Centre de Recherche en Numérique de Sfax

مركز البحث في الرقميات بصفاقس

3-D Vector Radiative Transfer for Vegetation Cover Polarized BRDF Modeling

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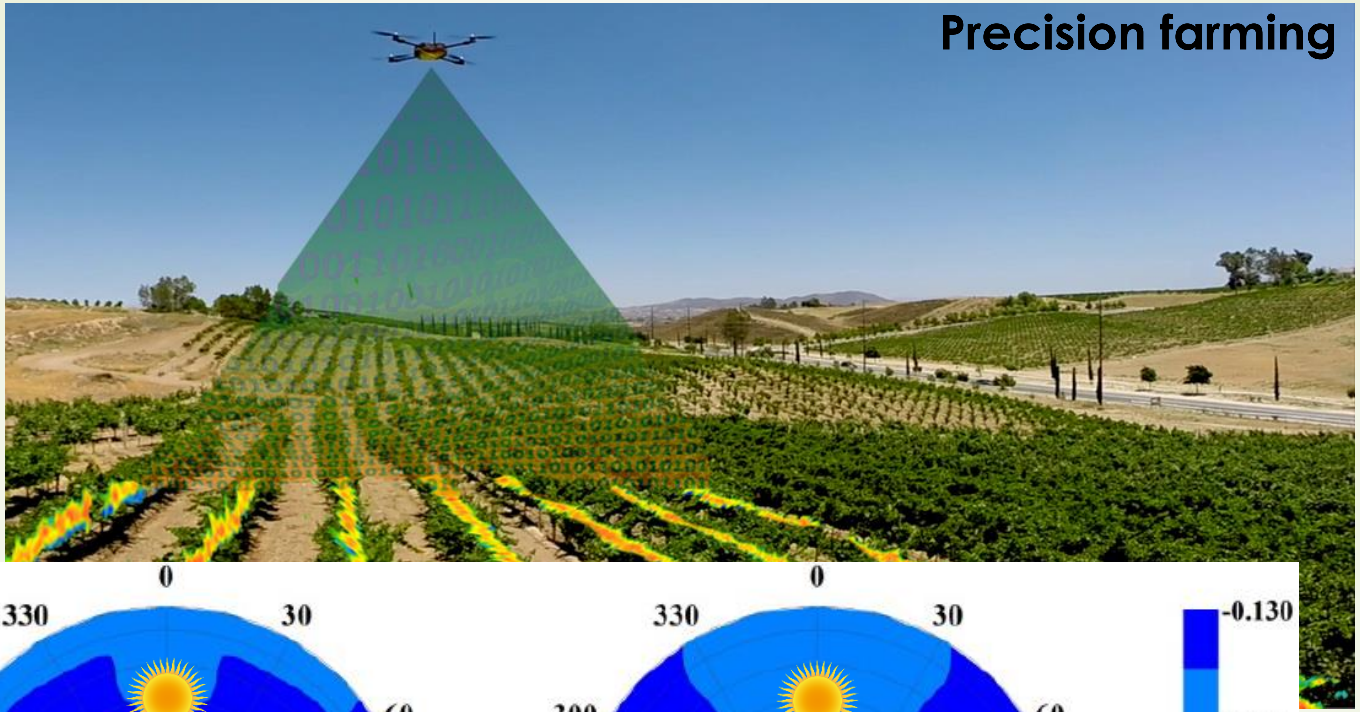
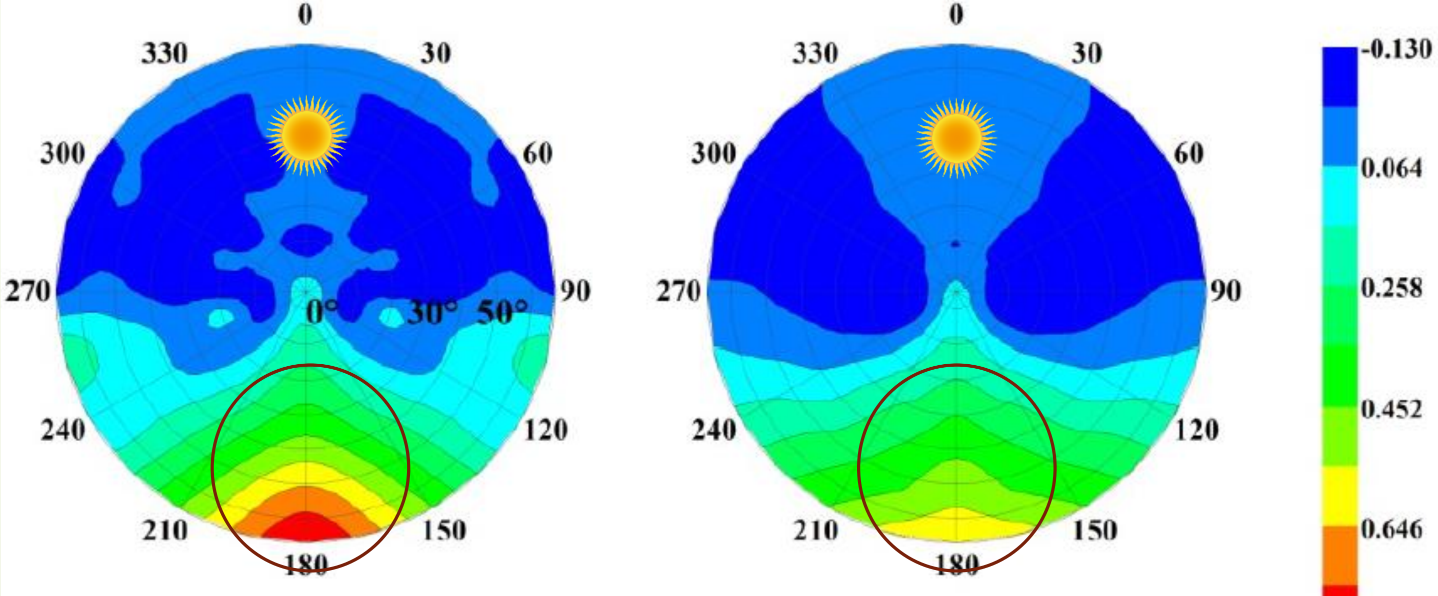
Plan

