



# Introduction to SAR Polarimetry

ESA-MOST Dragon 4 Cooperation

**ADVANCED LAND REMOTE SENSING  
INTERNATIONAL TRAINING COURSE**

**“龙计划4” 高级陆地遥感国际培训班**

**Eric POTTIER**

20-25 November 2017 | Yunnan Normal University  
Kunming, Yunnan Province, P.R. China

2017年11月20日—11月25日  
云南师范大学, 中国, 昆明

**University of Rennes 1 - France**



**Eric POTTIER**  
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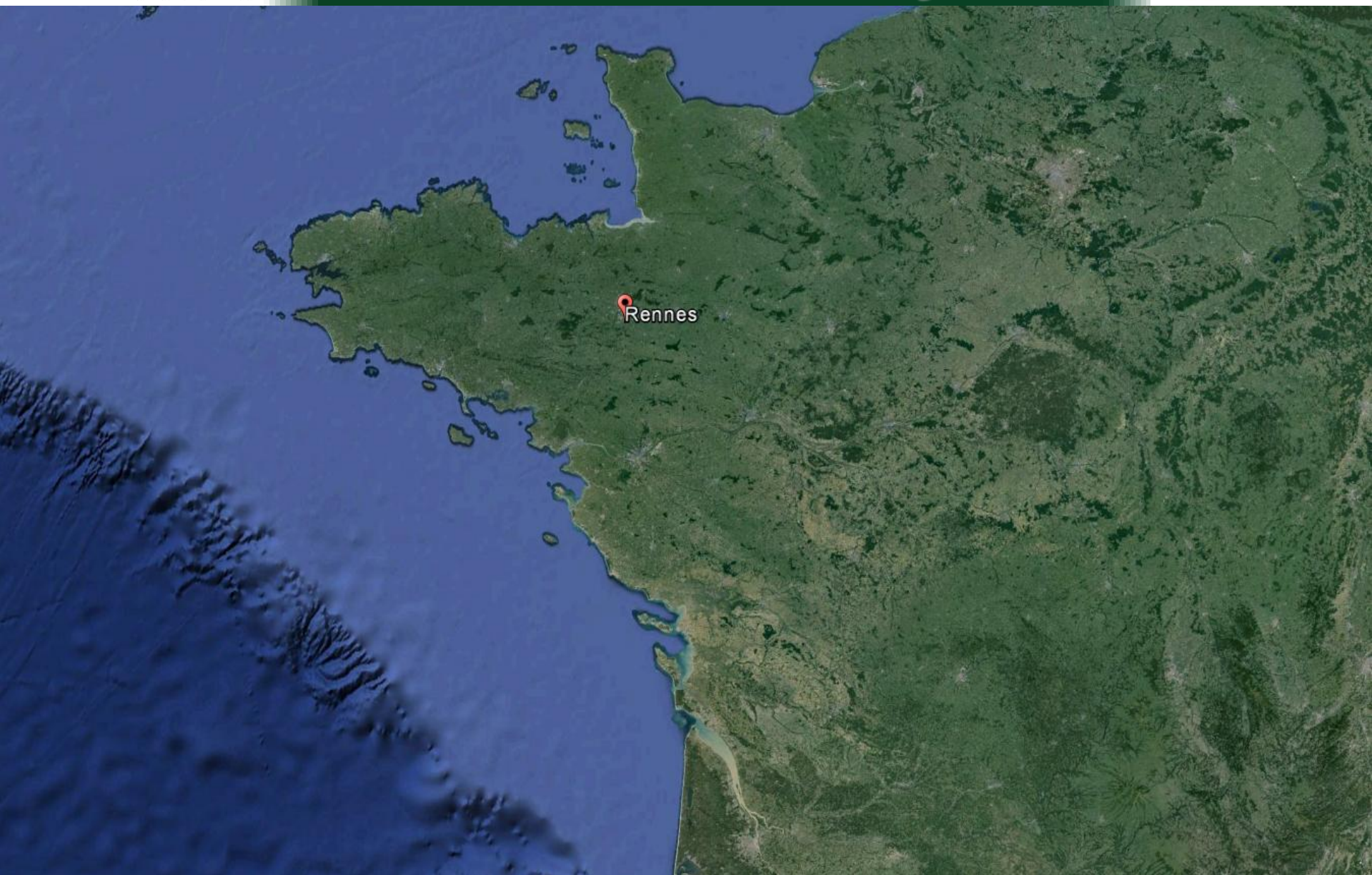


**SAR & Hyperspectral multi-modal Imaging and signal processing, Electromagnetic modeling**





# Rennes - Brittany

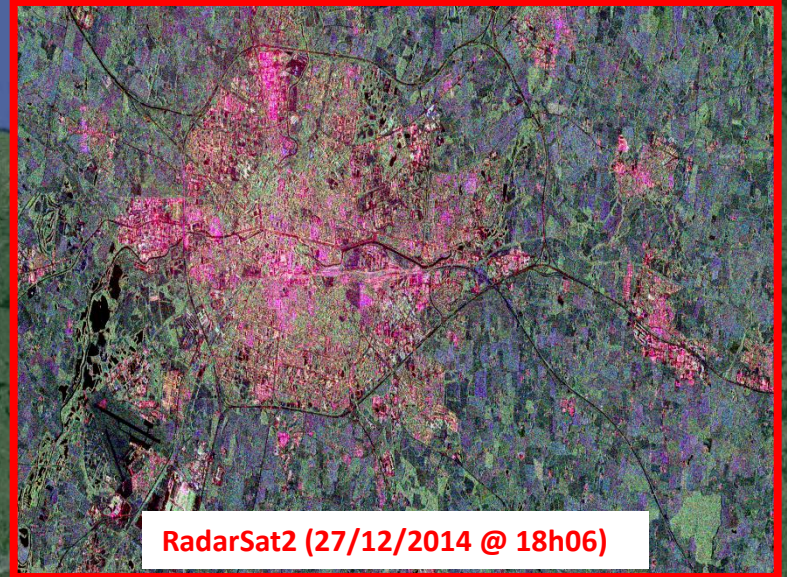




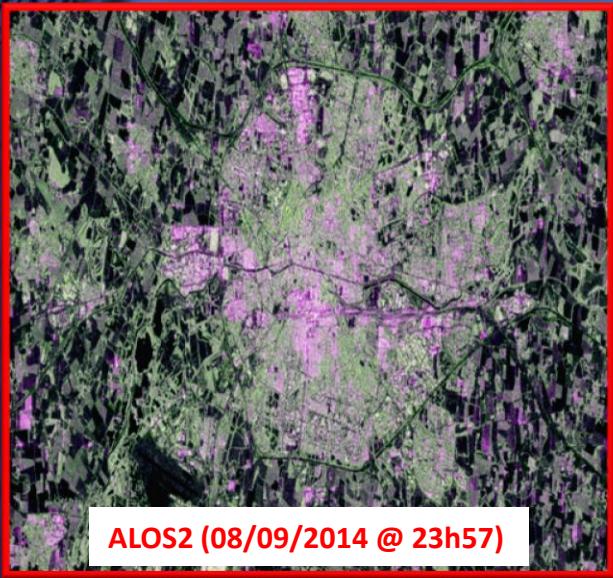
# Rennes - Brittany



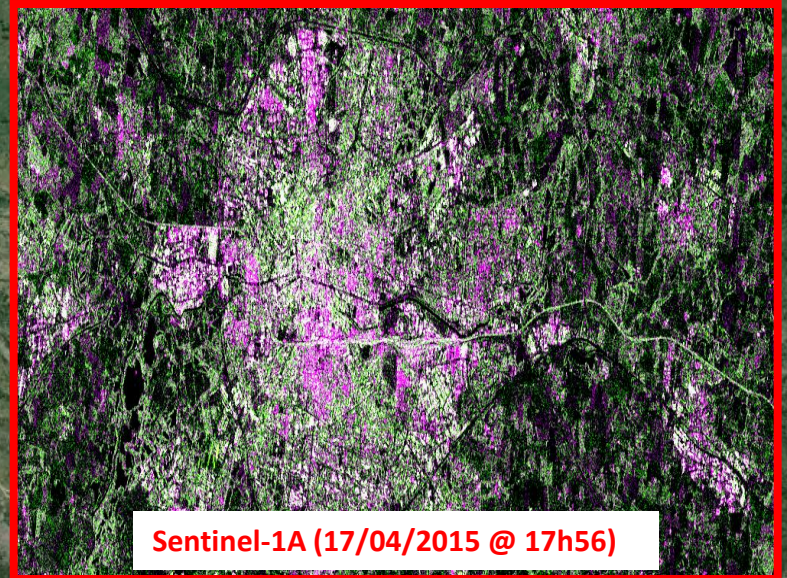
**ALOS1 (30/04/2008 @ 22h34)**



**RadarSat2 (27/12/2014 @ 18h06)**



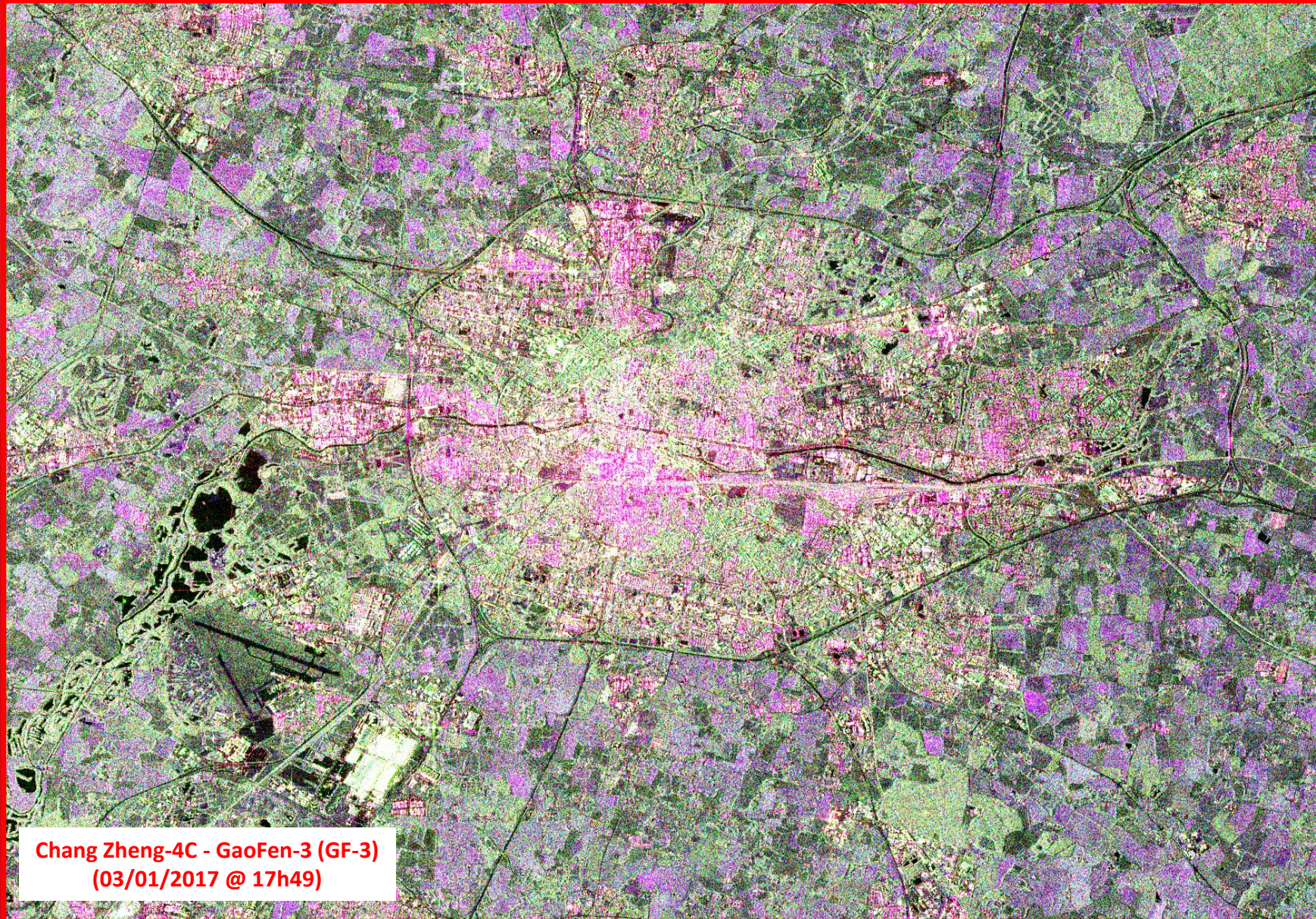
**ALOS2 (08/09/2014 @ 23h57)**



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



# Rennes - Brittany



**Chang Zheng-4C - GaoFen-3 (GF-3)**  
**(03/01/2017 @ 17h49)**





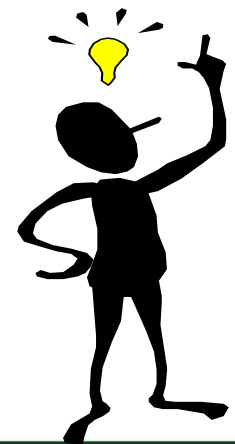
## Objective

### To provide

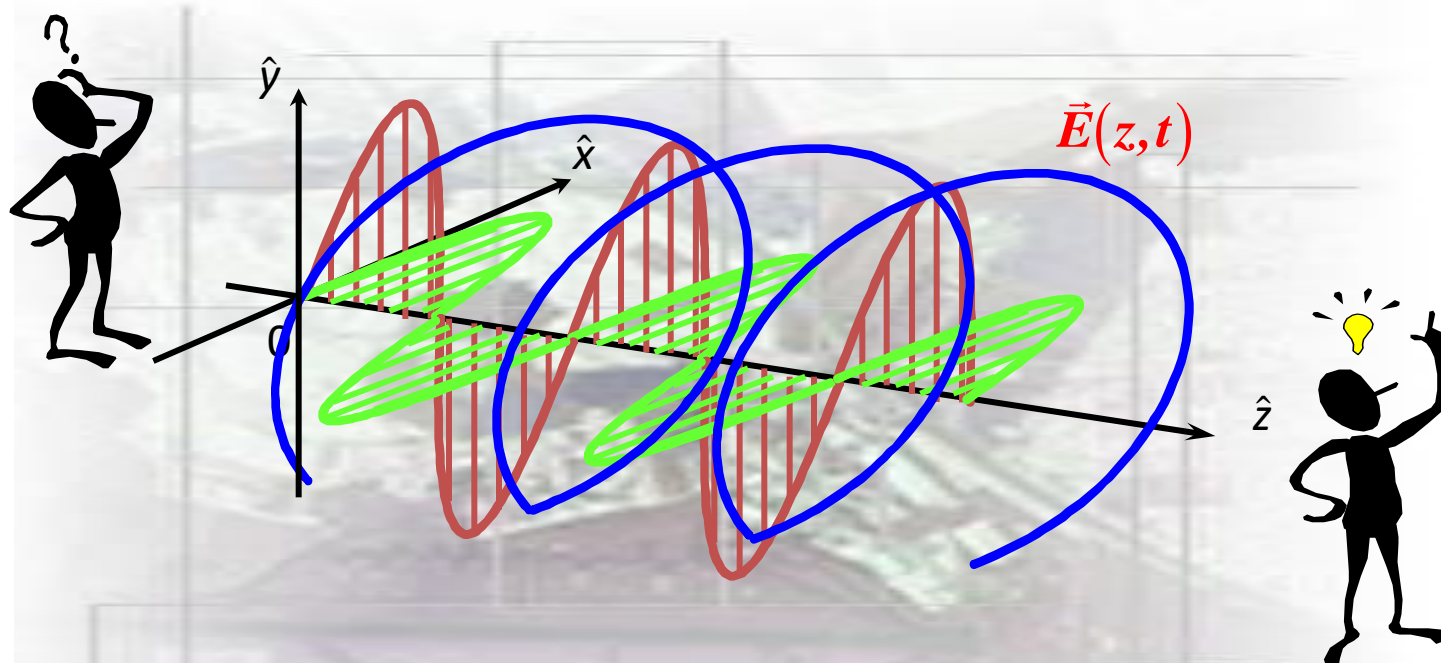
**the minimum, but necessary,  
amount of knowledge required**

**to understand  
scientific works on**

# SAR Polarimetry (PoISAR)







# GENERAL INTRODUCTION

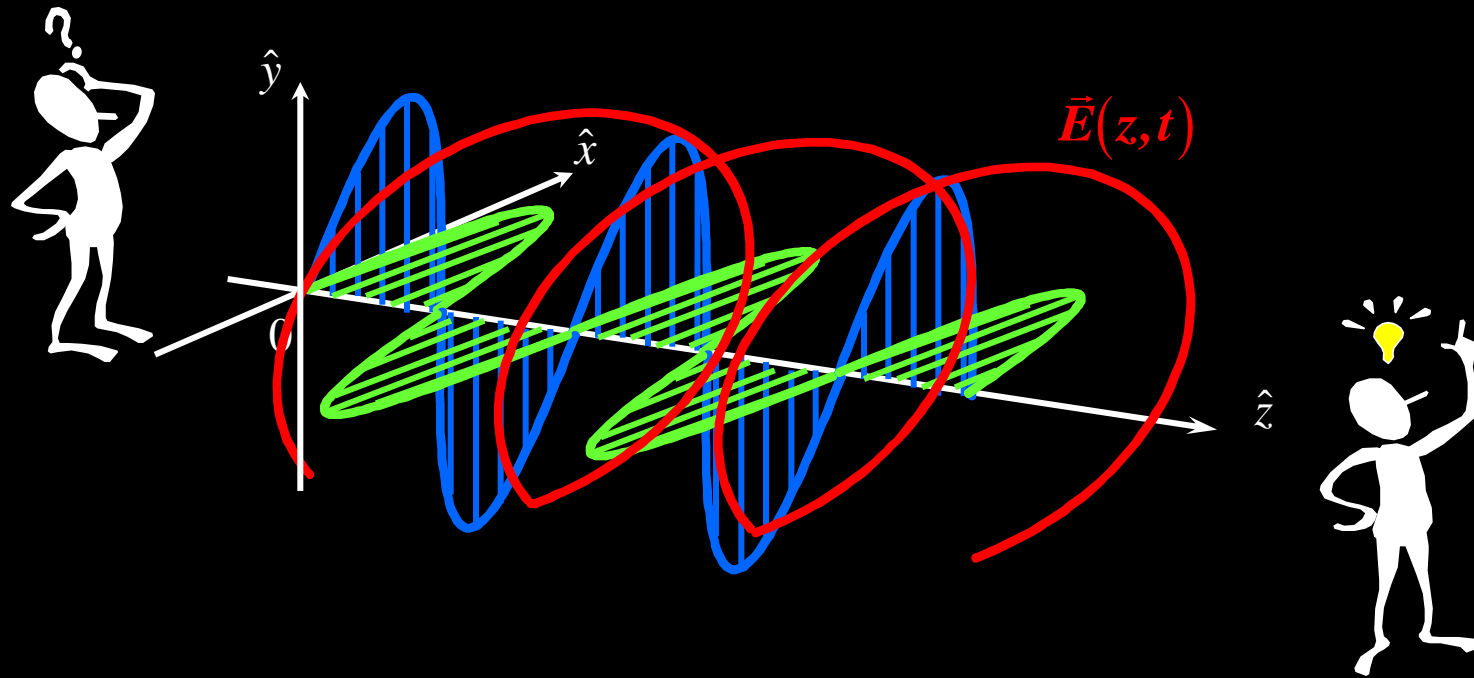


# RADAR POLARIMETRY



- **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

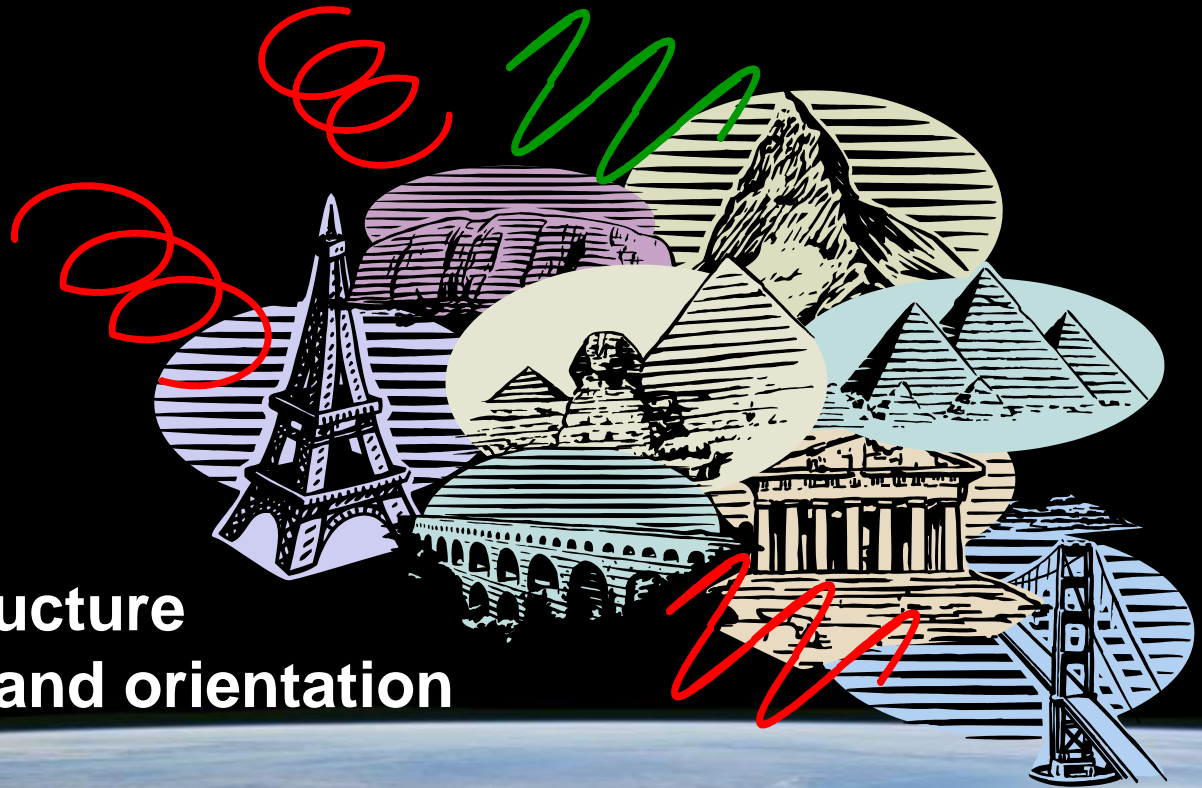
Radar Polarimetry deals with the full vector nature of polarized electromagnetic waves



# Radars 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

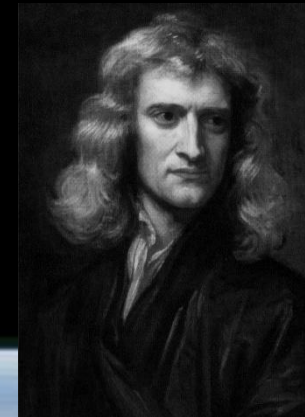


Huygens

Corpuscular model or  
« longitudinal » waves

**1704**

Corpuscular  
Model of light



Newton

**1808**

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



Malus

**X-1795**



# 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

« Transverse » nature of light waves

Electromagnetic theory of light

# 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



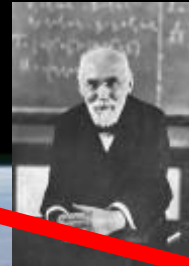
1892

Lie



1897

Lorentz



1908

Marconi



1922

Wiener





# 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

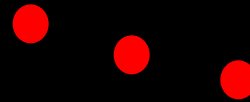


1954

Kennaugh



1952



# 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**



# 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



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

1990 - 2000  
Radar Polarimetry  
Scientific Progress

#L. Pottier (06/2017)

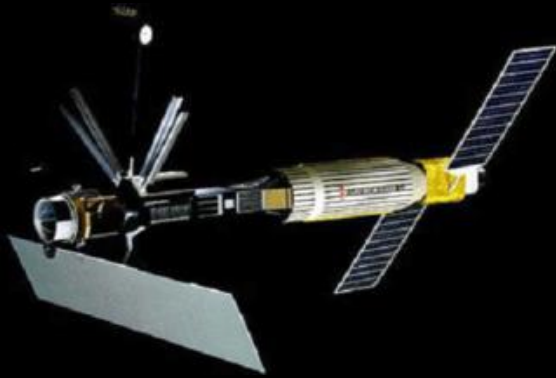
# Polarimetric Radar (SAR)



