The Pol-InSAR Course

Synthetic Aperture Radar (SAR)

Part 3: SAR Polarimetry

Prepared by DLR-HR's Pol-InSAR Team

German Aerospace Center (DLR), Microwaves & Radar Institute (HR), Pol-InSAR Research Group

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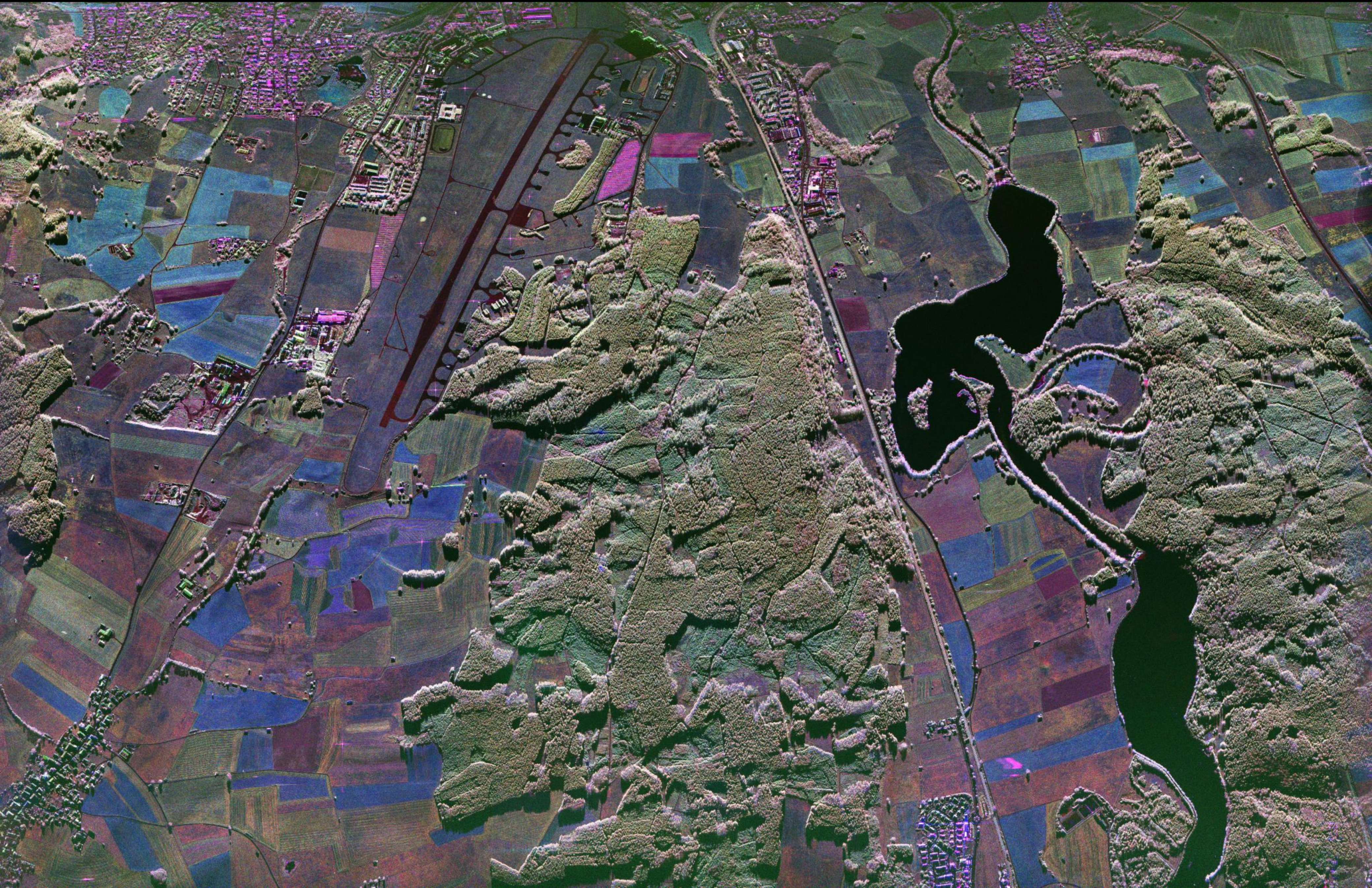
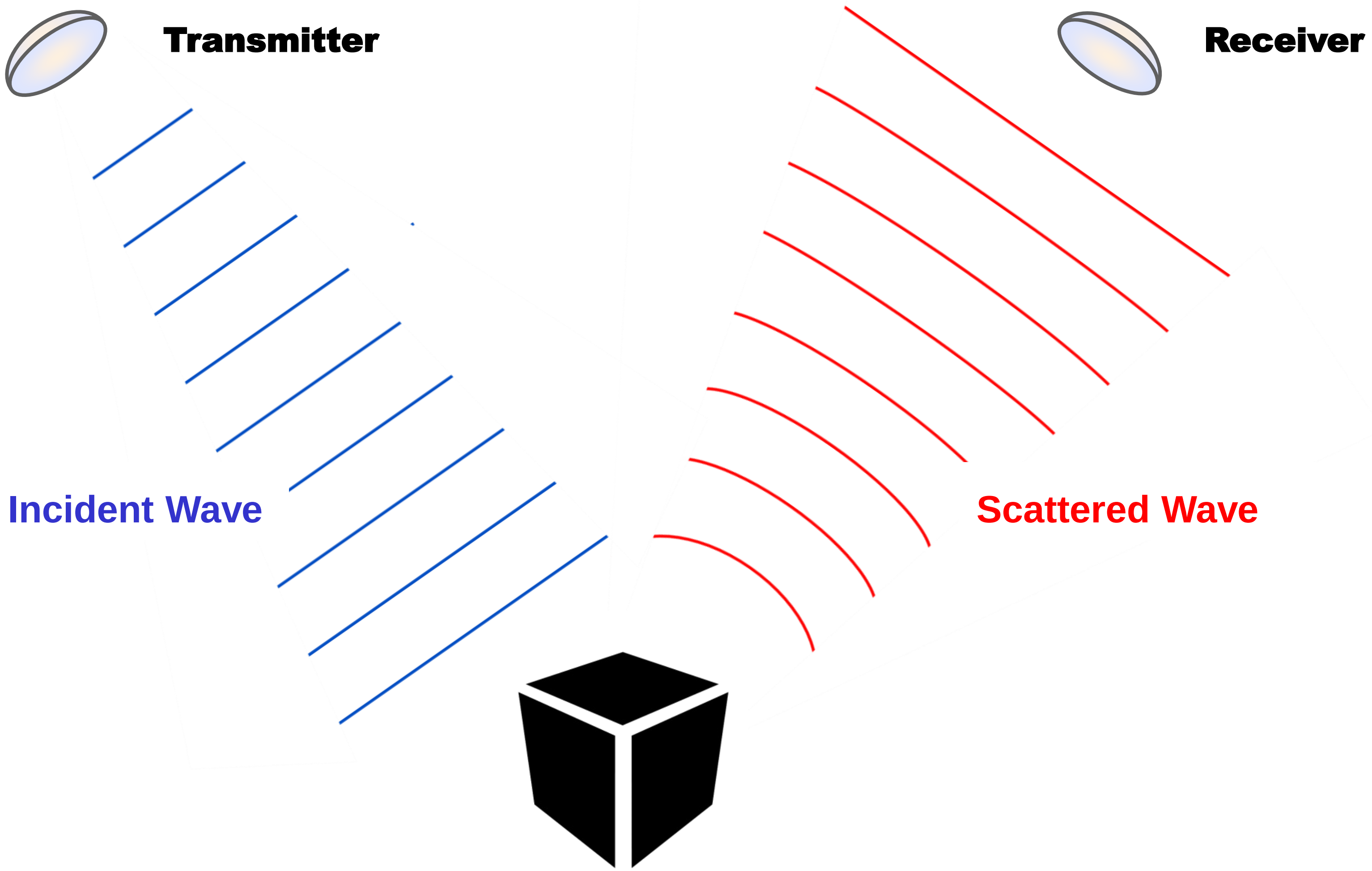
DLR esa ESAMAAP EEBIOMASS

F-SAR (DLR), Kaufbeuren, X-Band, HH - Pol

F-SAR (DLR), Kaufbeuren, X-Band, Quad-Pol

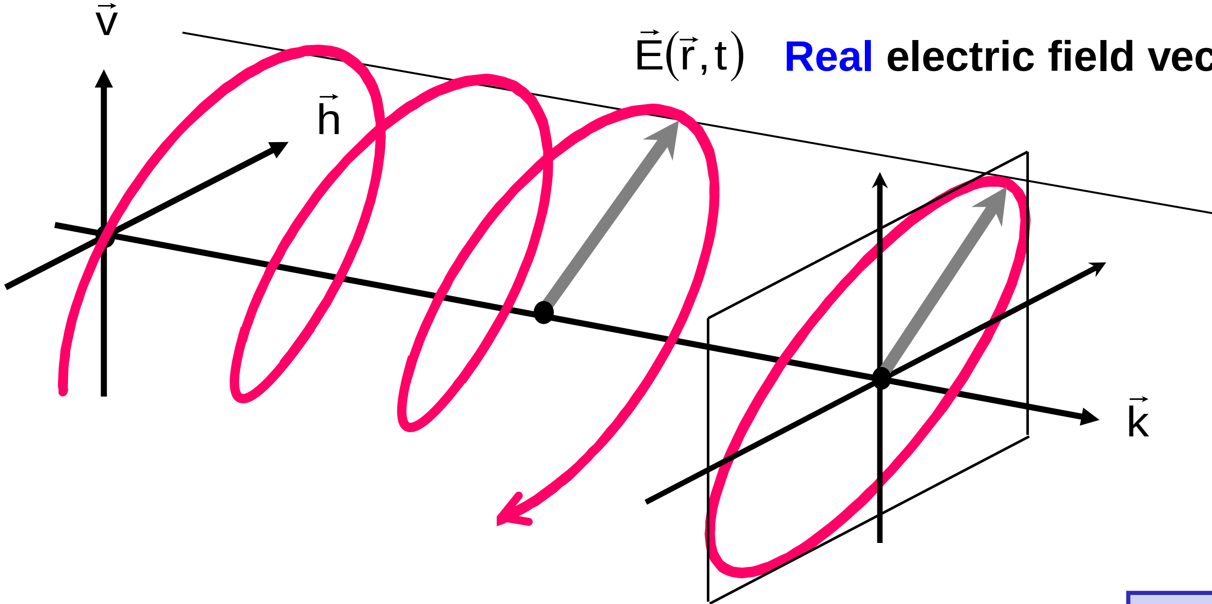


The Scattering Problem



The Scatterer transforms the incident into the scattered wave

$\vec{E}(\vec{r},t)$ **Real electric field vector** ⇨ $(\vec{h}, \vec{v}, \vec{k})$ **Coordinate system**

