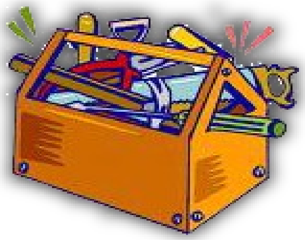
SAR POLARIMETRY BASICS

Laurent Ferro-Famil
ISAE-SUPAERO & CESBIO, University of Toulouse, France

Eric Pottier
IETR, University of Rennes, France

Laurent FERRO-FAMIL
laurent.ferro-famil@isae-supaero.fr

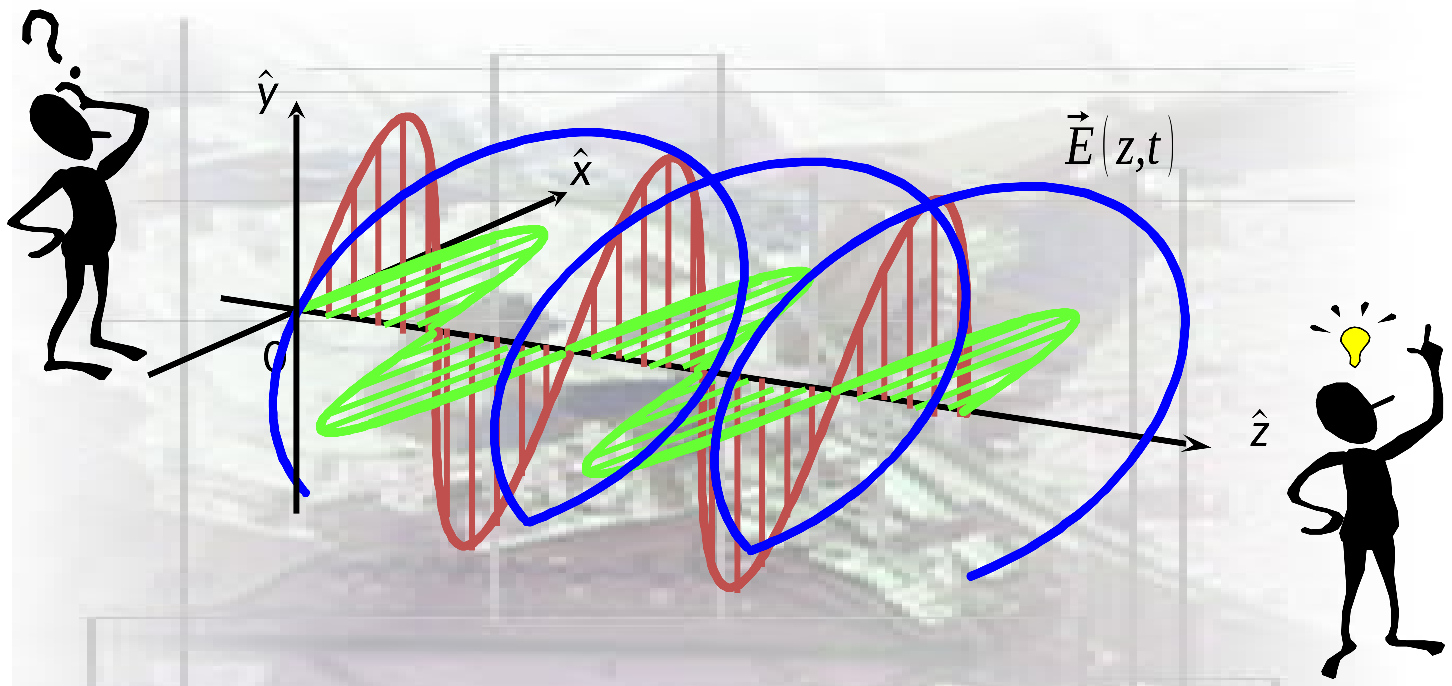
Eric POTTIER
eric.pottier@univ-rennes.fr



Objective

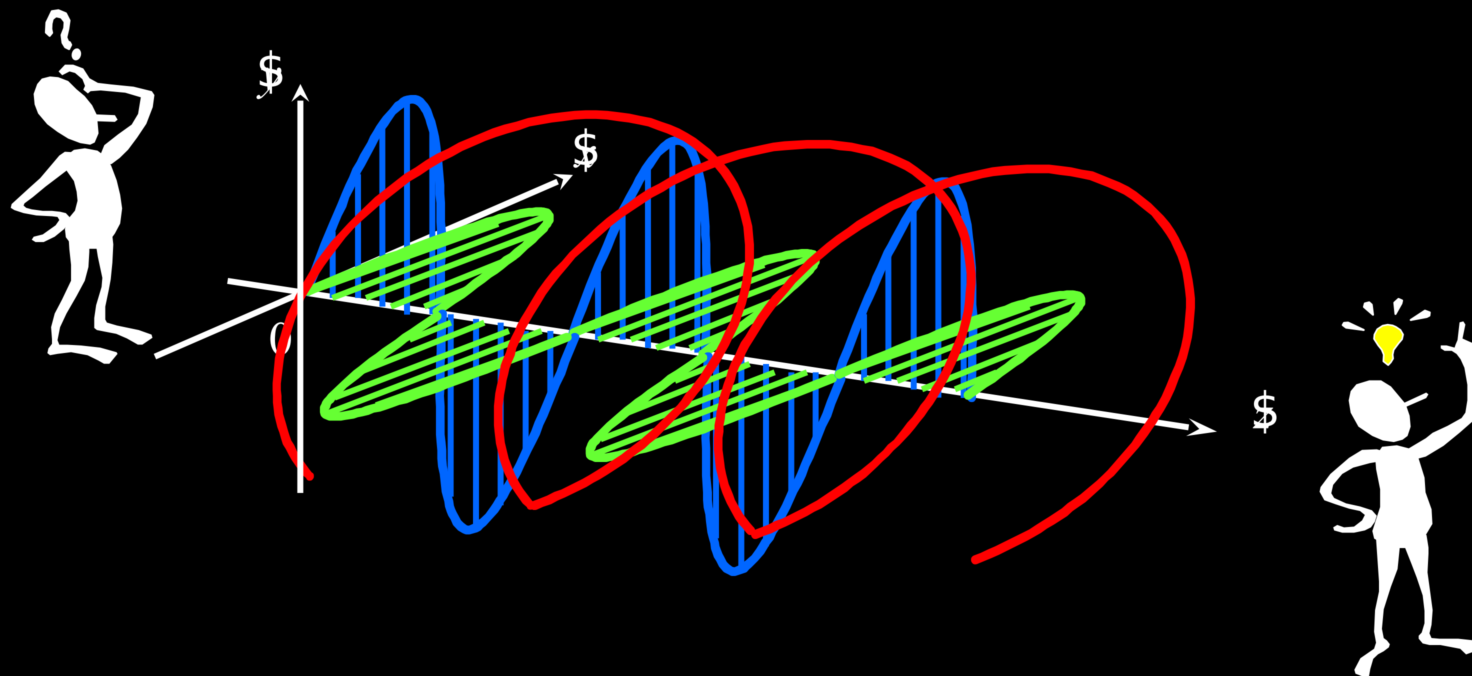
To provide the minimum, but necessary, amount of knowledge required to understand scientific works on :

SAR Polarimetry (PolSAR)
SAR Polarimetry + Interferometry (Pol-InSAR)
SAR Polarimetry + Tomography (Pol-TomSAR)



GENERAL INTRODUCTION

Radar Polarimetry

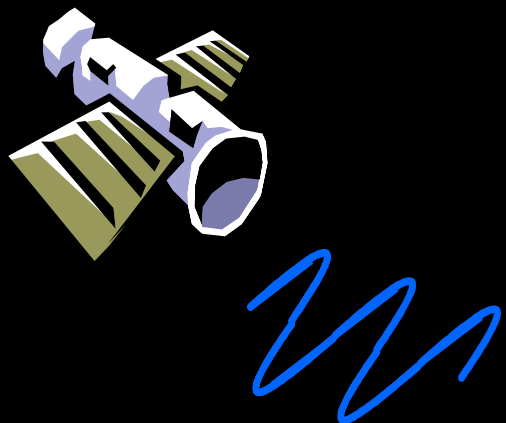


Radar Polarimetry (Polar : polarisation Metry: measure) is the science of acquiring, processing and analysing the polarization state of an electromagnetic field

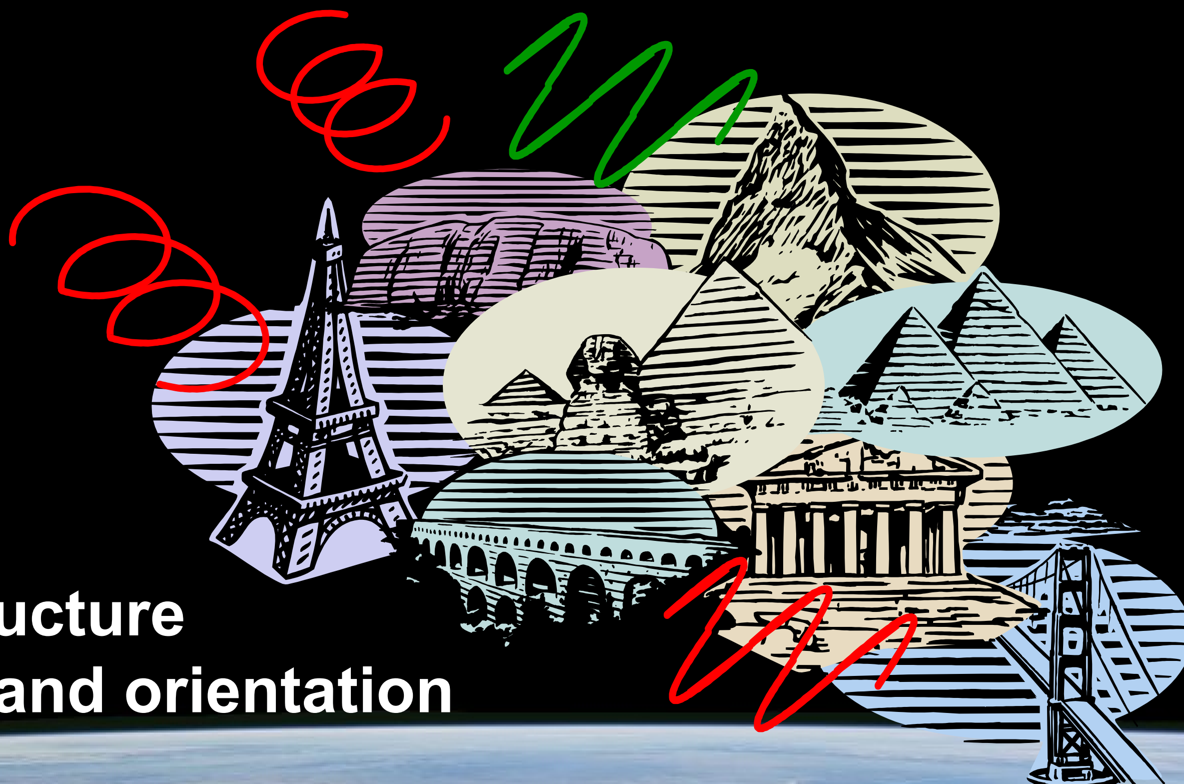
Radar Polarimetry deals with the full vector nature of polarized electromagnetic waves

© L. Ferro-Famil & E. Pottier

Radar Polarimetry



**The POLARISATION information
Contained in the waves backscattered
from a given medium is highly related to:**



**its geometrical structure
reflectivity, shape and orientation**

its geophysical properties such as humidity, roughness, …

© L. Ferro-Famil & E. Pottier

SAR Polarimetry Applications

Forest Vegetation

- Forest Height
- Forest Biomass
- Forest Structure
- Canopy Extinction
- Underlying Topography

- Forest Ecology
- Forest Management
- Ecosystem Change
- Carbon Cycle

Agriculture

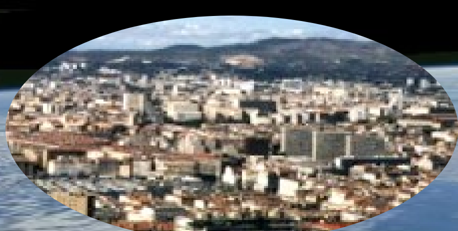
- Soil Moisture Content
- Soil roughness
- Height of Vegetation Layer
- Extinction of Vegetation Layer
- Moisture of Vegetation Layer

- Farming Management
- Water Cycle
- Desretification

Snow and Ice

- Topography
- Penetration Depth / Density
- Snow Ice Layer
- Snow Ice Extinction
- Water Equivalent

- Ecosystem Change
- Water Cycle
- Water Management



Urban Areas

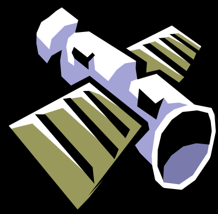
- Geometric Properties
- Dielectric Properties

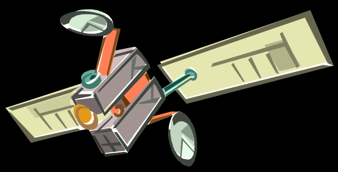
- Urban Monitoring

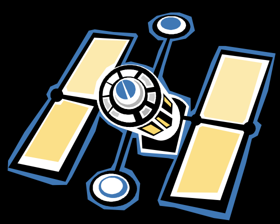
Courtesy of Dr. I. Hajnsek

© L. Ferro-Famil & E. Pottier

Polarimetric Radar (SAR)



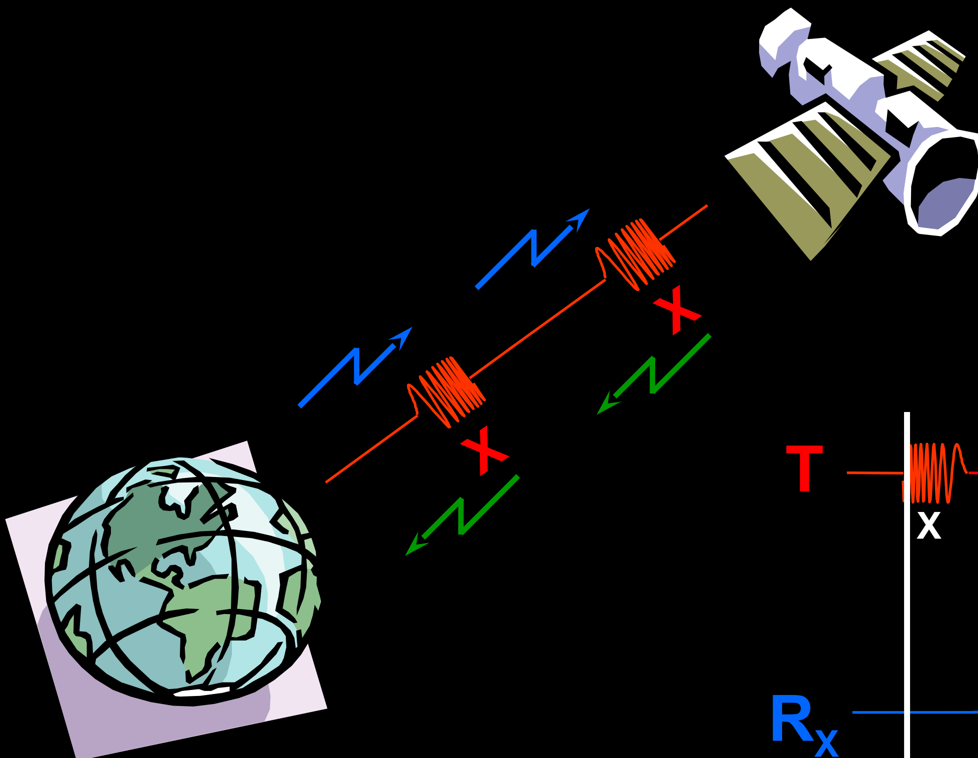


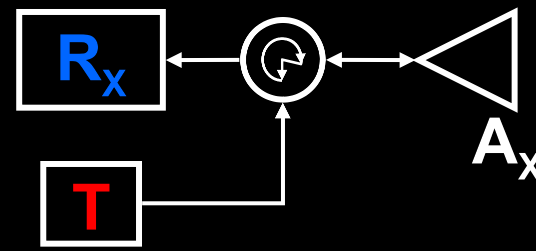


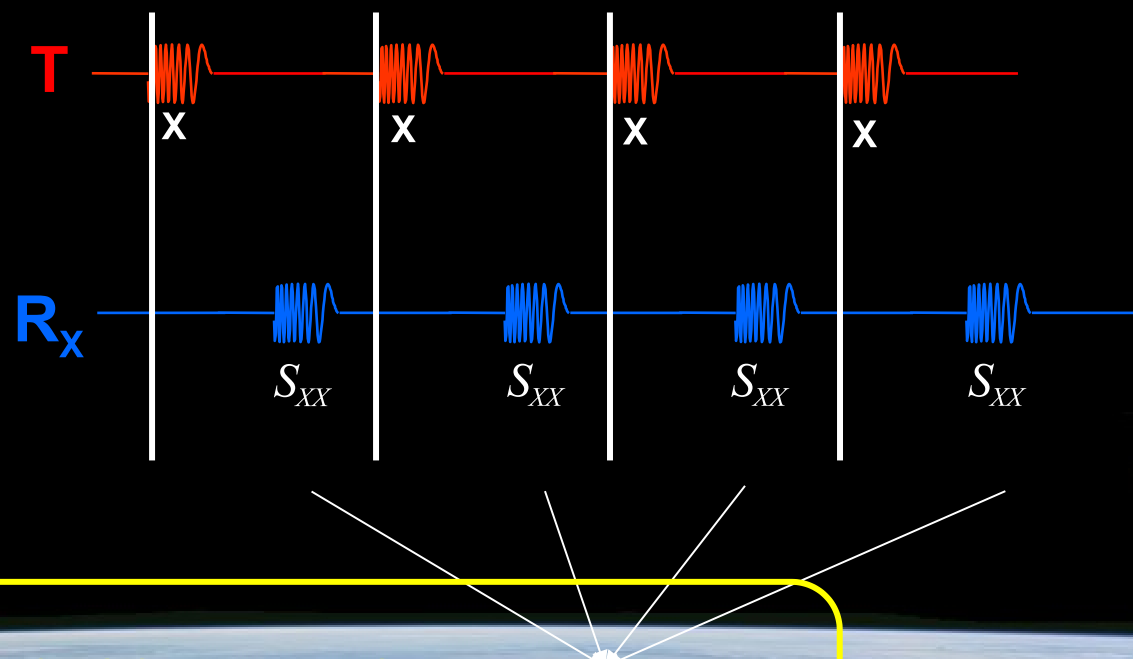
Spaceborne Sensors

© L. Ferro-Famil & E. Pottier

Scattering Coefficient







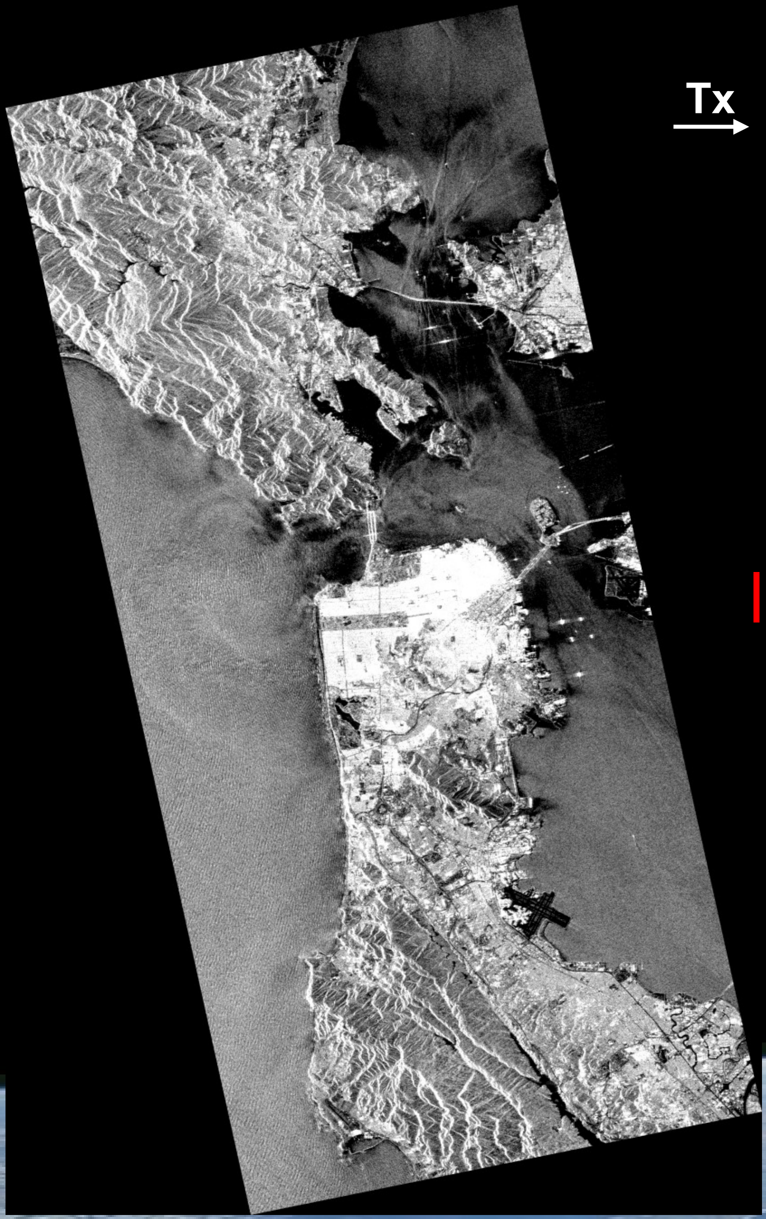
TRANSMITTER: X
RECEIVER: X

BACKSCATTERING COEFFICIENT $\{ S_{XX} \}$

NO POLARIMETRY

© L. Ferro-Famil & E. Pottier

Space-borne Sensors



Tx

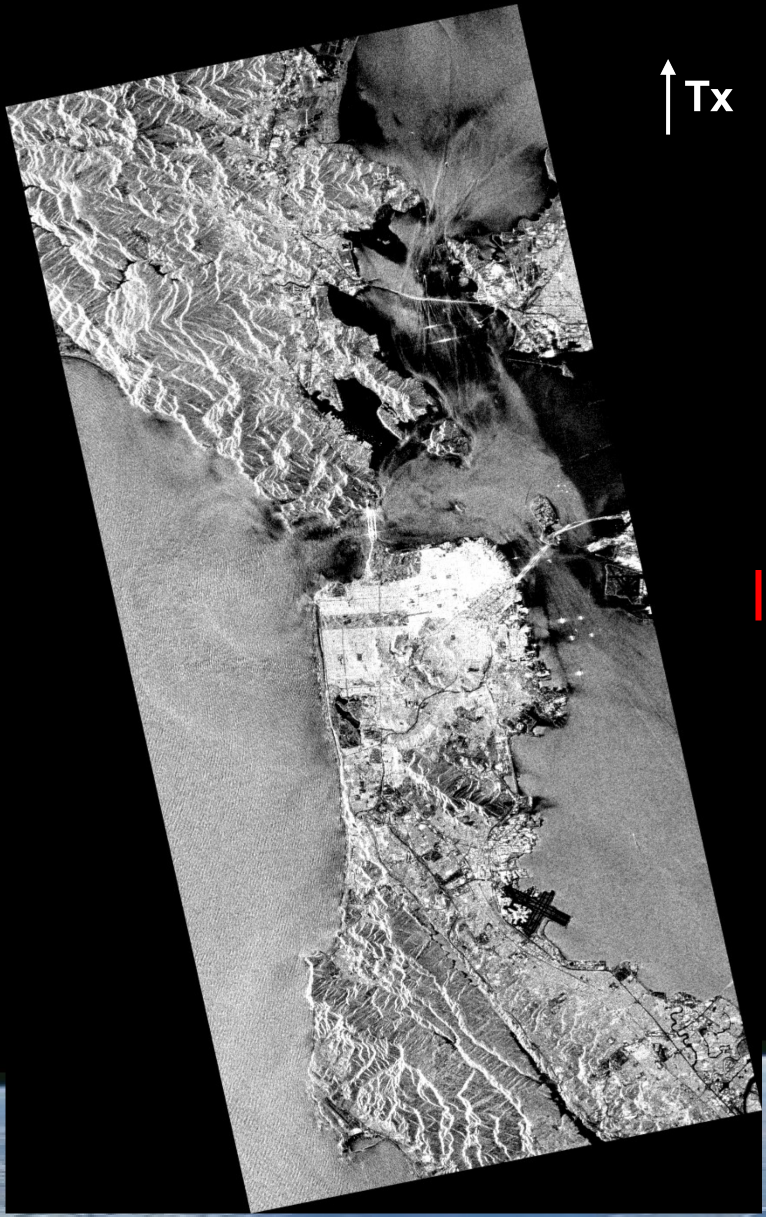
Rx

$|HH|_{dB}$

San Francisco Bay – (L-Band)

© L. Ferro-Famil & E. Pottier

Space-borne Sensors



Tx

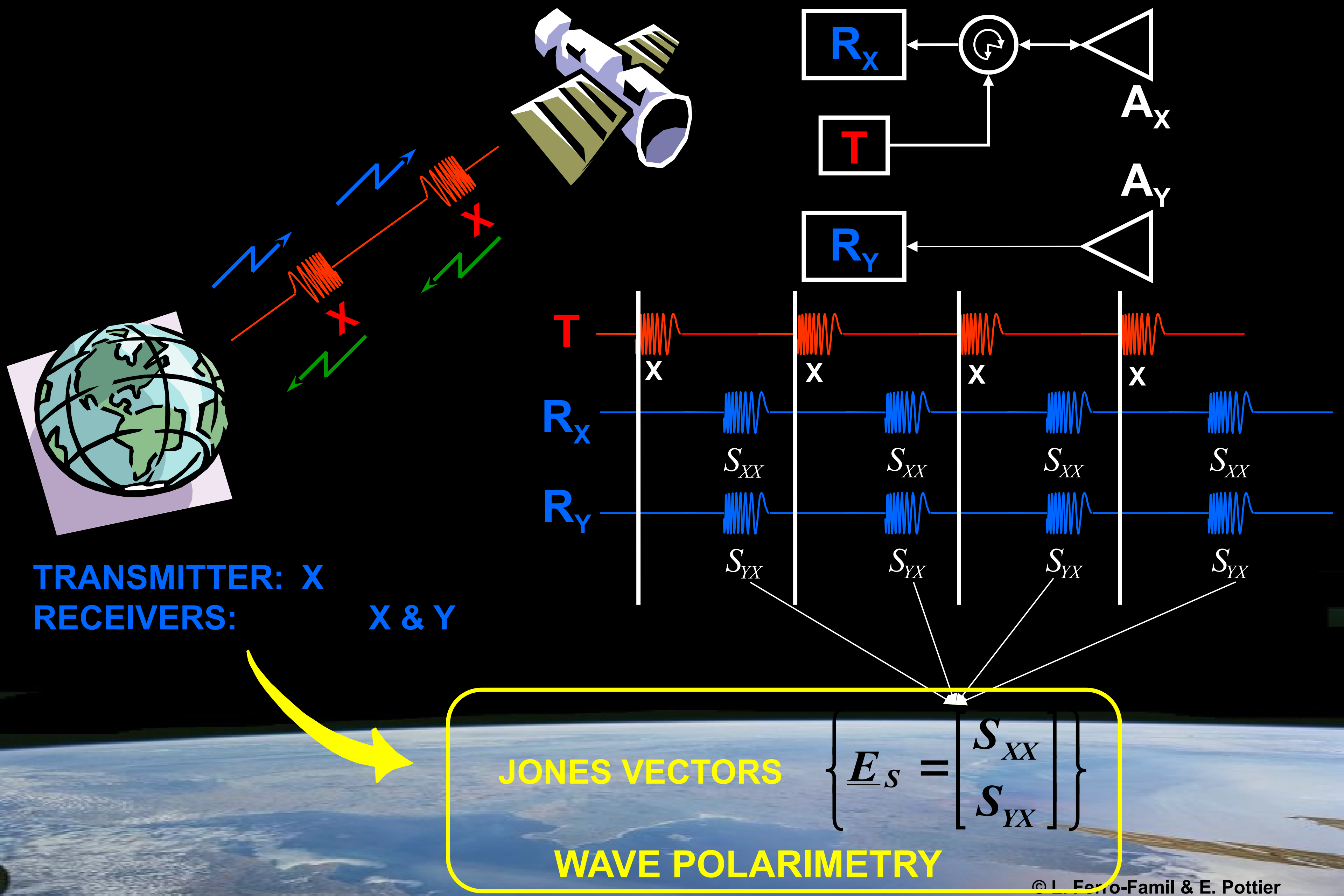
Rx

$|VV|_{dB}$

San Francisco Bay – (L-Band)

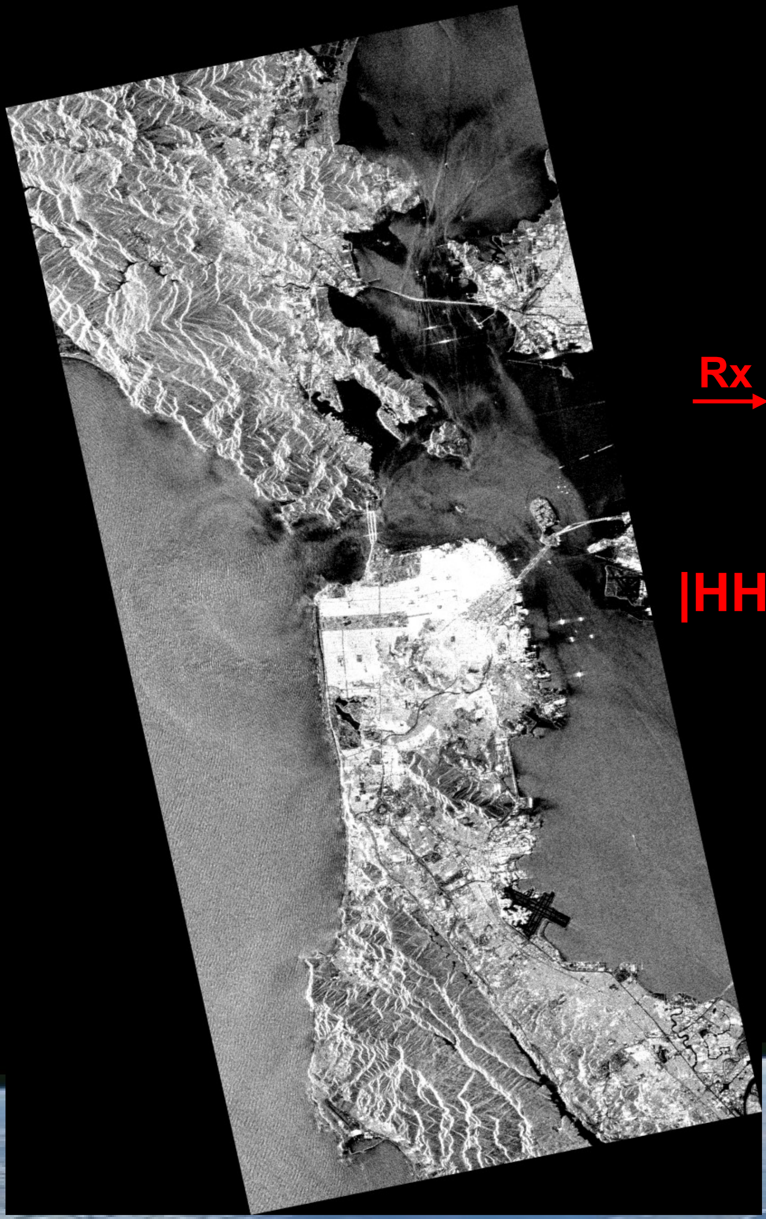
© L. Ferro-Famil & E. Pottier

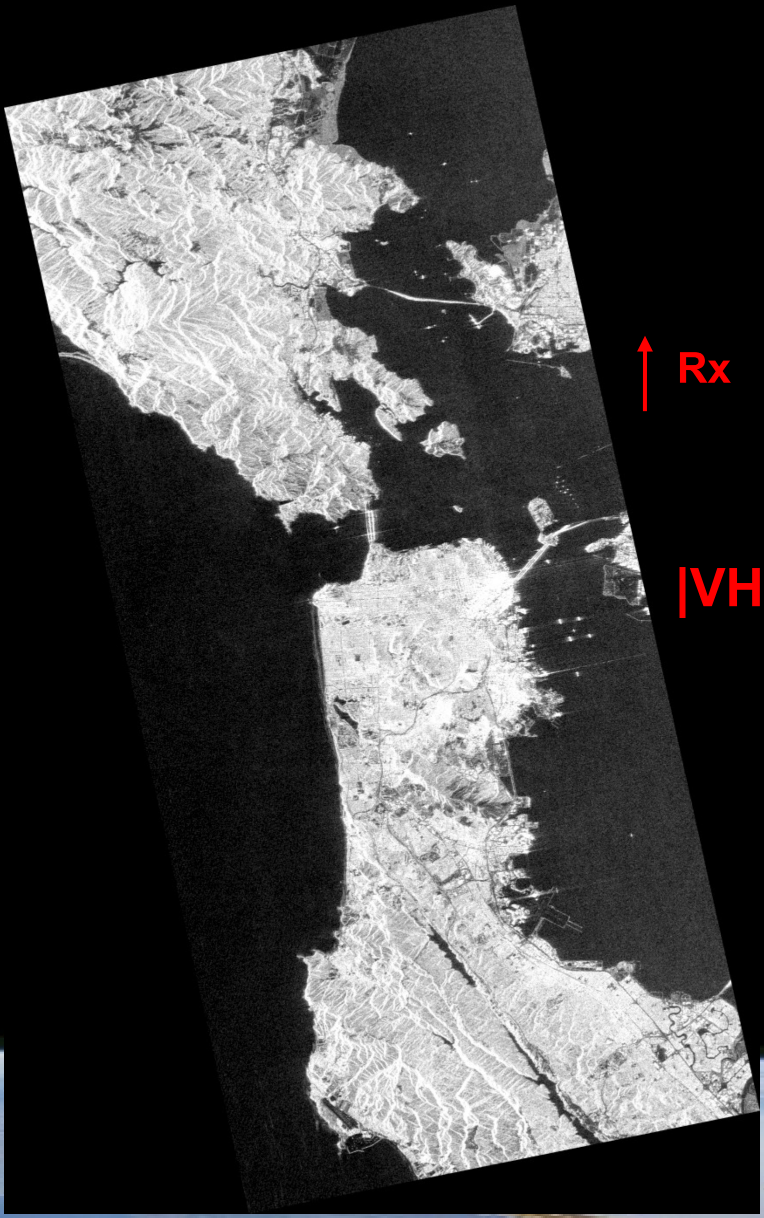
Wave Polarimetry



© L. Ferro-Famil & E. Pottier

Space-borne Sensors

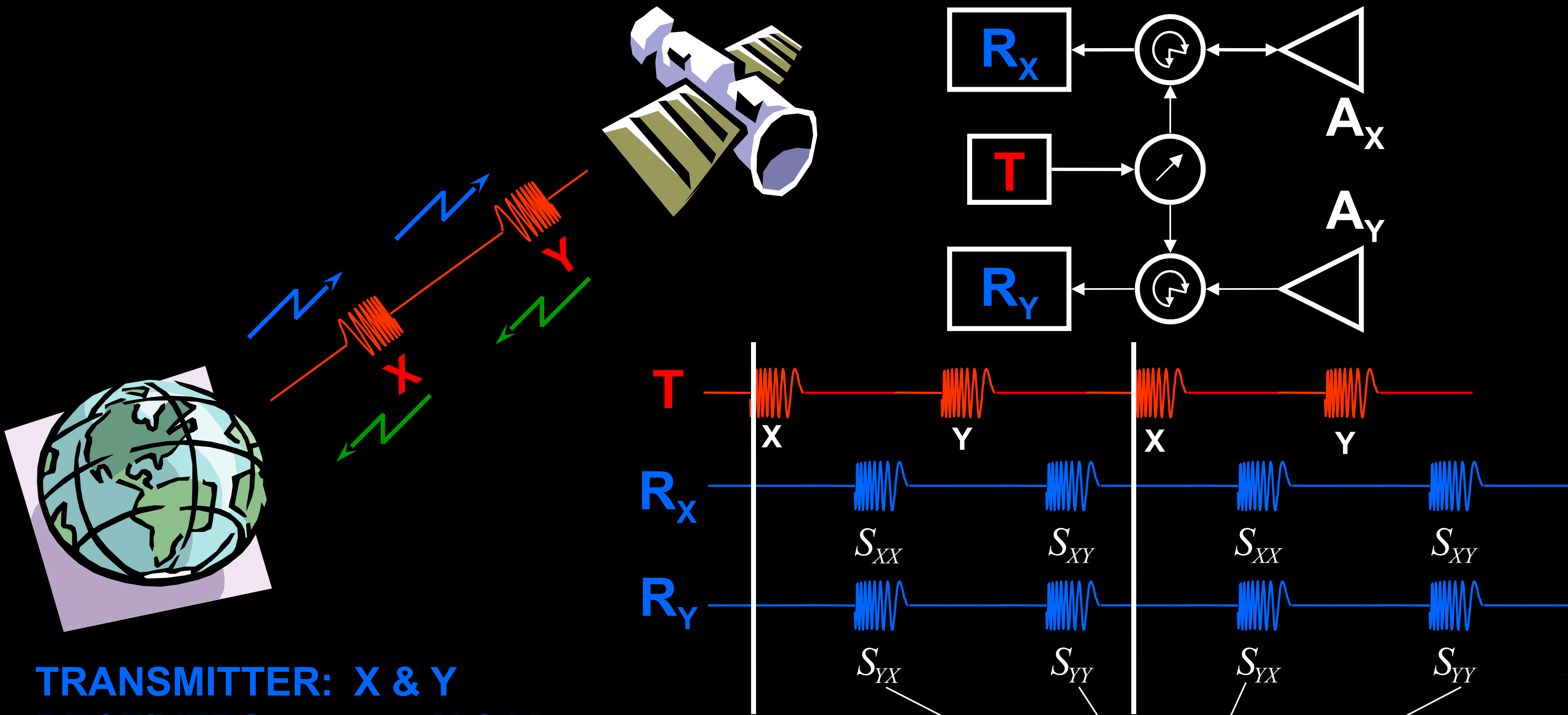




San Francisco Bay – (L-Band)

© L. Ferro-Famil & E. Pottier

Scattering Polarimetry



TRANSMITTER: X & Y

RECEIVERS: X & Y

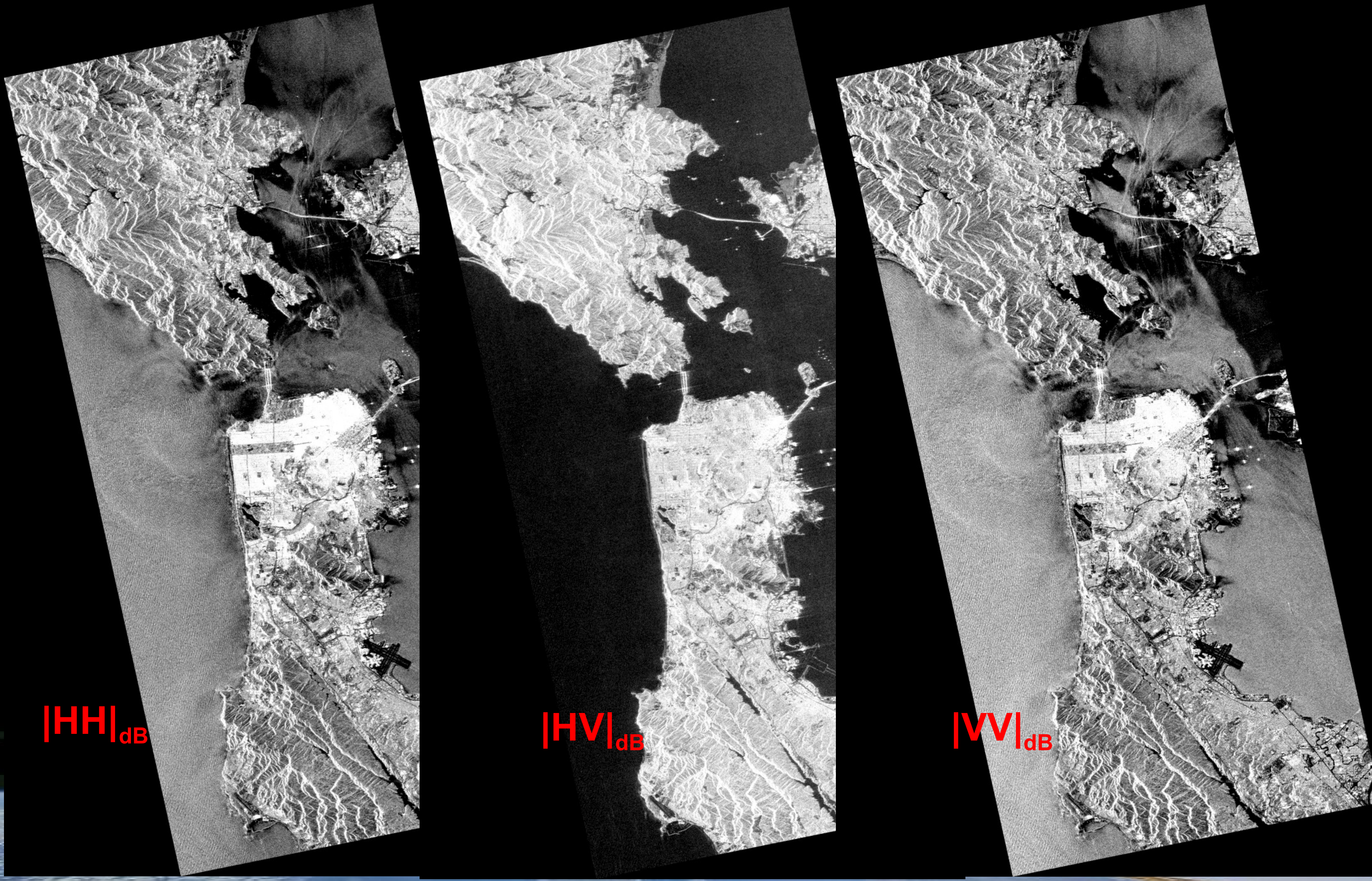
SINCLAIR MATRICES

$$\left\{ [S] = \begin{bmatrix} S_{XX} & S_{XY} \\ S_{YX} & S_{YY} \end{bmatrix} \right\}$$

SCATTERING POLARIMETRY

© L. Ferro-Famil & E. Pottier

Space-borne Sensors



San Francisco Bay – (L-Band)

© L. Ferro-Famil & E. Pottier

Space-borne Sensors

$|HH|_{dB}$

$|HV|_{dB}$

$|VV|_{dB}$

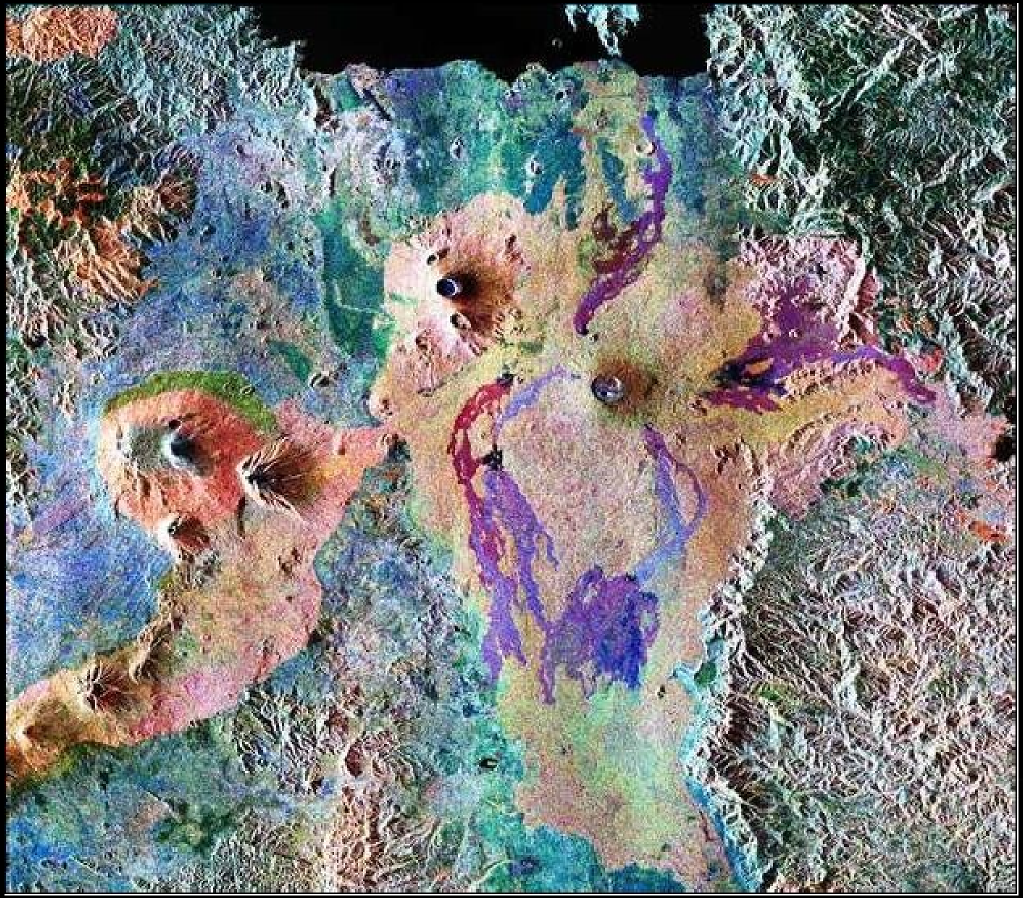
San Francisco Bay – (L-Band)

© L. Ferro-Famil & E. Pottier

Space-borne PolSAR Sensors

SIR-C / X-SAR

April 1994
L- and C-Band (Quad)
X-Band (Sngl)

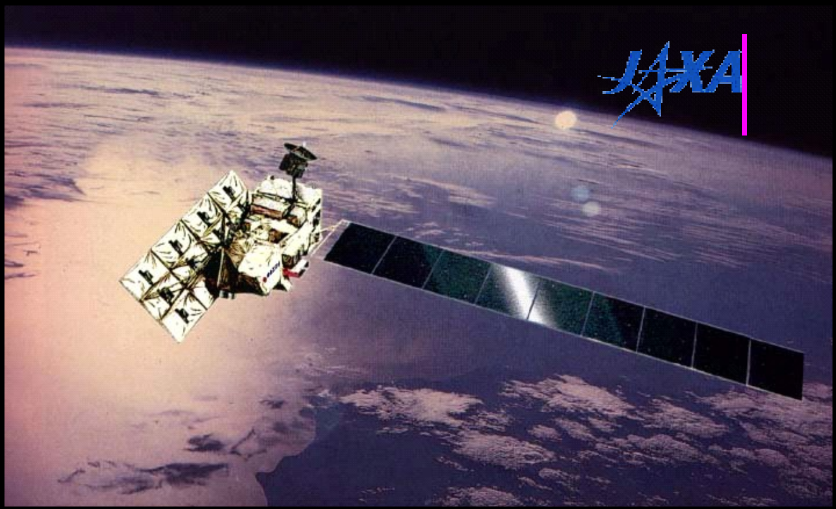


Rwanda, Zaire, Uganda

© L. Ferro-Famil & E. Pottier

Space-borne PolSAR Sensors

ALOS - PALSAR



January 2006
L-Band (Sngl / Twin / Quad)

ALOS : Advanced Land Observing Satellite
PALSAR : Phase Array L-Band SAR

© L. Ferro-Famil & E. Pottier

Space-borne PolSAR Sensors

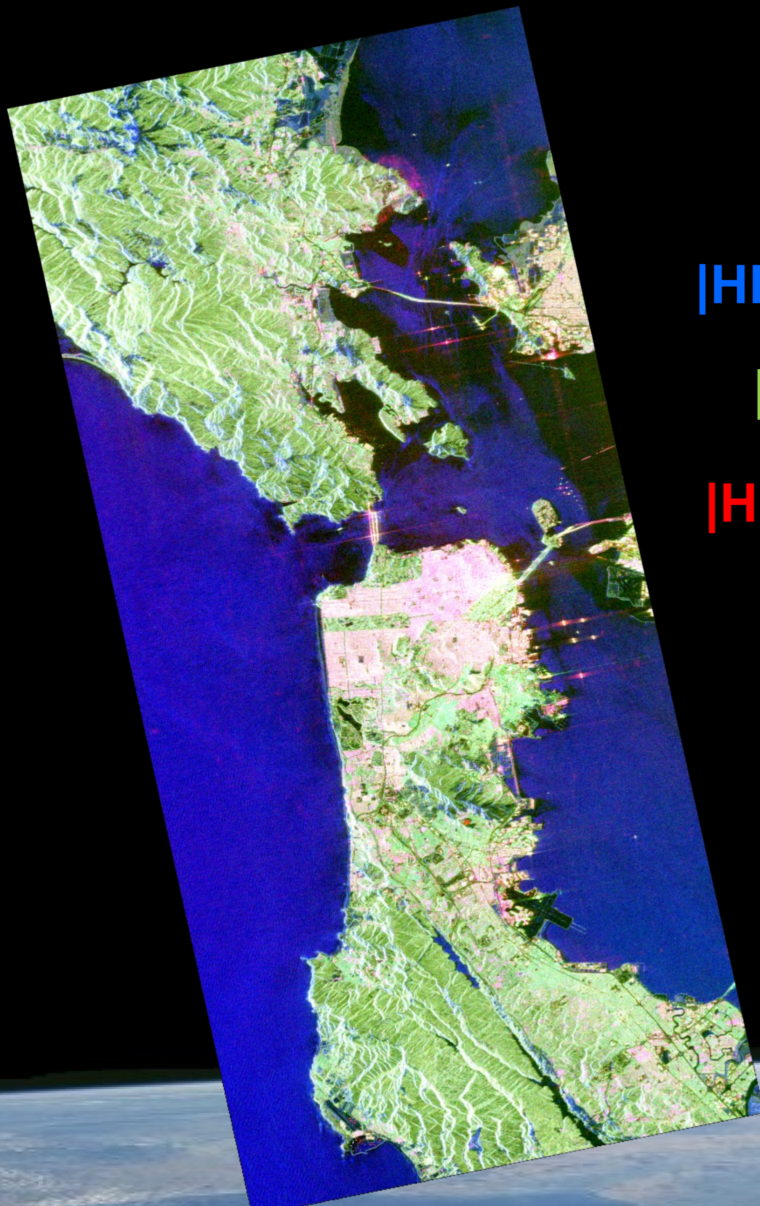
RADARSAT - 2

December 2007

C-Band (Quad)