- Problematic
- Leaf scattering properties
- Vegetation polarized reflectance
- Experimental results
- Conclusion

Problematic





Planophile LIDF

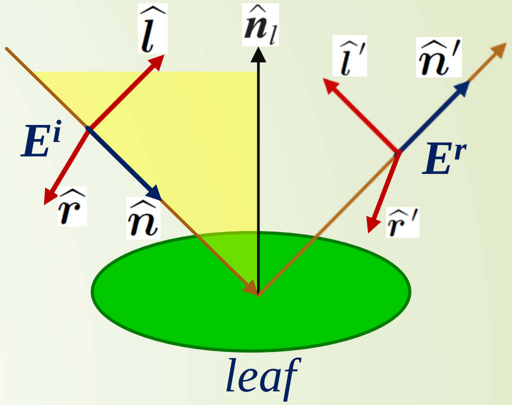
Erectophile LIDF

Polarimetric camera

Leaf interception and reflection

- $\boldsymbol{E}^i$: Transverse plane wave

$$\boldsymbol{E}^i = E_l^i \widehat{\boldsymbol{l}} + E_r^i \widehat{\boldsymbol{r}}$$



- Stokes vector

$$\boldsymbol{I} = \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} = \frac{1}{2}\sqrt{\frac{\epsilon_0}{\mu_0}} \begin{pmatrix} E_l E_l^* + E_r E_r^* \\ E_l E_l^* - E_r E_r^* \\ -E_l E_r^* - E_r E_l^* \\ j(E_r E_l^* - E_l E_r^*) \end{pmatrix}$$

