta glauca*** ***(Schwind, 1984)***



R. Schwind, Cell Tissue, 232, 53, (1983)

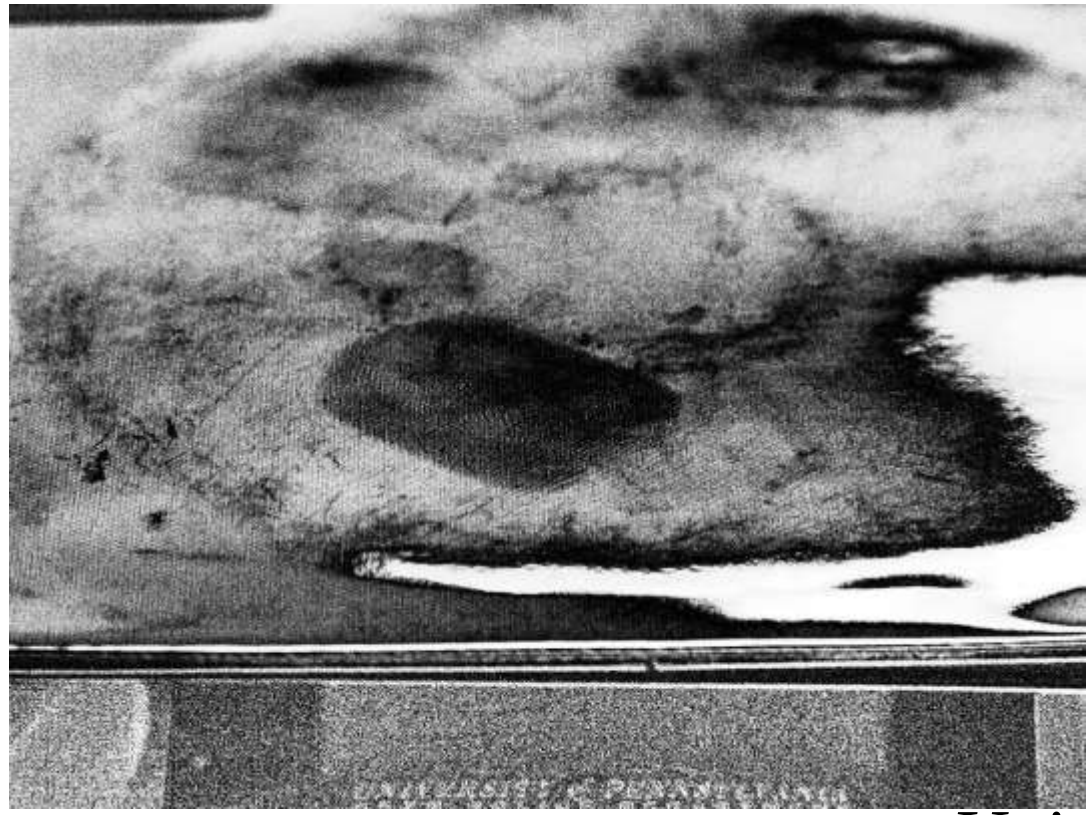
Surface Imaging

- ***What is this image?***

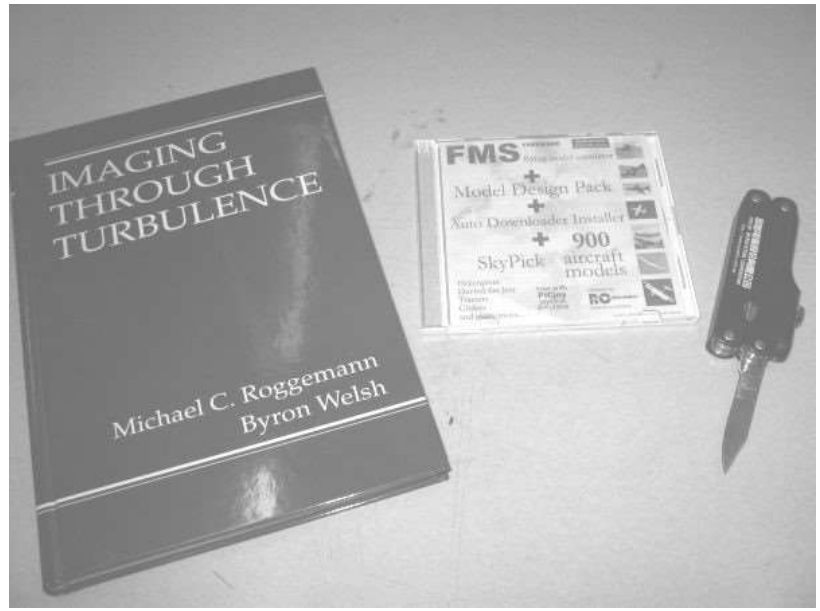
