Imagerie radar SAR

(*Synthetic Aperture Radar*)

Éric POTTIER

Formation CNRS
RADAR
17-19/10/2023

Remote Sensing

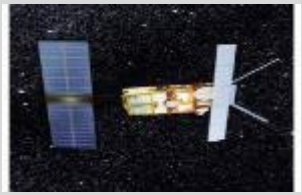
Optical vs. SAR sensor

Active system

Passive system

Spaceborne Sensors (past)

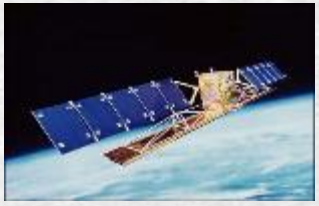
SEASAT
NASA/JPL (USA)
L-Band, 1978



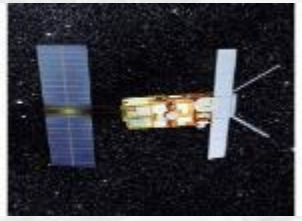
ERS-1
European Space Agency (ESA)
C-Band, 1991-2000

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

SIR-C/X-SAR
NASA/JPL, L- and C-Band (quad)
DLR / ASI, X-band
April and October 1994



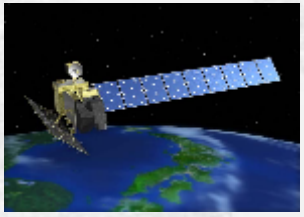
RadarSAT-1
Canadian Space Agency (CSA)
C-Band, 1995



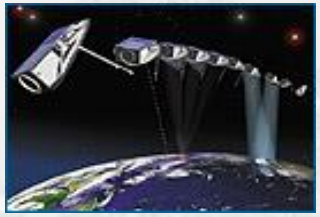
ERS-2
European Space Agency (ESA)
C-Band, 1995

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

ENVISAT / ASAR
European Space Agency (ESA)
C-Band (dual), 2002

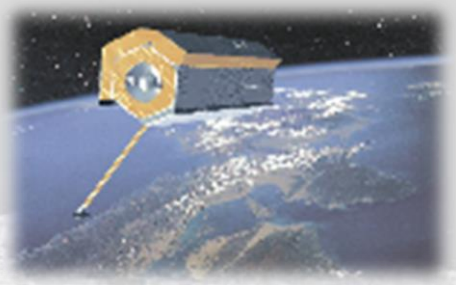


ALOS / PALSAR
Japanese Space Agency (NASDA)
L-Band (quad), 2004



SAR-Lupe
BWB, Germany
X-Band, 2005

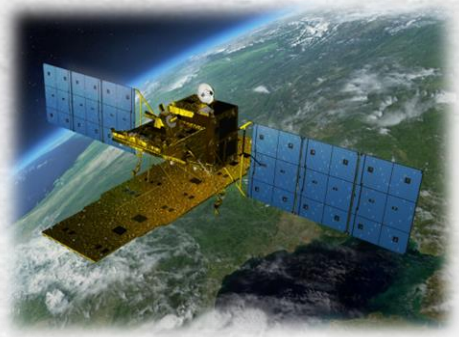
Spaceborne Sensors (current)



TerraSAR-X
German Aerospace Center (DLR) / Astrium
X-Band (sngl/dual/quad), 2005

RADARSAT-2
Canadian Space Agency (CSA)
C-Band (quad), 2005

COSMO SkyMed
Italian Space Agency (ASI) / Telespazio
X-Band (sngl/dual), 2007 - 2010

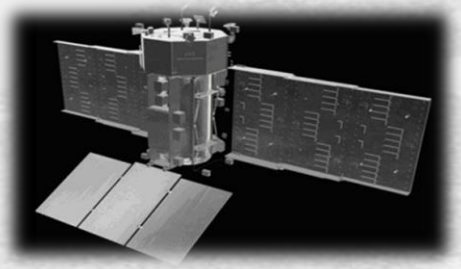


ALOS2 / PALSAR2
Japanese Space Agency (JAXA)
L-Band (sngl/dual/quad/hybrid), 2014

RISAT-1
India Space Agency (ISRO)
C-Band (sngl/dual/hybrid), 2015

SENTINEL-1a/b
European Space Agency (ESA)
C-Band (sngl/dual), 2014-2016

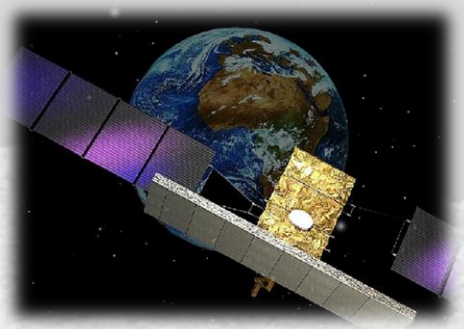
GaoFen-3 (GF-3)
China Academy of Space Technology (CAST)
C-Band (dual/quad), 2016



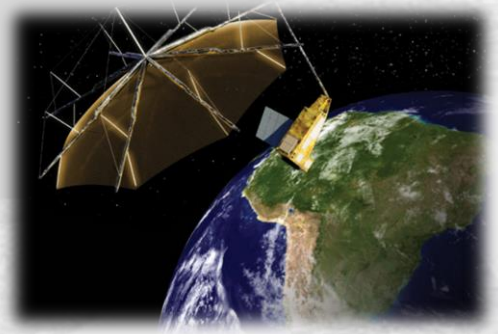
SAOCOM
Argentina Space Agency (CONAE)
L-Band (sngl/dual/twin), 2019

RADARSAT Constellation Mission (RCM)
Canadian Space Agency (CSA)
C-Band (sngle/dual/hybrid), 2019

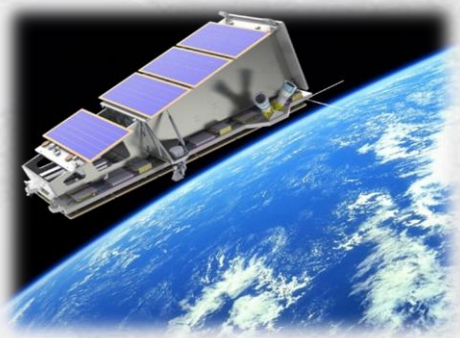
Spaceborne Sensors (future)



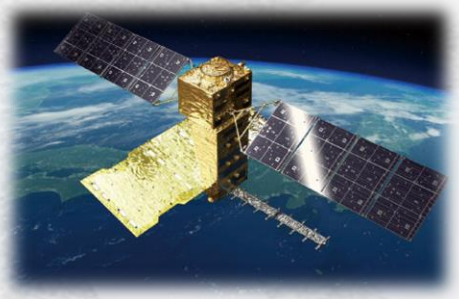
COSMO SkyMed – 2nd Generation (CSG)
Italian Space Agency (ASI) / Telespazio
X-Band (sngl/dual/quad), 2020



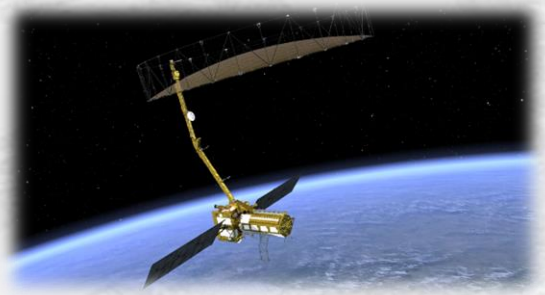
BIOMASS
European Space Agency (ESA)
P-Band (quad), ~~2021~~



NOVASAR-S
Surrey (UK)
S-Band (sngl/dual/quad), 2021



ALOS4 / PALSAR3
Japanese Space Agency (JAXA)
L-Band (quad), ~~2021-2022~~



NISAR
National Aeronautics and Space Administration (NASA)
India Space Agency (ISRO)
L- S-Band (sngl/dual/quad/hybrid), ~~2021-2022~~

SENTINEL-1c/d
European Space Agency (ESA)
C-Band (sngl/dual/quad), 2025

Outline

FREQUENCY BANDS
- Range-Azimuth Resolution
- Bio- & Geo-Physical Parameters

GEOMETRIC CONFIGURATION
- Geometric Configuration
- SAR Imaging Modes
- Geometric Effects

ACQUISITION MODES

SAR PRINCIPLES

PIMA : IETR AIRBORNE PLATFORM

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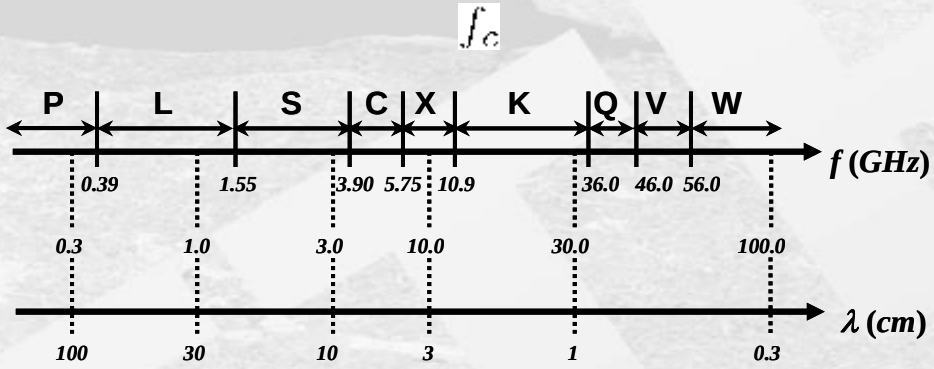
Frequency Bands

Frequency bands used for remote sensing applications

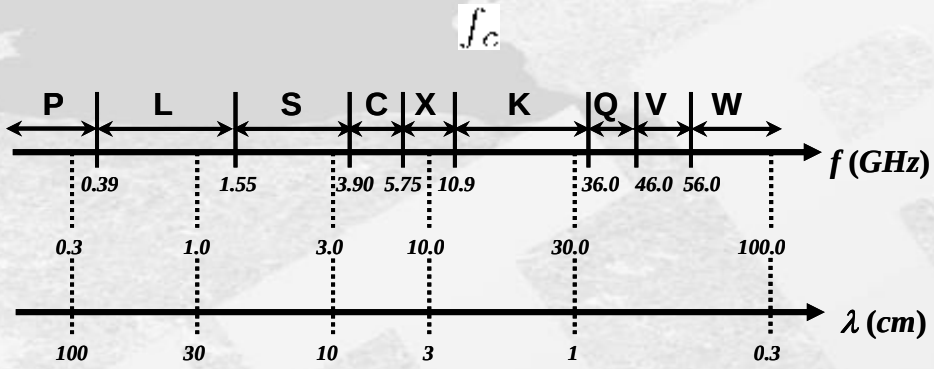


Range / Azimuth Resolution

Bio- Geo-Physical Parameters

Frequency Bands

Frequency bands used for remote sensing applications



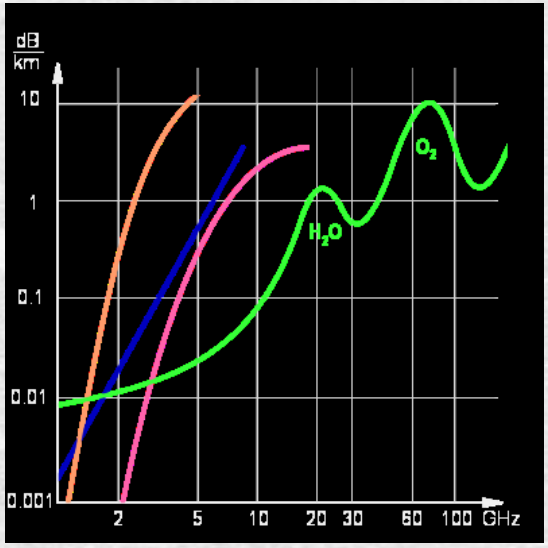
- Antenna spectral bandwidth

$$\frac{B_f}{f_c} \approx 10\%$$

- Different achievable resolutions

$$\delta_x \approx \frac{r_0 \lambda}{L_\phi} \qquad \delta r = \frac{c}{2B_f}$$

- Absorption of the atmosphere



Range / Azimuth Resolution

Tsukuba Science City (1997)

L-Band

Resolution: 5m

X-Band

Resolution: 2.5m

IETR Range / Azimuth Resolution

Sandia National Laboratories

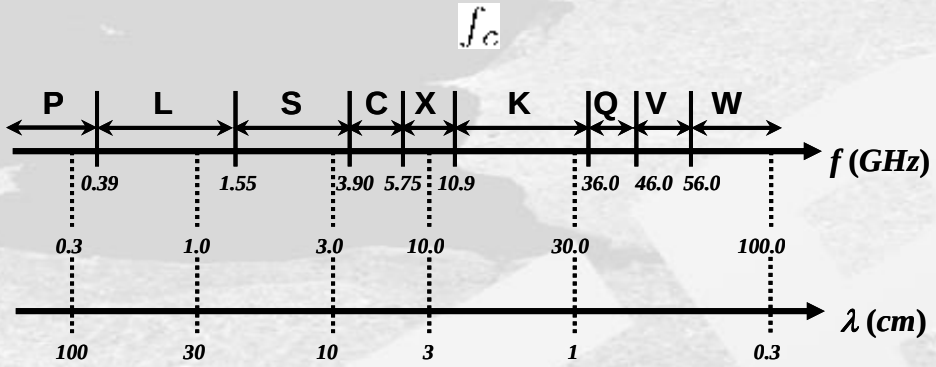
AMPS-P3 Ku-Band res: 1m

Washington DC, USA

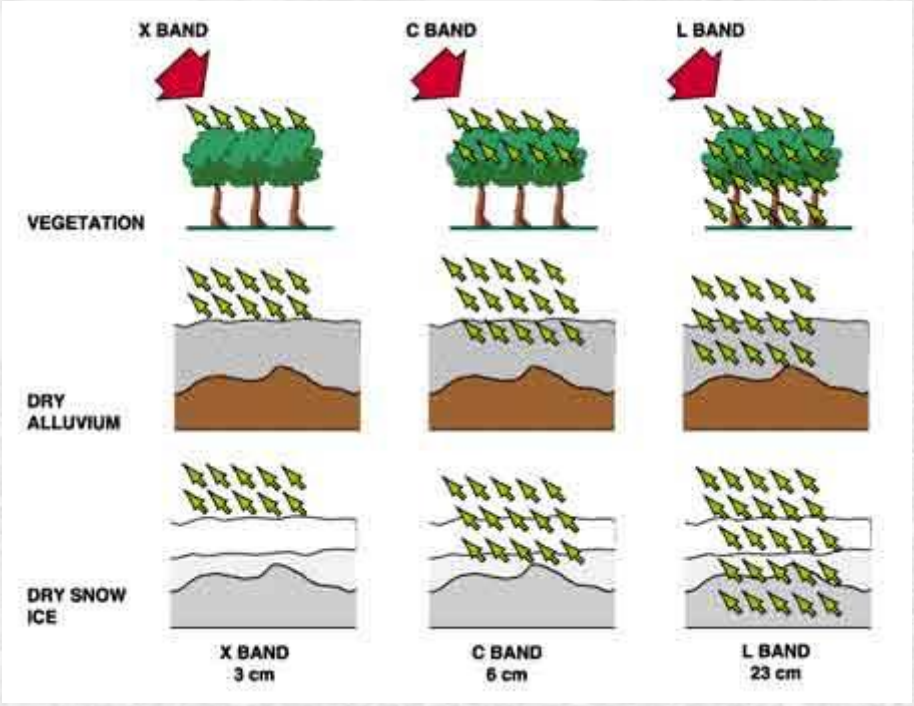
Range / Azimuth Resolution

Range / Azimuth Resolution

Frequency Bands



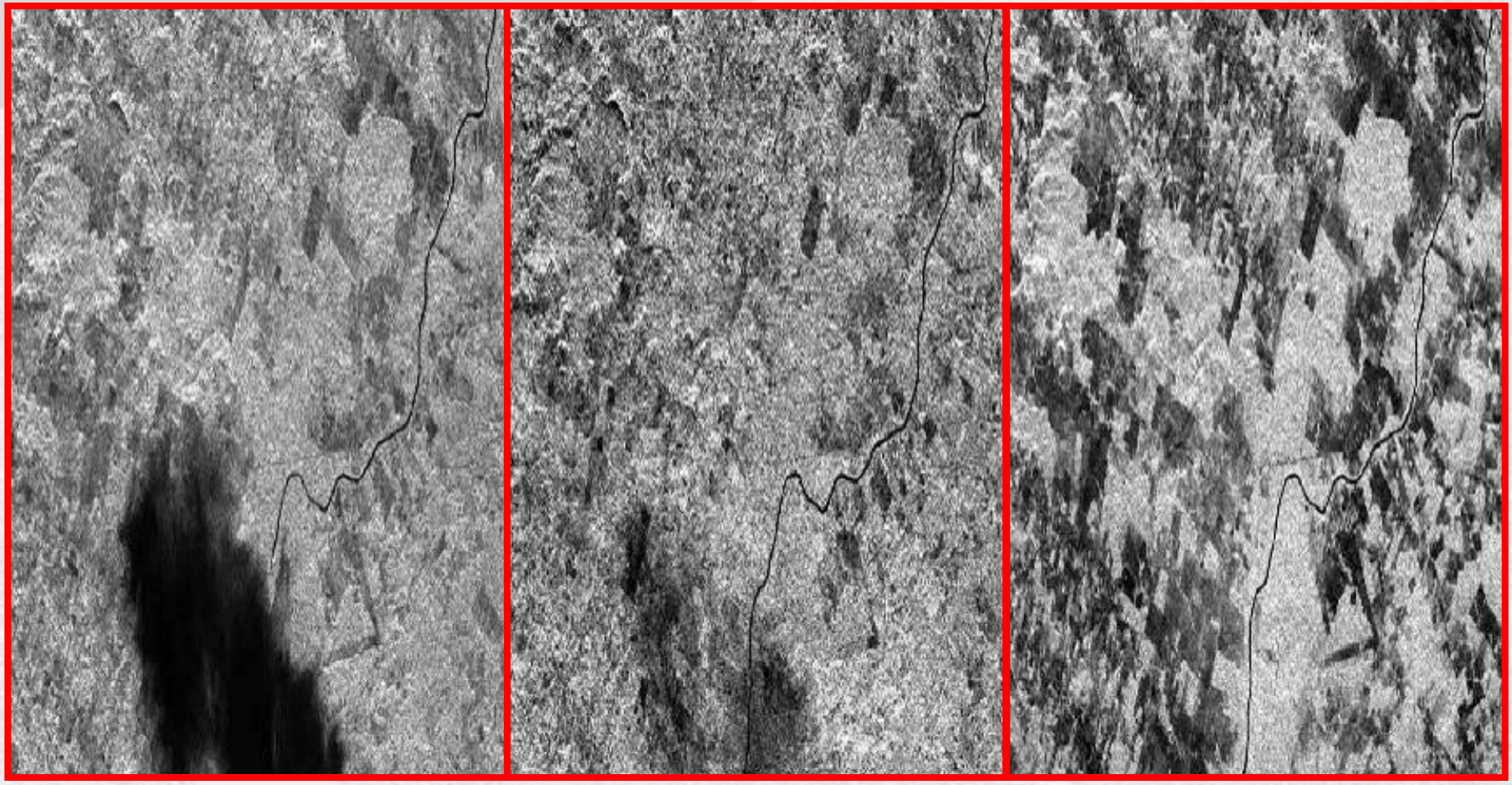
- Different sensitivity to geo-physical parameters (moisture, …)
- Different penetration depths into volumes



Courtesy of esa

Frequency Bands

Volume Scattering



X-Band (3cm) C-Band (5.6cm) L-Band (25cm)

Amazon Forest, Brazil

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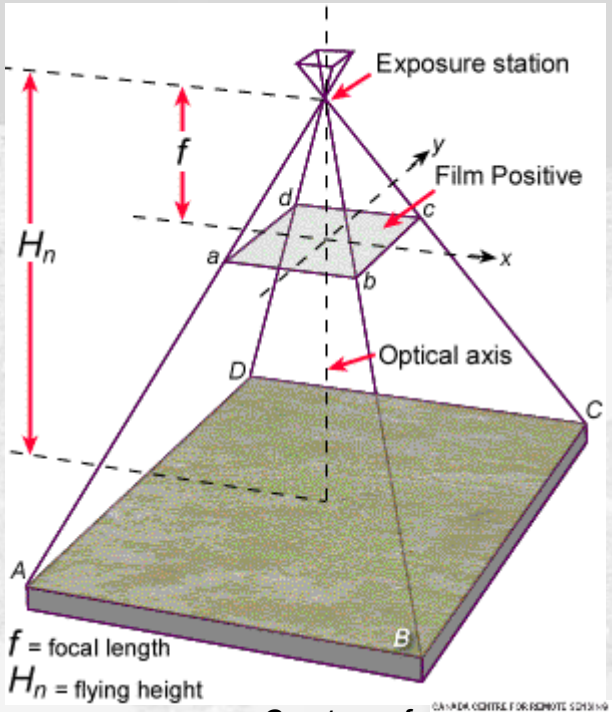
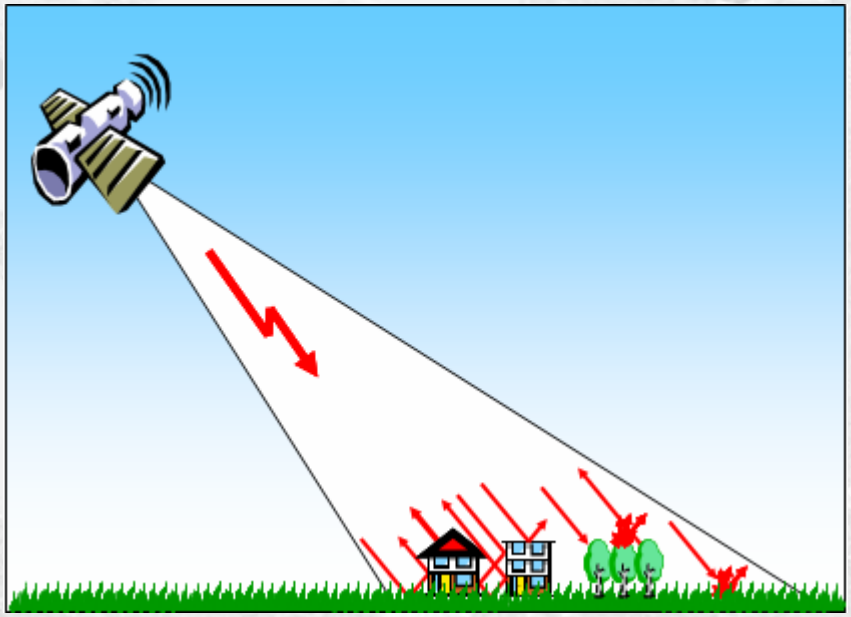
Geometric Configuration



Courtesy of Canada

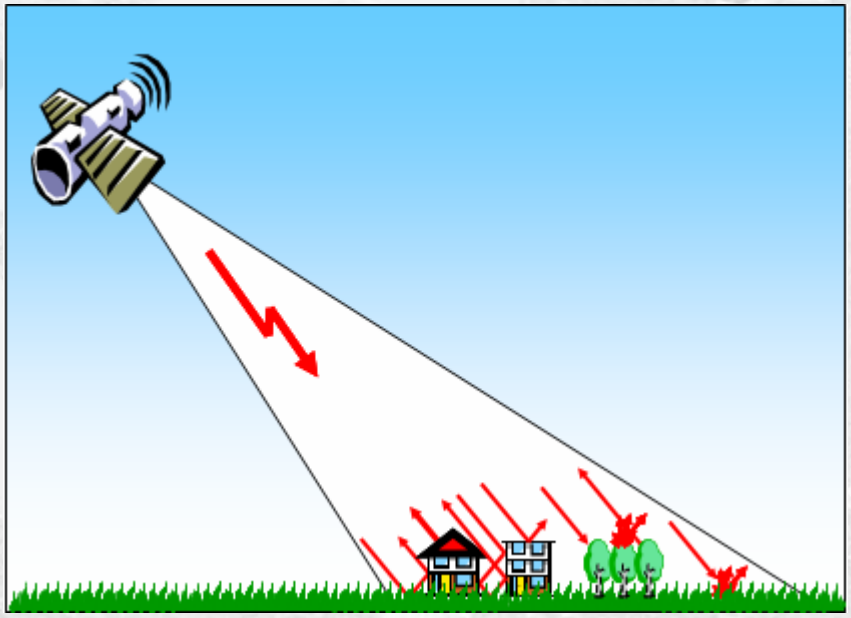


Photographic systems and most scanners employ a central, downward looking sensor and symmetrical geometry.

Radar imaging systems are characterized by a side looking sensor and asymmetrical geometry.

