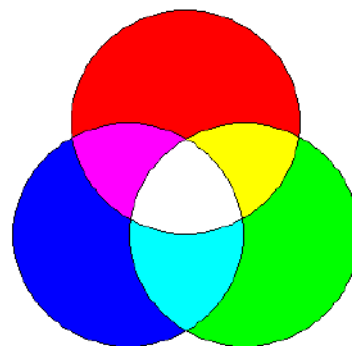
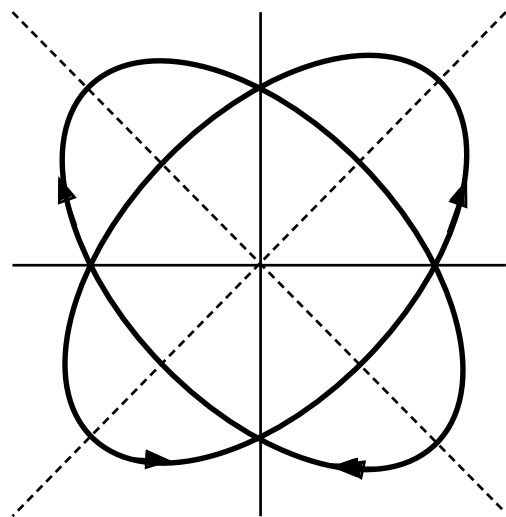


レーダ・ポーラリメトリ 技術の歴史と将来展望



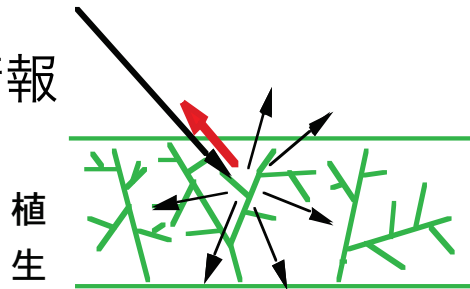
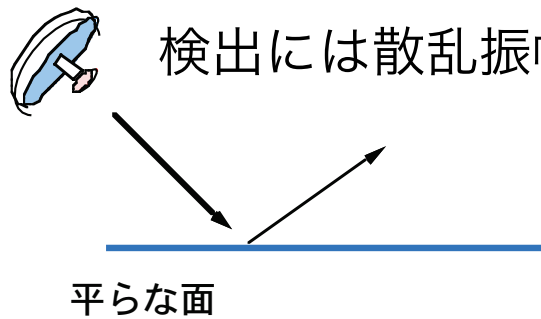
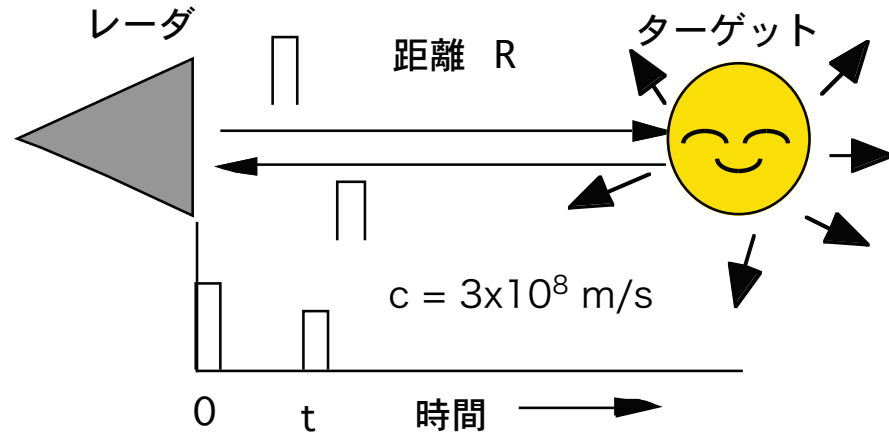
山口芳雄（新潟大学・産総研）

内容

- ① レーダについて
- ② 合成開口レーダ
- ③ 偏波について
- ④ レーダポーラリメトリ
- ⑤ PolSAR データの利用例
- ⑥ 将来展望

① Radar : Radio Detection and Ranging

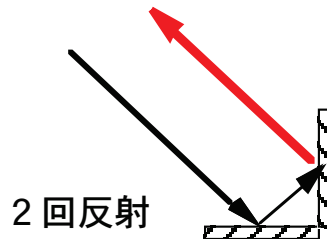
電波によるターゲット
の距離計測と検出
遅延時間と電波の散乱
を利用



$$\tau = \frac{2R}{c} \quad \text{遅延時間}$$

$$R = \frac{c\tau}{2} \quad \text{距離}$$

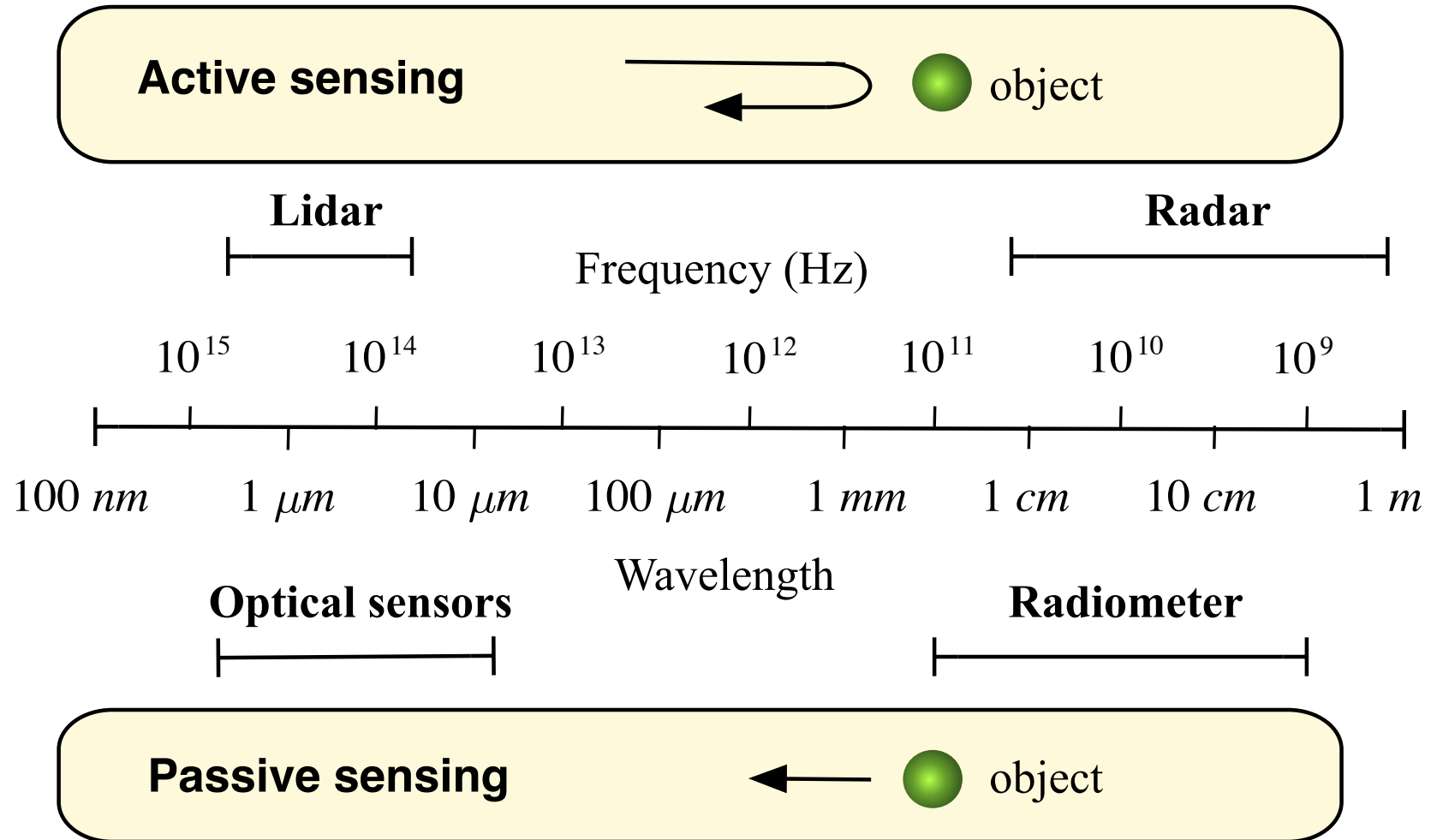
距離計測には遅延時間



電波伝搬特性

周波数 (波長) 依存性

Sensorとしてのレーダの位置づけ



レーダ周波数の呼称

Band	Frequency (GHz)	Remarks	λ (cm)
W	75 - 110	next to V (alphabet)	0.3
V	40 - 75	V ery high frequency	0.5
Ka	26.5 - 40	K urts a bove (German)	1
K	18 - 26.5	K urts (= Short, German)	1.5
Ku	12.5 - 18	K urts u nder (German)	2
X	8 - 12.5	e X treme short	3
C	4 - 8	C ompromise between X and S	5
S	2 - 4	S hort wavelength	10
L	1 - 2	L ong wavelength	25
P	0.3 - 1.0	P revious radar frequency	50

0.27 cm

0.4 cm

0.75 cm

2.5 cm

3.8 cm

7.5 cm

15 cm

30 cm

100 cm

レーダの発展

レーダの発明
1904

合成開口レーダ
(SAR) 1950

干渉レーダ
(InSAR)

電力
(スカラー)

映像レーダ

将来に向けた

衛星搭載SAR

多チャンネル化

航空機SAR

MIMO

偏波利用
(ベクトル)



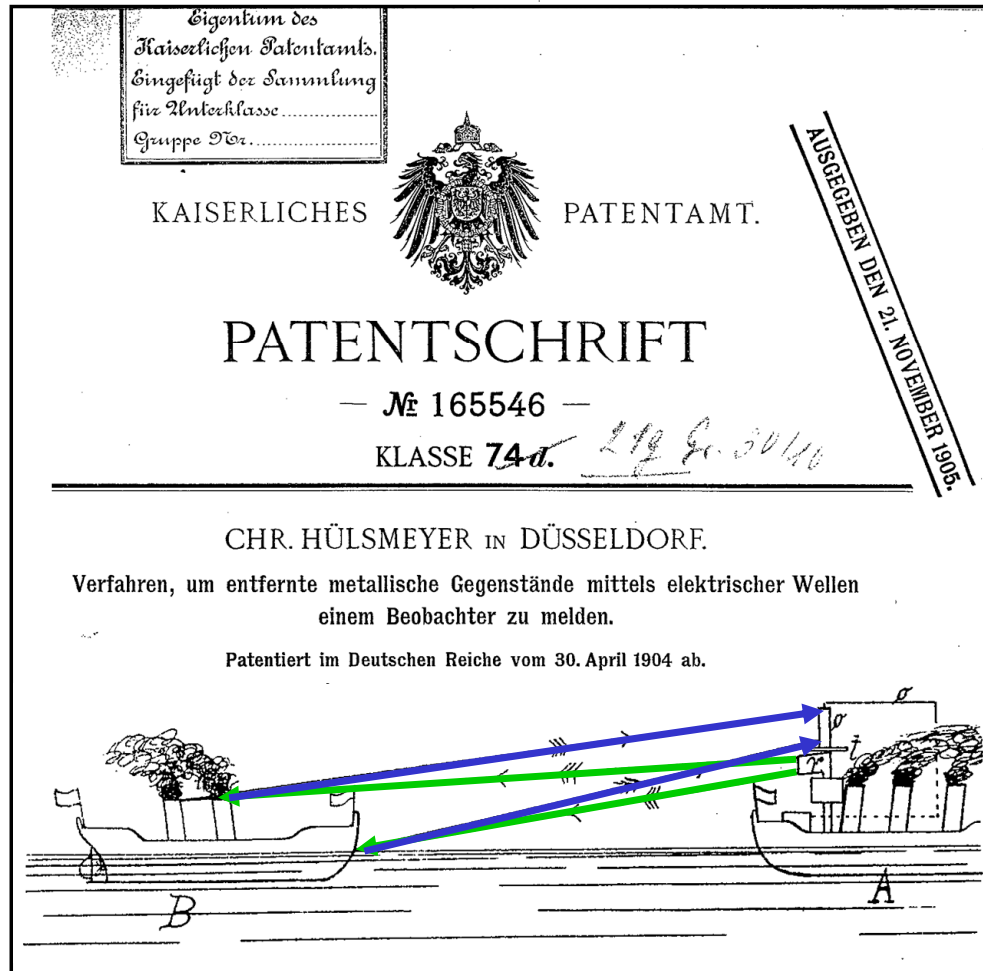
地上設置SAR

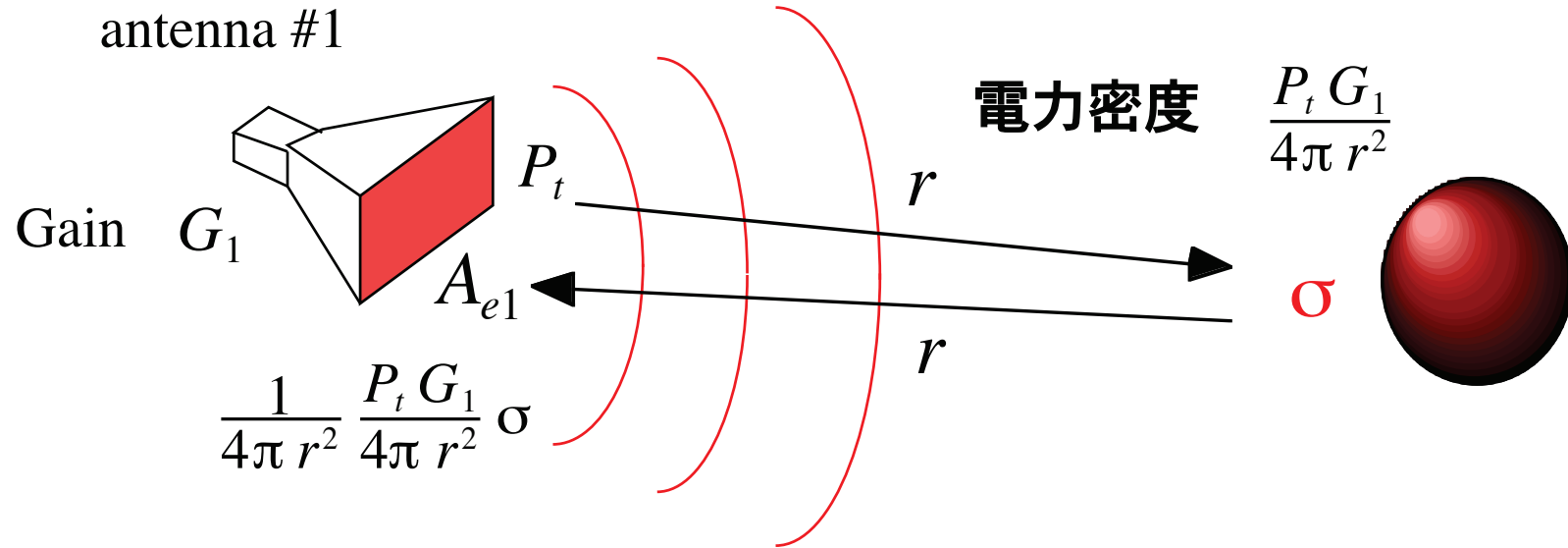
多周波化

GPR

レーダの発明 (船舶衝突防止用)

Christian Hülsmeyer and his "Radar" invention (1904)





レーダ方程式

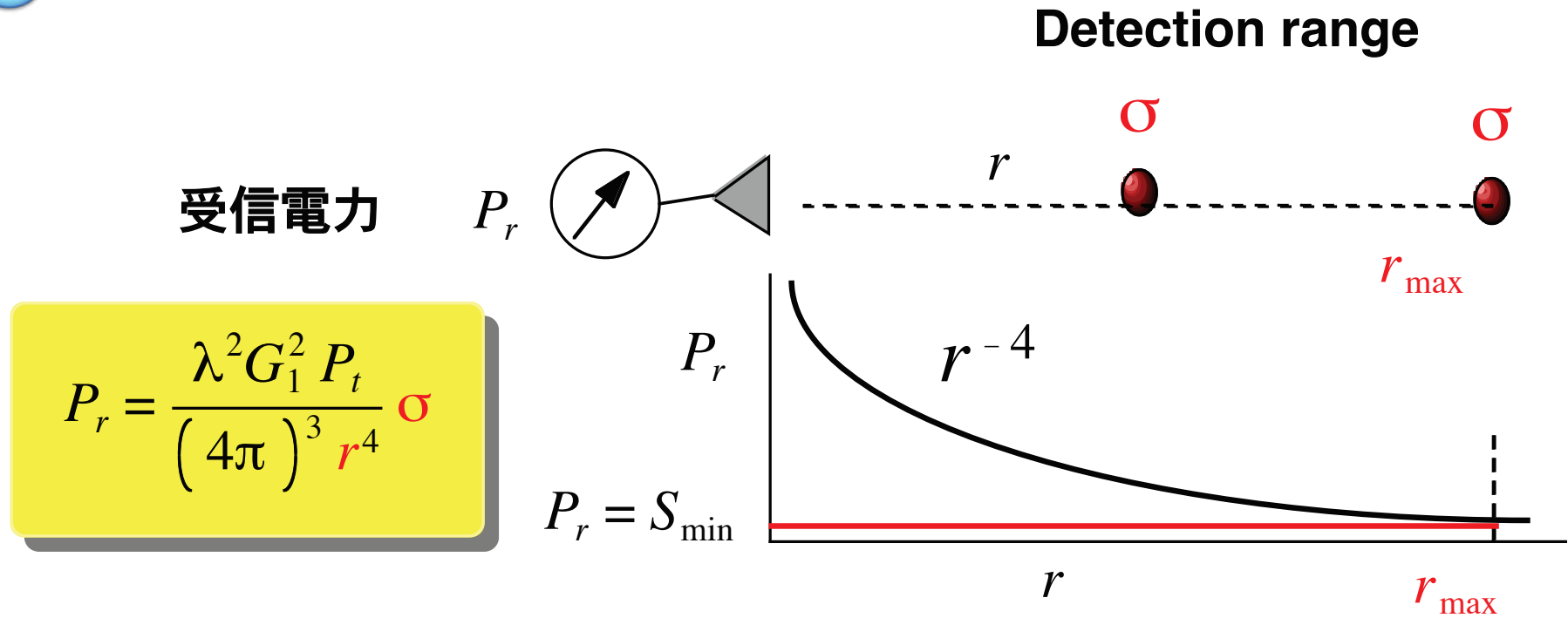
アンテナの受信電力 P_r

$$P_r = \frac{1}{4\pi r^2} \frac{P_t G_1}{4\pi r^2} \sigma A_{e1} = \frac{\lambda^2 G_1^2 P_t}{(4\pi)^3 r^4} \sigma$$

自由空間での伝搬損失 $\frac{\lambda^2}{(4\pi)^3 r^4}$

レーダ用語

最大探知距離 r_{\max}



最小感知電力

$$S_{\min} = \frac{\lambda^2 G_1^2 P_t}{(4\pi)^3 r_{\max}^4} \sigma \quad \rightarrow \quad r_{\max} = \left[\frac{\lambda^2 G_1^2 P_t}{(4\pi)^3 S_{\min}} \sigma \right]^{\frac{1}{4}}$$

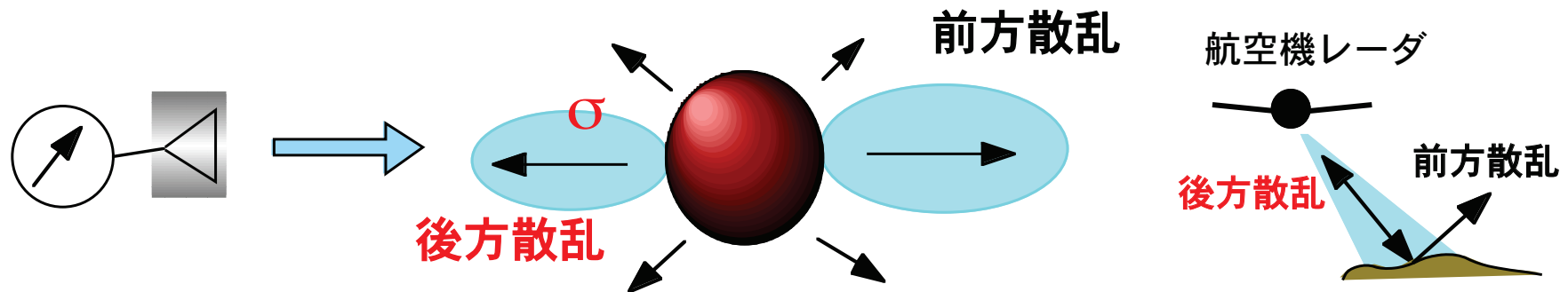
レーダ散乱断面積 σ RCS (Radar Cross Section)

レーダパラメータと無関係にターゲット固有の大きさを表す必要がある

電力的に見たターゲットの反射係数

$$\sigma(\theta, \varphi) = \lim_{r \rightarrow \infty} 4\pi r^2 \left| \frac{E^s(\theta, \varphi)}{E^i} \right|^2$$