© L. Ferro-Famil & E. Pottier

Space-borne Sensors



$|HH+VV|_{dB}$

$|HV|_{dB}$

$|HH-VV|_{dB}$

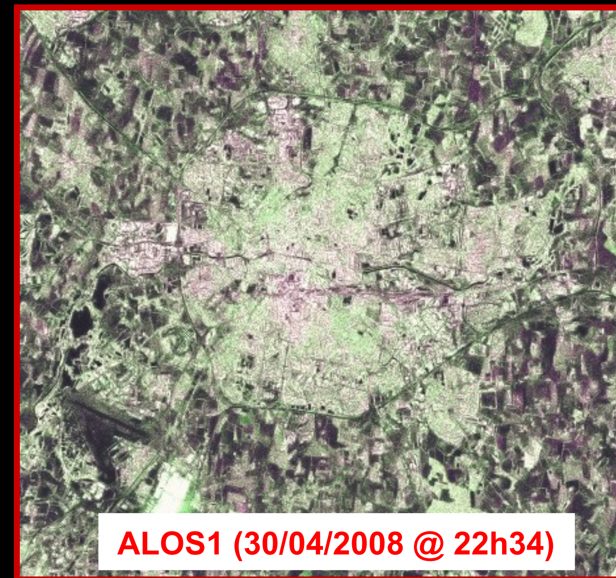
San Francisco Bay – (L-Band and C-Band)

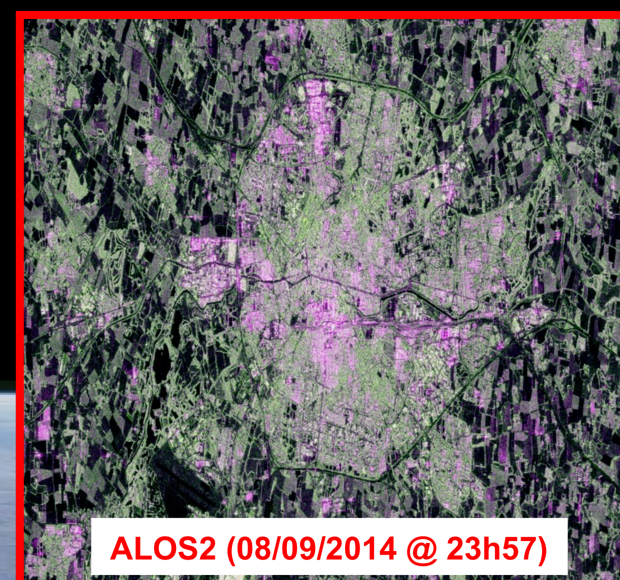
© L. Ferro-Famil & E. Pottier

Space-borne PolSAR Sensors

ALOS - 2

May 2014
L-Band (Quad)

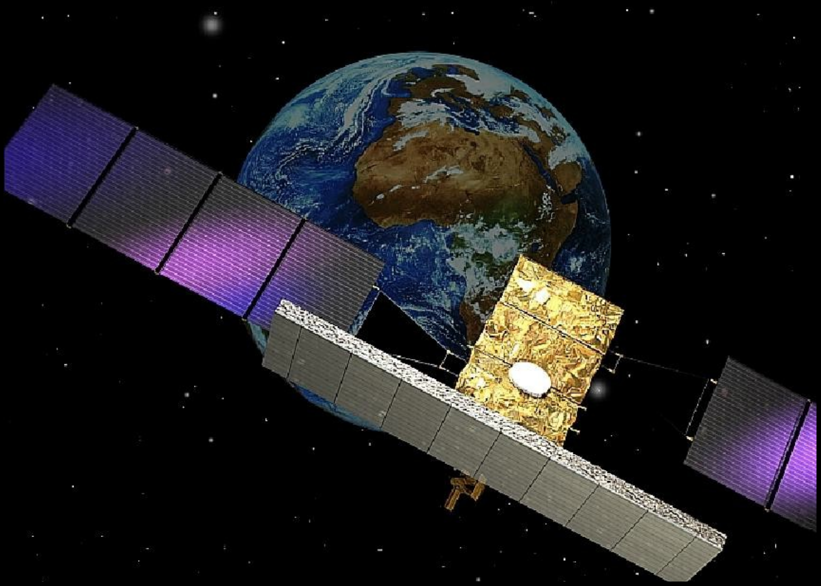




© L. Ferro-Famil & E. Pottier

Space-borne PolSAR Sensors

COSMO - SkyMed - CSG

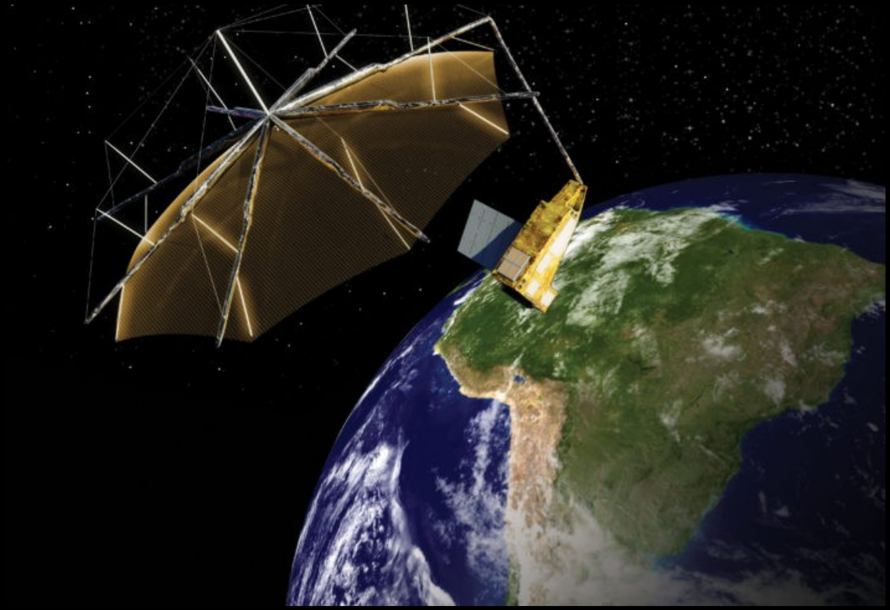


agenzia spaziale italiana — TELESPAZIO, A Finmeccanica / Thales Company

2A : 2018 2B : 2019

X-Band (Sngl / Dual / Quad Exp.)

Earth Explorer - BIOMASS



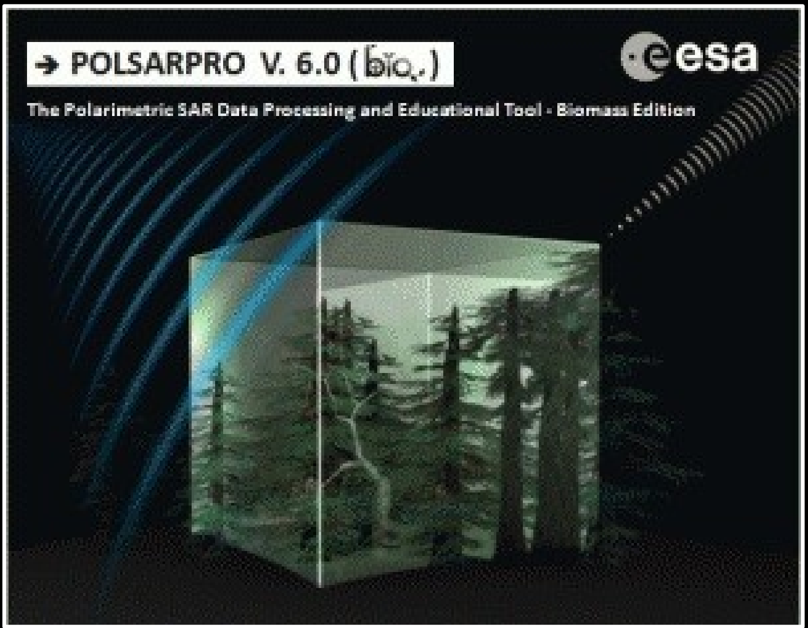
esa

2021

P-Band (Quad)

© L. Ferro-Famil & E. Pottier

ESA PolSARpro Toolbox



Polarimetric SAR data Processing and educational tool

esa since 2003

- +3000 registered users
- +70 foreign countries

International Collaborative Project

(Agencies, Research Centres, Universities)

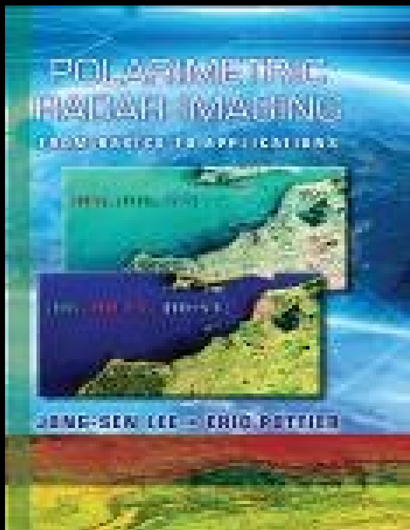
© L. Ferro-Famil & E. Pottier

Teaching / Training

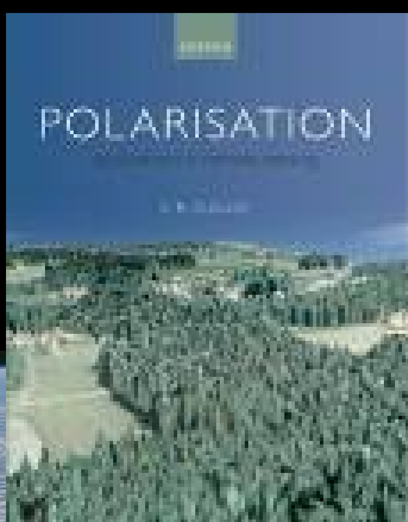
Next P.I Generations

© L. Ferro-Famil & E. Pottier

Books On Polarimetric Radar SAR, Polarimetric Interferometry

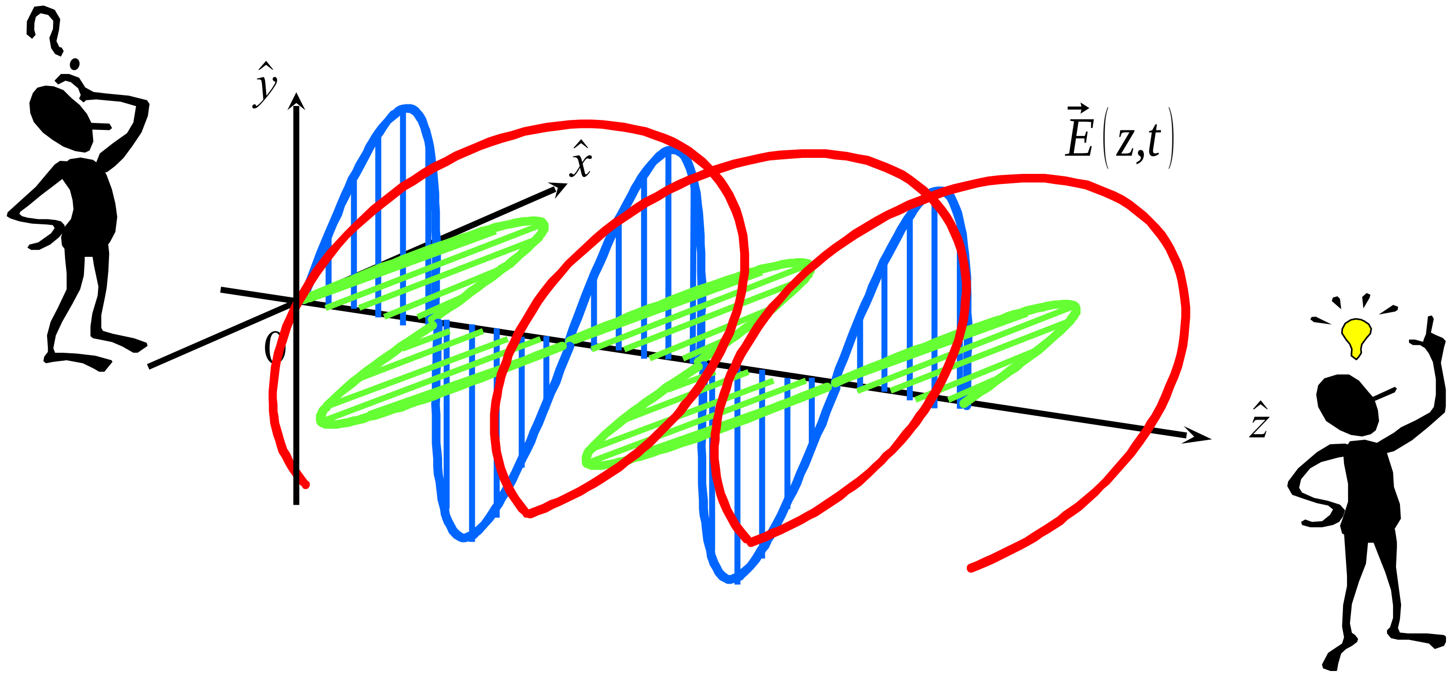


Polarimetric Radar Imaging: From basics to applications
Jong-Sen LEE – Eric POTTIER
CRC Press; 1st ed., February 2009, pp 422
ISBN: 978-1420054972

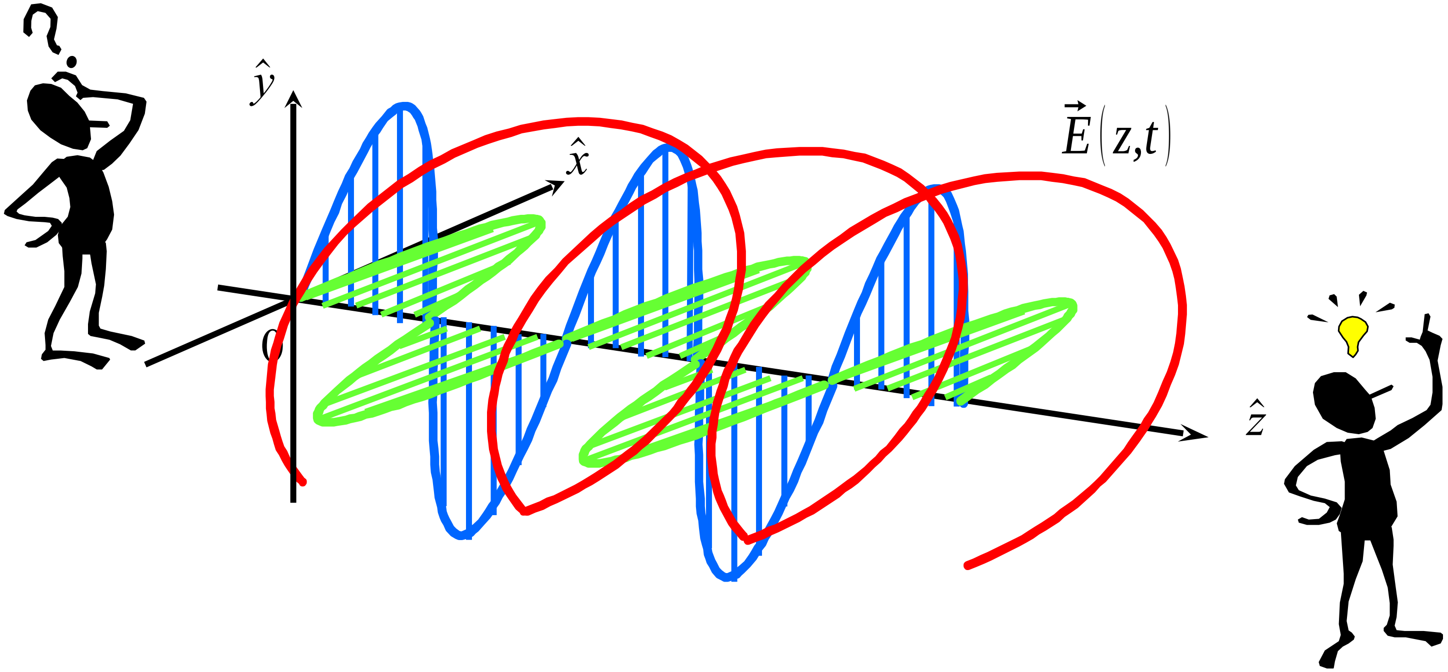


Polarisation: Applications in Remote Sensing
Shane R. CLOUDE
Oxford University Press, October 2009, pp 352
ISBN: 978-0199569731

© L. Ferro-Famil & E. Pottier



BASIC CONCEPTS



WAVE POLARIMETRY

PROPAGATION EQUATION

REAL ELECTRIC FIELD VECTOR $\vec{E}(z,t)$

MAXWELL EQUATIONS

MAXWELL – FARADAY EQUATION

$$\nabla \wedge \vec{E}(z,t) = -\frac{\partial \vec{B}(z,t)}{\partial t}$$

MAXWELL – AMPERE EQUATION

$$\nabla \wedge \vec{H}(z,t) = \vec{J}_T(z,t)$$

GAUSS THEOREM

$$\nabla \cdot \vec{D}(z,t) = \rho(z,t)$$

$$\nabla \cdot \vec{B}(z,t) = 0$$

σ (Conductivity)

μ (Permeability)

ε (Permittivity)

PROPAGATION EQUATION

$$\nabla \wedge \left(\nabla \wedge \vec{A} \right) = \nabla \left(\nabla \cdot \vec{A} \right) - \nabla \cdot \left(\nabla \vec{A} \right)$$

PROPAGATION EQUATION

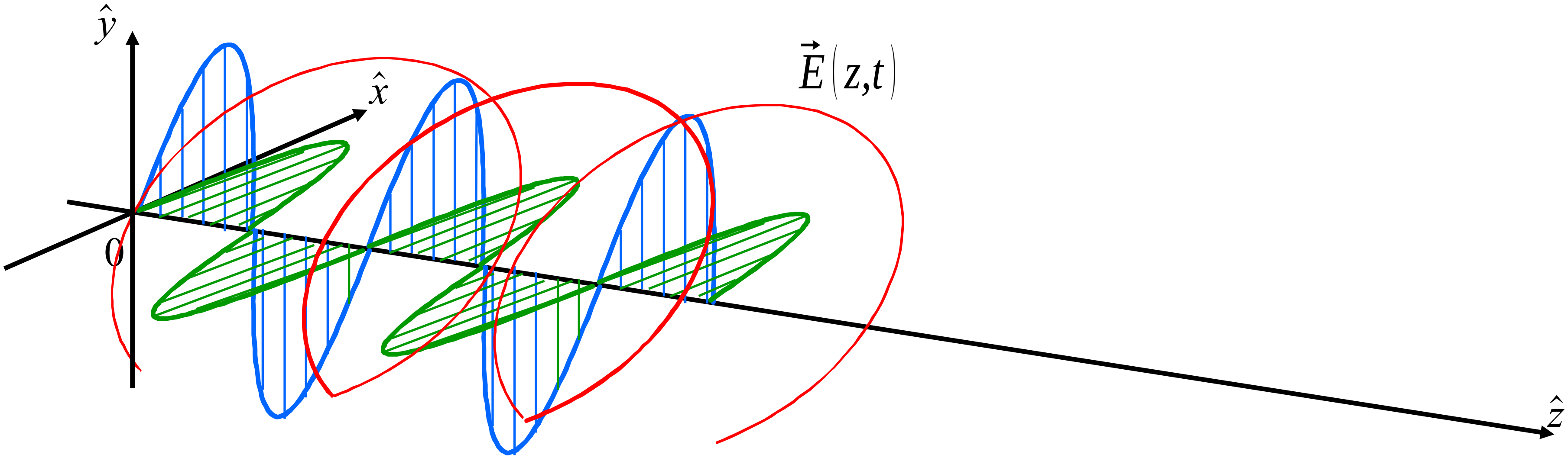
$$\nabla^2 \vec{E}\left(z,t\right) - \mu\varepsilon \frac{\partial^2 \vec{E}\left(z,t\right)}{\partial\ t^2} - \mu\sigma \frac{\partial\ \vec{E}\left(z,t\right)}{\partial\ t} = -\frac{1}{\varepsilon} \frac{\partial\ \rho\left(z,t\right)}{\partial\ t}$$

HELMHOLTZ PROPAGATION EQUATION

$$\nabla^2 \vec{E}\left(z,t\right) - \mu\varepsilon \frac{\partial^2 \vec{E}\left(z,t\right)}{\partial\ t^2} = 0$$

Source Free, Linear, Homogeneous, Isotropic, Dielectric and lossless Medium

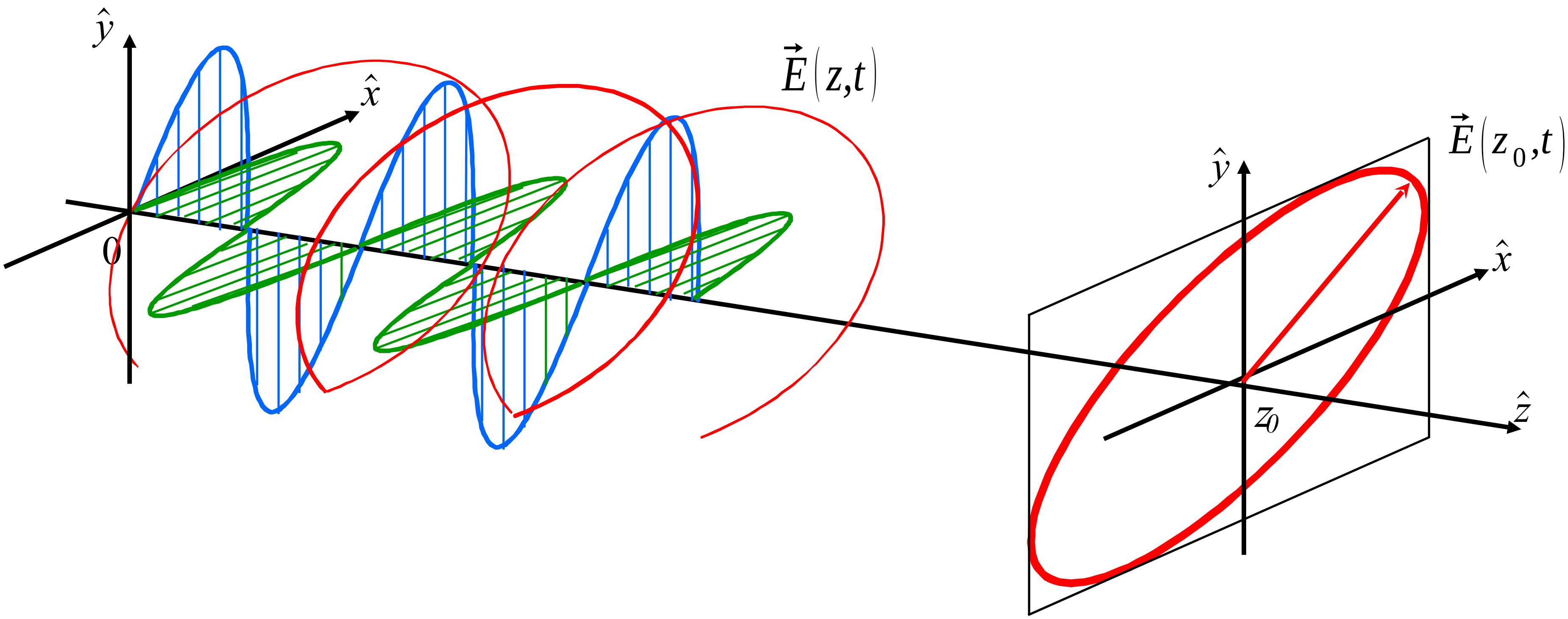
POLARISATION ELLIPSE



REAL ELECTRIC FIELD VECTOR

$$\vec{E}(z,t)=\begin{cases} E_x = E_{0x}\cos(\omega t - kz - \delta_x) \\ E_y = E_{0y}\cos(\omega t - kz - \delta_y) \\ E_z = 0 \end{cases}$$

POLARISATION ELLIPSE

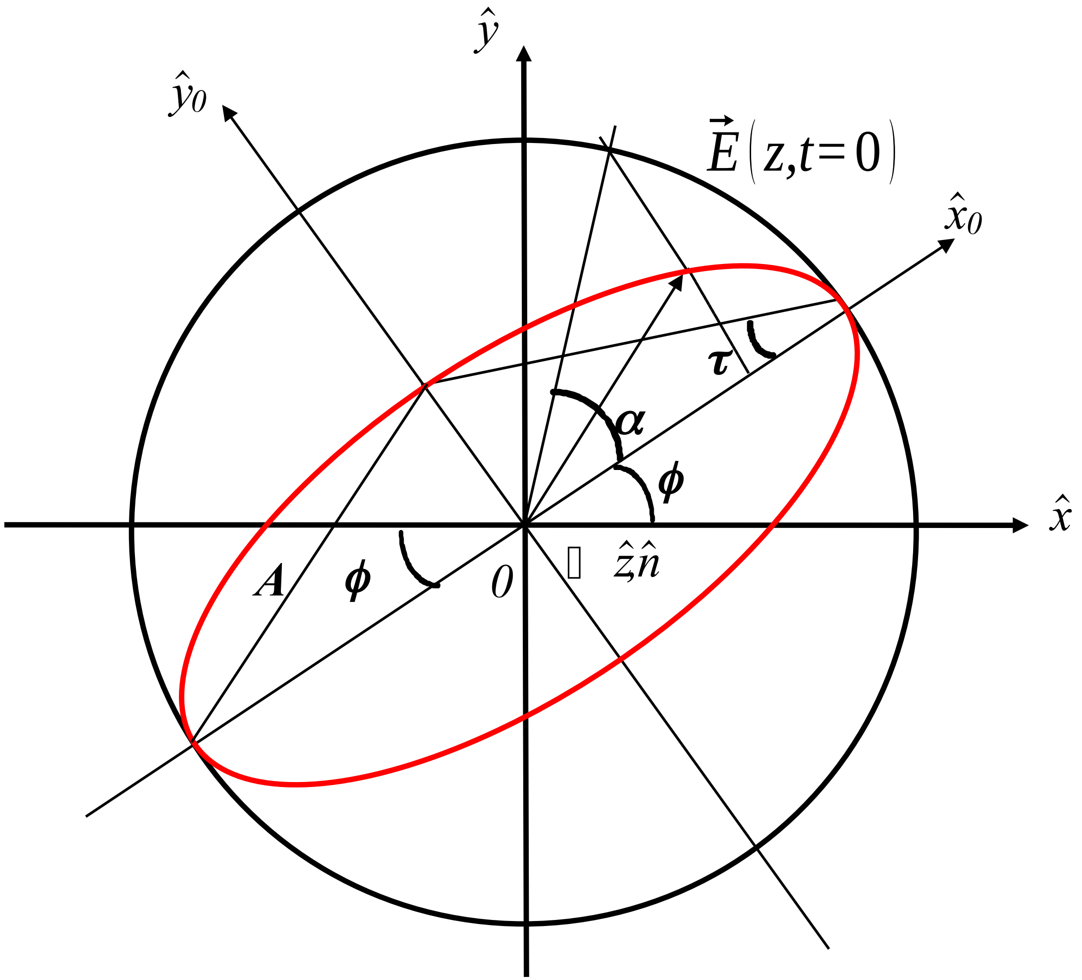


THE REAL ELECTRIC FIELD VECTOR MOVES IN TIME ALONG AN ELLIPSE

$$\left(\frac{E_x}{E_{0x}}\right)^2 - 2\frac{E_x E_y}{E_{0x}E_{0y}}\cos(\delta) + \left(\frac{E_y}{E_{0y}}\right)^2 = \sin^2(\delta)$$

With: $\delta = \delta_y - \delta_x$

POLARISATION ELLIPSE



A : **WAVE AMPLITUDE**

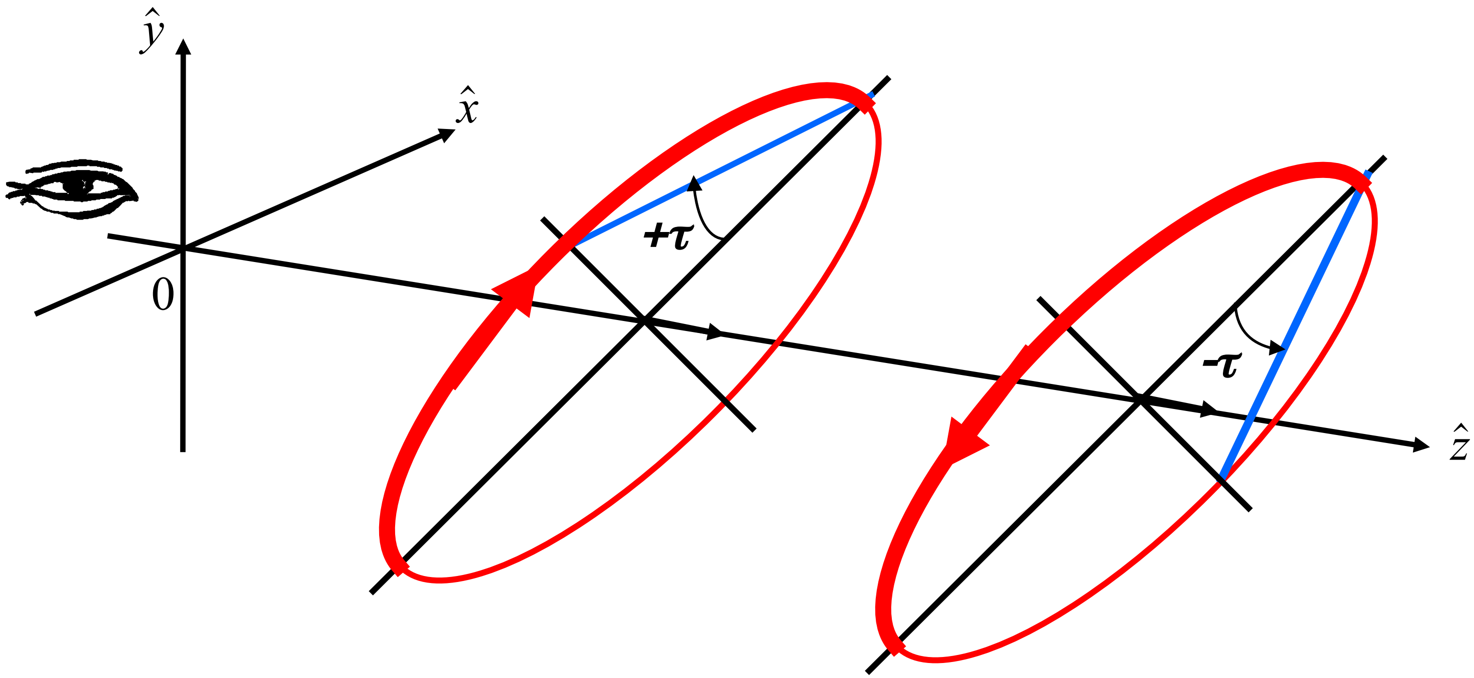
$\boldsymbol{\alpha}$: **ABSOLUTE PHASE**

$\boldsymbol{\phi}$: **ORIENTATION ANGLE** $-\frac{\pi}{2} \leq \varphi \leq \frac{\pi}{2}$

$\boldsymbol{\tau}$: **ELLIPTICITY ANGLE** $0 \leq \tau \leq \frac{\pi}{4}$

POLARISATION HANDENESS

ROTATION SENSE: LOOKING INTO THE DIRECTION OF THE WAVE PROPAGATION



ANTI-CLOCKWISE ROTATION	CLOCKWISE ROTATION
LEFT HANDED POLARISATION	**RIGHT HANDED POLARISATION**
⬇	⬇
ELLIPTICITY ANGLE : $\tau > 0$	ELLIPTICITY ANGLE : $\tau < 0$

$$-\frac{\pi}{4} \leq \tau \leq \frac{\pi}{4}$$

L. Ferro-Famil & E. Pottier

isae SUPAERO CESBIO IETR

JONES VECTOR

REAL ELECTRIC FIELD VECTOR

$$\vec{E}(z,t)=\begin{cases} E_x = E_{0x}\cos(\omega t - kz - \delta_x) \\ E_y = E_{0y}\cos(\omega t - kz - \delta_y) \\ E_z = 0 \end{cases}$$

PHASOR = JONES VECTOR

$$\underline{E} = \begin{bmatrix} E_x = E_{ox}\, e^{j\delta_x} \\ E_y = E_{oy}\, e^{j\delta_y} \end{bmatrix}$$

With: $\vec{E}(z,t) = \Re\left(\underline{E}\, e^{j(\omega t - kz)}\right)$

GEOMETRICAL PARAMETERS

ABSOLUTE PHASE

$$\alpha = \delta_x$$

AMPLITUDE

$$A = \sqrt{E_{0x}^2 + E_{0y}^2}$$

ORIENTATION ANGLE

$$\tan 2\varphi = 2\frac{E_{0x}E_{0y}}{E_{0x}^2 - E_{0y}^2}\cos\delta$$

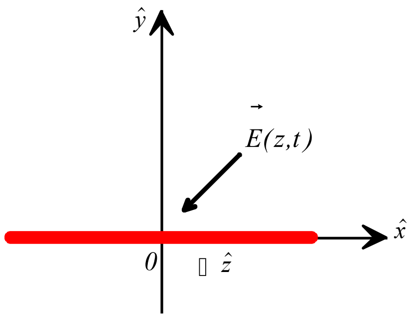
ELLIPTICITY ANGLE

$$\sin 2\tau = 2\frac{E_{0x}E_{0y}}{E_{0x}^2 + E_{0y}^2}\sin\delta$$

POLARISATION HANDENESS: ***Sign(τ)***

JONES VECTOR

HORIZONTAL POLARISATION STATE

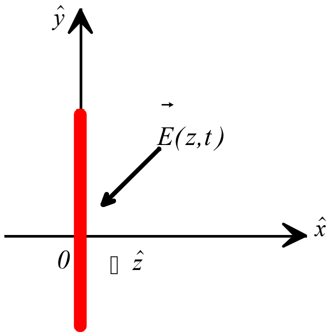


$$\underline{H} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$\varphi = 0$$

$$\tau = 0$$

VERTICAL POLARISATION STATE

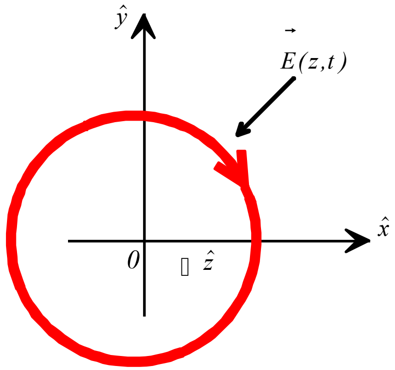


$$\underline{V} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$$\varphi = \frac{\pi}{2}$$

$$\tau = 0$$

LEFT CIRCULAR POLARISATION STATE

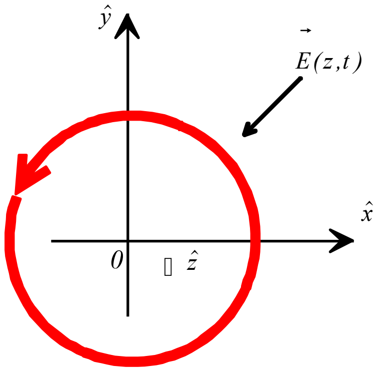


$$\underline{LC} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ j \end{bmatrix}$$

$$-\frac{\pi}{2} \leq \varphi \leq +\frac{\pi}{2}$$

$$\tau = +\frac{\pi}{4}$$

RIGHT CIRCULAR POLARISATION STATE

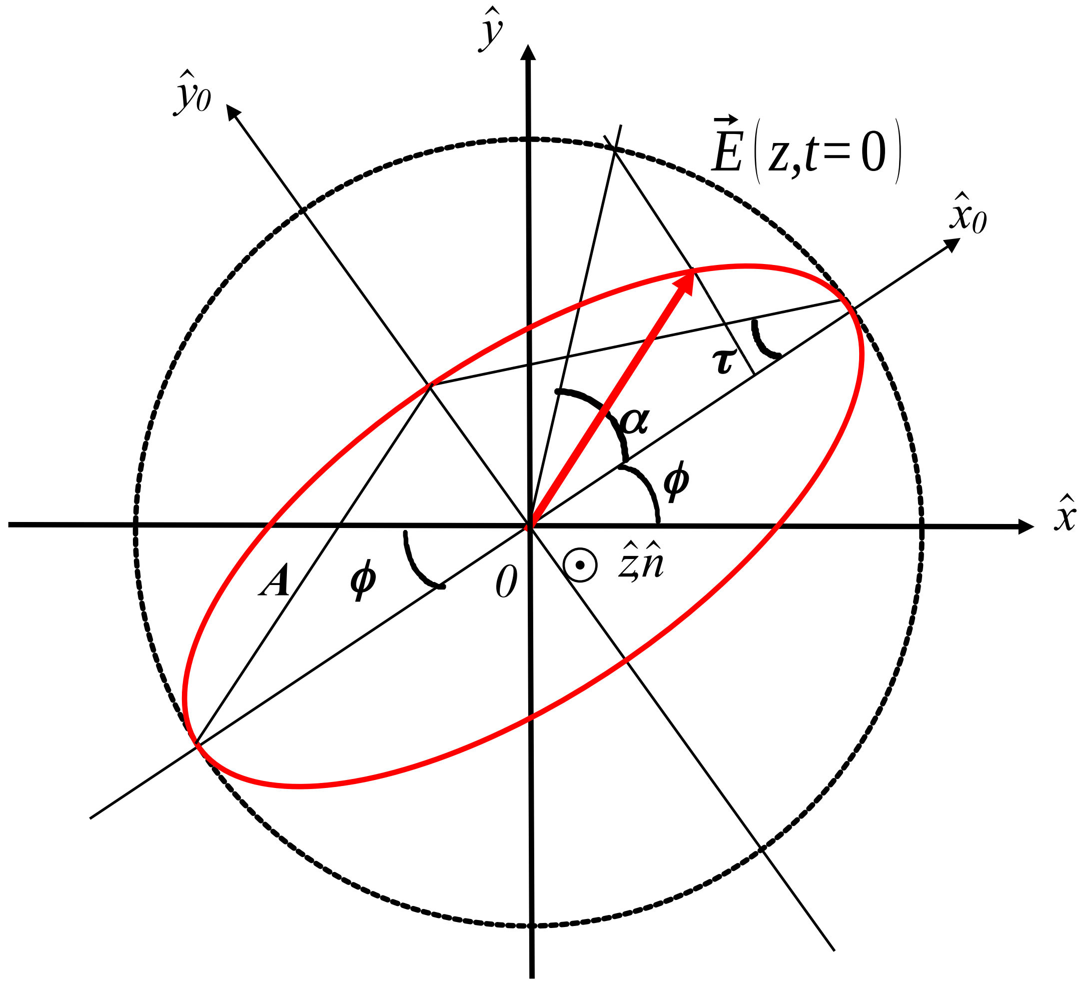


$$\underline{RC} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -j \end{bmatrix}$$

$$-\frac{\pi}{2} \leq \varphi \leq +\frac{\pi}{2}$$

$$\tau = -\frac{\pi}{4}$$

JONES VECTOR



$$\underline{E} = A \begin{bmatrix} \cos(\varphi) & -\sin(\varphi) \\ \sin(\varphi) & \cos(\varphi) \end{bmatrix} \begin{bmatrix} \cos(\tau) & j\sin(\tau) \\ j\sin(\tau) & \cos(\tau) \end{bmatrix} \begin{bmatrix} e^{-j\alpha} & 0 \\ 0 & e^{j\alpha} \end{bmatrix} \hat{u}_x$$

ORTHOGONAL JONES VECTOR

JONES VECTOR

$$\underline{E} \qquad \begin{bmatrix} E_x \\ E_y \end{bmatrix} = \begin{bmatrix} E_{ox}\, e^{j\delta_x} \\ E_{oy}\, e^{j\delta_y} \end{bmatrix}$$

$$= A \begin{bmatrix} \cos(\varphi) & -\sin(\varphi) \\ \sin(\varphi) & \cos(\varphi) \end{bmatrix} \begin{bmatrix} \cos(\tau) & j\sin(\tau) \\ j\sin(\tau) & \cos(\tau) \end{bmatrix} \begin{bmatrix} e^{-j\alpha} & 0 \\ 0 & e^{j\alpha} \end{bmatrix} \hat{u}_x$$

⬇

POLARISATION ALGEBRA

NORM OF A JONES VECTOR $\|\underline{E}\| = \sqrt{E_{0x}^2 + E_{0y}^2}$

SCALAR PRODUCT $\langle \underline{A}\underline{B} \rangle = \underline{A}^{*T}\underline{B}$

ORTHOGONALITY $\langle \underline{A}\underline{A}_{\perp} \rangle = 0$

ELLIPTICAL BASIS TRANSFORMATION

JONES VECTOR

$$\underline{E} = A\begin{bmatrix}\cos(\varphi) & -\sin(\varphi)\\ \sin(\varphi) & \cos(\varphi)\end{bmatrix}\begin{bmatrix}\cos(\tau) & j\sin(\tau)\\ j\sin(\tau) & \cos(\tau)\end{bmatrix}\begin{bmatrix}e^{-j\alpha} & 0\\ 0 & e^{j\alpha}\end{bmatrix}\hat{u}_x$$

ORTHOGONAL JONES VECTOR

$$\underline{E} = A\begin{bmatrix}\cos(\varphi) & -\sin(\varphi)\\ \sin(\varphi) & \cos(\varphi)\end{bmatrix}\begin{bmatrix}\cos(\tau) & j\sin(\tau)\\ j\sin(\tau) & \cos(\tau)\end{bmatrix}\begin{bmatrix}e^{-j\alpha} & 0\\ 0 & e^{j\alpha}\end{bmatrix}\hat{u}_y$$

$$\left[\underline{E}, \underline{E}\right] = A\begin{bmatrix}\cos(\varphi) & -\sin(\varphi)\\ \sin(\varphi) & \cos(\varphi)\end{bmatrix}\begin{bmatrix}\cos(\tau) & j\sin(\tau)\\ j\sin(\tau) & \cos(\tau)\end{bmatrix}\begin{bmatrix}e^{-j\alpha} & 0\\ 0 & e^{j\alpha}\end{bmatrix}\left[\hat{u}_x, \hat{u}_y\right]$$

ELLIPTICAL BASIS TRANSFORMATION

ELLIPTICAL BASIS TRANSFORMATION

SU(2) : SPECIAL UNITARY TRANSFORMATION MATRIX

$$\left[U(\varphi,\tau,\alpha)\right]=\begin{bmatrix}\cos(\varphi) & -\sin(\varphi)\\ \sin(\varphi) & \cos(\varphi)\end{bmatrix}\begin{bmatrix}\cos(\tau) & j\sin(\tau)\\ j\sin(\tau) & \cos(\tau)\end{bmatrix}\begin{bmatrix}e^{-j\alpha} & 0\\ 0 & e^{j\alpha}\end{bmatrix}$$

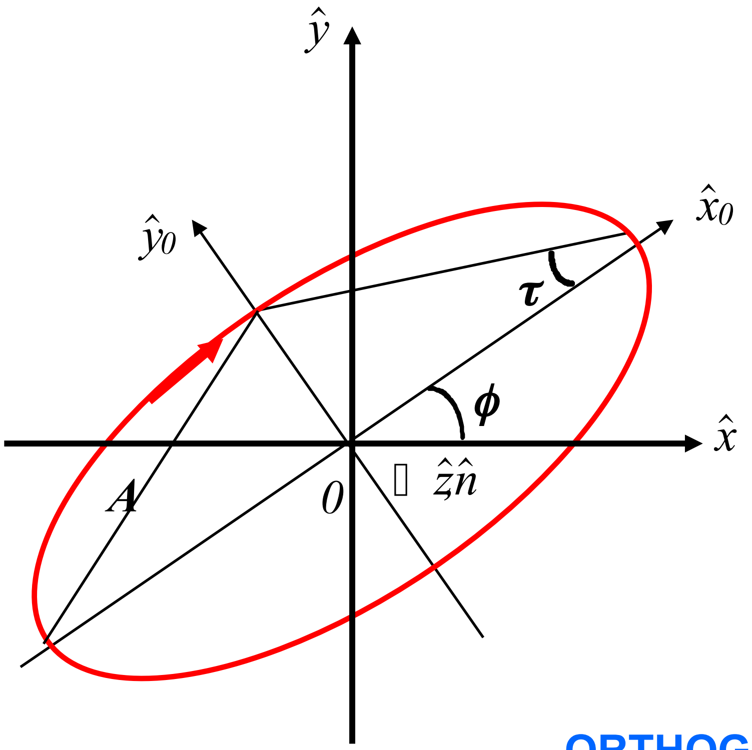
ELLIPTICAL BASIS TRANSFORMATION MATRIX

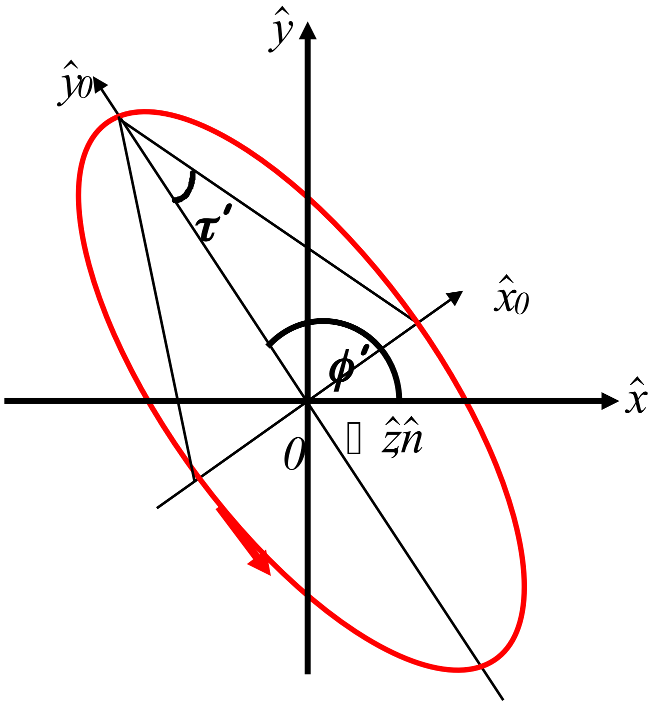
$$\left[U_{(A,A)\mapsto(B,B)}\right]$$

$$\left[U(\varphi,\tau,\alpha)\right]^{-1}$$

$$\begin{bmatrix}e^{j\alpha} & 0\\ 0 & e^{-j\alpha}\end{bmatrix}\begin{bmatrix}\cos(\tau) & -j\sin(\tau)\\ -j\sin(\tau) & \cos(\tau)\end{bmatrix}\begin{bmatrix}\cos(\varphi) & \sin(\varphi)\\ -\sin(\varphi) & \cos(\varphi)\end{bmatrix}$$