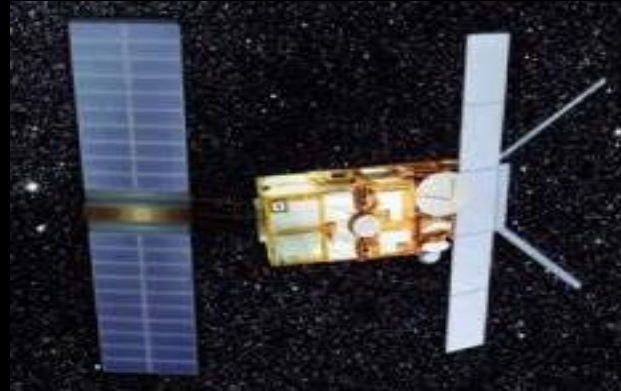
## Spaceborne Sensors



# 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

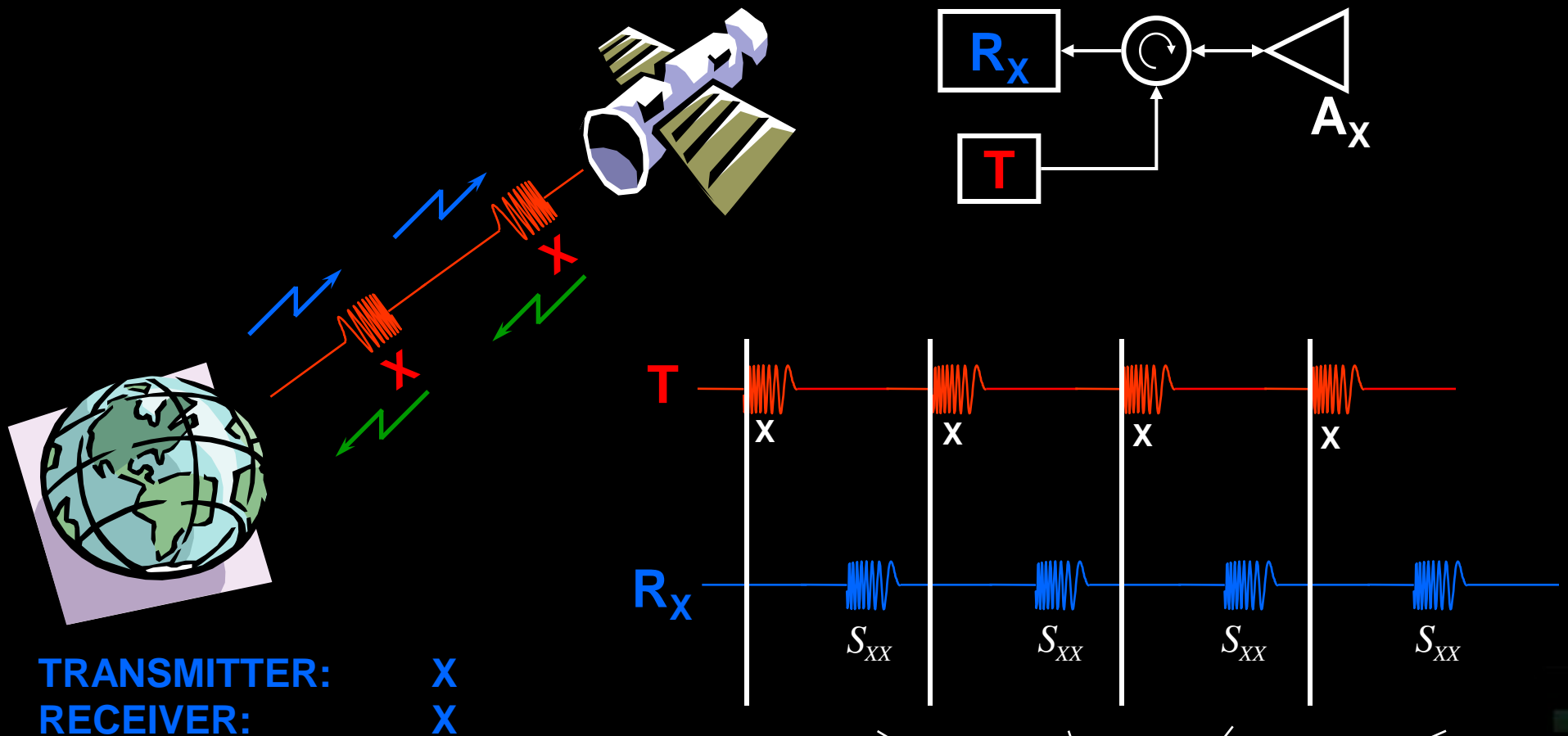


**ERS-2**  
European Space Agency (ESA)  
C-Band, 1995



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

# Scattering Coefficient



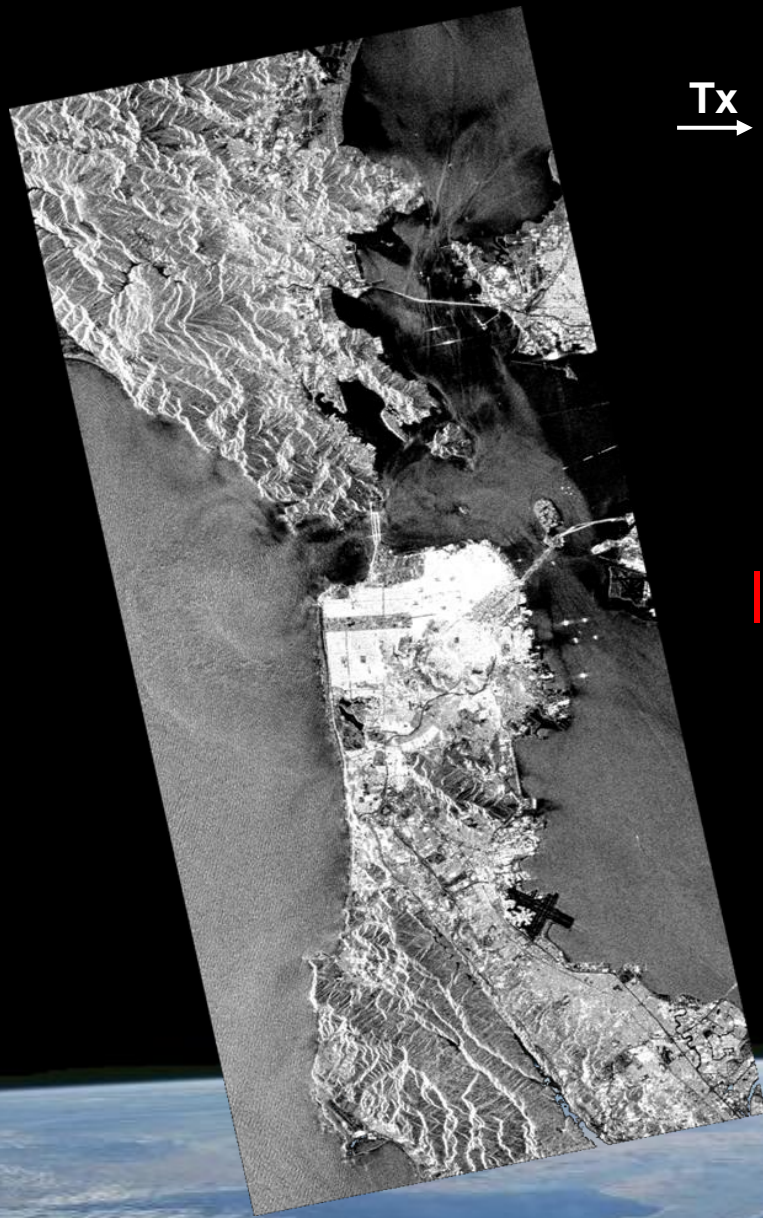
BACKSCATTERING  
COEFFICIENT

$$\{ S_{XX} \}$$

NO POLARIMETRY



# Space-borne Sensors



Tx  
→

Rx  
→

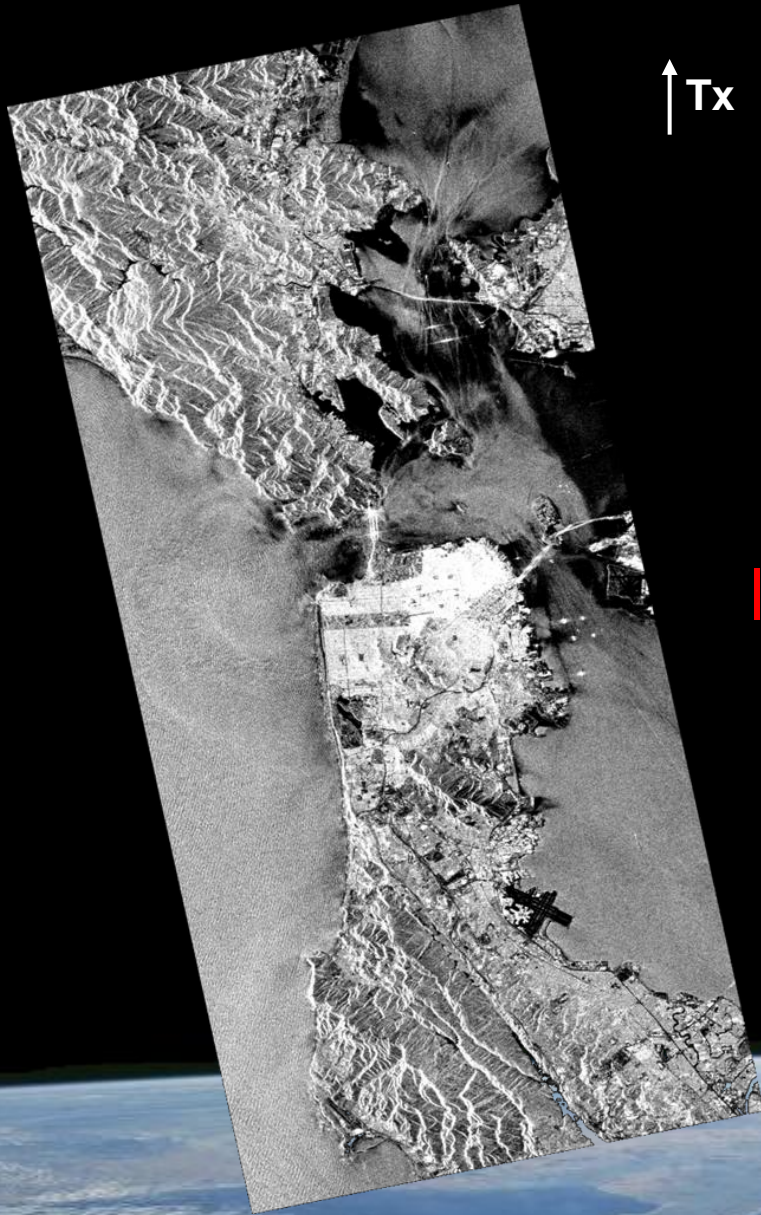
$|HH|_{dB}$



San Francisco Bay – (L-Band)



# Space-borne Sensors



↑ Tx

↑ Rx

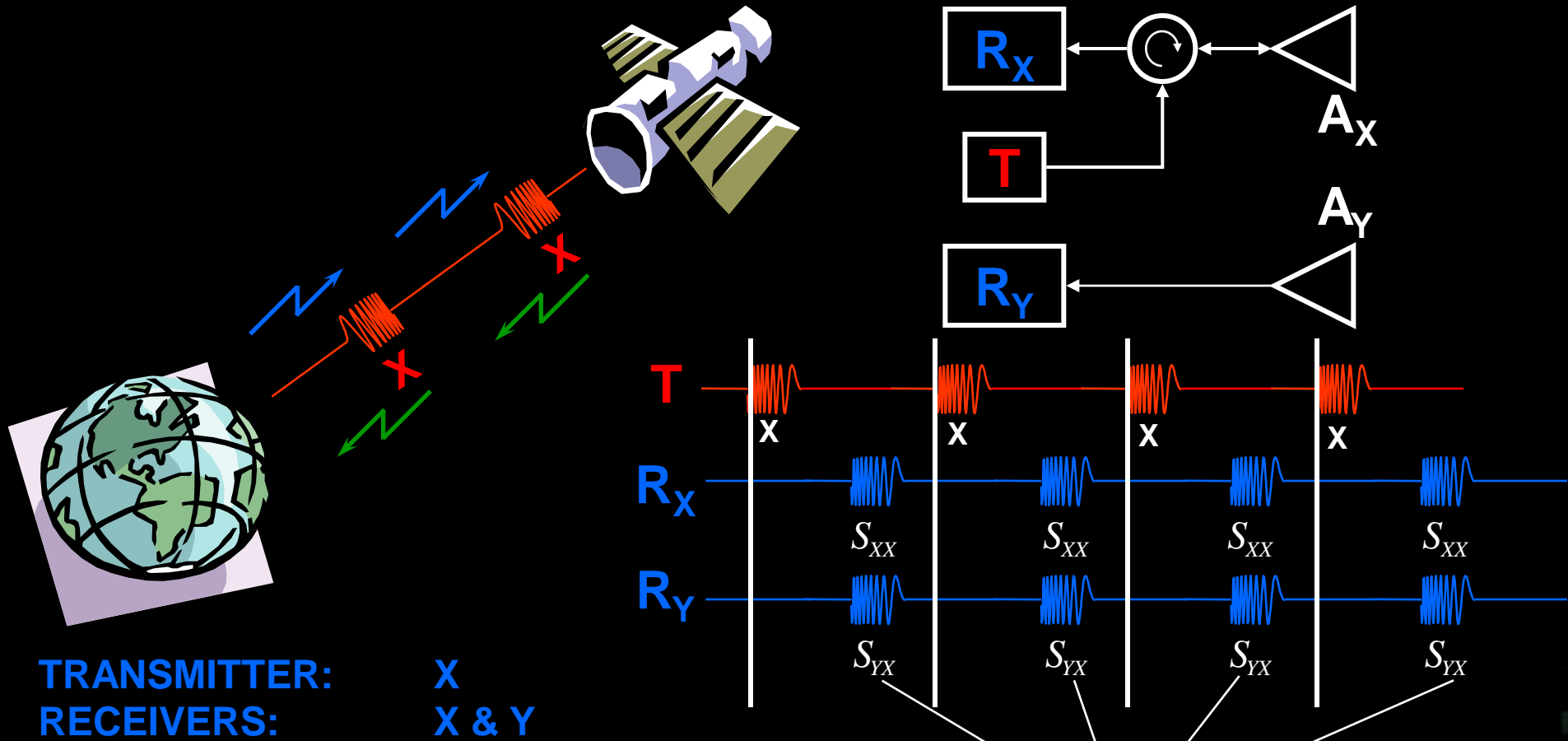
$|VV|_{dB}$



San Francisco Bay – (L-Band)



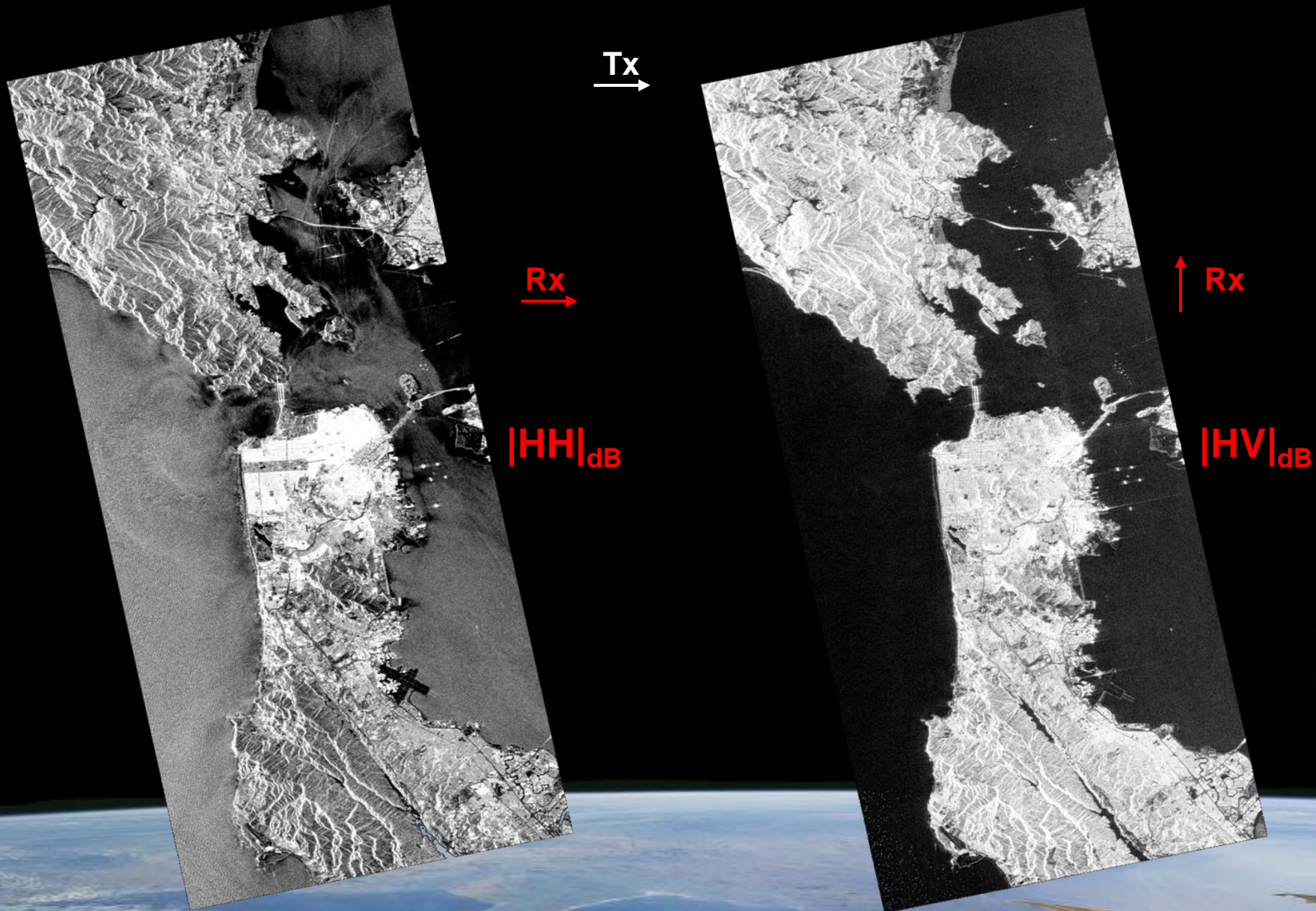
# Wave Polarimetry



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

WAVE POLARIMETRY

# Space-borne Sensors



San Francisco Bay – (L-Band)



# Space-borne PolSAR Sensors

## ENVISAT - ASAR

October 2001  
C-Band (Sngl / Dual Inc)



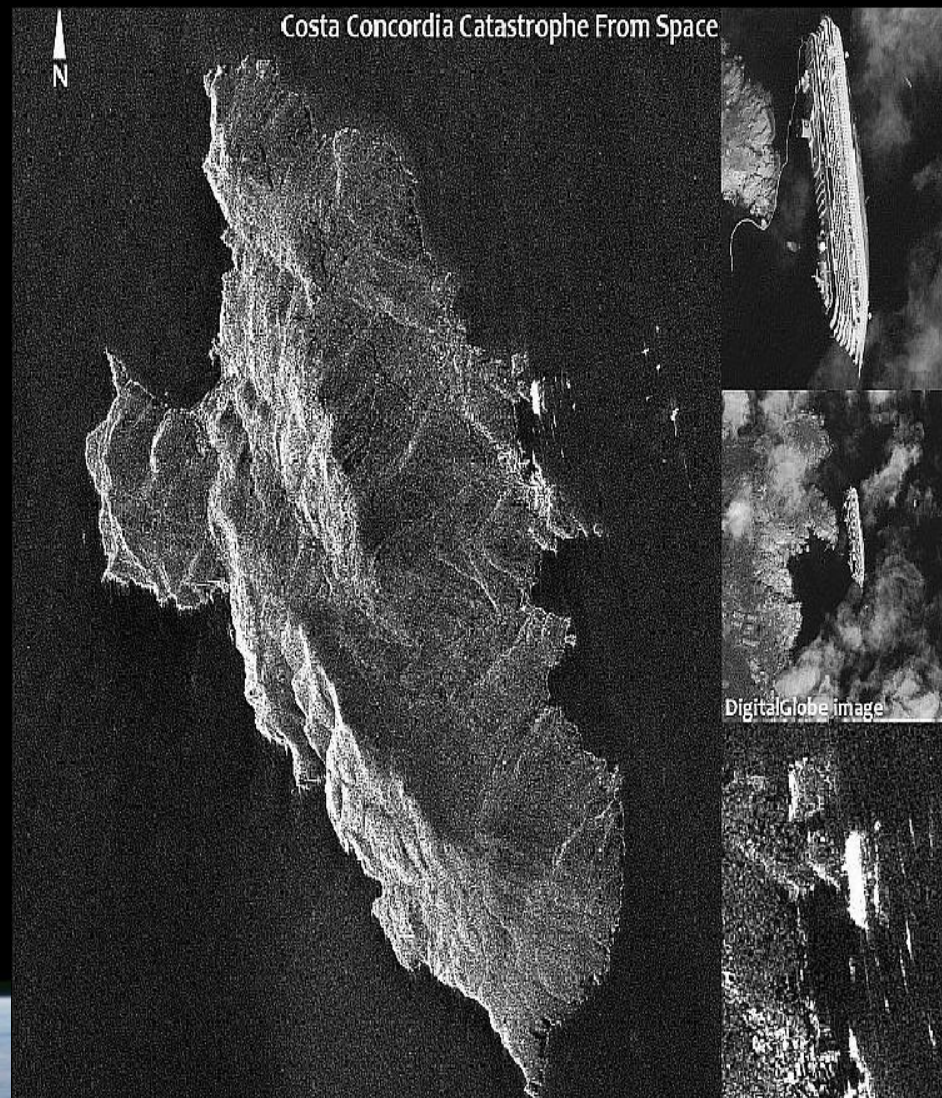


# Space-borne PoSAR Sensors

## COSMO - SkyMed



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.)





# Space-borne PolSAR Sensors

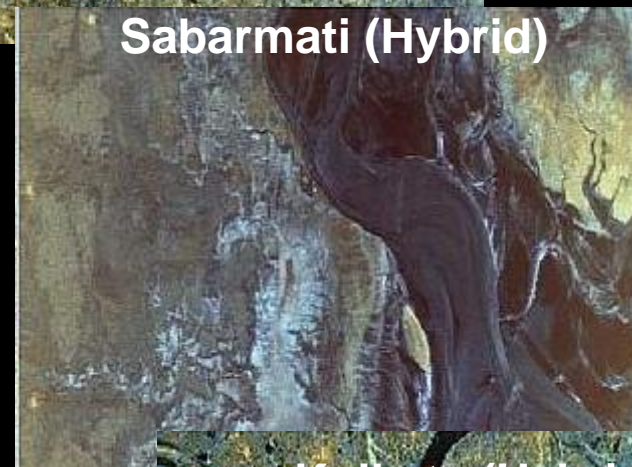
## RISAT-1A



26 April 2012

C-Band (Sngl, Dual, Hybrid)

*Operational since 2015*





# Space-borne PolSAR Sensors

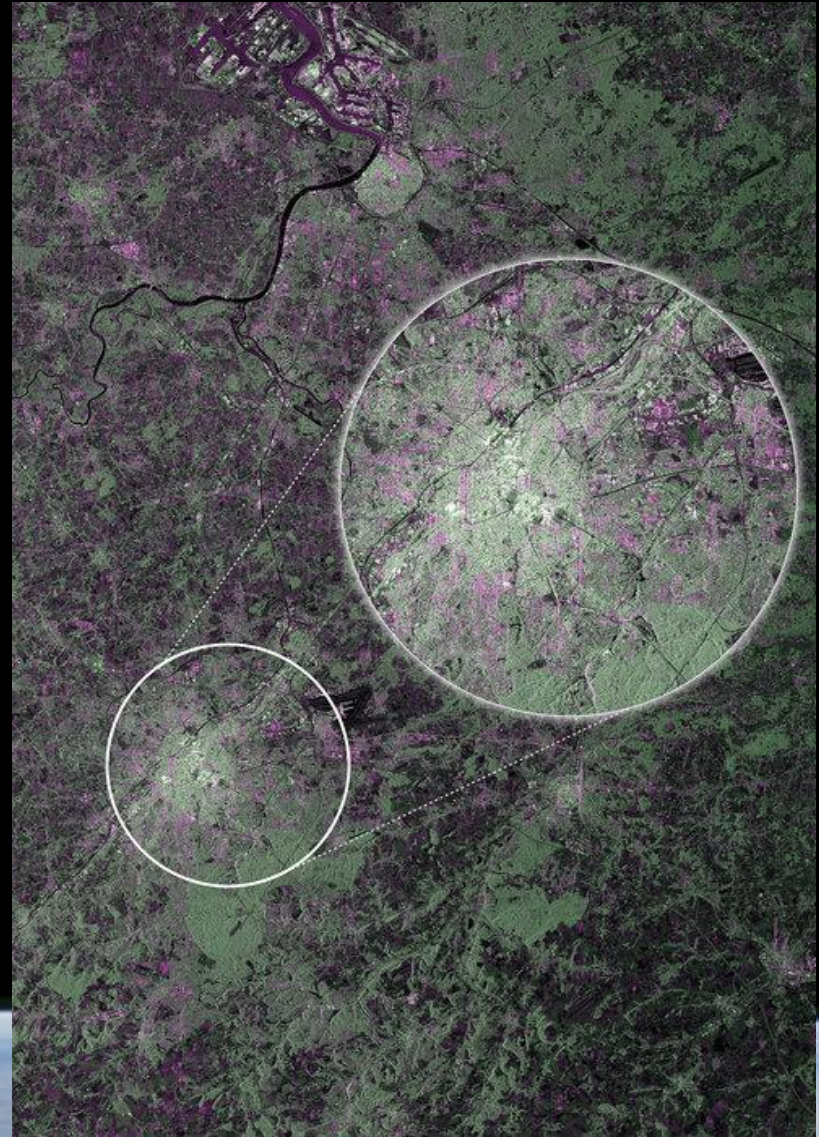
## SENTINEL – 1A



**S1A : April 2014      S1B : April 2016**

**C-Band (Sngl, Dual)**

**Revisit : 6 days**



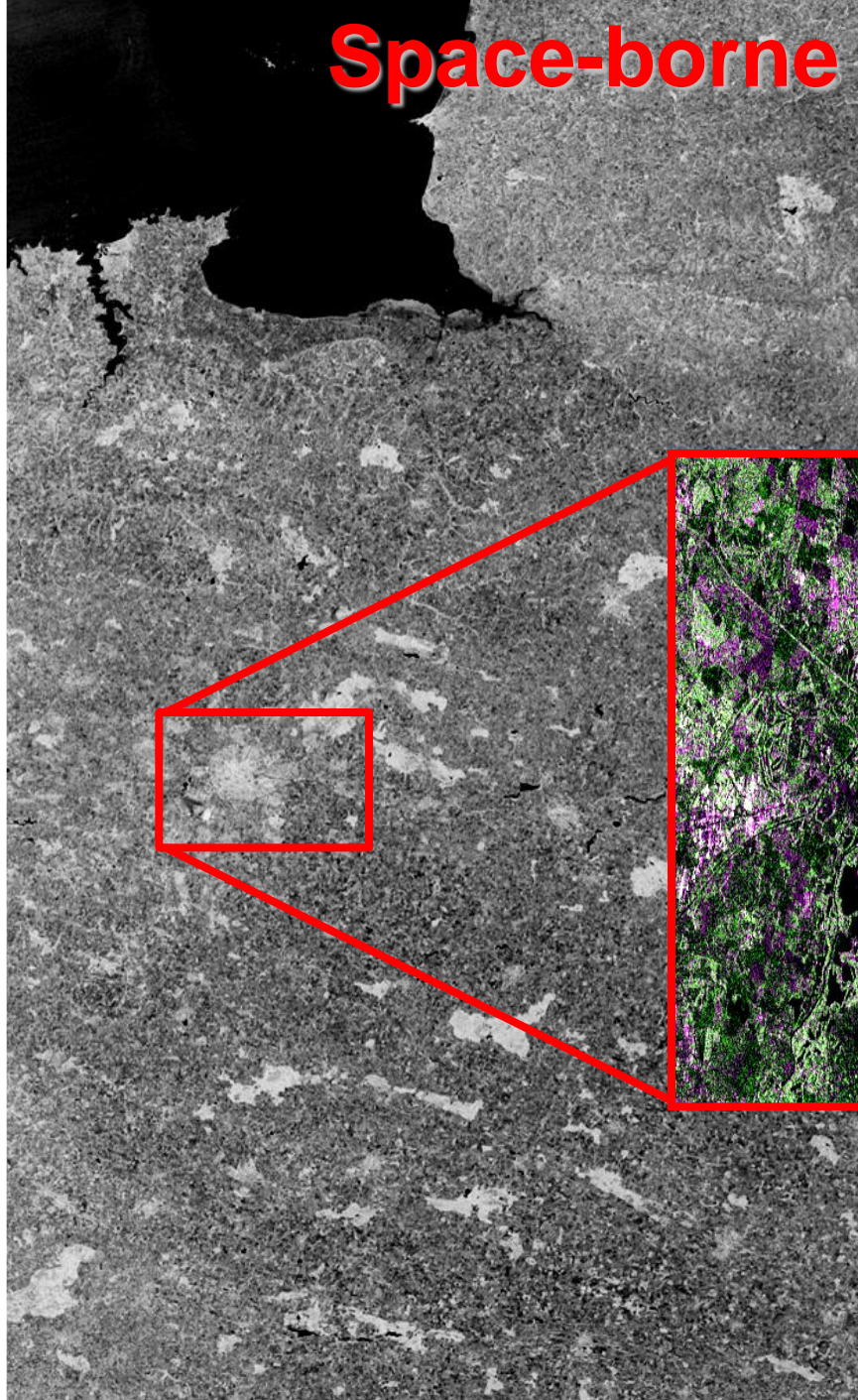
**Brussels – 12 April 2014**



# Space-borne PolSAR Sensors



Rennes  
Brittany  
France

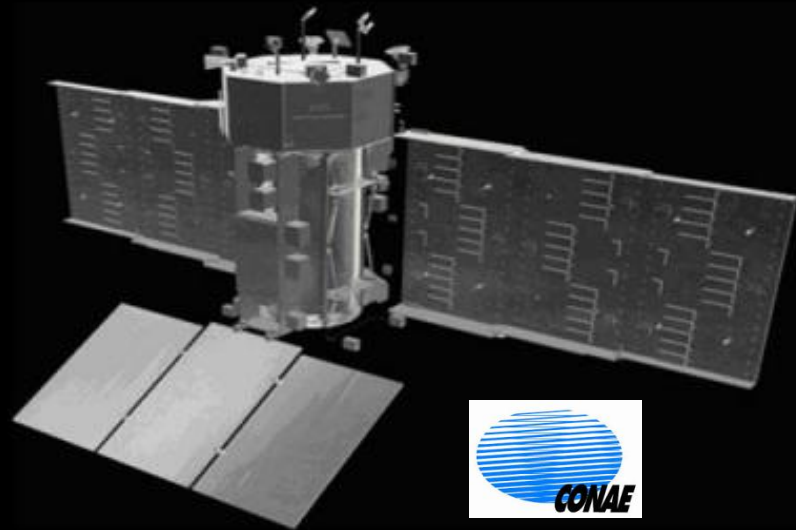


17/08/2016 @ 17h56



# 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)



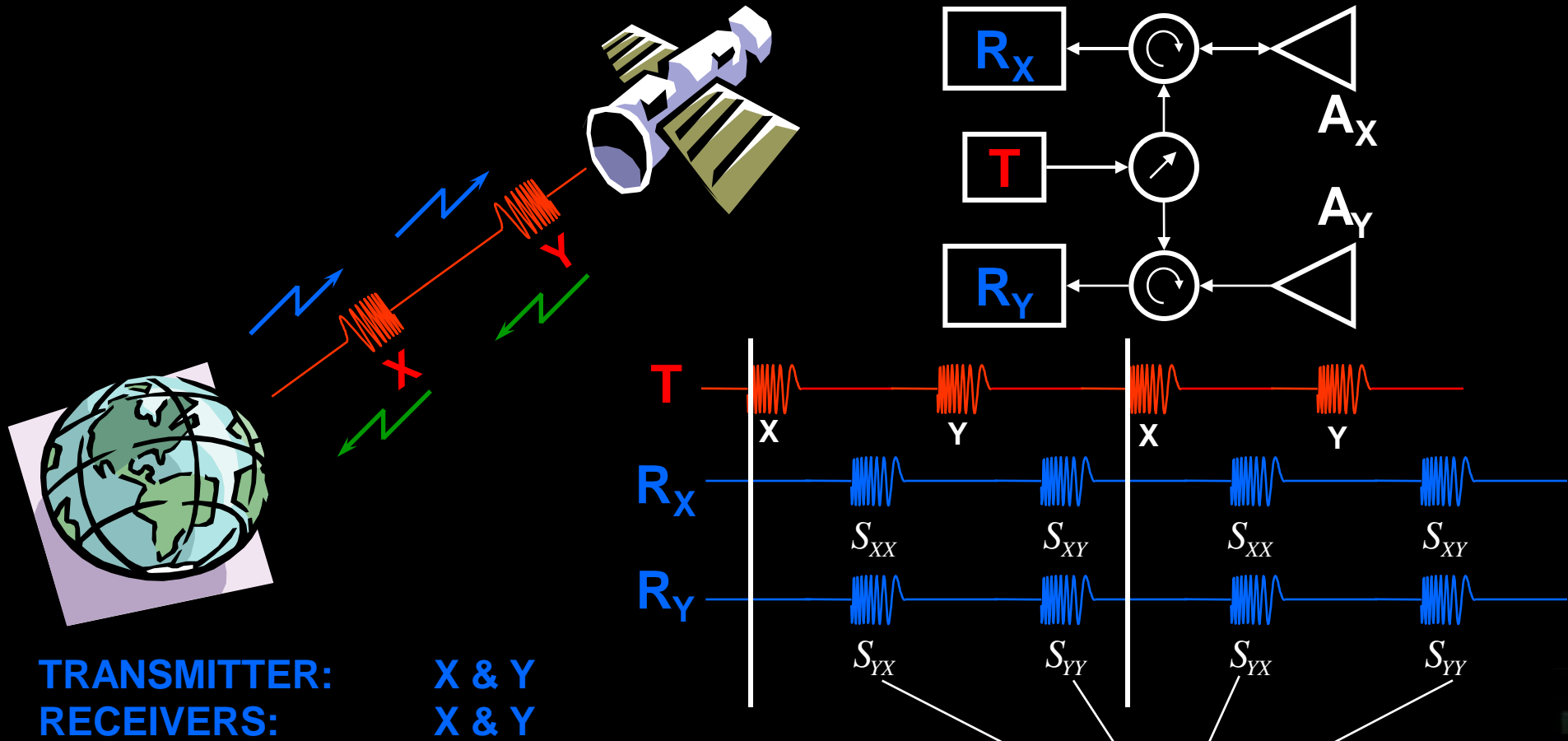
1A : 2017

1B / 1C : 2018

C-Band (Sngl, Dual, Hybrid)

