Introduction to SAR Polarimetry

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ESA–MOST China Dragon 4 Cooperation

2019 ADVANCED INTERNATIONAL TRAINING COURSE IN LAND REMOTE SENSING

中欧科技合作“龙计划”第四期 2019年陆地遥感高级培训班

18 to 23 November 2019 | Chongqing University, P.R. China

培训时间:2019 年11月18日-23日 主办方:重庆大学

Outline

- History
- Spaceborne Sensors
- Basic Concept
- PolSAR Processing Chain

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

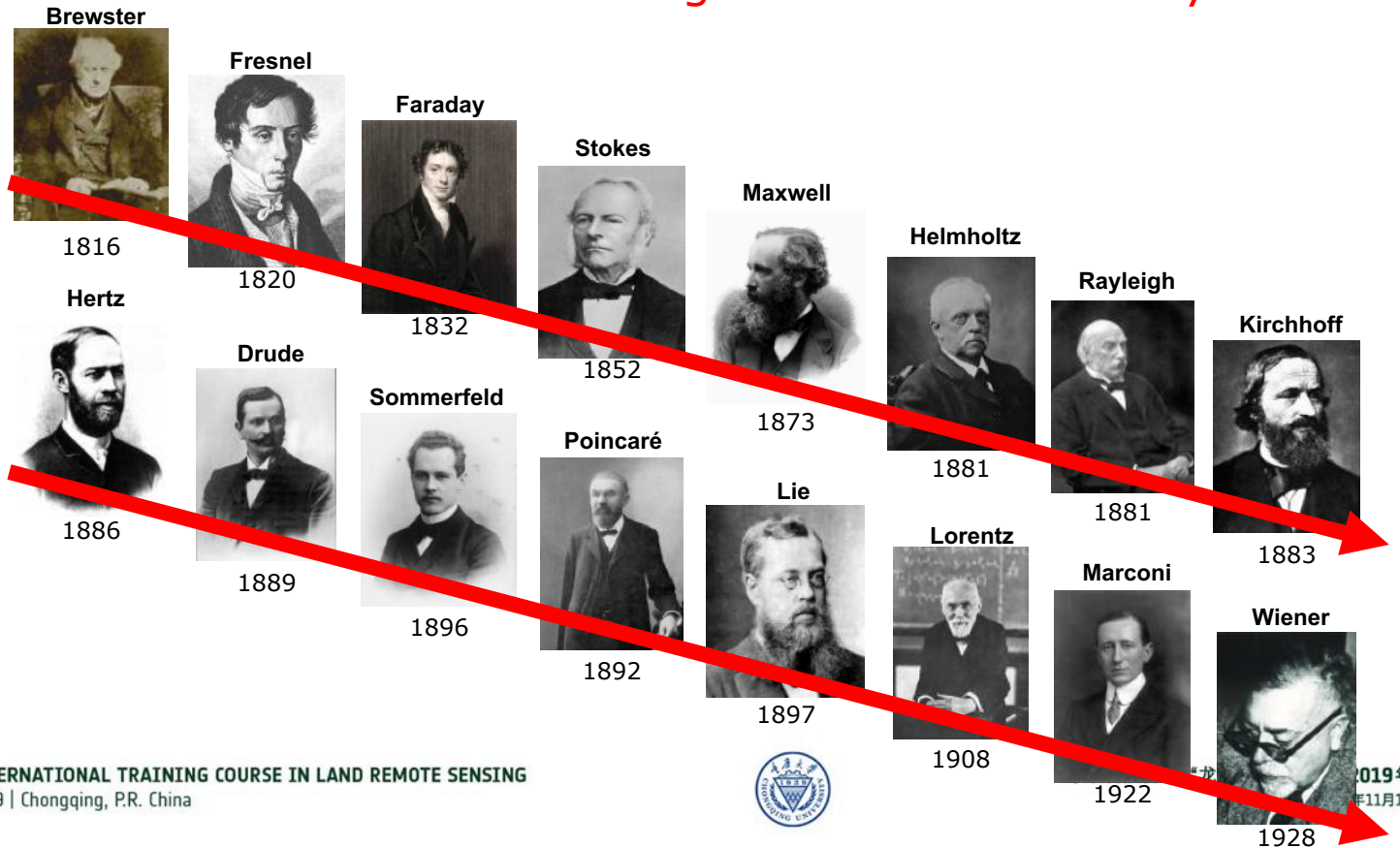
1704
Corpuscular Model of light

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



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

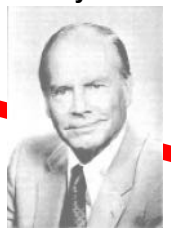
1950

1951

1954

1954

1952

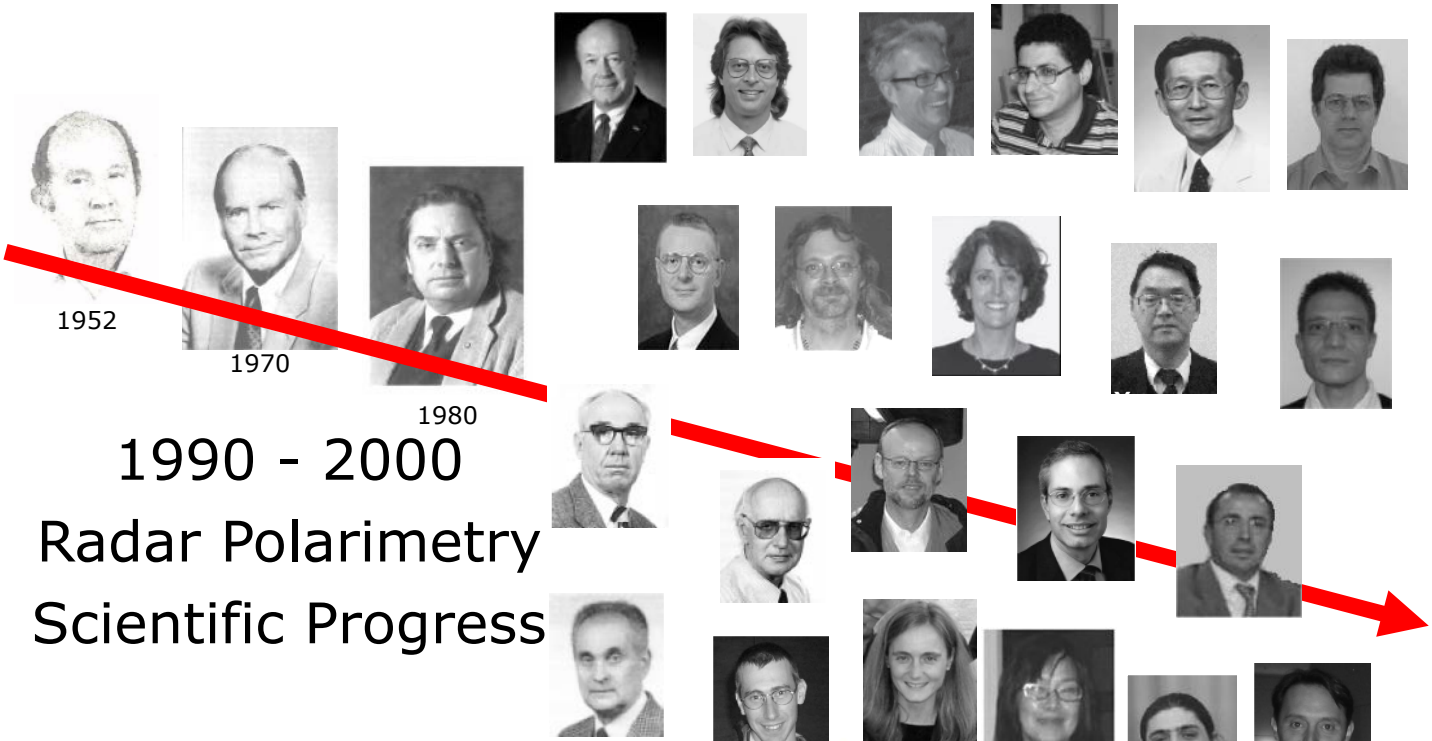


1970

1980

The Radar Polarimetric Triptych

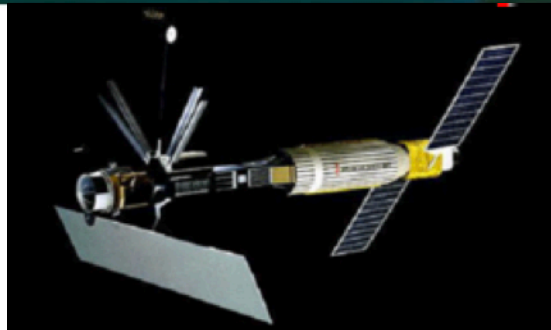
Non Exhaustive Chronological List of the Main Pionners who contributed to the discovery of Polarization leading to Radar Polarimetry



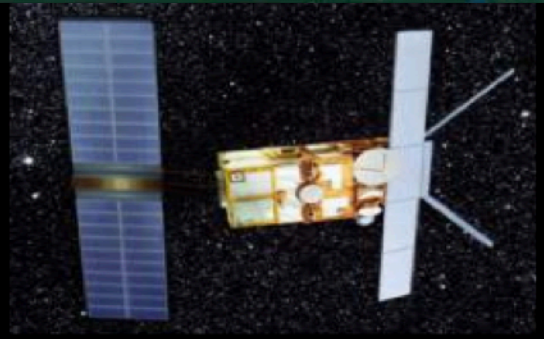
Outline

- History
- **Spaceborne Sensors**
- Basic Concept
- PolSAR Processing Chain

Space-borne Sensors



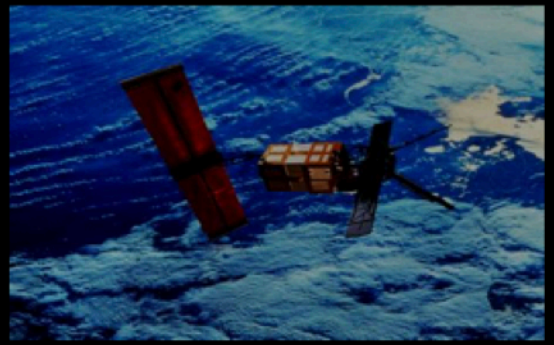
SEASAT
NASA/JPL (USA)
L-Band, 1978



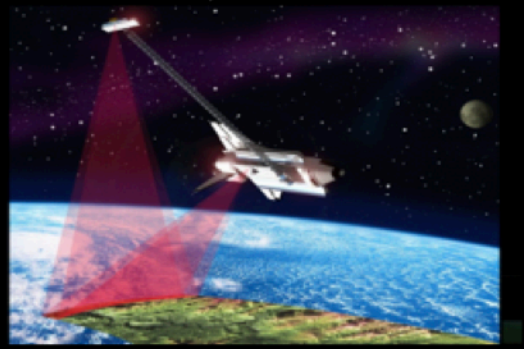
ERS-1
European Space Agency (ESA)
C-Band, 1991-2000