ORTHOGONAL JONES VECTOR

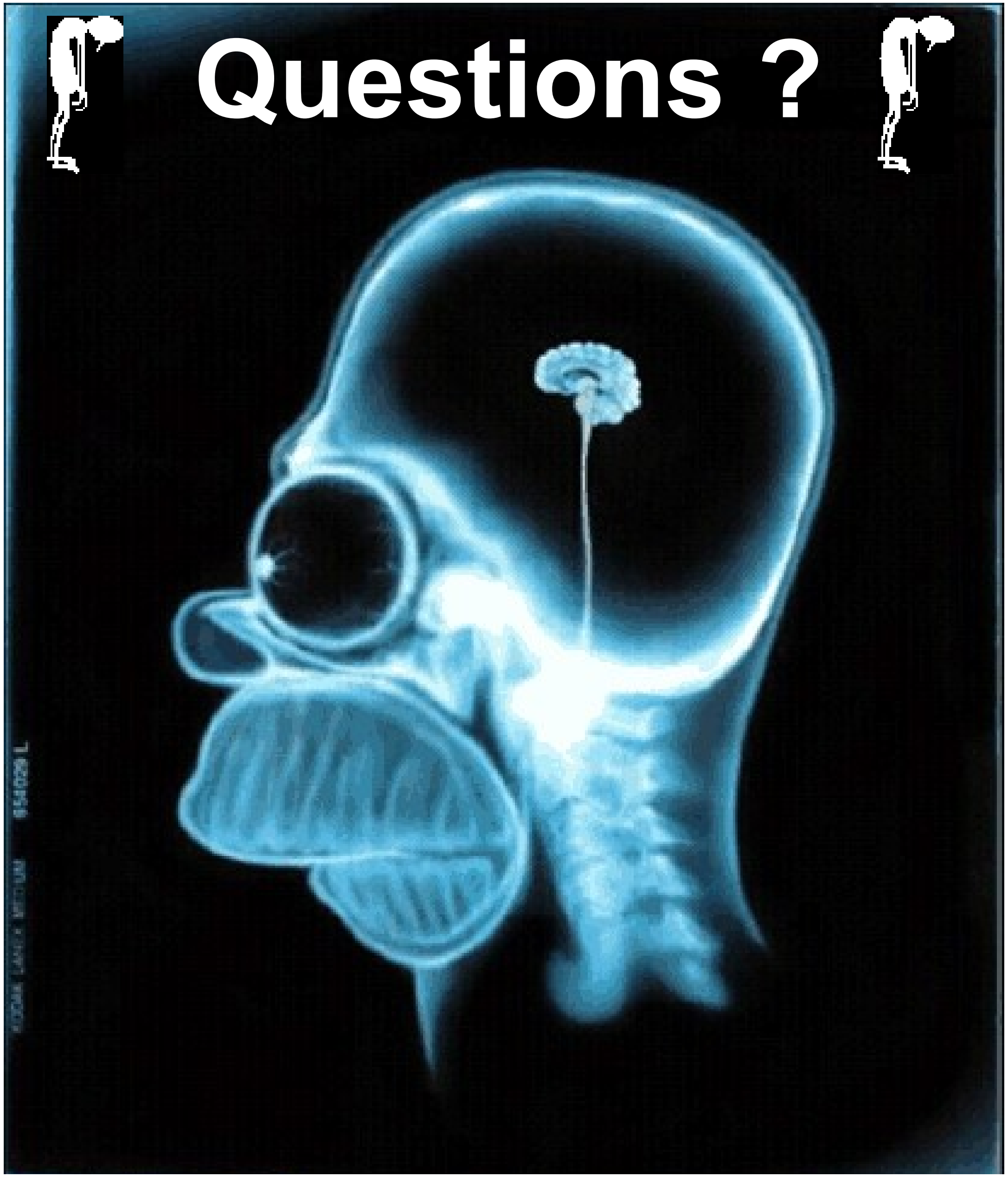


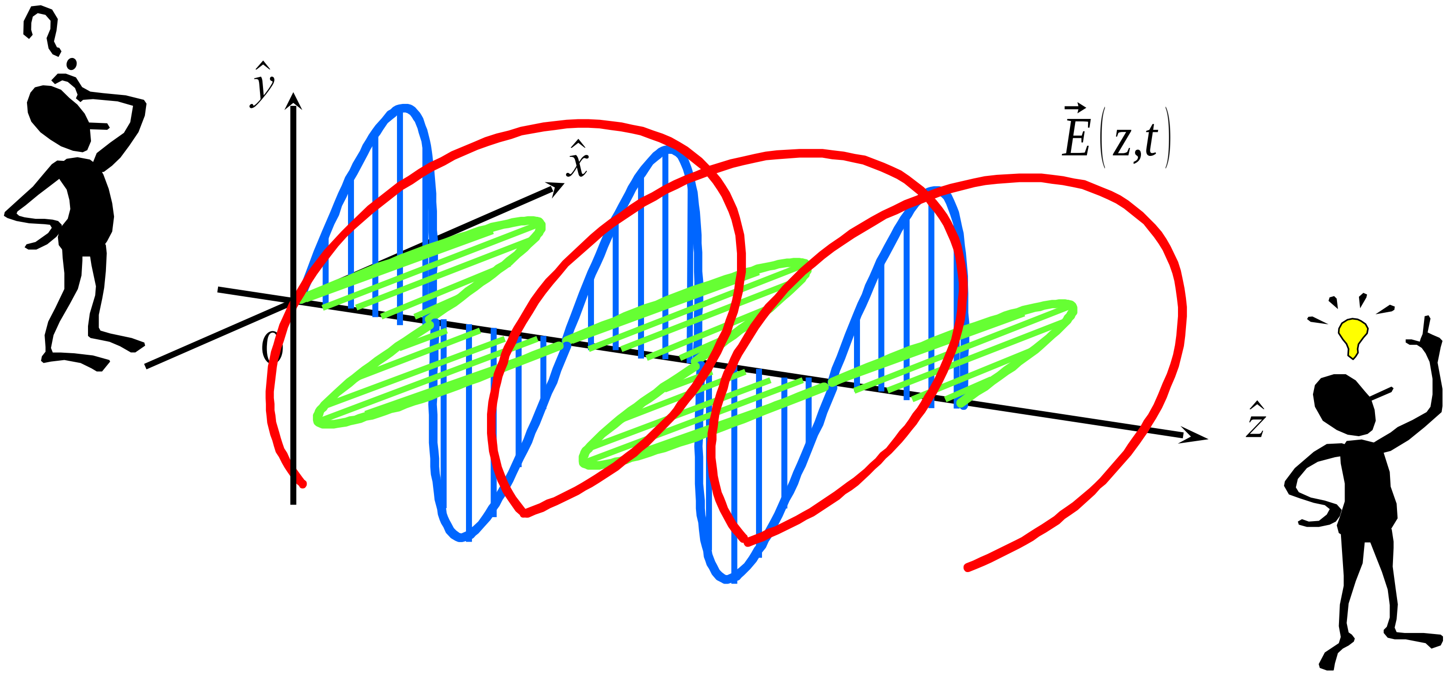


ORTHOGONALITY CONDITIONS

$$(\varphi,\tau) \mapsto \begin{cases} \varphi' = \varphi + \dfrac{\pi}{2} \\ \tau' = -\tau \end{cases}$$

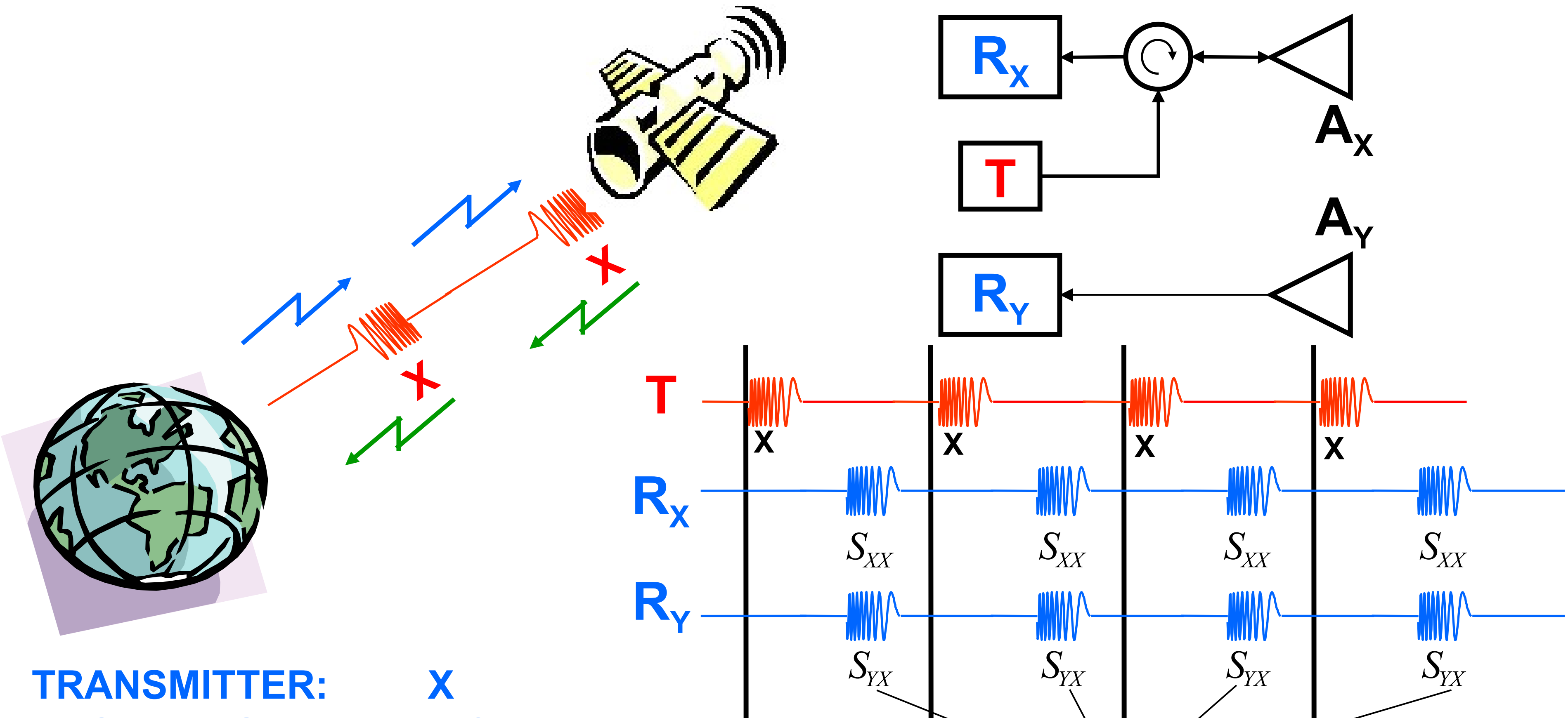
➡ **CHANGE OF POLARISATION HANDENESS**


Questions ?



SCATTERING POLARIMETRY

WAVE POLARIMETRY



TRANSMITTER: X

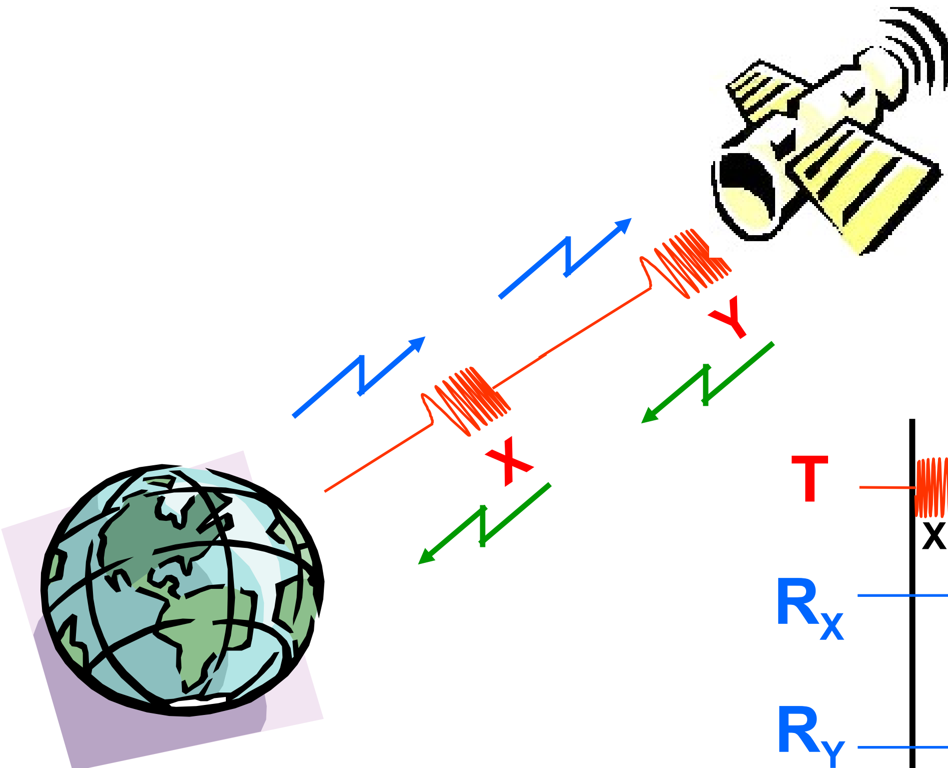
RECEIVERS: X & Y

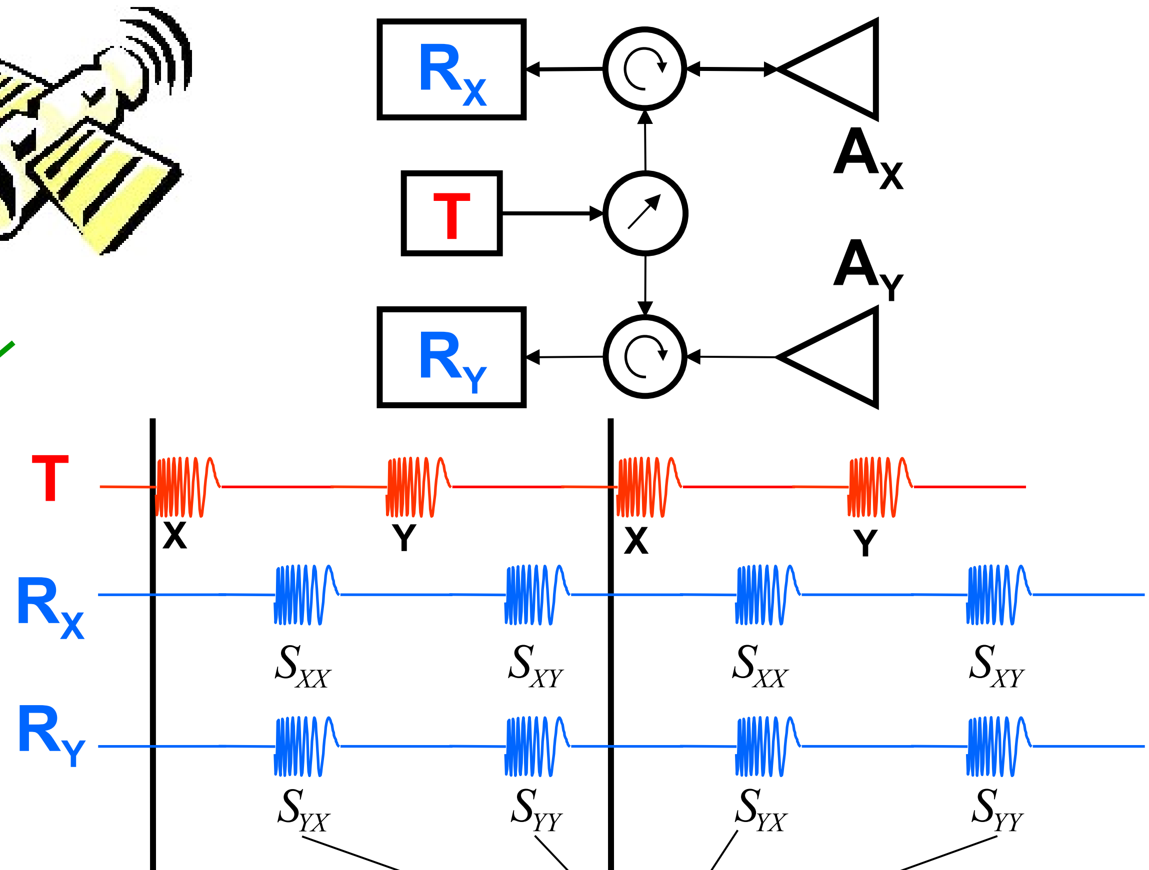
JONES VECTORS

$$\left\{ \underline{E}_S = \begin{bmatrix} S_{XX} \\ S_{YX} \end{bmatrix} \right\}$$

WAVE POLARIMETRY

SCATTERING POLARIMETRY





TRANSMITTER: X & Y

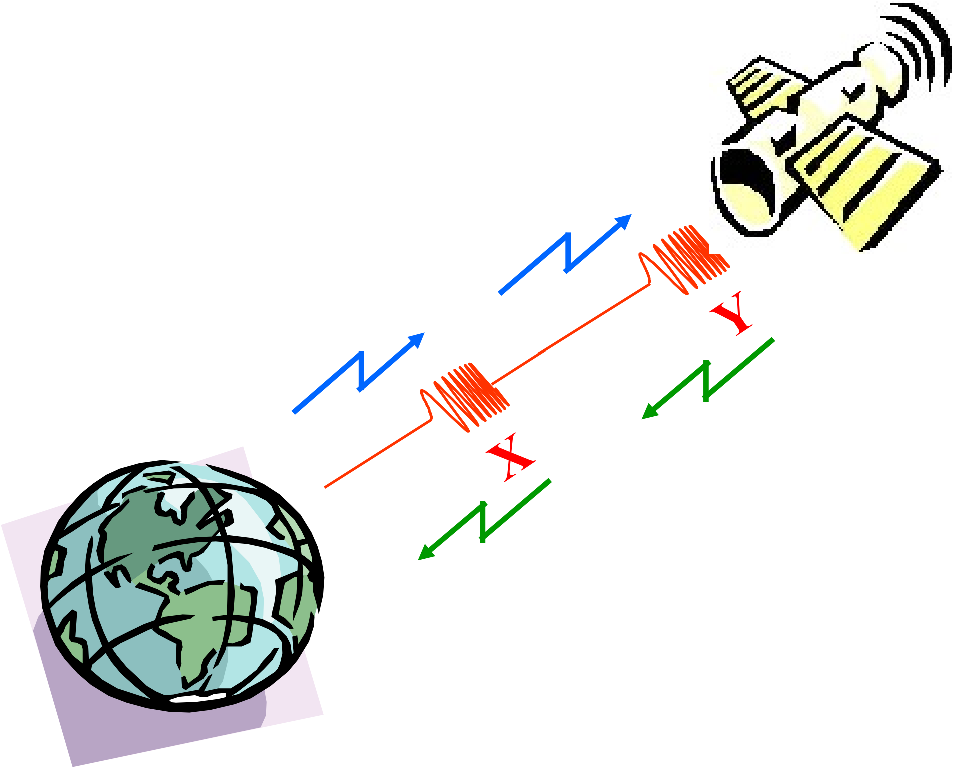
RECEIVERS: X & Y

SINCLAIR MATRICES

$$\left\{ [S] = \begin{bmatrix} S_{XX} & S_{XY} \\ S_{YX} & S_{YY} \end{bmatrix} \right\}$$

SCATTERING POLARIMETRY

POLARIMETRIC DESCRIPTORS



TRANSMITTER: X & Y
RECEIVERS: X & Y

THE DIFFERENT TARGET POLARIMETRIC DESCRIPTORS

[S]	SINCLAIR Matrix
<u>k</u>, <u>Ω</u>	Target Vectors
[K]	KENNAUGH Matrix
[T]	Coherency Matrix
[C]	Covariance Matrix

BACKSCATTERING MATRIX

$$[S]=\frac{e^{jkr}}{r}\begin{bmatrix} S_{XX} & S_{XY} \\ S_{XY} & S_{YY} \end{bmatrix}=\frac{e^{jkr}}{r}\underbrace{\begin{bmatrix} |S_{XX}|e^{j\varphi_{XX}} & |S_{XY}|e^{j\varphi_{XY}} \\ |S_{XY}|e^{j\varphi_{XY}} & |S_{YY}|e^{j\varphi_{YY}} \end{bmatrix}}$$

ABSOLUTE BACKSCATTERING MATRIX

$$[S]=\underbrace{\frac{e^{jkr}e^{j\varphi_{XX}}}{r}}\underbrace{\begin{bmatrix} |S_{XX}| & |S_{XY}|e^{j(\varphi_{XY}-\varphi_{XX})} \\ |S_{XY}|e^{j(\varphi_{XY}-\varphi_{XX})} & |S_{YY}|e^{j(\varphi_{YY}-\varphi_{XX})} \end{bmatrix}}$$

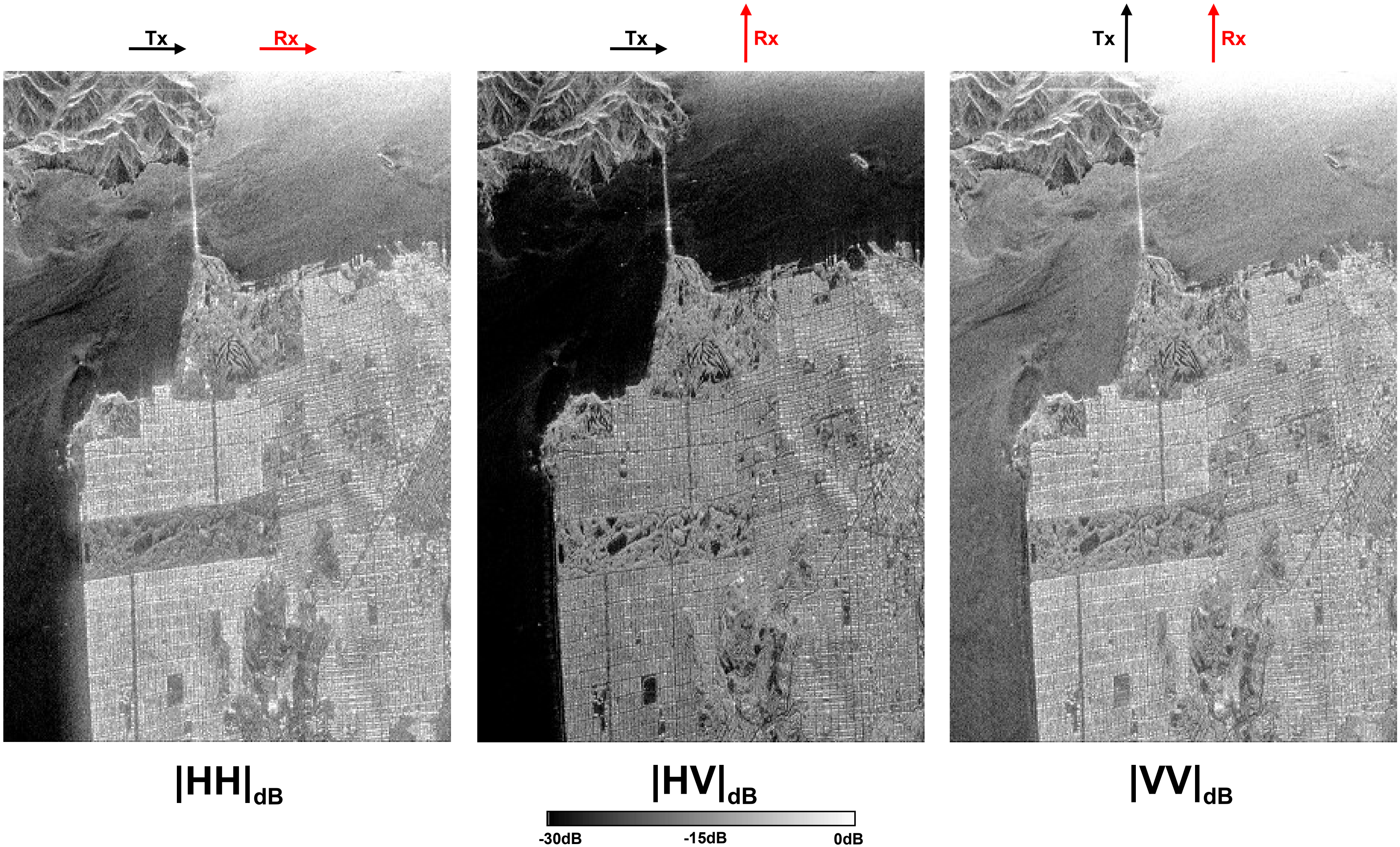
Absolute Phase Factor

RELATIVE BACKSCATTERING MATRIX

Five Parameters: 3 Amplitudes and 2 Phases

SCATTERER POLARIMETRIC DIMENSION = 5

SCATTERING POLARIMETRY



SCATTERING POLARIMETRY

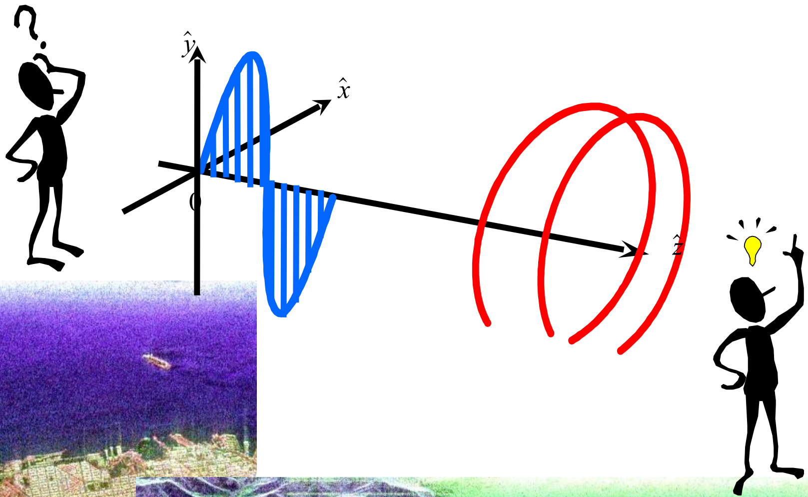
© Google Earth

Sinclair Color Coding

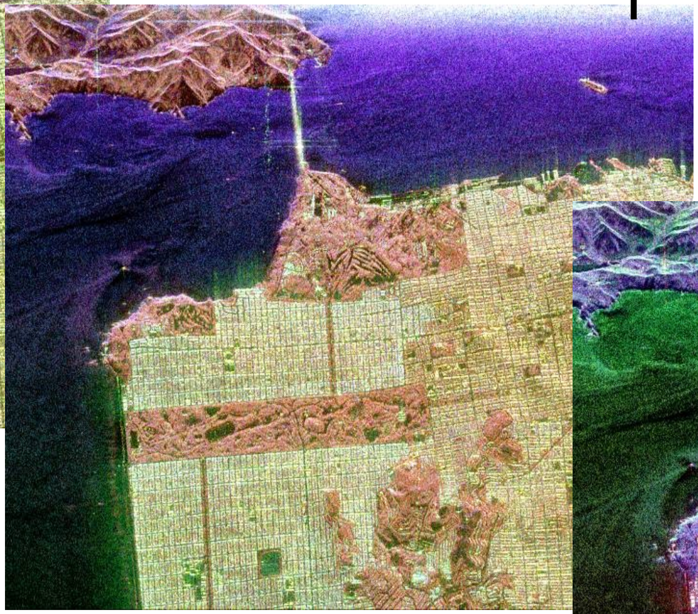
|HH| |HV| |VV|

L. Ferro-Famil & E. Pottier

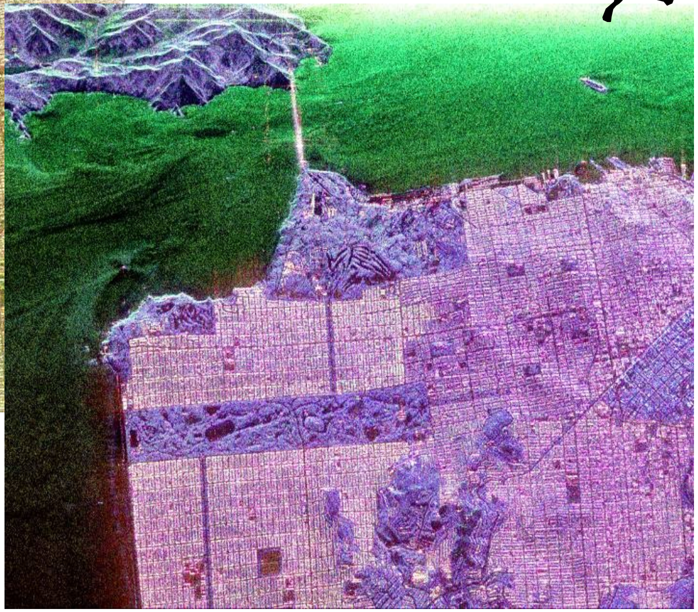
ELLIPTICAL BASIS TRANSFORMATION



Pauli Color Coding (H,V)



Pauli Color Coding (+45,-45)



Pauli Color Coding (L,R)

Ernst LÜNEBURG
(PIERS95 - Pasadena)

ELLIPTICAL BASIS TRANSFORMATION

$$\left[S_{(B,B)}\right]=\left[U_{(A,A)\mapsto(B,B)}\right]^T\left[S_{(A,A)}\right]\left[U_{(A,A)\mapsto(B,B)}\right]$$

CON-SIMILARITY TRANSFORMATION

$$\left[U_{(A,A)\mapsto(B,B)}\right]$$

SU(2) SPECIAL UNITARY ELLIPTICAL BASIS TRANSFORMATION MATRIX

$$\left[U_{(A,A)\mapsto(B,B)}\right] \qquad \left[U(\varphi,\tau,\alpha)\right]^{-1}$$

$$\begin{bmatrix} e^{j\alpha} & 0 \\ 0 & e^{-j\alpha} \end{bmatrix}\begin{bmatrix} \cos(\tau) & -j\sin(\tau) \\ -j\sin(\tau) & \cos(\tau) \end{bmatrix}\begin{bmatrix} \cos(\varphi) & \sin(\varphi) \\ -\sin(\varphi) & \cos(\varphi) \end{bmatrix}$$

$$\left[U_2(-\alpha)\right] \qquad \left[U_2(-\tau)\right] \qquad \left[U_2(-\varphi)\right]$$

ELLIPTICAL BASIS TRANSFORMATION

© Google Earth

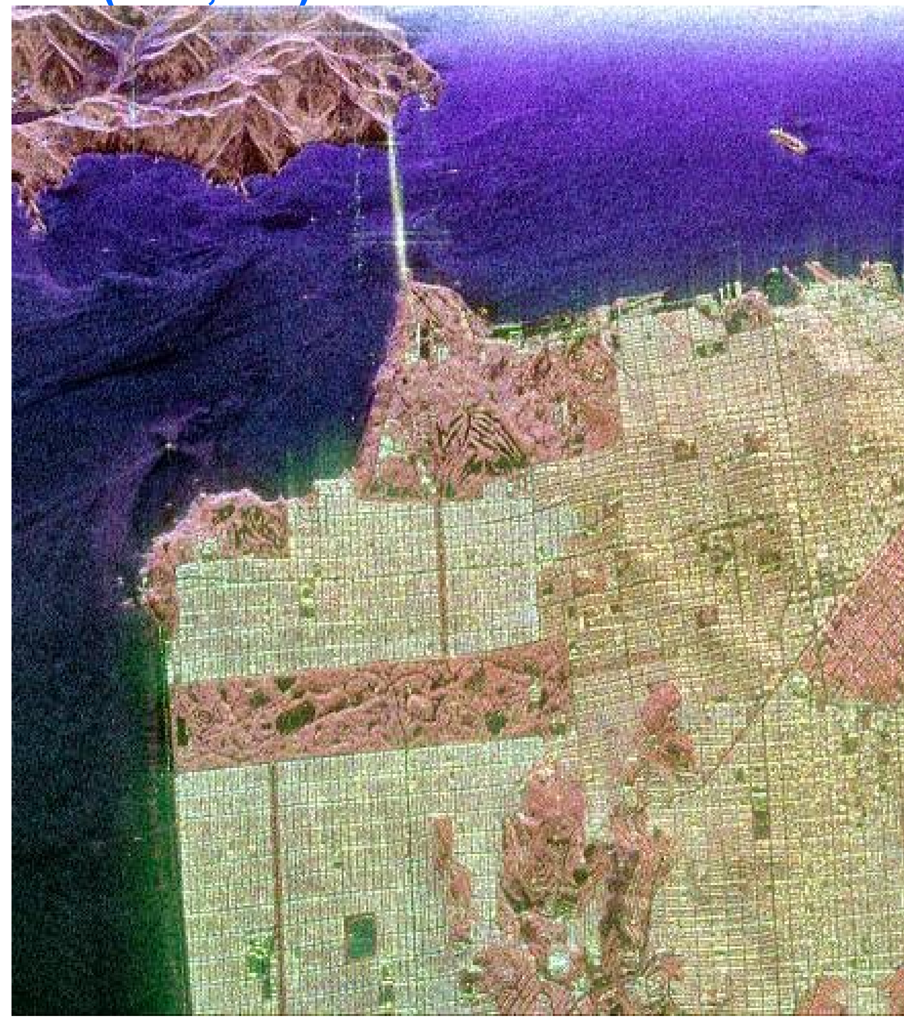
(H,V) POLARISATION BASIS

|HH+VV| **|HV |** **|HH-VV|**

ELLIPTICAL BASIS TRANSFORMATION

© Google Earth

(+45°,-45°) POLARISATION BASIS



|AA+BB| |AB | |AA-BB|

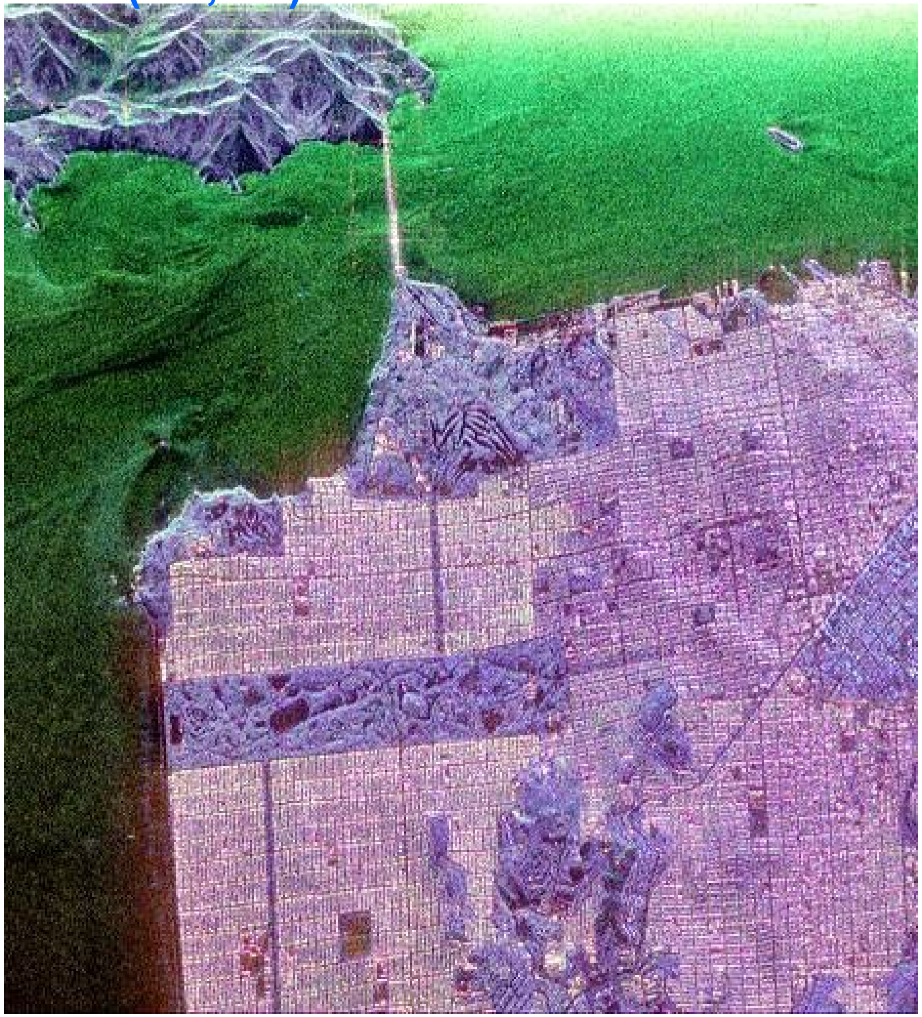
With: A=Linear +45°, B=Linear –45°

L. Ferro-Famil & E. Pottier

ELLIPTICAL BASIS TRANSFORMATION

© Google Earth

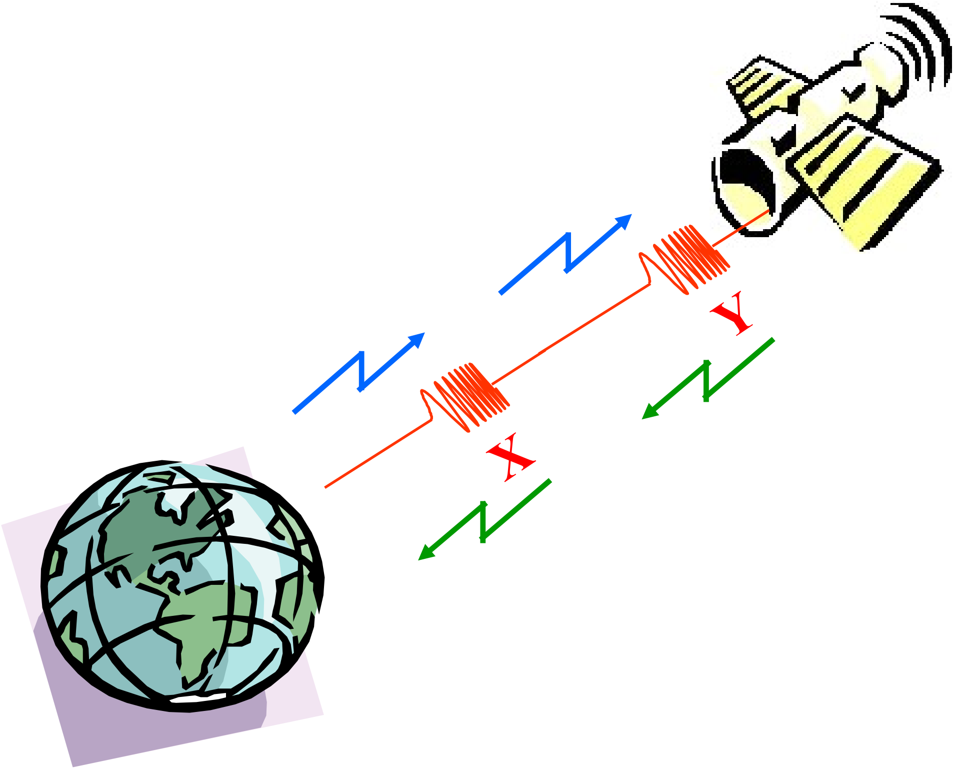
(LC,RC) POLARISATION BASIS



|LL+RR| **|LR |** **|LL-RR|**

L. Ferro-Famil & E. Pottier

POLARIMETRIC DESCRIPTORS



TRANSMITTER: X & Y
RECEIVERS: X & Y

THE DIFFERENT TARGET POLARIMETRIC DESCRIPTORS

[S] SINCLAIR Matrix
k, Ω Target Vectors
[K] KENNAUGH Matrix
[T] Coherency Matrix
[C] Covariance Matrix

TARGET VECTORS

SCATTERING VECTOR TRANSFORMATIONS

Pauli Scattering Vector:

$$\underline{k} = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{XX} + S_{YY} \\ S_{XX} - S_{YY} \\ 2 S_{XY} \end{bmatrix}$$

Lexicographic Scattering Vector:

$$\underline{\Omega} = \begin{bmatrix} S_{XX} \\ \sqrt{2} S_{XY} \\ S_{YY} \end{bmatrix}$$

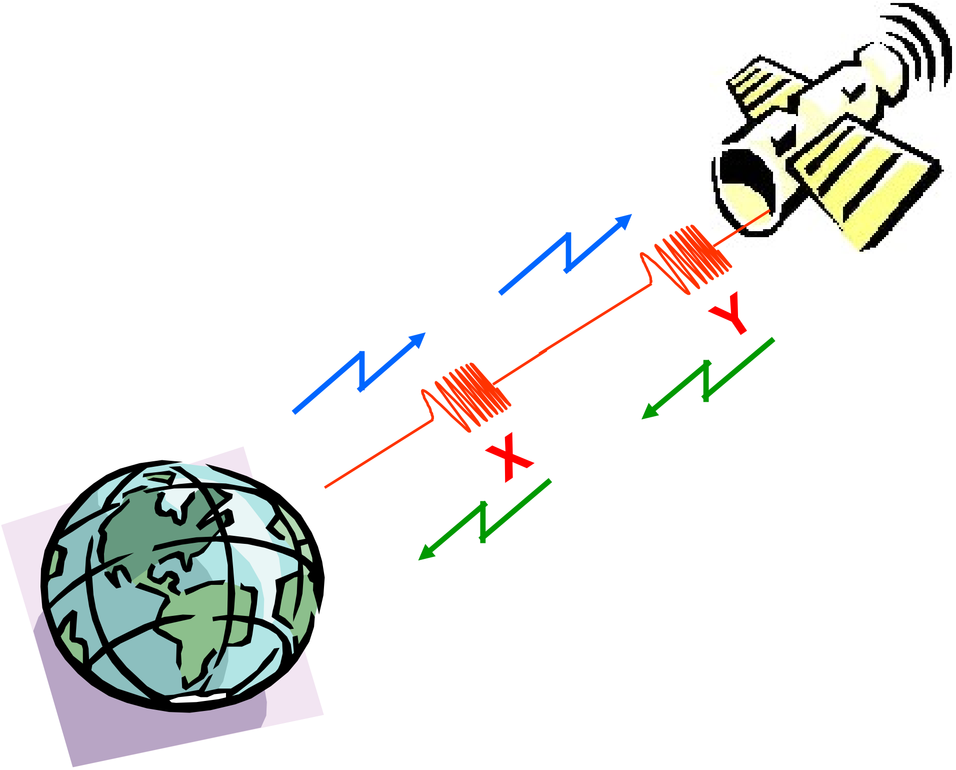
UNITARY TRANSFORMATION

$$\underline{k} = [D_3] \underline{\Omega} \quad and \quad \underline{\Omega} = [D_3]^{-1} \underline{k} = [D_3]^T \underline{k}$$

WHERE $[D_3]$ IS A SU(3) MATRIX IN ORDER TO PRESERVE THE NORM OF THE SCATTERING VECTOR

$$[D_3] = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 0 & 1 \\ 1 & 0 & -1 \\ 0 & \sqrt{2} & 0 \end{bmatrix}$$

POLARIMETRIC DESCRIPTORS



TRANSMITTER: X & Y
RECEIVERS: X & Y

THE DIFFERENT TARGET POLARIMETRIC DESCRIPTORS

[S]	SINCLAIR Matrix
k, Ω	Target Vectors
[K]	KENNAUGH Matrix
[T]	**Coherency Matrix**
[C]	Covariance Matrix

STATISTICAL DESCRIPTION

PARTIAL SCATTERING POLARIMETRY

COHERENCY MATRIX

MONOSTATIC CASE

PAULI SCATTERING VECTOR $\underline{k}$

$$\underline{k} = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{XX} + S_{YY} & S_{XX} - S_{YY} & 2 S_{XY} \end{bmatrix}^T$$

COHERENCY MATRIX [T]

$$[T] = \underline{k} \cdot \underline{k}^T = \begin{bmatrix} 2A_0 & C - jD & H + jG \\ C + jD & B_0 + B & E + jF \\ H - jG & E - jF & B_0 - B \end{bmatrix}$$

HERMITIAN MATRIX - RANK 1

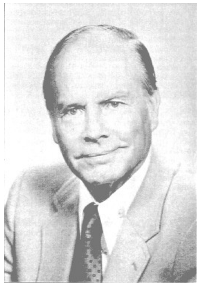
A0, B0+B, B0-B : HUYNEN TARGET GENERATORS

HUYNEN PARAMETERS

PHYSICAL INTERPRETATION

MAN-MADE TARGET DECOMPOSITION
IDENTIFICATION and ANALYSIS

« *PHENOMENOLOGICAL THEORY OF RADAR TARGETS* » (1970)



A0 : GENERATOR OF TARGET SYMMETRY

B0+B : GENERATOR OF TARGET NON-SYMMETRY

B0-B : GENERATOR OF TARGET IRREGULARITY

C : GENERATOR OF TARGET GLOBAL SHAPE (LINEAR)

D : GENERATOR OF TARGET LOCAL SHAPE (CURVATURE)

E : GENERATOR OF TARGET LOCAL TWIST (TORSION)

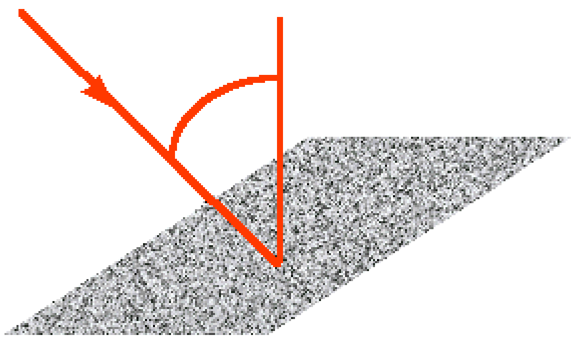
F : GENERATOR OF TARGET GLOBAL TWIST (HELICITY)

G : GENERATOR OF TARGET LOCAL COUPLING (GLUE)

H : GENERATOR OF TARGET GLOBAL COUPLING (ORIENTATION)

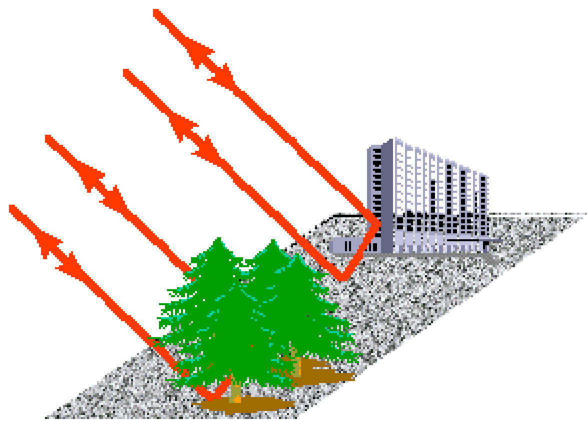
PHYSICAL INTERPRETATION

SINGLE BOUNCE SCATTERING (ROUGH SURFACE)



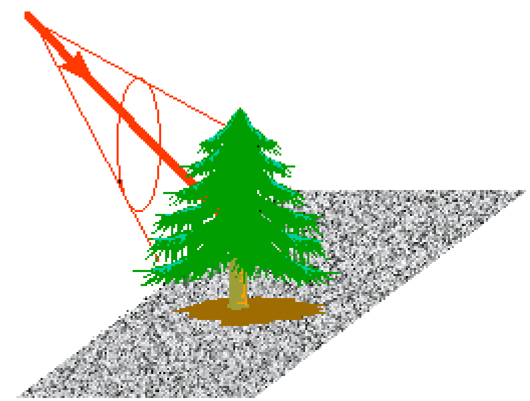
$$T_{11}=2A_0=|S_{XX}+S_{YY}|^2$$

DOUBLE BOUNCE SCATTERING



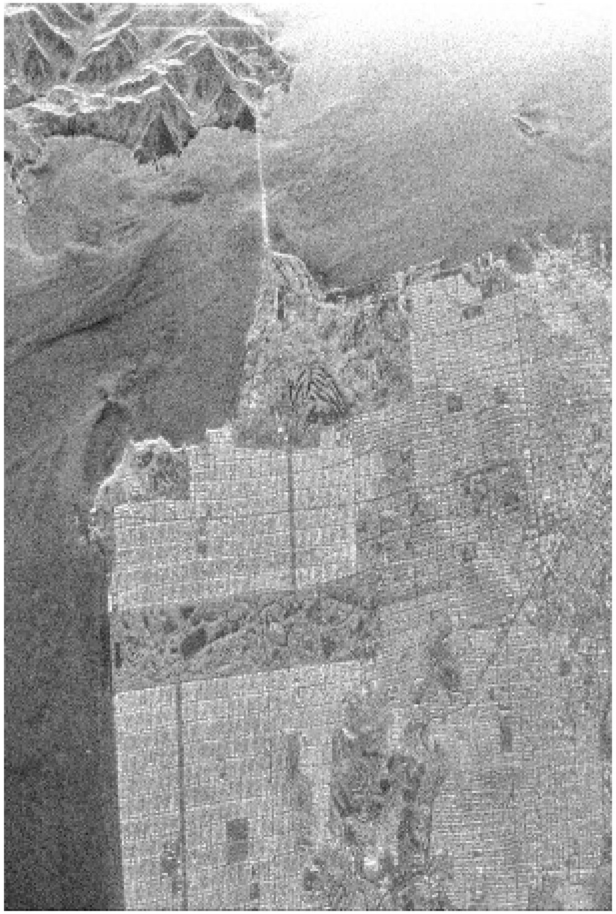
$$T_{22}=B_0+B=|S_{XX}-S_{YY}|^2$$

VOLUME SCATTERING



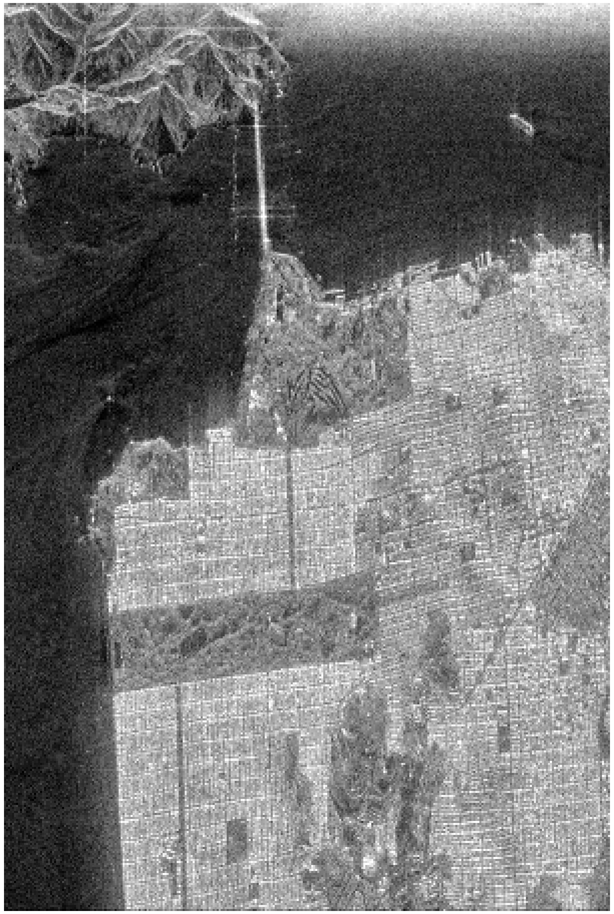
$$T_{33}=B_0-B=2|S_{XY}|^2$$

TARGET GENERATORS



$|HH+VV|_{dB}$

$|HV|_{dB}$



$|HH-VV|_{dB}$

TARGET GENERATORS

© Google Earth

(H,V) POLARISATION BASIS

|HH+VV| **|HV |** **|HH-VV|**

L. Ferro-Famil & E. Pottier

ELLIPTICAL BASIS TRANSFORMATION

SPECIAL UNITARY SU(2) GROUP

$$[U_2] = \underbrace{\begin{bmatrix} \cos(\varphi) & -\sin(\varphi) \\ \sin(\varphi) & \cos(\varphi) \end{bmatrix}}_{[U_2(\varphi)]} \underbrace{\begin{bmatrix} \cos(\tau) & j\sin(\tau) \\ j\sin(\tau) & \cos(\tau) \end{bmatrix}}_{[U_2(\tau)]} \underbrace{\begin{bmatrix} e^{-j\alpha} & 0 \\ 0 & e^{j\alpha} \end{bmatrix}}_{[U_2(\alpha)]}$$