Revisit : 4 days

# Scattering Polarimetry

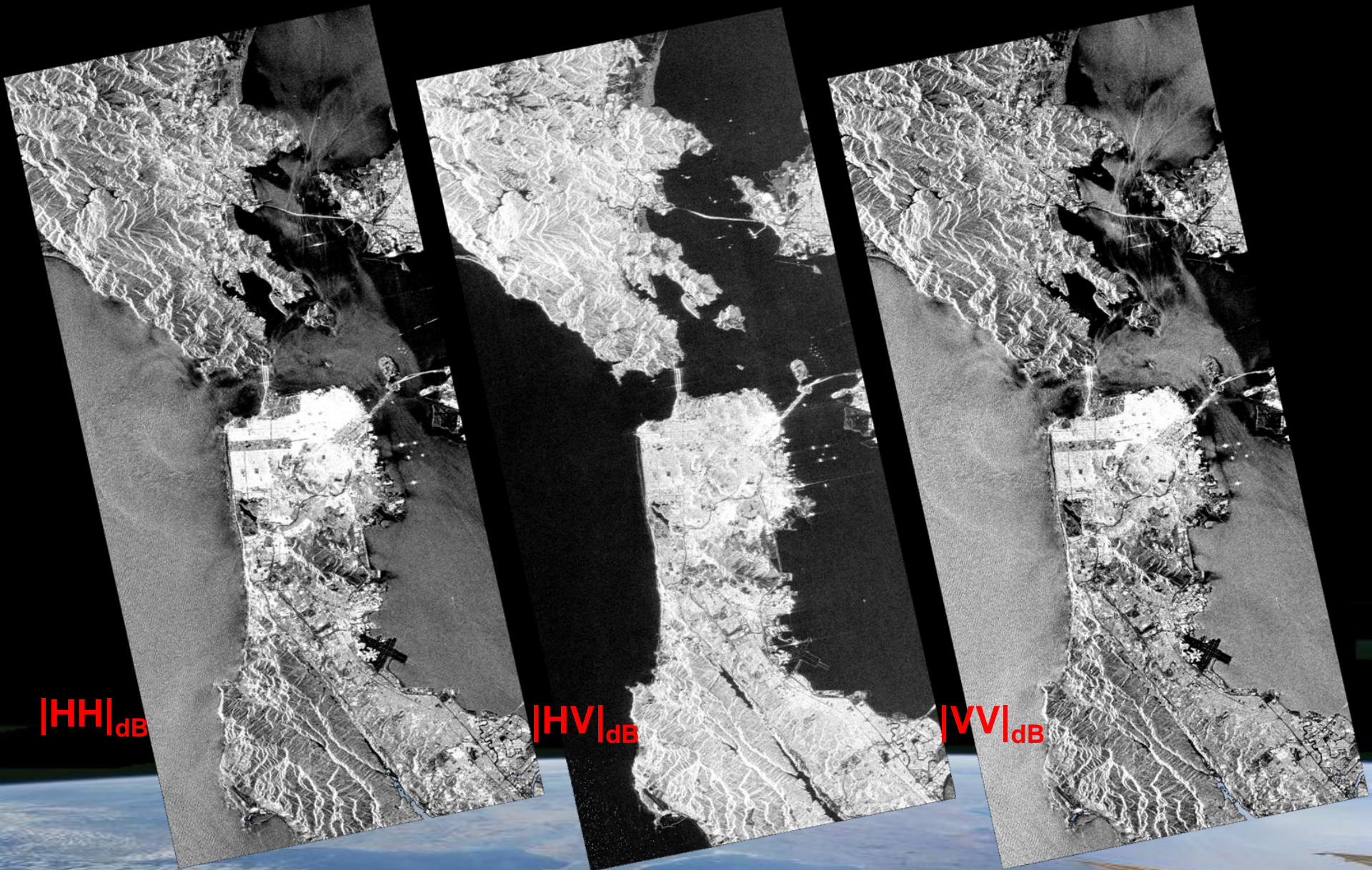


**SINCLAIR MATRICES**

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



# Space-borne Sensors



San Francisco Bay – (L-Band)



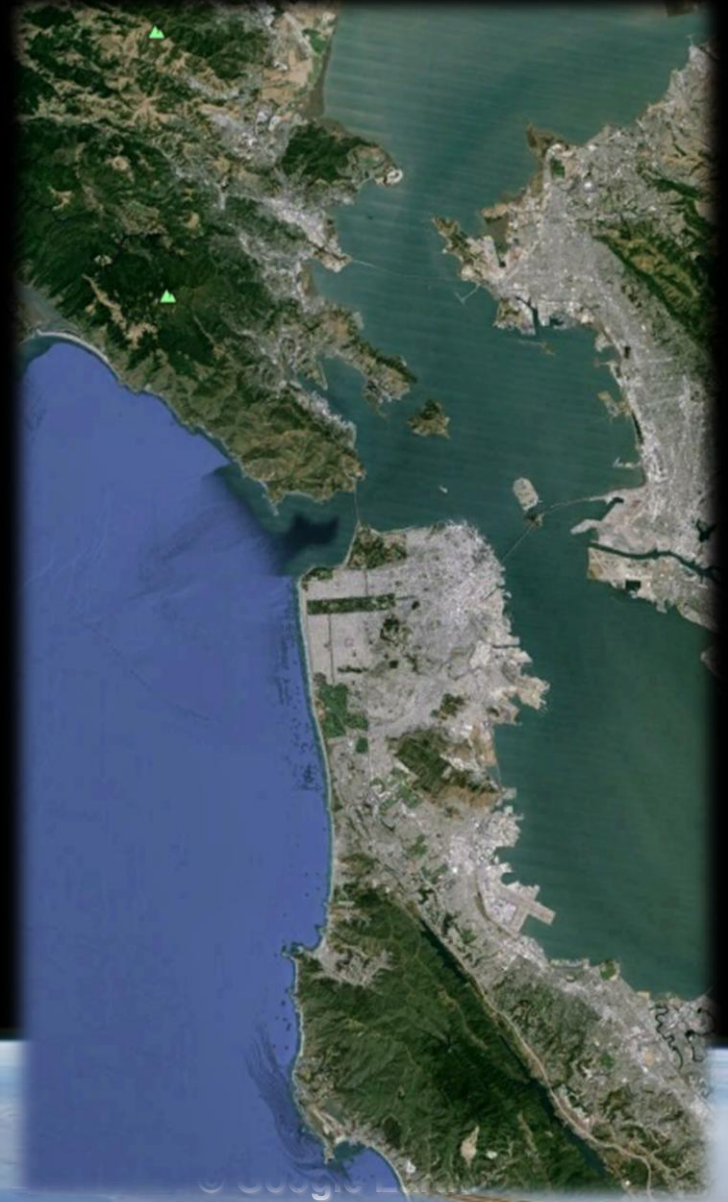
# Space-borne Sensors



$|HH|_{dB}$

$|HV|_{dB}$

$|VV|_{dB}$

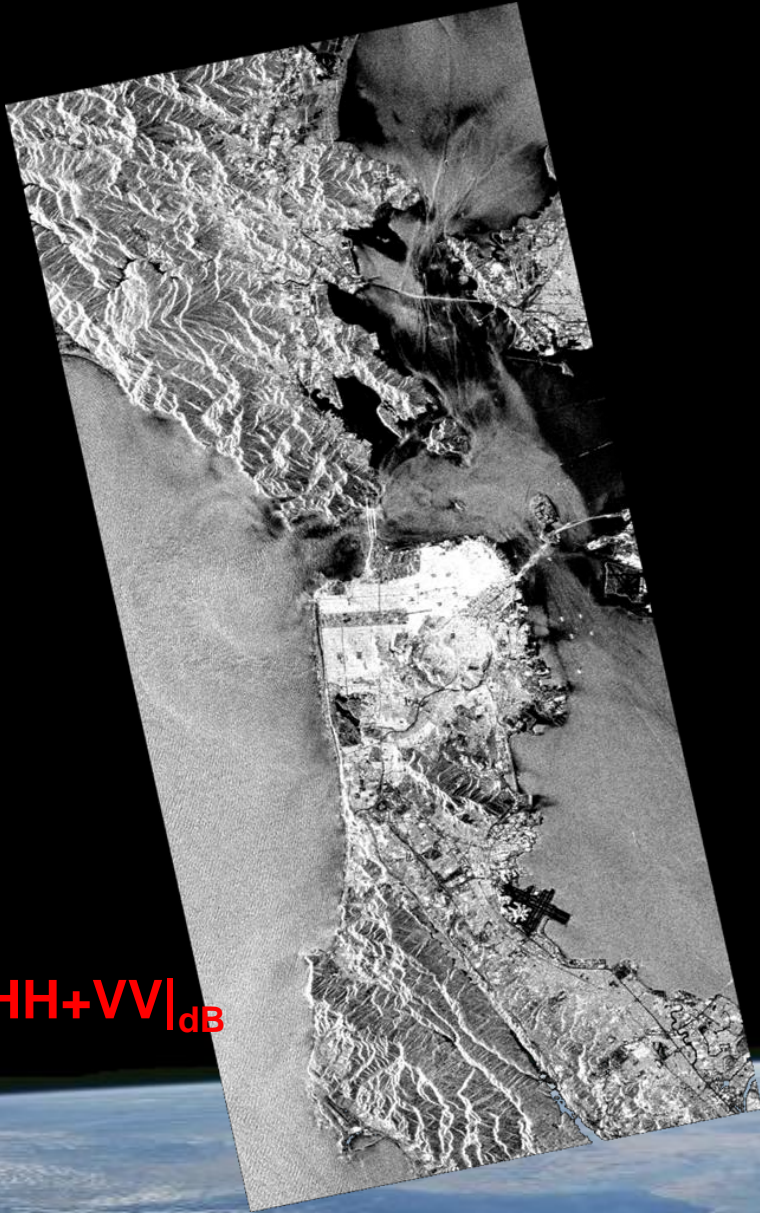


San Francisco Bay – (L-Band)

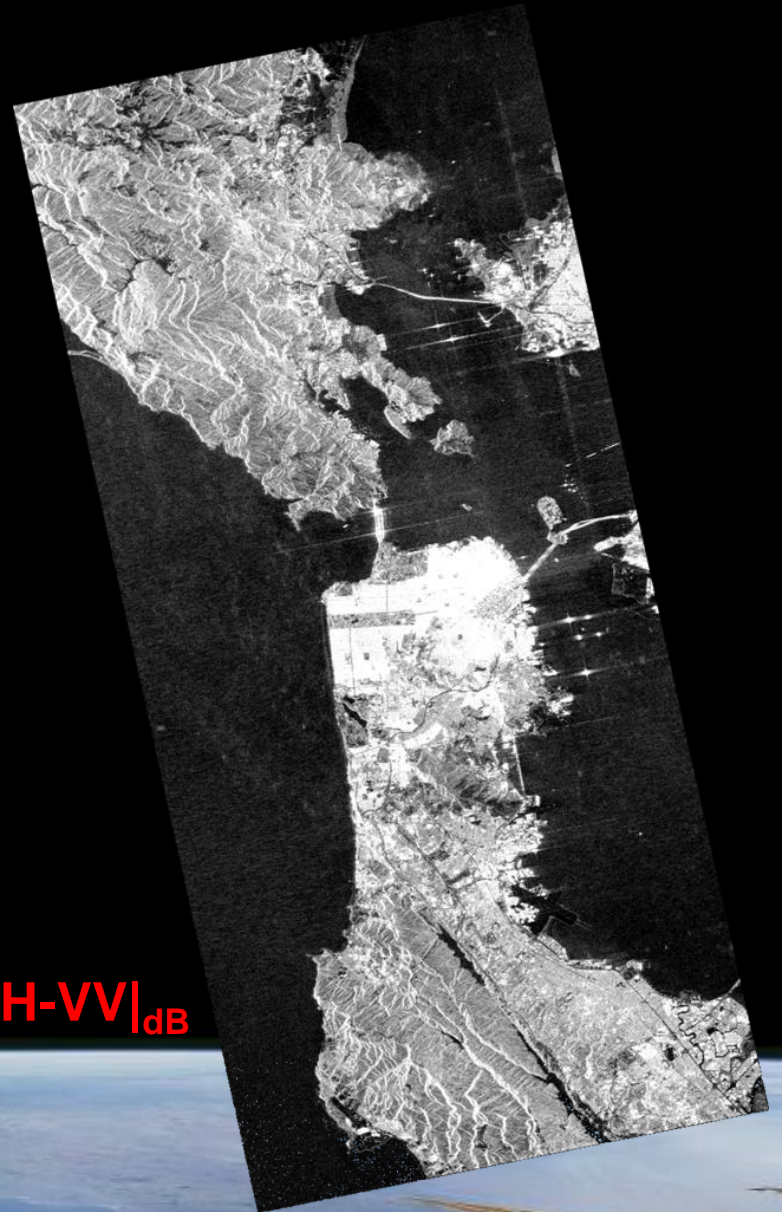


# Space-borne Sensors

$|HH+VV|_{dB}$



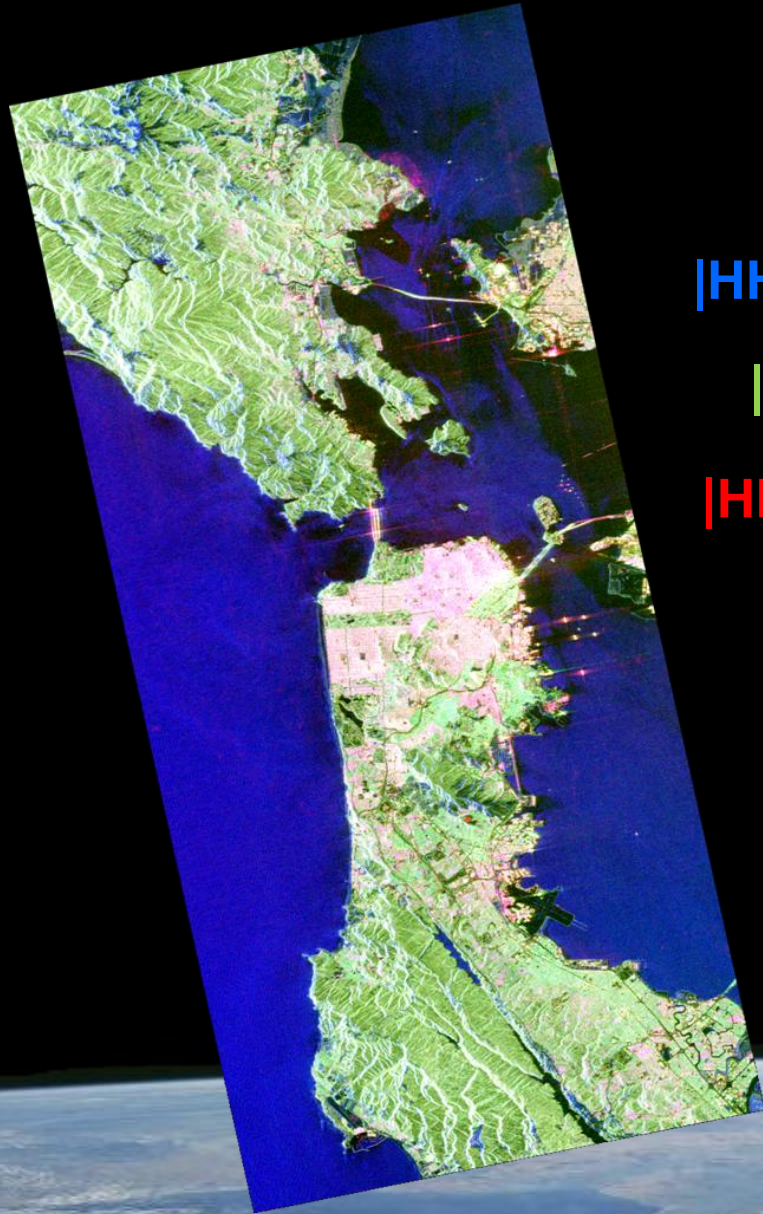
$|HH-VV|_{dB}$



San Francisco Bay – (L-Band)



# Space-borne Sensors



$|HH+VV|_{dB}$

$|HV|_{dB}$

$|HH-VV|_{dB}$

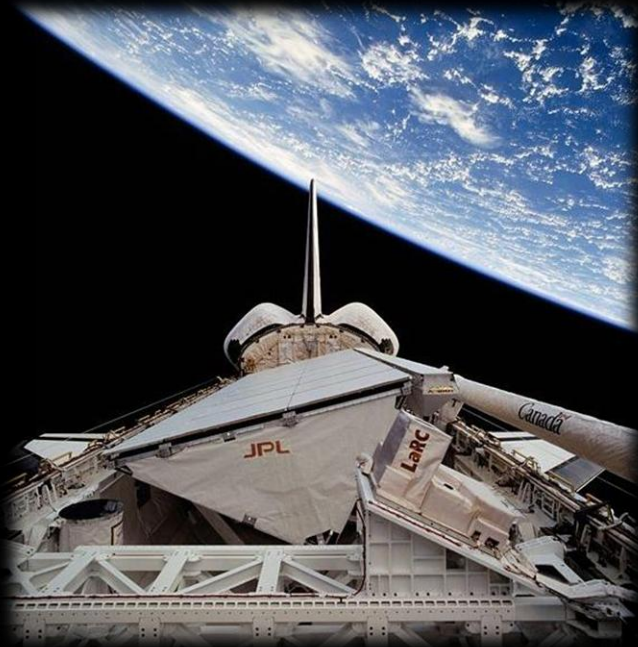


San Francisco Bay – (L-Band)

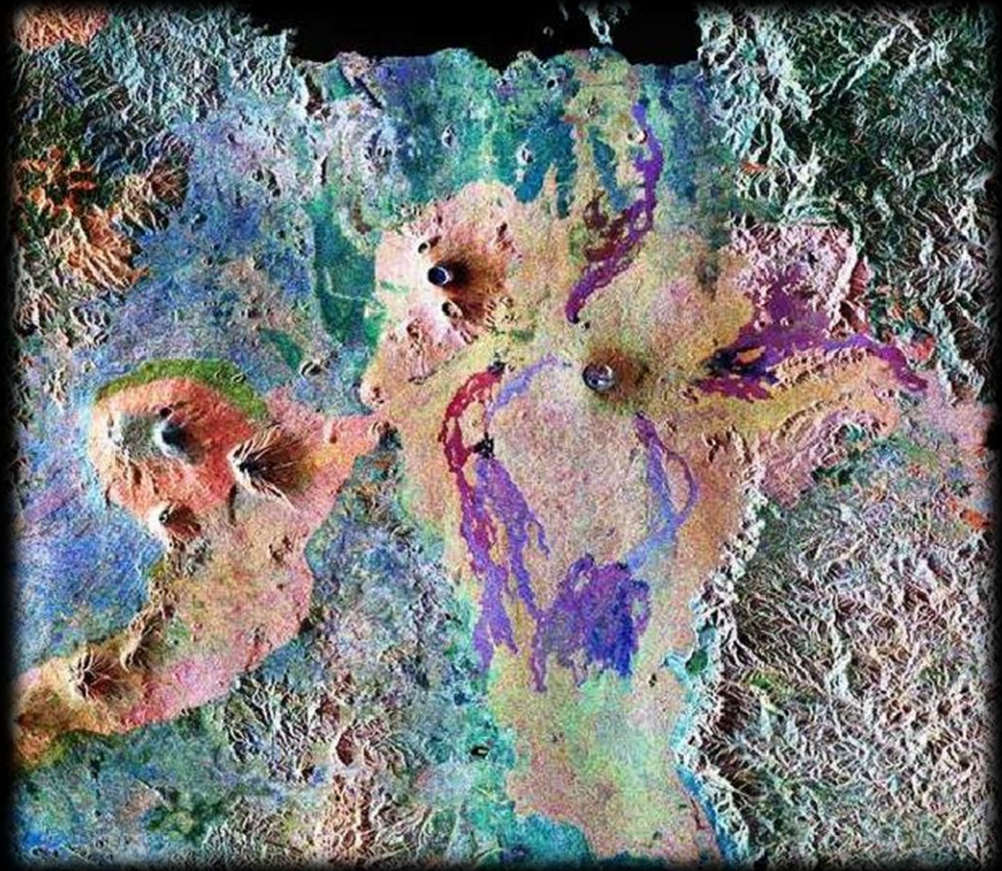


# Space-borne PolSAR Sensors

## SIR-C / X-SAR



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

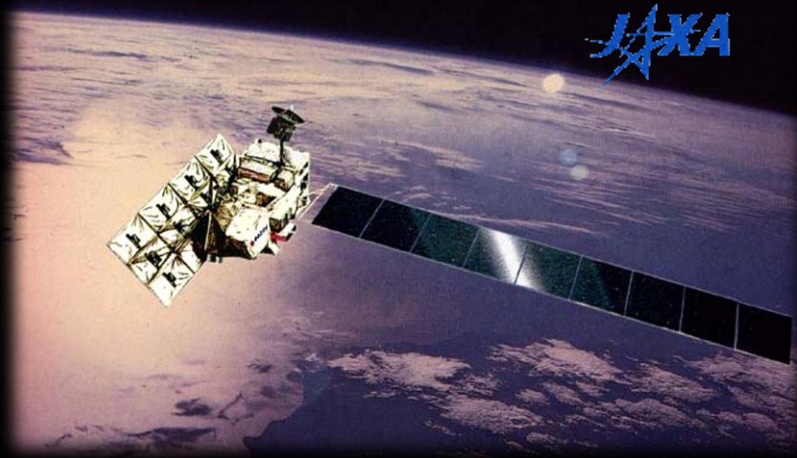


Rwanda, Zaire, Uganda



# Space-borne PolSAR Sensors

## ALOS - PALSAR



January 2006

L-Band (Sngl / Twin / Quad)

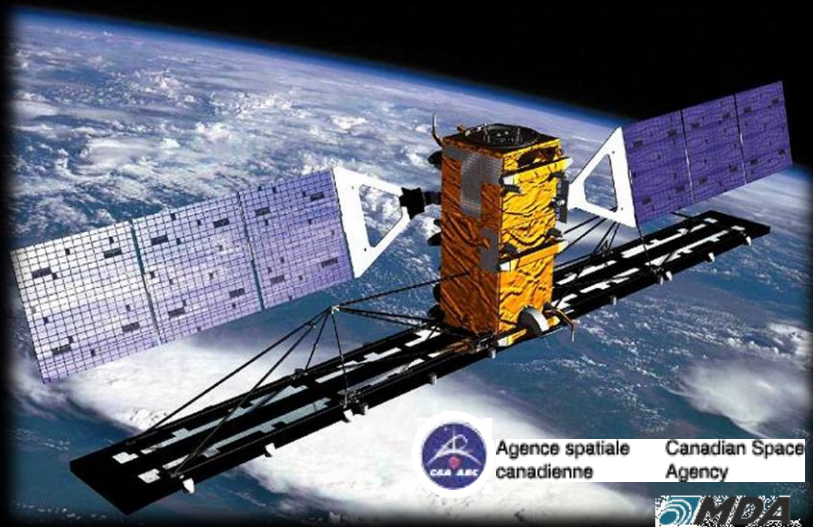


ALOS : Advanced Land Observing Satellite  
PALSAR : Phase Array L-Band SAR



# Space-borne PoISAR Sensors

## RADARSAT - 2

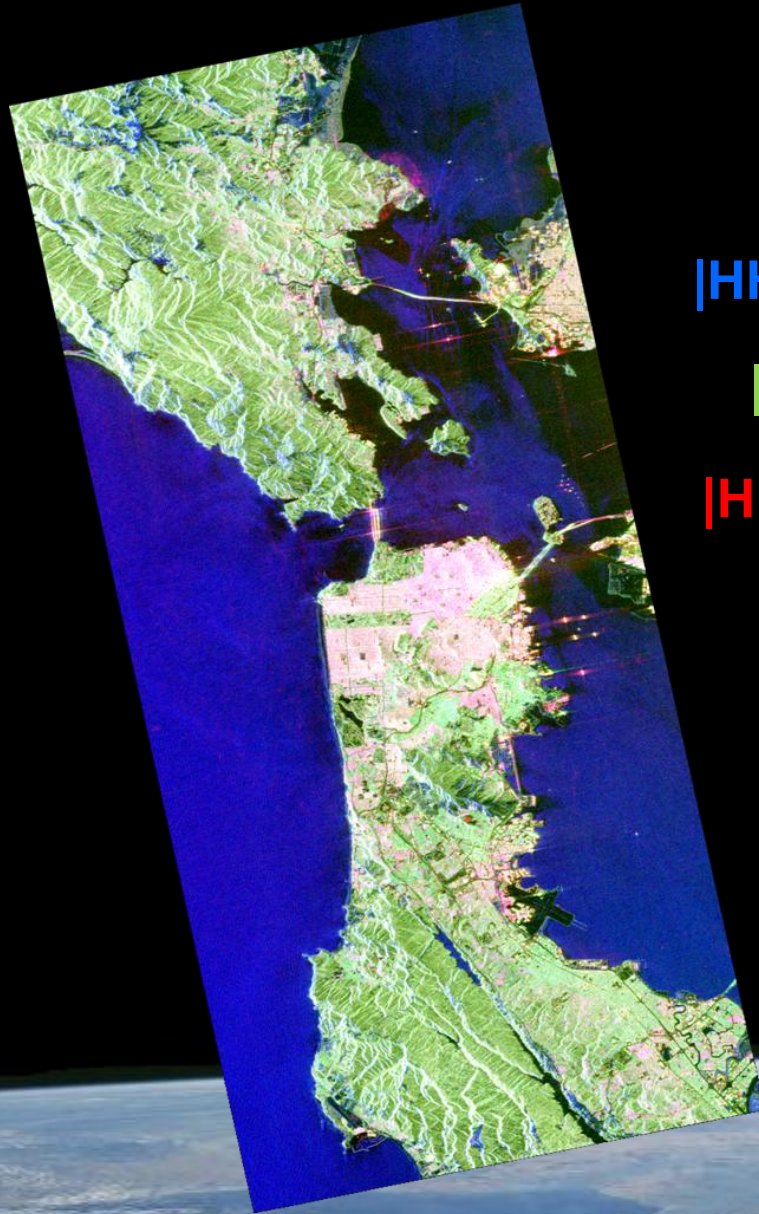


December 2007  
C-Band (Quad)





# Space-borne Sensors



$|HH+VV|_{dB}$

$|HV|_{dB}$

$|HH-VV|_{dB}$

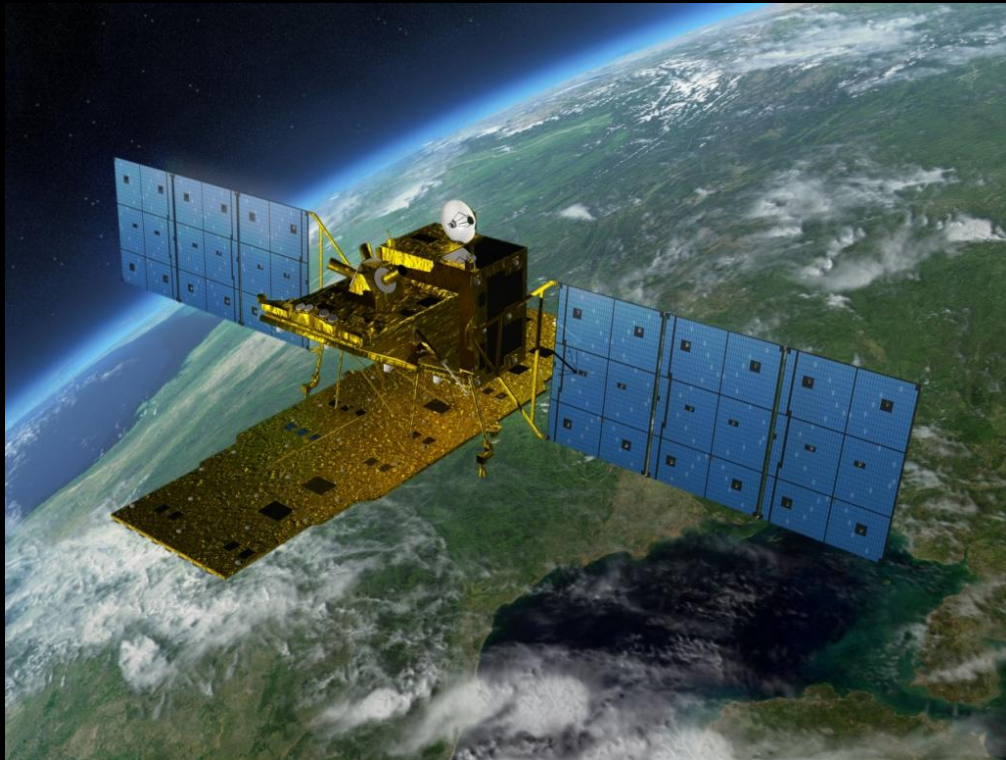


San Francisco Bay – (L-Band and C-Band)