- Leaf partially reflects specularly incident light

$$\begin{aligned} E_l^r &= R_l E_l^i \\ E_r^r &= R_r E_r^i \end{aligned}$$

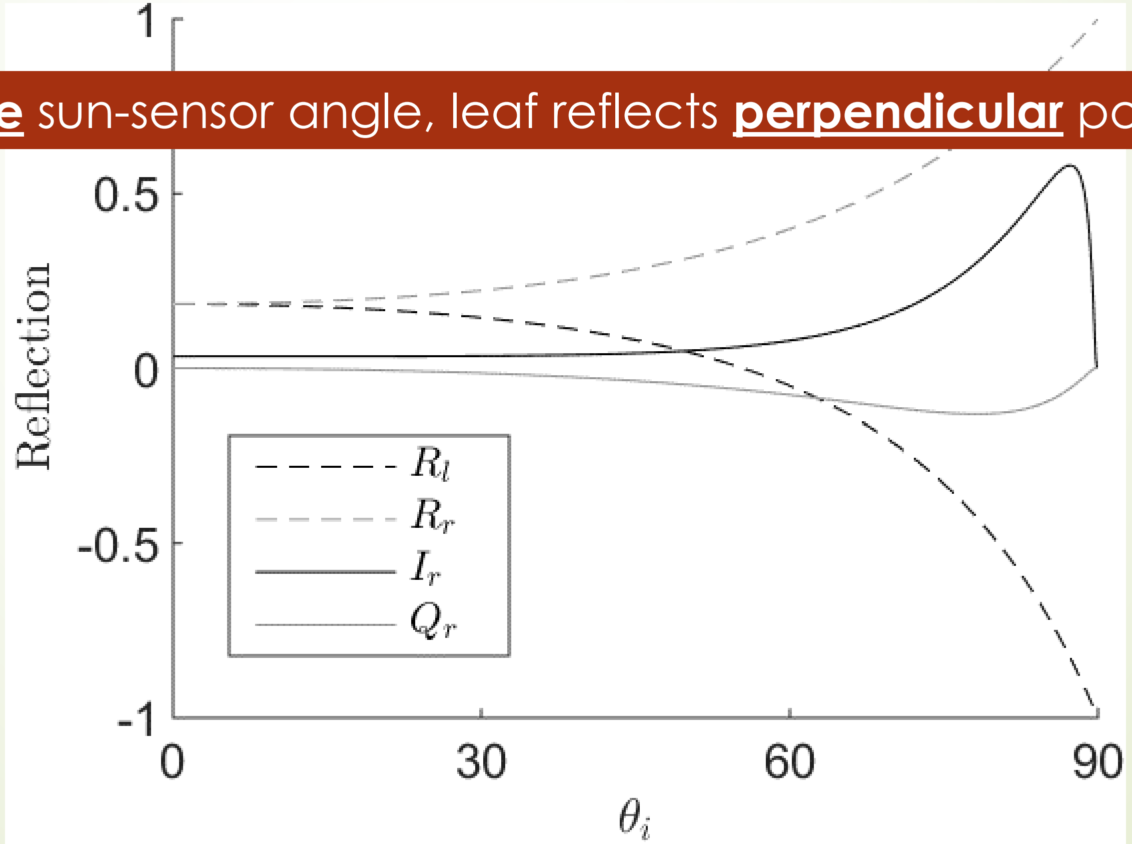
- In terms of Stokes vector :

Mueller matrix: M

$$\boldsymbol{I}_r = \frac{1}{2} \begin{pmatrix} R_l^2 + R_r^2 & R_l^2 - R_r^2 & 0 & 0 \\ R_l^2 - R_r^2 & R_l^2 + R_r^2 & 0 & 0 \\ 0 & 0 & 2R_l R_r & 0 \\ 0 & 0 & 0 & 2R_l R_r \end{pmatrix} \boldsymbol{I}_i$$