SPECIAL UNITARY SU(3) GROUP

$$\underbrace{\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(2\varphi) & \sin(2\varphi) \\ 0 & -\sin(2\varphi) & \cos(2\varphi) \end{bmatrix}}_{[U_3(2\phi)]} \underbrace{\begin{bmatrix} \cos(2\tau) & 0 & j\sin(2\tau) \\ 0 & 1 & 0 \\ j\sin(2\tau) & 0 & \cos(2\tau) \end{bmatrix}}_{[U_3(2\tau)]} \underbrace{\begin{bmatrix} \cos(2\alpha) & -j\sin(2\alpha) & 0 \\ -j\sin(2\alpha) & \cos(2\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix}}_{[U_3(2\alpha)]}$$

ELLIPTICAL BASIS TRANSFORMATION

SINCLAIR MATRIX

$$E^{s}_{(A,A)} = \left[S_{(A,A)}\right] E^{i}_{(A,A)} \qquad E^{s}_{(B,B)} = \left[S_{(B,B)}\right] E^{i}_{(B,B)}$$

$$\left[S_{(B,B)}\right] = \left[U_{(A,A)\mapsto(B,B)}\right]^{T} \left[S_{(A,A)}\right] \left[U_{(A,A)\mapsto(B,B)}\right]$$

CON-SIMILARITY TRANSFORMATION

COHERENCY MATRIX

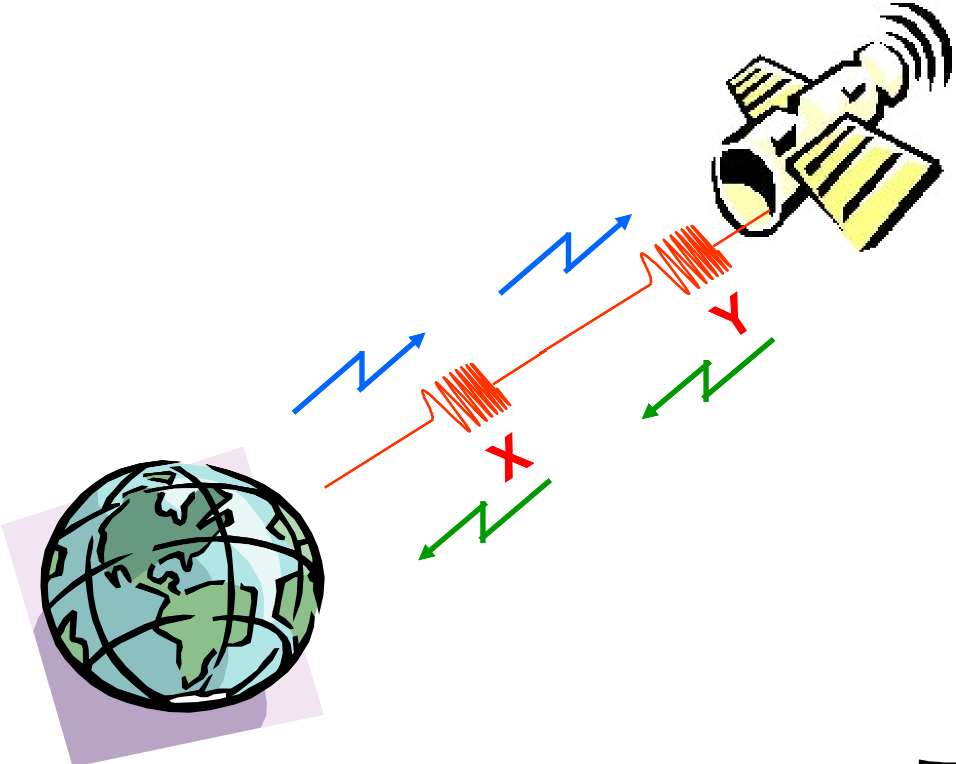
$$\left[T_{(B,B)}\right] = \left[U_{3(A,A)\mapsto(B,B)}\right] \left[T_{(A,A)}\right] \left[U_{3(A,A)\mapsto(B,B)}\right]^{-1}$$

SIMILARITY TRANSFORMATION

$$\left[U_{3(A,A)\mapsto(B,B)}\right]$$

U(3) SPECIAL UNITARY ELLIPTICAL BASIS TRANSFORMATION MATRIX

POLARIMETRIC DESCRIPTORS



TRANSMITTER: X & Y
RECEIVERS: X & Y

THE DIFFERENT TARGET POLARIMETRIC DESCRIPTORS

[S]	SINCLAIR Matrix
k, Ω	Target Vectors
[K]	KENNAUGH Matrix
[T]	Coherency Matrix
[C]	Covariance Matrix

STATISTICAL DESCRIPTION

PARTIAL SCATTERING POLARIMETRY

COVARIANCE MATRIX

MONOSTATIC CASE

LEXICOGRAPHIC SCATTERING VECTOR $\underline{\Omega}$

$$\underline{\Omega} = \begin{bmatrix} S_{XX} & \sqrt{2}\,S_{XY} & S_{YY} \end{bmatrix}^T$$

COVARIANCE MATRIX $[C]$

$$[C] = \underline{\Omega} \cdot \underline{\Omega}^T = \begin{bmatrix} S_{XX}S_{XX} & \sqrt{2}\,S_{XX}S_{XY} & S_{XX}S_{YY} \\ \sqrt{2}\,S_{XY}S_{XX} & 2\,S_{XY}S_{XY} & \sqrt{2}\,S_{XY}S_{YY} \\ S_{YY}S_{XX} & \sqrt{2}\,S_{YY}S_{XY} & S_{YY}S_{YY} \end{bmatrix}$$

HERMITIAN POSITIVE SEMI DEFINITE MATRIX - RANK 1

COVARIANCE-COHERENCY MATRICES

COHERENCY MATRIX

$$[T]=k\cdot k^{T}$$

$$\underline{k}=[D_{3\,or\,4}]\underline{\Omega}$$

COVARIANCE MATRIX

$$[C]=\underline{\Omega}\cdot\underline{\Omega}^{T}$$

UNITARY TRANSFORMATION

$$[T]=[D_{3\,or\,4}]\,[C]\,[D_{3\,or\,4}]^{T*¿}\,¿$$

$[T]$ and $[C]$ HAVE THE SAME EIGENVALUES

Both contain the same information about Polarimetric Scattering Amplitudes, Phase Angles and Correlations

$[T]$ is closer related to Physical and Geometrical Properties of the Scattering Process, and thus allows a better and direct physical interpretation

$[C]$ is directly related to the system measurables

$[T]$ is directly related to the Kennaugh matrix and the Huynen parameters

POLARIMETRIC DESCRIPTORS

SINCLAIR MATRIX

$$[S]=\begin{bmatrix} S_{XX} & S_{XY} \\ S_{YX} & S_{YY} \end{bmatrix}$$

EQUIVALENCE ?

SCATTERING VECTOR $\underline{k}$

$$\underline{k}=\frac{1}{\sqrt{2}}\left[S_{XX}+S_{YY} \quad S_{XX}-S_{YY} \quad 2S_{XY}\right]^T$$

⬇

COHERENCY MATRIX $[T]$

$$[T]=\underline{k}\cdot\underline{k}^T$$

SCATTERING VECTOR $\underline{\Omega}$

$$\underline{\Omega}=\left[S_{XX} \quad \sqrt{2}\,S_{XY} \quad S_{YY}\right]^T$$

⬇

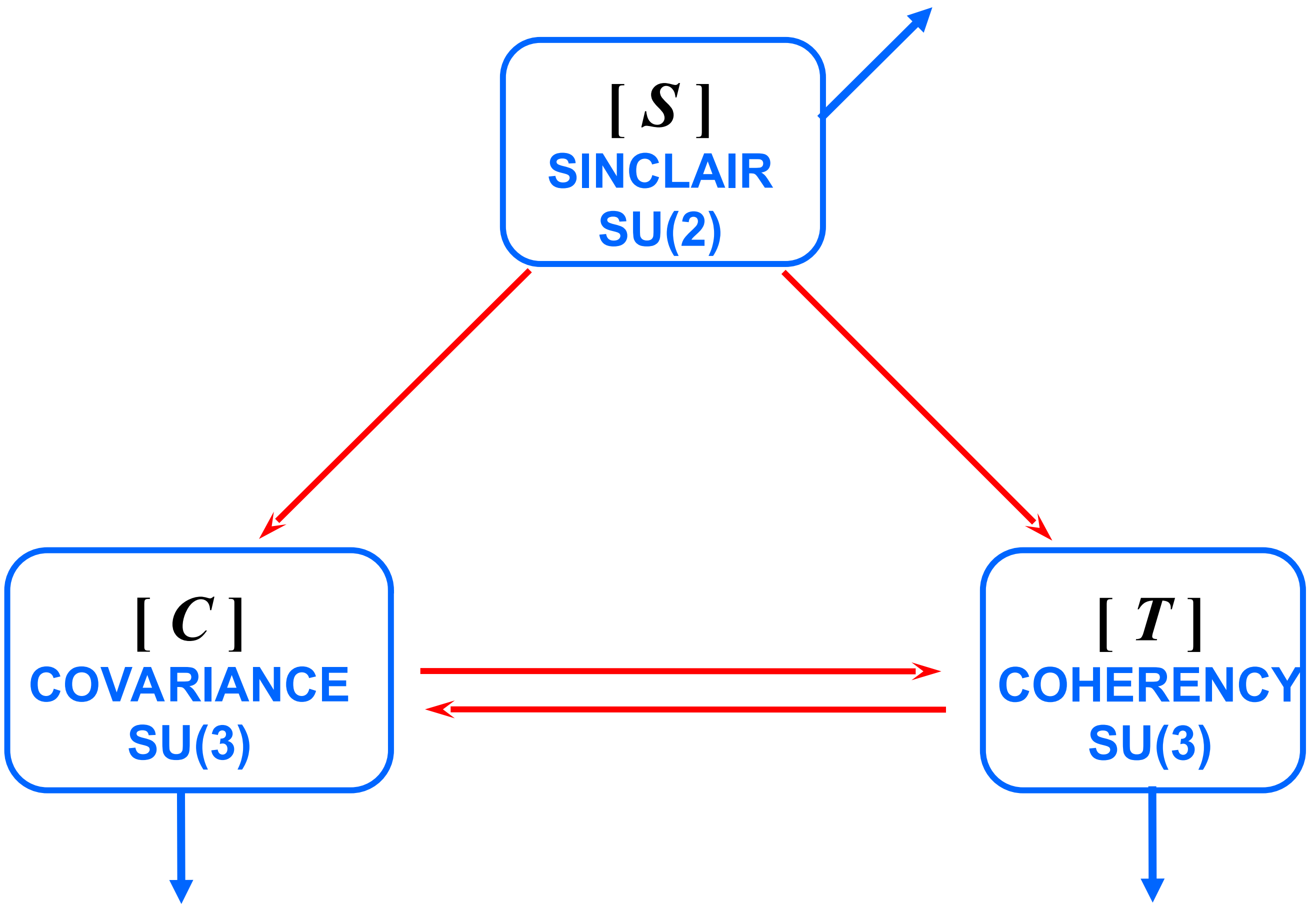
COVARIANCE MATRIX $[C]$

$$[C]=\underline{\Omega}\,\underline{\Omega}^{T*}$$

L. Ferro-Famil & E. Pottier

POLARIMETRIC DESCRIPTORS

$$[\,S'\,]=[\,U_2\,]^{T}[\,S\,]\,[\,U_2\,]$$



$$[\,C'\,]=[\,U_3\,]\,[\,C\,]\,[\,U_3\,]^{-1}$$

$$[\,T'\,]=[\,U_3\,]\,[\,T\,]\,[\,U_3\,]^{-1}$$

ELLIPTICAL BASIS TRANSFORMATION

SPECIAL UNITARY SU(2) GROUP

$$\begin{bmatrix}\cos(\varphi) & -\sin(\varphi)\\ \sin(\varphi) & \cos(\varphi)\end{bmatrix}\begin{bmatrix}\cos(\tau) & j\sin(\tau)\\ j\sin(\tau) & \cos(\tau)\end{bmatrix}\begin{bmatrix}e^{-j\alpha} & 0\\ 0 & e^{j\alpha}\end{bmatrix}$$

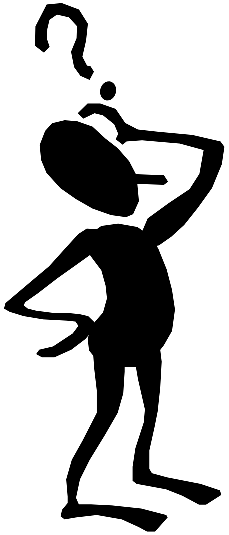
$$[U_2(\varphi)] \qquad [U_2(\tau)] \qquad [U_2(\alpha)]$$

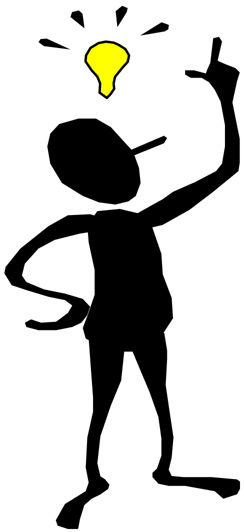
SPECIAL UNITARY SU(3) GROUP (T Matrix)

$$\begin{bmatrix}1 & 0 & 0\\ 0 & \cos(2\varphi) & \sin(2\varphi)\\ 0 & -\sin(2\varphi) & \cos(2\varphi)\end{bmatrix}\begin{bmatrix}\cos(2\tau) & 0 & j\sin(2\tau)\\ 0 & 1 & 0\\ j\sin(2\tau) & 0 & \cos(2\tau)\end{bmatrix}\begin{bmatrix}\cos(2\alpha) & -j\sin(2\alpha) & 0\\ -j\sin(2\alpha) & \cos(2\alpha) & 0\\ 0 & 0 & 1\end{bmatrix}$$

$$[U_3(2\phi)] \qquad [U_3(2\tau)] \qquad [U_3(2\alpha)]$$

TARGET EQUATIONS





POLARIMETRIC GOLDEN NUMBER

POLARIMETRIC TARGET DIMENSION

TARGET EQUATIONS

$$[S] = \begin{bmatrix} S_{XX} & S_{XY} \\ S_{YX} & S_{YY} \end{bmatrix}$$

5 DEGREES OF FREEDOM

$$|S_{XX}|, |S_{XY}|, |S_{YY}|$$

$$\varphi_{XY-XX}, \varphi_{YY-XX}$$

TARGET MONOSTATIC POLARIMETRIC « *DIMENSION* »

=

5

KENNAUGH MATRIX $[K]$

COHERENCY MATRIX $[T]$

9 HUYNEN REAL PARAMETERS

(A0, B0, B, C, D, E, F, G, H)

COVARIANCE MATRIX $[C]$

9 REAL PARAMETERS

$|XX|$, $|XY|$, $|YY|$,

$\mathrm{Re}(XXXY^*)$, $\mathrm{Im}(XXXY^*)$

$\mathrm{Re}(XXYY^*)$, $\mathrm{Im}(XXYY^*)$

$\mathrm{Re}(XYYY^*)$, $\mathrm{Im}(XYYY^*)$

9 - 5 = 4 TARGET EQUATIONS

TARGET EQUATIONS

PURE TARGET – MONOSTATIC CASE

$$[T] = \underline{k}\cdot\underline{k}^T = \begin{bmatrix} 2A_0 & C-jD & H+jG \\ C+jD & B_0+B & E+jF \\ H-jG & E-jF & B_0-B \end{bmatrix}$$

3x3 HERMITIAN MATRIX - RANK 1

↓

9 PRINCIPAL MINORS = 0

$$2A_0(B_0+B)-C^2-D^2=0 \qquad 2A_0(B_0-B)-G^2-H^2=0$$

$$-2A_0E+CH-DG=0 \qquad B_0^2-B^2-E^2-F^2=0$$

$$C(B_0-B)-EH-GF=0 \qquad -D(B_0-B)+FH-GE=0$$

$$2A_0F-CG-DH=0 \qquad -G(B_0+B)+FC-ED=0$$

$$H(B_0+B)-CE-DF=0$$

TARGET EQUATIONS

$$[S] = \begin{bmatrix} S_{XX} & S_{XY} \\ S_{YX} & S_{YY} \end{bmatrix}$$

5 DEGREES OF FREEDOM

$$|S_{XX}|, |S_{XY}|, |S_{YY}|$$

$$\varphi_{XY-XX}, \varphi_{YY-XX}$$

COHERENCY MATRIX $[T]$

9 HUYNEN REAL PARAMETERS

(*A0, B0, B, C, D, E, F, G, H*)

TARGET MONOSTATIC POLARIMETRIC « *DIMENSION* »

=

5

9 - 5 = 4 TARGET EQUATIONS

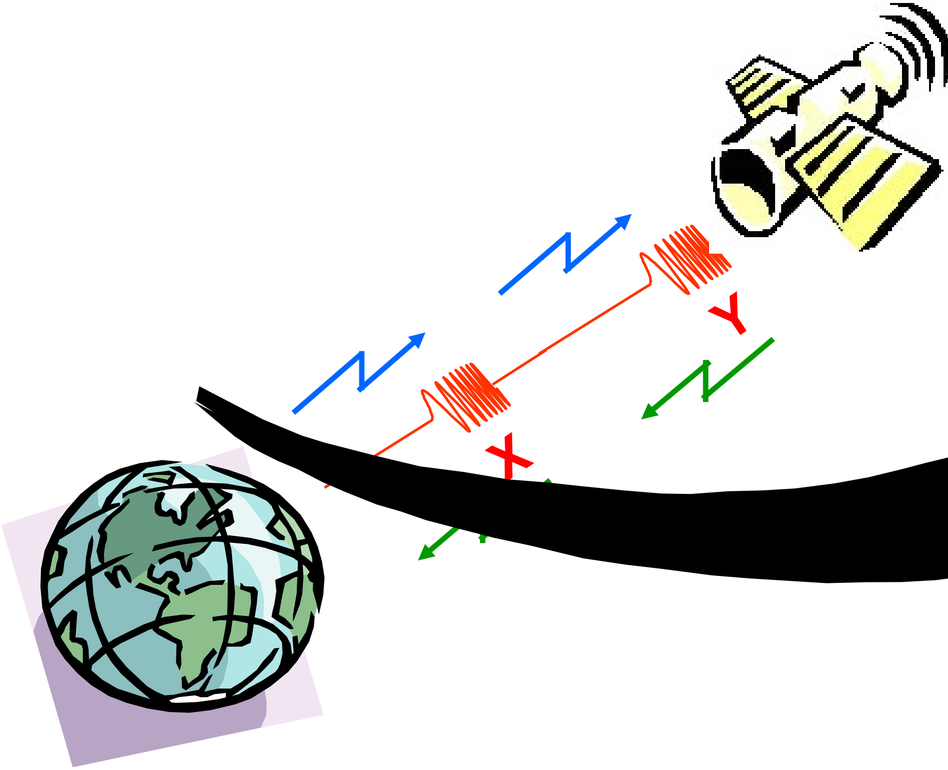
$$2A_0(B_0+B) \quad C^2+D^2$$

$$2A_0(B_0-B) \quad G^2+H^2$$

$$2A_0E \quad CH-DG$$

$$2A_0F \quad CG+DH$$

SCATTERING POLARIMETRY



SINCLAIR MATRIX $[S]$

TRANSMITTER: X & Y
RECEIVERS: X & Y

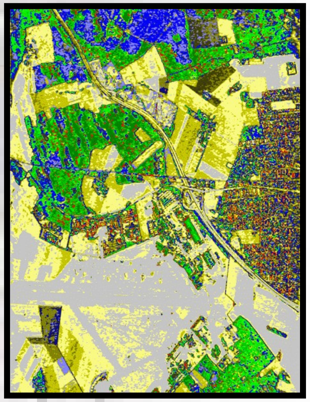
THE DIFFERENT TARGET POLARIMETRIC DESCRIPTORS

[S]	SINCLAIR Matrix
k, Ω	Target Vectors
[K]	KENNAUGH Matrix
[T]	Coherency Matrix
[C]	Covariance Matrix

POLARIMETRIC REMOTE SENSING

POLARIMETRIC REMOTE SENSING

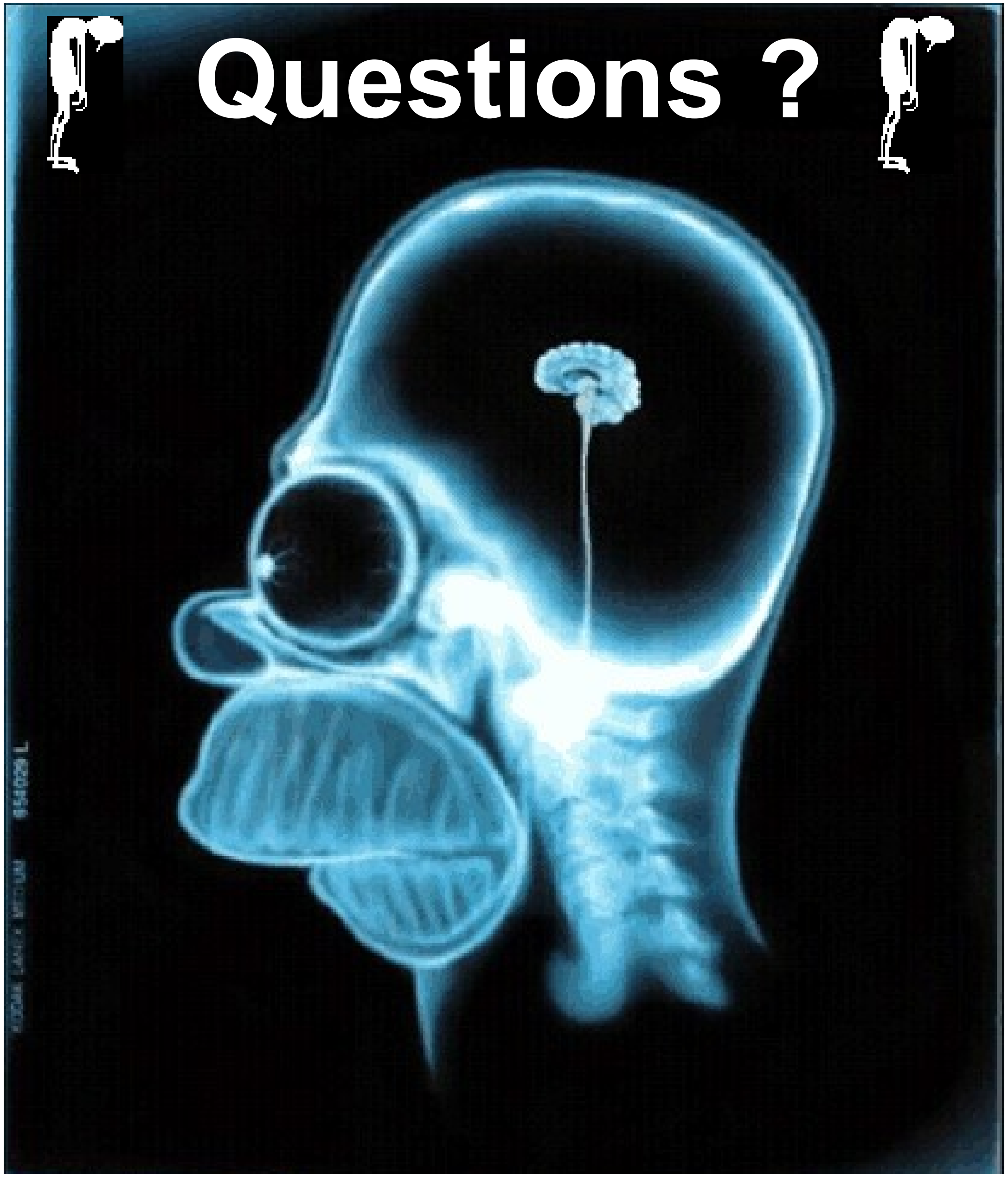
POL-SAR PROCESSING
PHENOMENOLOGIC
QUALITATIVE ANALYSIS

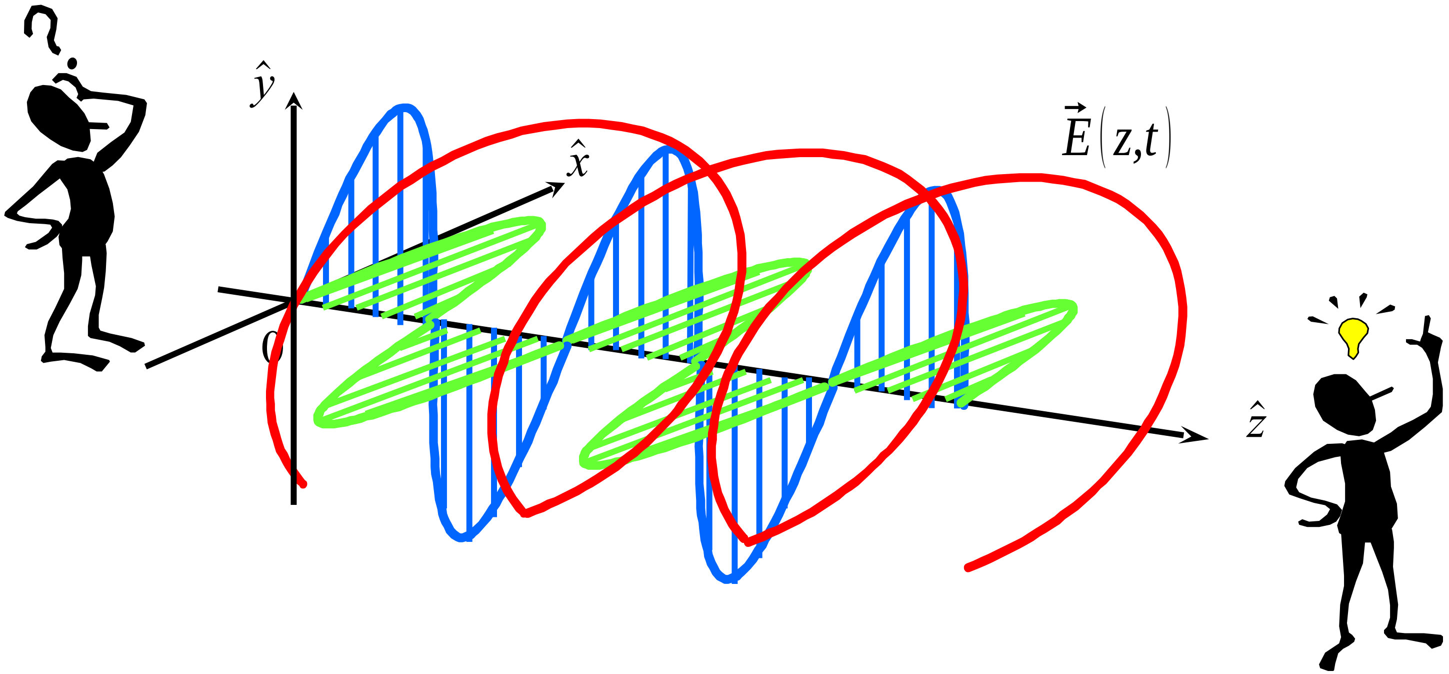


POLARIMETRIC SPECKLE FILTERING

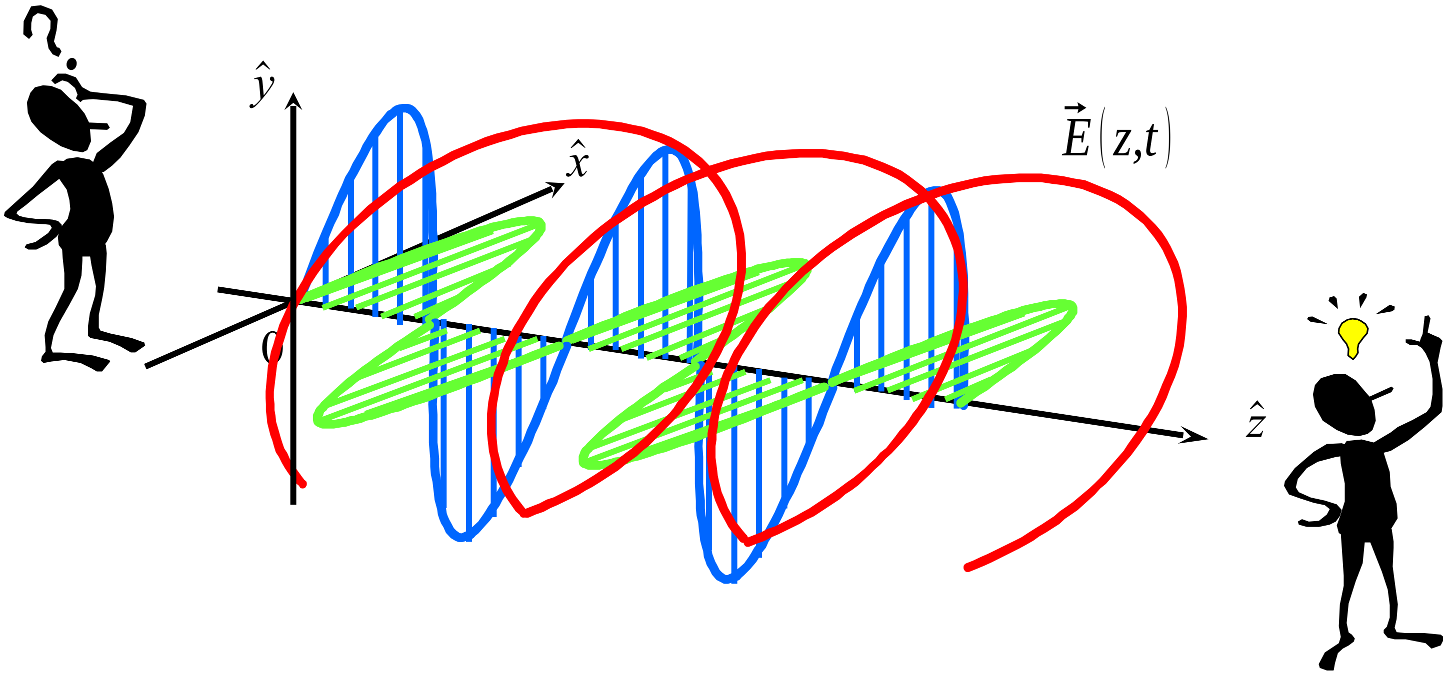
POLARIMETRIC TARGET DECOMPOSITION

POLARIMETRIC CLASSIFICATION
MONO/DUAL CHANNELS


Questions ?



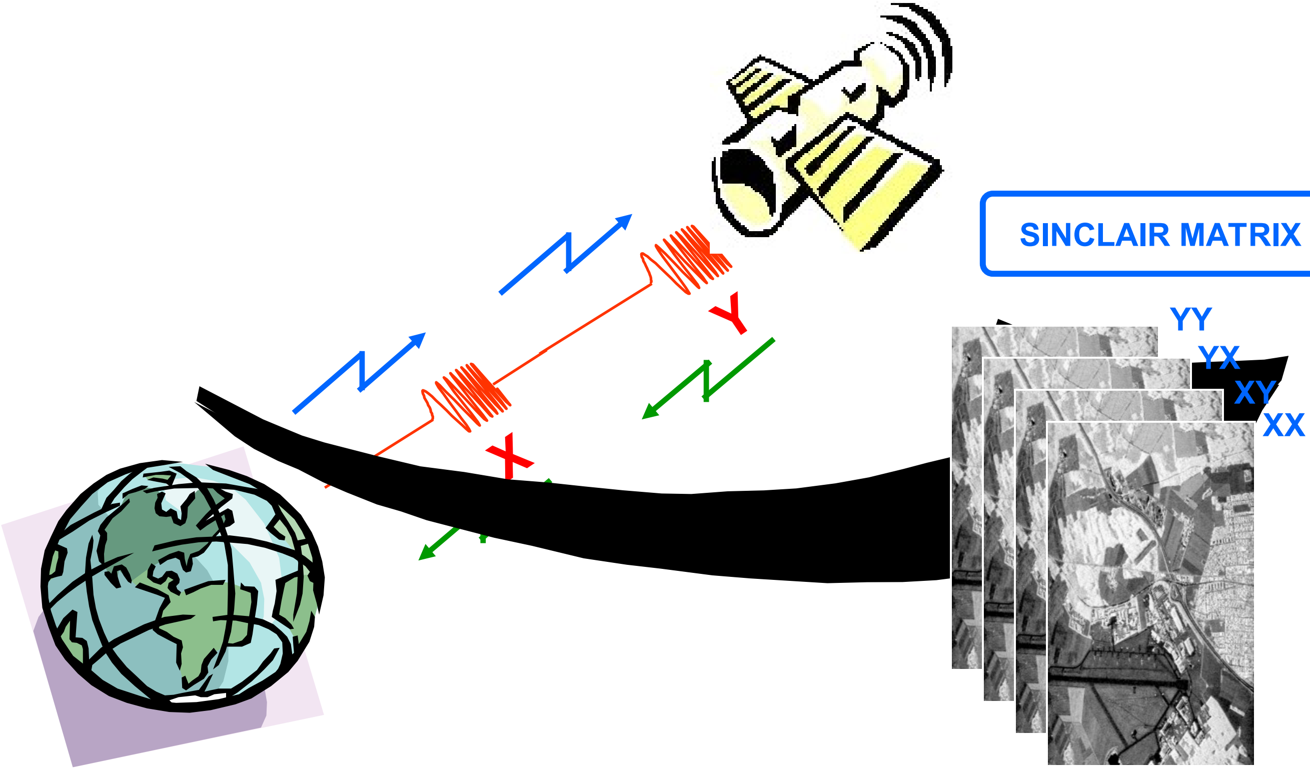
ADVANCED CONCEPTS



POLARIMETRIC REMOTE SENSING

L. Ferro-Famil & E. Pottier

SCATTERING POLARIMETRY



SINCLAIR MATRIX $[S]$

TRANSMITTER: X & Y
RECEIVERS: X & Y

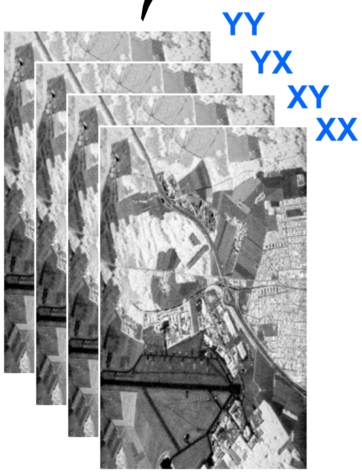
THE DIFFERENT TARGET POLARIMETRIC DESCRIPTORS

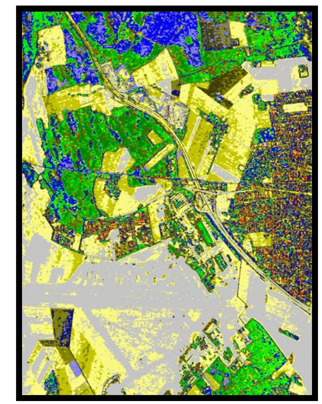
[S]	SINCLAIR Matrix
k, Ω	Target Vectors
[K]	KENNAUGH Matrix
[T]	Coherency Matrix
[C]	Covariance Matrix

POLARIMETRIC REMOTE SENSING

POLARIMETRIC REMOTE SENSING

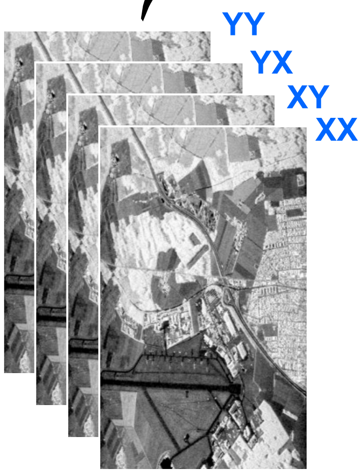
POL-SAR PROCESSING
PHENOMENOLOGIC
QUALITATIVE ANALYSIS

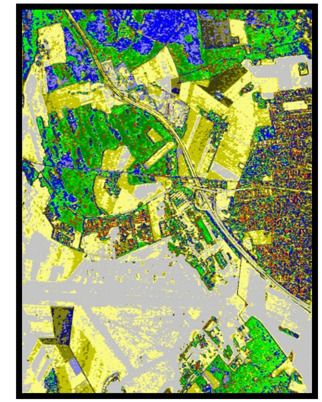




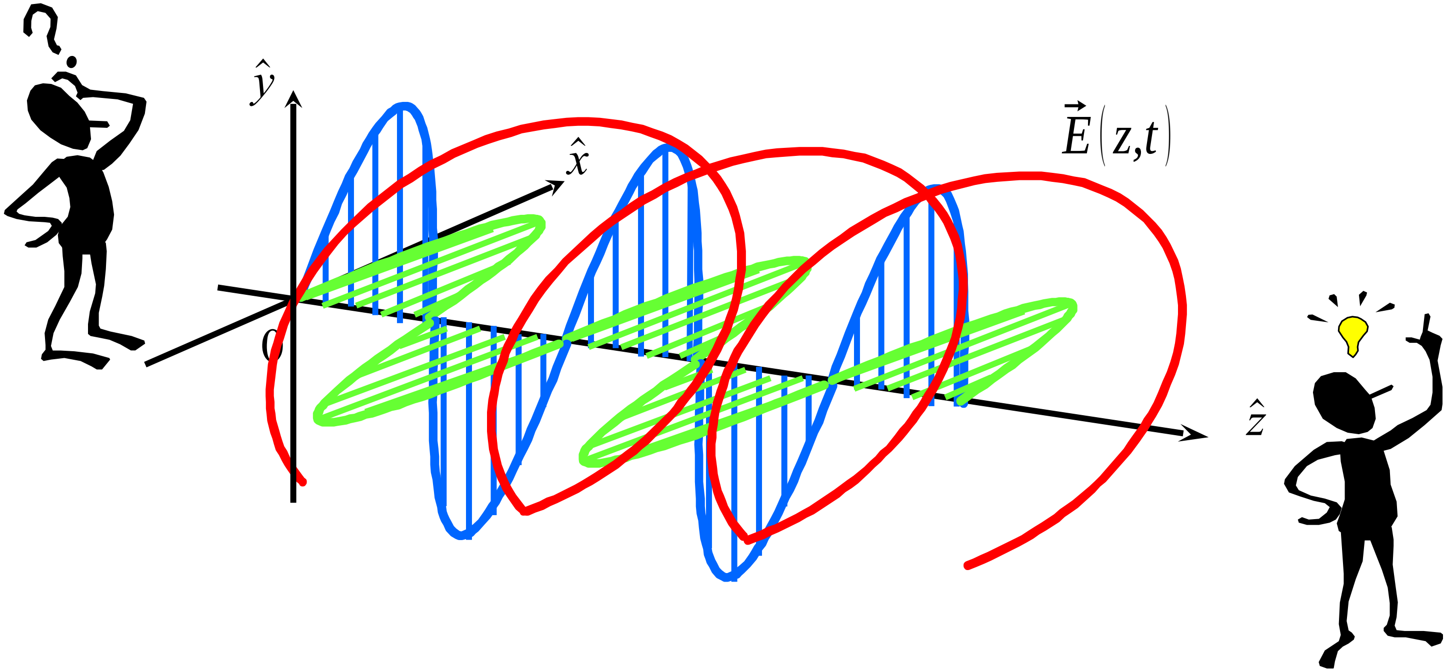
POLARIMETRIC SPECKLE FILTERING	→	POLARIMETRIC TARGET DECOMPOSITION	→	POLARIMETRIC CLASSIFICATION MONO/DUAL CHANNELS

POL-SAR PROCESSING
PHENOMENOLOGIC
QUALITATIVE ANALYSIS





POLARIMETRIC SPECKLE FILTERING → **POLARIMETRIC TARGET DECOMPOSITION** → **POLARIMETRIC CLASSIFICATION** MONO/DUAL CHANNELS

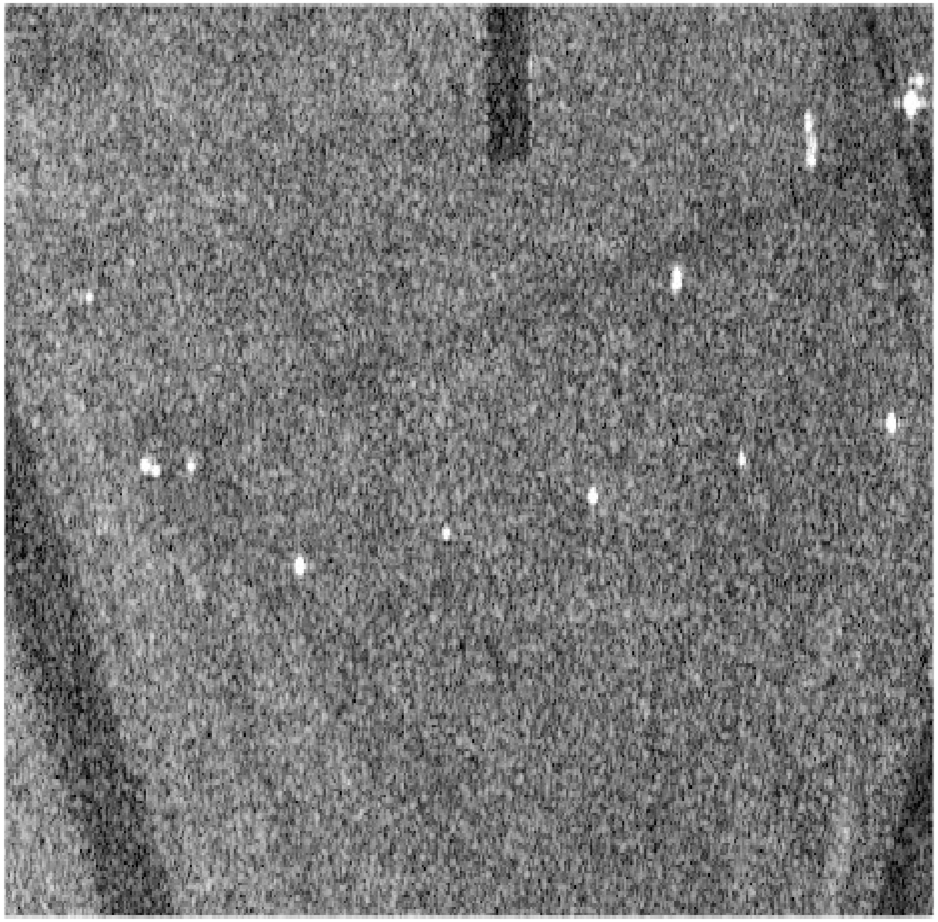


POLARIMETRIC SPECKLE FILTERING

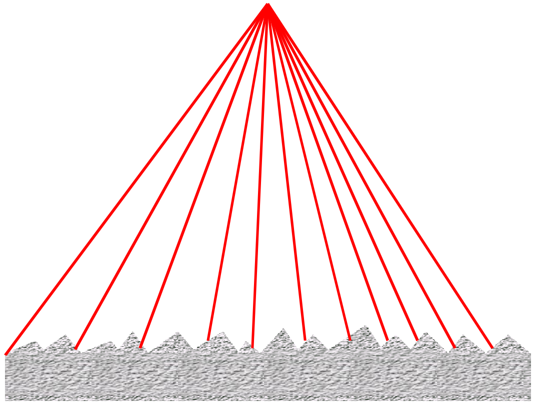
An Introduction

L. Ferro-Famil & E. Pottier

SPECKLE PHENOMENON



OBSERVATION POINT



SURFACE ROUGHNESS
WAVELENGTH

SCATTERING FROM DISTRIBUTED SCATTERERS

⬇

COHERENT INTERFERENCES OF WAVES SCATTERED FROM MANY RANDOMLY DISTRIBUTED ELEMENTARY SCATTERERS INSIDE THE RESOLUTION CELL

⬇

GRANULAR NOISE

⬇

SPECKLE PHENOMENON

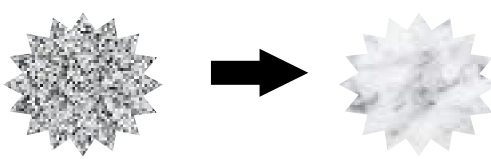
SPECKLE FILTERING

SPECKLE PHENOMENON

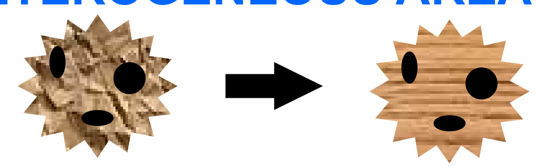
DISTORTION OF THE INTERPRETATION

SPECKLE FILTERING

HOMOGENEOUS AREA



HETEROGENEOUS AREA



SPECKLE REDUCTION
(RADIOMETRIC RESOLUTION)

DETAILS PRESERVATION
(SPATIAL RESOLUTION)

SPECKLE FILTERING

SPECKLE : MULTIPLICATIVE NOISE MODEL

« SPECKLE is a scattering phenomenon and not a noise. However, from the image SAR processing point of vue, the speckle can be modeled as multiplicative noise for extended target » (Lee, IGARSS-98)

$$\underline{y} = \begin{bmatrix} y_{HH} \\ y_{HV} \\ y_{VV} \end{bmatrix} = \begin{bmatrix} n_{HH} & 0 & 0 \\ 0 & n_{HV} & 0 \\ 0 & 0 & n_{VV} \end{bmatrix} \begin{bmatrix} x_{HH} \\ x_{HV} \\ x_{VV} \end{bmatrix} = \begin{bmatrix} x_{HH} n_{HH} \\ x_{HV} n_{HV} \\ x_{VV} n_{VV} \end{bmatrix}$$

SCATTERING FIELD (↑ y) — **NOISE** (↑ n) — **REFLECTIVITY DENSITY** (↑ x)

$$I_{pqpq} = y_{pq} y_{pq} = X_{pqpq} v_{pqpq}$$

INTENSITY

$$A_{pqpq} = \sqrt{I_{pqpq}} = \sqrt{y_{pq} y_{pq}}$$

AMPLITUDE

LINEAR SPECKLE FILTERS
Intensity / Amplitude – Single / Multi Look – Single Pol Channel

Median Filter
MAP Filter (Kuan)
Gradient Filter
Nagao Filter (Nagao)
Sigma Filter (Lee)
Frost Filter (Frost)
Geometrical Filter (Crimmins)
Morphological Filter (Safa, Flouzat)

.

Local Statistics Filter (Lee 80)
Refined Lee Filter (Lee 81)

J.S. Lee, et al. "Speckle Filtering of SAR images: A Review," Remote Sensing Reviews, Vol. 8, pp. 313-340, 1994.

J.S. Lee,"Speckle analysis and smoothing of SAR images," Computer Graphics and Image Processing, Vol. 17, 1981.

J.S. Lee,"Digital image enhancement and noise filtering by use of local statistics," IEEE PAMI, Vol. 2 No. 2, 1980.

J.S. Lee,"Refined filtering of image noise using local statistics," CVGIP, vol.15, 380-389, 1981.