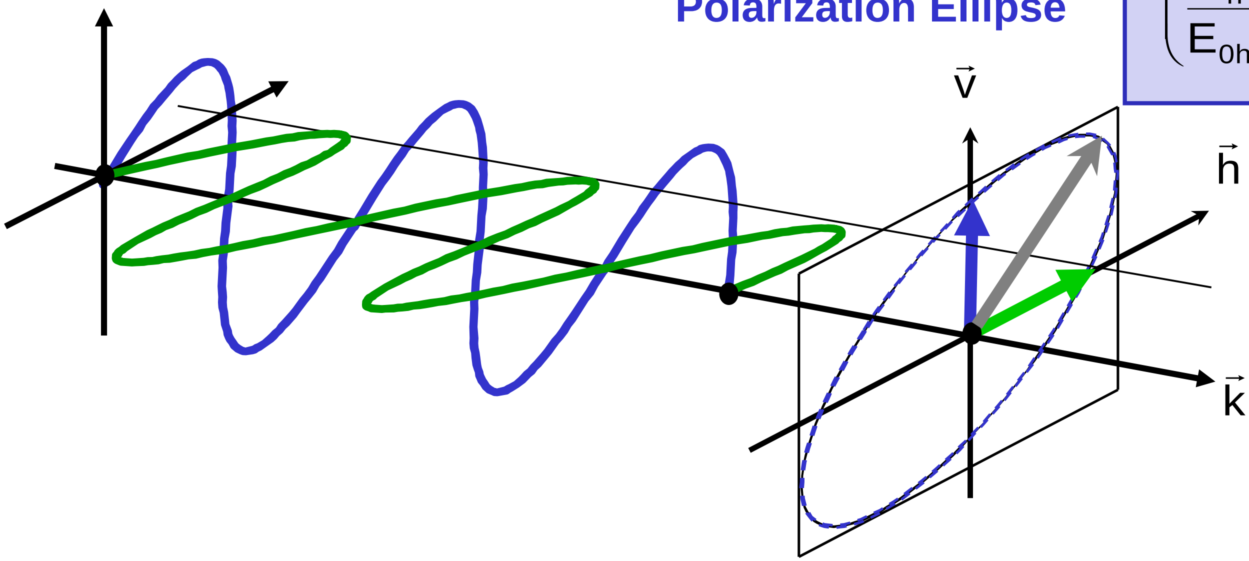


$$\vec{E}(\vec{r},t) = \begin{cases} E_h \\ E_v \\ E_k \end{cases}$$

Polarization Ellipse

$$\left(\frac{E_h}{E_{0h}}\right)^2 - 2\frac{E_h E_v}{E_{0h}E_{0v}}\cos(\delta) + \left(\frac{E_v}{E_{0v}}\right)^2 = \sin^2(\delta)$$

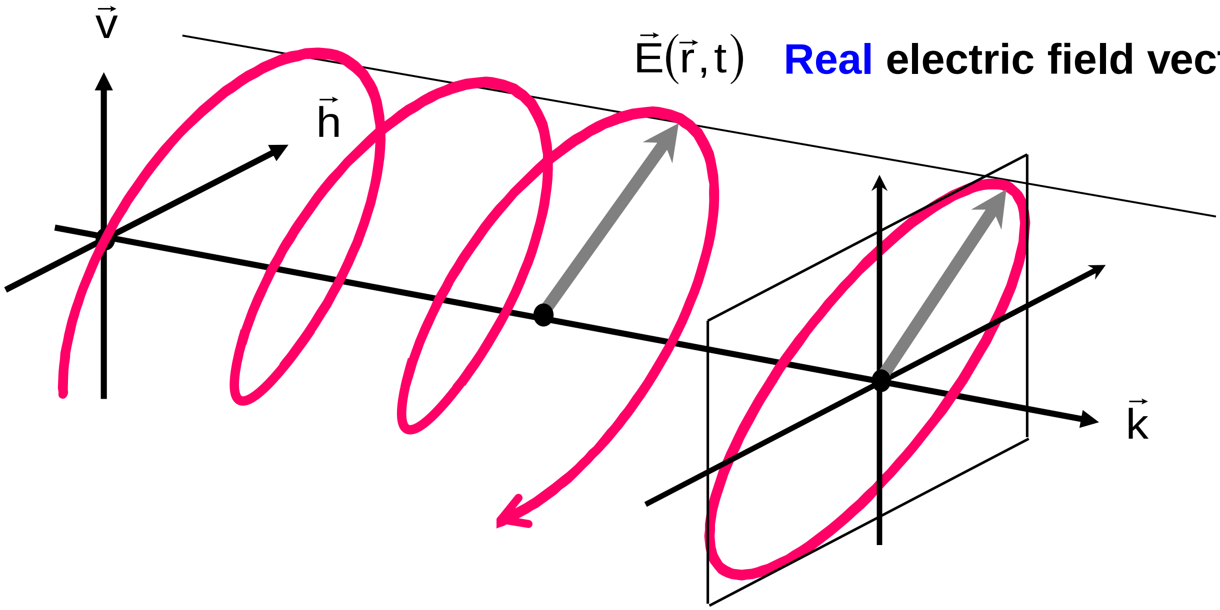
with: $\delta = \delta_v - \delta_h$



As a function of time the electric field vector $\vec{E}(\vec{r},t)$ traces out an ellipse which lies on a plane orthogonal to the direction of propagation (plane wave)

Polarisation is an intrinsic property of the wave; independent of the presence of a coordinate system. But, a coordinate system is needed to describe the polarisation state of the wave.

$\vec{E}(\vec{r},t)$ **Real electric field vector** ⇨ $(\vec{h},\ \vec{v},\ \vec{k})$ **Coordinate system**



⇩ **Plane Wave**

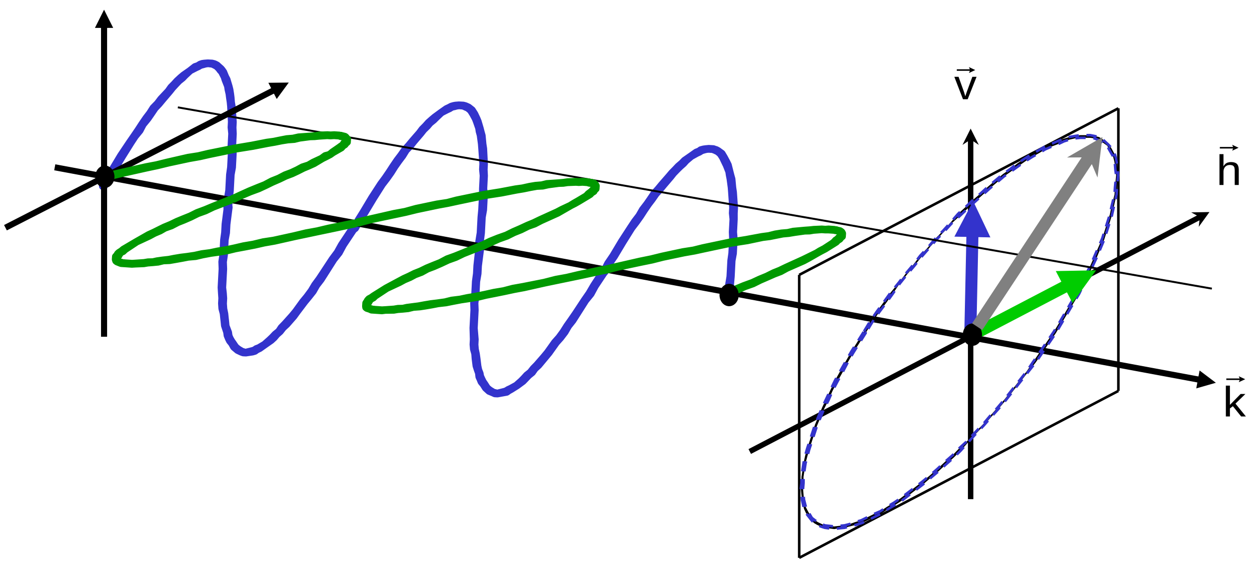
$$\vec{E}(\vec{r},t)=\begin{cases} E_h = E_{0h}\cos(\omega t - kr - \delta_h) \\ E_v = E_{0v}\cos(\omega t - kr - \delta_v) \\ E_k = 0 \end{cases}$$

⇩

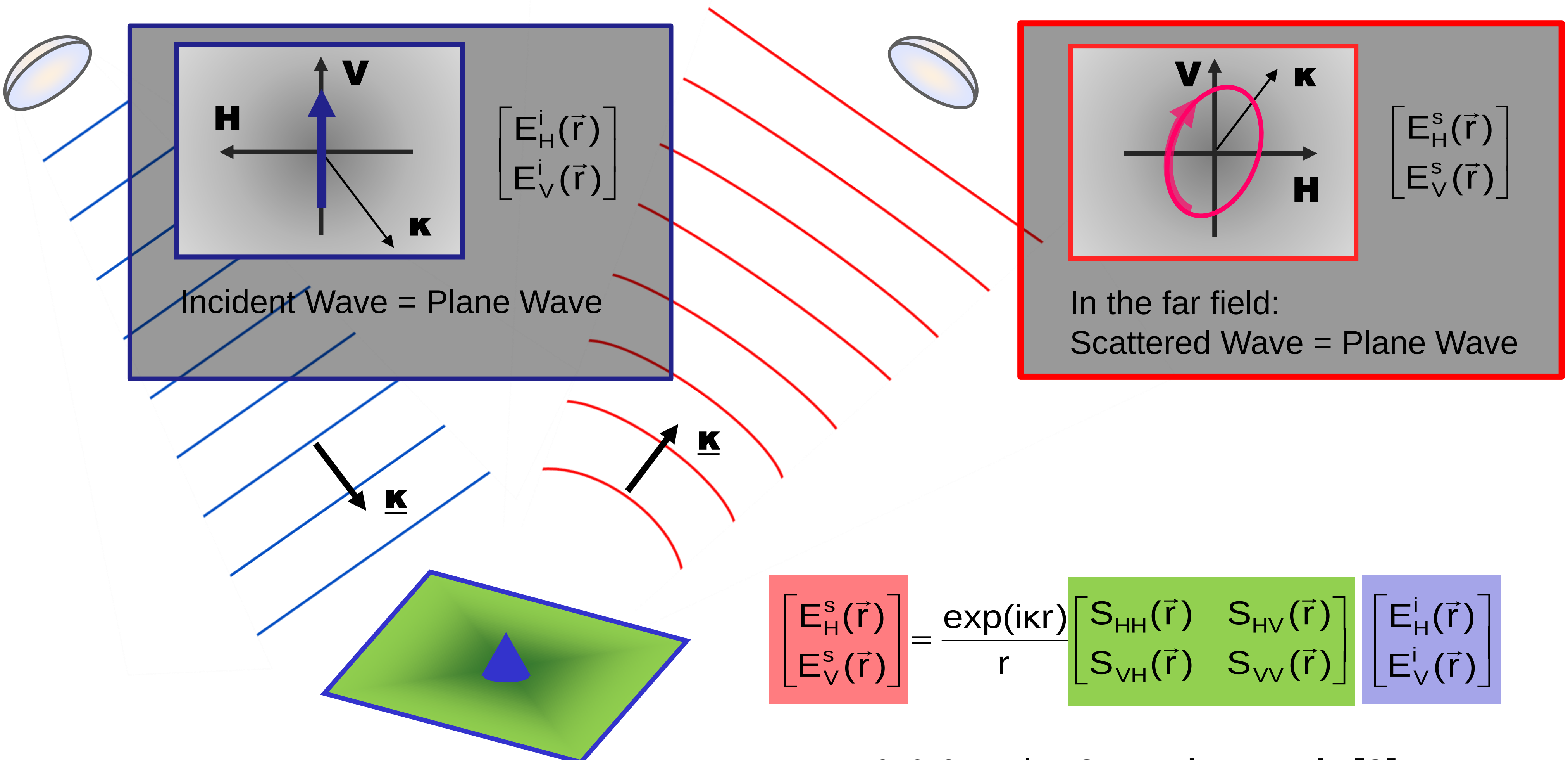
Jones vector:

$$\vec{E}=\begin{bmatrix}E_h\\E_v\end{bmatrix}=\begin{bmatrix}E_{0h}\exp(i\delta_h)\\E_{0v}\exp(i\delta_v)\end{bmatrix}\in C_2$$