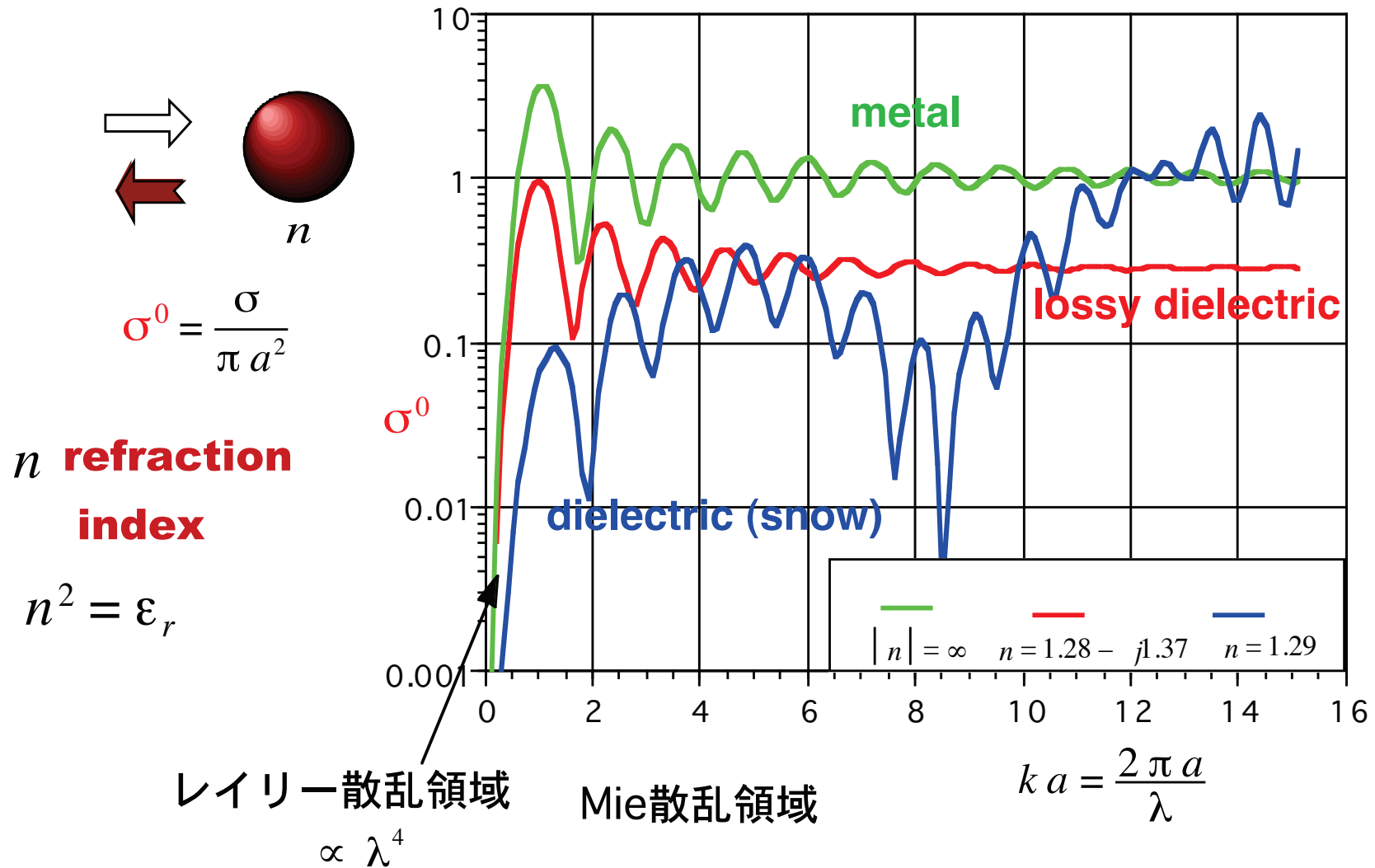
[dBm²]
[dBsm]



monostaticレーダでは後方散乱断面積が重要
ターゲットの比較に用いる

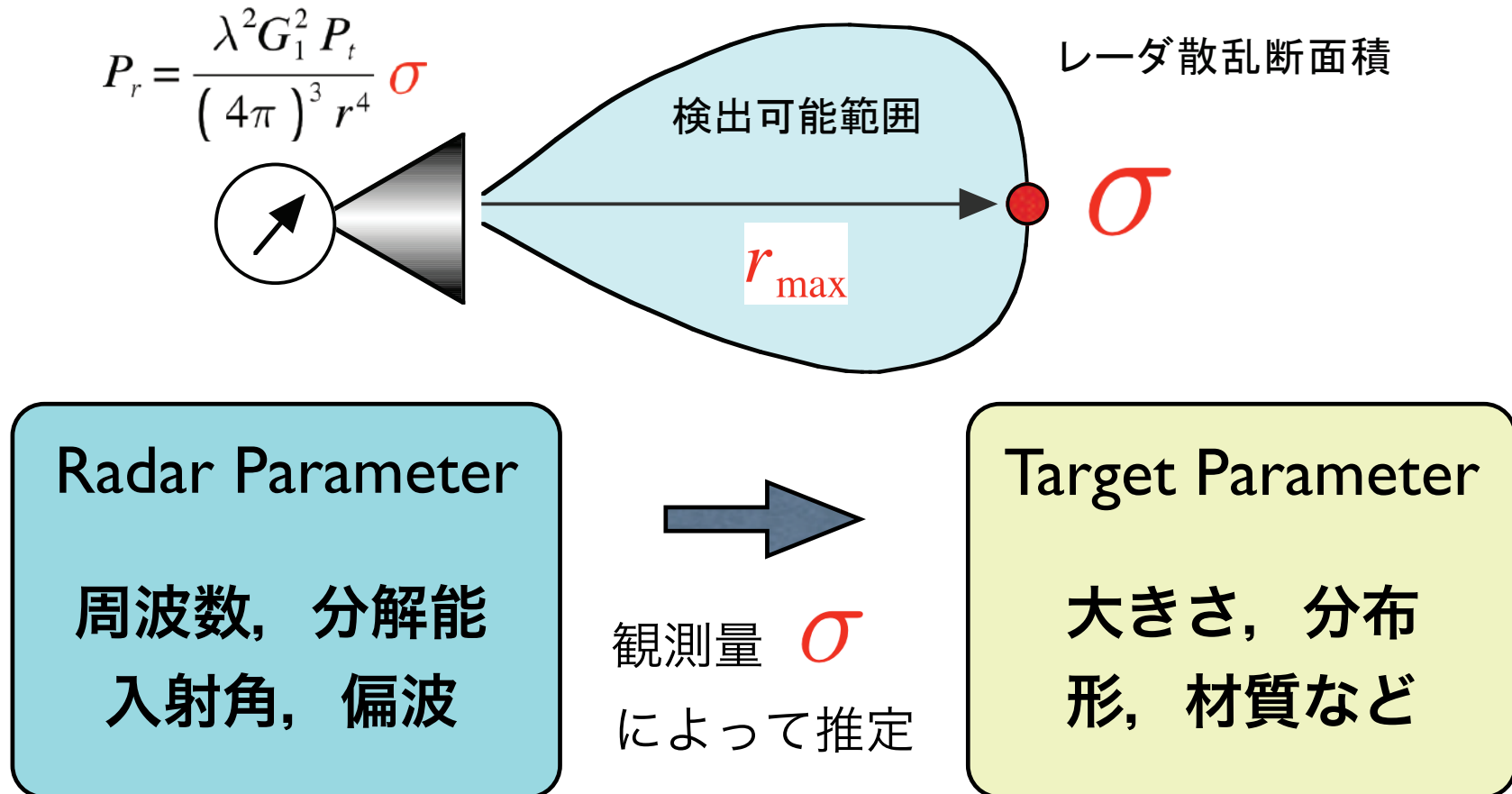
● ターゲットの散乱特性 周波数・波長依存性が重要

半径 a の球からの正規化後方散乱断面積



レーダの目的：ターゲットの情報を得る

通常のレーダ計測では、 σ によってターゲットの情報を計測する



レーダの利用分野（あらゆる場所で）

- 大気 気象 大気状態, オゾン, 温暖化ガス
- 陸域 災害監視（地滑り, 洪水, 浸水, 山火事）
火山活動, 地盤変動, 地震, 大雪
土地利用形態, 地図作成, 2D/3D-Map
穀物・森林モニタリング
砂漠化, 森林伐採
- 海洋 船舶検出, 温度分布
エルニーニョ, 波浪
- 宇宙 宇宙天文, 惑星探査
- 地中 地雷, 遺跡, ガス管, 水道管など



レーダの目的：ターゲットの情報を得る

電波のもつパラメータの利用

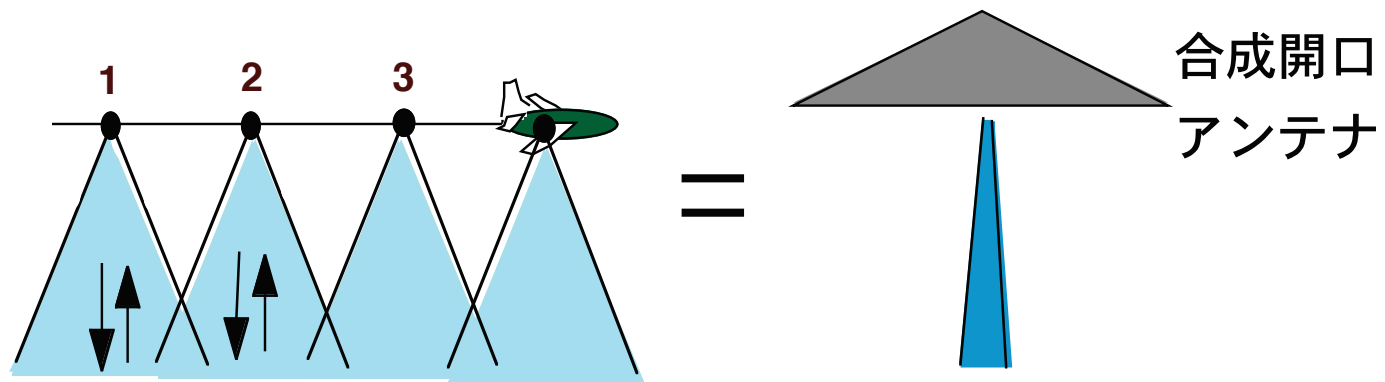
— 1 —

$$E_0 \cos(\omega t - k \cdot r + \theta)$$

★ **Amplitude** $|E_0|$ \Rightarrow 受信電力を利用

★ **Doppler frequency** ω 周波数シフトを利用

★ **Phase** θ \Rightarrow Synthetic Aperture Radar **SAR**



high resolution imaging

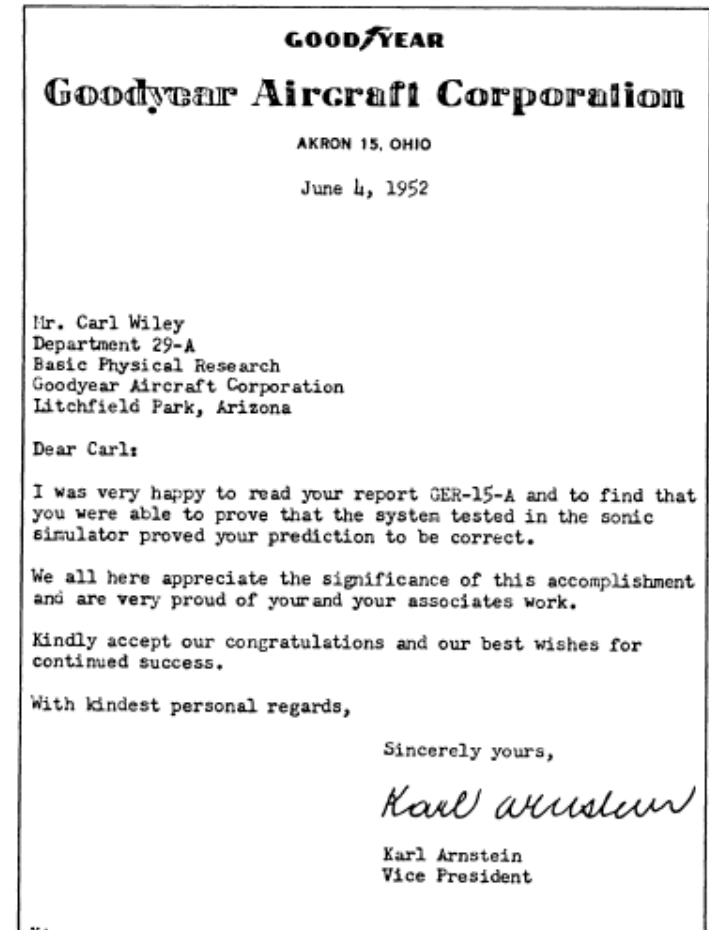
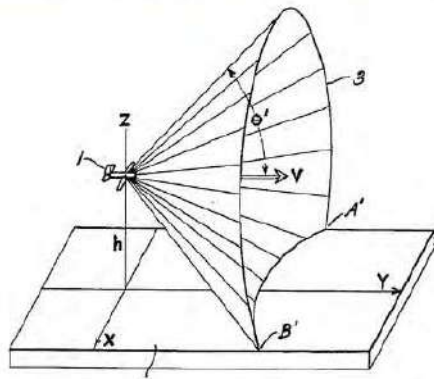
② 合成開口レーダ (SAR) の発明 (1950)

Carl Wiley and the Invention of the Synthetic Aperture Radar (Carl Wiley, Patent in 1954)

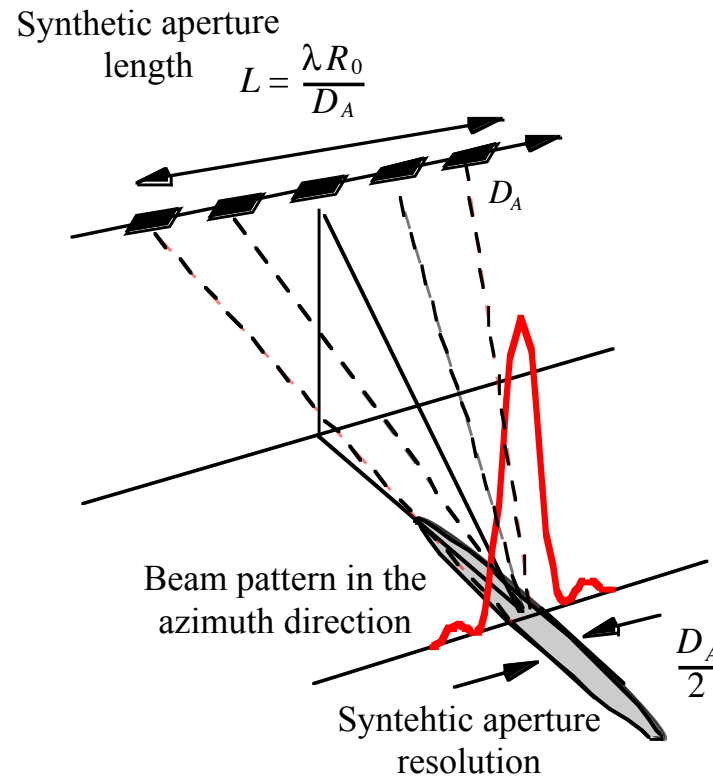
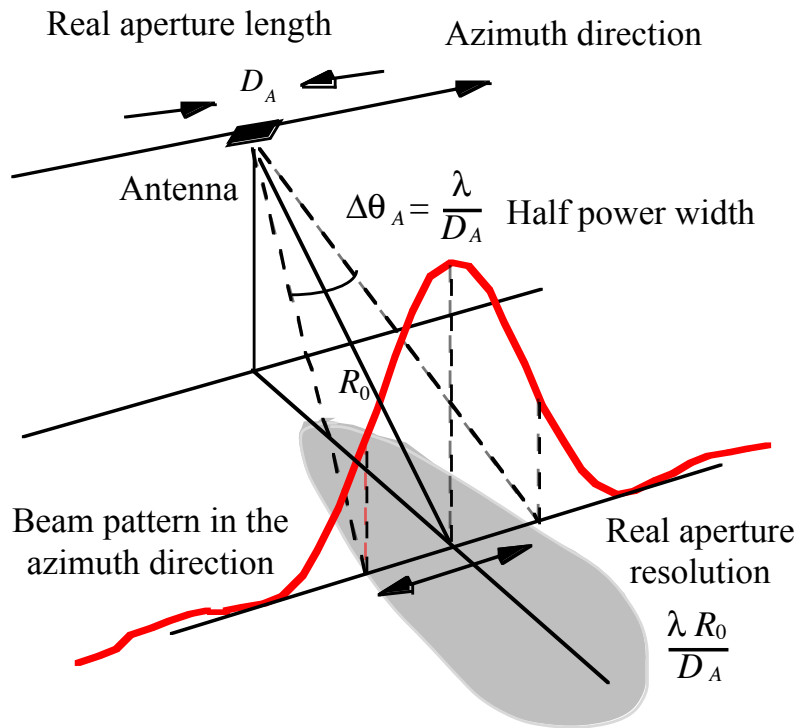
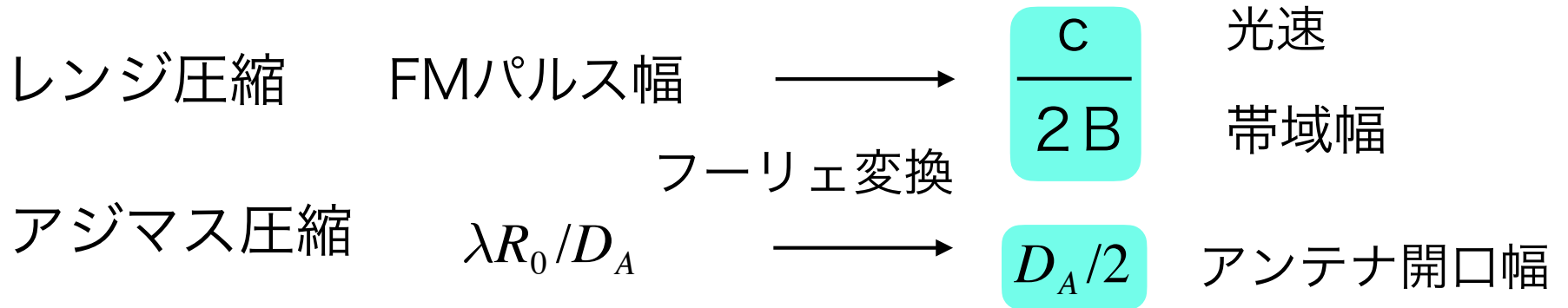
United States Patent Office 3,196,436
Patented July 20, 1965

3,196,436
**PULSED DOPPLER RADAR METHODS
AND APPARATUS**
Carl A. Wiley, Phoenix, Ariz., assignor to Goodyear Aero-
space Corporation, a corporation of Delaware
Filed Aug. 13, 1954, Ser. No. 449,559
14 Claims. (Cl. 343—17)

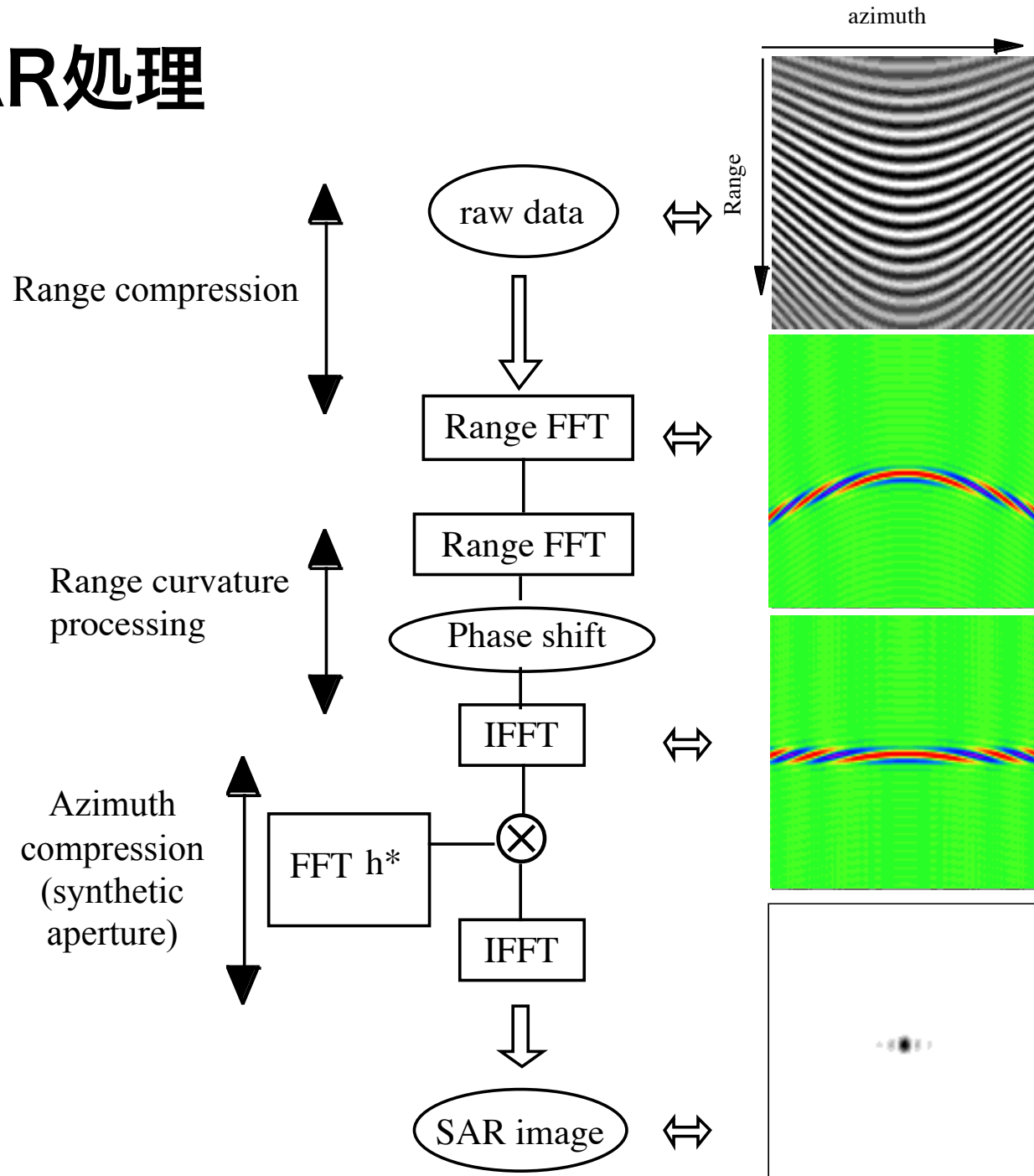
This invention relates to pulsed radar methods and apparatus, and, more particularly, to terrain mapping radars borne by moving objects, for example, an airplane, and making use of the Doppler frequency shift phenomenon to obtain angular resolutions, and/or scanning in azimuth.