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

Space-borne Dual-Pol SAR Sensors

ENVISAT - ASAR

October 2001
C-Band (Sngl / Dual Inc)

Space-borne Dual-Pol SAR Sensors

COSMO - SkyMed

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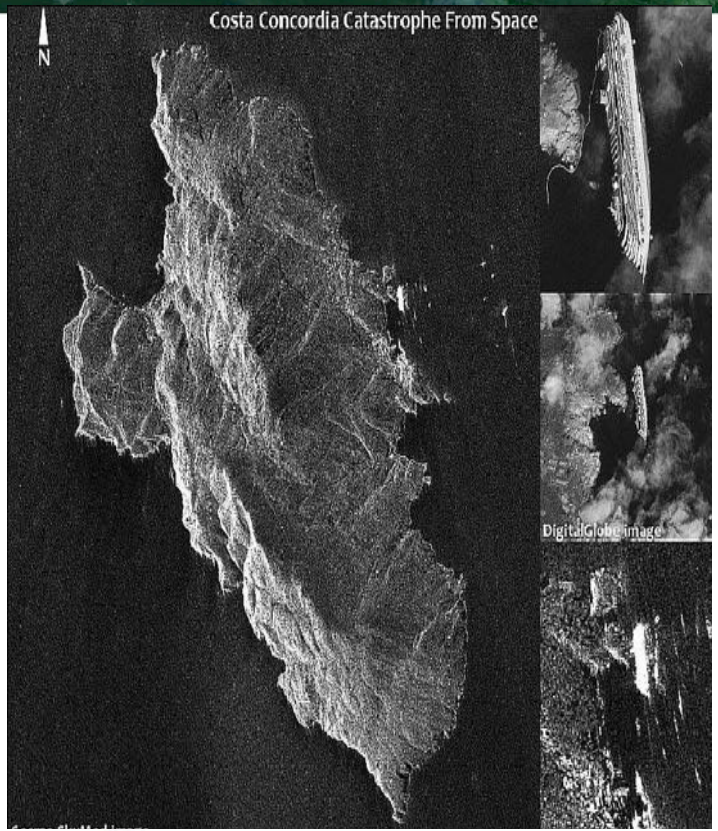
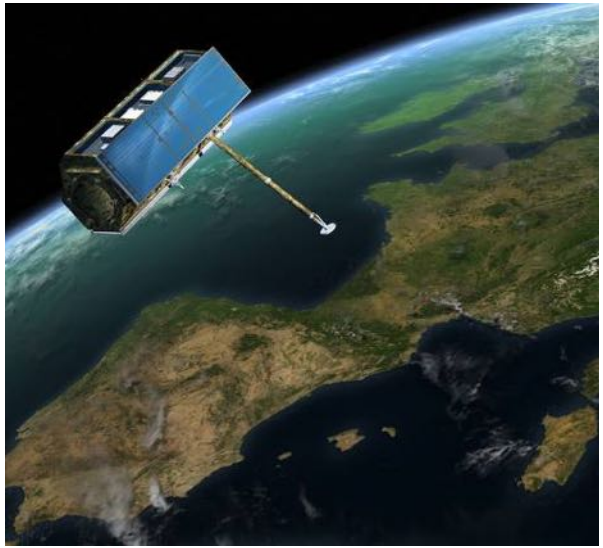
TELESPAZIO
A Finmeccanica / Thales Company

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



Space-borne Dual-Pol SAR Sensors

TerraSAR - X

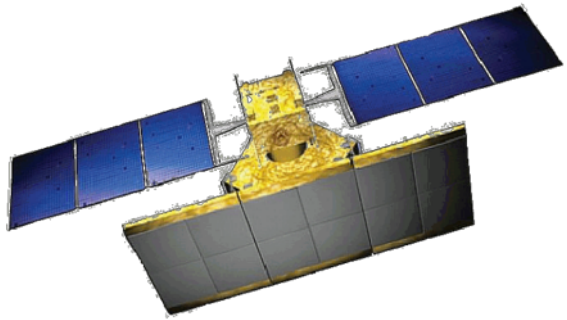


June 2007
X-Band (Sngl / Twin HH-VV / Quad Exp.)

DLR EADS ASTRIUM

Space-borne Dual-Pol SAR Sensors

RISAT-1A

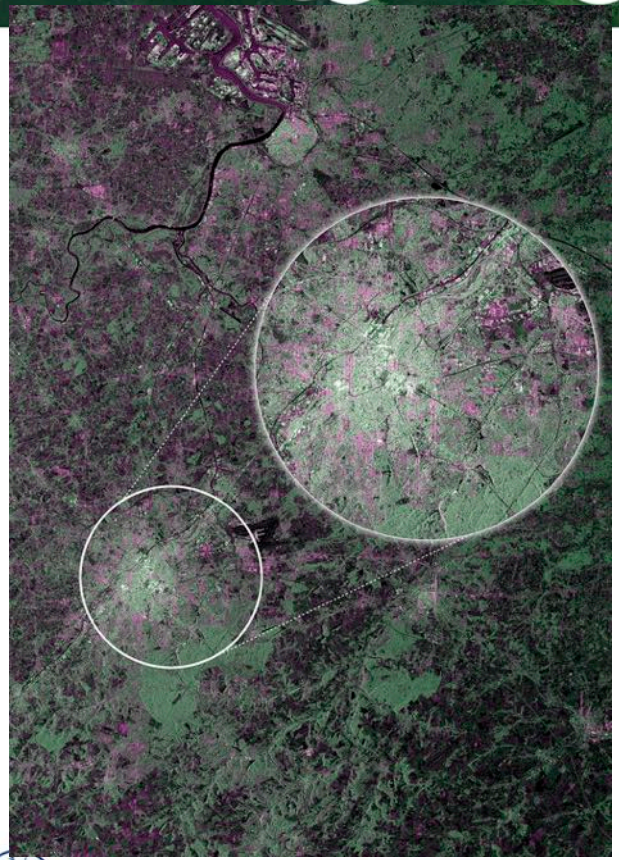


इसरो isro

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

Space-borne Dual-Pol SAR Sensors

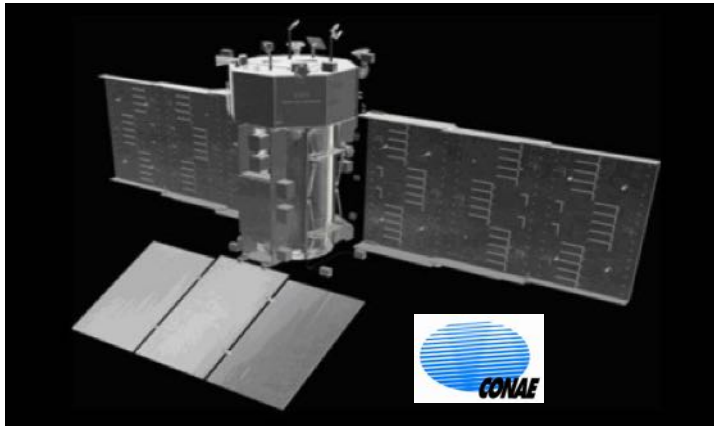
SENTINEL – 1A/B



S1A : April 2014 S1B : April 2016
C-Band (Sngl, Dual)
Revisit : 6 days

Space-borne Dual-Pol SAR 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)

2019 June 12
C-Band (Sngl, Dual, Hybrid)
Revisit : 4 days

Space-borne Quad-Pol SAR Sensors

SIR-C / X-SAR

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

Rwanda, Zaire, Uganda

Space-borne Quad-Pol SAR Sensors

ALOS - PALSAR

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

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

Space-borne Quad-Pol SAR Sensors

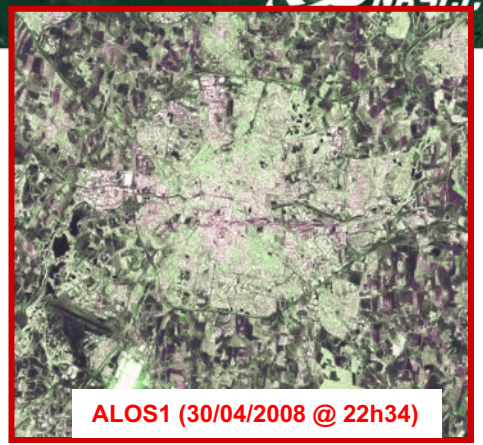
RADARSAT - 2

December 2007
C-Band (Quad)

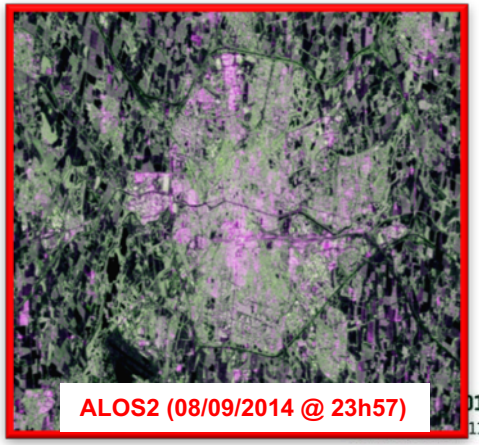
Space-borne Quad-Pol SAR Sensors

ALOS - 2

May 2014
L-Band (Quad)



ALOS1 (30/04/2008 @ 22h34)



ALOS2 (08/09/2014 @ 23h57)

Space-borne Quad-Pol SAR Sensors

GaoFen-3 (GF-3)

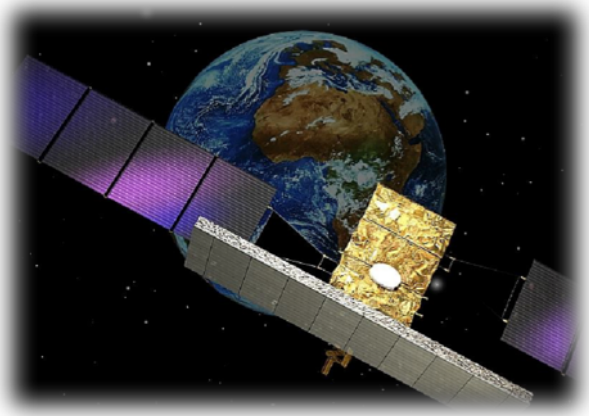
August 2016
C-Band (Quad)