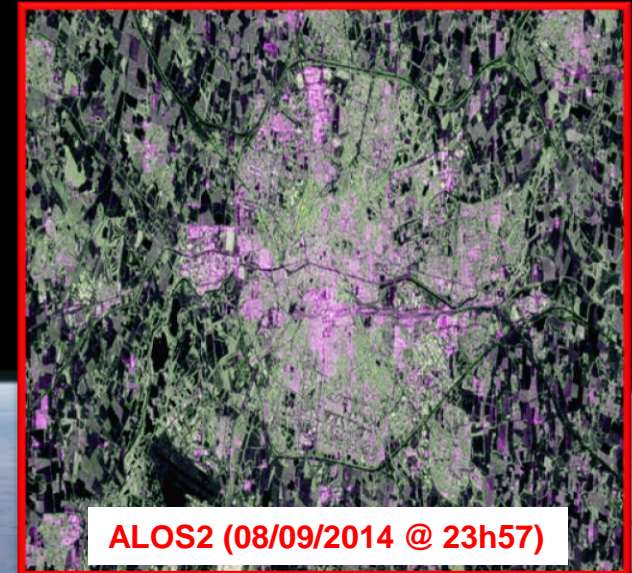
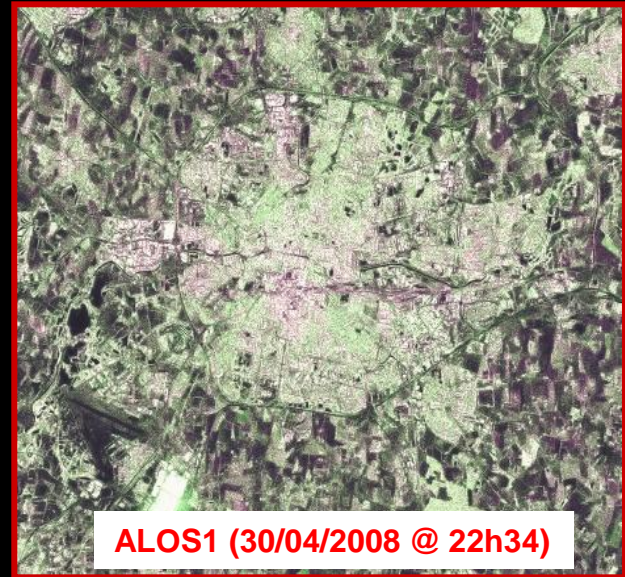


# Space-borne PolSAR Sensors

**ALOS - 2**



**May 2014**  
**L-Band (Quad)**

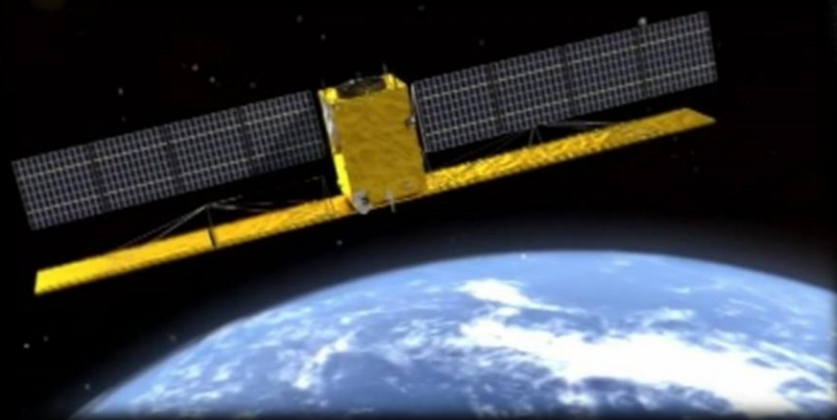




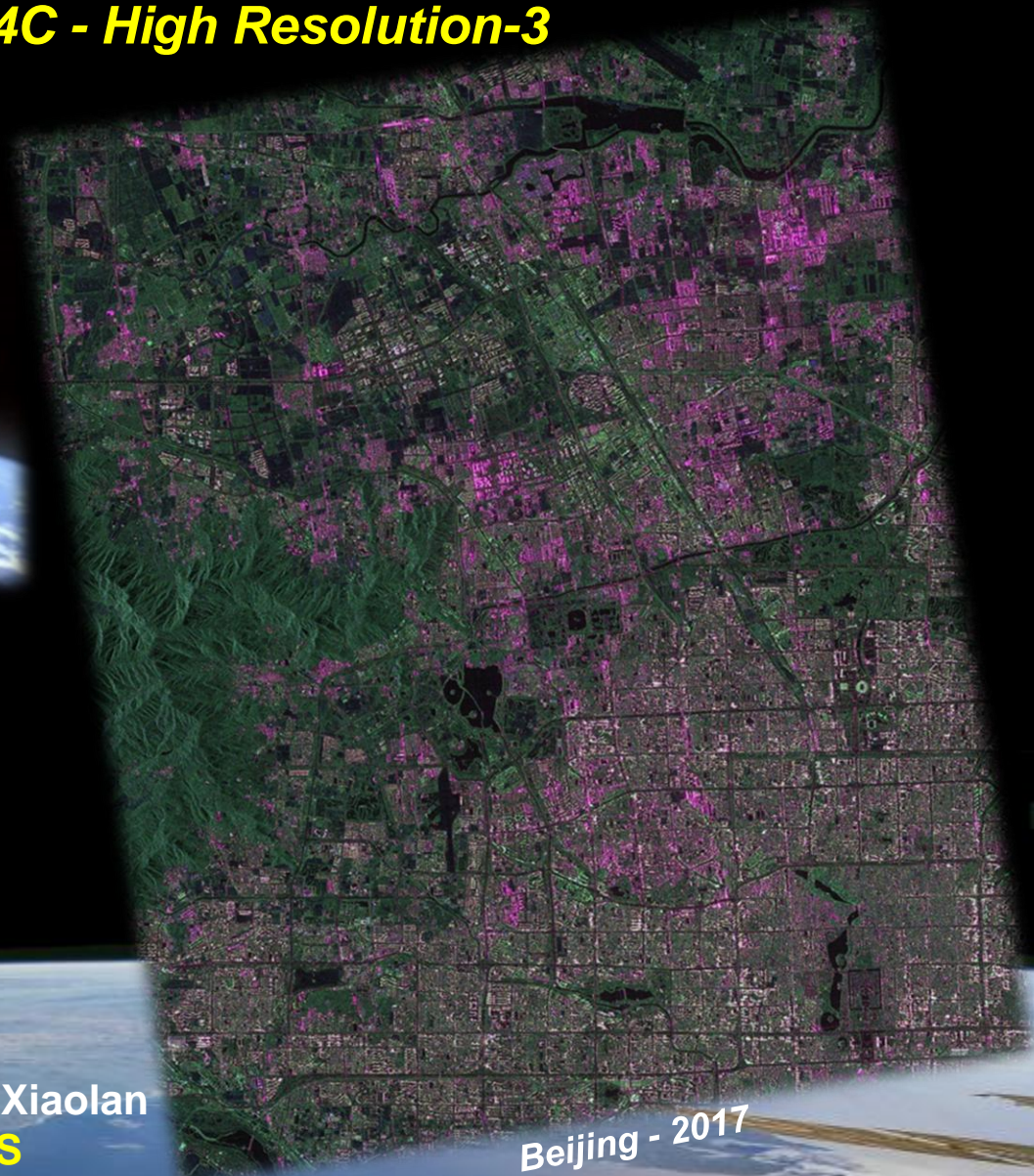
# Space-borne PolSAR Sensors

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

Long March-4C - High Resolution-3



August 2016  
C-Band (Quad)



Courtesy of Dr. Qiu Xiaolan  
IECAS / GIPAS

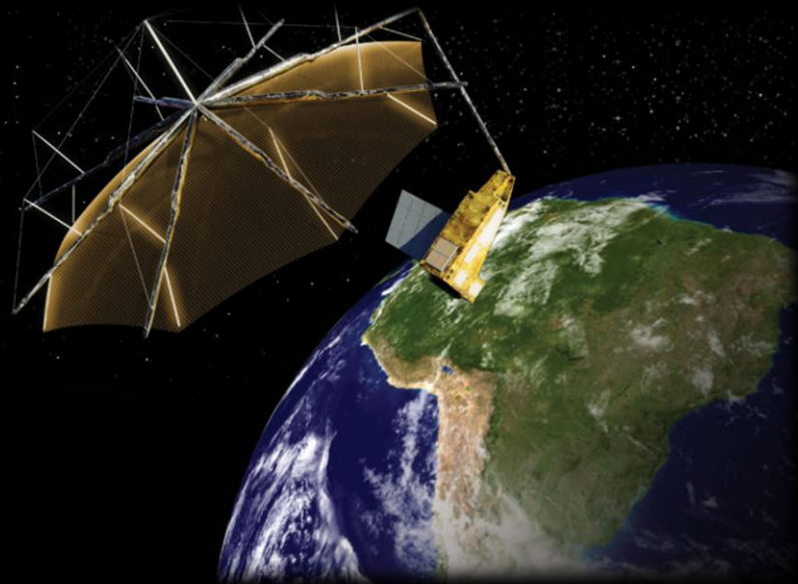
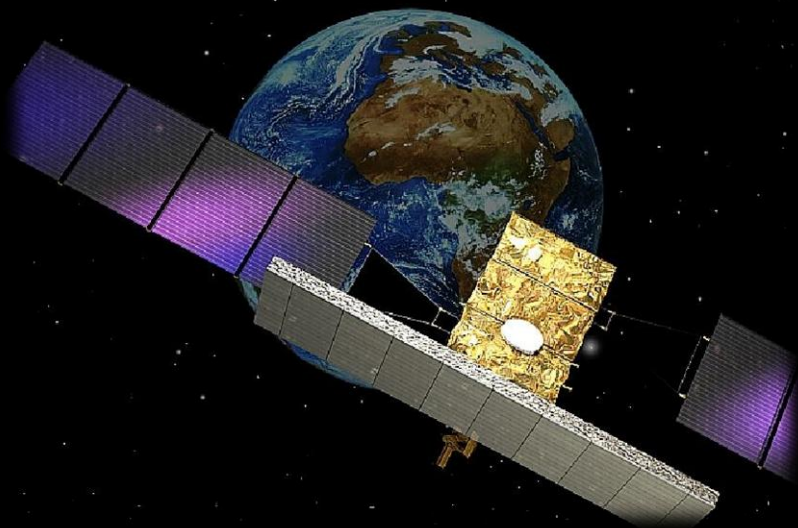
Beijing - 2017



# Space-borne PolSAR Sensors

**COSMO - SkyMed - CSG**

**Earth Explorer - BIOMASS**



**2A : 2018**

**2B : 2019**

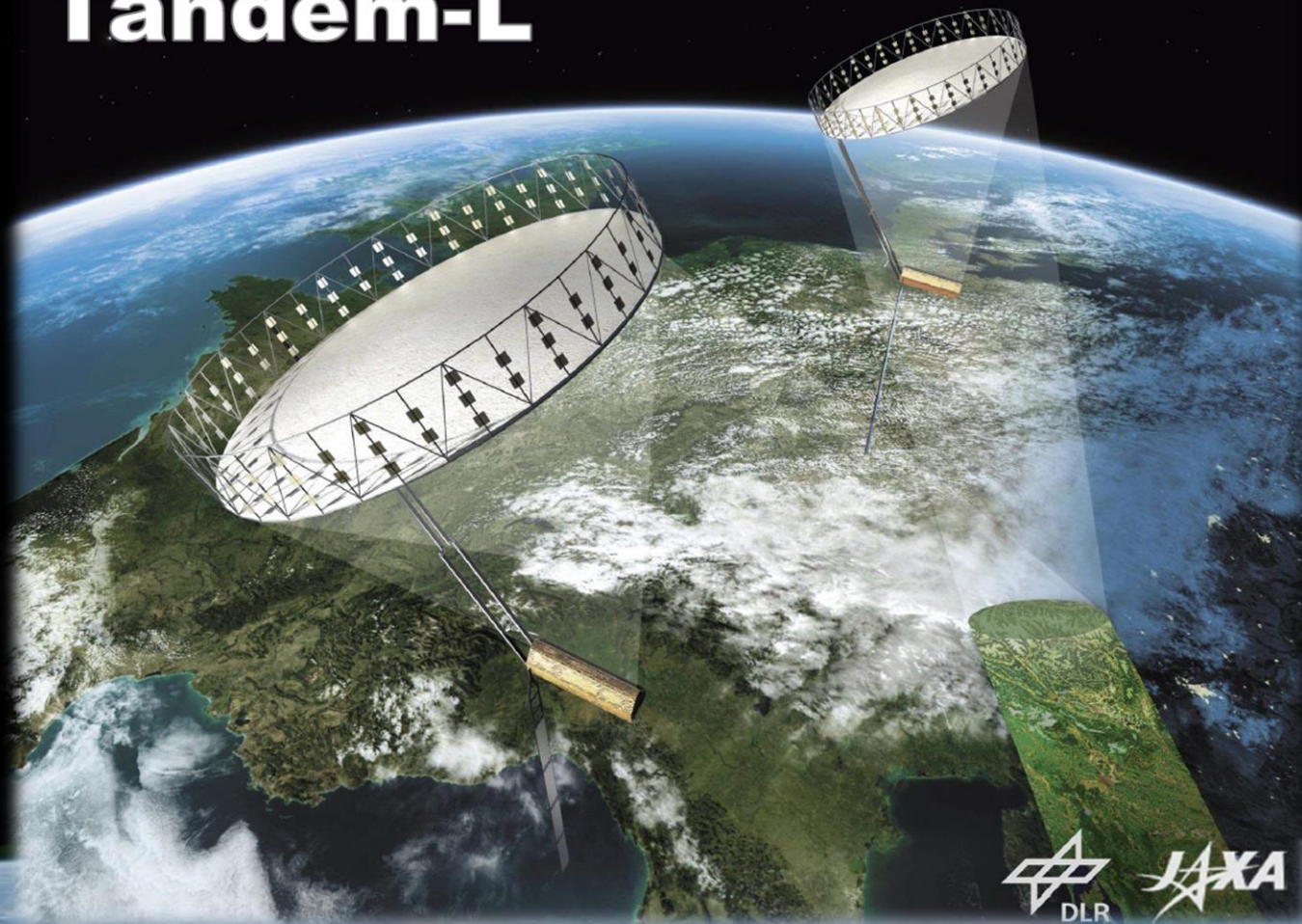
**2021**

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

**P-Band (Quad)**

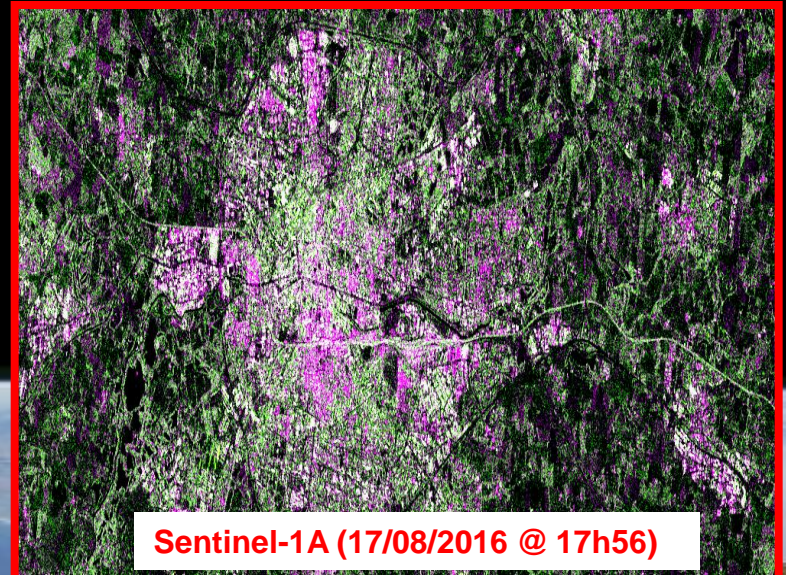
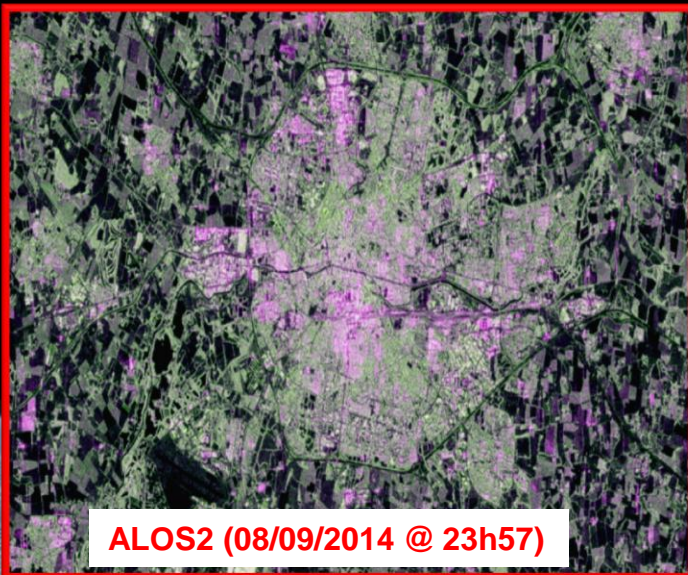
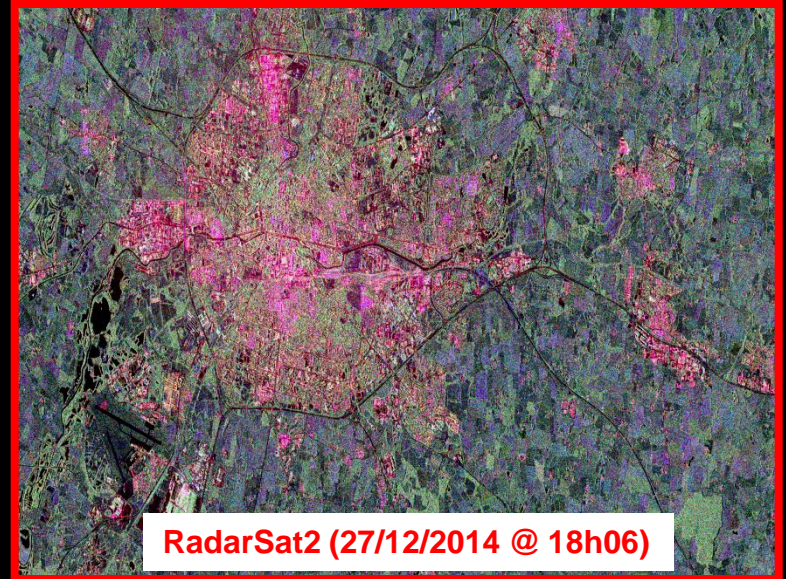
# Space-borne PolSAR Sensors

## Tandem-L





# Space-borne PolSAR Sensors





# Space-borne PolSAR Sensors



**Chang Zheng-4C - GaoFen-3 (GF-3)**  
**(03/01/2017 @ 17h49)**



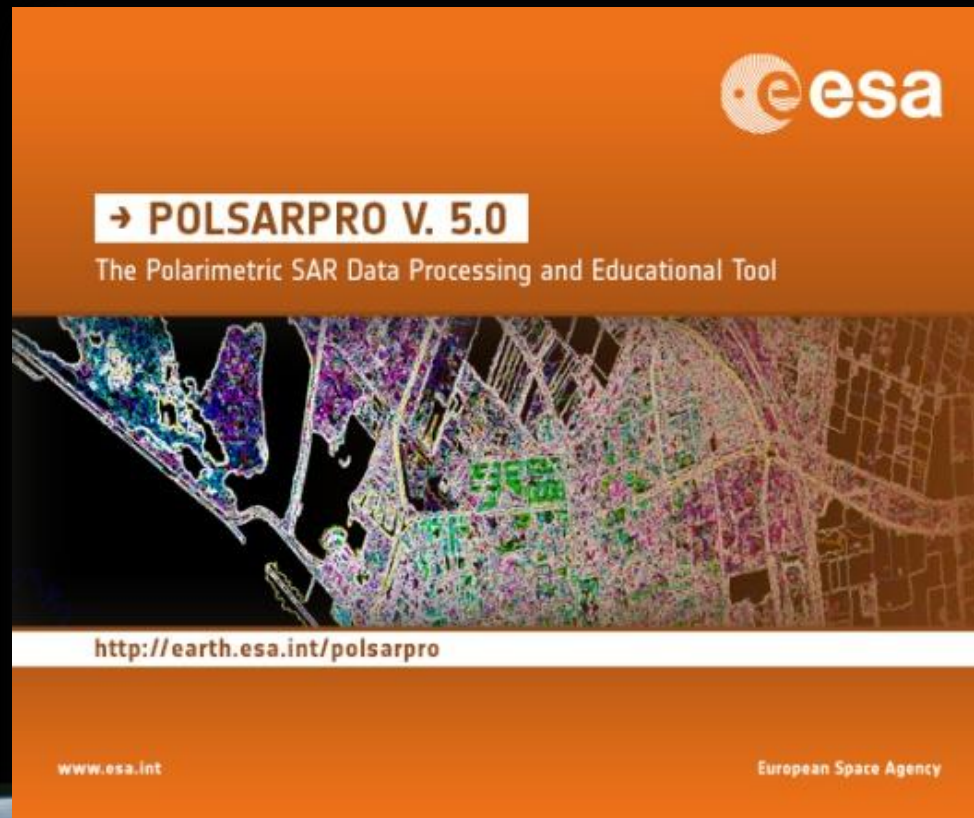
**What About**



**Software / Toolbox ?**

# ESA PolSARpro Toolbox

## The **P**olarimetric **SAR** Data **P**rocessing and Educational Toolbox



The image shows the cover of the PolSARpro V. 5.0 software box set. The cover is primarily orange. In the top right corner is the ESA logo. Below it, a white box contains the text '→ POLSARPRO V. 5.0'. Underneath that, the subtitle 'The Polarimetric SAR Data Processing and Educational Tool' is written. The central part of the cover features a colorful, multi-polarimetric SAR image of a coastal area with buildings and vegetation. At the bottom of the cover, a white bar contains the URL 'http://earth.esa.int/polsarpro'. The bottom left corner of the cover has 'www.esa.int' and the bottom right corner has 'European Space Agency'. The entire cover is set against a background of Earth as seen from space.

esa

→ POLSARPRO V. 5.0

The Polarimetric SAR Data Processing and Educational Tool

<http://earth.esa.int/polsarpro>

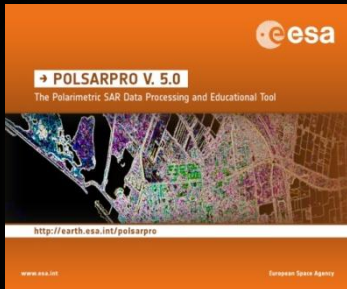
www.esa.int

European Space Agency



# 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.

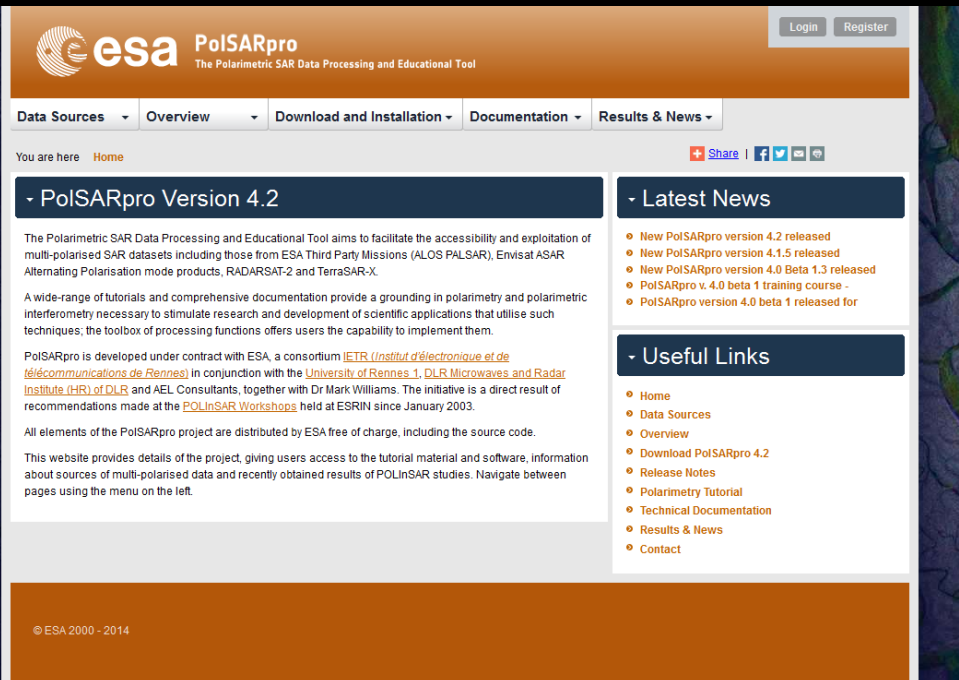
**Spaceborne sensors** : ALOS1, ALOS2, COSMO-SkyMed, RADARSAT-2, RISAT, Sentinel 1A/B, TerraSAR-X, Tandem-X,

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



The screenshot shows the ESA PolSARpro website. The header features the ESA logo and the text "PolSARpro The Polarimetric SAR Data Processing and Educational Tool". There are "Login" and "Register" buttons. A navigation menu includes "Data Sources", "Overview", "Download and Installation", "Documentation", and "Results & News". Below the menu, it says "You are here Home" and "Share" with social media icons. The main content area is divided into three columns: "PolSARpro Version 4.2", "Latest News", and "Useful Links".

**PolSARpro Version 4.2**

The Polarimetric SAR Data Processing and Educational Tool aims to facilitate the accessibility and exploitation of multi-polarised SAR datasets including those from ESA Third Party Missions (ALOS PALSAR), Envisat ASAR Alternating Polarisation mode products, RADARSAT-2 and TerraSAR-X.

A wide-range of tutorials and comprehensive documentation provide a grounding in polarimetry and polarimetric interferometry necessary to stimulate research and development of scientific applications that utilise such techniques, the toolbox of processing functions offers users the capability to implement them.

PolSARpro is developed under contract with ESA, a consortium IETR (*Institut d'électronique et de télécommunications de Rennes*) in conjunction with the *University of Rennes 1, DLR Microwaves and Radar Institute (HR) of DLR* and AEL Consultants, together with Dr Mark Williams. The initiative is a direct result of recommendations made at the *POLInSAR Workshops* held at ESRIN since January 2003.

All elements of the PolSARpro project are distributed by ESA free of charge, including the source code.

This website provides details of the project, giving users access to the tutorial material and software, information about sources of multi-polarised data and recently obtained results of POLInSAR studies. Navigate between pages using the menu on the left.