合成開口レーダ (SAR) の分解能



SAR处理



合成開口レーダ (SAR) の利点

- 飛行高度に無関係に高分解能データが得られる
- 天候によらず運用可能（電波の伝搬特性）
- 昼夜に関わらず、いつでも観測可能（電波の伝搬特性）
- 広い領域を同時に観測可能（アンテナ放射パターン）

衛星によるマイクロ波リモートセンシングへ

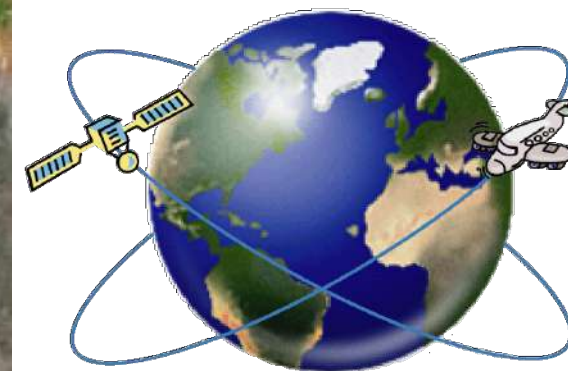
1978年 SEASAT衛星

現在はSARの黄金時代





Google Earth 光学画像



光学観測と比べて

レーダ観測の利点

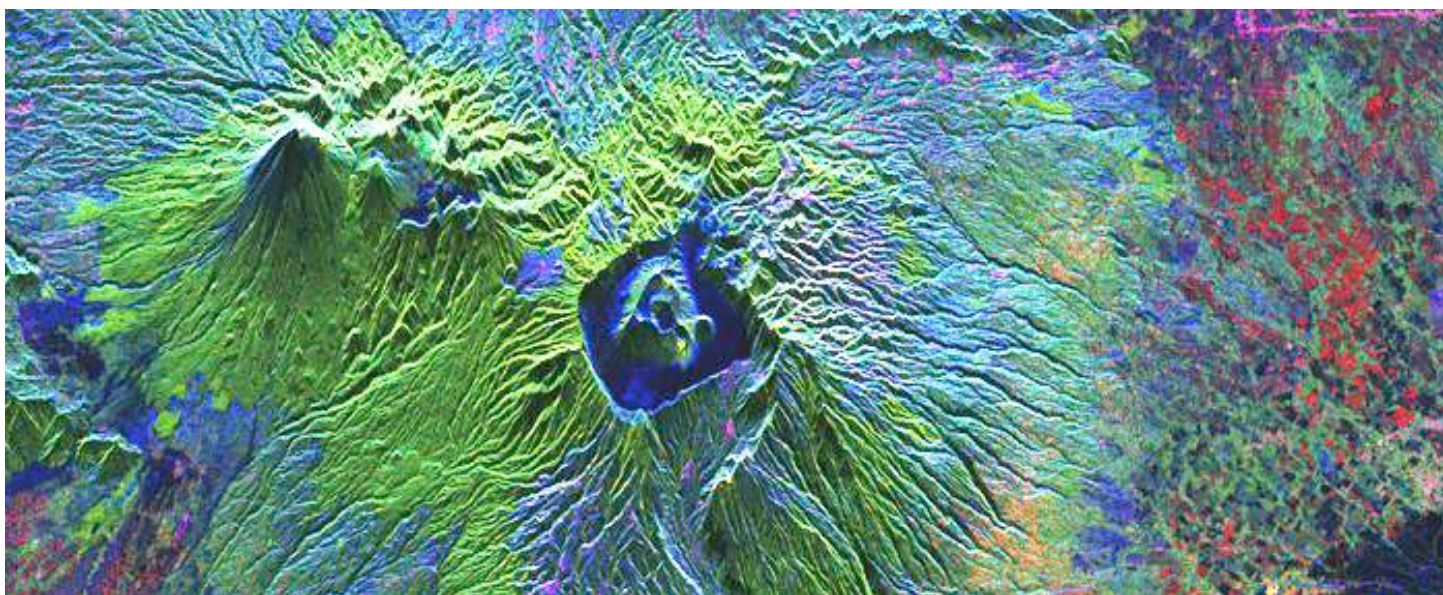
雲を透過

全天候型

昼夜を問わず

瞬時に

広い領域を



偏波レーダ画像 (ALOS-PALSAR)

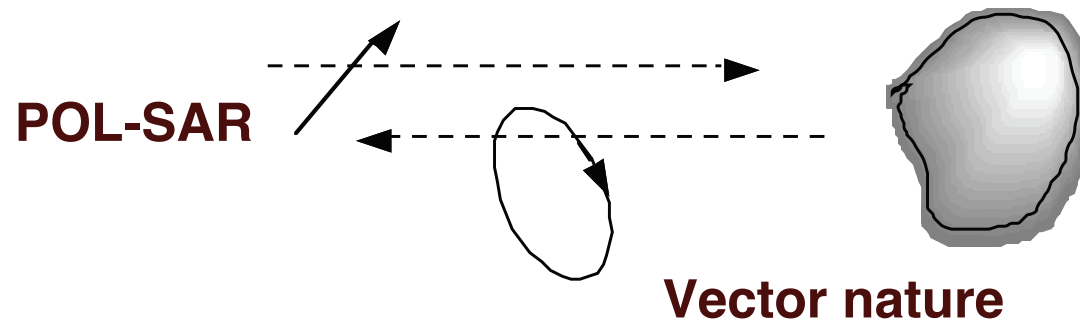
ターゲットの情報を得る

電波のもつパラメータの利用

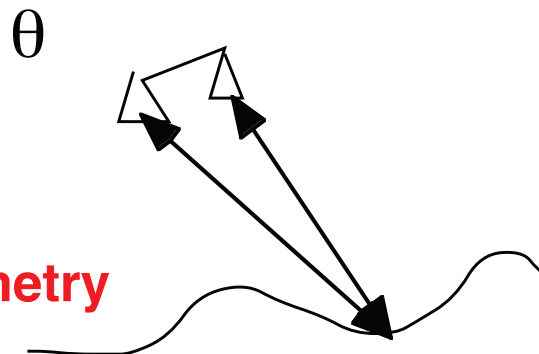
— 2 —

$$E_0 \cos(\omega t - k \cdot r + \theta)$$

★ **Polarimetry** E_0 ベクトルとして



★ **Interferometry** θ
3-D imaging

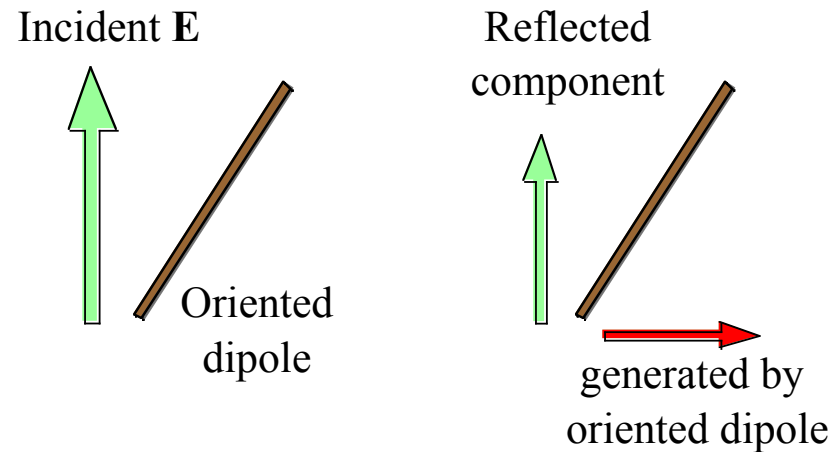


★ **Polarimetric Interferometry**

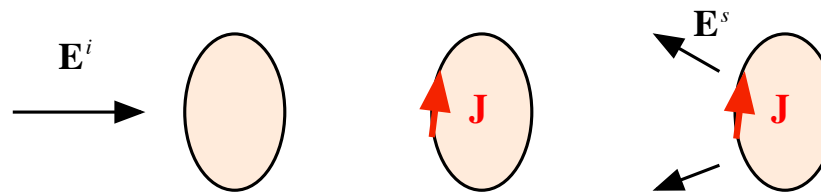
電界をベクトルとして扱うレーダの必要性

Radar Polarimetryの出発点

散乱現象



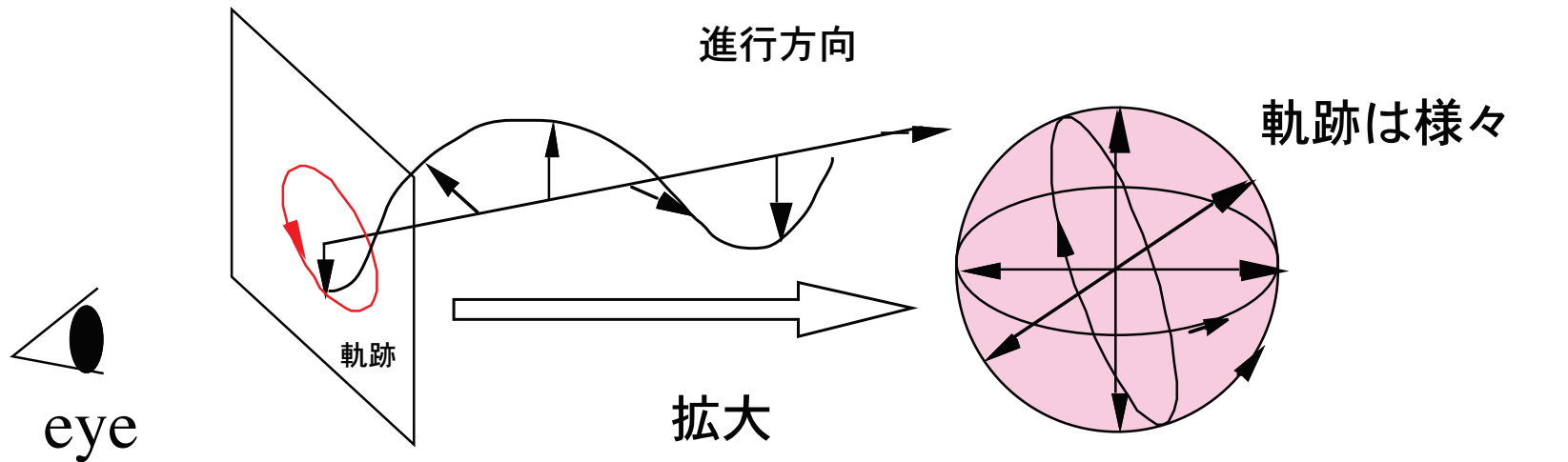
散乱の原理



散乱電界はターゲットの材質，形状に依存

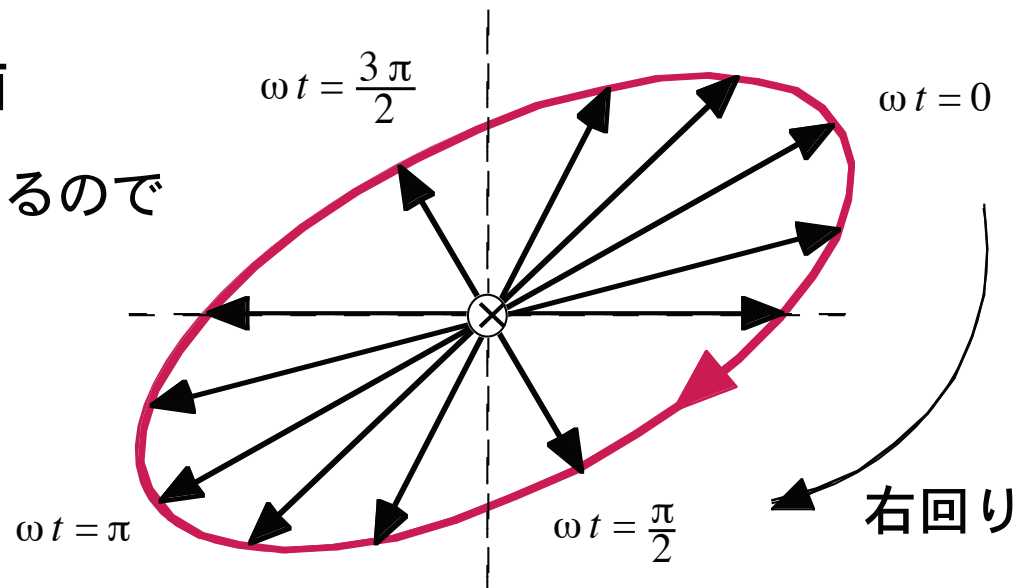
偏波とは

電波の進行方向の後側から見たとき、
ある断面内で、時間と共に電界の先端の描く軌跡



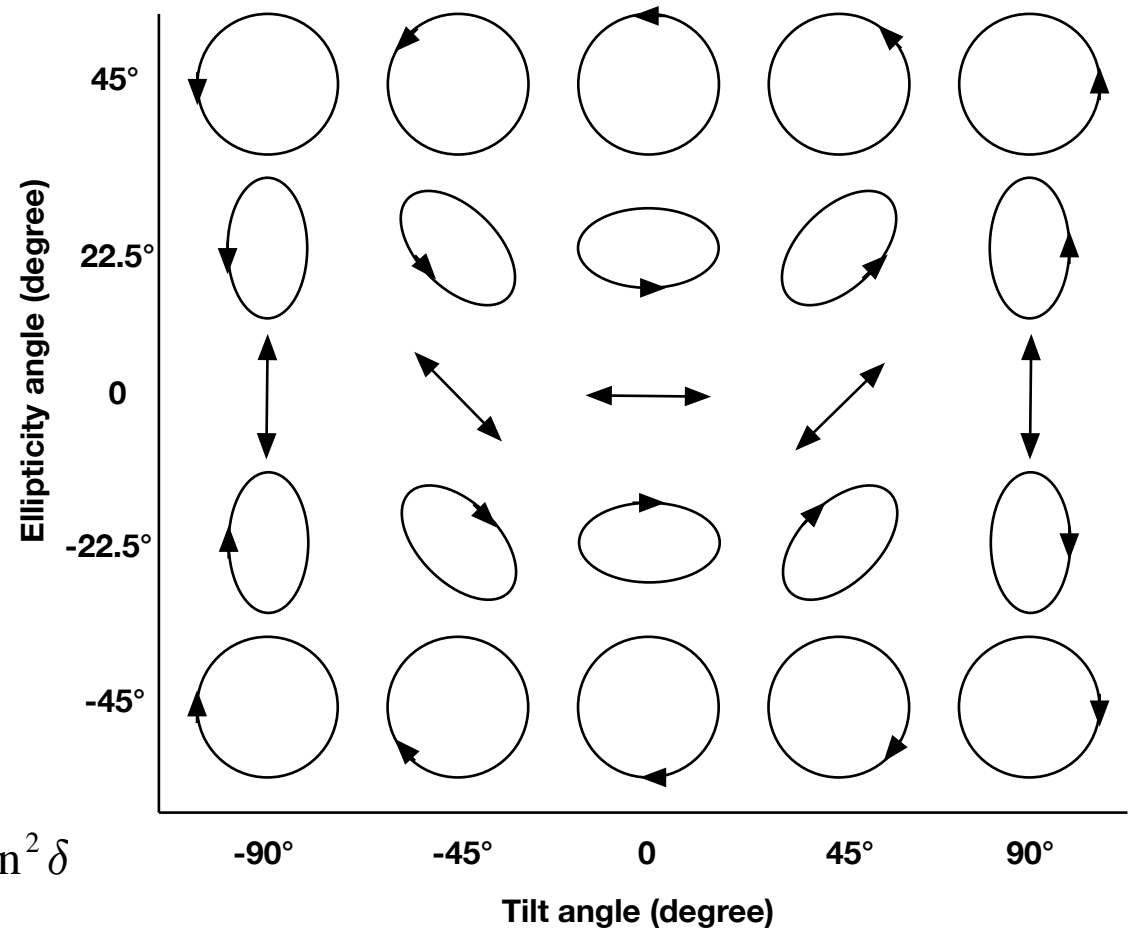
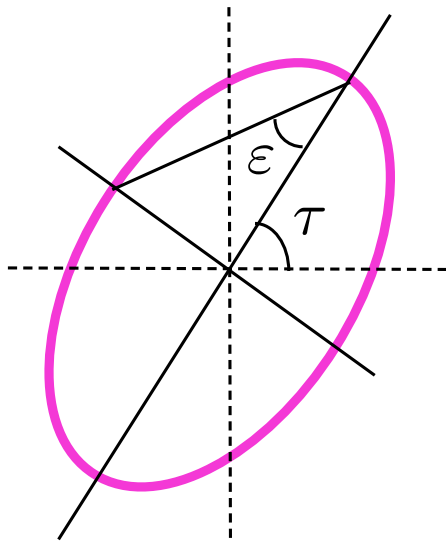
Transverse 面

電界と磁界は直交しているので
電界のみを考える



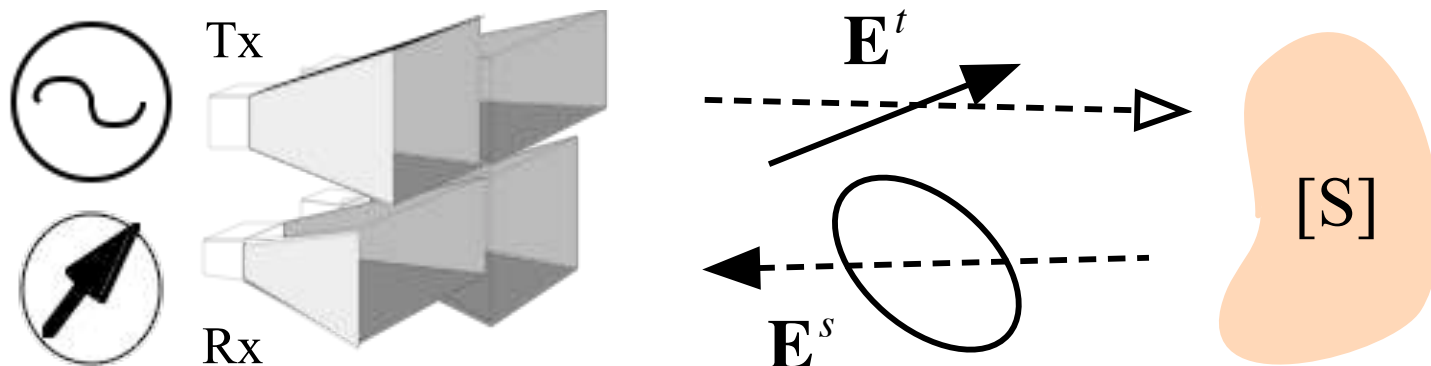
2つの直交成分を測ることによって、
散乱波の偏波状態が決定できる。

$$\boldsymbol{\varepsilon}(t) = \begin{bmatrix} \varepsilon_x(t) \\ \varepsilon_y(t) \end{bmatrix} = \begin{bmatrix} |E_x| \cos(\omega t + \phi_x) \\ |E_y| \cos(\omega t + \phi_y) \end{bmatrix}$$