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

IECAS

Space-borne Quad-Pol SAR Sensors

COSMO - SkyMed - CSG



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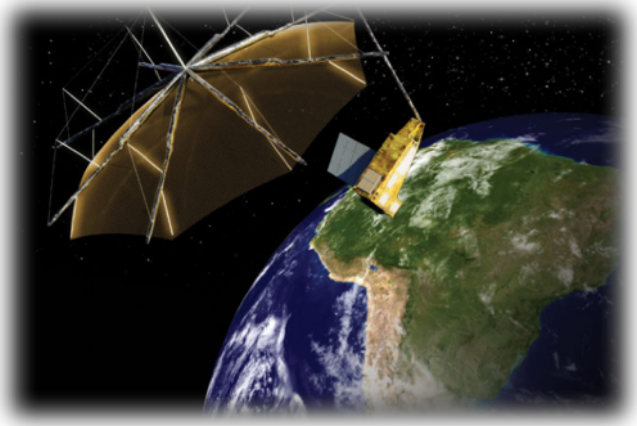
TELESPAZIO
A Finmeccanica / Thales Company

2A : 2018 2B : 2019

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

Earth Explorer - BIOMASS



esa

2022

P-Band (Quad)

Space-borne Quad-Pol SAR Sensors

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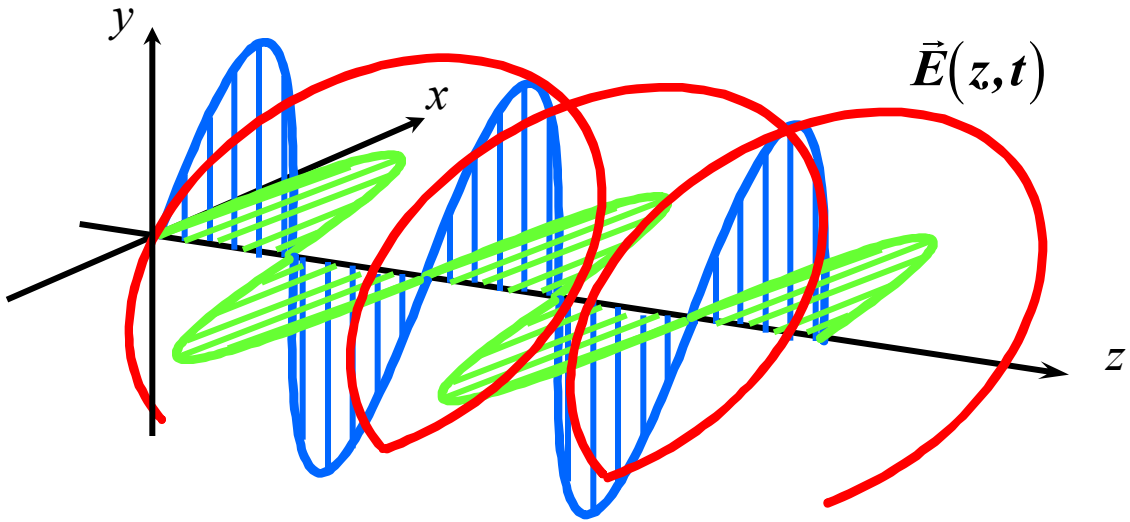
Radar Polarimetry

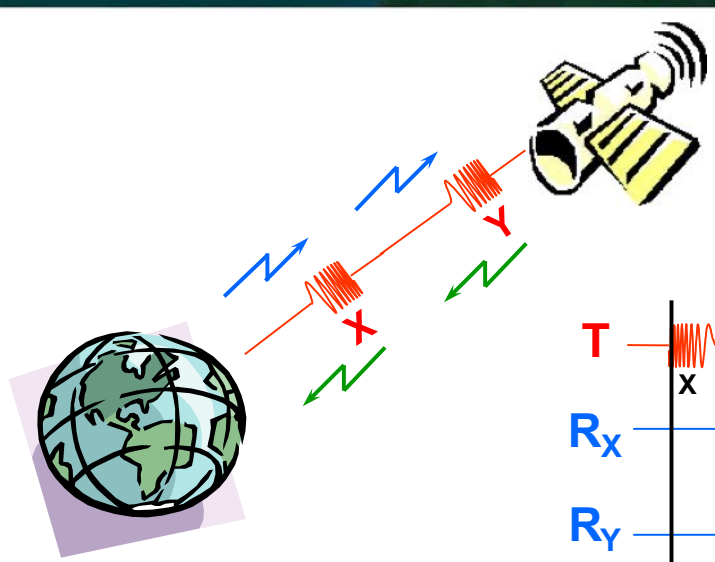


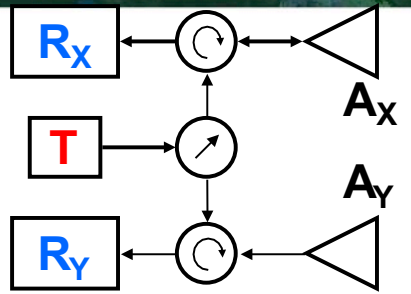
Radar Polarimetry (Polar : polarisation Metry: measure)

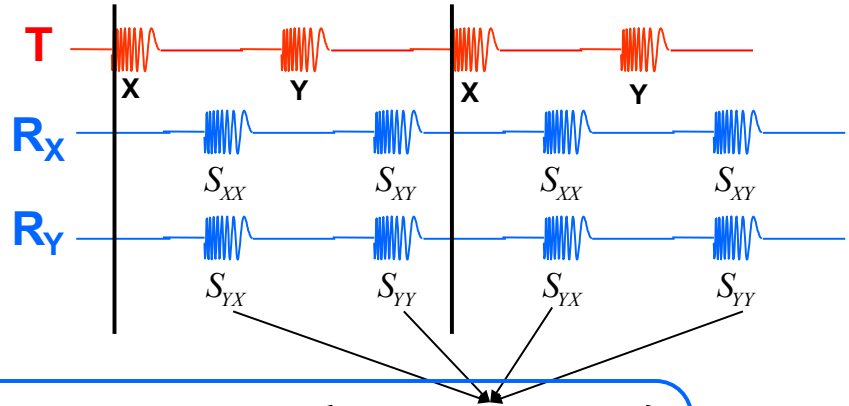
is the, processing and analysing

the polarization science of acquiring state of an electromagnetic field

Scattering Polarimetry







TRANSMITTER: X & Y
RECEIVERS: X & Y

SINCLAIR MATRICES

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

SCATTERING POLARIMETRY

Scattering Polarimetry

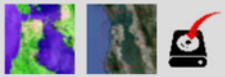
In monostatic case $S_{hv} = S_{vh}$

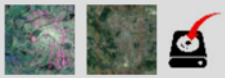
Single Pol	HH	VV	
Dual Pol	HH+HV	VV+HV	HH+VV
Quad Pol	HH+VV+HV		

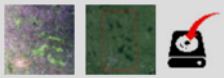
GF-3 data download

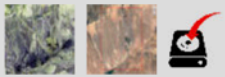
GaoFen-3 (GF-3)

Full (Quad) Polarimetric Sample Datasets


San Francisco Bay (USA) - 2017/09/15


Paris (France) - 2017/09/14


Rennes (France) - 2017/01/03


Skoura (Morocco) - 2017/09/14

South Pole - 2017/09/16

Visit the **IETR** and **IECAS** websites

PIWIK Analytics

Courtesy of Dr. Jili SUN, Dr. Bing HAN (IECAS), Dr. Xinzhe YUAN (NSOAS), Tao YAO (CNSA)

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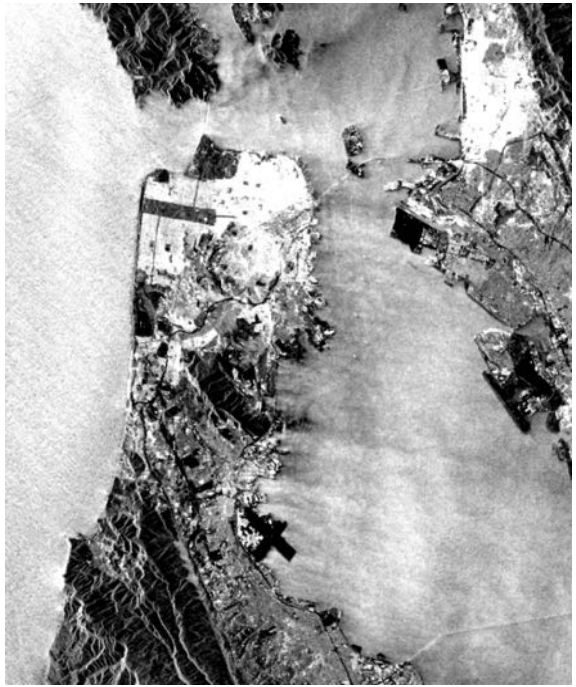
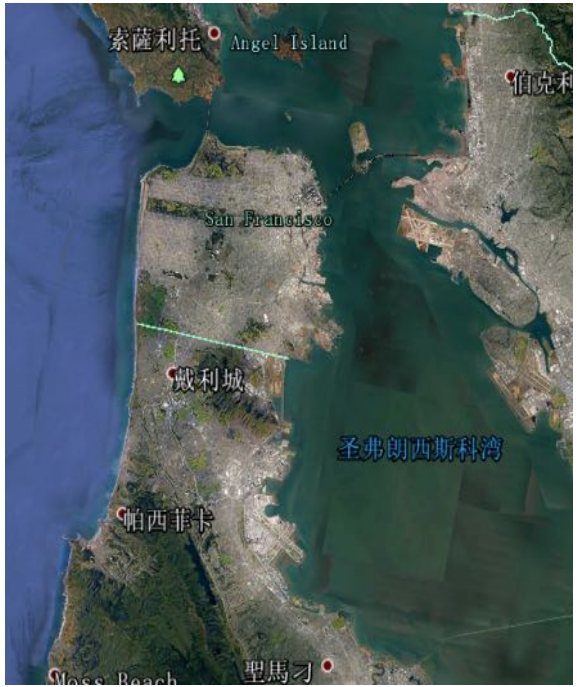
GF-3 @ San Francisco