Surface Imaging

p

Histogram equalized

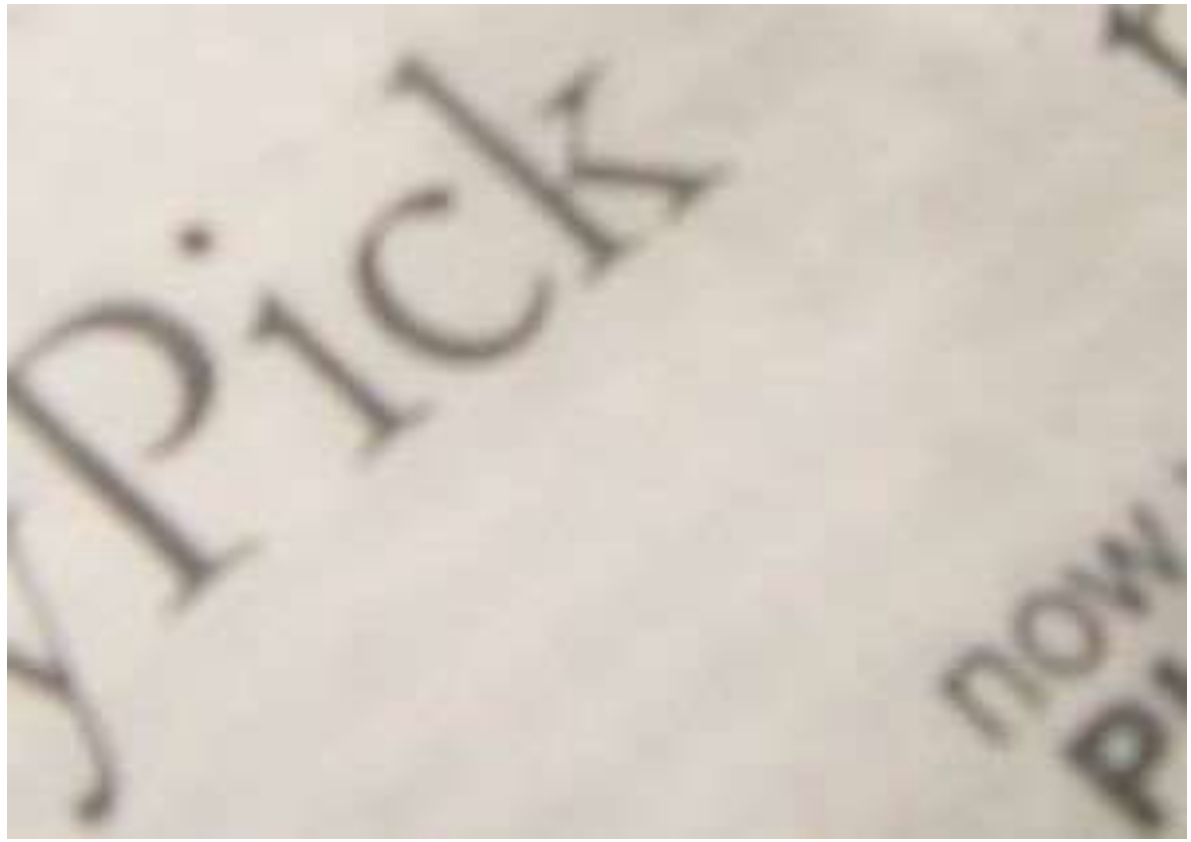


Fingerprint Imaging



S.-S. Lin, K. Yemelyanov,E. N. Pugh, Jr., and N. Engheta, J. Opt. Soc. Am. A, 23 (2006)

