Introduction to SAR Polarimetry (Lecture D2T2)

Eric POTTIER

University of Rennes 1

Eric POTTIER

eric.pottier@univ-rennes1.fr

IETR
INSTITUT D'ÉLECTRONIQUE ET DE TÉLÉCOMMUNICATIONS DE RENNES

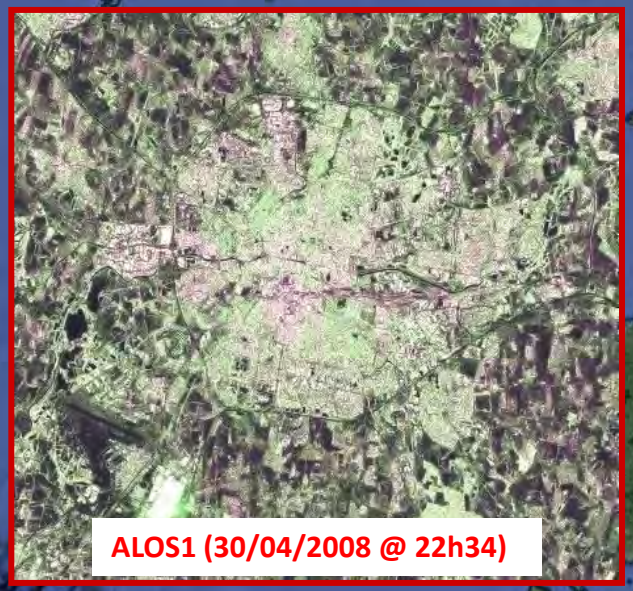
I.E.T.R. - UMR CNRS 6164
Université de Rennes I - Campus de Beaulieu
Pôle Micro Ondes Radar - Bat 11D
263 Avenue Général Leclerc
CS 74205 - 35042 Rennes Cedex – France

SAR & Hyperspectral multi-modal Imaging and sigNal processing, Electromagnetic modeling

UNIVERSITÉ DE RENNES 1

Rennes - Britanny

Rennes - Britanny



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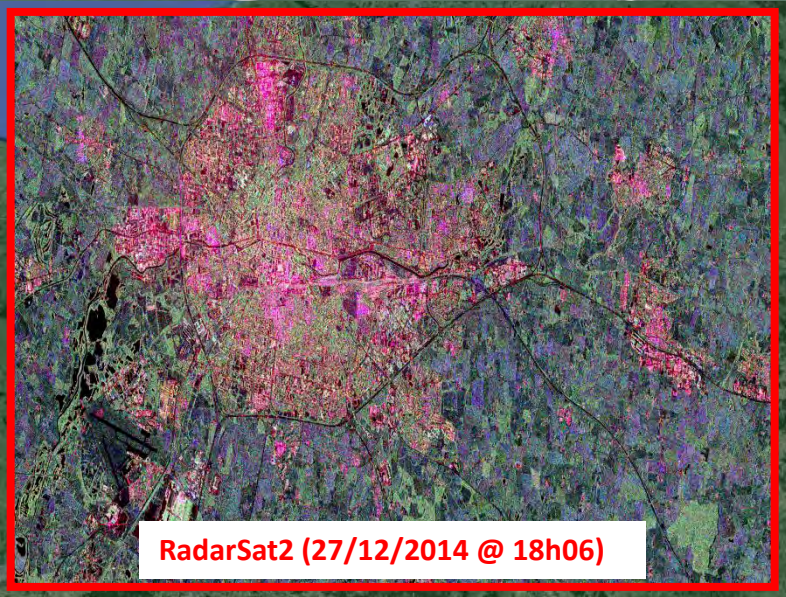
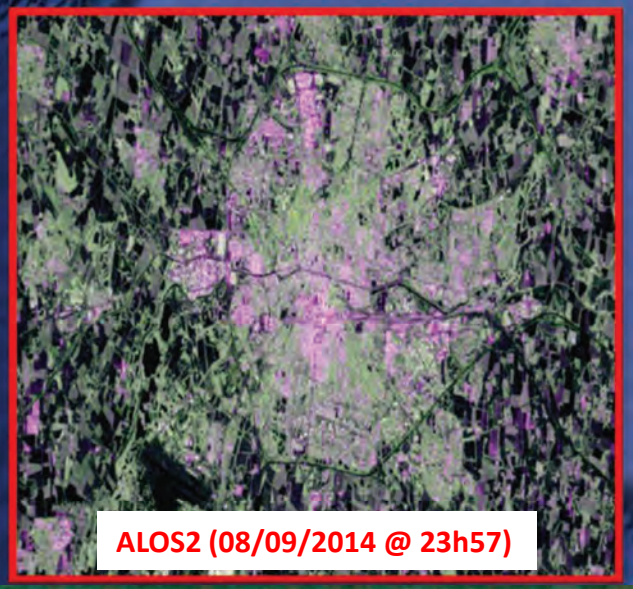
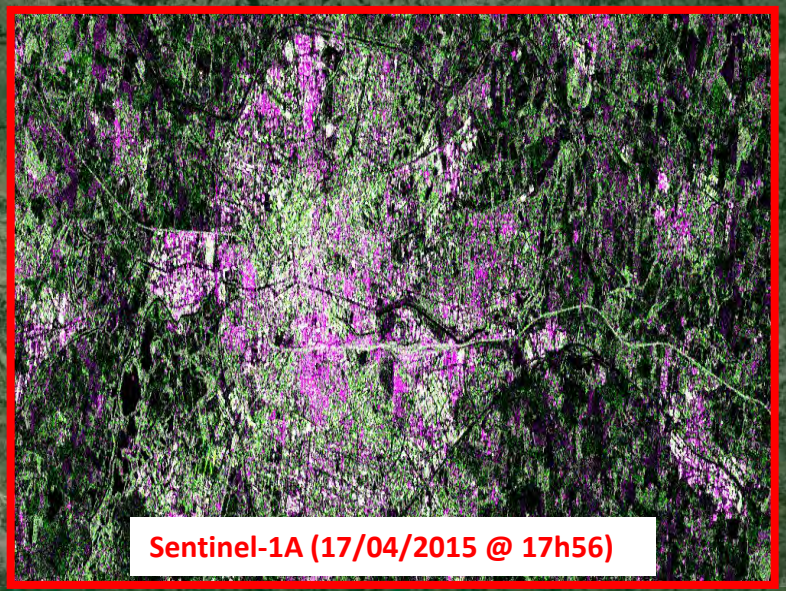


RadarSat2 (27/12/2014 @ 18h06)



ALOS2 (08/09/2014 @ 23h57)



Sentinel-1A (17/04/2015 @ 17h56)

Rennes

Objective

To provide

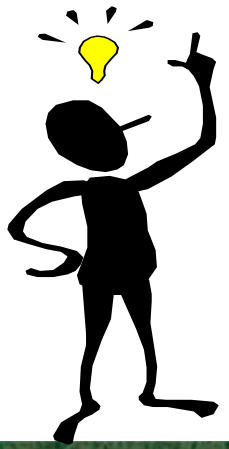
the minimum, but necessary,

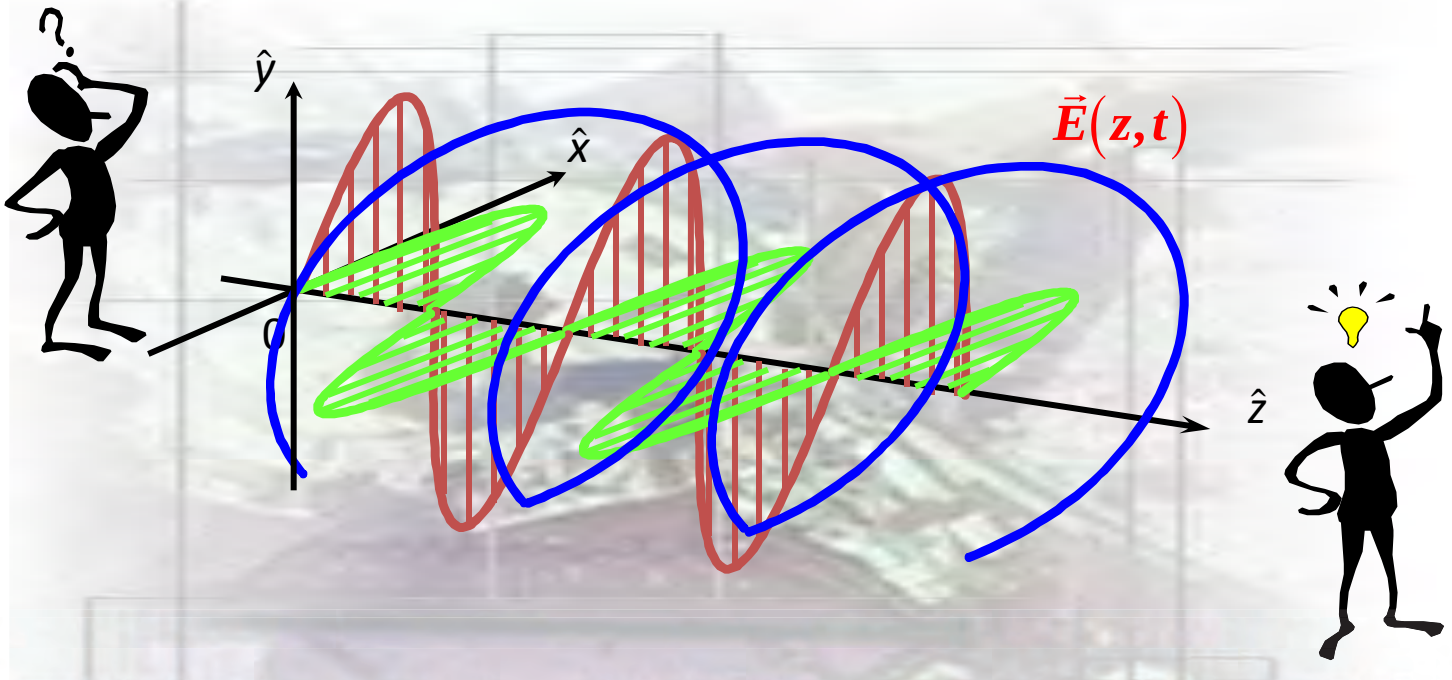
amount of knowledge required

to understand

scientific works on

SAR Polarimetry (PolSAR)



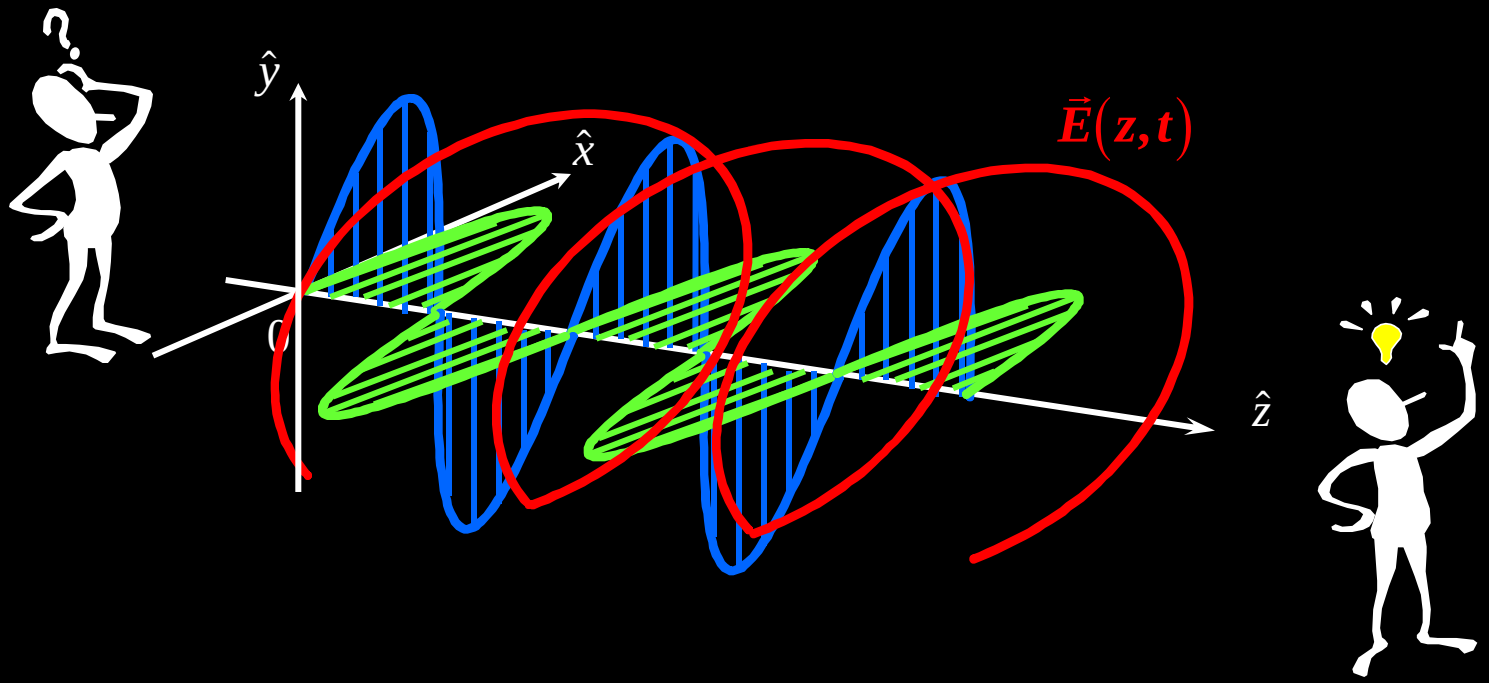


GENERAL INTRODUCTION

RADAR POLARIMETRY

- A bit of History
- Airborne and Space-borne Polarimetric SAR Sensors
- Software / Toolbox
- Learning / Training / Results

Radar Polarimetry

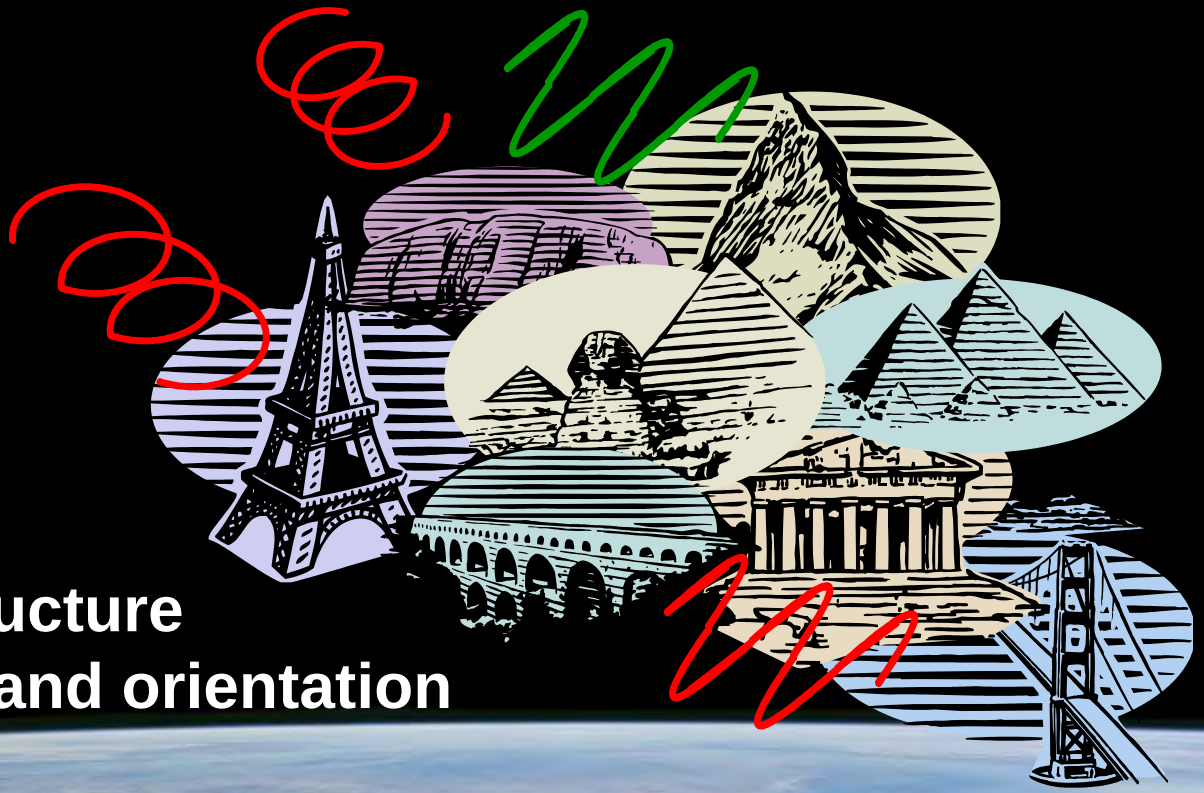


Radar Polarimetry (Polar : polarisation Metry: measure) is the science of acquiring, processing and analysing the polarization state of an electromagnetic field

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

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, …

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

A Bit Of History

Radar Polarimetry

Discovery of the Phenomena of Polarized Electromagnetic Energy

AD 1000
Use of the polarized skylight to locate a hidden sun

Crystal of calcite
Iceland Spar
Sunstone

1669
First known Quantitative work on light observation

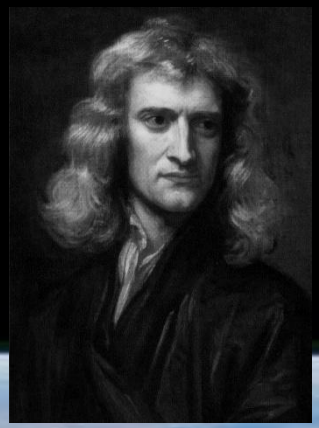
Bartholinus

Discovery of the double refraction in calcite

1677
Wave nature of light discovery
Explanation of the double refraction

Huygens

1704
Corpuscular Model of light



Newton

Corpuscular model or « longitudinal » waves

1808
Discovery of the polarization of light (intrinsic property of light and not of crystals)

Malus
X-1795

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Non Exhaustive Chronological List of the Main Pionners who contributed to the discovery of **Polarization** leading to Radar Polarimetry

Brewster

1816

Fresnel

1820

Faraday

1832

« Transverse » nature of light waves

Stokes

1852

Maxwell

1873

Helmholtz

1881

Electromagnetic theory of light

Rayleigh

1881

Kirchhoff

1883

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Non Exhaustive Chronological List of the Main Pionners who contributed to the discovery of **Polarization** leading to Radar Polarimetry


Brewster
1816


Fresnel
1820


Faraday
1832


Stokes
1852


Maxwell
1873


Helmholtz
1881


Rayleigh
1881


Kirchhoff
1883

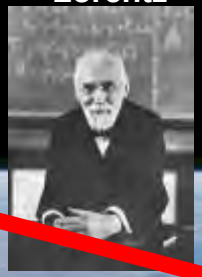

Hertz
1886


Drude
1889

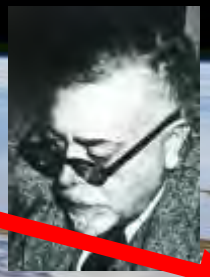

Sommerfeld
1896


Poincaré
1892


Lie
1897


Lorentz
1908


Marconi
1922


Wiener

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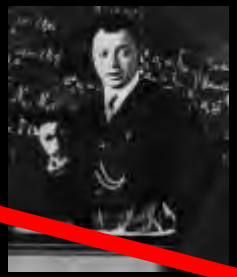
Non Exhaustive Chronological List of the Main Pionners who contributed to the discovery of **Polarization** leading to **Radar Polarimetry**

Pauli



1950

Deschamp

1951

Born

1954

Wolf

1954

Kennaugh

1952

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Non Exhaustive Chronological List of the Main Pionners who contributed to the discovery of Polarization leading to Radar Polarimetry

Kennaugh

1952

Huynen

1970

W. M. Boerner

1980

The Radar Polarimetric Triptych

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Non Exhaustive Chronological List of the Main Pionners who contributed to the discovery of Polarization leading to Radar Polarimetry


Kennaugh

1952


Huynen

1970


W. M. Boerner

1980


K. Raney


J.J. Van Zyl


A. Freeman


R. Touzi


J.S. Lee


T. Ainsworth


S.R. Cloude


E. Pottier


P. Dubois


Y. Yamaguchi


C. Lopez

1990 - 2000

Radar Polarimetry Scientific Progress


H. Mott


E. Lueneburg


E. Krogager


A. Moreira


Y.L. Desnos


Z. Czyz


K. Papathanassiou


I. Hajnsek


T. Le Toan


L. Ferro-Famil


J.C. Souyris

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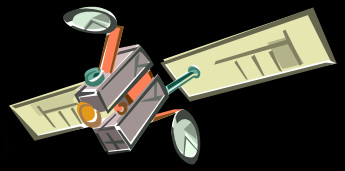
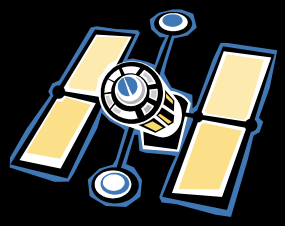
Polarimetric Radar (SAR)





Spaceborne Sensors

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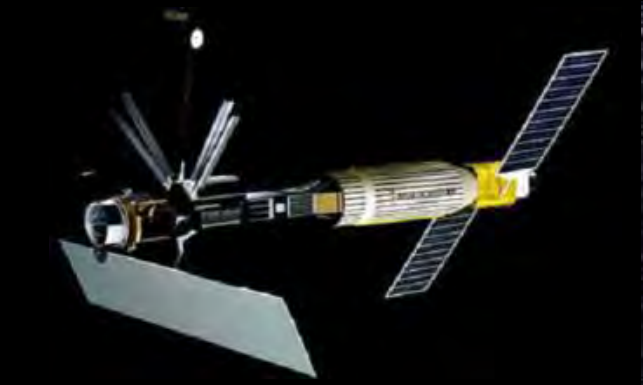
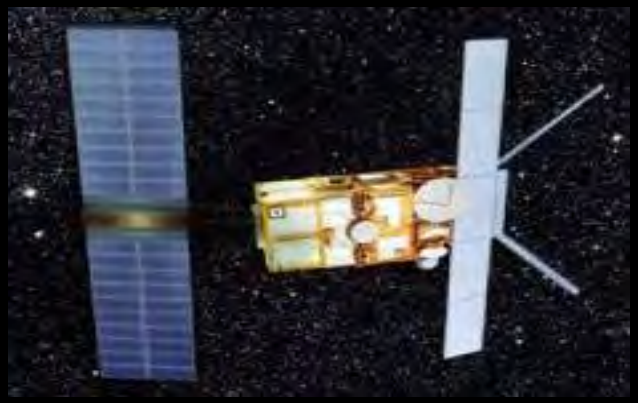
Space-borne Sensors



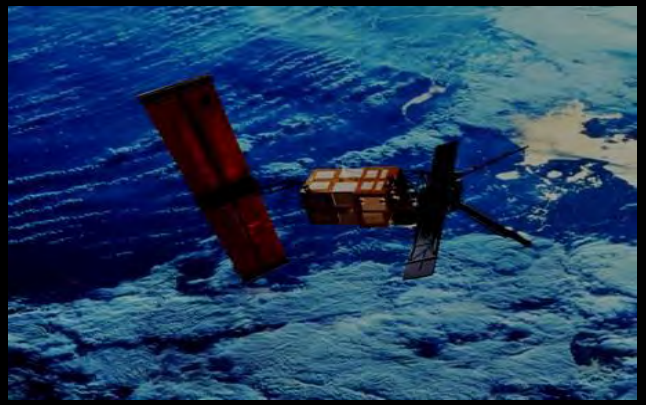
SEASAT
NASA/JPL (USA)
L-Band, 1978



ERS-1
European Space Agency (ESA)
C-Band, 1991-2000

J-ERS-1
Japanese Space Agency (NASDA)
L-Band, 1992-1998

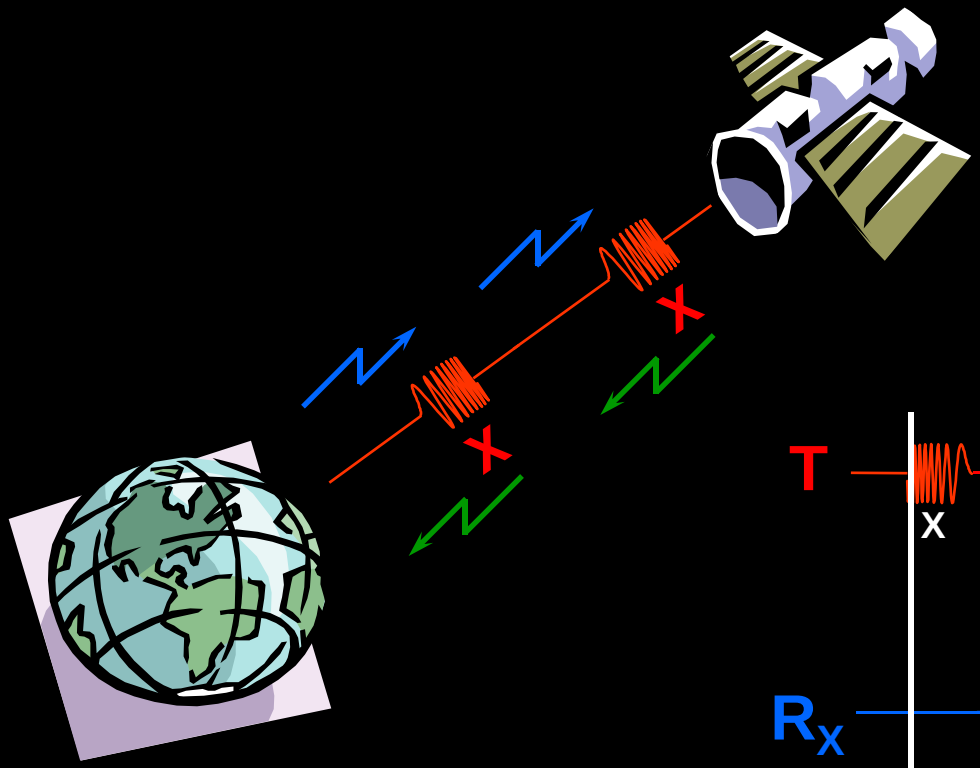
RadarSAT-1
Canadian Space Agency (CSA)
C-Band, 1995

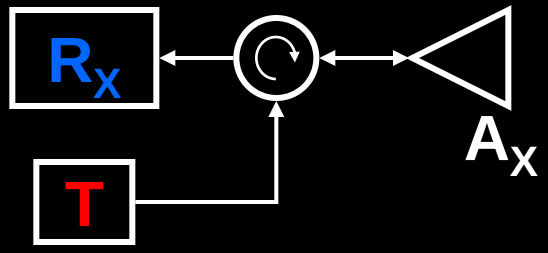


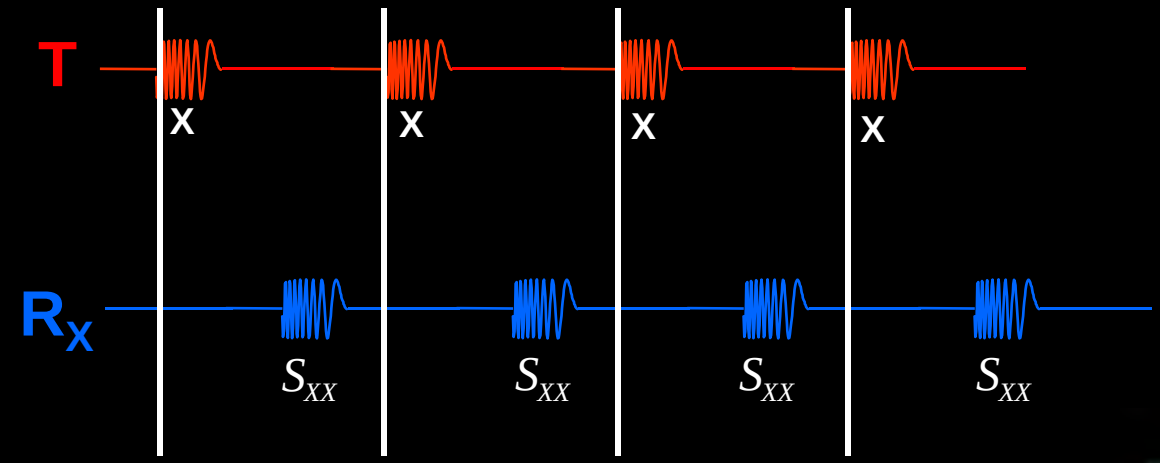
ERS-2
European Space Agency (ESA)
C-Band, 1995

Shuttle Radar Topography Mission
NASA/JPL (C-Band), DLR (X-Band)
February 2000

Scattering Coefficient







TRANSMITTER: X
RECEIVER: X

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

NO POLARIMETRY

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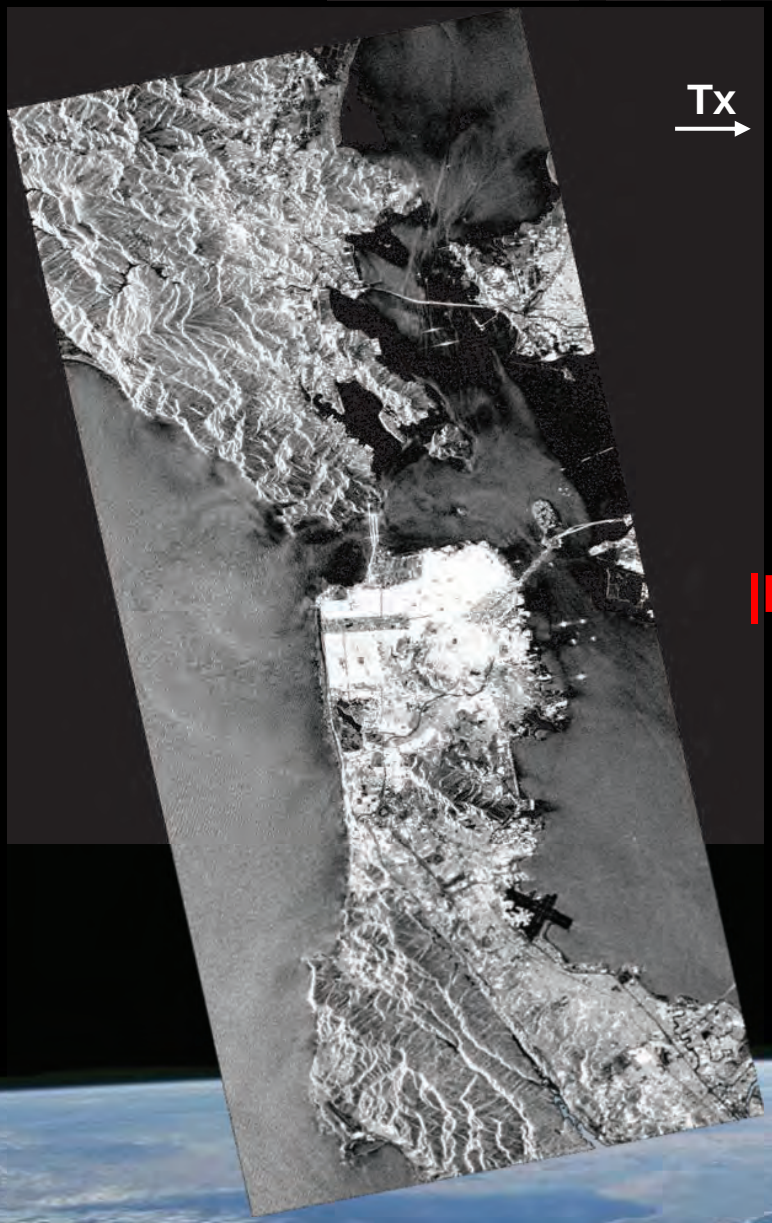
Space-borne Sensors