Geometric Configuration

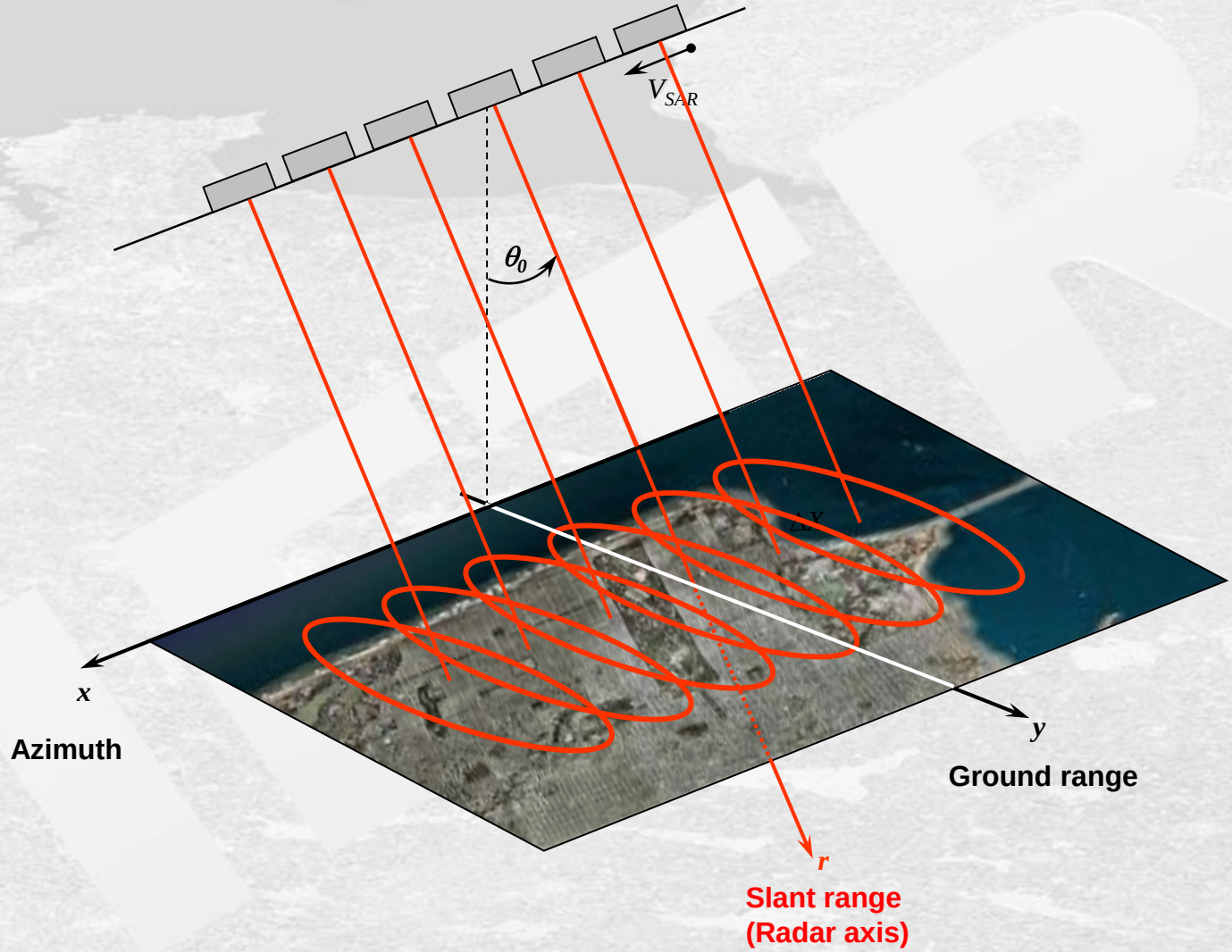
Left – Right Range Ambiguities.



No Left – Right Range Ambiguities.

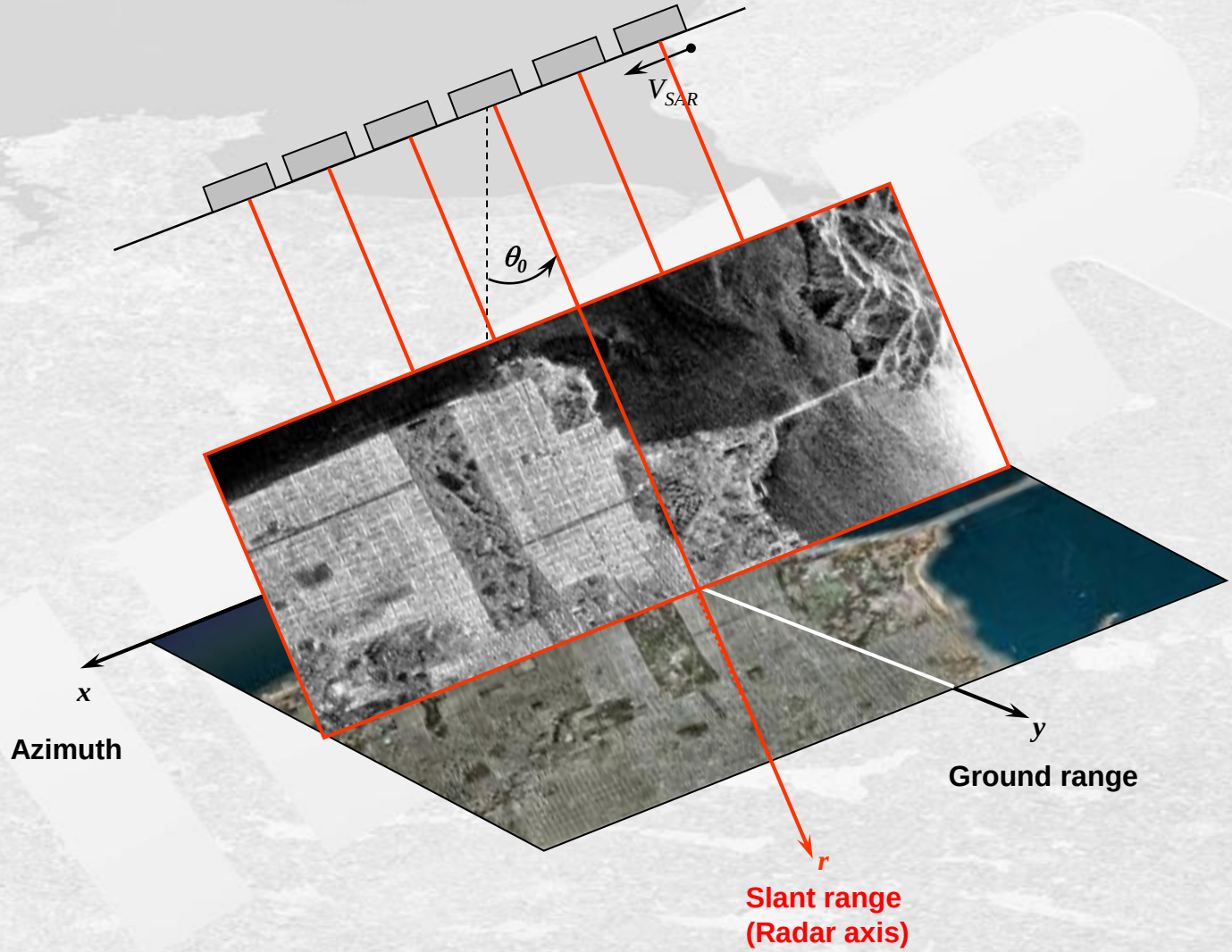
Side looking !

Geometric Configuration



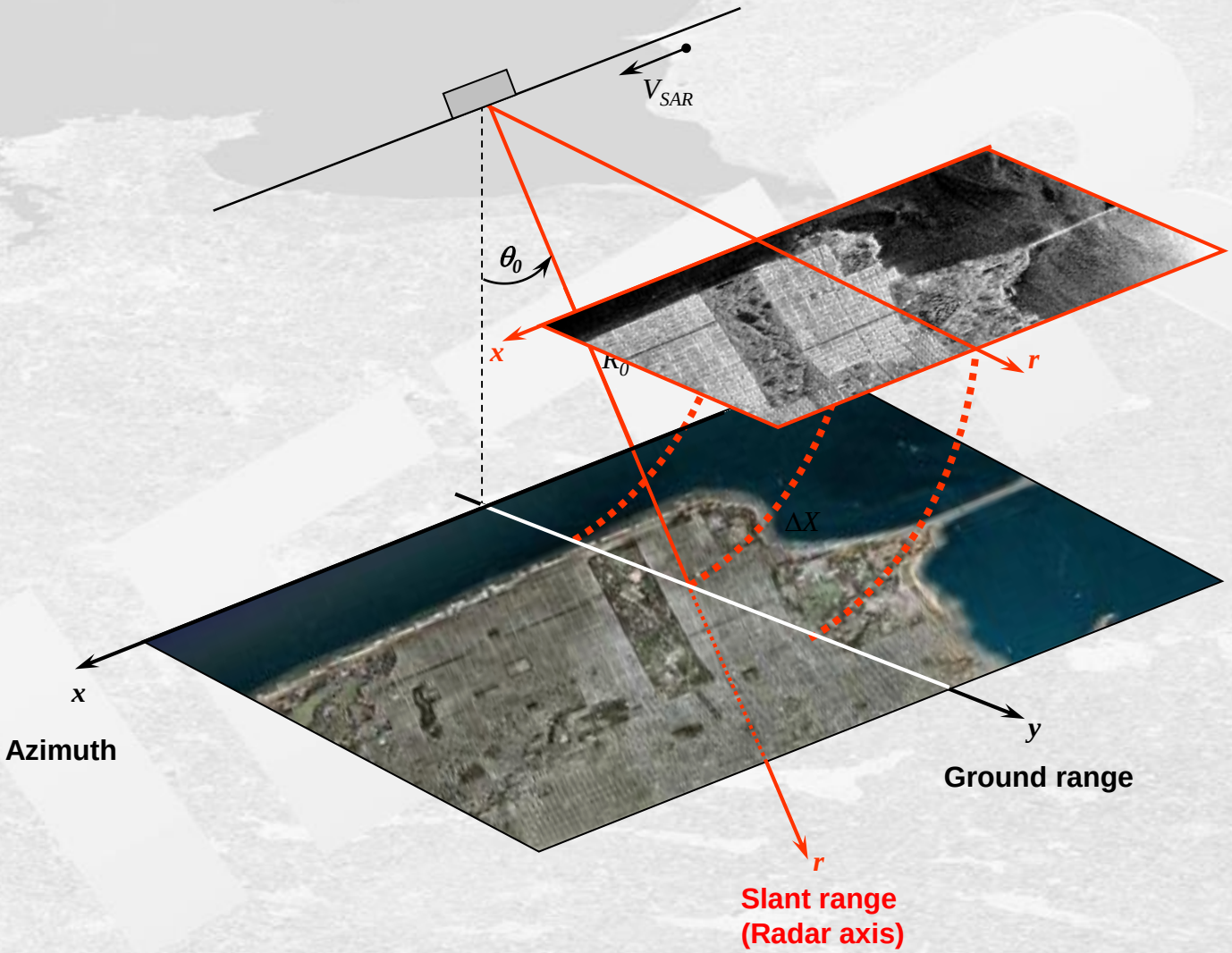
Broadside geometry

Geometric Configuration



Broadside geometry

Geometric Configuration



Broadside geometry

SAR Imaging Modes

Stripmap

SAR Imaging Modes

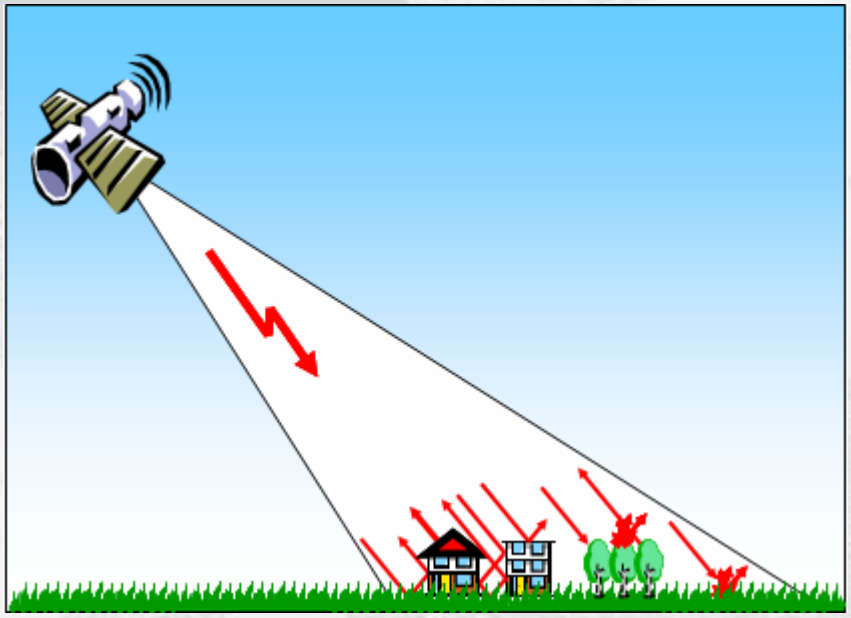
ScanSAR

SAR Imaging Modes

Spotlight

SAR Imaging Modes

Geometric Effects

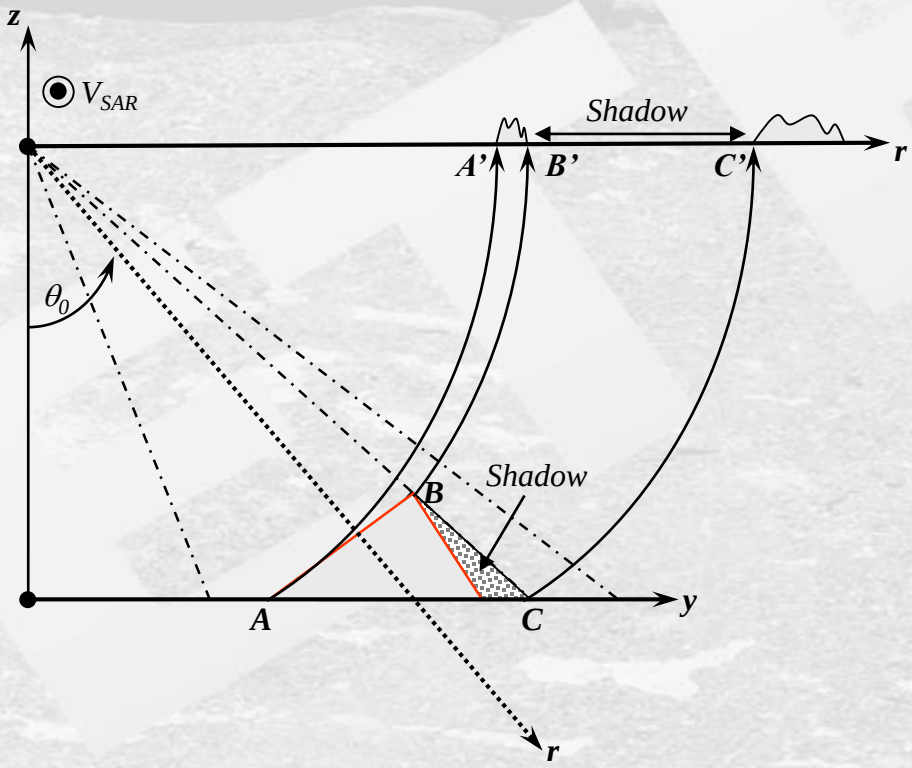


Side looking

Geometric Effects (artefacts)

Geometric Effects

Shadowing effect

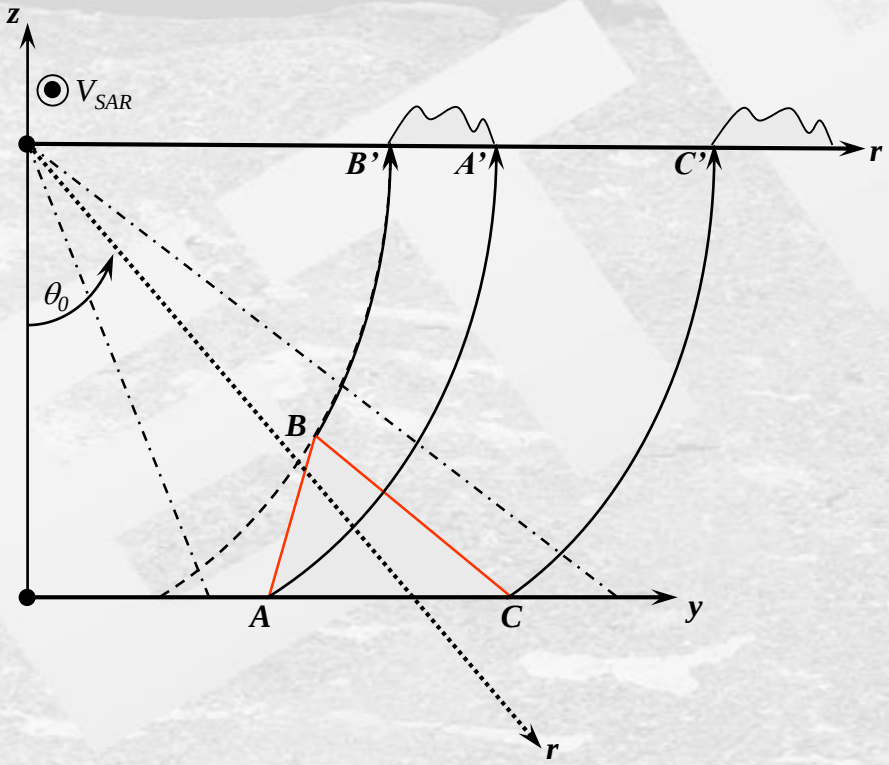


Geometric Effects

X band E-SAR image of Munich

Geometric Effects

Layover effect



Geometric Effects

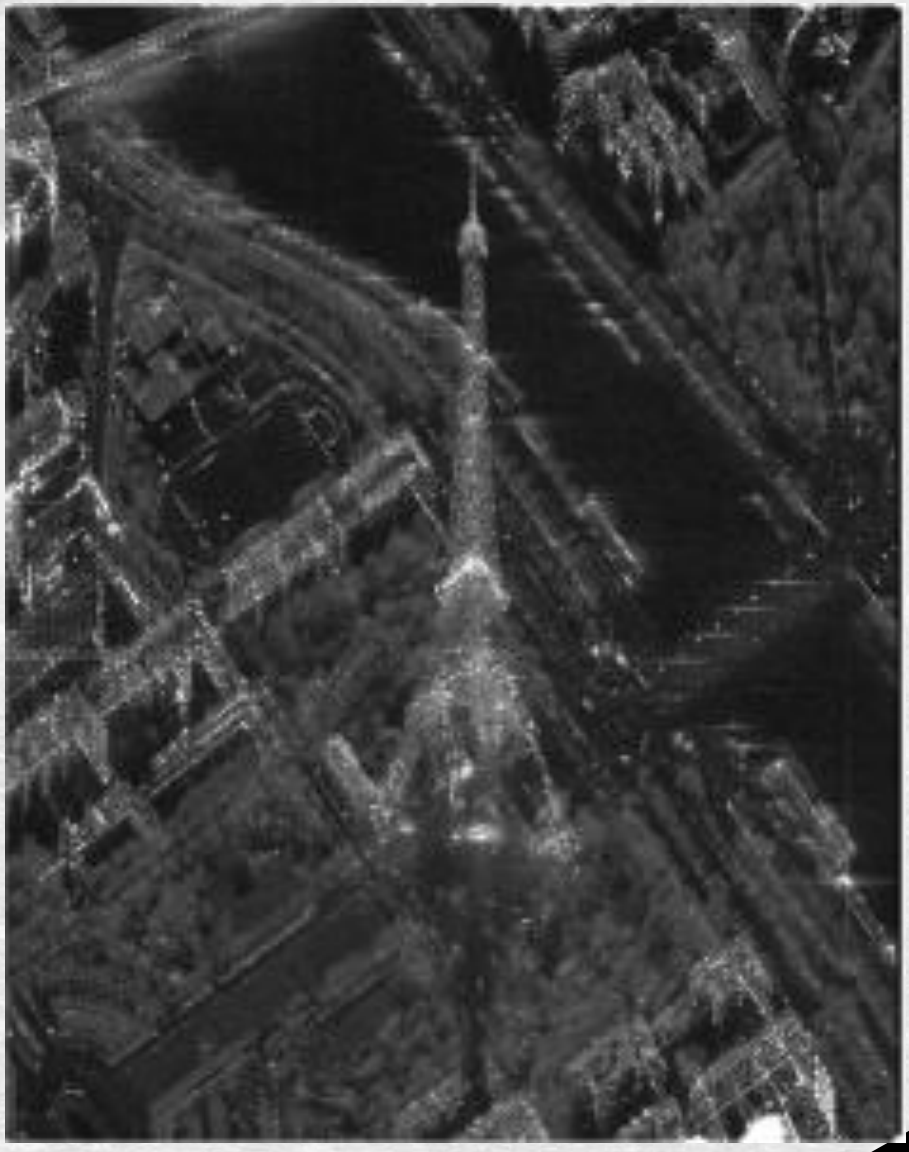
Layover/shadowing effect

Geometric Effects

Layover/shadowing effect

Geometric Effects

Layover/shadowing effect



Courtesy of Pr. F. Tupin (IMT)