The description can be considered as a component representation in the 2D complex vector space with basis $(\vec{h},\ \vec{v})$



The Scattering Problem



$$\begin{bmatrix}E^s_H(\vec r)\\E^s_V(\vec r)\end{bmatrix} = \frac{\exp(i\kappa r)}{r}\begin{bmatrix}S_{HH}(\vec r) & S_{HV}(\vec r)\\ S_{VH}(\vec r) & S_{VV}(\vec r)\end{bmatrix}\begin{bmatrix}E^i_H(\vec r)\\E^i_V(\vec r)\end{bmatrix}$$

2x2 Complex **Scattering Matrix [S]**

The Scatterer changes the polarisation of the incident wave.

In the literature also the $[S] = \frac{\exp(i\kappa r)}{i\kappa r}\begin{bmatrix}S_{HH}(\vec r) & S_{HV}(\vec r)\\ S_{VH}(\vec r) & S_{VV}(\vec r)\end{bmatrix}$ definition can be found. Be aware that there are indeed slight differences in the definition of [S].

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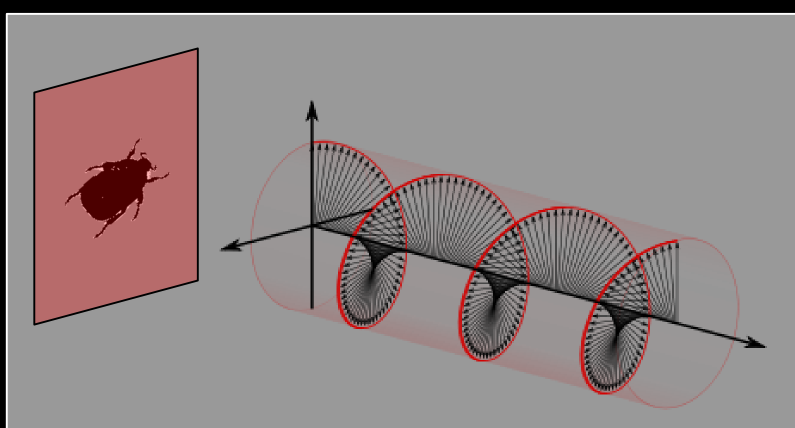
Vol. 92, No. 12, 21 April 2012, 1583–1599
Taylor & Francis
Taylor & Francis Group

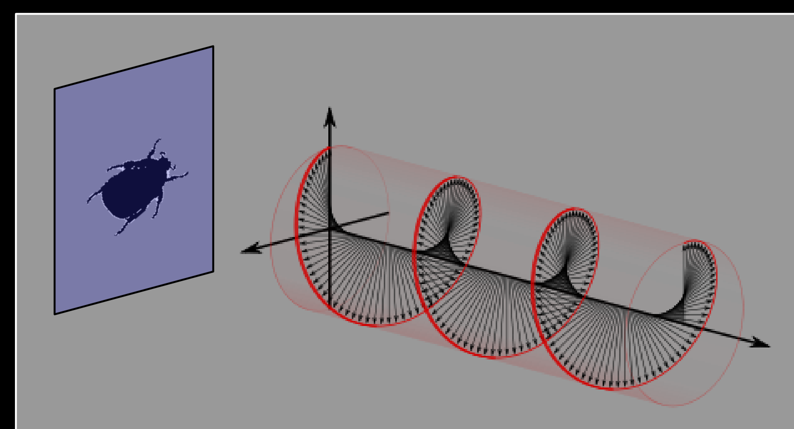
Chirality-induced polarization effects in the cuticle of scarab beetles: 100 years after Michelson

Hans Arwin*, Roger Magnusson, Jan Landin and Kenneth Järrendahl

Cetonia Aurata seen through a left circular filter

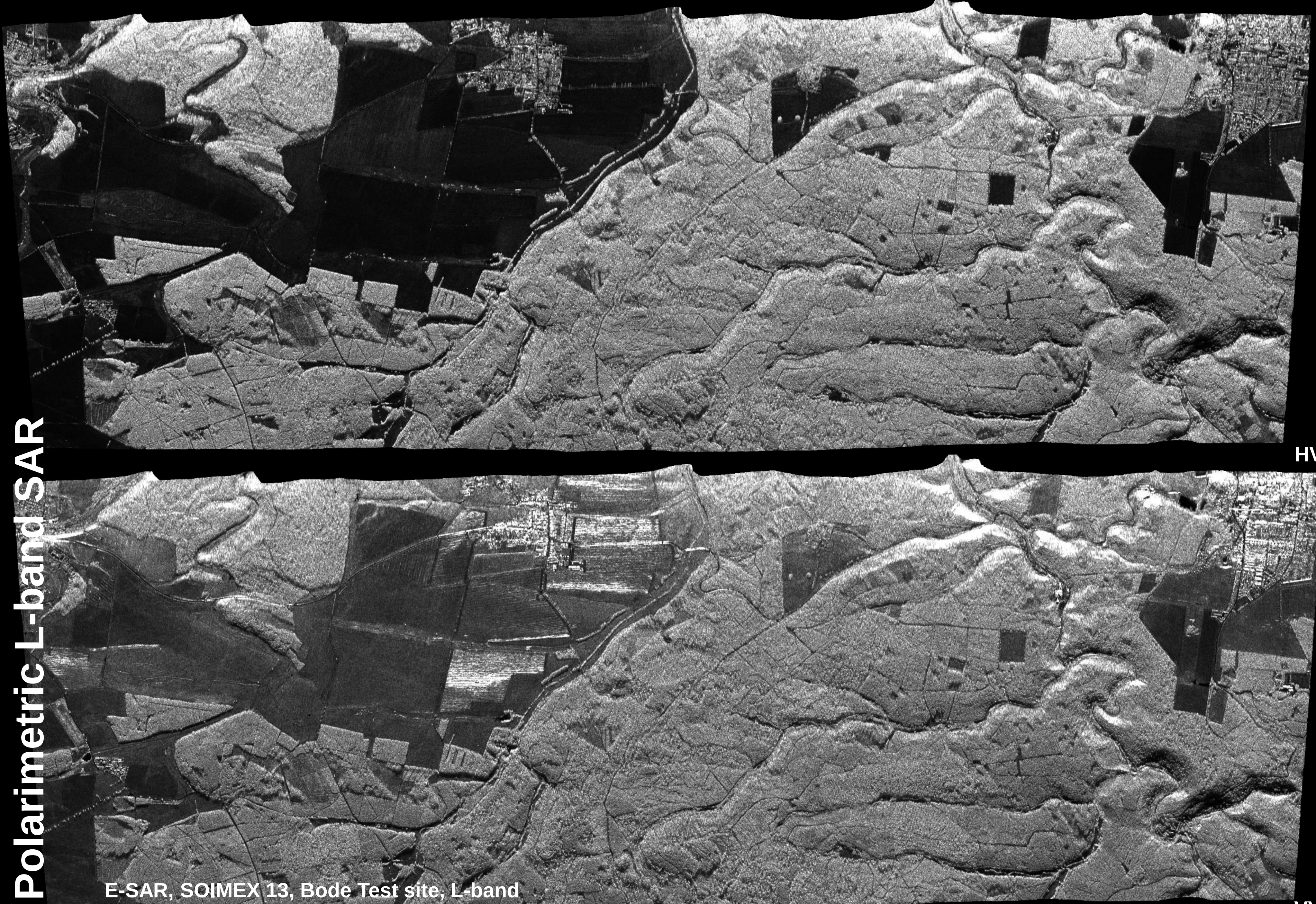
Cetonia Aurata seen through a right circular filter