San Francisco Bay – (L-Band)

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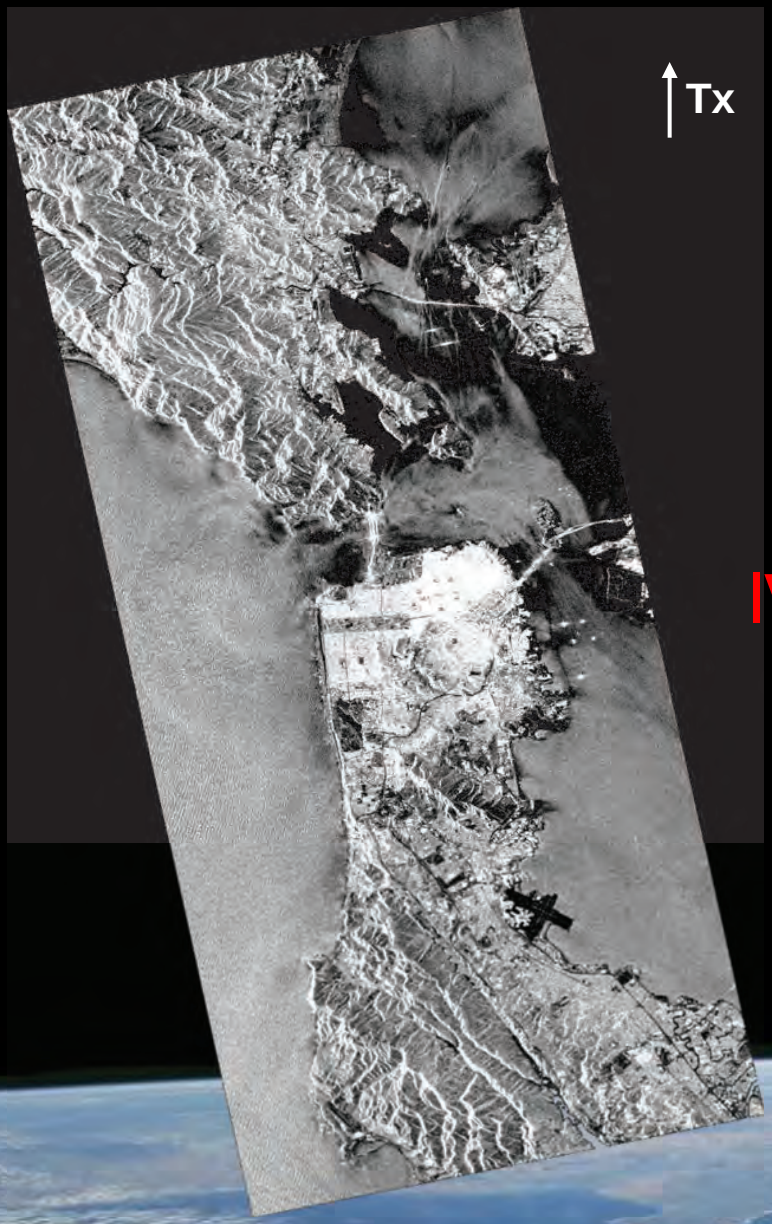
Space-borne Sensors



San Francisco Bay – (L-Band)

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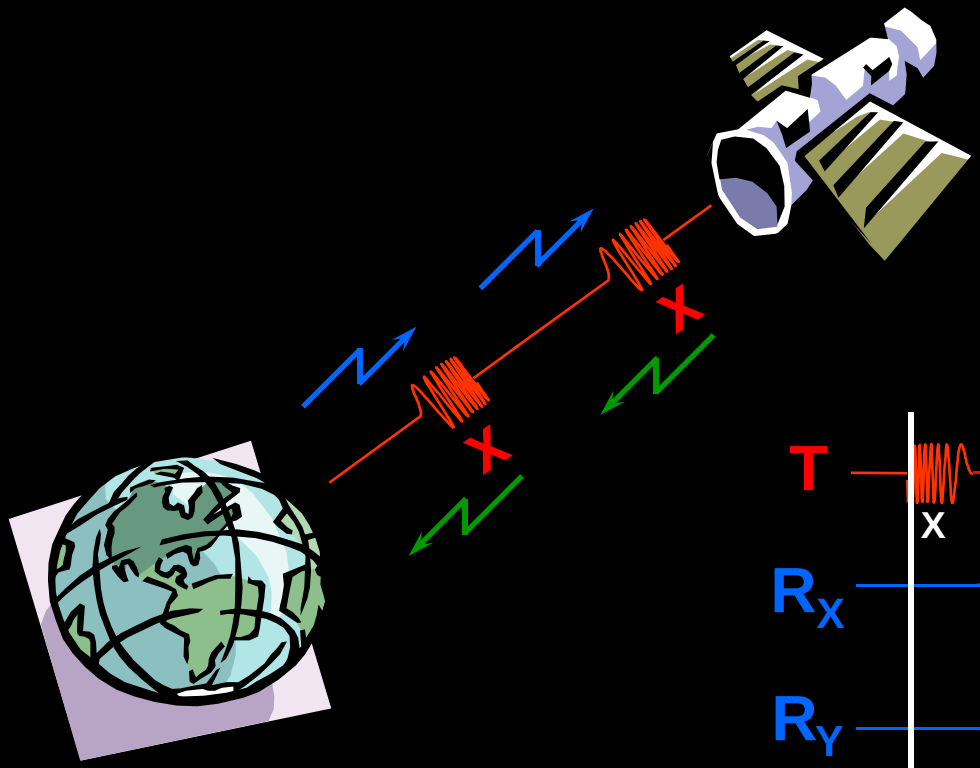
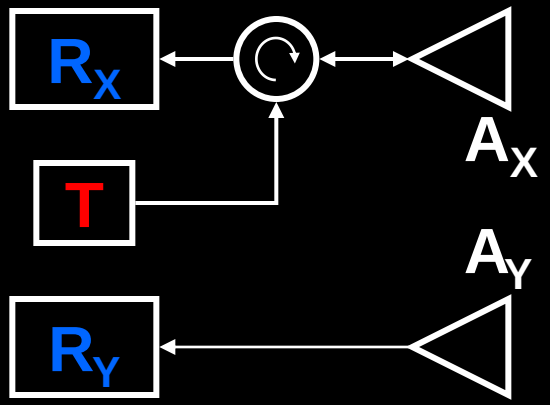
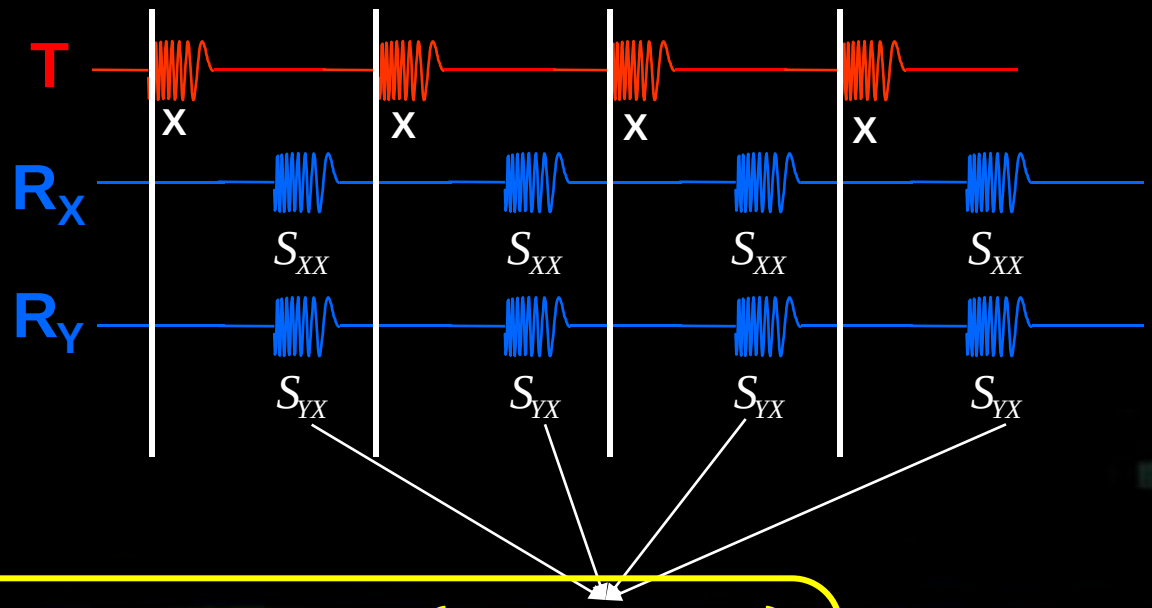
Wave Polarimetry







TRANSMITTER: X
RECEIVERS: X & Y

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

WAVE POLARIMETRY

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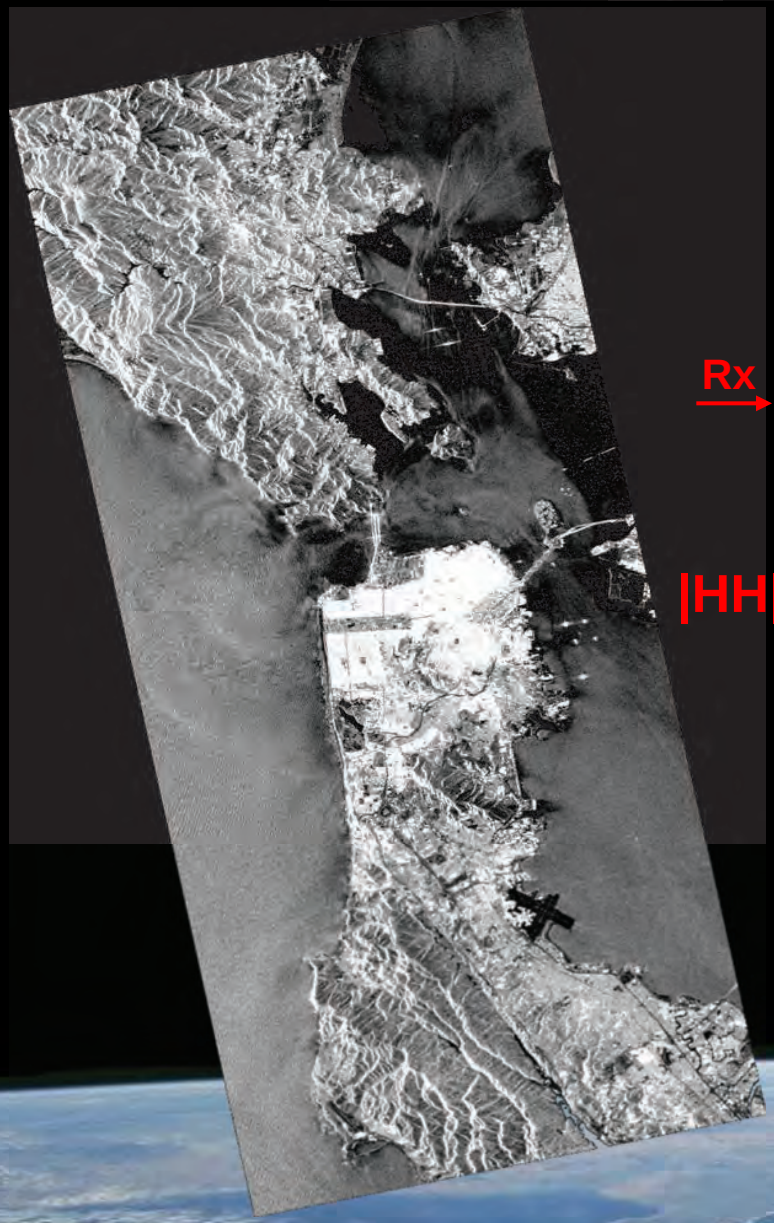
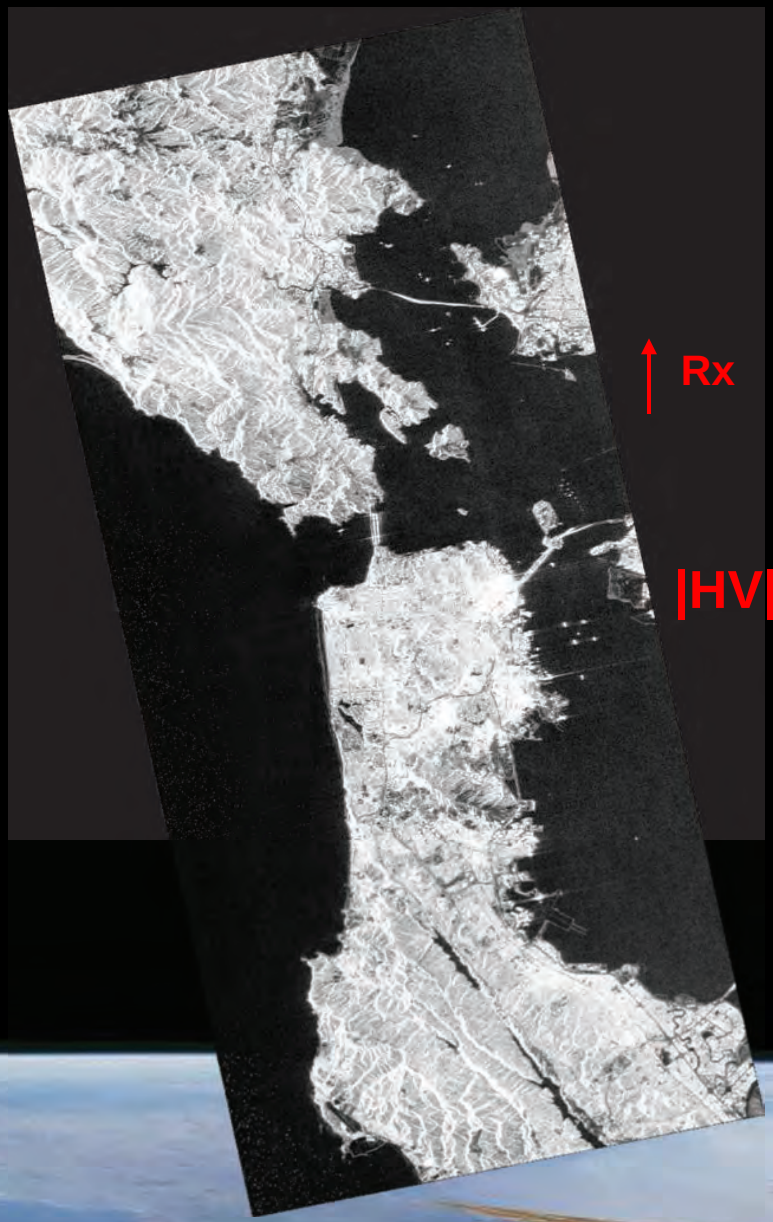
Space-borne Sensors



Tx

Rx

$|HH|_{dB}$



Rx

$|HV|_{dB}$

San Francisco Bay – (L-Band)

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Space-borne PolSAR Sensors

ENVISAT - ASAR

October 2001
C-Band (Sngl / Dual Inc)

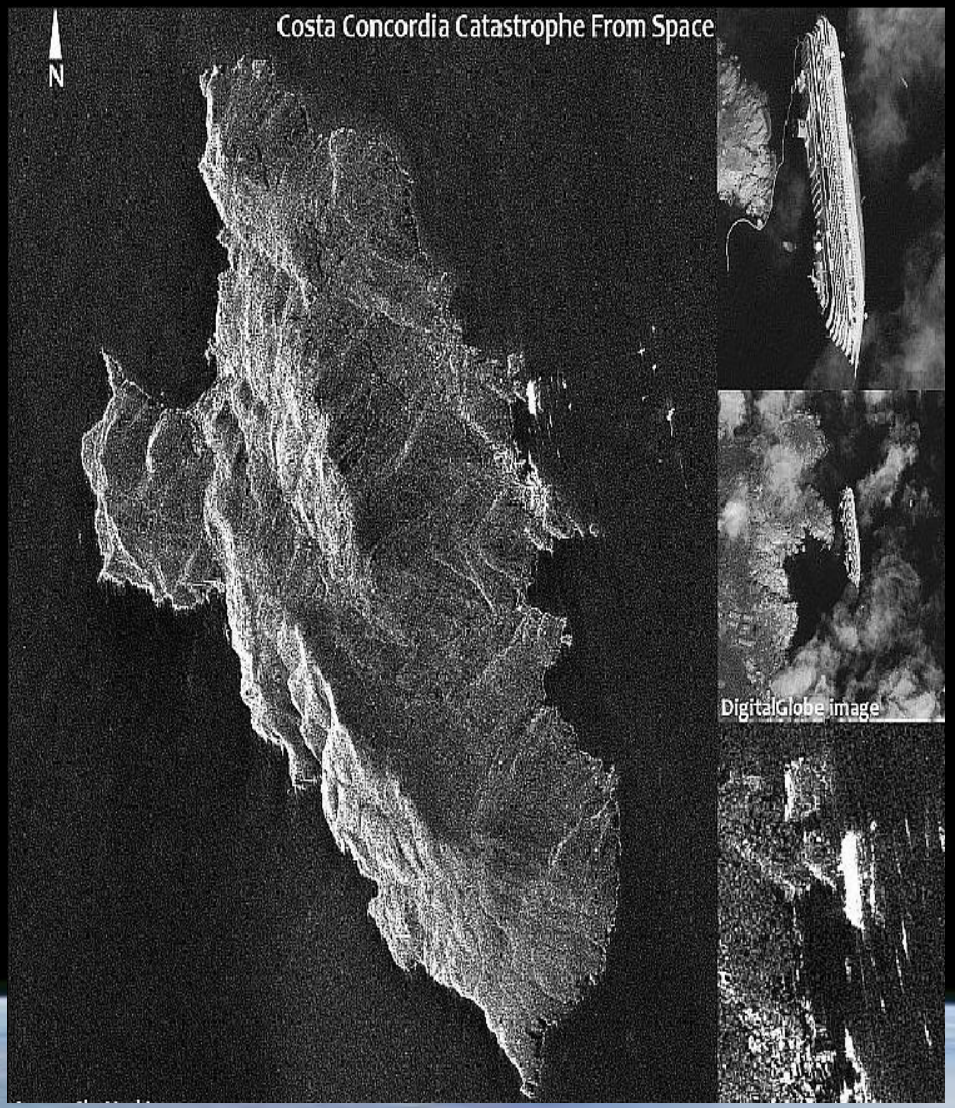
Space-borne PolSAR Sensors

COSMO - SkyMed

agenzia spaziale italiana

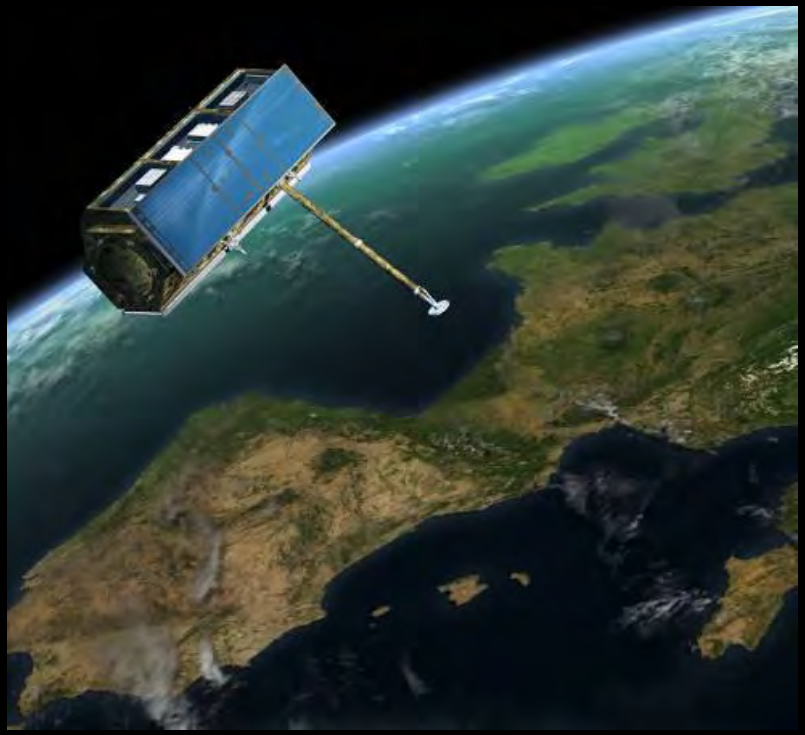
TELESPAZIO
A Finmeccanica / Thales Company

June 2007, Dec. 2007
Oct. 2008, Nov. 2010
X-Band (Sngl / Dual)
Revisit : 1 day



Space-borne PolSAR Sensors

TerraSAR - X



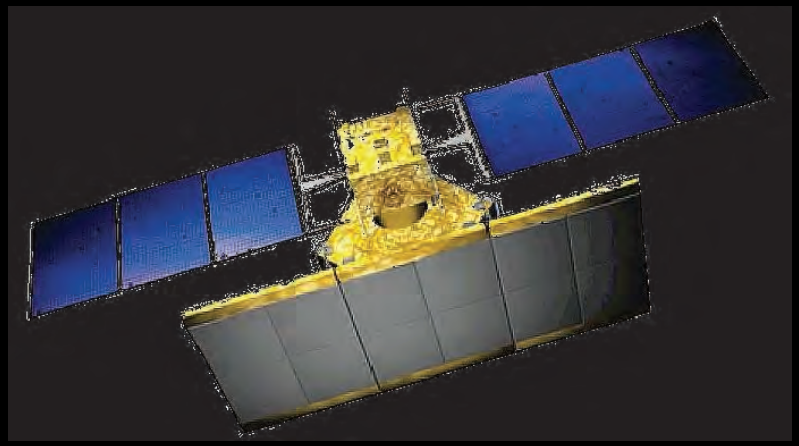
June 2007

X-Band (Sngl / Twin HH-VV / Quad Exp.)

DLR EADS ASTRIUM

Space-borne PolSAR Sensors

RISAT-1A



Rajasthan (Dual)

Sabarmati (Hybrid)

Kolkata (Hybrid)

26 April 2012
C-Band (Sngl, Dual, Hybrid)
Operational since 2015

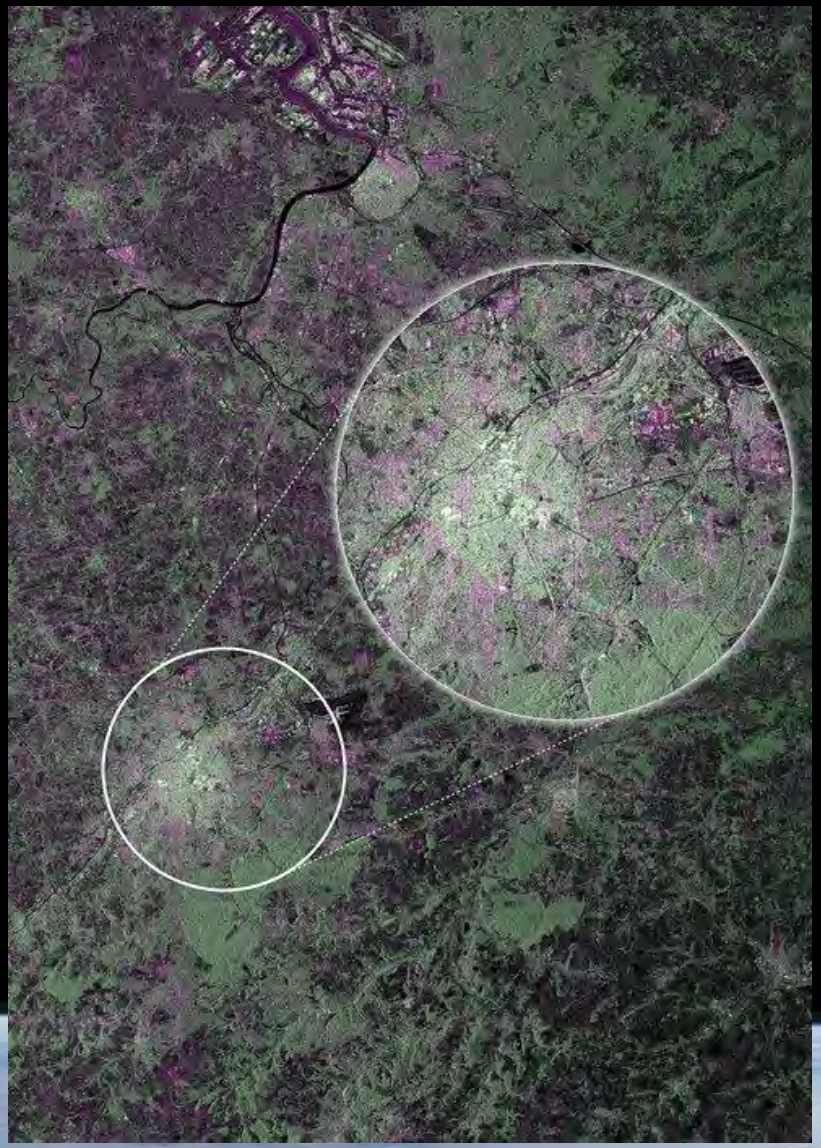
Space-borne PolSAR Sensors

SENTINEL – 1A

S1A : April 2014 S1B : April 2016

C-Band (Sngl, Dual)

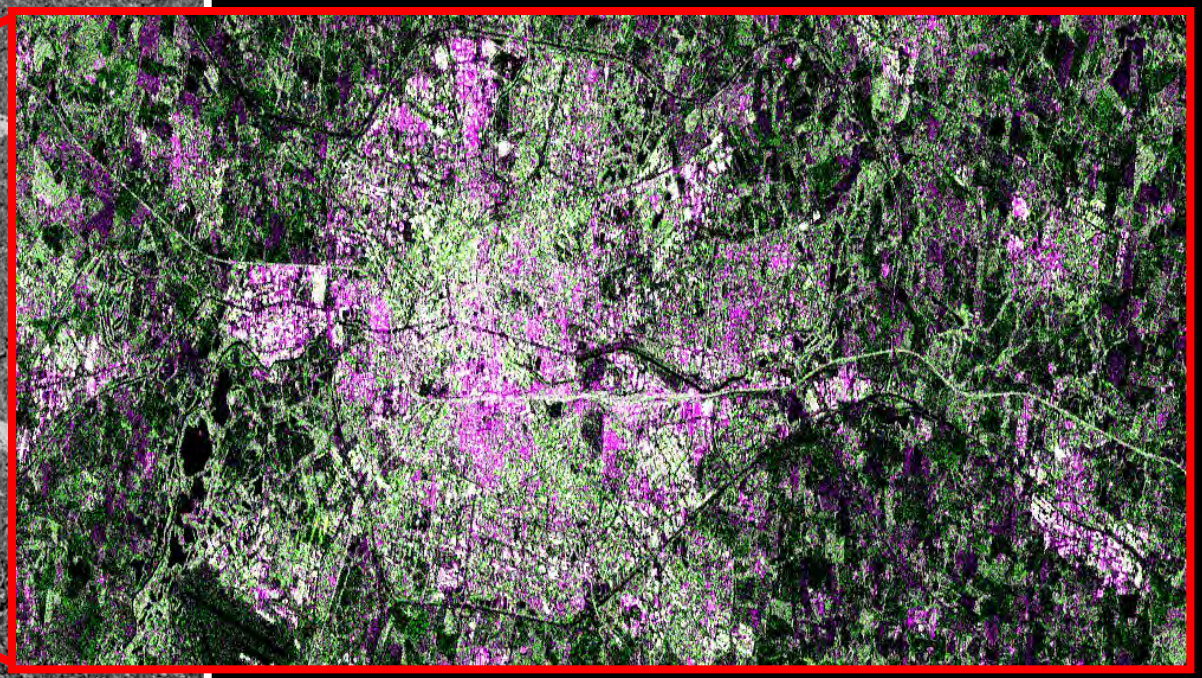
Revisit : 6 days



Brussels – 12 April 2014

Space-borne PolSAR Sensors

Rennes
Britanny
France



17/08/2016 @ 17h56

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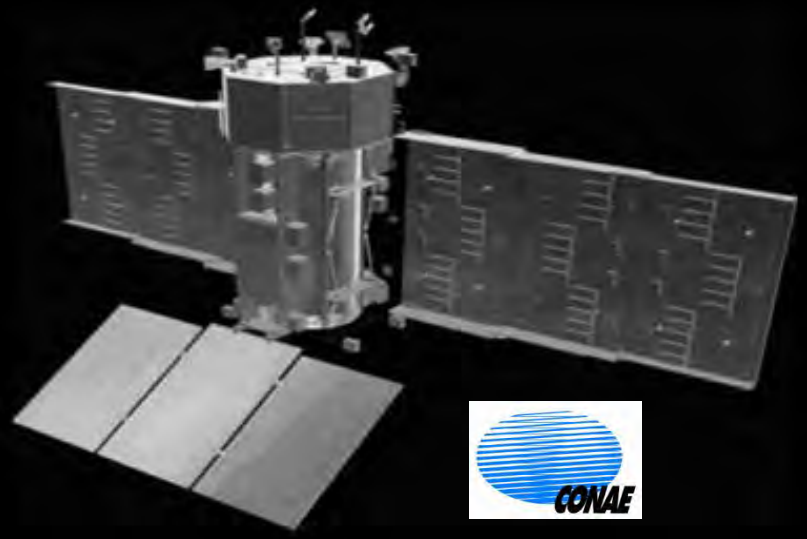
Space-borne PolSAR Sensors

https://scihub.copernicus.eu/

Space-borne PolSAR Sensors

SAOCOM – SAR-L



1A : 2017 1B : 2018
2A : 2019 2B : 2020
L-Band (Sngl, Dual, Twin HH-VV)
Revisit : 4 days