Fingerprint Imaging



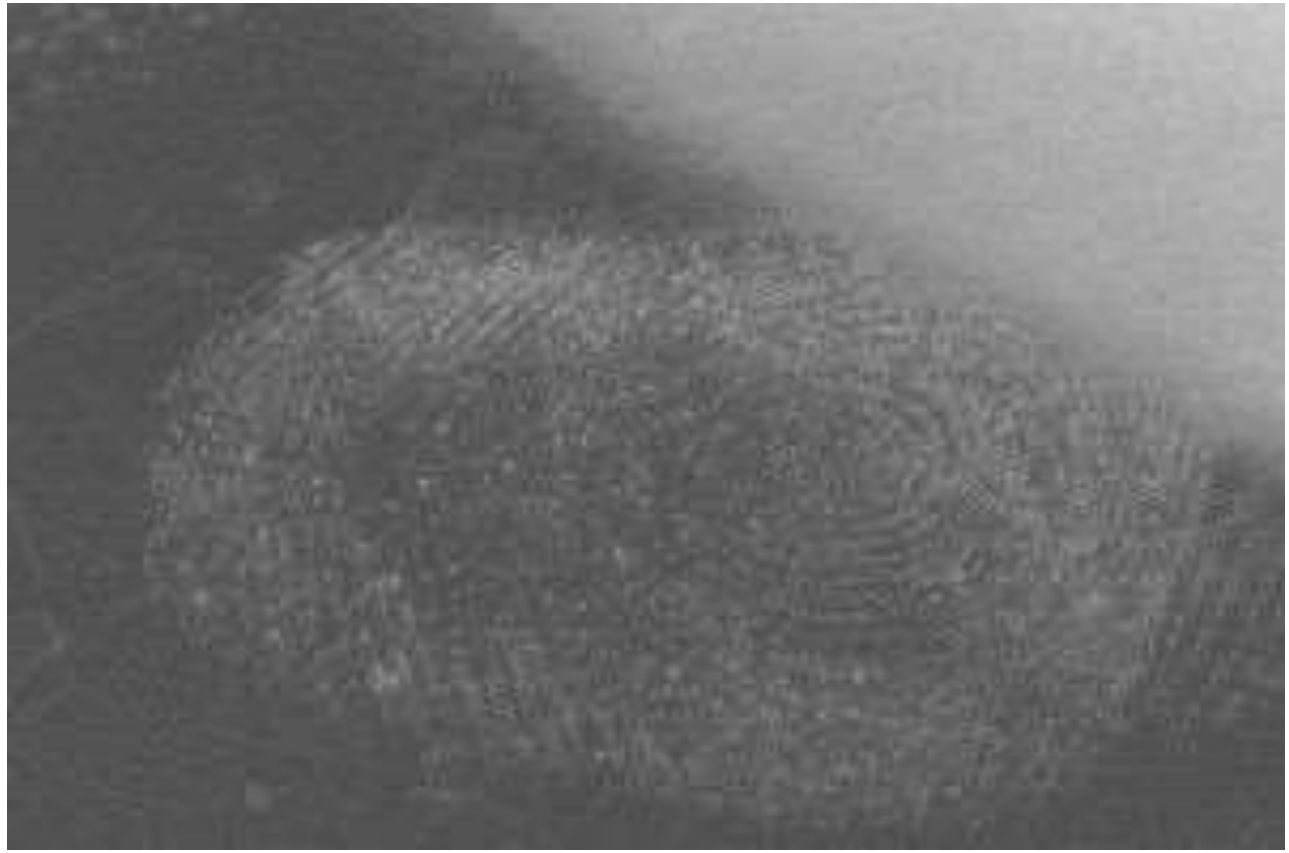
S.-S. Lin, K. Yemelyanov,E. N. Pugh, Jr., and N. Engheta, J. Opt. Soc. Am. A, 23 (2006)