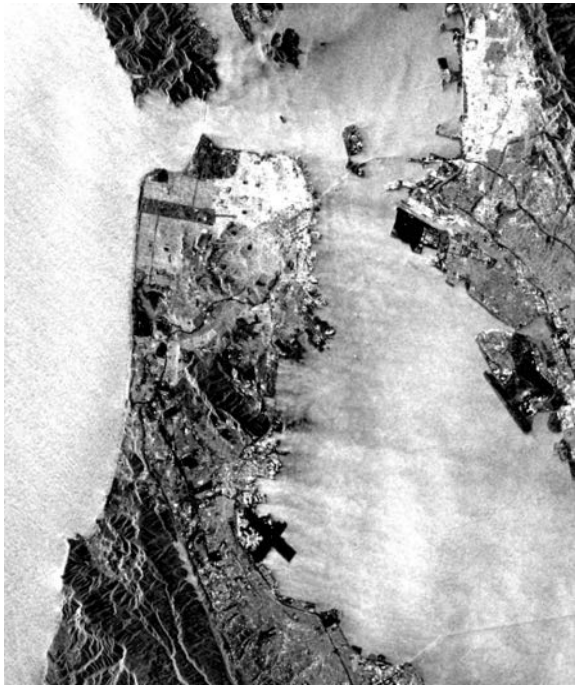


Tx → Rx

$|HH|_{dB}$

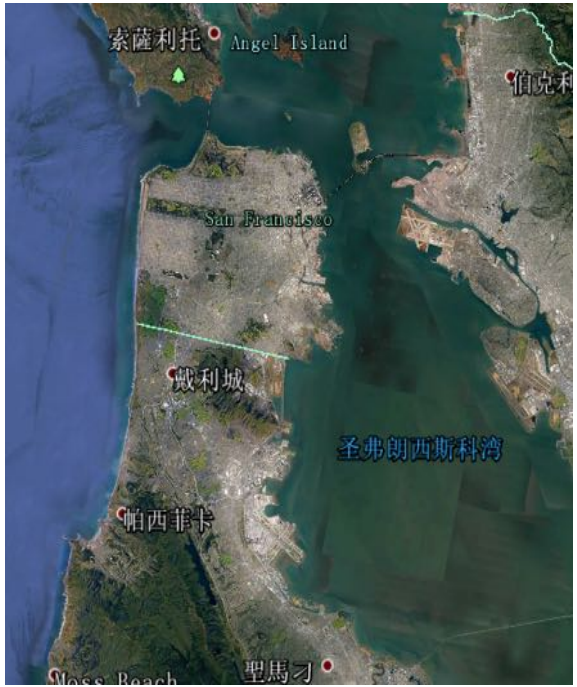


GF-3 @ San Francisco

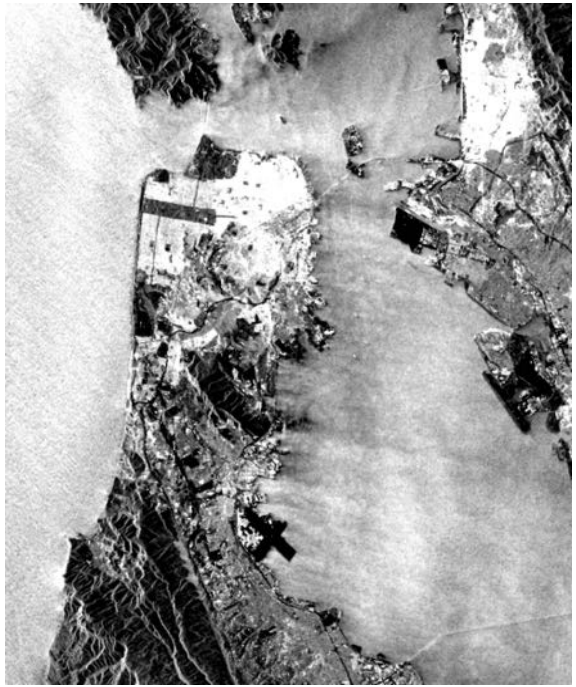


Tx Rx

$|VV|_{dB}$



GF-3 @ San Francisco



Tx

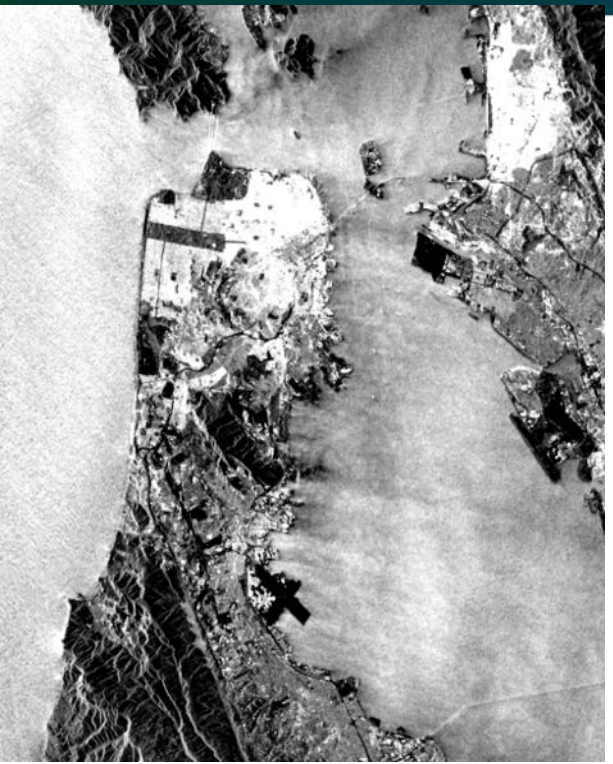
Rx

$|HH|_{dB}$

Rx

$|HV|_{dB}$

GF-3 @ San Francisco



$|HH|_{dB}$

$|HV|_{dB}$

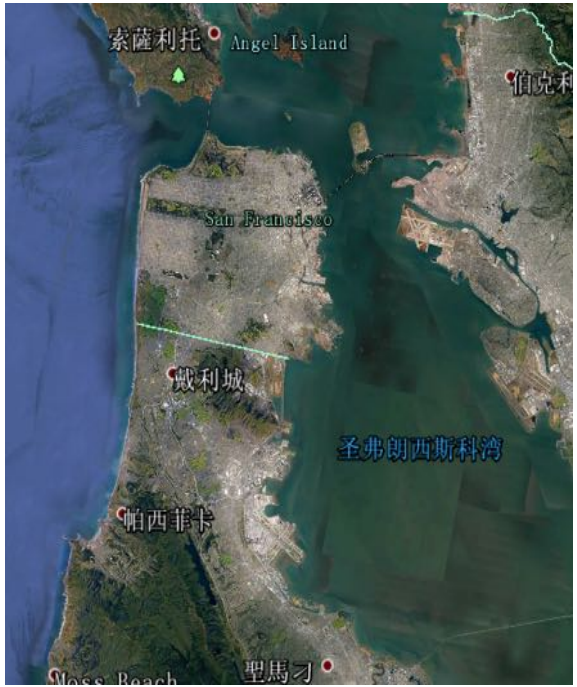
$|VV|_{dB}$

GF-3 @ San Francisco

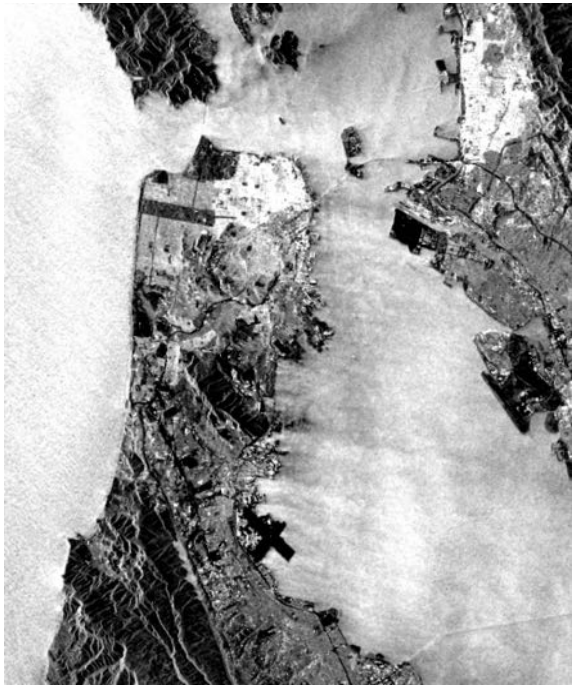
|HH|dB

|HV|dB

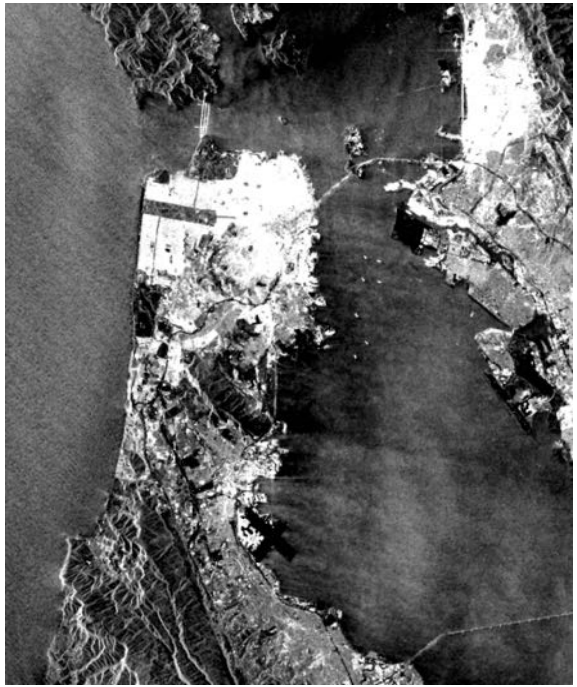
|VV|dB



GF-3 @ San Francisco

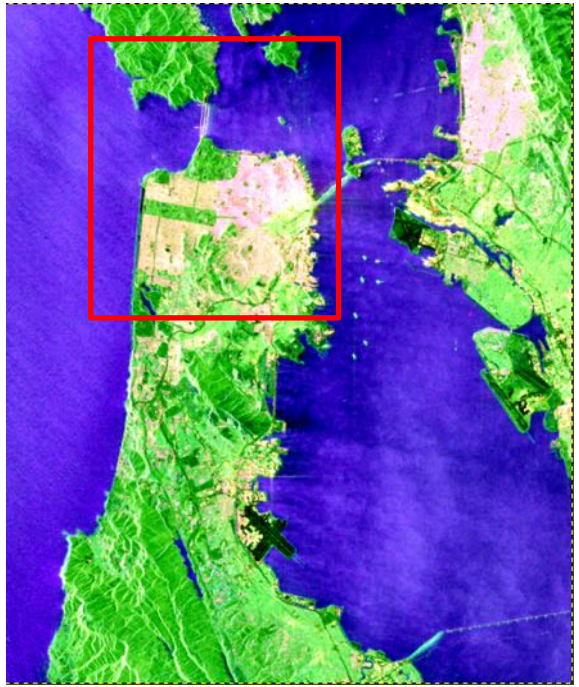


|HH+VV|dB



|HH-VV|dB

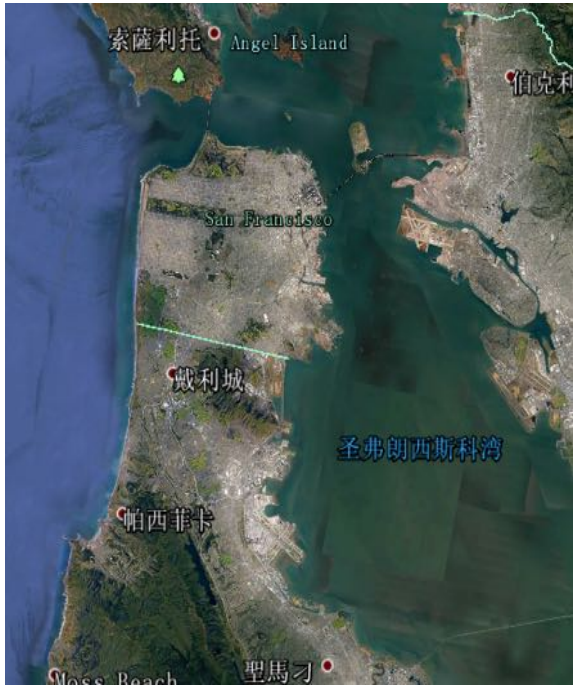
GF-3 @ San Francisco