RADARSAT Constellation Mission (RCM)

1A : 2017 1B / 1C : 2018
C-Band (Sngl, Dual, Hybrid)
Revisit : 4 days

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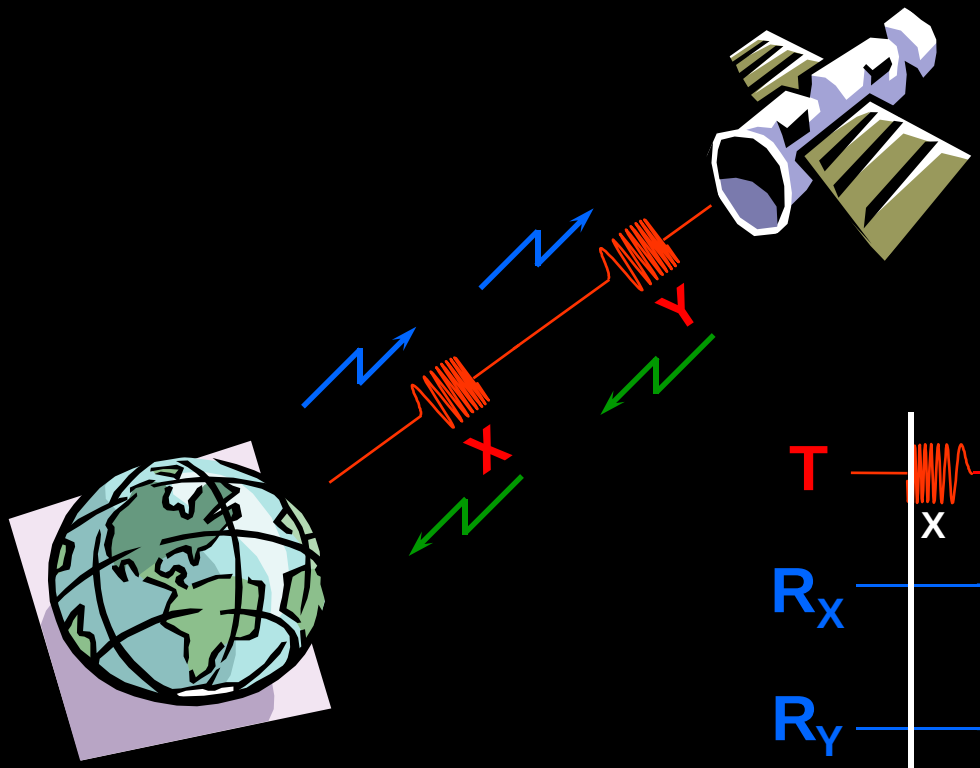
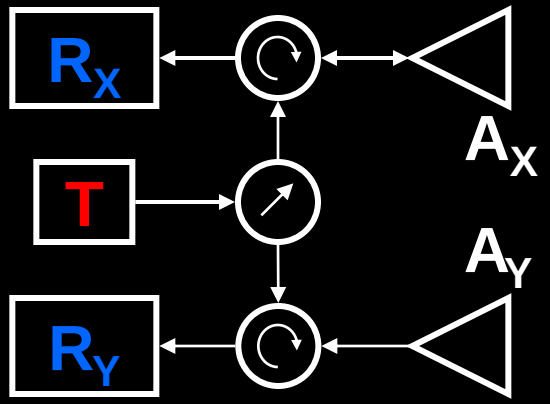
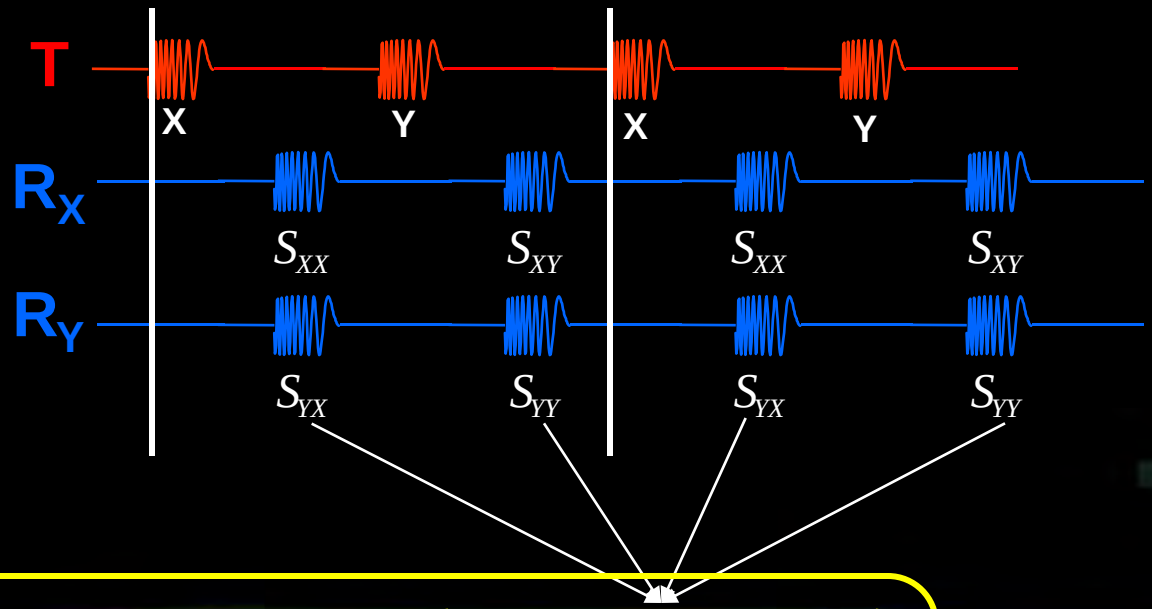
Scattering Polarimetry







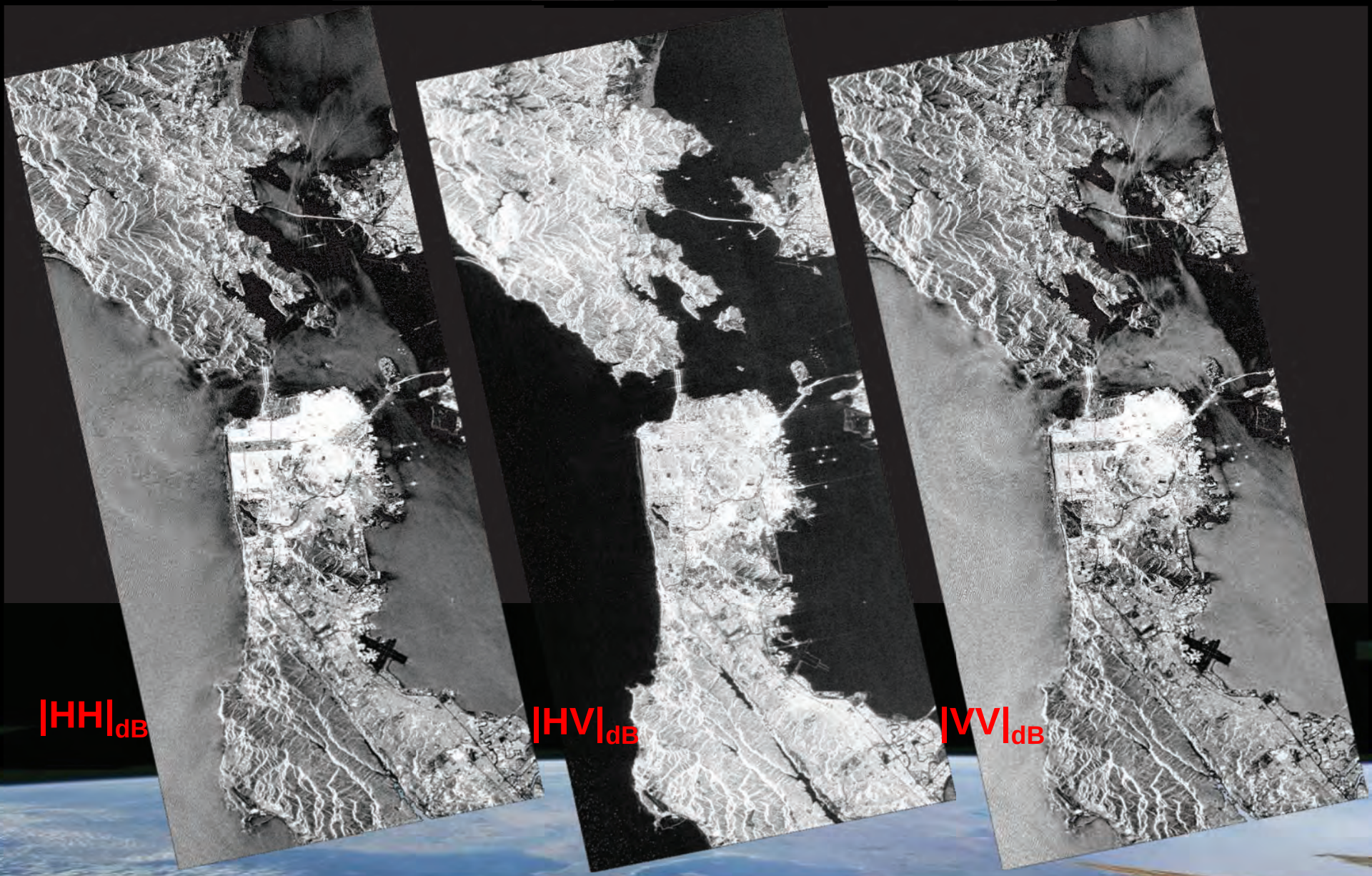
TRANSMITTER: X & Y
RECEIVERS: X & Y

SINCLAIR MATRICES

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

SCATTERING POLARIMETRY

Space-borne Sensors



San Francisco Bay – (L-Band)

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Space-borne Sensors

$|HH|_{dB}$

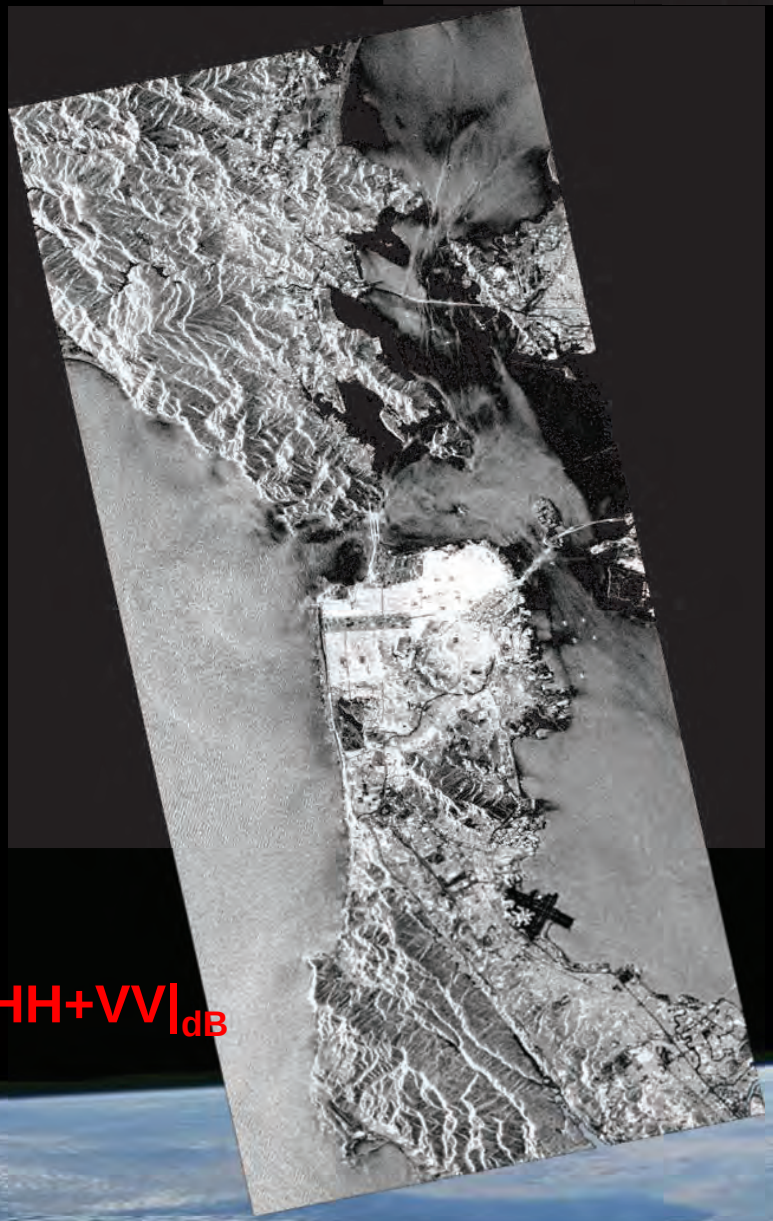
$|HV|_{dB}$

$|VV|_{dB}$

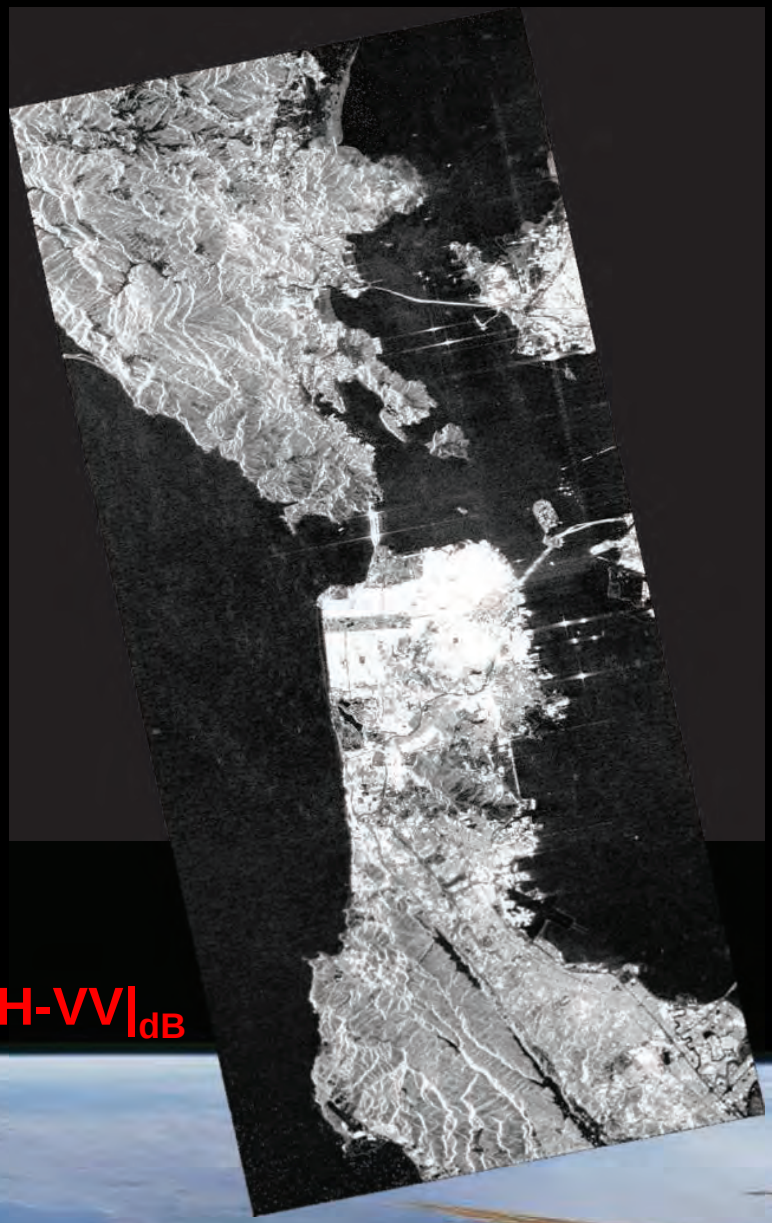
San Francisco Bay – (L-Band)

#E. Pottier (06/2017)

Space-borne Sensors



$|HH+VV|_{dB}$



$|HH-VV|_{dB}$

San Francisco Bay – (L-Band)

#E. Pottier (06/2017)

Space-borne Sensors

$|HH+VV|_{dB}$

$|HV|_{dB}$

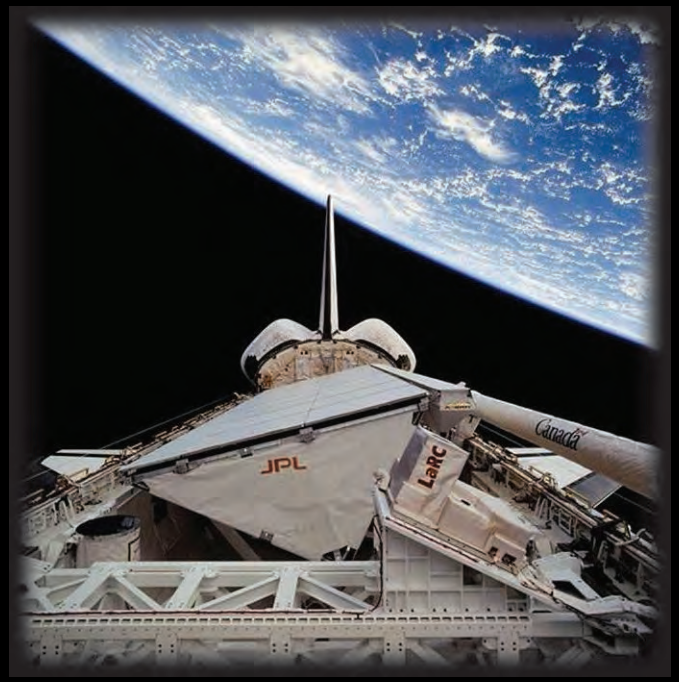
$|HH-VV|_{dB}$

San Francisco Bay – (L-Band)

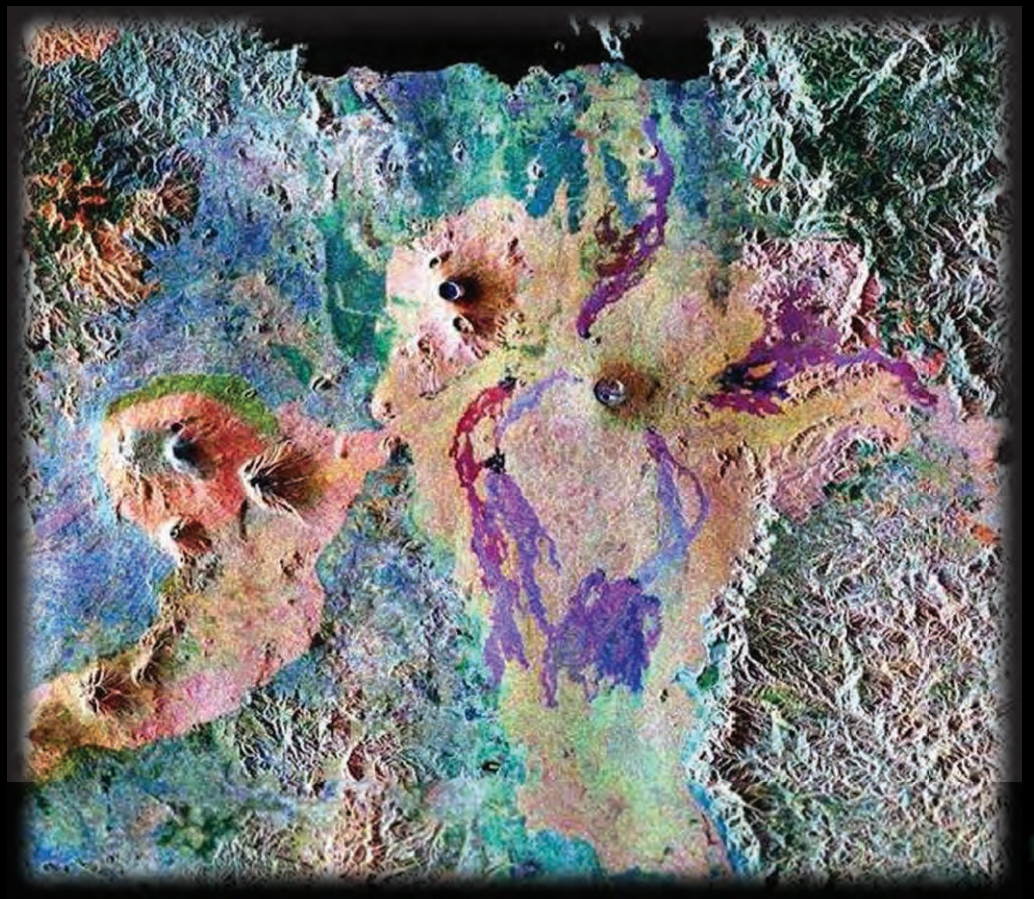
#E. Pottier (06/2017)

Space-borne PolSAR Sensors

SIR-C / X-SAR



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



Rwanda, Zaire, Uganda

Space-borne PolSAR Sensors

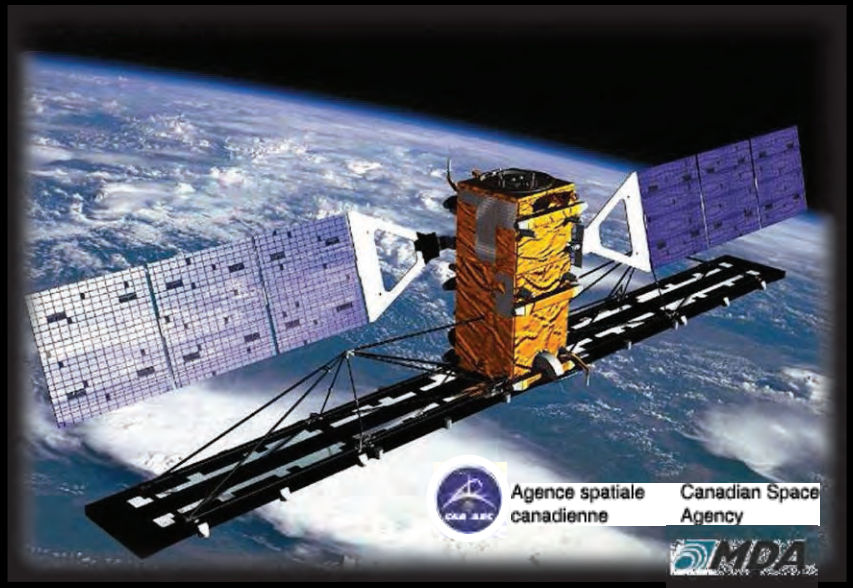
ALOS - PALSAR

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

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

Space-borne PolSAR Sensors

RADARSAT - 2



December 2007

C-Band (Quad)

Space-borne Sensors

$|HH+VV|_{dB}$

$|HV|_{dB}$

$|HH-VV|_{dB}$

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

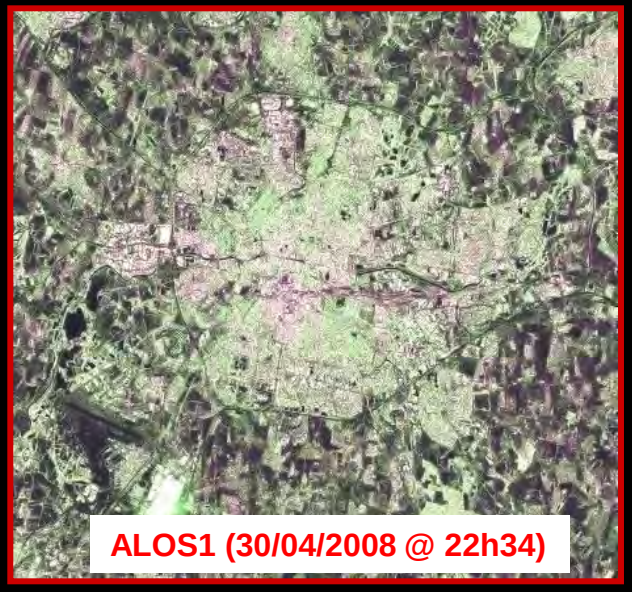
#E. Pottier (06/2017)

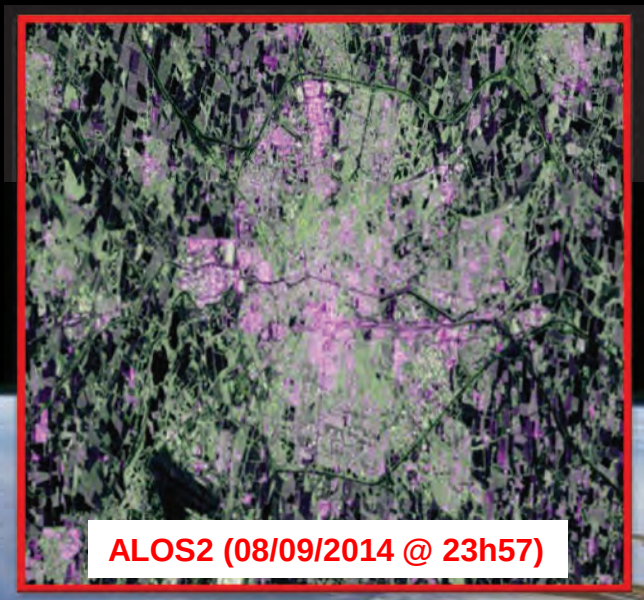
Space-borne PolSAR Sensors

ALOS - 2

May 2014

L-Band (Quad)





#E. Pottier (06/2017)

Space-borne PolSAR Sensors

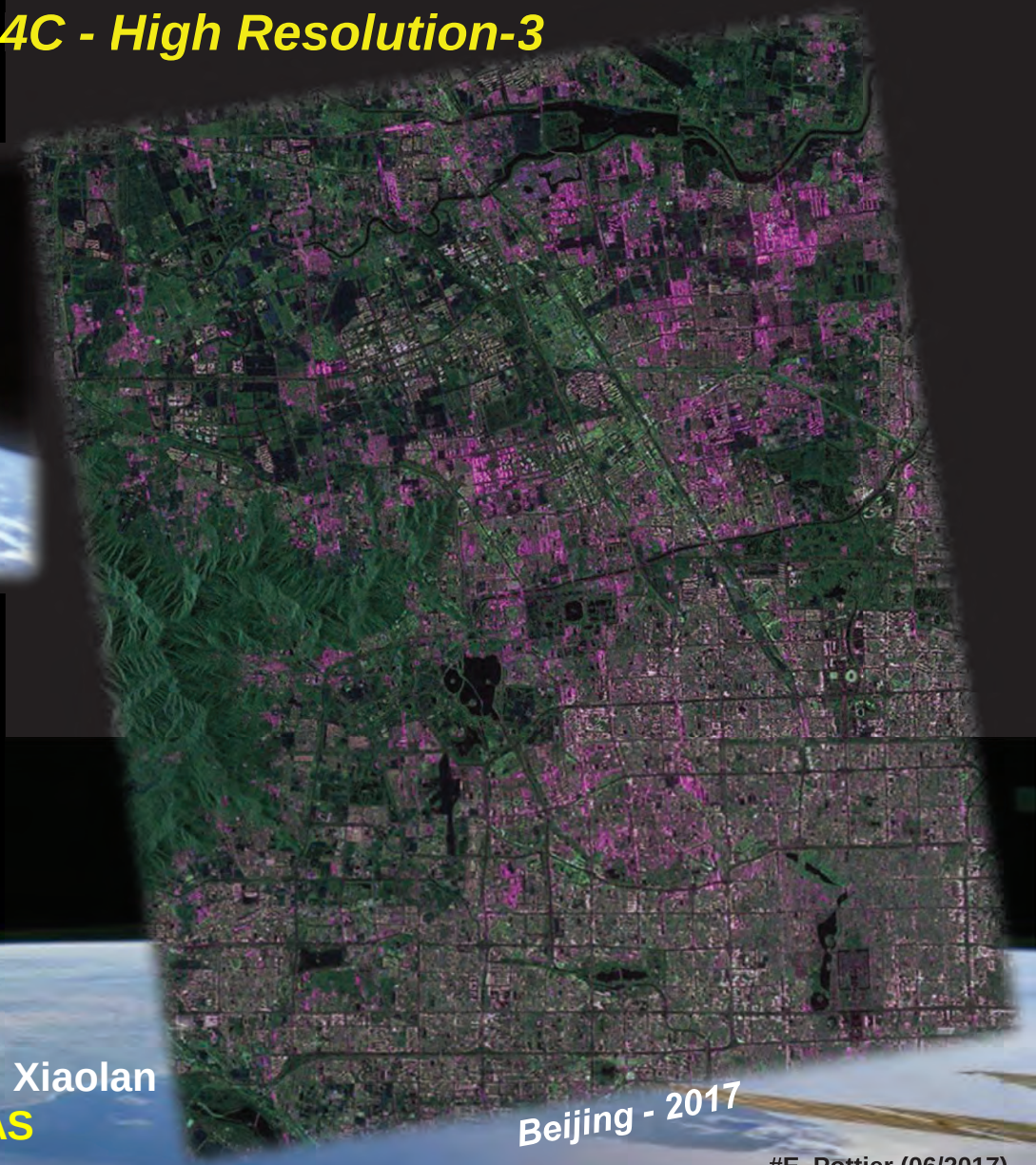
Chang Zheng-4C - GaoFen-3 (GF-3)

Long March-4C - High Resolution-3

August 2016

C-Band (Quad)

中国空间技术研究院
China Academy of Space Technology



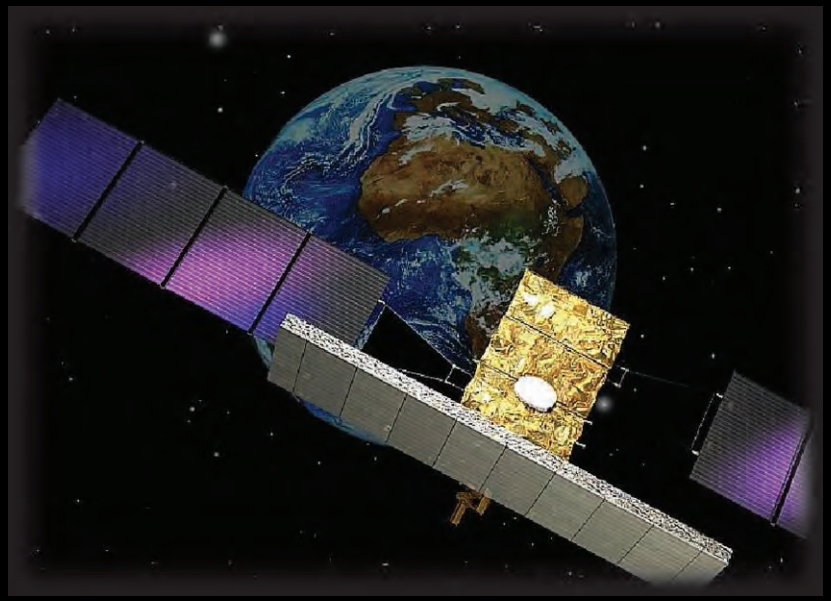
Courtesy of Dr. Qiu Xiaolan
IECAS / GIPAS