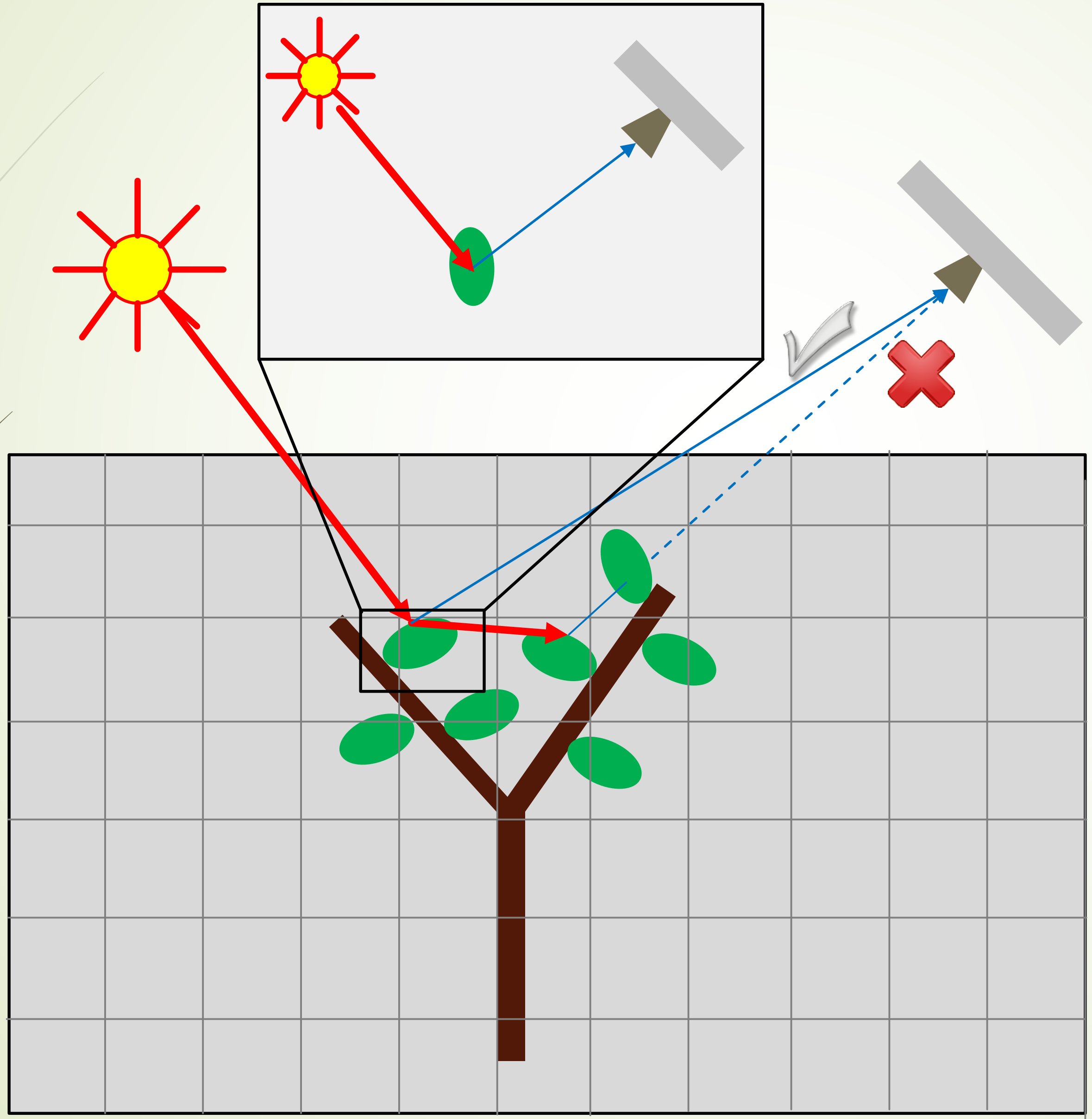
Polarization example

- Incident light is unpolarized : $\mathbf{I}_i = \begin{bmatrix}1\\0\\0\\0\end{bmatrix} \Rightarrow \mathbf{I}_r = \begin{bmatrix}I_r\\Q_r\\U_r\\V_r\end{bmatrix} = \frac{1}{2}\begin{bmatrix}R_l^2 + R_r^2\\R_l^2 - R_r^2\\0\\0\end{bmatrix}$



For **<u>large</u>** sun-sensor angle, leaf reflects **<u>perpendicular</u>** polarized light