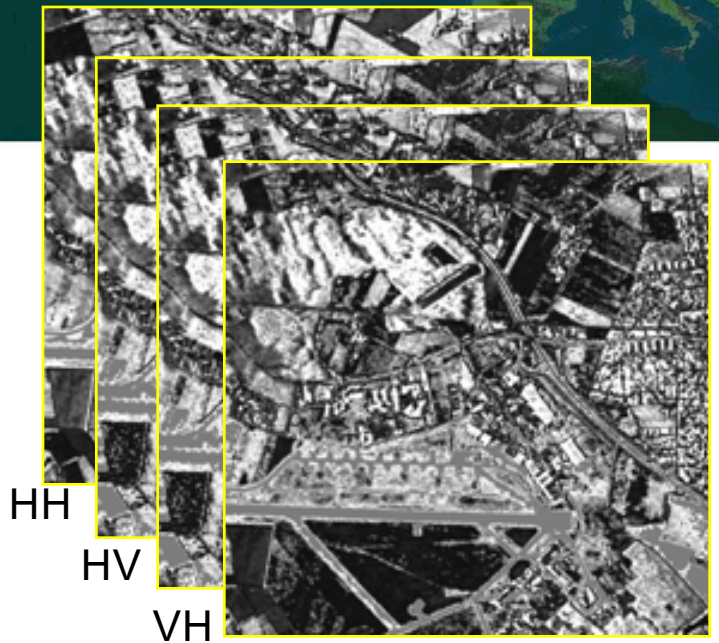


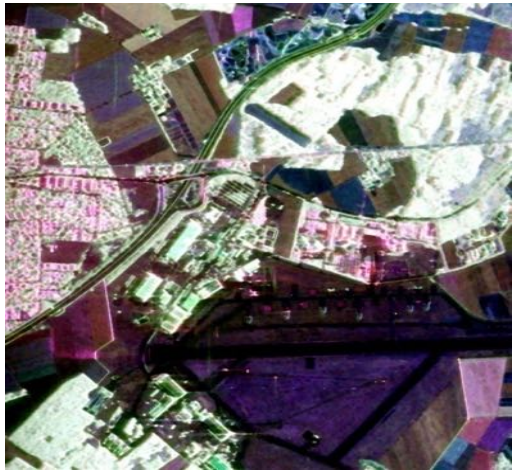
$|HH+VV|_{dB}$

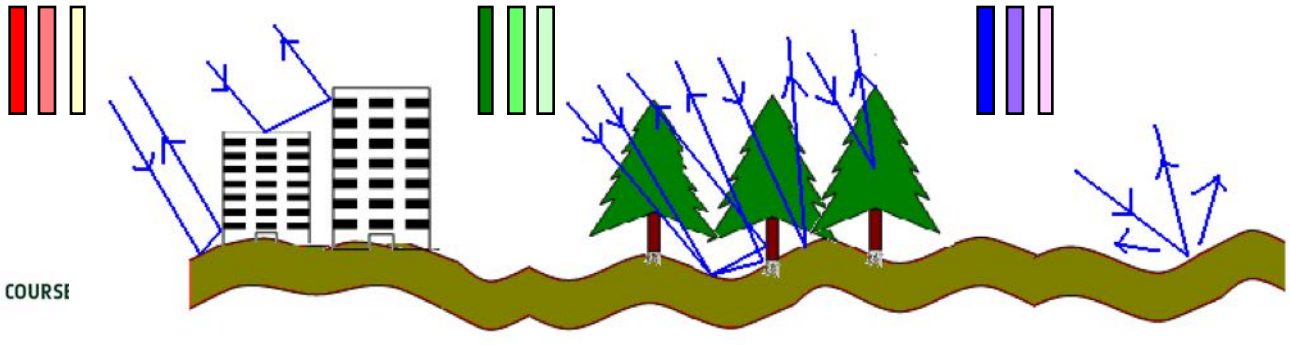
$|HV|_{dB}$

$|HH-VV|_{dB}$




HH
HV
VH
VV





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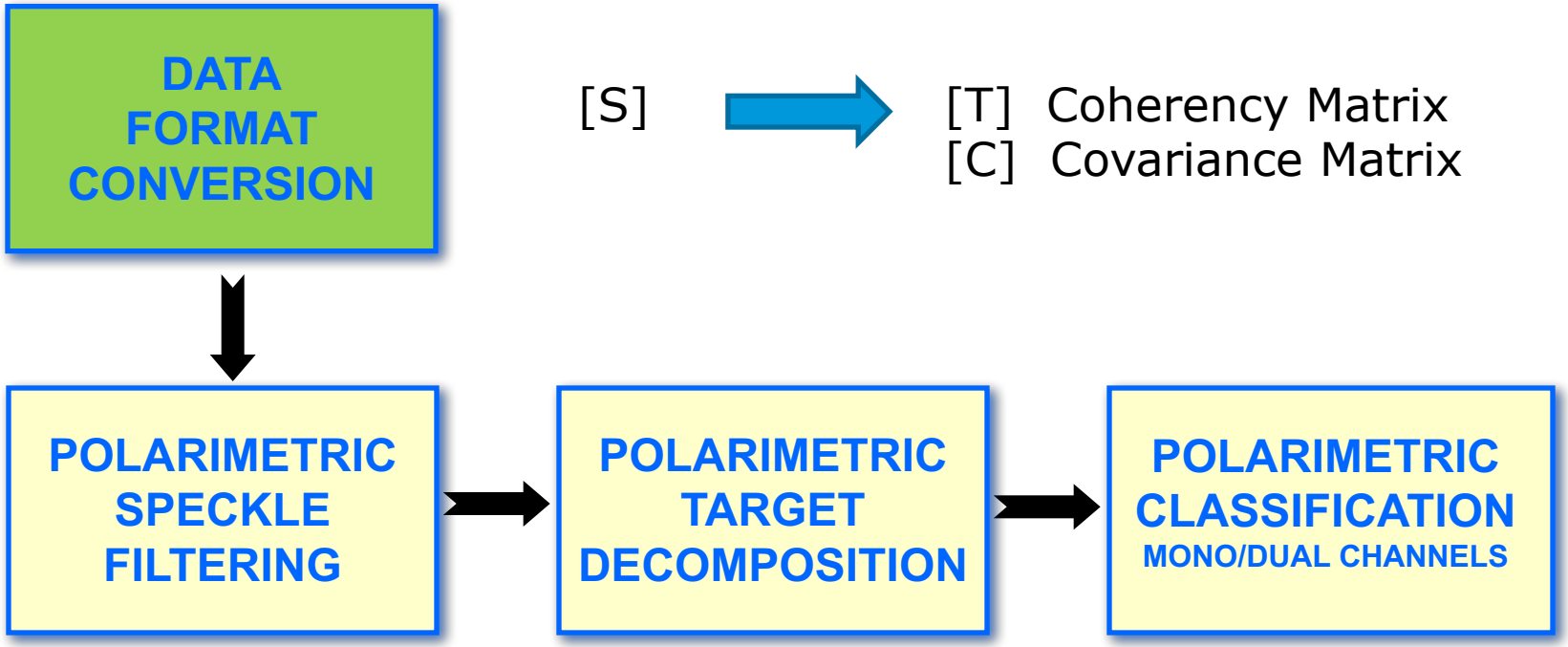
- **PolSAR Processing Chain**

PolSAR Processing Chain



Covariance Matrix

TARGET VECTOR ***k***

$$\vec{k}_{3L} = \left[s_{hh}, \sqrt{2} s_{hv}, s_{vv} \right]^T$$

$$[C] = \vec{k}_{3L} \vec{k}_{3L}^{*T} = \begin{bmatrix} |s_{hh}|^2 & \sqrt{2} s_{hh} s_{hv}^* & s_{hh} s_{vv}^* \\ \sqrt{2} s_{hv} s_{hh}^* & 2|s_{hv}|^2 & \sqrt{2} s_{hv} s_{vv}^* \\ s_{vv} s_{hh}^* & \sqrt{2} s_{vv} s_{hv}^* & |s_{vv}|^2 \end{bmatrix}$$