POLSAR SPECKLE FILTERING

- Preserving polarimetric properties
  - Filter all elements equally like multi-look Processing
  - Select pixels with the same scattering property
- Introduce no cross-talk
  - Filter each element separately but equally
- Reduce speckle while preserving image quality

J.S. Lee, M.R. Grunes and G. De Grandi, "Polarimetric SAR Speckle Filtering and Its Impact on Terrain Classification" *IEEE TGRS*, September 1999

POLSAR SPECKLE FILTERING

POLARIMETRIC VECTORIAL SPECKLE FILTER

$$\langle [T] \rangle = \frac{1}{N}\sum_{i=1}^{N} \underline{k}_i \underline{k}_i^T \rightarrow \quad \rightarrow [\hat{T}]$$

SPAN IMAGE

$$S_S = \langle T_{11} \rangle + \langle T_{22} \rangle + \langle T_{33} \rangle$$

$$k = \frac{\operatorname{var}(S)}{\operatorname{var}(S_S)} = \frac{CV_{S_S}^2 - \sigma_v^2}{CV_{S_S}^2 \left[1 + \sigma_v^2\right]}$$

LINEAR SCALAR LEE FILTER

$$\hat{S} = E(S_S) - k\left[E(S_S) - S_S\right]$$

J.S. LEE

Homogeneous Areas

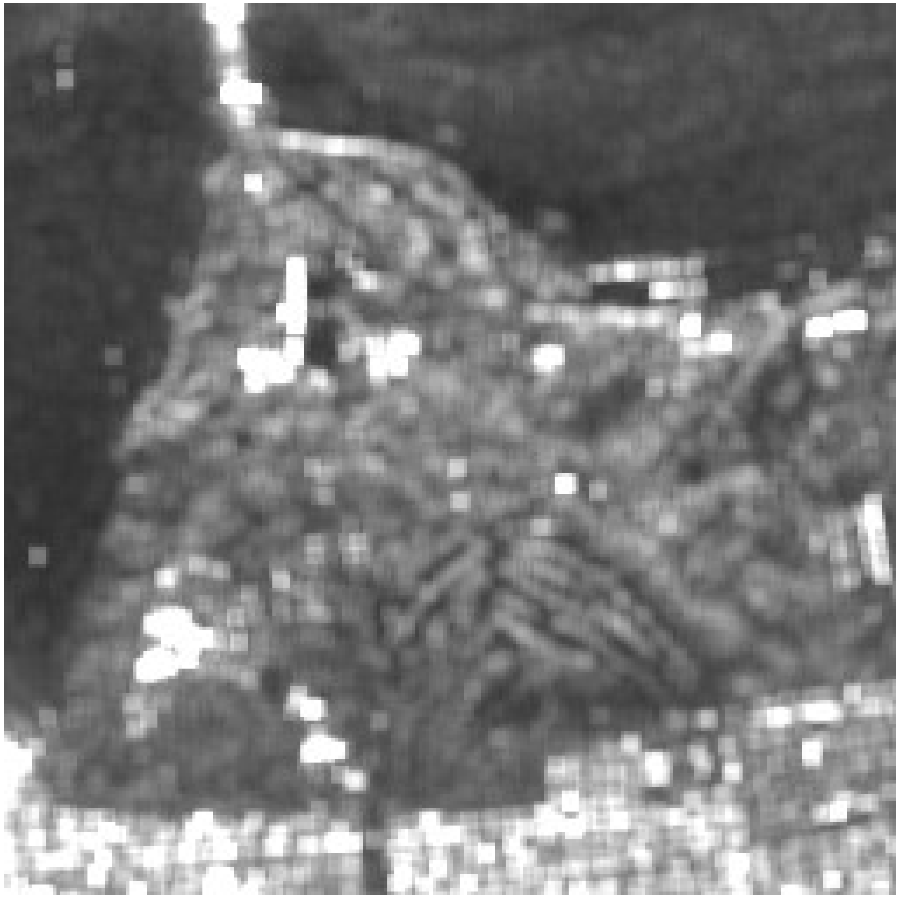
$$\operatorname{var}(S) \approx 0 \Rightarrow k = 0 \Rightarrow \hat{S} = E(S_S)$$

Highly Inhomogeneous Areas

$$\operatorname{var}(S) \mapsto \operatorname{var}(S_s) \Rightarrow k = 1 \Rightarrow \hat{S} = S_S$$

REFINED FILTER

POLSAR SPECKLE FILTERING



SAN FRANCISCO BAY JPL - AIRSAR L-band 1988

BoxCar Filter

POLSAR SPECKLE FILTERING

SAN FRANCISCO BAY JPL - AIRSAR L-band 1988

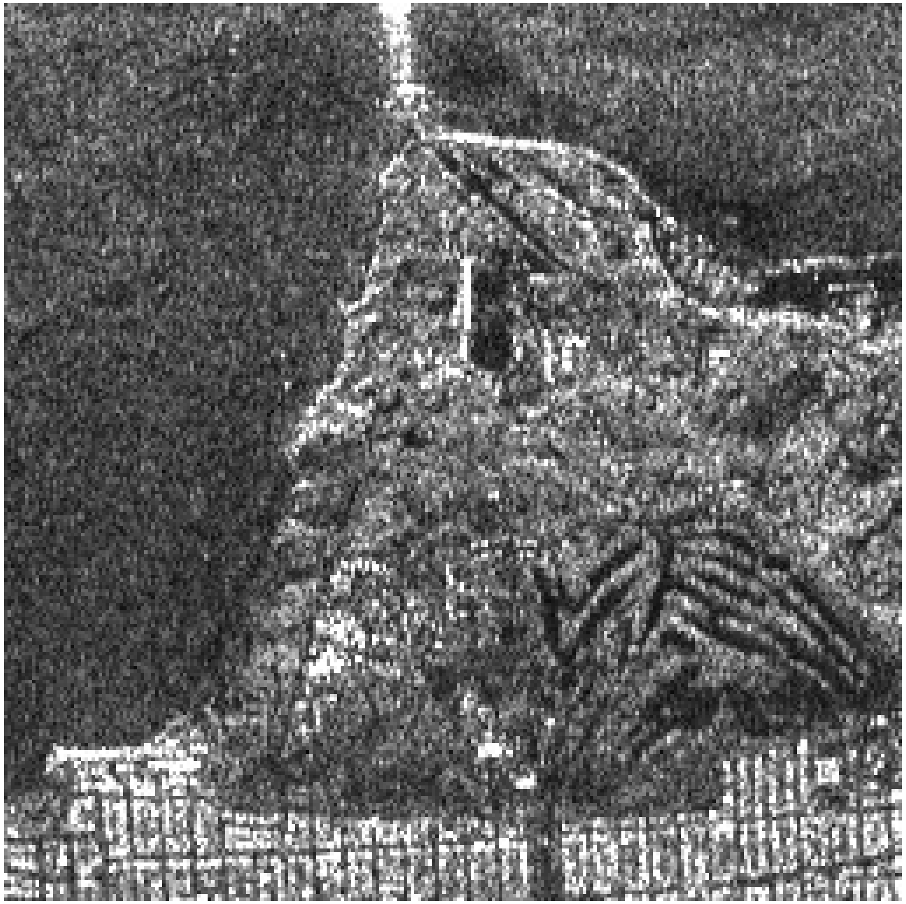
J.S. Lee, M.R. Grunes and G. De Grandi, "Polarimetric SAR Speckle Filtering and Its Impact on Terrain Classification" *IEEE TGRS*, September 1999

POLSAR SPECKLE FILTERING

SAN FRANCISCO BAY JPL - AIRSAR L-band 1988

J.S. Lee, D.L. Schuler, T.L. Ainsworth, M.R. Grunes, E Pottier, L. Ferro-Famil, "*Scattering Model Based Speckle Filetring of Polarimetric SAR Data*" IEEE – TGRS, vol 1, January 2006

POLSAR SPECKLE FILTERING



SAN FRANCISCO BAY JPL - AIRSAR L-band 1988

J.S. Lee, J.H Wen, T.L. Ainsworth, K.S. Chen, A.J. Chen, "*Improved Sigma Filter for Speckle Filtering of SAR Imagery*" IEEE – TGRS, vol 1, January 2009

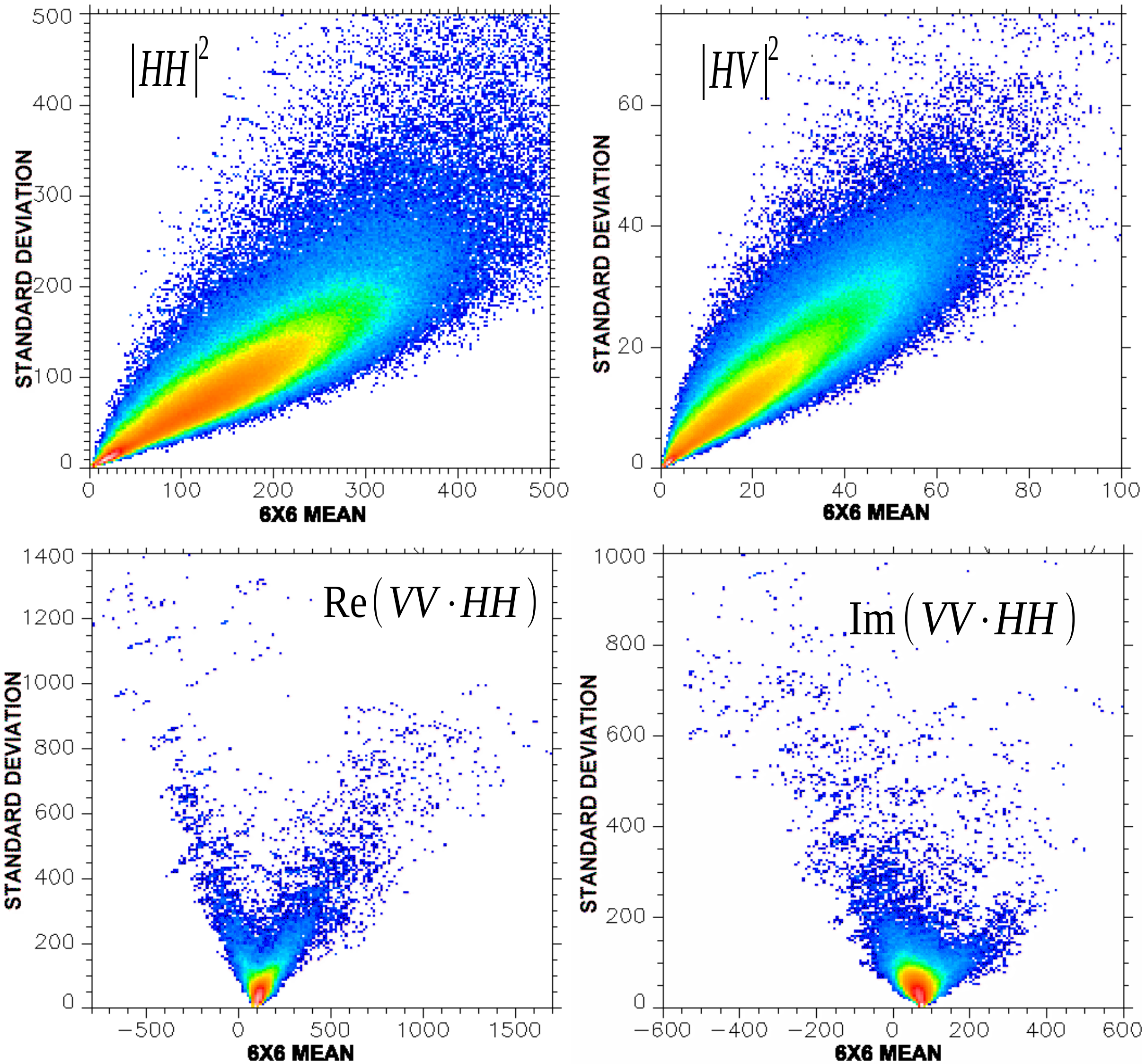
POLARIMETRIC SPECKLE FILTERING IS NOT AN EXACT SCIENCE
SUBJECTIVE, IMAGE DEPENDENT

Quantitative Criteria (J.S. Lee - IGARSS 98)

- Speckle Reduction (E.N.L)
- Edge Sharpness Preservation
- Line and Point Target Contrast Preservation
- Retention of Mean Values in Homogeneous Regions
- Retention of Texture Information
- Retention of Polarimetric Information (co, cross-correlations)
- Computational Efficiency
- Implementation Complexity

THE POLARIMETRIC SPECKLE LEE FILTER IS TODAY A GOOD COMPROMISE

POLSAR SPECKLE NOISE MODEL



Diagonal Terms

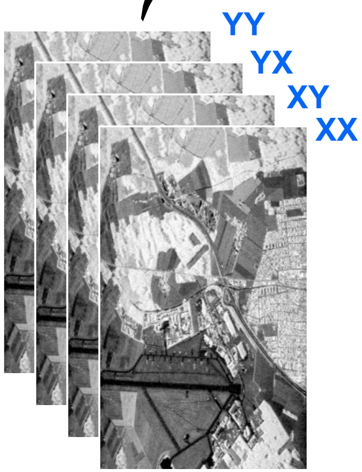
Multiplicative

Off-Diagonal Terms

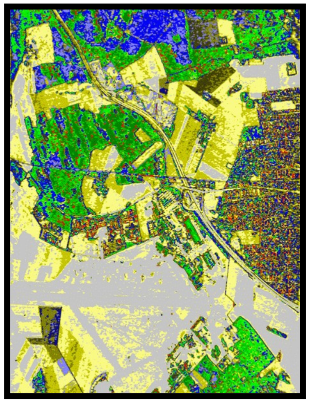
Additive/Multiplicative

J.S. Lee, M.R. Grunes and G. De Grandi, "Polarimetric SAR Speckle Filtering and Its Impact on Terrain Classification" *IEEE TGRS*, vol. 37, N°5, September 1999

POLARIMETRIC REMOTE SENSING



POL-SAR PROCESSING
PHENOMENOLOGIC
QUALITATIVE ANALYSIS



POLARIMETRIC SPECKLE FILTERING

POLARIMETRIC TARGET DECOMPOSITION

POLARIMETRIC CLASSIFICATION
MONO/DUAL CHANNELS

SPECKLE FILTERING

$$[T]' = \underline{k}\,\underline{k}^T$$

SPECKLE FILTER

AVERAGING DATA

↓

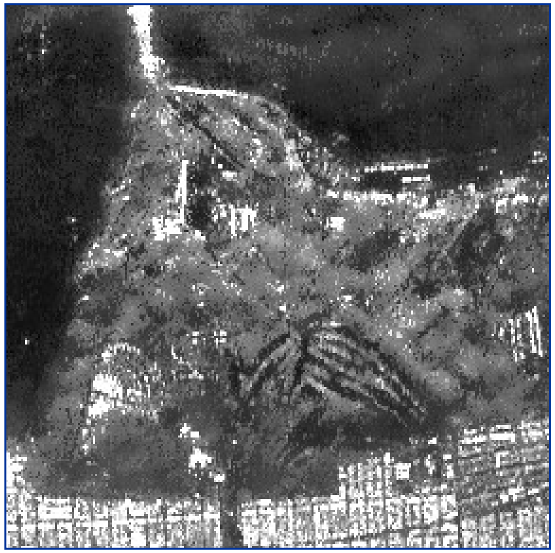
SECOND ORDER STATISTICS

COHERENCY MATRICES

↓

SMOOTHING AVERAGING

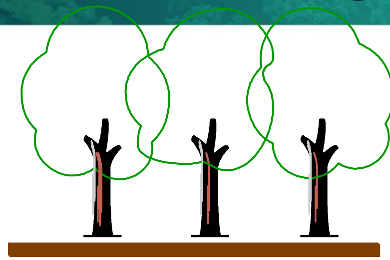
↓



$$\langle [T] \rangle = \frac{1}{N} \sum_{i=1}^{N} \underline{k}_i \underline{k}_i^T$$

CONCEPT OF THE DISTRIBUTED TARGET

TARGET DECOMPOSITIONS



PURE TARGET

COHERENCY MATRIX $[T]$

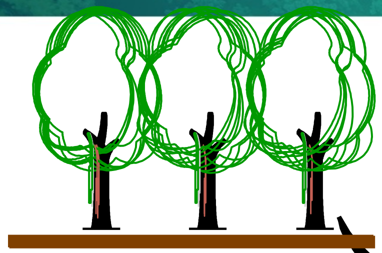
9 REAL DEPENDANT HUYNEN PARAMETERS (A0,B0,B,C,D,E,F,G,H)

POLARIMETRIC DISTRIBUTED TARGET « *DIMENSION* » = 5

9 - 5 = 4 TARGET EQUATIONS

$2A_0(B_0+B)$	C^2+D^2
$2A_0(B_0-B)$	G^2+H^2
$2A_0E$	$CH-DG$
$2A_0F$	$CG+DH$

TARGET DECOMPOSITIONS



DISTRIBUTED TARGET

COHERENCY MATRIX <[*T*]>

9 REAL INDEPENDANT HUYNEN PARAMETERS (<A0>,<B0>,<B>,<C>,<D>,<E>,<F>,<G>,<H>)

POLARIMETRIC DISTRIBUTED TARGET « *DIMENSION* » = 9

9 TARGET INEQUATIONS

$$2\langle A_0\rangle\left(\langle B_0\rangle+\langle B\rangle\right)\geq\langle C\rangle^2+\langle D\rangle^2$$

$$2\langle A_0\rangle\left(\langle B_0\rangle-\langle B\rangle\right)\geq\langle G\rangle^2+\langle H\rangle^2$$

$$2\langle A_0\rangle\langle E\rangle\geq\langle C\rangle\langle H\rangle-\langle D\rangle\langle G\rangle$$

$$2\langle A_0\rangle\langle F\rangle\geq\langle C\rangle\langle G\rangle+\langle D\rangle\langle H\rangle$$

$$\langle B_0\rangle^2\geq\langle B\rangle^2+\langle E\rangle^2+\langle F\rangle^2$$

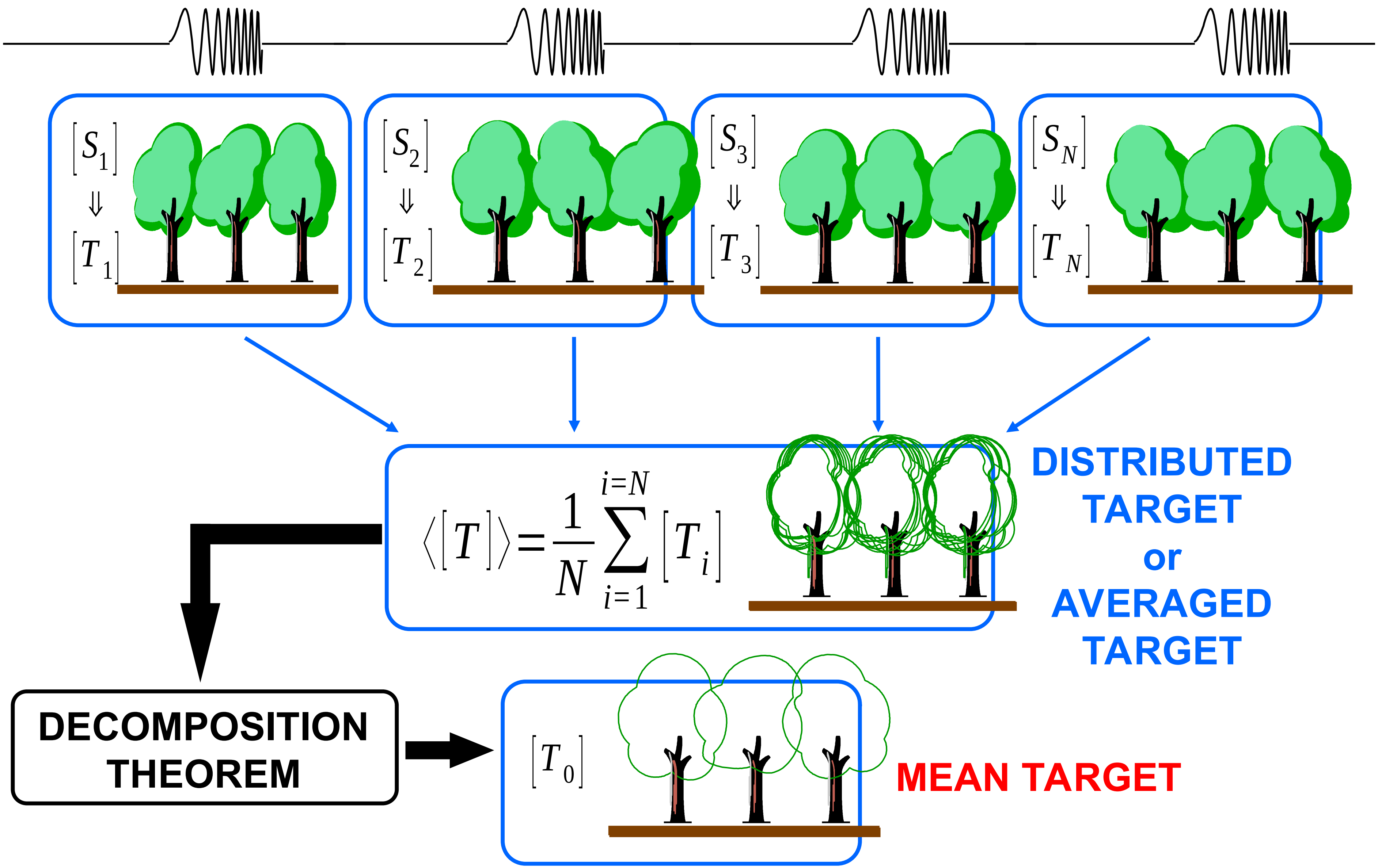
$$\langle H\rangle\left(\langle B_0\rangle+\langle B\rangle\right)\geq\langle C\rangle\langle E\rangle+\langle D\rangle\langle F\rangle$$

$$\langle G\rangle\left(\langle B_0\rangle+\langle B\rangle\right)\geq\langle C\rangle\langle F\rangle-\langle D\rangle\langle E\rangle$$

$$\langle C\rangle\left(\langle B_0\rangle-\langle B\rangle\right)\geq\langle H\rangle\langle E\rangle+\langle F\rangle\langle G\rangle$$

$$\langle D\rangle\left(\langle B_0\rangle-\langle B\rangle\right)\geq\langle F\rangle\langle H\rangle-\langle G\rangle\langle E\rangle$$

TARGET DECOMPOSITIONS



TARGET DECOMPOSITIONS

[S]

COHERENT DECOMPOSITION

- E. KROGAGER (1990)
- W.L. CAMERON (1990)

[K]

TARGET DICHOTOMY

- J.R. HUYNEN (1970)
- R.M. BARNES (1988)

[T] [C]

AZIMUTHAL SYMMETRY

EIGENVECTORS BASED DECOMPOSITION

- S.R. CLOUDE (1985)
- W.A. HOLM (1988)

MODEL BASED DECOMPOSITION

- A.J. FREEMAN – S.L. DURDEN (1992)
- Y. YAMAGUSHI (2005 - 2012), AN (2010)

EIGENVECTORS / EIGENVALUES ANALYSIS & MODEL BASED DECOMPOSITION

- J.J. VAN ZYL (1992-2008), M. ARII (2010)
- TSVM (R. TOUZI – 2007)

EIGENVECTORS / EIGENVALUES ANALYSIS ENTROPY / ANISOTROPY

- S.R. CLOUDE - E. POTTIER (1996-1997)

TARGET DECOMPOSITION FOR TARGETS WITH REFLECTION SYMMETRY

MODEL BASED DECOMPOSITION

A. FREEMAN – S. DURDEN (1992)

A. Freeman and S.L. Durden, "A Three-Component Scattering Model for Polarimetric SAR Data" IEEE TGRS, vol. 36, no. 3, May 1998

MODEL BASED DECOMPOSITION

3 COMPONENTS SCATTERING MECHANISM MODEL

$$\langle [T] \rangle = [T_S] + [T_D] + [T_V]$$

↓ SINGLE SCATTERING

↓ DOUBLE SCATTERING

↓ VOLUME SCATTERING

MODEL BASED DECOMPOSITION

3 COMPONENTS SCATTERING MECHANISM MODEL

$$\langle [T] \rangle = [T_S] + [T_D] + [T_V]$$

SINGLE SCATTERING — DOUBLE SCATTERING — VOLUME SCATTERING

$$T_{11} = f_S |\beta + 1|^2 + f_D |\alpha - 1|^2 + \frac{4 f_V}{3}$$

$$T_{12} = f_S (\beta + 1)(\beta - 1) + f_D (\alpha - 1)(\alpha + 1)$$

$$T_{22} = f_S |\beta - 1|^2 + f_D |\alpha + 1|^2 + \frac{2 f_V}{3}$$

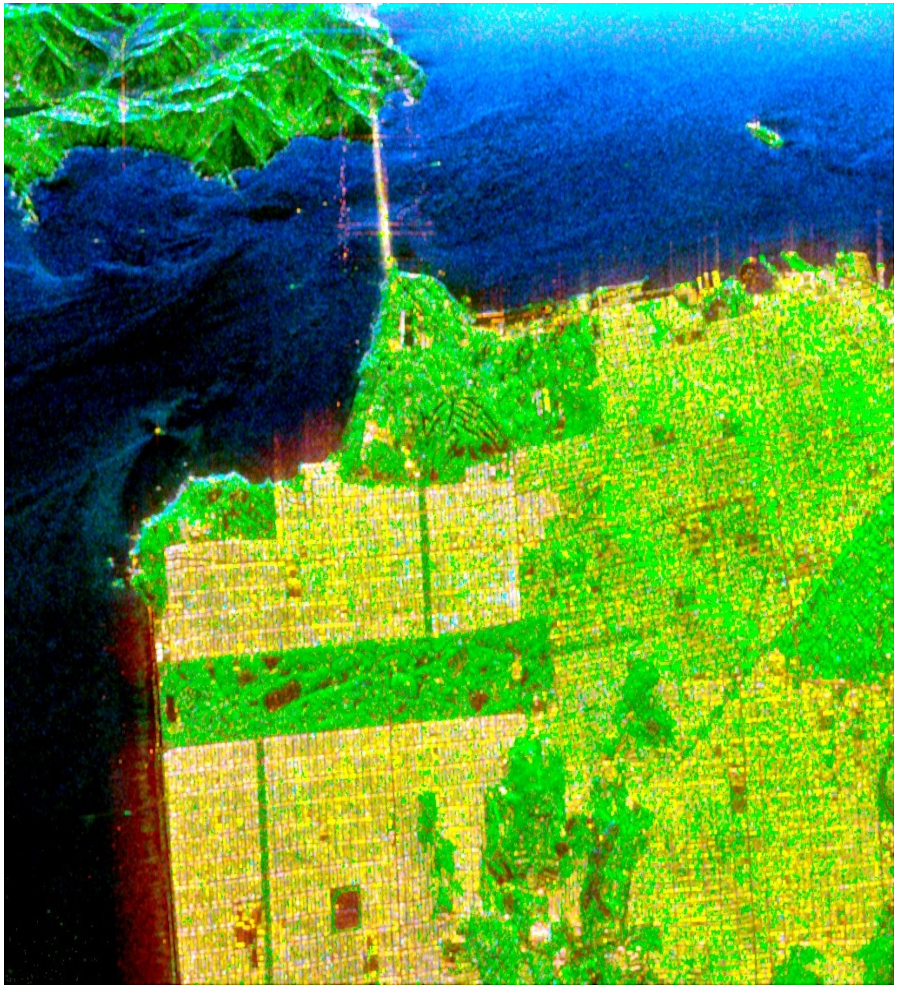
$$T_{33} = \frac{2 f_V}{3}$$

→ 5 UNKNOWN REAL COEFFICIENTS

→ 4 OBSERVED EQUATIONS

MODEL BASED DECOMPOSITION

$2A_0$ B_0+B B_0-B



$$ODD=f_S\left(1+\beta^2\right)$$

$$DBL=f_D\left(1+\alpha^2\right)$$

$$VOL=\frac{2f_V}{3}$$

TARGET DECOMPOSITION FOR TARGETS WITHOUT REFLECTION SYMMETRY

MODEL BASED - 4 COMPONENTS DECOMPOSITION

Y. YAMAGUCHI et al. (2005 - 2013)

MODEL BASED DECOMPOSITION

MEDIUM WITHOUT ANY REFLECTION SYMMETRY

4 COMPONENTS SCATTERING MECHANISM MODEL

$$\langle [T] \rangle = [T_S] + [T_D] + [T_V] + [T_H]$$

SINGLE SCATTERING | **DOUBLE SCATTERING** | **VOLUME SCATTERING** | **HELIX SCATTERING**

$$[S]_{\pm Helix} = \frac{1}{2}\begin{bmatrix} 1 & \pm j \\ \pm j & -1 \end{bmatrix}$$

$$\langle [T] \rangle_{Helix} = \frac{1}{2}\left\langle \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & \pm j \\ 0 & \mp j & 1 \end{bmatrix} \right\rangle$$

Non reflection Symmetric cases

Yamaguchi Y., Moriyama T., Ishido M. and Yamada H., "*Four-Component Scattering Model for Polarimetric SAR Image Decomposition*", IEEE Trans. Geos. Remote Sens., vol. 43, no. 8, August 2005.

Yamaguchi Y., Yajima Y. and Yamada H., "A Four-Component Decomposition of POLSAR Images Based on the Coherency Matrix", IEEE Geos. Rem. Sens. Letters, vol. 3, no. 3, July 2006.

2005 - 2006

MODEL BASED DECOMPOSITION

Y. Yamaguchi, A. Sato, W.M. Boerner, R. Sato, H. Yamada, "*4-component scattering power decomposition with rotation of coherency matrix*", IEEE TGRS vol. 49, no. 6, June 2011.

A. Sato, Y. Yamaguchi, G. Singh, and S.-E. Park, "*4-component scattering power decomposition with extended volume scattering model*", IEEE GRS Letters, vol. 9, no. 2, pp. 166–170, Mar. 2012.

G. Singh, Y. Yamaguchi, S.E. Park*, « General Four-Component Scattering Power Decomposition With Unitary Transformation of Coherency Matrix »* IEEE TGRS in press

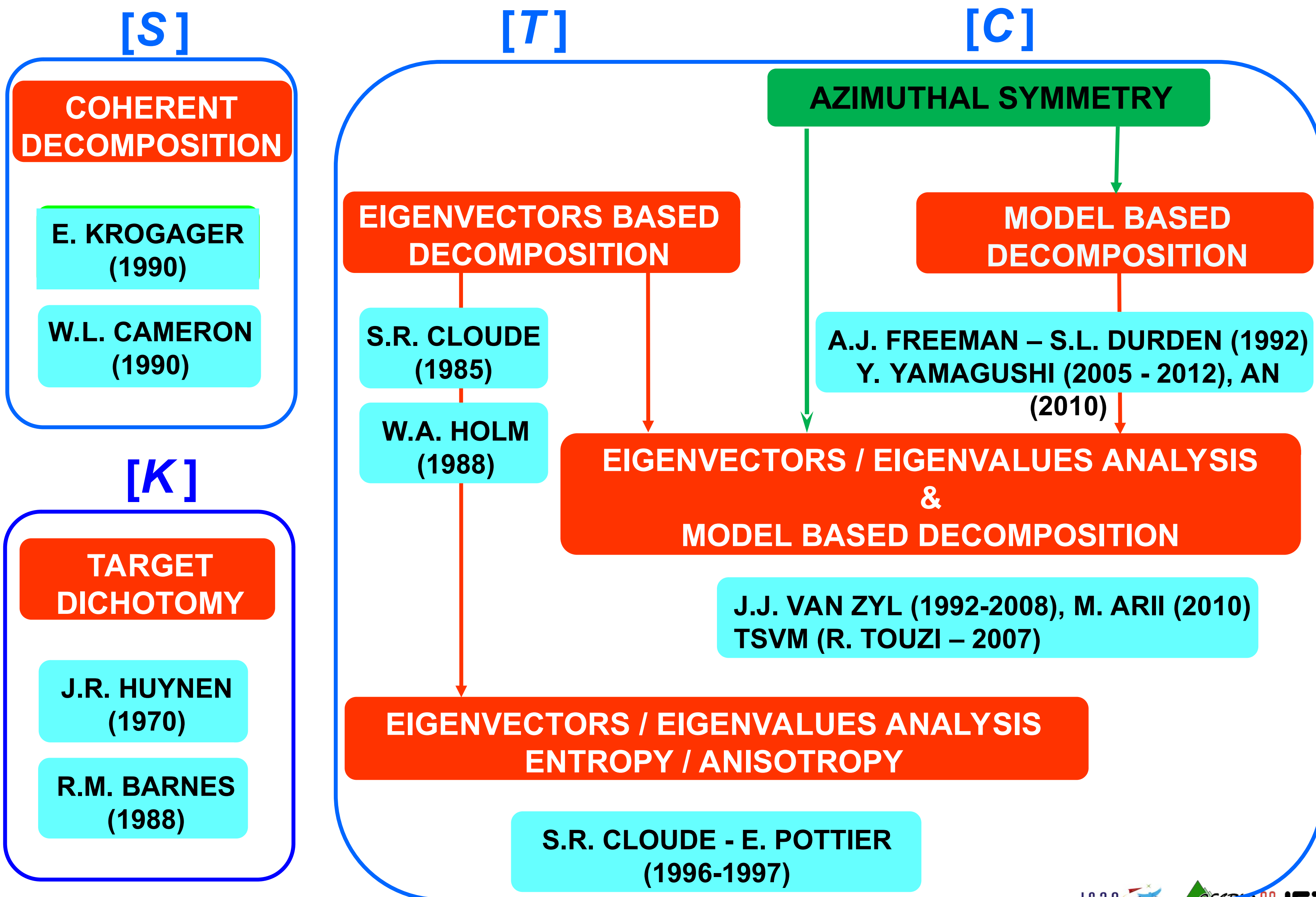
G. Singh, Y. Yamaguchi, S.E. Park*, Y. Cui, H. Kobayashi, « Hybrid Freeman/Eigenvalue Decomposition Method With Extended Volume Scattering Model »* IEEE GRS Letters, vol. 10, no. 1, Jan. 2013

MODEL BASED DECOMPOSITION

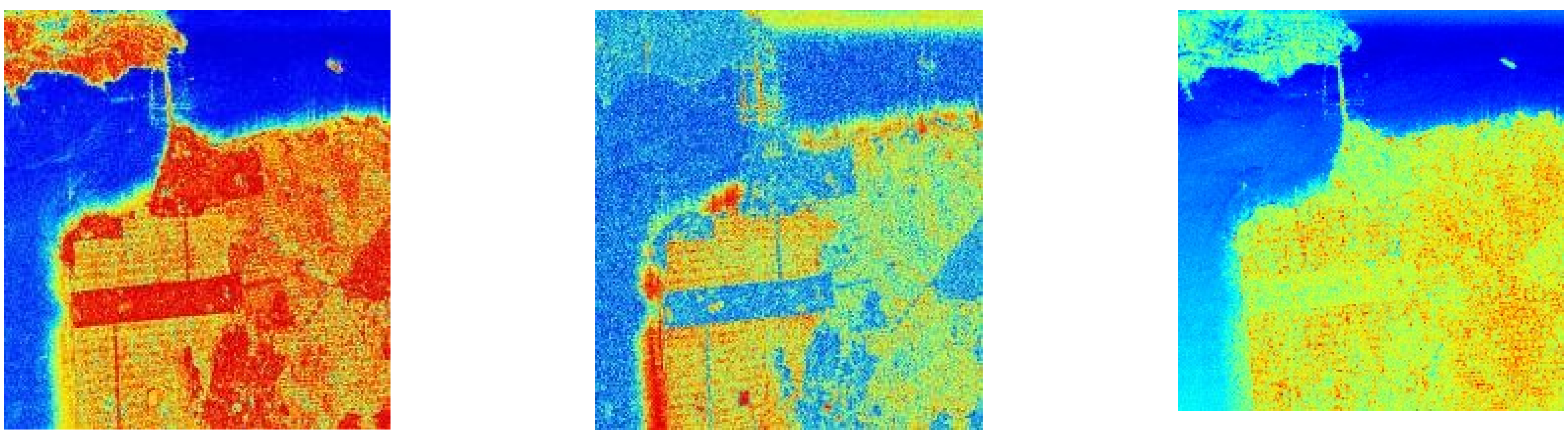
$2A_0$ B_0+B B_0-B

ODD DBL VOL

TARGET DECOMPOSITIONS



THE H / A / $\underline{\alpha}$ POLARIMETRIC TARGET DECOMPOSITION THEOREM



S.R. CLOUDE - E. POTTIER (1995 - 1996)

H / A / $\underline{\alpha}$ DECOMPOSITION

TARGET VECTOR

$$\underline{k} = \frac{1}{\sqrt{2}} \left[S_{XX} + S_{YY} \quad S_{XX} - S_{YY} \quad 2S_{XY} \right]^T$$

LOCAL ESTIMATE OF THE COHERENCY MATRIX

$$\langle [T] \rangle = \frac{1}{N} \sum_{i=1}^{N} \underline{k}_i \cdot \underline{k}_i^T = \frac{1}{N} \sum_{i=1}^{N} [T_i]$$

EIGENVECTORS / EIGENVALUES ANALYSIS

$$\langle [T] \rangle = [U_3][S][U_3]^{-1} = \begin{bmatrix} \underline{u}_1 & \underline{u}_2 & \underline{u}_3 \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix} \begin{bmatrix} \underline{u}_1 & \underline{u}_2 & \underline{u}_3 \end{bmatrix}^T$$

ORTHOGONAL EIGENVECTORS

REAL EIGENVALUES
$\lambda_1 > \lambda_2 > \lambda_3$

$$P_i = \frac{\lambda_i}{\sum_{k=1}^{3} \lambda_k}$$

H / A / α DECOMPOSITION

$$\langle [T] \rangle = [U_3][S][U_3]^{-1} = \begin{bmatrix} \underline{u}_1 & \underline{u}_2 & \underline{u}_3 \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix} \begin{bmatrix} \underline{u}_1 & \underline{u}_2 & \underline{u}_3 \end{bmatrix}^T$$

ORTHOGONAL EIGENVECTORS

REAL EIGENVALUES
$\lambda_1 > \lambda_2 > \lambda_3$

PARAMETERISATION OF THE SU(3) UNITARY MATRIX

$$[U_3] = \begin{bmatrix} \cos\alpha_1 e^{j\varphi_1} & \cos\alpha_2 e^{j\varphi_2} & \cos\alpha_3 e^{j\varphi_3} \\ \sin\alpha_1 \cos\beta_1 e^{j\varphi_1} e^{j\delta_1} & \sin\alpha_2 \cos\beta_2 e^{j\varphi_2} e^{j\delta_2} & \sin\alpha_3 \cos\beta_3 e^{j\varphi_3} e^{j\delta_3} \\ \sin\alpha_1 \sin\beta_1 e^{j\varphi_1} e^{j\gamma_1} & \sin\alpha_2 \sin\beta_2 e^{j\varphi_2} e^{j\gamma_2} & \sin\alpha_3 \sin\beta_3 e^{j\varphi_3} e^{j\gamma_3} \end{bmatrix}$$

TARGET 1 **TARGET 2** **TARGET 3**

H / A / $\underline{\alpha}$ DECOMPOSITION

PROBABILITIES

$$P_i = \frac{\lambda_i}{\sum_{k=1}^{3} \lambda_k}$$

AVERAGED PARAMETERS

$$\underline{\alpha} = P_1 \alpha_1 + P_2 \alpha_2 + P_3 \alpha_3 \qquad \underline{\beta} = P_1 \beta_1 + P_2 \beta_2 + P_3 \beta_3$$

$$\underline{g} = P_1 g_1 + P_2 g_2 + P_3 g_3 \qquad \underline{d} = P_1 d_1 + P_2 d_2 + P_3 d_3$$

UNITARY TARGET VECTOR ($\underline{u_0}$) OF THE MEAN DOMINANT MECHANISM

$$u_0 = \left[\cos(\underline{\alpha}) \quad \sin(\underline{\alpha})\cos(\underline{\beta})e^{j\underline{d}} \quad \sin(\underline{\alpha})\sin(\underline{\beta})e^{j\underline{g}}\right]^T$$

MEAN SCATTERING MECHANISM

UNITARY VECTOR $\underline{u}_0$

$$\underline{u}_0 = \begin{bmatrix} \cos(\underline{\alpha}) \\ \sin(\underline{\alpha})\cos(\underline{\beta})\, e^{j\underline{\delta}} \\ \sin(\underline{\alpha})\sin(\underline{\beta})\, e^{j\underline{\gamma}} \end{bmatrix}$$

TARGET MAGNITUDE

$$\underline{\lambda} = P_1\lambda_1 + P_2\lambda_2 + P_3\lambda_3 = \frac{\sum_{i=1}^{3}\lambda_i^2}{\sum_{k=1}^{3}\lambda_k}$$

TARGET VECTOR $\underline{k}_0$

$$\underline{k}_0 = \sqrt{\underline{\lambda}} \begin{bmatrix} \cos(\underline{\alpha}) \\ \sin(\underline{\alpha})\cos(\underline{\beta})\, e^{j\underline{\delta}} \\ \sin(\underline{\alpha})\sin(\underline{\beta})\, e^{j\underline{\gamma}} \end{bmatrix}$$

H / A / $\underline{\alpha}$ DECOMPOSITION

$2A_0$ $\quad B_0 + B$ $\quad B_0 - B$

$\sqrt{\underline{\lambda}}\cos(\underline{\alpha})$ $\quad \sqrt{\underline{\lambda}}\sin(\underline{\alpha})\cos(\underline{\beta})$

$\sqrt{\underline{\lambda}}\sin(\underline{\alpha})\sin(\underline{\beta})$

H / A / α DECOMPOSITION

ROLL INVARIANCE PROPERTY

SAME PHYSICAL PHENOMENOUS **WHATEVER THE ANTENNA** ***ORIENTATION ANGLE*** **AROUND THE** ***RADAR LINE OF SIGHT***

ORIENTED (θ) COHERENCY MATRIX

$$\langle [T(q)] \rangle = [U_R(q)] \langle [T] \rangle [U_R(q)]^{-1}$$

SU(3) UNITARY ROTATION MATRIX (θ)

$$[U_R(q)] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2q & \sin 2q \\ 0 & -\sin 2q & \cos 2q \end{bmatrix}$$

EIGENVECTORS / EIGENVALUES ANALYSIS

$$\langle [T(q)] \rangle = [U_3(q)][S][U_3(q)]^{-1}$$

EIGENVALUES λ_1 λ_2 λ_3 : ROLL INVARIANT

PROBABILITIES P_1 P_2 P_3 : ROLL INVARIANT

H / A / $\underline{\alpha}$ DECOMPOSITION

EIGENVECTORS UNITARY MATRIX

$$\left[U_3(q)\right]=\left[U_R(q)\right]\left[U_3\right]$$

PARAMETERIZATION OF THE UNITARY MATRIX

$$\left[U_3\right]=$$

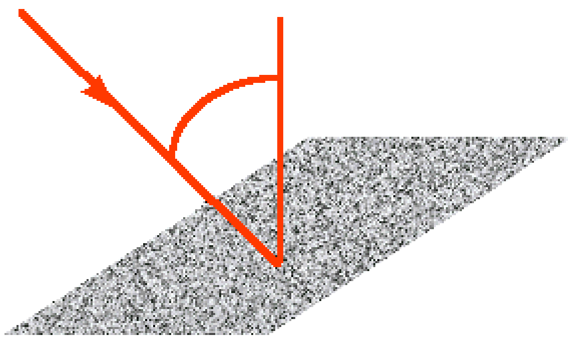
$\underline{\alpha}=P_1\alpha_1+P_2\alpha_2+P_3\alpha_3$ **: ROLL INVARIANT**

PHYSICAL INTERPRETATION

H / A / α DECOMPOSITION

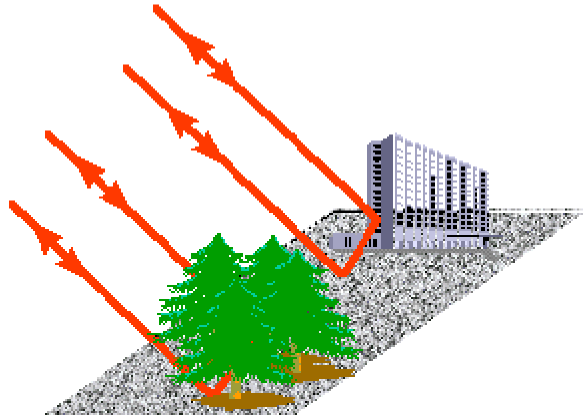
α PHYSICAL INTERPRETATION

SINGLE BOUNCE SCATTERING (ROUGH SURFACE)



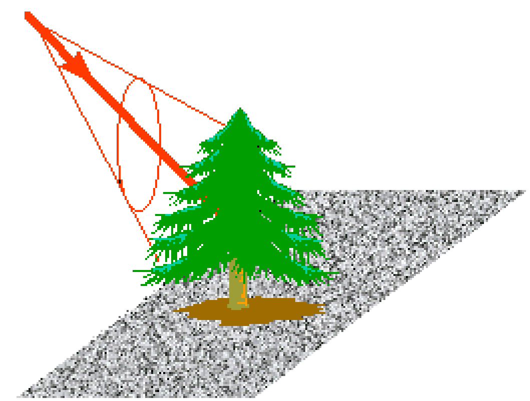
$$\alpha \rightarrow 0$$

DOUBLE BOUNCE SCATTERING



$$\alpha \rightarrow \frac{\pi}{2}$$

VOLUME SCATTERING



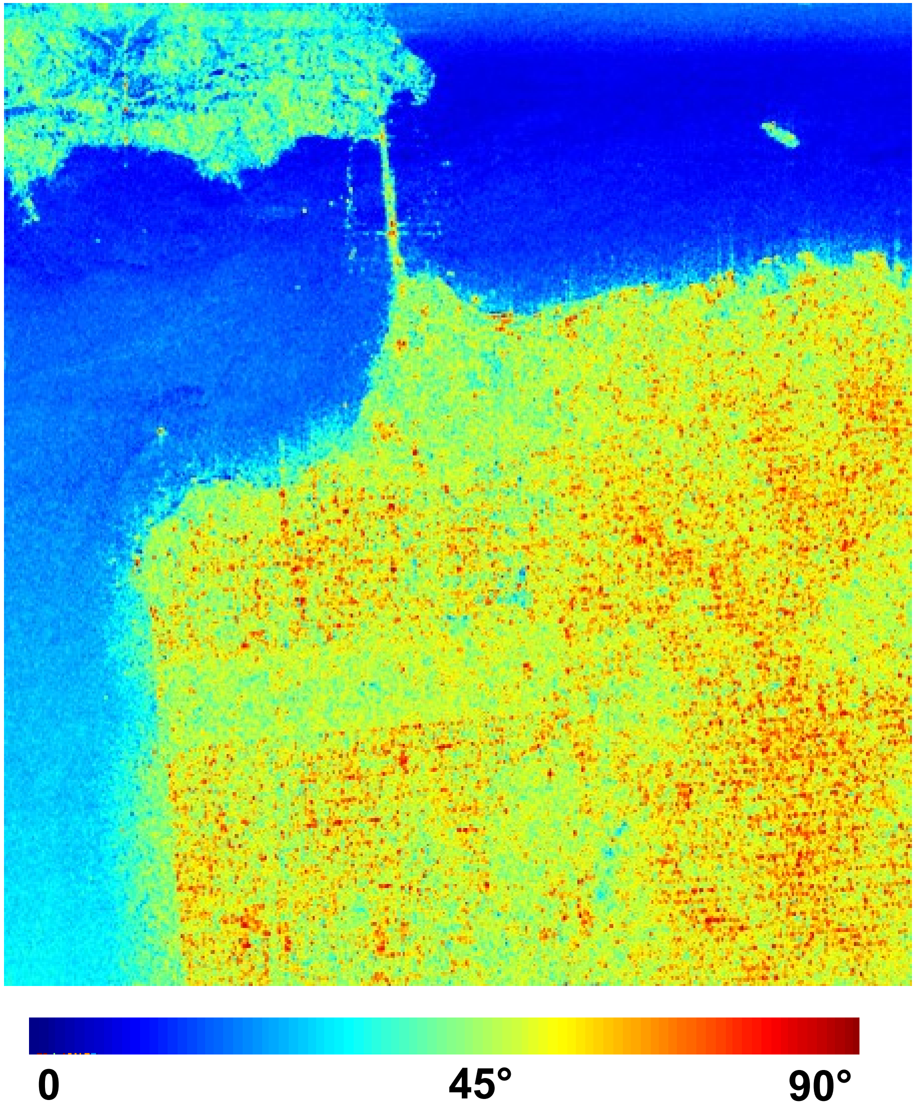
$$\alpha \rightarrow \frac{\pi}{4}$$

$$\underline{k}_0 = \sqrt{\lambda}\begin{bmatrix} \cos(\underline{\alpha}) \\ \sin(\underline{\alpha})\cos(\underline{\beta})\,e^{j\underline{\delta}} \\ \sin(\underline{\alpha})\sin(\underline{\beta})\,e^{j\underline{\gamma}} \end{bmatrix}$$

$$\underline{k} = \frac{1}{\sqrt{2}}\begin{bmatrix} S_{XX}+S_{YY} & S_{XX}-S_{YY} & 2S_{XY} \end{bmatrix}^T$$