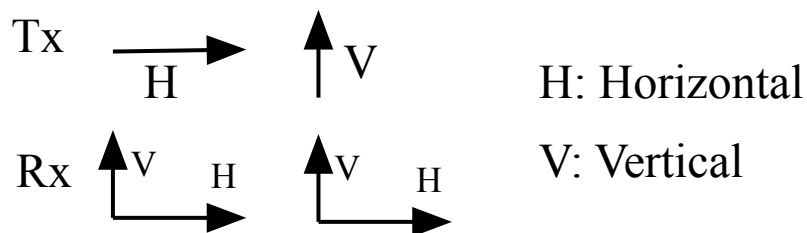


$$\frac{\varepsilon_x^2(t)}{|E_x|^2} - \frac{2 \varepsilon_x(t) \varepsilon_y(t)}{|E_x| |E_y|} \cos \delta + \frac{\varepsilon_y^2(t)}{|E_y|^2} = \sin^2 \delta$$

偏波レーダ = 散乱行列を取得するレーダ



$$\mathbf{E}^s = \begin{bmatrix} E_H^s \\ E_V^s \end{bmatrix} = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \begin{bmatrix} E_H^t \\ E_V^t \end{bmatrix} = [S] \mathbf{E}^s$$



Scattering Matrix

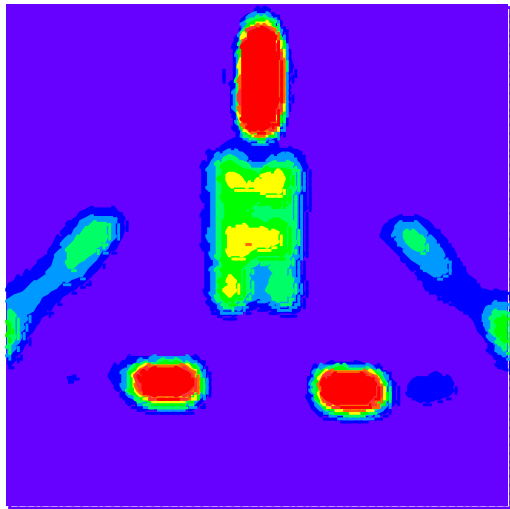
散乱行列

単一偏波に比べて情報量が4倍

散乱行列について

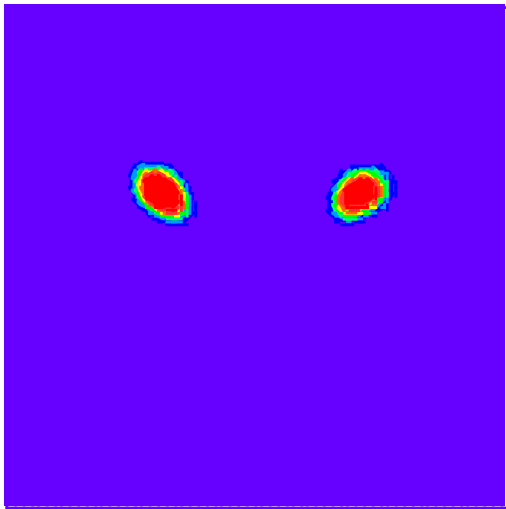
$$\begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}$$

S_{HH}

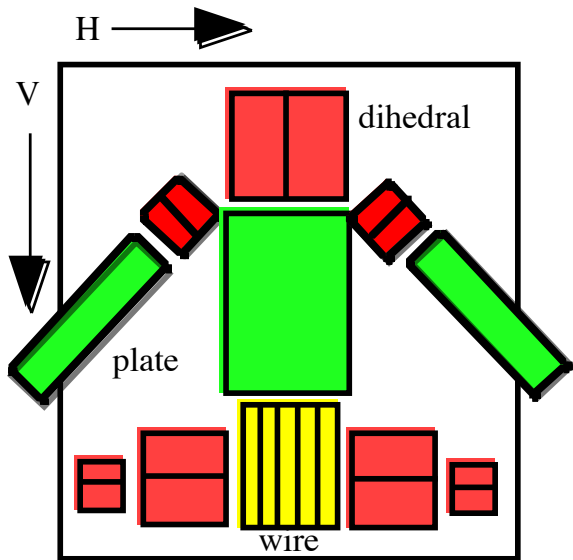


HH

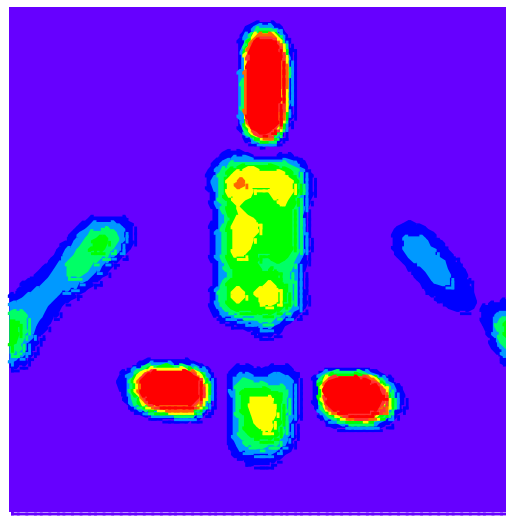
S_{HV}



HV



S_{VV}



VV

Historical development of polarimetry, ellipsometry

in W-M. Boerner et al. (eds.), *Direct and Inverse Methods in Radar Polarimetry*, Part 1, pp. 1-32, Kluwer Academic publishers, 1992.

自然界の生き物 昆虫, 底の魚, うなぎ等



偏光と偏光していない光を見分ける

振動方向, 波長依存性, Brewster 角入射

回遊に使う

うなぎは幼少期に赤色の直線偏光, 成長すると青色の円偏光に敏感になる

牛, ヤギなど家畜動物の目の角膜は水平偏光をよく通す.

ハチは日光の偏光分布から, 自分の飛行方向を見出す

Historical development of polarimetry, ellipsometry

バイキング (11世紀)

方解石をNavigatorに使った

日光が無くとも、方向を知ることができた

光線の透過時に、偏光状態によって、
2つの光線に分けられる



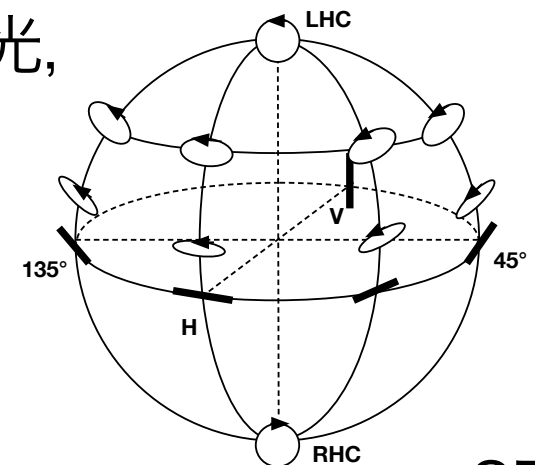
Bartolinus 偏光の発見 (1677)

Augustine Fresnel (1788-1827) 反射係数の定式化

Sir David Brewster (1815) 媒質と入射角の関係

George Gabriel Stokes (1819-1903): 完全偏光,
部分偏光, 無偏光の数学的記述

Henri Poincaré (1854-1912): ポアンカレ球
にて全ての偏光・偏波状態を表現



Pioneers in Radar Polarimetry

George Sinclair (1946): 2x2 coherent scattering matrix



Edward Morton Kennaugh (1948-1954): a new approach to radar theory and developed the “optimal target polarization concept” (circular polarization rain clutter rejection or cancellation)

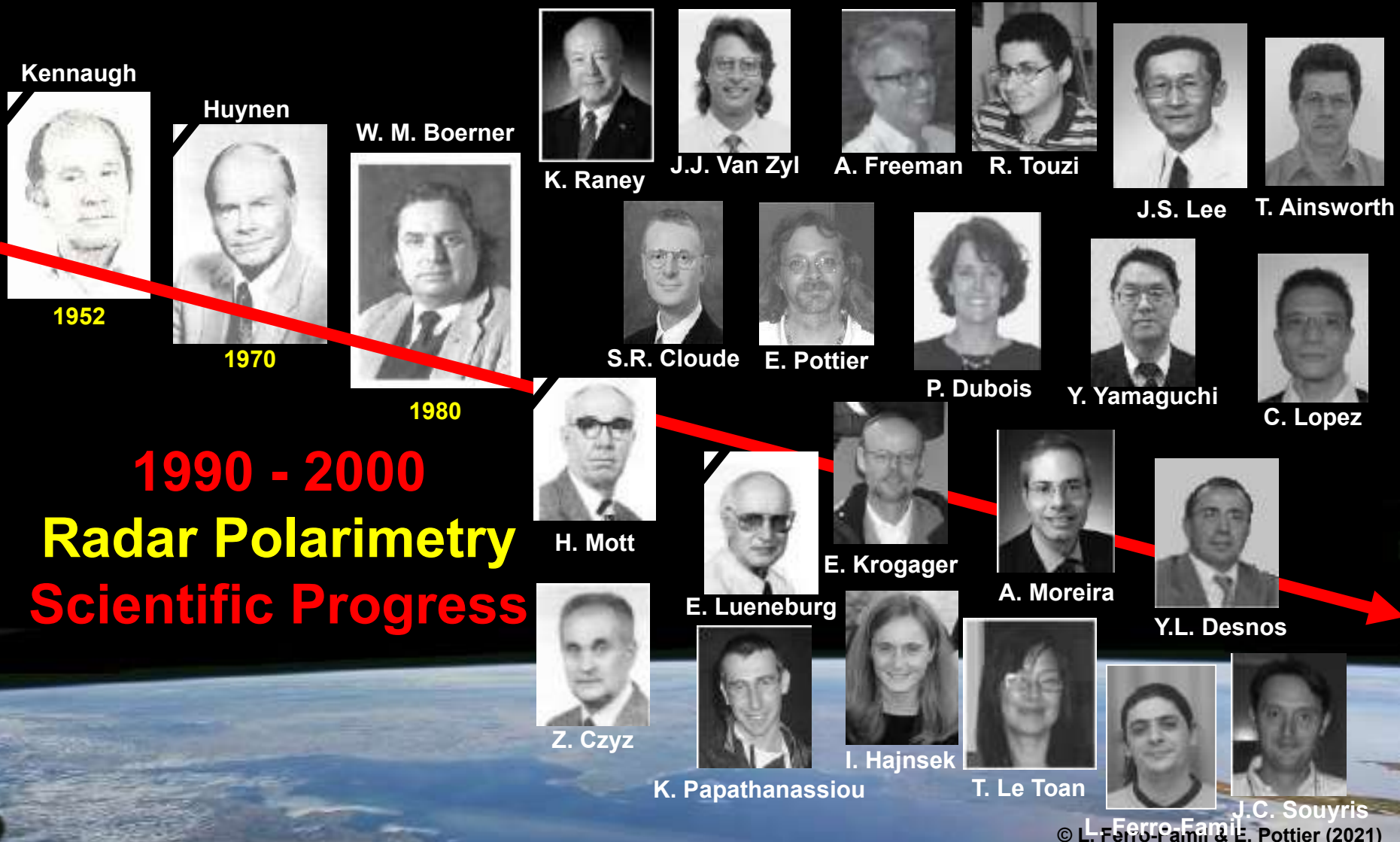


J. Richard Huynen (1970): radar target phenomenology based on an extensive amount of measurements on the relative phase scattering matrix



Wolfgang Martin Boerner (1937-2018):
Redevelopment of radar polarimetry and a great mentor for advancing new polarimetric radar technology

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

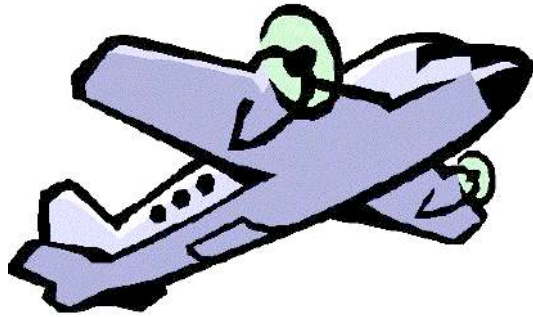


1990 - 2000
Radar Polarimetry
Scientific Progress

© L. Ferro-Famil & E. Pottier (2021)

⑤ PoISARデータの利用例

偏波行列とそれらの関係



データ取得

2次統計量

$$\langle S_{HH} S_{VV}^* \rangle$$

散乱行列

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

coherent case

3 x 3 の複素数の要素

$\langle [C] \rangle$ Covariance
(hardware friendly)

$\langle [T] \rangle$ Coherency
(user friendly)

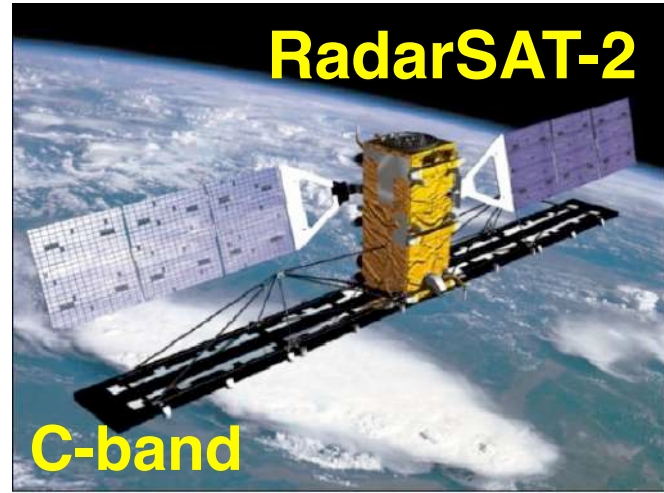
4 x 4 の実数要素

$\langle [K] \rangle$ Kennaugh

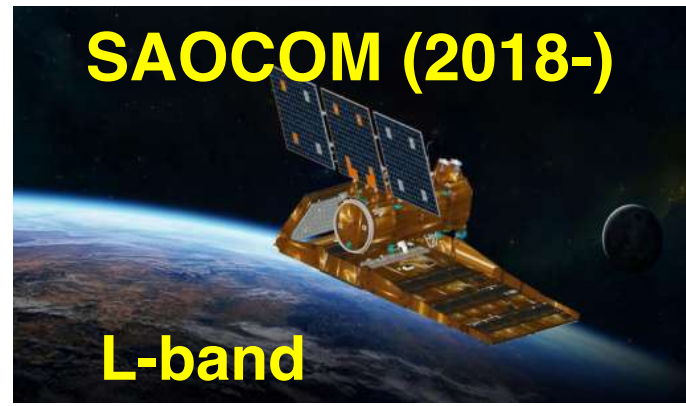
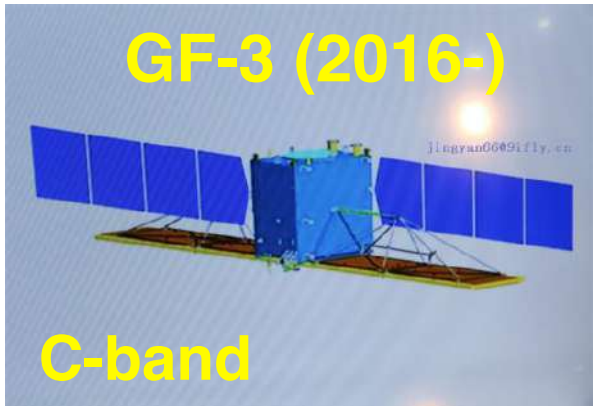
$\langle [M] \rangle$ Mueller

incoherent case

Space-borne PolSARの例



**All weather, Day/night,
Vast area, simultaneously**



独立情報量

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

monostatic radar

$$S_{HV} = S_{VH}$$

Coherent case

$$[S]_{relative} = \begin{bmatrix} |S_{HH}| & |S_{HV}| \angle (\phi^{HV} - \phi^{HH}) \\ |S_{VH}| \angle (\phi^{VH} - \phi^{HH}) & |S_{VV}| \angle (\phi^{VV} - \phi^{HH}) \end{bmatrix}$$

5

$$\mathbf{k}_P = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} + S_{VV} \\ S_{HH} - S_{VV} \\ 2S_{HV} \end{bmatrix}$$

散乱ベクトル 相対散乱行列

Incoherent case

Coherency, Covariance 行列

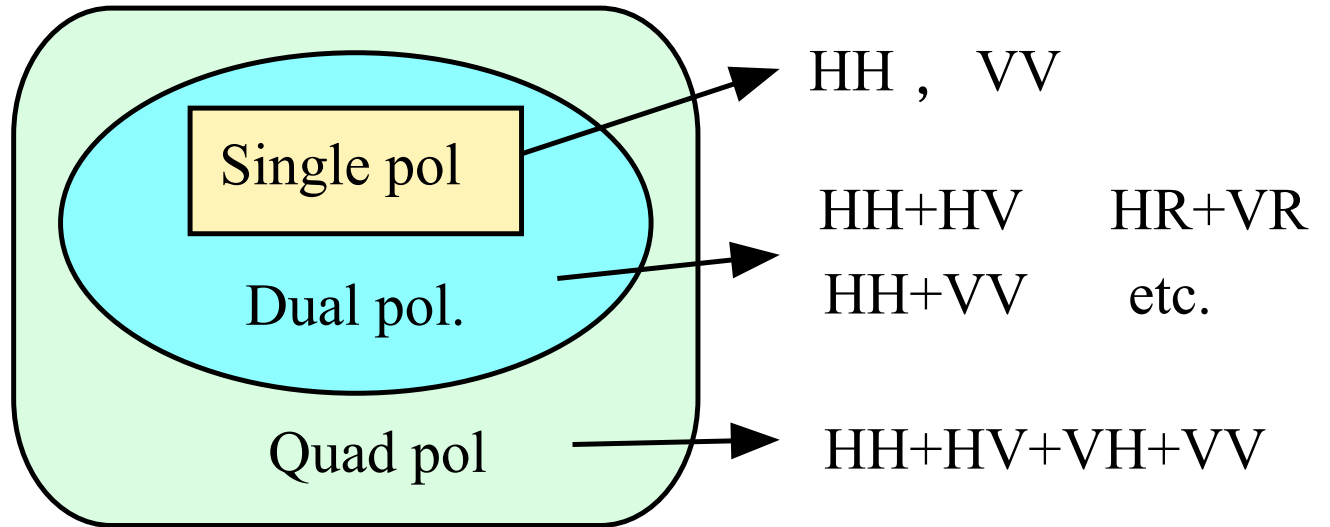
9

$$\langle [T] \rangle = \frac{1}{n} \sum^n \mathbf{k}_P \mathbf{k}_P^\dagger = \frac{1}{2}$$

$$\begin{bmatrix} \langle |S_{HH} + S_{VV}|^2 \rangle & \langle (S_{HH} + S_{VV})(S_{HH} - S_{VV})^* \rangle & \langle 2S_{HV}^*(S_{HH} + S_{VV}) \rangle \\ \langle (S_{HH} - S_{VV})(S_{HH} + S_{VV})^* \rangle & \langle |S_{HH} - S_{VV}|^2 \rangle & \langle 2S_{HV}^*(S_{HH} - S_{VV}) \rangle \\ \langle 2S_{HV}(S_{HH} + S_{VV})^* \rangle & \langle 2S_{HV}(S_{HH} - S_{VV})^* \rangle & \langle 4|S_{HV}|^2 \rangle \end{bmatrix}$$

Re Im Re Im

偏波データ と 情報量比較



Polarization データ 独立情報数 Covariance行列 (2次統計量)

Single	S_{HH}	1	→	$ S_{HH} ^2$	1
Dual	$[S_{HH} \ S_{HV}]$	3	→	$\begin{bmatrix} S_{HH} ^2 & S_{HH} S_{HV}^* \\ S_{HV} S_{HH}^* & S_{HV} ^2 \end{bmatrix}$	4
Quad.	散乱行列 $\begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}$	5	→	$\begin{bmatrix} S_{HH} ^2 & S_{HH} S_{HV}^* & S_{HH} S_{VV}^* \\ S_{HV} S_{HH}^* & S_{HV} ^2 & S_{HV} S_{VV}^* \\ S_{VV} S_{HH}^* & S_{VV} S_{HV}^* & S_{VV} ^2 \end{bmatrix}$	9

NASA- JPL 航空機AIRSARによる実験事柄

$$\text{Re} (S_{HH} S_{VV}^*) > 0$$

$$\text{Re} (S_{HH} S_{VV}^*) < 0$$

$$\begin{bmatrix} S_{HH} & S_{HV} \\ S_{HV} & S_{VV} \end{bmatrix} = \begin{bmatrix} -a & 0 \\ 0 & -b \end{bmatrix} \Rightarrow \begin{bmatrix} a & 0 \\ 0 & b \end{bmatrix}$$

(1) HH & VV : co-phase
Bragg scattering $b > a$

(2) out of phase $\begin{bmatrix} a & 0 \\ 0 & -b \end{bmatrix}$

metal = 180 deg.
dielectrics < 180 deg.