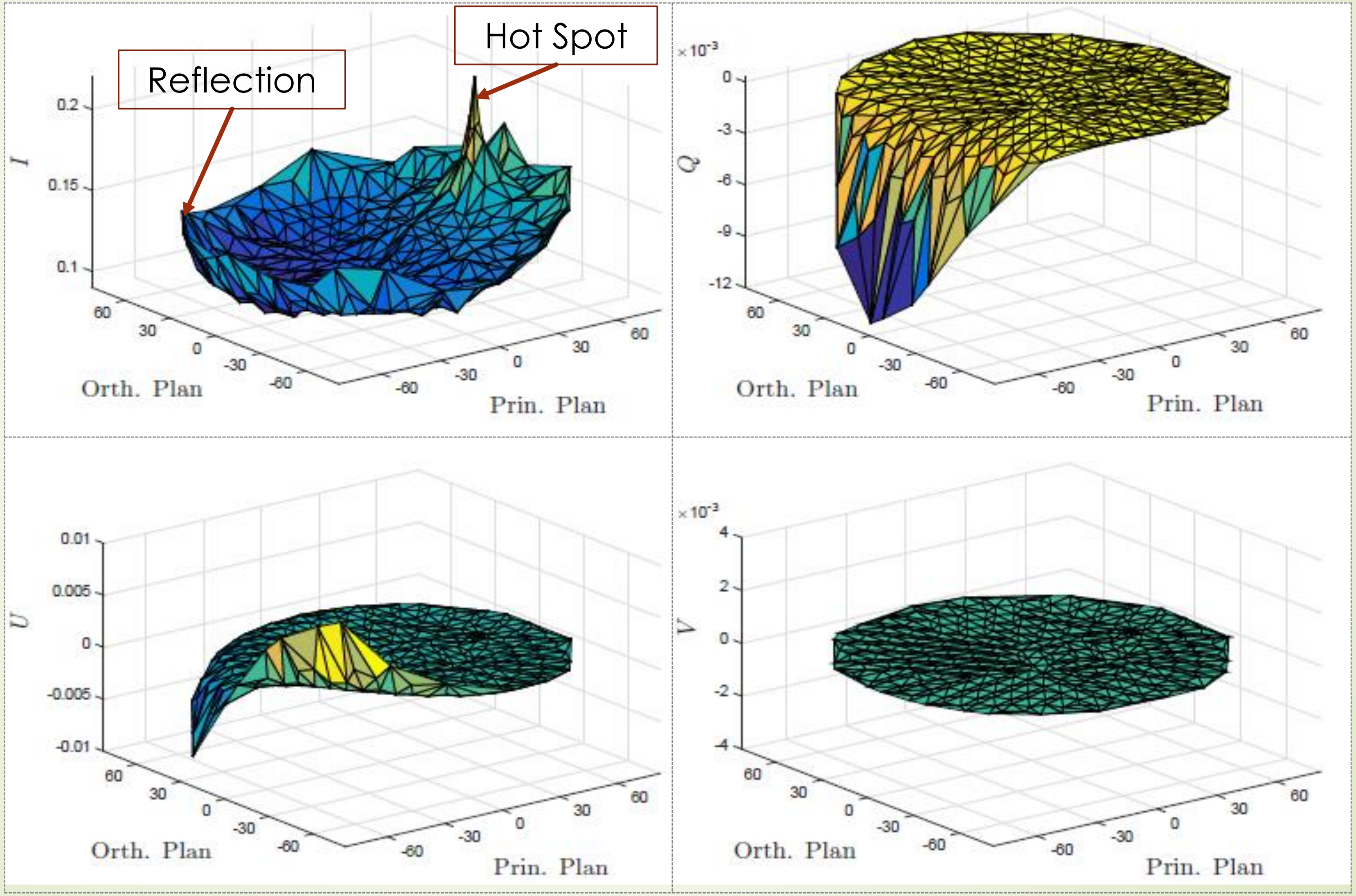
Monte Carlo: Ray Tracing



- **Tracking**
  - Voxel by voxel
  - Interception checking
- **Scattering**
  - Bi-Lambertian scattering
    - Random direction
    - Polarization remove
  - Specular reflection
    - Specular direction
    - Polarization introduction
- **Reflectance**
  - Photon spreading
  - Non-stationary MC:
    - leaf orientation randomize
    - Probability of reaching the sensor