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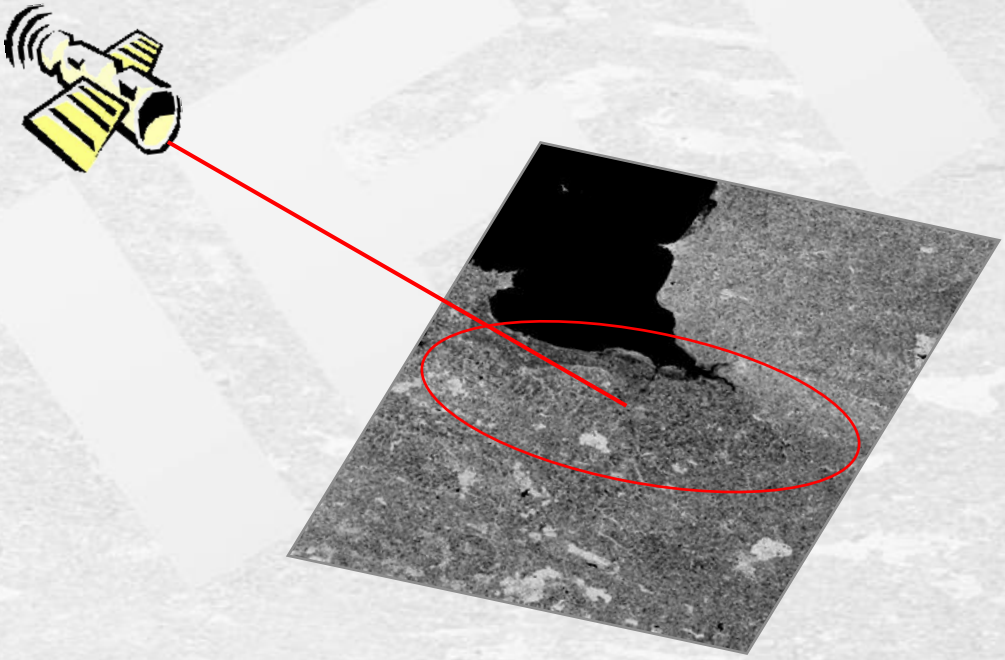
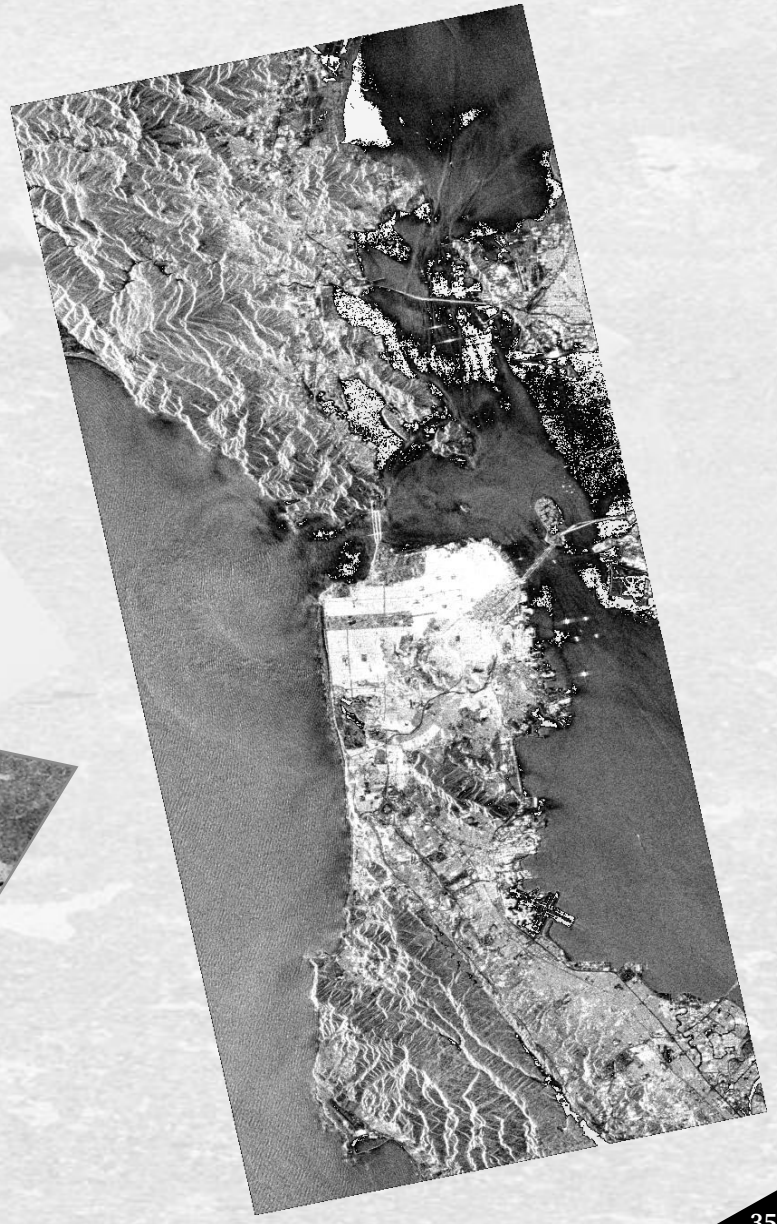
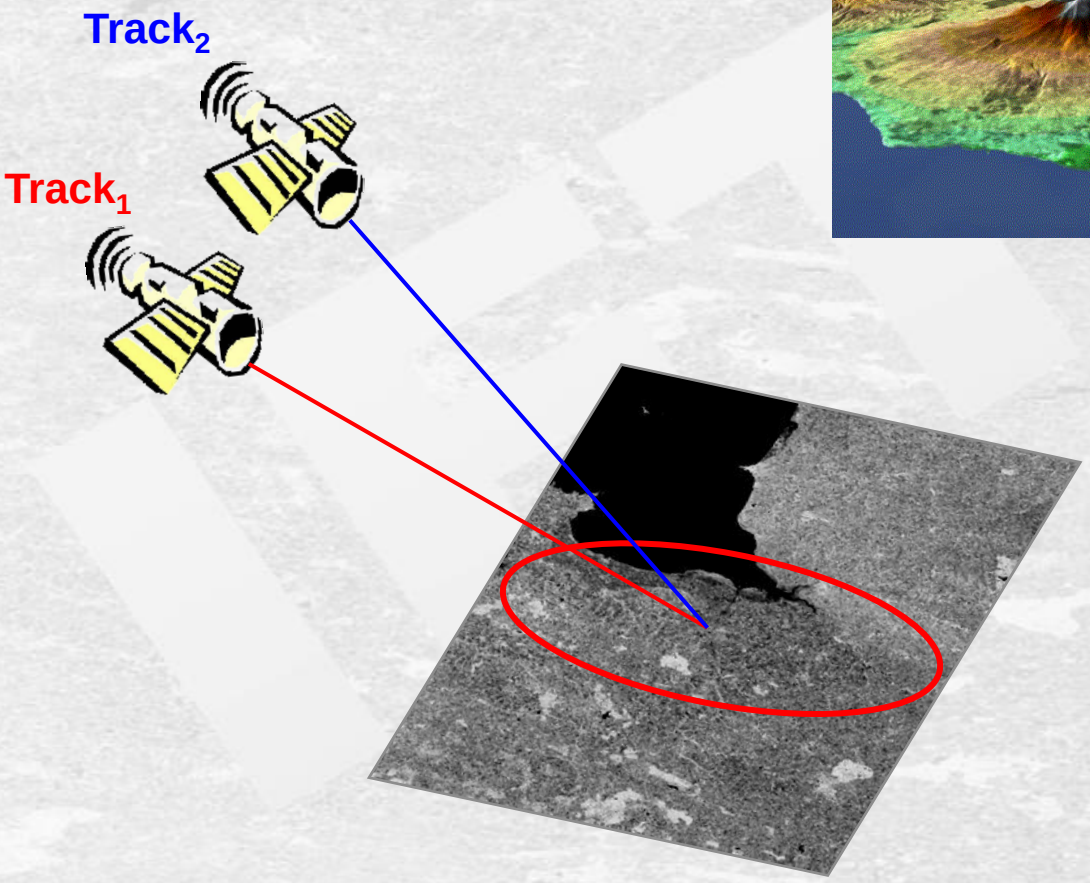
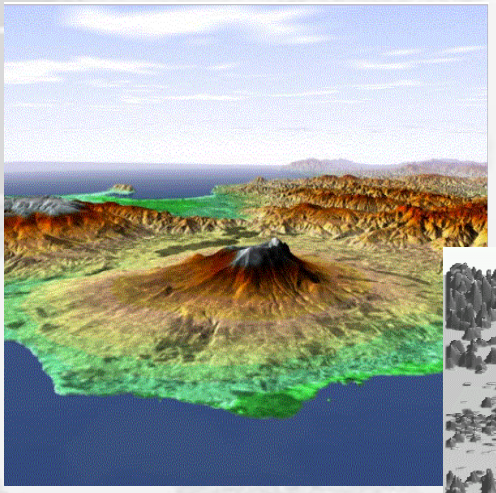
SAR Imaging

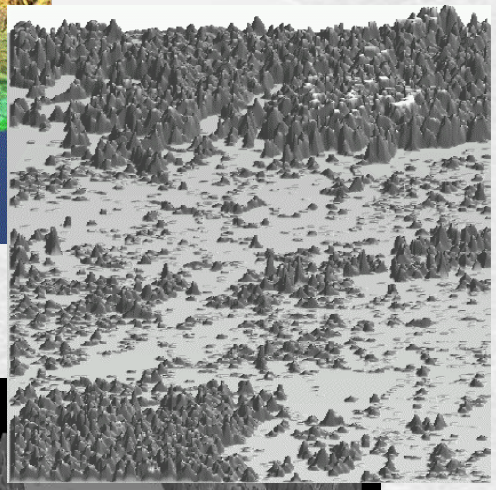


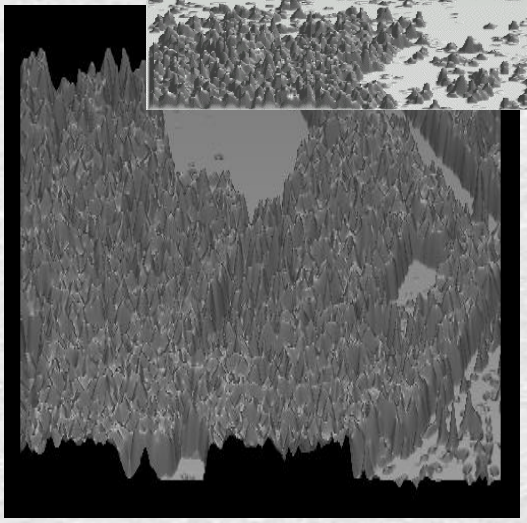


Interferometric SAR Imaging



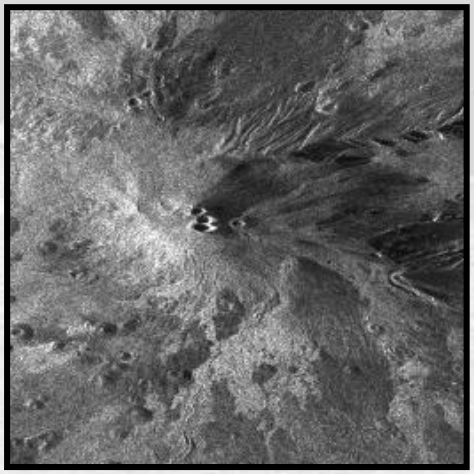




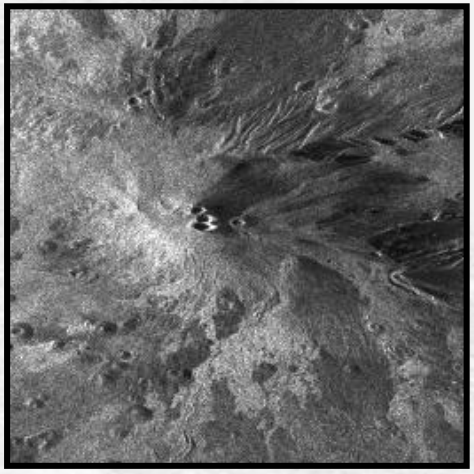


Interferometric SAR Imaging

s_1



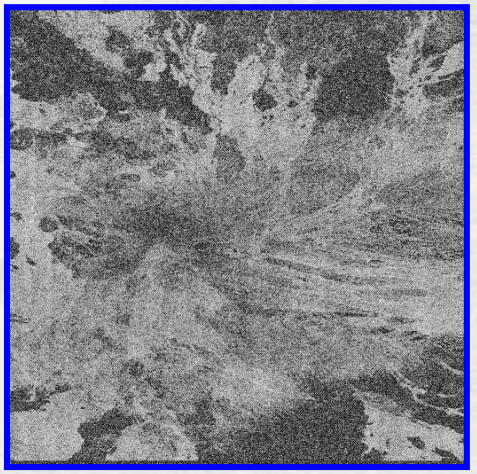
s_2



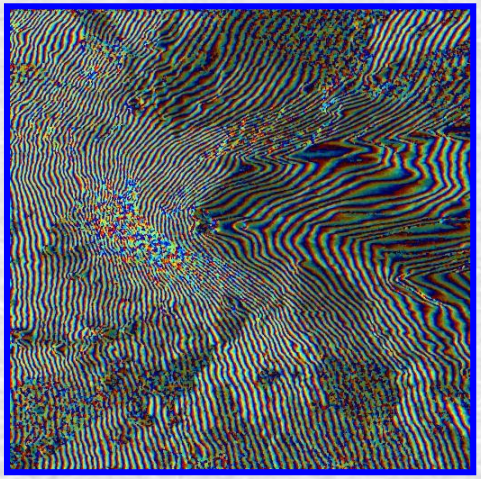
Interferometric coherence γ

$$\gamma = \frac{E\left(s_1 s_2^*\right)}{\sqrt{E\left(s_1 s_1^*\right) E\left(s_2 s_2^*\right)}} = \frac{E\left(s_1 s_2^*\right)}{\sqrt{\bar{I}_1 \bar{I}_2}} = |\gamma| e^{j\phi}$$

$|\gamma|$



ϕ



Phase fringes

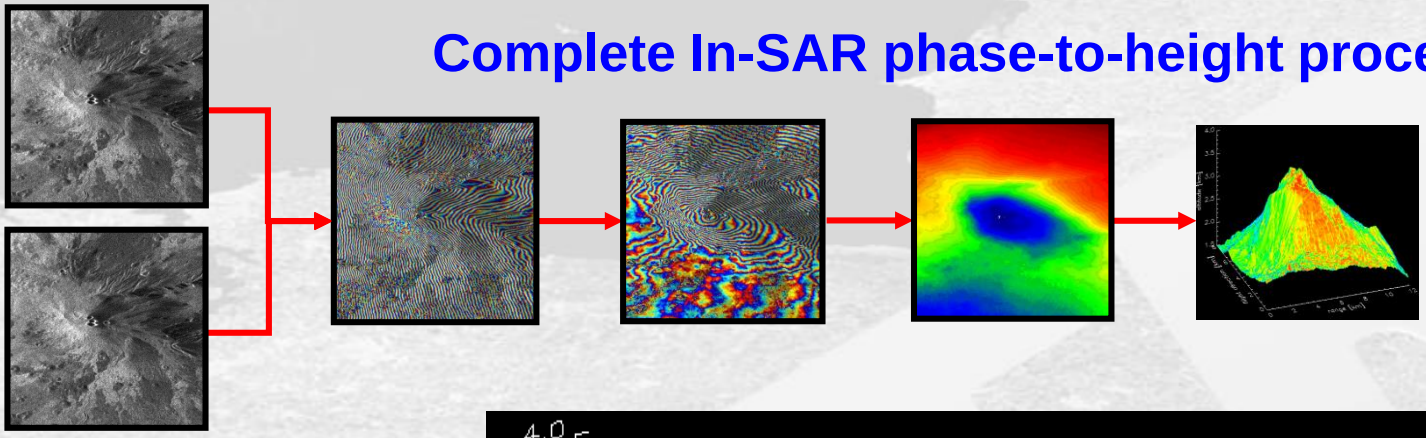
Contour lines

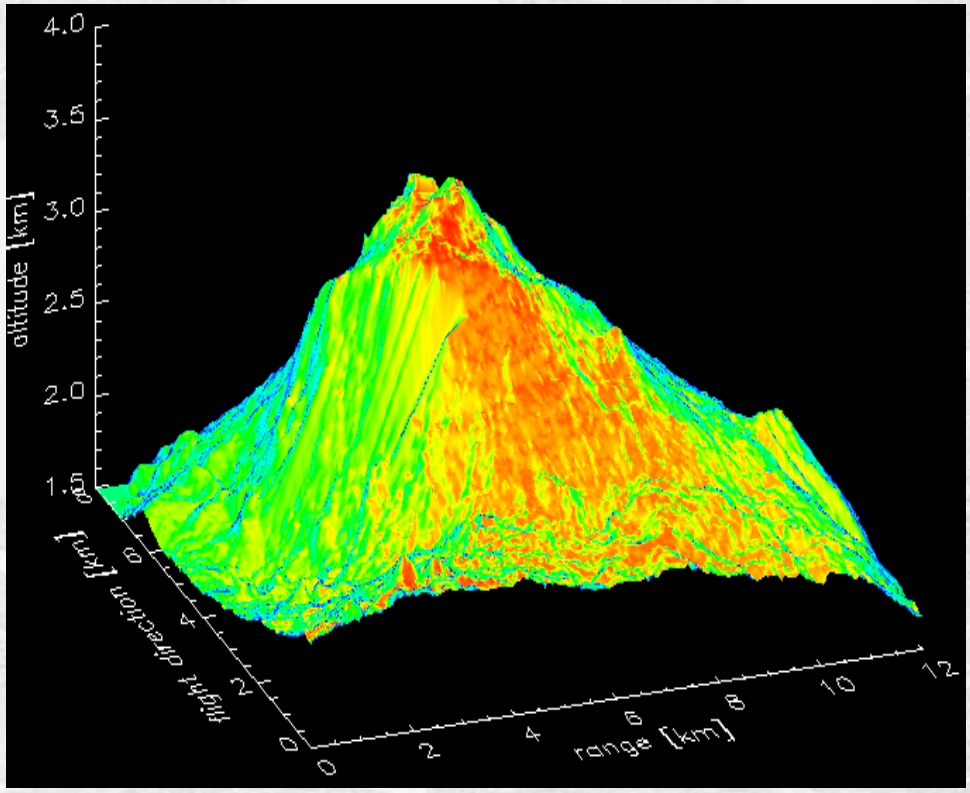
3-D World

$$\phi = \Delta\phi_{1\cdot 2} \approx \Delta\phi_{topo} + \Delta\phi_{fe}$$

Interferometric SAR Imaging

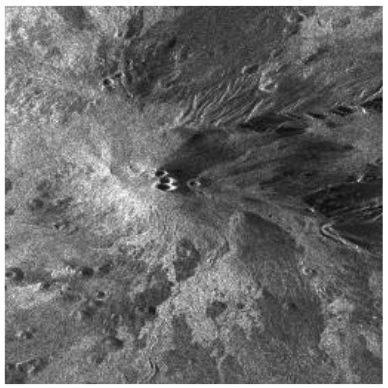
Complete In-SAR phase-to-height processing chain