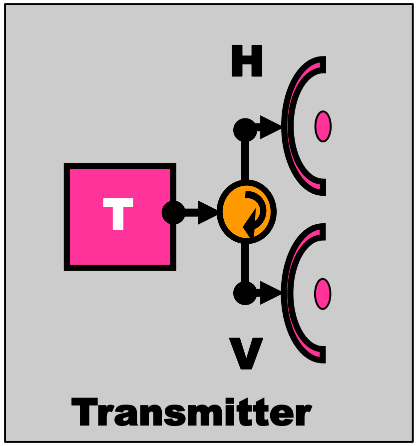
Cetonia Aurata

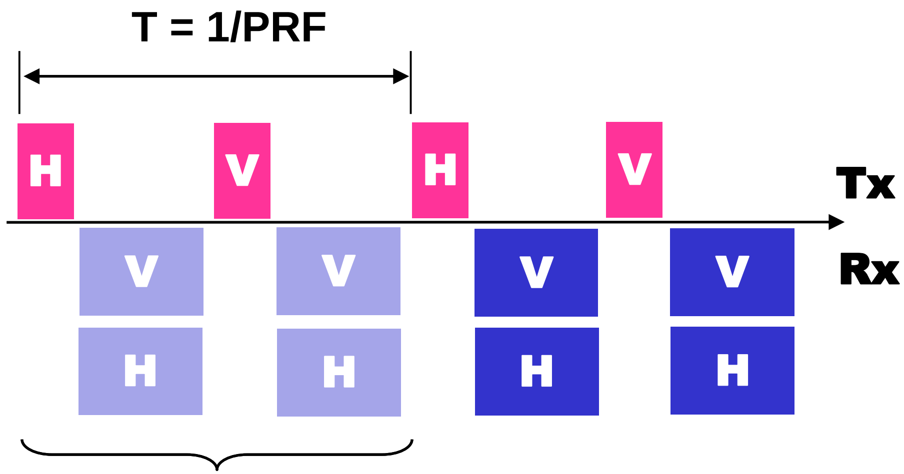
Polarimetric L-band SAR

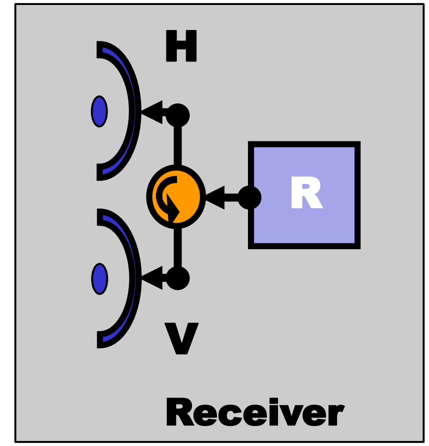


Bi- & Mono-Static Measurement of the Scattering Matrix

Bistatic
T & R Separated





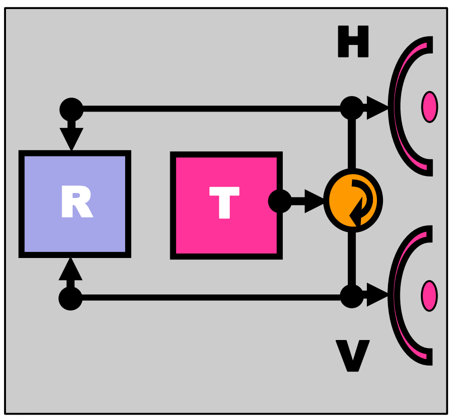


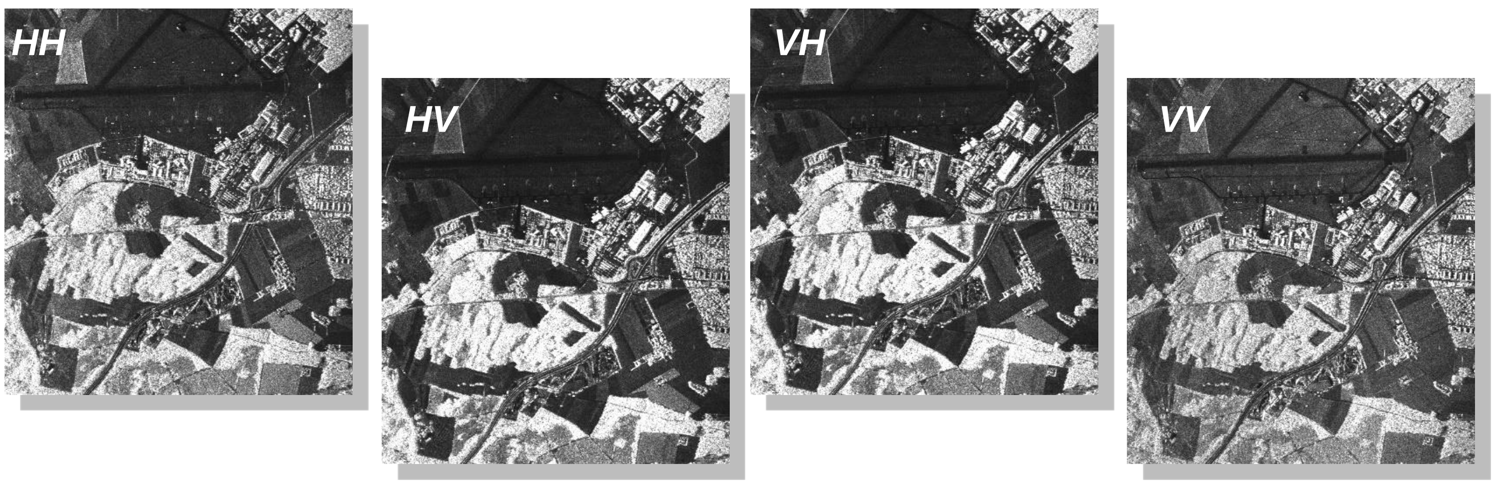
H $\begin{bmatrix} E_H^T \\ E_V^T \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$ **H V** $\begin{bmatrix} E_H^R \\ E_V^R \end{bmatrix} = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \begin{bmatrix} E_H^T \\ E_V^T \end{bmatrix} = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \begin{bmatrix} S_{HH} \\ S_{VH} \end{bmatrix}$

V $\begin{bmatrix} E_H^T \\ E_V^T \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$ **H V** $\begin{bmatrix} E_H^R \\ E_V^R \end{bmatrix} = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \begin{bmatrix} E_H^T \\ E_V^T \end{bmatrix} = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \begin{bmatrix} 0 \\ 1 \end{bmatrix} = \begin{bmatrix} S_{HV} \\ S_{VV} \end{bmatrix}$

$$\begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}$$

Monostatic
T & R Colocated





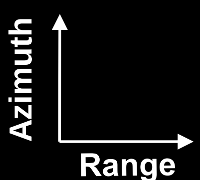
Scattering Amplitudes Images

HH

HV

VH

VV



Scattering Matrix

… also known as the Jones Matrix in the bistatic and Sinclair Matrix in the monostatic case

$$[S]=\begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \Rightarrow$$

4 Complex Scattering Amplitudes:

$$S_{IJ}=|S_{IJ}|\exp(i\varphi_{IJ}) = f(\text{ Frequency, Scattering, Geometry })$$

Total Scattered Power: $TP=\mathrm{Span}\;([S])=\mathrm{Trace}([S][S]^{+})=|S_{HH}|^2+|S_{HV}|^2+|S_{VH}|^2+|S_{VV}|^2$

Bistatic Scattering Matrix: $S_{HV}\neq S_{VH}$

Absolute Phase Factor

$$[S]=\begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}=\begin{bmatrix} |S_{HH}|\exp(i\varphi_{HH}) & |S_{HV}|\exp(i\varphi_{HV}) \\ |S_{VH}|\exp(i\varphi_{VH}) & |S_{VV}|\exp(i\varphi_{VV}) \end{bmatrix}=e^{i\varphi_{VV}}\begin{bmatrix} |S_{HH}|\exp i(\varphi_{HH}-\varphi_{VV}) & |S_{HV}|\exp i(\varphi_{HV}-\varphi_{VV}) \\ |S_{VH}|\exp i(\varphi_{VH}-\varphi_{VV}) & |S_{VV}| \end{bmatrix}$$

The bistatic scattering matrix contains **seven** independent parameters: 4 Amplitudes & 3 Phases

Monostatic Scattering Matrix: $S_{HV}=S_{VH}=S_{XX}$

$$[S]=\begin{bmatrix} S_{HH} & S_{XX} \\ S_{XX} & S_{VV} \end{bmatrix}=\begin{bmatrix} |S_{HH}|\exp(i\varphi_{HH}) & |S_{XX}|\exp(i\varphi_{XX}) \\ |S_{XX}|\exp(i\varphi_{XX}) & |S_{VV}|\exp(i\varphi_{VV}) \end{bmatrix}=e^{i\varphi_{VV}}\begin{bmatrix} |S_{HH}|\exp i(\varphi_{HH}-\varphi_{VV}) & |S_{XX}|\exp i(\varphi_{XX}-\varphi_{VV}) \\ |S_{XX}|\exp i(\varphi_{XX}-\varphi_{VV}) & |S_{VV}| \end{bmatrix}$$

The monostatic scattering matrix contains **five** independent parameters: 3 Amplitudes & 2 Phases

Scattering Matrix: Exercice !

$$[S] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}$$

4 Complex Scattering Amplitudes: $S_{IJ} = |S_{IJ}| \exp(i\varphi_{IJ})$

S_{ij}=f(Frequency, Geometry, , Scattering)

Pol. Powers: $|S_{HH}|^2, \; |S_{HV}|^2, \; |S_{VH}|^2, \; |S_{VV}|^2, \; |S_{HH}+S_{VV}|^2, \; |S_{HH}+S_{VV}|^2 \ldots$

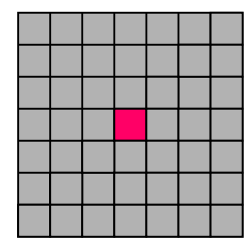
Total Scattered Power: $TP = \mathrm{Span}\;([S]) = \mathrm{Trace}([S][S]^{+}) = |S_{HH}|^2 + |S_{HV}|^2 + |S_{VH}|^2 + |S_{VV}|^2$

Pol. Phase Differences: $\varphi_{HH-VV} = \arg\{S_{HH}S_{VV}^{*}\}, \; \varphi_{HH-VH} = \arg\{S_{HH}S_{VH}^{*}\}, \; \varphi_{HV-VH} = \arg\{S_{HV}S_{VH}^{*}\}, \; \ldots$

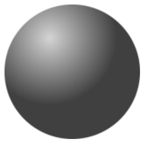
Pol. Coherence(s)*: $\tilde{\gamma} = \dfrac{|E\{\, S_{ij}S_{mn}^{*} \,\}|}{\sqrt{E\{\,|S_{ij}|^2\,\}\, E\{\,|S_{mn}|^2\,\}}} = \dfrac{|E\{\, S_{ij}S_{mn}^{*} \,\}|}{\sqrt{E\{\, S_{ij}S_{ij}^{*} \,\}\, E\{\, S_{mn}S_{mn}^{*} \,\}}}$ with $0 \leq |\,\tilde{\gamma}\,| \leq 1$

*) Normalised complex correlation coefficient(s)

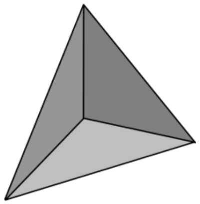
Coherence Estimator: $\tilde{\gamma} = \dfrac{\sum_{W} i_1[i,j]\; i_2^{*}[i,j]}{\sqrt{\sum_{W} |i_1[i,j]|^2 \sum_{W} |i_2[i,j]|^2}} = \dfrac{<i_1\, i_2^{*}>}{\sqrt{<i_1\, i_1^{*}>\; <i_2\, i_2^{*}>}}$



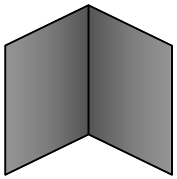
(Monostatic) Scattering Matrices of Canonical Scatterers



Sphere $[S] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$



Trihedral $[S] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$



Dihedral $[S] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$

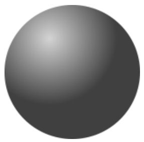
V Dipol $[S] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$

H Dipol $[S] = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$

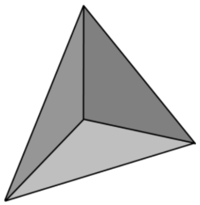
L Helix $[S] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} = \begin{bmatrix} 1 & -i \\ i & 1 \end{bmatrix}$

R Helix $[S] = \begin{bmatrix} 1 & i \\ -i & 1 \end{bmatrix}$

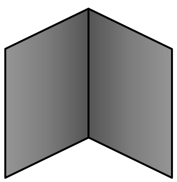
Scattering Matrices of Canonical Scatterers



Sphere $[S]=\begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}=\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$



Trihedral $[S]=\begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}=\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$



Dihedral $[S]=\begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}=\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$

V Dipol $[S]=\begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}=\begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$