Coherency Matrix

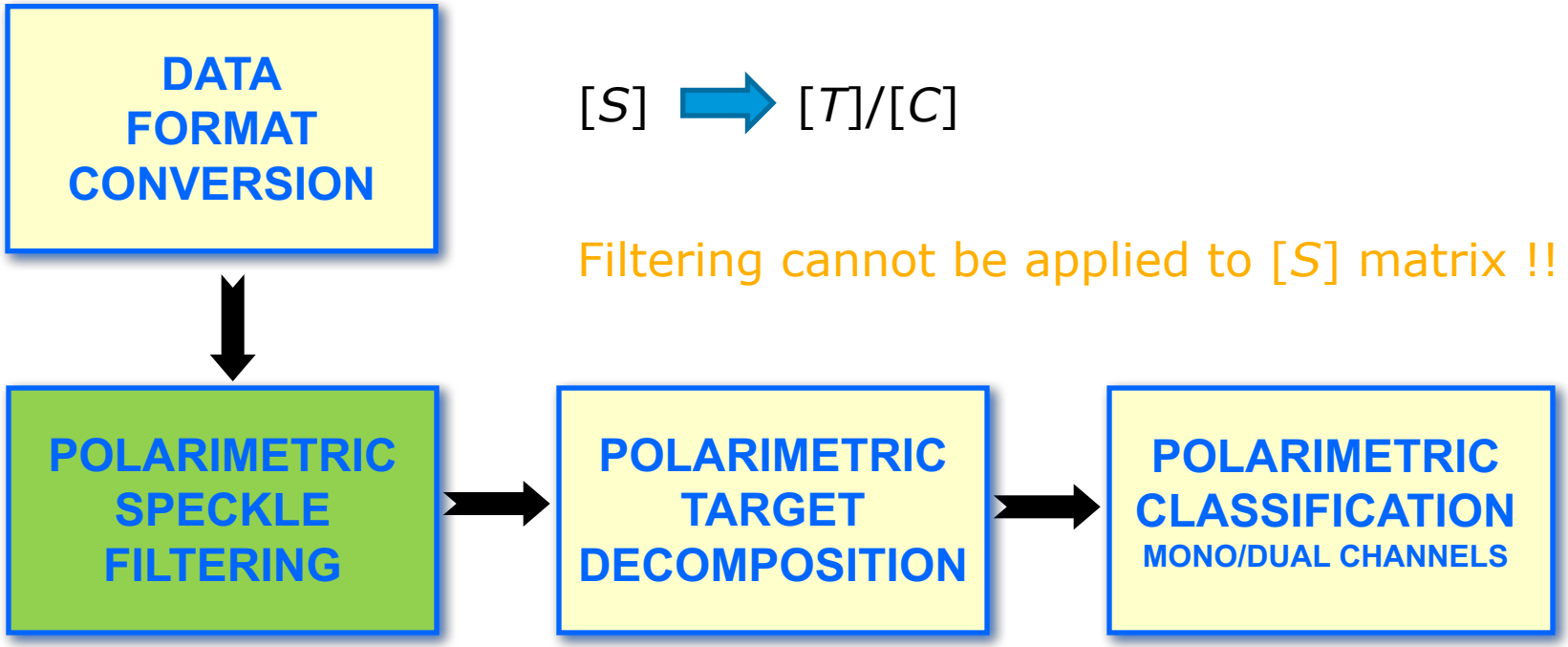
TARGET VECTOR *k*

$$\vec{k}_{3P} = \left[s_{hh} + s_{vv}, s_{hh} - s_{vv}, 2s_{hv} \right]^T$$

$$[T] = \vec{k}_{3P}\vec{k}_{3P}^{*T} = \frac{1}{2}\begin{bmatrix} |s_{hh}+s_{vv}|^2 & (s_{hh}+s_{vv})(s_{hh}-s_{vv})^* & 2(s_{hh}+s_{vv})s_{hv}^* \\ (s_{hh}-s_{vv})(s_{hh}+s_{vv})^* & |s_{hh}-s_{vv}|^2 & 2(s_{hh}-s_{vv})s_{hv}^* \\ 2s_{hv}(s_{hh}+s_{vv})^* & 2s_{hv}(s_{hh}-s_{vv})^* & 4|s_{hv}|^2 \end{bmatrix}$$

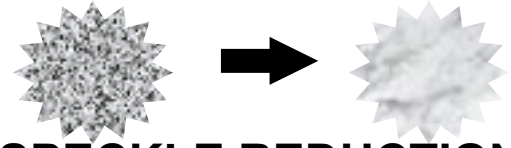
[*T*] is closer related to Physical and Geometrical Properties of the Scattering Process, and thus allows a better and direct physical interpretation

PolSAR Processing Chain



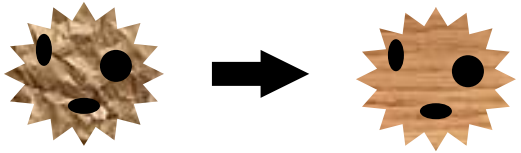
Speckle Filtering

HOMOGENEOUS AREA

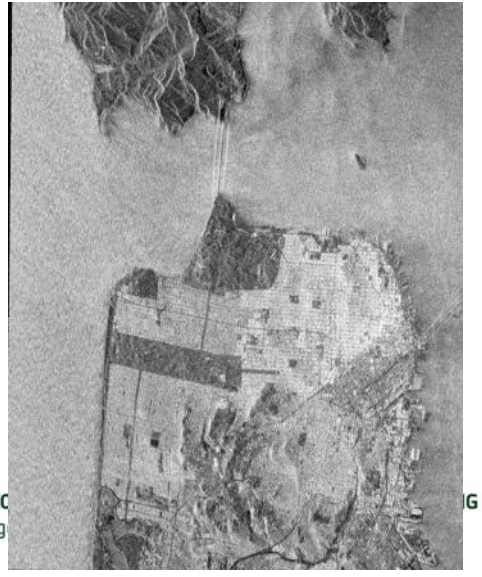


SPECKLE REDUCTION
(RADIOMETRIC RESOLUTION)

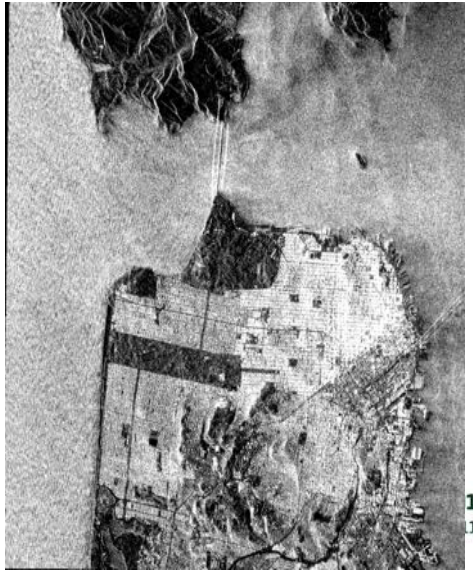
HETEROGENEOUS AREA



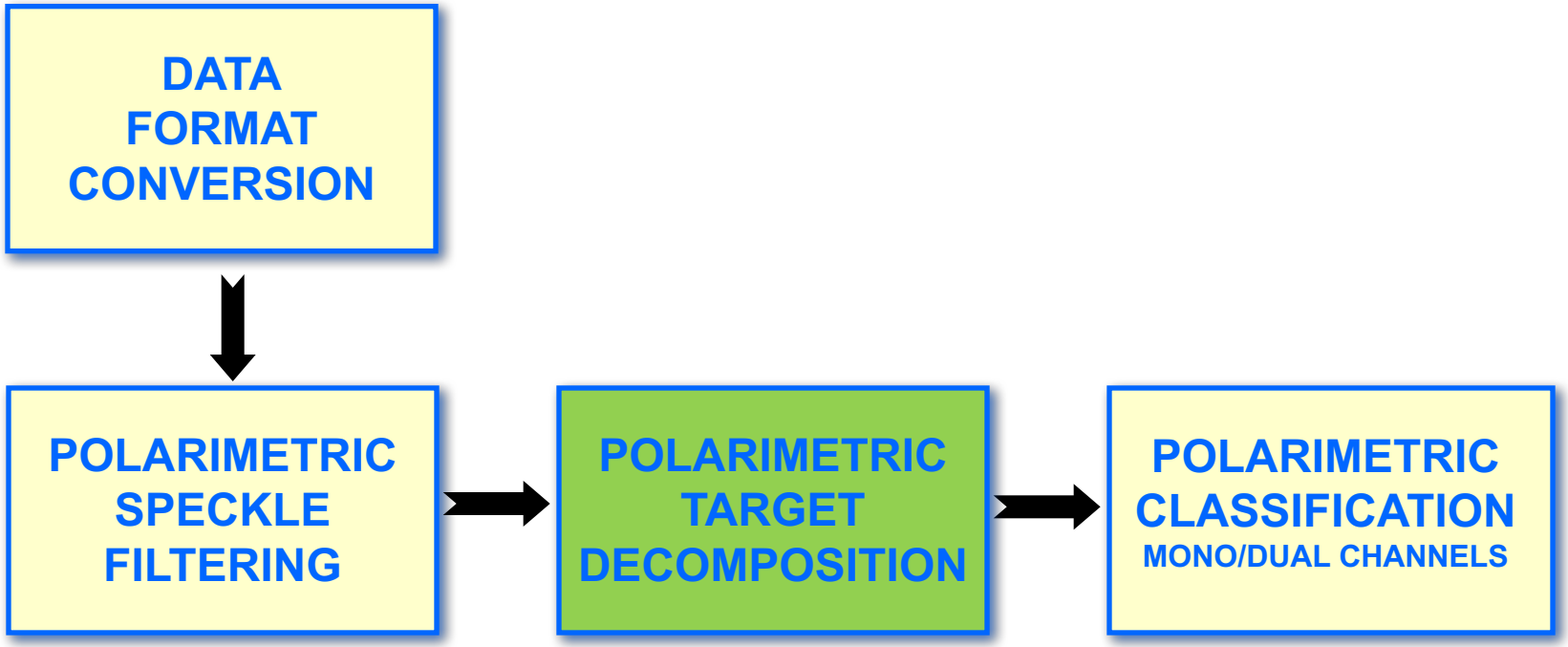
DETAILS PRESERVATION
(SPATIAL RESOLUTION)