Fingerprint Imaging

p – Histogram Equalized

S.-S. Lin, K. Yemelyanov, E. N. Pugh, Jr., and N. Engheta, J. Opt. Soc. Am. A, 23 (2006)

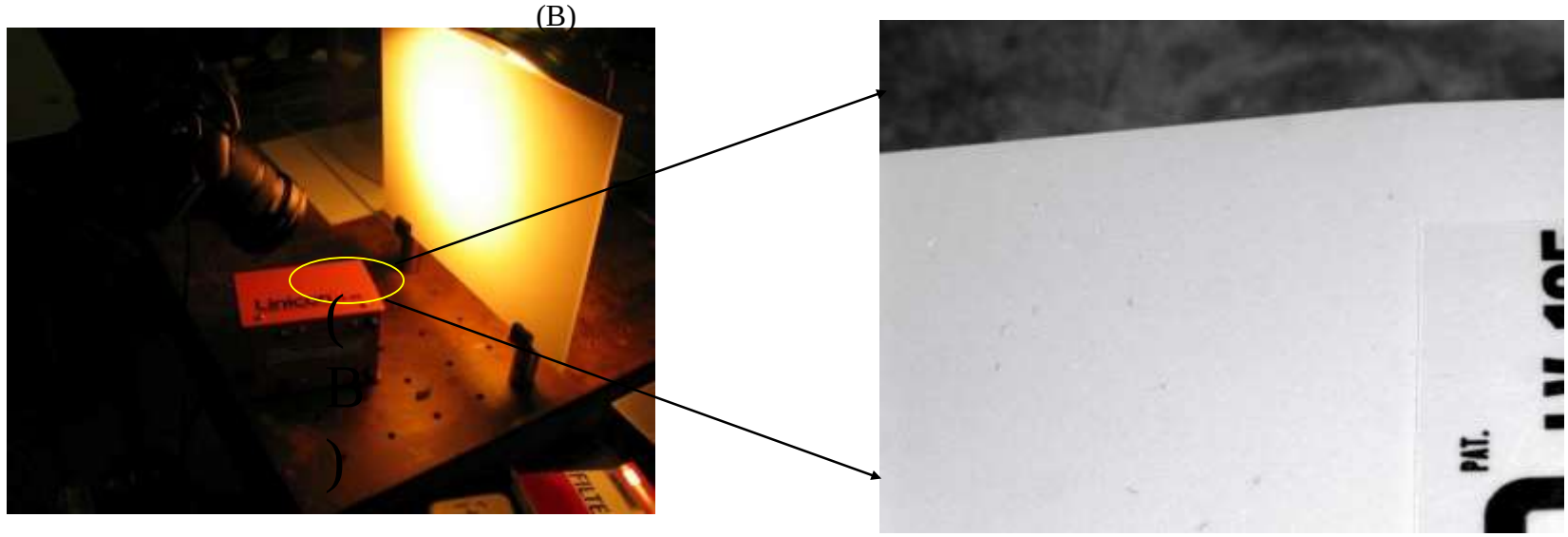
Fingerprint Imaging



p.Io – Histogram Equalized

S.-S. Lin, K. Yemelyanov, E. N. Pugh, Jr., and N. Engheta, J. Opt. Soc. Am. A, 23 (2006)

Fingerprint Imaging



Room Light-on, Special-Light-Off
Linear Contrast Enhanced

S.-S. Lin, K. Yemelyanov, E. N. Pugh, Jr., and N. Engheta, J. Opt. Soc. Am. A, 23 (2006)