L Helix $[S]=\begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}=\begin{bmatrix} 1 & -i \\ i & 1 \end{bmatrix}$

$$\begin{bmatrix} E_H^R \\ E_V^R \end{bmatrix}=\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} E_H^T \\ 0 \end{bmatrix}=\begin{bmatrix} E_H^T \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} E_H^R \\ E_V^R \end{bmatrix}=\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} 0 \\ E_V^T \end{bmatrix}=\begin{bmatrix} 0 \\ E_V^T \end{bmatrix}$$

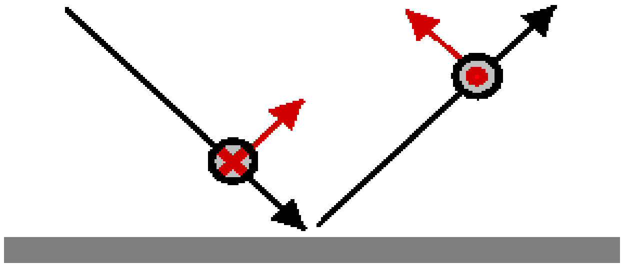
$$\begin{bmatrix} E_H^R \\ E_V^R \end{bmatrix}=\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}\begin{bmatrix} E_H^T \\ 0 \end{bmatrix}=\begin{bmatrix} E_H^T \\ 0 \end{bmatrix}$$

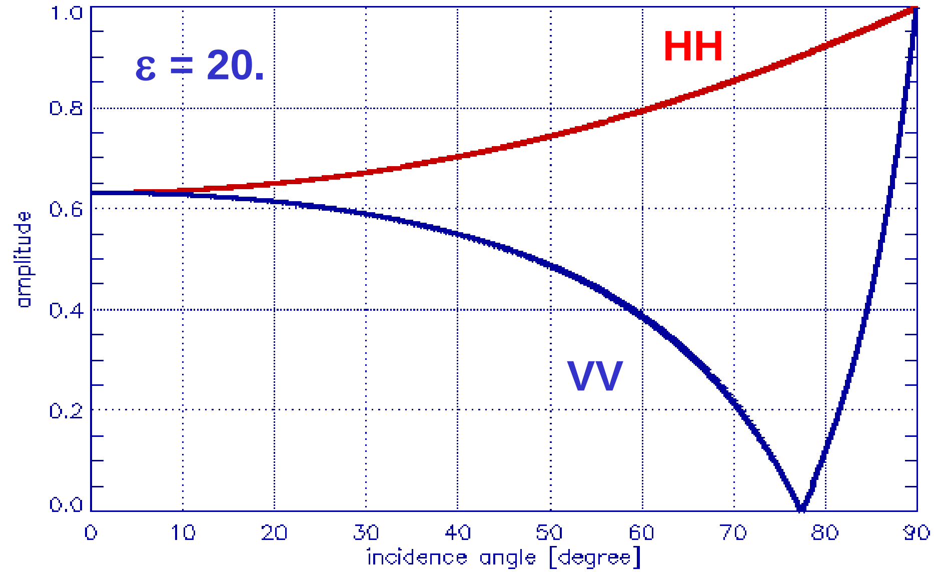
$$\begin{bmatrix} E_H^R \\ E_V^R \end{bmatrix}=\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}\begin{bmatrix} 0 \\ E_V^T \end{bmatrix}=\begin{bmatrix} 0 \\ -E_V^T \end{bmatrix}$$

$$\begin{bmatrix} E_H^R \\ E_V^R \end{bmatrix}=\begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} E_H^T \\ 0 \end{bmatrix}=\begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} E_H^R \\ E_V^R \end{bmatrix}=\begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} 0 \\ E_V^T \end{bmatrix}=\begin{bmatrix} 0 \\ E_V^T \end{bmatrix}$$

Canonical Scattering Processes: Fresnel Reflection





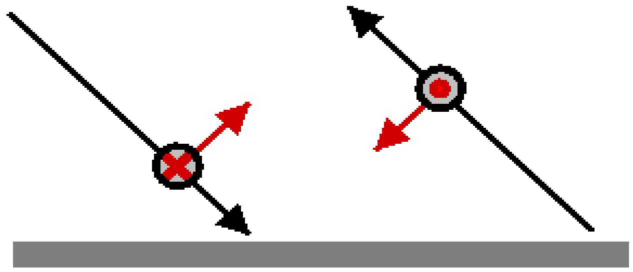
Scattering Matrix: $[S] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} = \begin{bmatrix} R_H & 0 \\ 0 & R_V \end{bmatrix}$

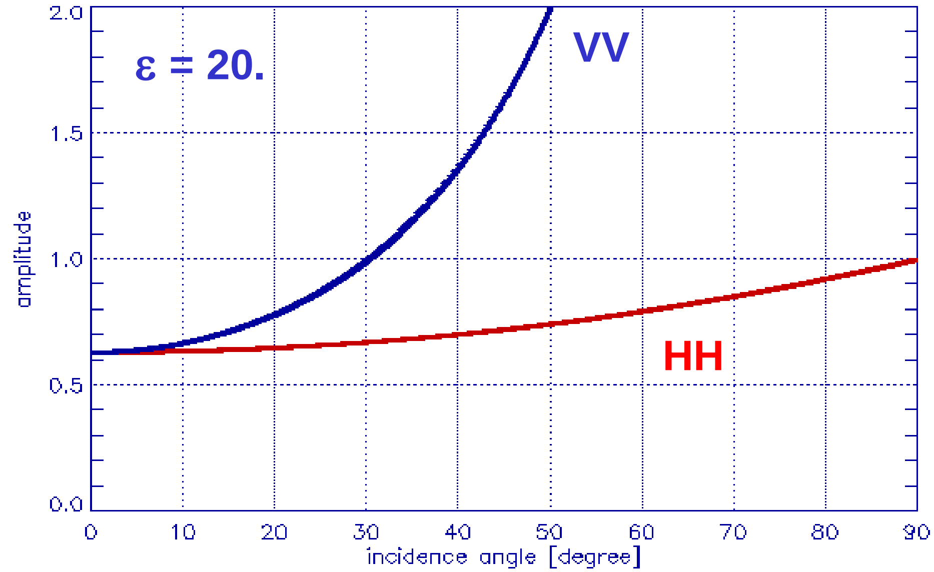
Fresnel Reflection Coefficients: $R_H = \dfrac{\cos\theta - \sqrt{\varepsilon - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon - \sin^2\theta}}$ and $R_V = \dfrac{\varepsilon\cos\theta - \sqrt{\varepsilon - \sin^2\theta}}{\varepsilon\cos\theta + \sqrt{\varepsilon - \sin^2\theta}}$

… which depend on the incidence angle θ and the dielectric constant of the surface ε

Characteristics: $|S_{HH}| \geq |S_{VV}|$

Canonical Scattering Processes: Bragg Scattering





Scattering Matrix: $[S] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} = \begin{bmatrix} R_H & 0 \\ 0 & R_V \end{bmatrix}$

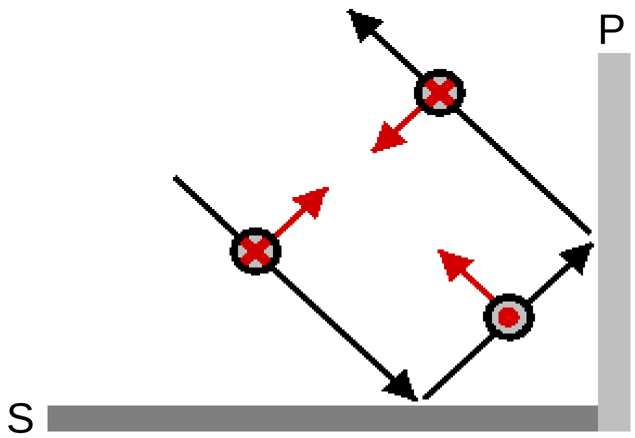
Bragg Scattering Coefficients: $R_H = \dfrac{\cos\theta - \sqrt{\varepsilon - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon - \sin^2\theta}}$ and $R_V = \dfrac{(\varepsilon - 1)[\sin^2\theta - \varepsilon(1 + \sin^2\theta)]}{\varepsilon\cos\theta + \sqrt{\varepsilon - \sin^2\theta}}$

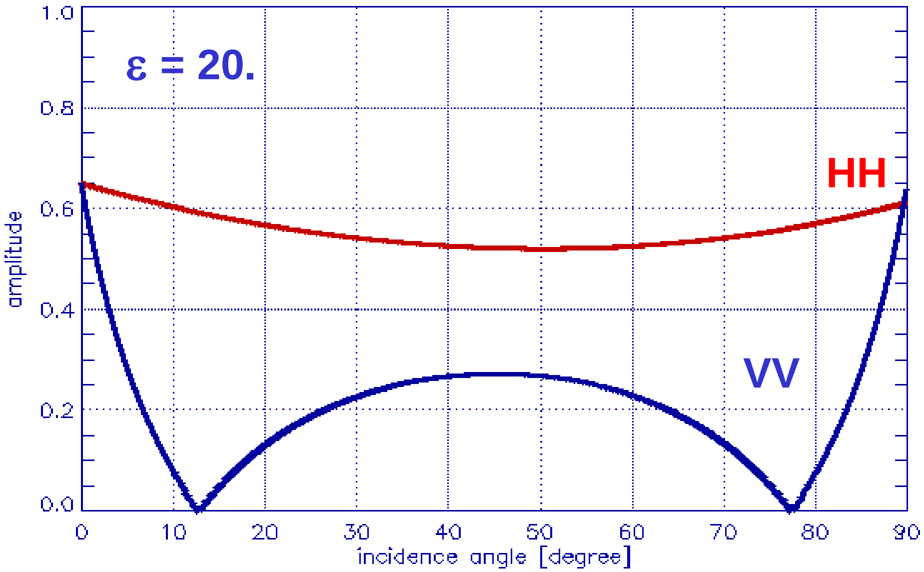
… which depend on the incidence angle θ and the dielectric constant of the surface ε

► Soil moisture inversion applications !