Beijing - 2017

#E. Pottier (06/2017)

Space-borne PolSAR Sensors

COSMO - SkyMed - CSG



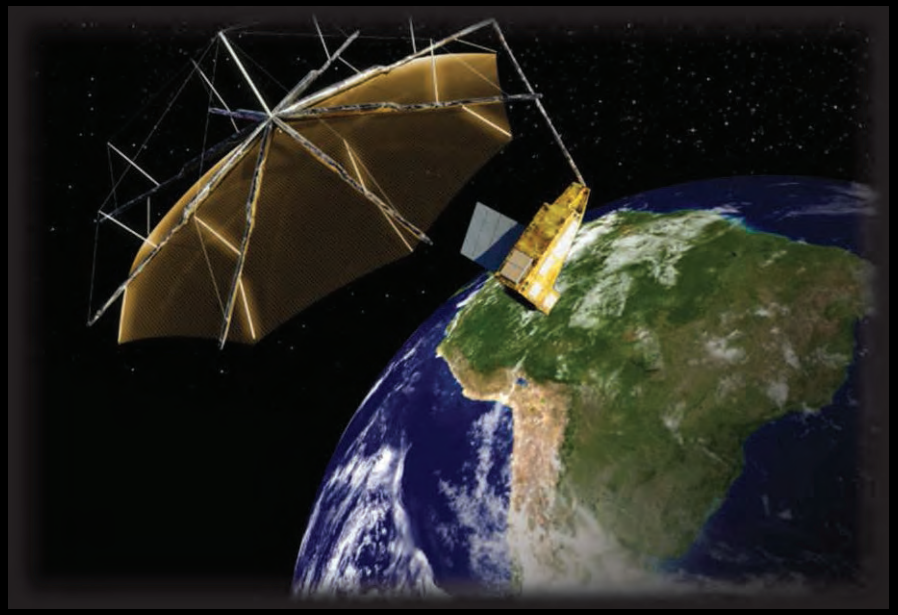
agenzia spaziale italiana

TELESPAZIO
A Finmeccanica / Thales Company

2A : 2018 2B : 2019

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

Earth Explorer - BIOMASS



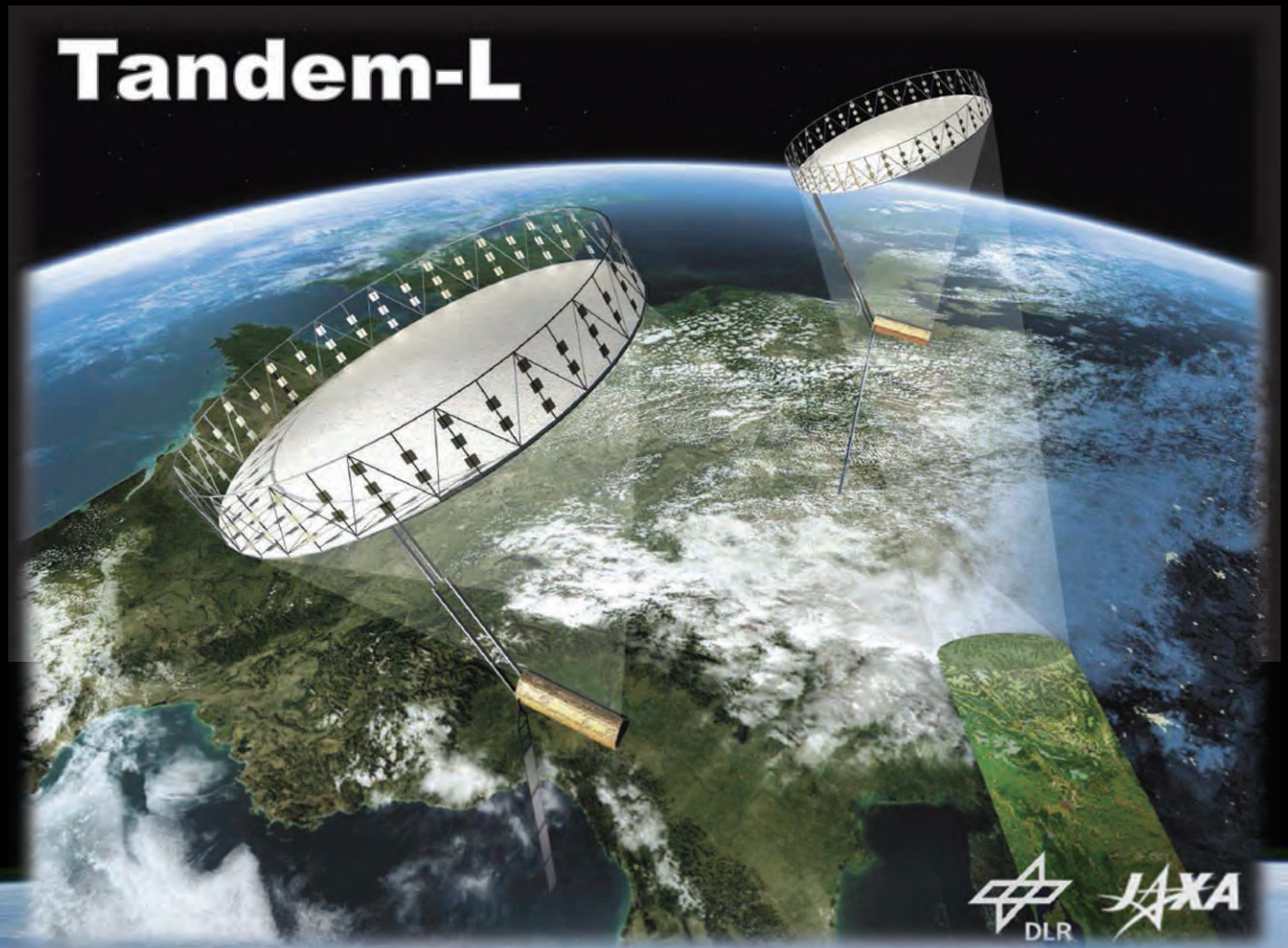
esa

2019

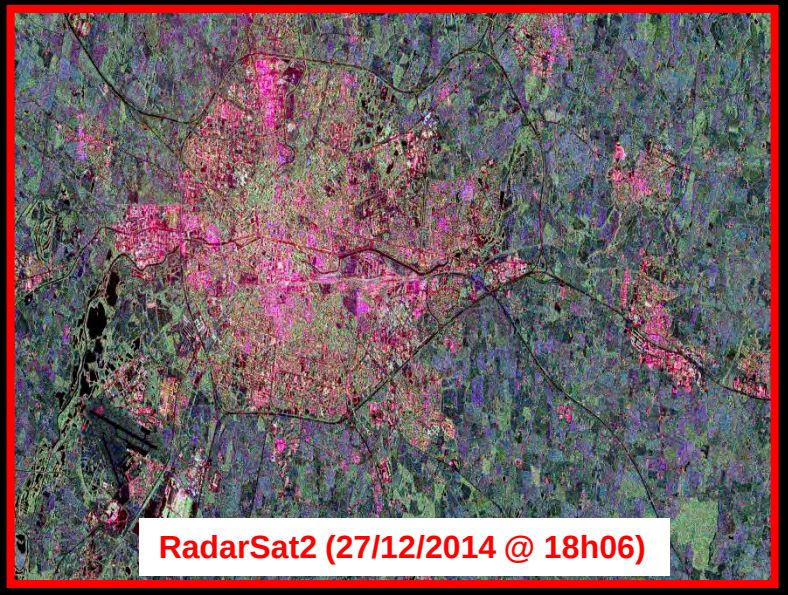
P-Band (Quad)

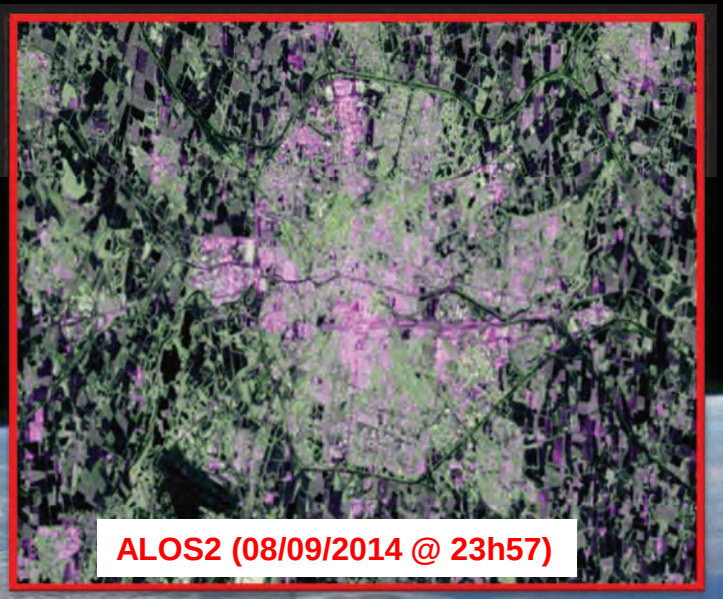
#E. Pottier (06/2017)

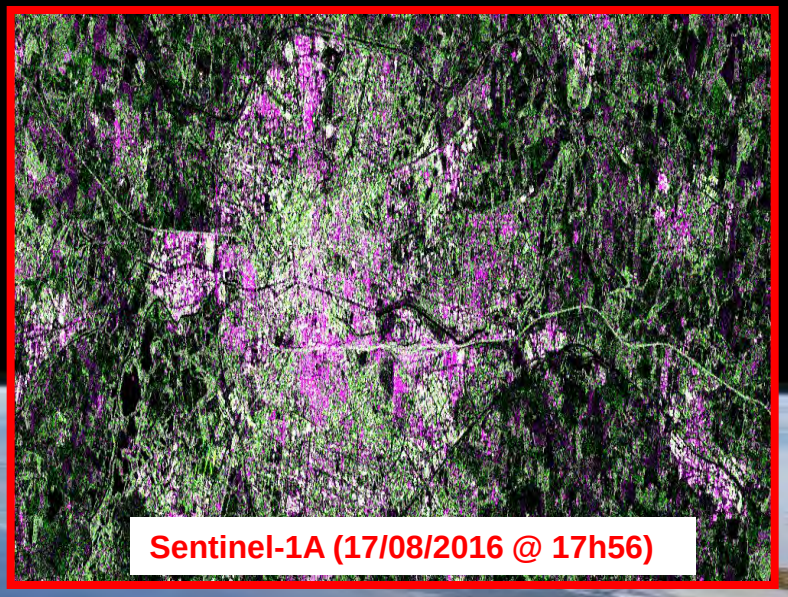
Space-borne PolSAR Sensors



Space-borne PolSAR Sensors







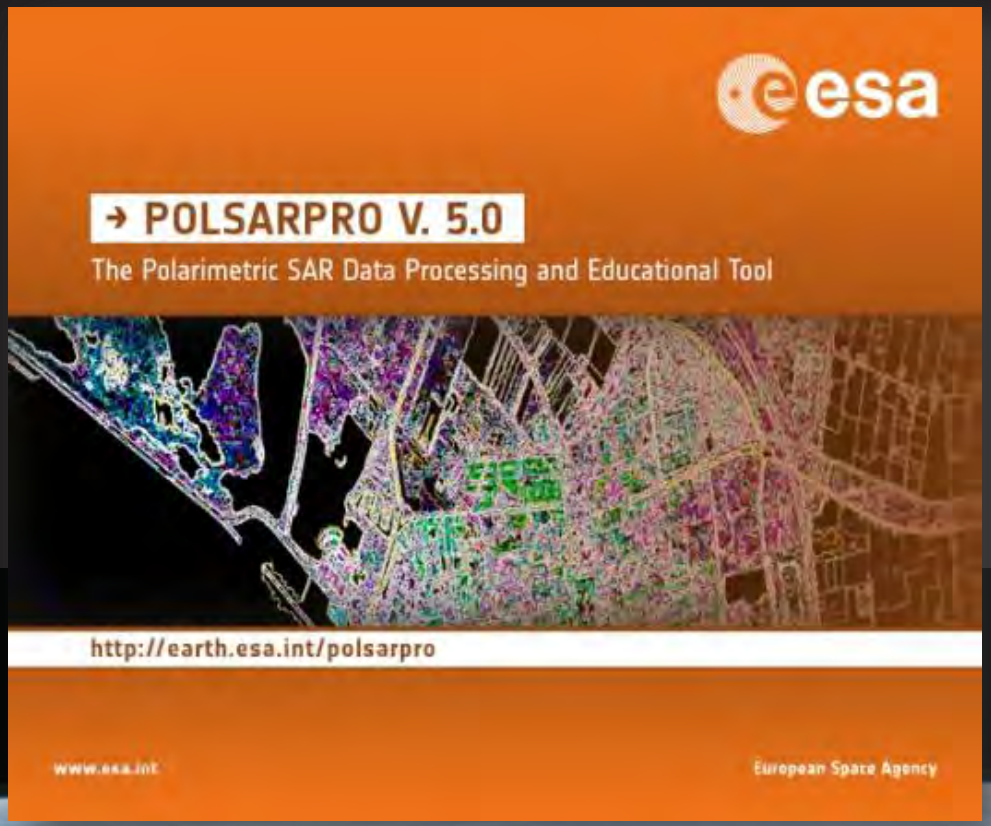
#E. Pottier (06/2017)

What About

Software / Toolbox ?

ESA PolSARpro Toolbox

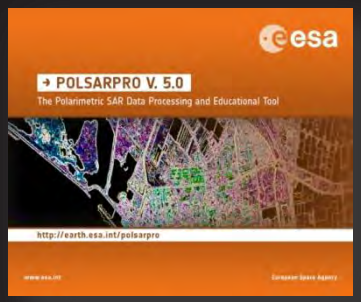
The Polarimetric SAR Data Processing and Educational Toolbox



#E. Pottier (06/2017)

ESA PolSARpro Toolbox

Polarimetric SAR data processing and educational toolbox



ESA funded project since 2003

+ 3000 registered users / + 70 foreign countries

Toolbox specifically designed to handle : Pol-SAR, Pol-InSAR and Pol-TimeSAR data

Educational Software offering a tool for self-education in the field of Polarimetric SAR data processing and analysis

International collaborative project : space agencies (4), research centres (14) and universities (19).

Airborne sensors : AIRSAR, CONVAIR, ESAR, EMISAR, FSAR, PISAR, SATHI, UAVSAR.

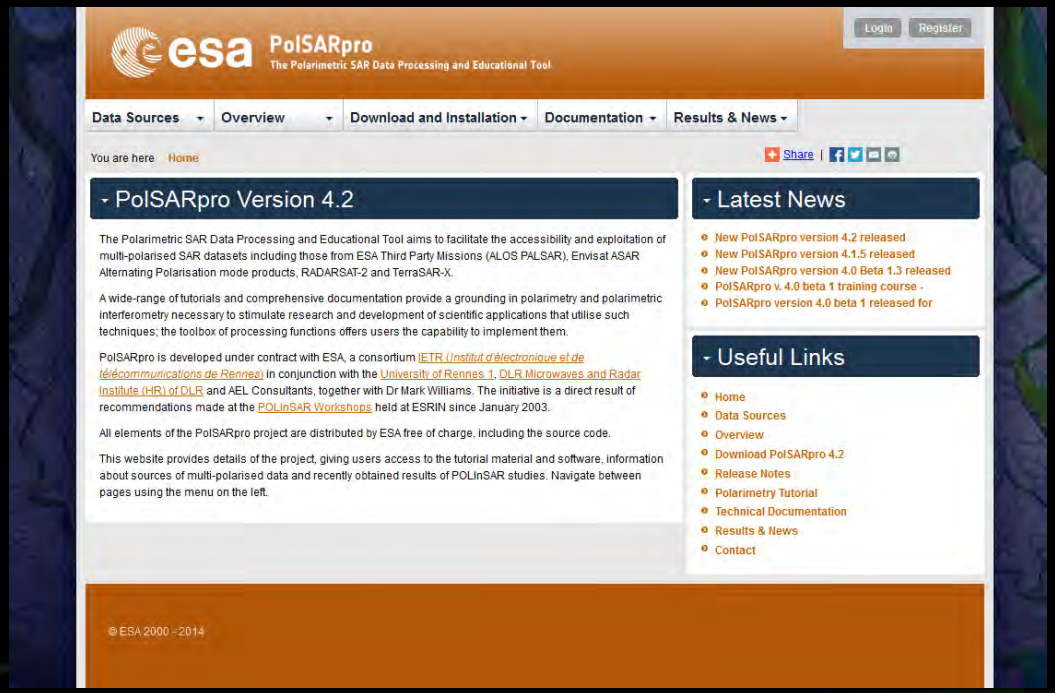
Spaceborne sensors : ALOS1, ALOS2, COSMO-Skymed, RADARSAT-2, RISAT, Sentinel 1A/B, TerraSAR-X, Tandem-X,

More than 550 different Pol-SAR, Pol-InSAR, Pol-TomSAR, Pol-TimeSAR functionalities.

ESA PolSARpro Toolbox

http://earth.esa.int/web/polsarpro

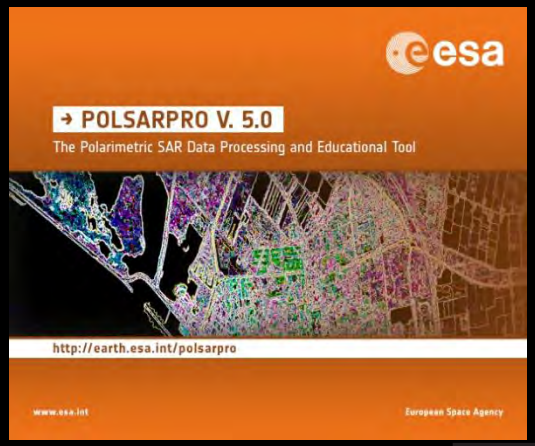
The Web Site provides

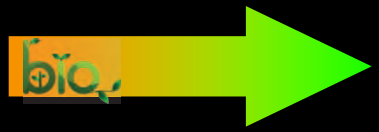


- **Details of the project**
- **Access to the tutorial and software**
- **Information about status of the development**
- **Demonstration Sample Datasets**

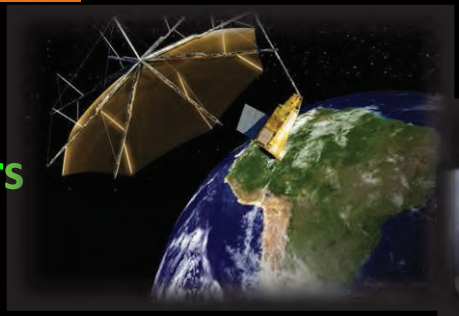
ESA PolSARpro Toolbox

ESA & third party fully polarimetric SAR missions (PolSARpro-Bio)



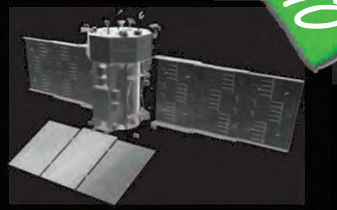


Future spaceborne sensors



BIOMASS

R.C.M



SAOCOM-CS

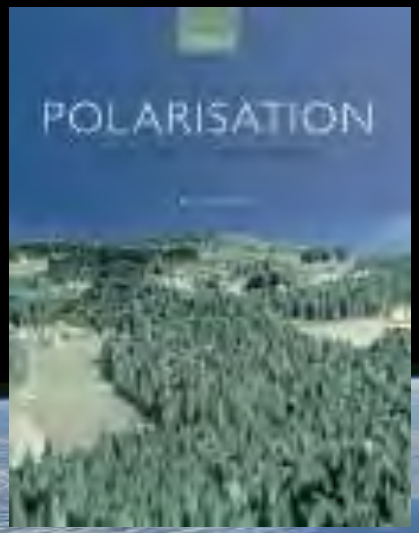
New functionalities : Pol-SAR, Pol-TomSAR and Pol-TimeSAR / Cloud-based infrastructure …

Learning / Training

Next P.I Generations

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

Books On Polarimetric Radar SAR, Polarimetric Interferometry

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Prof. Wen HONG, Dr. Qiang YIN et al.

Polarimetric Radar Imaging: From basics to applications
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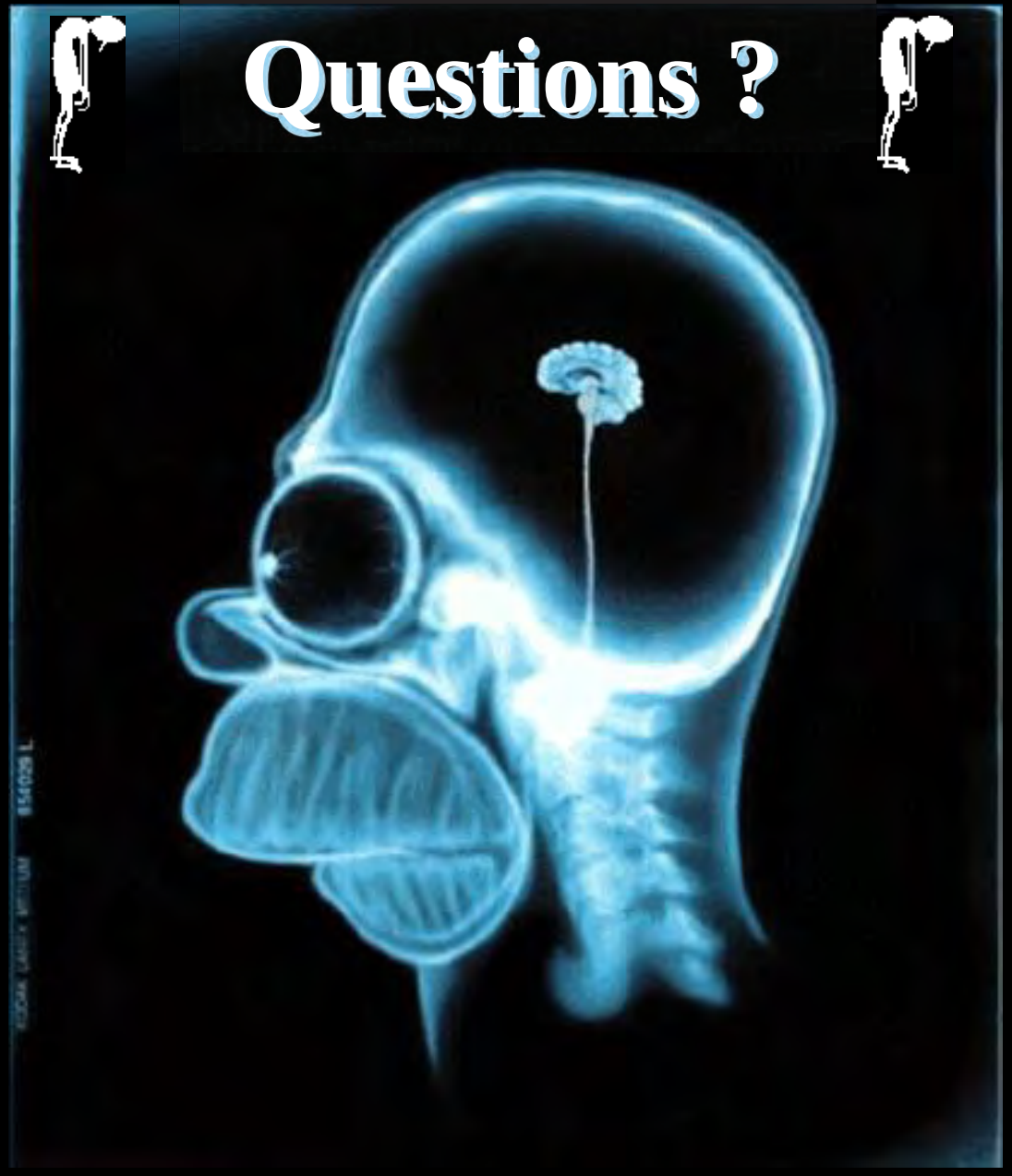
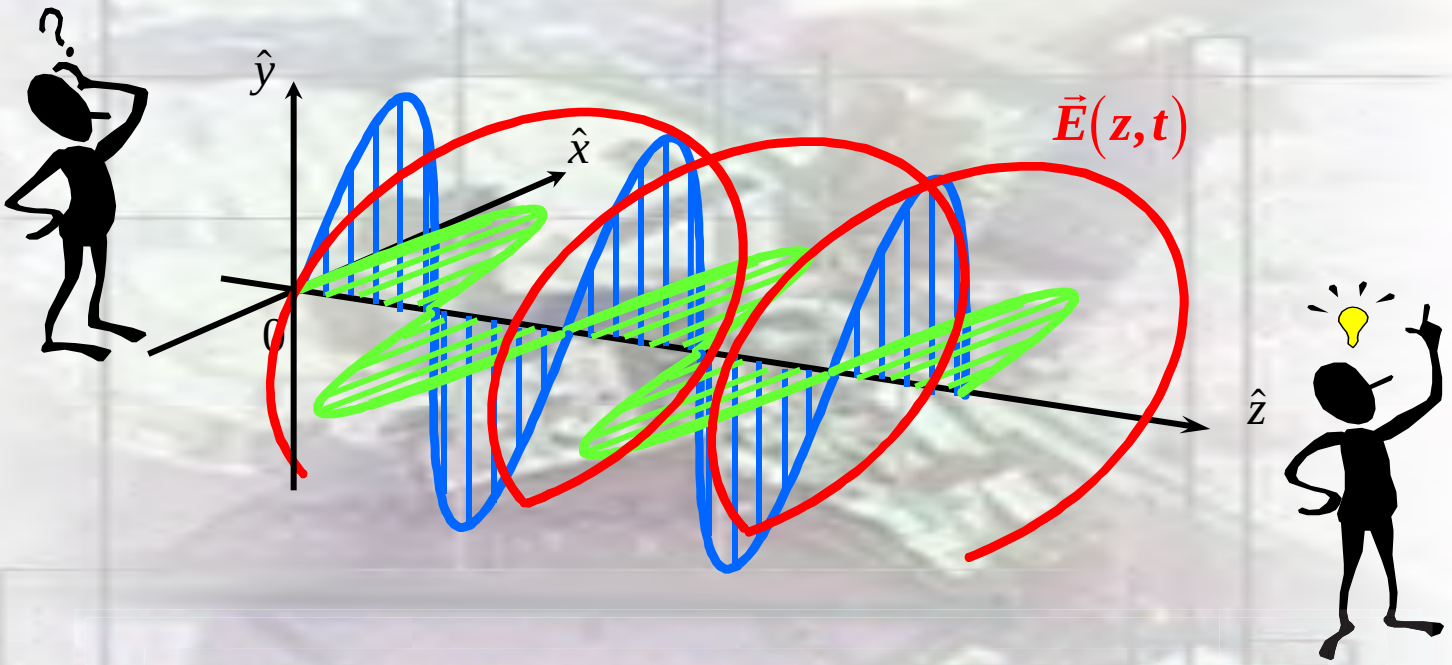
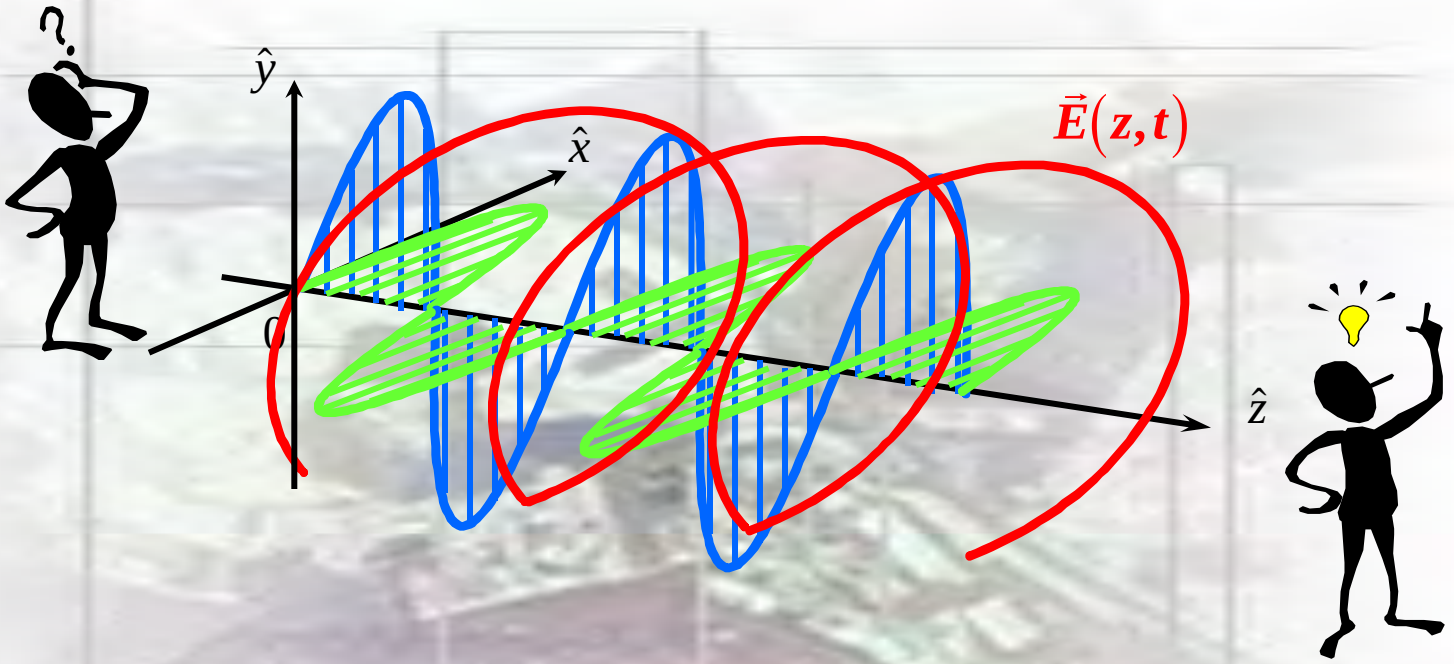
Questions ?