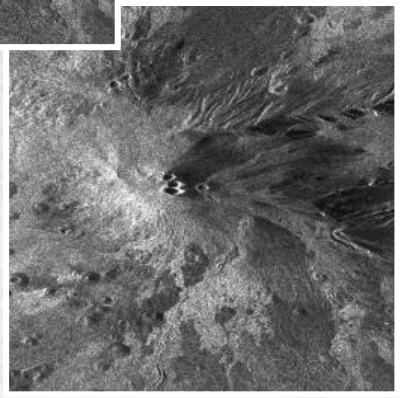


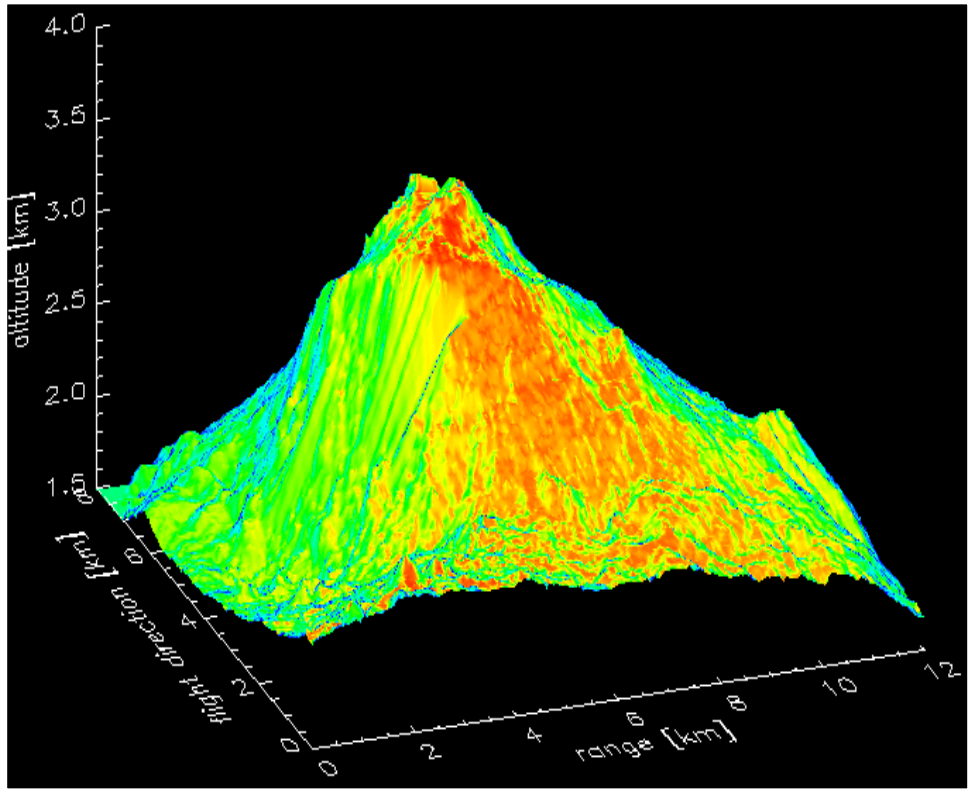


γ

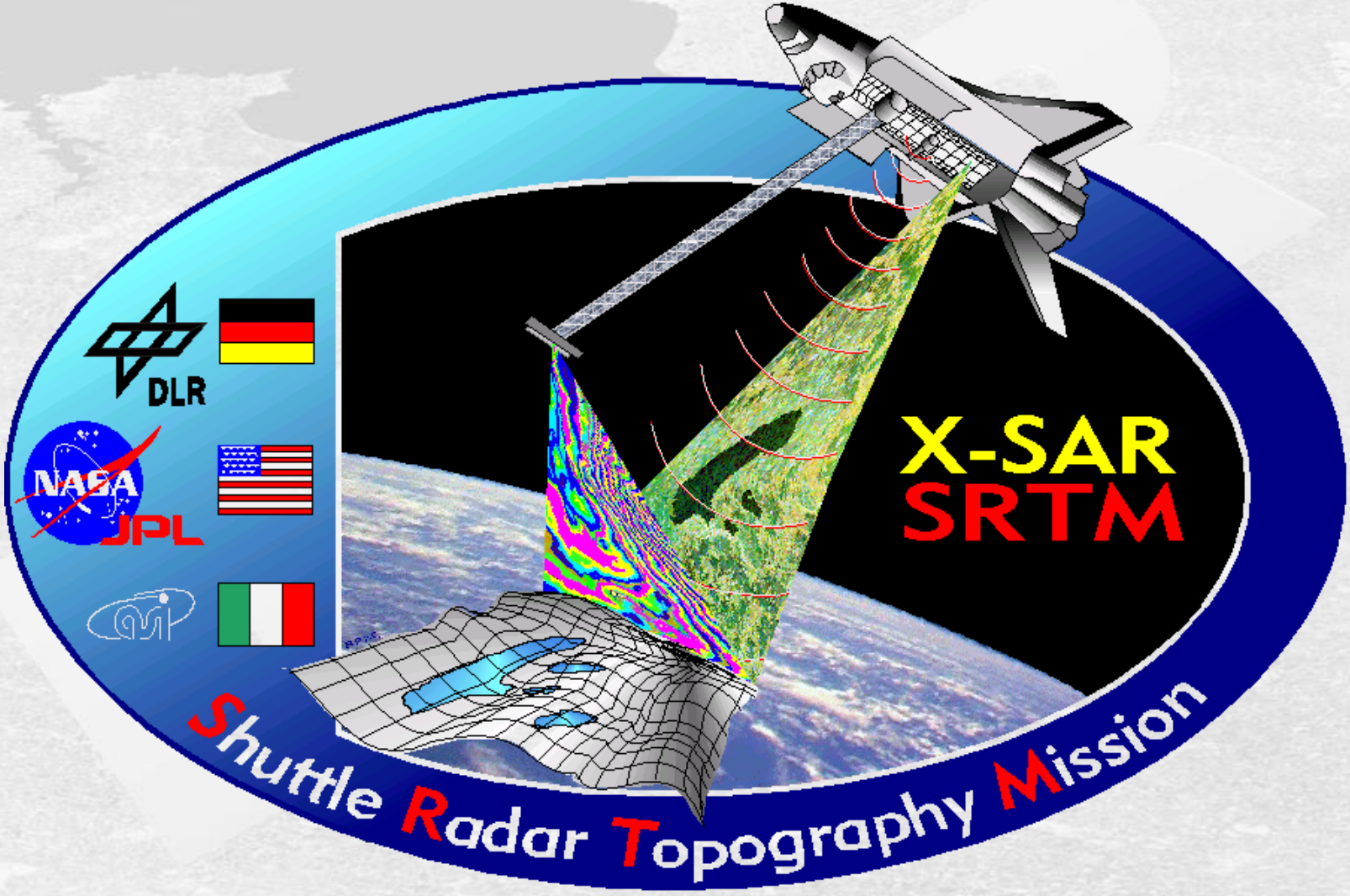
Interferometric SAR Imaging



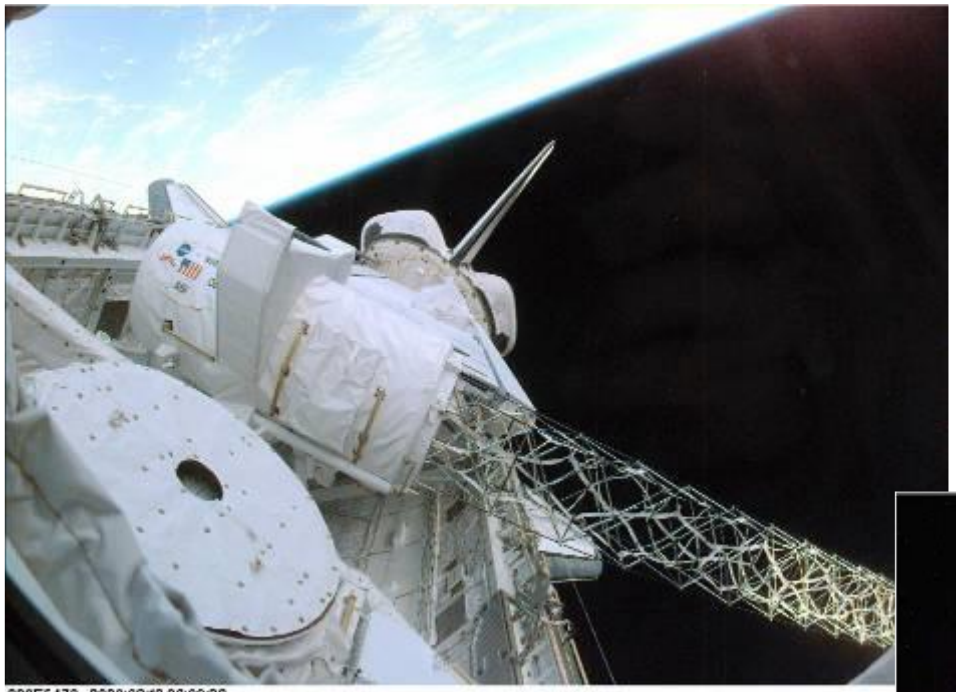


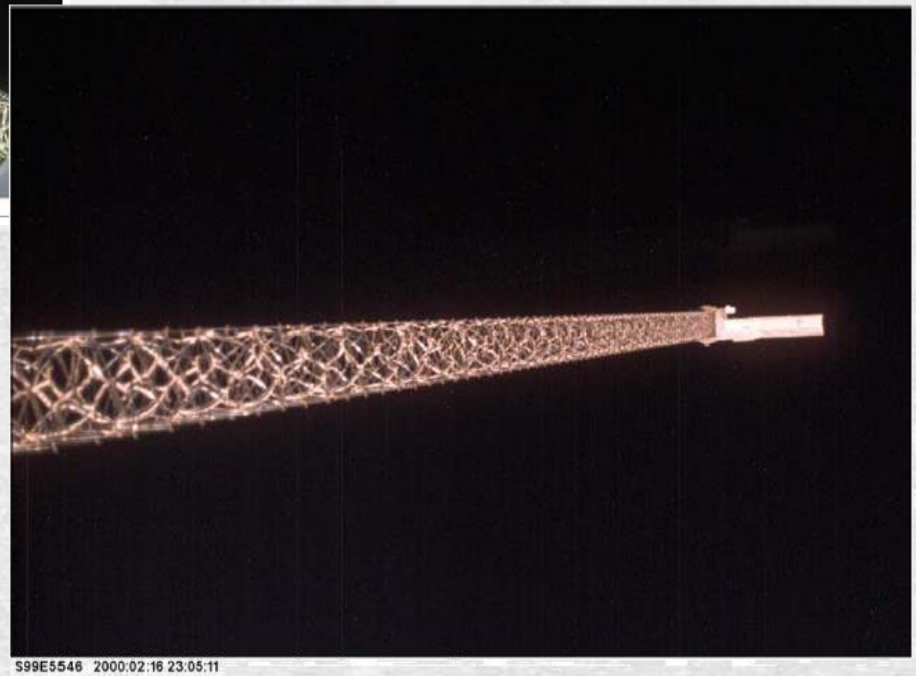


Interferometric SAR Imaging



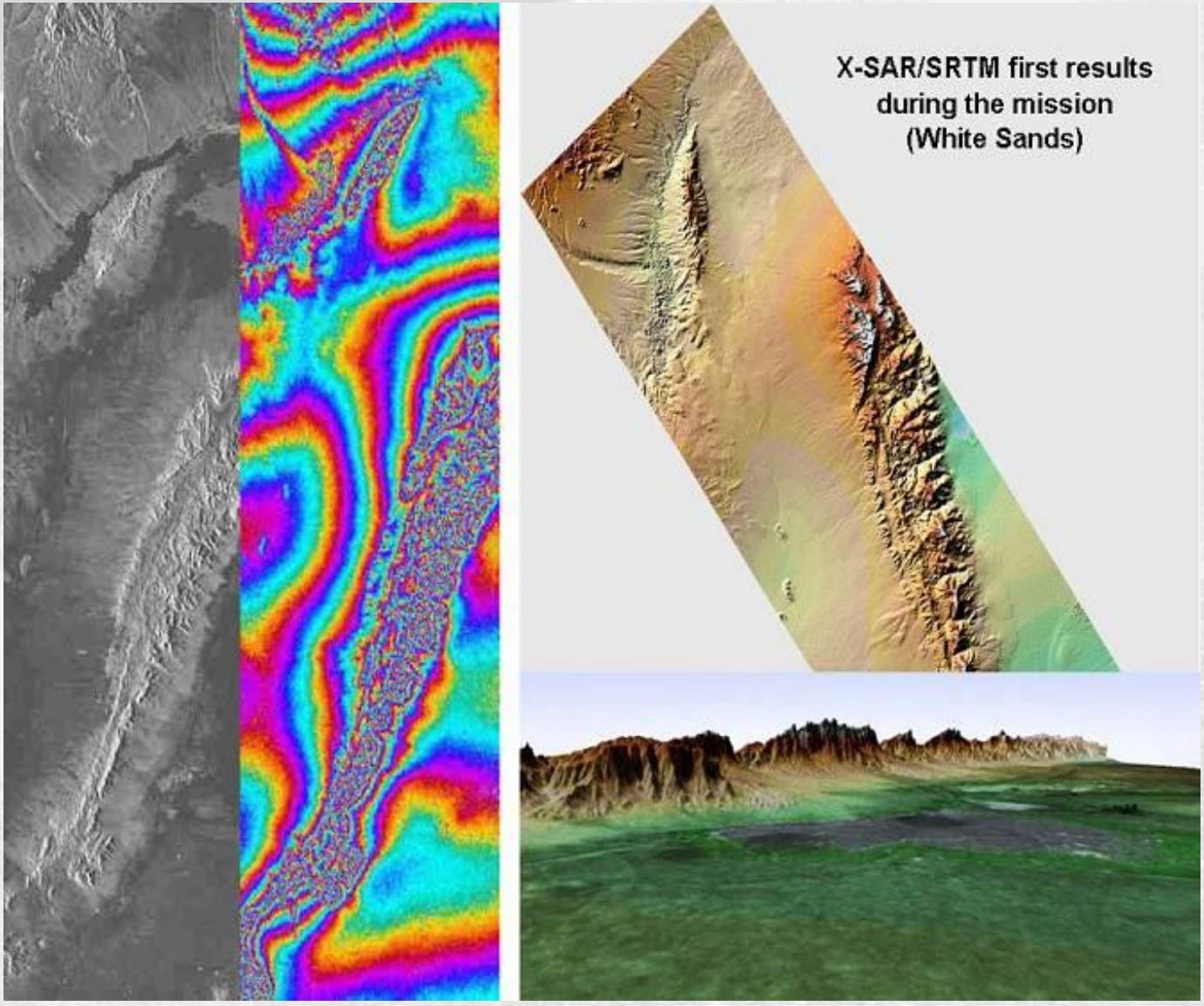
Interferometric SAR Imaging



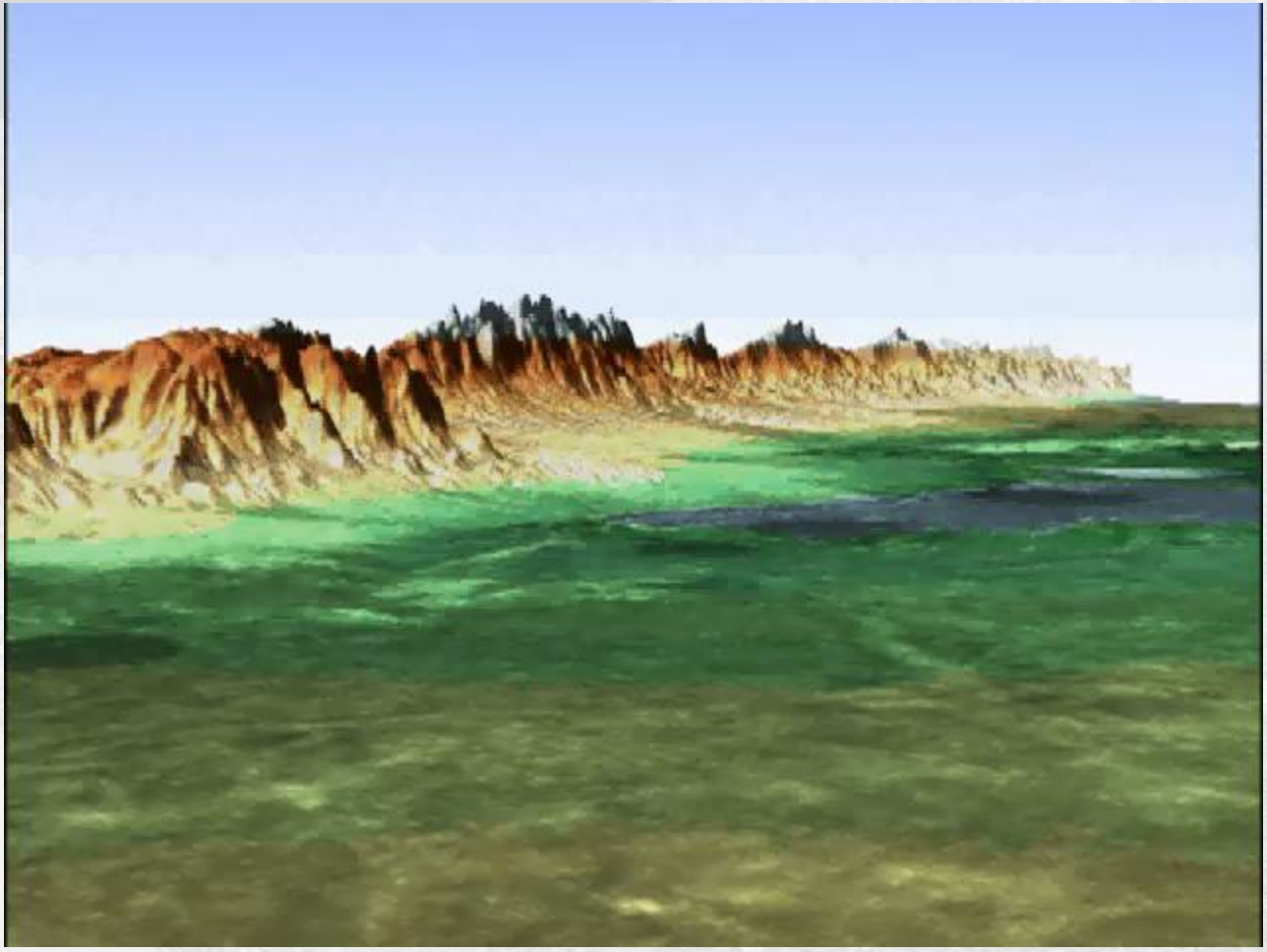


Interferometric SAR Imaging

SRTM / X-SAR Image of Area around White Sands - New Mexico (USA)

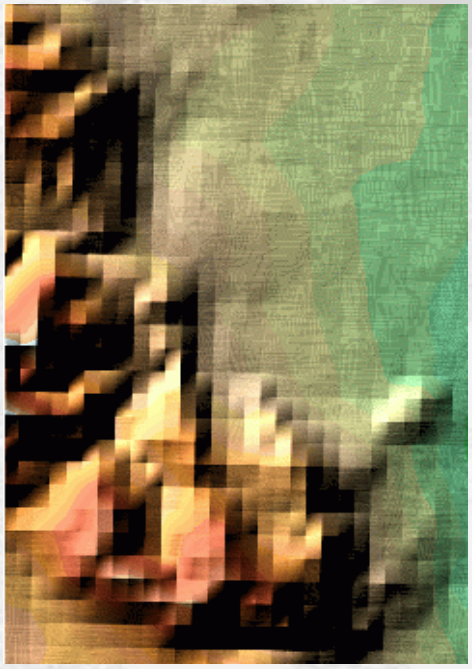


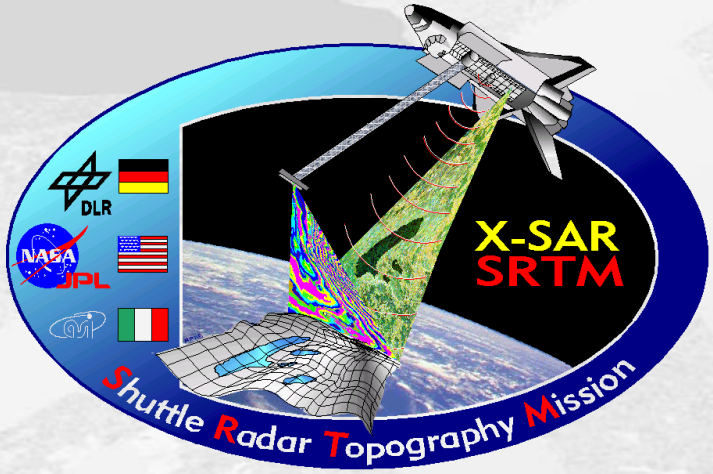
Interferometric SAR Imaging



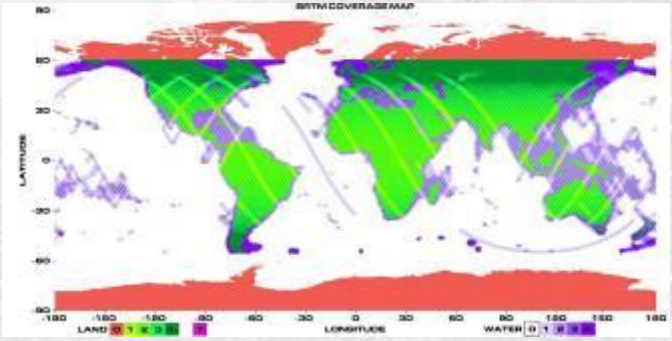
Interferometric SAR Imaging

SRTM / X-SAR





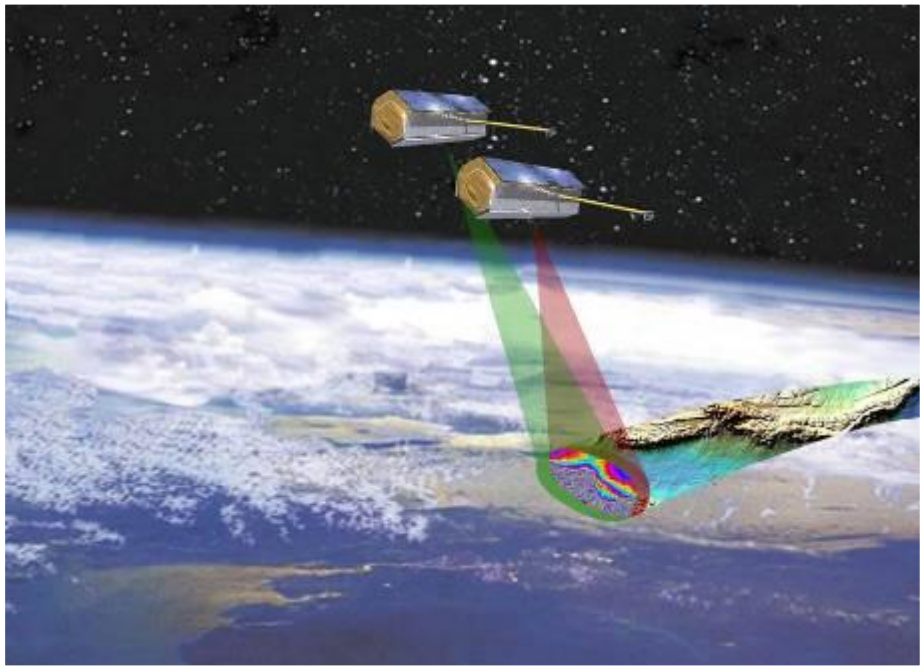
February 2000
Single Pol Channel



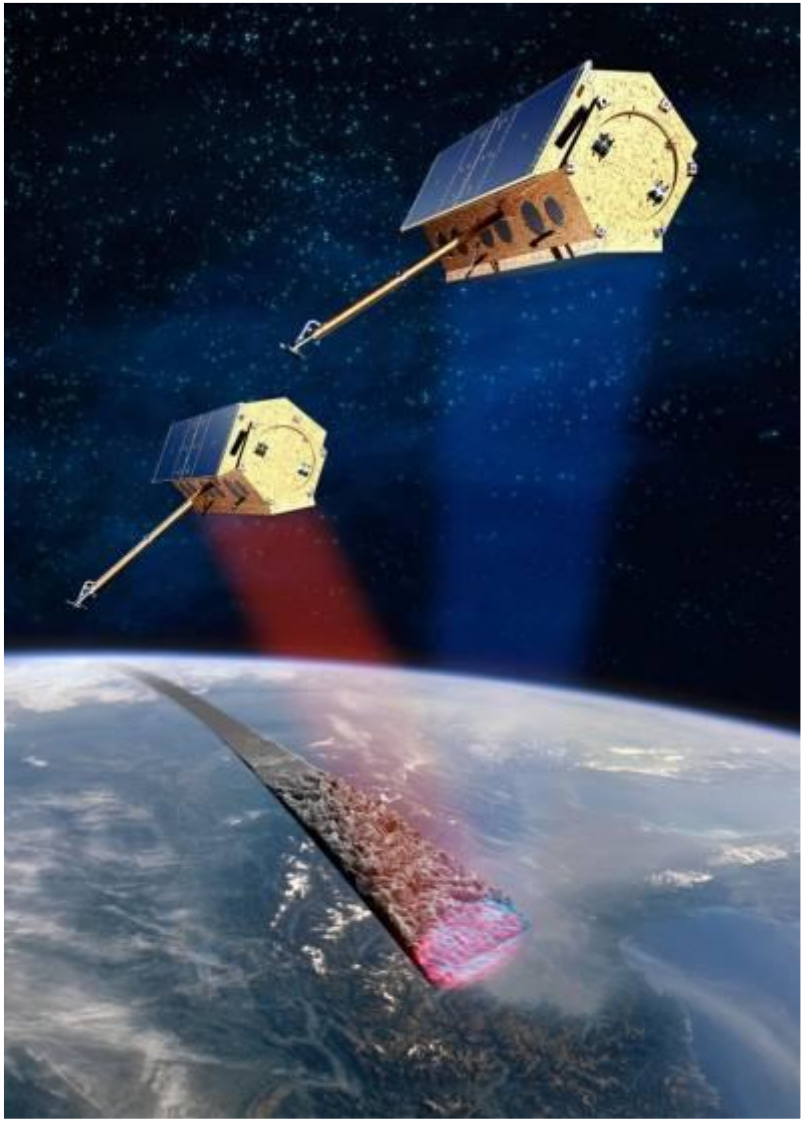
GTOP-030
Spatial Resolution: 30 Arc Sec = 1km
Height Accuracy : 100 m – 500 m

SRTM: X-SAR
Spatial Resolution: 1 Arc Sec = 30m
Height Accuracy : 6-10 m

Interferometric SAR Imaging

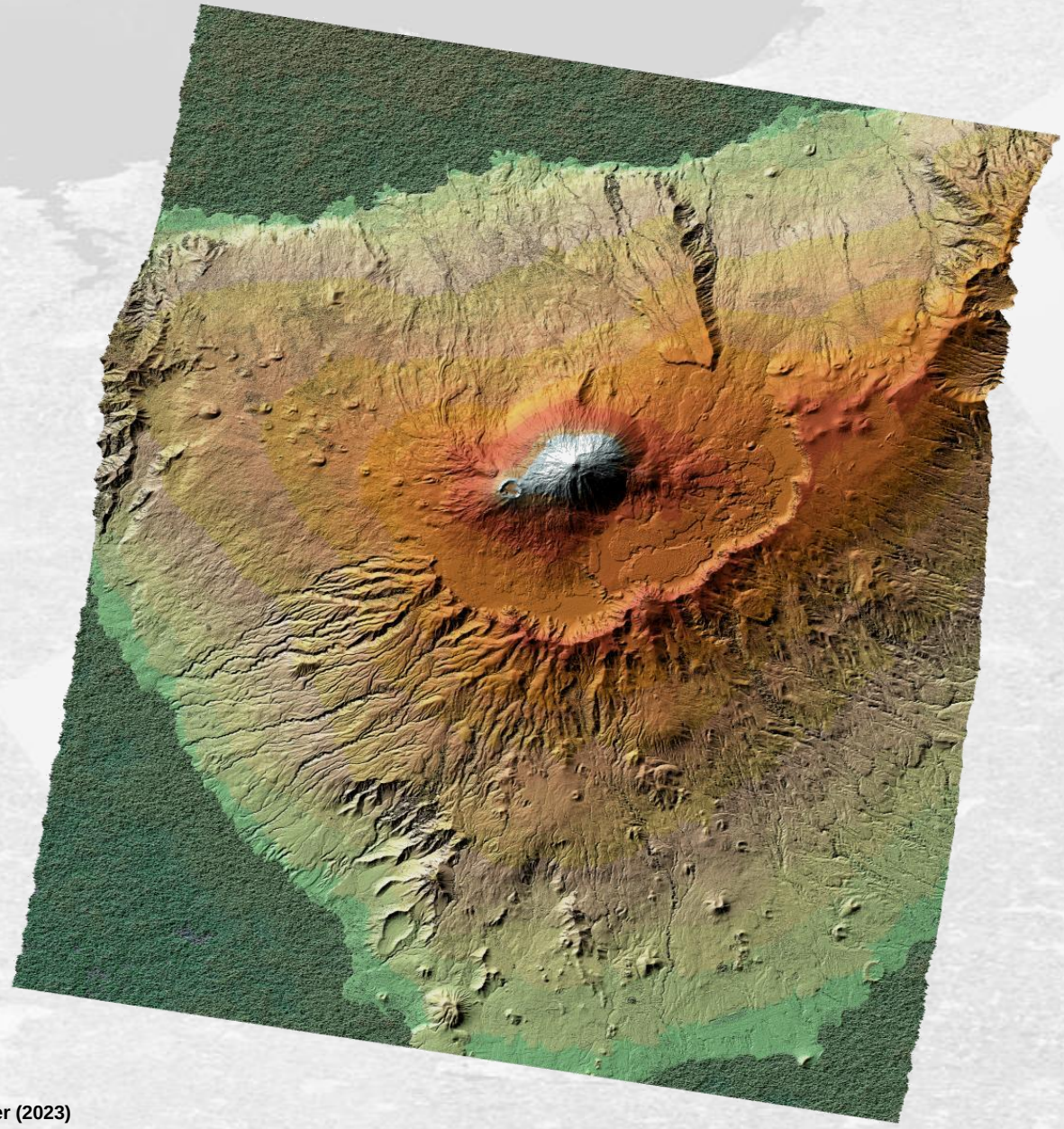


TerraSAR - X



Interferometric SAR Imaging

Interferometric SAR Imaging

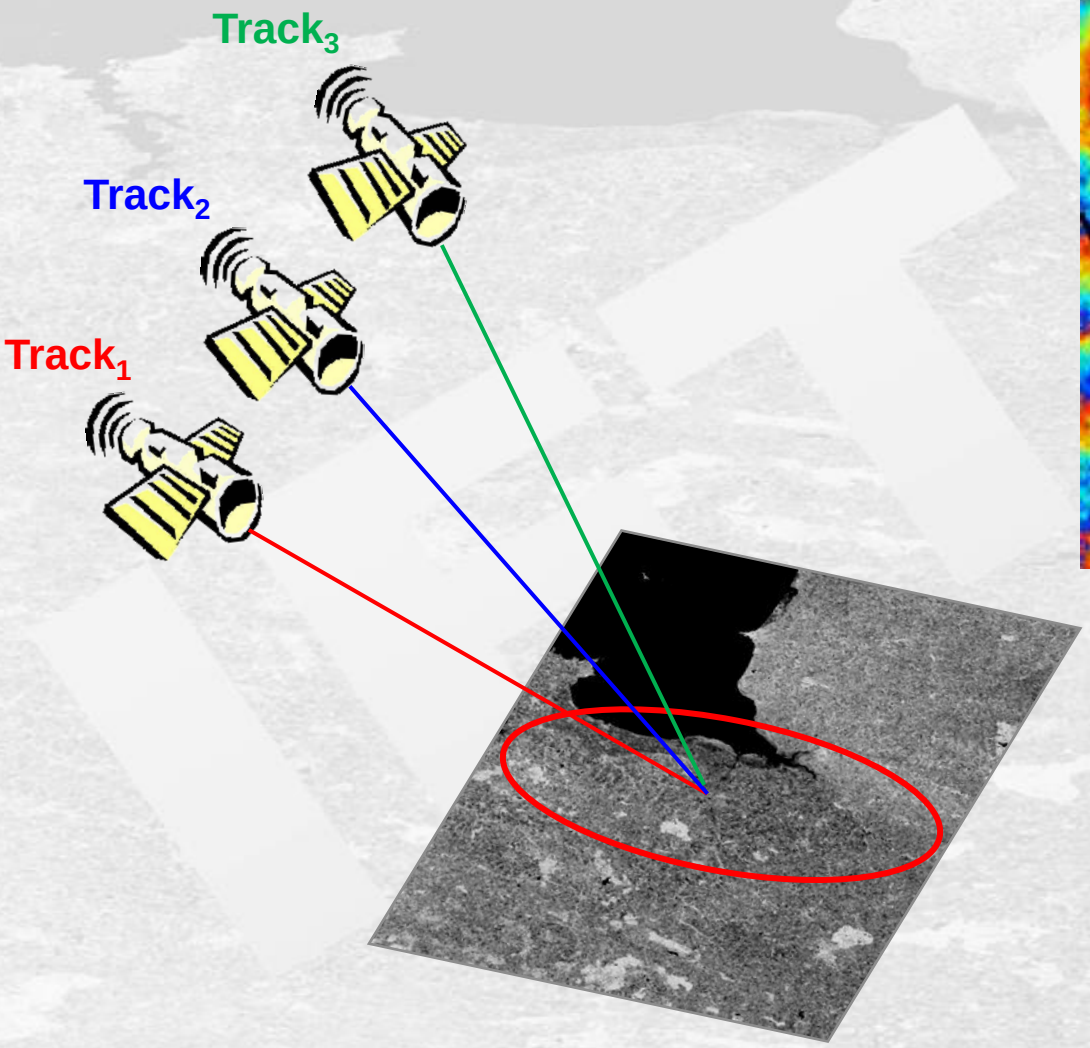


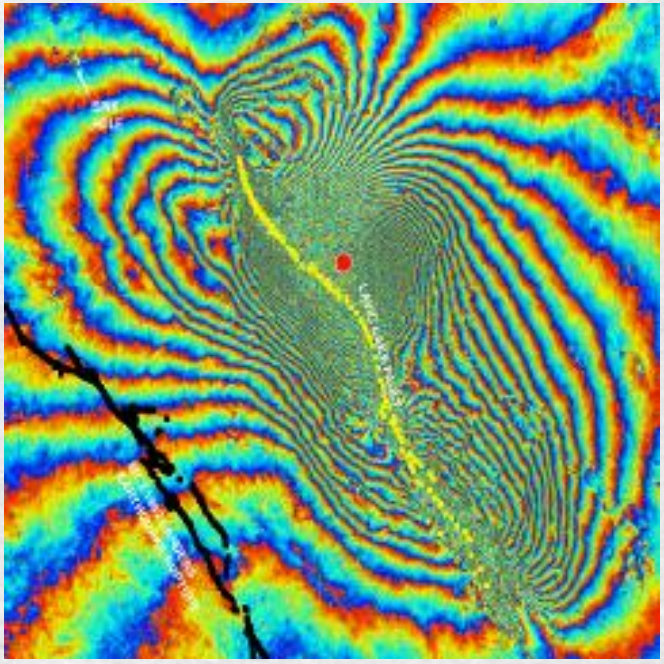
Mont ETNA (2012)