(3) Reflection Symmetry

$$\langle S_{HH} S_{HV}^* \rangle \approx 0, \langle S_{VV} S_{HV}^* \rangle \approx 0$$

for natural vegetation

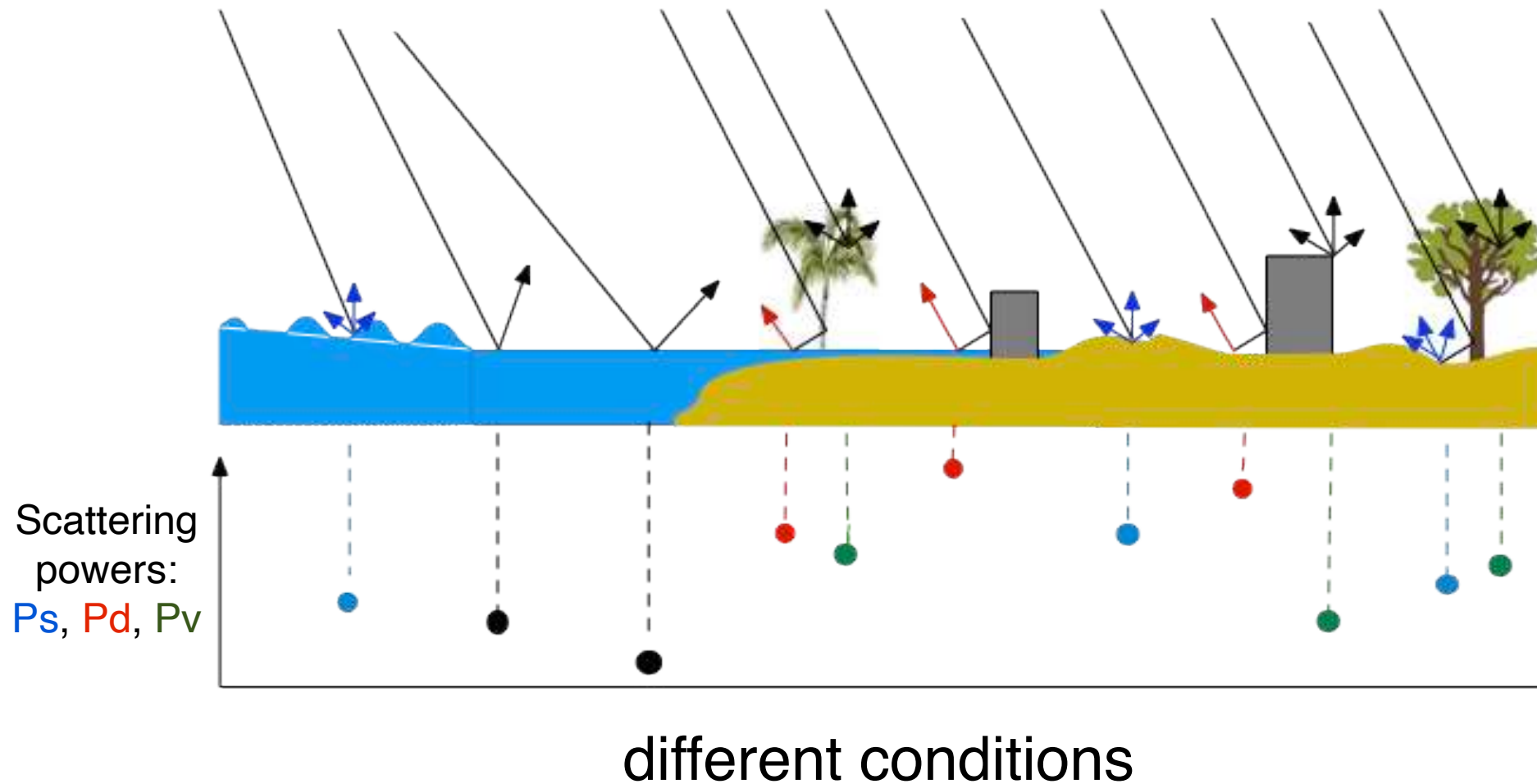
想定される散乱シナリオ (洪水の例)

表面散乱: P_s

2回反射散乱: P_d

体積散乱: P_v

(Bragg 散乱を含む)



PoISAR画像の解析

偏波電力の利用

検出・推定

Decomposition

数学的
物理的
Hybrid

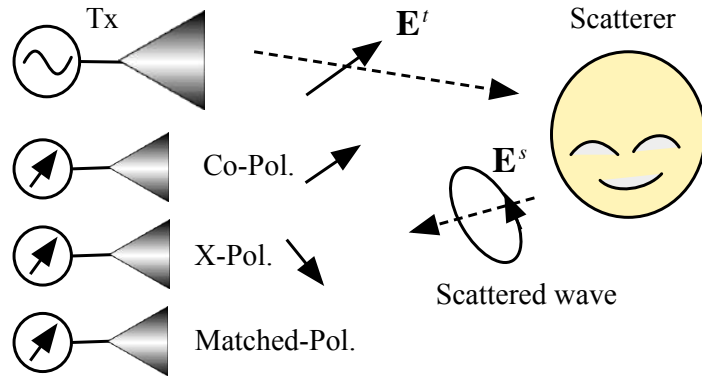
散乱メカニズム
による分類

Correlation
Similarity

散乱情報
の抽出

偏波電力

偏波チャンネル



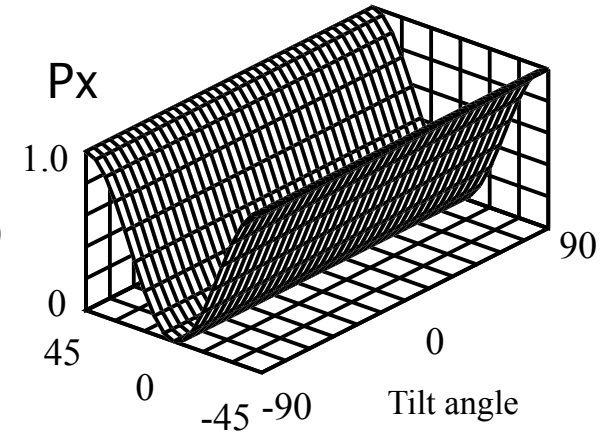
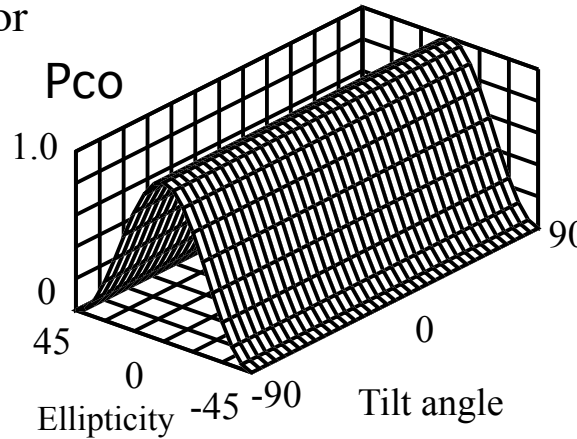
ターゲットの
推定が可能

校正の確認

Trihedral Corner Reflector
Plate, Sphere

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

$$[K] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix}$$

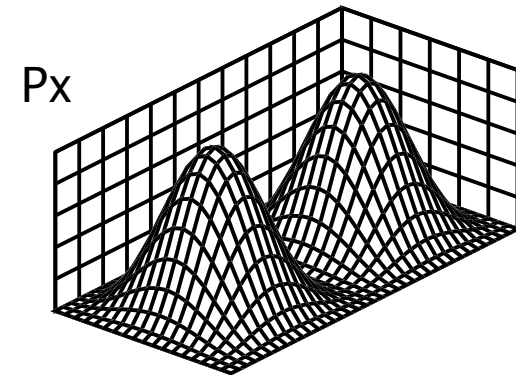
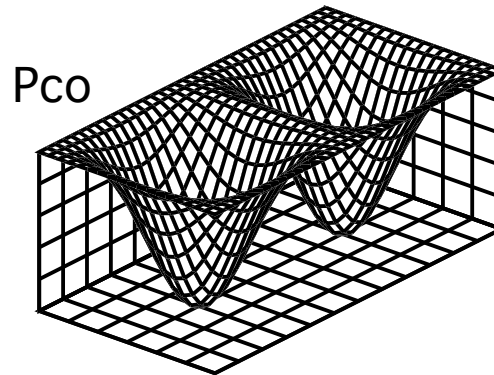


偏波シグネチャ

Dihedral Corner
Reflector

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

$$[K] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

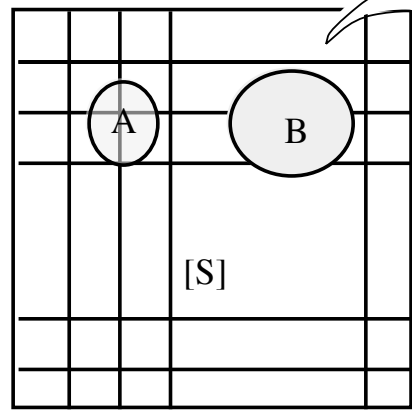


偏波電力

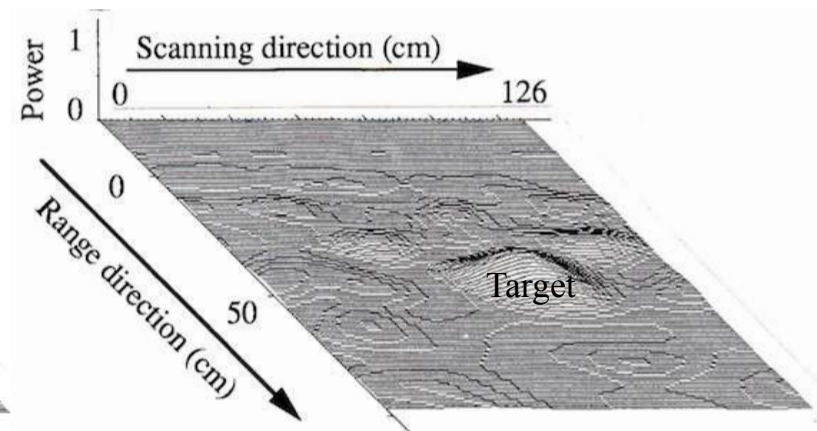
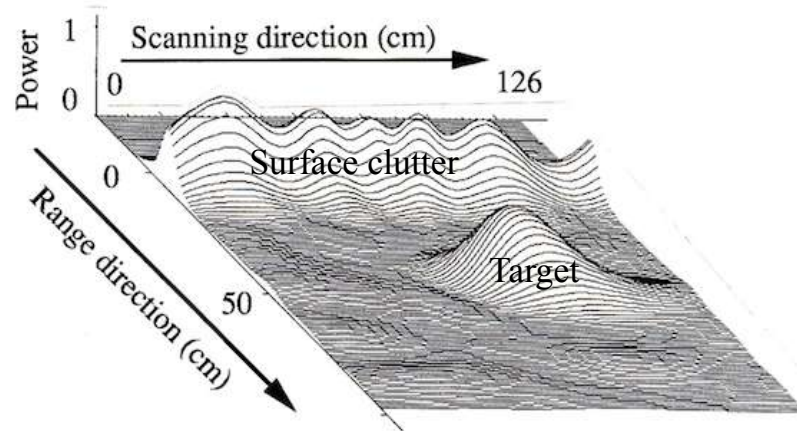
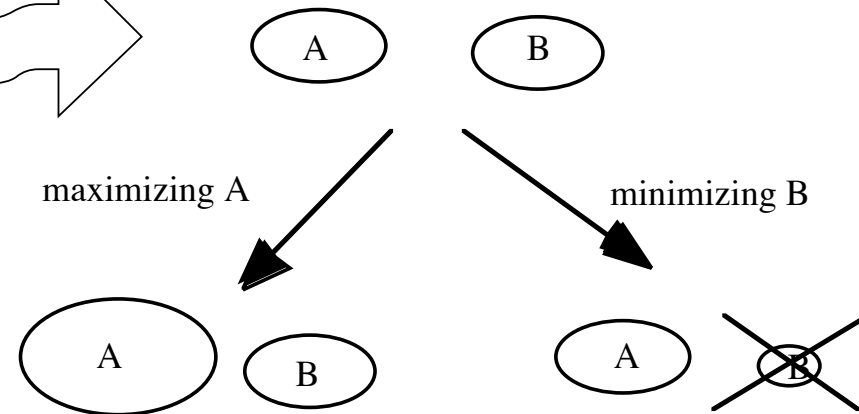
Optimal Polarization State for

$$C = \frac{\text{desired power}}{\text{undesired power}}$$

Fully Polarimetric SAR Image



Two Targets



Target **Max** のPol. State で再イメージング

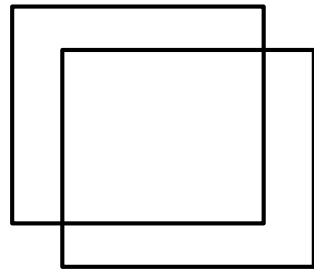
Surface **Null** Imaging

POLSAR image/data analyses

Scattering matrix
= Quad-Pol. data

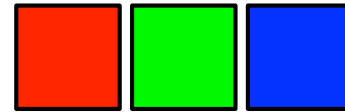


<Average>



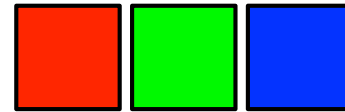
Covariance matrix
Coherency matrix

HV Basis

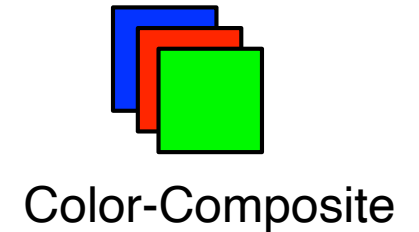


HH, 2HV, VV

Pauli Basis

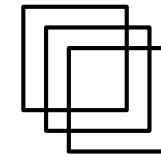
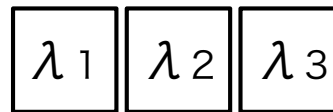


HH-VV, 2HV, HH+VV

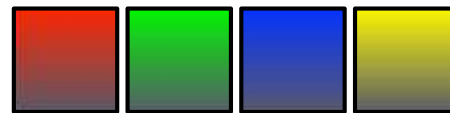


Eigenvalue

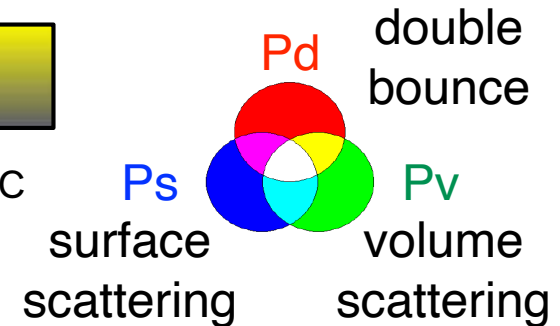
Entropy, Alpha-angle, Anisotropy

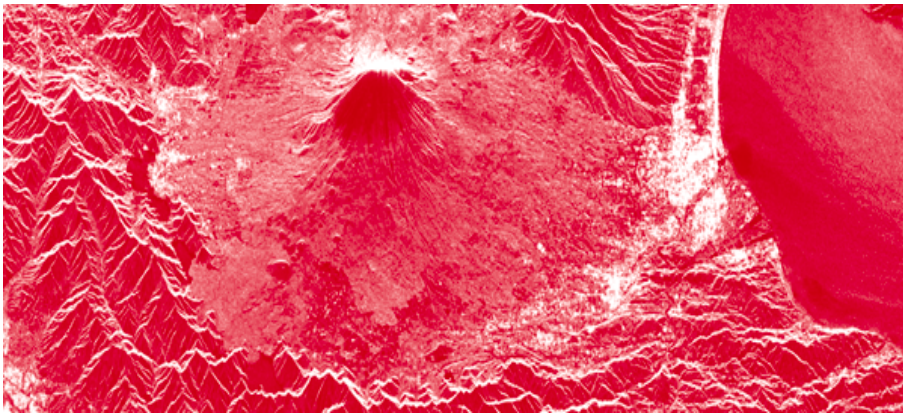


Scattering Power Decomposition

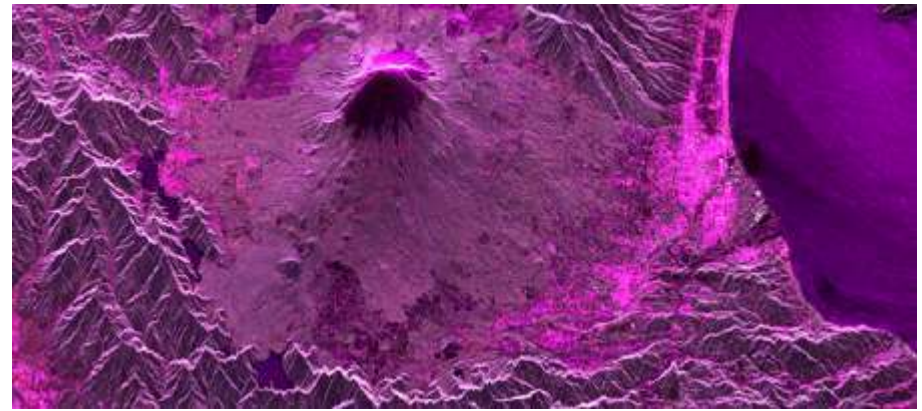


Pd, Pv, Ps, Pc

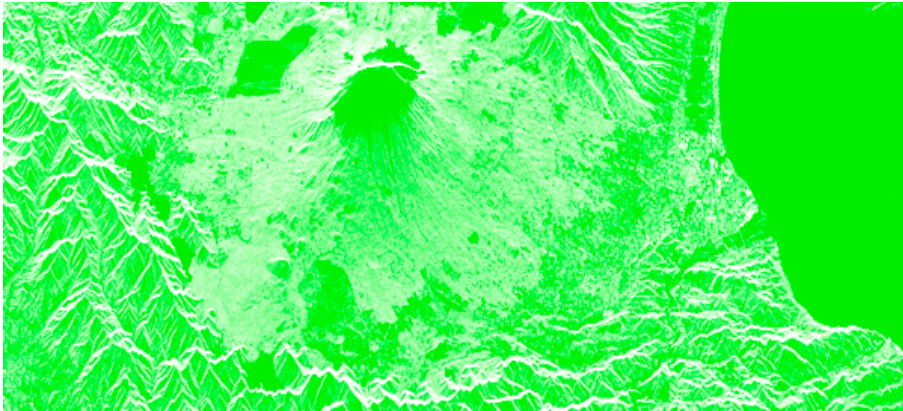




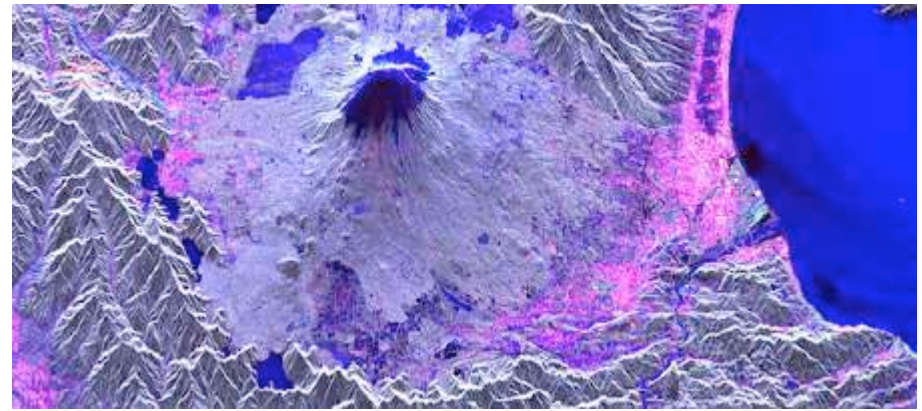
HH



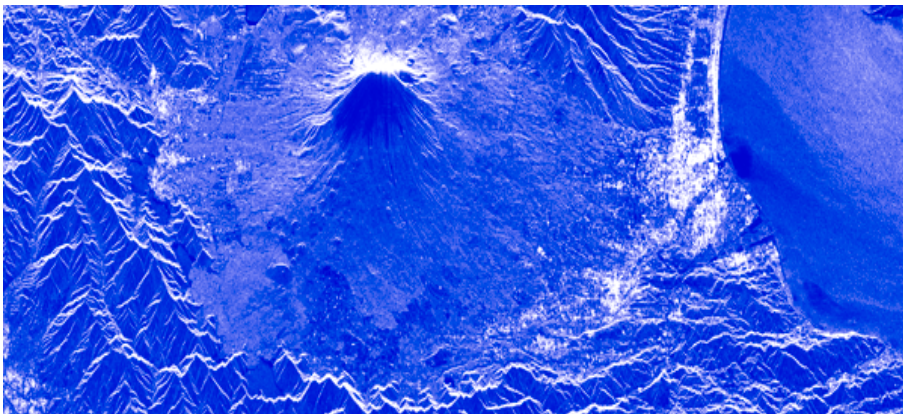
HH, 2HV, VV



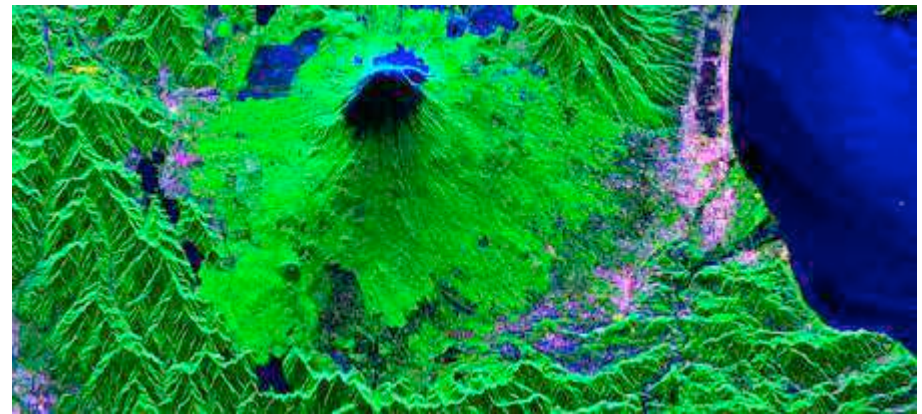
HV



HH-VV, 2HV, HH+VV



VV



Pd, Pv, Ps

Decomposition

Coherency, Covariance行列の分解

- 数学的 固有値・固有ベクトル (Cloude, Pottier, et al.1997-)

$$\langle [T] \rangle = \frac{1}{n} \sum \mathbf{k}_p \mathbf{k}_p^\dagger = [U_3] \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix} [U_3]^\dagger = \sum_{i=1}^3 \lambda_i \mathbf{e}_i \mathbf{e}_i^\dagger$$