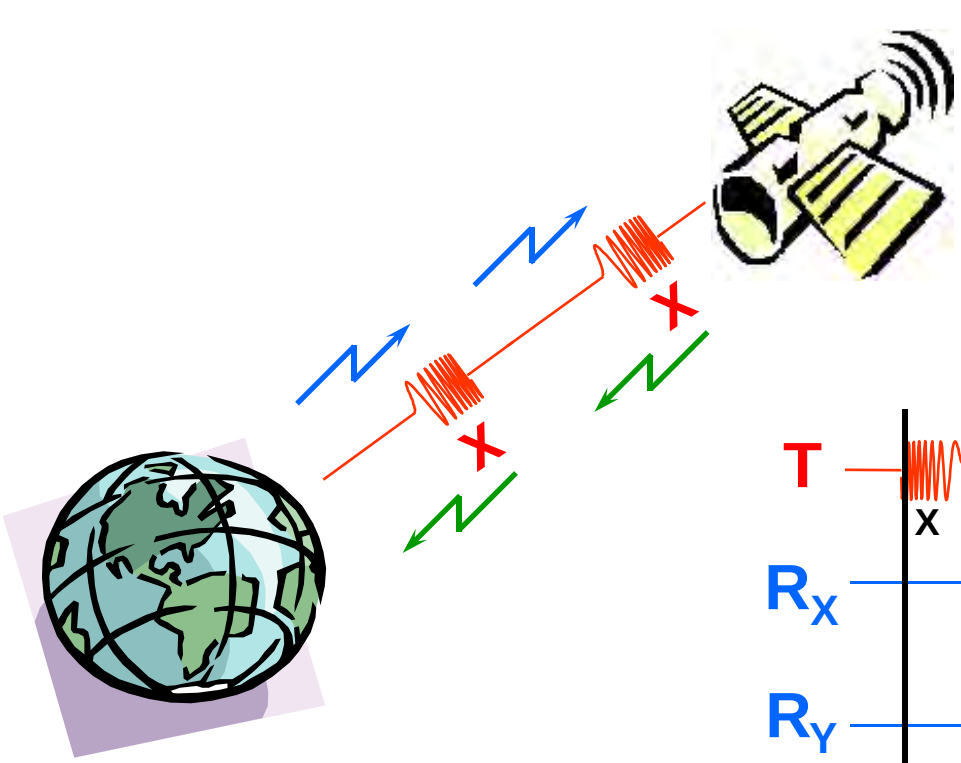


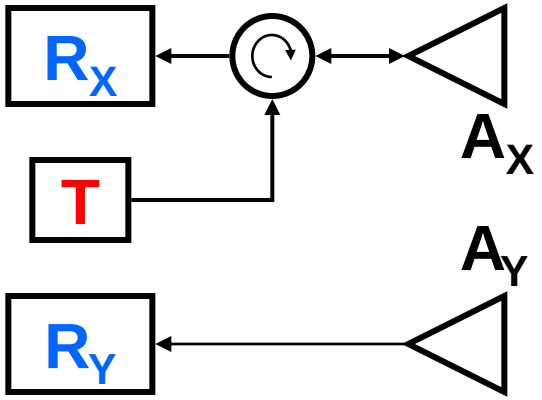
BASIC CONCEPTS

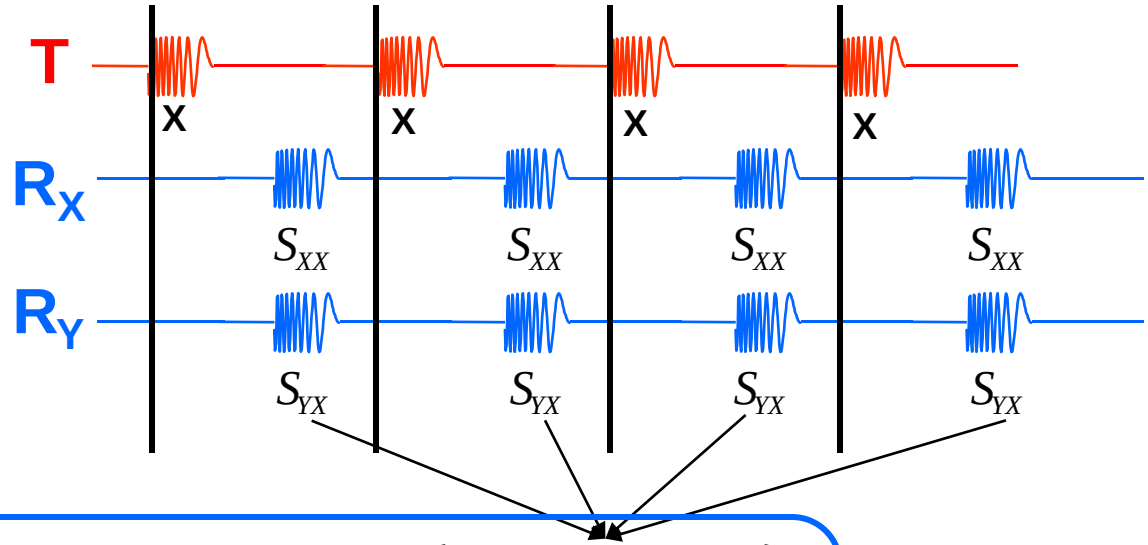


SCATTERING POLARIMETRY

WAVE POLARIMETRY





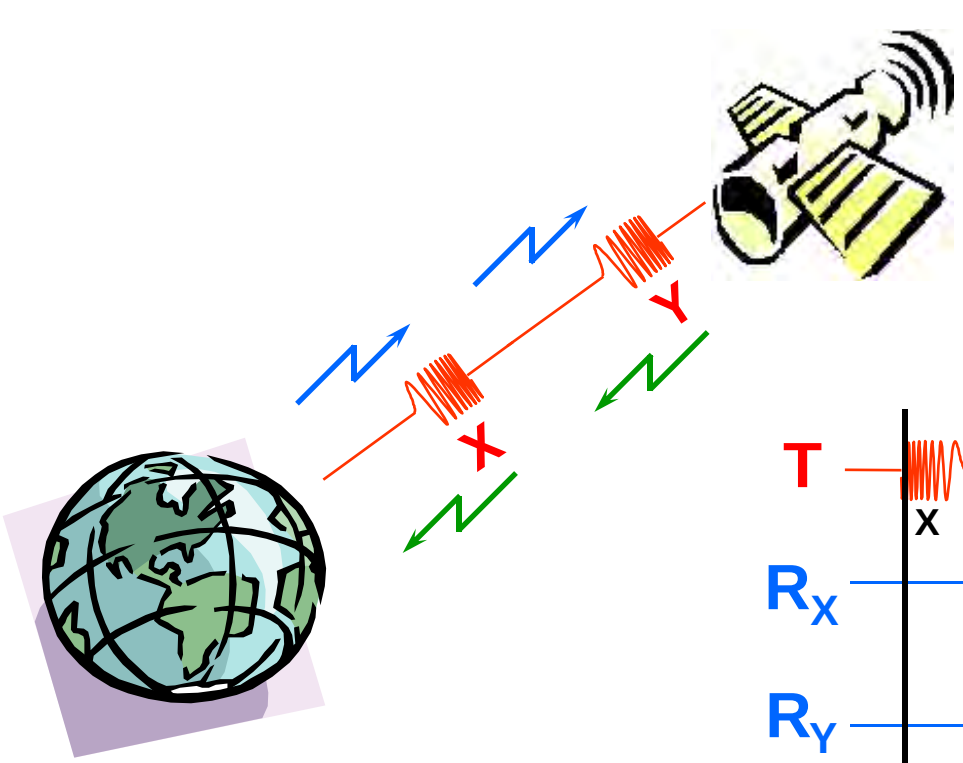


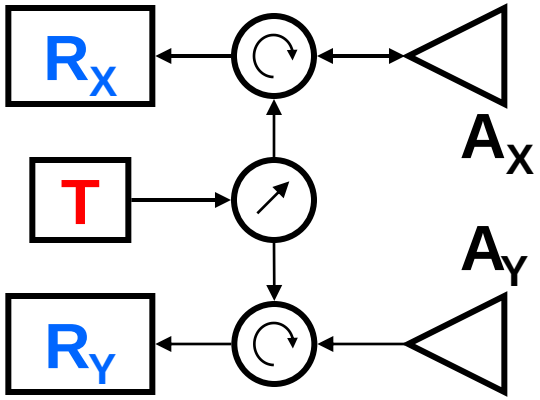
TRANSMITTER: X
RECEIVERS: X & Y

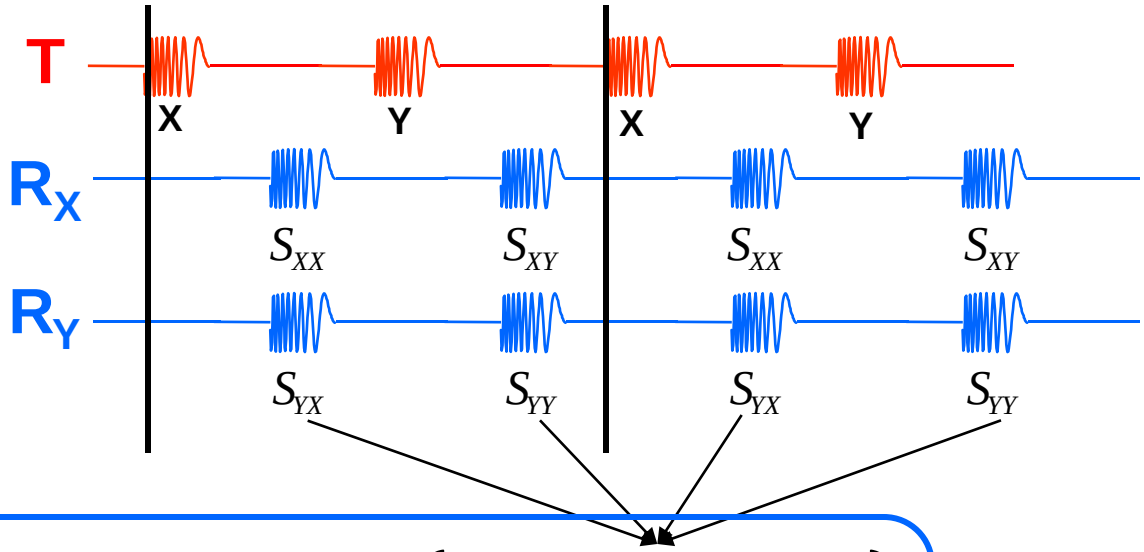
JONES VECTORS $\left\{ \underline{E}_S = \begin{bmatrix} S_{XX} \\ S_{YX} \end{bmatrix} \right\}$

WAVE POLARIMETRY

SCATTERING POLARIMETRY







TRANSMITTER: X & Y
RECEIVERS: X & Y

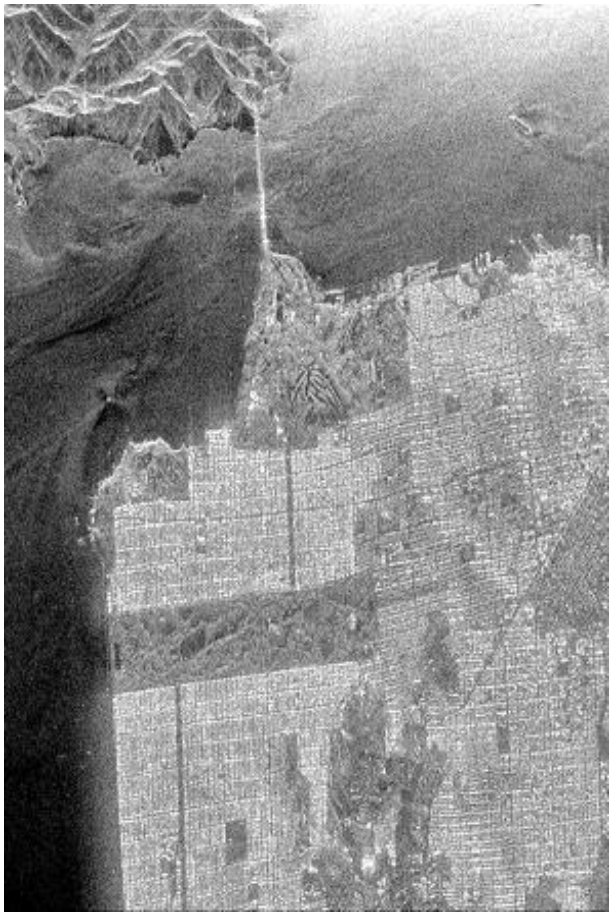
SINCLAIR MATRICES

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

SCATTERING POLARIMETRY

SCATTERING POLARIMETRY

Tx → Rx



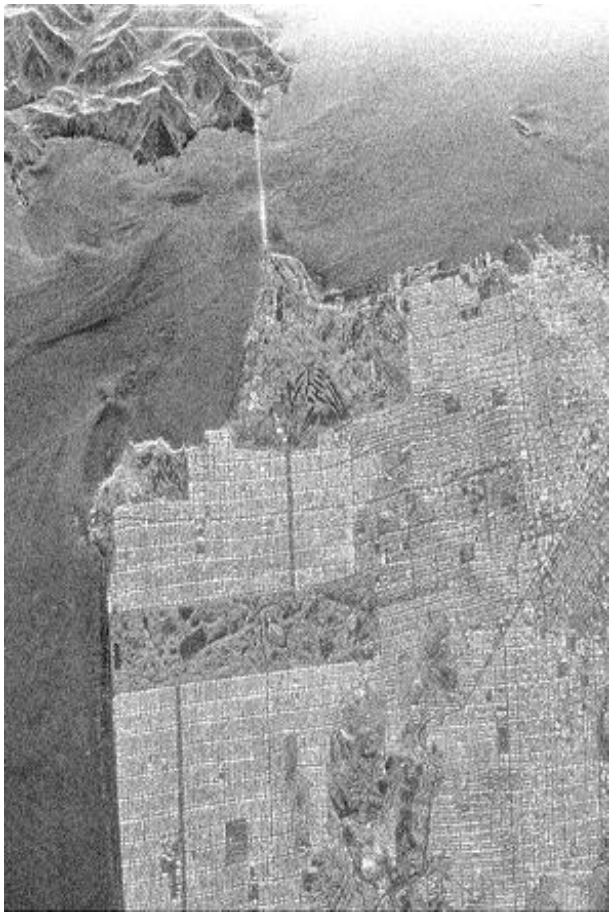
$|HH|_{dB}$

Tx → Rx

$|HV|_{dB}$

-30dB -15dB 0dB

Tx ↑ Rx ↑



$|VV|_{dB}$

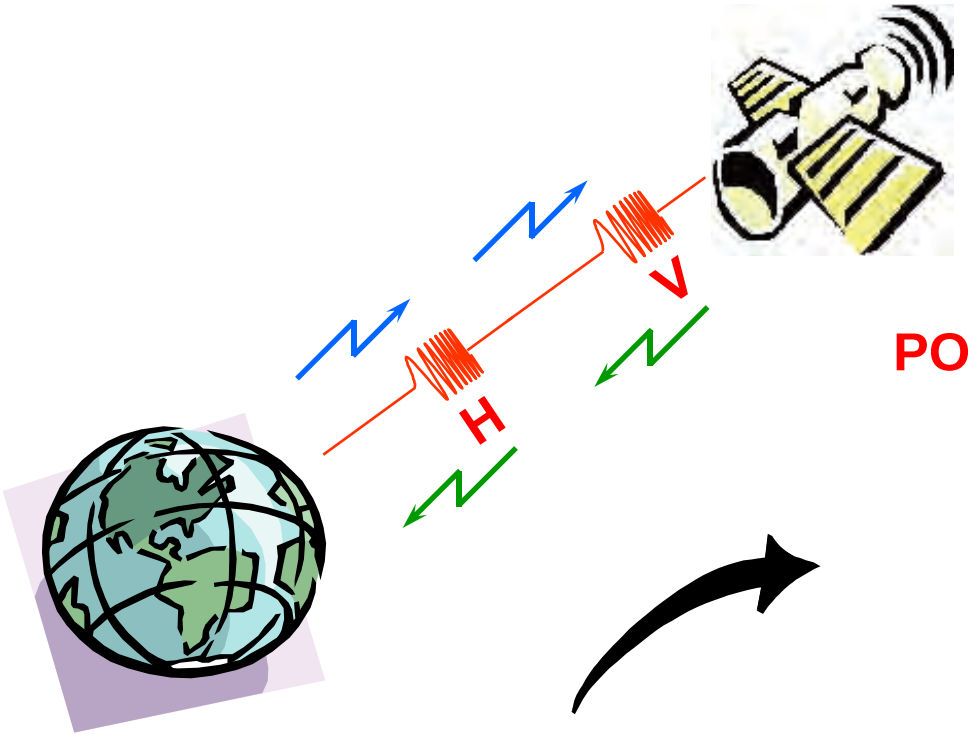
SCATTERING POLARIMETRY

Sinclair Color Coding

© Google Earth

|HH| |HV| |VV|

SINCLAIR MATRIX



TRANSMITTER: H & V
RECEIVERS: H & V

POLARIMETRIC DESCRIPTORS

[S] SINCLAIR Matrix

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

k Target Vector

[T] 3x3 COHERENCY Matrix

COHERENCY MATRIX

TARGET VECTOR $\underline{k}$

$$\underline{k} = \frac{1}{\sqrt{2}}\left[S_{HH} + S_{VV} \quad S_{HH} - S_{VV} \quad 2S_{HV}\right]^T$$

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

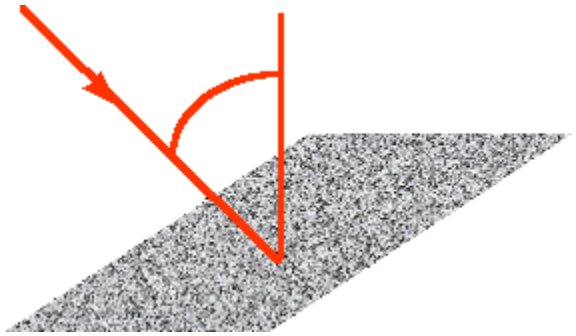
A0, B0+B, B0-B : HUYNEN TARGET GENERATORS

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

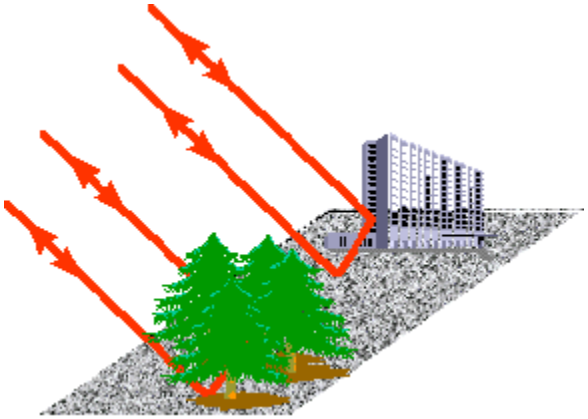
TARGET GENERATORS

PHYSICAL INTERPRETATION

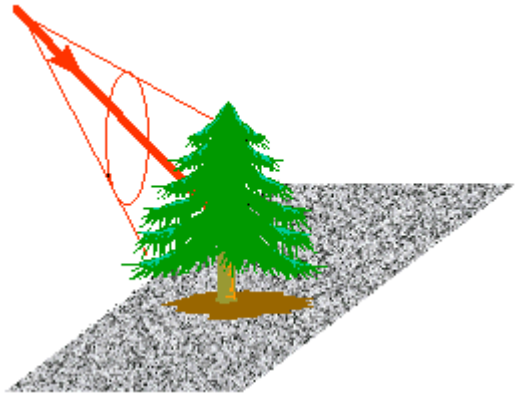
SINGLE BOUNCE SCATTERING
(ROUGH SURFACE)



DOUBLE BOUNCE SCATTERING



VOLUME SCATTERING

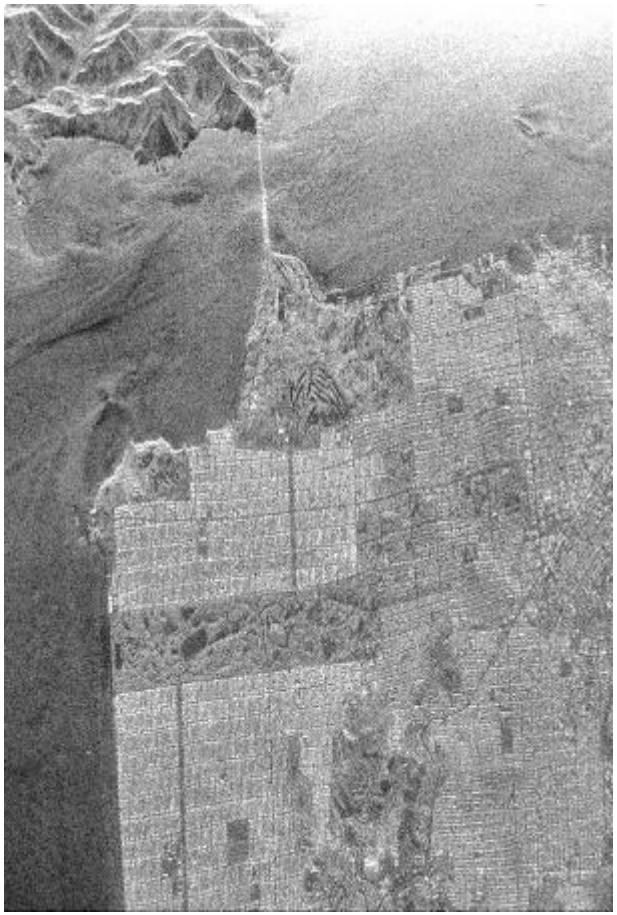


$$T_{11} = 2A_0 = \left|S_{XX} + S_{YY}\right|^2$$

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

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

TARGET GENERATORS



$|HH+VV|_{dB}$

$|HV|_{dB}$

-30dB -15dB 0dB

$|HH-VV|_{dB}$

TARGET GENERATORS

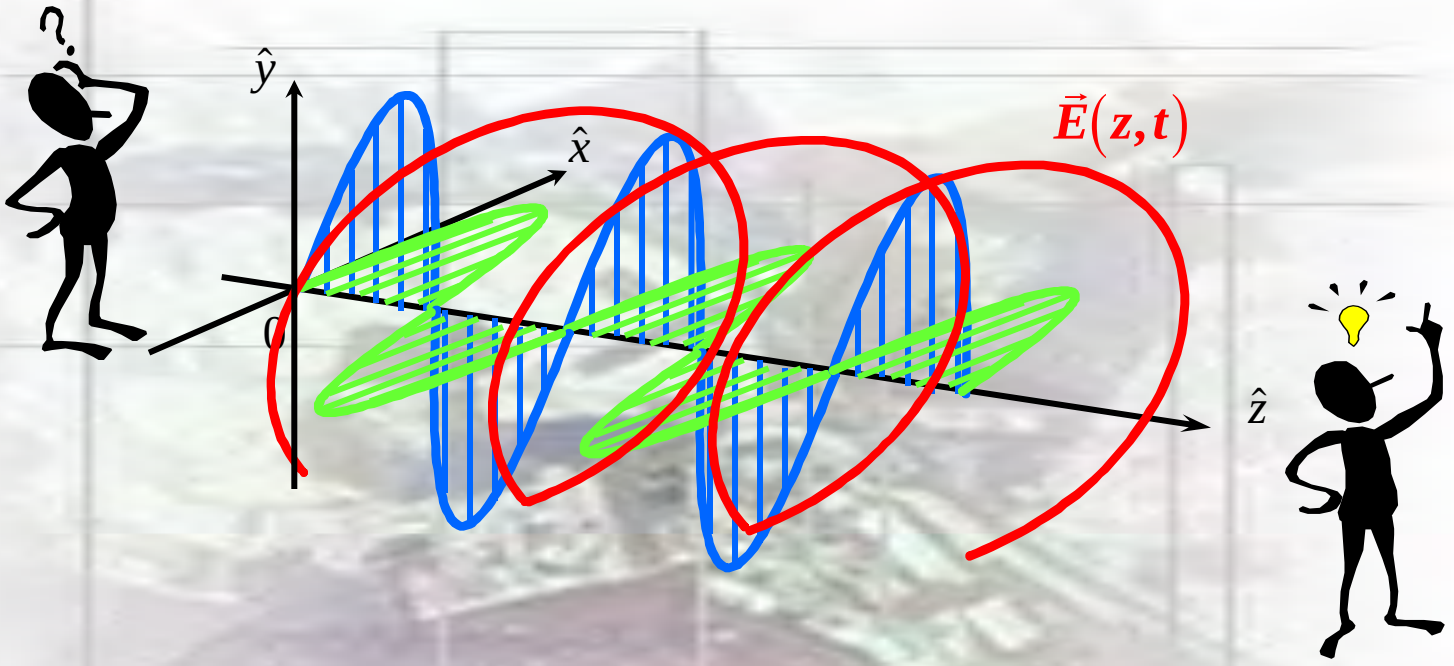
(H,V) POLARISATION BASIS

© Google Earth

|HH+VV|

|HV |

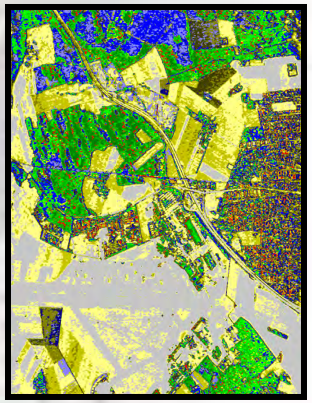
|HH-VV|



POLARIMETRIC REMOTE SENSING

POLARIMETRIC REMOTE SENSING

POL-SAR PROCESSING
PHENOMENOLOGIC
QUALITATIVE ANALYSIS



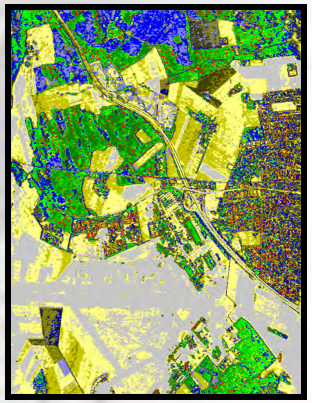
POLARIMETRIC SPECKLE FILTERING

POLARIMETRIC TARGET DECOMPOSITION

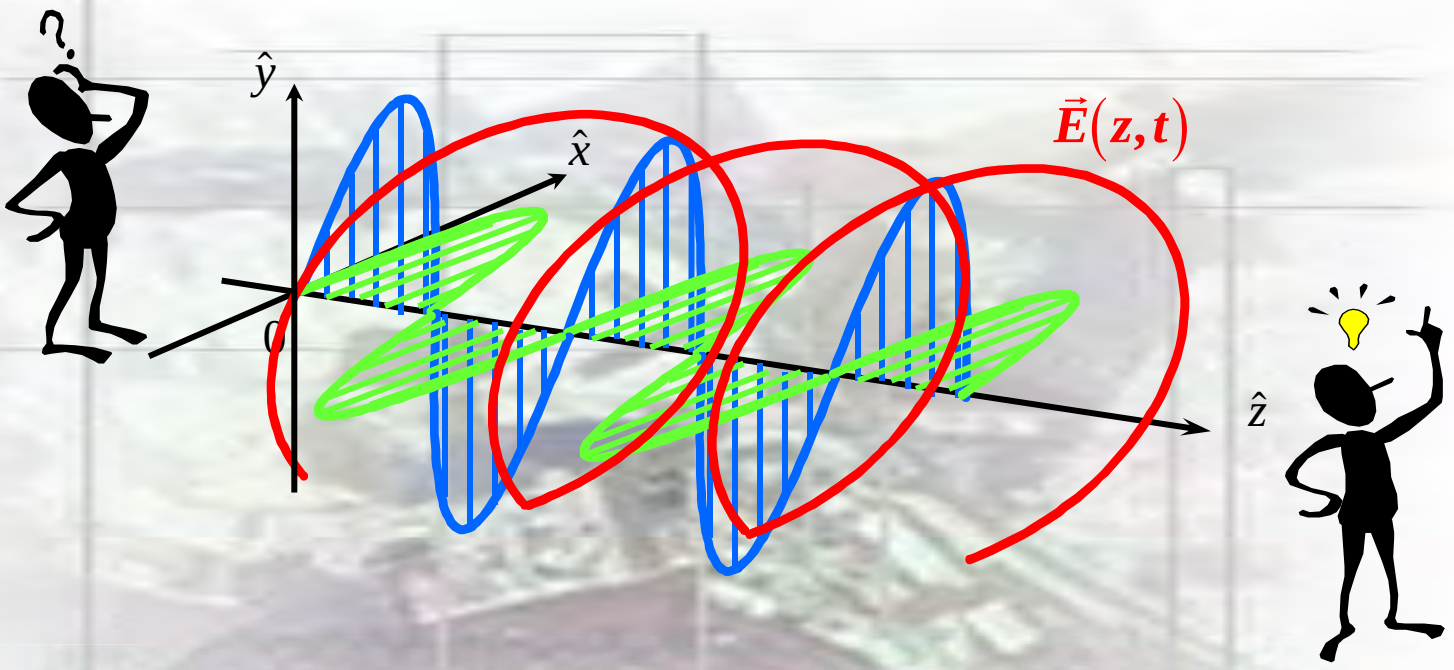
POLARIMETRIC CLASSIFICATION
MONO/DUAL CHANNELS

POLARIMETRIC REMOTE SENSING

POL-SAR PROCESSING
PHENOMENOLOGIC
QUALITATIVE ANALYSIS



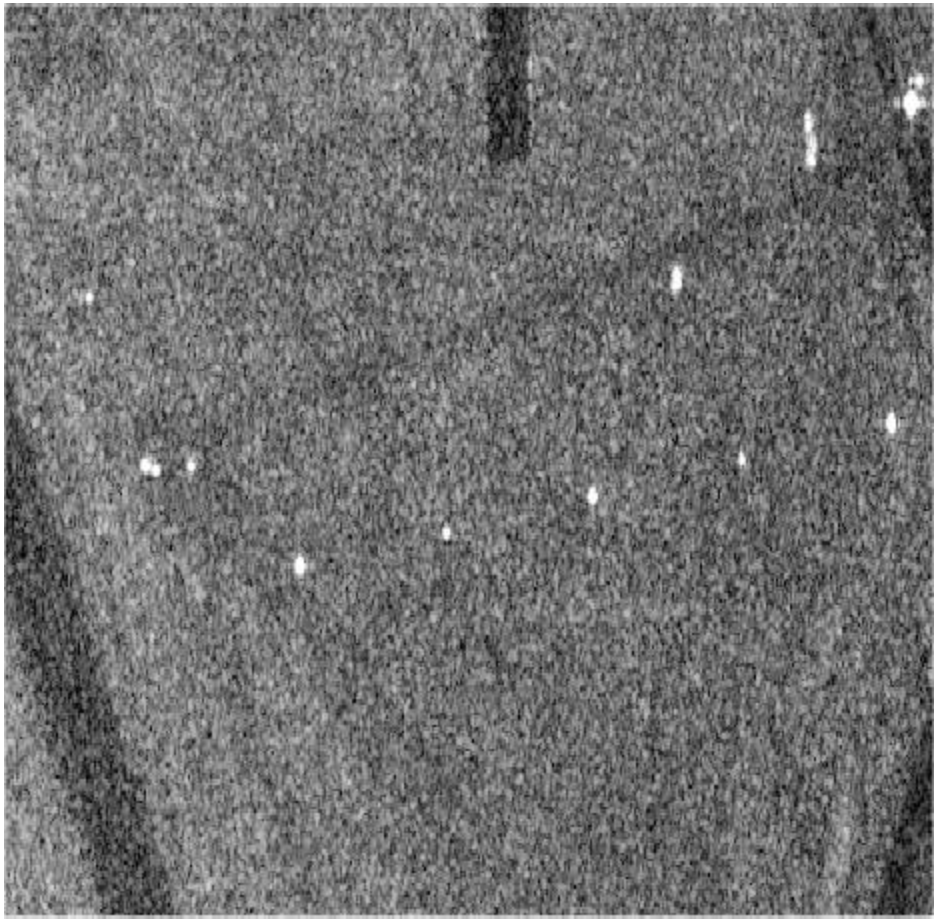
POLARIMETRIC SPECKLE FILTERING → **POLARIMETRIC TARGET DECOMPOSITION** → **POLARIMETRIC CLASSIFICATION**
MONO/DUAL CHANNELS