Filtering



PolSAR Processing Chain



H / A / α DECOMPOSITION

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

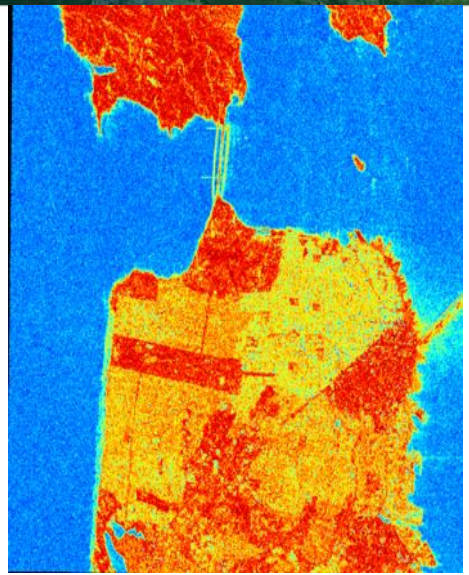
$\lambda_1 > \lambda_2 > \lambda_3$

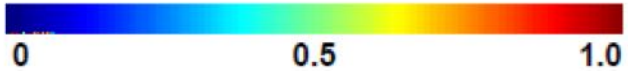
H / A / α DECOMPOSITION

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

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

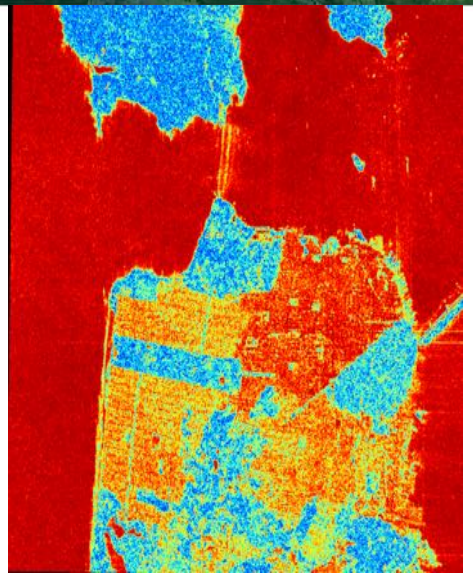
$H = 1$

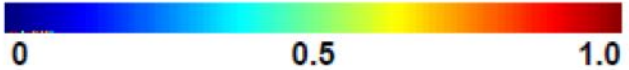
H / A / α DECOMPOSITION

ANISOTROPY

(EIGENVALUES SPECTRUM)

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





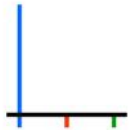
COMPLEMENTARY TO ENTROPY

DISCRIMINATION WHEN H > 0.7

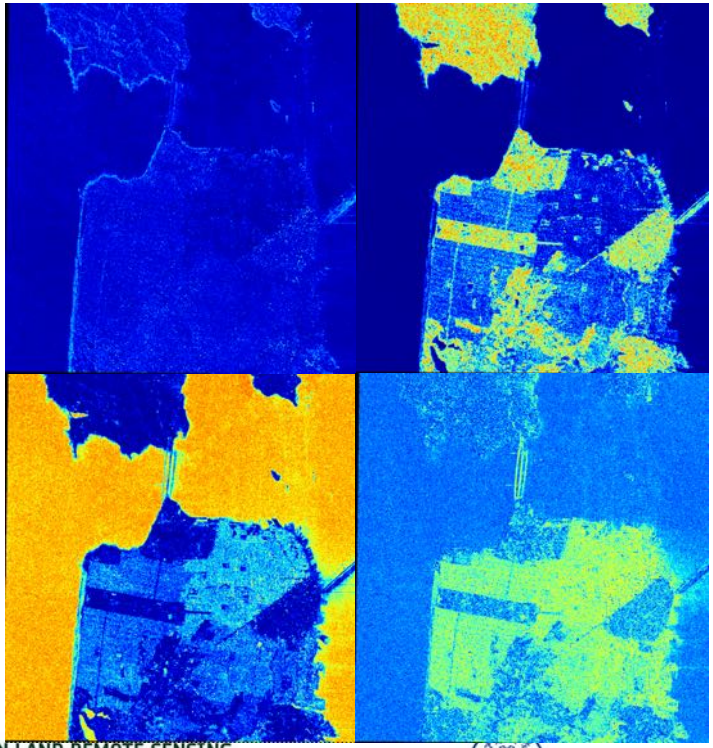
ROLL INVARIANT

H / A / α DECOMPOSITION

(1-H)(1-A)



1 MECHANISM



H(1-A)

3 MECHANISMS

A(1-H)

2 MECHANISMS

HA

2 MECHANISMS

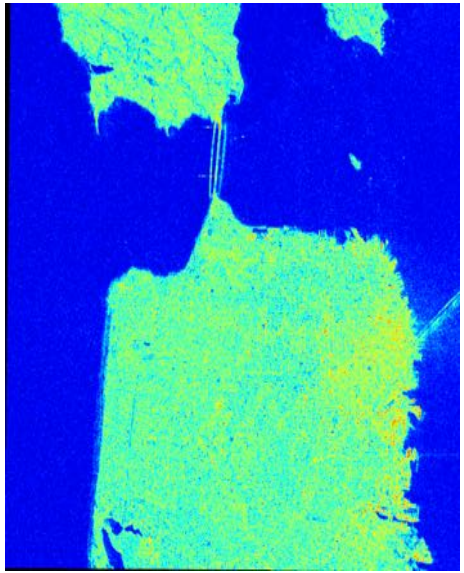
EIGENVECTOR MATRIX PARAMETER

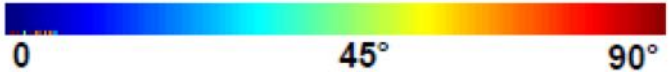
$$[U_3]=\begin{bmatrix} \cos\alpha_1 e^{j\phi_1} & \cos\alpha_2 e^{j\phi_2} & \cos\alpha_3 e^{j\phi_3} \\ \sin\alpha_1\cos\beta_1 e^{j\phi_1} e^{j\delta_1} & \sin\alpha_2\cos\beta_2 e^{j\phi_2} e^{j\delta_2} & \sin\alpha_3\cos\beta_3 e^{j\phi_3} e^{j\delta_3} \\ \sin\alpha_1\sin\beta_1 e^{j\phi_1} e^{j\gamma_1}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