Entropy Alpha-bar Anisotropy

Good for
classification

- 物理的 散乱モデル分解 (Freeman, Yamaguchi, et al. 1998-)

$$\langle [T] \rangle = P_1[T_1] + P_2[T_2] + P_3[T_3] + P_4[T_4] + \dots$$

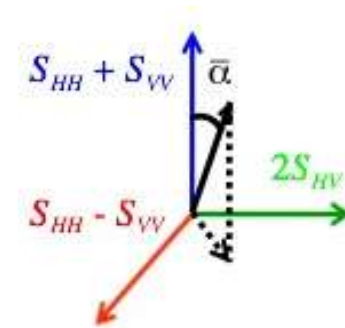
RGB Color-coding by powers

Easy to
interpret

- Hybrid 負の電力発生を抑えるための組合せ手法

Eigenvalue expansion

$$\langle [T] \rangle = \frac{1}{n} \sum \mathbf{k}_p \mathbf{k}_p^\dagger = [U_3] \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix} [U_3]^\dagger = \sum_{i=1}^3 \lambda_i \mathbf{e}_i \mathbf{e}_i^\dagger$$



Probability $P_i = \frac{\lambda_i}{\lambda_1 + \lambda_2 + \lambda_3} \quad (i = 1, 2, 3)$

Entropy $H = - \sum_{i=1}^3 P_i \log_3 P_i \quad (0 \leq H \leq 1)$

Alpha-bar $\bar{\alpha} = \sum_{i=1}^3 P_i \alpha_i \quad (0^\circ \leq \bar{\alpha} \leq 90^\circ)$

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



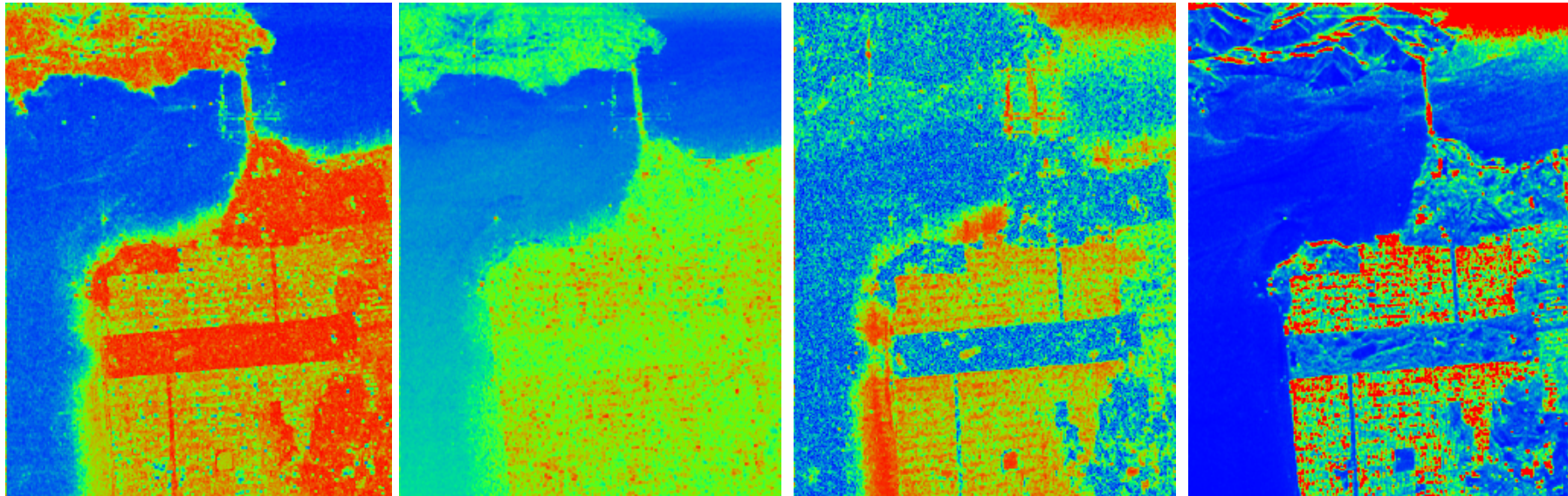
S. Cloude



E. Pottier

1. S. R. Cloude, and E. Pottier, "An entropy based classification scheme for land applications of polarimetric SAR," *IEEE Trans. Geosci. Remote Sensing*, vol. 35, no. 1, pp. 68-78, Jan. 1997.
2. J. S. Lee and E. Pottier, *Polarimetric Radar Imaging from Basics to Applications*, CRC Press, 2009
3. S. R. Cloude, *Polarisation applications in remote sensing*, Oxford University Press, 2009.

San Francisco

 H α A TP

min.



max.

Entropy

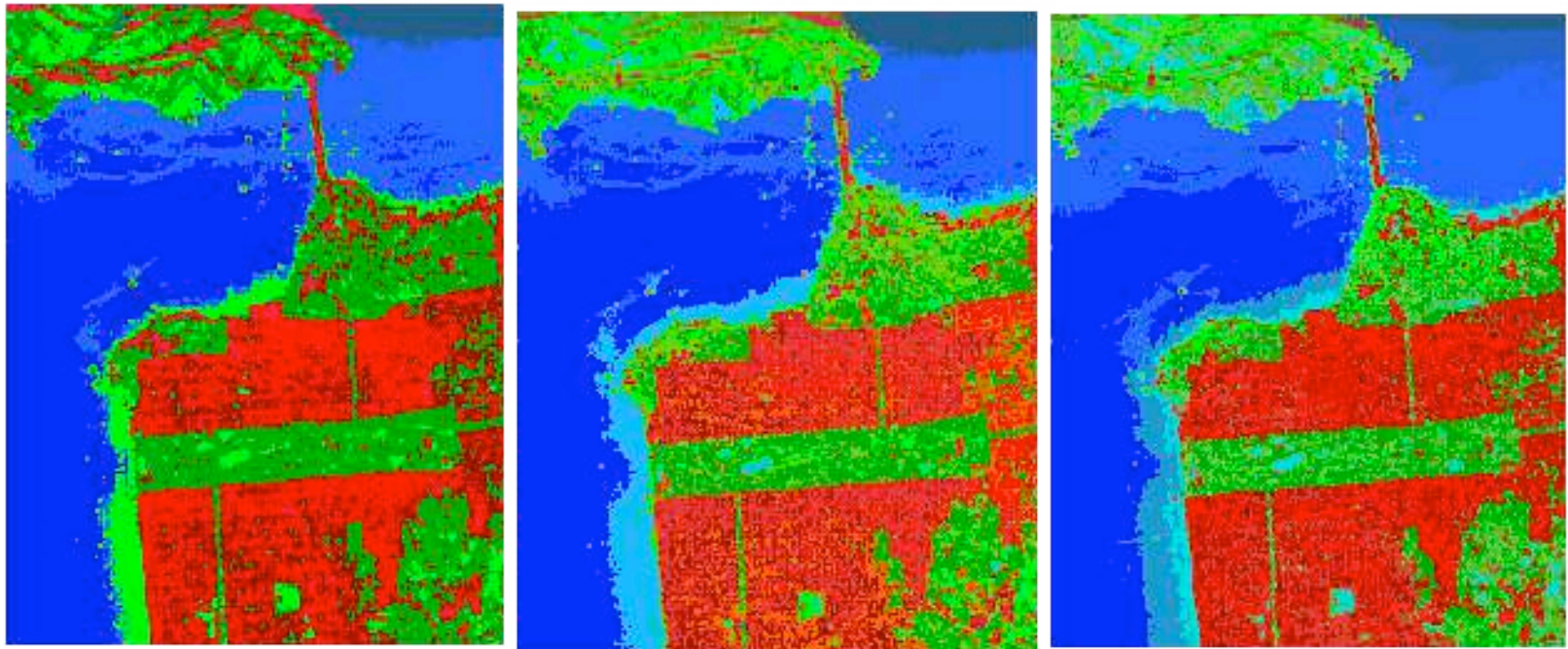
Alpha-bar

Anisotropy

Total Power

固有値による数学的な普遍性がある

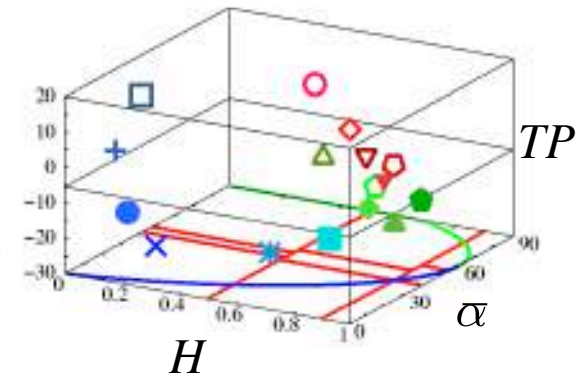
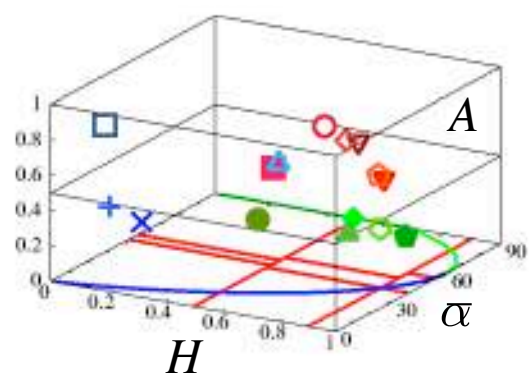
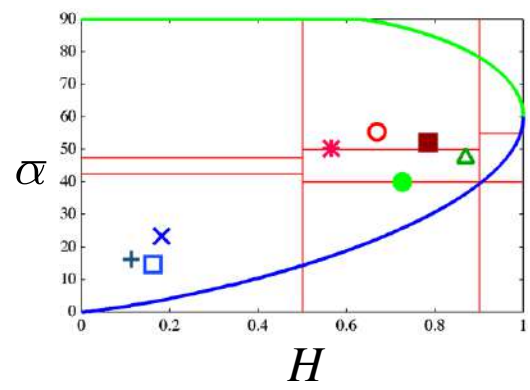
Classification by H, alpha, anisotropy, total power San Francisco



$H - \bar{\alpha}$

$H / \bar{\alpha} / A$

$H / \bar{\alpha} / TP$

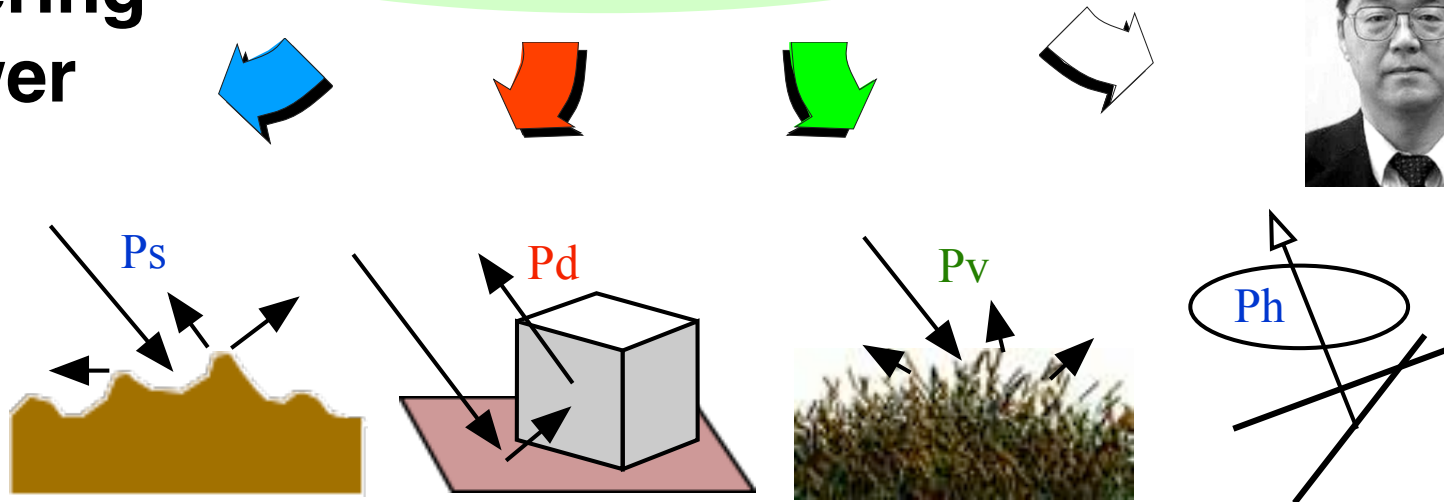


● 物理的な散乱モデル分解 (Freeman, Yamaguchi, et al. 1998-)

Measured Covariance Matrix
--> scattering mechanisms



Scattering Power



Surface

Double bounce

Volume

Helix

Scattering Model

Based on

- * the Second order statistics
- * the Experimental evidence

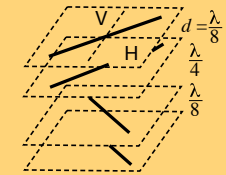
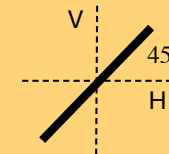
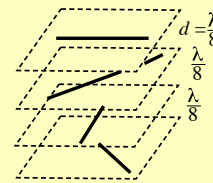
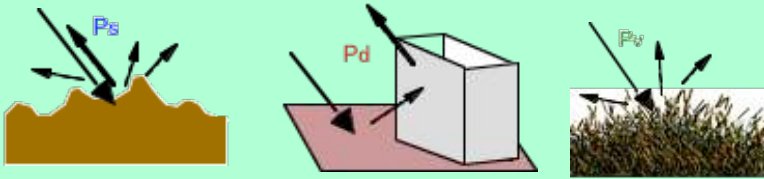
Decomposition schemes development

Model-based scattering power decomposition

- FDD: Freeman & Durden: 3-component (1998)
 - **Y40**: 3-comp. + **helix** scattering = 4-comp. (2005)
 - **Y4R**: 4-comp. with **rotation** (2011)
 - **S4R**: Y4R + **extended volume** scattering (2012)
 - **G4U**: S4R with **unitary** transform (2013)
 - **6SD**: 6-comp. with **rotation** (2017)
 - **5SD**: 5-comp. with double **unitary** transform (2022)
- ↓
- 他多数 (毎月提案がある? ほど)

6SD: 6-comp. with rotation

G. Singh, Y. Yamaguchi, "Model-based six-component scattering matrix power decomposition," *IEEE TGRS*, vol. 56, no. 10, pp. 5687-5704, Oct. 2018.



$$\langle [T(\theta)] \rangle = P_s [T_s] + P_d [T_d] + P_v [T_v] + P_h [T_h] + P_{od} [T_{od}] + P_{cd} [T_{cd}]$$

$$\begin{bmatrix} 1 & \beta^* & 0 \\ \beta & |\beta|^2 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad \begin{bmatrix} |\alpha|^2 & \alpha & 0 \\ \alpha^* & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad \frac{1}{4} \begin{bmatrix} 2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\frac{1}{2} \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & \pm j \\ 0 & \mp j & 1 \end{bmatrix}$$

$$\frac{1}{2} \begin{bmatrix} 1 & 0 & \pm 1 \\ 0 & 0 & 0 \\ \pm 1 & 0 & 1 \end{bmatrix}$$

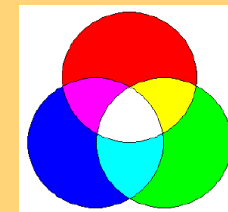
$$\frac{1}{2} \begin{bmatrix} 1 & 0 & \pm j \\ 0 & 0 & 0 \\ \mp j & 0 & 1 \end{bmatrix}$$

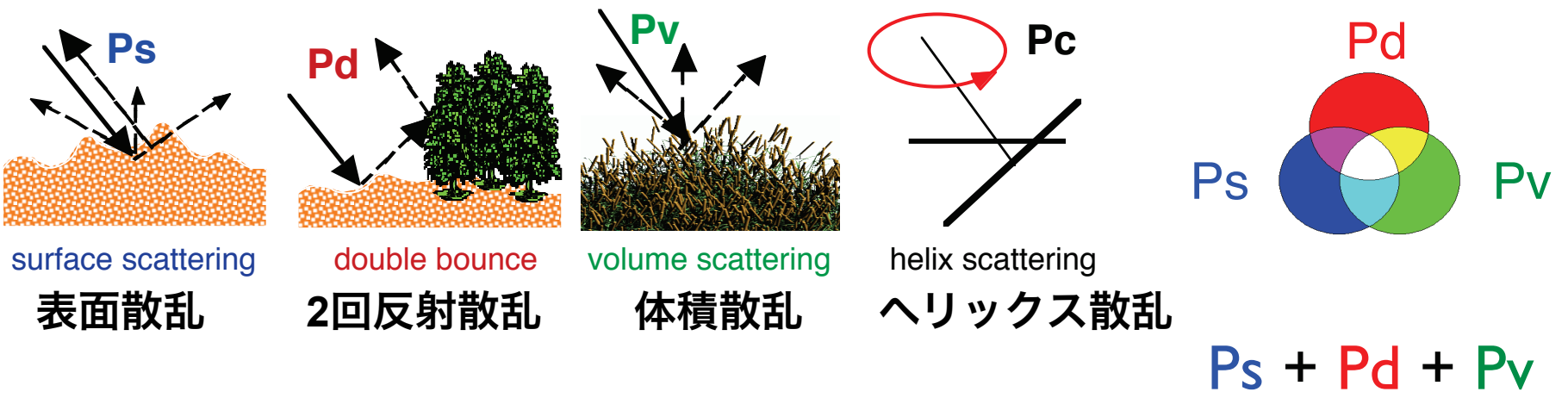
$$\frac{1}{30} \begin{bmatrix} 15 & 5 & 0 \\ 5 & 7 & 0 \\ 0 & 0 & 8 \end{bmatrix}$$

$$\frac{1}{30} \begin{bmatrix} 15 & -5 & 0 \\ -5 & 7 & 0 \\ 0 & 0 & 8 \end{bmatrix}$$

$$\frac{1}{15} \begin{bmatrix} 0 & 0 & 0 \\ 0 & 7 & 0 \\ 0 & 0 & 8 \end{bmatrix}$$