**Latest News**

- New PolSARpro version 4.2 released
- New PolSARpro version 4.1.5 released
- New PolSARpro version 4.0 Beta 1.3 released
- PolSARpro v. 4.0 beta 1 training course -
- PolSARpro version 4.0 beta 1 released for

**Useful Links**

- Home
- Data Sources
- Overview
- Download PolSARpro 4.2
- Release Notes
- Polarimetry Tutorial
- Technical Documentation
- Results & News
- Contact

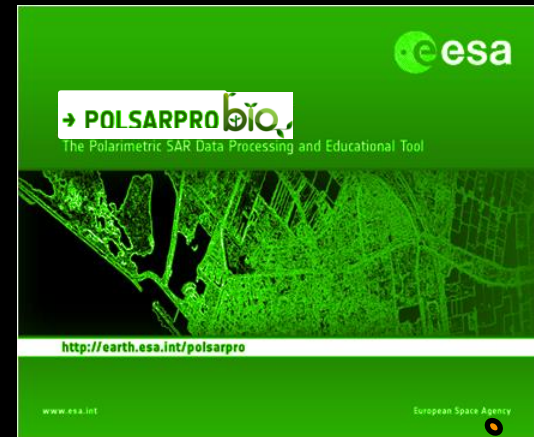
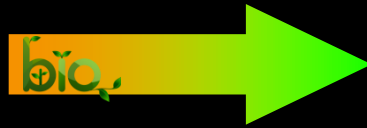
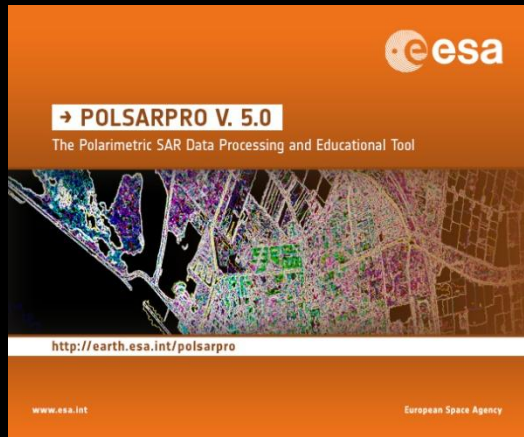
© ESA 2000 - 2014

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

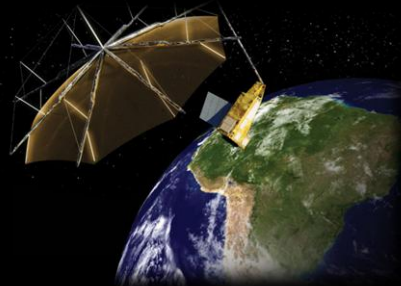


# ESA PolSARpro Toolbox

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



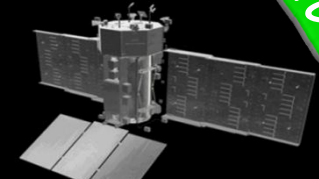
Future spaceborne sensors



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

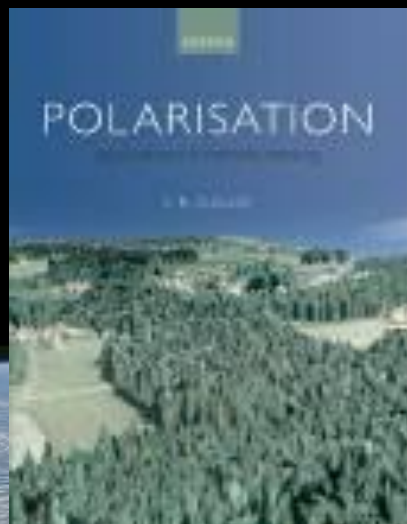


## **Polarimetric Radar Imaging: From basics to applications**

**Jong-Sen LEE – Eric POTTIER**

CRC Press; 1st ed., February 2009, pp 422

ISBN: 978-1420054972



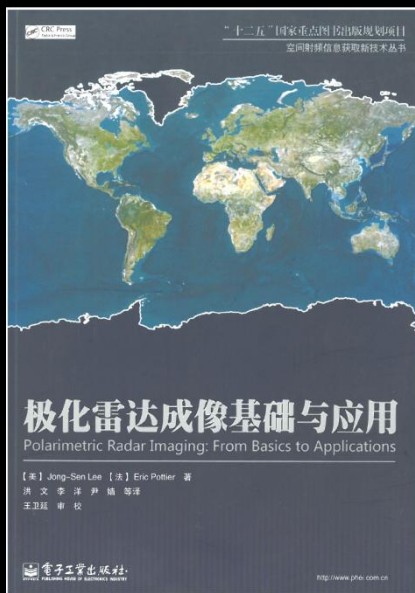
## **Polarisation: Applications in Remote Sensing**

**Shane R. CLOUDE**

Oxford University Press, October 2009, pp 352

ISBN: 978-0199569731

# Books On Polarimetric Radar SAR, Polarimetric Interferometry



## Polarimetric Radar Imaging: From basics to applications

*Jong-Sen LEE – Eric POTTIER*

CRC Press; 1st ed., February 2009, pp 422

ISBN: 978-1420054972

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



## Polarisation: Applications in Remote Sensing *Shane R. CLOUDE*

Oxford University Press, October 2009, pp 352

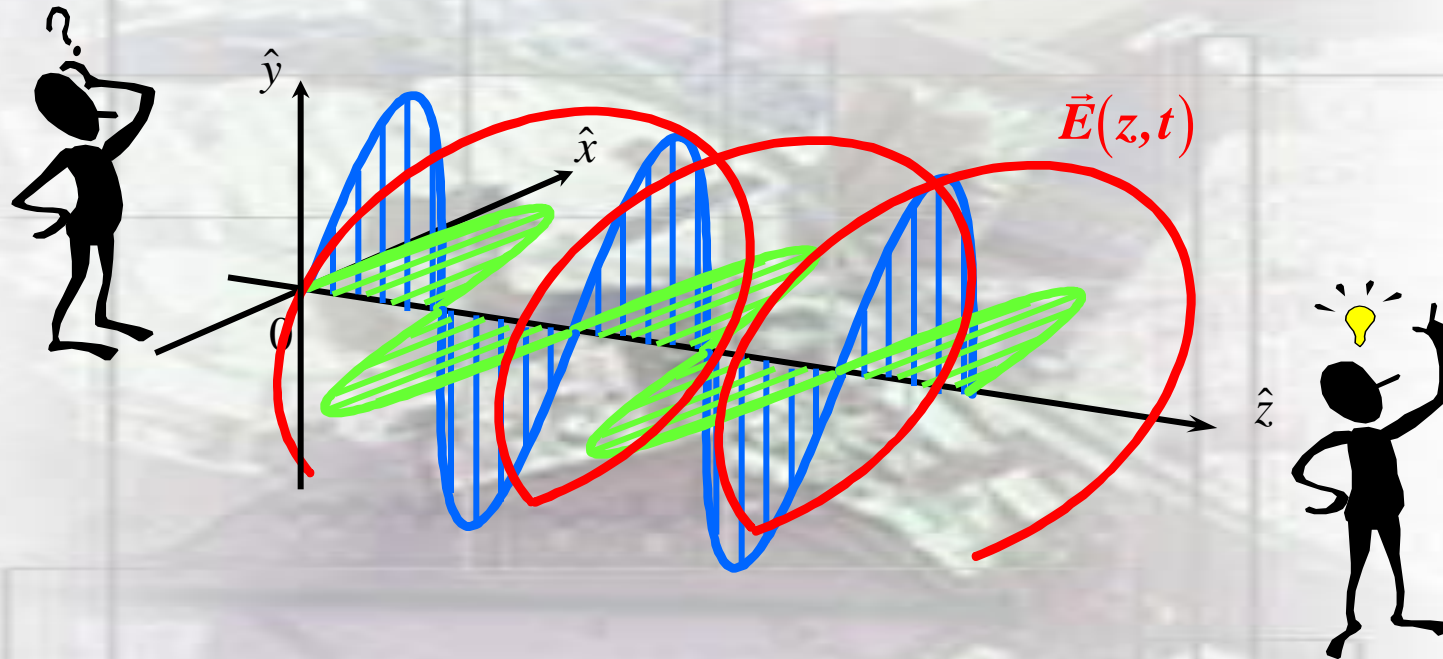
ISBN: 978-0199569731



# Questions ?

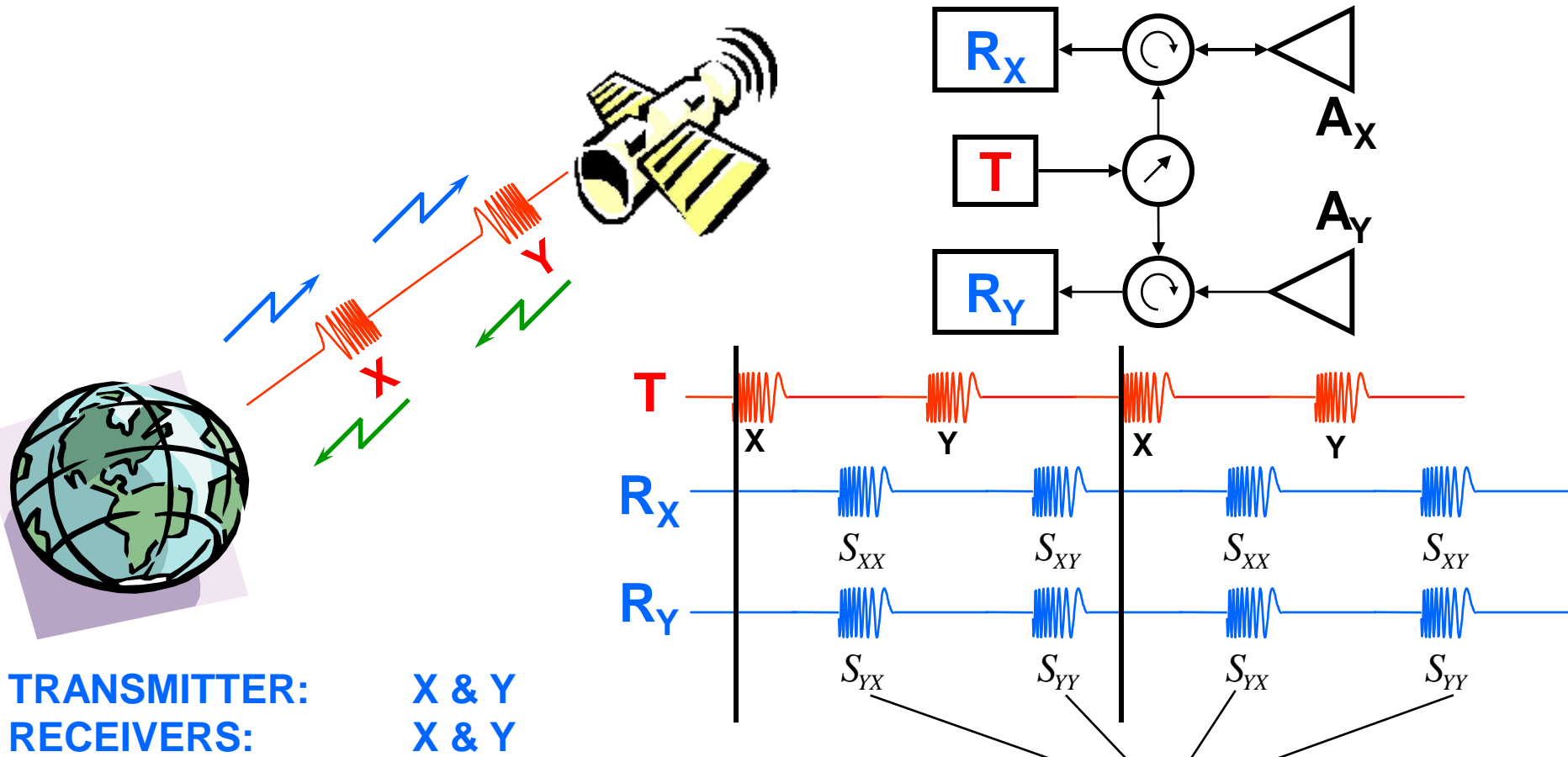


©2004 JAMES W. HUNTUM #54-028 L



# BASIC CONCEPTS





TRANSMITTER:  
RECEIVERS:

X & Y  
X & Y

SINCLAIR MATRICES

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

## SCATTERING POLARIMETRY

Tx → Rx →

Tx → Rx ↑

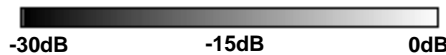
Tx ↑ Rx ↑



$|HH|_{dB}$

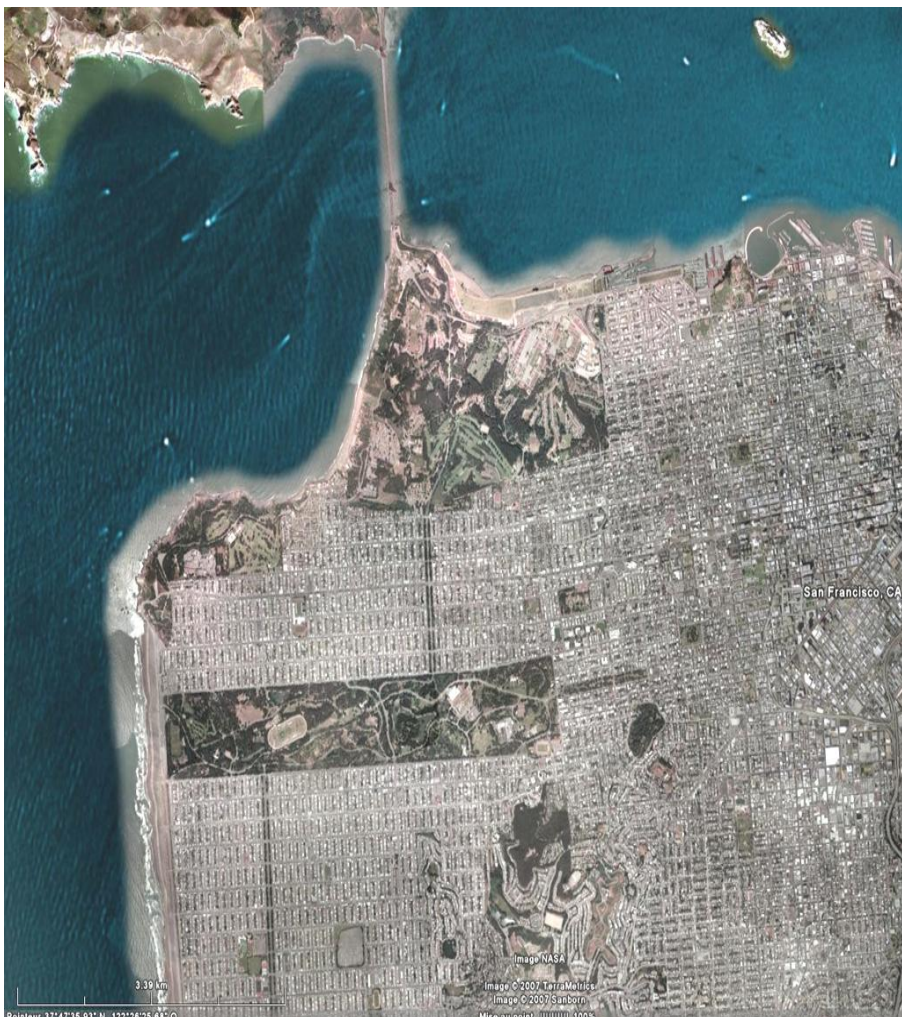
$|HV|_{dB}$

$|VV|_{dB}$





## Sinclair Color Coding



© Google Earth

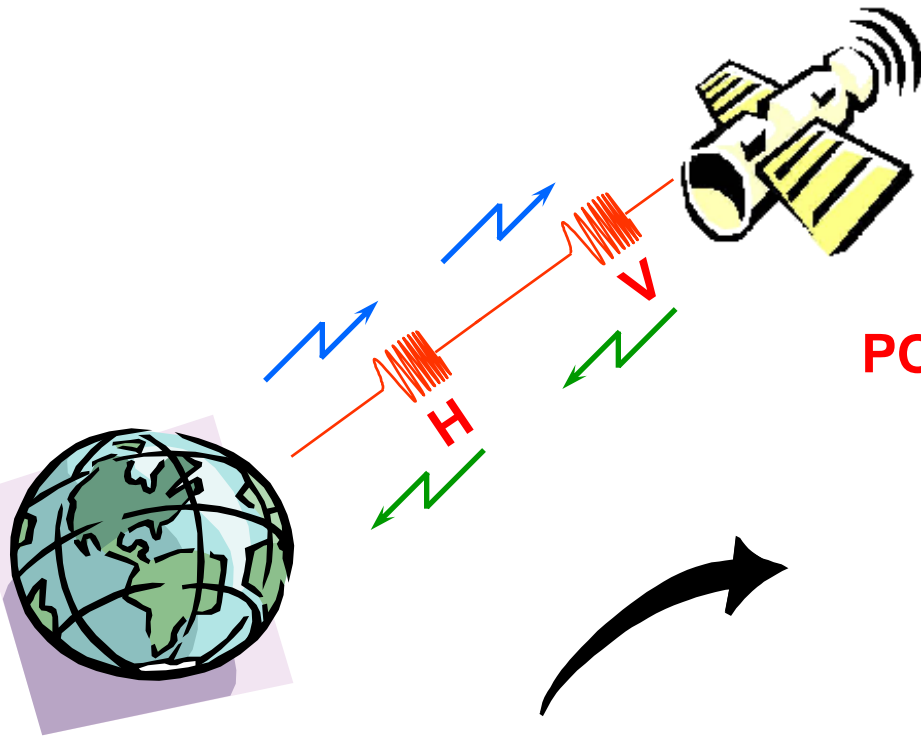


|HH|

|HV|

|VV|





## 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

**TRANSMITTER:** H & V  
**RECEIVERS:** H & V



## TARGET VECTOR $\underline{k}$

$$\underline{k} = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} + S_{VV} & S_{HH} - S_{VV} & 2S_{HV} \end{bmatrix}^T$$



## 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

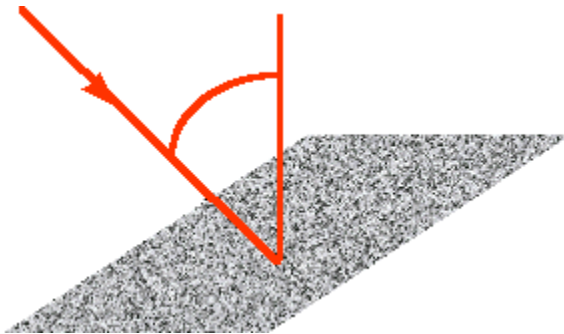
$A_0, B_0+B, B_0-B$  : HUYNEN TARGET GENERATORS



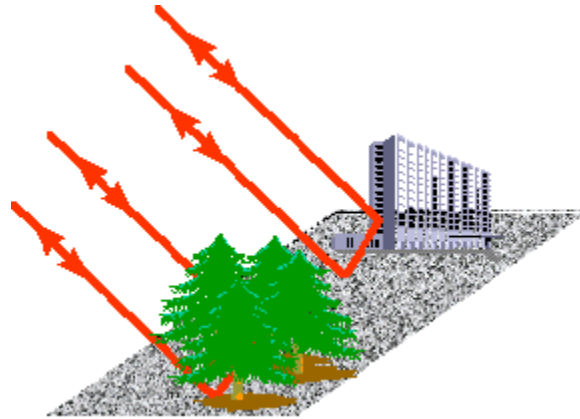
$[T]$  is closer related to Physical and Geometrical Properties of the Scattering Process, and thus allows a better and direct physical interpretation

## PHYSICAL INTERPRETATION

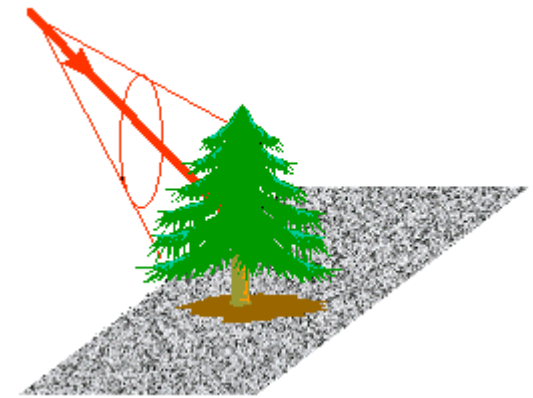
**SINGLE BOUNCE SCATTERING (ROUGH SURFACE)**