Characteristics: S_{HH} and S_{VV} are in phase and $|S_{HH}| \leq |S_{VV}|$

Canonical Scattering Processes: Dihedral Scattering





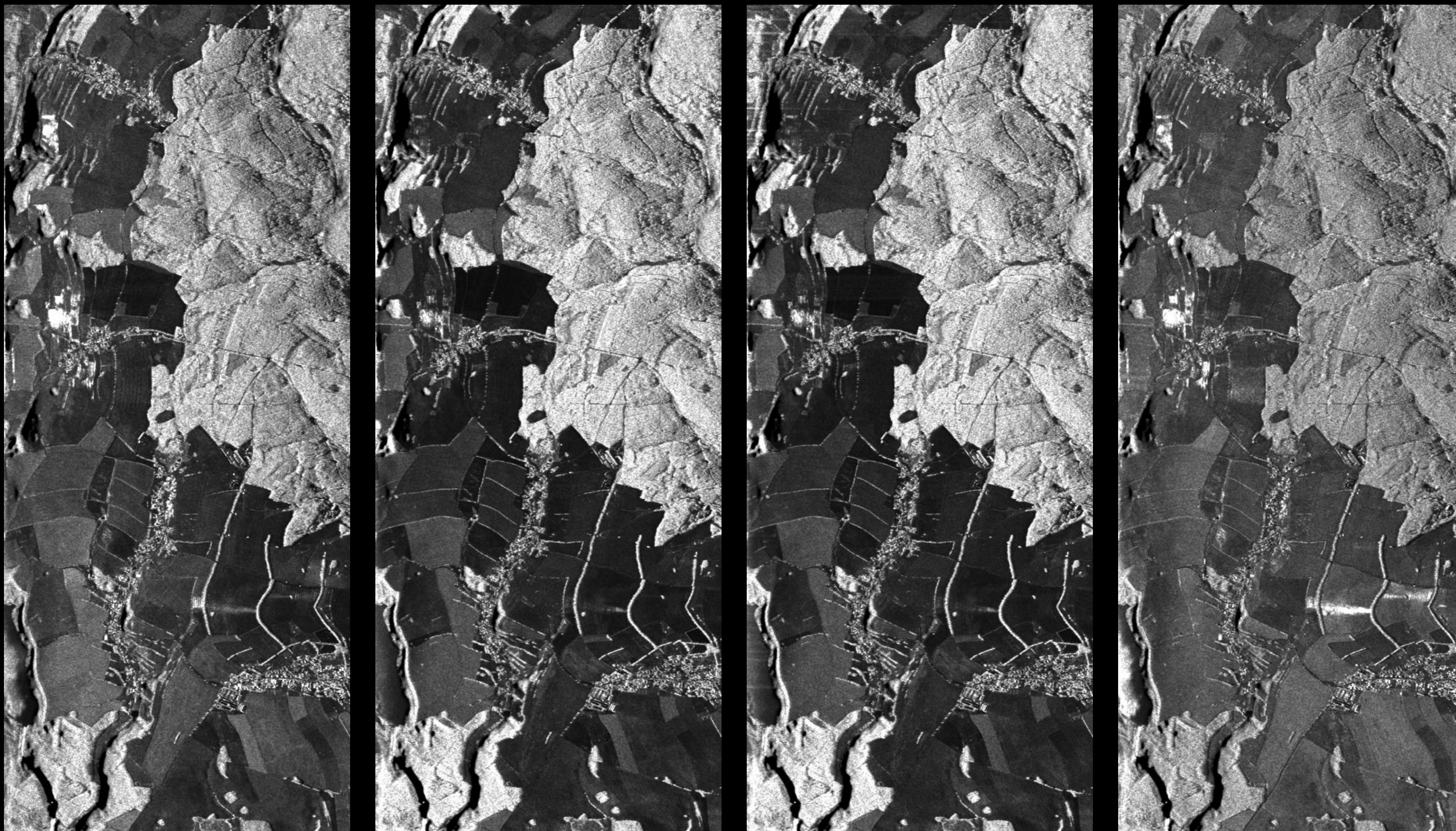
Scattering Matrix: $[S]=\begin{bmatrix}1 & 0\\ 0 & -1\end{bmatrix}\begin{bmatrix}1 & 0\\ 0 & e^{i}\end{bmatrix}\begin{bmatrix}R_{SS} & 0\\ 0 & R_{PS}\end{bmatrix}\begin{bmatrix}R_{ST} & 0\\ 0 & R_{PT}\end{bmatrix}=\begin{bmatrix}R_{SS}R_{ST} & 0\\ 0 & -R_{PS}R_{PT}e^{i}\end{bmatrix}$

Fresnel Reflection Coefficients	Horizontal Plane	$R_{SS}=\dfrac{\cos\theta-\sqrt{\varepsilon_S-\sin^2\theta}}{\cos\theta+\sqrt{\varepsilon_S-\sin^2\theta}}$ and	$R_{PS}=\dfrac{\varepsilon_S\cos\theta-\sqrt{\varepsilon_S-\sin^2\theta}}{\varepsilon_S\cos\theta+\sqrt{\varepsilon_S-\sin^2\theta}}$
	Vertical Plane	$R_{PS}=\dfrac{\cos\theta'-\sqrt{\varepsilon_P-\sin^2\theta'}}{\cos\theta'+\sqrt{\varepsilon_P-\sin^2\theta'}}$ and	$R_{PT}=\dfrac{\varepsilon_P\cos\theta'-\sqrt{\varepsilon_P-\sin^2\theta'}}{\varepsilon_P\cos\theta'+\sqrt{\varepsilon_P-\sin^2\theta'}}$

Characteristics: S_{HH} and S_{VV} are phase shifted by 180º (i.e., π) and $|S_{HH}| \geq |S_{VV}|$