Fingerprint Imaging

Special-Light-On
Histogram Equalized

Special-Light-On
Cropped – Linear Contrast Enhancement

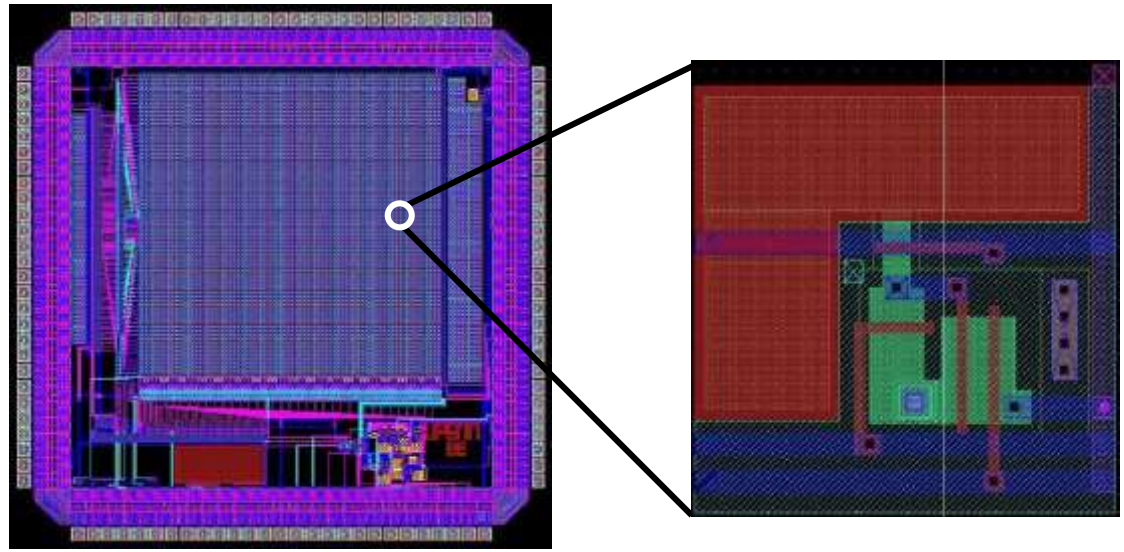
S.-S. Lin, K. Yemelyanov,E. N. Pugh, Jr., and N. Engheta, J. Opt. Soc. Am. A, 23 (2006)

Fingerprint Imaging

S.-S. Lin, K. Yemelyanov,E. N. Pugh, Jr., and N. Engheta, J. Opt. Soc. Am. A, 23 (2006)

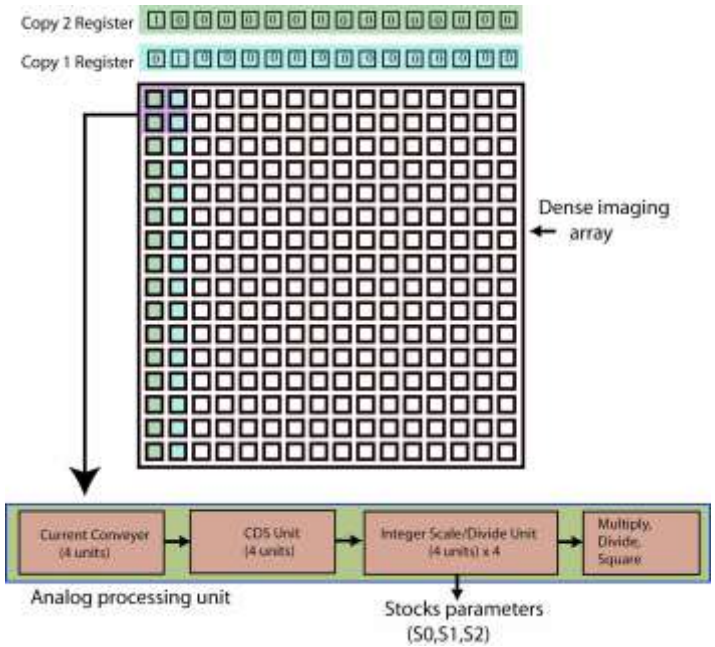
Integrated Microelectronic Polarimetric Camera Systems