Interferometric SAR Imaging

Mont ETNA (2012)

Differential In-SAR Imaging





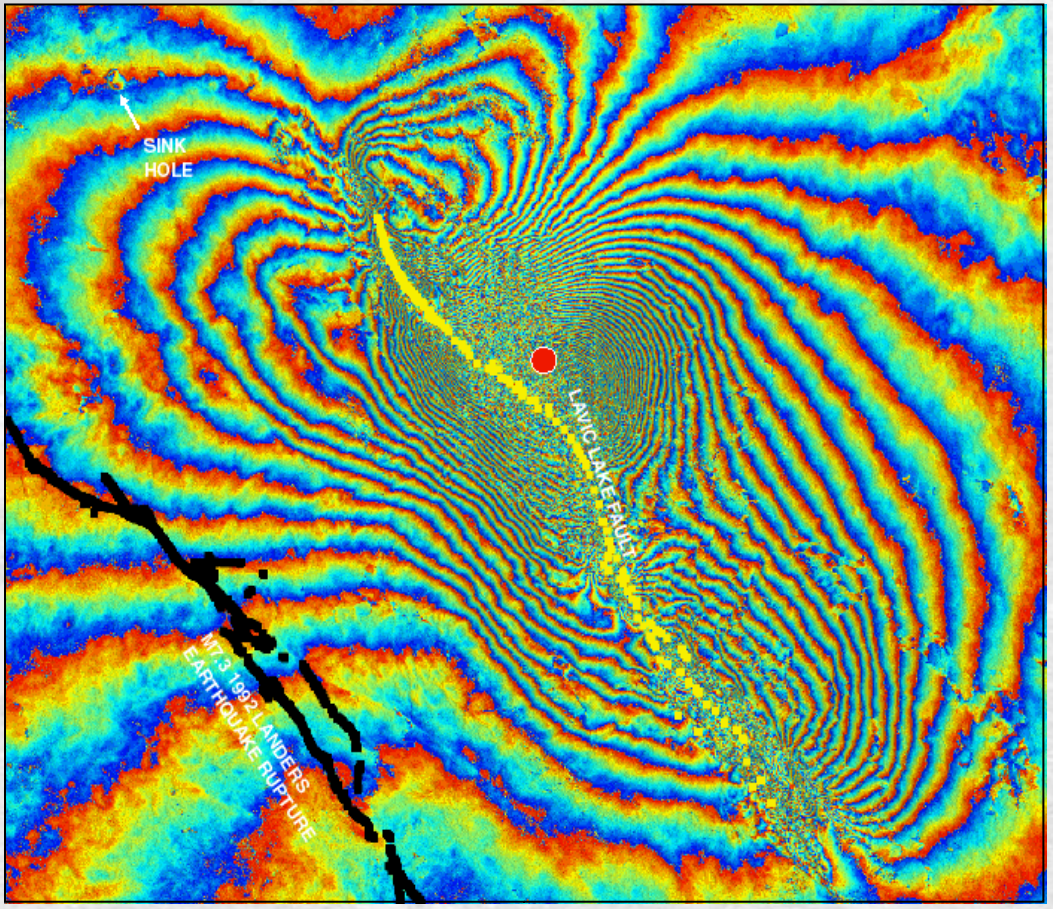
Differential In-SAR Imaging

Differential Interferogram - Hector Mine (California, USA)

Hearthsquake 16 October 1999

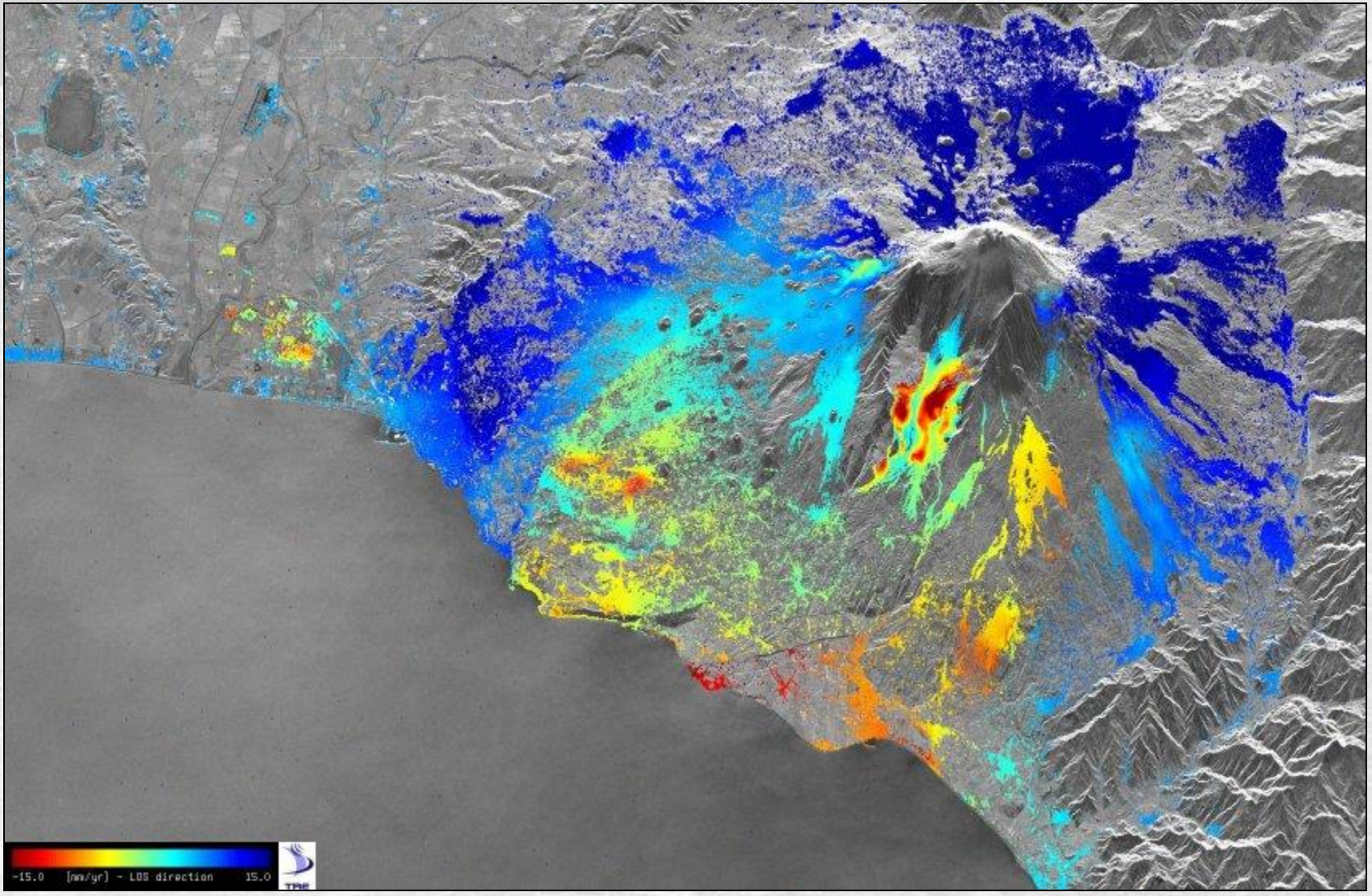
Each color fringe corresponds to a 2.8 cm displacement.

Temporal Basis = 35 days

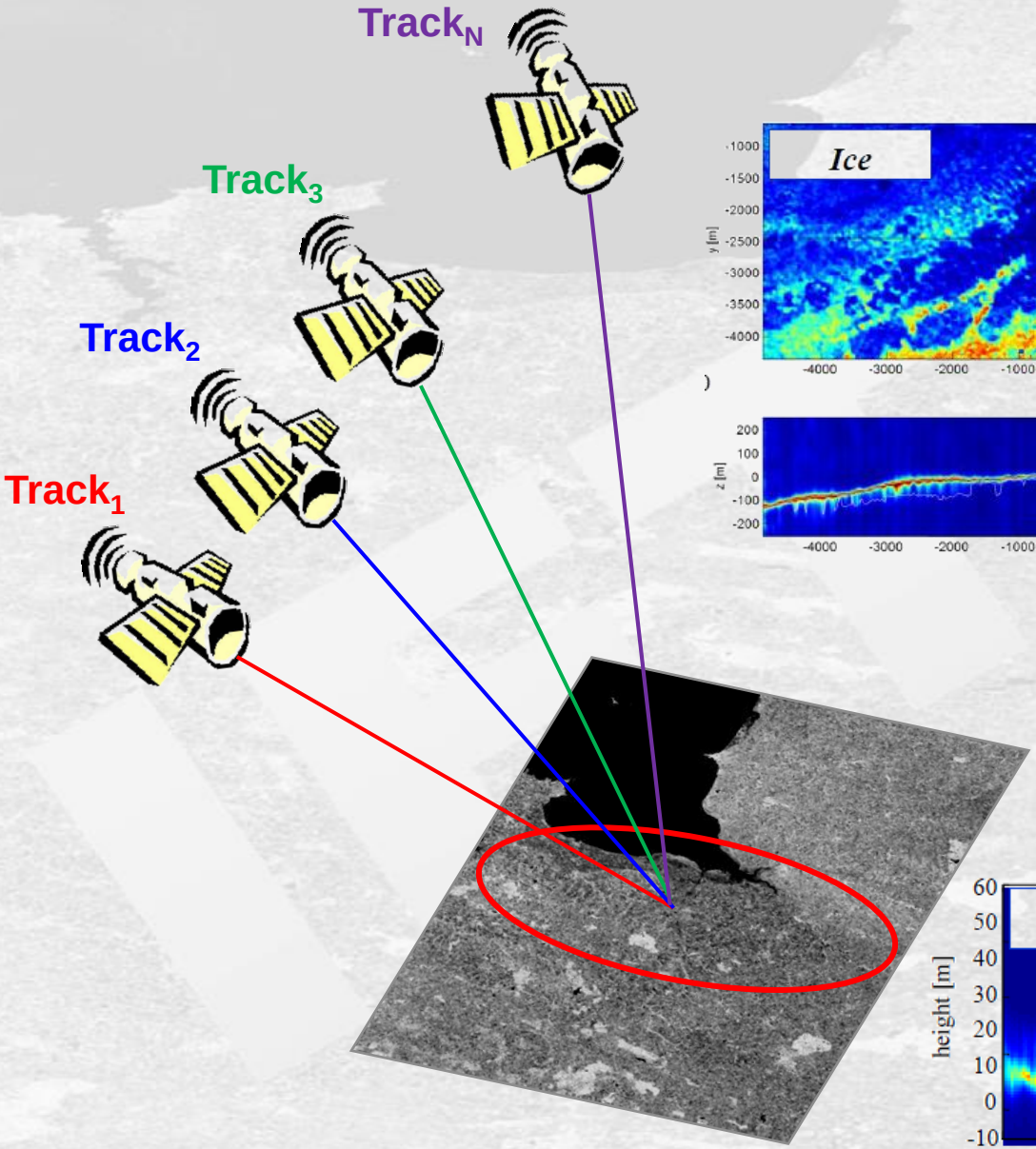


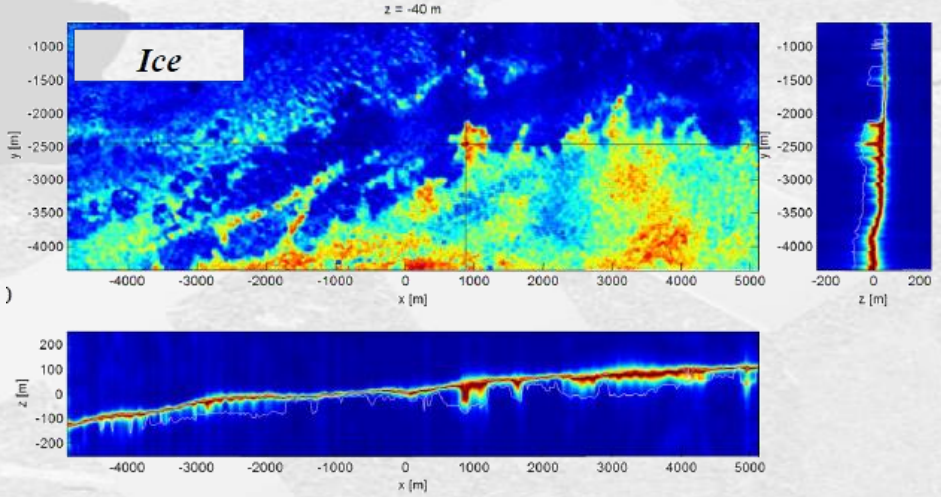
Courtesy of Dr J. Mallorqui, UPC, Barcelona, Spain

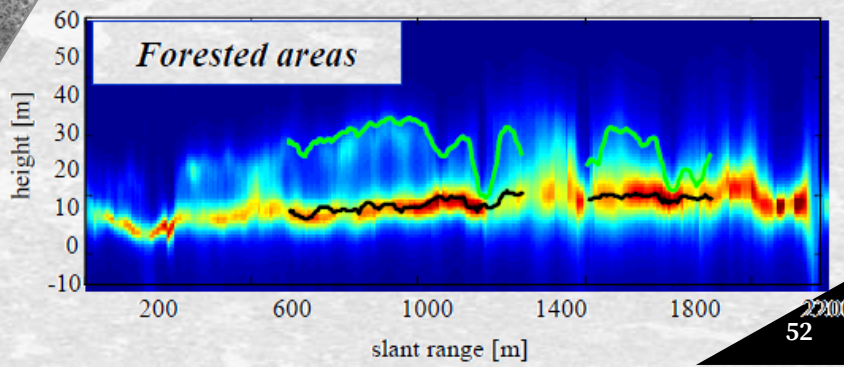
Differential In-SAR Imaging



Tomography SAR Imaging



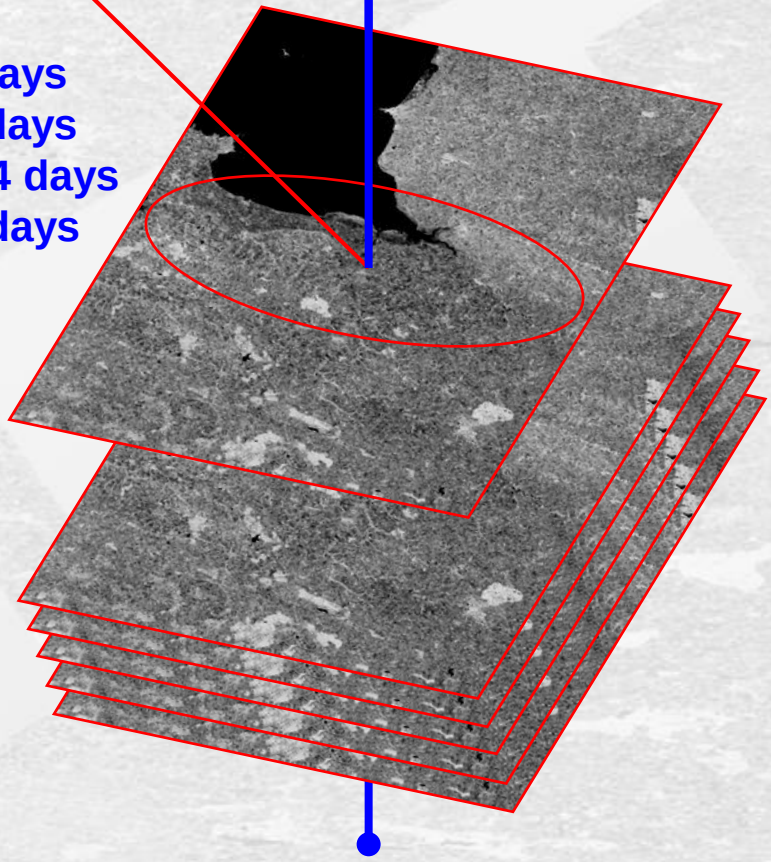




Time series SAR Imaging

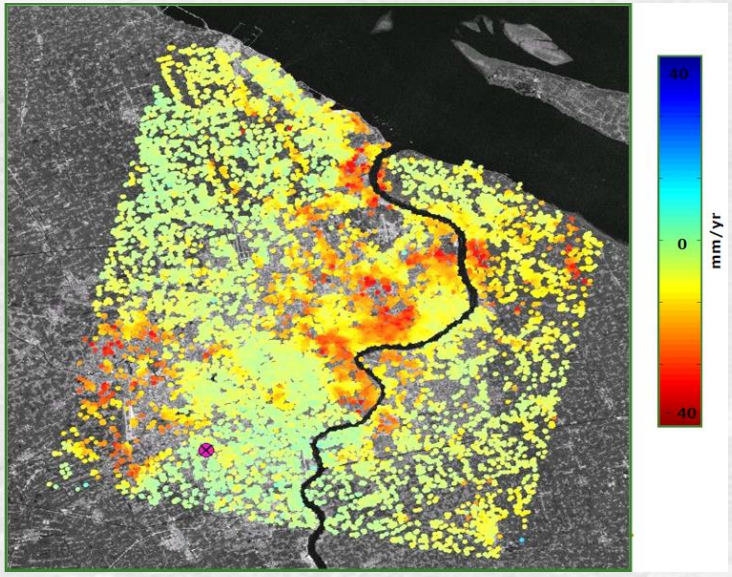
Track$_{1..N}$

time



Revisit time :

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

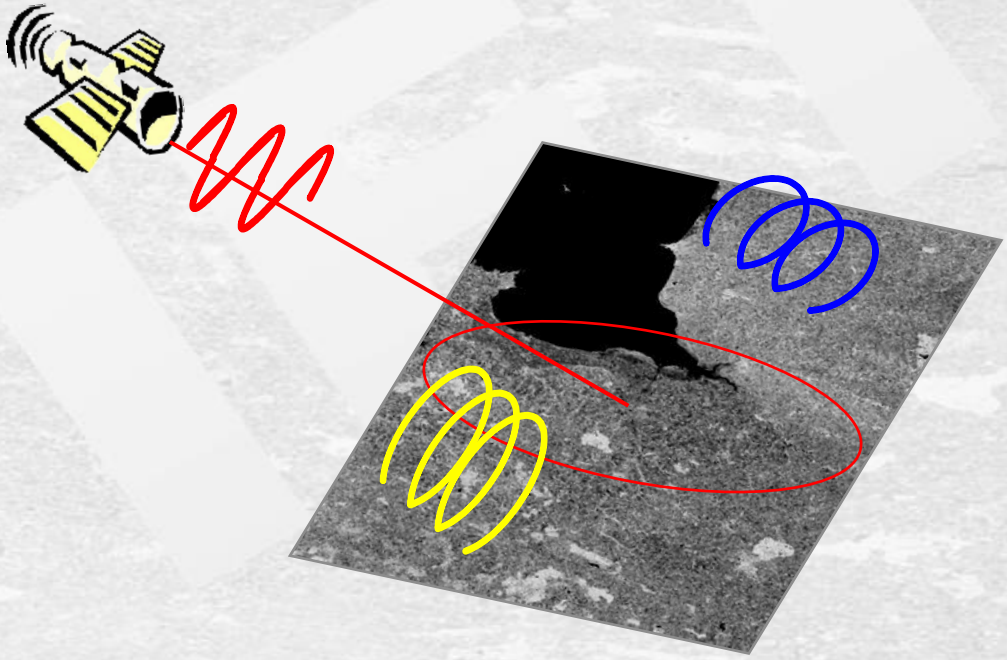


Subsidence Monitoring

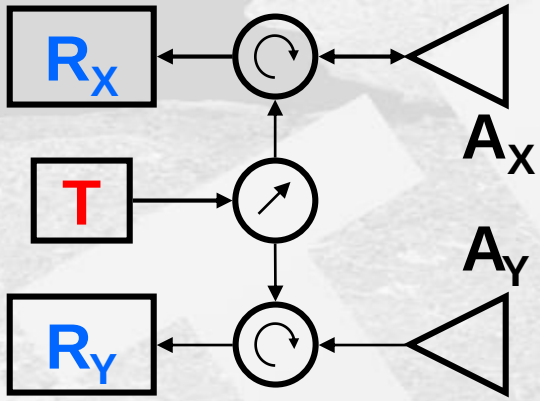
Permanent scatterers
Coherent scatterers

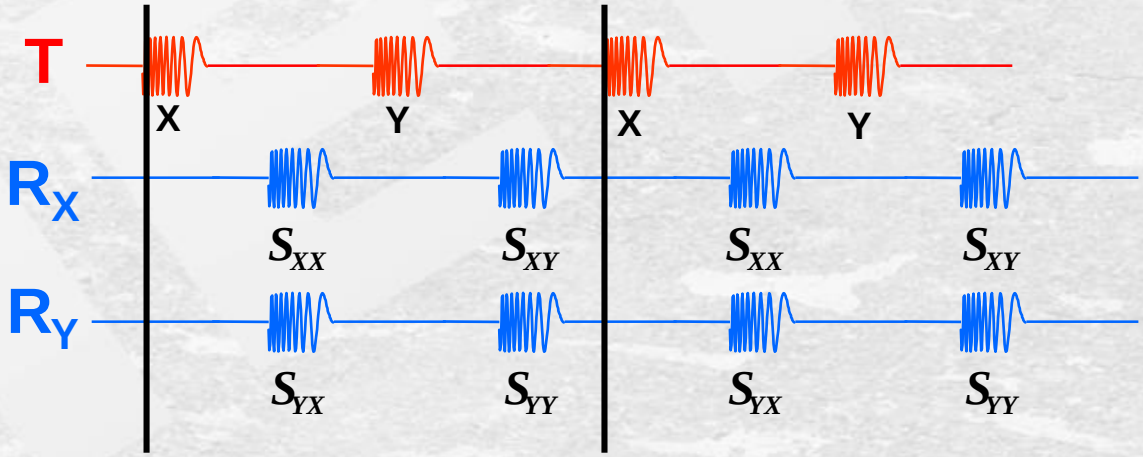
Polarimetry = scatterer type

Polarimetric SAR Imaging

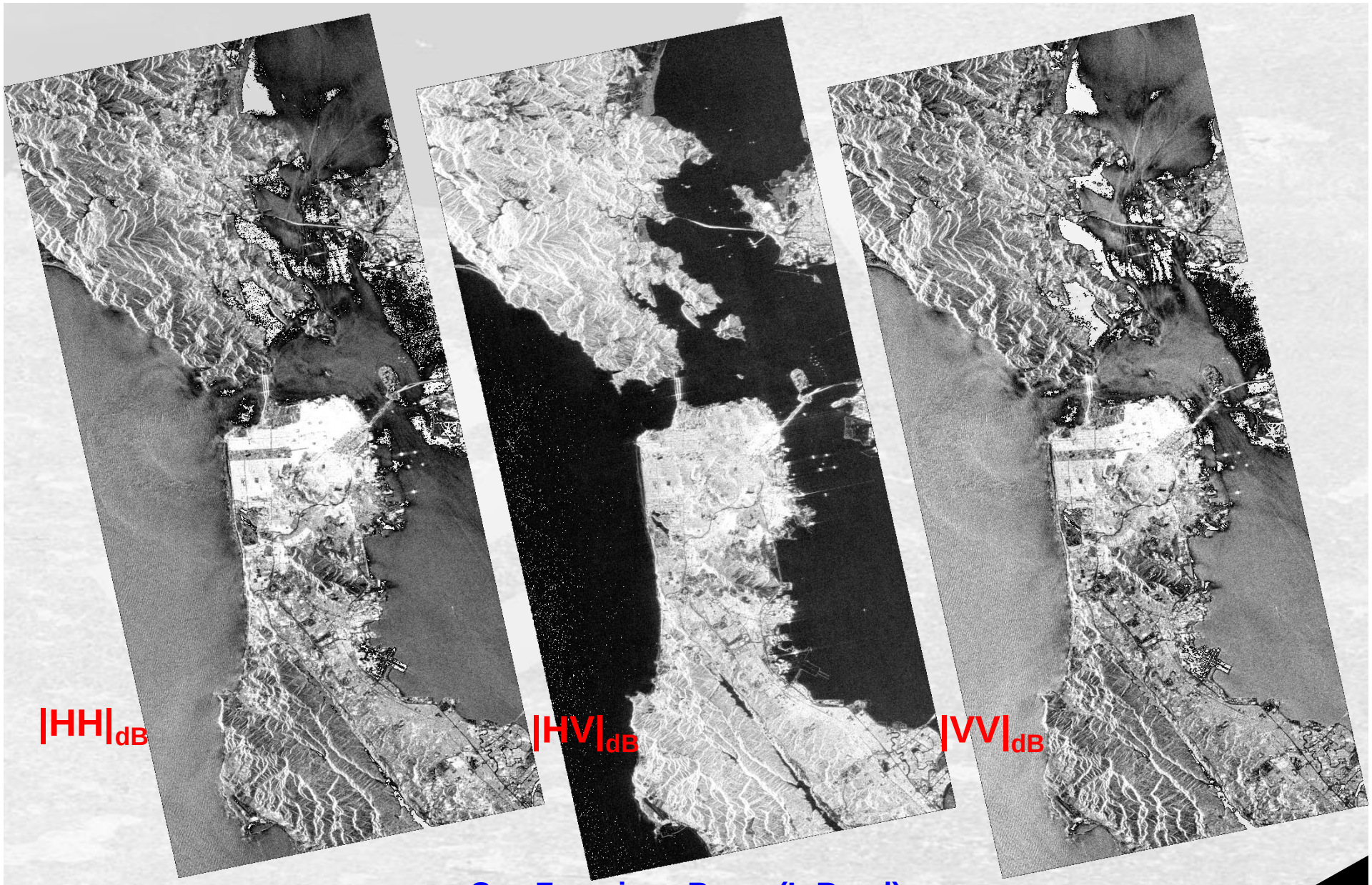


Polarimetric SAR Imaging



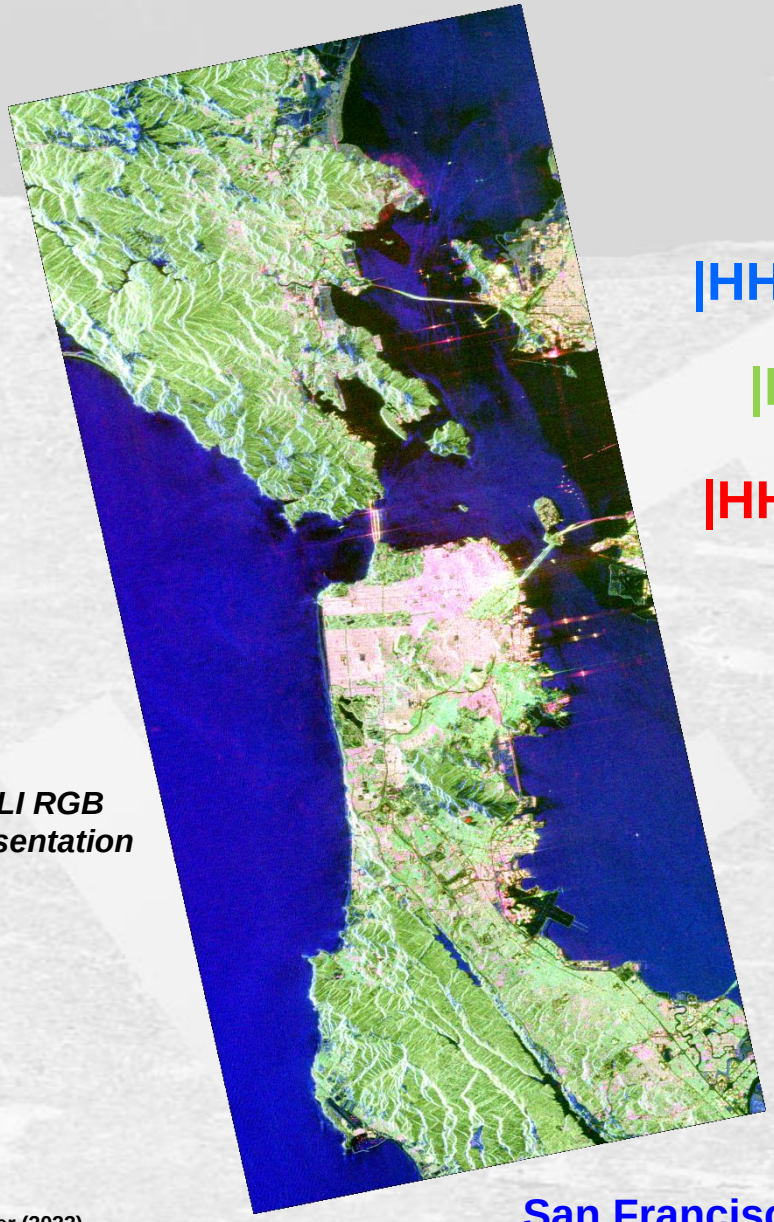


Polarimetric SAR Imaging



San Francisco Bay – (L-Band)