H / A / $\underline{\alpha}$ DECOMPOSITION

$2A_0$ B_0+B B_0-B



$\underline{\alpha}$ PARAMETER

L. Ferro-Famil & E. Pottier

H / A / α DECOMPOSITION

EIGENVALUES λ_1 λ_2 λ_3 : ROLL INVARIANT

PROBABILITIES P_1 P_2 P_3 : ROLL INVARIANT

ENTROPY

(DEGREE OF RANDOMNESS
STATISTICAL DISORDER)

$$H = -\sum_{i=1}^{3} P_i \log_3 \left(P_i \right)$$

PURE TARGET

$\lambda_1 = SPAN \quad \lambda_2 = 0 \quad \lambda_3 = 0$

$H = 0$

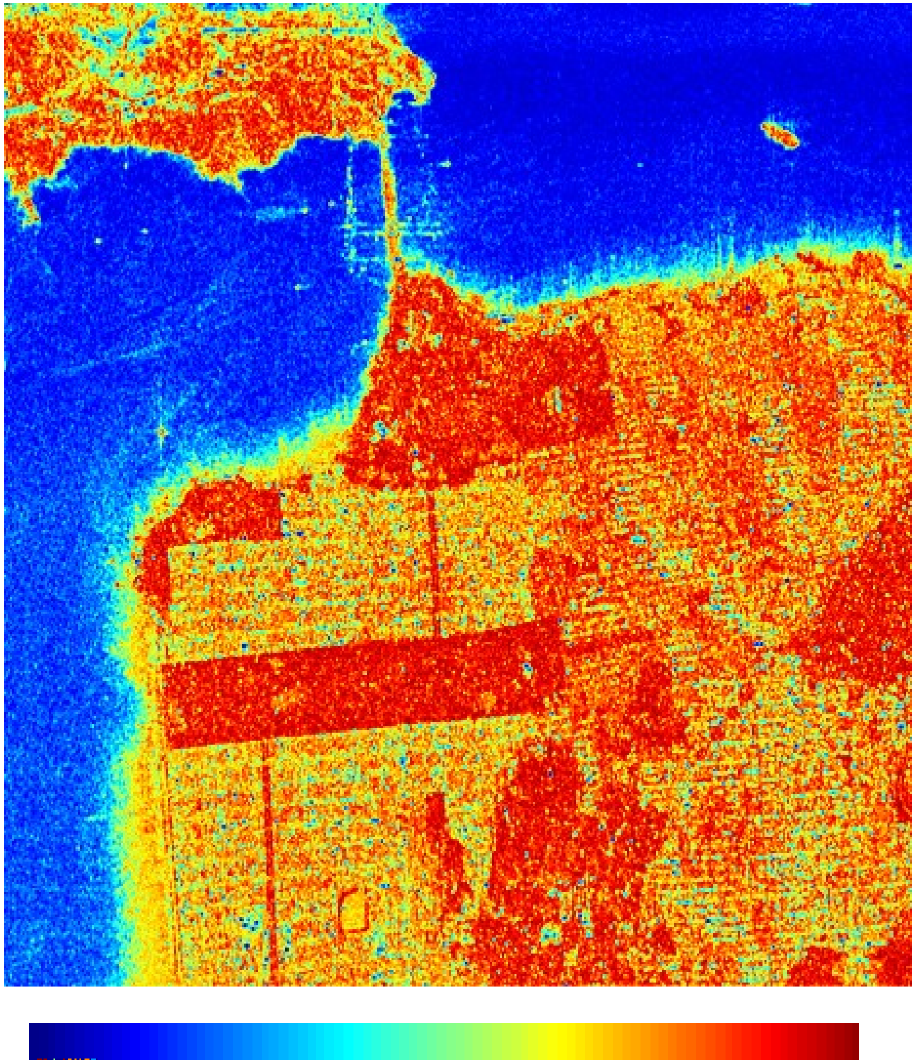
DISTRIBUTED TARGET

$\lambda_1 = \lambda_2 = \lambda_3 = SPAN / 3$

$H = 1$

H / A / <u>α</u> DECOMPOSITION

$2A_0$ $\quad$ B_0+B $\quad$ B_0-B



L. Ferro-Famil & E. Pottier

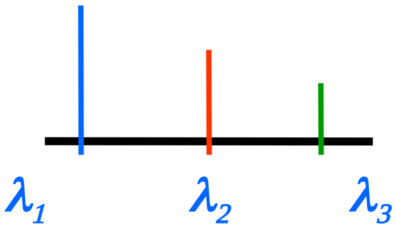
H / A / α DECOMPOSITION

DIFFICULT MECHANISM DISCRIMINATION WHEN : H > 0.7

ANISOTROPY

(EIGENVALUES SPECTRUM)

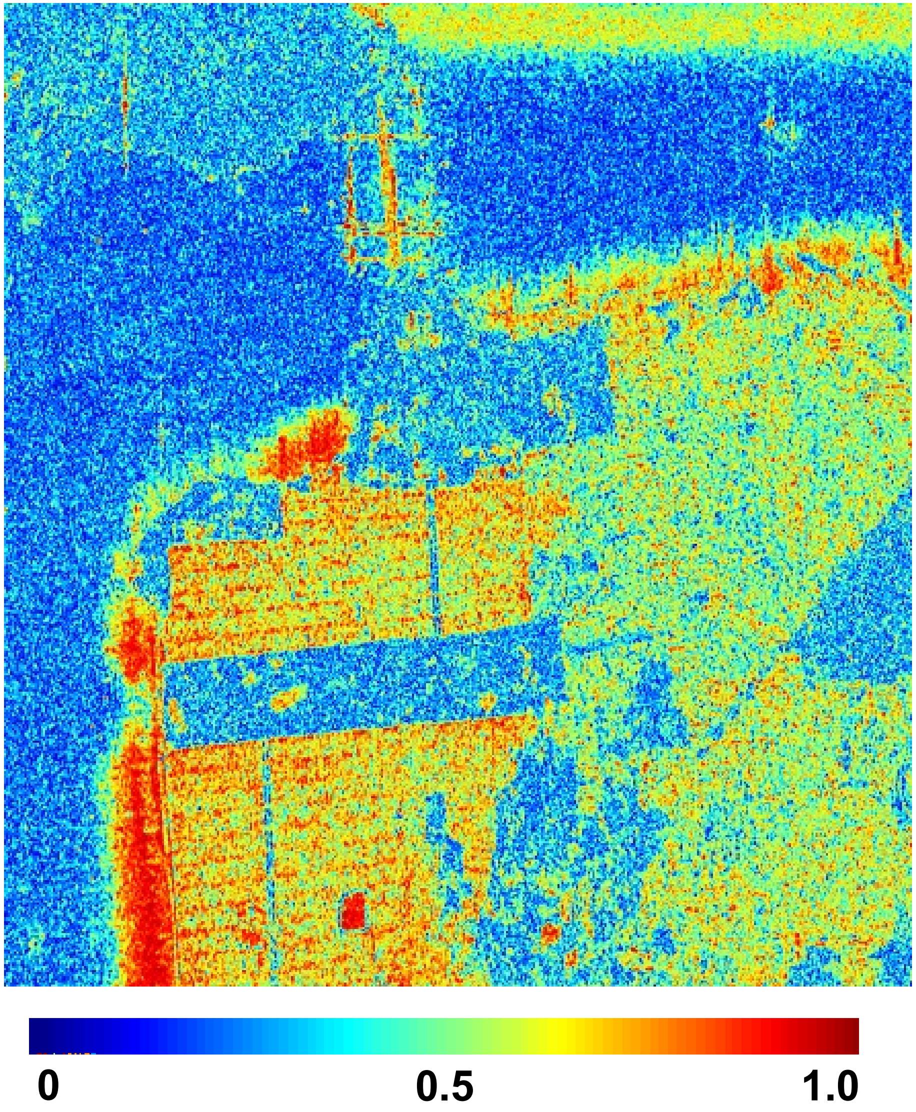
$$A = \frac{\lambda_2 - \lambda_3}{\lambda_2 + \lambda_3}$$



- COMPLEMENTARY TO ENTROPY
- DISCRIMINATION WHEN H > 0.7
- ROLL INVARIANT

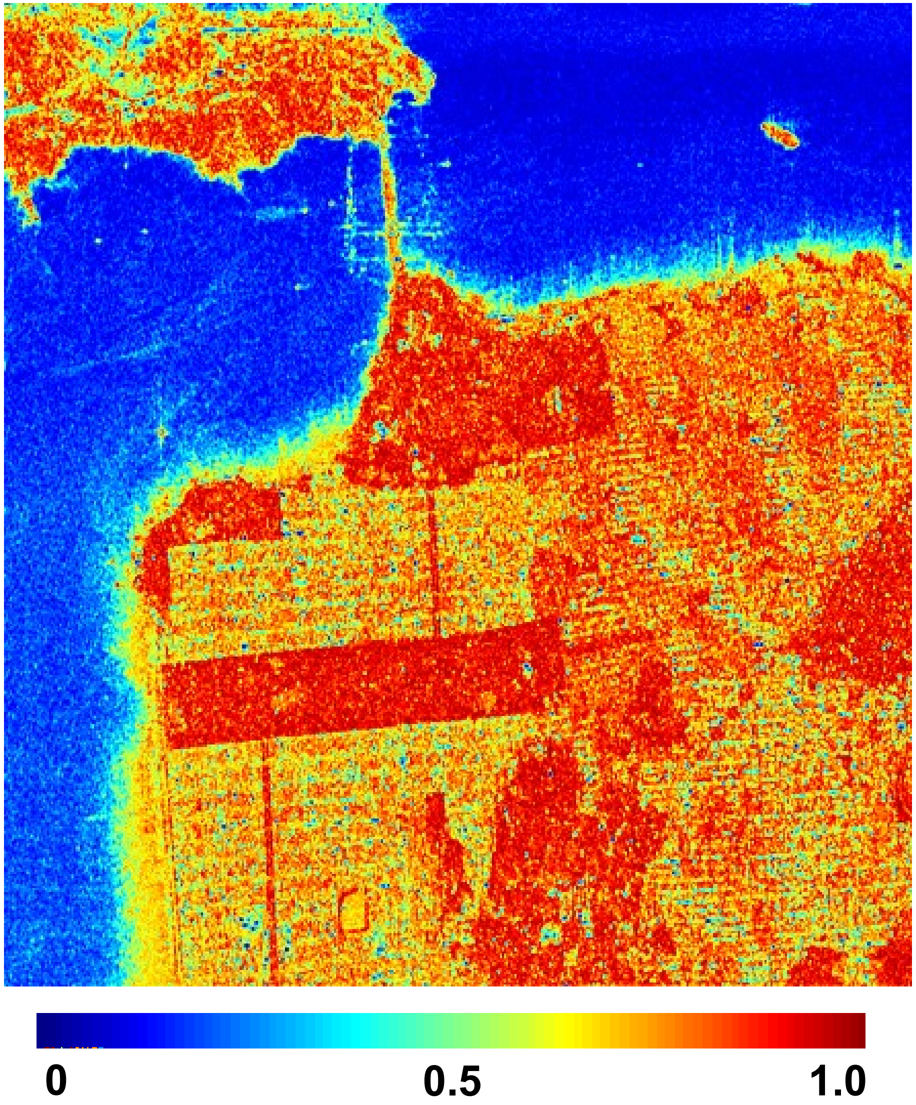
H / A / $\underline{\alpha}$ DECOMPOSITION

$2A_0$ B_0+B B_0-B

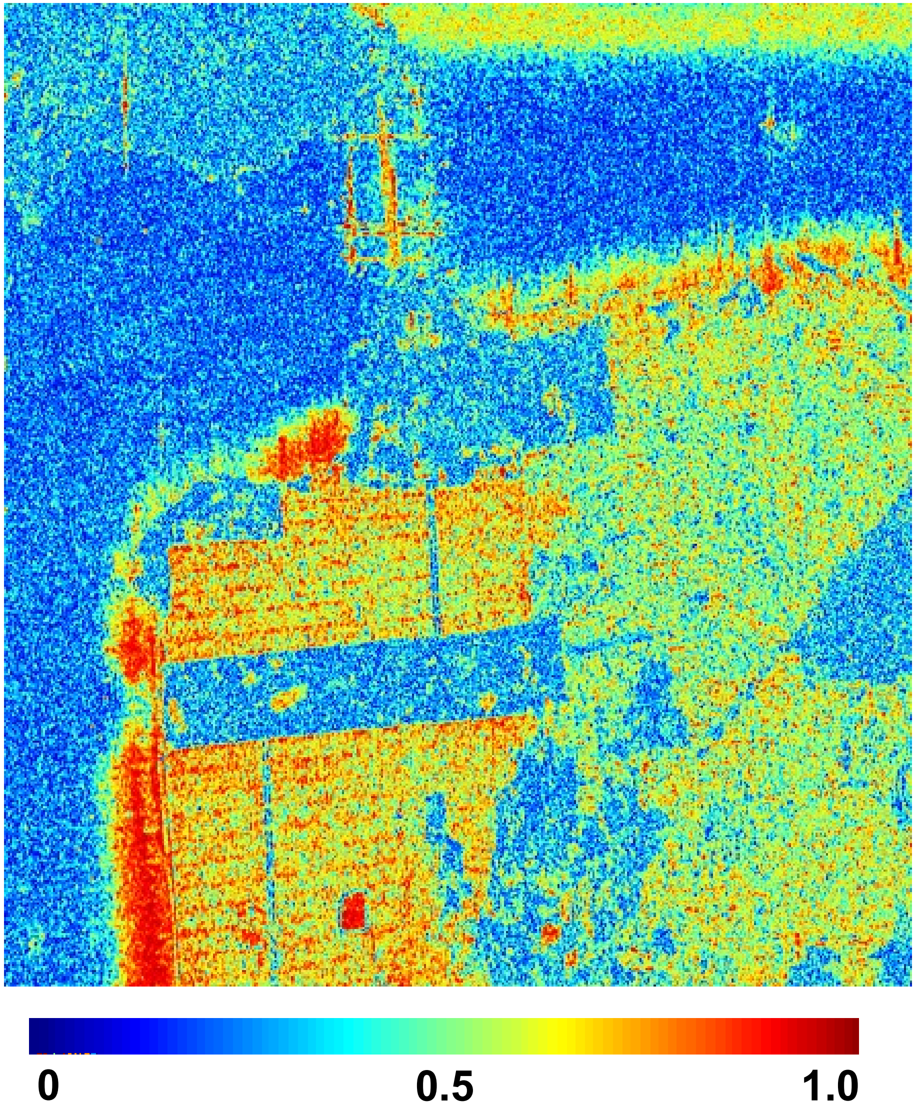


L. Ferro-Famil & E. Pottier

H / A / $\underline{\alpha}$ DECOMPOSITION

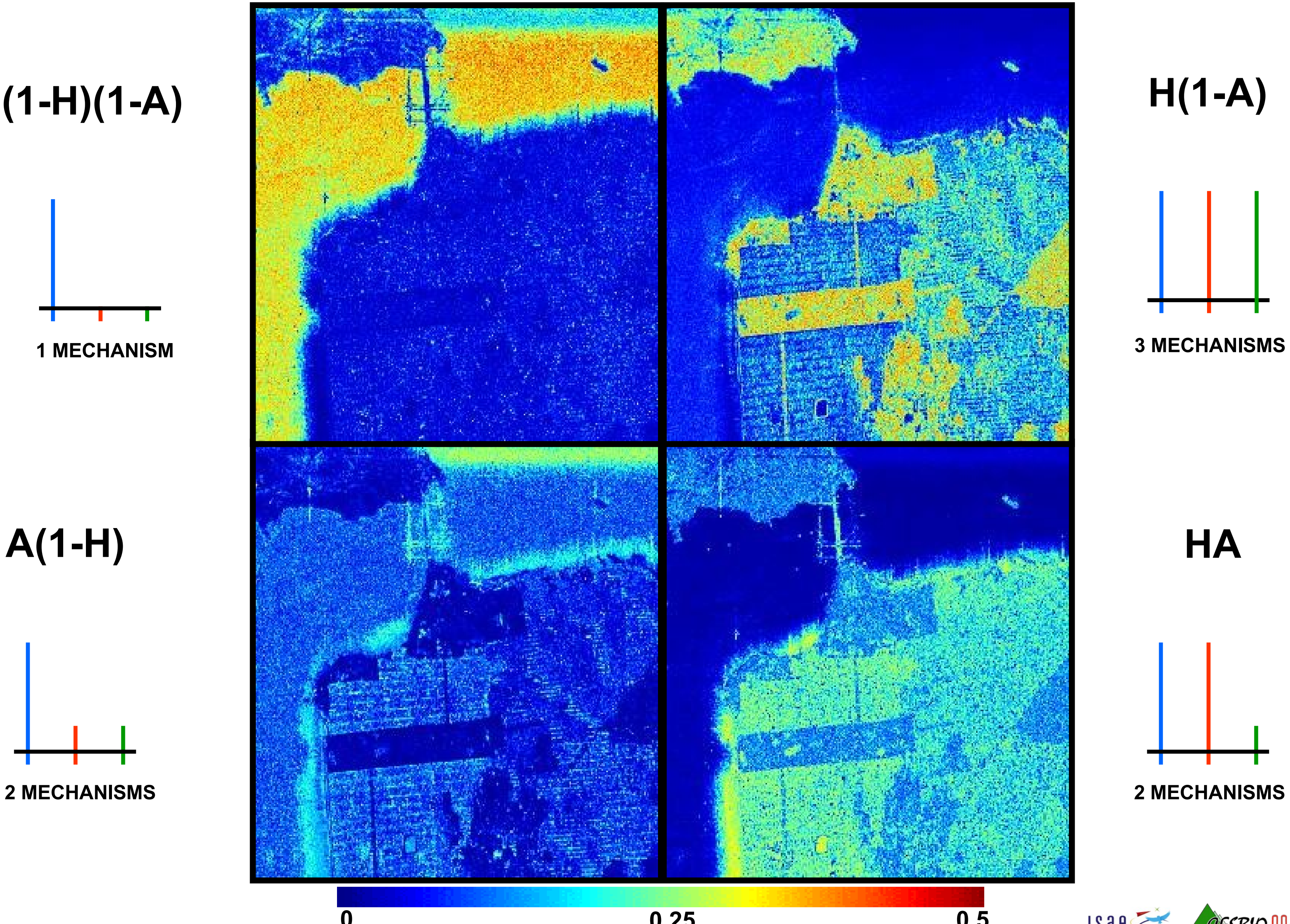


ENTROPY (H)



ANISOTROPY (A)

H / A / α DECOMPOSITION



L. Ferro-Famil & E. Pottier

S. Allain

S.E.R.D and D.E.R.D PARAMETERS
(*Single- and Double-bounce Eigenvalue Relative Difference*)

$$SERD = \frac{\lambda_S - \lambda_{3_{NOS}}}{\lambda_S + \lambda_{3_{NOS}}} \qquad DERD = \frac{\lambda_D - \lambda_{3_{NOS}}}{\lambda_D + \lambda_{3_{NOS}}}$$

T. Ainsworth

POLARIZATION FRACTION

$$PF = 1 - \frac{3\lambda_3}{Span} = 1 - \frac{3\lambda_3}{\lambda_1 + \lambda_2 + \lambda_3} \qquad 0 \leq PF \leq 1$$

POLARIZATION ASYMMETRY

$$PA = \frac{(\lambda_1 - \lambda_3) - (\lambda_2 - \lambda_3)}{(\lambda_1 - \lambda_3) + (\lambda_2 - \lambda_3)} = \frac{\lambda_1 - \lambda_2}{Span - 3\lambda_3} \qquad 0 \leq PA \leq 1$$

EIGENVALUE-BASED PARAMETERS

J. Van Zyl

RADAR VEGETATION INDEX

$$RVI = \frac{4\lambda_3}{\lambda_1 + \lambda_2 + \lambda_3} \qquad 0 \le RVI \le \frac{4}{3}$$

S.L. Durden

PEDESTAL HEIGHT

$$PH = \frac{\min(\lambda_1, \lambda_2, \lambda_3)}{\max(\lambda_1, \lambda_2, \lambda_3)} = \frac{\lambda_3}{\lambda_1} \qquad 0 \le PH \le 1$$

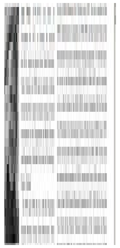
E. Luneuburg

TARGET RANDOMNESS

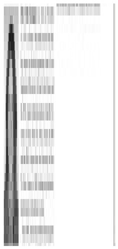
$$p_R = \sqrt{\frac{3}{2}}\sqrt{\frac{\lambda_2^2 + \lambda_3^2}{\lambda_1^2 + \lambda_2^2 + \lambda_3^2}} \qquad 0 \le p_R \le 1$$

EIGENVALUE-BASED PARAMETERS

ALTERNATIVE ENTROPY PARAMETERS DERIVATION



J. Praks



E. Colin

Normalized Coherency Matrix

$$N_3 = \langle k^{T*} \cdot k \rangle^{-1}$$

$$H \approx 2.52 + 0.78 \log_3 \left(\left| N_3 + 0.16 \, I_{D3} \right| \right)$$

ENTROPY

J. Morio

P. Réfrégier

L. Ferro-Famil & E. Pottier

SHANNON POLARIMETRIC ENTROPY (2006)

$$SE = \log\left(\pi^3 e^3 |T_3|\right) = SE_I + SE_P$$

$$SE_I = 3\log\left(\frac{\pi \; e \; I_T}{3}\right) = 3\log\left(\frac{\pi \; e \; \mathbf{Tr}\left(T_3\right)}{3}\right)$$

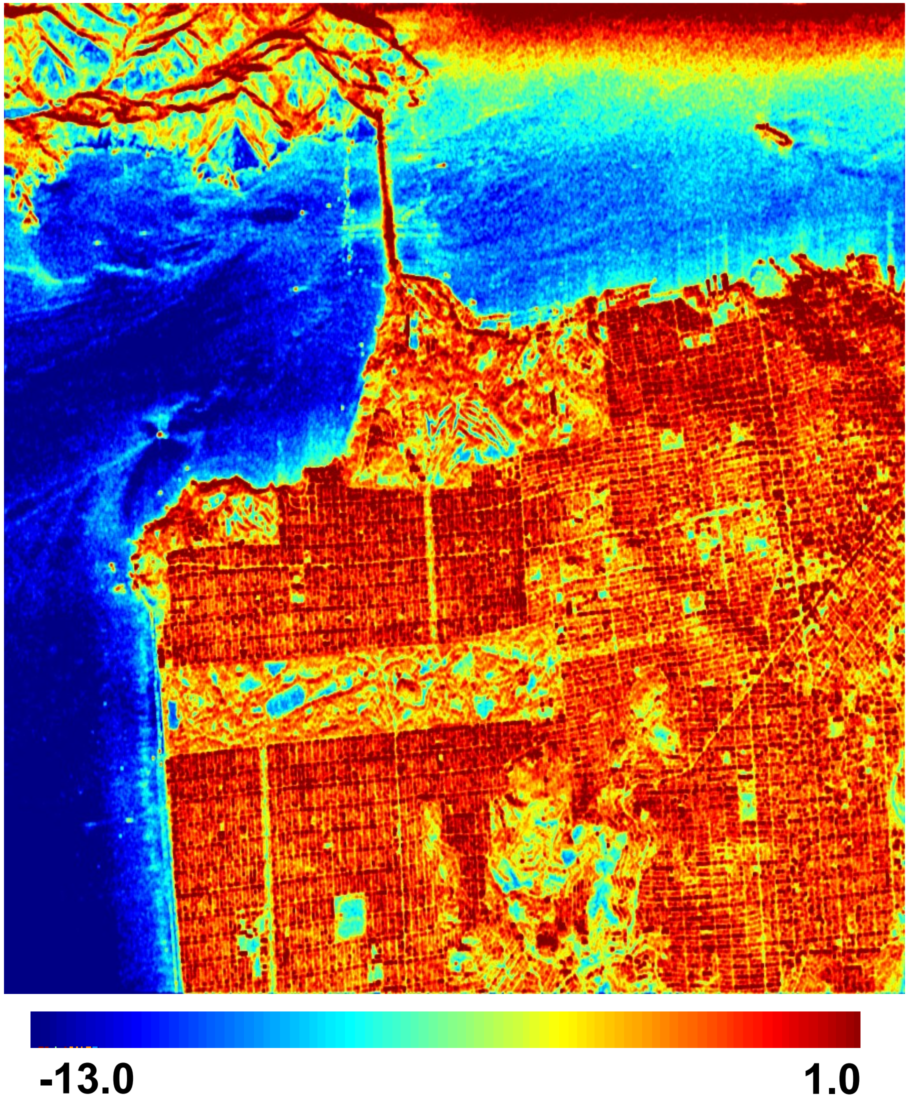
INTENSITY

$$SE_P = \log\left(1 - p_T^2\right) = \log\left(27 \frac{|T_3|}{\mathbf{Tr}\left(T_3\right)^3}\right)$$

DEGREE OF POLARIZATION

EIGENVALUE-BASED PARAMETERS

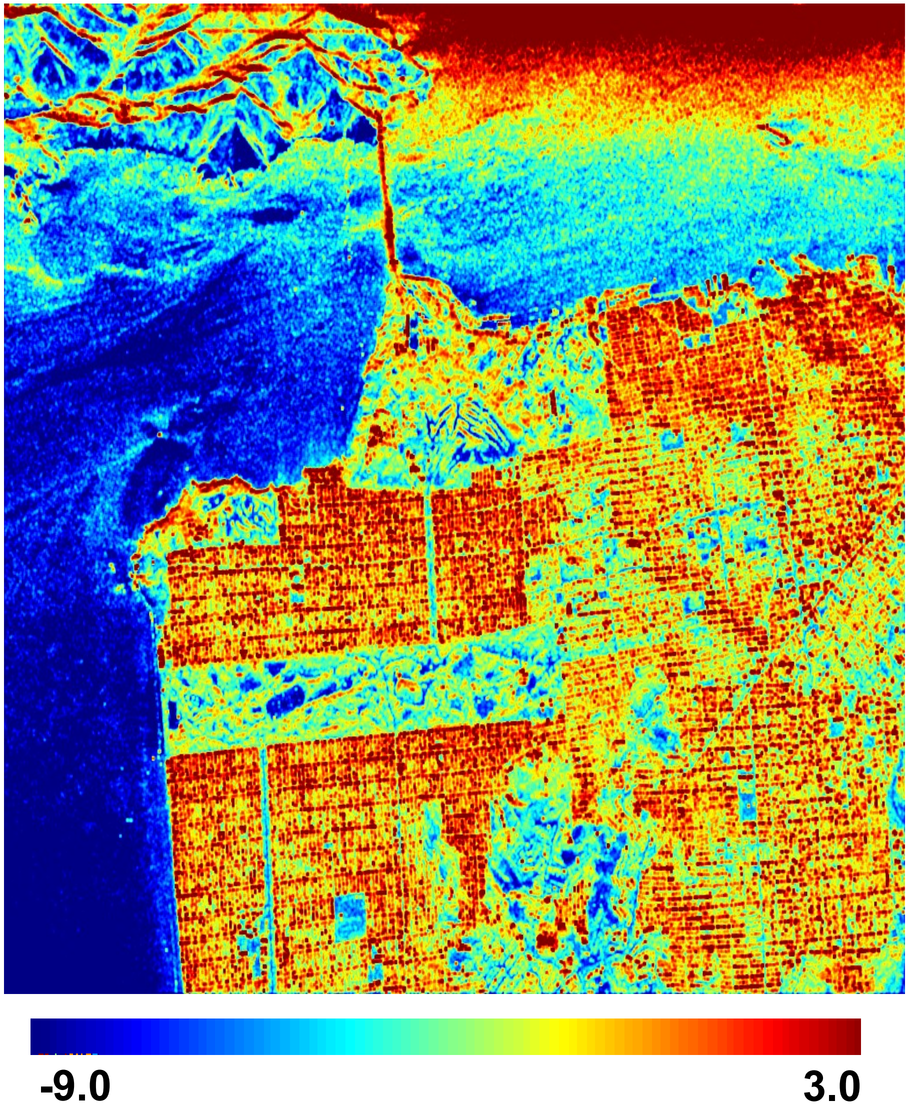
$2A_0$ B_0+B B_0-B



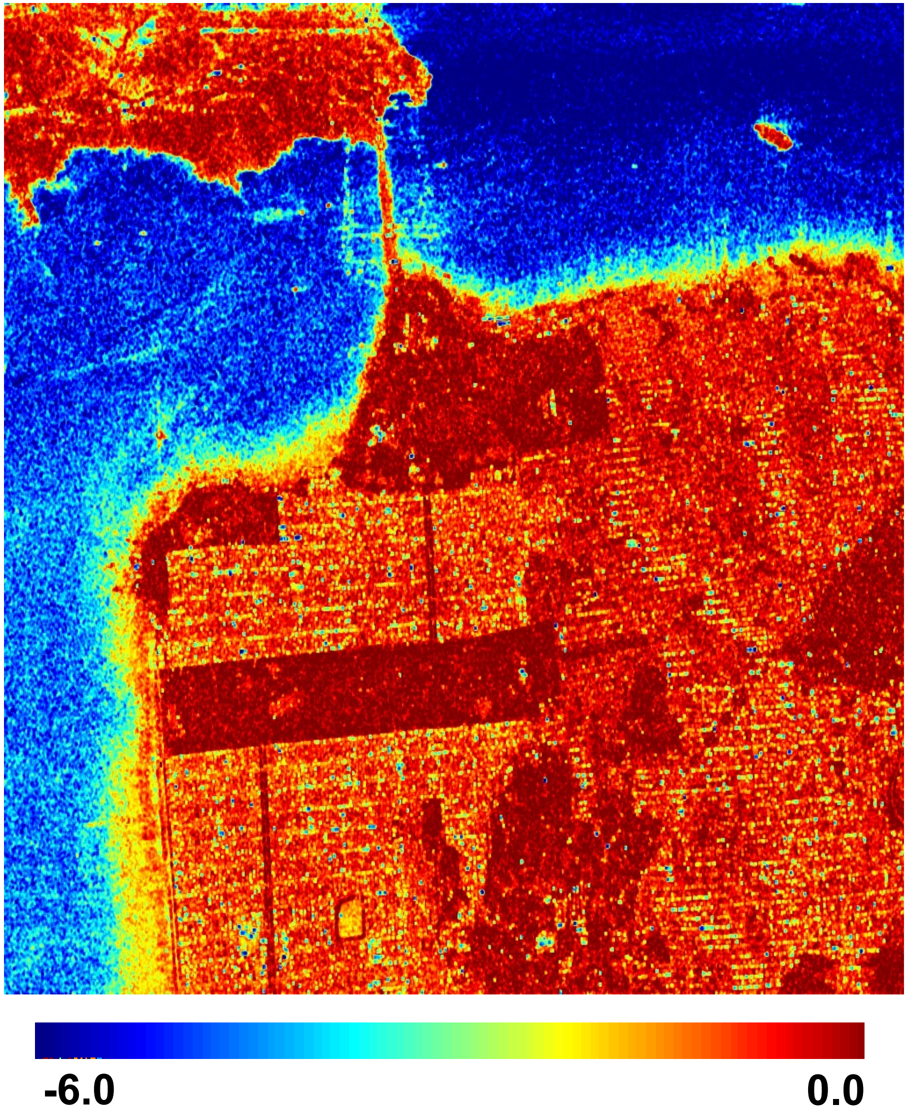
SHANNON ENTROPY (SE-norm)

L. Ferro-Famil & E. Pottier

EIGENVALUE-BASED PARAMETERS



SHANNON ENTROPY (SE-I)



SHANNON ENTROPY (SE-P)

H / A / $\underline{\alpha}$ DECOMPOSITION

ENTROPY

$$H = -\sum_{i=1}^{3} P_i \log_3\left(P_i\right)$$

$\underline{\alpha}$ PARAMETER

$$\underline{\alpha} = P_1\alpha_1 + P_2\alpha_2 + P_3\alpha_3$$

ANISOTROPY

$$A = \frac{\lambda_2 - \lambda_3}{\lambda_2 + \lambda_3}$$

3 ROLL INVARIANT PARAMETERS

$$\underline{I} = \begin{bmatrix} \underline{\alpha} \\ H/A \\ H/\left(1-A\right) \\ \left(1-H\right)/A \\ \left(1-H\right)/\left(1-A\right) \end{bmatrix}$$

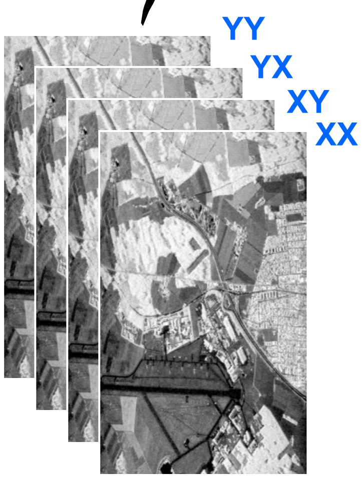
→ **PHYSICAL SCATTERING MECHANISM**

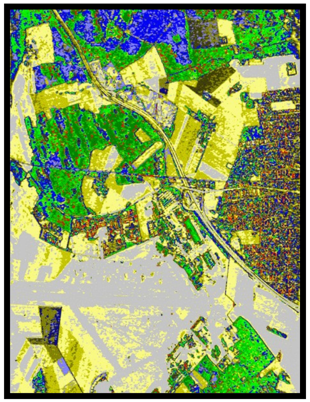
→ **TYPE OF SCATTERING PROCESS**

SEGMENTATION / CLASSIFICATION

POLARIMETRIC REMOTE SENSING

POL-SAR PROCESSING
PHENOMENOLOGIC
QUALITATIVE ANALYSIS

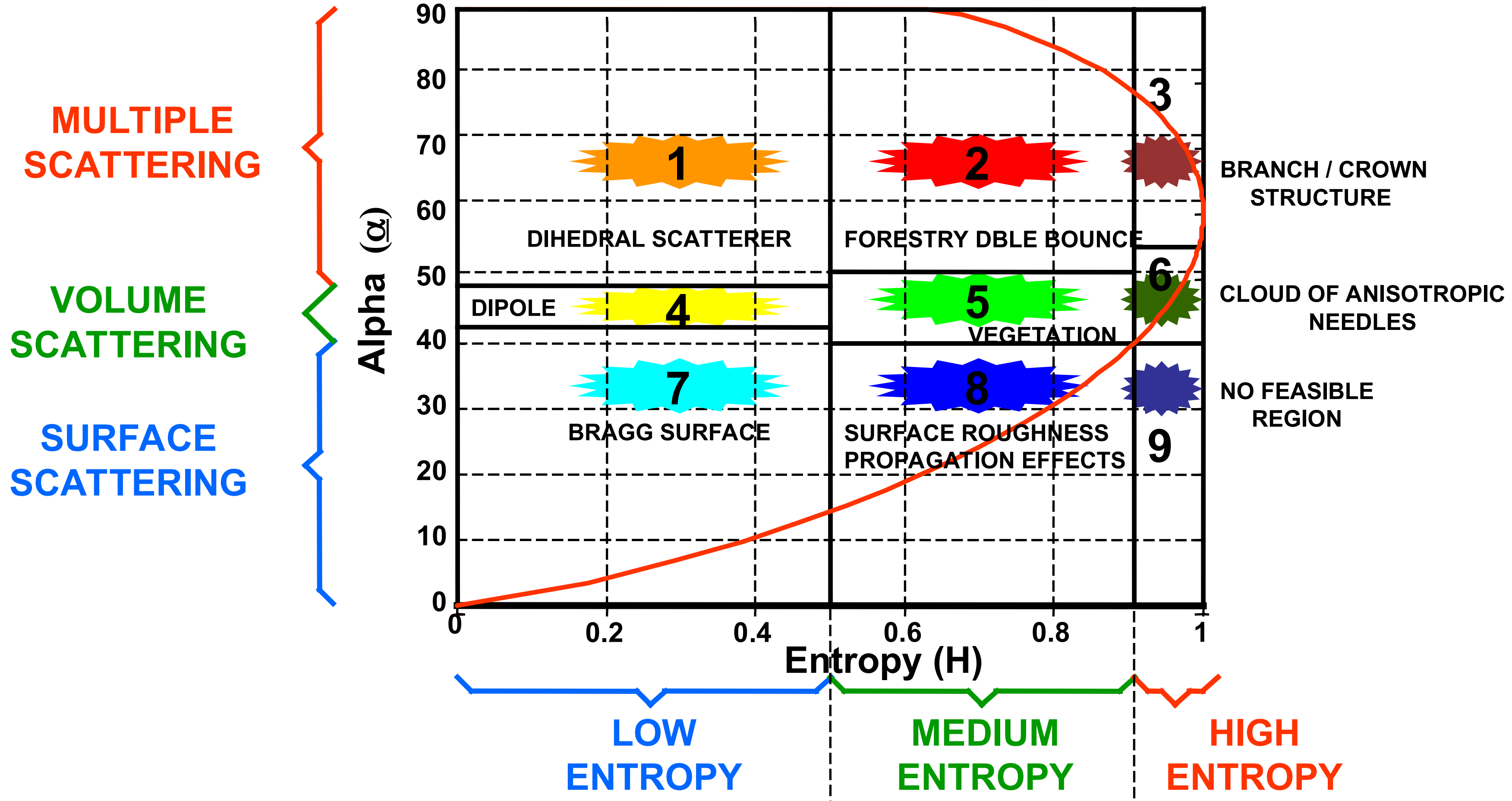




POLARIMETRIC SPECKLE FILTERING → **POLARIMETRIC TARGET DECOMPOSITION** → **POLARIMETRIC CLASSIFICATION**
MONO/DUAL CHANNELS

H / $\underline{\alpha}$ CLASSIFICATION

SEGMENTATION OF THE H / $\underline{\alpha}$ SPACE

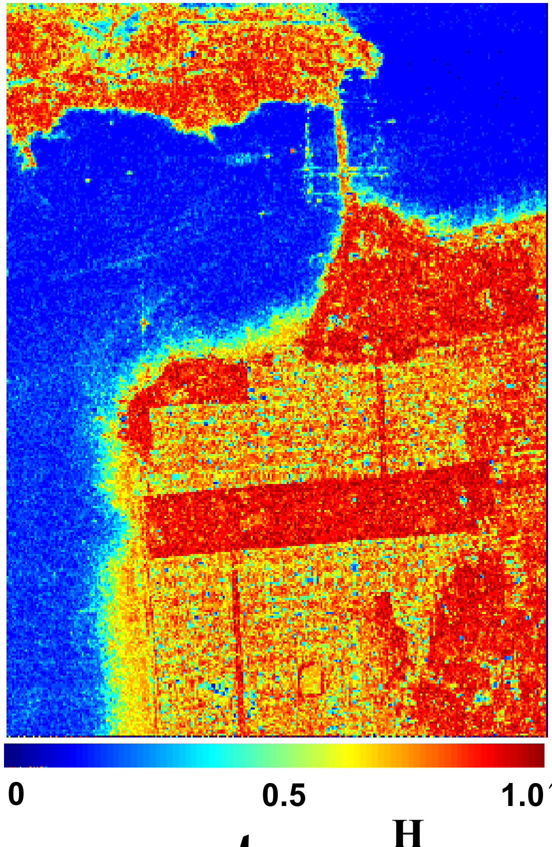


PERTURBATION OF 1st ORDER SCATTERING THEORIES DUE TO 2nd ORDER EVENTS

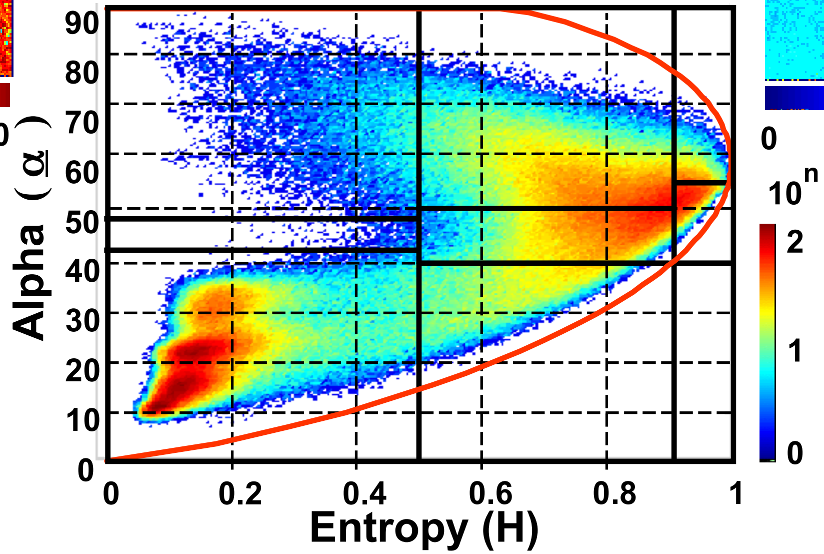
DEGREE OF ARBITRARINESS (SCATTERING PROCESSES RANDOM NOISE

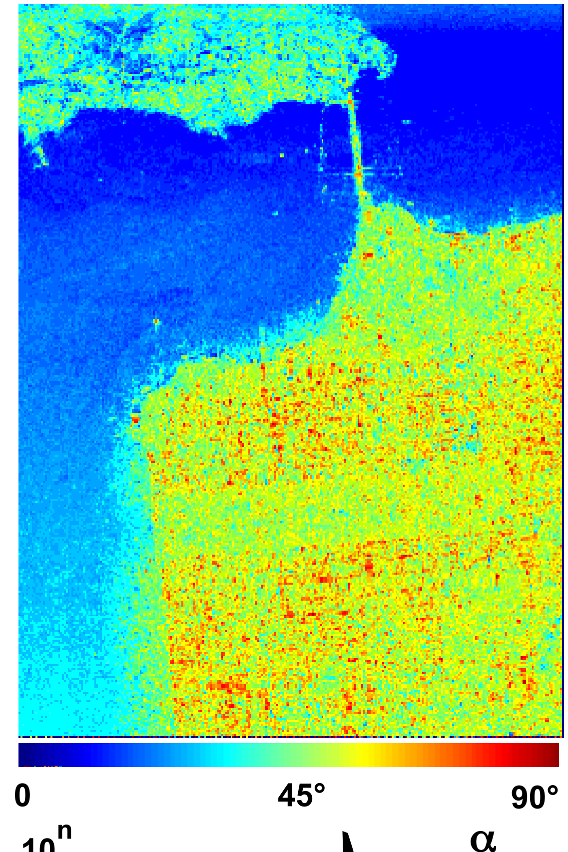
L. Ferro-Famil & E. Pottier

H / α CLASSIFICATION



POLSAR DATA DISTRIBUTION IN THE H / α PLANE



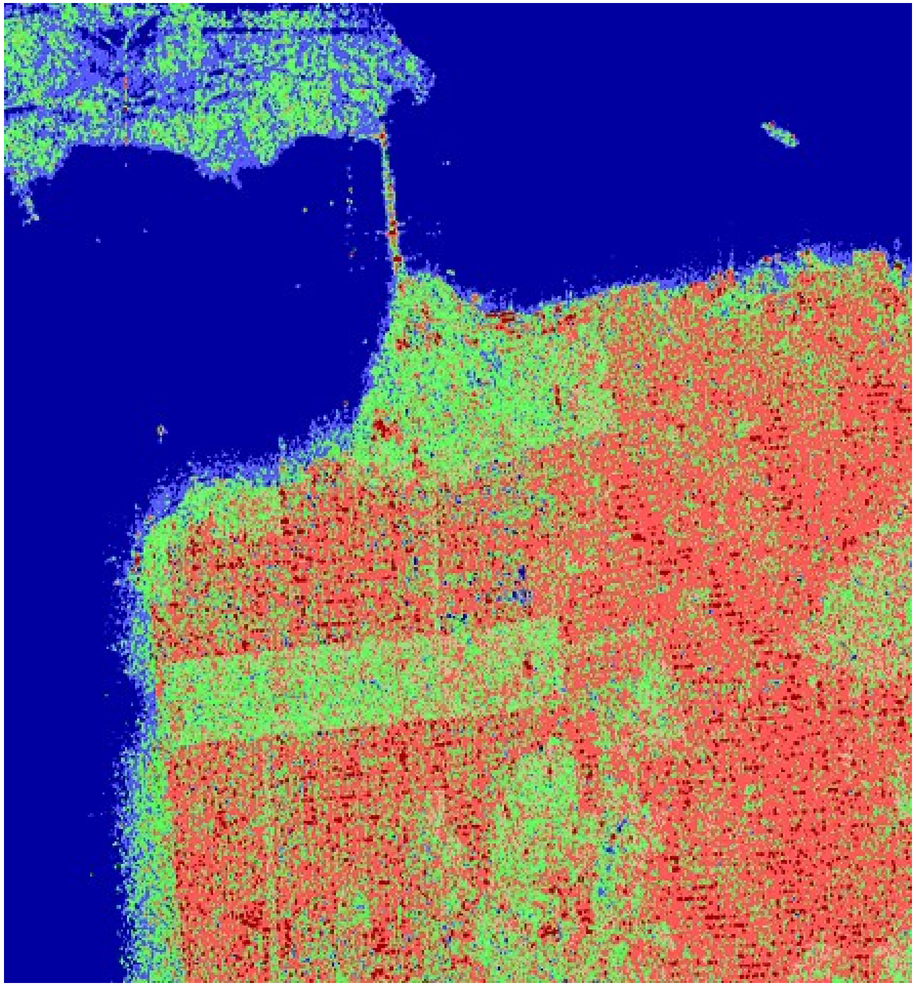


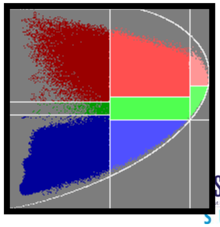
L. Ferro-Famil & E. Pottier

H / α CLASSIFICATION

$2A_0$ $\quad B_0+B$ $\quad B_0-B$

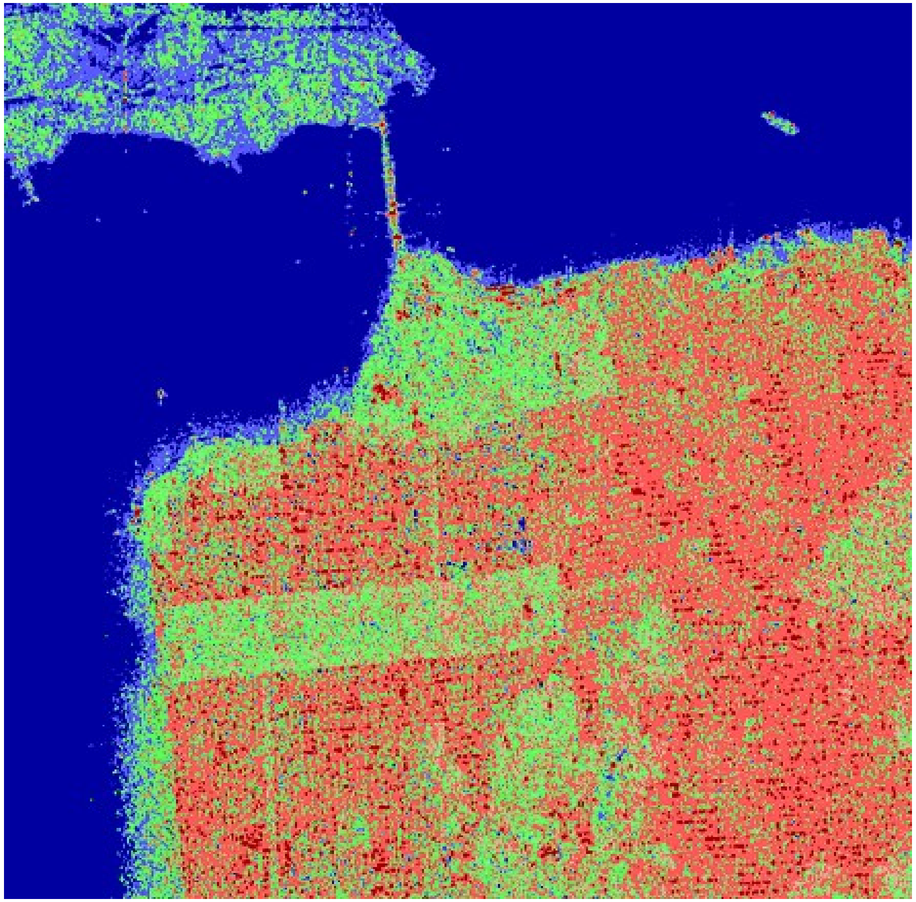
H - α classification

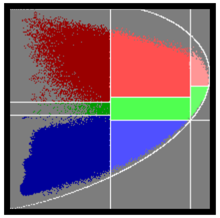




H / α CLASSIFICATION

H-α classification





H / α Classification Space
Sub-divised into 9 basic zones

⬇

Location of the boundaries is arbitrary and generically

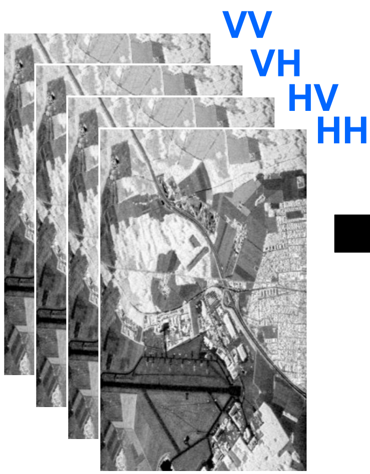
Degree of arbitrariness on the setting of these boundaries