**DOUBLE BOUNCE SCATTERING**



**VOLUME SCATTERING**



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

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

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

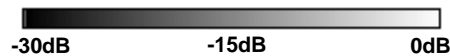




$|HH+VV|_{dB}$



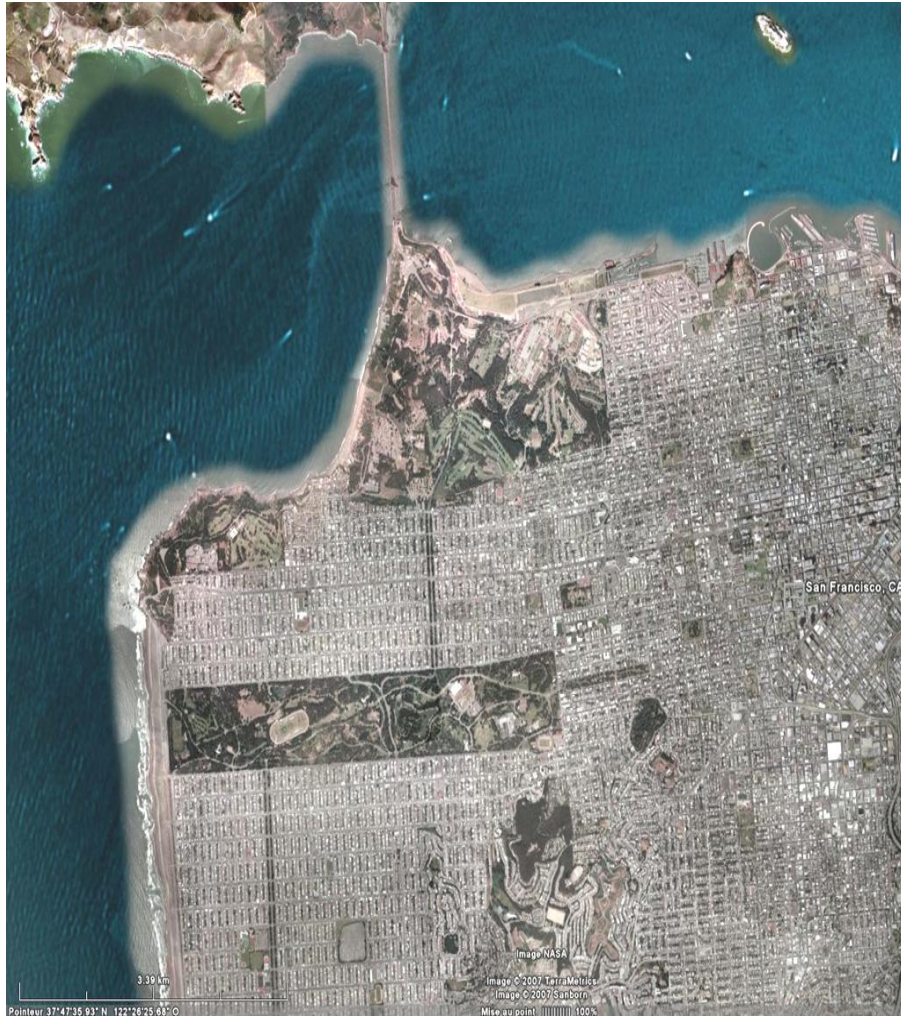
$|HV|_{dB}$



$|HH-VV|_{dB}$



## (H,V) POLARISATION BASIS



© Google Earth

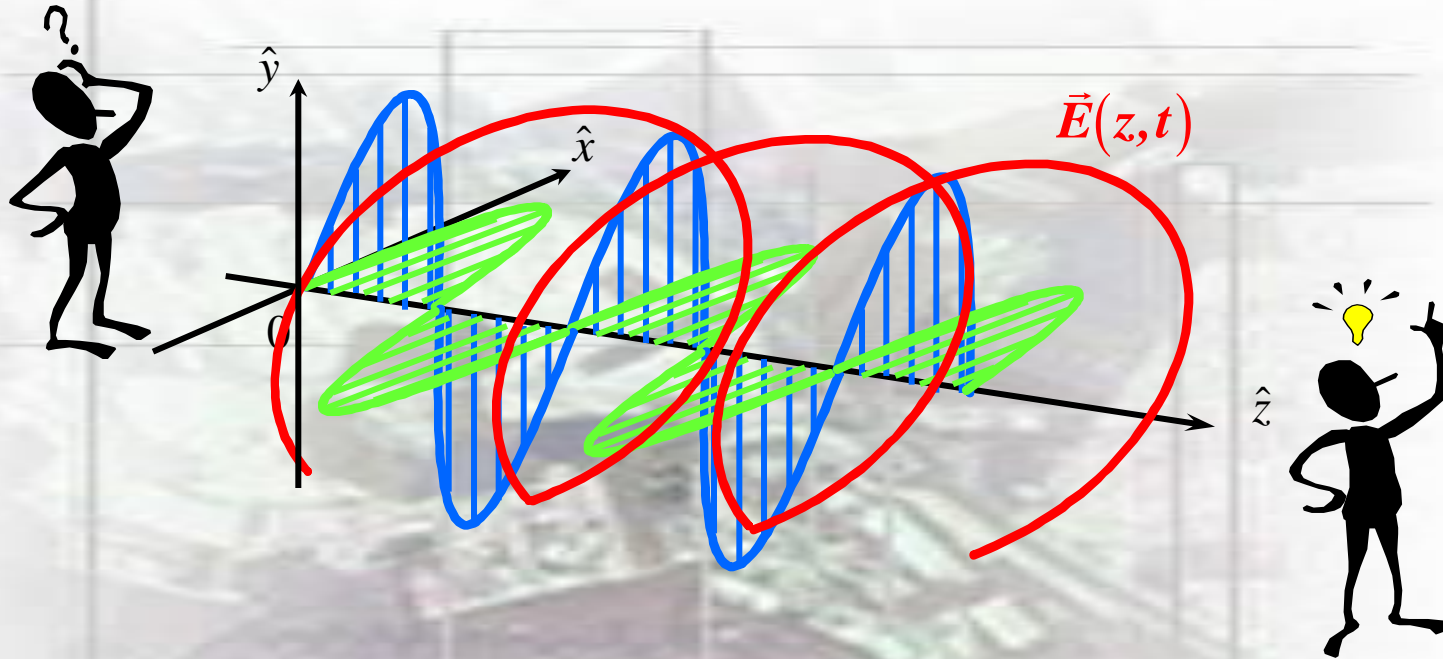


|HH+VV|

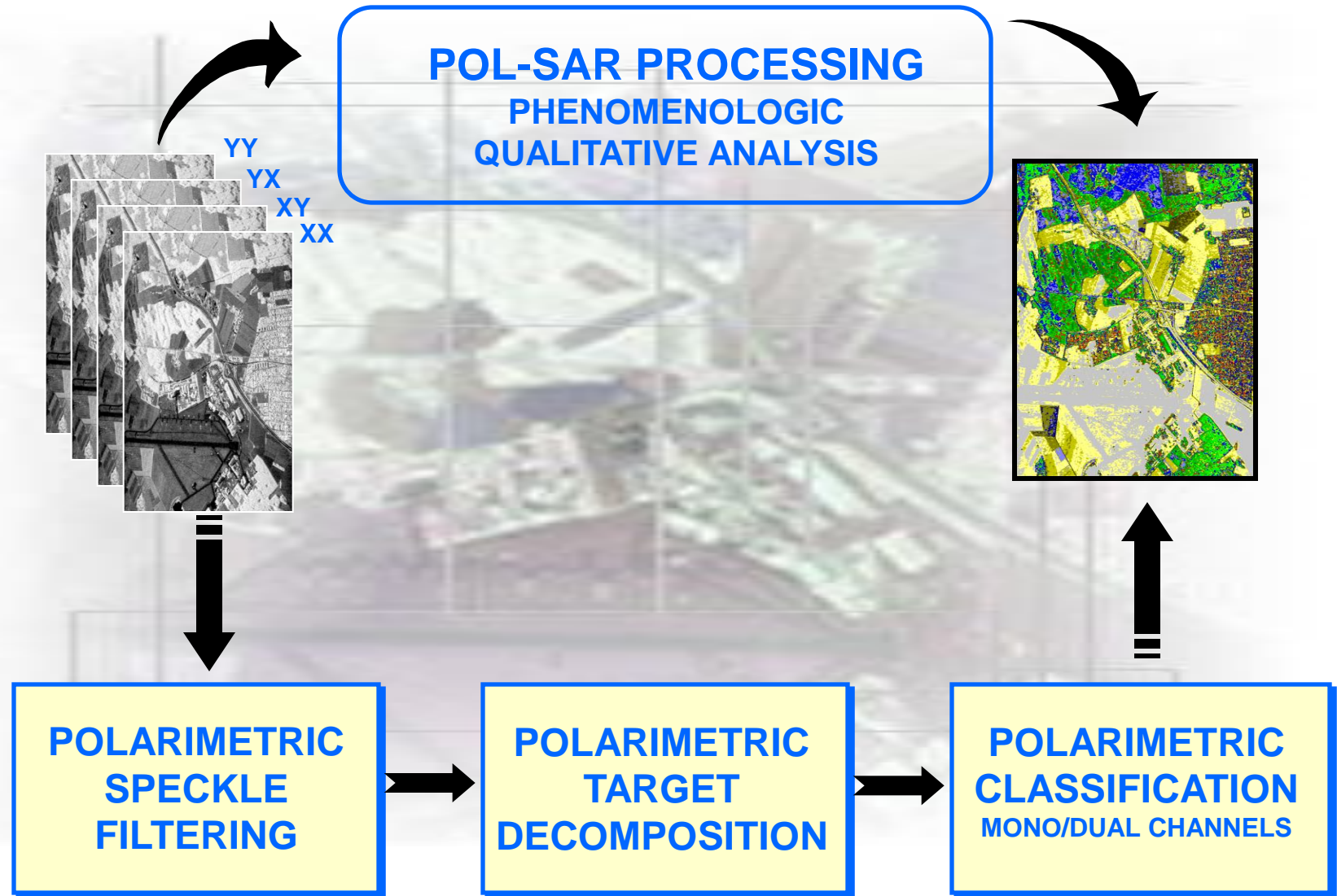
|HV|

|HH-VV|

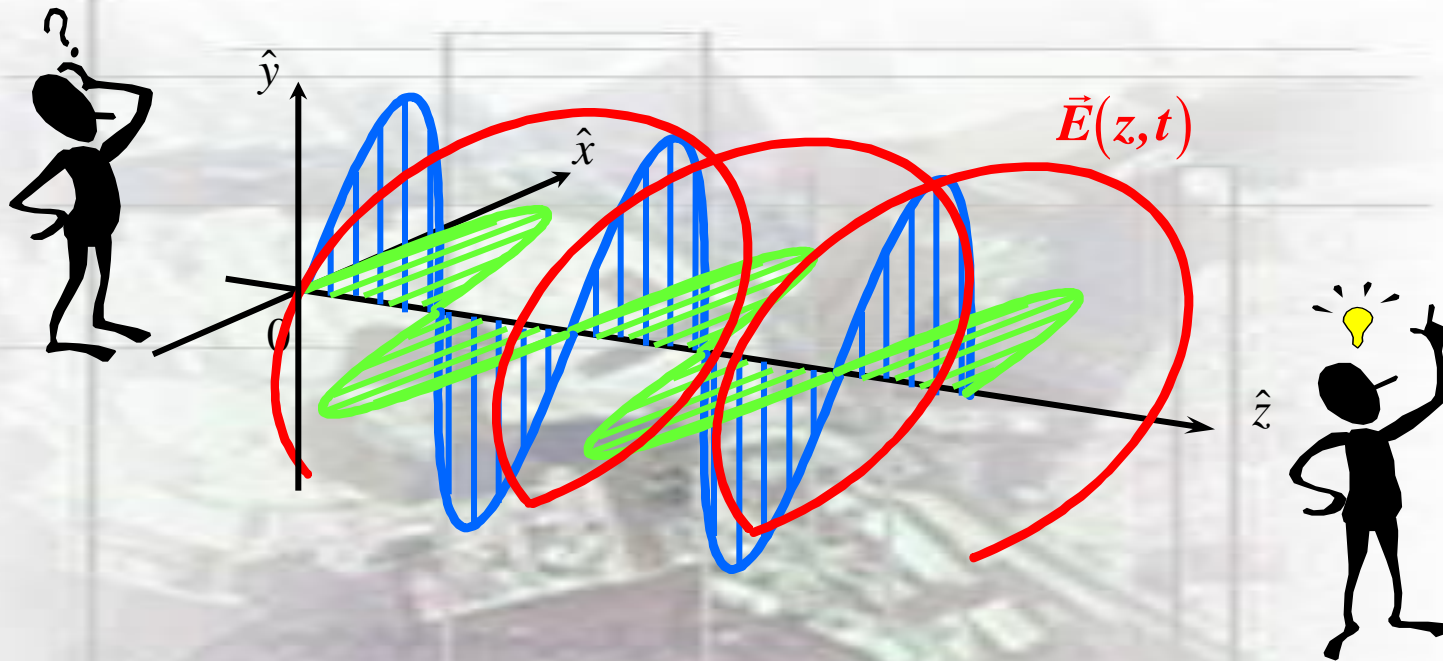




# POLARIMETRIC REMOTE SENSING

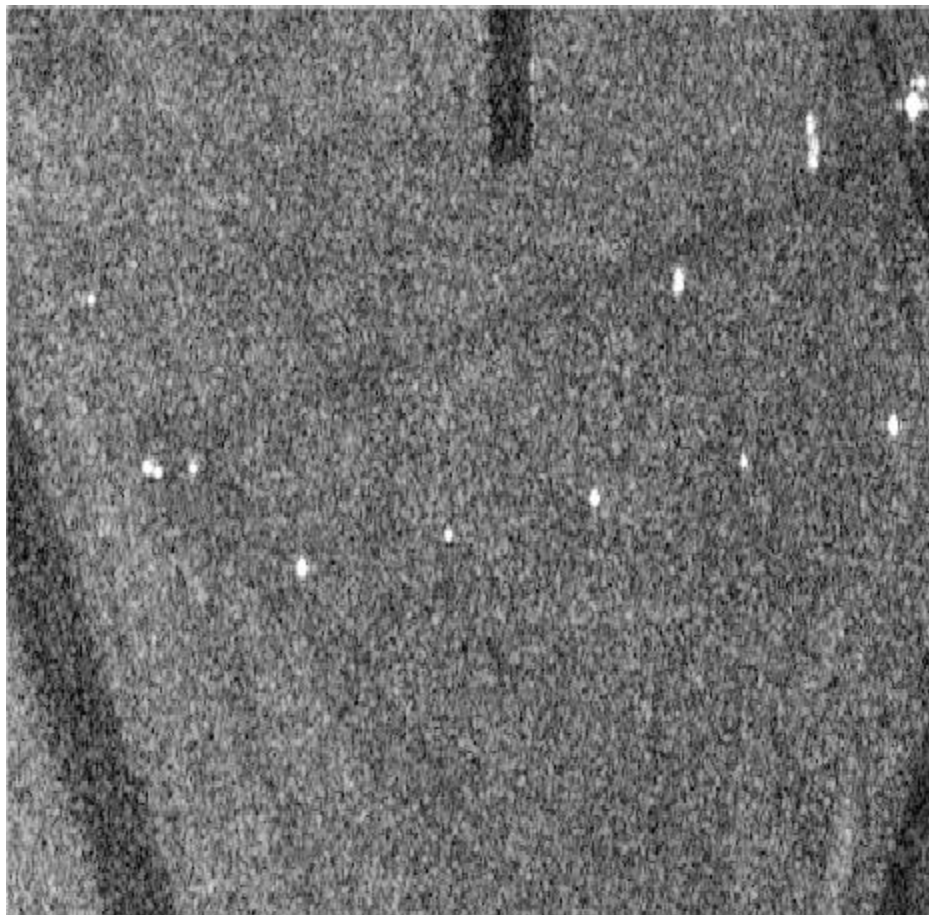




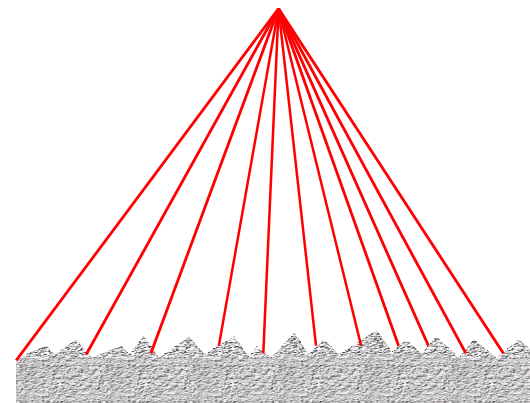


# POLARIMETRIC SPECKLE FILTERING

## An Introduction



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 PHENOMENON



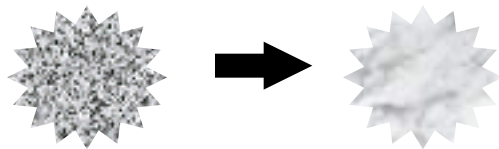
## DISTORTION OF THE INTERPRETATION



## SPECKLE FILTERING

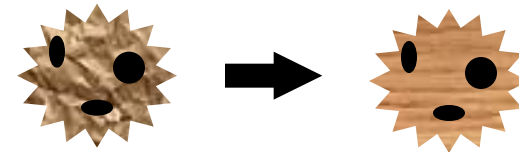


### HOMOGENEOUS AREA

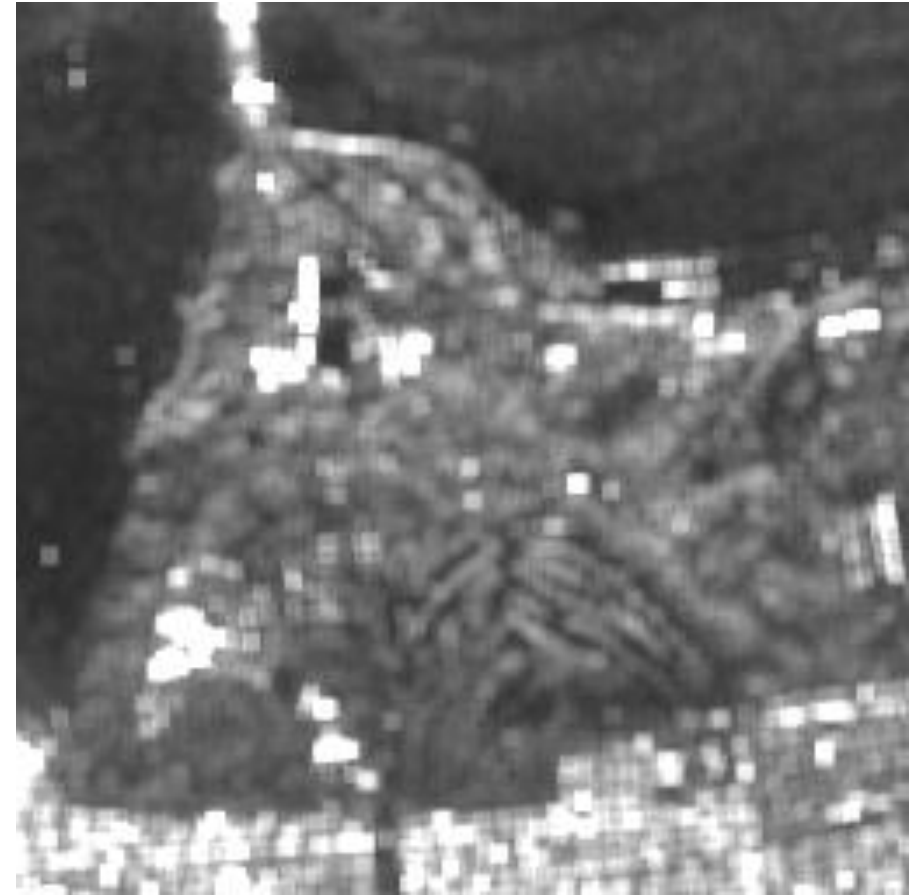


### SPECKLE REDUCTION (RADIOMETRIC RESOLUTION)

### HETEROGENEOUS AREA



### DETAILS PRESERVATION (SPATIAL RESOLUTION)



**SAN FRANCISCO BAY JPL - AIRSAR L-band 1988**

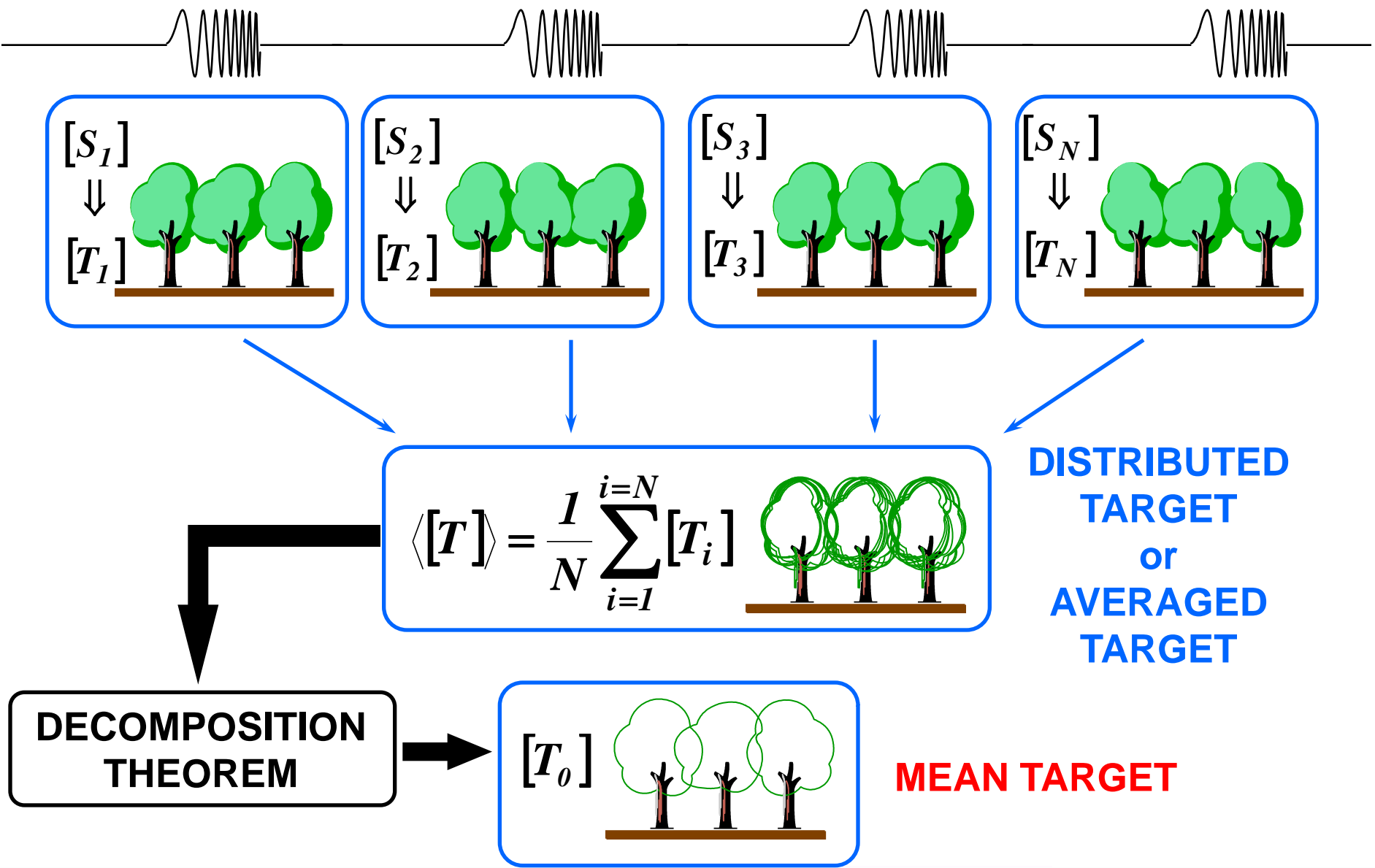
## BoxCar Filter



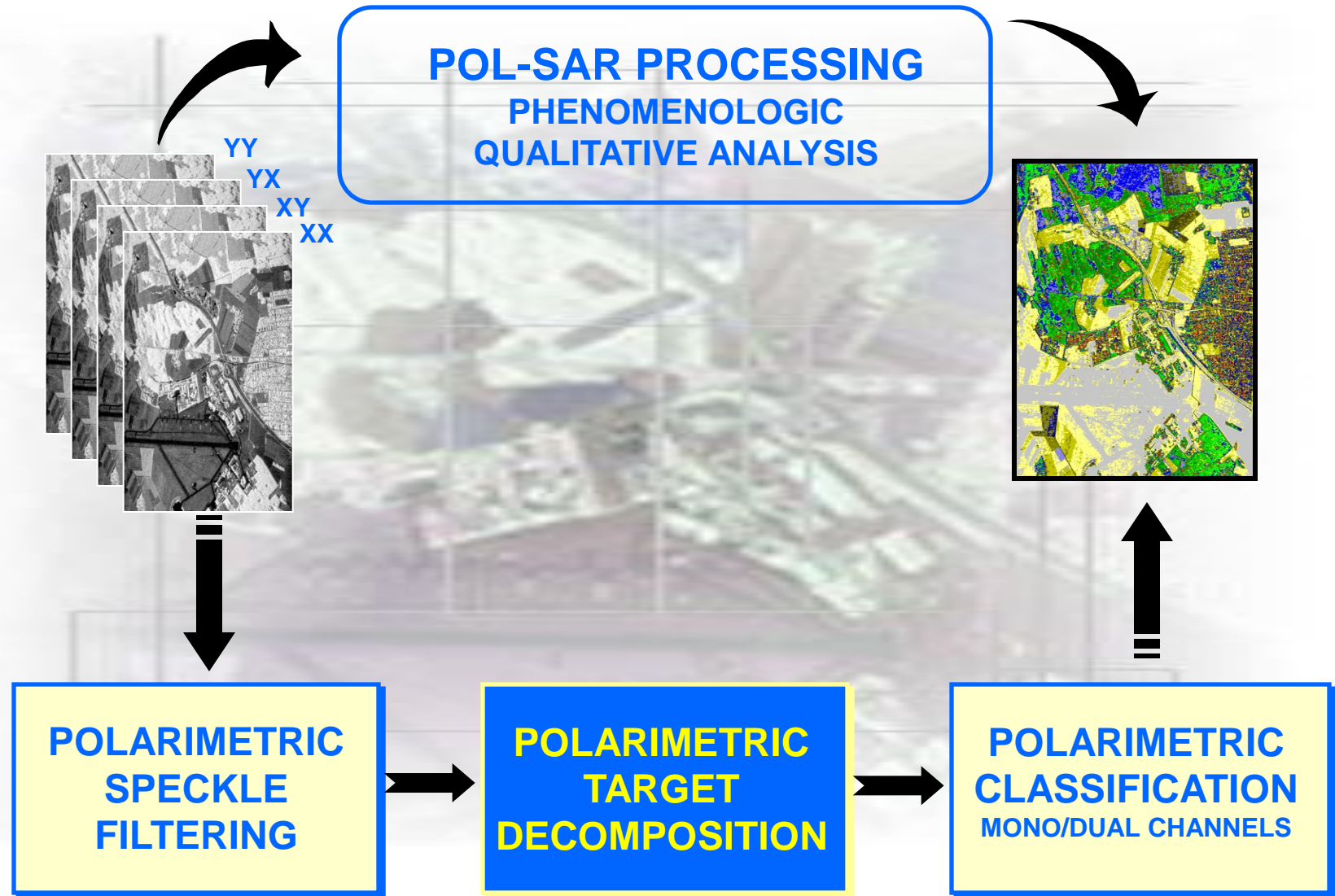


## SAN FRANCISCO BAY JPL - AIRSAR L-band 1988

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







[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**

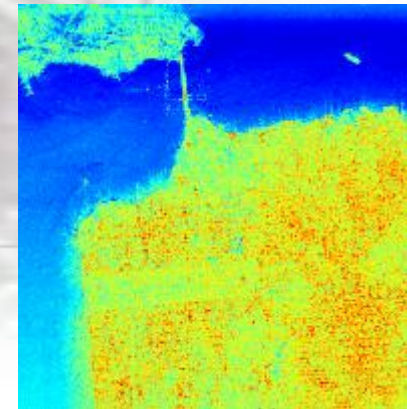
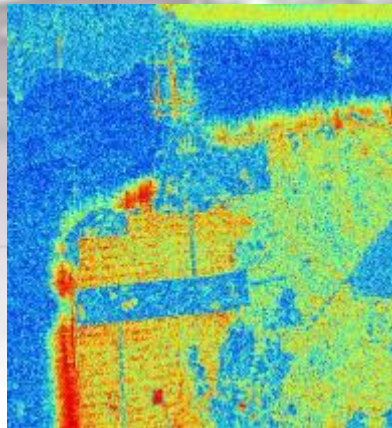
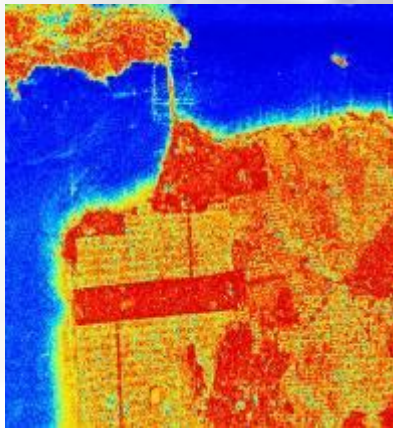
A.J. FREEMAN – S.L. DURDEN (1992)  
Y. YAMAGUSHI (2005 - 2012), AN (2010)

**EIGENVECTORS / EIGENVALUES ANALYSIS & MODEL BASED DECOMPOSITION**

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



# THE $H/A/\alpha$ POLARIMETRIC TARGET DECOMPOSITION THEOREM



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

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

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

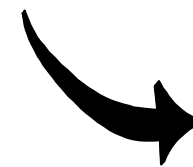
EIGENVECTORS / EIGENVALUES ANALYSIS

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

ORTHOGONAL EIGENVECTORS

REAL EIGENVALUES

$$\lambda_1 > \lambda_2 > \lambda_3$$



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



EIGENVALUES  $\lambda_1 \lambda_2 \lambda_3$  : 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

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

$$H = 0$$

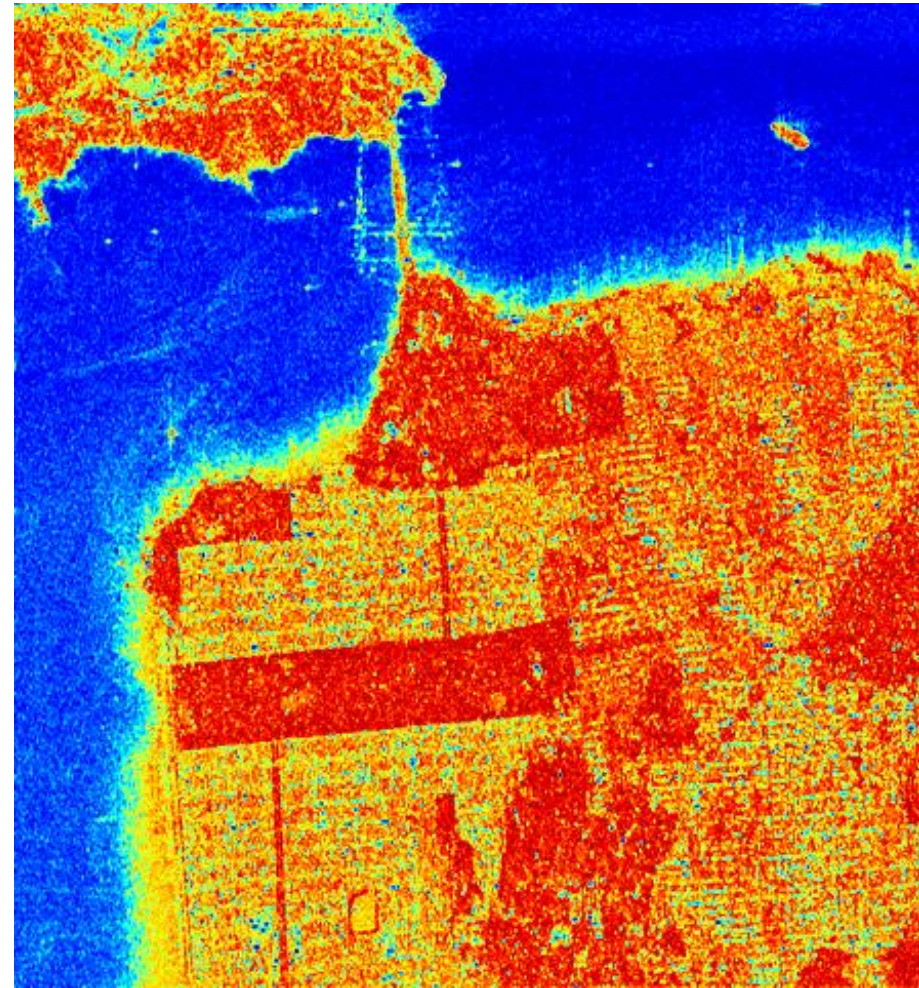


### DISTRIBUTED TARGET

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

$$H = 1$$





$2A_0$

$B_0 + B$

$B_0 - B$



ENTROPY (H)

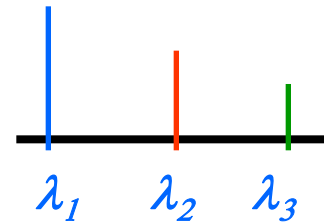


DIFFICULT MECHANISM DISCRIMINATION WHEN :  $H > 0.7$



**ANISOTROPY**  
(EIGENVALUES SPECTRUM)

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



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



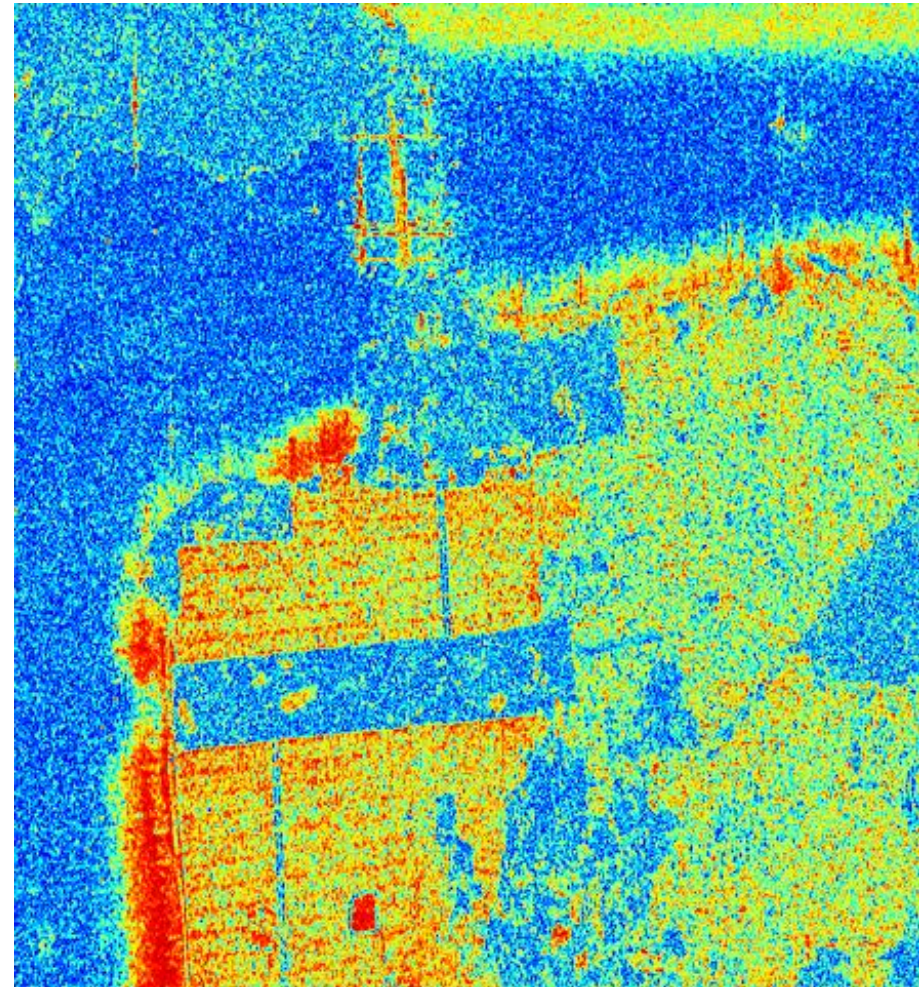
# H / A / $\alpha$ DECOMPOSITION



$2A_0$

$B_0 + B$

$B_0 - B$



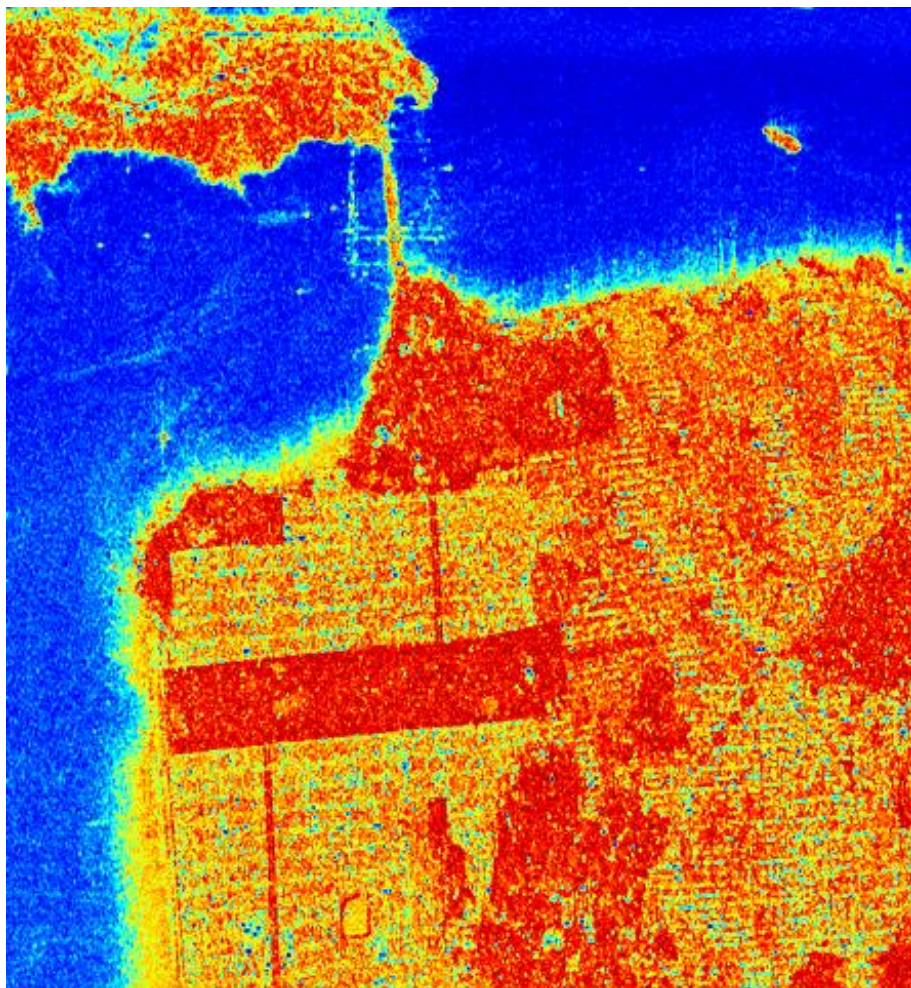
0

0.5

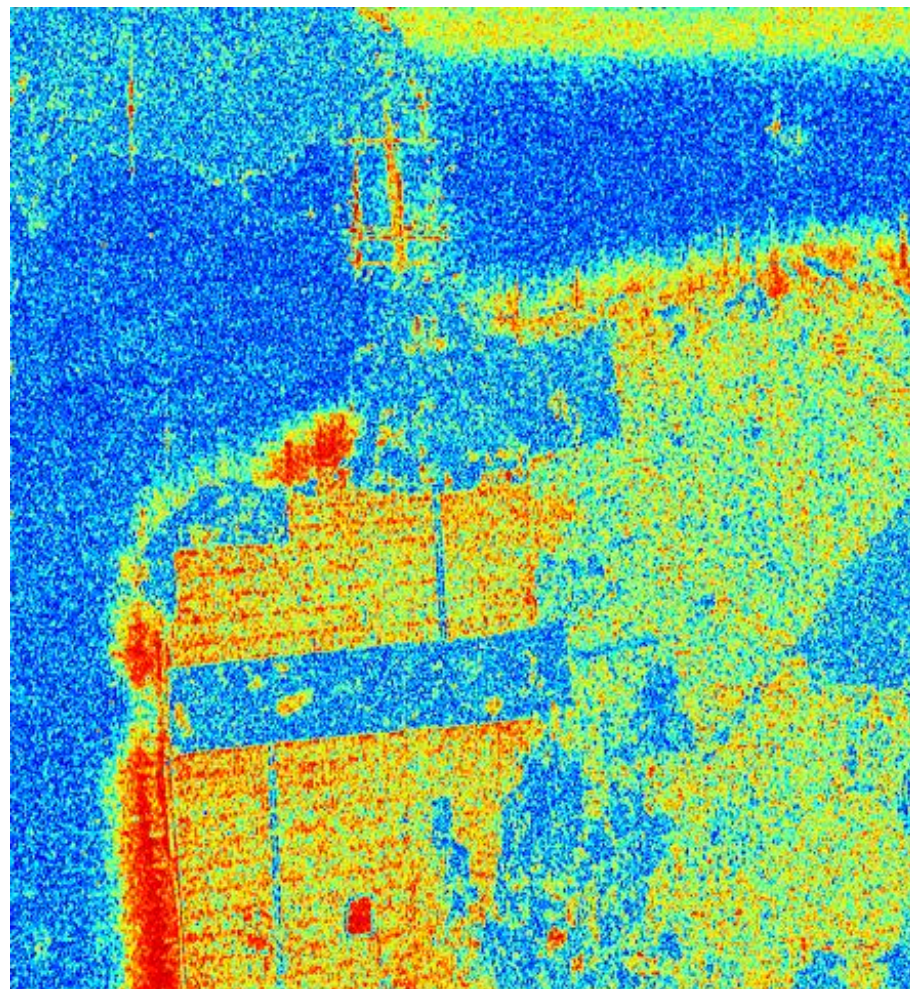
1.0

ANISOTROPY (A)