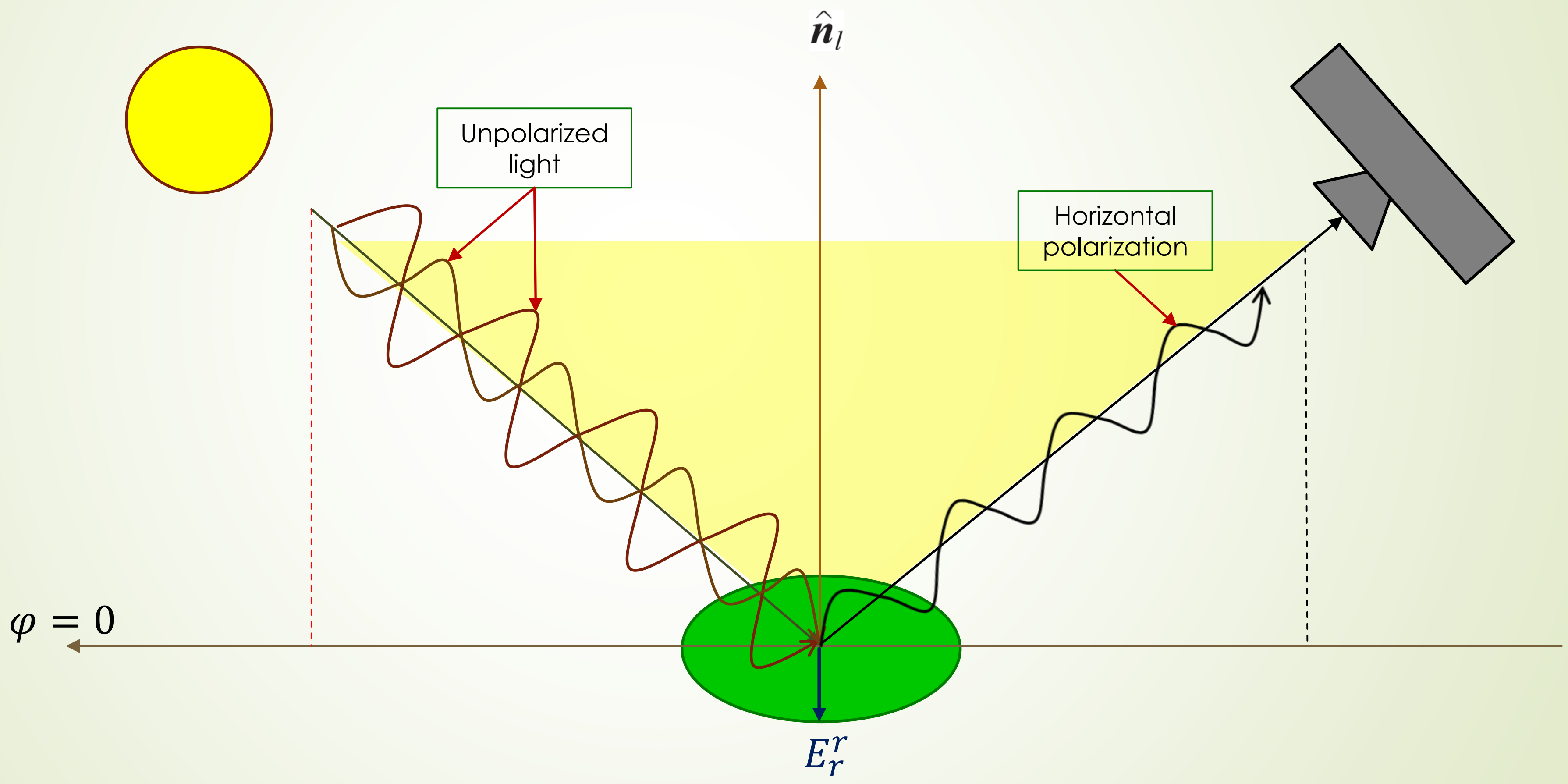
Experimental Results

LAI=2; $(\rho, \tau) = (0.2, 0, 2)$; LiDF=planophile; $\theta_s = 50^o$;