⬇

Segmentation is offered merely to illustrate the unsupervised classification strategy and to emphasize the geometrical segmentation of physical scattering processes

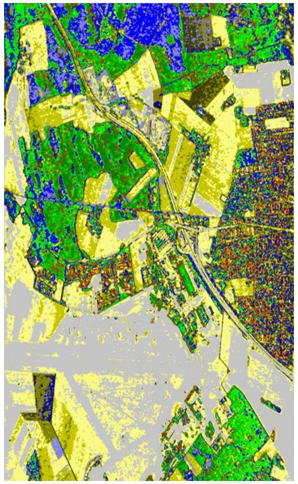
WISHART PDF

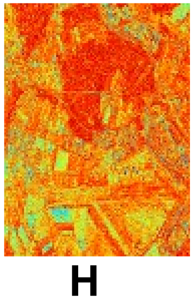
$$P\left(\langle[T]\rangle/[T_m]\right)=\frac{L^{Lp}\,|\langle[T]\rangle|^{L-p}\,e^{-L\,Tr\left([T_m]^{-1}\langle[T]\rangle\right)}}{\pi^{\frac{p(p-1)}{2}}\,\Gamma(L)\ldots\Gamma(L-p+1)\,|[T_m]|^{L}}$$

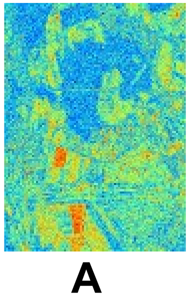


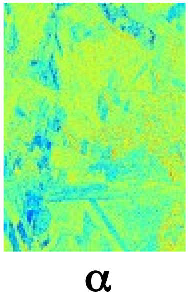
UNSUPERVISED POLSAR CLASSIFICATION

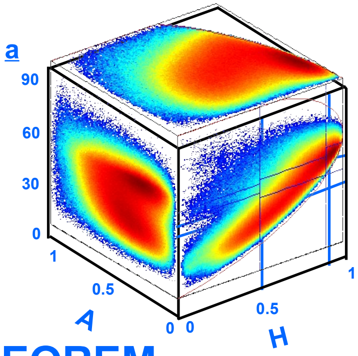
E.POTTIER, J.S LEE (2000)











H / A / a DECOMPOSITION THEOREM

WISHART CLASSIFIER

Target Vector

$$\underline{X} = \begin{bmatrix} S_{HH} & \sqrt{2}\,S_{HV} & S_{VV} \end{bmatrix}^T \qquad P(X) = \frac{1}{\pi^3 \left|[C]\right|} e^{-X^T [C]^{-1} X}$$

$$\underline{k} = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} + S_{VV} & S_{HH} - S_{VV} & 2\,S_{HV} \end{bmatrix}^T \qquad P(k) = \frac{1}{\pi^3 \left|[T]\right|} e^{-k^T [T]^{-1} k}$$

Coherency Matrix

$$\langle [T] \rangle = \frac{1}{N} \sum_{i=1}^{N} \underline{k}_i \cdot \underline{k}_i^T = \frac{1}{N} \sum_{i=1}^{N} [T_i]$$

$$P\left(\langle [T] \rangle / [T_m]\right) = \frac{L^{Lp} \left|\langle [T] \rangle\right|^{L-p} e^{-L\ Tr\left([T_m]^{-1} \langle [T] \rangle\right)}}{\pi^{\frac{p(p-1)}{2}}\ \Gamma(L) \ldots \Gamma(L-p+1) \left|[T_m]\right|^L}$$

COMPLEX WISHART DISTRIBUTION

L: Number of Look p: Polarimetric Dimension

H / α - WISHART CLASSIFIER

k - mean CLASSIFICATION PROCEDURE

PROVIDE INITIAL $[T_m]^{(0)}$ FOR EACH CLASS

↓

CLASSIFY THE WHOLE IMAGE WITH THE DISTANCE PROCEDURE

$$\langle[T]\rangle \in [T_m] \text{ if } \; d_m(\langle[T]\rangle) < d_j(\langle[T]\rangle) \; \forall \; j \neq m$$

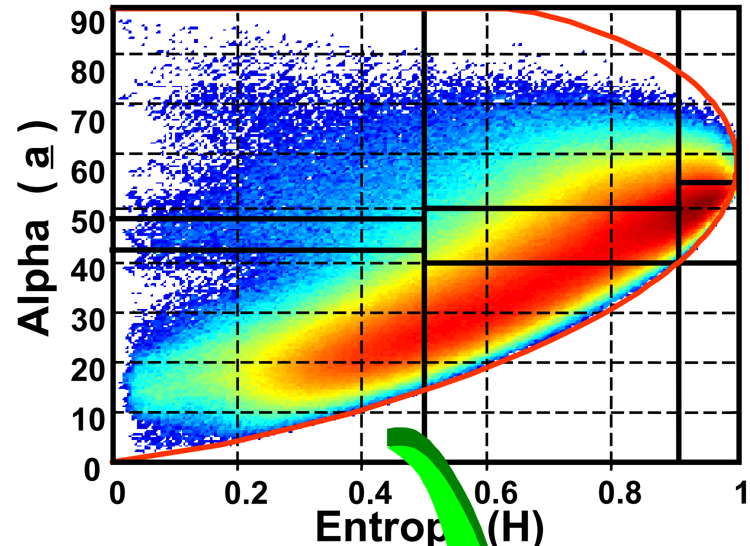
↓

COMPUTE $[T_m]^{(k+1)}$ FOR EACH CLASS USING THE CLASSIFIED PIXELS OF STEP 2

$$[T_m]^{(k+1)} = \frac{1}{N_m} \sum_{j=1}^{j=N_m} \langle[T]\rangle_j$$

↓

TERMINAISON CRITERION ? (no → back to step 2; yes → end)



$$[T_m]^{(0)} = \frac{1}{N_m} \sum_{k=1}^{k=N_m} \langle[T]\rangle_k$$

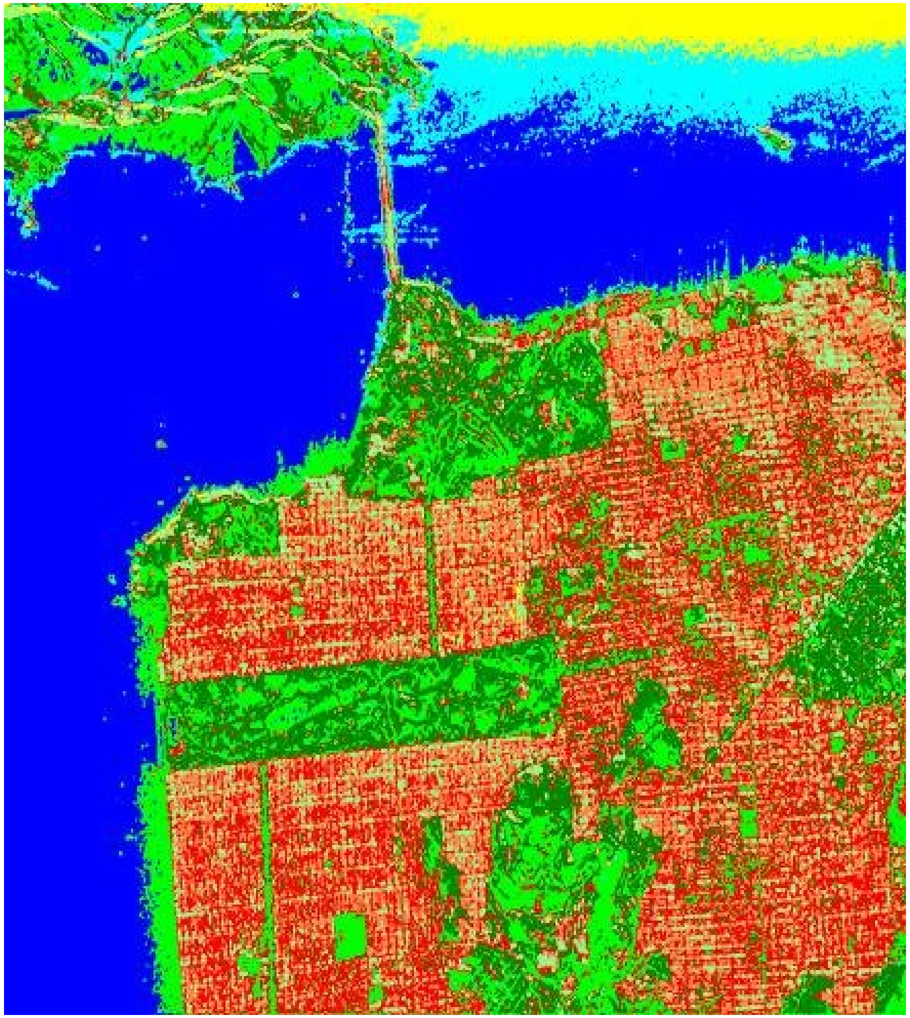
Cluster Center of the class *m*
(Lee 1998)

H / $\underline{\alpha}$ - WISHART CLASSIFIER

SAN FRANCISCO BAY JPL - AIRSAR L-band 1988

$2A_0$ $B_0 + B$ $B_0 - B$

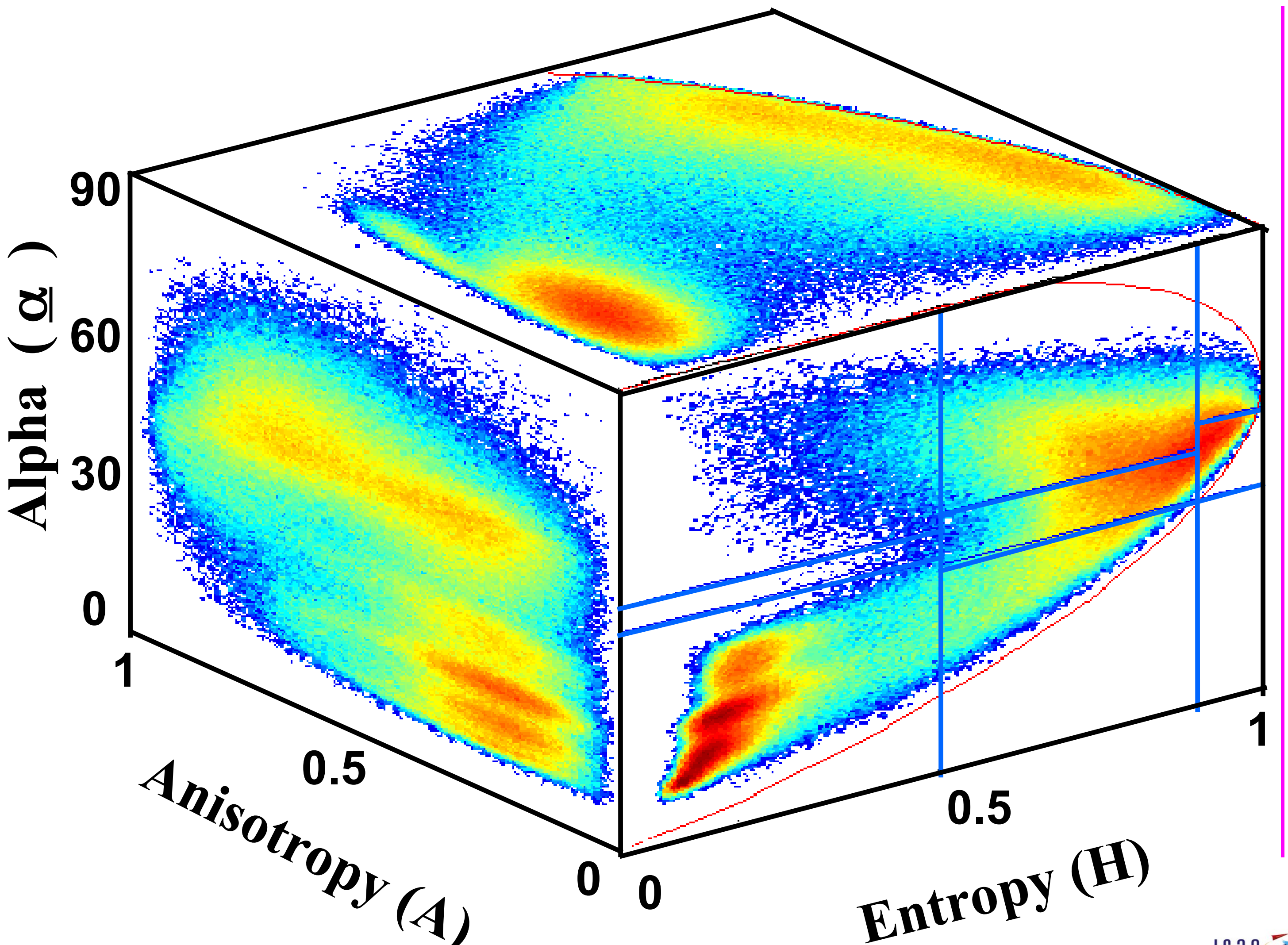
4th ITERATION



C1 C2 C3 C4 C5 C6 C7 C8

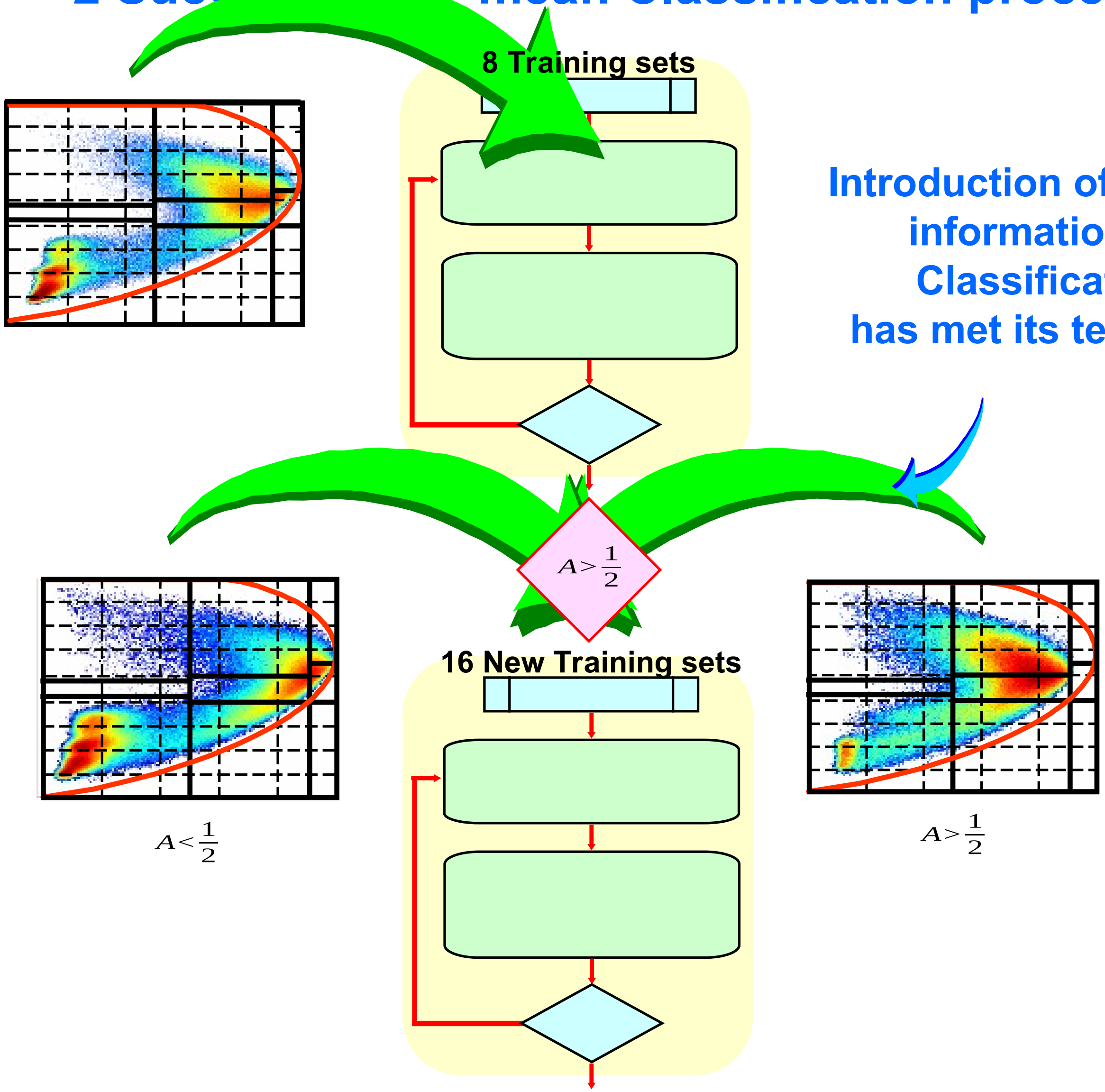
H / A / $\underline{\alpha}$ - WISHART CLASSIFIER

POLSAR DATA DISTRIBUTION IN THE H / A / $\underline{\alpha}$ SPACE



H / A / $\underline{\alpha}$ - WISHART CLASSIFIER

2 Successive k - mean Classification procedures



Introduction of the Anisotropy (A) information once the first Classification procedure has met its termination criterion

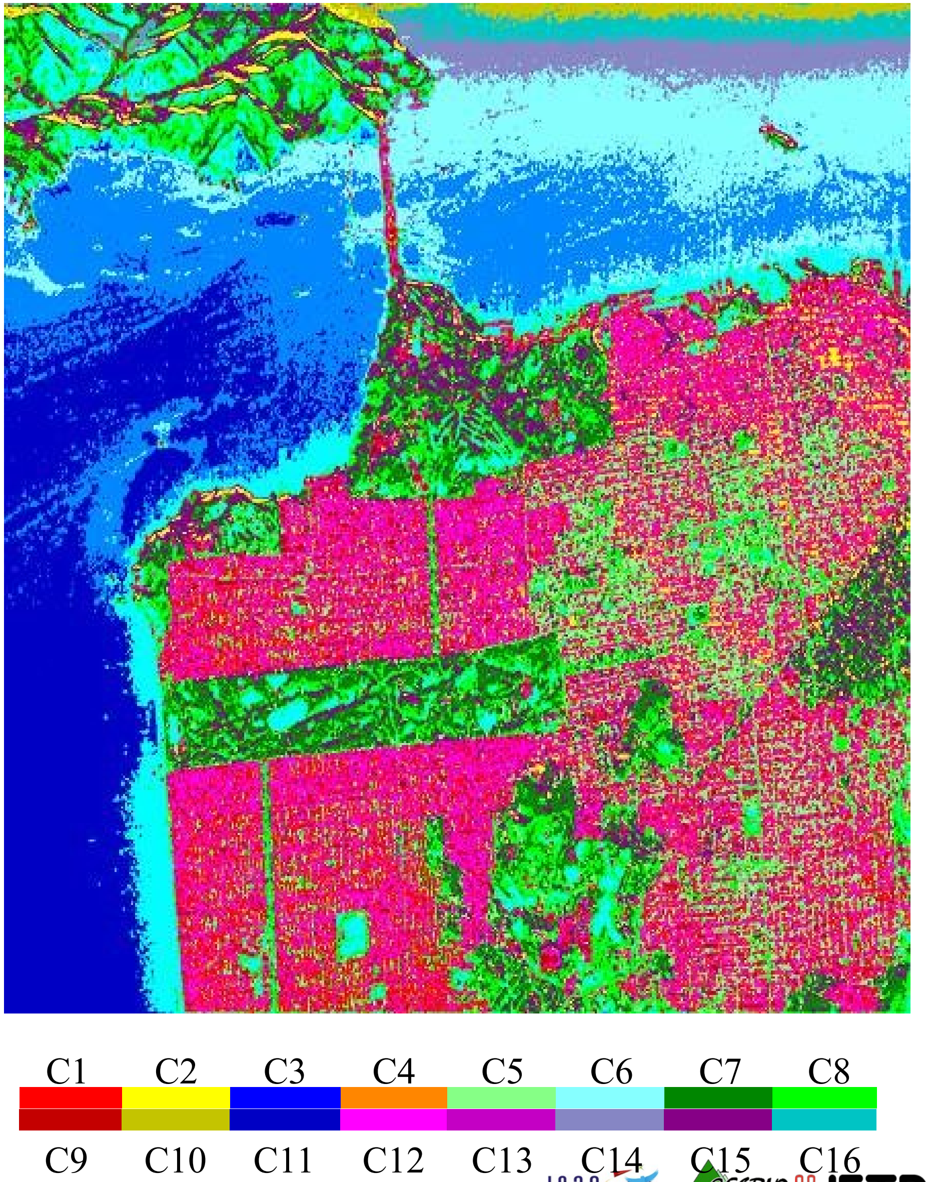
L. Ferro-Famil & E. Pottier

H / A / $\underline{\alpha}$ - WISHART CLASSIFIER

SAN FRANCISCO BAY JPL - AIRSAR L-band 1988

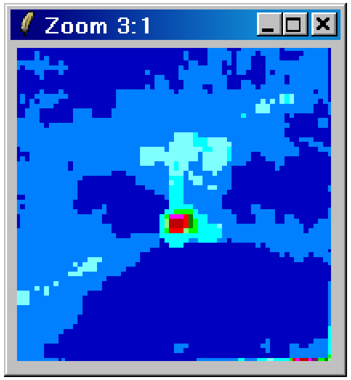
$2A_0$ B_0+B B_0-B

4th ITERATION

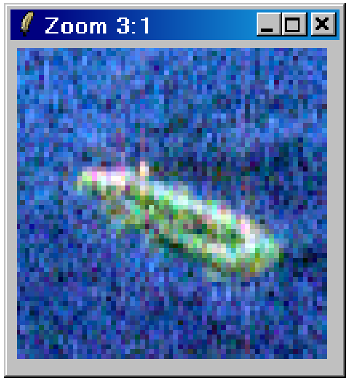


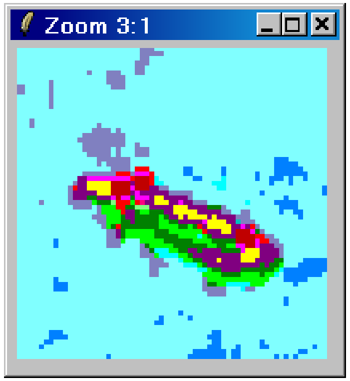
L. Ferro-Famil & E. Pottier

H / A / $\underline{\alpha}$ - WISHART CLASSIFIER



SAN FRANCISCO BAY JPL - AIRSAR L-band 1988

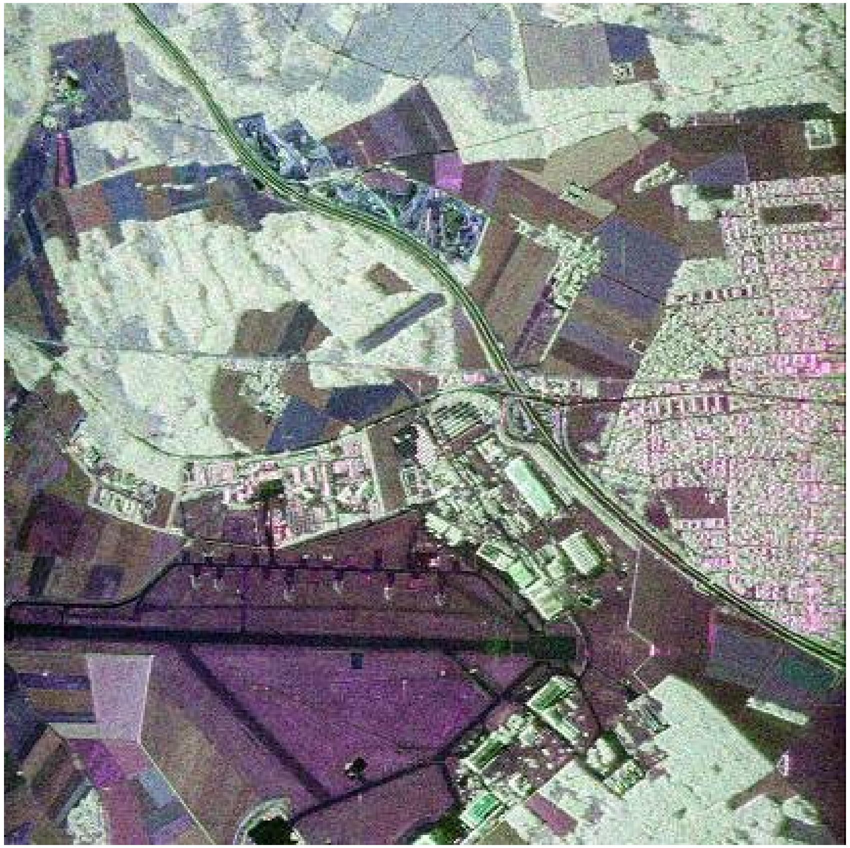




$2A_0$ B_0+B B_0-B

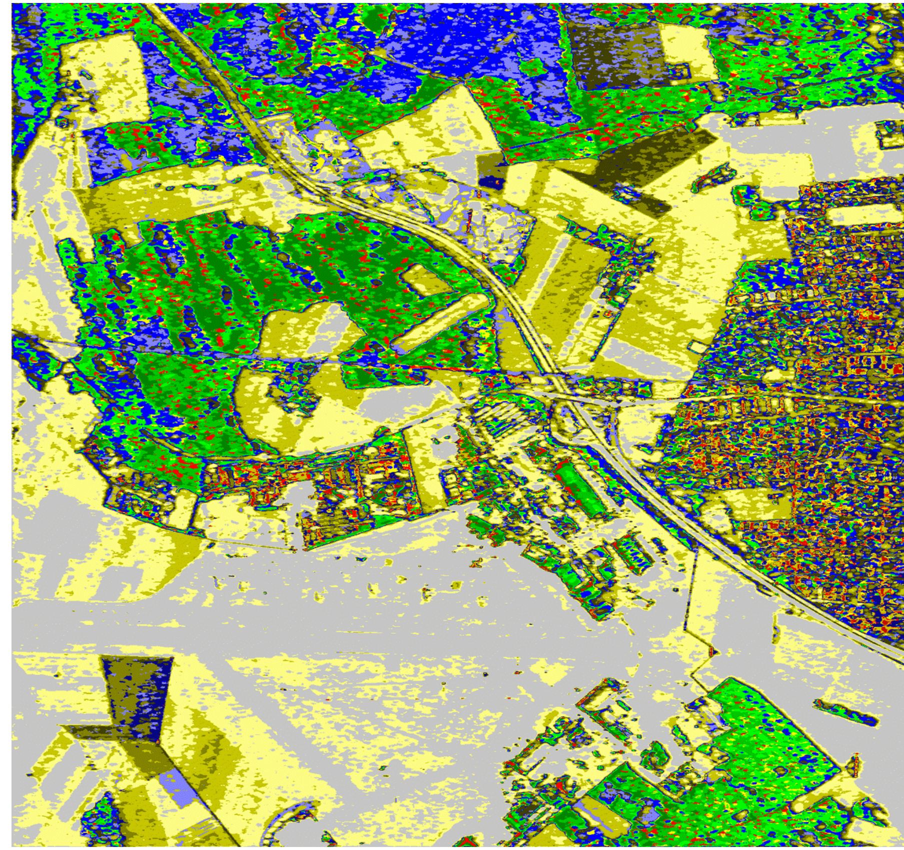
H / A / α - WISHART CLASSIFIER

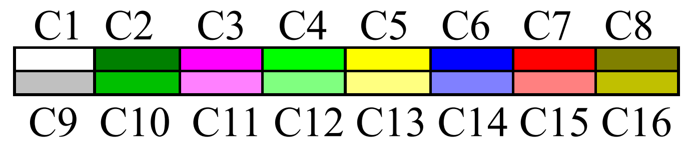
OBERPFAFFENHOFEN - ESAR L-band



$2A_0$ B_0+B B_0-B

H / A / α and WISHART CLASSIFIER

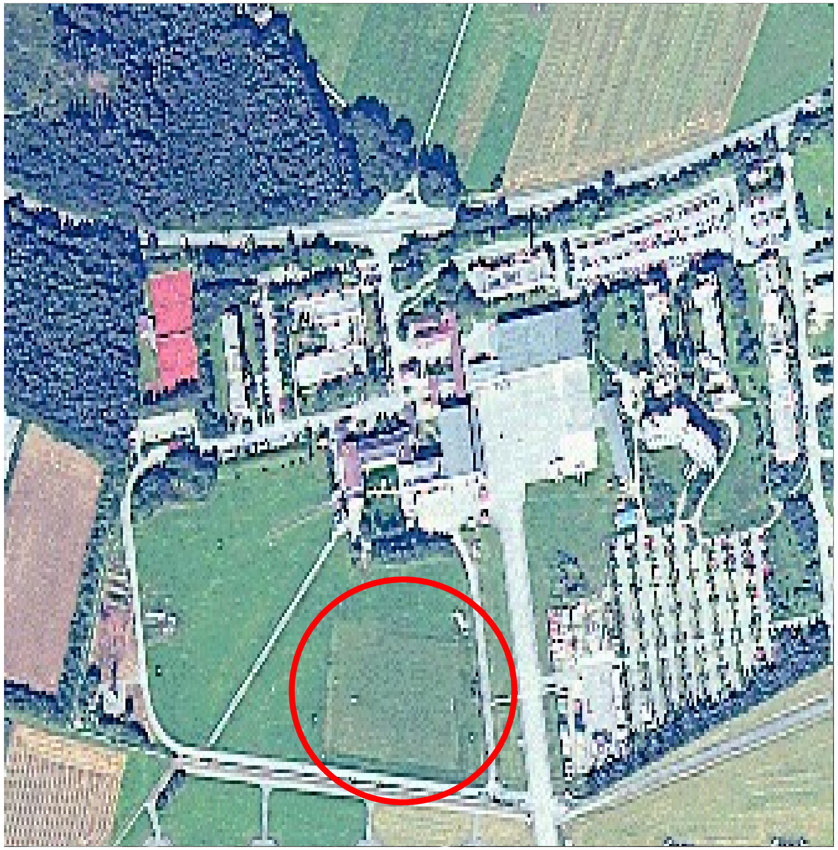




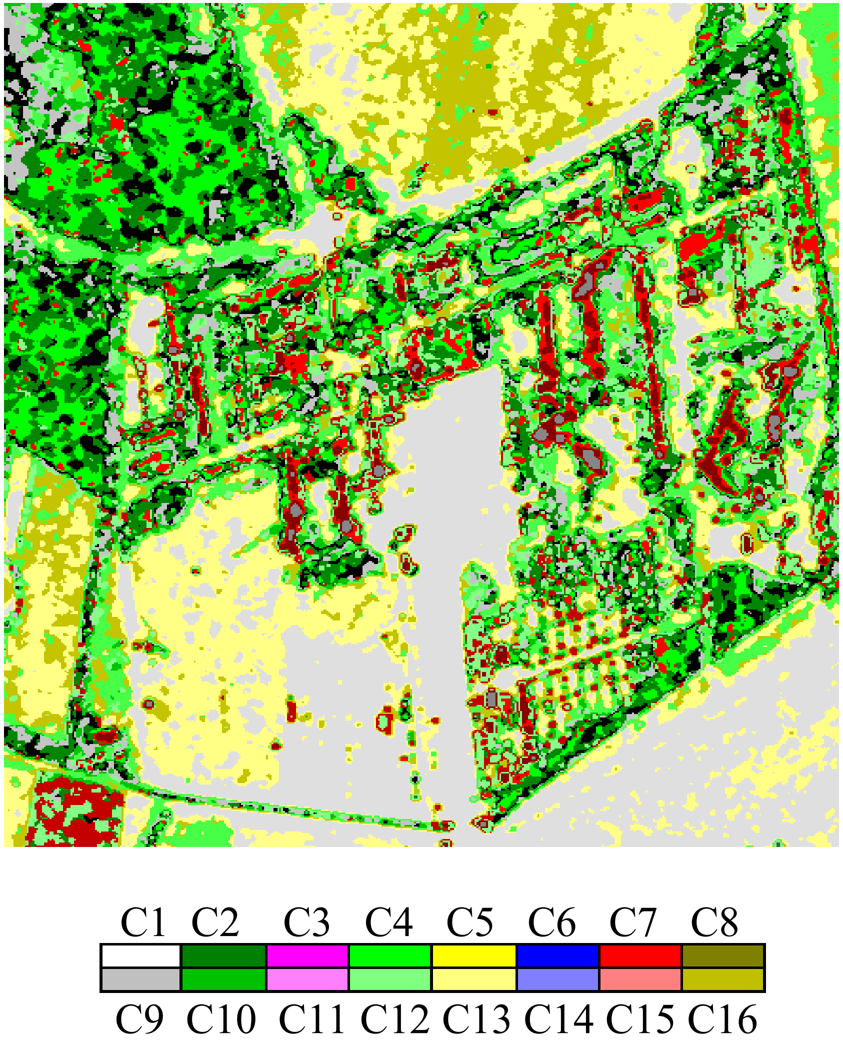
L. Ferro-Famil & E. Pottier

H / A / $\underline{\alpha}$ - WISHART CLASSIFIER

OBERPFAFFENHOFEN - ESAR L-band

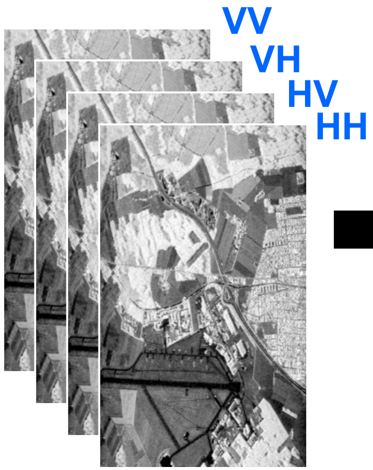


H / A / $\underline{\alpha}$ and WISHART CLASSIFIER



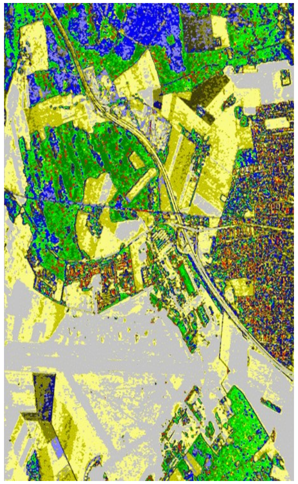
WISHART PDF

$$P\left(\langle[T]\rangle / [T_m]\right) = \frac{L^{Lp}\, |\langle[T]\rangle|^{L-p}\, e^{-L\, Tr\left([T_m]^{-1}\langle[T]\rangle\right)}}{\pi^{\frac{p(p-1)}{2}}\, \Gamma(L) \ldots \Gamma(L-p+1)\, |[T_m]|^{L}}$$



UNSUPERVISED POLSAR CLASSIFICATION

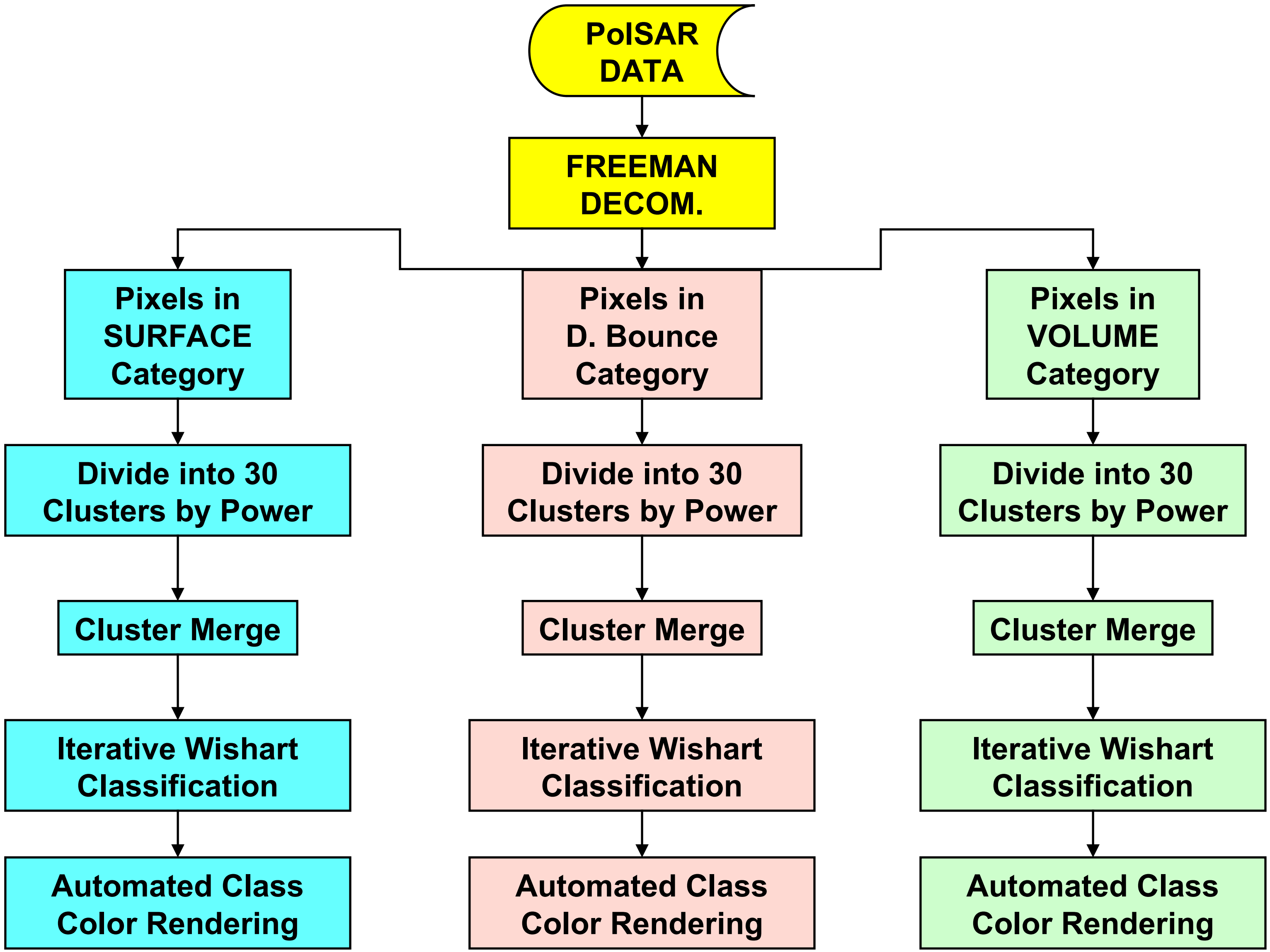
E.POTTIER, J.S LEE (2000)



Unsupervised Classification Preserving Scattering Mechanisms

J.S. Lee, M.R. Grunes, E. Pottier and L. Ferro-Famil, "Segmentation of polarimetric SAR images that preserves scattering mechanisms" Proceedings of EUSAR2002

PROCEDURE – FLOW CHART



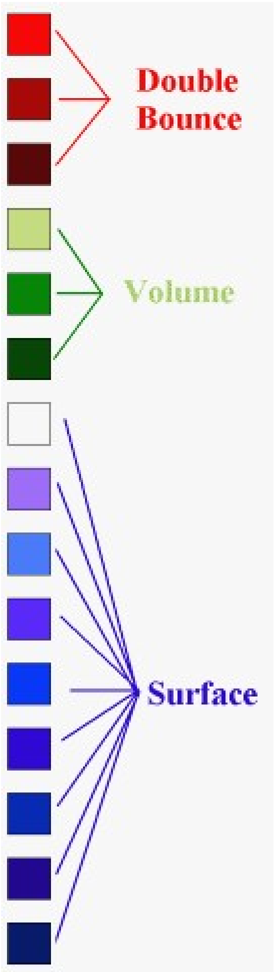
Cluster Merging $D_{ij} = \frac{1}{2}\left\{ \ln\left(|V_i|\right) + \ln\left(|V_j|\right) + Tr\left(V_i^{-1} V_j + V_j^{-1} V_i\right) \right\}$

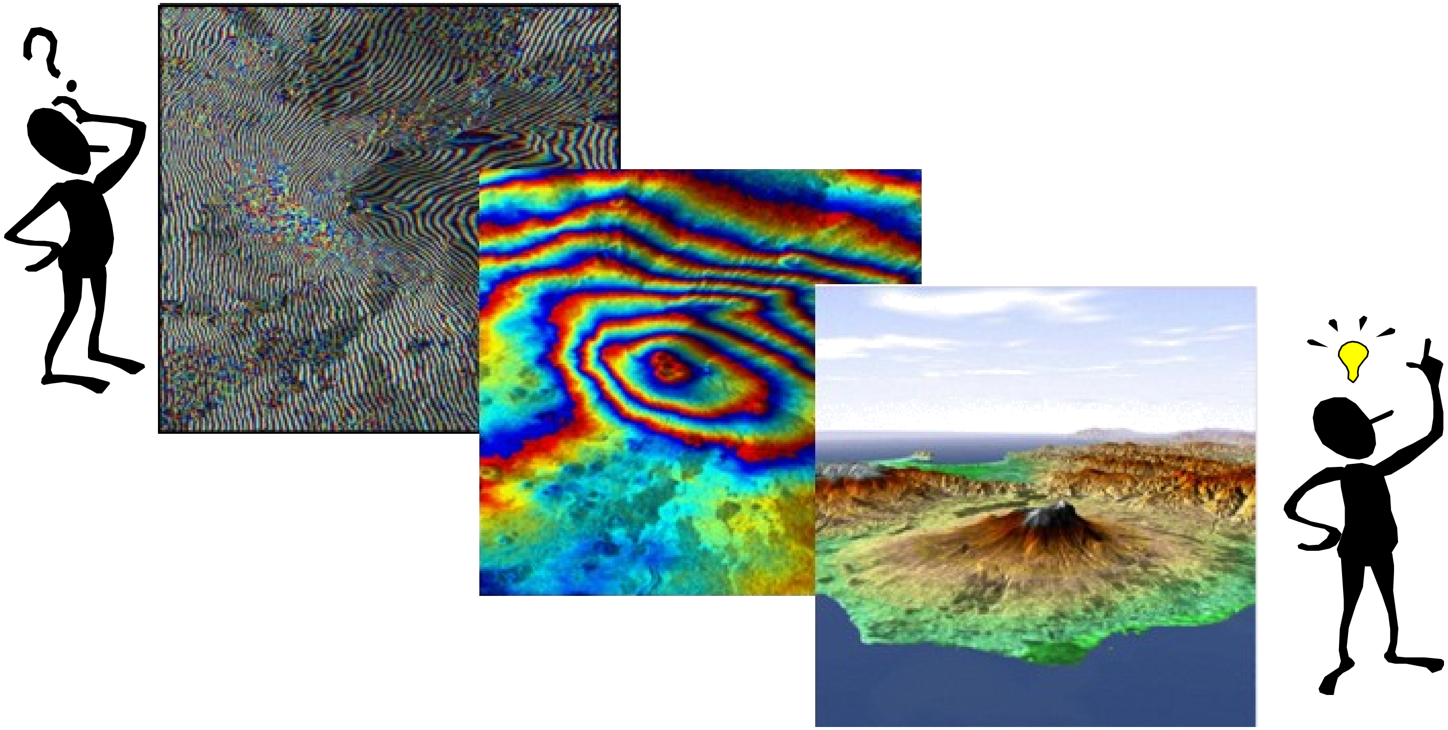
FREEMAN - WISHART CLASSIFIER

Courtesy of Dr J.S Lee

|HH-VV|, |HV|, |HH+VV|

4th Iteration (15 classes)

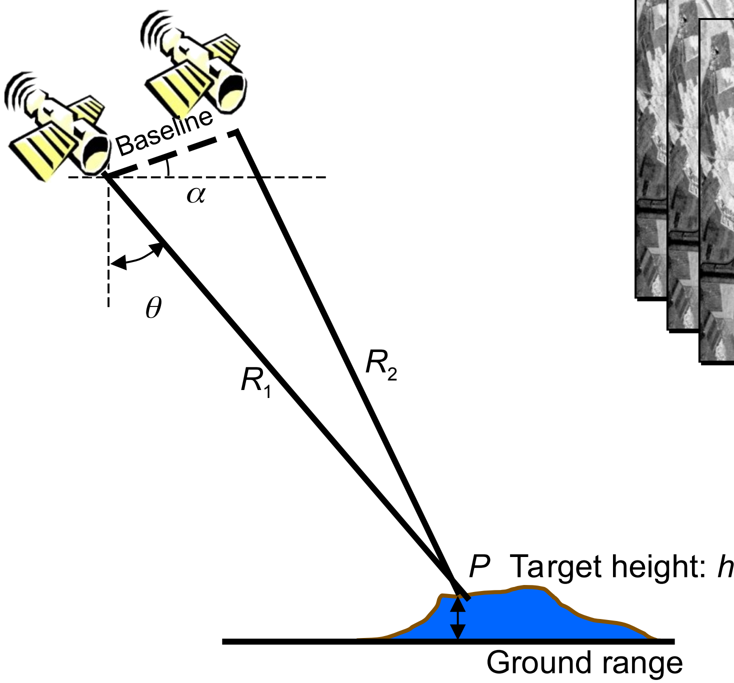


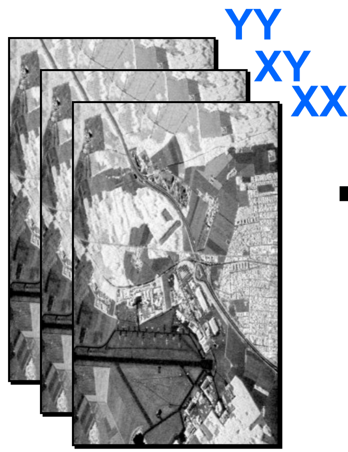


POLARIMETRIC INTERFEROMETRIC SAR POL-InSAR

L. Ferro-Famil & E. Pottier

POL-InSAR





$$\underline{k}_1 = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{XX_1} + S_{YY_1} \\ S_{XX_1} - S_{YY_1} \\ 2S_{XY_1} \end{bmatrix}$$

$$\underline{\underline{k}} = \begin{bmatrix} \underline{k}_1 \\ \underline{k}_2 \end{bmatrix}$$

POLARIMETRIC INTERFEROMETRIC TARGET VECTOR

$$\underline{k}_2 = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{XX_2} + S_{YY_2} \\ S_{XX_2} - S_{YY_2} \\ 2S_{XY_2} \end{bmatrix}$$

POL-InSAR

$$\underline{\underline{k}} = \begin{bmatrix} \underline{k}_1 \\ \underline{k}_2 \end{bmatrix}$$

POLARIMETRIC INTERFEROMETRIC TARGET VECTOR

$$\langle [T_6] \rangle = \langle \underline{\underline{k}} \cdot \underline{\underline{k}}^{T*} \rangle = \begin{bmatrix} \langle \underline{k}_1 \cdot \underline{k}_1^{T*} \rangle & \langle \underline{k}_1 \cdot \underline{k}_2^{T*} \rangle \\ \langle \underline{k}_2 \cdot \underline{k}_1^{T*} \rangle & \langle \underline{k}_2 \cdot \underline{k}_2^{T*} \rangle \end{bmatrix} = \begin{bmatrix} \langle [T_1] \rangle & \langle [\Omega_{12}] \rangle \\ \langle [\Omega_{12}]^{T*} \rangle & \langle [T_2] \rangle \end{bmatrix}$$

POLARIMETRIC INTERFEROMETRIC COHERENCY MATRIX (6x6)

$\langle [T_1] \rangle$ **HERMITIAN POLARIMETRIC COHERENCY MATRIX (3x3)**

$\langle [T_2] \rangle$ **HERMITIAN POLARIMETRIC COHERENCY MATRIX (3x3)**

$\langle [\Omega_{12}] \rangle$ **NON HERMITIAN POLARIMETRIC INTER-COHERENCY MATRIX (3x3)**

DUAL CHANNELS POLINSAR UNSUPERVISED SEGMENTATION

$$\langle [T_6] \rangle =$$

POLARIMETRIC INTERFEROMETRIC COHERENCY MATRIX (6x6)