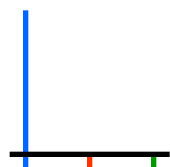
ENTROPY (H)



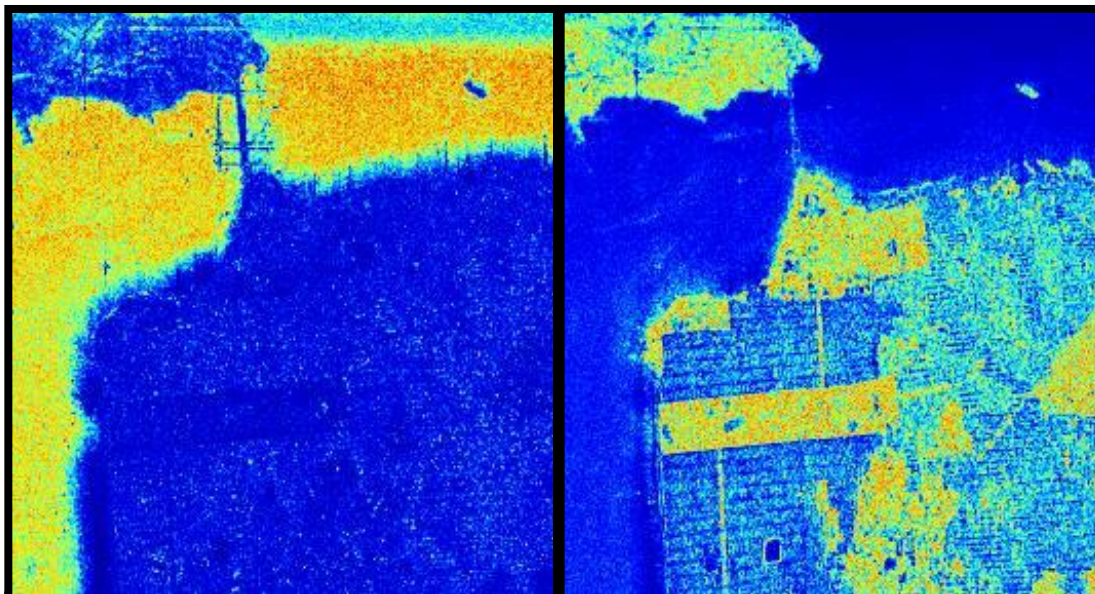
ANISOTROPY (A)



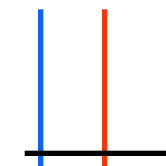
(1-H)(1-A)



1 MECHANISM

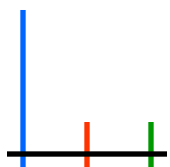


H(1-A)

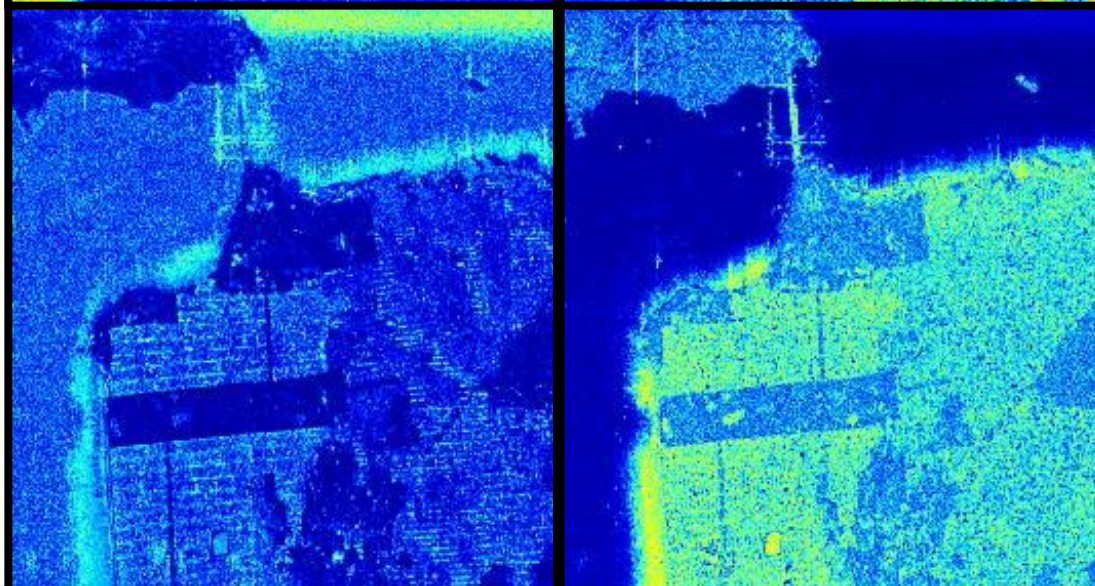


3 MECHANISMS

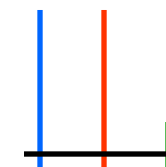
A(1-H)



2 MECHANISMS



HA



2 MECHANISMS



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

ORTHOGONAL  
EIGENVECTORS

REAL EIGENVALUES

$$\lambda_1 > \lambda_2 > \lambda_3$$



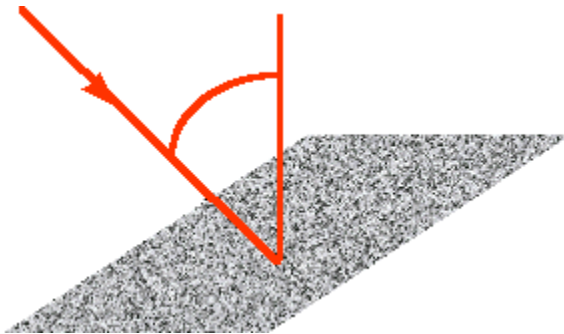
## PARAMETERISATION OF THE SU(3) UNITARY MATRIX

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

TARGET 1
TARGET 2
TARGET 3

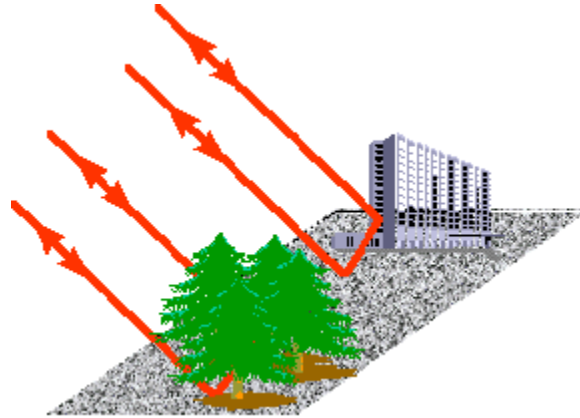
$$\underline{\alpha} = P_1 \alpha_1 + P_2 \alpha_2 + P_3 \alpha_3 \quad \text{PHYSICAL INTERPRETATION}$$

## SINGLE BOUNCE SCATTERING (ROUGH SURFACE)



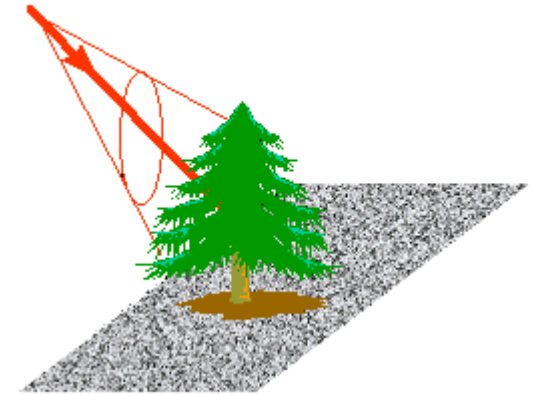
$$\begin{aligned} a \mapsto b \Rightarrow v \mapsto 0 \\ \Downarrow \\ \underline{\alpha} \mapsto 0 \end{aligned}$$

## DOUBLE BOUNCE SCATTERING



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

## VOLUME SCATTERING



$$\begin{aligned} a \gg b \Rightarrow \varepsilon \approx v \\ \Downarrow \\ \underline{\alpha} \mapsto \frac{\pi}{4} \end{aligned}$$



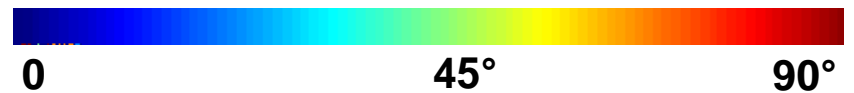
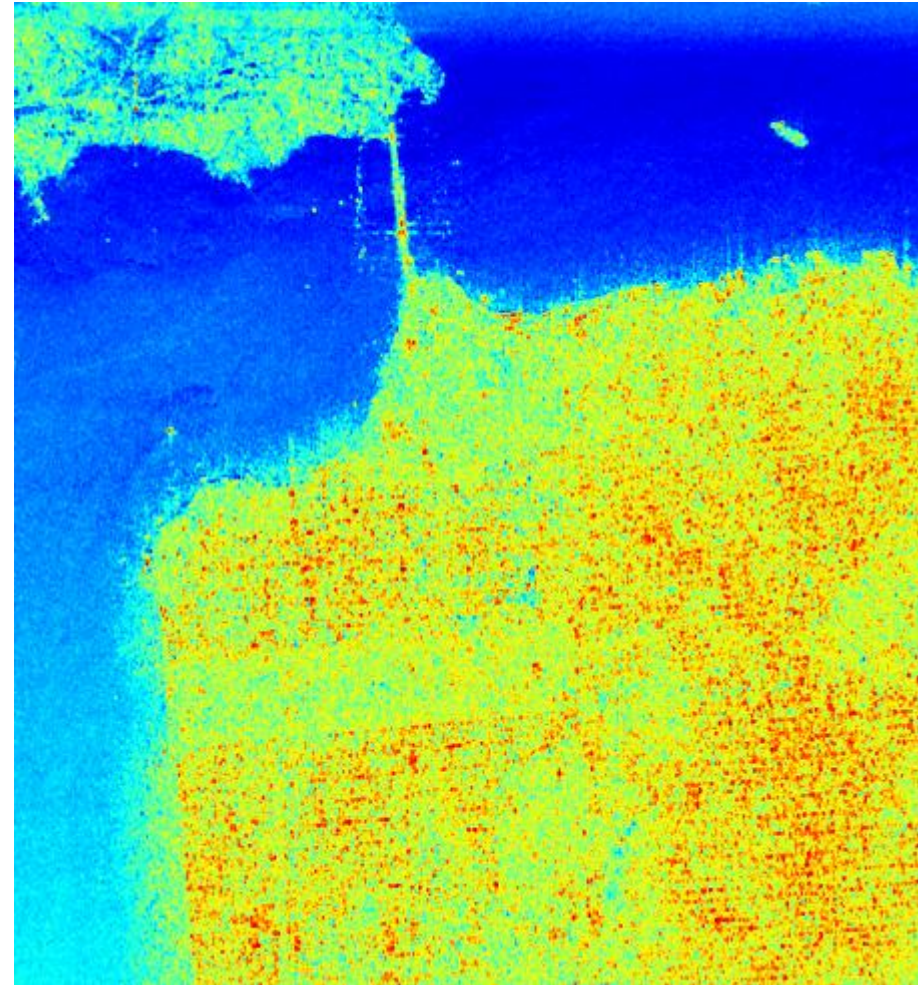
# H / A / $\alpha$ DECOMPOSITION



$2A_0$

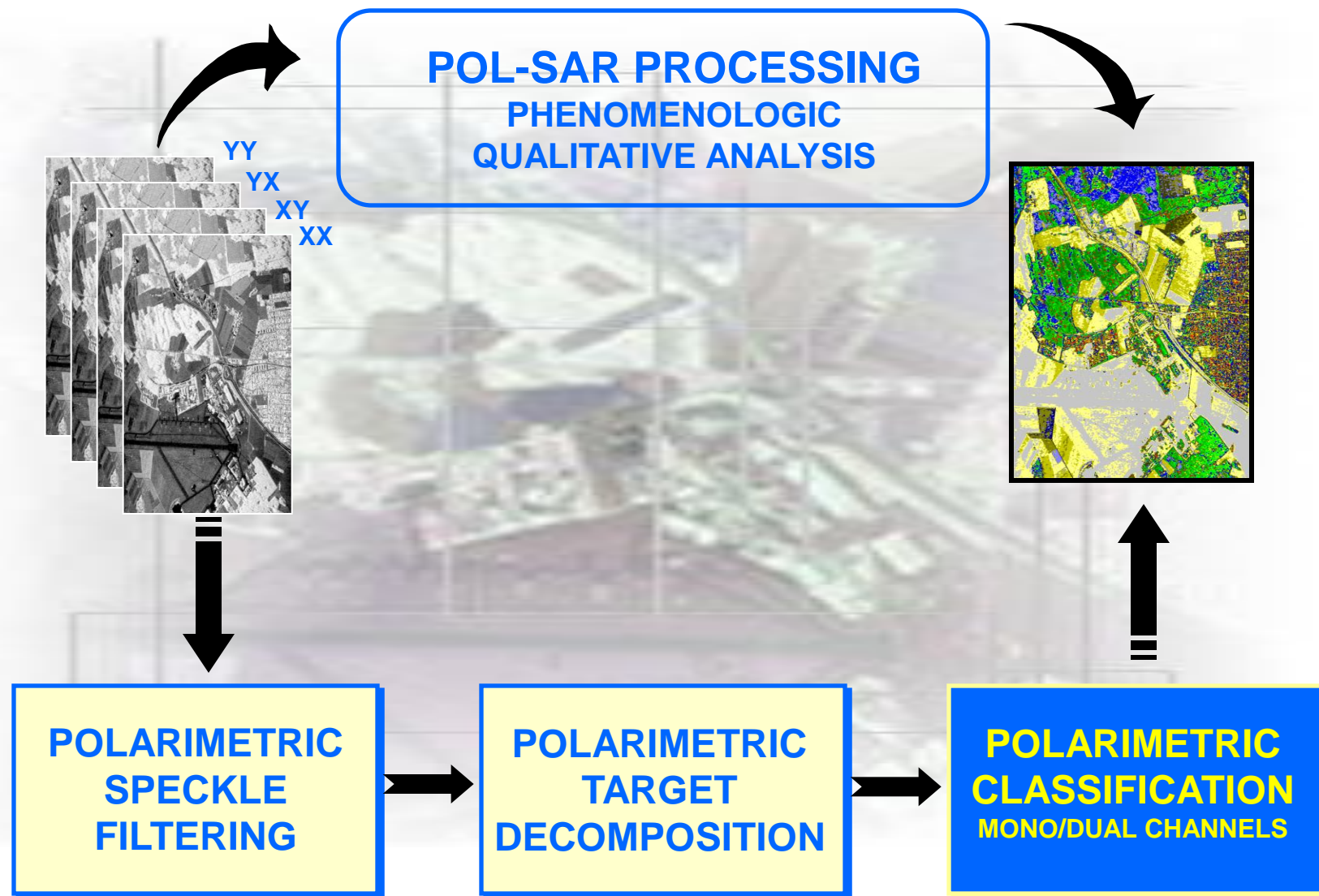
$B_0 + B$

$B_0 - B$



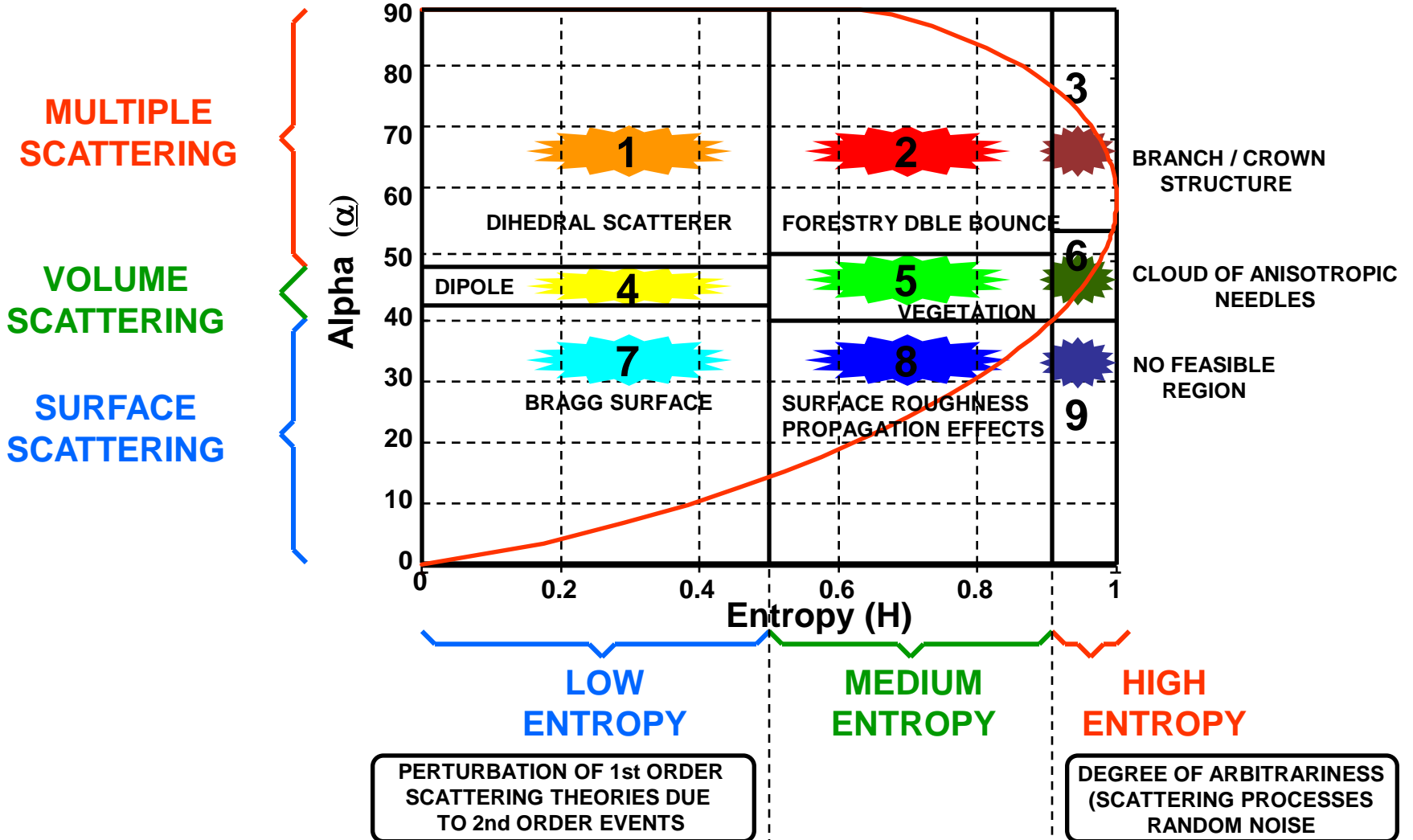
$\alpha$  PARAMETER

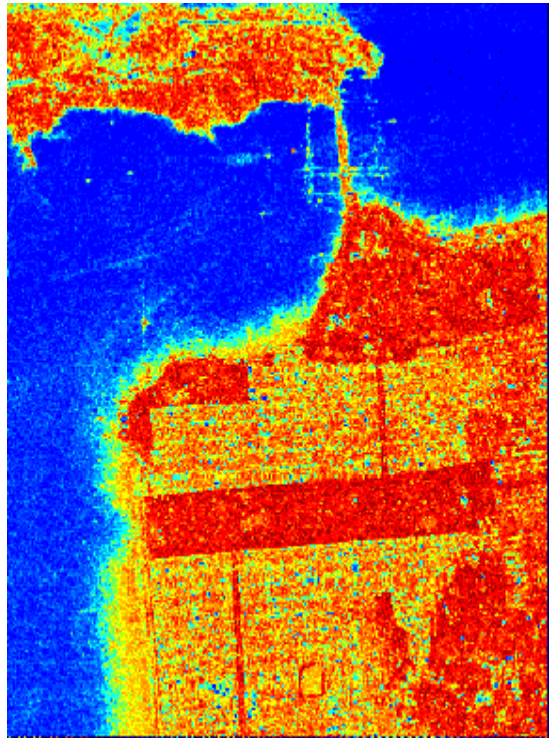






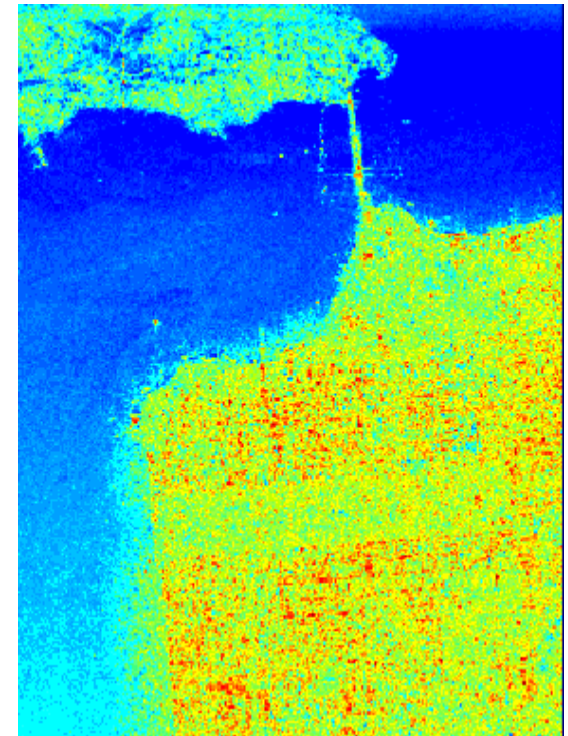
## SEGMENTATION OF THE H / $\alpha$ SPACE



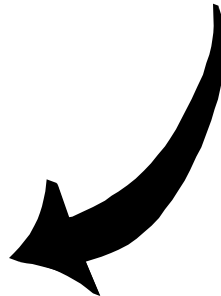
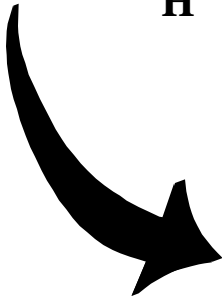
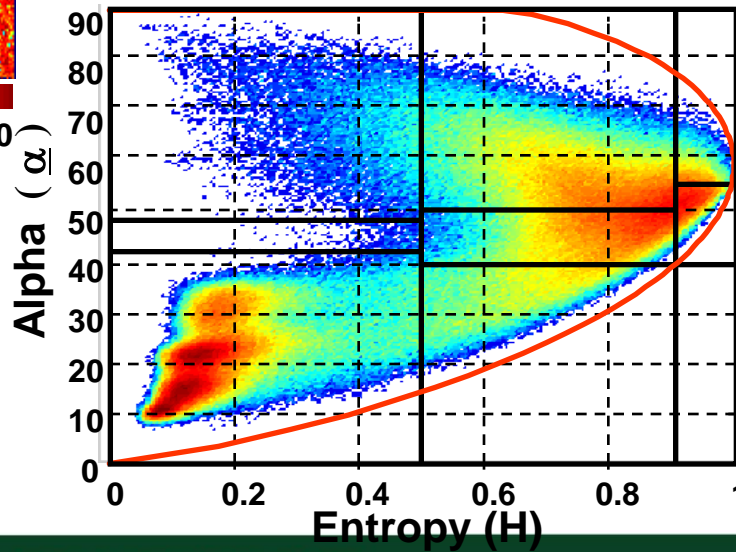


0 0.5 1.0  
**H**

POLSAR DATA  
 DISTRIBUTION  
 IN THE  
 H /  $\alpha$  PLANE

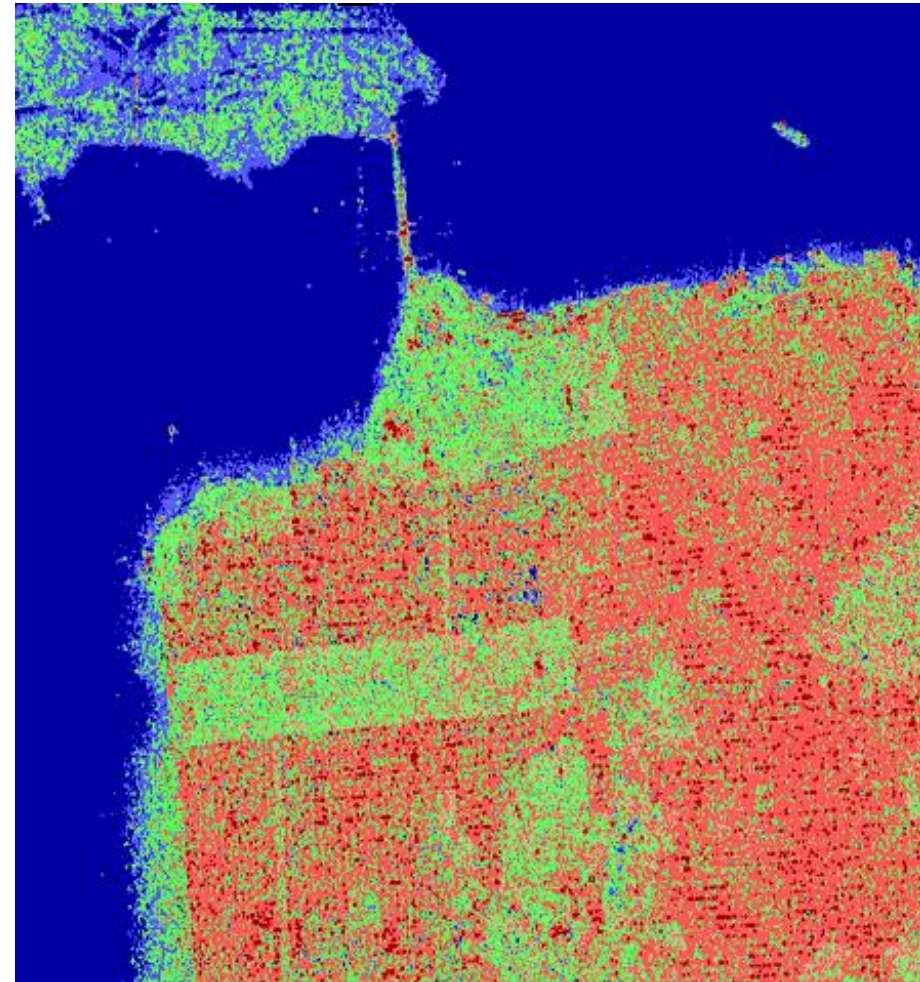


0 45° 90°  
 $\alpha$





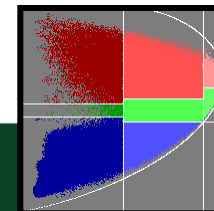
## H - $\alpha$ classification



$2A_0$

$B_0 + B$

$B_0 - B$

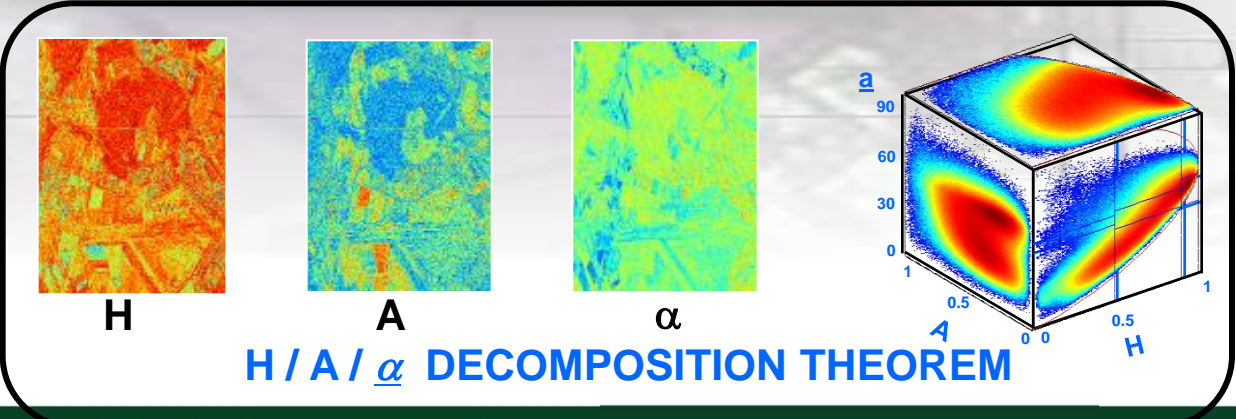
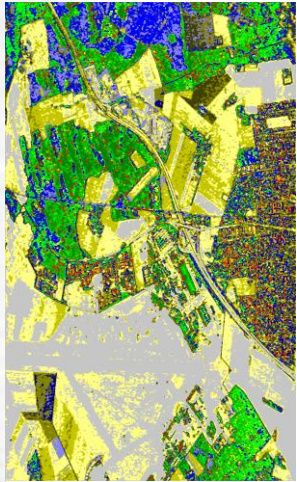