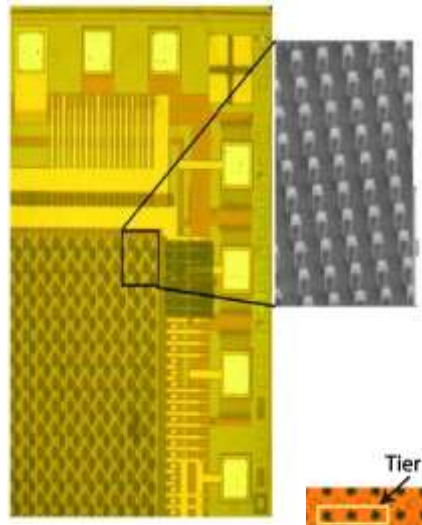
- ***With Viktor Gruev and Jan Van der Spiegel***

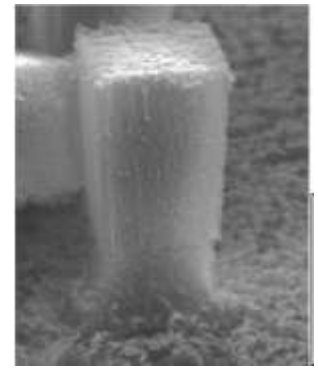


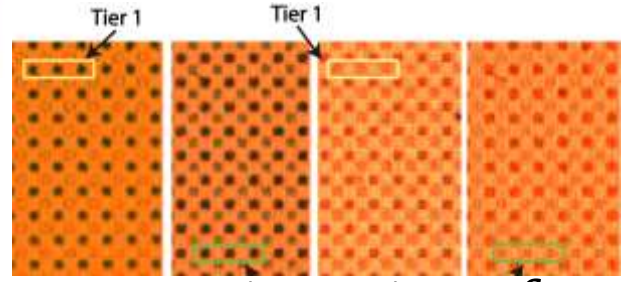
Integrated Microelectronic Polarimetric Camera Systems

- ***With Viktor Gruev and Jan Van der Spiegel***





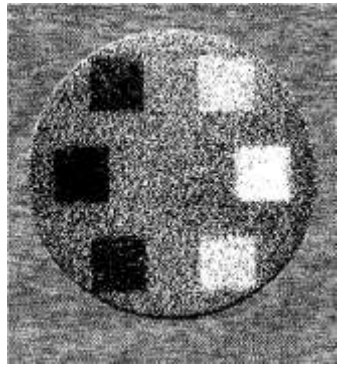


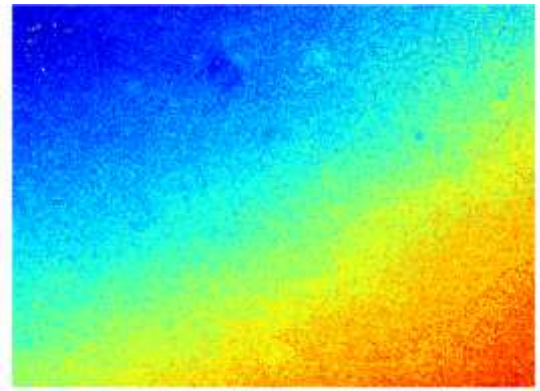


V. Gruev, A. Ortu, N. Lazarus, J. Van der Spiegel, and N. Engheta,Optics Express, 15 (2007)

Summary

- ***We can learn from the nature to explore interesting imaging systems***
- ***Polarization Vision is an interesting mechanism in imaging and sensing***





Thank you very much

University of Pennsylvania