Polarimetric SAR Imaging

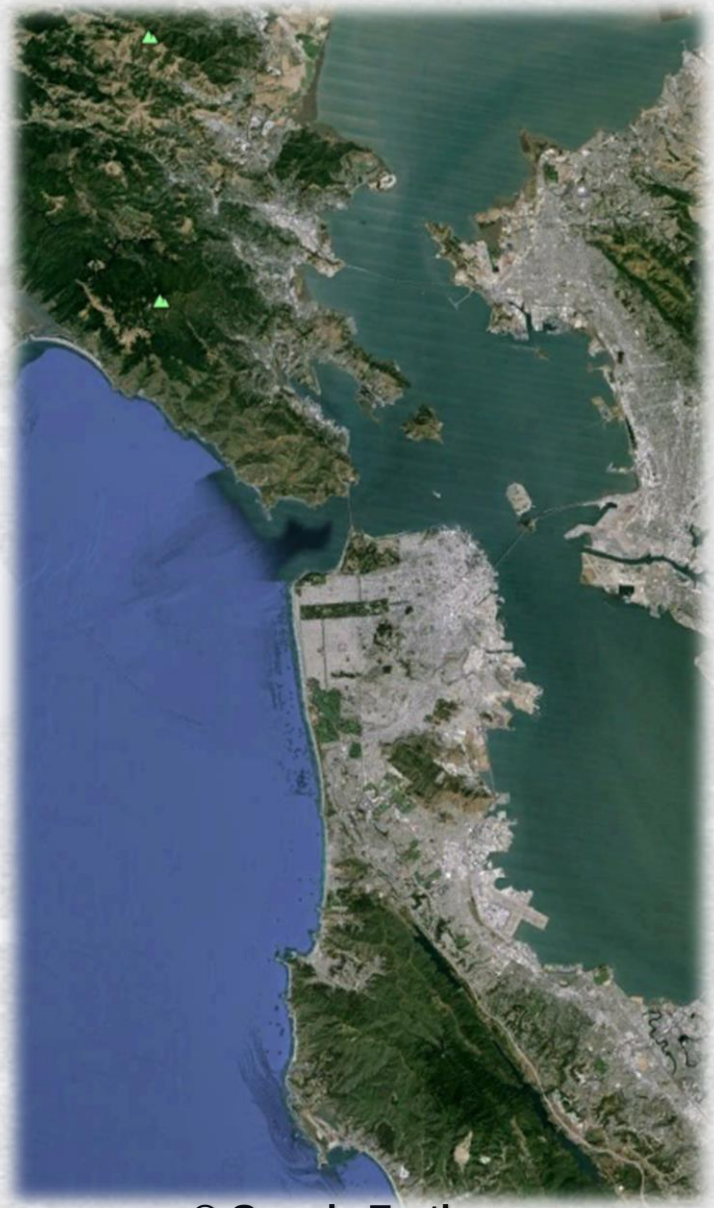


PAULI RGB Representation

$|HH+VV|_{dB}$

$|HV|_{dB}$

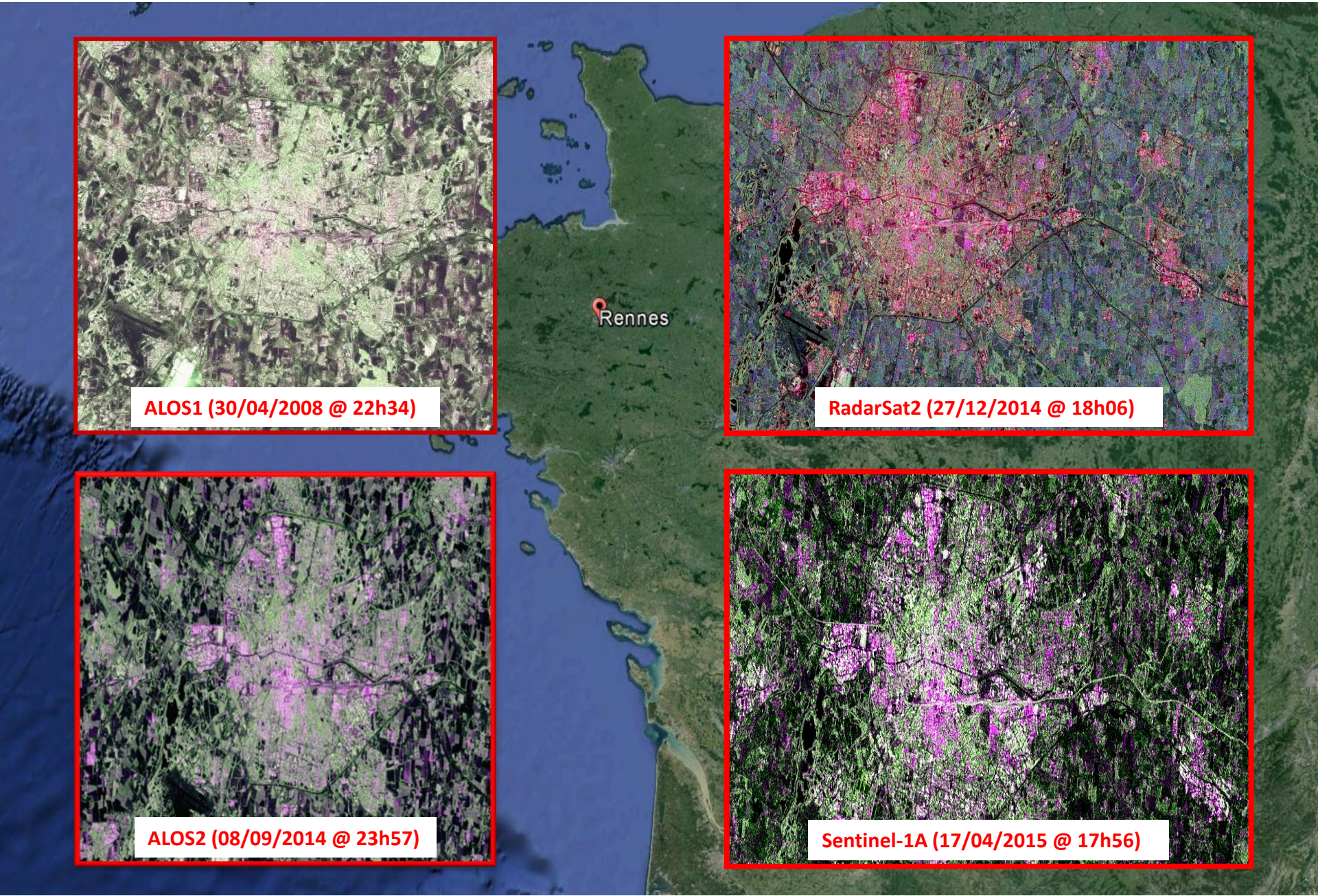
$|HH-VV|_{dB}$



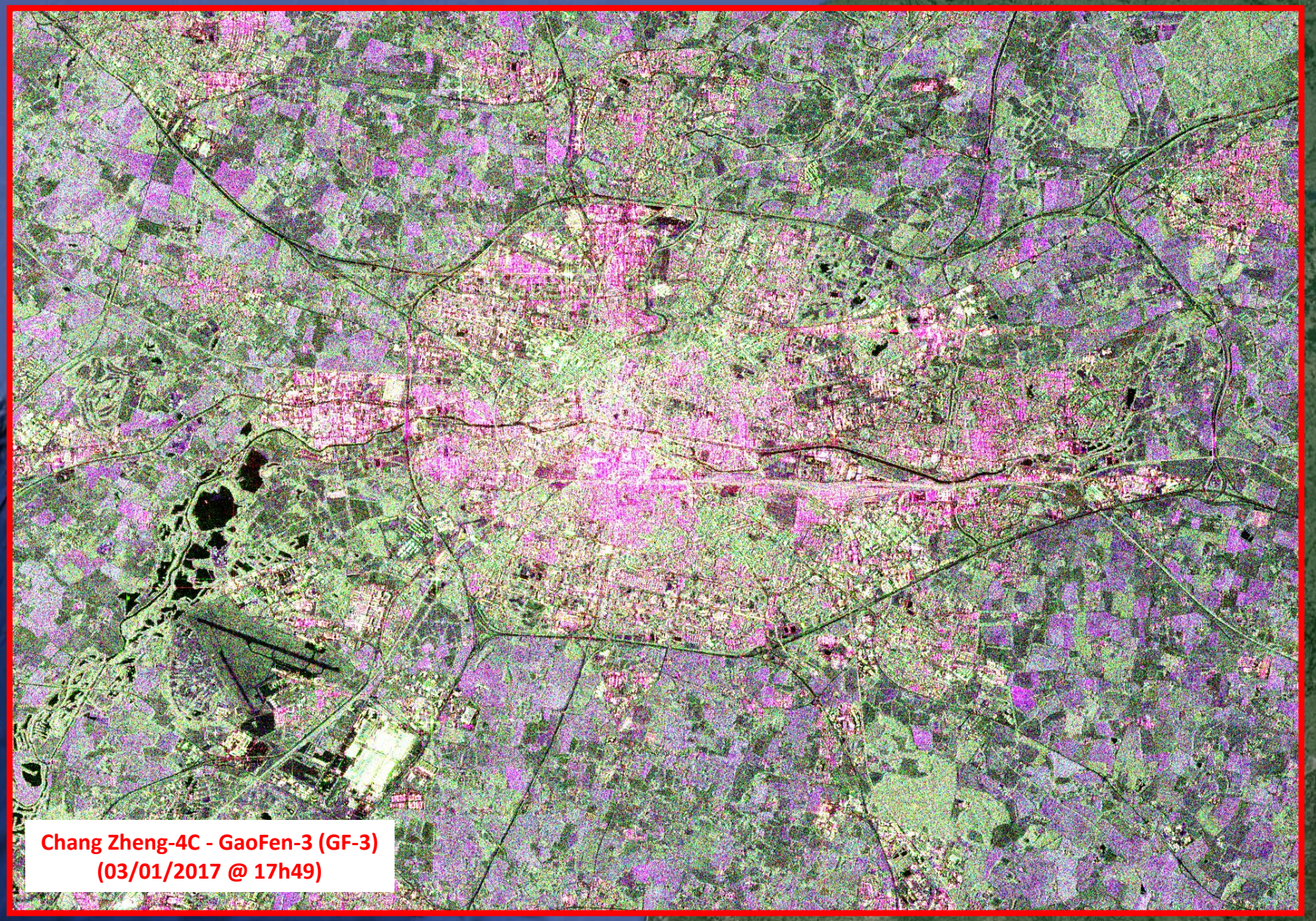
San Francisco Bay – (L-Band)

© Google Earth

Polarimetric SAR Imaging



Polarimetric SAR Imaging



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

Outline

FREQUENCY BANDS
- Range-Azimuth Resolution
- Bio- & Geo-Physical Parameters

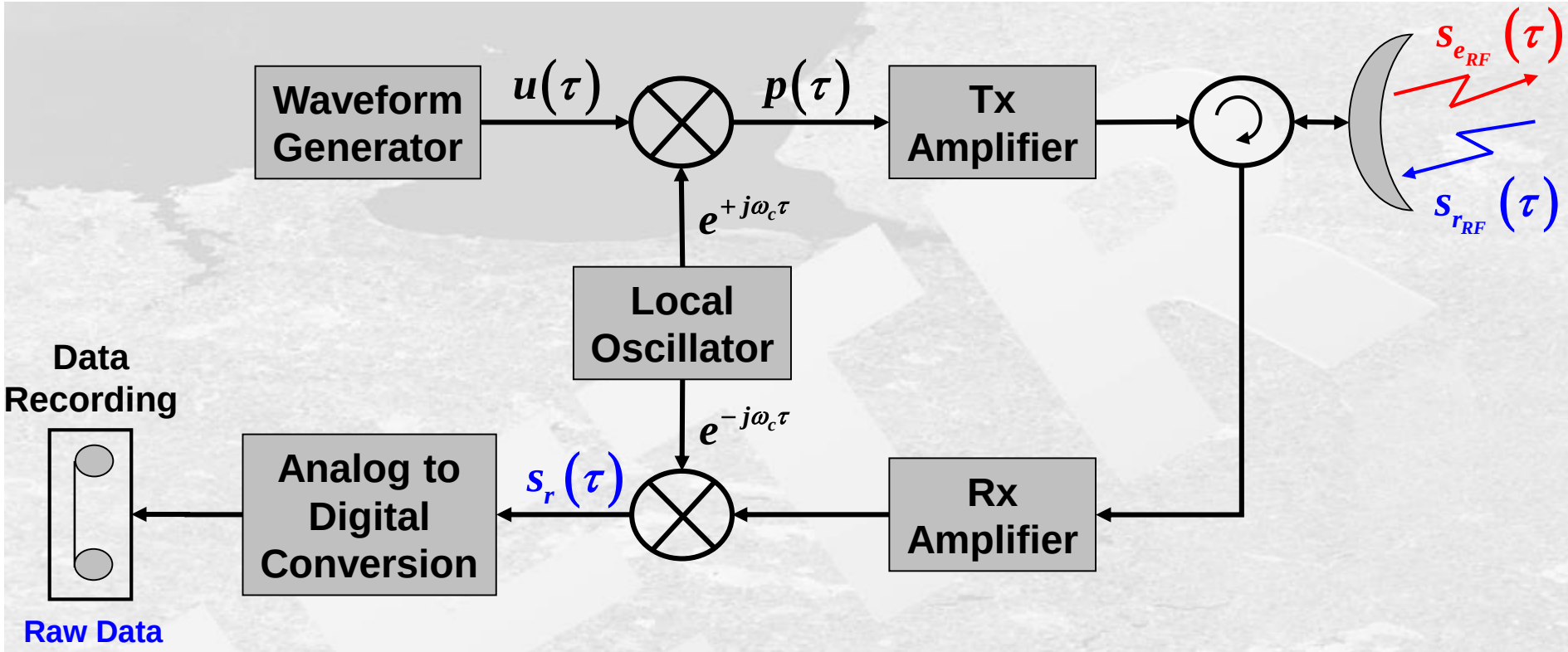
GEOMETRIC CONFIGURATION
- Geometric Configuration
- SAR Imaging Modes
- Geometric Effects

ACQUISITION MODES

SAR PRINCIPLES

PIMA : IETR AIRBORNE PLATFORM

Coherent radar synopsis



Main signals

$u(\tau)$: baseband waveform

$p(\tau)$: modulated waveform (around ω_c)

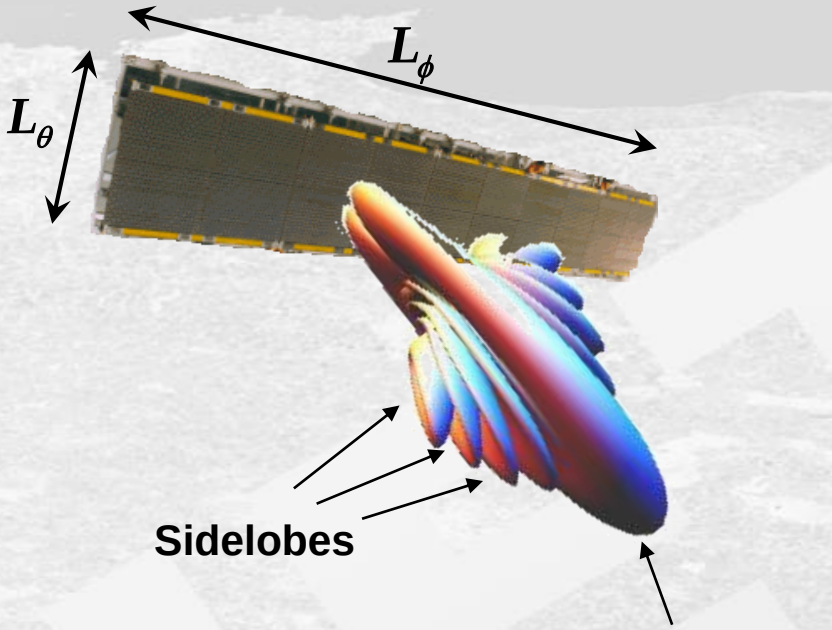
$s_r(\tau)$: Rx baseband (demodulated) signal

Coherent system

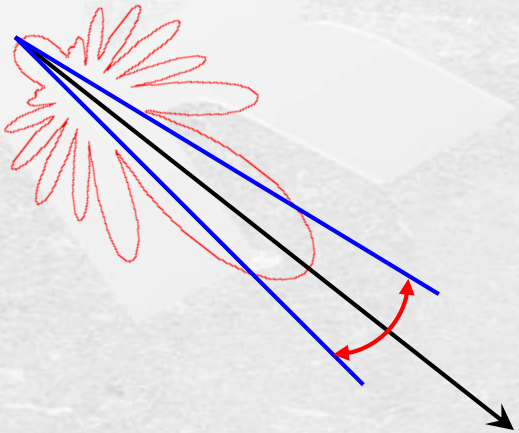
- Linear components
- Synchronized Tx-Rx carriers
- $s_r(\tau) \in \mathbb{R}$

Antenna features

Antenna Pattern



Antenna Beamwidth



Antenna apertures :

Elevation $\theta_a \approx \frac{\lambda}{L_\theta}$

Azimuth $\phi_a \approx \frac{\lambda}{L_\phi}$

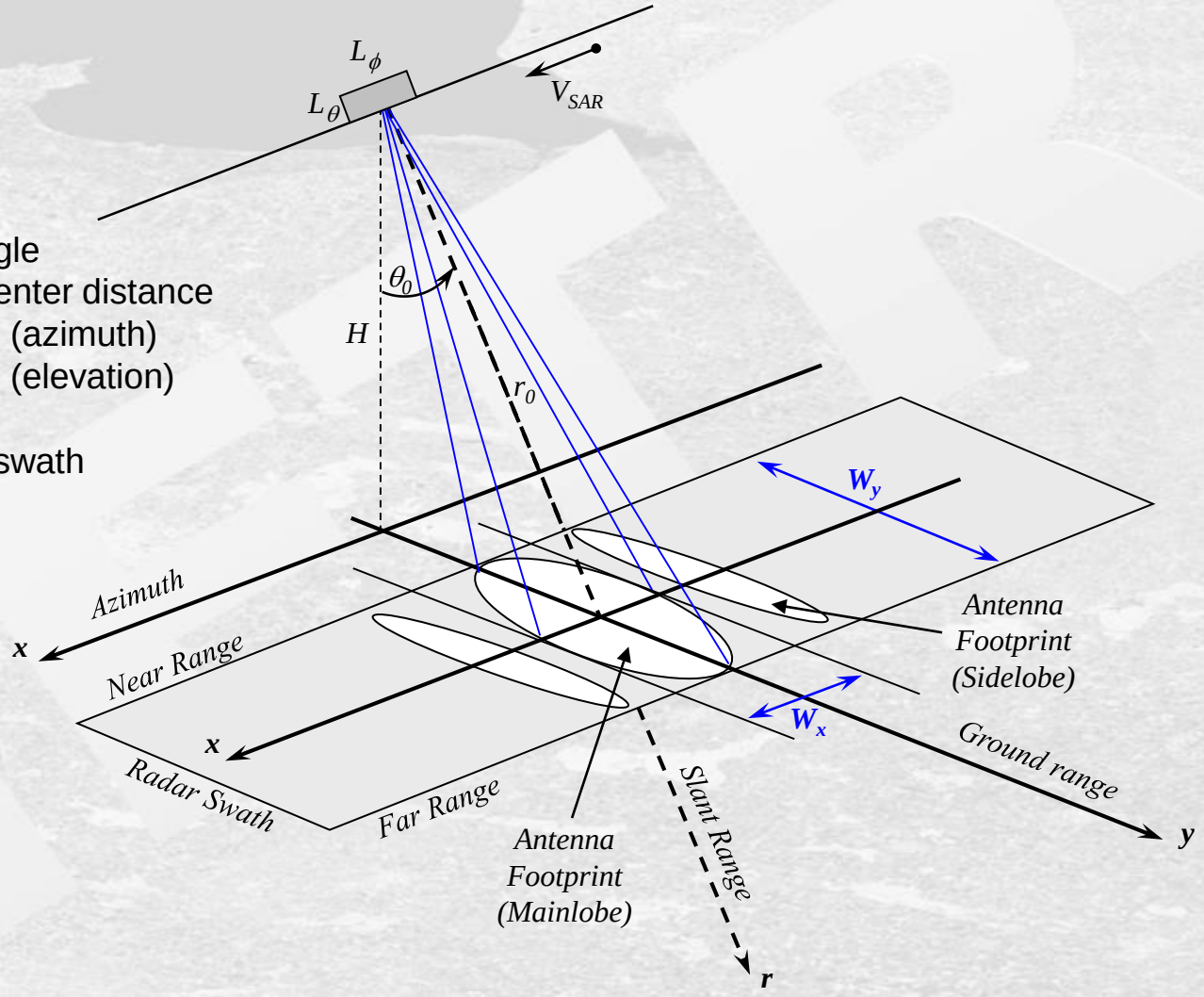
Approximation :
Uniform aperture illumination function

$$G(\theta,\phi) \approx G \cdot rect\left(\frac{\theta}{\theta_a}\right) \cdot rect\left(\frac{\phi}{\phi_a}\right)$$