TARGET 1 TARGET 2 TARGET 3

$$\alpha = p_1\alpha_1 + p_2\alpha_2 + p_3\alpha_3$$

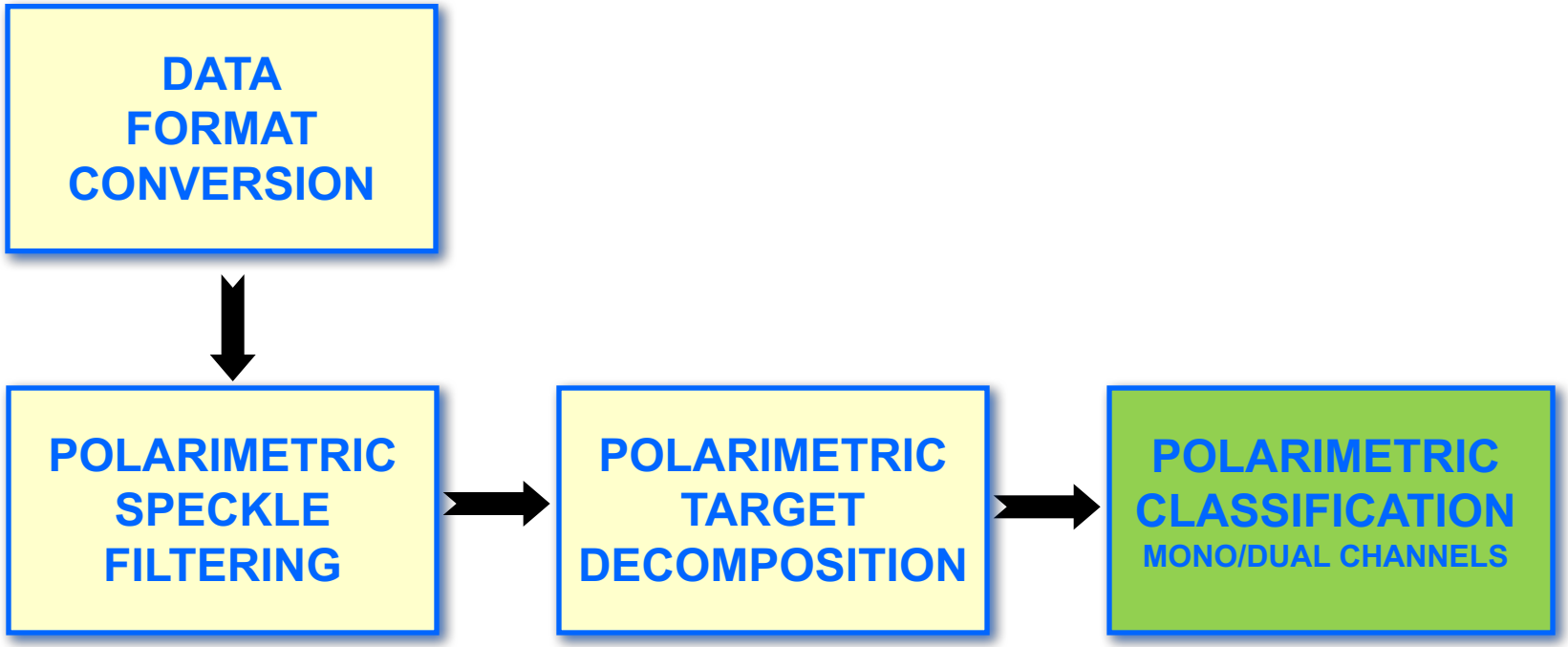
H / A / α DECOMPOSITION



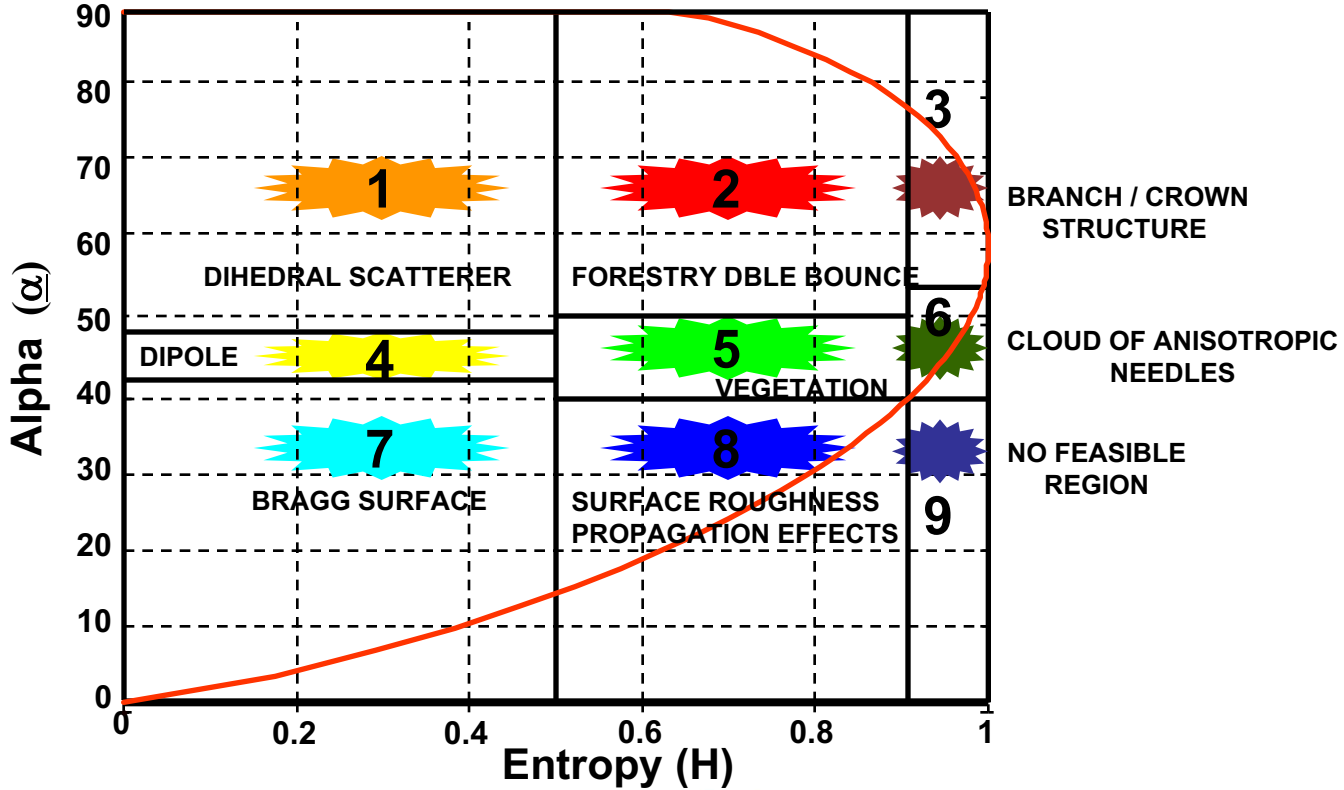


α PARAMETER

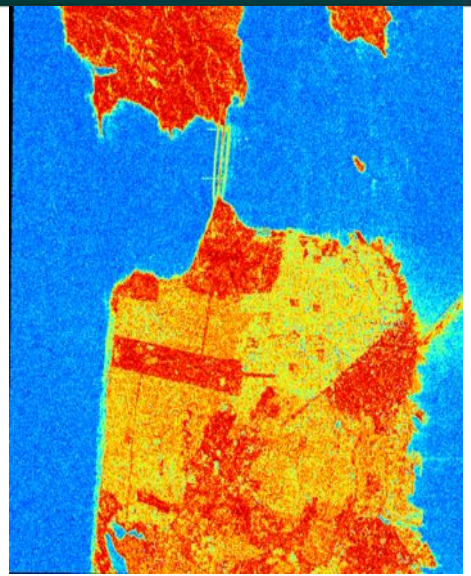
PolSAR Processing Chain



H / α CLASSIFICATION

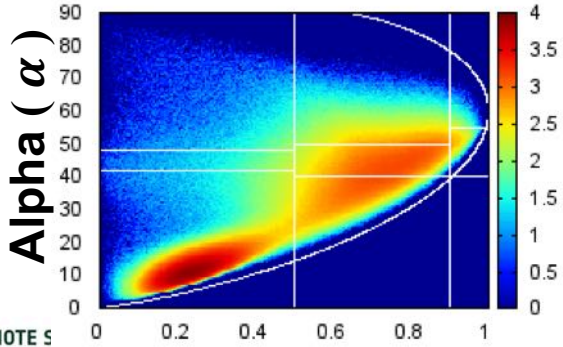


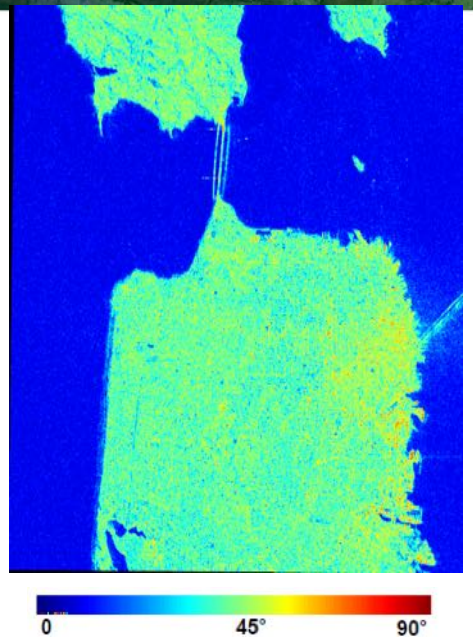
H / α CLASSIFICATION



H

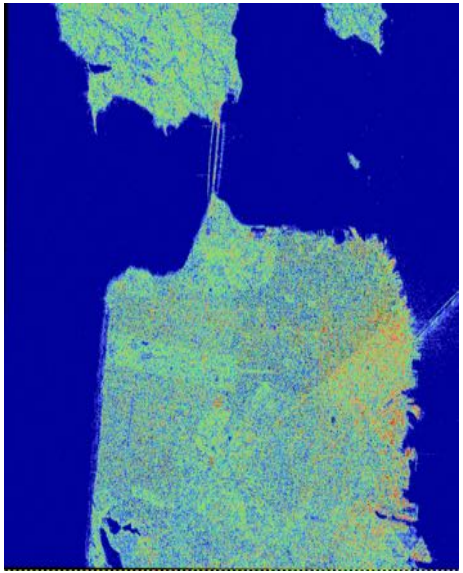
POLSAR DATA DISTRIBUTION IN THE H / α PLANE





α

H / α CLASSIFICATION

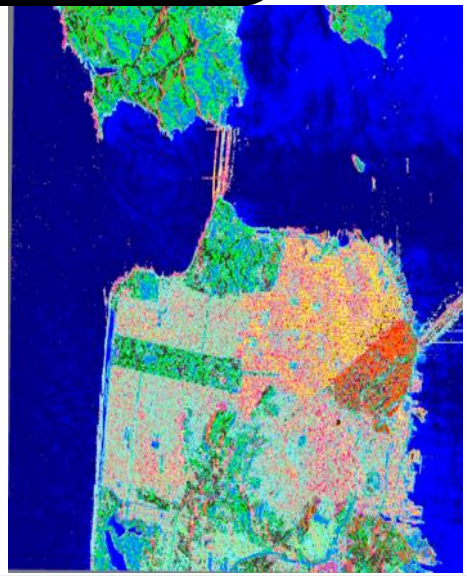


H - α classification

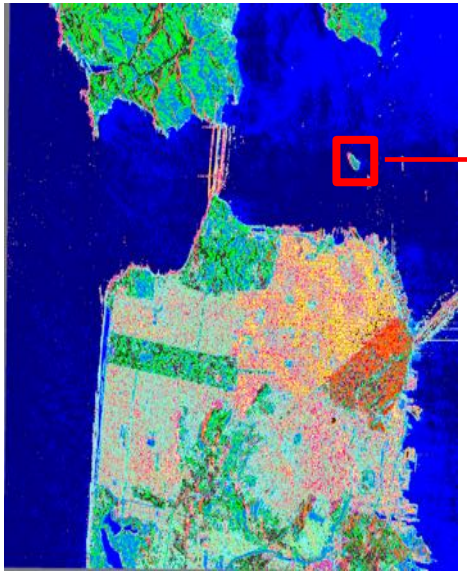
WISHART H / A / α CLASSIFICATION

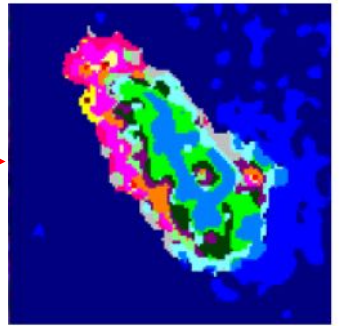
WISHART PDF

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



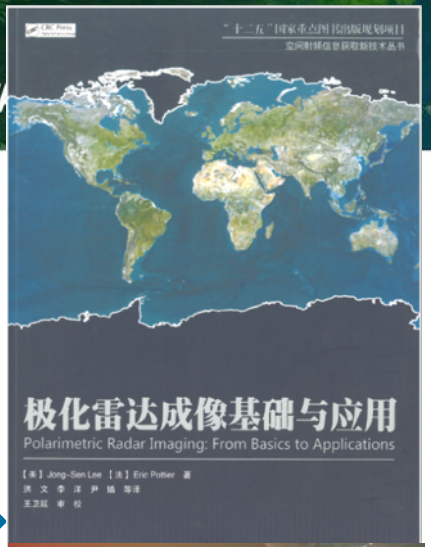
WISHART H / A / $\underline{\alpha}$ CLASSIFICATION



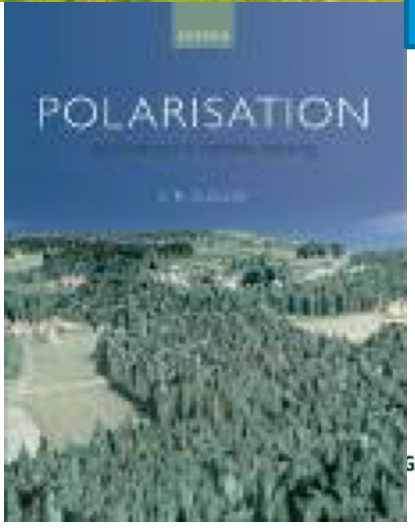


POLSAR BOOKS

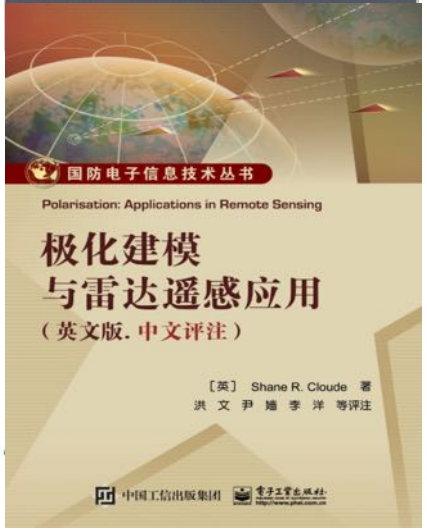
Polarimetric Radar Imaging: From basics to applications
Jong-Sen LEE – Eric POTTIER
CRC Press; 1st ed., February 2009, pp 422



TRANSLATION By Wen HONG's group



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



Introduction to SAR Polarimetry

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