accounting for
8/8

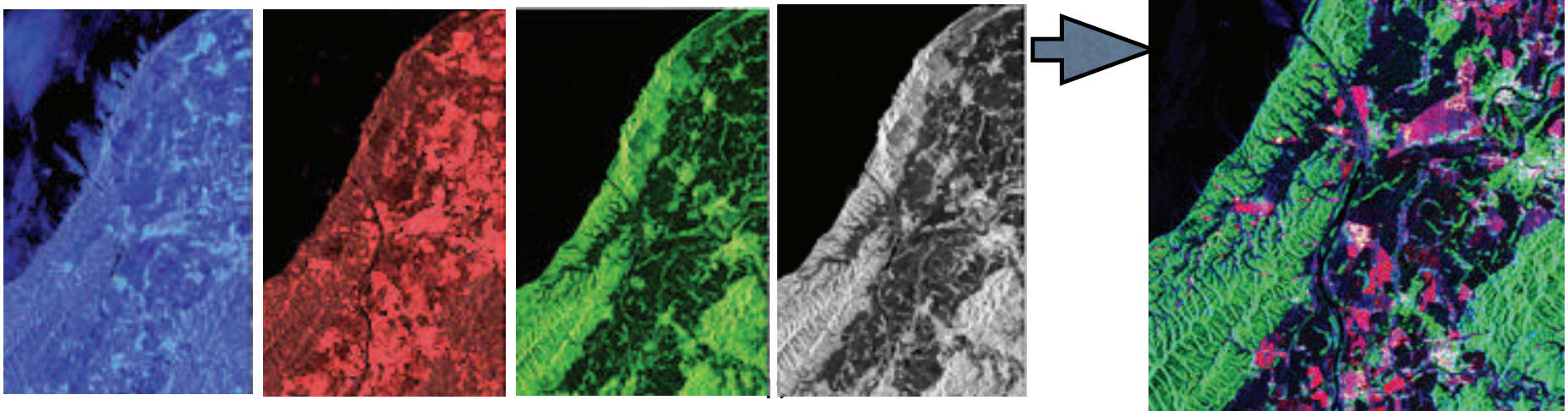




散乱行列から2次統計量の行列へ

散乱電力分解

P_s P_d P_v P_c



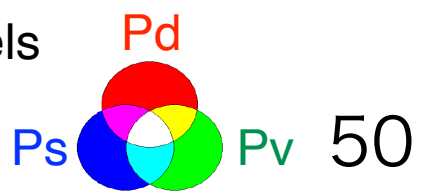


Amazon - Flooding

Scattering Power Decomposition C3D with 5x10 pixels

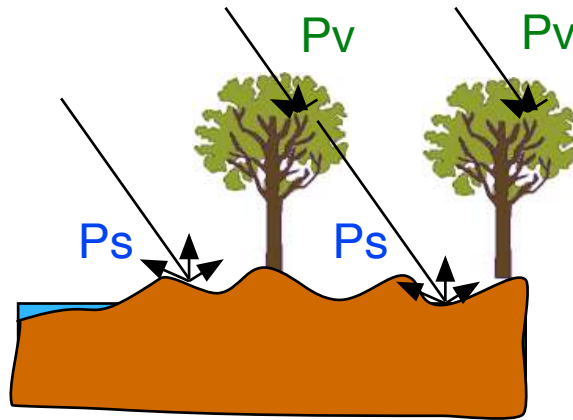
ALOS2104987050-160503 © JAXA

Off nadir angle 28°

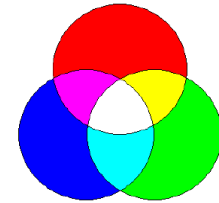


川底からの散乱変化

通常状態

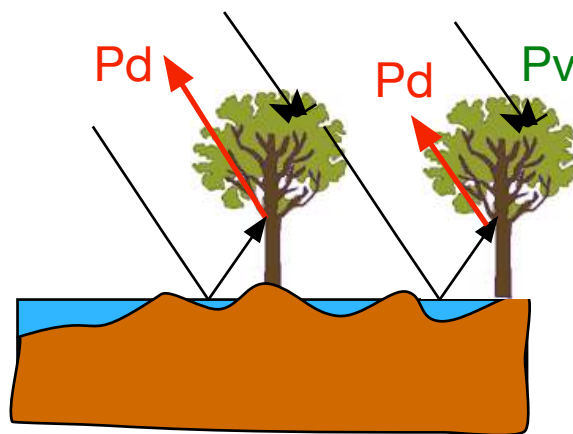


P_v が大
 P_s は小さい



Green 優勢

洪水時

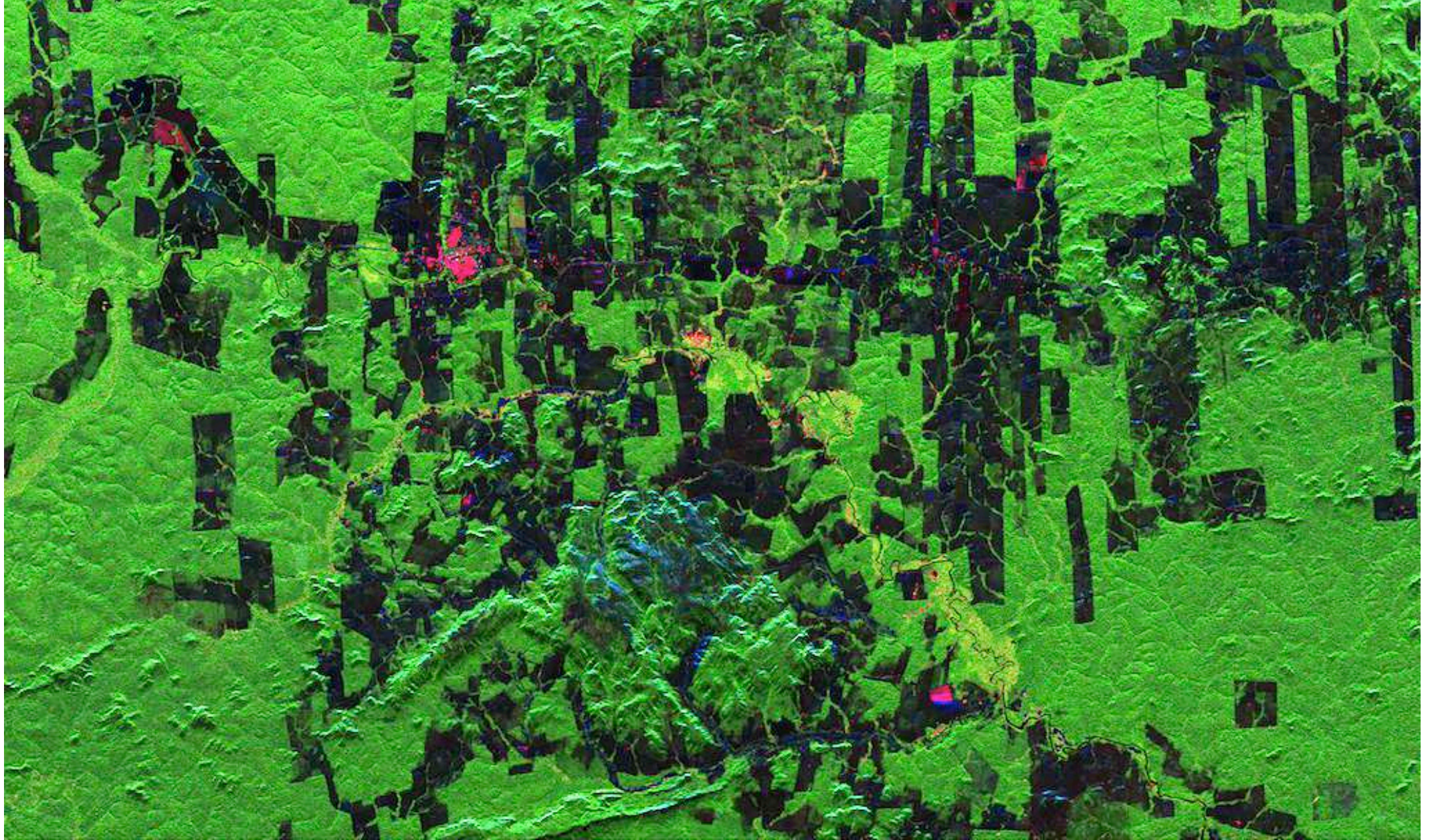


L-band wave 森林透過

水面の鏡面反射

P_d が増える

$P_v + P_d = \text{Yellow}$ の増加

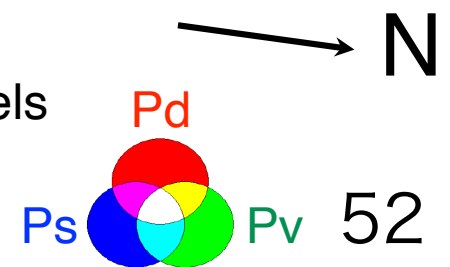


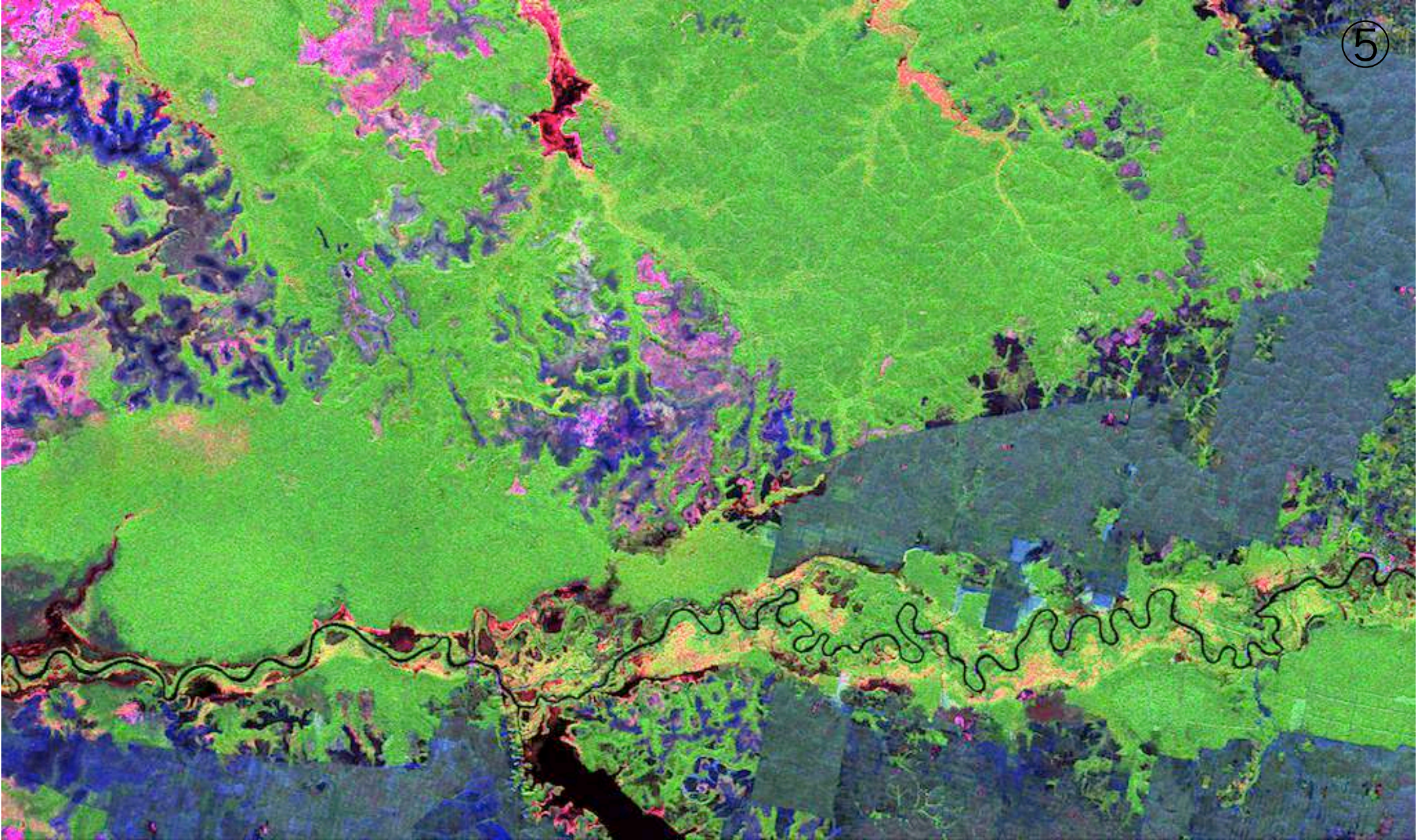
Amazon - Deforestation

Scattering Power Decomposition **6SD** with 5x10 pixels

ALOS2101287020-160408 © JAXA

Off nadir angle **32.7°**



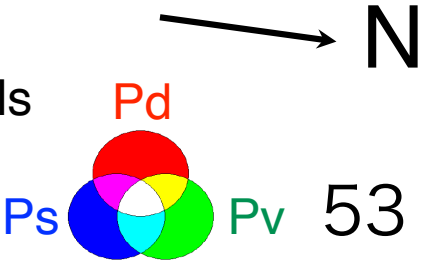


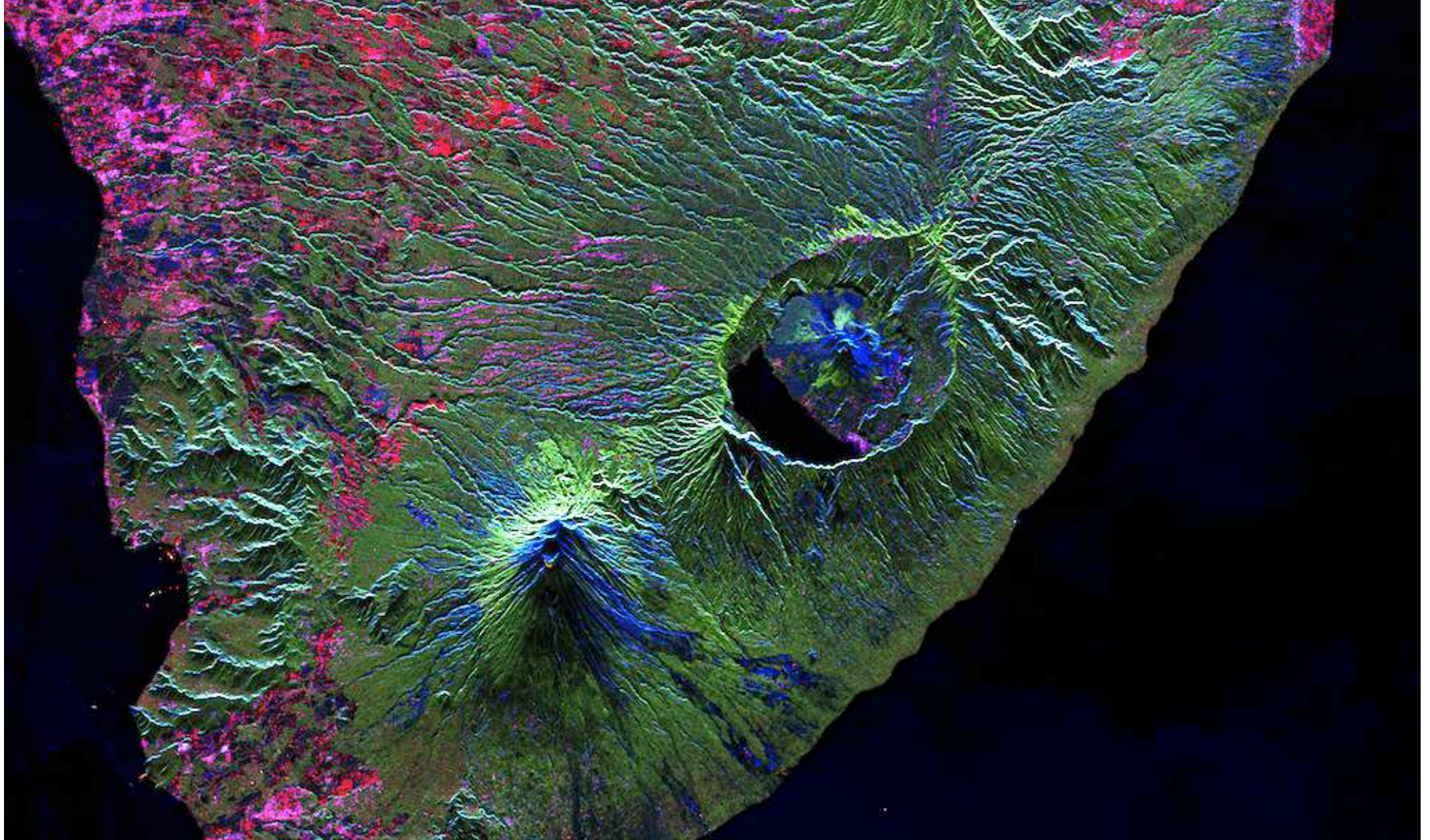
Seruyan Regency, Indonesia

Scattering Power Decomposition **6SD** with 5x10 pixels

ALOS2048137130-150414 © JAXA

Off nadir angle **32.7°**





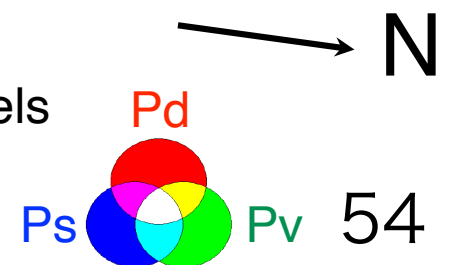
Gunung Agung Volcano, Bali

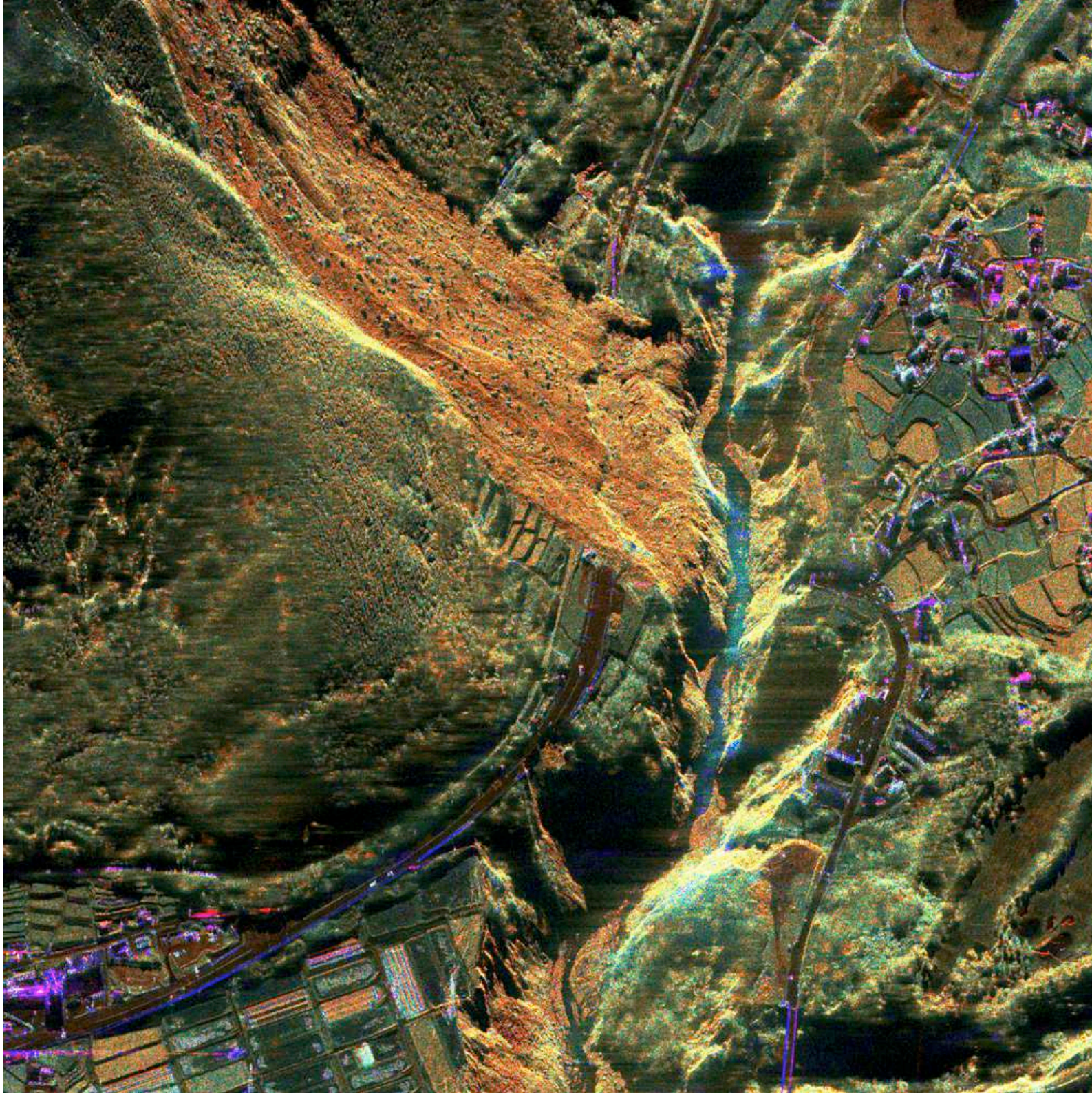


Scattering Power Decomposition **6SD** with 5x10 pixels

ALOS2047397020-150409 © JAXA

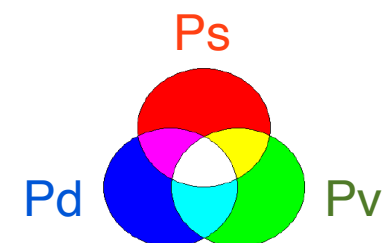
Off nadir angle **32.7°**





**Pi-SAR-2X
@NICT**

**30 cm
resolution**



**Minami-Aso
Village
20160417**

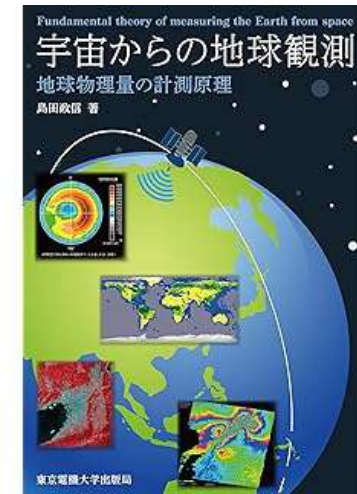
レーダ，合成開口レーダ，ポーラリメトリ関連図書



2017



2007



2021



2009



2020



2023

⑥ 将来展望



Global Environmental Defense

3D-polarimetric & Interferometric imaging for global environmental remote sensing