Antenna features

Broadside geometry

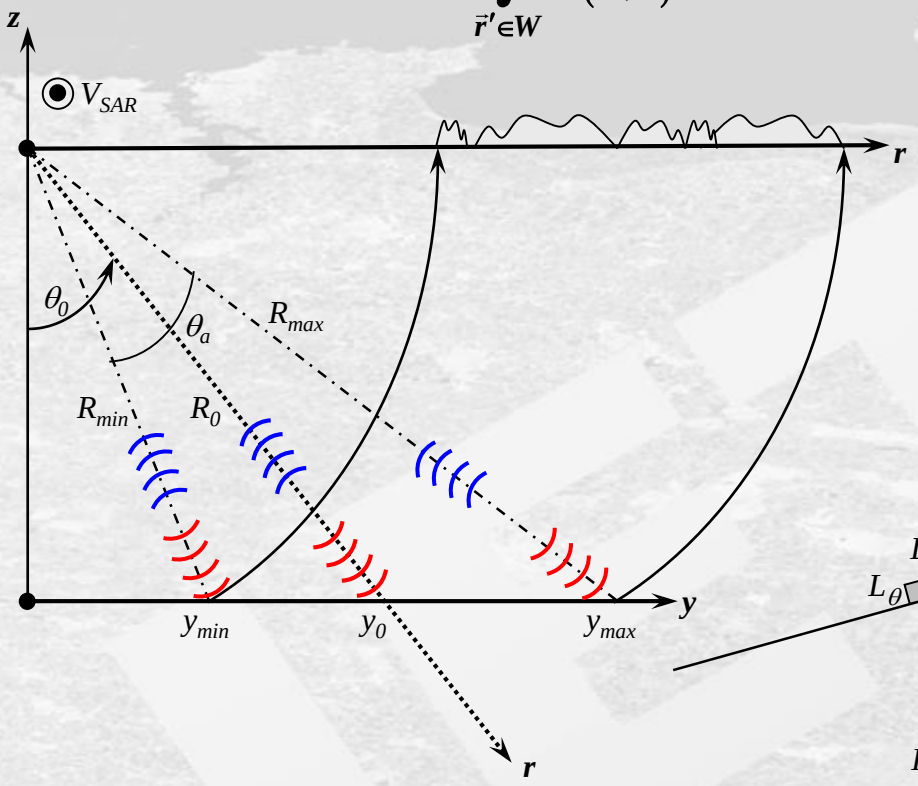
H : Sensor Height
V_{SAR}: SAR velocity
θ_0 : Range look angle
r_0 : Radar-swath center distance
L_ϕ : Antenna length (azimuth)
L_θ : Antenna length (elevation)
W_x : Azimuth swath
W_y : Ground range swath

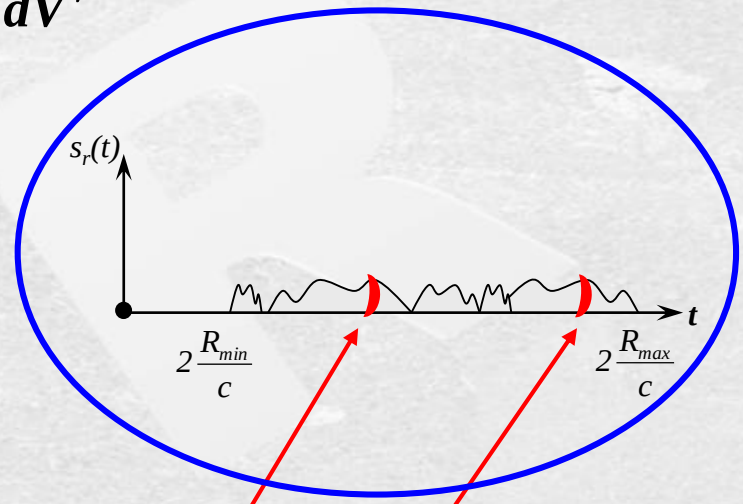


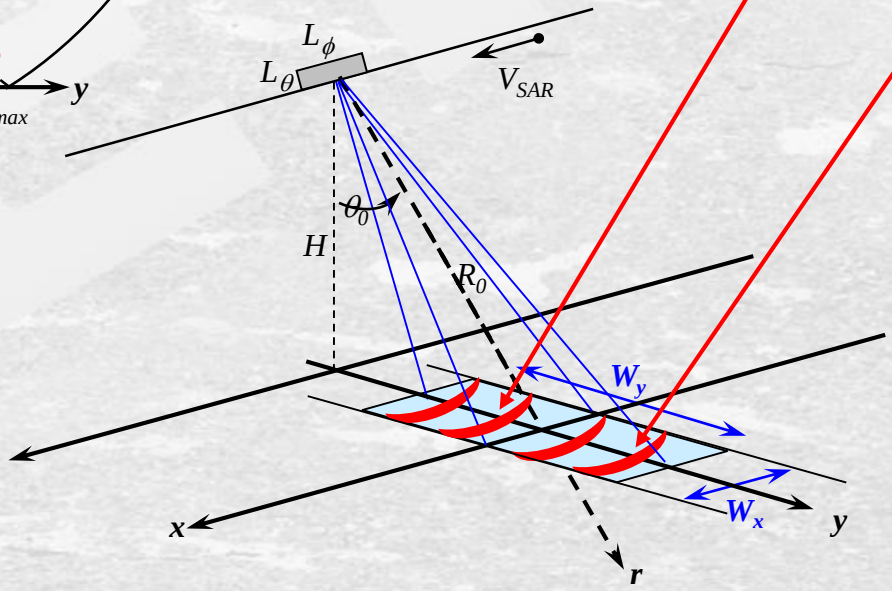
Radar Signal

Baseband received signal :

$$s_r(\tau) = \int_{\vec{r}' \in W} J_{(d',\tau')} a_c(\vec{r}') u(\tau - \tau') e^{-j\omega_c \tau'} dV'$$



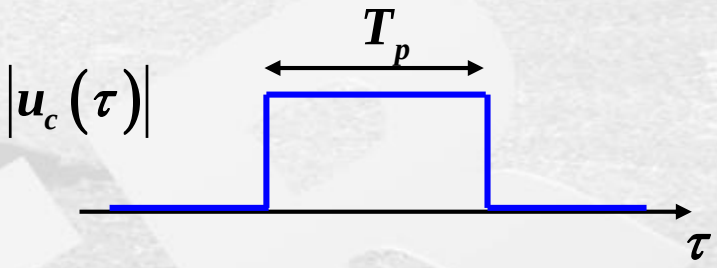


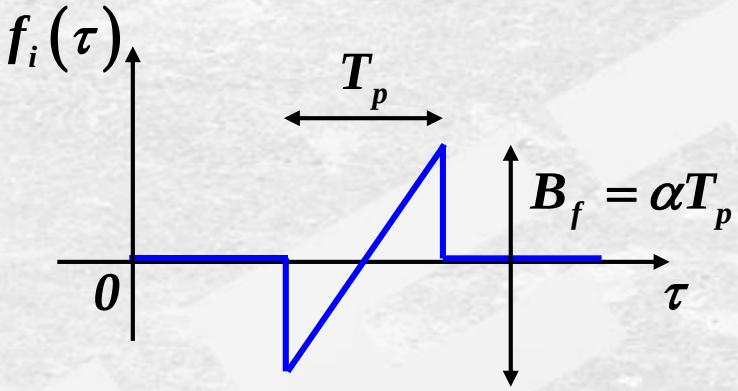


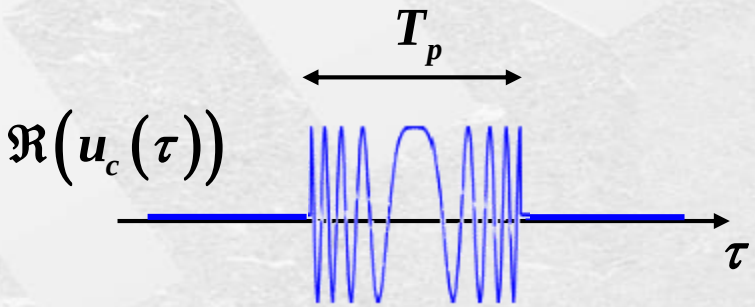
Range Imaging

- **Chirp : Pulsed LFM signal**

$$u_c(\tau) = rect\left(\frac{\tau}{T_P}\right) e^{j\pi\alpha\tau^2}$$







- **Radar impulse response :**

$$h_c(\tau) = u_c(\tau) * u_c^*(-\tau)$$

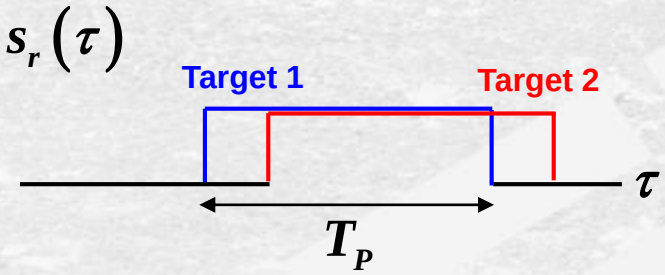
$$= T_p \cdot tri\left(\frac{\tau}{2T_p}\right) sinc\left(\pi B_f\, tri\left(\frac{\tau}{2T_p}\right)\tau\right)$$

Range Imaging

- **Chirp : Pulsed LFM signal**

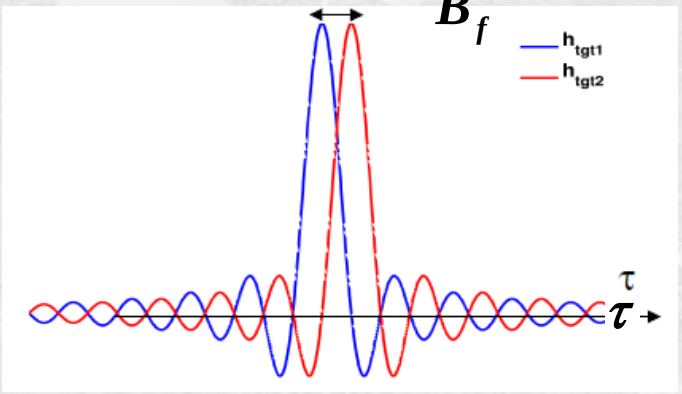
$$u_c(\tau) = rect\left(\frac{\tau}{T_P}\right) e^{j\pi\alpha\tau^2}$$

$$h_c(\tau) \propto sinc(\pi B_f \tau)$$



$$g_r(\tau) = u_c^*(-\tau)$$

$$\Delta\tau = \frac{1}{B_f}$$



- **Range resolution :** $\delta_d = \frac{c}{2B_f}$

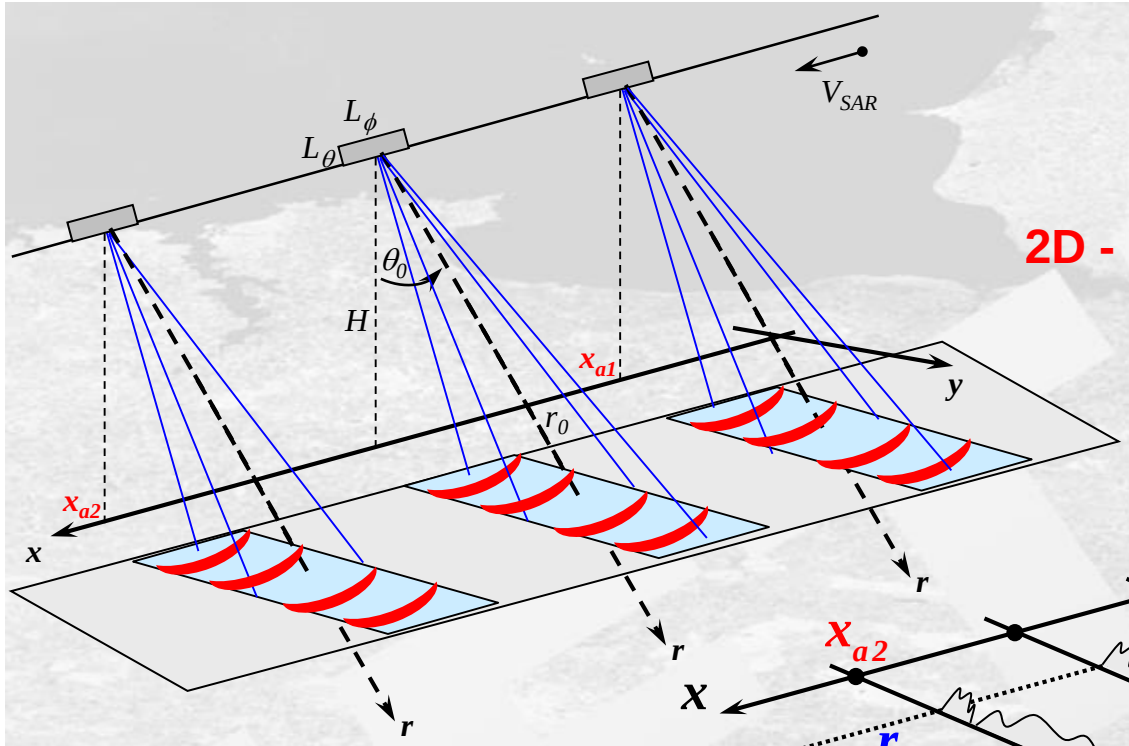
- **Range ambiguity :** $d_{amb} = \frac{cT}{2}$

- **Resolution :** $\delta_d \downarrow \Rightarrow B_f \uparrow \Leftrightarrow T_p \uparrow$

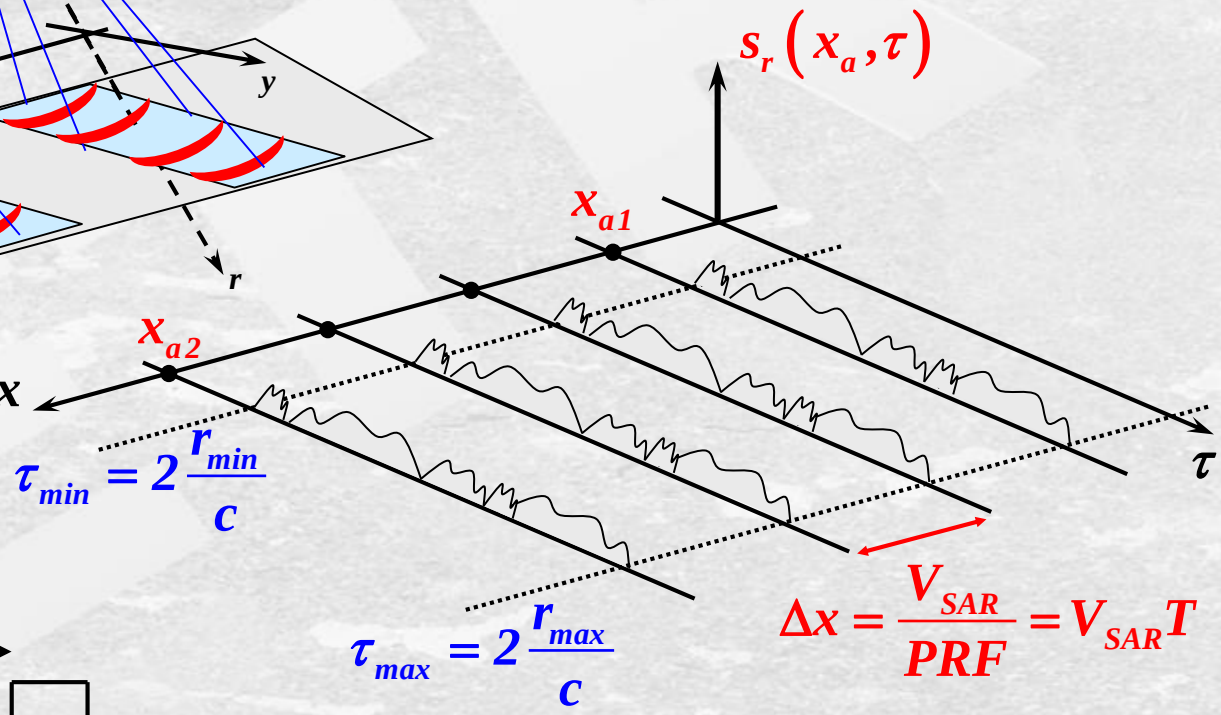
- **Detection :** $SNR_{rf} \uparrow \Rightarrow T_p \uparrow$

Long overlapping chirps !

Azimuth imaging



2D - Received (azimuth-range) signal



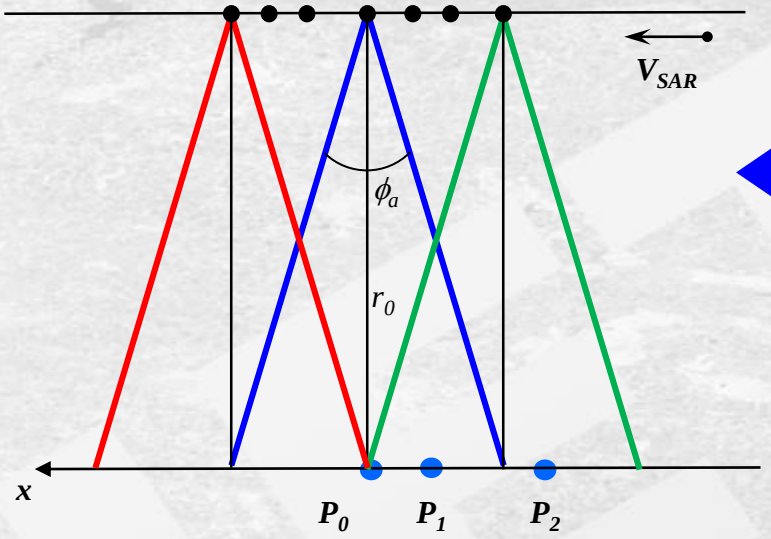
$$\tau_{min} = 2\frac{r_{min}}{c}$$

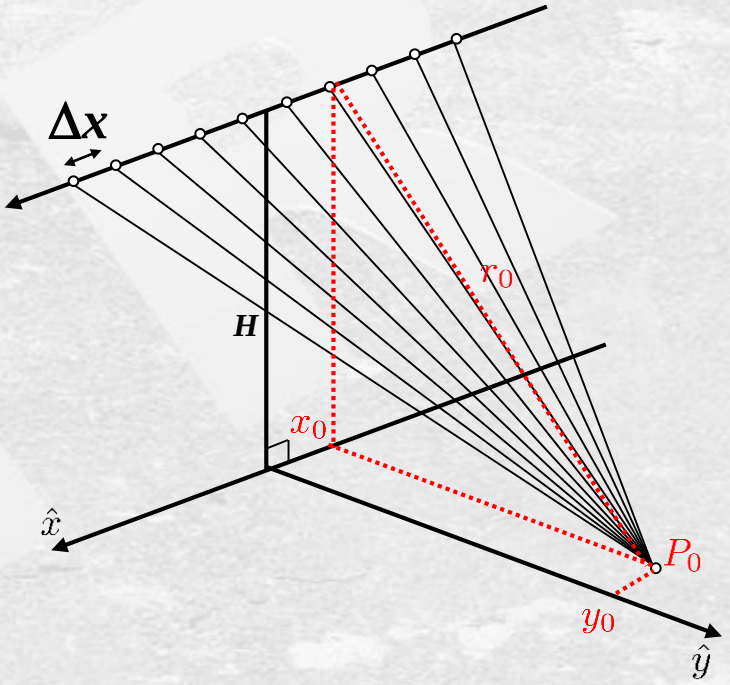
$$\tau_{max} = 2\frac{r_{max}}{c}$$

$$\Delta x = \frac{V_{SAR}}{PRF} = V_{SAR}T$$

Approximation *STOP and GO*

Azimuth imaging



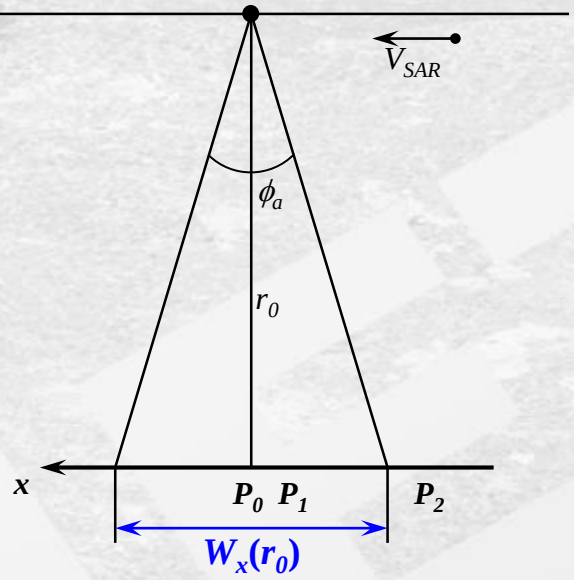


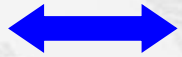
Equivalent antenna array

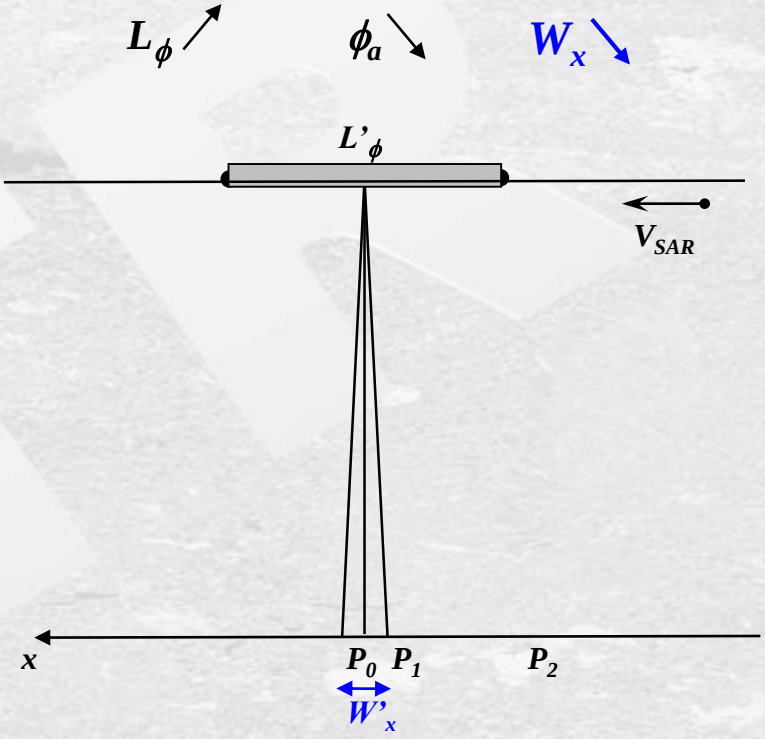
Pulse Repetition Frequency: PRF

Azimuth sampling (array spacing) $\Delta x = \frac{V_{SAR}}{PRF}$

Azimuth imaging





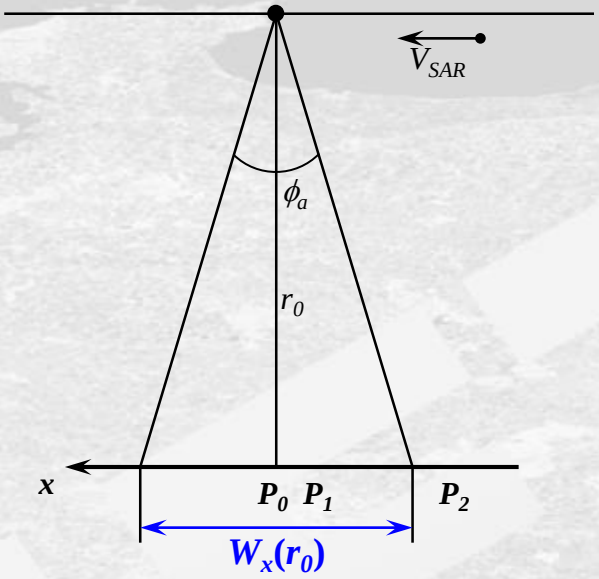


Real Aperture Radar (RAR)

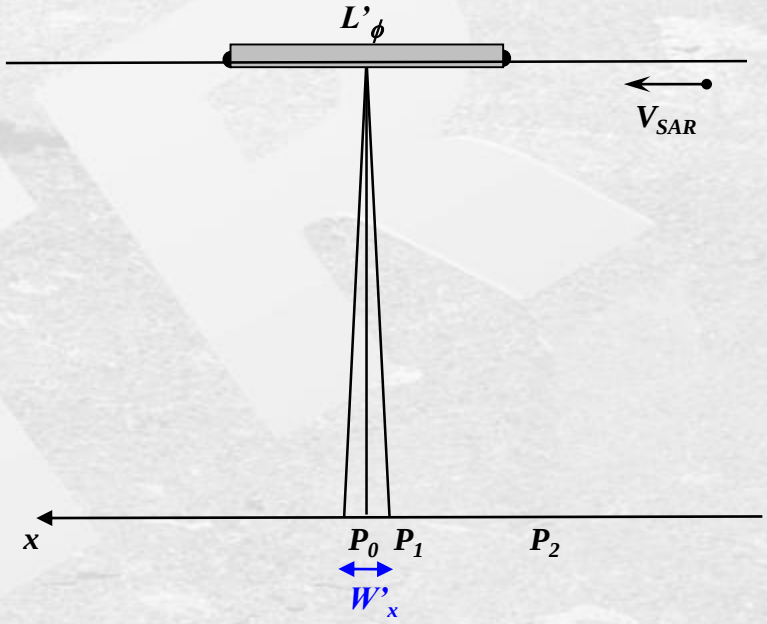
Synthetic Aperture Radar (SAR)