$\theta' = 90-\theta$

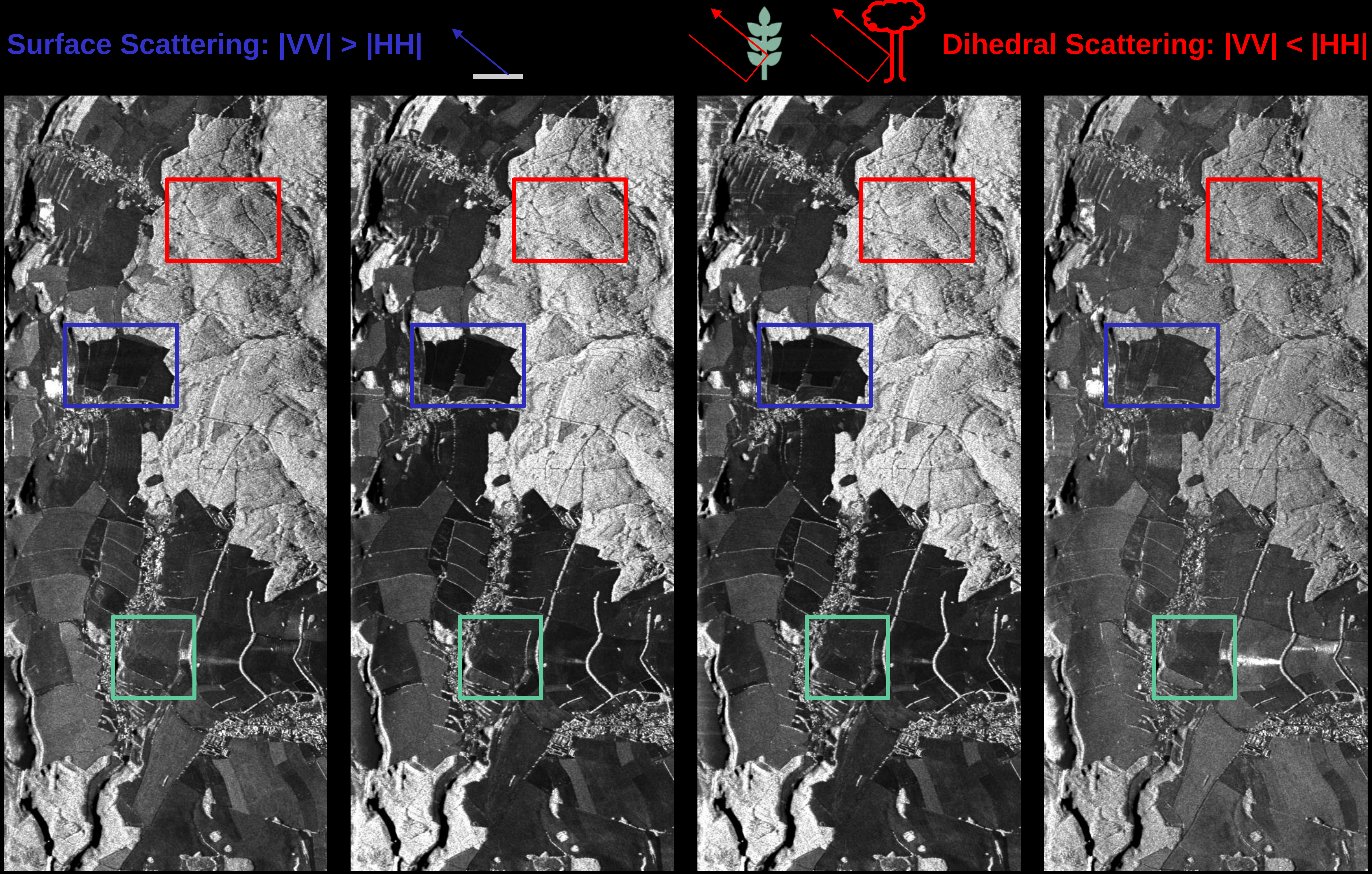
Scattering Amplitudes



HH HV VH VV

Surface Scattering: |VV| > |HH|

Dihedral Scattering: |VV| < |HH|



HH

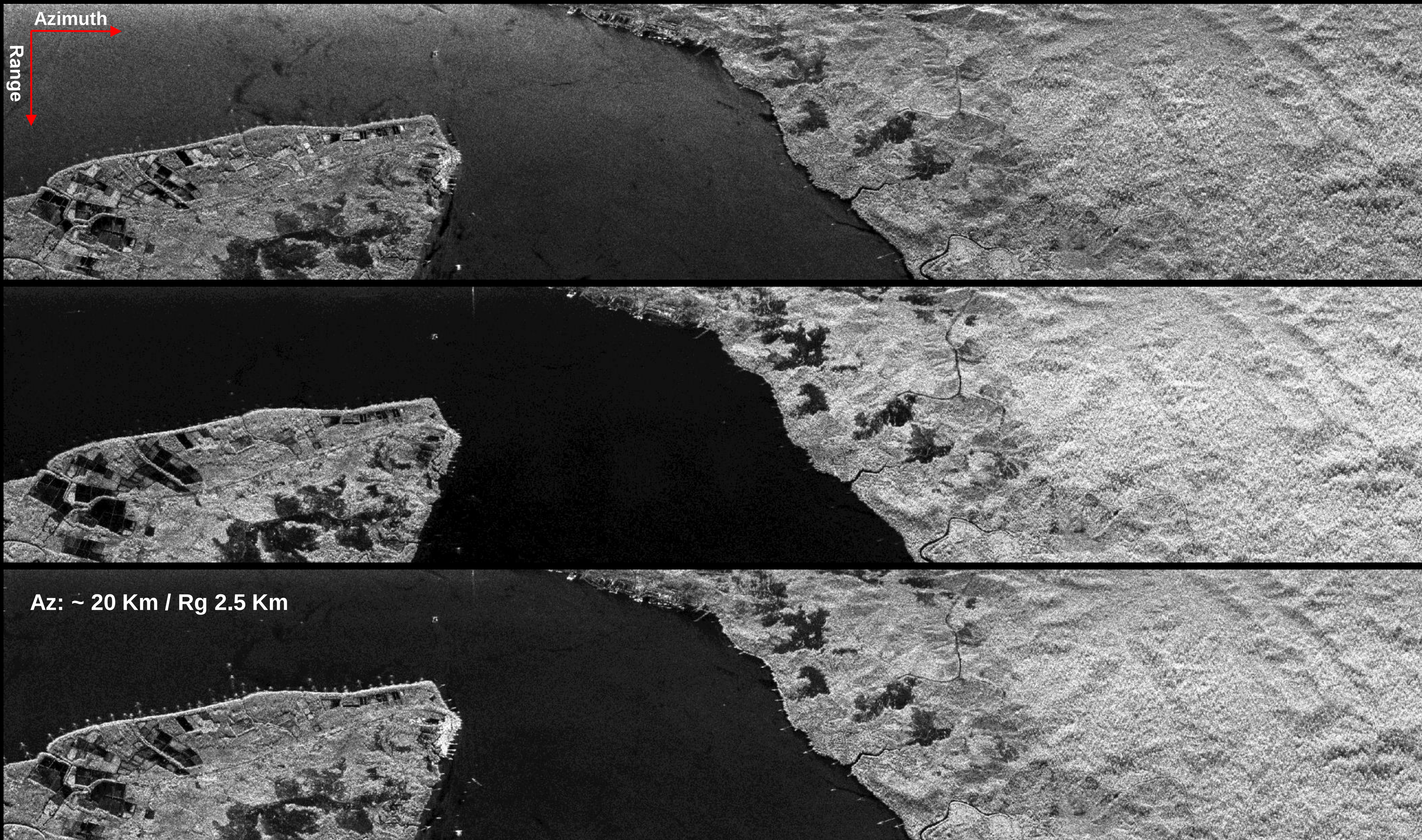
HV

VH

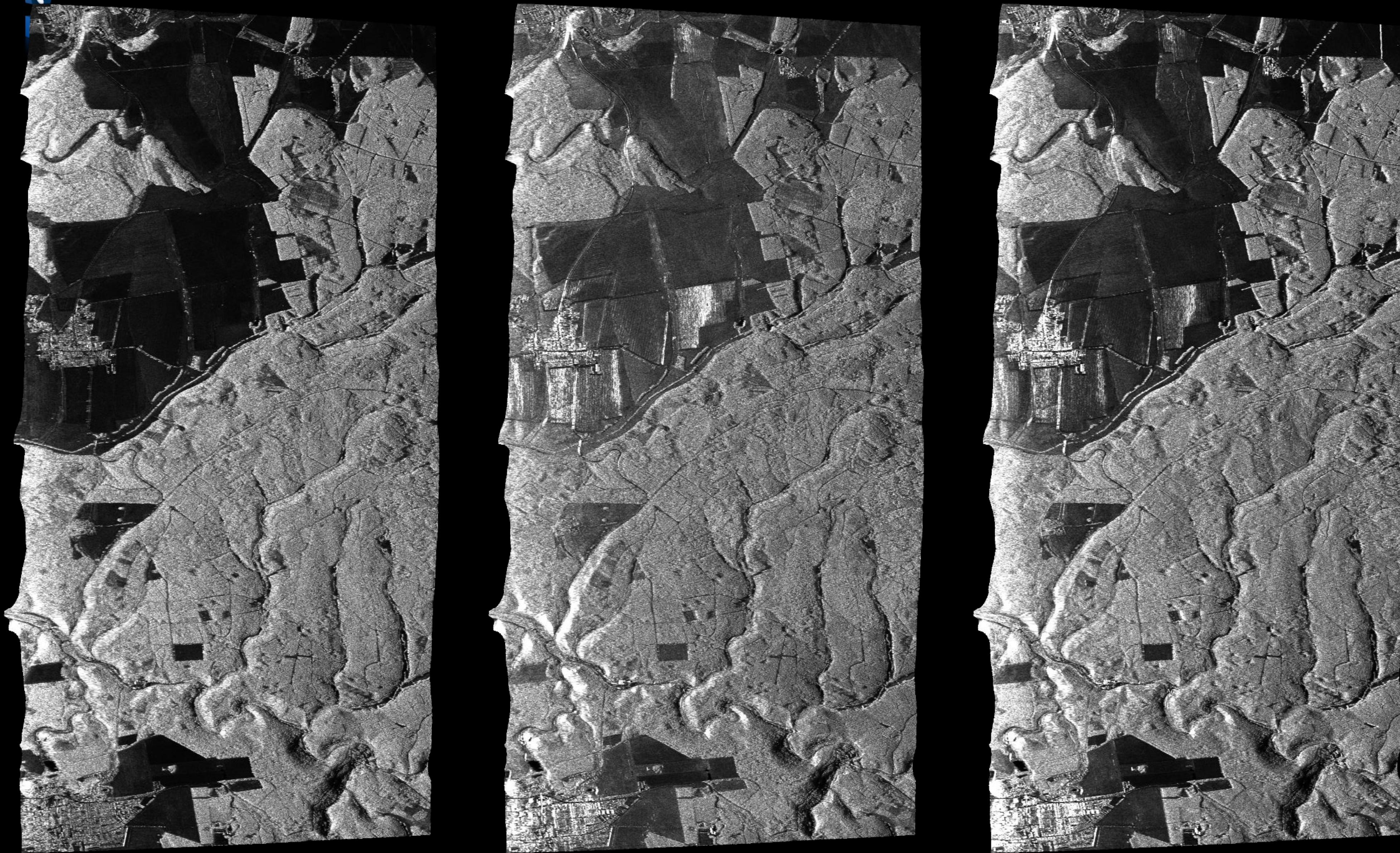
VV

Polarimetric Backscatter Images: HH, HV, VV. Which is which ?

E-SAR L-band / Test Site: Sungai Wain South, Indonesia



Polarimetric Backscatter Images: HH, HV, VV. Which is which ?

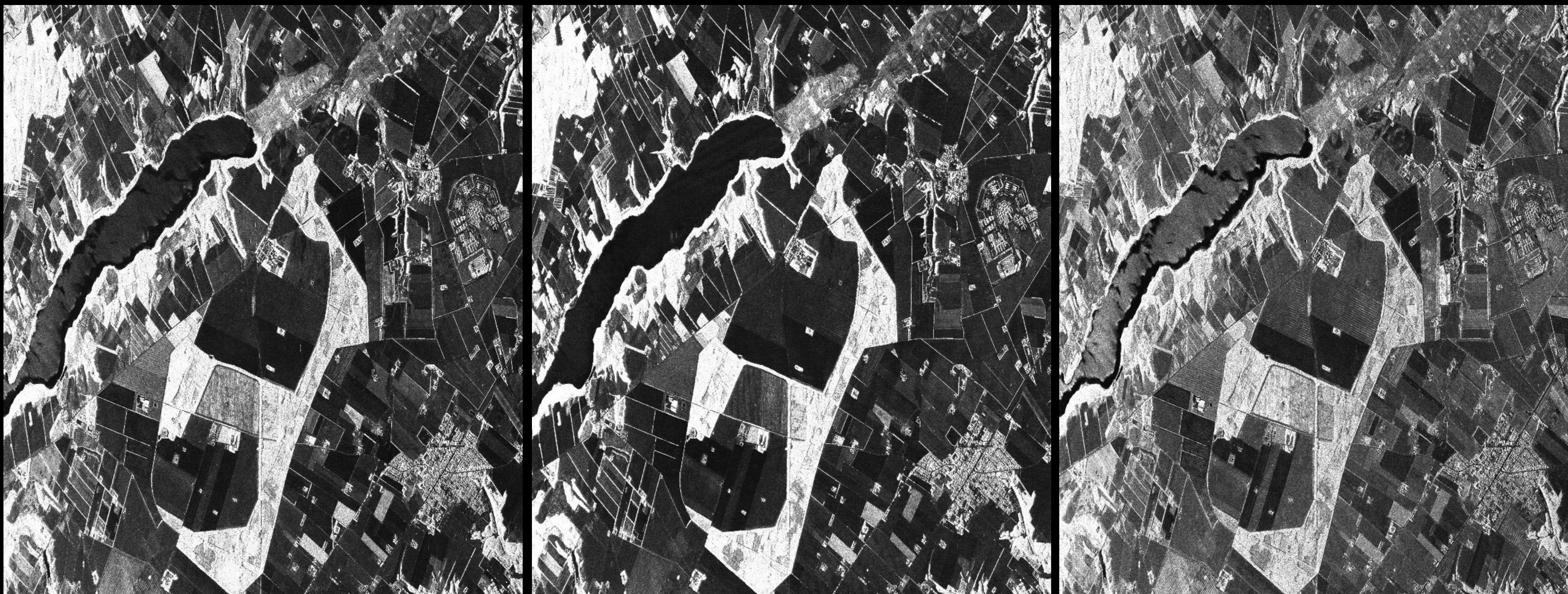


E-SAR, SOIMEX 13, Bode Test site, L-band

Polarimetric Backscatter Images: HH, HV, VV. Which is which ?

L-band

EMI-SAR / Test Site: Foulum,Denmark

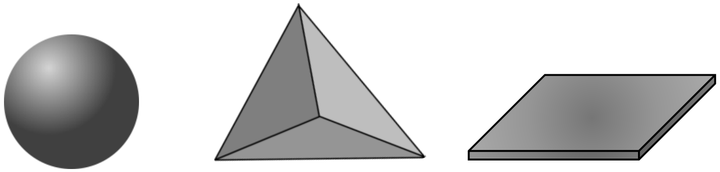


Pauli Decomposition

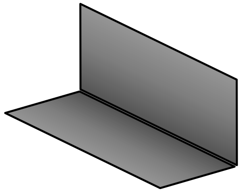
… decomposition of the scattering matrix into four scattering mechanisms:

$$[S] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} = \begin{bmatrix} a+b & c-id \\ c+id & a-b \end{bmatrix} = a\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} + b\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} + c\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} + d\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$$

- $[S_a] = a\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ **Single Scattering:** $S_{HH} = S_{VV}$

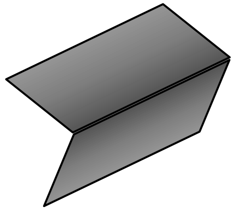


- $[S_b] = b\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$ **Dihedral Scattering:** $S_{HH} = -S_{VV}$



- $[S_c] = c\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$ **Dihedral Scattering** $S_{HV} = S_{VH} \neq 0$ $S_{HH} = S_{VV} = 0$

  (… rotated by $\pi/2$ about the LOS)



- $[S_d] = d\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$ **Helix Scattering:** Transforms all polarisation states into their orthogonal states (disappears in backscattering as $S_{HV} \neq S_{VH}$)

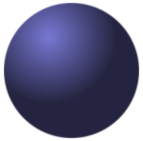
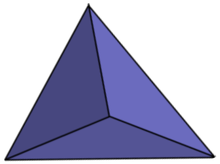
In the monostatic case [S] is decomposed into three orthogonal scattering mechanisms $[S_a]$, $[S_b]$, $[S_c]$.