Prof. Wolfgang -M. Boerner (75) at IGARSS 2012 Plenary

Precise Change Detection

Frequency allocation issue

Fully polarimetric + constellation SAR

ALOS-1/2 Pol-Images are available at

<https://gsrt.digiarc.aist.go.jp/landbrowser/index.html>

レーダの発展 2

電力
(スカラー)

偏波利用
(ベクトル)



映像レーダ

衛星搭載SAR

航空機SAR

地上設置SAR

GPR

将来に向け

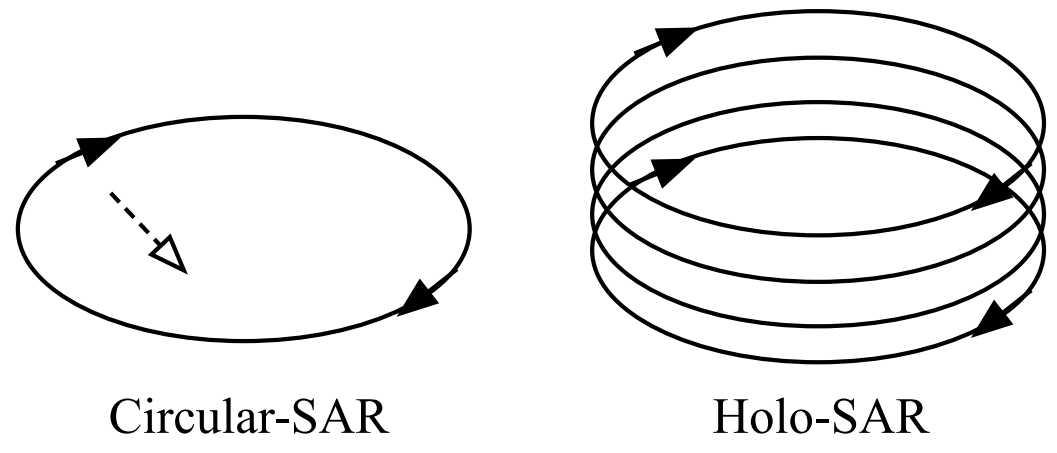
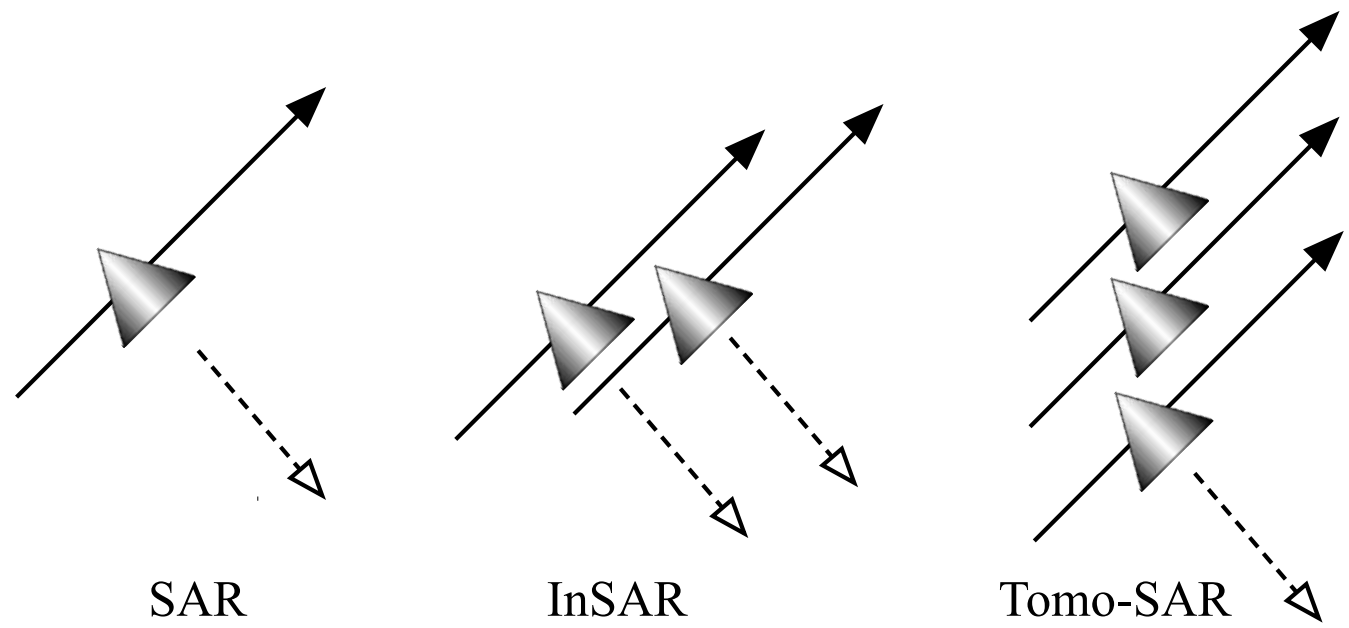
Multi-dimension

MIMO

多周波化

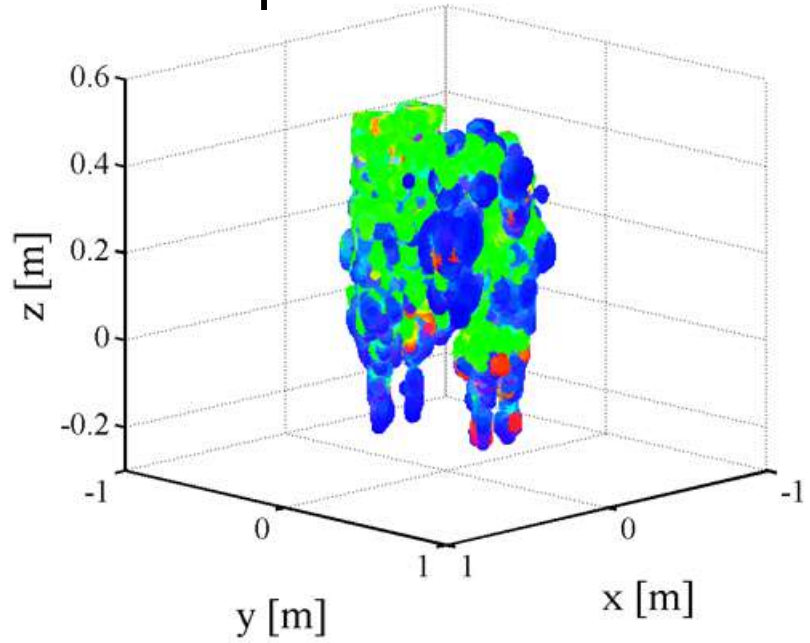
将来展望

Polarimetric-XX configuration



Example

3D Polarimetric Holo-SAR measurement

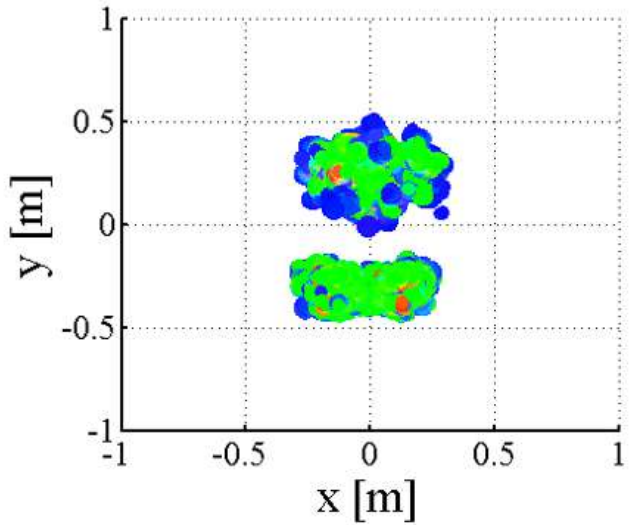


3-D view of trees

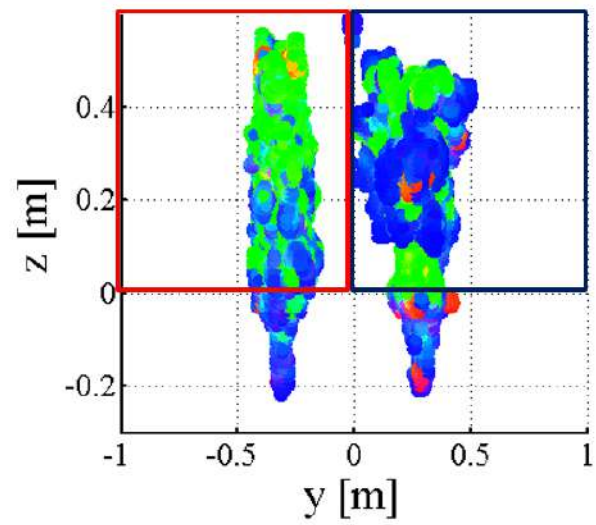


Photo

Freq. 13-17 GHz
 1 m scan in height
 Conifer
 Broad-leaf



Top view



Side view

Decomposition power ratio

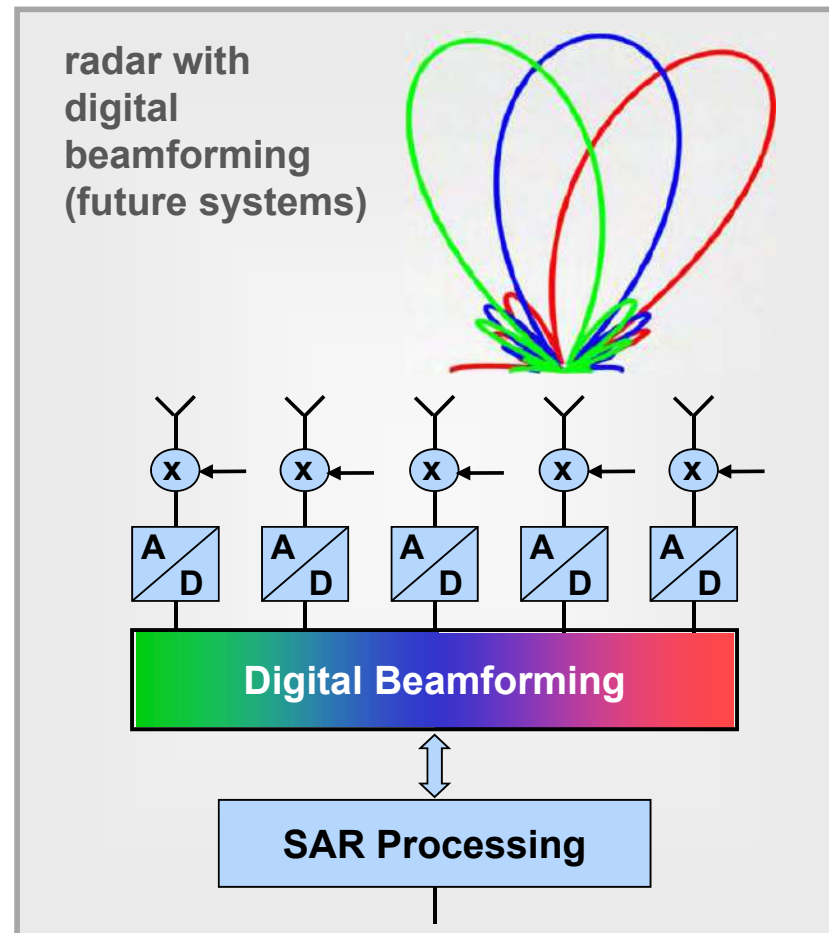
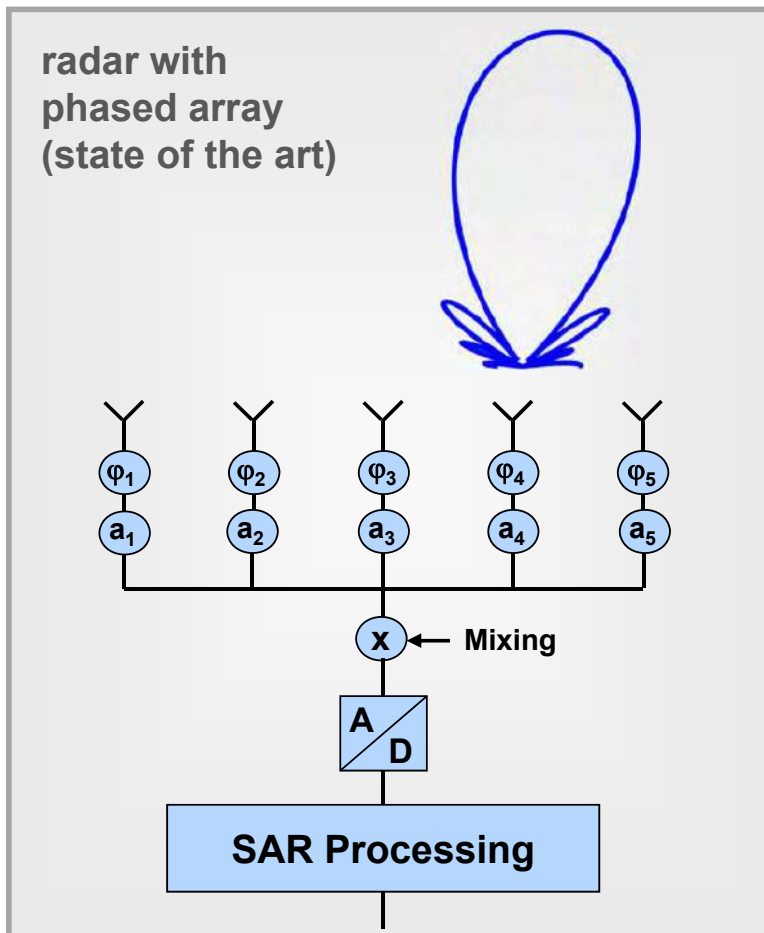
	Ps	Pd	Pv	Ph
Conifer	22.5	5.4	71.8	0.3
Broad-leaf	48.3	4.9	44.7	2.1

将来展望

Phased Array \rightarrow DBF



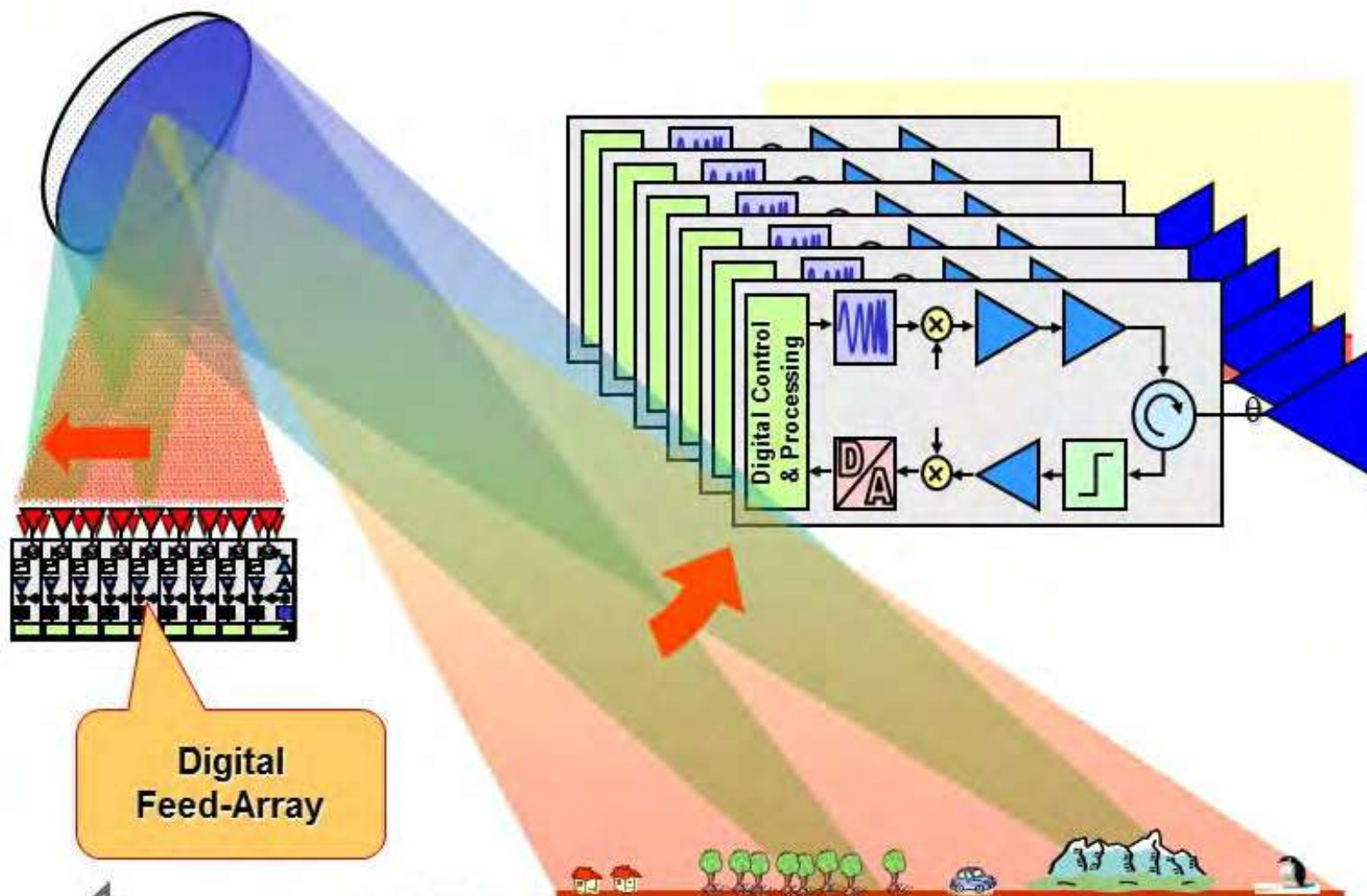
Digital Beamforming (DBF) / Multichannel SAR



将来展望

for wide area surveillance

Digital Beamforming with Reflector Antennas



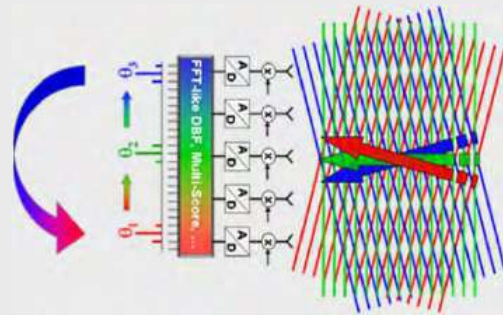
将来展望

Multi-dimensional SAR

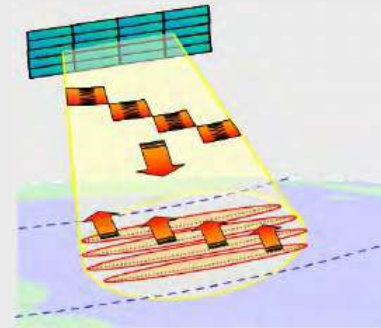


New SAR Technologies

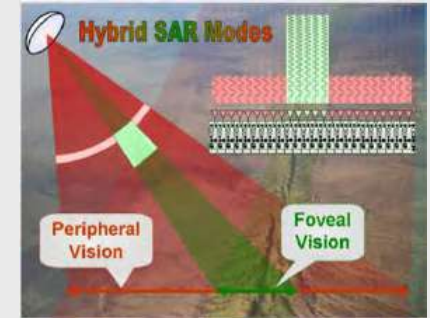
Digital Beamforming



MIMO-SAR

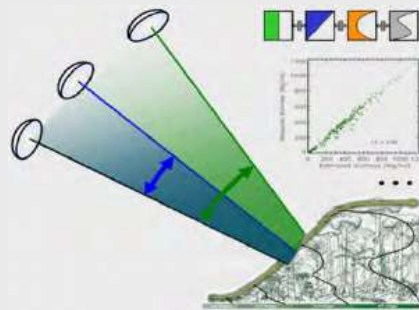


Hybrid & Adaptive SAR

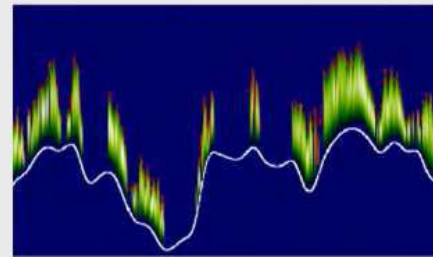


New Techniques and Retrieval Algorithms

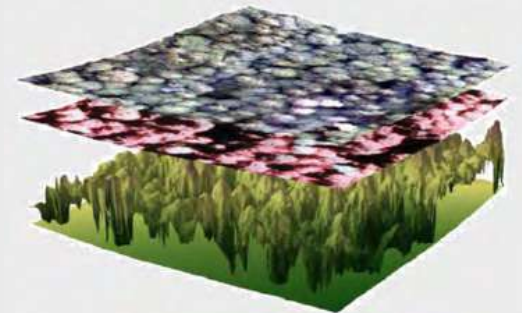
Multi-Dimensional SAR



3-D & 4-D Imaging



Data Fusion



Thank you for your attention !



Some Polarimetry Community Members gathered in the International Polarimetric SAR Workshop in Niigata 2012