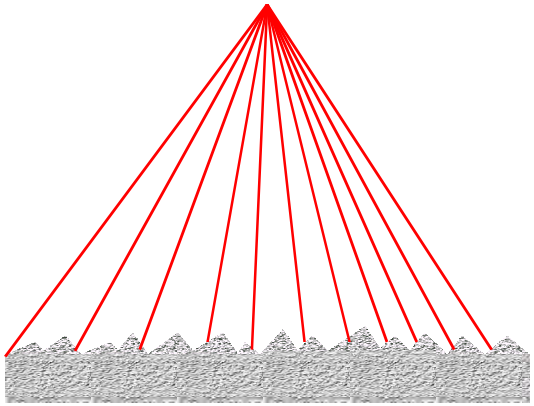
POLARIMETRIC SPECKLE FILTERING

An Introduction

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

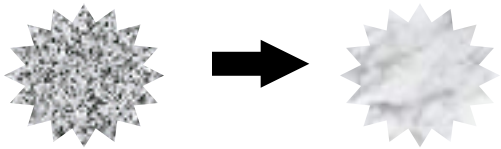
SPECKLE PHENOMENON

↓

DISTORTION OF THE INTERPRETATION

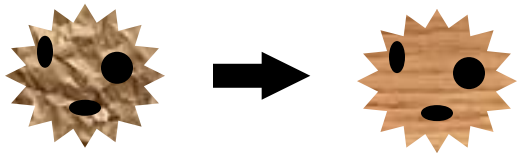
SPECKLE FILTERING

HOMOGENEOUS AREA



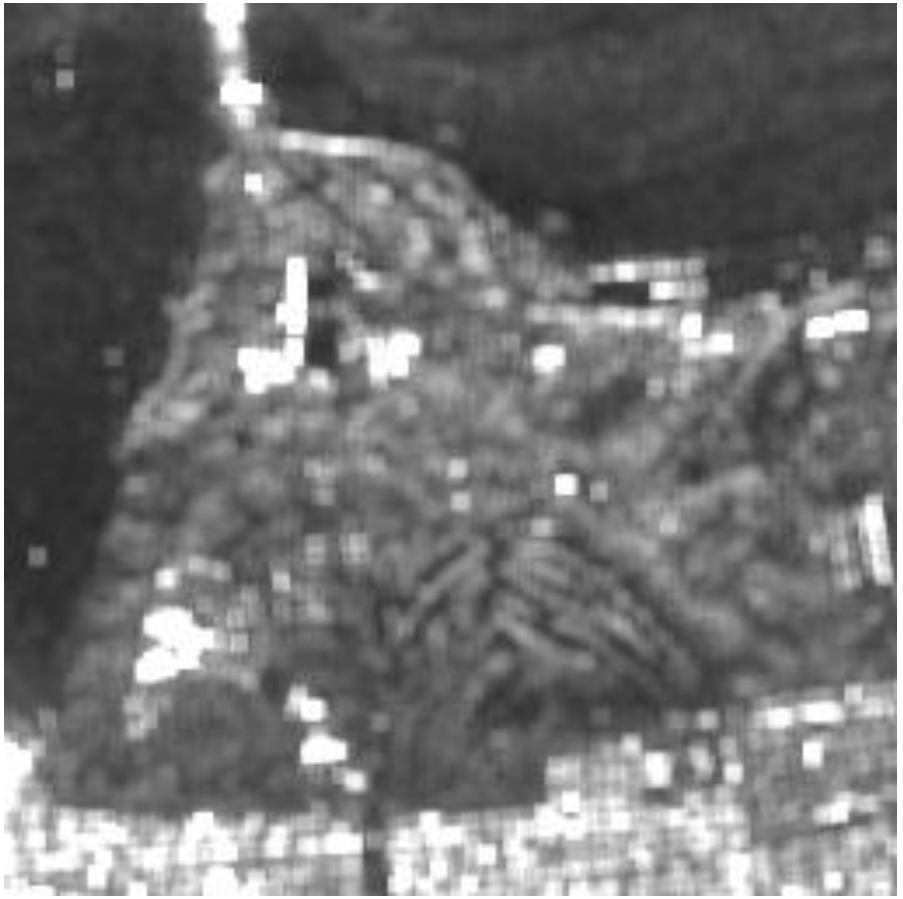
SPECKLE REDUCTION
(RADIOMETRIC RESOLUTION)

HETEROGENEOUS AREA



DETAILS PRESERVATION
(SPATIAL RESOLUTION)

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

SPECKLE FILTERING

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

SPECKLE FILTER

AVERAGING DATA

SECOND ORDER STATISTICS

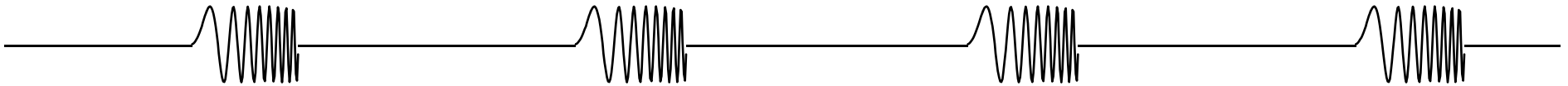
COHERENCY MATRICES

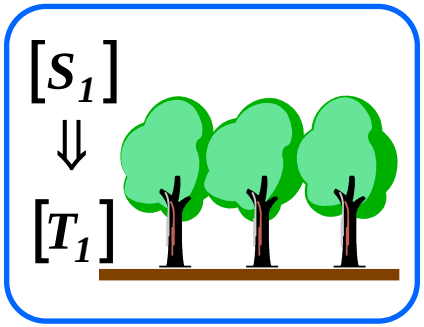
SMOOTHING AVERAGING

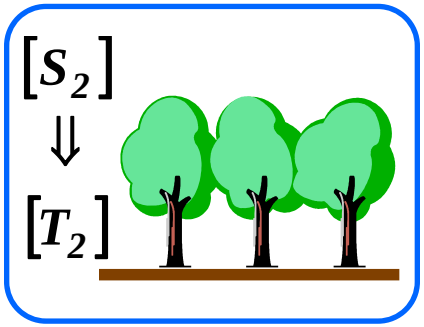
$$\langle [T] \rangle = \frac{1}{N} \sum_{i=1}^{N} \underline{k}_i \, \underline{k}_i^{*T}$$

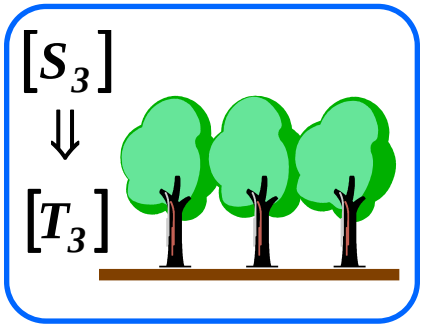
CONCEPT OF THE **DISTRIBUTED TARGET**

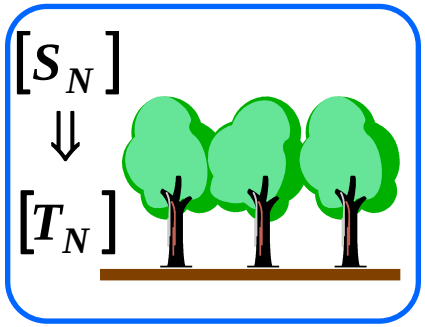
TARGET DECOMPOSITIONS



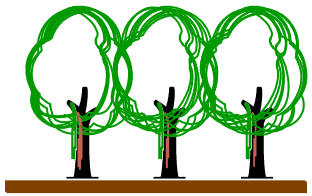






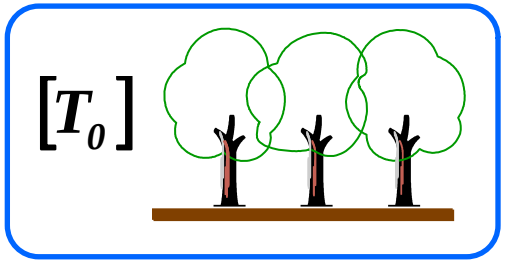


$$\langle [T] \rangle = \frac{1}{N} \sum_{i=1}^{i=N} [T_i]$$



DISTRIBUTED TARGET or AVERAGED TARGET

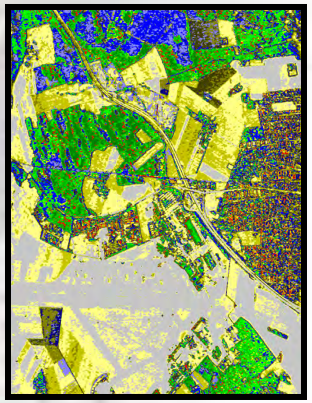
DECOMPOSITION THEOREM



MEAN TARGET

POLARIMETRIC REMOTE SENSING

POL-SAR PROCESSING
PHENOMENOLOGIC
QUALITATIVE ANALYSIS



POLARIMETRIC SPECKLE FILTERING

POLARIMETRIC TARGET DECOMPOSITION

POLARIMETRIC CLASSIFICATION
MONO/DUAL CHANNELS

TARGET DECOMPOSITIONS

[S]

COHERENT DECOMPOSITION

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

[K]

TARGET DICHOTOMY

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

[T]

EIGENVECTORS BASED DECOMPOSITION

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

EIGENVECTORS / EIGENVALUES ANALYSIS ENTROPY / ANISOTROPY

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

[C]

AZIMUTHAL SYMMETRY

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)

TARGET DECOMPOSITIONS

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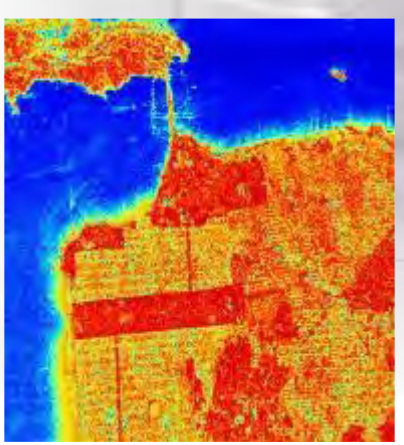
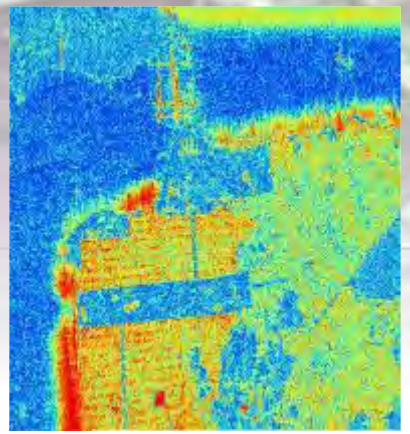
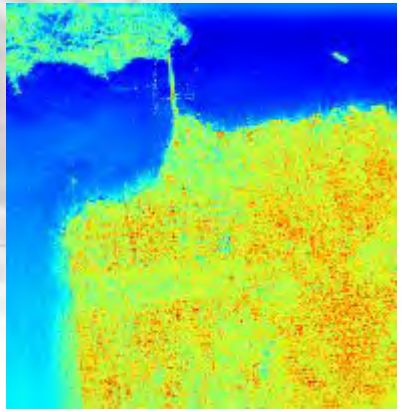
- S.R. CLOUDE - E. POTTIER (1996-1997)

THE H / A / α POLARIMETRIC TARGET DECOMPOSITION THEOREM







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

H / A / α DECOMPOSITION

TARGET VECTOR

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

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

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

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

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

ORTHOGONAL EIGENVECTORS

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

PARAMETERISATION OF THE SU(3) UNITARY MATRIX

$$[U_3] = \begin{bmatrix} \cos\alpha_1 e^{j\phi_1} & \cos\alpha_2 e^{j\phi_2} & \cos\alpha_3 e^{j\phi_3} \\ \sin\alpha_1 \cos\beta_1 e^{j\phi_1} e^{j\delta_1} & \sin\alpha_2 \cos\beta_2 e^{j\phi_2} e^{j\delta_2} & \sin\alpha_3 \cos\beta_3 e^{j\phi_3} e^{j\delta_3} \\ \sin\alpha_1 \sin\beta_1 e^{j\phi_1} e^{j\gamma_1} & \sin\alpha_2 \sin\beta_2 e^{j\phi_2} e^{j\gamma_2} & \sin\alpha_3 \sin\beta_3 e^{j\phi_3} e^{j\gamma_3} \end{bmatrix}$$

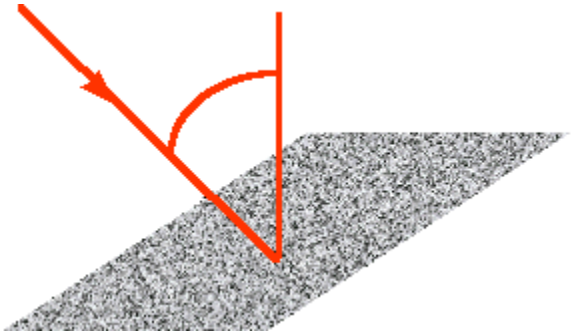
TARGET 1 **TARGET 2** **TARGET 3**

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

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

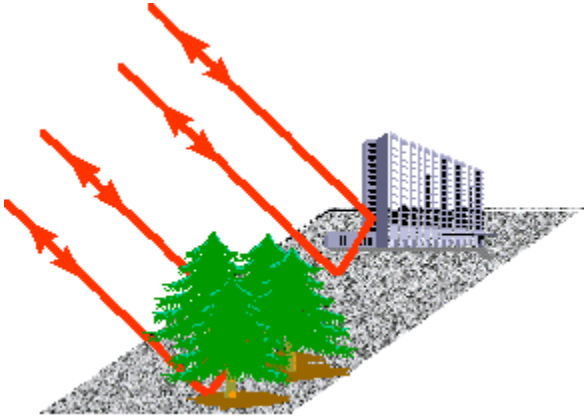
PHYSICAL INTERPRETATION

SINGLE BOUNCE SCATTERING
(ROUGH SURFACE)



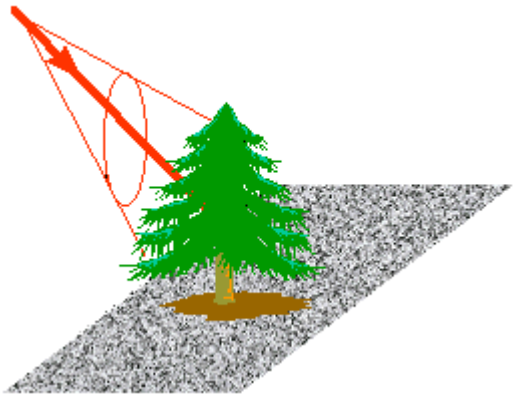
$$a \mapsto b \Rightarrow \nu \mapsto 0$$
$$\Downarrow$$
$$\underline{\alpha} \mapsto 0$$

DOUBLE BOUNCE SCATTERING



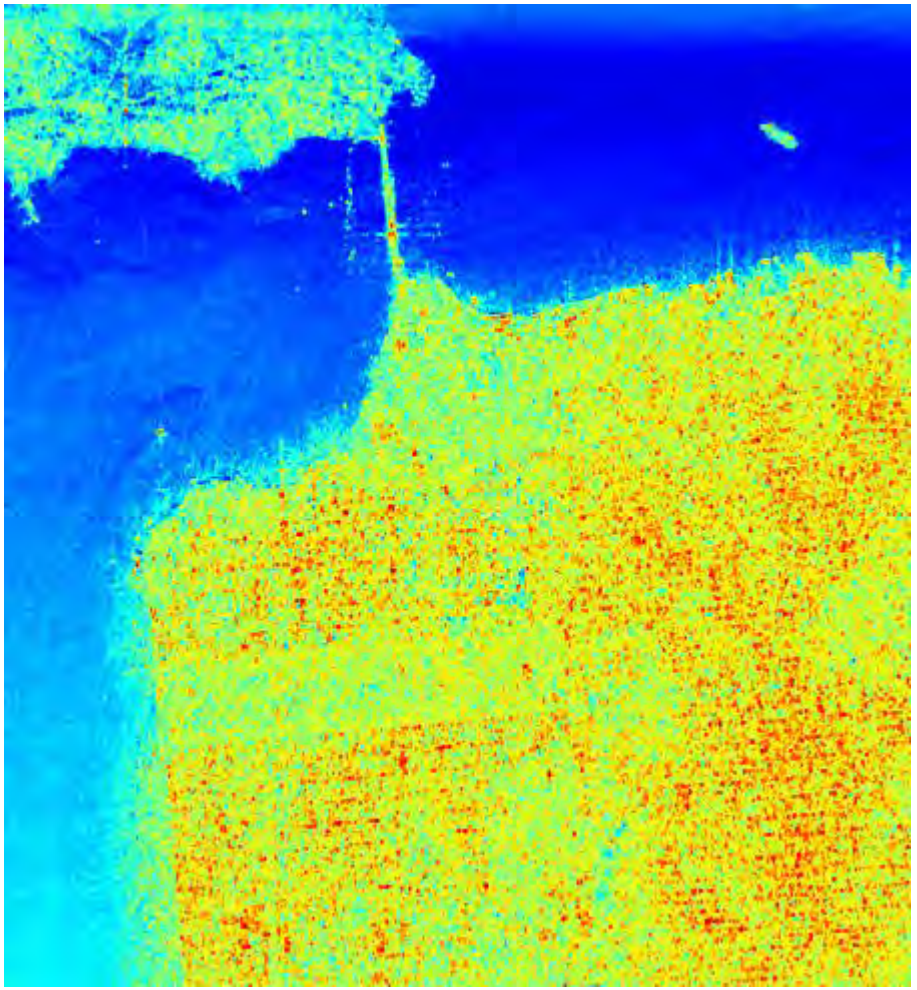
$$a \mapsto -b \Rightarrow \varepsilon \mapsto 0$$
$$\Downarrow$$
$$\underline{\alpha} \mapsto \frac{\pi}{2}$$

VOLUME SCATTERING



$$a >> b \Rightarrow \varepsilon \approx \nu$$
$$\Downarrow$$
$$\underline{\alpha} \mapsto \frac{\pi}{4}$$

H / A / α DECOMPOSITION



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

α PARAMETER

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)

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

PURE TARGET

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

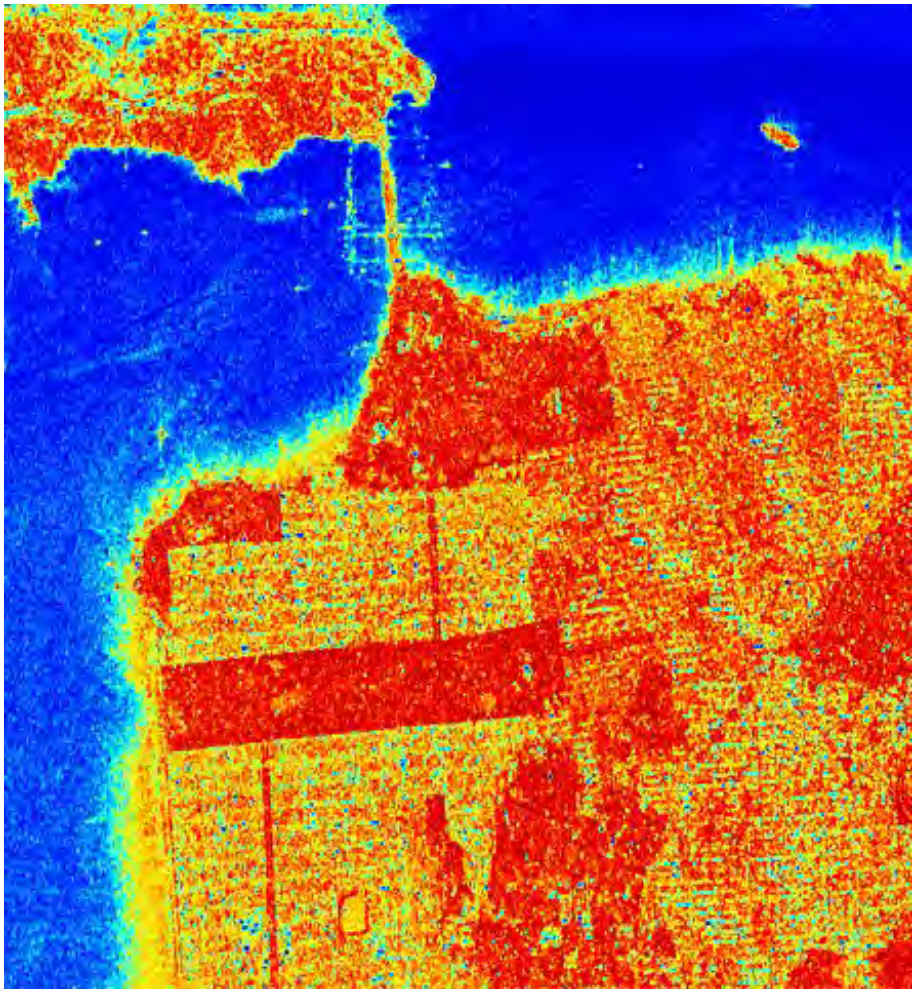
$H = 0$

DISTRIBUTED TARGET

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

$H = 1$

H / A / α DECOMPOSITION



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

0 0.5 1.0

ENTROPY (H)

H / A / α DECOMPOSITION

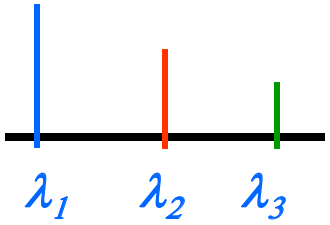
DIFFICULT MECHANISM DISCRIMINATION WHEN : H > 0.7

↓

ANISOTROPY

(EIGENVALUES SPECTRUM)

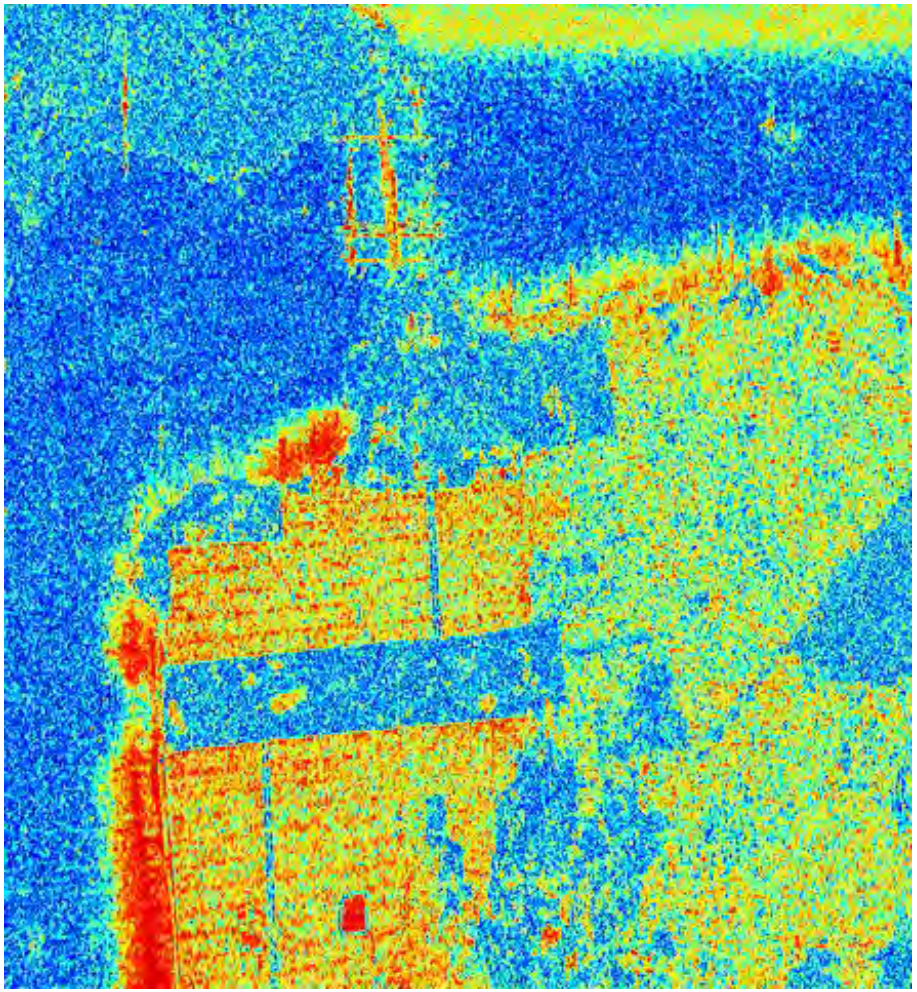
$$A = \frac{\lambda_2 - \lambda_3}{\lambda_2 + \lambda_3}$$



↓

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

H / A / α DECOMPOSITION

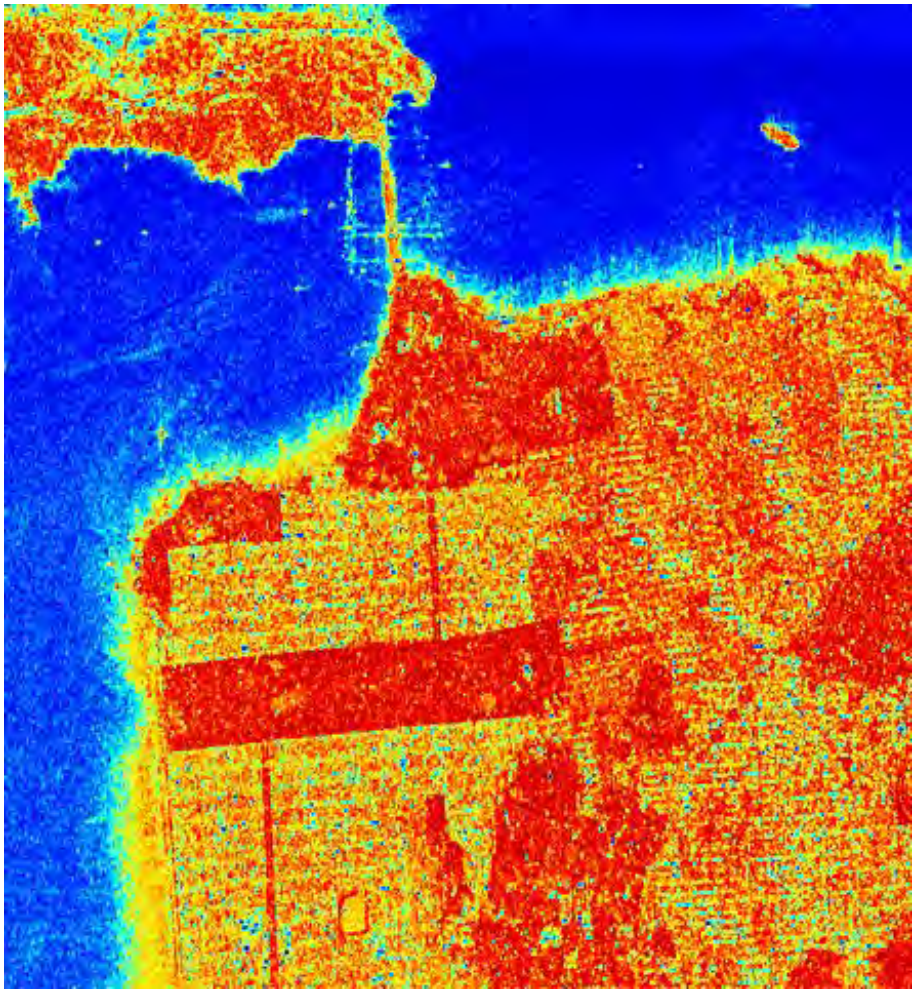


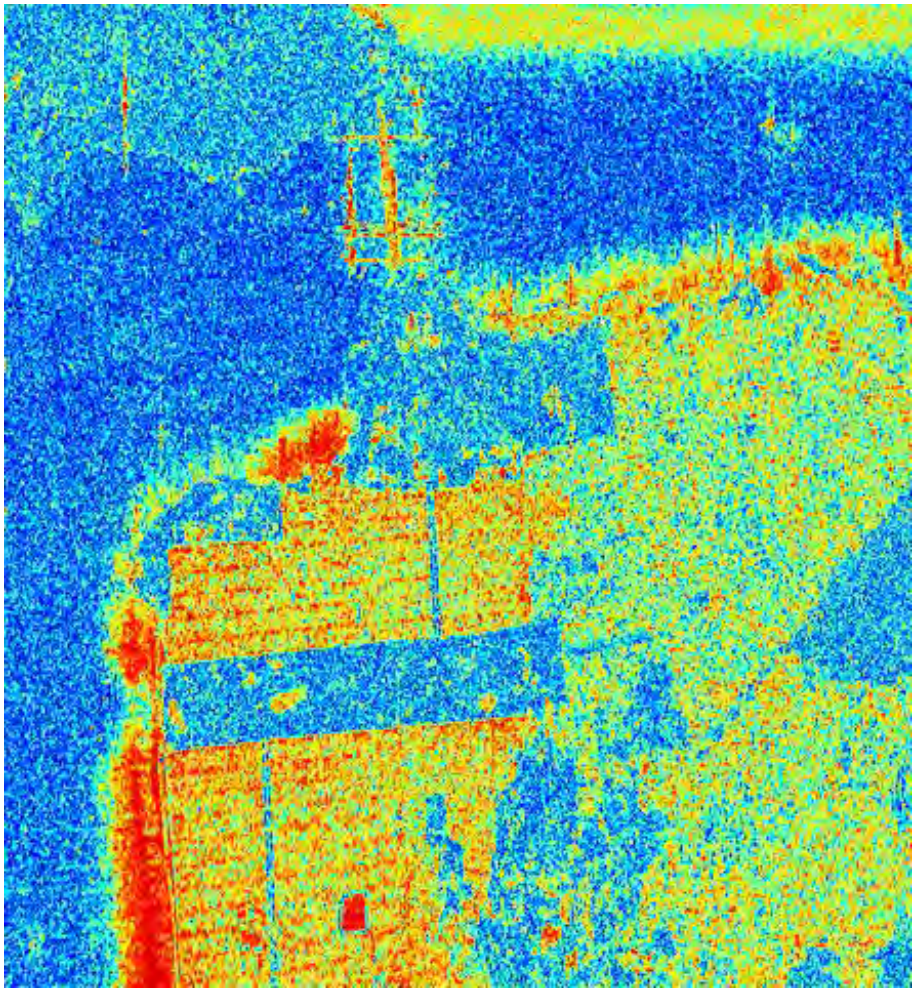
$2A_0$ $B_0 + B$ $B_0 - B$

0 0.5 1.0

ANISOTROPY (A)