$\langle [T_6] \rangle$ FOLLOWS A WISHART DISTRIBUTION

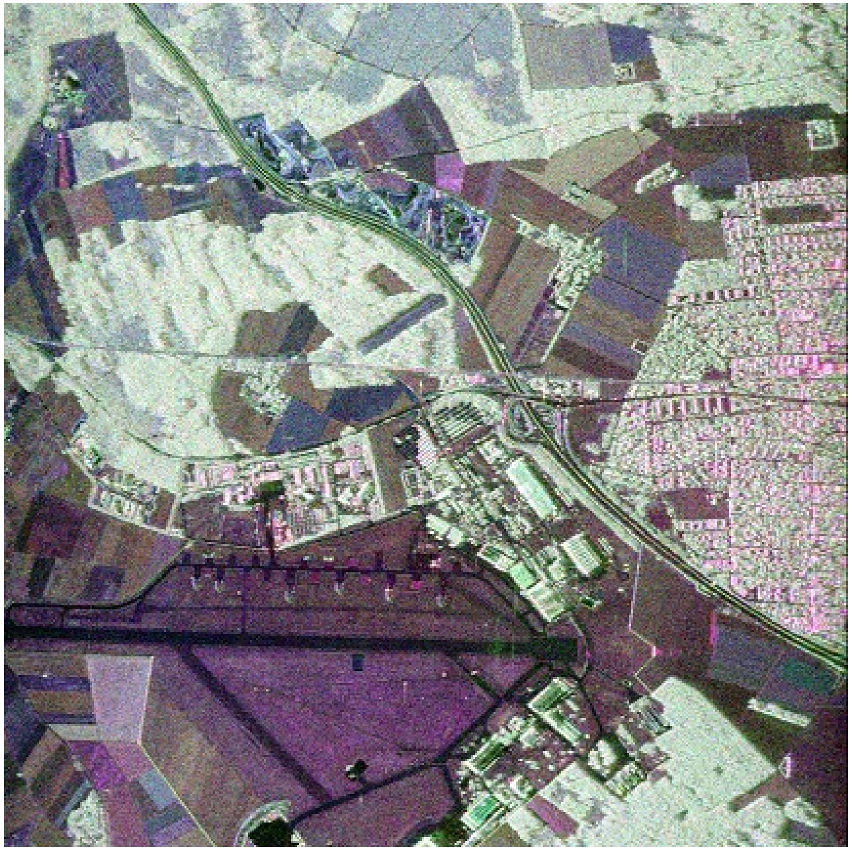
$$P\left(\langle [T_6]\rangle / [\Sigma_m]\right) = \frac{\left|\langle [T_6]\rangle\right|^{L-p} \exp\left(-tr\left([\Sigma_m]^{-1}\langle [T_6]\rangle\right)\right)}{K(L,p)\left|[\Sigma_m]\right|^{L}} = W_C\left(L,[\Sigma_m]\right)$$

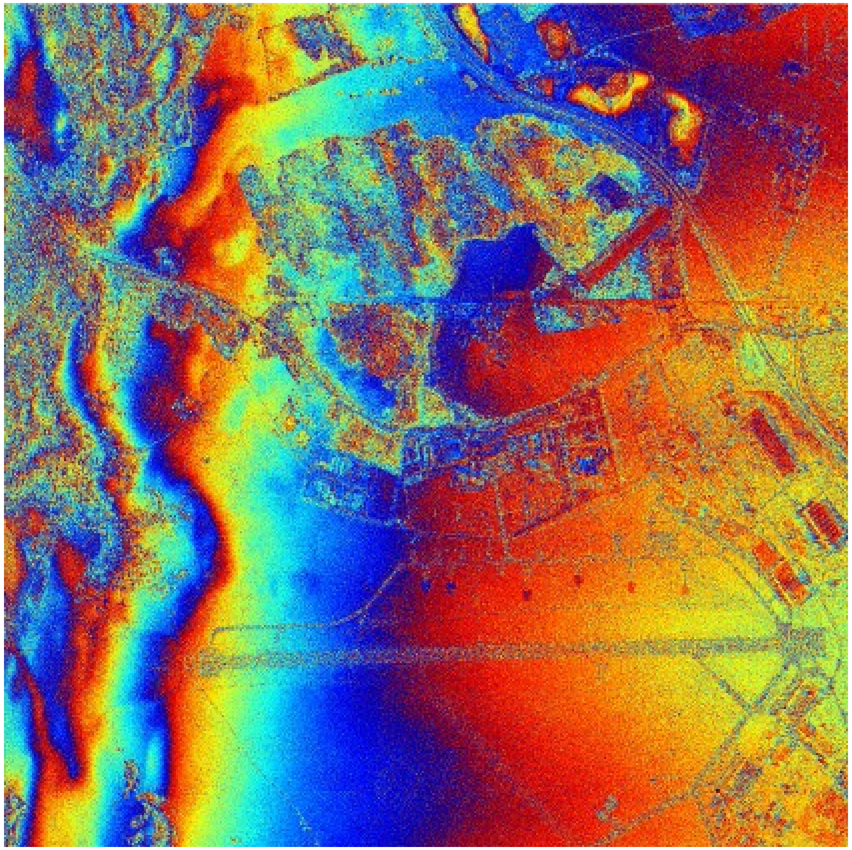
L: Number of Look
p: Polarimetric Dimension

With: $$K(L,p) = \frac{\pi^{\frac{p(p-1)}{2}}}{L^{Lp}} \Gamma(L)\ldots\Gamma(L-p+1)$$

$[\Sigma m]$: Cluster Center of the class *m*

POL-InSAR



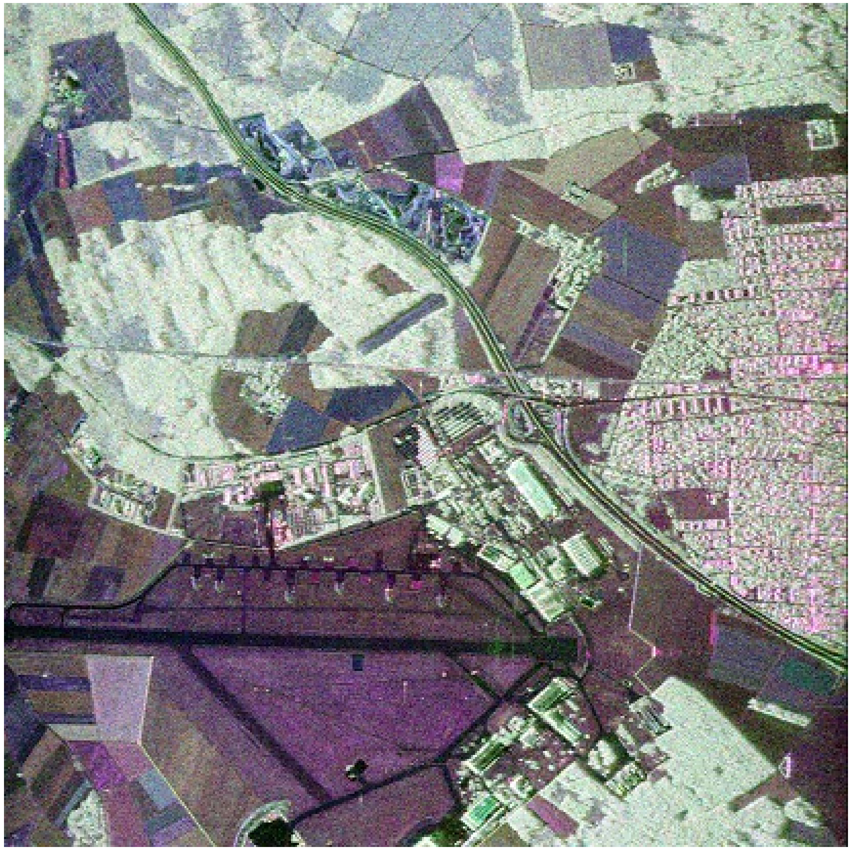


DLR E-SAR L Band
Pol-In SAR (1.5m x 3m) – Baseline 15m

POL-SAR INFORMATION

IN-SAR INFORMATION Arg(γ)

POL-InSAR

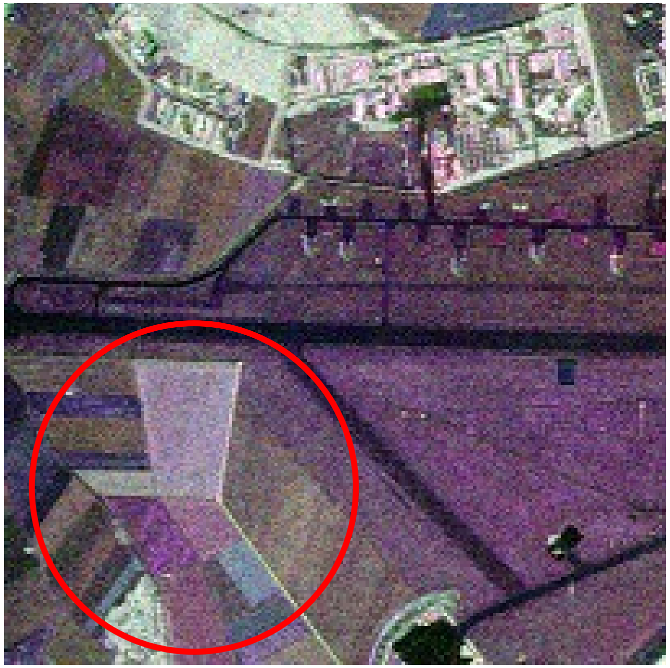


DLR E-SAR L Band
Pol-In SAR (1.5m x 3m) – Baseline 5m

POL-SAR INFORMATION

IN-SAR INFORMATION $|\gamma|$

COMPLEMENTARY INFORMATION



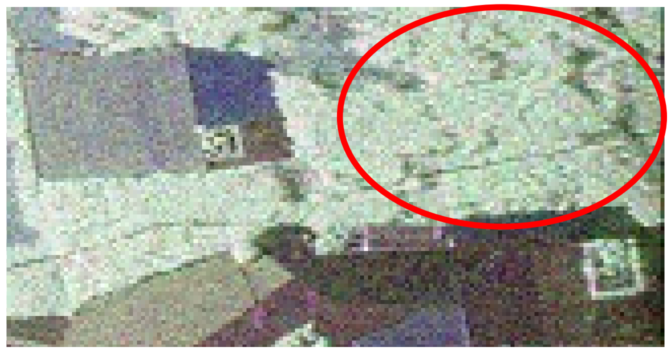
HETEROGENEOUS AREA

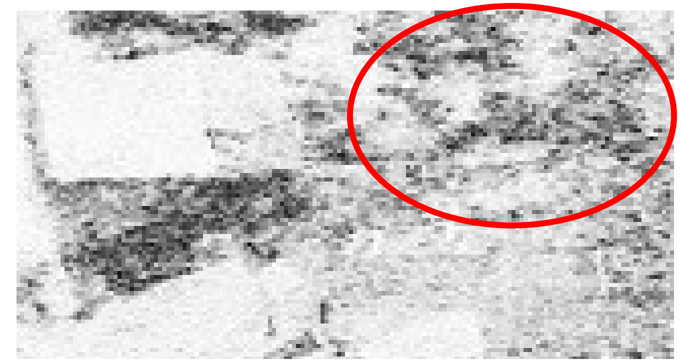
DIFFERENT POLARIMETRIC SCATTERING MECHANISMS

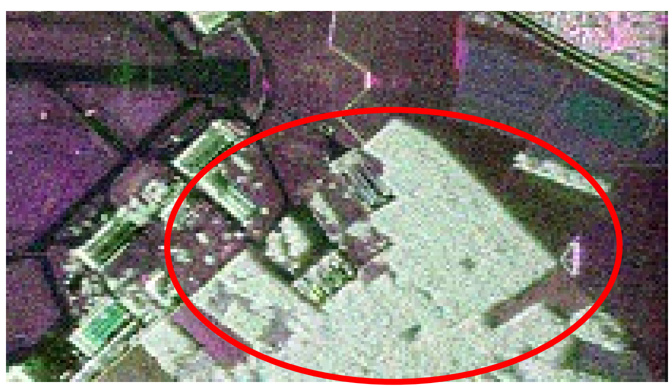
HOMOGENEOUS AREA

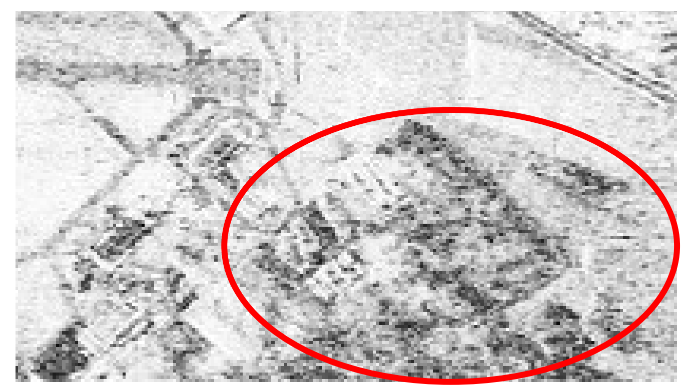
CONSTANT INTERFEROMETRIC COHERENCE

POL-InSAR









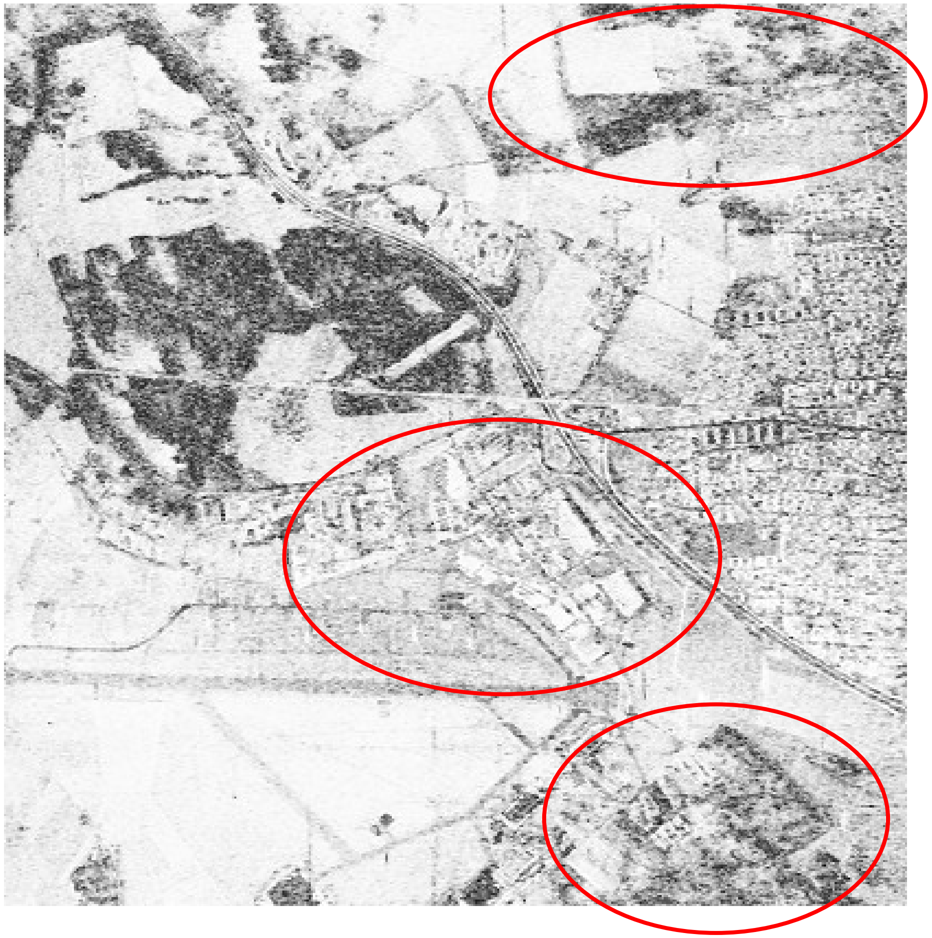
HOMOGENEOUS AREA

SAME POLARIMETRIC SCATTERING MECHANISMS

HETEROGENEOUS AREA

DIFFERENT INTERFEROMETRIC COHERENCE

POL-InSAR

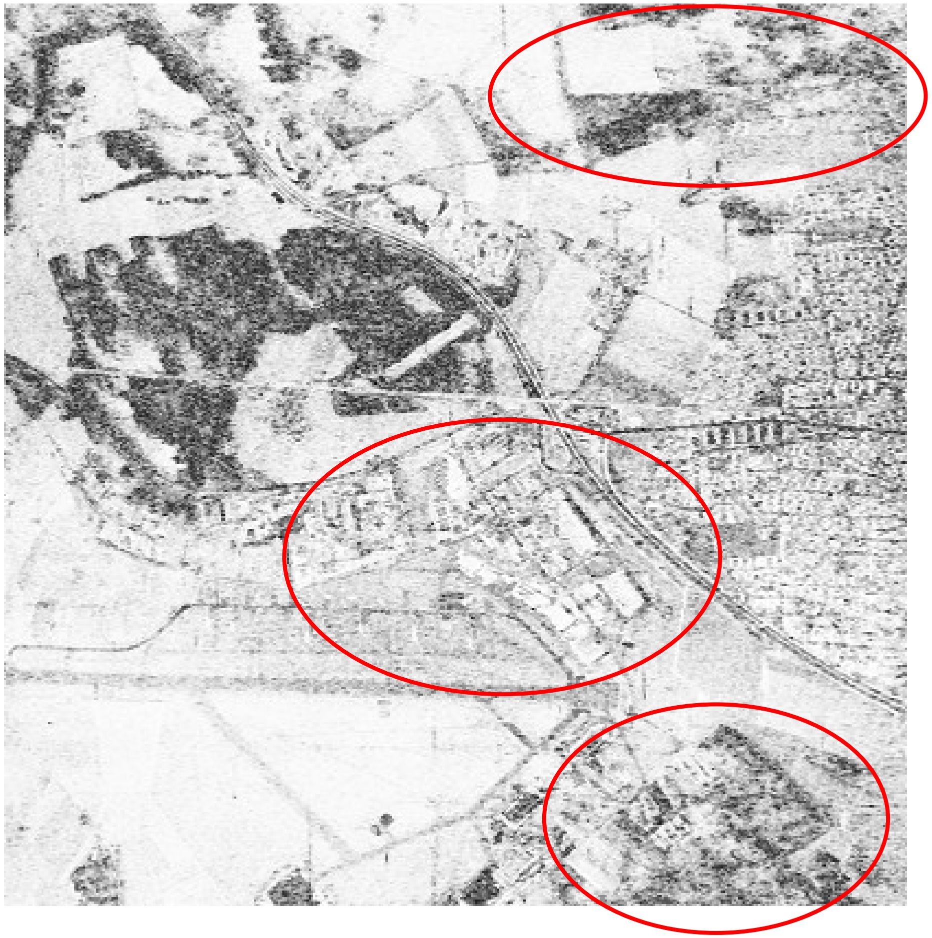


INTERFEROMETRIC COHERENCE γ

$2A_0$ B_0+B B_0-B

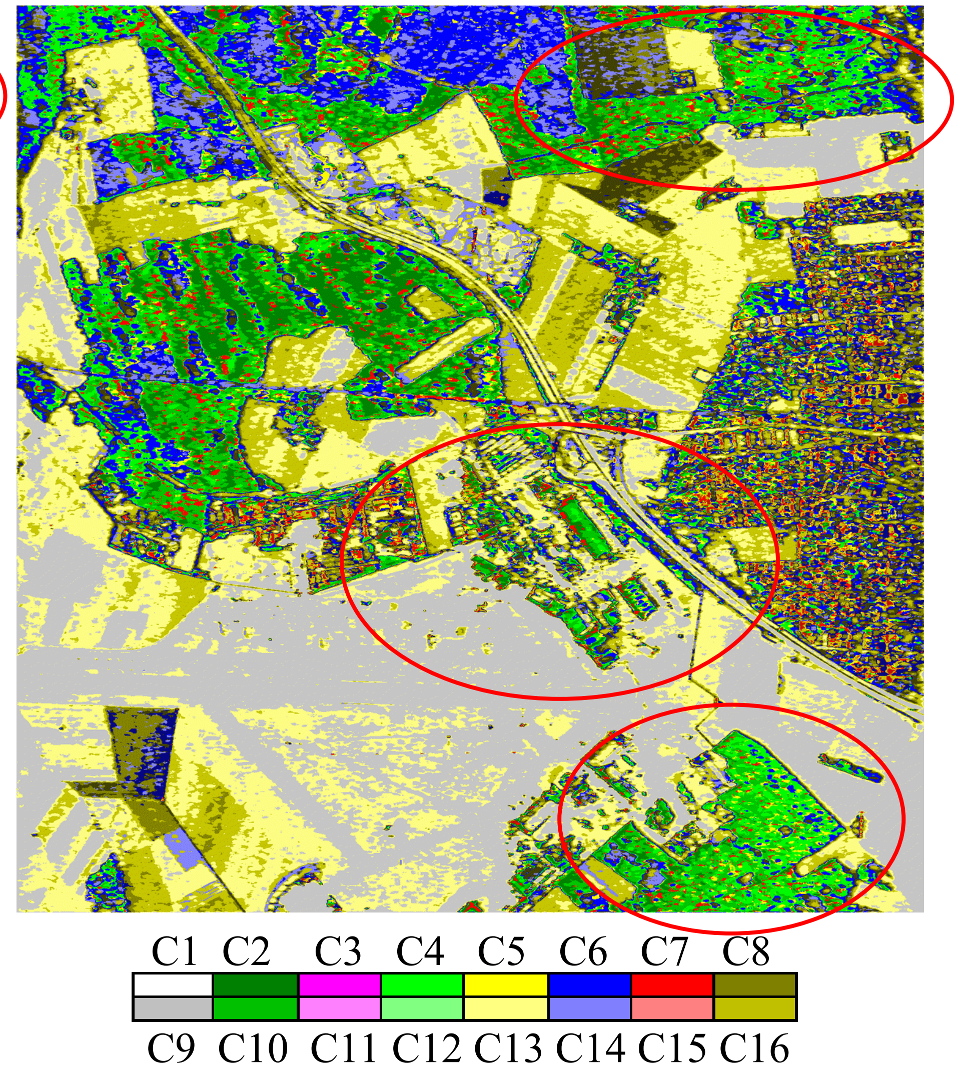
L. Ferro-Famil & E. Pottier

POL-InSAR



INTERFEROMETRIC COHERENCE γ

Wishart H-A-$\underline{\alpha}$ segmentation

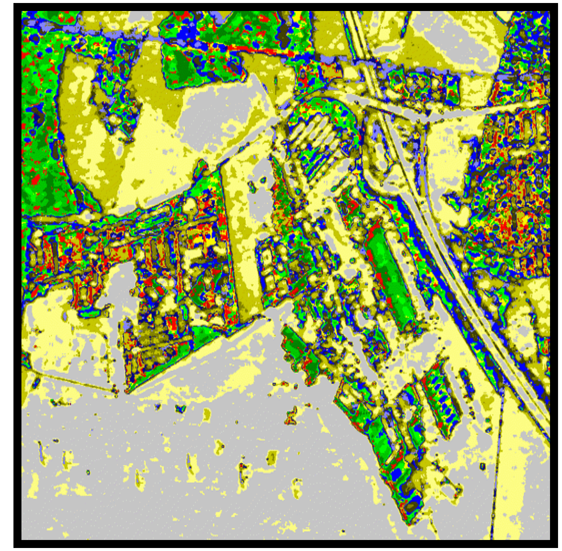


POL-InSAR

Optical Image

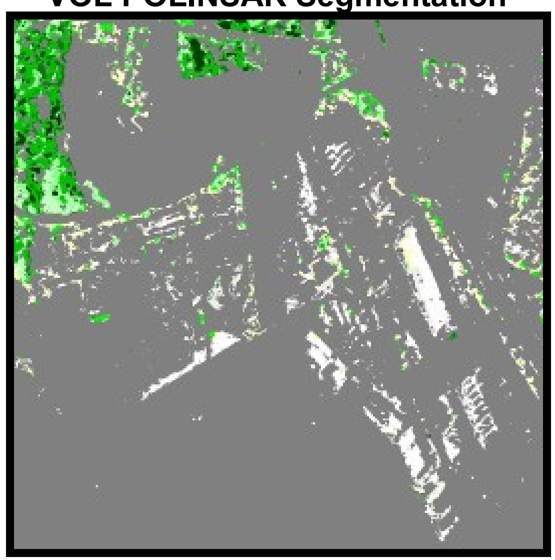
POLSAR Image

POLSAR Segmentation



INSAR Image

VOL POLINSAR Segmentation



POLINSAR Segmentation

Oriented buildings segmented from vegetated areas

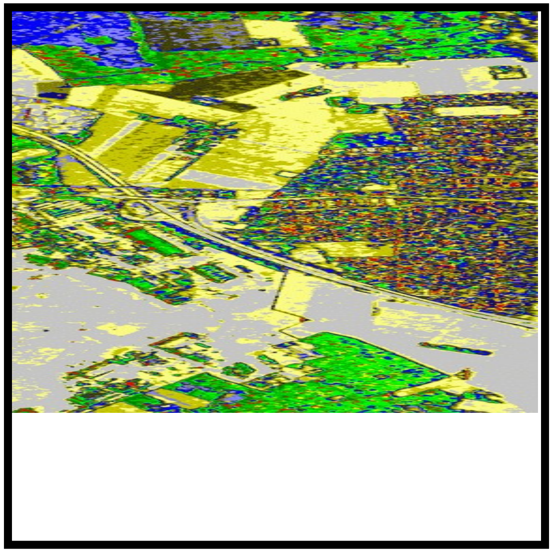
L. Ferro-Famil & E. Pottier

POL-InSAR

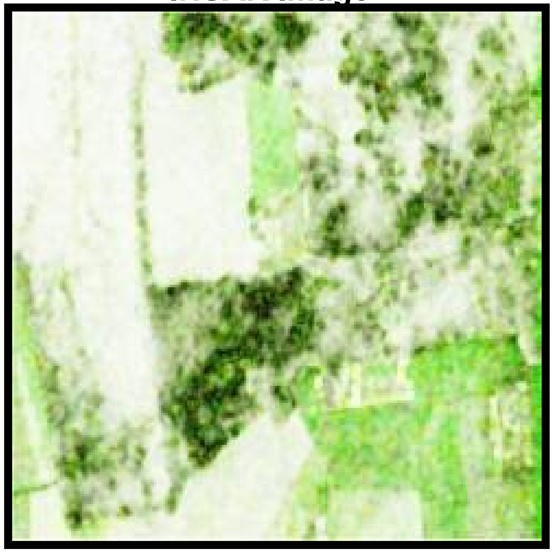
Optical Image

POLSAR Image

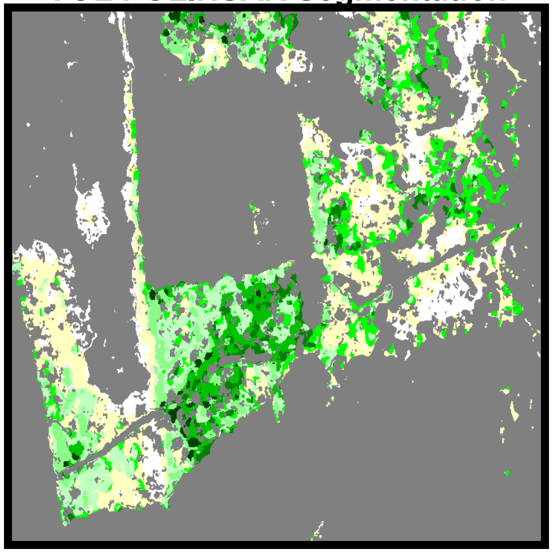
POLSAR Segmentation



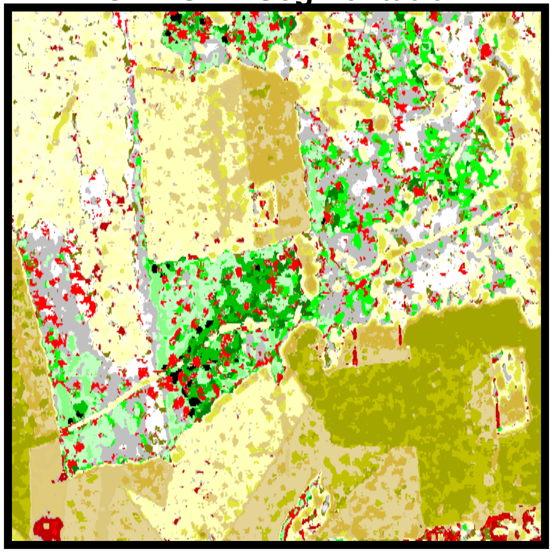
INSAR Image



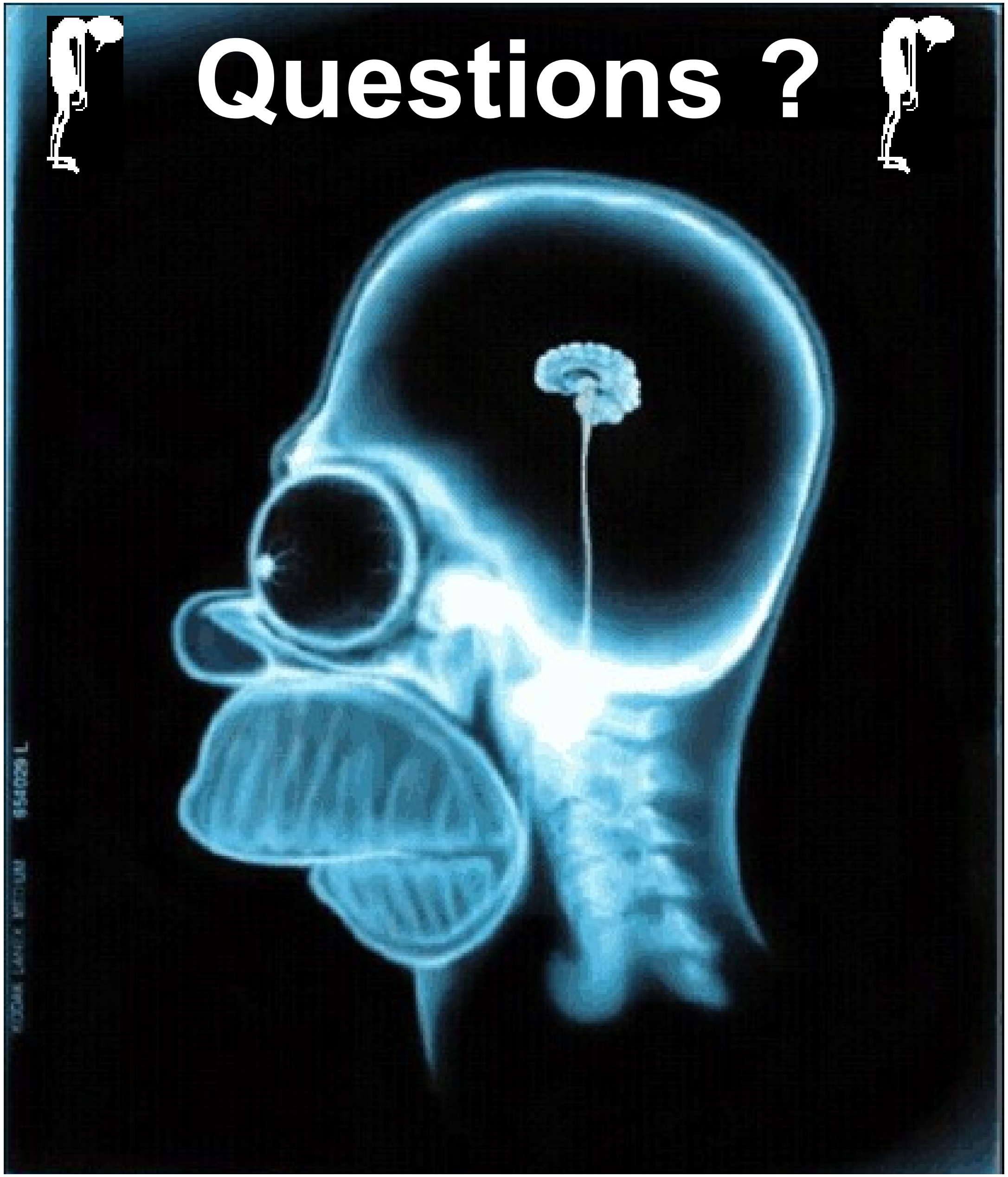
VOL POLINSAR Segmentation



POLINSAR Segmentation



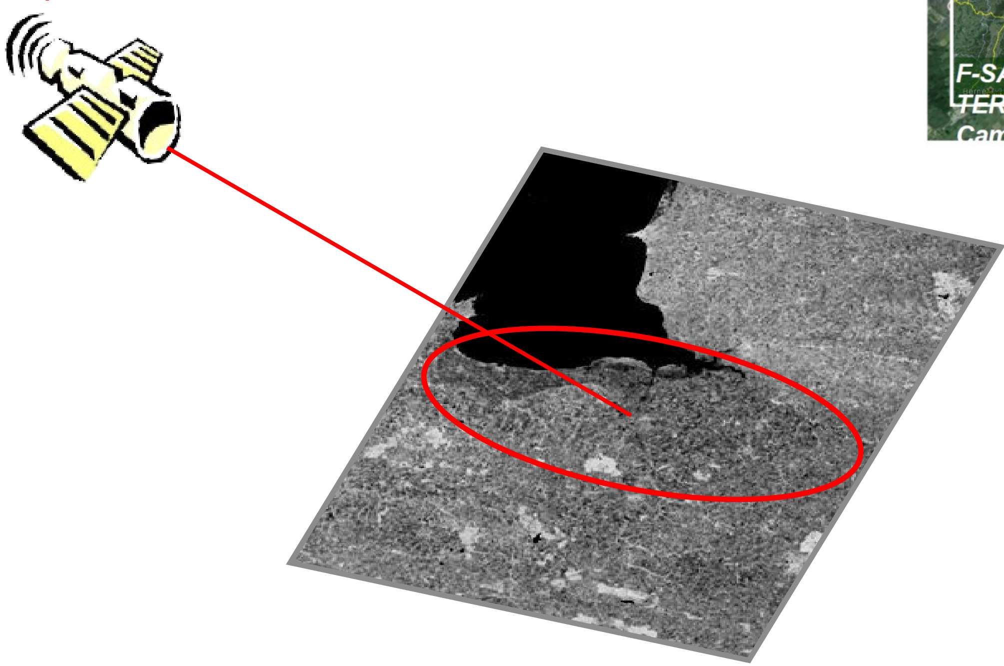
Low density forested areas segmented from dense forest

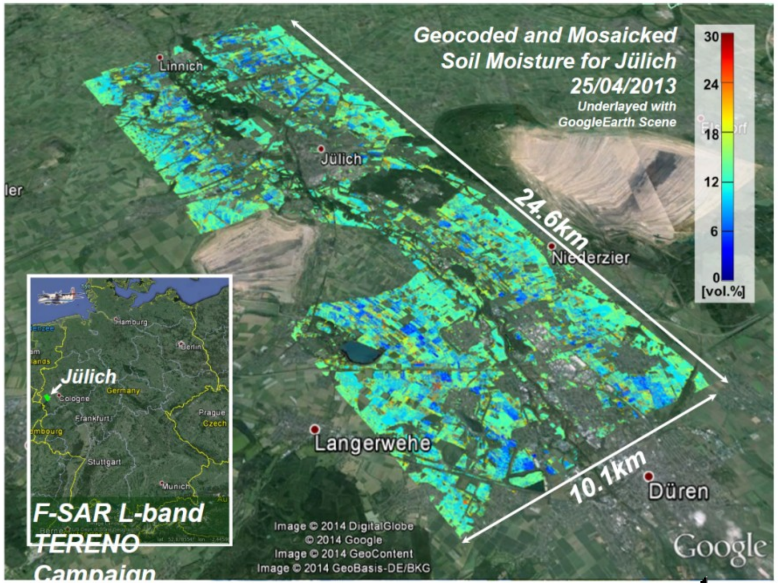

Questions ?

POLARIMETRY

PolSAR

Track$_1$





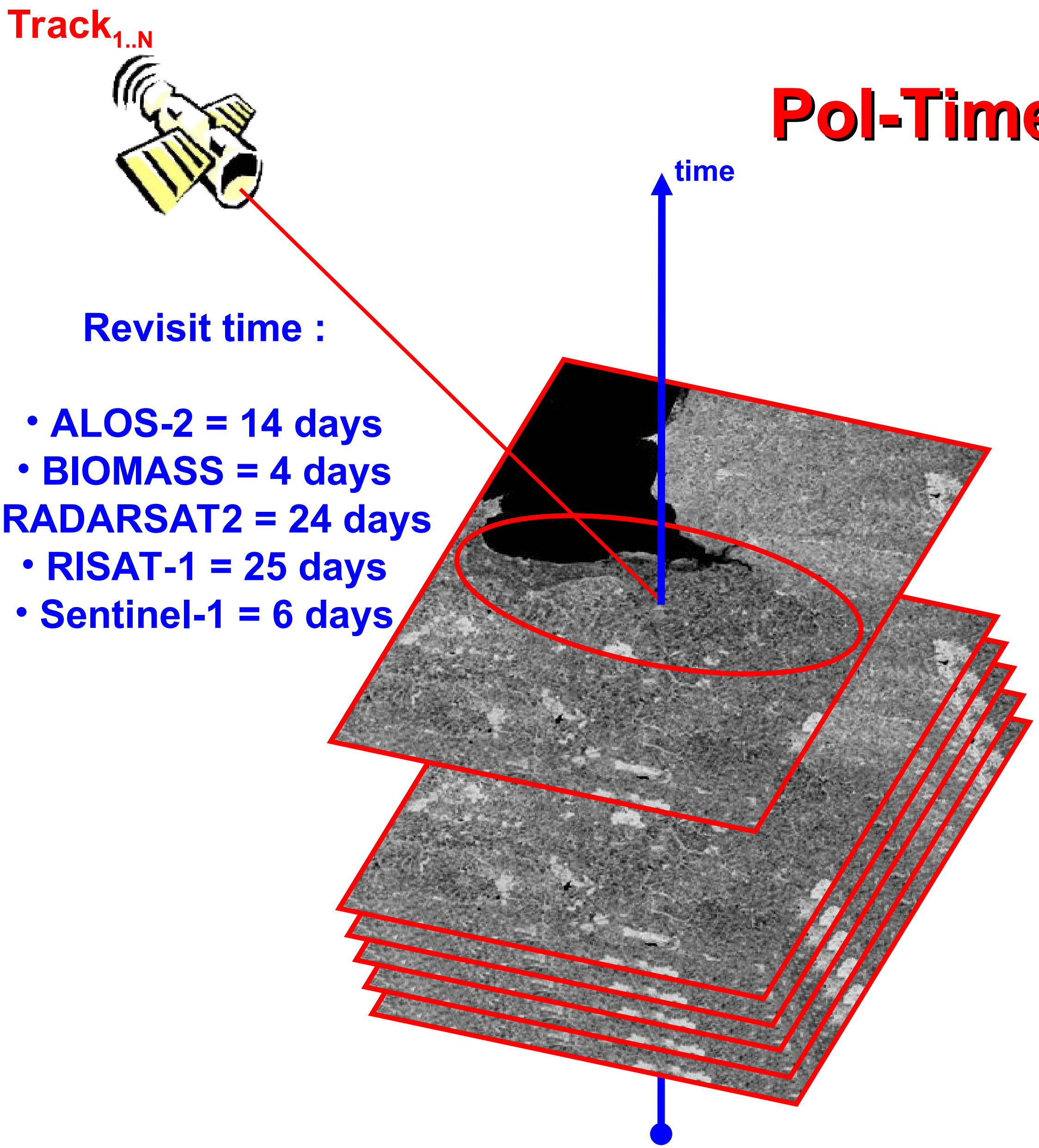
Soil moisture

DLR

Urban monitoring

ISAE SUPAERO CESBIO IETR

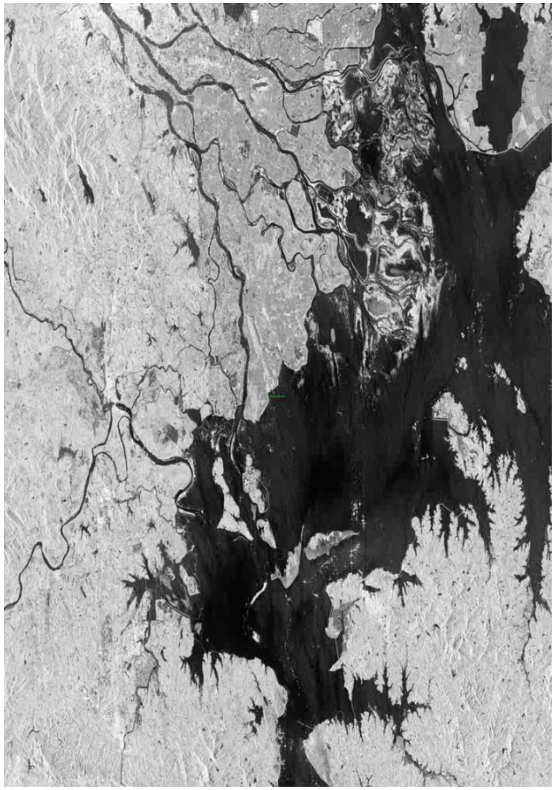
TIME-SERIES



Pol-TimeSAR

Revisit time :

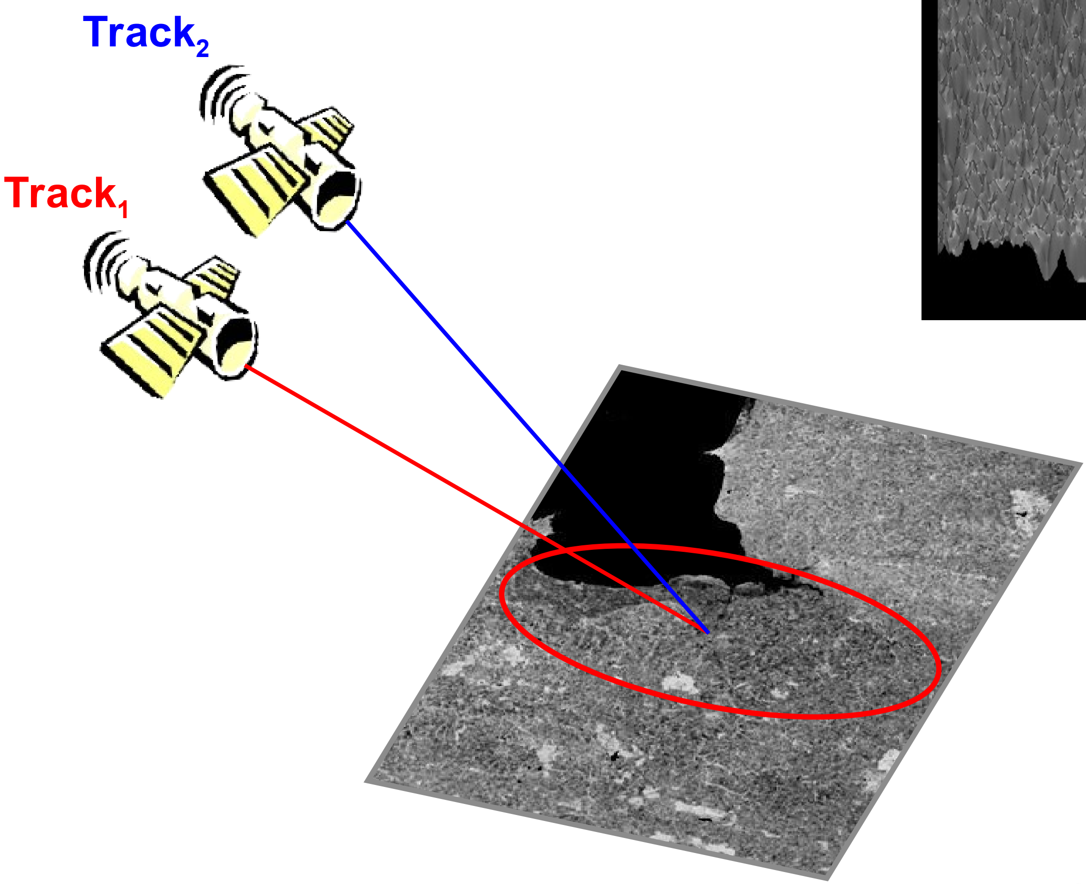
- ALOS-2 = 14 days
- BIOMASS = 4 days
- RADARSAT2 = 24 days
- RISAT-1 = 25 days
- Sentinel-1 = 6 days

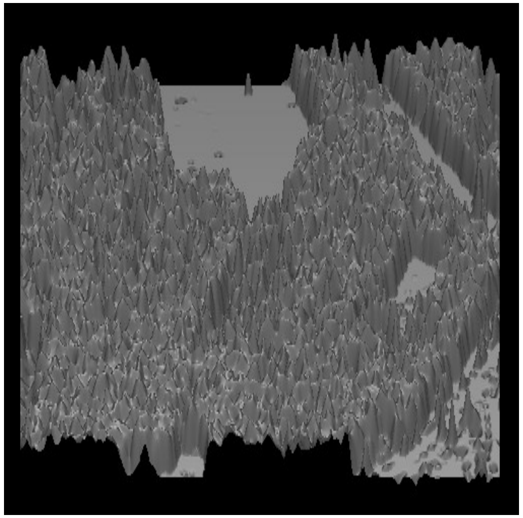


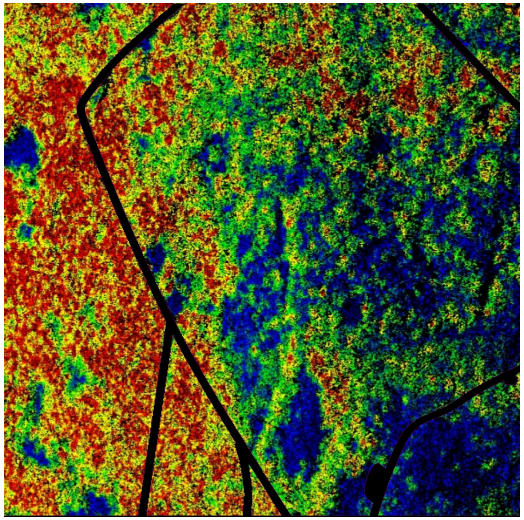
Polarimetric feature temporal evolution

POLARIMETRY + INTERFEROMETRY

Pol-InSAR

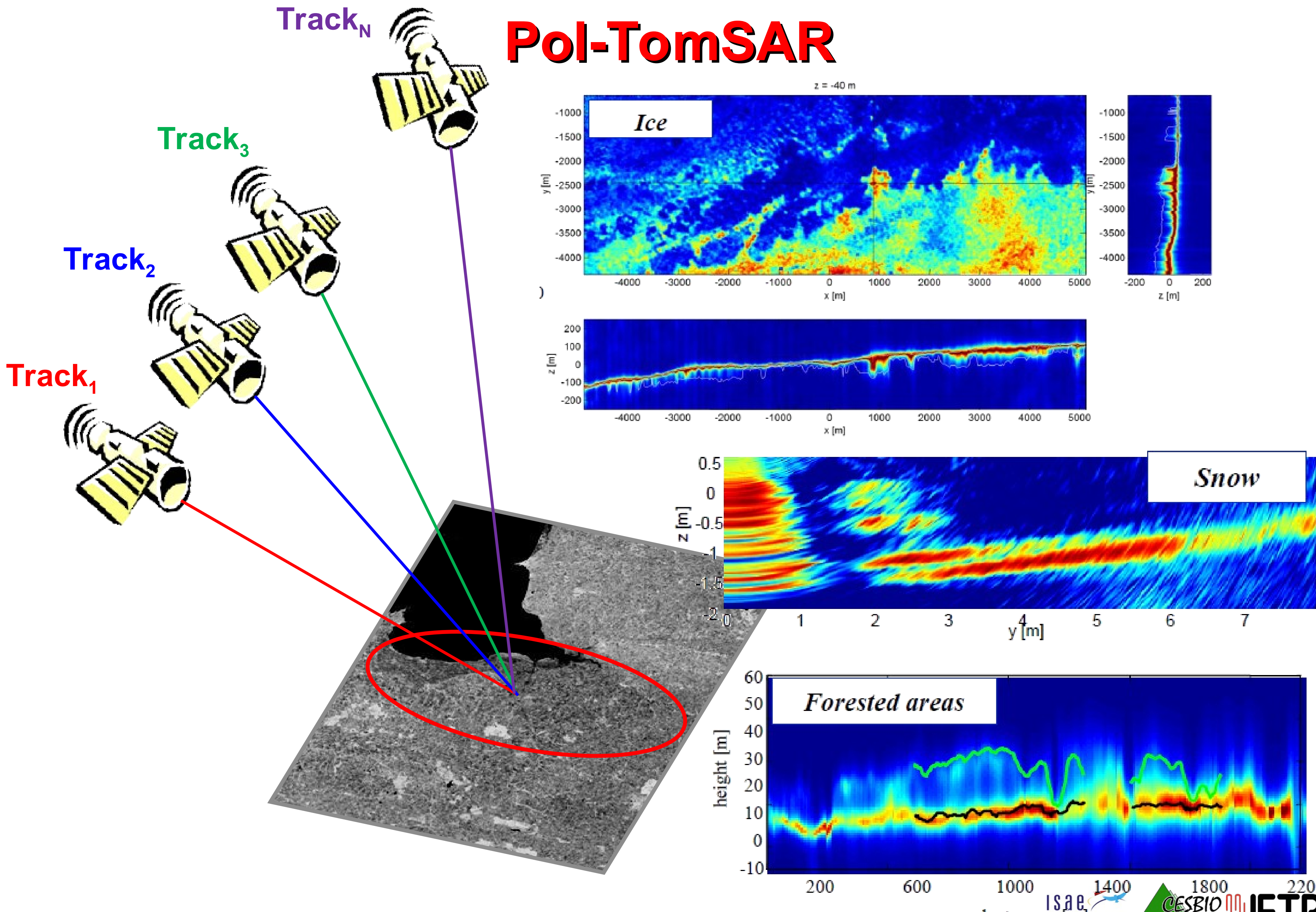






DLR Courtesy of Dr. K. Papathanassiou

POLARIMETRY + TOMOGRAPHY



L. Ferro-Famil & E. Pottier

Questions ?