Pauli Decomposition

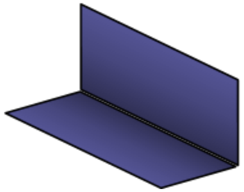
… decomposition of the scattering matrix into four scattering mechanisms:

$$[S] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} = \begin{bmatrix} a+b & c-id \\ c+id & a-b \end{bmatrix} = a\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} + b\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} + c\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} + d\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$$

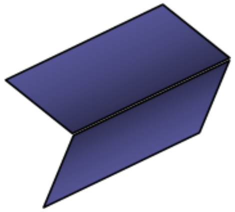
- $[S_a] = a\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ **Single Scattering** $a = S_{HH} + S_{VV}$


- $[S_b] = b\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$ **Dihedral Scattering** $b = S_{HH} - S_{VV}$



- $[S_c] = c\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$ **Dihedral Scattering** $c = S_{HV} + S_{HV}$



- $[S_d] = d\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$ **Helix Scattering** $d = S_{HV} - S_{HV}$


Scattering Amplitudes: Pauli Basis

|HH-VV|

|HV|

|HH+VV|

Pauli RGB

Interpretation of Scattering Mechanisms

Scattering Matrix $[S]=\begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}$ $\Rightarrow$ **Pauli Scattering Vector** $\vec{k}_{3P}=\frac{1}{\sqrt{2}}\begin{bmatrix} S_{HH}+S_{VV} \\ S_{HH}-S_{VV} \\ 2S_{XX} \end{bmatrix}$

Unitary Representation of [S]: $\vec{e}=\frac{1}{|\vec{k}_{3P}|}\vec{k}_{3P}=\begin{bmatrix} \cos\alpha\ \exp(i\gamma) \\ \sin\alpha\ \cos\beta\ \exp(i\delta) \\ \sin\alpha\ \sin\beta\ \exp(i\varepsilon) \end{bmatrix}=\frac{1}{\sqrt{2}\,|\vec{k}_{3P}|}\begin{bmatrix} S_{HH}+S_{VV} \\ S_{HH}-S_{VV} \\ 2S_{XX} \end{bmatrix}$

Parameterisation of $\vec{e}$ in terms of five (scattering) angles: $\alpha,\ \beta,\ \gamma,\ \delta,\ \varepsilon$

$$|\vec{k}_{3P}|=TP=\frac{1}{2}|S_{HH}+S_{VV}|^2+\frac{1}{2}|S_{HH}-S_{VV}|^2+\frac{1}{2}|S_{HV}+S_{VH}|^2$$

Point Reduction Theorem:

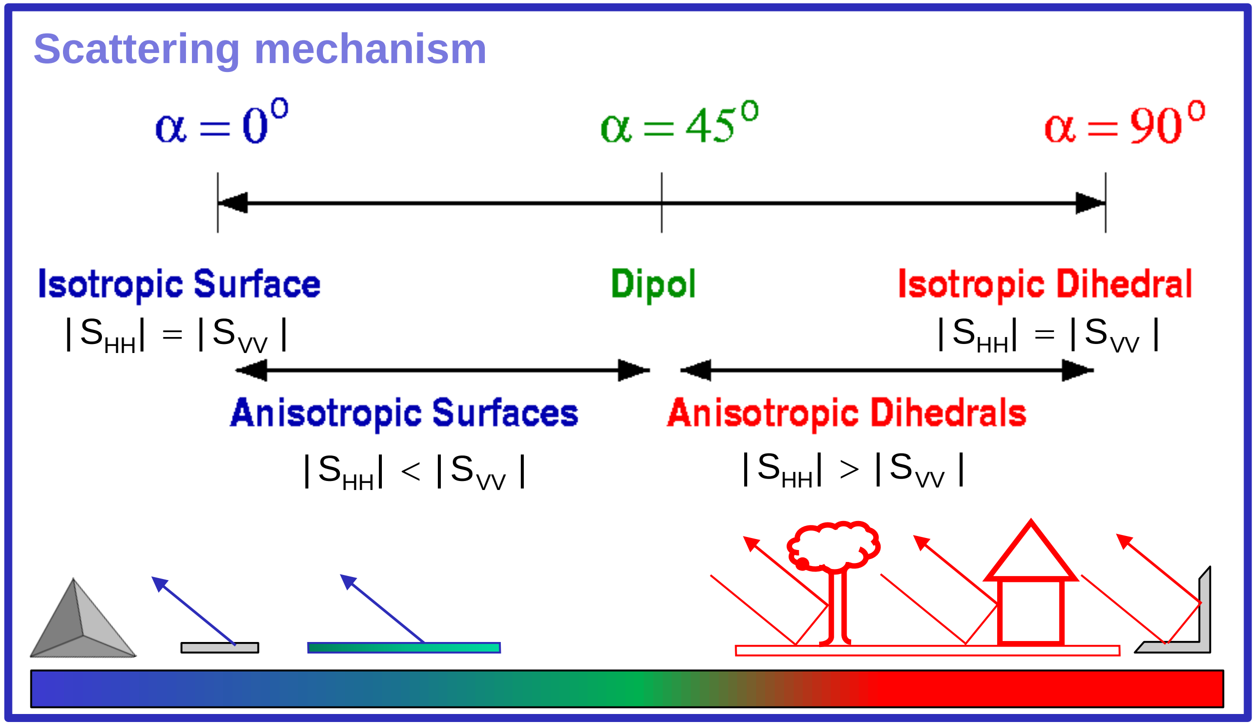
(Scattering) Phase Term LOS orientation Scattering mechanism

$$\vec{e}=\begin{bmatrix} \cos\alpha\ \exp(i\varphi_1) \\ \sin\alpha\ \cos\beta\ \exp(i\varphi_2) \\ \sin\alpha\ \sin\beta\ \exp(i\varphi_3) \end{bmatrix}=\begin{bmatrix} \exp(i\varphi_1) & 0 & 0 \\ 0 & \exp(i\varphi_2) & 0 \\ 0 & 0 & \exp(i\varphi_3) \end{bmatrix}\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\beta & -\sin\beta \\ 0 & \sin\beta & \cos\beta \end{bmatrix}\begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

Interpretation of Scattering Mechanisms

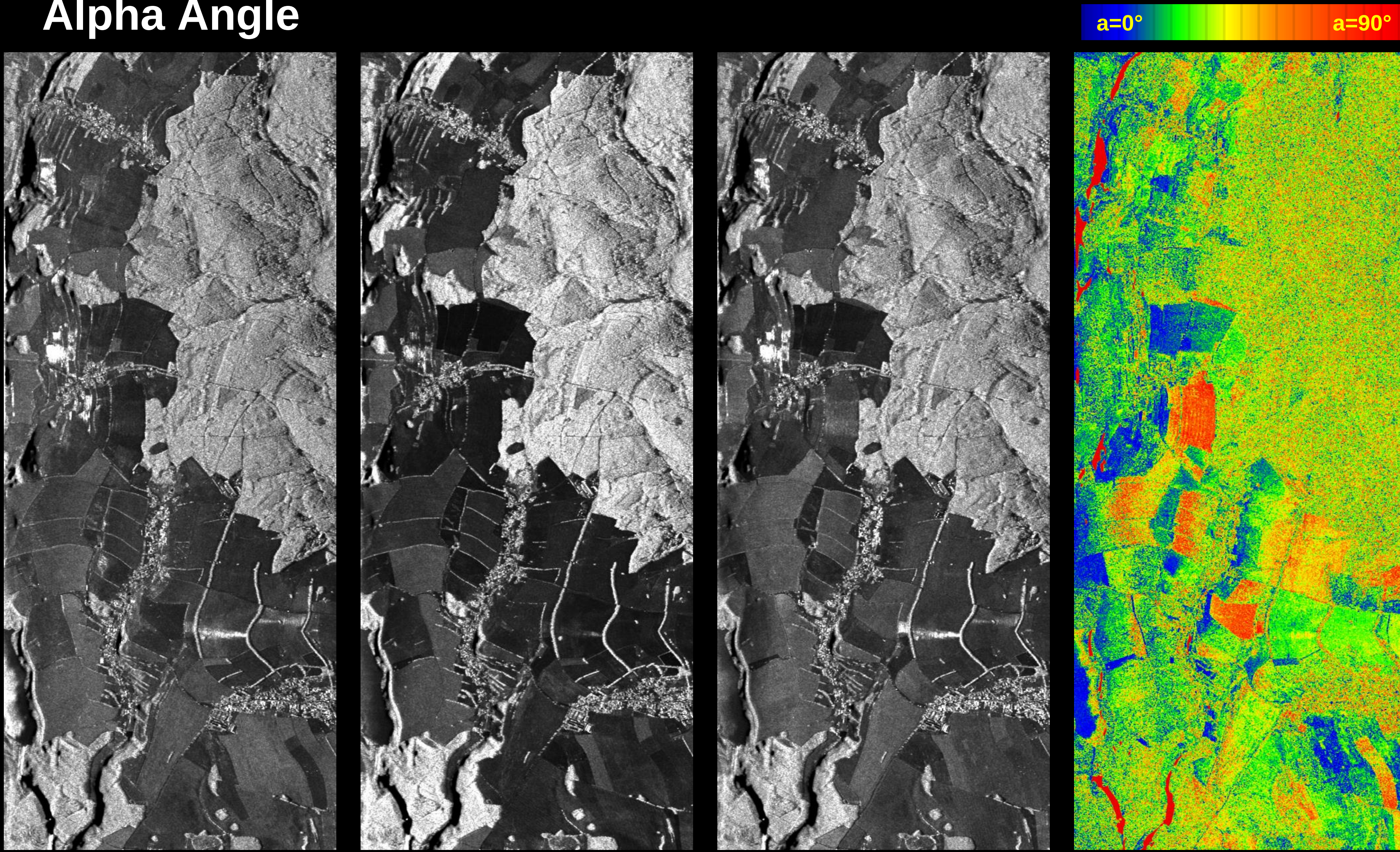
Unitary Representation of [S]:

$$\vec{e} = \frac{1}{|\vec{k}_{3P}|}\vec{k}_{3P} = \begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = \begin{bmatrix} \cos\alpha\ \exp(i\gamma) \\ \sin\alpha\ \cos\beta\ \exp(i\delta) \\ \sin\alpha\ \sin\beta\ \exp(i\varepsilon) \end{bmatrix} = \frac{1}{\sqrt{2}\,|\vec{k}_{3P}|}\begin{bmatrix} S_{HH}+S_{VV} \\ S_{HH}-S_{VV} \\ 2S_{XX} \end{bmatrix} \quad \Rightarrow \quad \alpha = a\cos(|e_1|)$$



Polarimetry is sensitive to orientation, structure and dielectric properties of scatteter(s).

Alpha Angle



|HH-VV| |HV| |HH+VV| Alpha Angle α

The Pol-InSAR Course

Synthetic Aperture Radar (SAR)

Part 3: SAR Polarimetry

Prepared by DLR-HR's Pol-InSAR Team

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