Azimuth imaging

Real Aperture Radar (RAR)



Synthetic Aperture Radar (SAR)



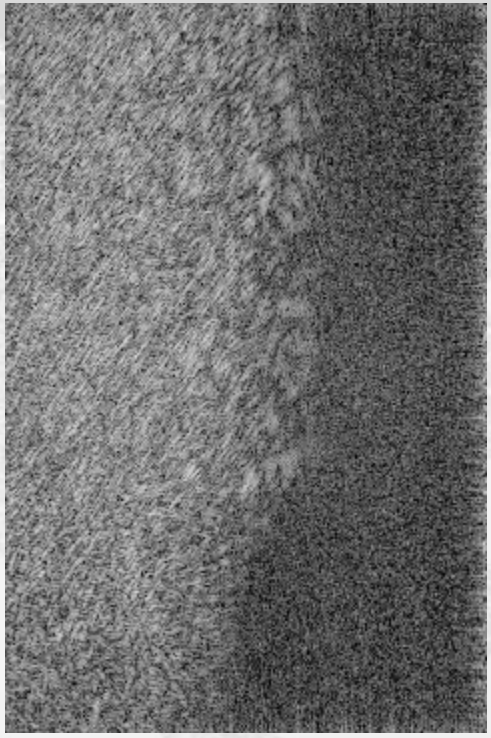
$$\delta_x = W_x(r_0) = r_0\phi_a = r_0\frac{\lambda}{L_\phi}$$

$$\delta'_x = W'_x(r_0) = r_0\phi'_a = r_0\frac{\lambda}{L'_\phi} = \frac{L_\phi}{2}$$

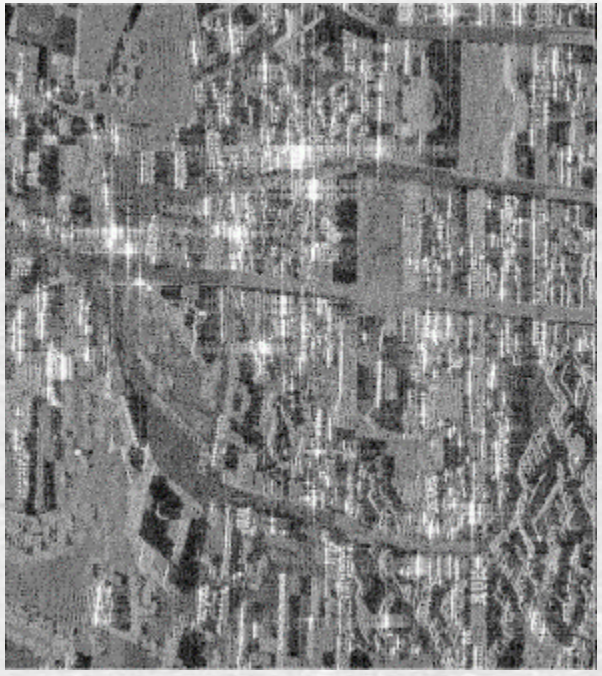
with : $L'_\phi = 2W_x(r_0) = 2\frac{r_0\lambda}{L_\phi}$

SAR Imaging Techniques

Raw data



SAR image



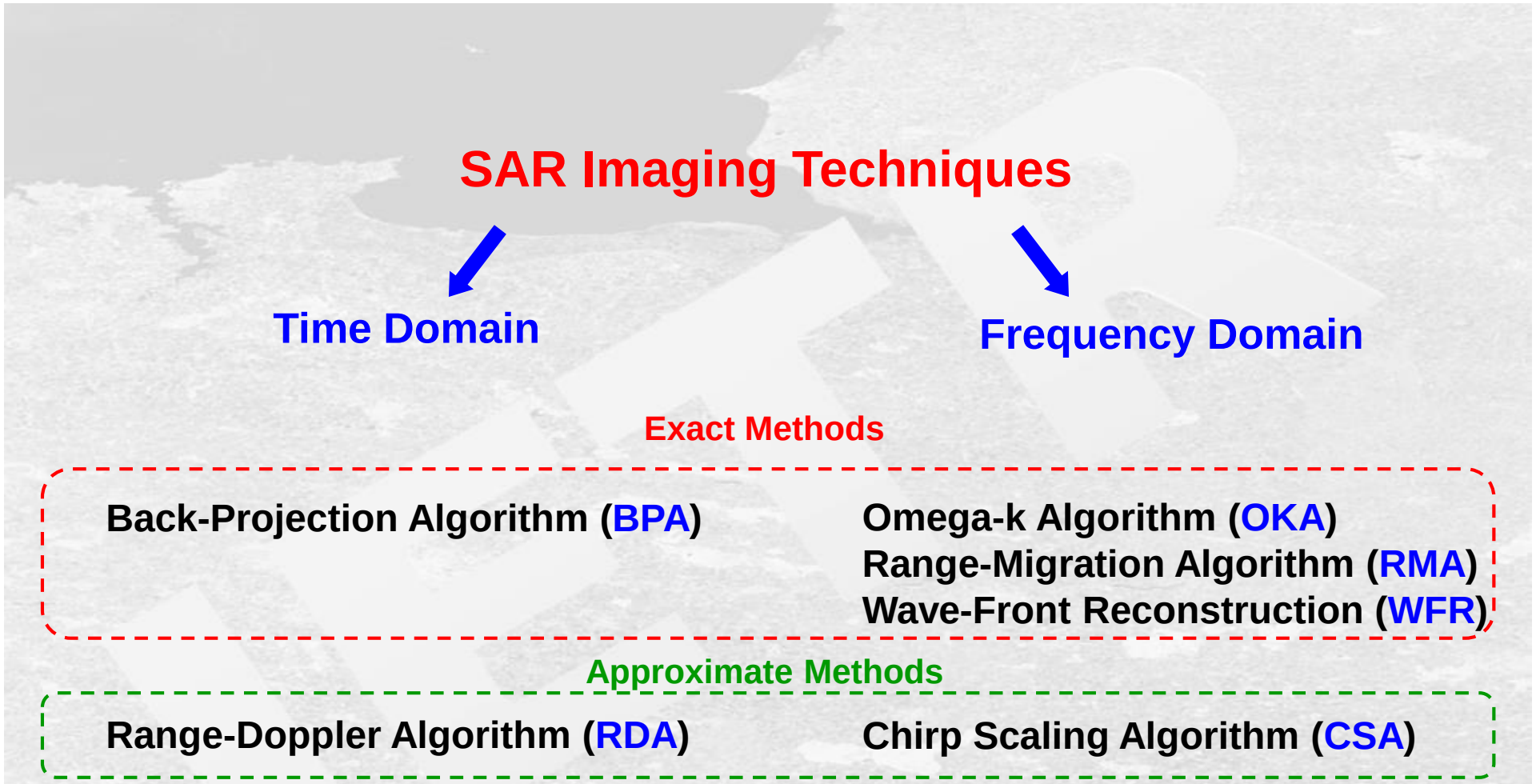
2D – Received (azimuth-range) signal

$$s_r\left(x_a,\tau\right)$$

2D – (azimuth-range) focused signal

$$s_{raf}\left(x,r\right)$$

SAR Imaging Techniques



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SAR PRINCIPLES

PIMA : IETR AIRBORNE PLATFORM

Plateforme PIMA

Plate-forme d'Ingénierie Multimodale Aéroportée

Responsables :

- **Eric POTTIER (Pr UR1)**
- **Guy GRUNFELDER (IE CNRS)**

Plateforme PIMA

- Plate-forme acquise (hors CPER) et créée le 3 mars 2015.
- Labellisée *Plate-forme de Recherche de l'Université de Rennes 1* le 7 juin 2017.

https://www.youtube.com/watch?v=fQlpGS3rXSA


IETR
UNIVERSITÉ DE RENNES 1
cnrs
PIMA
CTLS
F-JVJC
IETR
RENNES 1
Plateforme d'Ingénierie Multimodale Aéroportée
Région BRETAGNE
METROPOLE Rennes
PIMA
©2021

L'aéronef

CTLS – Flight Design (ULM classe 3)

- *Flights up to 6000 m*
- *Flight Range : 1500 km*
- *Flight life : 8 h*

Basé à l'ACRIV : *Aéroport de Rennes – St Jacques* (LFRN)

La Zone Aviation

La Zone Aviation

Le Hangar Aviation

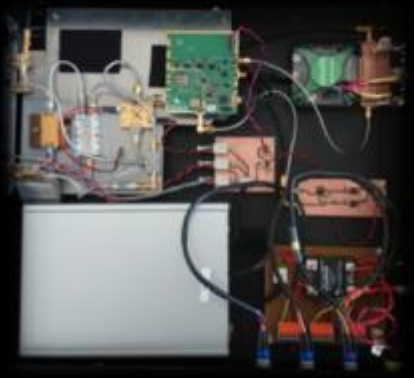
Hangar Aviation
(15m x 15m x 6m)

Dédié à la préparation des activités aériennes

PIMA

Système Radar Imageur

Pocket SAR
Bande C – v1
(2016)



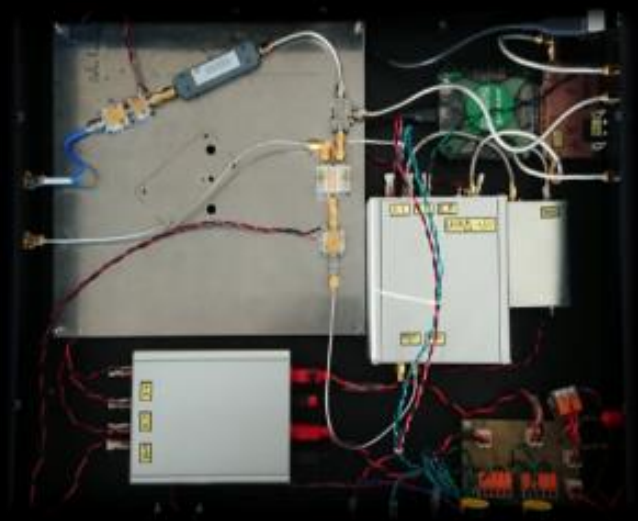
Pocket SAR
Bande C – v2
(2018)

- Mode FMCW
- Sweep : Triangle PRF = 1 kHz
- f_{MIN} = 9,5 GHz - f_{MAX} = 10,5 GHz
- Synthétiseur : TI LMX2492

- Antennes : Cornet 20dB Flann Microwave
  - $\Theta_{AZ} = \Theta_{EL}$ = 20 ° - Polarisation VV

- Carte Acq : ADLINK PCI-9826H / 512(G), 20Ms/s

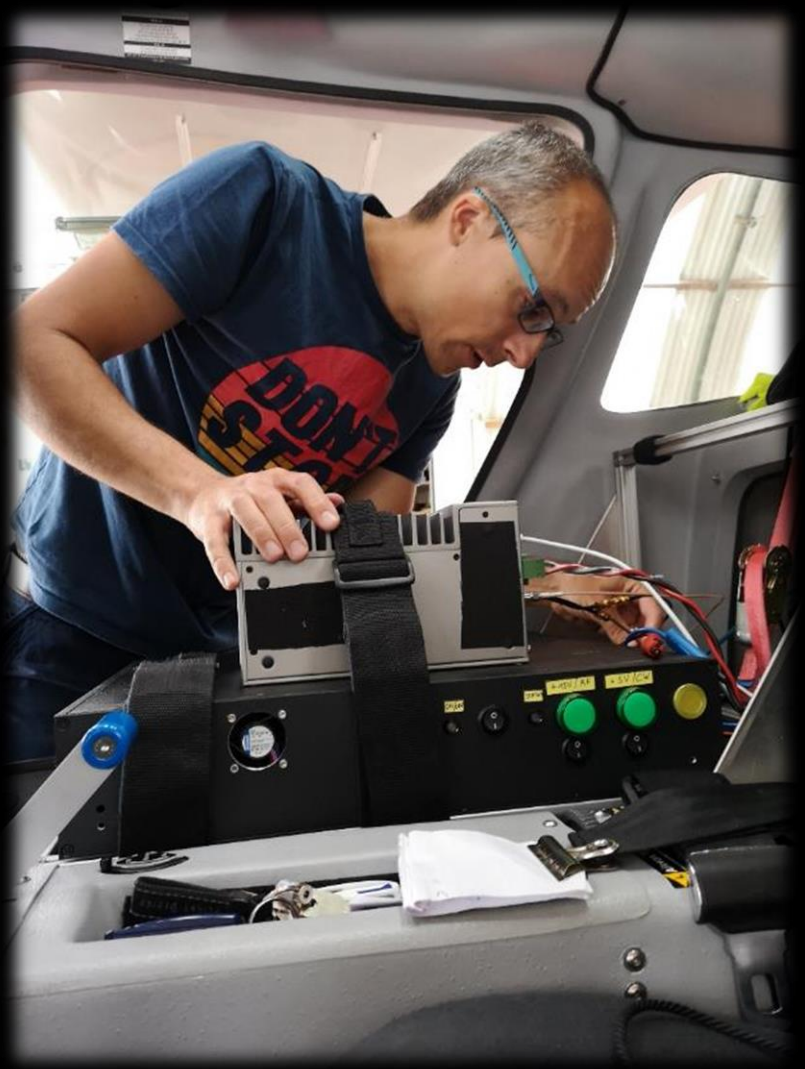
Pocket SAR - X
(2020)



Radar imageur PoSAR-X (*Pocket SAR – Bande X*)

PIMA

Système Radar Imageur



Radar imageur PoSAR-X (*Pocket SAR – Bande X*)

PIMA

Système Radar Imageur

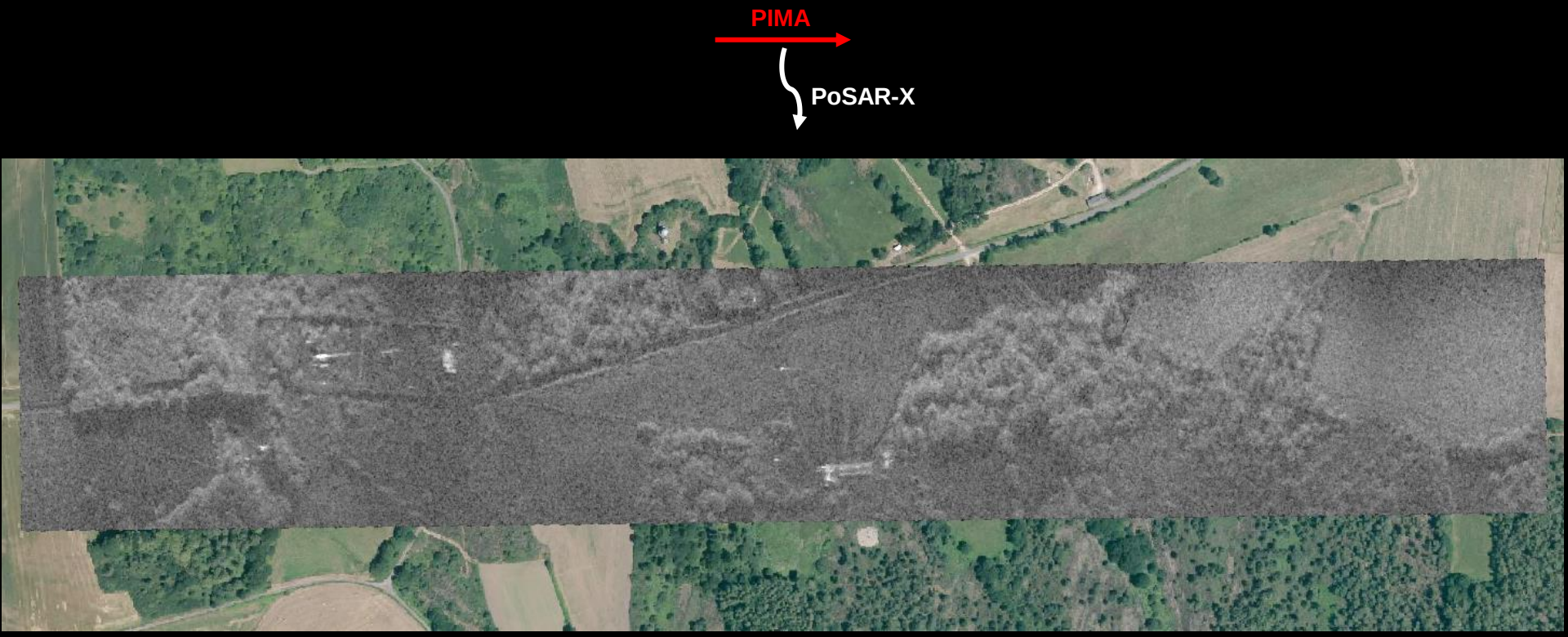


Image radar SAR – Bande X (*Résolution = 50 cm*)

Système Radar Imageur

Image radar SAR – Bande X (*Résolution = 25 cm*)

Système Radar Imageur

Image radar SAR – Bande X (*Résolution = 25 cm*)

DGA

Validation
Qualification
DGA-MI
octobre 2020

PIMA

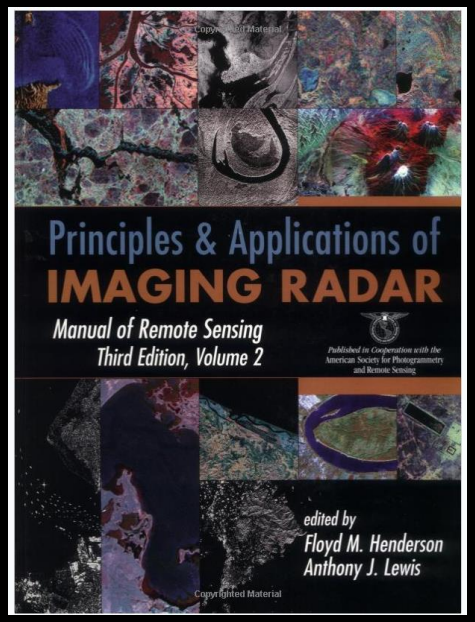
Contact : ctls.ietr@univ-rennes1.fr

https://www.ietr.fr/pima/

Learning / Training

Next P.I Generations

Books On Polarimetric Radar, Polarimetric Interferometry SAR



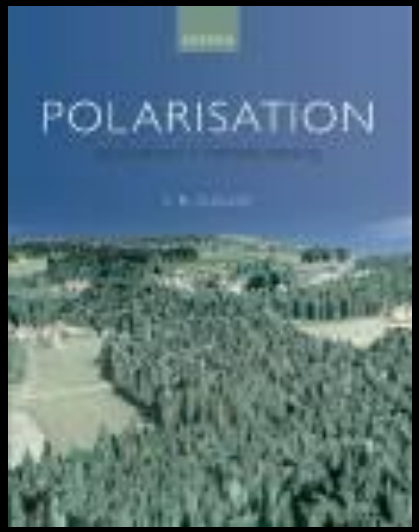
Polarimetric in Radar Remote Sensing : Basic and Applied Concepts

W-M. BOERNER, H. MOTT, E. LÜNEBURG, C. LIVINGSTONE, B. BRISCO, R.J. BROWN, J. SCOTT PATERSON
Contributors : S.R. CLOUDE, E. KROGAGER, J.S. LEE, D.L. SCHULER, J.J. VAN ZYL, D. RANDALL, P. BUDKEWITSCH and E. POTTIER

Manual of Remote Sensing, Third Edition, Volume 2, 867p, 1998. Edited by Floyd M. Henderson and Anthony J. Lewis, John Wiley & Sons, Inc.,
ISBN 0-471-29406-3

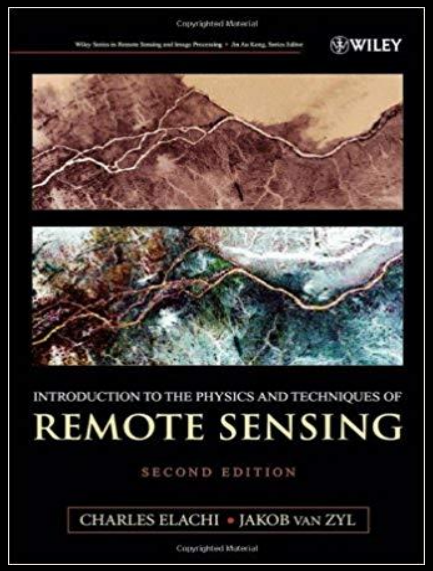
Books On Polarimetric Radar, Polarimetric Interferometry SAR

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, Polarimetric Interferometry SAR



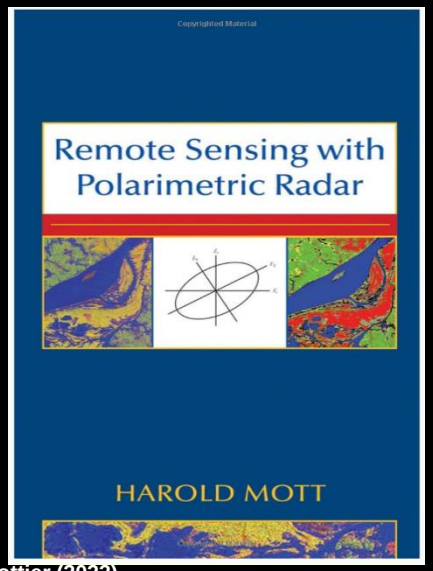
Introduction To The Physics and Techniques of Remote Sensing

Charles ELACHI – Jakob J. VAN ZYL

Wiley-Interscience; 2nd edition (July 31, 2007),

ISBN-10 0-471-47569-6

ISBN-13 978-0471475699



Remote Sensing with Polarimetric Radar

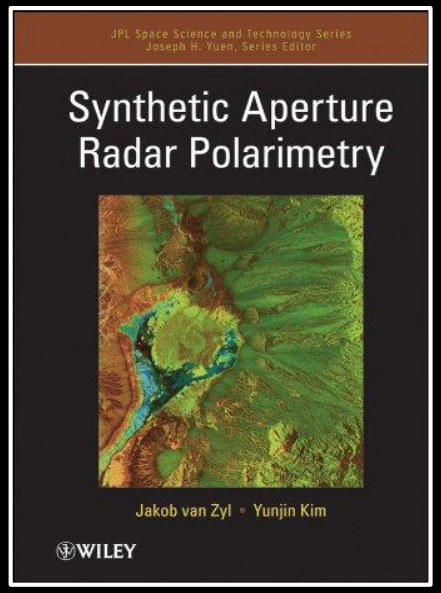
Harold MOTT

Wiley-IEEE Press; 1st edition (January 2, 2007),

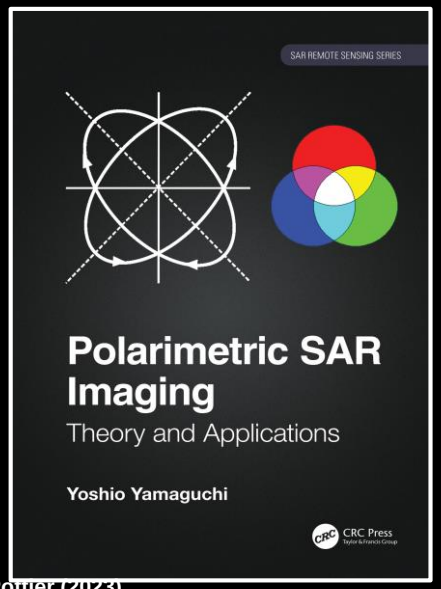
ISBN-10 0-470-07476-0

ISBN-13 978-0470074763

Books On Polarimetric Radar, Polarimetric Interferometry SAR

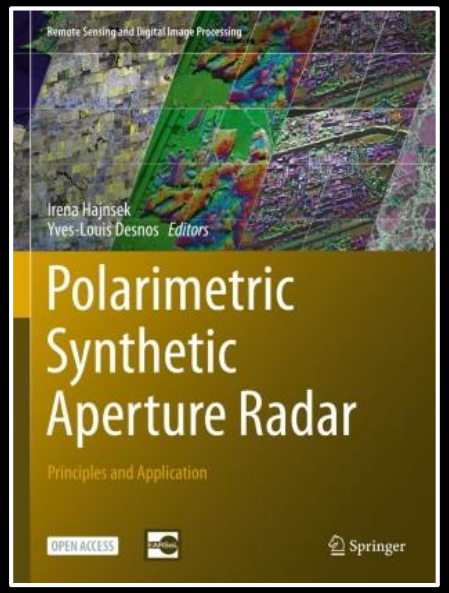


Synthetic Aperture Radar Polarimetry
Jakob J. VAN ZYL – Yunjin KIM
Wiley; 1st edition (October 14, 2011),
ISBN-10 1-118-11511-2
ISBN-13 978-1118115114



Polarimetric SAR Imaging : Theory and Applications
Yoshio Yamaguchi
CRC Press; 1st ed., August 2020, pp 350
ISBN: 978-1003049753

Books On Polarimetric Radar, Polarimetric Interferometry SAR



Polarimetric Synthetic Aperture Radar : Principles and applications

Irena HAJNSEK – Yves-Louis DESNOS editors

Springer; 1st edition (Marsh 30, 2021),

ISBN 978-3-030-56502-2

https://link.springer.com/content/pdf/10.1007%2F978-3-030-56504-6.pdf

Questions ?