H / A / α DECOMPOSITION





0 0.5 1.0

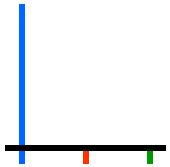
ENTROPY (H)

0 0.5 1.0

ANISOTROPY (A)

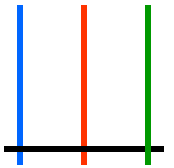
H / A / α DECOMPOSITION

(1-H)(1-A)

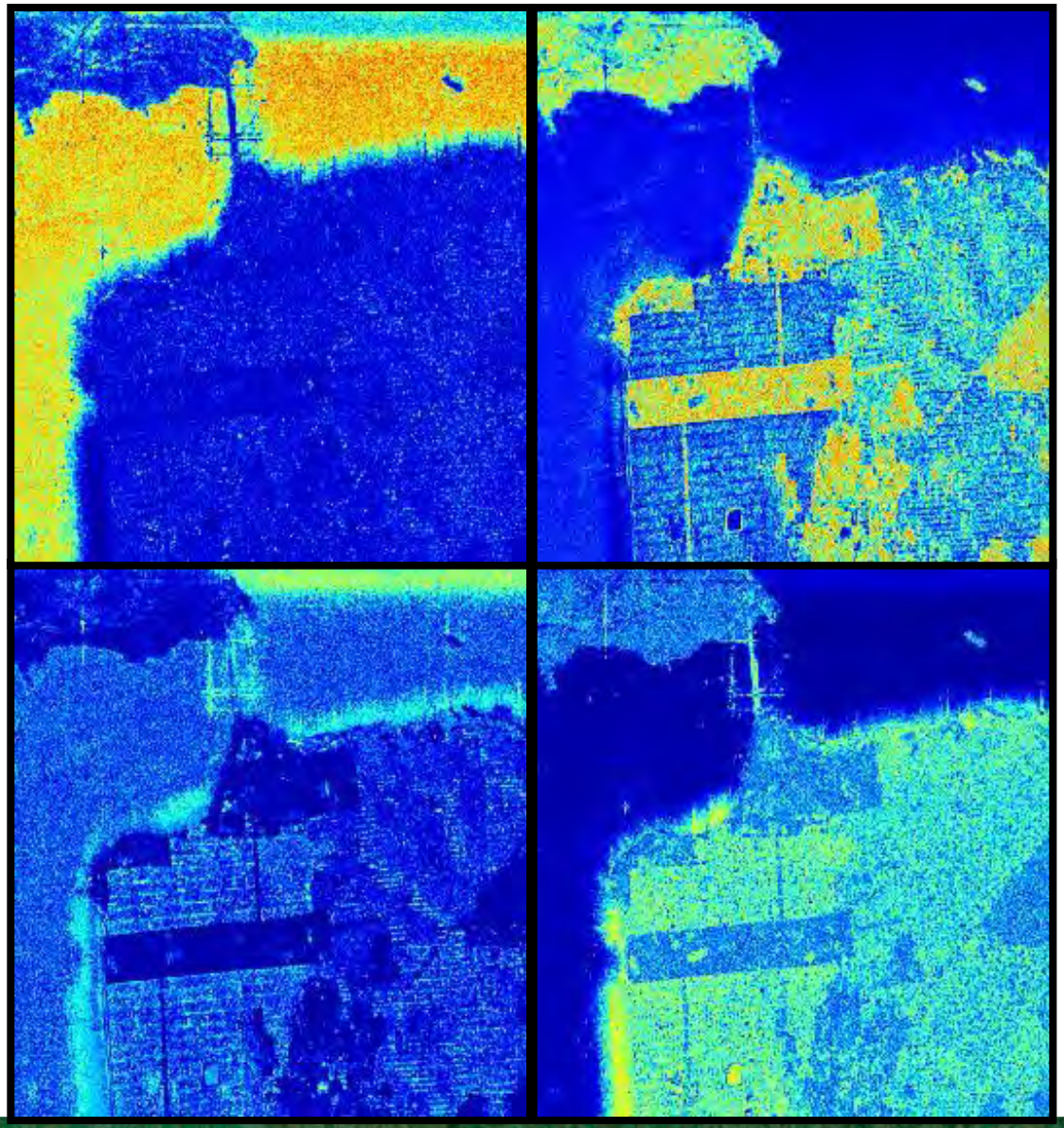


1 MECHANISM

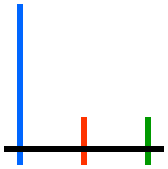
H(1-A)



3 MECHANISMS

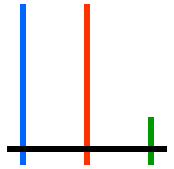


A(1-H)



2 MECHANISMS

HA

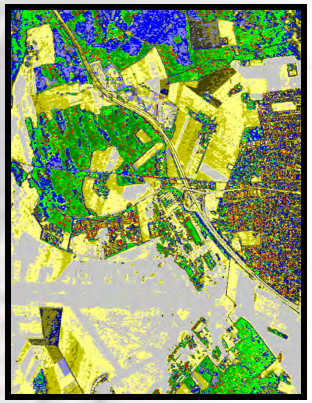


2 MECHANISMS

0 0.25 0.5

POLARIMETRIC REMOTE SENSING

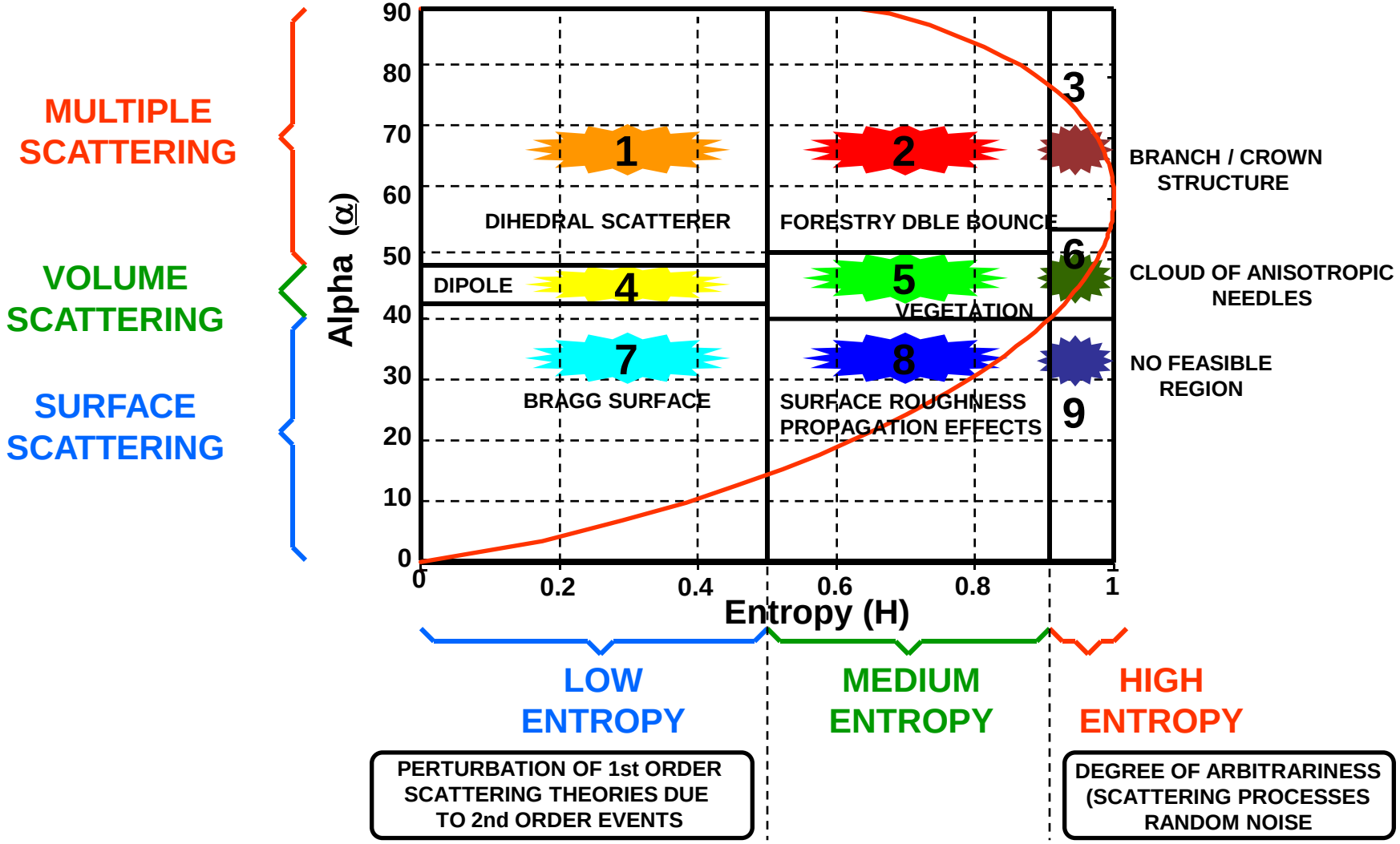
POL-SAR PROCESSING
PHENOMENOLOGIC
QUALITATIVE ANALYSIS



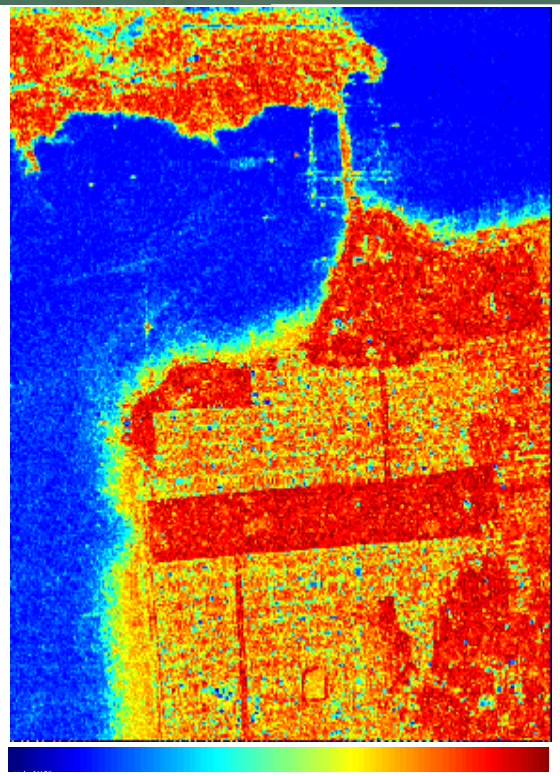
POLARIMETRIC SPECKLE FILTERING → **POLARIMETRIC TARGET DECOMPOSITION** → **POLARIMETRIC CLASSIFICATION**
MONO/DUAL CHANNELS

H / α CLASSIFICATION

SEGMENTATION OF THE H / α SPACE



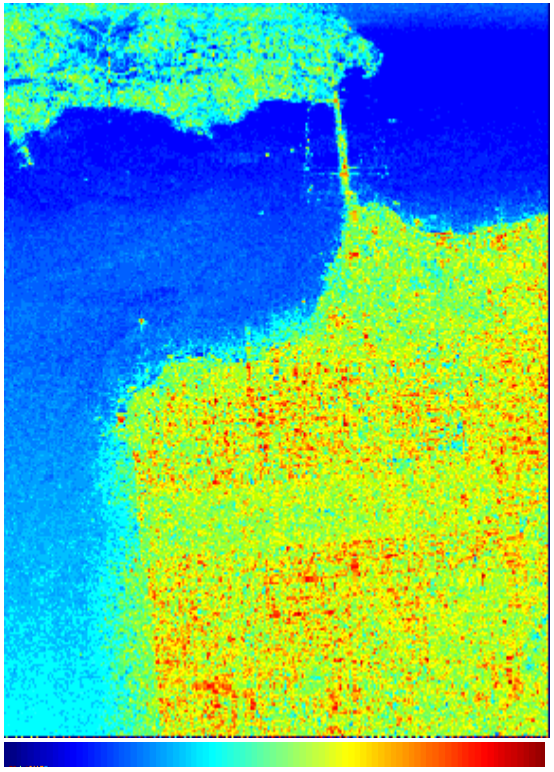
H / α CLASSIFICATION



0 0.5 1.0

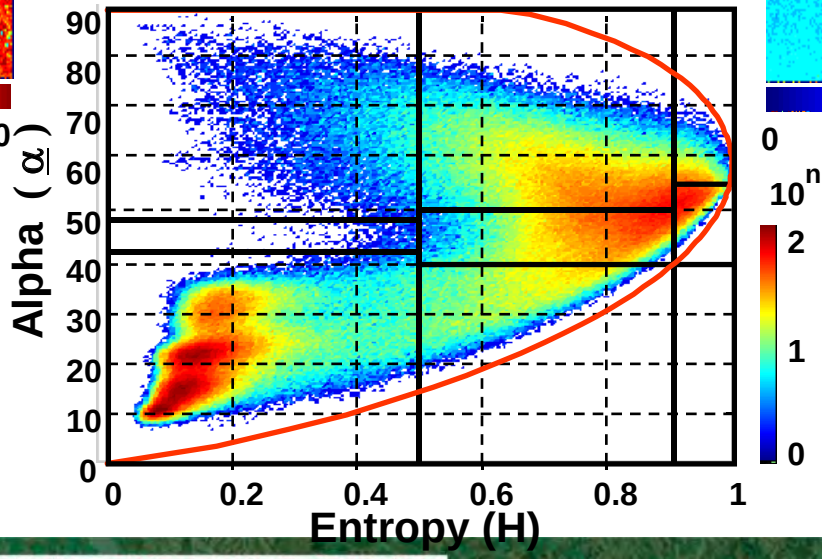
H

POLSAR DATA DISTRIBUTION IN THE H / α PLANE



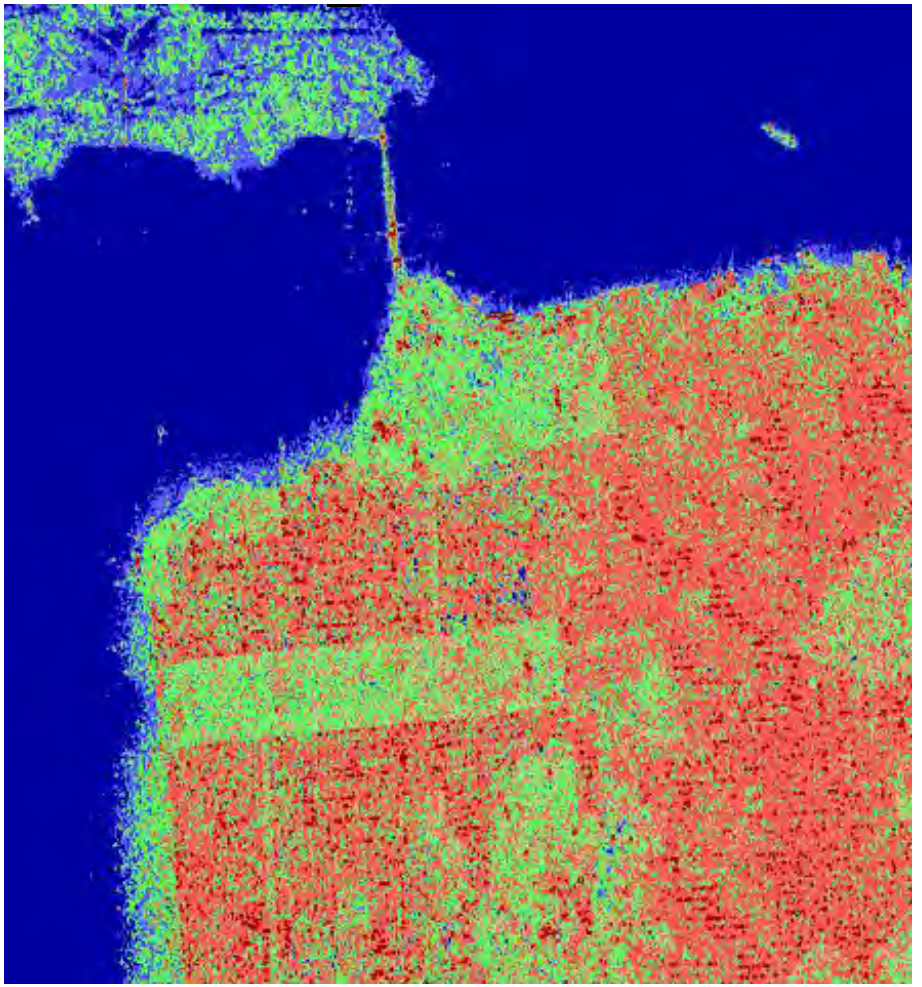
0 45° 90°

α

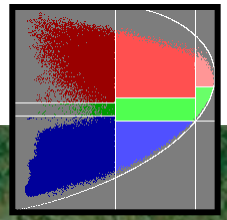


H / α CLASSIFICATION

H - α classification



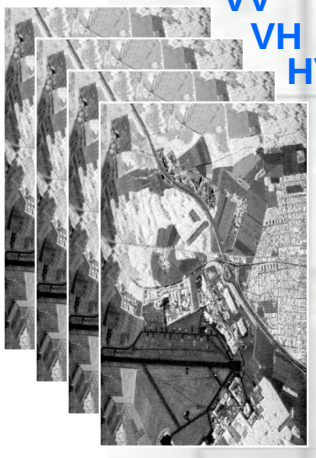
$2A_0$ $B_0 + B$ $B_0 - B$



POLARIMETRIC REMOTE SENSING

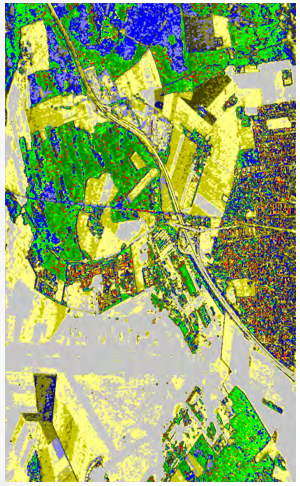
WISHART PDF

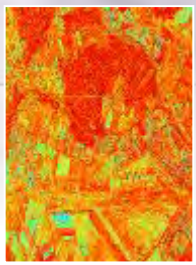
$$P\left(\langle[T]\rangle/[T_m]\right)=\frac{L^{Lp}\left|\langle[T]\rangle\right|^{L-p}e^{-LTr\left([T_m]^{-1}\langle[T]\rangle\right)}}{\pi^{\frac{p(p-1)}{2}}\Gamma(L)\ldots\Gamma(L-p+1)\left|[T_m]\right|^{L}}$$



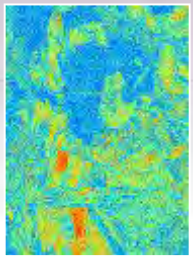
UNSUPERVISED POLSAR CLASSIFICATION

E.POTTIER, J.S LEE (2000)

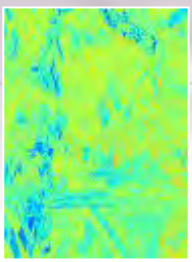




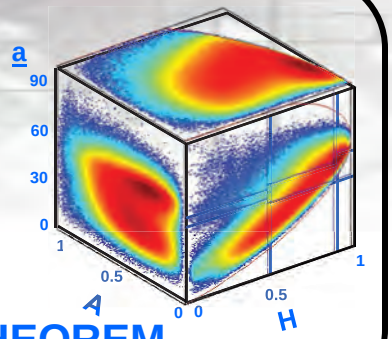
H



A



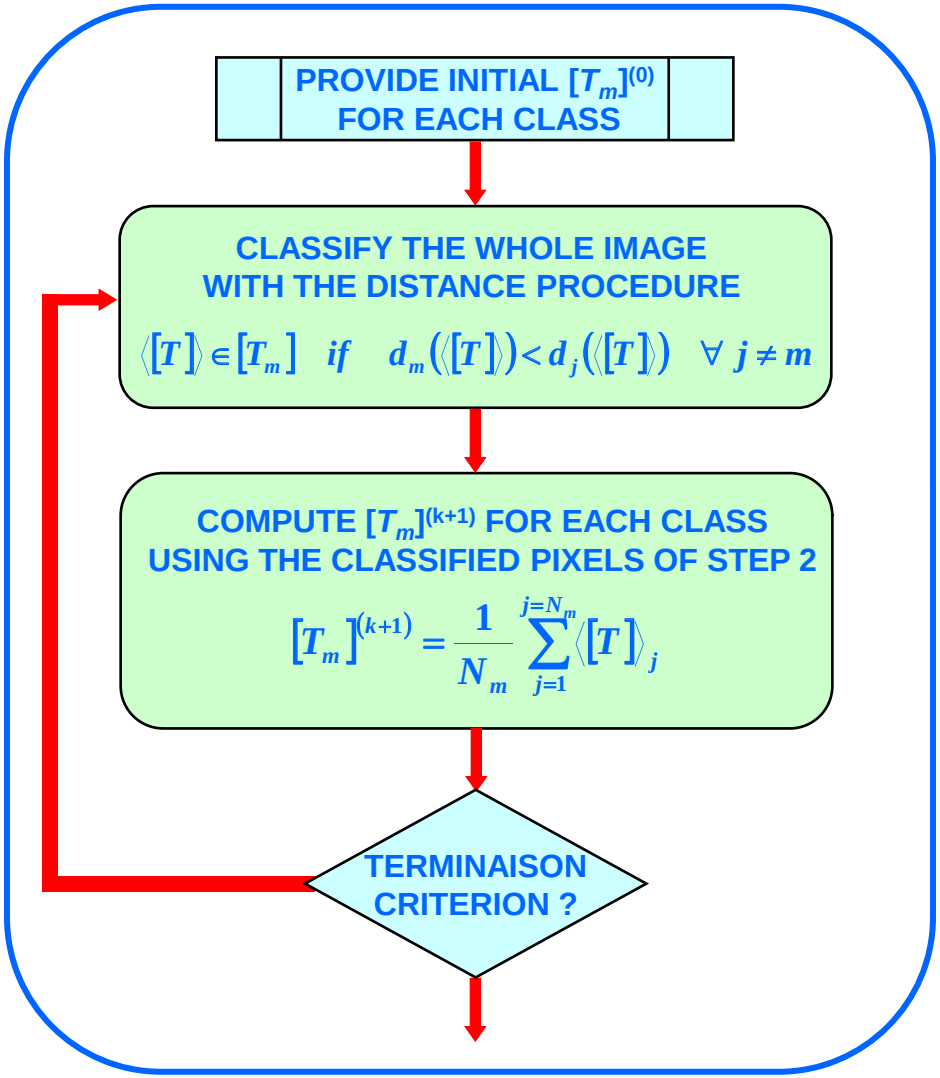
α

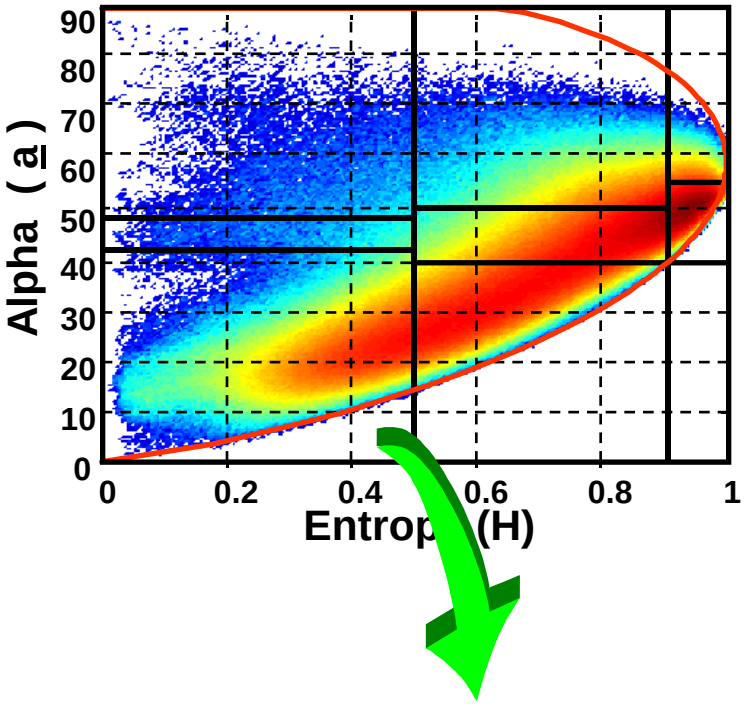


H / A / α DECOMPOSITION THEOREM

H / α - WISHART CLASSIFIER

k - mean CLASSIFICATION PROCEDURE





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

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

H / α - WISHART CLASSIFIER

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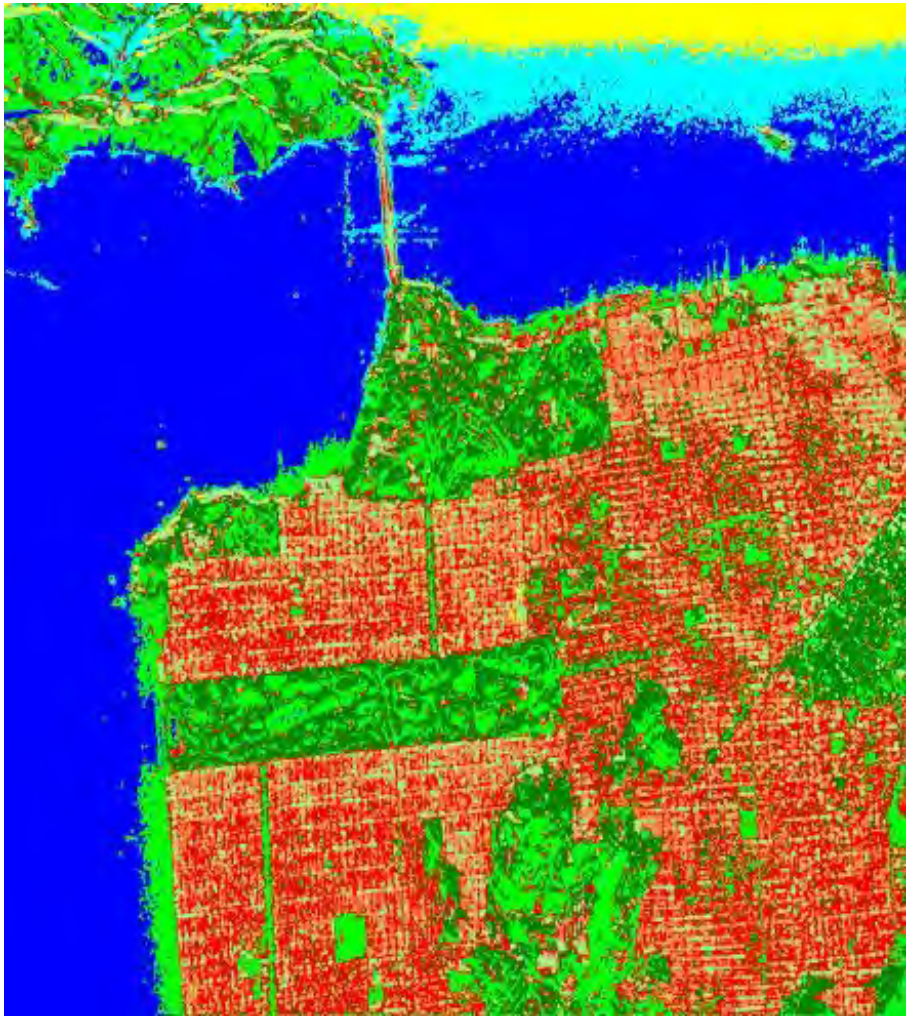
4th ITERATION