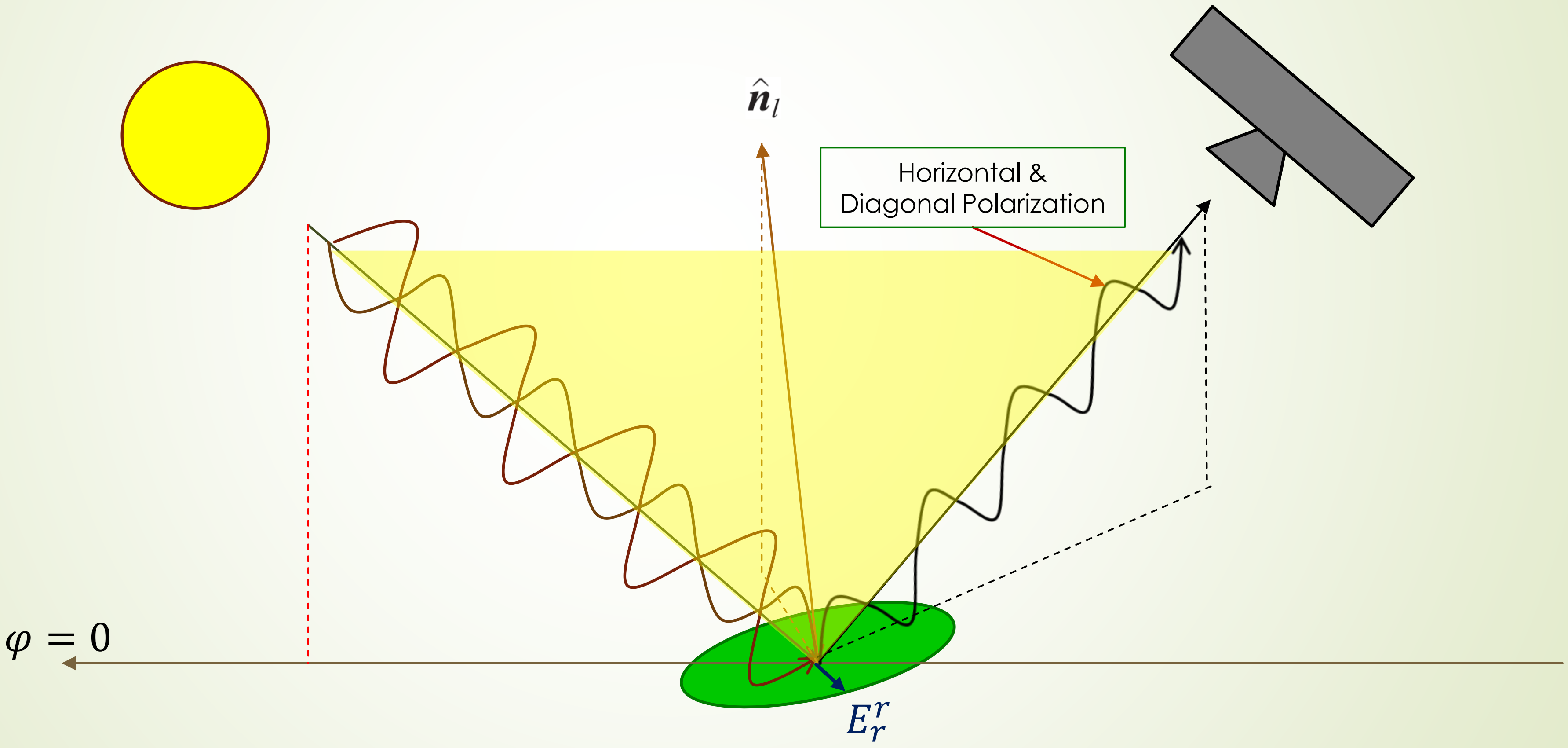
Forward Interpretation:

Horizontal polarization



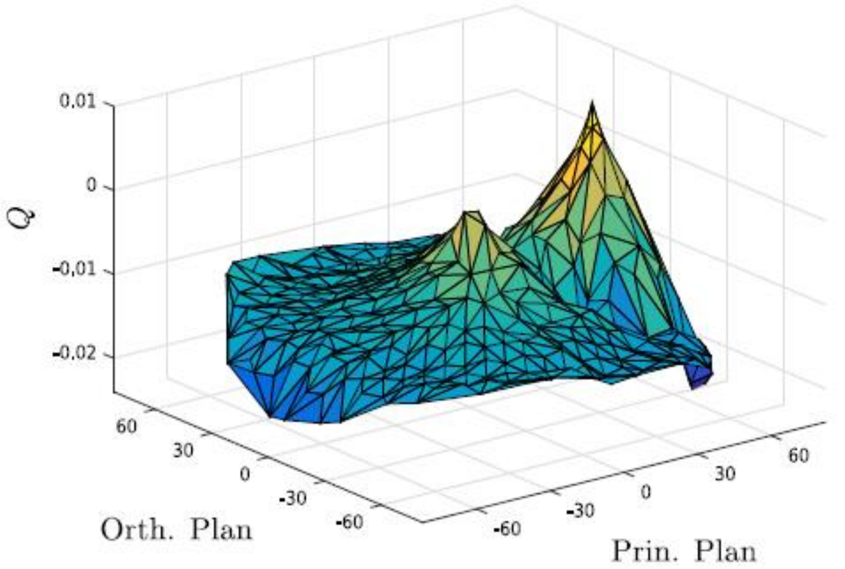
Inclined-Forward Interpretation:

Diagonal Polarization

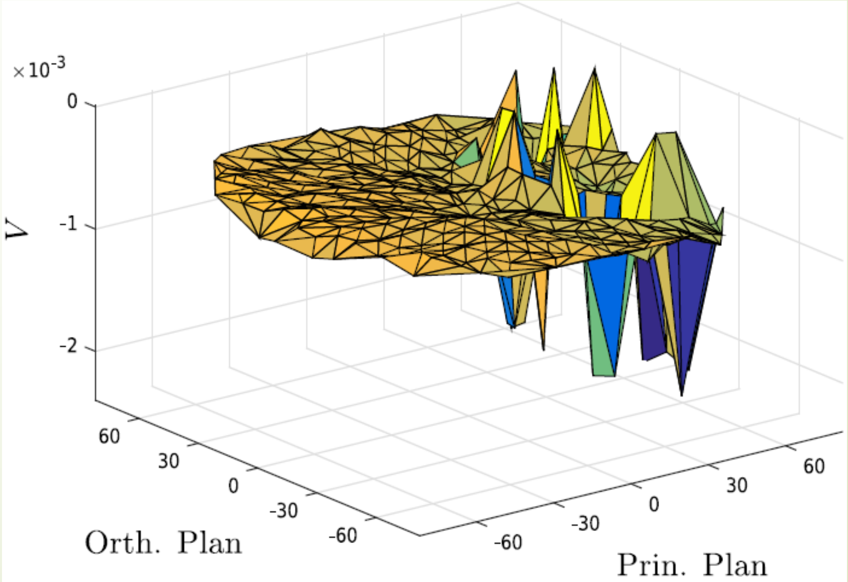


More realistic results

- Leaves produce negative polarization: coherent scattering in the backscattering direction (Martin et al. 2010)

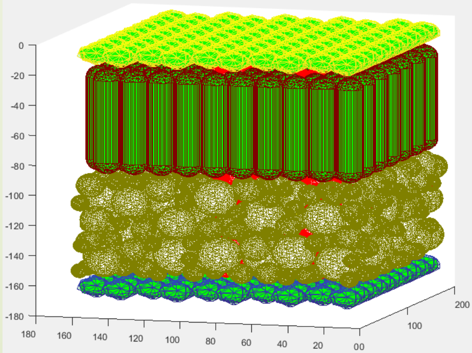


- Leaves produce circular polarization: circular dichroism due to the asymmetric chlorophyll absorption (Martin et al. 2010)



Conclusion

- Forward VRTM is proposed
  - Mueller Matrix
  - Monte Carlo ray tracing
- Results
  - Leaves highly polarize light for high sun-sensor angles
  - Horizontal polarization is observed in forward direction
  - Diagonal polarization is observed in the inclined-forward direction
- Perspectives
  - Extend the model to simulate polarization within leaves
  - Couple within leaves and within canopy models



Thank you for your attention