WISHART PDF 
$$P(\langle [T] \rangle / [T_m]) = \frac{L^L p \langle [T] \rangle^{L-p} e^{-LTr([T_m]^{-1} \langle [T] \rangle)}}{\pi^{\frac{p(p-1)}{2}} \Gamma(L) \dots \Gamma(L-p+1) [T_m]^L}$$



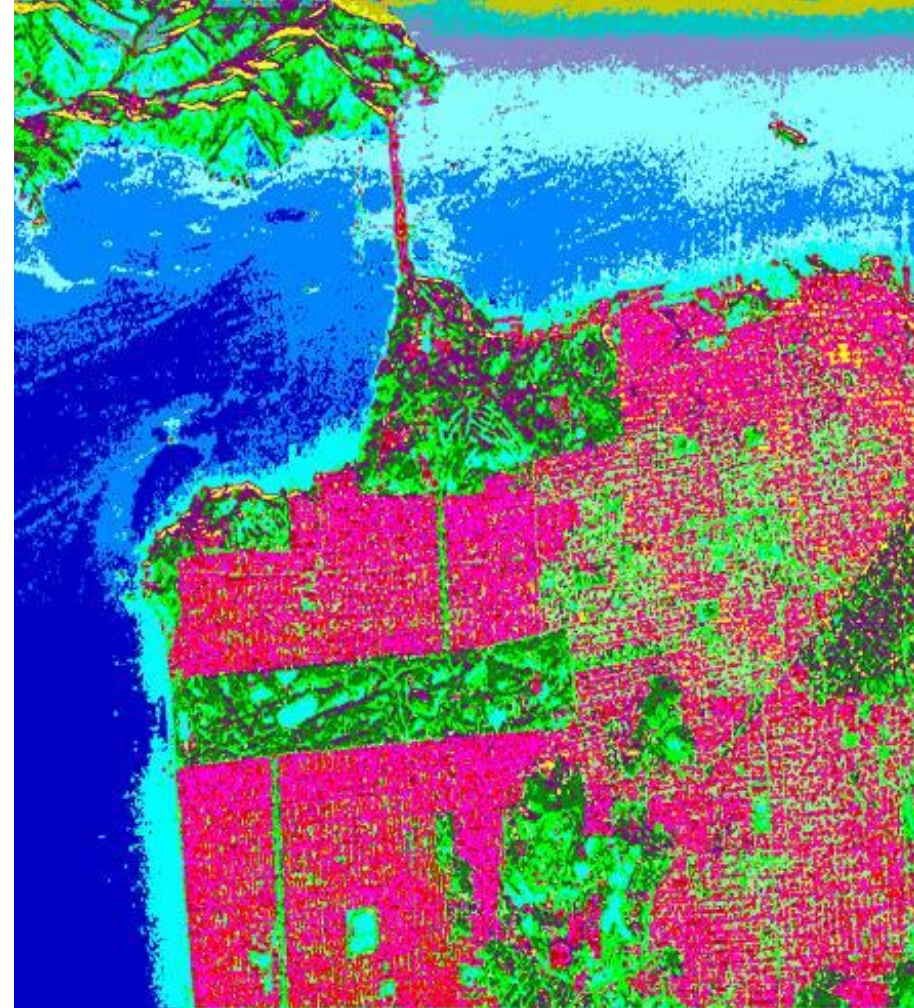
**UNSUPERVISED  
POLARSAR  
CLASSIFICATION**  
E.POTTIER, J.S LEE (2000)





SAN FRANCISCO BAY JPL - AIRSAR L-band 1988

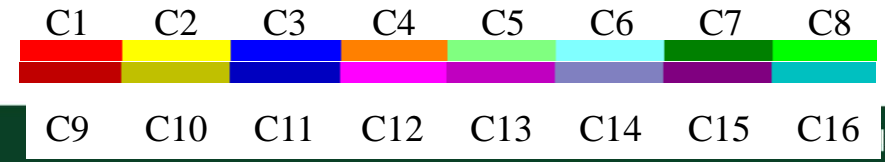
4th ITERATION



$2A_0$

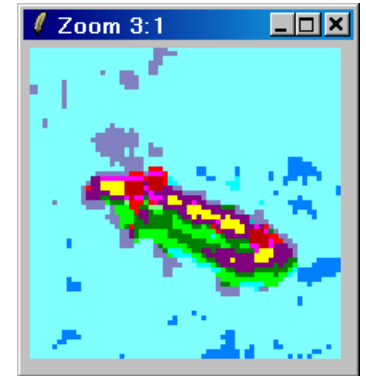
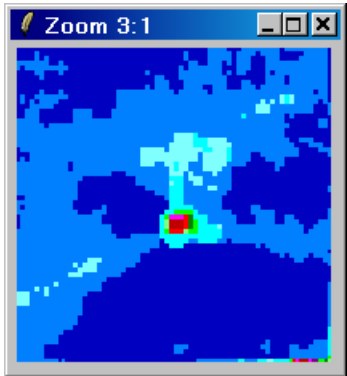
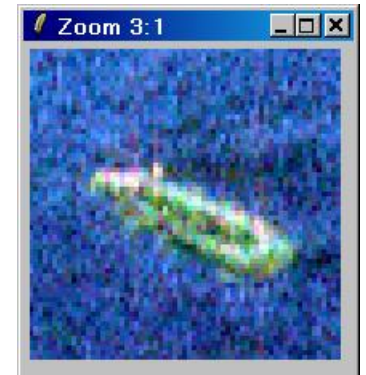
$B_0 + B$

$B_0 - B$





## SAN FRANCISCO BAY JPL - AIRSAR L-band 1988



$$2A_0$$

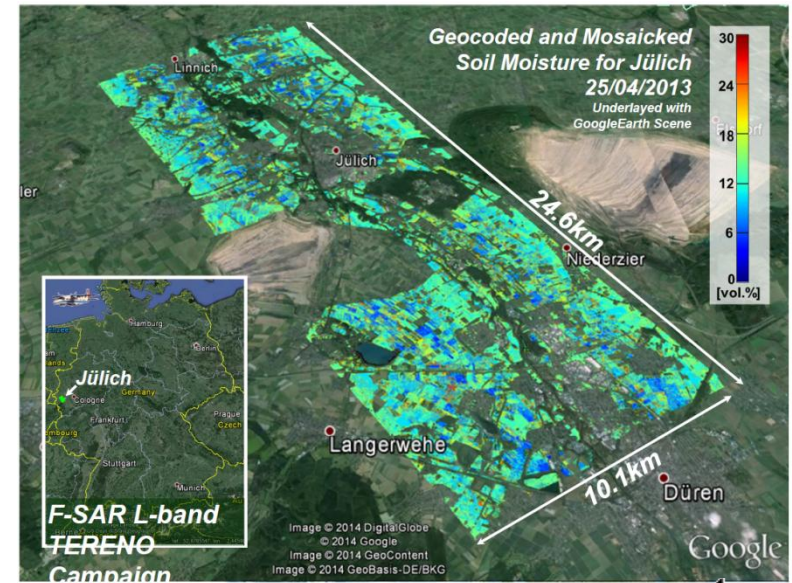
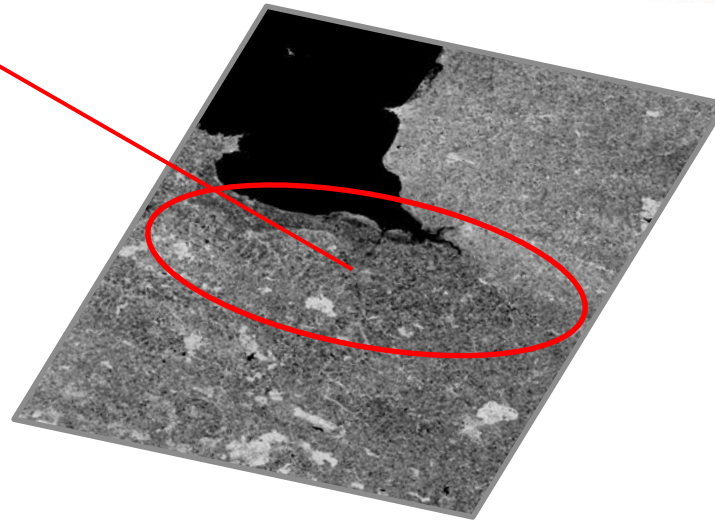
$$B_0 + B$$

$$B_0 - B$$



## PoISAR

Track<sub>1</sub>

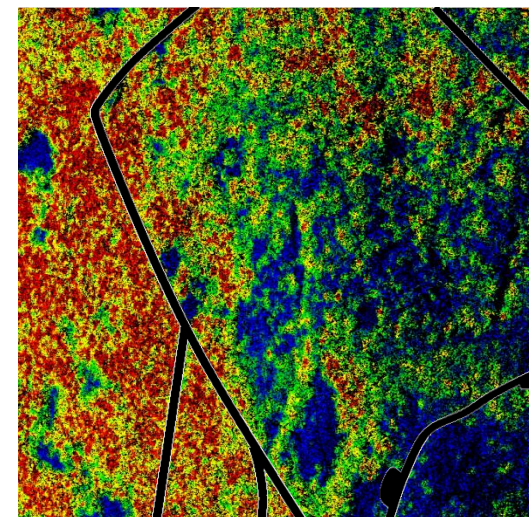
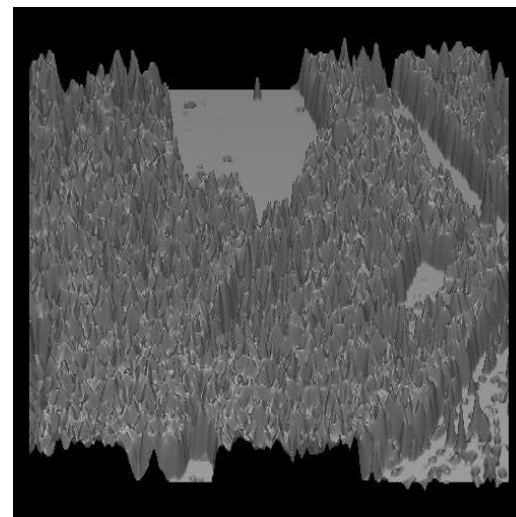
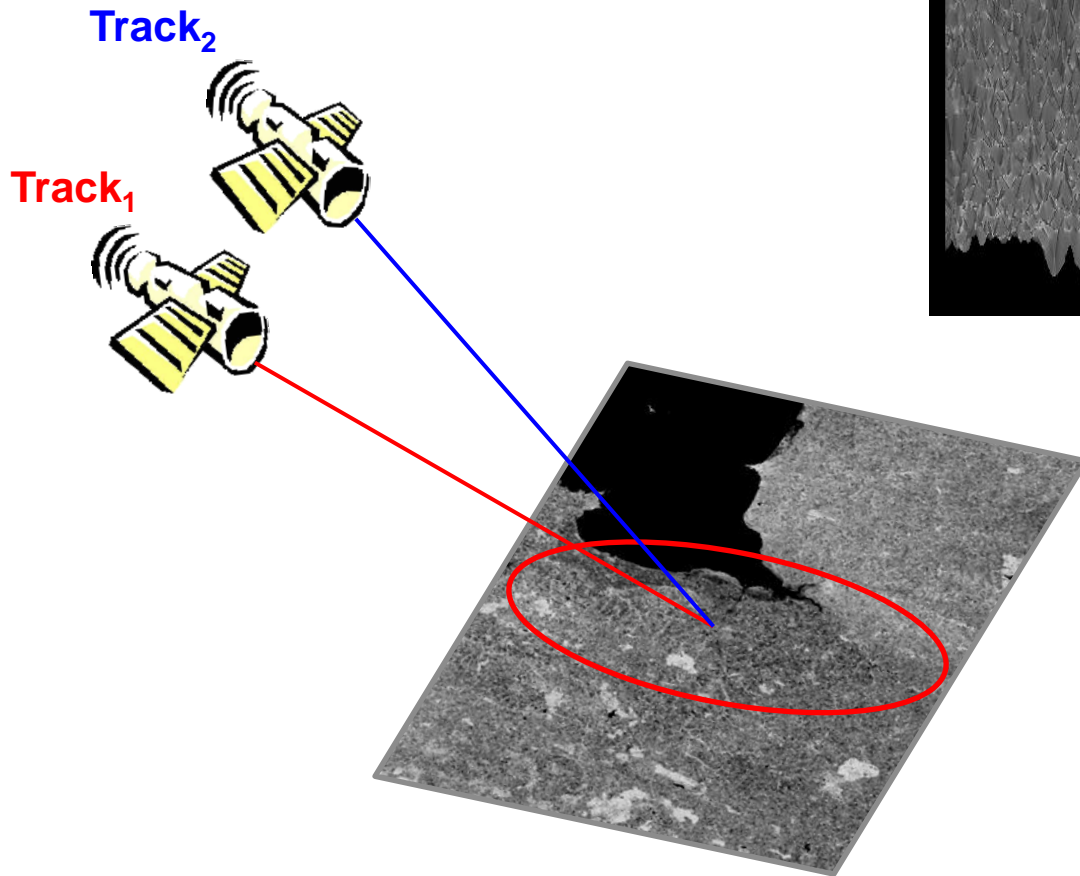


Soil moisture



Urban monitoring

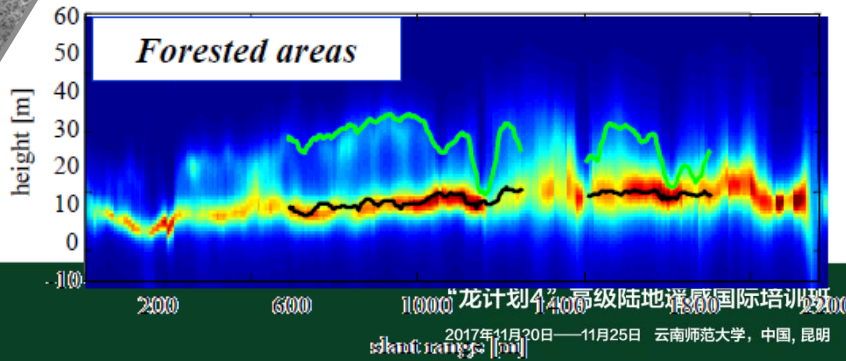
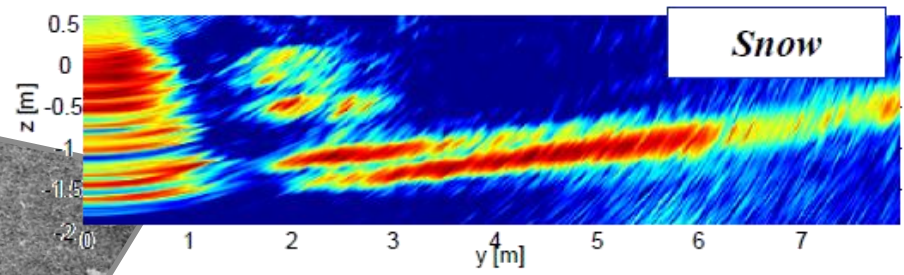
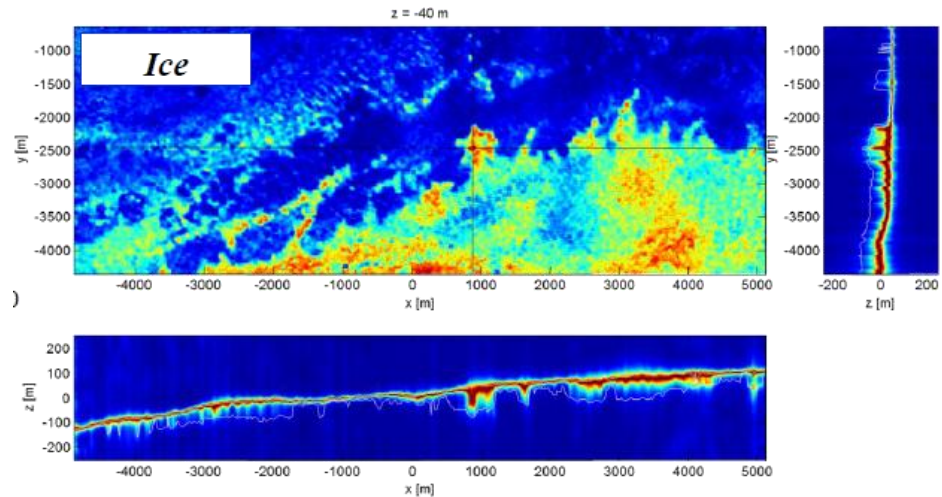
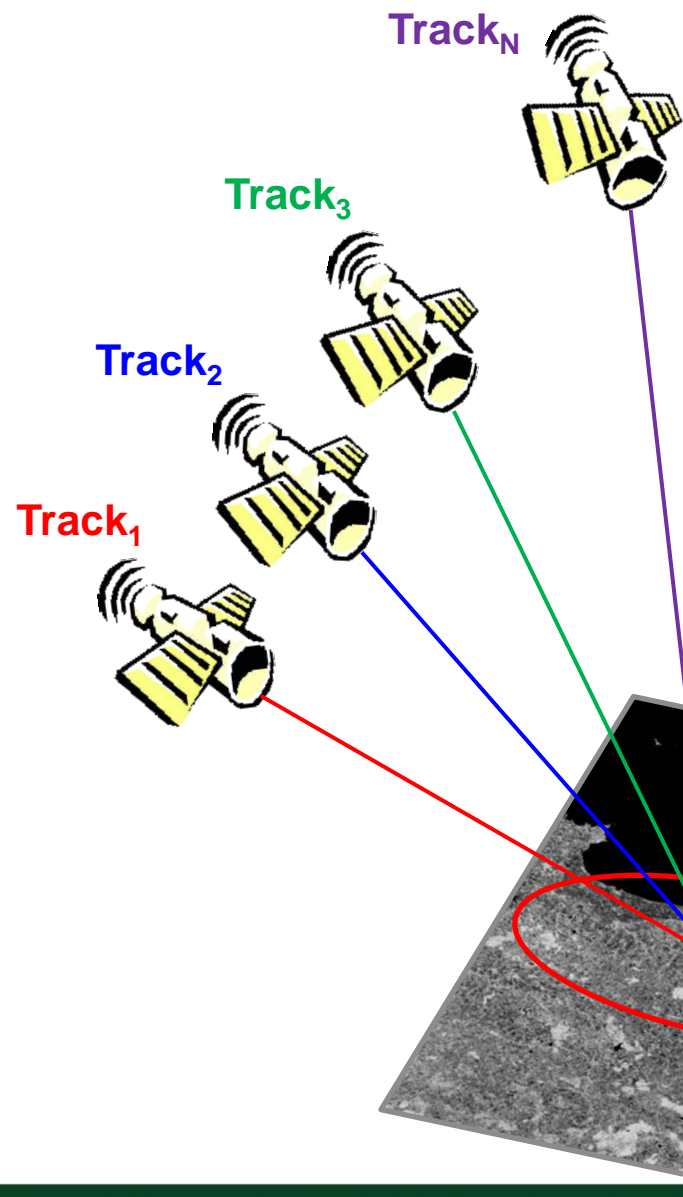
# Pol-InSAR



Courtesy of Dr. K. Papathanassiou



## Pol-TomSAR



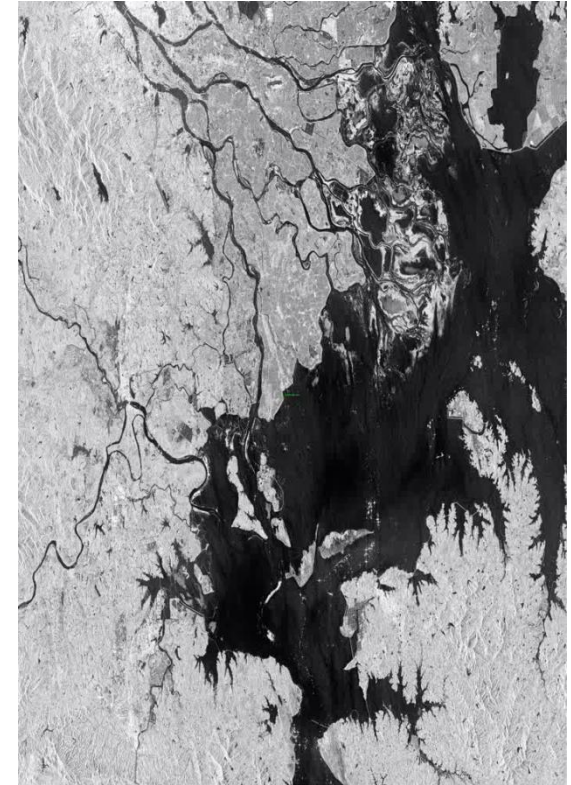
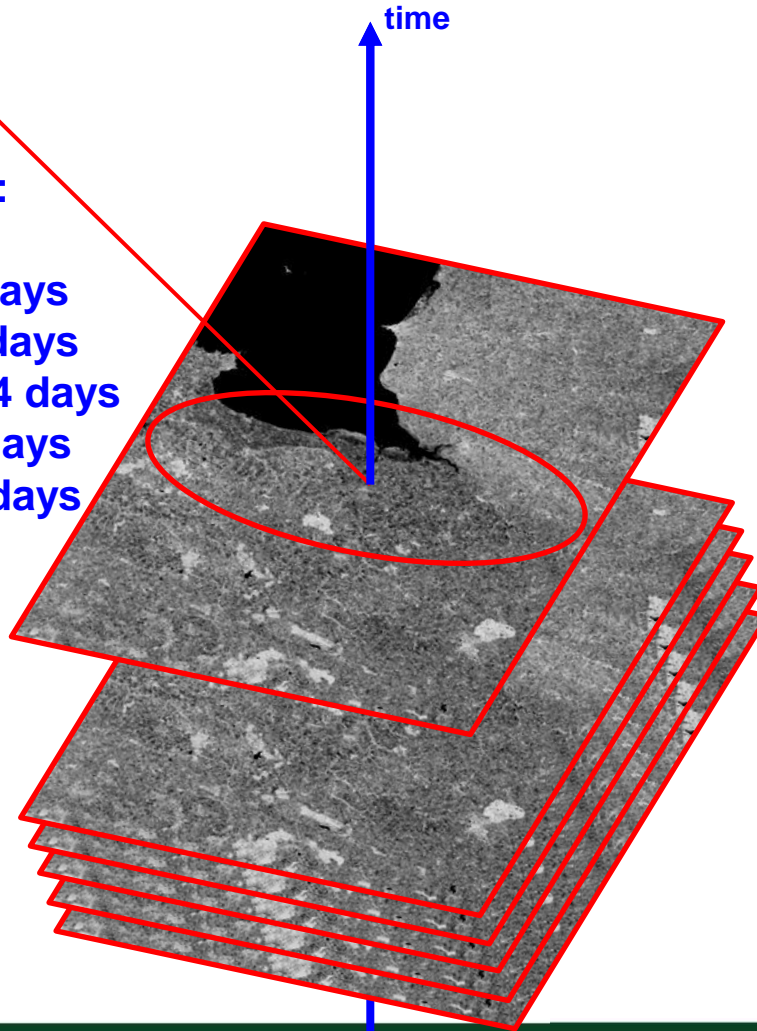
Track<sub>1..N</sub>



## Pol-TimeSAR

Revisit time :

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



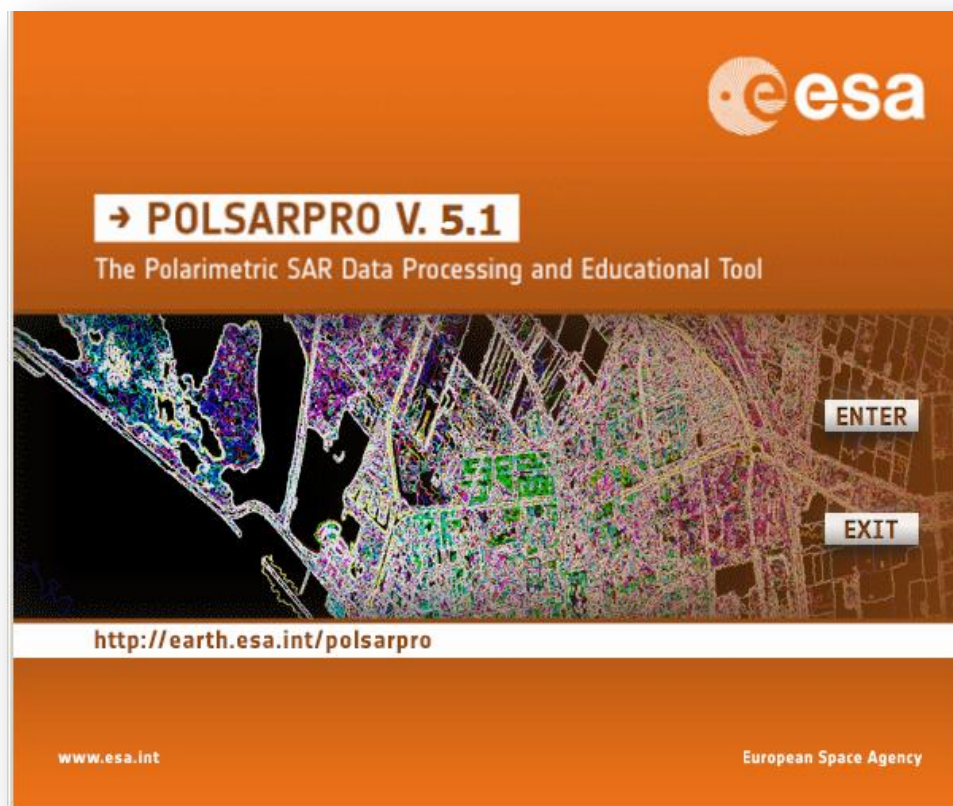
Polarimetric feature temporal evolution



# Questions ?

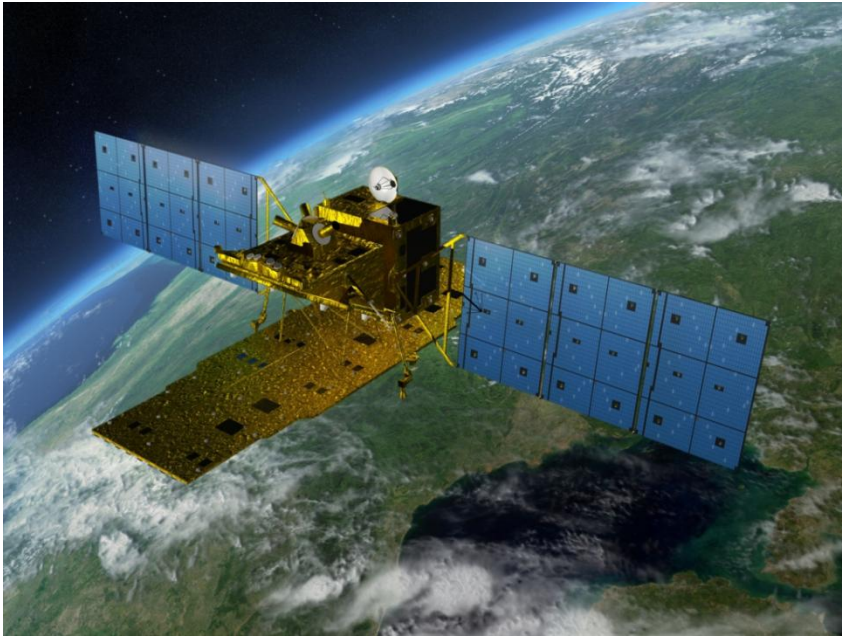


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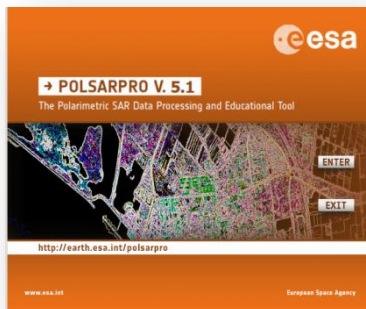


## PoISARpro v5.1 Software Training Course





## L-Band (Quad - 2015)



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Image Landsat/Copernicus