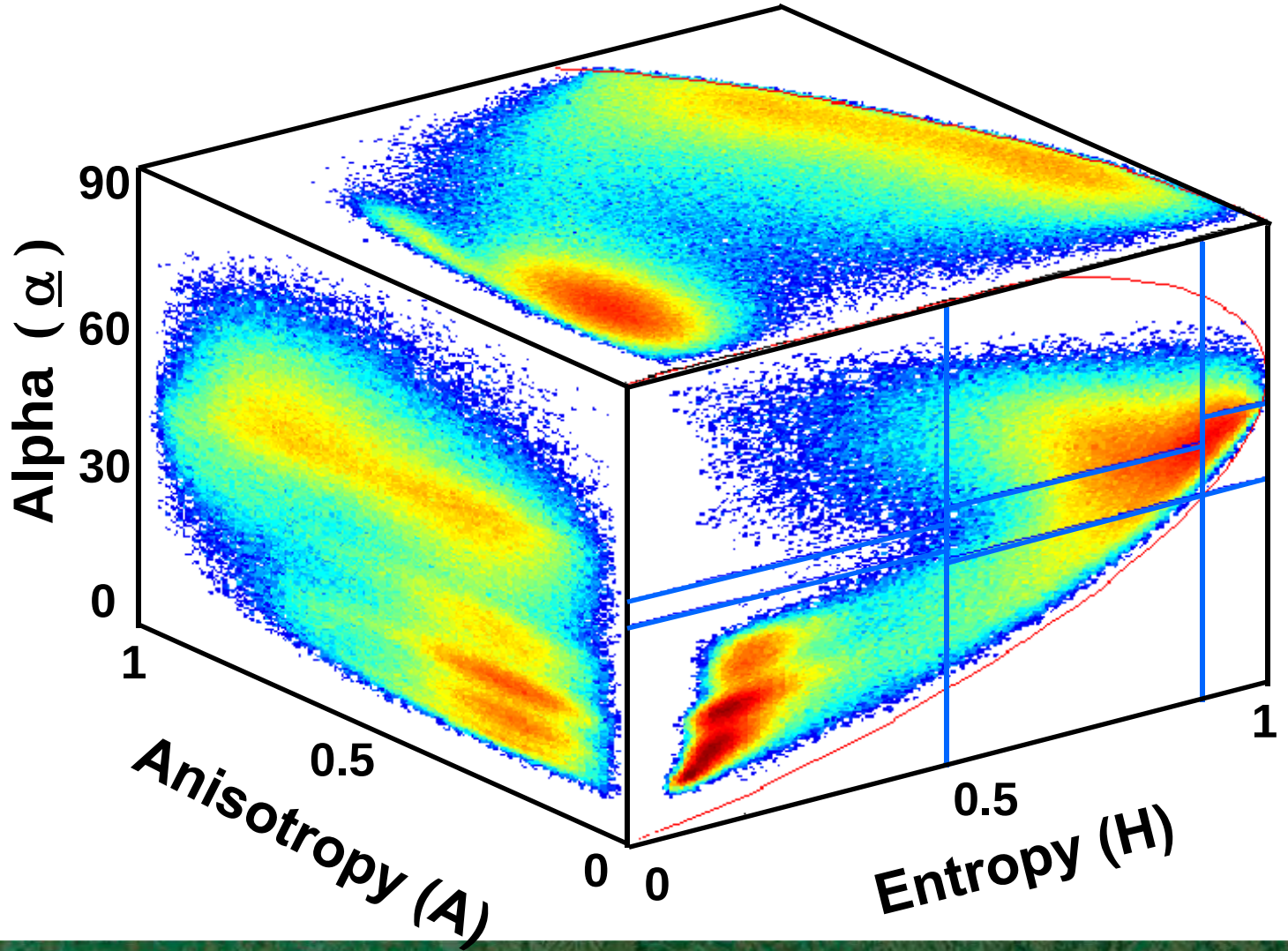


$2A_0$ $B_0 + B$ $B_0 - B$

C1 C2 C3 C4 C5 C6 C7 C8

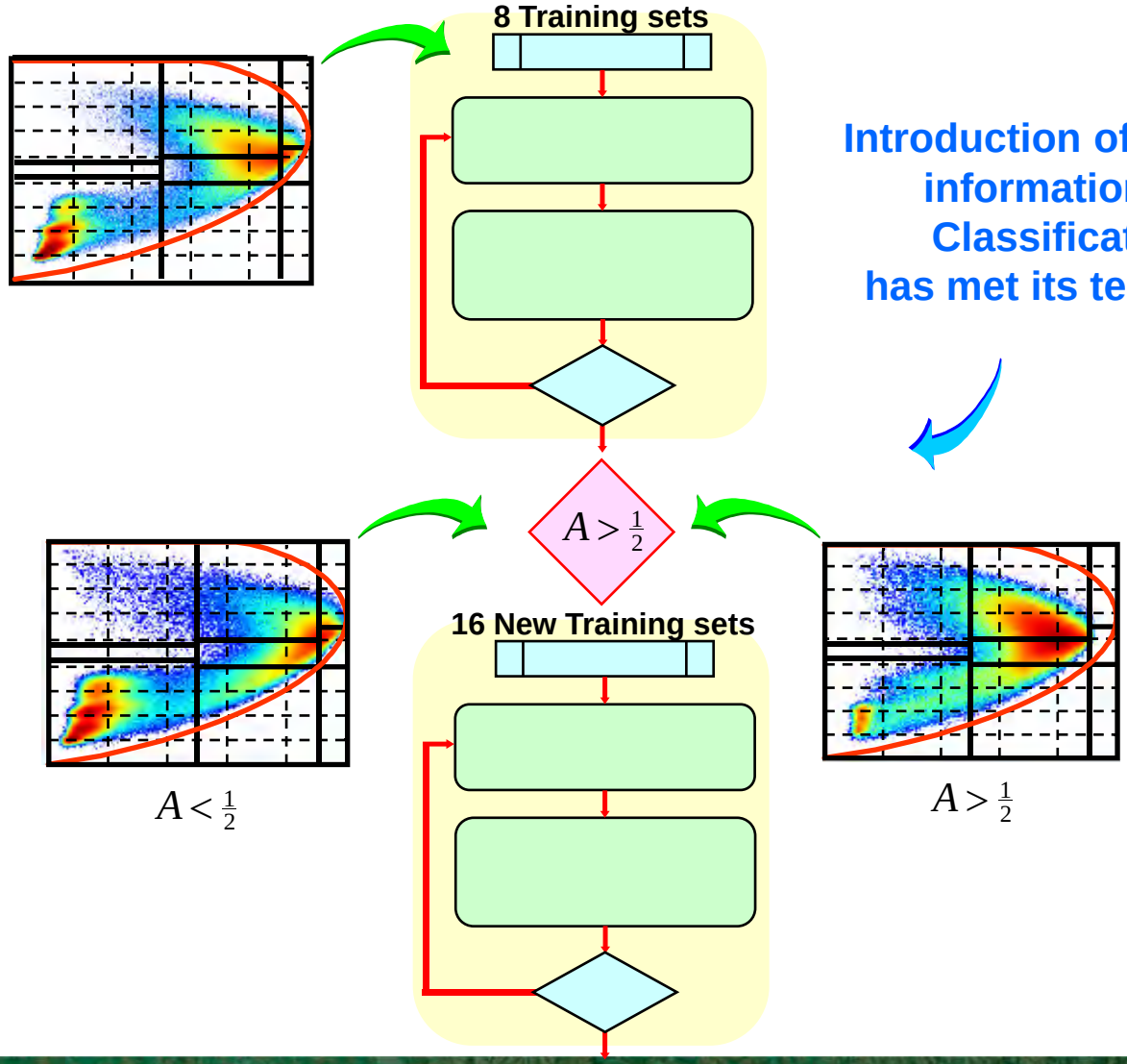
H / A / $\underline{\alpha}$ - WISHART CLASSIFIER

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



H / A / α - WISHART CLASSIFIER

2 Successive k - mean Classification procedures



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

H / A / α - WISHART CLASSIFIER

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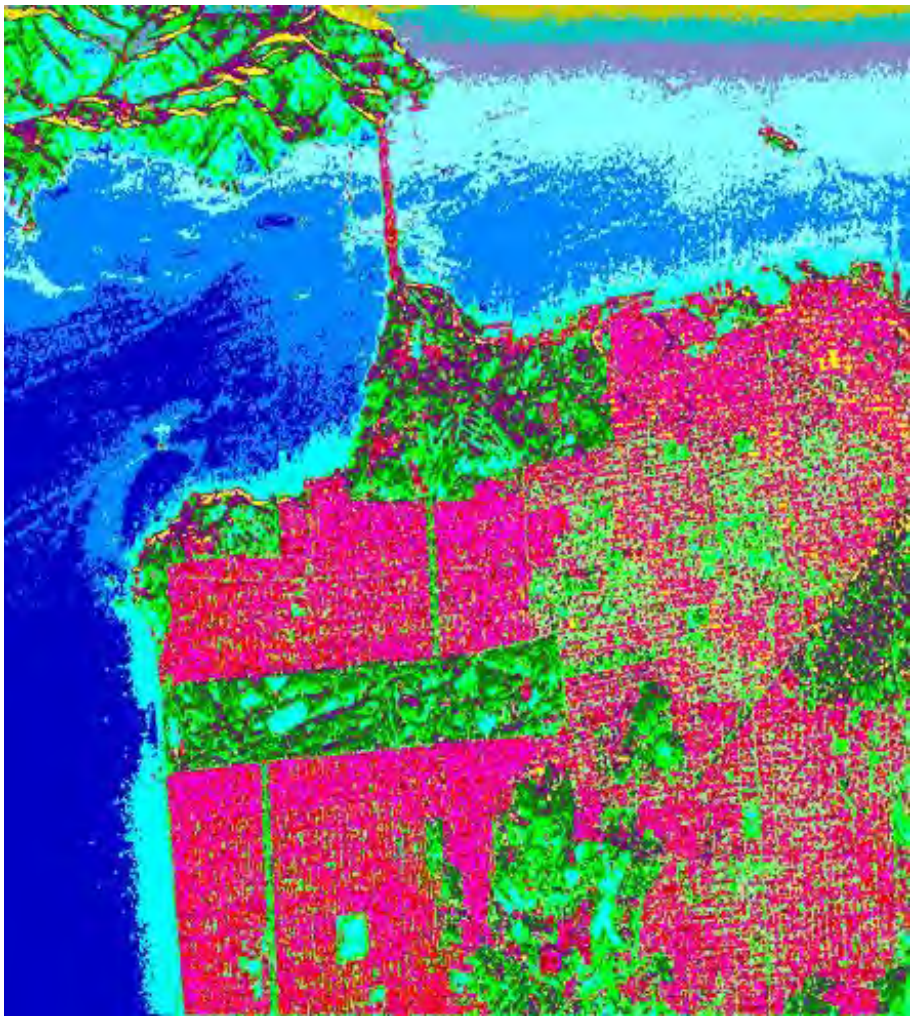
4th ITERATION



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

C1 C2 C3 C4 C5 C6 C7 C8

C9 C10 C11 C12 C13 C14 C15 C16

H / A / α - WISHART CLASSIFIER

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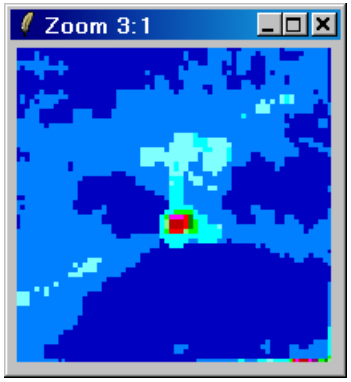
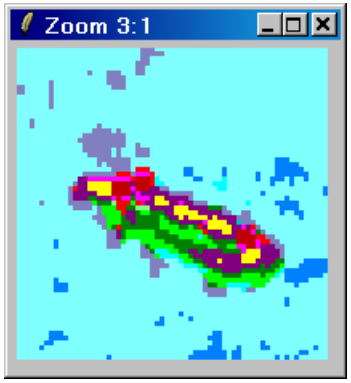
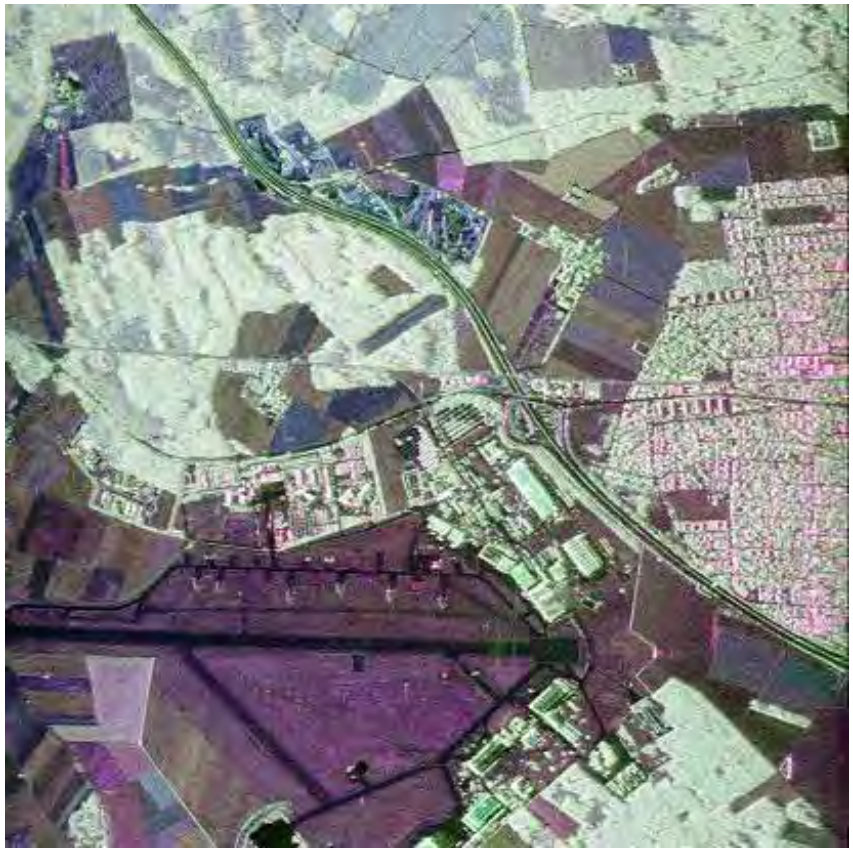




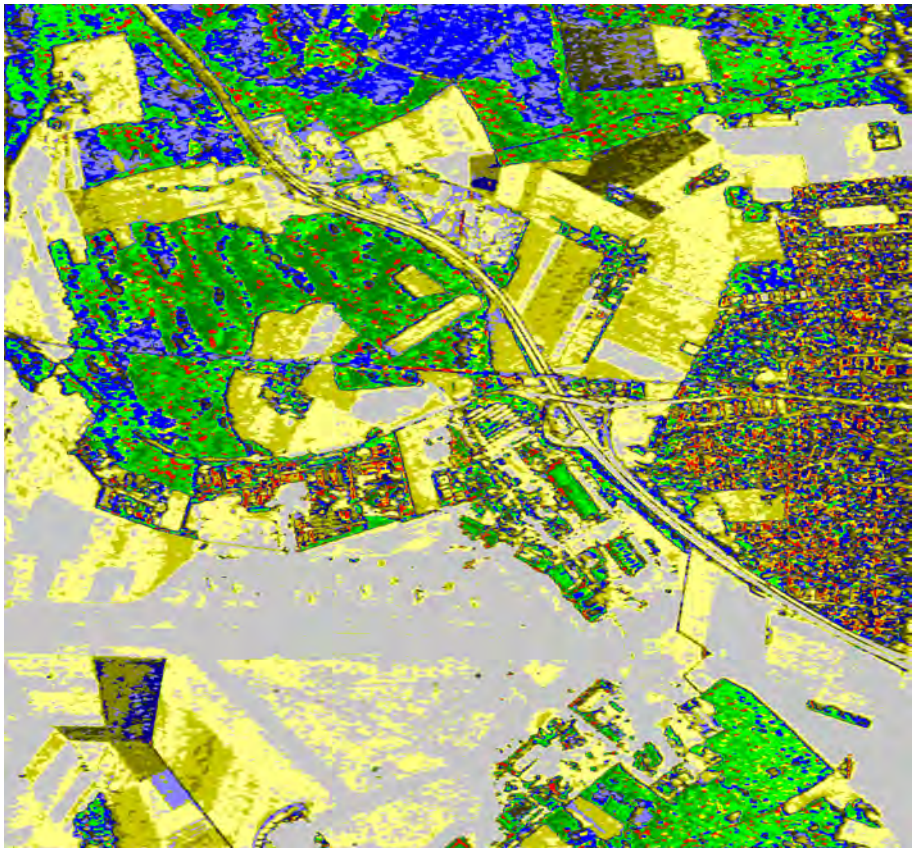
$2A_0$ $B_0 + B$ $B_0 - B$

H / A / α - WISHART CLASSIFIER

OBERPFAFFENHOFEN - ESAR L-band



H / A / α and WISHART CLASSIFIER



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

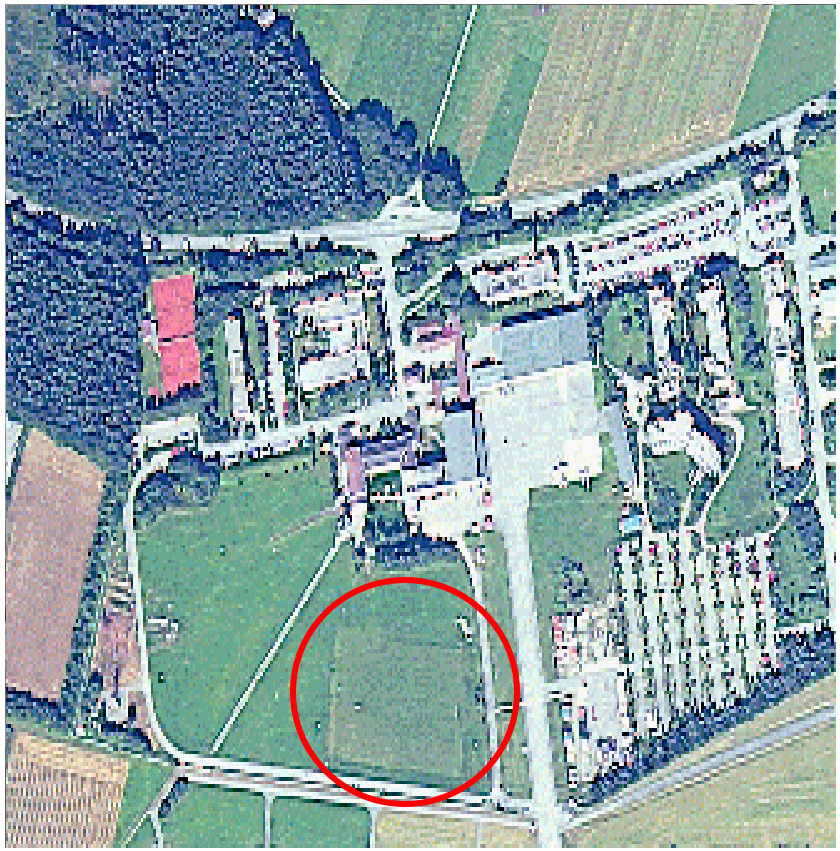
DLR

C1 C2 C3 C4 C5 C6 C7 C8

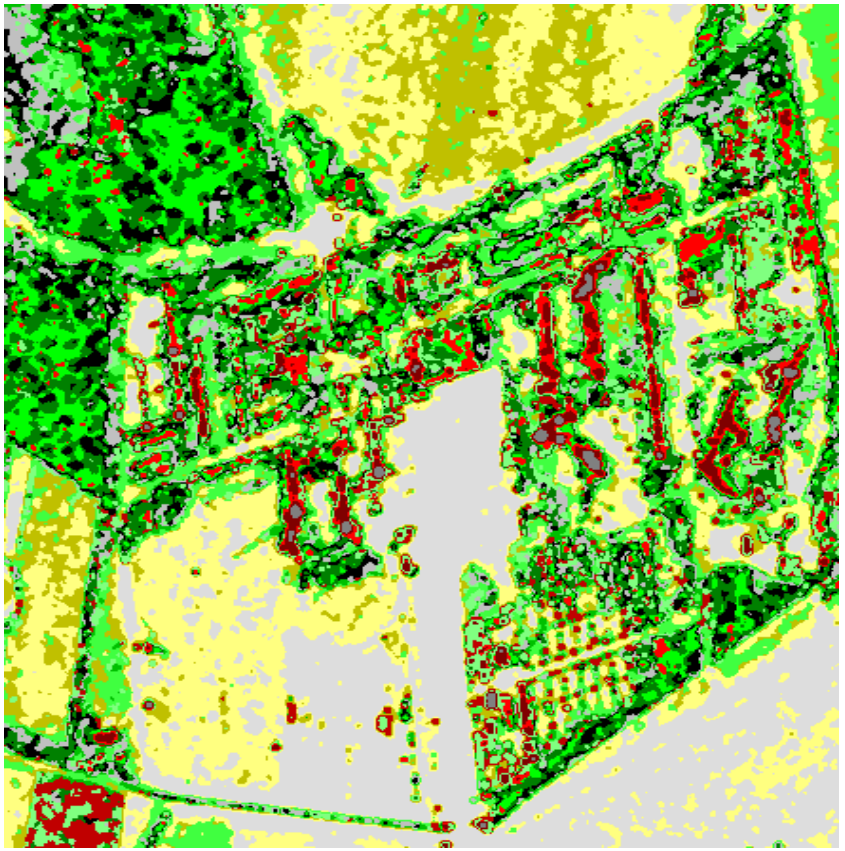
C9 C10 C11 C12 C13 C14 C15 C16

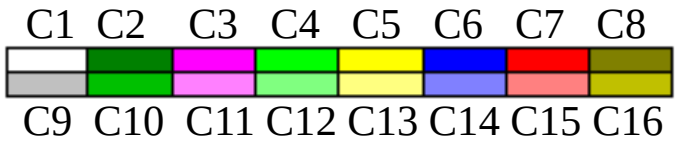
H / A / α - WISHART CLASSIFIER

OBERPFAFFENHOFEN - ESAR L-band

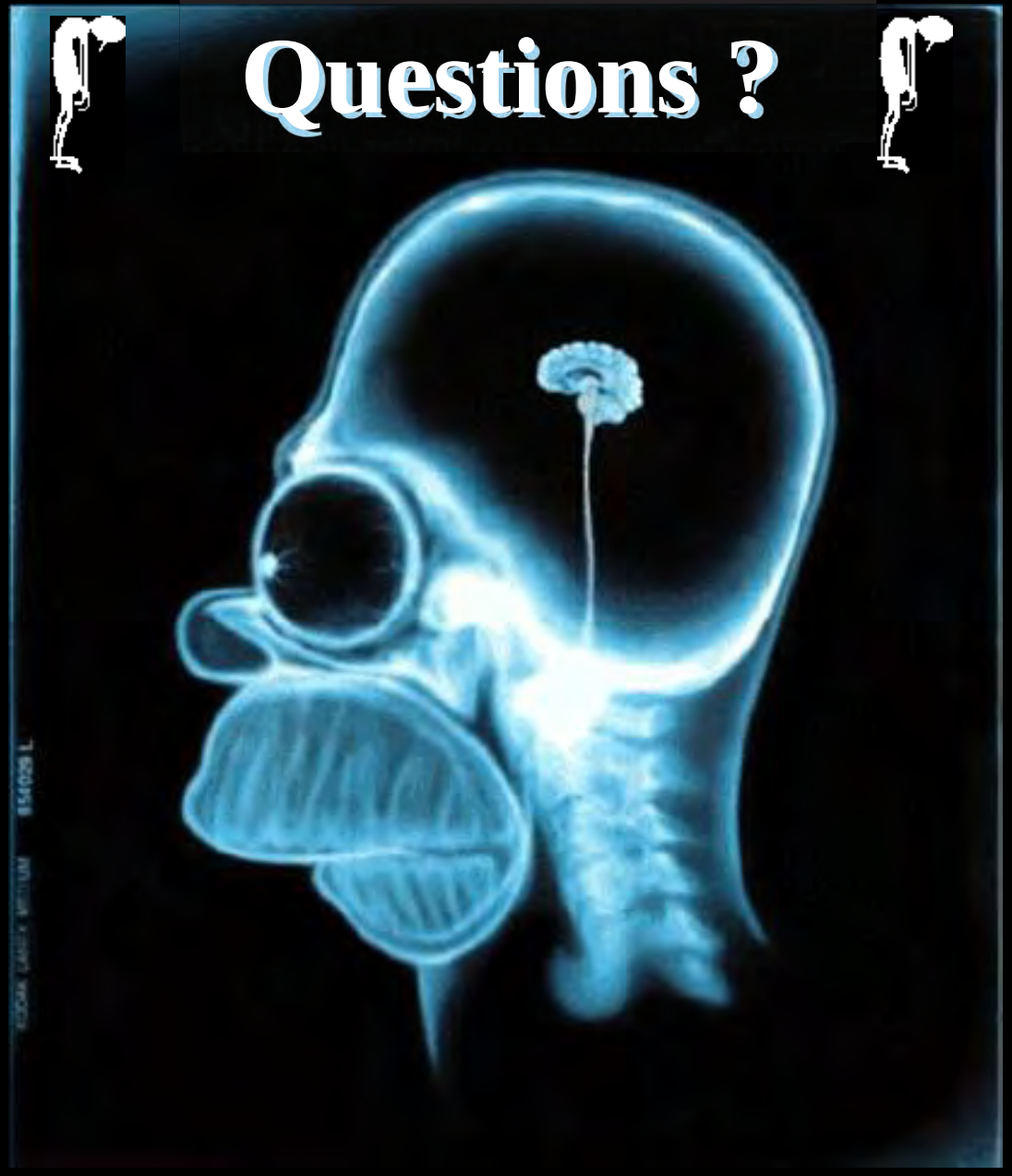


H / A / α and WISHART CLASSIFIER

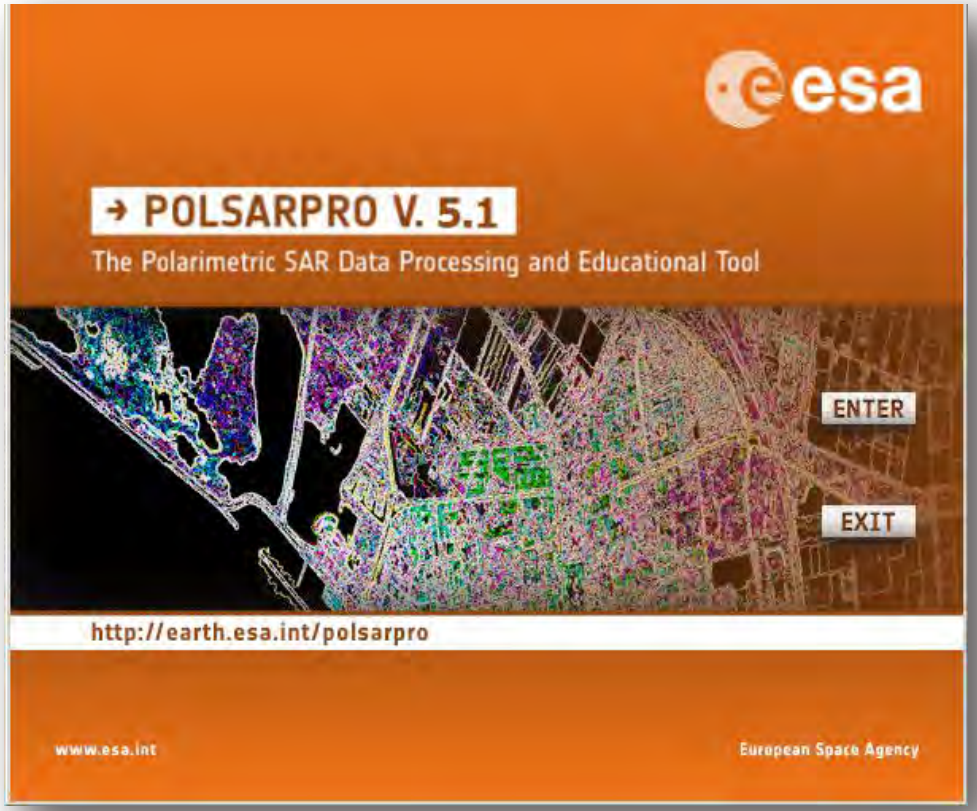




Questions ?



PolSARpro v5.1 SOFTWARE



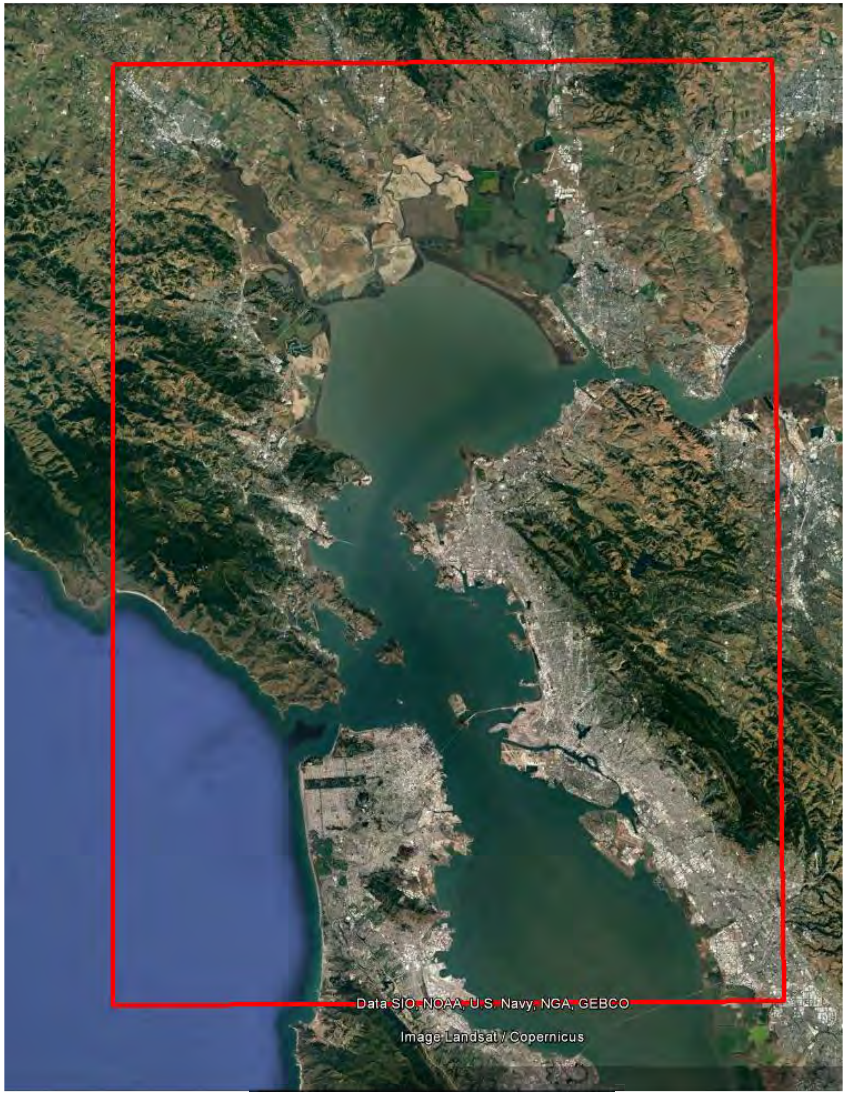
PolSARpro v5.1 Software Training Course

SAN FRANCISCO BAY

ALOS2 - PALSAR

JAXA

L-Band (Quad - 2015)



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